Resultados e previsões de processos de produção exclusiva para o experimento LHCb

Anderson Kohara, Daniel Ernani, Eduardo Basso,
Murilo Rangel e Victor Goncalves

Begin

LHCb has published measurements of exclusive processes that are useful to test phenomenological models containing very interesting aspects of QCD and EW.

Brazil theorists have published predictions for these measurements, and there is a good interaction between them and the LHCb experiment.

In this talk, one LHCb measurement and a collection of predictions will be presented

This talk aims to list some results to demonstrate the interaction between theorists and experimentalists.

There are many other interesting publications demonstrating that LHCb experimentalists and theorists in Brazil have a good interaction.

Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5\,\mathrm{TeV}$

- $J/\psi \to \mu^+\mu^-$ events with no additional activity from the same vertex
- muon selection
  - $p_{\mathrm{T}\,\mu} > 500$ MeV
  - $2.0 < \eta_\mu < 4.5$
- J/ψ selection
  - $p_{\mathrm{T}\,J/\psi} < 1$ GeV

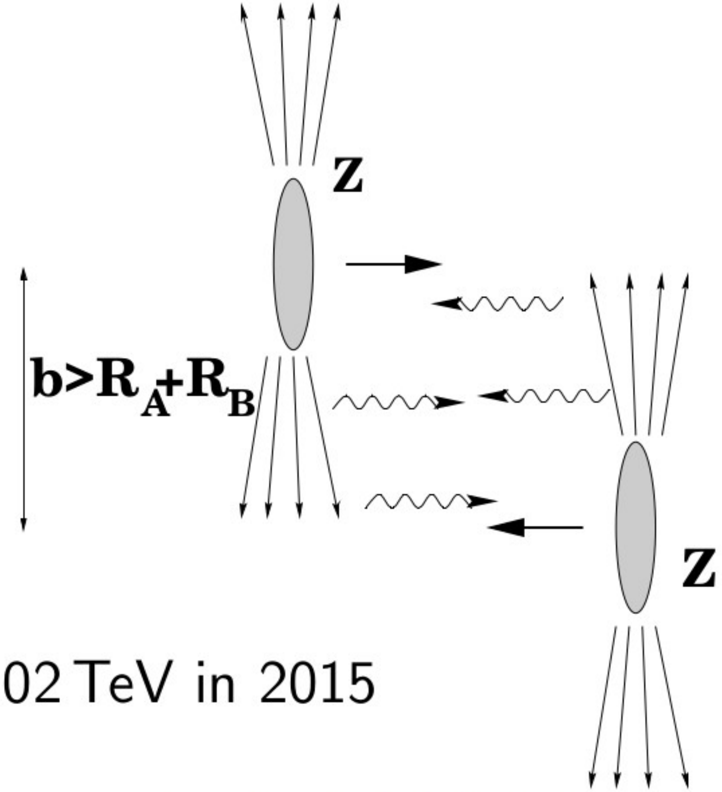
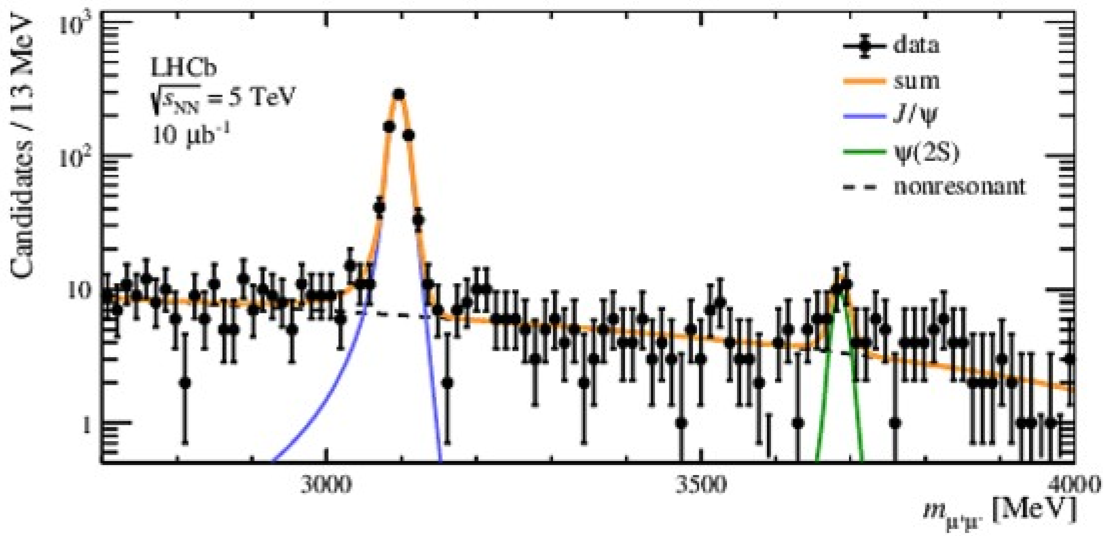


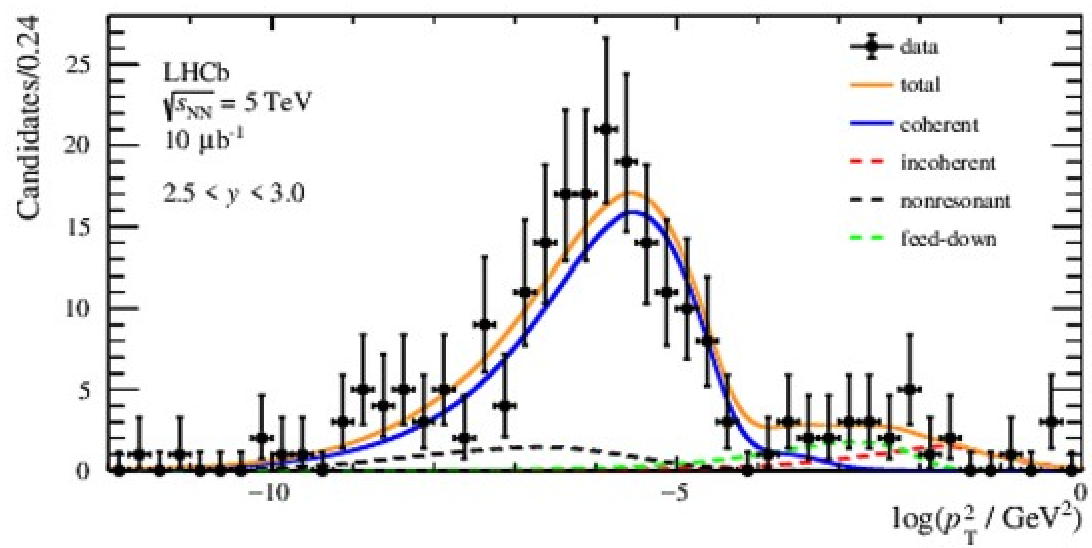
diagram from Phys.Rept. 458 (2008) 1-171

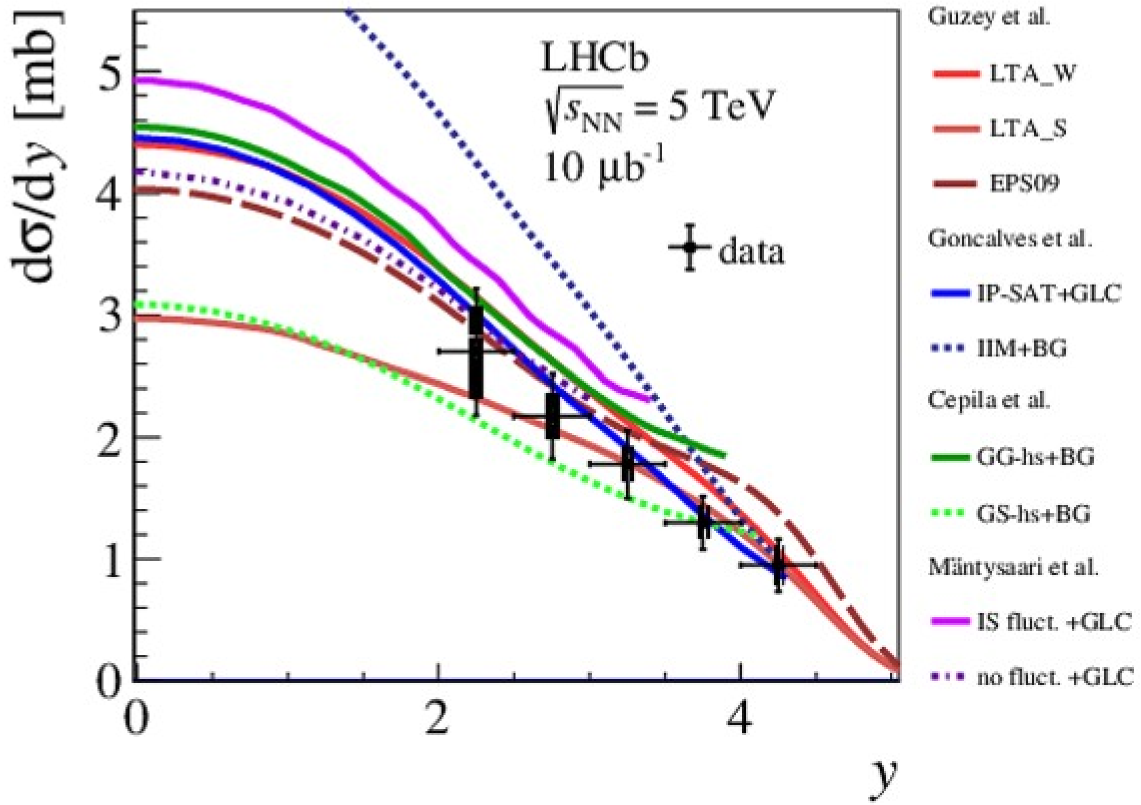
Using data taken in lead-lead collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$ in 2015

Signal extraction



Using mass fit and p_T^2 to calculate signal yields





Discussion with Brazilian groups in order to compare curves and improve comparisons with 2018 data which is currently in collaboration review.

Searching for axionlike particles with low masses in pPb and $PbPb$ collisions

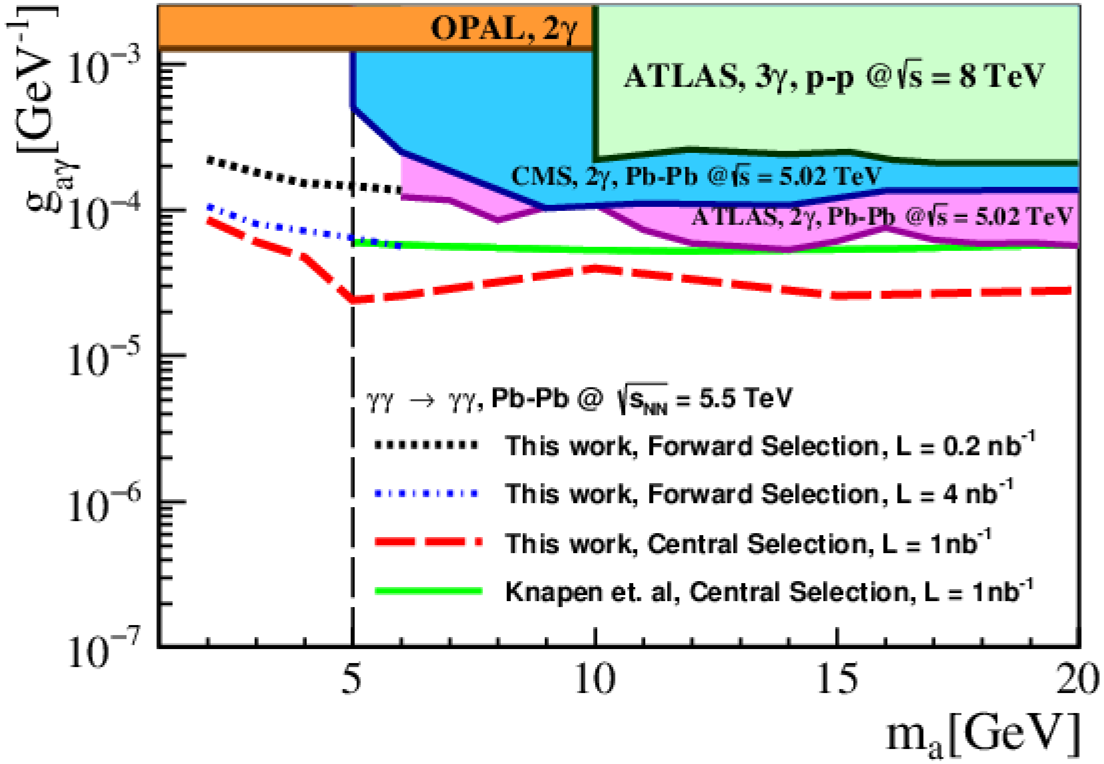
V. P. Gonçalves,[1,*] D. E. Martins,[2,†] and M. S. Rangel[3,‡]

Production of axionlike particles in PbPb collisions at the LHC, HE–LHC and FCC: A phenomenological analysis, R.O. Coelho, V.P. Goncalves, D.E. Martins, M.S. Rangel, e-Print: 2002.06027 [hep-ph], Published in: Phys.Lett.B 806 (2020), 135512

Searching for axionlike particles with low masses in pPb and PbPb collisions, V.P. Goncalves, D.E. Martins, M.S. Rangel, e-Print: 2103.01862 [hep-ph]

Using LHCb experimental constraints, the limits for ALPs are calculated.

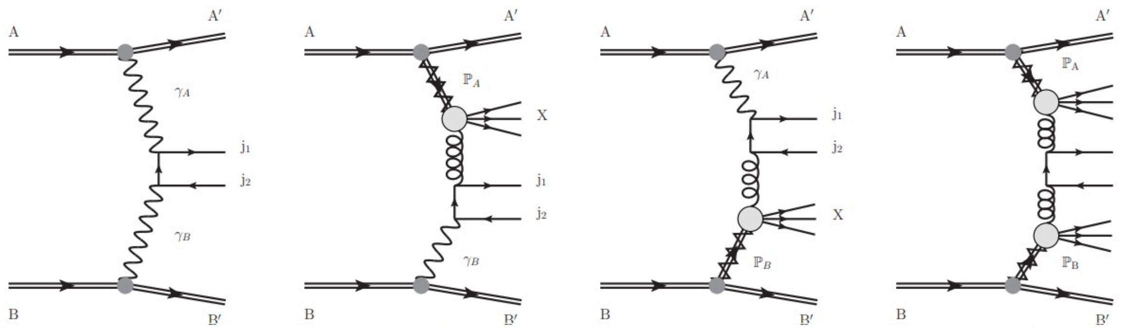
Data analysis is on-going.



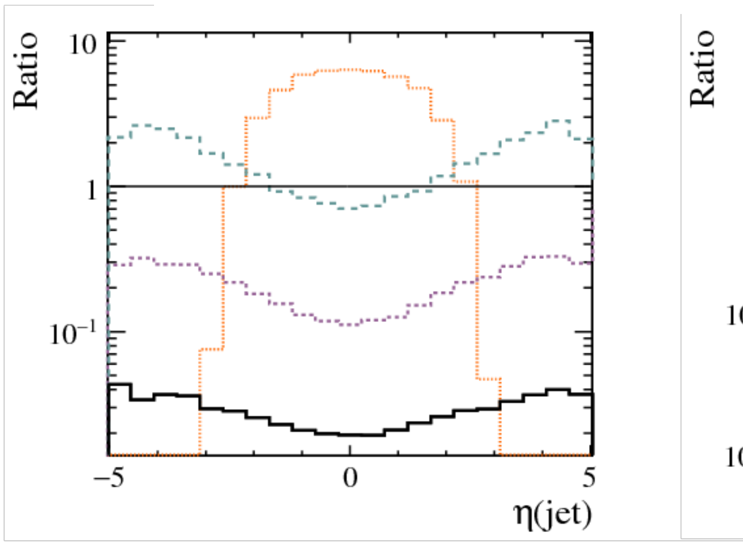
Photon and Pomeron – induced production of Dijets in pp, pA and AA collisions

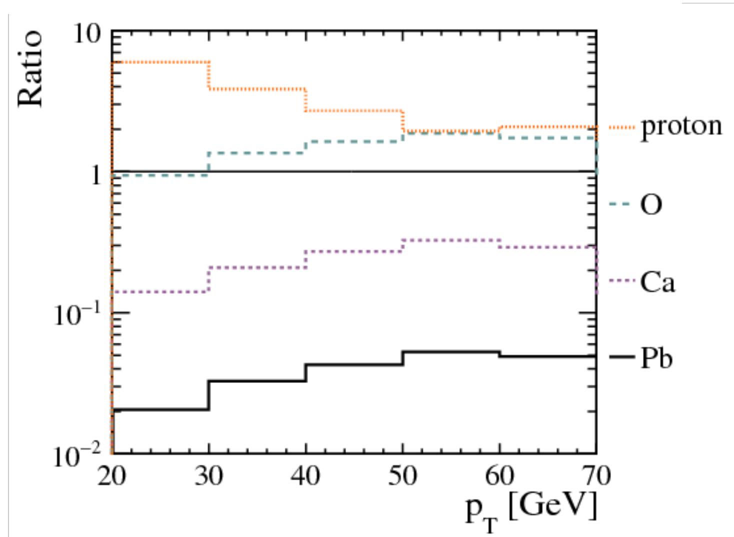
E. Basso[1], V. P. Goncalves[2], A. K. Kohara[3,4] and M. S. Rangel[3]

Published in: Eur.Phys.J.C 77 (2017) 9, 600



(a) (b) (c) (d)





+ Calculation using a nuclear pomeron model considering absorption effects.

+ Ratio between pomeron-pomeron and gamma-pomeron change drastically for each nuclear species in AA collisions.

+ Data analyses depends on person-power.

Exclusive dilepton production at forward rapidities in $PbPb$ collisions

V. P. Goncalves[1], D. E. Martins[2], M. S. Rangel[2]

Published in: Eur.Phys.J.C 81 (2021) 3, 220

PbPb @ 5.5 TeV	$\sigma(\tau^+\tau^-)$ [pb]									
Process	Diffractive					Exclusive				
Decay	$e^\pm\mu^\mp$	$\mu^+\pi^-$	$\mu^-\pi^+$	$e^+\pi^-$	$e^-\pi^+$	$e^\pm\mu^\mp$	$\mu^+\pi^-$	$\mu^-\pi^+$	$e^+\pi^-$	$e^-\pi^+$
Generation	2958.0					6.7×10^8				
Channel	152.1	11.1	7.8	11.8	8.6	3.6×10^7	5.2×10^7	5.2×10^7	5.3×10^7	5.2×10^7
$p_T(l, chg) > 1.0$ GeV	18.7	0.07	0.07	0.03	0.02	5.4×10^6	6.2×10^6	6.2×10^6	6.3×10^6	6.6×10^6
$2.0 \leq \eta_{chg,l} \leq 4.5$	2.4	0.0	0.0	0.0	0.0	2.5×10^5	2.5×10^5	2.6×10^5	2.7×10^5	2.5×10^5
$p_T(l + chg) > 2.0$ GeV	0.9	0.0	0.0	0.0	0.0	8530.0	11272.0	10358.0	8225.0	12795.0
HERSCHEL	0.7	0.0	0.0	0.0	0.0	8530.0	11272.0	10358.0	8225.0	12795.0
Sum	1.4	0.0				17060.0	42650.0			

TABLE III: Predictions for the ditau production at forward rapidities in $PbPb$ collisions at $\sqrt{s} = 5.5$ TeV in exclusive and diffractive interactions considering the different decay channels.

