Central Exclusive Production at LHCb

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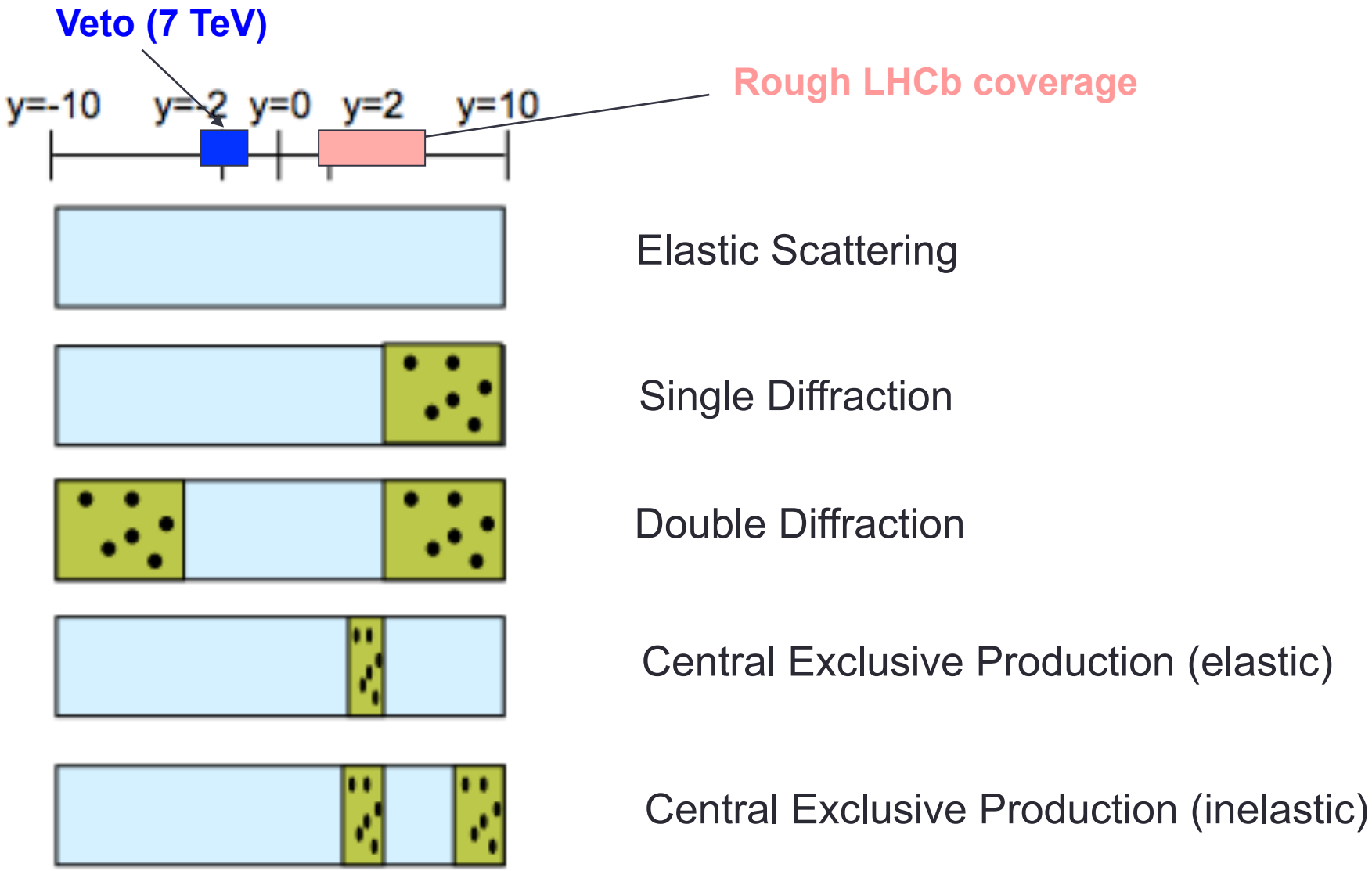
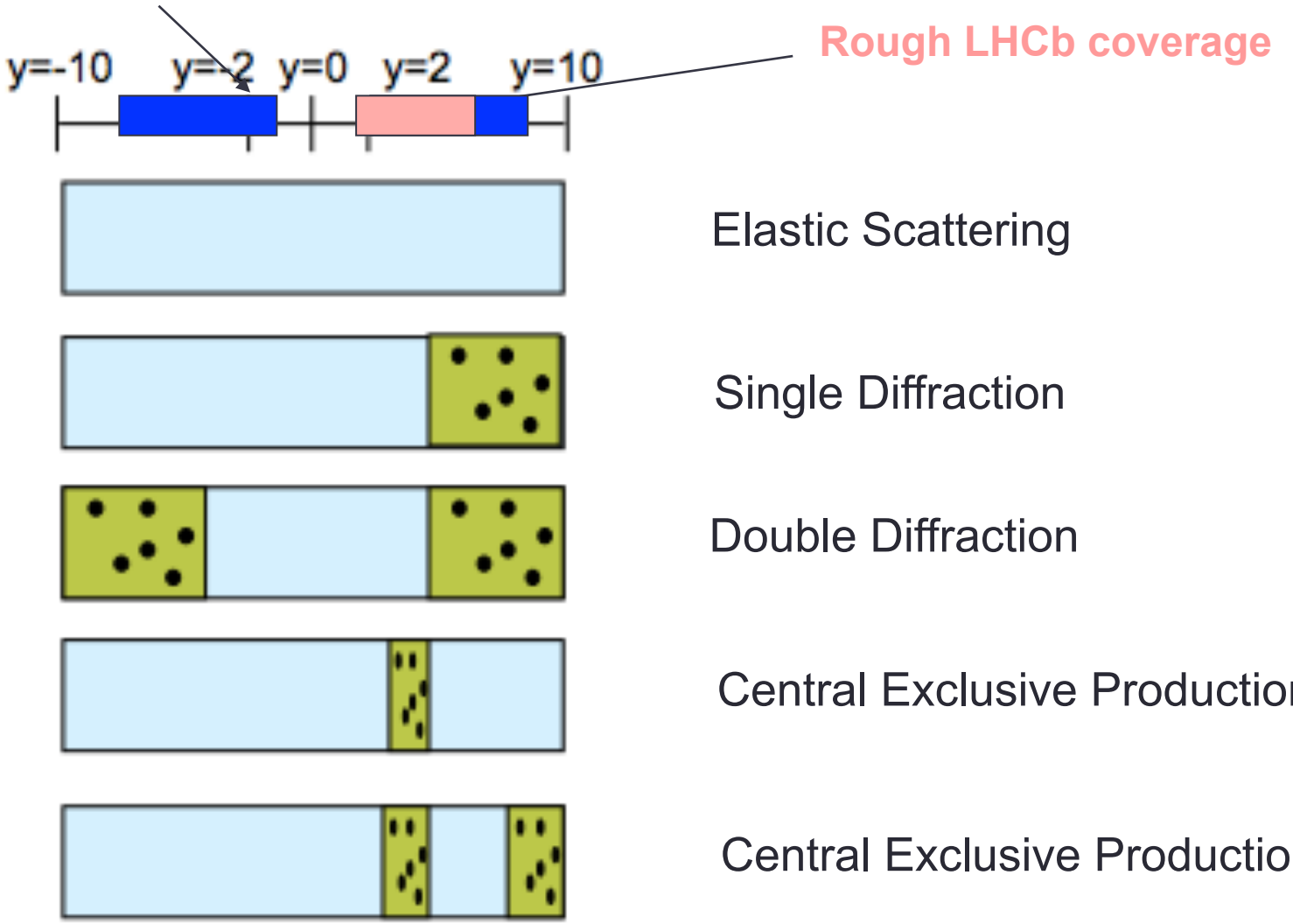
Outline

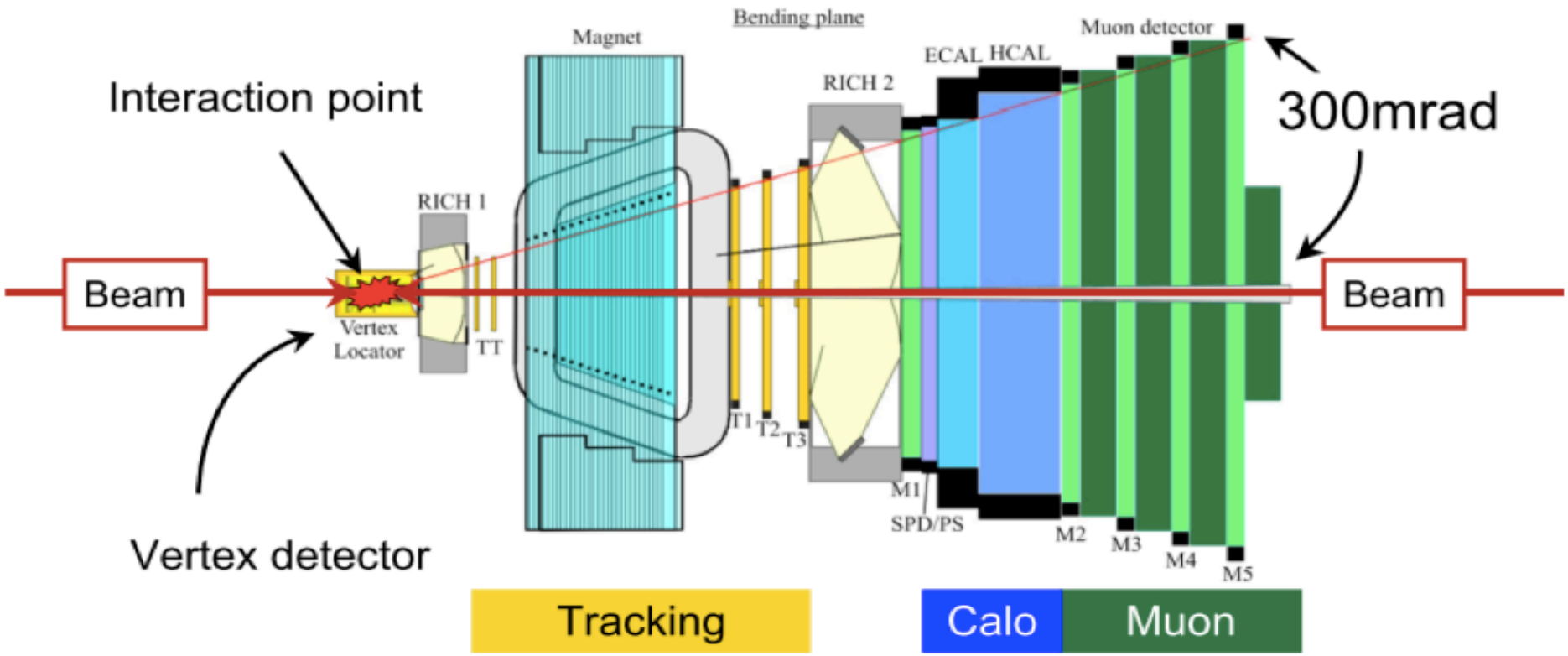
- LHCb: very well suited to study CEP
  - Trigger
  - New Forward Scintillation Counters
- Past:
  - Overview of measurements at 7 TeV
- Present:
  - Current measurements at 13 TeV
- Future
  - Plans for future analyses.


Veto (7 TeV)
Rough LHCb coverage
y=-10
y=-2
y=0
y=2
y=10
Elastic Scattering
Single Diffraction
Double Diffraction
Central Exclusive Production (elastic)
Central Exclusive Production (inelastic)

Veto including new Forward Shower Counters (13 TeV)

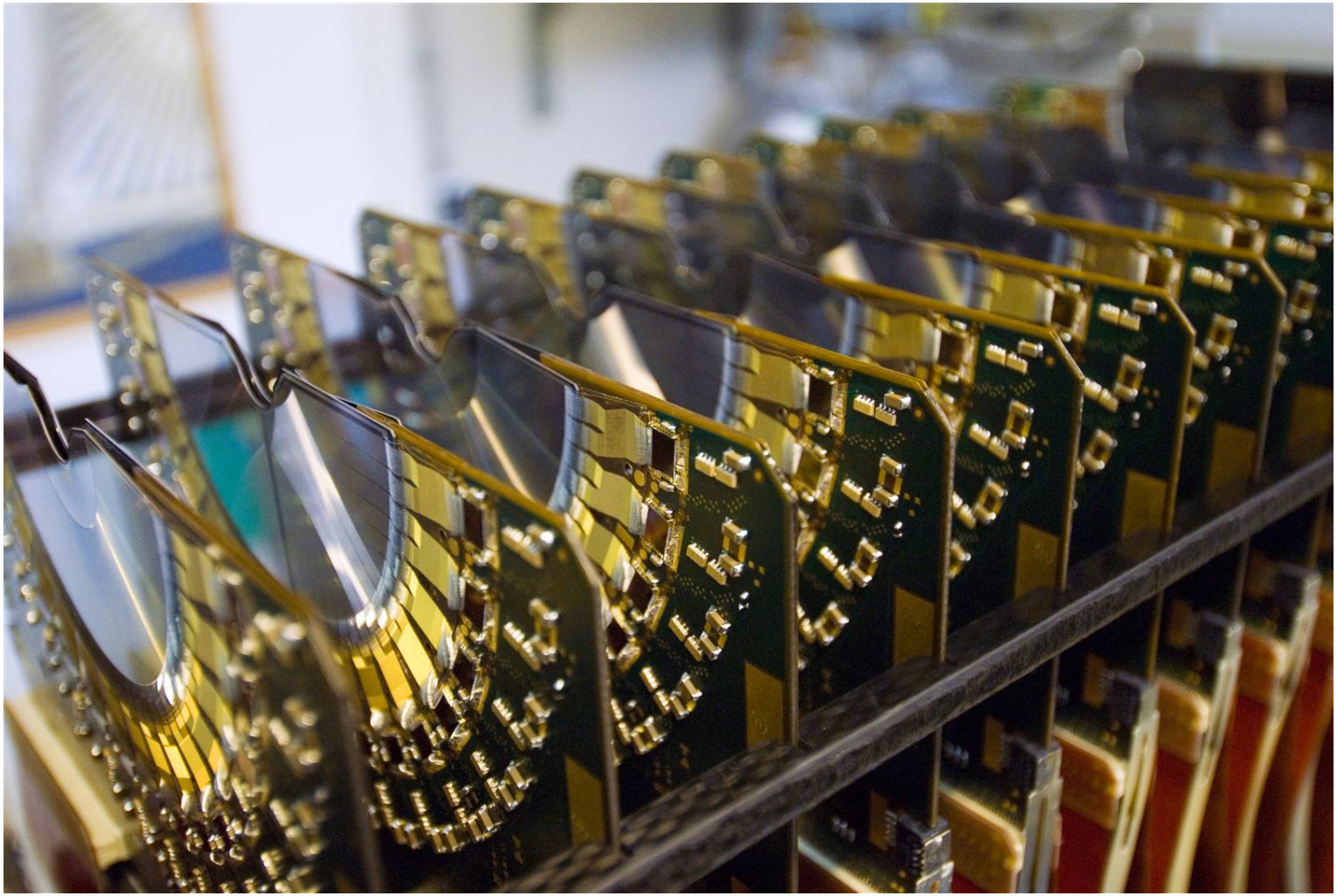


The LHCb detector

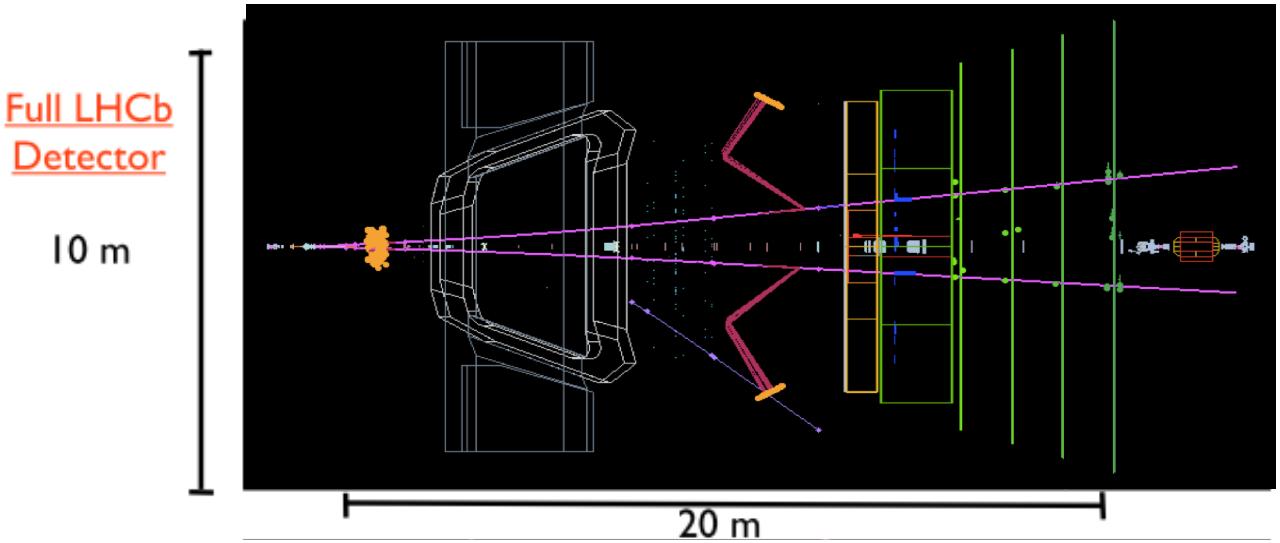


Fully instrumented:	$2 < \eta < 5$
Veto region (< 2015):	$-3.5<\eta<-1.5$
Veto region (>= 2015):	$-8<\eta<-1.5$, $5<\eta<8$

