TMDs and GPDs at LHCb

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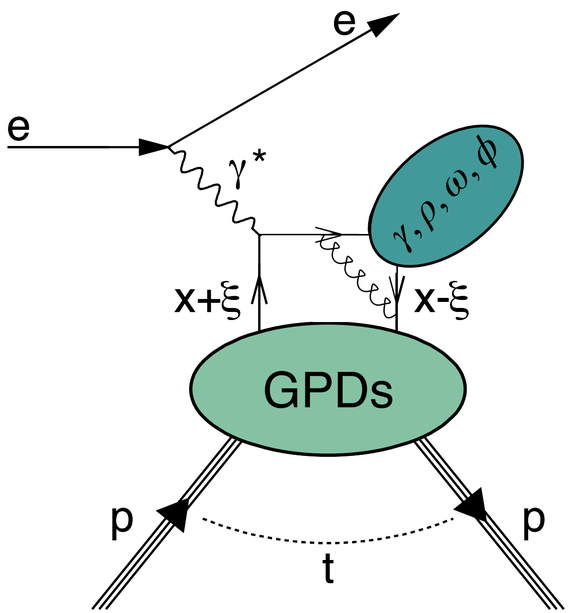
University of Alcalá

AdT

Transversity 2024
June 3–7, 2024
Trieste University, Italy

Access to GPDs



Hard exclusive meson production

Hard scale=large Q^2

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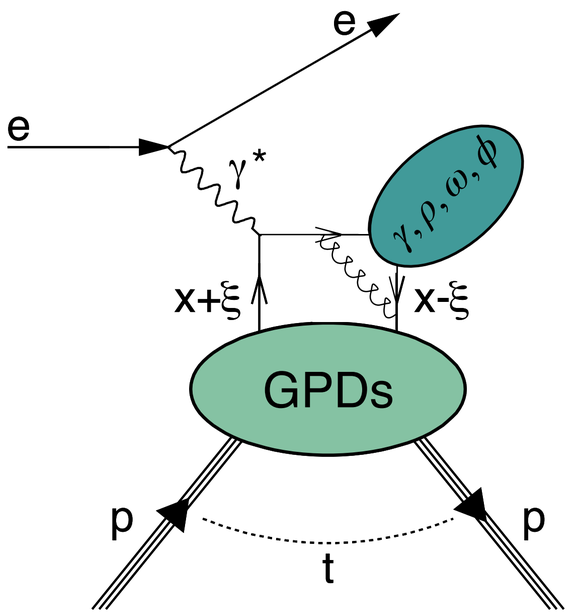

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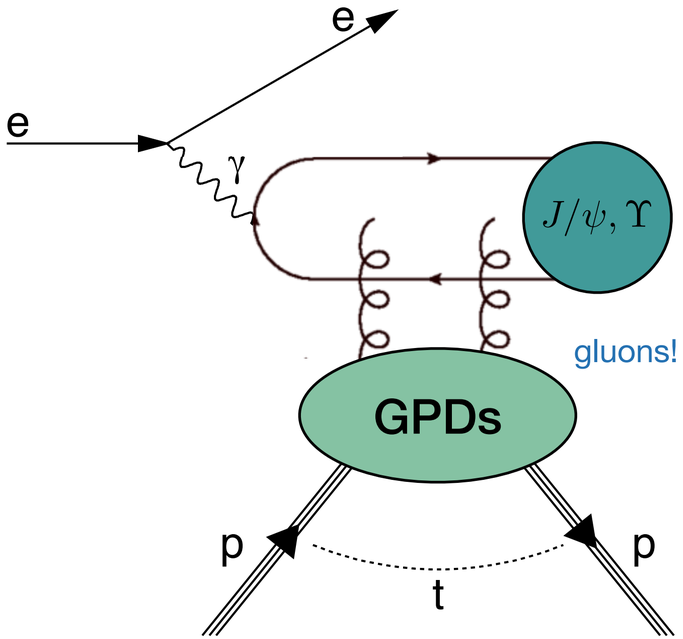

Exclusive meson photoproduction
Hard scale = large charm/bottom-quark mass

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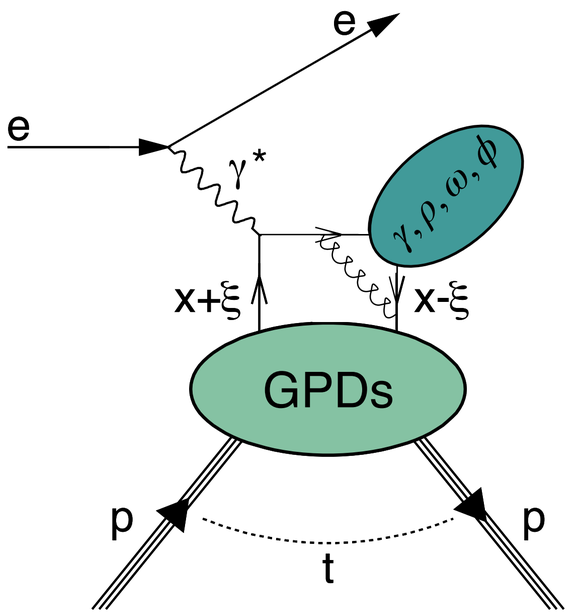

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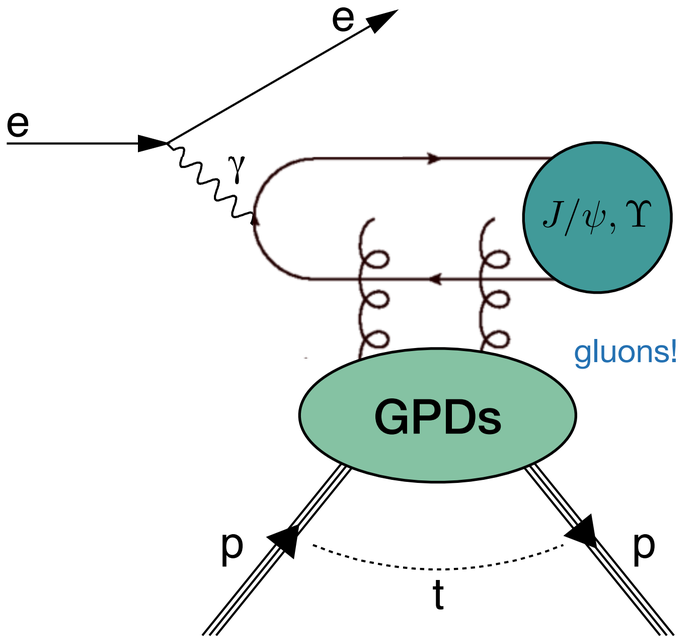

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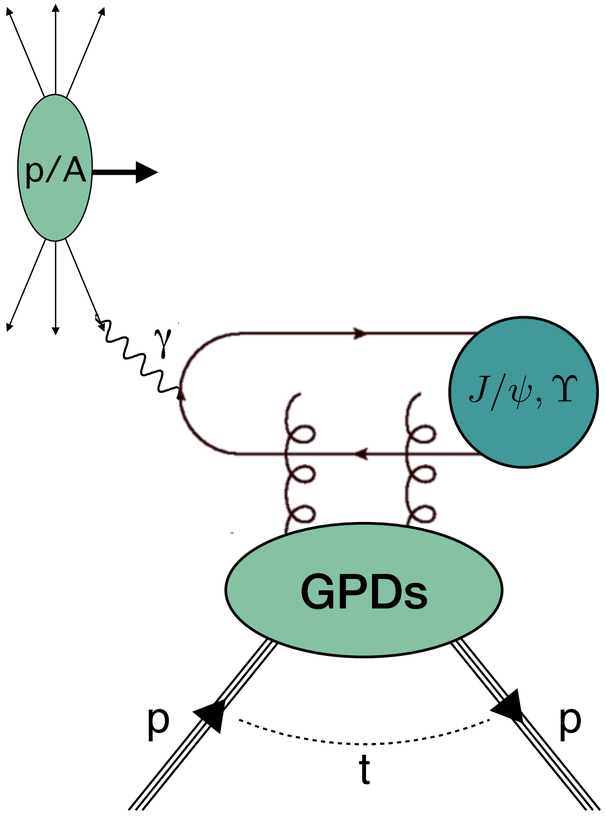

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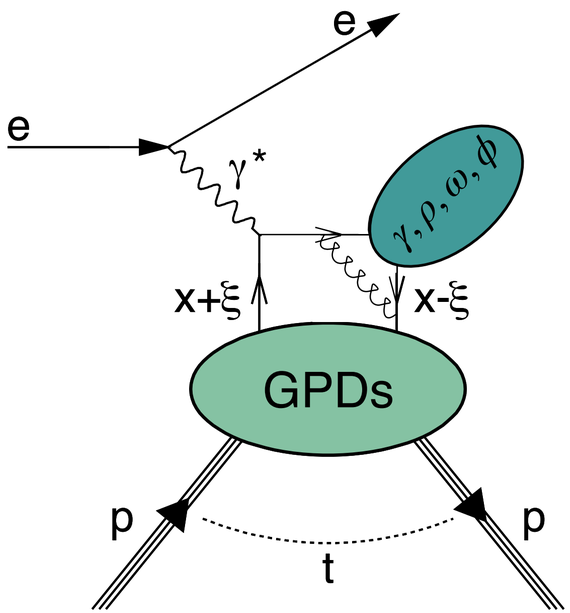

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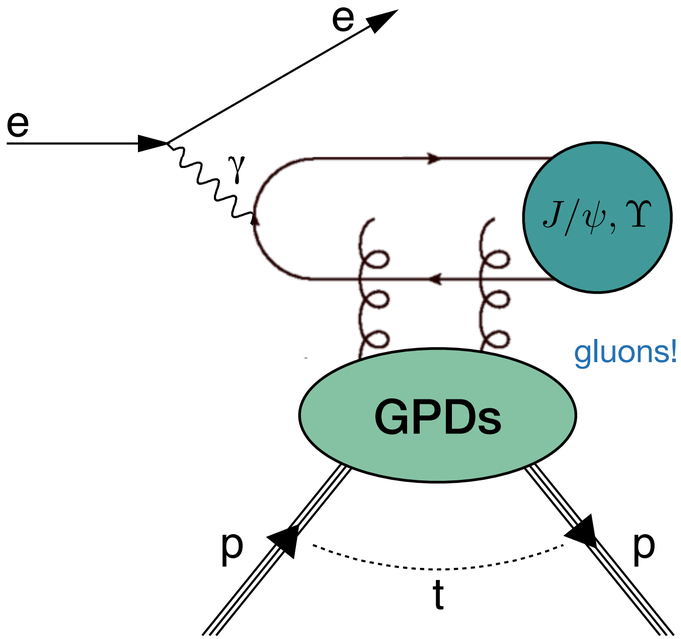

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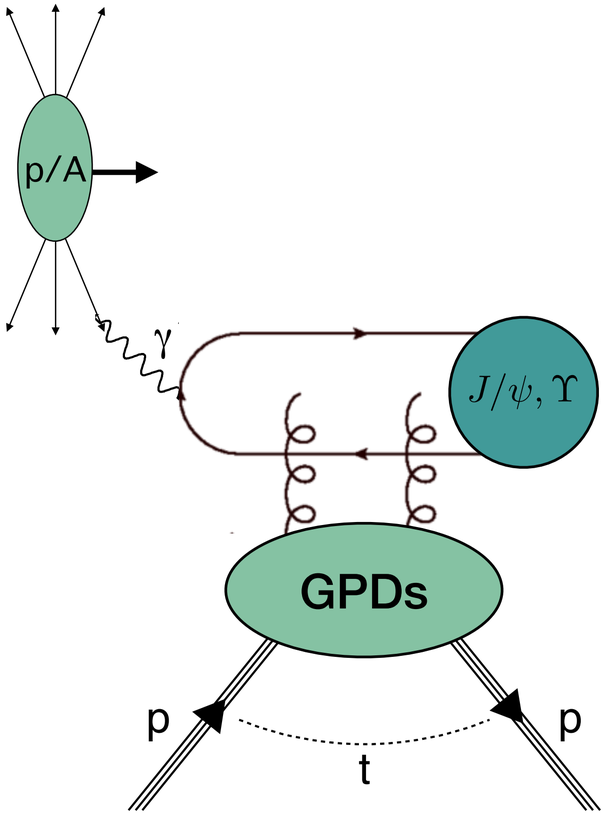

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down to $x_B=10^{-4}$ at HERA/EIC

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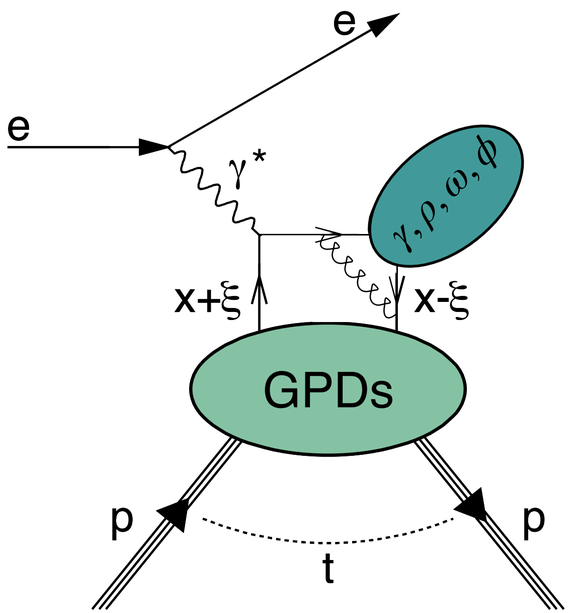

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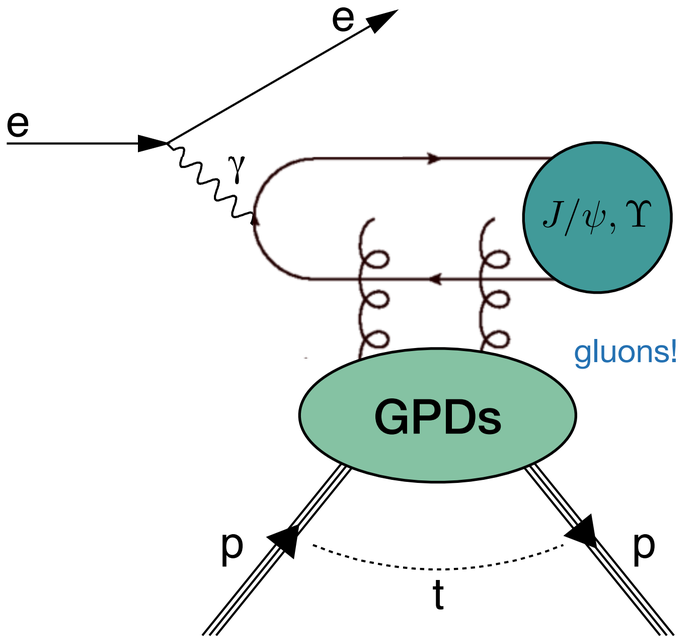

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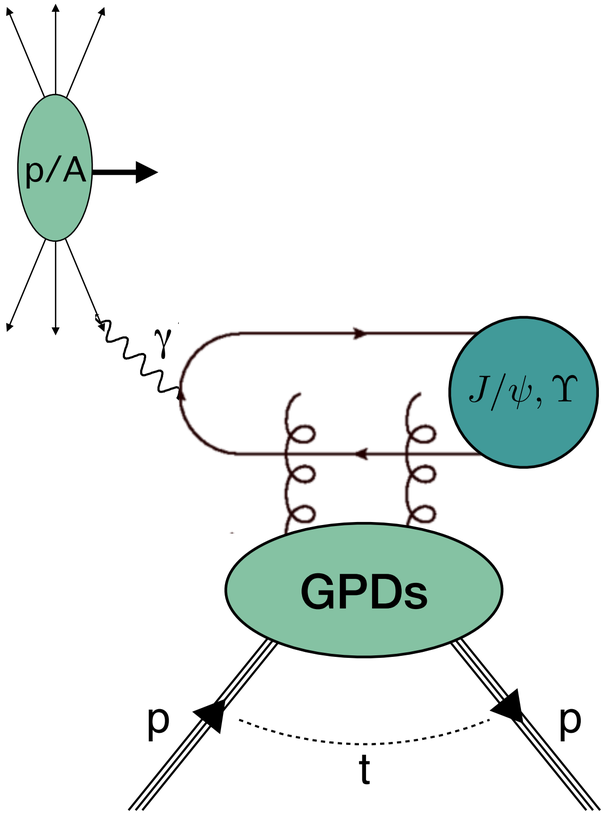

Exclusive meson photoproduction
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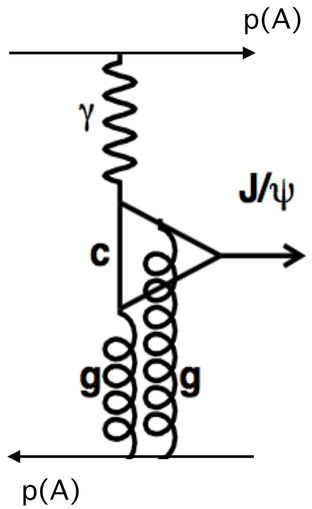
down to $x_B=10^{-4}$ at HERA/EIC

down to $x_B=10^{-6}$ at LHC!

Measurement of exclusive production at LHCb



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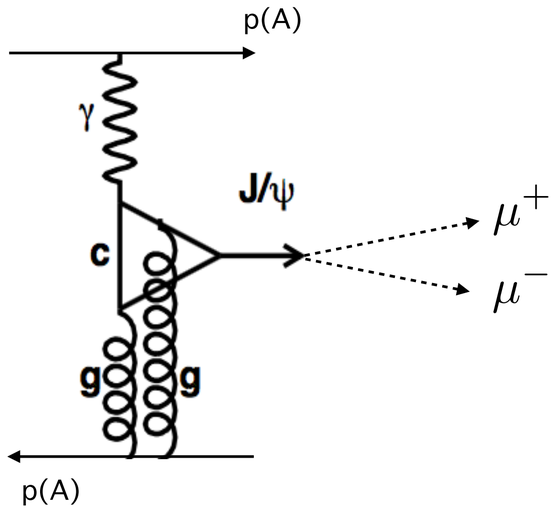

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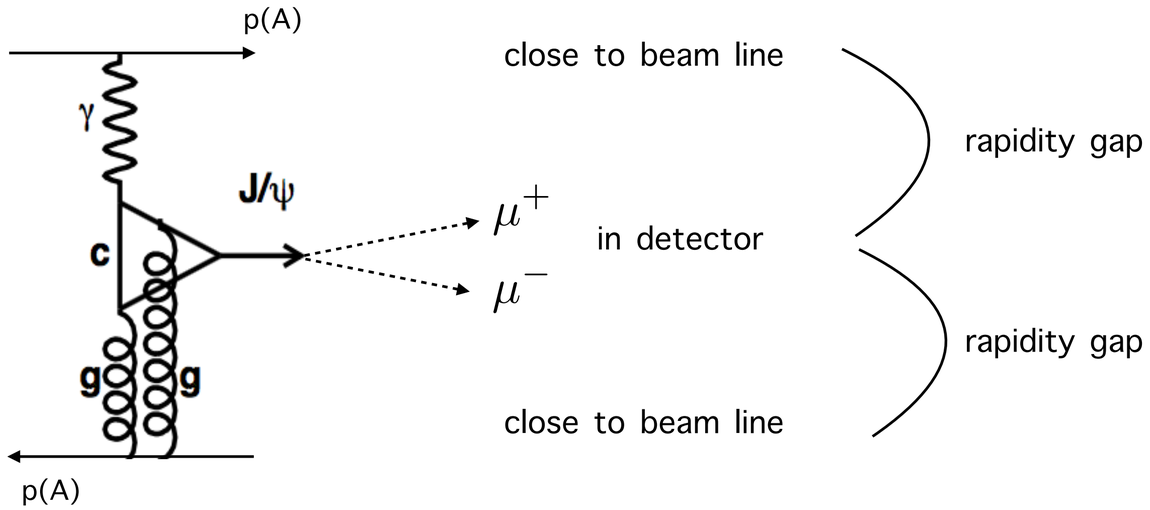

