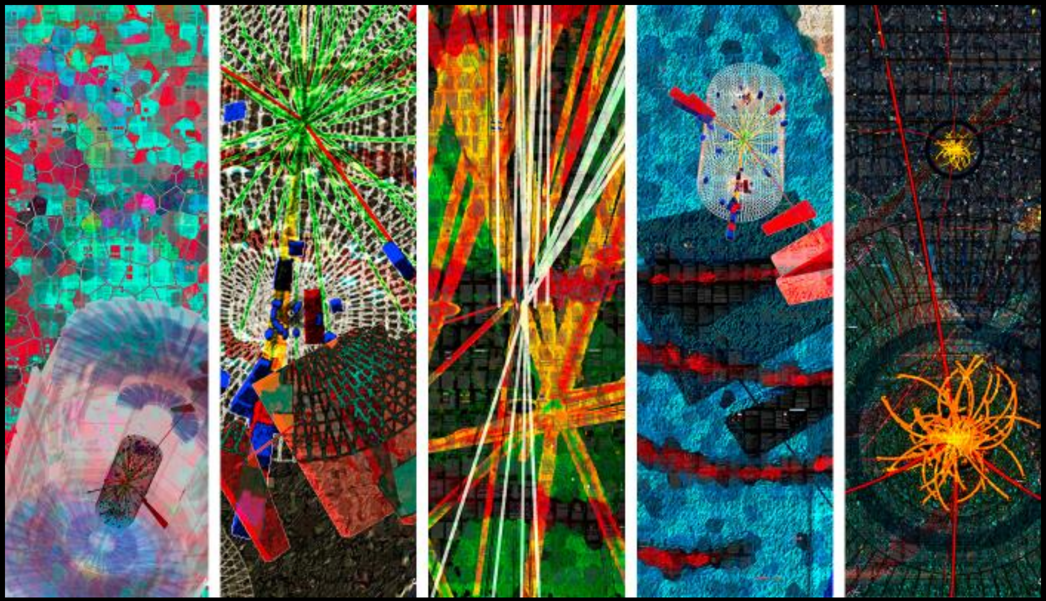
Highlights and Perspectives



XXVI th Rencontres de Blois

Meenakshi Narain

Brown University

May 18-23, 2014

Thank You All

- For an excellent set of talks & making this week full of insights and intellectual stimulation.

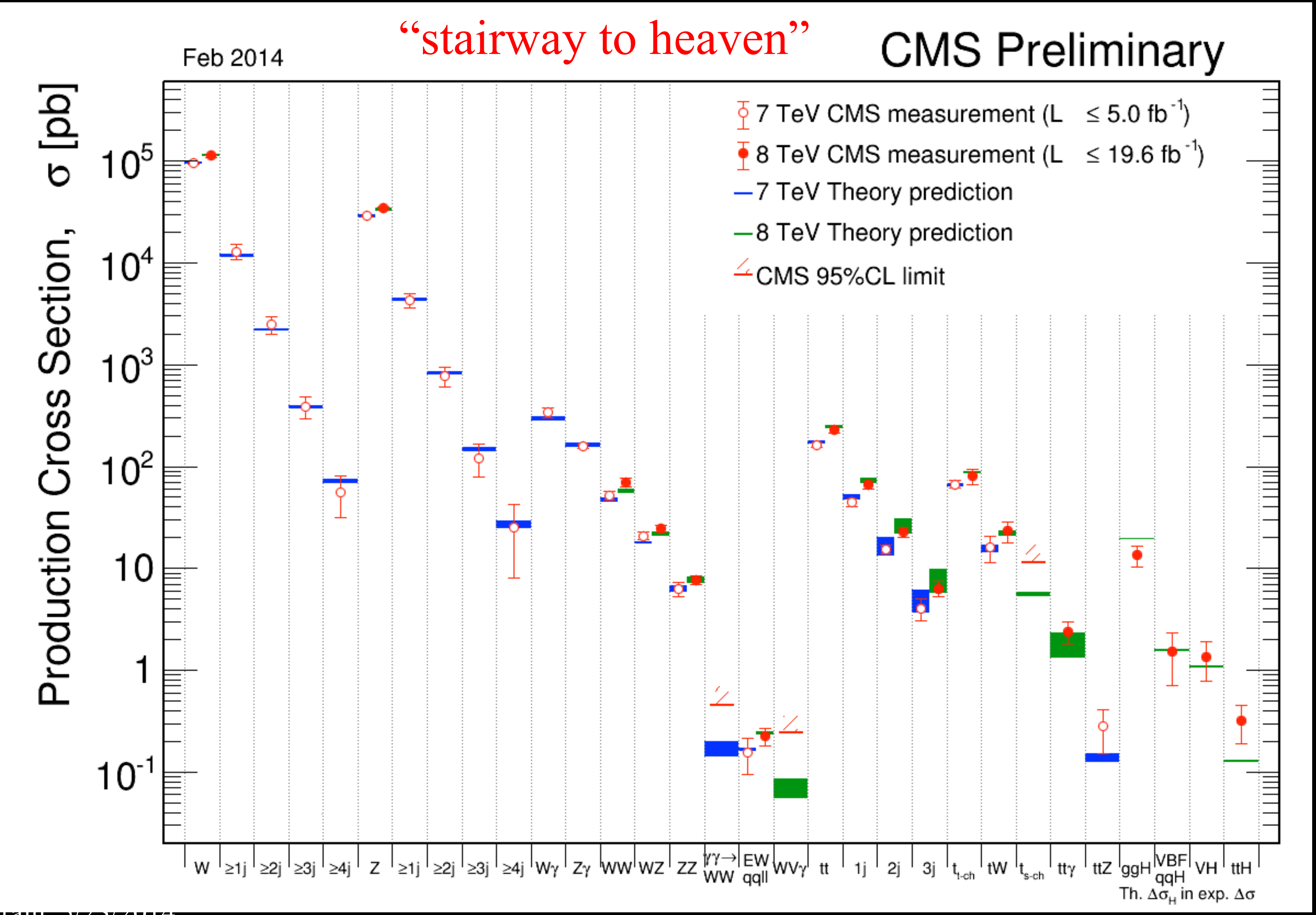
26th Rencontres de Blois
Château de Blois, 18th - 23rd May 2014

- In the following slides, I have made some biased selection of topics.
- I apologize for any mis-representations and omissions.

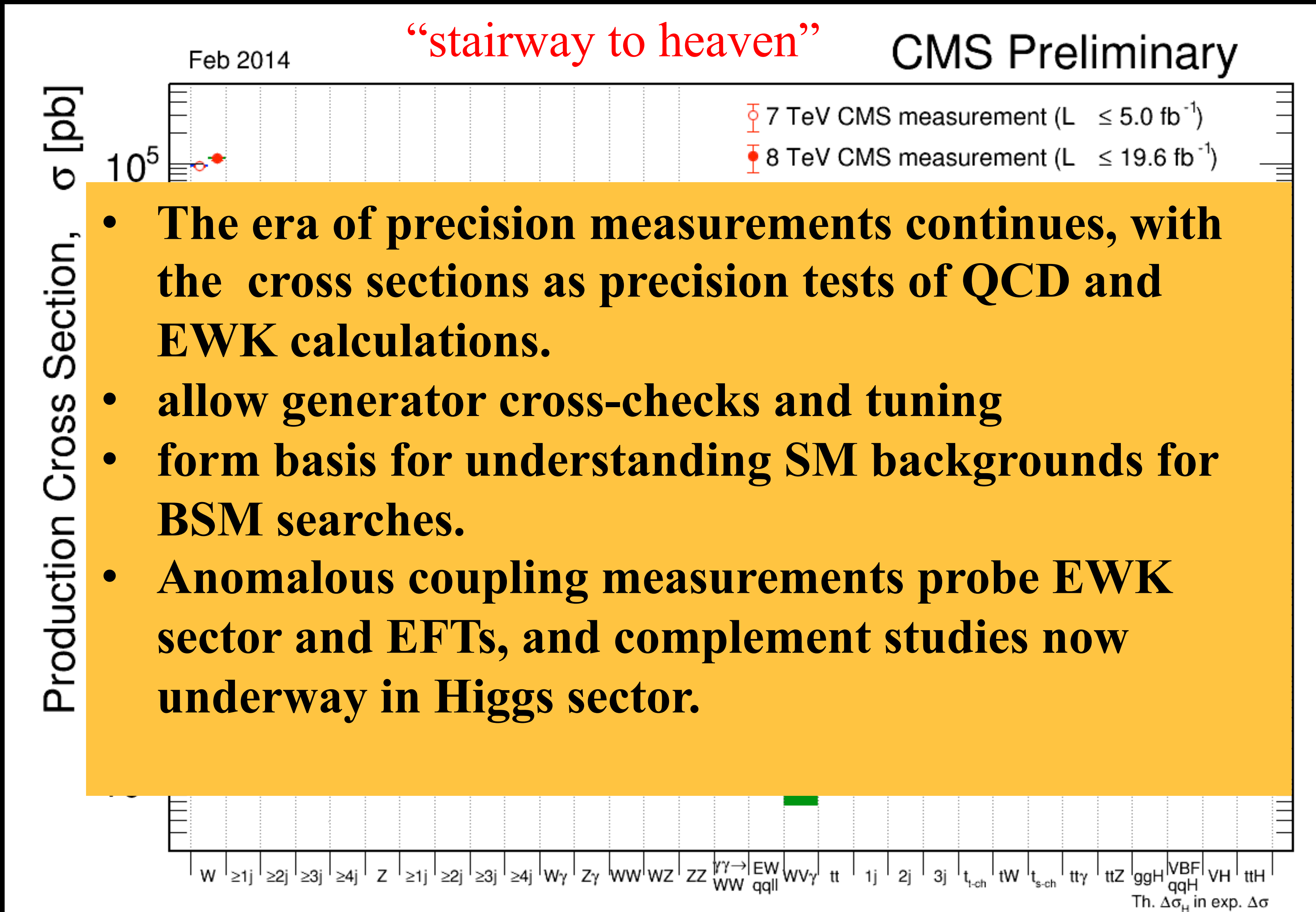
STANDARD MODEL HIGHLIGHTS

Slawek, Tovey, Grojean, Glazov, Ubiali,

SM cross section measurements



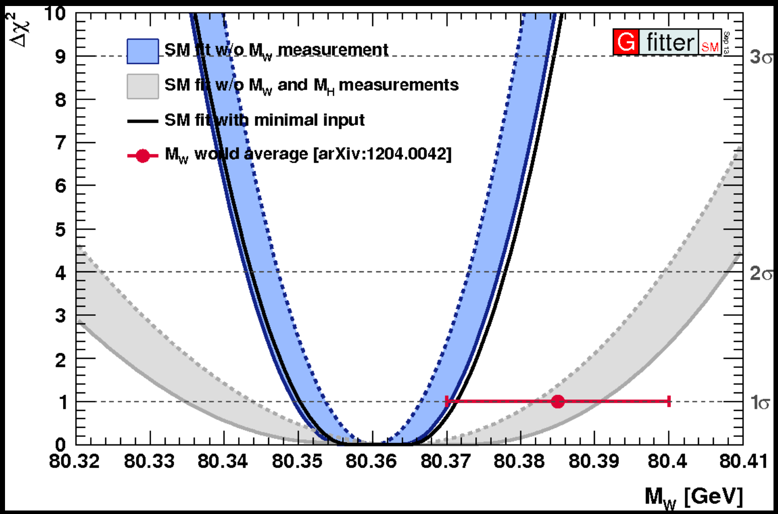
SM cross section measurements



- **The era of precision measurements continues, with the cross sections as precision tests of QCD and EWK calculations.**
- **allow generator cross-checks and tuning**
- **form basis for understanding SM backgrounds for BSM searches.**
- **Anomalous coupling measurements probe EWK sector and EFTs, and complement studies now underway in Higgs sector.**

W Mass measurement

- Indirect (with Higgs mass in the fit):
  M_W=80,359±11 MeV
- World average (direct):
  M_W=80,385±15 MeV



Perform careful analysis of relations between improvements in experimental measurements, their effect on the parametric uncertainties and the impact of theoretical uncertainties

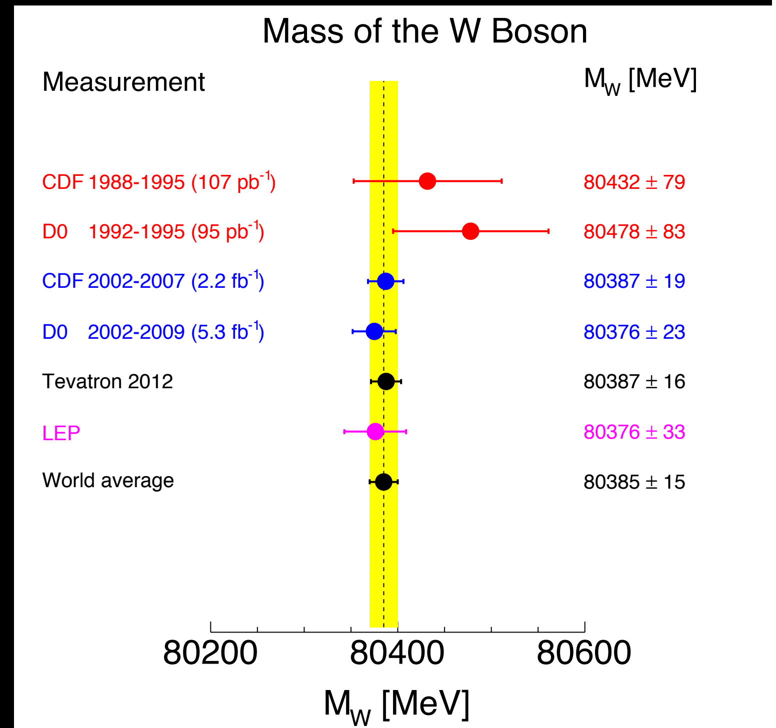
$$M_W \xrightarrow{SM} (80.368\,\mathrm{GeV})\,(1 + 1.42\,\delta M_Z + 0.21\,\delta G_F - 0.43\,\delta\alpha + 0.013\,\delta M_t - 0.0011\,\delta\alpha_S - 0.00075\,\delta M_H)\,. \quad (3)$$

	M_T	a_{had}	M_z	Missing HO	Total
ΔM_W [MeV]	5.4	2.8	2.6	4.0	7.6

W Mass

- Important physics measurement in the LHC program
  - Large samples of W, Z Run1
  - Differences in W+ and W- production,
- Challenges for LHC for precision M_W determination:
  - Theoretical understanding of the $p_T(W)$
  - Improved PDFs (need x2)
  - Pile-up effects on soft recoil
- LHC could achieve a precision of 8(5) MeV wit 300(3000) fb^{-1}

arXiv:1310.7608

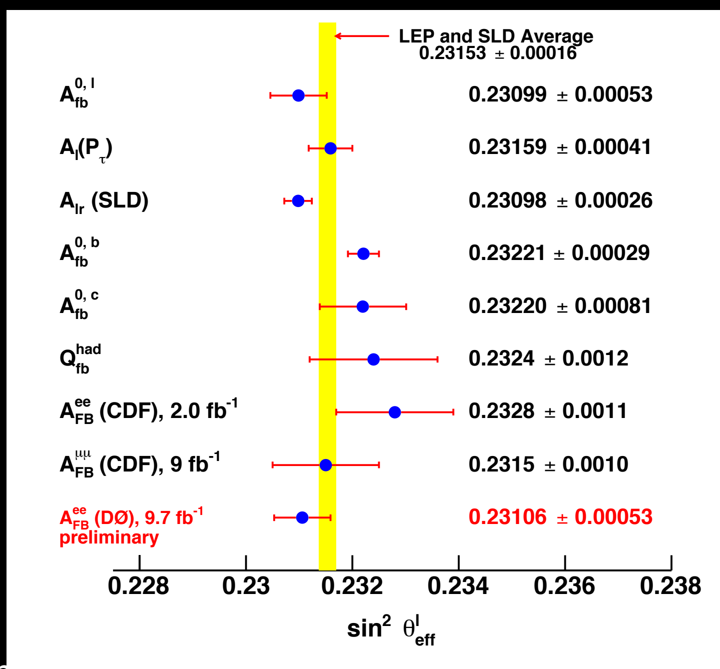


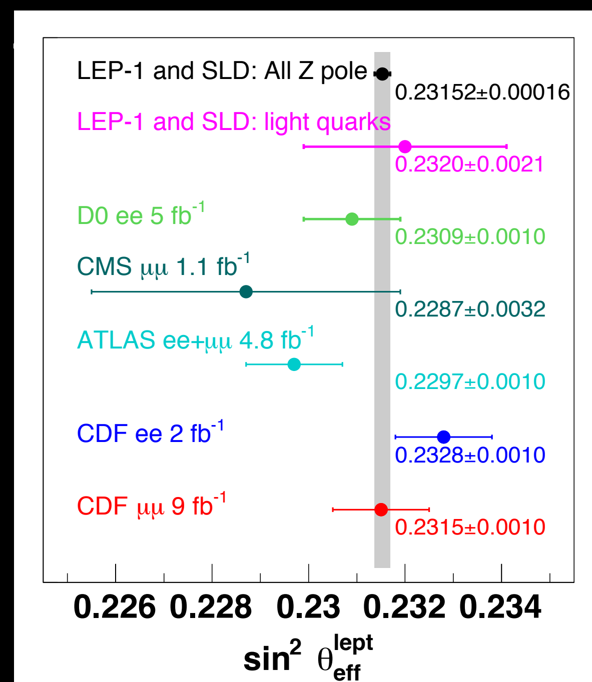
ΔM_W [MeV]	LHC		
$\sqrt{s}$ [TeV]	8	14	14
$\mathcal{L}$[fb^{-1}]	20	300	3000
PDF	10	5	3
QED rad.	4	3	2
$p_T(W)$ model	2	1	1
other systematics	10	5	3
W statistics	1	0.2	0
Total	15	8	5

NLO-QCD, normalized transverse mass distribution

A_{FB} and $\sin^2(\vartheta_W)$: Tevatron & LHC

- Important input to global tests of the EWK theory
  - In hadron collisions A_{FB} in DY (muon, electrons) sensitive to the $\sin^2(\vartheta_W)$
  - $\sin^2(\vartheta_W^{eff})$ from angular coeff. (A_4) and ResBos predictions (template fit)
  - Polar angle Born level distribution: $1+\cos^2\vartheta + A_4\cos\vartheta$; $A_{FB}=3/8A_4$
- Tevatron precision close to LEP/SLC
  - Systematics dominated by the PDFs
- D0 with preliminary measurement in electron data set
  - More precise energy calibrations and increased data size

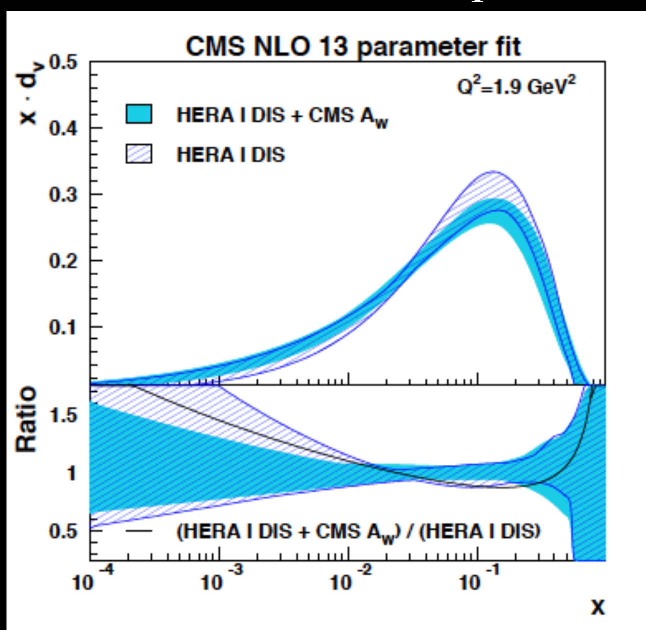




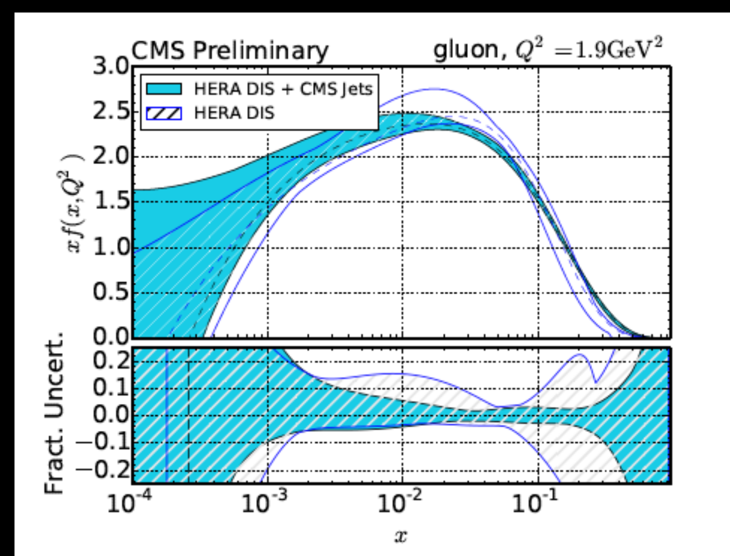
Constraning PDFs

- input from HERA, Tevatron and LHC msm’ts
- PDF uncertainties are often limiting factor in achieving precise predictions
  - e.g. theory predictions for BSM high mass production
  - main uncertainty in Higgs production and in determination of M_W
- Use LHC data – W charge asymmetry, jets & photons

CMS W asymmetry + HERA DIS
leads to d-valence PDF improvement



CMS inclusive jet data+ HERA DIS
prefers harder gluon,
reduces uncertainty at high **x**.

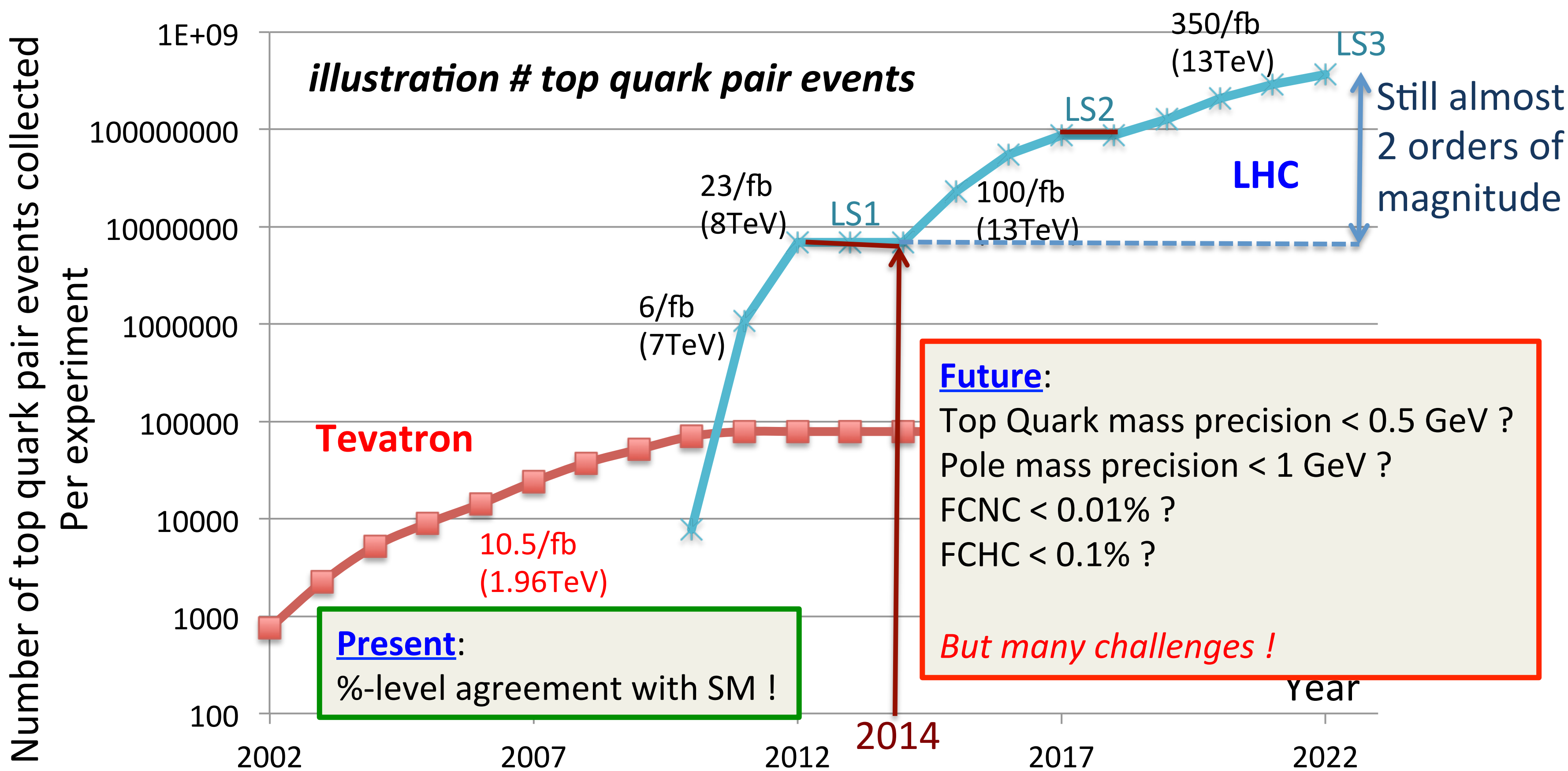


STATUS OF
TOP QUARK PHYSICS

D'Hondt, Kehoe, Steiger, Tkazcyk, Uwer

Production at Tevatron and LHC

20 years for almost 6 orders of magnitude → the Top Quark era

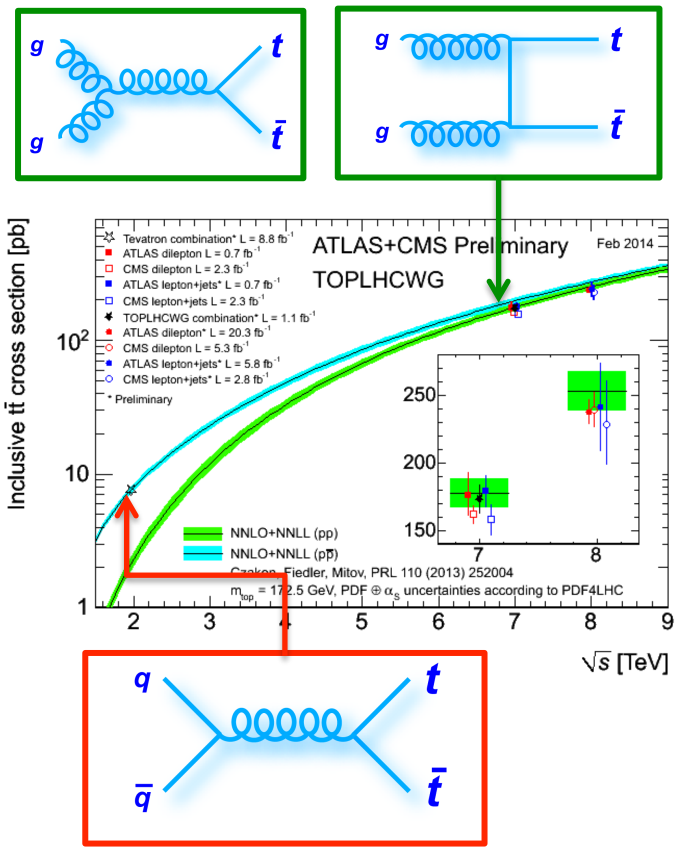


(caveat: assumed 13 TeV collisions with a cross section of 800 pb)

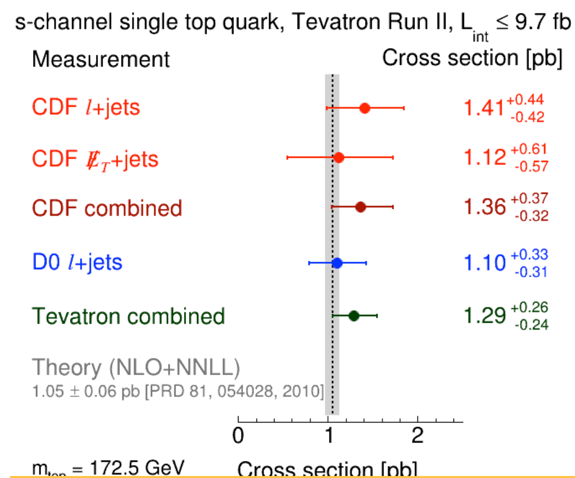
Top Quark production

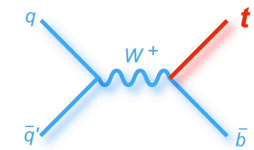
Strong collaboration between theoretical and experimental researchers

Strong pair production



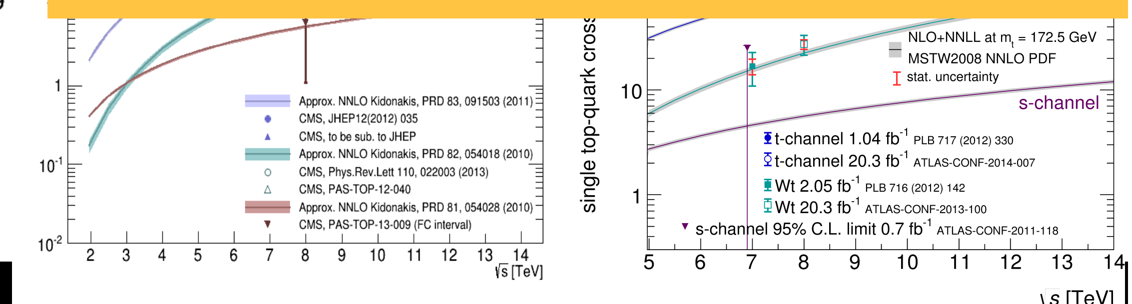
EWK Single top production





Tevatron s-channel observed significance is 6.3 σ

A good year for single top quark at the Tevatron and the LHC!!



