LHCb plans with photoinduced interactions in pA

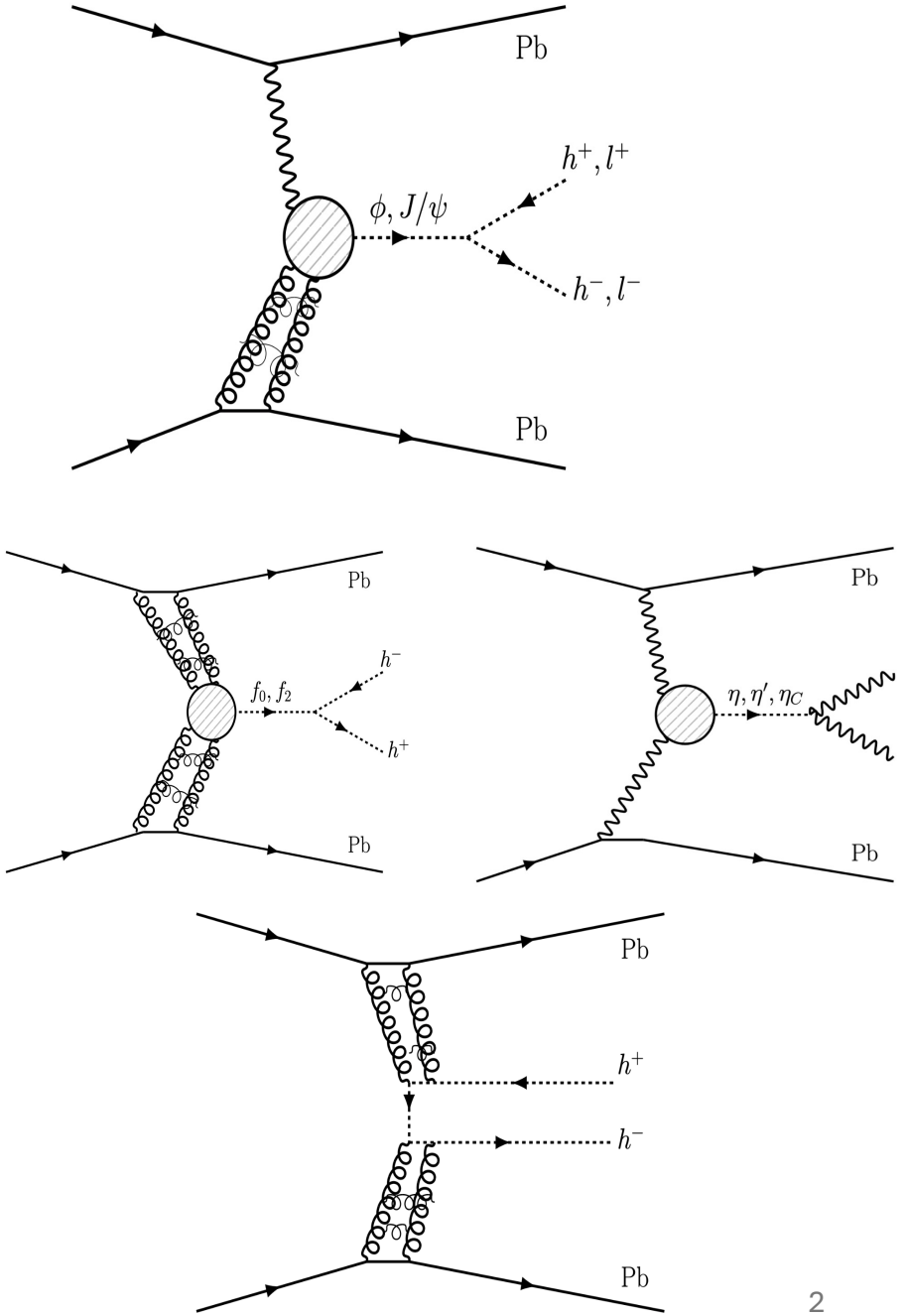
Daniel Brandenburg
On behalf of the LHCb Collaboration

Physics with high-luminosity proton-nucleus collisions at the LHC
July 5th, 2024
CERN Council Chamber 503/1-001

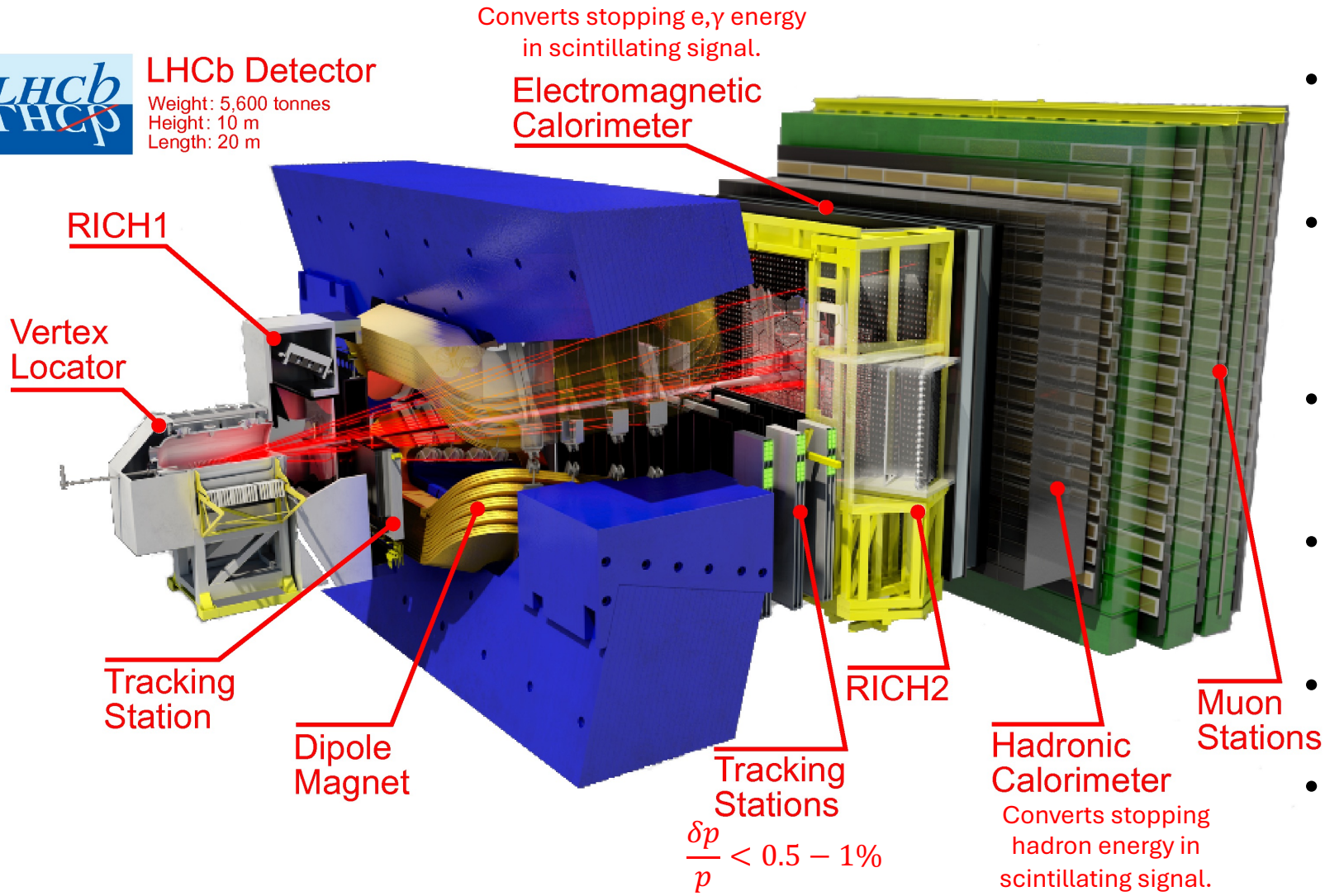
Supported in part by an Early Career award from the U.S. DEPARTMENT OF ENERGY
Office of Science

Outline & Physics Topics

- LHCb Detector + unique capabilities
- Odderon search in pA and AA
- Photoproduction (in pp, pA, and AA)
  - Vector meson production
- Exotic states, scalar and tensor mesons from $\mathbb{P} + \mathbb{P}$ and $\gamma + \gamma$ interactions
  - Searches for glueballs + tetraquark states
- Summary + Plans



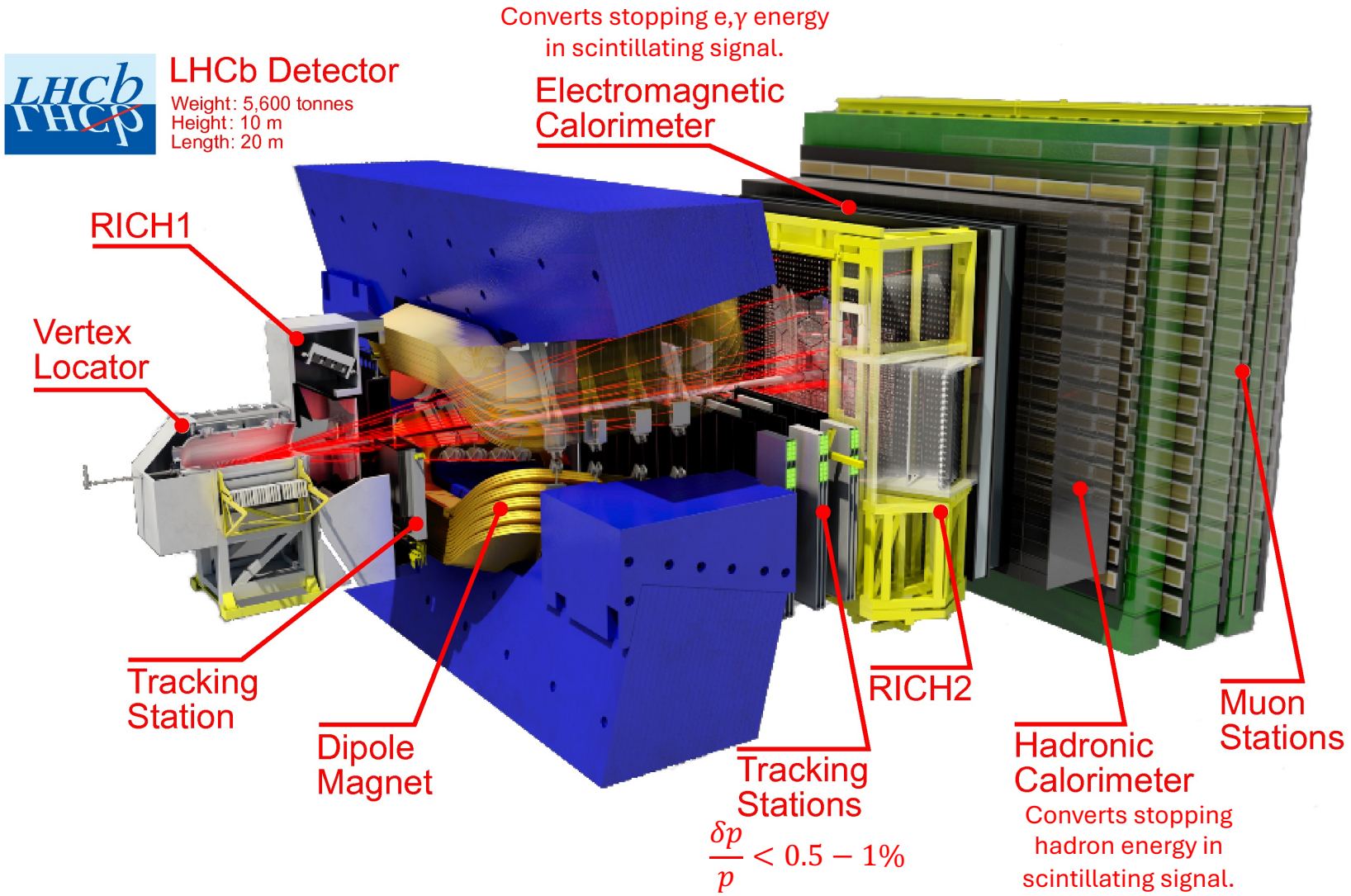
The LHCb detector

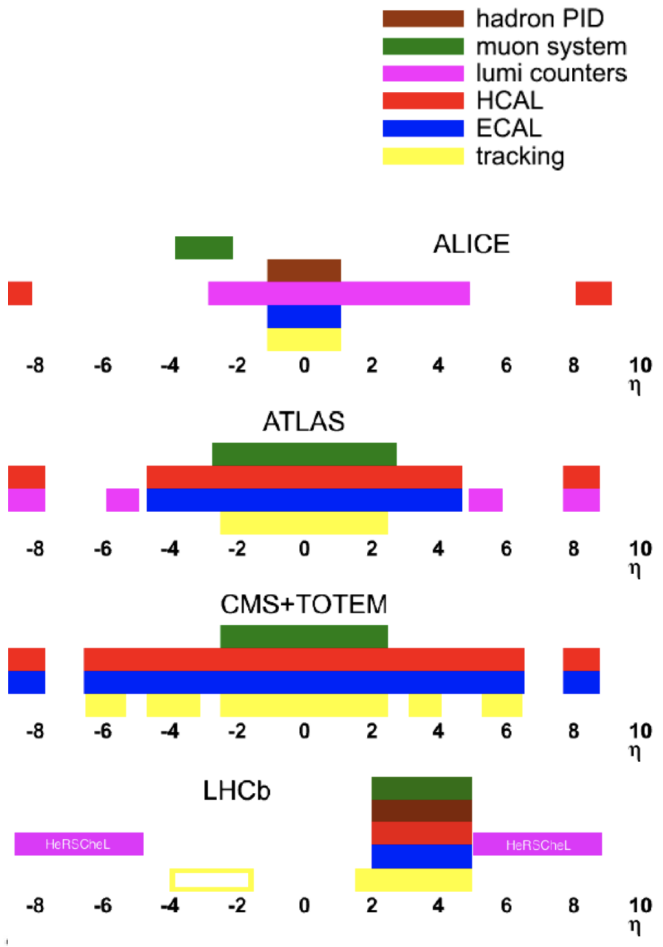


- Unique coverage
  - Rapidity
  - Low transverse momentum
- Collider & Fixed Target modes
  - Unique coverage
  - Access lower COM energies at LHC
- SMOG2
  - Enables fixed target mode
  - Plethora of collision species
- Resolution
  - Precise vertex determination
  - Powerful invariant mass resolution
- Particle Identification
  - $e, \mu, \pi, K, p, \gamma$ in $1 < p < 100$ GeV
- Unique forward instrumentation for pp, pPb, PbPb physics

