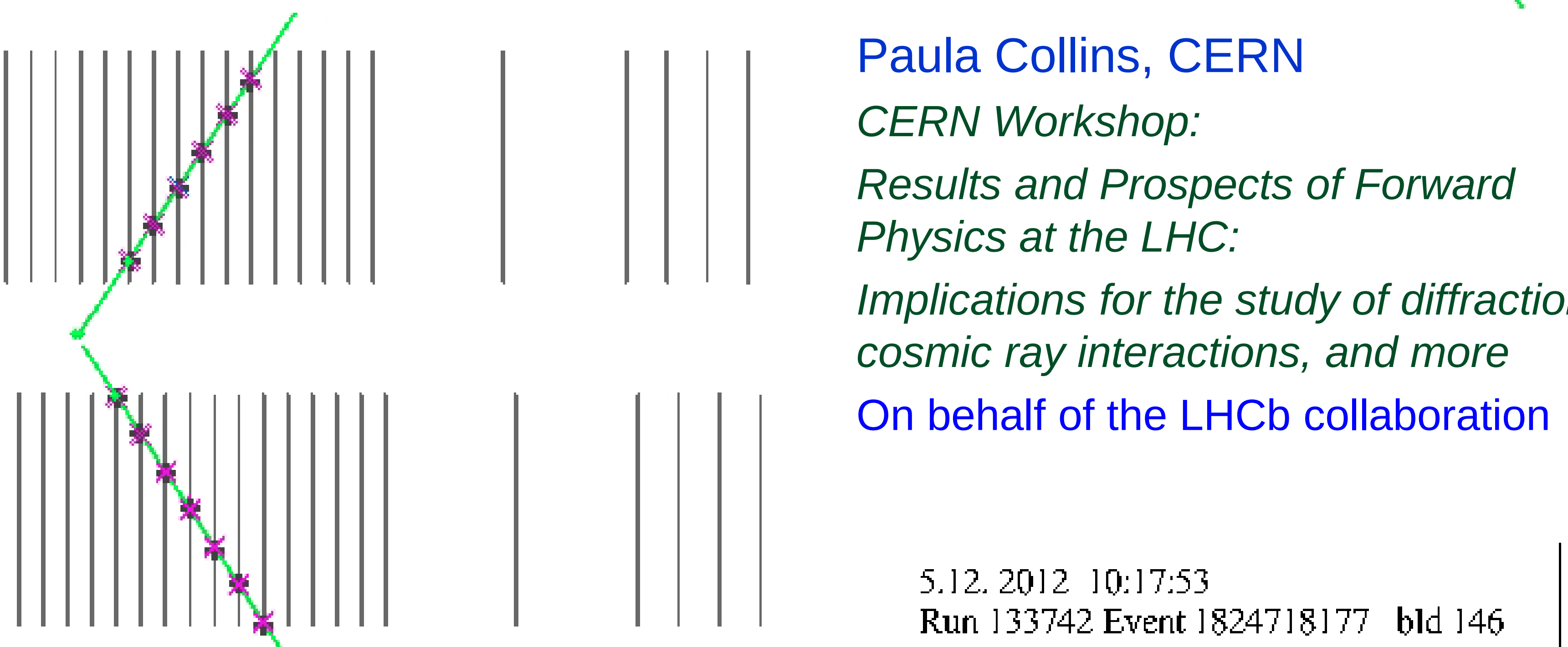
LHCb Central Exclusive Production Results and Prospects



Paula Collins, CERN

CERN Workshop:

Results and Prospects of Forward Physics at the LHC:

