LHCb PDF results

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On behalf of the LHCb Collaboration

3rd Annual Large Hadron Collider Physics Conference,
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3rd September 2015

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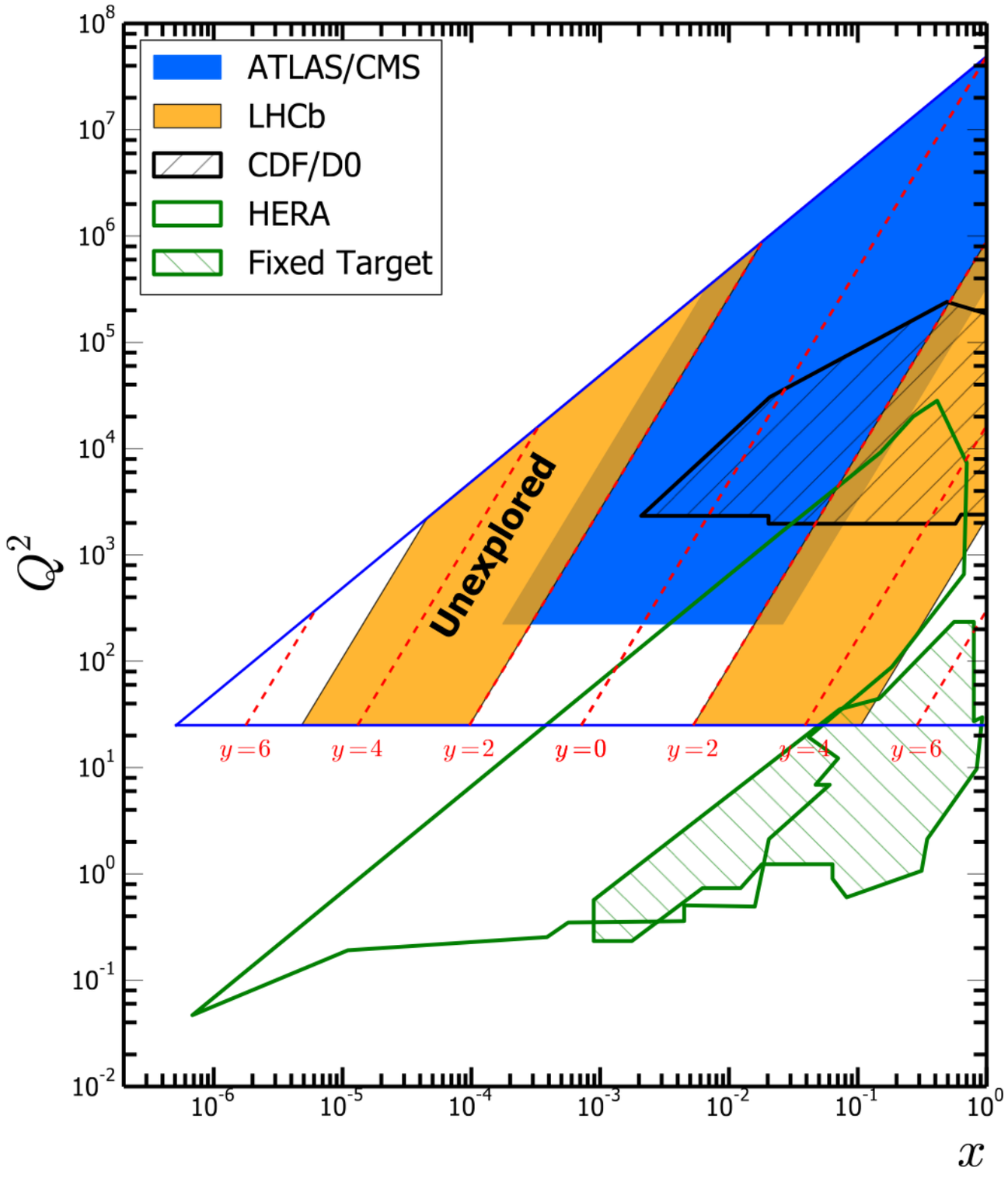
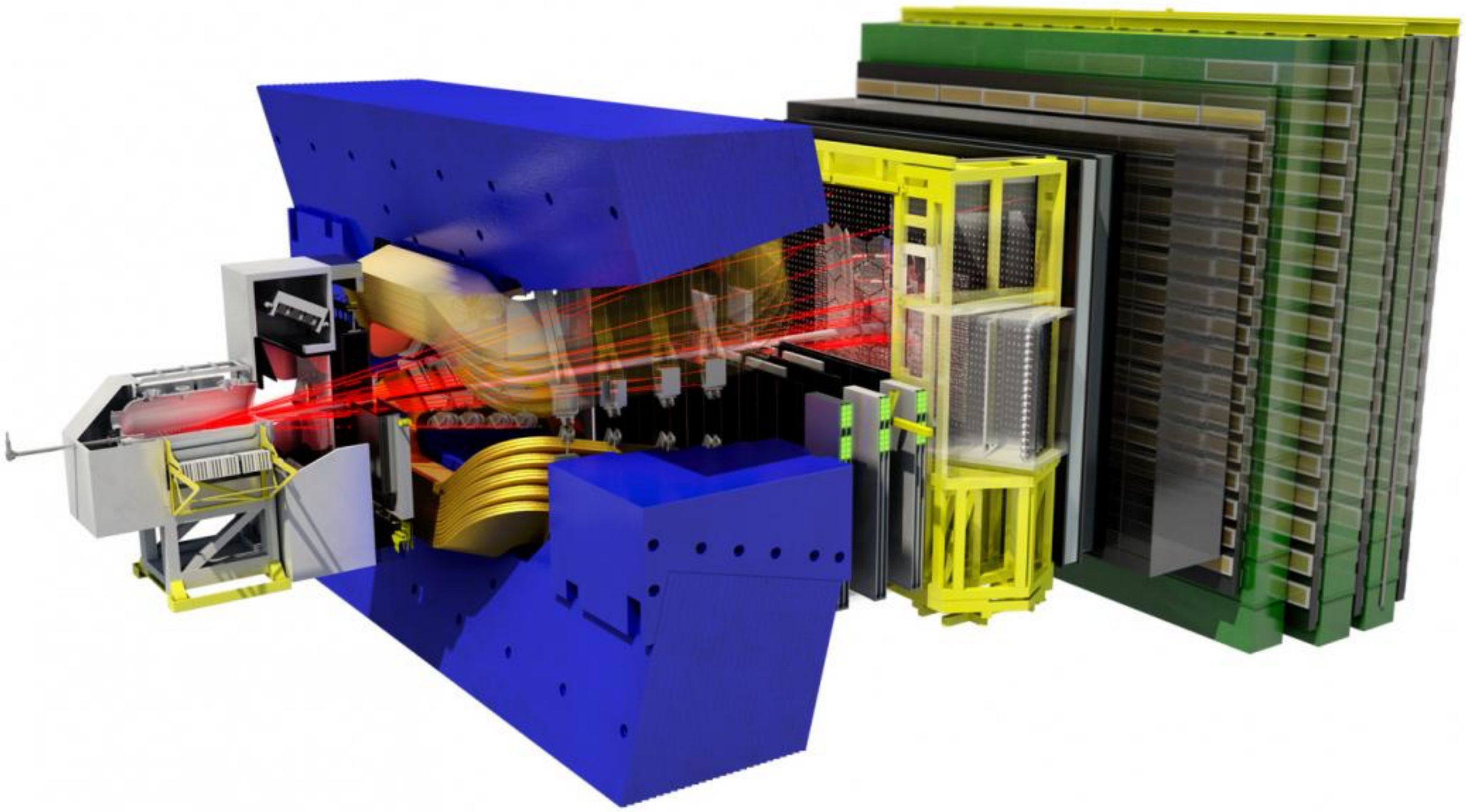


LHCb probes a unique region of the proton structure

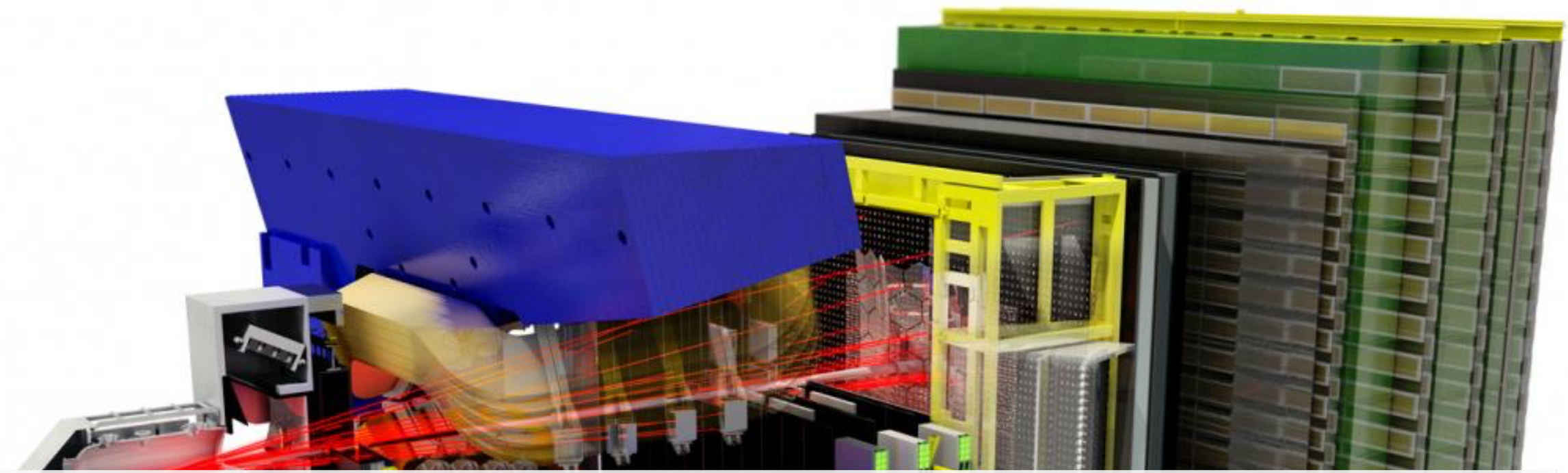
JINST 3 (2008) S08005

The LHCb detector



JINST 3 (2008) S08005

The LHCb detector



Excellent Run-I performance (Int. J. Mod. Phys. A 30, 1530022 (2015)).
Features relevant for PDF sensitive measurements:

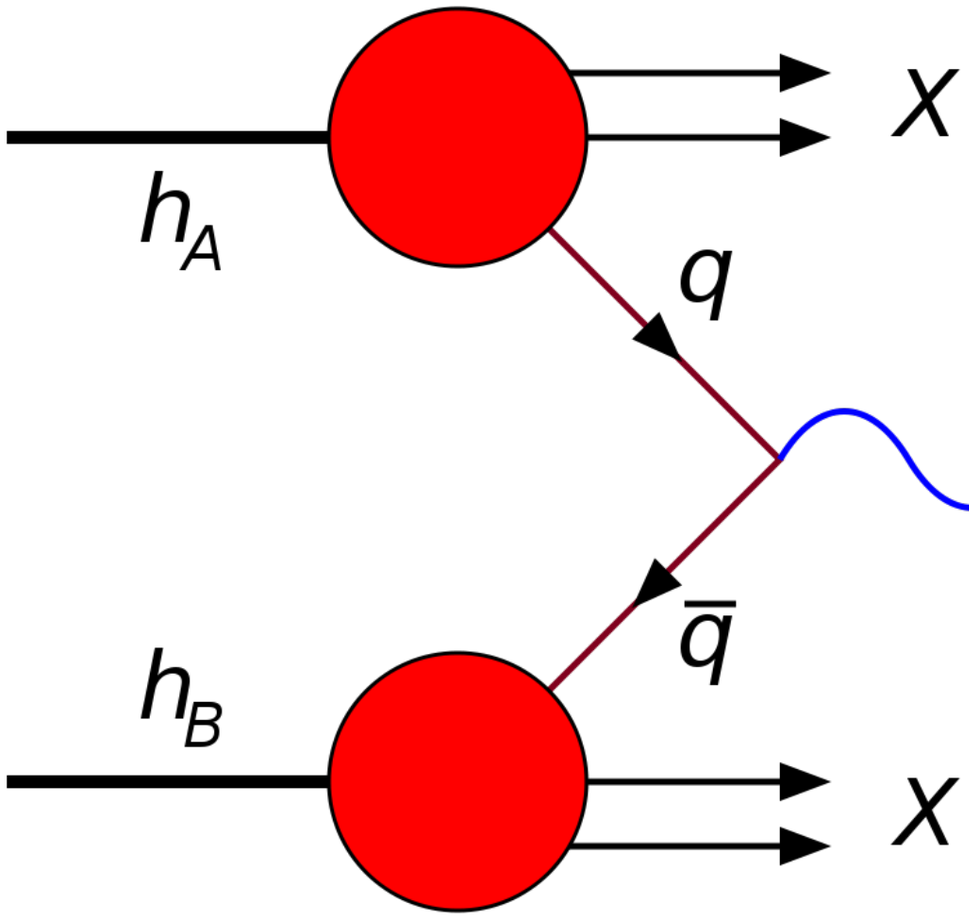
- $2 < \eta < 5$
- Excellent tracking and muon-ID
- Good jet reconstruction, and excellent light, c, b separation

2012 (8 TeV) luminosity determined to 1.16% (JINST 9 P12005, 2014)

Outline

- Inclusive W and Z production
- W and Z plus jets (including b and c tagged)
- Brief mention of other PDF sensitive results

Inclusive W&Z production



$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$

I'll discuss the following:

$Z/\gamma^* \rightarrow \mu\mu$ and W/Z ratios	7 TeV, 1 fb^{-1}	**JHEP 08 (2015) 039** [LHCB-PAPER-2015-001]
$W \rightarrow \mu\nu$ production	7 TeV, 1 fb^{-1}	**JHEP 12 (2014) 079** [LHCB-PAPER-2014-033]
Low mass Drell-Yan	7 TeV, 37 pb^{-1}	**LHCb-CONF-2012-013**