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

The LHCb detector

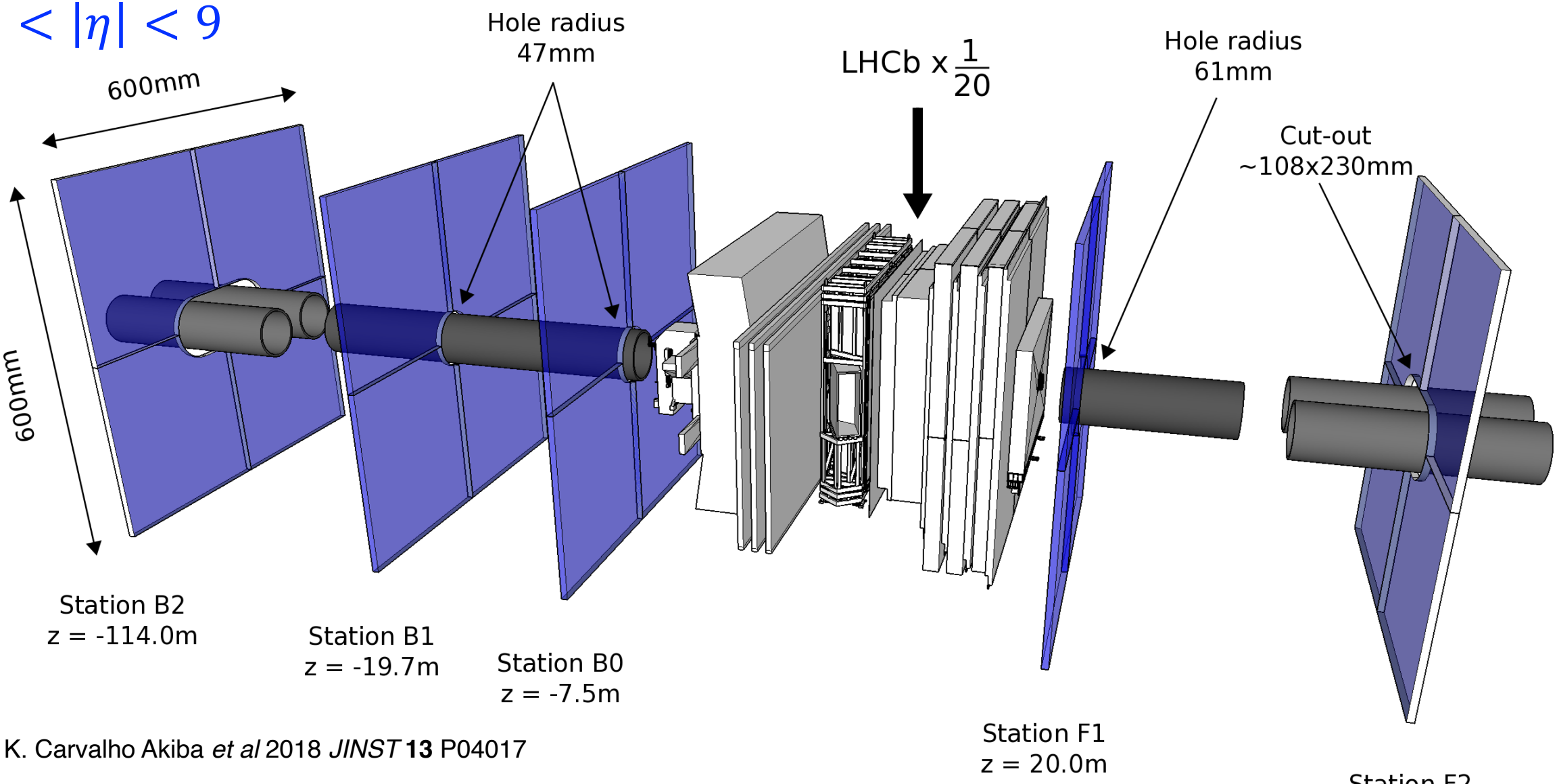




J. of Instr.,3(08):S08005, 2008

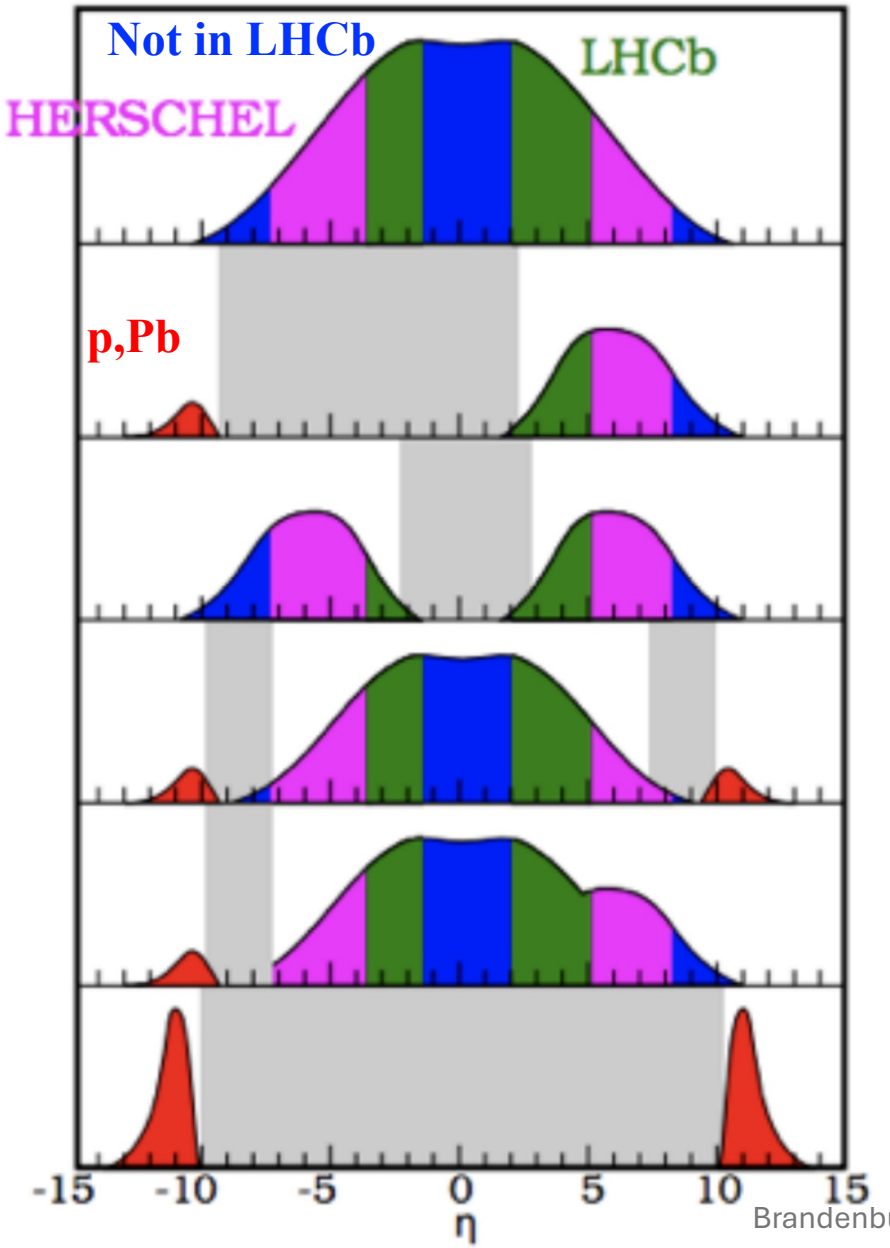
HeRSCheL: High-Rapidity Shower Counters for LHCb

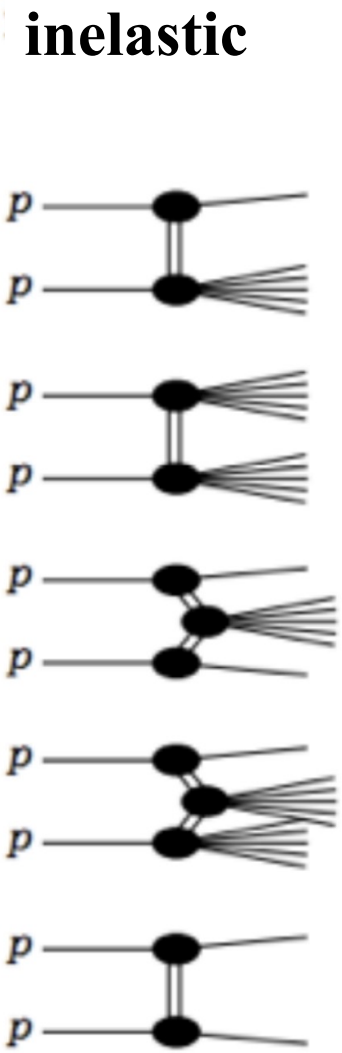
$5 < |\eta| < 9$



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

LHCb rapidity coverage





inelastic

single diffraction

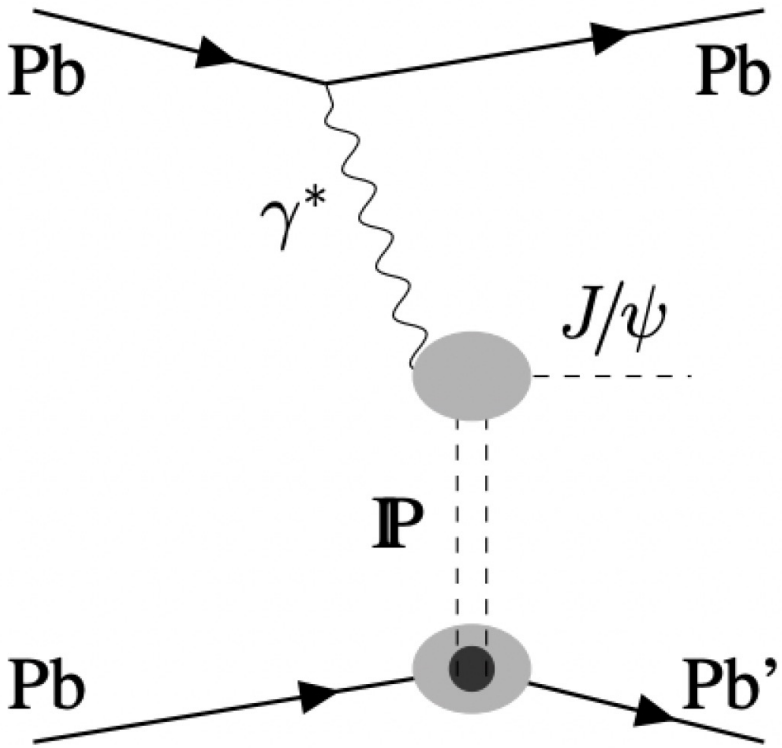
double diffraction

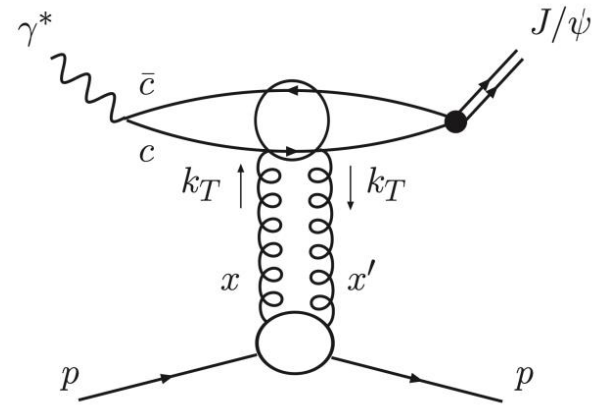
CEP+UPC elastic

CEP+UPC inelastic

Elastic

Motivations for photoinduced measurements in pA





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: $r(W_+)$

photon flux: $\left(\frac{dn}{dk_+}\right)$

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

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

Challenge in pp, AA

- Photon source ambiguity
- Uncertainty on survival fraction in pp

Benefit of pA

- pPb vs. Pbp -> disambiguate photon emitter
- Better control on survival fraction

Odderon search in pPb and PbPb

Isolating the Odderon in central production in high energy pA and AA collisions

- C-even mesons can be produced in exclusive events either via the fusion of two C-even objects (Pomeron-Pomeron) or two C-odd objects ($\gamma + Odderon$)

McNulty, Khoze, Martin, Ryskin, Eur. Phys. J. C 80, 288 (2020)

Would provide first ***direct*** observation of the odderon

Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements

V. M. Abazov *et al.* (D0 collaboration[†]["id", "col1"], TOTEM Collaboration[‡]["id", "col2"])
Phys. Rev. Lett. **127**, 062003 – Published 4 August 2021

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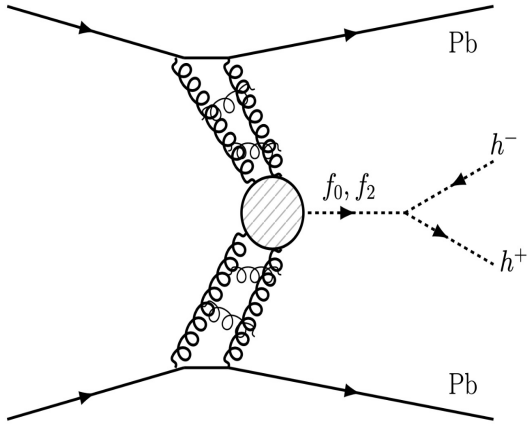
More

Phys. Rev. Lett. 127, 062003 (2021)



Odderon search approach

McNulty, Khoze, Martin, Ryskin, Eur. Phys. J. C 80, 288 (2020)

- Study the production of C-even mesons
- $f_2(1270)$ is an especially good candidate

$f_2(1270)$ $I^G(J^{PC}) = 0^+(2^{++})$

$$\mathrm{PP} \to f_2, \quad \mathrm{P}R \to f_2, \quad \gamma\mathrm{O} \to f_2, \quad \gamma R \to f_2,$$

- P = Pomeron, R=Reggeon, O = Odderon, γ = photon
- Signatures of Odderon:
  - Enhanced $f_2(1270)$ production
  - Asymmetry when beam/target are flipped (pPb vs. Pbp)

- C-even mesons due to Odderon-γ fusion could be quite large, up to the μb level

L. A. Harland-Lang, V. A. Khoze, A. D. Martin and M. G. Ryskin, Phys. Rev. D 99, no. 3, 034011 (2019) [arXiv:1811.12705 [hep-ph]].