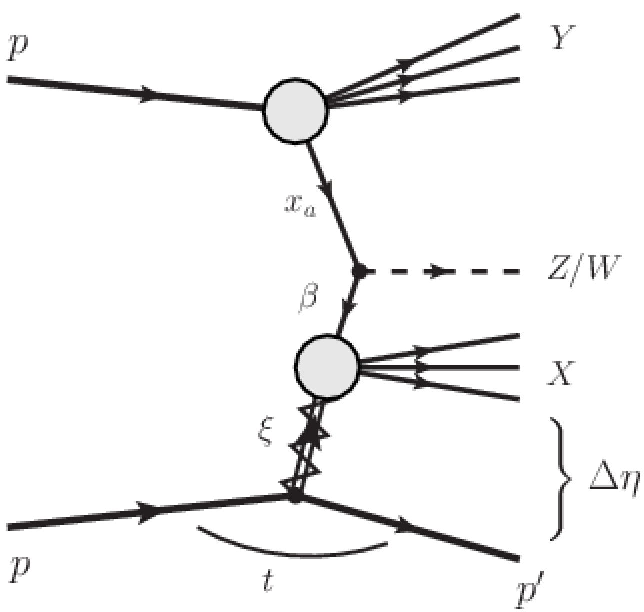
Demonstration that the background associated to the diffractive production can be strongly suppressed. Tau production in semi and purely leptonic decay channels can be studied which can be useful to search for BSM physics.

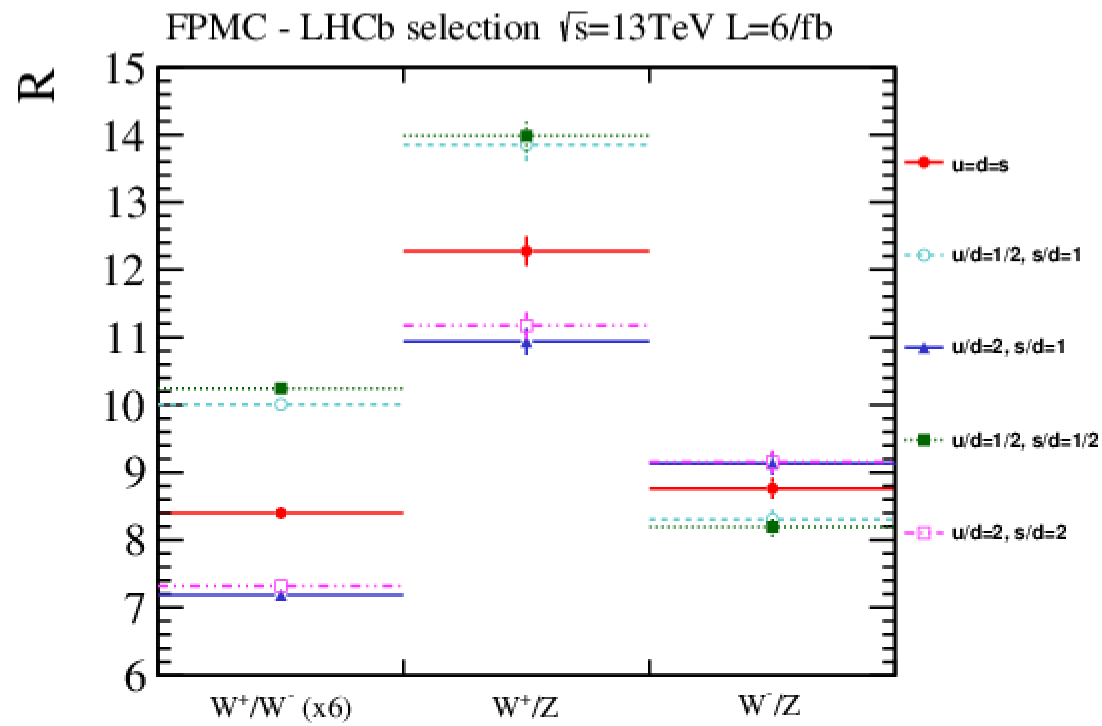
Data analyses depends on person-power.

Diffractive gauge boson production at the LHC as a probe of the flavour content of the Pomeron

E. A. F. Basso[1], V. P. Goncalves[2], D. E. Martins[3], M. S. Rangel[3]

Published in: Phys.Rev.D 99 (2019) 3, 034017





Magnitude of the distributions are shown to be sensitive to the assumptions about the content of u, d and s quarks in the Pomeron. Proposed the analysis of the ratio between cross sections will reduce the impact of the absorptive corrections in our predictions.

Data analyses depends on person-power.

Summary

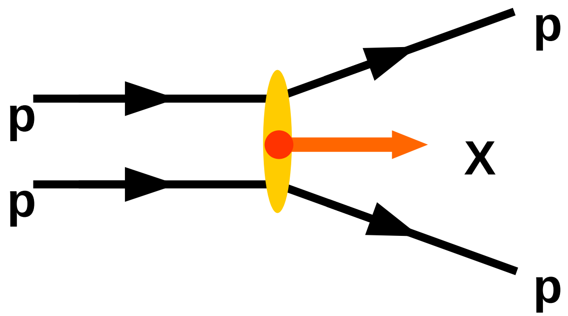
→ In Brazil, experimentalists and theorists are collaborating in different topics, including exclusive production in the LHCb experiment

→ This interaction is very important for the experiment and there is space for improvements. Few ideas below:

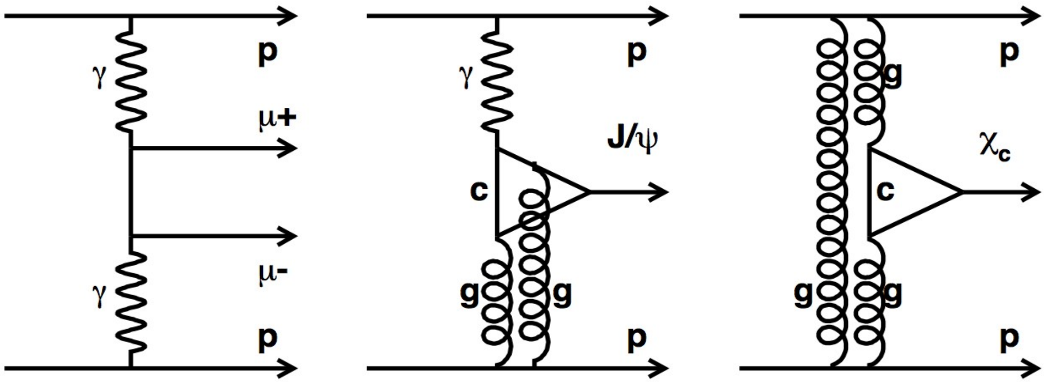
- == workshops
- == schools
- == short-period visits

THANK YOU!!!!!

Central Exclusive Production (CEP)



, e.g.,

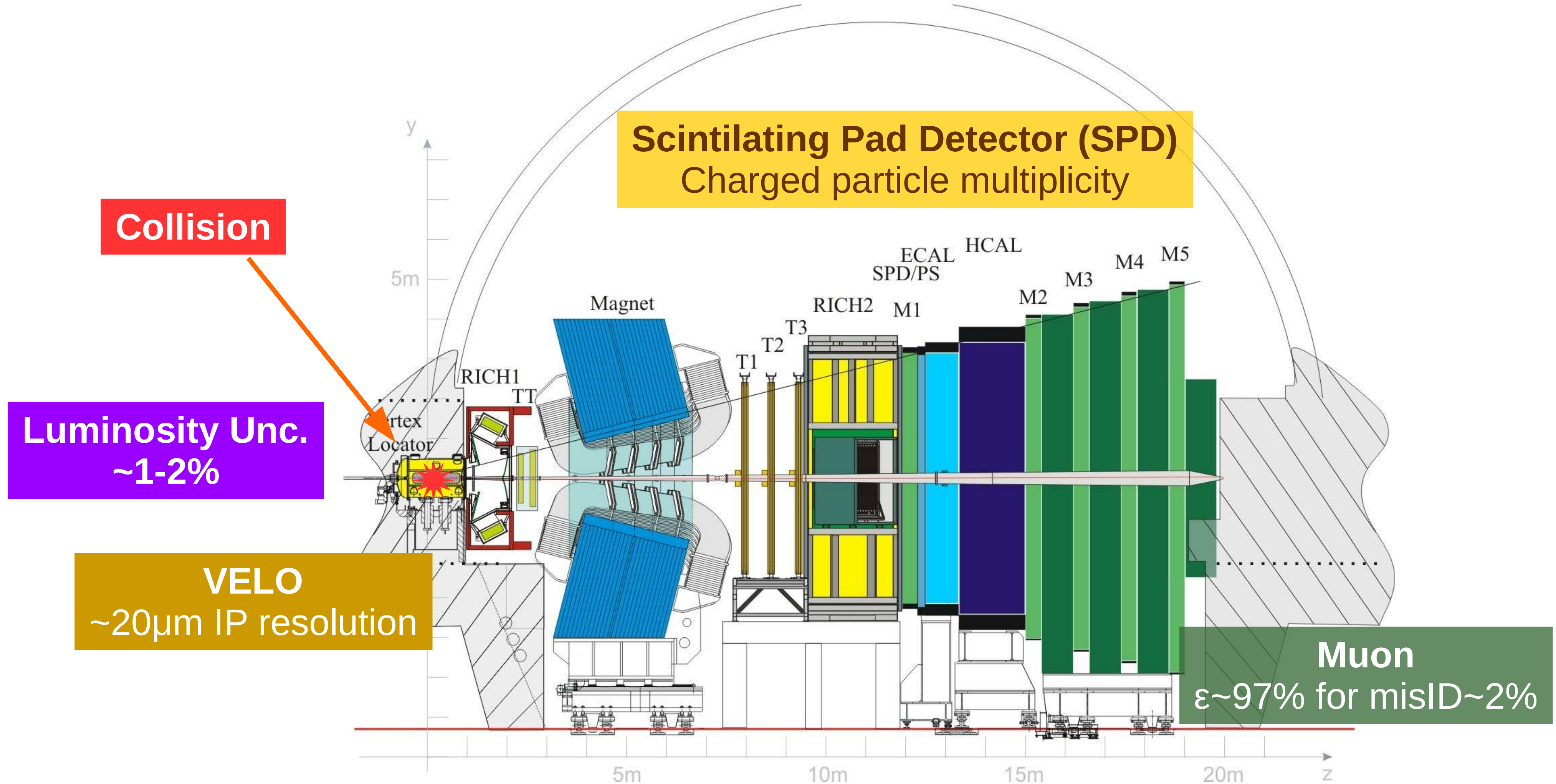


Motivation

- colorless object production (X) in a very clean environment: theory vs data
- understanding of soft → hard QCD scale
- input to phenomenological models: saturation, pomeron/oderon interaction, …
- sensitive to low-x gluon density in the proton down to 5×10^{-6}

LHCb Detector

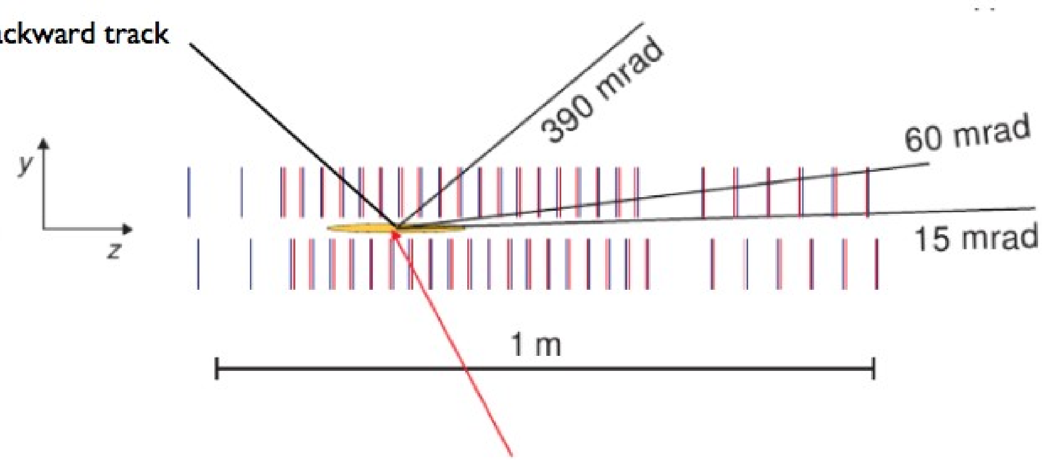
LHCb is a single arm spectrometer fully instrumented in the forward region (2.0<η<5.0)
Designed for heavy flavour physics ↔ Explored for general purpose physics



Tracking (magnet)
0.4%-0.6% momentum resolution (0.2-100 GeV)

LHCb detector

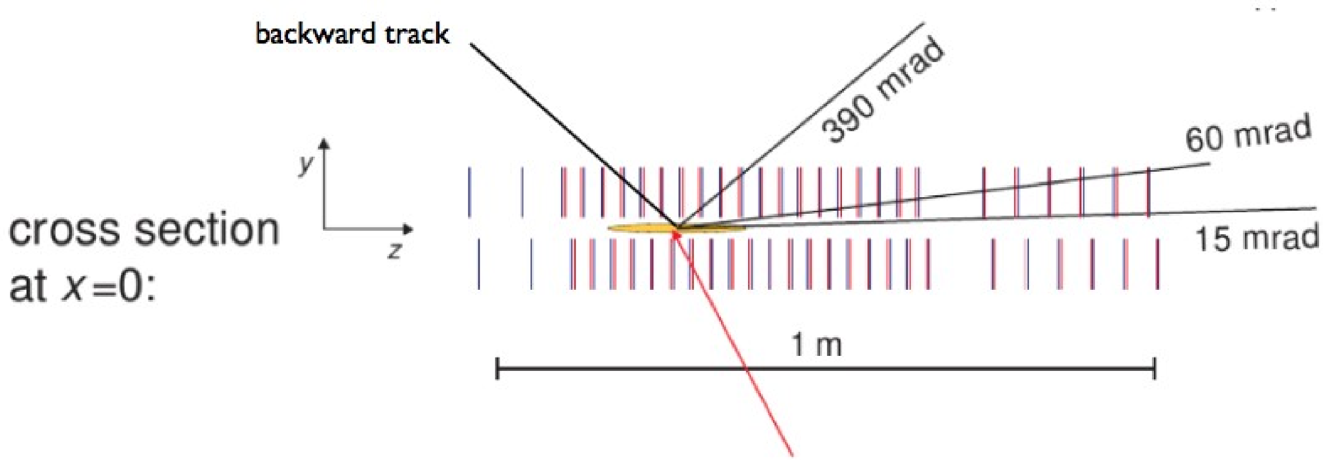
cross section at $x = 0$:



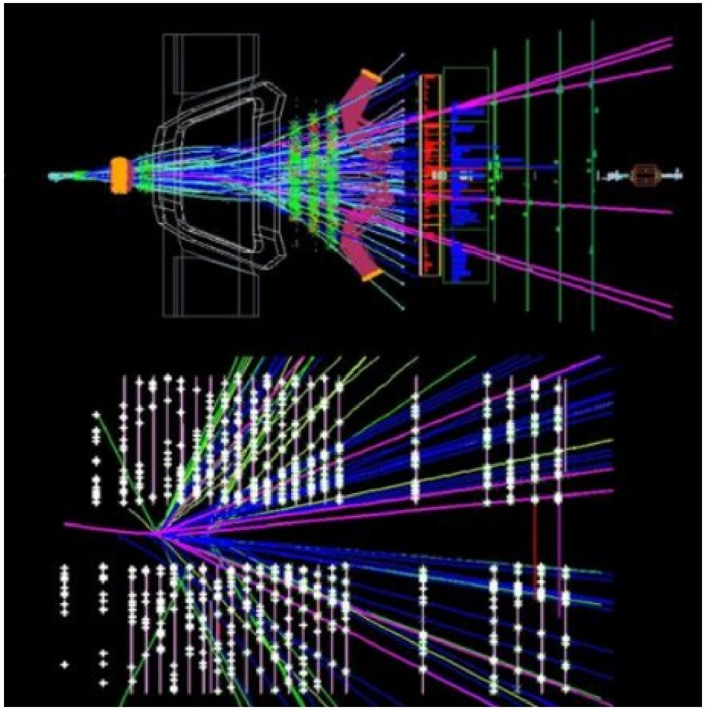
VELO

→ surrounds the interaction point
→ no magnetic field
→ allows backward tracks $(-3.5 < \eta < -1.5)$

