Searches for non-Susy new physics at CMS

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Particle Physics and Cosmology

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on behalf of the CMS collaboration

Outline

- Introduction
  - motivation and general strategy
- CMS in brief
- Searches with high-p^T leptons final state (new heavy resonances)
  - W', Z', LQ
- Searches with di-photon final state
  - LED, RS graviton
- New Physics with jets
  - di-jet and multi-jet mass resonances
- Summary

Motivations and strategy

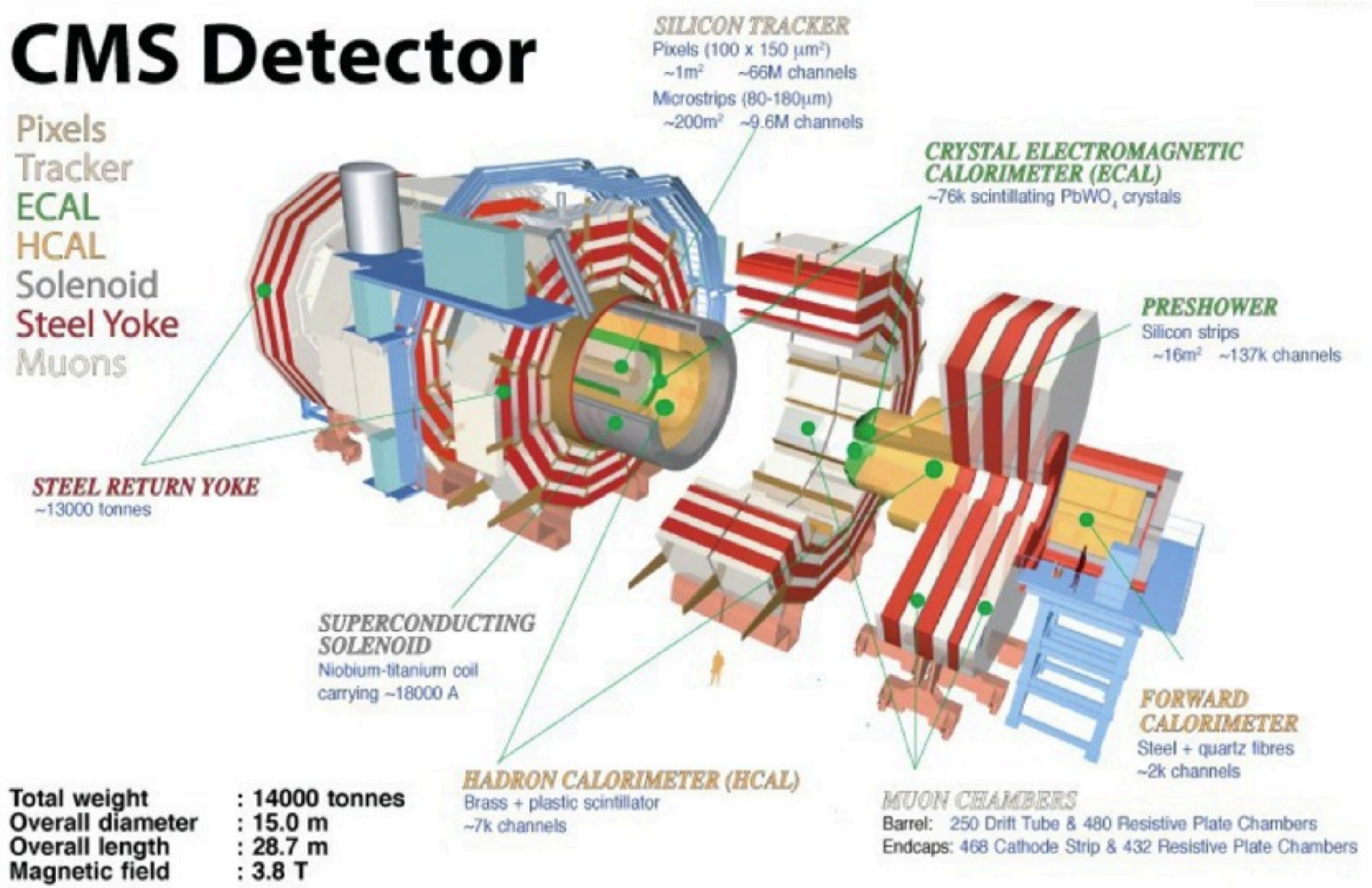
- Many physics theories have been built to extend the SM
- These theories foresee a quantity of new particles
  - Left-right symmetry of electroweak interactions
    - Extend the SM gauge group to include right-handed interactions
  - Extra dimensions
    - Kaluza-Klein (KK) tower of heavy copies of all SM fields
  - General extensions of the SM gauge group
    - e.g. Little Higgs models
  - Technicolor
  - GUT
  - Composite models
    - Higgs not just an elementary particle
  - ......

} W', Z', RS graviton, LQ, micro black holes, ...

- General strategy:
  - excess in data in the high $P_T/M_T/M_{inv}$ region with respect to the SM expectations (MC)
  - if no excess is observed -> determine the exclusion limit.
- It is crucial to have a good description of the backgrounds
  - accurate shape model
  - accurate normalization

The CMS detector

- Full 2010 dataset used in the analysis presented (~35 pb^{-1} @ 7 TeV)



High p^T leptons final state

- Detect high-pT leptons means to optimize reconstruction and identification in order to maximize the efficiency in the high-pT region

  - Electrons:
    - Electromagnetic clusters with consistent shower shape
    - Spatially matched to a reconstructed track in η and φ
    - Isolated in calorimeter and tracker

- **CaloDriven**
- **resol gets better with E**
- **jet background**

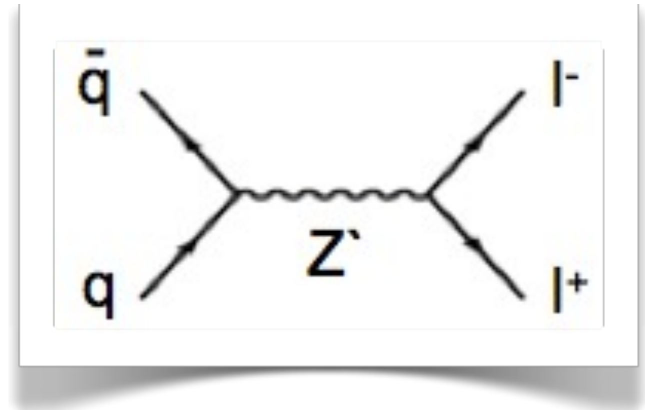
  - Muons:
    - Tracks in muon system matched to tracks in inner tracking system
    - Isolated in tracking system and calorimeter
    - More than 10 hits in silicon tracker
    - Transverse impact parameter < 2mm

- **TrackerDriven**
- **resol gets worse with p^T**
- **cosmic background (pair)**

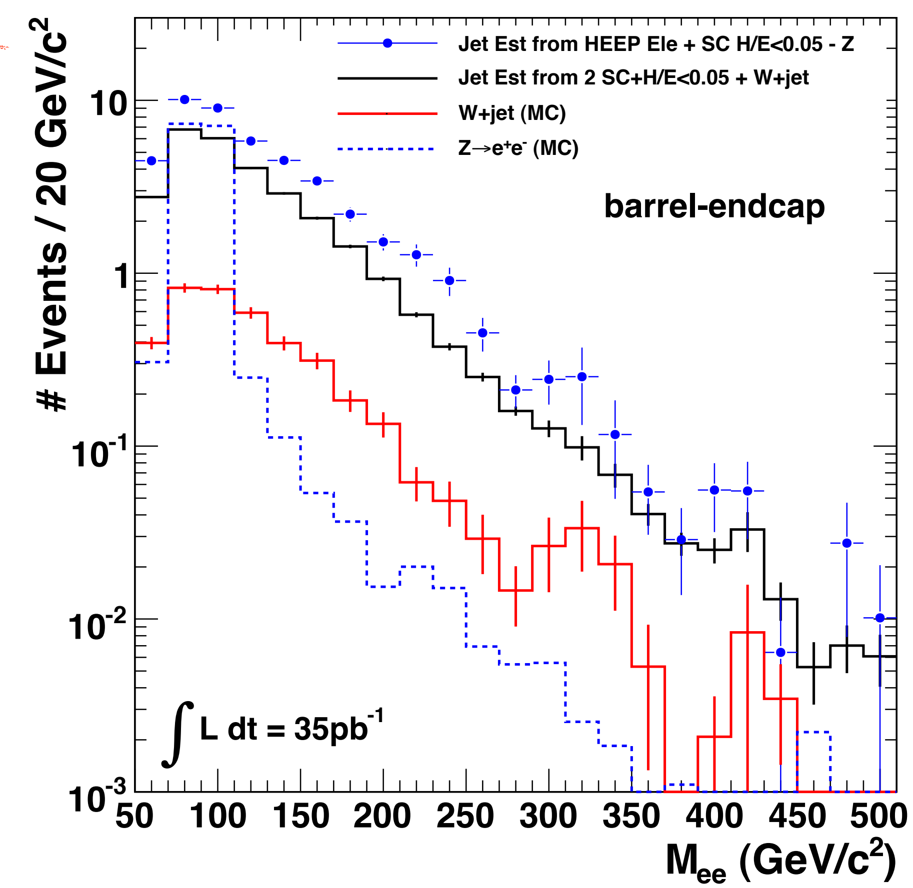
- Robust and efficient lepton trigger is needed

Z' -> ll

- Clean signature with 2 high-p^T leptons in the final state passing the eleId or muId
- Focus on Z' and RS Graviton models as benchmark
- Complementary searches: lepton univer., different subdet., ...



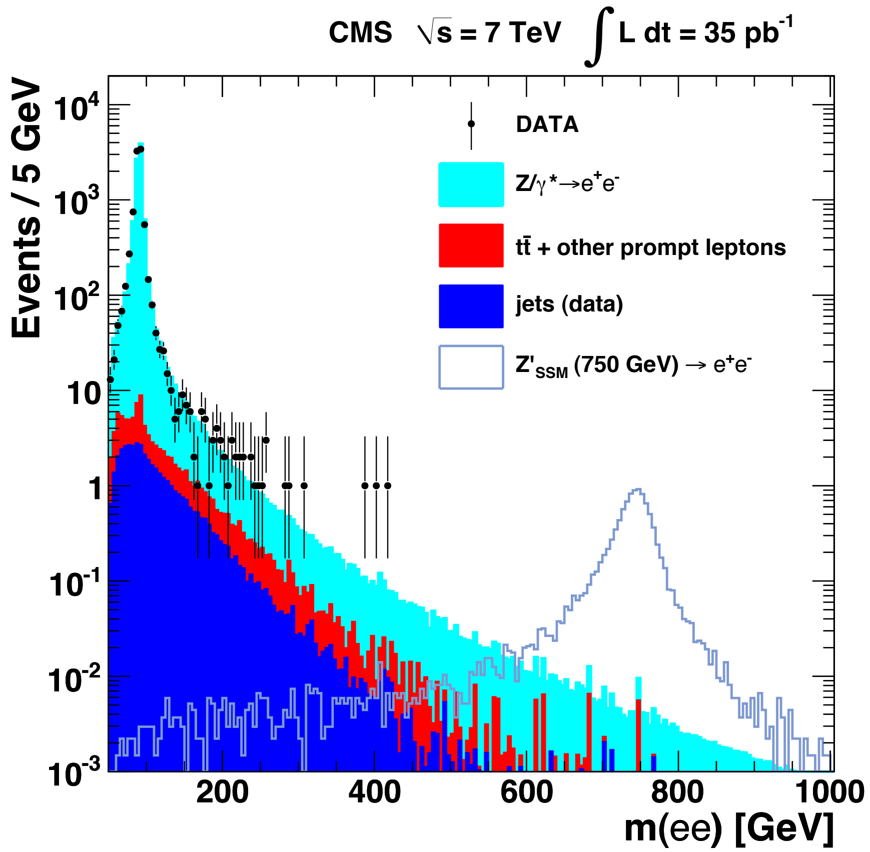
- Main backgrounds:
  - SM Drell-Yan -> irreducible
    - normalized to data
  - TTbar + TTbar-like -> two real leptons (tt,WZ,WW,tW,Z->ττ)
  - Jet Background -> jet fakes a lepton (W+jet,di-jet)
    - fake rate method
  - Cosmics muons bkg -> di-muons from cosmic-rays
    - impact parameter selection
    - 3D angle between the two muons selection

