

# Study of exclusive processes in ultra-peripheral collisions at LHCb

Charlotte Van Hulse  
University of Alcalá

AdT

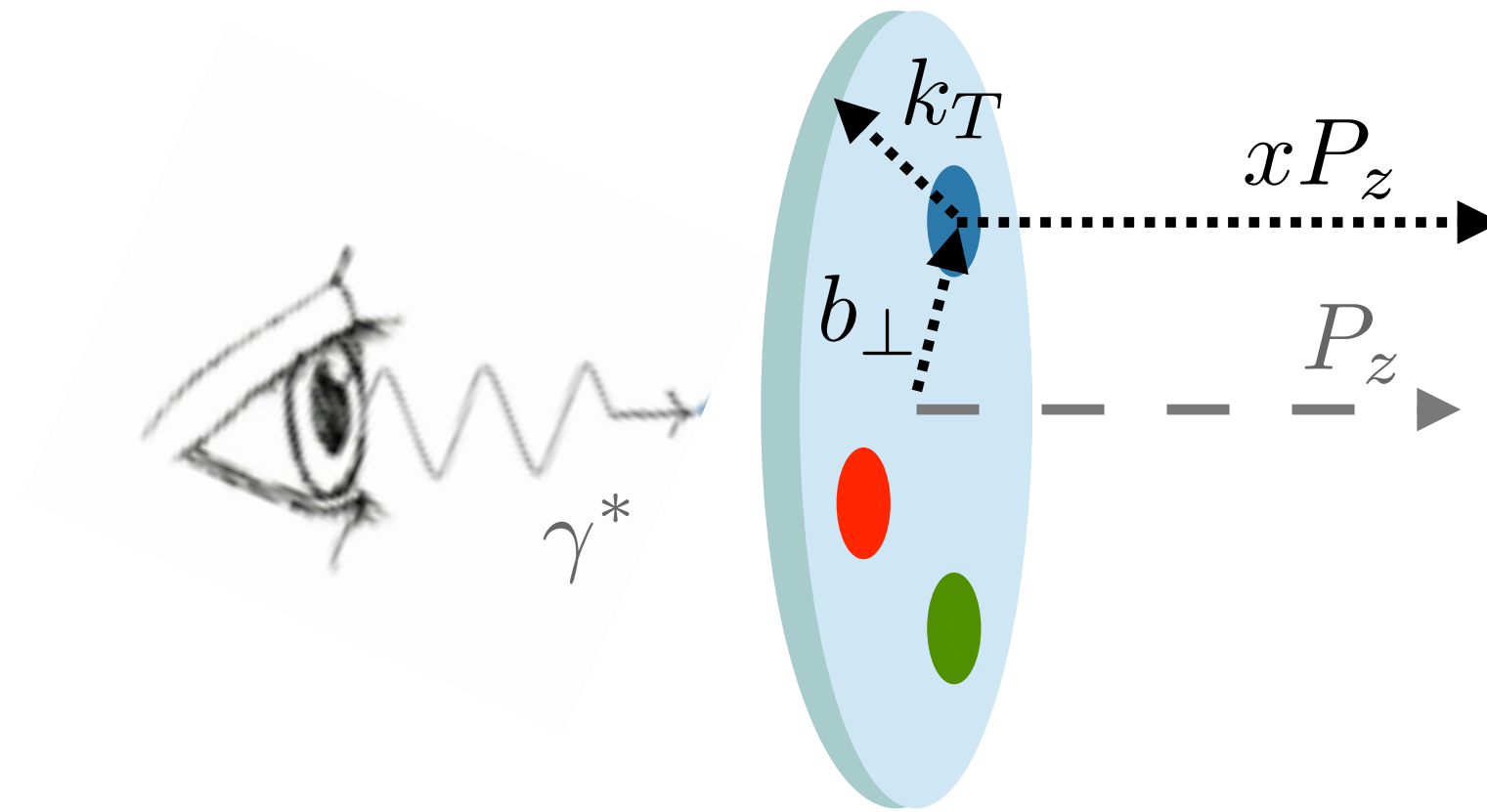


Comunidad  
de Madrid

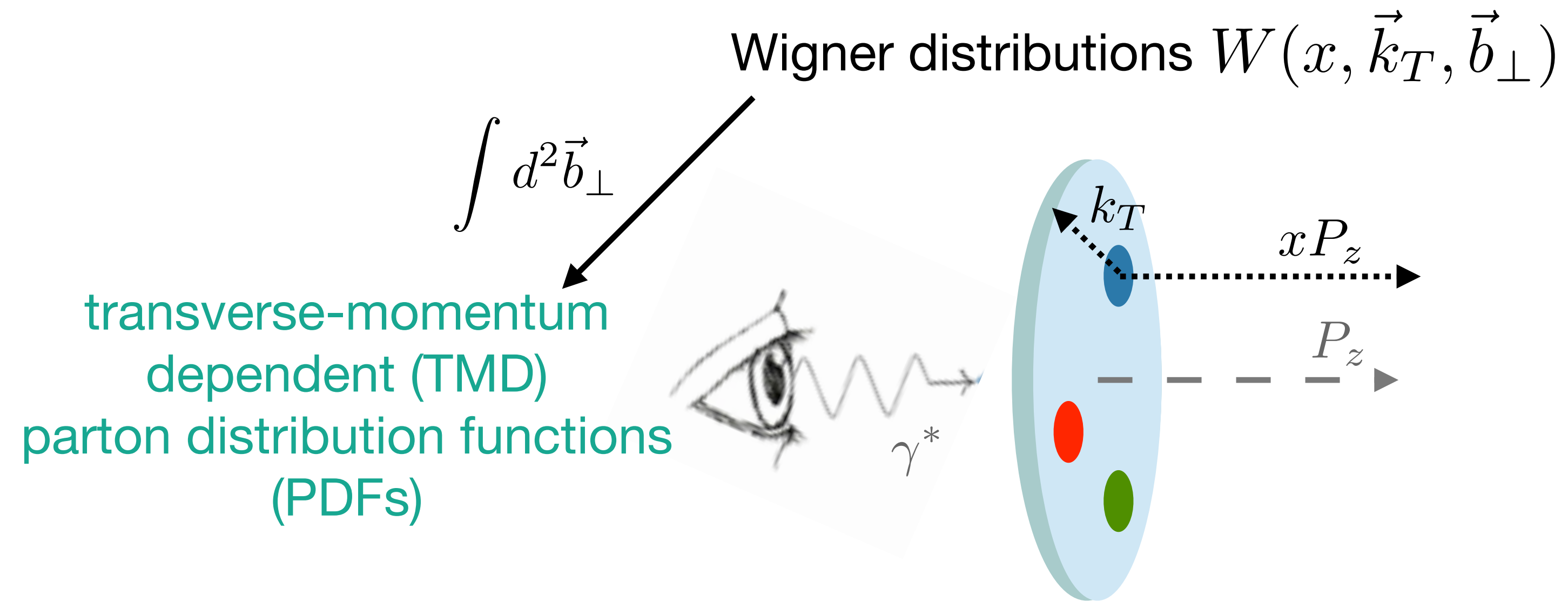
8th Red LHC workshop  
May 28-30, 2024  
UCM, Madrid

# The various dimensions of the nucleon structure

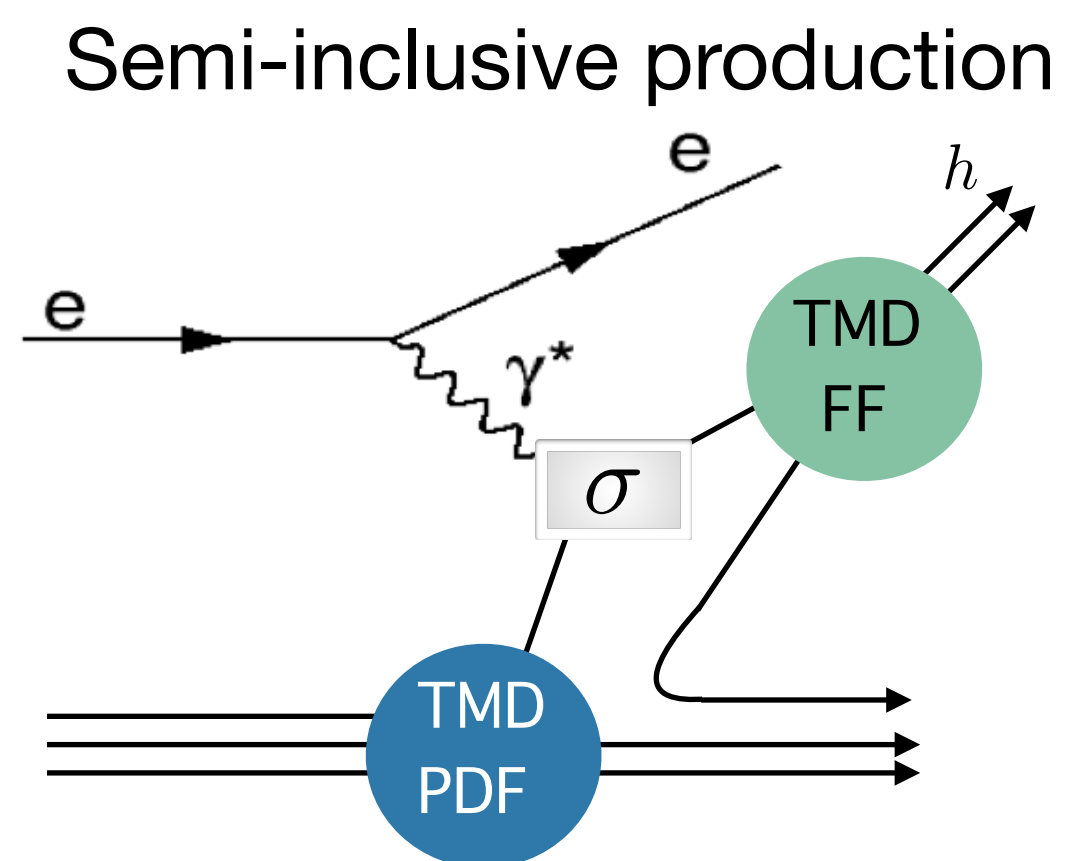
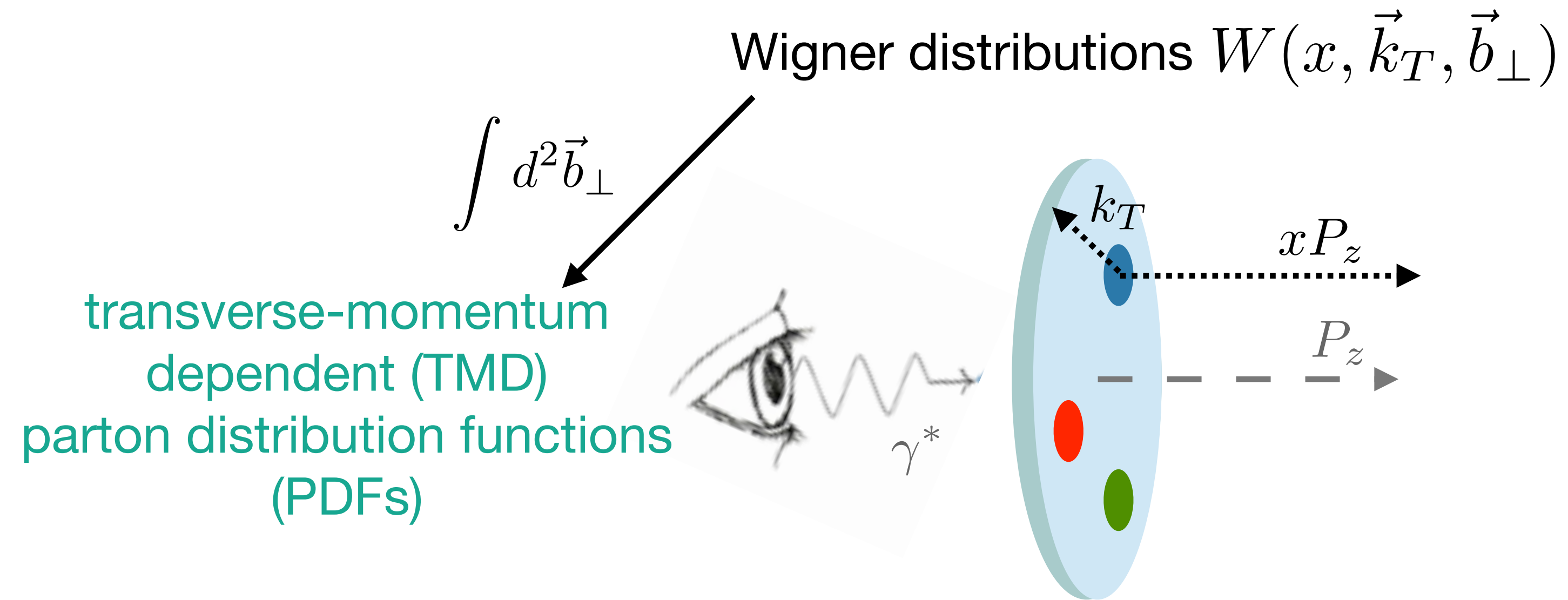
Wigner distributions  $W(x, \vec{k}_T, \vec{b}_\perp)$



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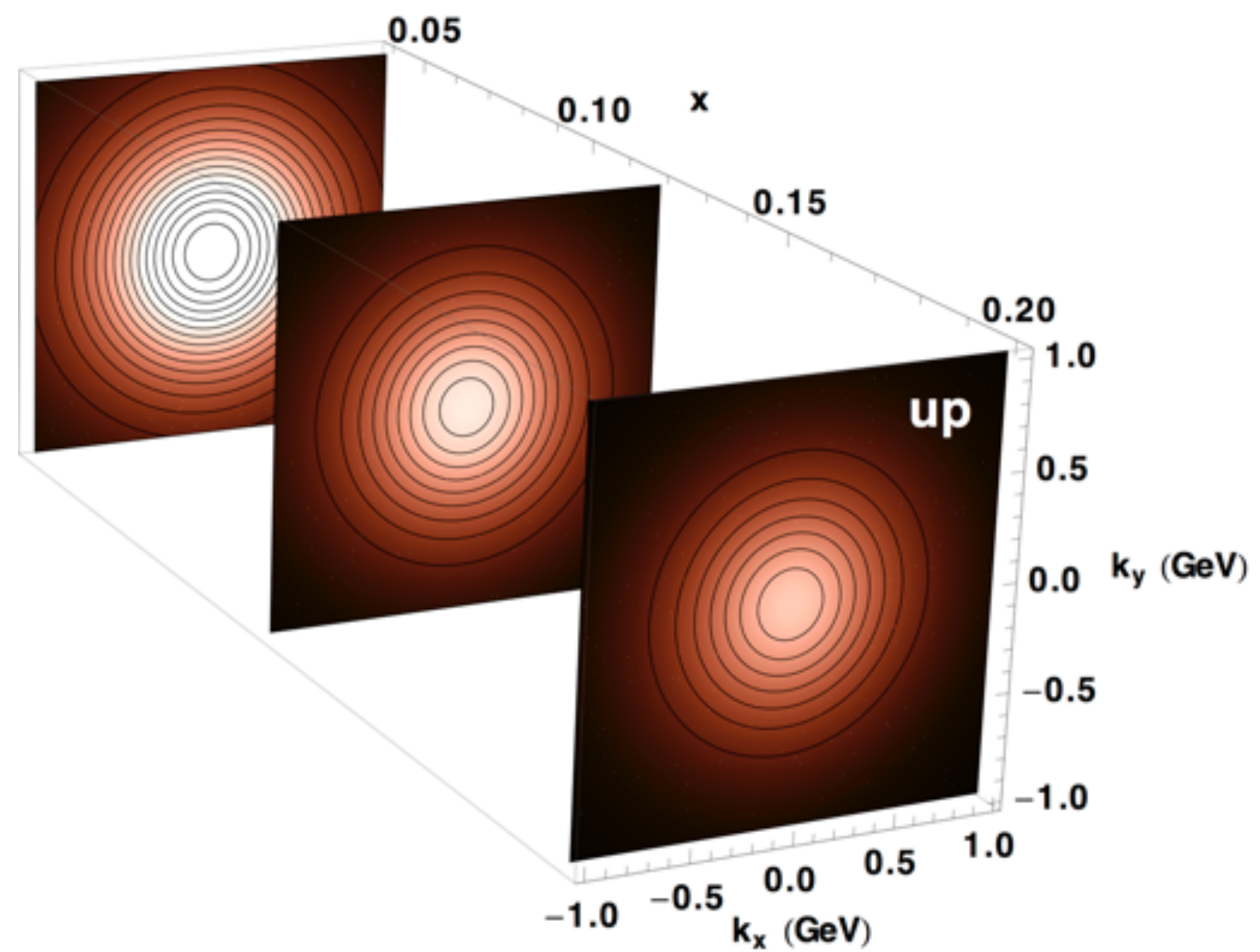
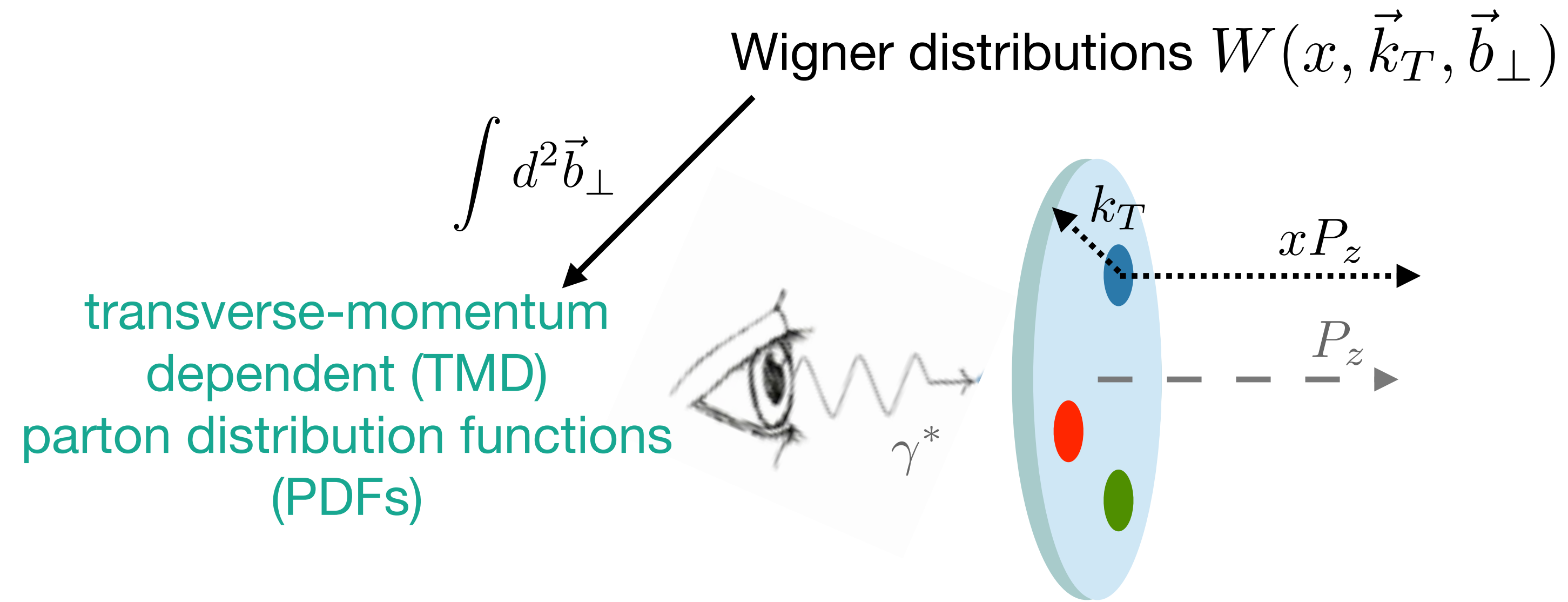


