QCD AND EW MEASUREMENTS IN THE FORWARD REGION AT LHCb

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On behalf of the LHCb collaboration

24th Rencontres de Blois. 27th May – 1st June, 2012

Relevant papers and notes

Publications

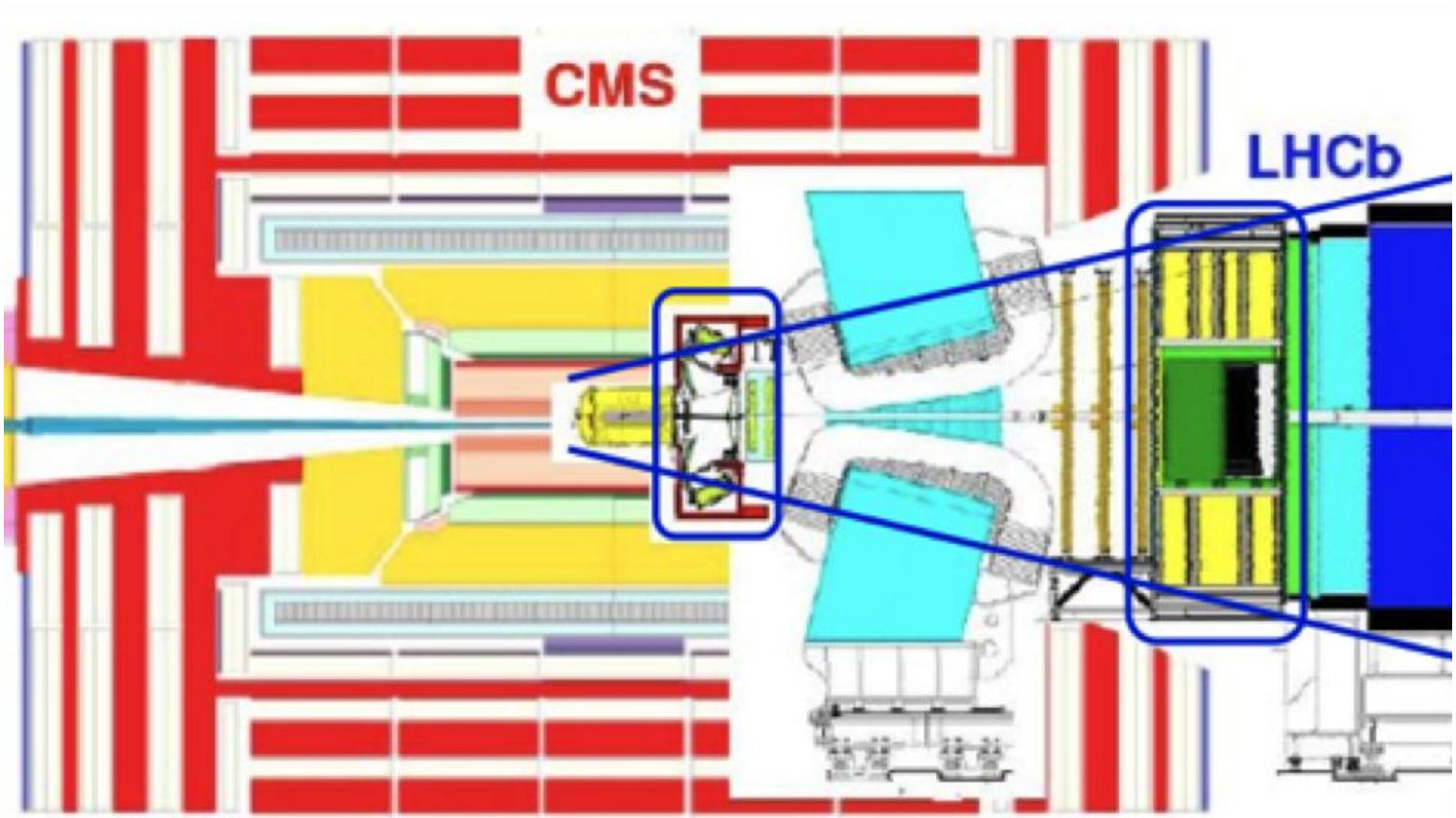
- W->μν and Z->μμ (**arXiv:1204.1620 [hep-ex]**)
- Charged particle multiplicities (**Eur.Phys.J. C72 (2012) 1947**)
- Inclusive ϕ cross-section (**Phys.Lett. B703 (2011) 267-273**)
- V0 production (**JHEP 1108 (2011) 034**)
- Prompt K0S (**Phys.Lett. B693 (2010) 69-80**)

Preliminary

- Inclusive Drell-Yan production (LHCb-CONF-2012-013)
- Z->ee (LHCb-CONF-2012-011)
- Z->ττ (LHCb-CONF-2012-012)
- Forward energy flow (LHCb-CONF-2012-012)
- Central Exclusive Meson Production (LHCb-CONF-2011-022)

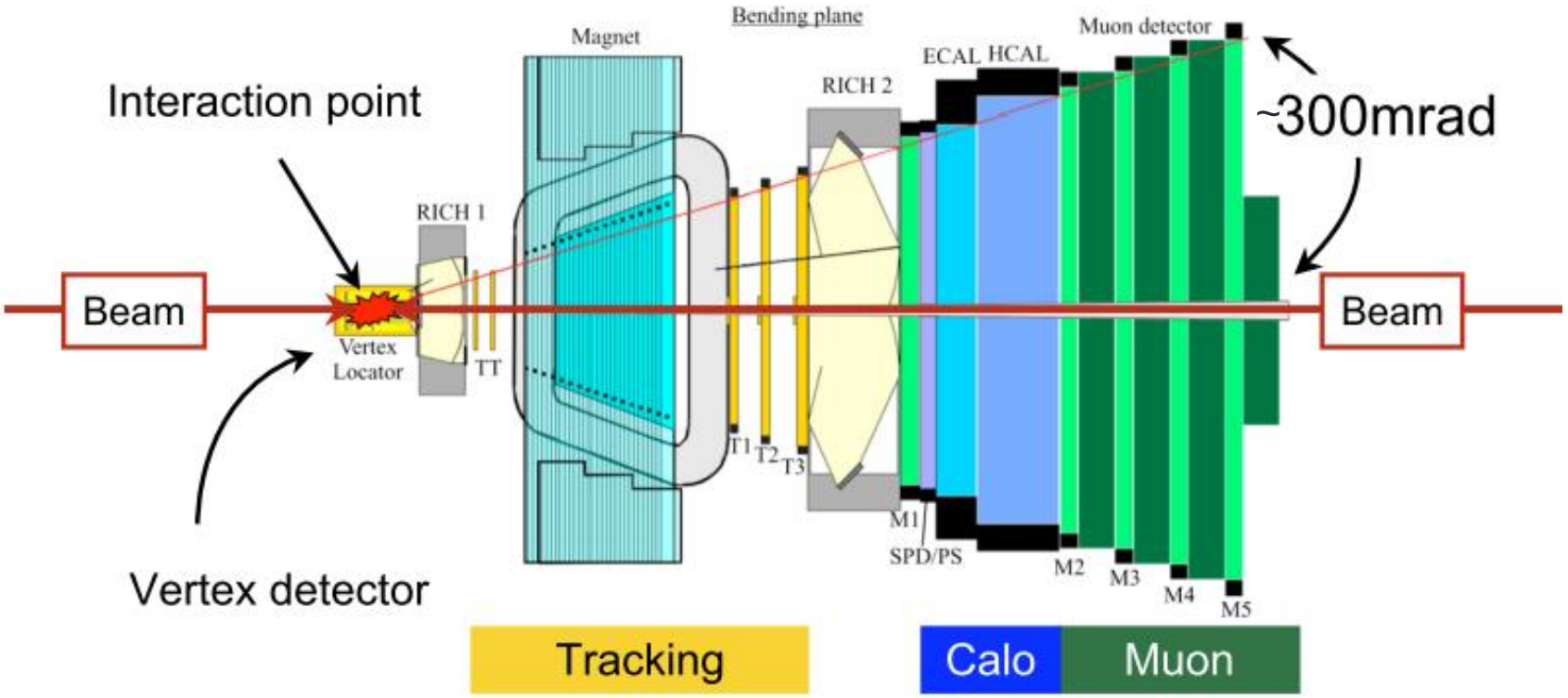
LHCb: a forward detector

Complementary physics programme to ATLAS and CMS.

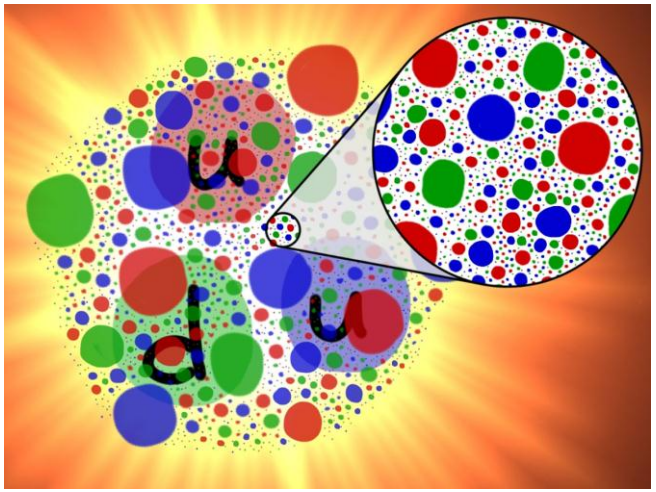


Fully instrumented in region: $2 < \eta < 5$
Some detection: $-3.5 > \eta > -1.5$

LHCb: a forward detector



Trigger: $p_\mu > 3$ GeV, $pt_\mu > 0.5$ GeV, $m_{\mu\mu} > 2.5$ GeV



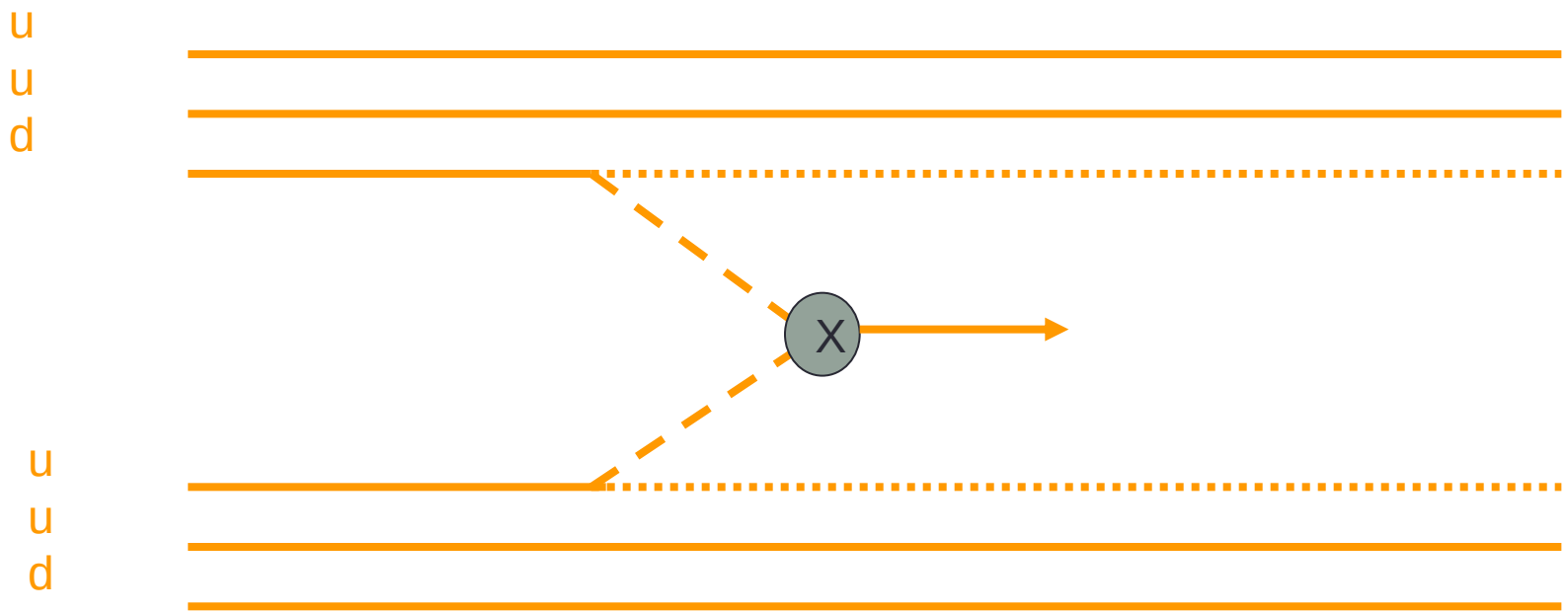
Parton Density Function (PDF):

$$f_q(x,Q^2)$$

Probability that the proton contains this parton with this momentum fraction

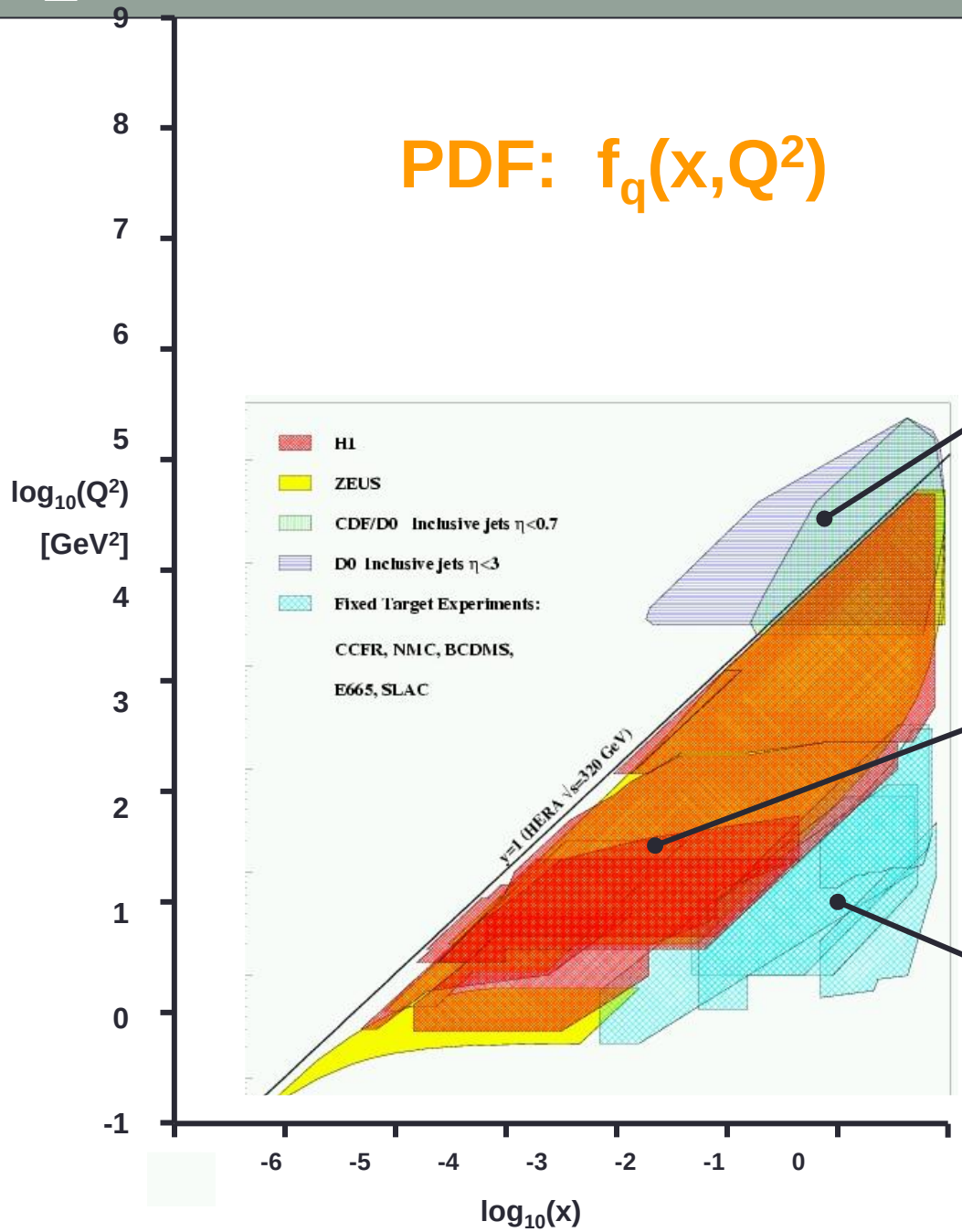
Q = Invariant mass of parton interaction

