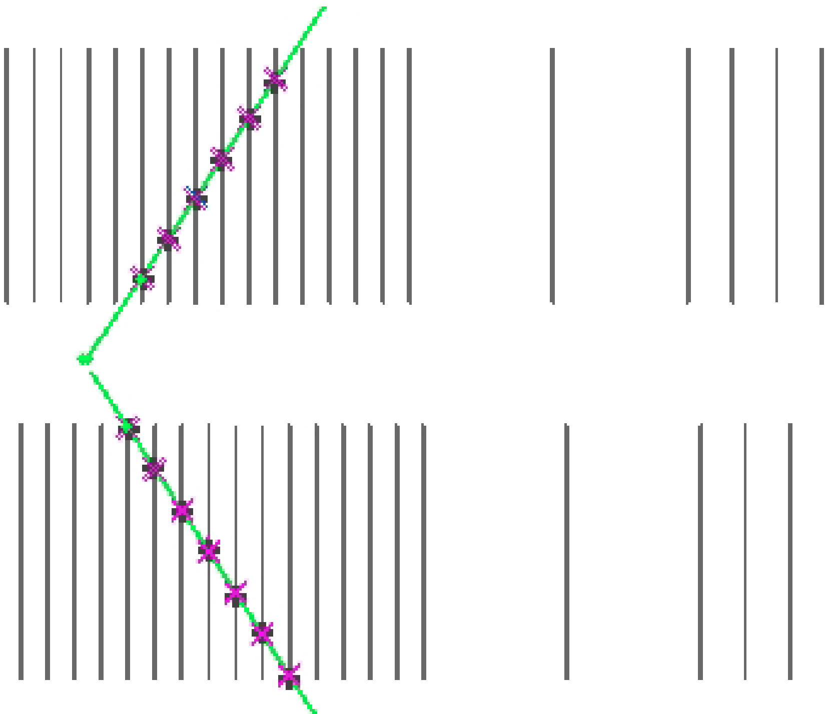
LHCb Central Exclusive Production Results and Prospects



Paula Collins, CERN

Workshop on photon-induced collisions at the LHC

June 2-4 2014

On behalf of the LHCb collaboration

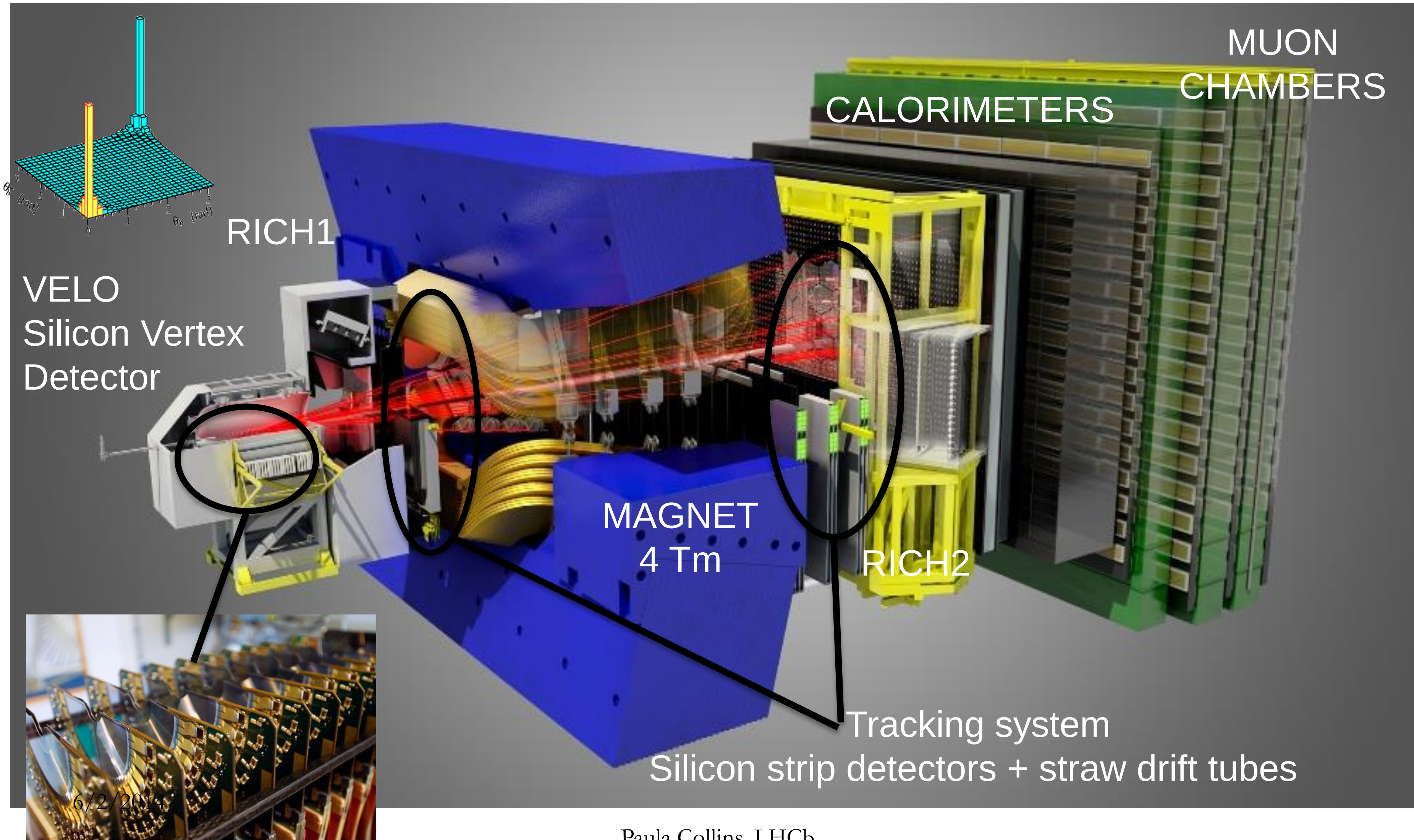
5.12. 2012 10:17:53
Run 133742 Event 1824718177 bld 146

Talk Outline

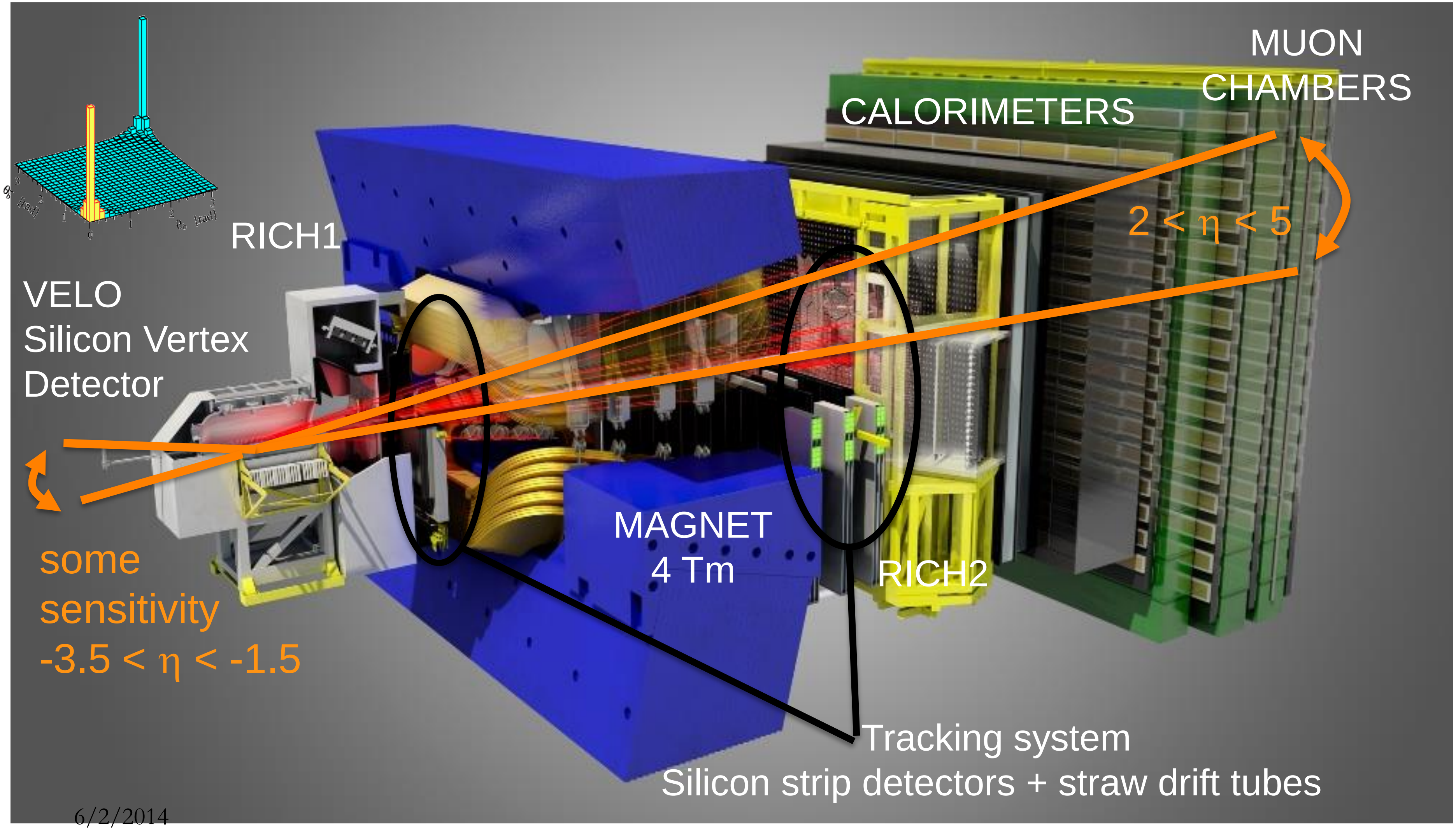
- CEP @ LHCb
- CEP → muons
  - LHCb 2010 and 2011 results for J/ψ, ψ(2s):
    - JPG 40 (2013) 045001
    - arXiv: 1401.3288 (accepted by JPG)
  - Exclusive QED di-photon and $\chi_{c0,1,2}$(1P) production
    - LHCb-CONF-2011-022
  - Future prospects
- CEP →hadrons
  - Physics motivation to enhance reach for hadronic final states
  - New trigger strategy
- Extending LHCb coverage with forward shower counters – the Herschel project

