LHCb Forward Physics Status and Plans

Ronan McNulty (UCD Dublin)
on behalf of the LHCb collaboration

LHC Forward Physics and Diffraction
21-24 Mar 2018, Madrid.

Overview

1. LHCb and Herschel Detector
   arXiv:1801.04281

2. Analyses:
   - pp at 13 TeV
   - pPb and Pbp at 8 TeV
   - PbPb at $\sqrt{s_{NN}}$ = 5 TeV

3. Odderon and prospects for CEP in future

Overview

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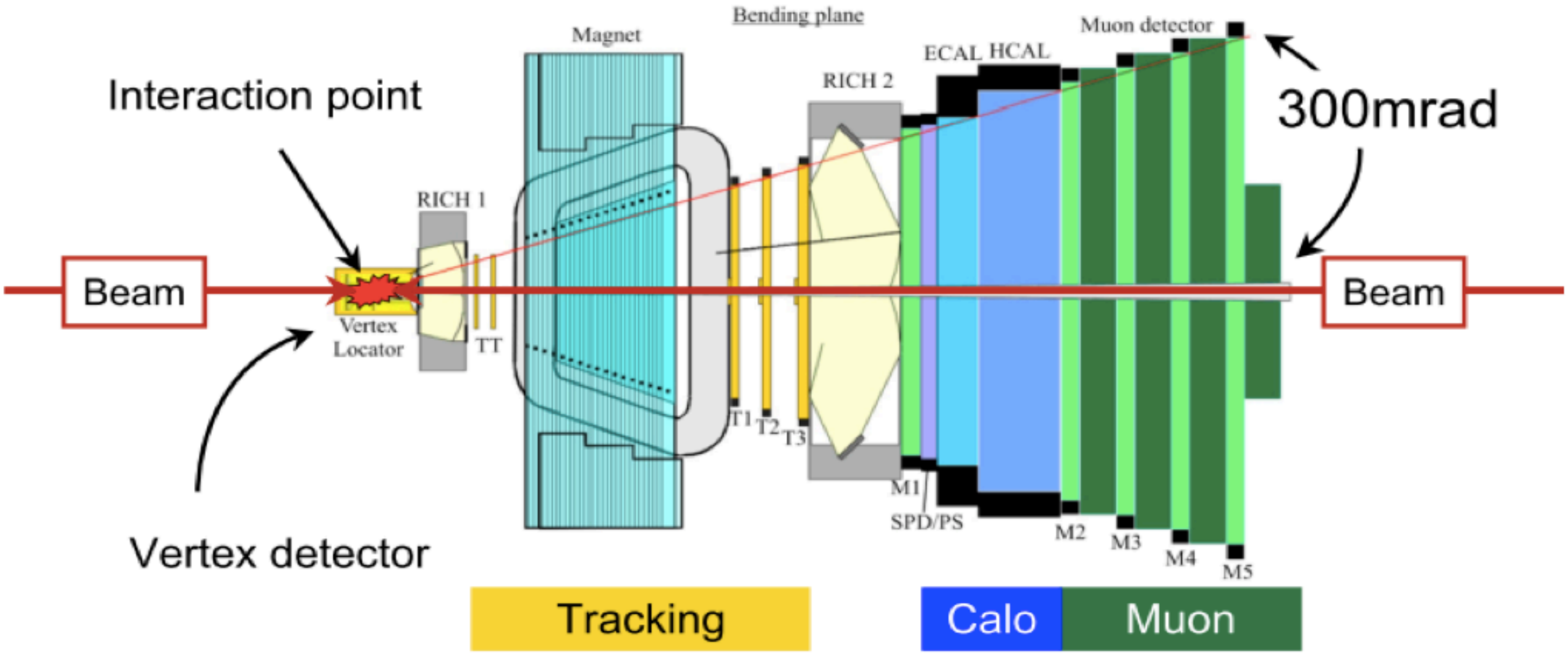
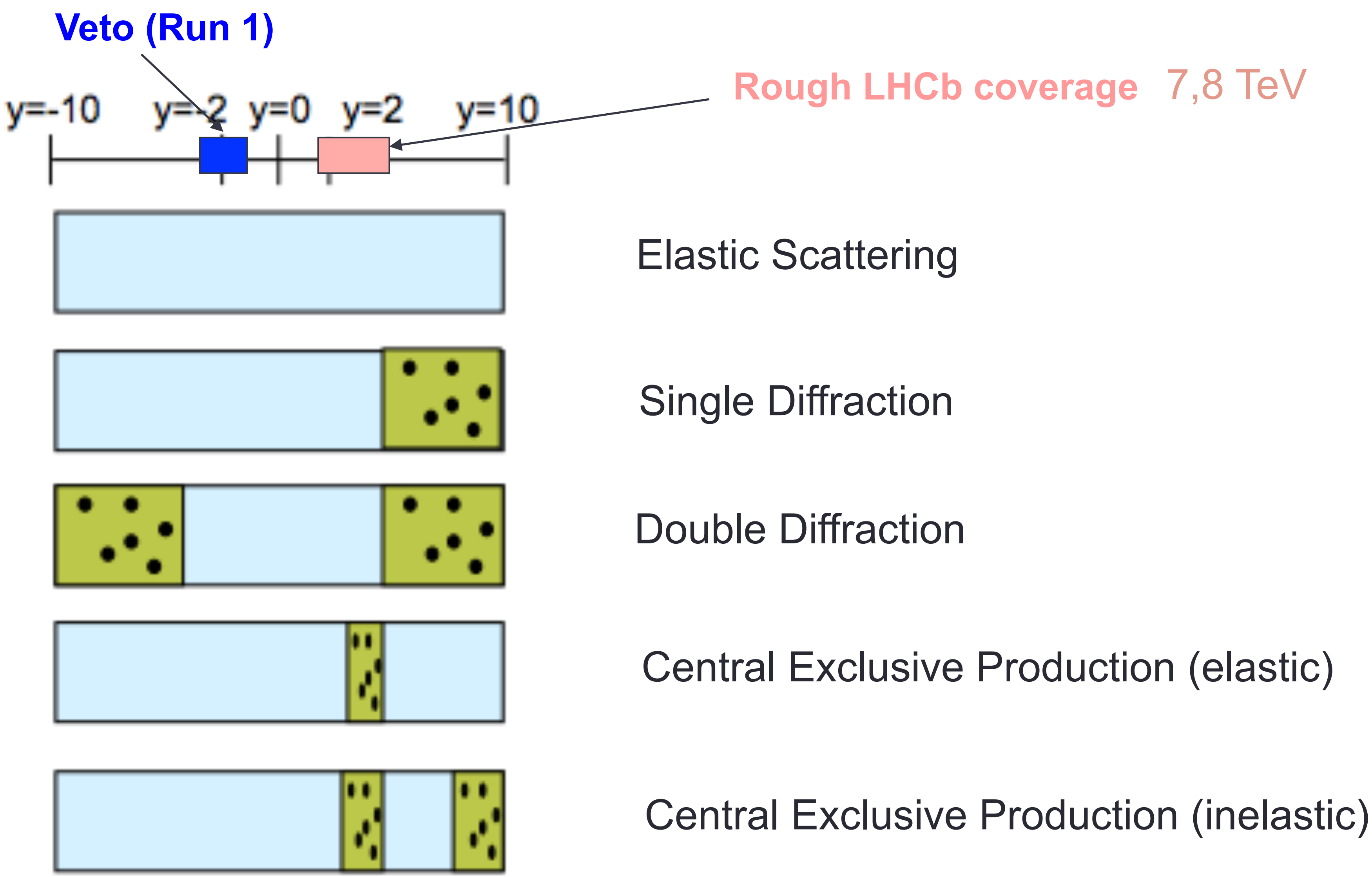
3. Odderon and prospects for CEP in future

