

# Central Exclusive Production of $J/\psi$ and $\psi(2S)$ at 13 TeV (and future CEP prospects for LHCb)



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ECT workshop on forward physics  
26-29 September 2016.

# Outline

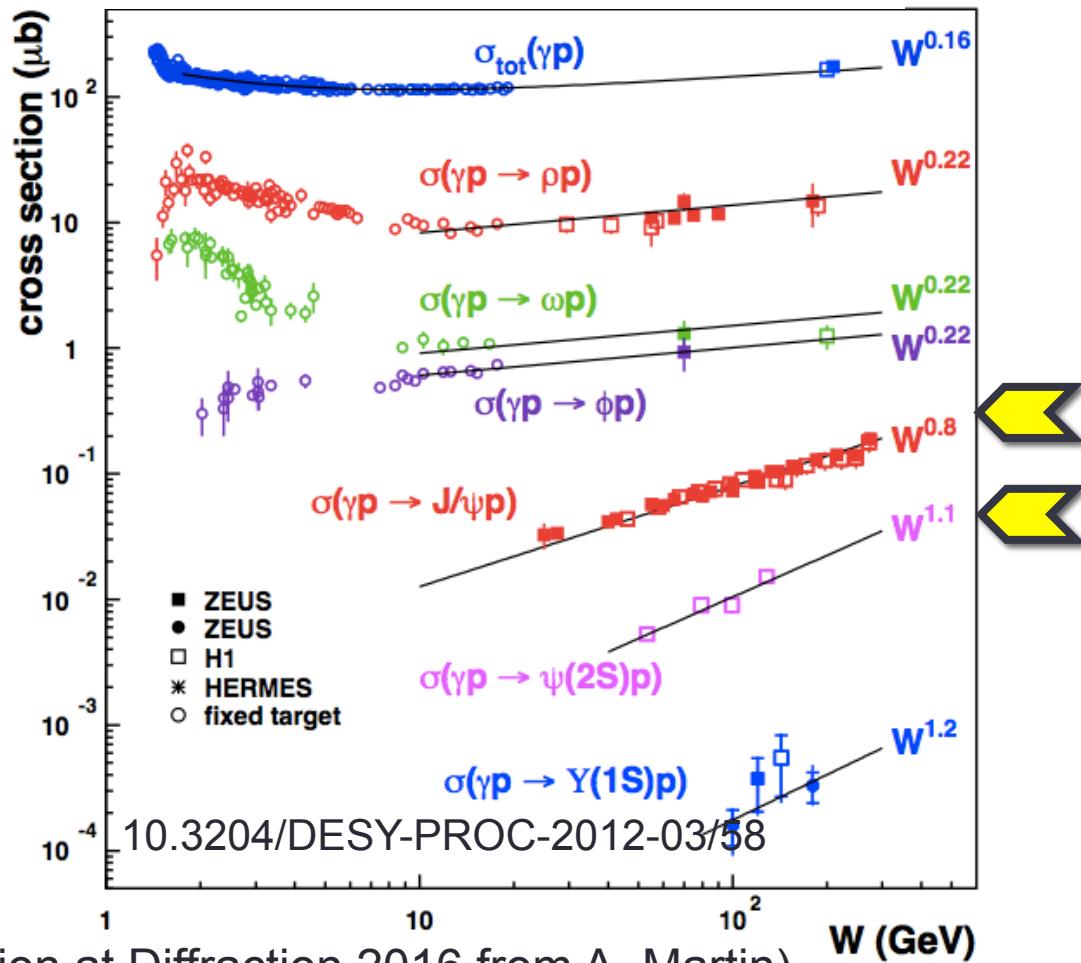
- Limitation for CEP using 7 TeV data
- New detector
- Measurement of exclusive  $J/\psi$  at 13 TeV
- Prospects for (other) CEP in future

# HERA vector meson photo-production results

$$\frac{d\sigma}{dt} (\gamma^* p \rightarrow J/\psi p) \Big|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha} \left[ \frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g(x, \bar{Q}^2) \right]^2 \left( 1 + \frac{Q^2}{M_{J/\psi}^2} \right)$$

Note:

- soft/hard transition
- $\sigma \sim x^\lambda$
- $g(x, Q^2)$   
(down to  $x=2E-6$ )



(Theory status: see presentation at Diffraction 2016 from A. Martin)

# Extraction of gluon PDF

See Alan Martin,  
Diffraction 2016, Catania.

## Problems of using exclusive $J/\psi$ data in global PDF fits?

### 1. Process described by GPD's

→ however not a problem for  $\xi \ll x \ll 1$

$$GPD(x, \xi) = PDF(x) \times \text{Shuvaev transform}$$

hep-ph/9902410

### 2. Bad convergence of LO, NLO,... pert. series in collinear factorization at low $\xi$ and low scales

## Conclusion

Subtract<sup>n</sup> of  $NLO(|q^2| < Q_0^2)$  plus choice  $\mu_F = M_\psi/2$   
(no double counting) (resum of double logs)

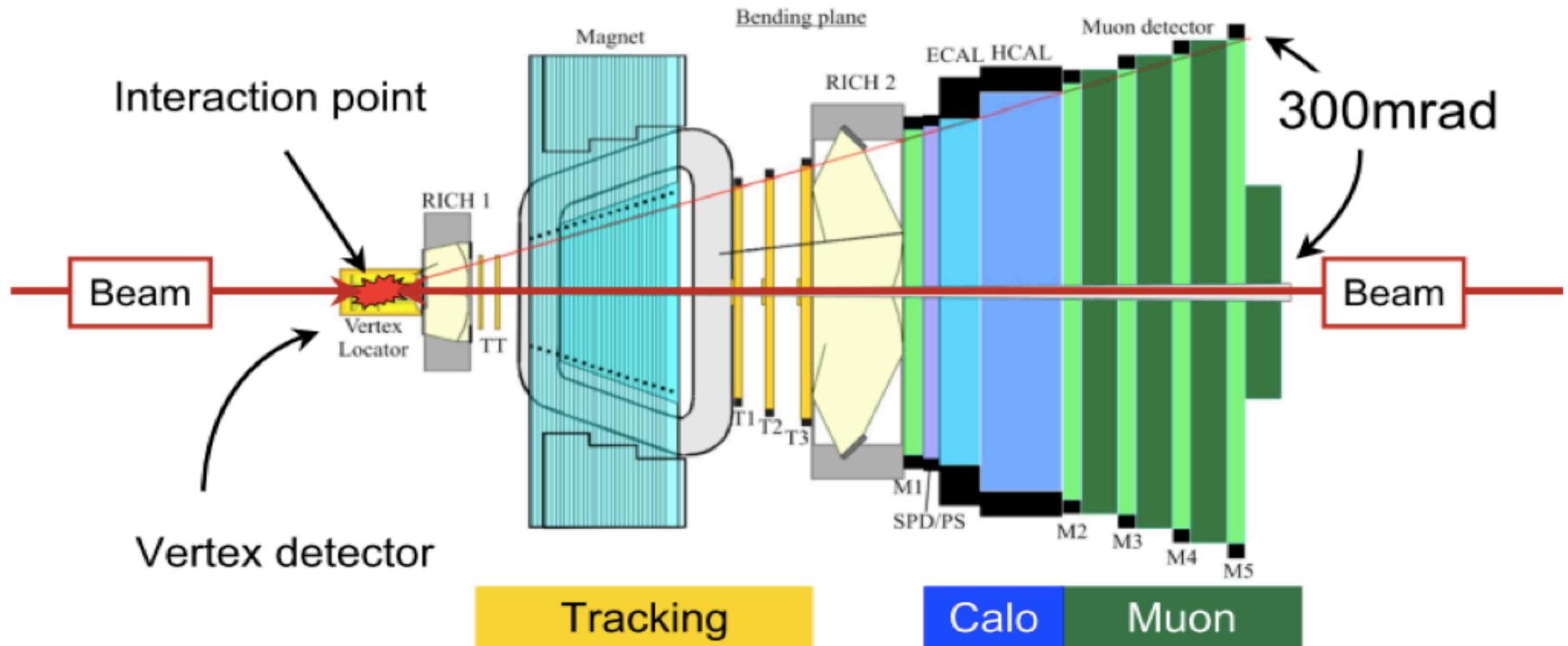
leads to small NLO correction & small residual scale ( $\mu_f$ ) dependence --- so provides reasonable accuracy for the NLO  $pp \rightarrow p + J/\psi + p$  amplitude in the collinear (MS( $\bar{b}$ )) fact<sup>n</sup> scheme,

and opens the possibility of such high precision data in the forward  $J/\psi$  direction being used in global parton analyses to determine the low  $x$  gluon PDF

# Central Exclusive Production of J/ $\psi$ and $\psi(2S)$ mesons

Data-taking year	Energy	Integrated Luminosity	Paper
2010	7 TeV	37 pb <sup>-1</sup>	JPG 40 (2013) 045001
2011	7 TeV	930 pb <sup>-1</sup>	JPG 41 (2014) 055002
2015	13 TeV	204 pb <sup>-1</sup>	LHCb-CONF-2016-007