$x = Qe^{\pm y}/\sqrt{s}$ [y is rapidity, √s c.o.m]



$$s_X(Q^2) = \sum_{a,b} \int_0^1 dx_1\, dx_2\, f_a(x_1,Q^2)\, f_b(x_2,Q^2)\, \hat{s}_{ab\to X}(x_1,x_2,Q^2)$$

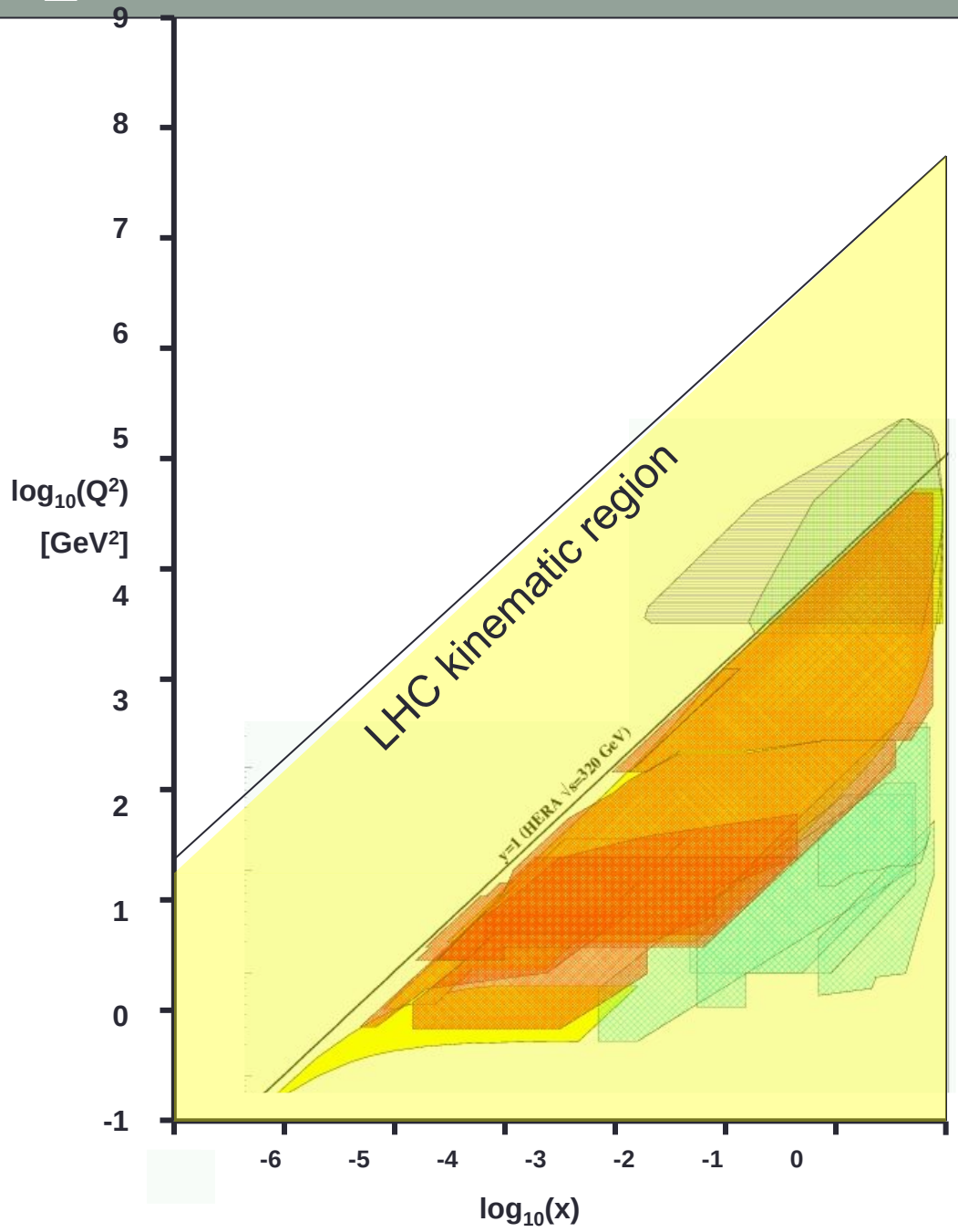
PDF: $f_q(x,Q^2)$

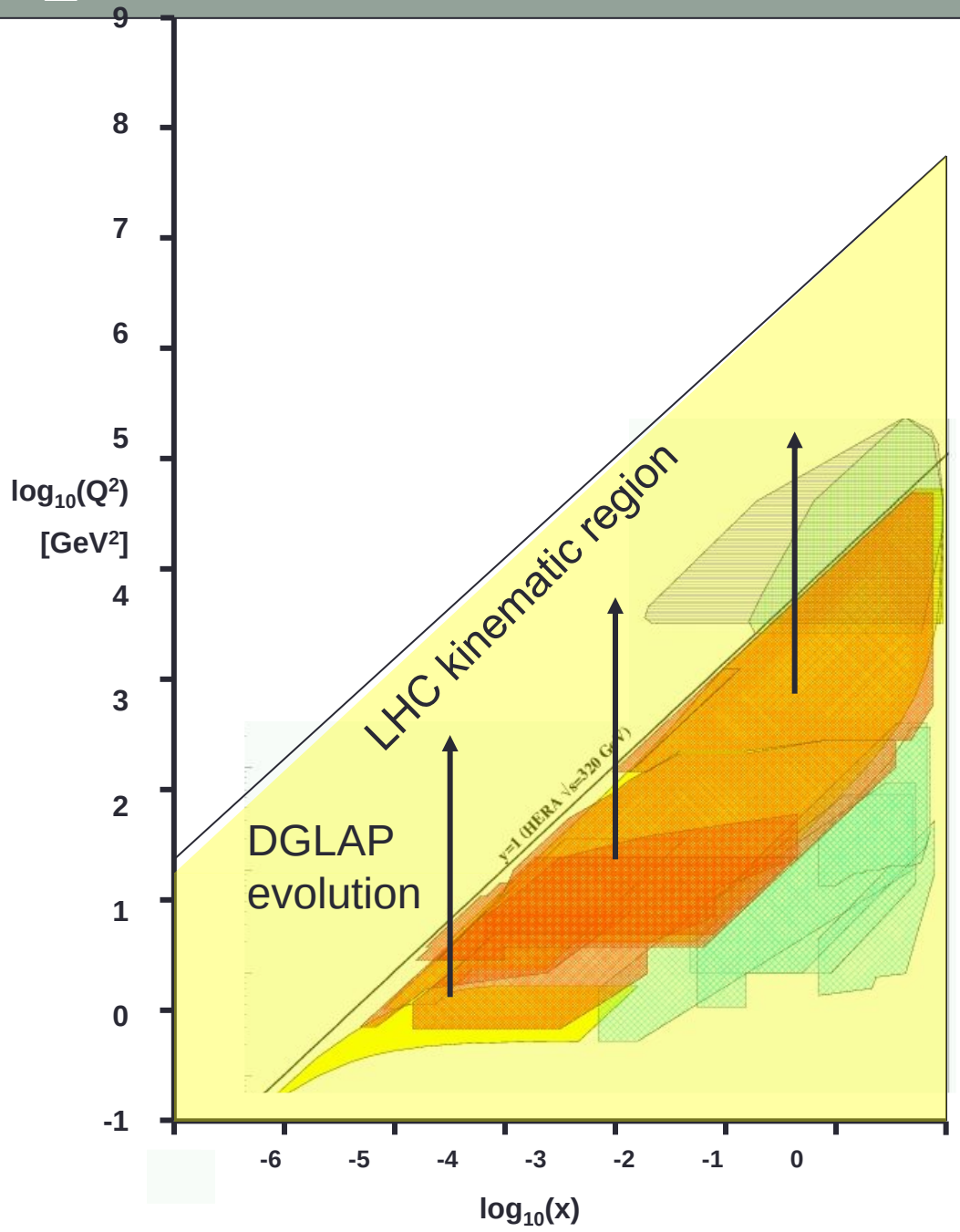


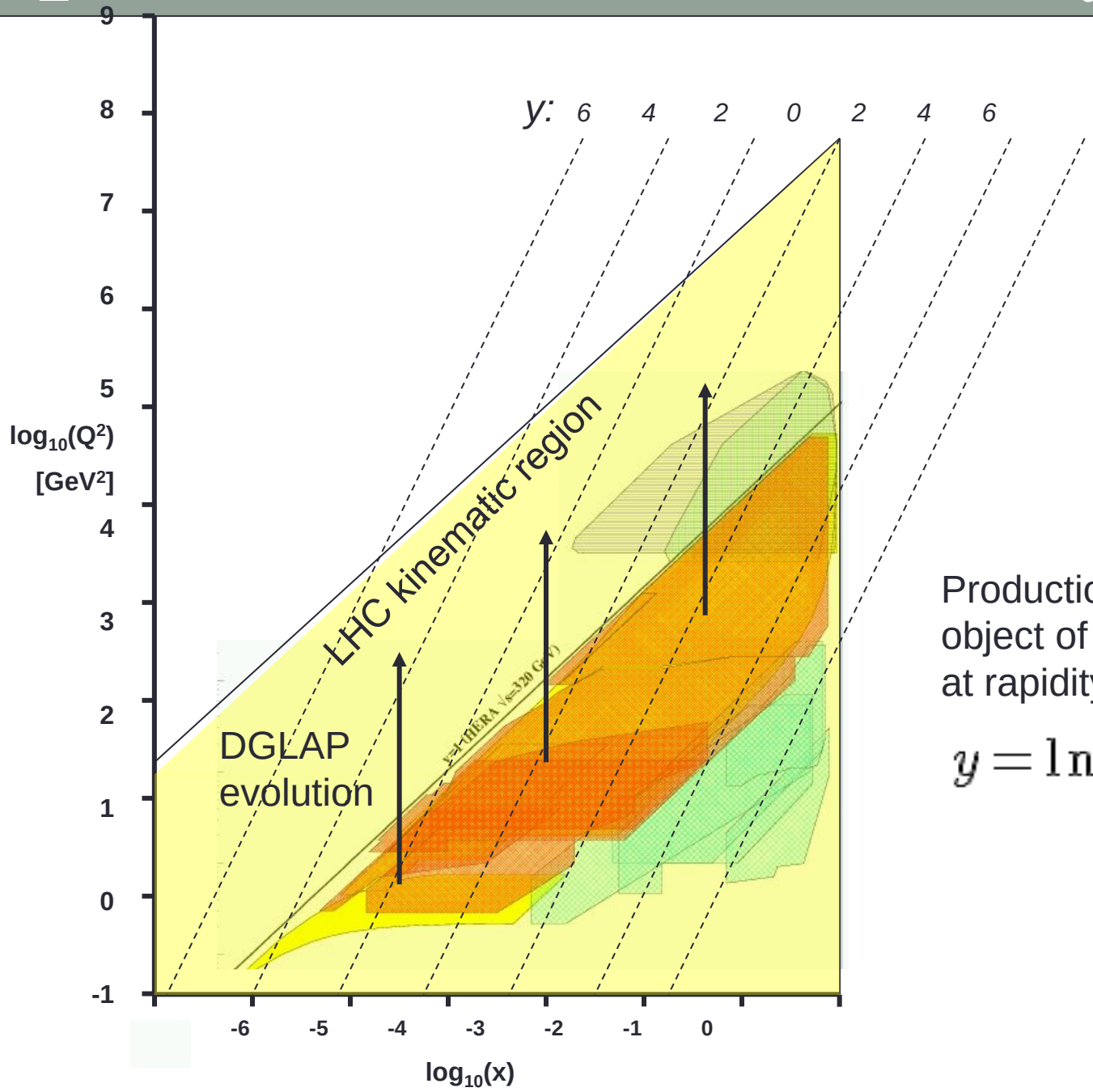
Tevatron

HERA

Fixed target

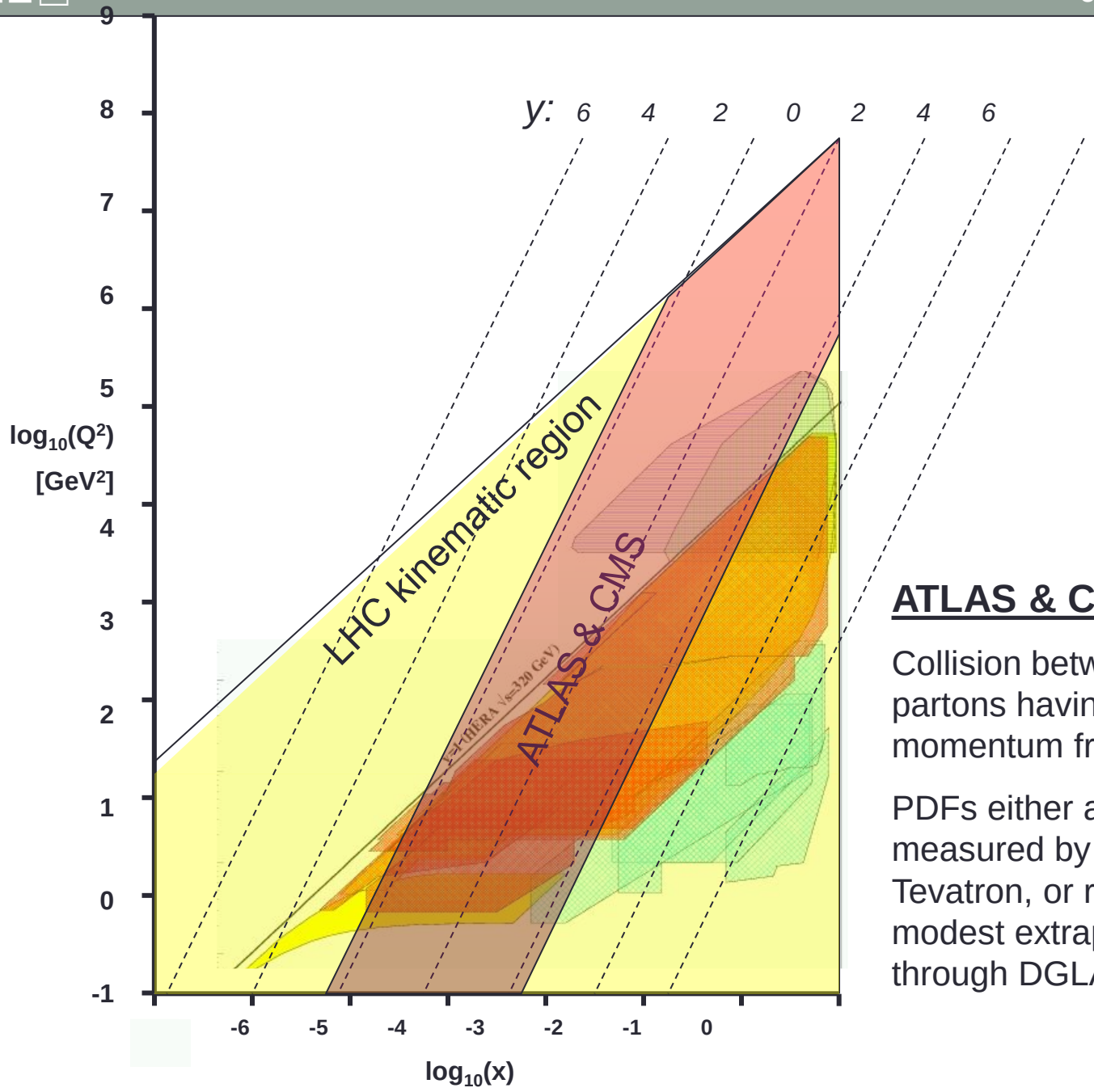

LHC kinematic region
y=1 (HERA √s=320 GeV)
log10(Q2) [GeV2]
log10(x)
9
8
7
6
5
4
3
2
1
0
-1
-6
-5
-4
-3
-2
-1
0