Signal and Backgrounds in C-even mesons

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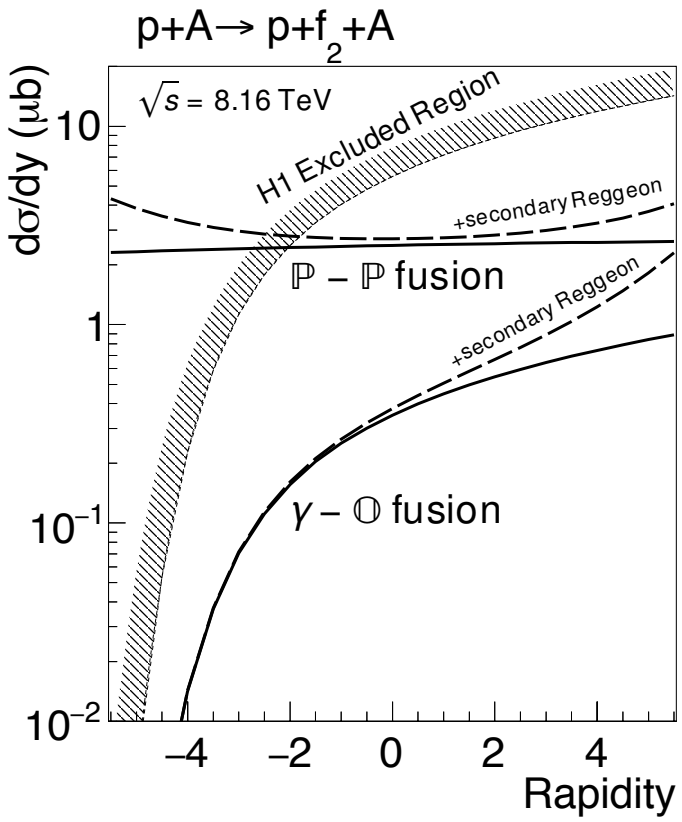
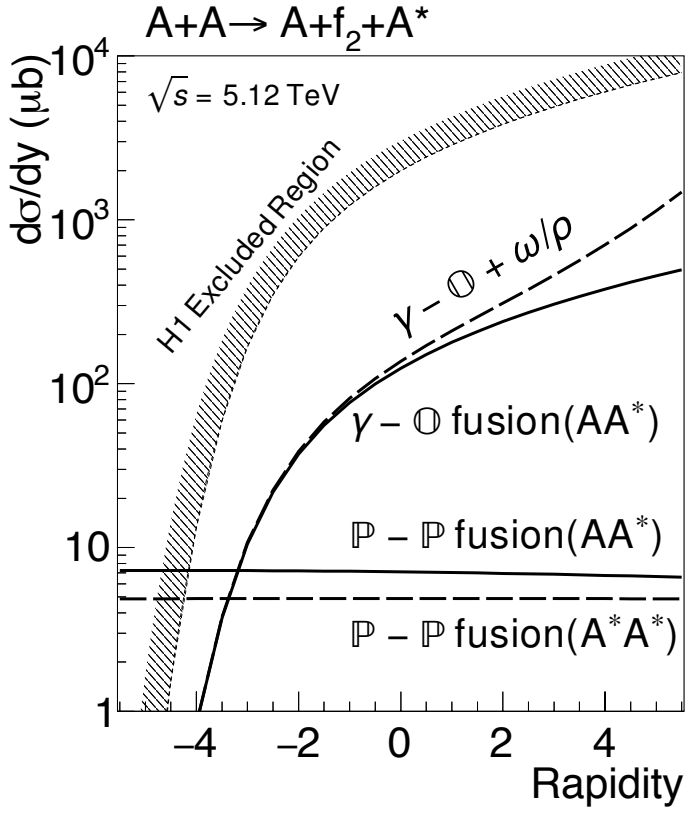




Require exclusive events with 'gap', Survival fraction:

$$S^2_{pN}(b_t) \;=\; \exp(-\sigma_{\mathrm{tot}}(pN)\; T_A(b_t))\;,$$

$$T_A(b) = \int_{-\infty}^{\infty} dz(\rho_p(z,b) + \rho_n(z,b))\;.$$

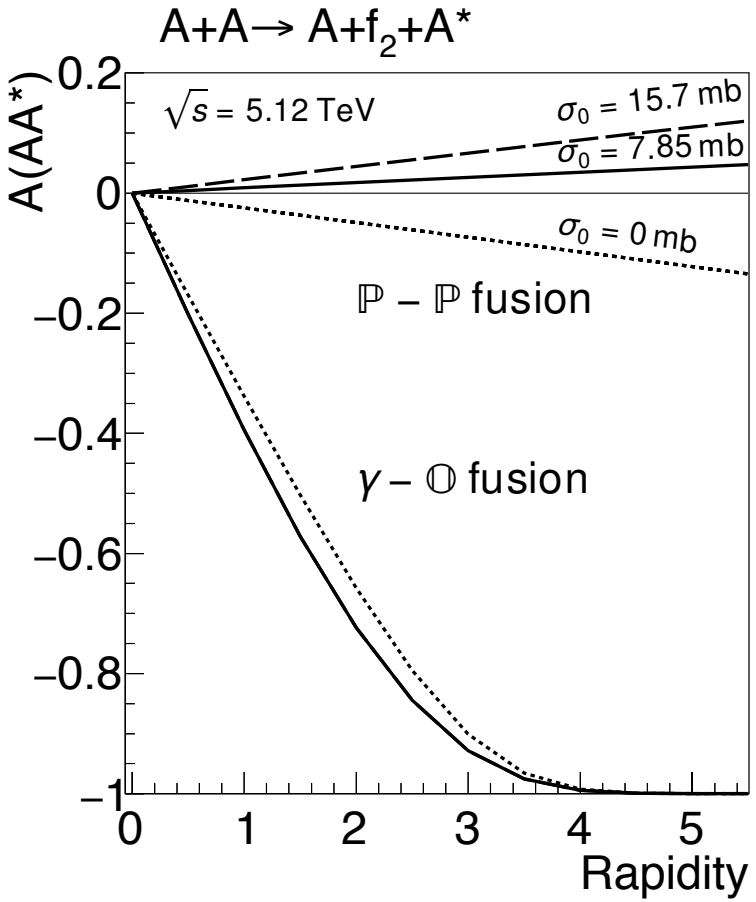
McNulty, Khoze, Martin, Ryskin, Eur. Phys. J. C 80, 288 (2020)

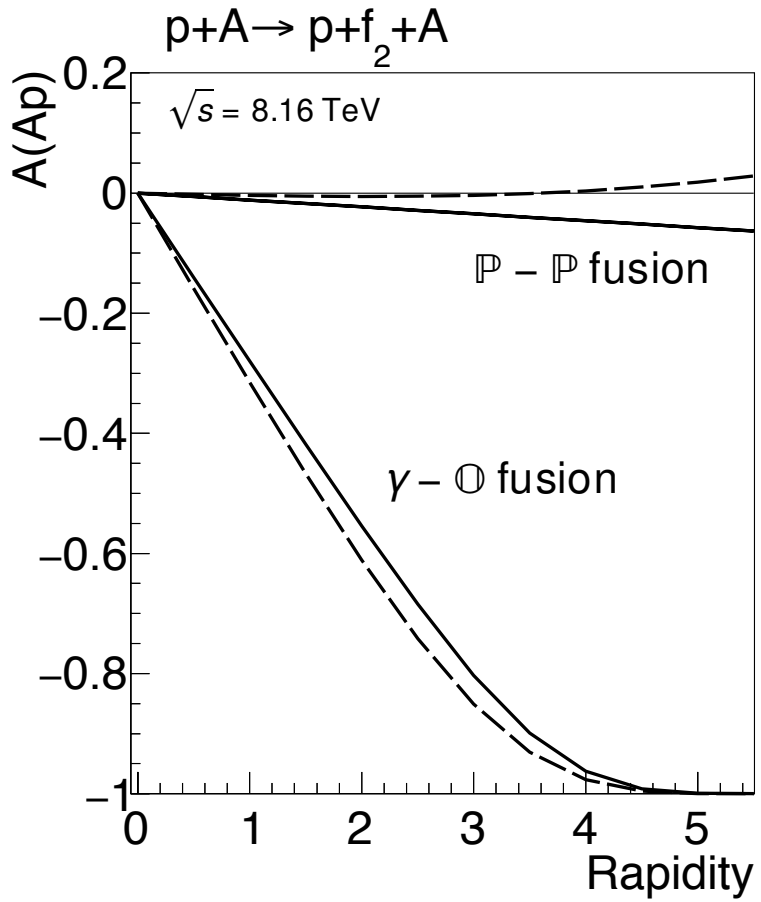
Signal and Backgrounds in C-even mesons

- 'Flipping' beam provides enhanced sensitivity to Odderon signal
- A(pPb) uses measurements of pPb vs. Pbp for the same y_{f_2}
- In PbPb collisions – 'flip' by requiring breakup on one side or the other

$$\mathrm{A}(AA^*) = \frac{\sigma(A^*A) - \sigma(AA^*)}{\sigma(A^*A) + \sigma(AA^*)} .$$

$$\mathrm{A}(Ap) = \frac{\sigma(pA) - \sigma(Ap)}{\sigma(pA) + \sigma(Ap)} ,$$

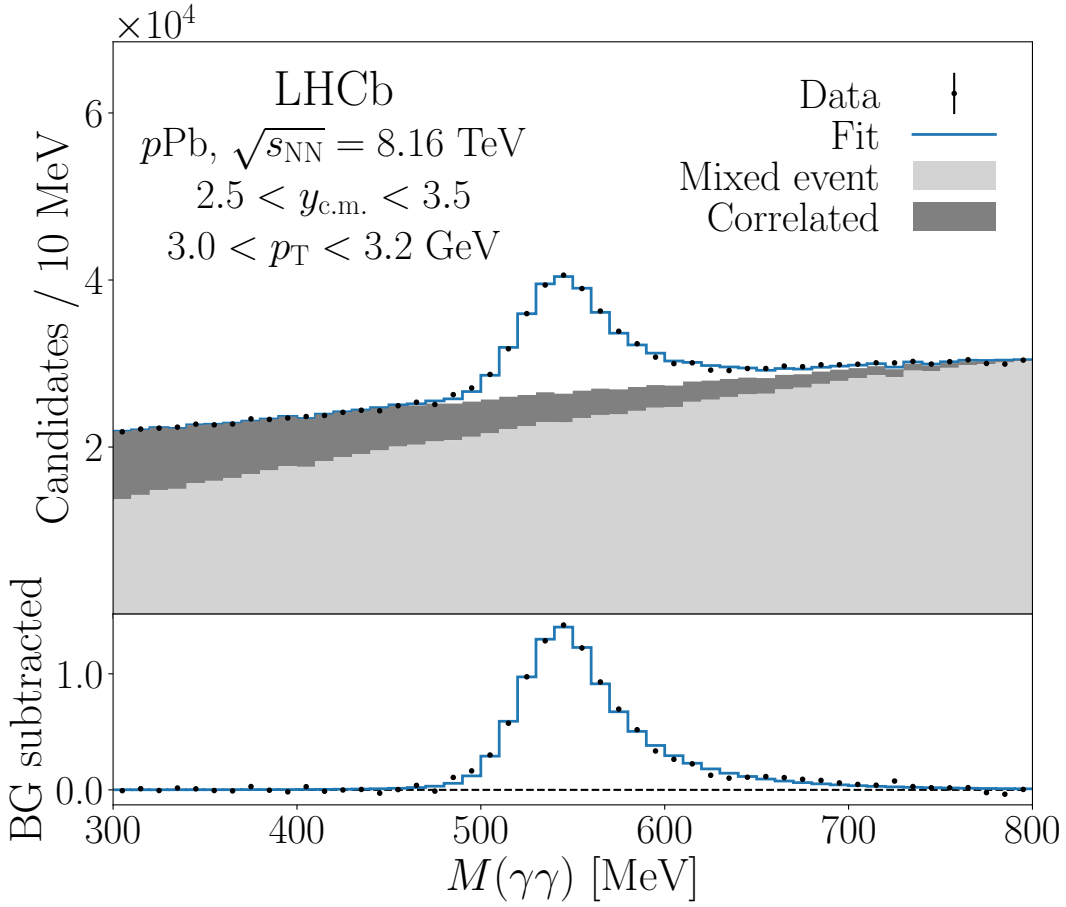


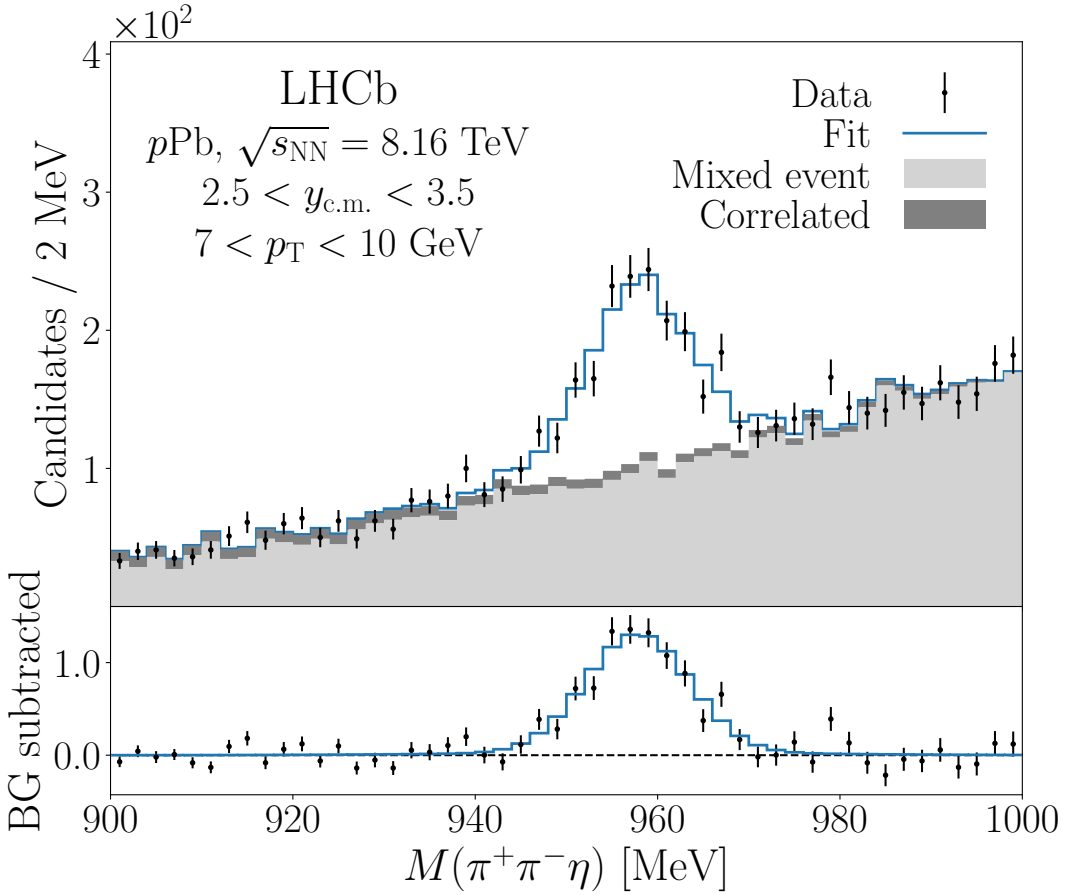


McNulty, Khoze, Martin, Ryskin, Eur. Phys. J. C 80, 288 (2020)