JHEP08(2015)039

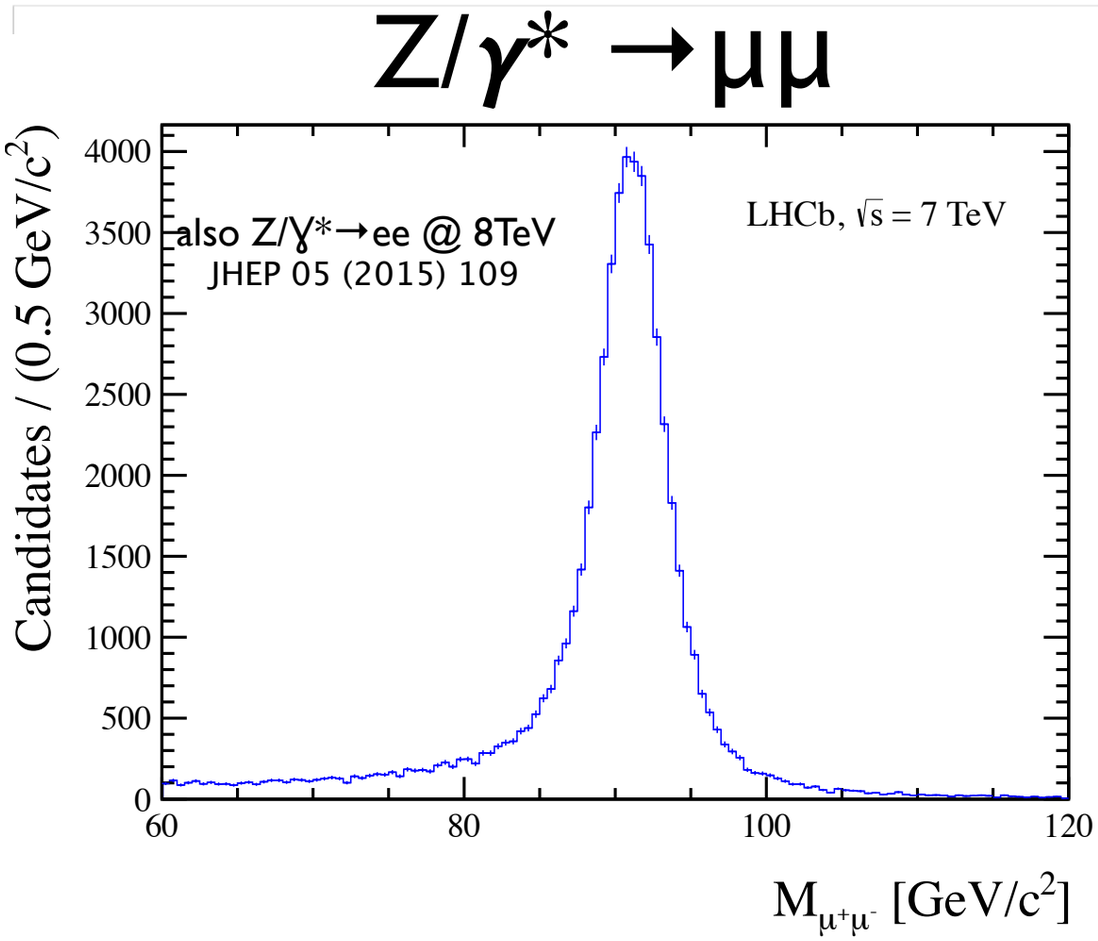
JHEP 12 (2014) 079

Inclusive W&Z production at 7 TeV

$p_T(\mu) > 20$ GeV, $2 < \eta < 4.5$,

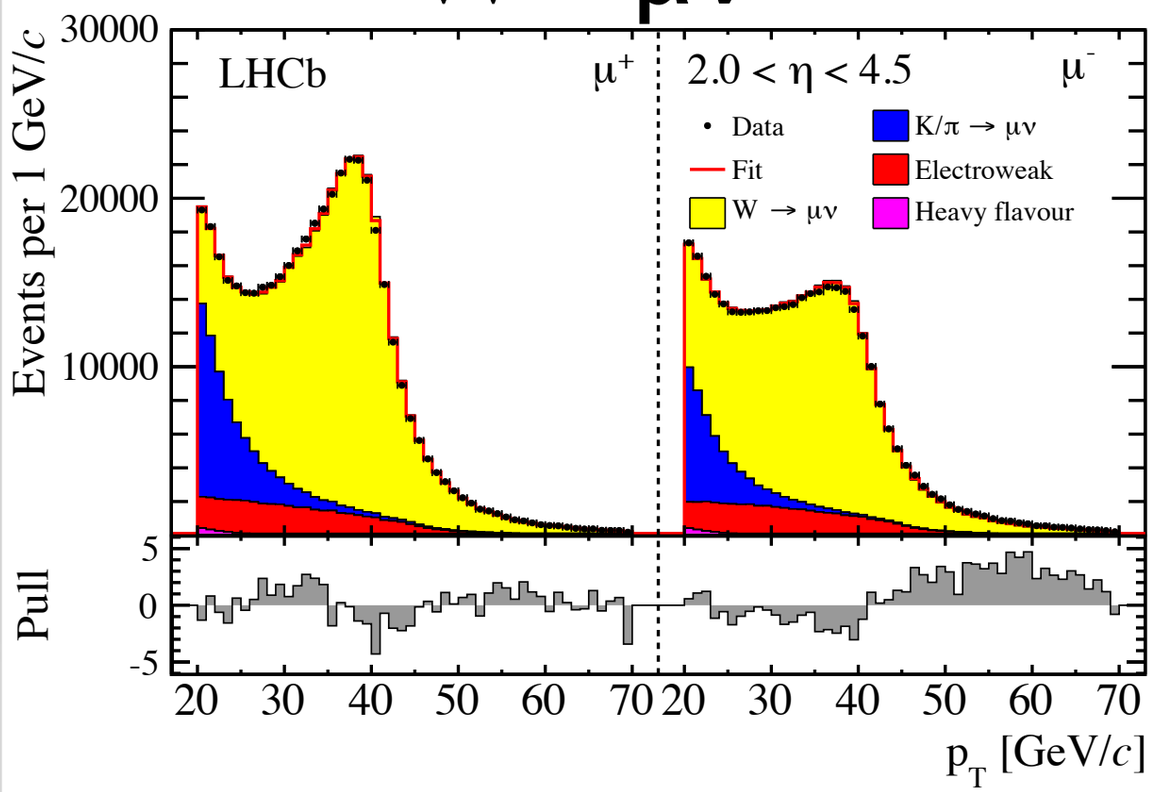
$60 < M < 120$ GeV (Z/γ^*)

$Z/\gamma^* \rightarrow \mu\mu$



60k candidates with >99% purity

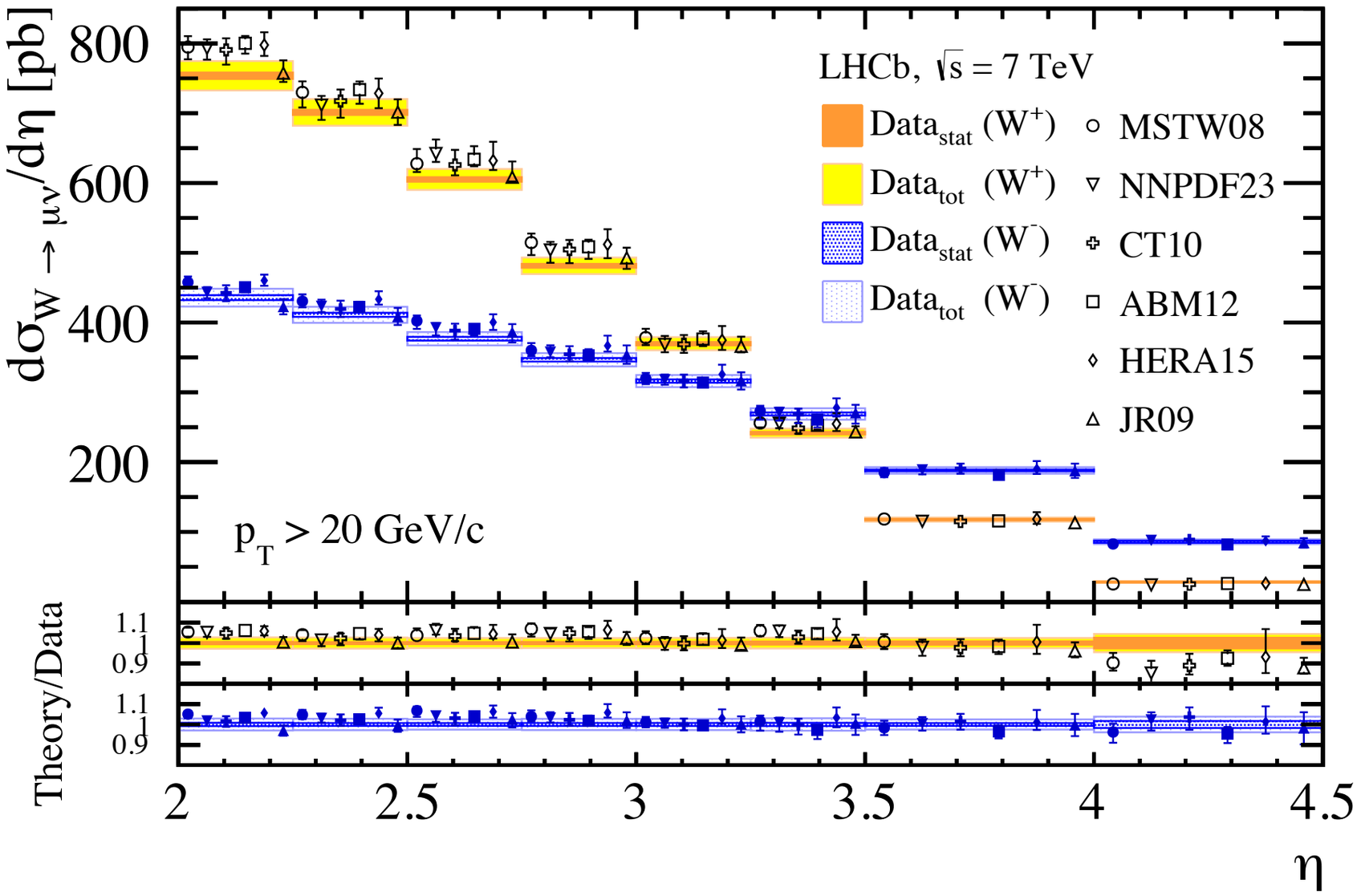
$W \rightarrow \mu\nu$



900k candidates with 70% purity

JHEP 12 (2014) 079

W production at 7 TeV

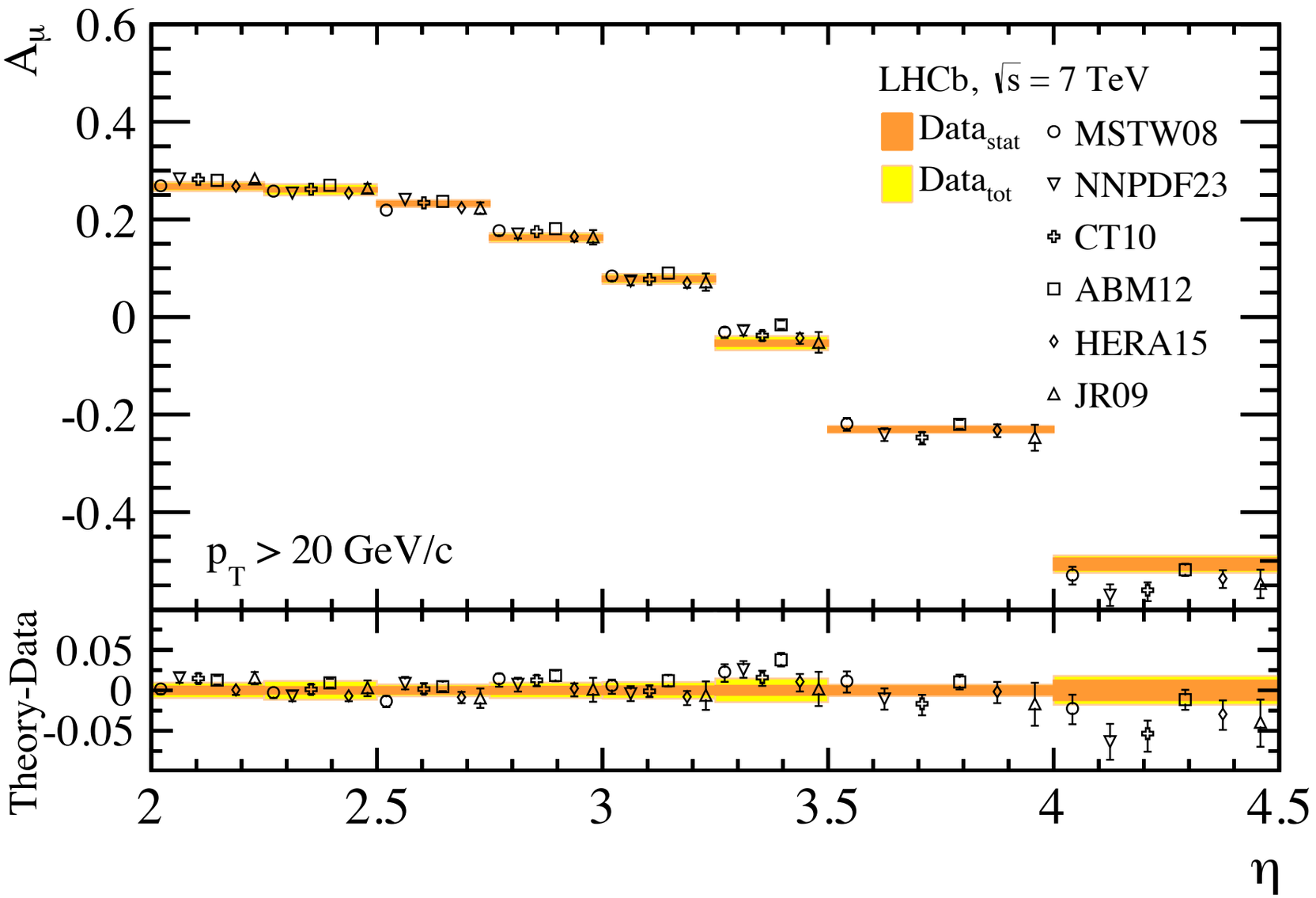


Cross sections are in good agreement with NNLO predictions[1,2]

