STATUS AND PROSPECTS FOR CENTRAL EXCLUSIVE PRODUCTION AT LHCB

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on behalf of the LHCb collaboration.

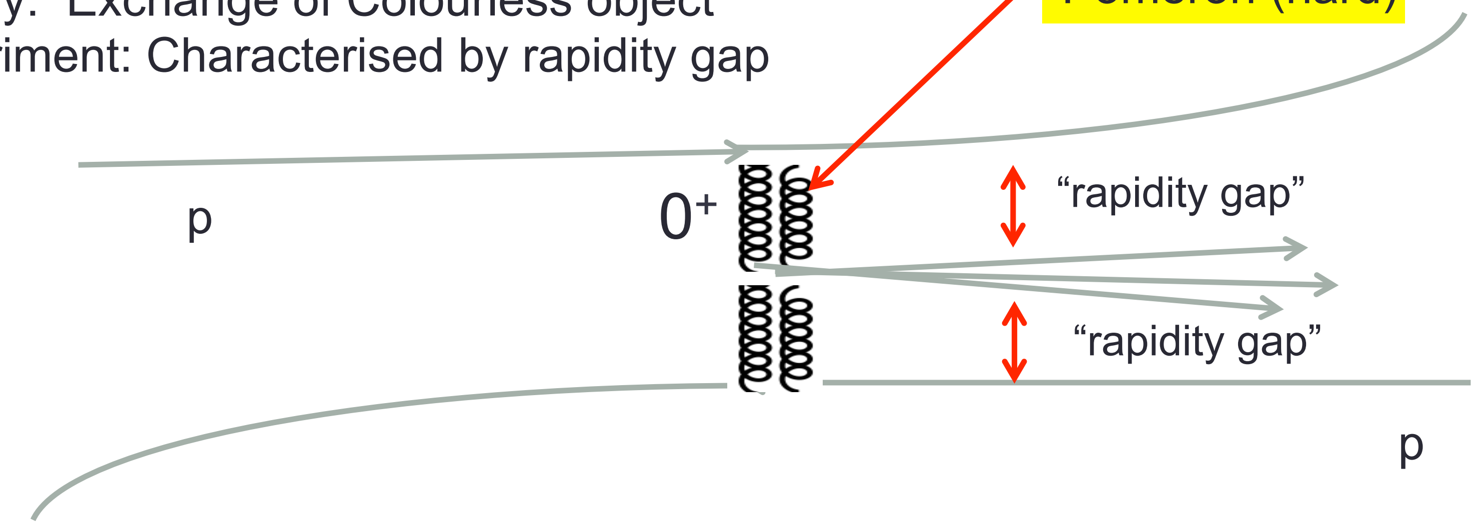
LHC WG on Forward Physics and Diffraction

Overview

- Unique attributes of LHCb
- Status
  - Exclusive J/ψ and ψ’ [JPG 40 (2013) 045001.]
  - Exclusive χ_c [[LHCb-CONF-2011-022]
  - Exclusive γγ➔μμ [LHCb-CONF-2011-022]
- Near Future (with 2010,11,12 data)
  - Vector mesons
  - Charm
- Future running
  - Possible upgades

Central Exclusive Production

Theory: Exchange of Colourless object
Experiment: Characterised by rapidity gap



Elastic diffractive: clean environment to study vacuum, and in particular, transition between soft and hard pomeron.

$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

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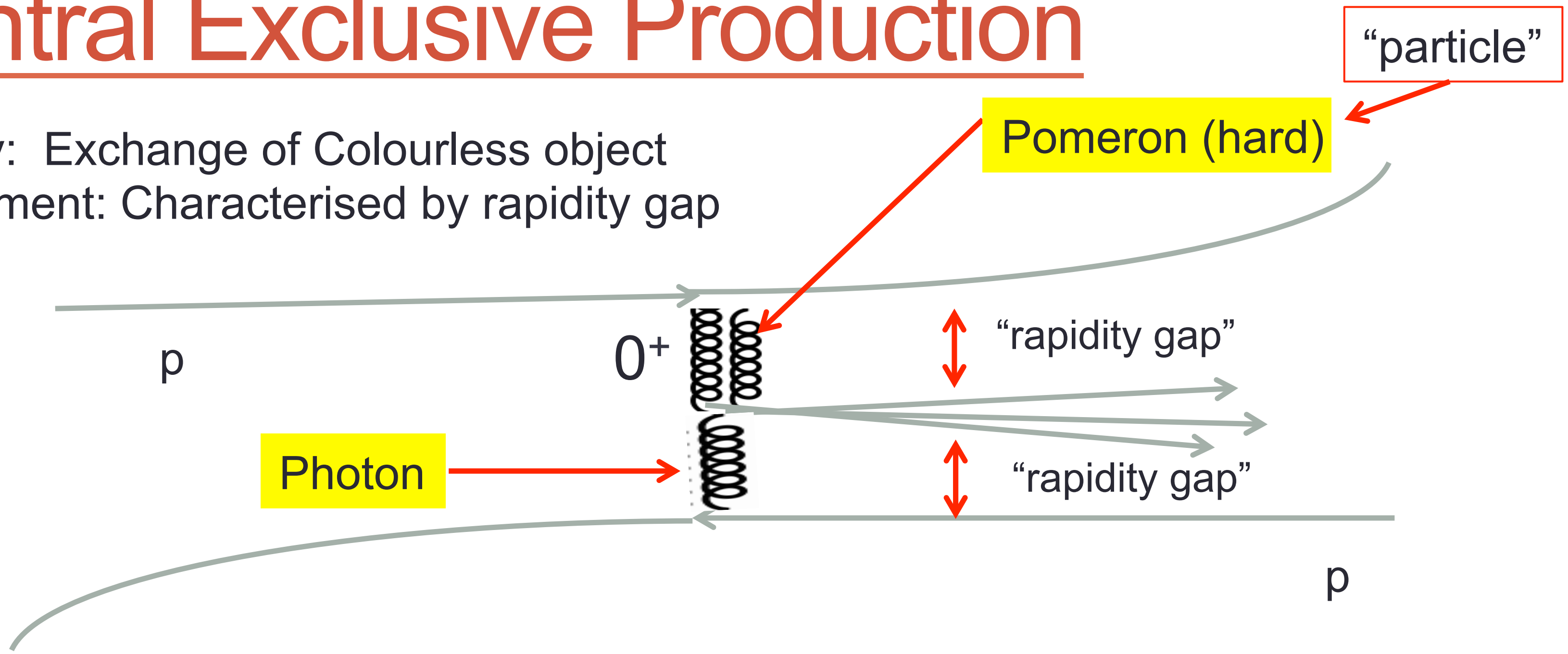

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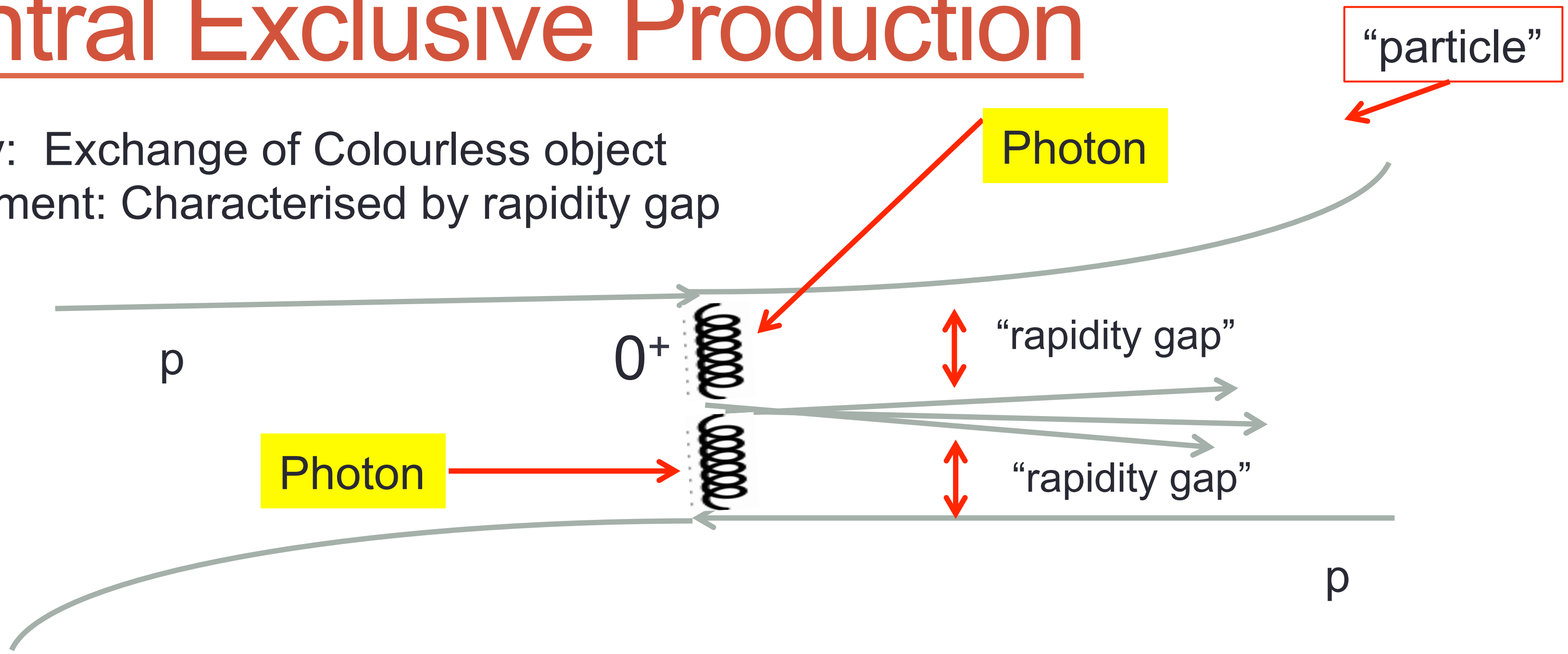