Implications for the study of diffraction, cosmic ray interactions, and more

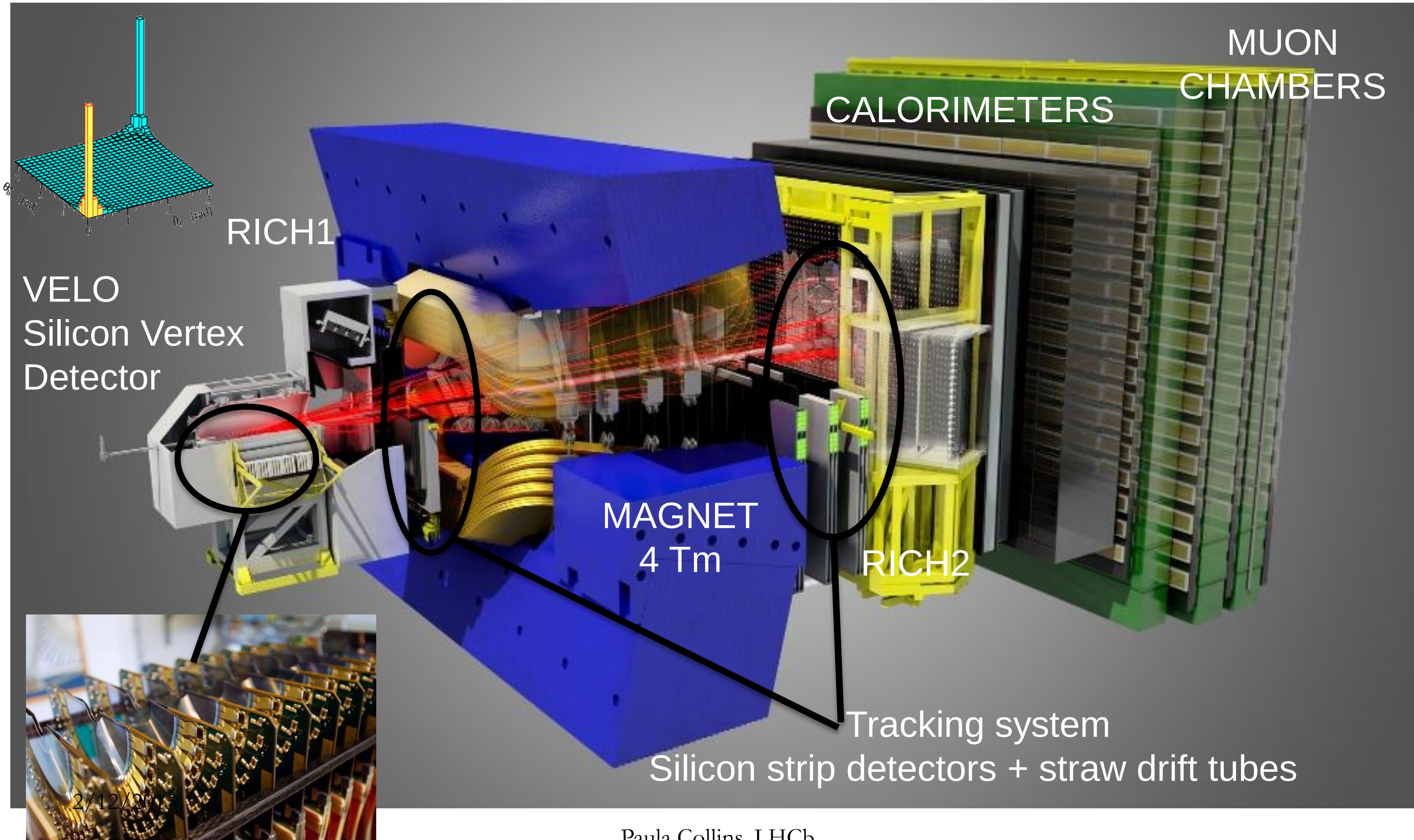
On behalf of the LHCb collaboration

Talk Outline

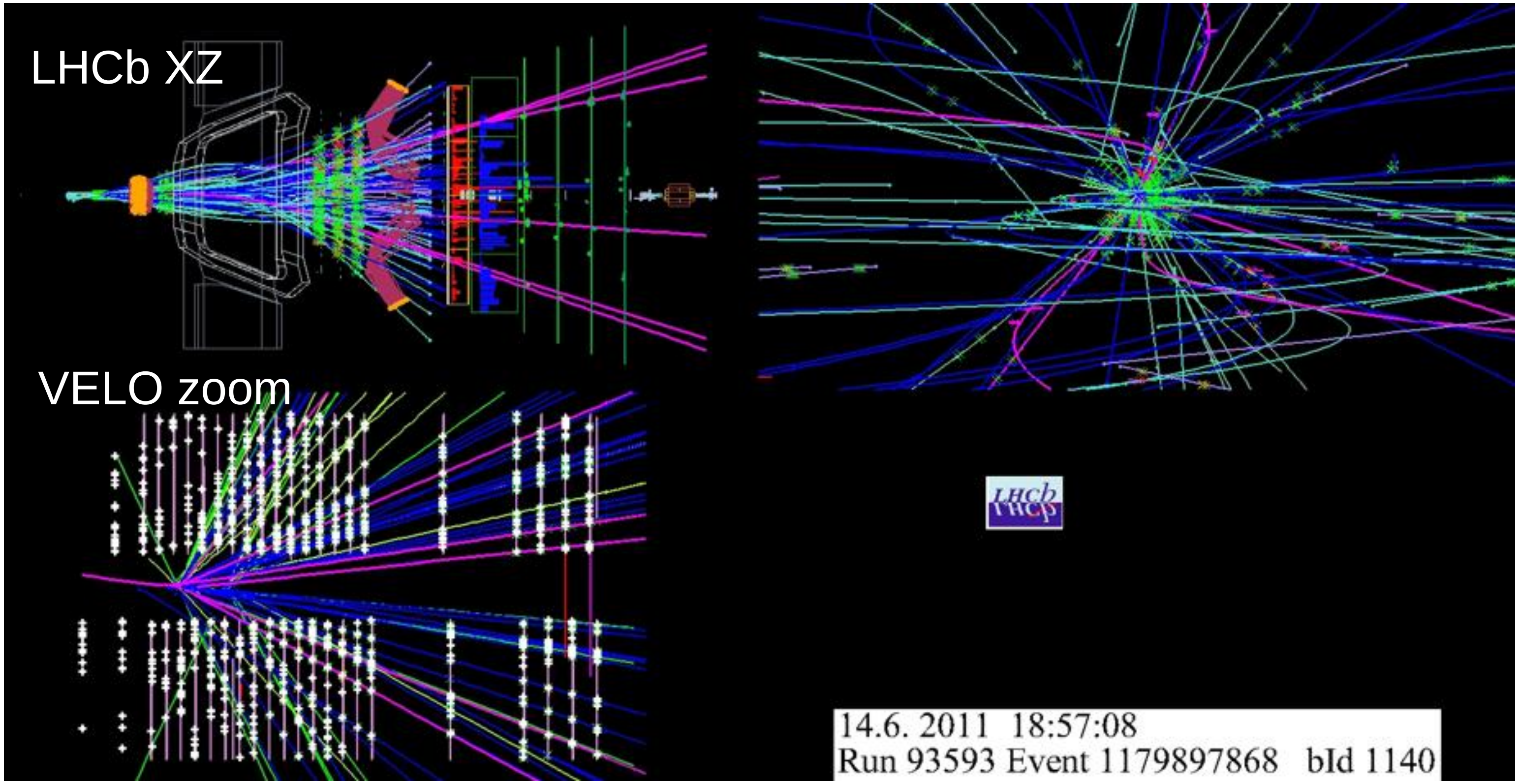
- CEP @ LHCb
- CEP → muons
  - LHCb 2010 results for J/ψ, $\psi(2s)$:
    - ArXiv:1301.708, paper accepted by Journal of Physics G
  - Exclusive QED di-photon and $\chi_{c0,1,2}(1P)$ production
    - LHCb-CONF-2011-022
  - Future prospects
- CEP →hadrons
  - Physics motivation to enhance reach for hadronic final states
  - New trigger strategy
- Future Prospects for CEP at LHCb

LHCb Detector

Single arm forward spectrometer dedicated to precision flavour physics



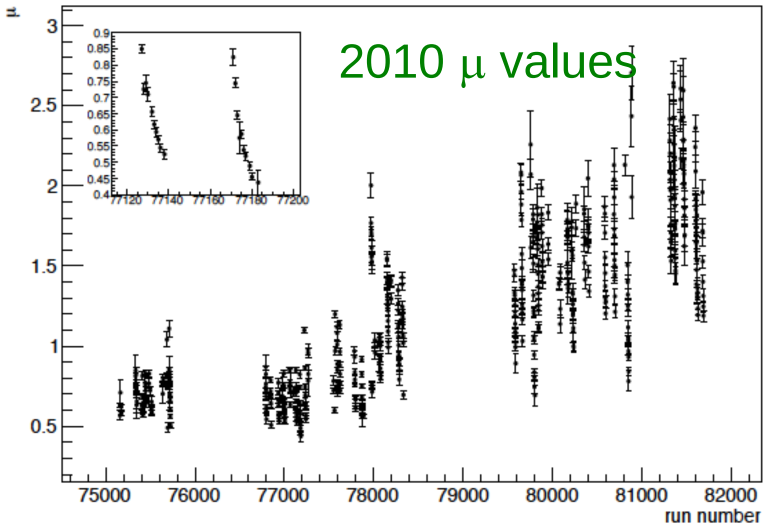
$B_s \rightarrow \mu^+\mu^-$ event in LHCb



Not a typical event – but a very typical topology!