[1]Gavin *et al.*, **1011.3540**;
[2]Li, Petriello, **1208.5967**

JHEP 12 (2014) 079

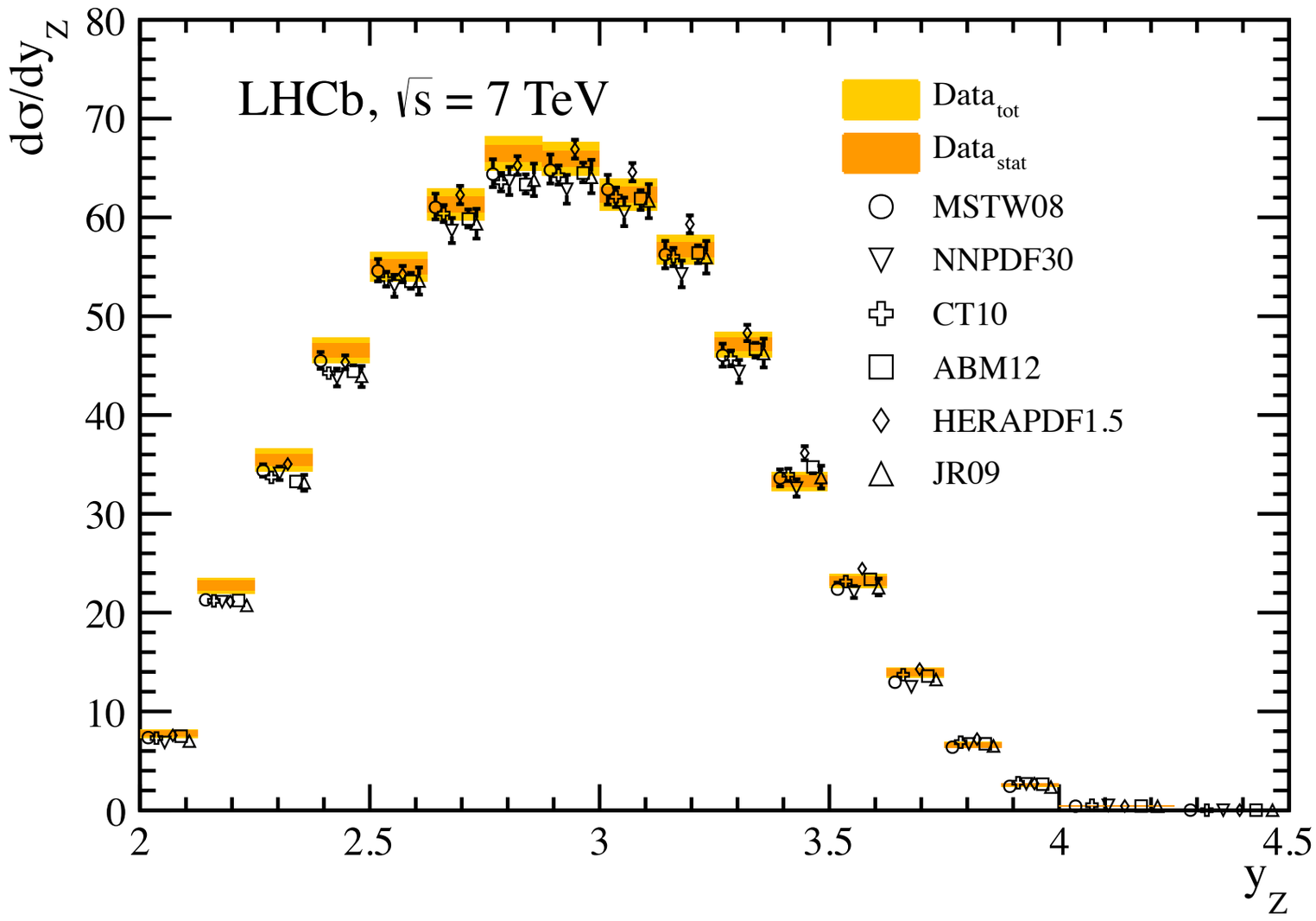
W production at 7 TeV



Likewise for the charge asymmetry

JHEP 08 (2015) 039

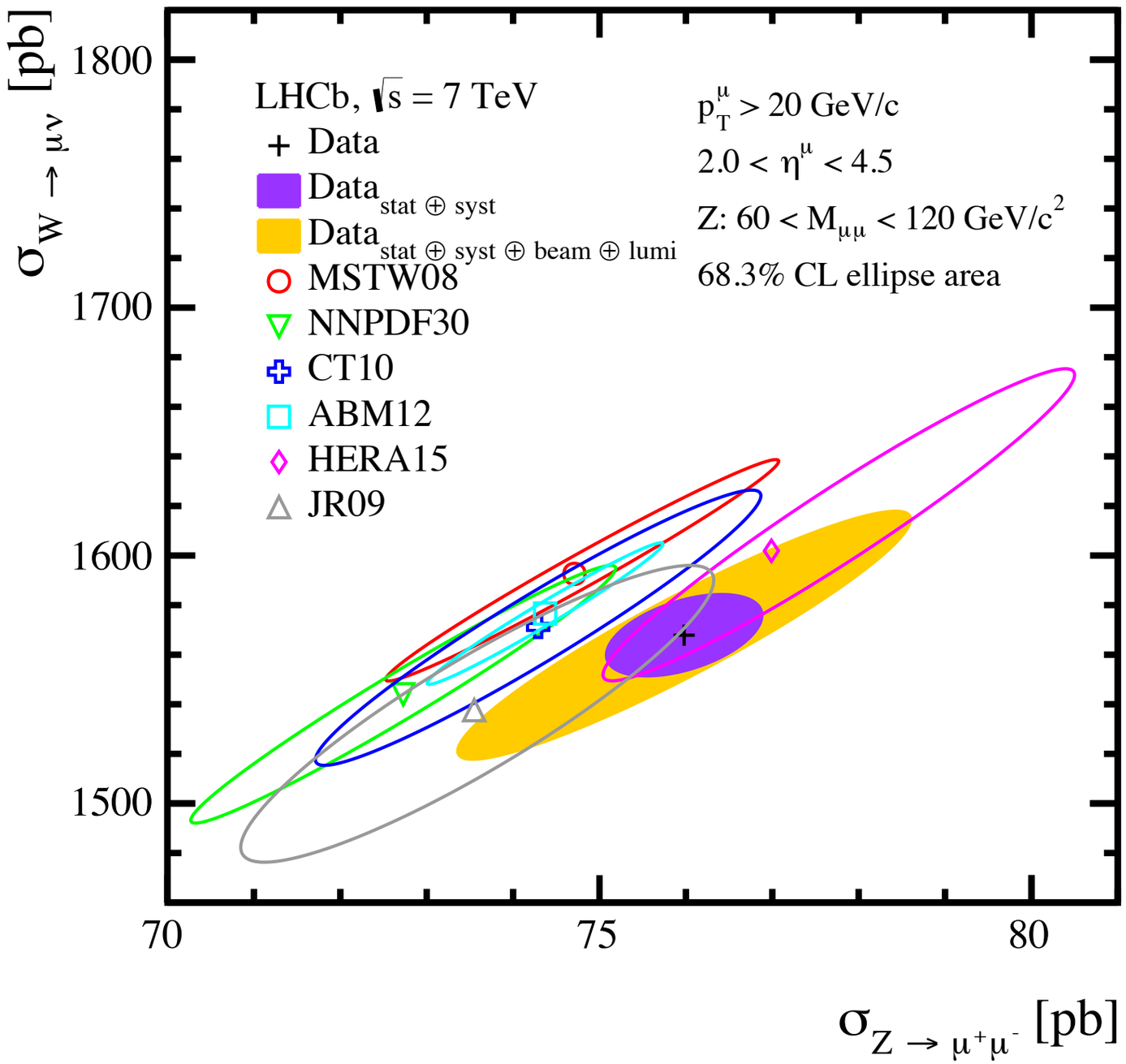
Z production at 7 TeV



Agreement tested down to few % level, with $O(\alpha_s^2)$ predictions using various PDF sets

W/Z ratios

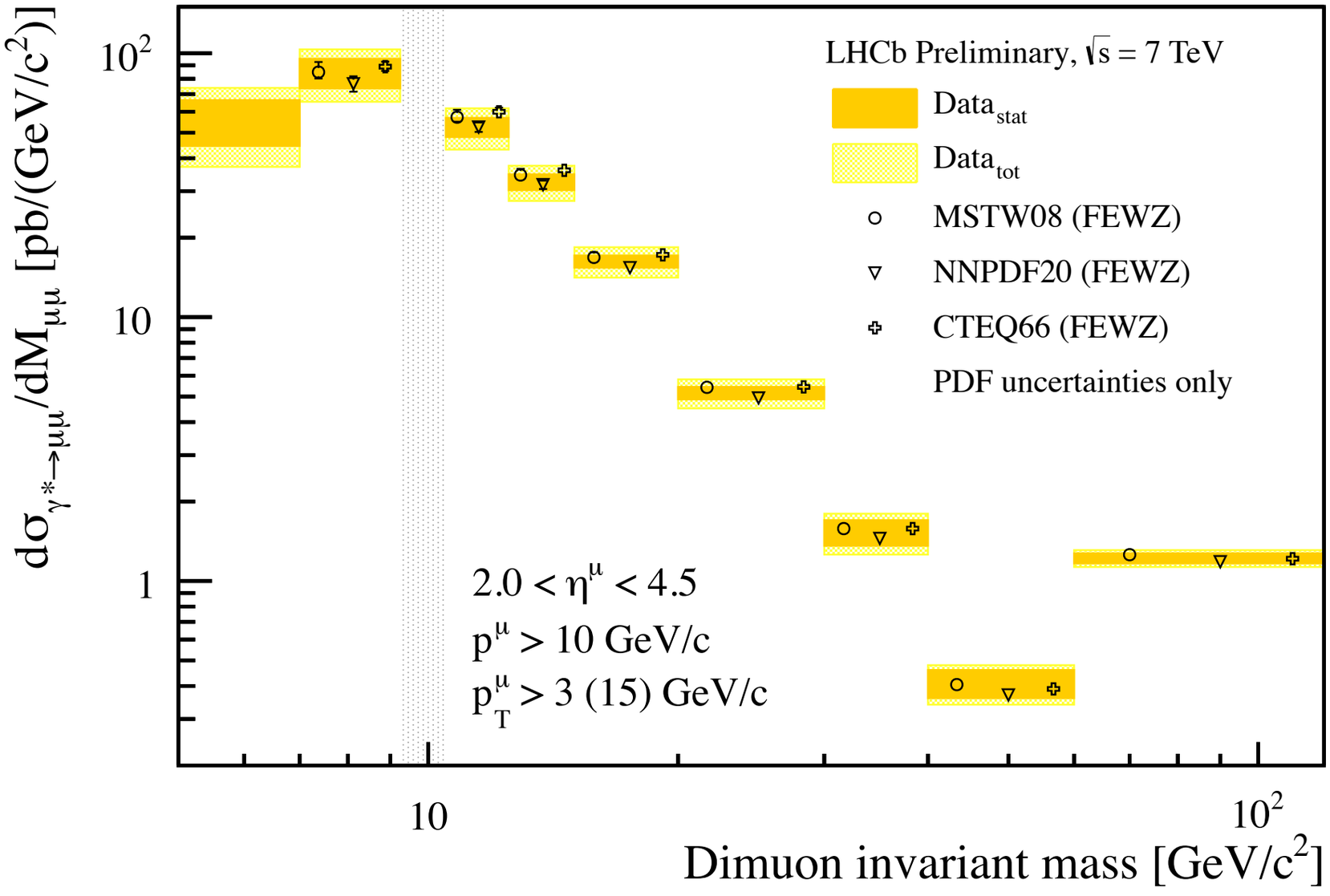
More information in the correlations between observables



More figures **here**

Low mass Drell-Yan

Complementary constraint at lower Q^2 and lower x.



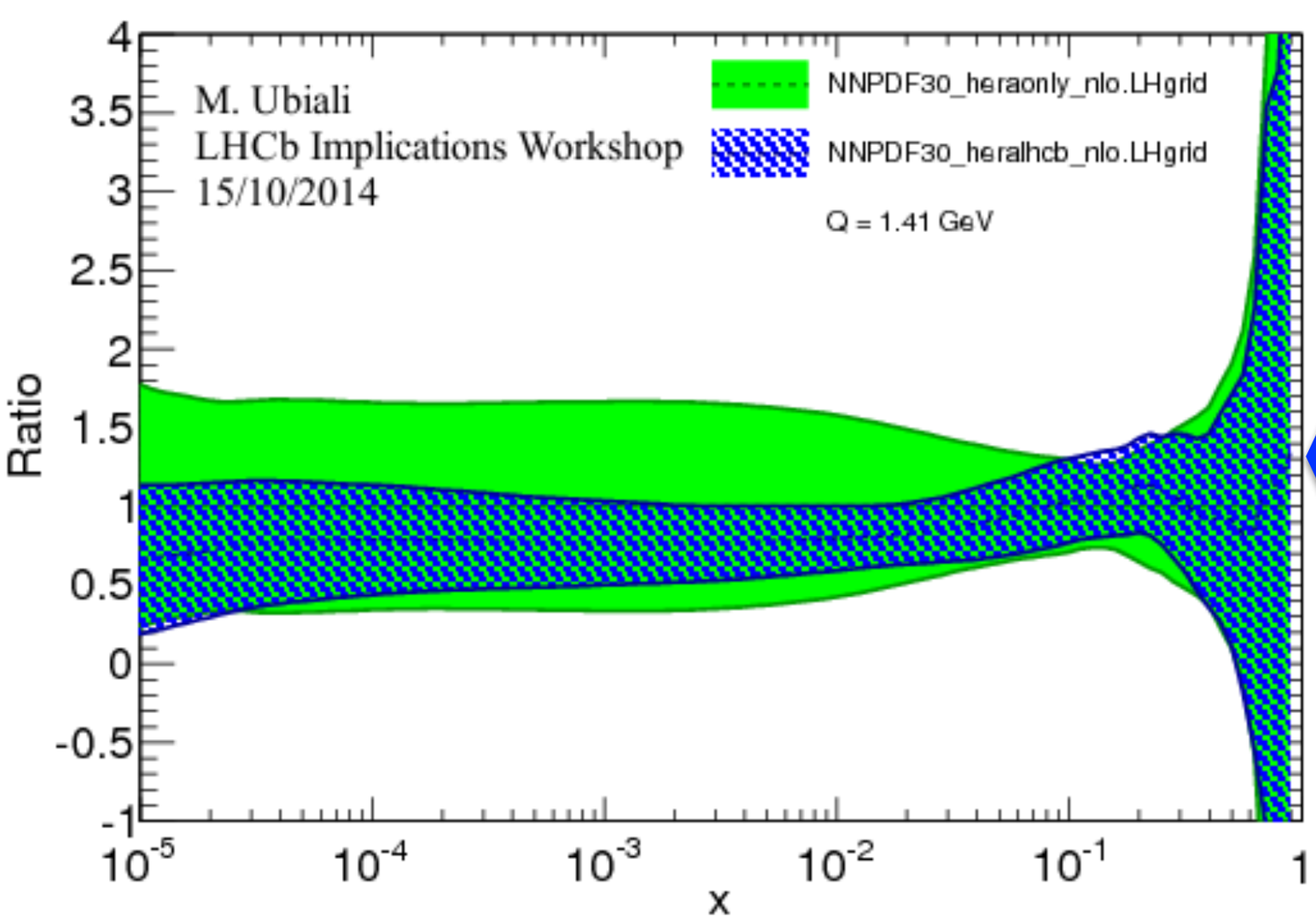
$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$

Agrees well with predictions, within limiting statistical uncertainties.
Update planned at 7, 8, 13 TeV. Also high mass DY…

Impact on PDFs

See M. Ubiali, LHCb Implications workshop, 15/10/2014 (**slides**)

xd(x,Q)



NNPDF3.0
HERA only

Earlier LHCb measurements

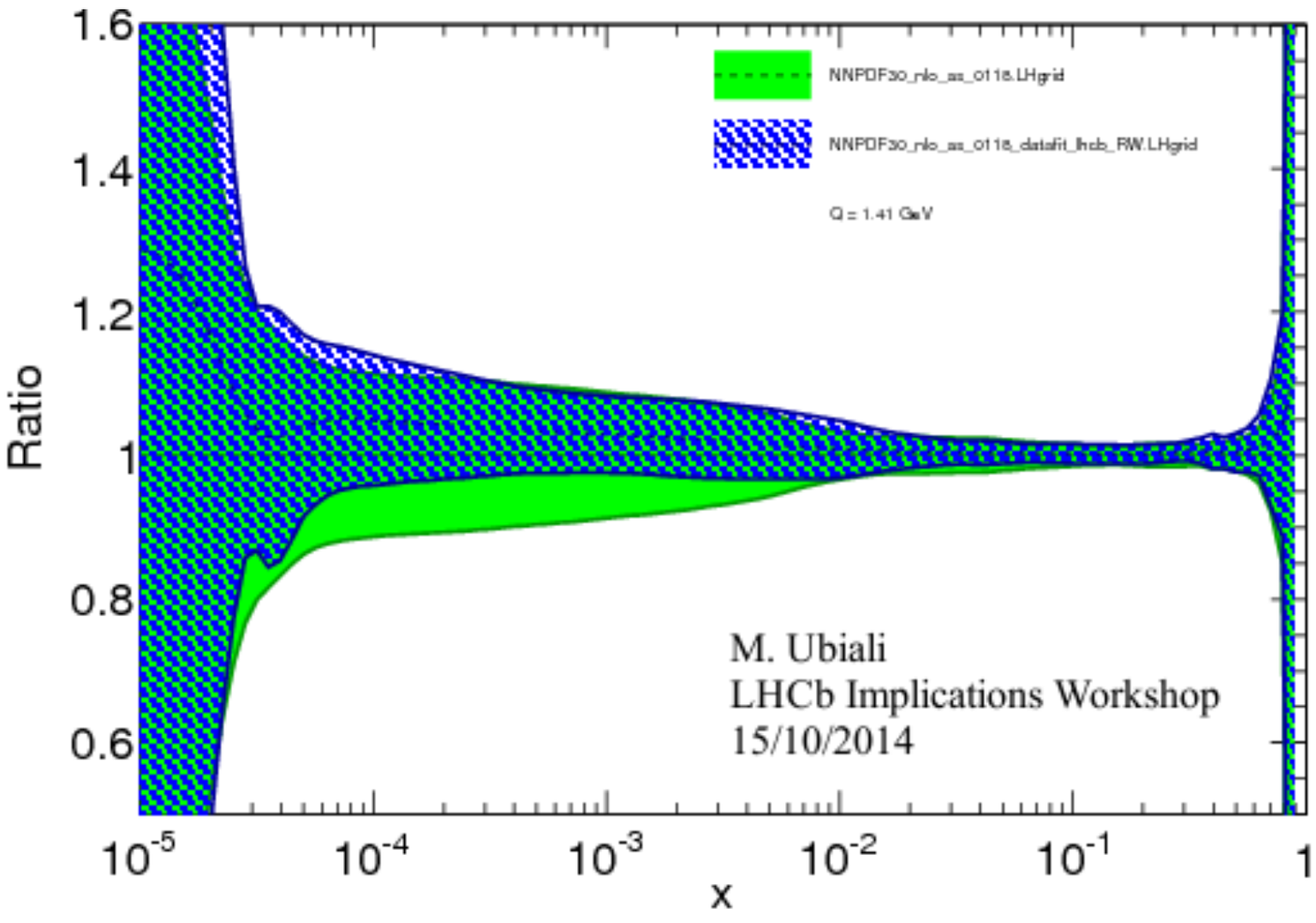
W → μν, 7 TeV, 37 pb^{-1}
JHEP 1206 (2012) 058

Z → ee, 7 TeV, 1 fb^{-1}
JHEP 05 (2015) 109

Impact on PDFs

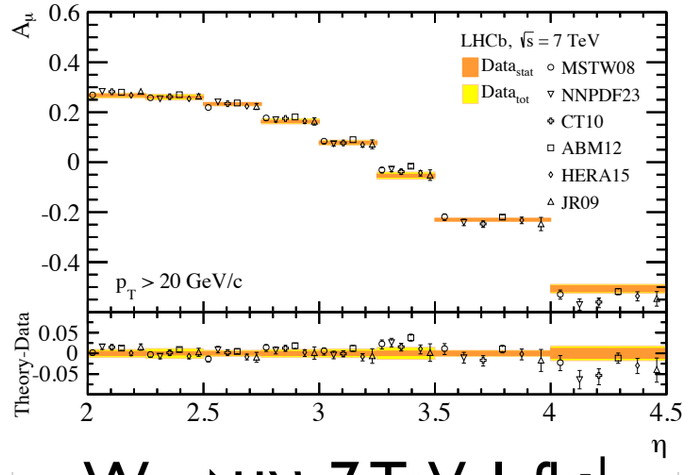
See M. Ubiali, LHCb Implications workshop, 15/10/2014 (**slides**)

xu(x,Q)



NNPDF3.0
(incl. early LHCb W,Z data)