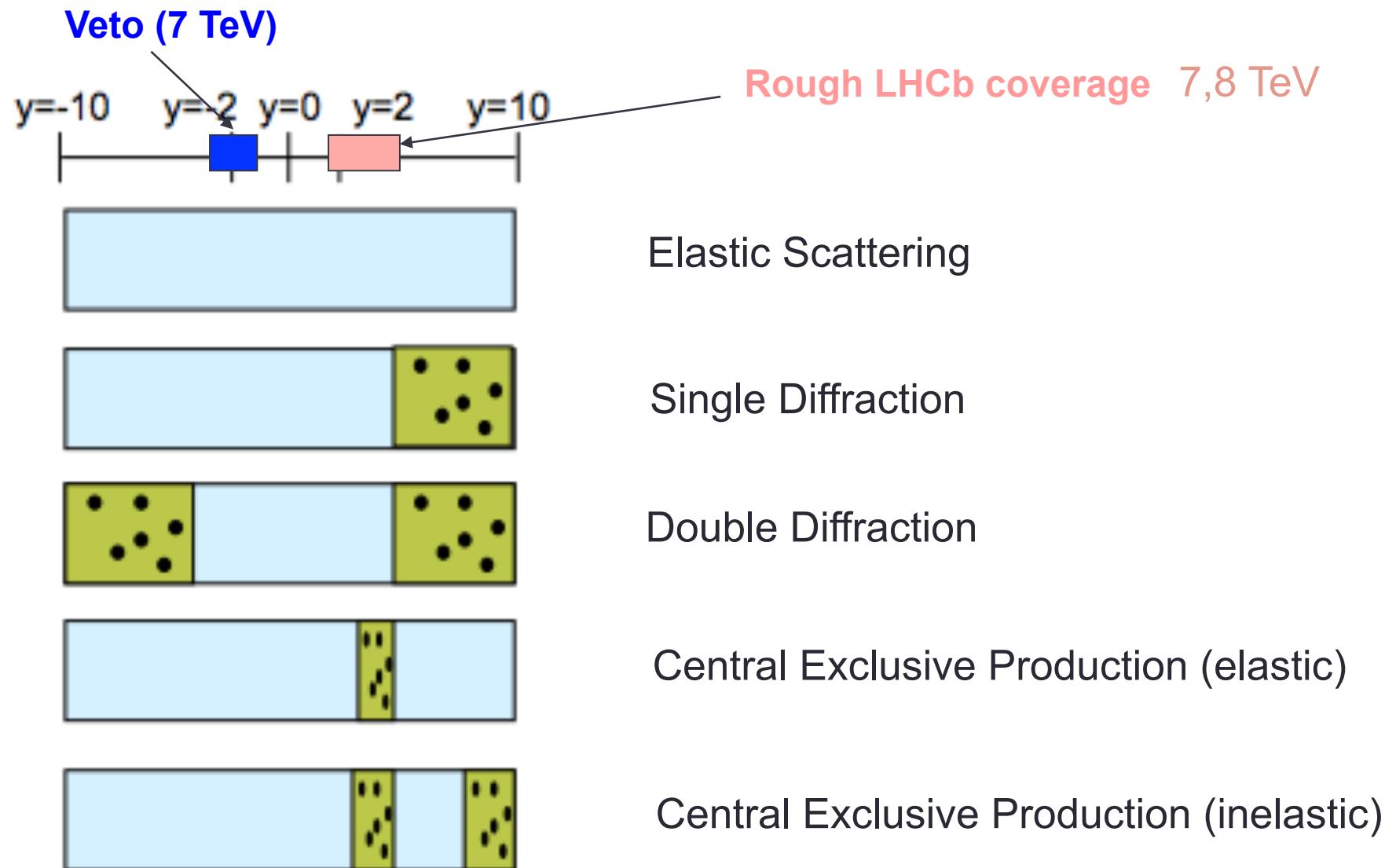
# The LHCb detector

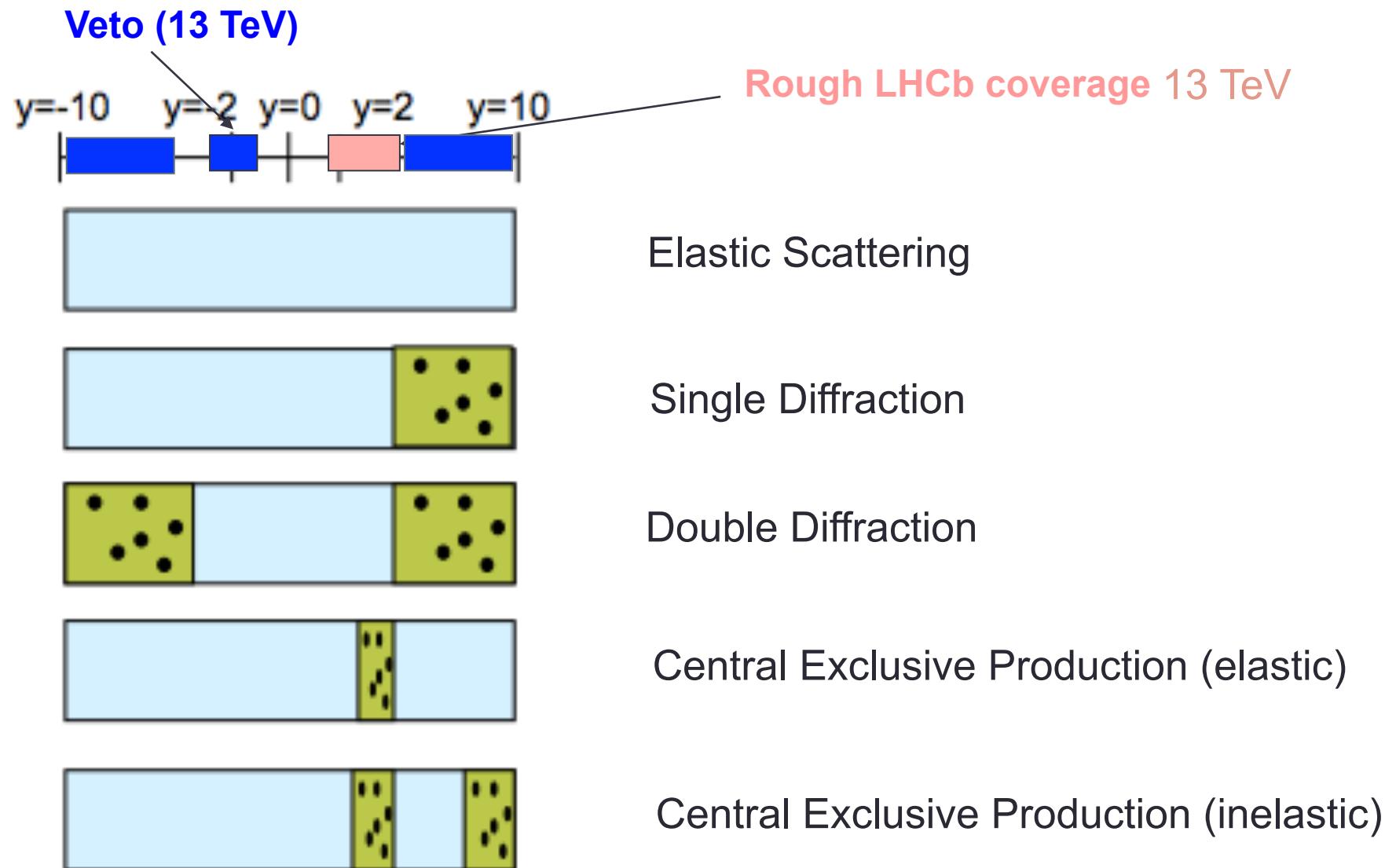


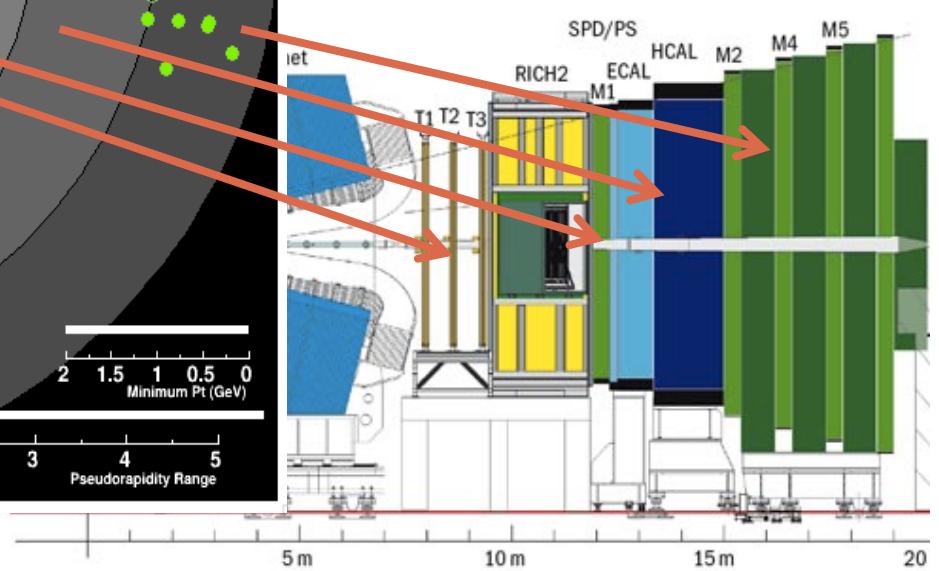
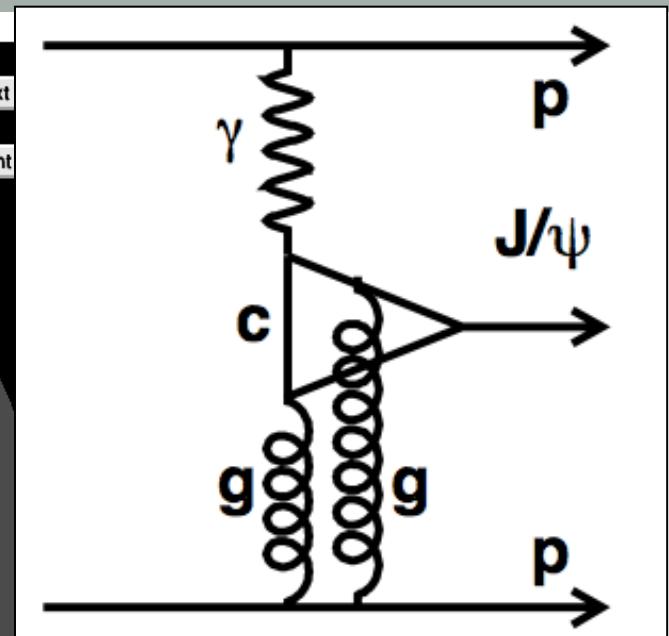
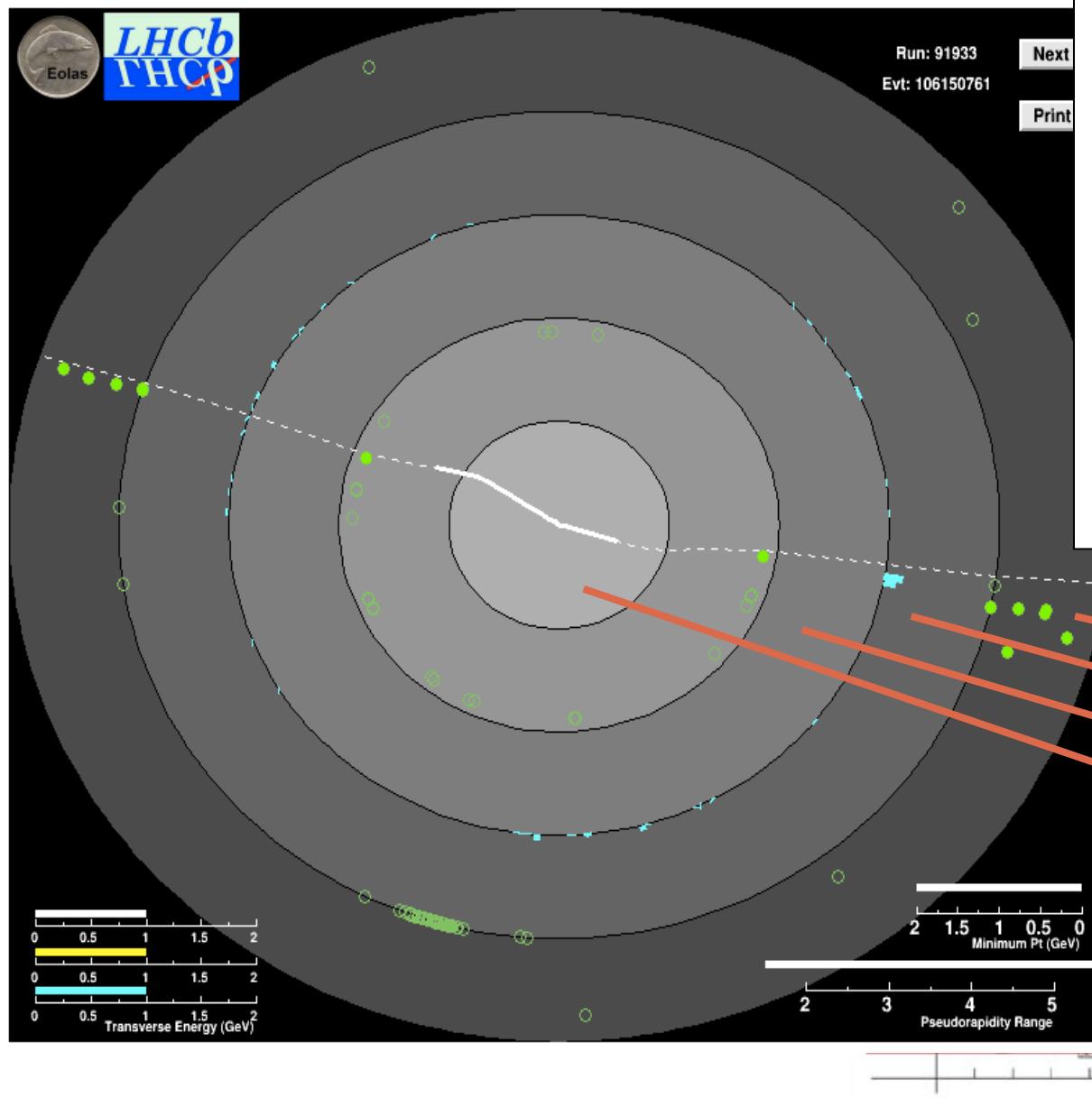
Fully instrumented:  $2 < \eta < 5$

Veto region (< 2015):  $-3.5 < \eta < -1.5$

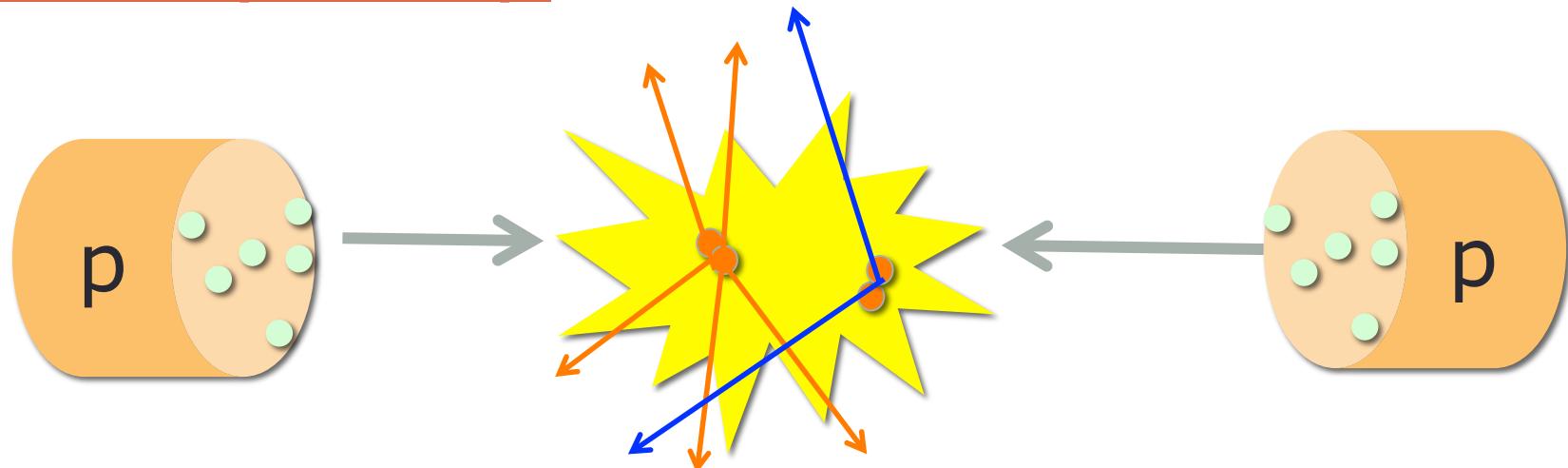
Veto region ( $\geq 2015$ ):  $-10 < \eta < -5, 5 < \eta < 10$







# Beam pile-up



High luminosity requires  
multiple proton interactions per  
beam-crossing.