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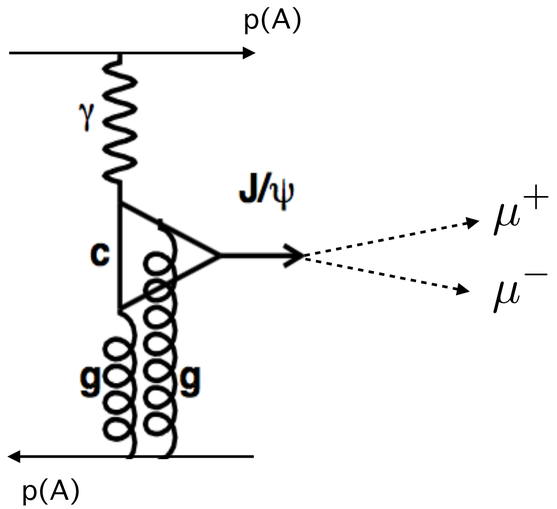
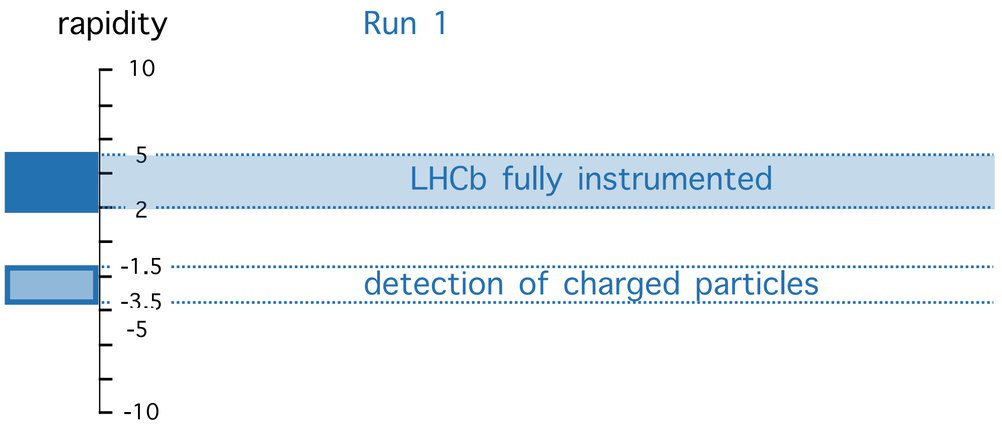
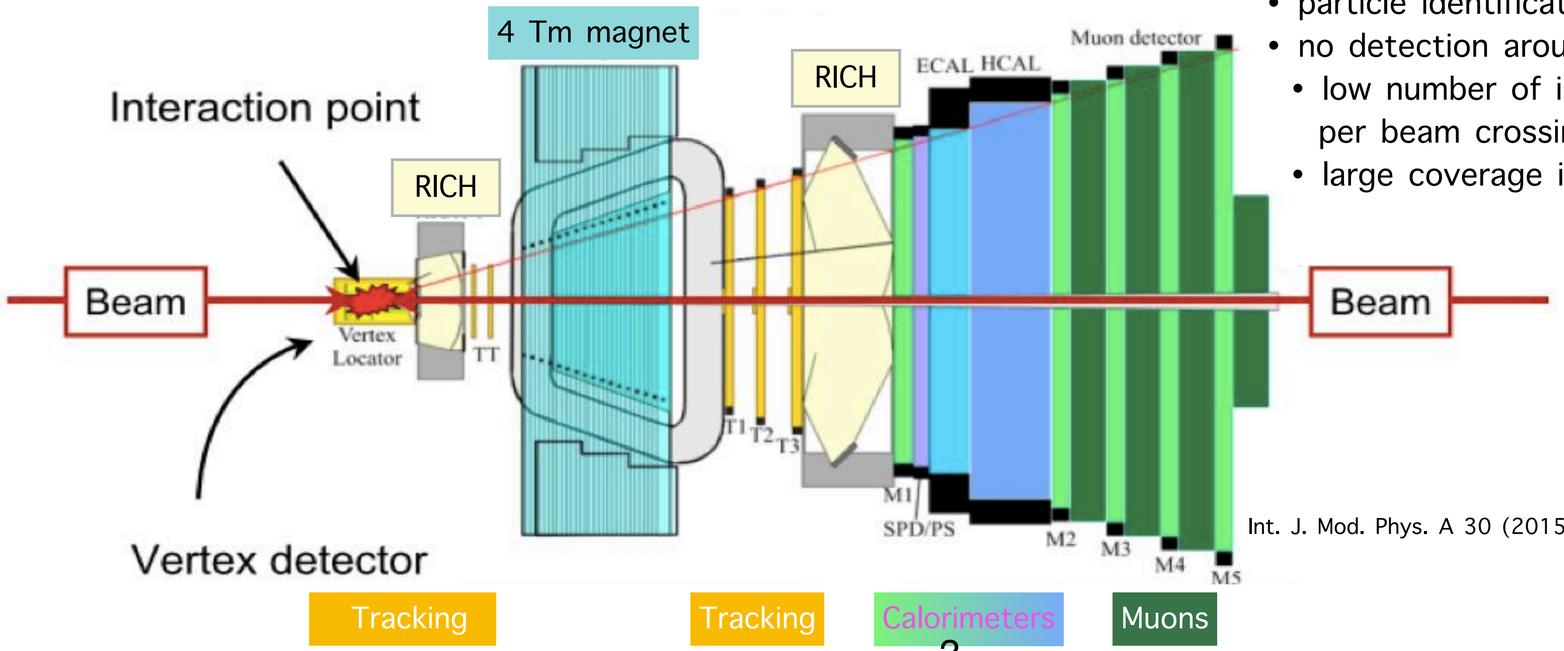




- low p_T threshold: p_T>400 MeV
- particle identification
- no detection around beam line but
  - low number of interactions per beam crossing: 1.1–1.5
  - large coverage in rapidity



Int. J. Mod. Phys. A 30 (2015) 1530022

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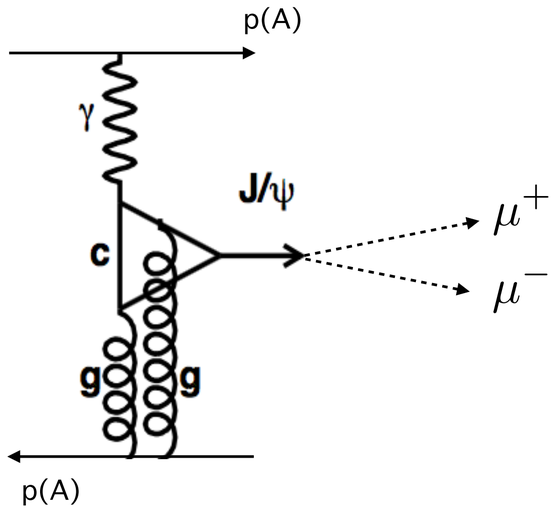

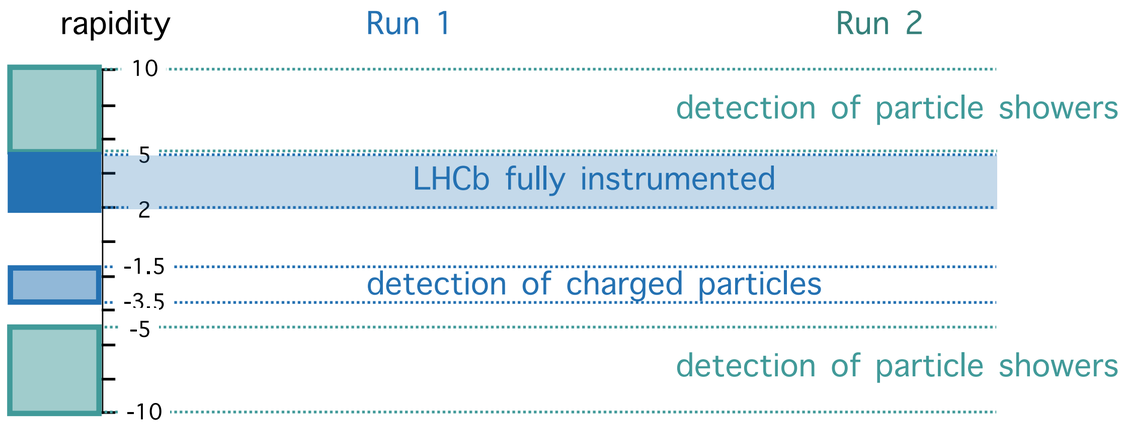

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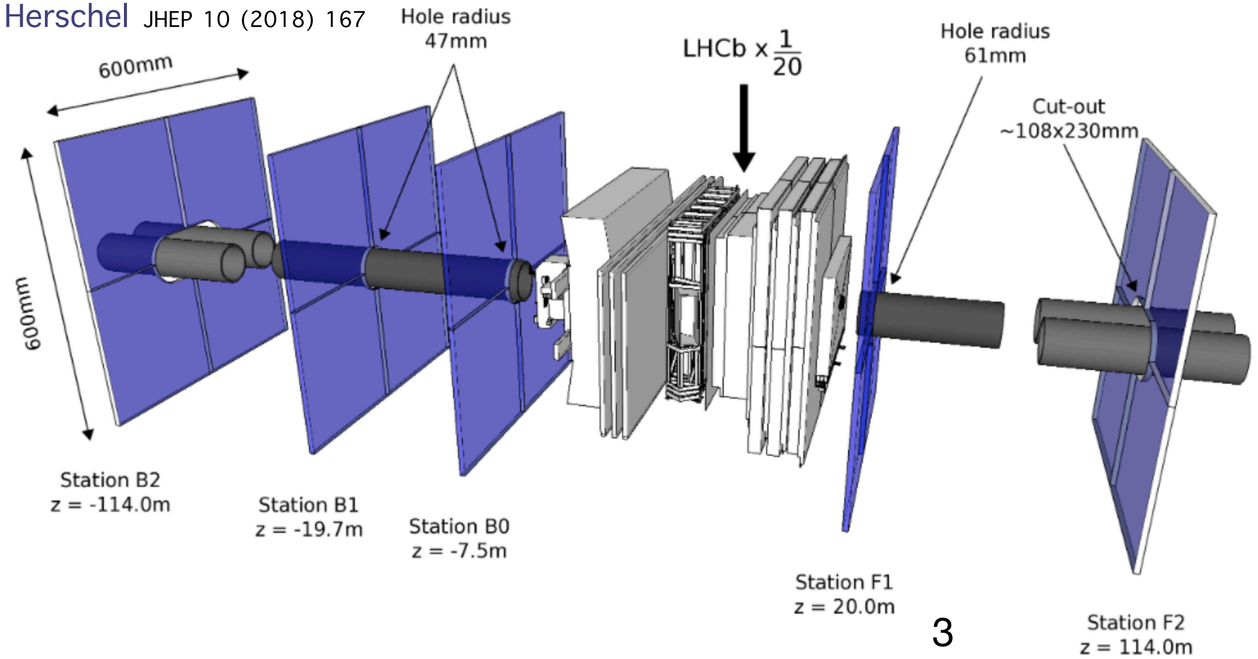
Herschel JHEP 10 (2018) 167

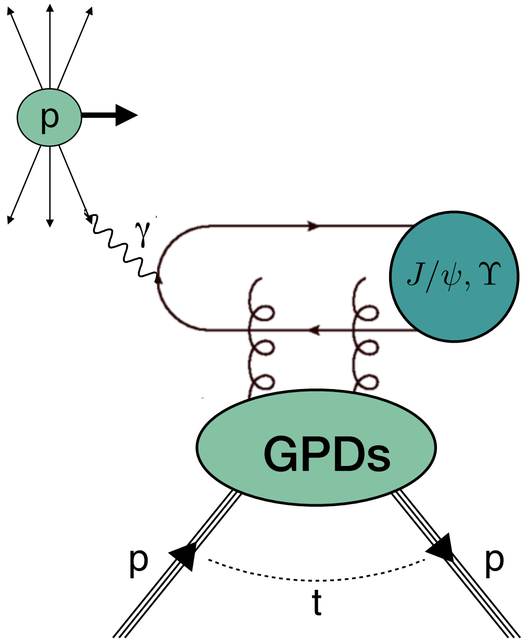


Exclusive single ψ production in pp collisions

- Exclusive J/ψ and ψ(2S): $\sqrt{s} = 7$ TeV and part of $\sqrt{s} = 13$ TeV data (from 2015)

  → x_B down to 2×10^{-6}

- Reconstruction via dimuon decay, with $2<\eta<4.5$.
- No other detector activity.
- Quarkonia J//ψ and ψ(2S): $2<y<4.5$ and $p_T^2<0.8$ GeV^2



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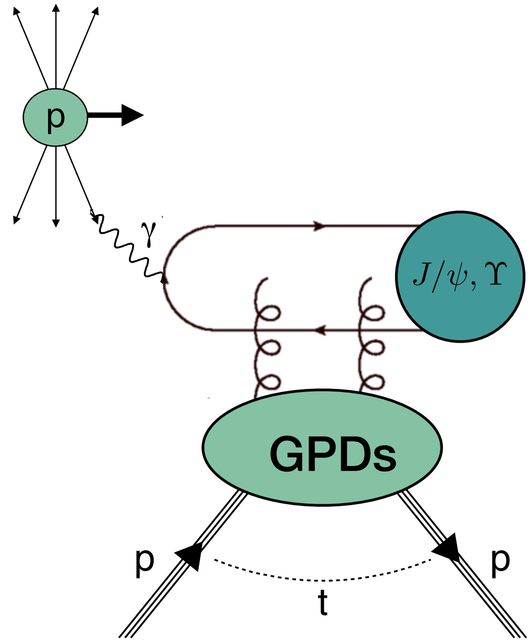
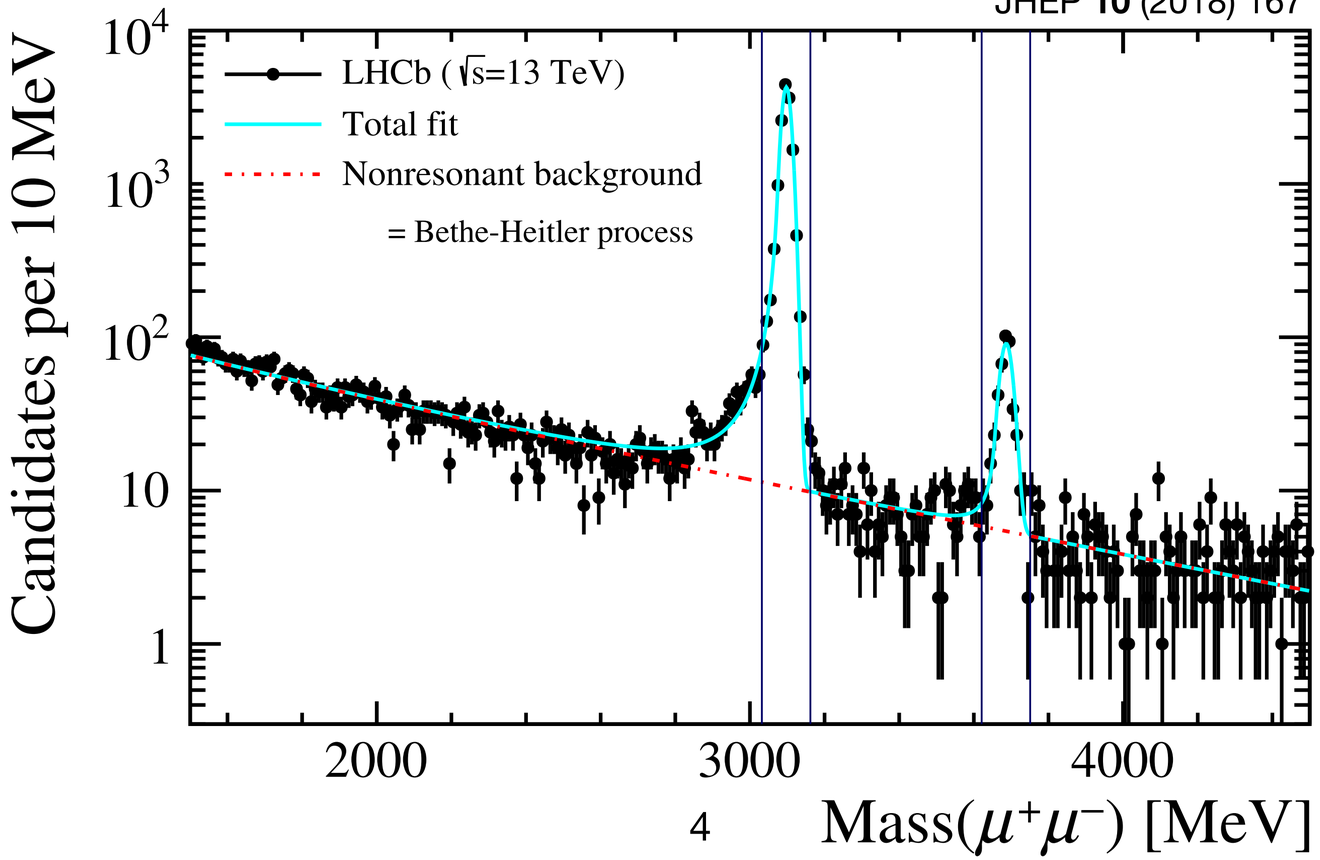


JHEP **10** (2018) 167



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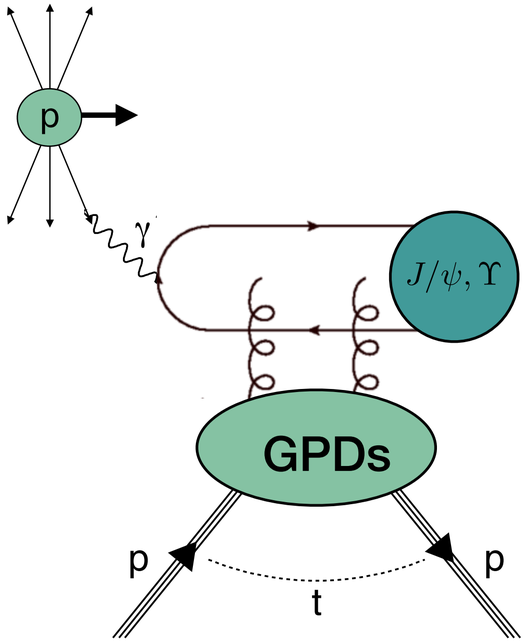