LHCb and CEP

LHCb very well suited to studies of CEP production



Access to high rapidities

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

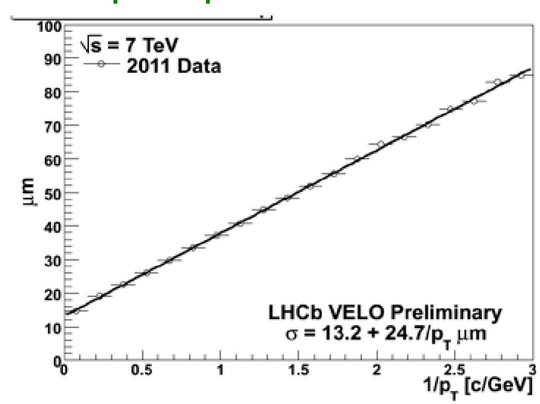
Relatively low pileup

Analysis greatly simplified by using single interaction events
$\rightarrow$ intrinsic efficiency = exp($-\mu$)
For 2010 (2012) ~ 21% (19%) of total luminosity available

Trigger

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

VELO impact parameter resolution



Excellent particle ID

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

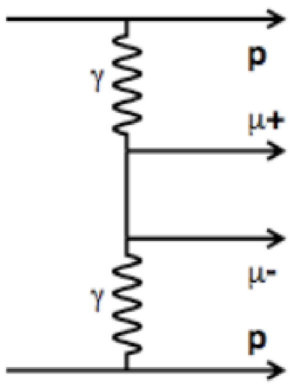
Sensitivity to low p and low p_T particles

both at trigger stage, and for precise reconstruction

di-μ CEP signals in LHCb

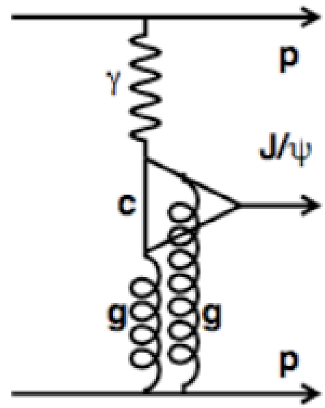
Exchange of a colourless object: γ, pomeron → two muons (+ photon) + rapidity gaps
Single elastic process → protons escape undetected in beampipe

Non-resonant di-μ (di-γ fusion)



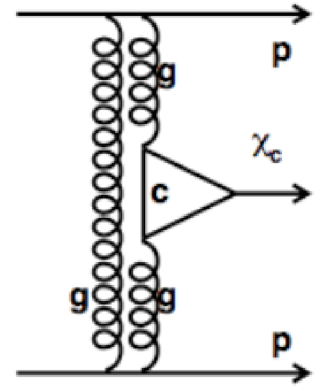
Ideal for luminosity measurement

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



allows odderon search

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



test of CEP theory + Higgs predictions

Resonant, probe of gluon density at low x

LPAIR
(A.G.Shamov and V.I.Telnov, NIM A 494 (2002) 51)

Starlight
(S.R.Klein and J.Nystrand, Phys. Rev. Lett. 92 (2004) 142003)

SuperChiC:MC for CEP
(L.A.Harland-Lang, V.A.Khoze, M.G.Ryskin, W.J.Stirling, arXiv:0909.4748[hep-ph])

Fully reconstructed signal MC

di-μ triggering in LHCb

Typical events

Many tracks + high Pt objects

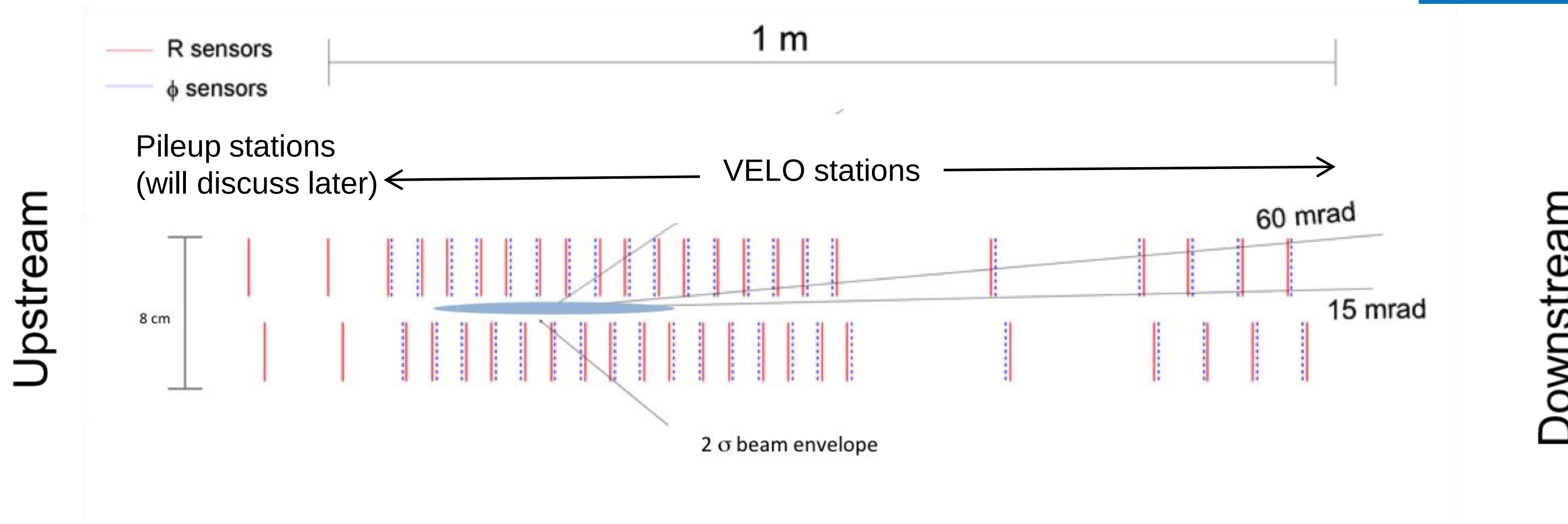
Picked up with high efficiency by standard LHCb triggers