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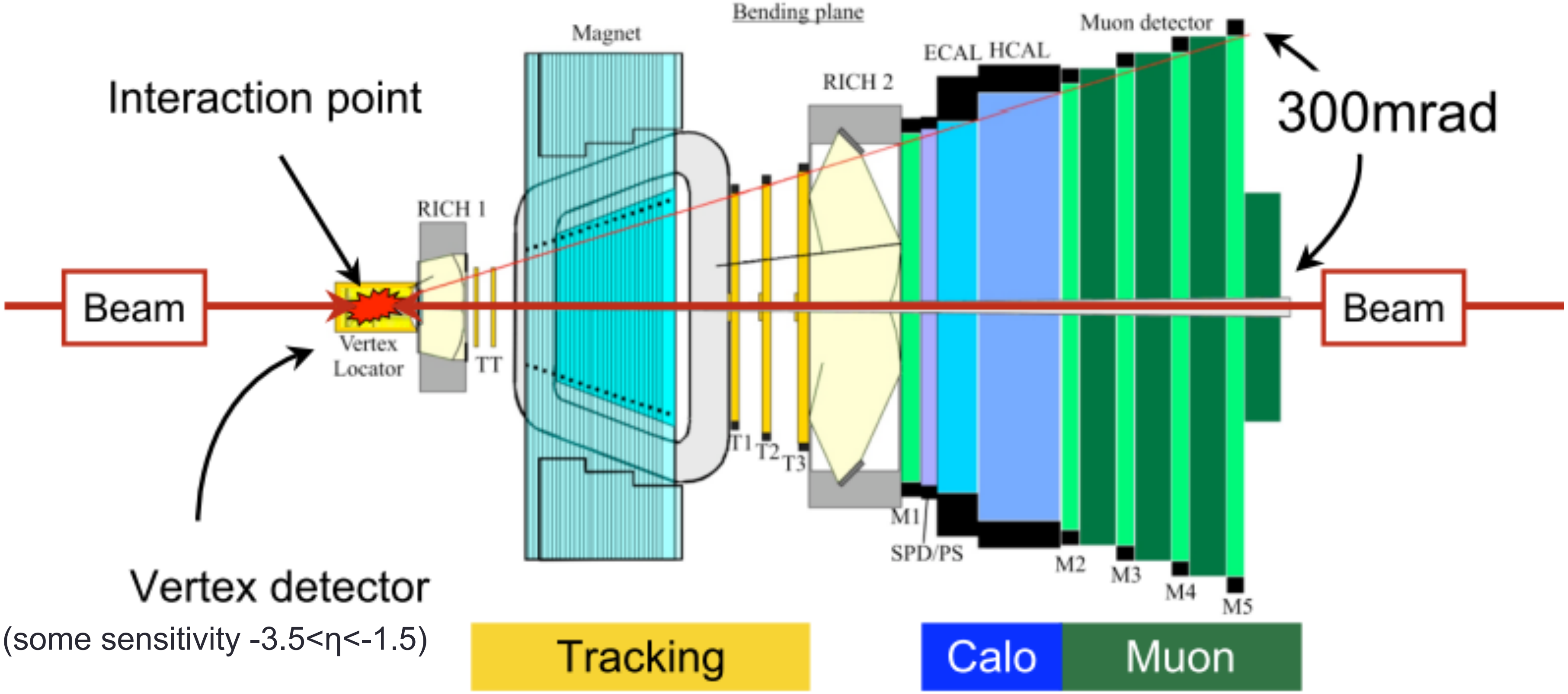
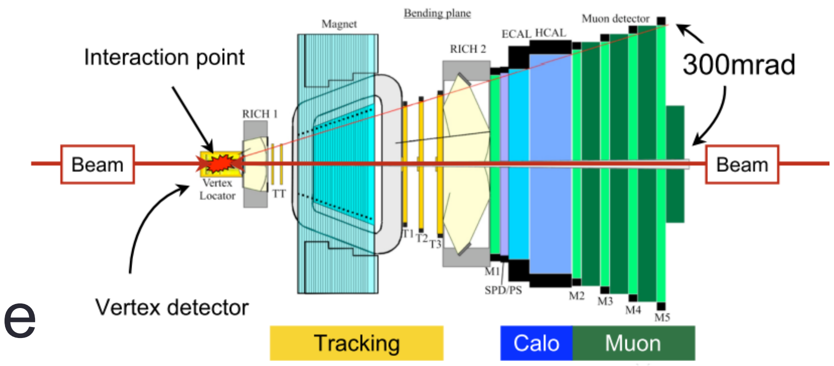
The LHCb detector



Fully instrumented within $1.9 \leq \eta \leq 4.9$

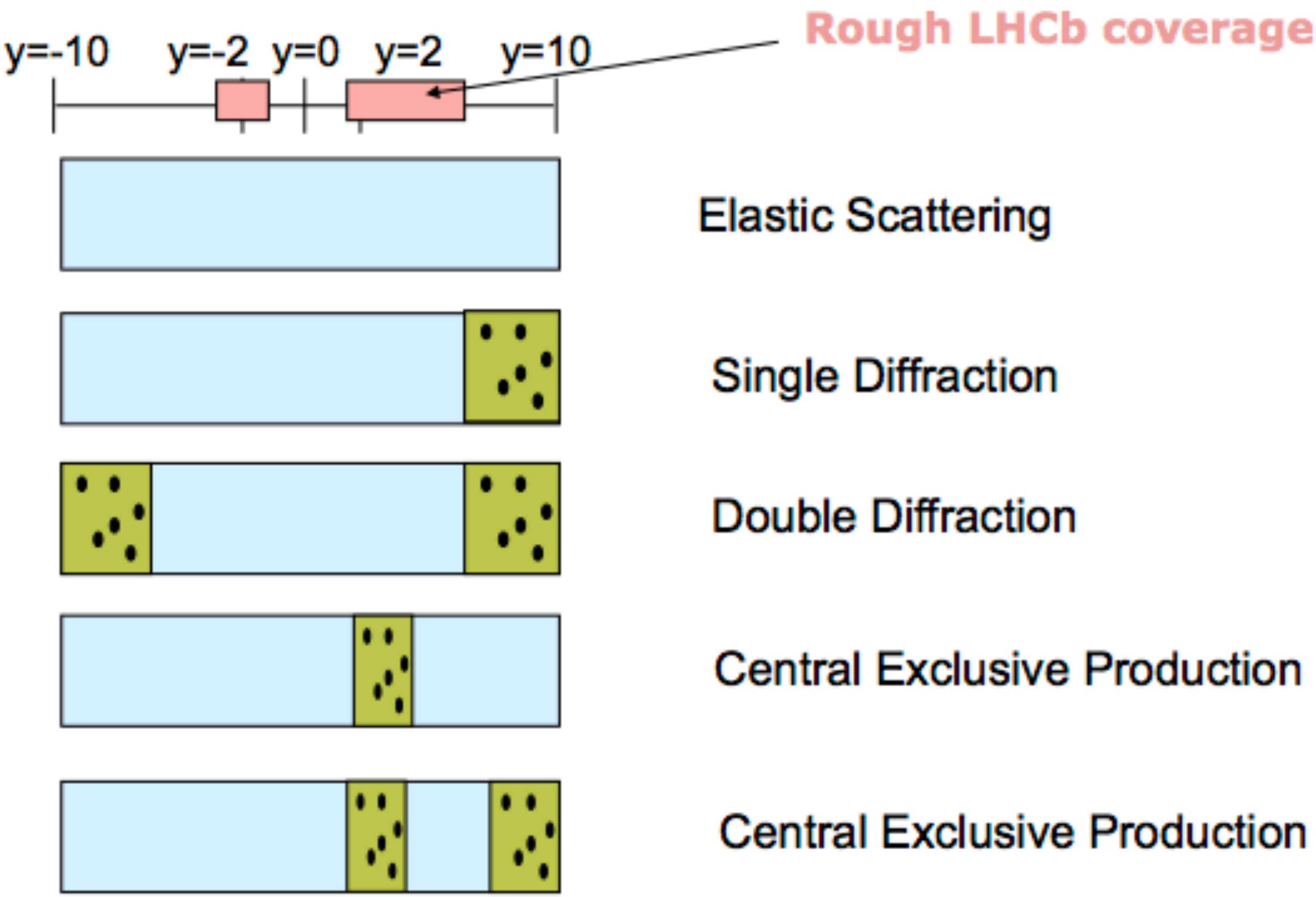
Trigger: $p_{\mu} > 3$ GeV, $pt_{\mu} > 0.4$ GeV, $m_{\mu\mu} > 2.5$ GeV

Advantages for CEP



- Quite wide pseudorapidity coverage
  - Forward track 1.5<η<5.
  - Backward track -1.5>η>-3. (depends on z_{beam})
- Ability to trigger on low p_T leptons, pions, kaons, photons
  - Muons: p_T>400 MeV
  - Hadronic energy: E_T >1 GeV
  - Particle identification with RICH: π, K, p
- Low beam pile-up conditions throughout 2010,11,12.
  - 2010: 37pb^{-1}. 21% is single interaction
  - 2011: 1fb^{-1}. 24% has single interaction
  - 2012: 2fb^{-1}. 19% has single interaction

Graphical Representation



Elastic Scattering

Single Diffraction

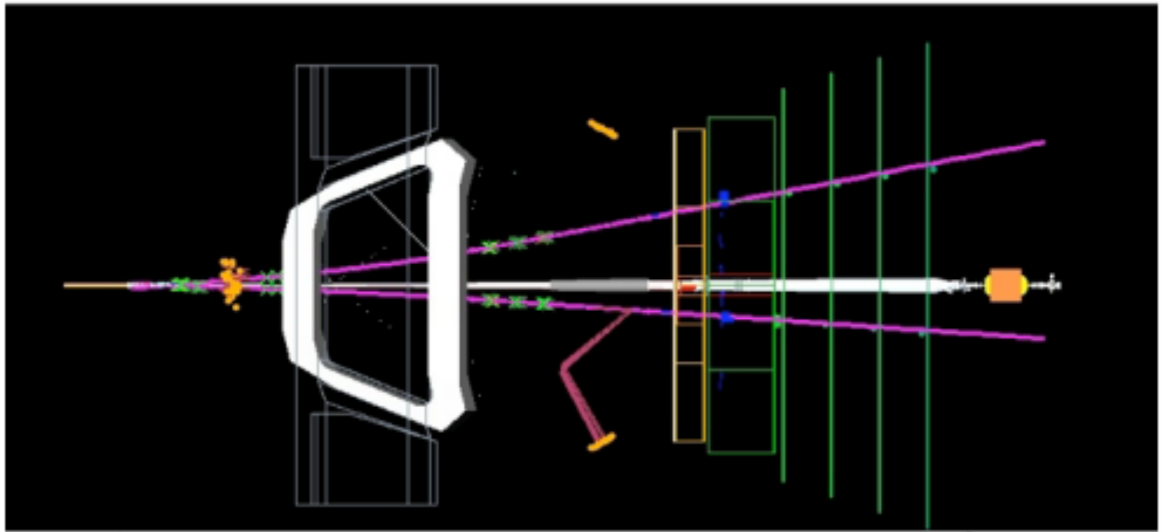
Double Diffraction

Central Exclusive Production (elastic)

Central Exclusive Production (inelastic)