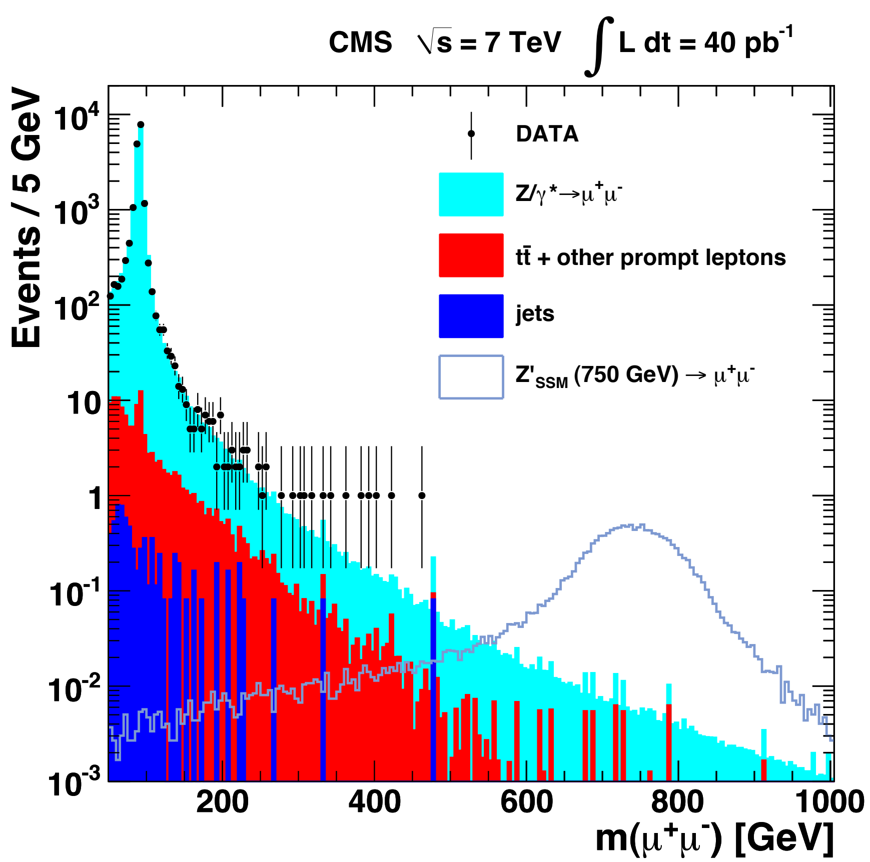


- The bkg with prompt leptons is from MC but cross checked against the e-mu spectrum

	M>60 GeV/c²	M>120 GeV/c²	M>200 GeV/c²
data	95 ± 10 (stat)	33 ± 6 (stat)	6 ± 2 (stat)
MC	80.4 ± 2.4 (sys)	27.1 ± 0.8 (sys)	7.0 ± 0.2 (sys)

Final selection and results



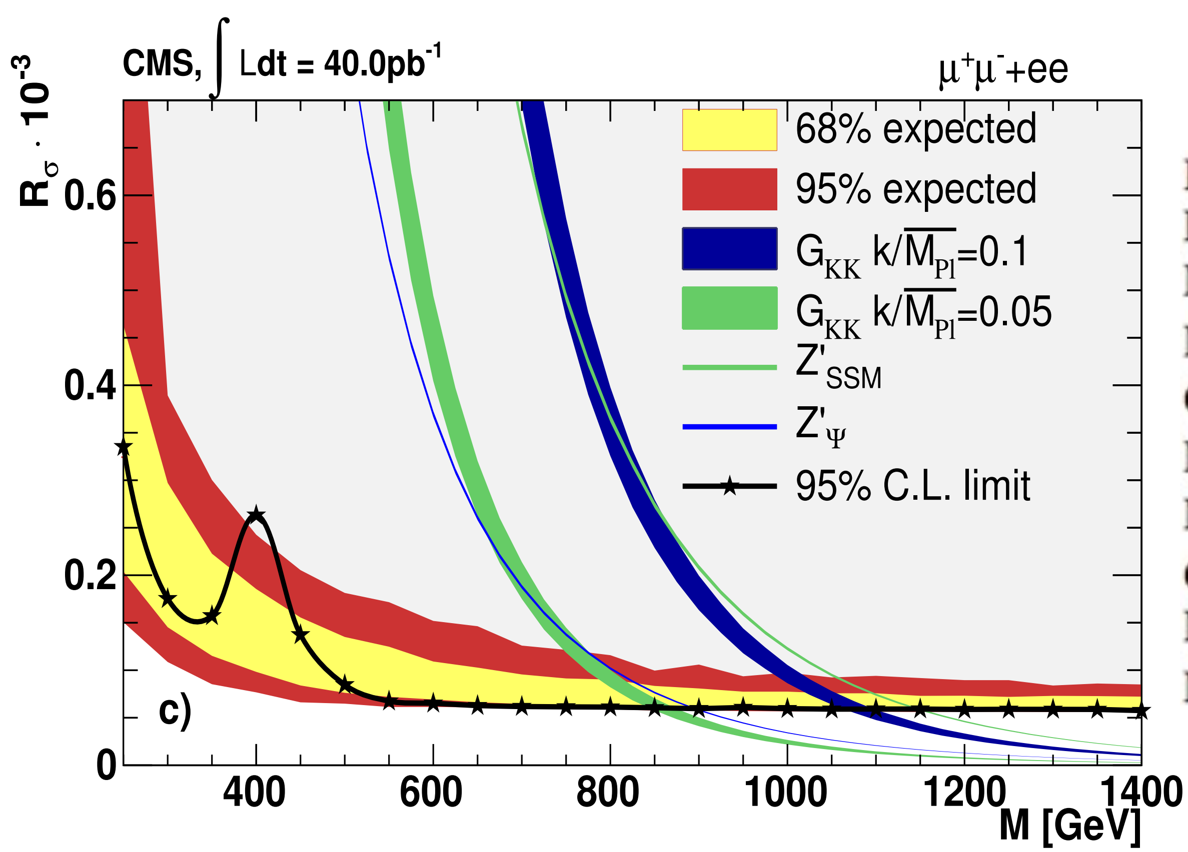


- By focusing on the ratio, the uncertainty on the integrated lumi is eliminated

$$\frac{\sigma \times BR(Z')}{\sigma \times BR(Z^0)} = \frac{N(Z')}{N(Z^0)} \times \frac{A(Z^0)}{A(Z')} \times \frac{\epsilon(Z^0)}{\epsilon(Z')}$$

Channel	μμ	ee	combined
Z_{SSM}	1027 GeV	958 GeV	1140 GeV
Z_ψ	792 GeV	731 GeV	887 GeV
G_{kk}, k/M_{Pl} = 0.05	778 GeV	729 GeV	855 GeV
G_{kk}, k/M_{Pl} = 0.10	987 GeV	931 GeV	1079 GeV

Exclusion @ 95% C.L.



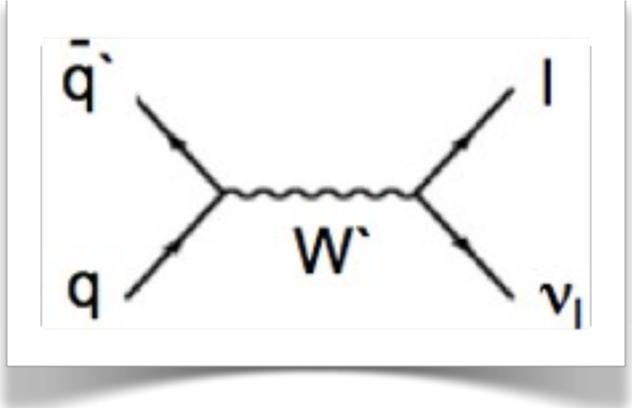
Published CDF/D0 limits
D0, ee,γγ 5.4 fb⁻¹:
$M(Z'_{SSM}) > 1023$ GeV
$M(G_{KK}, {}^{k/M=0.1}) > 1050$ GeV
CDF, μμ, 2.3 fb⁻¹:
$M(Z'_{SSM}) > 1030$ GeV
$M(G_{KK}, {}^{k/M=0.1}) > 921$ GeV
CDF, ee , 2.5 fb⁻¹:
$M(Z'_{SSM}) > 963$ GeV
$M(G_{KK}, {}^{k/M=0.1}) > 848$ GeV

W' -> lν

- Altarelli reference model tested (carbon copy of SM W boson)
- Signature: single and isolated high-pT lepton + large MET

- Kinematic selections:
  - Δφ (lepton, MET) > 2.5
  - 0.4 < lepton ET / MET < 1.5

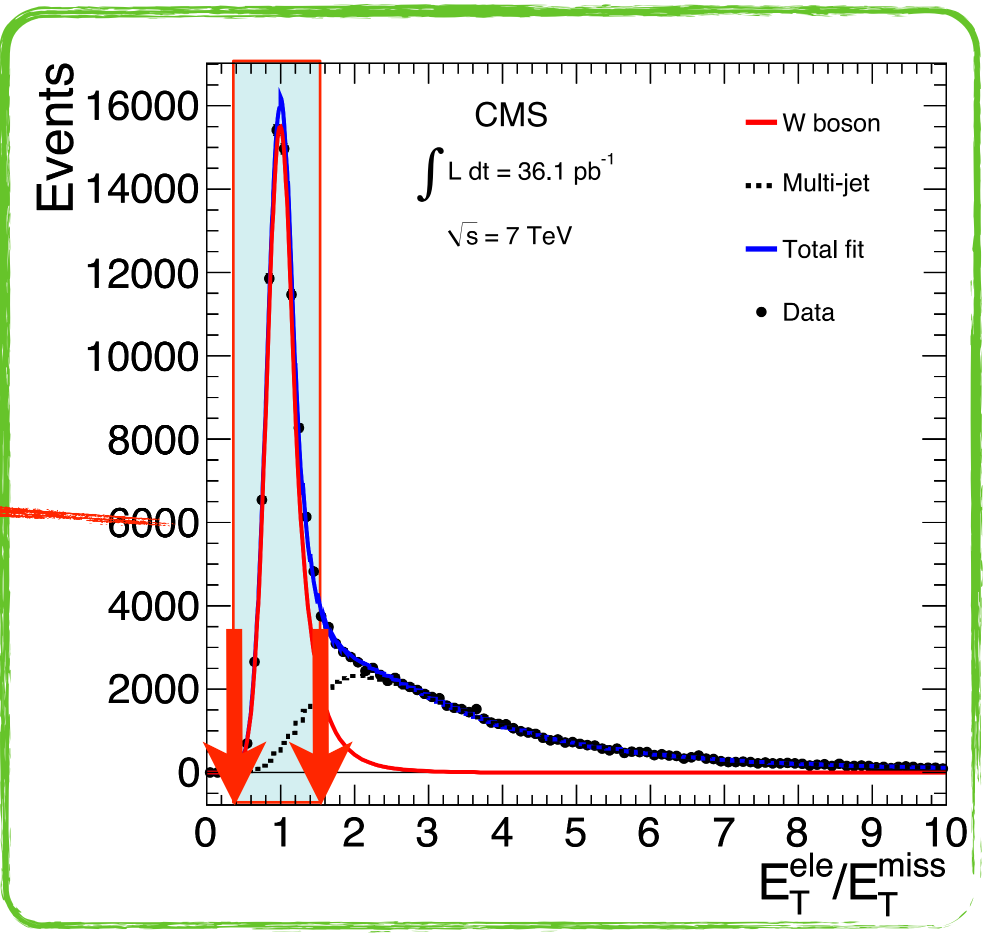
} lepton and MET balance: both module and direction



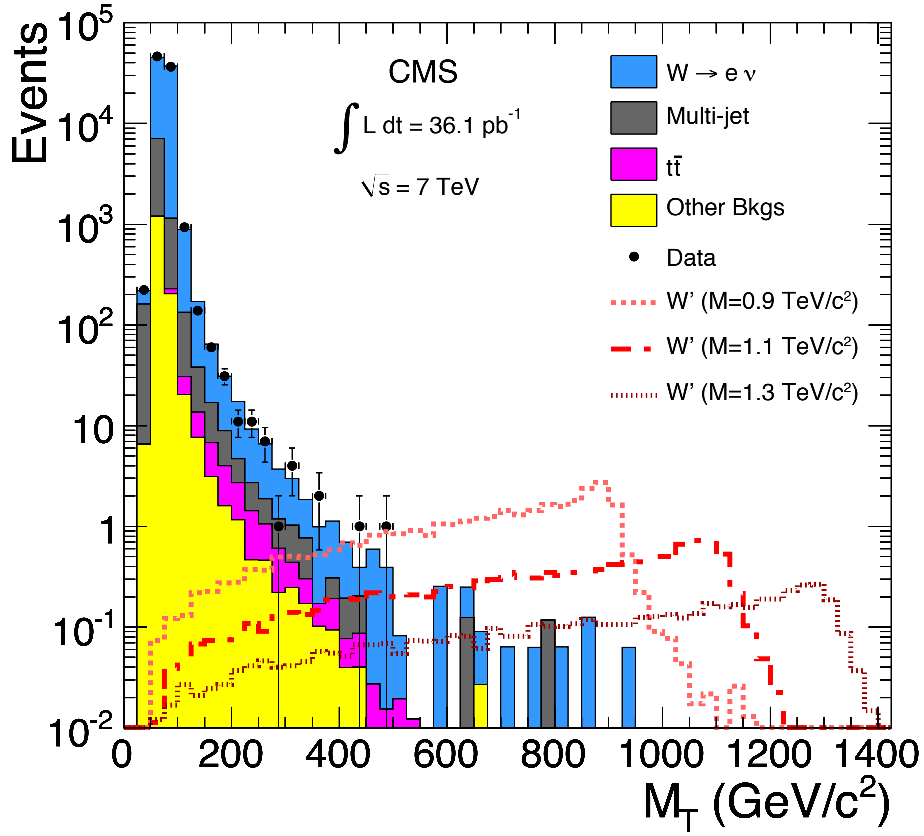
- Main background: irreducible Standard Model W -> lν
- Bkg estimate in the high-pT region: two different approaches for electron and muon channels

