

Exclusive J/ ψ and $\psi(2S)$ Vector Meson Production

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on behalf of the LHCb Collaboration



● LHCb Experiment

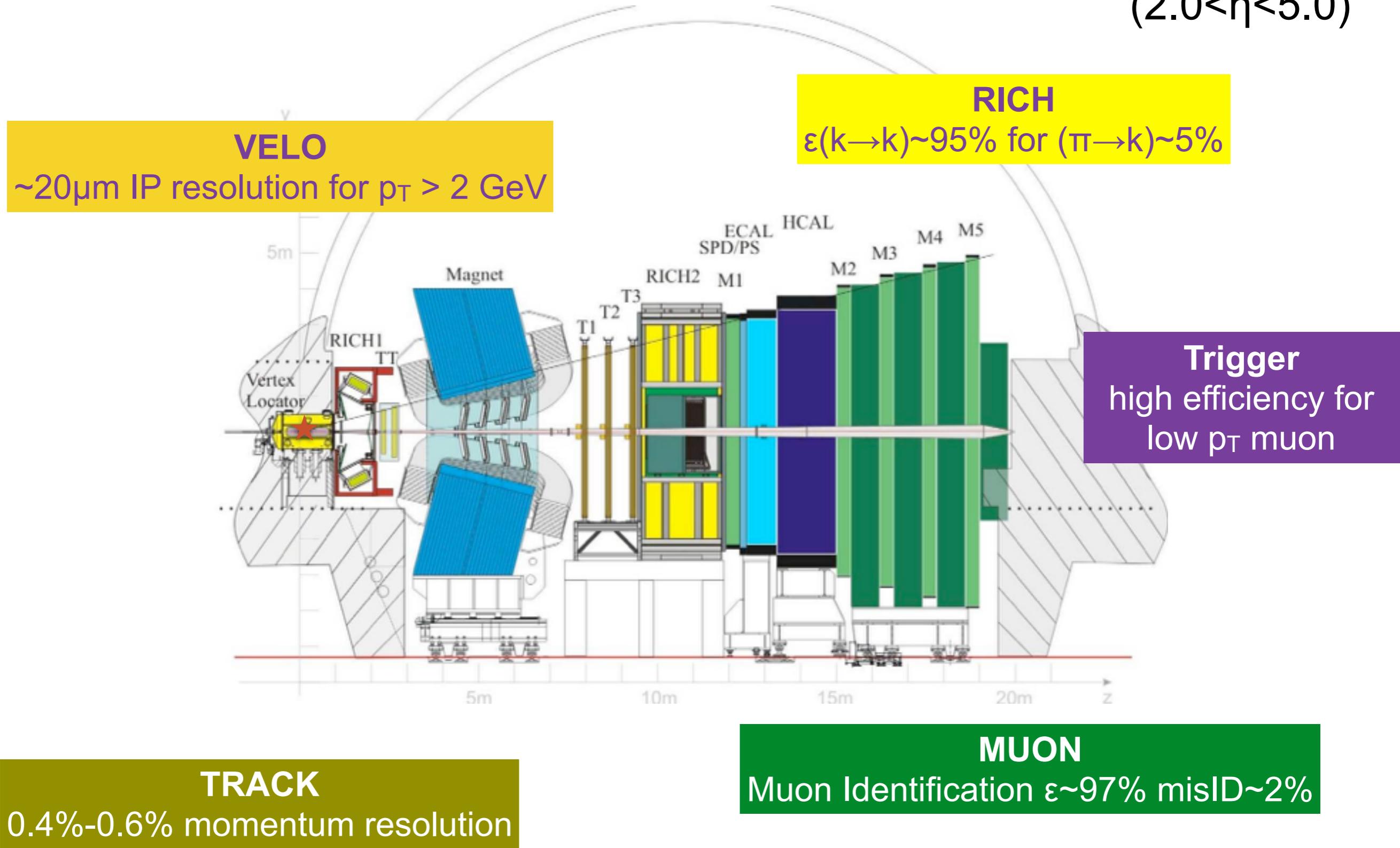
● Measurements

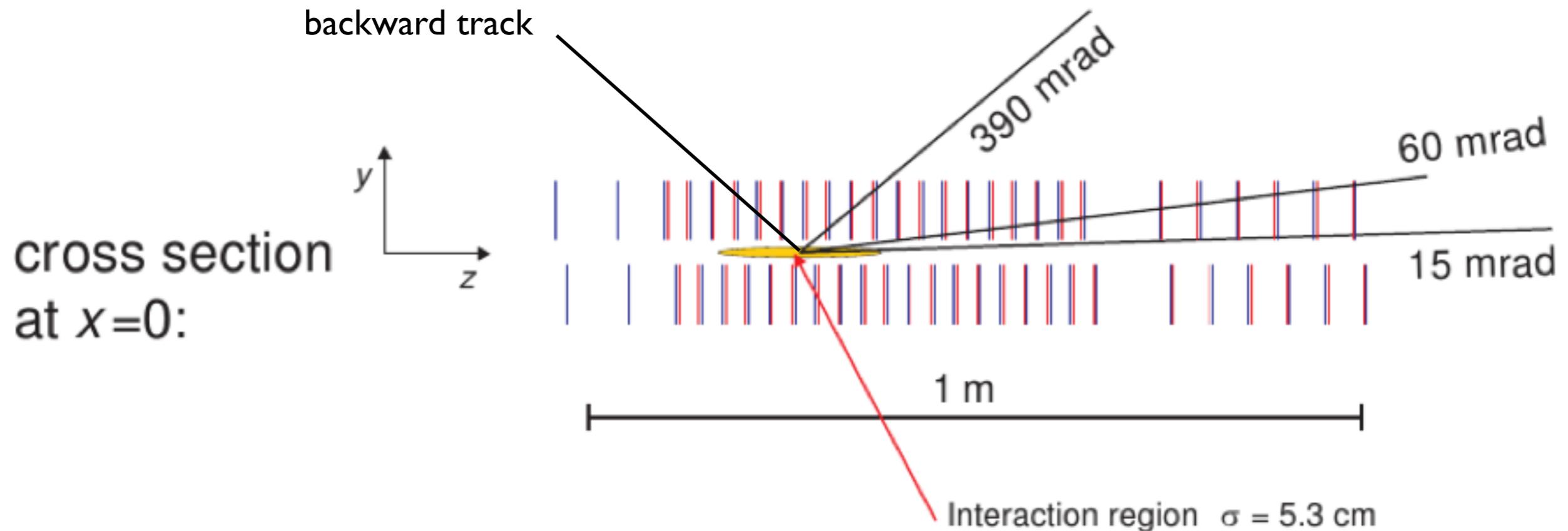
Central Exclusive Production of J/ψ and $\psi(2S)$
Observation exclusive charmonium pair