Full LHCb Detector

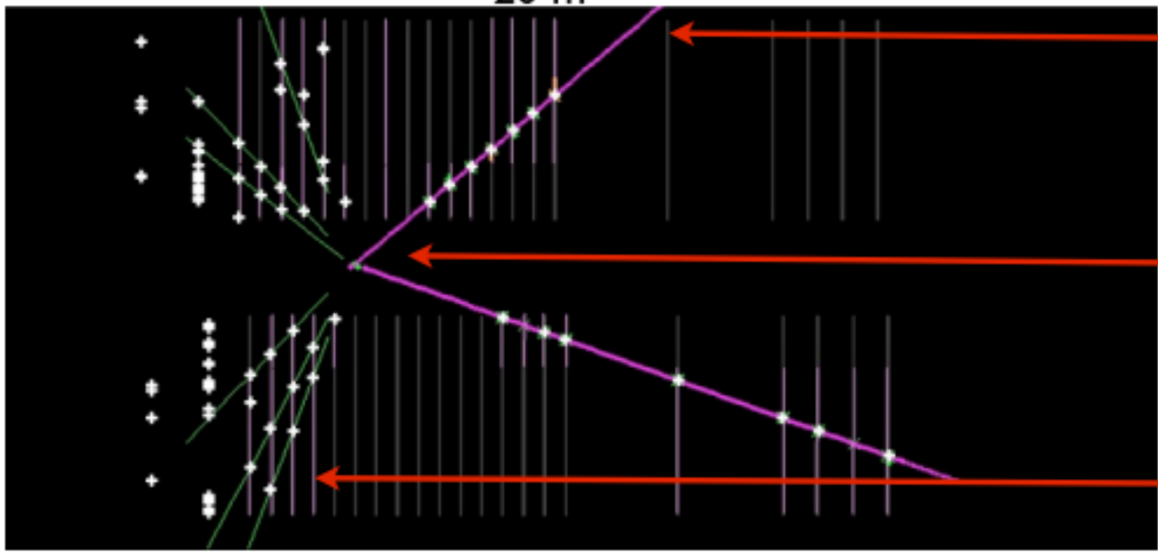
10 m



20 m

VELO Close Up

8.4 cm



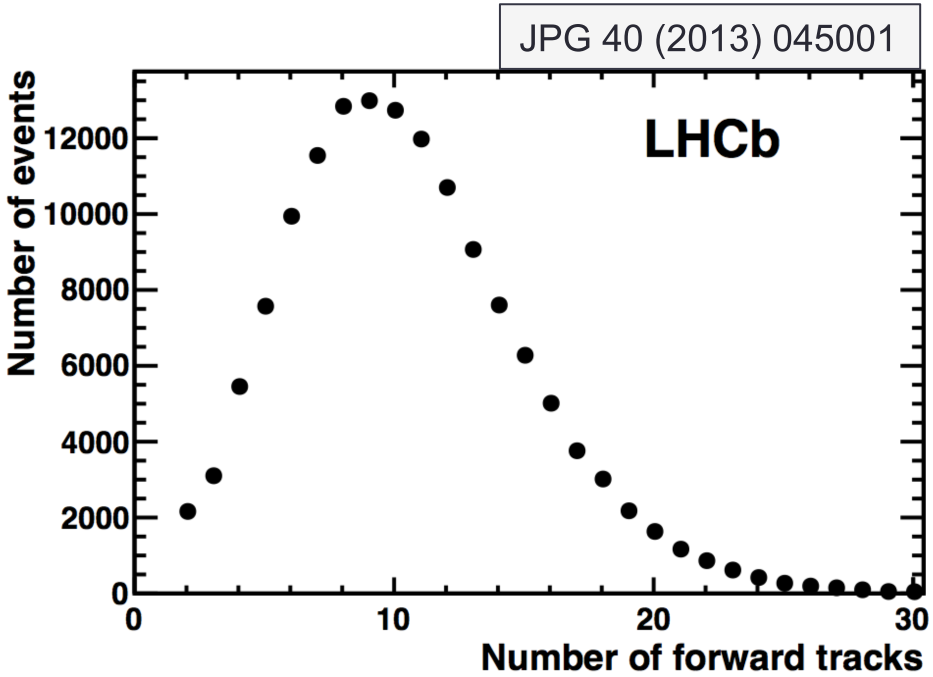
1 m

Muon

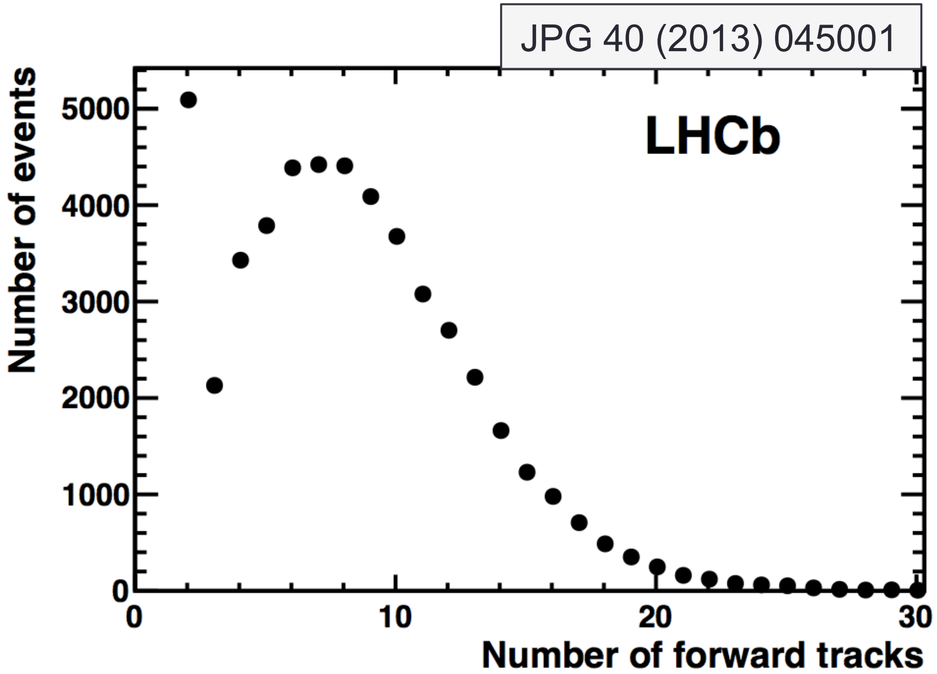
Primary Vertex

Backward Tracks

Effect of rapidity gap requirement on muon triggered events

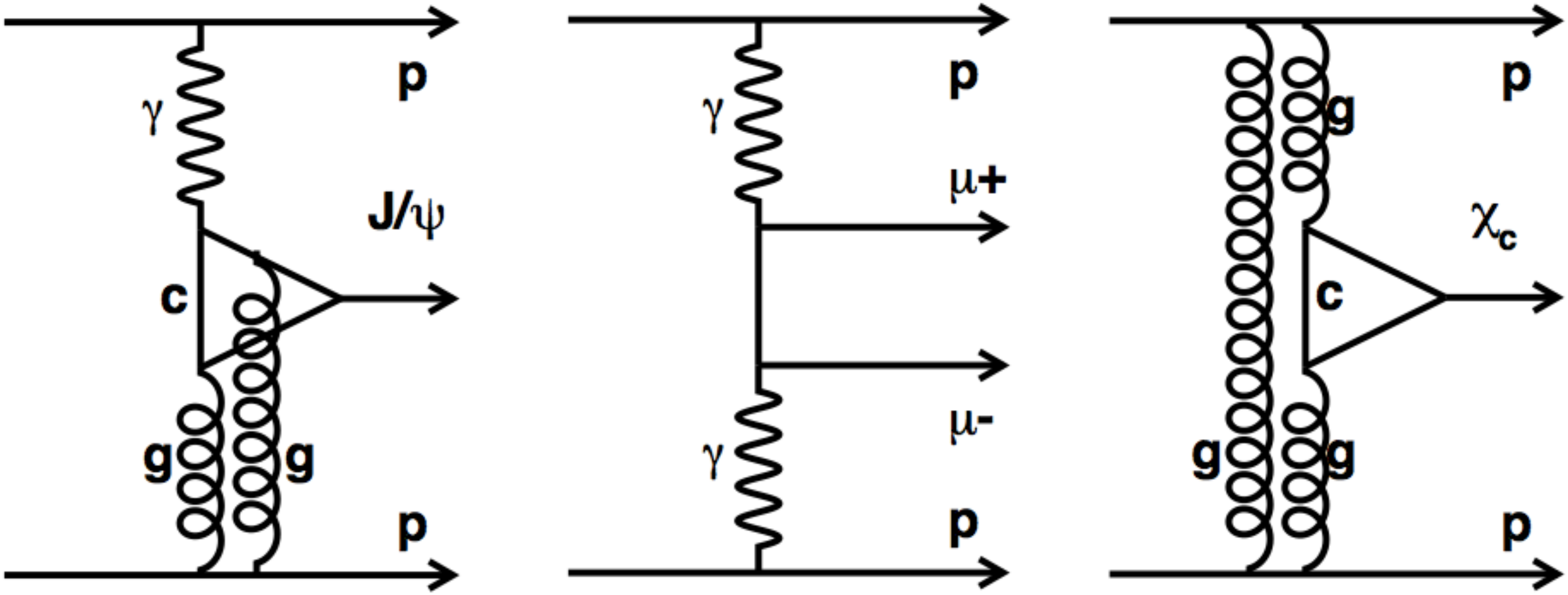


All triggered events



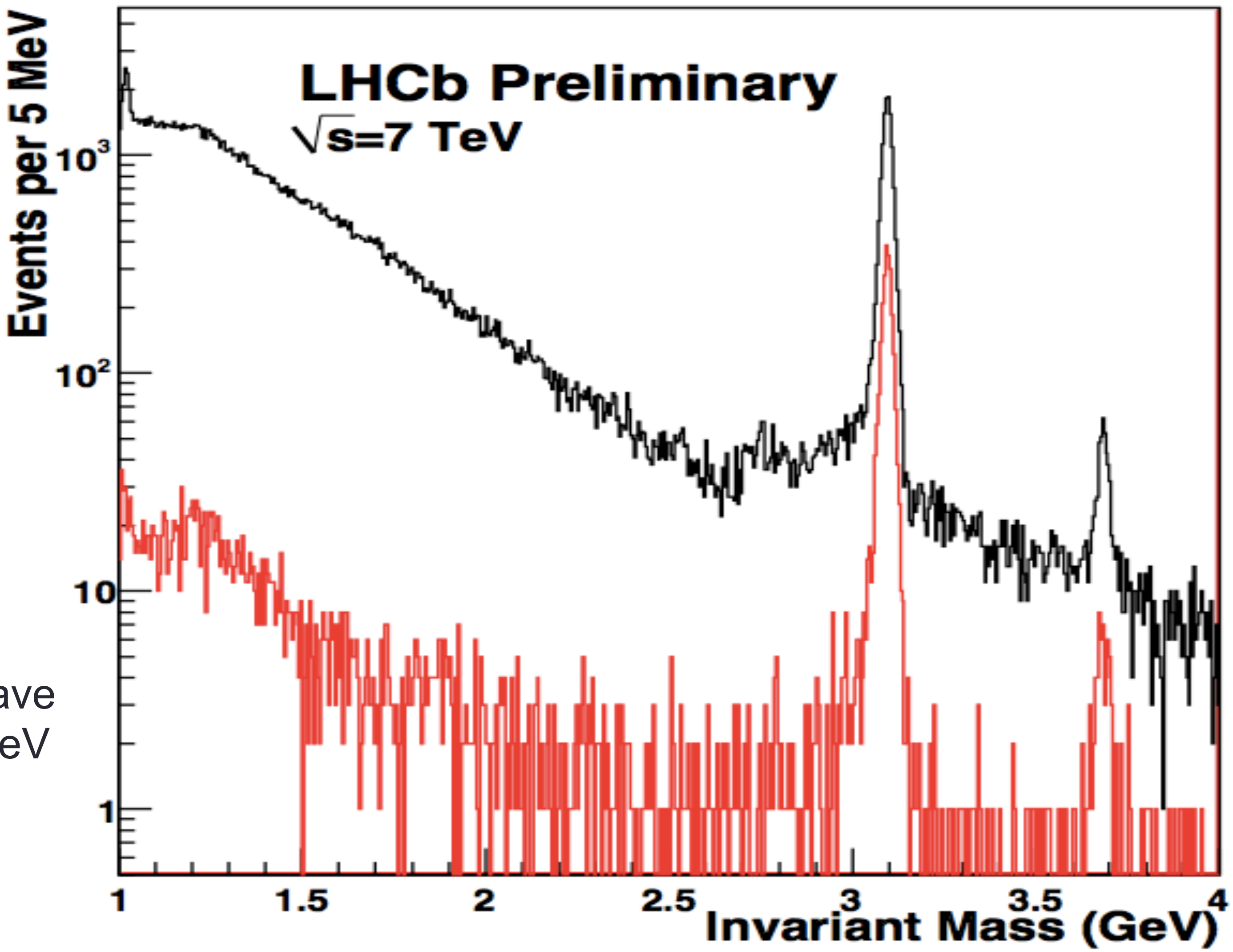
With veto on backward tracks

Current results: CEP di-muon signals



SuperChic: L. Harland-Lang, V. Khoze, M. Ryskin, W. Stirling, EPJ.C65 (2010) 433-448
Starlight: S.R. Klein & J. Nystrand, PRL 92 (2004) 142003.
LPAIR: J.A.M. Vermaseren, NPB 229 (1983) 347.

Before and after requiring precisely two tracks



Tracks have
p_T>400MeV
2<η<5

Exclusive J/ψ and ψ(2S)

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IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **40** (2013) 045001 (17pp) doi:10.1088/0954-3899/40/4/045001