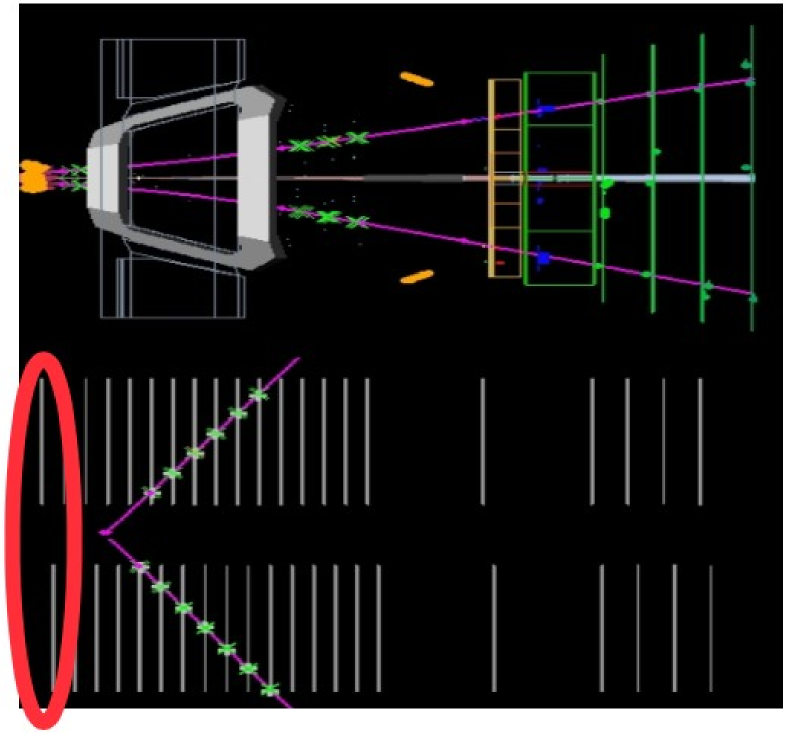
LHCb detector



Typical Event

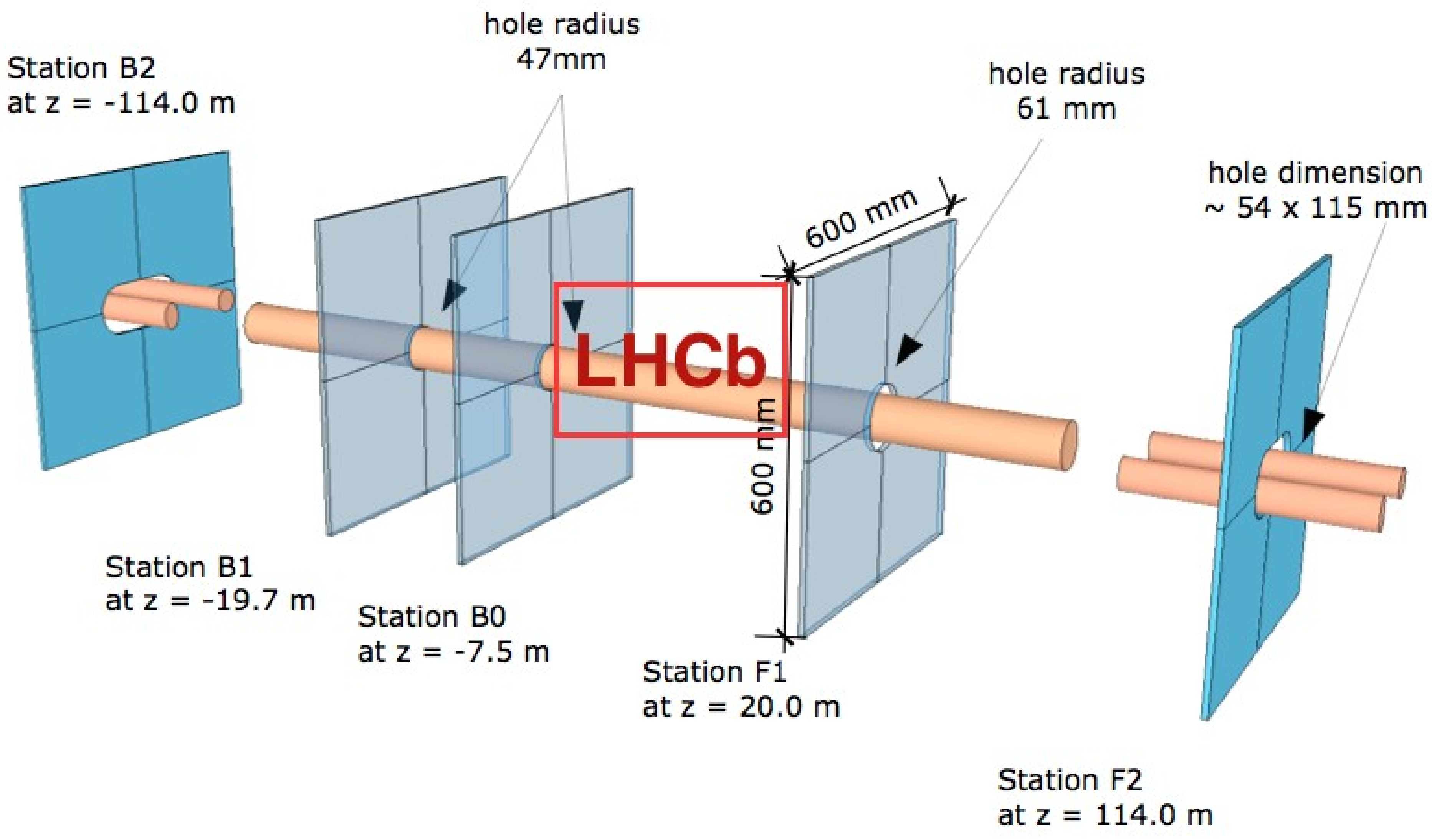


CEP-like event: 2muons

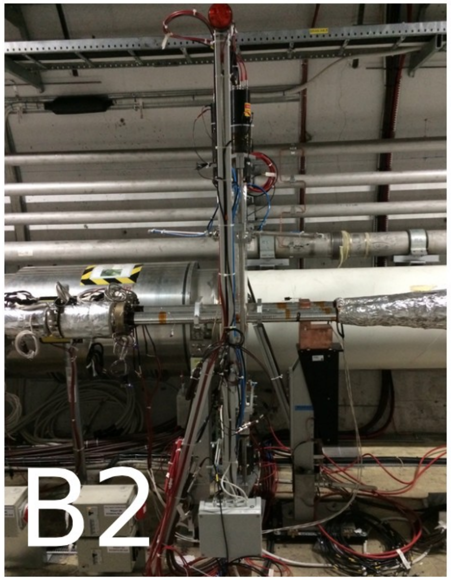


High **R**apidity **S**hower **C**ounters for **L**HCb – HERSCHEL

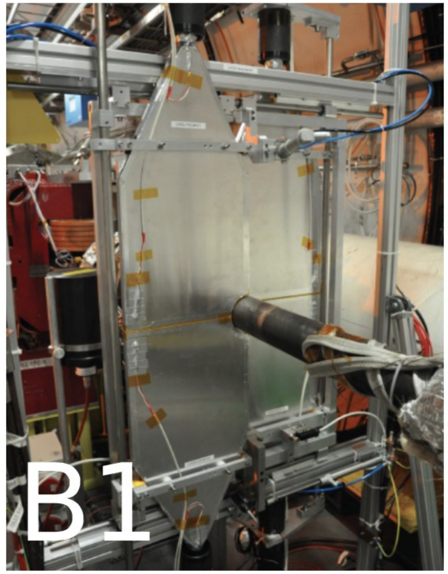
- installed at the end of 2014 → increase pseudorapidity coverage
- 5 stations with 4 scintillators with PMT
- able to detect forward particle showers and veto events wth these



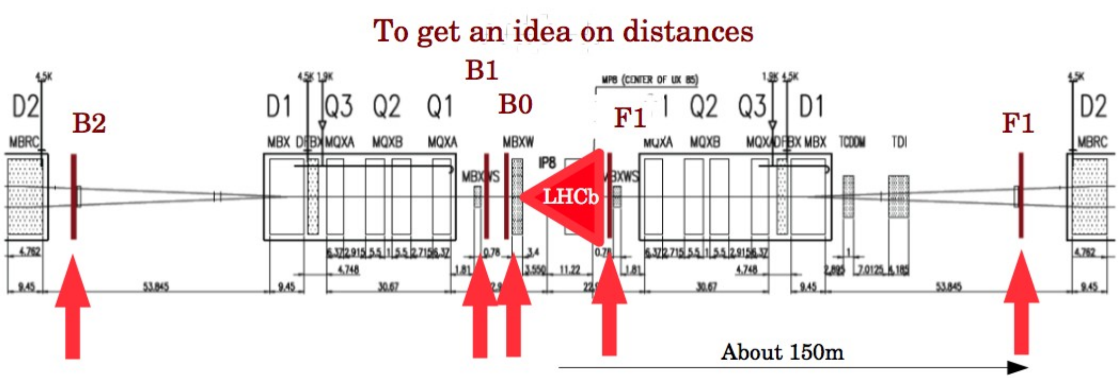
-114m



-19.7m



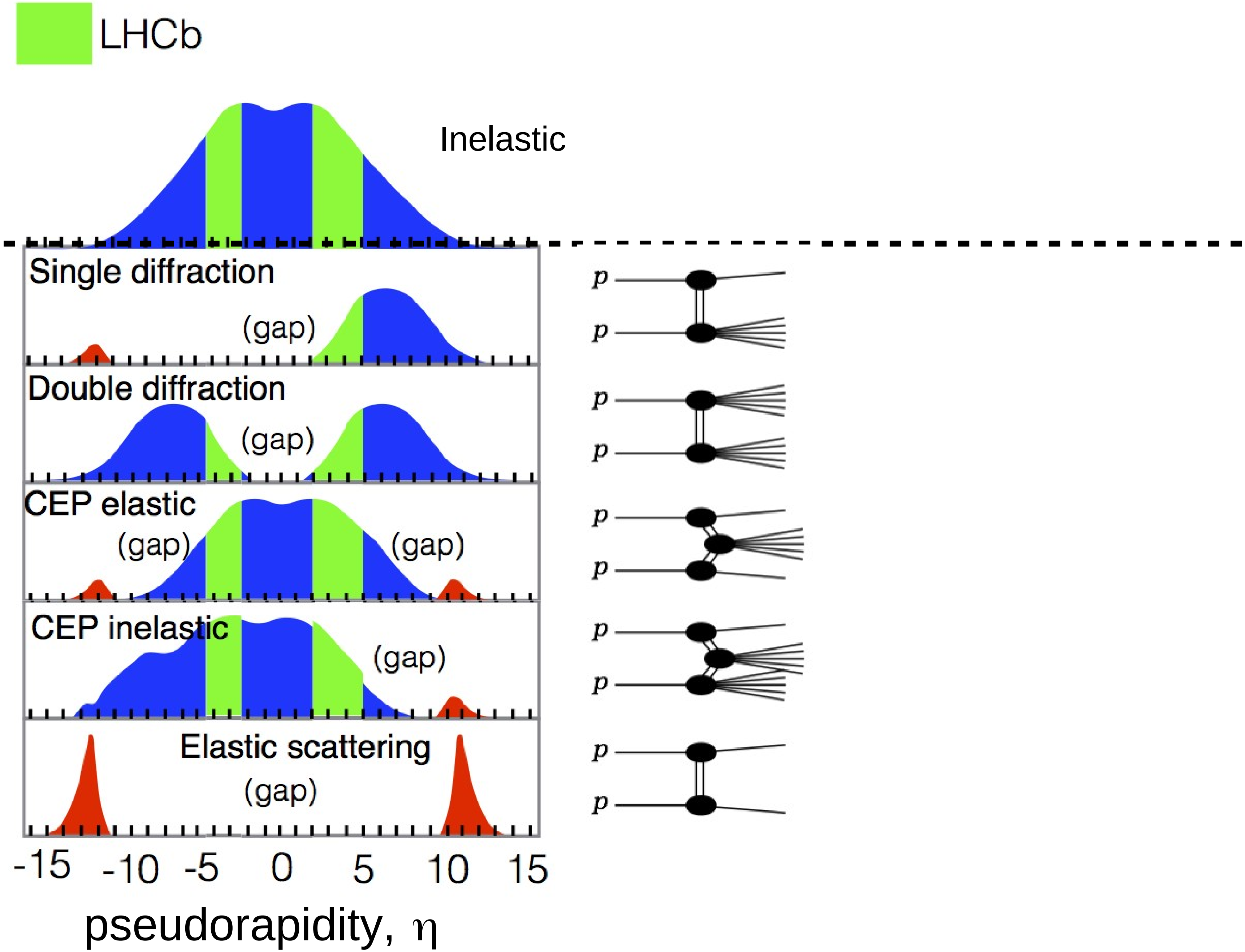
-7.5m



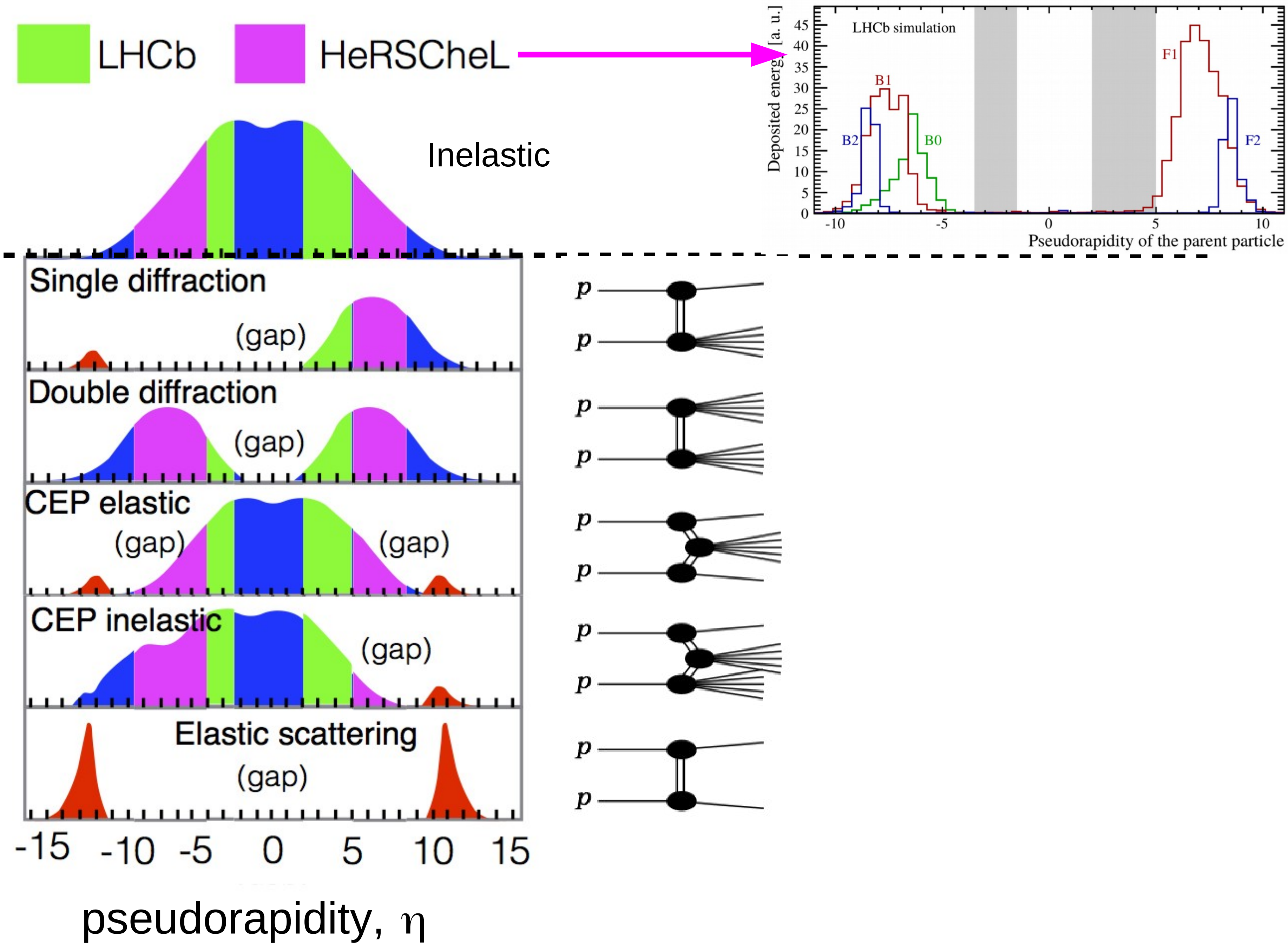
20m

114m

Collision signatures at LHCb

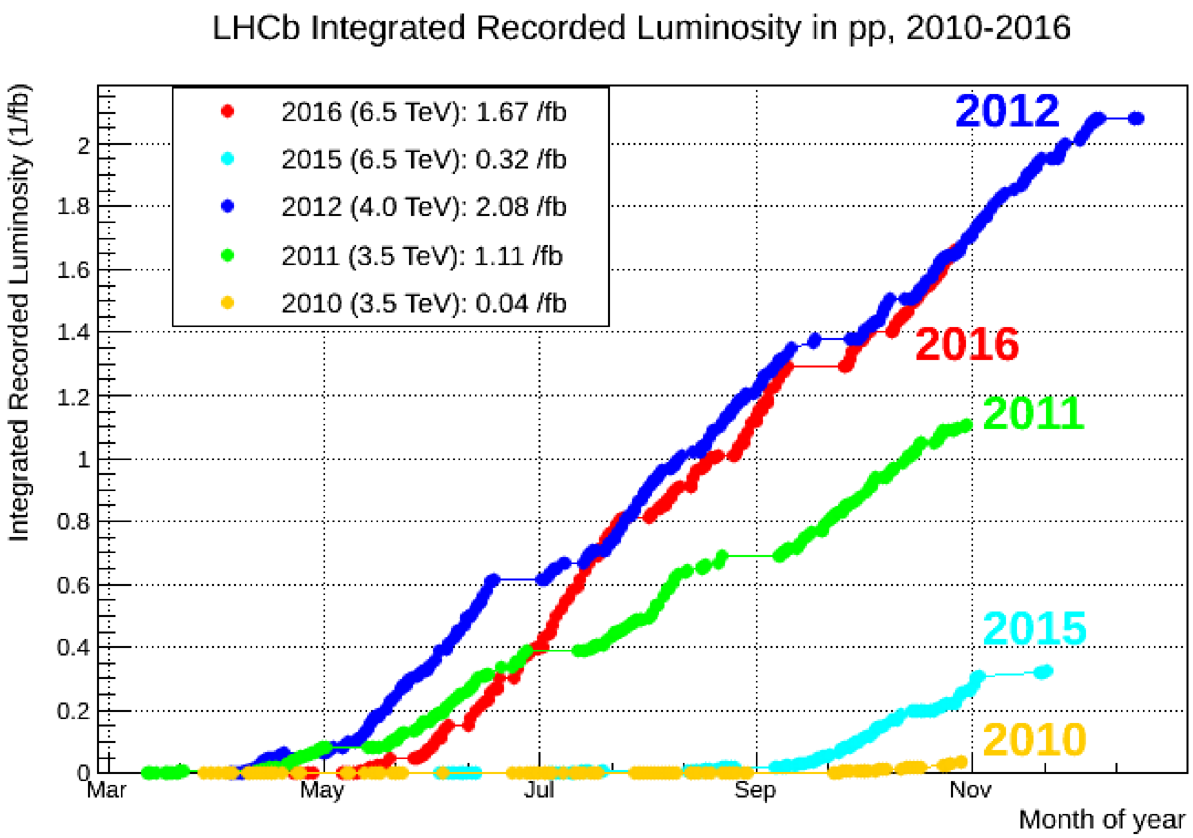


Collision signatures at LHCb



LHCb datasets

Data used in the results presented in these slides:
2010 → L=36/pb at 7 TeV
2011 → L=1/fb at 7 TeV
2012 → L=2/fb at 8 TeV
2015 → L=204/pb at 13 TeV



Pile-up conditions
$P(N) = e^{\mu}\mu^{N}/N!$
μ = average number of visible interactions

2010 → μ~1.6, P(1)~21%
2011 → μ~1.4, P(1)~25%
2012 → μ~1.7, P(1)~19%
2015 → μ~1.1, P(1)~35%

General Strategy

– LHCb has no proton tag detectors
 → use regions void of particle production (gaps)

– Trigger on low multiplicity events
 → using SPD and/or tracks (future results will use Herschel at Run-II)

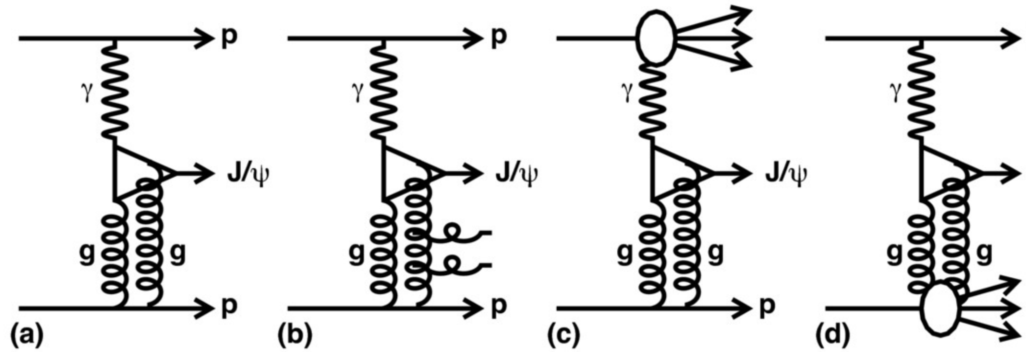
– Select candidate and no other activity in the detector
 → Detector acceptance: $2.0 < \eta(\text{track}) < 4.5$
 → Require no backward tracks: $-1.5 < \eta < -3.5$ (+Herschel at Run-II)

– Backgrounds:
→ feed-down: if X object is a resonance, it could be a decay product of Y
 Ex: In J/ψ CEP: $\chi_c^0 \rightarrow J/\psi + \gamma$
→ inelastic (proton dissociation): p_T^2 distribution is used to fit CEP and non-CEP
→ other diffractive production: estimated with event generators