η and η' in pp and pPb

10.1103/PhysRevC.109.024907

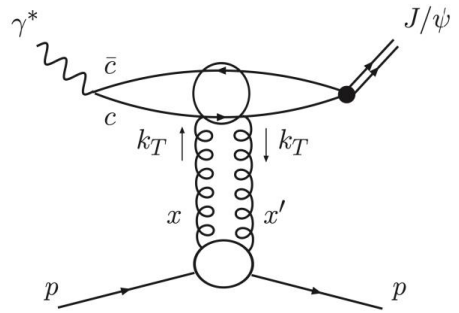




- Clear identification of η and η' via invariant mass reconstruction in pPb
- η reconstructed from γ pairs identified in ECAL (clusters $p_T > 500$ MeV + isolated from charged tracks)
- η' reconstructed from η candidates ($500 < M_{\gamma\gamma} < 600$ MeV) and charged pion pairs

Photoproduction measurements from CEP

LHCb measurements cover a unique range in W with high precision



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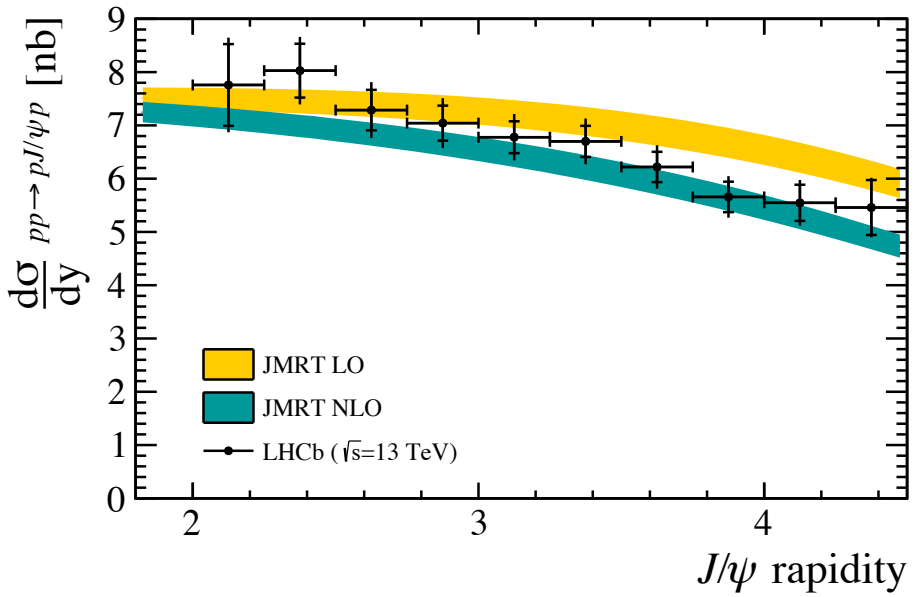

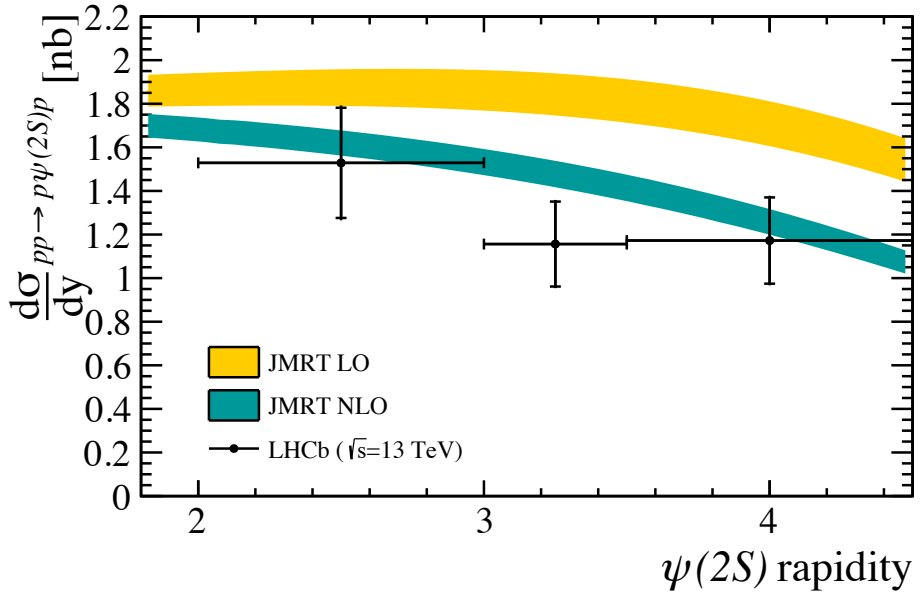

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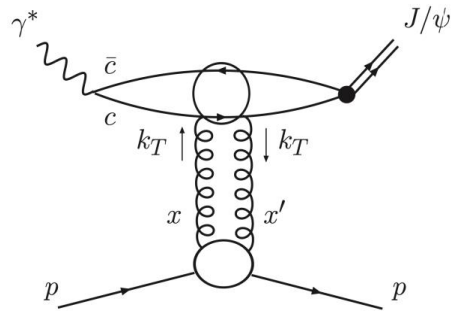

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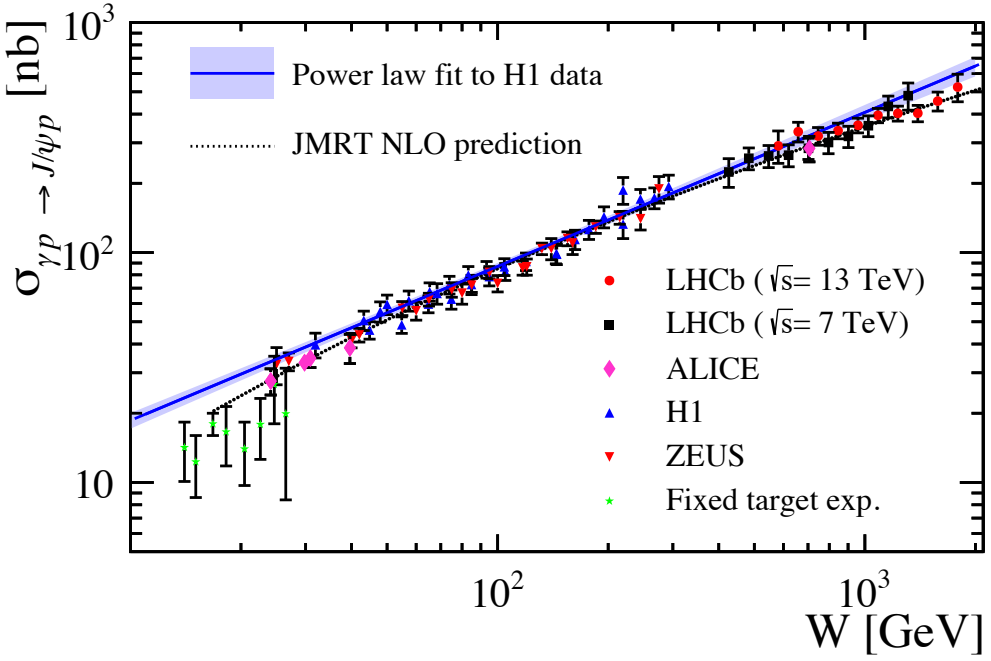

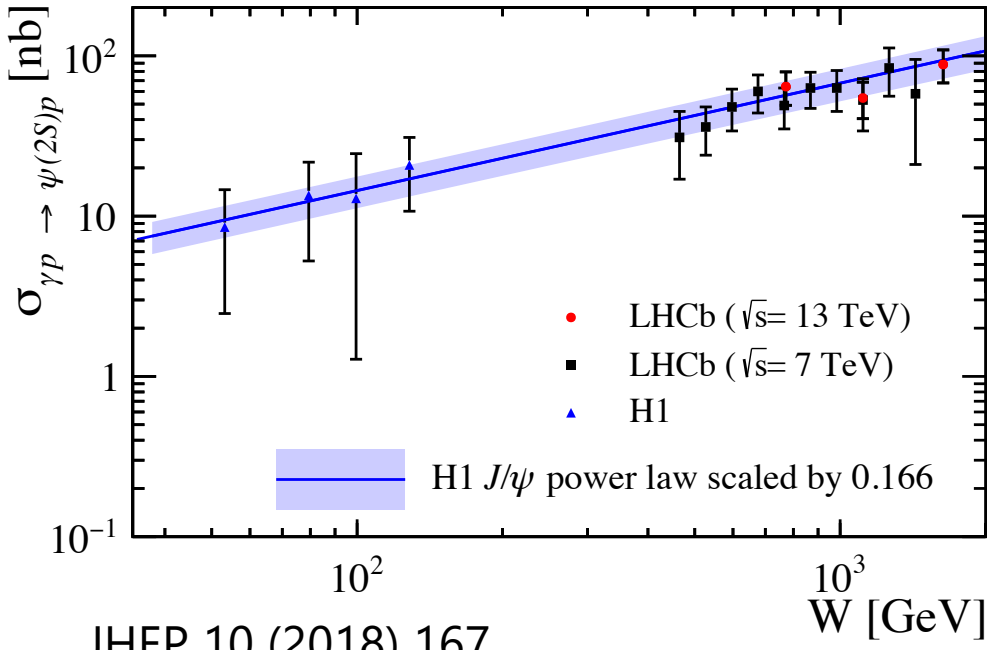

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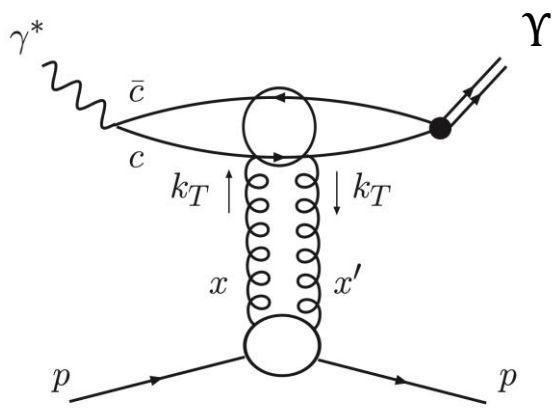
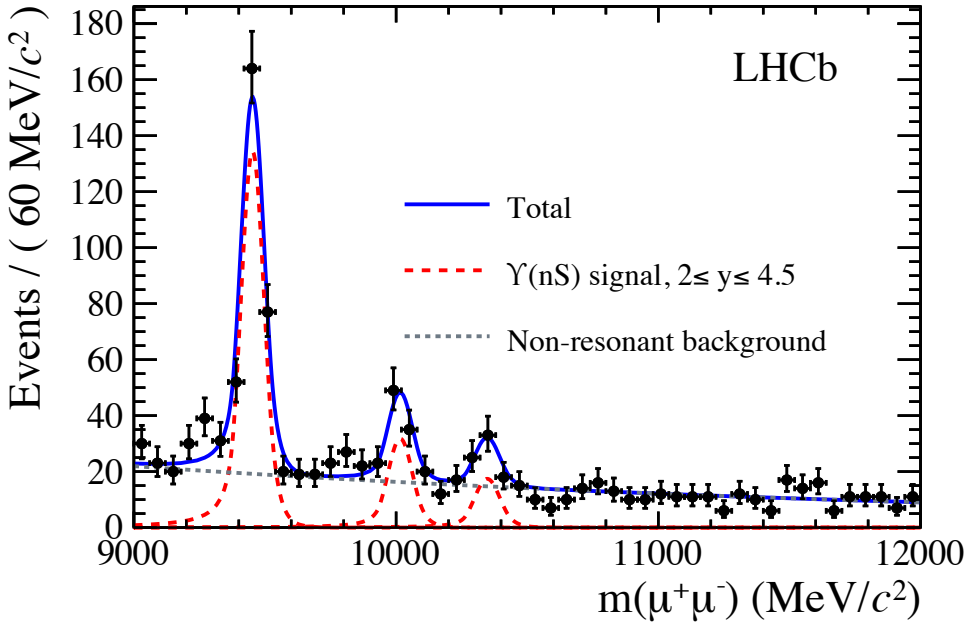
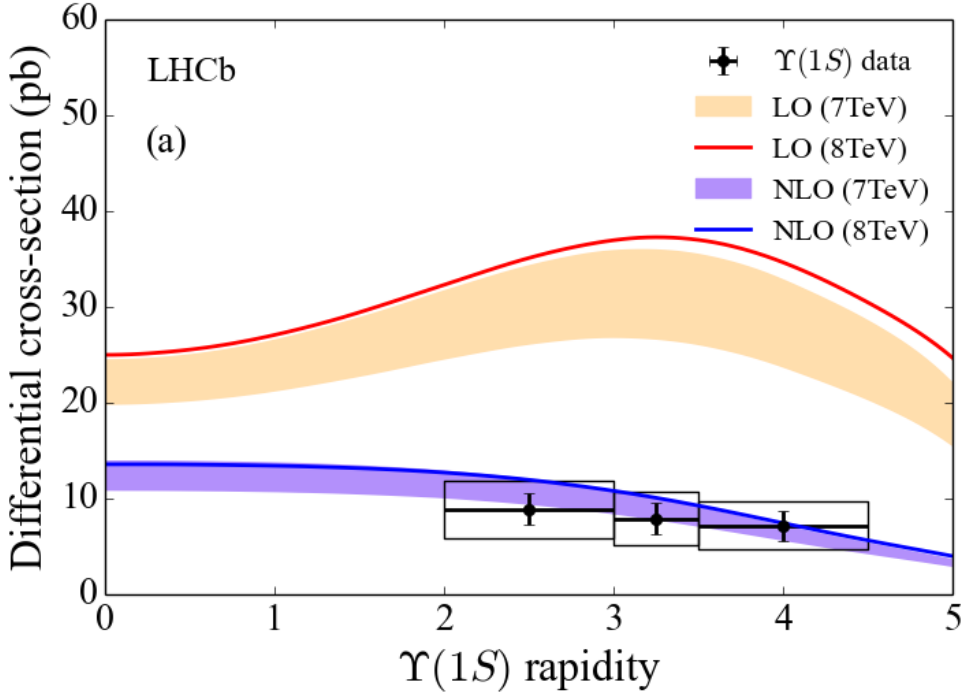
Bottomonia photoproduction in CEP