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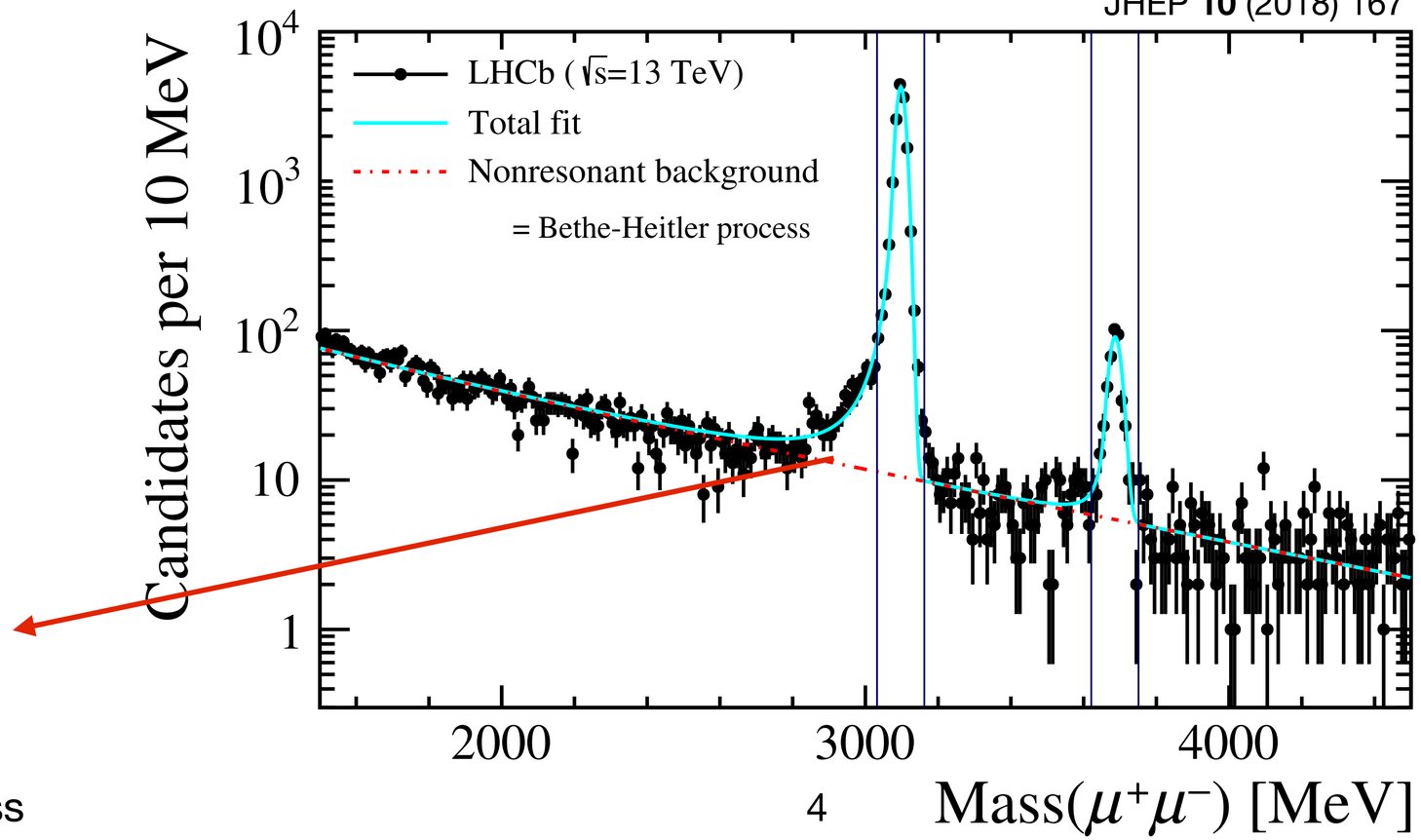
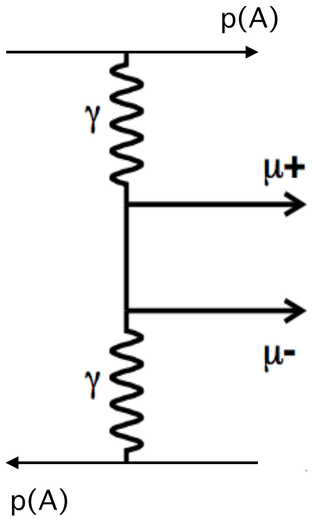
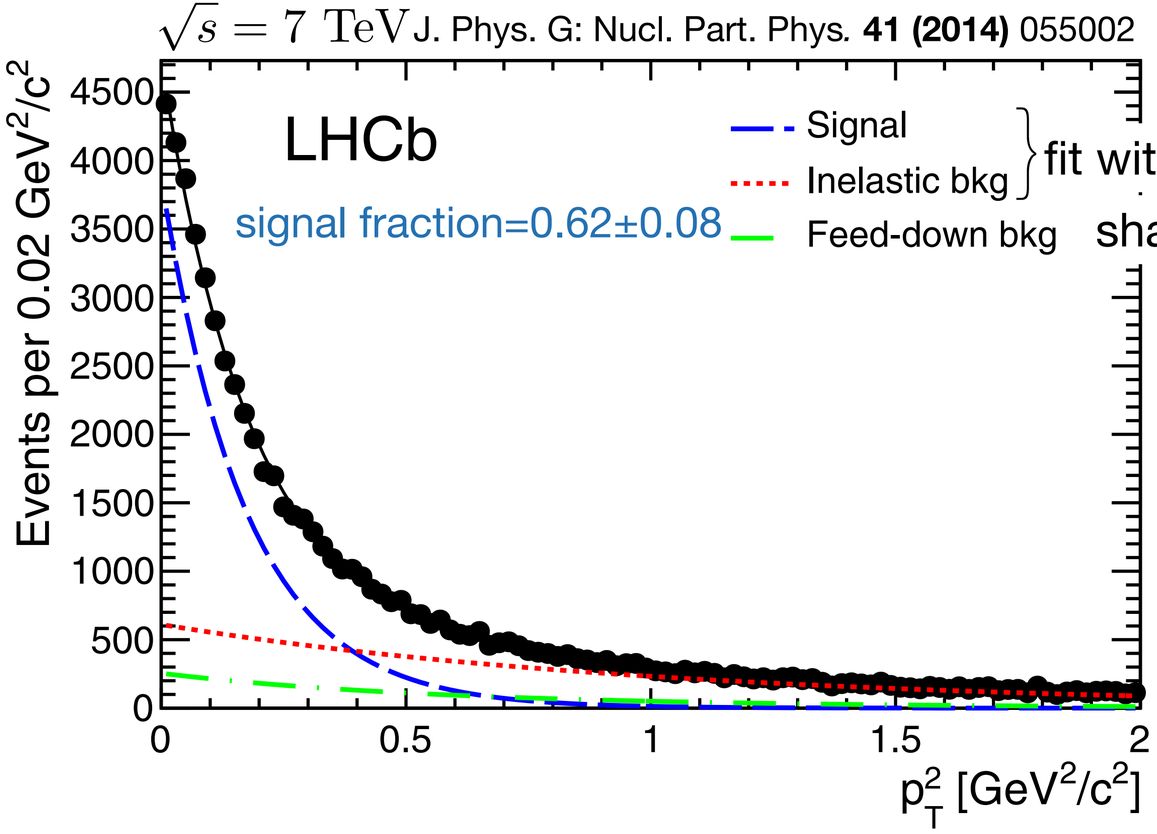




Bethe-Heitler process

Background: feed down and proton dissociation



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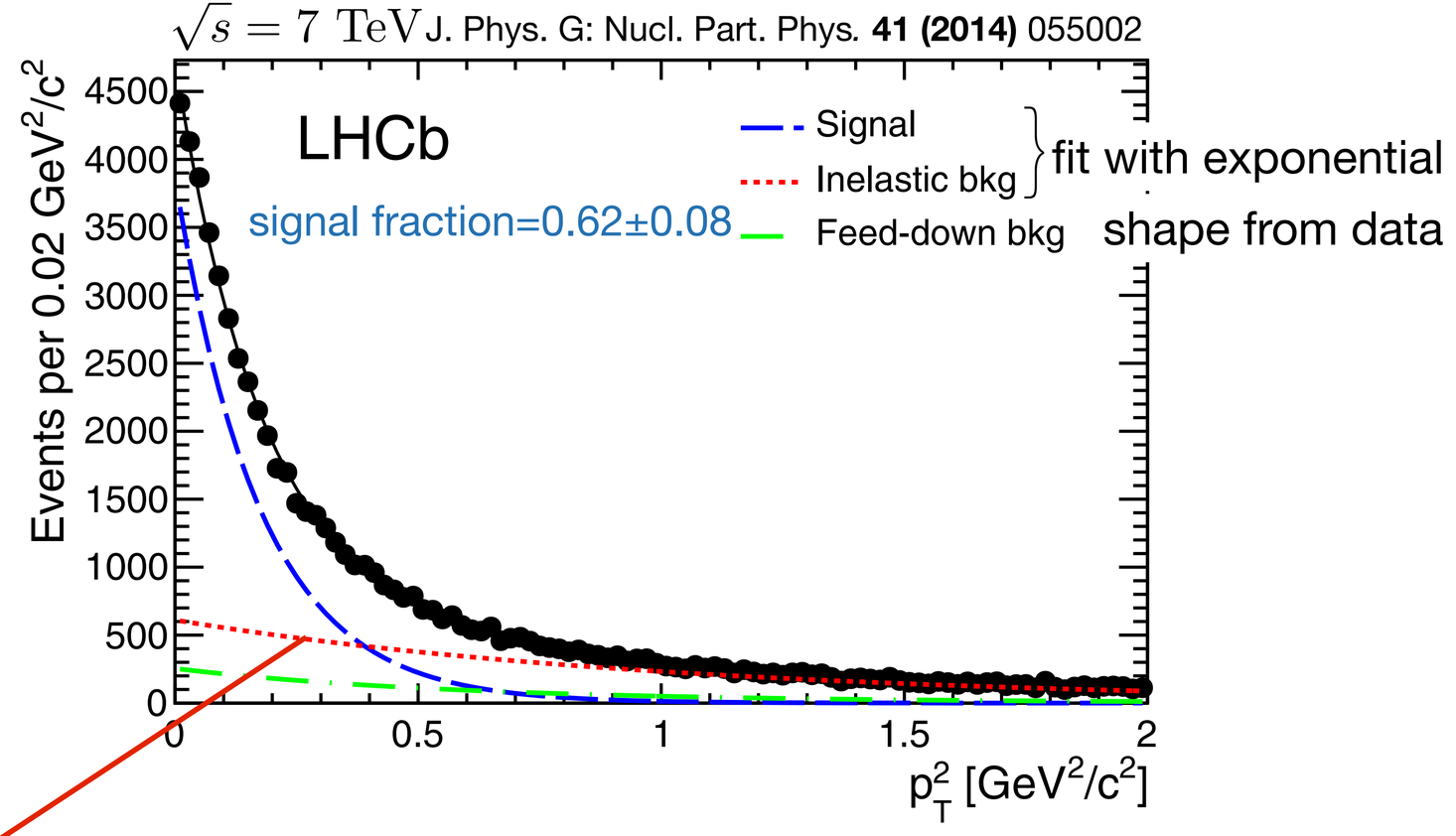

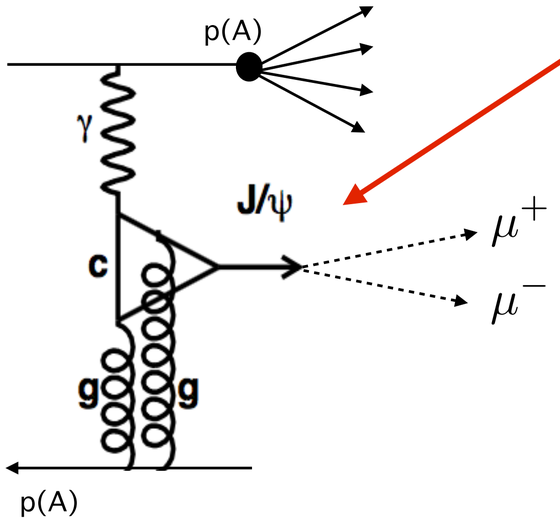

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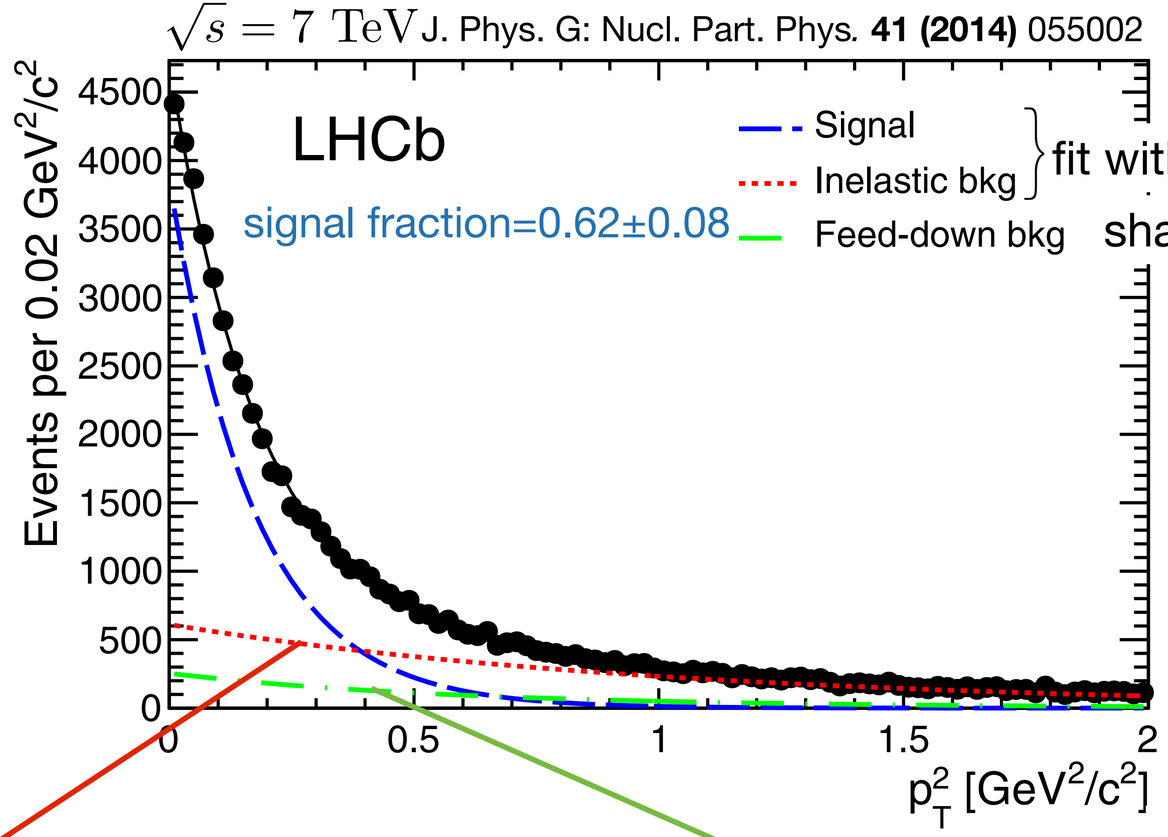

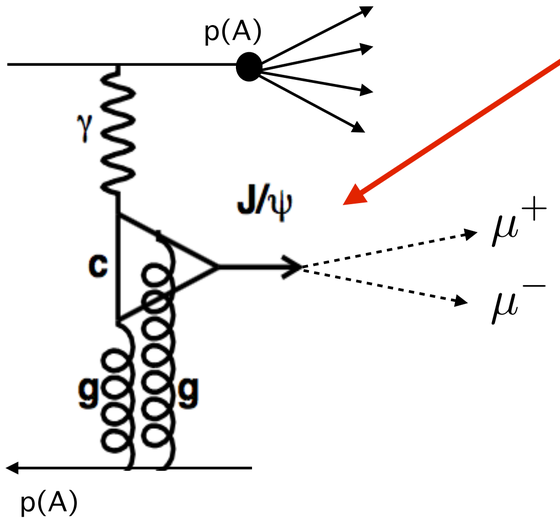

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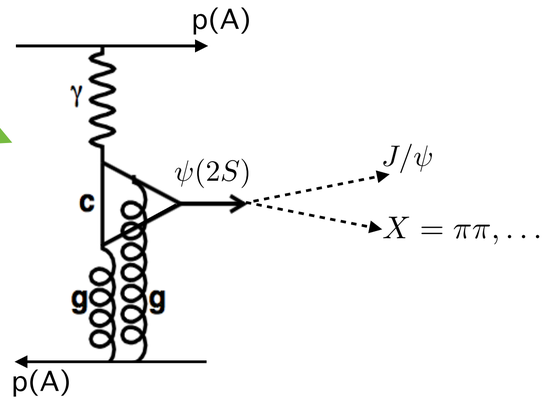
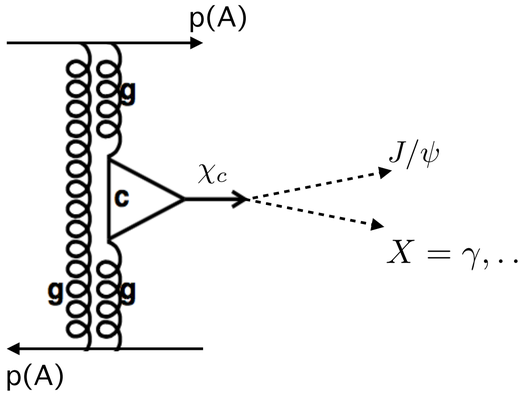
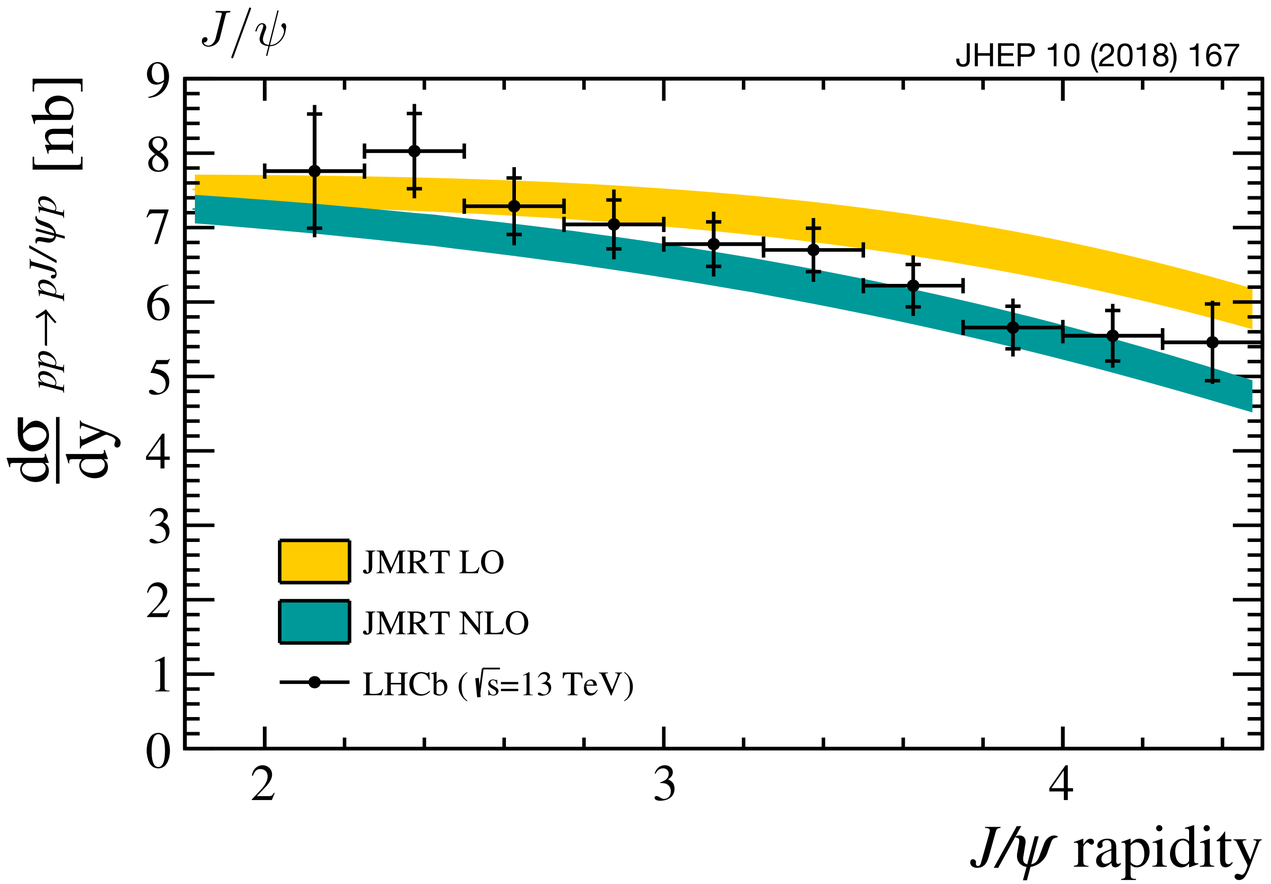




J/ψ feed-down background

pp cross section



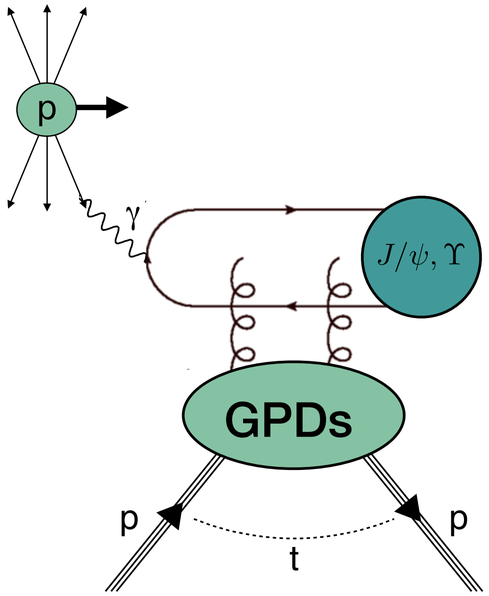
JMRT prediction, based on gluon PDF:

At low x_B, approximate GPD to gluon PDF

$$\left.\frac{d\sigma}{dt}\right|_{t=0} \propto [g(x_B)]^2$$

Z. Phys. C**57** ('93) 89–92;
arXiv:1609.09738

Extraction of the J/ψ photoproduction



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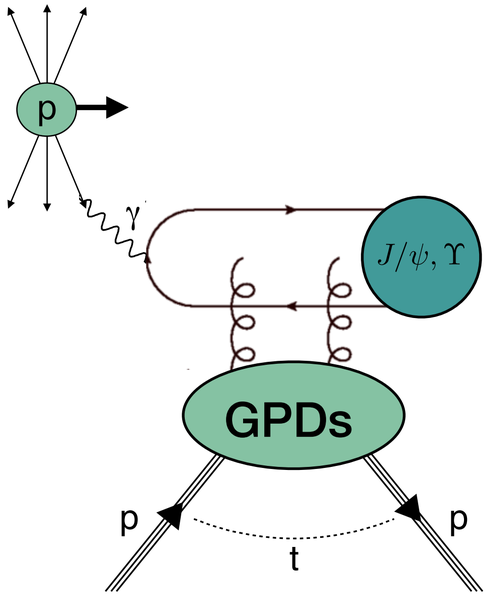

pp: ambiguity in ID of photon emitter

- r = gap survival factor
- $k_{\pm} = \frac{M_{\psi}}{2} e^{\pm y}$ = photon energy
- $\frac{dn}{dk_{\pm}}$ = photon flux
- $W_{\pm}^2 = 2k_{\pm}\sqrt{s}$ = γp invariant mass

relation pp and γp cross section:

$$\sigma_{pp\to p\psi p} = r(W_+)k_+\frac{\mathrm{d}n}{\mathrm{d}k_+}\sigma_{\gamma p\to\psi p}(W_+) + r(W_-)k_-\frac{\mathrm{d}n}{\mathrm{d}k_-}\sigma_{\gamma p\to\psi p}(W_-)$$