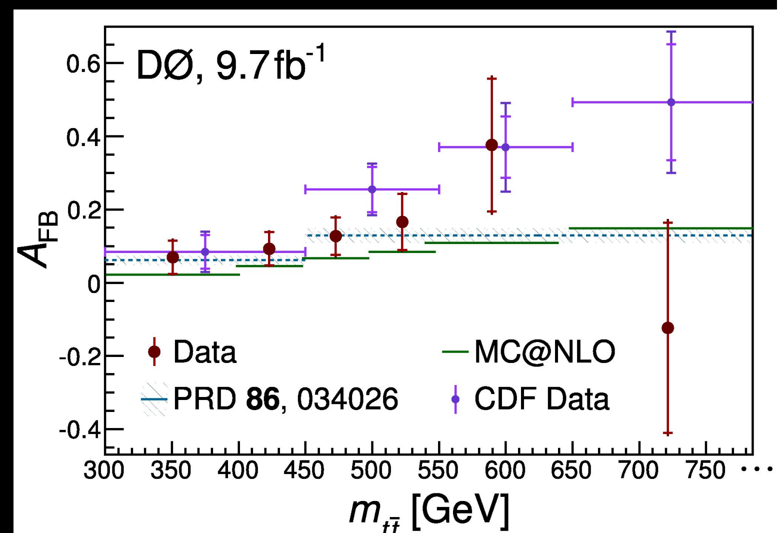
A_{FB} and lessons to be learned

	CDF [1]	CDF [7]	DØ [2]	SM (this work)
A^t_{FB}	0.150 ± 0.055			0.058 ± 0.004
$A^{t\bar{t}}$	0.158 ± 0.075	0.162 ± 0.047	0.196 ± 0.065	0.088 ± 0.006
$A^{t\bar{t}}(\lvert\Delta y\rvert \leq 1)$	0.026 ± 0.118	0.088 ± 0.047		$0.061^{+0.004}_{-0.003}$
$A^{t\bar{t}}(\lvert\Delta y\rvert > 1)$	[illegible]	[illegible]	[illegible]	[illegible]
$A^{t\bar{t}}(M_{t\bar{t}} \leq 450\text{ GeV})$	[illegible]	[illegible]	[illegible]	[illegible]
$A^{t\bar{t}}(M_{t\bar{t}} > 450\text{ GeV})$	0.475 ± 0.114	0.296 ± 0.067		$0.129^{+0.008}_{-0.006}$

At most 2.4 σ deviation "Some tension"

- The signal which could have been the first indication of new physics seems to have disappeared
- Charge asymmetry = just another subtle quantum effect?
- Nothing particular to learn…
  …apart from understanding the quantum level !!!
- Important to probe theory at quantum level

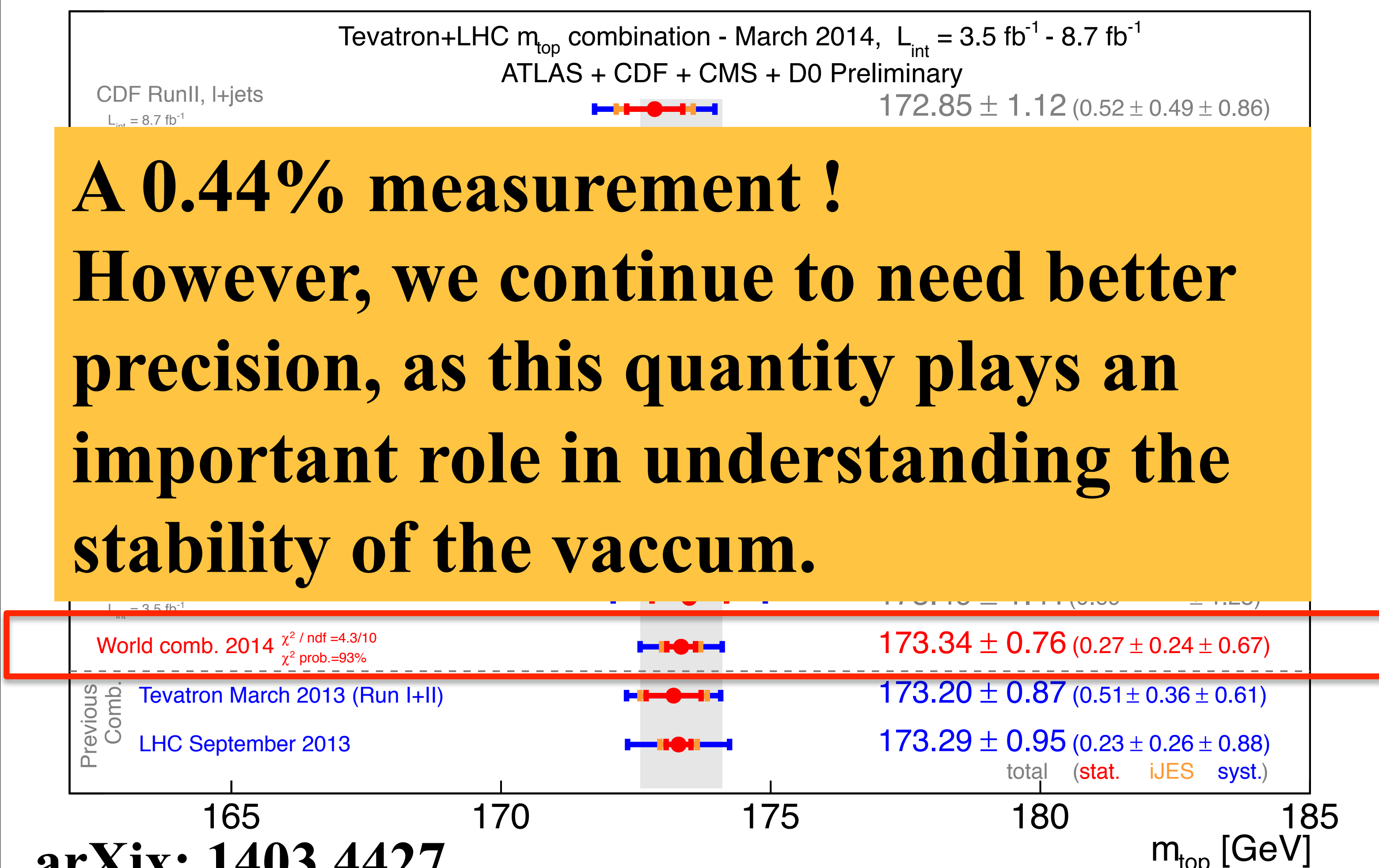
→ We should measure these effects even if they look un-spectacular or out of reach as far as the SM predictions are concerned



$A_{FB} = (10.6 \pm 3)\%$

Now in agreement with SM

Top Quark Mass



A 0.44% measurement !
However, we continue to need better precision, as this quantity plays an important role in understanding the stability of the vaccum.

arXix: 1403.4427

D0 updte – single measurement :

$$M_t = 174.98 \pm 0.58 \text{ (stat.+JSF)} \pm 0.49 \text{ (syst.) GeV}$$
$$= 174.98 \pm 0.76 \text{ GeV}$$

Narain, 5/23/2014

arXiv:/1405.1756

Top Quark Mass: theory issues

- Confinement prevents us from seeing free top-quarks
- What is the meaning of the top-quark mass ?
  - Value depends on renormalization scheme used to define the parameters in theor. predictions
- Measure mass in specific scheme through comparison/fit:

$$O_{th.}(m_t^R, \ldots) \quad \Longleftrightarrow \quad O_{exp.}$$

- "The systematic uncertainty related to the specific MC choice is found to be marginal with respect to the possible intrinsic difference between the top-quark mass implemented in any MC and the pole mass definition"

Related uncertainty

$$\Delta m \approx 0.5 \text{ GeV}$$

[arXiv 1403.4427]

HEAVY FLAVOR PHYSICS HIGHLIGHTS

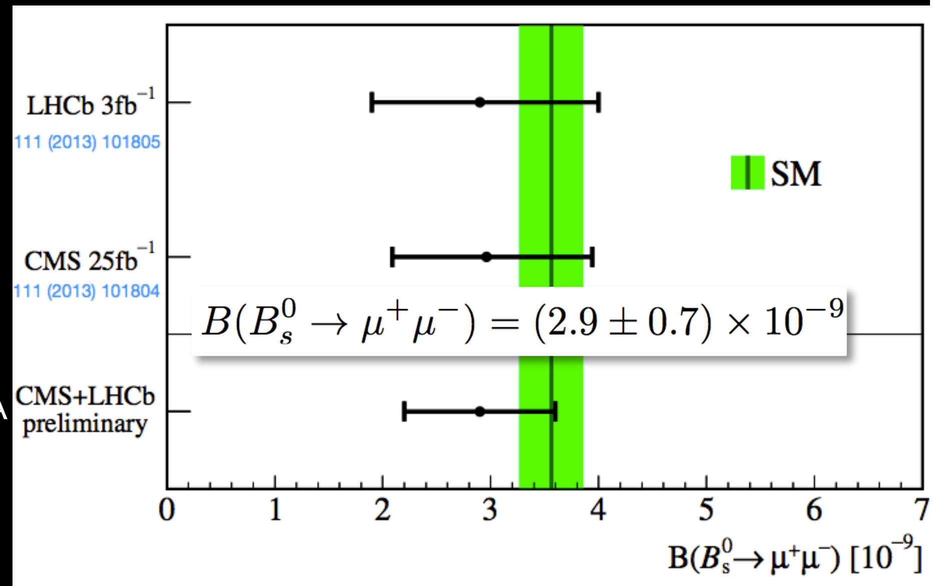
Koppenburg, Piilonen, Tovey

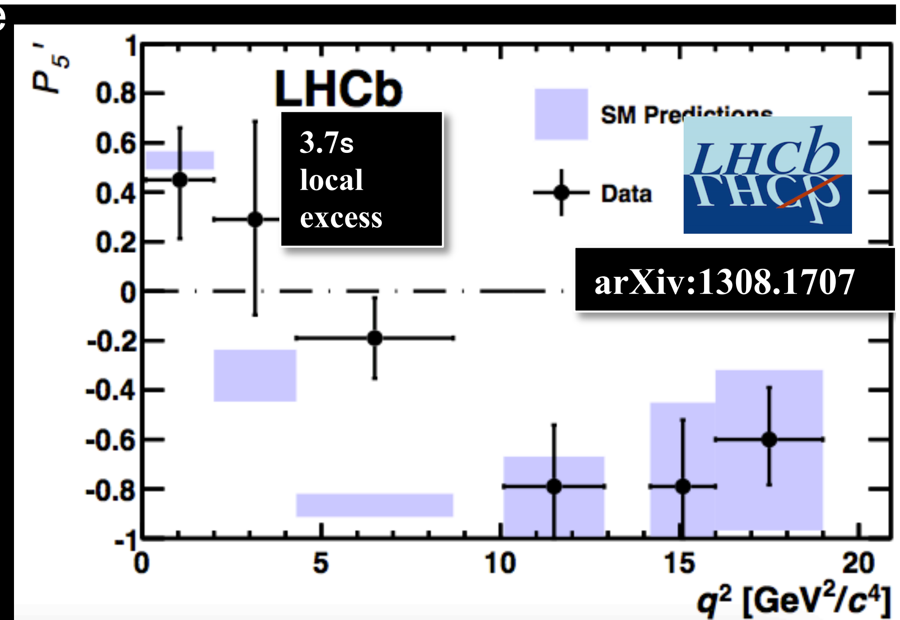
Rare decays

- First observation of $B^0_s \rightarrow \mu^+\mu^-$ from LHCb+CMS combination.
  - Consistent with SM expectation

    $$B(B_s^0 \to \mu^+\mu^-) = (3.56 \pm 0.30) \times 10^{-9}$$

  - Strong constraints on BSM physics, e.g. SUSY with large tanβ and small m_A
- $b \rightarrow s\mu^+\mu^-$ rare processes sensitive to BSM couplings
  - LHCb study e.g. $B^0 \rightarrow K^{*0++}\mu^+\mu^-$ measure angular variables as well as differential cross-section
  - Range of measurements mostly in excellent agreement with SM
  - Some tension in amplitude observable P5' at low q^2 in 7 TeV data
  - Analysis of 8 TeV data underway



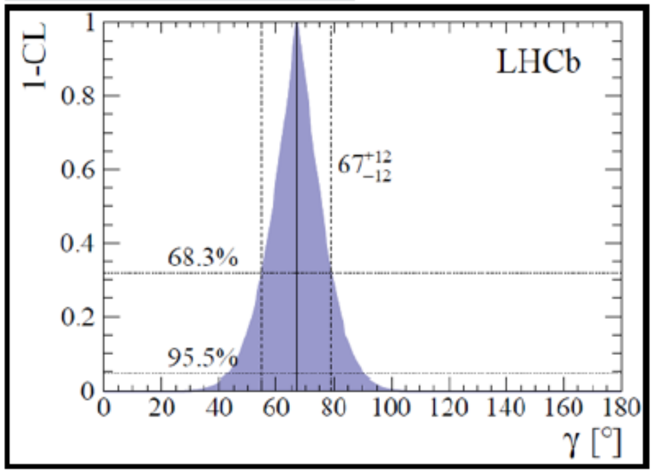


LHCb is having a big impact

$B^- \to \overset{(-)}{D}{}^0 K^-$ to measure ϕ_3 $(=\gamma)$: all 3 methods

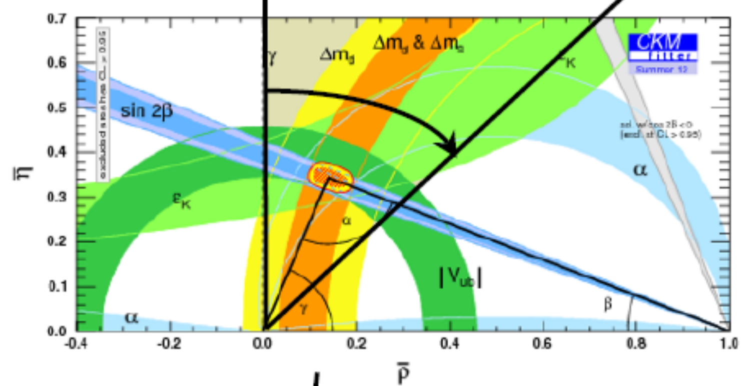
Combined ADS, GLW (1 fb^{-1}) and GGSZ (3 fb^{-1})

PLB **726**, 151 (2013)

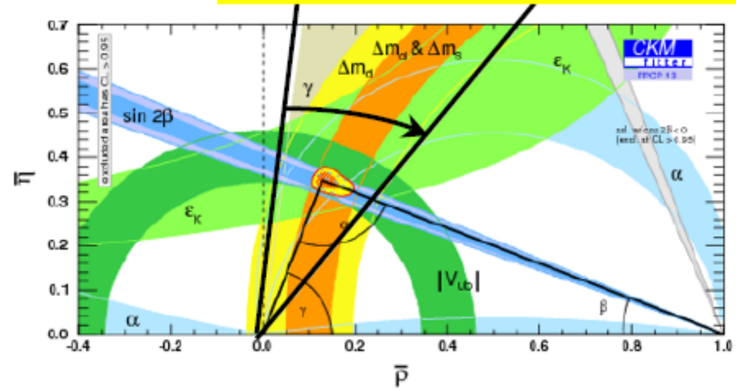


$$\gamma = (67 \pm 12)^\circ$$

2012: Before 1st LHCb results



2013: After including LHCb results

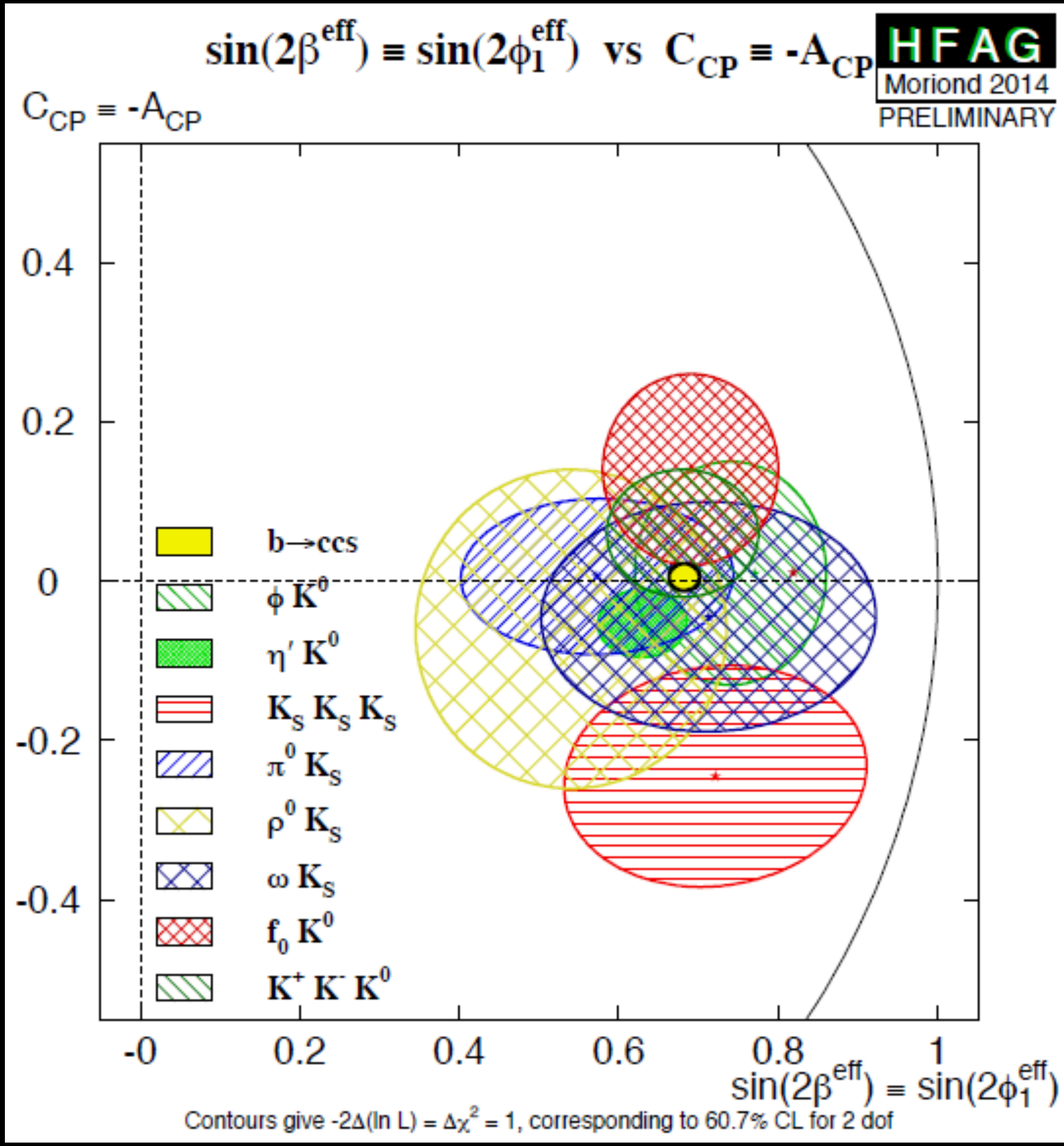


Piilonen

By 2018, expect $\sigma_\gamma \sim 4^o$

Alas – no new physics yet

- Many new CP-asymmetry results emerging from Belle, LHCb, etc
- No significant deviations from SM expectations



ν NEWS

Gouvea, Lisi, Mezetto, DeYoung, Chen, Kaufman, Becerici-Schmidt, Sgalaberna, Yermia, Qian,

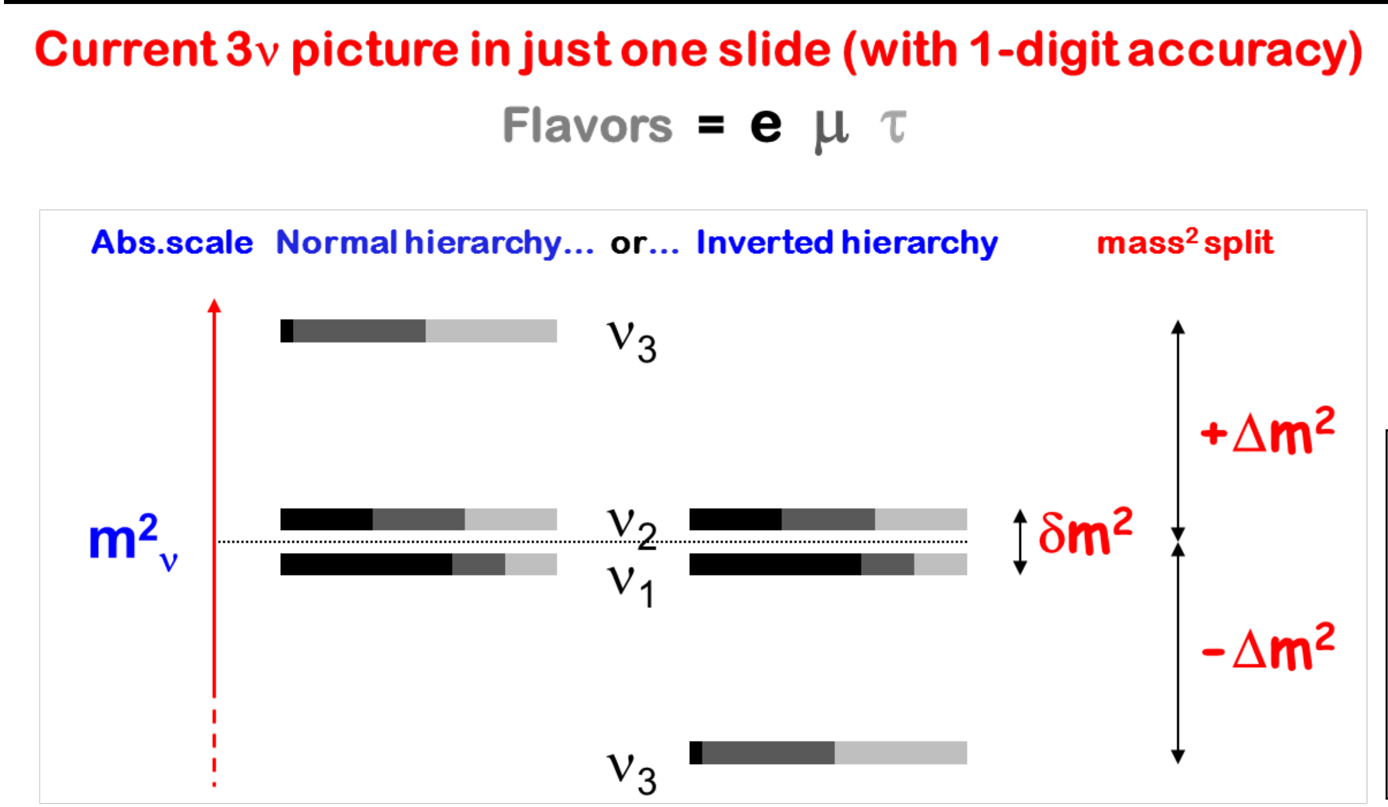
open questions

An “experiment driven field”

- what are mixing angles and mass differences?
- normal or inverted mass hierarchy?
- what are the absolute mass values?
- Dirac or Majorana fermion?
- is there CP violation?
- How many 3 neutrino flavors/is there a sterile neutrino?

neutrino masses and heirarchy

- Why are the neutrinos so light?
- Mass hierarchy?



Knowns:
dm^2 ~ 8 x 10^{-5} eV^2
Dm^2 ~ 2 x 10^{-3} eV^2
sin^{2}q$_{12}$ ~ 0.3
sin^{2}q$_{23}$ ~ 0.5
sin^{2}q$_{13}$ ~ 0.02

Unkowns:
d (CP)
sign(Dm^2)
octant(sin^{2}q$_{23}$)
absolute mass scale
Dirac/Majorana nature

No significant preference for NH vs IH from global fit to *ν*3 hypothesis.
Intriguing hint of nonzero CP violation, with sinδ < 0 ... (*)

ν oscillations

- T2K results
  - $\nu_\mu \rightarrow \nu_\mu$ disappearance
    - world's best measurement of $\sin^2\vartheta_{23}$

90% 1D confidence intervals

NH: $0.428 < \sin^2\theta_{23} < 0.598$
$2.34 < \Delta m^2_{32}\ (eV^2/c^4) < 2.68\ (\times 10^{-3})$

IH: $0.427 < \sin^2\theta_{23} < 0.596$
$2.31 < \Delta m^2_{13}\ (eV^2/c^4) < 2.64\ (\times 10^{-3})$

  - $\nu_\mu \rightarrow \nu_e$ appearance
    - first conclusive observation ($7.3\boldsymbol{\sigma}$)
    - tension with reactors for certain values of $\boldsymbol{\delta}_{CP}$

Best-fit value

NH: $\sin^2 2\theta_{13} = 0.140\ ^{+0.038}_{-0.032}$
IH: $\sin^2 2\theta_{13} = 0.170\ ^{+0.045}_{-0.037}$

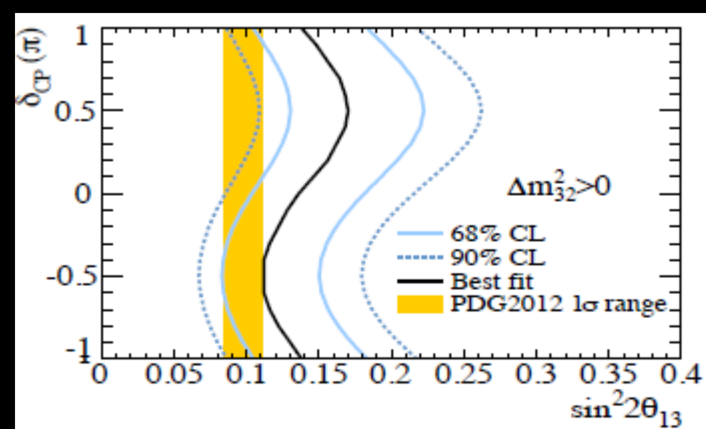
$\Delta m^2_{21} = 7.60 \times 10^{-5}\ eV^2/c^4$, $\sin^2\theta_{12} = 0.306$, $\sin^2\theta_{23} = 0.5$, $|\Delta m^2_{32}| = 2.4 \times 10^{-3}\ eV^2/c^4$, $\delta_{CP} = 0$

  - ν_μ and ν_e joint fit for $\boldsymbol{\delta}_{CP}$
    - best fit at $\boldsymbol{\delta}_{CP} \approx$-pi/2

90% CL allowed intervals

NH: $-1.18\pi < \delta_{CP} < 0.15\pi$

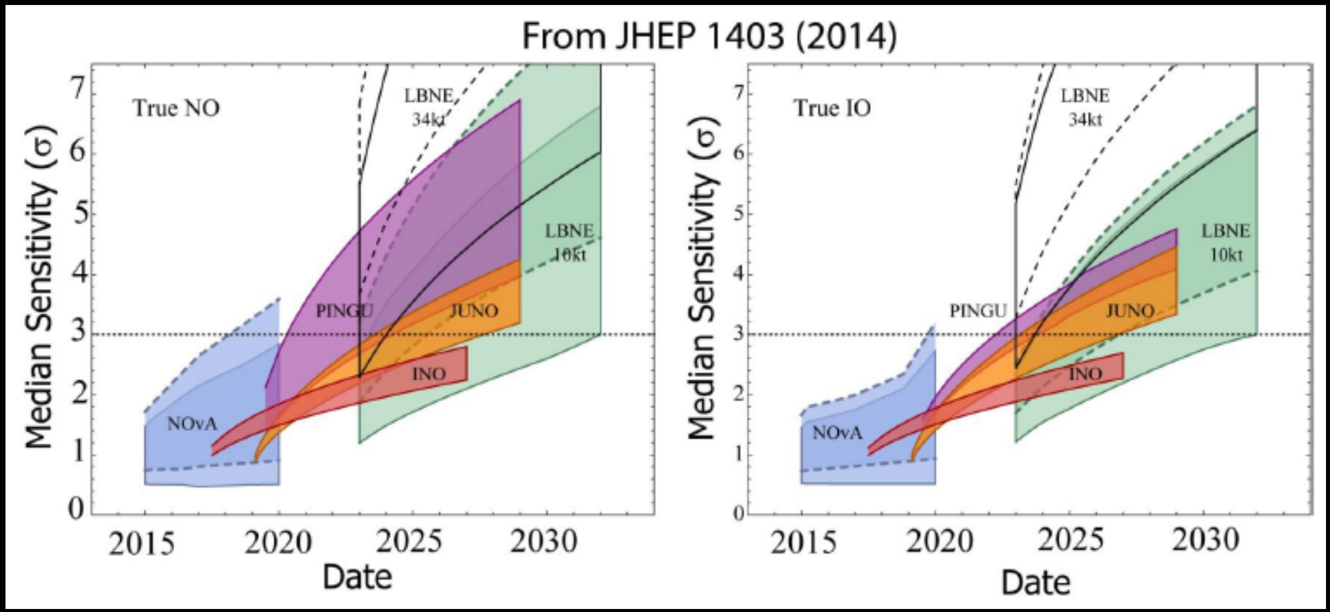
IH: $-0.91\pi < \delta_{CP} < -0.08\pi$



ν oscillations

- Double Chooz
  - rate+shape fit $\sin^2 2\theta_{13}=0.109\pm0.035$
  - reactor rate modulation $\sin^2 2\theta_{13}=0.097\pm0.035$
- Daya Bay
  - $\sin^2 2\theta_{13}=0.090^{+0.008}_{-0.009}$
  - $|\Delta m_{ee}^2|=2.59^{+0.20}_{=0.19}$ x 10^{-3} eV^2
- we are seeing the beginning of precision ν physics

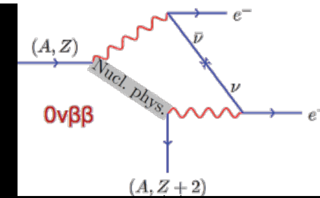
mass hierarchy searches



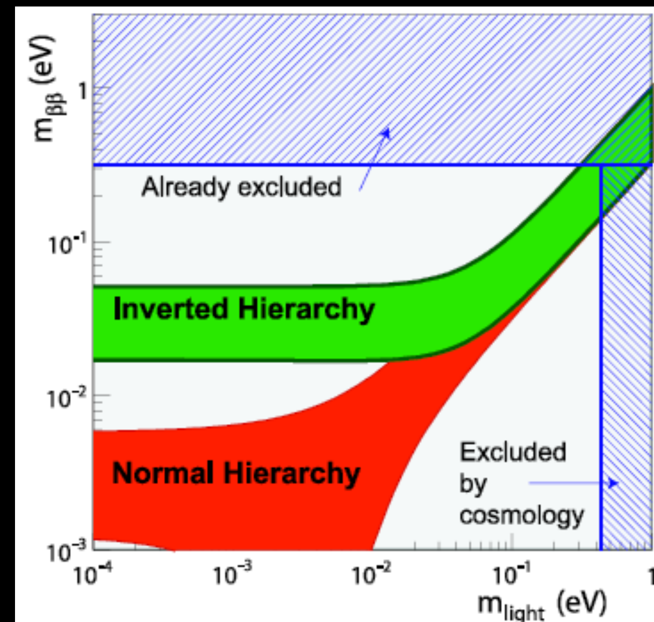
- there is sensitivity to reject inverted hierarchy
- normal hierarchy more difficult, requires LBNE
- don’t expect an answer for another 8-10 years

- MH generates fake CP effects in neutrino oscillations, hiding genuine CP asymmetries. Knowing MH would improve long baseline sensitivities on CP (but LBL experiments can measure MH by themselves)

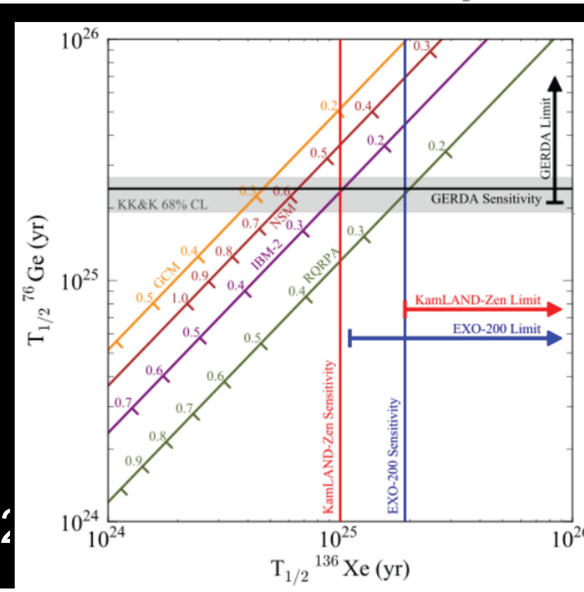
$0\nu\beta\beta$



- occurs if ν is a Majorana fermion
- could reject Majorana hypothesis for inverted hierarchy
  - If oscillations tell us that we have an inverted hierarchy, but the 0vββlimits extend down to 10 meV, probably the Majorana hypothesis would be in trouble.

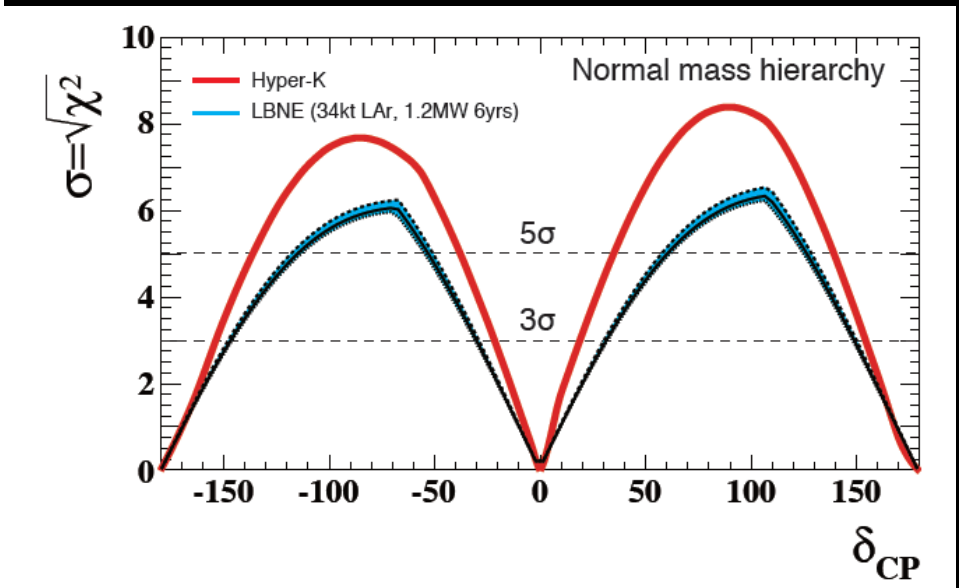


- EXO 200 (^{136}Xe gas)
  - $t_{1/2}$>1.1x10^{25} y
  - $m_{\beta\beta}$<190-450 meV
- GERDA (^{76}Ge in liquid Argon)
  - $t_{1/2}$>2.1x10^{25} y
  - $t_{1/2}$>3x10^{25} y combined with HdM and IGEX
  - disfavors claim by Klapdor-Kleingrothaus PLB 586 (2

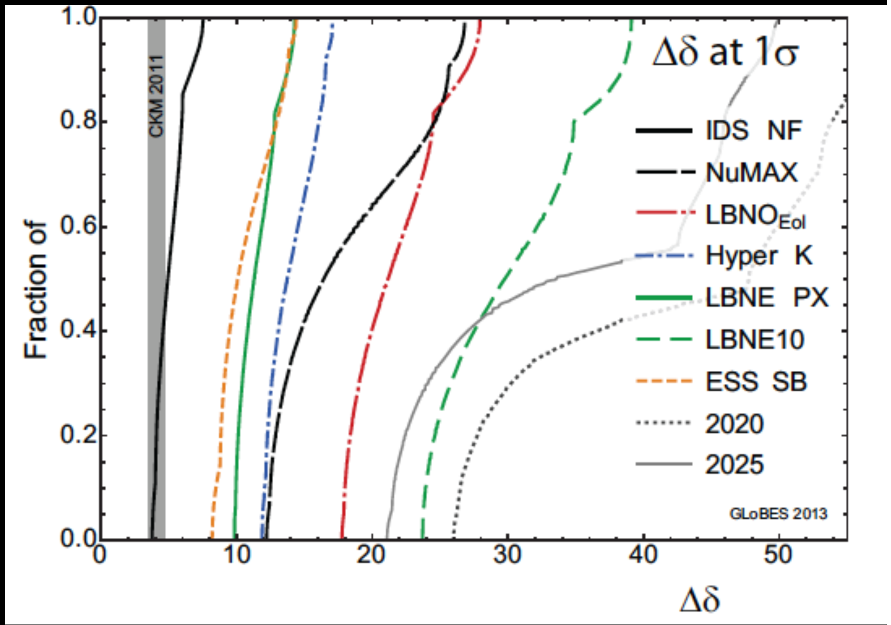


CP violation sensitivity

- reasonable sensitivity to CPV phase
- comparison of Hyper-K and LBNE



LBNE sensitivity from Fig.4.11 of arXiv:1307.7335



From SnowMass paper arXiv: 1310.430, Original paper: arXiv: 1311.1822v2

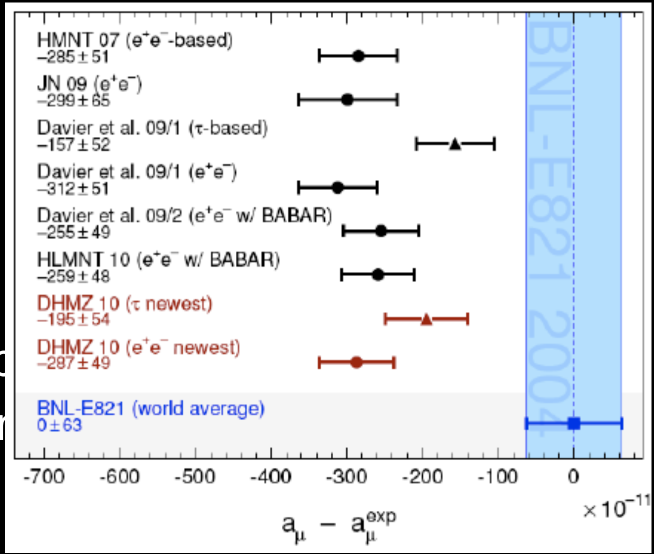
lepton flavor violation

- not seen yet, and expected to be tiny in νSM

Gouvea

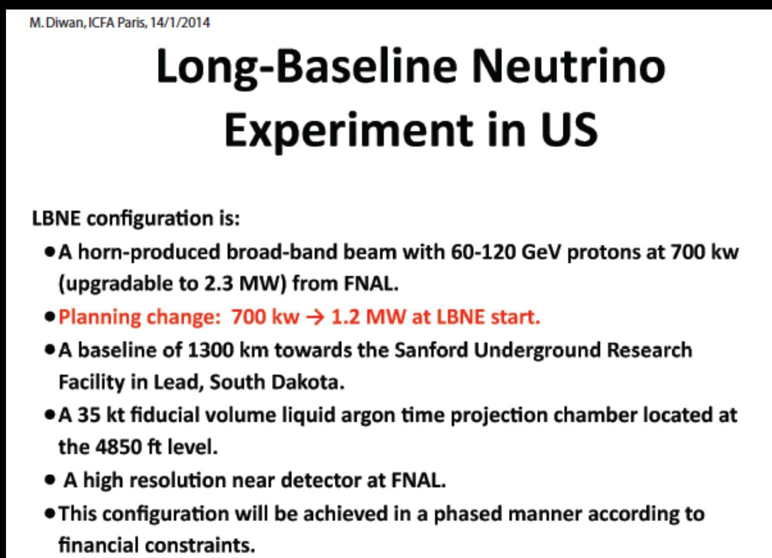
6. If there is new physics at the electroweak scale, there is every reason to believe that CLFV is well **within the reach of next generation experiments**. Indeed, it is fair to ask: 'Why haven't we seen it yet?'
   - It is fundamental to probe **all** CLFV channels. While in many scenarios $\mu \to e\gamma$ is the "largest" channel, there is no theorem that guarantees this (and many exceptions).