Number of interactions (N) /crossings,  
distributed

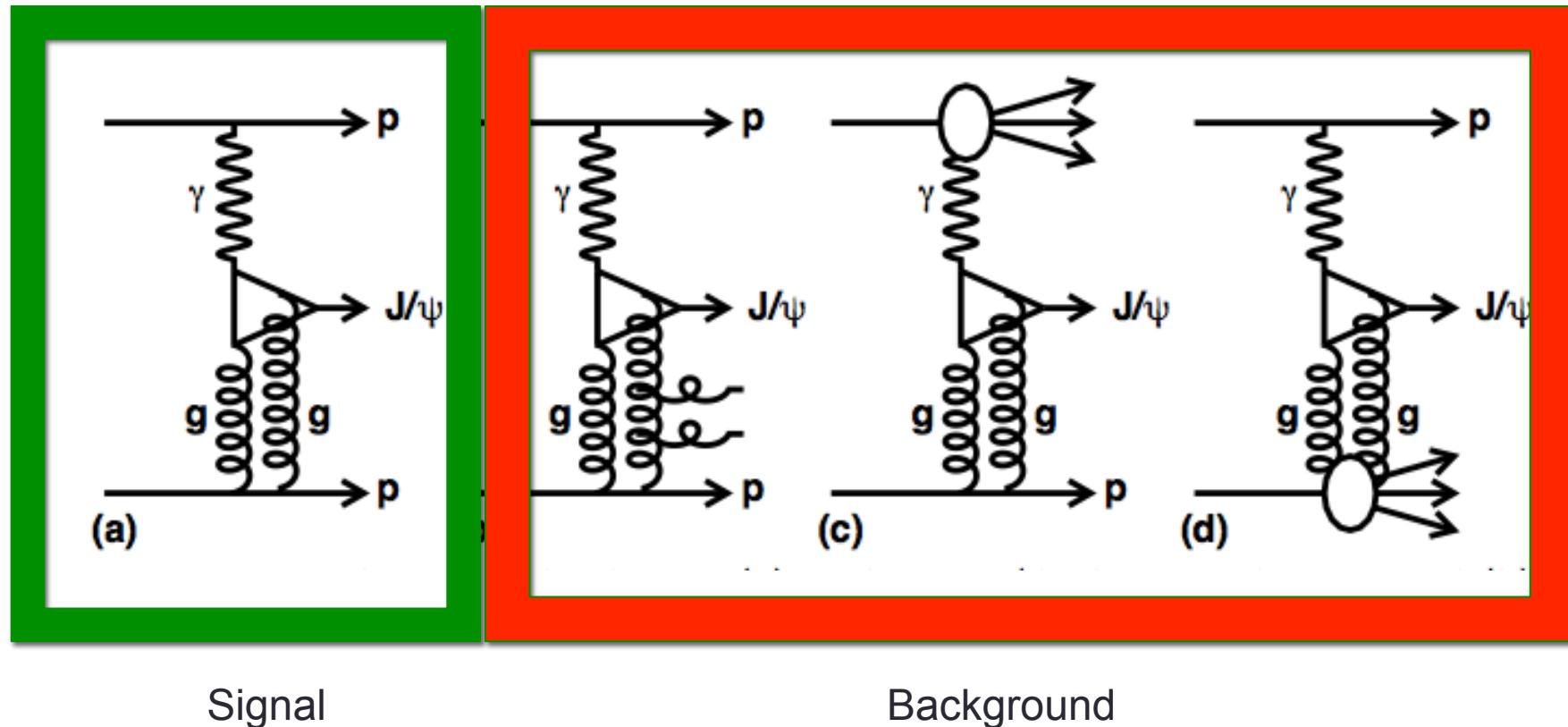
$$f(N) = \frac{e^\mu \mu^N}{N!}$$

Average #interactions

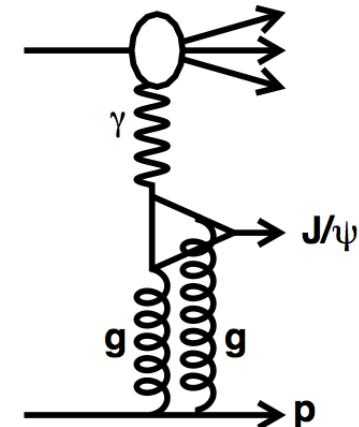
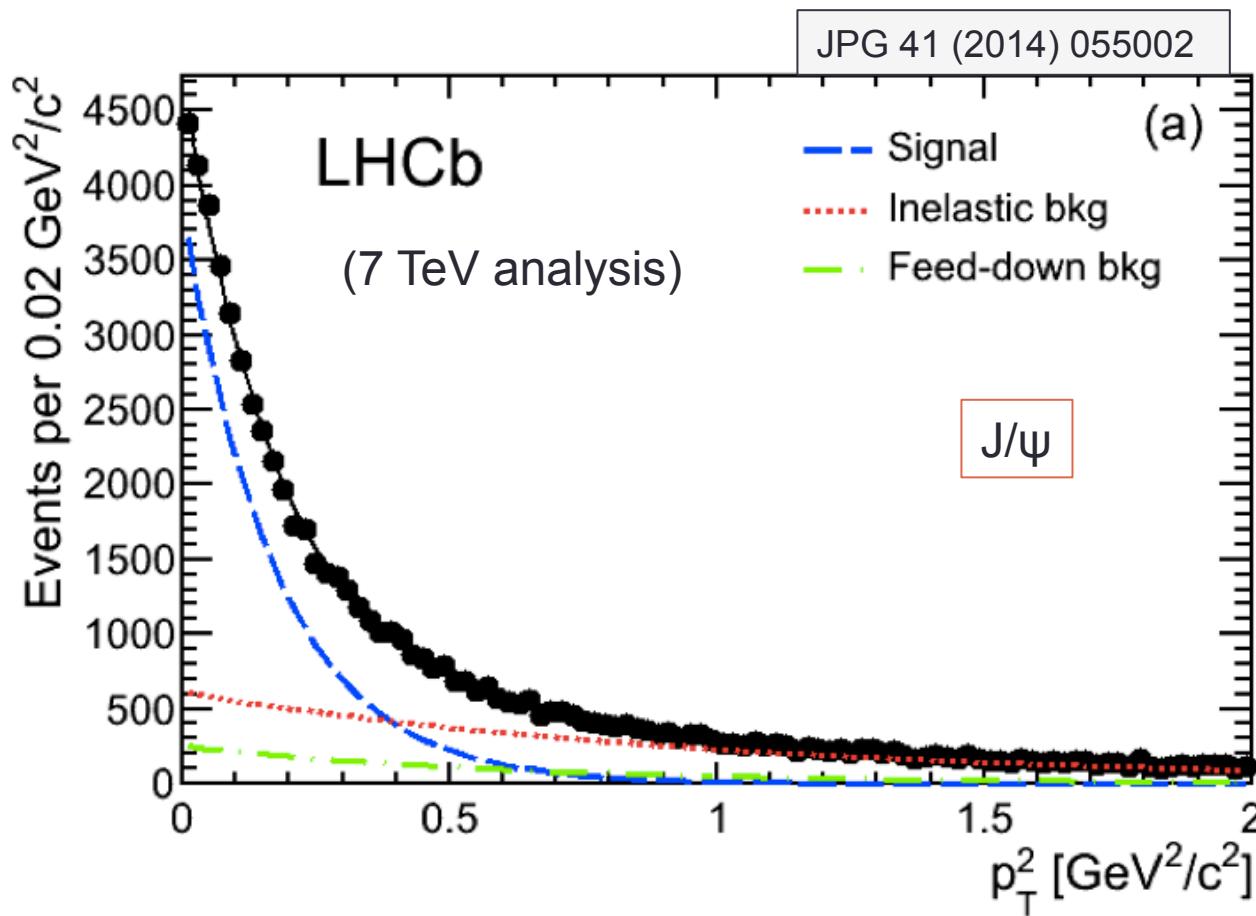
For LHCb in 2011,  $\bar{\mu}=1.4$   
(25% of interactions useful)

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

# Inelastic background



# Inelastic background $J/\psi$



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

HERA measured:

$b_s = 4.9 \text{ GeV}^{-2}$   
 $b_{pd} = 1.1 \text{ GeV}^{-2}$

LHCb Expect:

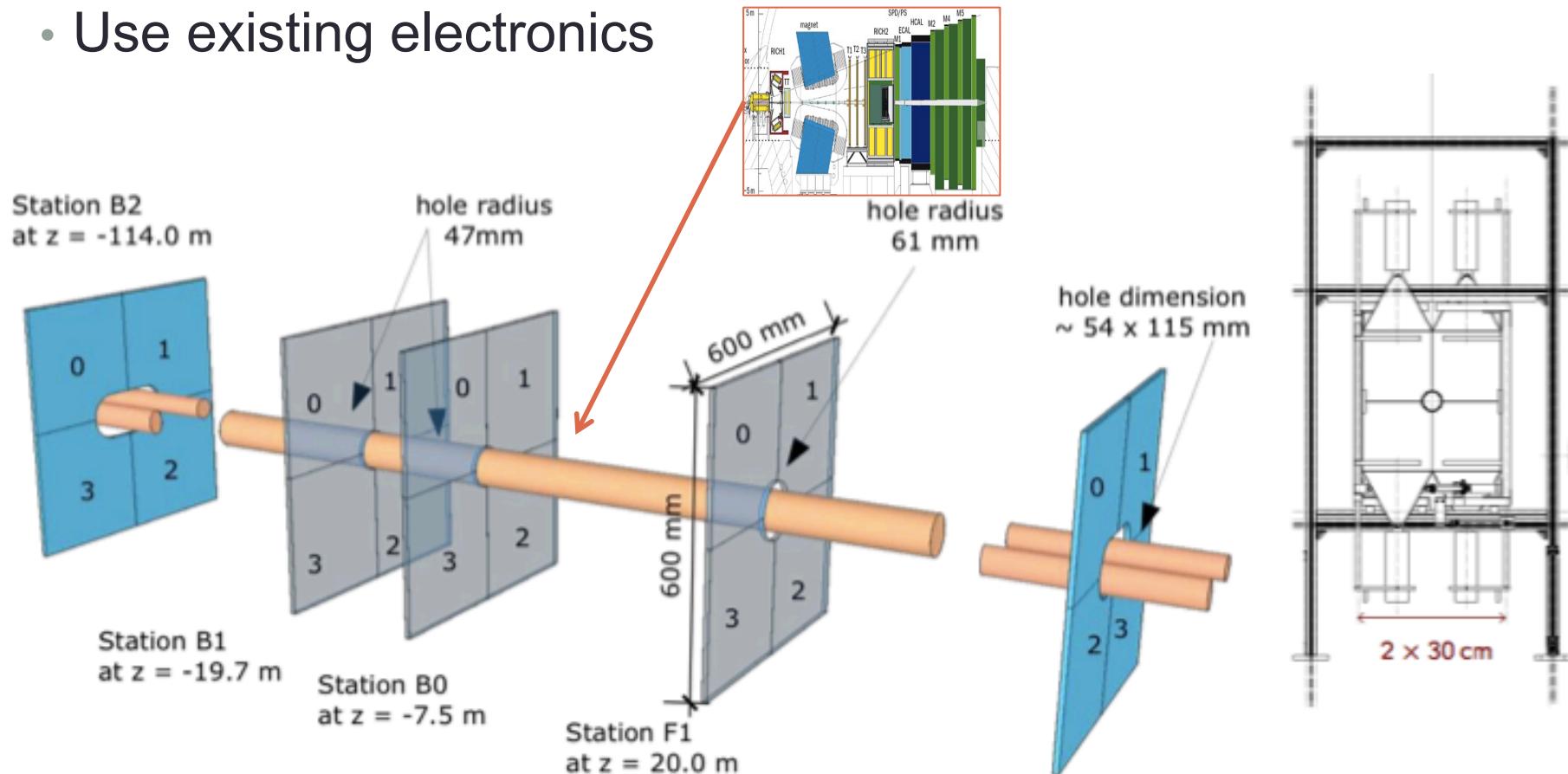
$b_s \sim 6 \text{ GeV}^{-2}$   
 $b_{pd} \sim 1 \text{ GeV}^{-2}$

LHCb Fit:

$b_s = 5.70 \pm 0.11 \text{ GeV}^{-2}$   
 $b_{pd} = 0.97 \pm 0.04 \text{ GeV}^{-2}$