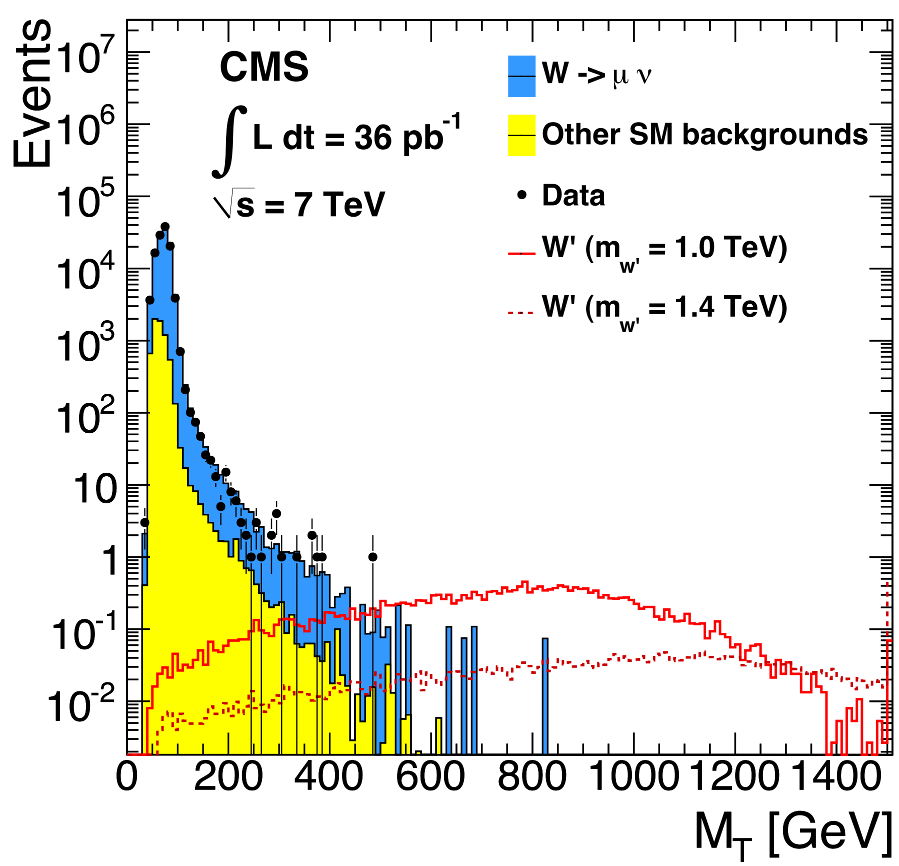
  - Invert the isolation requirement and use the shape of M^T from non-isolated electrons
  - Fit data E^T/MET distribution with QCD template (from non-iso) + W template (from MC), leaving the two normalizations as free parameters.
  - M^T spectra are normalized to the template area in the region 0.4 < Et/MET < 1.5

  - Sideband fit in a region where signal ~1%
    - Breit-Wigner fit in the range: 180 GeV < M^T < 350 GeV
  - Extrapolation in the high-p^T region
  - Cross check with MC



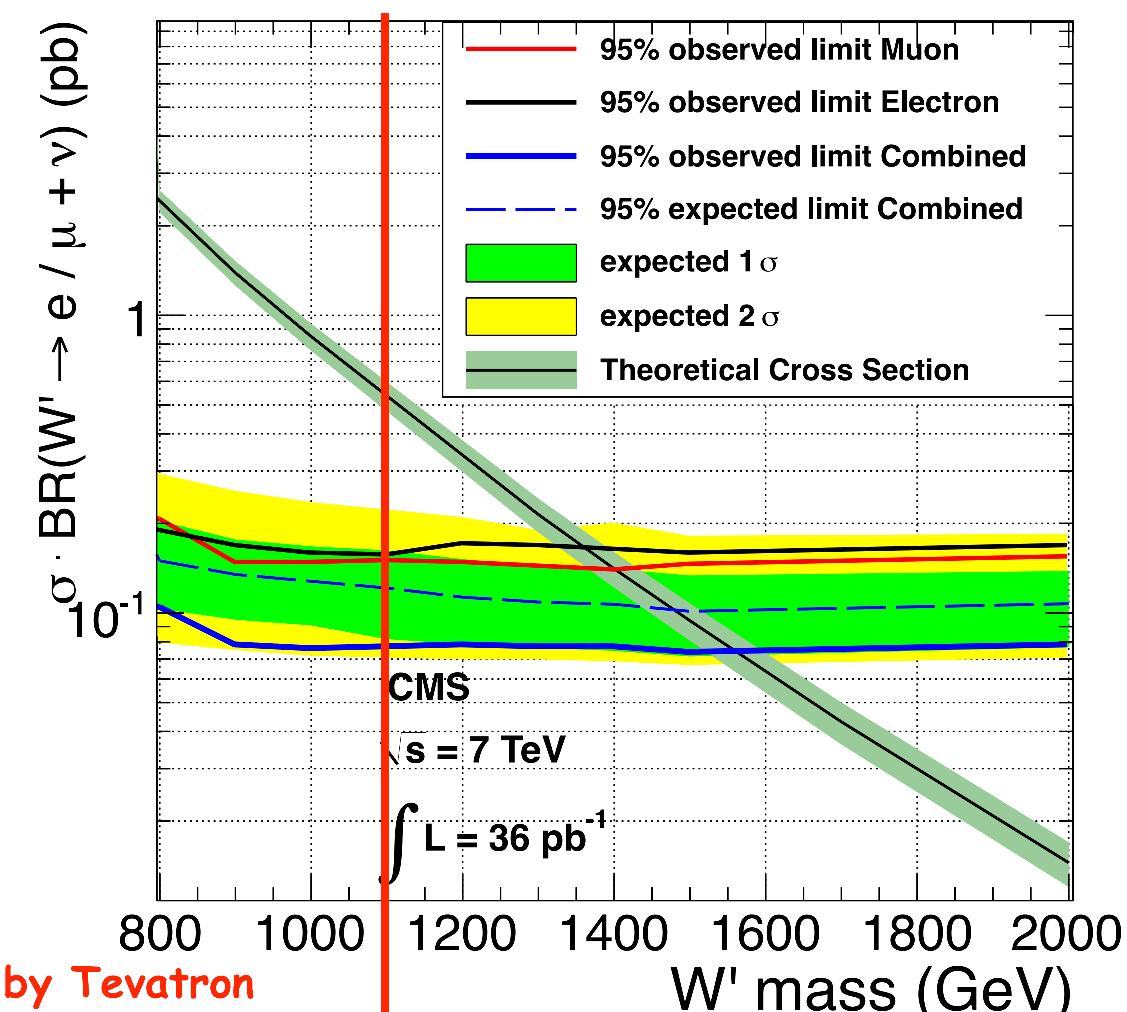
Final selection and results





- Good agreement between data and SM prediction
- Exclusion limit up to M(W') = 1.58 TeV @ 95% C.L.
- Cut and count method: sliding search window to optimize the limit

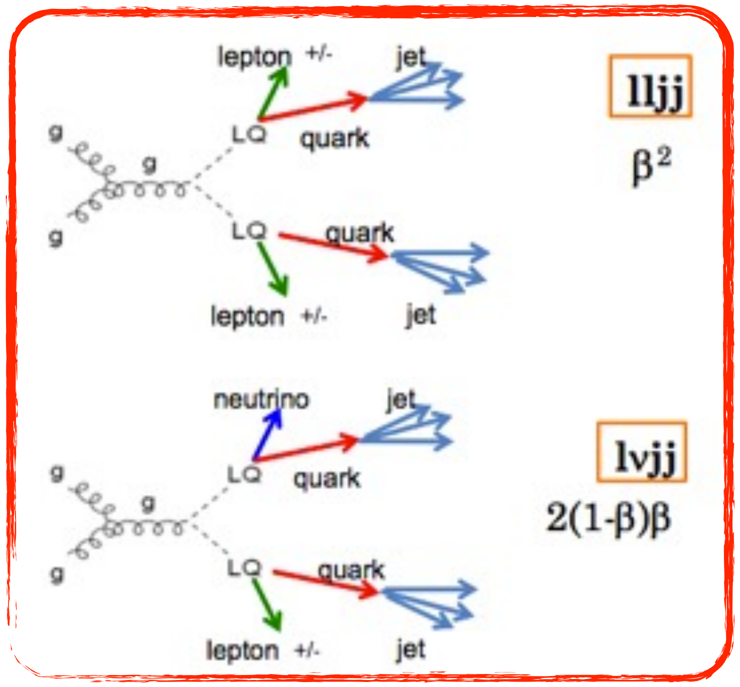
$$M_T = \sqrt{2 \cdot E_T^{ele} \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{eE_T^{miss}})}$$