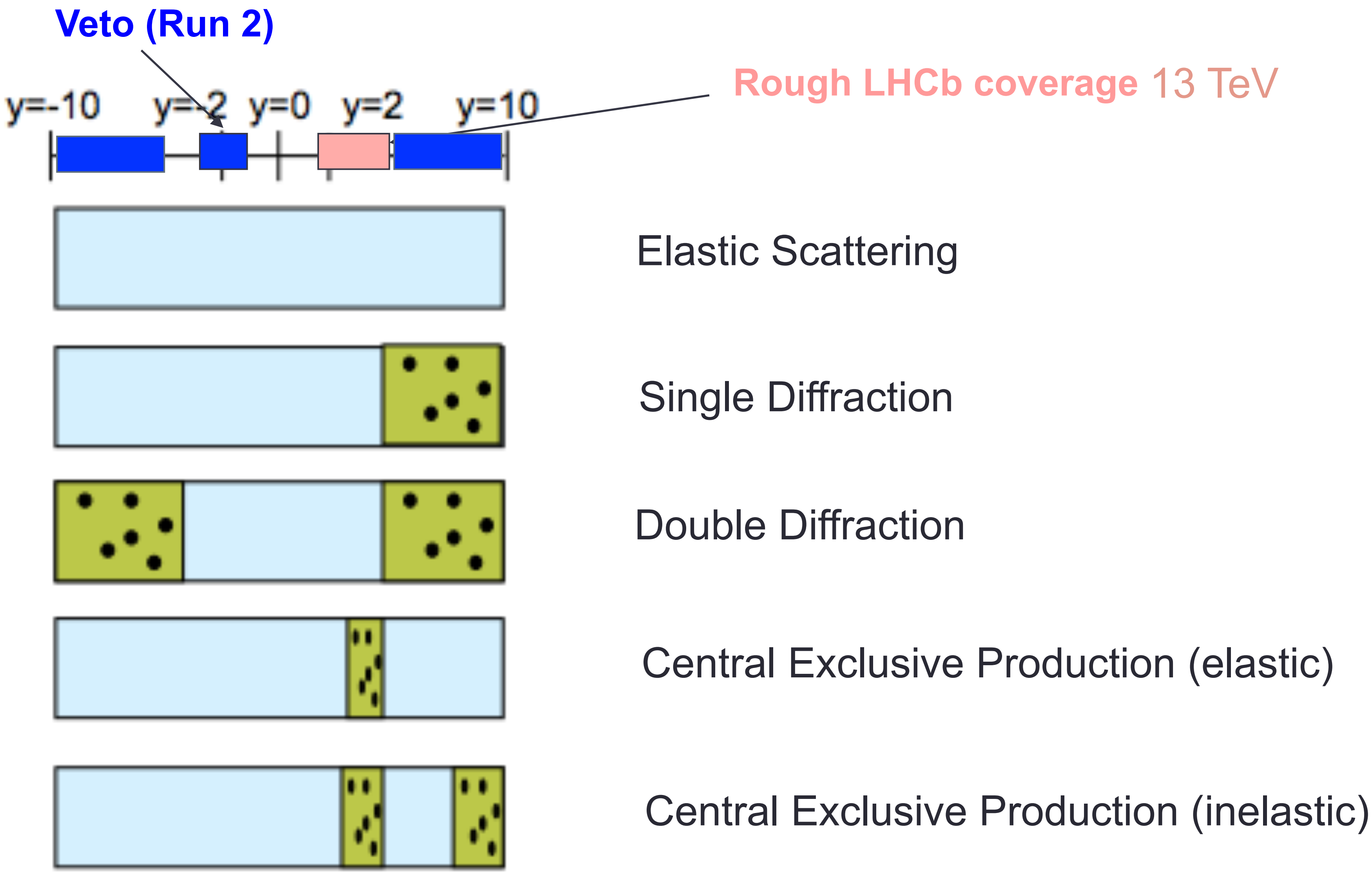
The LHCb detector

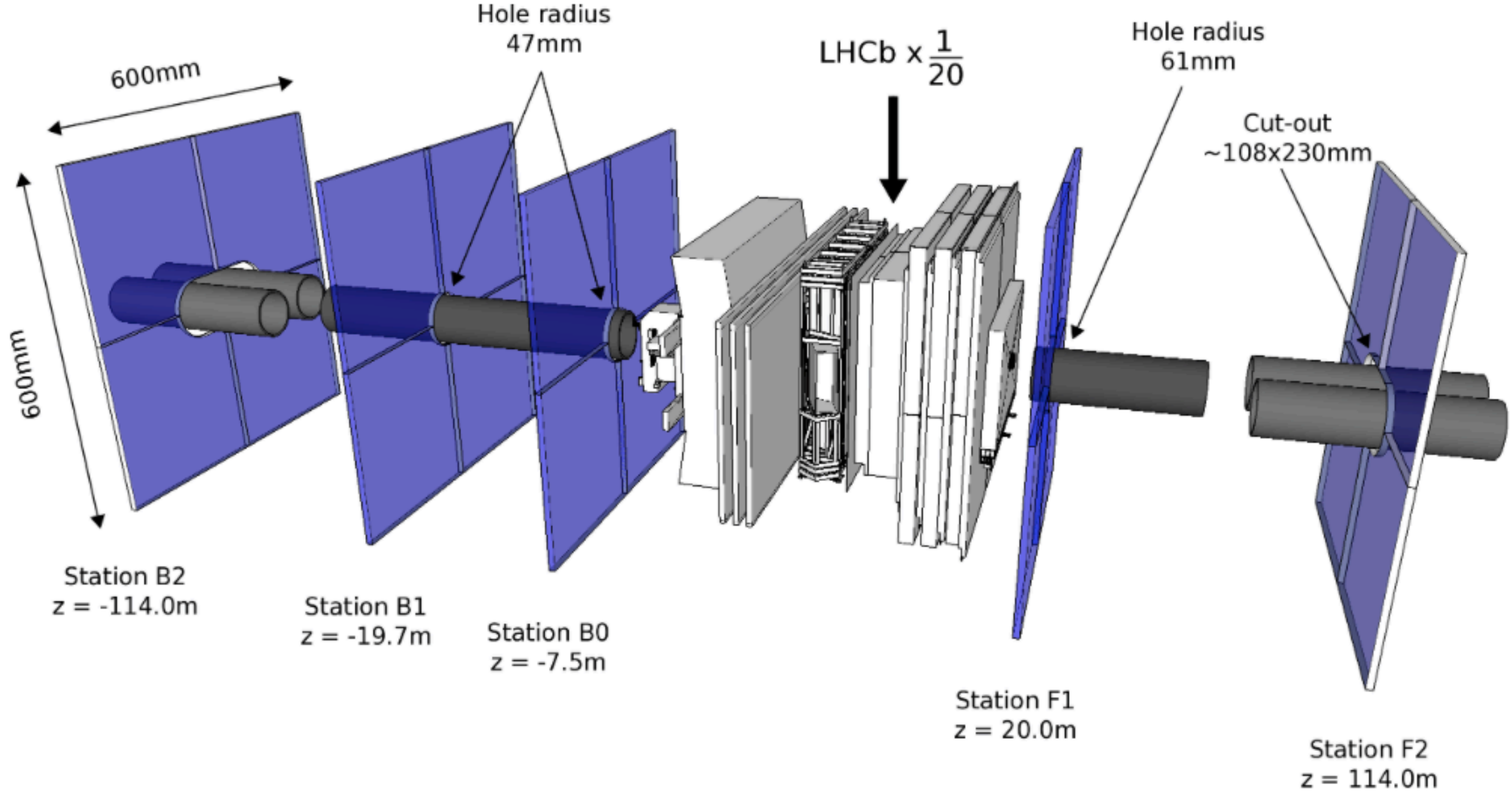
Int. J. Mod. Phys. A 30 (2015) 1530022

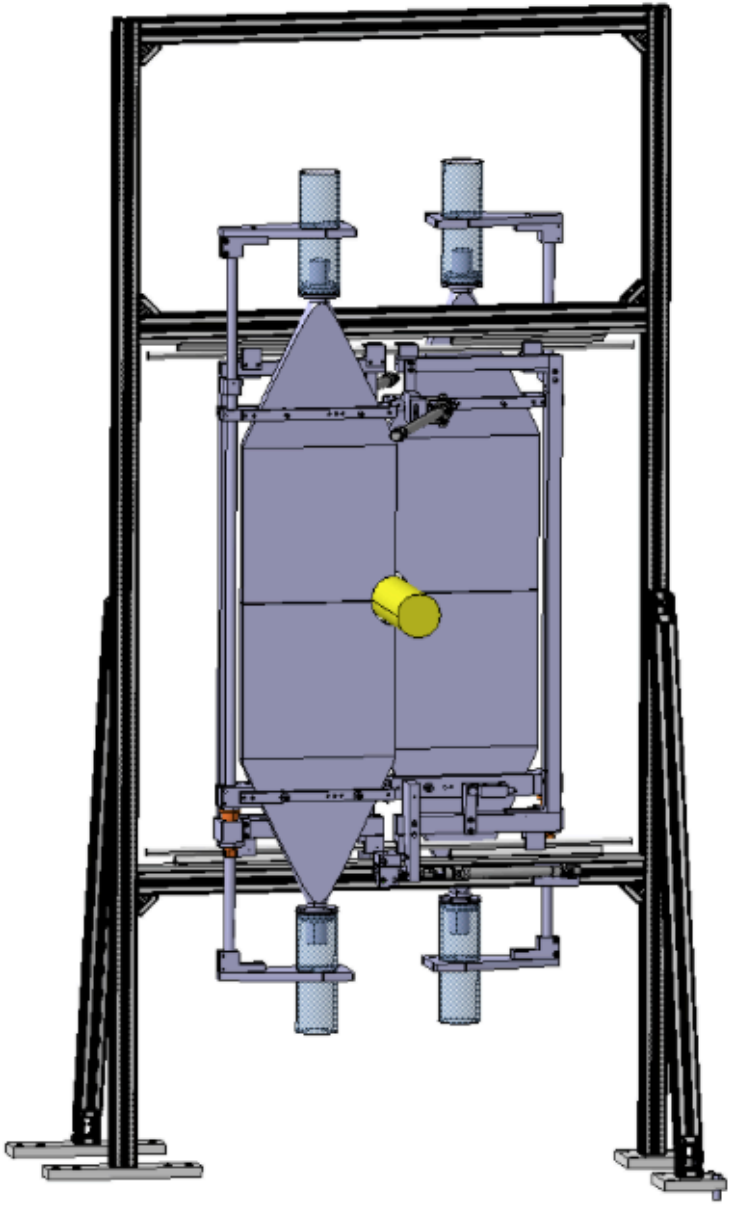


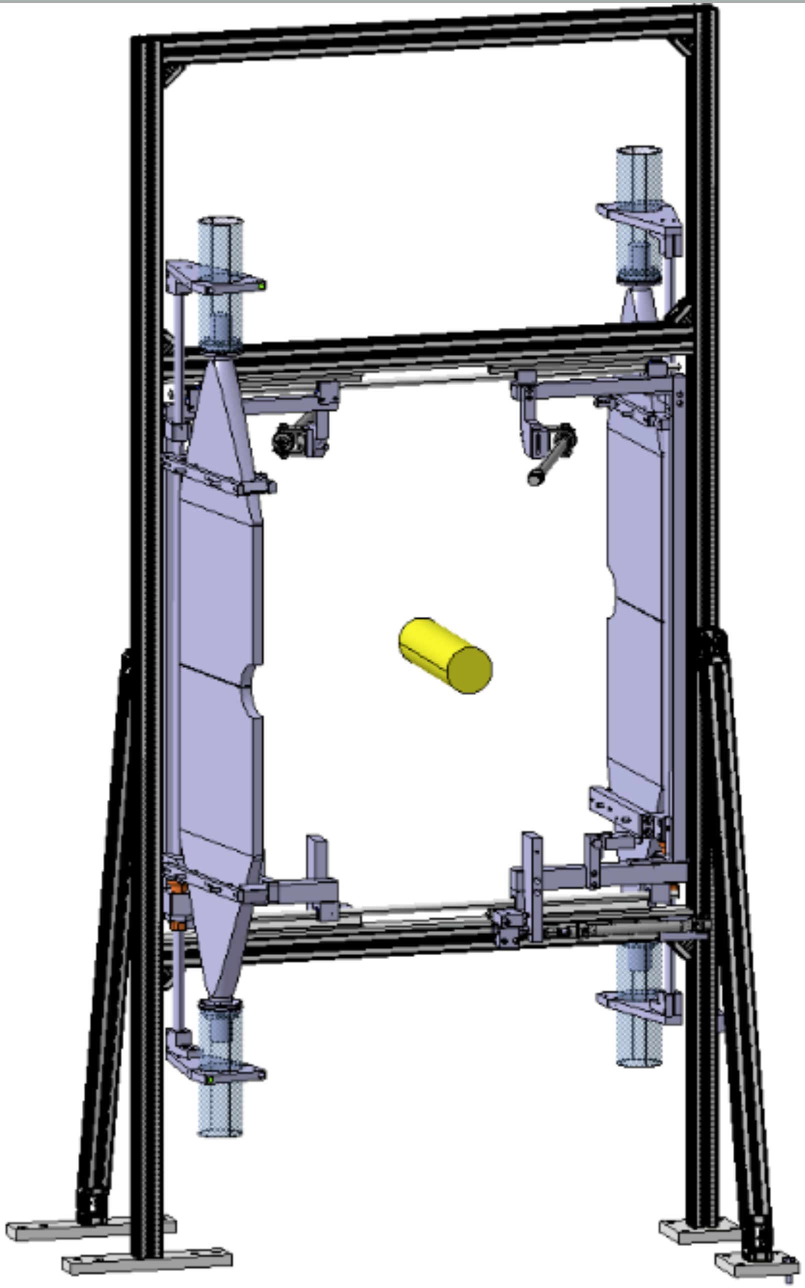
Fully instrumented: $2 < \eta < 5$
Veto region (Run 1): $-3.5<\eta<-1.5$
Veto region (Run 2): $-10<\eta<-5$, $5<\eta<10$


Veto (Run 1)
y=-10
y=-2
y=0
y=2
y=10
Rough LHCb coverage 7,8 TeV
Elastic Scattering
Single Diffraction
Double Diffraction
Central Exclusive Production (elastic)
Central Exclusive Production (inelastic)


Veto (Run 2)
Rough LHCb coverage 13 TeV
y=-10
y=-2
y=0
y=2
y=10
Elastic Scattering
Single Diffraction
Double Diffraction
Central Exclusive Production (elastic)
Central Exclusive Production (inelastic)


Hole radius
47mm
600mm
LHCb x 1/20
Hole radius
61mm
Cut-out
~108x230mm
600mm
Station B2
z = -114.0m
Station B1
z = -19.7m
Station B0
z = -7.5m
Station F1
z = 20.0m
Station F2
z = 114.0m

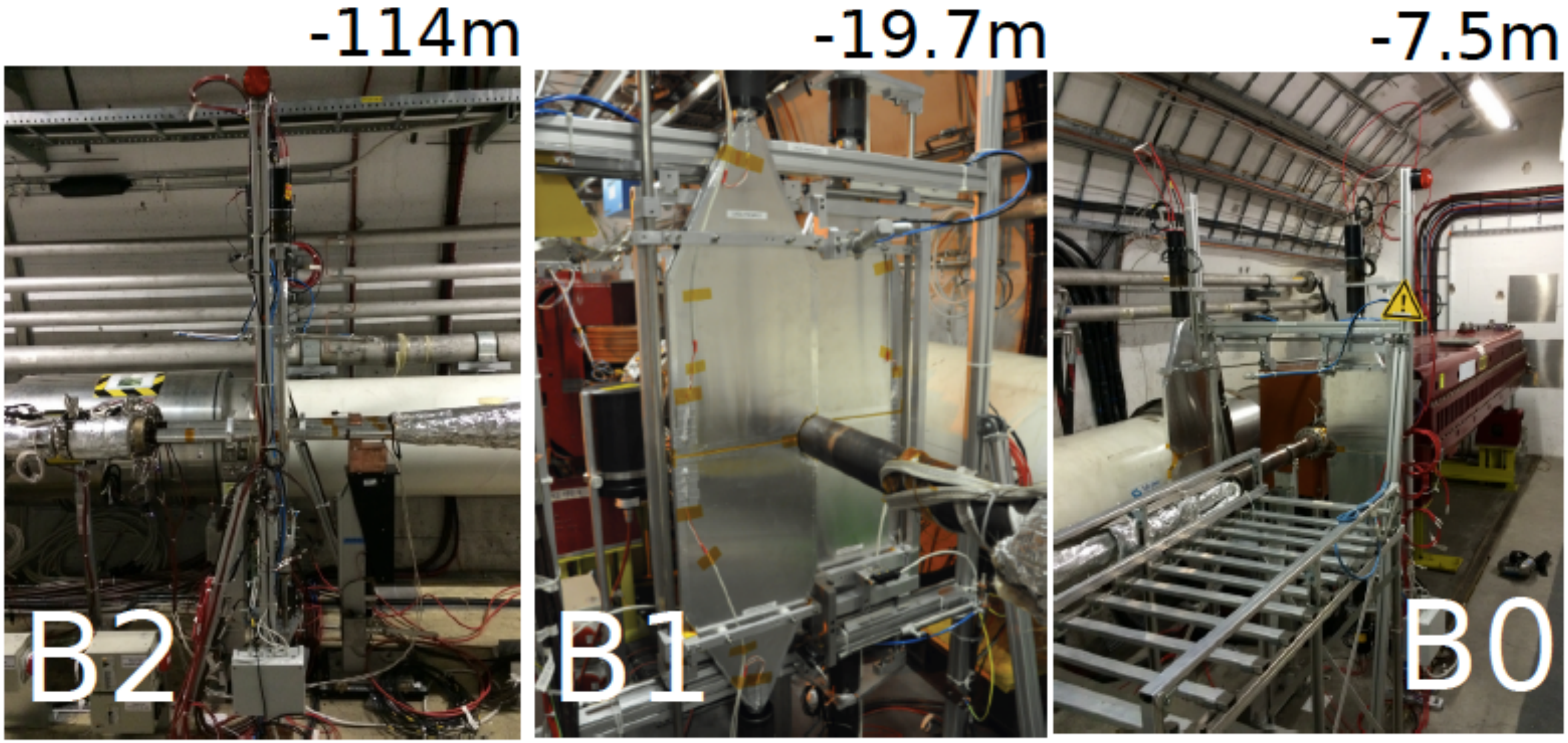




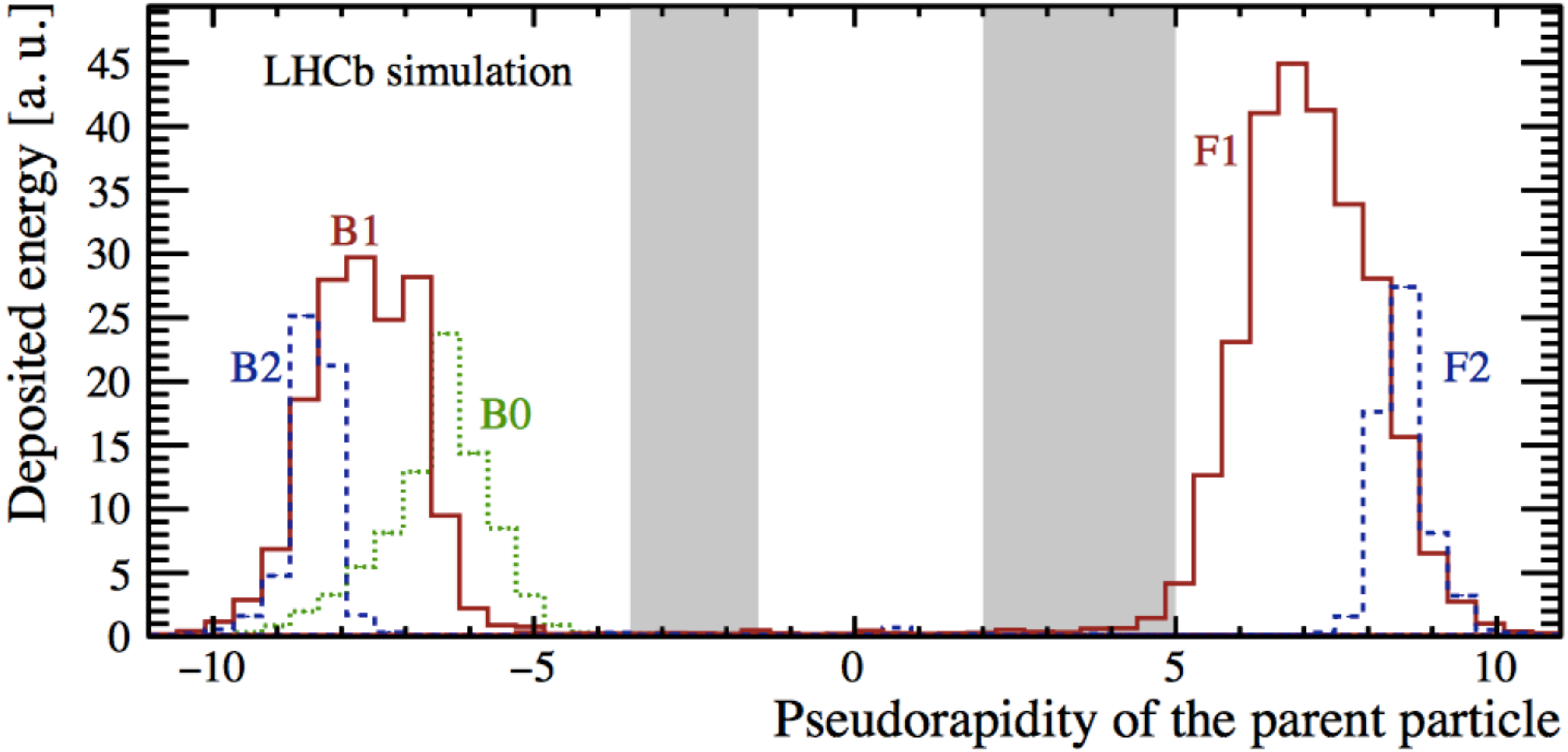
Scintillators, light-guides and PMTs

Backward Stations

Installation finished in 2014



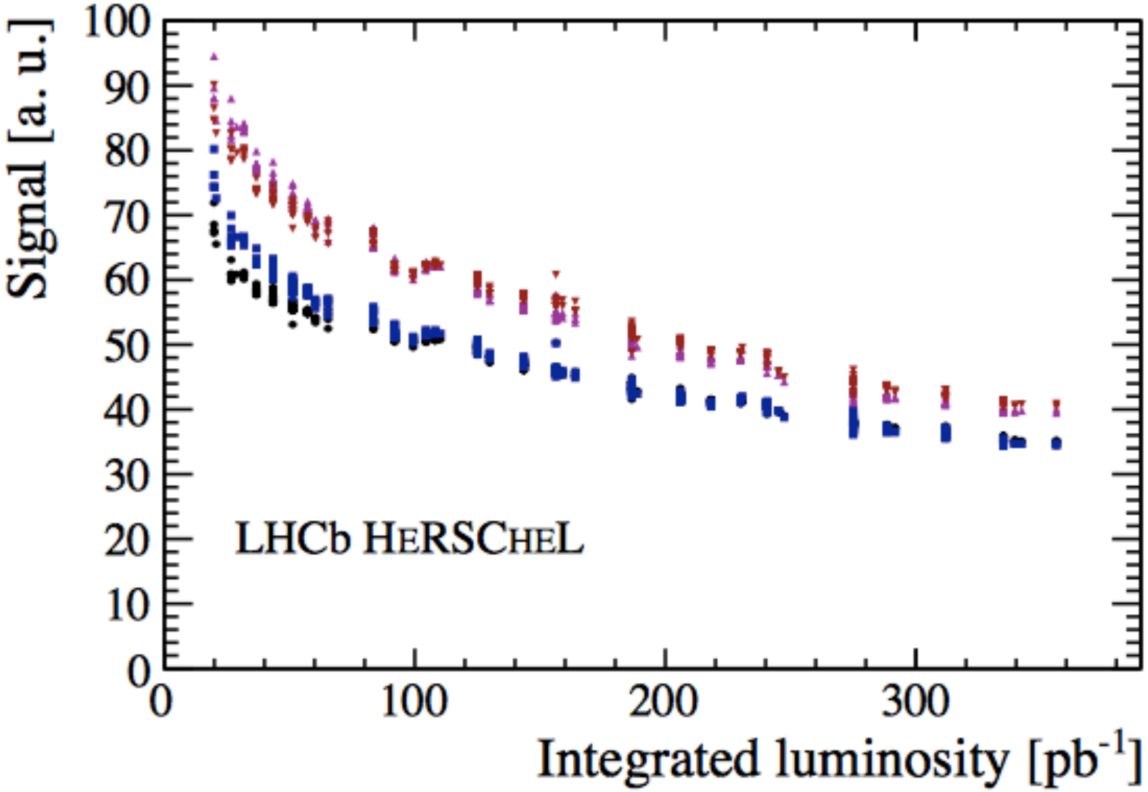
Acceptance



Showers induced by high-rapidity particles interacting with machine elements
Ideally wish to veto on any activity: threshold depends on signal and noise.

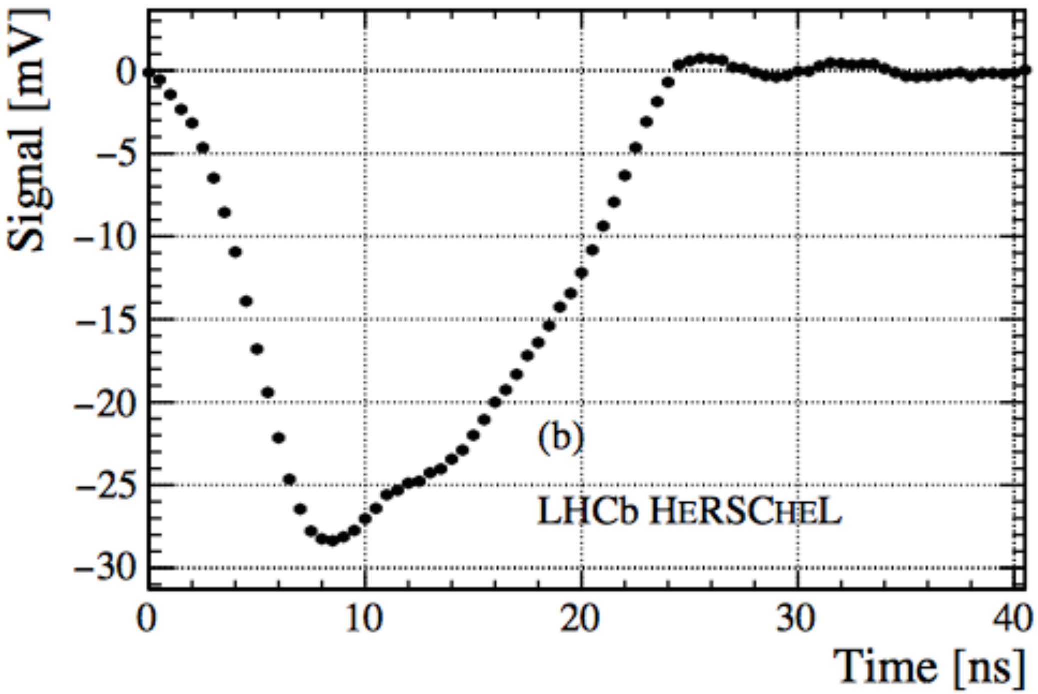
Signal

Start of 2015: MIPs give 2-5 ADC counts, although some degradation with aging. Particles traversing Herschel give ‘a few’ ADC counts.