# High rapidity shower counters for LHCb

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



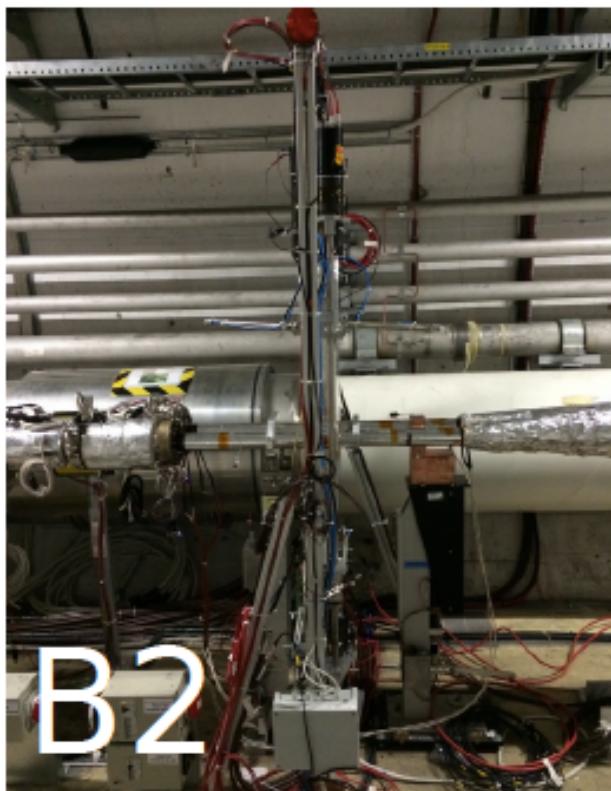
# Scintillators and PMTs



# Backward Stations

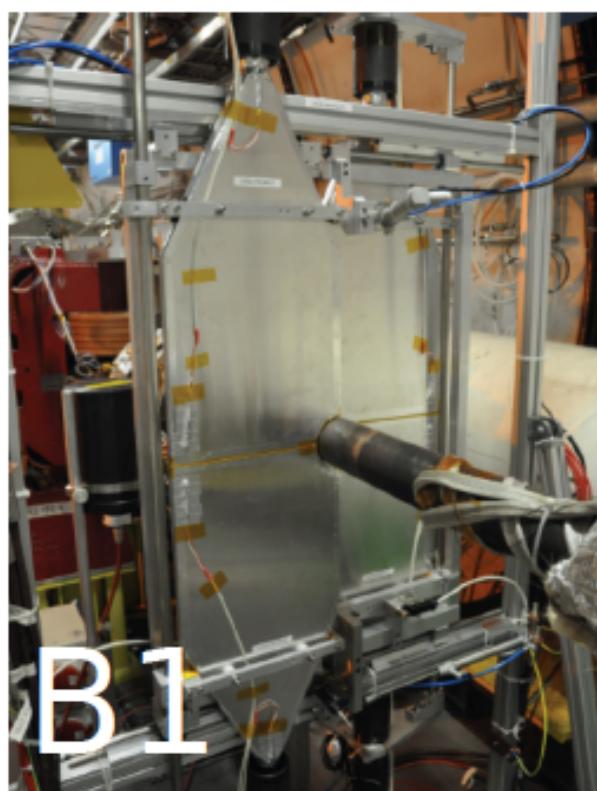
Installation finished in 2014

-114m



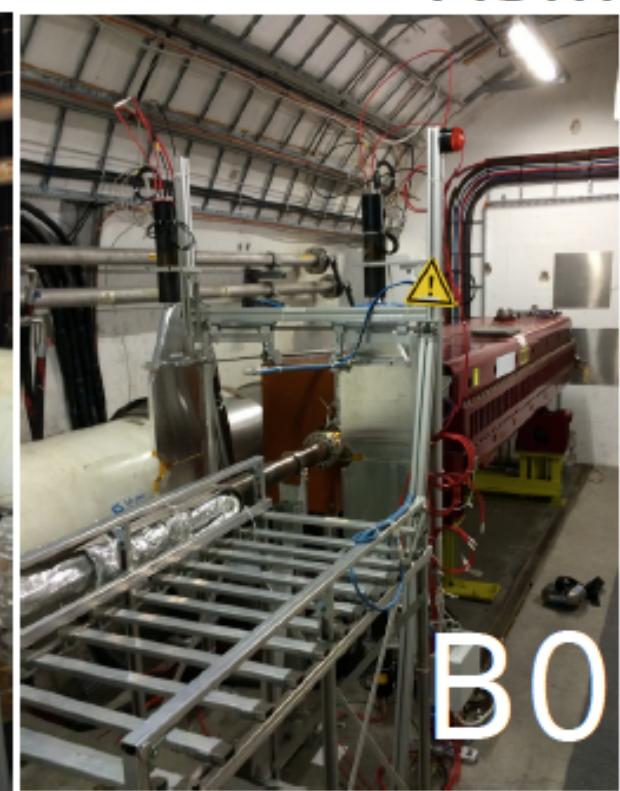
B2

-19.7m



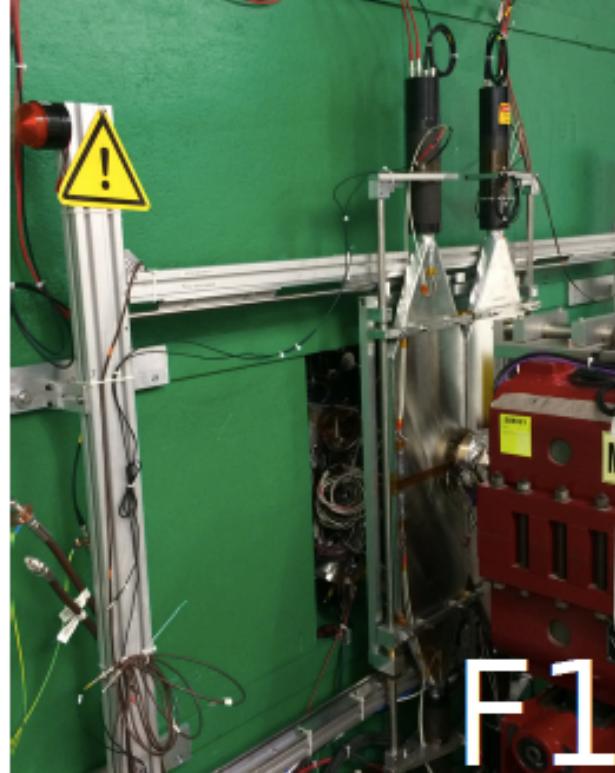
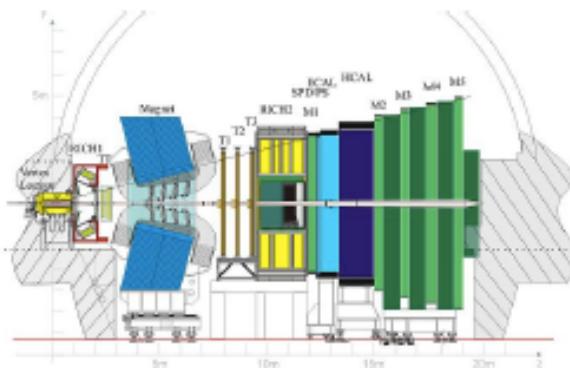
B1