- Near Future (Optimistic View)
  - MEG: $\mu \to$e at several 10^{-14}
  - g-2 measurement 3-4 x more precise
  - COMET (Phase I) $\mu \to$e at 10^{-14}
  - Mu2e/COMET (Phase II) $\mu \to$e at 10^{-17}
  - PSI:μ $\to$eee at 10^{-15}
  - SuperB: Rare processes at 10^{-10}
  - Next-next-generation: $\mu \to$e at several 10^{-18} (or p
  - Next-next-generation: deeper probe of muon edr
  - Muon Beams/Rings: $\mu \to$e at several 10^{-20}?



Future experiments

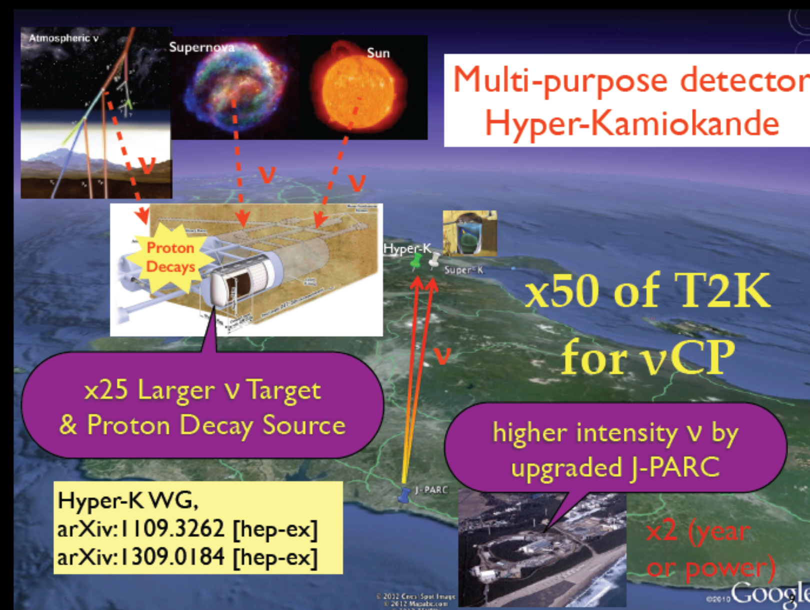
- Two major international collaborations, “LBNF” and T2HK, are growing


M. Diwan, ICFA Paris, 14/1/2014

Long-Baseline Neutrino Experiment in US

LBNE configuration is:

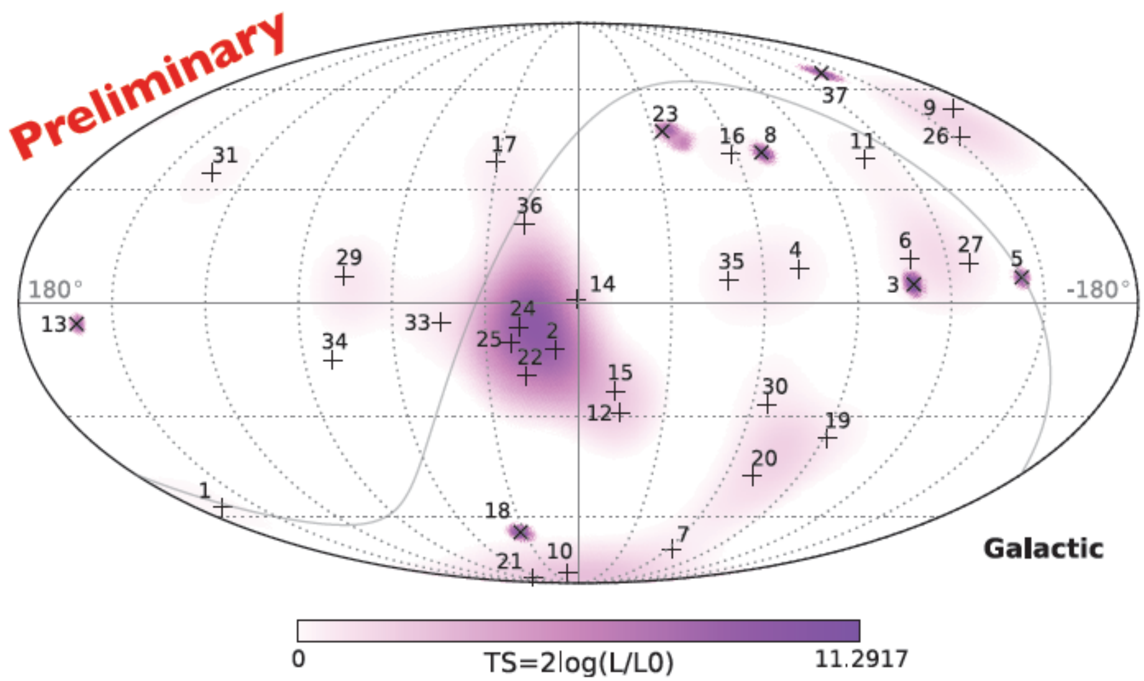
- A horn-produced broad-band beam with 60-120 GeV protons at 700 kw (upgradable to 2.3 MW) from FNAL.
- Planning change: 700 kw → 1.2 MW at LBNE start.
- A baseline of 1300 km towards the Sanford Underground Research Facility in Lead, South Dakota.
- A 35 kt fiducial volume liquid argon time projection chamber located at the 4850 ft level.
- A high resolution near detector at FNAL.
- This configuration will be achieved in a phased manner according to financial constraints.



IceCube Sky Map

- Compelling evidence for an astrophysical flux of neutrinos at energies of 100 TeV – 2 PeV
  - Energy spectrum around dN/dE ~ $E_\nu^{-2.0}$ to $E_\nu^{-2.4}$
  - Probably require either softer spectrum or a cutoff at 3-5 PeV
  - Consistent with equal fluxes of each neutrino flavor

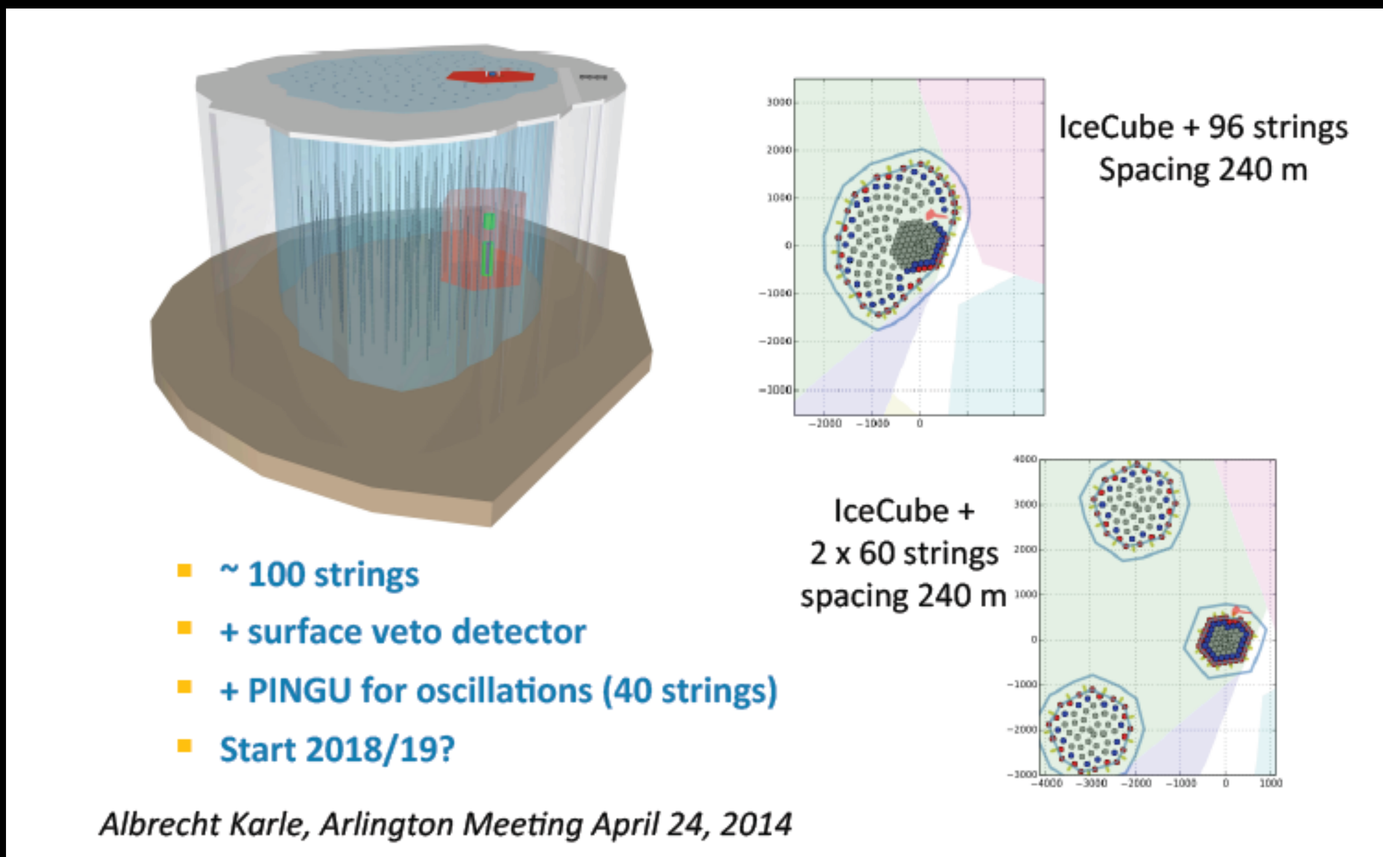
- Consistent with an isotropic flux, although cannot rule out that a substantial part comes from a few bright sources
  - At least some of the flux comes from extragalactic sources



[Claudio Kopper, Moriond EW 2014]

Next Generation IceCube

- Extending analyses, but with current instruments, event rates are low and progress will be slow
  - Several proposals for next-generation detectors



Cosmology constraints on ν mass

- Cosmological detection of neutrino mass, Σm_ν.

	$\sigma(r)$	$\sigma(N_{eff})$	$\sigma(\Sigma m_\nu)$
Current CMB	**0.1**	**0.34**	**117** meV
2016 Stage 2: SPTpol	0.03	0.12	96 meV
2020 Stage 3: SPT-3G	0.01	0.06	61[a] meV
2024 Stage 4: CMB-S4	**0.001**	**0.02**	**16**[b] meV

The CMB measurements will achieve important benchmarks:

- Energy scale of inflation? Test large vs small field inflation
- Dark Radiation? New physics in neutrino or dark sector?

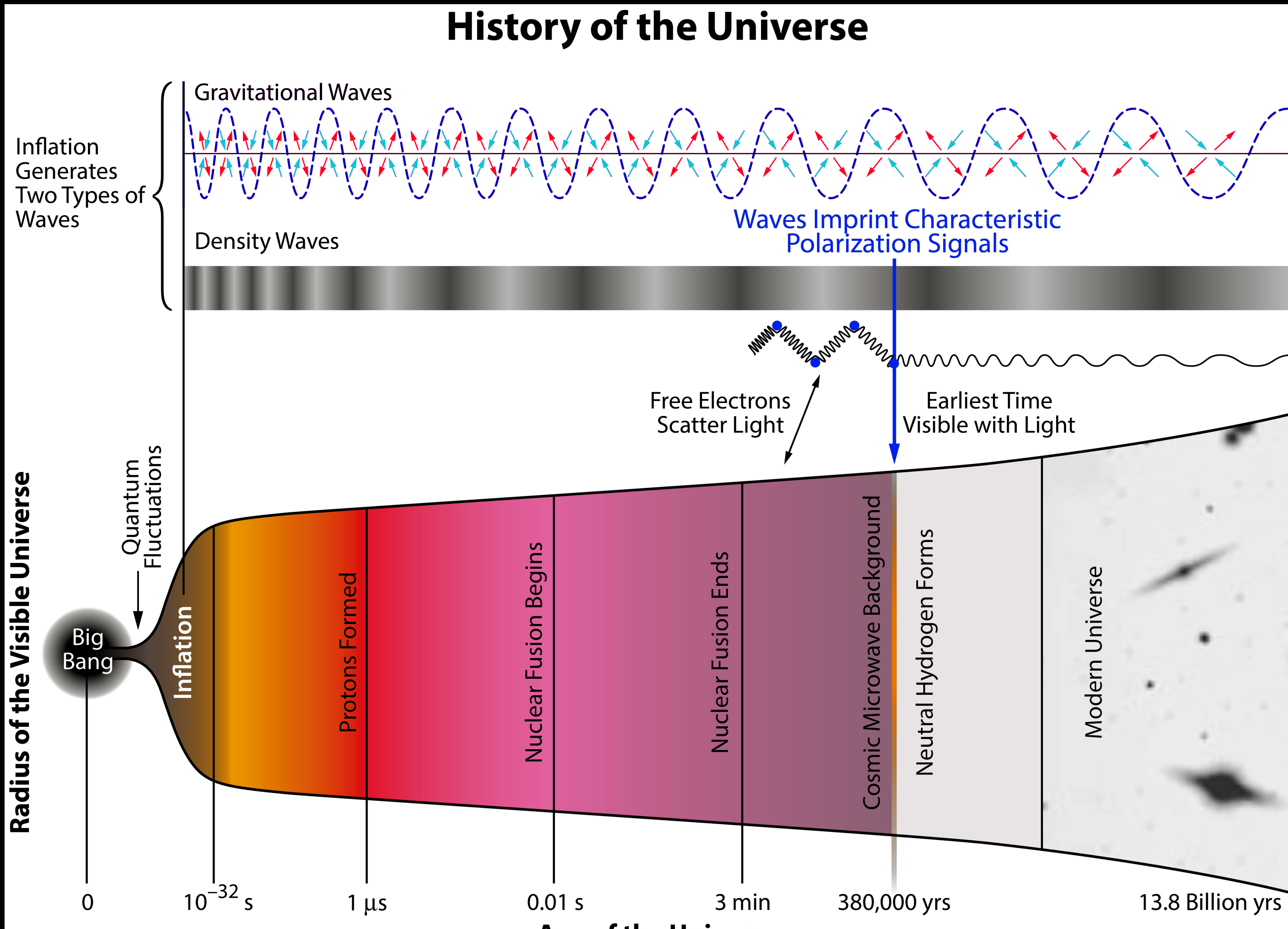
Snowmass: CF5 Neutrinos + Inflation documents arXiv:1309.5383, 1309.5381, see also Wu et al., arXiv:1402.4108

Clarence Chang

COSMOLOGY

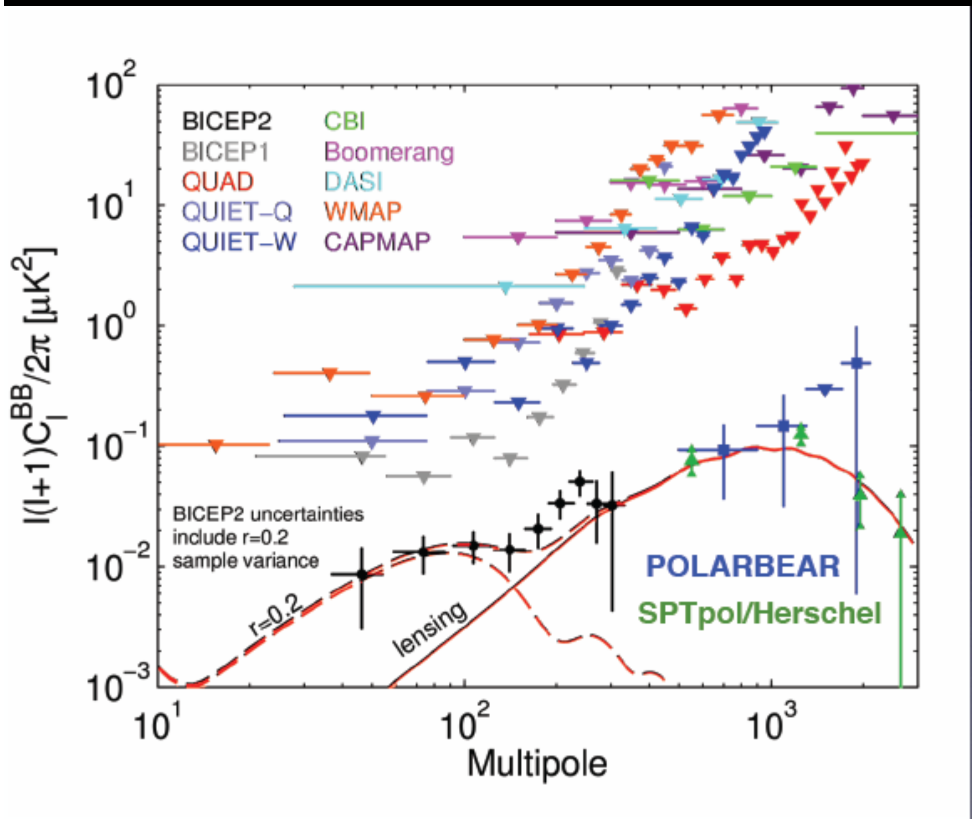
Ganga, Ohm, Fillipini, Chang, Regnault, Soares-Antos

Relic Gravitational Waves – B-Modes



http://bicepkeck.org/visuals.html

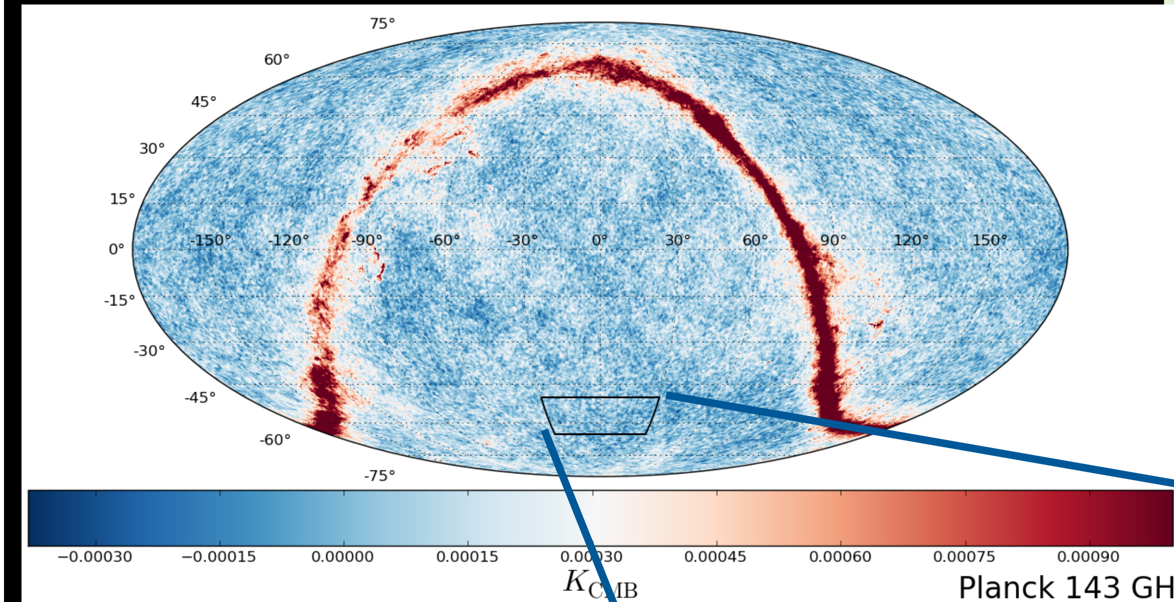
BICEP2: detection of gravitational waves



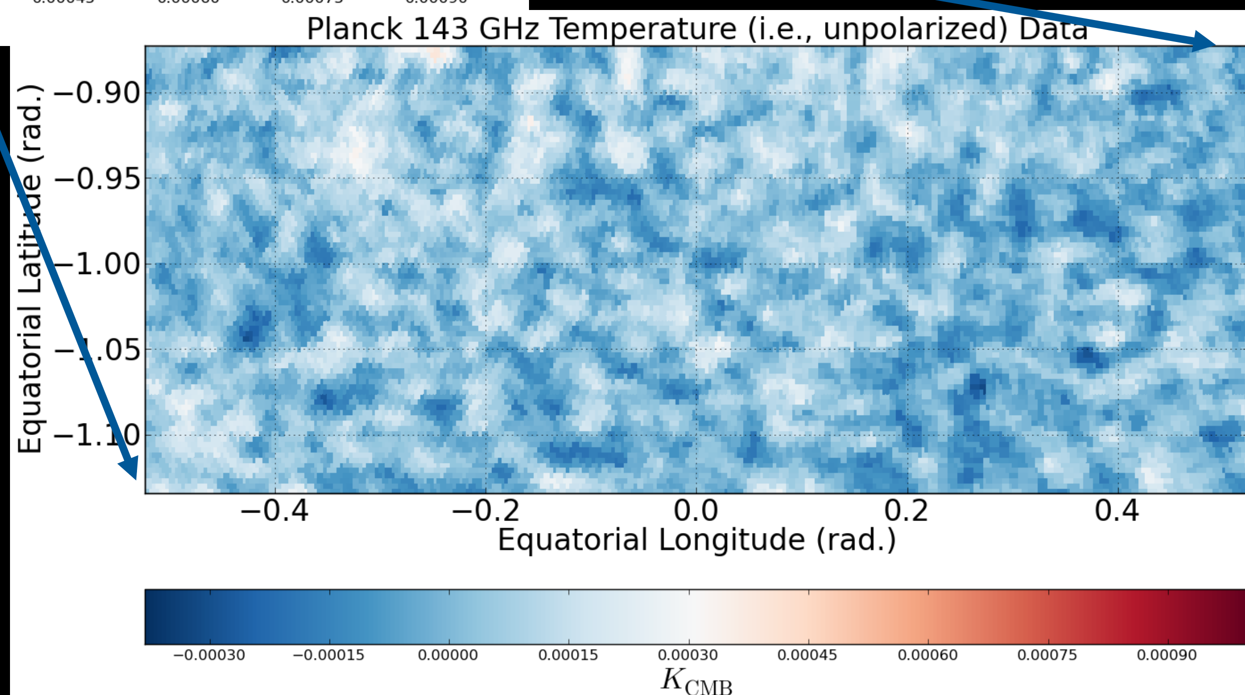
Deepest polarization maps ever made

- 5.3σ excess above lensed ΛCDM; r=0 isfavored at 7σ (no foreground)
- Extensive studies disfavor systematic error as origin
- Foregrounds do not appear to constitute the bulk of the signal
- No-foreground constraint on tensor/ scalar ratio: $r = 0.20^{+0.07}_{-0.05}$
- Consistent with expectations for primordial gravitational waves from GUT-scale inflation

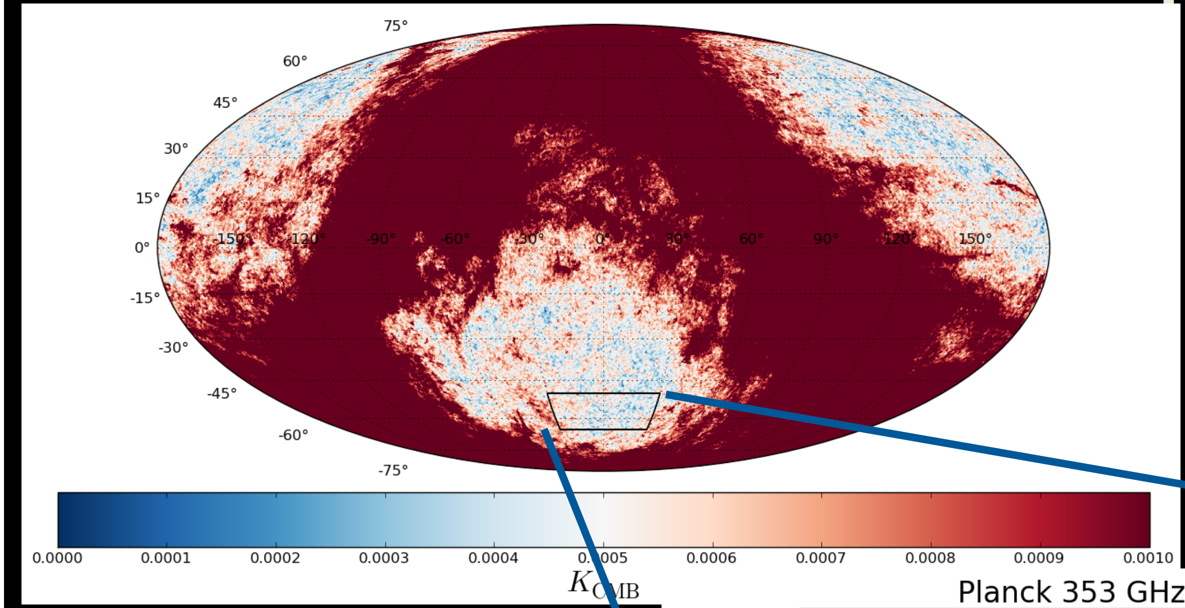
Planck 143 GHz Temperature Map



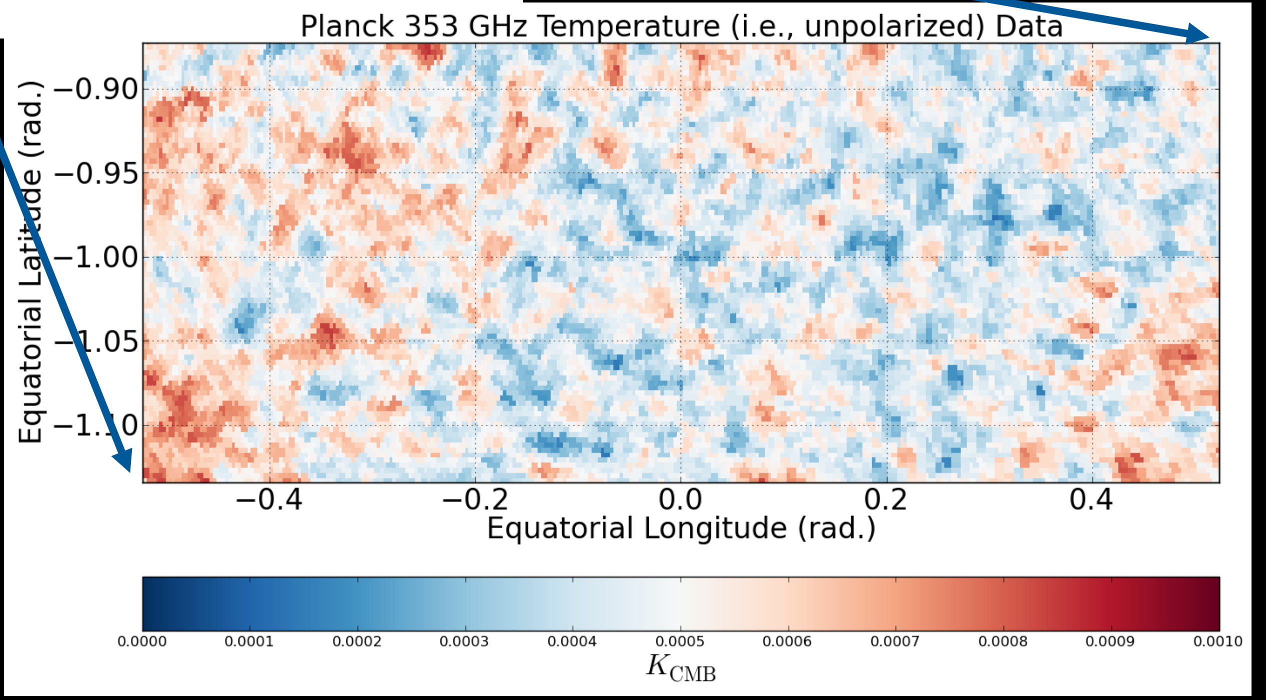
This is a *temperature* map. The analysis for *polarization* is ongoing.



Planck 353 GHz Temperature Map



This is a *temperature* map. The analysis for *polarization* is ongoing.



What Planck is Working on Now

Stokes Q & U at 353 GHz from Planck

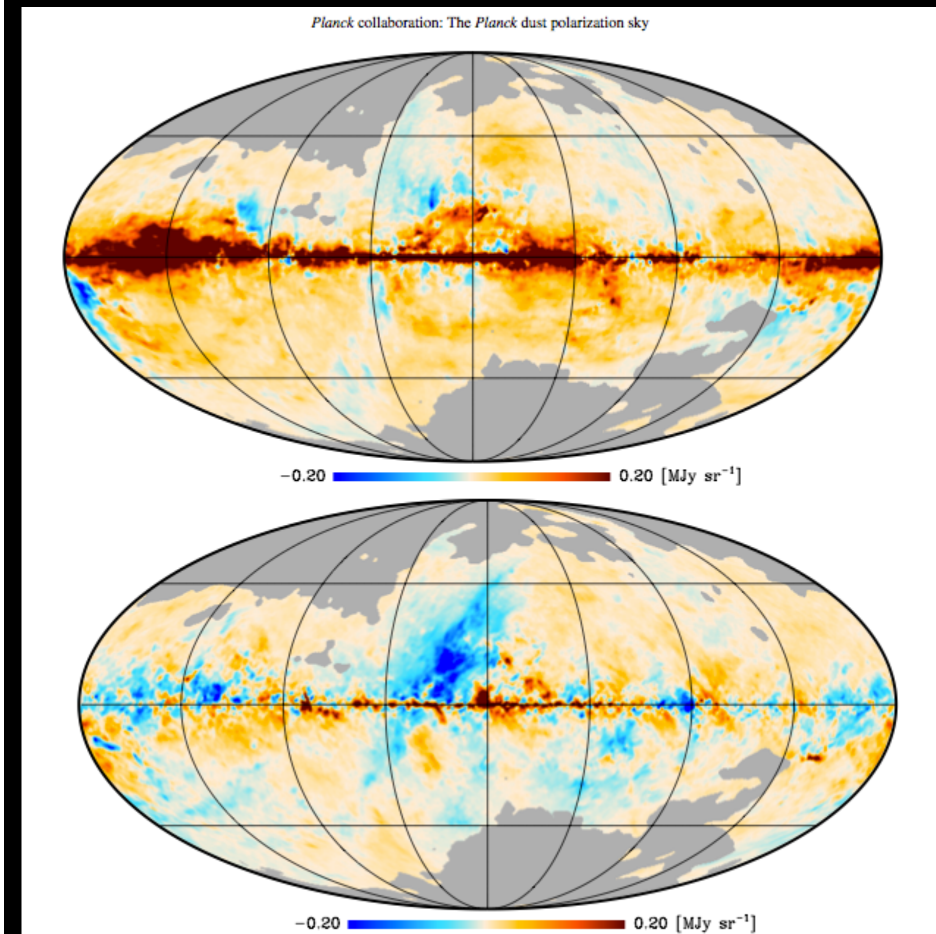


Fig. 1. *Planck* 353 GHz polarization maps at 1° resolution. *Upper*: *Q* Stokes parameter map. *Lower*: *U* Stokes parameter map. The maps are shown with the same colour scale. High values are saturated to enhance mid-latitude structures. The values shown have been bias corrected as described in Sect. 2.3. These maps, as well as those in following figures, are shown in Galactic coordinates with the galactic center in the middle and longitude increasing to the left. The data is masked as described in Sect. 2.4.

arXiv:1405.0871v1 [astro-ph.GA] 5 May 2014

BICEP has more sensitivity than Planck in their field at 150 GHz

BUT, Galactic dust is MUCH brighter at 353 GHz than at 150 GHz

Planck should be able to say much about polarized dust contamination over the full sky, and over the BICEP2 field

Cosmological Probes

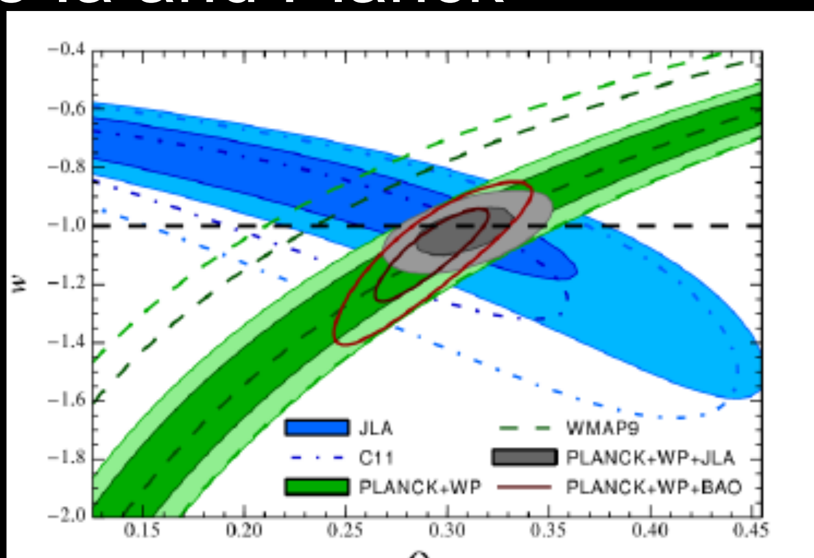
- The smooth Universe
  - Type Ia Supernovae
  - Baryon acoustic oscillations

"0th order cosmology"
Kinematic probes

- Inhomogeneities
  - Clusters
  - Lensing by Large scale structures
  - Redshift space distorsions

"1st order cosmology"
Dynamical probes

- SNe Ia and Planck



- Planck + SNe Ia

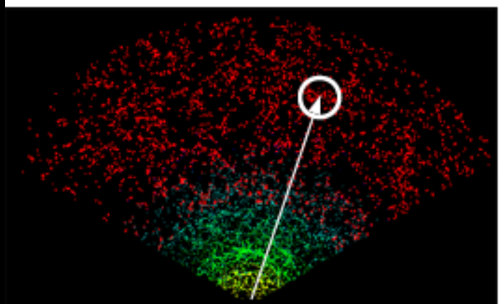
$$w = -1.018 \pm 0.057$$

- FoM ~ 30 (SNe + Planck + BOSS)
- Note : Planck + BAO

$$w = -1.01 \pm 0.08$$

Cosmological Probes

- Baryon Acoustic Oscillations

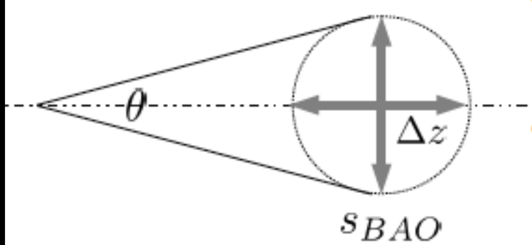


- Transverse direction

$$s_{BAO\perp} = (1+z)D_A(z)\Delta\theta$$

- Parallel direction

$$s_{BAO\parallel} = \frac{c}{H(z)}\Delta z$$



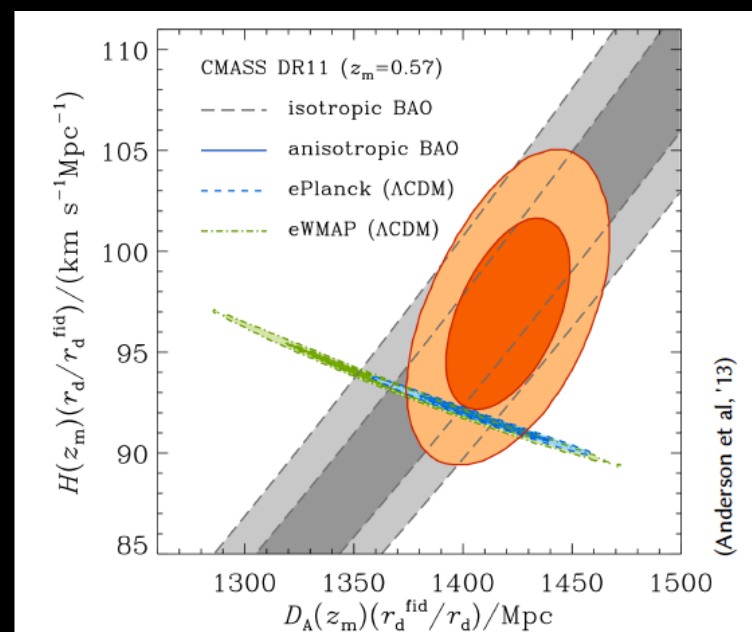
- "Angle averaged" ruler

$$D_V = s_{BAO} \times \left(D_A^2 \frac{cz}{H}\right)^{1/3}$$

- with more statistics

→ separate D_A(z) & H(z)

recent development:
disentangle H and angular distance
direct measurement of H and D_A
at that redshift

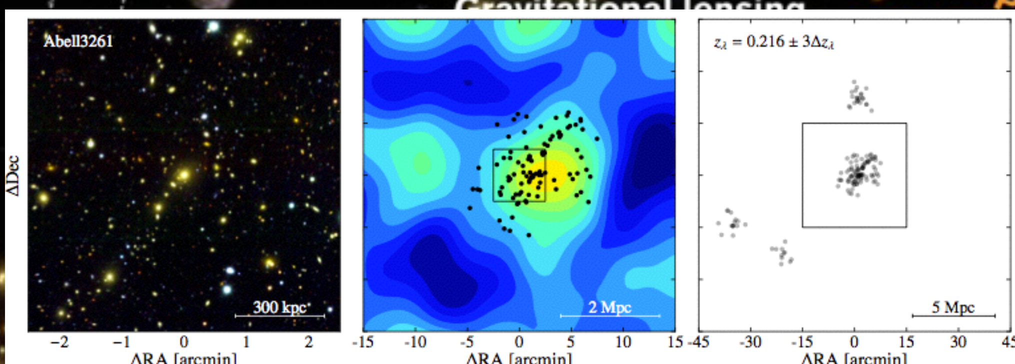


Narain, 5/23/2014

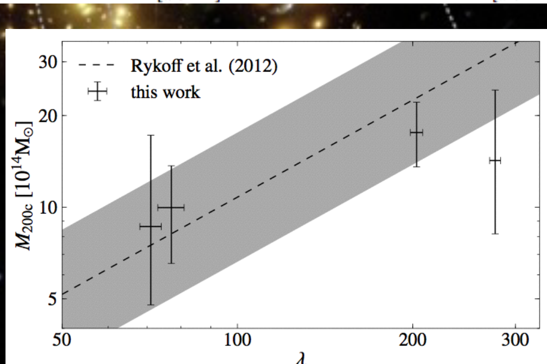
Dark Energy Survey

- completed its 1st season
- successful validation phase.