+ latest LHCb $W \to \mu\nu$



$W \to \mu\nu$, 7 TeV, 1 fb^{-1}

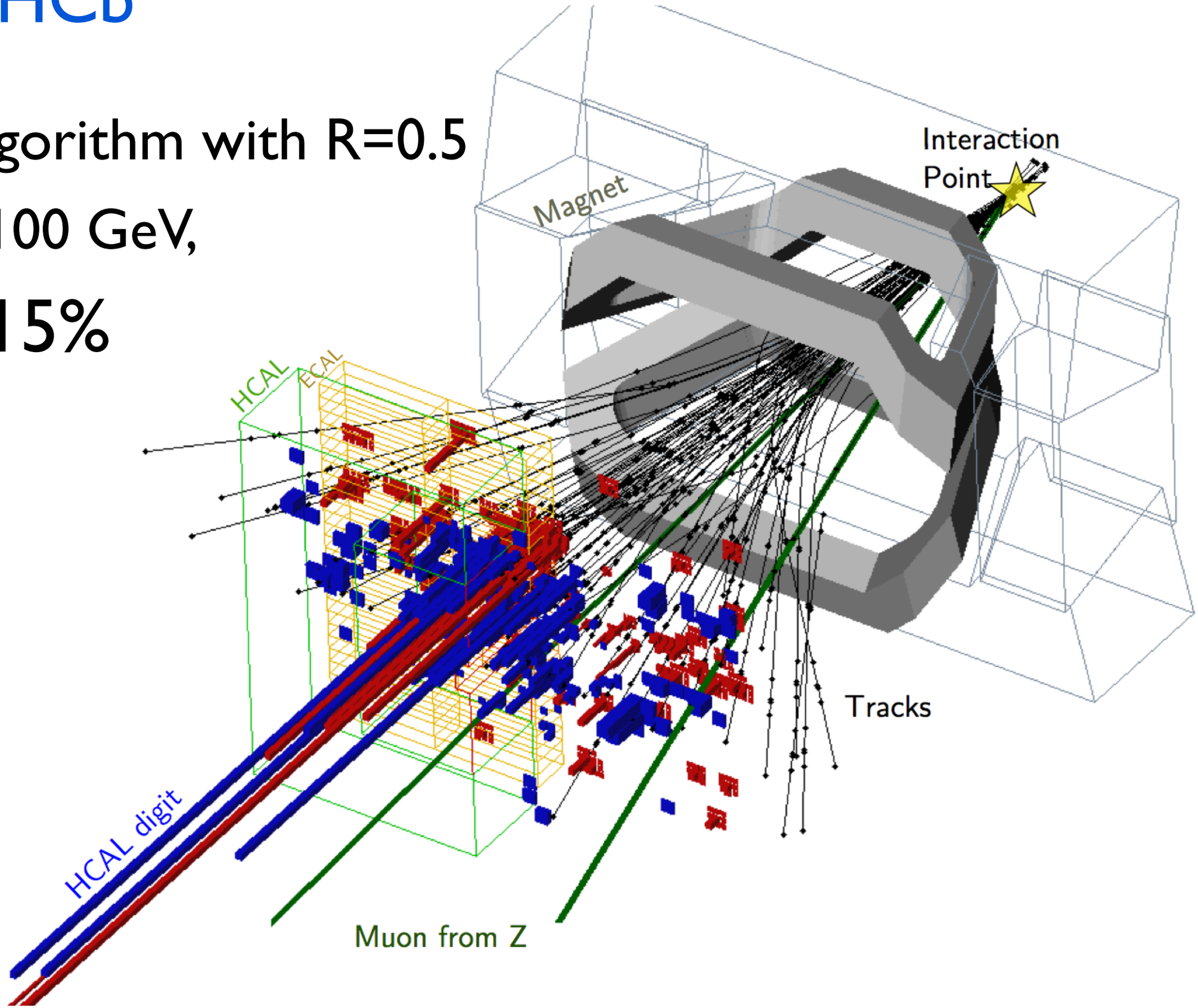
JHEP 12 (2014) 079

Jets in LHCb

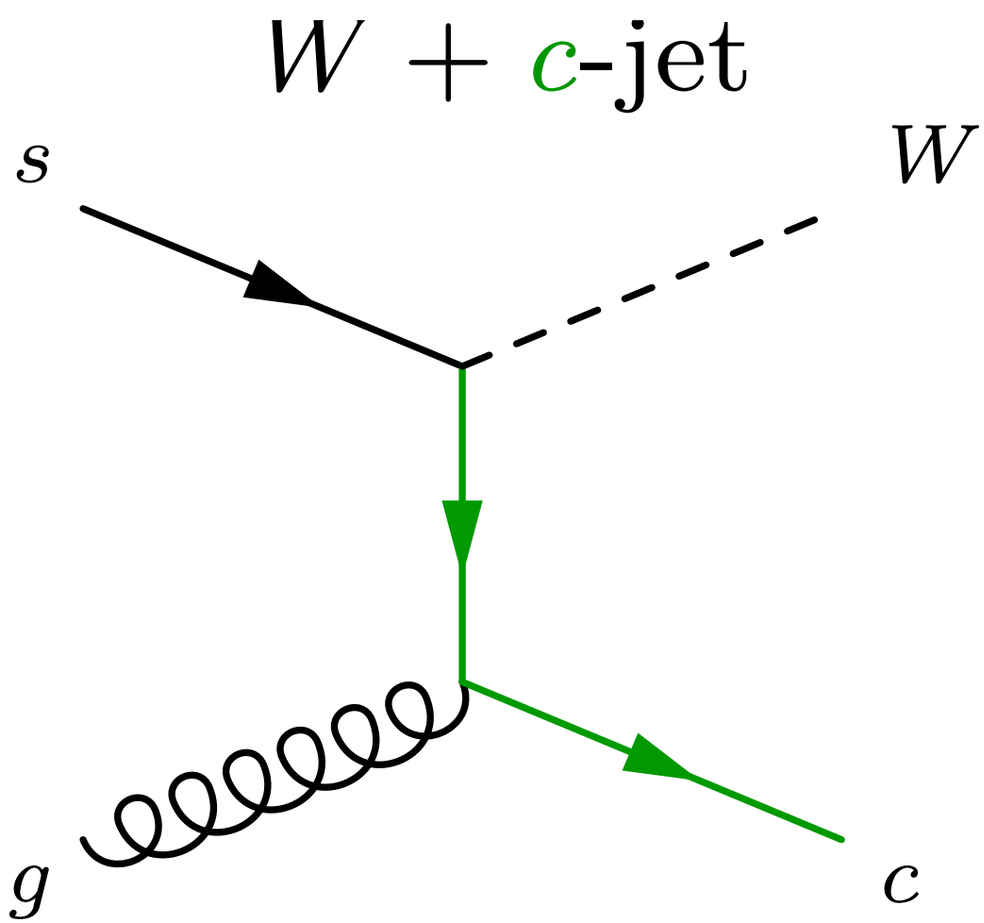
Anti-k_T algorithm with R=0.5

For p_T < 100 GeV,

$\Delta E/E \sim 15\%$



V+jets

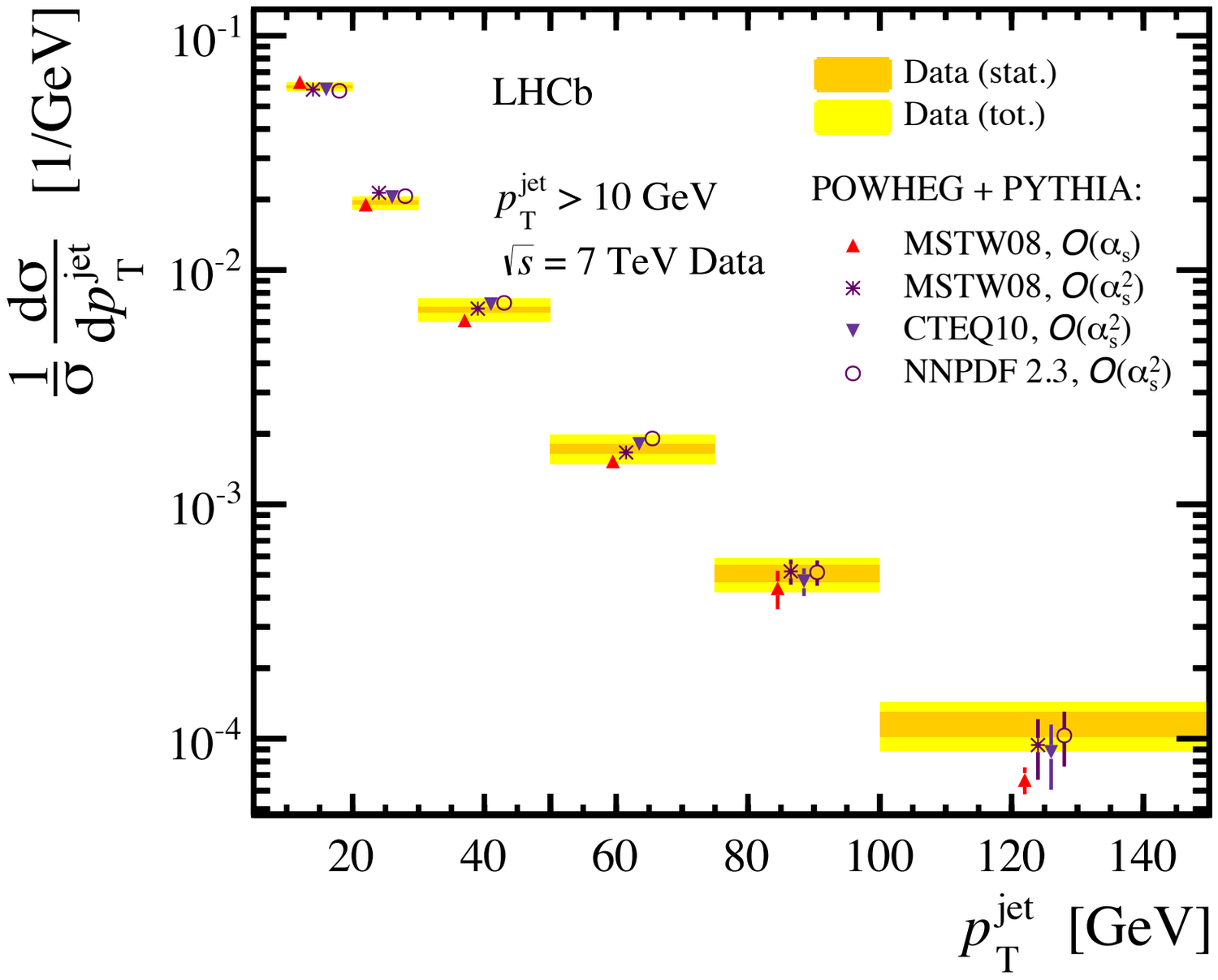


I'll discuss the following:

W+b,c and friends	7,8 TeV, 3 fb^{-1}	**arXiv:1505.04051**
b&c tagging of jets at LHCb	7,8 TeV, 3 fb^{-1}	**JINST 10 (2015) P06013** LHCB-PAPER-2015-016
Z+b	7 TeV, 1 fb^{-1}	**JHEP 01 (2015) 064** [LHCB-PAPER-2014-055]
Z+jet	7 TeV, 1 fb^{-1}	**JHEP01 (2014) 033** [LHCB-PAPER-2013-058]

Z+jet

JHEP 01 (2014) 033

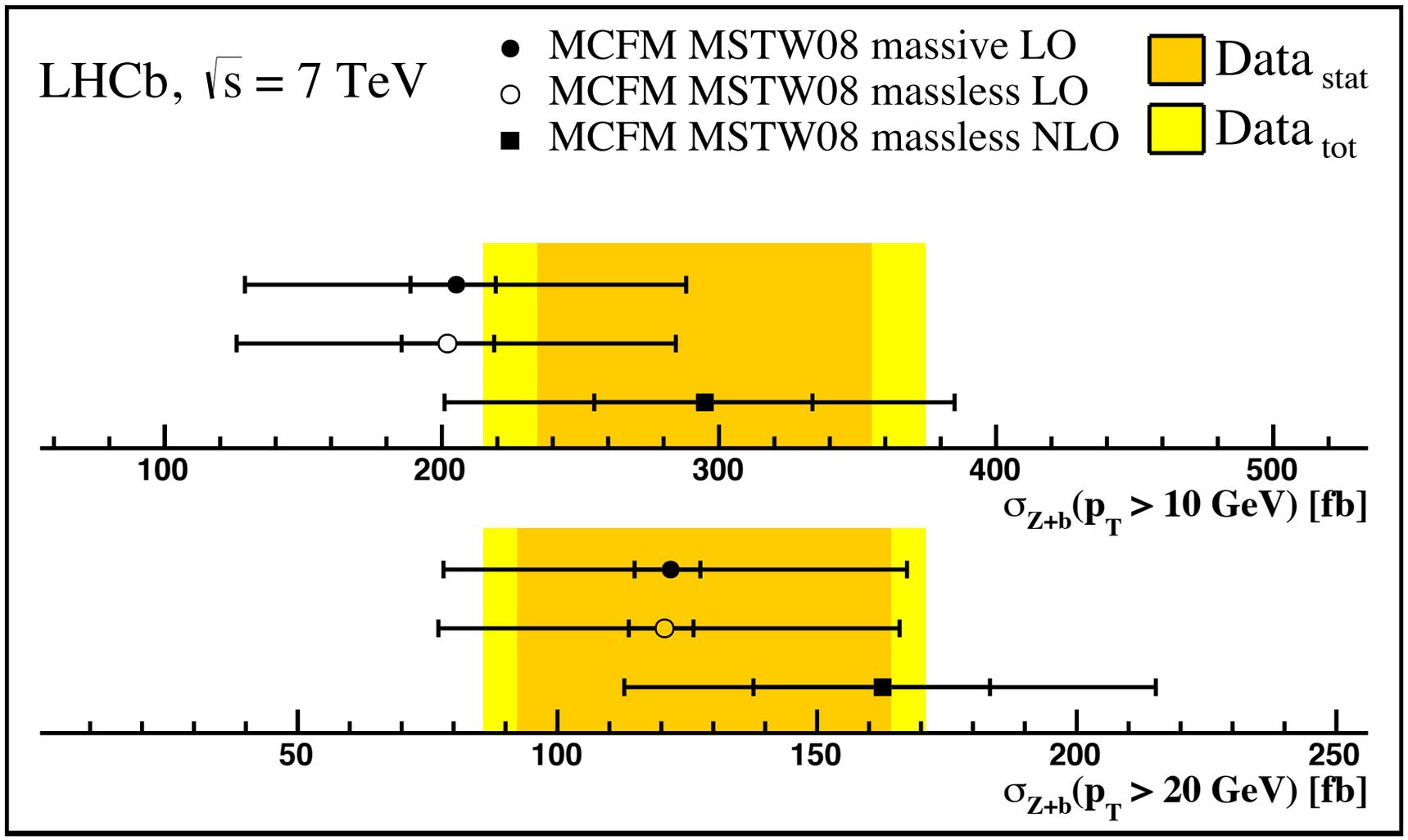


Fiducial cuts:
$p_T(jet) > 20$ GeV,
$2 < \eta(jet) < 4.5$,
$\Delta R(\mu,jet) > 0.4$

Good agreement with $O(\alpha_s^2)$ predictions using various PDFs

Z+b

Beauty component extracted using template fit based on secondary vertex properties (since superseded by dedicated b/c-tagging algorithm JINST 10 (2015) P06013)



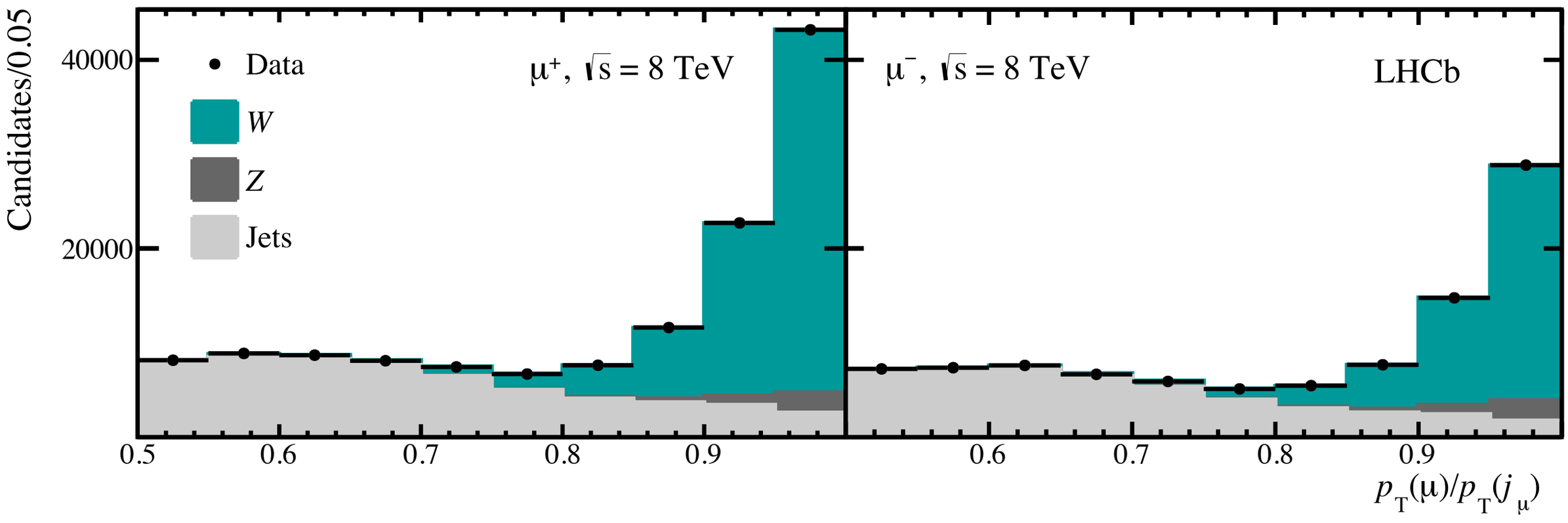
Good agreement with NLO prediction

W+jets and friends

arXiv:1505.04051

Fiducial cuts:
$p_T(\mu) > 20$ GeV,
$2 < \eta(\mu) < 4.5$
$p_T(\text{jet}) > 20$ GeV,
$2.2 < \eta(\text{jet}) < 4.2$
$p_T(\mu+\text{jet}) > 20$ GeV