-7.5m

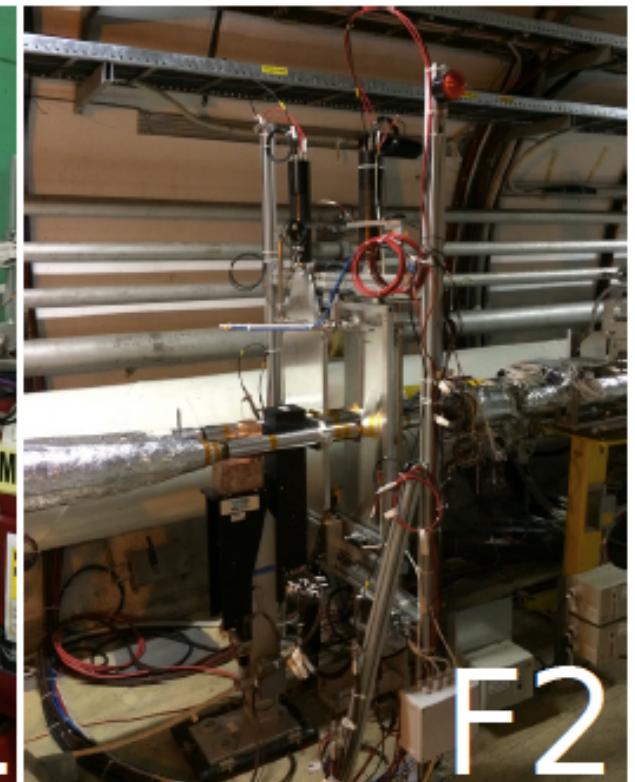


B0

# Forward Stations



20m



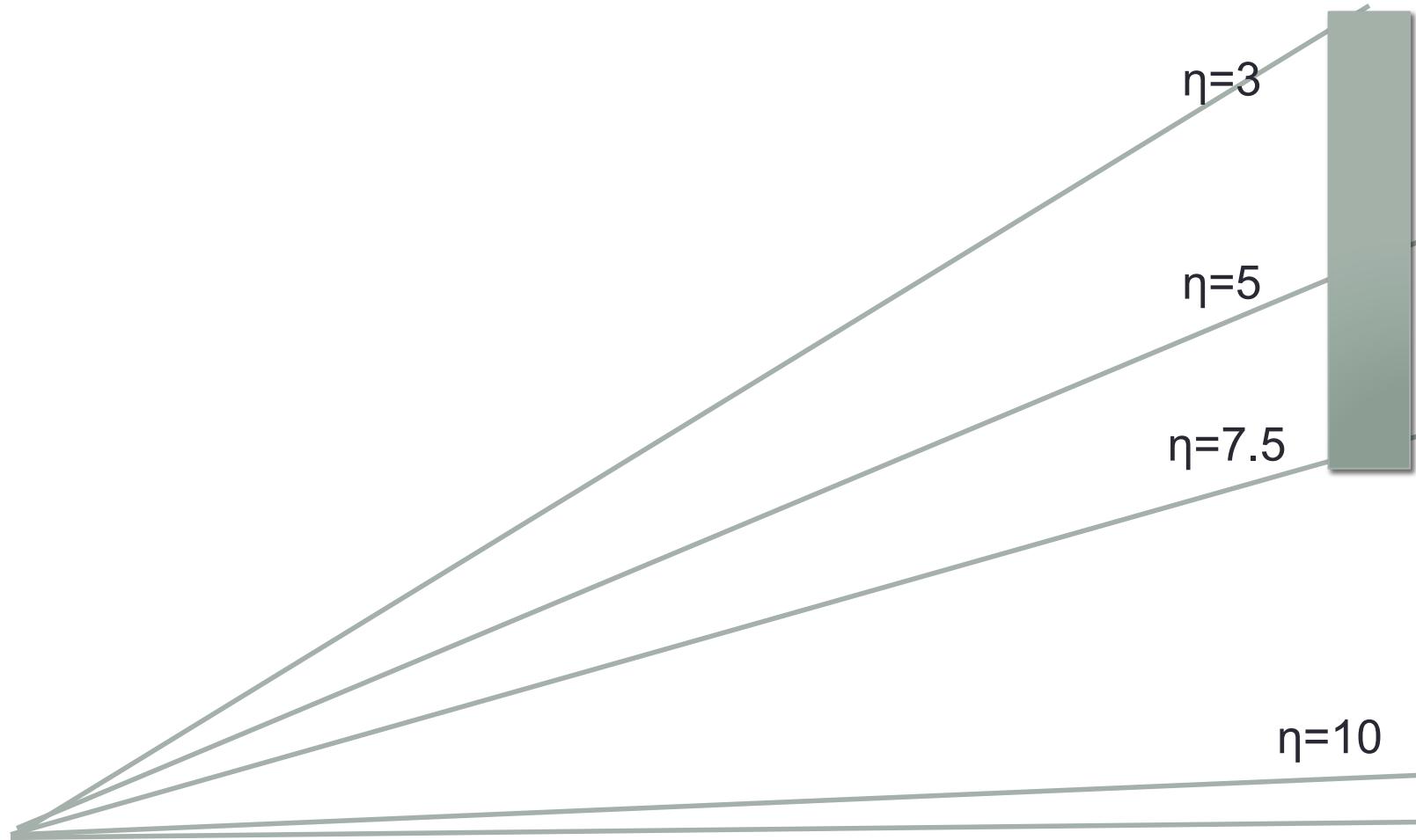
114m

F1

F2

~200 pb<sup>-1</sup> of data available with stable calibrations

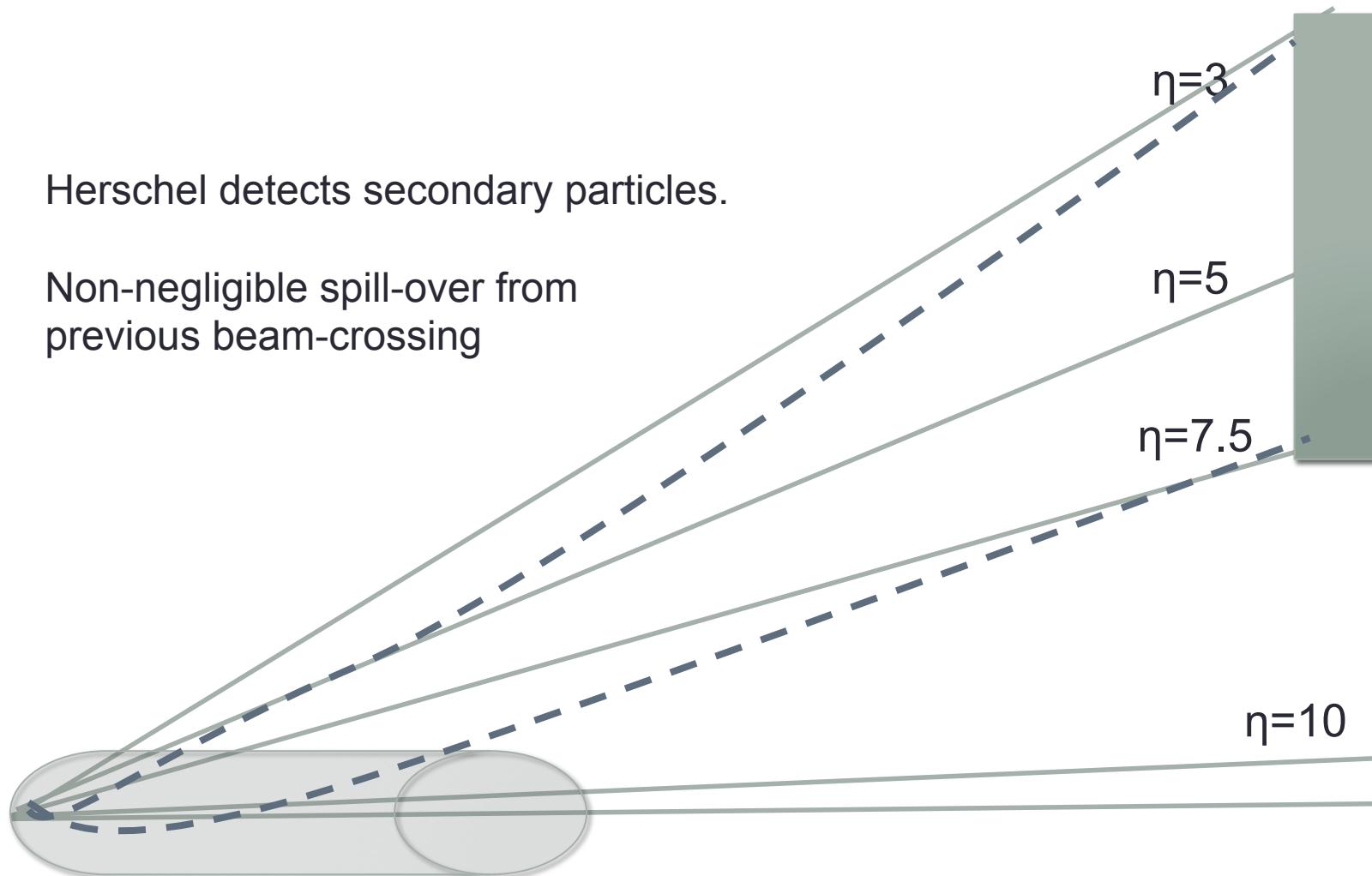
# Pseudorapidity reach of Herschel



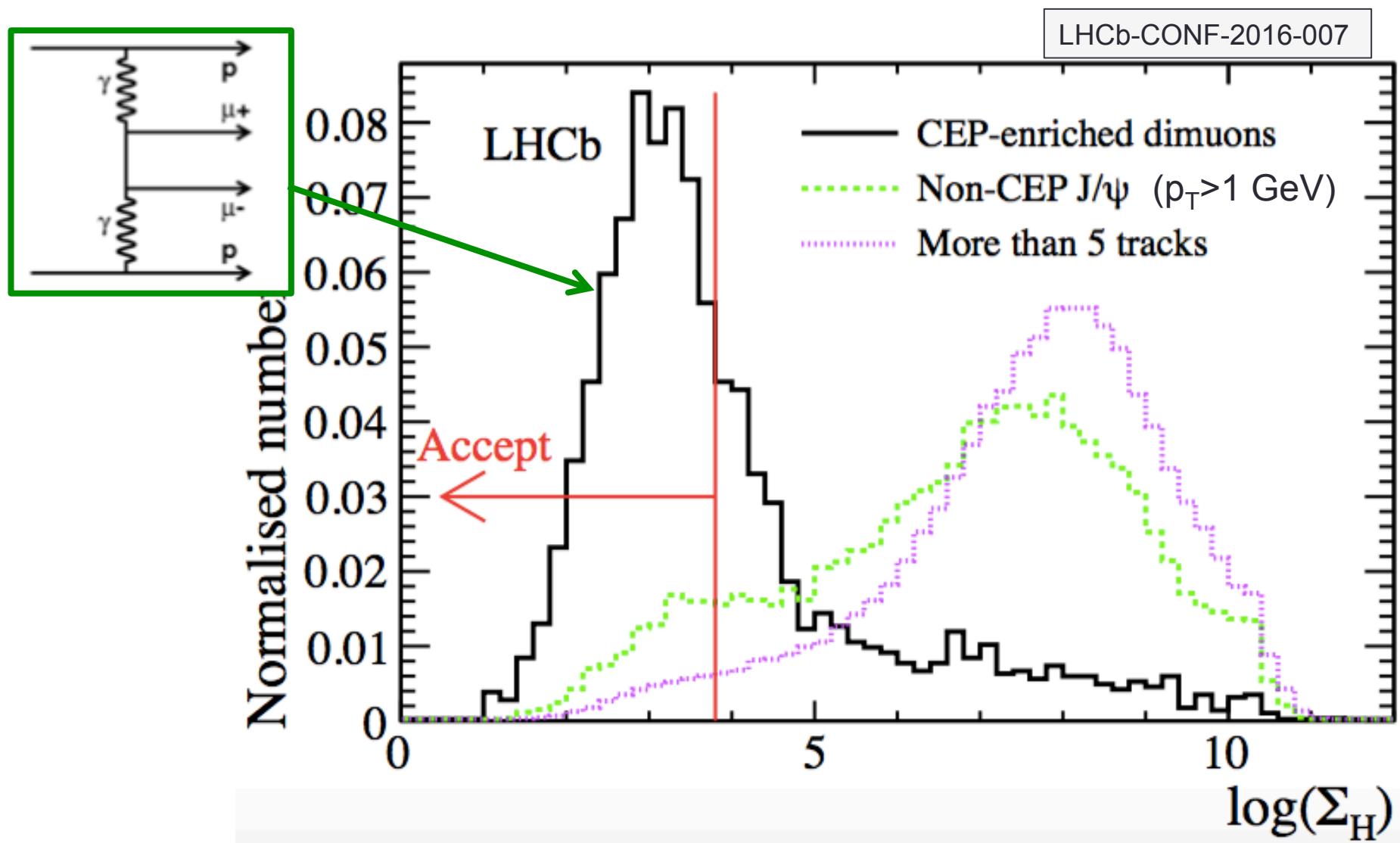
# Pseudorapidity reach of Herschel

Herschel detects secondary particles.

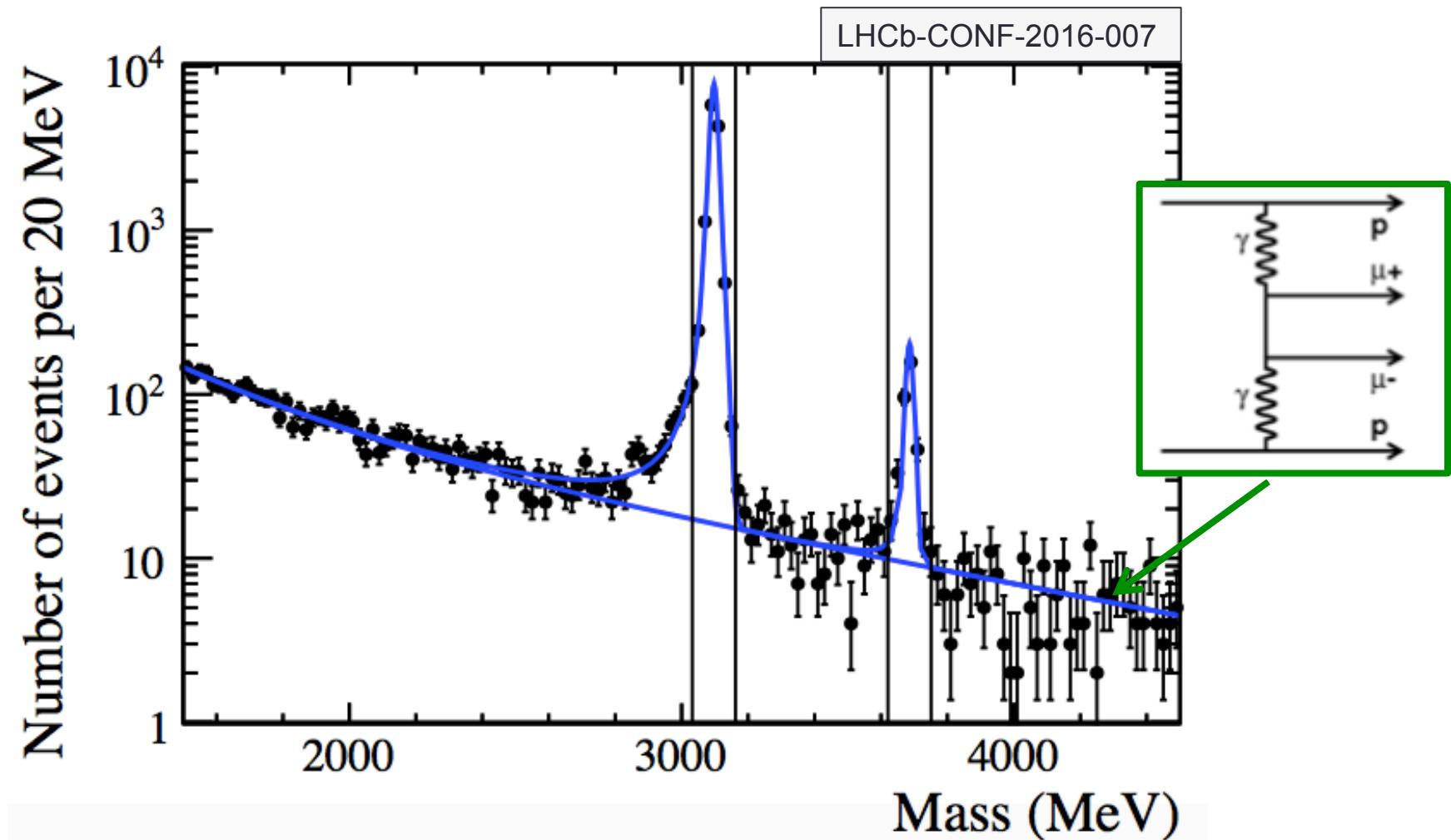
Non-negligible spill-over from  
previous beam-crossing



# Sum Herschel deposits in quadrature



# Non-resonant background very small



Distributions not background-subtracted.  
12992  $J/\psi$  and 382  $\psi(2s)$

$L=208 \pm 4 \text{ pb}^{-1}$   
Average pile-up 1.08

# Cross-section measurement J/ψ / ψ(2S)

Purity: (found from data)

1. non-resonant bkg (1%)
2. Feeddown (6%)
3. Inelastic Jpsi production (21%)

Bkg HALVED FROM 7 TeV analysis

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

Number of events observed

Luminosity

Acceptance (MC)

Efficiency: (found from data)

1. Trigger
2. Tracking & muon id.
3. Single interaction beam-crossing
4. Herschel efficiency (from QED dimuons)

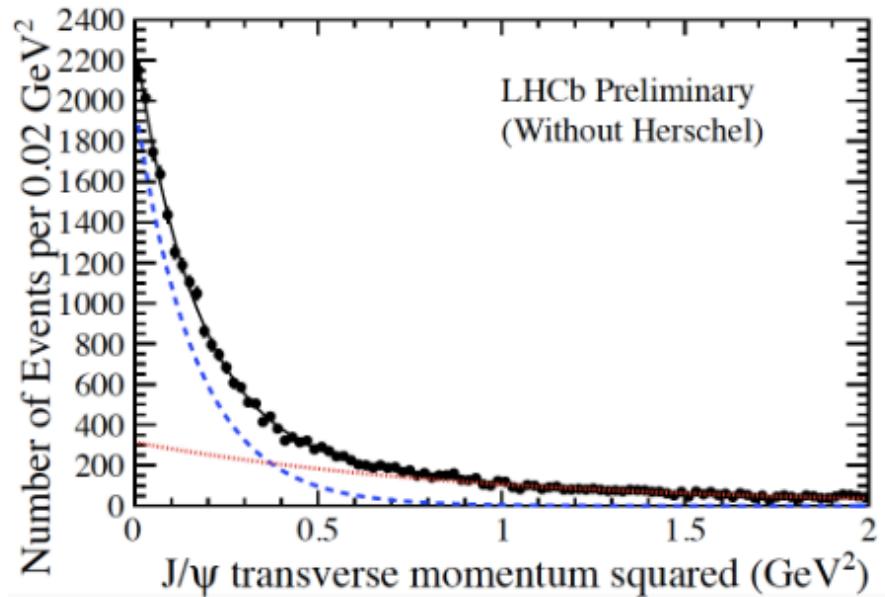
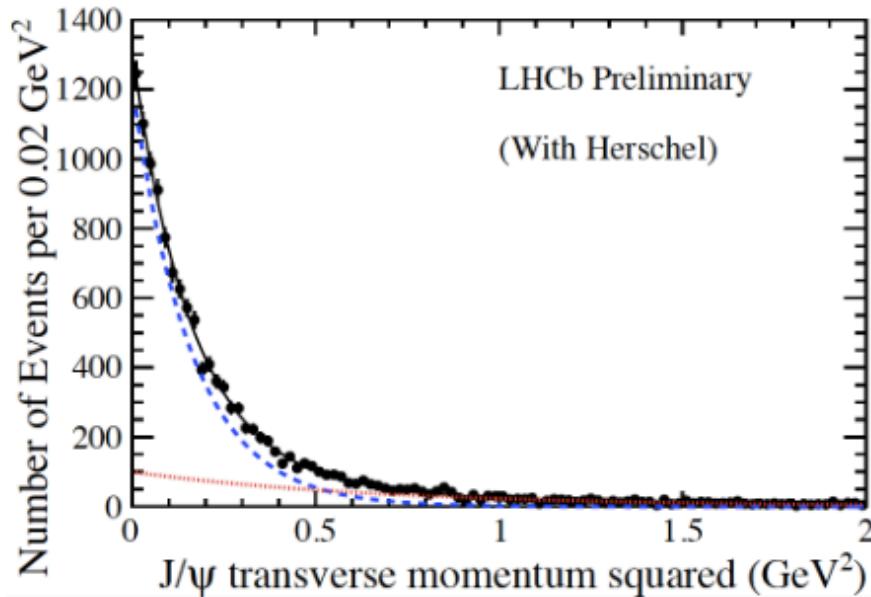
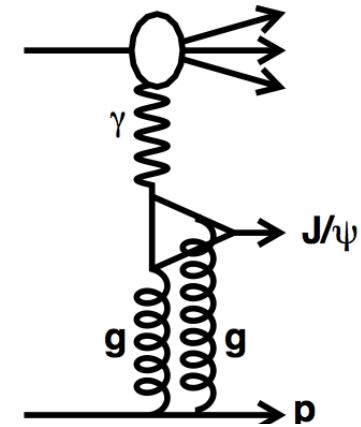
$$P(n) = \frac{\mu^n e^{-\mu}}{n!}$$

