

Ultraperipheral Collisions at LHCb

Cesar Luiz da Silva for the LHCb Collaboration

Los Alamos National Lab

31st International Workshop on Deep Inelastic Scattering – Grenoble (France)



U.S. DEPARTMENT OF
ENERGY

Office of Science



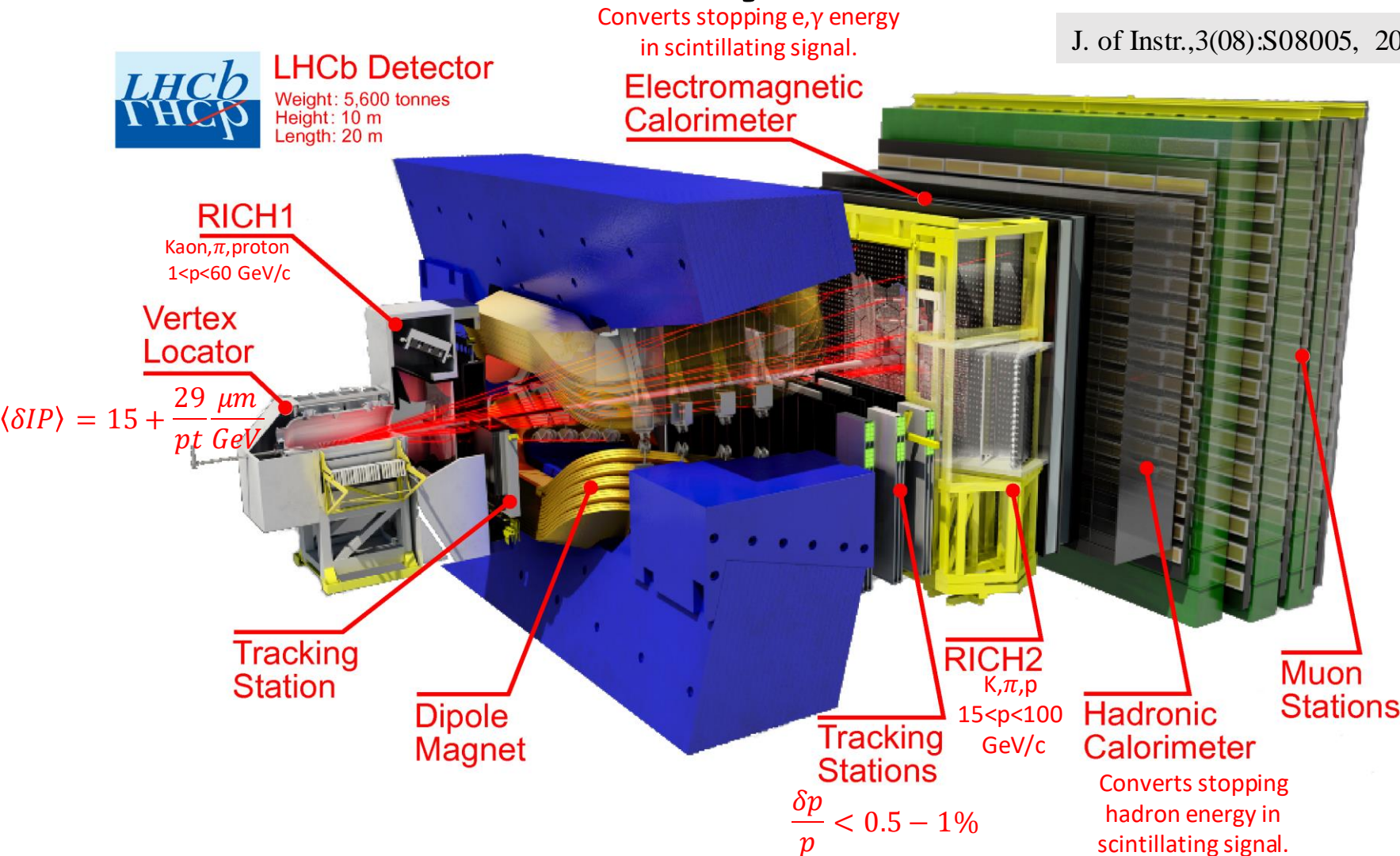
The LHC beauty detector Runs 1 & 2

J. of Instr.,3(08):S08005, 2008

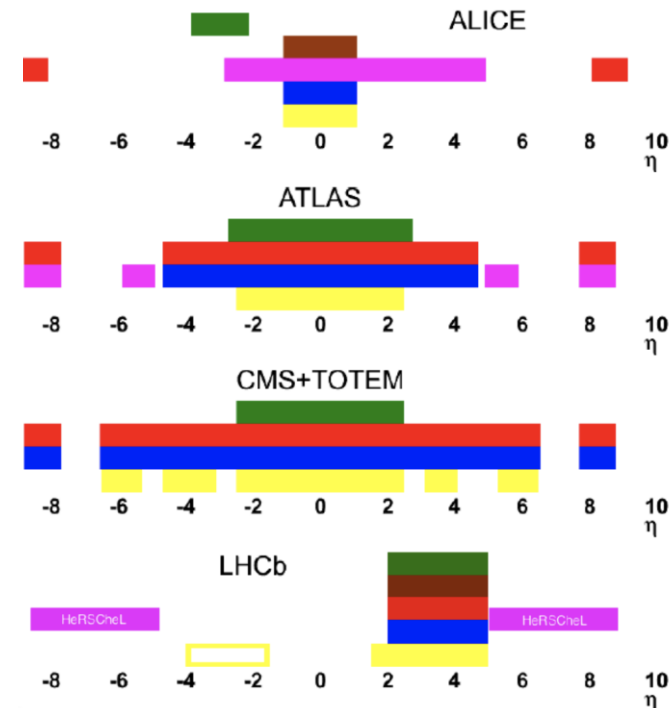


LHCb Detector

Weight: 5,600 tonnes
Height: 10 m
Length: 20 m



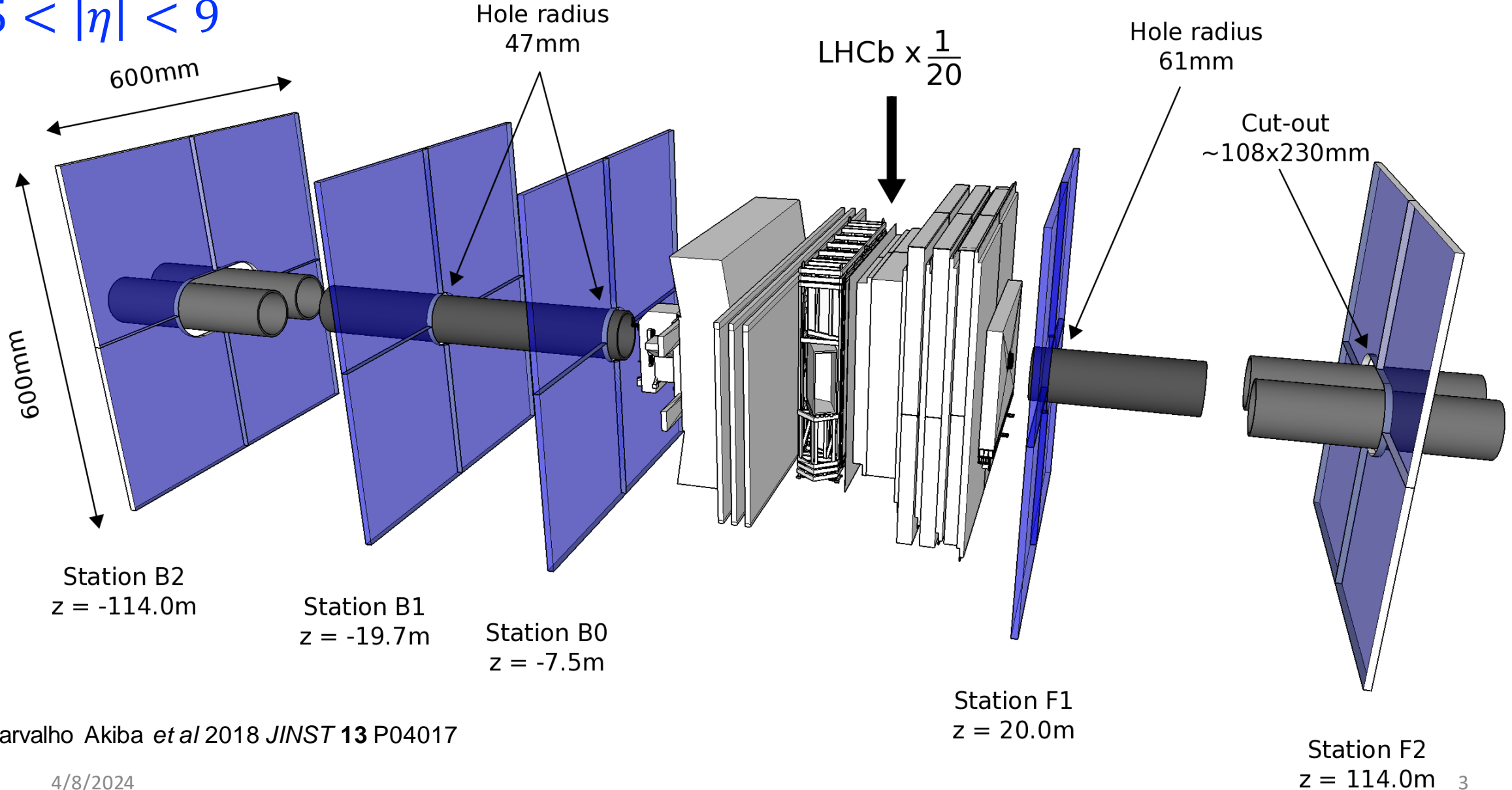
- hadron PID
- muon system
- lumi counters
- HCAL
- ECAL
- tracking



- Dedicated to Flavor Physics
- $e, \mu, \pi, K, p, \gamma$, particle identification in $1 < p < 100$ GeV/c
- Unique forward instrumentation for heavy ion physics

HeRSChel detector: high-rapidity shower counters for LHCb

$$5 < |\eta| < 9$$

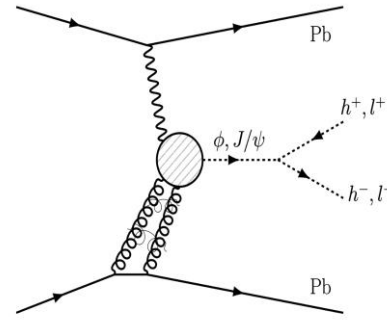


K. Carvalho Akiba *et al* 2018 *JINST* **13** P04017

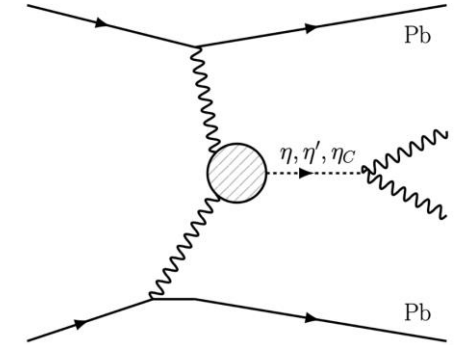
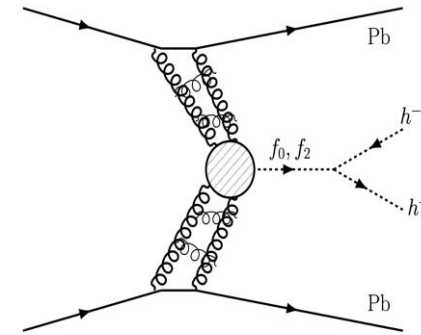
4/8/2024

LHCb has detector coverage and particle identification for an entire UPC program

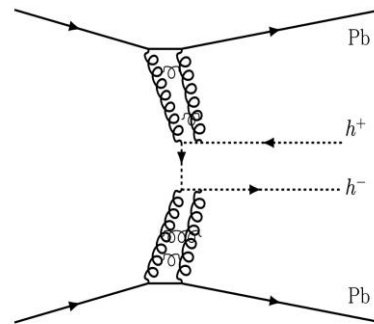
- Photoproduction of vector mesons



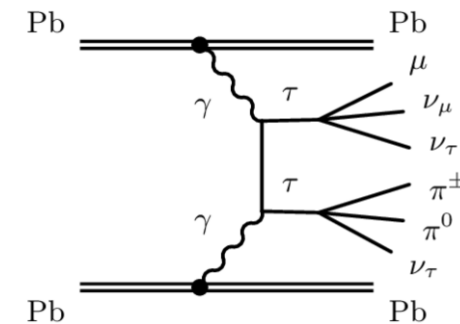
- scalar and tensor mesons from pomeron+pomeron and $\gamma\gamma$ interactions
- Glueball and tetraquark searches