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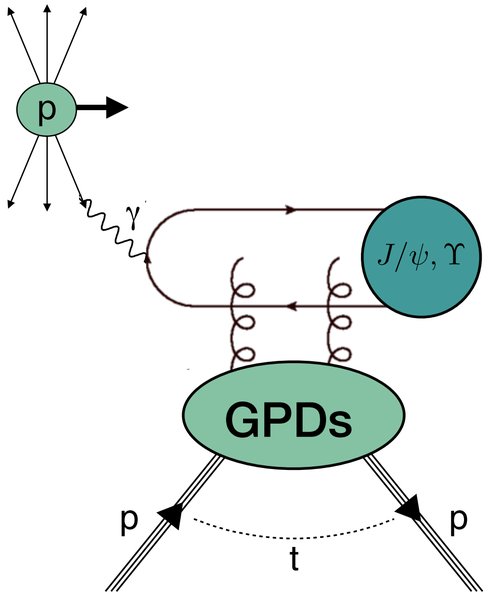

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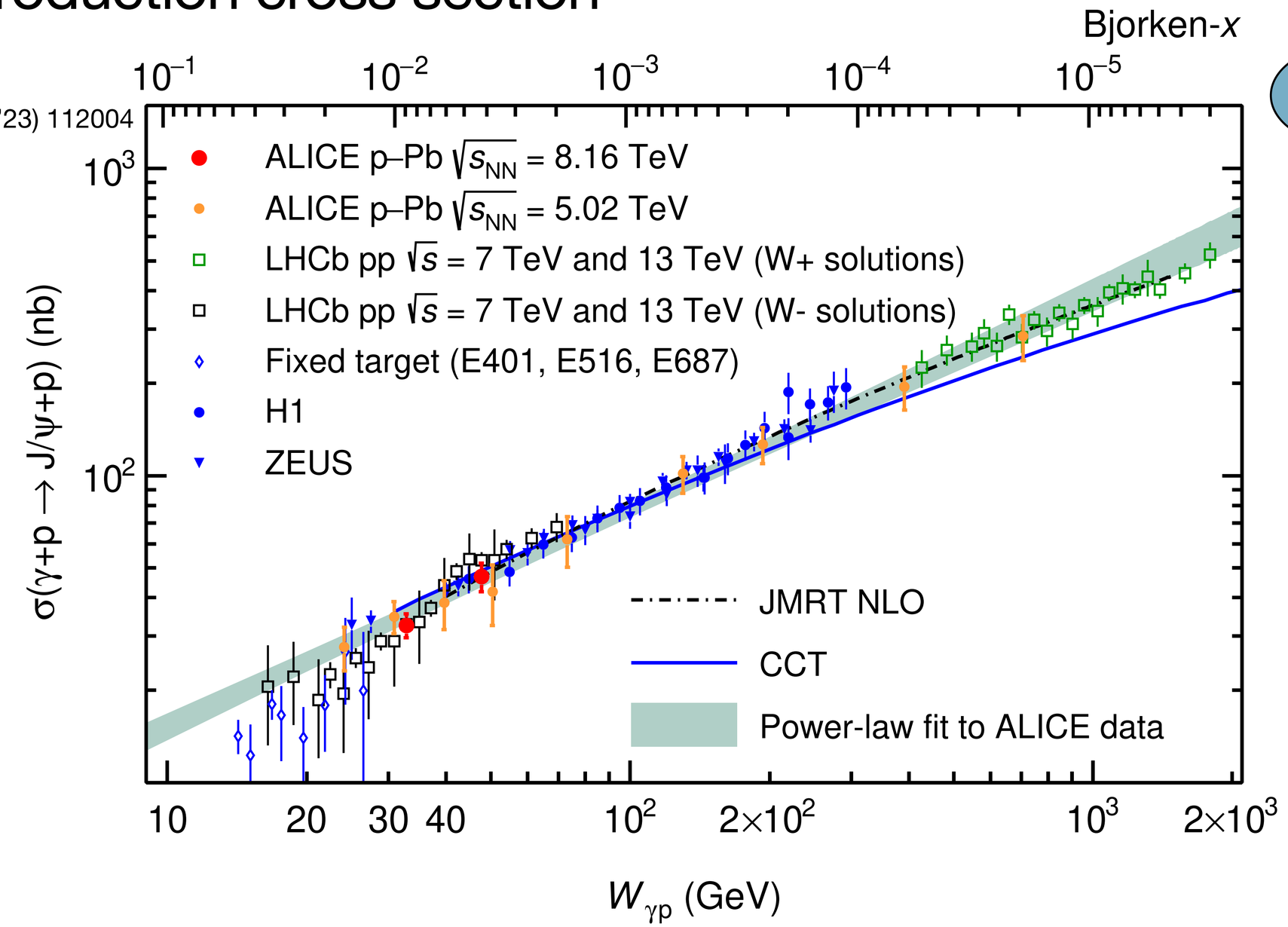
LHCb used HERA data for low-E_γ (W_-) contribution.

J/ψ photoproduction cross section

Phys. Rev. D **108** ('23) 112004



GPD H

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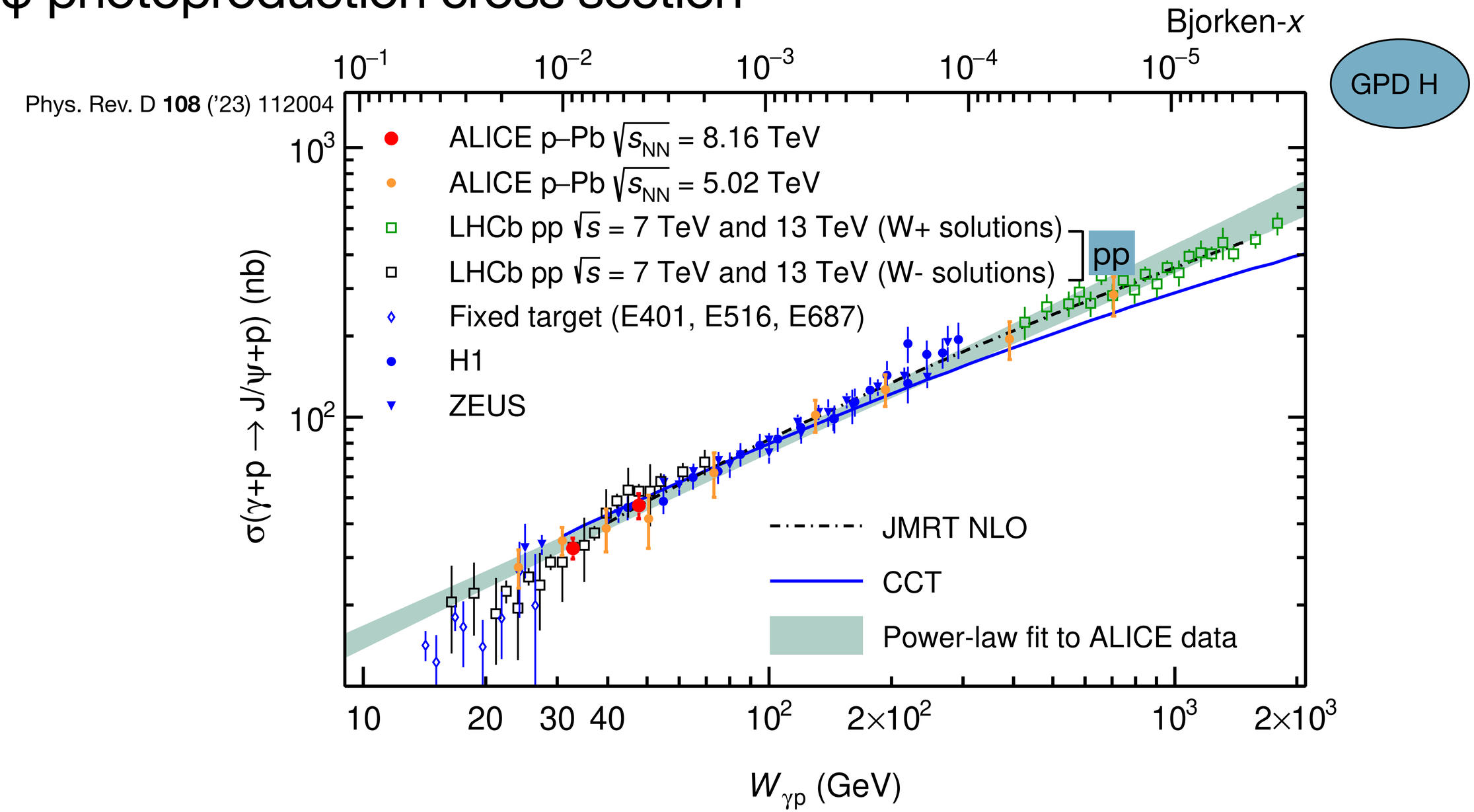

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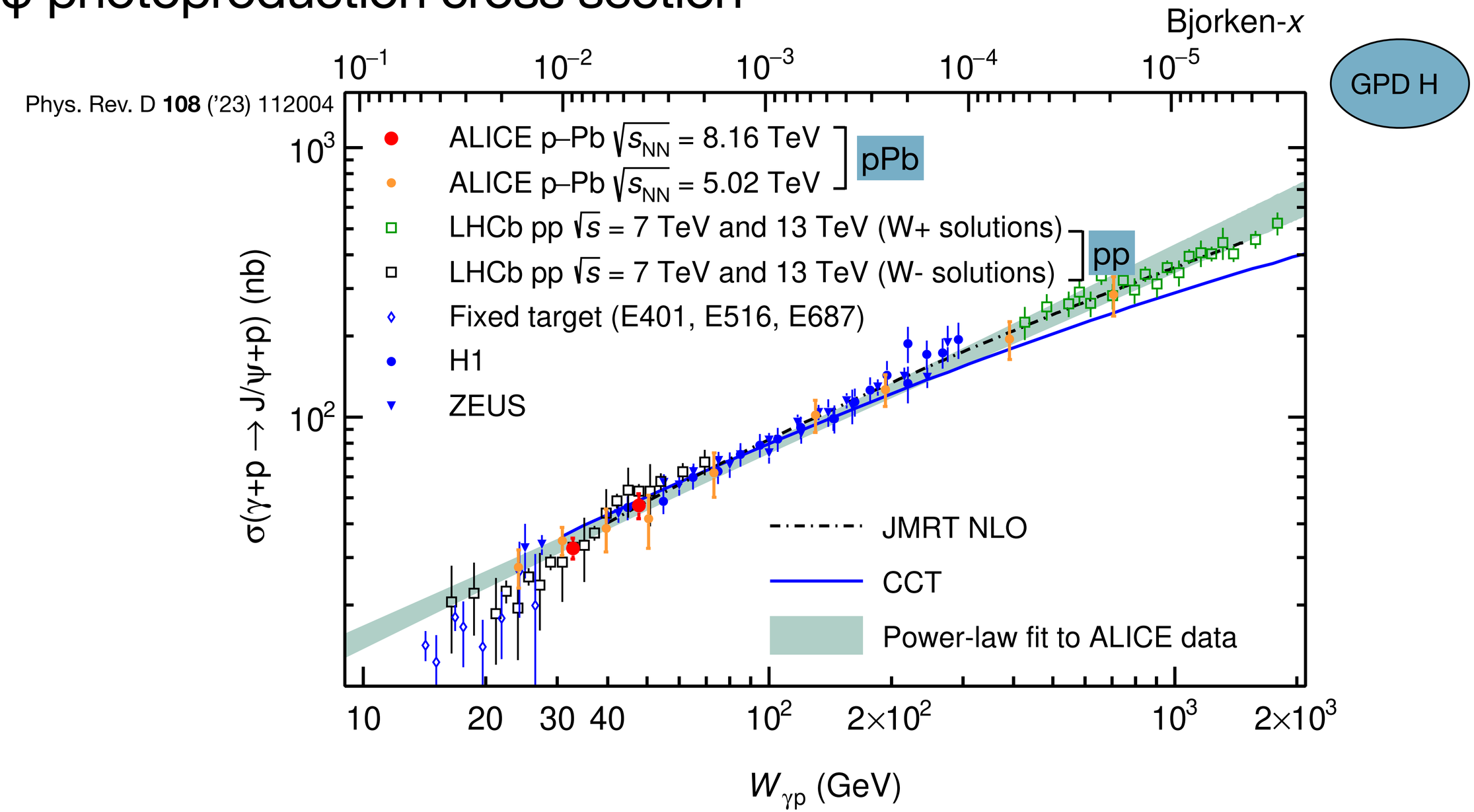

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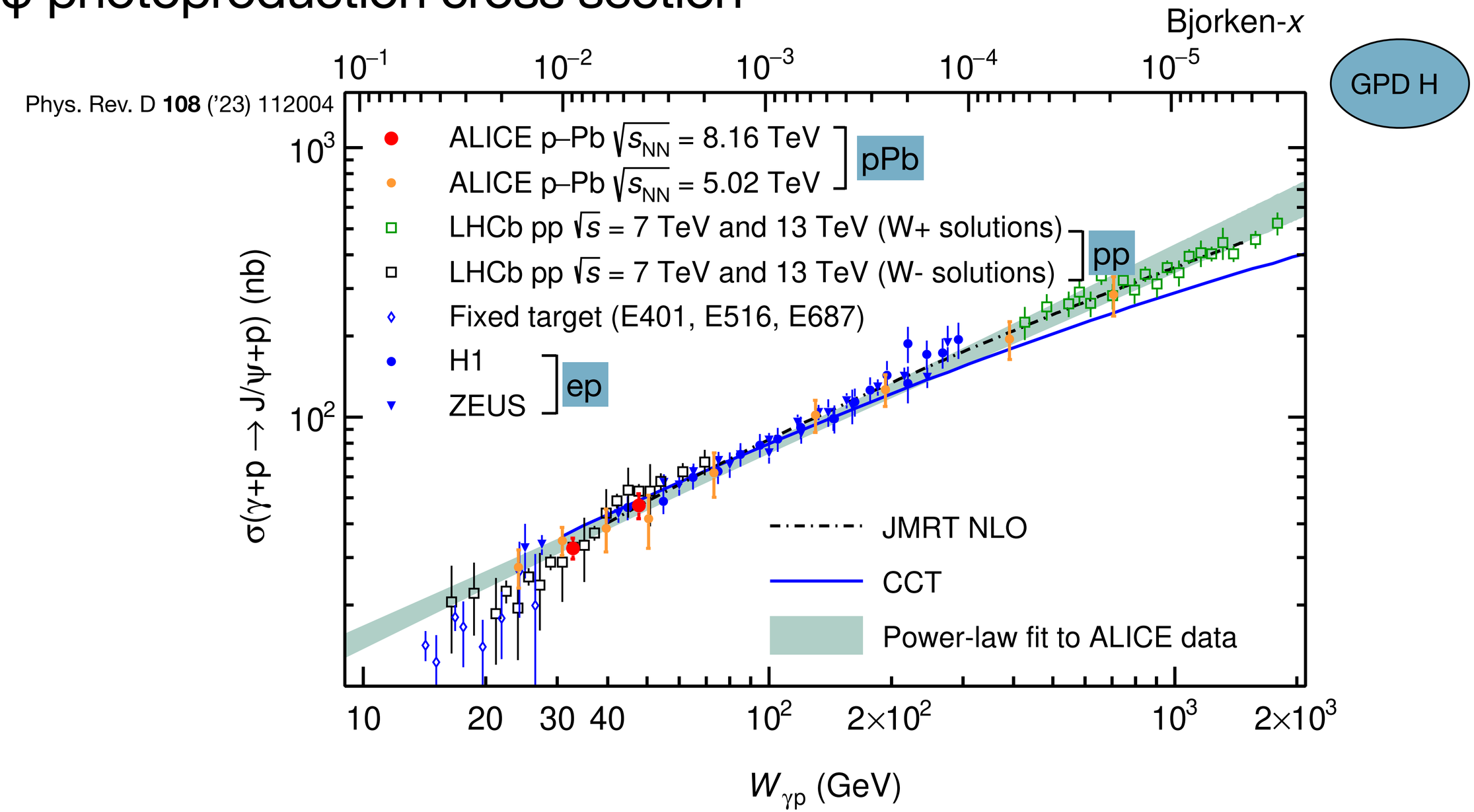

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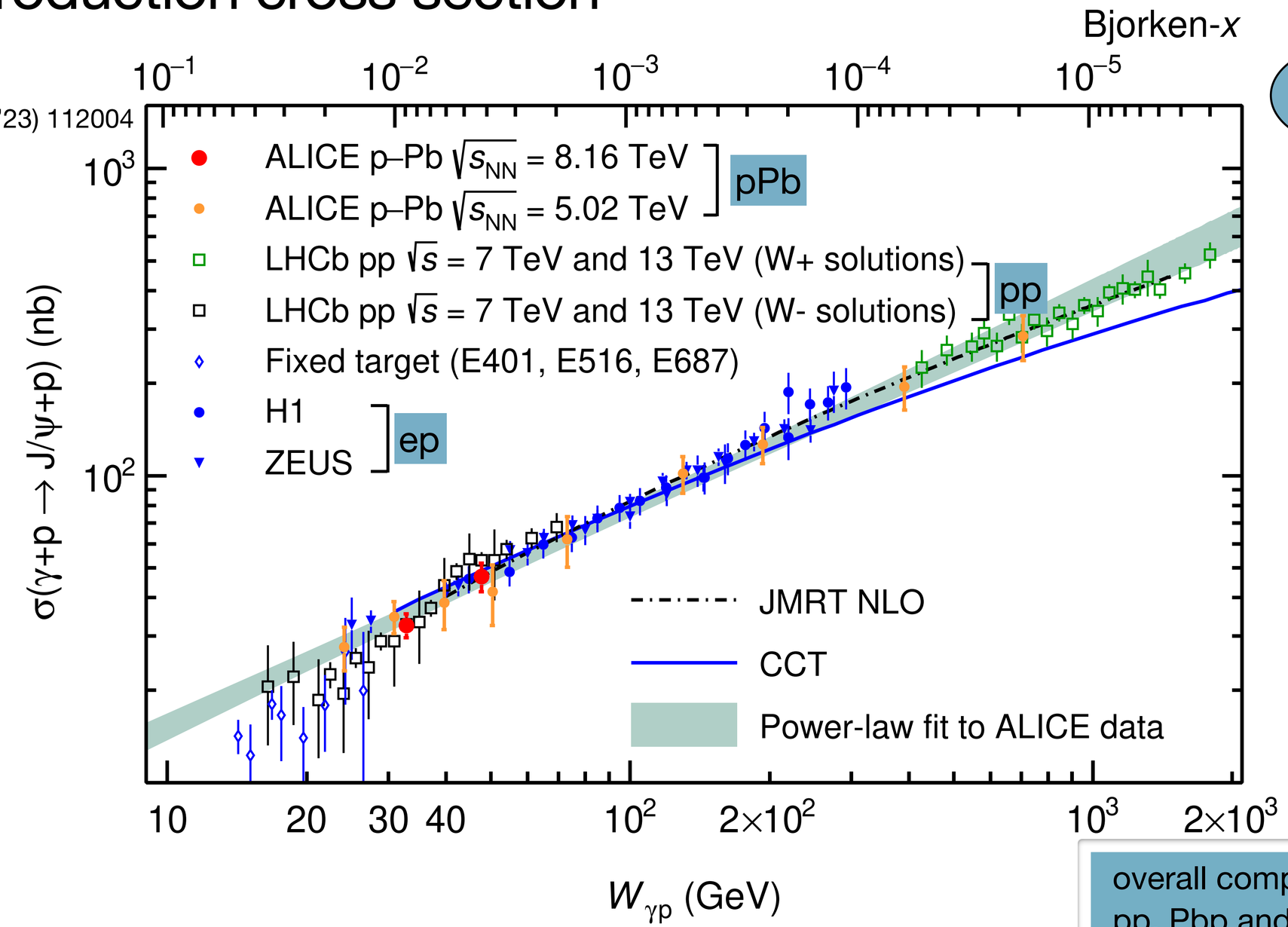
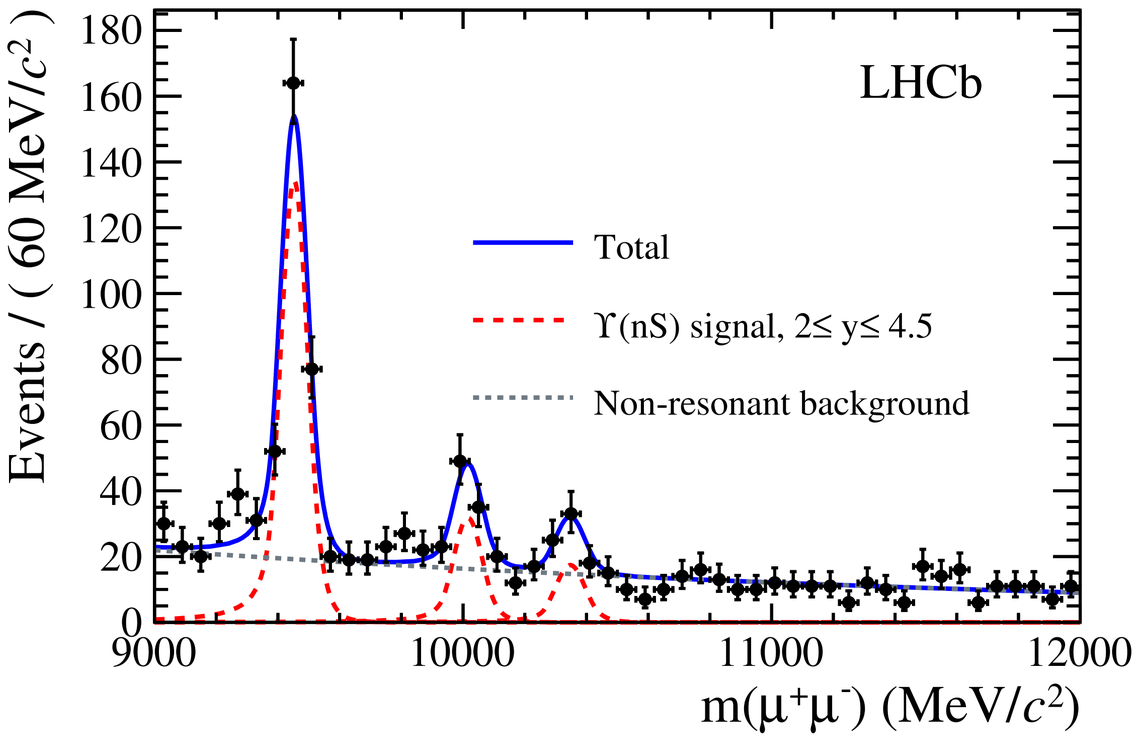