LHC kinematic region
DGLAP
evolution
log10(Q2)
[GeV2]
log10(x)
9
8
7
6
5
4
3
2
1
0
-1
-6
-5
-4
-3
-2
-1
0



Production of object of mass Q at rapidity

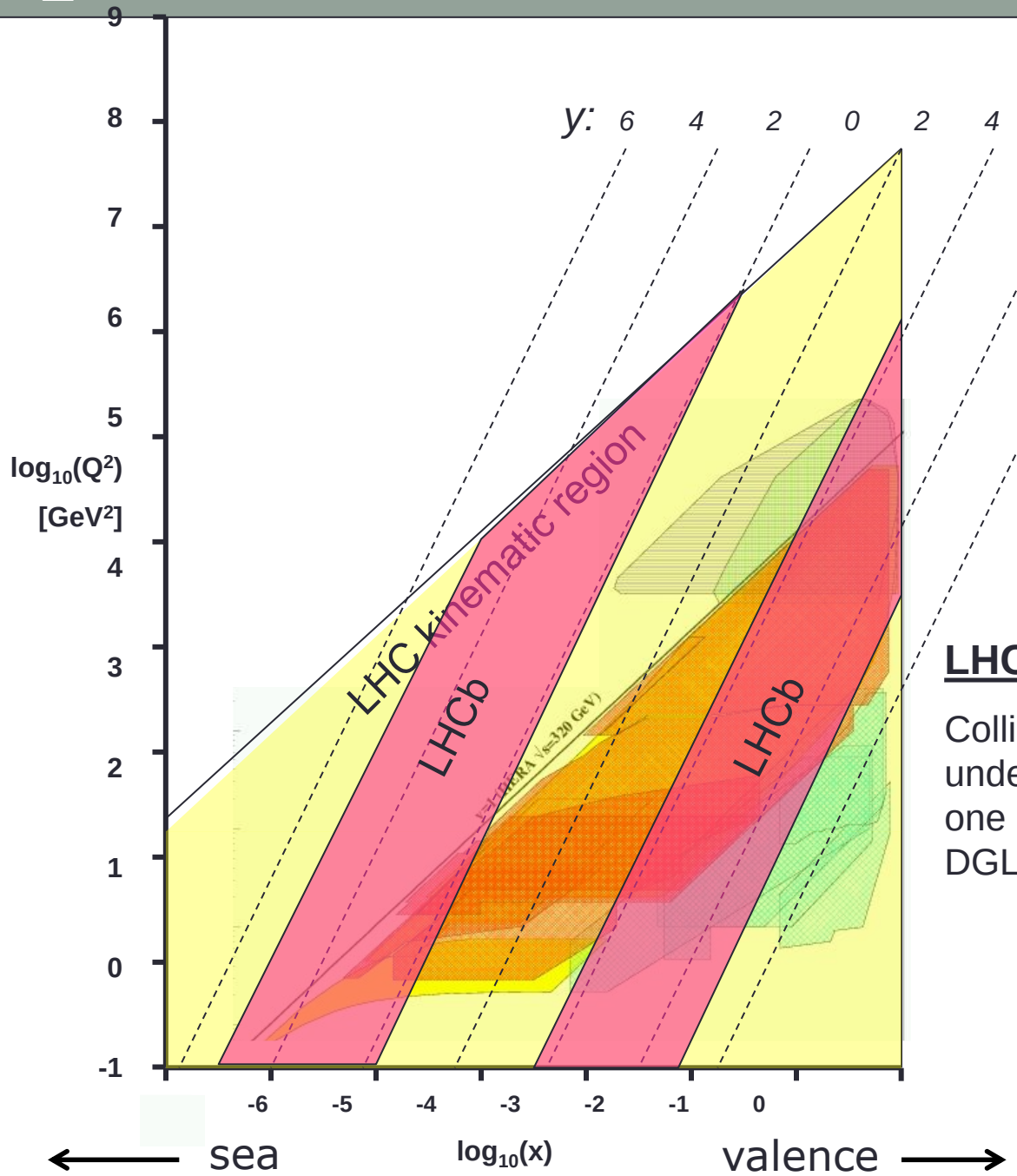
$$y = \ln\left(x\frac{\sqrt{s}}{Q}\right)$$



ATLAS & CMS:

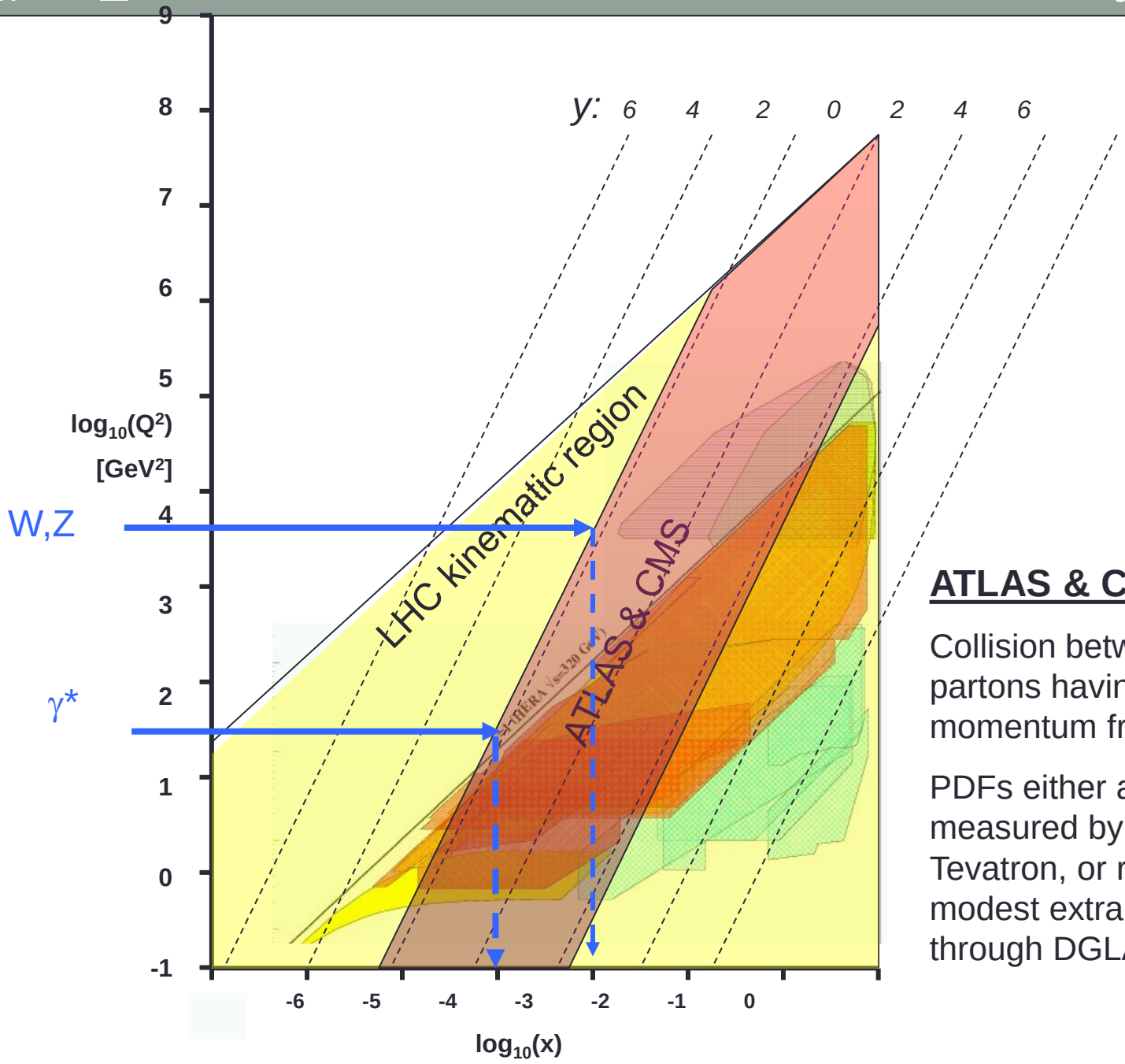
Collision between two partons having similar momentum fractions.

PDFs either already measured by HERA or Tevatron, or requiring modest extrapolation through DGLAP.



LHCb:

Collision between one well understood parton and one unknown or large DGLAP evolved parton.



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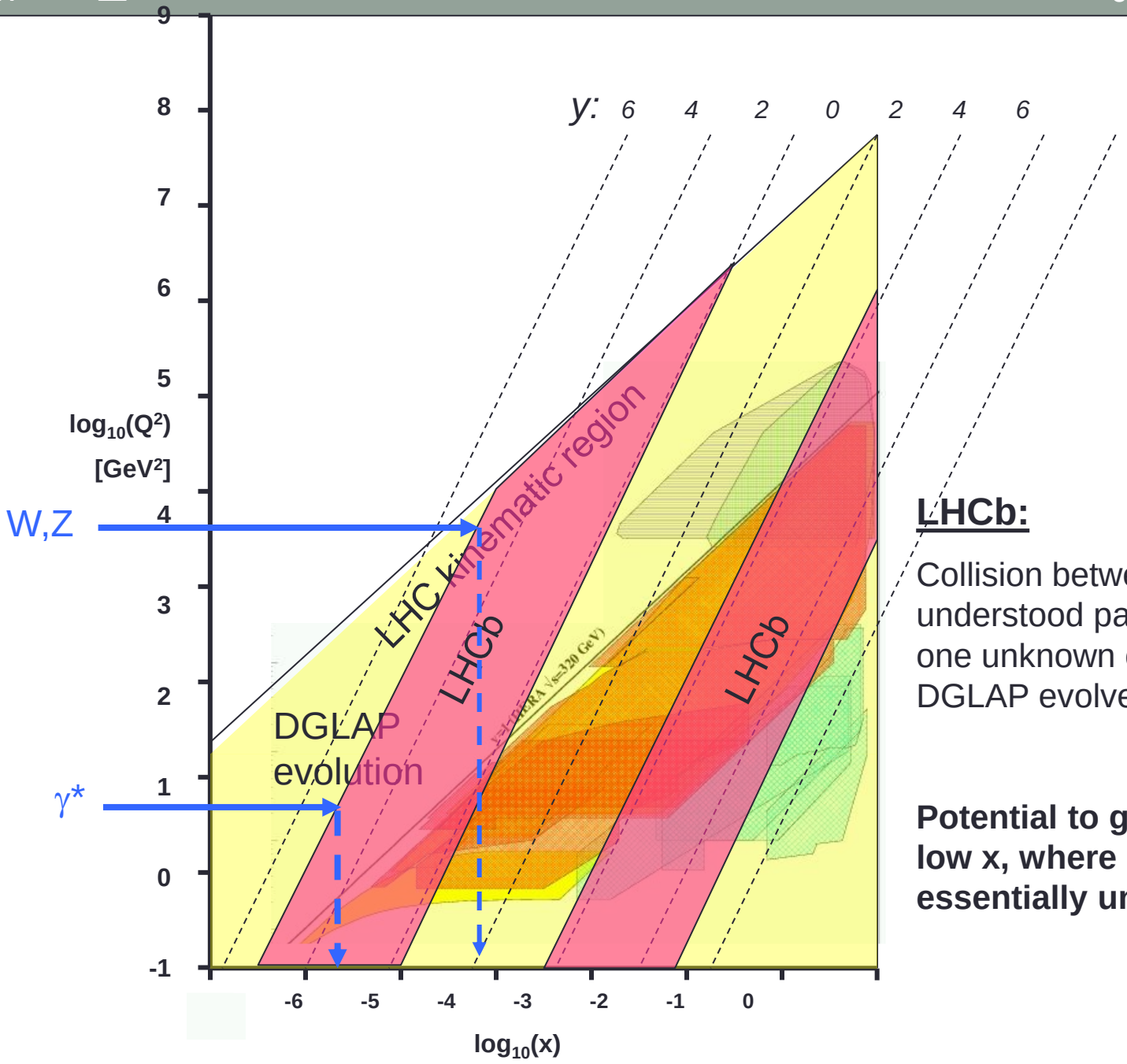
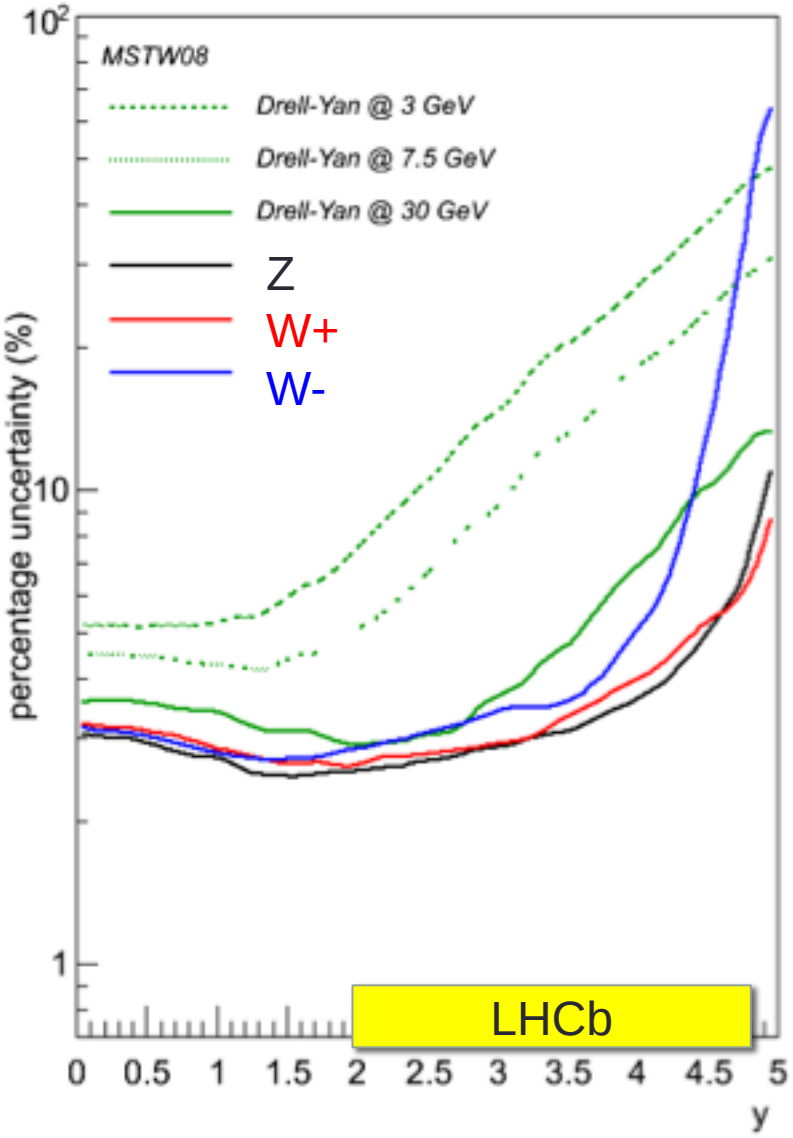