● Summary

LHCb Experiment

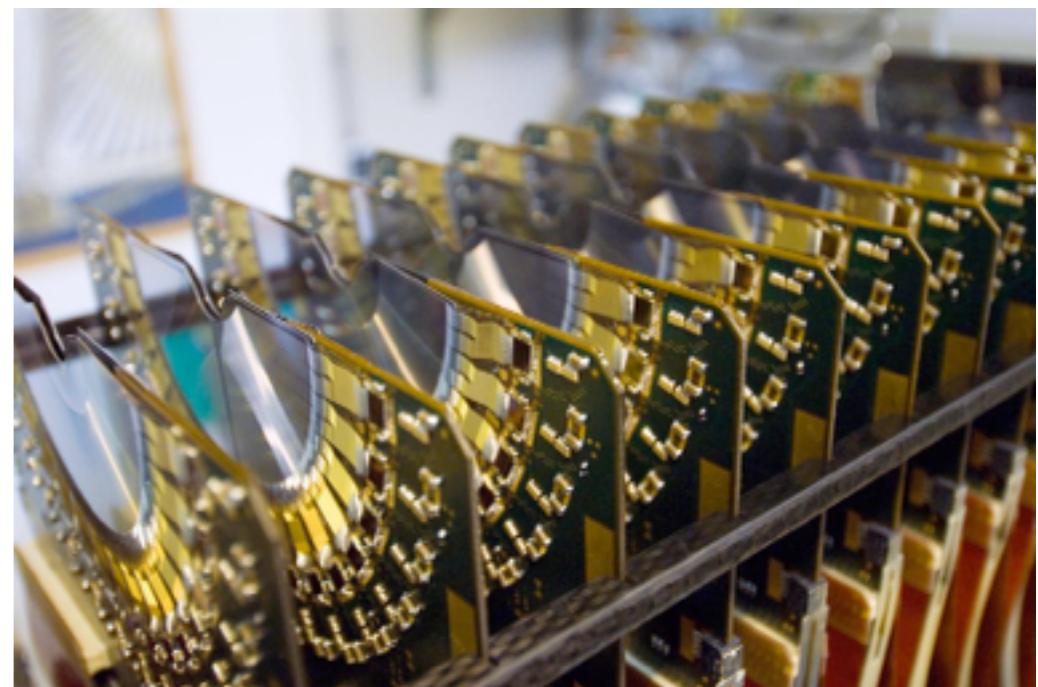
LHCb is a **single arm spectrometer** fully **instrumented** in the forward region
 $(2.0 < \eta < 5.0)$



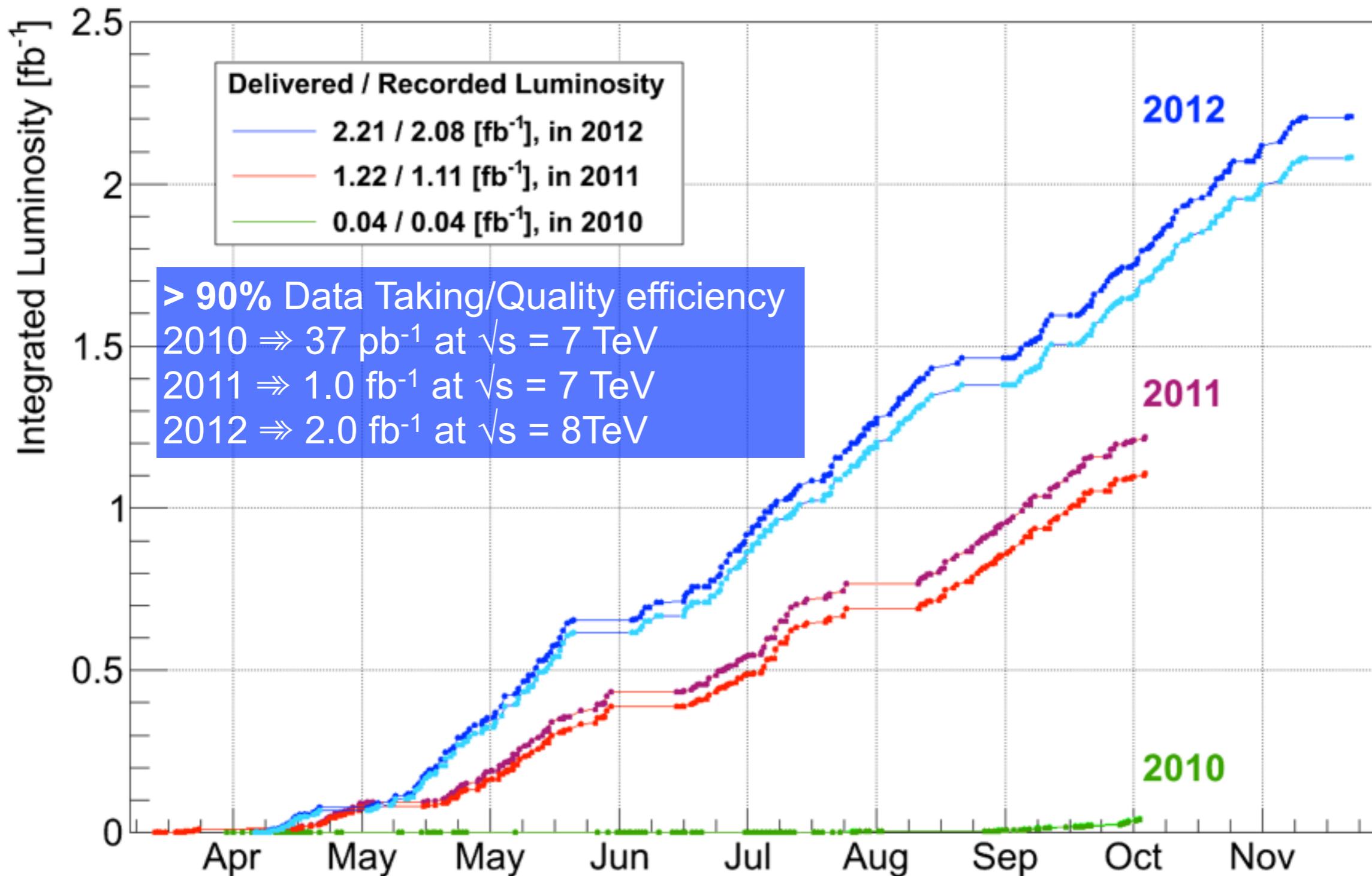


VELO

- surrounds the interaction point
- allows backward tracks ($-3.5 < \eta < -1.5$)



Data



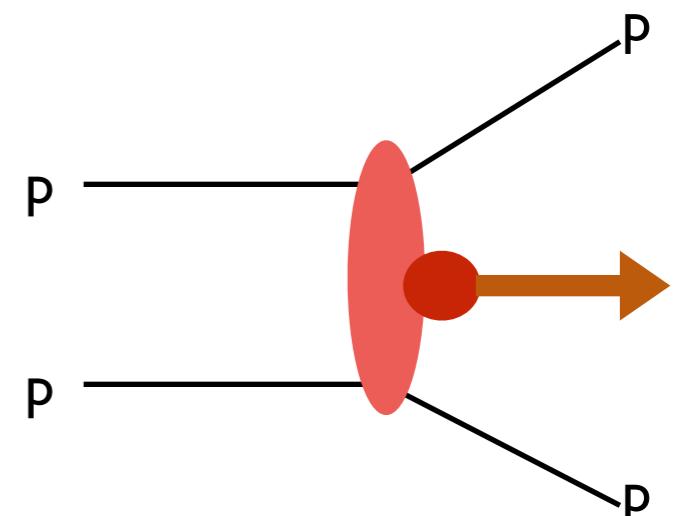
Central Exclusive Production (CEP)

Motivation

- understanding of soft to hard QCD scale
- input for **phenomenological** models: saturation, pomeron/oderon interactions, ...
- sensitive to low-x gluon density in the proton down to 5×10^{-6}

Data and General Strategy

- Trigger:
 - Low Multiplicity: number of SPD hits < 10
 - Two muons with $p_T > 400$ MeV
- **No** Backward Tracks
- **No** Photons
- **One** Primary Vertex (~20% of Total Sample)