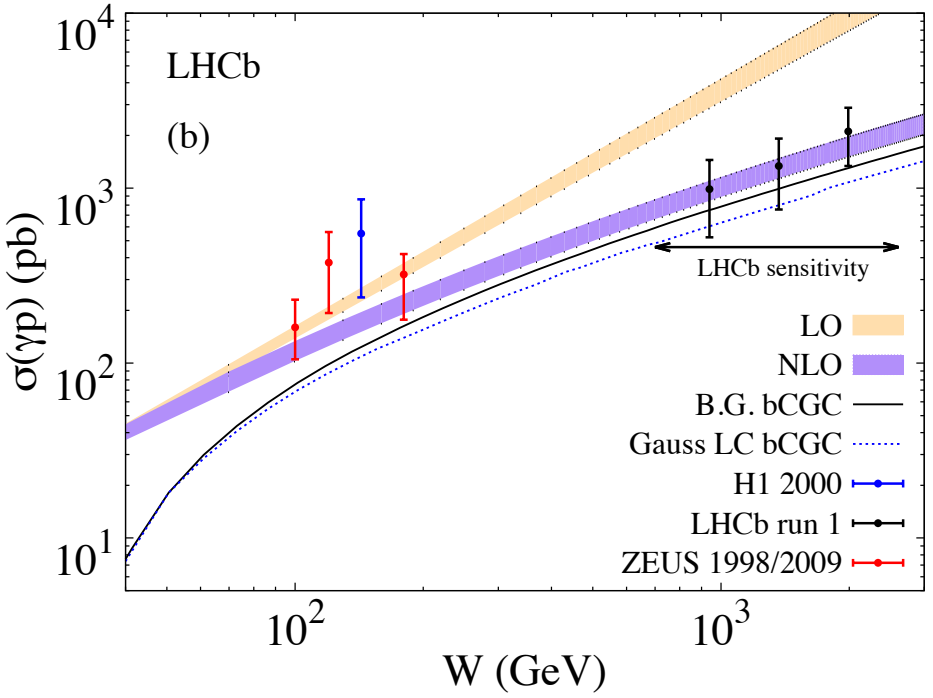
- Access to Bottomonia $\Upsilon(nS)$
- $Q^2 \approx 25$ GeV^2



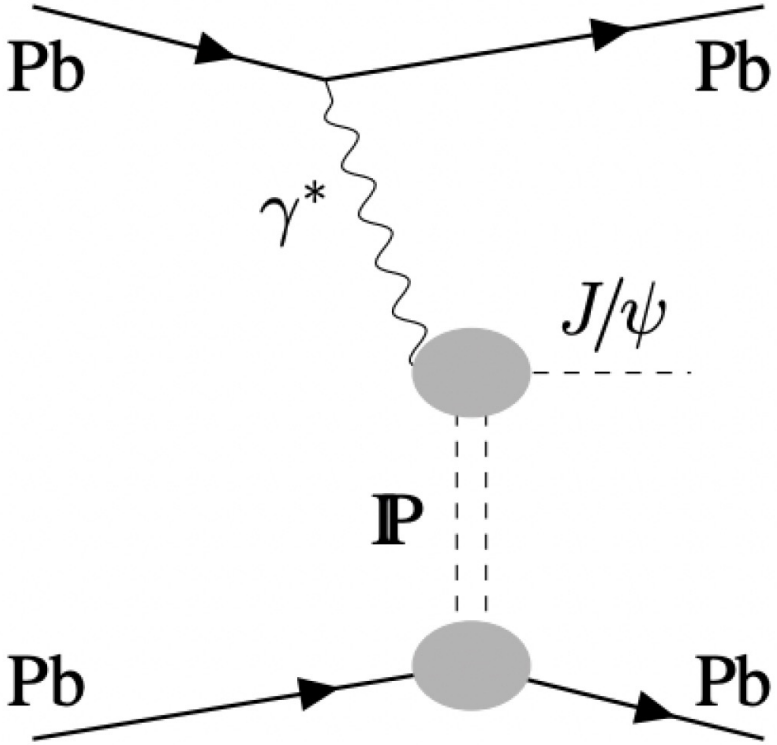
JHEP 1509 (2015) 084



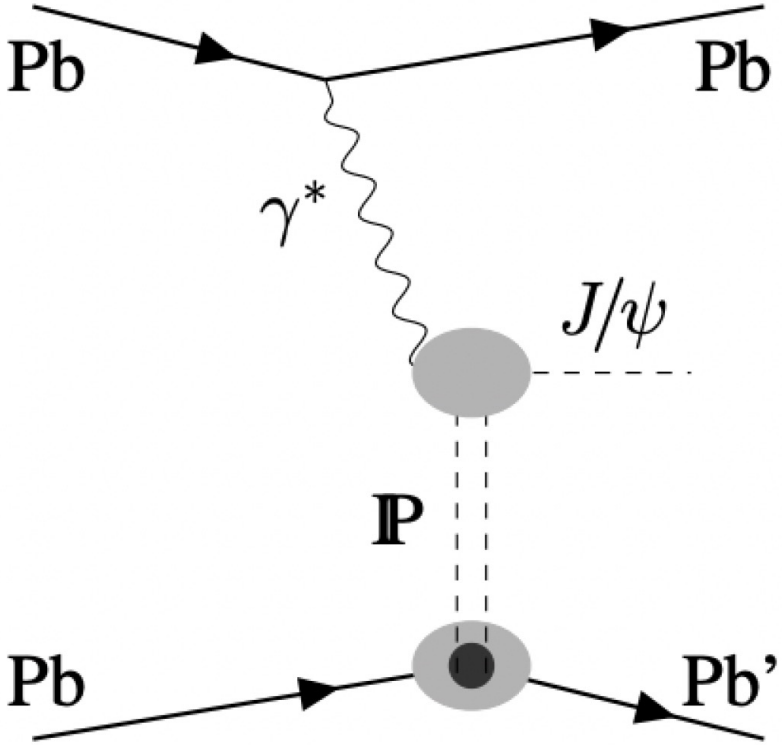




Vector Meson Photoproduction in UPC of PbPb



Coherent



Incoherent

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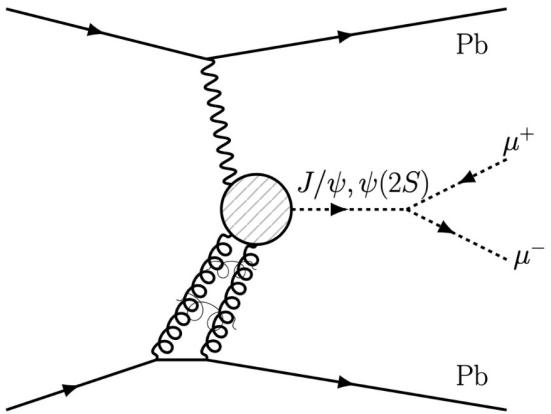
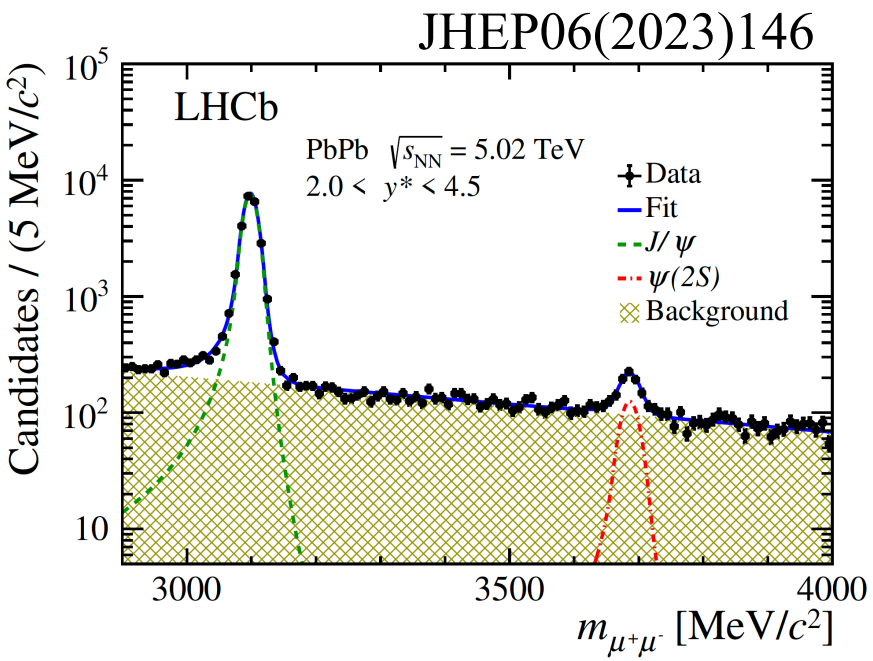
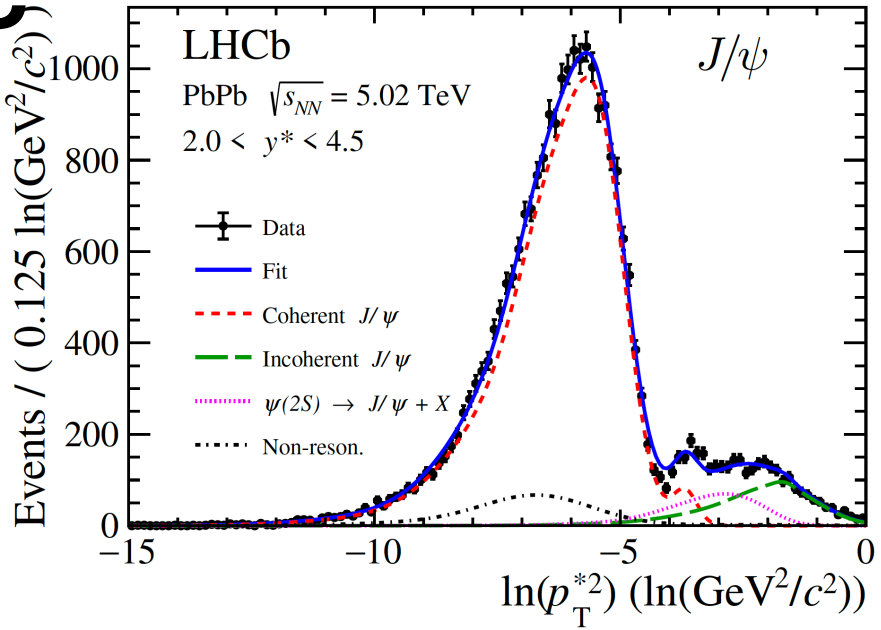
Efficient separation of coherent and incoherent thanks to HeRSCheL

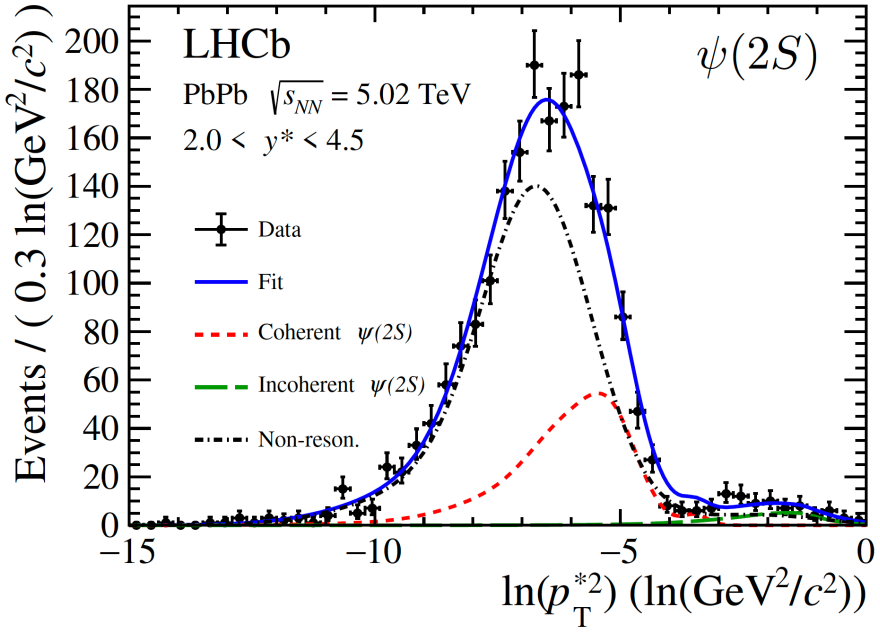
pA will allow disambiguation of photon emitter / nuclear target + crucial baseline for photoproduction compared to pp, AA

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



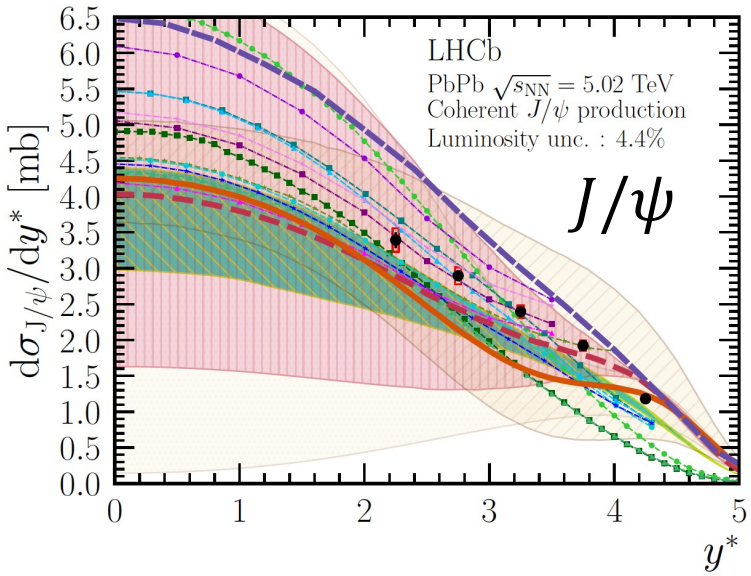


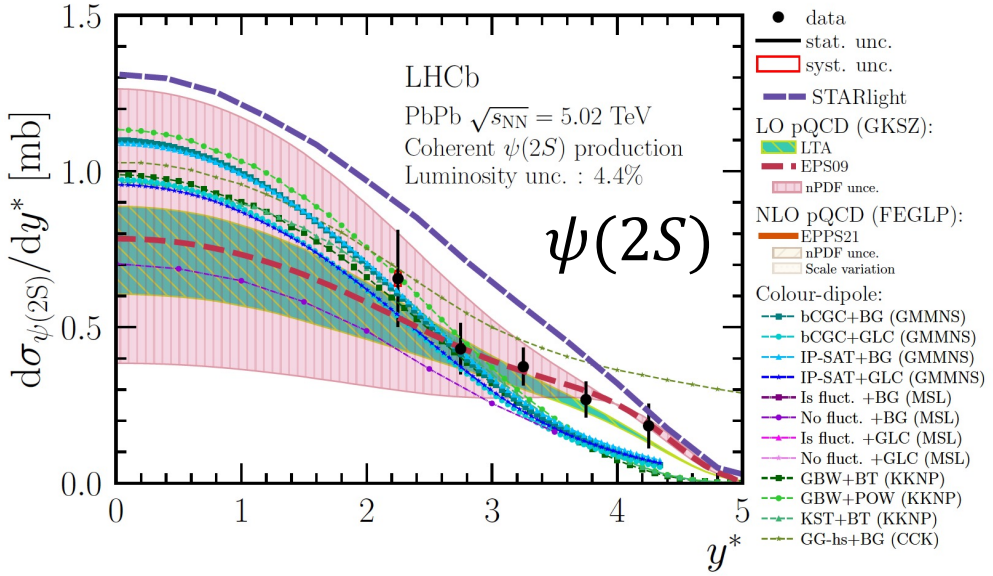




- Excellent separation between coherent and incoherent components, thanks to
  - HeRSCHeL
  - High p_T resolution – allows measurement of $d\sigma/dp_T$ at LHC