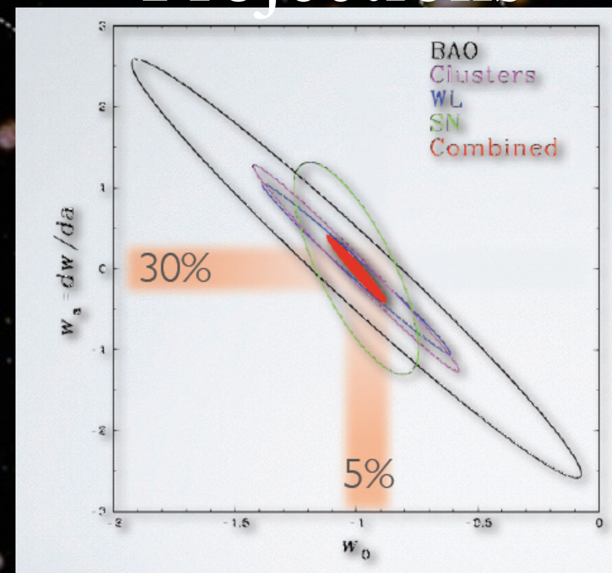
construct cluster masses



Baryon acoustic oscillations



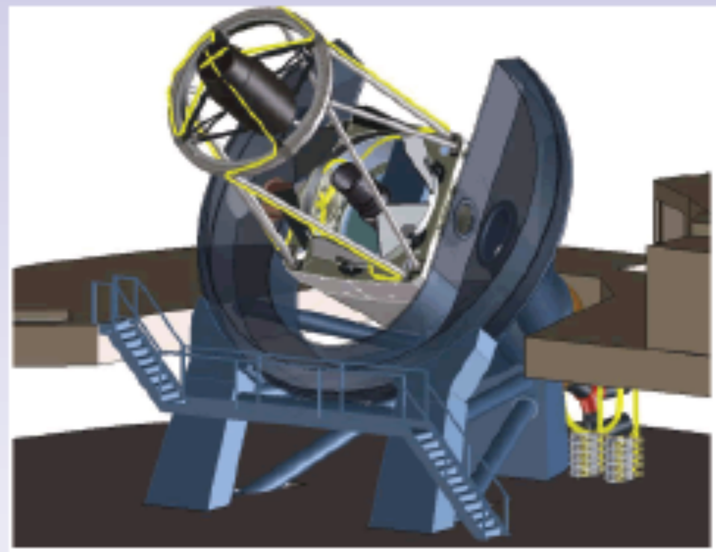
Projections



- 5000 deg^2, 0.9” seeing, 24th mag(redshift~1.4)
- 300M galaxies, shapes, 100K clusters, 4K SNe
- 3-5x improved Dark Energy measurement

Future precision cosmology

- includes LSST and DESI



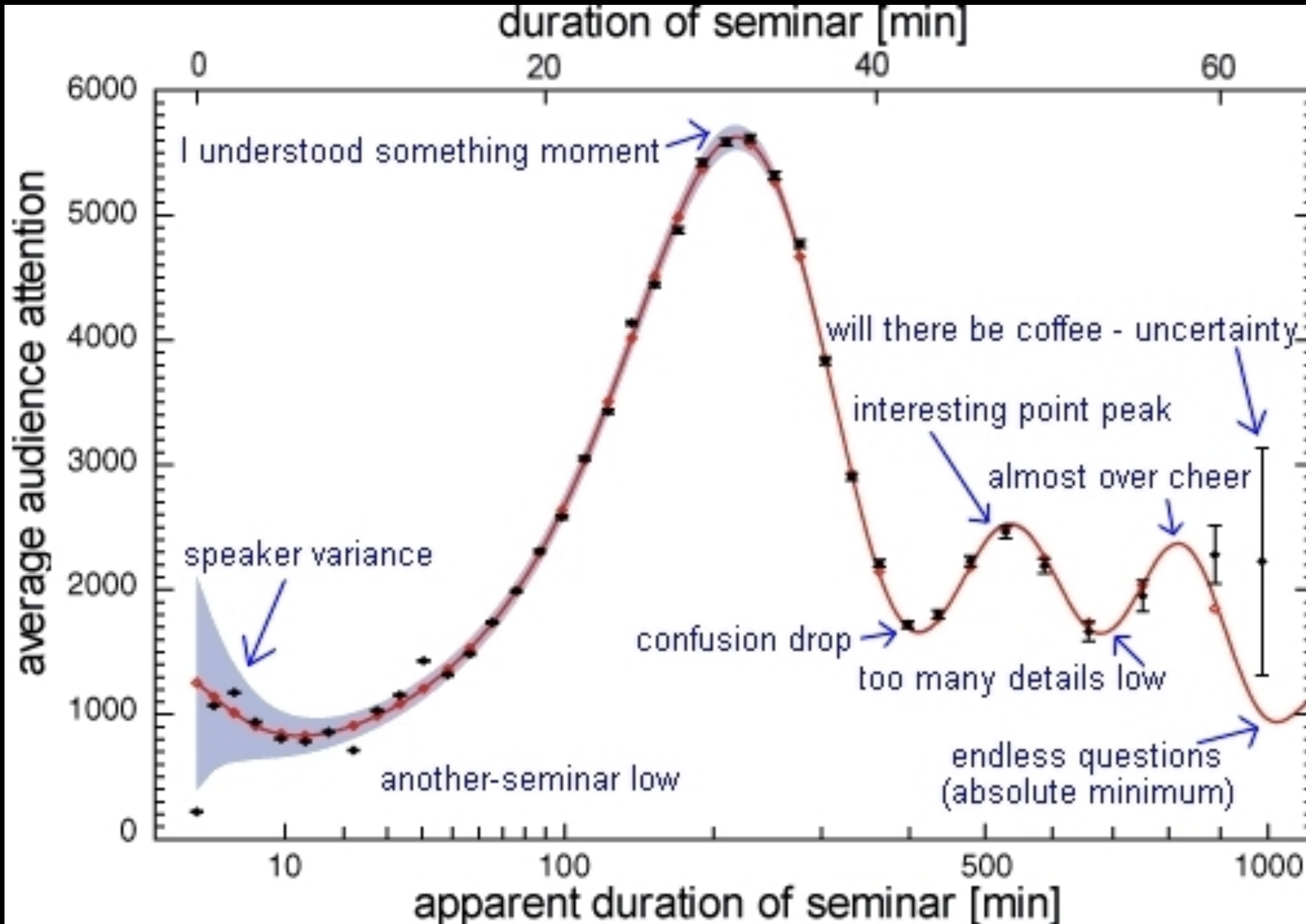
LSST:

- Photometric experiment: takes pictures of the sky
- 5 bands can give an estimate of a redshift

DESI:

- Spectroscopic experiment: takes spectra
- Spectra give redshifts - real 3D experiment

power spectrum for this summary



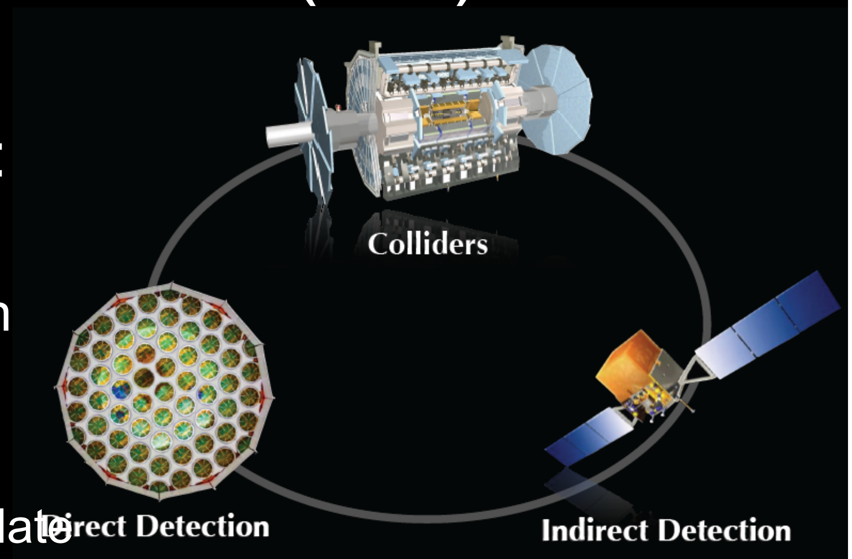
Narain, 5/23/2014

DARK MATTER

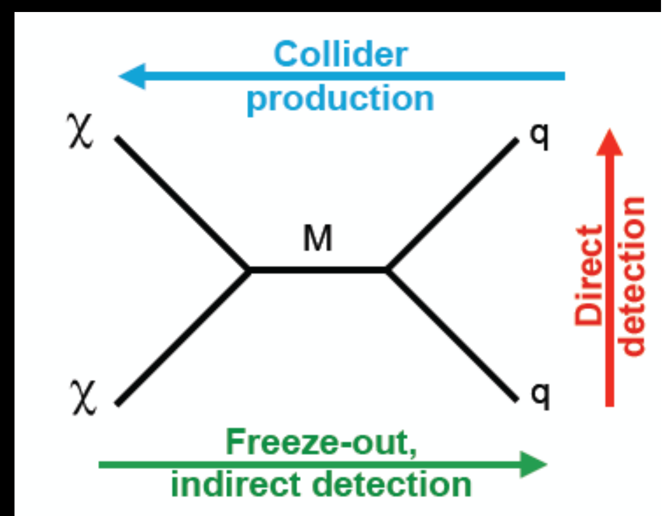
Bertone, Serfass, Hambye, Schuster

WIMP Searches

- WIMPs are preferred dark matter (DM) candidates
- Different but synergistic searches:
  - – direct detection via nuclear recoil
  - – indirect detection via coannihilation in space
  - – direct production at the LHC
    - e.g. SUSY provides a leading candidate
    - or testing the effective operator as in direct searches
    - Very new: Higgs portal to DM

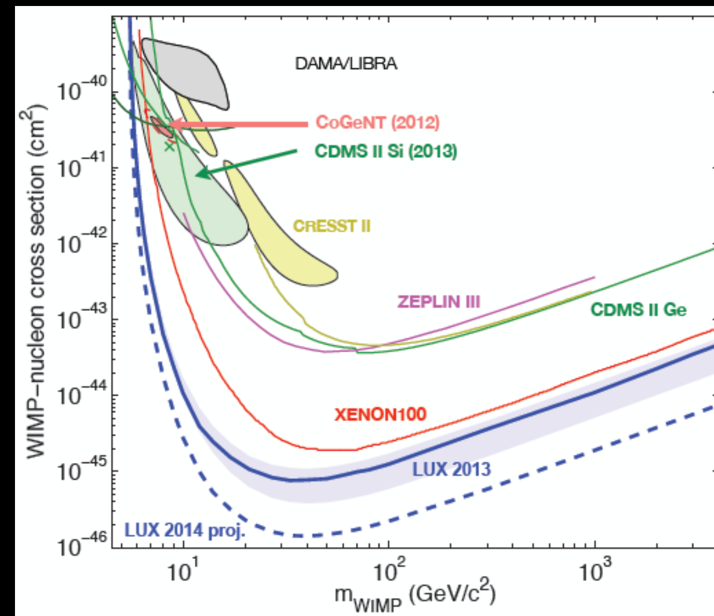


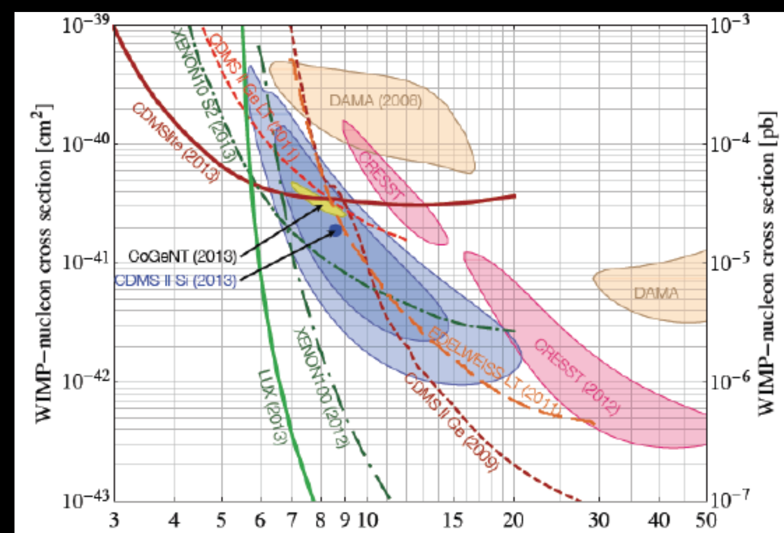
- All three processes are topological permutations of one and the same diagram:



direct detection

- LUX (2013):
  - large impact on the around 10 GeV mass region
  - possibly improved sensitivity by lowering the 3keV cutoff
- SuperCDMS
  - CDMSlite prototype results now the most sensitive in the low mass region
- The hints of light, ~10 GeV DM candidate from Cogent and CDMS have not been confirmed





arXiv:1309.3259

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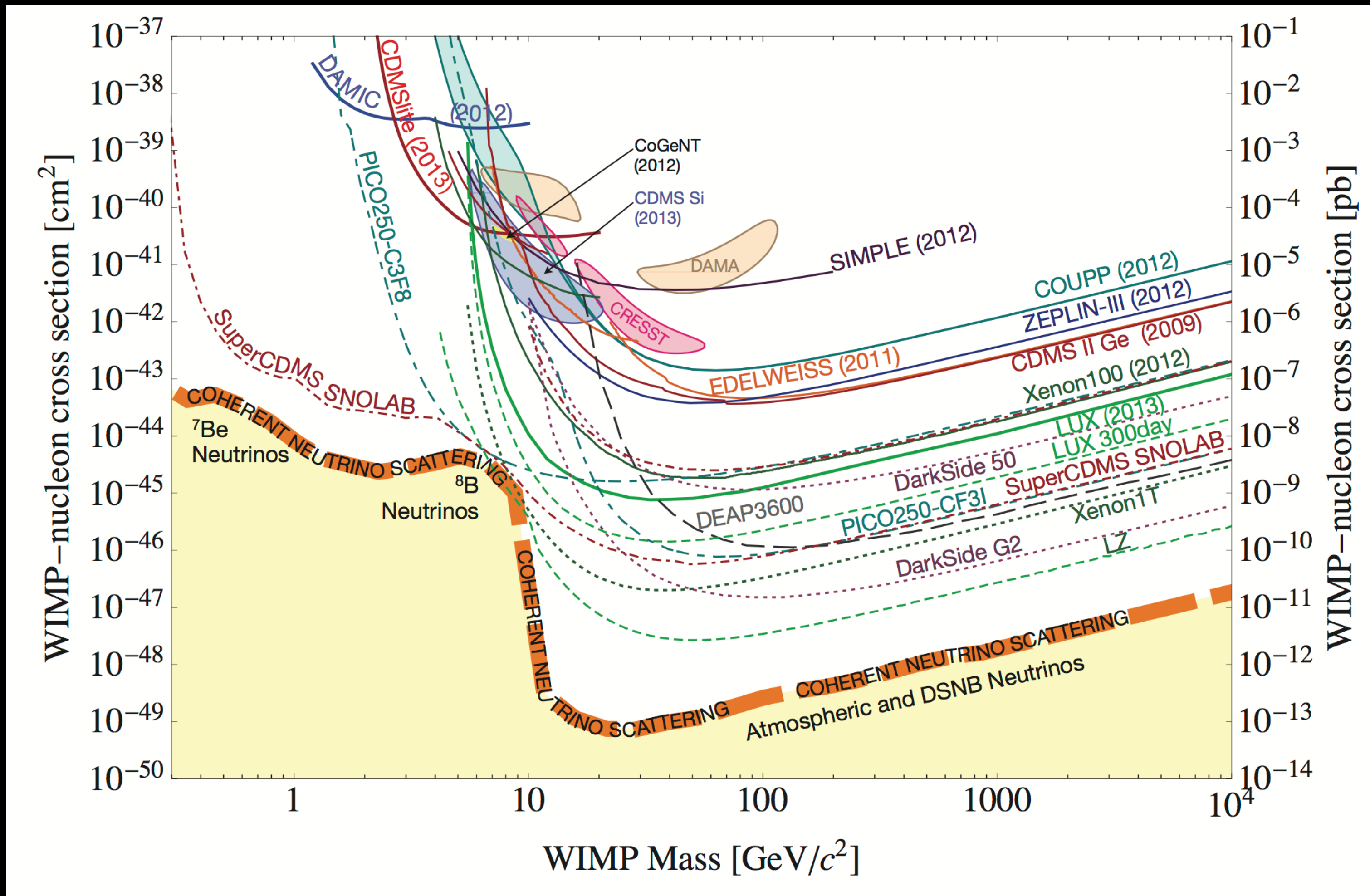
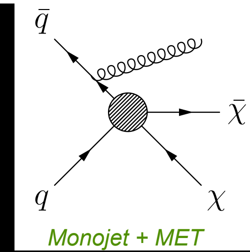
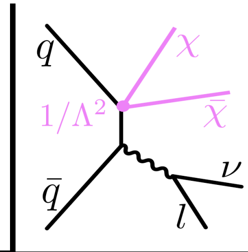
direct detection



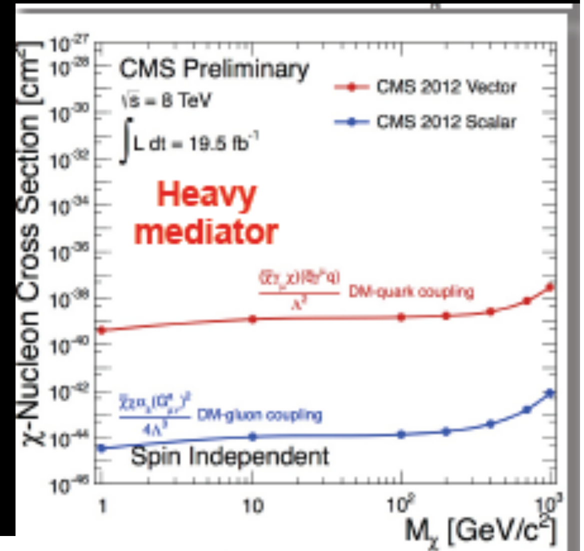
- the low-mass DM reach will hit the irreducible solar neutrino background limit with the next generation of kton detectors
  - issue could be addressed by detectors with directional pointing capability (DRIFT DMRPC)

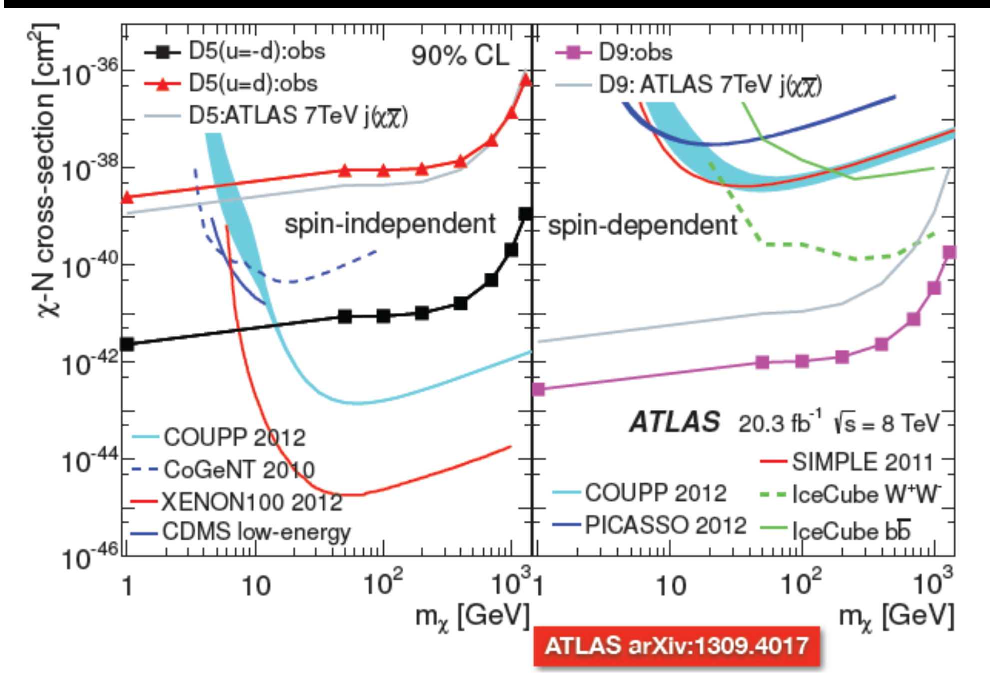
direct production: LHC Mono-Mania

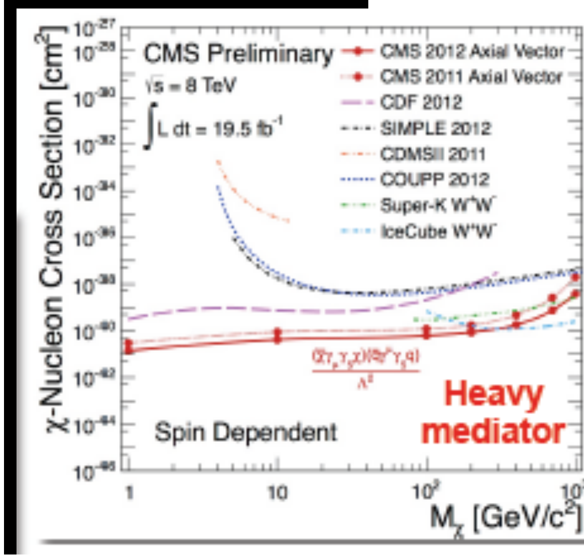




- Searches in monojet, monophoton, and monolepton, mono-W final states a la direct detection experiments by triggering on an ISR jet, photon, or W($l\nu$):
  - Limits are somewhat model-dependent (sensitive to the mediator mass); yet competitive
  - Offer unique sensitivity to DM-gluon couplings

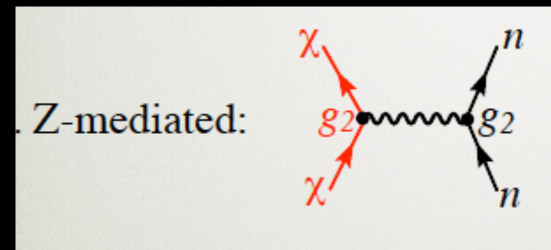


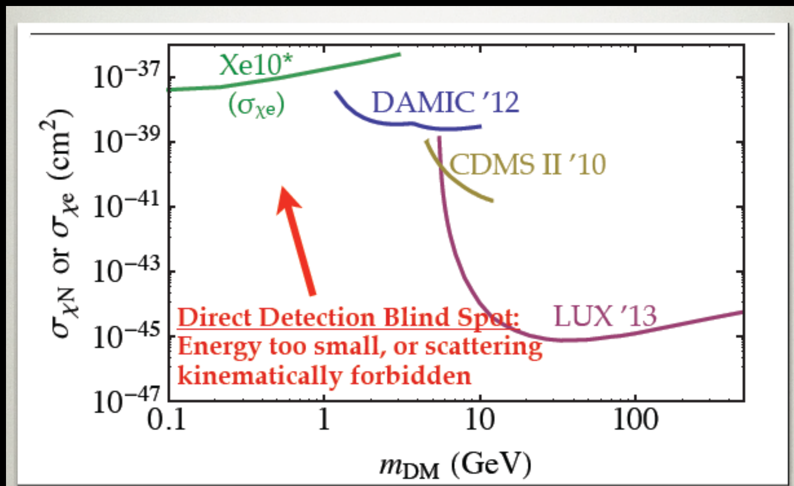




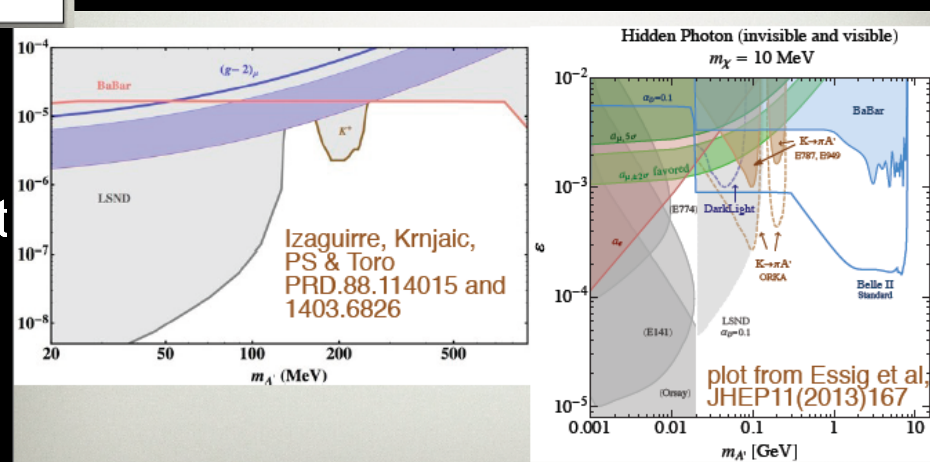
Light Dark Matter

- probe DM just below the weak scale
- Weak-scale mediators provide reasonable annihilation rate and range of DM-scattering rates





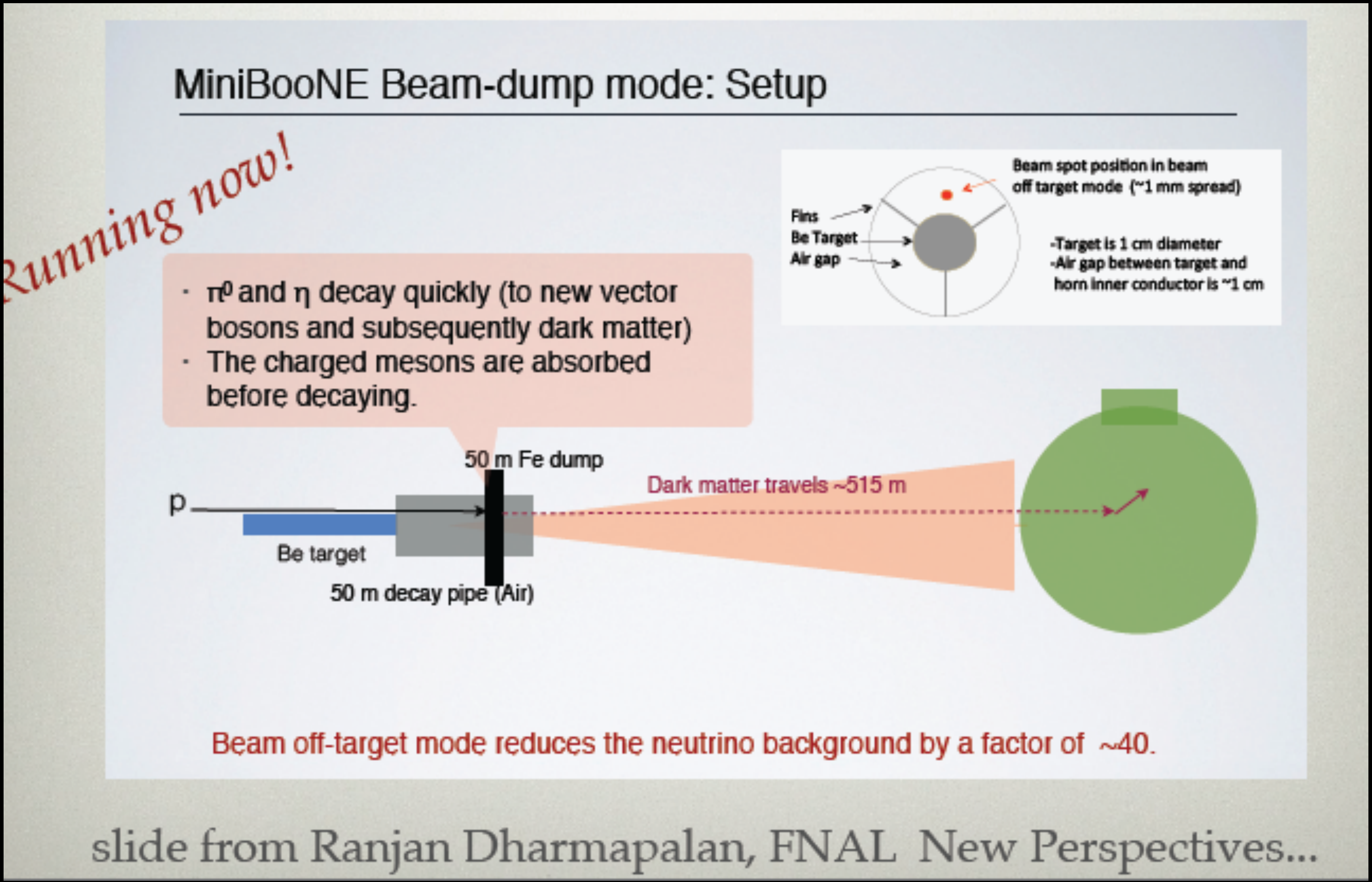
- DM production at GeV scale
  - B-factories can make an impact



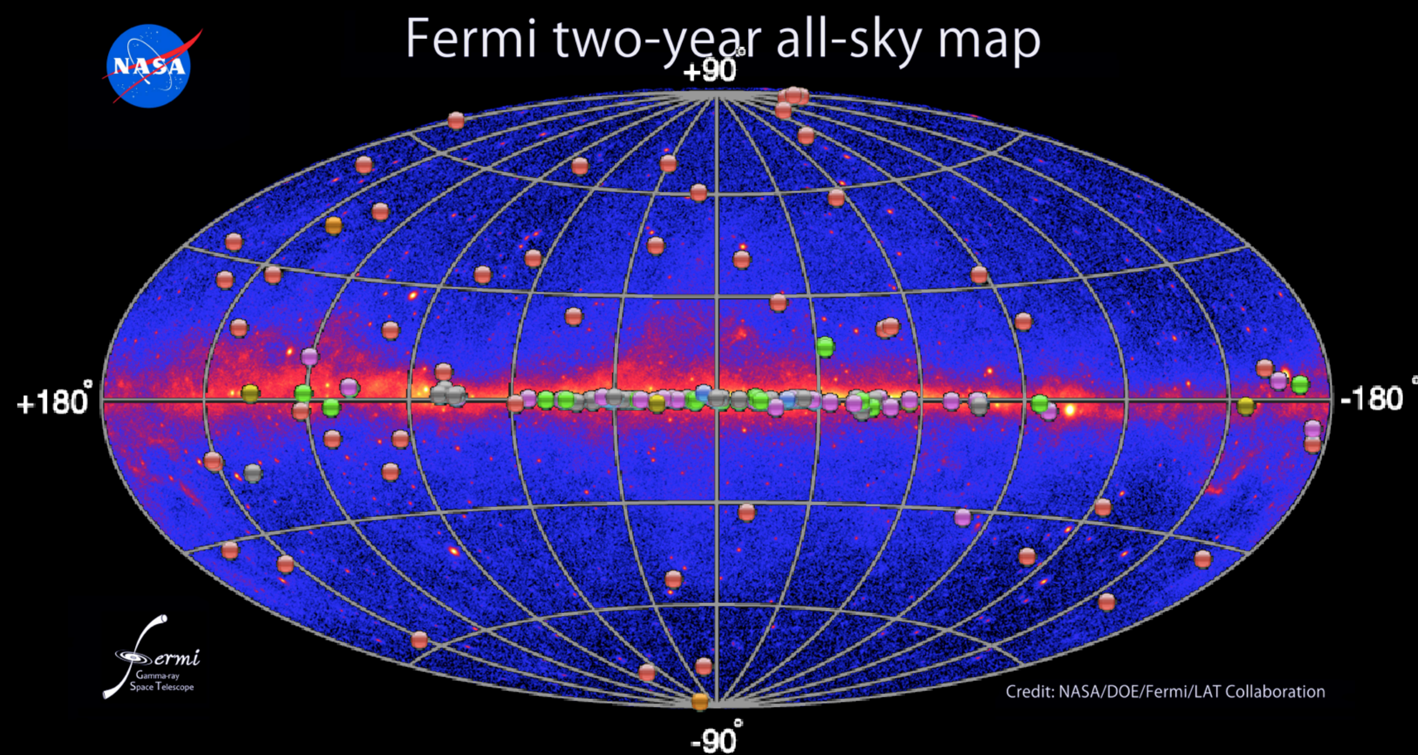
Narain, 5/23/2014

e.g. Searches with proton beams

•



Indirect detection: γ ray sky (2014)