Backgrounds

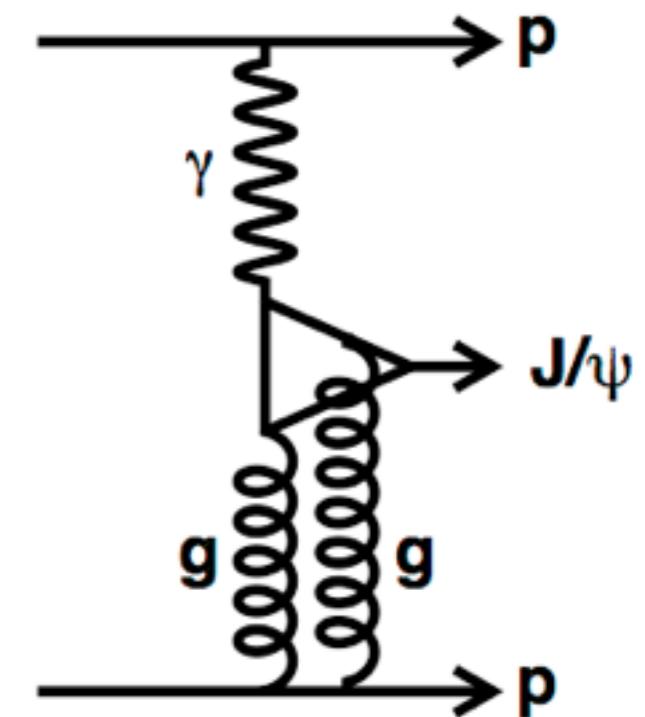
- **non-resonant**
- **feed-down** from other exclusive productions
- **inelastic production**: one or both proton dissociates

CEP of J/ψ and ψ(2S)

Selection ($2011 \rightarrow 1/\text{fb}$)

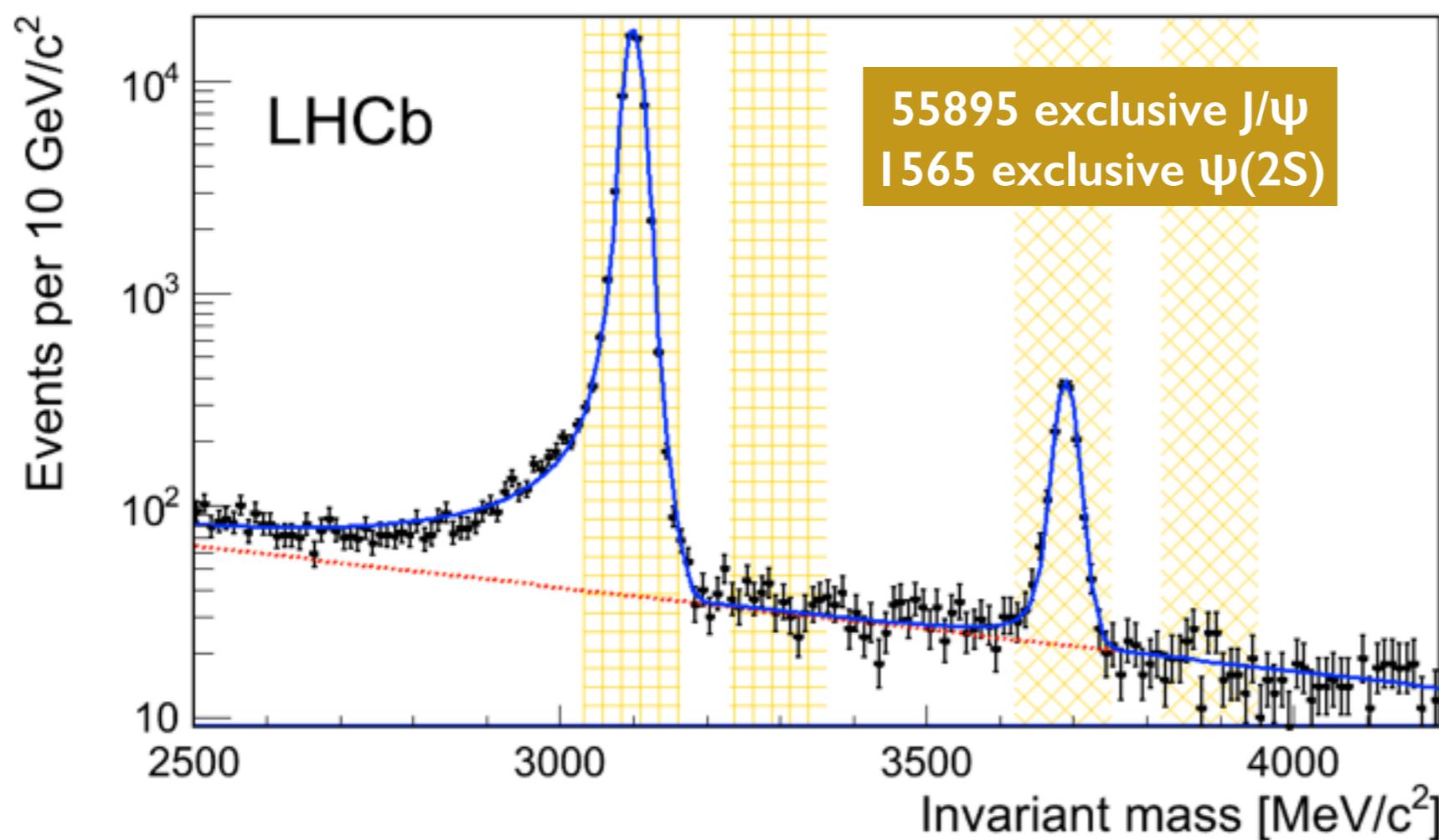
- Precisely two forward muons
- $M(\mu\mu)$ **within** 65 MeV of J/ψ mass
- $p_T^2(\mu\mu) < 0.8 \text{ GeV}^2$

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signal fit - Crystal-Ball function (ad-hoc asymmetrical function)