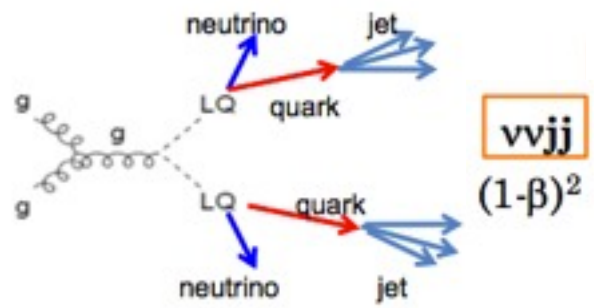


Excluded by Tevatron below 1.1 TeV

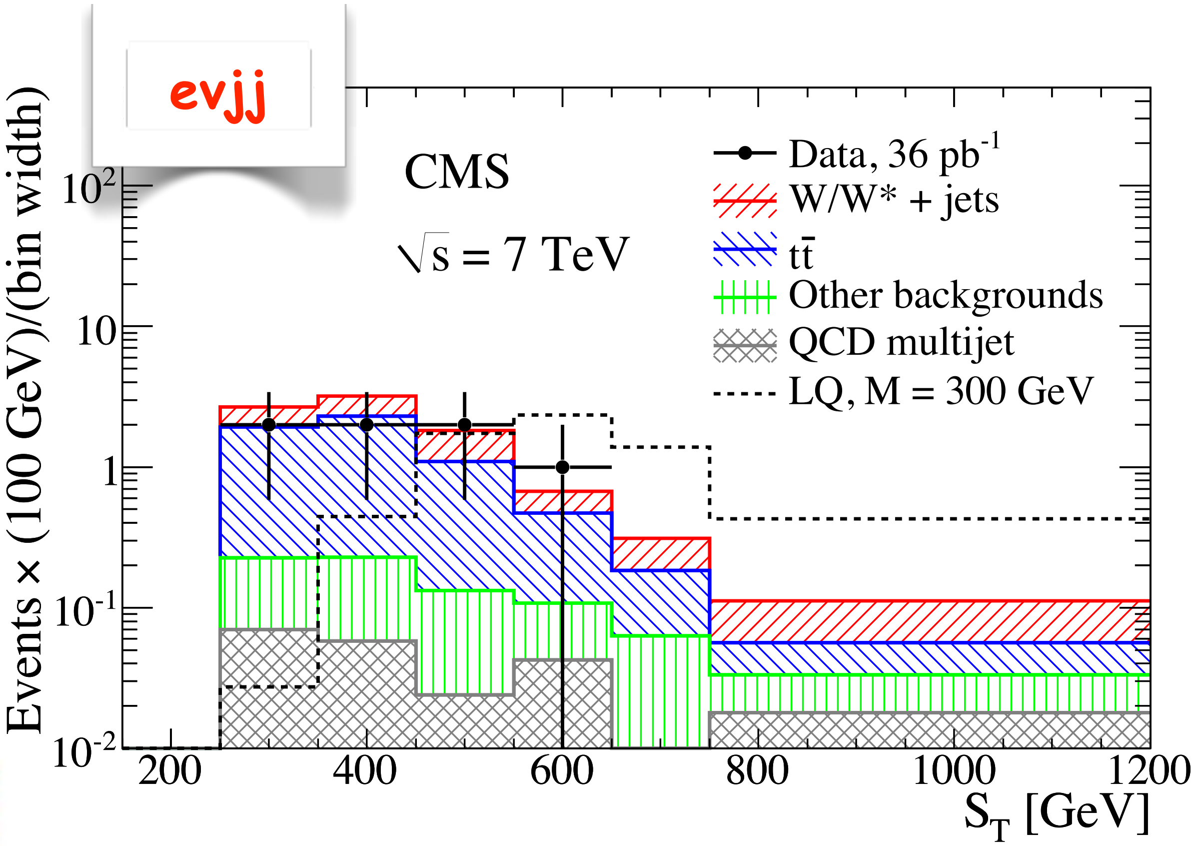
Scalar LQ pair -> lljj, lνjj

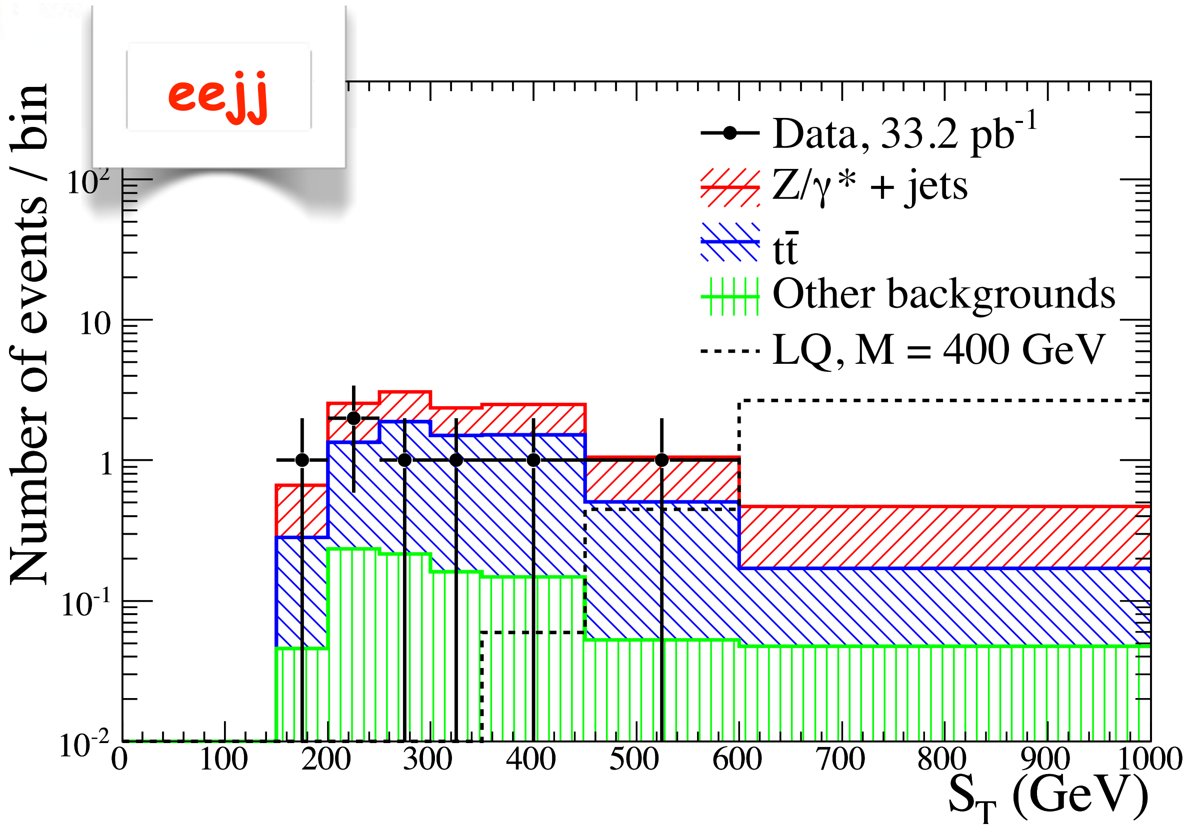
- Three LQ generations and three signatures
- Characterized by two free parameters
  - M_{LQ} = LQ mass; λ = LQ - l - q coupling < λ_{EM} ~ 0.3
- Look for an excess in the S^T distribution
  - $S^T = p^T(l_1) + p^T(l_2) + p^T(j_1) + p^T(j_2) > f(M_{LQ})$





S^T most powerful variable in discr S and B
M_{lj} is affected by combinatorics

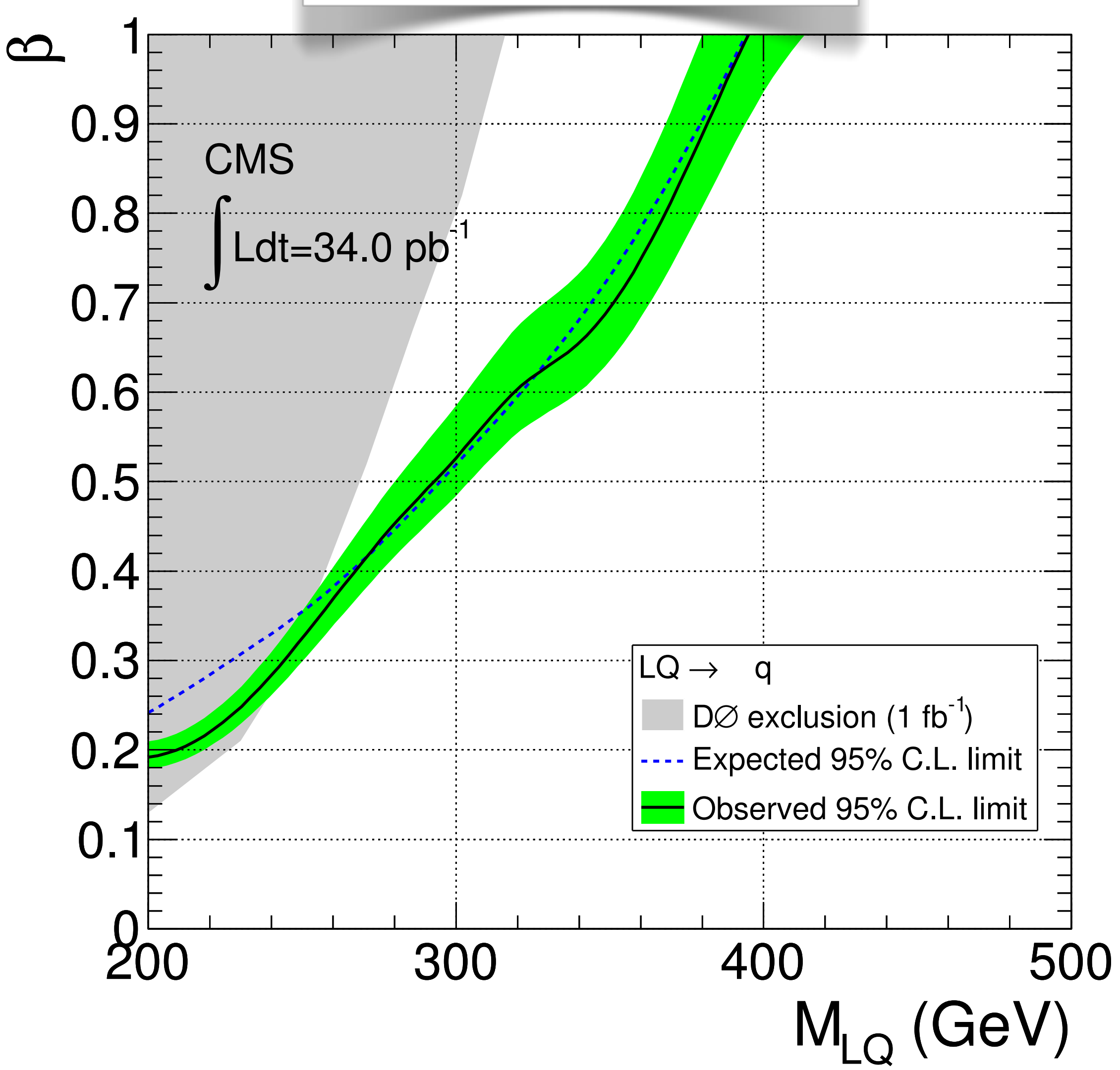




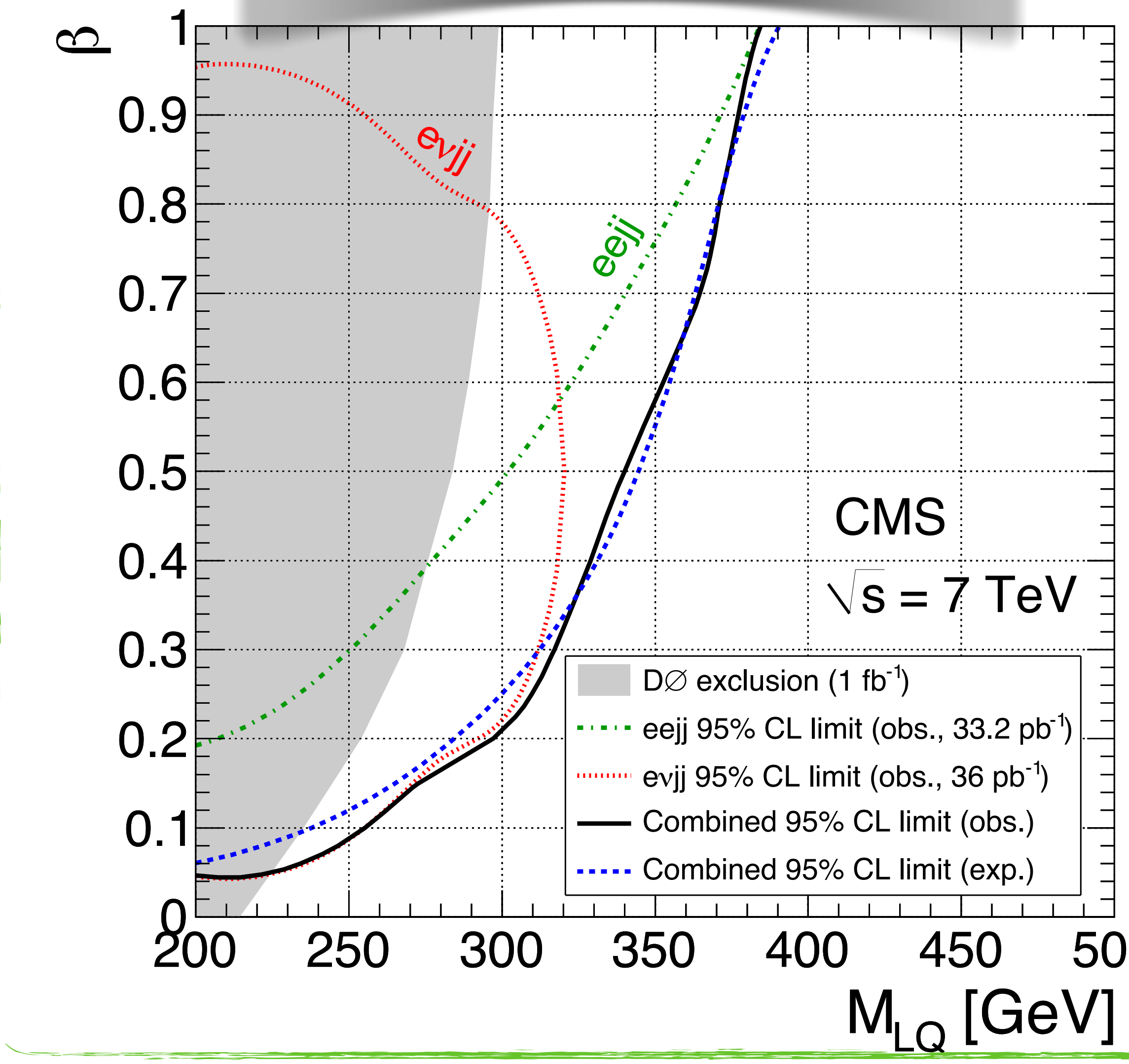
Limits on σ_{prod}(LQ pair) and M_{LQ}

- The data are consistent with SM background expectation
  - Upper limits on the LQ cross section are set using a Bayesian approach
- The existence of first and second generation LQs with mass below 384 and 394 GeV, respectively, are excluded for β=1
- Exceed Tavatron limits for almost the entire β range

2nd gen LQ: μμjj

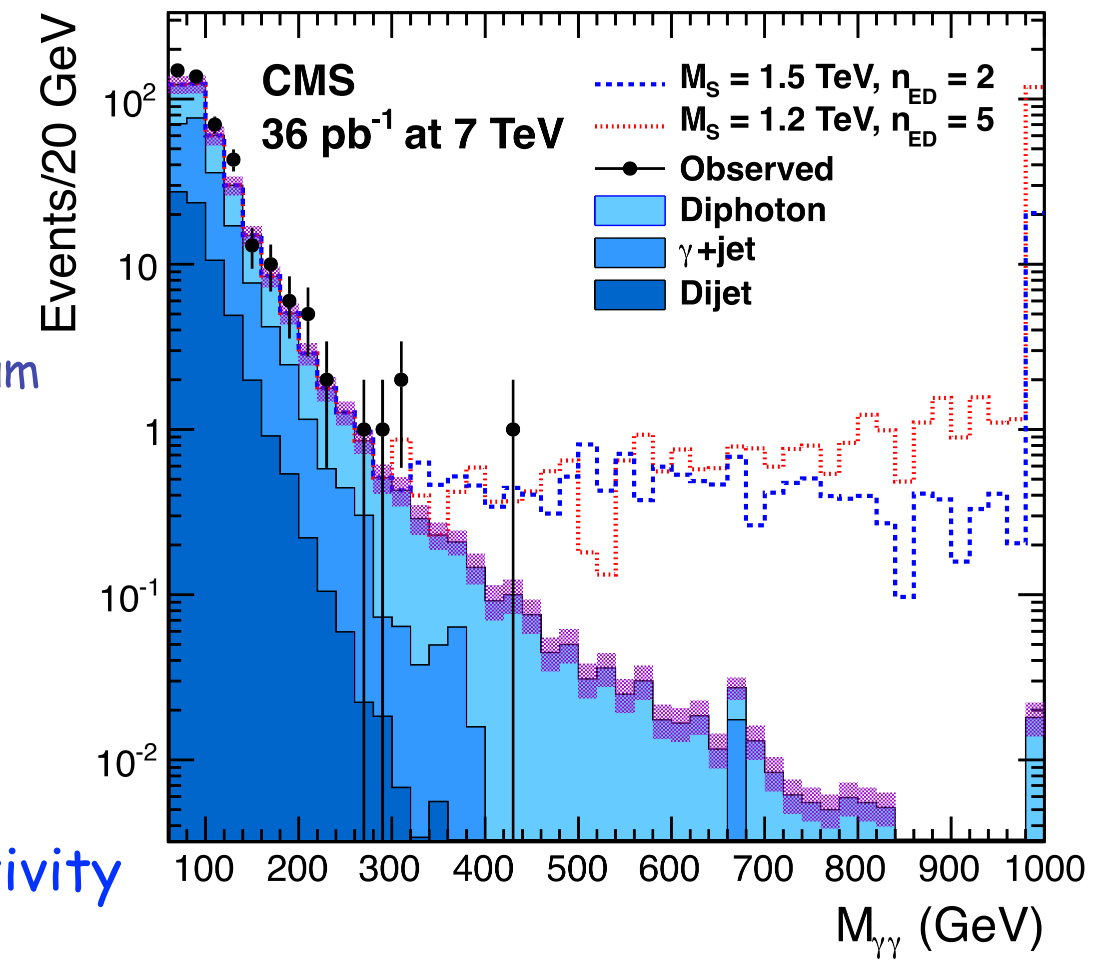


1st gen LQ: eνjj + eejj



Di-photon final state: LED, RSG

1. ADD Model
   - Looking for broad excess @ high mass in γγ spectrum
   - set limits on M_S vs n
   - M_S = UV cut-off in σ; n = # of extra dimensions
2. RS graviton
   - Looking for narrow resonances @ high mass in γγ spectrum
   - set limit on the graviton mass and coupling param