Signal

Pulse designed to be within 25ns
2015 running had 50ns gaps between p-p crossings
2016,17 running was at 25ns



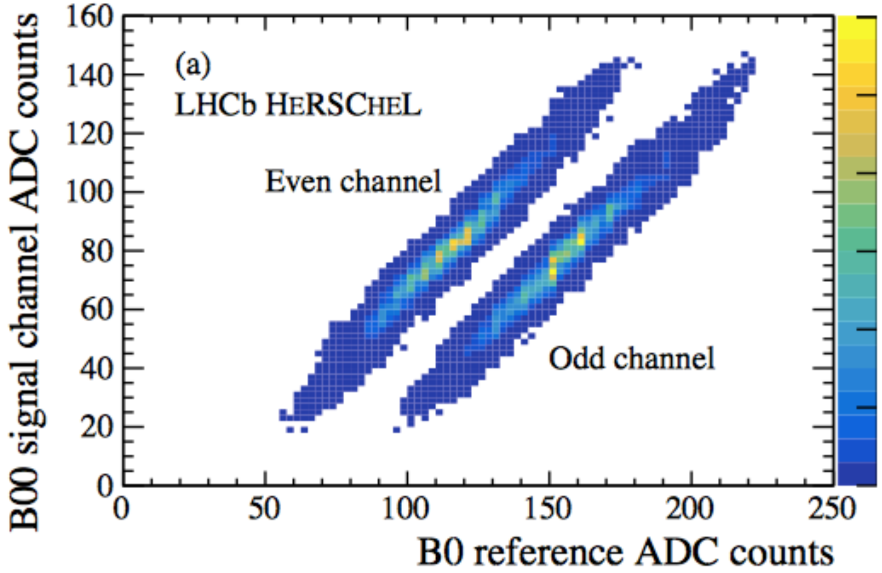
Measured during proton beam-dump tests

Noise

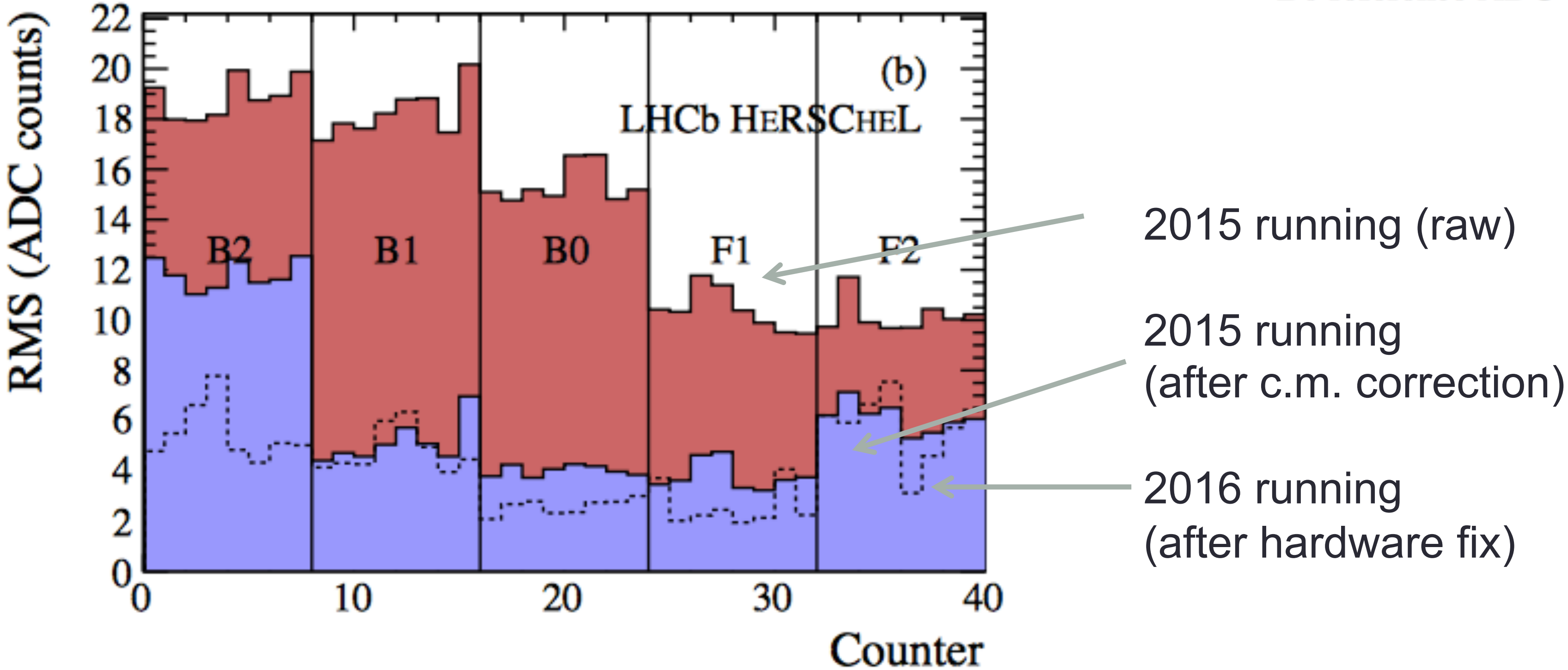
- Detector Effects
  - Common-mode noise (only in 2015)   [10-20 ADC counts]
  - Intrinsic noise   [2-10 counts]
  - Time dependence due to aging and voltage settings

- Collider Effects
  - Pile-up due to average number of collisions per bunch-crossing (0.1 – 2.5)
  - Spill-over in high-luminosity running
  - More spill-over in 25ns running compared to 50ns running.

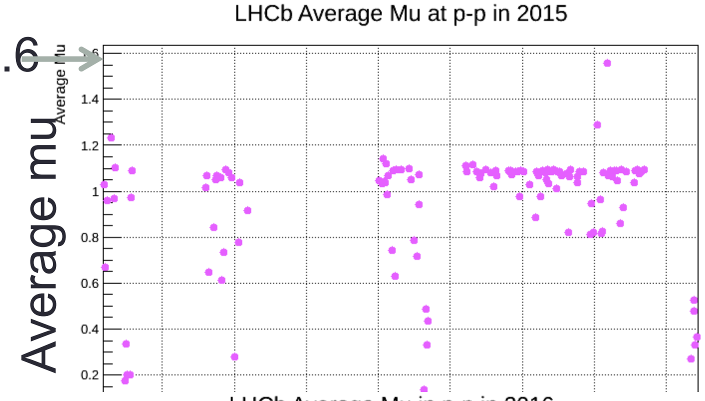
Common-mode noise

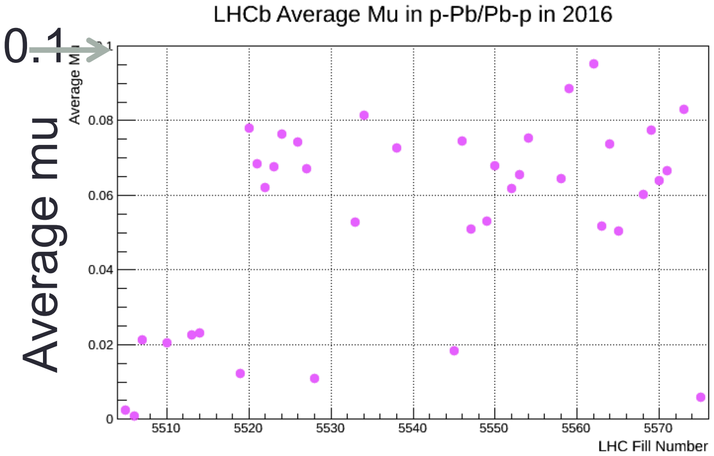


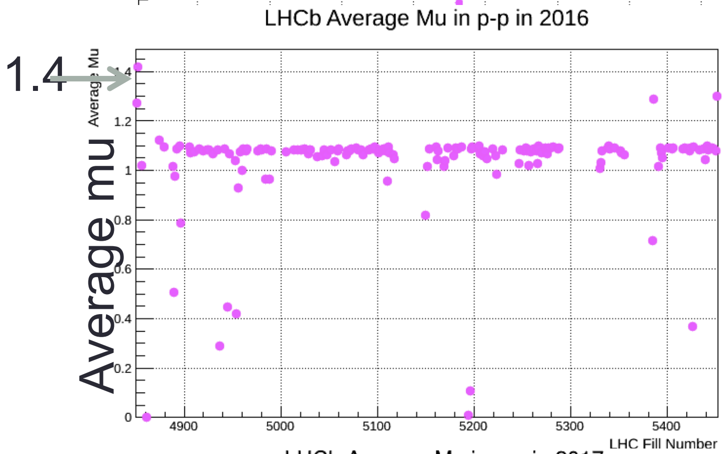
After corrections, intrinsic noise is roughly at level of one mip

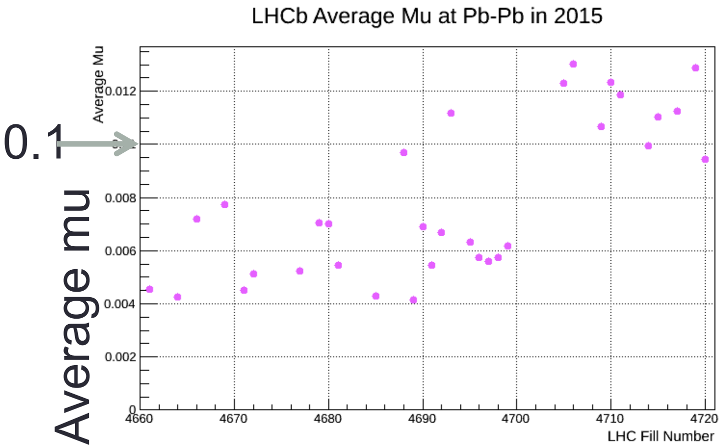


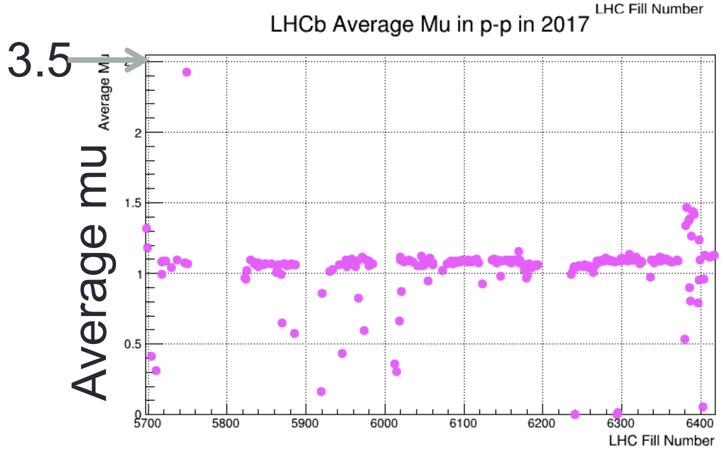
Average No. interactions per crossing





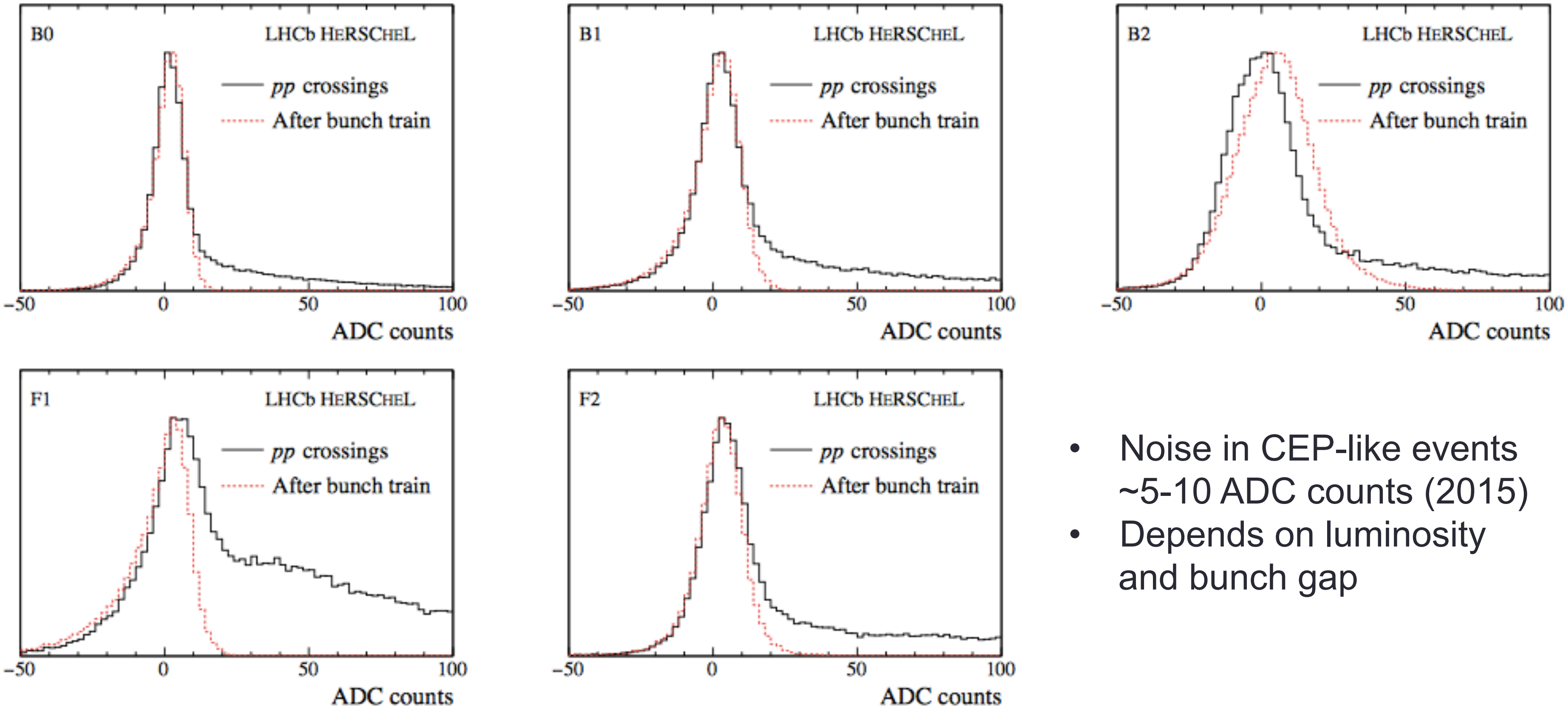






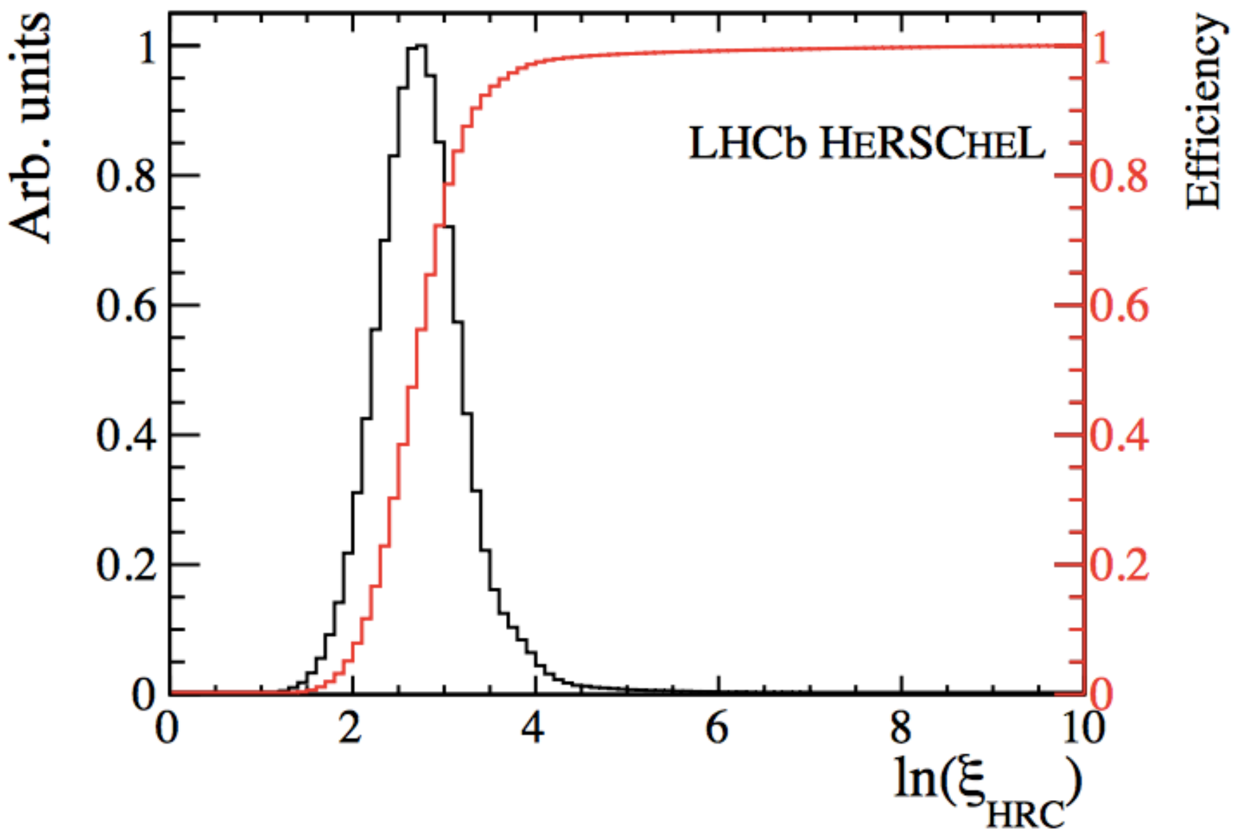
Electronic spillover

Assess using response in first empty-empty bunch-crossings after p-p bunch-crossing. These are a proxy for genuine CEP events.