Exclusive J/ψ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 7$ TeV

Results based on 37pb^{-1} of data taken in 2010

Motivations:

- Deeper understanding of QCD
- Sensitivity to PDF
- Search for odderon
- Search for saturation effects

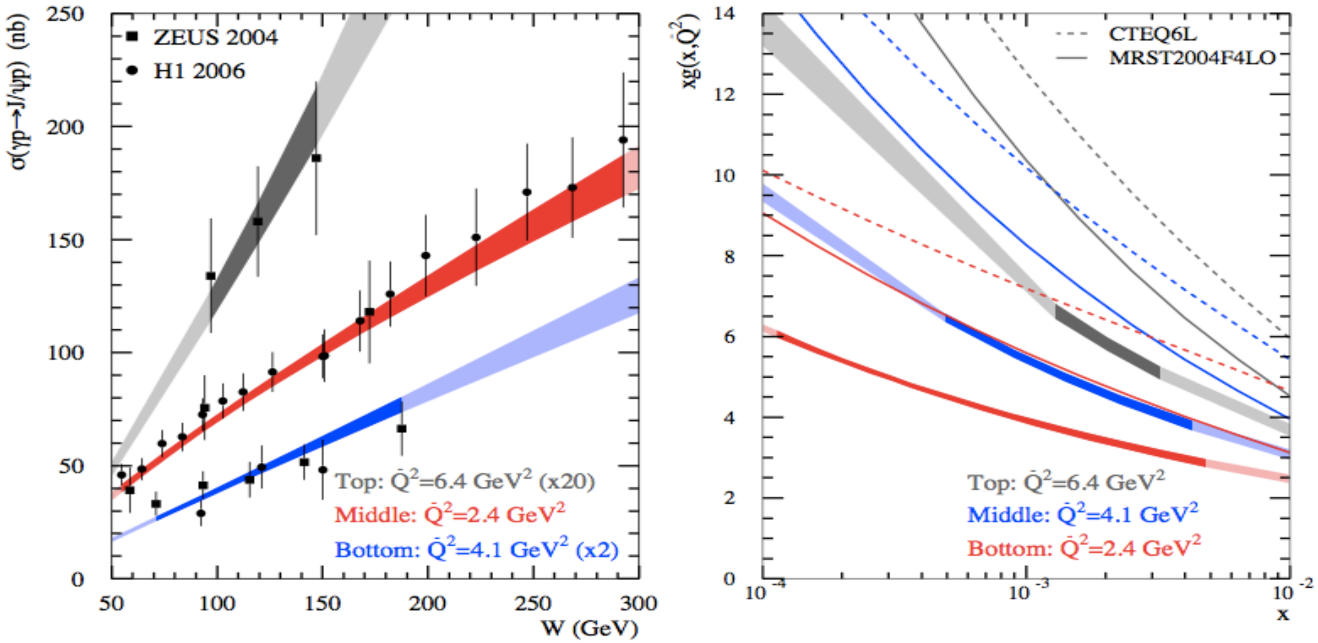
Sensitivity to gluon PDF

$xg \propto x^{-\lambda}$

Gluon PDF enters squared

Leading order cross-section

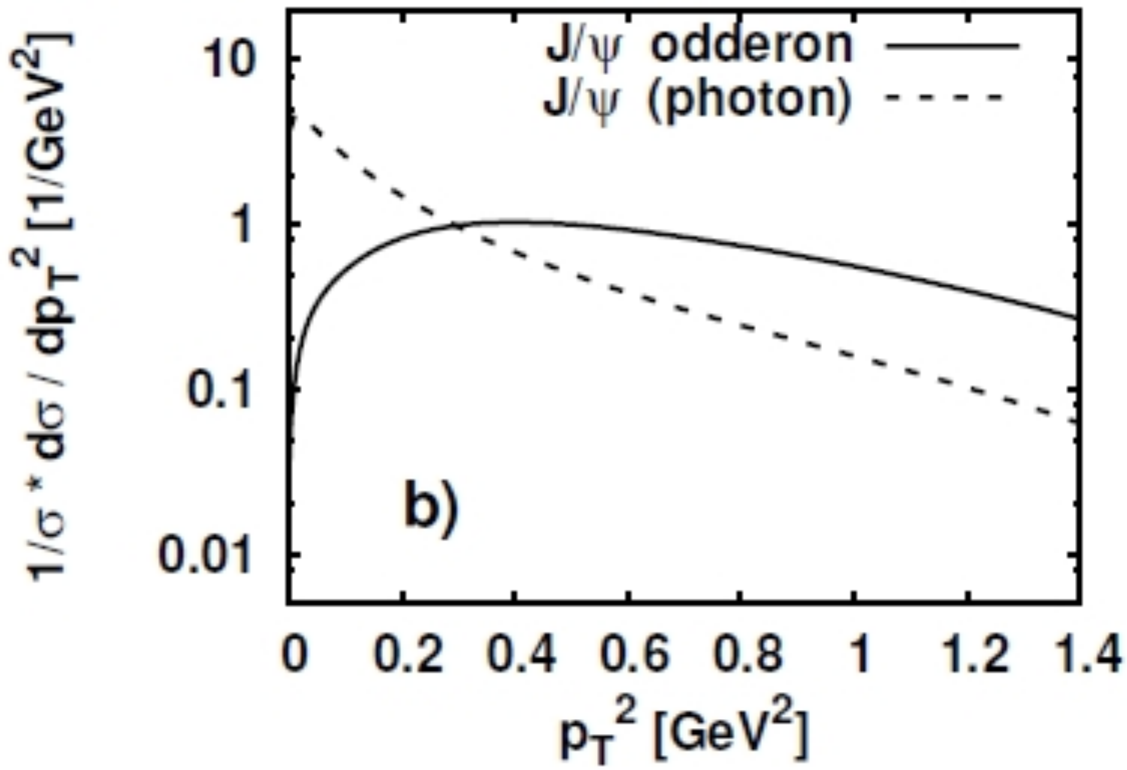
$$\frac{d\sigma}{dt}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x,\bar{Q}^2)\right]^2 \left(1 + \frac{Q^2}{M_{J/\psi}^2}\right)$$



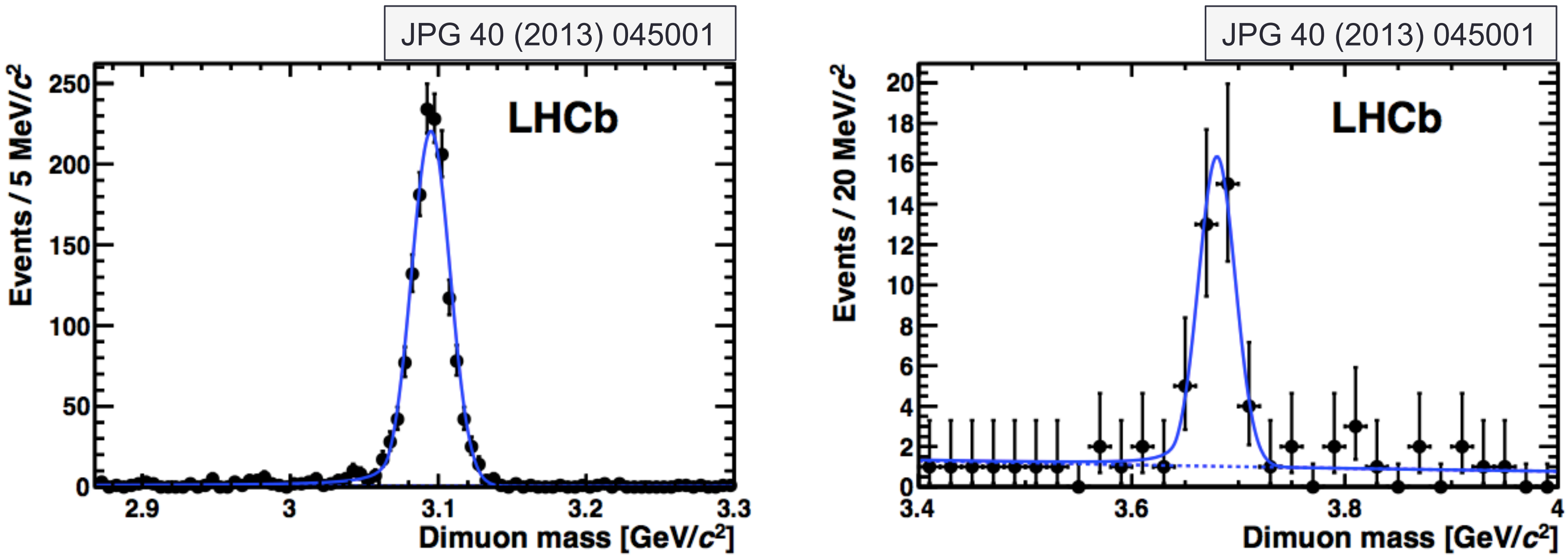
Examples of dependence of Jpsi cross-section on PDF (left) and extraction of gluon PDF (right) from Martin, Nockles, Ryskin, Teubner, arXiv:0709.4406v1

Search for odderon

- Motyka, DIS 2008.