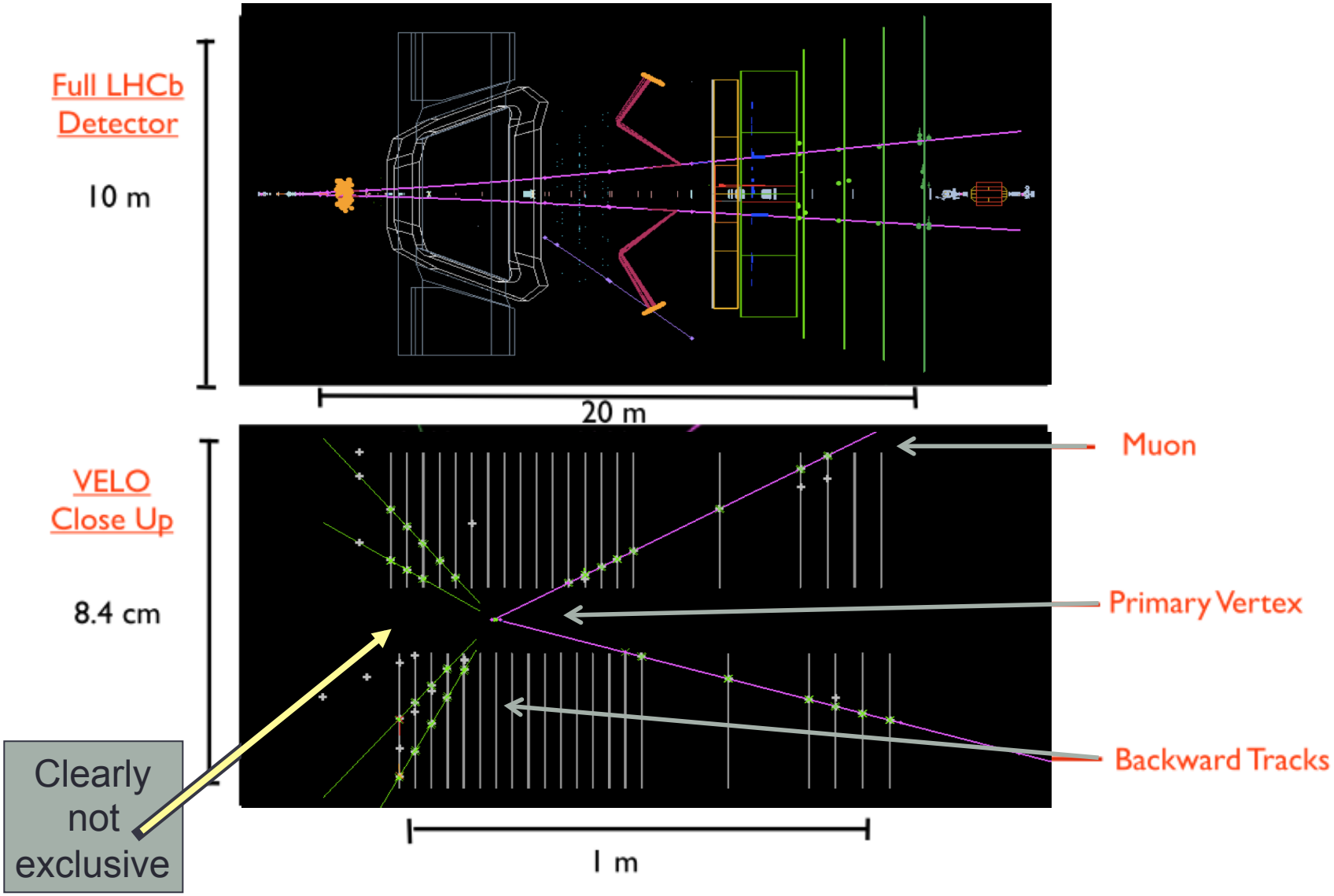
VELO sub-detector

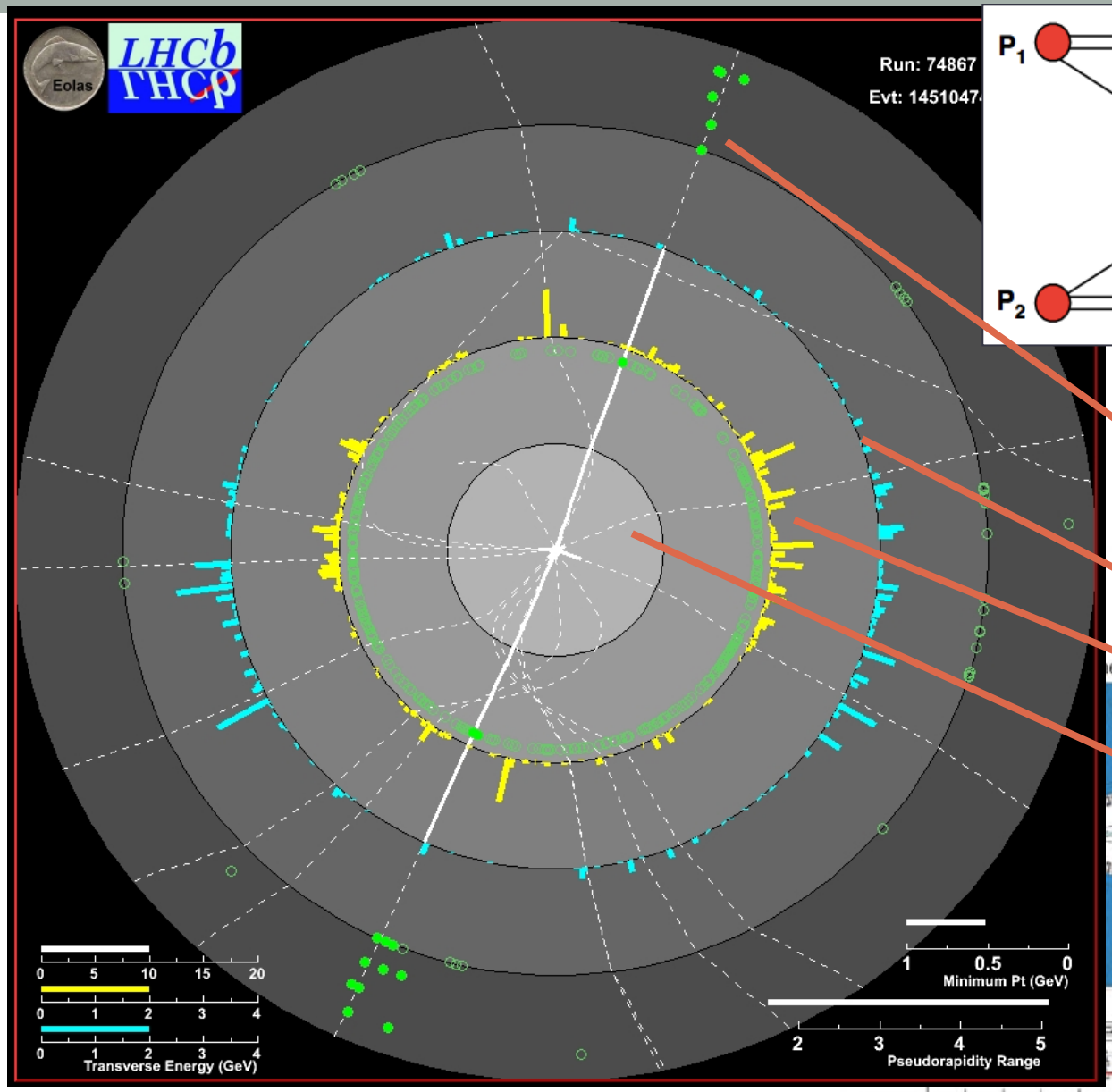


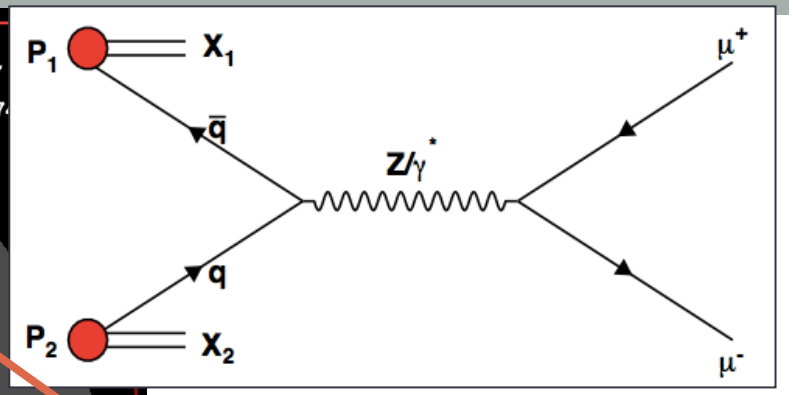
Use of backwards tracks

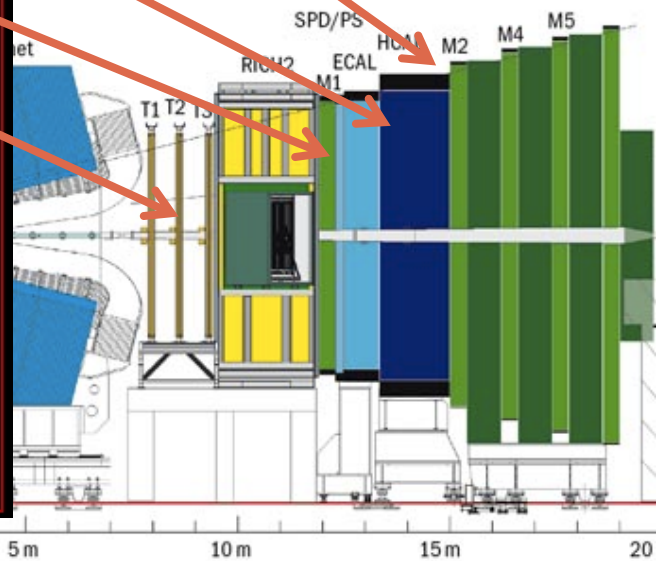


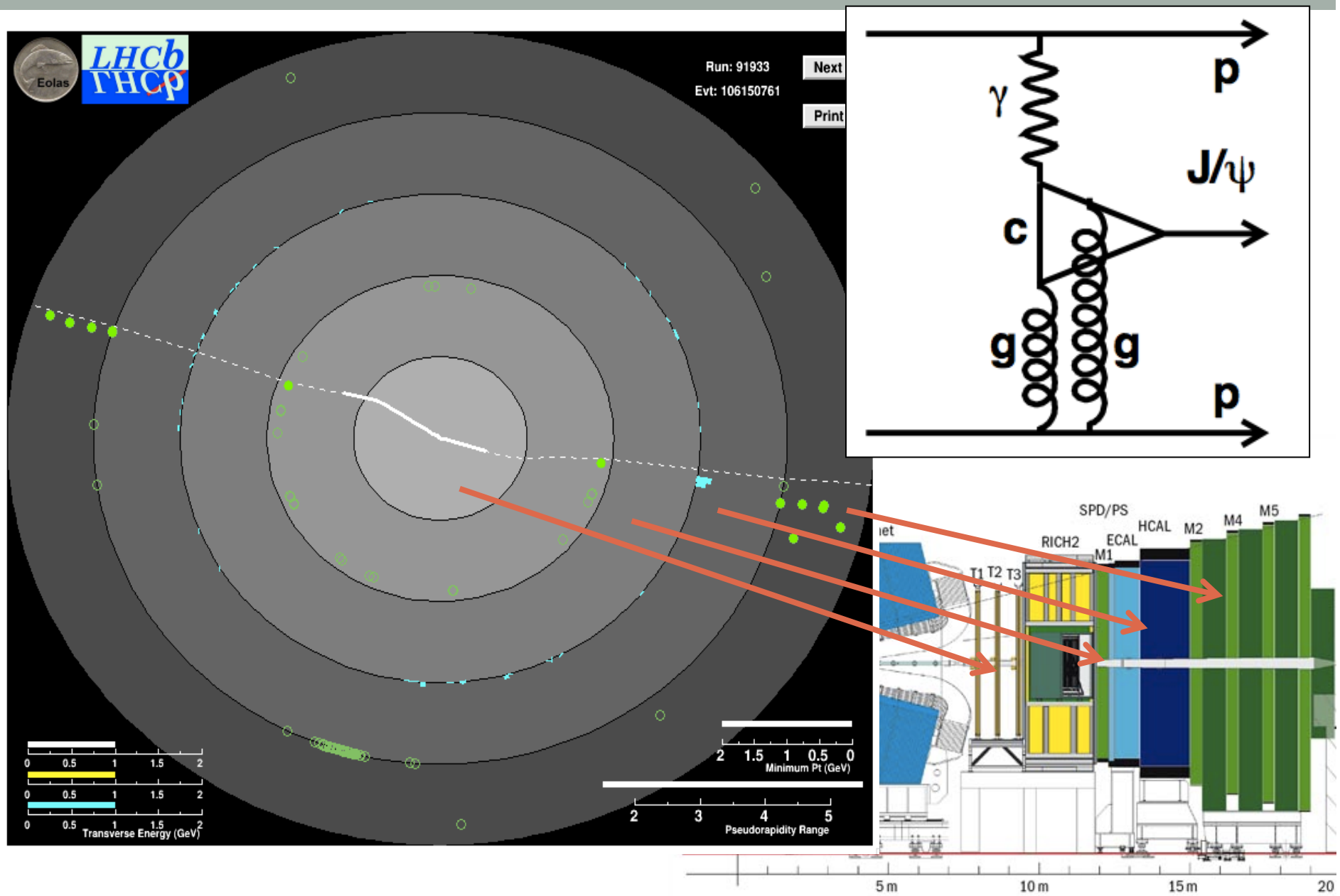
Use of backwards tracks




Eolas
LHCb
Run: 74867
Evt: 1451047
0 5 10 15 20
0 1 2 3 4
0 1 2 3 4
Transverse Energy (GeV)
1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range


P1
X1
q̄
Z/γ*
q
P2
X2
μ+
μ-


SPD/PS
ECAL
M1
M2
M4
M5
T1 T2
5 m
10 m
15 m
20


Eolas
LHCb
Run: 91933
Evt: 106150761
Next
Print
0 0.5 1 1.5 2
Transverse Energy (GeV)
2 1.5 1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range
γ
p
J/ψ
c
g
g
p
SPD/PS
HCAL
M2
M4
M5
RICH2
ECAL
M1
T1 T2 T3
5 m
10 m
15 m
20