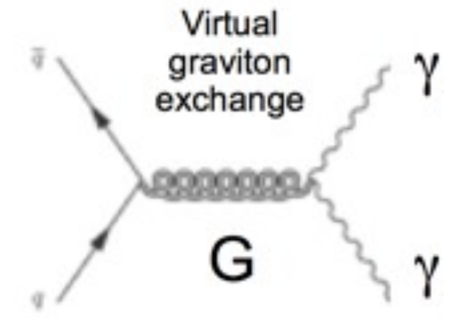


- Main backgrounds:
  - di-photon irreducible (Born+Box)
  - γ+jet and multijet (photon misidentification)
  - fake rate method from non-iso photons
- $M_{\gamma\gamma}$ and η optimized to produce the highest sensitivity
  - |η| < 1.4 for both the analysis

1. **The existence of the RSG is excluded below 371 (945) GeV/c² for k/M_P = 0.01 (0.1)**

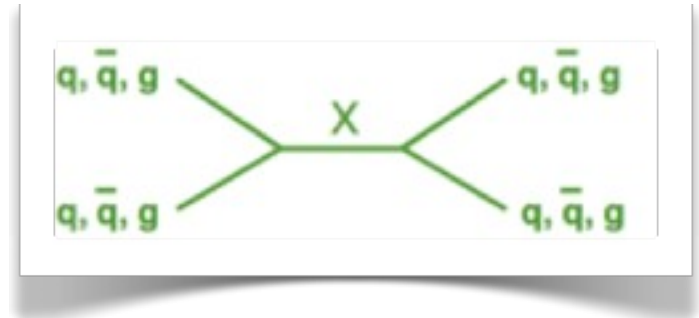
2. **Limit on strength of Extra Dimensions effect/UV cut-off**

	GRW	Hewett		HLZ					
		Pos.	Neg.	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
Full	1.94	1.74	1.71	1.89	2.31	1.94	1.76	1.63	1.55
Trunc.	1.84	1.60	1.50	1.80	2.23	1.84	1.63	1.46	1.31

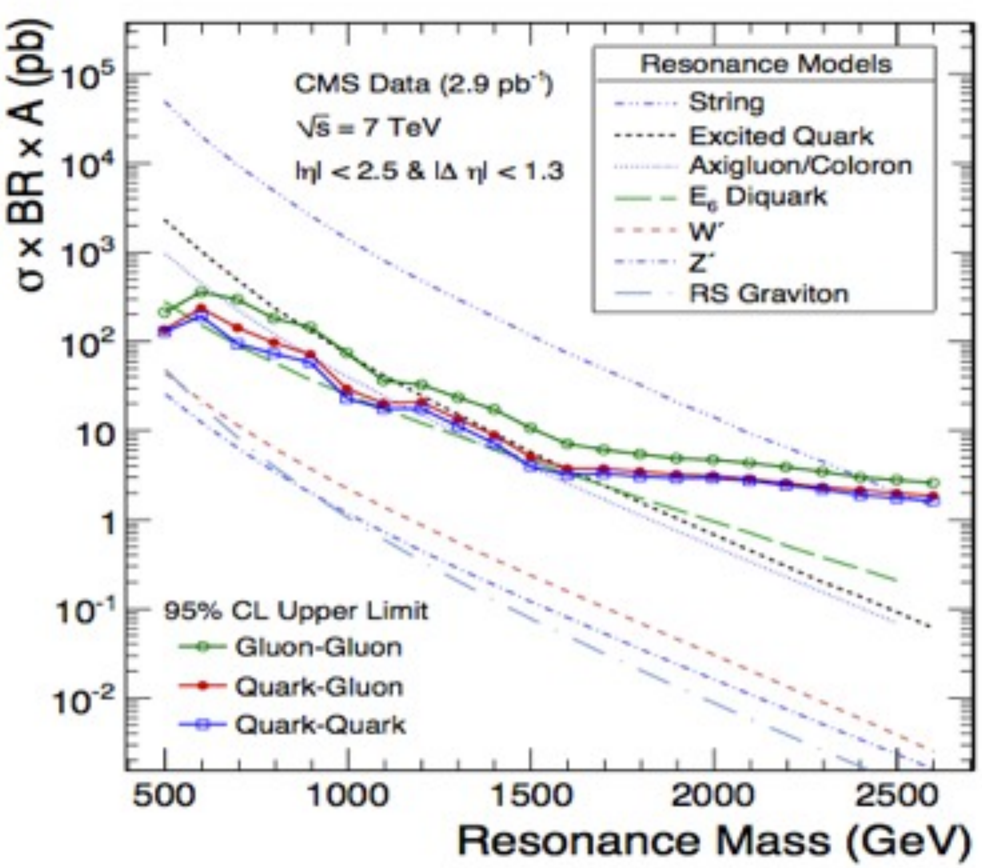


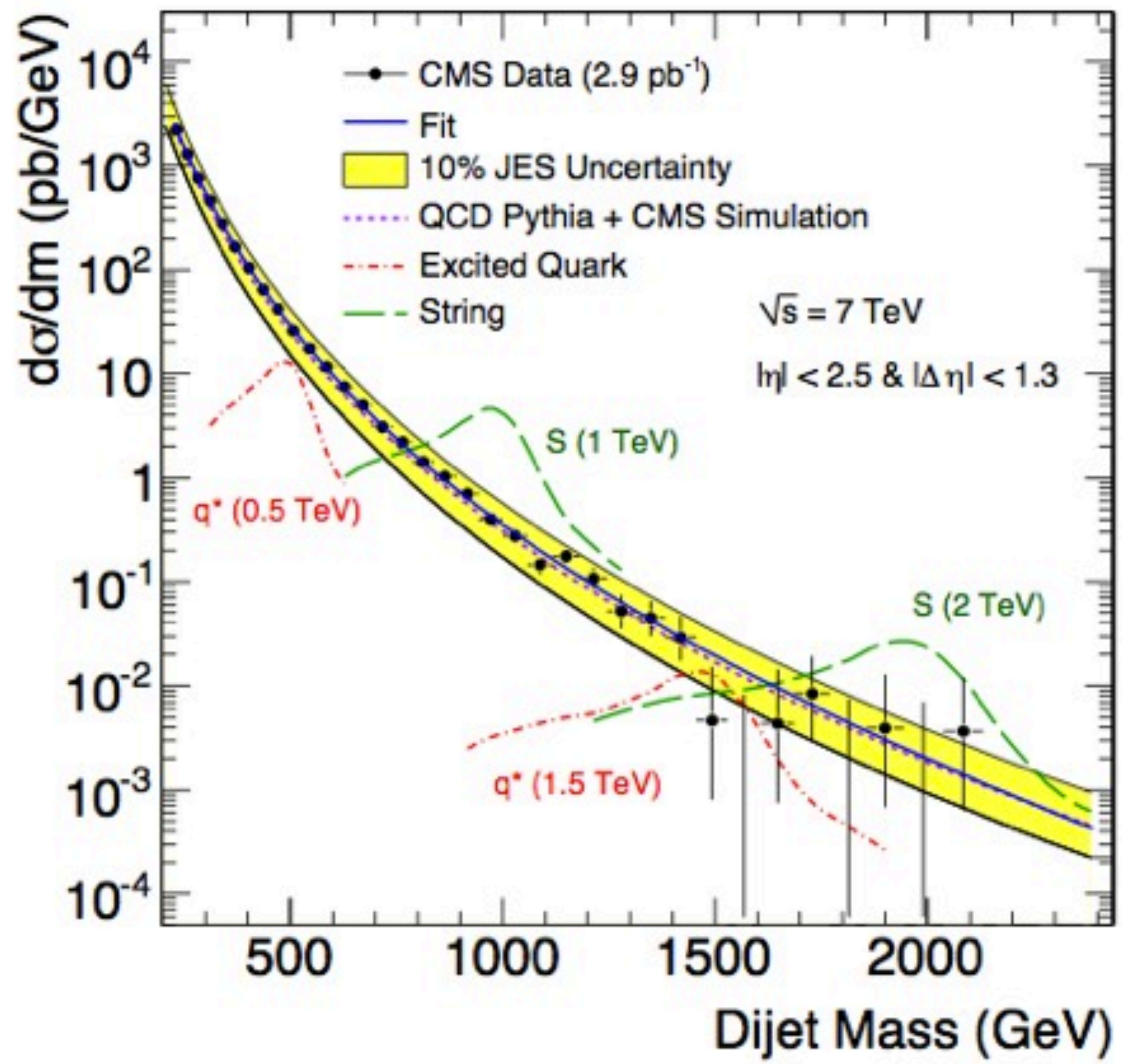
Di-jet mass resonances

- Look for bumps in dijet mass spectrum
- Select di-jet in event with $|\eta_1, \eta_2| < 2.5$ & $|\Delta\eta| < 1.3$
- Sensitive to the coupling of new massive object to q and g
- New model-independent limits on 7 models



- Main Systematics (23-49%)
  - Jet Energy Scale (15 – 38%)
  - Background shape parameterization
    - Alternate 4 parameter fit function
  - Jet Energy Resolution
  - Luminosity (from 11% to 4% recently)