background fit - exponential



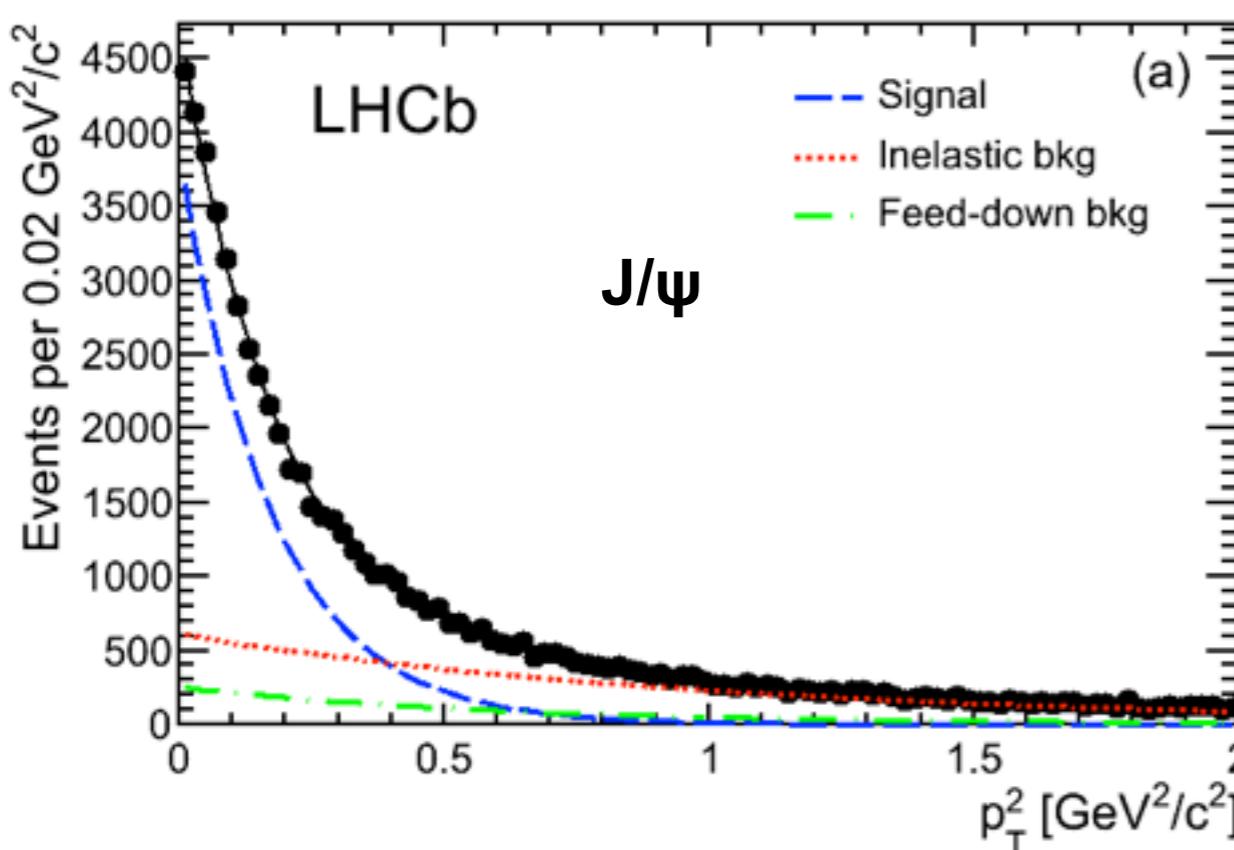
CEP of J/ ψ and $\psi(2S)$

Background

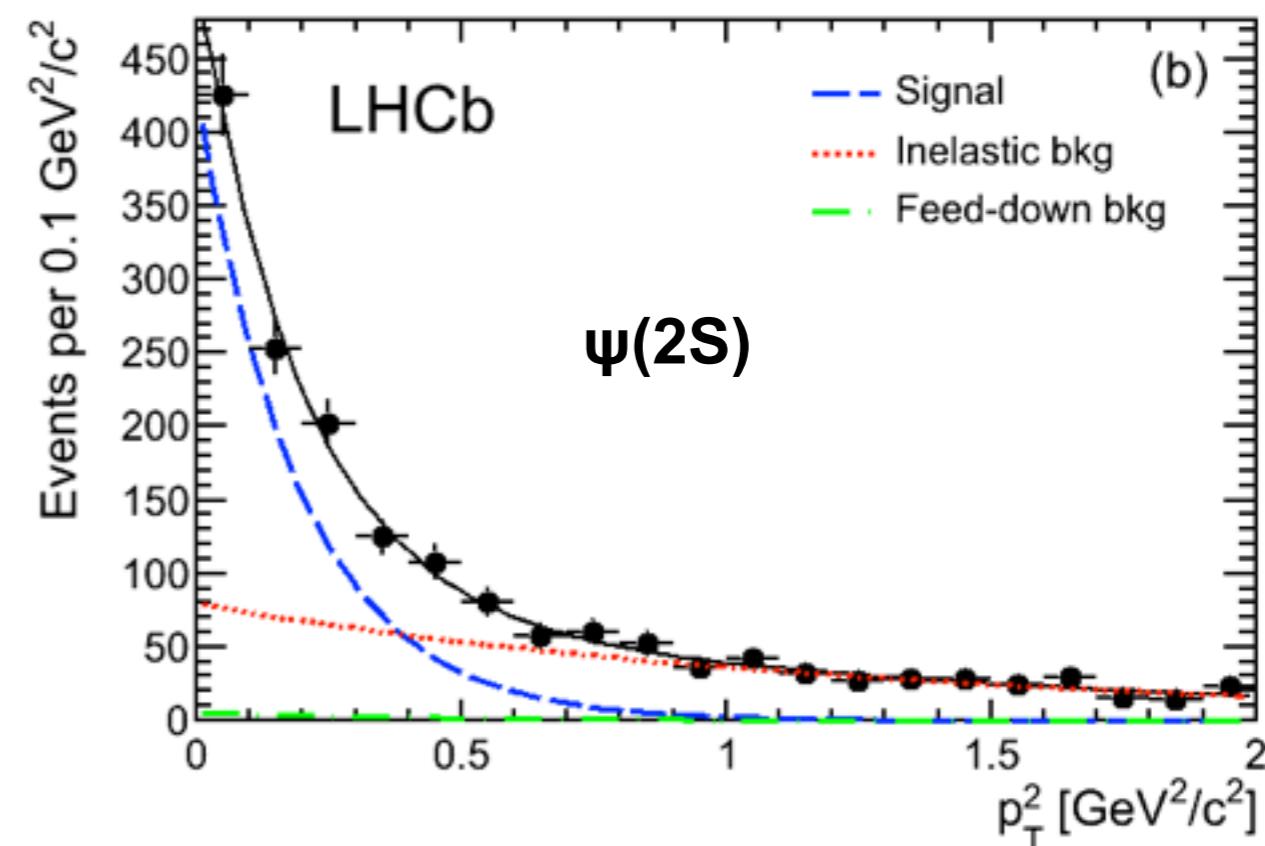
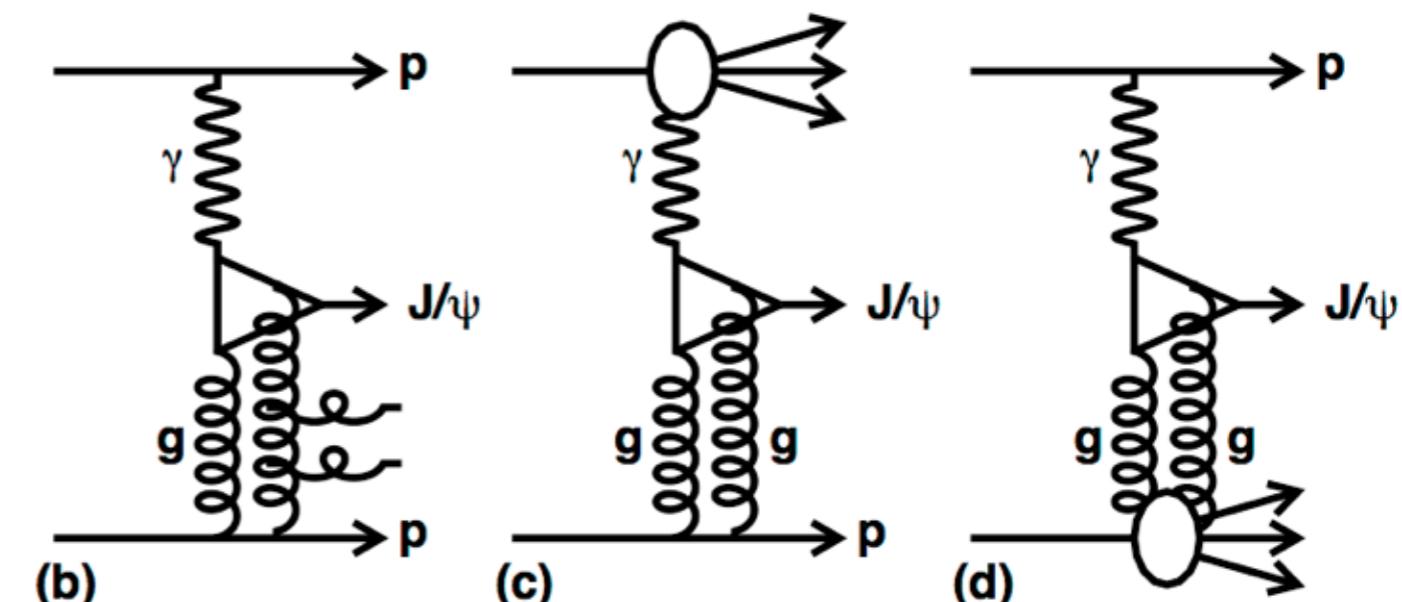
- Inelastic exponential fit to p_T^2
- Feed-down shape taken from data
 $\chi_c \rightarrow J/\psi\gamma$ and $\psi(2S) \rightarrow J/\psi\pi\pi\pi$