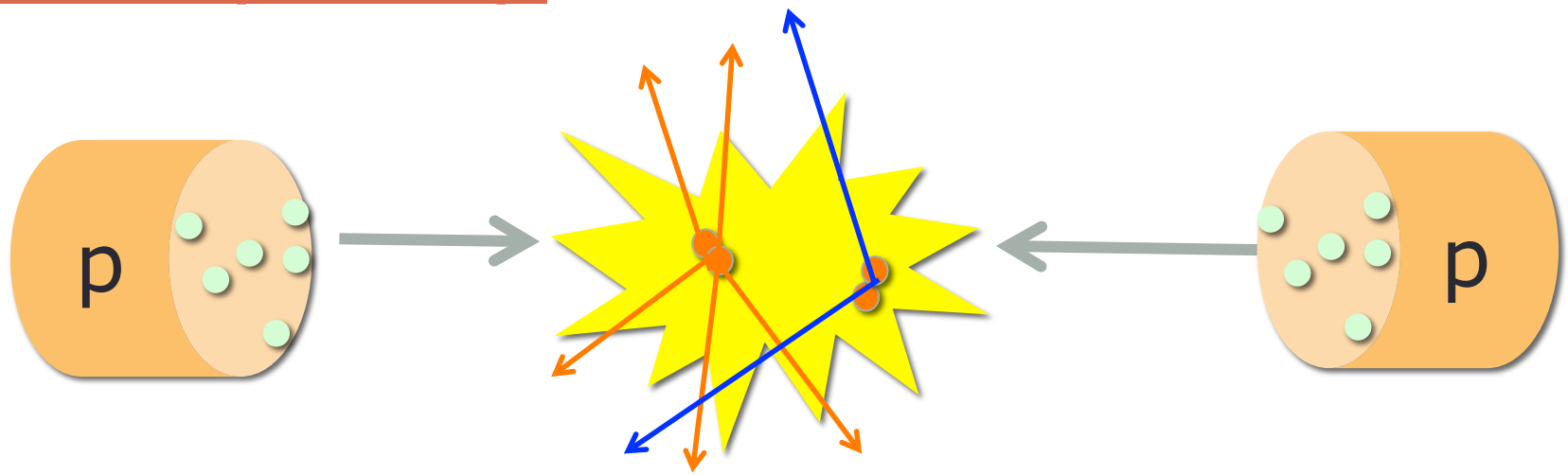
Trigger

- Trigger on Low multiplicity events

- At 7 TeV
  - Muons > 400 MeV. Dimuon masses down to ω with pT=0

- At 13 TeV
  - Hadrons with SumEt>500 MeV.
  - Two EM object > 400 MeV
  - Single photons or electrons > 800 MeV

Beam pile-up



High luminosity requires multiple proton interactions per beam-crossing.

For LHCb in 2011, $\bar{\mu}$=1.4 (25% of interactions useful)

Number of interactions (N) /crossings, distributed

Average #interactions

$$f(N) = \frac{e^{\mu}\mu^{N}}{N!}$$

For LHCb in 2015, $\bar{\mu}$=1.08 (35% interactions useful)

Central Exclusive Production of J/ψ and ψ(2S) mesons

Data-taking year	Energy	Integrated Luminosity	Paper
2010	7 TeV	$37pb^{-1}$	JPG 40 (2013) 045001
2011	7 TeV	$930pb^{-1}$	JPG 41 (2014) 055002

Central Exclusive Production of Υ(1S), Υ(2S), Υ(3S) mesons

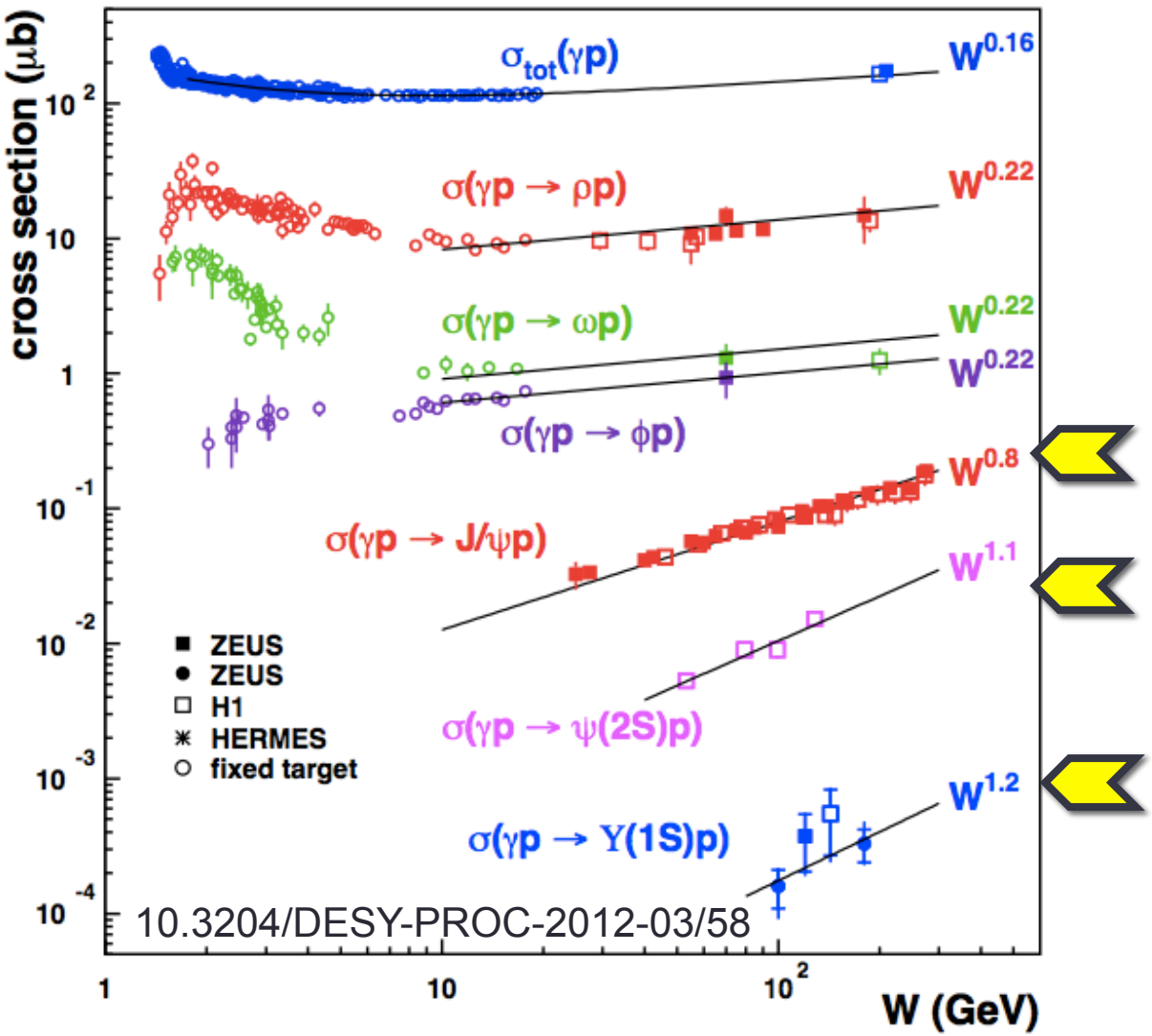
Data-taking year	Energy	Integrated Luminosity	Paper
2011	7 TeV	$945\ pb^{-1}$	JHEP 09 (2015) 084
2012	8 TeV	$1985\ pb^{-1}$	

HERA vector meson photo-production results

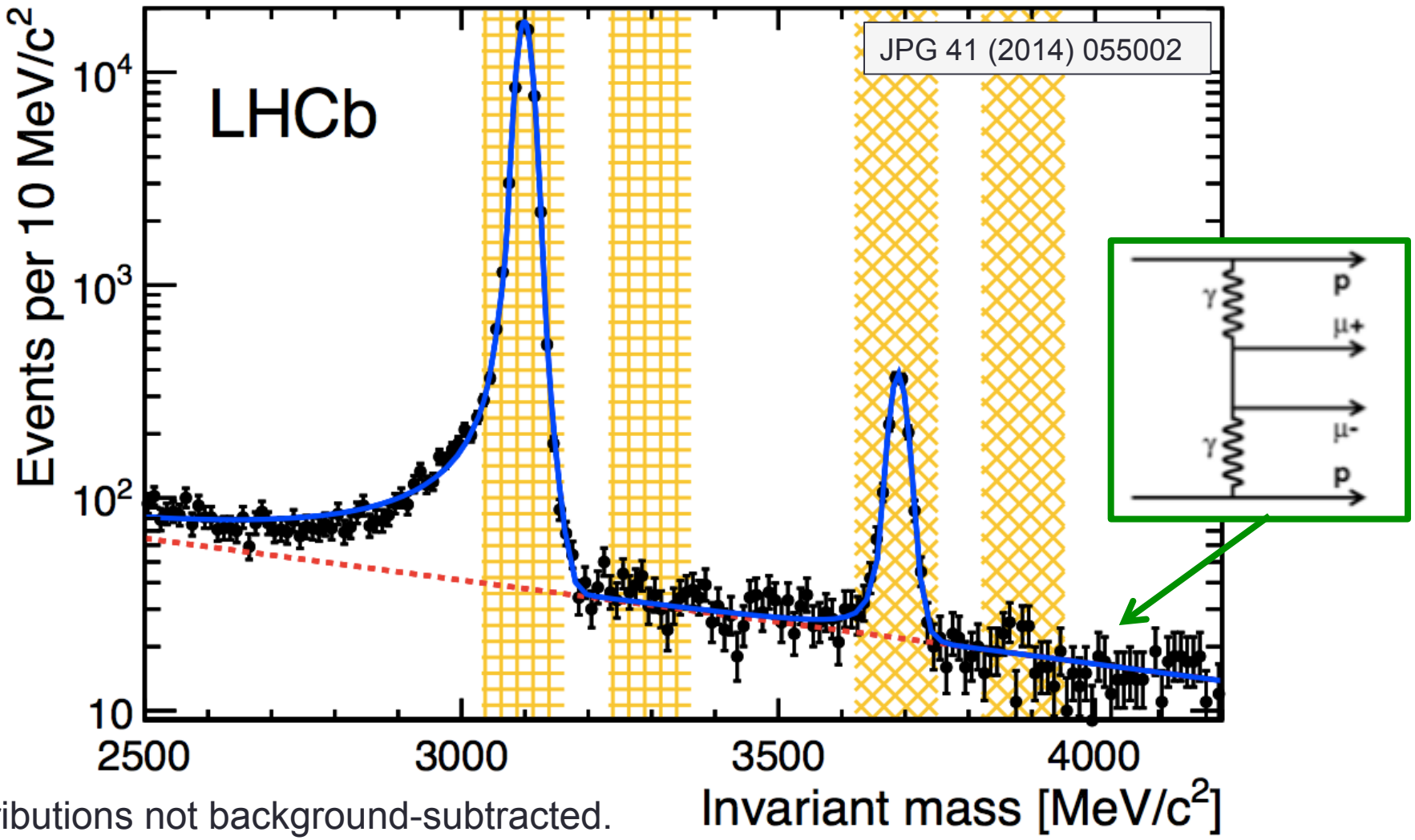
Note:

- $\sigma \sim x^{\lambda}$
- soft/hard
- $g(x,Q^2)$

  (at x=1E-5)

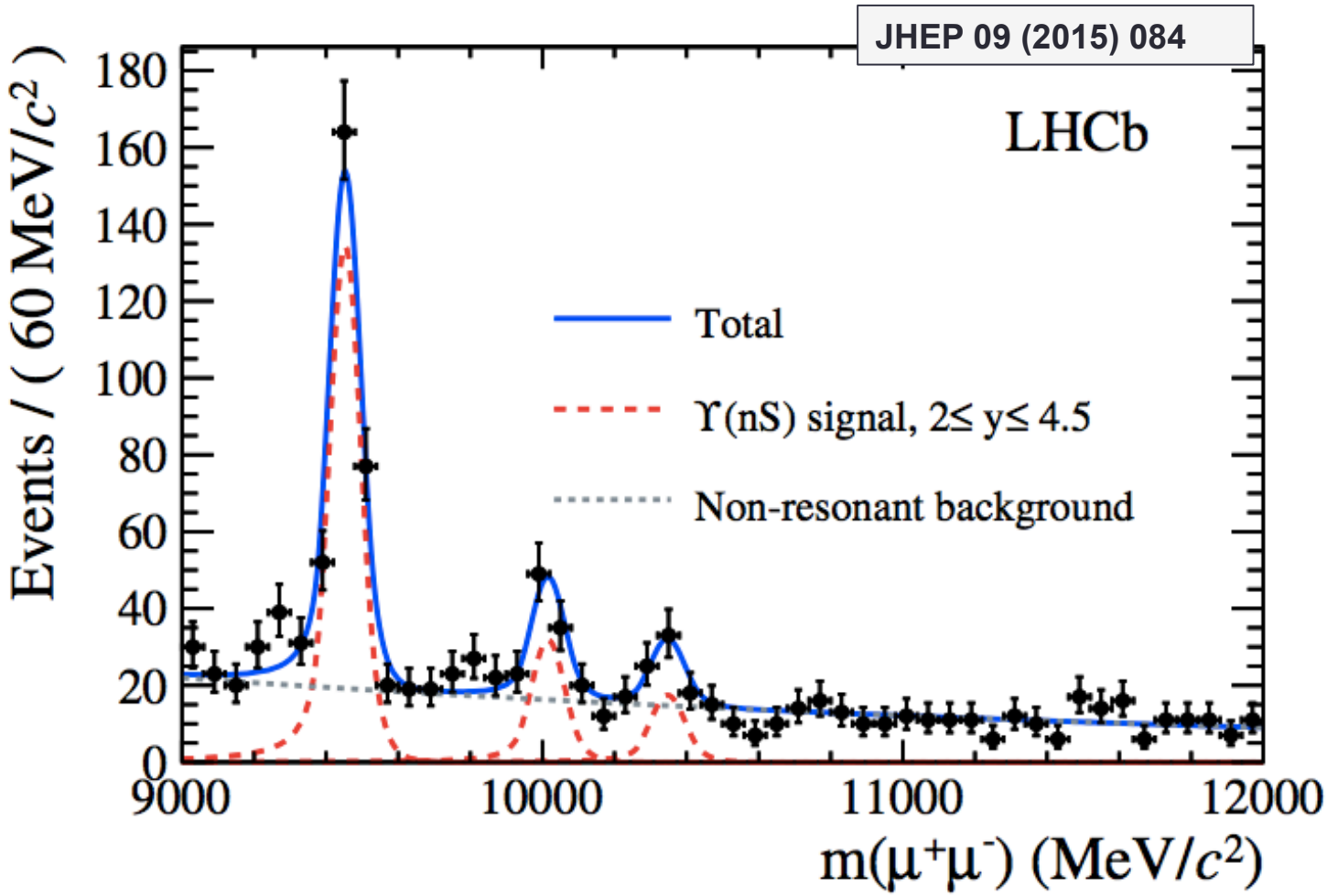


Non-resonant background very small



Distributions not background-subtracted.
55985 J/ψ and 1565 ψ(2s)

Non-resonant background relatively larger



Distributions not background-subtracted. 270 ϒ(1S), 70 ϒ(2S), 40 ϒ(3s)

Cross-section measurement J/ψ / ψ(2S)

Purity: (found from data)
1. non-resonant bkg (1% / 17%)
2. Feeddown (10% / 2%)
3. Inelastic Jpsi production (40% / 40%)