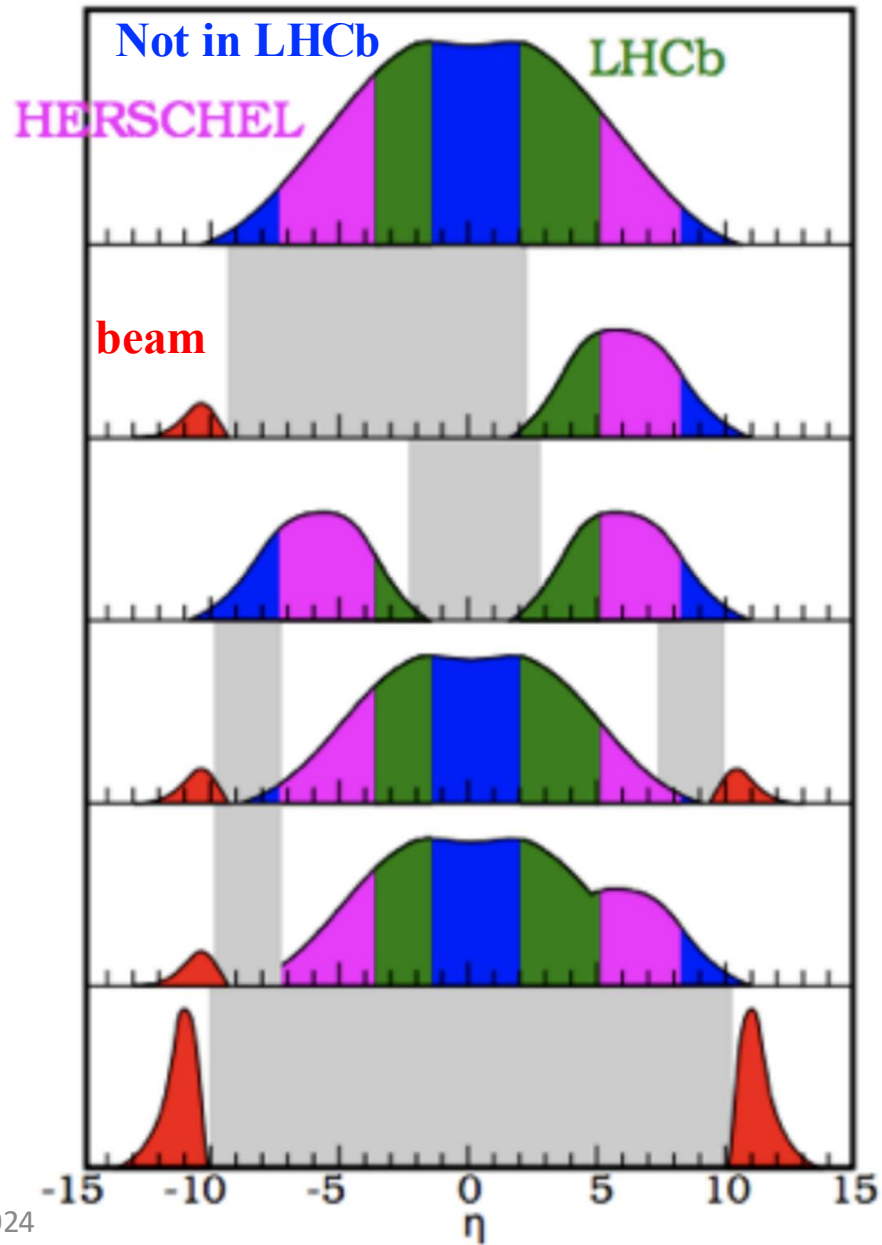
- Non-resonant spectrum



- BSM : τ g-2 with hadron decays and lepton $p_T \ll 1$ GeV/c



Rapidity coverage



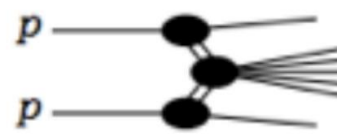
inelastic



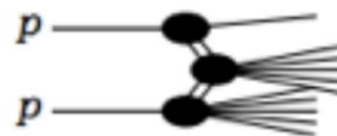
single diffraction



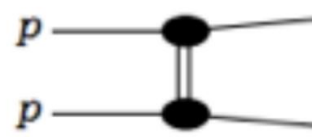
double diffraction



CEP+UPC elastic



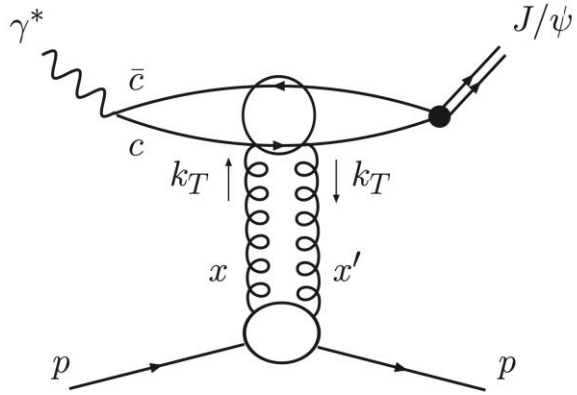
CEP+UPC inelastic



Elastic

Brief History of CEP measurements in LHCb

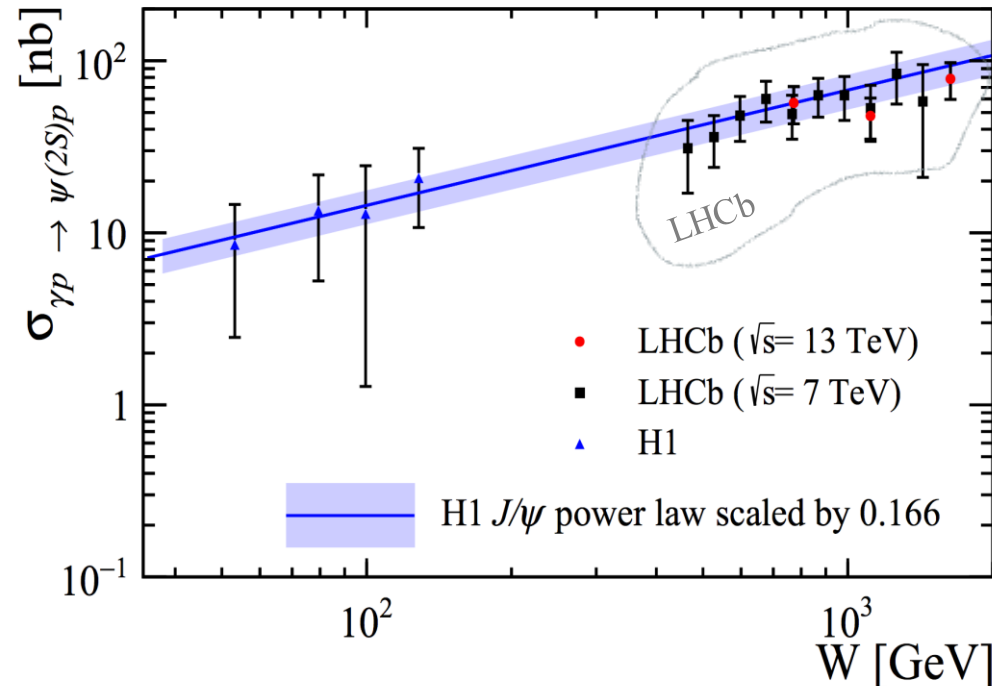
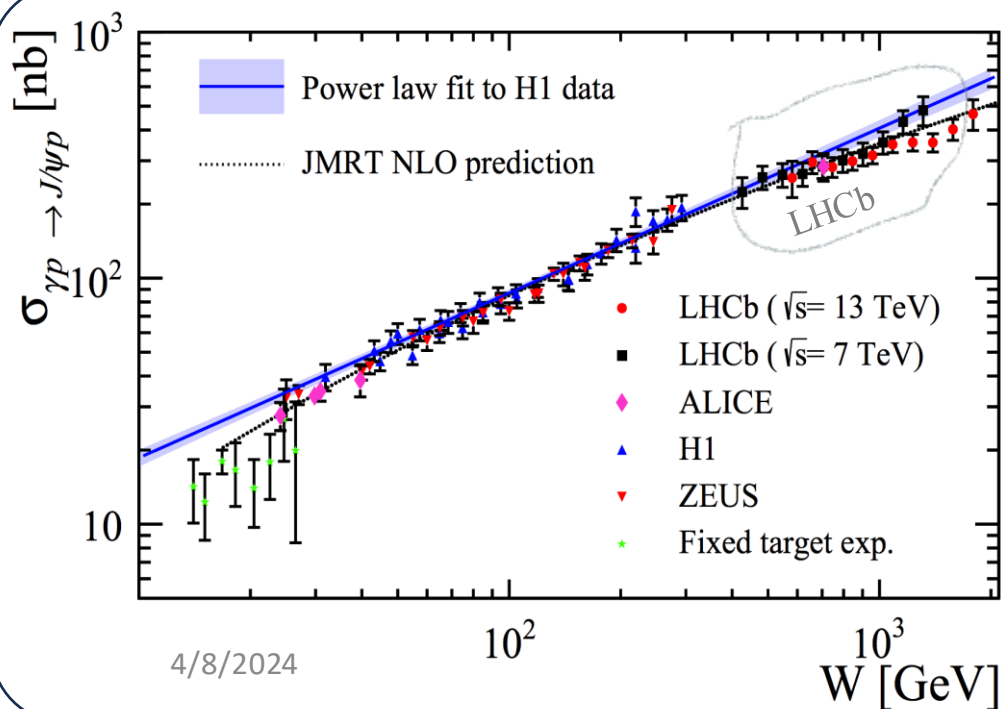
$J/\psi, \psi(2S)$ Photo-production cross-section in CEP



JHEP11(2013)085

photon energy
 $k_{\pm} \equiv (M_{\psi}/2)e^{\pm y_{\psi}}$

Invariant mass of the photon-proton system
 $W_{\pm}^2 = 2k_{\pm}\sqrt{s}$

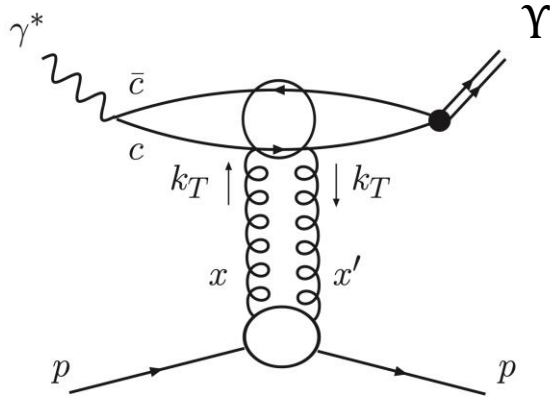


JHEP 10 (2018) 167

$W^2 \equiv 2k\sqrt{s}$

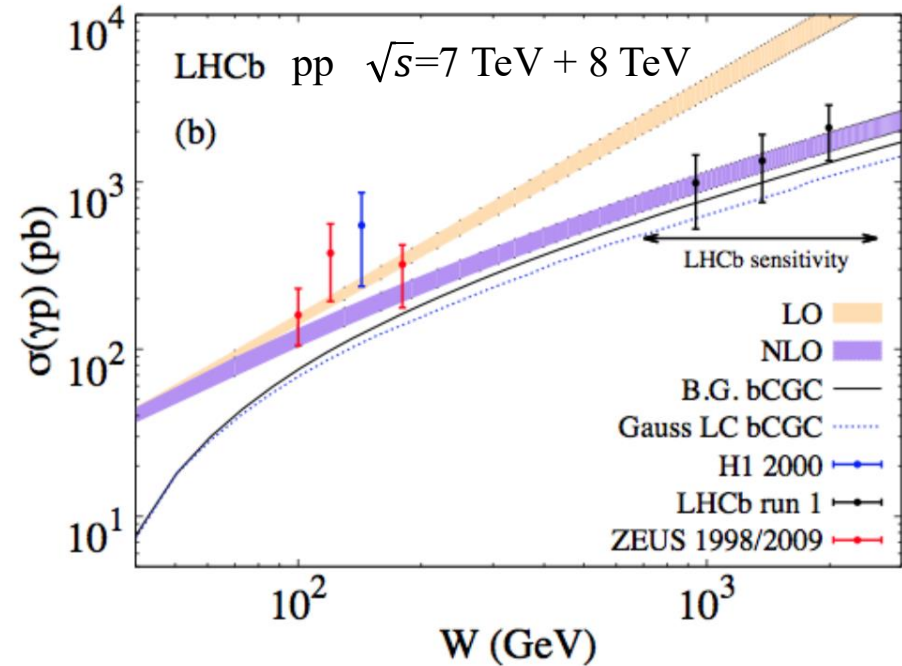
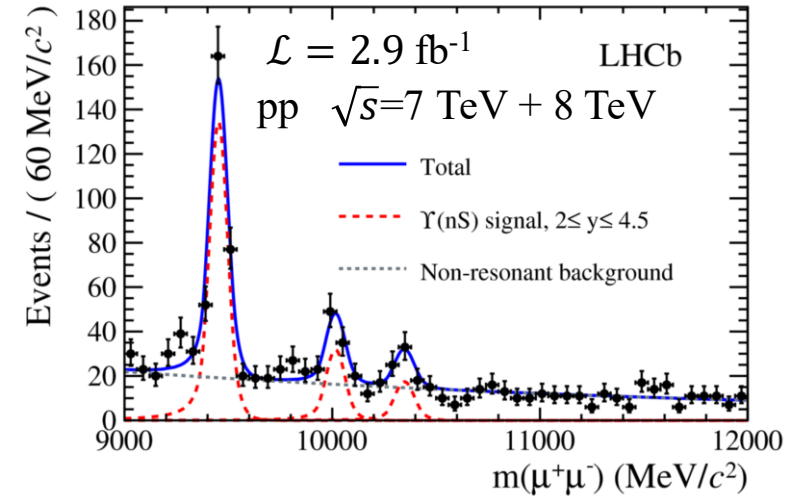
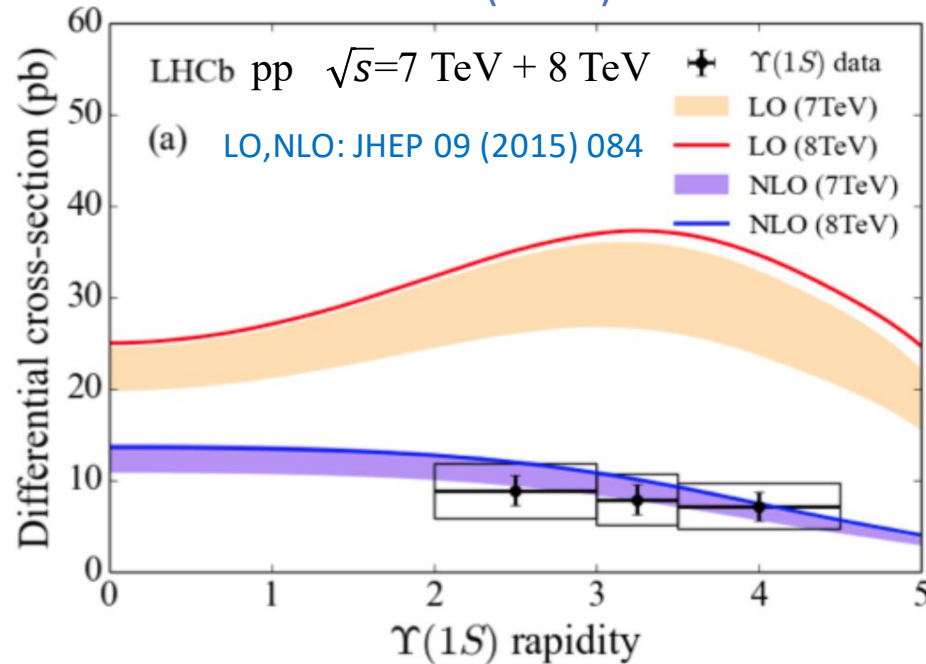
HeRSChel sel.

Bottomonia photo-production cross-section in CEP



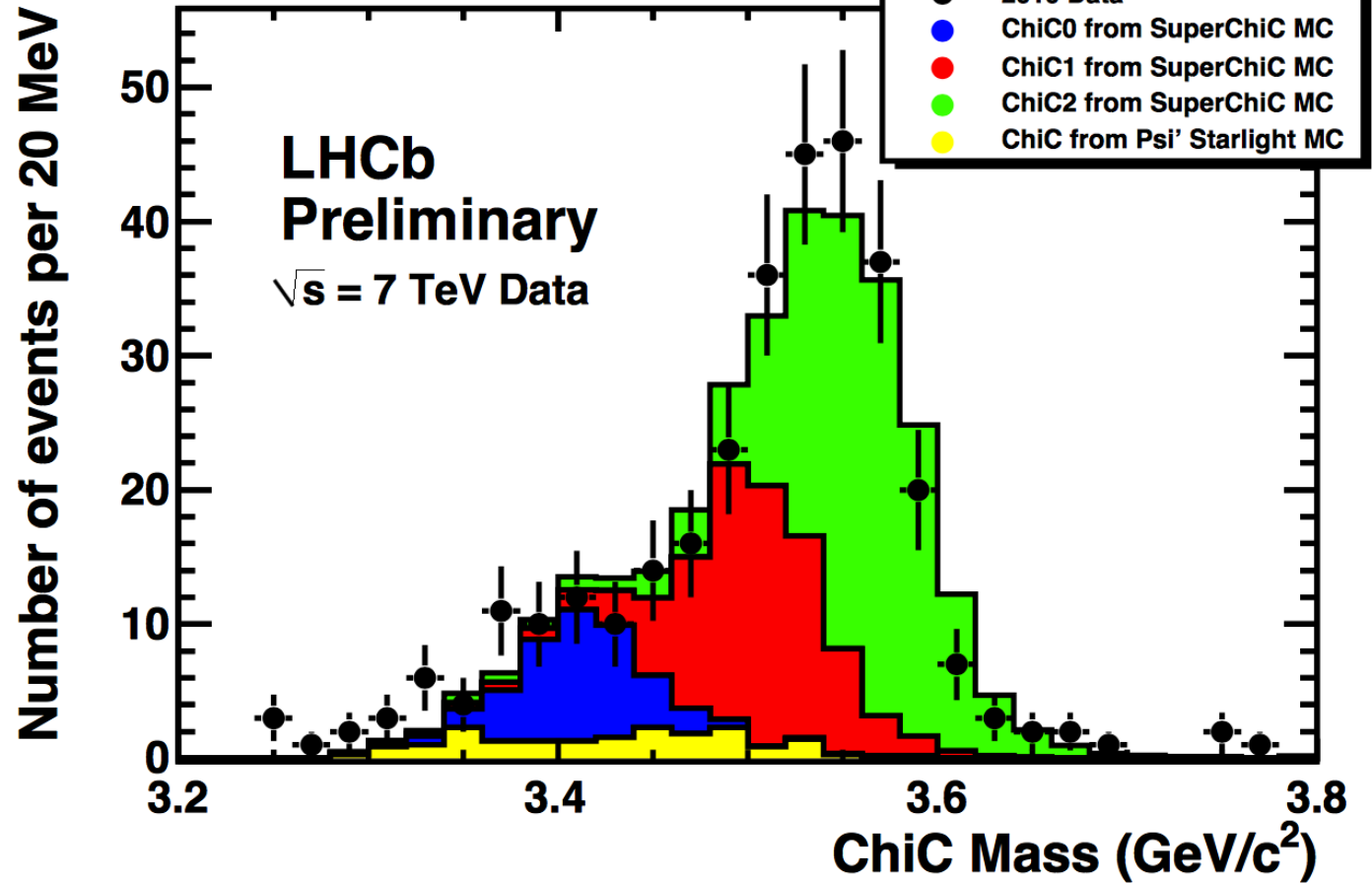
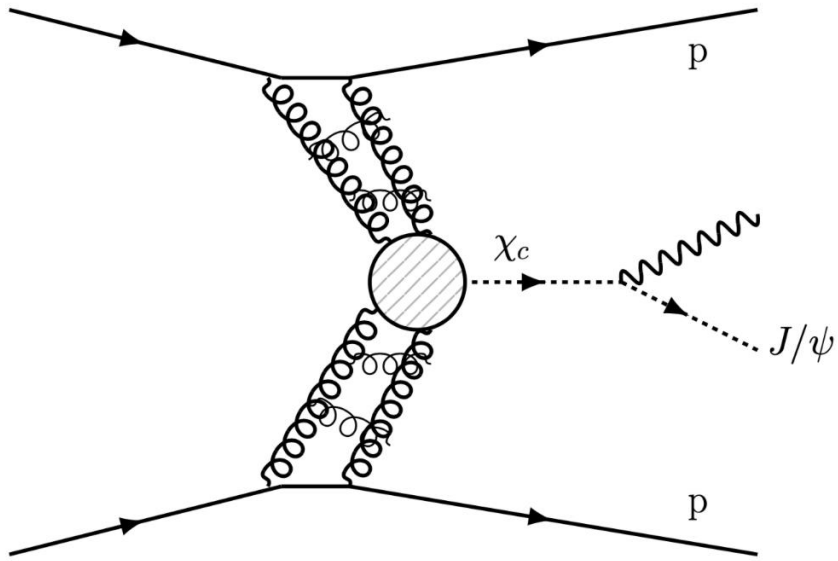
$$Q^2 \approx 25 \text{ GeV}^2$$