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Signal fit exponential to p_T^2



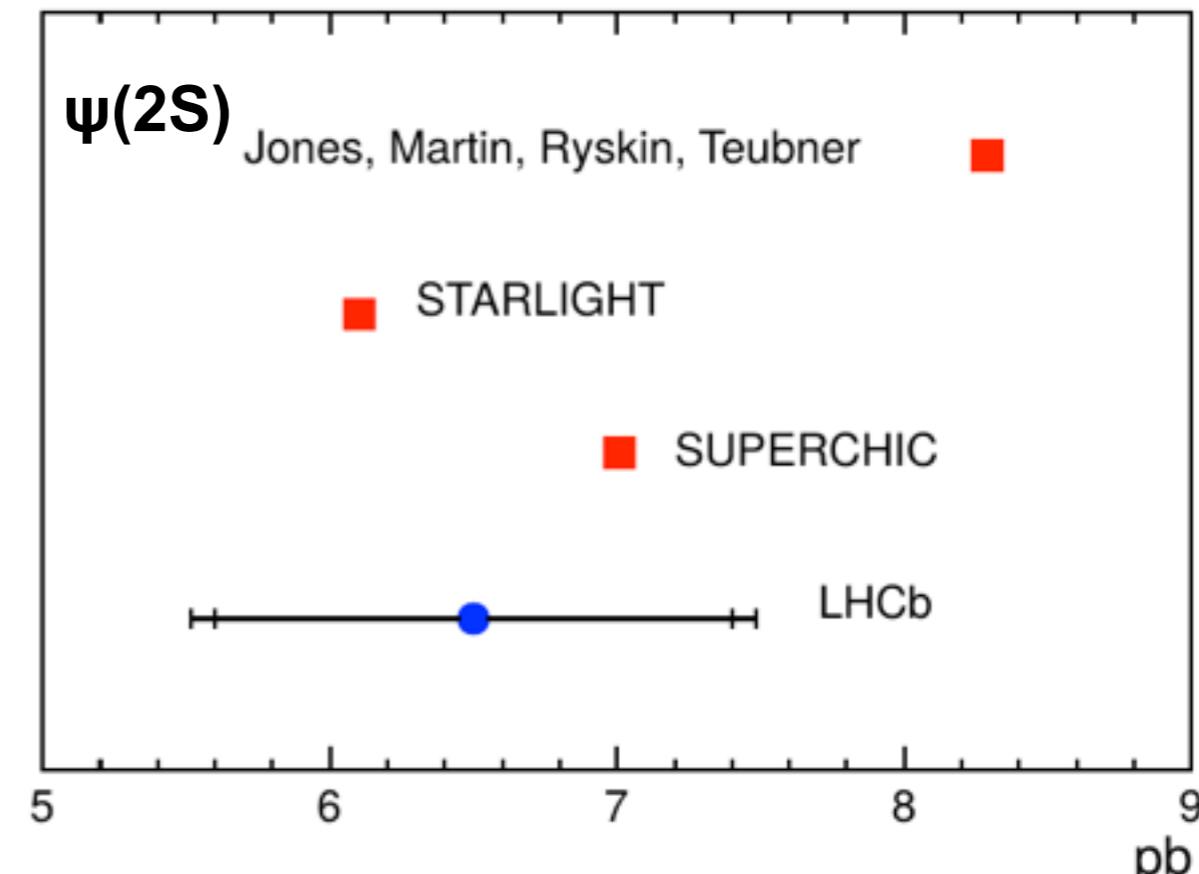
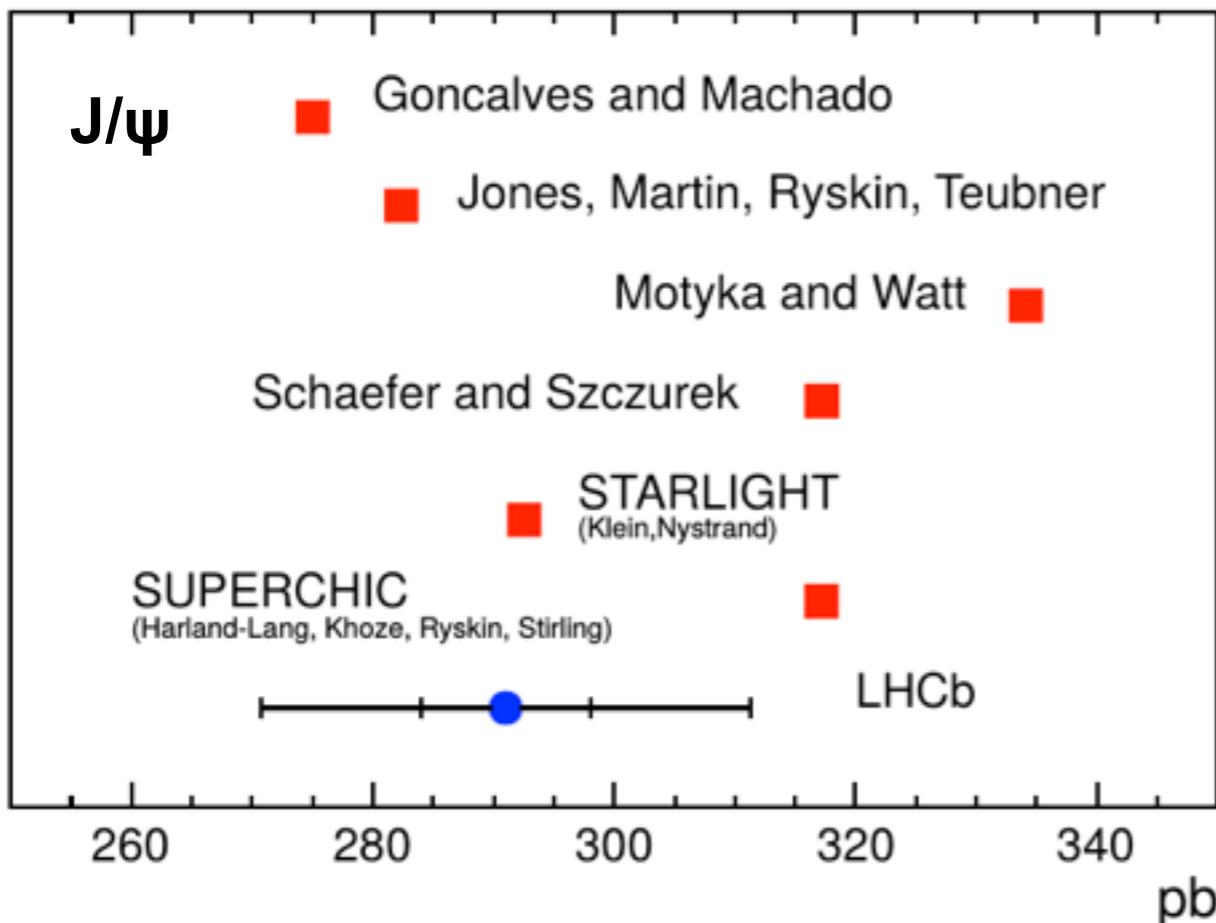
- Overall purities:
 - **(59.2 ± 1.2)** % for J/ψ events
 - **(52.0 ± 7.0)** % for $\psi(2S)$ events
 - **$p_T < 0.8 \text{ GeV}^2$**