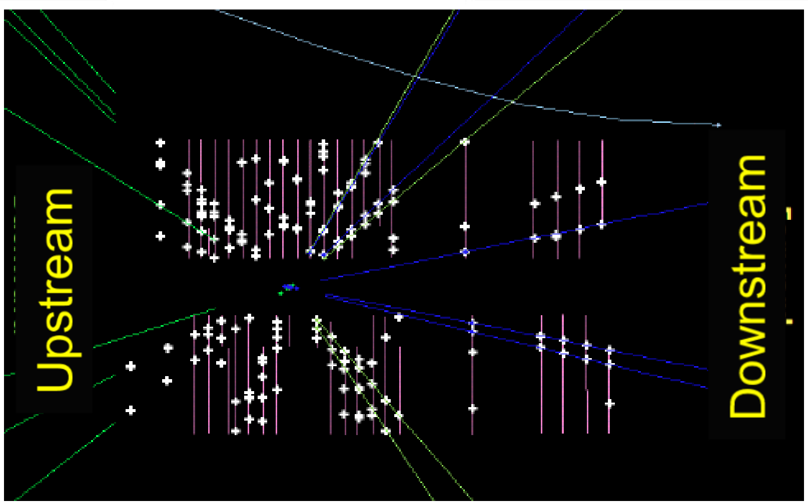
CEP events

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

Exploit VELO coverage





VELO view of low multiplicity triggered di-μ event

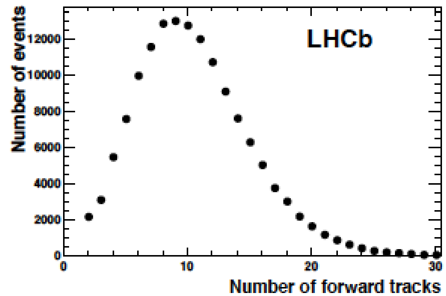
Backwards tracks are clearly reconstructable
(note no momentum information)

Rapidity gap coverage ~ 1-2 units, depending on z vertex position

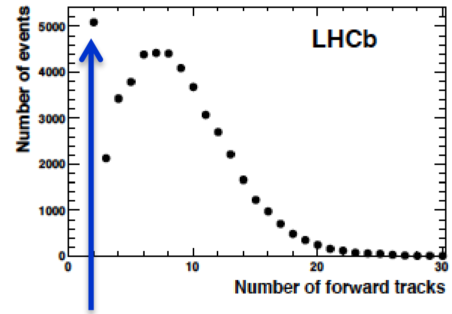
Rapidity gap selection of CEP candidates