JHEP 1509 (2015) 084



P-wave charmonia

LHCb-CONF-2011-022

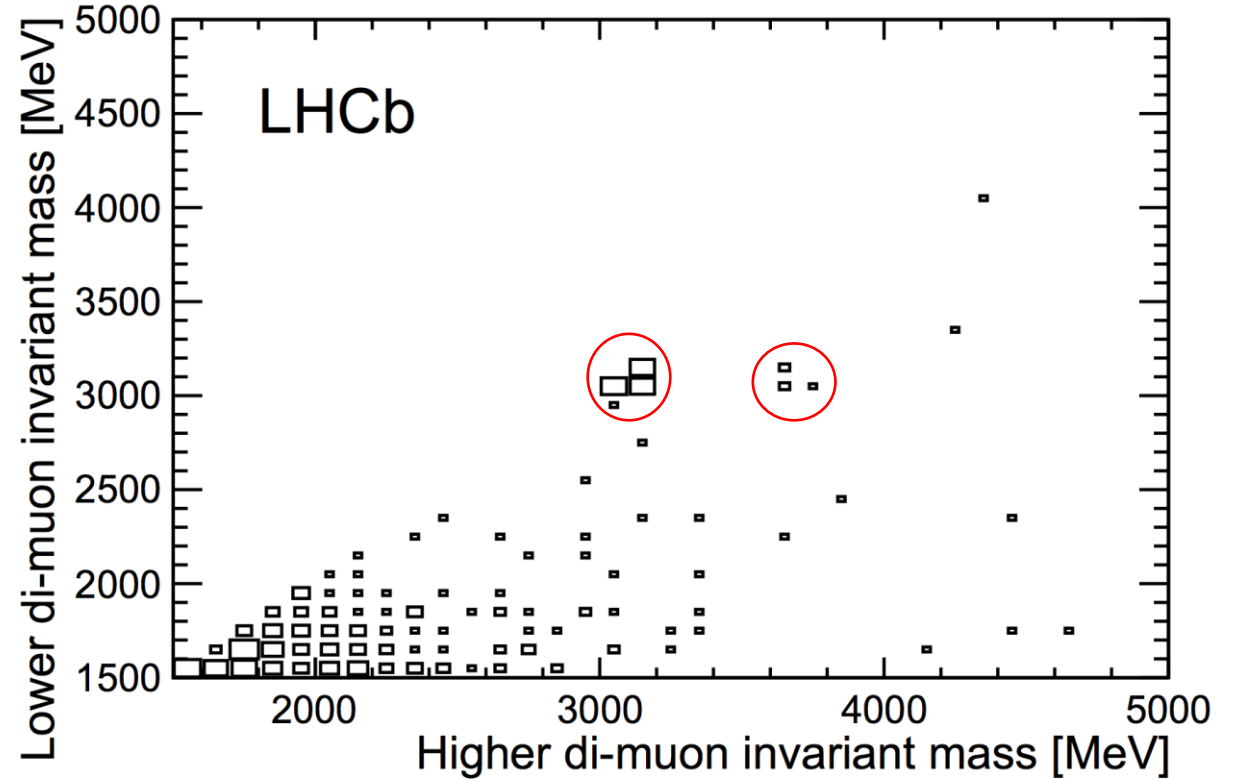
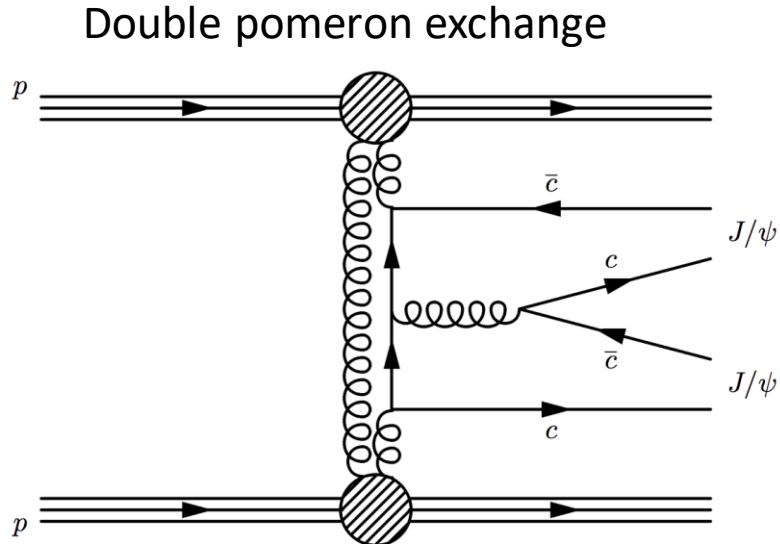


Can access oderon production.

New measurement using HeRSChel on target.

Double Charmonium production

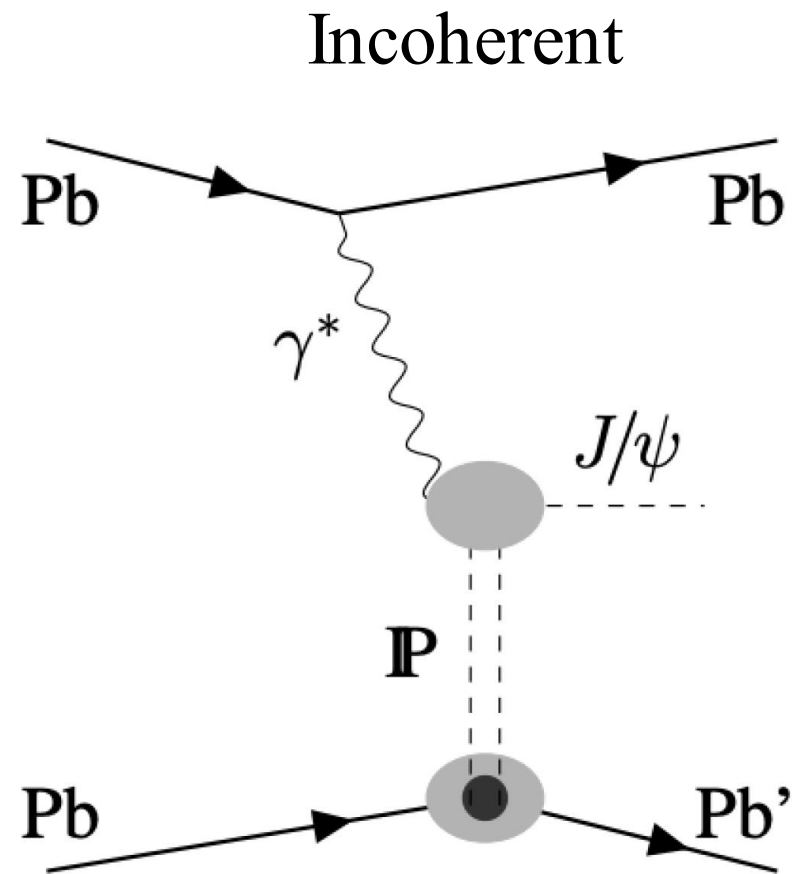
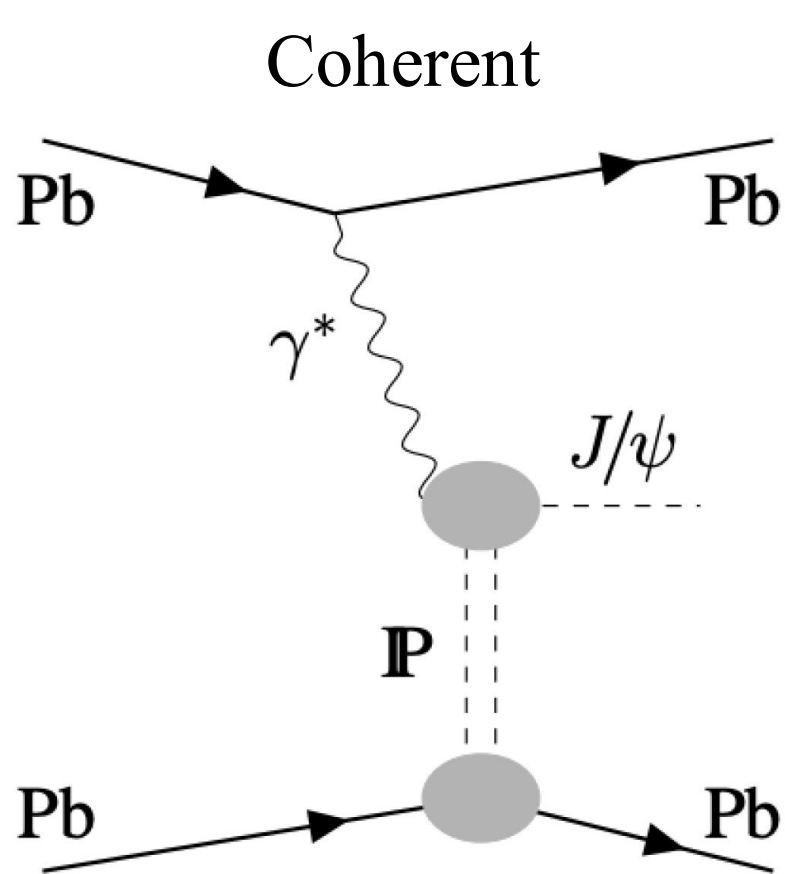
J.Phys.G41 (2014)115002



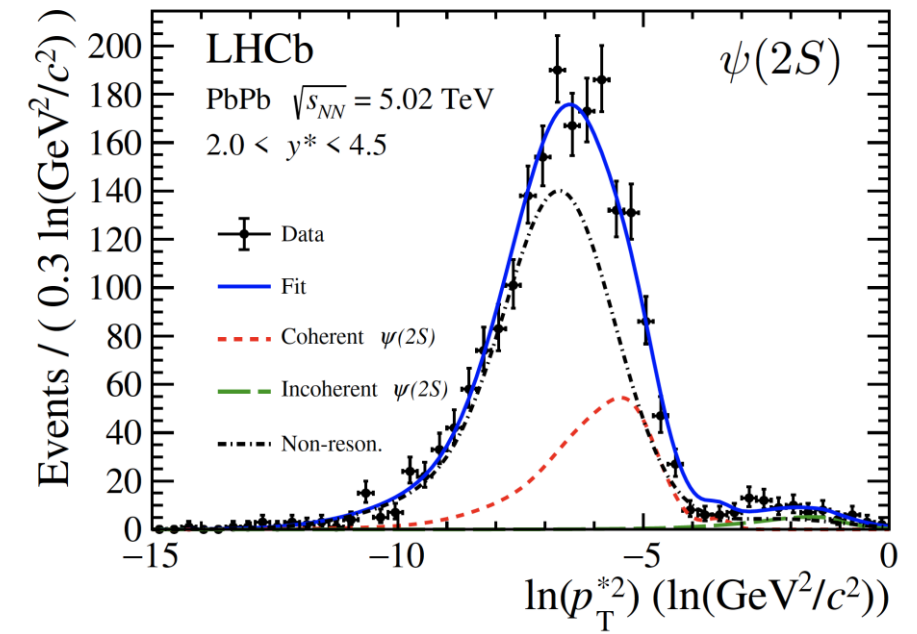
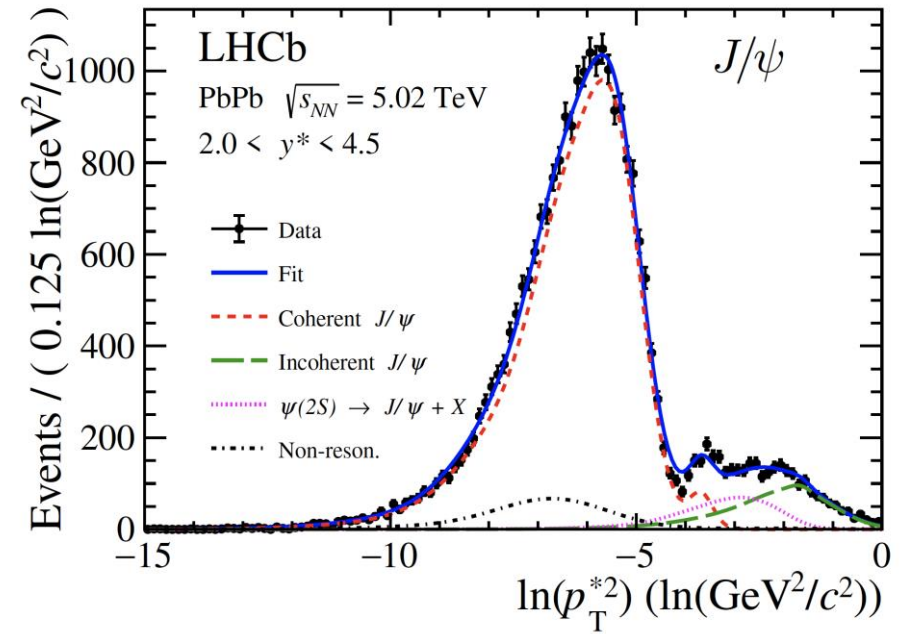
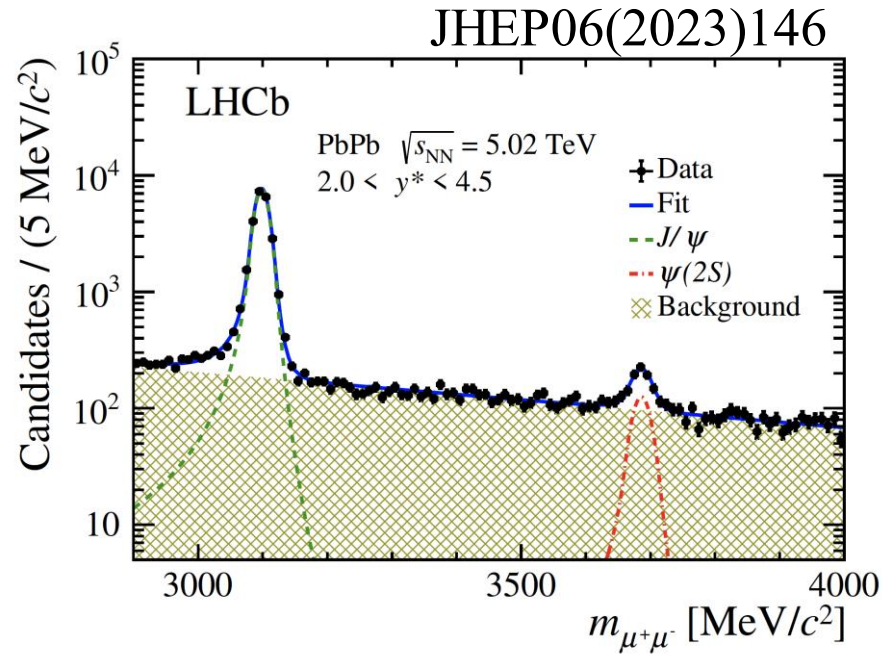
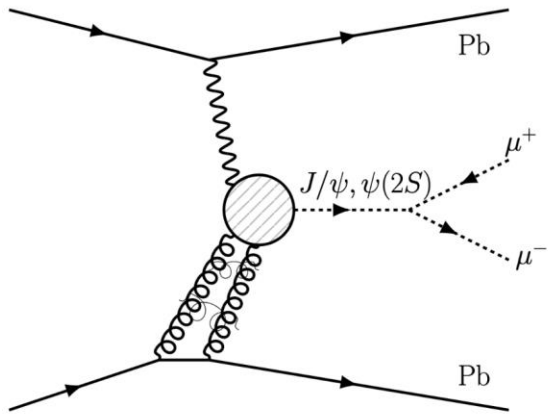
$$\begin{aligned} \sigma_{J/\psi J/\psi} &= 58 \pm 10(\text{stat}) \pm 6(\text{syst}) \text{ pb}, \\ \sigma_{J/\psi \psi(2S)} &= 63_{-18}^{+27}(\text{stat}) \pm 10(\text{syst}) \text{ pb}, \\ \sigma_{\psi(2S)\psi(2S)} &< 237 \text{ pb}, \\ \sigma_{\chi_{c0}\chi_{c0}} &< 69 \text{ nb}, \\ \sigma_{\chi_{c1}\chi_{c1}}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