LHCb Detector

Single arm forward spectrometer dedicated to precision flavour physics

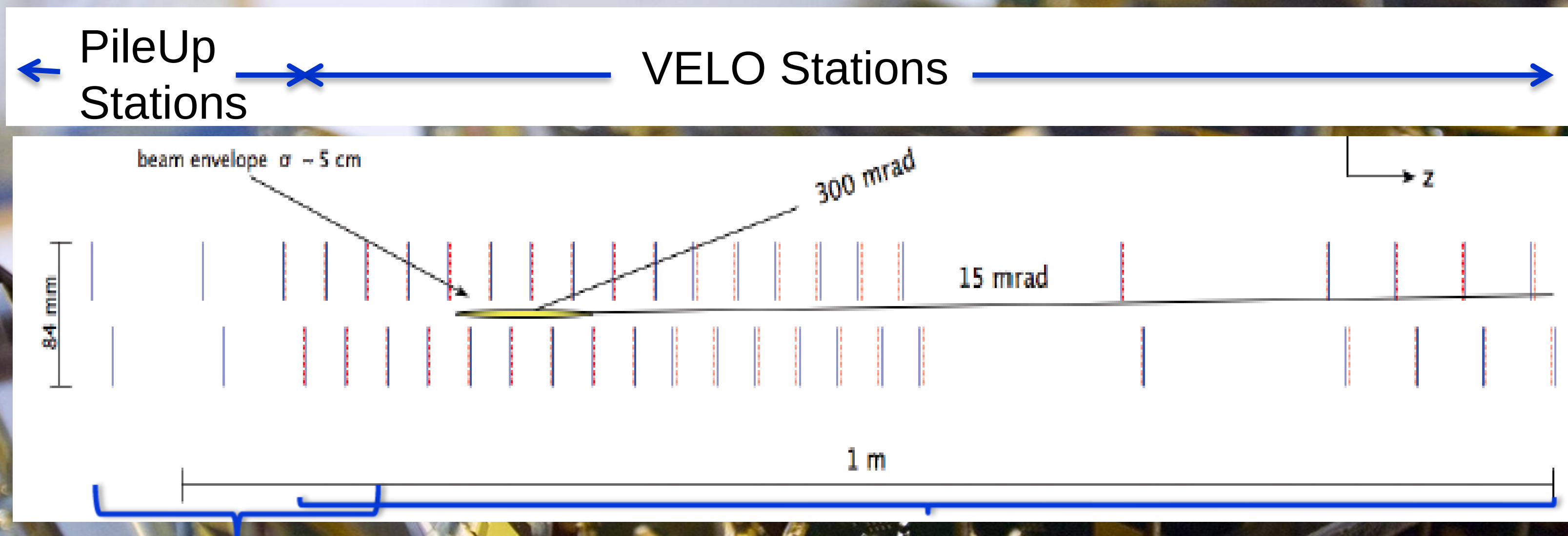


LHCb Angular Coverage



VELO Sub Detector

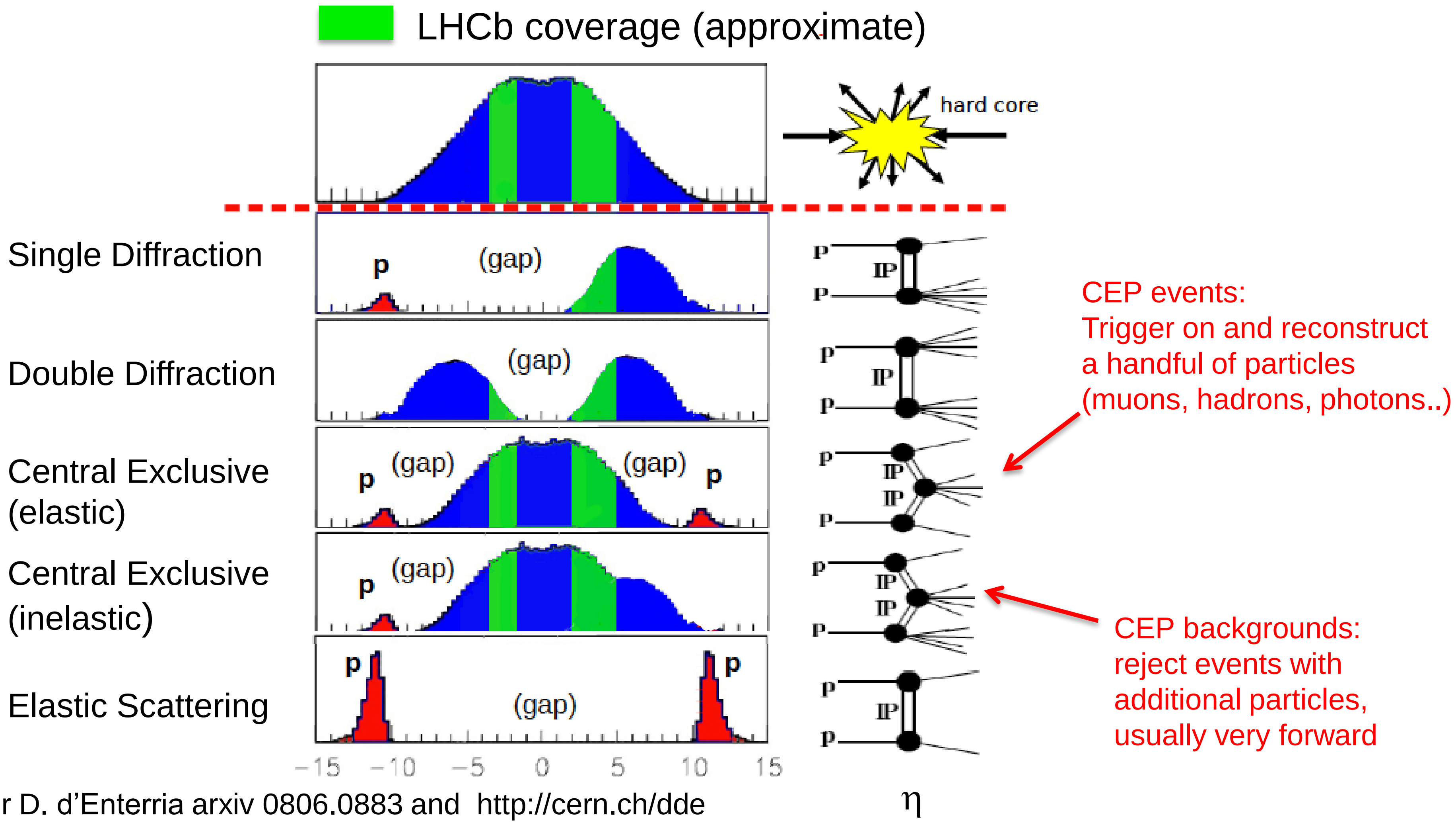
VELO Sub Detector



Backward region:
track reconstruction ~1.5<η<-3.5
no momentum measurement
Triggering capability at 40 MHz

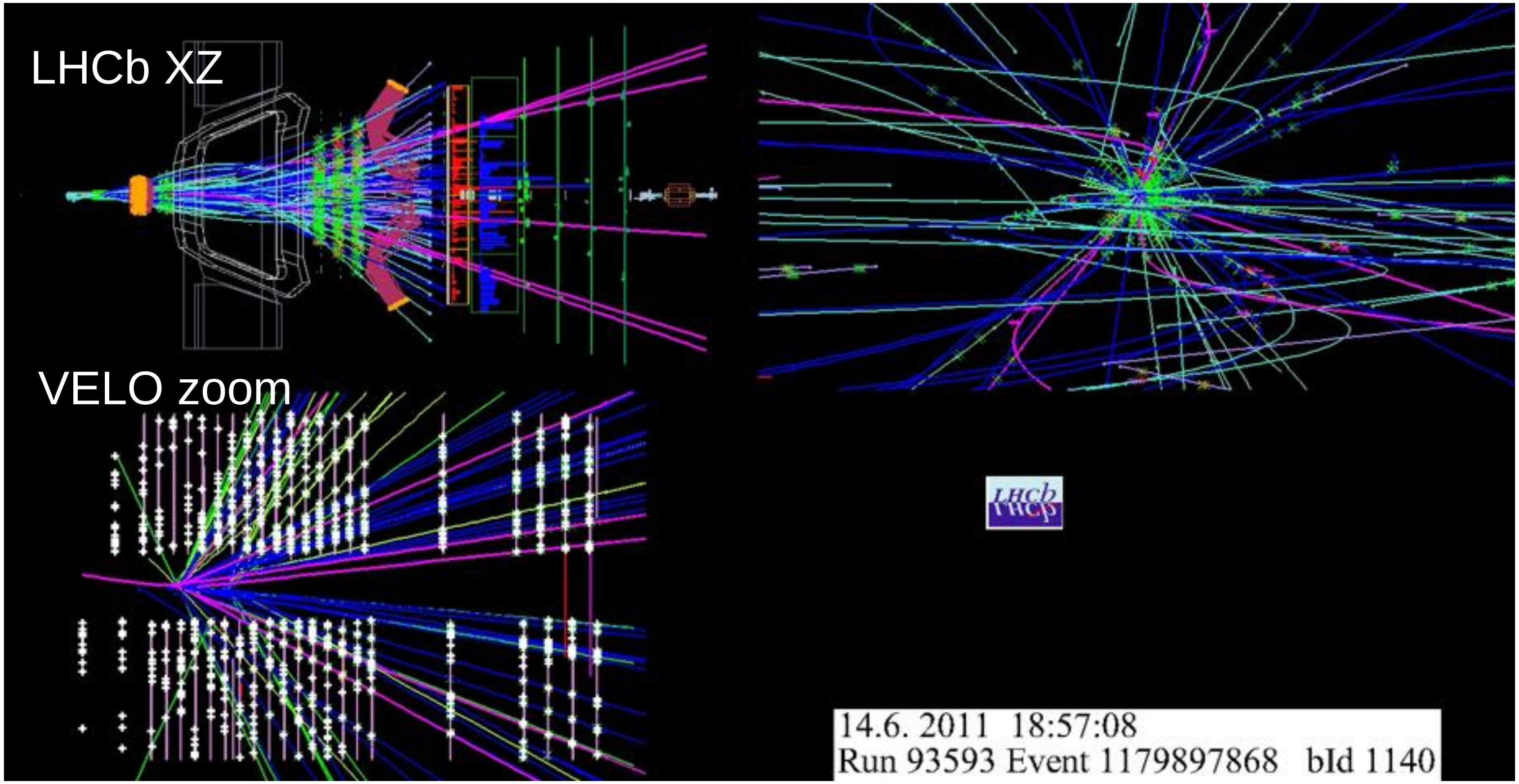
Forward region:
Efficient track reconstruction ~2<η<5
1 MHz output to trigger farm

CEP events and backgrounds



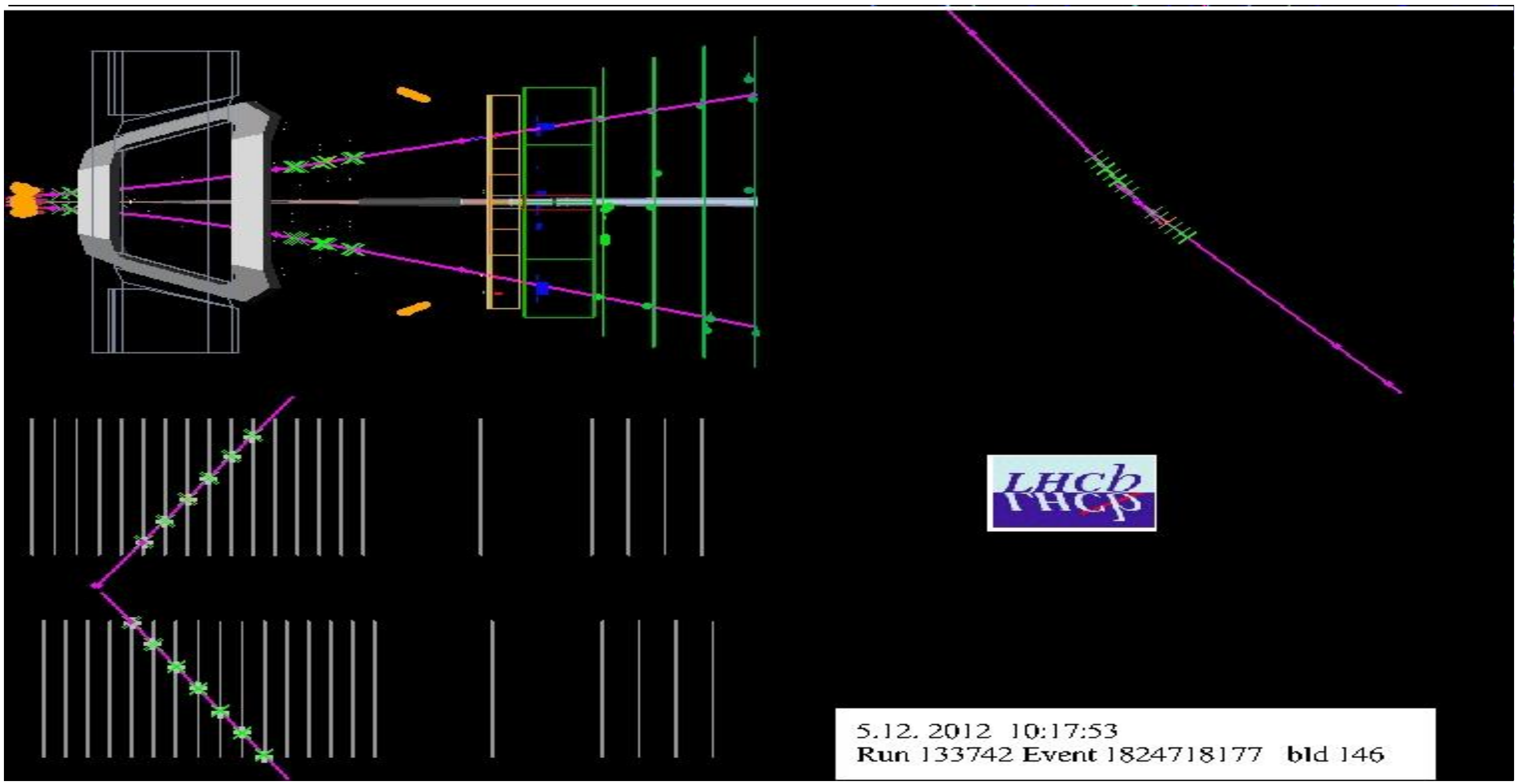
After D. d'Enterria arxiv 0806.0883 and http://cern.ch/dde

$B_s \rightarrow \mu^+\mu^-$ event in LHCb



Not a typical event – but a very typical topology!

CEP event in LHCb



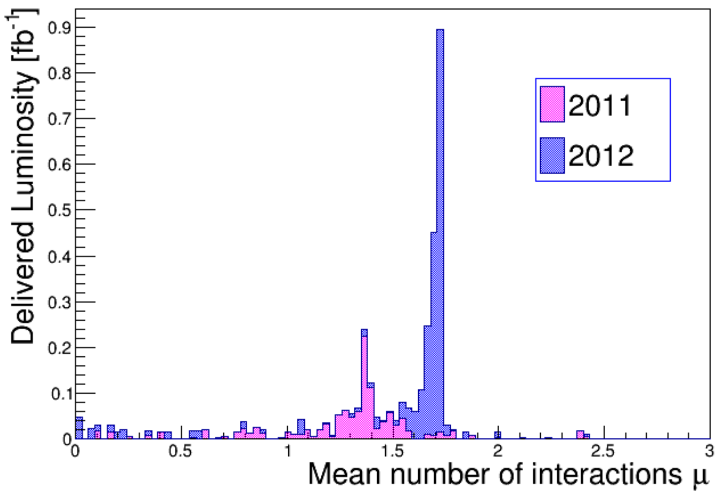
Two muons and no other activity

LHCb and Pile-Up

So far LHCb CEP Analyses have used single interaction events to more effectively veto additional activity

LHCb benefits from low pileup conditions – with move to 25 ns this will give a huge yield in LS2

Year	2010	2011	2012	2015-17
Integrated Luminosity (fb^{-1})	0.04	1.1	2.1	~5
Useful fraction for CEP studies (e-$^{\mu}$)	21%	24%	19%	~37%



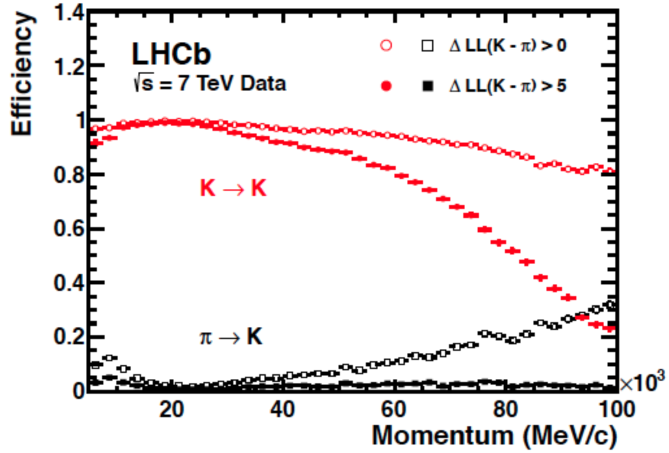
Fraction of crossings with N interactions is given by