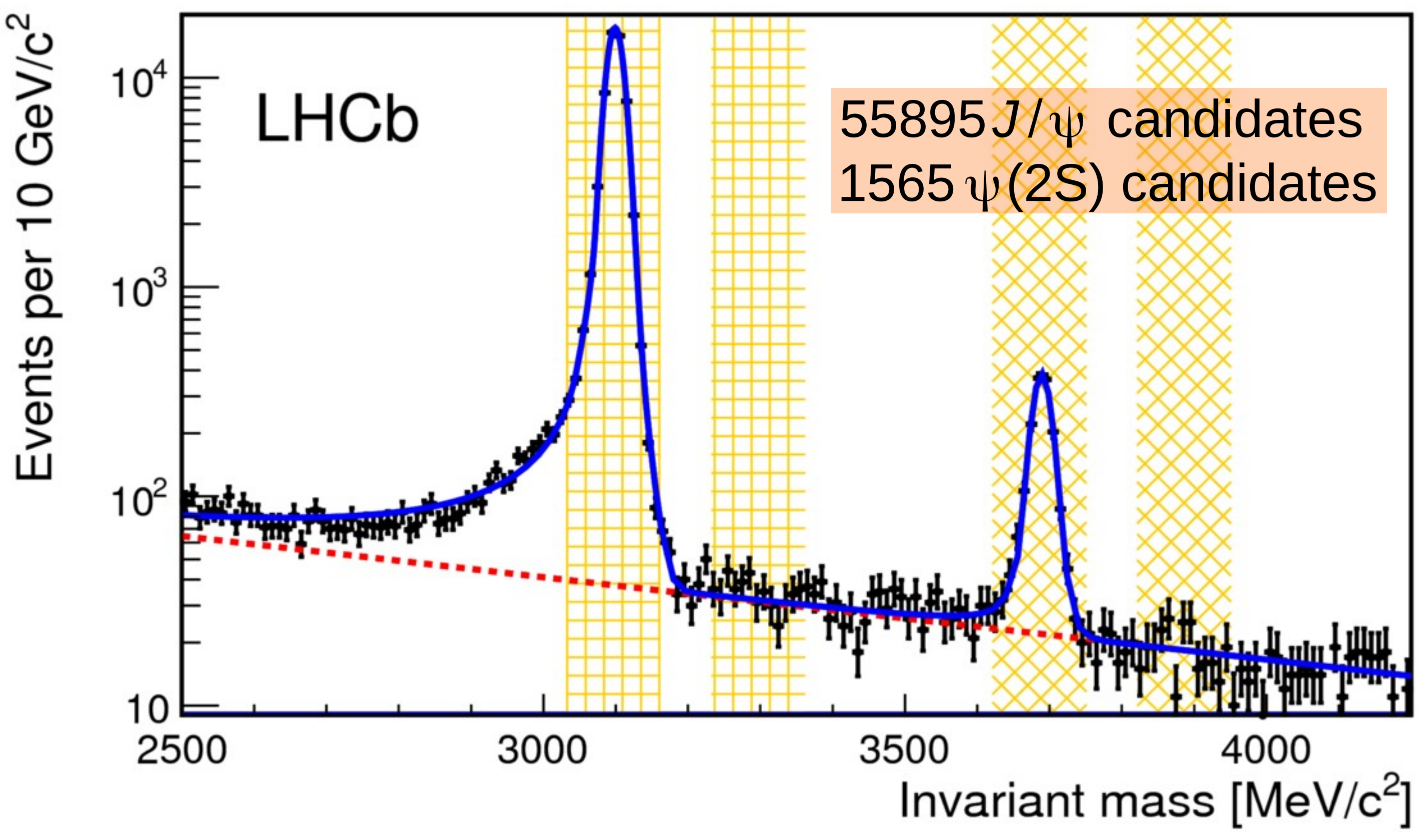
J/ψ and $\psi(2S)$ - 7 TeV

J.Phys.G40 (2014) 055002

2011 dataset with L=1/fb



Signal fit – Crystal-Ball function (ad-hoc asymmetric function)
Background fit - expoential



J.Phys.G40 (2014) 055002

Template fit to data

→ Inelastic background: exponential (HERA extrapolation b_{in}~1 GeV^{-2})

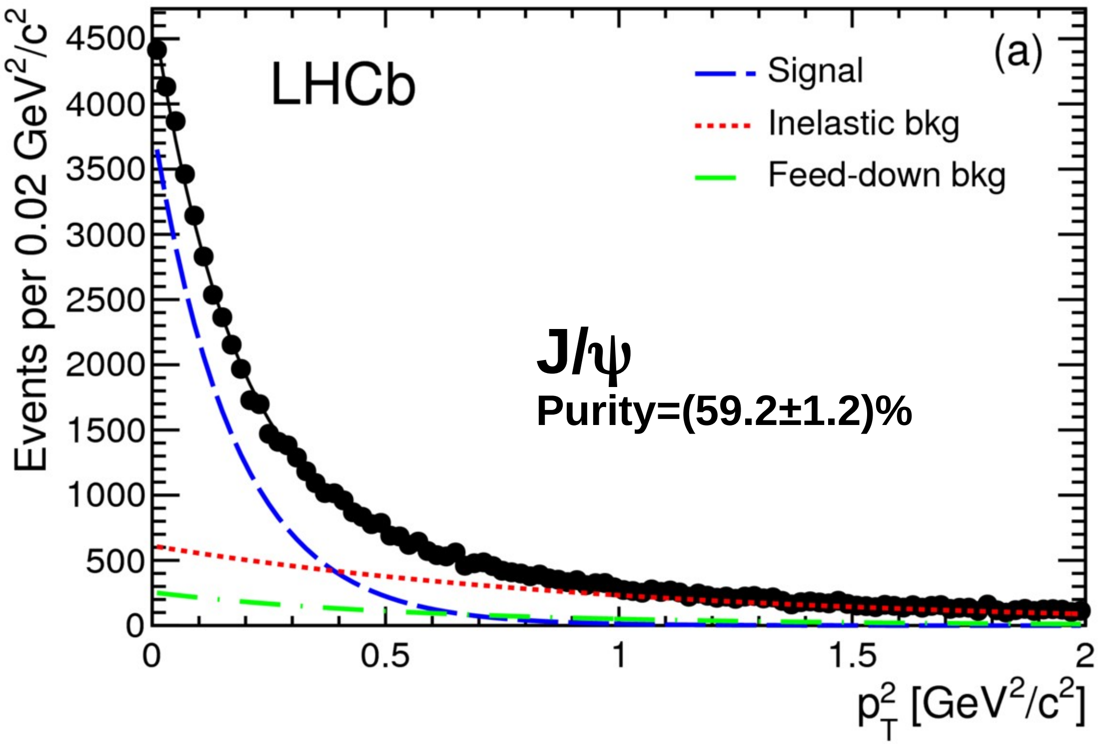
→ Feed-down background: data driven from reconstructed decays

→ Signal: exponential (HERA b_{el}~ 6 GeV^{-2})

→ J/ψ feed-down: $(\chi_{c0}, \chi_{c1}, \chi_{c2})$, ψ(2S)

→ ψ(2S) feed-down: $X(3872)$, χ_c(2P)

$$f_{\rm el}\, e^{-b_{\rm el} p_{\rm T}^2} + f_{\rm in}\, e^{-b_{\rm in} p_{\rm T}^2} + f_{\rm fd}\, \mathcal{P}_{\rm fd}(p_{\rm T}^2)$$



background fractions

feed-down 10.1 %

inelastic 49.1 %

$$b_{\rm el} = 5.70 \pm 0.11\ {\rm GeV}^{-2}$$

$$b_{\rm in} = 0.97 \pm 0.04\ {\rm GeV}^{-2}$$

Template fit to data

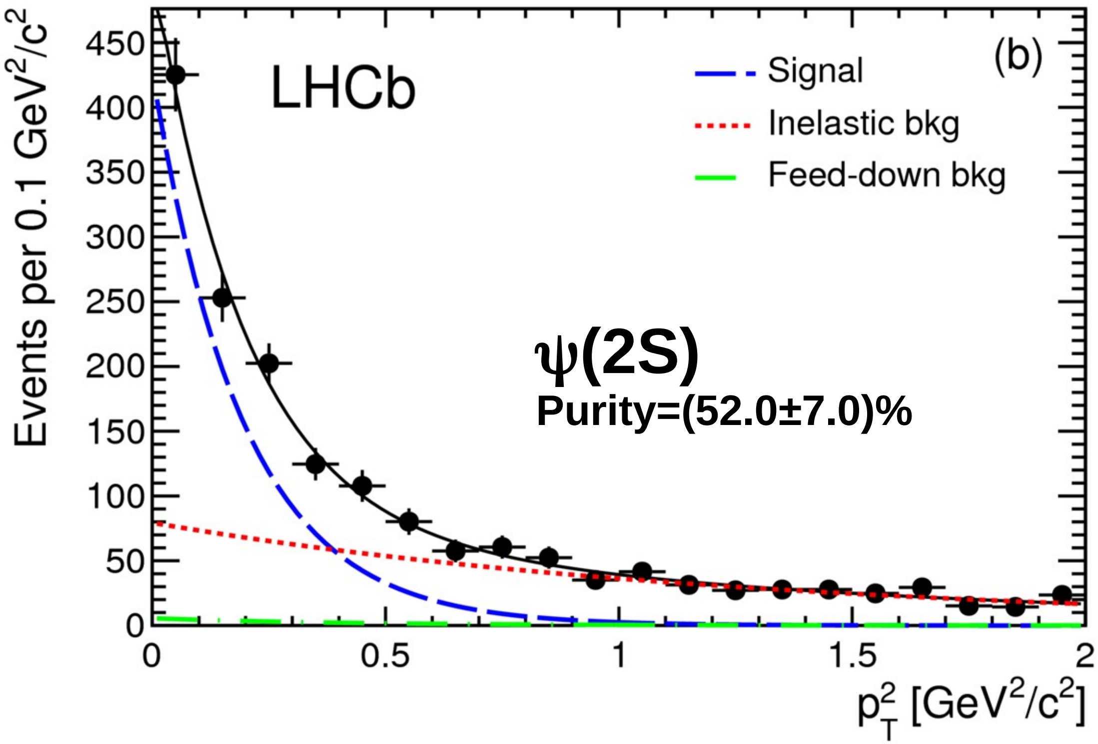
→ Inelastic background: exponential (HERA b_{in}~ 1 GeV^{-2})

→ Feed-down background: data driven from reconstructed decays

→ Signal: exponential (HERA b_{el}~ 6 GeV^{-2})

→ J/ψ feed-down: $(\chi_{c0}, \chi_{c1}, \chi_{c2})$, ψ(2S)

→ ψ(2S) feed-down: $X(3872)$, χ_c(2P)



background fractions

feed-down 2.0 %

inelastic 36.0 %

$$b_{\rm el} = 5.1 \pm 0.7\ {\rm GeV}^{-2}$$

$$b_{\rm in} = 0.8 \pm 0.2\ {\rm GeV}^{-2}$$

Cross-section measurement

$$\left(\frac{d\sigma}{dy}\right)_i = \frac{\rho N_i}{A_i \epsilon_i \Delta y (\epsilon_{single} L)}$$

For each bin i, we have

→ N_i is the number of candidates

→ ρ is the purity

→ A_i is the acceptance

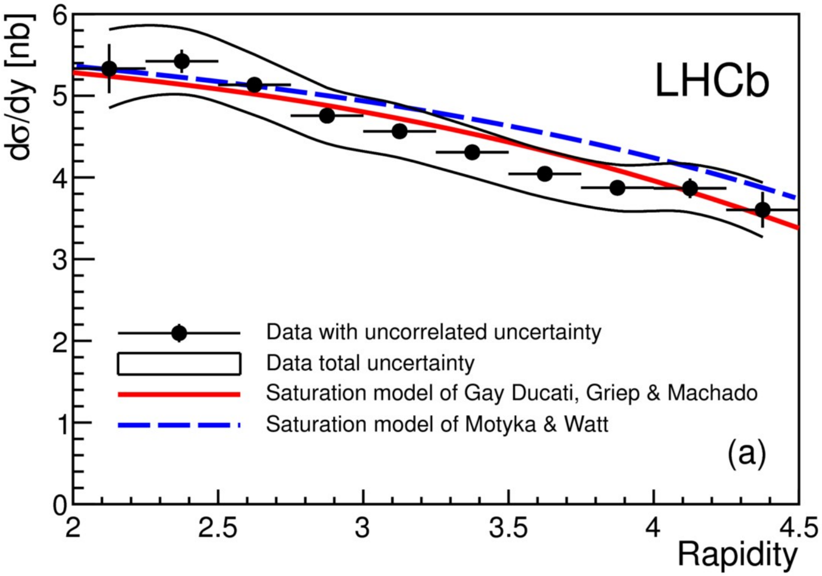
→ Δy is the bin width

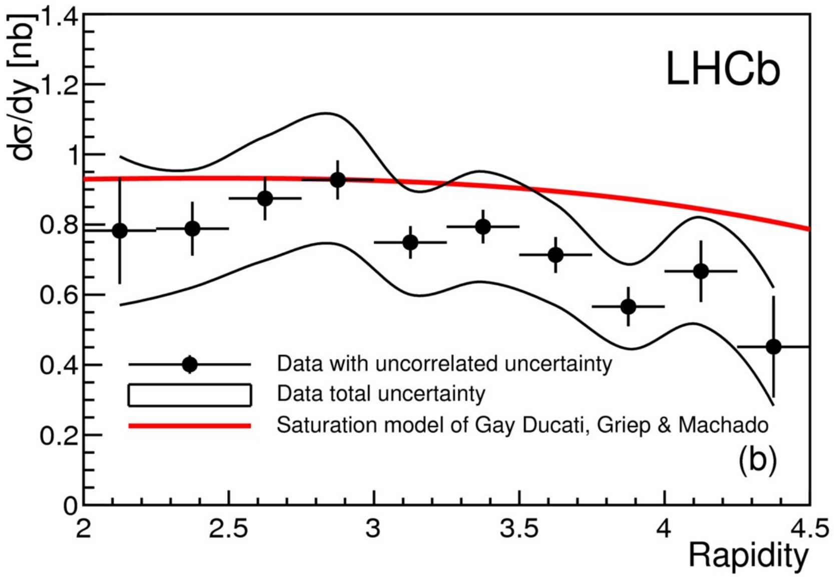
→ L is the integrate luminosity

→ ϵ_i is the efficiency for selecting single interaction events

Correlated uncertainties expressed as a percentage of the final result	
$\epsilon_{\rm sel}$	1.4%
Purity determination (J/ψ)	2.0%
Purity determination ($\psi(2S)$)	13.0%
$^*\epsilon_{\rm single}$	1.0%
*Acceptance	2.0%
*Shape of the inelastic background	5.0%
*Luminosity	3.5%
[illegible]	[illegible]

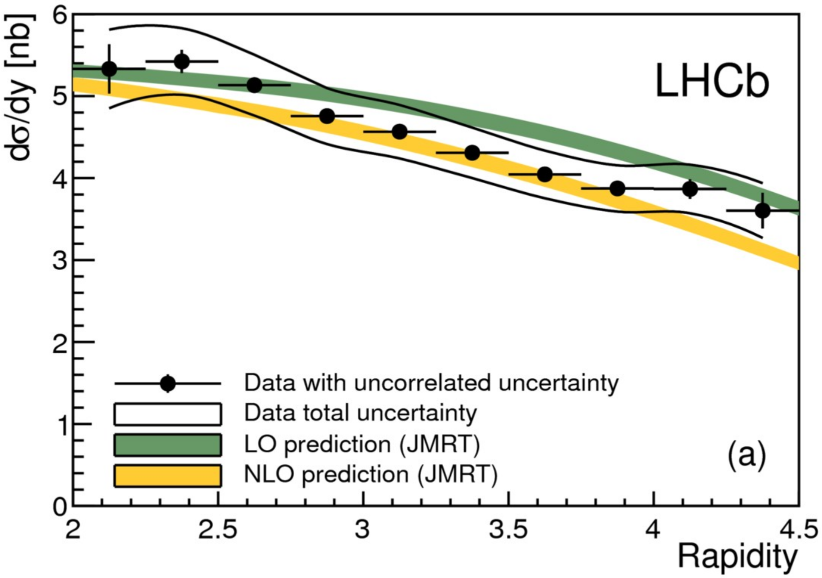
J.Phys.G40 (2014) 055002

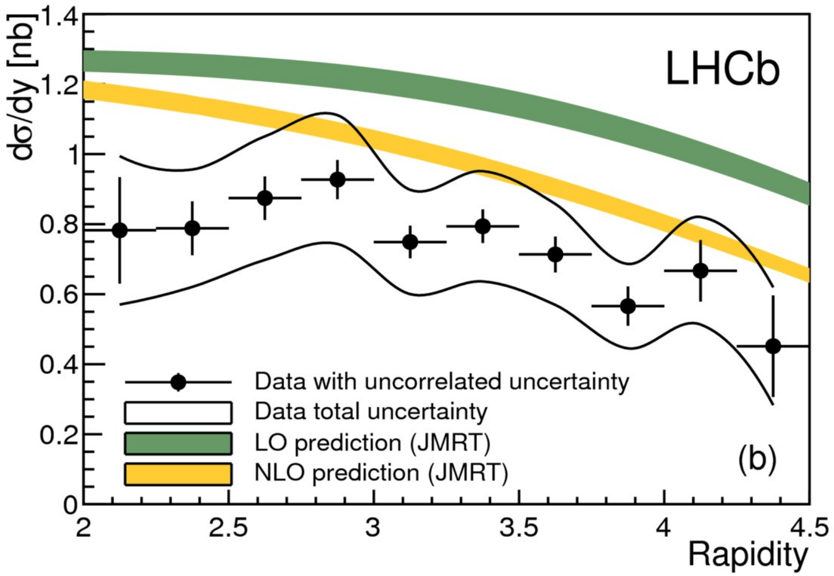




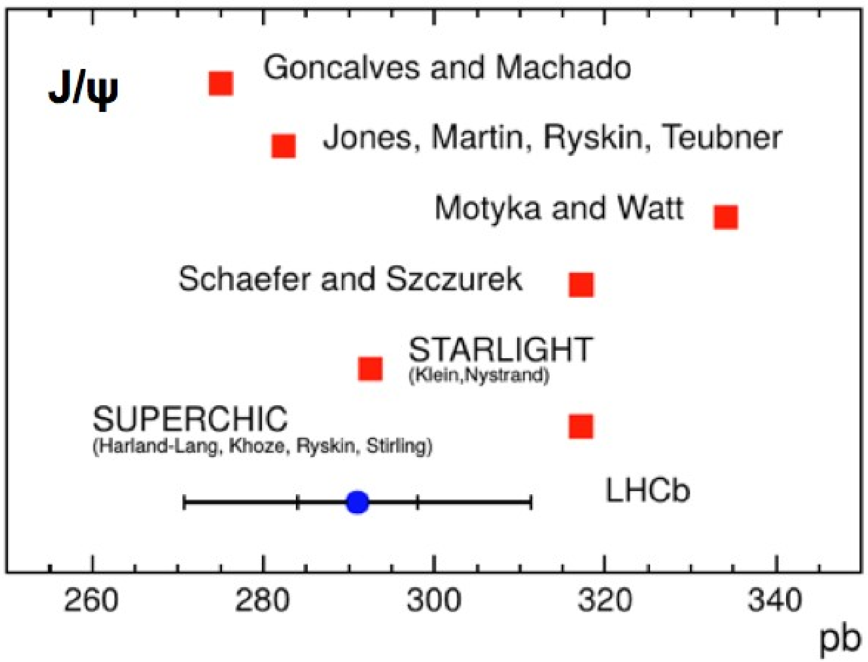
J/ψ

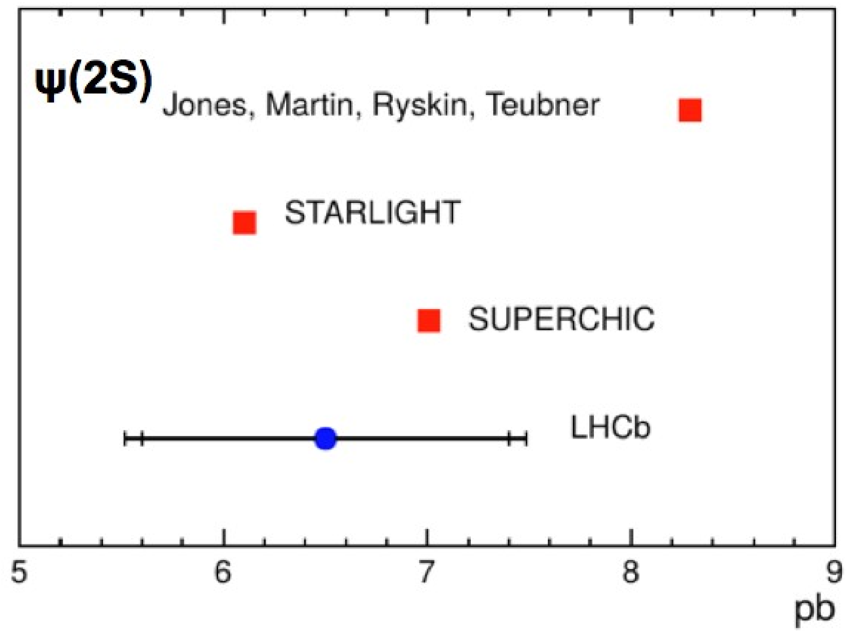
$\psi(2S)$





J/ψ and $\psi(2S)$ - 7 TeV





Cross section times BF to two muons with $2.0 < \eta < 4.5$

$\sigma(J/\psi) = 291 \pm 7(\text{stat}) \pm 19(\text{syst})$ pb

$\sigma(\psi(2S)) = 6.5 \pm 0.9(\text{stat}) \pm 0.4(\text{syst})$ pb

in good agreement with predictions

G&M: Phys. Rev. C84 (2011) 011902
JRMT: JHEP 1311 (2013) 085
M&W:Phys. Rev. D78 (2008) 014023
Sch&SPhys. Rev. D76 (2007) 094014
Starlight: Phys. Rev. Lett. 92 (2004) 142003
Superchic: Eur. Phys. J. C65 (2010) 433