Number of events observed

$$\frac{d\sigma}{dy} = \frac{pN}{A\varepsilon L\Delta y}$$

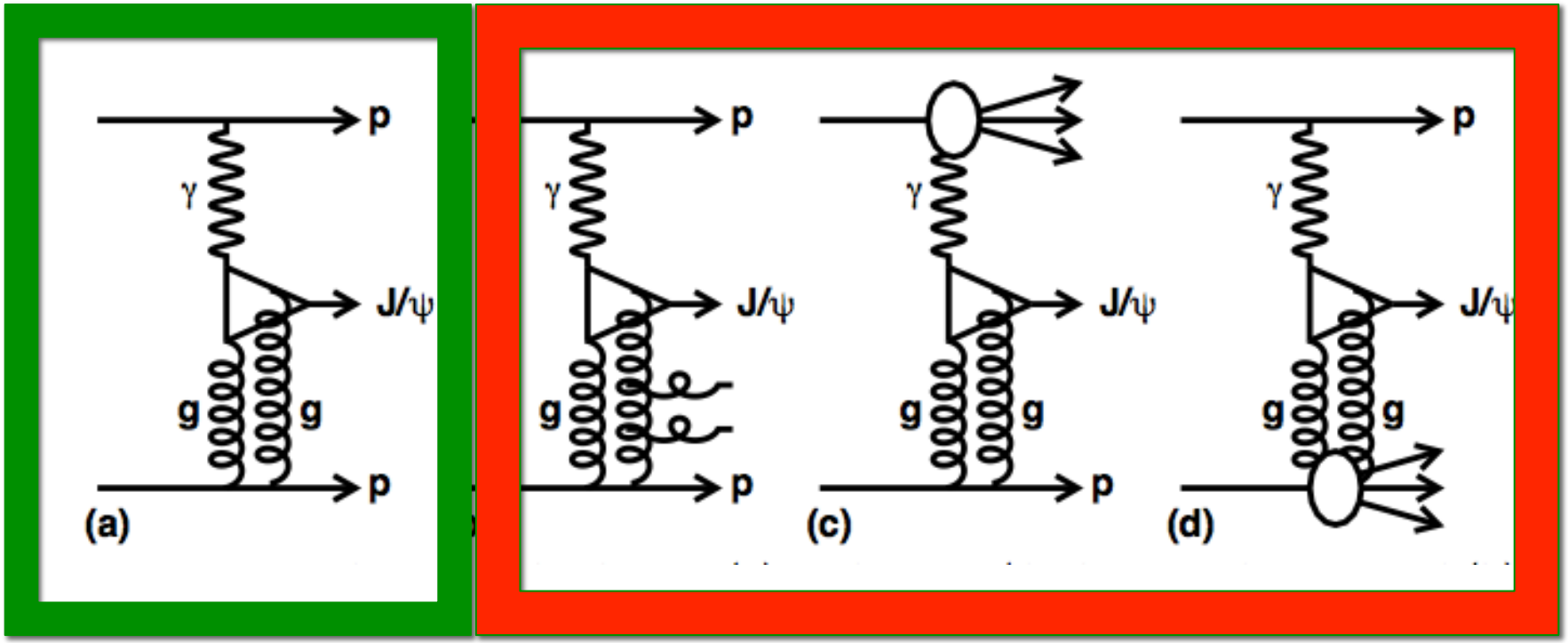
Luminosity

Acceptance (MC)

Efficiency: (found from data)
1. Trigger
2. Tracking & muon id.
3. Single interaction beam-crossing

$$P(n) = \mu^n e^{-\mu} / n!$$

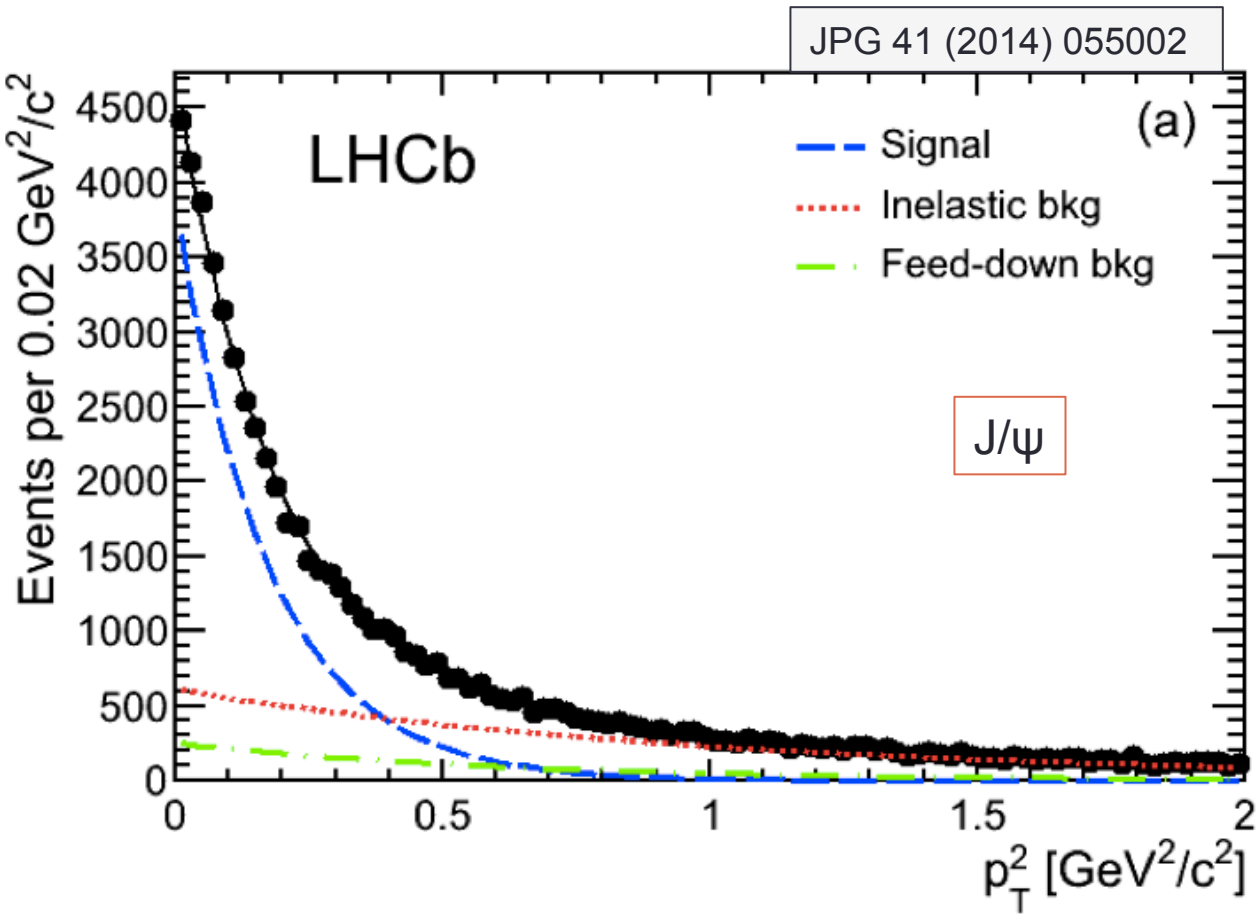
Inelastic background

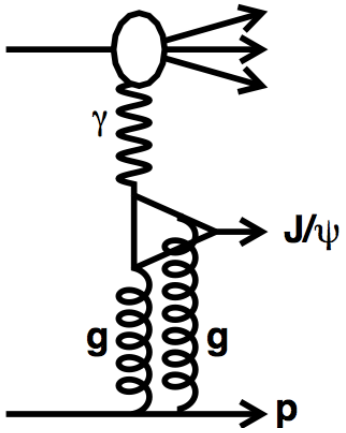


Signal

Background

Inelastic background J/ψ





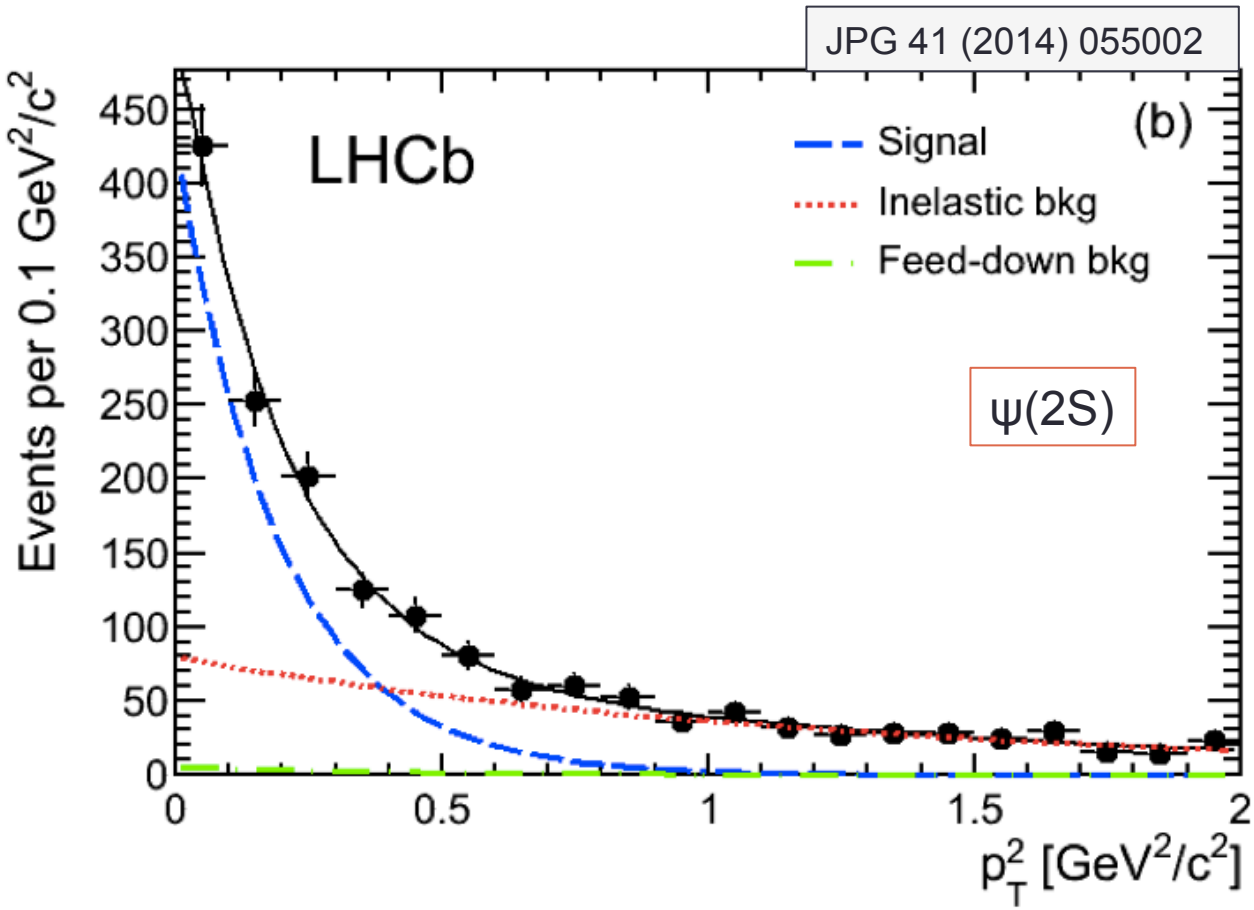
Regge theory: $\frac{d\sigma}{dt} \sim e^{bt}$

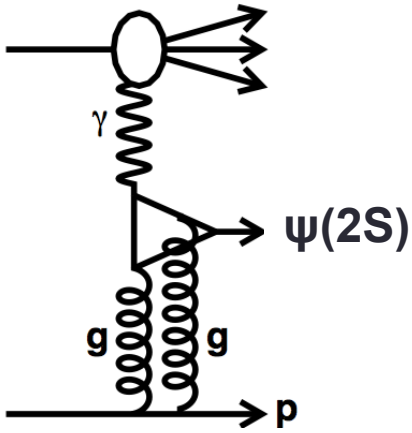
HERA measured:
b_s=4.9 GeV^{-2}
b_{pd}=1.1 GeV^{-2}

LHCb Expect:
b_s ~ 6 GeV^{-2}
b_{pd}~ 1 GeV^{-2}

LHCb Fit:
b_s=5.70±0.11 GeV^{-2}
b_{pd}=0.97±0.04 GeV^{-2}

Inelastic background ψ(2S)