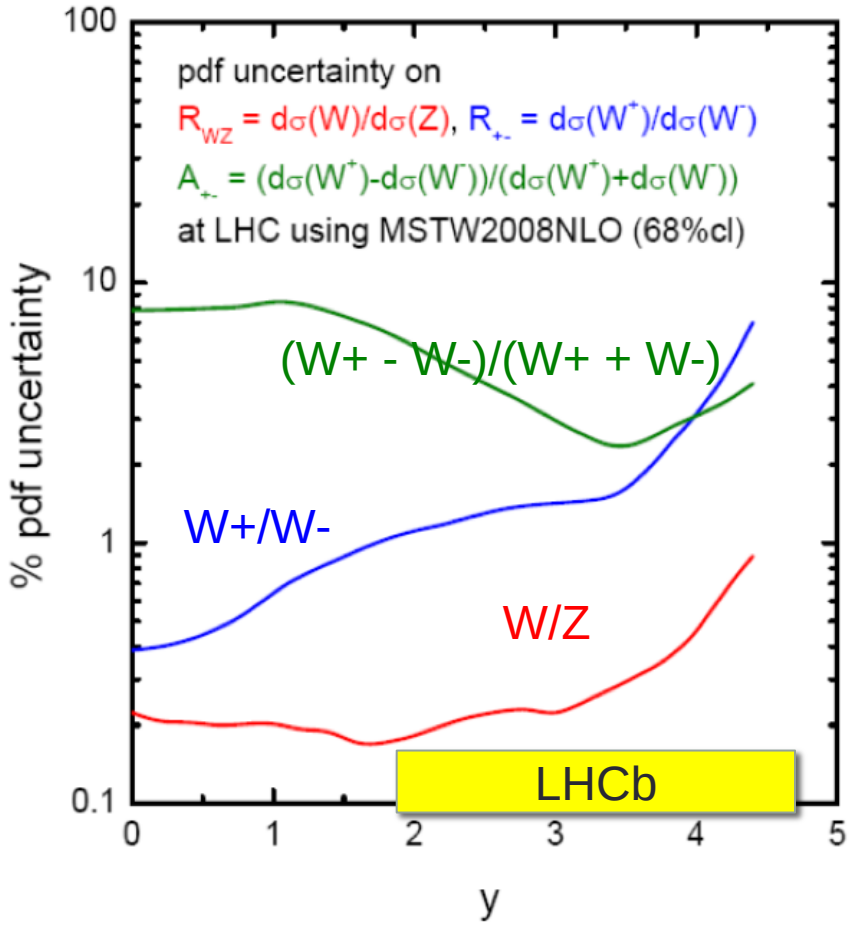
LHCb:

Collision between one well understood parton and one unknown or large DGLAP evolved parton.

Potential to go to very low x, where PDFs essentially unknown

Theoretical uncertainty due to PDF





LHCb can test the electroweak theory and constrain the PDFs

Datasets and Cross-section definitions

Cross-sections only defined within LHCb acceptance

- Z: $pt_{\mu}>20$ GeV. $2<\eta_{\mu 1}, \eta_{\mu 2}<4.5$
- W: $pt_{\mu}>20$ GeV.

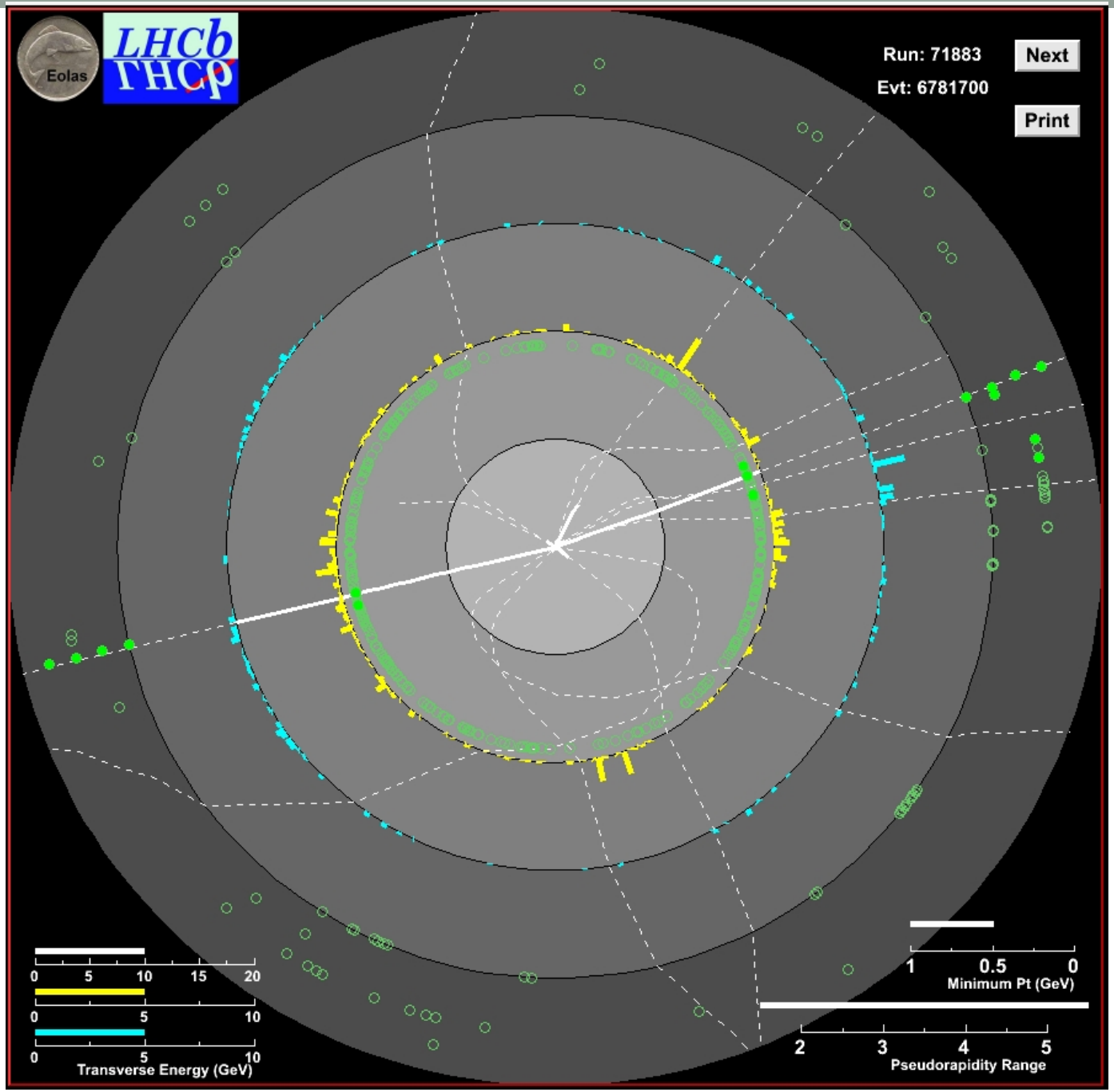
$$\sigma = pN / \varepsilon L$$

Efficiencies(ε) and (most) purities(*p*) determined from data

Luminosity: $\int L_{2010} \approx 37\, pb^{-1}$

$\int L_{2011} \approx 1\, fb^{-1}$

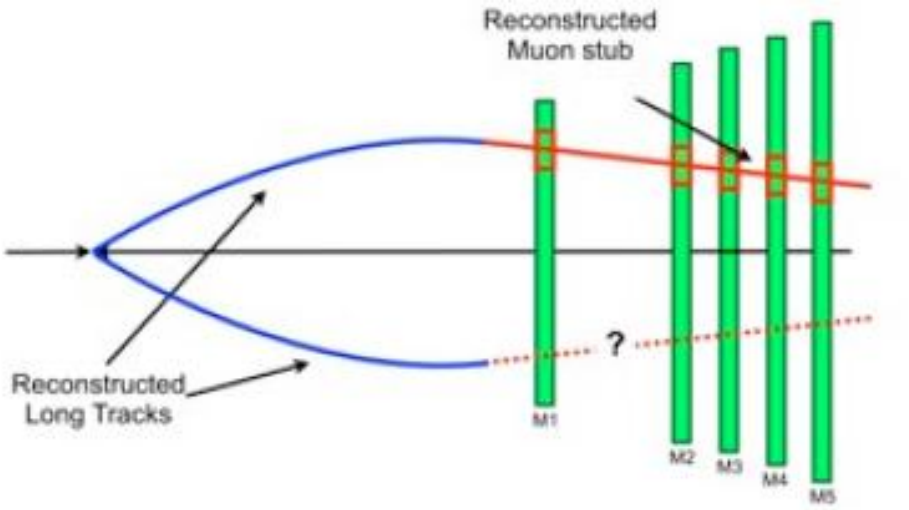
First Z candidate



Efficiency determined from data

$$\varepsilon_Z = A_Z \varepsilon_Z^{track} \varepsilon_Z^{muon} \varepsilon_Z^{trig} \varepsilon_Z^{selection}$$

$$\varepsilon_W = A_W \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{trig} \varepsilon_W^{selection}$$



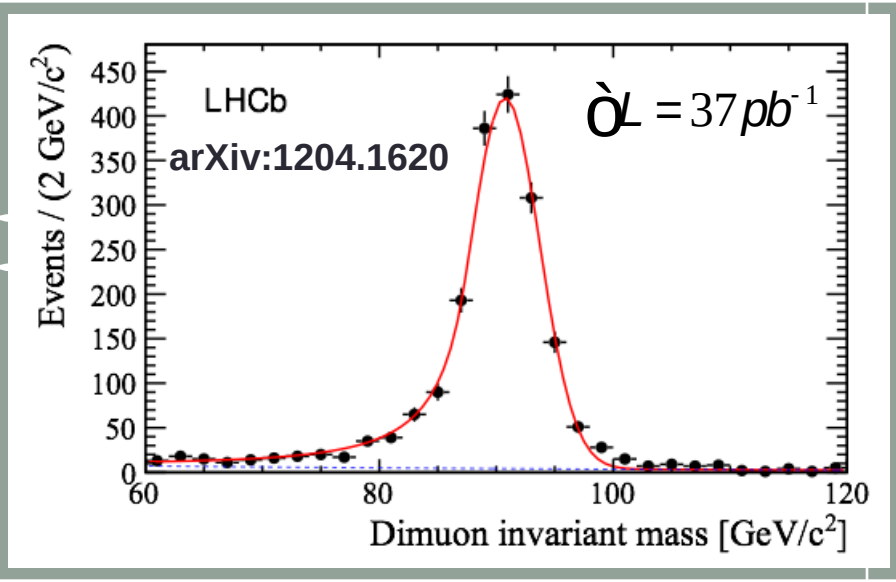
Determine from data (Z events)

Tag: 1 identified muon

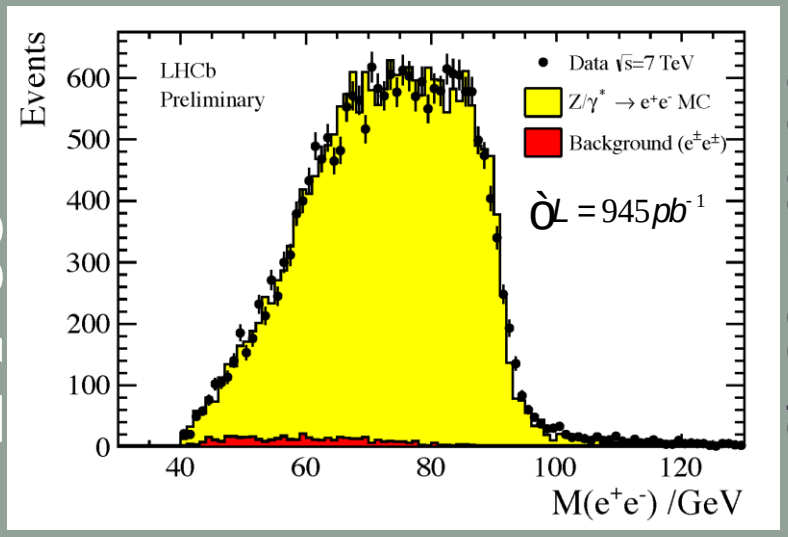
Probe: 1 track

Z observed in ee, μμ and ττ final states

Z→μμ



Z→ee



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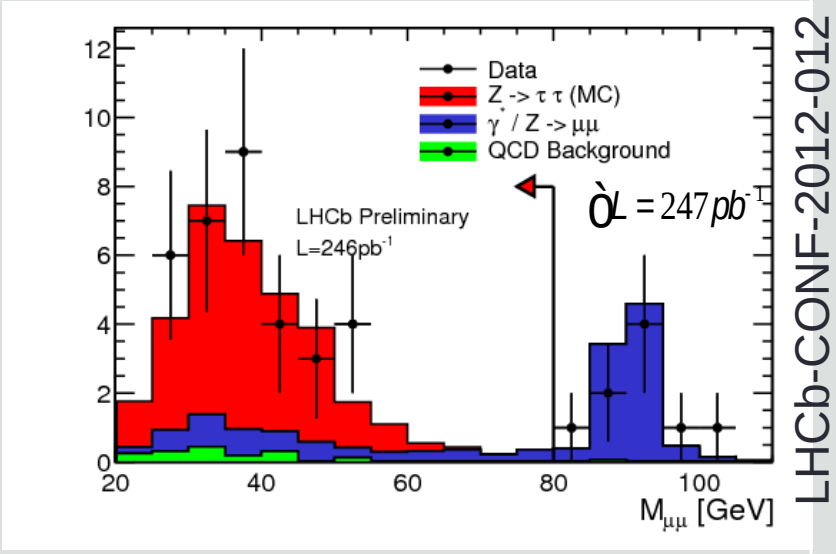
Z→ττ→μμνν



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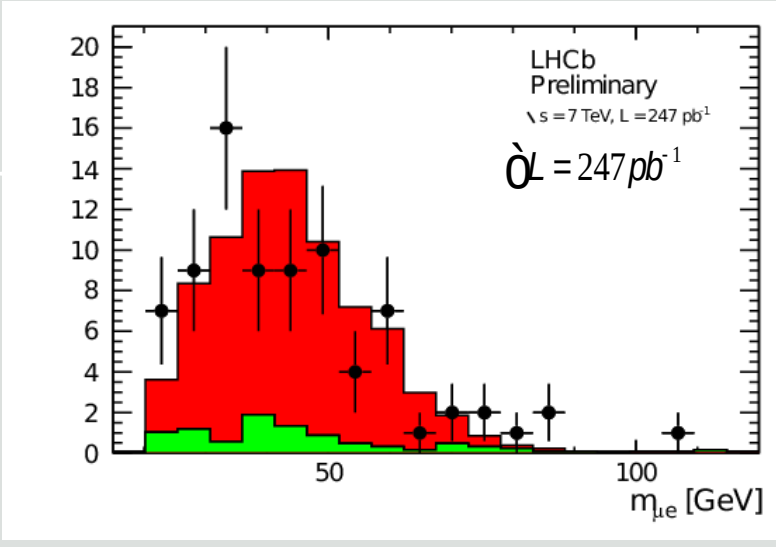
Z→ττ→eμνν