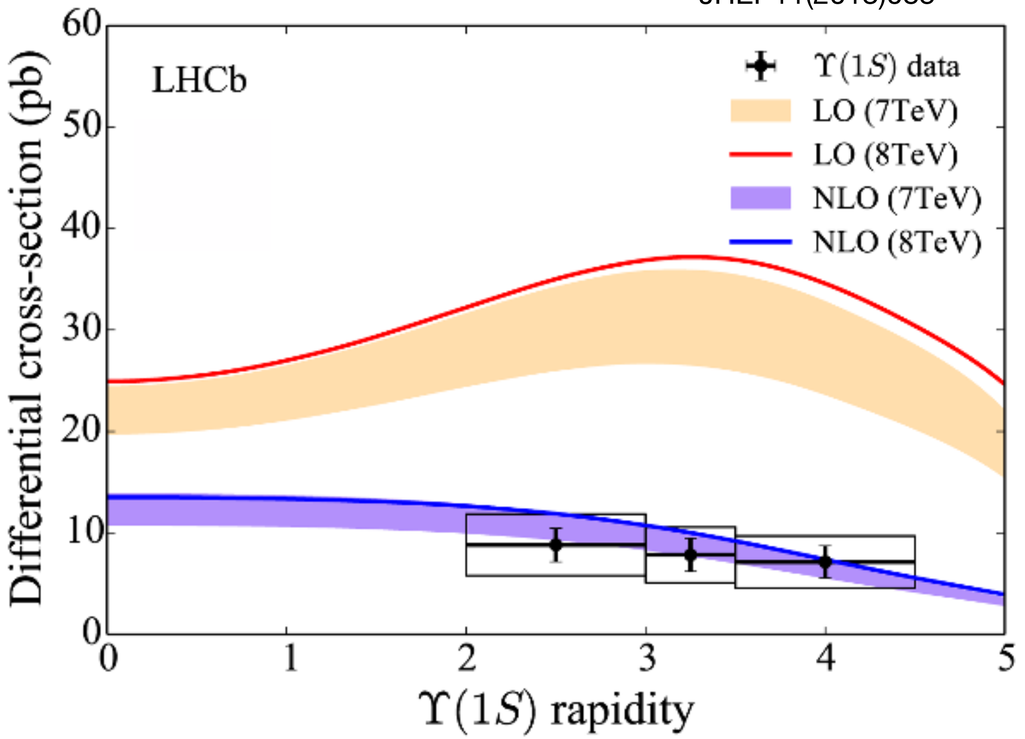
GPD H

overall compatibility between pp, Pbp and ep data: hint of universality of underlying physics

Exclusive single ϒ production in pp collisions



JHEP11(2013)085



higher Q^2 scale

Ultra-peripheral PbPb collisions

What object are we probing?

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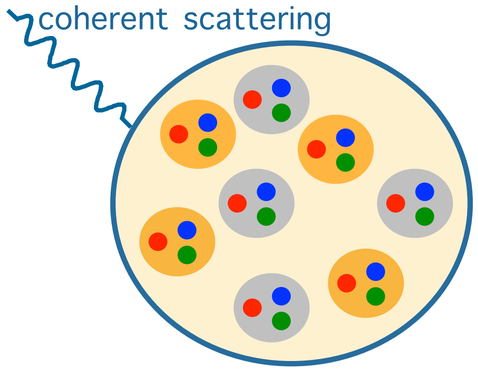

Coherent interaction: interaction with target as a whole.
~ target remains in same quantum state.

Ultra-peripheral PbPb collisions

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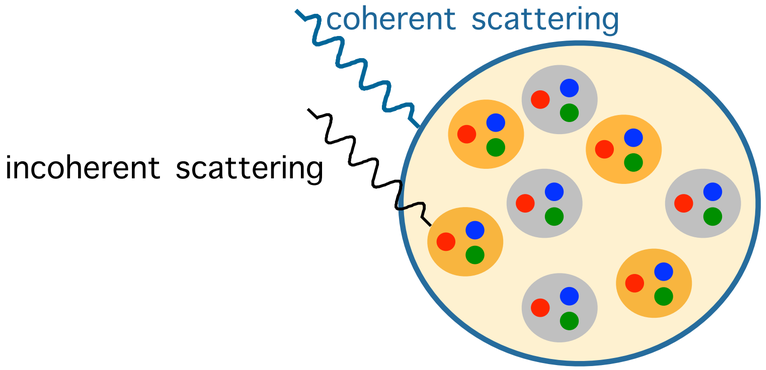

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Incoherent interaction: interaction with constituents inside target.
~ target does not remain in same quantum state.
Ex.: target dissociation, excitation

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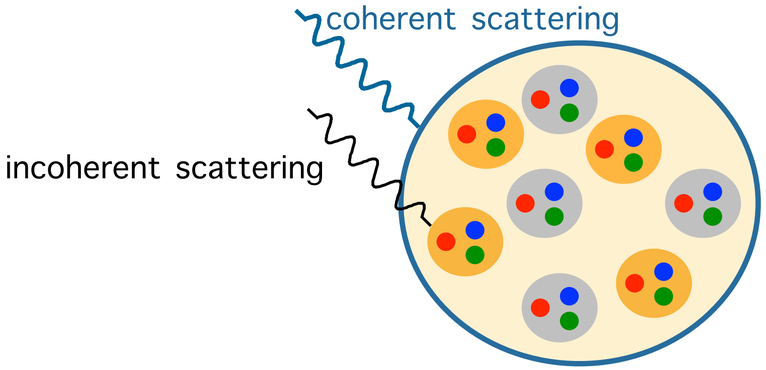

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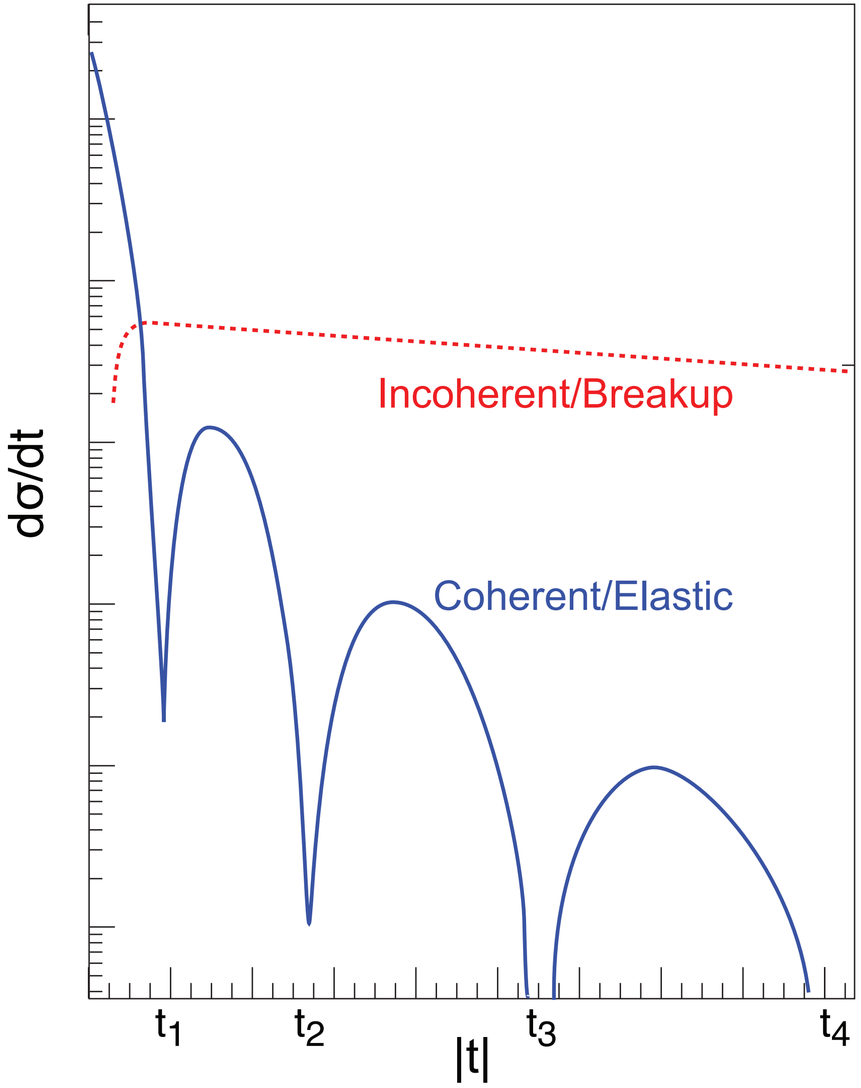
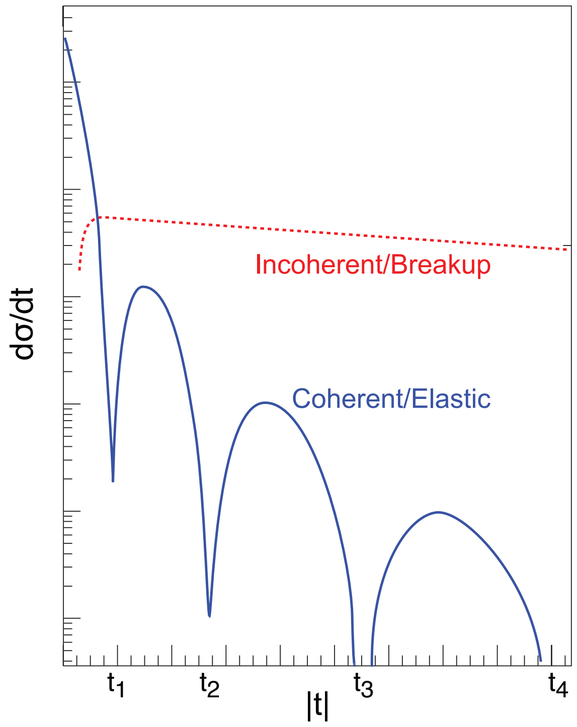


Experimental important points

- Good separation of coherent and incoherent production. Not easy!



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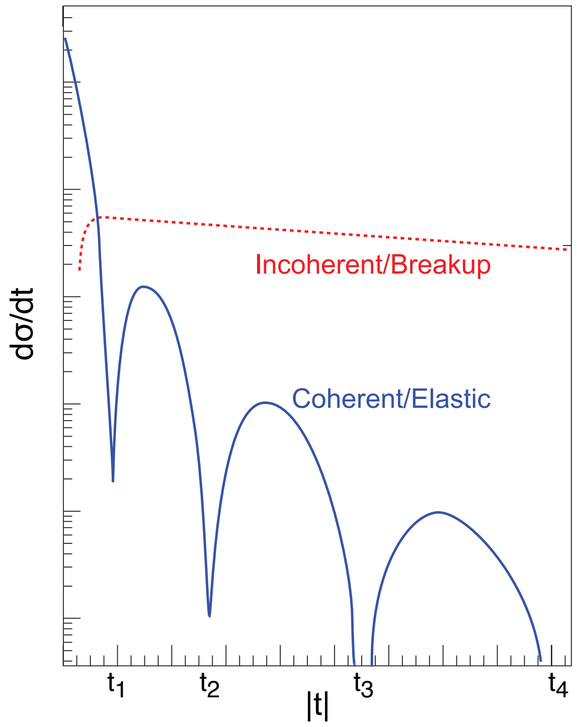

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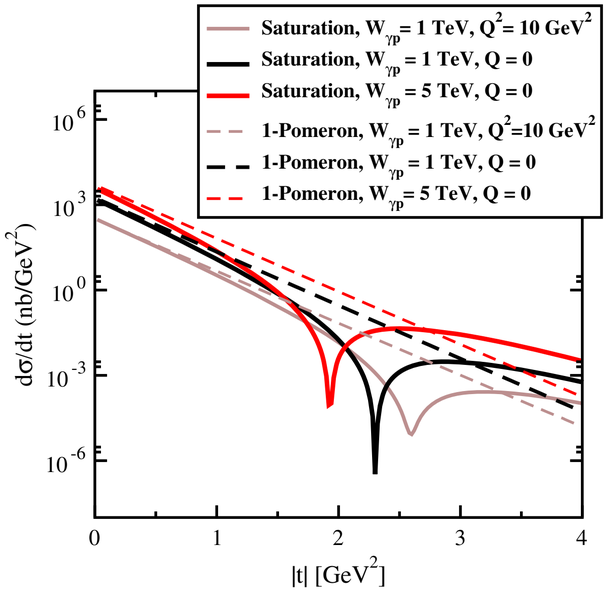
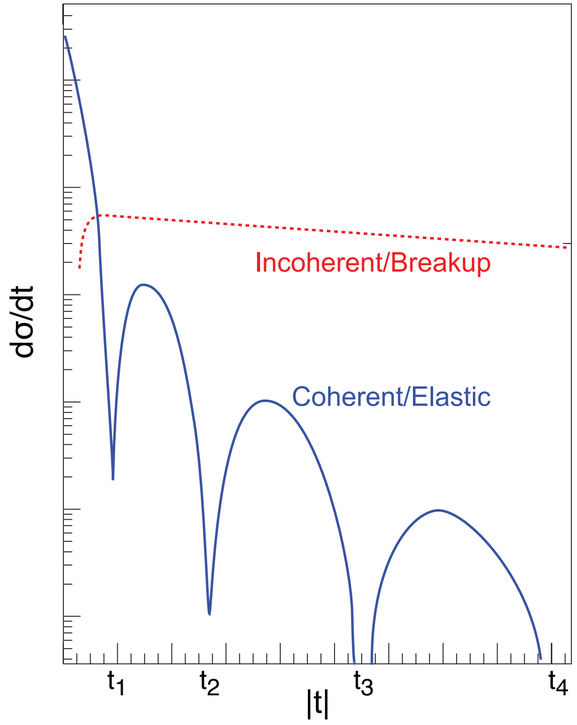
  - Saturation:

    determine dip position indirectly
    via slope and probe its dependence
    With $W_{\gamma p}$





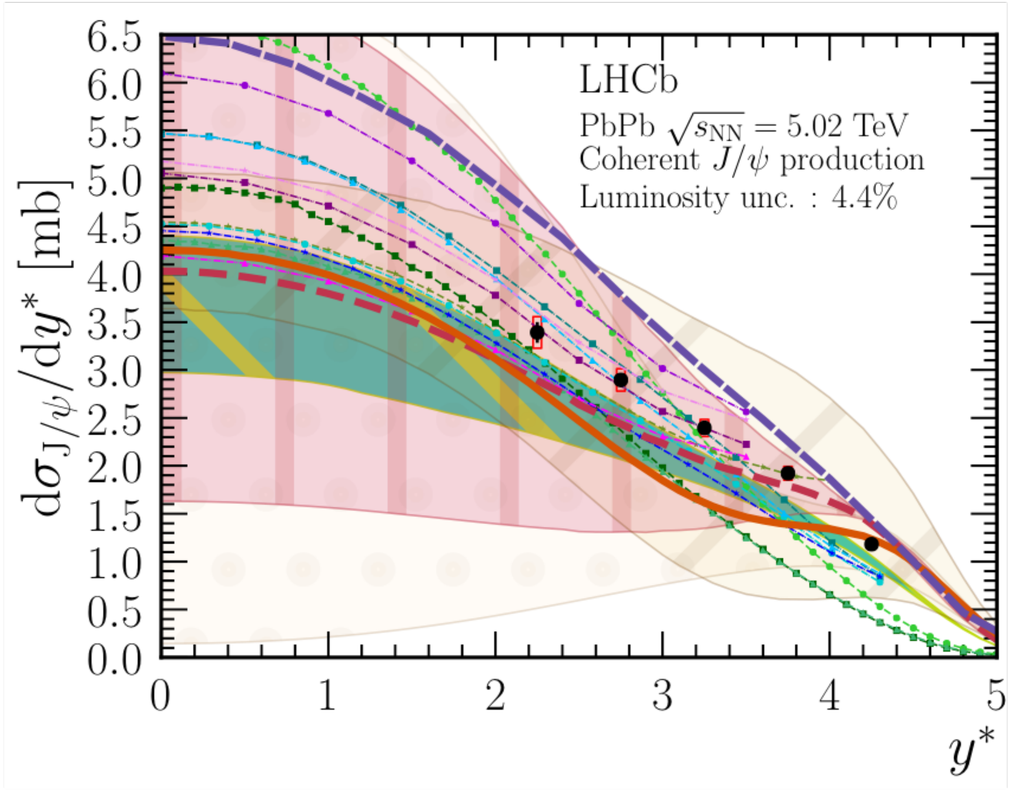
Coherent production in PbPb: y dependence

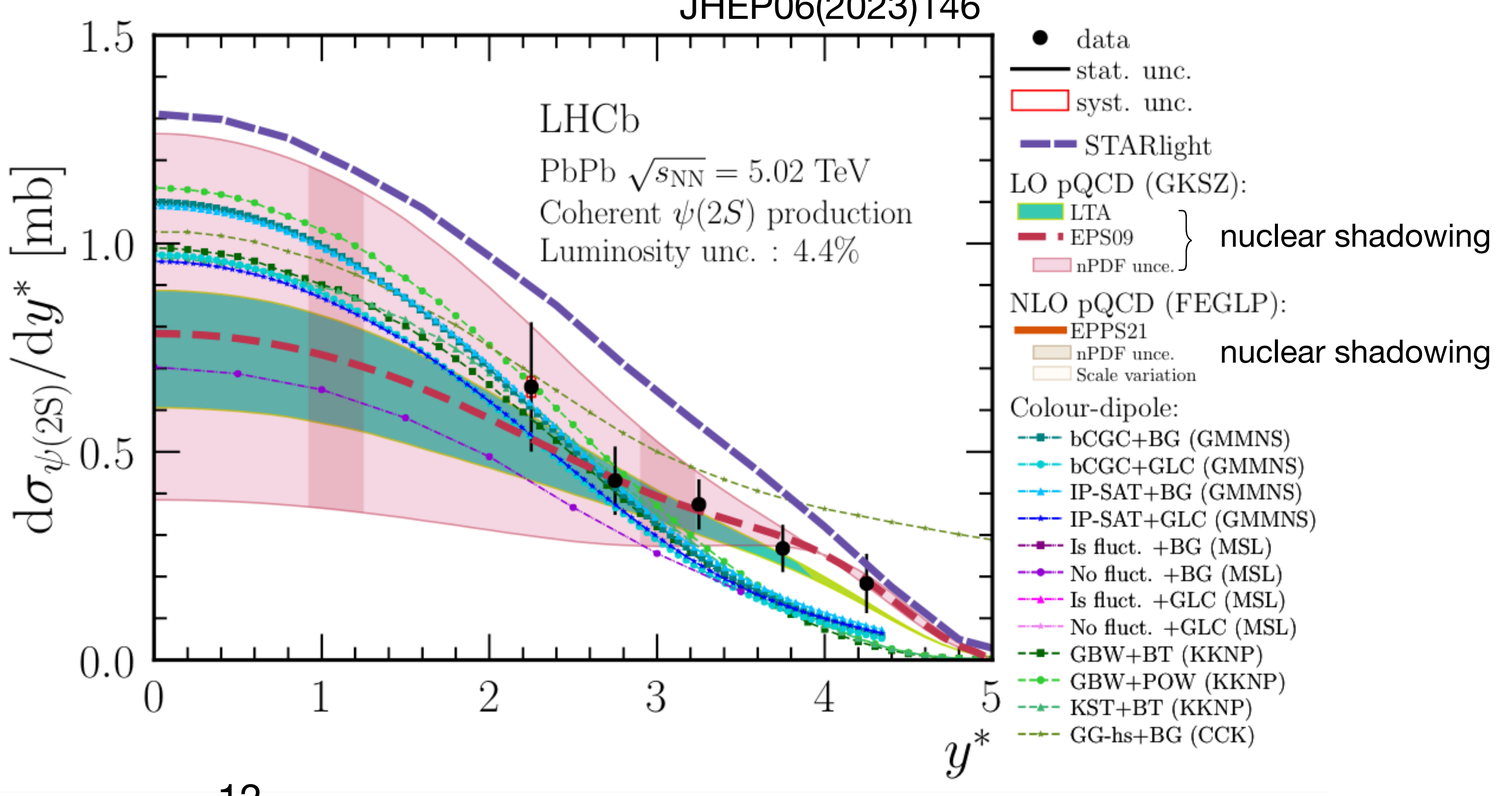
- $\sqrt{s_{NN}} =$ 5.02 TeV data.
- $L_{\rm int} = 228 \pm 10 \mu{\rm b}^{-1}$

$$\sigma^{\rm coh}_{J/\psi} = 5.965 \pm 0.059 \pm 0.232 \pm 0.262\,{\rm mb}$$
$$\sigma^{\rm coh}_{\psi(2S)} = 0.923 \pm 0.086 \pm 0.028 \pm 0.040\,{\rm mb}$$