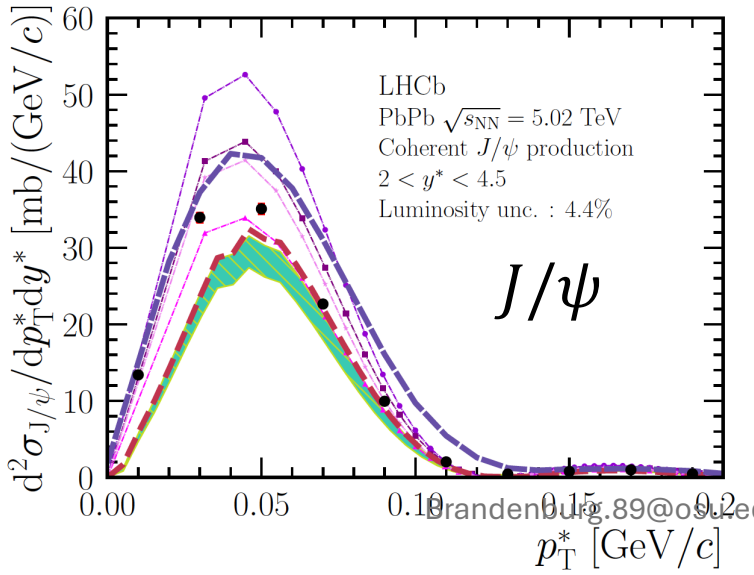
J/ψ and $\psi(2S)$: Comparison With Theory

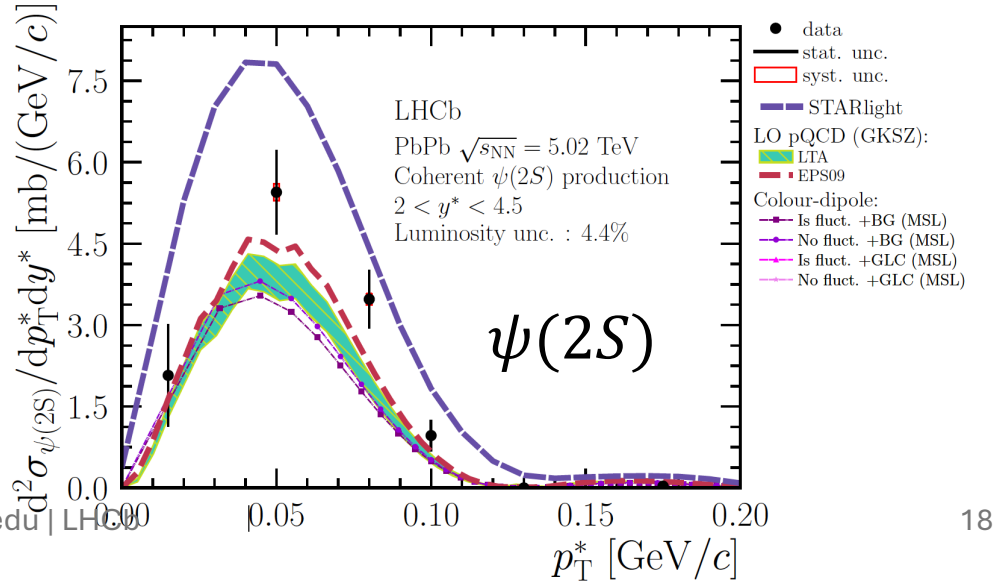




Comparison with:
- LO pQCD
- NLO pQCD
- Color-dipole models
- Gluon saturation models
- Sub-nucleonic fluctuations

JHEP06(2023)146





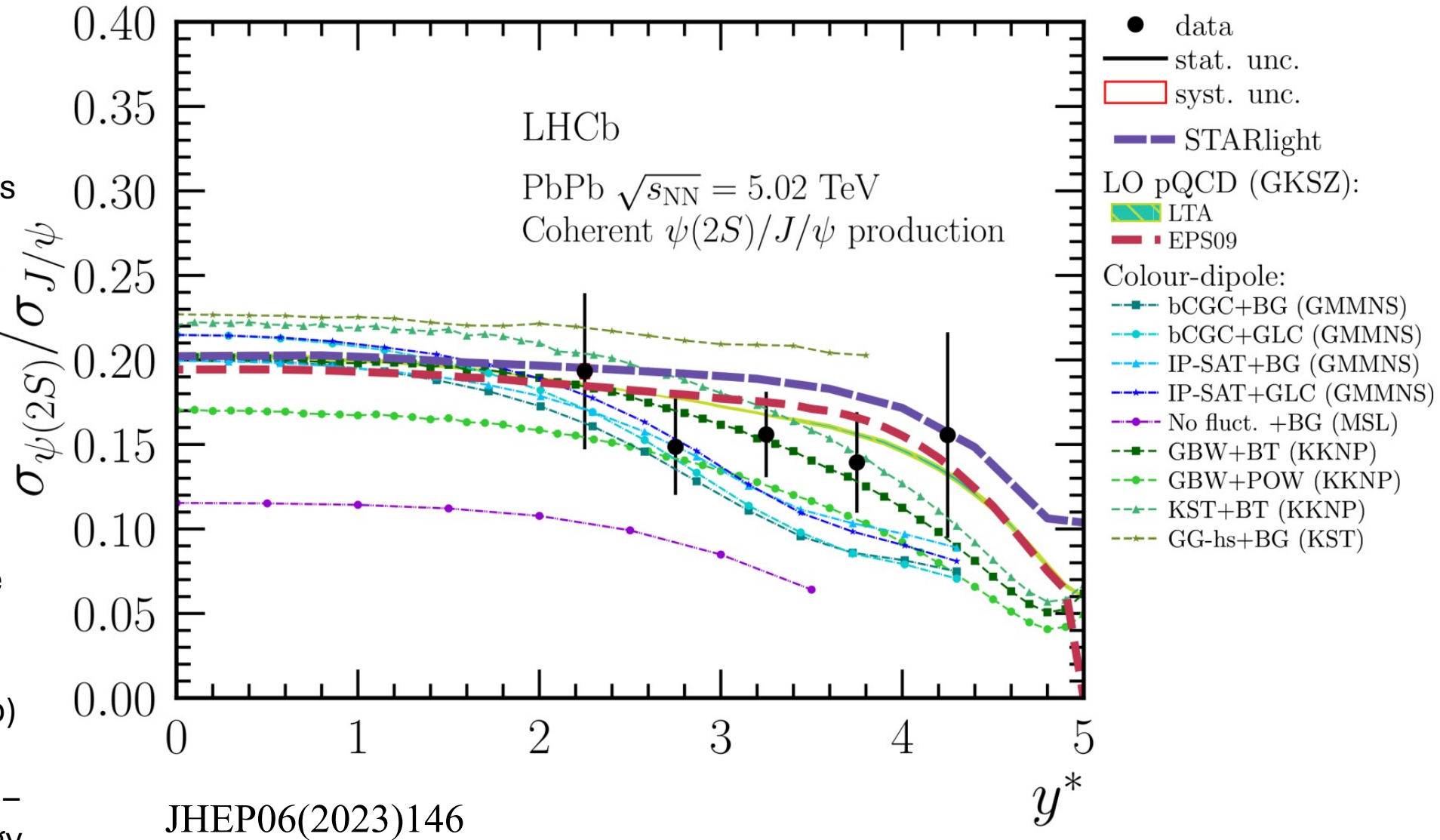
J/ψ and $\psi(2S)$: Comparison With Theory

Comparison with:
- LO pQCD
- Color-dipole models
- Gluon saturation models
- Sub-nucleonic fluctuations

Future measurements will help distinguish model predictions

Measurements with high-lumi pA will provide unique constraints

Flipping beam (pPb vs. Pbp) will allow LHCb to cover forward/backward rapidity – large range in photon energy



JHEP06(2023)146

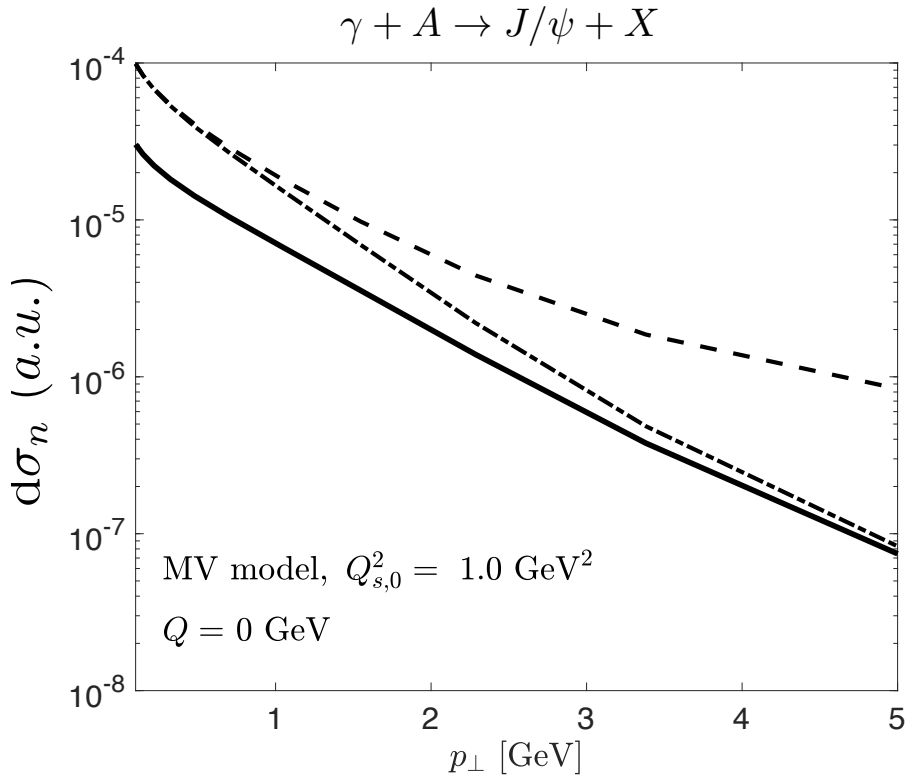
Quarkonium production in UPCs

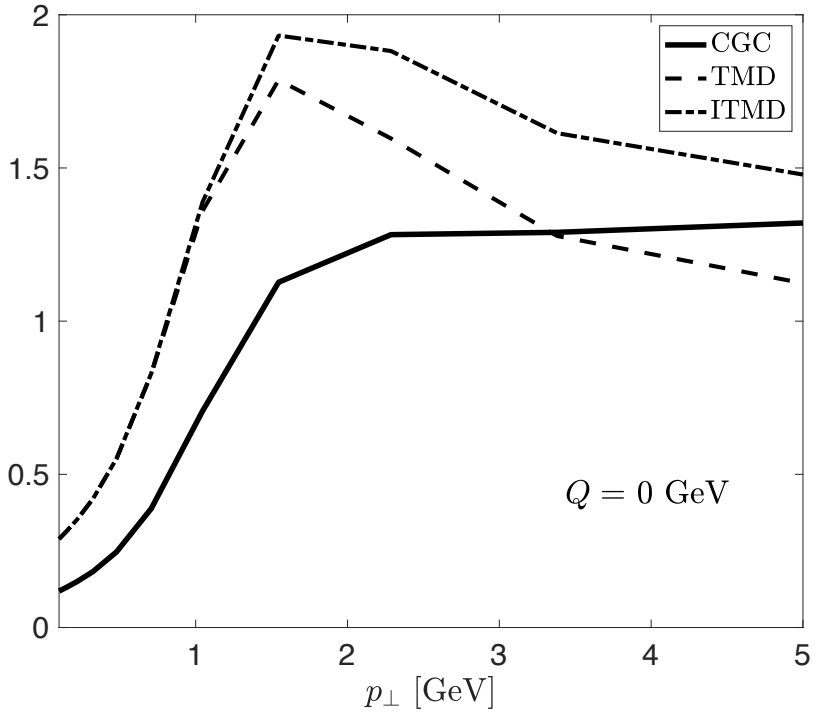
arXiv:2404.10833 [nucl-th]

Nuclear modification ratio in UPCs

Farid Salazar (INT @ U. Washington)

$$R_{\gamma A} = \frac{1}{A}\frac{\mathrm{d}\sigma_{\gamma A}}{\mathrm{d}\sigma_{\gamma p}}$$