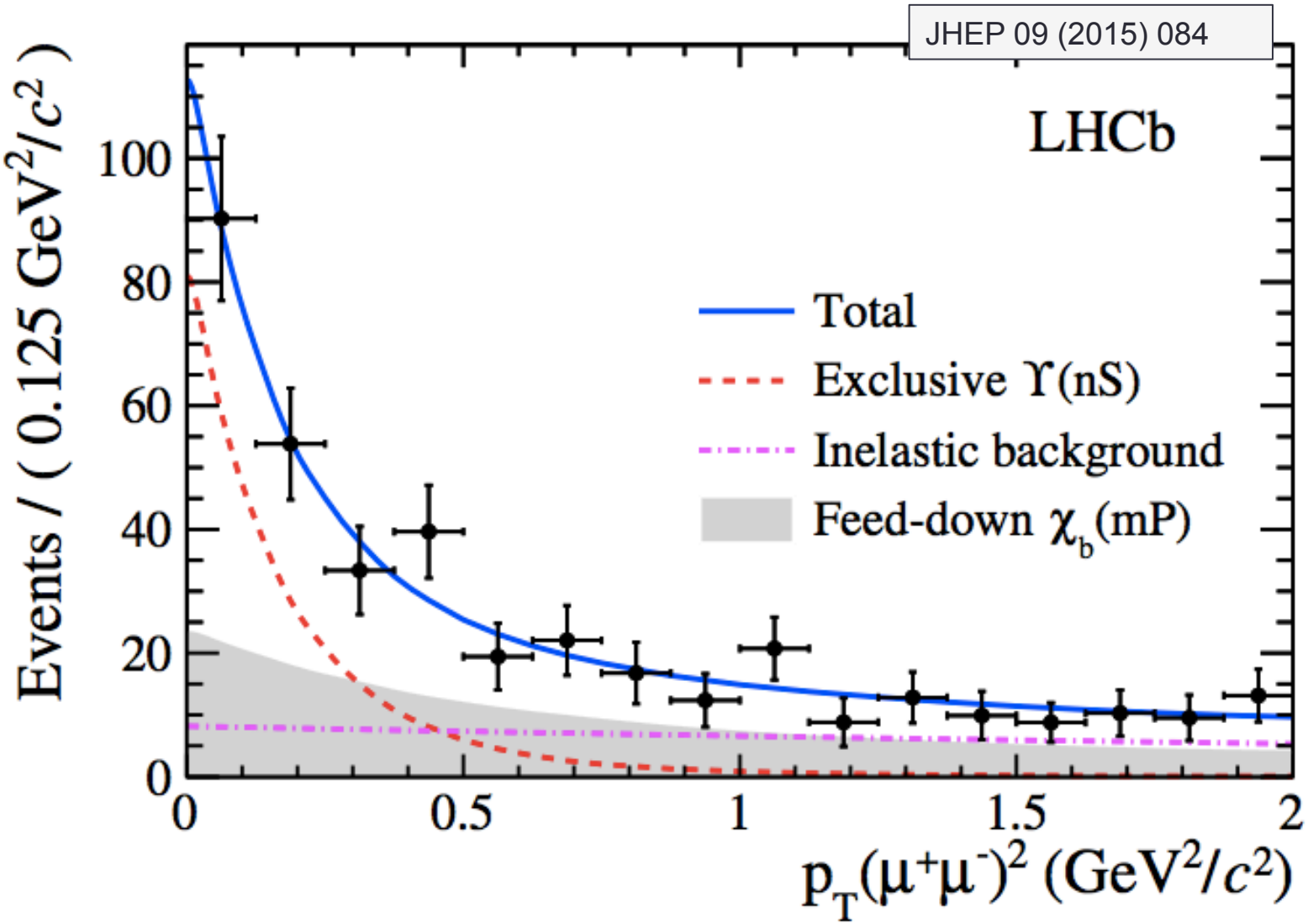
$$\frac{d\sigma}{dt} \sim e^{bt}$$

HERA measured:
b_s=4.2 GeV^{-2}
b_{pd}=0.6 GeV^{-2}

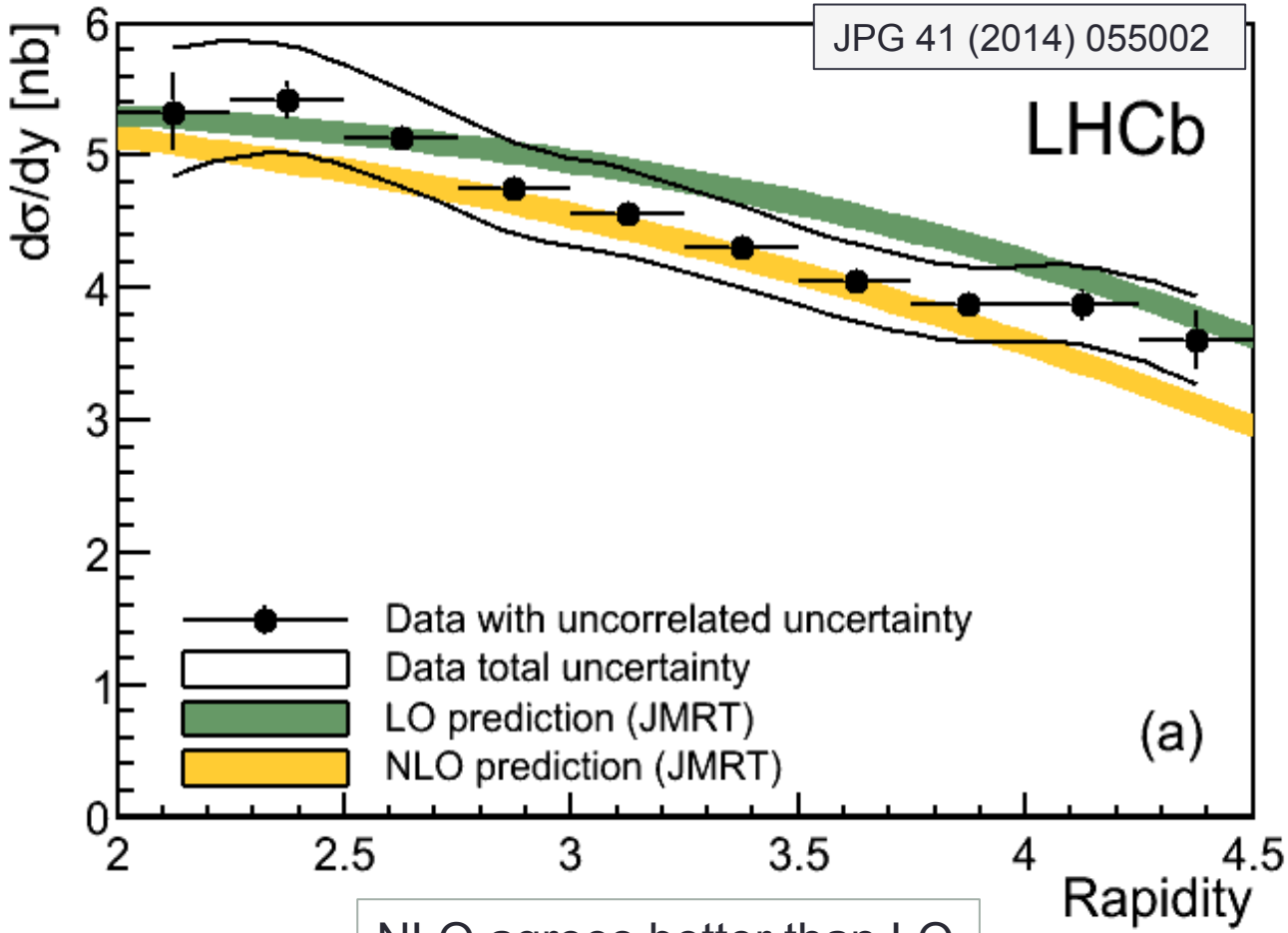
LHCb Expect:
b_s ~ 5.5 GeV^{-2}
b_{pd}~ 0.6 GeV^{-2}

LHCb Fit:
b_s=5.1±0.7 GeV^{-2}
b_{pd}=0.8±0.2 GeV^{-2}

Fit to ϒ (background subtracted) p_T^2



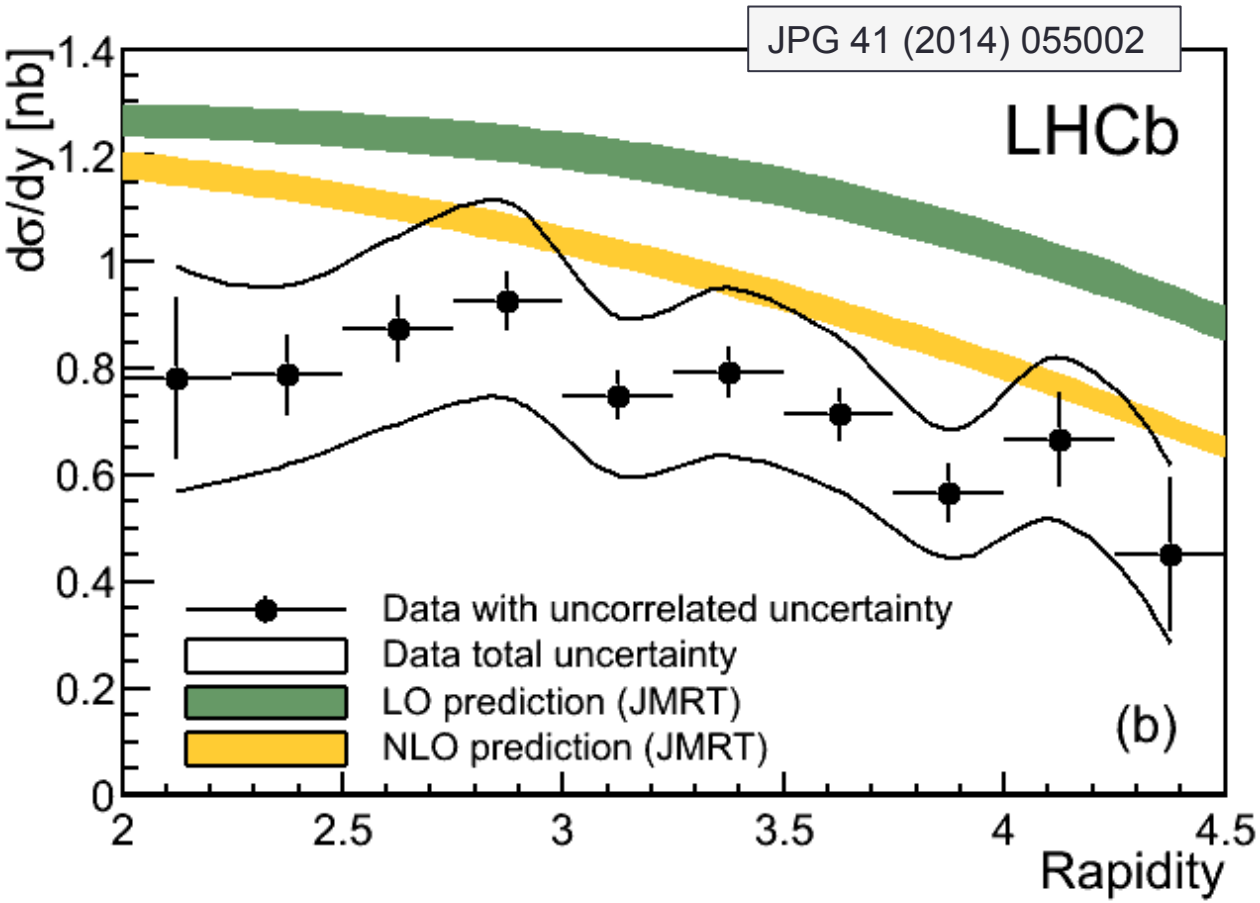
Differential cross-sections J/ψ



NLO agrees better than LO

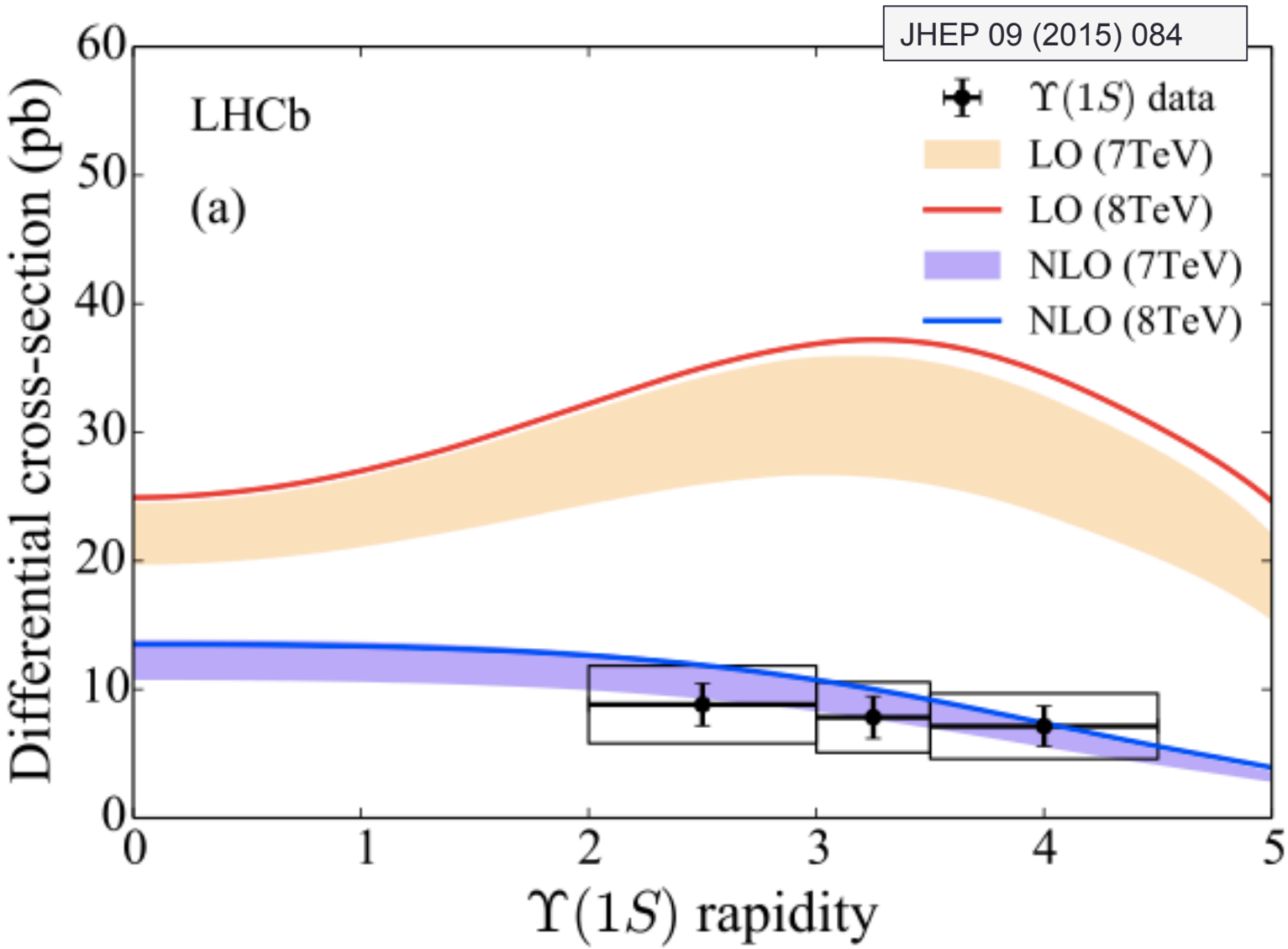
S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

Differential cross-sections ψ(2S)



NLO agrees better than LO

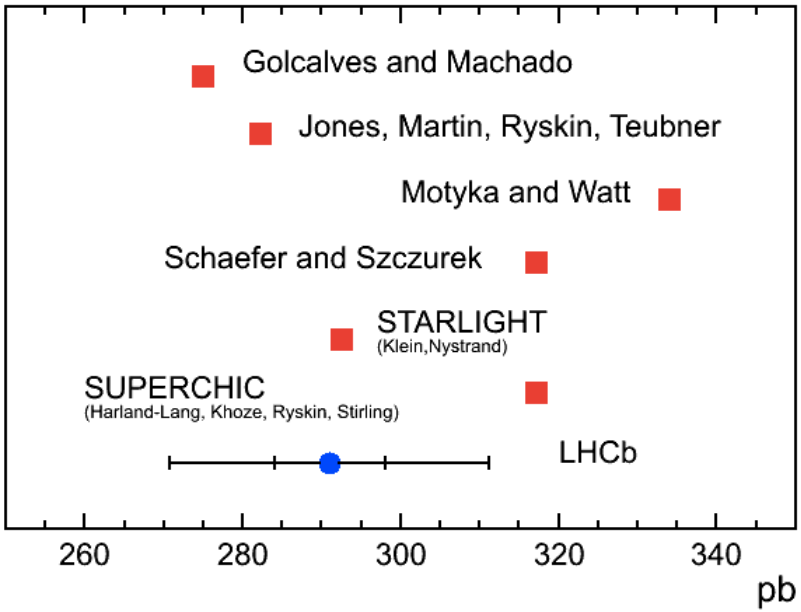
ϒ Cross-section



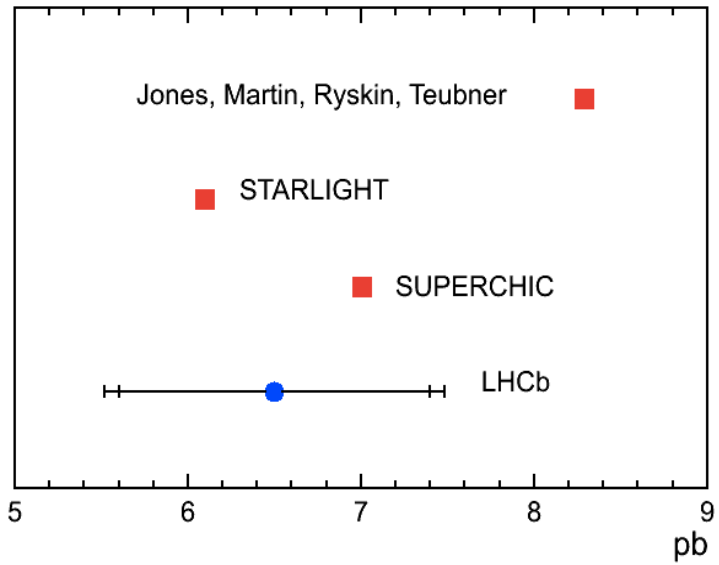
Integrated Cross-sections

Cross-section*BR for both muons in pseudorapidity range 2<η<4.5:

J/ψ



ψ(2S)

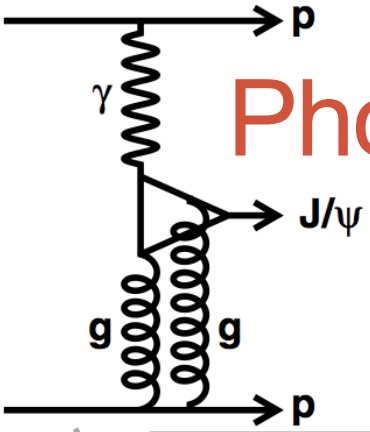


Υ

$$\begin{aligned}
\sigma(pp \to p\Upsilon(1S)p) &= 9.0 \pm 2.1 \pm 1.7 \text{ pb}, \\
\sigma(pp \to p\Upsilon(2S)p) &= 1.3 \pm 0.8 \pm 0.3 \text{ pb, and} \\
\sigma(pp \to p\Upsilon(3S)p) &< 3.4 \text{ pb at the 95\% confidence level},
\end{aligned}$$

Good agreement with all theory estimates

Photo-production cross-section



LHCb measure

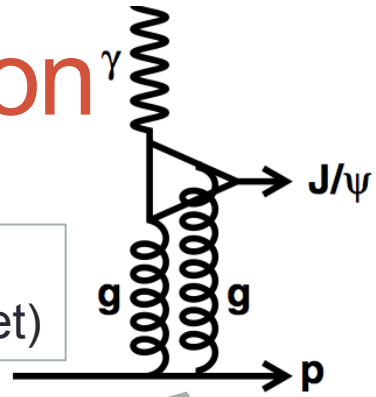


Photo-production
(HERA / fixed target)