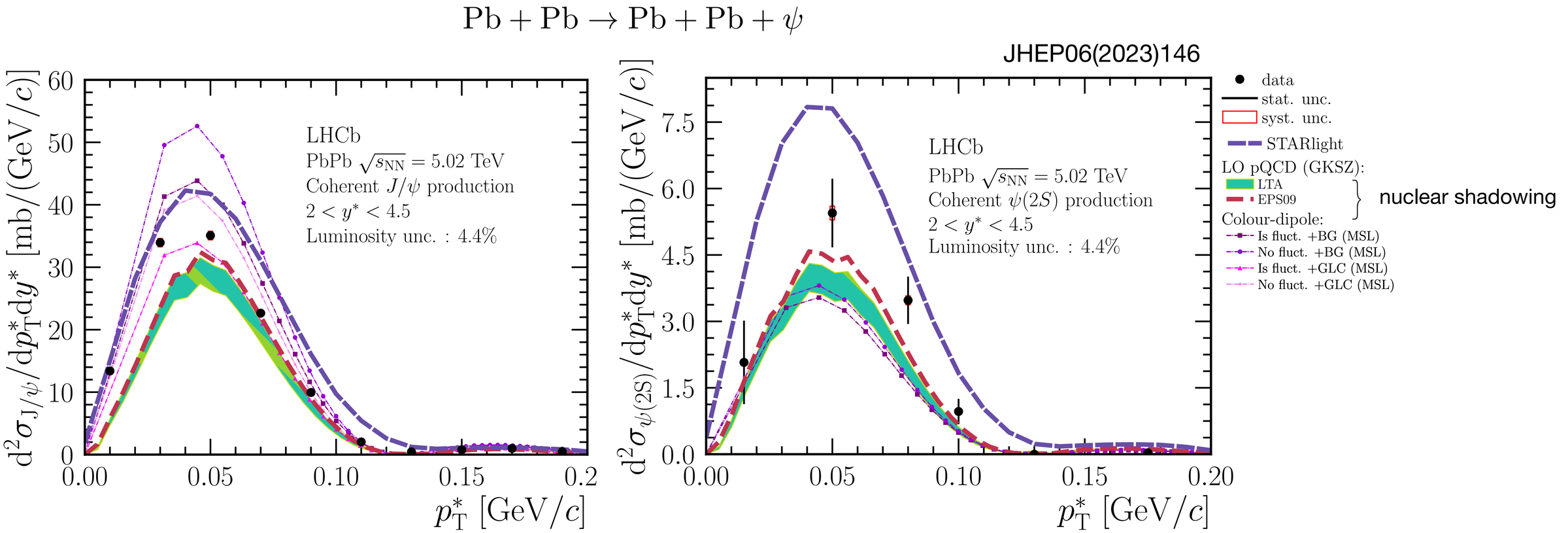
$$\rm Pb + Pb \to Pb + Pb + \psi$$

JHEP06(2023)146





Coherent production in PbPb: p_T dependence



TMD PDFs at the LHC

quark polarisation

nucleon polarisation

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_{1T}\, h_{1T}^\perp$

gluon polarisation

nucleon polarisation

	U	circular	linear
U	f_1^g		$h_1^{\perp g}$
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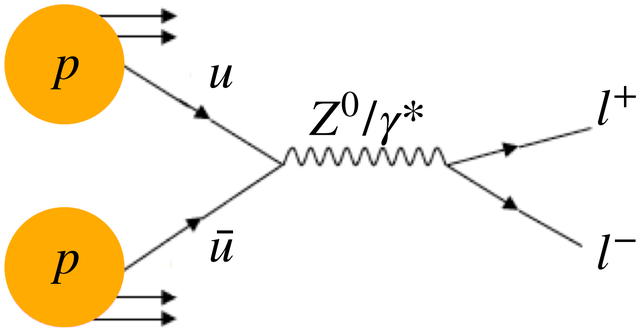
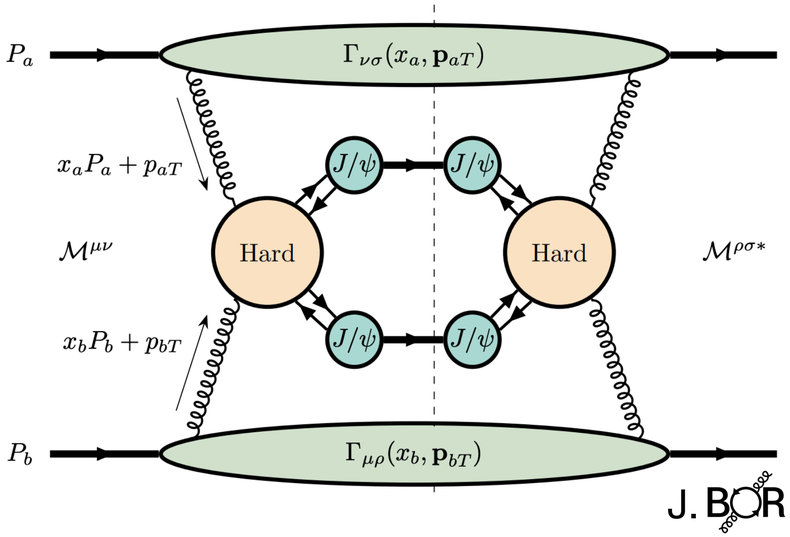
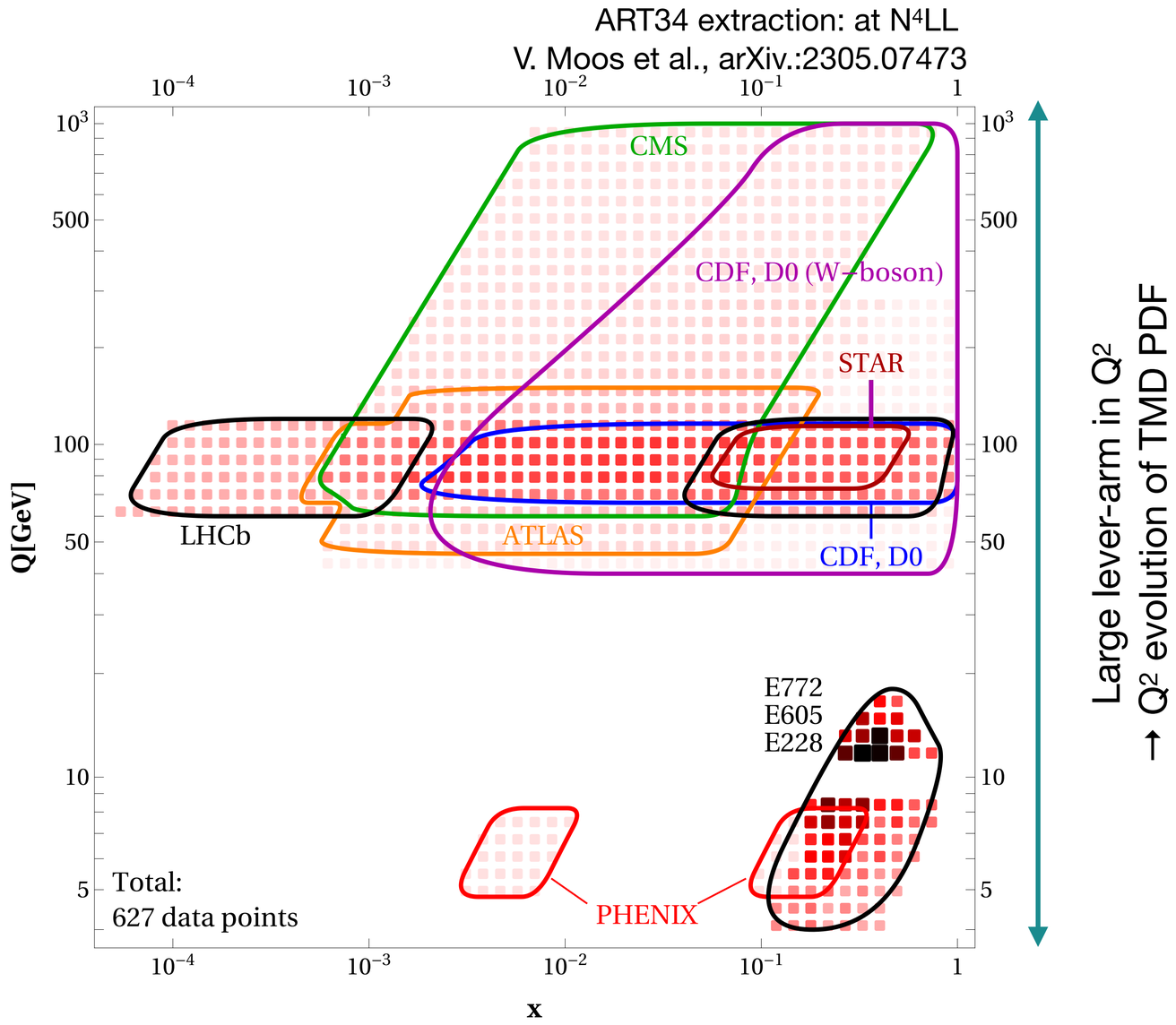




J. BOR

Spin-independent quark TMD PDFs



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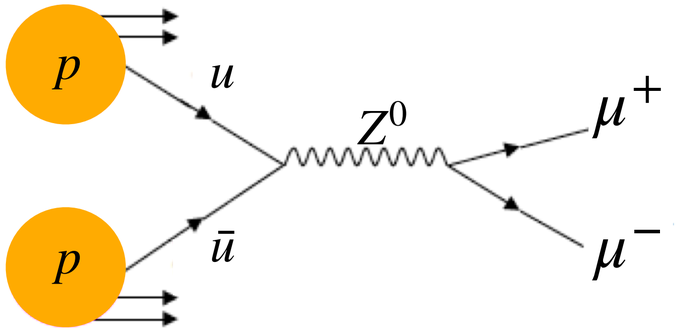

$\sqrt{s} = 13$ TeV

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Muons:

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$p_T > 20$ GeV/c

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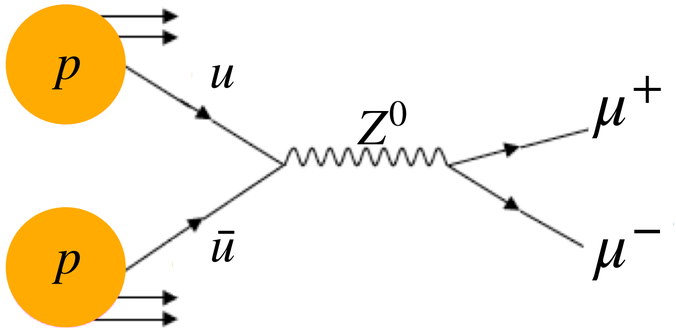

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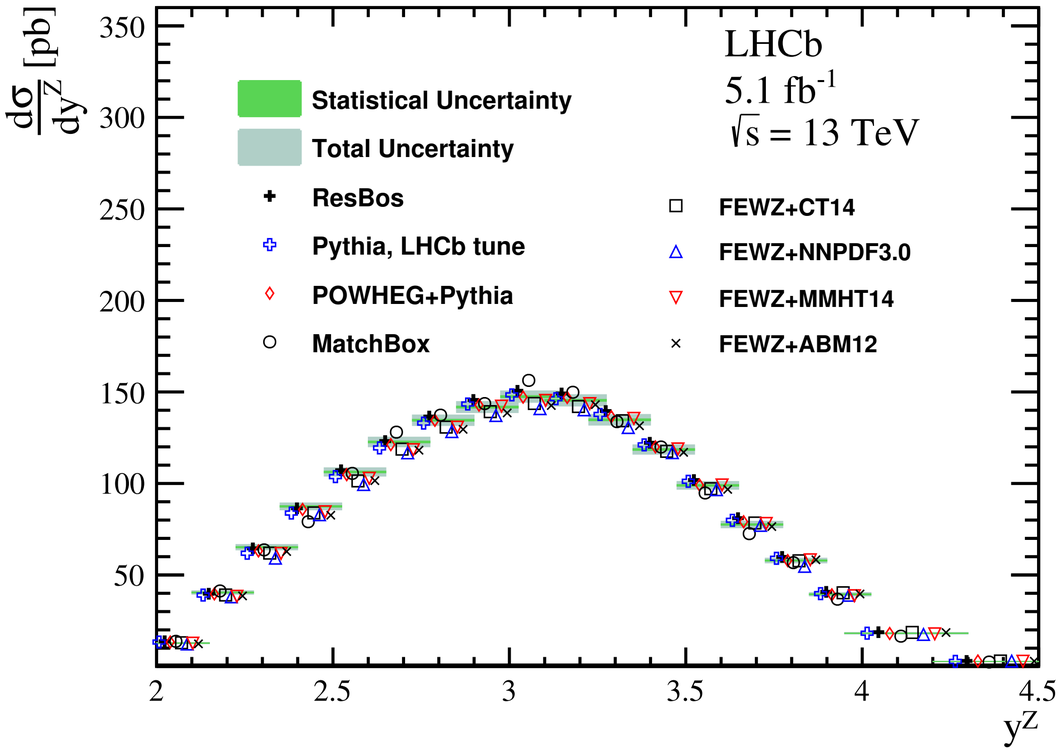
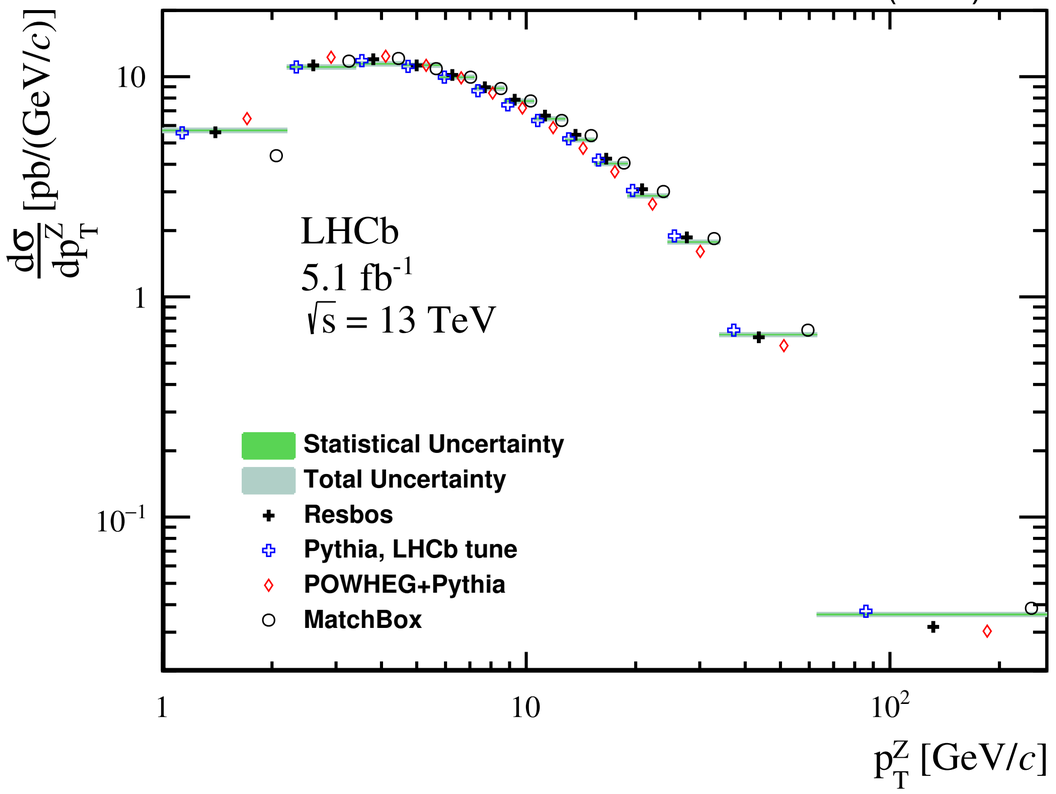


JHEP07(2022)026



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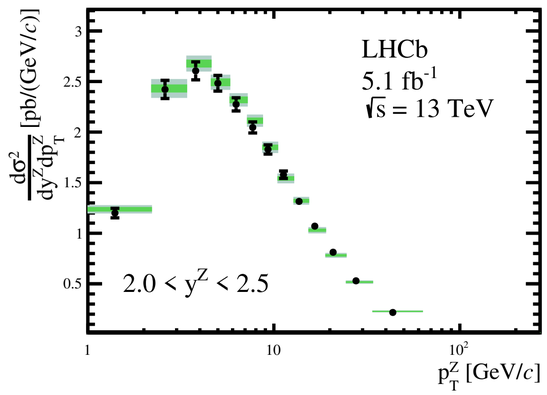
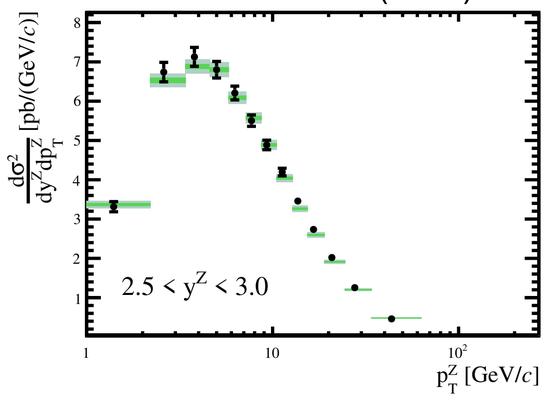
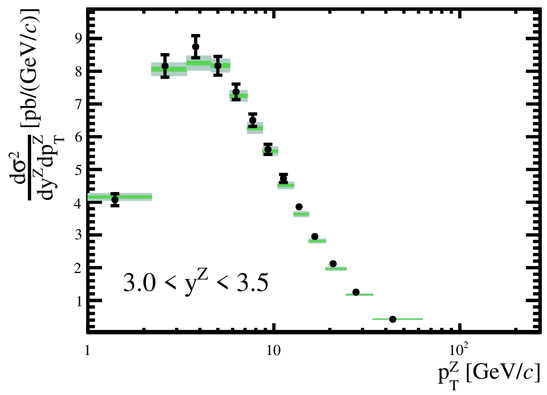
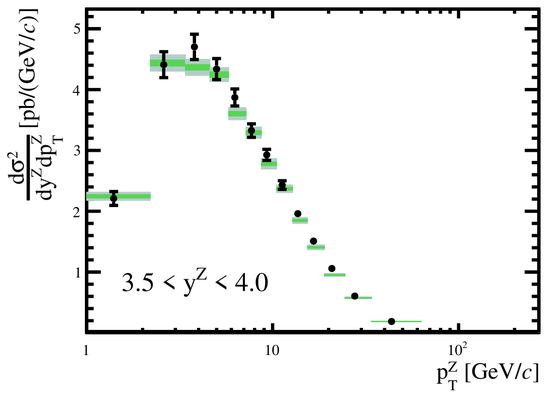
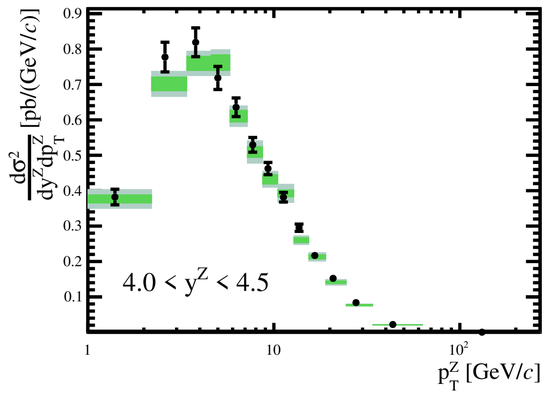
JHEP07(2022)026