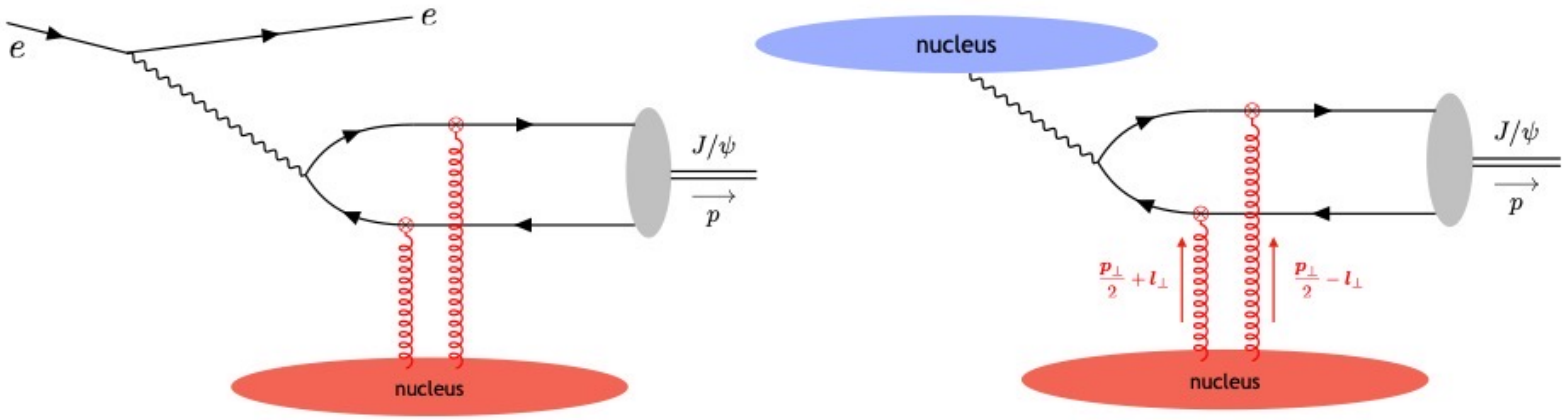




Genuine higher saturation contributions have the largest effect in photo-production (e.g. UPC) which cause a large suppression of the cross-section and the nuclear modification ratio at low pT

Quarkonium production in UPCs

arXiv:2406.01684 [hep-ph]



Photon is quasi-real, take $Q^2 \to 0$ limit of our $\gamma^* A$ results (only transverse polarization survives)

Improved TMD regime of validity is very narrow: $Q_s^2 \ll M_{J/\psi}^2$

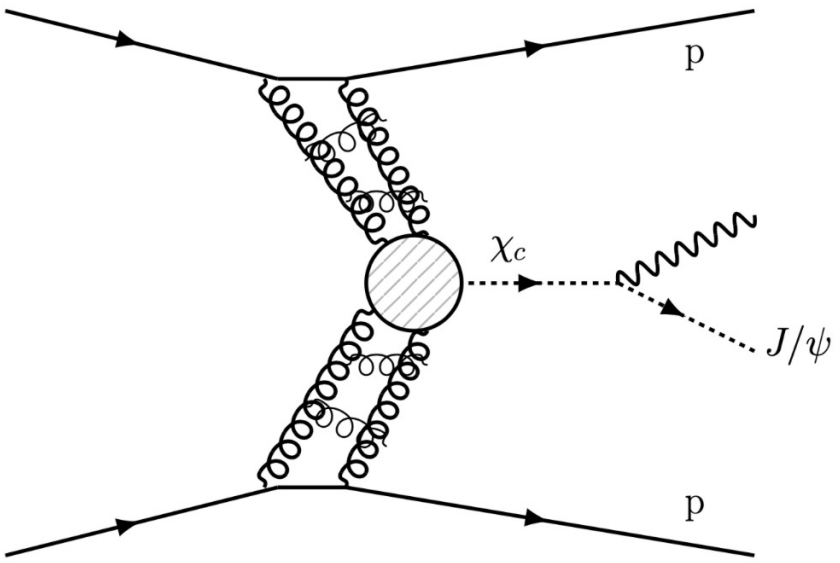
but for large nuclei at high energies $Q_s^2 \sim M_{J/\psi}^2$ Need full CGC calculation!

J/ψ production in UPCs could be very sensitive to **"higher genuine saturation corrections"** only present in the **full CGC calculation**

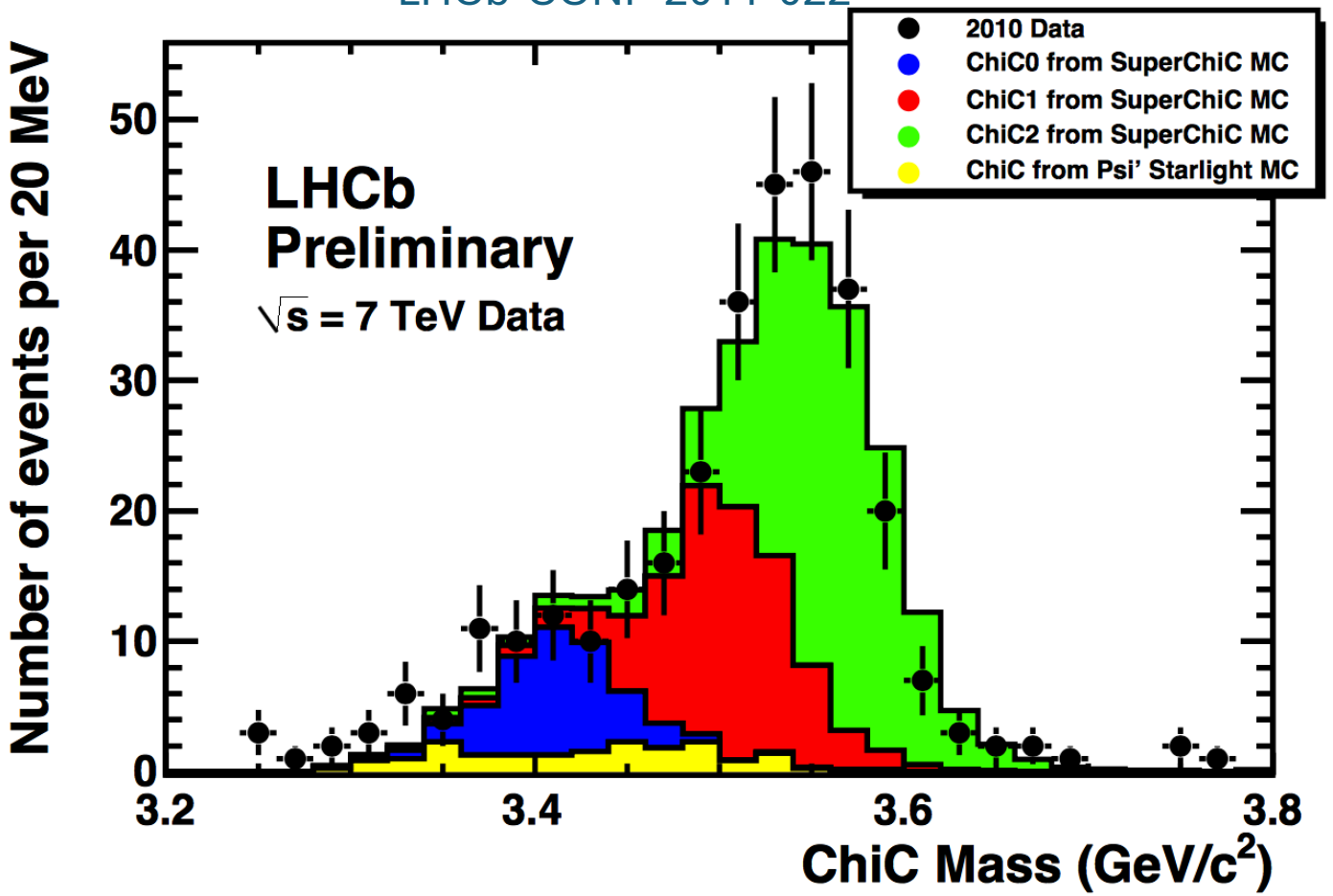
Better sensitivity than dijets since $M_{J/\psi}^2 \ll M_{dijet}^2$. Sudakov effect (soft radiation) should be smaller.

Farid Salazar (INT @ U. Washington)

χ_c states in photo production

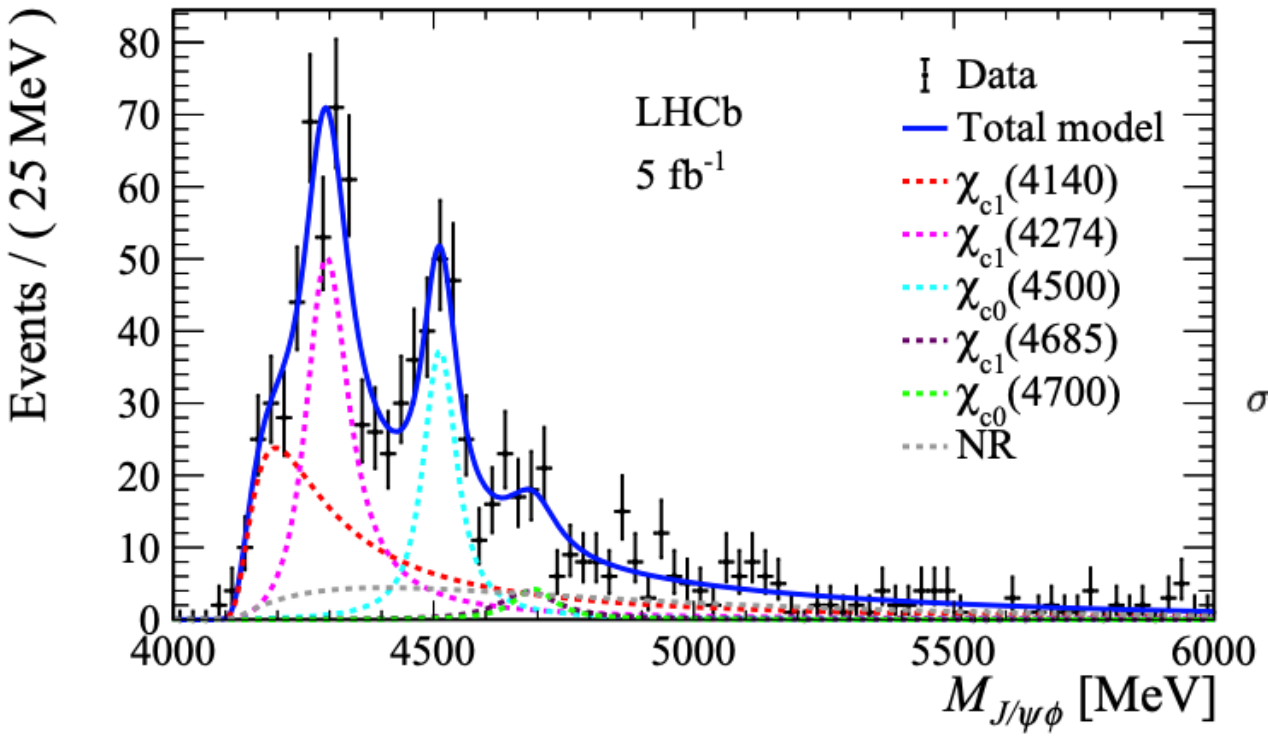


LHCb-CONF-2011-022



New results: χ_c states in photo production

LHCb-PAPER-2023-043 in preparation



$$\sigma_{\chi_{c1}(4140)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4140)} = (0.85 \pm 0.16 \pm 0.30)\,\text{pb},$$
$$\sigma_{\chi_{c1}(4274)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4274)} = (0.77^{+0.14}_{-0.13} \pm 0.18)\,\text{pb},$$
$$\sigma_{\chi_{c0}(4500)} \times \mathcal{B}_{\text{eff}}^{\chi_{c0}(4500)} = (0.44^{+0.09}_{-0.08} \pm 0.07)\,\text{pb},$$
$$\sigma_{\chi_{c1}(4685)+\chi_{c0}(4700)} \times \mathcal{B}_{\text{eff}}^{\chi_{c1}(4685)+\chi_{c0}(4700)} = (0.14^{+0.07}_{-0.06} \pm 0.06)\,\text{pb},$$
$$\sigma_{NR} \times \mathcal{B}_{\text{eff}}^{NR} = (0.46^{+0.25\ +0.21}_{-0.19\ -0.22})\,\text{pb},$$

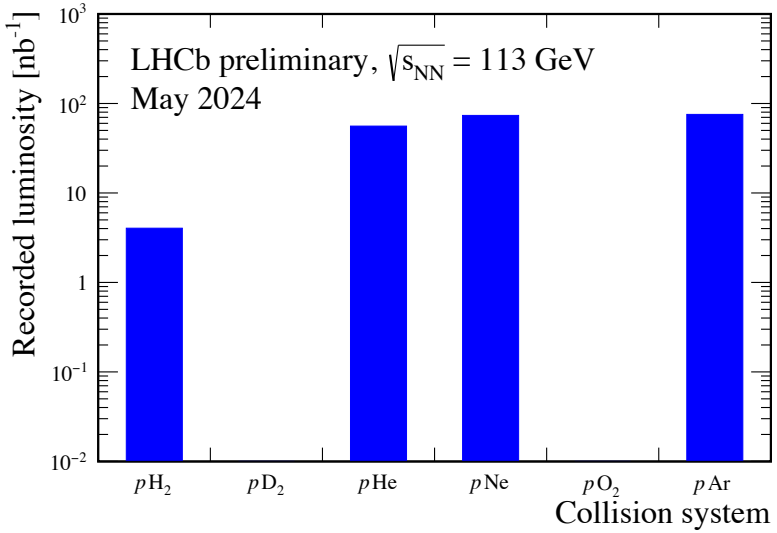
First exotic measurement in events with no other activity.

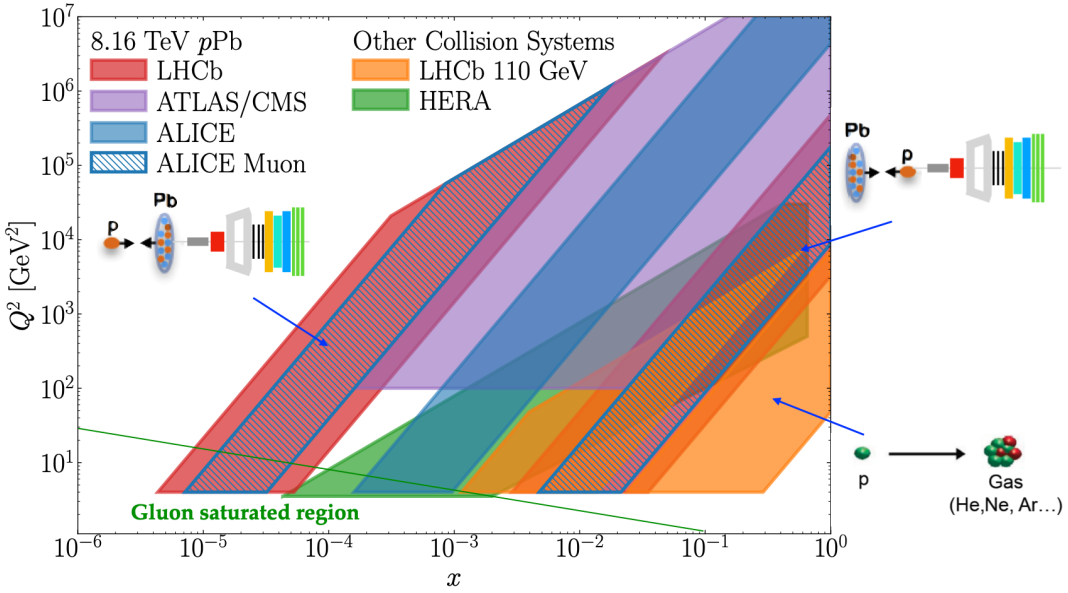
Golden measurement to understand exotic production.