LHCb-CONF-2012-012

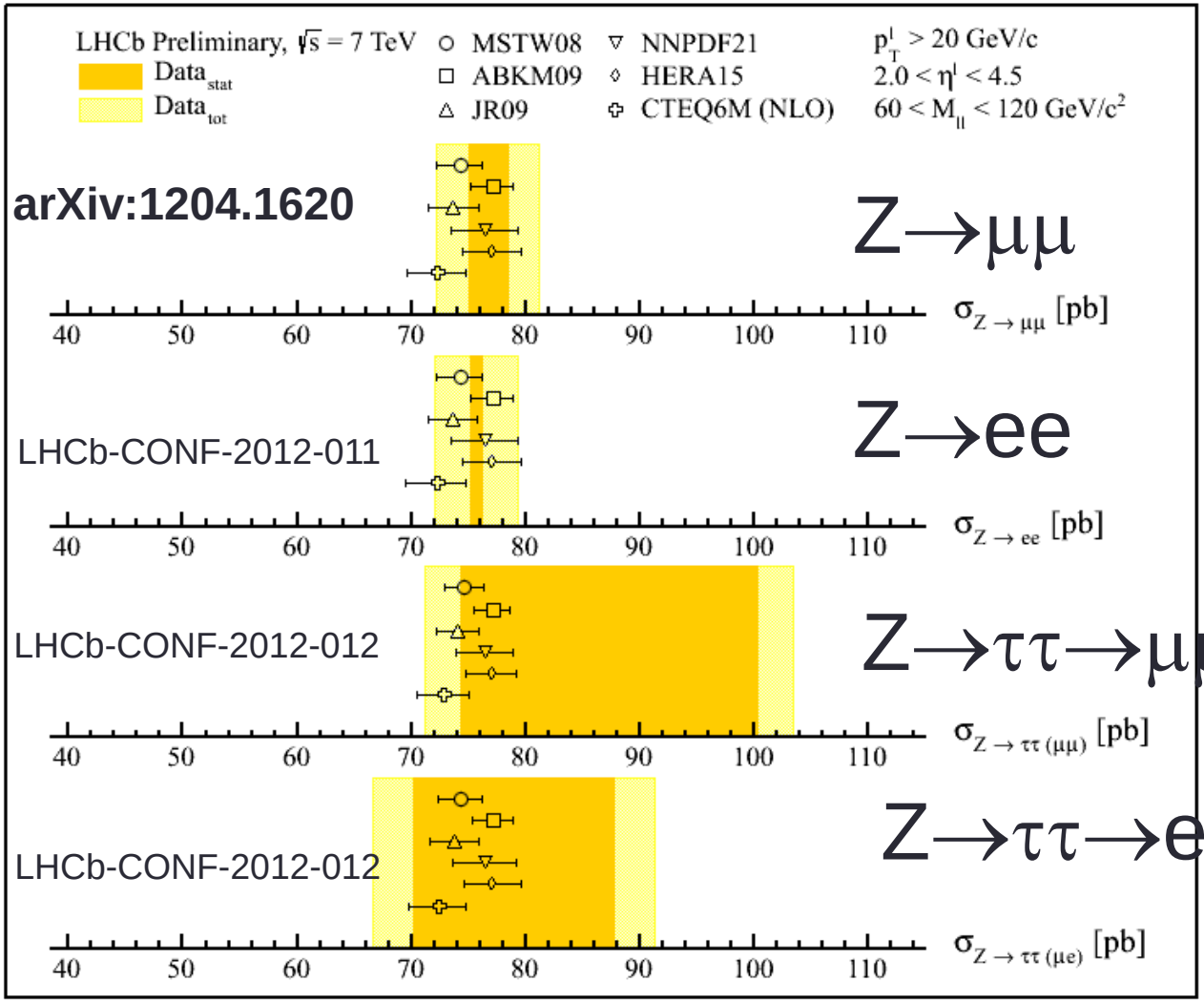
Z cross-sections in ee, μμ and ττ final states

$\int L = 37\,pb^{-1}$

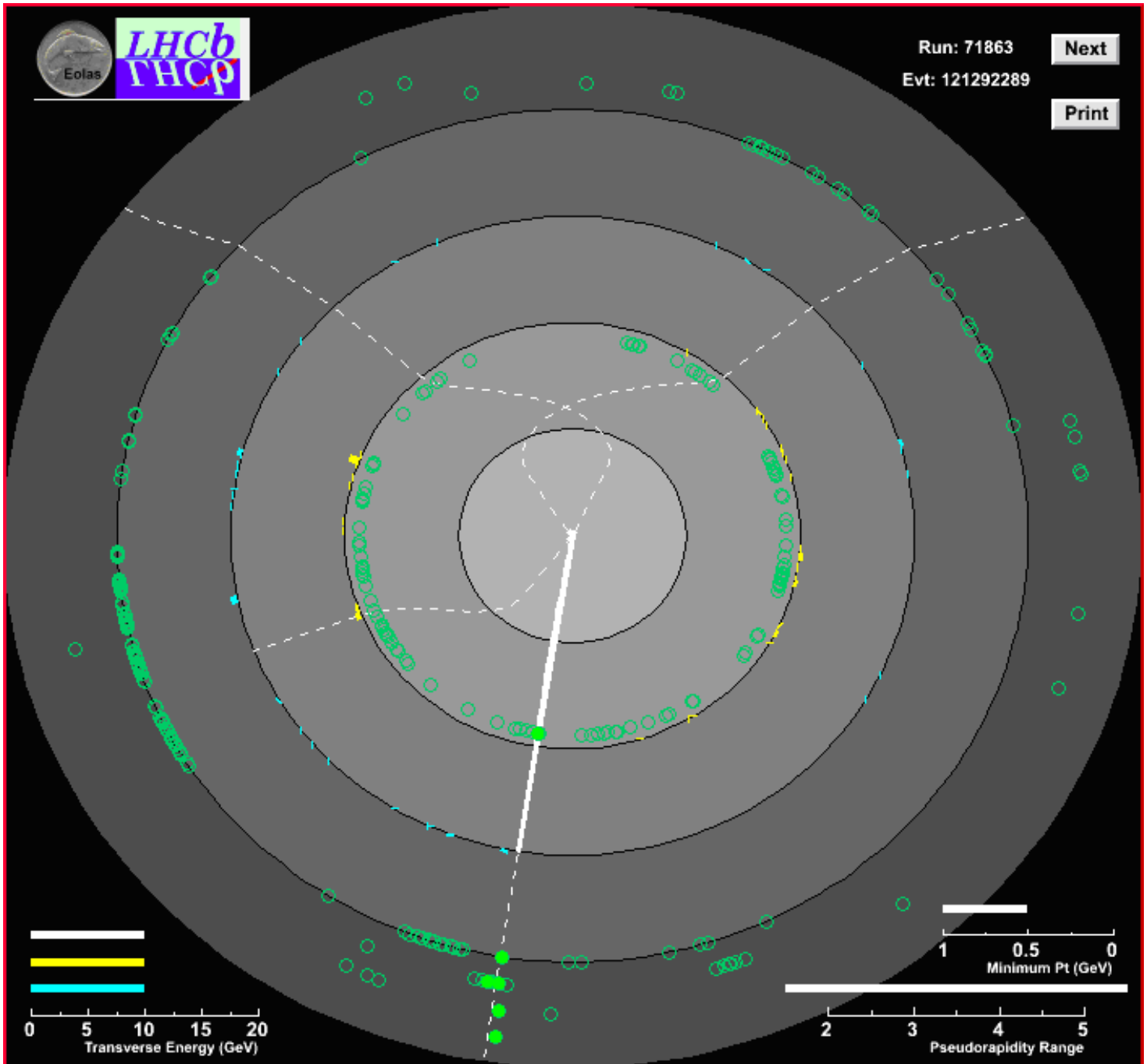
$\int L = 945\,pb^{-1}$

$\int L = 247\,pb^{-1}$

$\int L = 247\,pb^{-1}$



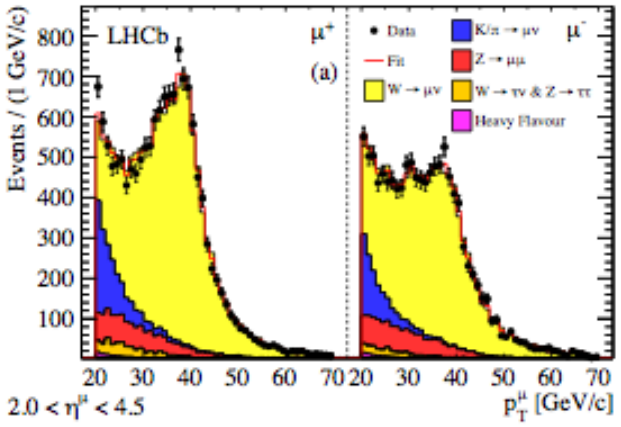
First W candidate

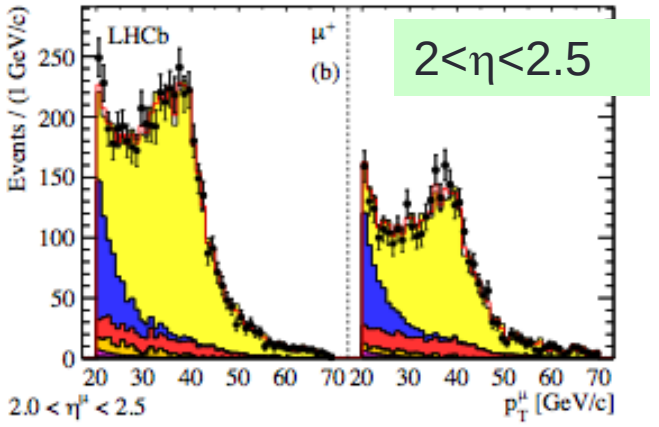


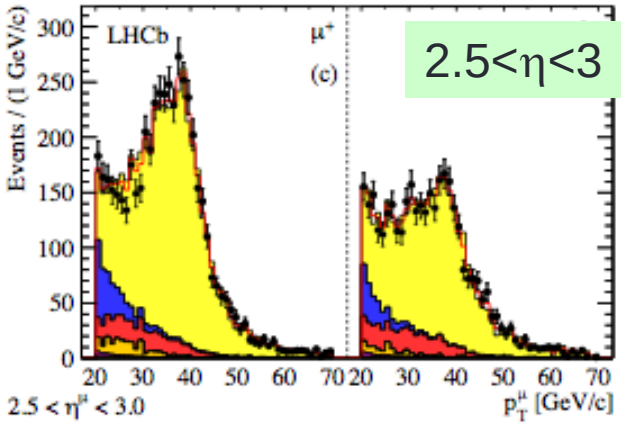
Composition of W→μν selection

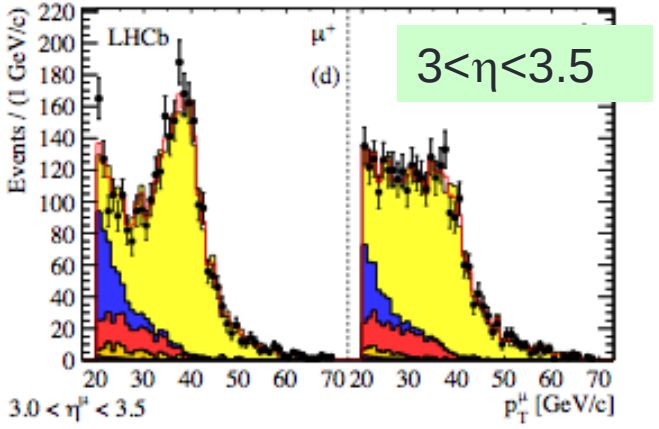
arXiv:1204.1620

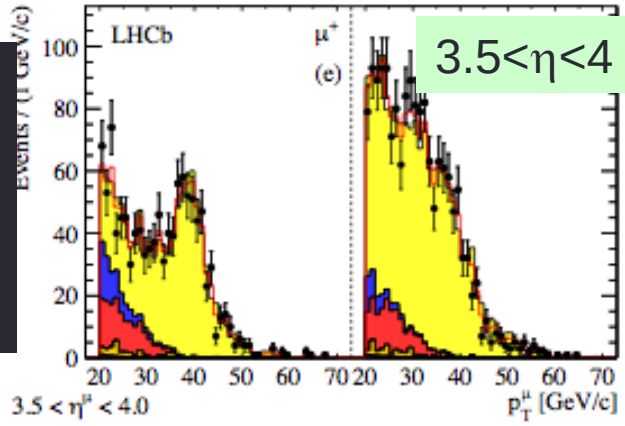
$\grave{o}L = 37 pb^{-1}$

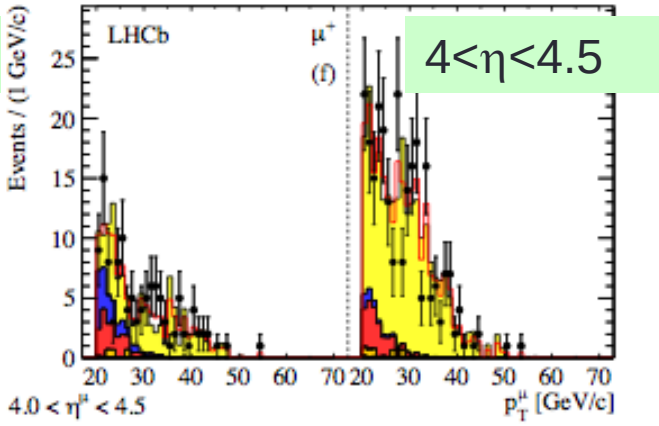








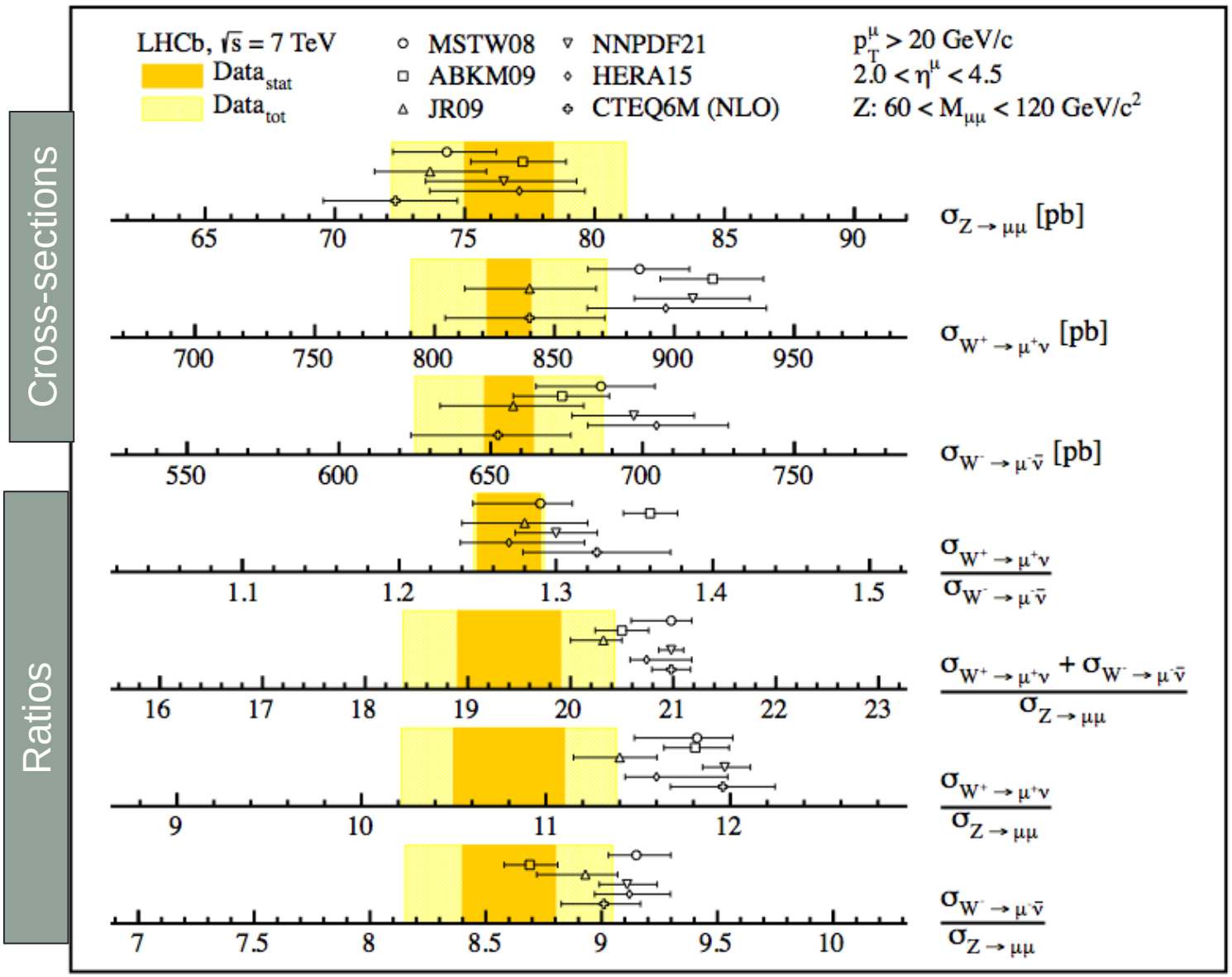




W
QCD (π/K) (data)
Z
W->τν
b,c->μX (data)