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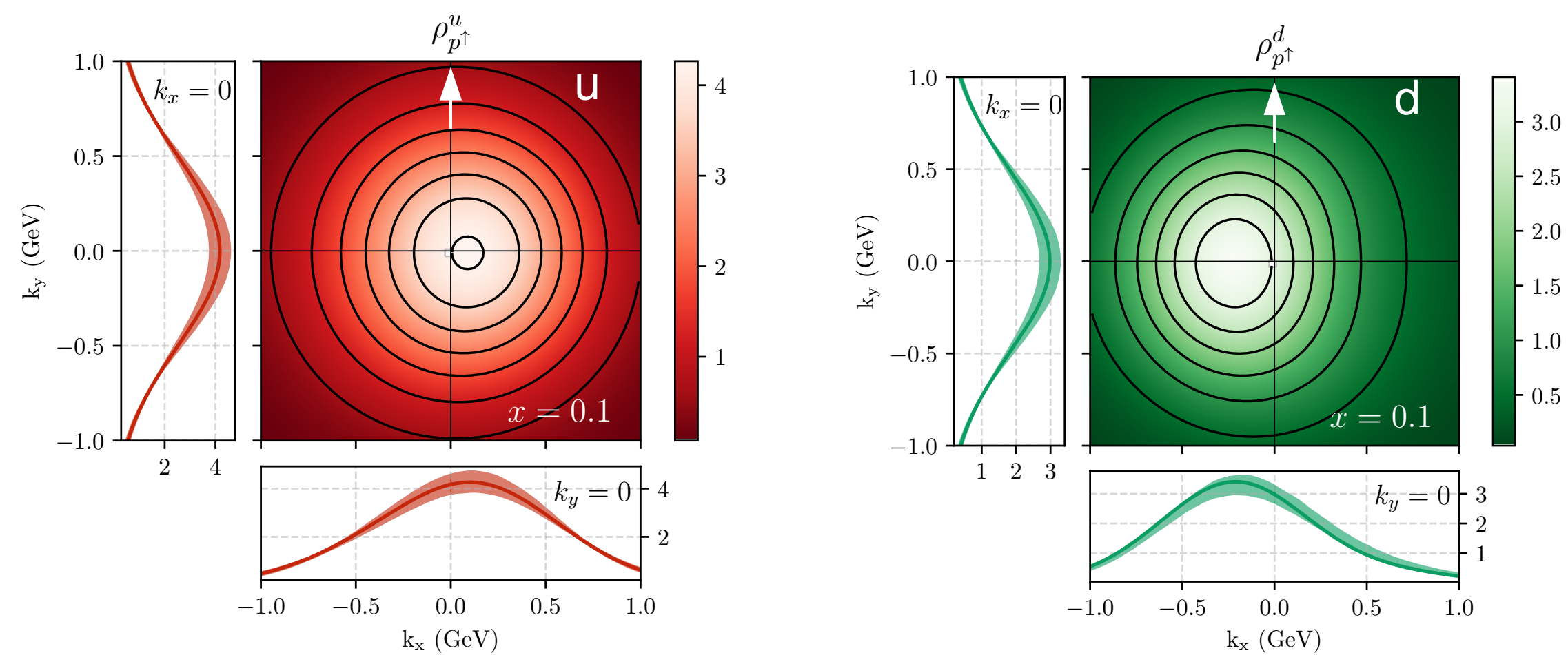
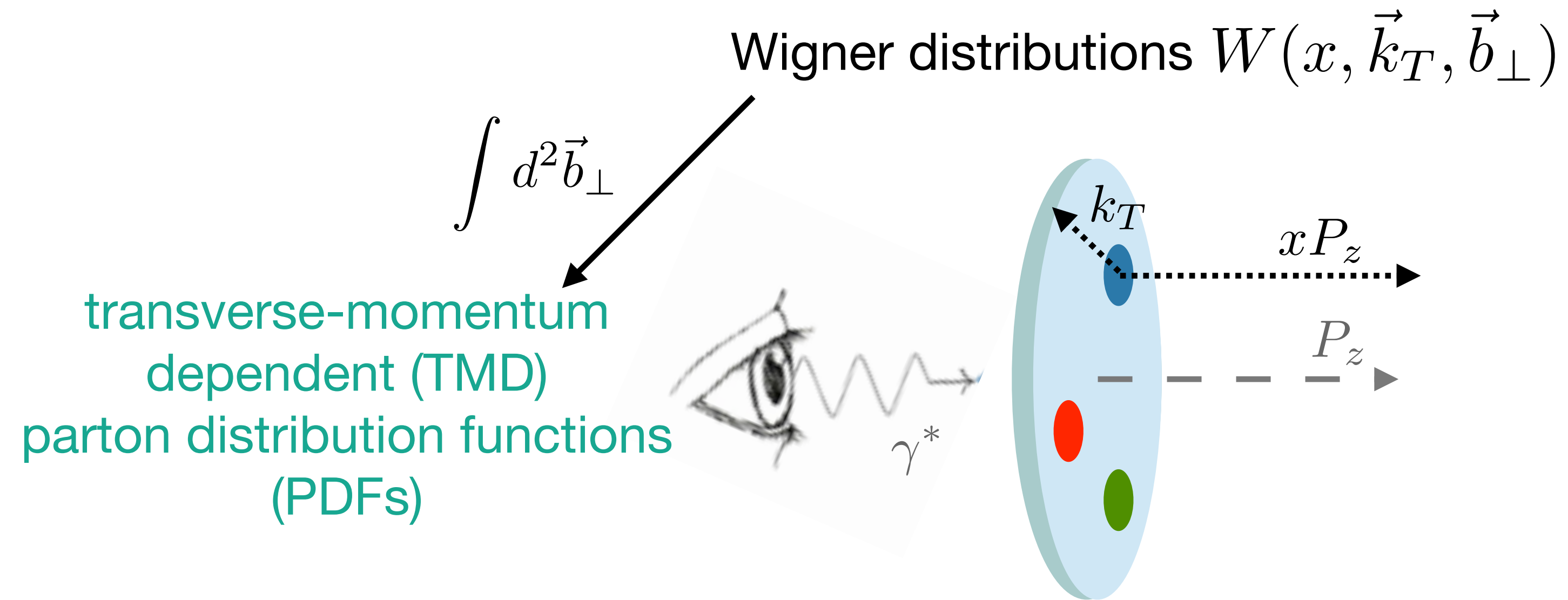