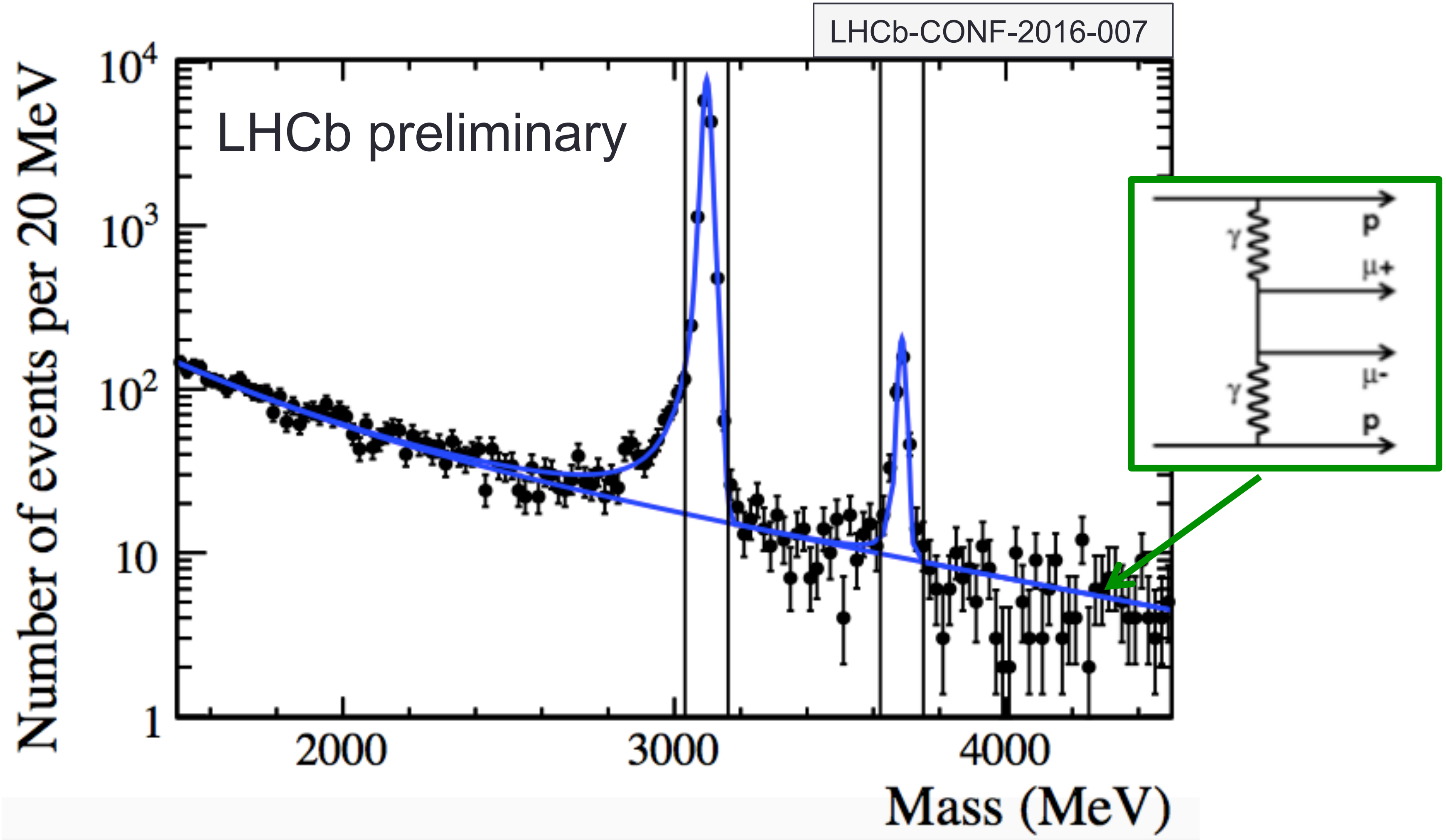
- Noise in CEP-like events ~5-10 ADC counts (2015)
- Depends on luminosity and bunch gap

Combine calibrated empty signals into **Herschel discriminant**

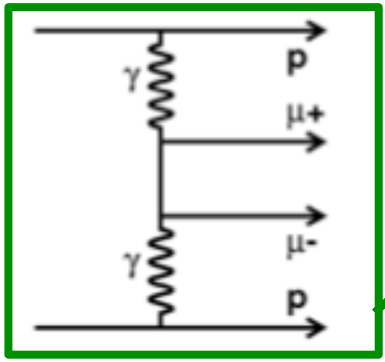


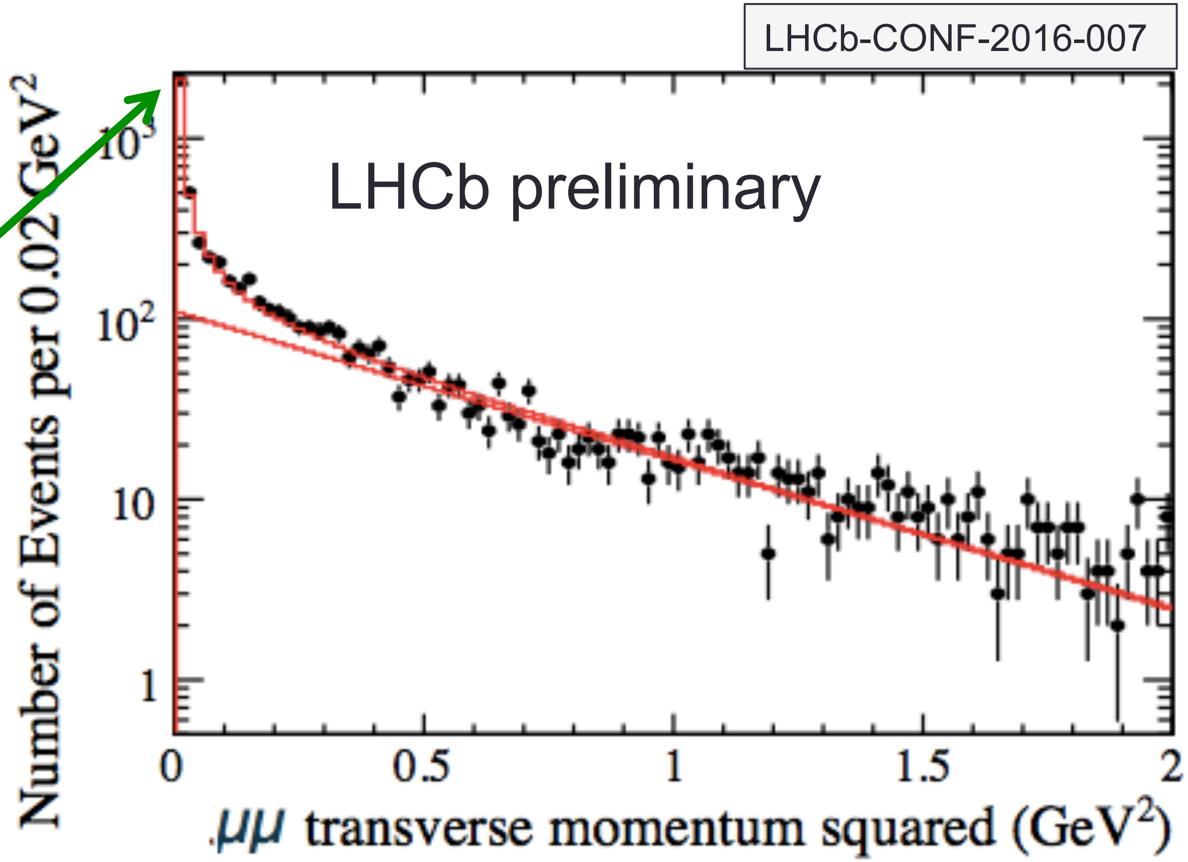
Response of Herschel in 2015 running conditions, when no particles pass through

Sample 1: Response to CEP events (QED μμ)



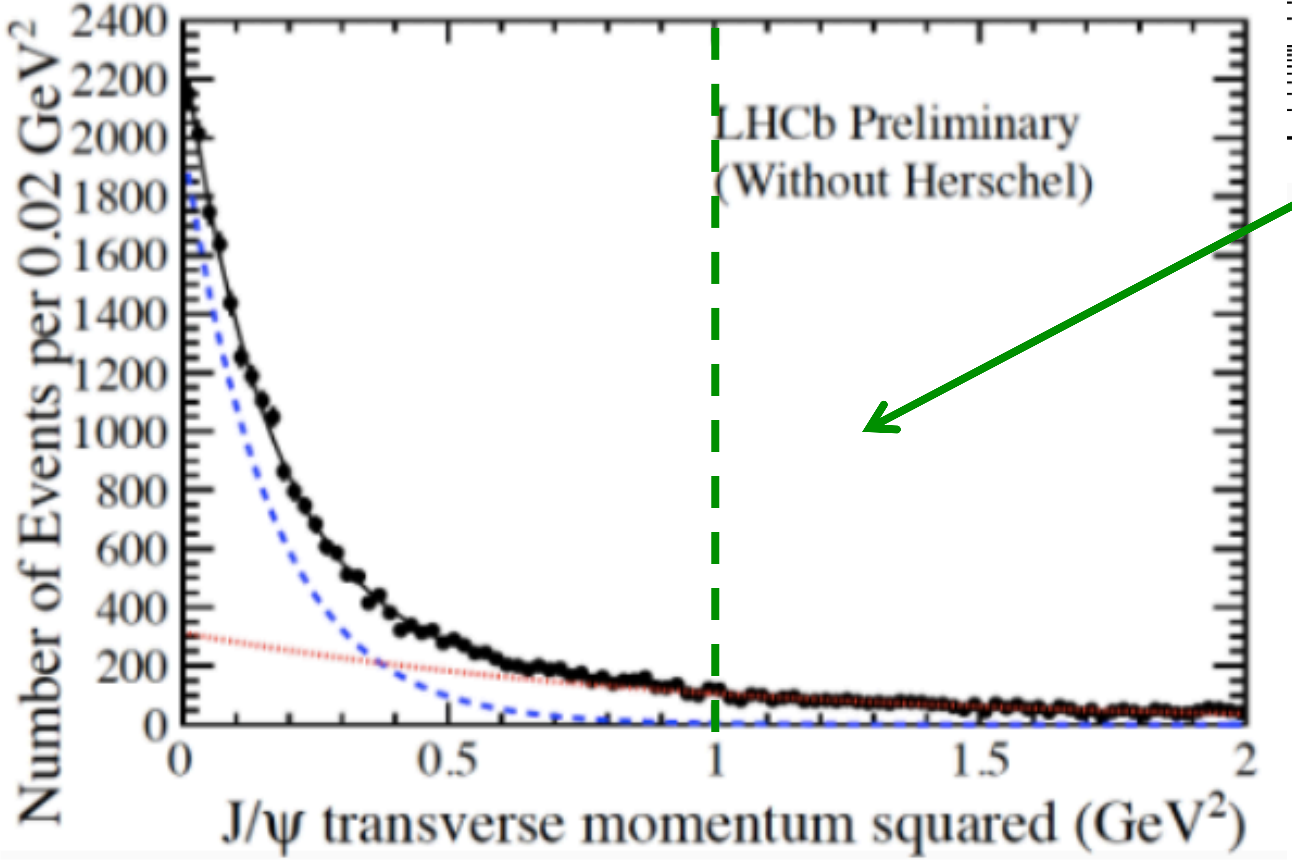
Sample 1: Response to CEP events

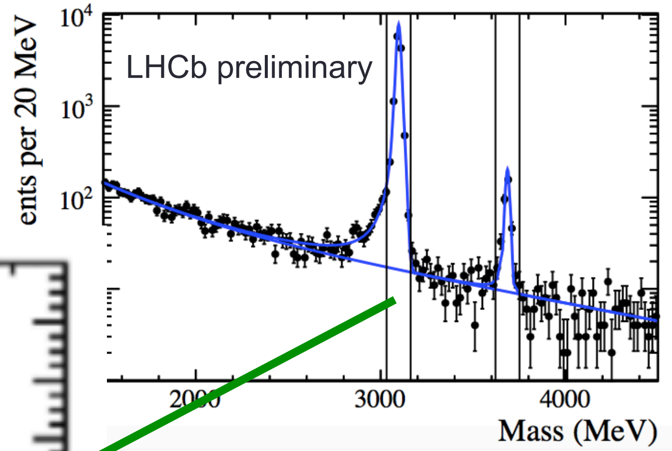




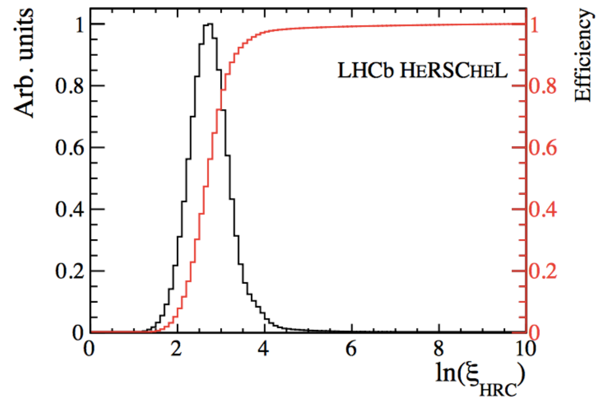
First bin is > 95% pure CEP QED di-muons.

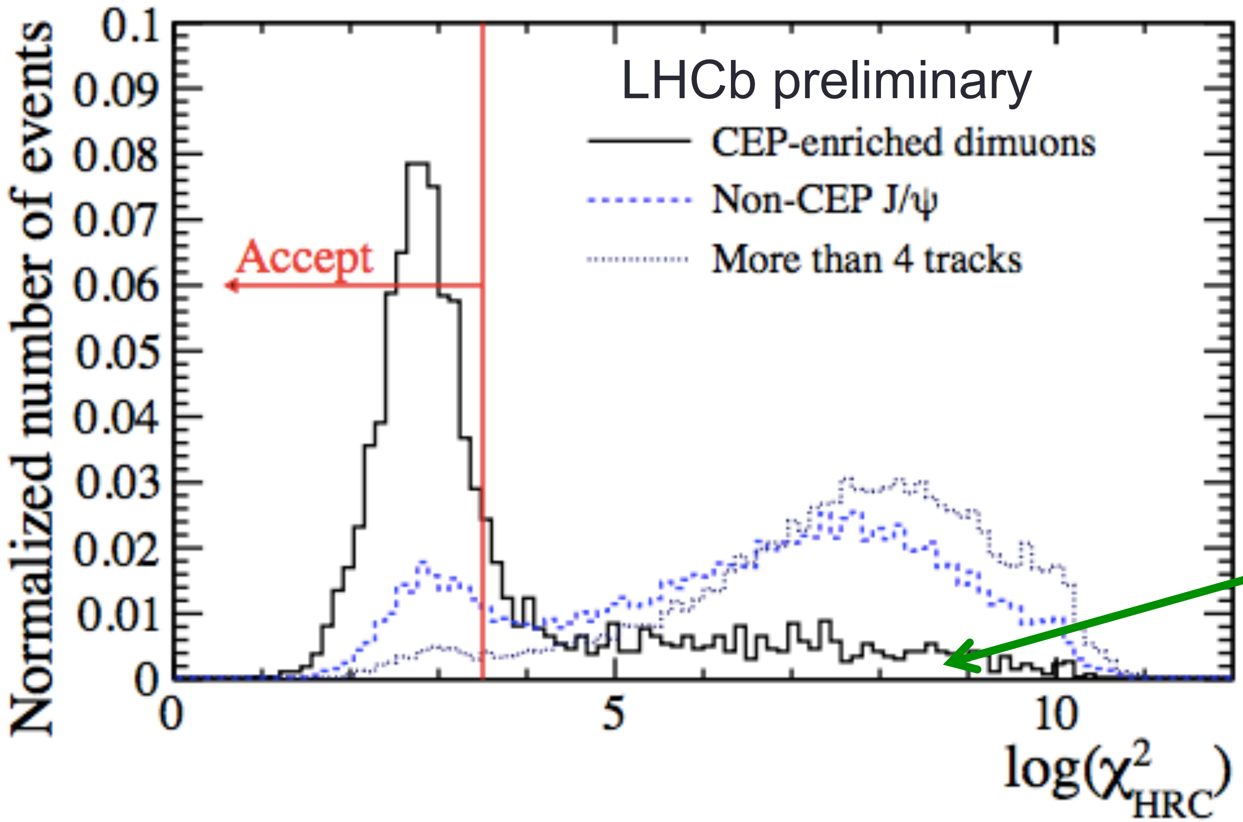
Sample 2: Non-CEP events (J/ψ dissociation)





Herschel discriminant for physics signals





CEP QED looks like empty-empty events

Evidence for pile-up (much reduced in pPb/ Pb p running)

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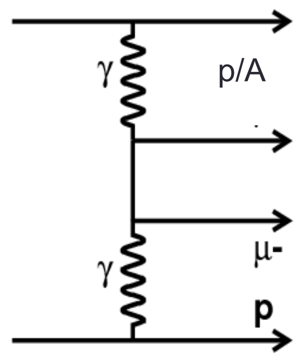
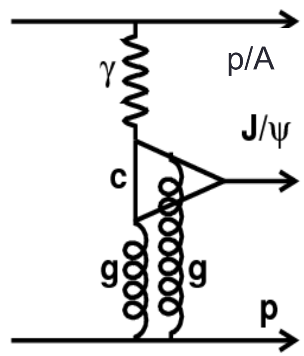
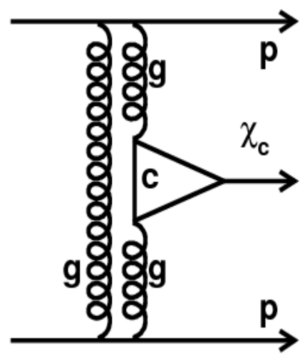
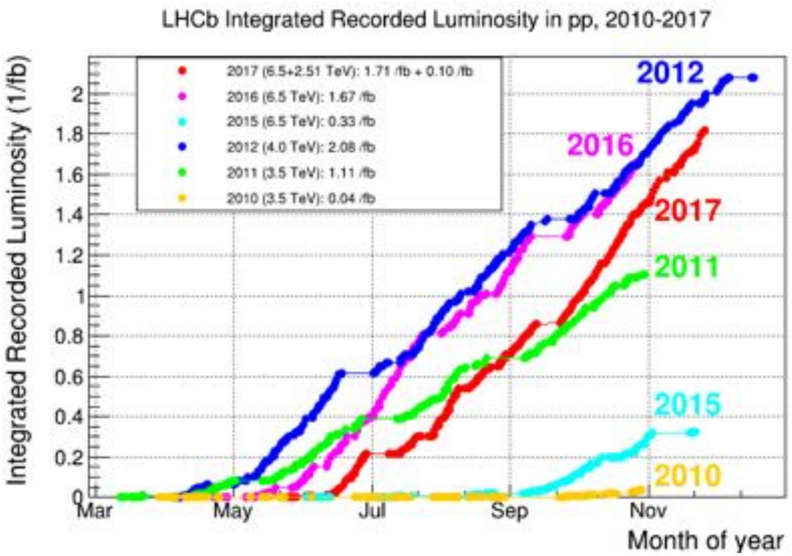
3. Odderon and prospects for CEP in future

pp / pPb / Pbp / PbPb data-taking

	γγ	γP	PP
			
p-p			Dominant
p-Pb		Enhanced	
Pb-Pb	Strongly enhanced	Enhanced	

Collisions

pp Collider



Ion fixed target

Type	√s	Lumi (μb^{-1})
p-Ne	86.6 GeV	
Pb-Ne	54.5 GeV	0.05
p-Ne	110 GeV	0.5
p-He	110 GeV	0.5
p-Ar	110 GeV	~3
p-Ar	68.6 GeV	~0.05
Pb-Ar	68.6 GeV	~0.05
p-He	110 GeV	1.7
p-He	86.6 GeV	~17
p-He	110 GeV	0.07
p-Ne	110 GeV	~1.0
p-Ne	68.6 GeV	~200

(indicative luminosities)

Ion Collider

- pA/Ap beam-beam collisions
  - 2013 p-Pb /Pb-p run @ 5 TeV (~1nb^{-1})
  - 2016 p-Pb /Pb-p run @ 5 and 8 TeV (~30nb^{-1})
- A-A collisions
  - 2015 Pb-Pb run @ 5 TeV (~4ub^{-1})
  - 2017 Xe-Xe run @ 5.4 TeV (~0.4ub^{-1})