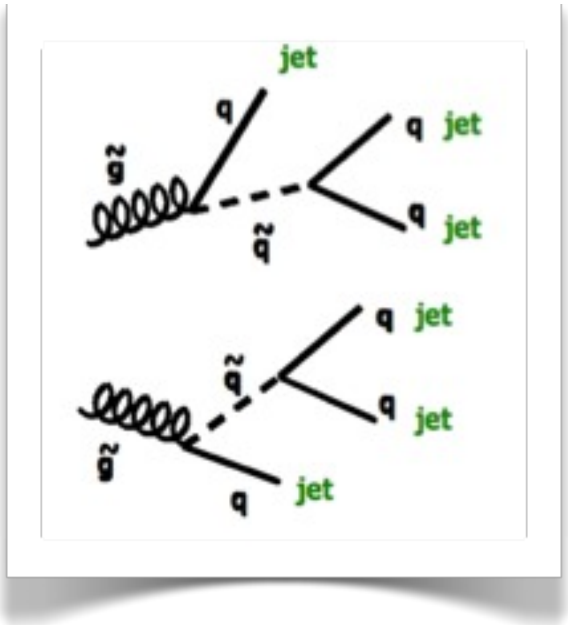




Bayesian approach with flat prior used to set the limit

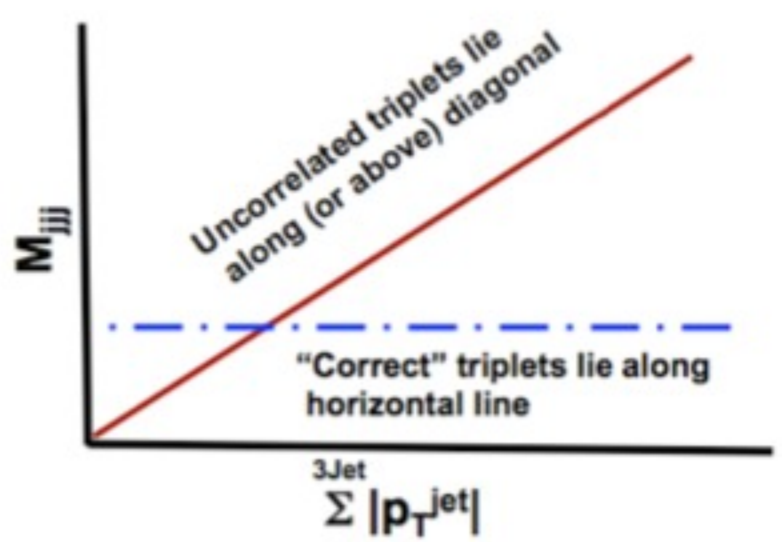
Three-Jet resonances

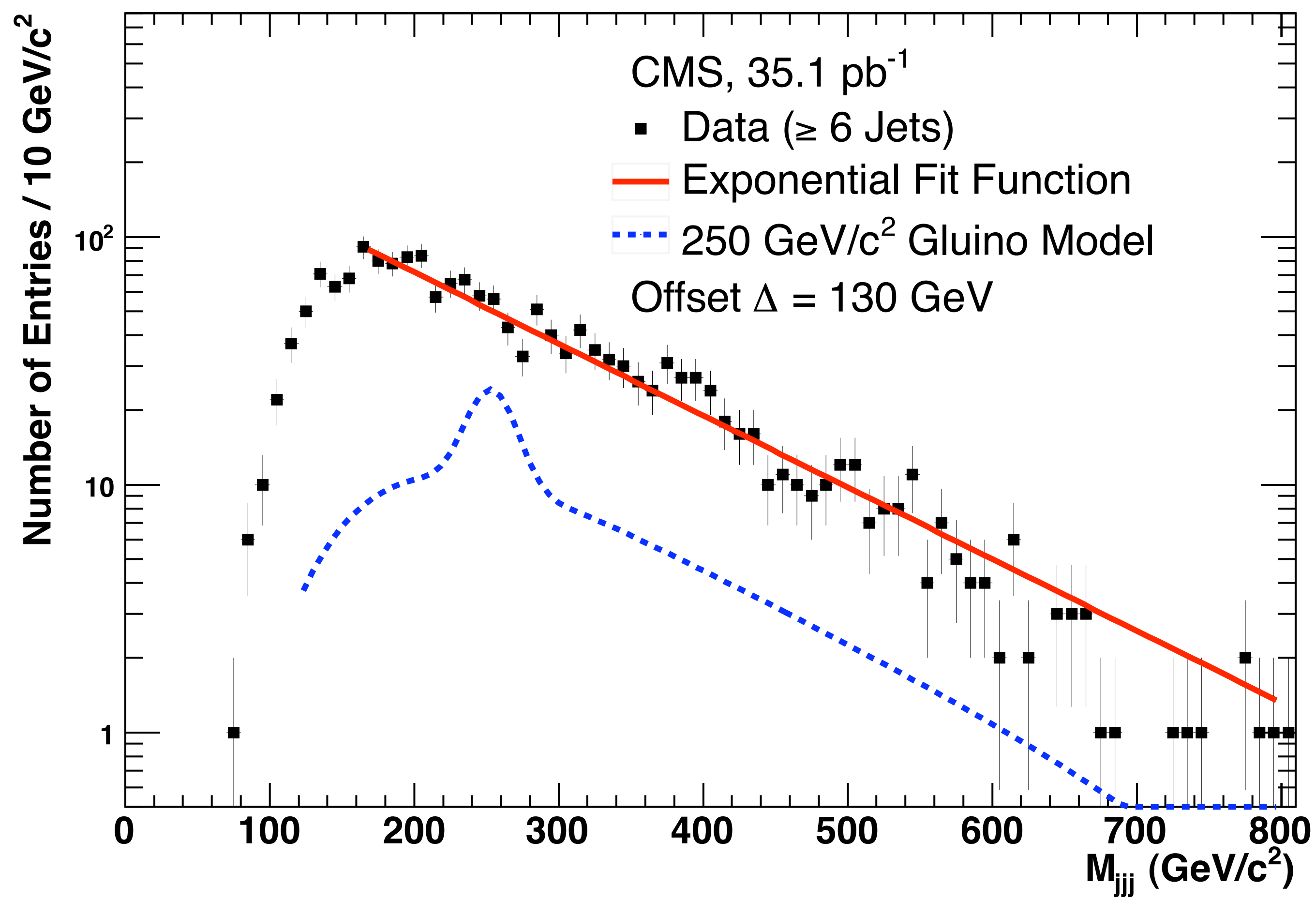
- Searching for strongly coupled resonances decaying to 3j
  - Benchmark model: R-parity violating gluino decays
  - pair-produced + strongly coupled to uds quarks



- Require > 6 jets in the event
- Jet p^T > 45 GeV (for each jet)
- Construct M_{jjj} triplets (20 combinations)

- backgrounds from:
  - QCD SM events
  - uncorrelated triplets





Final selection and results

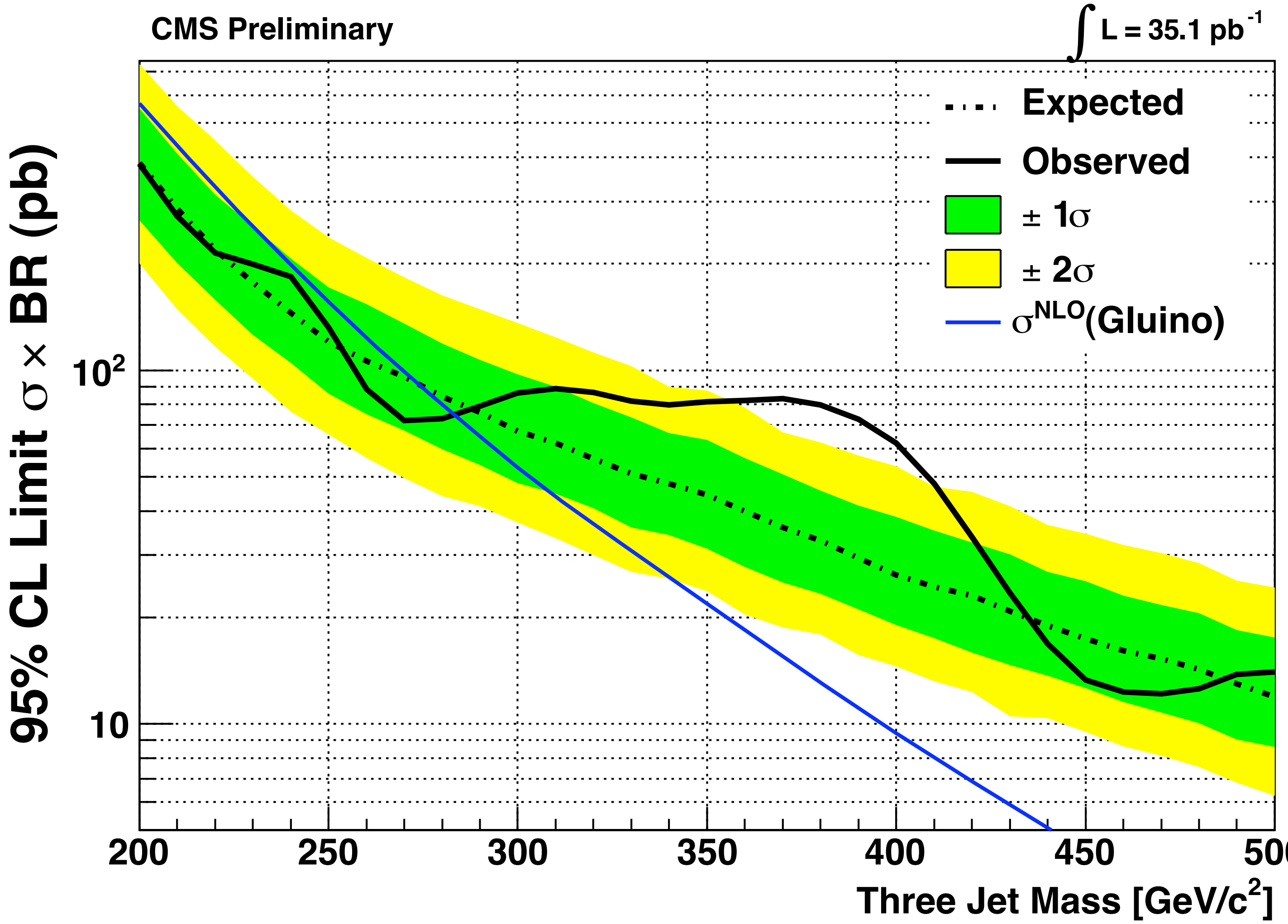
- To reduce the uncorrelated triplets (18 conbinations) require each event to pass:
  $M_{jjj} < \Sigma\ |P^{T}_{jet}| - \Delta$ (offset)

- Δ offset is adjusted to optimize the signal sensitivity
  - signal triplets -> constant mass
- Exponential bkg shape with fixed parameters from the fit of $N_{jet} = 4$ sample

- 95% CL limit from Bayesian likelihood approach

- Exclusion for gluinos (RPV decay) for masses $200 < M < 280$ GeV/c^2

- 1st limit from pp collisions



Summary

- Good understanding of the detector and backgrounds in a variety of channels
  - validation of data-driven background estimation methods
- Only a small selection of the exotica results from CMS is shown here
  - more than 20 papers already published
- No signals of the new physics observed in the 2010 LHC data yet
  - Analyses of > 400 pb^{-1} ongoing
  - New results are in the pipe-line. Stay tune!
- In most cases the exclusion limits are world's best limit

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

BACKUP

Large Extra Dimension (ADD model)

$$M_D^{n+2} \propto M_{Pl}^2 / r^n$$

- Hierarchy problem: $M_{Pl} \sim 10^{19}$ GeV, $M_{EW} \sim 10^2$ GeV
- The ADD model solves it
  - "n" extra dimensions in space of size "r"
  - Gravity only propagates through multi-D space
- **True Planck scale (M_D) lowered to TeV scale**

→ graviton production possible at LHC

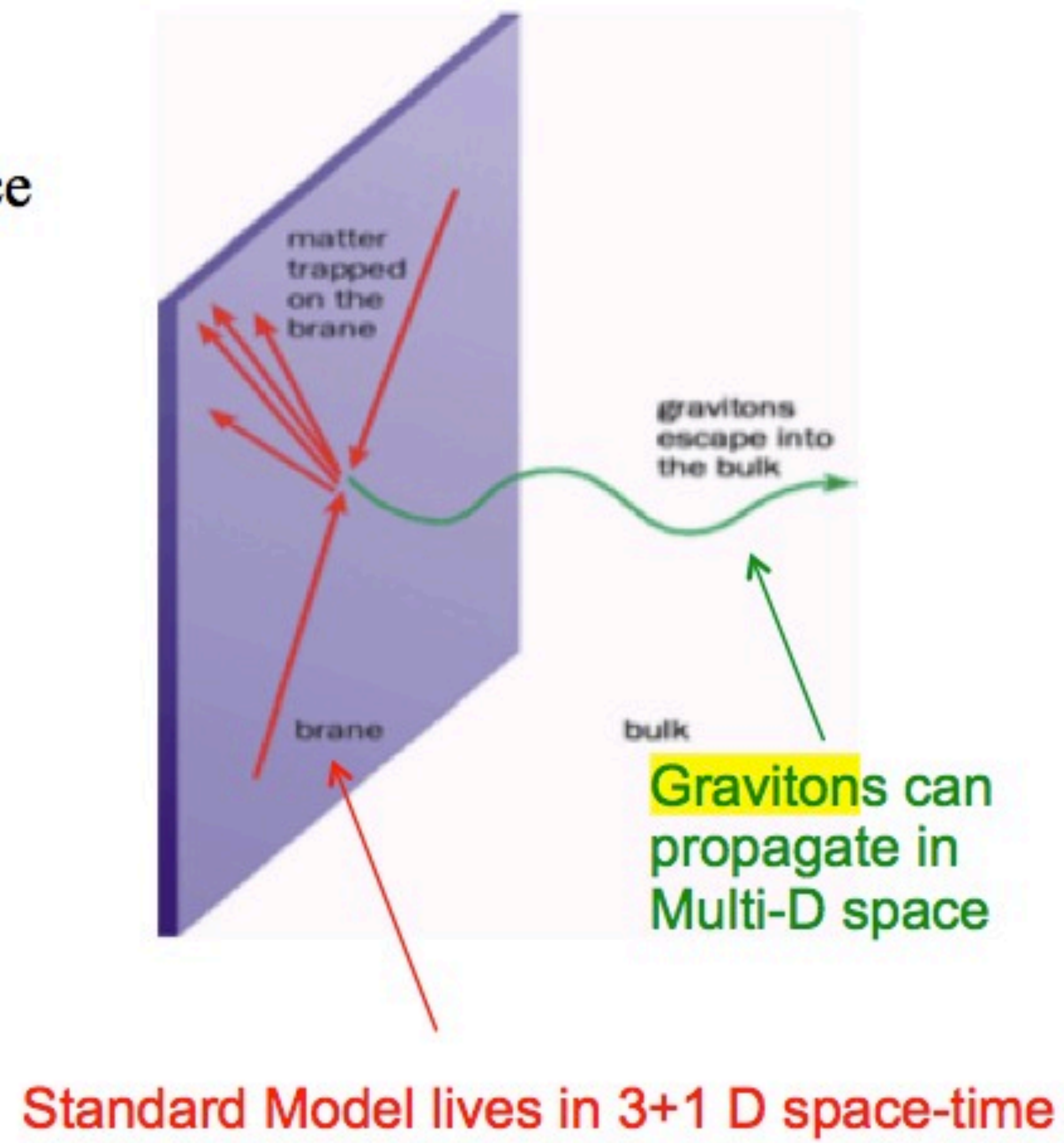
- We have searched for LED in:

1) Di-photon (γγ)

2) Di-muon (μμ)

3) Mono-jet + MET

4) Microscopic Black Holes



Overview of main systematics (I)

Systematic uncertainties arise from detector performance and theoretical uncertainties on background and signal modeling

Luminosity:

- 11% uncertainty (recently improved to 4%)

Trigger and lepton reconstruction/identification efficiency

- use Z Tag&Probe method
- measured within few % uncertainty
- extrapolation with MC for very high p^T range
  - main contribution (8%) to systematic uncertainty on Z' to Z efficiency ratio in the e-channel

Energy scale/resolution

- Electrons/photons
  - ECAL scale from $Z \to ee$ and low mass $\gamma\gamma$ resonances (1%-3% accuracy)
  - extrapolation to high pT exploiting ECAL linearity, MC, cross-check in data exploiting electron shower shape
- Muons
  - from $Z \to \mu\mu$
  - cosmics provide validation at high pT

Overview of main systematics (II)

Missing transverse energy

- model hadronic recoil from Z→ee/Z → μμ events
  - along with energy scale and eff. uncertainty affects the bkg estimation in W' → eν searches (total ~28% uncertainty for MT > 500 GeV)