# Inelastic background J/ $\psi$

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

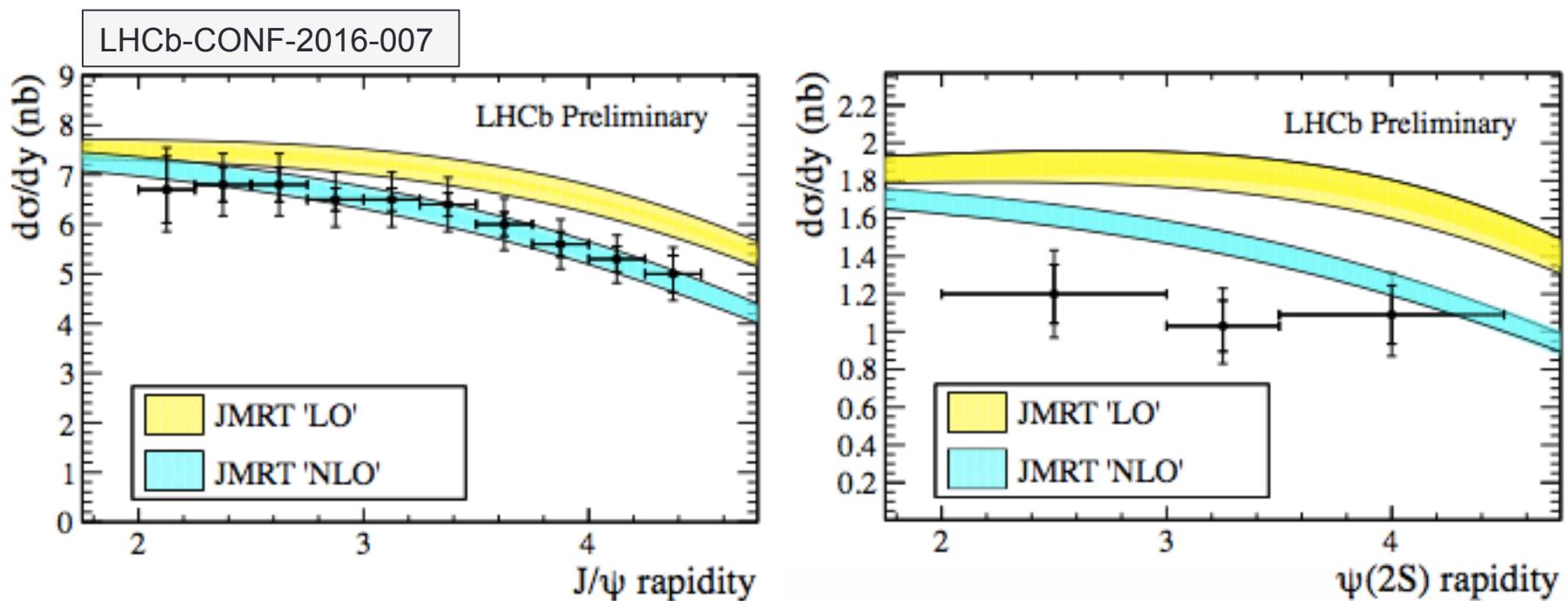
b-slope of signal is same with/without Herschel

b-slope of bkg changes (because you veto higher-pT events)



Consistent cross-section results with/without Herschel.  
Backgrounds roughly halved using Herschel

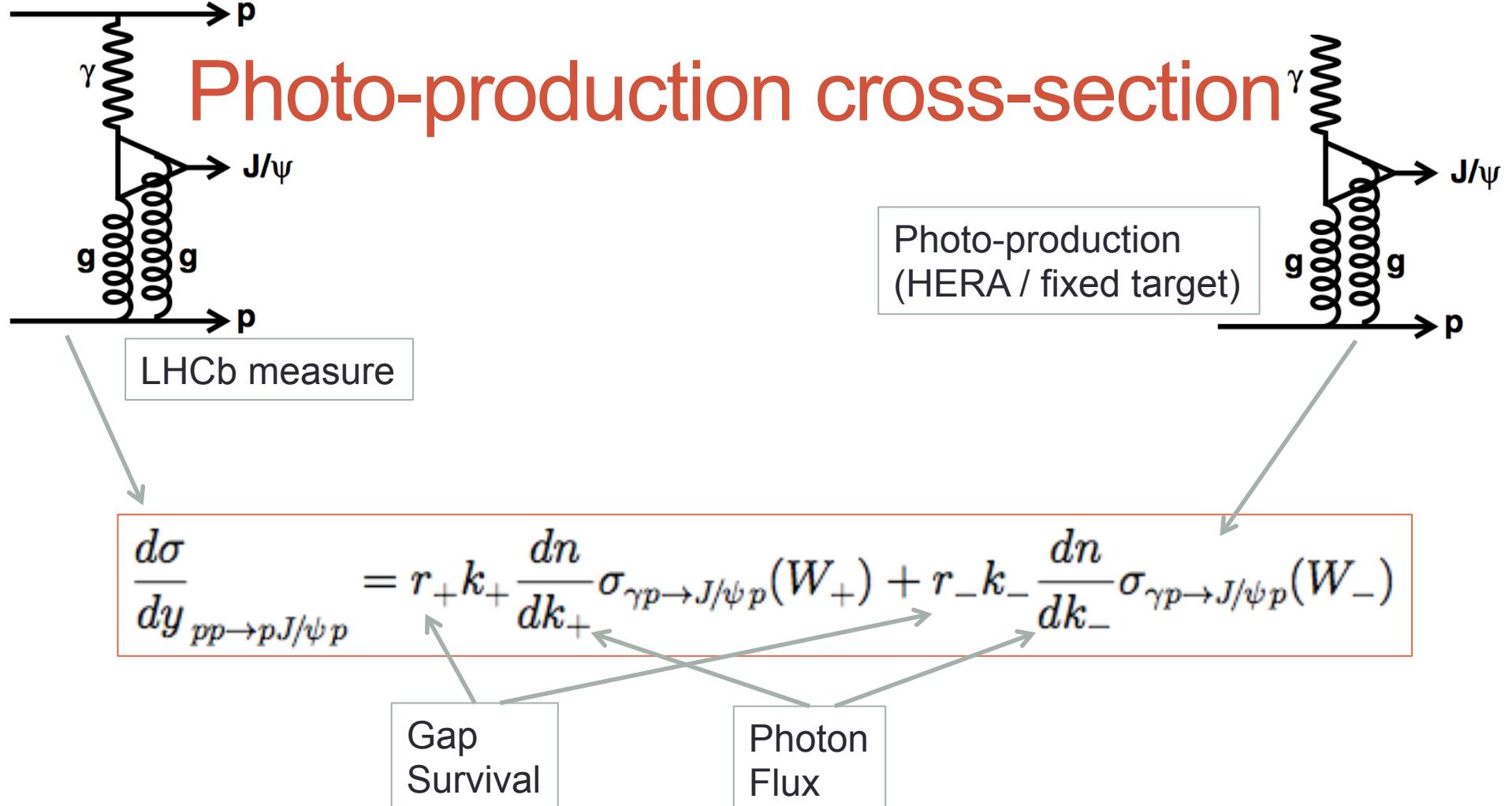
# Differential cross-sections J/ $\psi$ and $\psi(2S)$



NLO agrees better than LO

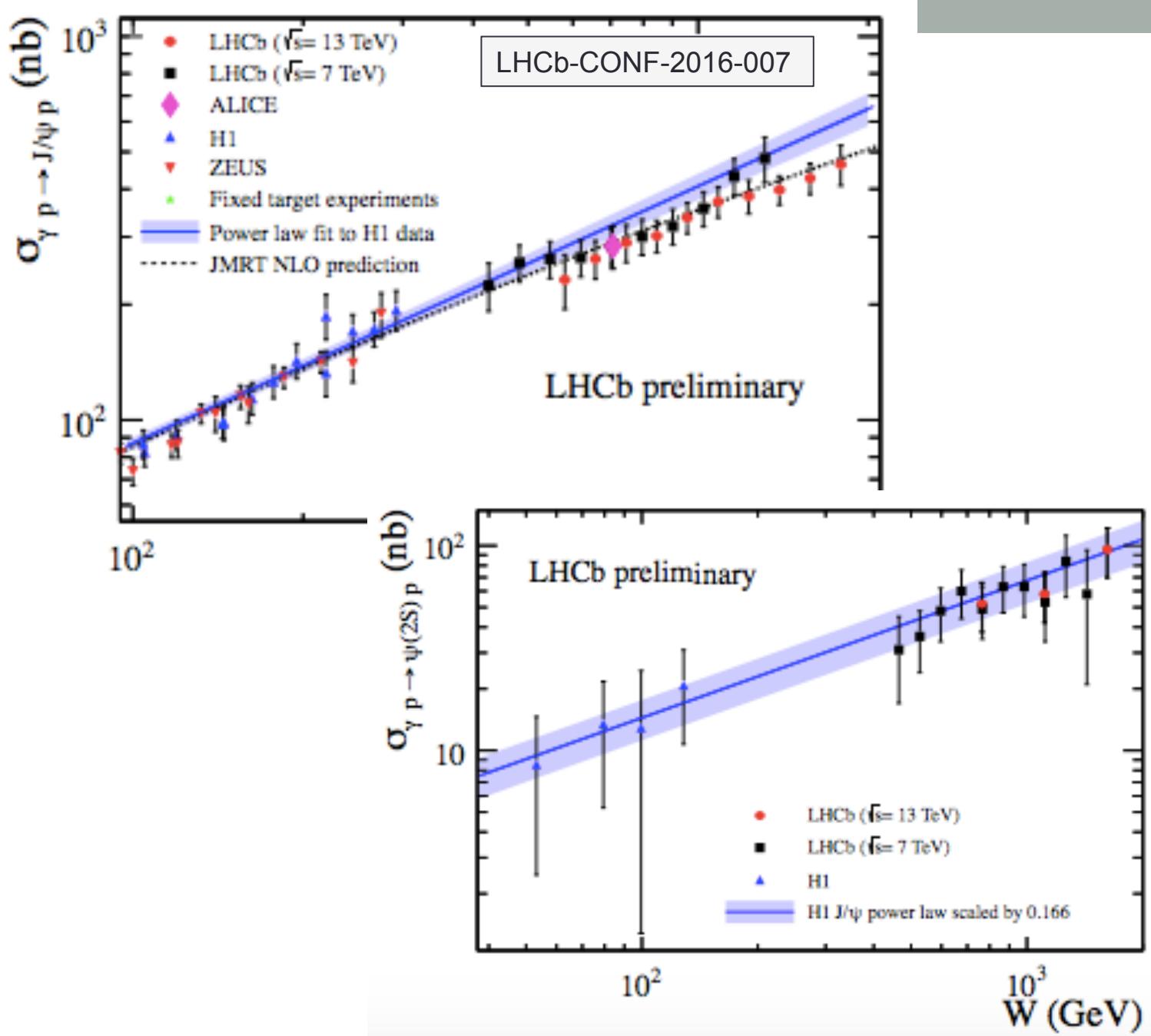
S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small  $x$  gluon via exclusive  $J/\psi$  and  $\Upsilon$  production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

S. P. Jones, A. D. Martin, M. G. Ryskin, and T. Teubner, *Predictions of exclusive  $\psi(2S)$  production at the LHC*, J. Phys. **G41** (2014) 055009, arXiv:1312.6795.



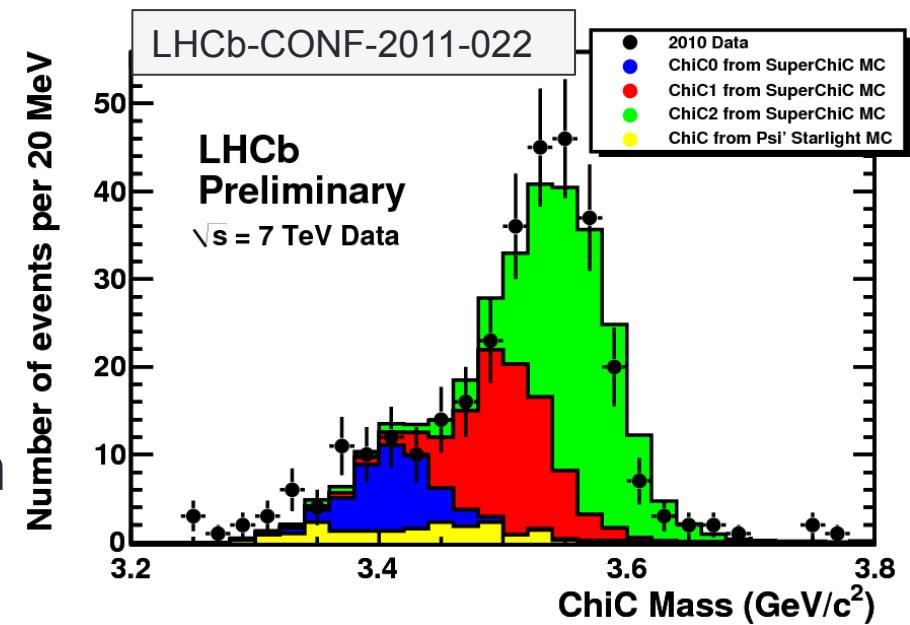
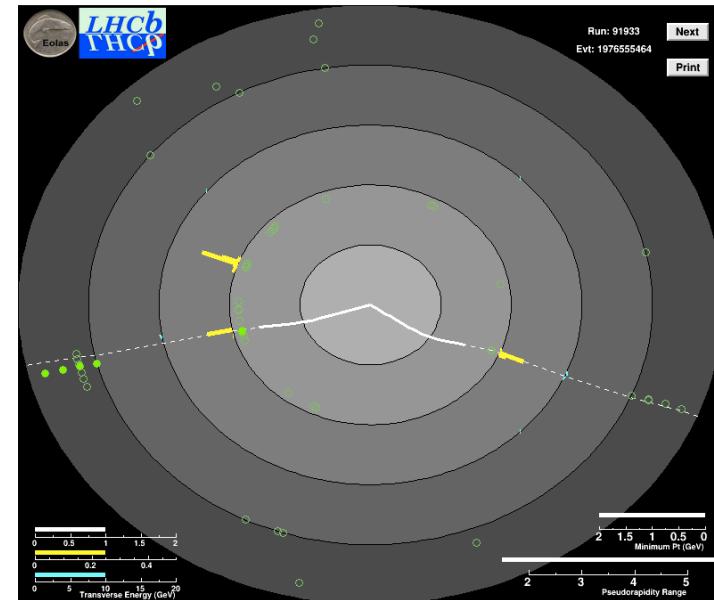
HERA measured power-law:  $\sigma_{\gamma p \rightarrow J/\psi p}(W) = 81(W/90 \text{ GeV})^{0.67} \text{ nb}$   
 Use this for  $W-$  solution (in previously measured region). LHCb measures  $W+$