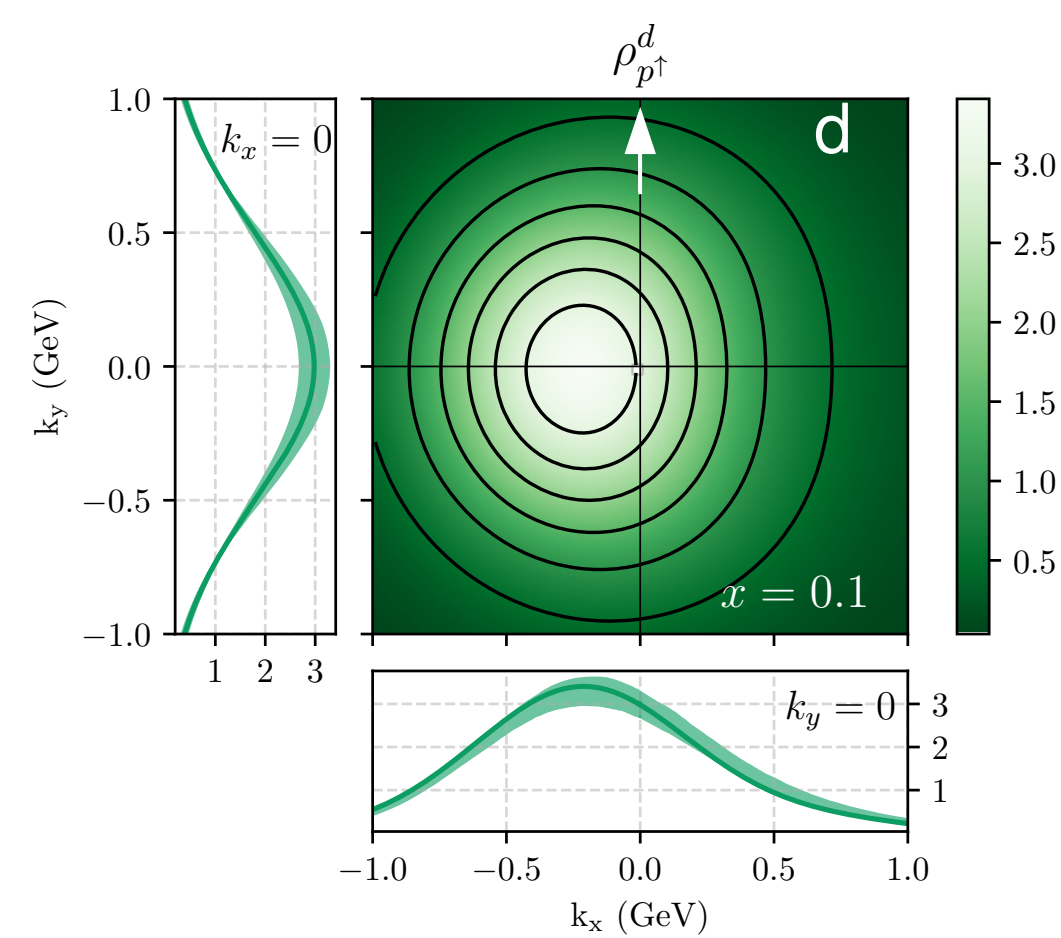
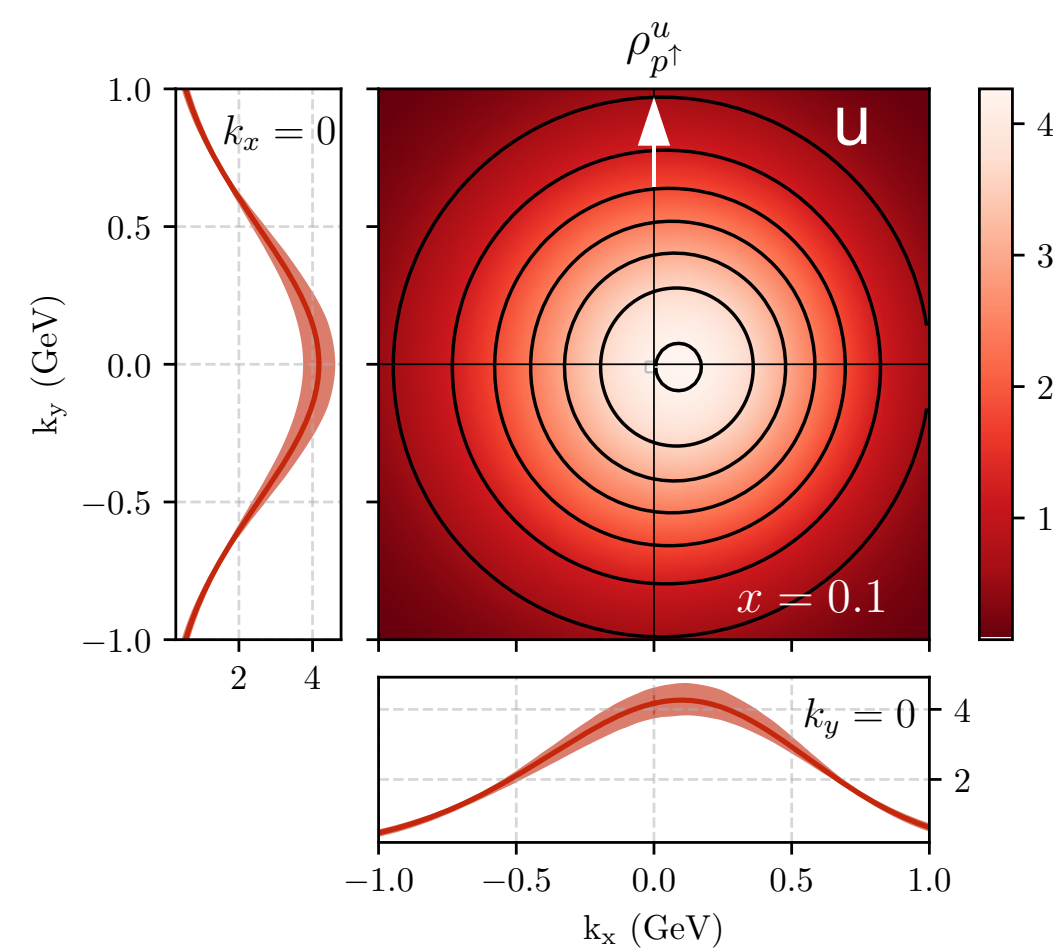
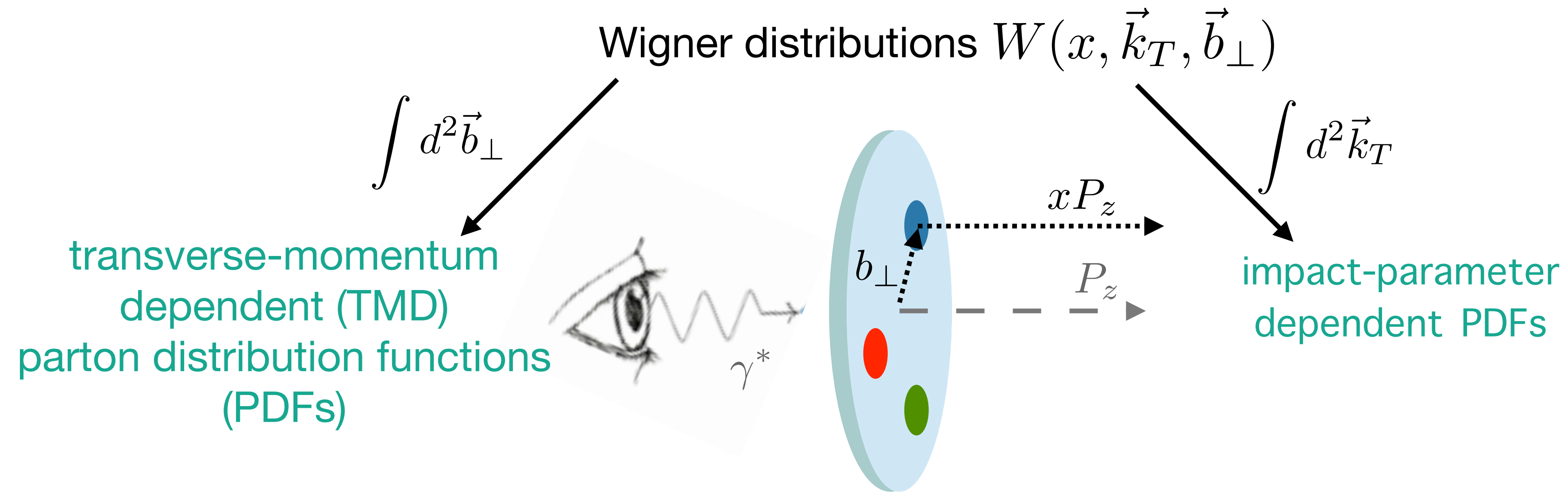
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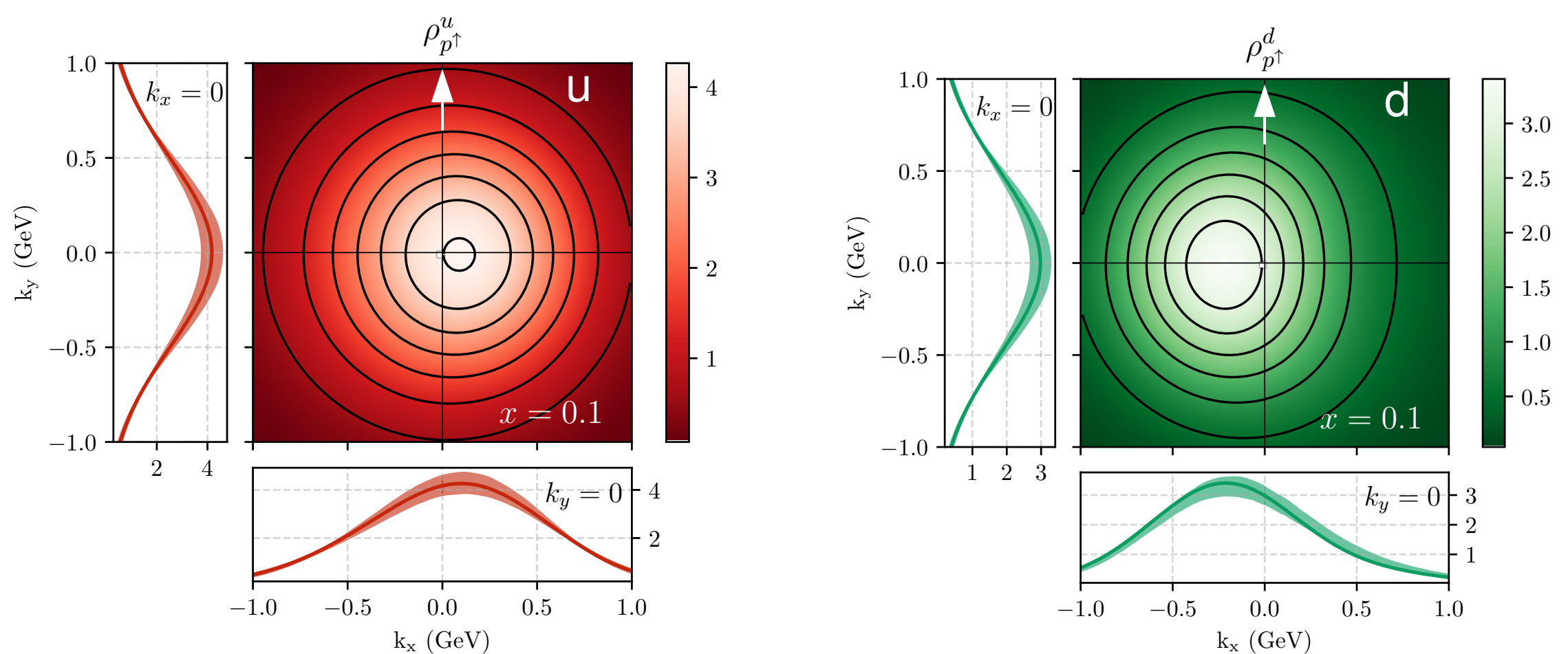
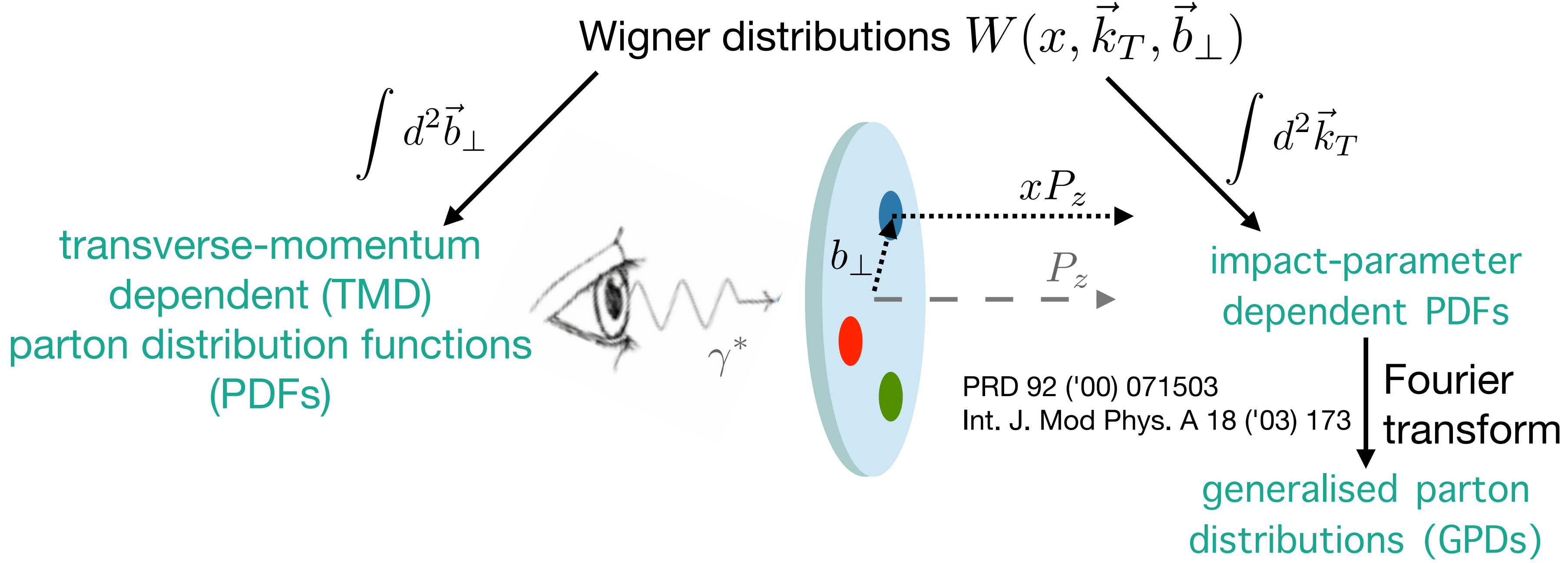
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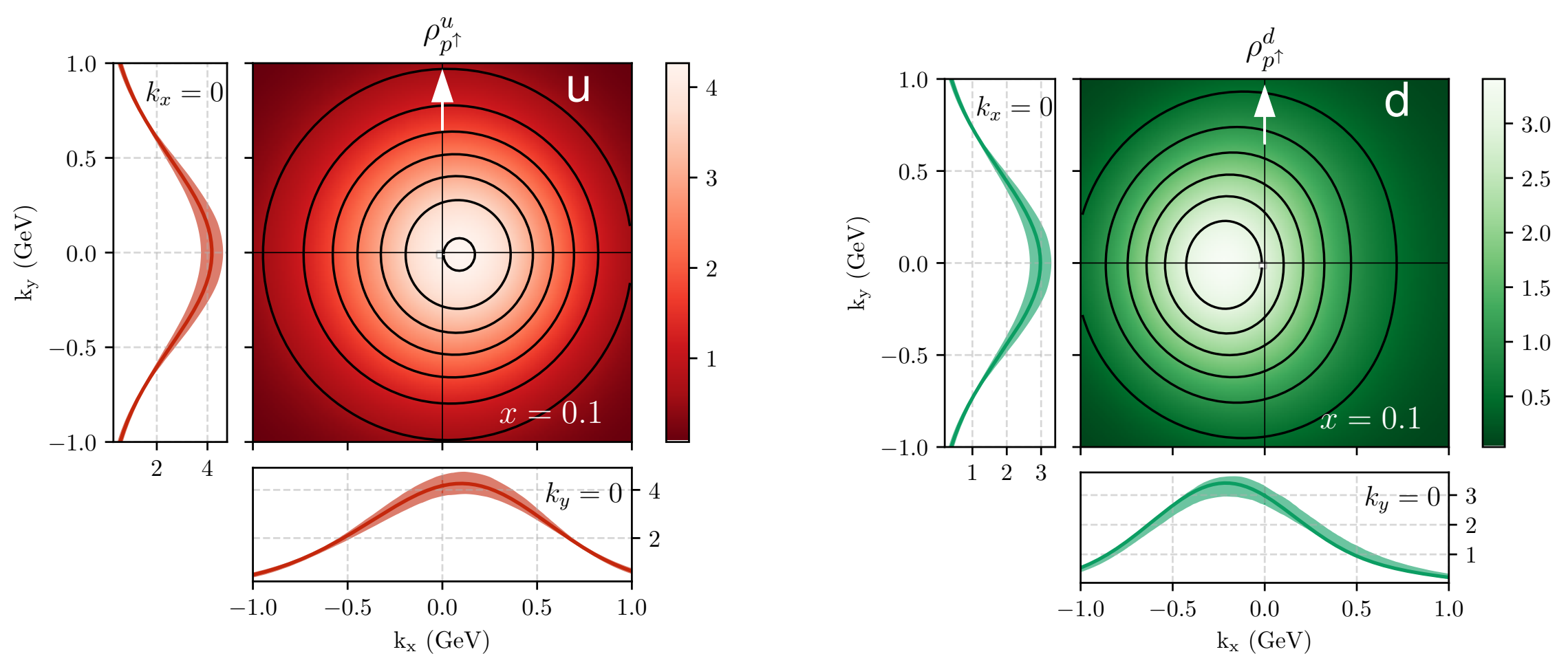
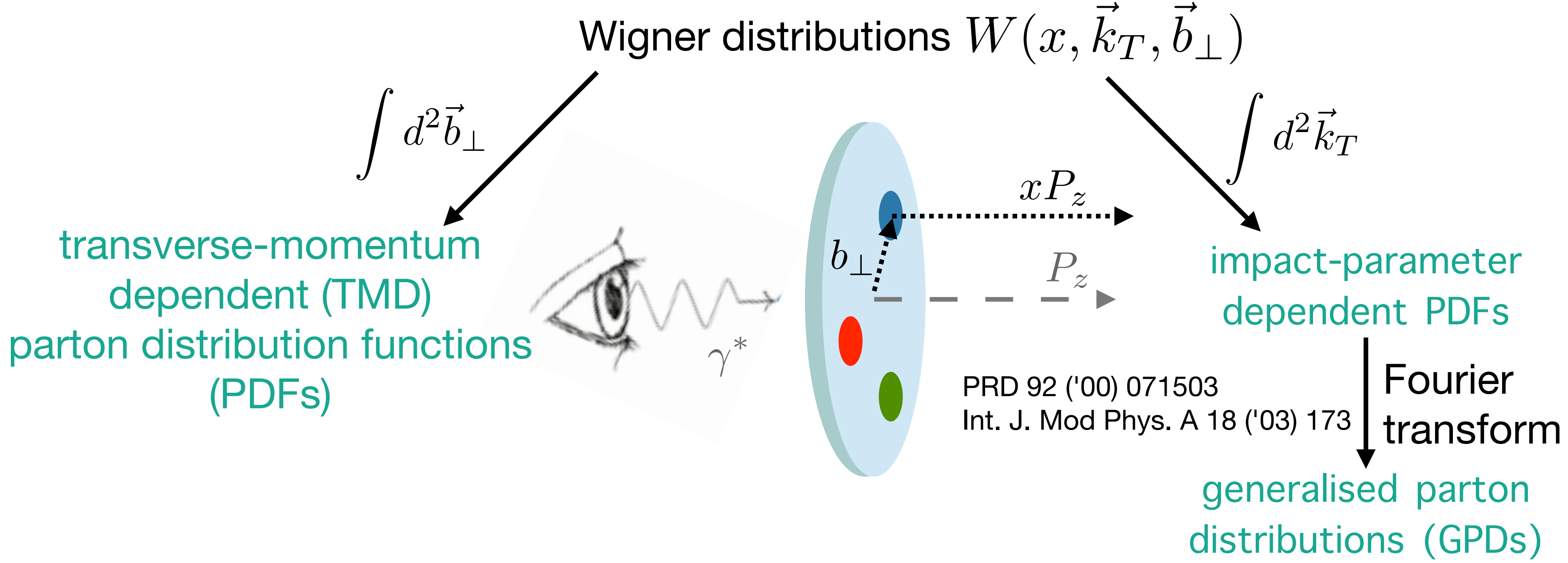


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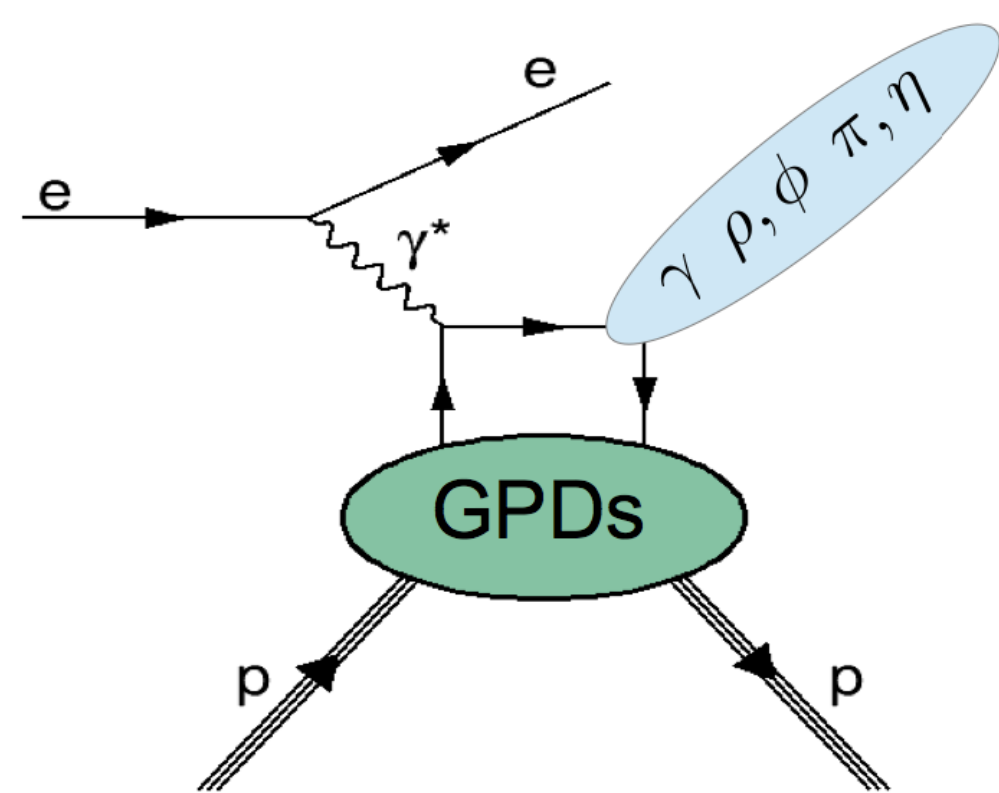