Electron/muons/photon fake rates

- Uncertainty estimated comparing results with different datasets/selections, and applying to control samples. Large uncertainties (25%-50%) but marginal impact in the high mass/pt region

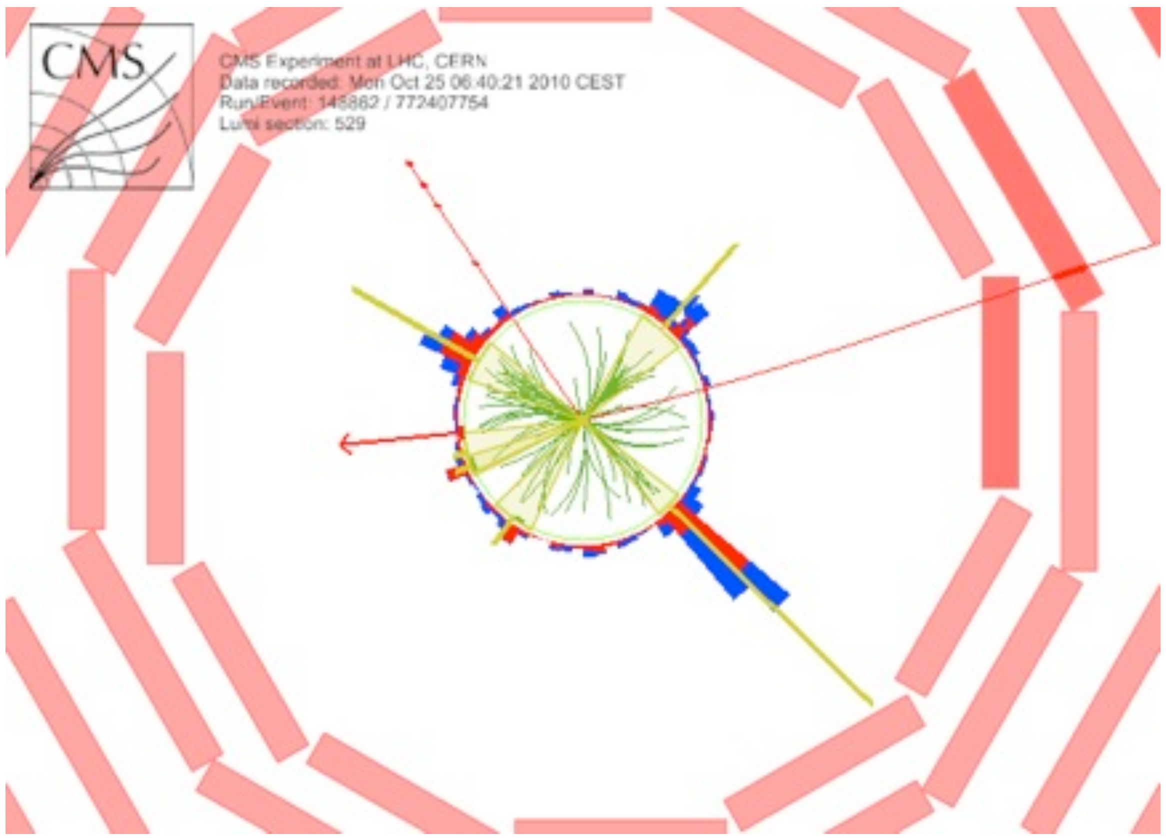
Theoretical uncertainties

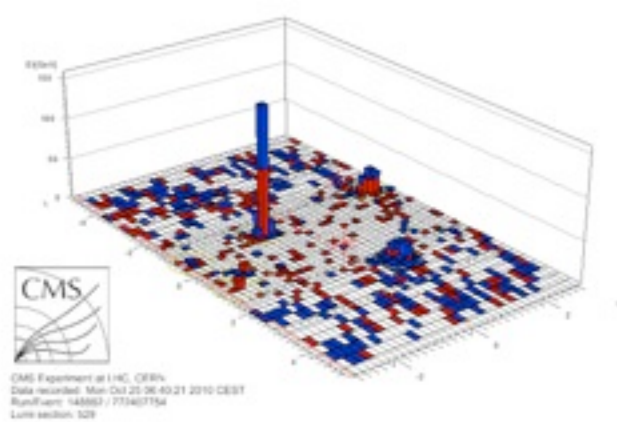
- PDF uncertainties – reweighting PDF sets
- QCD higher order corrections estimated varying factorization and renormalization scales

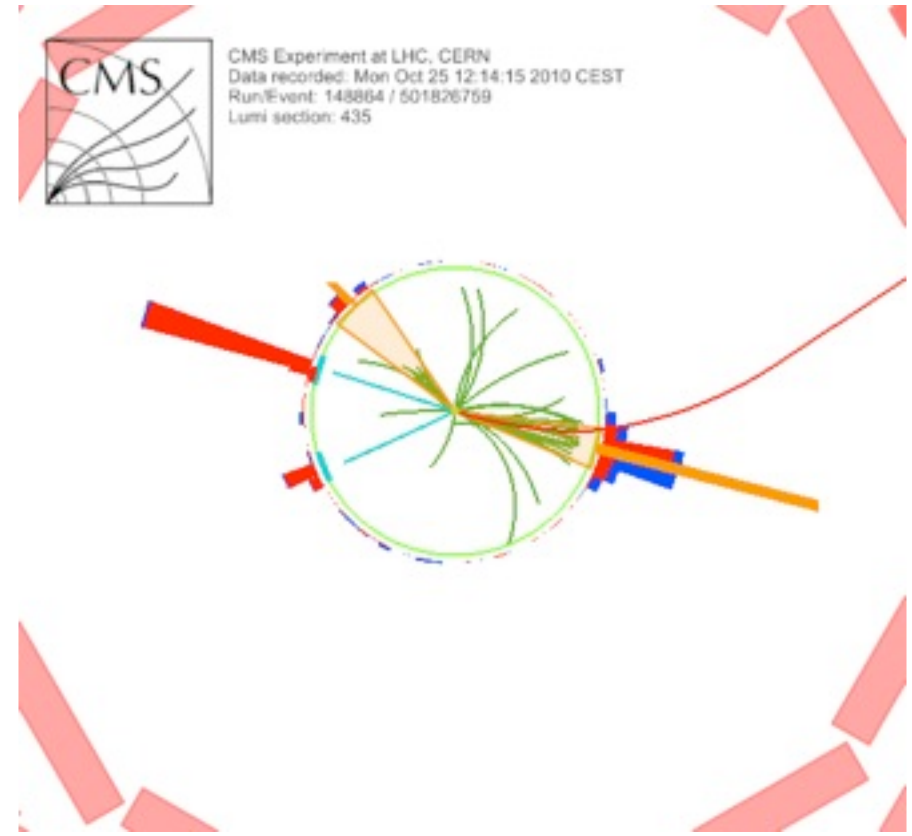
*SETTING **UPPER LIMITS:***

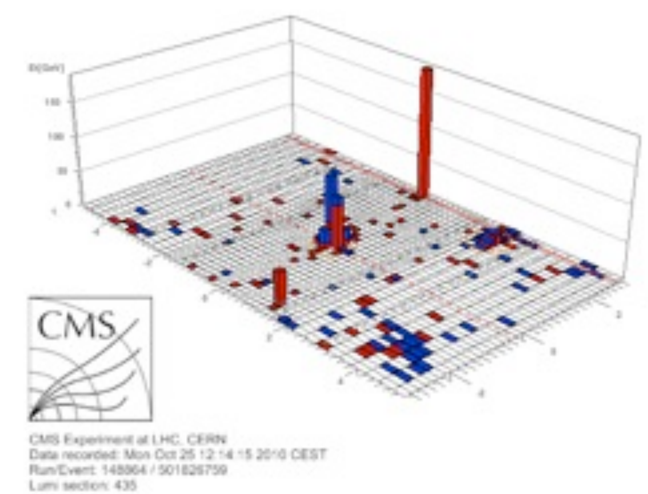
- *Simple **Bayesan approach** to set 95% C.L. Exclusion limit*
- *Flat prior for signal cross section*
- *Systematic uncertainties treated as nuisance parameters with log-normal prior distribution*