# Photo-production cross-section



# Future Analyses (1)

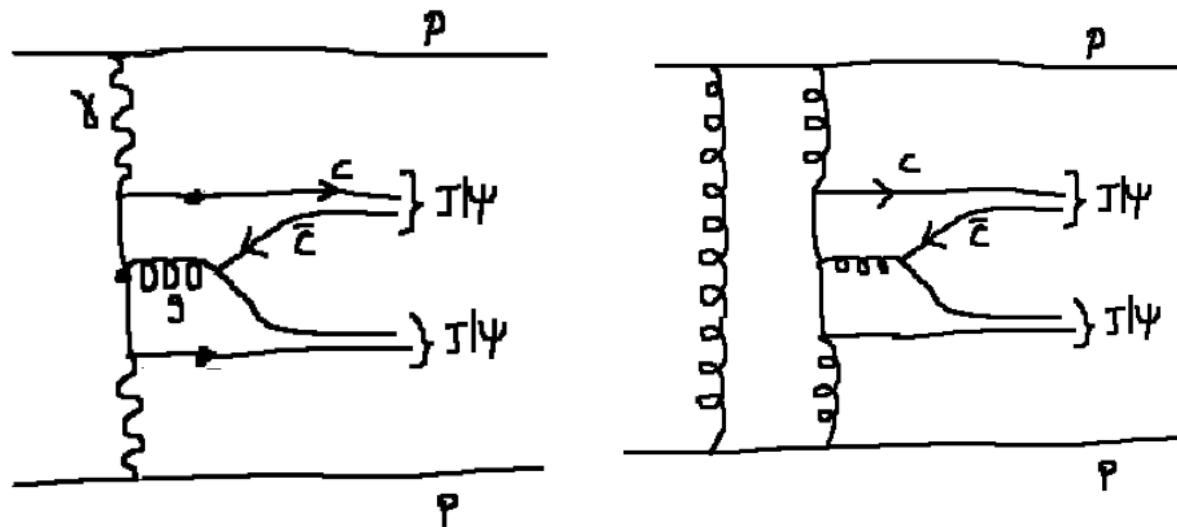
- Priority:  $\chi c$  production
- Difficult resolving 3 states
- Finding dissociative contribution
- Photon conversions have better mass resolution
- Look in hadronic modes
- Use Herschel to evaluate proton dissociation contribution

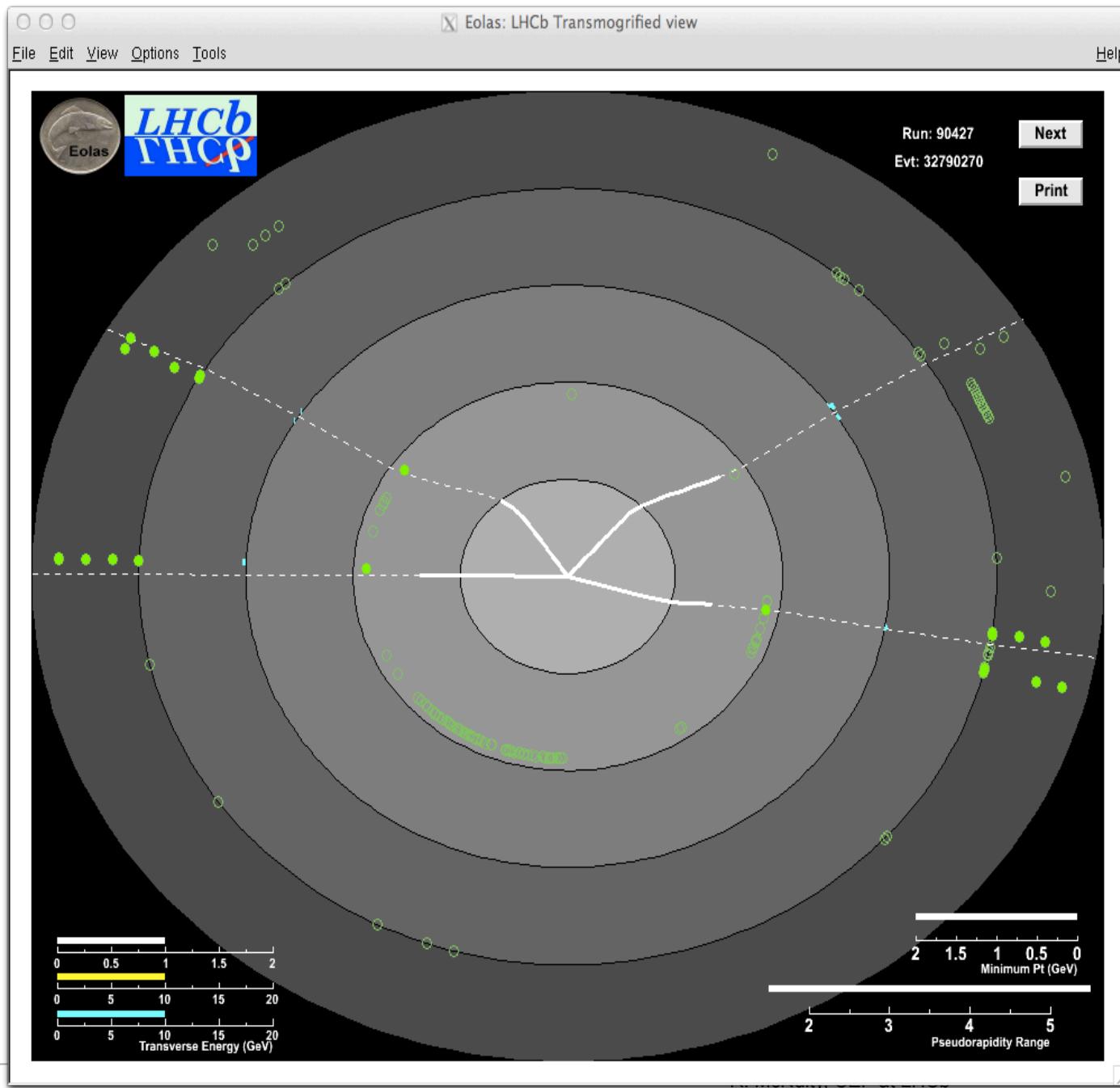


## Future (2): More statistics in Double Charmonia

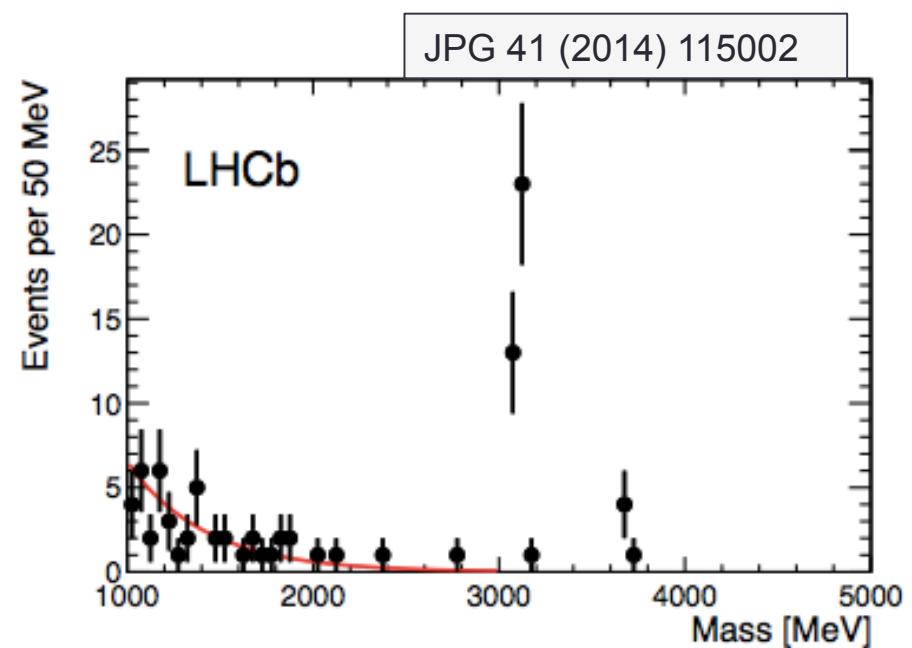
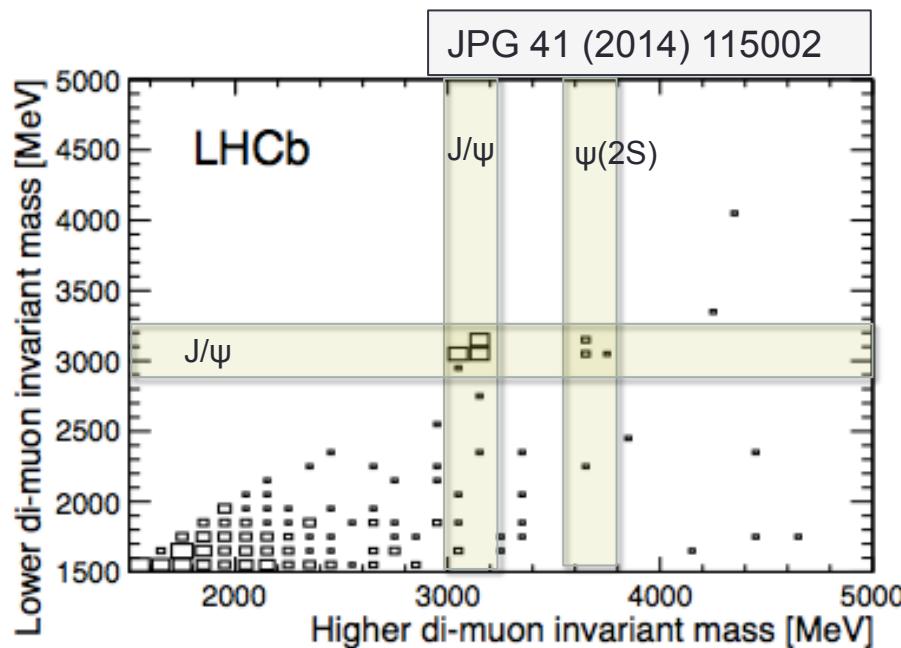
(As discussed yesterday, but in a different, complementary mode. No DPS here)

Data-taking year	Energy	Integrated Luminosity	Paper
2011	7 TeV	945 pb <sup>-1</sup>	JPG 40 (2013) 045001
2012	8 TeV	1985 pb <sup>-1</sup>	





# Invariant masses of 4-muons



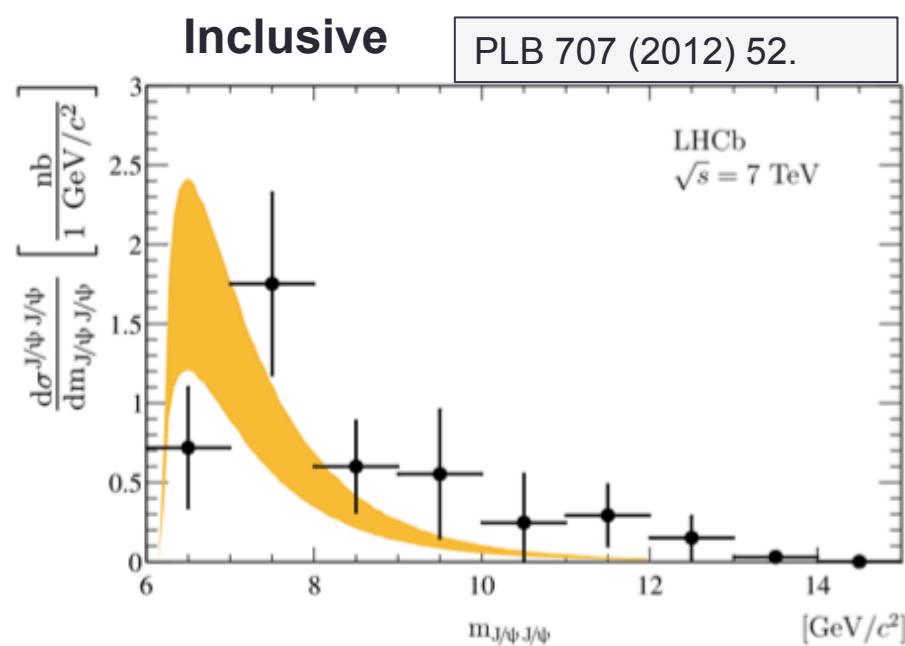
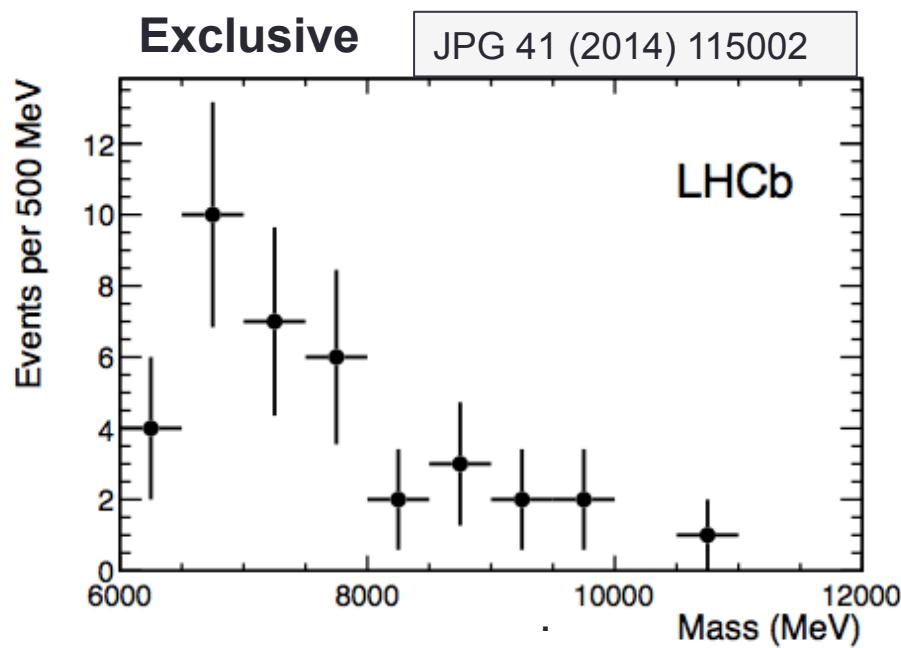
*Dimuon spectrum having required  
other two muons have  $J/\psi$  mass*