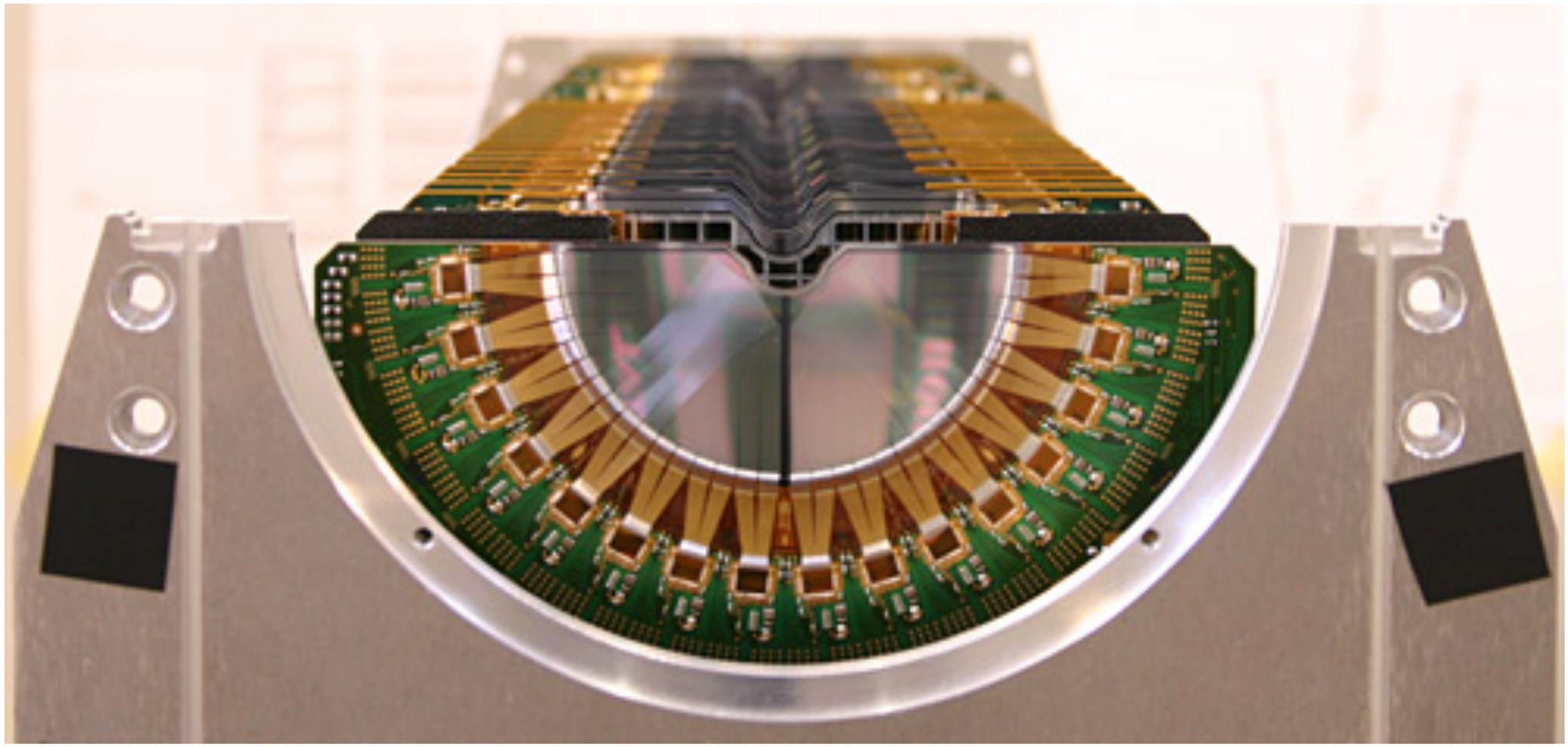
Extract the W+jet signal using a fit to the muon isolation



Now try to fit the b and c components…

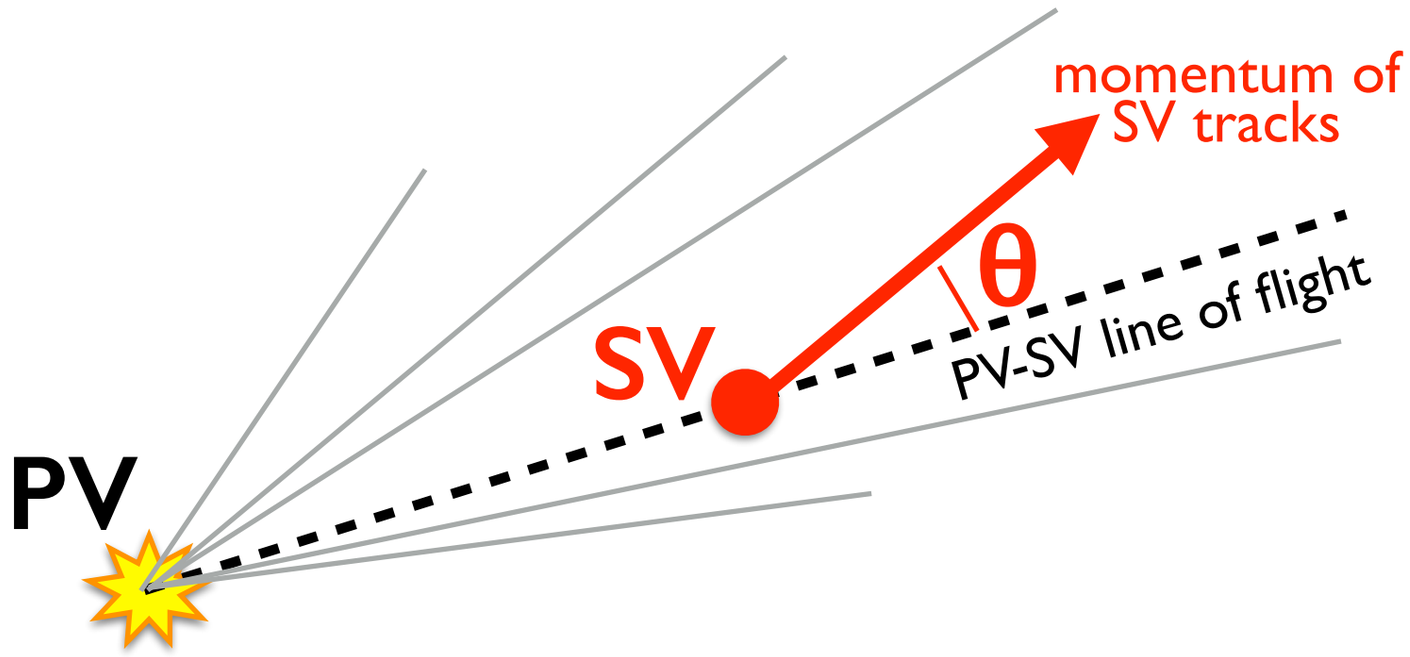
b,c tagging of jets

Exploit the excellent performance of the VErtex LOcator
(2014 JINST 9 P09007)



b,c tagging of jets

The "corrected mass" of a Secondary Vertex in a jet

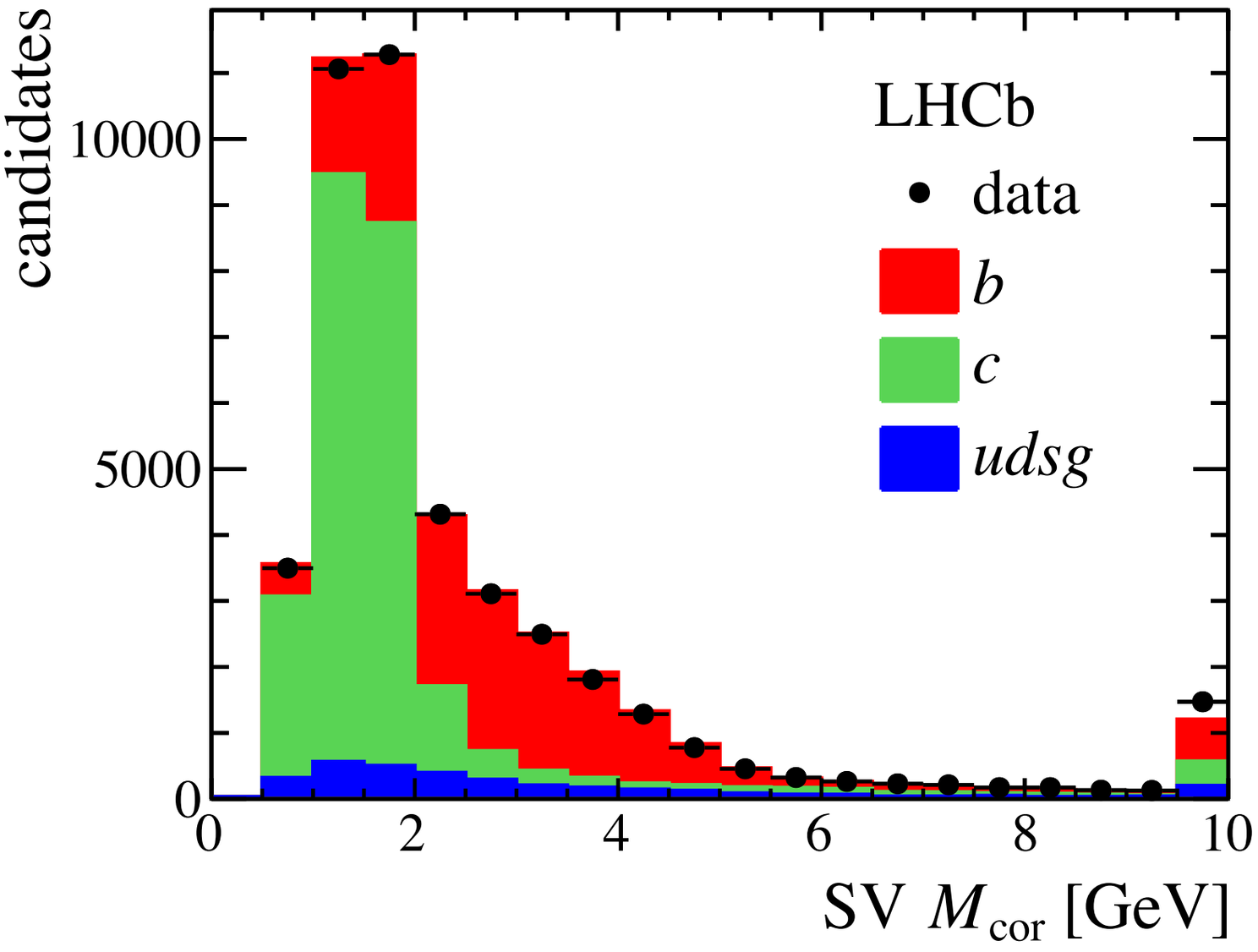


$$M_{cor}(SV) = \sqrt{M^2 + p^2 sin^2\theta} + psin\theta.$$

JINST 10 (2015) P06013

b,c tagging of jets

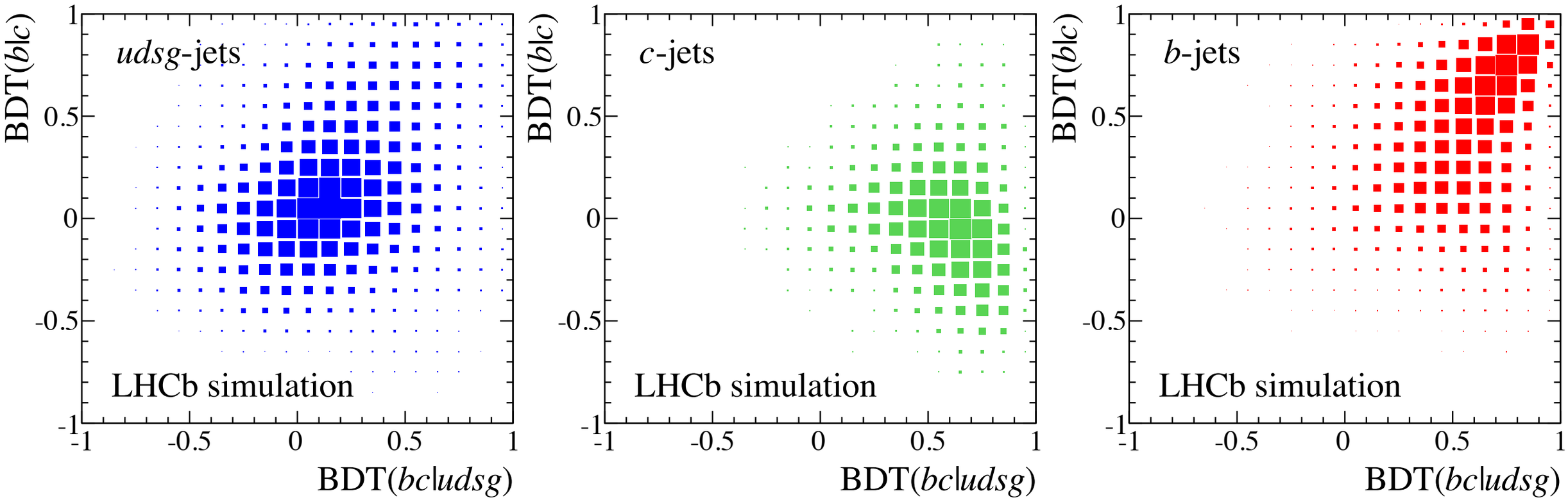
The "corrected mass" of a Secondary Vertex in a jet



JINST 10 (2015) P06013

b,c tagging of jets

Two Boosted Decision Trees based on 10 variables, incl. M_{corr}.
One trained for b|c and one for bc|light.