Comparison to theory

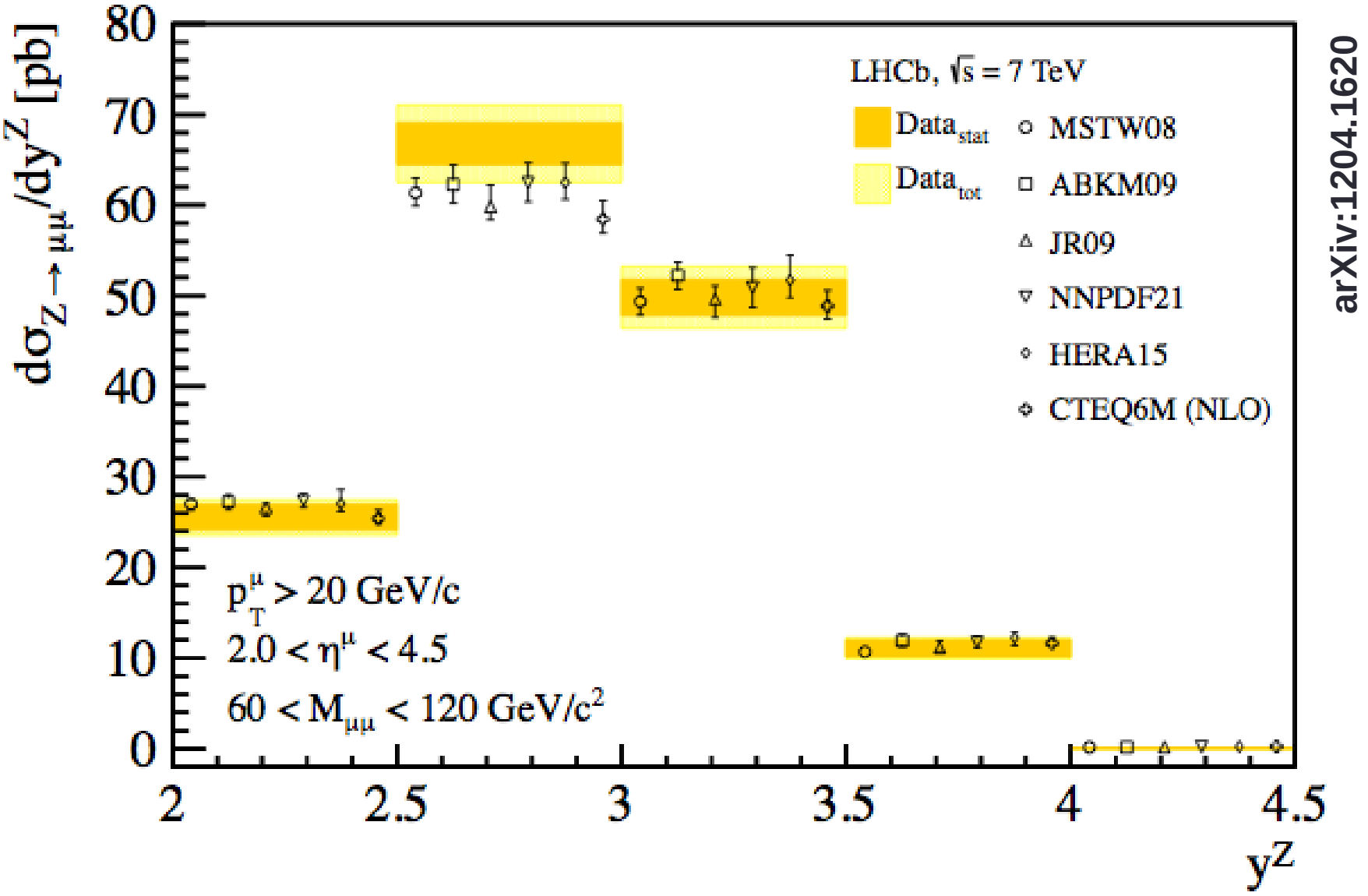
$\int L = 37\,pb^{-1}$



arXiv:1204.1620

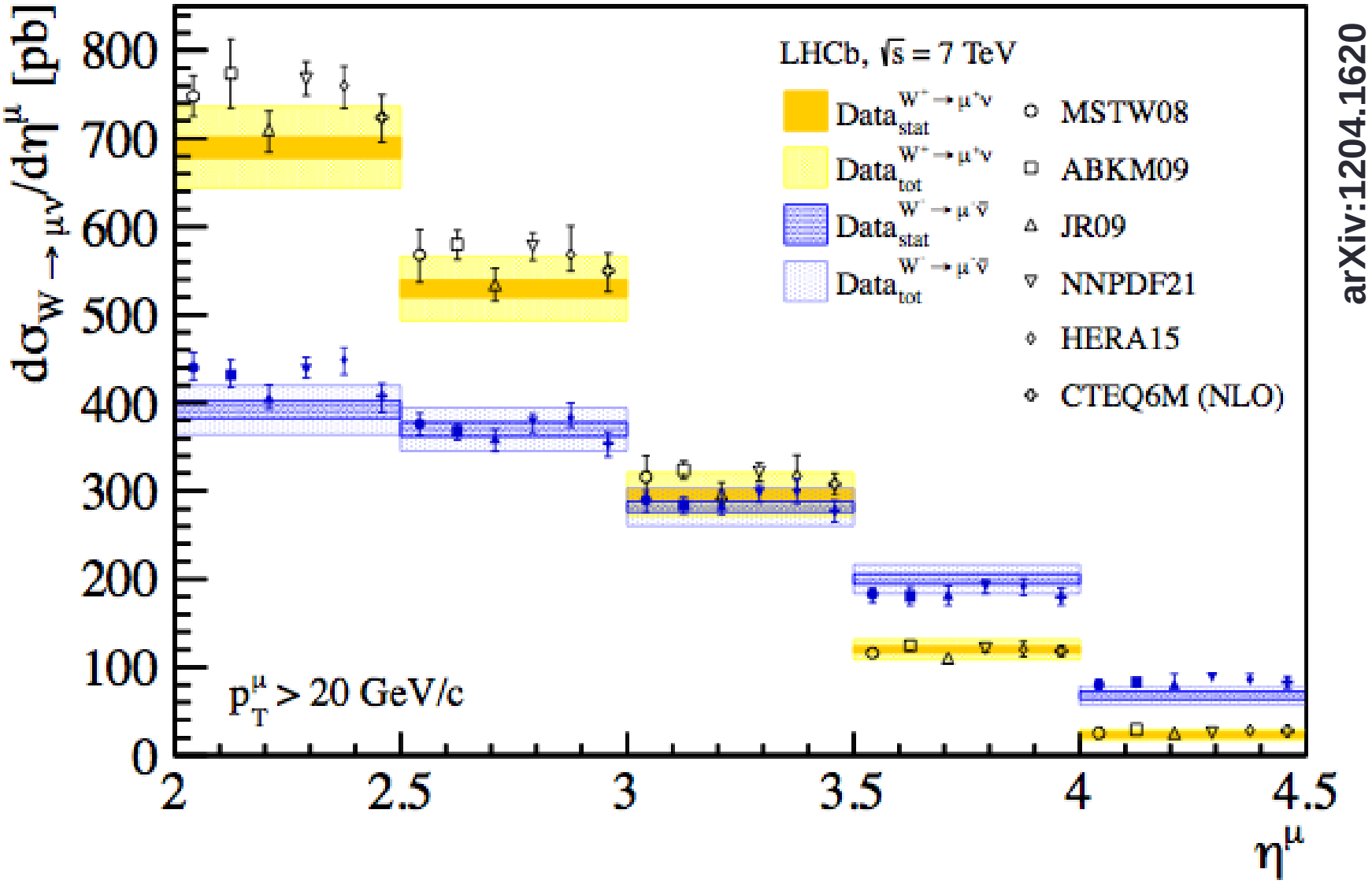
Differential Z distribution v y

$\int L = 37 pb^{-1}$



Differential W distribution v muon η

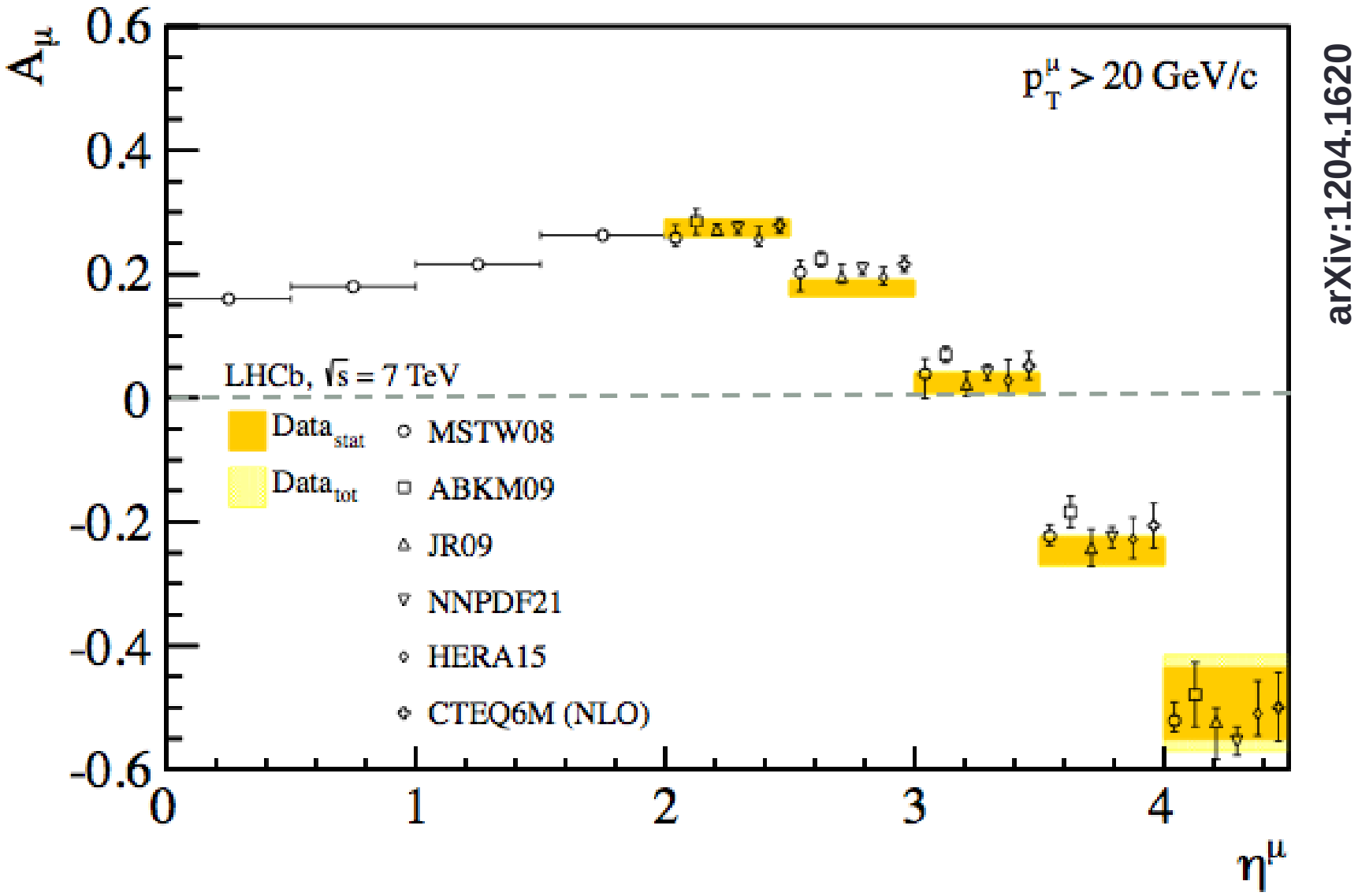
$\grave{o}L = 37 pb^{-1}$



arXiv:1204.1620

W charge asymmetry

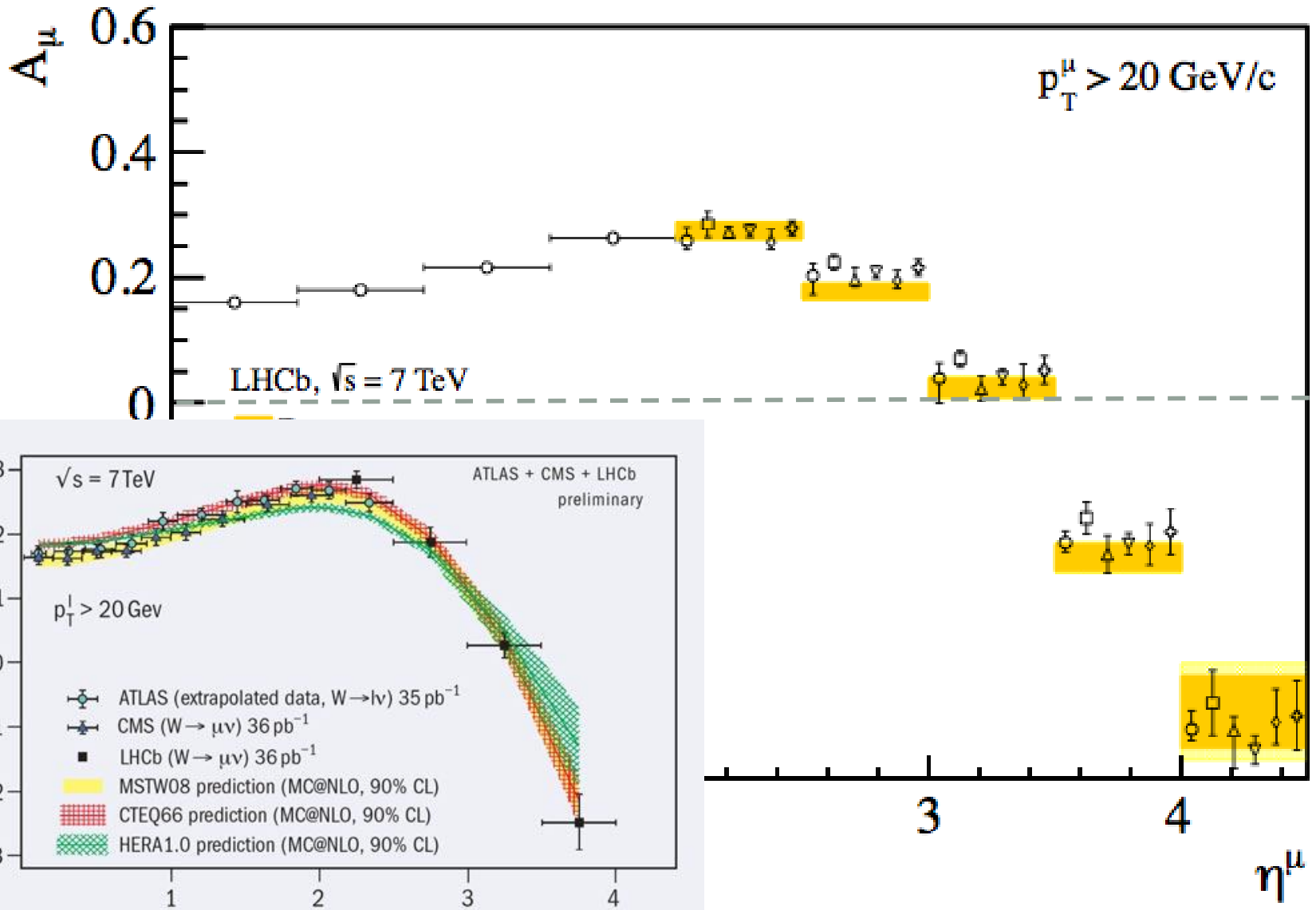
$\int L = 37 pb^{-1}$



arXiv:1204.1620

W charge asymmetry

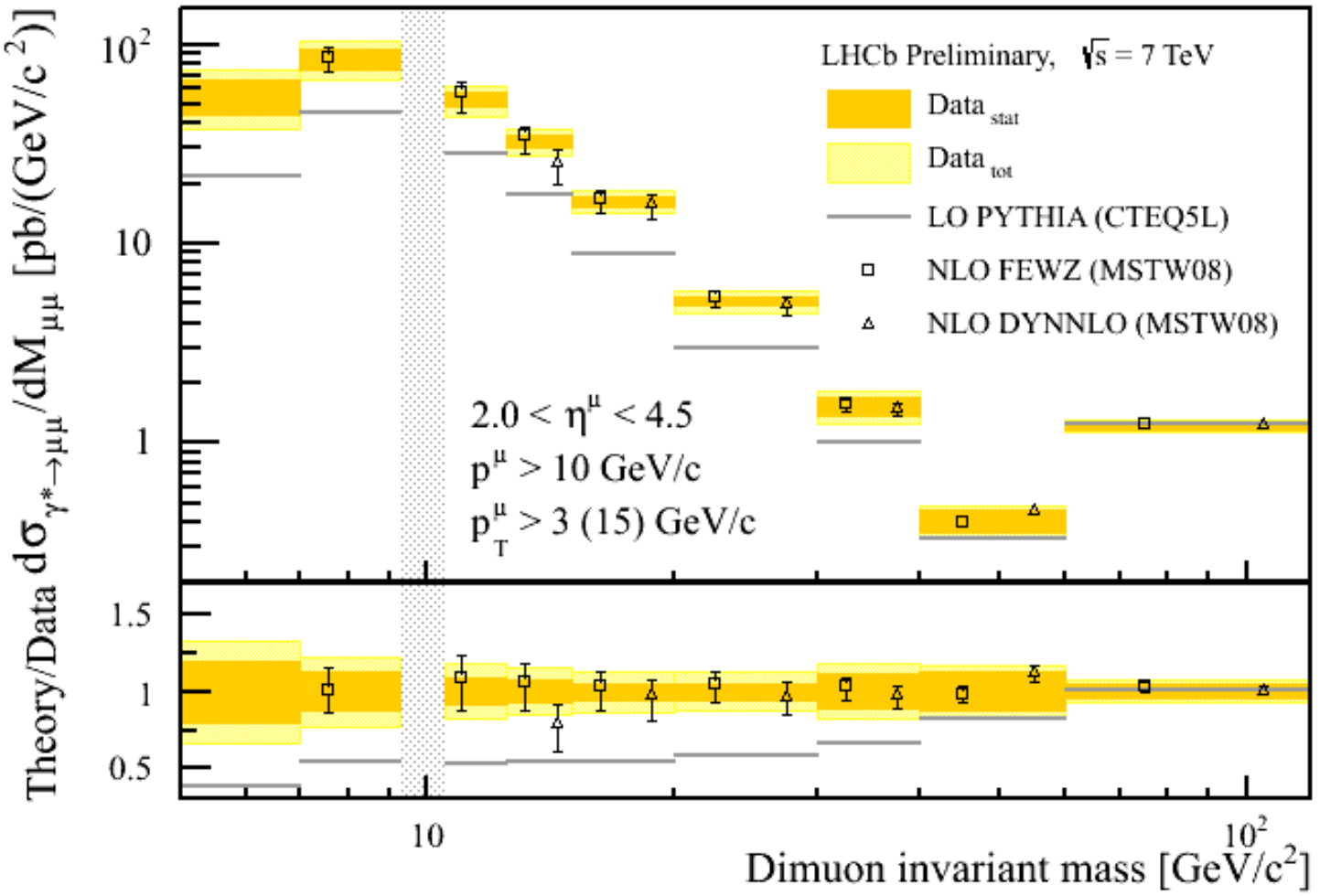
$\grave{O}L = 37 pb^{-1}$



arXiv:1204.1620

DY→μμ cross-section measured down to 5 GeV.

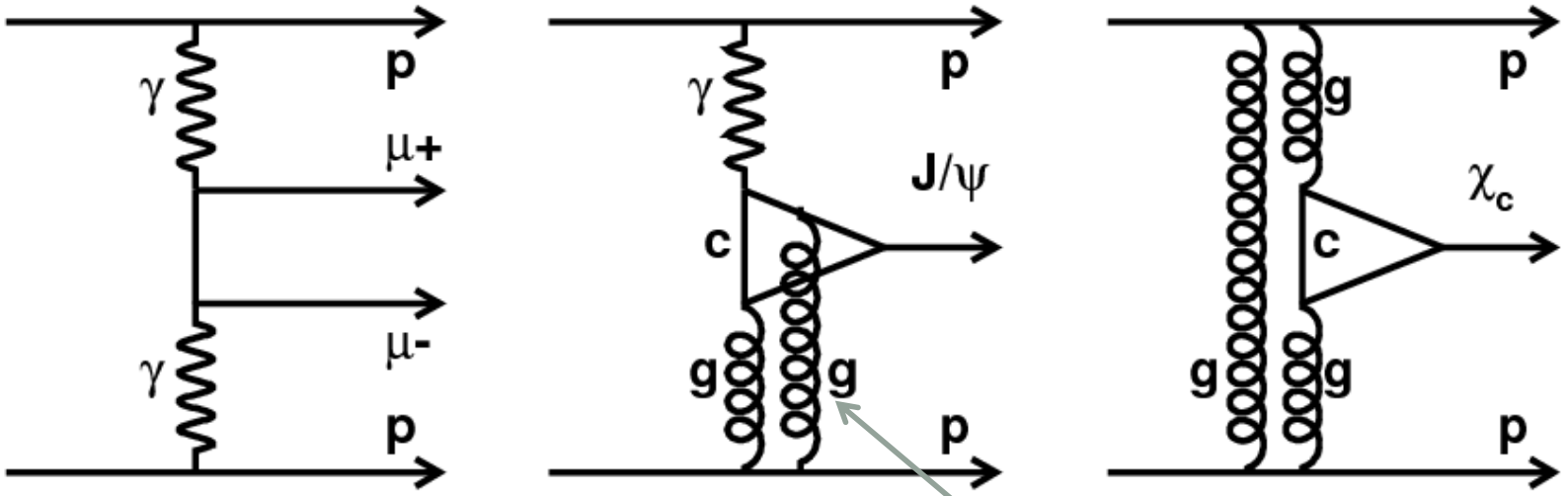
$\grave{O}L = 37 pb^{-1}$



Probes PDF down to x=8x10-6. First measurements in unexplored region