J/ψ and $\psi(2S)$ - 7 TeV

J.Phys.G40 (2014) 055002

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

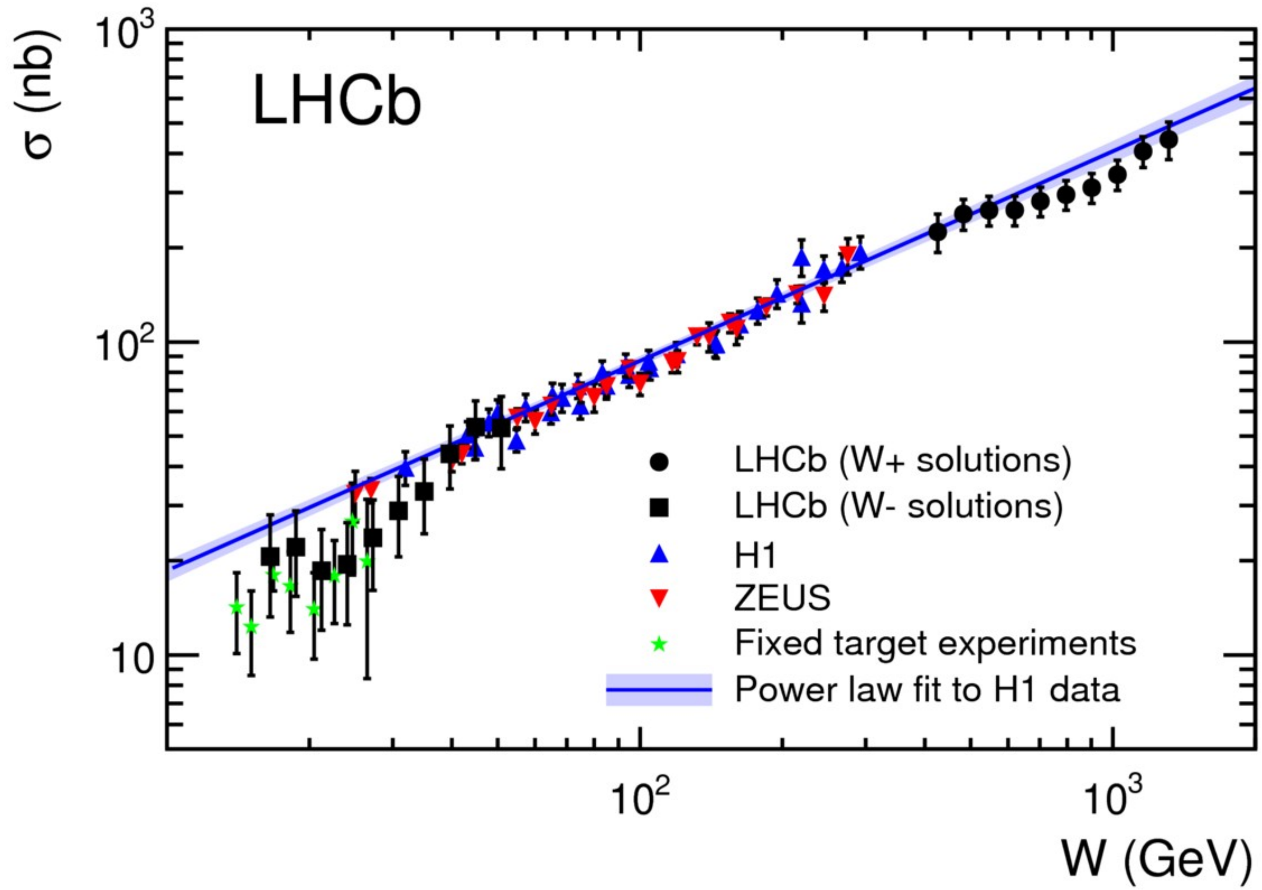
$dn/dk_\pm$ are photon fluxes for photons of energy $k_\pm \approx (M_{J/\psi}/2)\exp(\pm|y|)$

$(W_\pm)^2 = 2k_\pm\sqrt{s}$, and $r_\pm$ are absorptive corrections

Assuming HERA result for W_+

$\sigma(W) = 81(W/90GeV)^{0.67} nb$

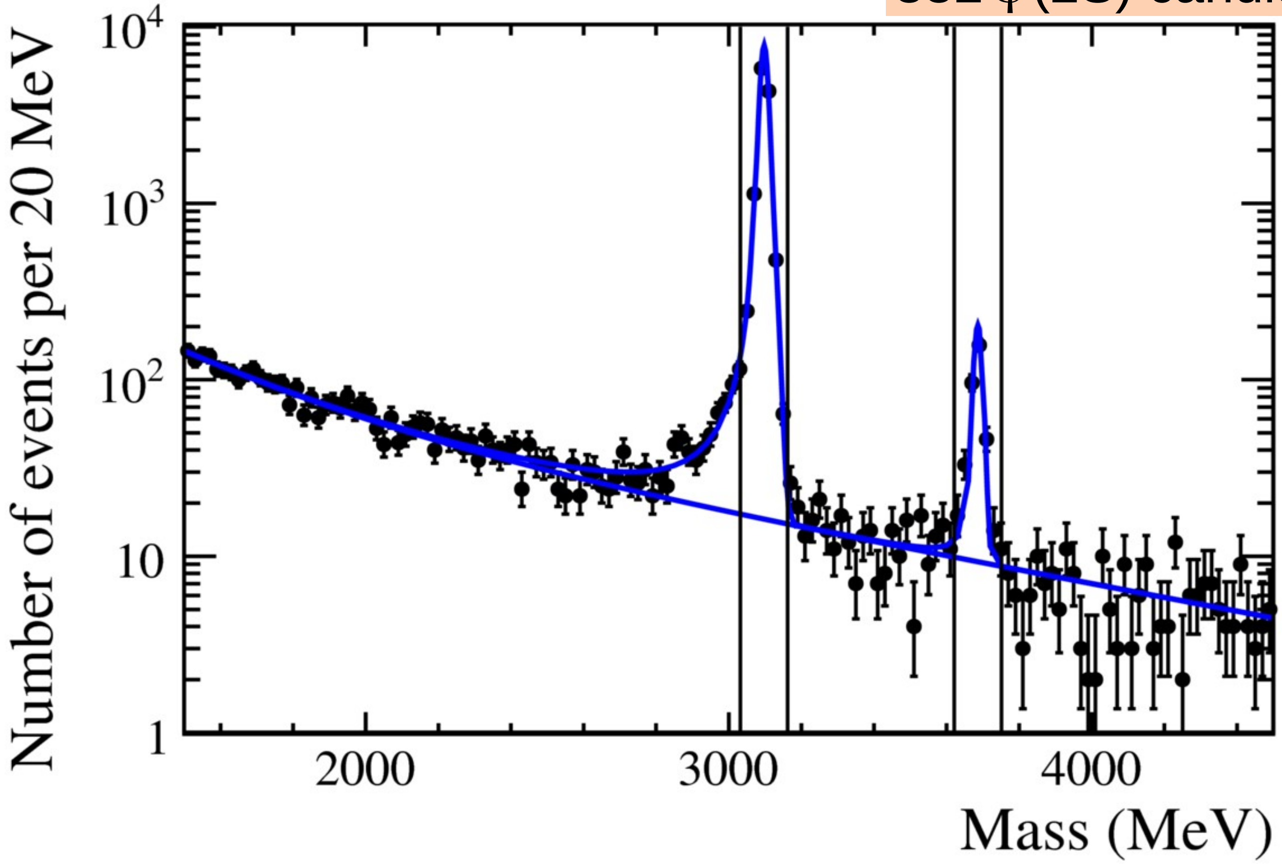
one can obtain $\sigma(W_-)$
and vice-versa



J/ψ and $\psi(2S)$ - 13 TeV

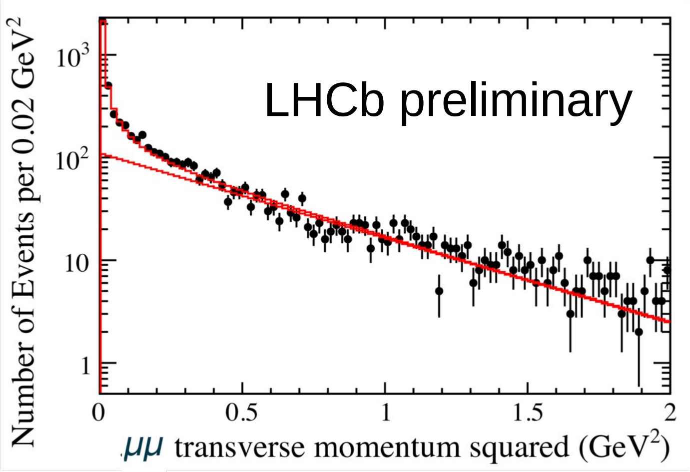
2015 dataset with L=204/pb

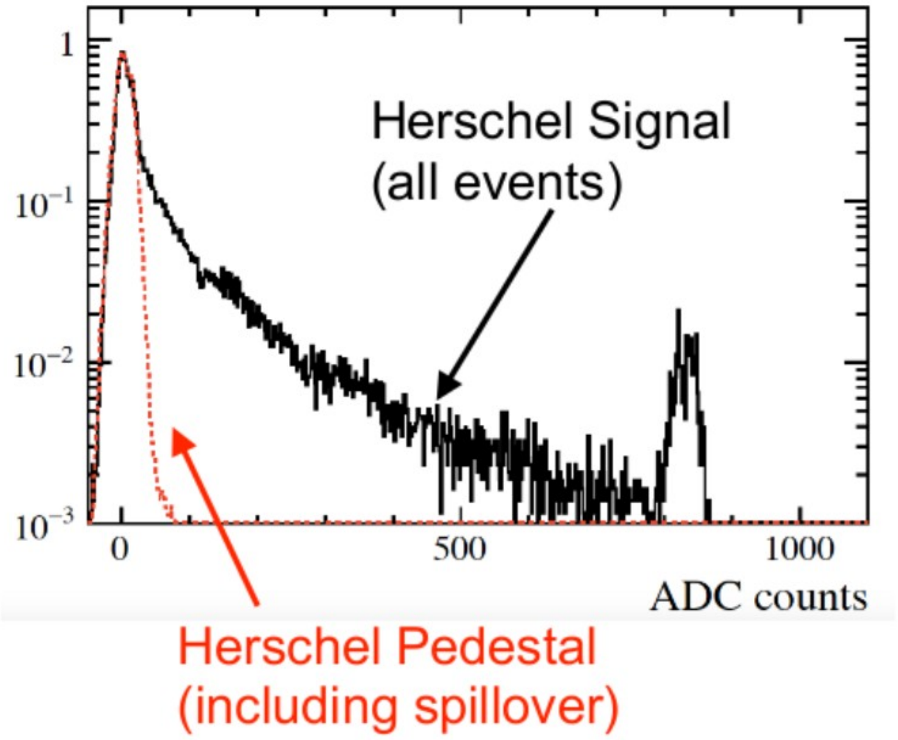
12992 J/ψ candidates
382 $\psi(2S)$ candidates

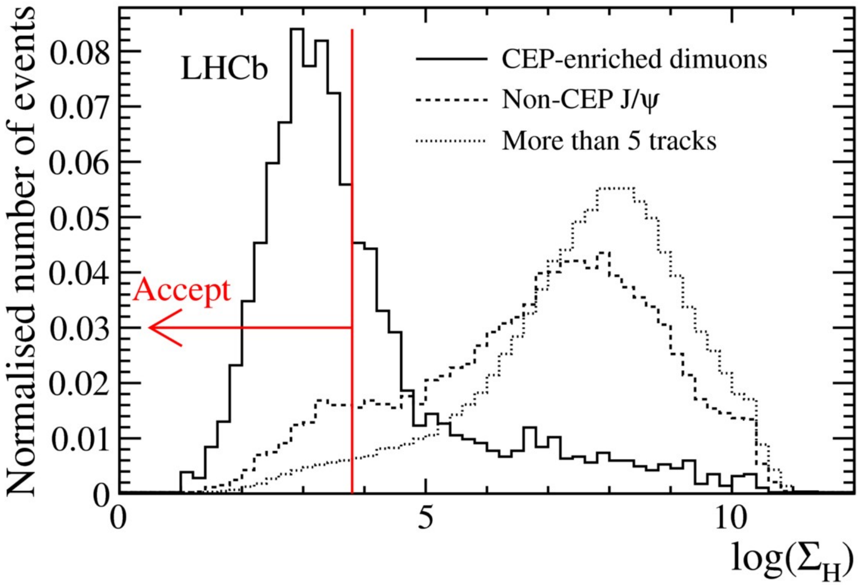


Herschel requirement

Using non-resonant DiMuon events, high multiplicity and high p_T J/ψ







Log of the quadratic sum of the normalized signals in each of the 20 channels

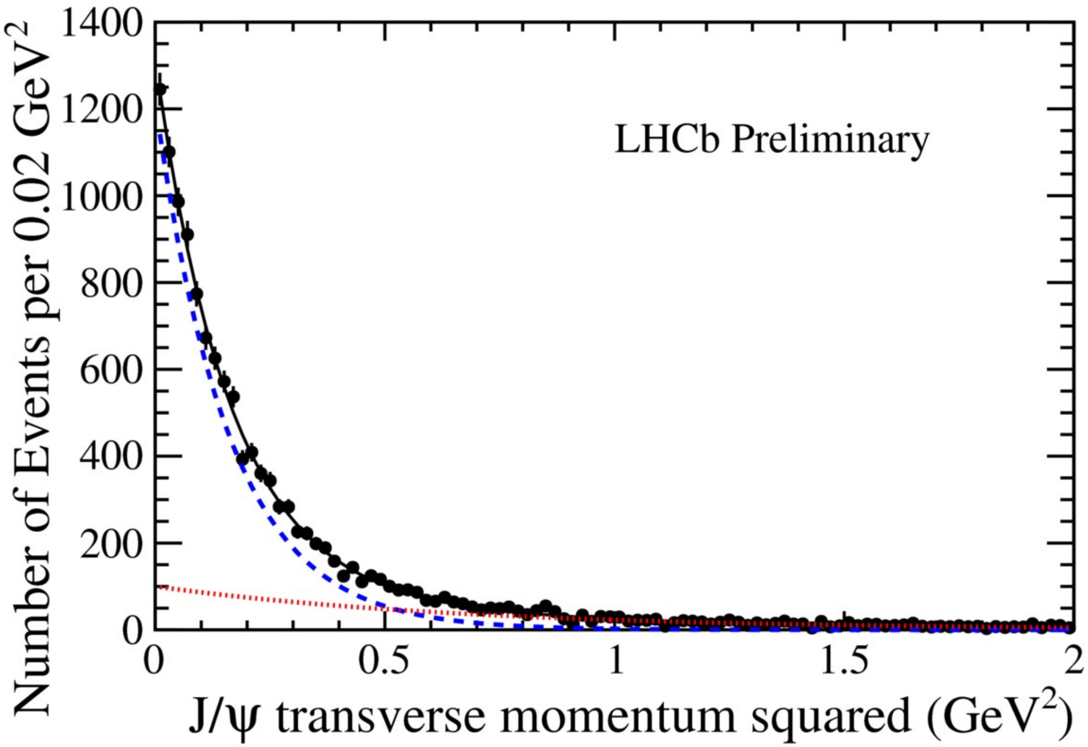
Background fractions

Non-resonant estimated from DiMuon mass → 0.009

Feed-down estimated using data → 0.059 (compared to 0.101 at 7 TeV)

Proton dissociation extracted from fit to p_T^2 after subtracting non-resonant and feed-down background

$$f_{\rm el} b_s \exp\left(-b_s p_{\rm T}^2\right) + (1 - f_{\rm el}) b_b \exp\left(-b_b p_{\rm T}^2\right)$$



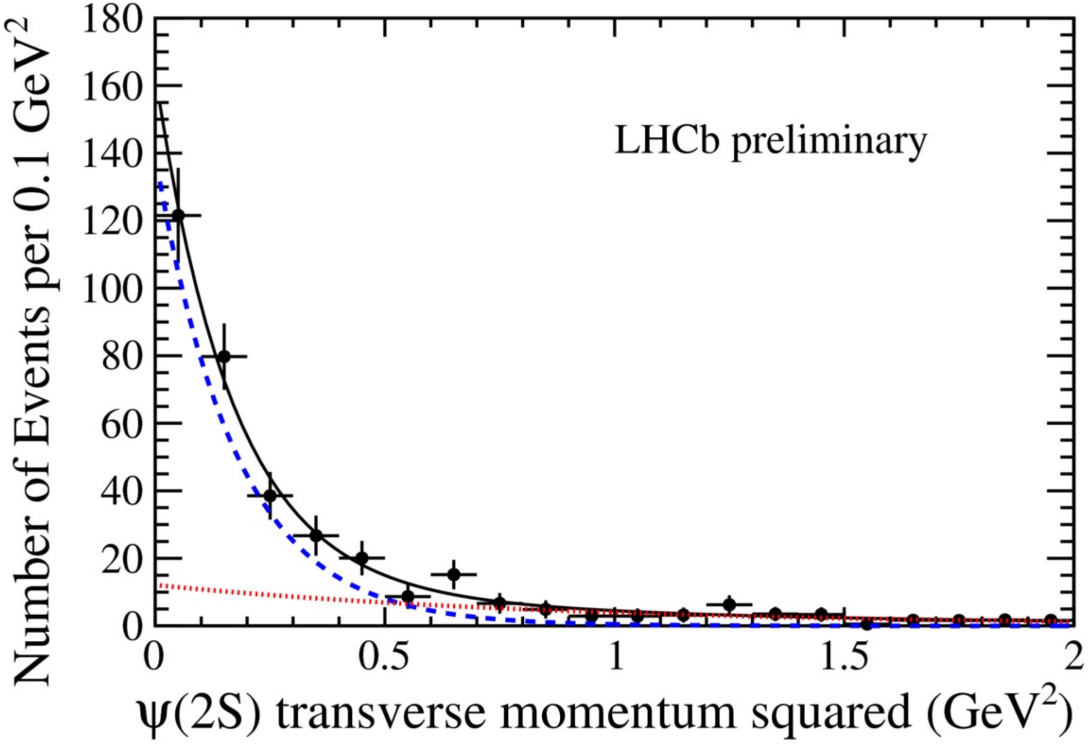
b_s=6.2±0.2 GeV^{-2} b_b=1.5±0.1 GeV^{-2} f_{el}=0.805±0.027