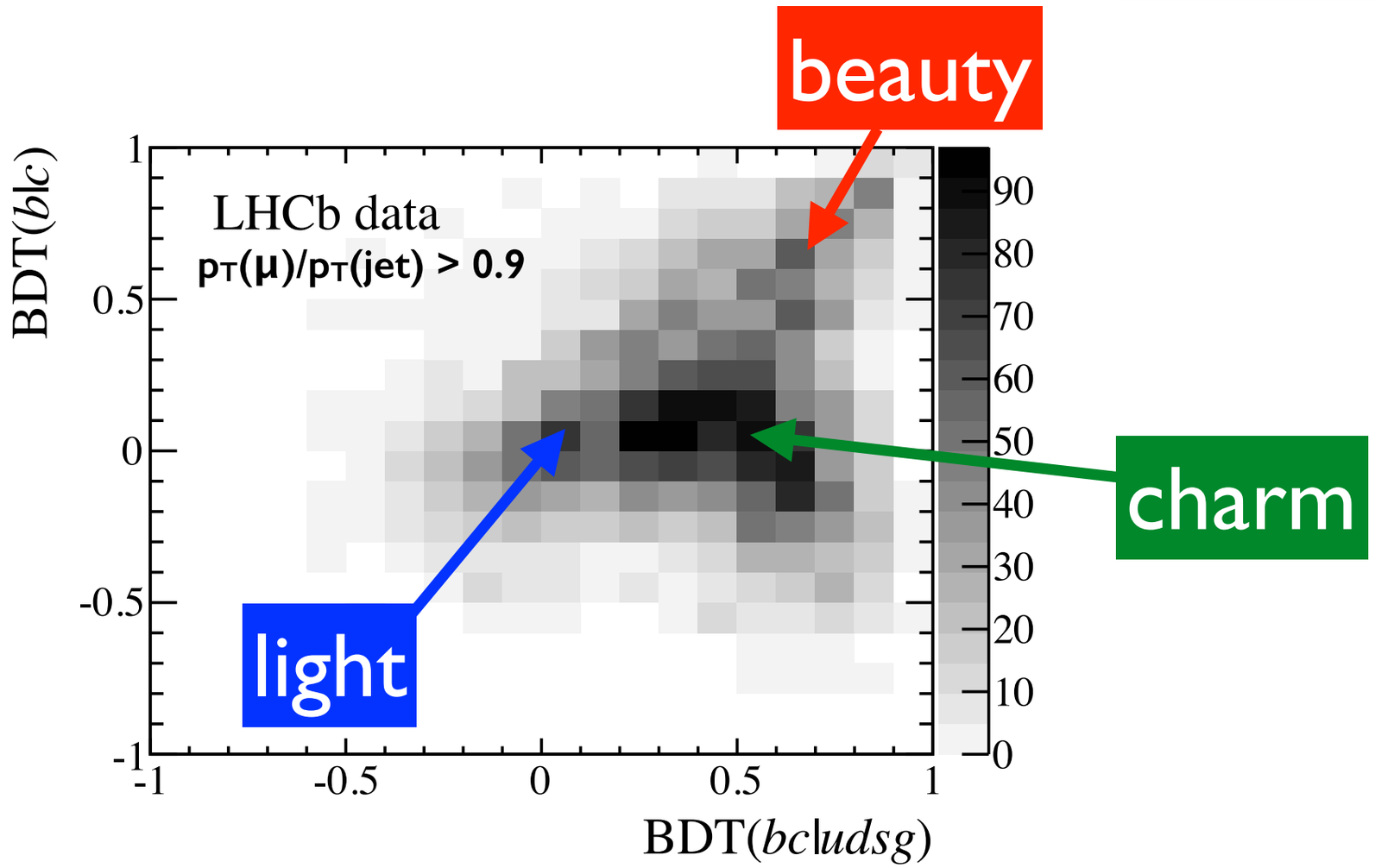


For mis-ID rate of < 1%:
- 65% efficiency for beauty
- 25% for charm

*For p_T > 20 GeV, 2.2 < η < 4.2

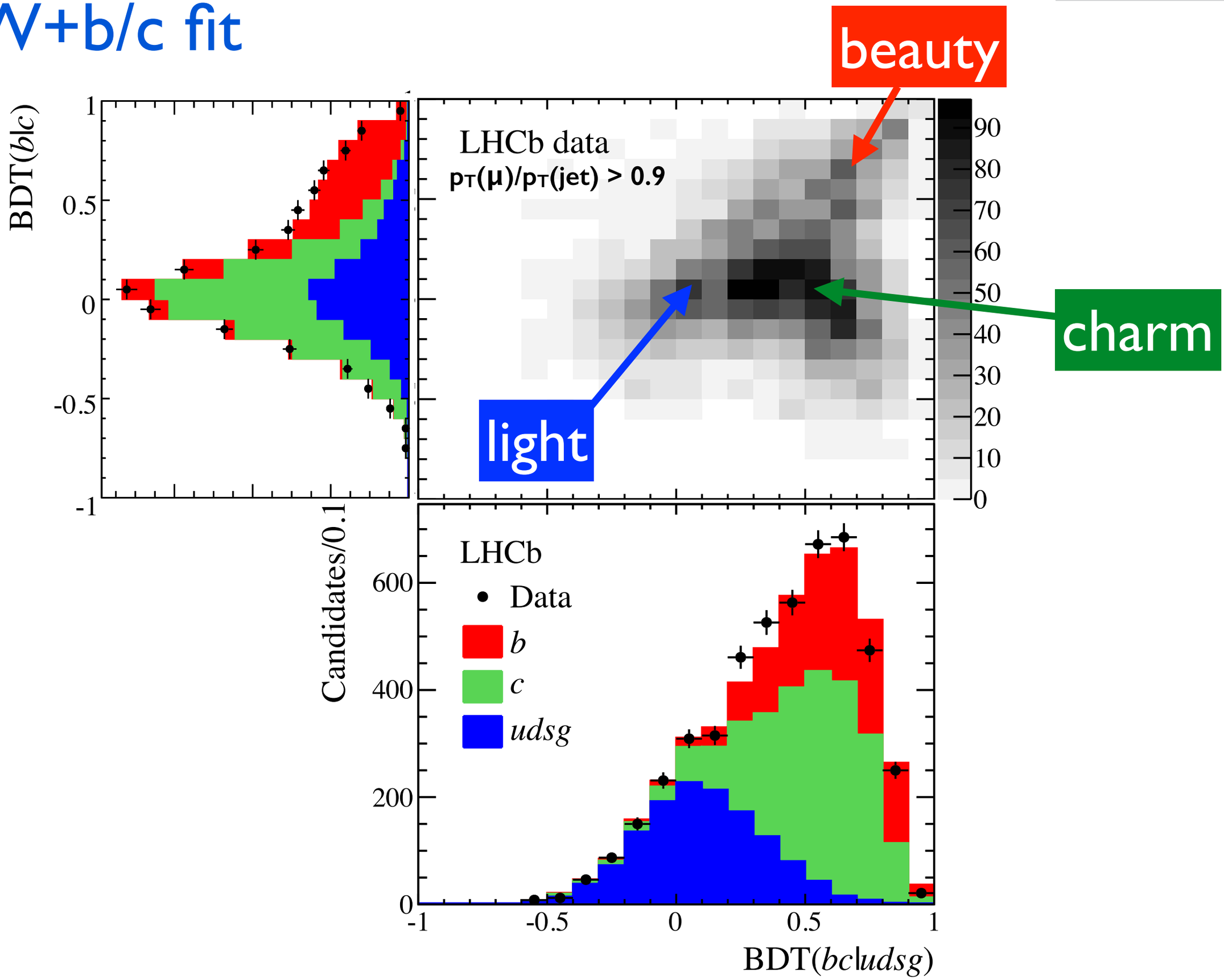
W+b/c fit

arXiv:1505.04051



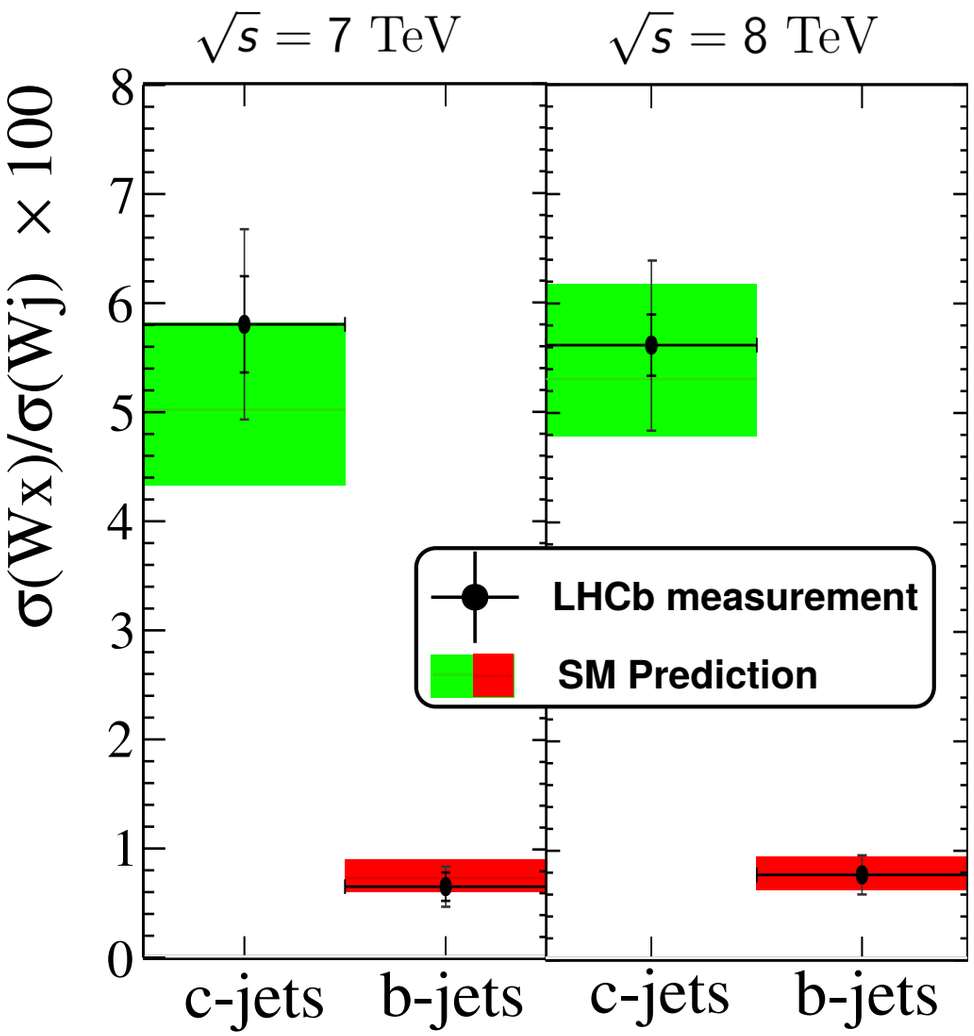
arXiv:1505.04051

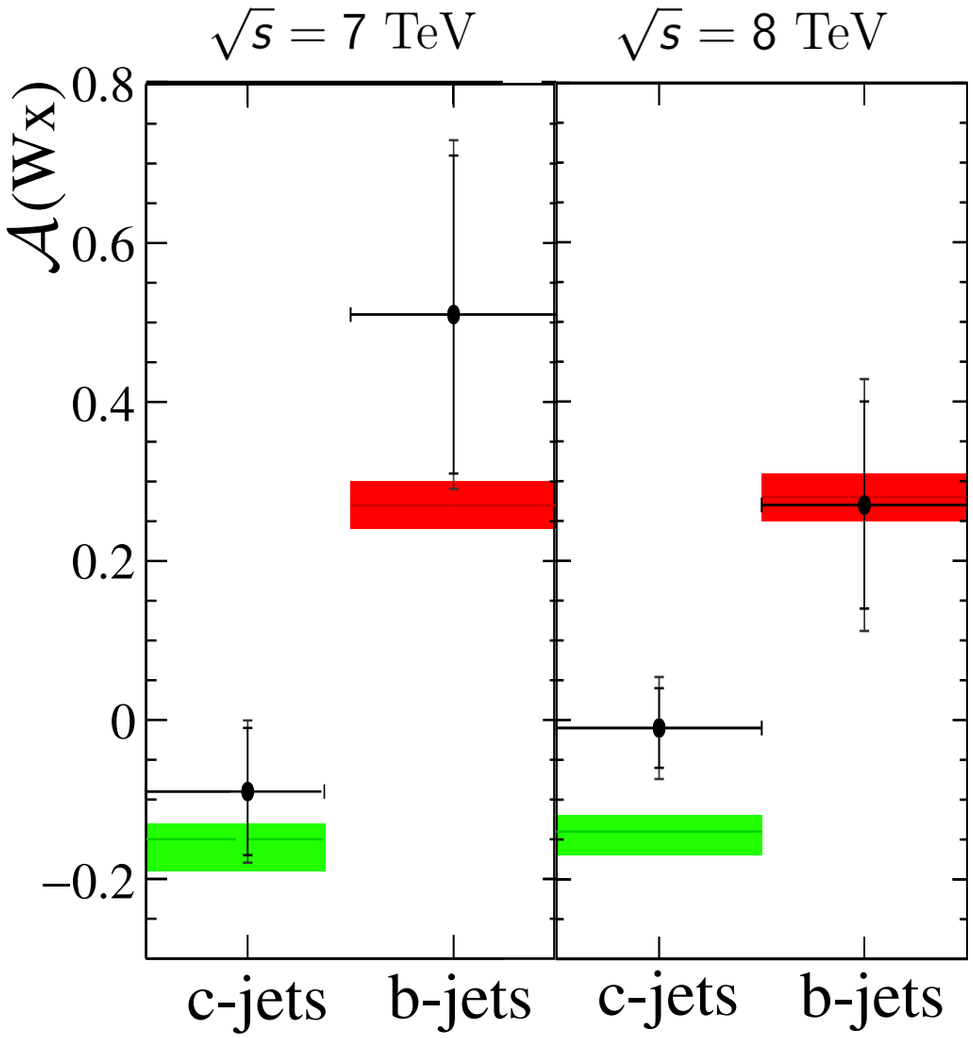
W+b/c fit



arXiv:1505.04051

W+b/c results





Good agreement with predictions (NLO MCFM, CT10)

Also measure W+jet / Z+jet. Full table **here**

More PDF sensitive measurements

- Top production constrains the low- and high-x gluon (arXiv:1506.00903). See LHCP talk of S. Farry.

- Heavy Flavour production: gluon at low-x, low Q^2

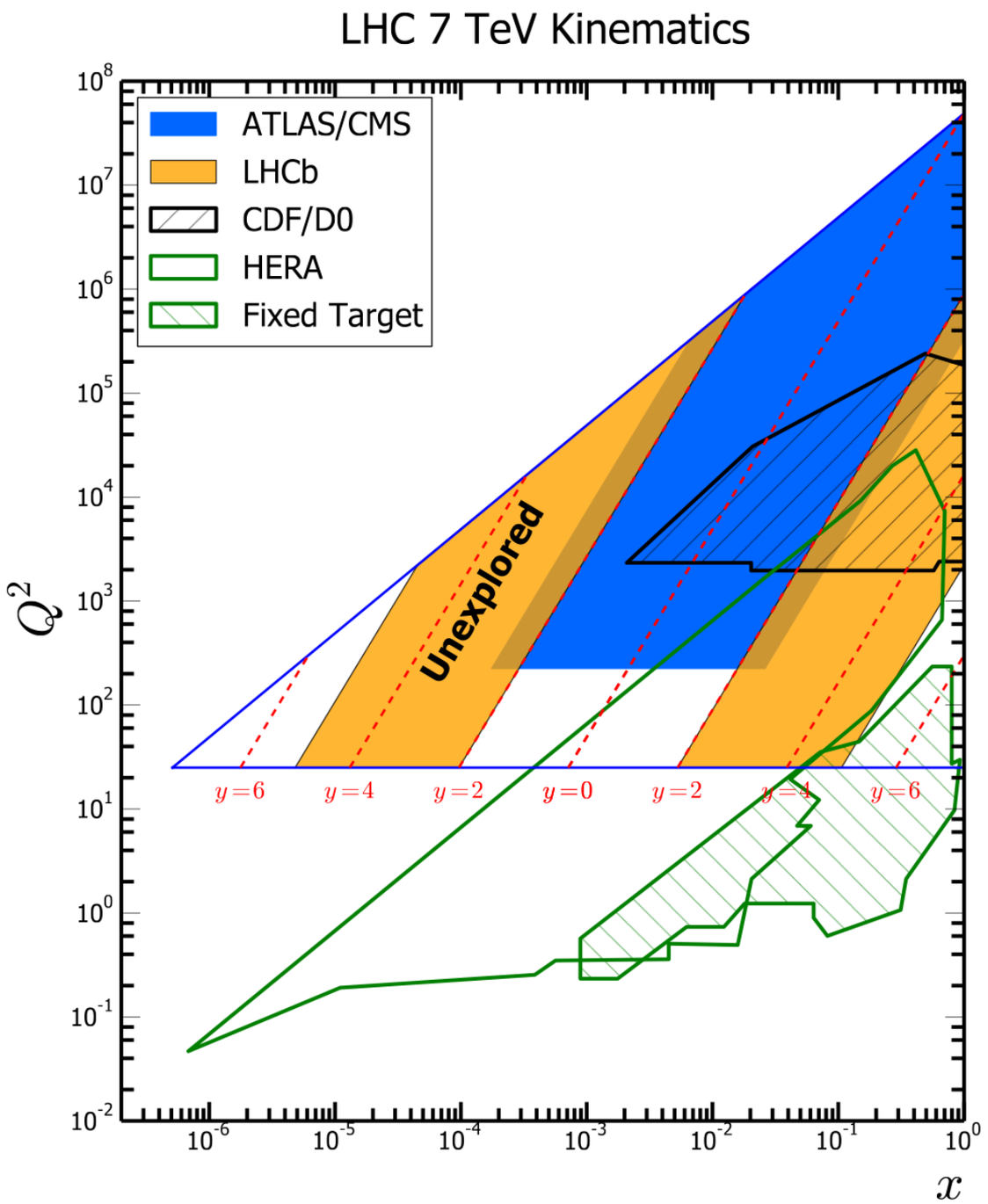
B^+ cross section	7 TeV, 35 pb^{-1}	JHEP 04 (2012) 093
Charm production	7 TeV, 15 nb^{-1}	Nucl. Phys. B 871 (2013) 1-20
NEW Charm production See LHCP talk of A. Pearce	13 TeV, 5 pb^{-1}	LHCB-PAPER-2015-041
NEW J/psi (and b-fraction) Also in LHCP talk of A. Pearce	13 TeV, 3 pb^{-1}	arXiv:1509.00771