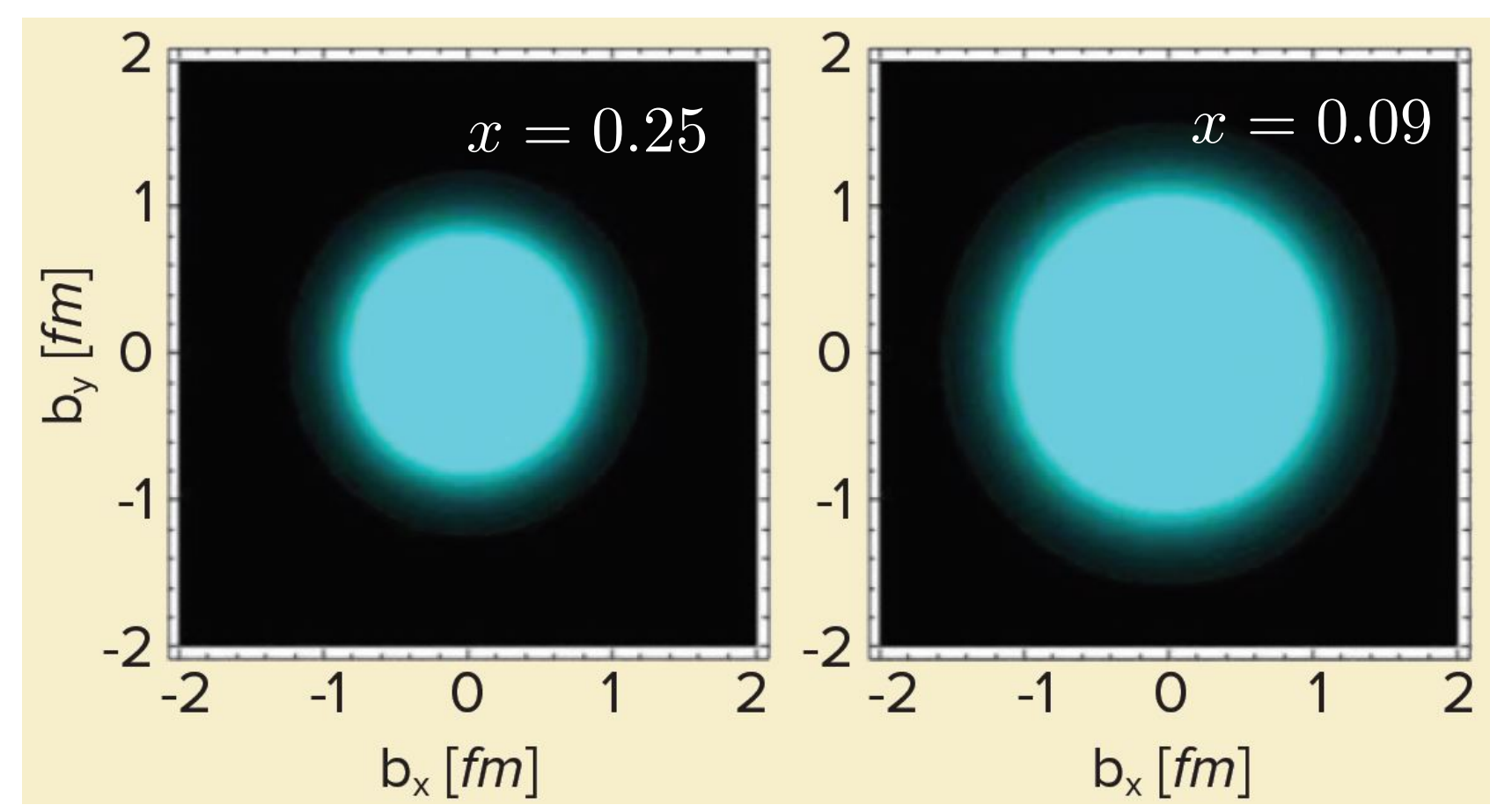
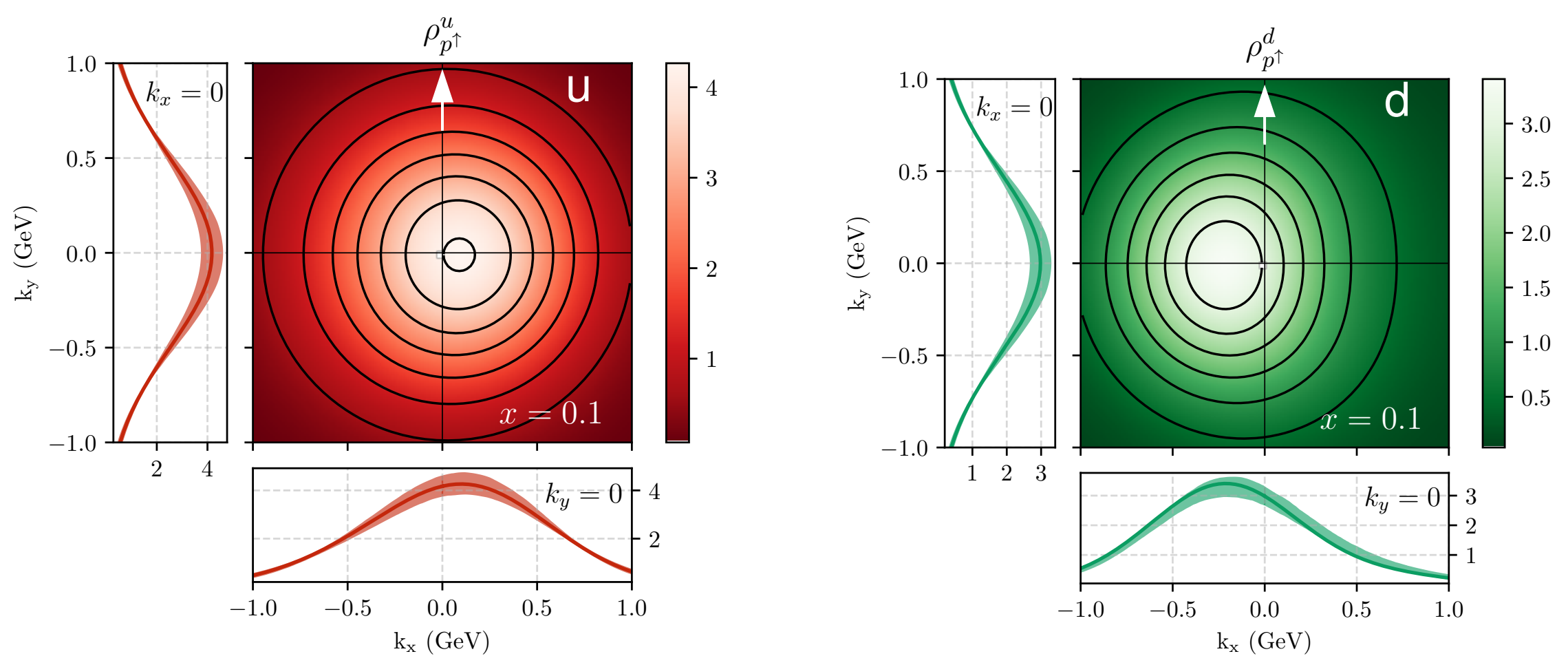
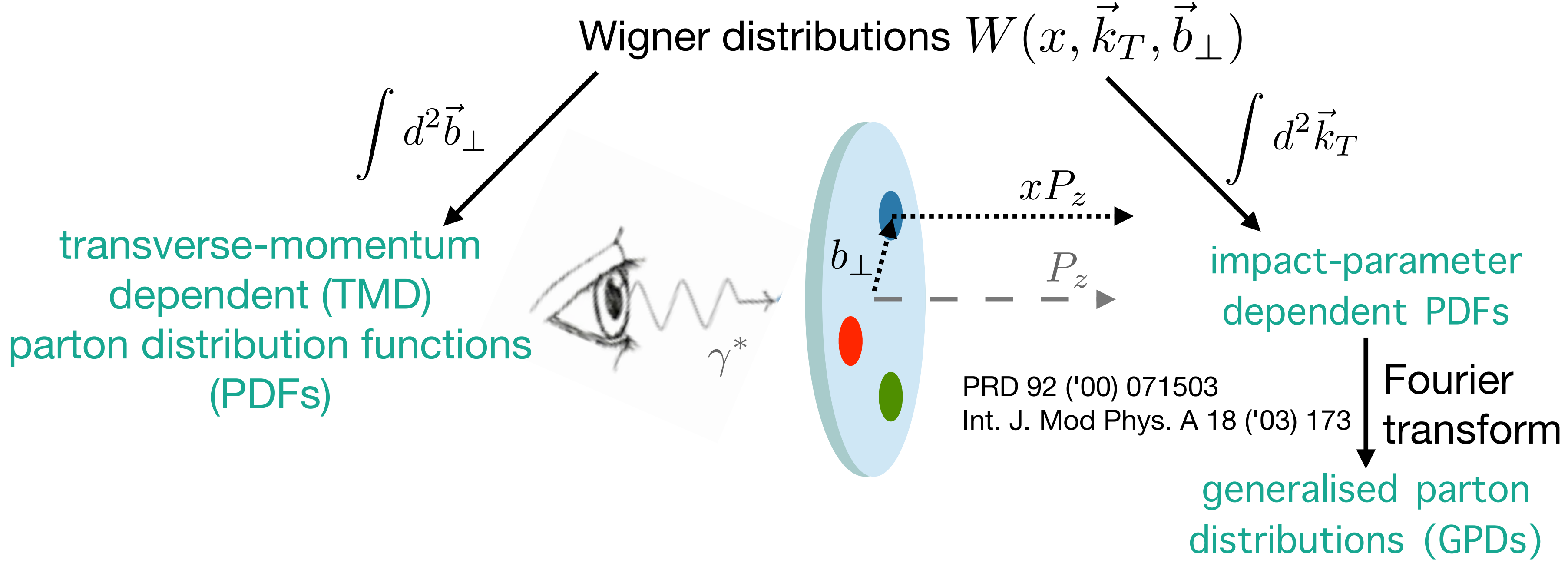
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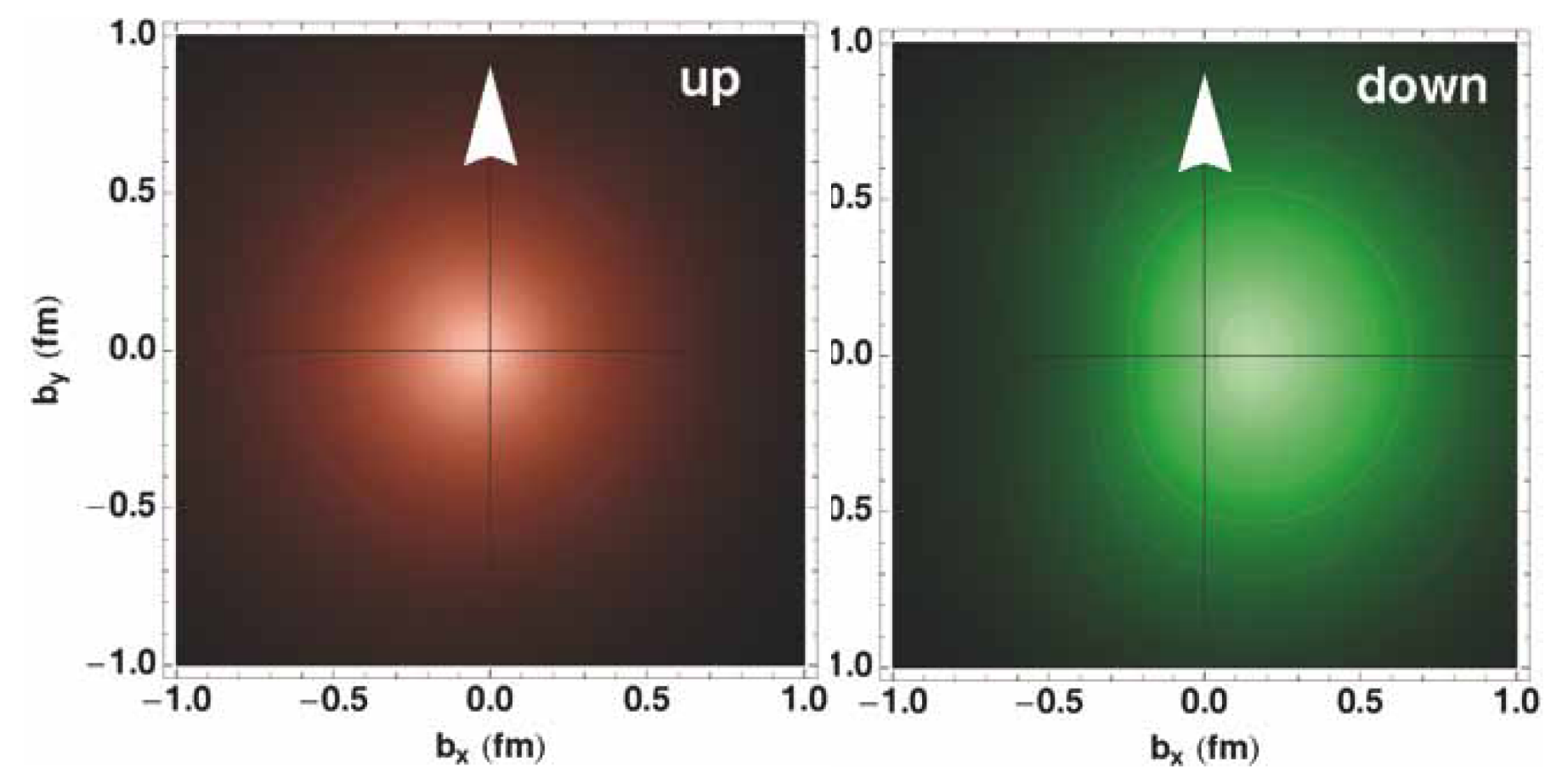
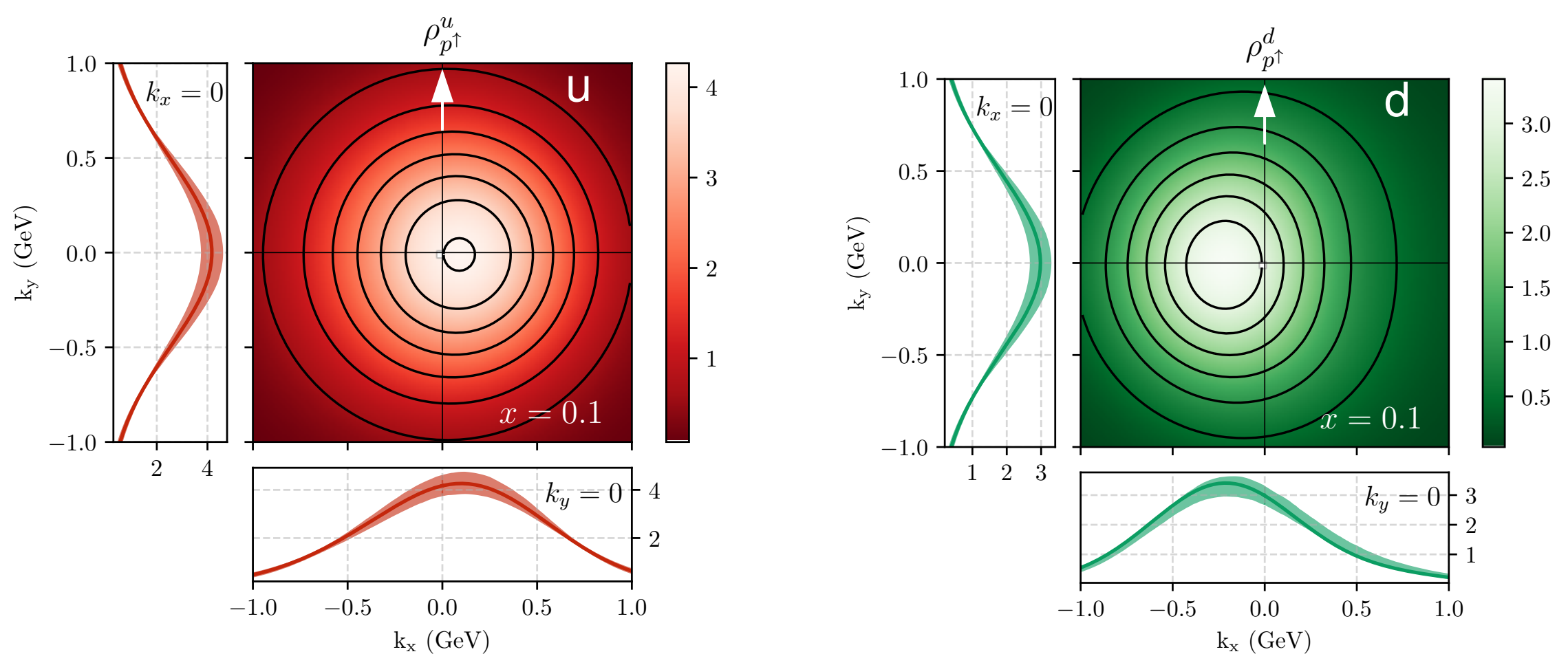
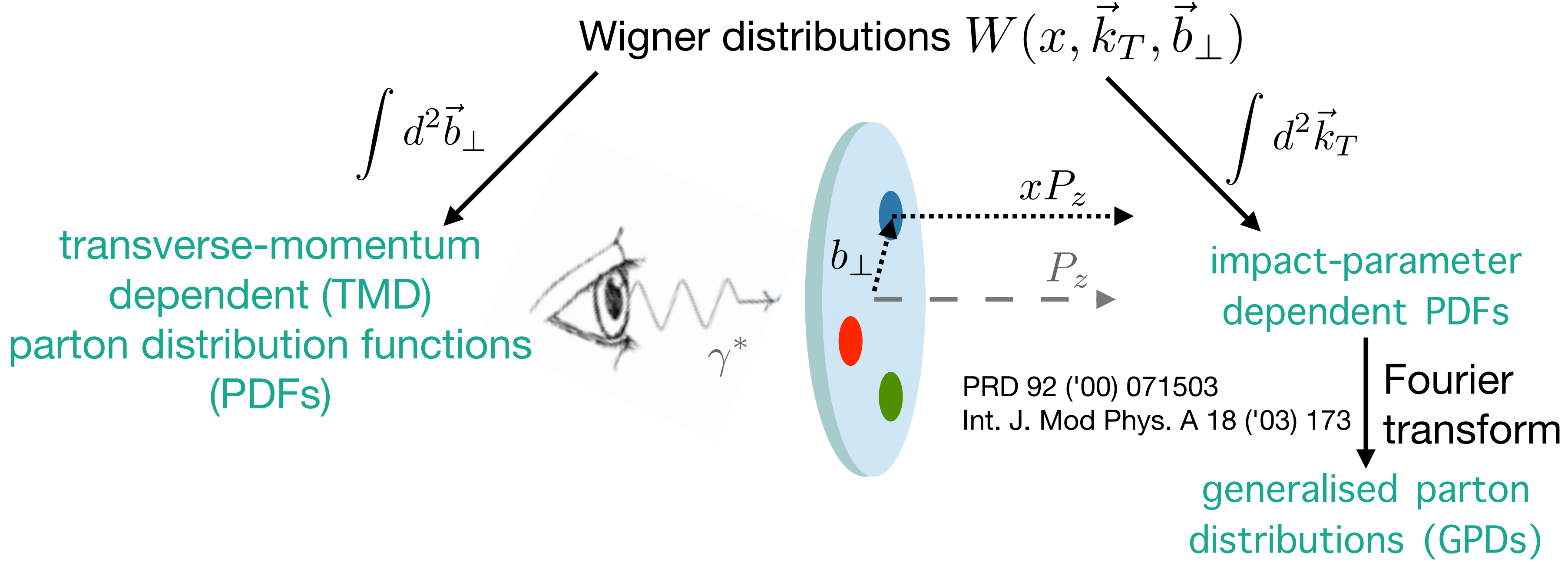
## Exclusive production