Di-μ triggered events

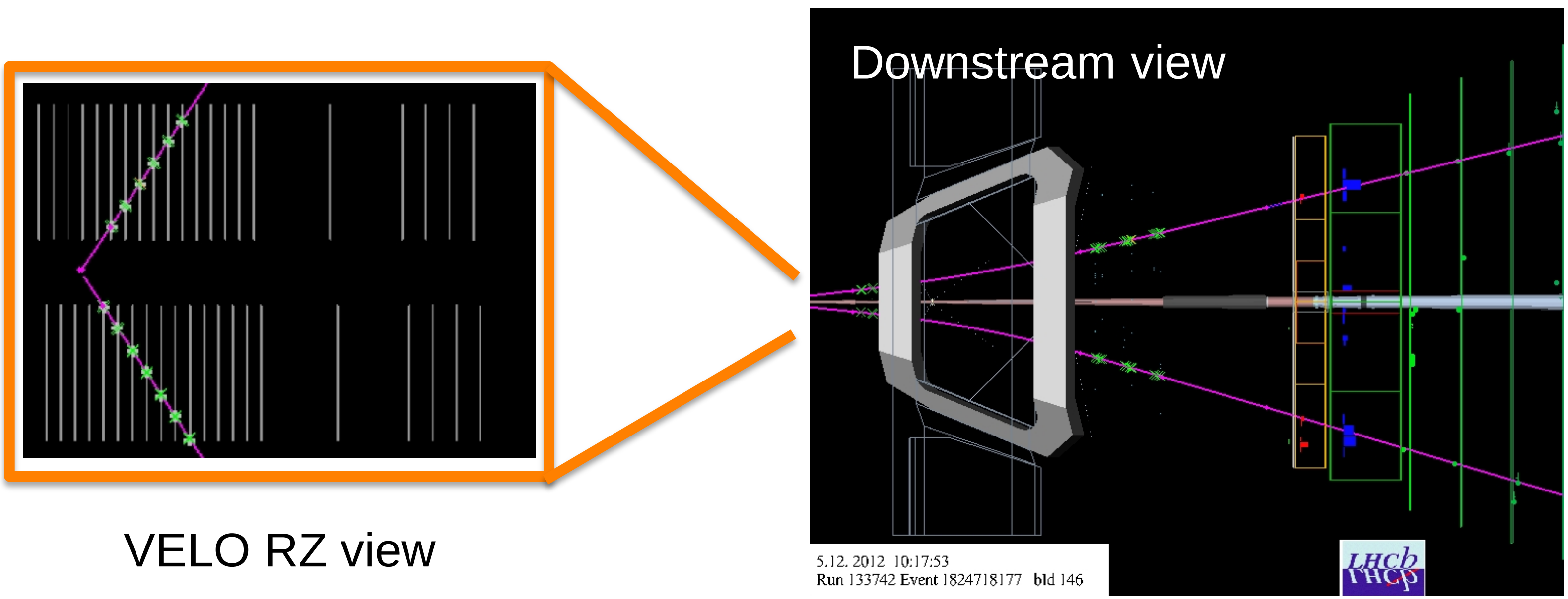
Backward tracks>0



Backward tracks=0



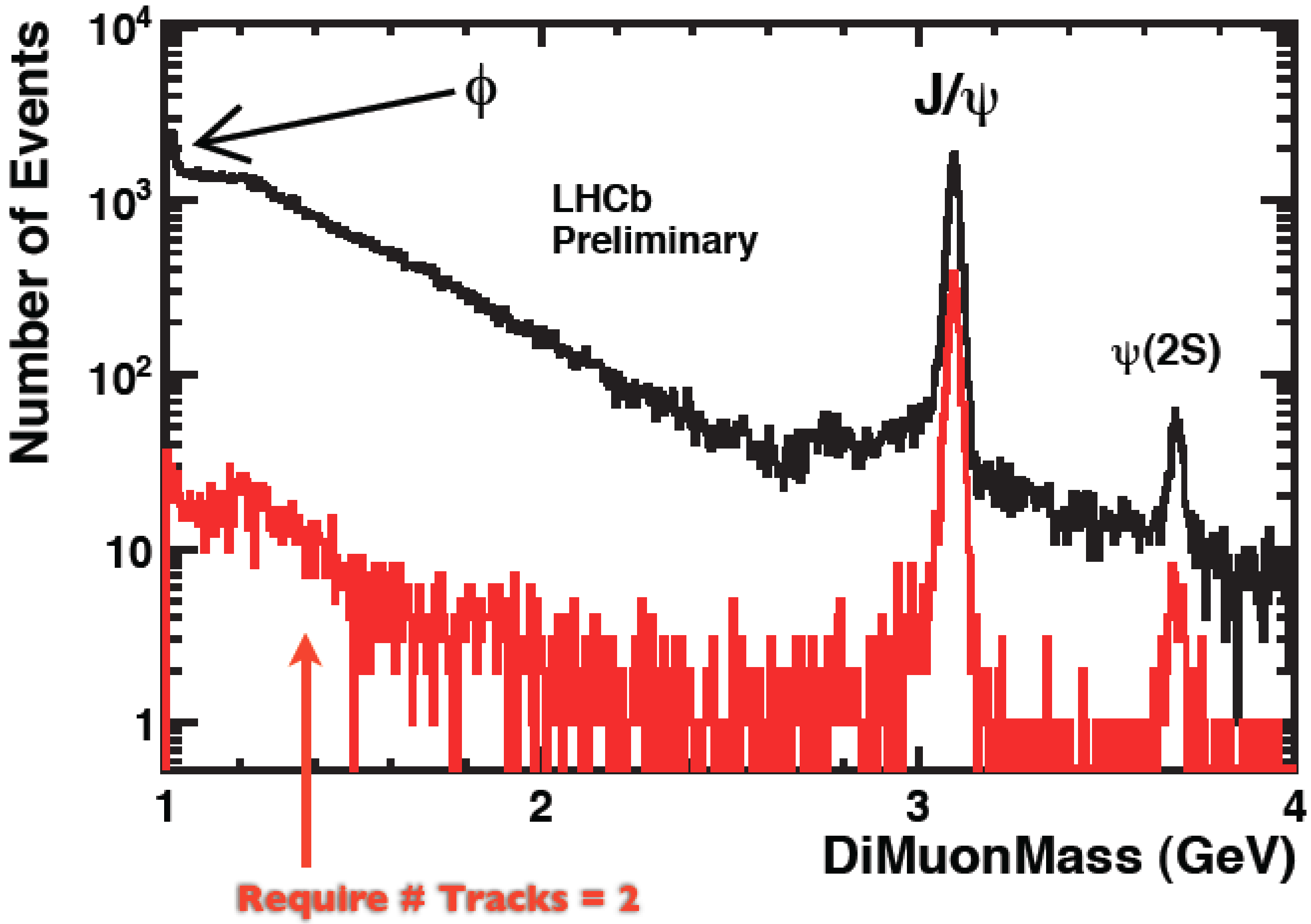
CEP candidates



VELO RZ view

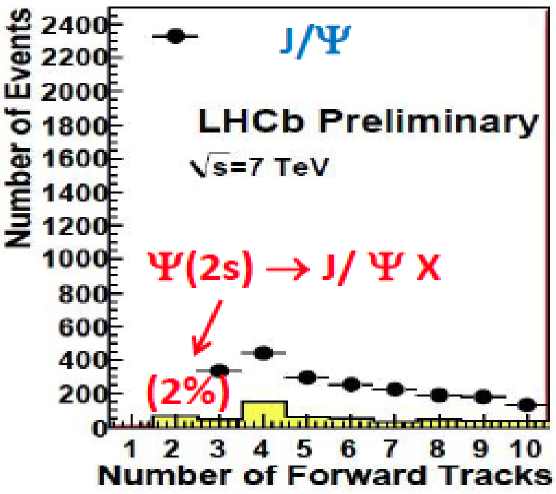
Exclusive dimuon candidates

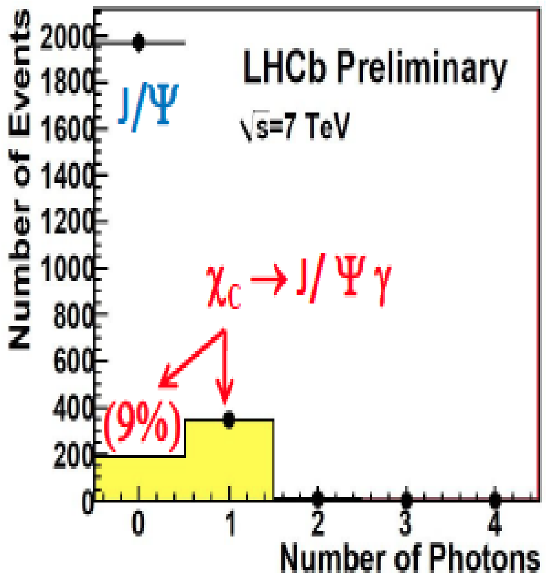
Events passing 2010 Low Multiplicity Dimuon Trigger



Feed-down backgrounds

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



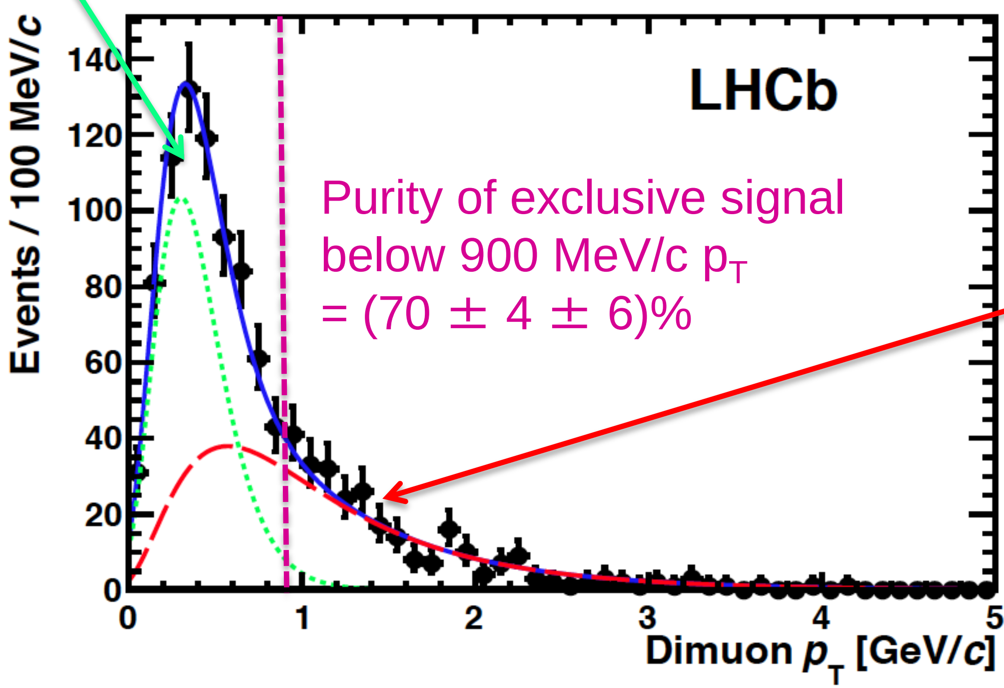


Feed-down from $\chi_c \rightarrow J/\psi\ \gamma$
with undetected γ
Require # photons = 0
Estimate residual background from SuperChic
+ full LHCb simulation,normalised to data