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

Photo-production in PbPb UPC



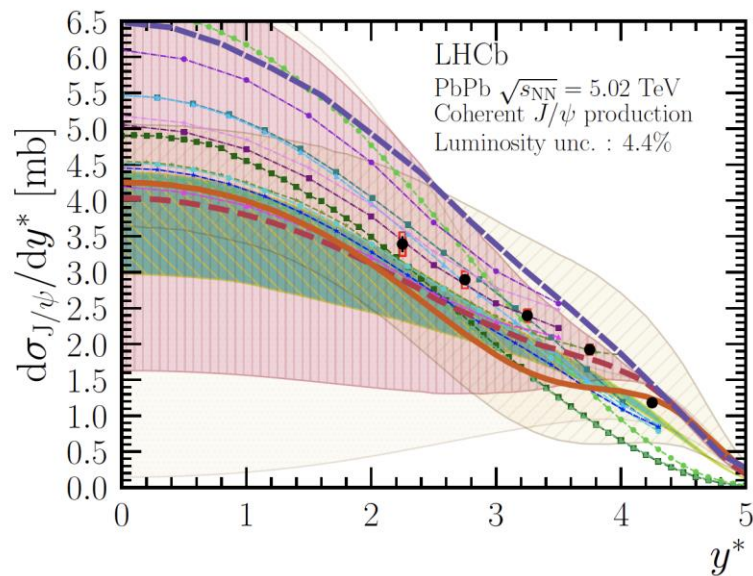
J/ψ , $\psi(2S)$ photoproduction in UPC



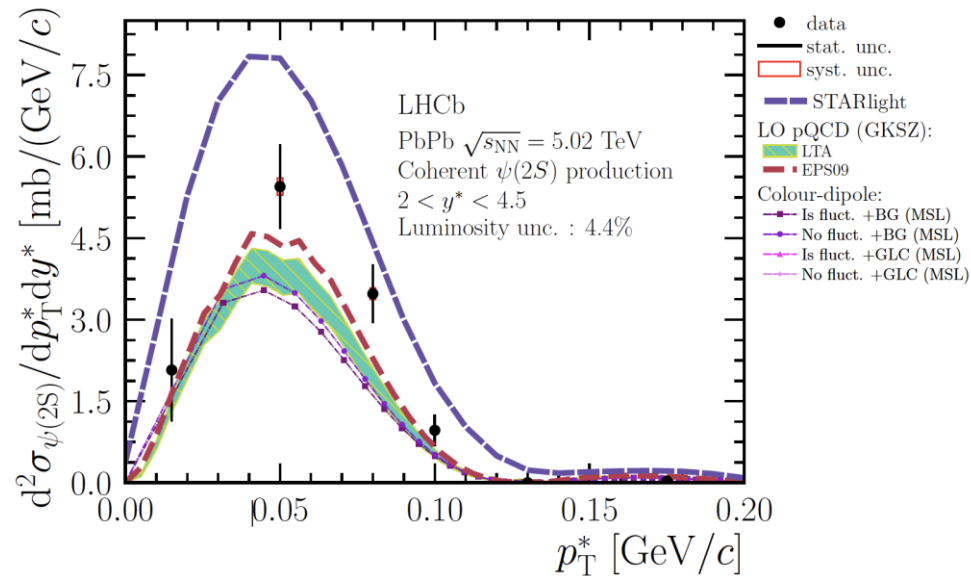
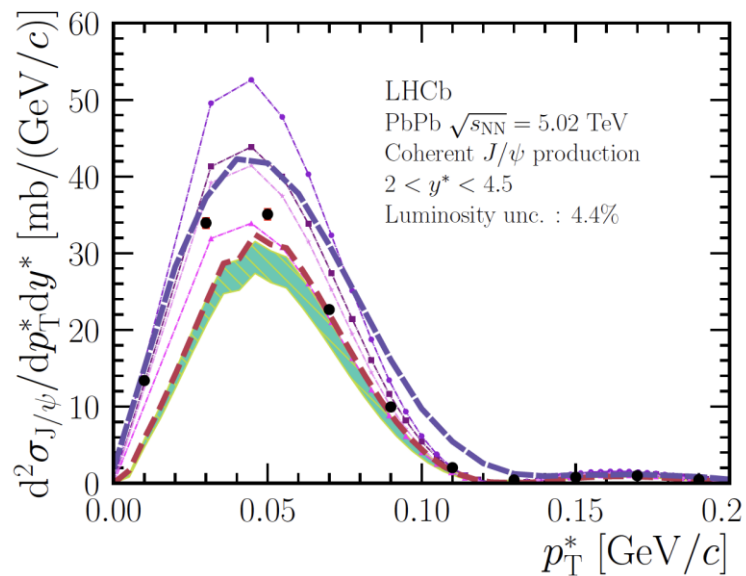
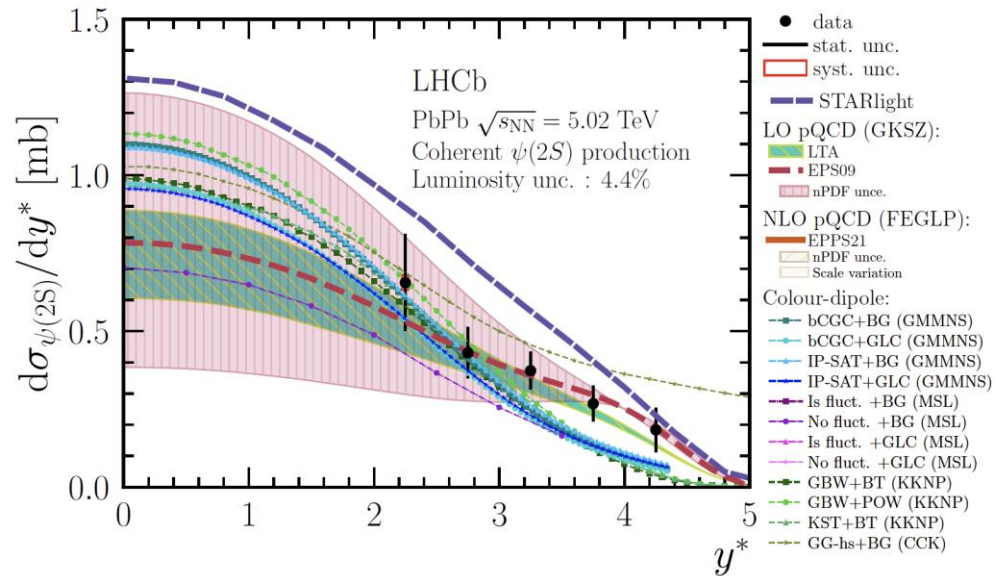
- Excellent separation between coherent and incoherent components, thanks to
 - HeRSCHeL
 - High p_T resolution

Comparison with theoretical models

J/ψ



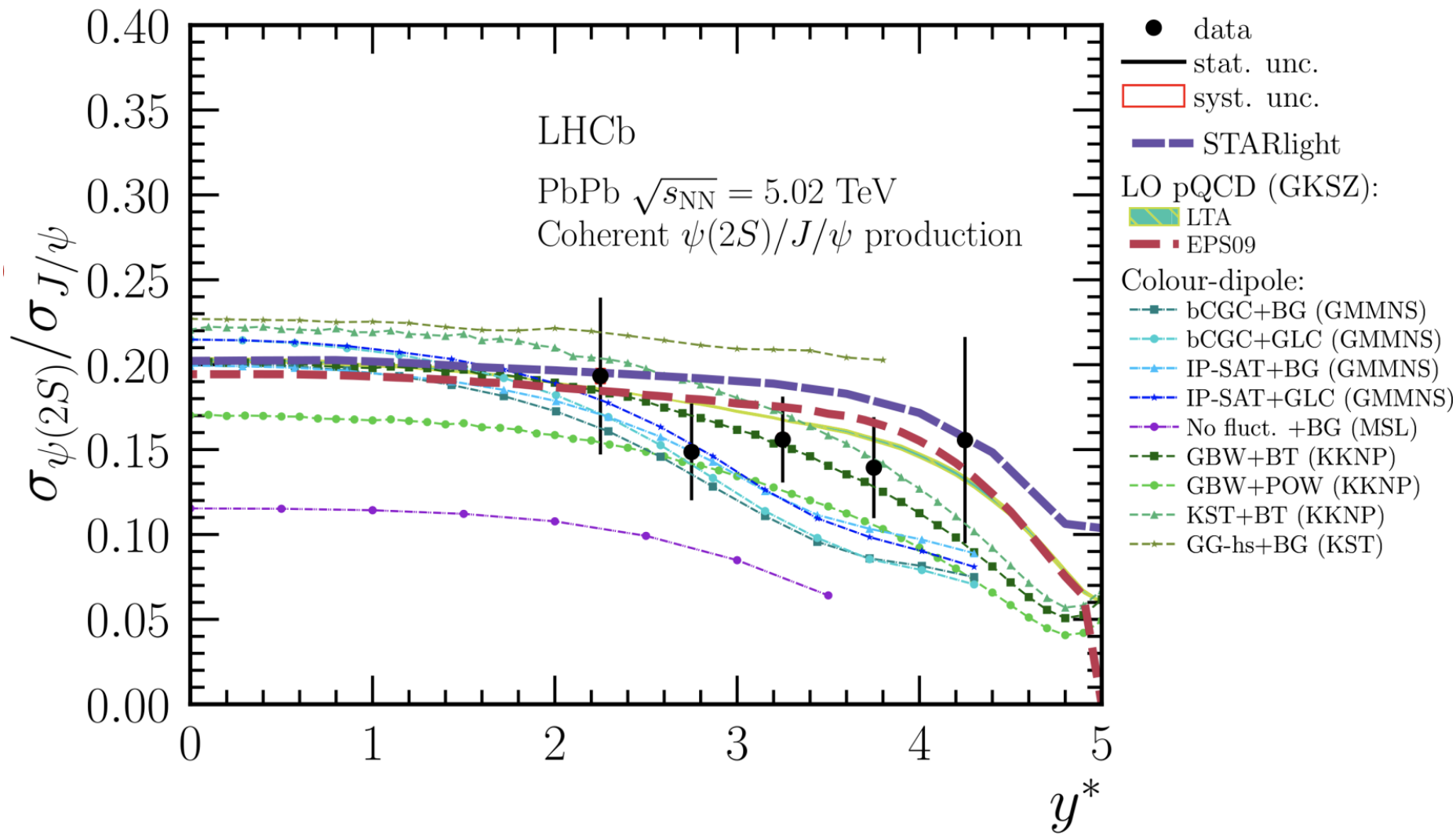
$\psi(2S)$



JHEP06(2023)146

Comparison with theoretical models

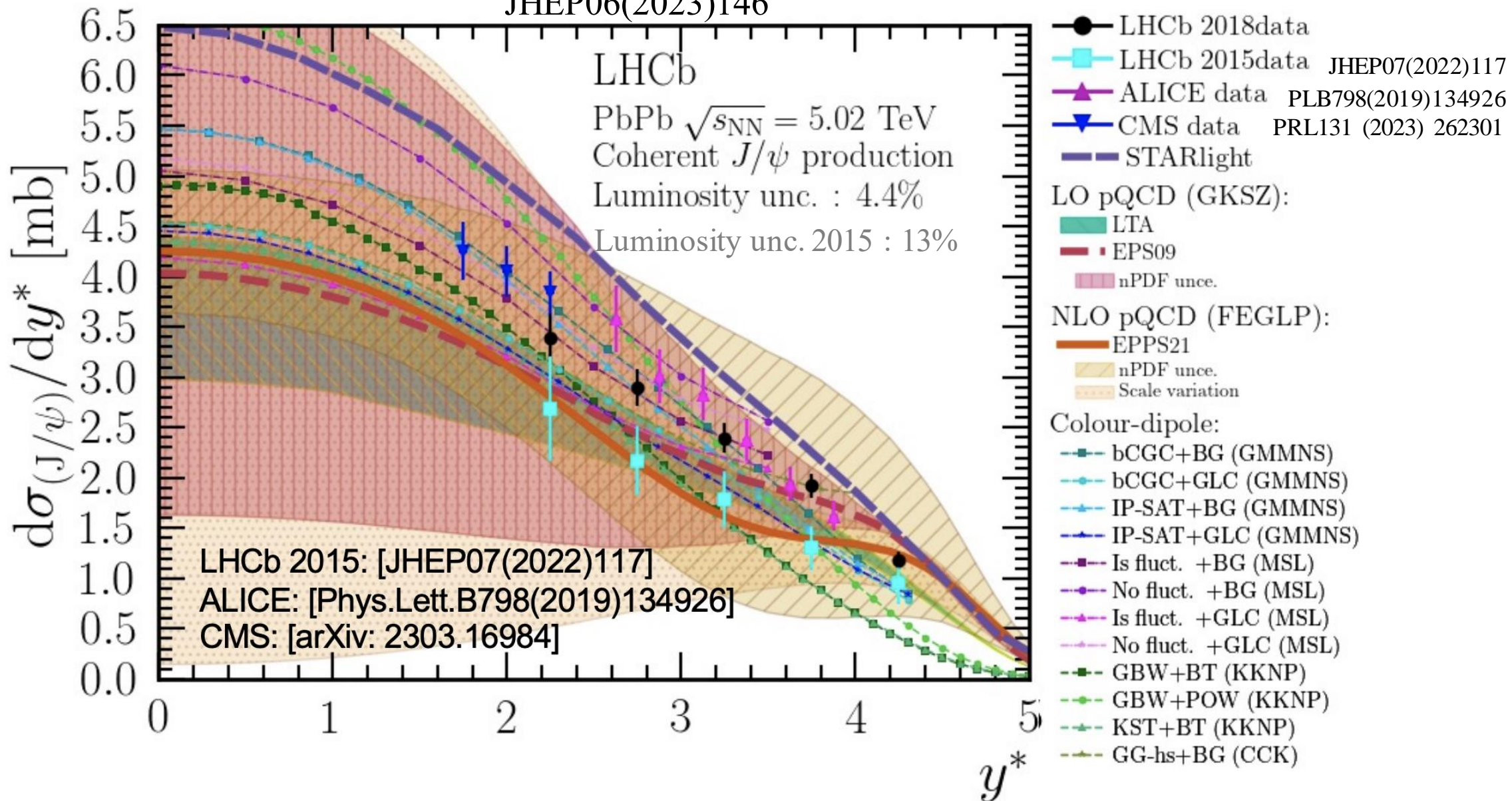
JHEP06(2023)146



Ratio sensitive to the color-dipole size in Color-Glass Condensate model.