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

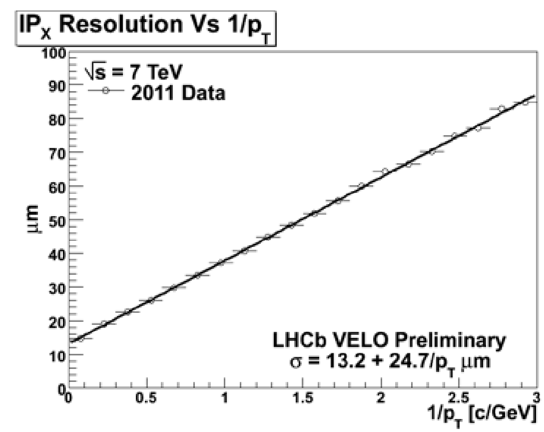
LHCb for CEP

LHCb very well suited to studies of CEP production

RICH Particle ID performance



VELO impact parameter resolution



Access to high rapidities

$2 < \eta < 5$ acceptance for forward tracking;
good complementarity with ATLAS/CMS
Some sensitivity to backwards tracks with $-3.5 < \eta < -1.5$

Relatively low pileup

Analysis greatly simplified by using single interaction events

Trigger

First level trigger output rate of 1 MHz
muon/calo + some VELO information available
Flexibility available at second level trigger with full event information

Excellent particle ID

Possibility to distinguish CEP decays to K,p,μ,π final states

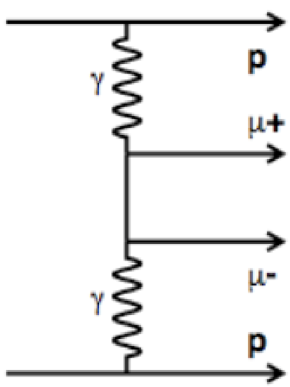
Sensitivity to low p and low p_T particles

both at trigger stage, and for precise reconstruction

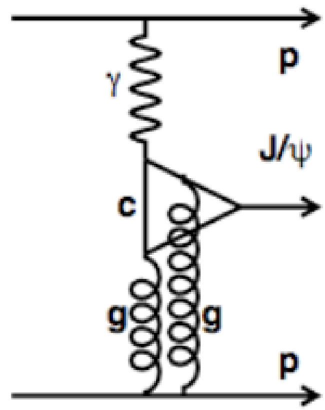
Di-μ (+γ) CEP signals in LHCb

Exchange of a colourless object: γ, pomeron → two muons (+ photon) + rapidity gaps
Single elastic process → protons escape undetected in beampipe

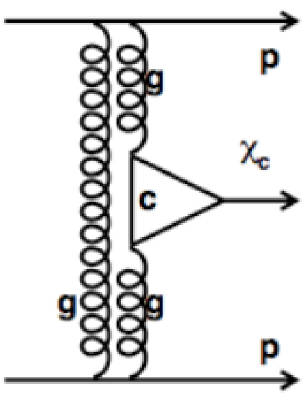
Non-resonant di-μ
(di-γ fusion)



di-μ from J/ψ, ψ(2S)
(γ pomeron fusion)



di-μ from $\chi_c \rightarrow J/\psi\ \gamma$
(di-pomeron exchange)



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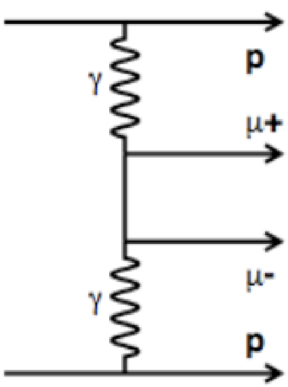

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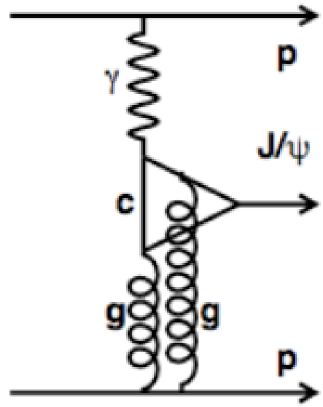

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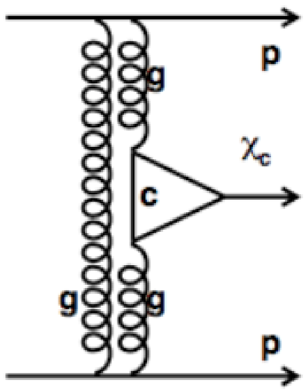
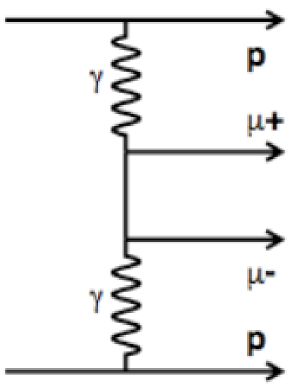


Non resonant dimuon production
QED Process – accurate predictions
Candidate for precise luminosity determination at the LHC

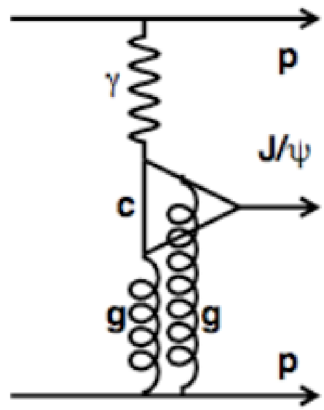
Di-μ (+γ) CEP signals in LHCb

Exchange of a colourless object: γ, pomeron → two muons (+ photon) + rapidity gaps
Single elastic process → protons escape undetected in beampipe

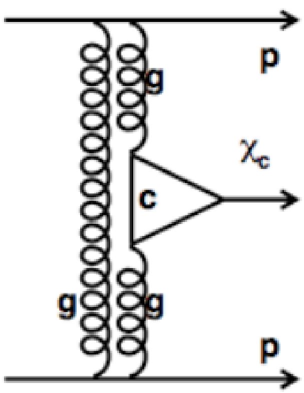
di-γ fusion



di-μ from J/ψ, ψ(2S)
(γ pomeron fusion)



di-μ from $\chi_c \rightarrow J/\psi\ \gamma$
(di-pomeron exchange)

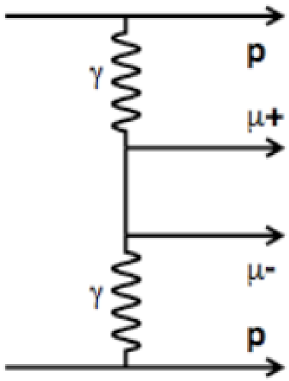


Resonant process
Photoproduction: Test of QCD and description of diffraction and soft process
Sensitive to diffractive PDF at very low x (to 5 x 10^{-6})
Search for Odderon and saturation effects

Di-μ (+γ) CEP signals in LHCb

Exchange of a colourless object: γ, pomeron → two muons (+ photon) + rapidity gaps
Single elastic process → protons escape undetected in beampipe

di-γ fusion



di-μ from J/ψ, ψ(2S)
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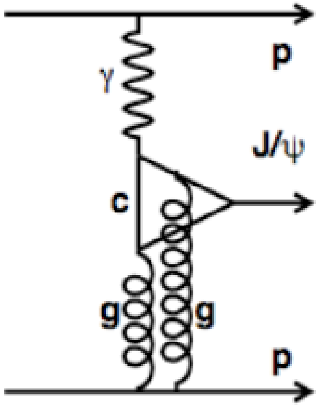
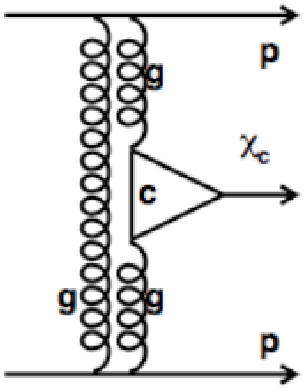


di-μ from $\chi_c \to J/\psi\ \gamma$
(di-pomeron exchange)



Resonant process
Double Pomeron exchange
Standard candle for other DPE processes e.g. Higgs

di-μ triggering in LHCb

Typical events

Many tracks + high P_T objects

Picked up with high efficiency by standard LHCb triggers

CEP events

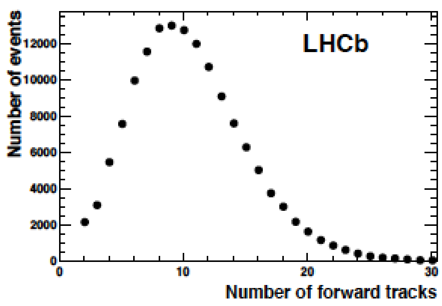
No other activity in event; low P_T

Dedicated high efficiency trigger:
Level 0: 1μ (p_T>400 MeV) or 2μ (p_T> 80 MeV)
+ low multiplicity calorimeter signature
High Level Trigger: di-μ candidate with p_T<900MeV or M>2.7 GeV/c^2

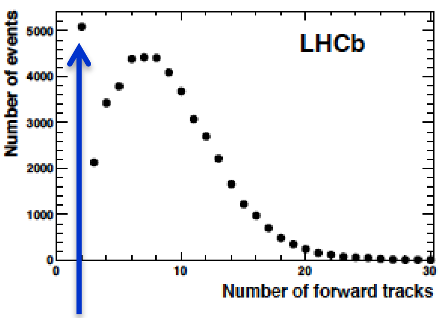
Rapidity gap selection of CEP candidates