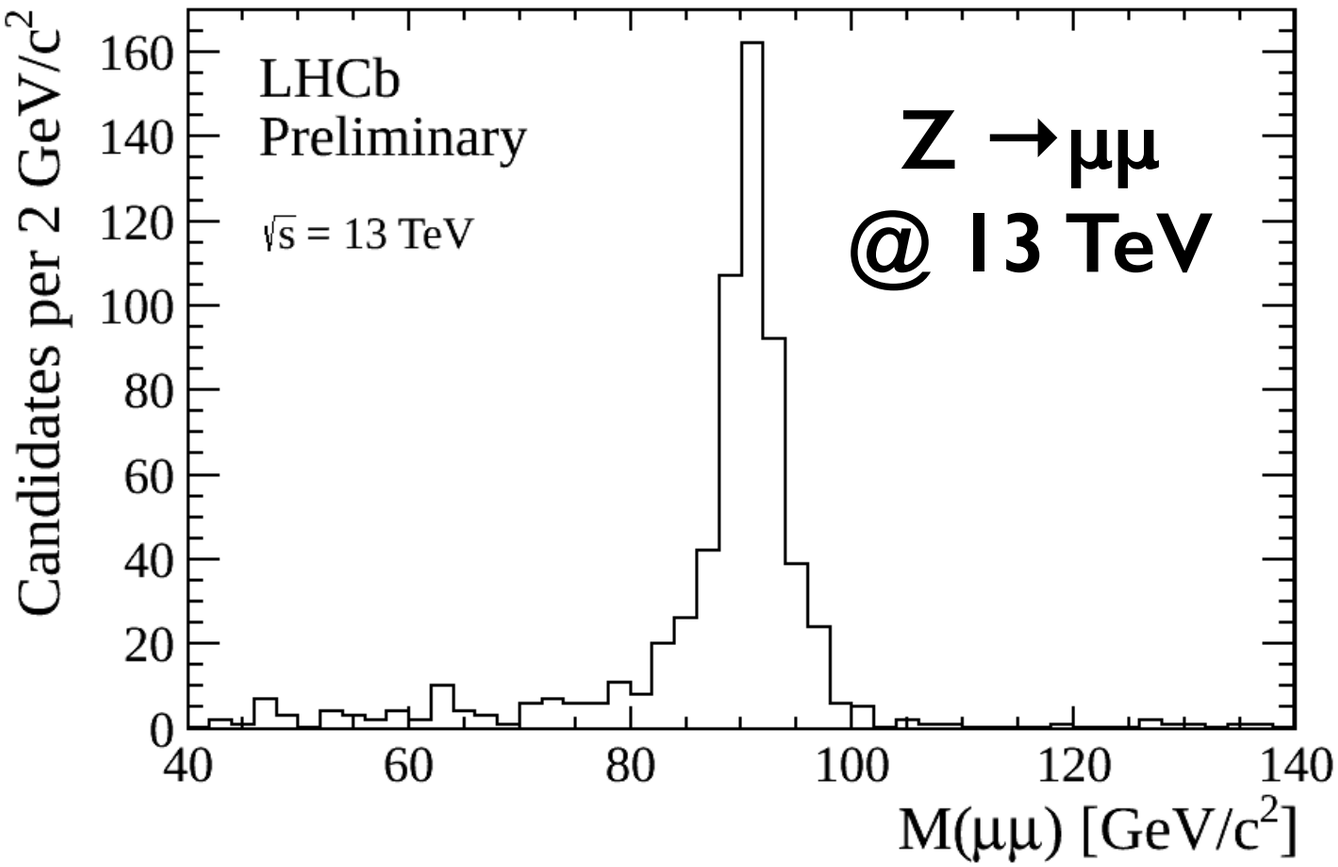
13 TeV

- Central Exclusive Production constrains the gluon at $x < 10^{-5}$. E.g. exclusive Υ (arXiv:1505.08139). See LHCP talk of V. Coco.

Conclusions and outlook

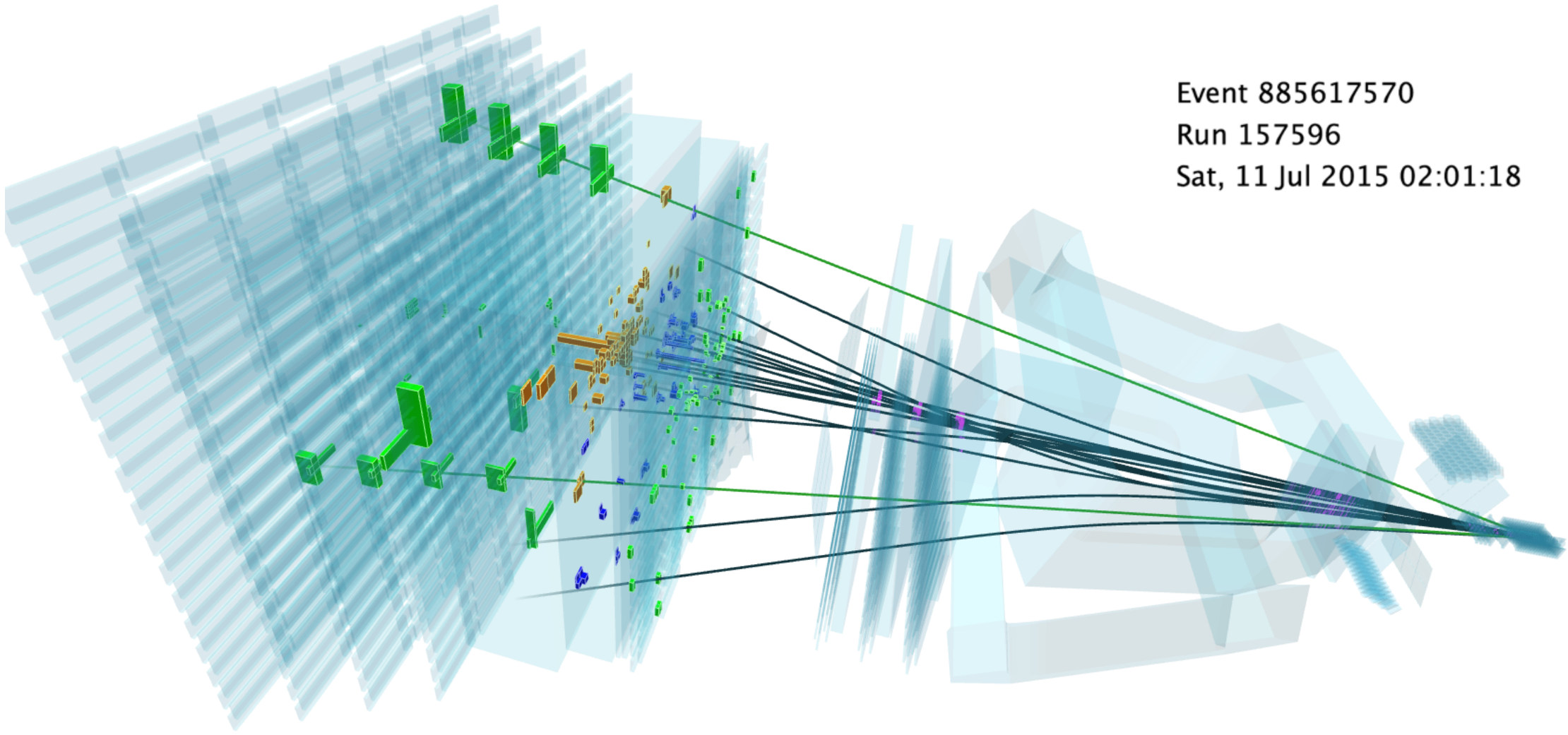
- LHCb provides a unique probe at low- and high-x.
- Already many Run-I measurements of W and Z (inclusive, light jets, b & c jets), top, HF and CEP…





Backup slides

Z → μμ candidate



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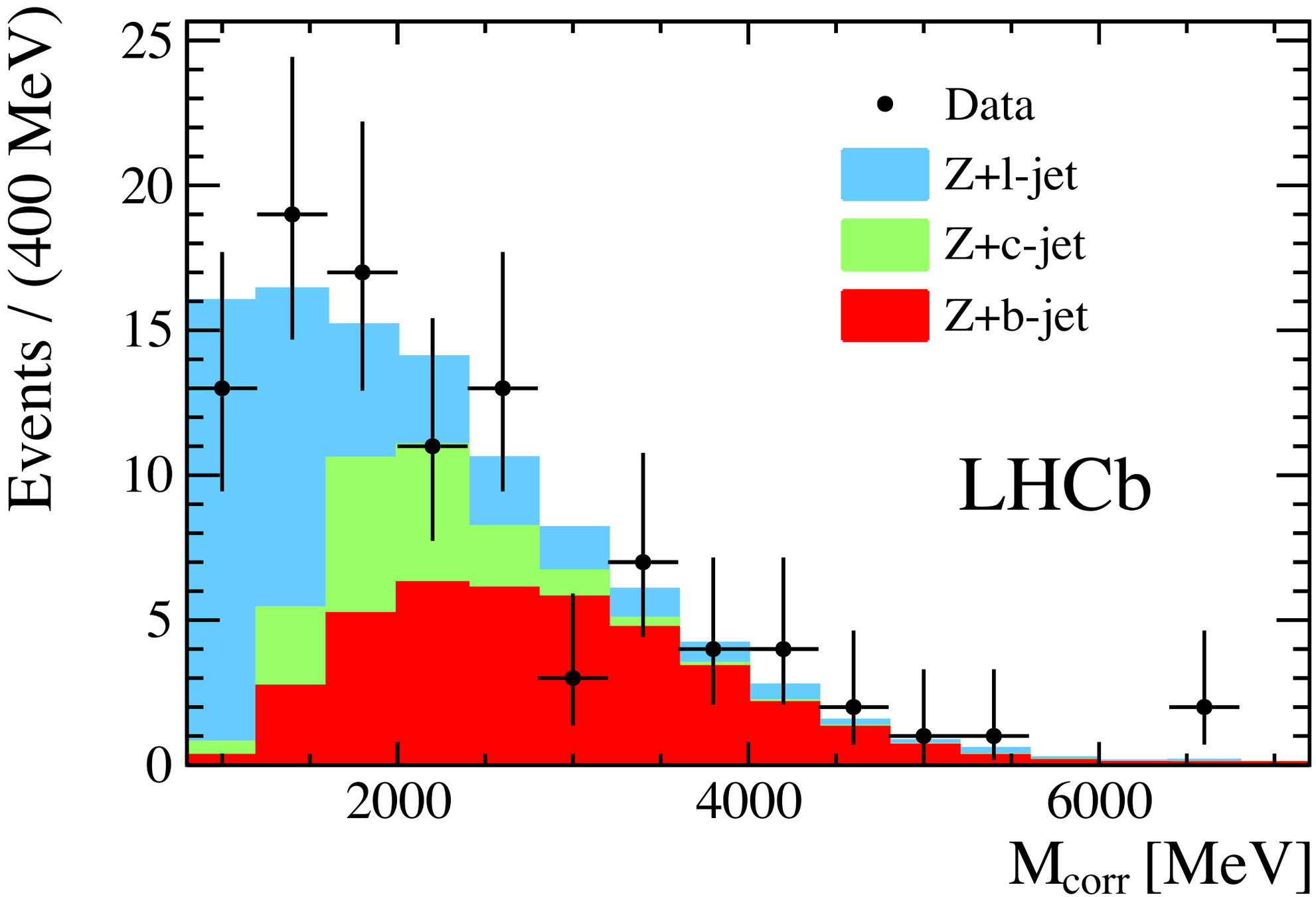
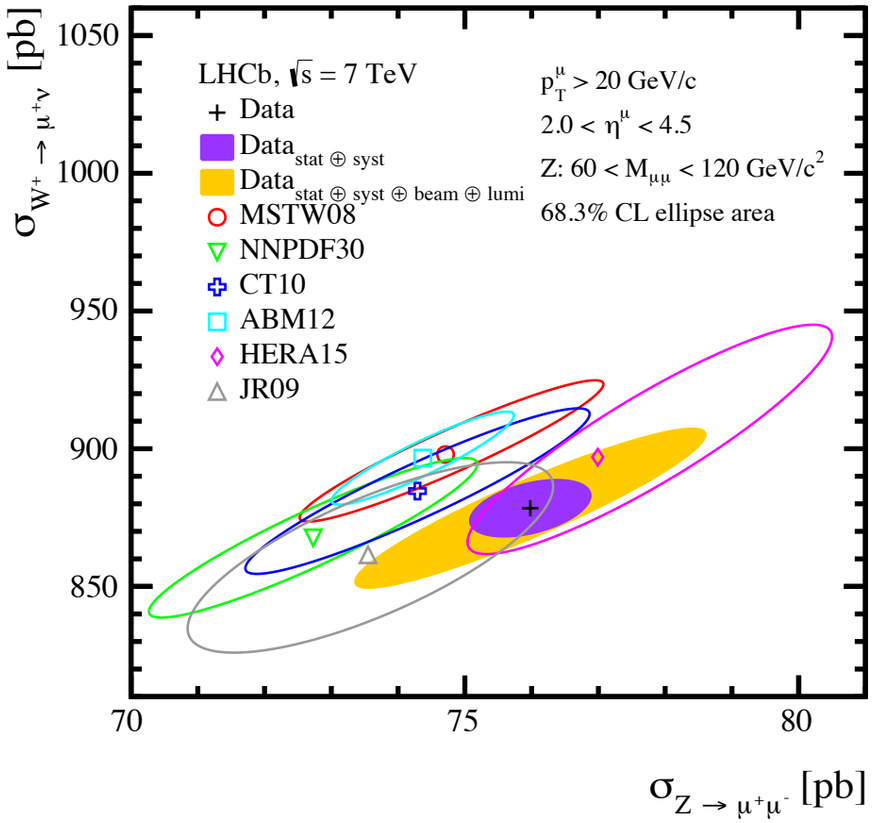
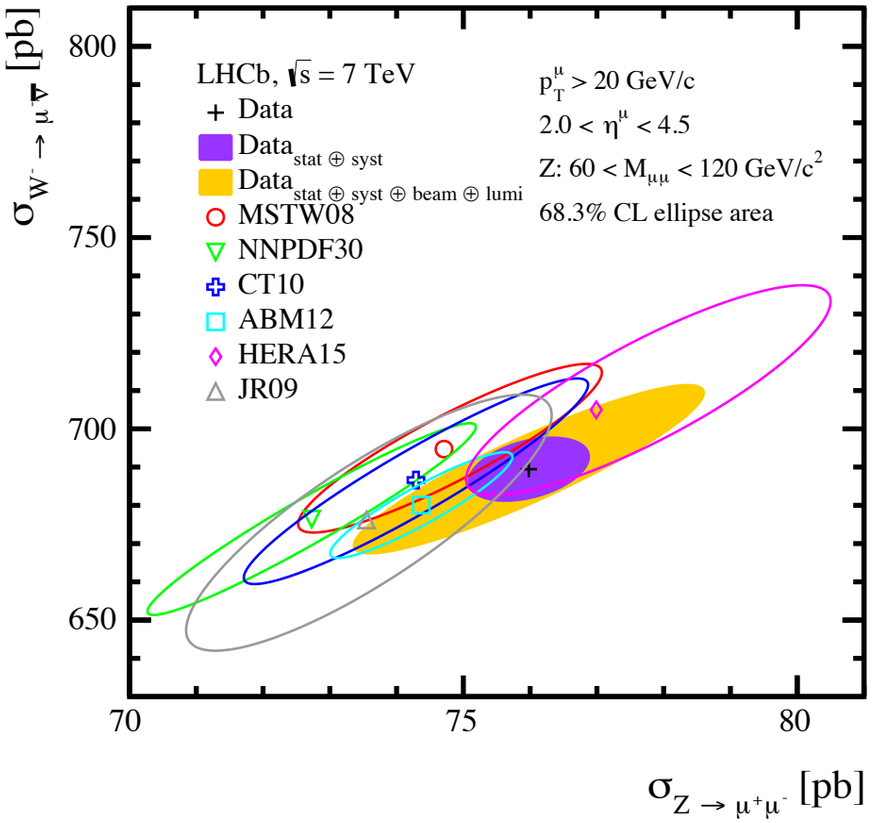
Run 157596
Sat, 11 Jul 2015 02:01:18