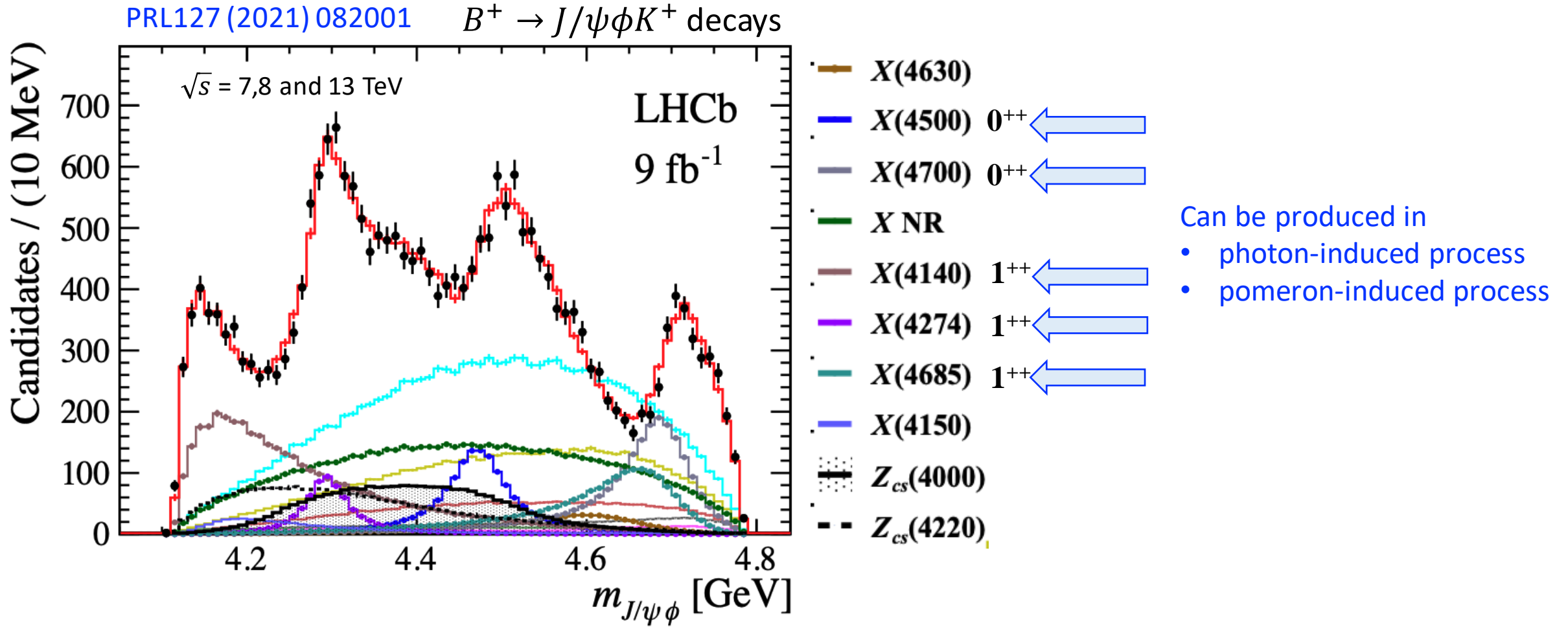
Comparison with previous results

JHEP06(2023)146



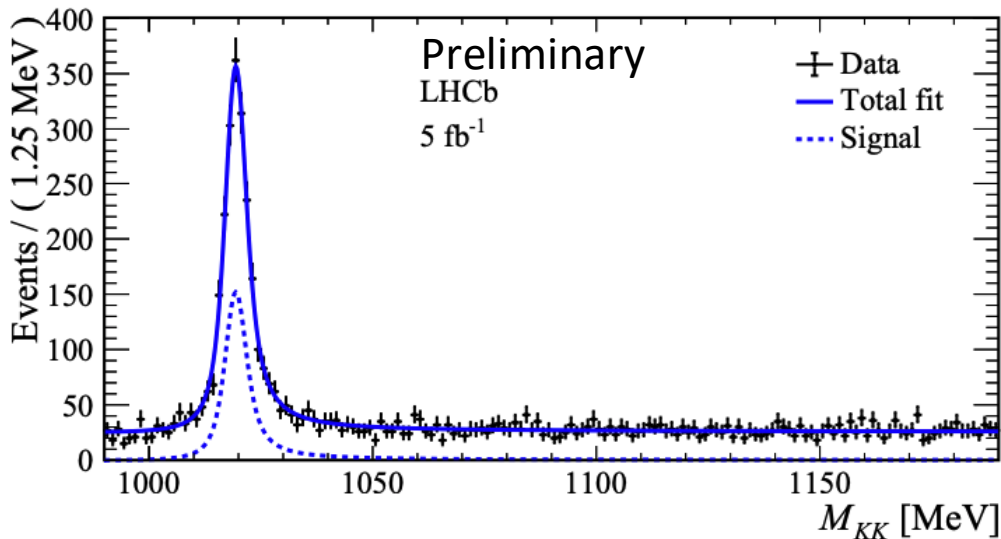
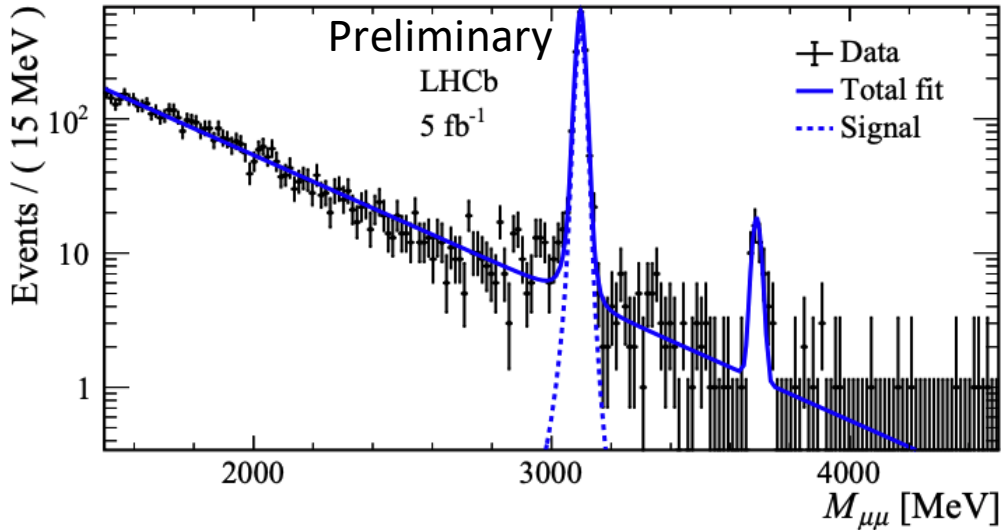
Exotic search in exclusive events

Exotics in Inelastic pp collisions.



Exotic search in CEP events

LHCb-PAPER-2023-043 in preparation

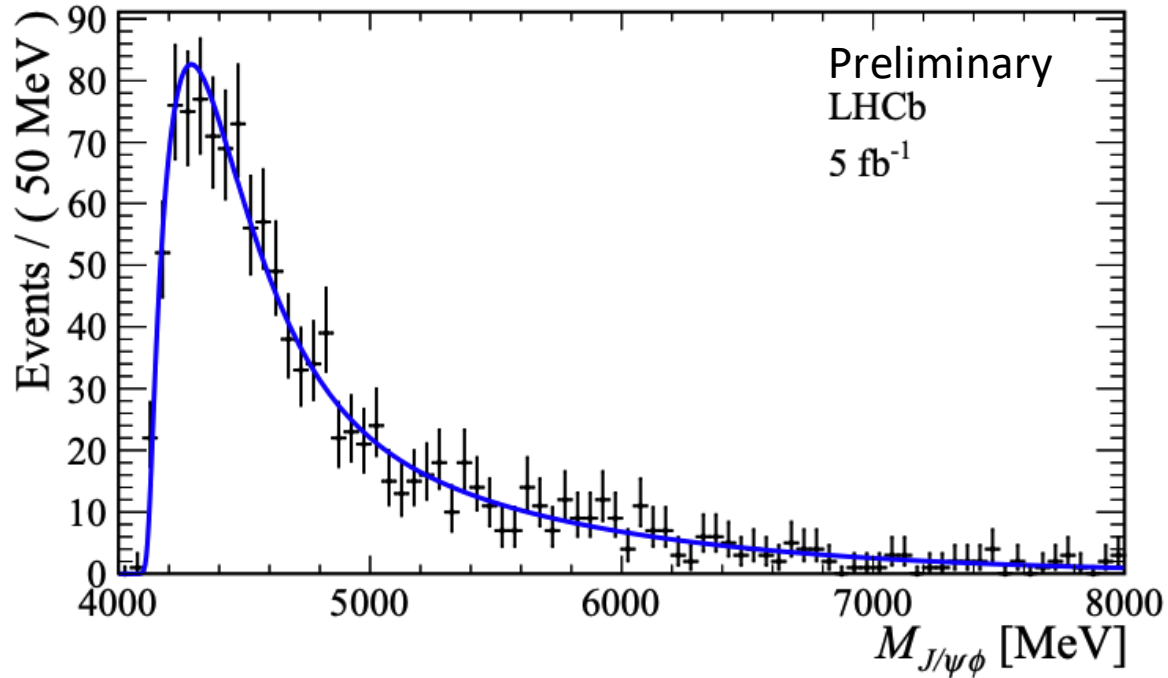


- $pp \sqrt{s}=13$ TeV
- Only two muons + two kaons detected in the event
- $2 < \eta < 5$ $p_T > 200$ MeV/c
- 69% of $J/\psi\phi$ candidates from events where at least one proton is wounded
- LHCb detects $\phi \rightarrow K^+K^-$ decays in CEP and UPC PbPb
- 20% detection efficiency for $J/\psi\phi$ pairs

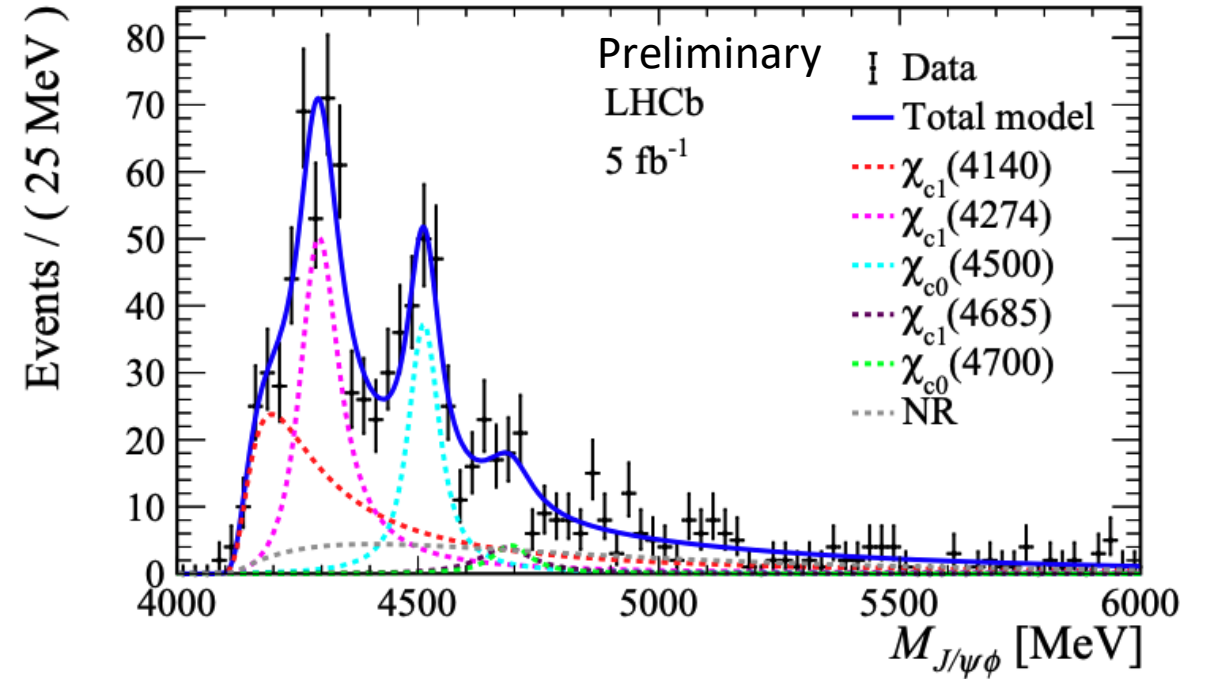
Exotic search in CEP events

LHCb-PAPER-2023-043 in preparation

Side-band: > 4 tracks in the event



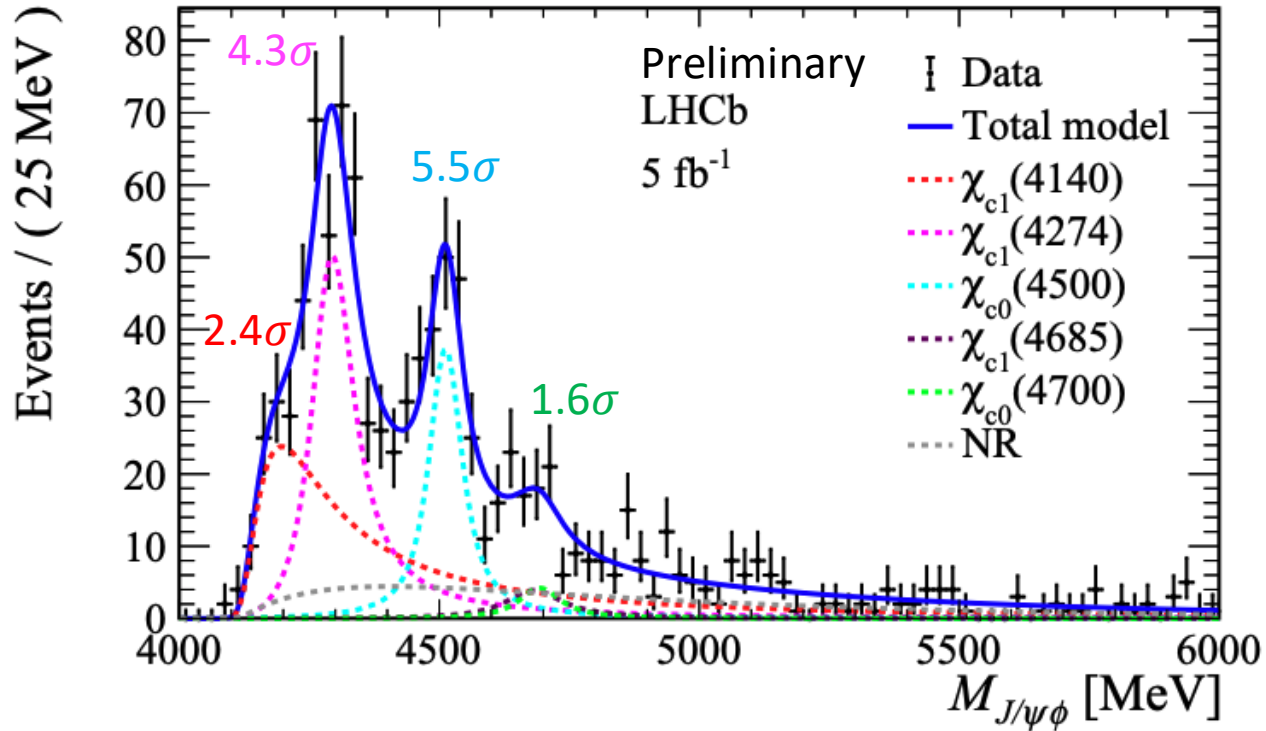
4 tracks in the event



- Peaks described by relativistic Breit-Wigner function convoluted with Gaussian
- Mass and widths fixed to values in PRL127 (2021) 082001