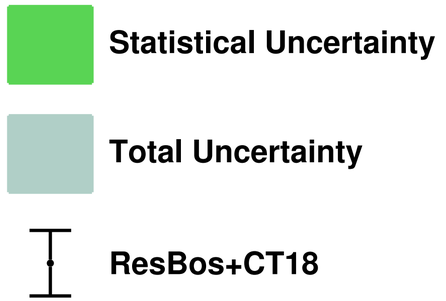












Gluon TMDs via $J/\psi J/\psi$ production

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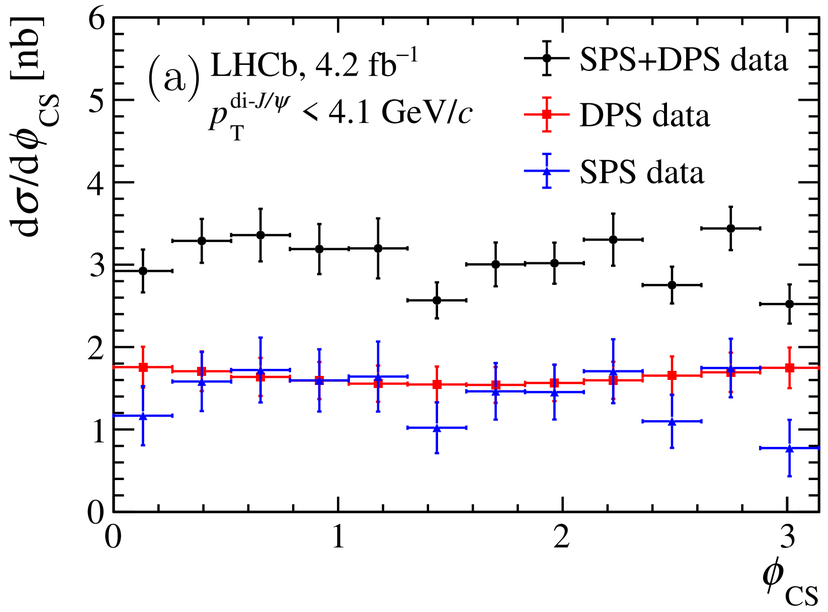
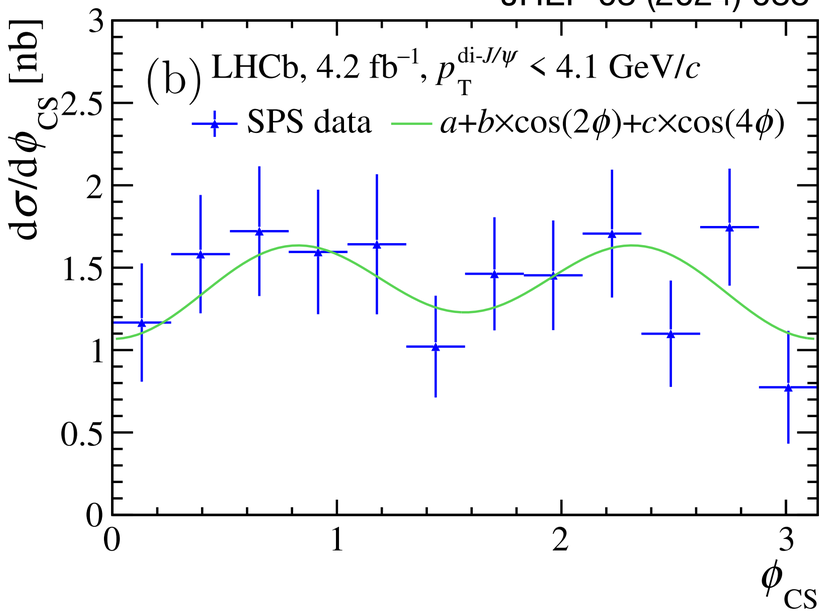
JHEP 03 (2024) 088





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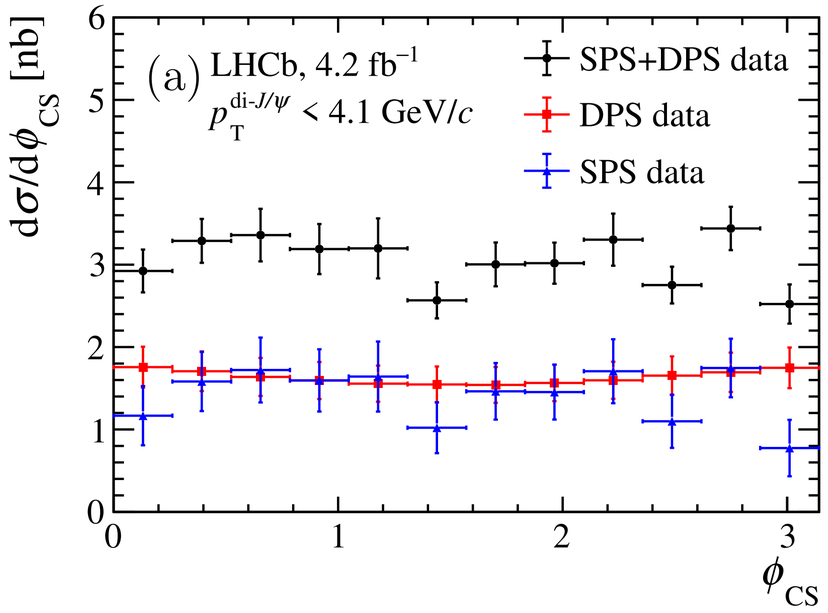

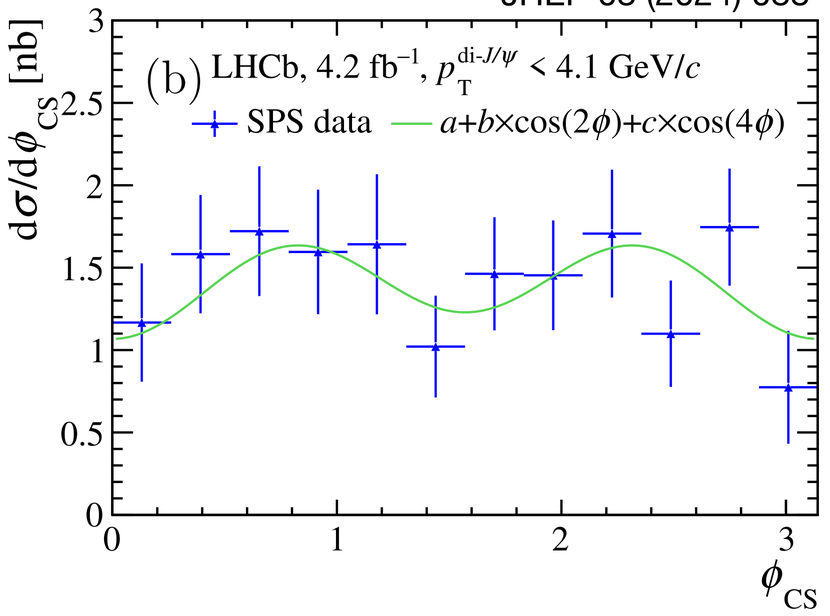

JHEP 03 (2024) 088

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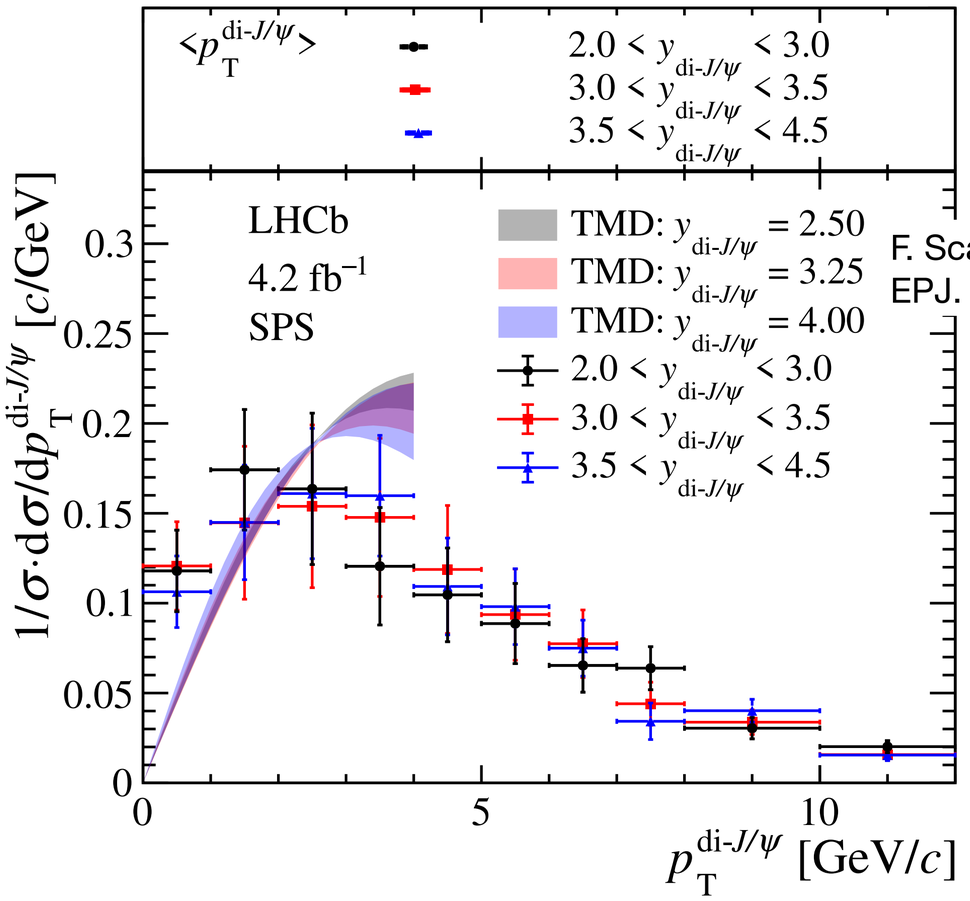
Spin-independent gluon TMDs via $J/\psi J/\psi$ production

JHEP 03 (2024) 088



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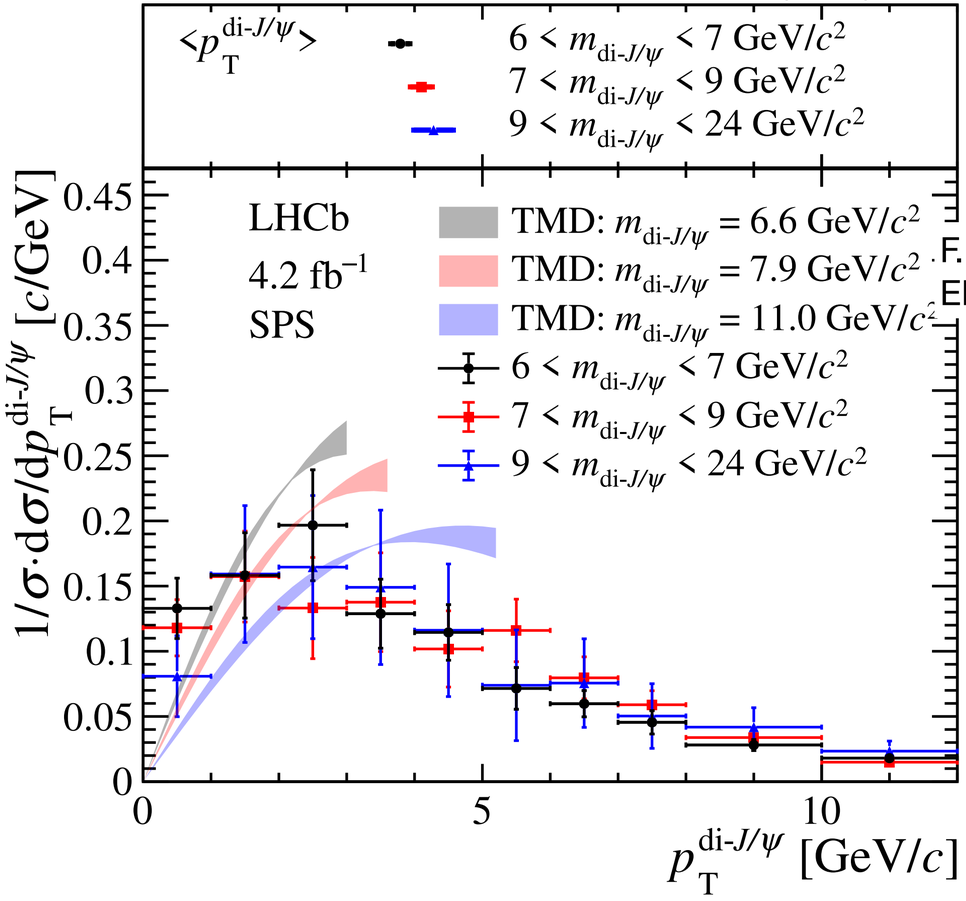
JHEP 03 (2024) 088



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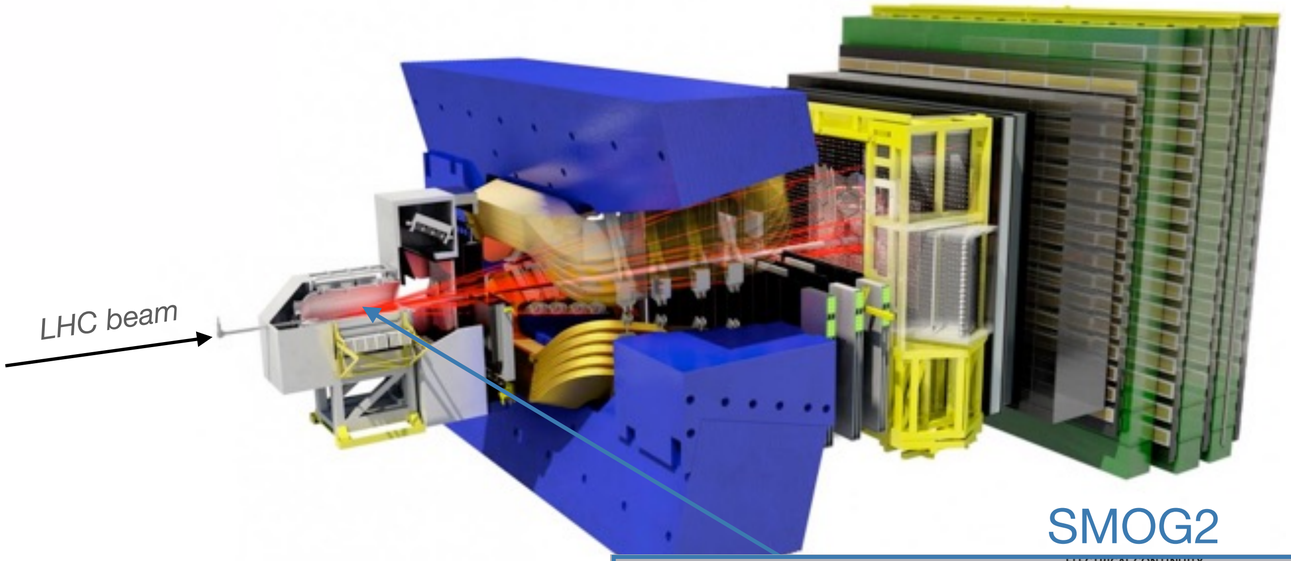
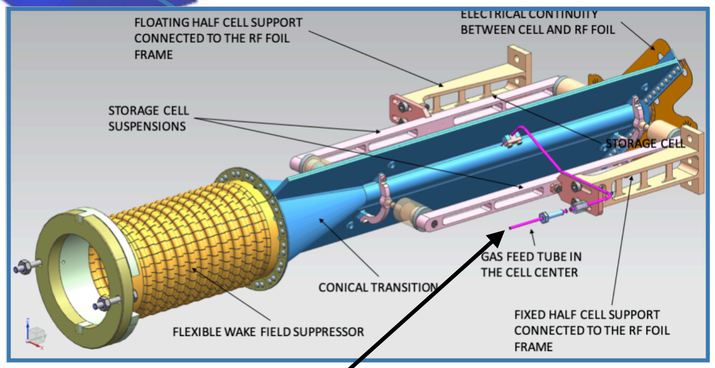
Fixed target at LHCb

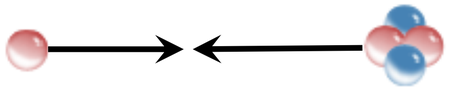
RUN3



SMOG2



protons gas (He, Ne, Ar)



$\sqrt{s_{NN}} = 115$ GeV

$-2.78 < y_{CM} < 0.2$

inject gas: He, Ne, Ar, and H_2, D_2

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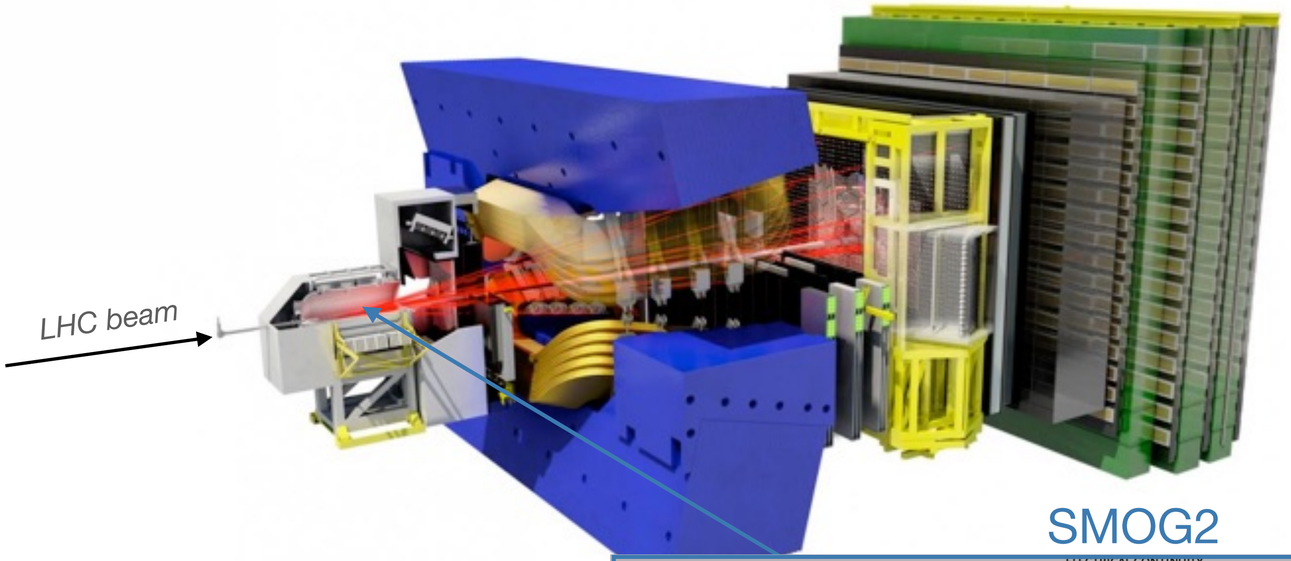
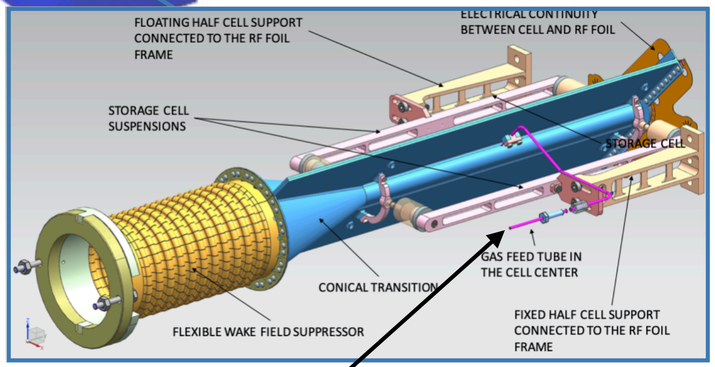


SMOG2



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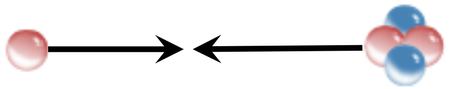