CEP of J/ Ψ and $\Psi(2S)$

Cross Section x BR

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

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

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

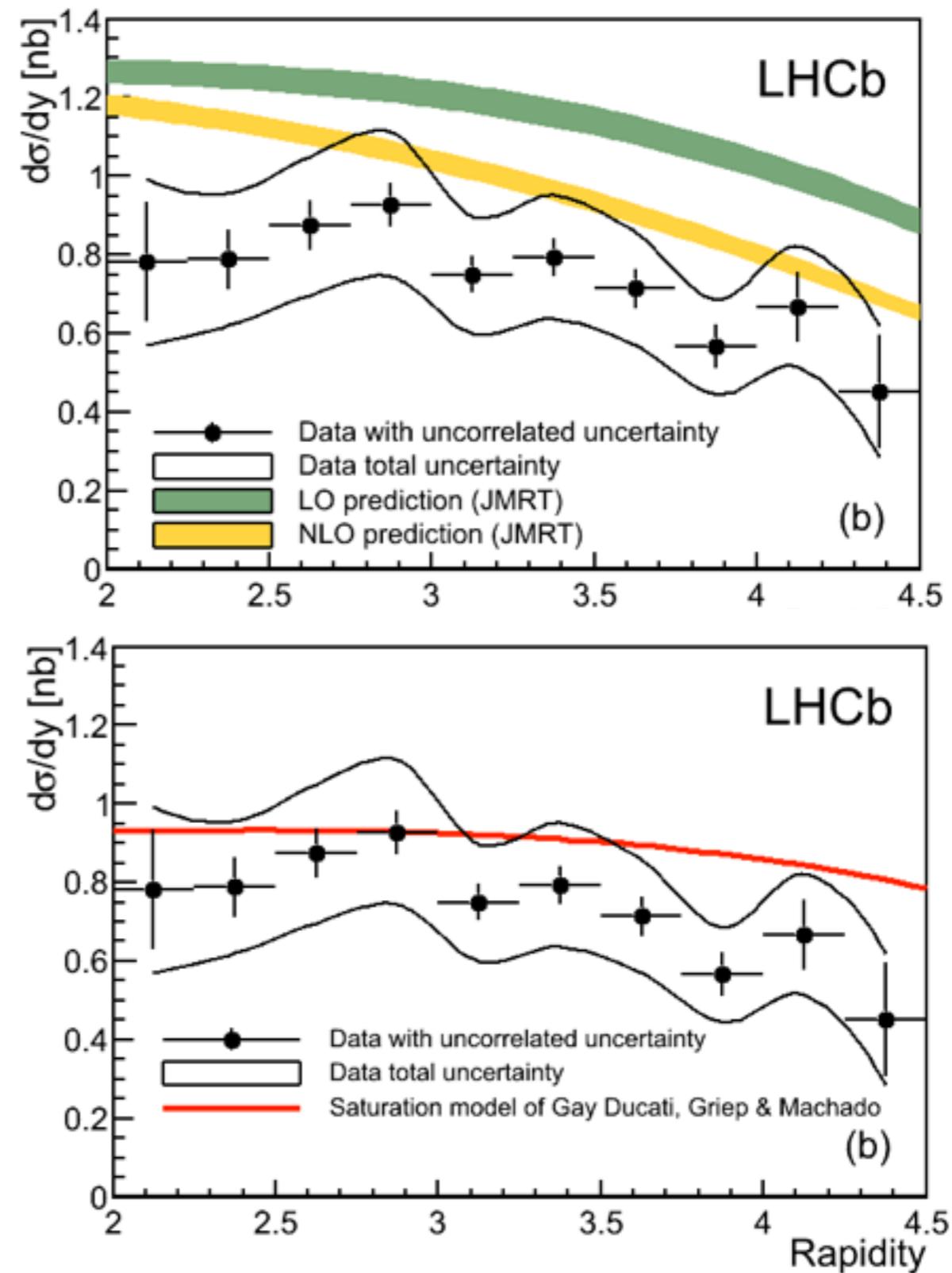
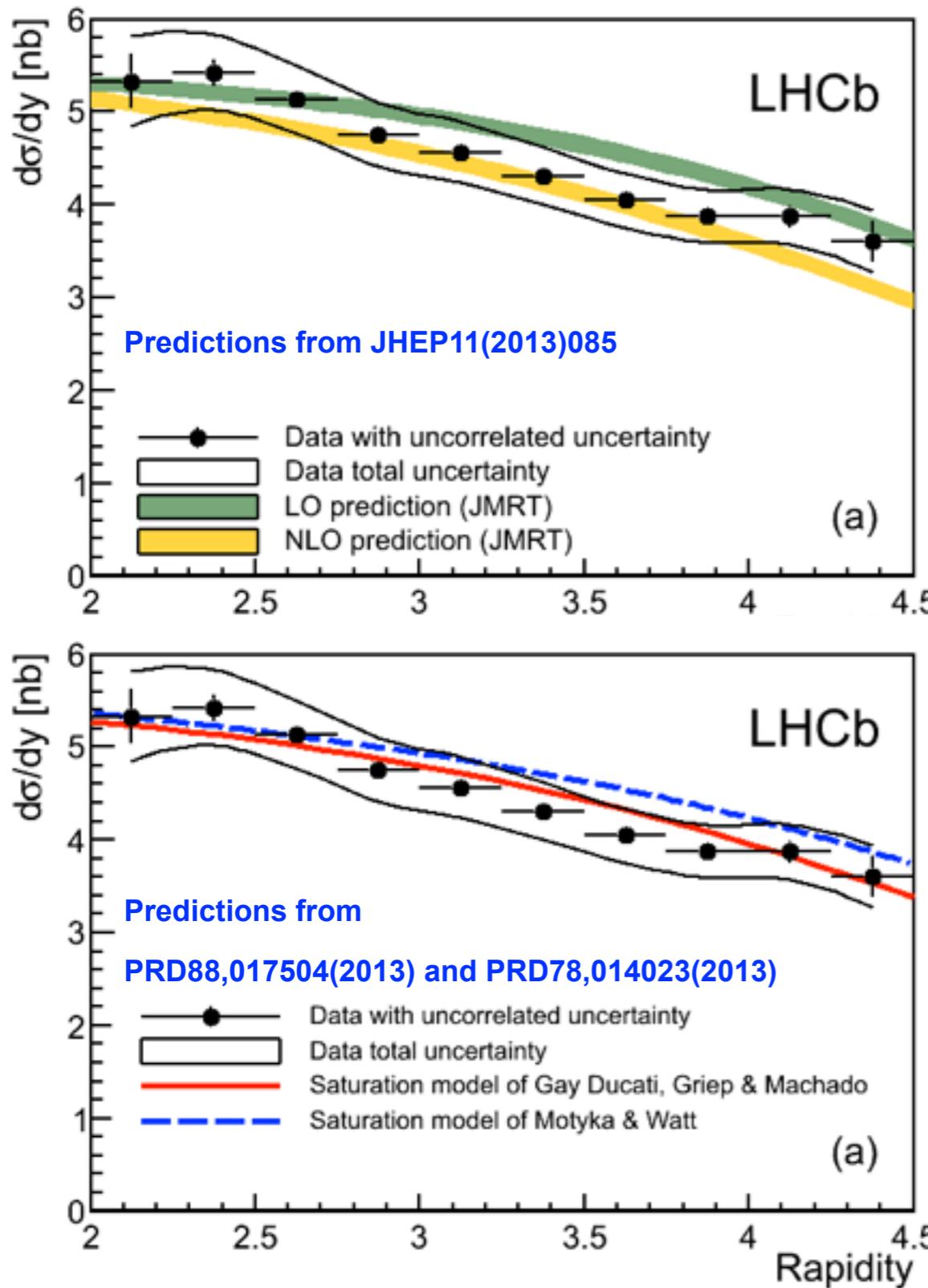
in good agreement with predictions