Fermi 2FGL

~1800 sources
significant fraction Extragalactic
many Galactic sources confused with diffuse emission

TeVCat

~50 extragalactic sources
~100 Galactic sources

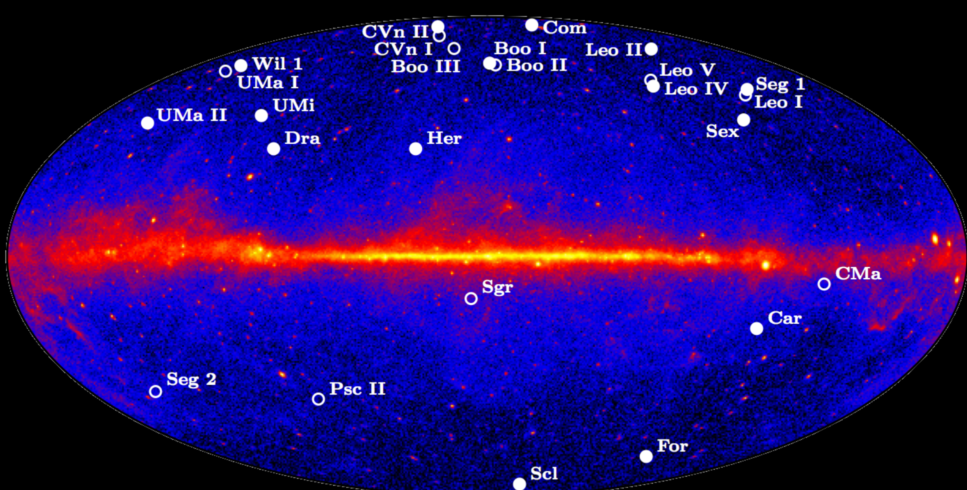
GeV Dwarf Measurements

Analysis strategy

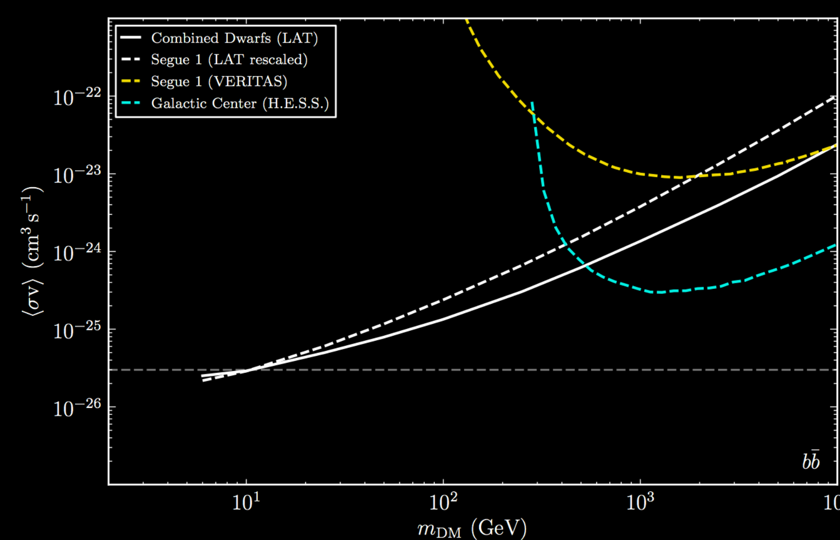
- Milky Way satellites are DM dominated, no astrophysical γ-ray sources expected
- Stack 25 dwarfs in 4 yrs of Fermi-LAT data
- Search for emission (0.5 – 500 GeV for individual objects and complete sample
- Determine DM content of 18 dwarfs using stellar kinematics
- Infer limits on <*σv*>

Fermi results:

- No signal seen,
- ULs at level of instrument sensitivity
- Some of the tightest constraints in 2 GeV – 10 TeV energy range



Phys. Rev. D (2013), **89**, 042001



Indirect Detection

Recent results: Daylan et al. arXiv:1402.6703

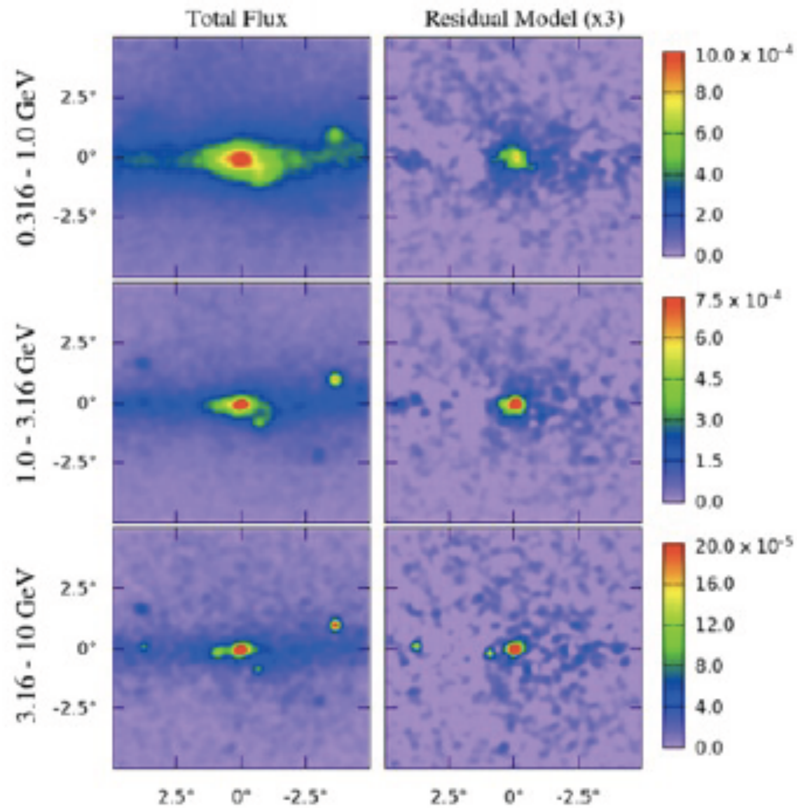
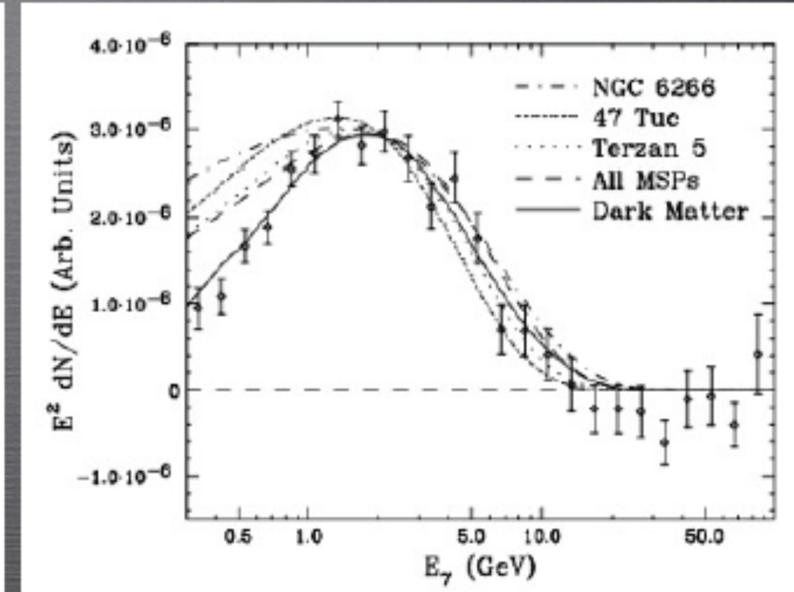
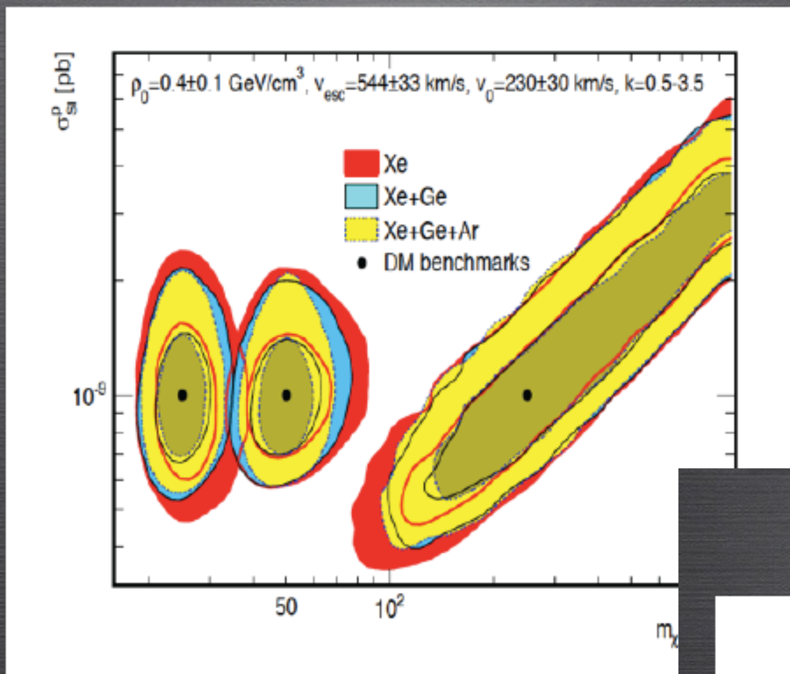


FIG. 9: The raw gamma-ray maps (left) and the residual maps after subtracting the best-fit Galactic diffuse model, 20 cm template, point sources, and isotropic template (right), in units of photons/cm^2/s/sr. The right frames clearly contain a significant central and spatially extended excess, peaking at ~1-3 GeV. Results are shown in galactic coordinates, and all maps have been smoothed by a 0.25° Gaussian.



"Within these maps, we find the GeV excess to be robust and highly statistically significant, with a spectrum, angular distribution, and overall normalization that is in good agreement with that predicted by simple annihilating dark matter models"

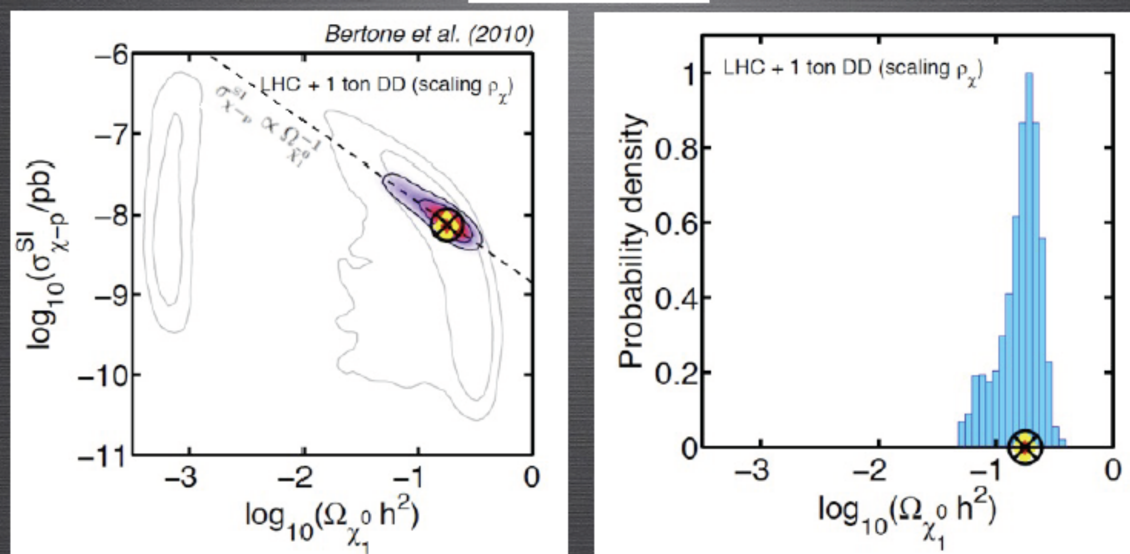
Complemetarity of direct detection targets



Pato, Baudis, GB, Ruiz, Strigari, Trotta, arXiv:101

Direct detection + LHC simulation

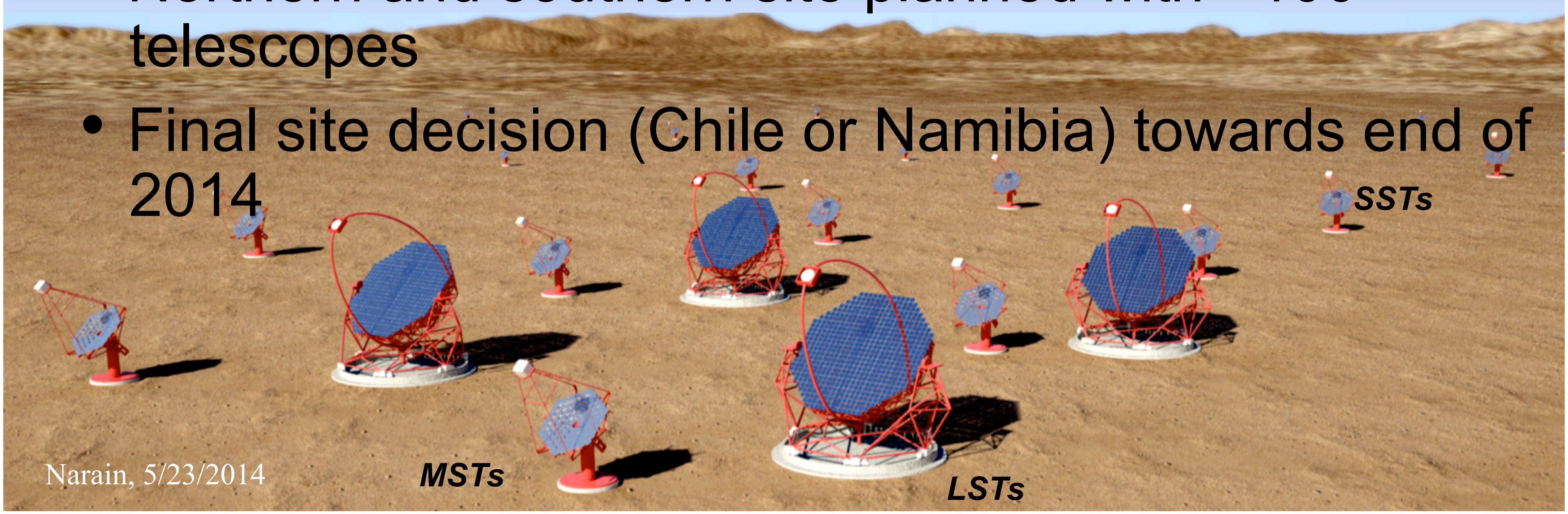
$$\frac{\rho_\chi}{\rho_{dm}} = \frac{\Omega_\chi}{\Omega_{dm}}$$



Future Plans…

The Cherenkov Telescope Array is coming

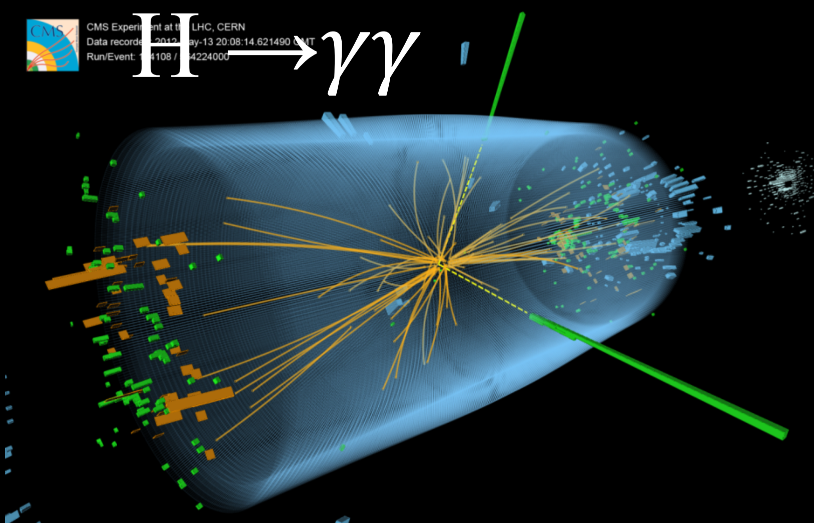
- Worldwide collaboration / open observatory / 200M€ project
- Huge performance improvement in all aspects (PSF, energy range, sensitivity)
- Northern and southern site planned with >100 telescopes
- Final site decision (Chile or Namibia) towards end of 2014

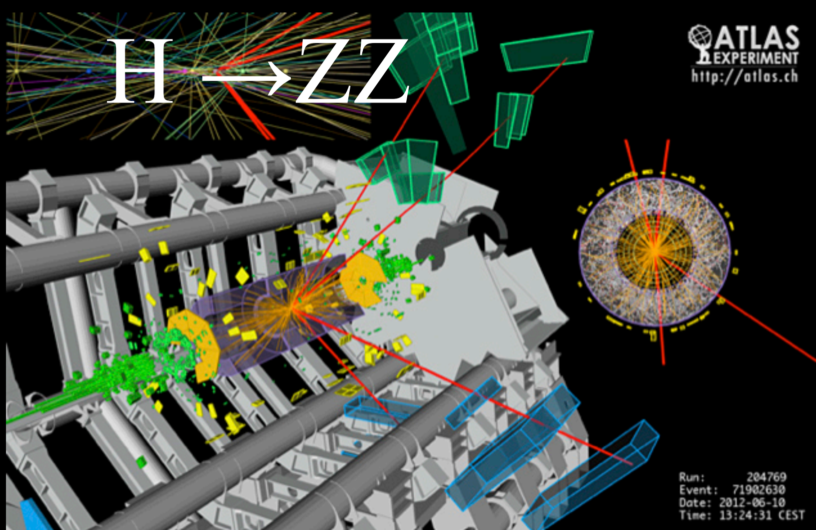


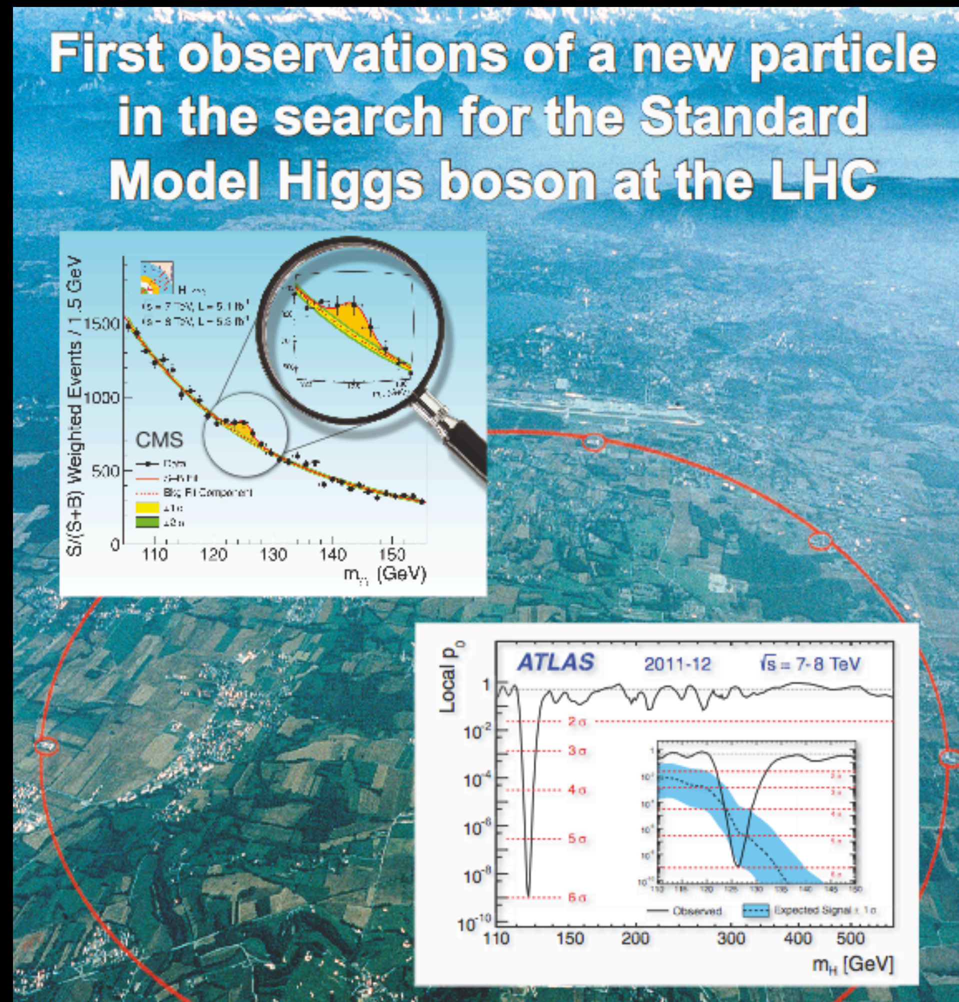
HIGGS
& ITS IMPLICATIONS

Cranmer, Dawson, Fayard, Grojean, Tomalin, Olsen, Pralavorio

Discovery of a Higgs Boson





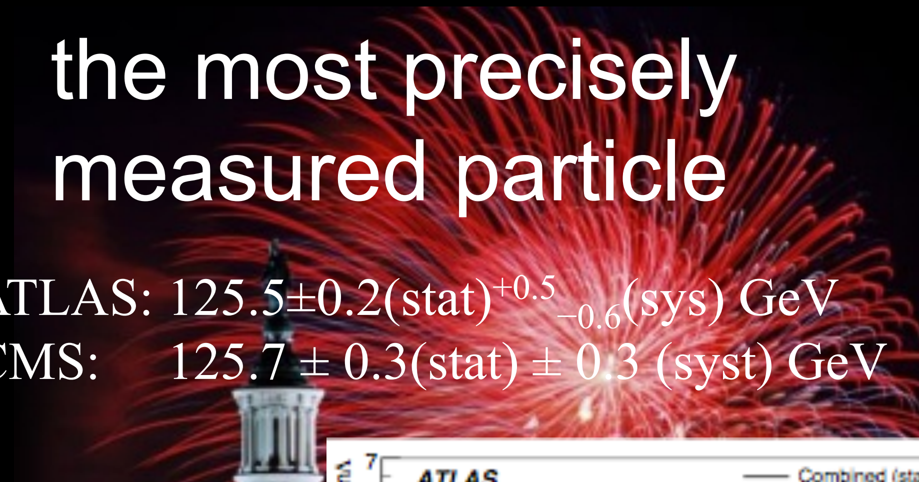


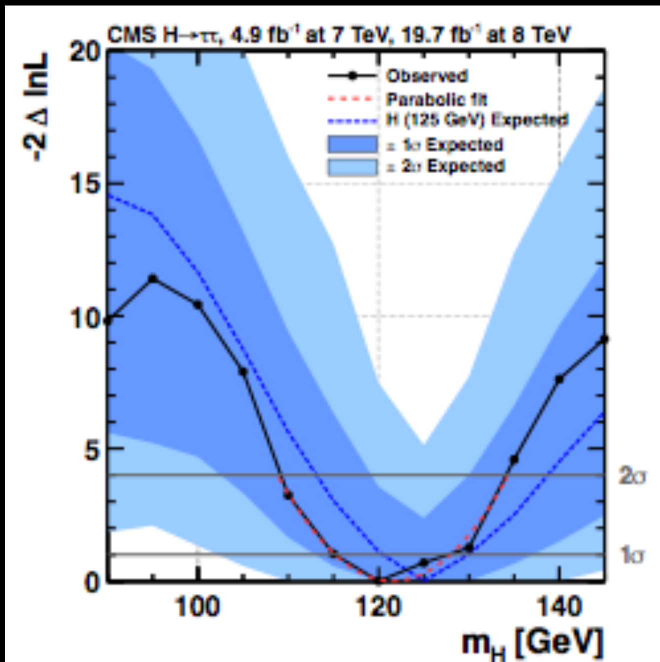
discovery ...1.8 years later

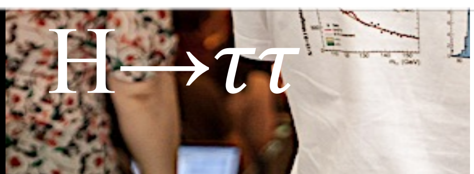
the most precisely measured particle

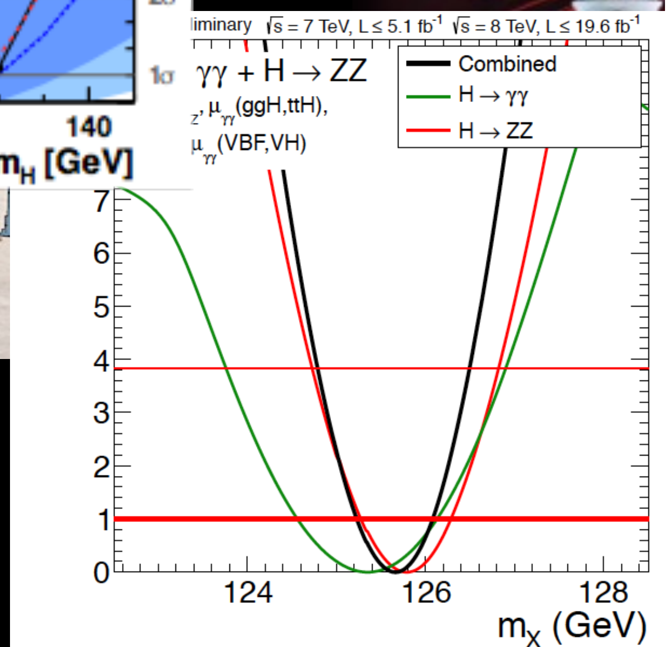
ATLAS: $125.5 \pm 0.2(\text{stat})^{+0.5}_{-0.6}(\text{sys})$ GeV

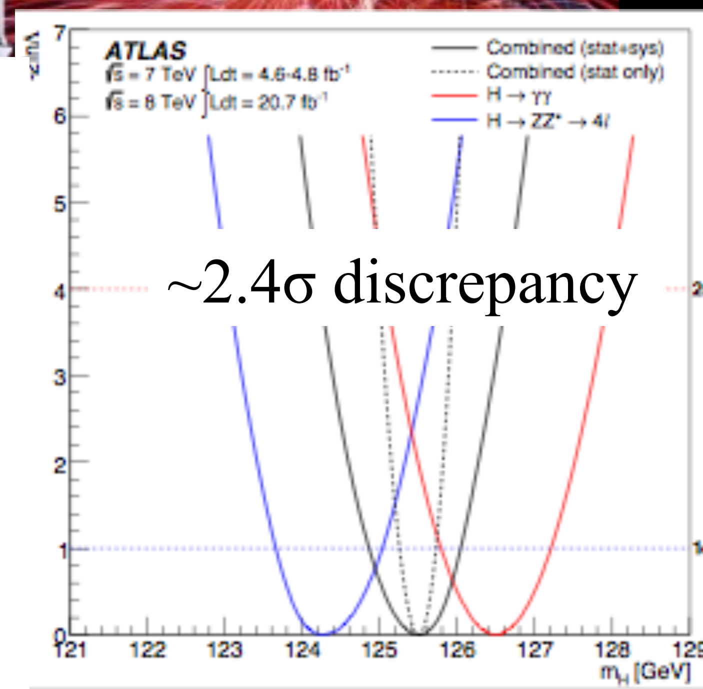
CMS: $125.7 \pm 0.3(\text{stat}) \pm 0.3$ (syst) GeV





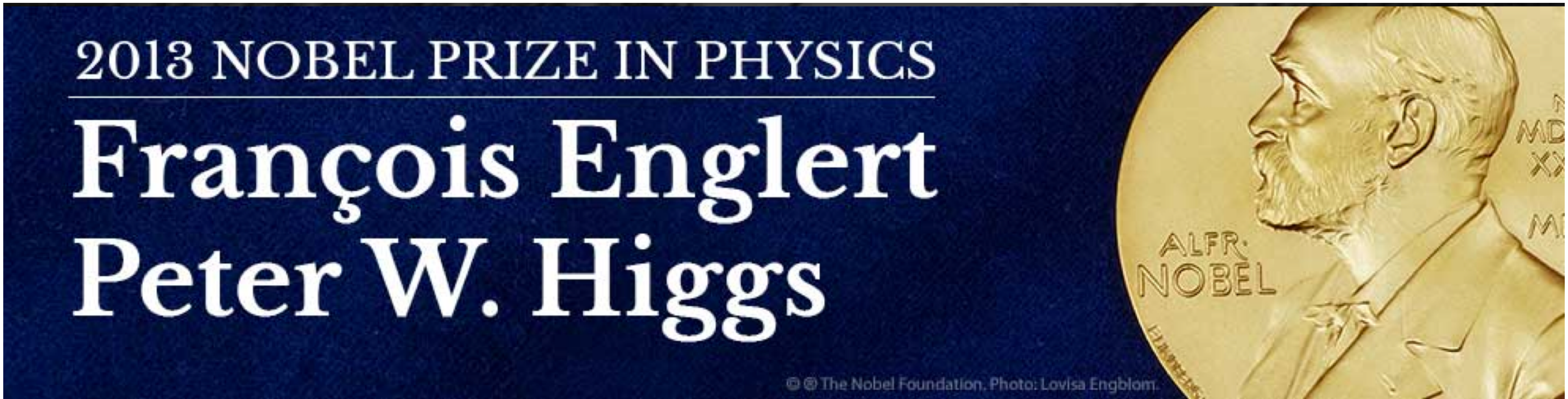






~2.4σ discrepancy

Narain, 5/23/2014



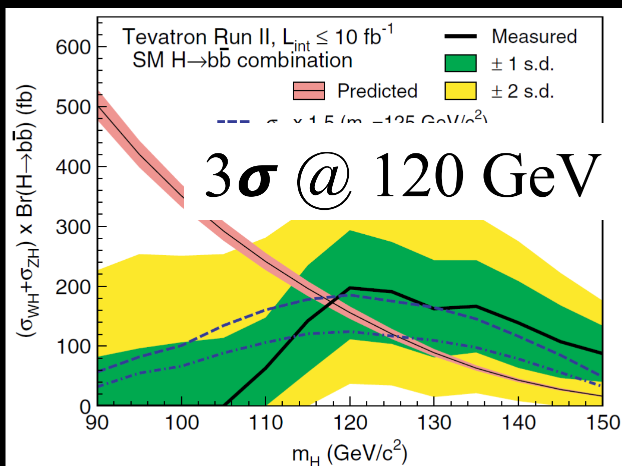
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

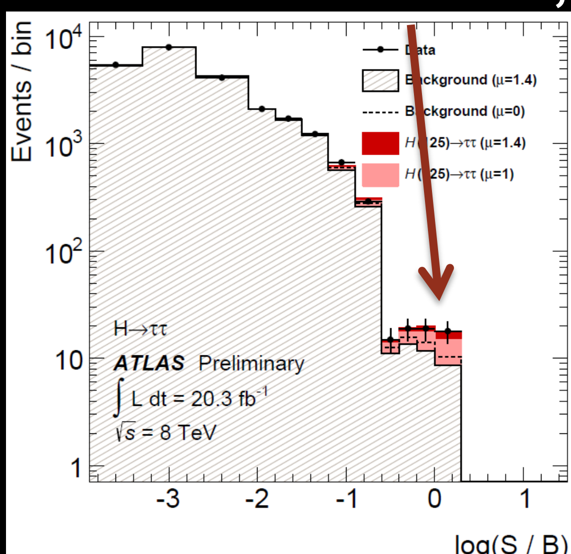
ATLAS and CMS physicists celebrate the announcement of the 2013 prize together in Building 40 on Oct. 8th

Decays to Fermions

- Tevatron: H →bb



- LHC: H→ττ, bb



LHC: ttH

Only access to real top couplings to Higgs

CMS

ttH Channel	$\mu = \sigma/\sigma_{SM}$ ($m_H = 125.7$ GeV)
$\gamma\gamma$	$-0.2^{+2.4}_{-1.9}$
$b\bar{b}$	$+1.0^{+1.9}_{-2.0}$
$\tau\tau$	$-1.4^{+6.3}_{-5.5}$
4l	$-4.8^{+5.0}_{-1.2}$
3l	$+2.7^{+2.2}_{-1.8}$
Same-sign 2l	$+5.3^{+2.2}_{-1.8}$
Combined	$+2.5^{+1.1}_{-1.0}$

Significance (125.7 GeV) 2.7**σ**

Exp (obs)

μ<1.8 (4.3) x SM

ATLAS

Signal Strength	μ	error
Single Lepton	1.3	1.6
Dilepton	2.9	2.3
Combination	1.7	1.4

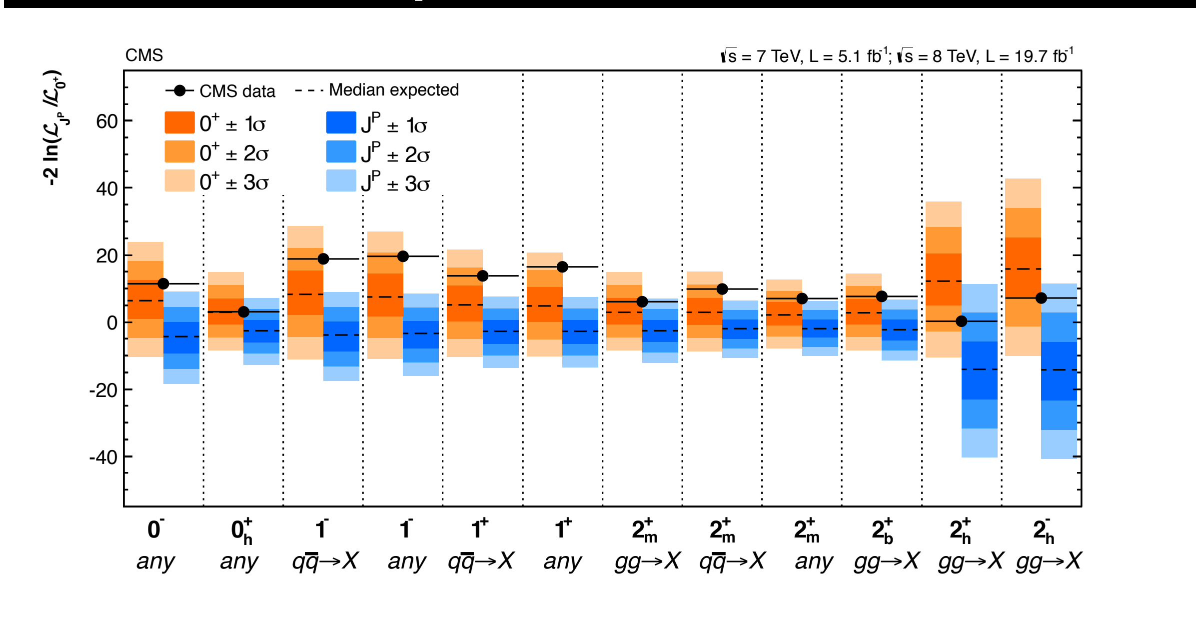
Significance (125 GeV) = 1.3**σ**

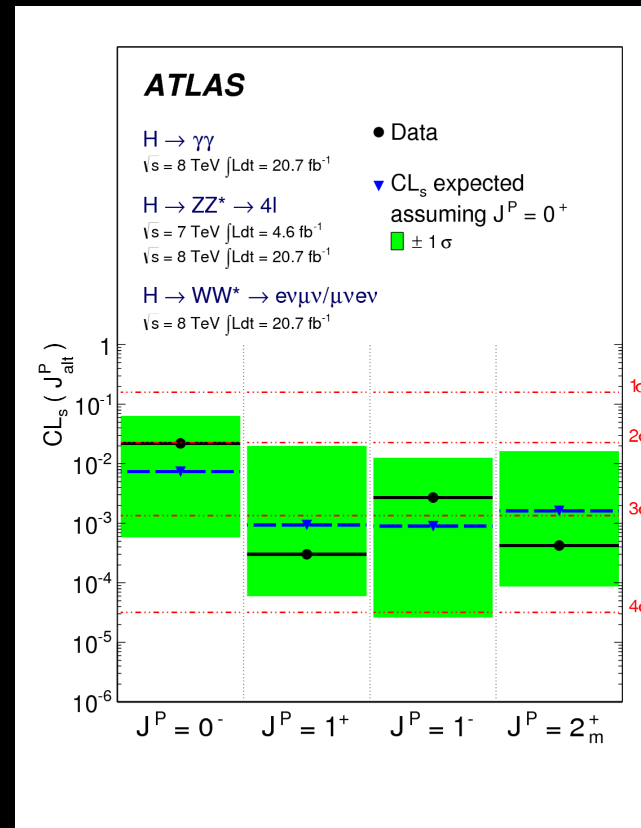
Exp (obs)