Signal + Inelastic background

Signal shape

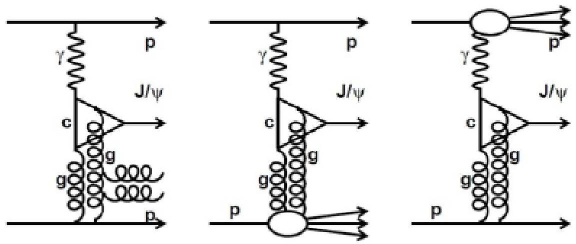
Estimated from Superchic using exp(- b p_T^2)
Slope b estimated from explicit calculation using HERA data: 6.1 +/- 0.3 GeV^{-2}
Fit gives b = 5.8 +/- 1 GeV^{-2}



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



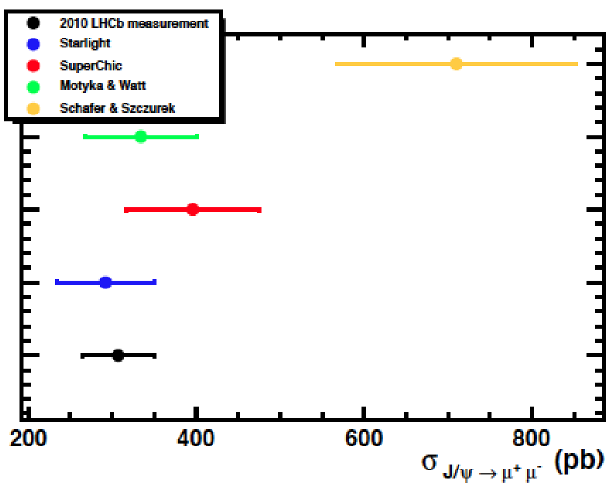
J/ψ and ψ(2S) Results

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

$$\sigma_{pp\to J/\psi(\to\mu^+\mu^-)}(2.0 < \eta_{\mu^\pm} < 4.5) = 307 \pm 21 \pm 36 \text{ pb},$$

$$\sigma_{pp\to\psi(2S)(\to\mu^+\mu^-)}(2.0 < \eta_{\mu^\pm} < 4.5) = 7.8 \pm 1.3 \pm 1.0 \text{ pb},$$

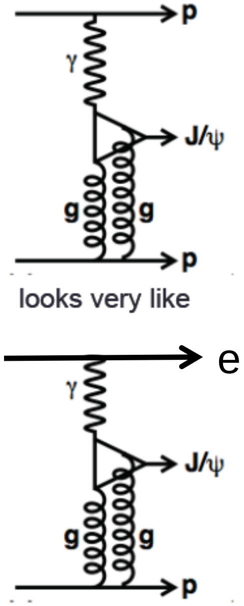
Measured cross sections are consistent with theoretical predictions
L. Motyka & G. Watt, W Shafer & A. Szczurek, SuperChic, Starlight



Ratio of ψ(2S) to J/ψ:	0.19 +/- 0.03
Starlight prediction:	0.16
Shafer & Szczurek:	0.2
HERA:	0.166 +/- 0.012
CDF:	0.14 +/- 0.05