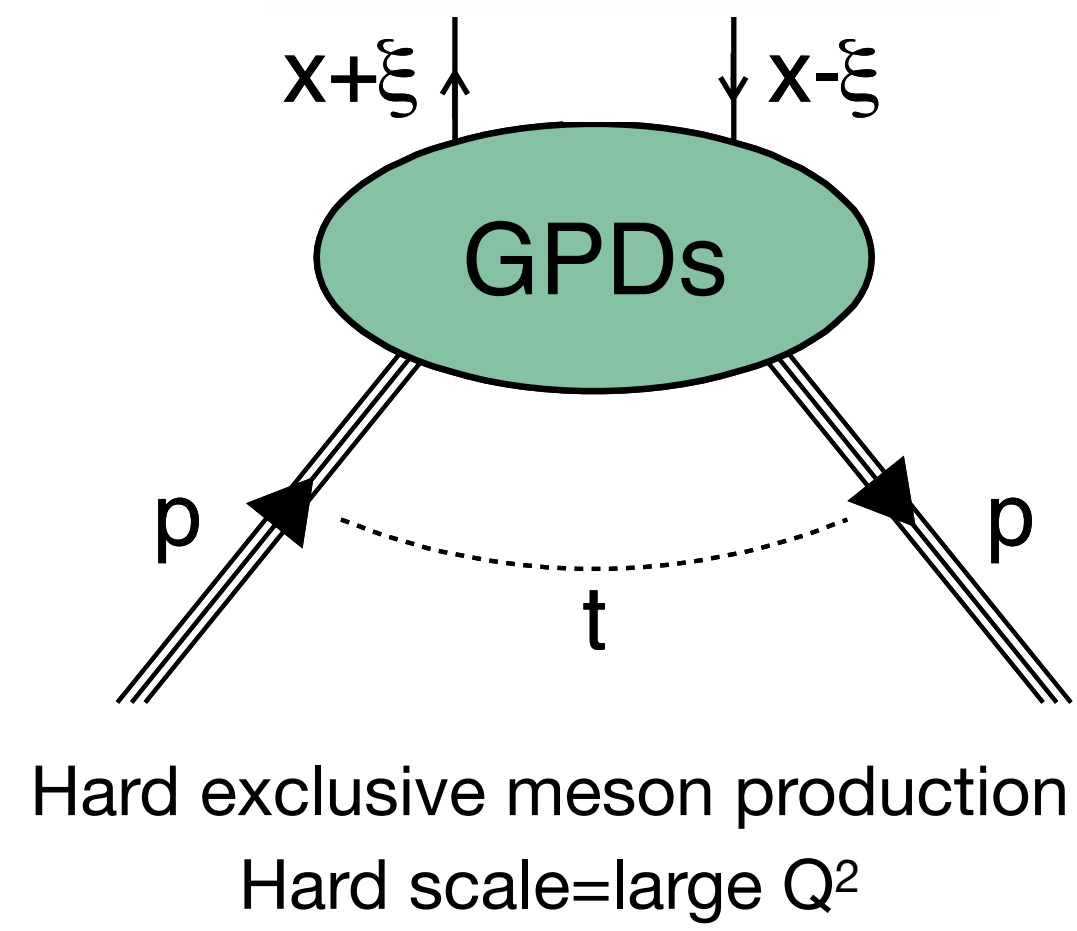
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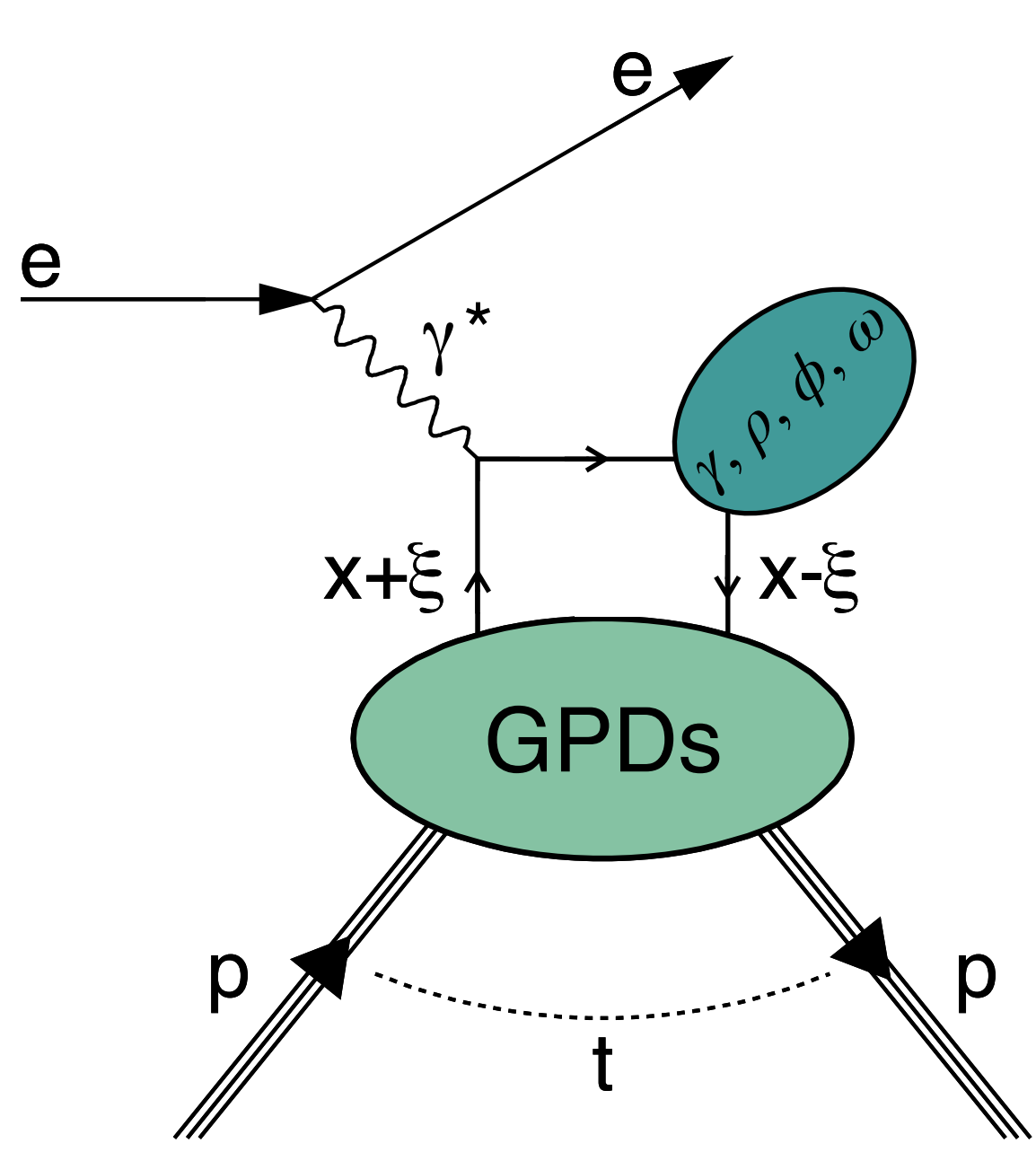