Background fractions

Non-resonant estimated from DiMuon mass → 0.175

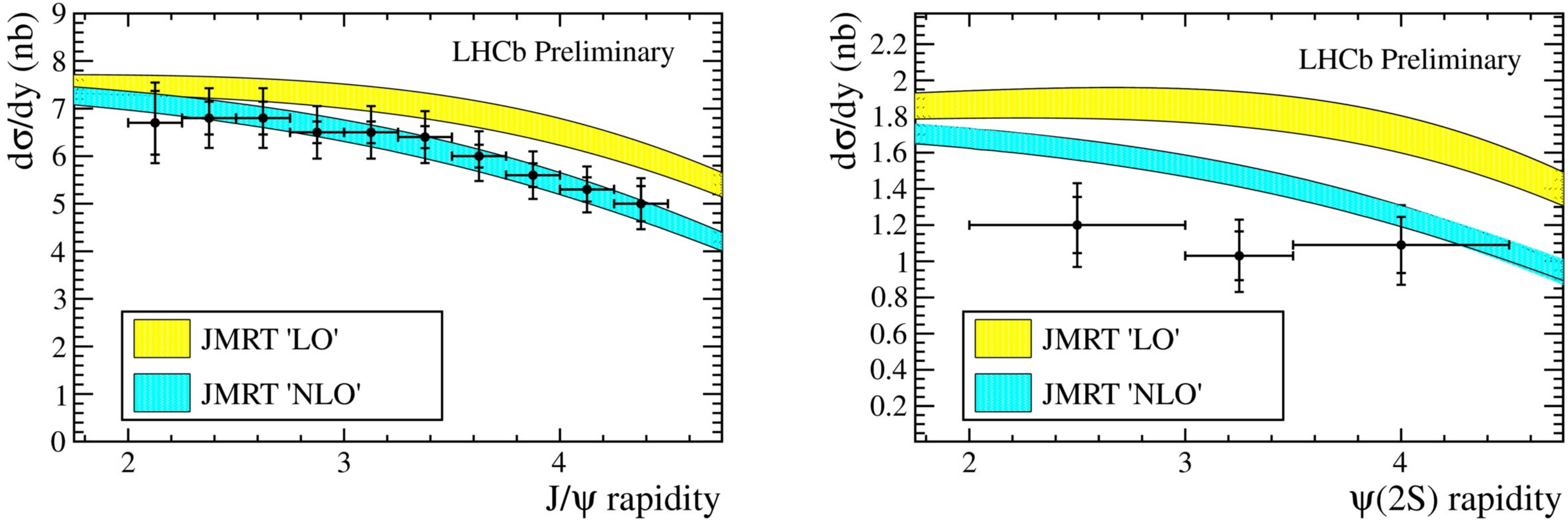
Feed-down neglected in this preliminary result

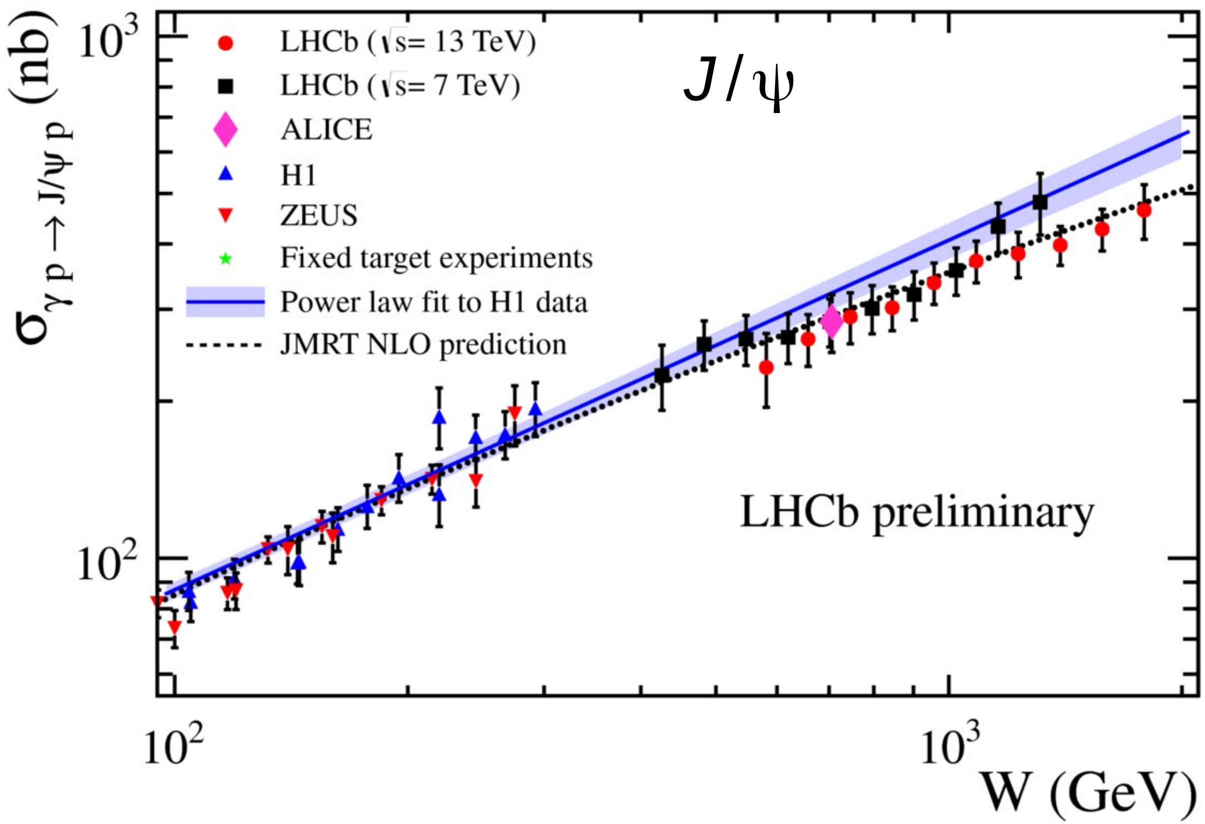
Proton dissociation extracted from fit to p_T^2 after subtracting non-resonant and feed-down background



$b_s=5.7\pm1.0$ GeV^{-2} $b_b=1.1\pm0.6$ GeV^{-2} $f_{el}=0.79\pm0.13$

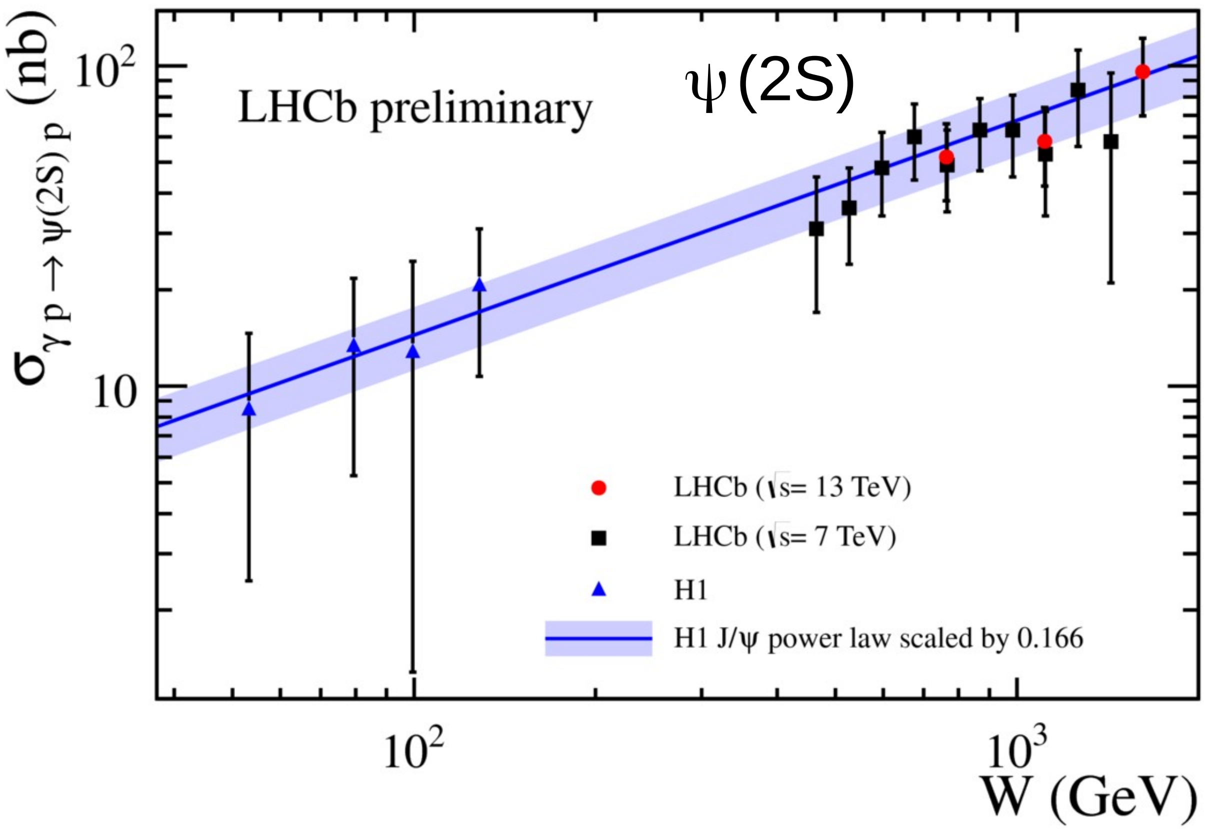
J/ψ and $\psi(2S)$ - 13 TeV





7 and 13 TeV results are in agreement
Power-law fit is not sufficient to explain data
Good agreement with JMRT NLO

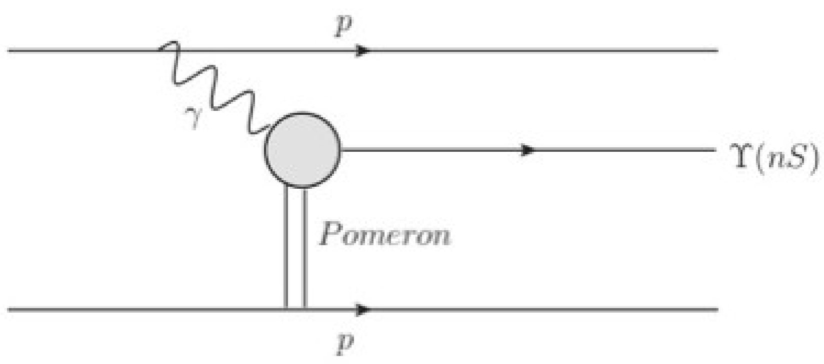
J/ψ and $\psi(2S)$ - 13 TeV



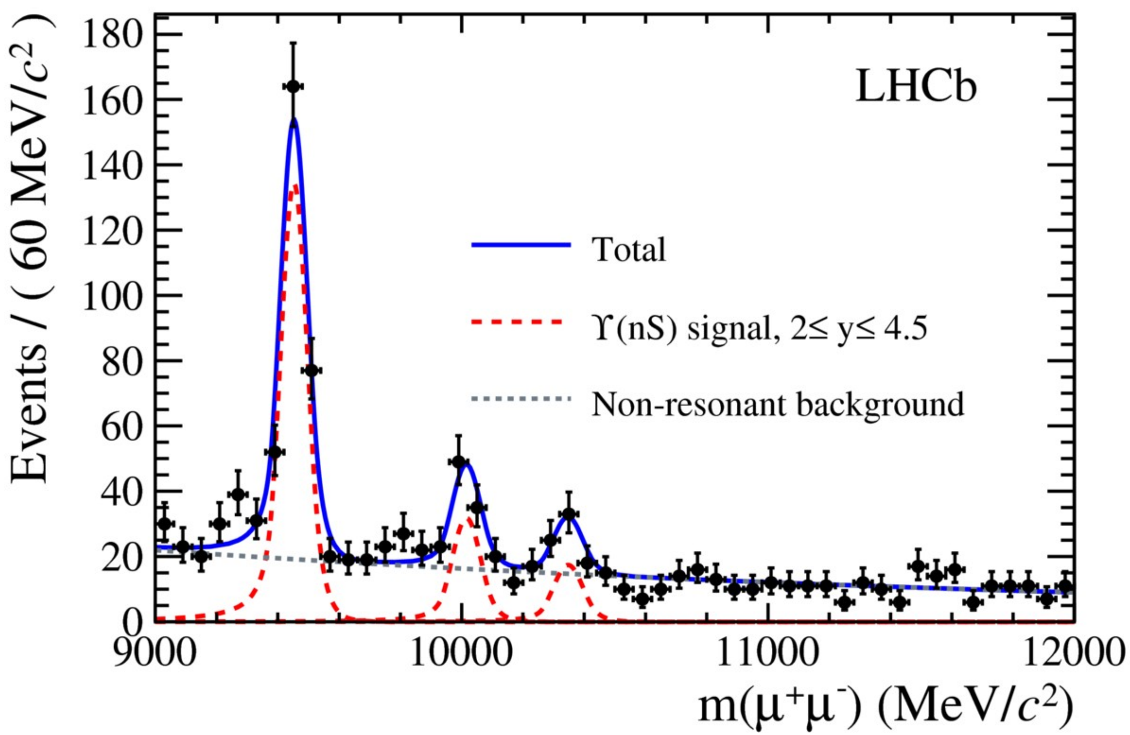
Only W_+ solution possible
Good agreement with H1 extrapolation

Exclusive Υ production

Run-I data set L=1/fb at 7 TeV and L=2/fb at 8 TeV



+ Analysis strategy similar to J/ψ



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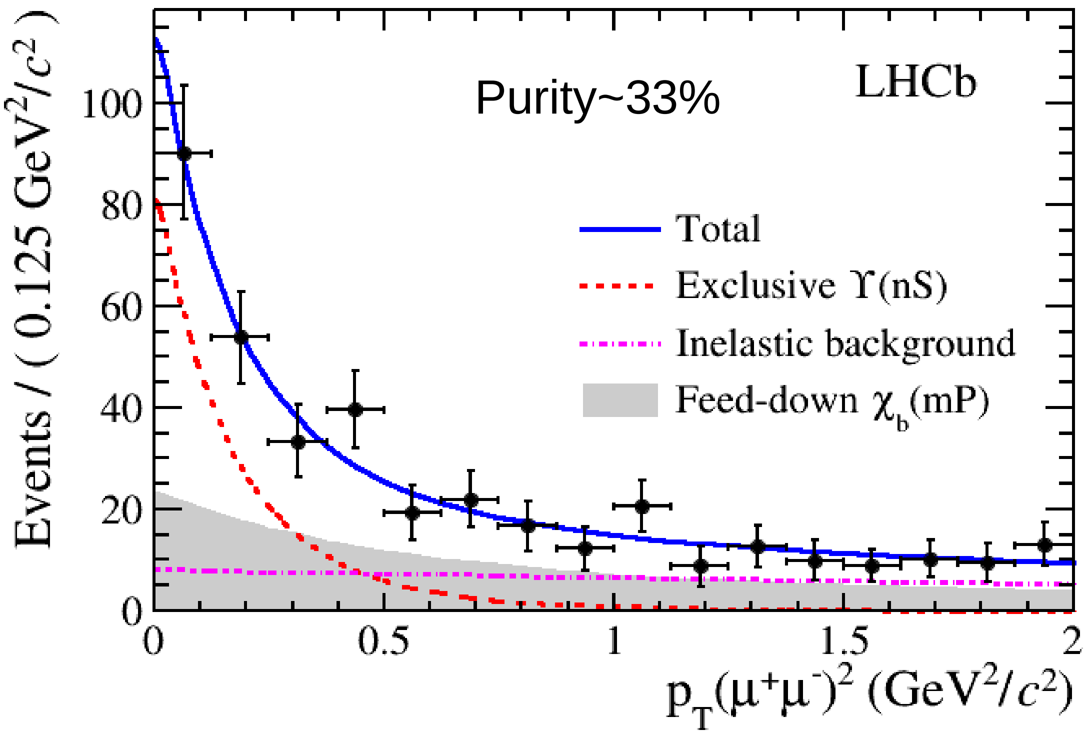
Background fractions

Non-resonant estimated from DiMuon mass

Feed-down estimated using simulation and data input $\chi_b \rightarrow \Upsilon + \gamma$

Proton dissociation extracted from fit to p_T^2 using sWeights

Signal template is obtained from SuperChiC



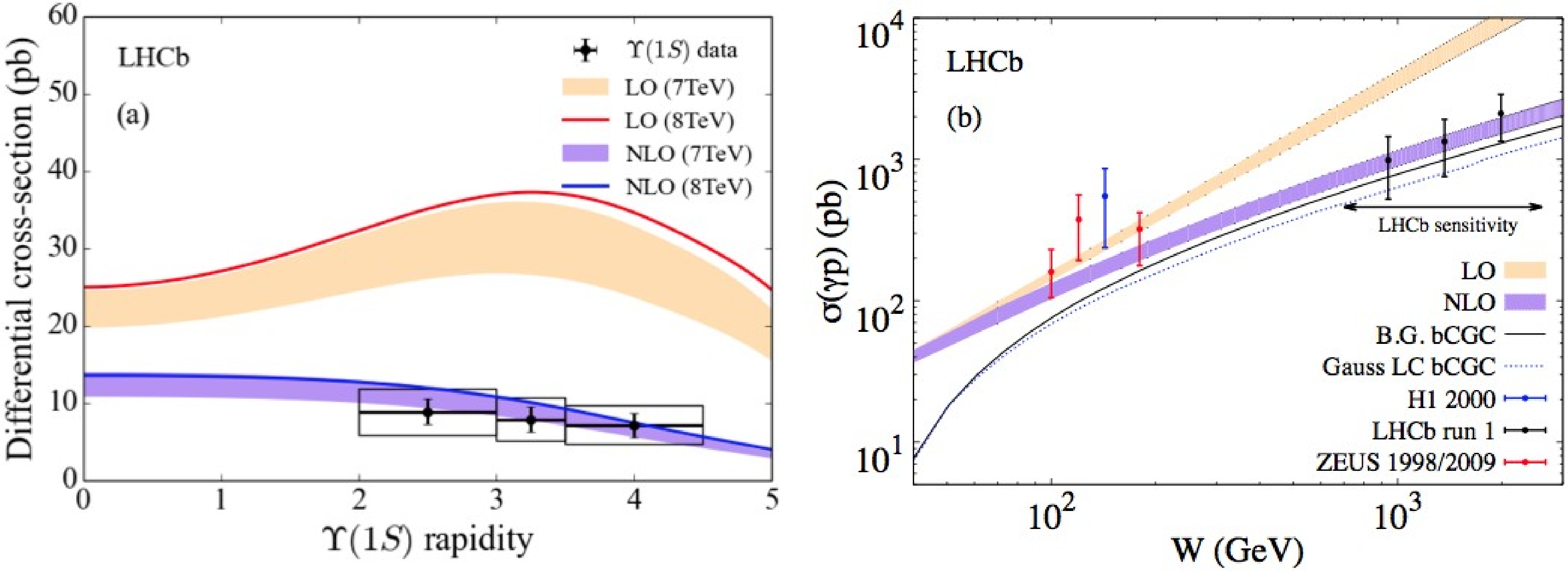
background fractions

feed-down 39%

inelastic 28%

Exclusive Υ production

$$\sigma(pp \to p\Upsilon(1S)p) = 9.0 \pm 2.1 \pm 1.7 \text{ pb}$$
$$\sigma(pp \to p\Upsilon(2S)p) = 1.3 \pm 0.8 \pm 0.3 \text{ pb}$$



Rapidity dependence in agreement with NLO calculation

Photon-proton cross-section extrapolated from measurement can be compared with different phenomenological models

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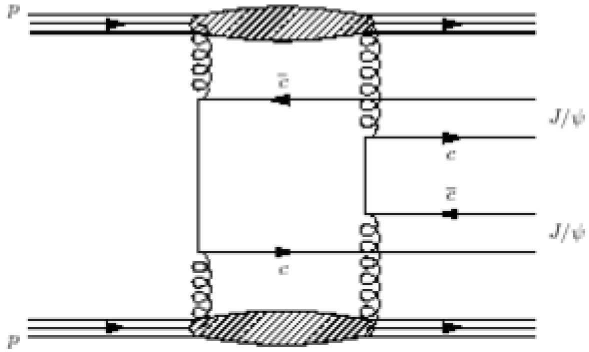
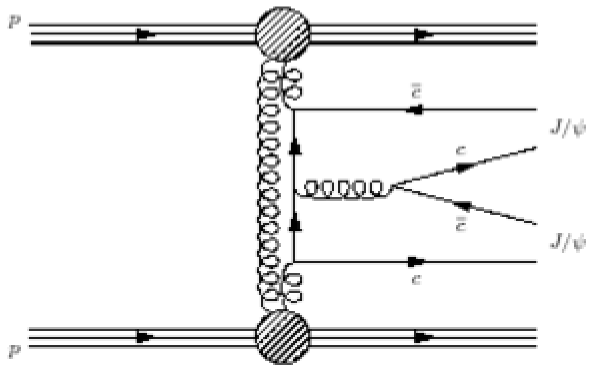