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

CEP of J/ Ψ and $\Psi(2S)$

Differential Cross Section

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CEP of J/ Ψ and $\Psi(2S)$

γp Cross Section

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Compare to HERA γp data using known photon flux for a photon (energy k)

measured

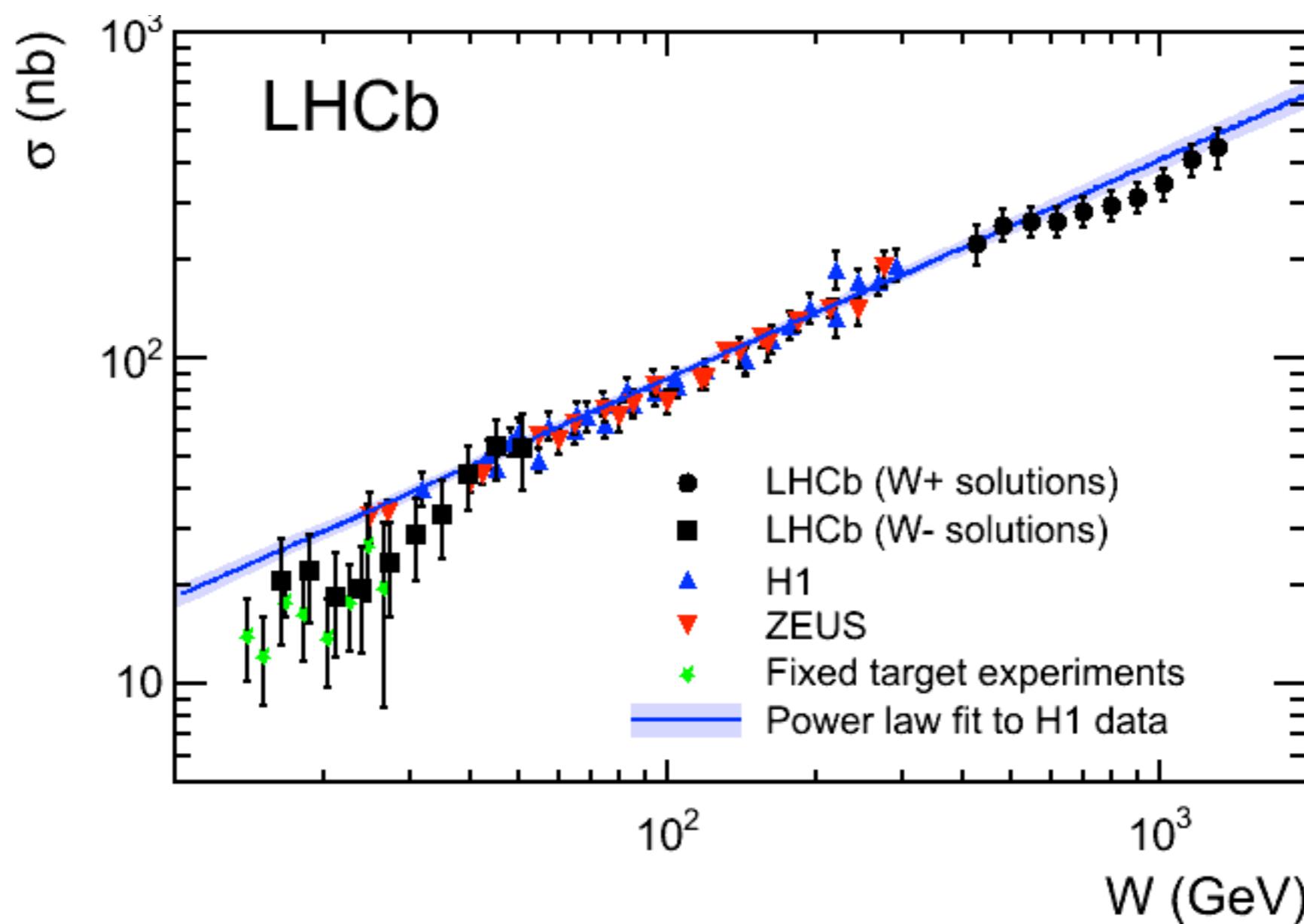
$$\frac{d\sigma}{dy_{pp \rightarrow pVp}} = r(y) [k_+ \frac{dn}{dk_+} \sigma_{\gamma p \rightarrow Vp}(W^+)] + k_- \frac{dn}{dk_-} \sigma_{\gamma p \rightarrow Vp}(W^-)$$

gap survival

extracted

$$[k_+ \frac{dn}{dk_+} \sigma_{\gamma p \rightarrow Vp}(W^+)] + k_- \frac{dn}{dk_-} \sigma_{\gamma p \rightarrow Vp}(W^-)$$

photon flux

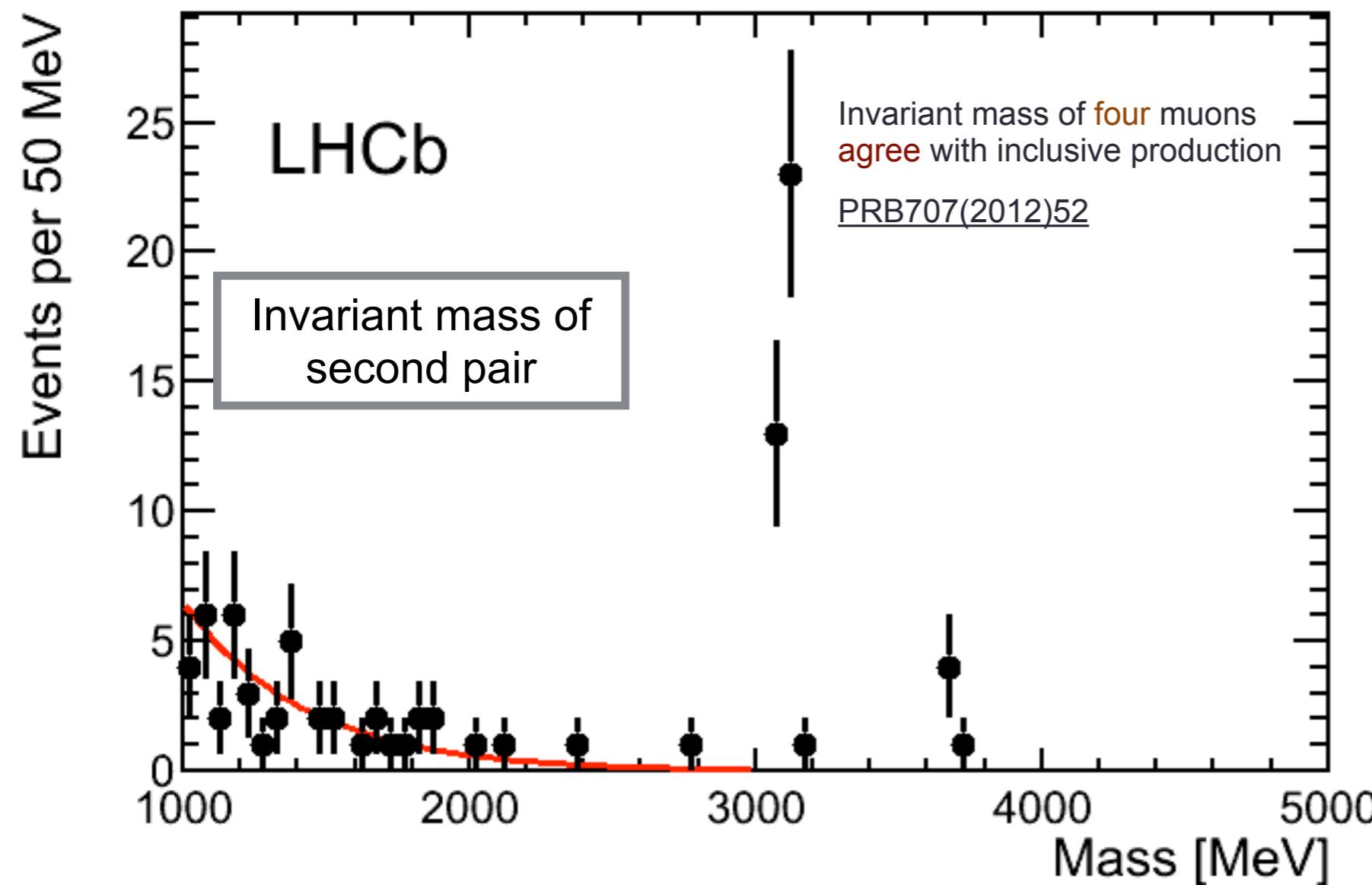
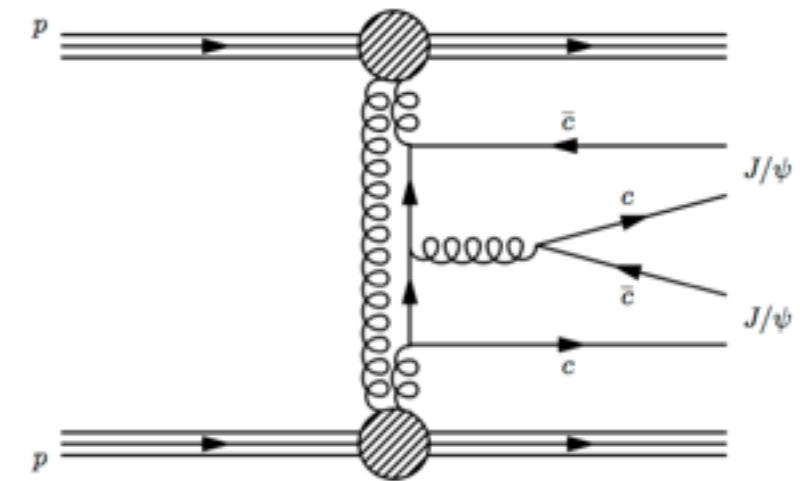