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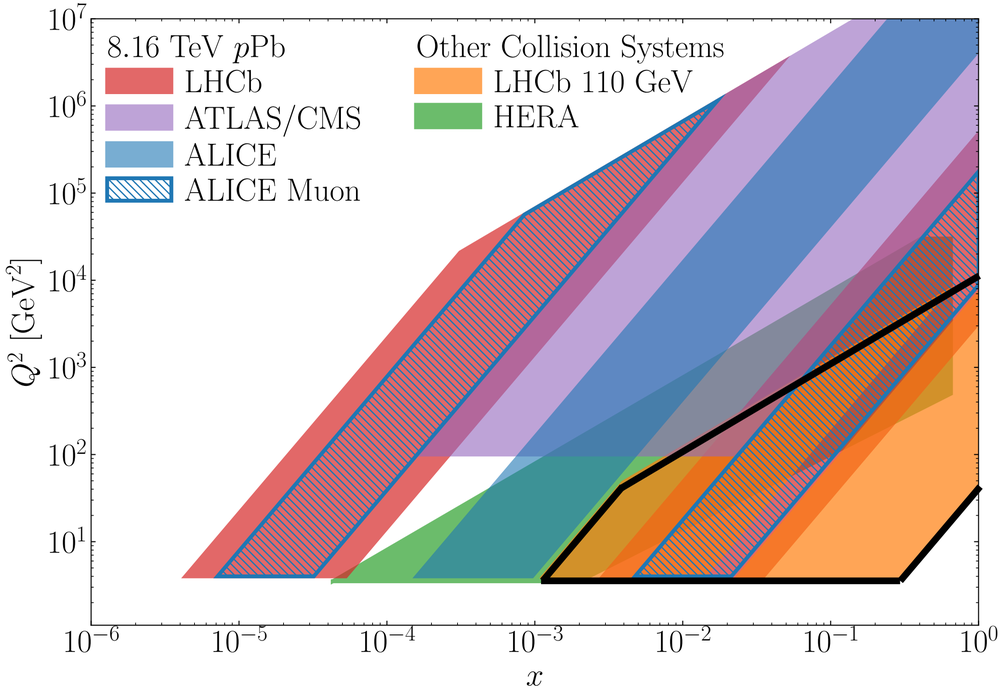
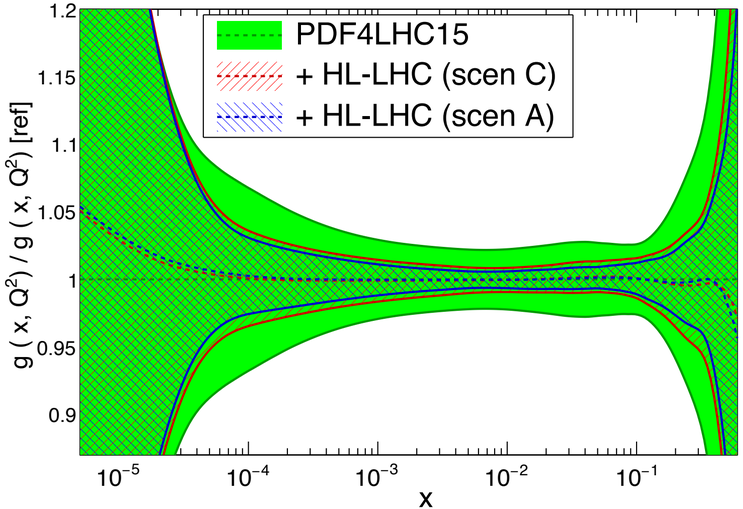


PDFs at the HL-LHC (Q = 10 GeV)



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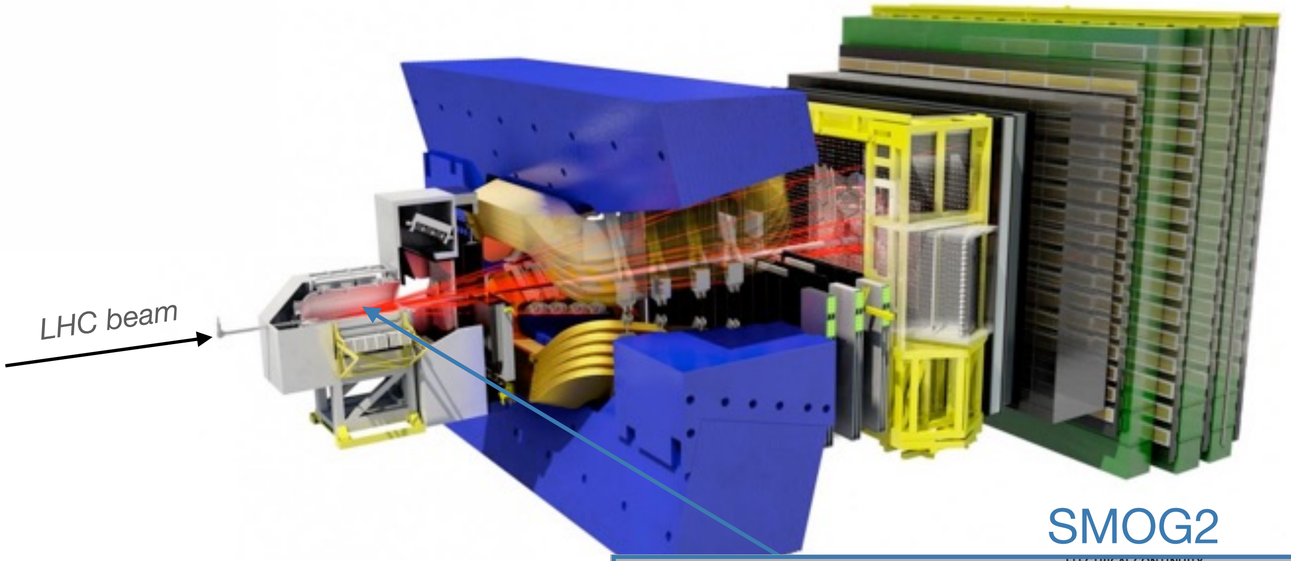
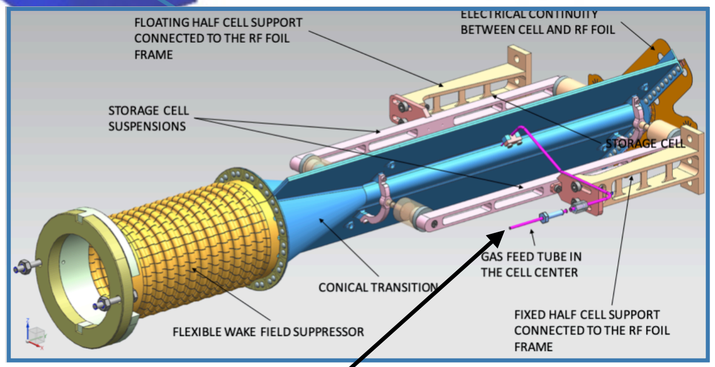
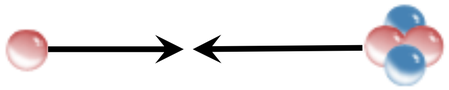


SMOG2



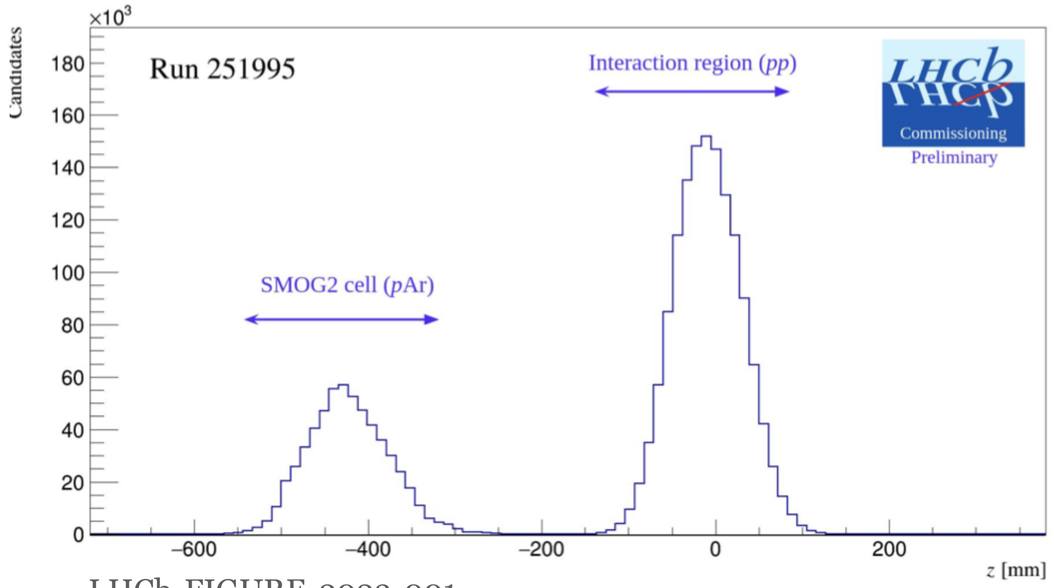
protons gas (He, Ne, Ar)



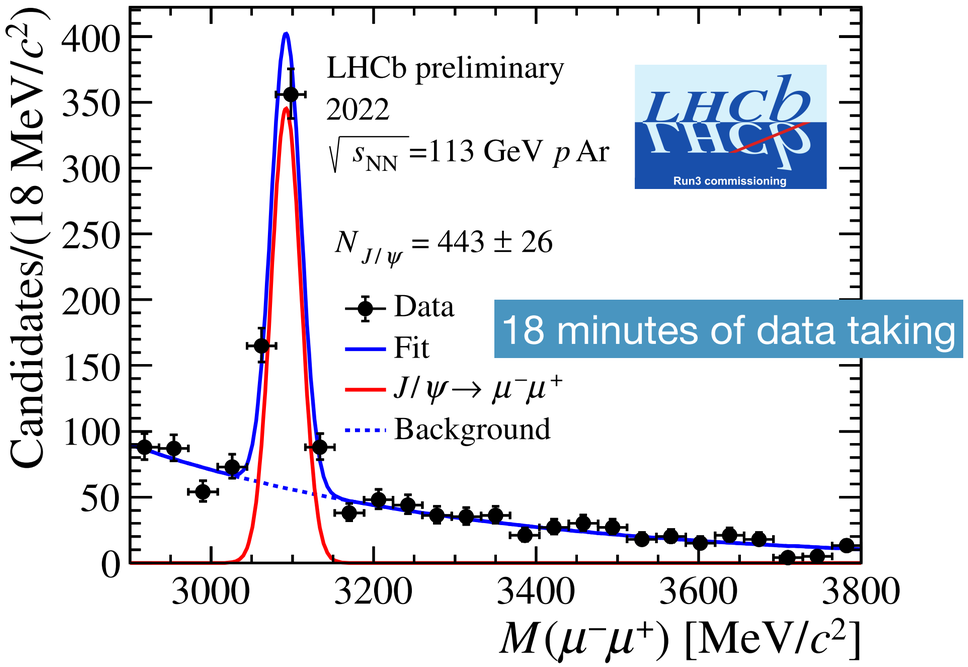
$\sqrt{s_{NN}} = 115$ GeV

-2.78<y_{CM}<0.2

inject gas: He, Ne, Ar, and H_2, D_2



LHCb-FIGURE-2023-001



SMOG2

GPDs: nucleon and nuclear GPDs in high-x_B region

exclusive measurements with SMOG2 (RUN3):

		pp	pHe	pXe
special runs	continuous $\mu^+\mu^-$	$\sigma = 61.931$ pb $= 686$ evts	$\sigma = 113.6$ pb $= 0$ evts	$\sigma = 17.6$ nb $= 29\ 10^3$ evts
data collection in parallel with pp	$J/\psi \to \mu^+\mu^-$	$\sigma = 20.467$ pb $= 2302$ evts	$\sigma = 27.3$ pb $= 0$ evts	$\sigma = 1.3$ nb $= 21\ 10^3$ evts
	$\phi \to K^+K^-$	$\sigma = 184$ pb $= 12\ 10^3$ evts	$\sigma = 109.4$ pb $= 5$ evts	$\sigma = 11.0$ nb $= 102\ 10^3$ evts

total uncertainty on cross section: 5-10%

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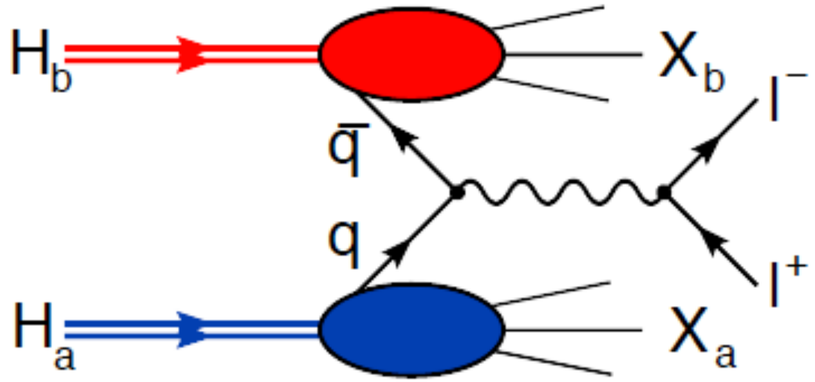
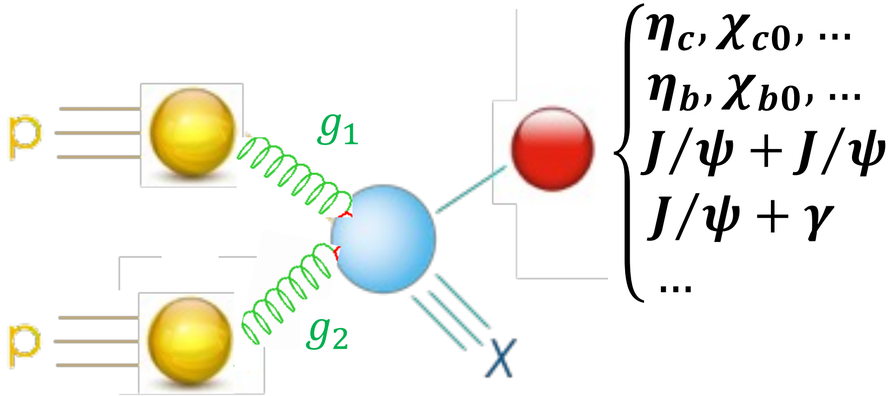
TMDs: Boer-Mulders, gluon TMDs in high-x_B region



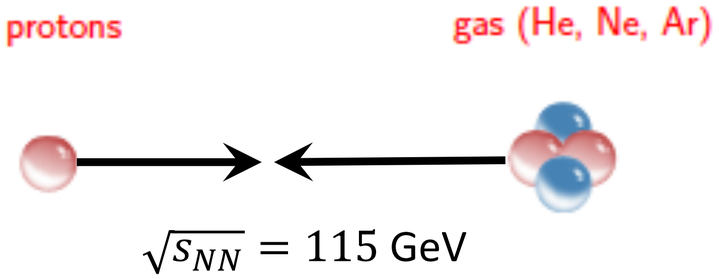


Dominant process: $\bar{q}(x_{beam}) + q(x_{target}) \to \mu^+\mu^-$

Fixed target at LHCb

Proposal for Run 5:

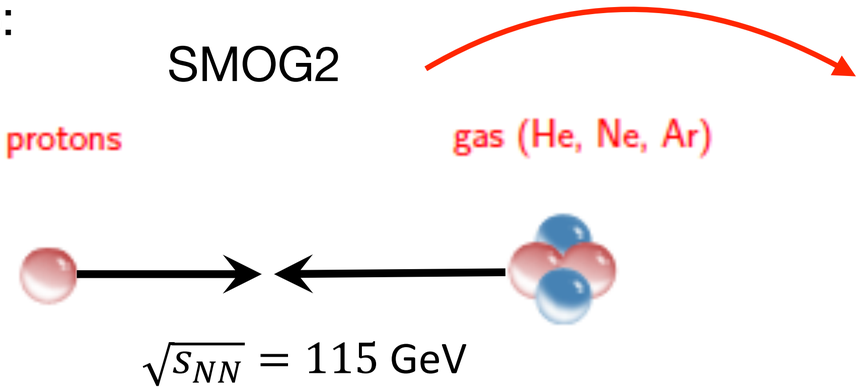
SMOG2



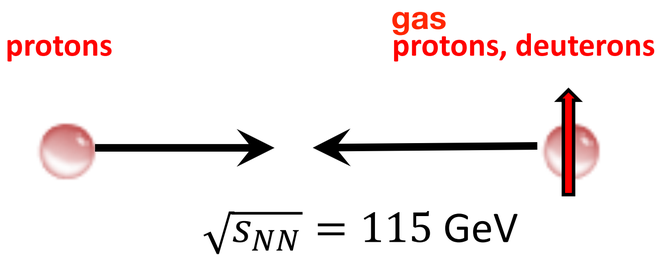
Fixed target at LHCb

Proposal for Run 5:

SMOG2



LHCSPIN: transversely polarised gas target

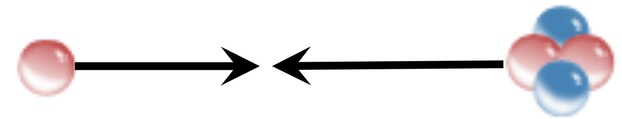


⟶ access to spin-dependent PDFs,
TMD PDFs and GPDs at the LHC

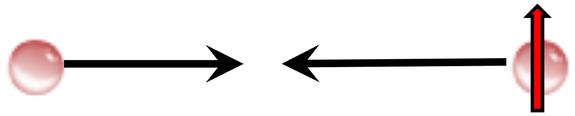
Fixed target at LHCb

Proposal for Run 5:

SMOG2 → LHCSPIN: transversely polarised gas target



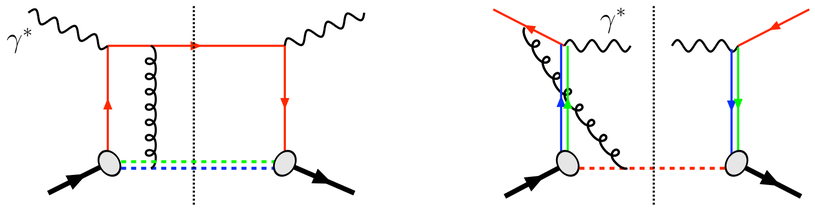
$\sqrt{s_{NN}} = 115$ GeV



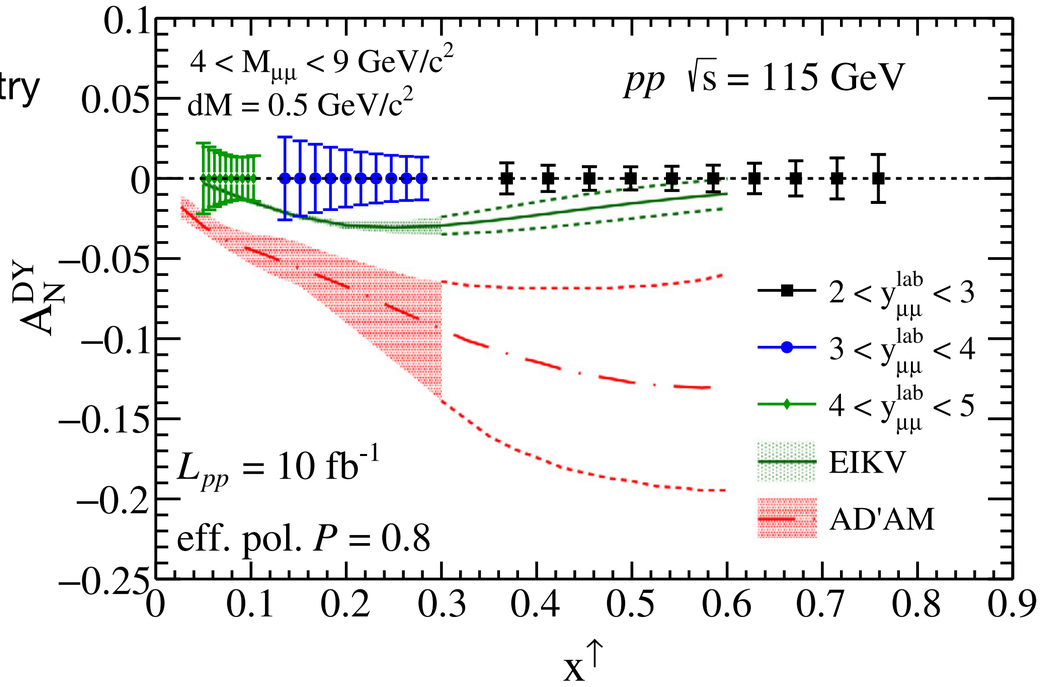
$\sqrt{s_{NN}} = 115$ GeV

⟶ access to spin-dependent PDFs, TMD PDFs and GPDs at the LHC

Sivers TMD PDF
via Drell-Yan asymmetry



$$f_{1T}^{\perp}\Big|_{\text{SIDIS}} = -f_{1T}^{\perp}\Big|_{\text{DY}}$$



Summary

- pp at LHCb provides complementary information about TMD PDFs and GPDs
  - Unique potential to probe very low x_B, down to 10^{-6}
  - Probe universality of TMD PDFs/GPDs (where applicable)

- PbPb at LHCb
  - access to nuclear TMD PDFs/GPDs
  - potential to probe saturation effects

- Fixed target: potential to constrain TMD PDFs and GPDs in the poorly constrained high x_B region