Exotic search in CEP events

LHCb-PAPER-2023-043 in preparation



$$\begin{aligned} \sigma_{\chi_{c1}(4140)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4140)} &= (0.85 \pm 0.16 \pm 0.30) \text{ pb}, \\ \sigma_{\chi_{c1}(4274)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4274)} &= (0.77^{+0.14}_{-0.13} \pm 0.18) \text{ pb}, \\ \sigma_{\chi_{c0}(4500)} \times \mathcal{B}_{\text{eff}}^{\chi_{c0}(4500)} &= (0.44^{+0.09}_{-0.08} \pm 0.07) \text{ pb}, \\ \sigma_{\chi_{c1}(4685) + \chi_{c0}(4700)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4685) + \chi_{c0}(4700)} &= (0.14^{+0.07}_{-0.06} \pm 0.06) \text{ pb}, \\ \sigma_{NR} \times \mathcal{B}_{\text{eff}}^{NR} &= (0.46^{+0.25}_{-0.19} \pm 0.21) \text{ pb}, \end{aligned}$$

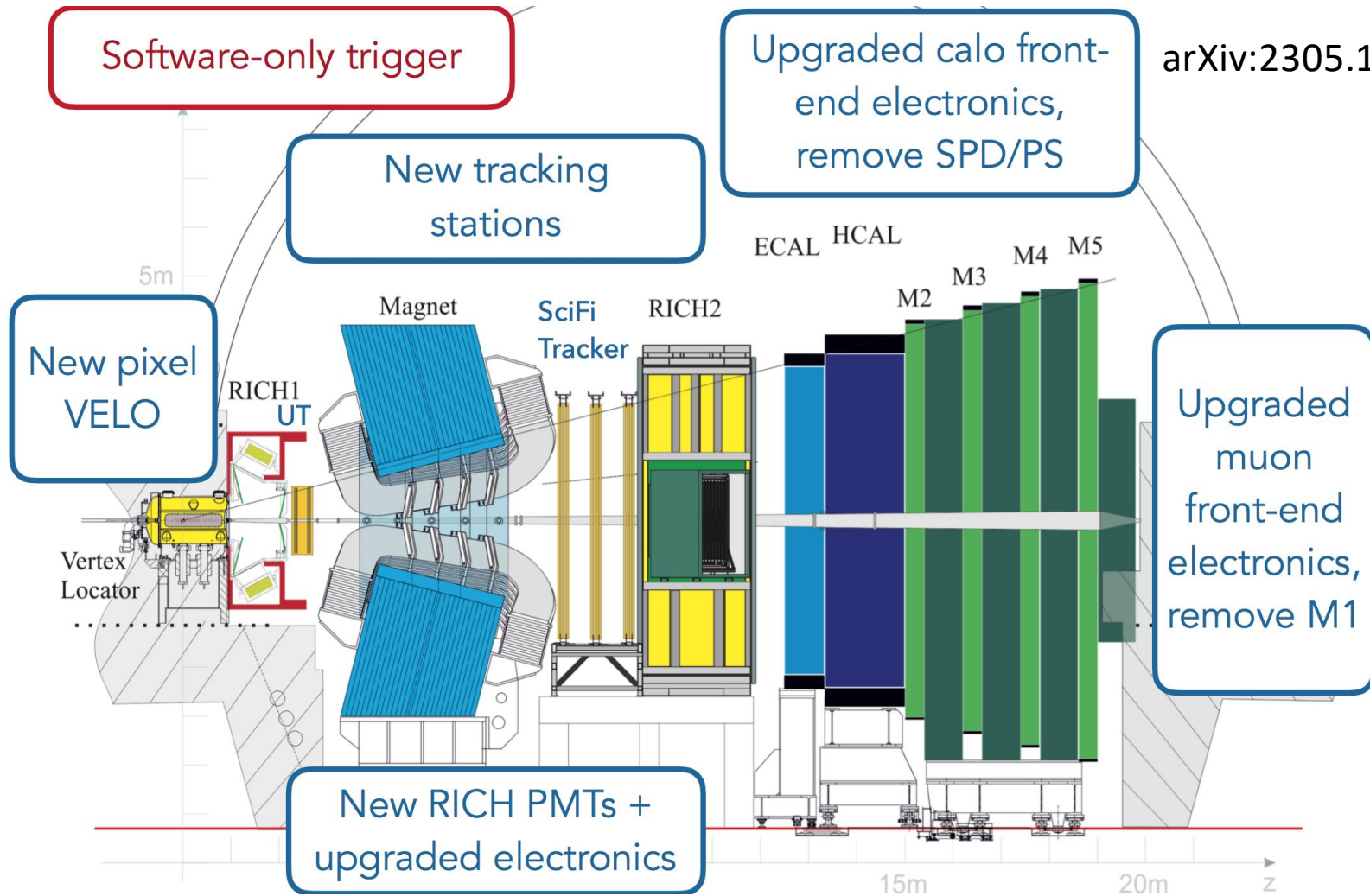
First exotic measurement in events with no other activity.

Golden measurement to understand exotic production.

Results coming up

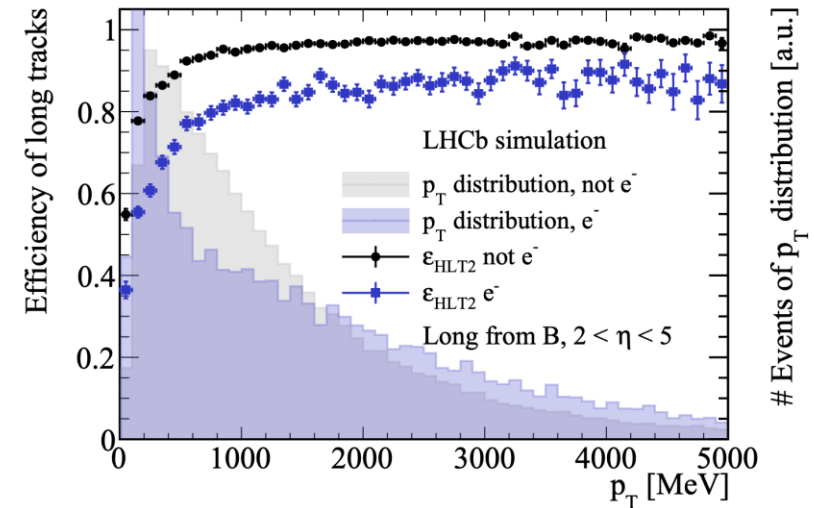
- **Near future**
 - Mass spectrum of K^+K^- pairs in UPC
 - Vector, scalar and tensor mesons from γ + pomeron, $\gamma + \gamma$ and double pomeron interaction
- **Further future**
 - UPC in pPb collisions
 - Resolves photon direction ambiguities
 - Incoherent J/ψ
 - probes gluon densities in individual nucleons
 - Control of fluctuations
 - ϕ photoproduction in UPC
 - Covers gluon density at lower Q^2 and x than J/ψ
 - Low- p_T τ g-2 from $\gamma\gamma \rightarrow \tau\tau$

The LHCb Upgrade I

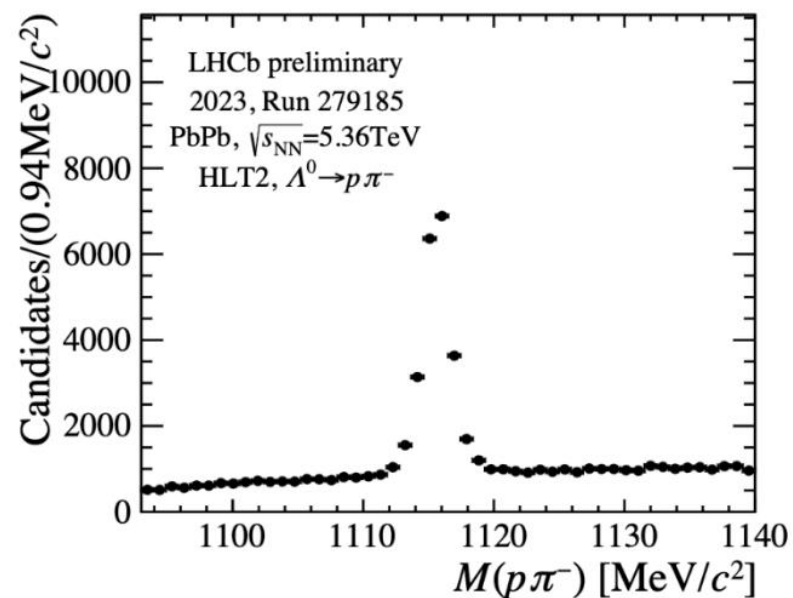
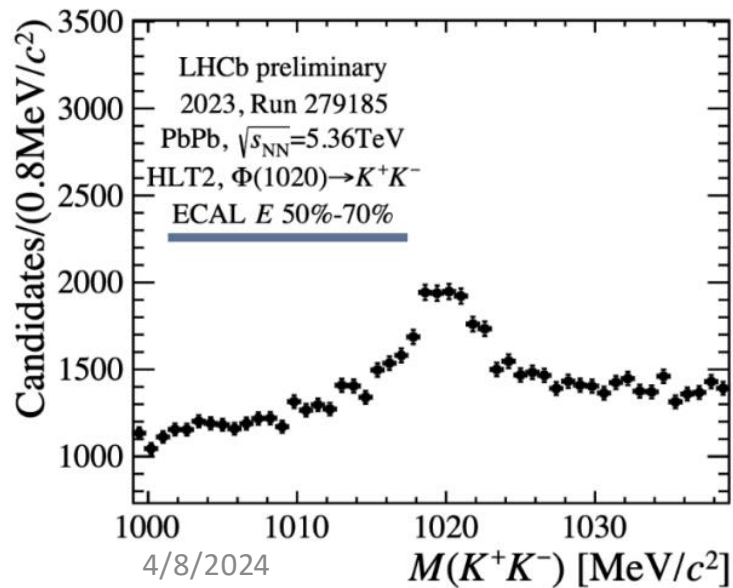
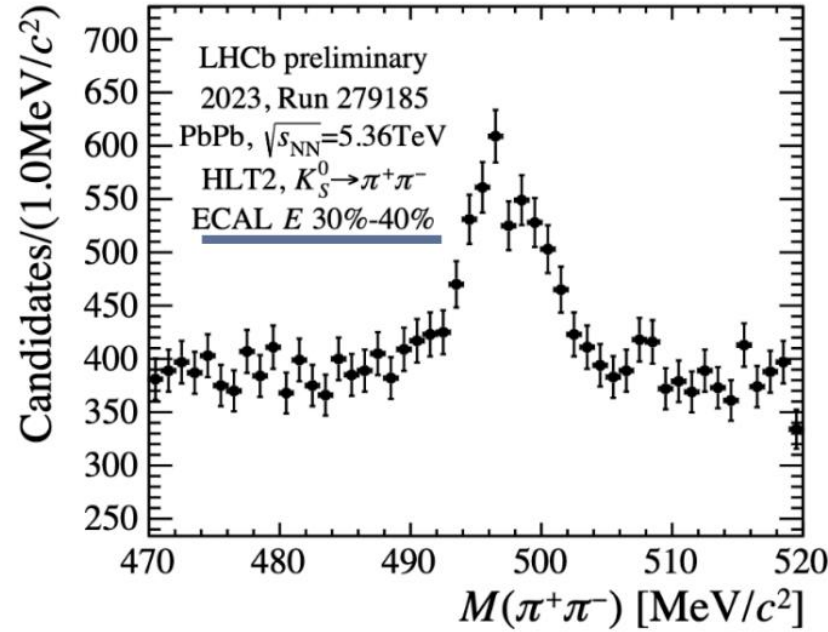
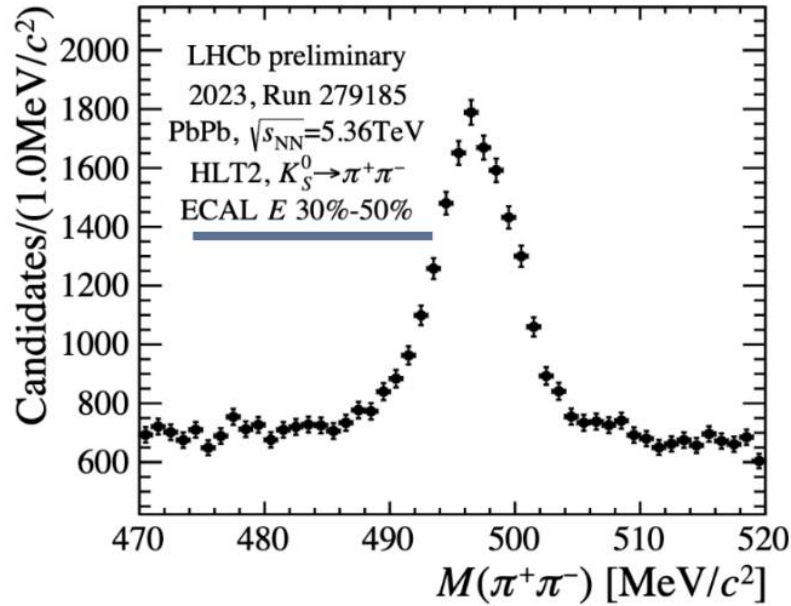


arXiv:2305.10515

40 MHz data acquisition
 No hardware trigger
 Real time data reconstruction



Detector performance in 2023 PbPb run



LHCb can for the first time take PbPb data up to 30% centrality !!

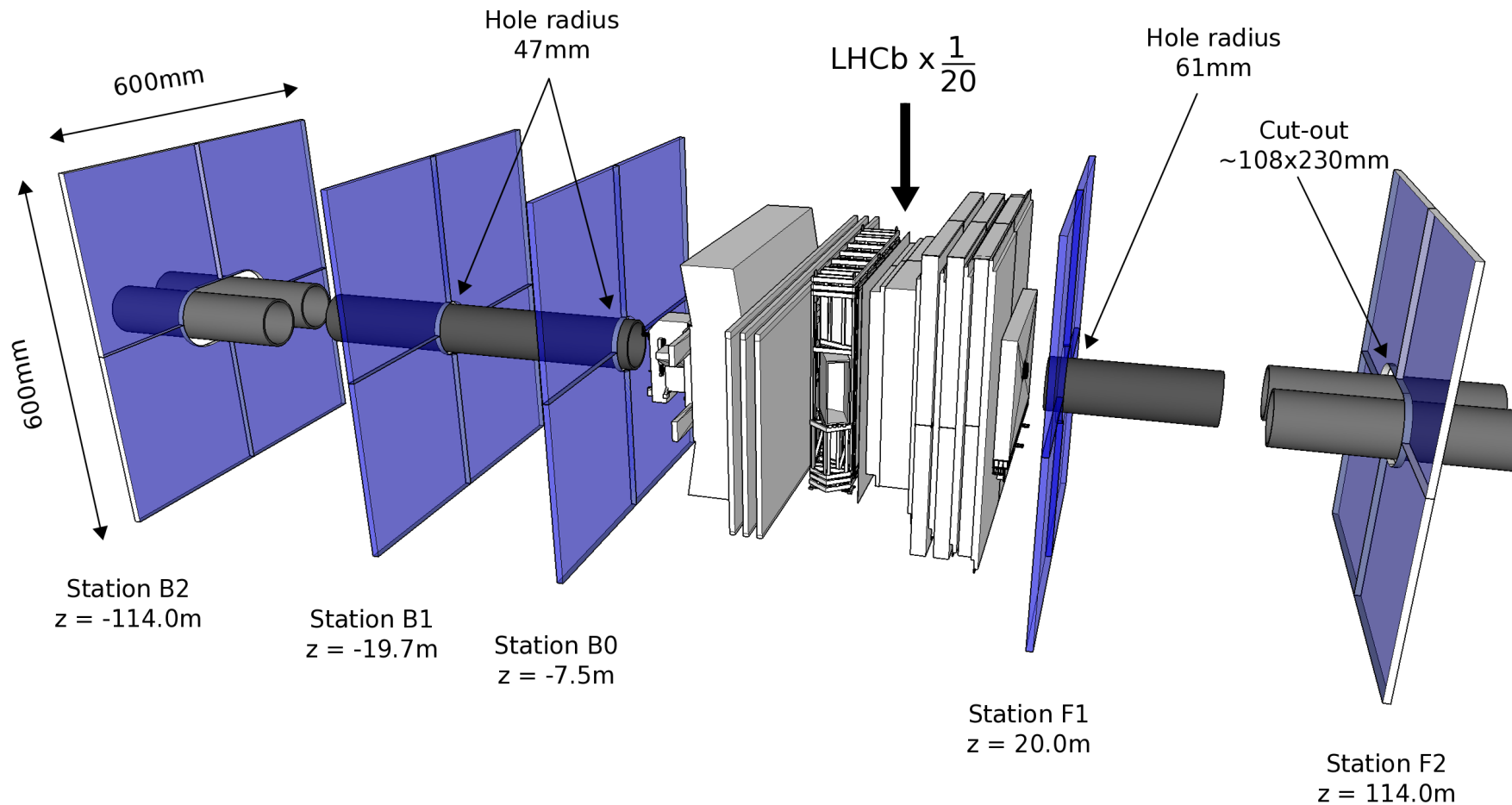
Full centrality in fixed target mode (SMOG)

40 minutes of data taking.