2011 dataset with L=1/fb
2012 dataset with L=2/fb

Trigger

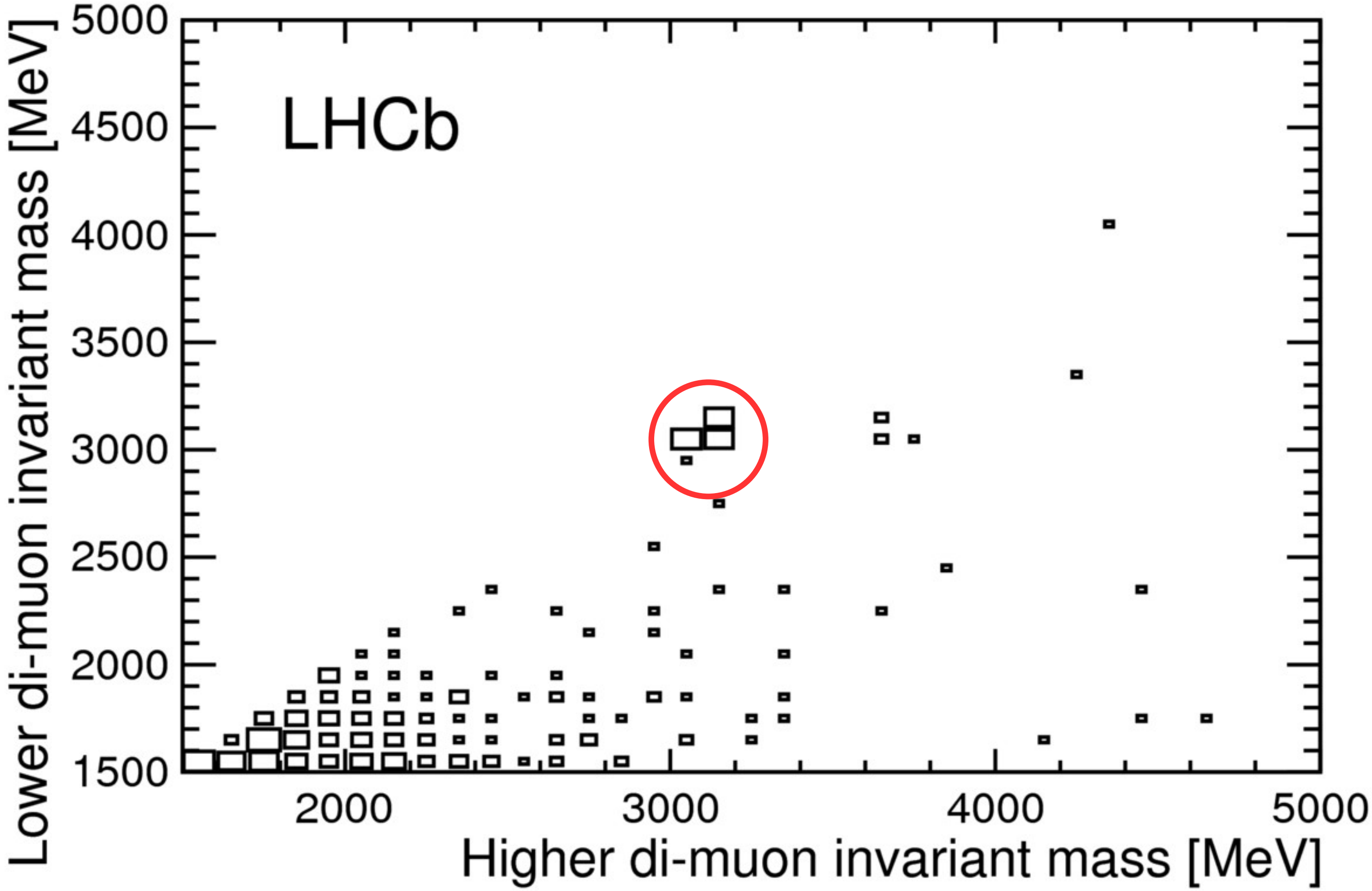
DiMuon (p_T(muon)>400 MeV) in coincidence with SPD multiplicity < 10

Candidate selection

Exactly four forward tracks (three identified as muons)

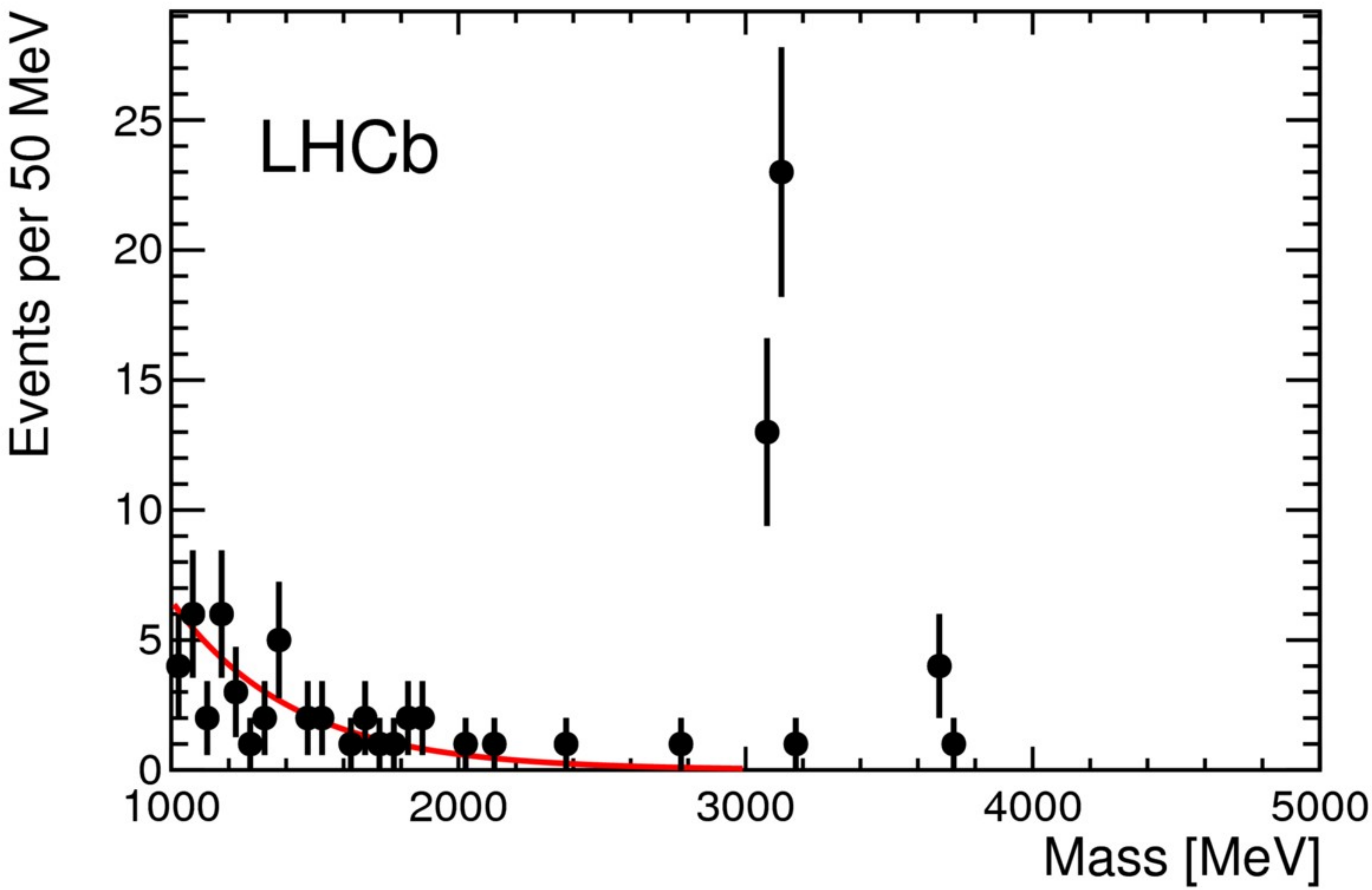
Charmonium pairs

J.Phys.G41 (2014)115002



Charmonium pairs

J.Phys.G41 (2014)115002



Mass of the second pair when the first pair has a mass consistent with the J/ψ or the ψ(2S)

Extrapolation of exponential fit up to 2500 MeV is used to estimate non-resonant background
=> 0.3±0.1(0.07±0.02) for J/ψ (ψ(2S))

Charmonium pairs

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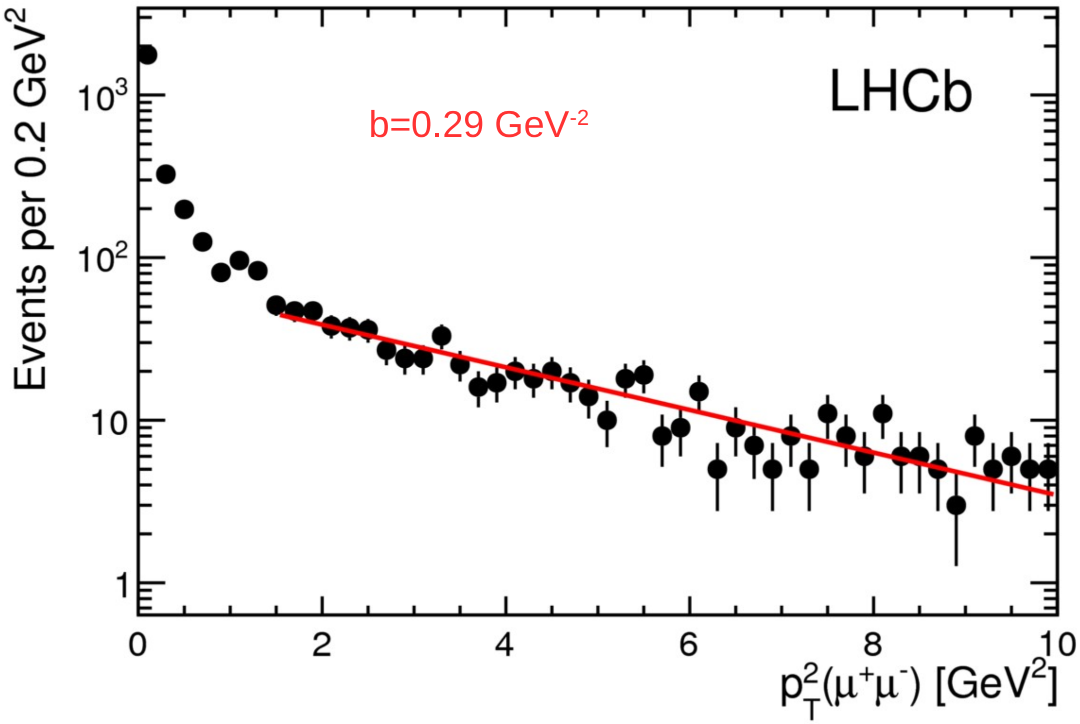
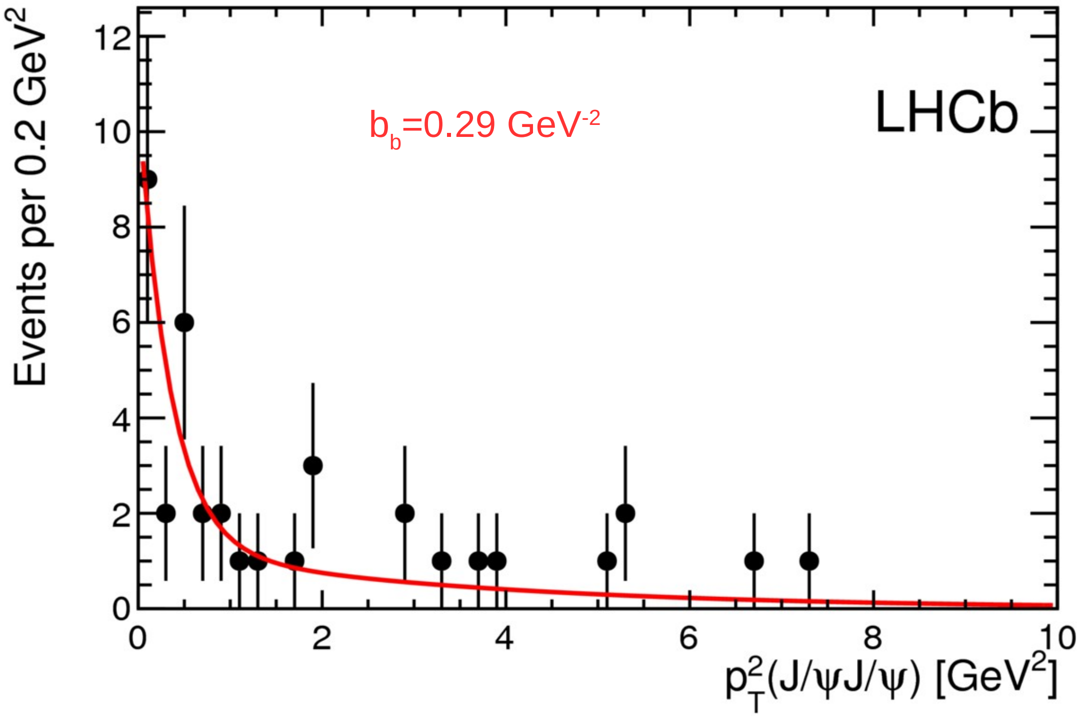
Feed-down from J/ψ ψ(2S) as J/ψ J/ψ estimated from data => 2.9±2.0

Proton dissociation estimated from p_T^2 fit using events with DiMuon mass = [6,9] GeV



Signal estimated using a fit to data



$$b_s = 2.9 \pm 1.3\, GeV^{-2} \text{ and } f_{el} = 0.42 \pm 0.13$$

$$J/\psi \text{ CEP} \rightarrow b_s = 5.70 \pm 0.11\, GeV^{-2}$$

Different signal slope from double charmonium to single charmonium

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Candidates

37 J/ψ-J/ψ

5 J/ψ-ψ(2S)

0 ψ(2S)-ψ(2S)

Cross-section measurements without proton dissociation correction

Limits calculated at 90% CL

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

$$\frac{\sigma(J/\psi\,\psi(2S))}{\sigma(J/\psi\, J/\psi)} = 1.1^{+0.5}_{-0.4}$$

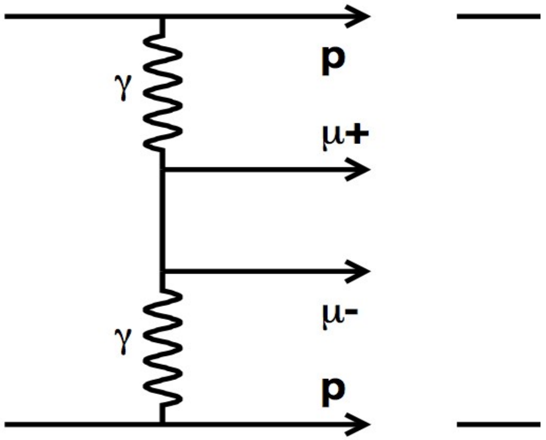
$$\frac{\sigma(\psi(2S))}{\sigma(J/\psi)} = 0.17 \pm 0.02$$

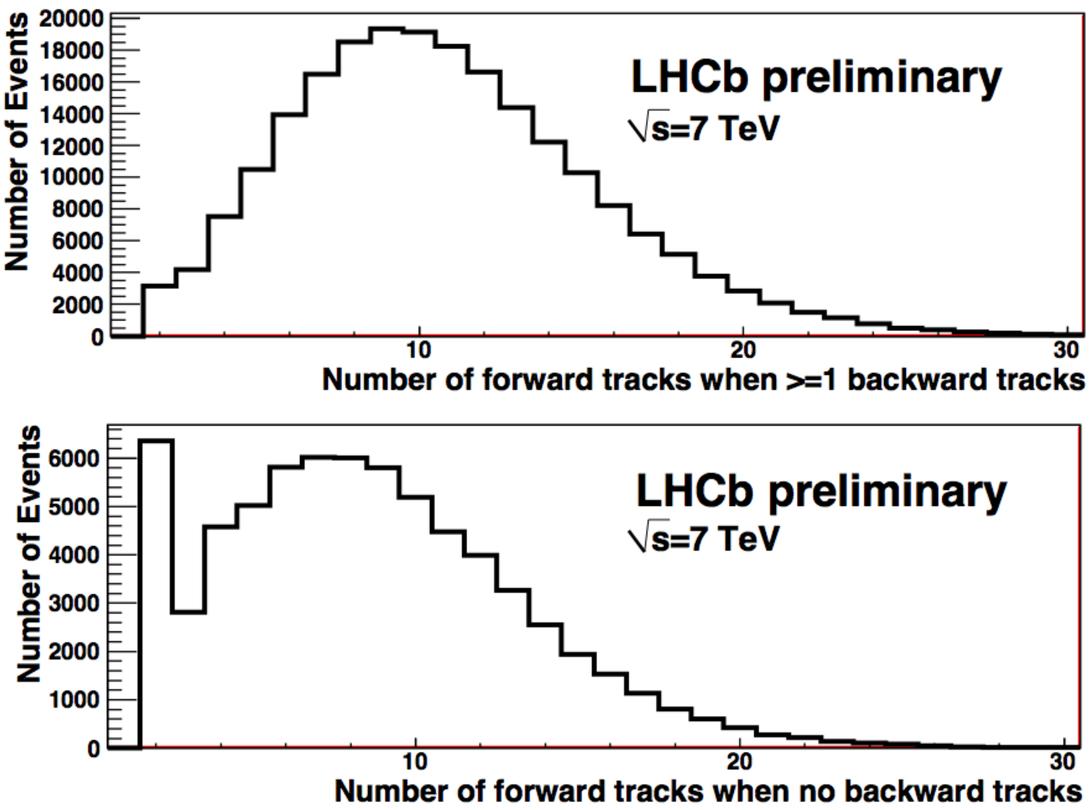
$$\sigma^{J/\psi\, J/\psi} / \sigma^{J/\psi} |_{\text{exclusive}} = (2.1 \pm 0.8) \times 10^{-3}$$

$$\sigma^{J/\psi\, J/\psi} / \sigma^{J/\psi} |_{\text{inclusive}} = (5.1 \pm 1.0 \pm 0.6^{+1.2}_{-1.0}) \times 10^{-4}$$

Non-resonant DiMuon

- Data collected in 2010 (L=36/pb)





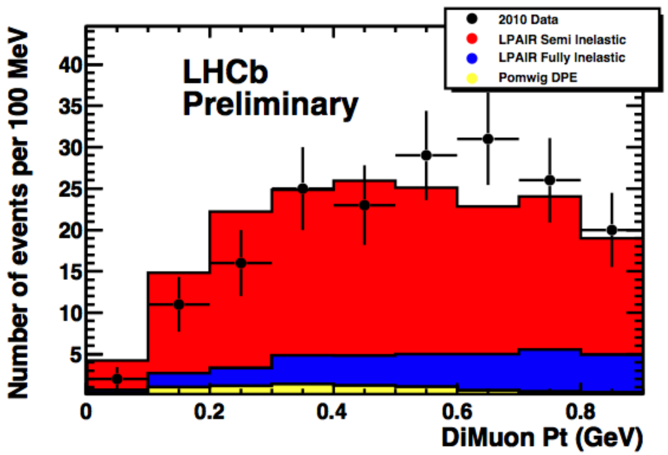
Non-resonant DiMuon

DiMuon selection

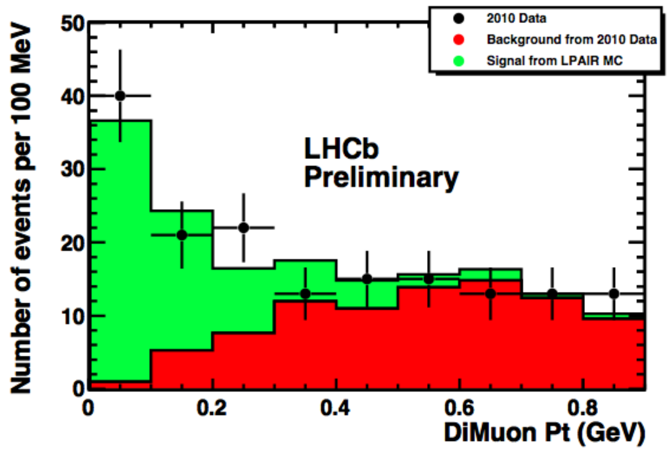
- Candidates of J/ψ and ψ(2S) are vetoed
- Muon p_T > 80 MeV
- DiMuon Mass > 2.5 GeV
- DiMuon p_T < 0.9 GeV