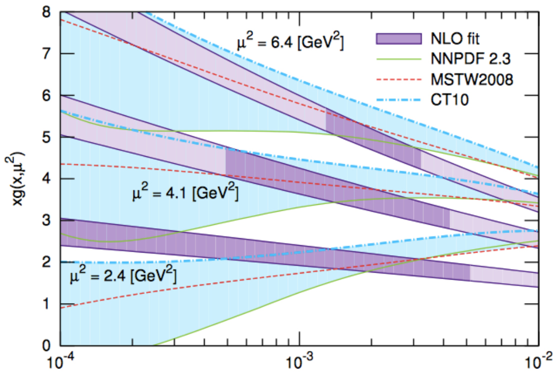
Photo-production

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

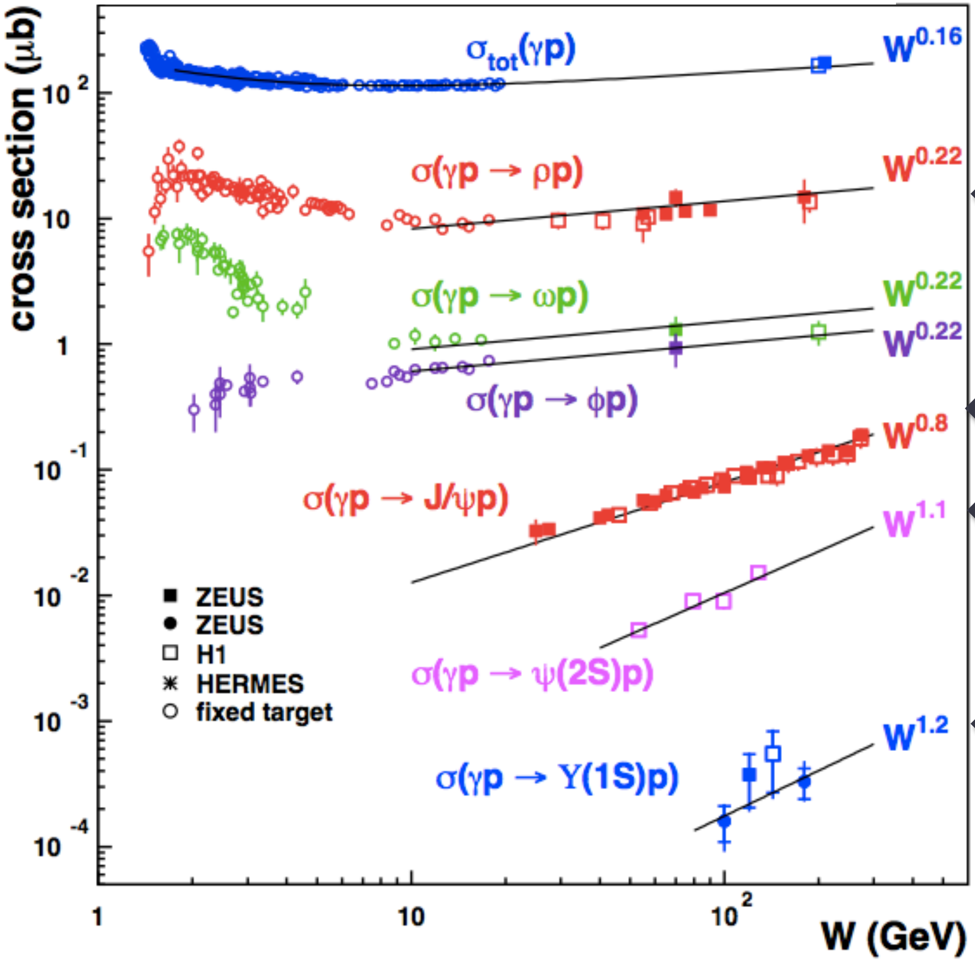
Note:

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

  (down to x=2E-6)

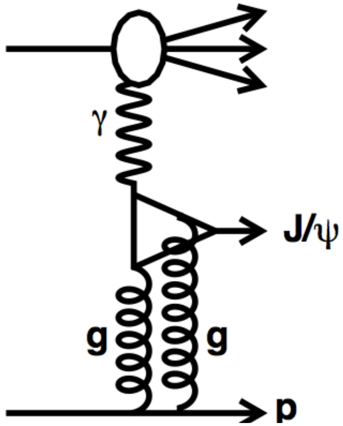


JHEP 1311 (2013) 085



10.3204/DESY-PROC-2012-03/58

Inelastic background J/ψ



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)

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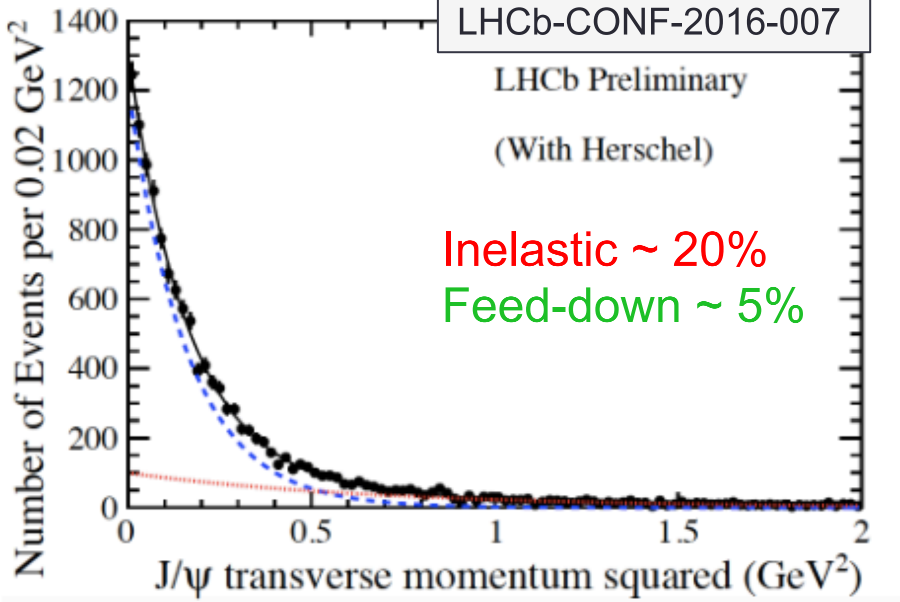
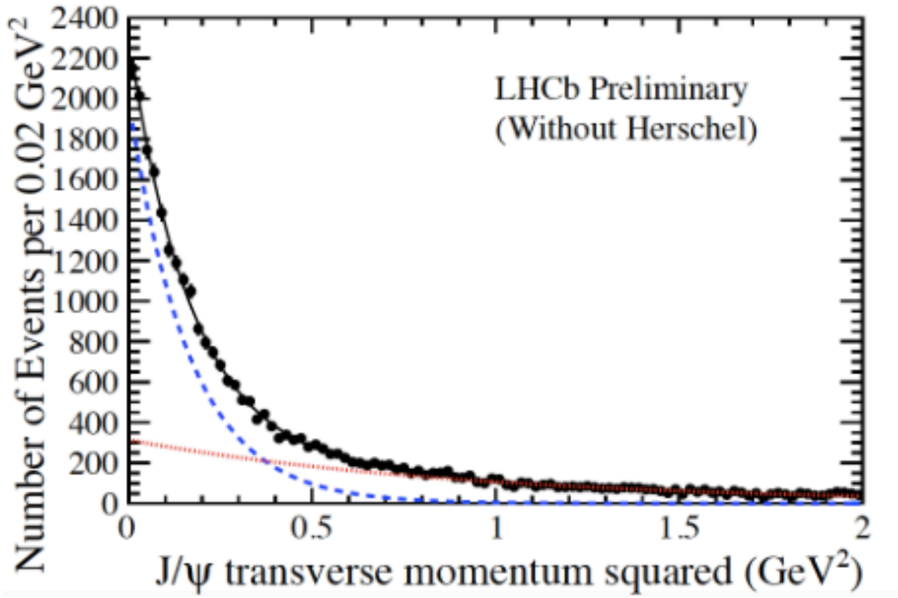
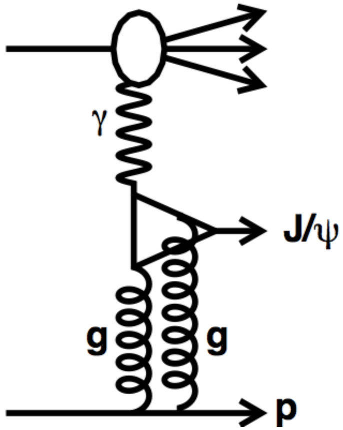




Consistent cross-section results with/without Herschel.
Backgrounds roughly halved using Herschel (but not eliminated.....)

Inelastic background J/ψ



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)

New Technique:

$N_{HRC} = \varepsilon N_{sig} + \beta(p_T) N_{bkg}$

$N_{anti\text{-}HRC} = [1-\varepsilon] N_{sig} + [1-\beta(p_T)]\, N_{bkg}$

ε known from QED sample
Pure bkg sample obtained => Signal derived
(Will be detailed in paper, currently in collaboration review)

Differential cross-sections J/ψ and ψ(2S)

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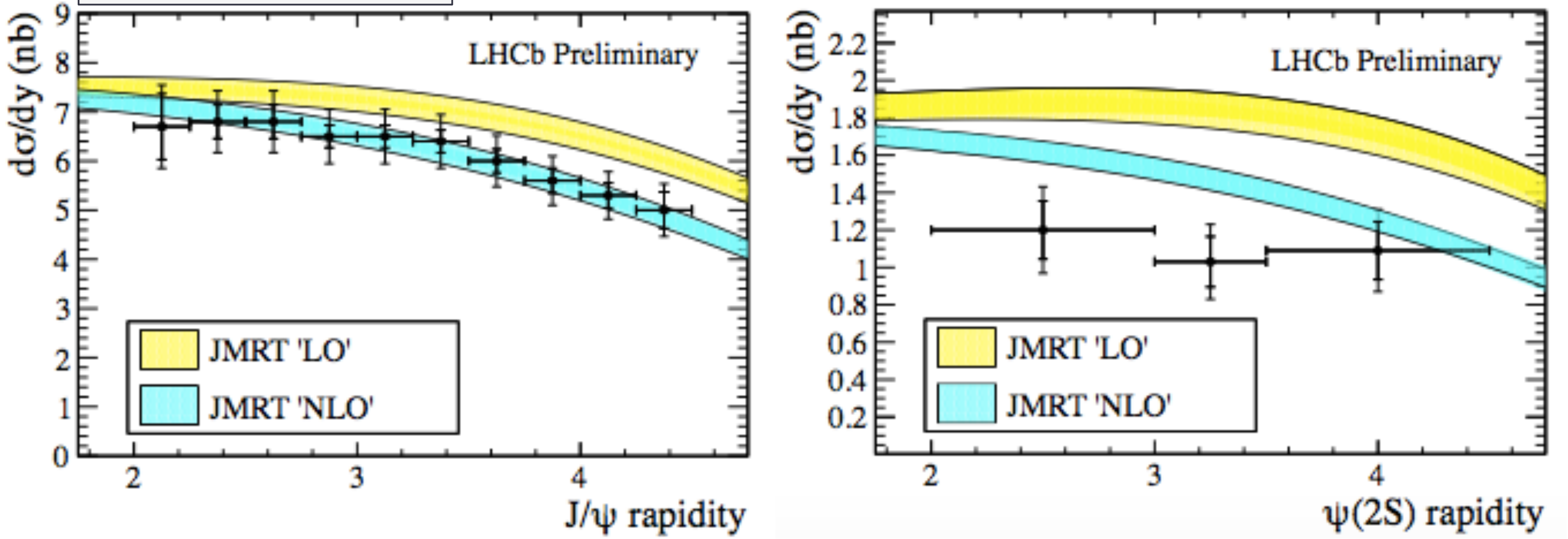
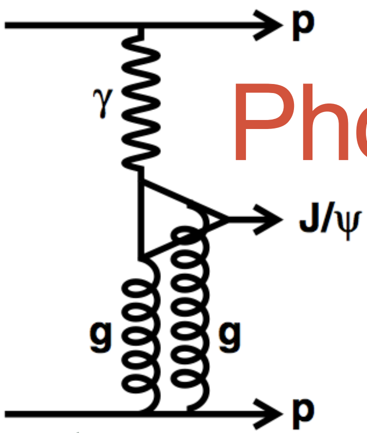


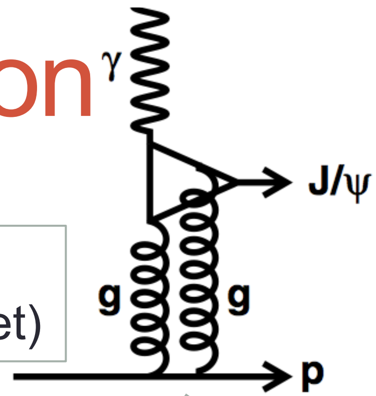
NLO agrees better than LO

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.

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.

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 W- solution (in previously measured region). LHCb measures W+

Photo-production cross-section

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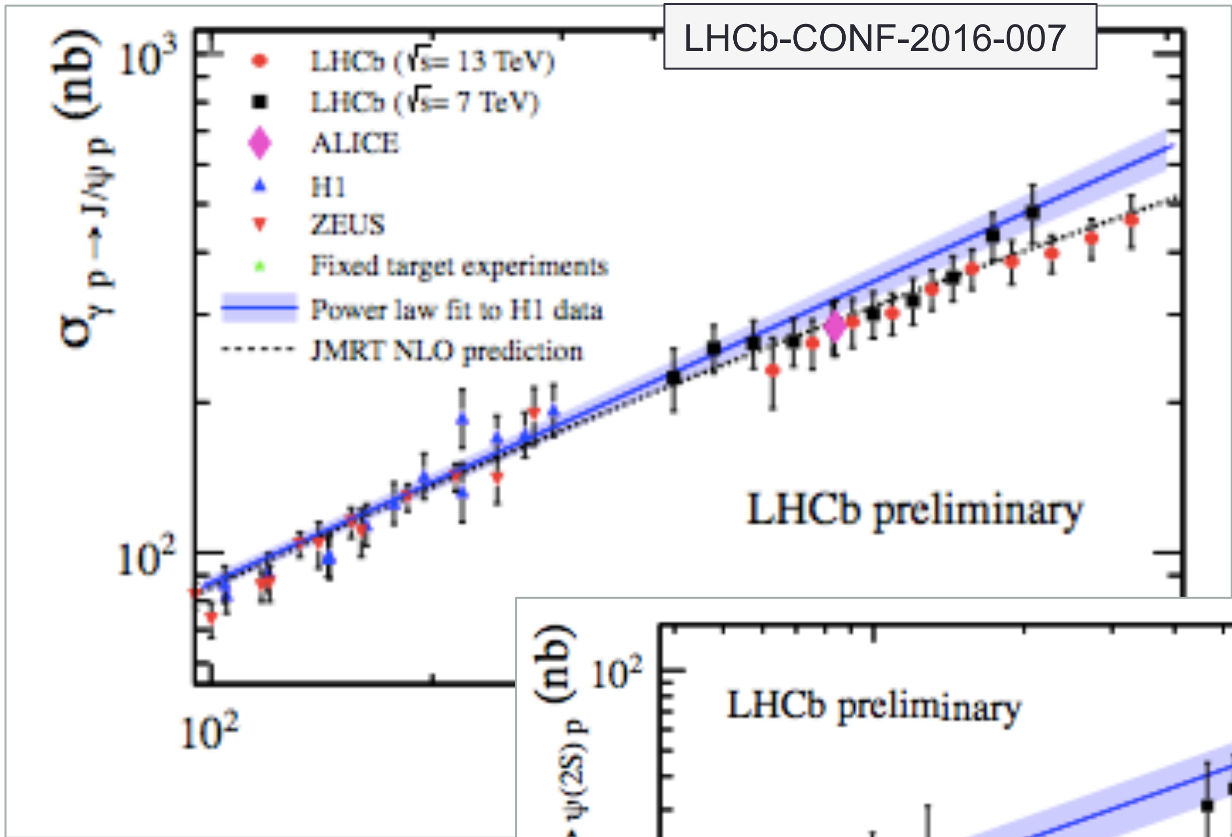
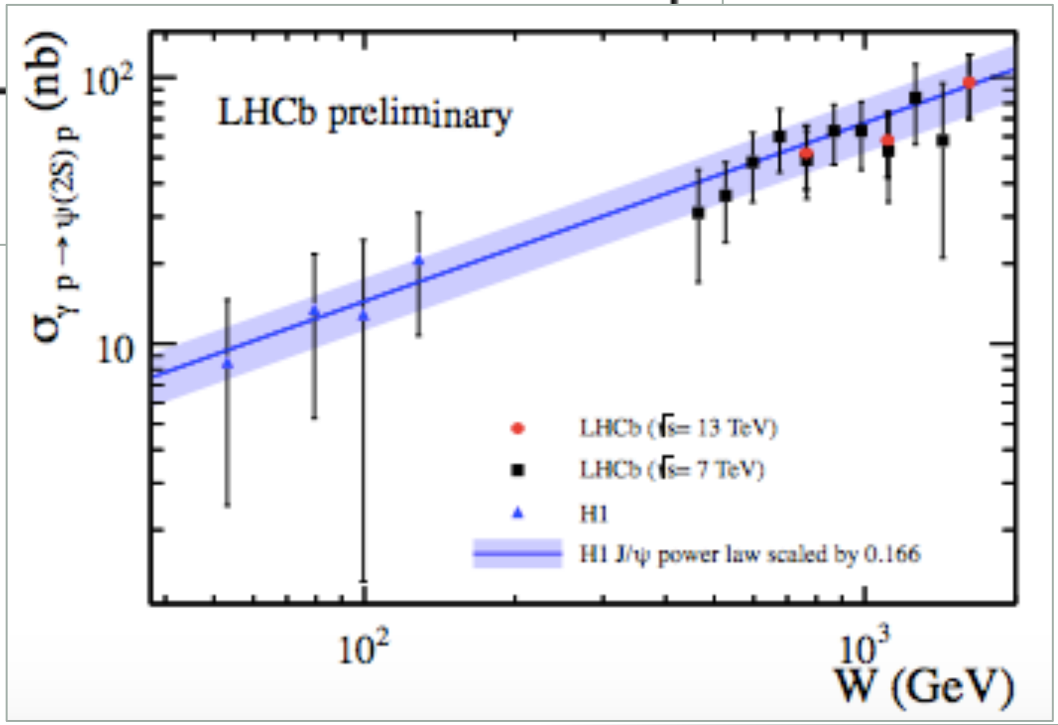
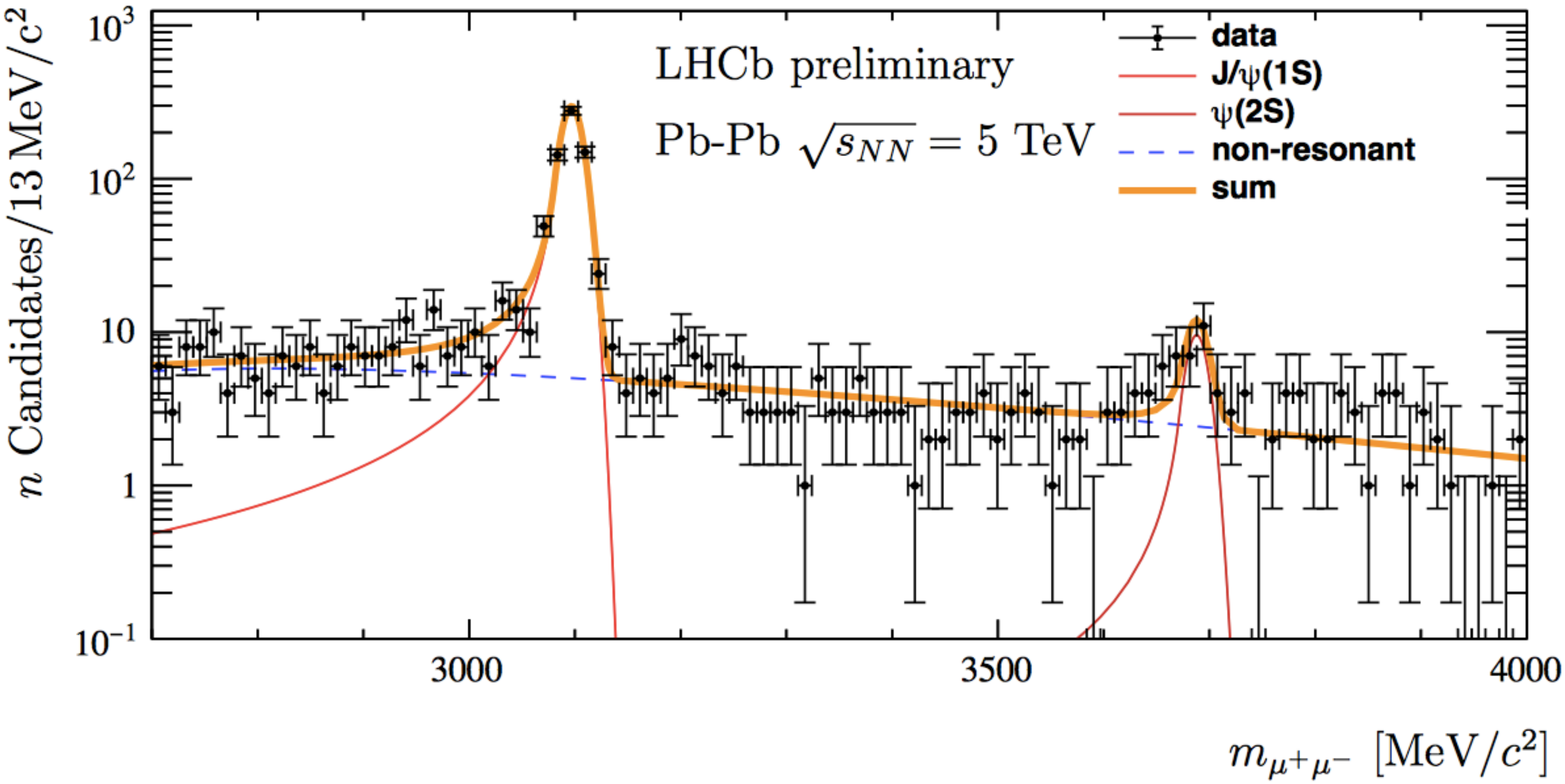
J/ψ