Di-μ triggered events

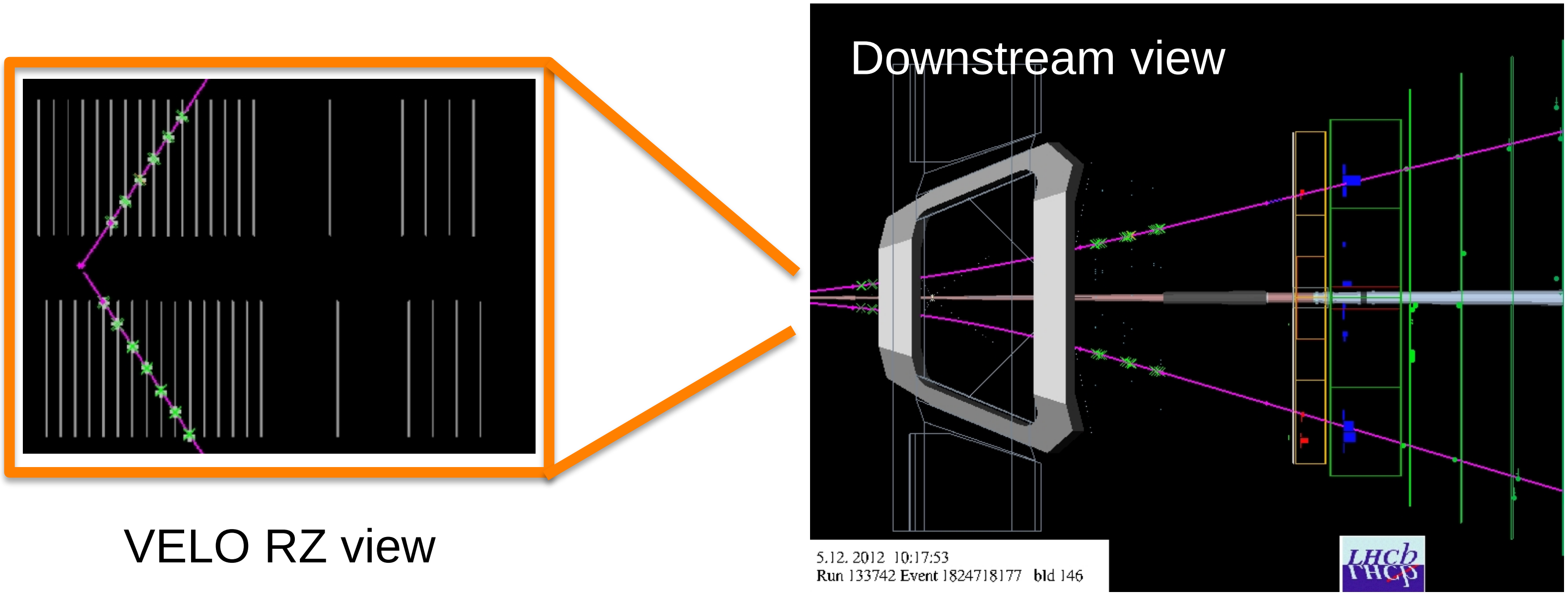
Backward tracks>0



Backward tracks=0



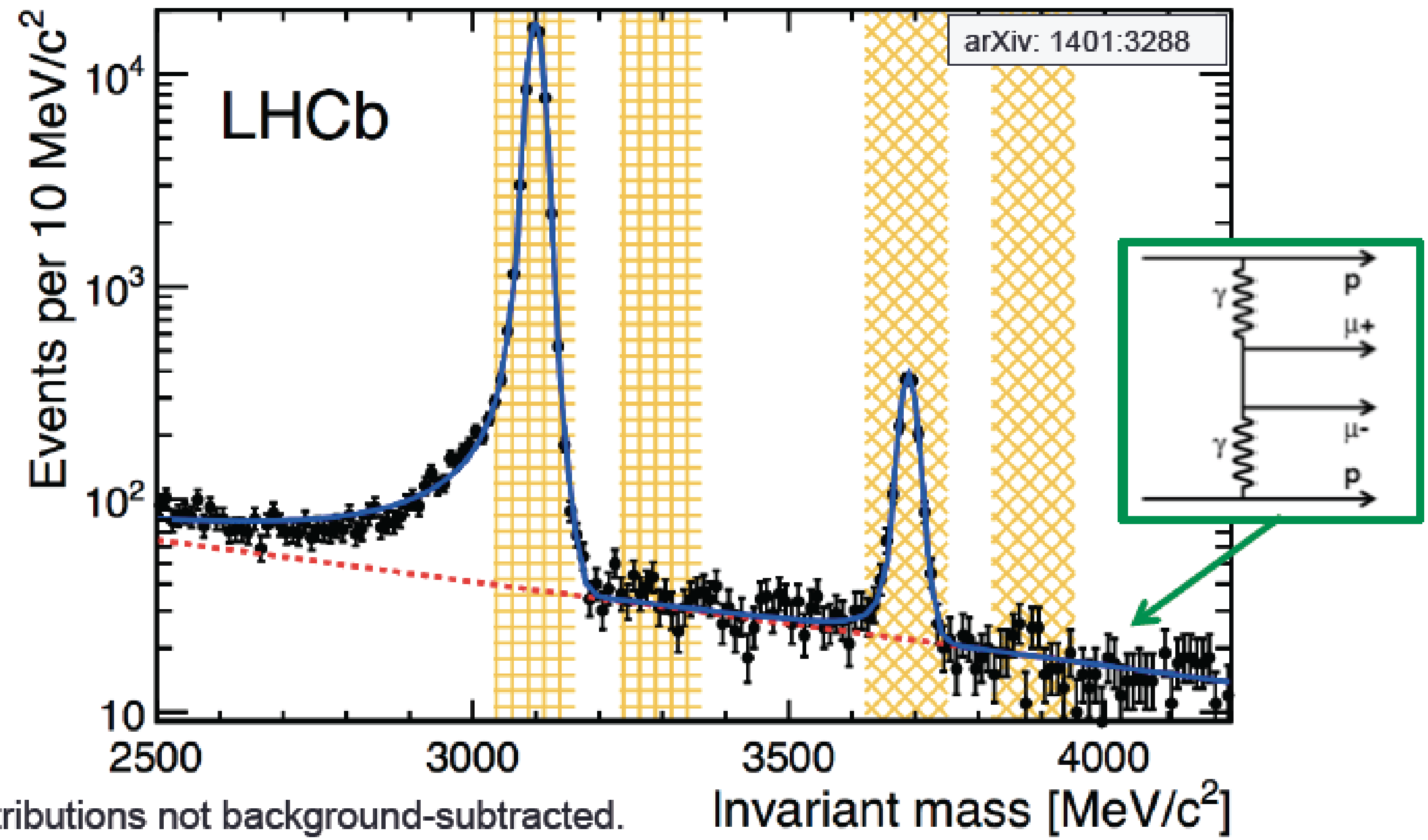
CEP candidates



VELO RZ view

Exclusive dimuon candidates

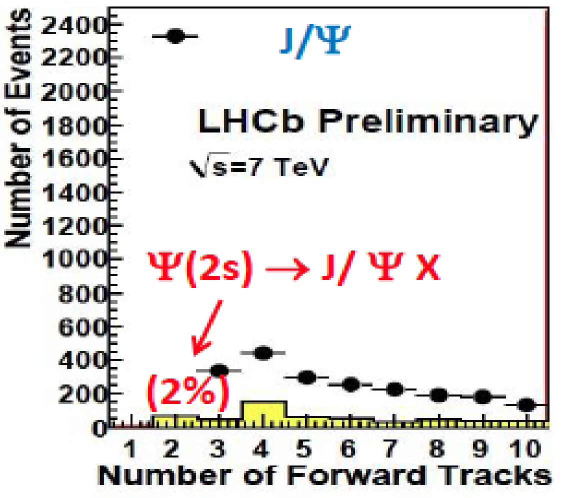
Events passing 2011 Low Multiplicity Dimuon Trigger

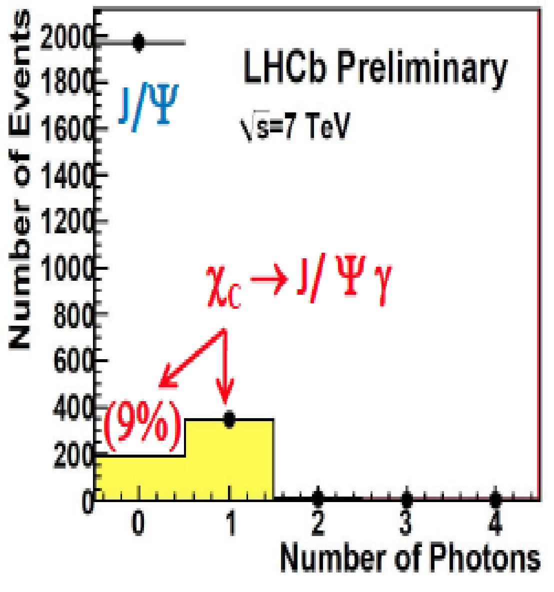


Distributions not background-subtracted.
55985 J/ψ and 1565 ψ(2s)

Feed-down backgrounds

Feed-down from $\psi(2s) \to J/\psi\ X$
with undetected X (e.g. X = $\pi^+ \pi^-$)
Require # Tracks = 2
Estimate residual background from Starlight
+ full LHCb simulation, normalised to data





Feed-down from $\chi_c \to J/\psi\ \gamma$
with undetected γ
Require # photons = 0
Estimate residual background from SuperChic
+ full LHCb simulation,normalised to data

Cross Section Measurement

Similar procedure for ψ/ψ(2s)

Purity extracted from
1. non resonant background (1%/17%)
2. Feeddown (10%/2%)
3. Inelastic background (40%/40%)

$$\frac{d\sigma}{dy} = \frac{pN}{A\epsilon\mathcal{L}_{\mathrm{single}}\Delta \mathrm{y}}$$

Number of observed events

Acceptance (MC)

Efficiency extracted from data

Fraction of useable luminosity

$$f(N) = \frac{e^{-\mu}\mu^N}{N!}$$ with N=0

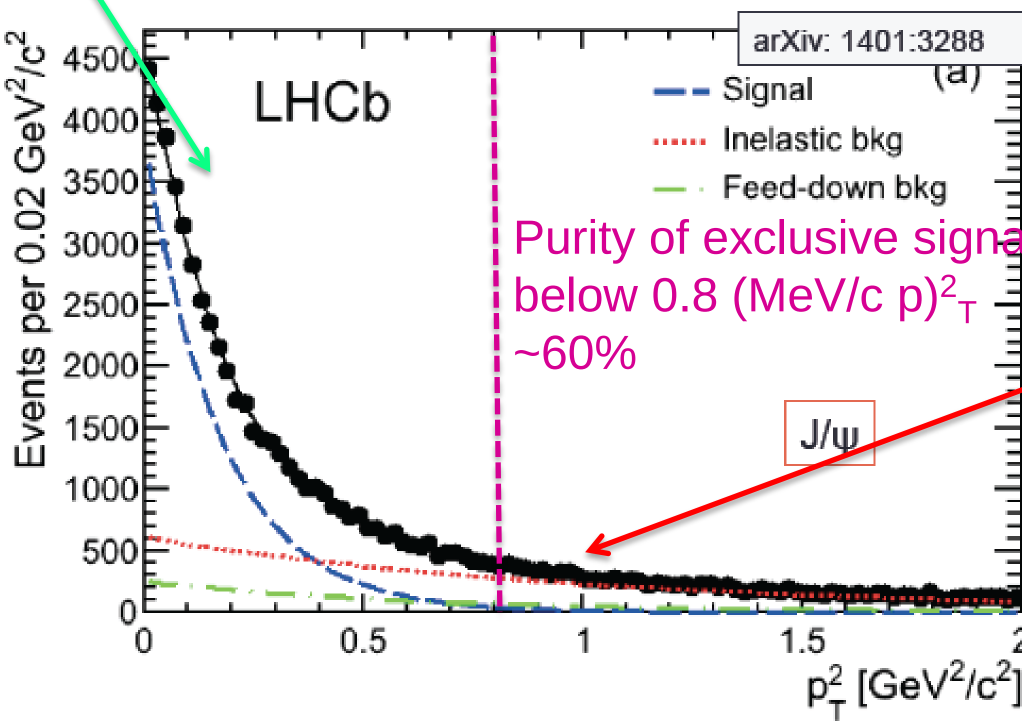
Signal + Inelastic background (ψ)

Signal shape

Estimated from Superchic using $\exp(-b\, p_T^2)$

Slope b estimated from explicit calculation using HERA data: ~ 6 GeV^{-2} (signal) ~1 GeV^{-2} (bckd)

Fit gives b = 5.70 +/- 0.11 GeV^{-2} (signal) and = 0.97 +/- 0.04 GeV^{-2} (bckd)



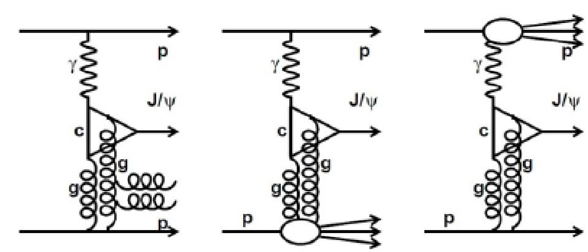
Purity of exclusive signal below 0.8 (MeV/c p)^2_T ~60%

Inelastic backgrounds

One/two of the protons dissasociates / additional gluon radiations

Extra particles are undetected

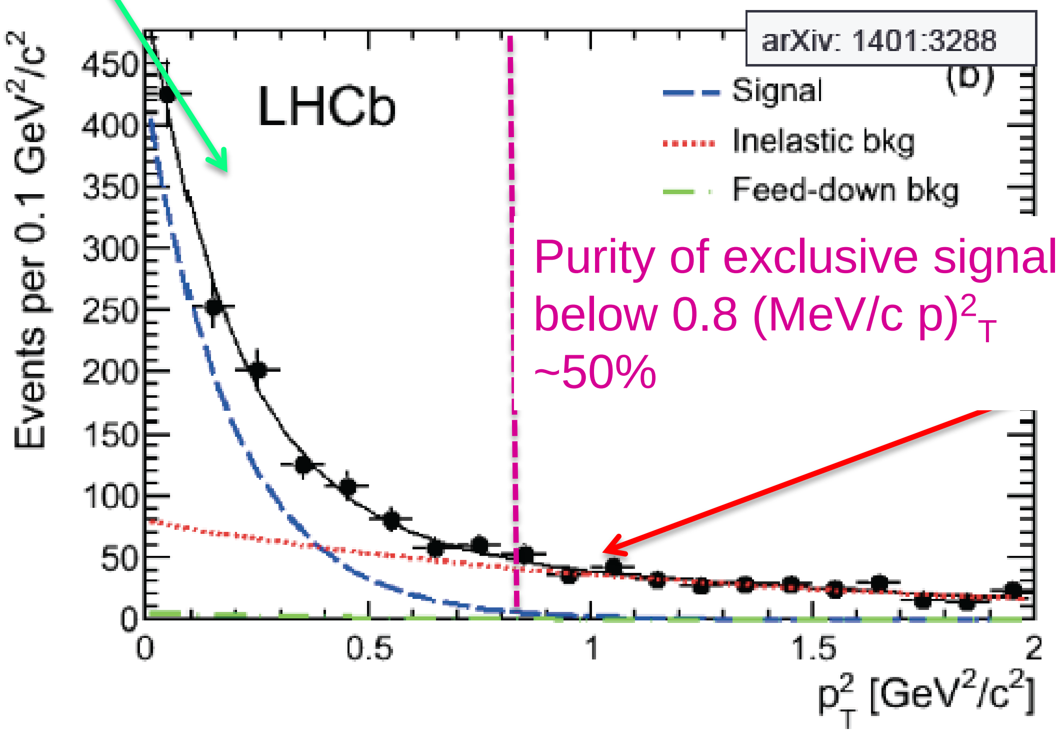
P_T shape estimated from data, behaviour as a function of number of tracks cross checked with PYTHIA and LPAIR



Signal + Inelastic bckd (ψ(2S))

Signal shape

Estimated from Superchic using exp(- b p_T^2)
Slope b estimated from calculation using HERA data: ~ 5.5 GeV^{-2} (signal) ~0.6 GeV^{-2} (bckd)
Fit gives b = 5.1 +/- 0.7 GeV^{-2} (signal) and = 0.8 +/- 0.2 GeV^{-2} (bckd)

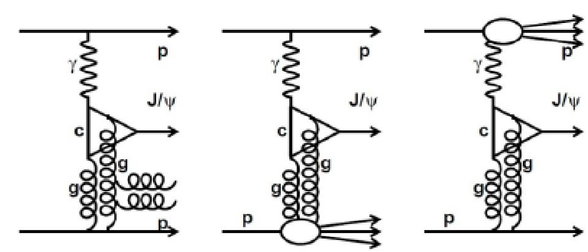


Purity of exclusive signal below 0.8 (MeV/c p)^2_T ~50%

Inelastic backgrounds

One/two of the protons dissasociates / additional gluon radiations
Extra particles are undetected