CEP of Charmonium Pair Production

S-wave Selection (2011+2012 → 3/fb)

- Exactly **four** forward tracks
- **Three** identified muons
- J/ψ and $\psi(2S)$ within [-200,+65] MeV from nominal mass

[ArXiv:1407.5973](#)



Candidates:

- 37 in $J/\psi J/\psi$
- 5 in $J/\psi \psi(2S)$
- 0 in $\psi(2S) \psi(2S)$

Extrapolation of **Exponential fit up to 2500 MeV** is used to estimate non-resonant background
 $\Rightarrow 0.3 \pm 0.1 (0.07 \pm 0.02)$ for J/ψ ($\psi(2S)$)

Feed-down from $J/\psi \psi(2S)$ as $J/\psi J/\psi \Rightarrow 2.9 \pm 2.0$ (Negligible feed-down from pairs of P-wave)

Proton dissociation estimated from p_T^2 fit for **theory comparison** $\Rightarrow 0.42 \pm 0.13$ purity

CEP of Charmonium Pair Production

ArXiv:1407.5973

Results

Measurements without proton dissociation correction

Limits are calculated at 90% CL

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

$$\frac{\sigma(J/\psi \psi(2S))}{\sigma(J/\psi J/\psi)} = 1.1^{+0.5}_{-0.4} \quad \frac{\sigma(\psi(2S))}{\sigma(J/\psi)} = 0.17 \pm 0.02$$

Measurements in agreement with preliminary theoretical uncertainties

- PRD84(2011)094023 and Khoze et. al (in preparation)

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

Agreement between inclusive and CEP

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

- LHCb has a unique coverage in η and low p_T at LHC
- CEP of J/ ψ and $\psi(2S)$
 - CEP method at LHCb to understand QCD at low-x
 - good agreement with NLO calculation
 - plans to extend method to other particles
- CEP of Charmonium Pair Production
 - First observation of pair production of S-wave charmonia in CEP
 - Upper limits calculated for pairs of P-wave charmonia CEP
 - Preliminary theoretical predictions are in agreement with measurements
 - Due to small sample size, no strong conclusion about ratios between inclusive-exclusive and J/ ψ $\psi(2S)$ as J/ ψ J/ ψ
- Measurements are valuable information for theory models

BACK UP

CEP of Charmonium Pair Production

[ArXiv:1407.5973](#)

P-wave Selection (2011+2012 → 3/fb)

- At least two two forward muons
- $M(\mu\mu)$ within 65 MeV of J/ψ mass
- $\chi_{c0} \rightarrow J/\psi\gamma$ selection

Only two events found

- o 1 event with 1 photon and it is consistent with $\chi_{c0} \rightarrow J/\psi\gamma \Rightarrow$ CEP of $\chi_{c0}\chi_{c0}$ Candidate
- o 1 event with 2 photons consistent with $\pi^0 \rightarrow \gamma\gamma$

Both events are consistent with CEP of $J/\psi\psi(2S)$, where $\psi(2S) \rightarrow J/\psi\pi^0\pi^0$

- Simulation predicts $2.8 \pm 0.2 (0.5 \pm 0.5)$ with one(two) photons

No candidates found for CEP of $\chi_{c1}\chi_{c1}$ or $\chi_{c2}\chi_{c2}$

Feed-down background from $J/\psi\psi(2S)$

$\Rightarrow 0.8 \pm 0.8$, 0.2 ± 0.2 and 0.1 ± 0.1 for $\chi_{c0}\chi_{c0}$, $\chi_{c1}\chi_{c1}$ and $\chi_{c2}\chi_{c2}$, respectively

CEP of Charmonium Pair Production

Results

[ArXiv:1407.5973](#)

$$\sigma^{M_1 M_2} = \frac{N_{M_1 M_2} - N_{\text{bkg}}}{(f_{\text{single}} L) \ A \in \mathcal{B}(M_1 \rightarrow \mu\mu(\gamma)) \ \mathcal{B}(M_2 \rightarrow \mu\mu(\gamma))}$$

- $N_{M_1 M_2}$ = number of candidate meson pairs selected
- N_{bkg} = number of background events
- L = integrated luminosity
- f_{single} = fraction of beam crossings with a single interaction
- \mathcal{B} = branching fraction for the meson decay

	$J/\psi J/\psi$	$J/\psi \psi(2S)$	$\psi(2S)\psi(2S)$	$\chi_{c0}\chi_{c0}$	$\chi_{c1}\chi_{c1}$	$\chi_{c2}\chi_{c2}$
$N_{M_1 M_2}$	37	5	0	1	0	0
N_{bkg}	3.2 ± 2.0	0.07 ± 0.02	< 0.01	0.8 ± 0.8	0.2 ± 0.2	0.1 ± 0.1
A	0.35 ± 0.03	0.36 ± 0.03	0.36 ± 0.03	0.29 ± 0.03	0.29 ± 0.03	0.29 ± 0.03
ϵ	0.80 ± 0.04	0.80 ± 0.04	0.80 ± 0.04	0.58 ± 0.06	0.66 ± 0.05	0.69 ± 0.05
$f_{\text{single}} L [\text{pb}^{-1}]$				596 ± 21		
$\mathcal{B}(J/\psi \rightarrow \mu\mu)$					0.0593 ± 0.0006	
$\mathcal{B}(\psi(2S) \rightarrow \mu\mu)$					0.0077 ± 0.0008	
$\mathcal{B}(\chi_{c0} \rightarrow J/\psi \gamma)$					0.0117 ± 0.0008	
$\mathcal{B}(\chi_{c1} \rightarrow J/\psi \gamma)$					0.344 ± 0.015	
$\mathcal{B}(\chi_{c2} \rightarrow J/\psi \gamma)$					0.195 ± 0.008	