# Experimental access to GPDs

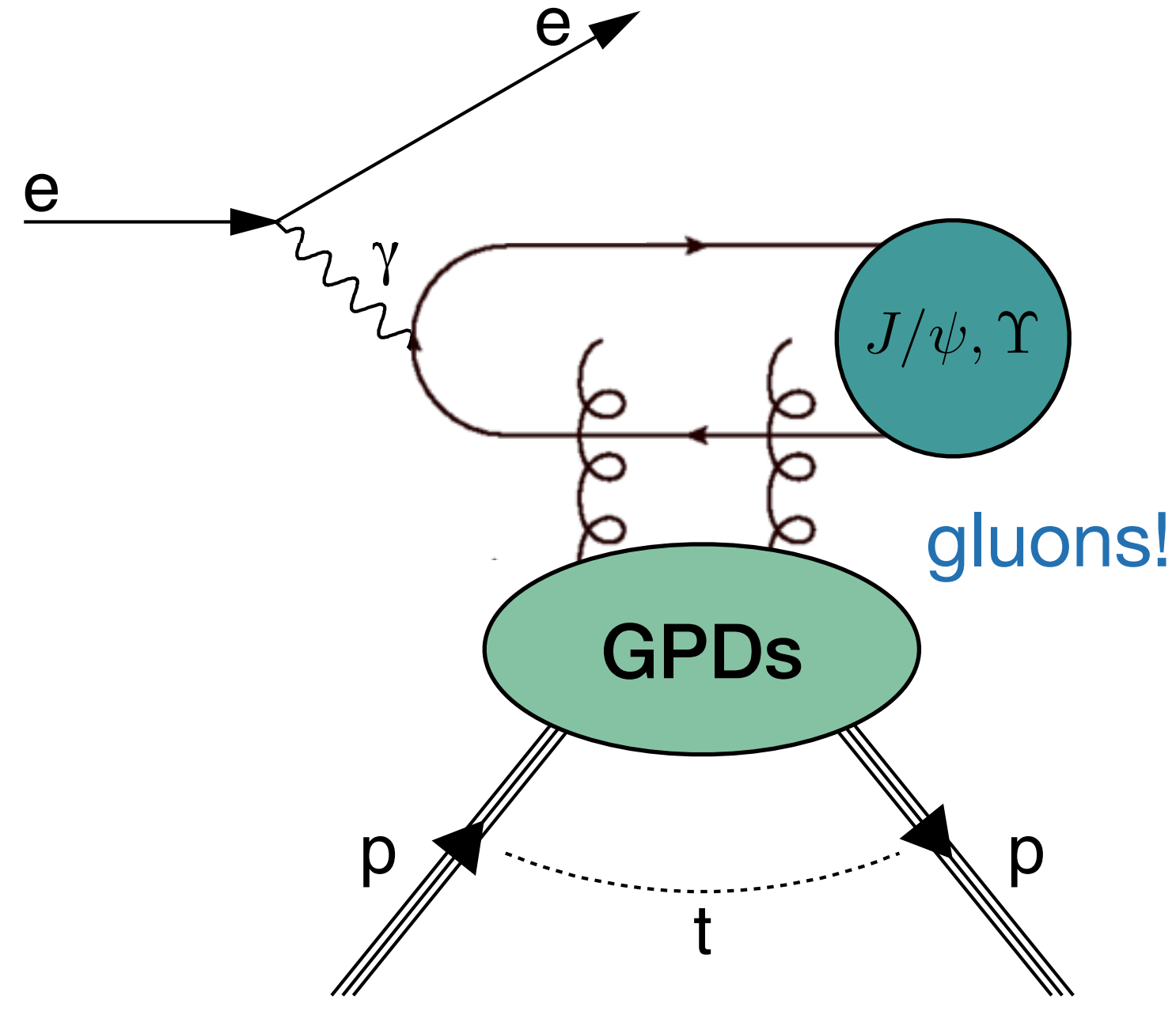




# Experimental access to GPDs



Hard exclusive meson production  
Hard scale=large  $Q^2$

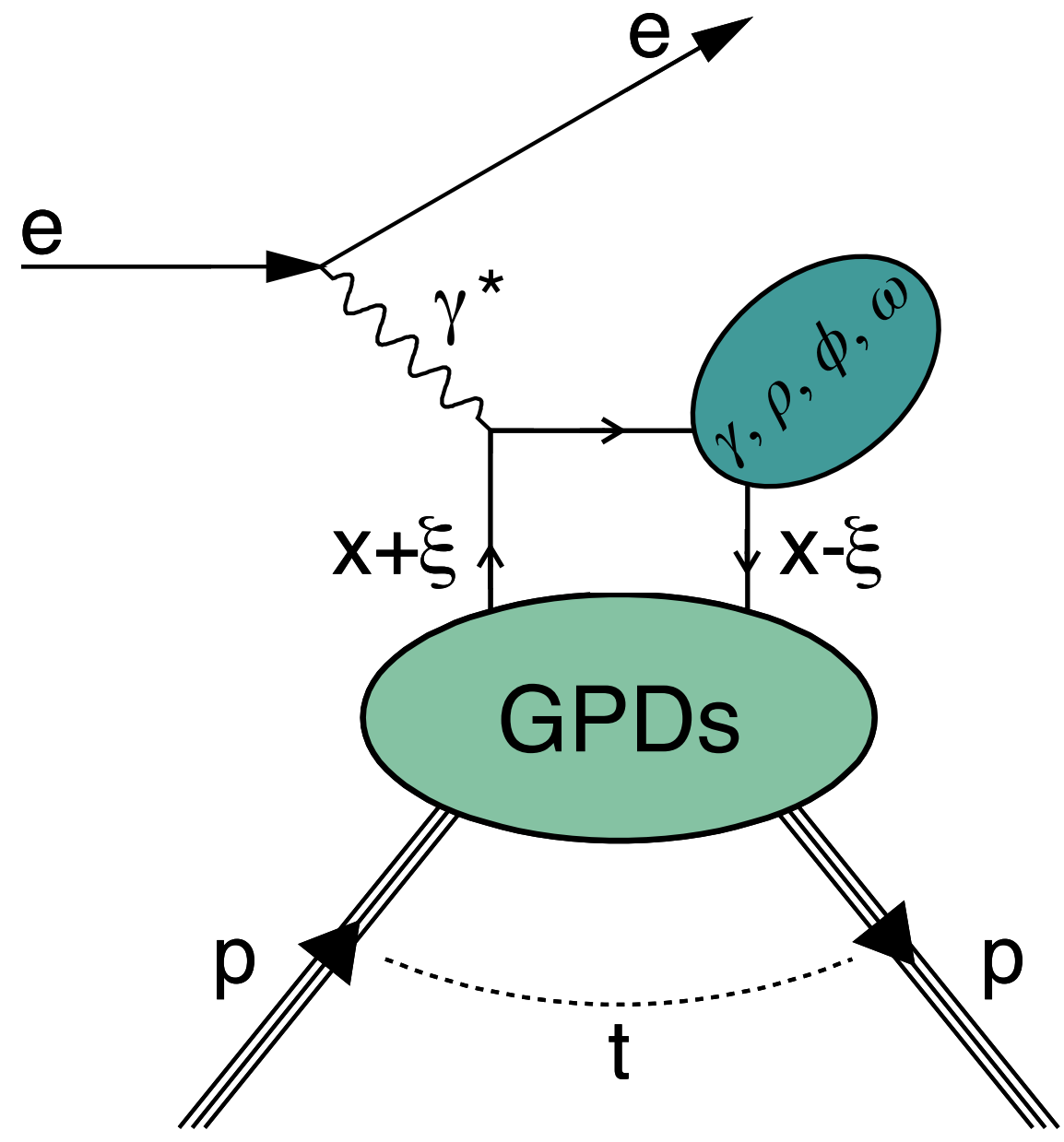


Exclusive meson photoproduction  
Hard scale = large charm/bottom-quark mass

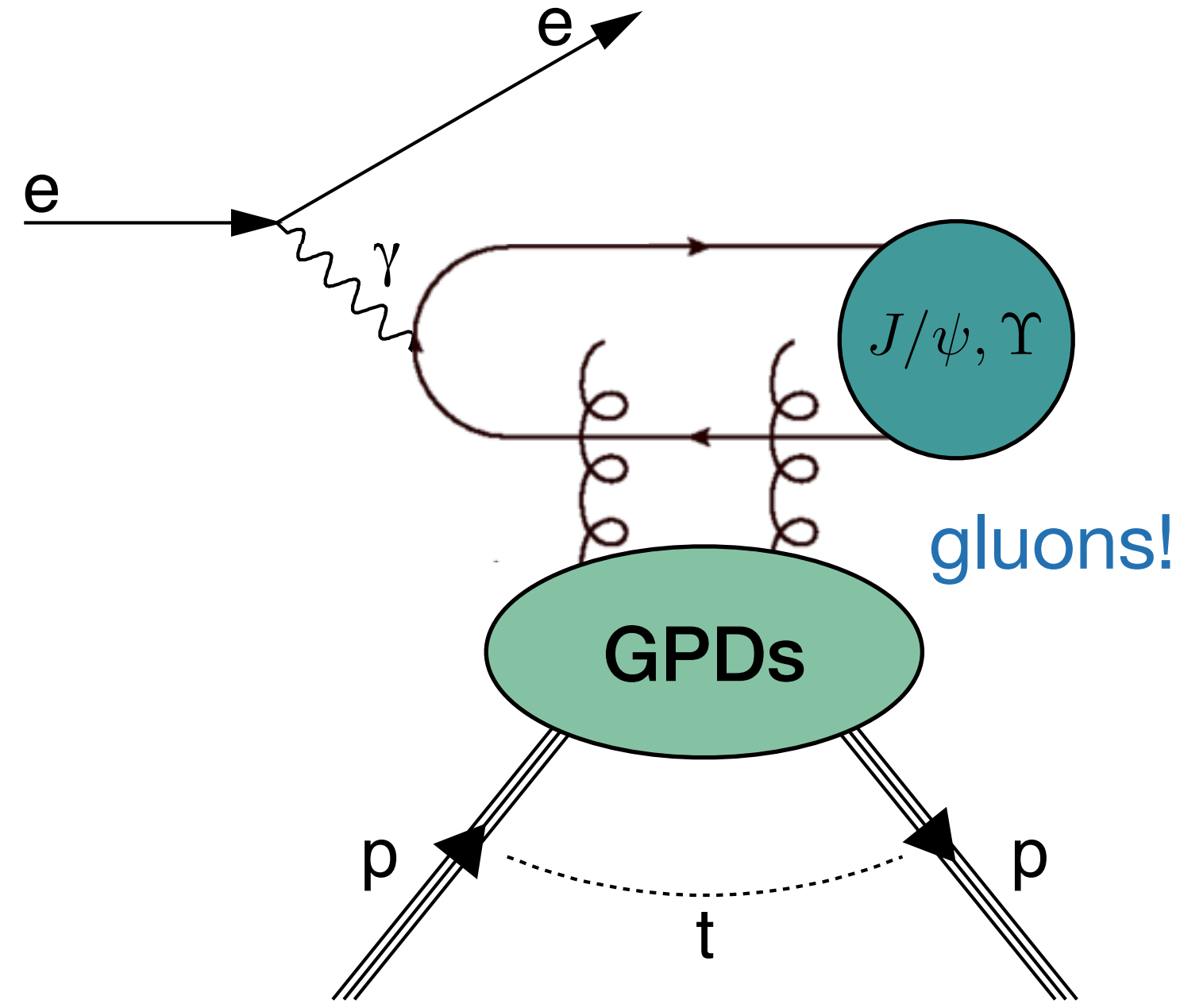
fixed target: medium/large  $x_B$

colliders HERA/EIC: small  $x_B$ , down to  $x_B=10^{-4}$

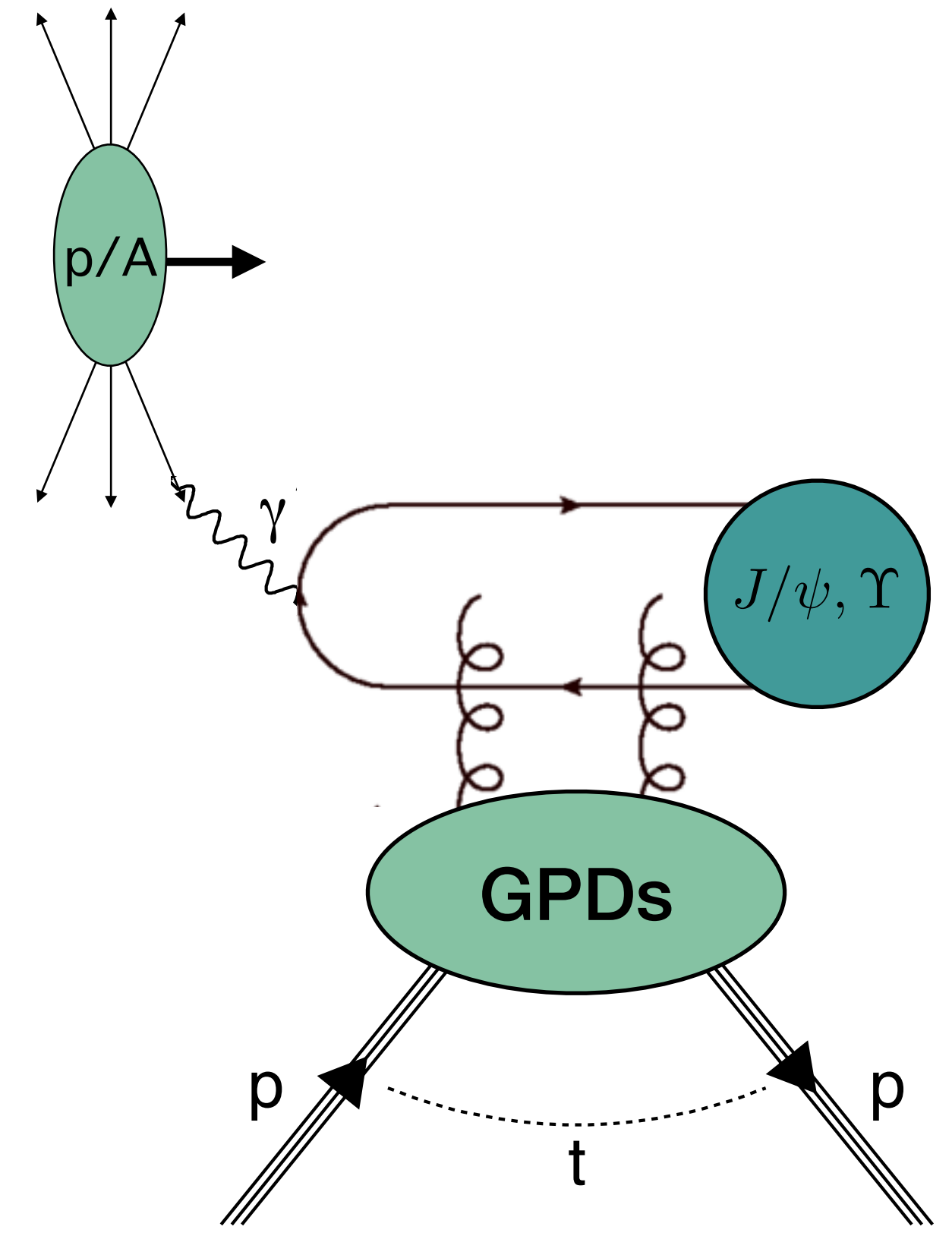
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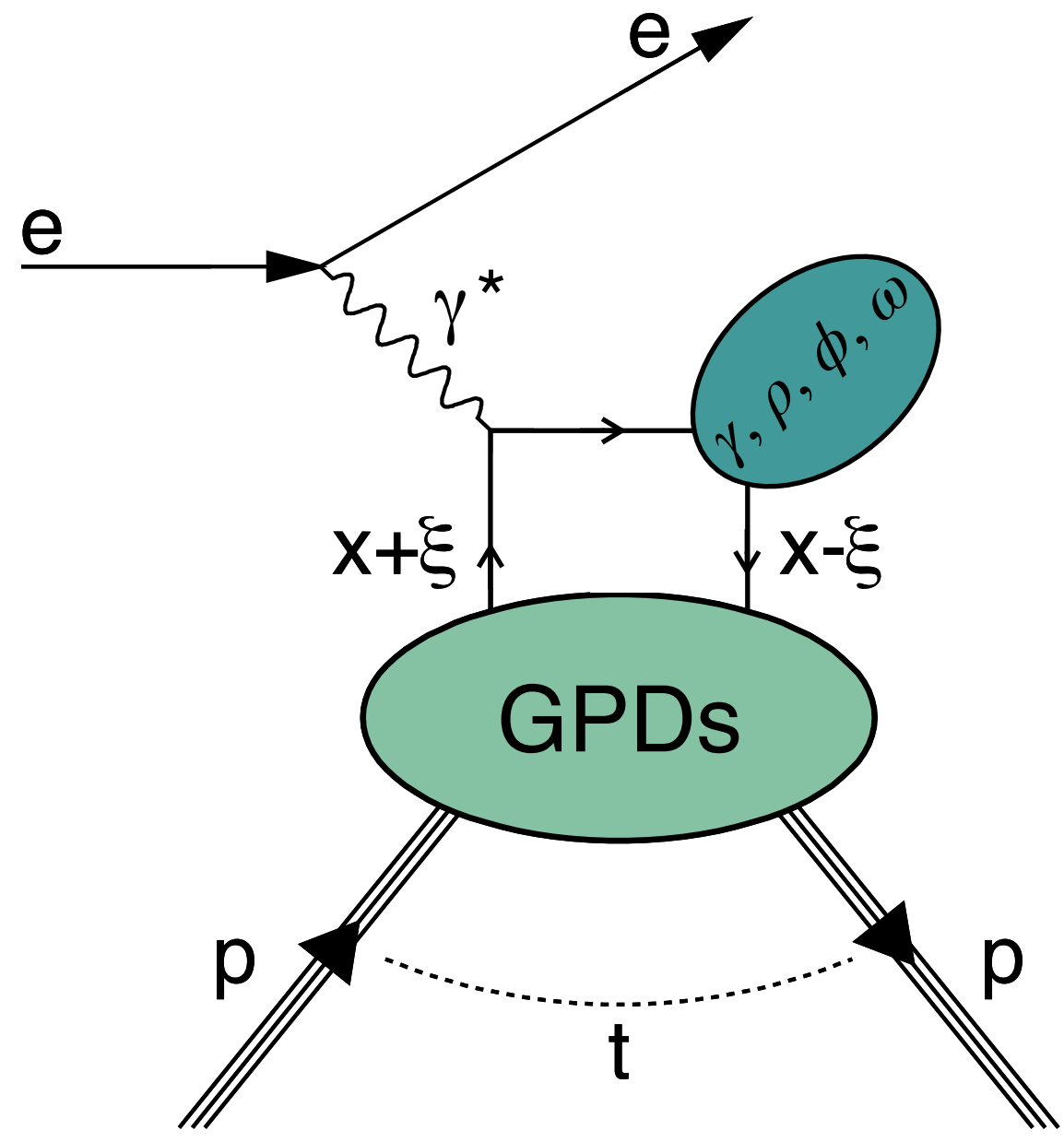


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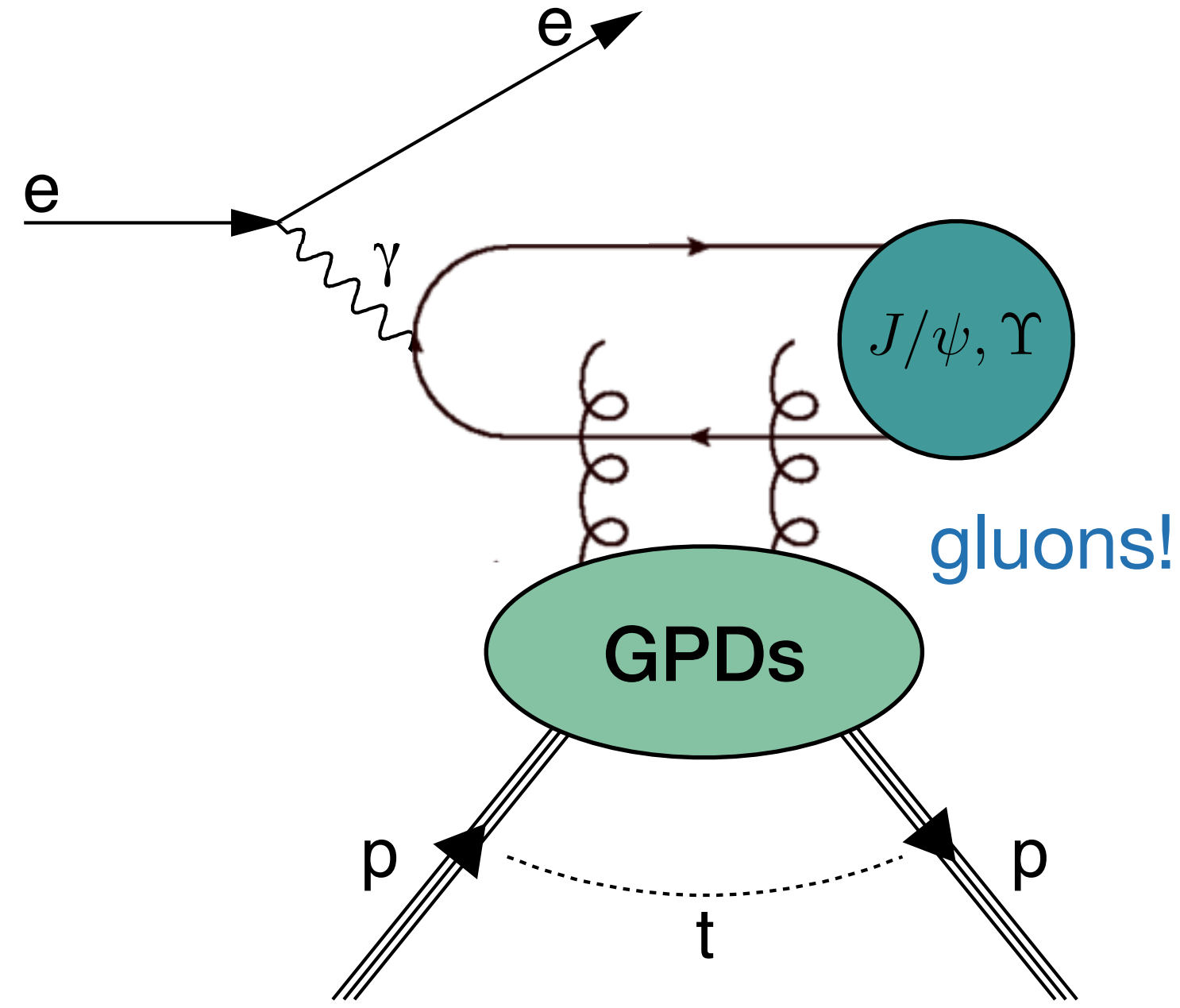
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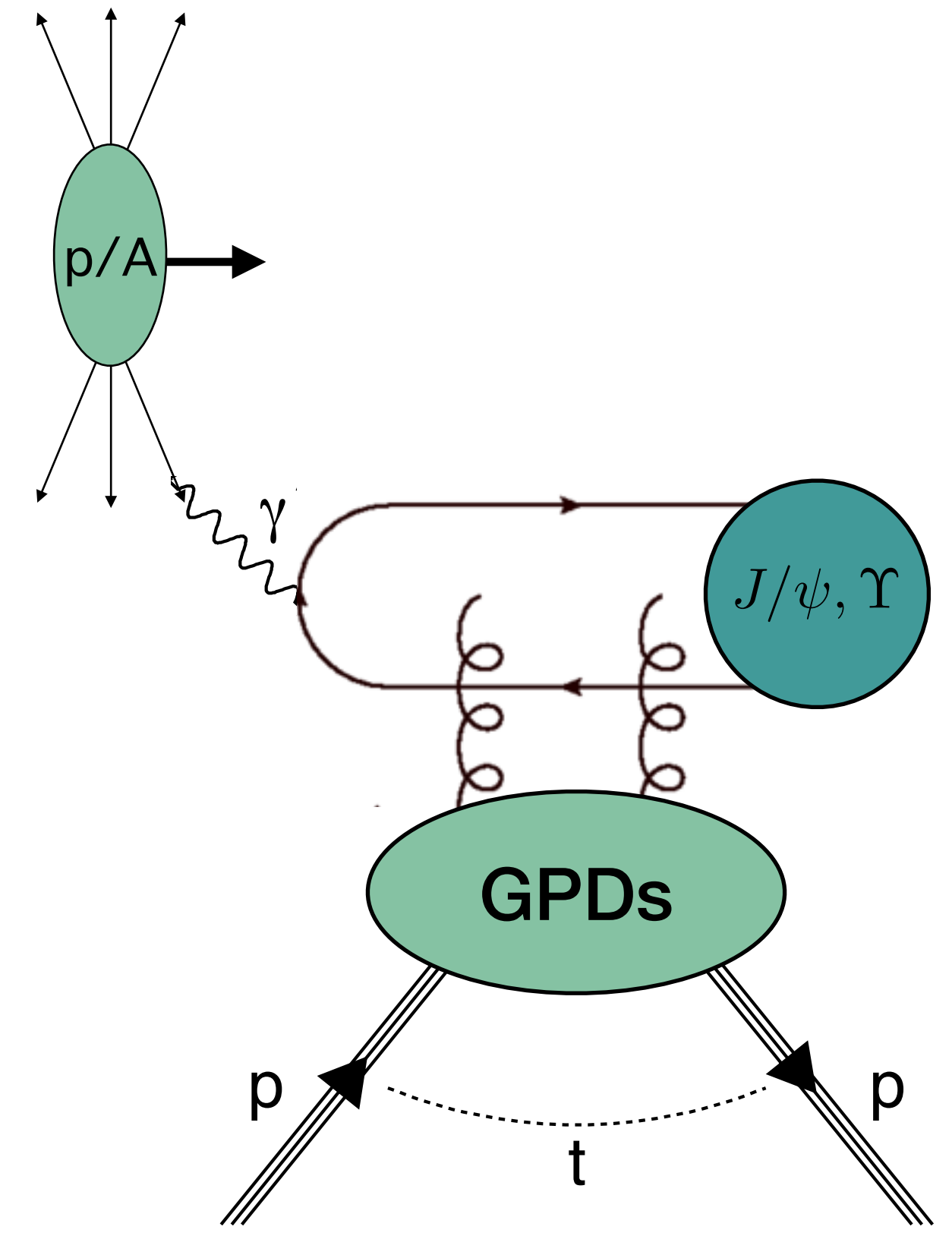
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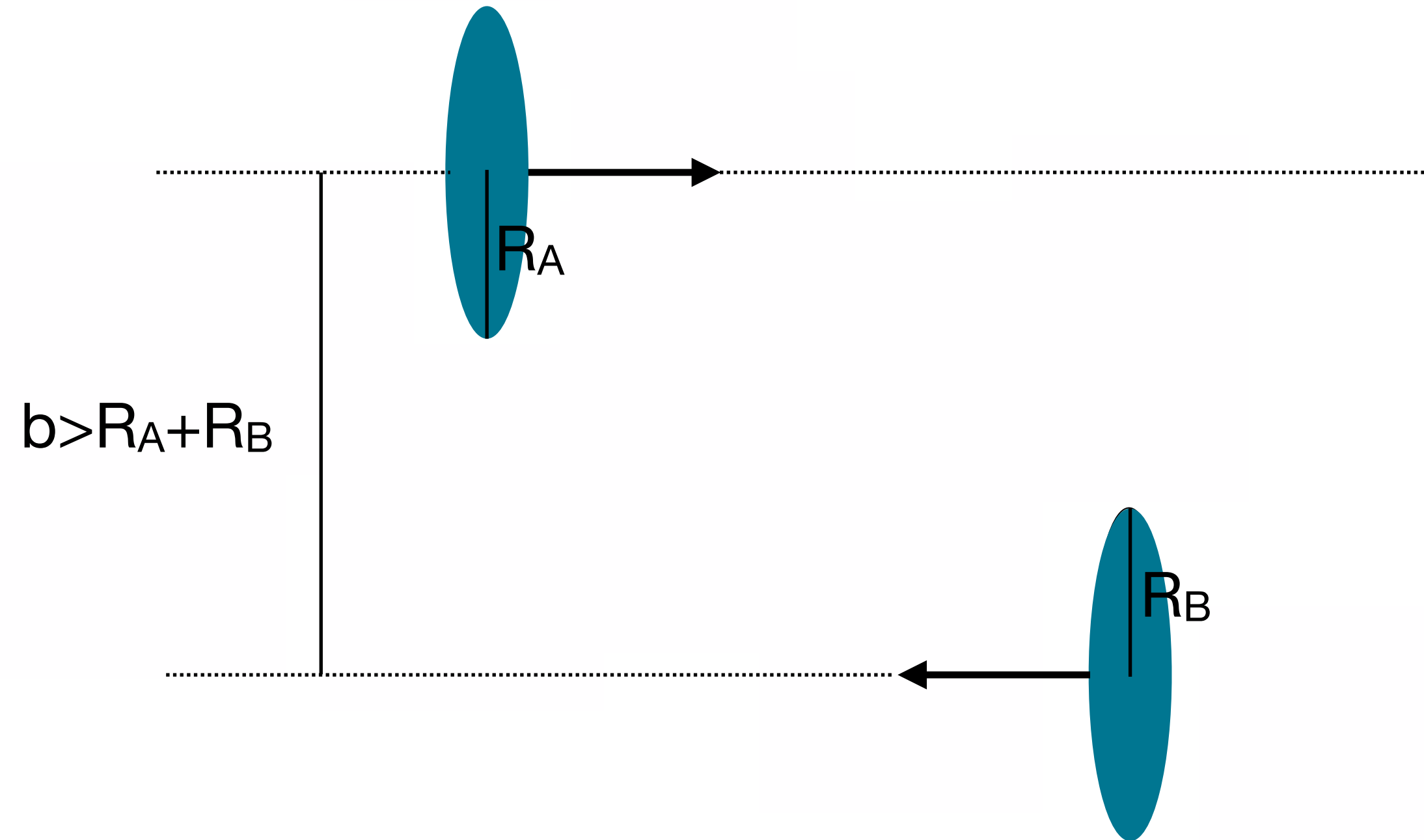
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down to  $x_B=10^{-6}$  at LHC!