Central Exclusive Production with Dimuon final states

Phenomena where a **colourless object** creates a particle



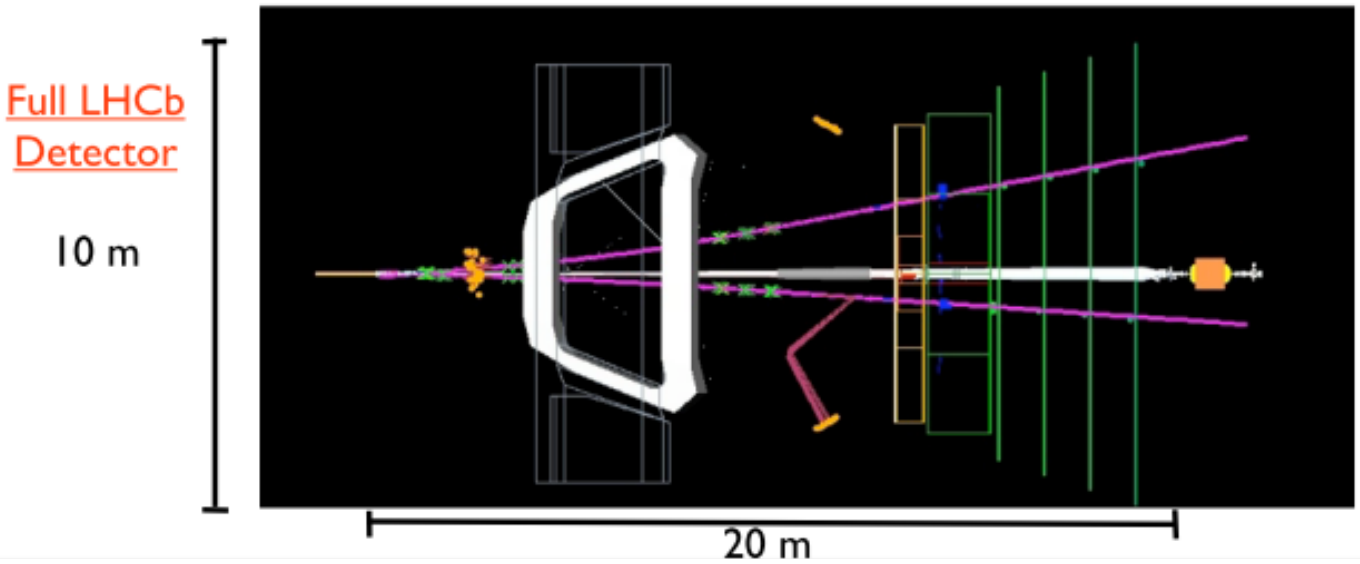
QED **Photo production** **Double pomeron exchange**

(Note: $J/\psi \rightarrow \mu\mu$ and $\chi_c \rightarrow J/\psi$)

Because the proton doesn't break up,
this gives a very unusual signature for a hadron collider.

Sensitivity to $xg(x,Q^2)$ at $Q^2 \sim 9, x \sim 5 \times 10^{-6}$

Use of backward tracks to define rapidity gap



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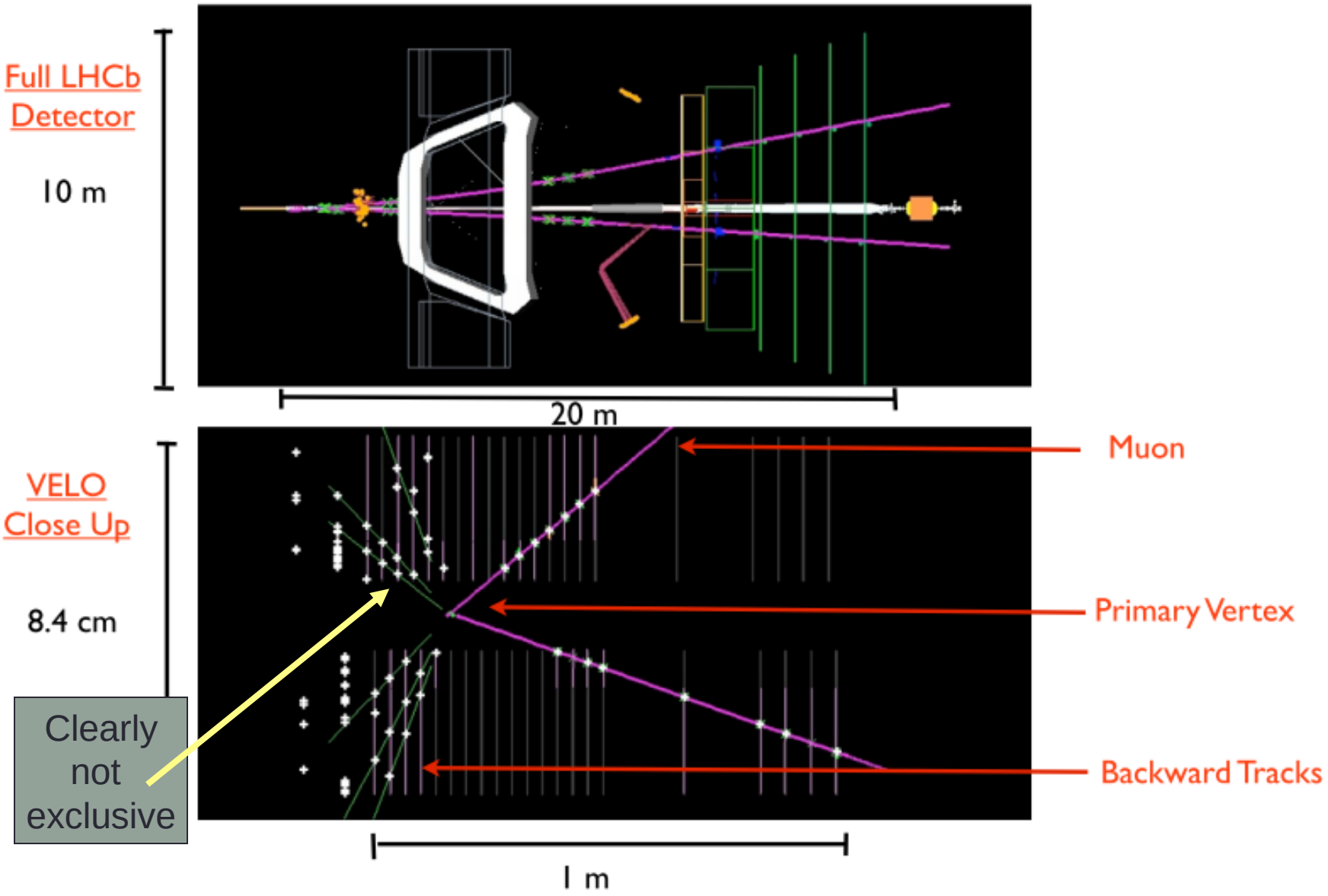
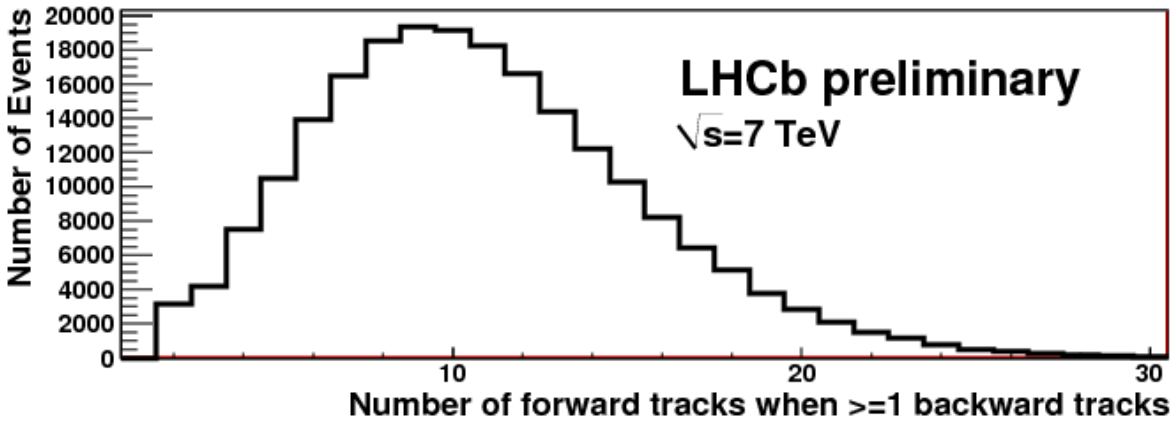
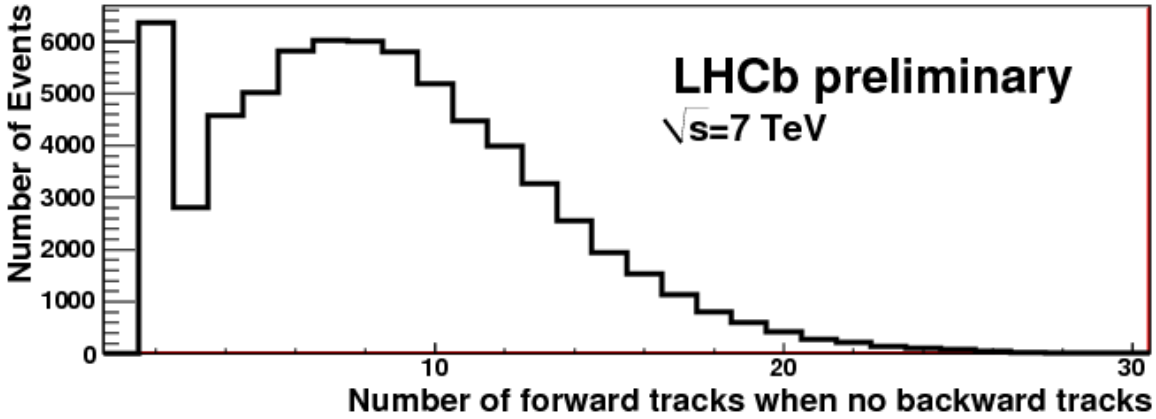