* SuperChic prediction does not include survival factor

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

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

For each point there are two solutions for W, the photon-proton c.m. energy

→ use power law behaviour for photoproduction $\sigma(W) = aW^{\delta}$

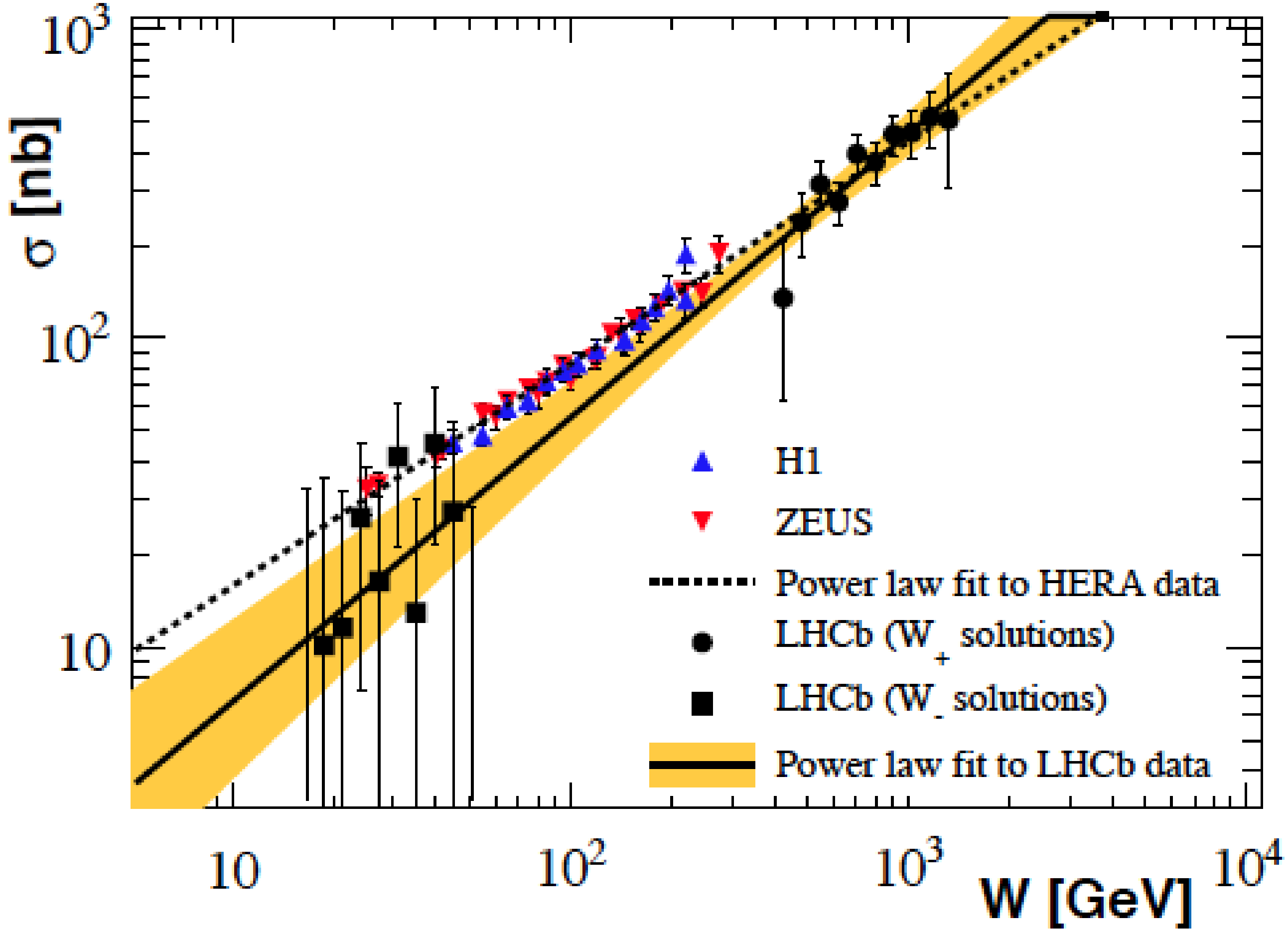
Fit to the differential data gives

$$a = 0.8^{+1.2}_{-0.5}\ \text{nb}$$

$$\delta = 0.92 \pm 0.15$$

→ Consistent with HERA data

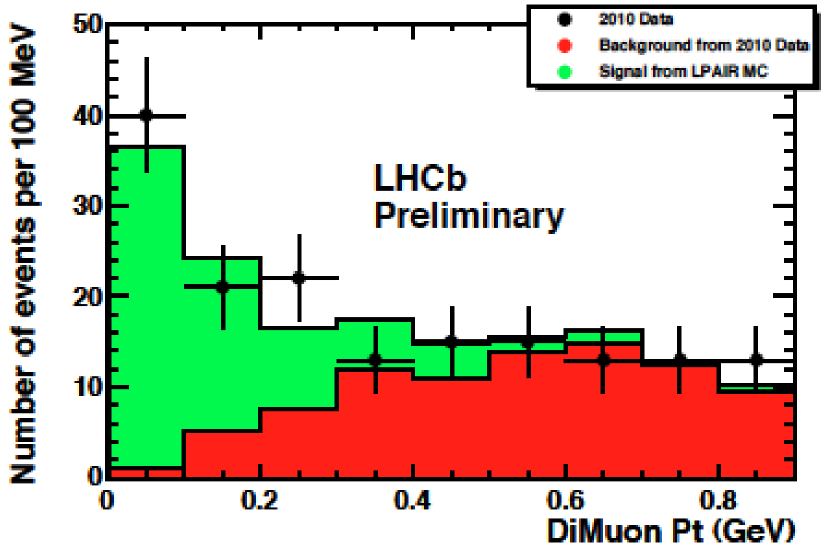
J/ψ photoproduction σ

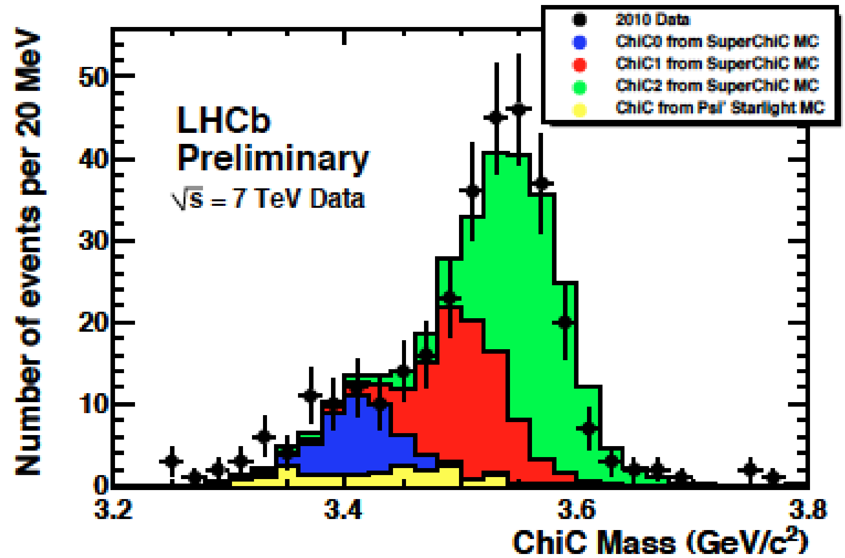


Exclusive diphoton dimuons and X_c

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

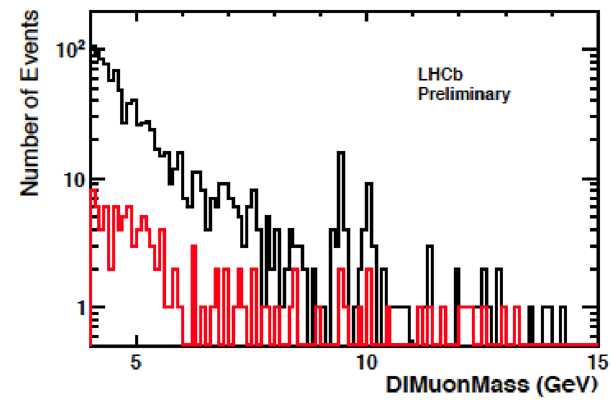
$\sigma_{\chi_{c2} \to \mu^+\mu^-\gamma}$ = 28.0 +/- 5.4 +/- 9.7 +/- 5.4 pb

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

CEP di-μ Future Prospects

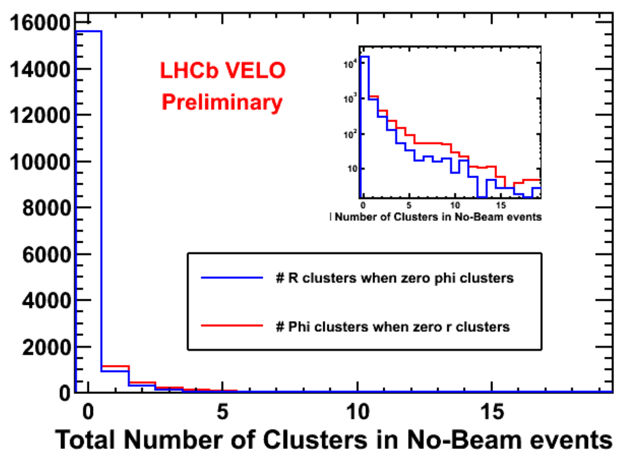
LHCb published results correspond to 2010 dataset
2011-2012 p-p dataset is ~ 80 times larger