$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

Gap Survival

Photon Flux

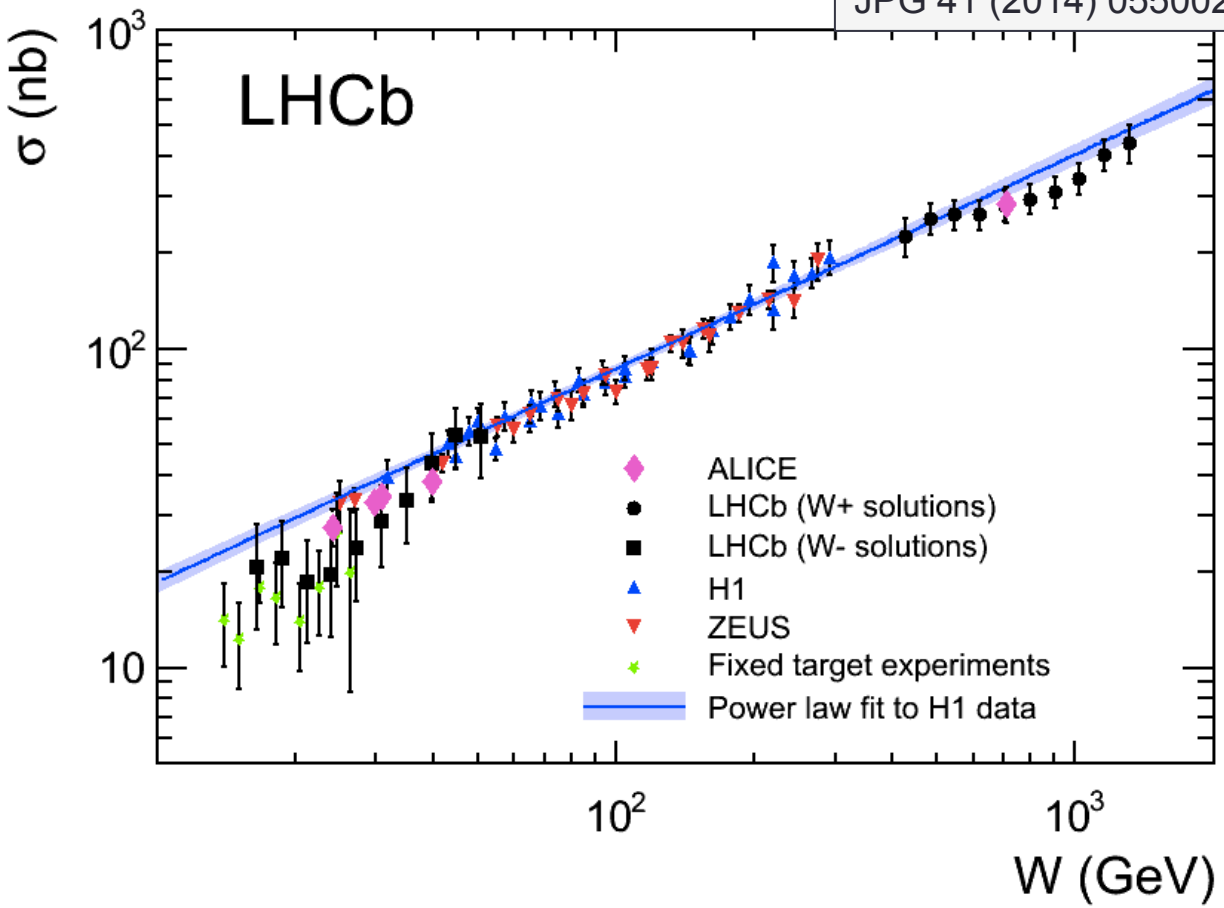
HERA measured power-law: $\sigma_{\gamma p\to J/\psi p}(W) = 81(W/90\,\mathrm{GeV})^{0.67}\,\mathrm{nb}$
Use this for one cross-section on RHS – LHCb measure the other solution

Photo-production cross-section

Measure Plot HERA

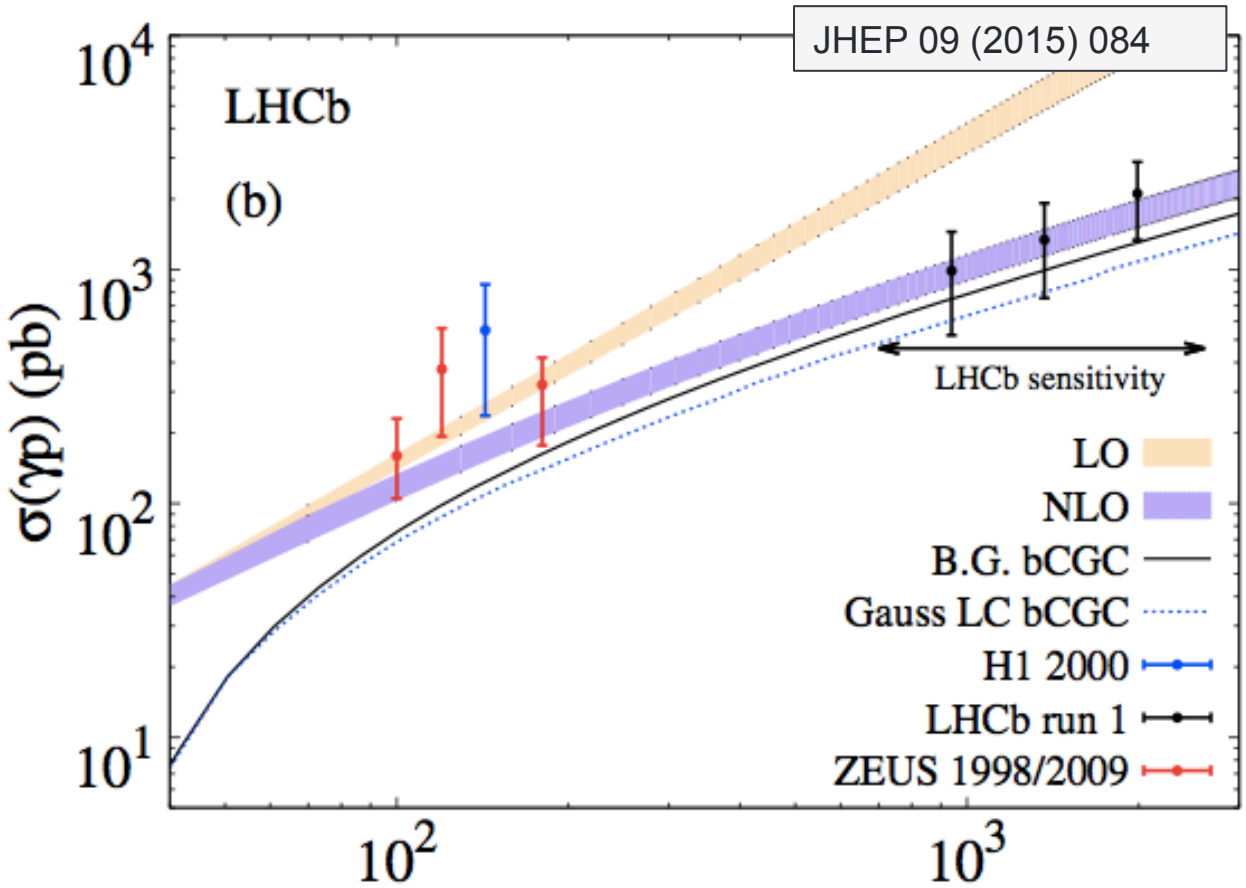
$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

JPG 41 (2014) 055002



Consistent picture of J/ψ production across experiments at different energies

Derived photo-production cross-section



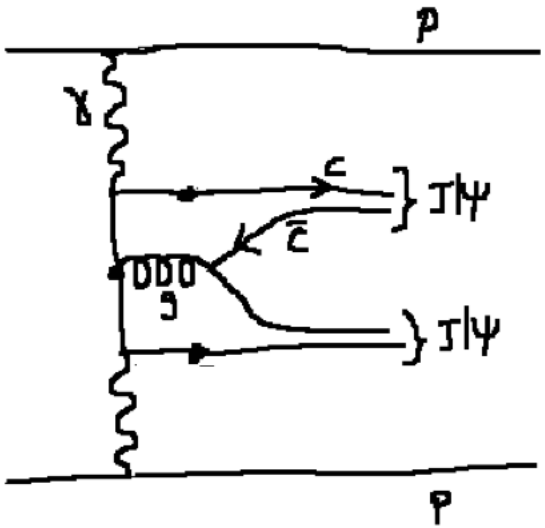
$$\frac{d\sigma}{dy}_{pp\to p,\Upsilon p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to \Upsilon p}(W_+) + \cancel{r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)}$$

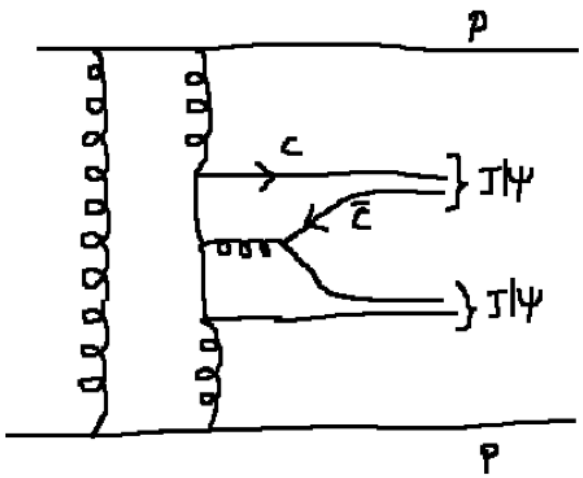
ignored

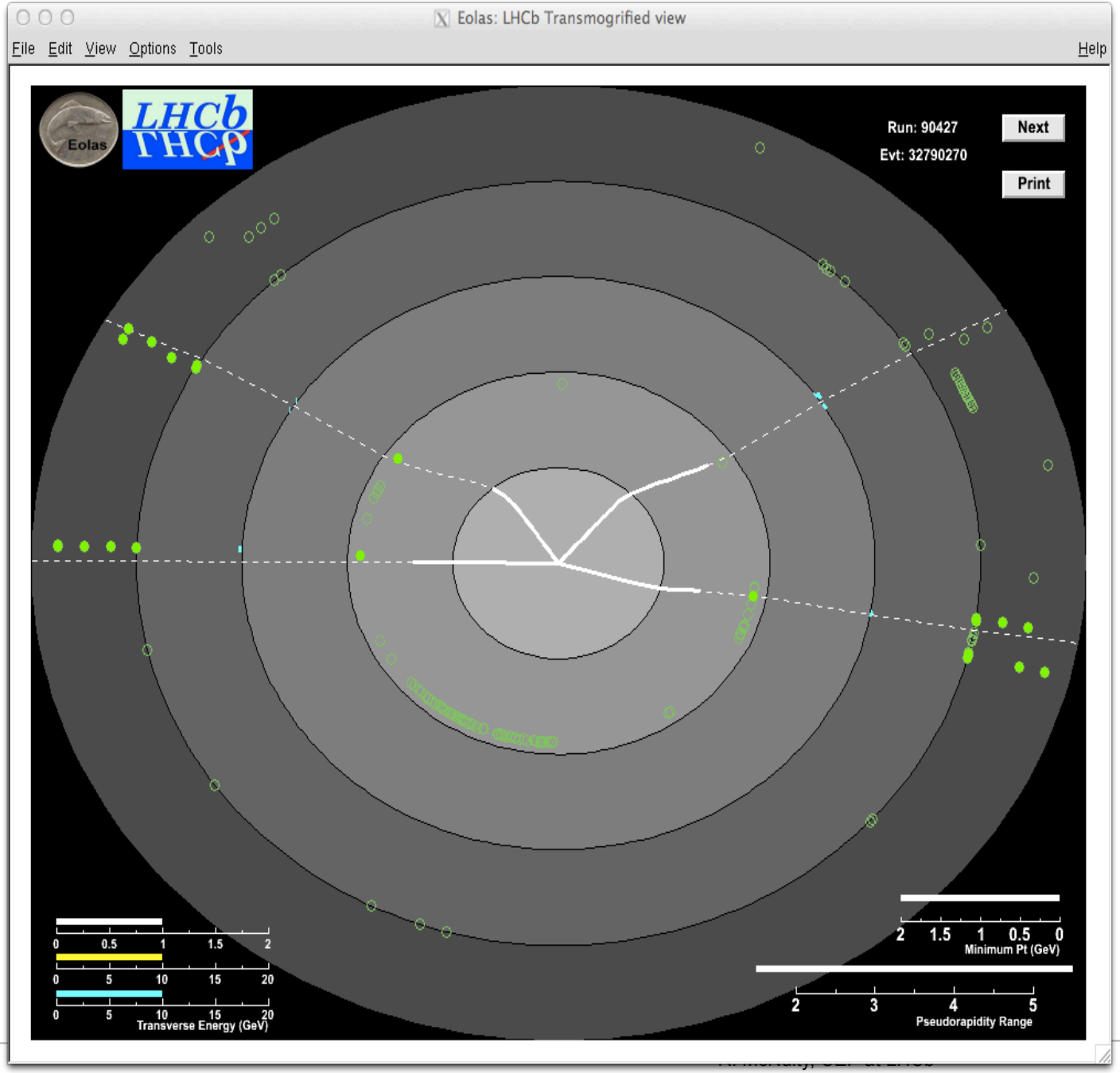
Double Charmonia

An example of the unexpected, visible when you have very clean signals....

Data-taking year	Energy	Integrated Luminosity	Paper
2011	7 TeV	945 pb^{-1}	JPG 40 (2013) 045001
2012	8 TeV	1985 pb^{-1}	

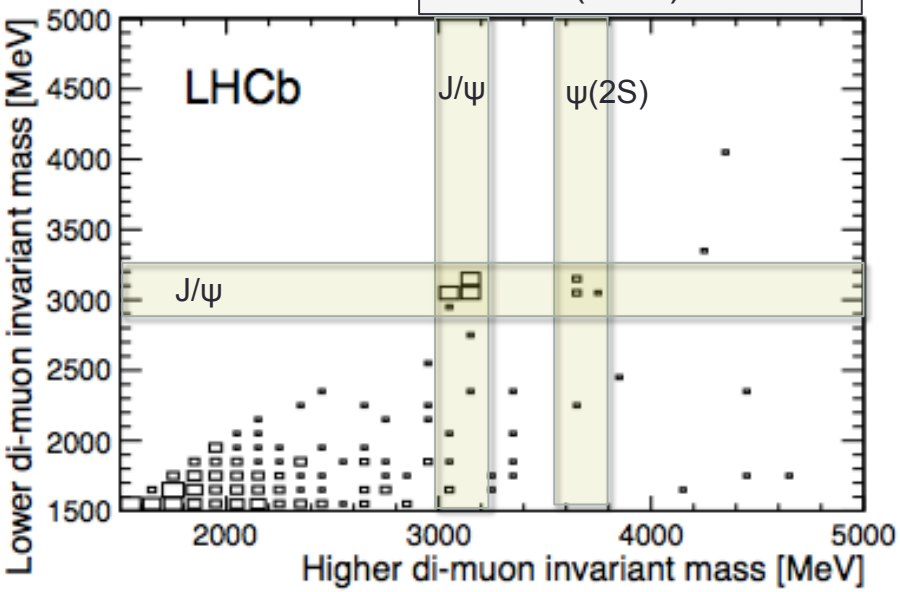




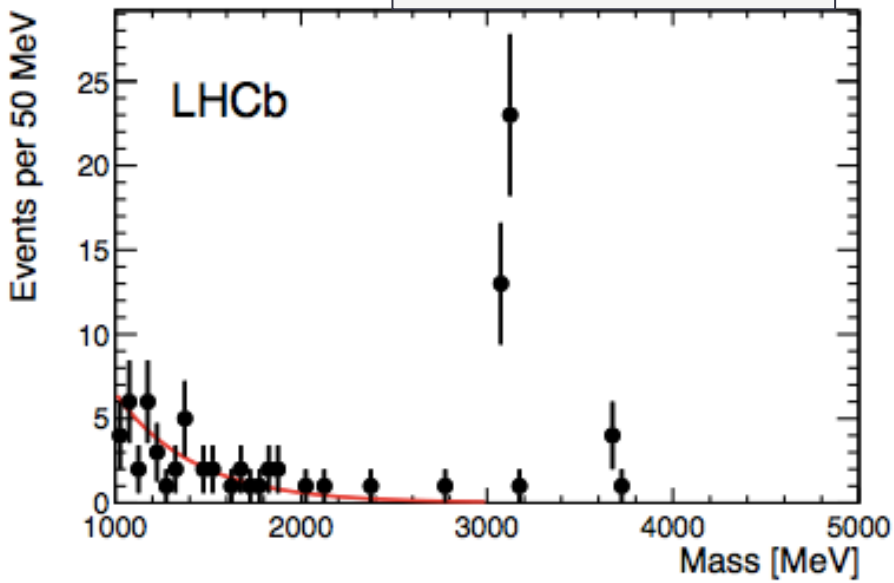

Eolas: LHCb Transmogrified view
File Edit View Options Tools
Help
Eolas
LHCb
Run: 90427
Evt: 32790270
Next
Print
0 0.5 1 1.5 2
0 5 10 15 20
0 5 10 15 20
Transverse Energy (GeV)
2 1.5 1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range