Non-resonant background very small



Distributions are not background-subtracted.
37pb-1 of data: 1492 J/ψ and 40 ψ(2s)

Cross-section measurement

Purity:
1. non-resonant bkg (1%)
2. Chi_c feeddown (9%)
3. Psi' feedown (2%)
4. Inelastic Jpsi production (30%)

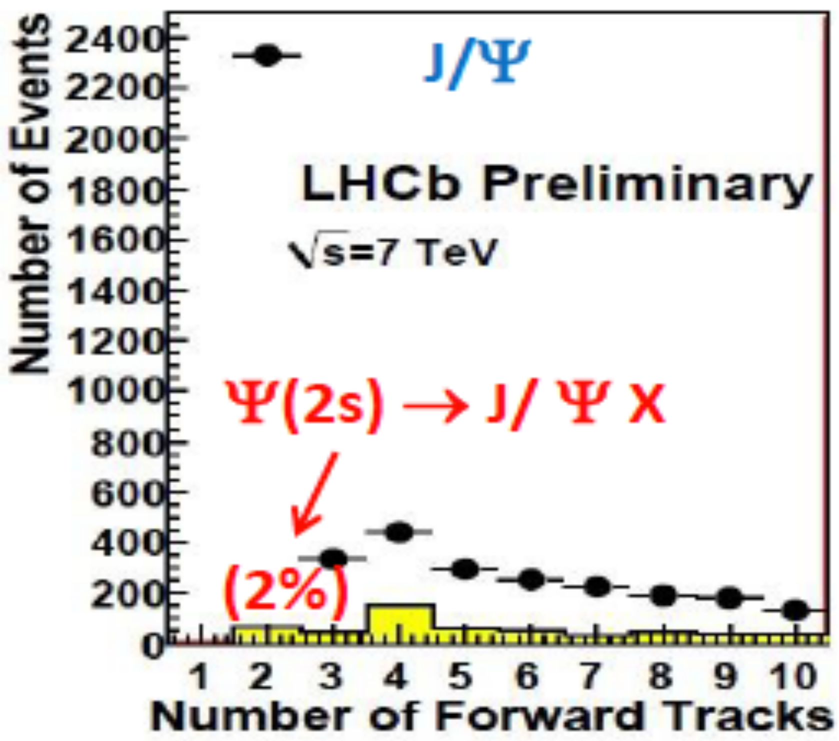
Number of events observed

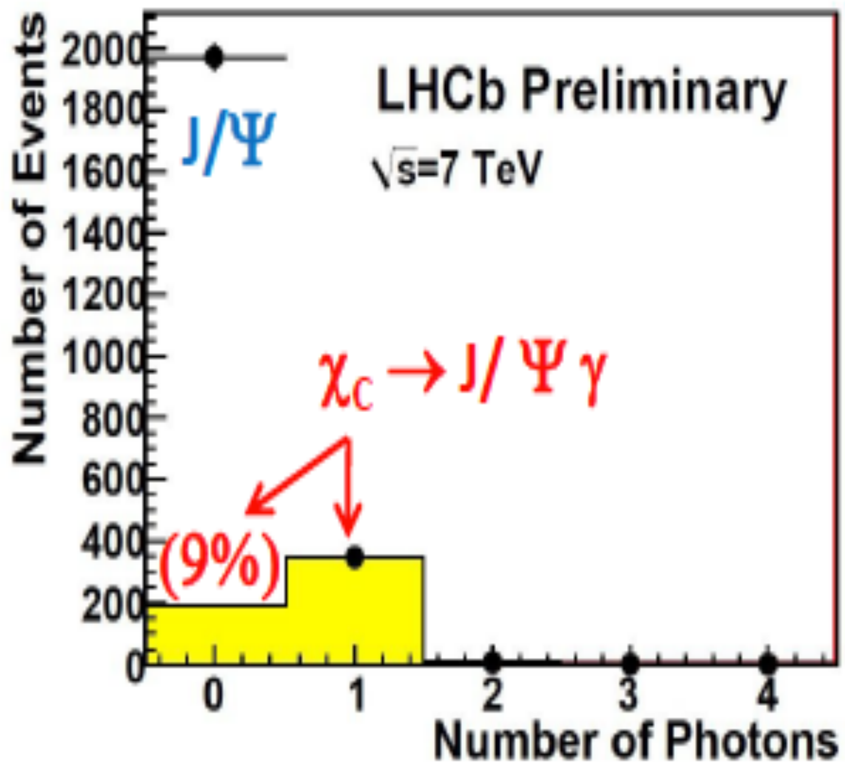
$$\sigma = \frac{pN}{\varepsilon L}$$

Luminosity

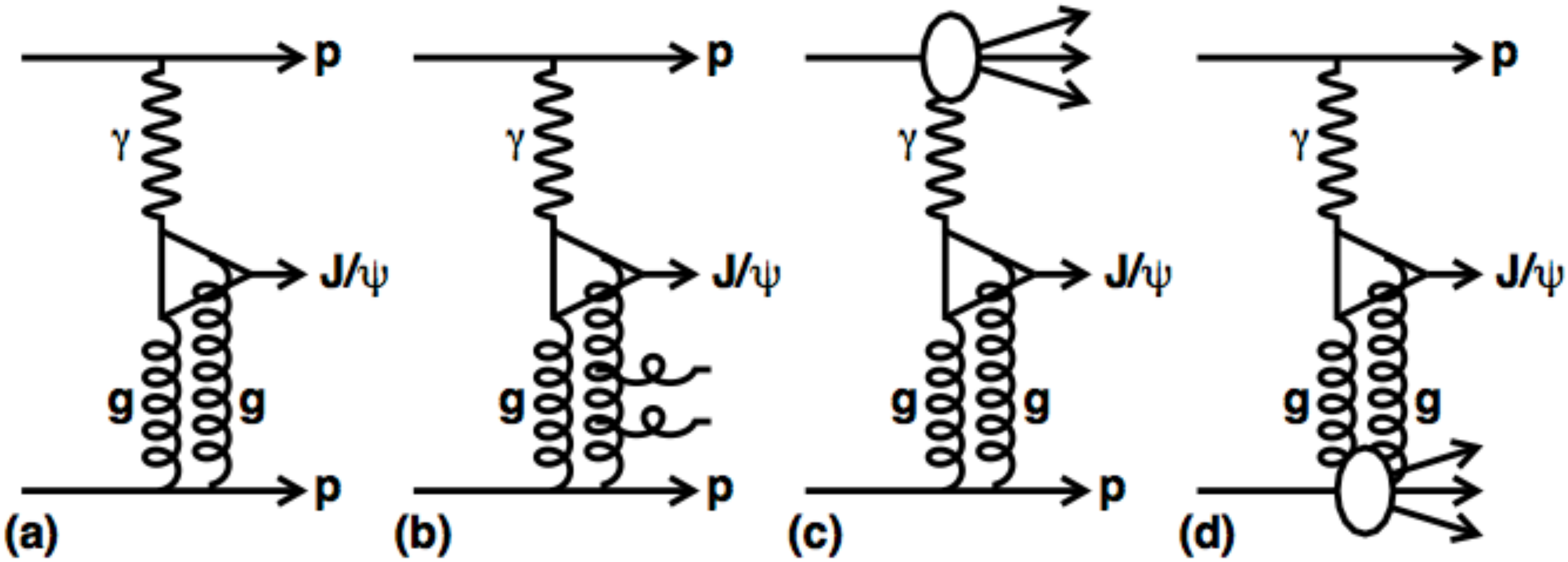
Efficiency:
1. Trigger
2. Tracking & muon id.
3. Single interaction beam-crossing ← $P(n) = \mu^n e^{-\mu} / n!$

Feed-down backgrounds





Inelastic background



Characterise p_T spectrum of background using shapes with 3-8 tracks and extrapolate to 2 track case.

Inelastic background

Signal shape

Estimated from Superchic using exp(- b p_T^2) (arXiv: 0909.4748)

Take b from HERA data. Extrapolate to LHCb energies to get b= 6.1 +/- 0.3 GeV^{-2}

Crosscheck: Fit to spectrum below with b free gives b = 5.8 +/- 1 GeV^{-2}

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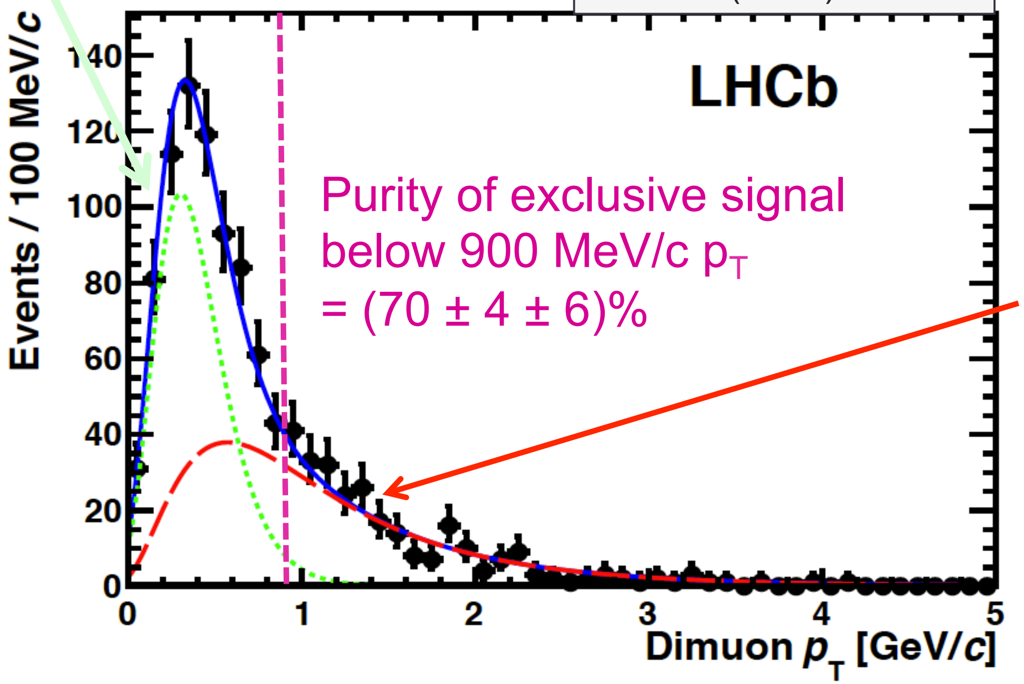


Inelastic background shape

Estimated from data.
Characterise shape for 3-8 tracks and extrapolate to 2 tracks.