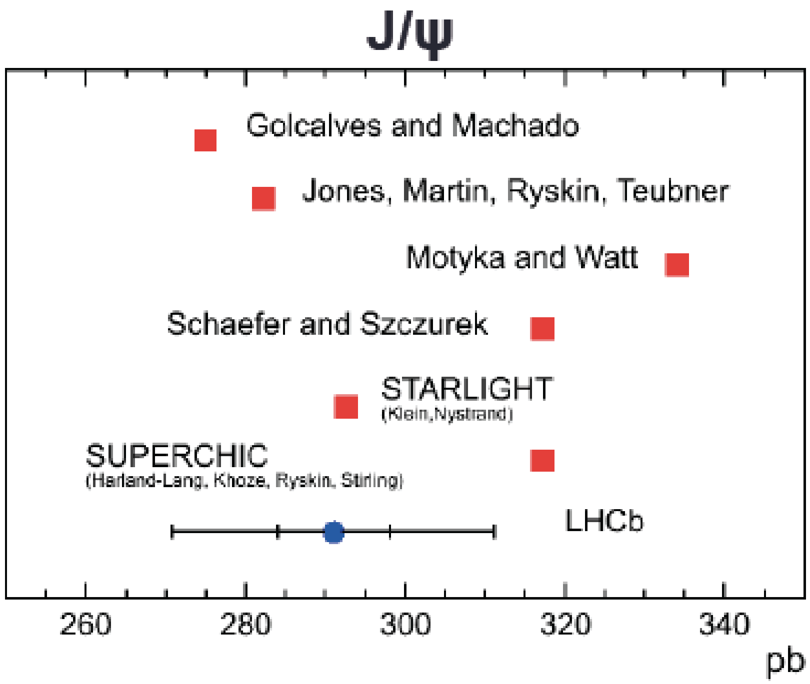
P_T shape estimated from data, behaviour as a function of number of tracks cross checked with PYTHIA and LPAIR

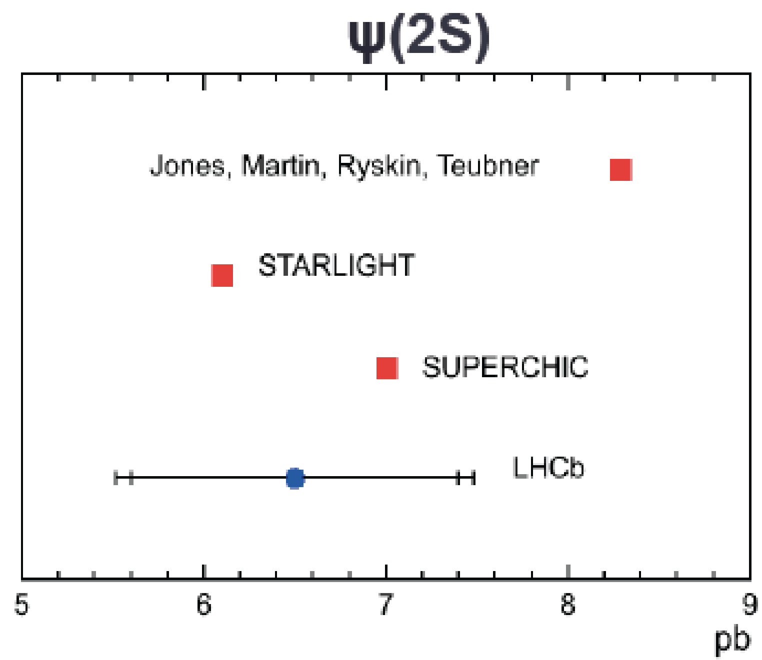


J/ψ and ψ(2S) Results

Cross section x branching ratio with decay products in LHCb acceptance:

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

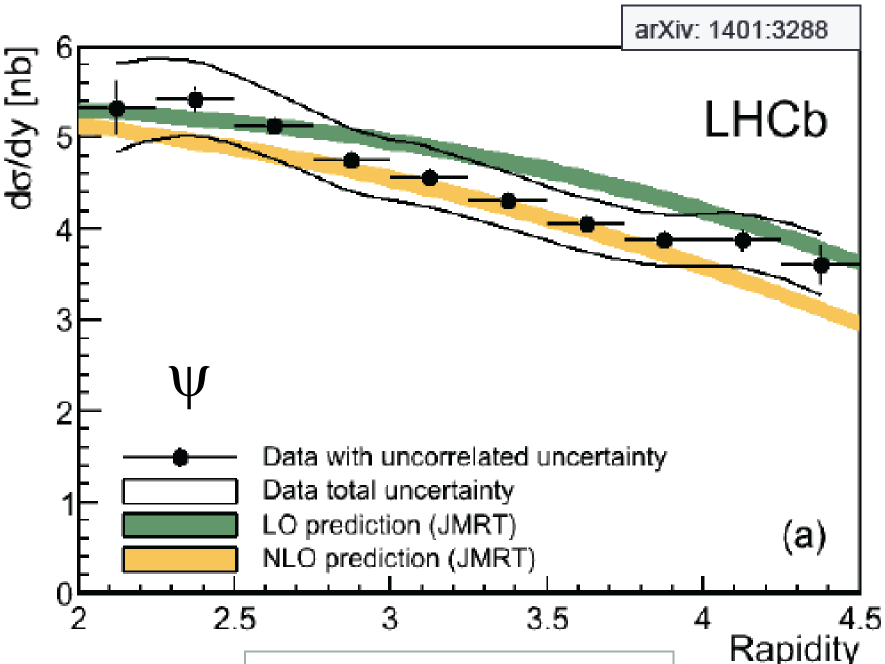




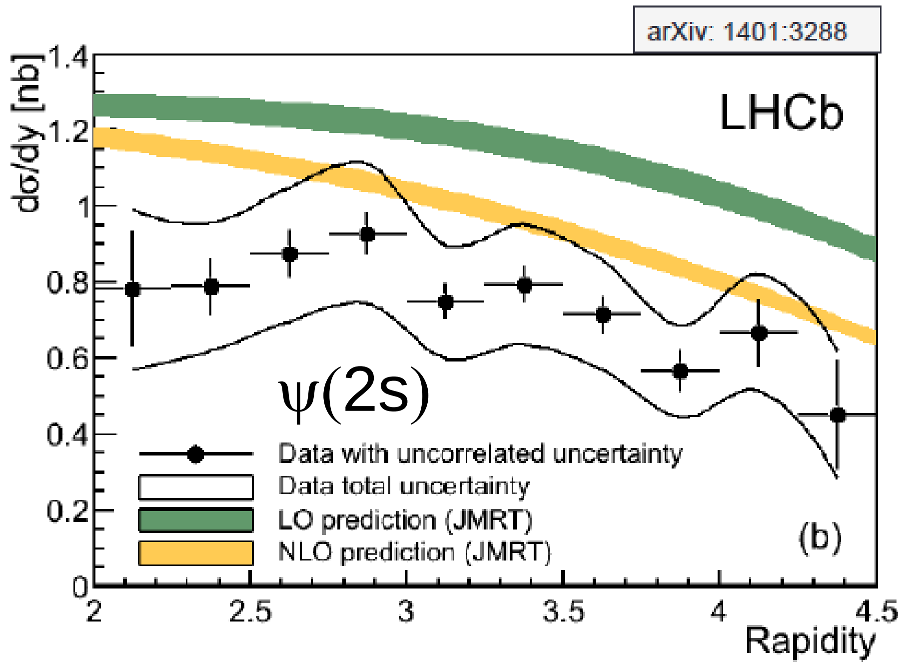
Major contribution to systematic purity determination

* SuperChic prediction does not include survival factor

Differential cross sections



NLO agrees better than LO



NLO agrees better than LO

J/ψ production σ as a function of rapidity

Differential cross section re-calculated in 10 rapidity bins

Results can then be compared to H1/ZEUS data
using known photon flux for a photon of energy k

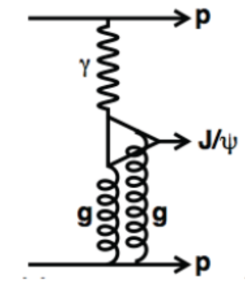
$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W^+) + k_- \frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W^-)\right]$$

Absorptive correction

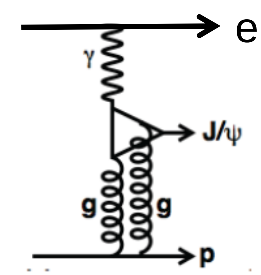
$$r(y) = 0.85 - \frac{0.1|y|}{3}$$

Photon Energy spectrum

$$\frac{dn}{dk} = \frac{\alpha_{em}}{2\pi k}\left[1+\left(1-\frac{2k}{\sqrt{s}}\right)^2\right]\left(\log A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right)$$



looks very like



For each point there are two solutions for W, the photon-proton c.m. energy
→ use power law behaviour for photoproduction σ(W) = aW^{δ}

Fit to the differential data:

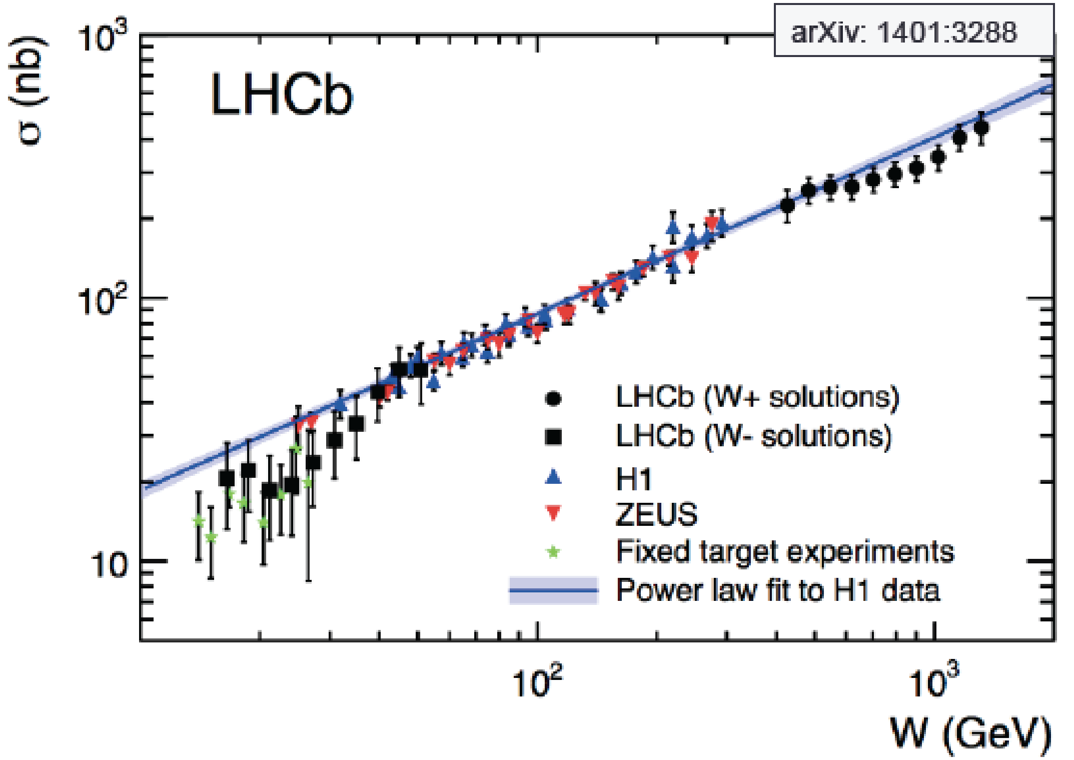
a = 81/90
δ = 0.67

J/ψ photoproduction σ

Measure Plot HERA

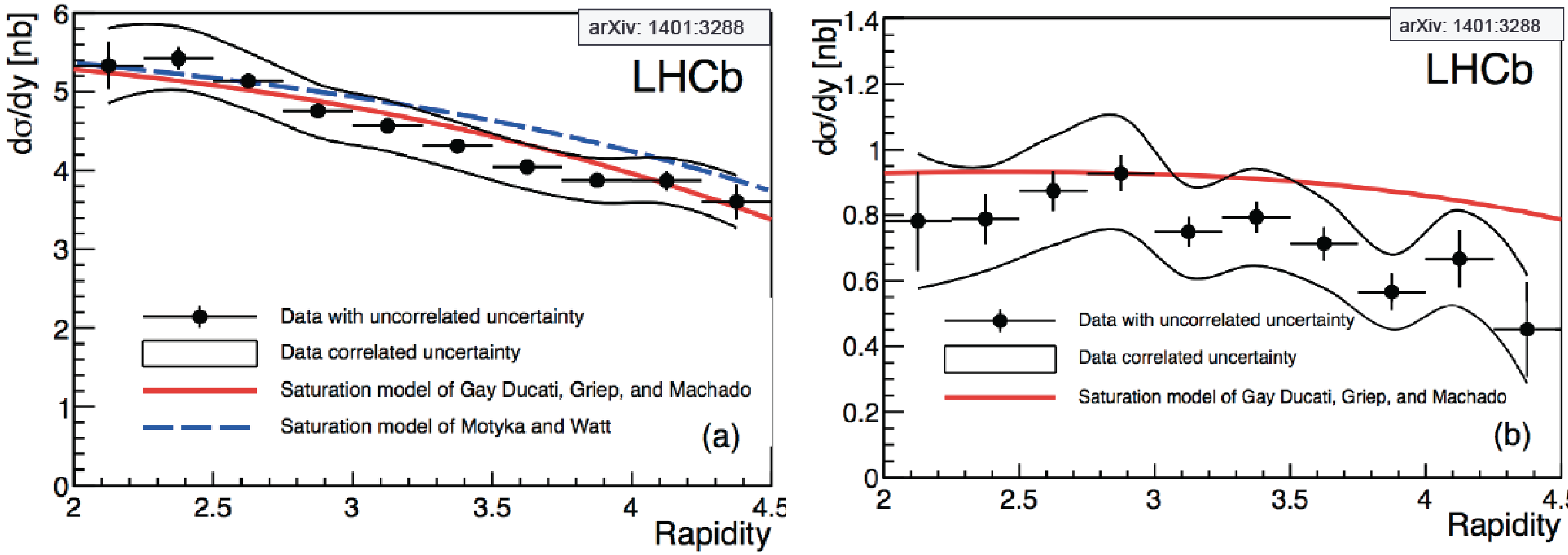
$$\left.\frac{d\sigma}{dy}\right|_{pp\to pJ/\psi\, p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