# Ultra-peripheral collisions

large-impact-parameter interactions

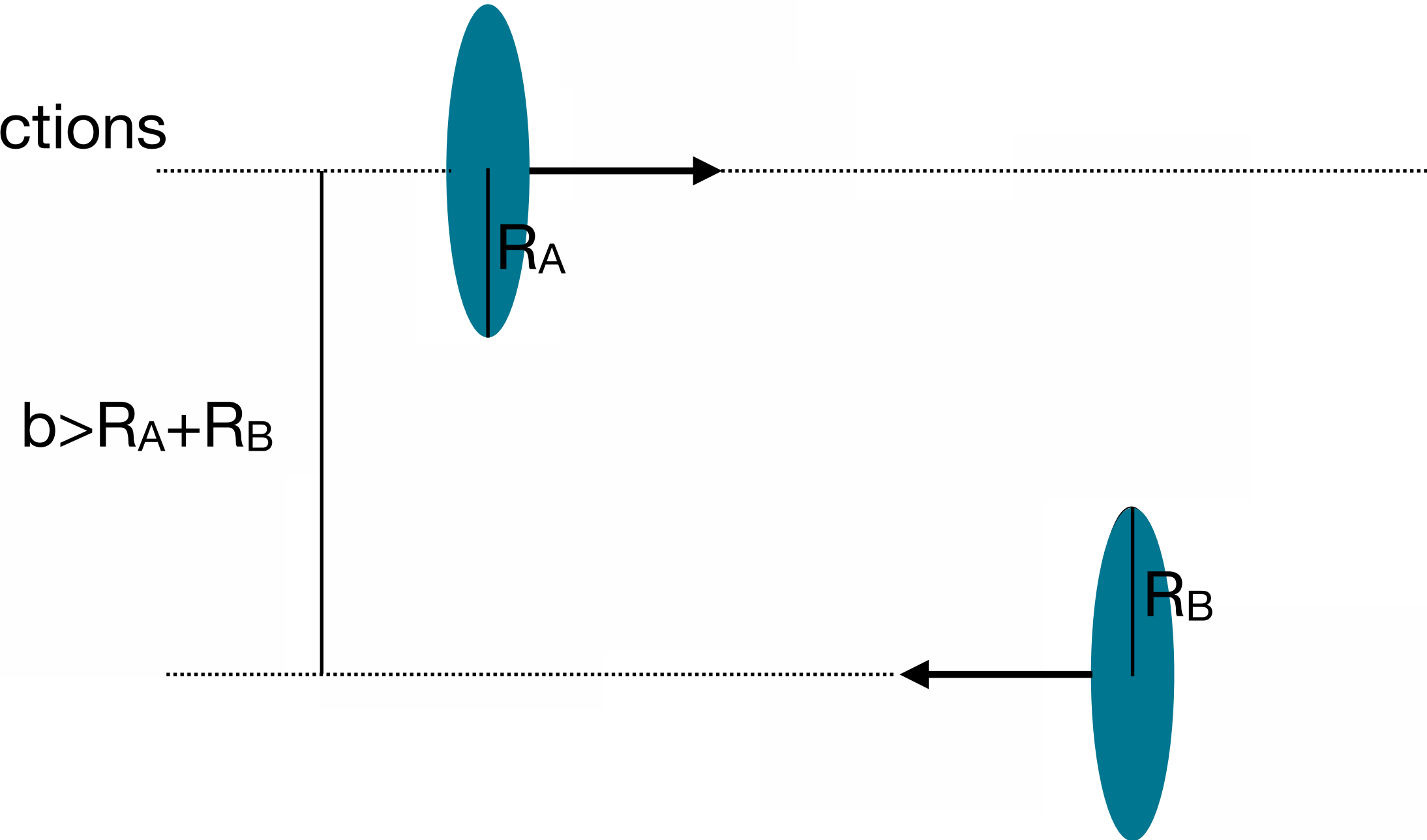


# Ultra-peripheral collisions

large-impact-parameter interactions

hadronic interactions strongly suppressed

instead: electromagnetic interactions

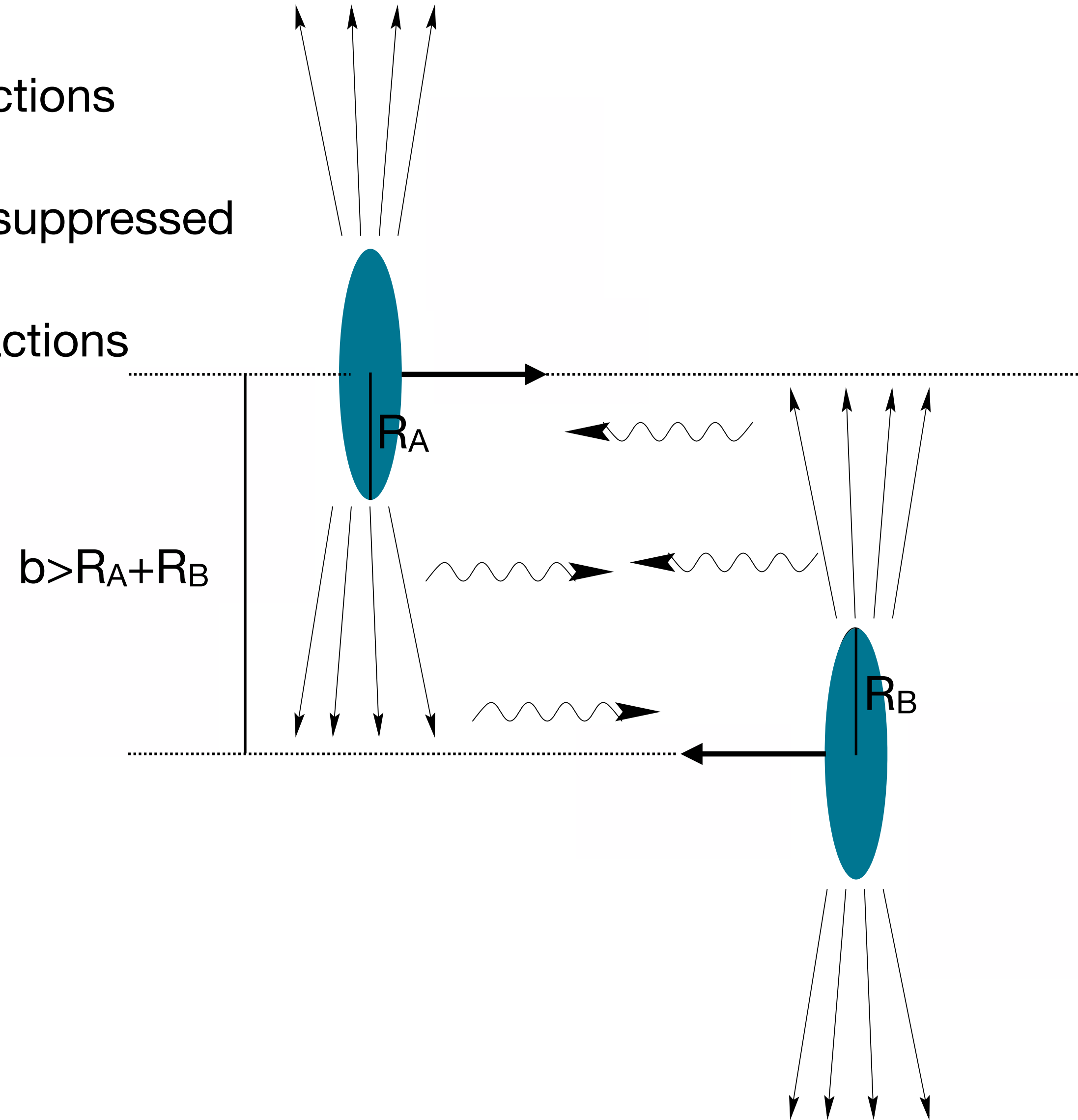


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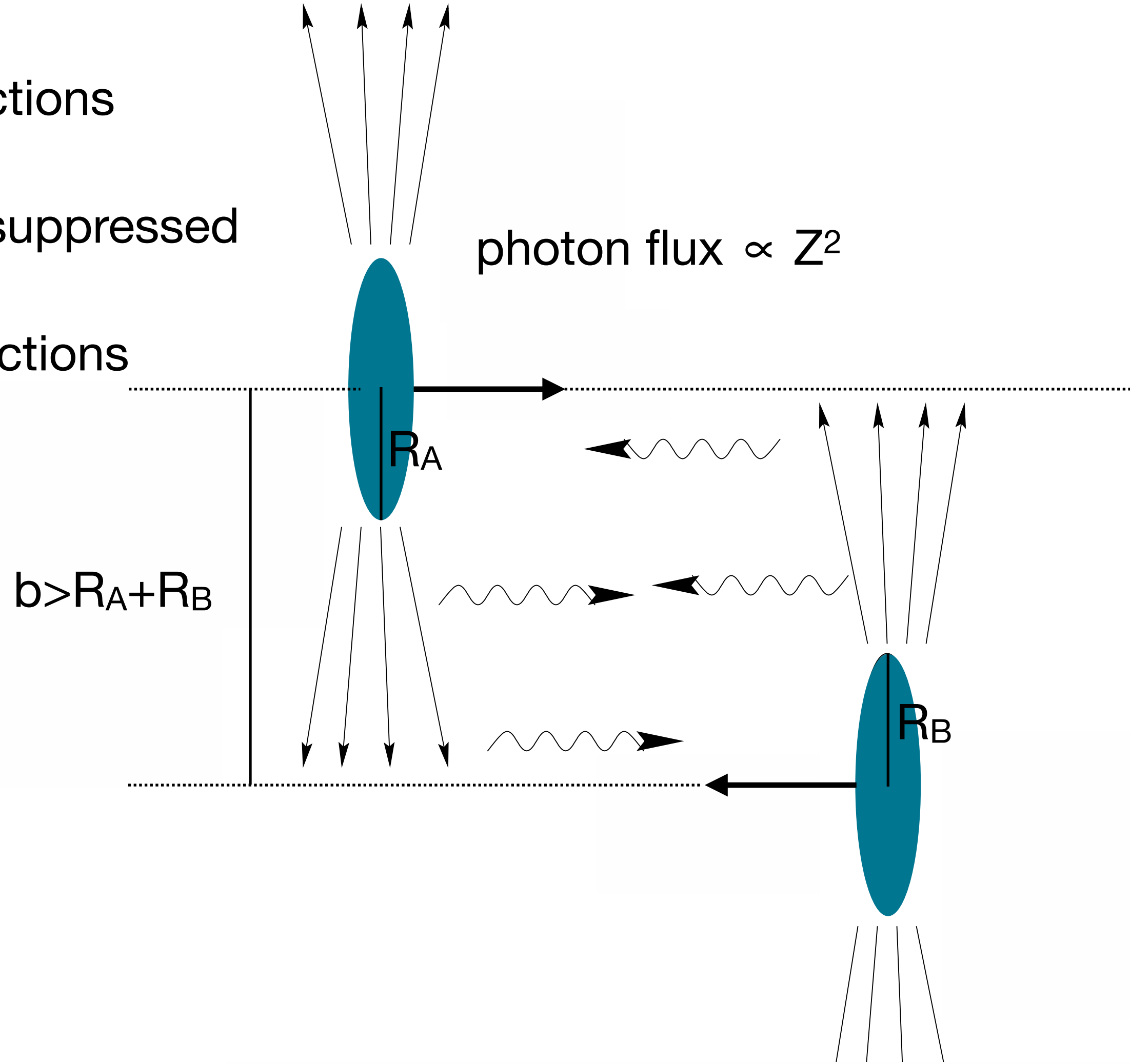