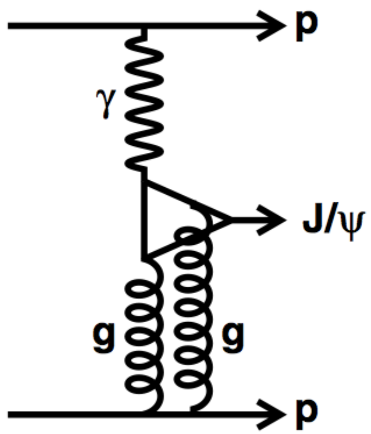
This approach works for QED production of dimuons, tested using LPAIR simulation.
Also checked with PYTHIA simulation of diffractive events.

LHCb compared to theory & experiment

Predictions	$\sigma_{pp\to J/\psi\,(\to\mu^+\mu^-)}$	$\sigma_{pp\to\psi(2S)(\to\mu^+\mu^-)}$
Gonçalves and Machado	275	
STARLIGHT	292	6.1
Motyka and Watt	334	
SUPERCHIC[a]	396	
Schäfer and Szczurek	710	17
LHCb measured value	$307 \pm 21 \pm 36$	$7.8 \pm 1.3 \pm 1.0$

[a] SUPERCHIC simulation does not include a gap survival factor.

All predictions (bar Schaefer&Szcaurek) have similar approach and give similar results and are consistent with our data.



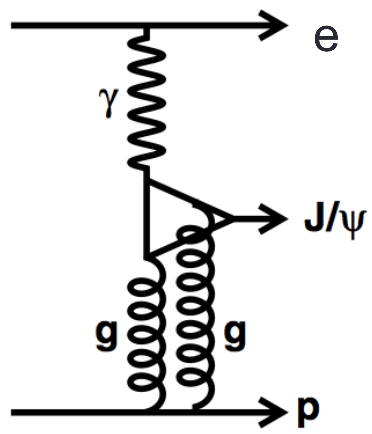
LHCb compared to HERA

$$W^2 \equiv (q+p_2)^2 = x_\gamma s - Q^2 \ ,$$

Twofold ambiguity

$$x_\gamma = \frac{M_{\psi\perp}}{\sqrt{s}} e^{y_\psi} \ ,$$

$$x = \frac{M_{\psi\perp}}{\sqrt{s}} e^{-y_\psi} \ ,$$



LHCb c/s is HERA c/s weighted by photon spectrum + gap survival factor (r)

$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_- \frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right],$$

$$k_\pm \approx (m_V/2)\exp(\pm|y|),$$

LHCb differential data fitted assuming power law dependence $\sigma(W) = aW^\delta$

Power law results

LHCb	HERA
$a = 0.8^{+1.2}_{-0.5}\, nb$	$a = 3nb$
$\delta = 0.92 \pm 0.15$	$\delta = 0.72$

LHCb compared to theory & experiment

$$\left.\frac{d\sigma}{dy}\right|_{pp\to pVp} = r(y)\left[k_+\frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_-\frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right]$$

measured

from fit

plotted

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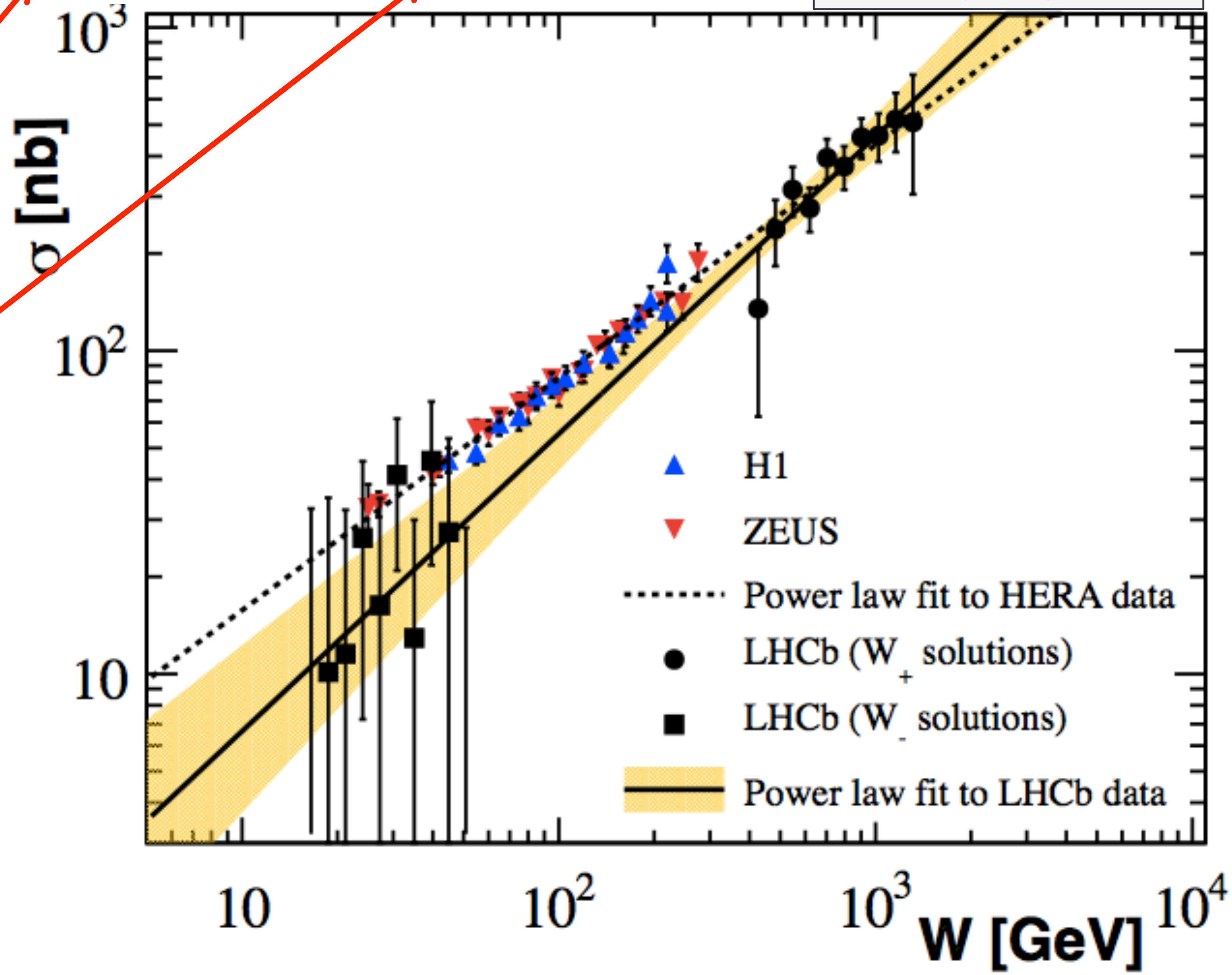
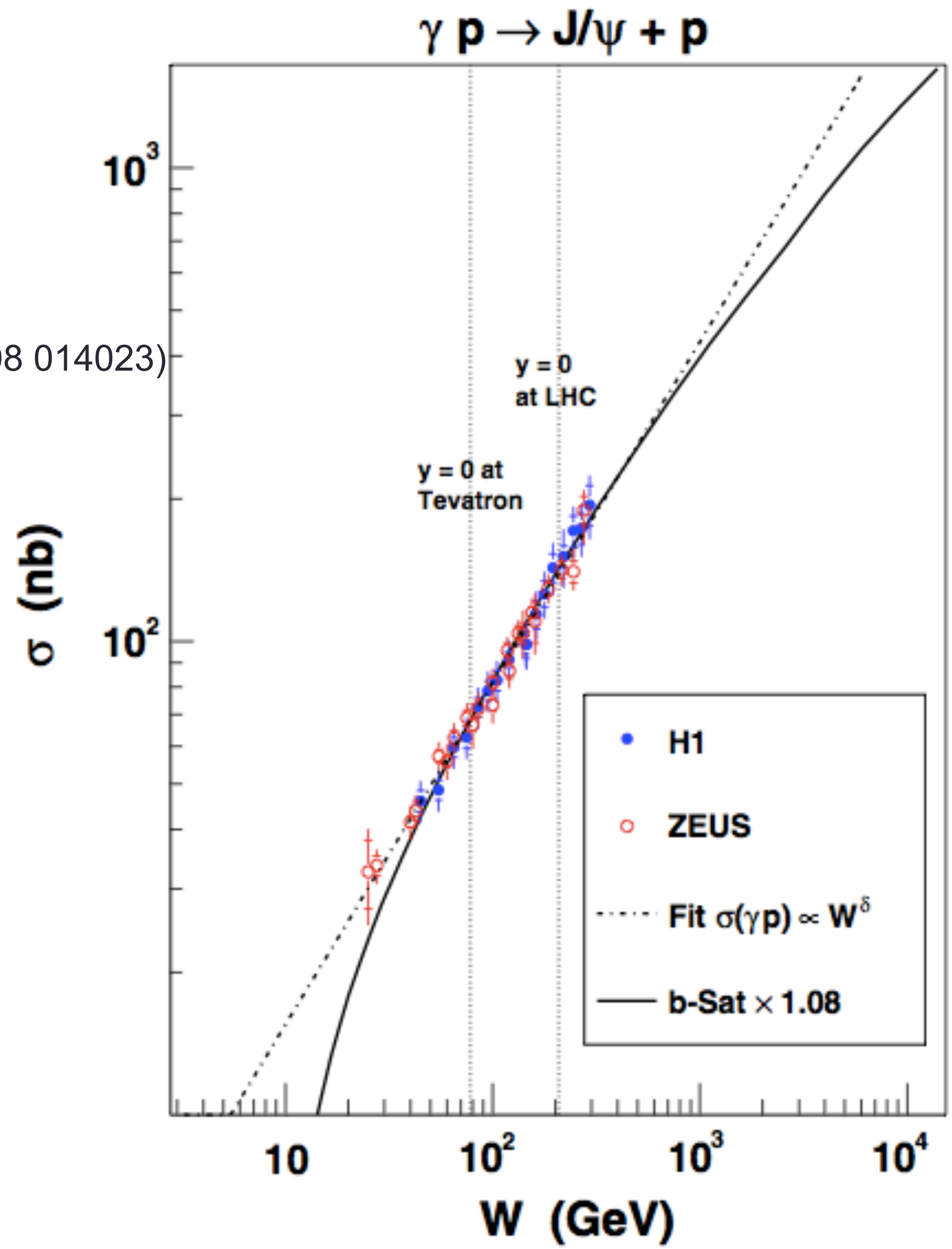
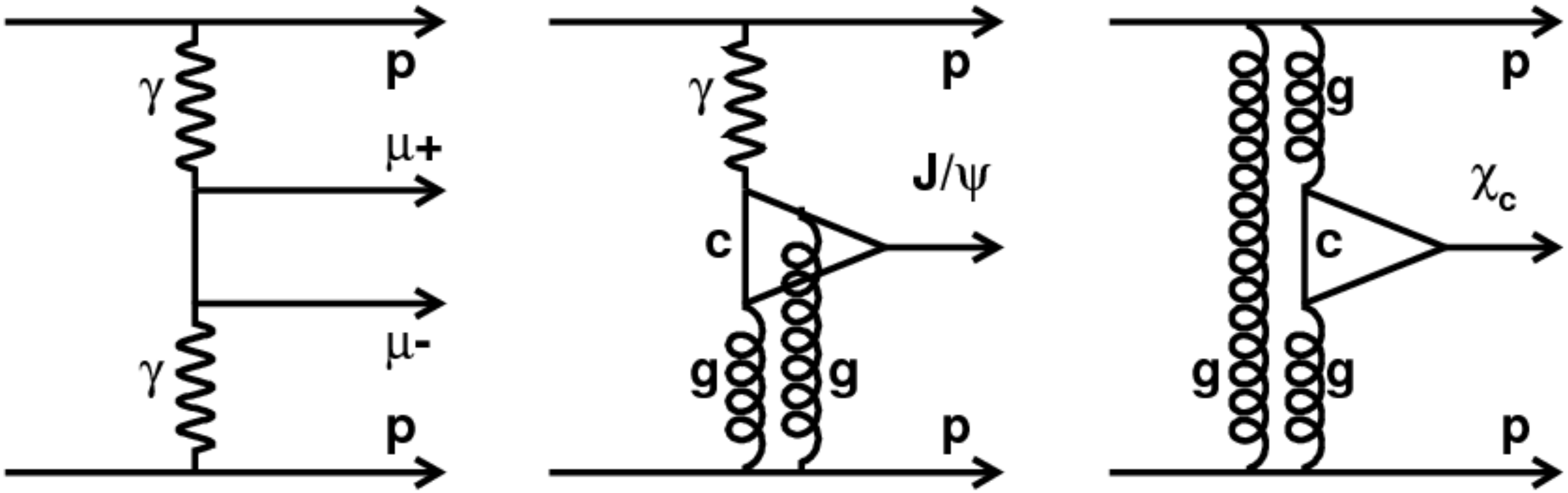