Selection requirement:

Require precisely 4 tracks, at least three identified as muons

# Cross-section results

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

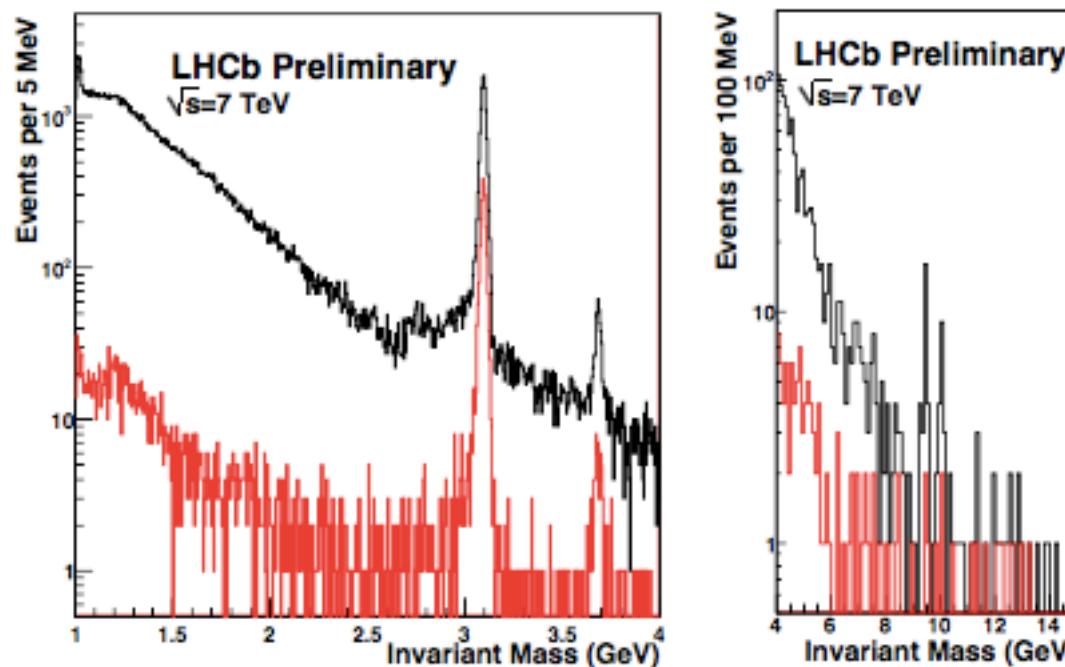


# Trigger improvements for 13 TeV

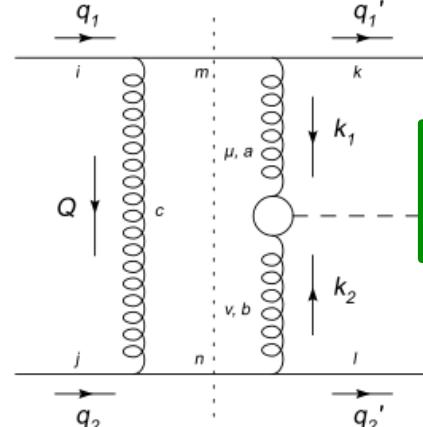
- Trigger on Low multiplicity events.
- At 7 TeV
  - Muons > 400 MeV. Dimuon masses down to  $\omega$  with  $pT=0$ .
- At 13 TeV
  - Hadrons with  $\text{SumEt} > 500 \text{ MeV}$ .
  - Two EM object > 400 MeV
  - Single photons or electrons > 800 MeV

## Future (3): Dimuons

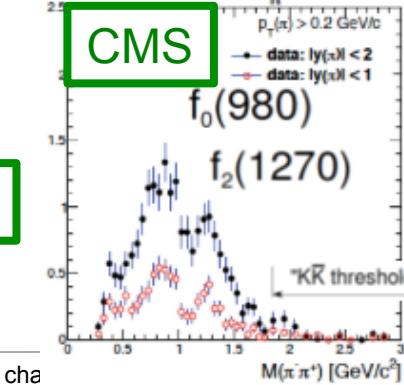
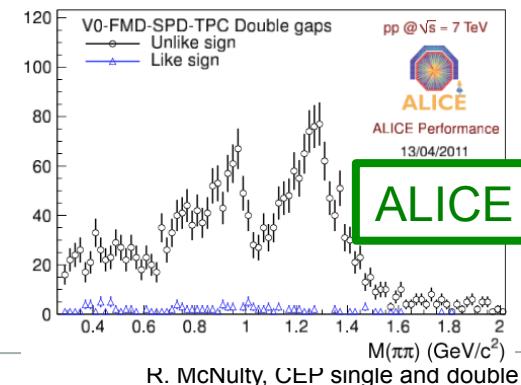
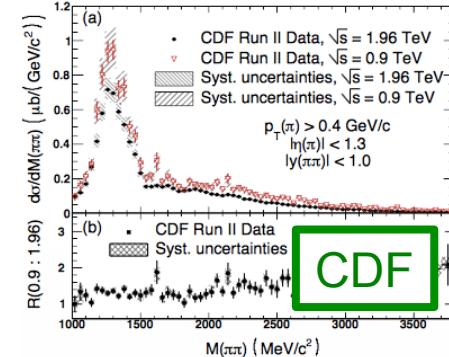
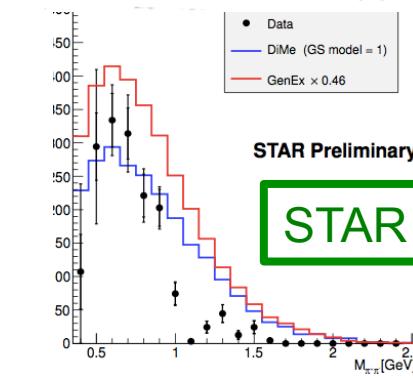
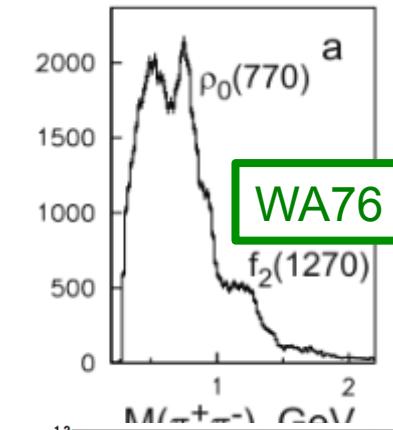
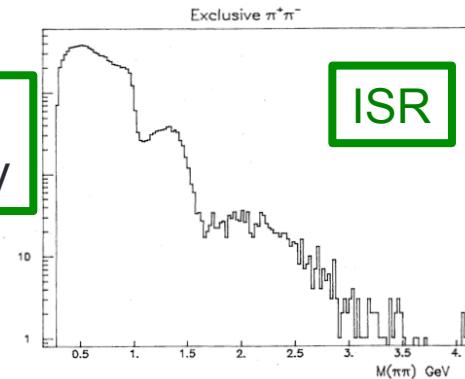
- Phi production
- QED diphoton production of muons
- Drell-Yan single diffraction (discussed yesterday – maybe possible)



# Future (4): Mass spectroscopy + glueballs



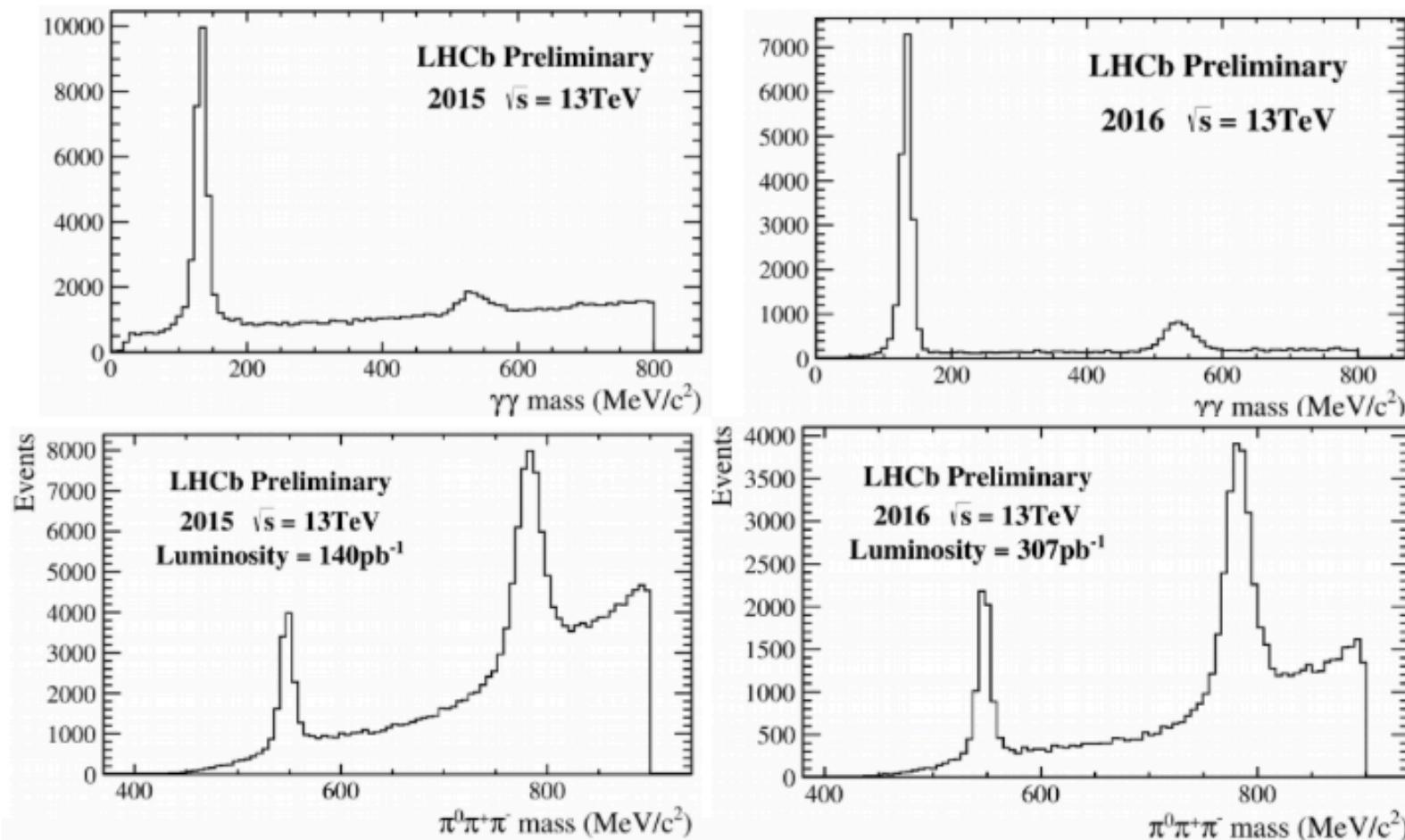
DPE  
Glue Laboratory



- $\pi\pi$ ,  $KK$ ,  $\eta\eta$   $\omega\omega$  etc.
- Similar distributions from many experiments but do we have a coherent picture?
- Accessible at LHCb
  - Large data samples
  - Low  $m_{hh}$  trigger
  - good particle ID
  - small pile-up

# Reconstruction of neutral mesons

- e.g.



# Conclusions

- New results from LHCb since last Forward physics meeting
  - Exclusive J/ $\psi$  at 13 TeV
  - Significant reduction in backgrounds
  - Data driven so far:
    - theoretical input could improve further (Discussion)
  - Improvements in theory mean gluon extraction may be possible
- Future:
  - Exclusive  $\chi c$  at 13 TeV
  - Various muonic and hadronic states.