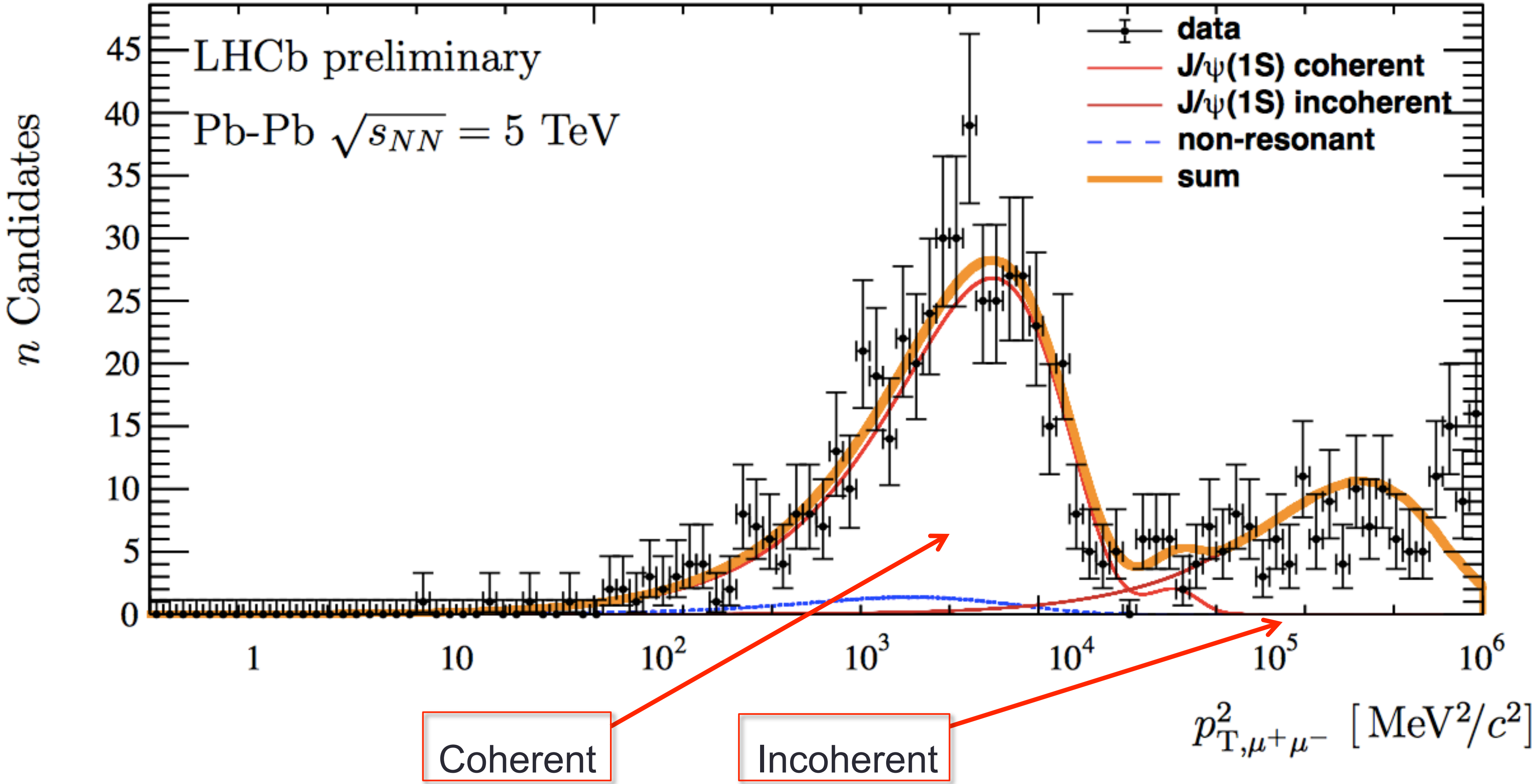
ψ(2S)



Pb-Pb collisions



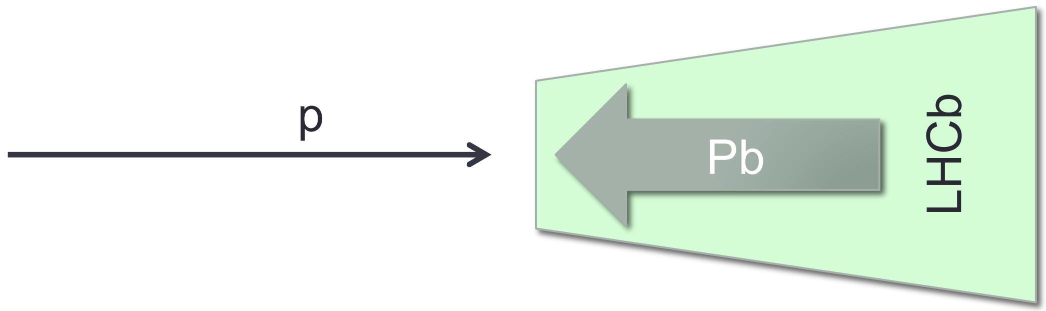
Pb-Pb collisions



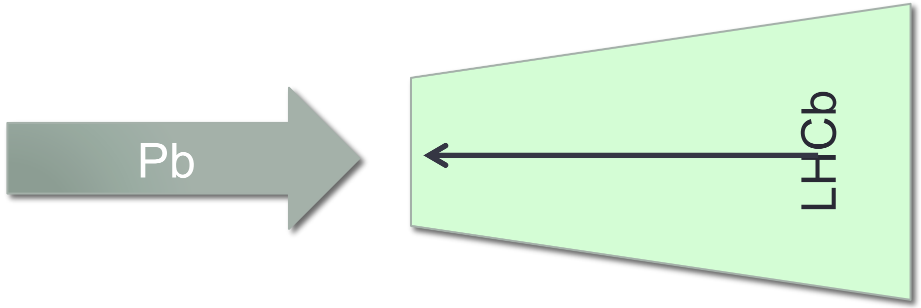
(Herschel can separate each component)

p-Pb interactions

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



J/ψ sensitivity in 1.5<y<4.0

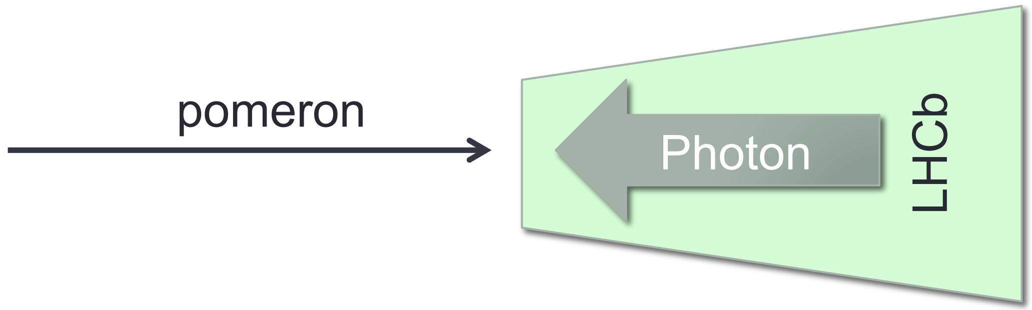


J/ψ sensitivity in -5.0<y<-2.5

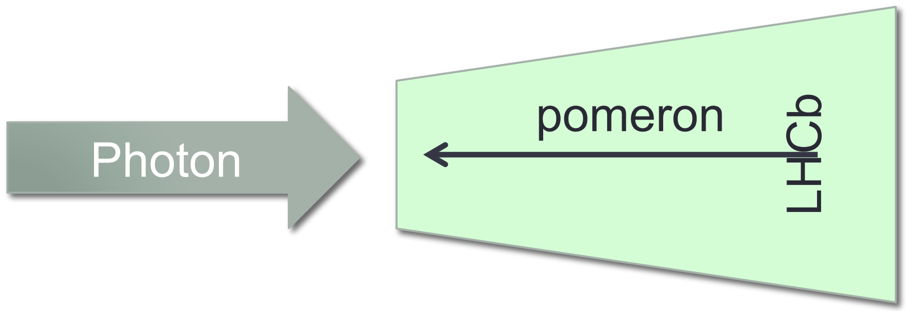
Photon flux proportional to Z^2. Removes two-fold ambiguity

p-Pb interactions

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



J/ψ sensitivity in 1.5<y<4.0
(Low W region)

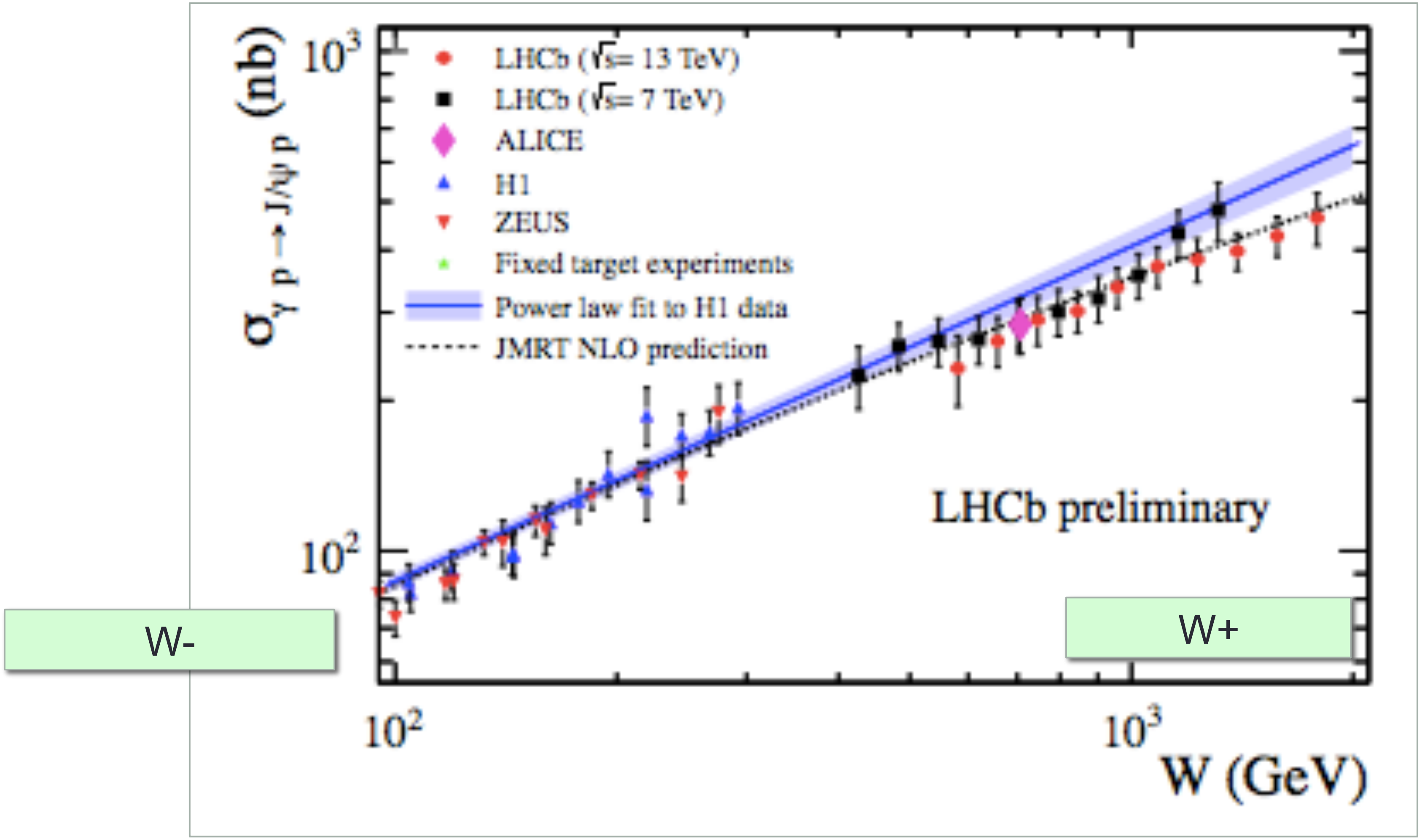


J/ψ sensitivity in -5.0<y<-2.5
(High W region)

Photon flux proportional to Z^2. Removes two-fold ambiguity

p-Pb interactions

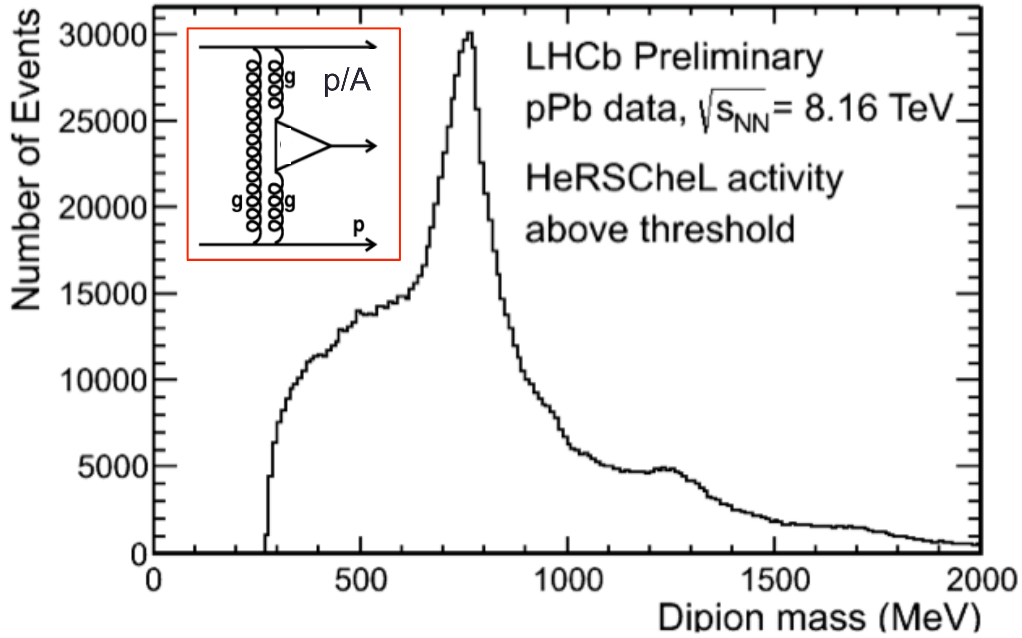
$$\frac{d\sigma}{dy}_{pp\to pJ/\psi\, p} = r_+ k_+ \frac{dn}{dk_+} \sigma_{\gamma p\to J/\psi\, p}(W_+)$$

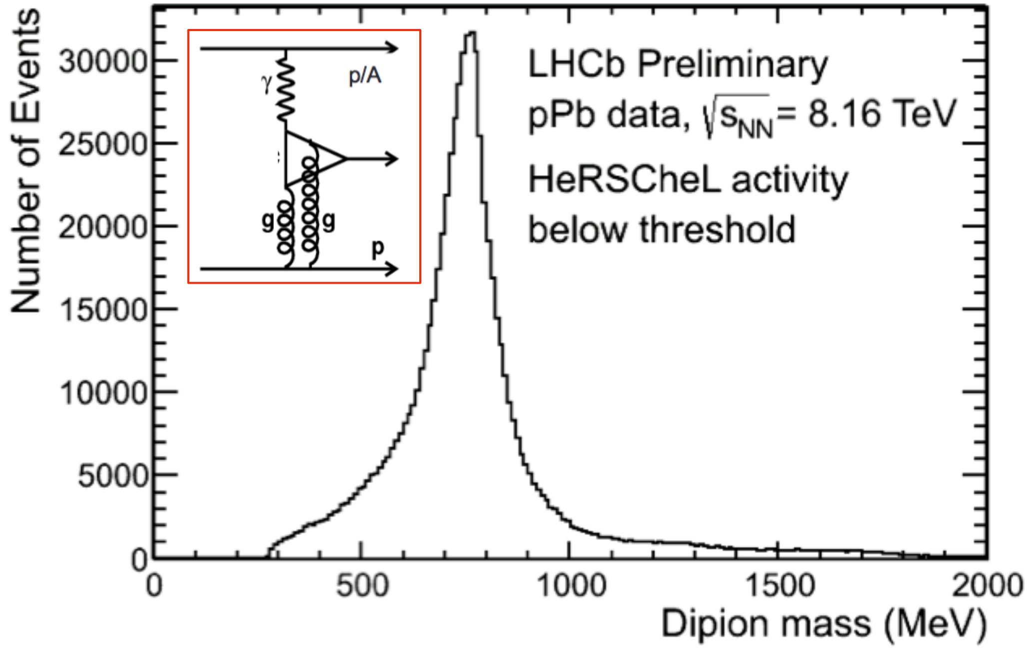


Dipions in pA/Ap

- pp->p(ππ)p has contributions from DPE (f0, f2 etc) and photoproduction (ρ).
- Difficult to disentangle (e.g. f0 appearing as shoulder on ρ)
- Difficult to separate exclusive from dissociation