arXiv: 1401:3288



Deviation from pure power-law. i.e. NLO required or only power-law for $W>W_0$

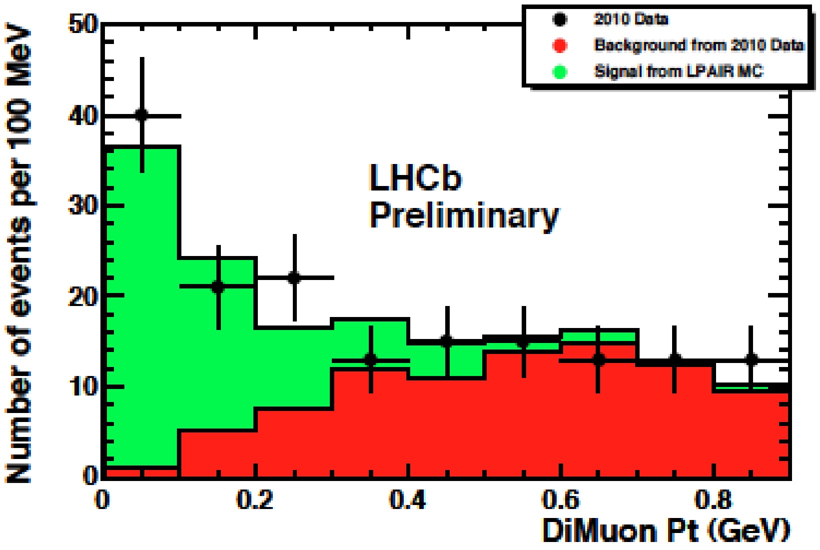
Sensitivity to saturation effects



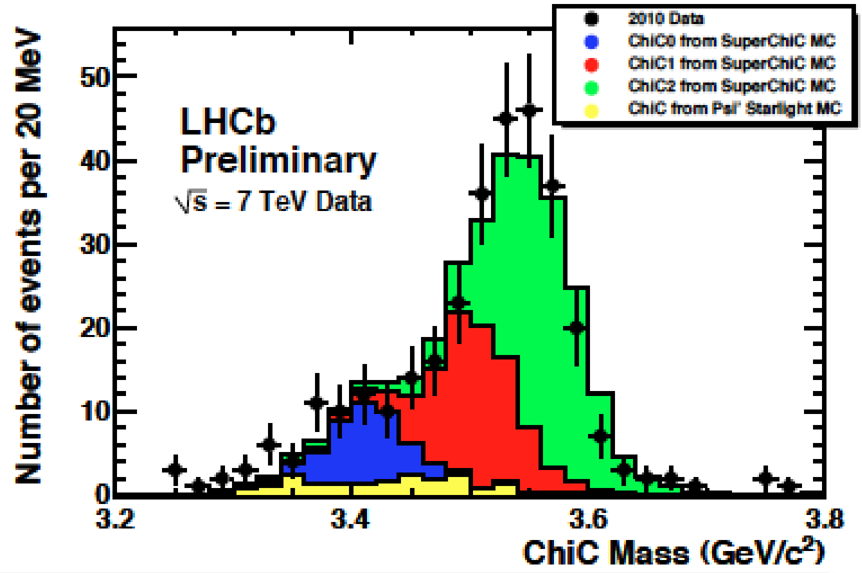
Motka, Watt, PRD 78 014023 (2008)
Gay Ducati et al., arXiv: 1305.4611

Exclusive diphoton dimuons and X_c

Dimuons with mass>2.5 GeV
+ resonances excluded



$J/\psi + \gamma$ mass



LHCb
Preliminary
Result
LHCb-CONF-2011-022

$\sigma_{\chi_{c0}\to\mu^+\mu^-\gamma}$ = 9.3 +/- 2.2 +/- 3.5 +/- 1.8 pb

$\sigma_{\chi_{c1}\to\mu^+\mu^-\gamma}$ = 16.4 +/- 5.3 +/- 5.8 +/- 3.2 pb

$\sigma_{\chi_{c2}\to\mu^+\mu^-\gamma}$ = 28.0 +/- 5.4 +/- 9.7 +/- 5.4 pb

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

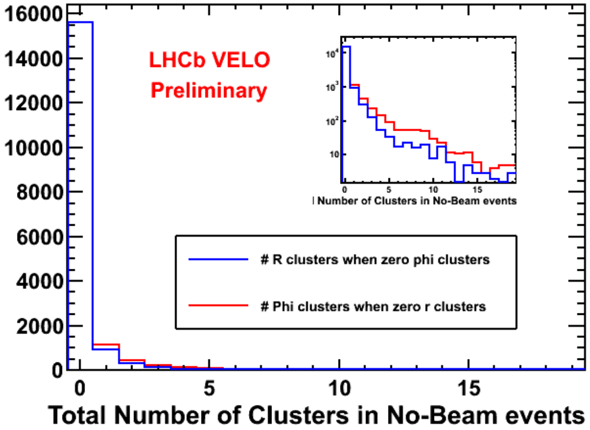
CEP di-μ Future Prospects

Mass peaks hinted at will benefit from higher stats; low mass vector mesons, upsilons, di-μ + X states…

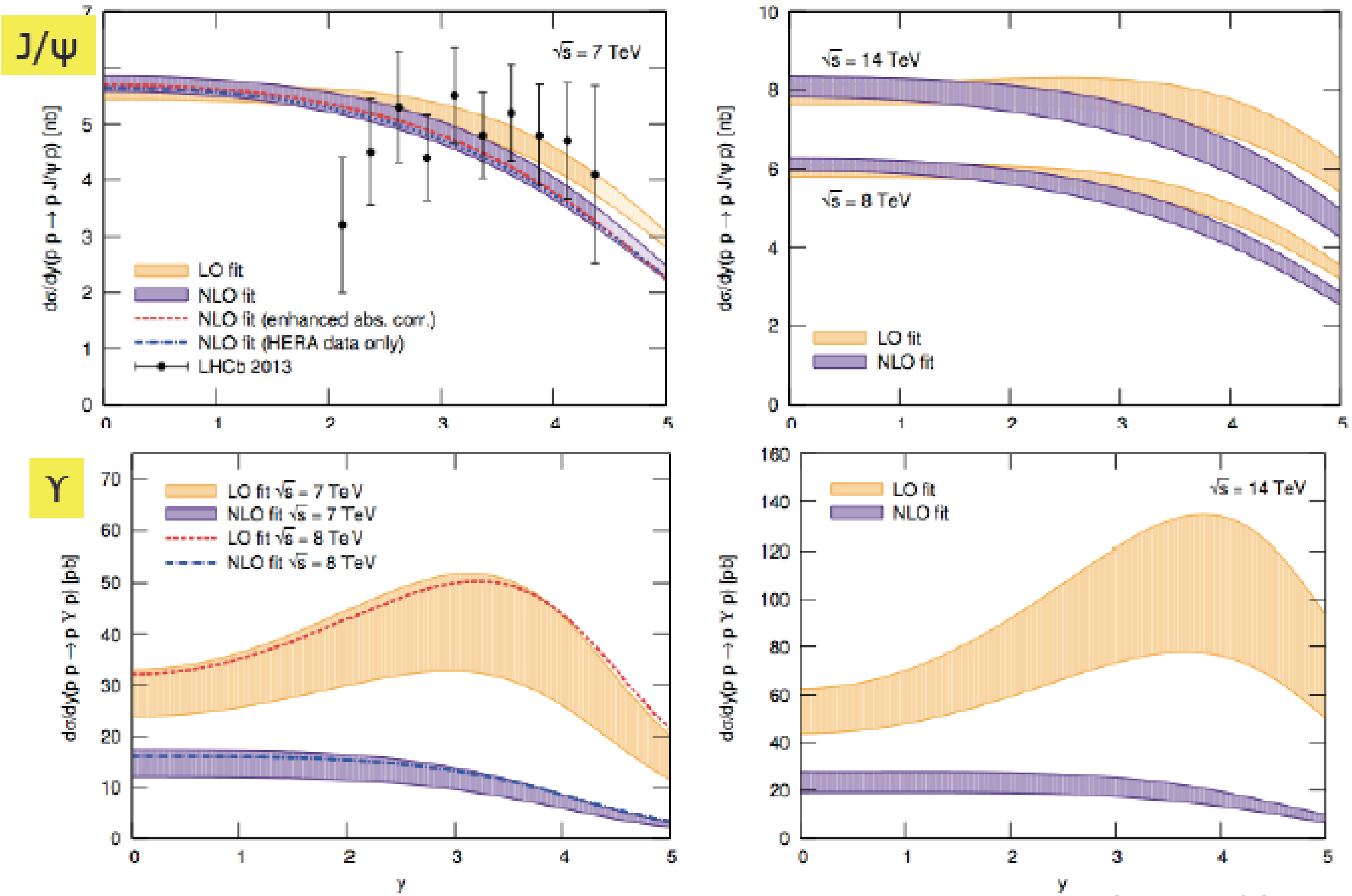
More accurate measurements of branching ratios and ratios of branching ratios, improved fits to signal and background (simulation of central exclusive J/ψ with additional gluon interactions would be welcome!)

Use of LHCb detector activity e.g. VELO clusters, not just tracks, to reject backgrounds

Use of converted photons to improve χ mass resolutions

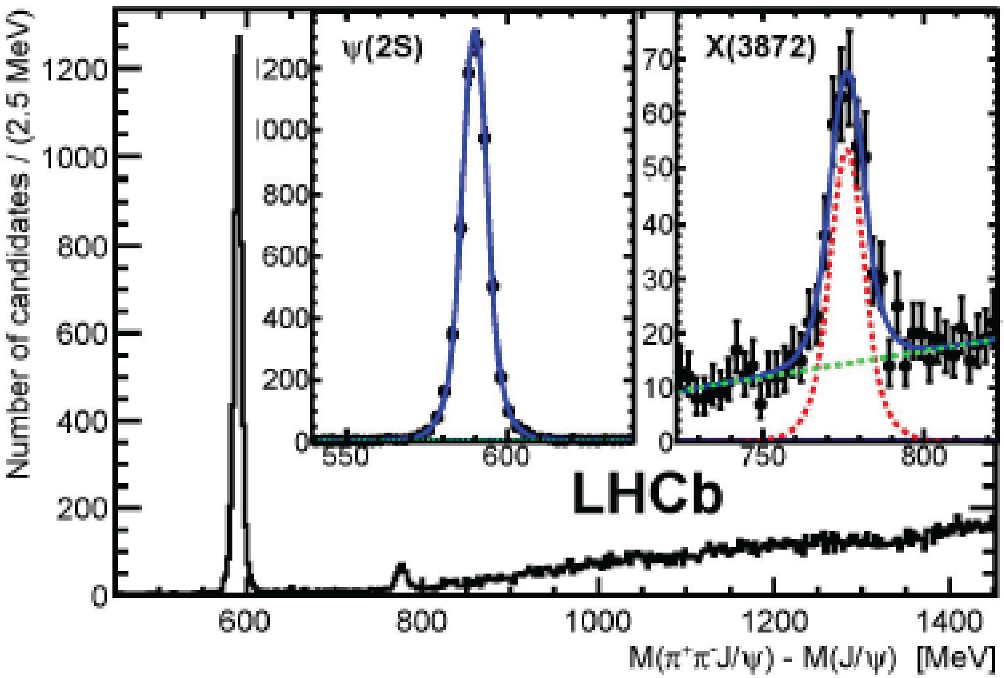


Predictions: arXiv 1307.7099



Jones, Martin, Ryskin, Teubner

X(3872)



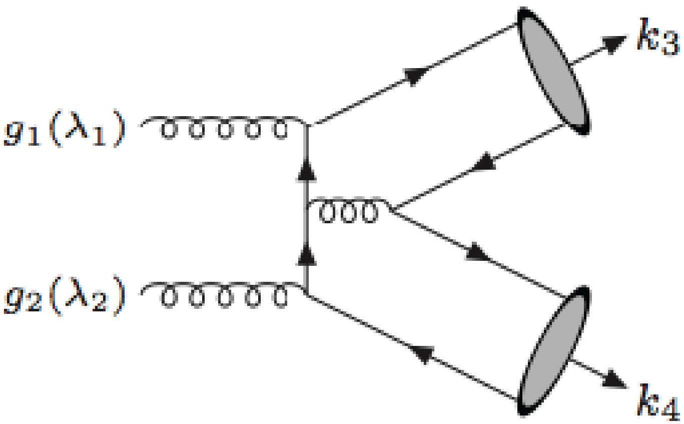
Has been observed inclusively
arXiv: 1112.5310
Could it be produced exclusively?