Select 4-muon exclusive events

JPG 41 (2014) 115002



JPG 41 (2014) 115002



Dimuon spectrum having required other two muons have J/ψ mass

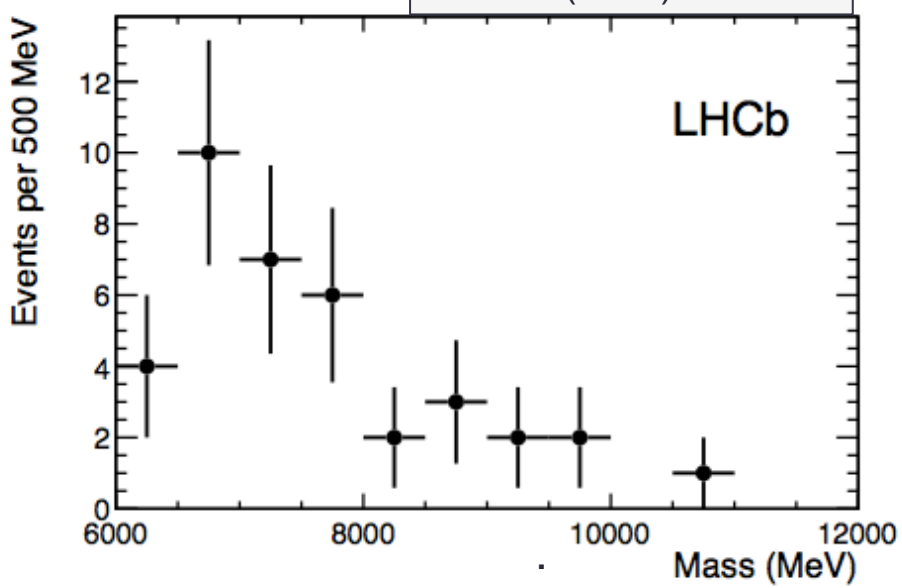
Selection requirement:
Require precisely 4 tracks, at least three identified as muons

Cross-section results

$$\sigma^{J/\psi\,J/\psi} = 58 \pm 10(\text{stat}) \pm 6(\text{syst})\,\text{pb},$$
$$\sigma^{J/\psi\,\psi(2S)} = 63^{+27}_{-18}(\text{stat}) \pm 10(\text{syst})\,\text{pb},$$
$$\sigma^{\psi(2S)\psi(2S)} < 237\,\text{pb},$$
$$\sigma^{\chi_{c0}\chi_{c0}} < 69\,\text{nb},$$
$$\sigma^{\chi_{c1}\chi_{c1}} < 45\,\text{pb},$$
$$\sigma^{\chi_{c2}\chi_{c2}} < 141\,\text{pb},$$

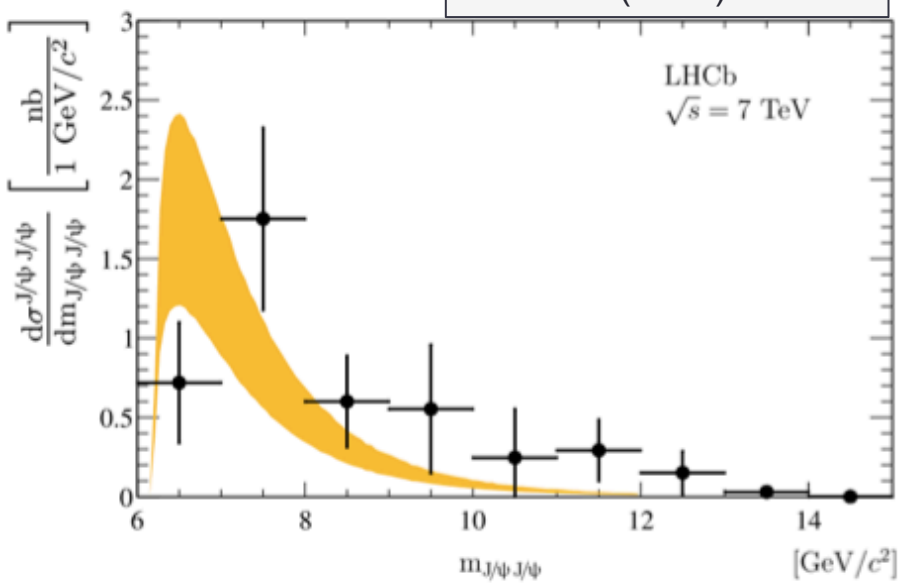
Exclusive

JPG 41 (2014) 115002



Inclusive

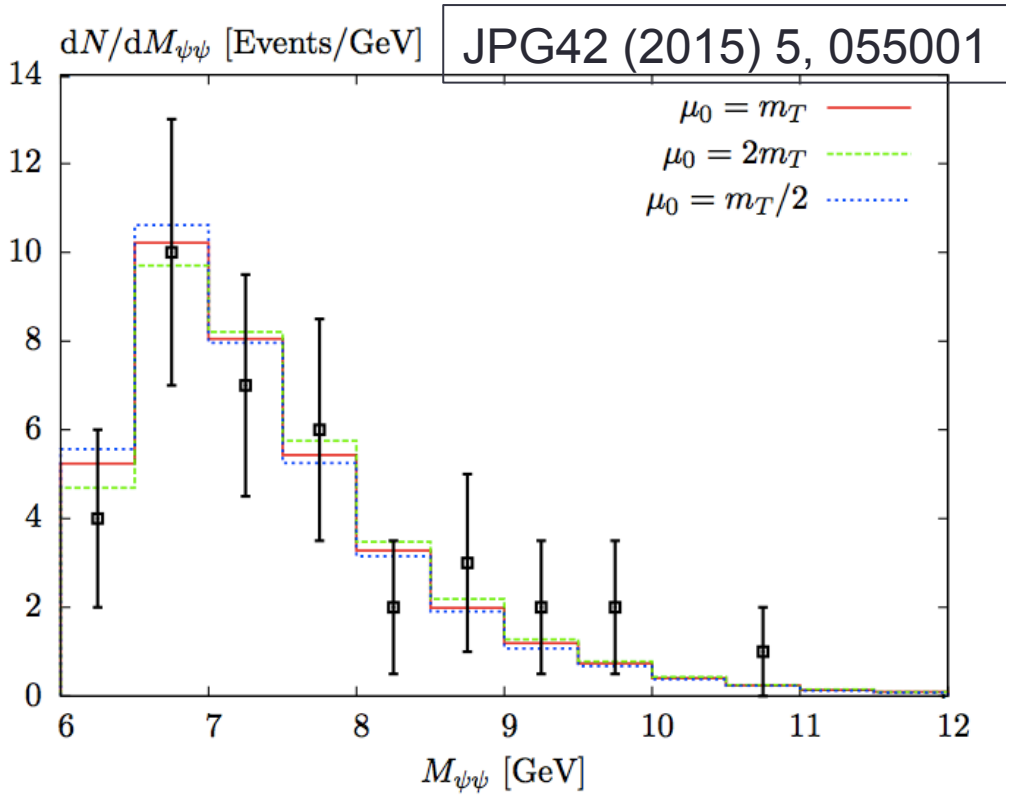
PLB 707 (2012) 52.



Comparison to theory

LHCb estimate exclusive cross-section. **24+-9 pb**

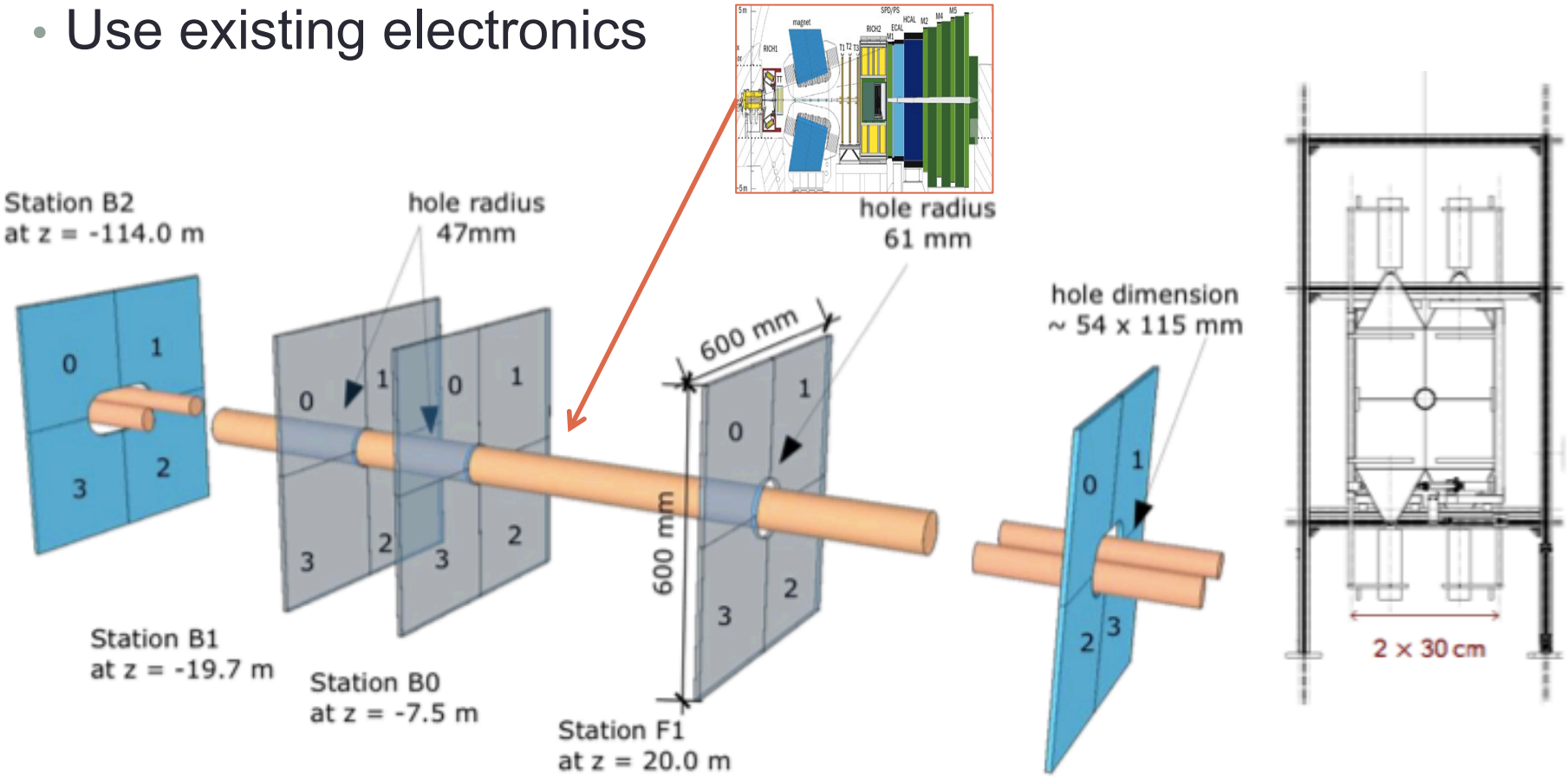
Harland-Lang, Khoze, Ryskin: (arXiv: 1409.4785) **2-7 pb**



Shape agrees well (theory normalised to data).

High rapidity shower counters for LHCb

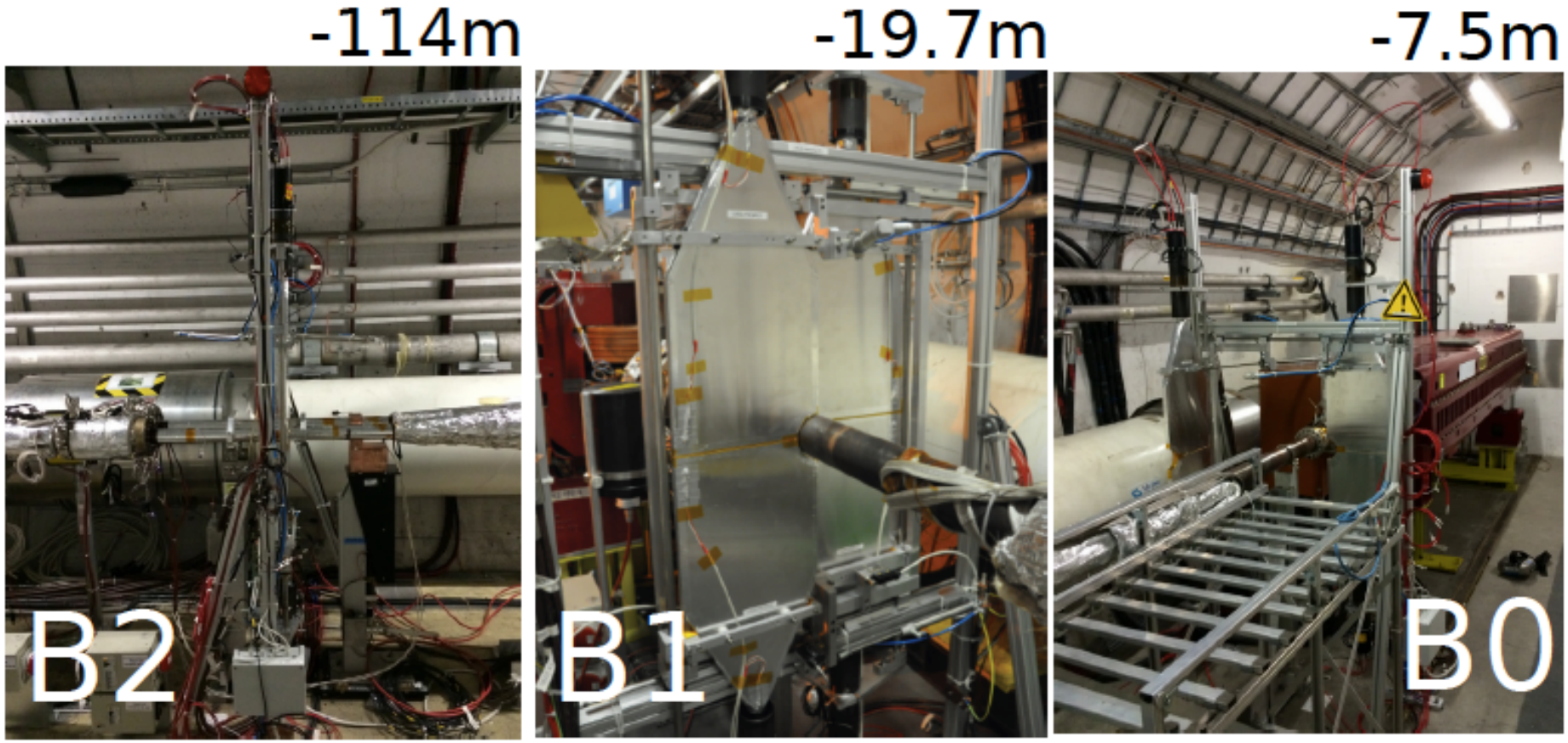
- Increase rapidity gap with scintillators in forward region
- Use existing electronics