- pA->p(ππ)A has enhanced photoproduction
- Remarkably clean resonance
- x down to 10^{-6}, W up to 1 TeV



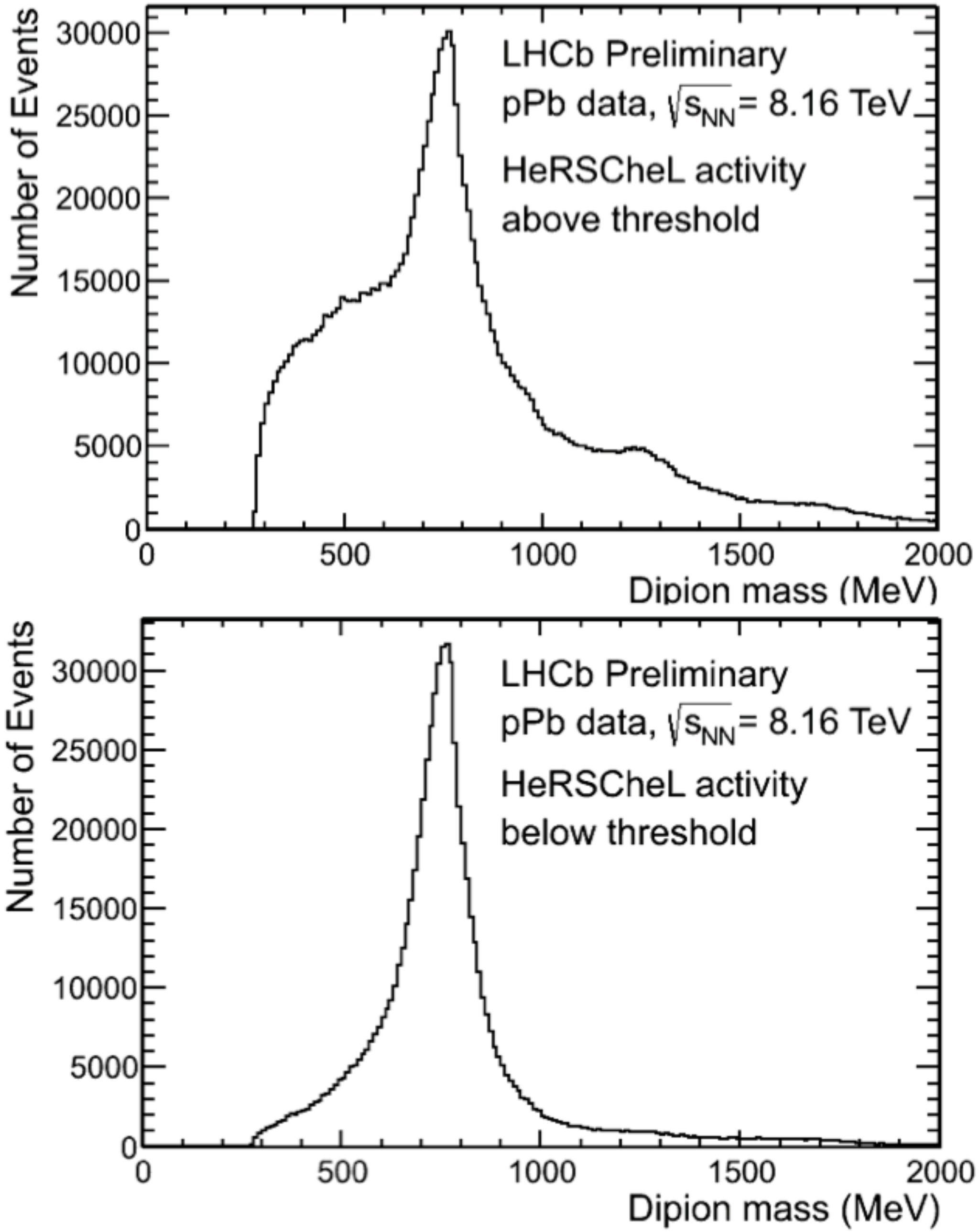


Dipions in pA/Ap

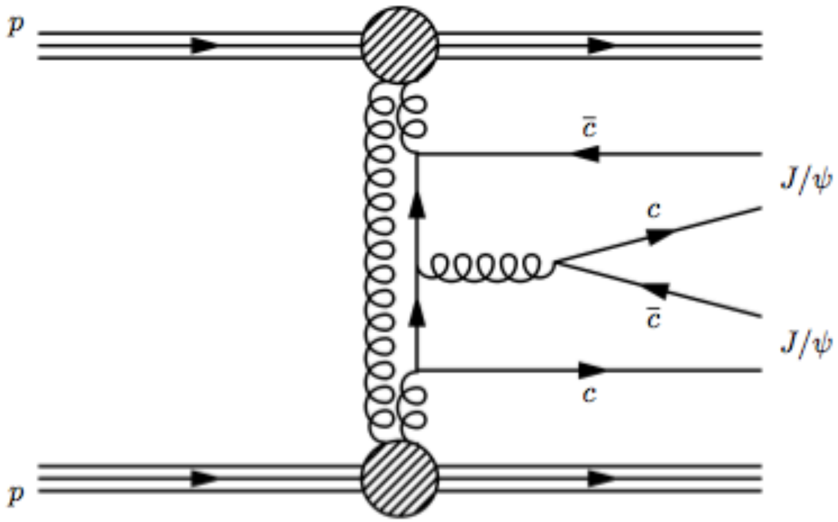
- Use pA to study photo-production

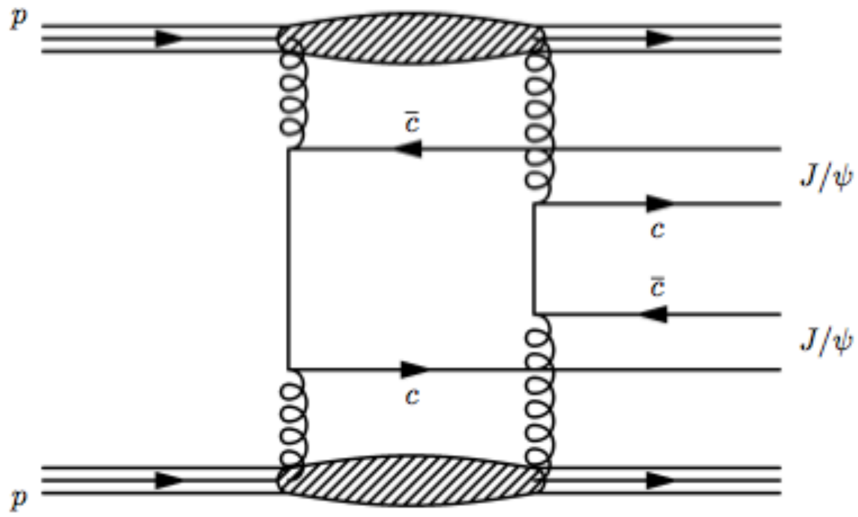
- Use pp for DPE

- Use PbPb for gamma-gamma



Double J/ψ production

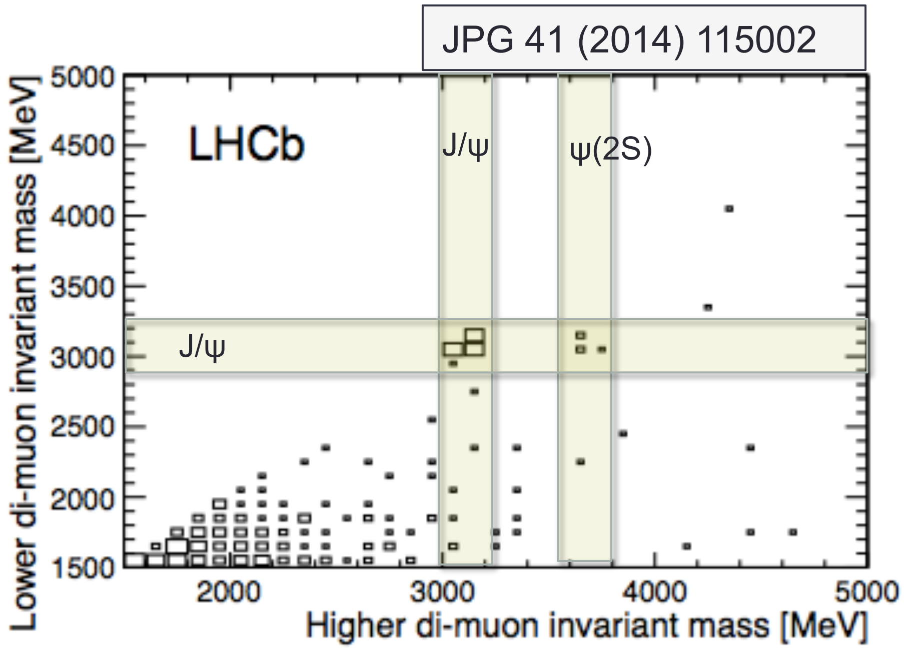


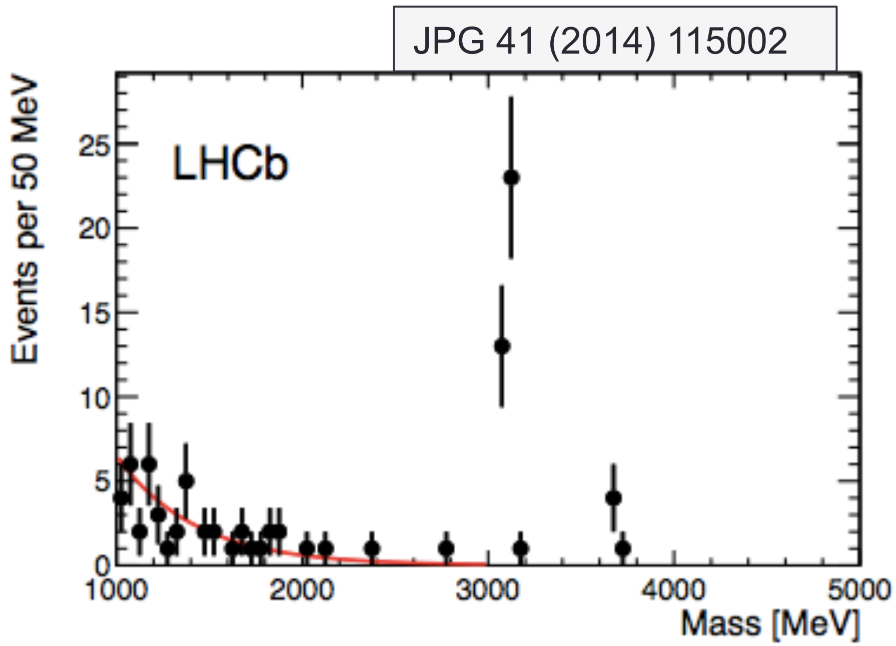


Final state theoretically studied in diphoton production (linear collider) but not through double pomeron exchange (hadron collider)

Sensitivity to higher mass states (tetraquarks, η_b)
Inclusive production has attracted much interest (DPS effects)

Select 4-muon exclusive events





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

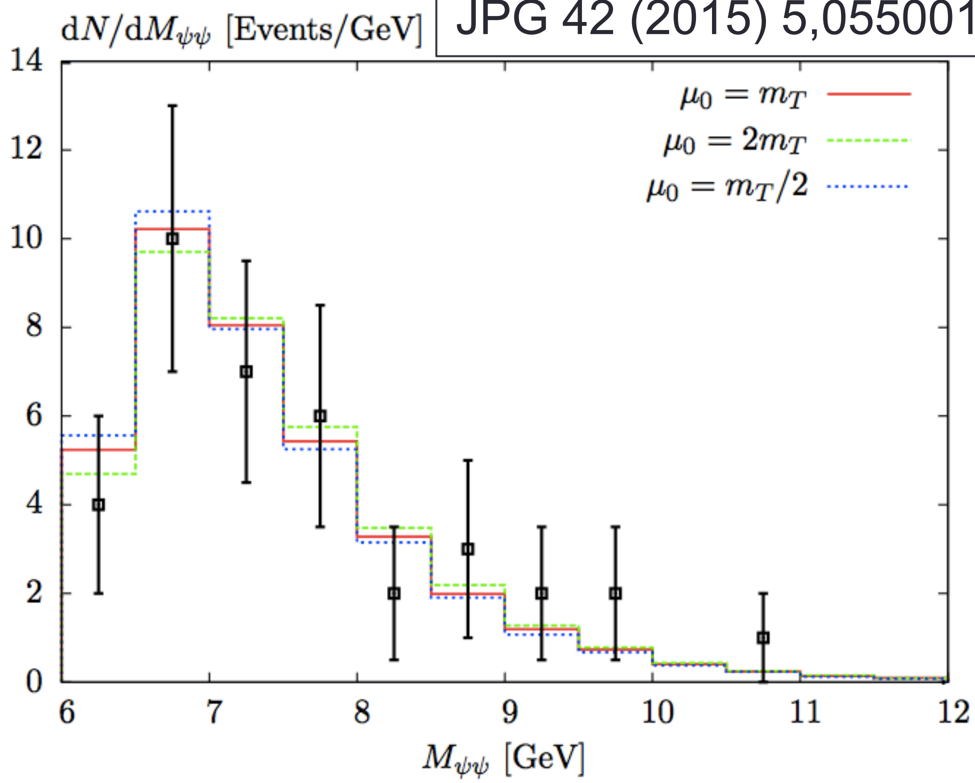
Selection requirement:
Require precisely 4 tracks, at least three identified as muons

Comparison to theory

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

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

arXiv: 1409.4785
JPG 42 (2015) 5,055001



Shape agrees well (theory normalised to data).

Overview

1. LHCb and Herschel Detector
   arXiv:1801.04281

2. Analyses:
   - pp at 13 TeV
   - pPb and Pbp at 8 TeV
   - PbPb at $\sqrt{s_{NN}} = 5$ TeV

3. Odderon and prospects for CEP in future

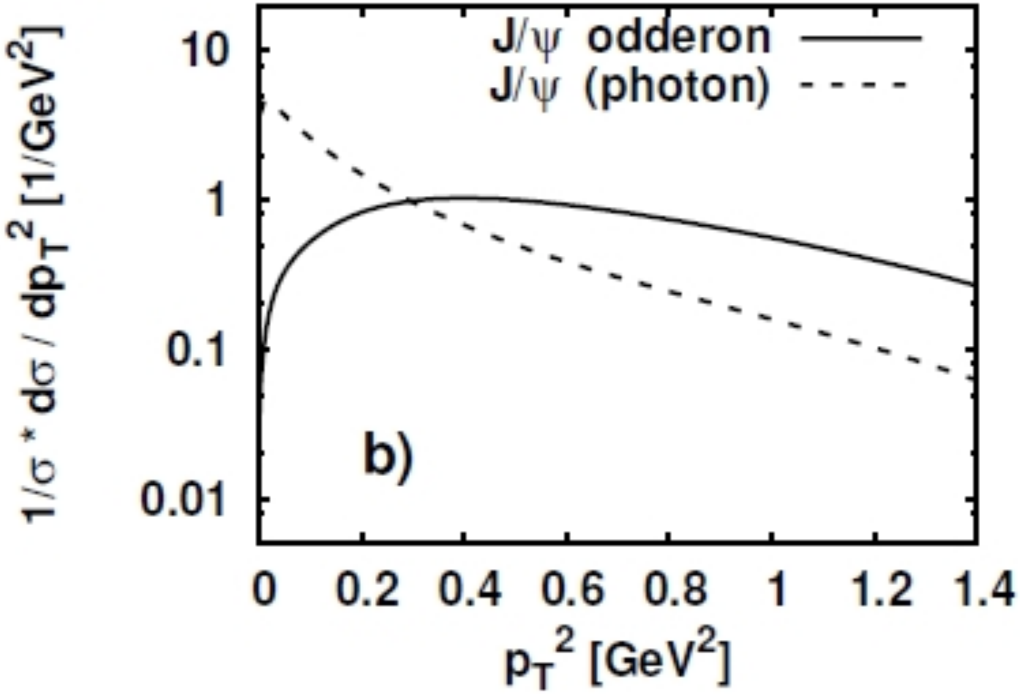
Did TOTEM experiment discover the Odderon?

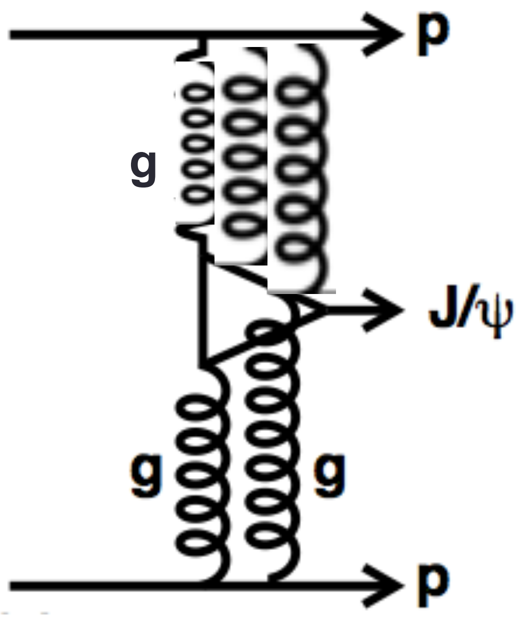
Can LHCb experiment discover the Odderon?

Can LHCb experiment discover the Odderon?

1) Photoproduction -> Odderoproduction
2) Pomeron-Odderon Interference
3) Two photon physics -> Two odderon physics
4) Other ideas?