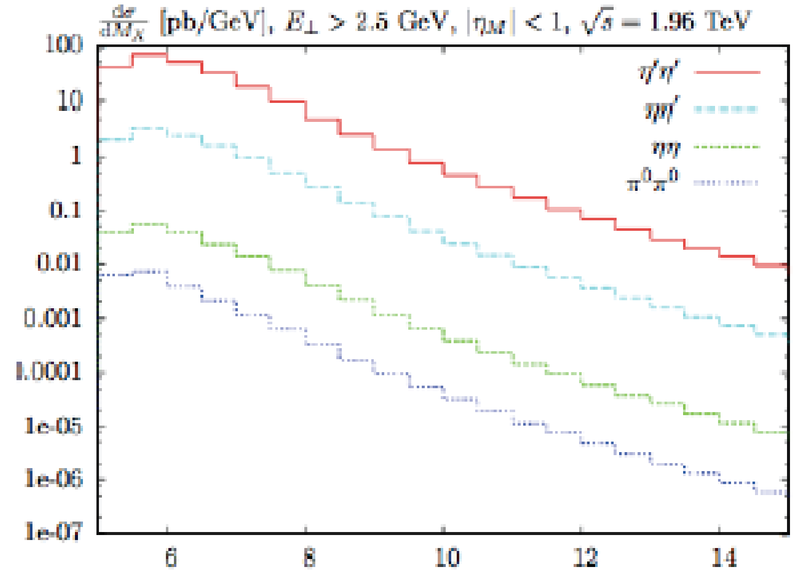
J^{PC} of X(3872) shown by LHCb to be 1^{++} (arXiv: 1302.6269)
χ_c has been hinted at by LHCb to be produced exclusively

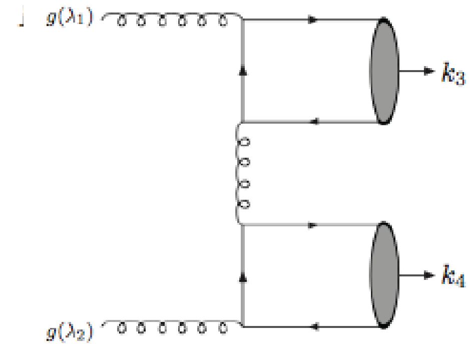
Observation of X(3872) produced in CEP can shed light on its nature in particular its fraction as a bound state

Di-meson production

arXiv: 1105.1626, arXiv: 1405.0018







Vanishing cross section when gluons in Jz=0
Flavour non-singlet mesons suppressed (e.g. ππ/KK)
Flavour singlet (e.g. $\eta'\eta'$ production) can proceed via

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:

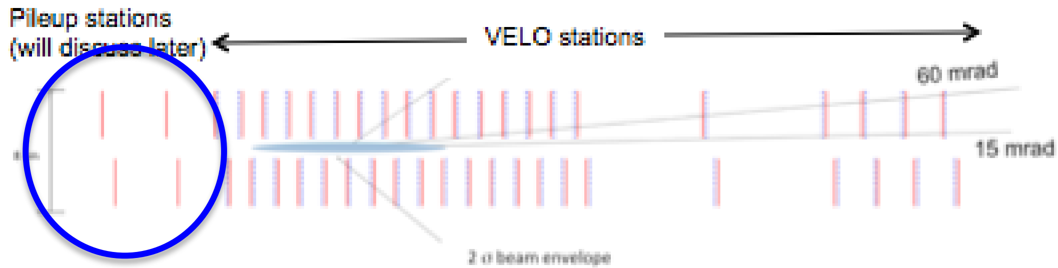
Use of "Pile-up" stations ("upstream" silicon sensors) at L0 stage to veto backwards activity

+

Greater pass through trigger rate exploiting small events and short processing times

+

Soft p_T cuts essential for hadronic final states from low p_T objects



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

CEP→hadrons at LHCb

Main physics goals:

- Study charmonium states decaying into two and four-body final states (*e.g.* $\chi_{c0} \to K^+K^-, \pi^+\pi^-$) to complement di-muon studies

- Study production of open charm in such events

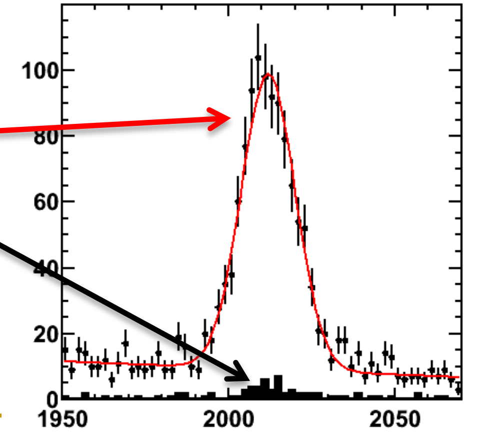
- Spectroscopy: e.g. search for higher mass charmonia states decaying to open charm, *e.g.* $\chi_{c2}(2P)$

New trigger has collected ~ 1.4 fb^{-1} of integrated luminosity (~ 19% useful for CEP)

Dedicated trigger lines include:

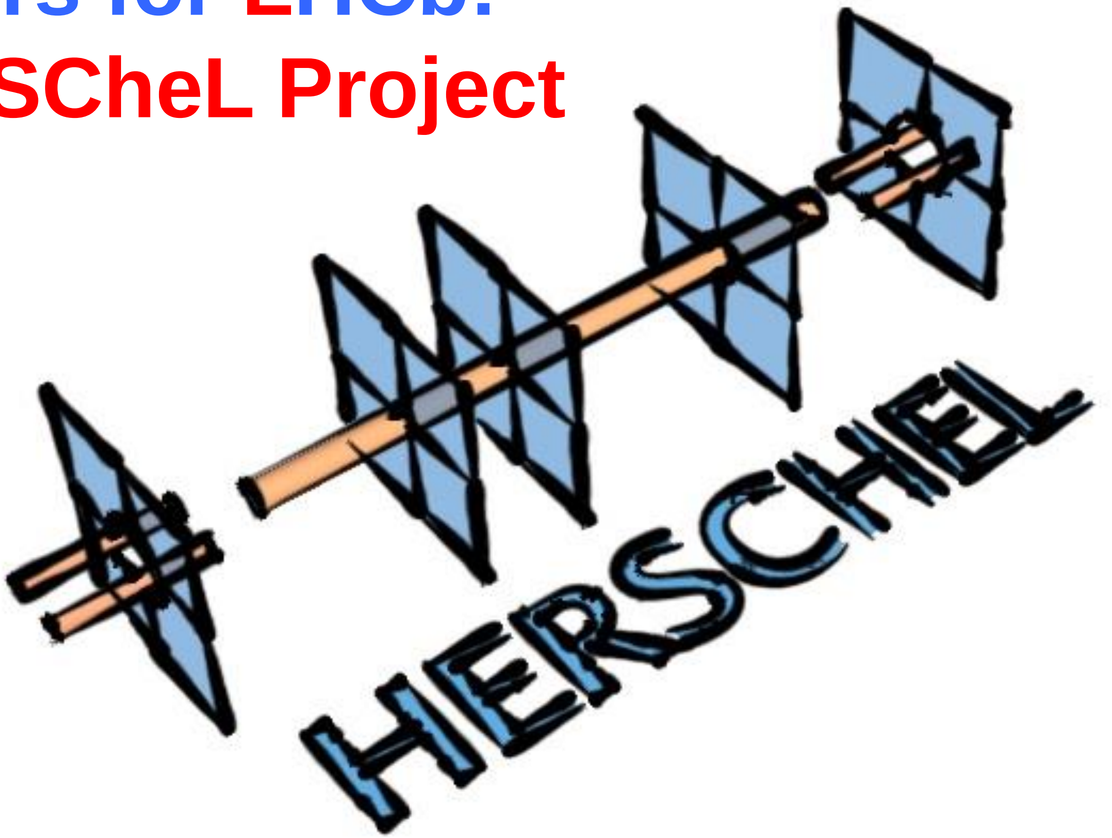
- standard D decays
- charmonia decays to 2 and 4 body final states
- Inclusive di kaon line
- Low mass resonance line to search for e.g. K_S, Φ

D* yield in low multiplicity events
after June 2012
before June2012



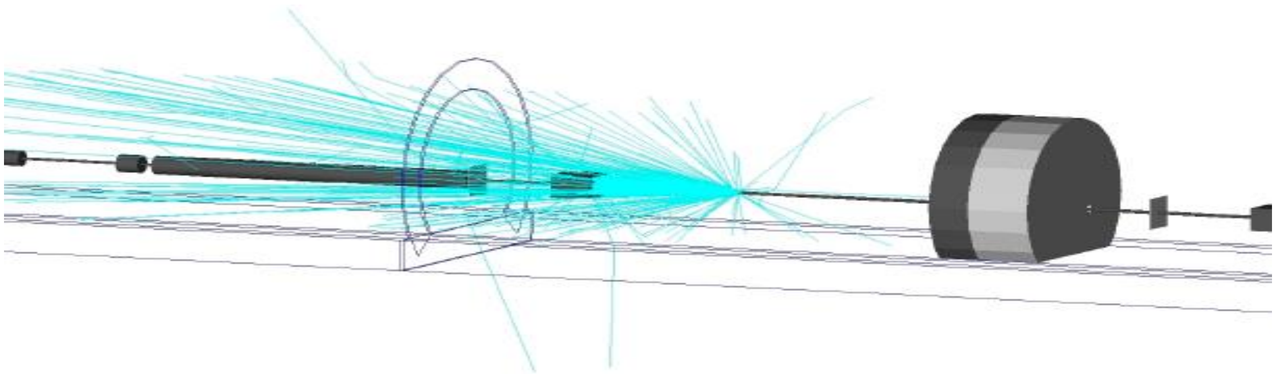
Extending LHCb coverage

High Rapidity Shower Counters for LHCb:
The HeRSCheL Project



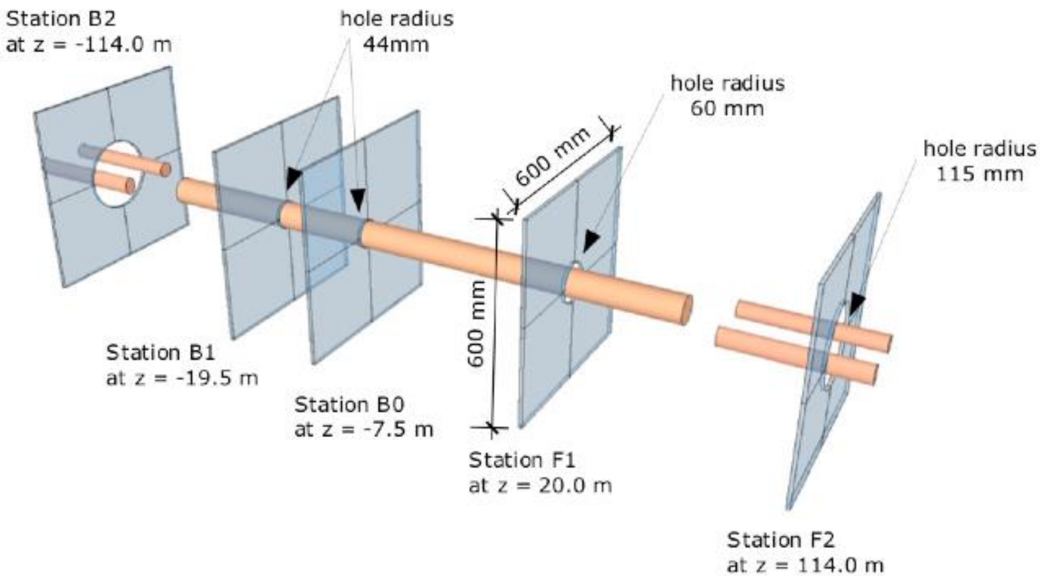
Extending LHCb Coverage

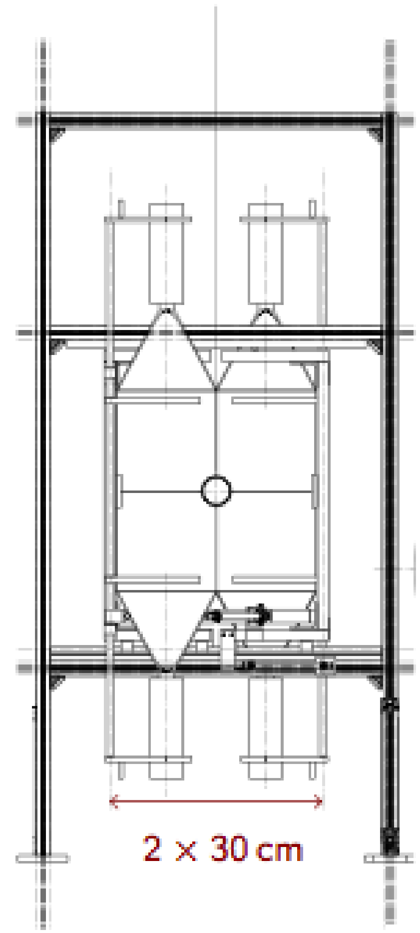
- LHCb plans to accumulate >5-6 fb-1 of data in low pile-up conditions (μ~1) during Run II, providing a unique opportunity to extend the forward physics programme
- Idea of Herschel is to install scintillation counters in the tunnel where the beam pipe is accessible
  - Detect showers from high rapidity particles interacting with beam pipe elements



  - Central Exclusive Physics, which currently suffers from a large background of undetectable events where the proton breaks up in the forward direction will be greatly enhanced
  - FSC will also act as general rapidity gap detectors and will identify very forward showers in low mass diffractive excitation
  - LHCb readout also offers potential to incorporate signals into trigger at L0 (40 MHz) trigger
  - Other topics such luminosity measurement and understanding of machine backgrounds may also benefit
- Similar systems have been successfully deployed at CDF and CMS