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

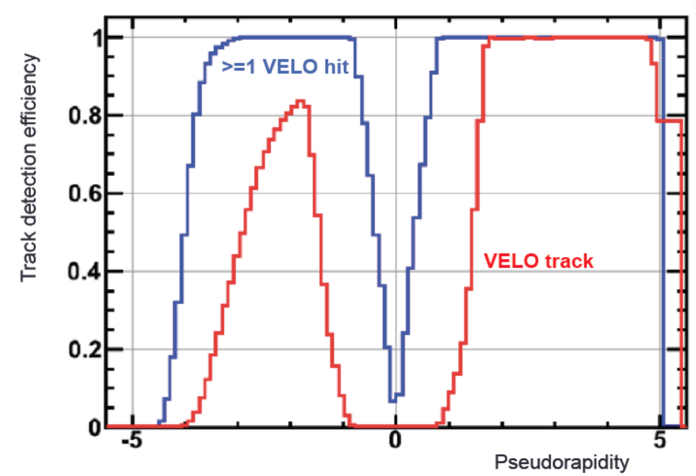


More accurate measurements of branching ratios and ratios of branching ratios, improved fits to signal and background (simulation of central exclusive J/ψ with additional gluon interactions would be welcome!)

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



Potential improvement in coverage



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:

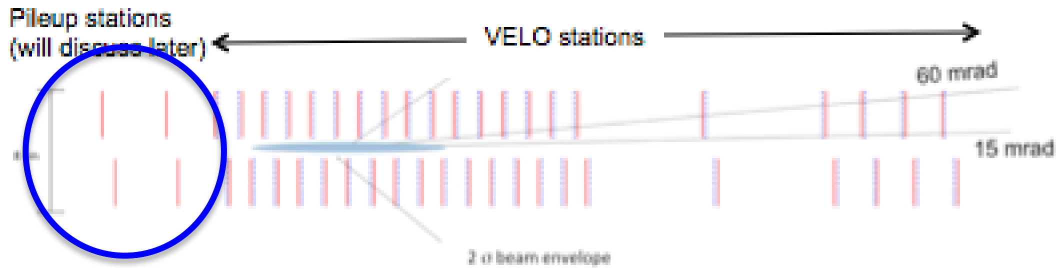
Use of "Pile-up" stations ("upstream" silicon sensors) at L0 stage to veto backwards activity

\+

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:

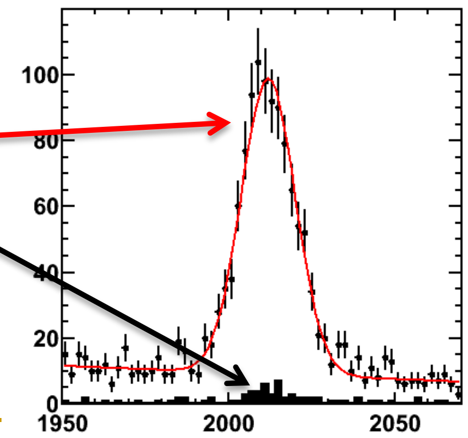
- Study charmonium states decaying into two and four-body final states (*e.g.* $\chi_{c0} \to K^+K^-, \pi^+\pi^-$) to complement di-muon studies
- Study production of open charm in such events
- Spectroscopy: e.g. search for higher mass charmonia states decaying to open charm, *e.g.* $\chi_{c2}(2P)$

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



CEP at LHCb: Future Prospects

LS1 – LS2 running

Expect greater CEP yield with move to 25 ns running (20%→40% useable luminosity)

Wider programme could be possible with installation of scintillator counters

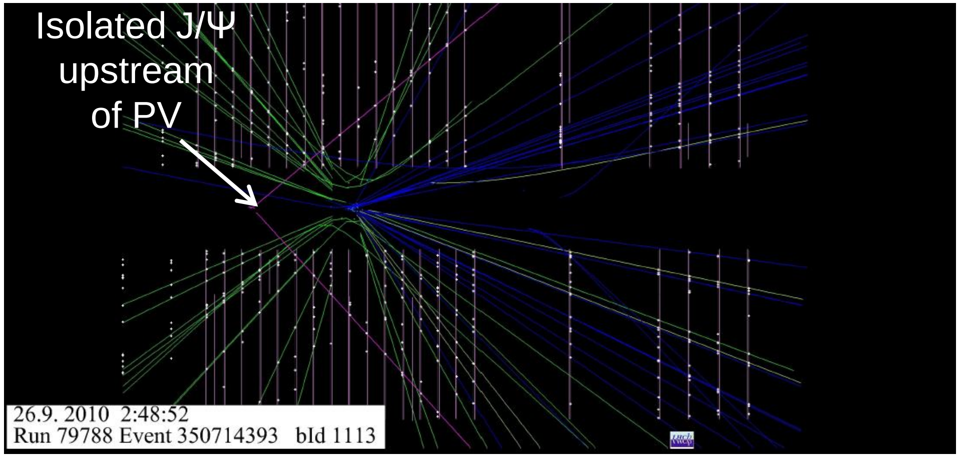
LHCb Upgrade

Increased stats will access low production x-sec (e.g. $\chi_{b,}$) and open up spectroscopy studies

At $2x10^{33}$ yield of CEP events in single interactions will drop, however flexible upgraded software trigger could select CEP vertices in pileup events

LHCb strengths of low p_T acceptance + PID remain powerful assets

Installation of proton taggers several 100 m up(down)stream from interaction point would widen programme and are well suited to LHCb upgrade trigger structure



Conclusions

- New published LHCb CEP di-μ results
- J/ψ, $\psi(2S)$ cross sections + comparison to HERA J/ψ photoproduction
- Updated numbers will have significantly improved statistics + access to new states
- LHCb trigger upgrade has allowed a significant amount of low multiplicity hadronic data to be collected – analyses underway
- CEP studies should prosper at future LHCb, both after the shutdown and at the upgrade. Stay tuned!

Backup

Table 2: Relative systematic uncertainties on the measurement.

Source	Uncertainty (%)
Luminosity	3.5
Trigger efficiency	4
Tracking efficiency	2
Identification efficiency	5
Selection efficiency	1
Single interaction efficiency	0.7
$\psi(2S)$ background (J/ψ analysis)	0.3
χ_c background (J/ψ analysis)	0.8
Signal shape of dimuon $p_{\rm T}$ fit	6
Background shape of dimuon $p_{\rm T}$fit	6