1. Odderoproduction



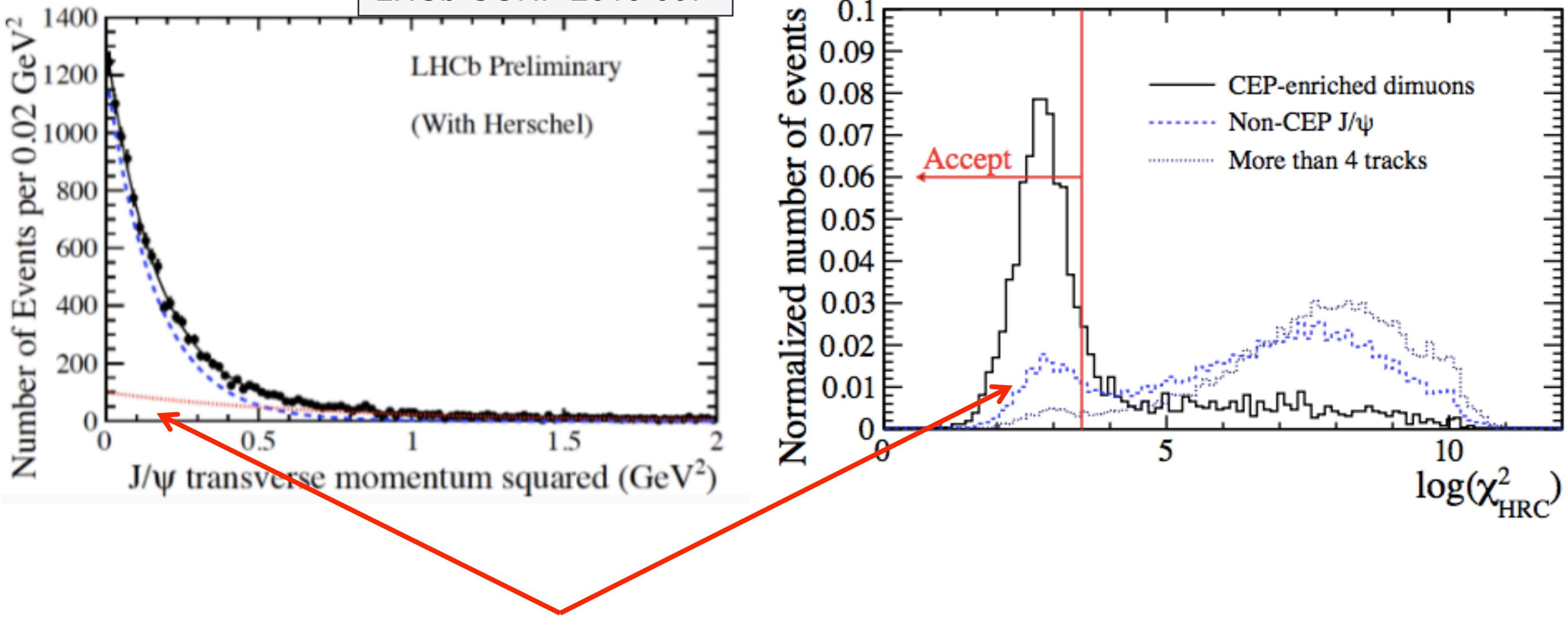


Bzdak, Motyka, Szymanowski, Cudell
PRD 75 (2007) 094023
arXiv:0808.2216

$d\sigma^{corr}/dy$	J/ψ		Υ	
	odderon	photon	odderon	photon
Tevatron	0.3–1.3–5 nb	0.8–5–9 nb	0.7–4–15 pb	0.8–5–9 pb
LHC	0.3–0.9–4 nb	2.4–15–27 nb	1.7–5–21 pb	5–31–55 pb

1. Odderoproduction

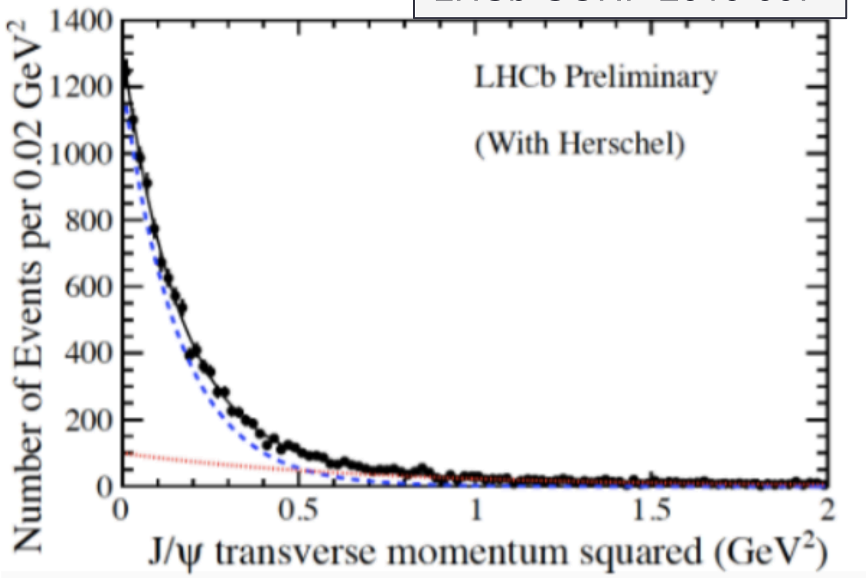
LHCb-CONF-2016-007

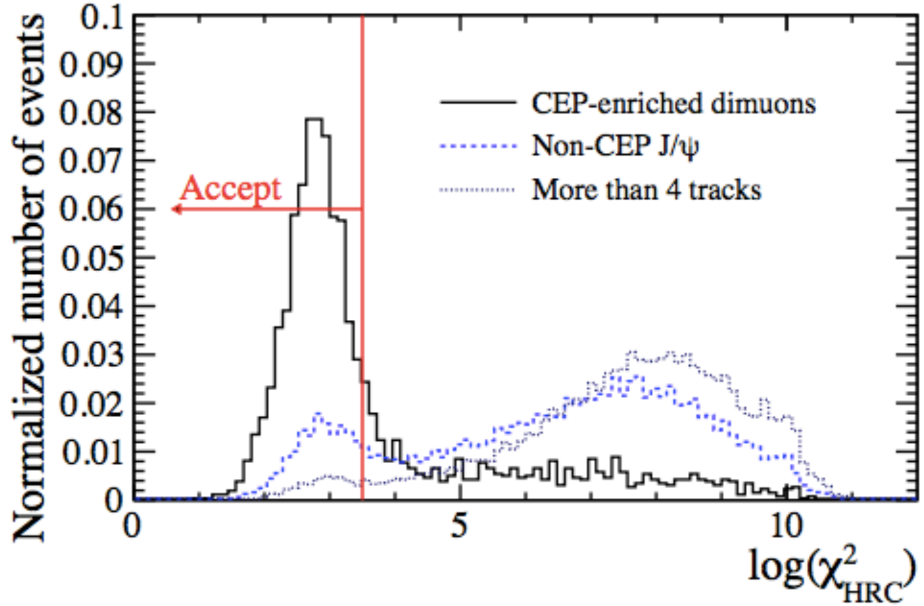


Proton dissociation or Odderoproduction ? !

1. Odderoproduction

LHCb-CONF-2016-007





LHCb

Did ~~TOTEM~~ experiment discover the Odderon?

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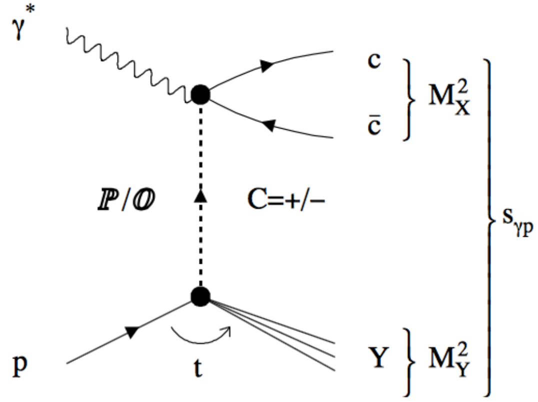
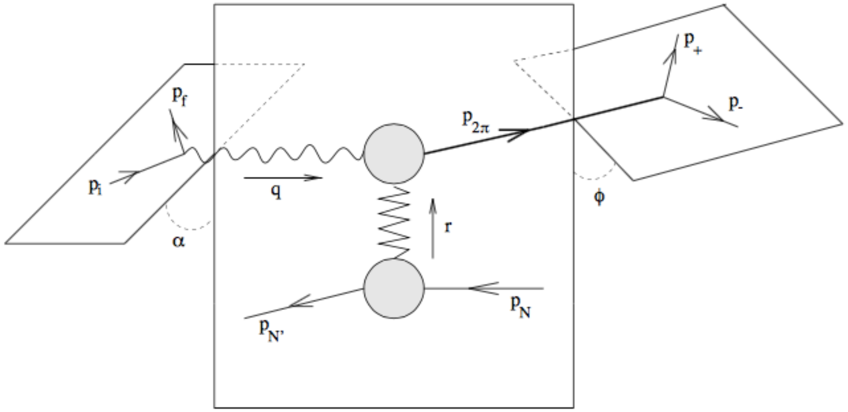
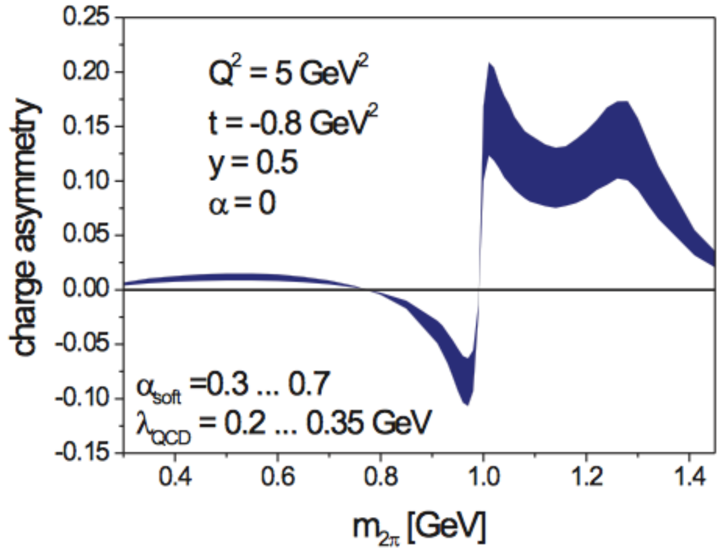
2. Odderon-Pomeron Interference

Brodsky, Rathsman, Merino,
PLB461 (1998) 114.
Hagler, Pire, Szymanowski, Teryaev,
EPJ26 (2002) 261.

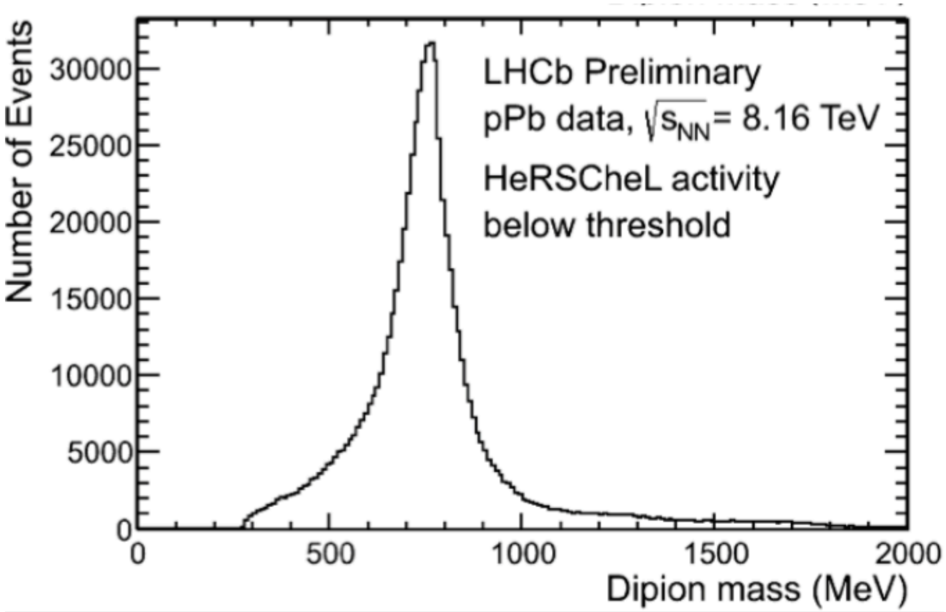


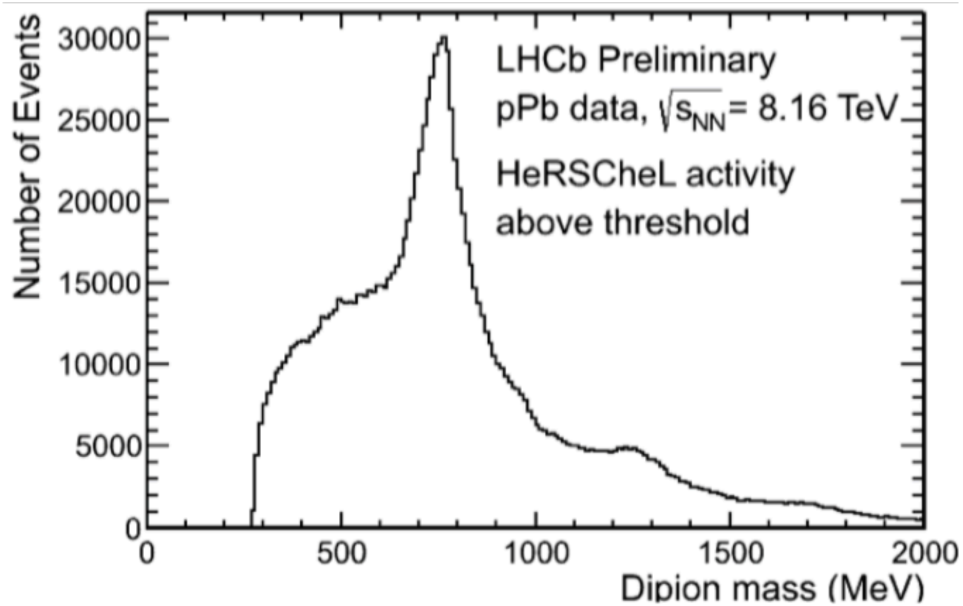
$$A(Q^2,t,m_{2\pi}^2,y,\alpha)=\frac{\sum\limits_{\lambda=+,-}\int\cos\theta\, d\sigma(s,Q^2,t,m_{2\pi}^2,y,\alpha,\theta,\lambda)}{\sum\limits_{\lambda=+,-}\int d\sigma(s,Q^2,t,m_{2\pi}^2,y,\alpha,\theta,\lambda)}=\frac{\int d\cos\theta\cos\theta\; N_{charge}}{\int d\cos\theta\; D}$$





2. Odderon Pomeron Interference





Can LHCb

~~Did TOTEM~~ experiment discover the Odderon?

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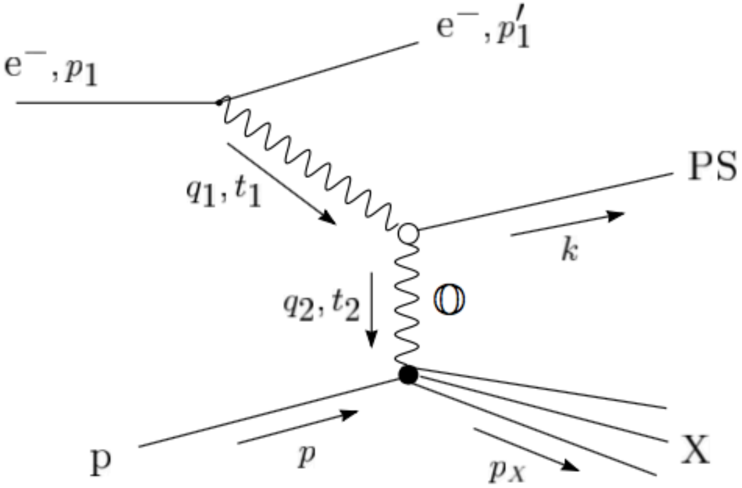
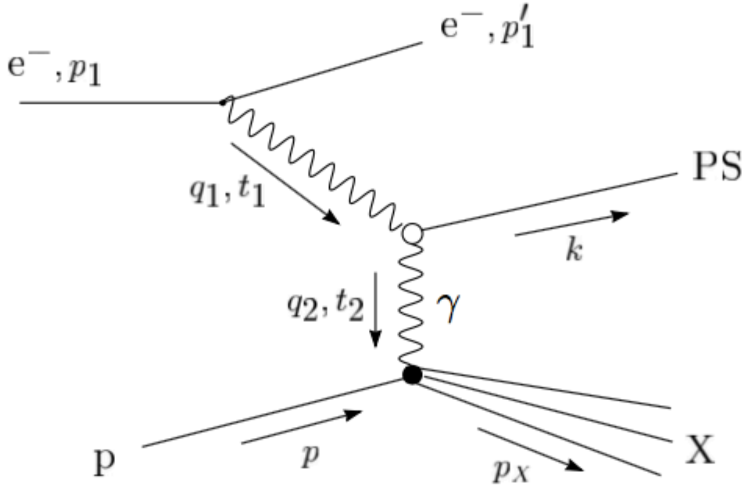
3. Gamma-Odderon Production

$\gamma p \to \eta p$, $\gamma p \to \pi^0 p$, $\gamma\gamma \to \pi^0\pi^0$

Czyzewski et al., PLB398 (1997) 400.
Berger et al., EPJ C9 (1999) 491.





In pp colisions, photon flux small so γγ cross-section small (and calculable)
Photon-Odderon production 'small'/unknown
Pomeron-Pomeron production suppressed.

Future Analyses

pp

- Low mass and charm spectroscopy
- New hadronic triggers selecting pions with pT>100 MeV
- Electromagnetic trigger for photons/electrons pT>1GeV
- μμ, ππ, KK, pp, γγ, ee. π0, η ω etc
- Ability of Herschel to suppress non-exclusive backgrounds
- odderon / glueball / exotics / tetraquark searches

pPb/Pbp

- Photoproduction: Jpsi, Phi, rho
- Very clean signals with Herschel since little pile-up or spill-over
- Search for saturation
- Quantify nuclear supressions factors

PbPb

- Two-photon physics
- Light-by-light scattering

Summary

- Several CEP pp measurements at 7 and 8 TeV using muons.
  - Limited by understanding exclusivity.
- New Herschel detector for Run 2.
  - Calibration and performance shown
  - Affected by beam conditions
  - Significant impact on physics
- First measurement at 13 TeV with lower backgrounds.
- Excellent prospects for future, including hadronic modes.