Background

- Muon mis-id: random triggers without muon id cuts
- Diffractively produced DiMuon contribution estimated by POMWIG
- Inelastic production estimated using LPAIR and normalized to data



More than 2 fwd tracks



Only 2 fwd tracks

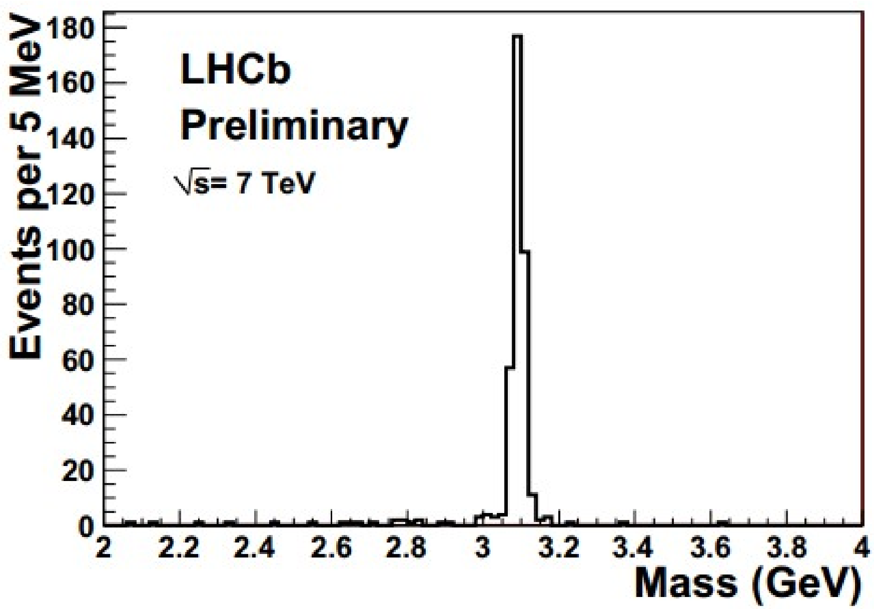
$$\sigma_{pp\to p\mu^+\mu^- p}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5; m_{\mu+\mu-} > 2.5\ \mathrm{GeV/c^2}) = 67 \pm 10 \pm 7 \pm 15\ \mathrm{pb}$$

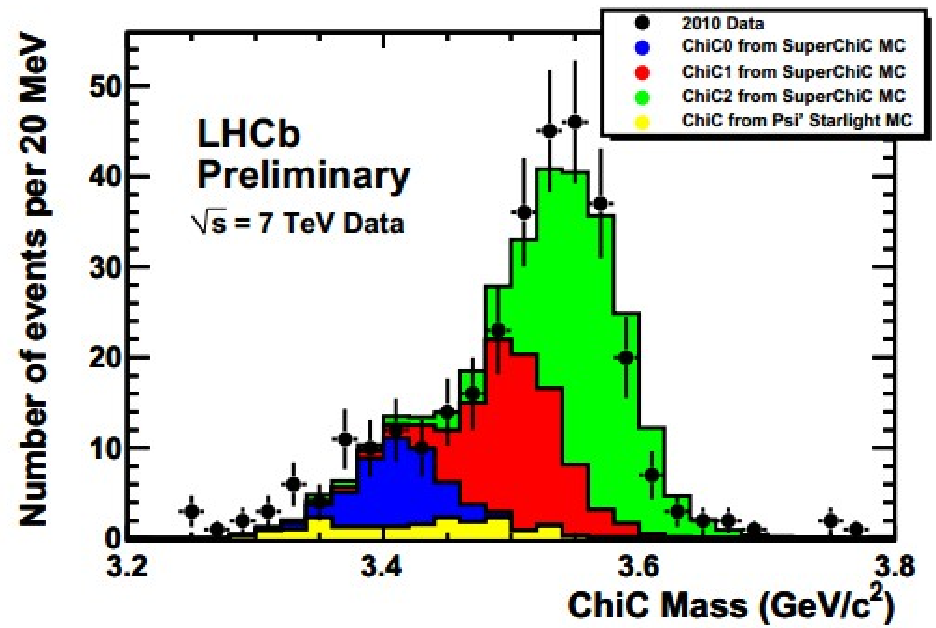
42 pb (LPAIR prediction)

Analysis update is ongoing.

→ Same data as non-resonant DiMuon
→ J/ψ candidate plus one photon (E_T>200 MeV)

+ Exclusive spectrum estimated by SuperChic fitted to data
+ Inelastic contamination higher than other CEP (60%)





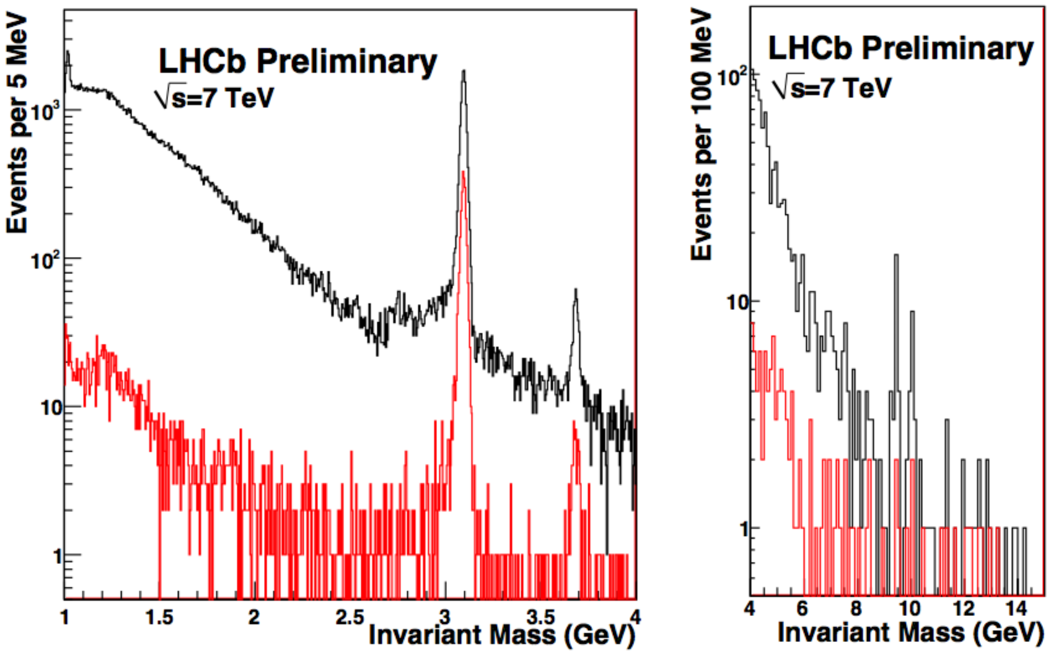
$$\sigma_{\chi_{c0}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 9.3\pm2.2\pm3.5\pm1.8 \text{ pb}$$

$$\sigma_{\chi_{c1}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 16.4\pm5.3\pm5.8\pm3.2 \text{ pb}$$

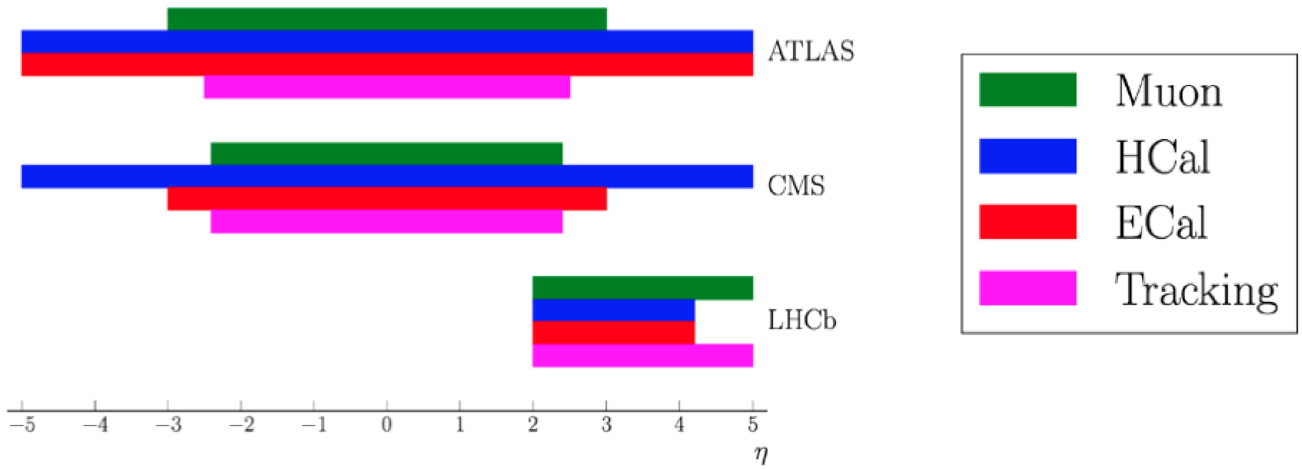
$$\sigma_{\chi_{c2}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 28.0\pm5.4\pm9.7\pm5.4 \text{ pb}$$

Analysis update is ongoing.

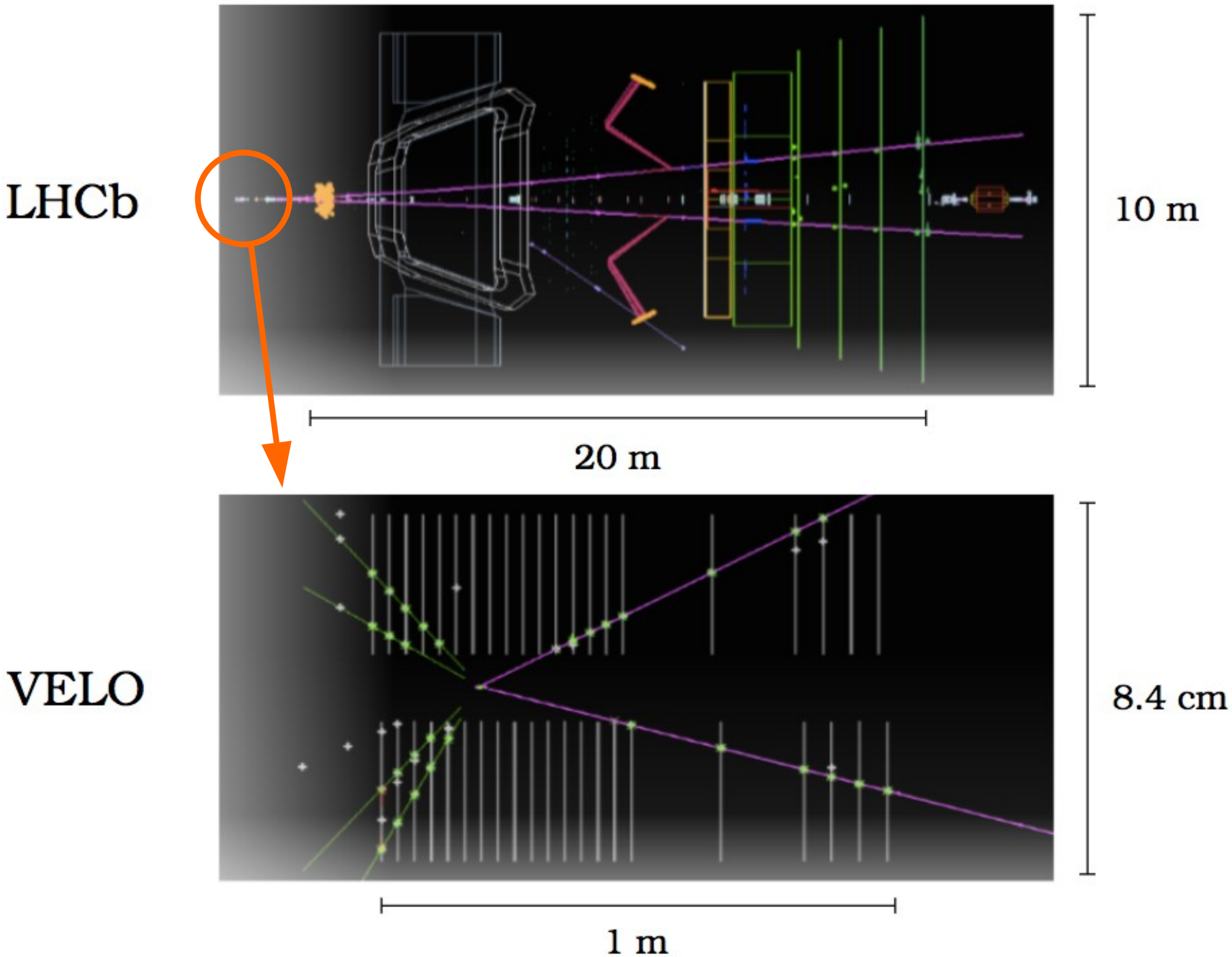
Non-resonant DiMuon



LHCb



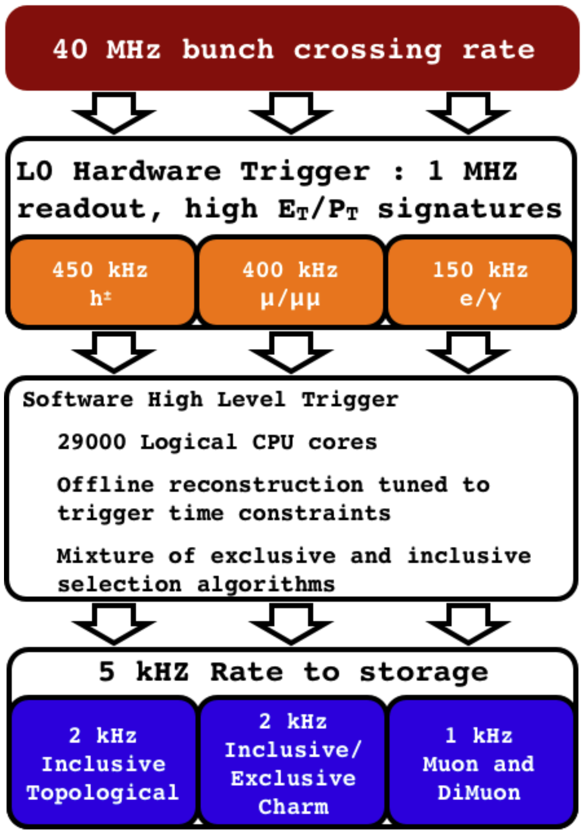
LHCb detector

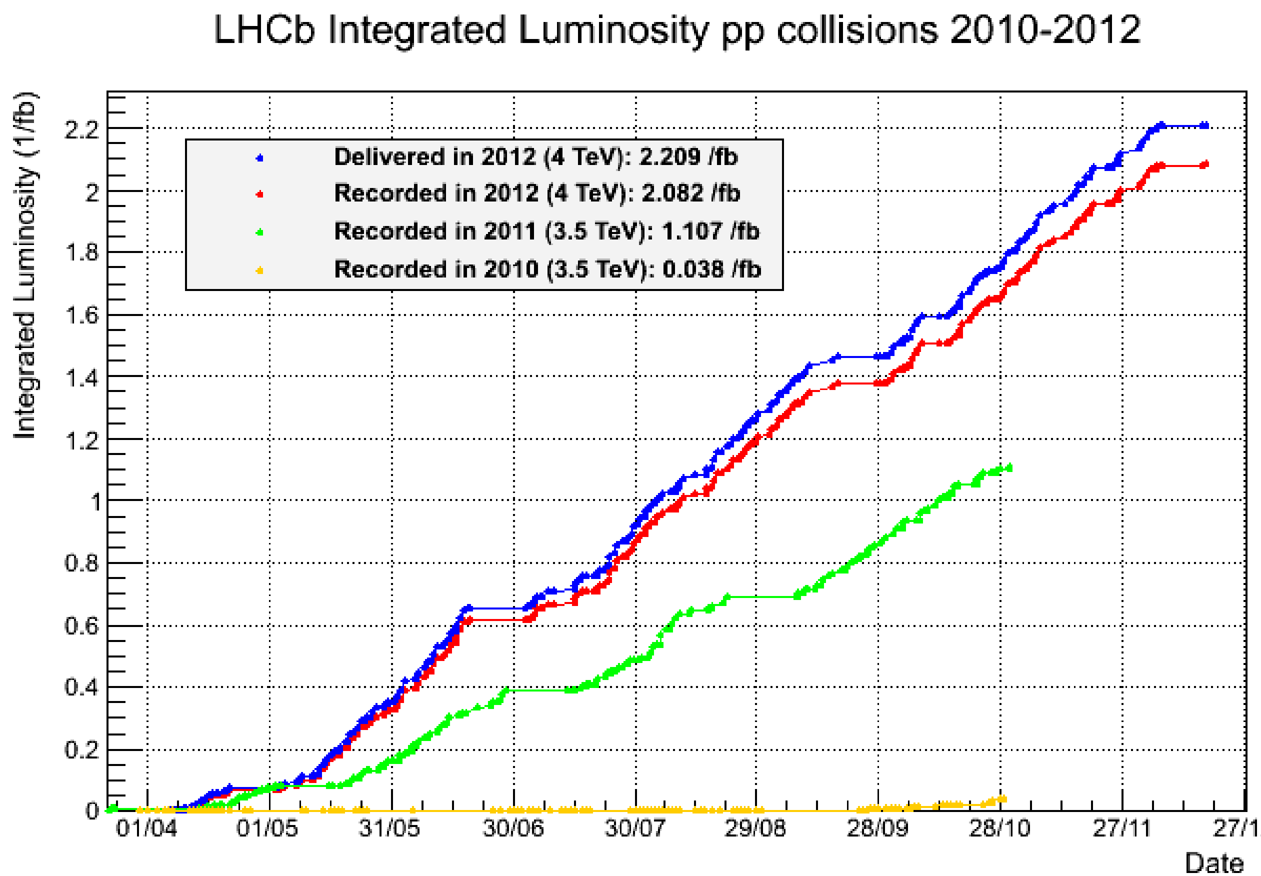


Backward track reconstruction is useful

Phil Ilten's slides – MPI at LHC

LHCb Data





>90% data taking efficiency

>99% DQ efficiency

2010 → 37/pb at $\sqrt{s}$ = 7 TeV

2011 → 1.0/fb at at $\sqrt{s}$ = 7 TeV

2012 → 2/fb at at $\sqrt{s}$ = 8 TeV

Central exclusive J/ψ and ψ(2S)

J.P.G40 (2013) 045001

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

[10] 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.

[11] S. R. Klein and J. Nystrand, *Photoproduction of quarkonium in proton-proton and nucleus-nucleus collisions*, Phys. Rev. Lett. **92** (2004) 142003.

[12] 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.

[13] W. Schäfer and A. Szczurek, *Exclusive photoproduction of J/ψ in proton-proton and proton-antiproton scattering*, Phys. Rev. **D76** (2007) 094014, arXiv:0705.2887.

[7] L. Motyka and G. Watt, *Exclusive photoproduction at the Fermilab Tevatron and CERN LHC within the dipole picture*, Phys. Rev. **D78** (2008) 014023, arXiv:0805.2113.