μ<2.6 (4.1) x SM

Spin and Parity

- $J^P = 0^+$ preferred





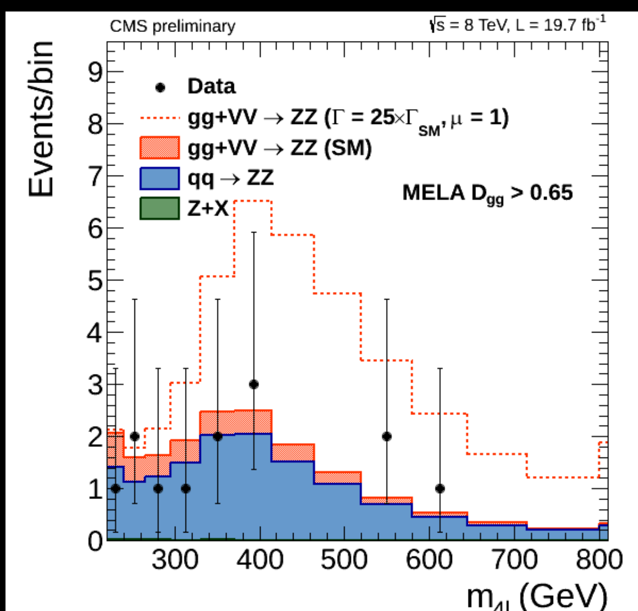
- Strong exclusion of a spin 1 resonance
- 0^- and gravitons like resonances excluded at >3σ level

Width of the Higgs

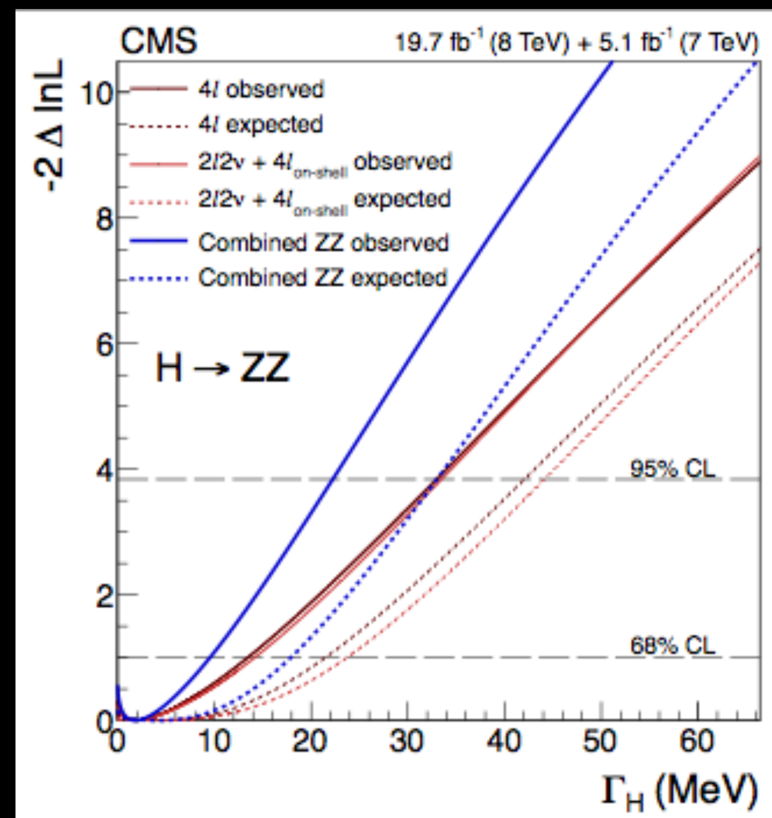
- The width of the SM Higgs is 4.15 MeV << O(GeV) resolution
- ambiguity as Rate ∝ Br = Γ/Γ_{SM}
- off-shell effects sensitive to width

$$\sigma^{\text{on-peak}}_{gg\to H\to ZZ} \propto \frac{g^2_{ggH}g^2_{HZZ}}{\Gamma_H}, \qquad \sigma^{\text{off-peak}}_{gg\to H\to ZZ} \propto g^2_{ggH}g^2_{HZZ}.$$

F. Caola and K. Melnikov, [arXiv:1307.4935]
See also: N. Kauer, G. Passarino, Campbell et al



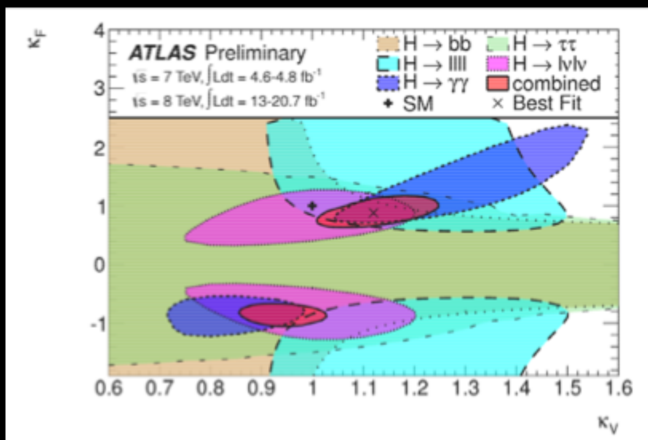
$\Gamma_H < 22$ MeV

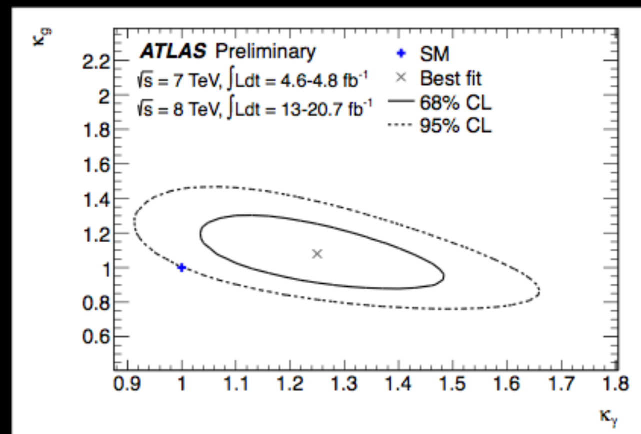


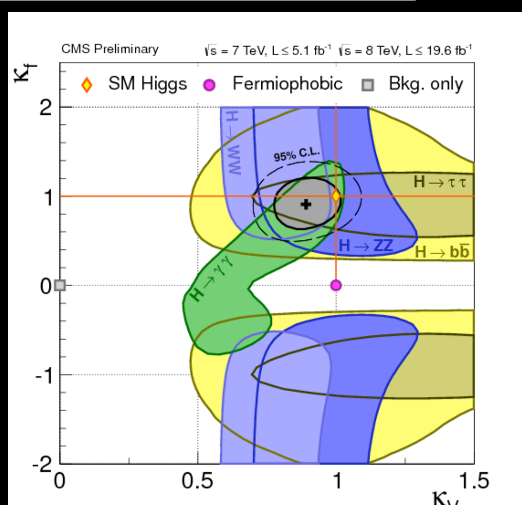
Narain, 5/23/2014

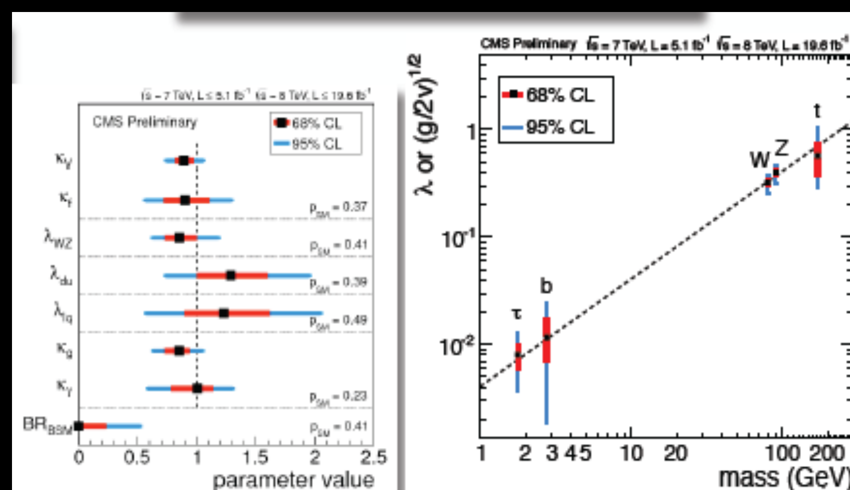
Higgs Couplings

- Assume one scale factor for fermion and vector couplings κ_V=κ_W =κ_Z & κ_F=κ_t=κ_b=κ_τ
- Assume H→$\gamma\gamma$, gg→H and total width of the Higgs depends only on κ_V and κ_F (asume no BSM physics)



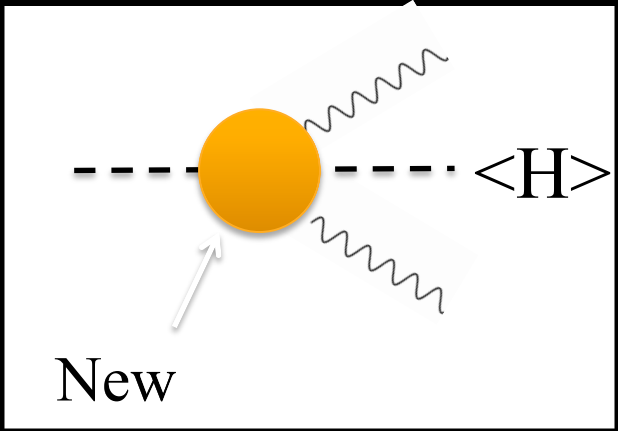






Higgs Couplings and New Physics

- New particles lead to deviations in Higgs couplings



Generic effects scale with $1/m^2$ of new particles

Typically: Target precision for Higgs couplings < 5%

- As LHC limits on new particles increase, target precision decreases
- Progress requires 2-prong approach: Search for new Higgs bosons and measure Higgs couplings
- If we don't find new particles…..
  - Higgs searches and coupling measurements are complementary
  - Effects on Higgs physics from high scales expected to be small
  - We are just starting to probe the interesting region
- It's all about decoupling and effective theories

measure properties precisely

- Higgs couplings with 300 fb^{-1} @14 TeV
  ⇒2015 onwards
- Higgs couplings with 3000 fb^{-1} at HL-LHC
  ⇒2020 onwards

Table 1-20. *Expected precisions on the Higgs couplings and total width from a constrained 7-parameter fit assuming no non-SM production or decay modes. The fit assumes generation universality ($\kappa_u \equiv \kappa_t = \kappa_c$, $\kappa_d \equiv \kappa_b = \kappa_s$, and $\kappa_\ell \equiv \kappa_\tau = \kappa_\mu$). The ranges shown for LHC and HL-LHC represent the conservative and optimistic scenarios for systematic and theory uncertainties. ILC numbers assume (e^- [illegible] ions of (−0.8, 0.3) at 250 and 500 GeV and (−0.8, 0.2) at 1000 GeV, plus a 0.5% theory uncertainty. CLIC numbers assu[illegible]) for energies above 1 TeV. TLEP numbers assume unpolarized beams.*

[illegible]y	LHC	HL-L[illegible]	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC	TLEP (4 IPs)
[illegible] (GeV)	14,000	14,000	[illegible]0/500	250/500	250/500/1000	250/500/1000	350/1400/3000	240/350
$\int \mathcal{L} dt$ (fb^{-1})	300/expt	3000/expt	[illegible]500	1150+1600	250+500+1000	1150+1600+2500	500+1500+2000	10,000+2600
κ_γ	5 − 7%	2 − 5%	[illegible]	4.4%	3.8%	2.3%	−/5.5/<5.5%	1.45%
κ_g	6 − 8%	3 − 5%	[illegible]	1.1%	1.1%	0.67%	3.6/0.79/0.56%	0.79%
κ_W	4 − 6%	2 − 5%	[illegible]	0.21%	0.21%	0.2%	1.5/0.15/0.11%	0.10%
κ_Z	4 − 6%	2 − 4%	[illegible]	0.24%	0.50%	0.3%	0.49/0.33/0.24%	0.05%
κ_ℓ	6 − 8%	2 − 5%	[illegible]	0.98%	1.3%	0.72%	3.5/1.4/<1.3%	0.51%
$\kappa_d = \kappa_b$	10 − 13%	4 − 7%	[illegible]	0.60%	0.51%	0.4%	1.7/0.32/0.19%	0.39%
$\kappa_u = \kappa_t$	14 − 15%	7 − 10%	[illegible]	1.3%	1.3%	0.9%	3.1/1.0/0.7%	0.69%

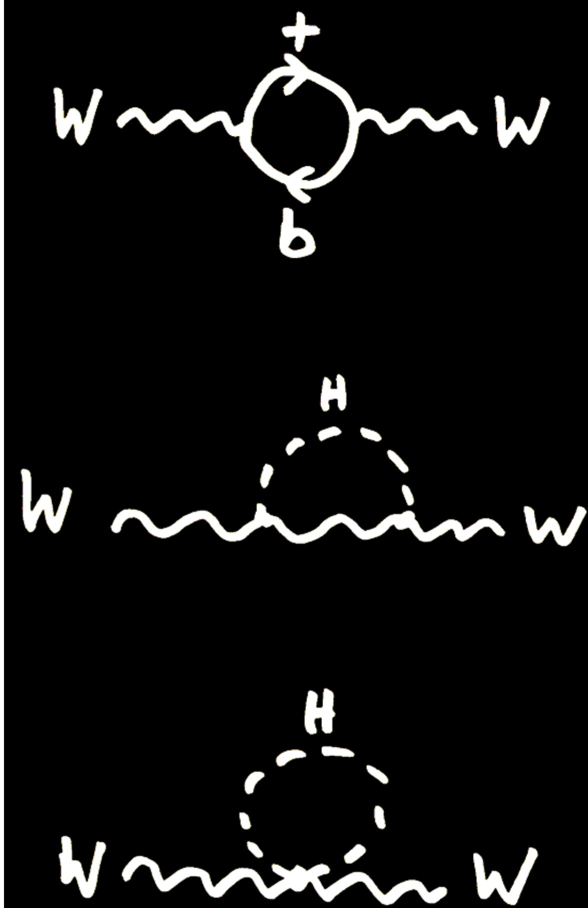
Higgs WG@ Snowmass '13

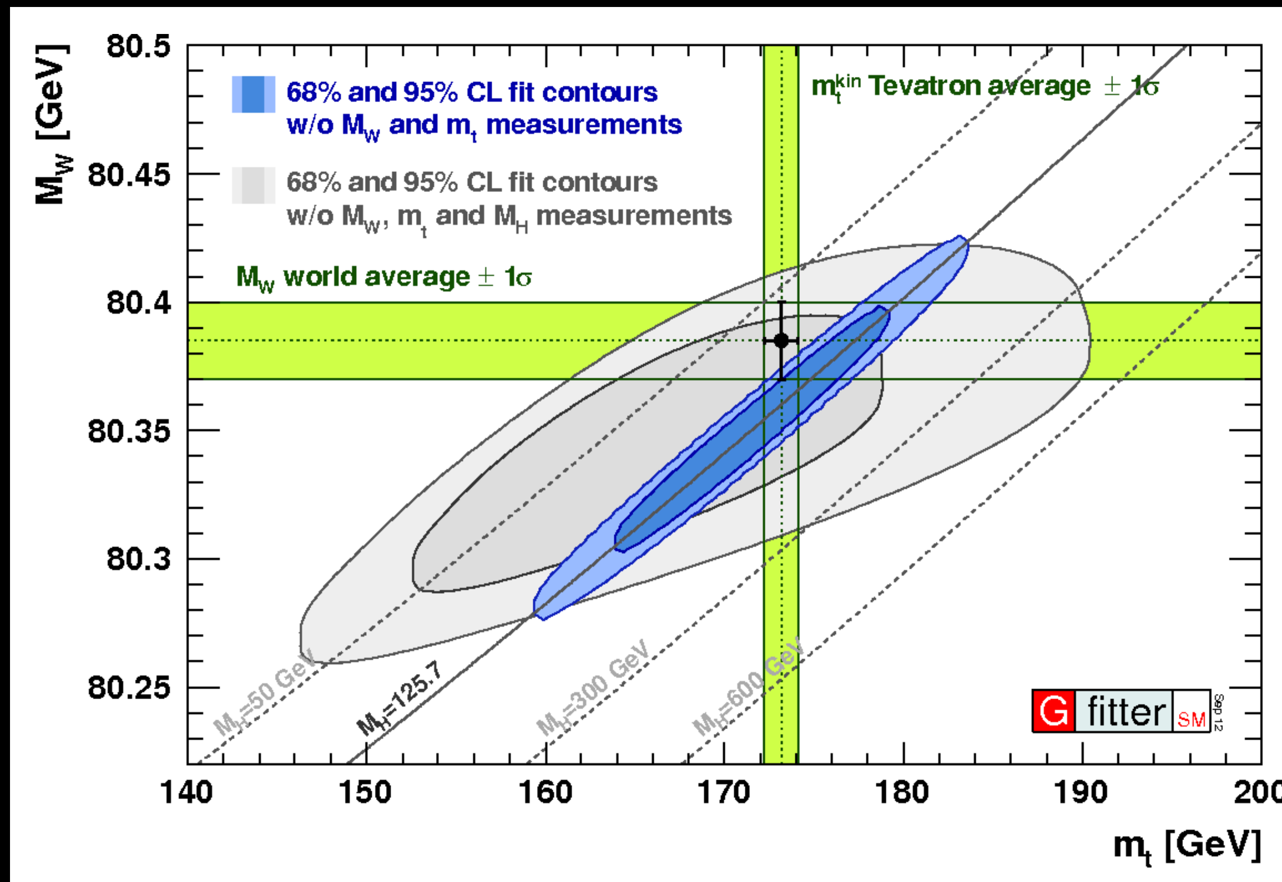
4-15%

Rich experimental program of (sub)percent precision

Consistency of the SM

- Higgs, W boson mass and top quark mass

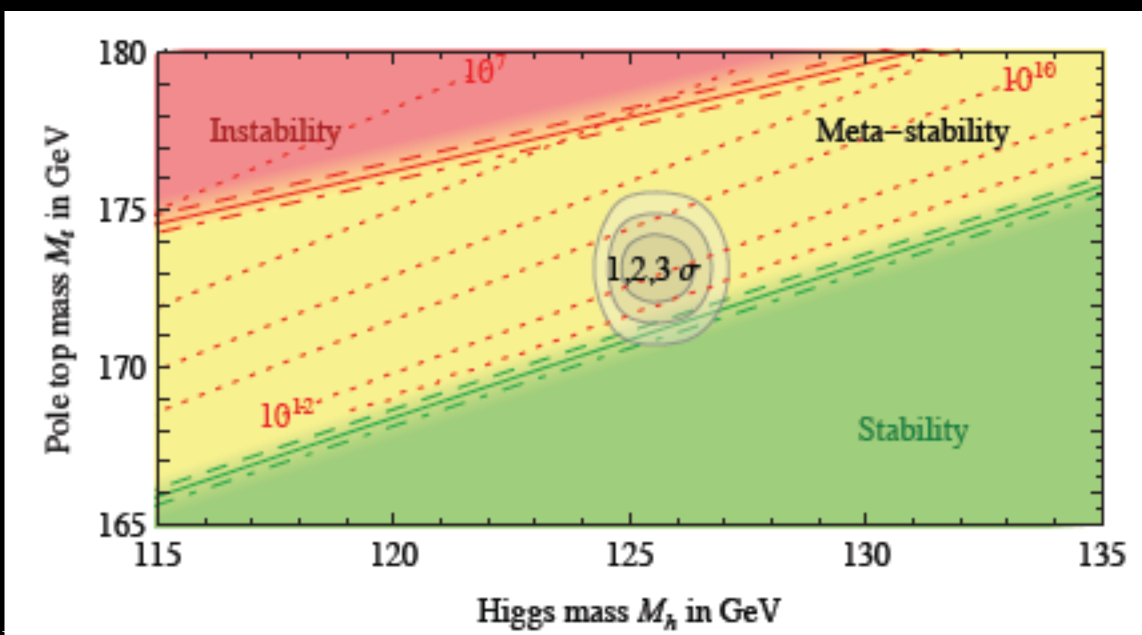


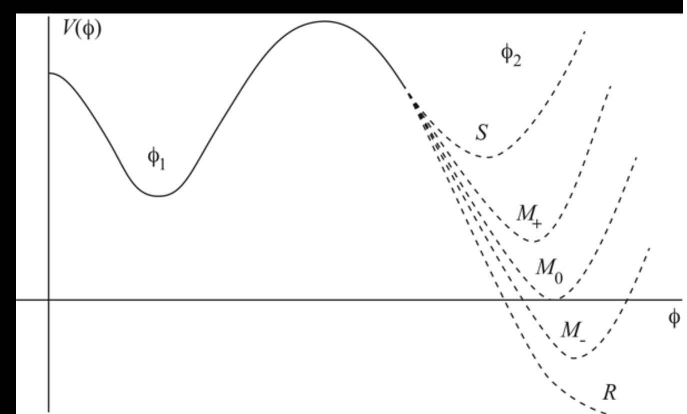


from gfitter.desy.de

The Nature of the Vacuum

- Simultaneous measurement of the Higgs boson and top quark masses allowed for the first time to infer properties of the very vacuum we leave in!
  - We are in a highly fine-tuned situation: the vacuum is at the verge of being either stable or metastable!
  - ~1 GeV in either of the two masses is all it takes to tip the scales!
- Perhaps Nature is trying to tell us something here?
  - Important to improve on the precision of top quark mass msm't
- Are statements about stability are independent of th enature of the new physics ??



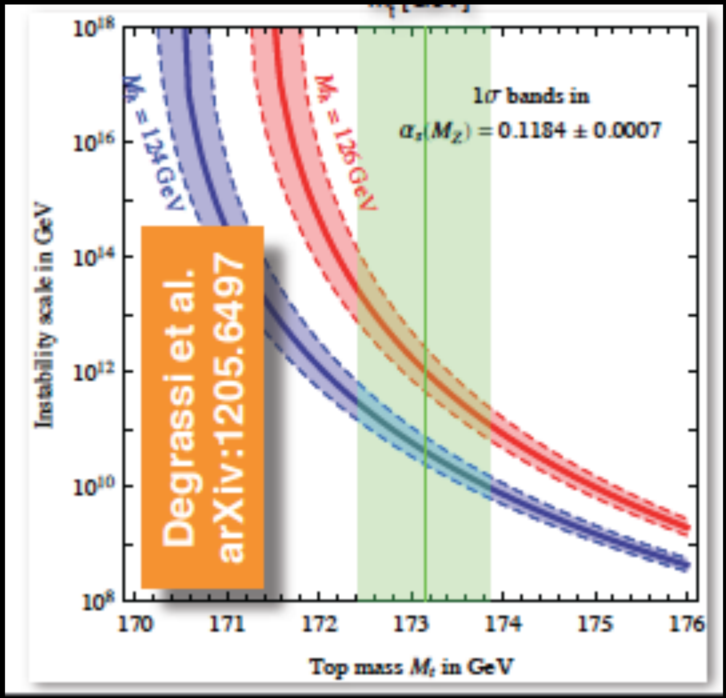


Implications of a light Higgs…

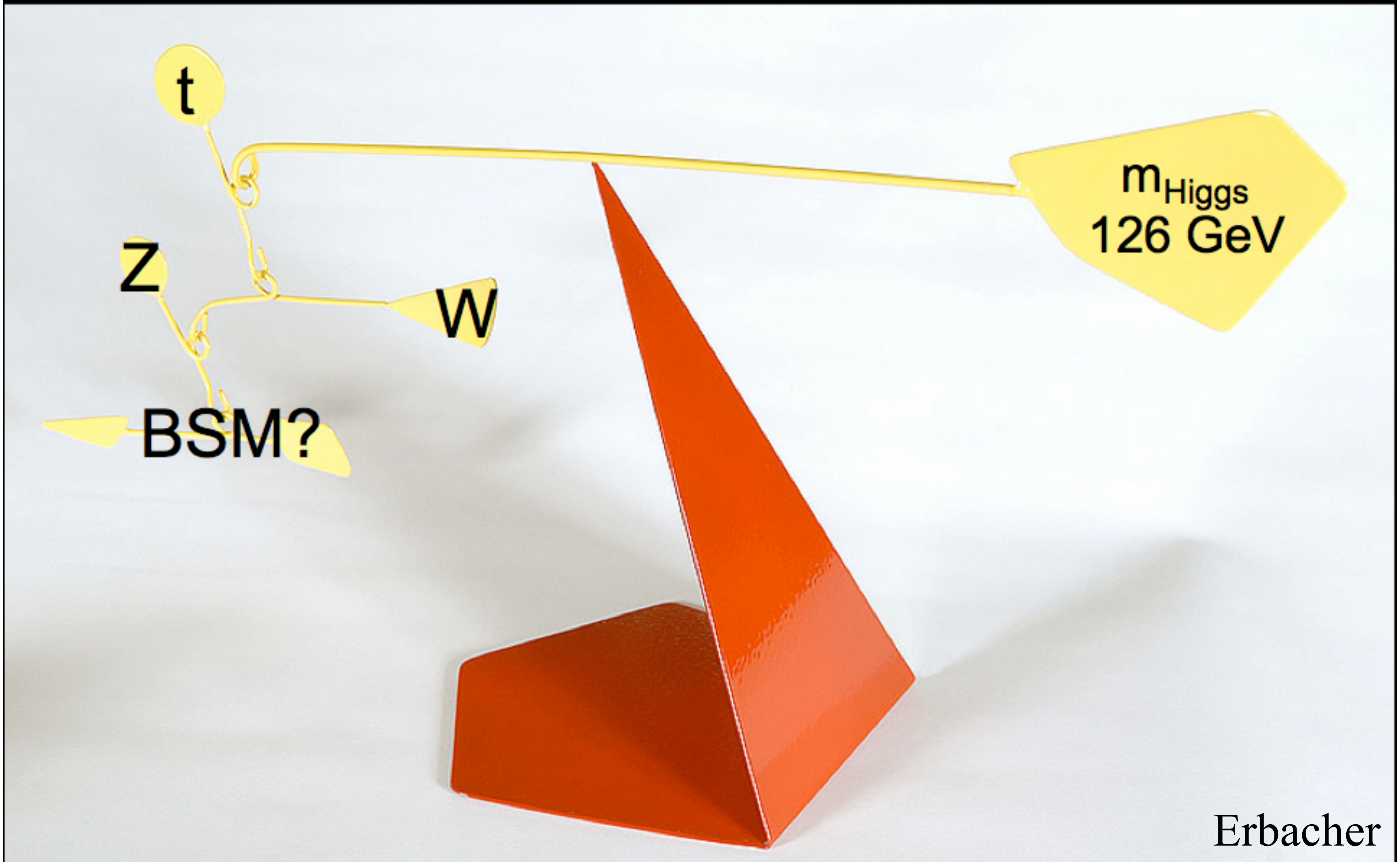
- Vacuum stability arguments require new physics to come at a scale ~10^{11} GeV or less

- Nevertheless, a metastable vacuum could survive w/o new physics

- In a sense, a 125 GeV Higgs boson is maximally challenging and rich experimentally, but also inflicts “maximum pain” theoretically, as it is not so easy to accommodate



Hierarchy Problem: Naturalness



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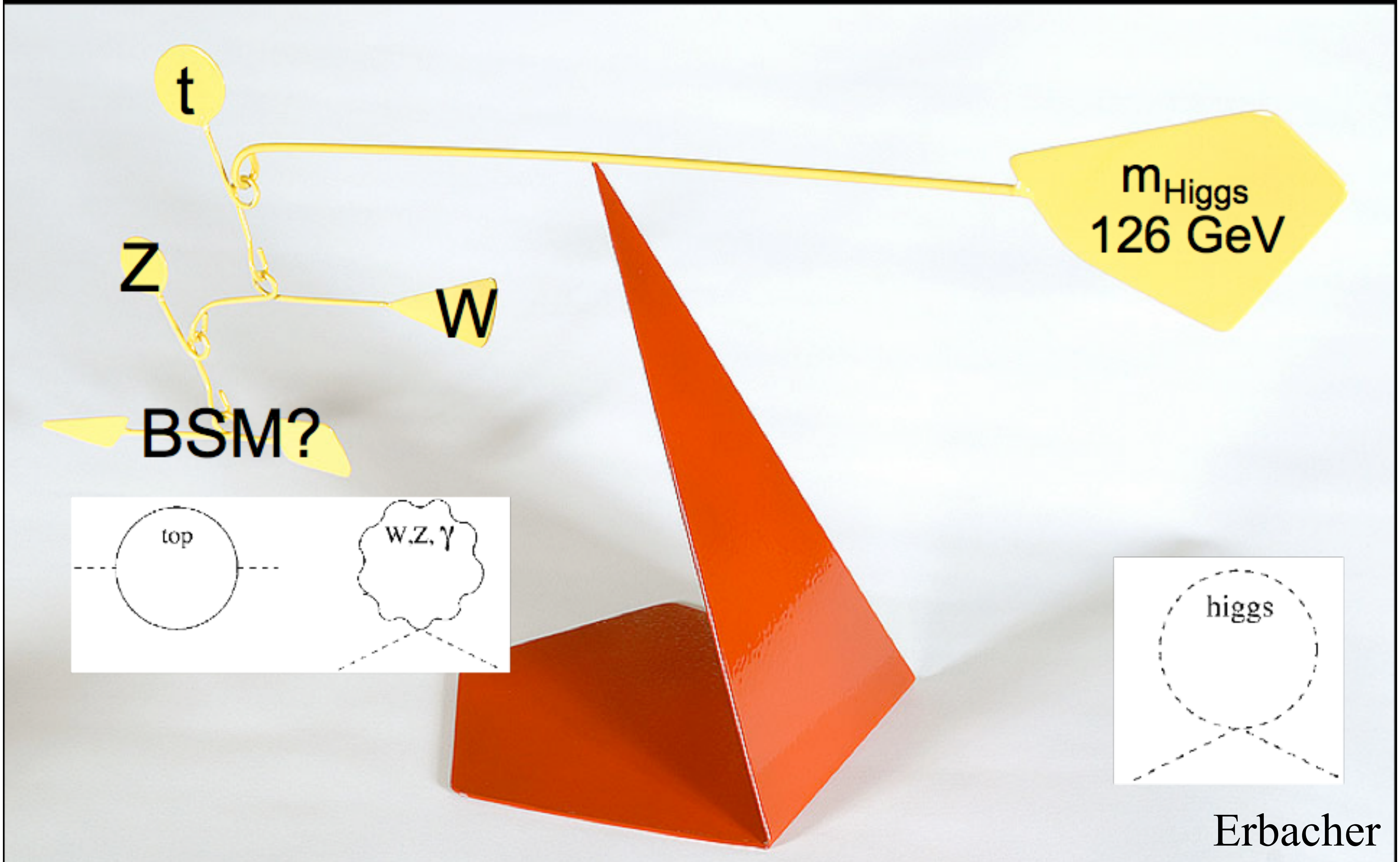
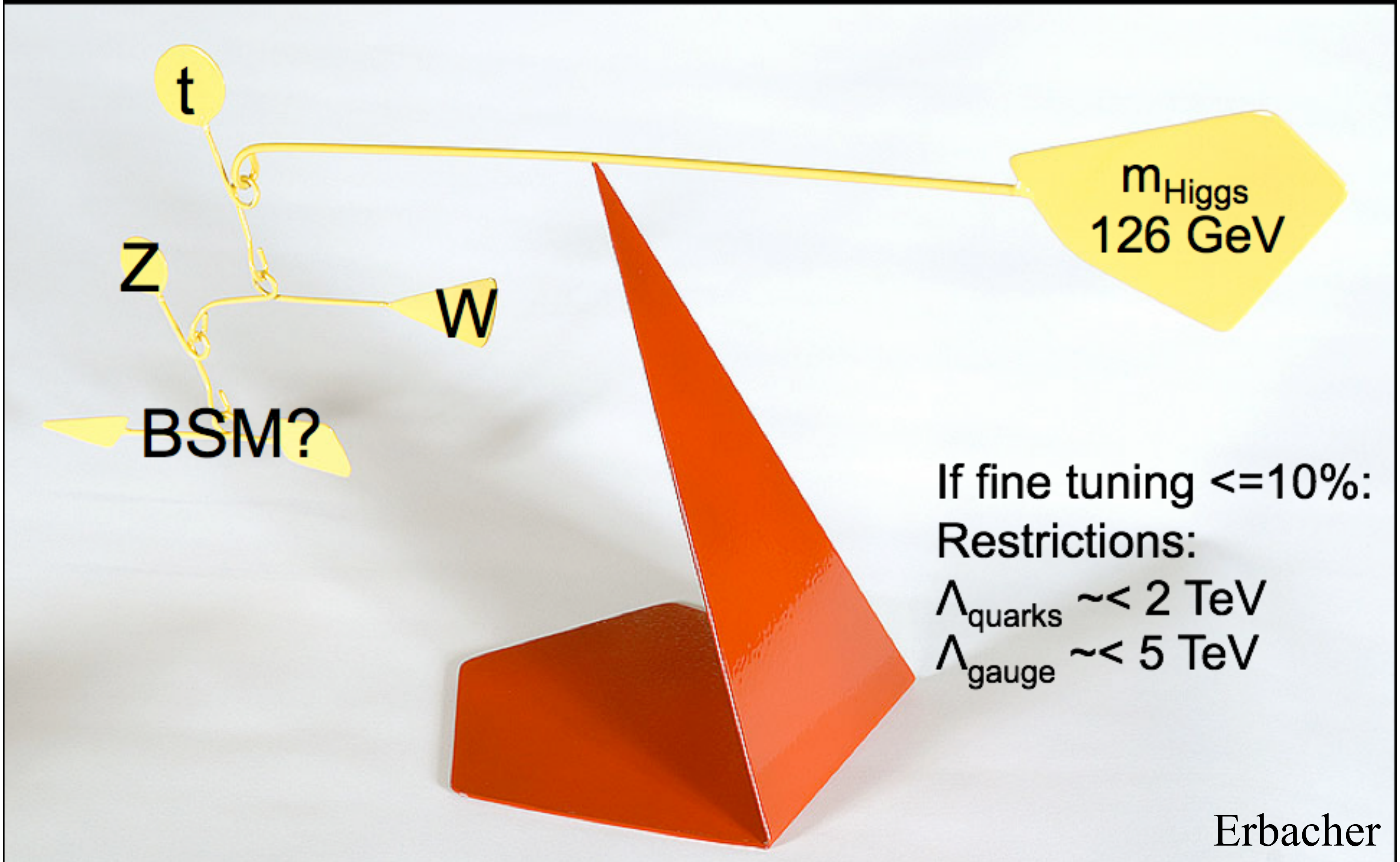
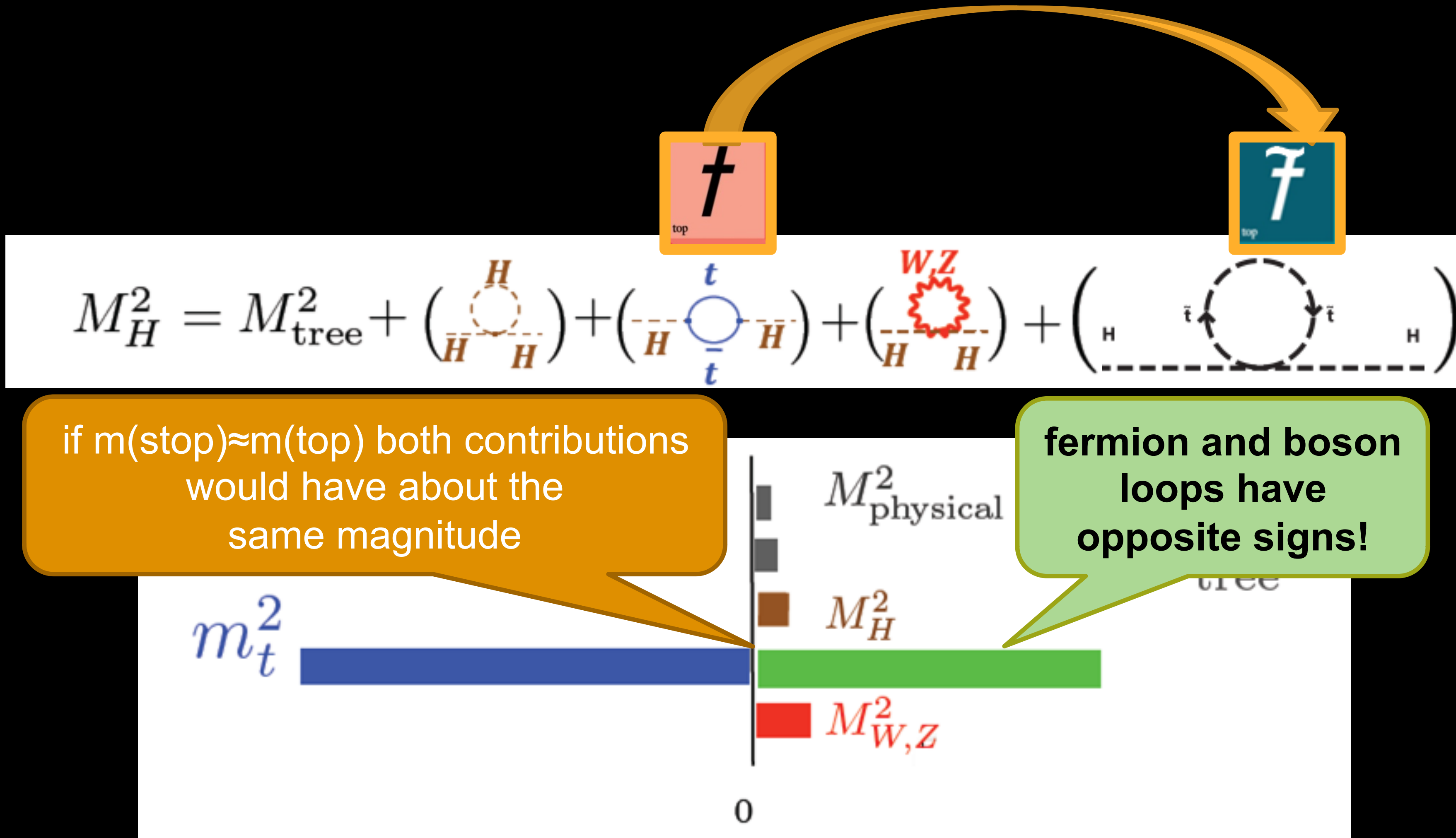