Number of tracks





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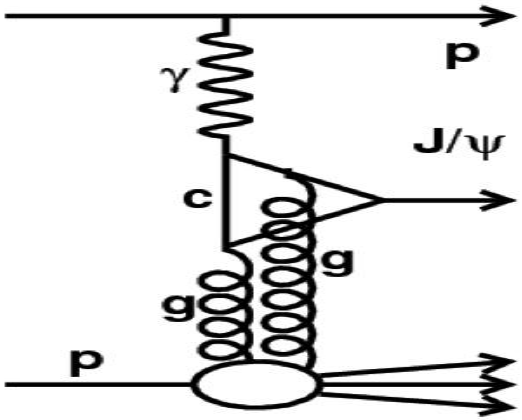
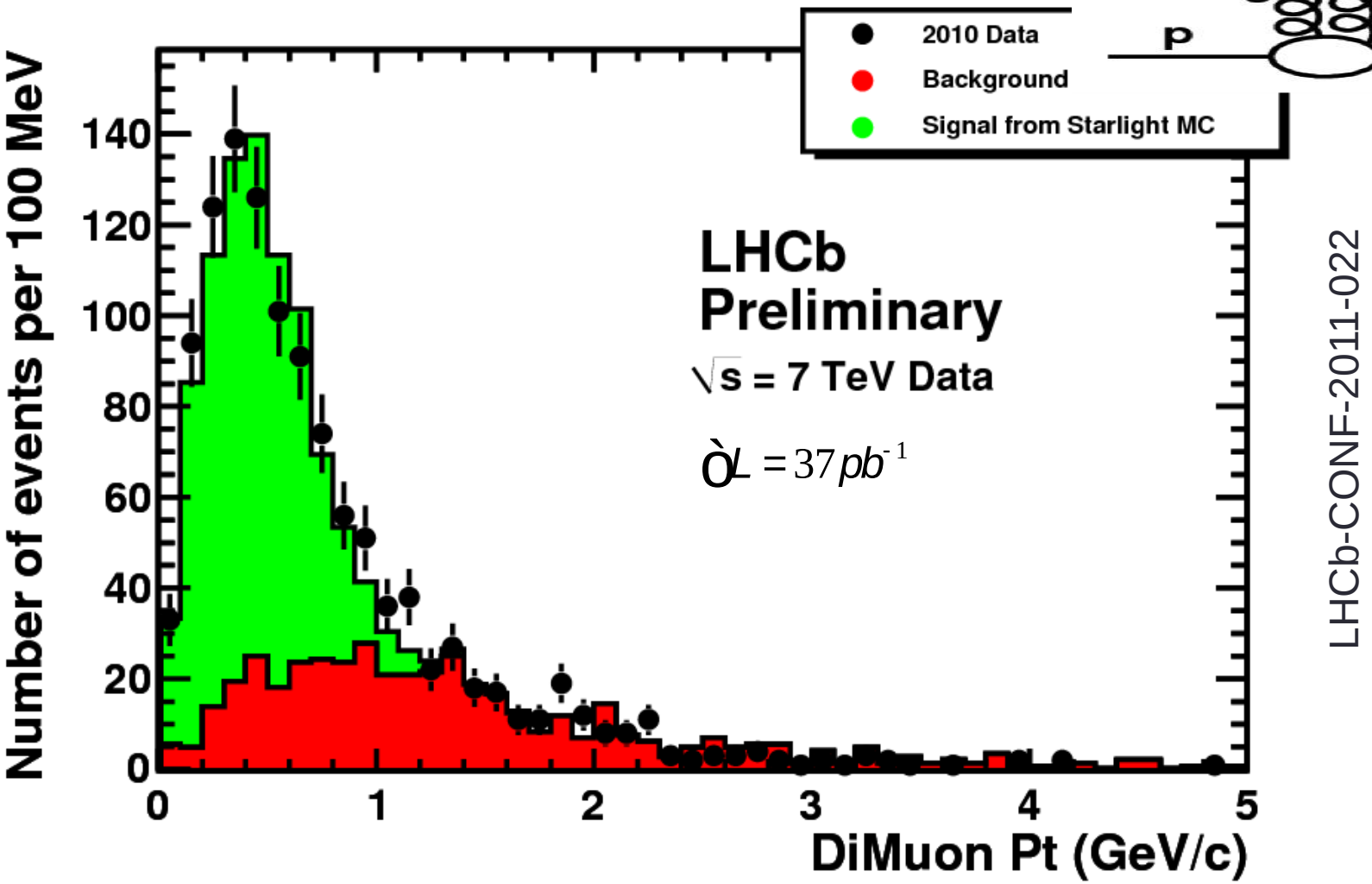
Requiring a gap, there is evidence for central exclusive production decaying to two muons.

Estimating non-exclusive backgrounds

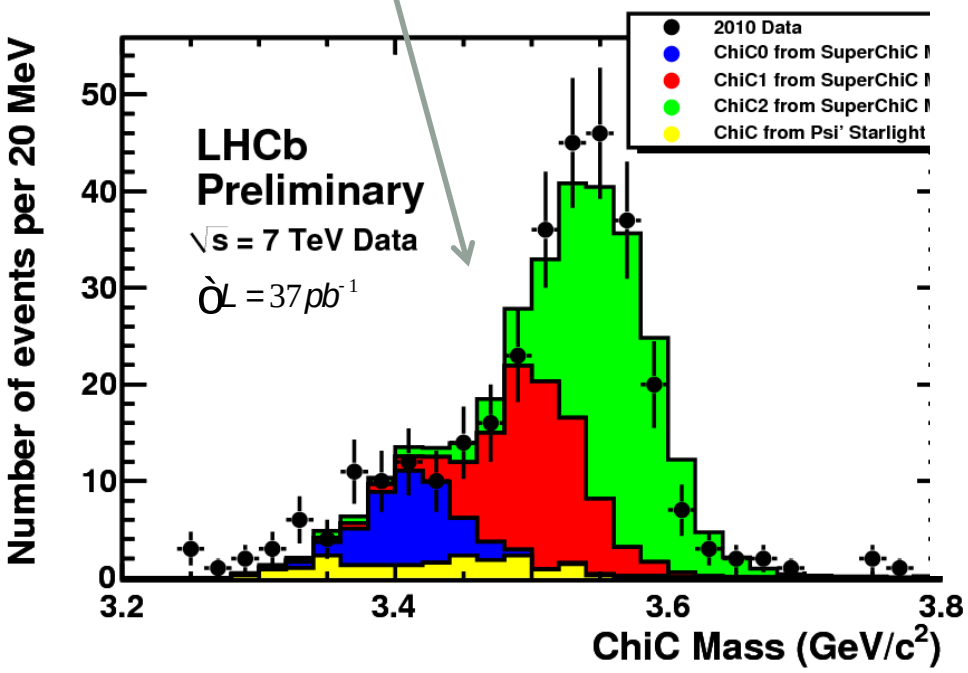


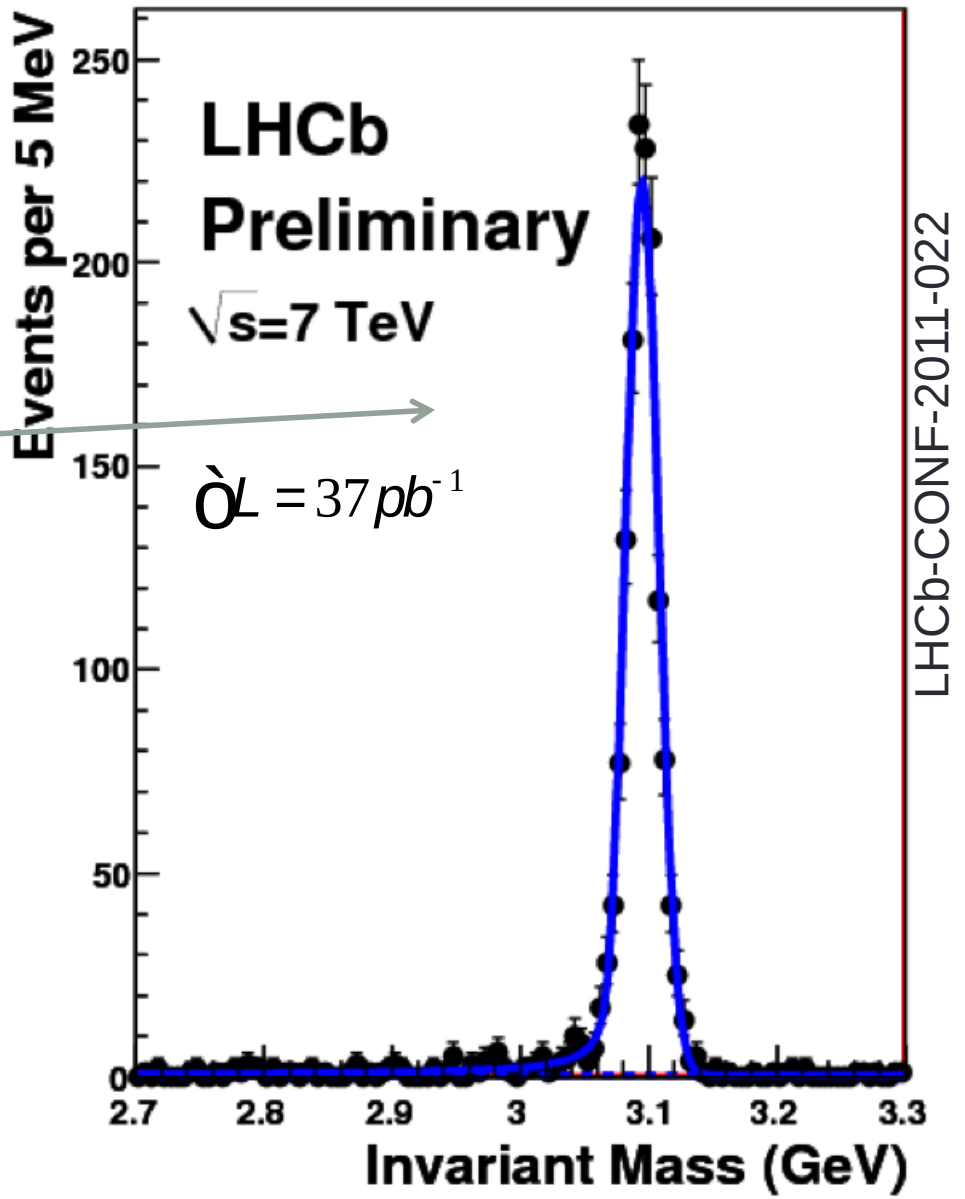


LHCb-CONF-2011-022

Invariant mass of exclusive dimuons

+0 photons
+1 photon. (χ_c)





This is not background subtracted !

Systematic uncertainties and cross-sections

	J/ψ	ψ'	χ_{c0}	χ_{c1}	χ_{c2}	diphoton
ϵ_{track}	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.96 ± 0.03
$\epsilon_{\mu id}$	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03
ϵ_{γ}			0.61 ± 0.08	0.75 ± 0.05	0.78 ± 0.04	
ϵ_{sel}	0.95	0.95	0.76	0.76	0.76	0.35
Efficiency	0.71 ± 0.06	0.71 ± 0.06	0.34 ± 0.06	0.43 ± 0.05	0.44 ± 0.04	0.25 ± 0.02
# Events	1468 ± 38	40 ± 6	25 ± 6	56 ± 18	99 ± 29	40 ± 6
Purity	0.71 ± 0.03	0.67 ± 0.03	0.39 ± 0.13	0.39 ± 0.13	0.39 ± 0.13	0.97 ± 0.01
L_{eff} (pb^{-1})	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	2.3 ± 0.5
Cross-section	474 ± 12	12.2 ± 1.8	9.3 ± 2.2	16.4 ± 5.3	28.0 ± 5.4	67 ± 10
$\times BR$ (pb)	$\pm 45 \pm 92$	$\pm 1.2 \pm 2.4$	$\pm 3.5 \pm 1.8$	$\pm 5.8 \pm 3.2$	$\pm 9.7 \pm 5.4$	$\pm 5 \pm 15$

$$\sigma_{J\psi\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 474 \pm 12 \pm 45 \pm 92\ \mathrm{pb}$$

$$\sigma_{\psi'\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 12.2 \pm 1.8 \pm 1.2 \pm 2.4\ \mathrm{pb}$$

$$\sigma_{\chi_0\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_{\gamma} < 4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8\ \mathrm{pb}$$

$$\sigma_{\chi_1\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_{\gamma} < 4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2\ \mathrm{pb}$$

$$\sigma_{\chi_2\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_{\gamma} < 4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4\ \mathrm{pb}$$

$$\sigma_{pp\to p\mu^+\mu^- p}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5; m_{\mu+\mu-} > 2.5GeV) = 67 \pm 10 \pm 5 \pm 15\ \mathrm{pb}$$

Stat sys lumi

Comparison to Theory

J/ψ:
474 +-103 pb

Starlight (Klein & Nystrand) 292 pb
SuperChic (Harland-Lang, Khoze, Ryskin, Stirlin) 330 pb
Motyka & Watt 330 pb
Schäfer & Szczurek 710 pb

ψ':
12.2 +- 3.2 pb

Starlight (Klein & Nystrand) 6 pb
Schäfer & Szczurek ~ 17 pb

σ(ψ')/σ(J/ψ):
0.20 +- 0.03

Starlight (Klein & Nystrand) 0.16
Schäfer & Szczurek ~ 0.2
HERA: 0.166 +- 0.012 (lower $\sqrt{(\gamma p)}$)
CDF: 0.14 +- 0.05 (lower $\sqrt{(\gamma p)}$)

χ_0: 9.3 +- 4.5 pb χ_1: 16.4 +- 7.1 pb χ_2: 28.0 +-12.3 pb

SuperChic: 14 pb 10 pb 3 pb

pμμp: 67 +- 19 pb

LPAIR (J. Vermaseren) 42 pb

Summary

- W,Z,γ* and CEP measurements test the Standard Model, (QED, EW and QCD) and constrain PDFs.
- A unique kinematic range is accessible using LHCb, down to $x=5\times10^{-6}$.

- With current statistics, everything is consistent.

- Full analysis of 2011 data, and new 2012 data (at 8 TeV) underway. The higher energy means that even smaller x-values are being probed.