LQs event display





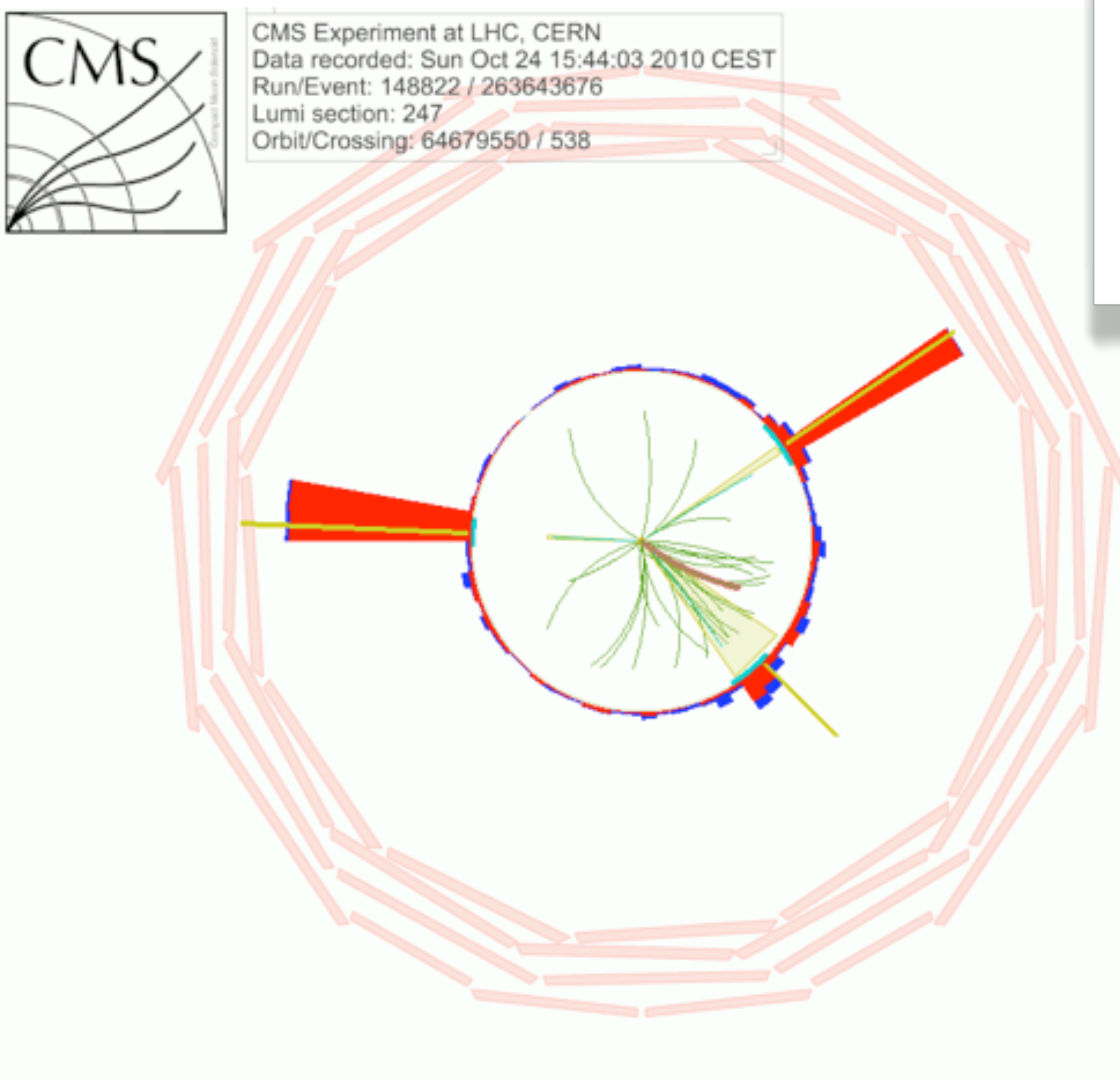


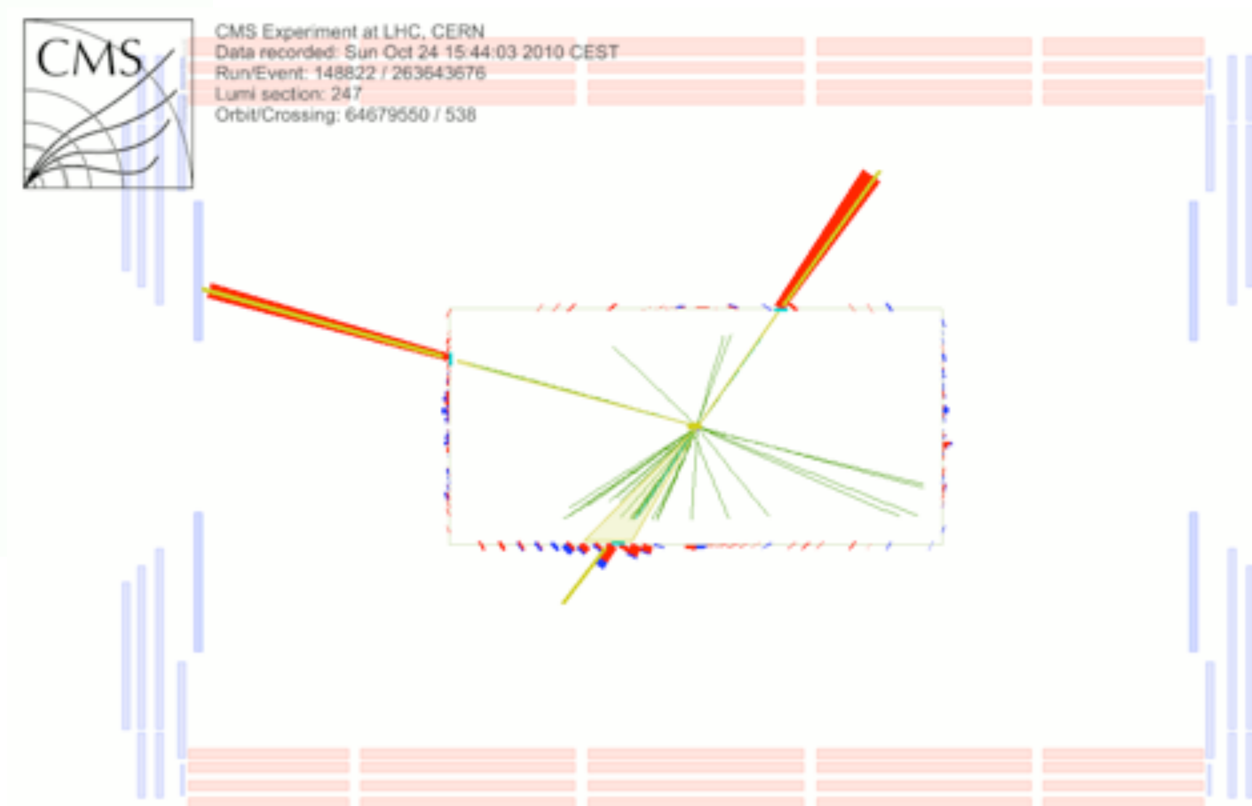


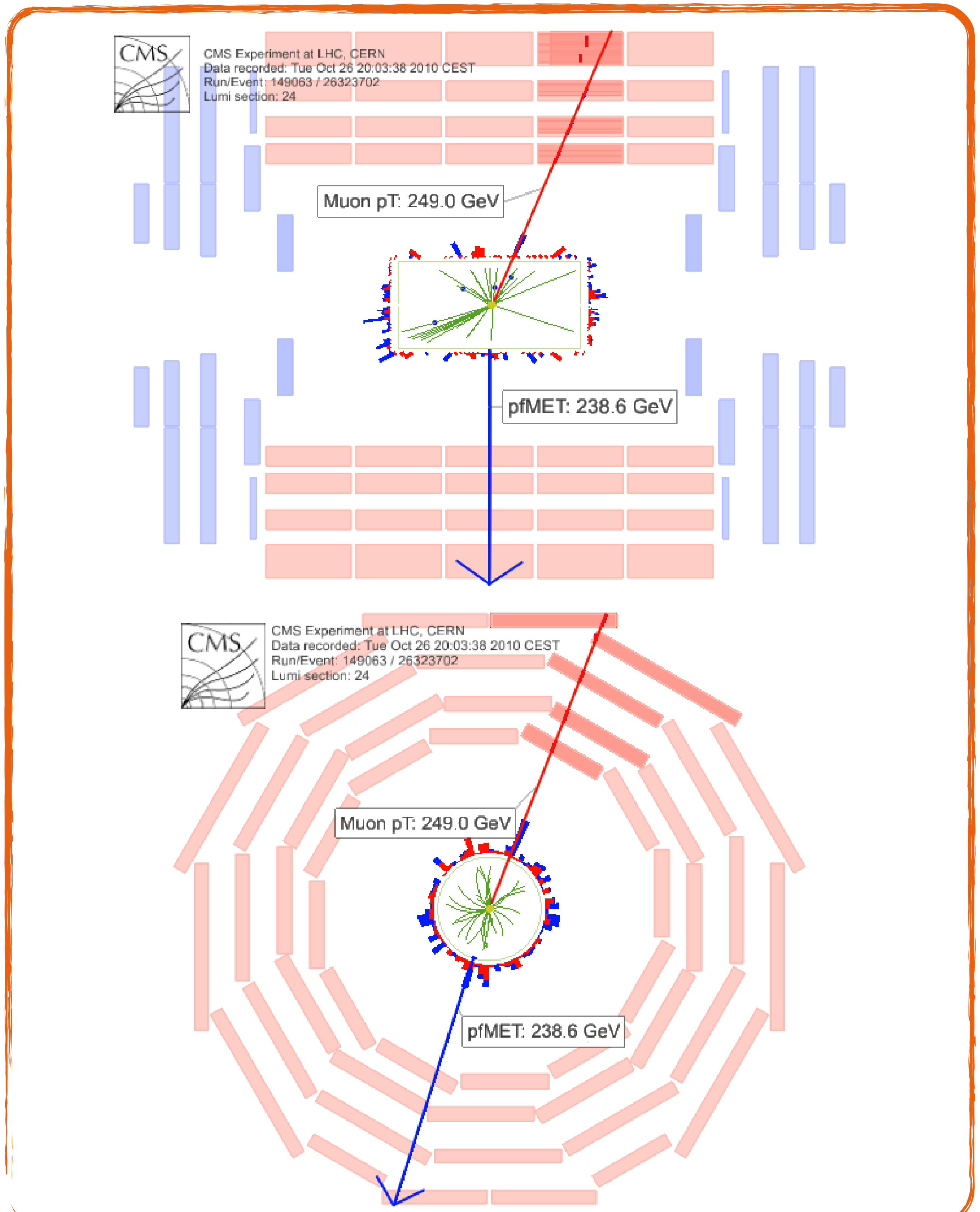
Z' high mass event display

Collection: Electrons

	▽pT	eta	phi	E/p	H/E	fbrem	dei	dpi	charge
1	125.0	-2.003	3.091	0.787	0.008	0.674	0.001	-0.001	-1
2	83.8	0.669	0.600	5.923	0.000	0.791	-0.000	0.042	1
0	8.7	-0.636	-0.835	1.196	0.000	0.008	-0.009	0.054	1






CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 20:03:38 2010 CEST
Run/Event: 149063 / 26323702
Lumi section: 24
Muon pT: 249.0 GeV
pfMET: 238.6 GeV
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 20:03:38 2010 CEST
Run/Event: 149063 / 26323702
Lumi section: 24
Muon pT: 249.0 GeV
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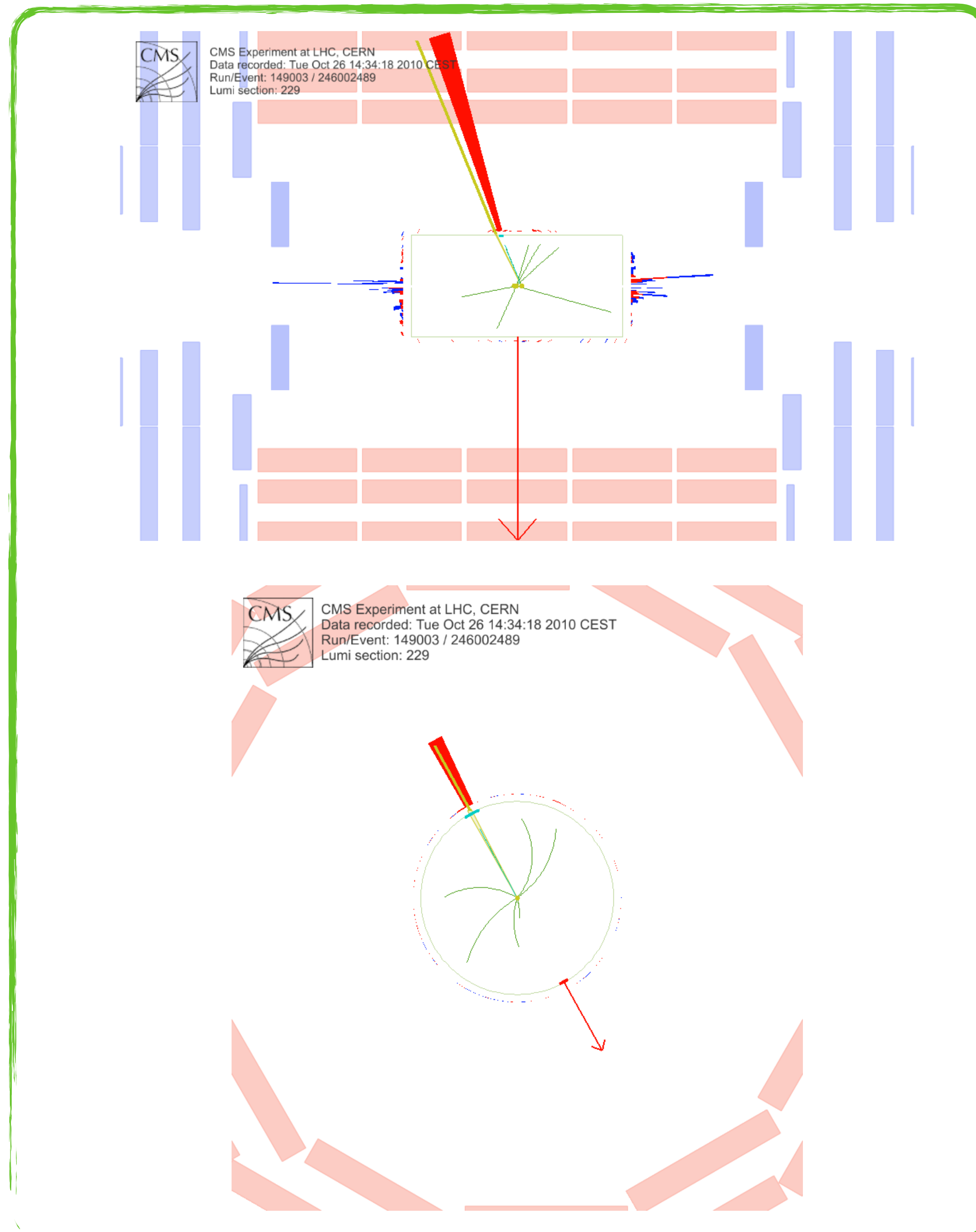
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 14:34:18 2010 CEST
Run/Event: 149003 / 246002489
Lumi section: 229
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 14:34:18 2010 CEST
Run/Event: 149003 / 246002489
Lumi section: 229

Bayesian upper limit

- A Bayesian tool to calculate the expected and observed 95% C.L. upper limits is used

$$\int_{-\infty}^{\sigma_{\mathrm{up}}(n)} p(\sigma|n, A, \mathcal{L}, b)\mathrm{d}\sigma = \frac{\int_{-\infty}^{\sigma_{\mathrm{up}}(n)} L'(n|\sigma, A, \mathcal{L}, b)\pi(\sigma)\mathrm{d}\sigma}{\int_{-\infty}^{+\infty} L'(n|\sigma, A, \mathcal{L}, b)\pi(\sigma)\mathrm{d}\sigma} = 0.95$$

Flat prior

$$\pi(\sigma) = \begin{cases} 0 & \sigma < 0 \\ 1 & \sigma \geq 0 \end{cases}$$

$$L'(n|\sigma, A, \mathcal{L}, b) = \int_0^{+\infty}\int_0^{+\infty}\int_0^{+\infty} L(n|\sigma, A', \mathcal{L}', b')\, \underbrace{g(A')h(\mathcal{L}')f(b')}\, \mathrm{d}A'\mathrm{d}\mathcal{L}'\mathrm{d}b'$$

$g(A'),\ h(\mathcal{L}'),\ f(b')$ **Log-normal distributions describing** uncertainties in *A'*, *ℒ'*, *b'*

Poisson distribution

$$L(n|\sigma, A', \mathcal{L}', b') = \frac{(\sigma A'\mathcal{L}' + b')^n}{n!} e^{-(\sigma A'\mathcal{L}' + b')}$$

Expected upper limit

$$<\sigma_{\mathrm{up}}> = \sum_{n=0}^{+\infty} \sigma_{\mathrm{up}}(n) L(n|\sigma = 0, A, \mathcal{L}, b)$$

n = number of observed events
A = acceptance×efficiency
ℒ = integrated luminosity
b = expected number of background events

Channel combination

- **Extension to two channels**, currently straightforward extension of the implemented Bayesian upper limit for a counting exp.

$$\Pi_{\mathbf{post}}\left(\sigma|N_{\mathbf{obs,1}},N_{\mathbf{obs,2}}\right) = \int dL\, d\epsilon_1\, db_1\, d\epsilon_2\, db_2$$
$$\frac{\left(\sigma\cdot L\cdot\epsilon_1+b_1\right)^{N_{\mathbf{obs,1}}}}{N_{\mathbf{obs,1}}!}\cdot e^{-(\sigma\cdot L\cdot\epsilon_1+b_1)}\cdot\frac{\left(\sigma\cdot L\cdot\epsilon_2+b_2\right)^{N_{\mathbf{obs,2}}}}{N_{\mathbf{obs,2}}!}\cdot e^{-(\sigma\cdot L\cdot\epsilon_2+b_2)}$$
$$\cdot\pi\left(b_1\right)\cdot\pi\left(\epsilon_1\right)\cdot\pi\left(b_2\right)\cdot\pi\left(\epsilon_2\right)\cdot\pi\left(L\right)\cdot\pi_{poi}\left(\sigma\right)$$

- **Underlying Assumptions**:
  - Identical branching ratio for electron and muon channel
  - Uncertainty on luminosity fully correlated
  - Uncertainties on signal efficiency and background currently fully uncorrelated (also tested fully correlated → same limit)