Hierarchy Problem: Naturalness



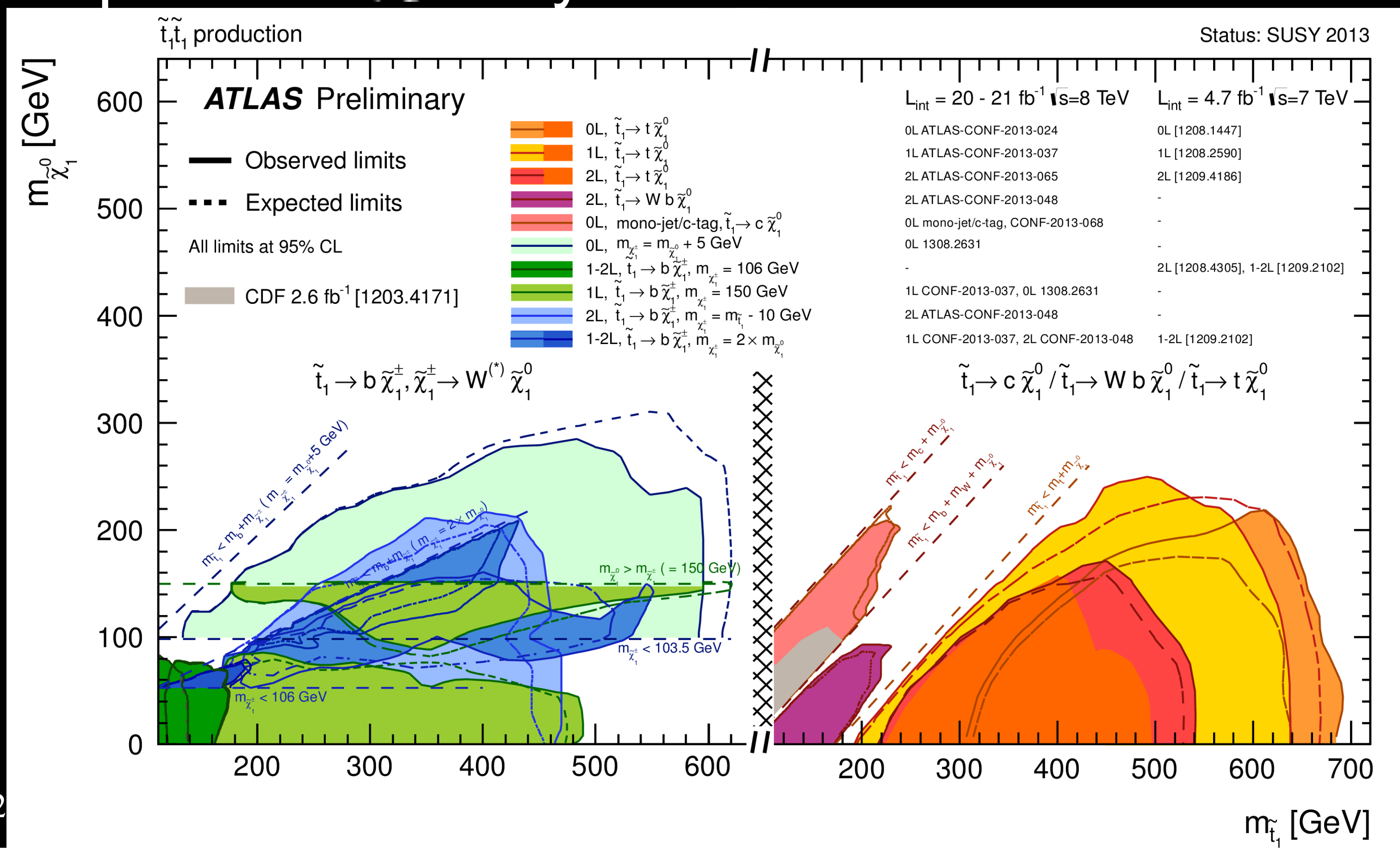
Supersymmetry

every known particle has a partner with the same properties but different spin by 1/2



top partners: light stop squarks

- direct stop production
- no stop quarks with mass < 700 GeV
  - except when $\tilde{\chi}^0$ very massive



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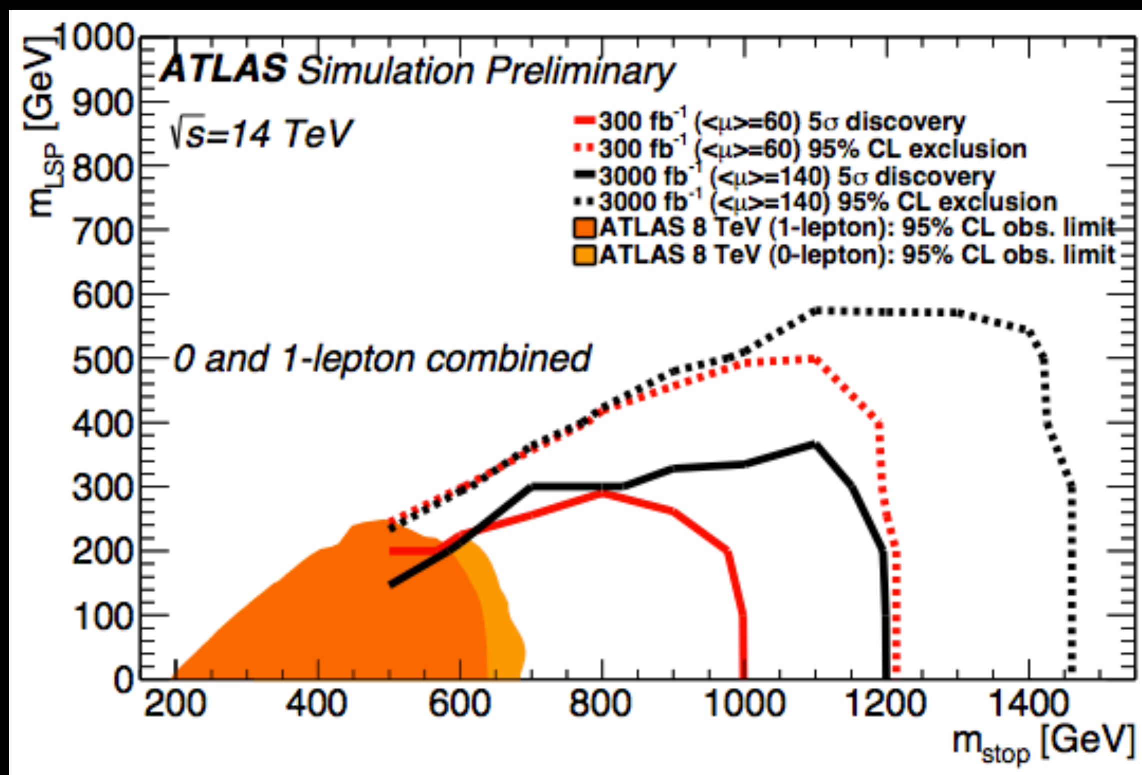
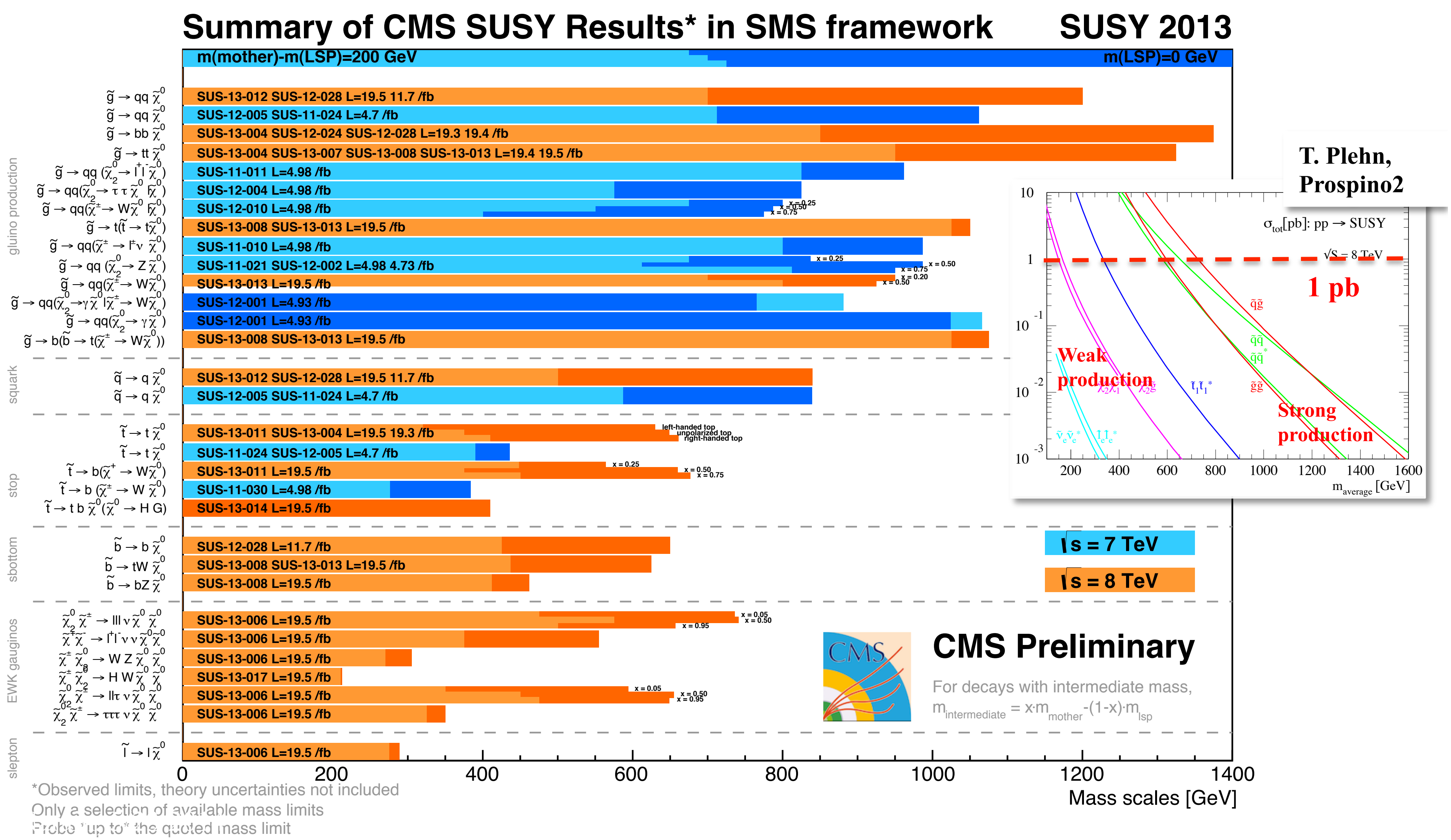
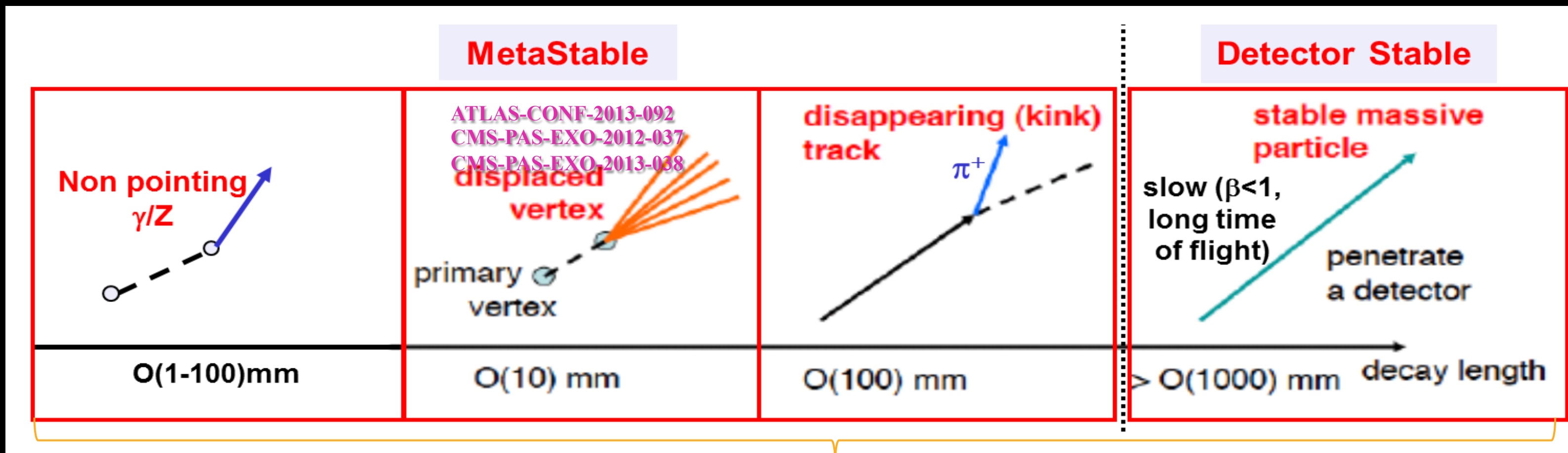


Supersymmetry

- Limits on light squarks and gluinos approaching or exceeding 1 TeV
- Increasing emphasis on EW gauginos and heavy sflavour

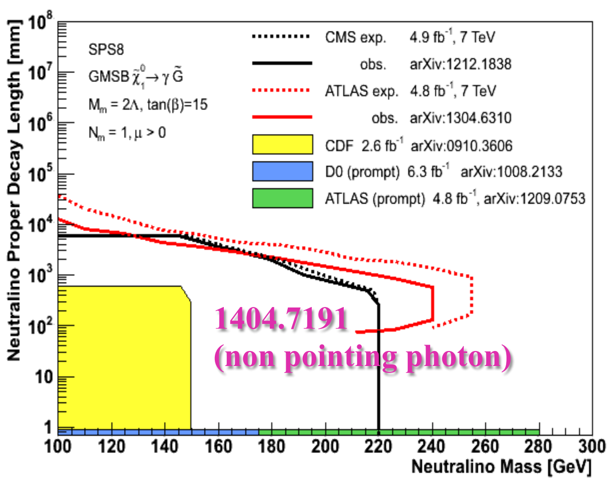


Long Lived Particles

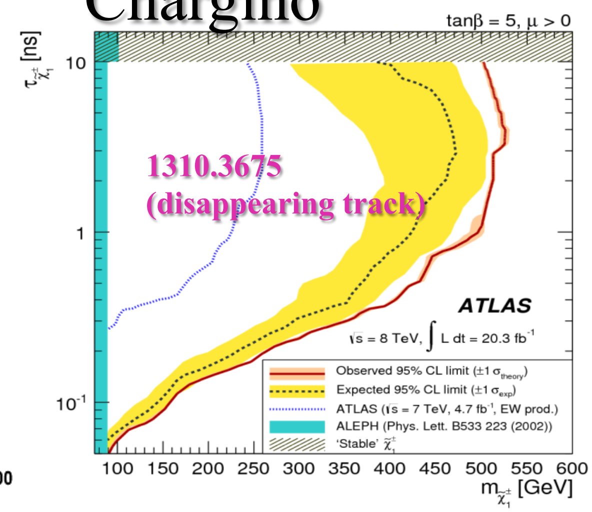


Lifetime-Mass limits

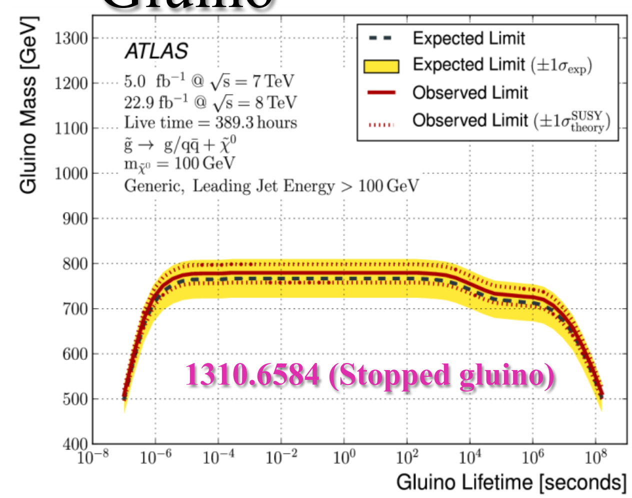
Neutralino



Chargino



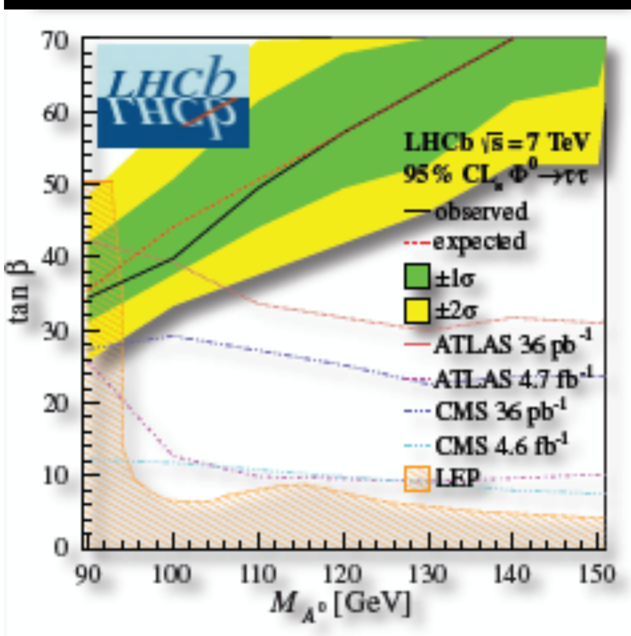
Gluino

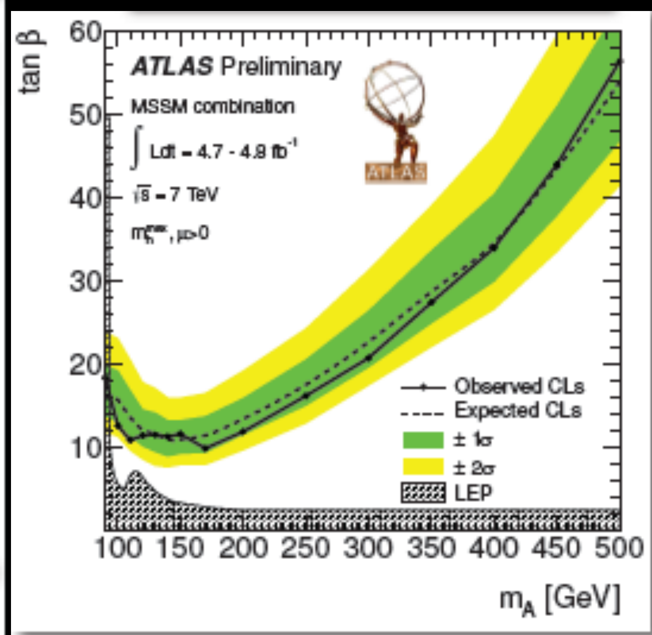


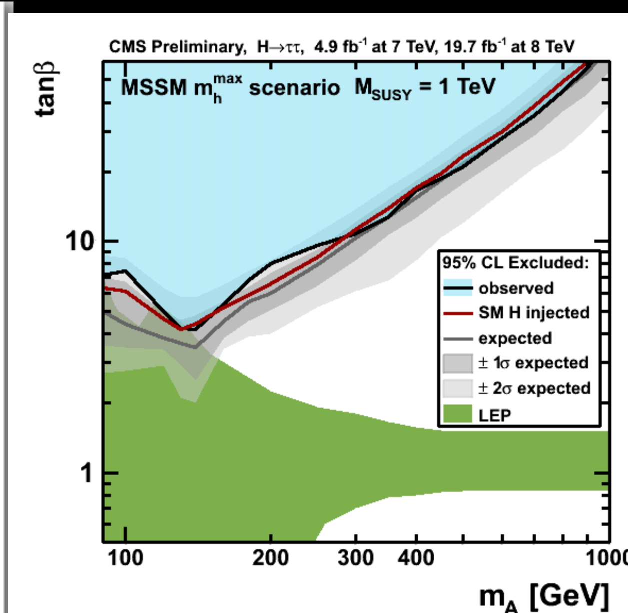
See also 1305.0491 (CMS), 1211.1597 (ATLAS), ATLAS-CONF-2013-058

is it the only Higgs boson?

- Supersymmetric Models require at least 2 Higgs fields
  - more complicated Higgs sector
  - differ in coupling to quarks and leptons
  - five physical scalar particles:
    CP-even: h_0, H_0, CP-odd: A_0, charged: $H^{\pm}$







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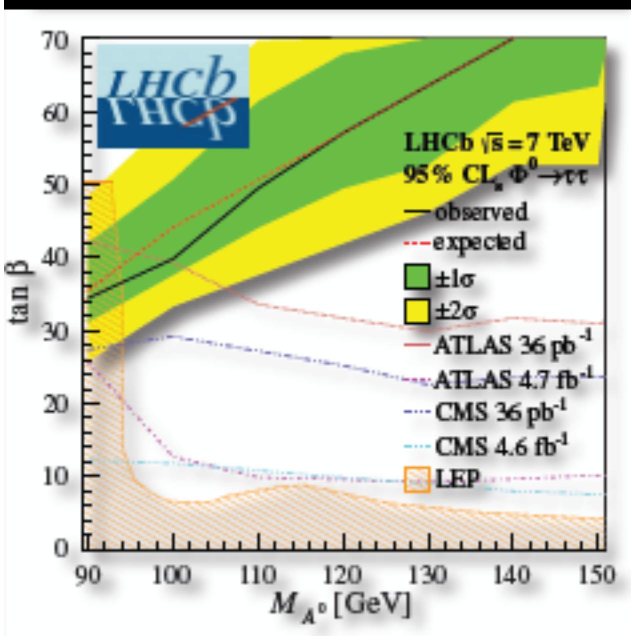
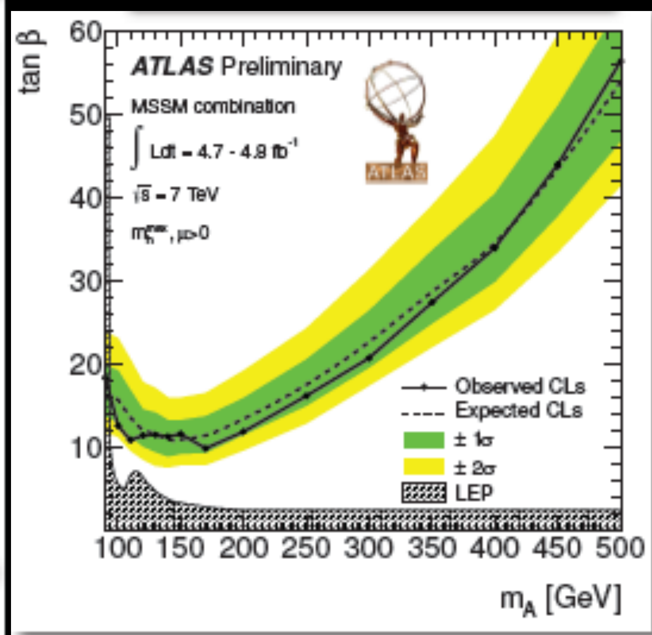
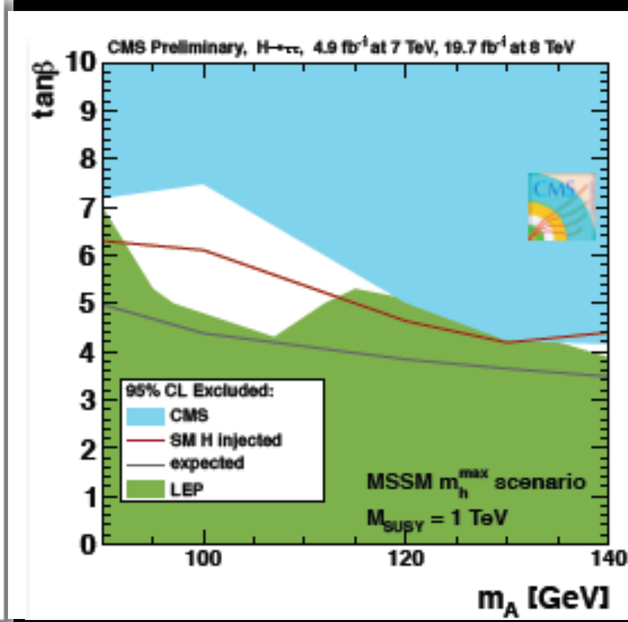
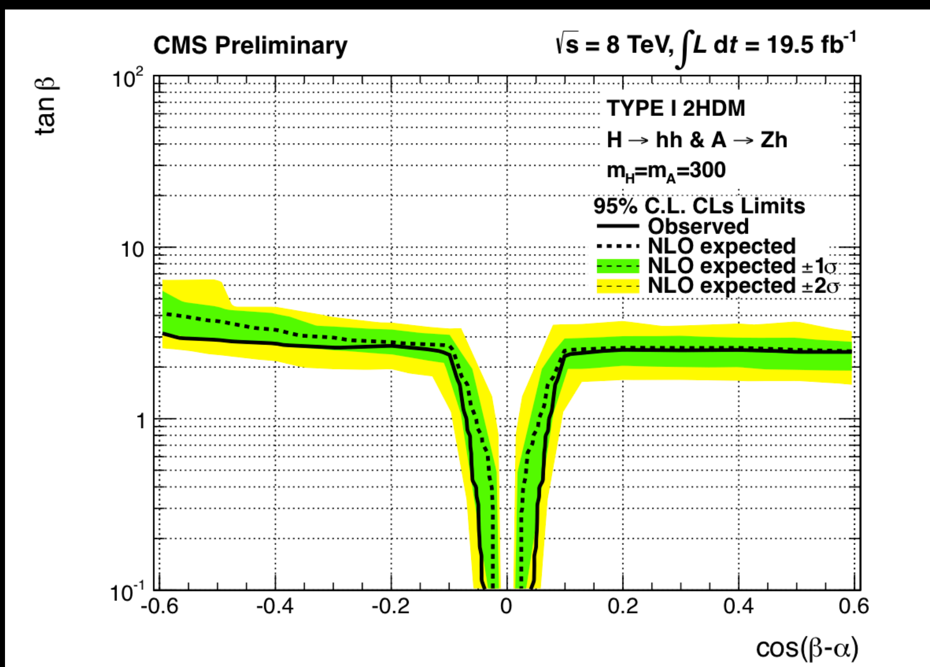


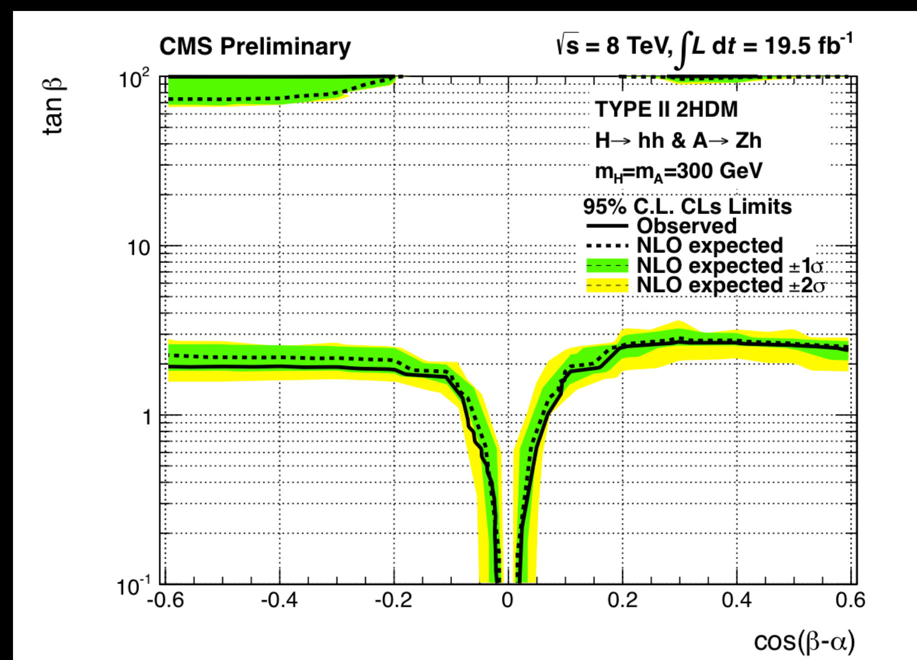




Is it the only Higgs Boson

- Two Higgs Doublet Models
- Decays heavy scalar *H→hh* and pseudo-scalar *A→Zh* of the and Higgs bosons

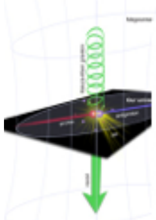


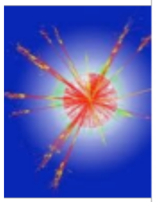


SEARCHES FOR “EXOTIC BSM SIGNATURES”

Blekman, Etzion, Thomas, Vivarelli , Contreas

(partial) List of Exotic Models





Extra dimensions:
- RS Kaluza Klein (KK) Graviton
  (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD
  (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification (GUT) symmetries
- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson
- (top antitop to dileptons, l+j, all had)

S8- color octet scalars (dijets)

String resonance (dijets,)

Benchmark Sequential SM (SSM) Z', W'

W' (lepton+MET, dijets, tb)

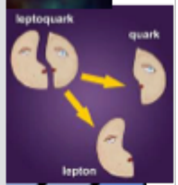
W* (lepton+MET, dijets)

Quantum Black Holes (dijet, l+j)

Black Holes (l+jets, same sign leptons)

Technihadrons (dileptons, dibosons)




Dark Matter
- WIMPs (monojet, monophotons,monoX..)