<<1% of the entire data set

Very promising for new UPC results.

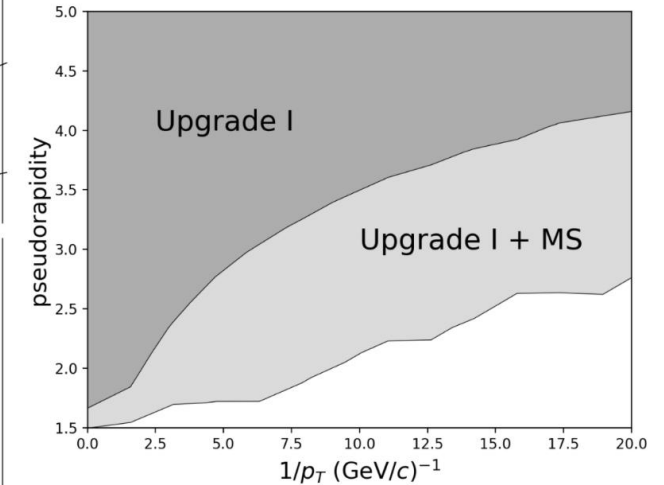
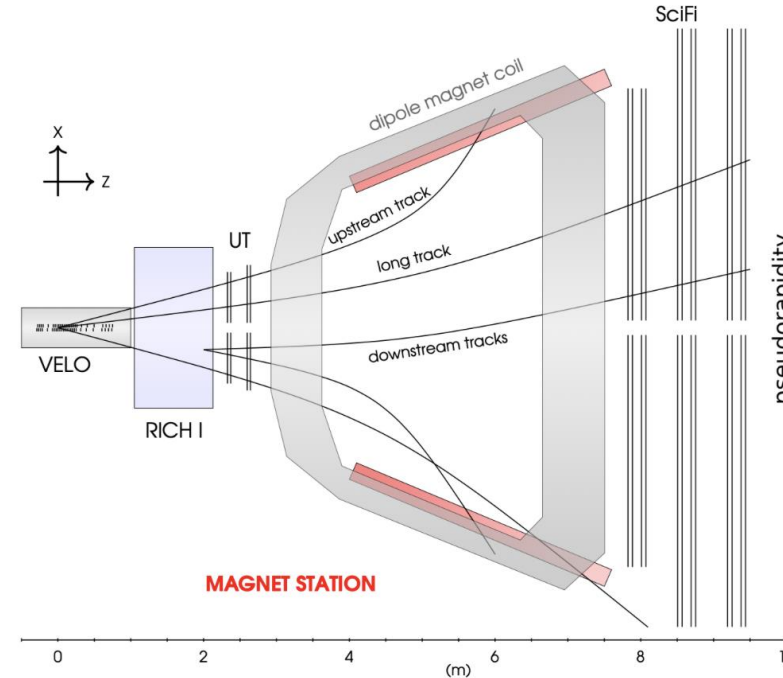
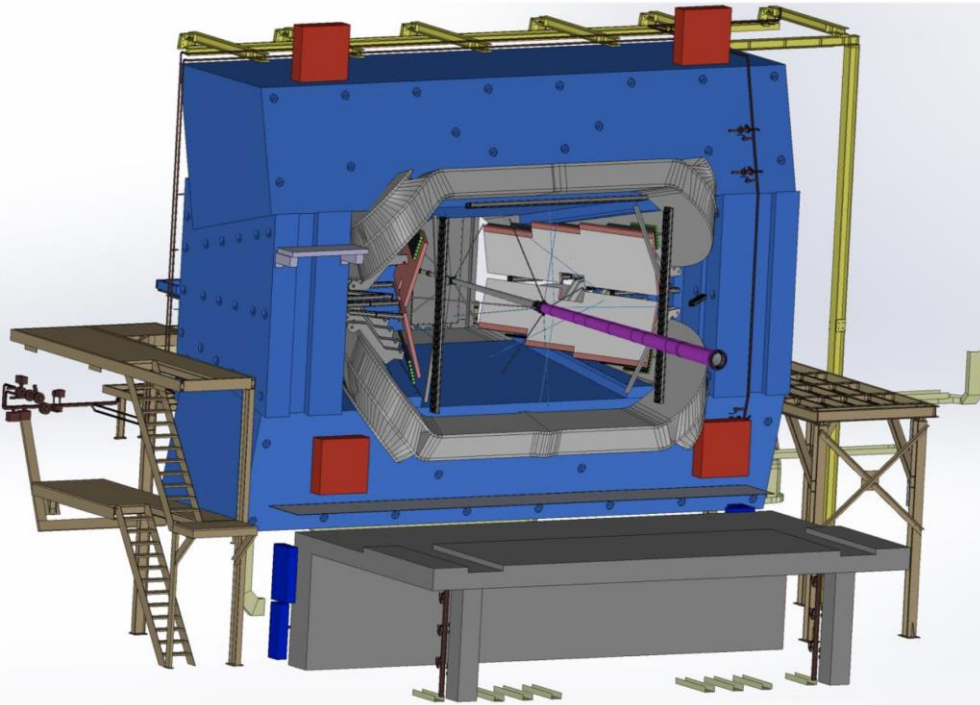
Future Upgrades : New HeRSChel



Replace radiation damaged scintillators.
 ϕ segmentation for reaction plane determination.

Future Upgrades : Magnet Station

Upgrade 2 talk in WG6: Mr Xuhao Yuan



- Instrument the internal magnet walls with a scintillator-based soft particle tracker
- tracking $p_T > 50 \text{ MeV}/c$
 - Essential to complete the UPC program
 - high-statistics low-mass vector, scalar and tensor mesons
 - Exotic hadrons with multiple decay products
 - Low-mass dielectrons and photon conversions
- Looking for US institutions to join a DOE proposal, installation starting during LS3

Take away

- LHCb is an ideal experiment for CEP,UPC studies. The sky is the limit, thanks to
 - Software-based trigger
 - Excellent particle identification
 - Low- p_T tracking
- First measurement of tetraquark states in exclusive events !
- LHCb is a new detector now and ready for Run3
- Future upgrades dedicated to CEP, UPC
- LHCb is a good example of a high data/people ratio in CEP and UPC physics
 - Heartbreaking opportunities missing because of the lack of people to do analysis
 - Upgrade 1b and II are very good opportunities to be part of the LHCb QCD programs

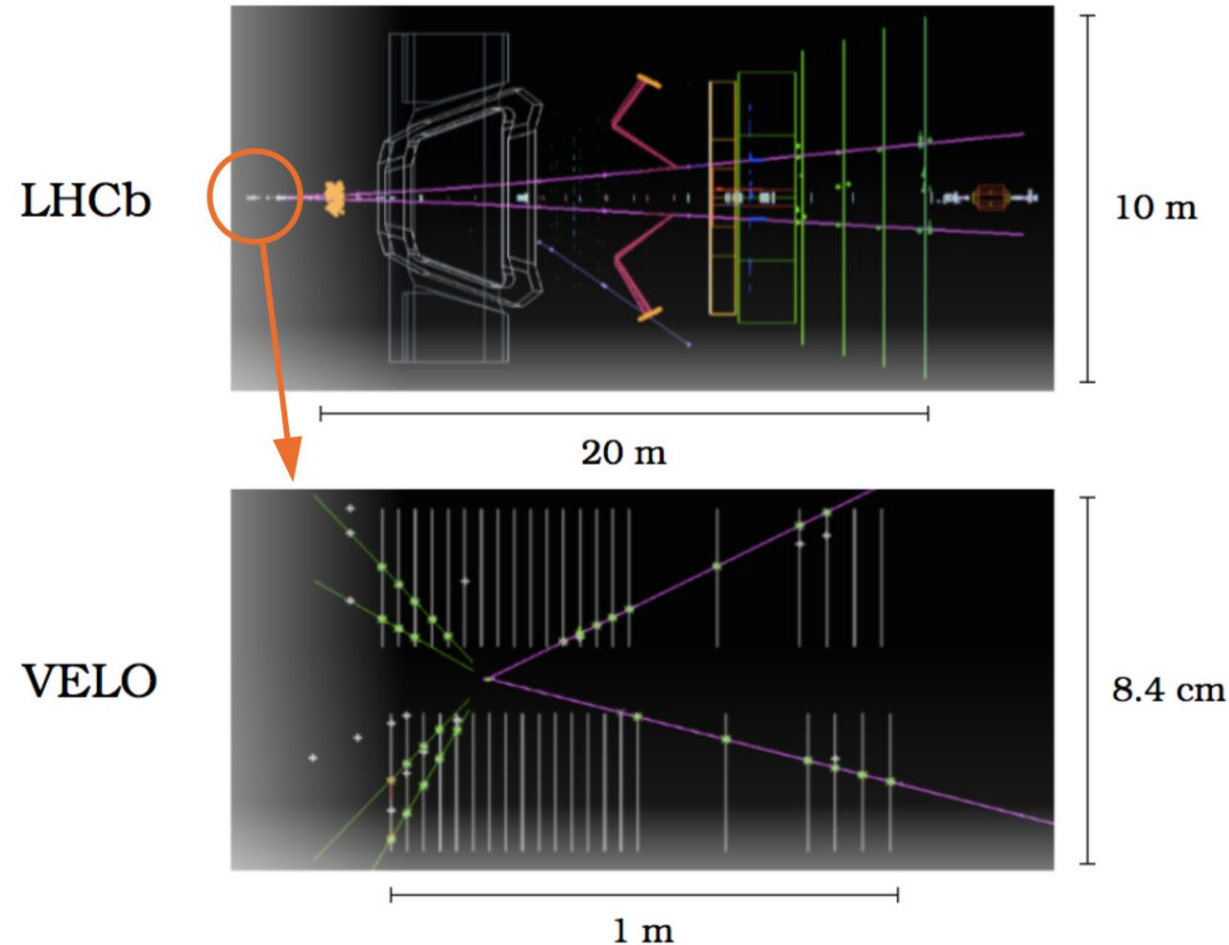
BACKUP

Trigger Conditions for UPC events

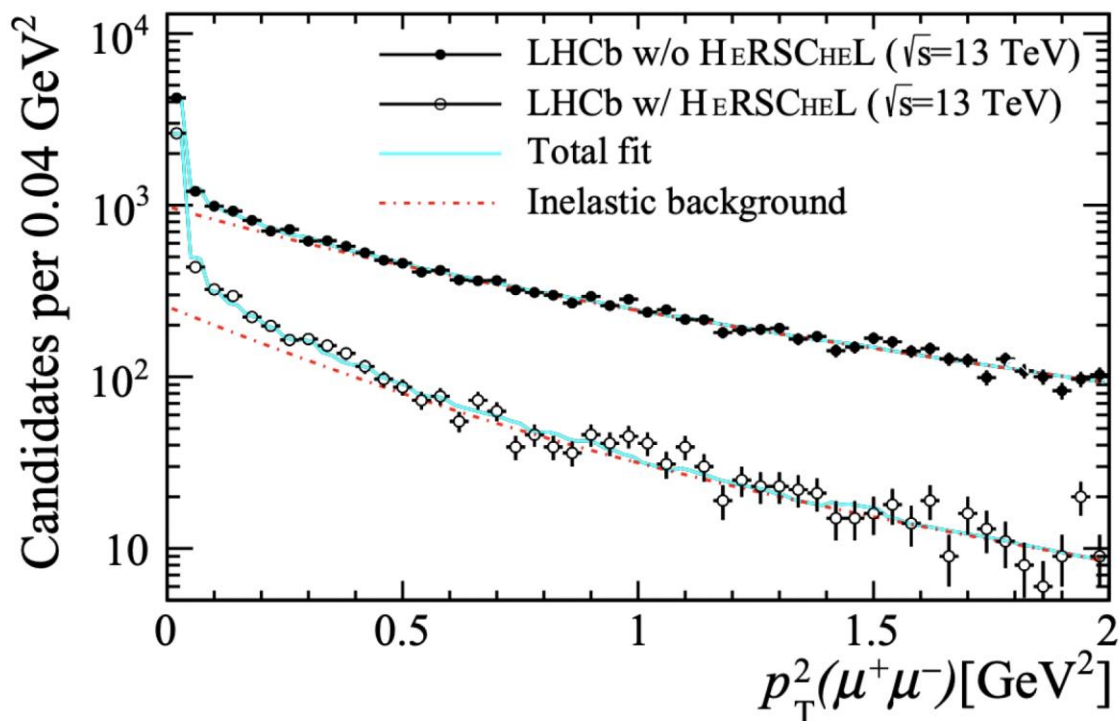
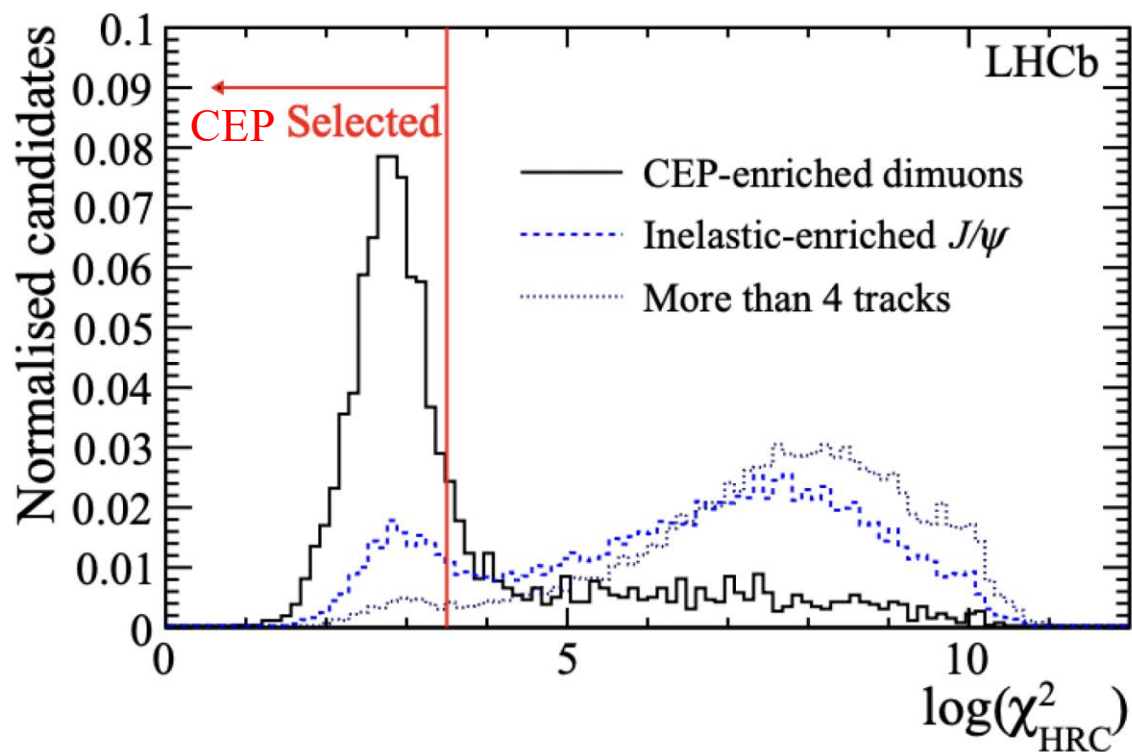
- long track (tracks with hits in all tracking detectors) [1,20]
- SPD hits (ECAL raw hits) < 2000
- Event selected by software
- NO pre-scale