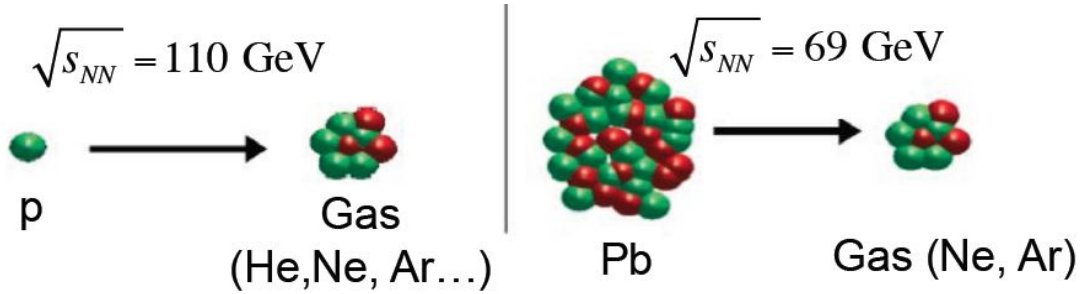
LHCb: Complements of SMOG2

- SMOG2 provides pA/Ap in fixed target mode
  - Access to lower $\sqrt{s_{NN}}$ at LHC
  - Mid-rapidity coverage
- Collider mode + fixed target mode pPb, Pbp – unique to LHCb

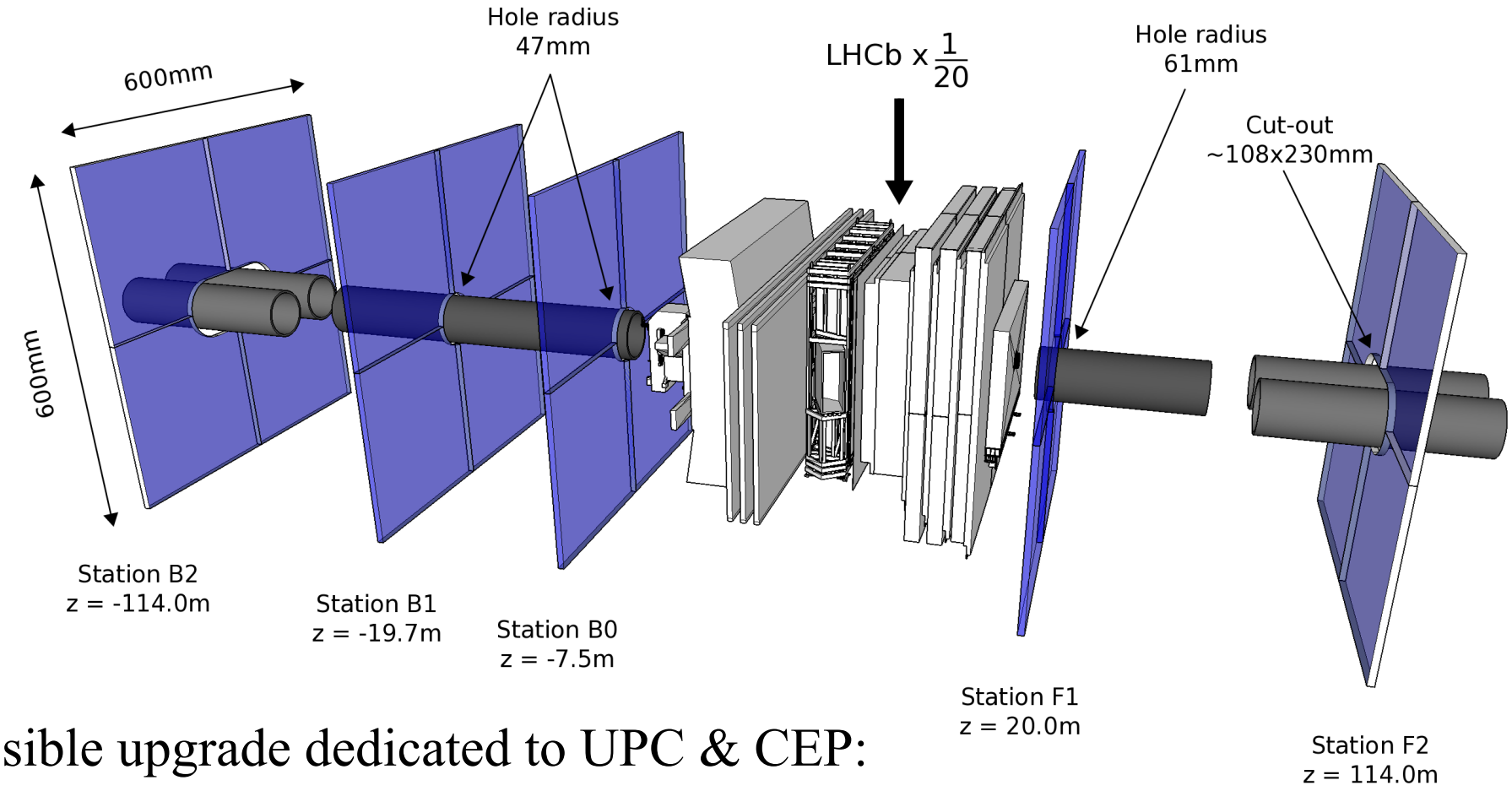
LHCb-Figure-2024-005







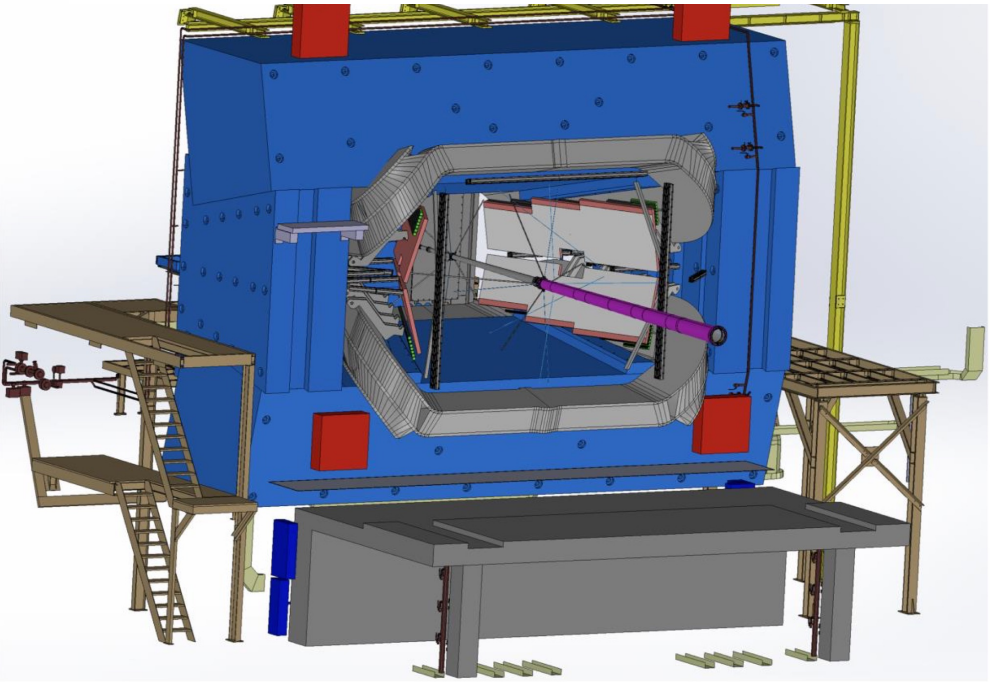
Possible Future Upgrades: Resurrecting HeRSCHeL

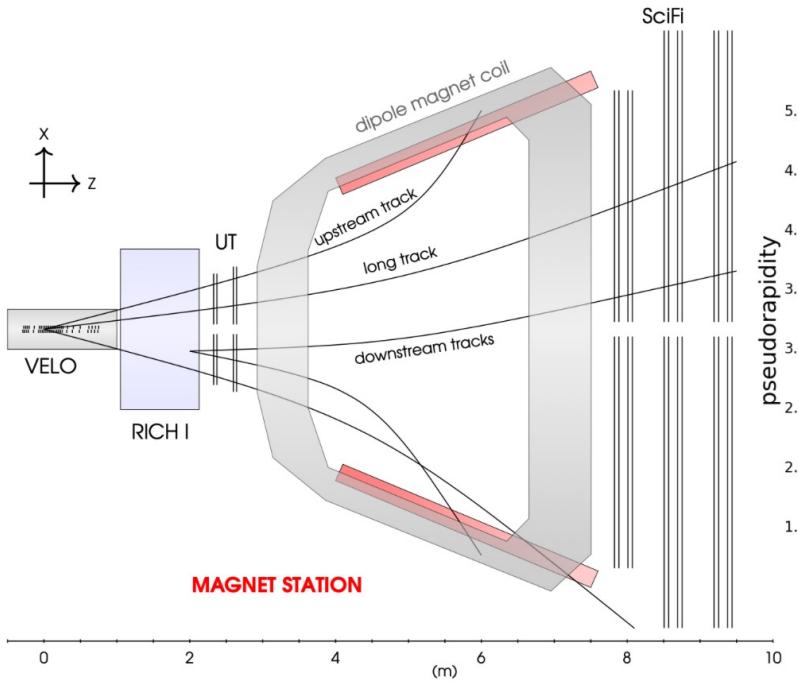


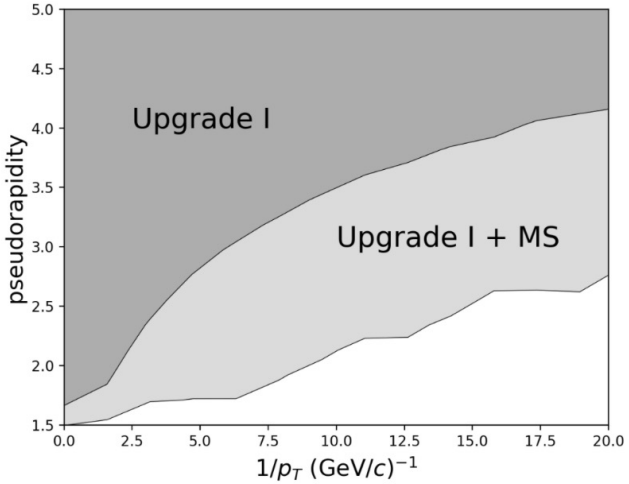
Possible upgrade dedicated to UPC & CEP:

- Replace radiation damaged scintillators.
- Add additional station for symmetry

Future Upgrades : Magnet Stations





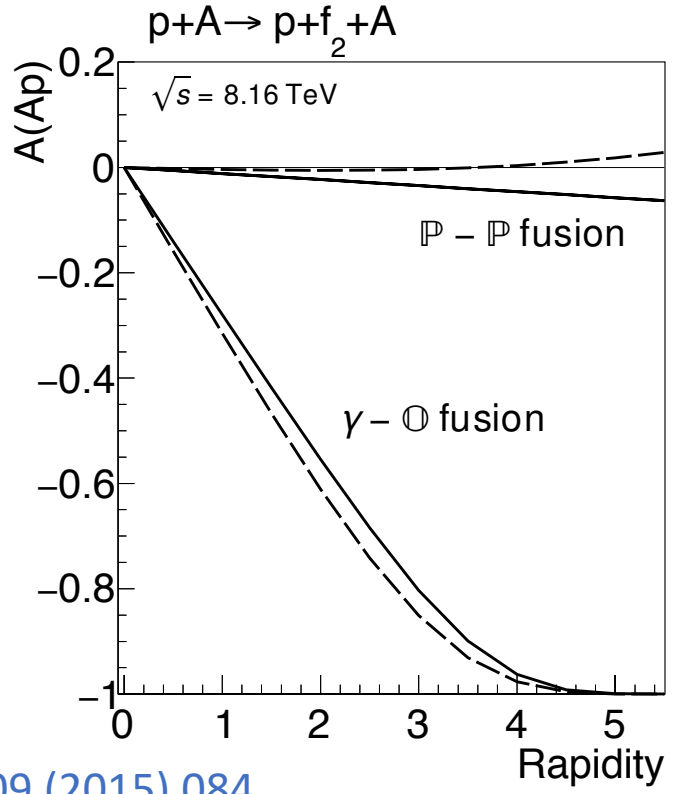


- Instrument the internal magnet walls with a scintillator-based soft particle tracker
- Tracking for p_T>50 MeV/c
  - Essential to complete the UPC program
  - High-statistics low-mass vector, scalar and tensor mesons
  - Exotic hadrons with multiple decay products
  - Low-mass dielectrons and photon conversions

Summary

- LHCb is a powerful detector for pp, pA, AA physics
  - Software-based trigger
  - Excellent particle identification
  - Unique coverage (rapidity and low-pT)
  - Collider + Fixed target modes
- Recent / Results coming soon!
  - Photoproduction in PbPb UPC
  - First measurement of **exclusive** $\chi \to J/\psi\phi$ in pp collisions
  - UPC K^+K^- production
  - Unique look at UPC ρ^0 production in PbPb
- Each analysis is possible and physics potential is significant for high-lumi pA
- Upgrades on the horizon
  - Potential future upgrades dedicated to forward physics program!
    - Improved HerSCHeL for UPC and CEP measurements
  - Even lower pT tracking via Magnet Stations

McNulty, Khoze, Martin, Ryskin, Eur. Phys. J. C 80, 288 (2020)



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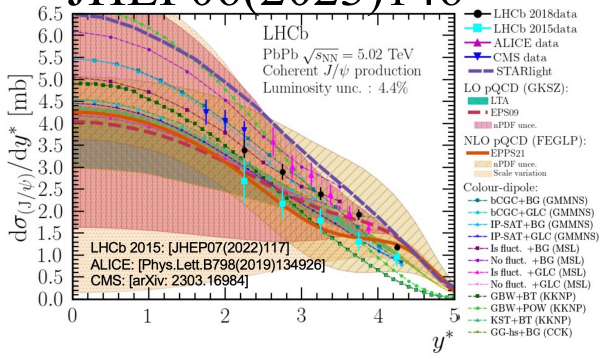

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