Excited fermions
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (Ist, 2nd, 3rd generations)

higgs -> hidden sector (displaced vertices, lepton jets)

Contact Interaction
- llqq CI
- 4q CI (dijets)

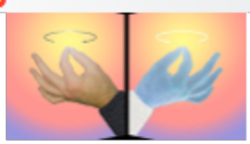
Doubly charged Higgs (multi leptons, same sign leptons)

4^{th} generation
- t'->Wb, t'->ht, b'-Zb, b'->Wt
- (dileptons, same sign leptons, l+J)

VLQ-Vector Like quarks

Magnetic Monopols (and HIP)

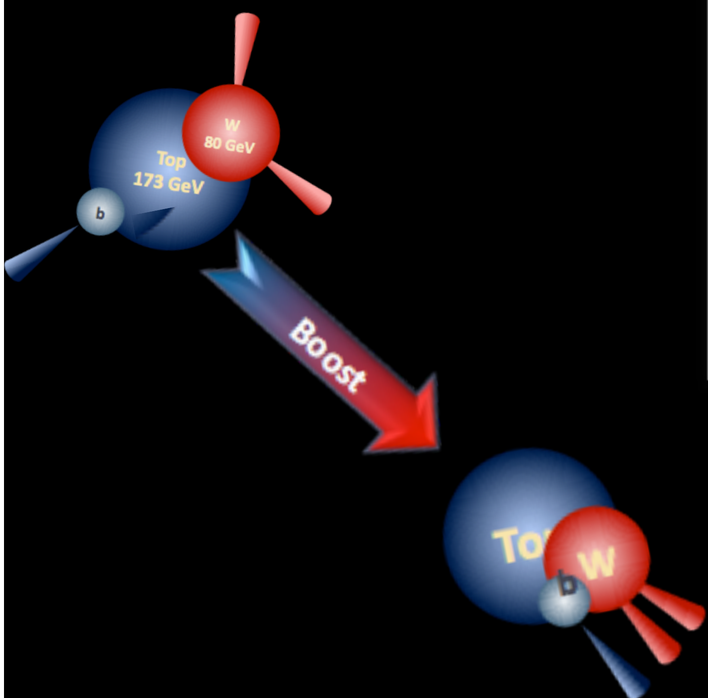
Heavy Majorana neutrino and RH W

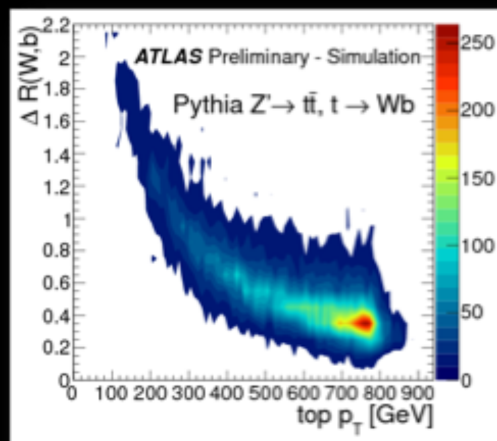


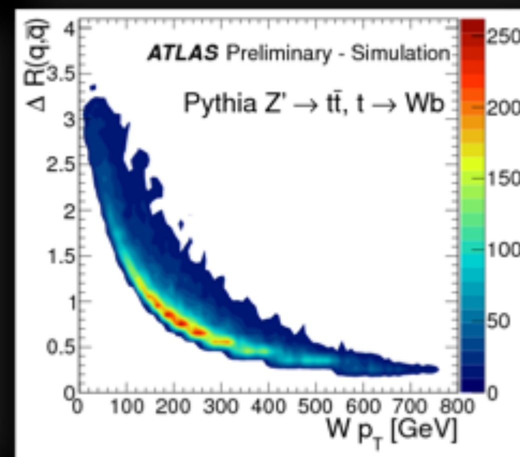

SEARCHES USING TOP QUARKS

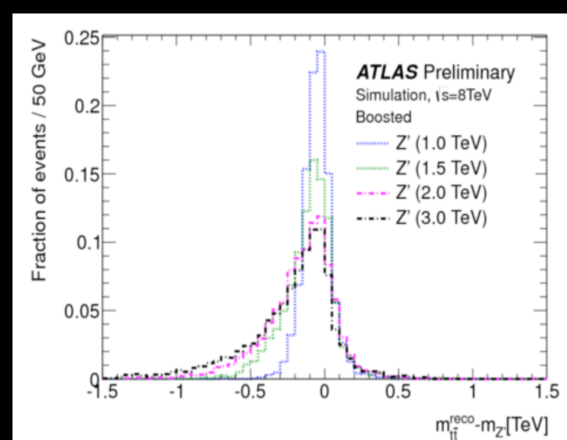
Heavy Particles decaying to top

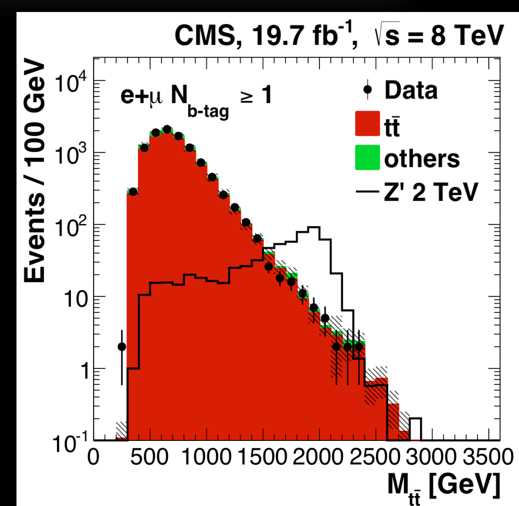
- Traditionally, top quark decay products are separated due to the large mass of the top quark and W boson...
- However, these heavy masses are non trivial to reonstruct under ~TeV scale boost



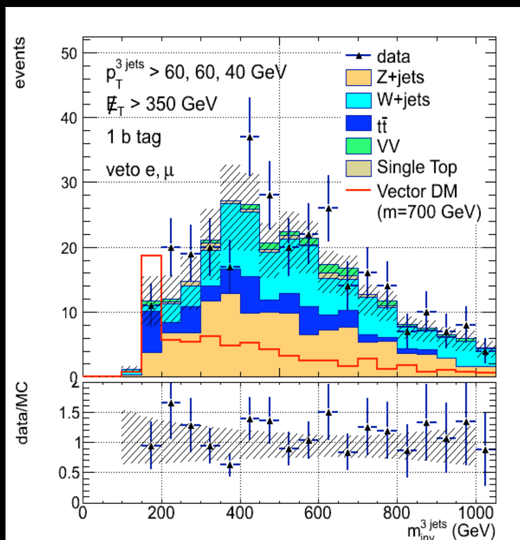


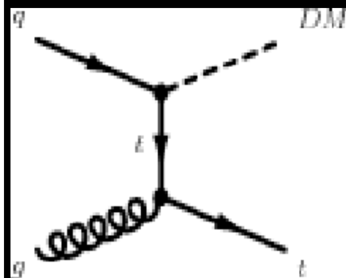


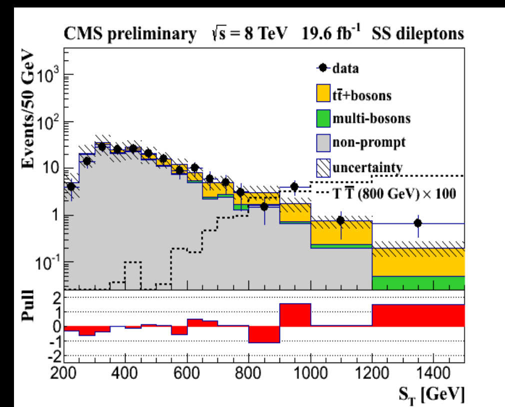


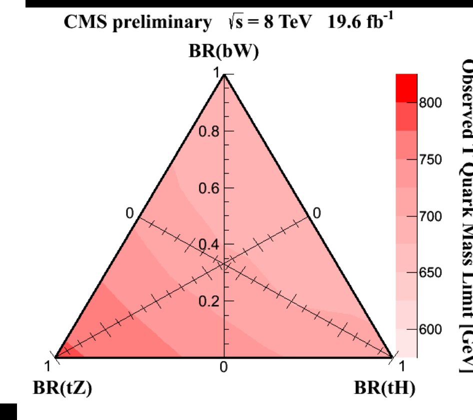


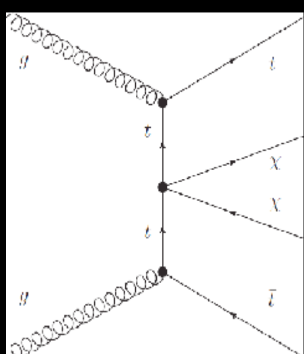
Heavy Top/B → t+(Z/W/h) and top(s)+DM

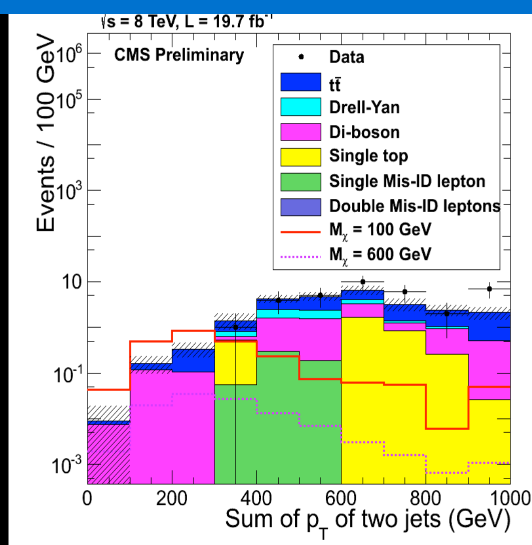


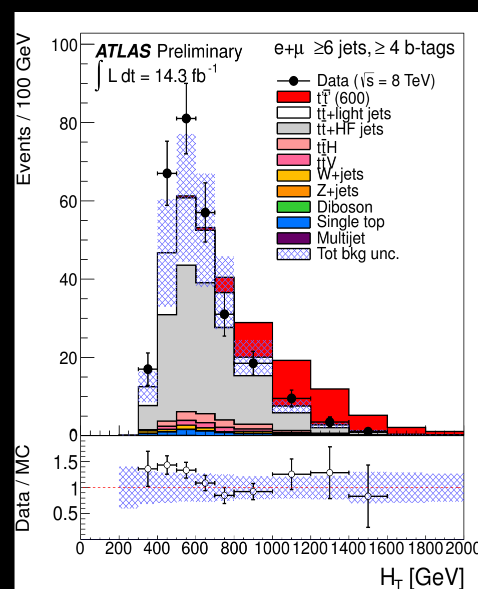


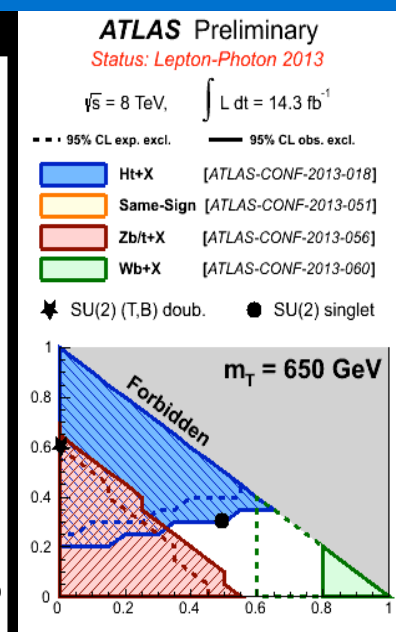






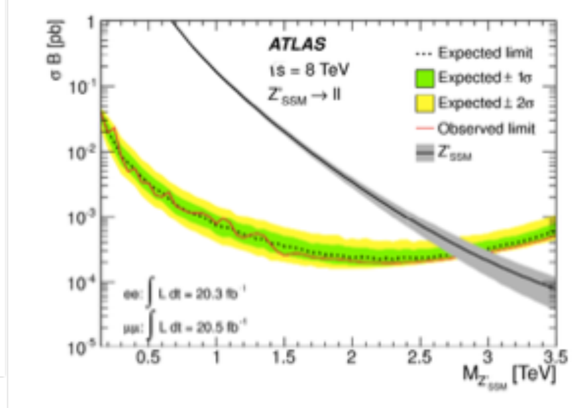


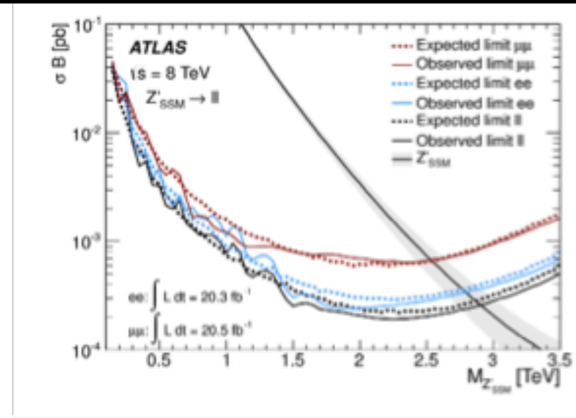


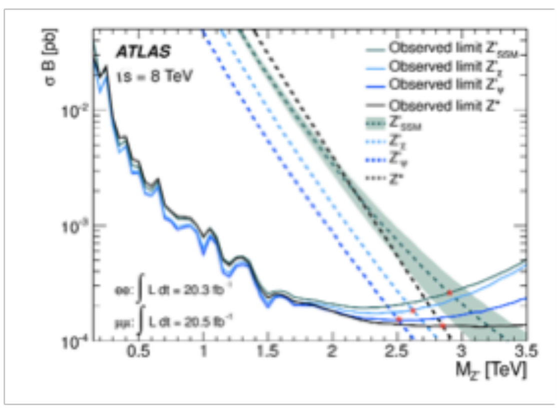


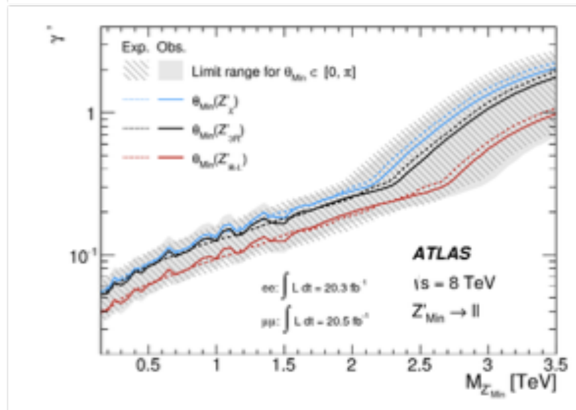
Search for dilepton resonances

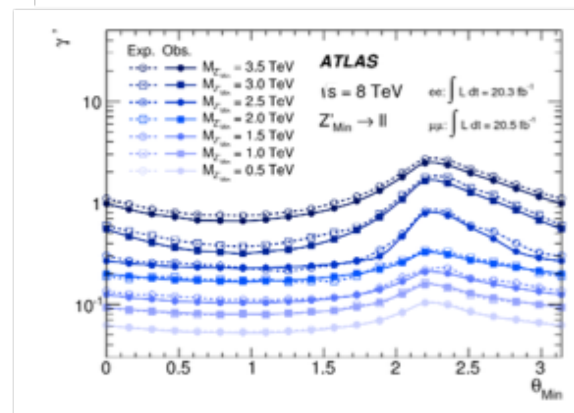
	σB [fb]		
Model	$M = 1$ TeV	$M = 2$ TeV	$M = 3$ TeV
Z'_{SSM}	170	3.4	0.21
Z'_{χ}	93	1.5	0.062
Z'_{ψ}	47	0.87	0.032
Z^{*}	300	4.0	0.076
G^{*}, $k/\overline{M}_{\mathrm{Pl}}$=0.1	190	1.8	0.044
RS QBH	56	0.40	0.0065
ADD QBH	11000	96	1.8
MWT, $\tilde{g} = 2$	31	0.17	N/A

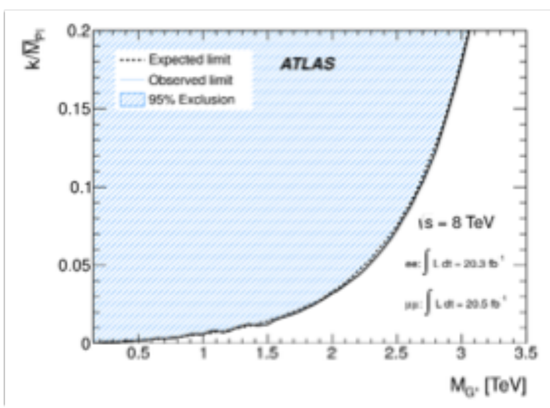


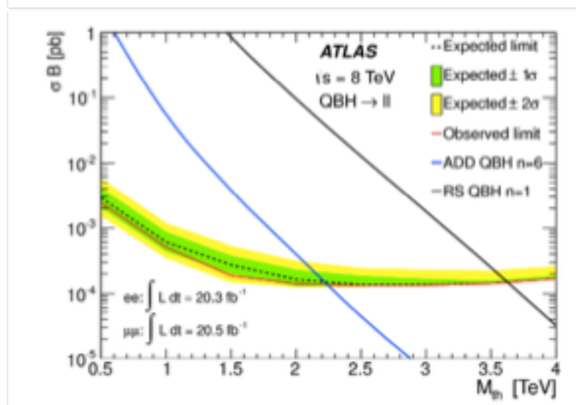


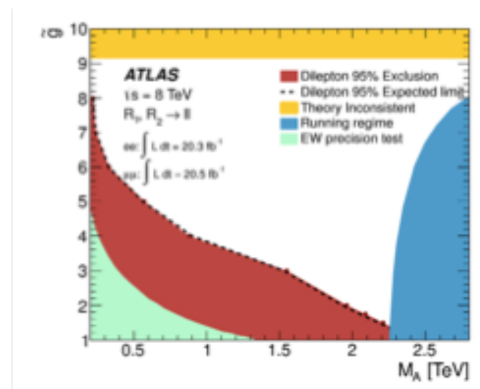










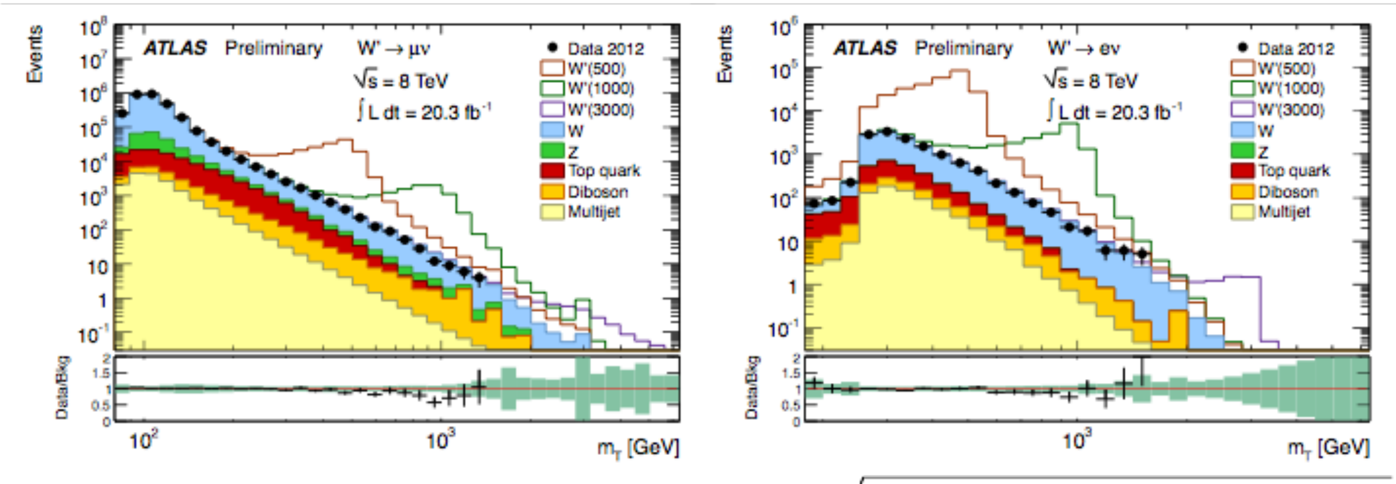


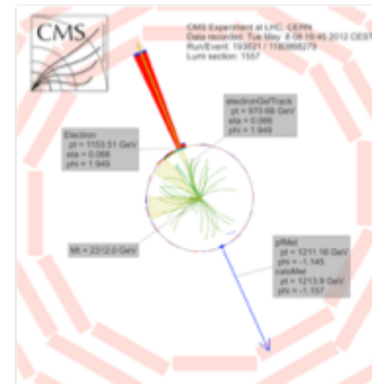
Search for Single Lepton states

- Search for excess in transverse mass of e or μ with low mass neutrino
- Interpret as SSM W' (no interference with SM W)
- Interpret also as excited chiral boson (W*) with equivalent couplings

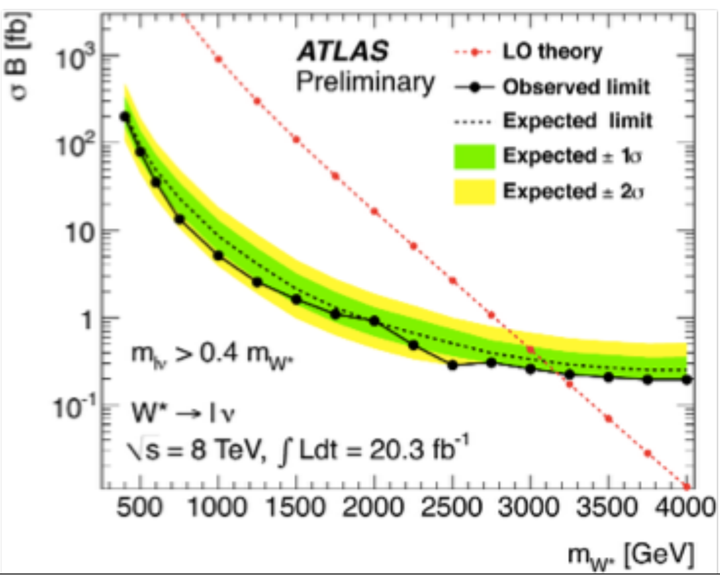
ATLAS-CONF-2014-017

[CMS EXO-12-060]





$$M_T = \sqrt{2 \cdot P_T^l \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{l,E_T^{miss}})}$$



	$m_{W'}$ [TeV]		m_{W^*} [TeV]	
decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	3.15	3.15	3.04	3.04
$\mu\nu$	2.98	2.98	2.80	2.80
both	3.19	3.27	3.08	3.17

M(W'SSM)	expected	observed
CMS	> 3.40 TeV	> 3.35 TeV
ATLAS	> 3.19 TeV	> 3.27 TeV
ATLAS 7 TeV		> 2.55TeV

ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 2014

ATLAS Preliminary

$\int \mathcal{L}\, dt = (1.0 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [\mathrm{fb}^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell/\gamma\gamma$	2γ or $2e, \mu$	–	–	4.7	M_S 4.18 TeV	$n = 3$ HLZ NLO	1211.1150
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	ATLAS-CONF-2014-016
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.47 TeV	$k/\overline{M}_{Pl} = 0.1$	ATLAS-CONF-2013-017
	RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell\ell qq/\ell\ell\ell\ell$	2 or 4 e, μ	2 j or –	–	1.0	G_{KK} mass 845 GeV	$k/\overline{M}_{Pl} = 0.1$	1203.0718
	RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	14.3	g_{KK} mass 0.5-2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.86 TeV		ATLAS-CONF-2013-017
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\, \ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		ATLAS-CONF-2014-015
	LRSM $W'_R \rightarrow t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	5.0	Λ 13.9 TeV	$\eta_{LL} = -1$	1211.1150
	CI $uutt$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C \rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator	–	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator	–	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $BB \rightarrow Zb + X$	2 e, μ	≥ 2 b	–	14.3	B mass 725 GeV	B in (B,Y) doublet	ATLAS-CONF-2013-056
	Vector-like quark $BB \rightarrow Wt + X$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \rightarrow qg$	–	2 j	–	13.0	q^* mass 3.84 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2012-148
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e \rvert$=0.055, $\lvert V_\mu \rvert$=0.063, $\lvert V_\tau \rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \rightarrow \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q \rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g \rvert = 1g_D$	1207.6411

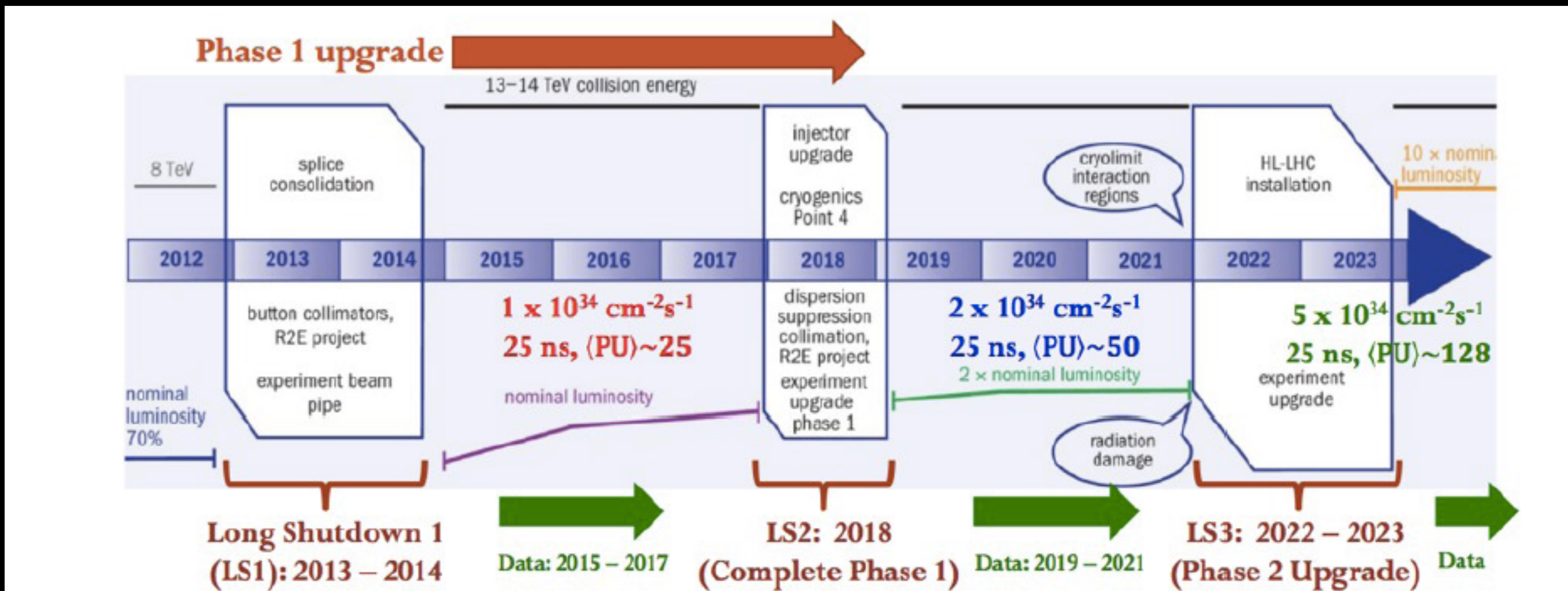
$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

Mass scale [TeV]: 10^{-1}, 1, 10

*Only a selection of the available mass limits on new states or phenomena is shown.

LHC reach for new particles?

- LHC plans:



2015-2017 and 2018-2021
run at design energy/luminosity
pp collisions at 13-14 TeV
15x as much data as in 2012

2024+
high-luminosity LHC
pp collisions at 14 TeV
150x as much data as in 2012

LHC reach for new particles?

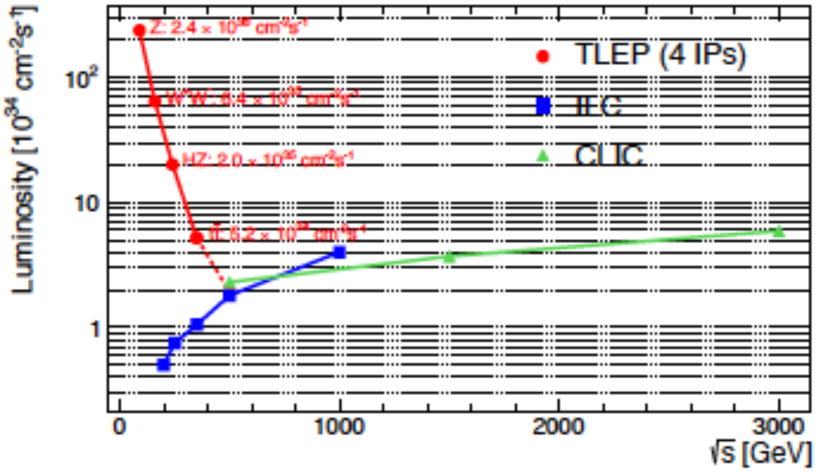
- with the full LHC program
- discover stop squarks
  - if m(stop) < 1100 GeV
- discover top partner quark
  - if m(T') < 1800 GeV
- if there is new physics that stabilizes the Higgs boson mass it should show up at the LHC in the coming two decades

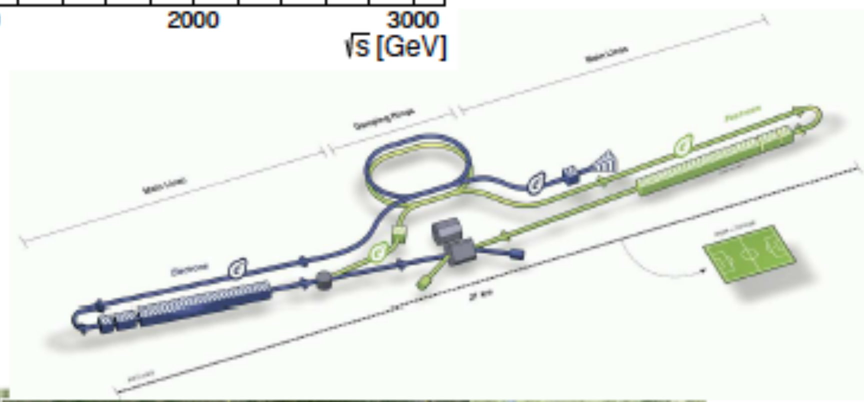
Colliders: near and far future

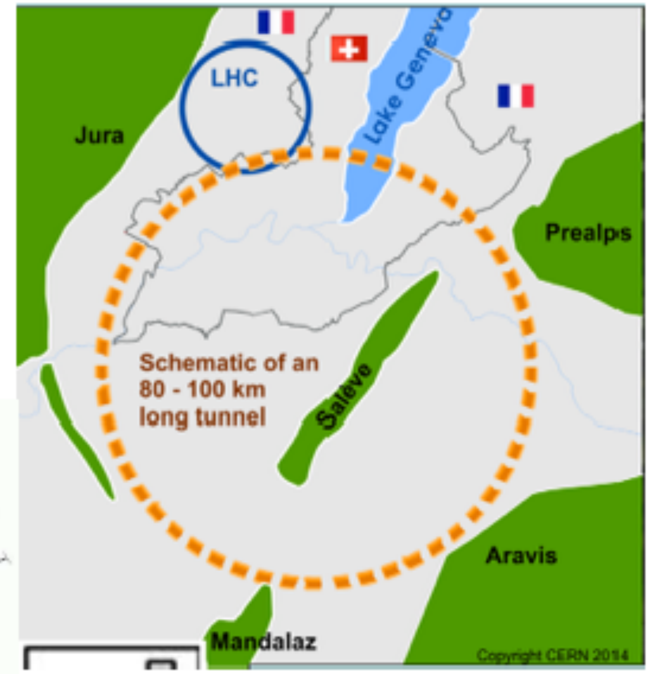
- The fun is just beginning!
- LHC:
  - premium in increasing √s close to 14 TeV
  - High-Luminosity LHC with a factor of 200 more data
    - Good prospects for precision measurements, discovering additional Higgs, and other new particles needed
- Future plans beyond the LHC:
  - e+e- Linear Collider start @ 250 GeV
  - LEP3: e+e- ring in the LHC tunnel @240 GeV
  - TLEP: a new 80 km ring e+e- @350 GeV
  - pp collider around 100 TeV.

The dream machines

Center for Cosmology and Particle Physics







- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel

FUTURE STRATEGY

towards the future…

- European strategy report May 2013
- US community study in summer 2013 and “Particle Physics Project Prioritization Panel “ aka P5 report – yesterday (22, May 2014)
- P5 report: science drivers
  - Use the Higgs boson as a new tool for discovery
  - pursue the physics associated with neutrino mass
  - Identify the new physics of dark matter
  - Understand cosmic acceleration: dark energy and inflation
  - Explore the unknown: new particles, interactions, and physical principles
- Pursue the most important opportunities.
- Pursue a program to address the five science Drivers

european strategy

- top priority: exploit LHC and its upgrades
- design studies of pp and e+e- machines, coupled with accelerator R&D program
- welcome the ILC initiative from Japan, encourage a proposal for European participation
- CERN should develop a neutrino program. Explore the possibility of major participation in a long baseline program in US or Japan.
- Europe should support a diverse theory program including high performance computing and software development.
- Experiments with unique reach in Europe should be supported as well as participation in other regions of the world.
- Detector R&D should be supported strongly at CERN and other institutes and infrastructure and engineering capabilities maintained and developed.
- CERN should seek closer collaboration with ApPEC.
- CERN shoudl continue to work with NuPECC.

USA/P5

- Complete the Mu2e and muon g-2 projects.
- The LHC upgrades constitute our highest-priority near-term large project.
- Complete LSST as planned.
- Proceed immediately with a broad 2nd dark matter direct detection program.
- In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.
- Form a new international collab. for a Long-Baseline Neutrino Facility in U.S.
- Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm.
- U.S. should engage in modest and appropriate levels of ILC accel. & det design
- Upgrade the Fermilab proton accelerator to provide proton beams of >1 MW at the start of the new long-baseline neutrino facility.
- Build DESI as a major step forward in dark energy science, if funding permits.
- Support CMB experiments as part of the core particle physics program.
- Support one or more third-generation direct detection experiment.
- Invest in CTA if the critical NSF Astronomy funding can be obtained.

Table 1
Summary of Scenarios

Project/Activity	Scenarios: Scenario A	Scenario B	Senario C	Science Drivers: Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contributions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, some reductions with redirection to PIP-II development	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C
DM G3	Y, reduced	Y	Y			✓			C
PINGU	Further development of concept encouraged				✓	✓			C
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I
Additional Small Projects (beyond the Small Projects Portfolio above)									
DESI	N	Y	Y		✓		✓		C
Short Baseline Neutrino Portfolio	Y	Y	Y		✓				I

Conclusion

- We live in an exciting time...
  - 2012 ATLAS and CMS discover Higgs boson
  - 2012 Daya Bay measures non-zero ϑ_{13}
  - 2014 BICEP2 observes inflationary gravitational waves
- The 25th Rencontres de Blois highlighted the potential for groundbreaking discoveries ahead
  - neutrino masses and mixing
  - the nature of dark matter
  - precise measurements of the Higgs boson
  - new physics at the energy frontier
- To an even more exciting 25 years!

Congratulations !!

- 25th Anniversary of “Rencontre de Blois”

Many Thanks to

Profs. Tran Than Van & Kim Van

Dr. Boaz Klima

The Secretariat Staff &

The Scientific Organizing Committee

for an excellent conference at a beautiful venue