Deviations from power law

Saturation model (Motyka&Watt PRD 78 2008 014023) has deviation from pure power law.



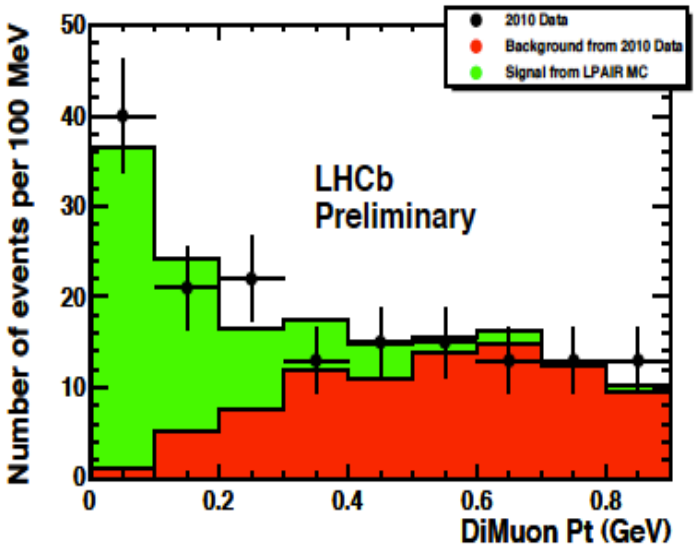
Photon-photon and Pomeron-pomeron dimuon production

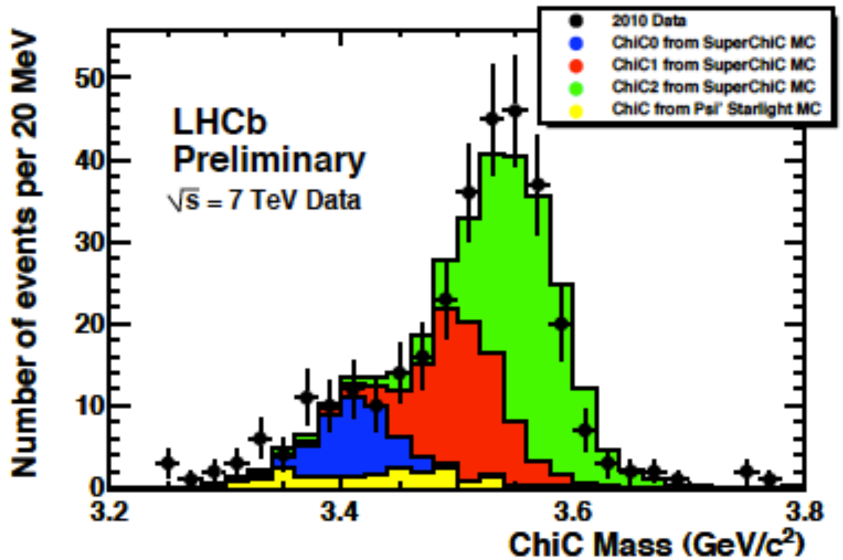


χ_c 0,1,2 decay to Jpsi+photon
Vacuum state should be 0

Photon-photon and Pomeron-pomeron dimuon production

LHCb-CONF-2011-022





$$\sigma_{\chi_{c0}\to\mu^+\mu^-\gamma} = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb}$$
$$\sigma_{\chi_{c1}\to\mu^+\mu^-\gamma} = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb}$$
$$\sigma_{\chi_{c2}\to\mu^+\mu^-\gamma} = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb}$$

$$\sigma_{\gamma\gamma\to\mu^+\mu^-} = 67 \pm 10 \pm 5 \pm 15 \text{ pb}$$

SuperChic	(BR)
14 pb	1%
10 pb	34%
3 pb	20%
LPAIR	
42pb	

In broad agreement with theory and enhanced X_{c0} due to J_z=0 selection rule.
$X_{c2.}$ higher than prediction, but non-elastic background may be larger than for X_{c0}

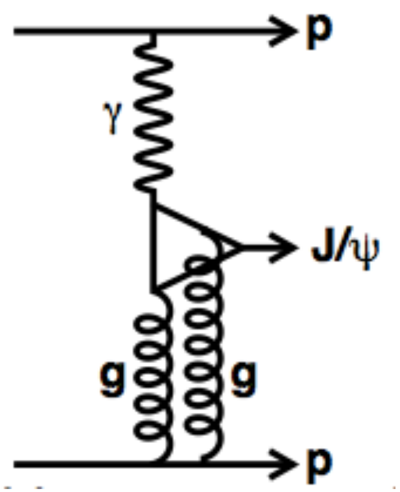
Future measurements with current data

- 100 times as much data being analysed

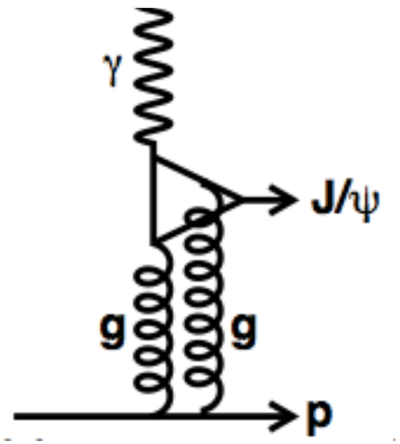
Extensions to 2010 measurements

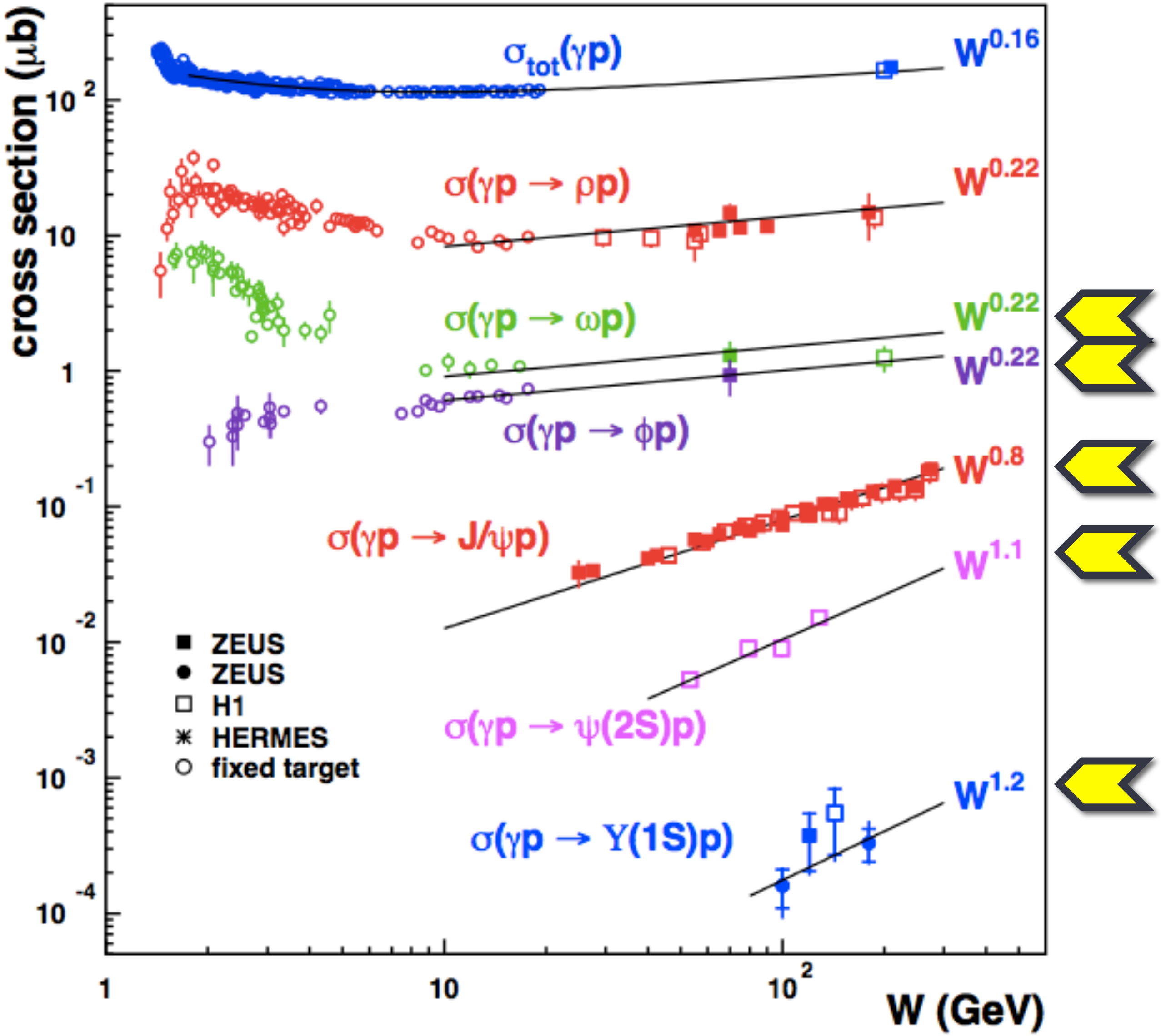
- <2% measurement of luminosity possible
- More precise fits to determine backgrounds to Xc0,Xc1,Xc2
- Precise measurement of J/ψ power law dependence
- Measurement of other vector mesons