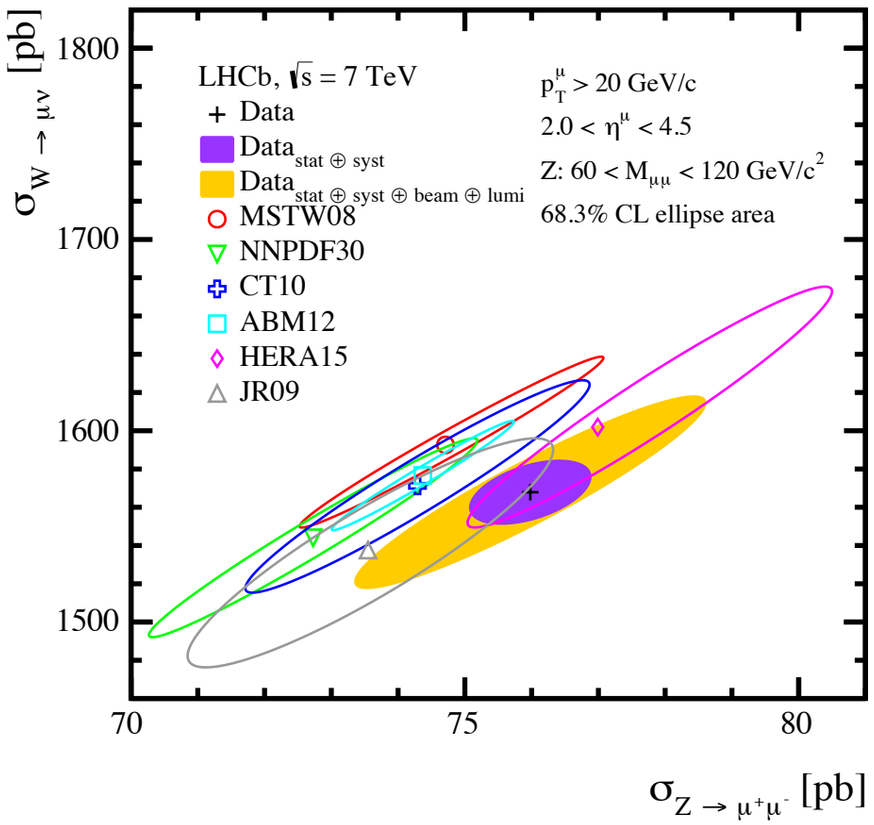
JHEP 01 (2015) 064

Corrected mass in Z+b




LHCb, √s = 7 TeV
Data
Data stat ⊕ syst
Data stat ⊕ syst ⊕ beam ⊕ lumi
MSTW08
NNPDF30
CT10
ABM12
HERA15
JR09
p_T^μ > 20 GeV/c
2.0 < η^μ < 4.5
Z: 60 < M_μμ < 120 GeV/c^2
68.3% CL ellipse area
σ_W+ → μ+ν [pb]
σ_Z → μ+μ- [pb]


LHCb, √s = 7 TeV
Data
Data stat ⊕ syst
Data stat ⊕ syst ⊕ beam ⊕ lumi
MSTW08
NNPDF30
CT10
ABM12
HERA15
JR09
p_T^μ > 20 GeV/c
2.0 < η^μ < 4.5
Z: 60 < M_μμ < 120 GeV/c^2
68.3% CL ellipse area
σ_W- → μ-ν̄ [pb]
σ_Z → μ+μ- [pb]


LHCb, √s = 7 TeV
Data
Data stat ⊕ syst
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MSTW08
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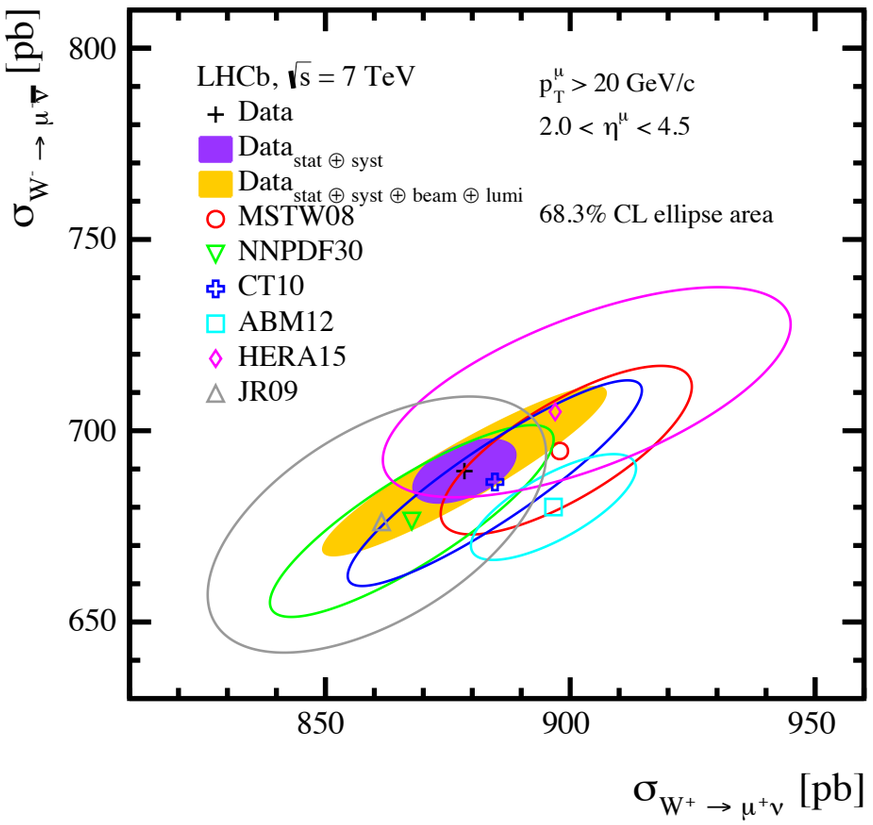
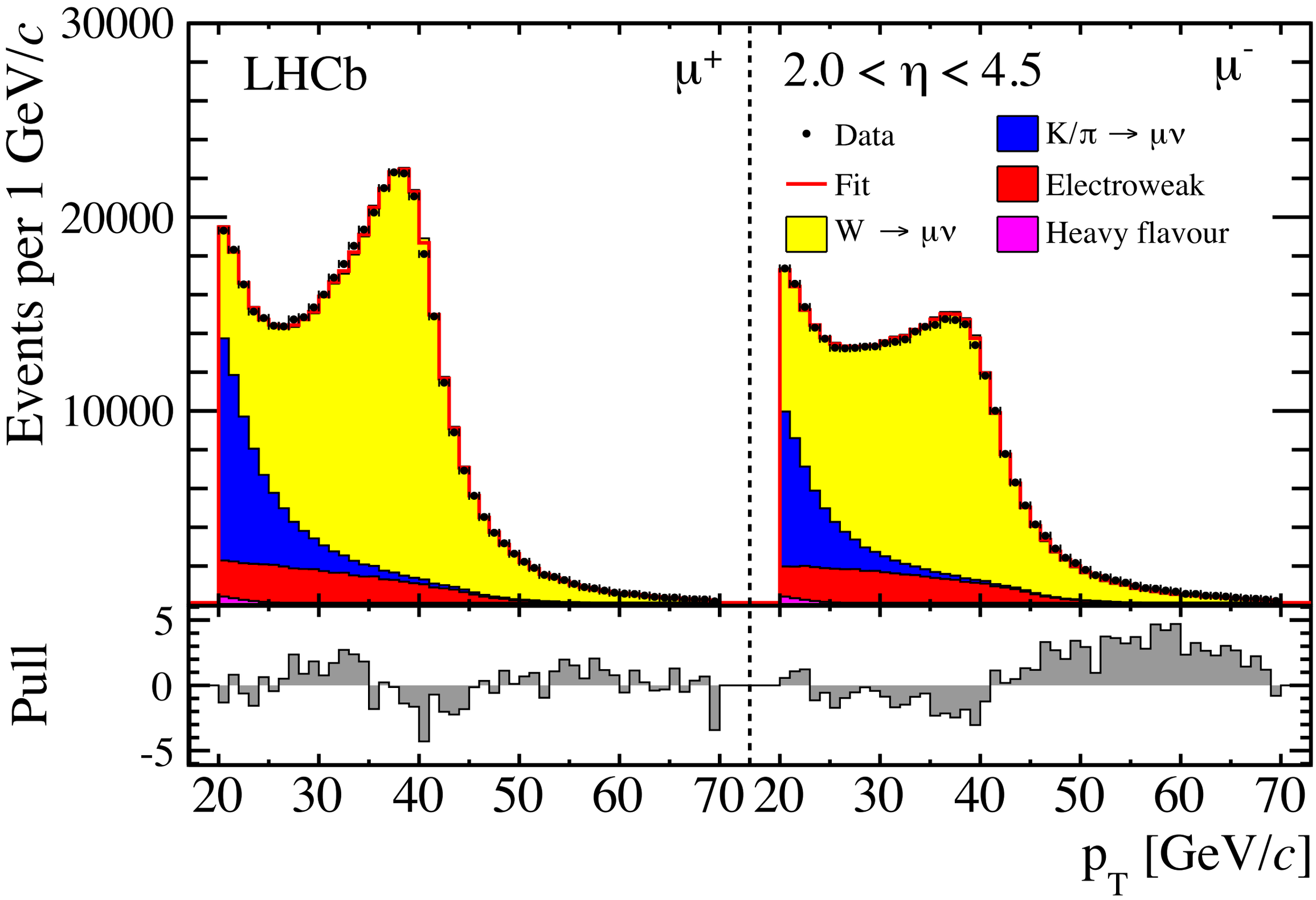
2.0 < η^μ < 4.5
Z: 60 < M_μμ < 120 GeV/c^2
68.3% CL ellipse area
σ_W → μν [pb]
σ_Z → μ+μ- [pb]


LHCb, √s = 7 TeV
Data
Data stat ⊕ syst
Data stat ⊕ syst ⊕ beam ⊕ lumi
MSTW08
NNPDF30
CT10
ABM12
HERA15
JR09
p_T^μ > 20 GeV/c
2.0 < η^μ < 4.5
68.3% CL ellipse area
σ_W- → μ-ν̄ [pb]
σ_W+ → μ+ν [pb]

arXiv:1505.04051

W+jet results

	Results		SM prediction	
	7 TeV	8 TeV	7 TeV	8 TeV
$\frac{\sigma(Wb)}{\sigma(Wj)} \times 10^2$	$0.66 \pm 0.13 \pm 0.13$	$0.78 \pm 0.08 \pm 0.16$	$0.74^{+0.17}_{-0.13}$	$0.77^{+0.18}_{-0.13}$
$\frac{\sigma(Wc)}{\sigma(Wj)} \times 10^2$	$5.80 \pm 0.44 \pm 0.75$	$5.62 \pm 0.28 \pm 0.73$	$5.02^{+0.80}_{-0.69}$	$5.31^{+0.87}_{-0.52}$
$\mathcal{A}(Wb)$	$0.51 \pm 0.20 \pm 0.09$	$0.27 \pm 0.13 \pm 0.09$	$0.27^{+0.03}_{-0.03}$	$0.28^{+0.03}_{-0.03}$
$\mathcal{A}(Wc)$	$-0.09 \pm 0.08 \pm 0.04$	$-0.01 \pm 0.05 \pm 0.04$	$-0.15^{+0.02}_{-0.04}$	$-0.14^{+0.02}_{-0.03}$
$\frac{\sigma(W^+j)}{\sigma(Zj)}$	$10.49 \pm 0.28 \pm 0.53$	$9.44 \pm 0.19 \pm 0.47$	$9.90^{+0.28}_{-0.24}$	$9.48^{+0.16}_{-0.33}$
$\frac{\sigma(W^-j)}{\sigma(Zj)}$	$6.61 \pm 0.19 \pm 0.33$	$6.02 \pm 0.13 \pm 0.30$	$5.79^{+0.21}_{-0.18}$	$5.52^{+0.13}_{-0.25}$

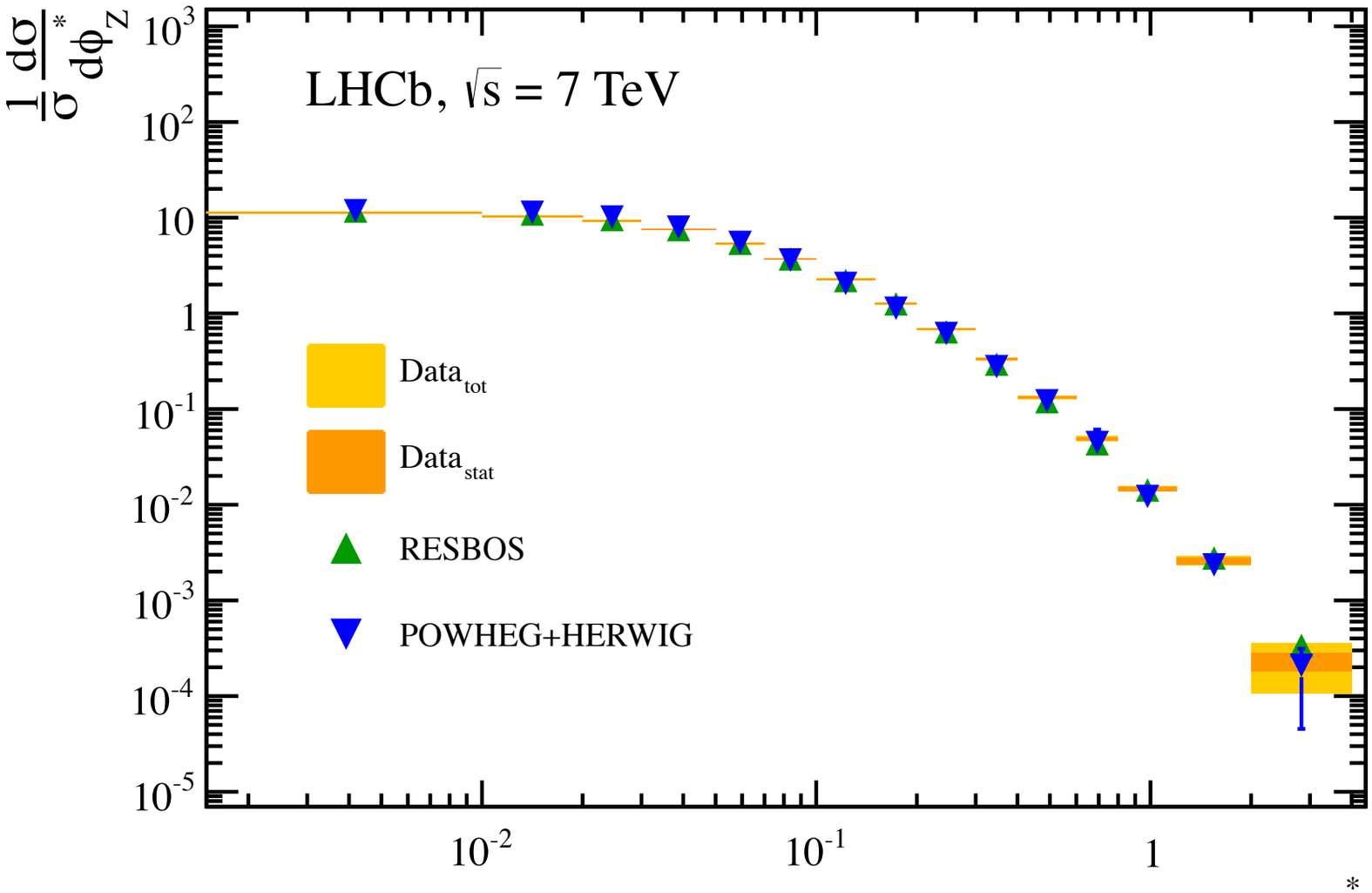

LHCb
μ+
2.0 < η < 4.5
μ-
Data
Fit
W → μν
K/π → μν
Electroweak
Heavy flavour
Events per 1 GeV/c
30000
20000
10000
Pull
5
0
-5
20
30
40
50
60
70
20
30
40
50
60
70
p_T [GeV/c]

W systematics

Source	$\Delta\sigma_{W^+\to\mu^+\nu}$ [%]	$\Delta\sigma_{W^-\to\mu^-\overline{\nu}}$ [%]	ΔR_W [%]
Template shape	0.28	0.39	0.59
Template normalisation	0.10	0.10	0.06
Reconstruction efficiency	1.21	1.20	0.12
Selection efficiency	0.33	0.32	0.18
Acceptance and FSR	0.18	0.12	0.21
Luminosity	1.71	1.71	—

JHEP 08 (2015) 039

Z production at 7 TeV



$$\phi_Z^* \equiv \frac{\tan\left(\phi_{\mathrm{acop}}/2\right)}{\cosh\left(\Delta\eta/2\right)}$$

Φ* distribution well described by RESBOS and POWHEG+HERWIG

Eur. Phys. J. C71 (2011) 1600