Detector Layout





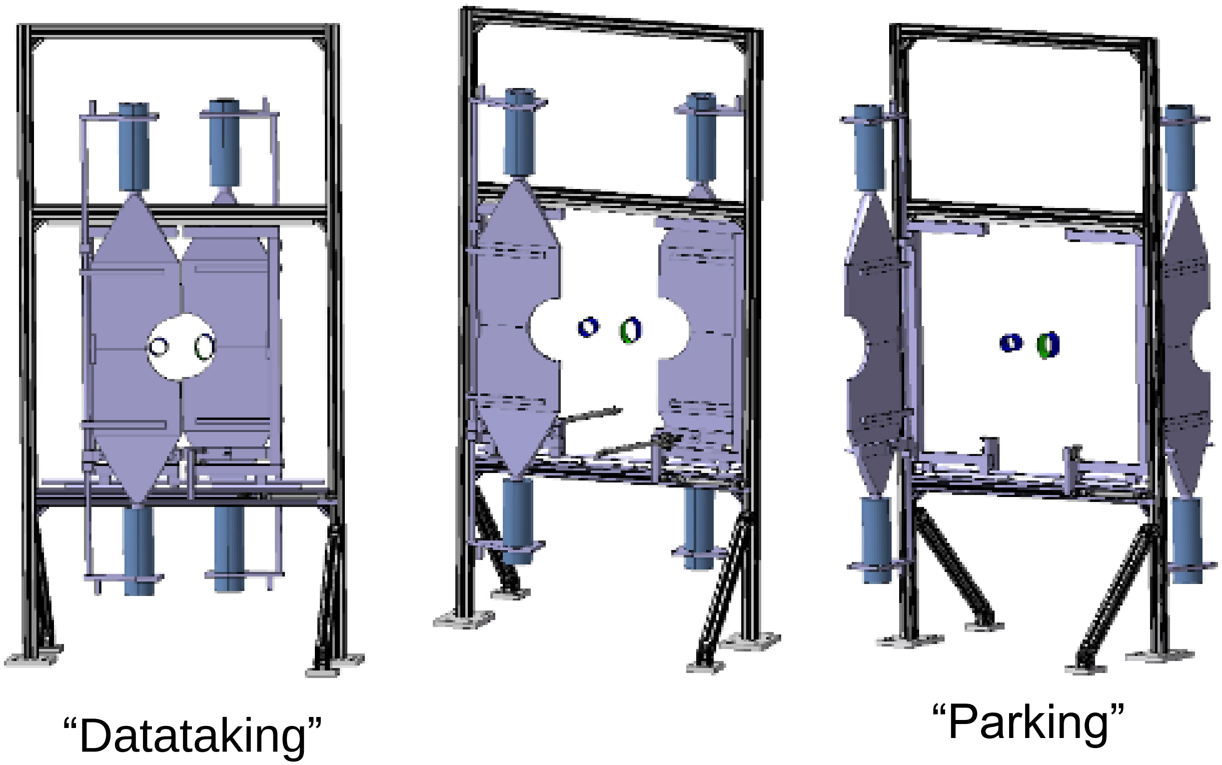
Detectors consist of 4 plastic scintillator plates, 20 mm thick, glued to “fishtail” light guides

Two different radii of inner cut-out depending on beampipe layout

PMT identified, and under test Hamamatsu R1828-01

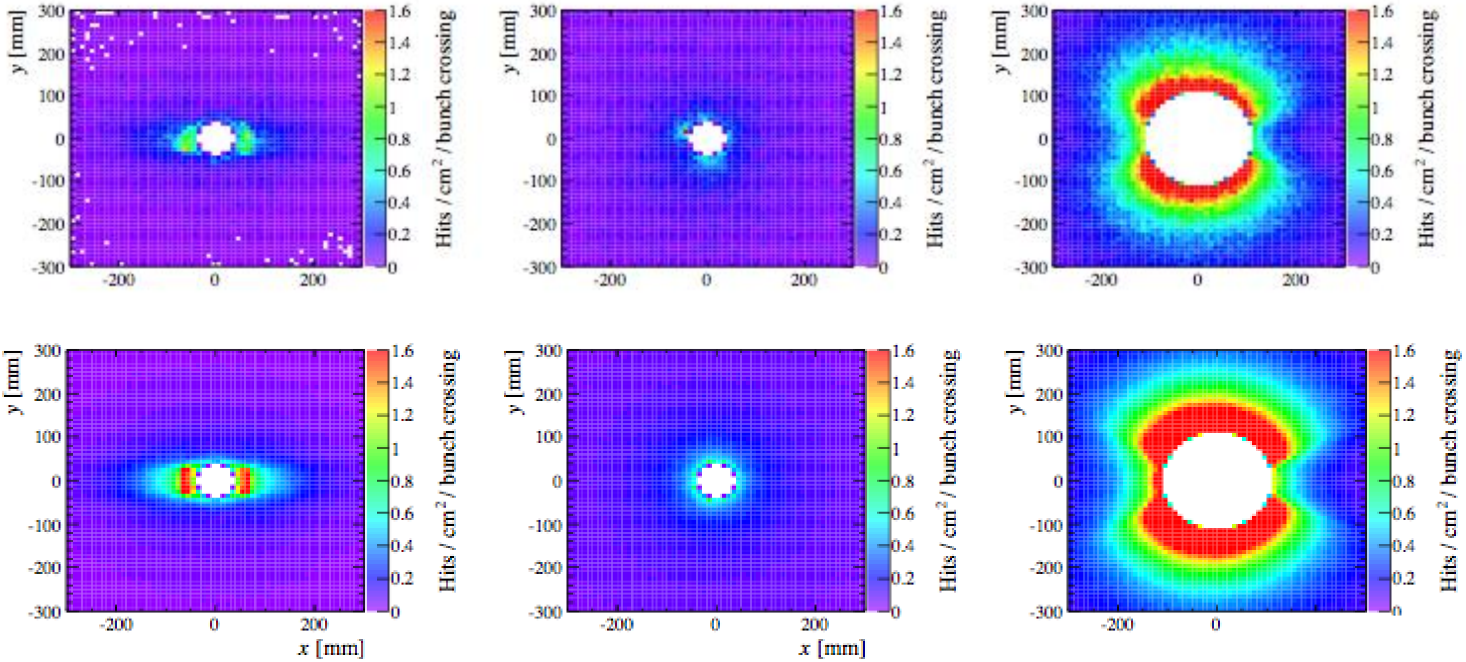
- 0.2 mA average anode current
- Customised high-rate base being produced
- Benefit from experience of LHCb BLS experience

Mechanical Supports



- Support frame of station at +20 m is attached to shielding wall between muon system and LHC tunnel
- Supports for other stations are bolted to tunnel floor
- Pneumatic motion system to retract scintillators from high fluence region if data taking is not possible for extended time periods

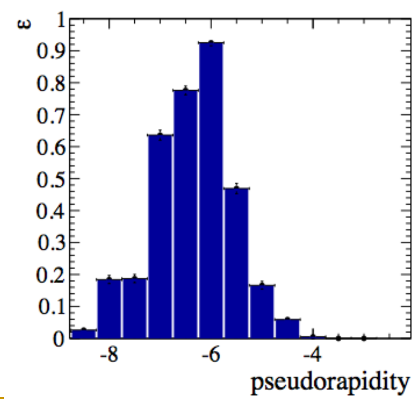
Simulation – Rates and Efficiencies



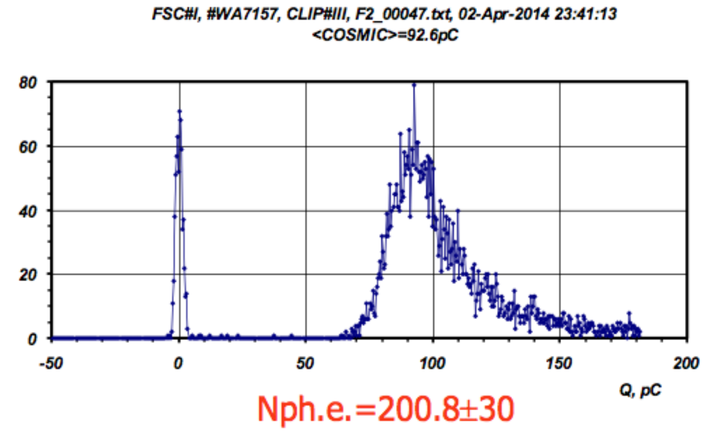
CEP-like events

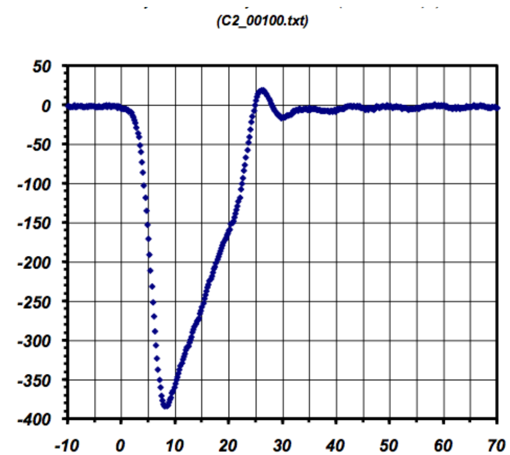
Minimum bias events with pileup

- Efficiency is good even for low energy particles, beyond geometric acceptance (due to showering) shown here for pions with pT=1.5 GeV
- Each station must be sensitive to ~ 100 hits to effectively veto single diffractive events, while tolerating
- ~2500 hits/event in minimum bias operating conditions



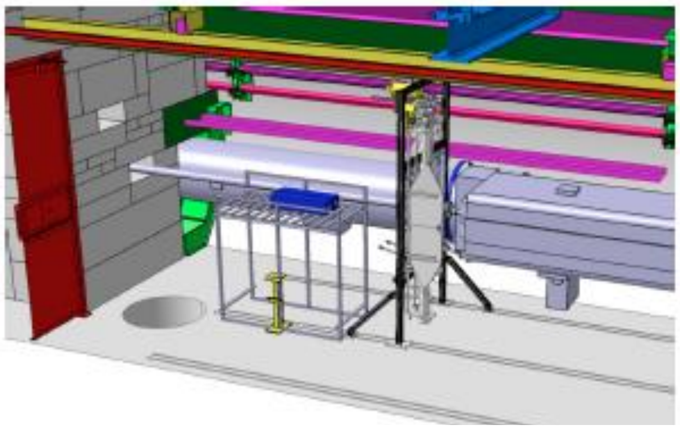
PMT, base + light guide, preliminary cosmic tests

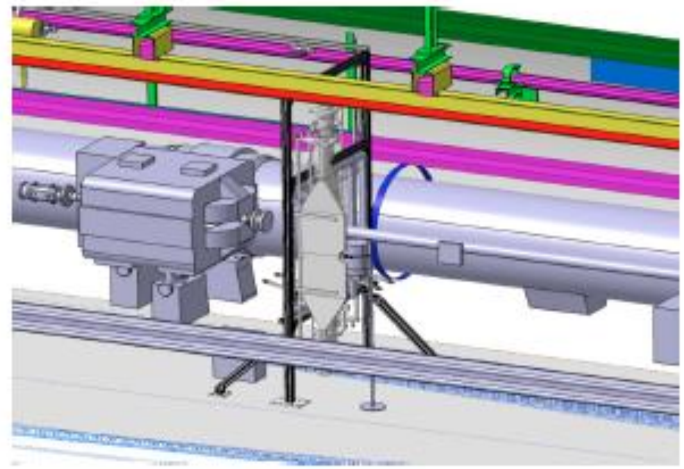


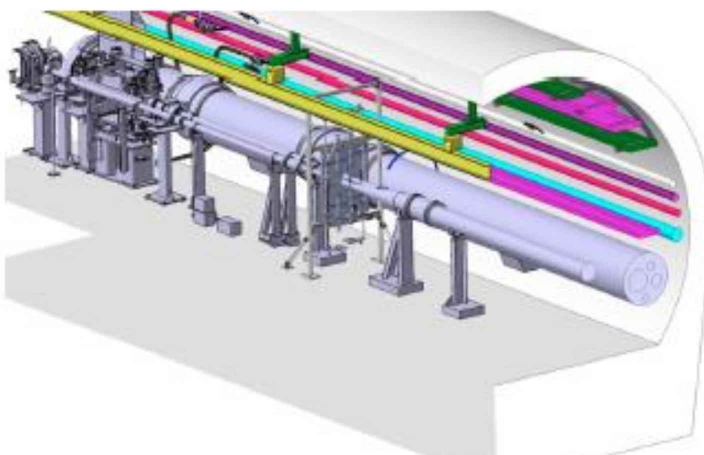


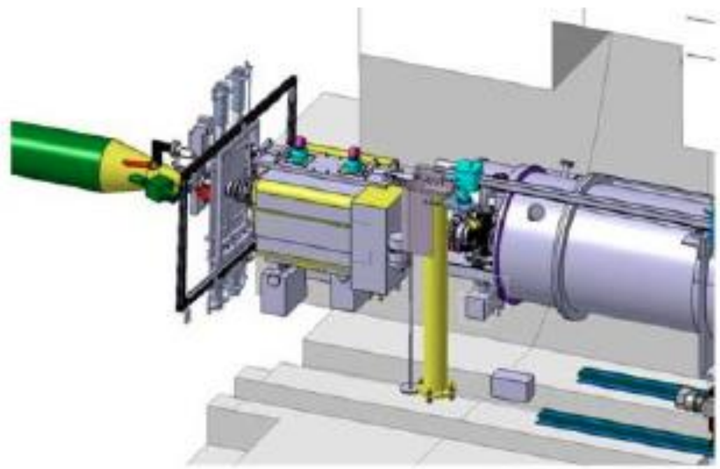
Dedicated base with zener diodes to control voltage at input dynodes under test
Cosmic stand results indicate light yield of ~200 p.e.
Different geometries of wave guide under study
Clipping scheme implemented to eliminate spillover to next bunch crossing
Schedule is very tight, especially concerning tunnel installations

Integration into LHC Layout









Conclusions

- LHCb has a rich programme of CEP measurements ahead
  - 2011+2012 data at 3.5 and 4 TeV, with ~20% of luminosity useable; to repeat and refine previous measurements and add many new final states
  - Hadronic triggers active in 2012; probe χ_c production and search for open charm production
  - Herschel project underway, to add significant background rejection for LS2
- Thank you for your attention

Backup

Comparison to theory

V. P. Gonçalves and M. V. T. Machado, *Vector meson production in coherent hadronic interactions: an update on predictions for RHIC and LHC*, Phys. Rev. **C84** (2011) 011902, arXiv:1106.3036.

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L. A. Harland-Lang, V. A. Khoze, M. G. Ryskin, and W. J. Stirling, *Central exclusive χ_c meson production at the Tevatron revisited*, Eur. Phys. J. **C65** (2010) 433, arXiv:0909.4748.