LHCb compared to theory & experiment



looks very like





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- New ideas using hadronic modes
  - Pion or kaon pairs e.g. from Xc0.
  - Combine leptons and hadrons: search for X(3872), X(4260)
  - New trigger in 2012 data

Triggering on CEP→hadrons

Low multiplicity hadronic final states require special treatment to survive LHCb trigger
June 2012: New Trigger implemented → significant improvement!

Threefold strategy:

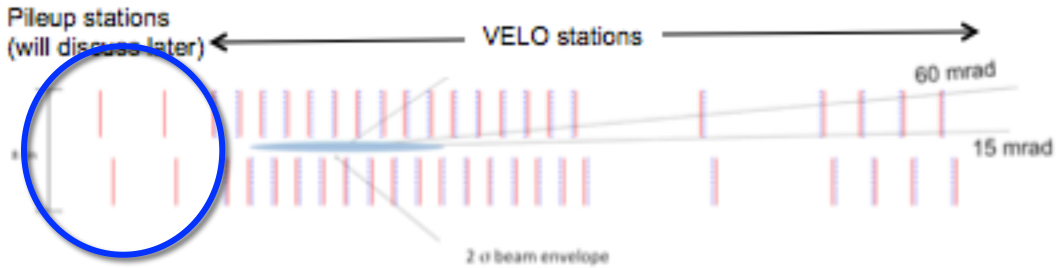
Use of “Pile-up” stations (“upstream” silicon sensors) at L0 stage to veto backwards activity

\+

High rate real-time triggering exploiting small events and short processing times.

\+

Soft p_T cuts and reconstruction of resonances, using particle ID, in trigger

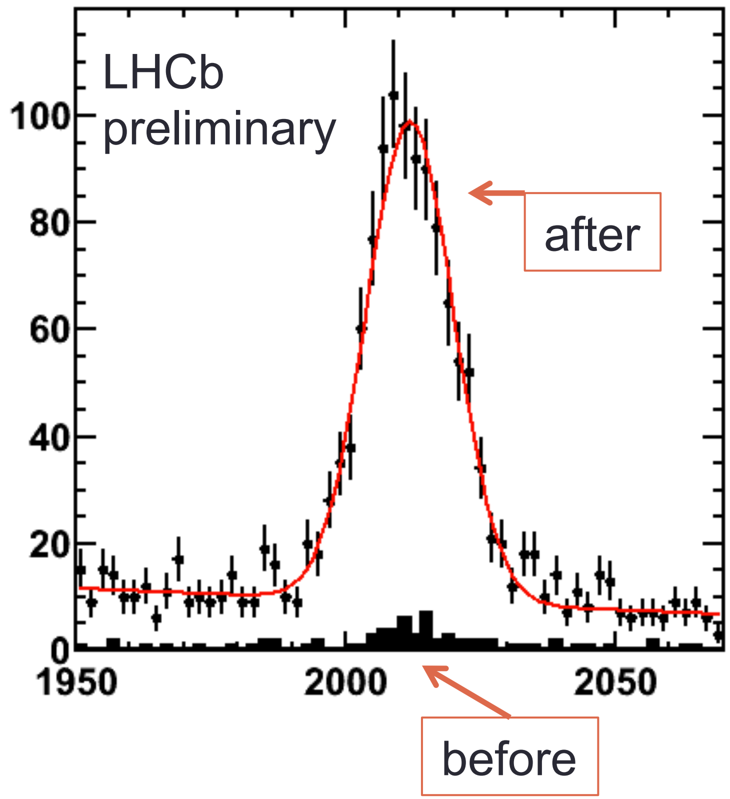


Silicon sensors
at 8.2<R<42mm and z>-315mm
40 MHz readout
Very effective VETO

Triggering on CEP->hadrons

- Charm spectroscopy in CEP events.
- Selection of D,K_s,Φ at trigger level.

e.g. improvement in D* yield in low multiplicity events



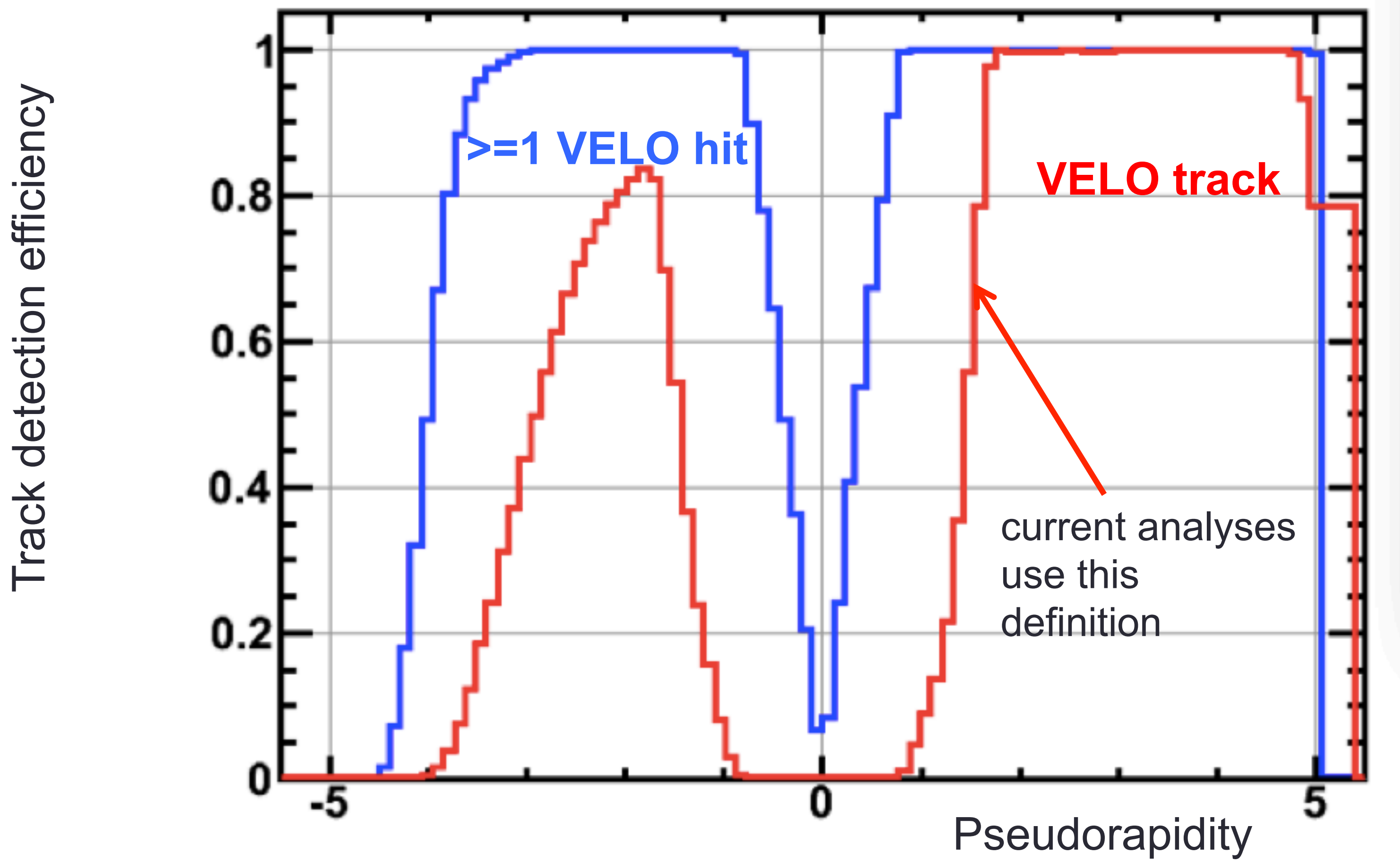
Future running (2015-)

- Are the events truly CEP?
  - Measurements are limited by uncertainty with what is happening outside of our acceptance, in particular, close to the beam.

- Solutions:
  - Increase the coverage; extend the rapidity gap.
  - Measure the recoiling protons.

Increase the rapidity gap:

Modest extension of gap already possible vetoing on any activity in VELO



but you really want to fill in the region 5<η<9

Future running:

- Near future: Increase the gap
- Thoughts of installing scintillators in the tunnel
  - Given the beam-pipe radius, these would need to be ~100m from interaction point in order to improve on the existing excellent forward reach of LHCb.
  - May or may not be incorporated into trigger.

- Further future:
- Ideally would like proton taggers from 2018.
  - Could learn a lot from existing design experience of ATLAS/CMS.

Conclusions

- LHCb, due to its forward acceptance and running conditions is well suited to investigating CEP.
- CEP measurements using muons have been performed at LHCb
- More muon analyses and hadron analyses currently underway.
- We need to increase our rapidity gap
- Welcome this forum:
  - discussion with theorists on priorities for measurements.
  - discussions on future improvements to detector.