Data sets

| | |
|-----------------|-----------------------------|
| 2015 PbPb 5 TeV | $4 \mu\text{b}^{-1}$ |
| 2018 PbPb 5 TeV | $214 \mu\text{b}^{-1}$ |
| 2023 PbPb 5 TeV | $\sim 210 \mu\text{b}^{-1}$ |



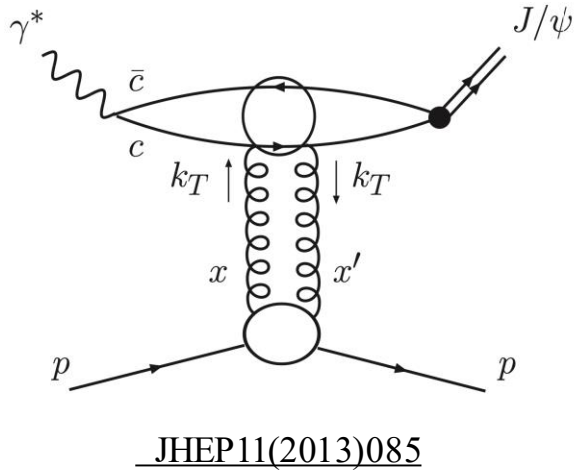
Herschel Detector Discrimination



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- The Figure of Merit (left) is a χ^2 quantity that includes hits from all twenty counters and accounts for correlations among counters based on activity above the noise
 - By subtracting the background, an exclusive sample of signal events is obtained
- The p_T^2 distribution of dimuons (right) with and without the requirement on the $\log(\chi^2)$

$J/\psi, \psi(2S)$ Photo-production cross-section in CEP



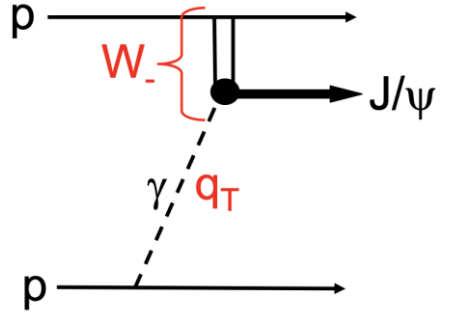
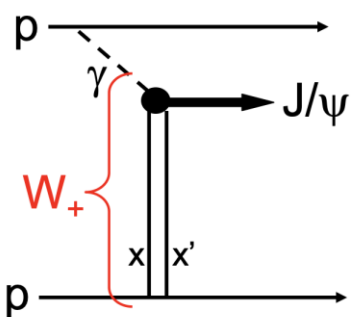
photon energy
 $k_{\pm} \equiv (M_{\psi}/2)e^{\pm y_{\psi}}$

Invariant mass of the photon-proton system
 $W_{\pm}^2 = 2k_{\pm}\sqrt{s}$

External inputs
 gap survivor photon flux

Photoproduction result from H1(HERA)
 parametrization = $a \left(\frac{W}{90 \text{ GeV}}\right)^{\delta}$

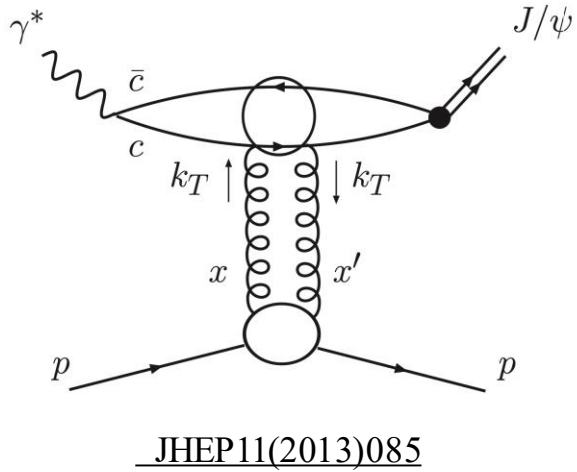
$$\sigma_{pp \rightarrow p\psi p} = r(W_+) \left(\frac{dn}{dk_+}\right) k_+ \sigma_{\gamma p \rightarrow \psi p}(W_+) + r(W_-) \left(\frac{dn}{dk_-}\right) k_- \sigma_{\gamma p \rightarrow \psi p}(W_-)$$



- $\sigma_{pp \rightarrow p\psi p}(W)$ has contributions from photon coming from both forward and backward going proton in CMS

- Goal:** Extract ψ photoproduction cross – section $\sigma_{\gamma p \rightarrow \psi p}(W)$ from measured $\sigma_{pp \rightarrow p\psi p}(W)$

$J/\psi, \psi(2S)$ Photo-production cross-section in CEP



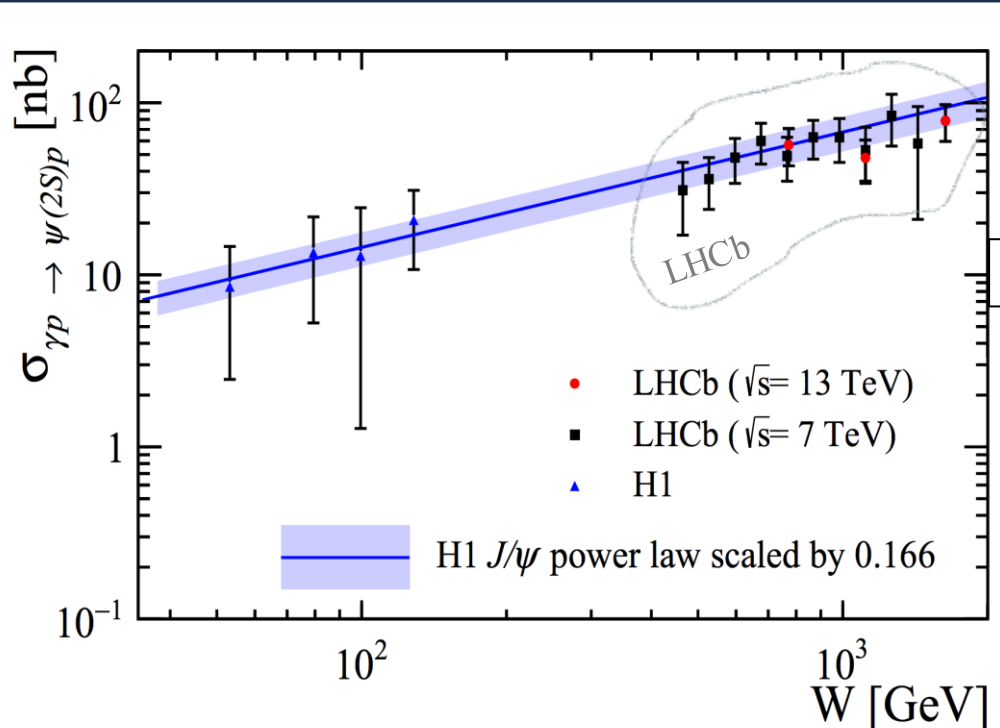
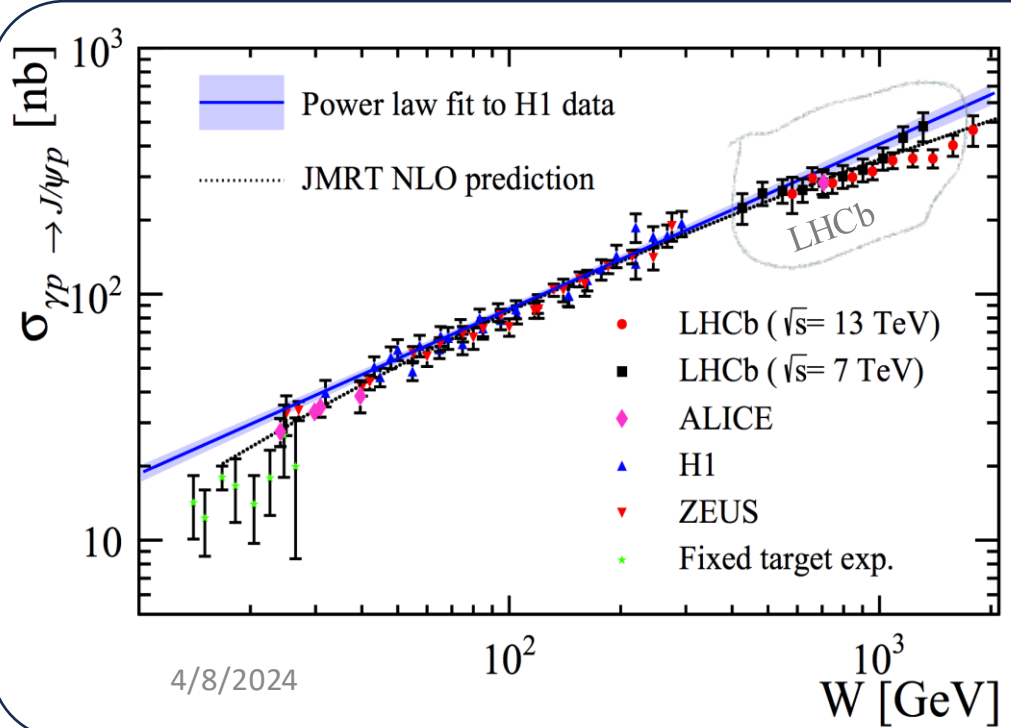
photon energy
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Invariant mass of the photon-proton system
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External inputs
 gap survivor photon flux

$$\sigma_{pp \rightarrow p\psi p} = r(W_+) \left(\frac{dn}{dk_+} \right) k_+ \sigma_{\gamma p \rightarrow \psi p}(W_+) + r(W_-) \left(\frac{dn}{dk_-} \right) k_- \sigma_{\gamma p \rightarrow \psi p}(W_-)$$

Photoproduction result from H1(HERA) parametrization = $a \left(\frac{W}{90 \text{ GeV}} \right)^{\delta}$

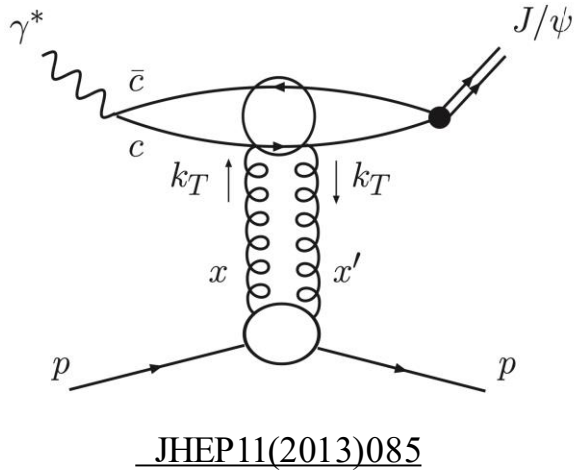


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$$W^2 \equiv 2k\sqrt{s}$$

HeRSChel sel.

$J/\psi, \psi(2S)$ Photo-production cross-section in CEP



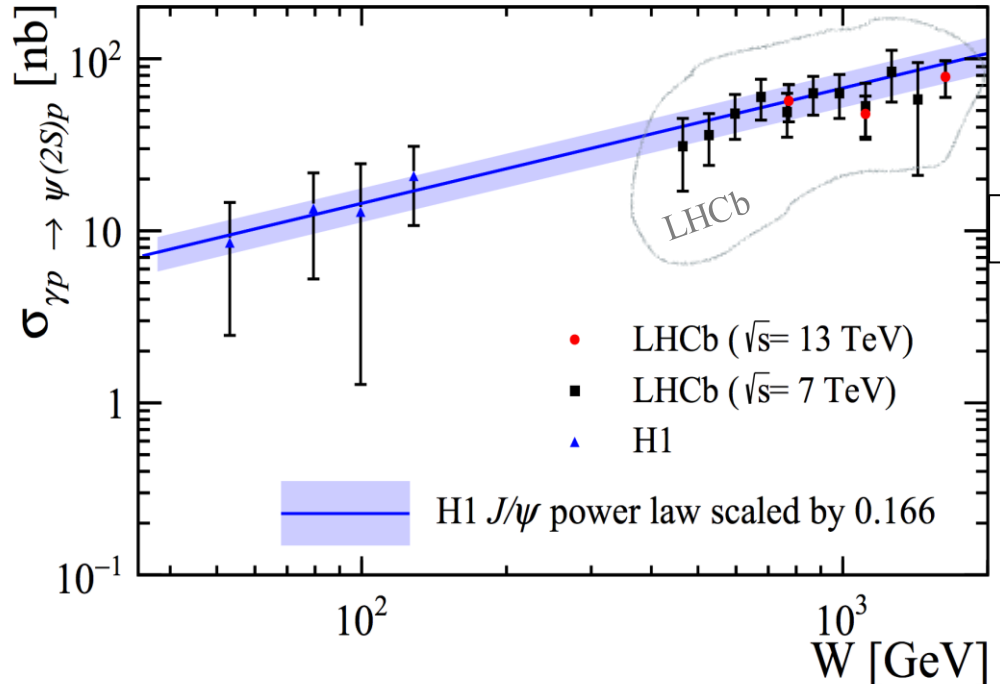
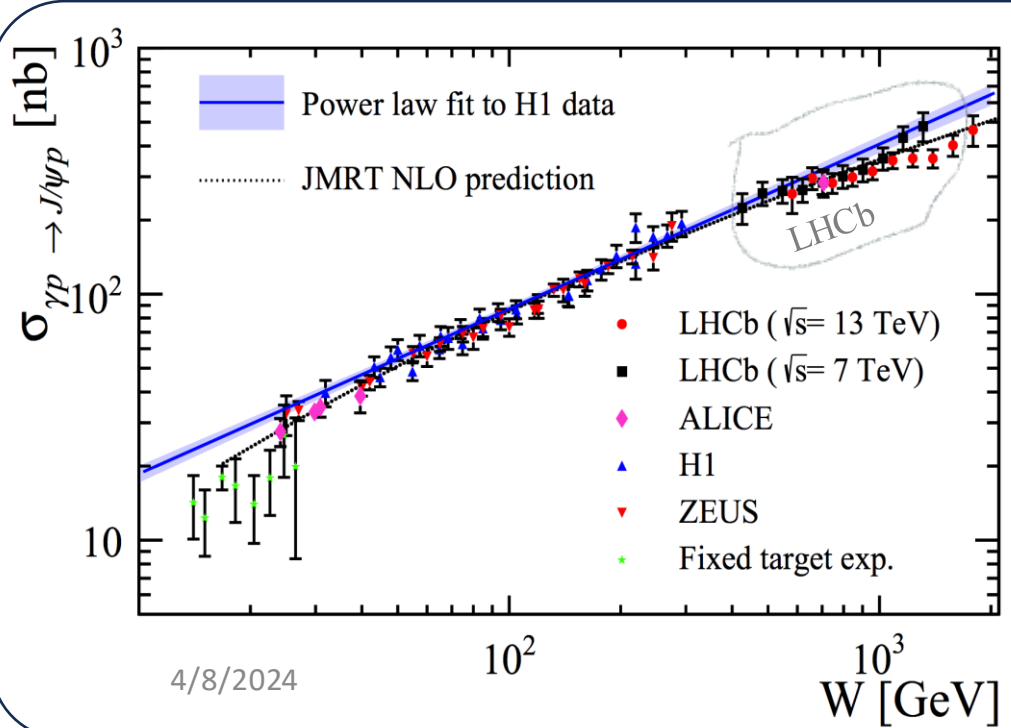
photon energy
 $k_{\pm} \equiv (M_{\psi}/2)e^{\pm y_{\psi}}$

Invariant mass of the photon-proton system
 $W_{\pm}^2 = 2k_{\pm}\sqrt{s}$

External inputs
 gap survivor photon flux

$$\sigma_{pp \rightarrow p\psi p} = r(W_+) \left(\frac{dn}{dk_+} \right) k_+ \sigma_{\gamma p \rightarrow \psi p}(W_+) + r(W_-) \left(\frac{dn}{dk_-} \right) k_- \sigma_{\gamma p \rightarrow \psi p}(W_-)$$

Photoproduction result from H1(HERA)
 parametrization = $a \left(\frac{W}{90 \text{ GeV}} \right)^{\delta}$



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$$W^2 \equiv 2k\sqrt{s}$$

HeRSChel sel.