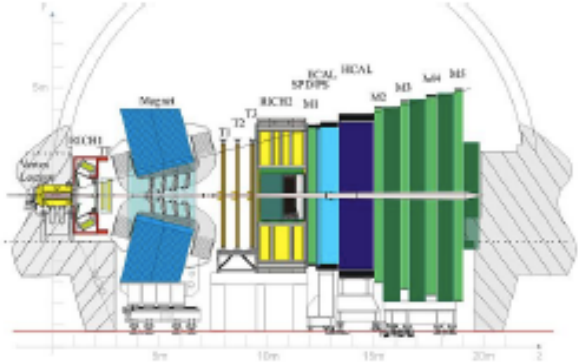
Scintillators and PMTs

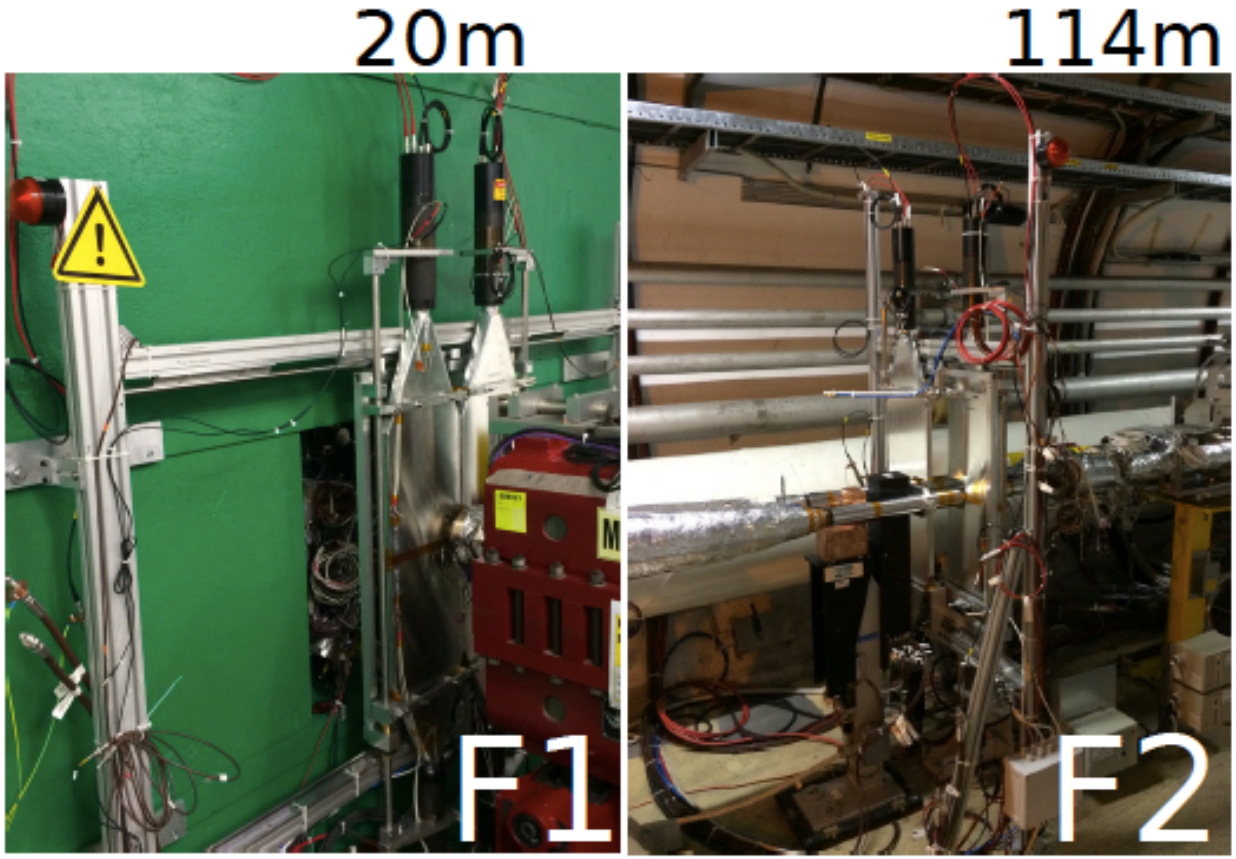
Backward Stations

Installation finished in 2014



Forward Stations

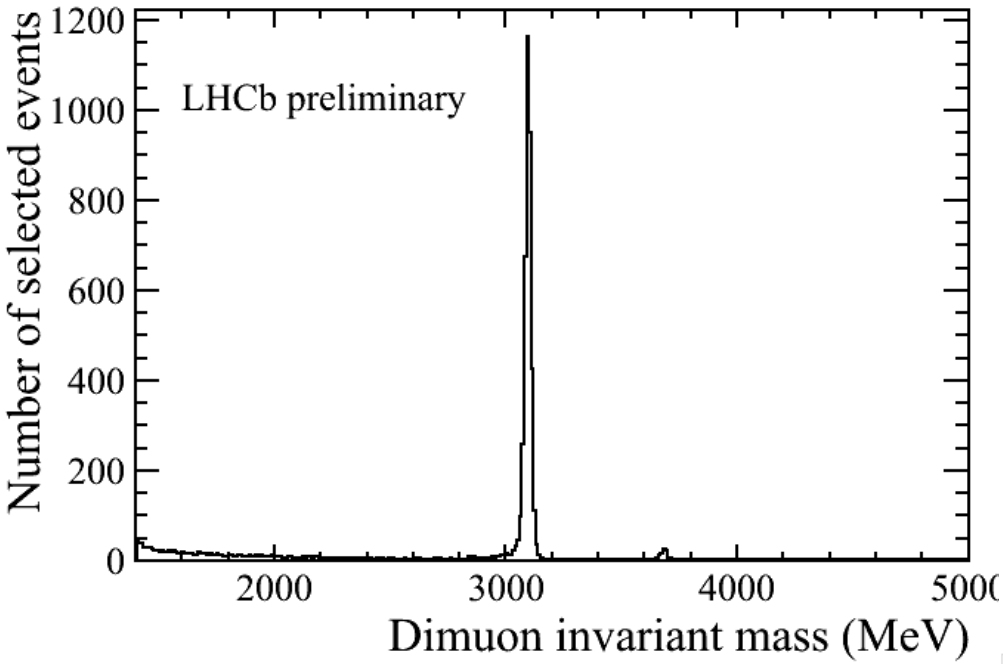


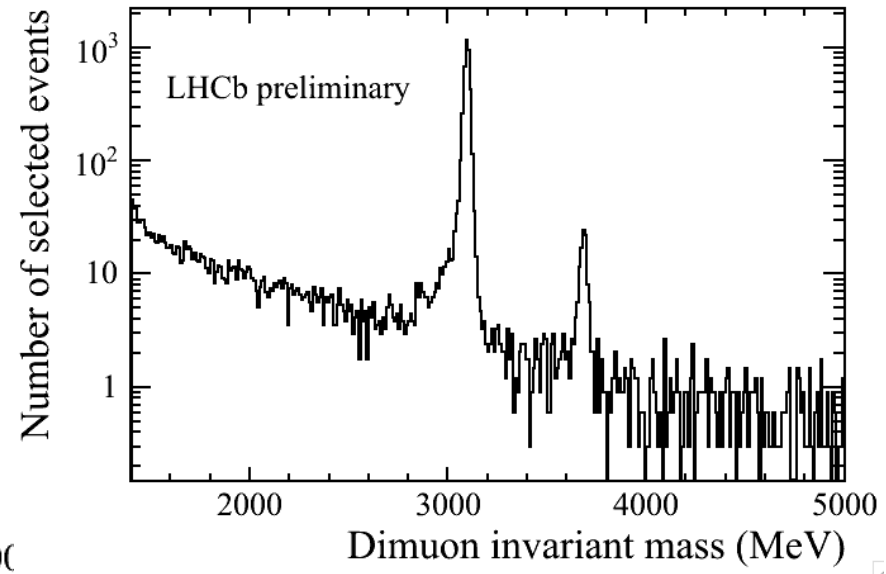


~200 pb^{-1} of data available with stable calibrations

J/ψ analysis at 13 TeV

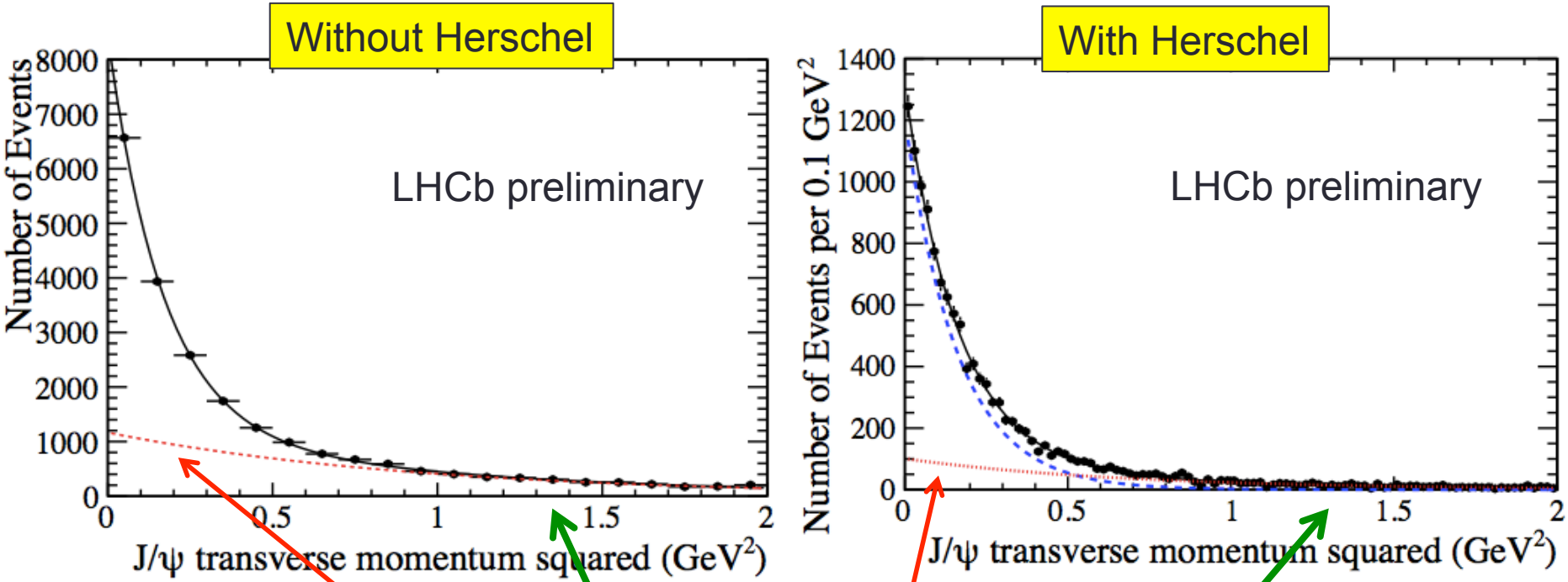
Essentially same prescription as 7 TeV but include Herschel as veto on activity
Increases rapidity gap from 5 units to 11.





J/ψ analysis at 13 TeV

Approximate halving in background coming from proton dissociation below 0.8 GeV^2



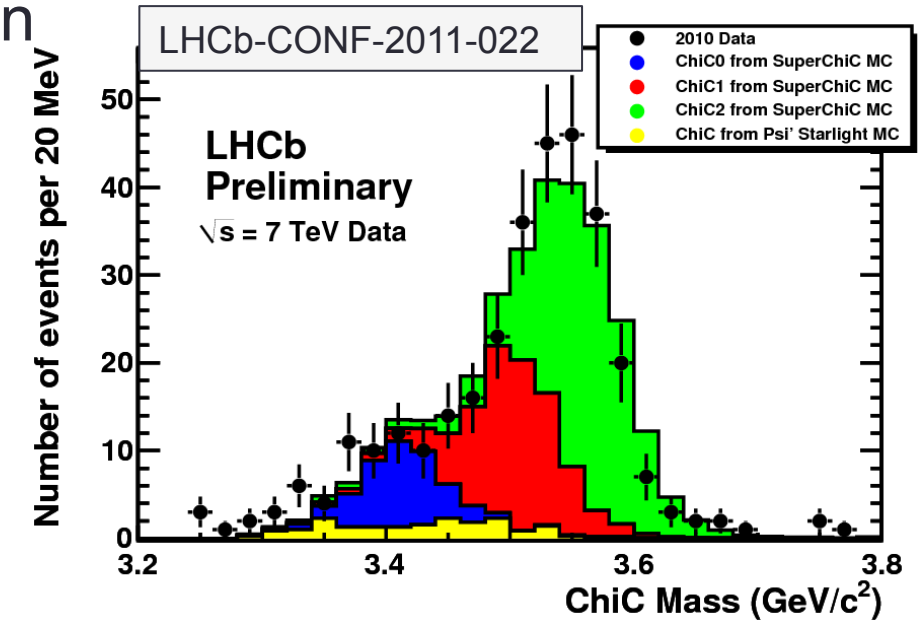
Estimate of proton dissociation background

Strong suppression of non-elastic events

Future Analyses

- Priority: χc production

- Difficult resolving 3 states
- Finding dissociative contribution



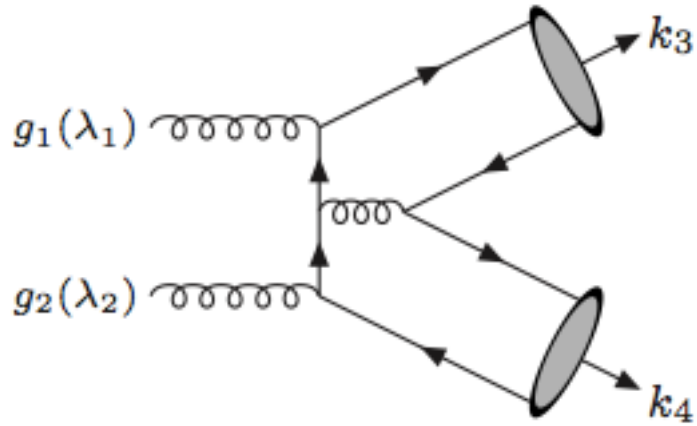
- Look in hadronic modes
- Use Herschel to understand proton dissociation

Future Analyses

- Low mass spectroscopy using ππ and KK modes.

- Hadronic triggers allow us almost go down to ππ threshold.
- Very good particle ID

- Some hope for ηη using EM triggers
- DD modes possible using hadronic triggers
- Might be good laboratory to study exotics



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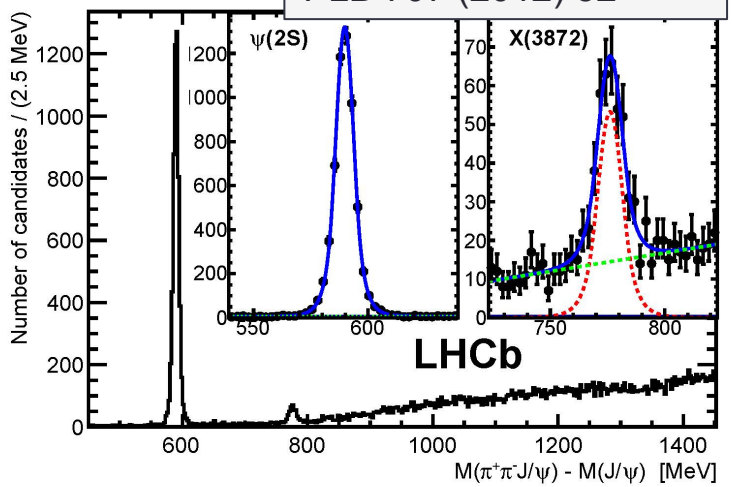

Conclusions

- Measurements to date use muon final states
- Identified biggest obstacle to progress and installed new detector
- Calibration and understanding of Herschel improving weekly.
-
- J/ψ 13 TeV result will be available shortly with a lot more to follow.