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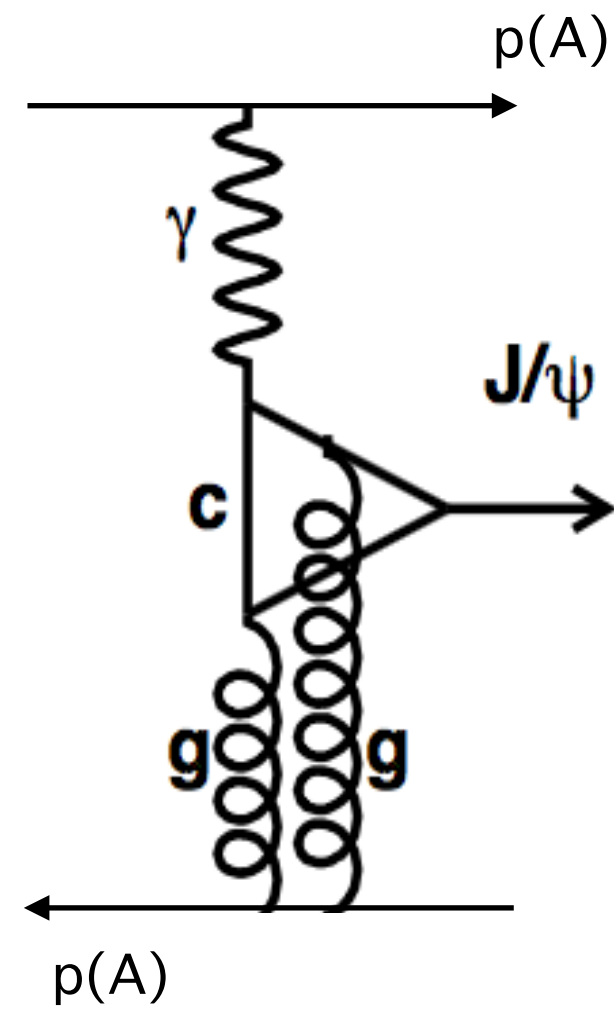
photon virtuality  $Q^2 < \left(\frac{\hbar c}{R_A}\right)^2$

→ quasi-real photons

maximum photon energy =  $\frac{2\gamma\hbar c}{b_{\min}}$

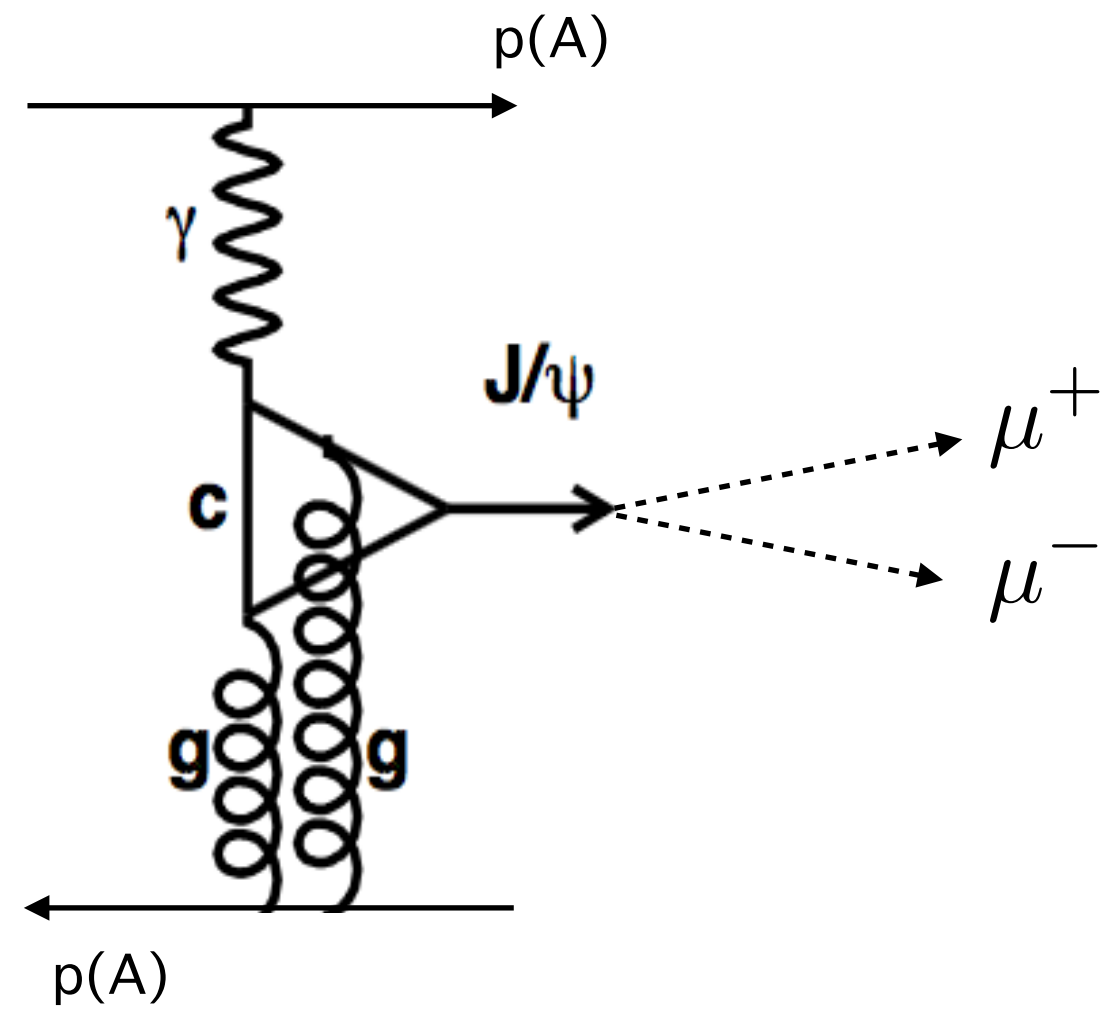
| System | $\sqrt{s_{AB}}$ | $E_A$   | $E_B$     | (a) $\gamma_{A\leftrightarrow B}$ | (b) $E_{\gamma Max}$ | (c) $E_{\gamma Max}^{rest}$ | (d) $W_{\gamma p}^{max}$ |
|--------|-----------------|---------|-----------|-----------------------------------|----------------------|-----------------------------|--------------------------|
| pPb    | 5.02 TeV        | 4 TeV   | 1.567 TeV | $1.43 \times 10^7$                | 28 MeV               | 0.4 PeV                     | 0.86 TeV                 |
| pPb    | 8.16 TeV        | 6.5 TeV | 2.56 TeV  | $3.78 \times 10^7$                | 28 MeV               | 1 PeV                       | 1.4 TeV                  |
| pp     | 13 TeV          | 6.5 TeV | 6.5 TeV   | $9.6 \times 10^7$                 | 116 MeV              | 11 PeV                      | 4.6 TeV                  |

# Measurement of exclusive production at LHCb

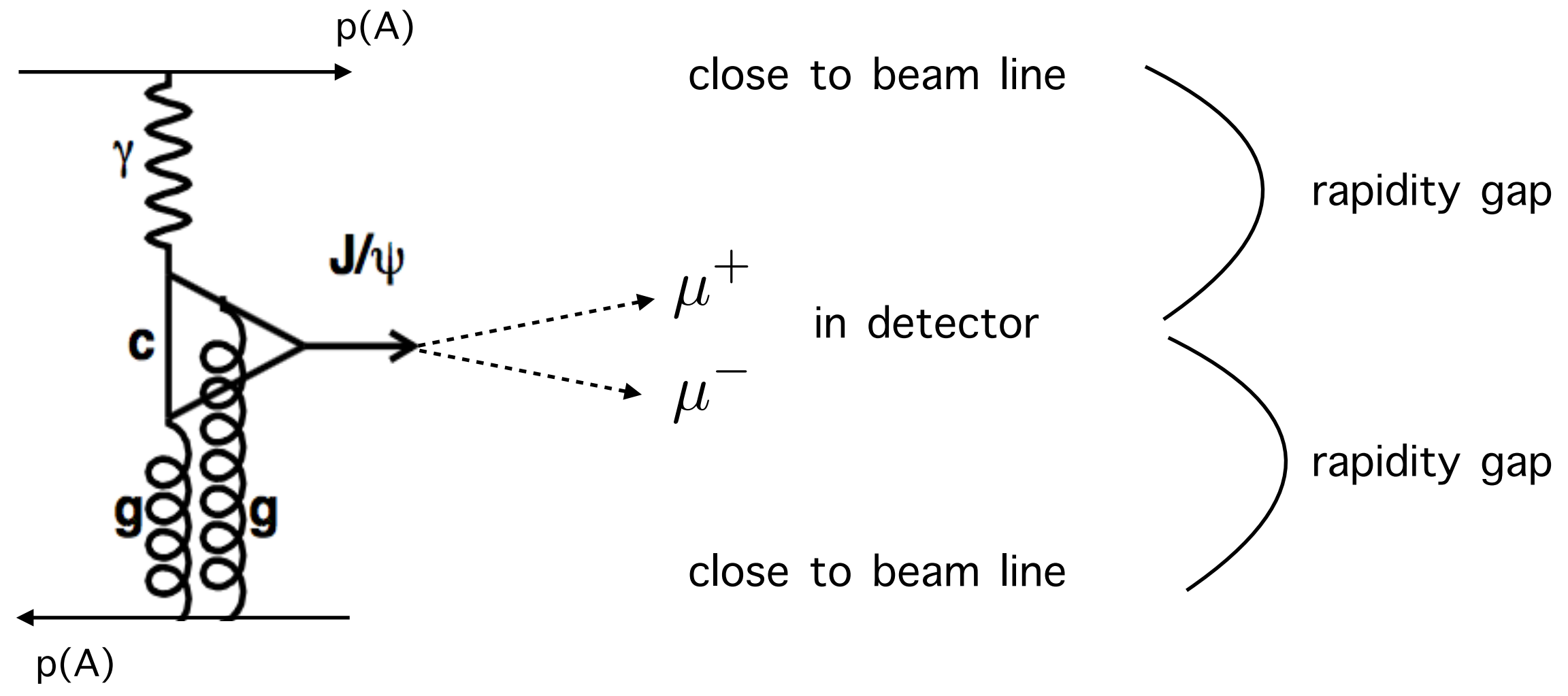




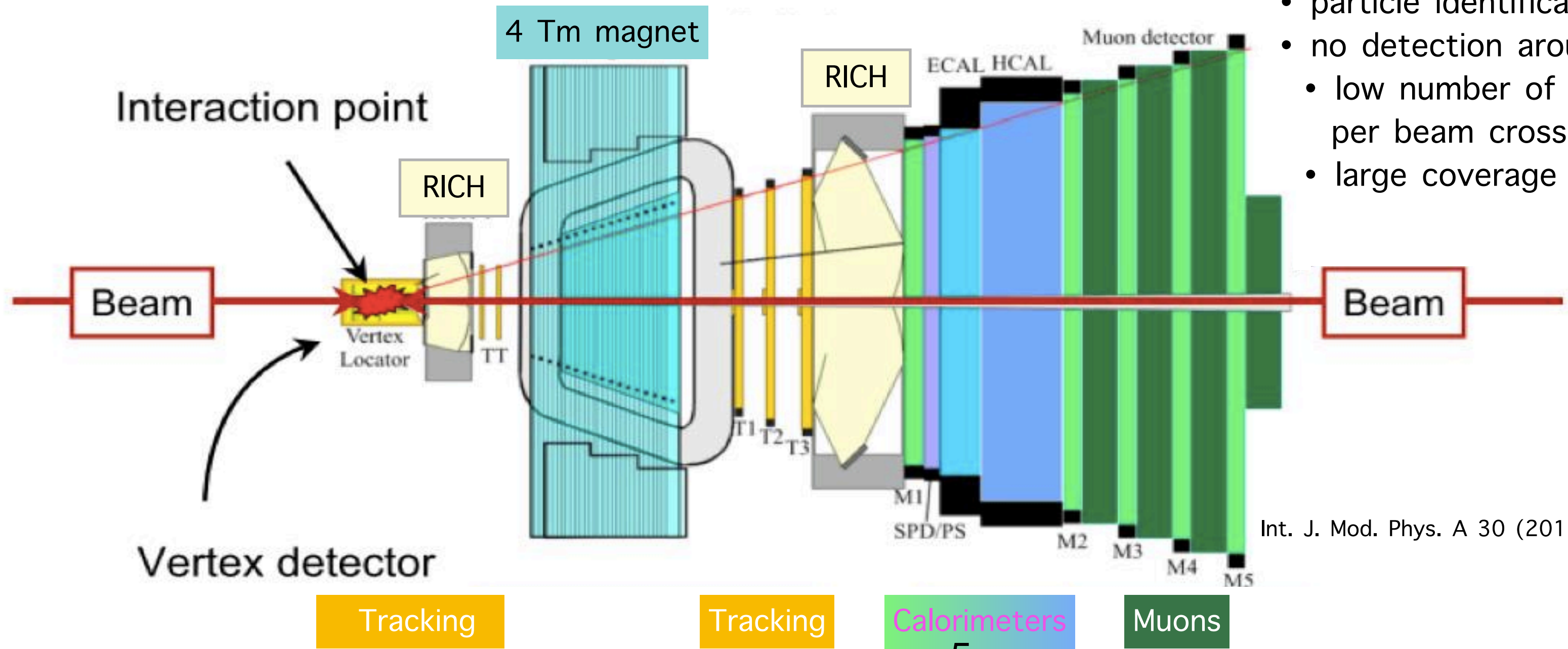
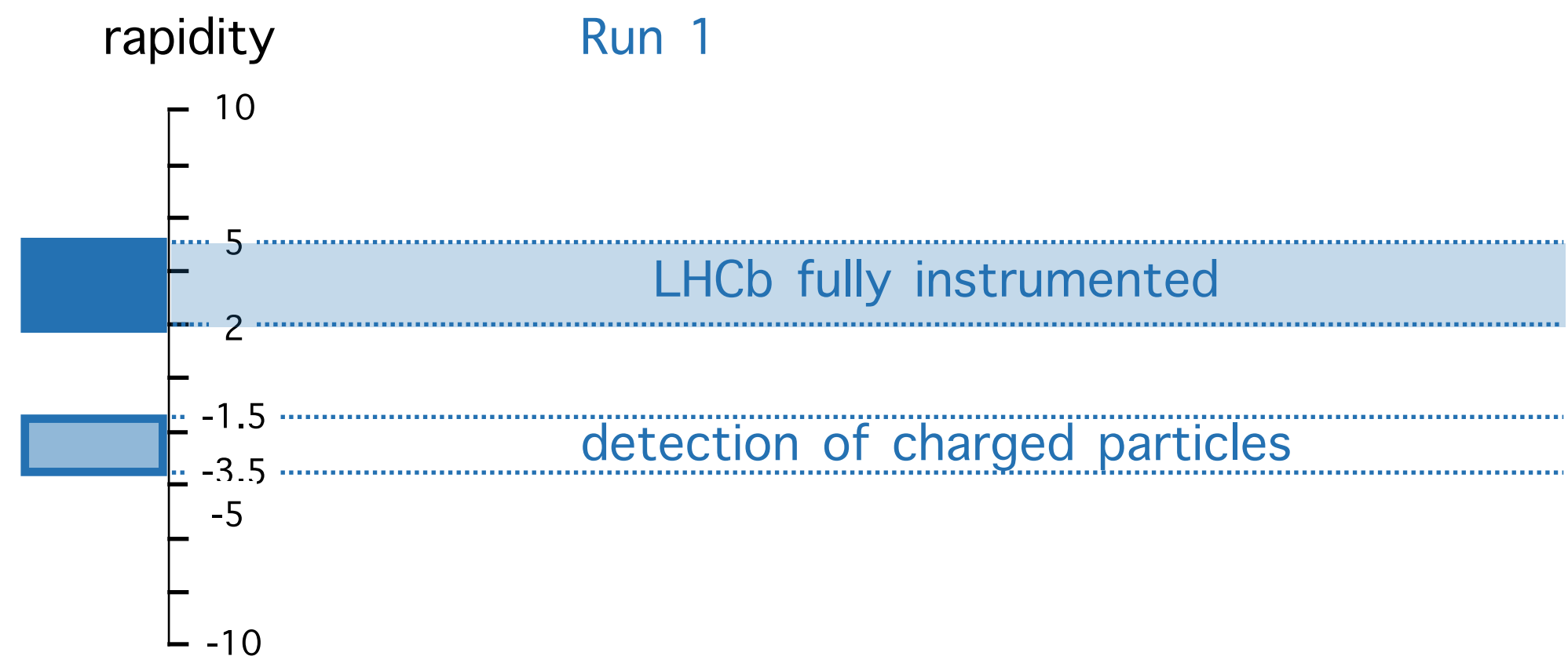
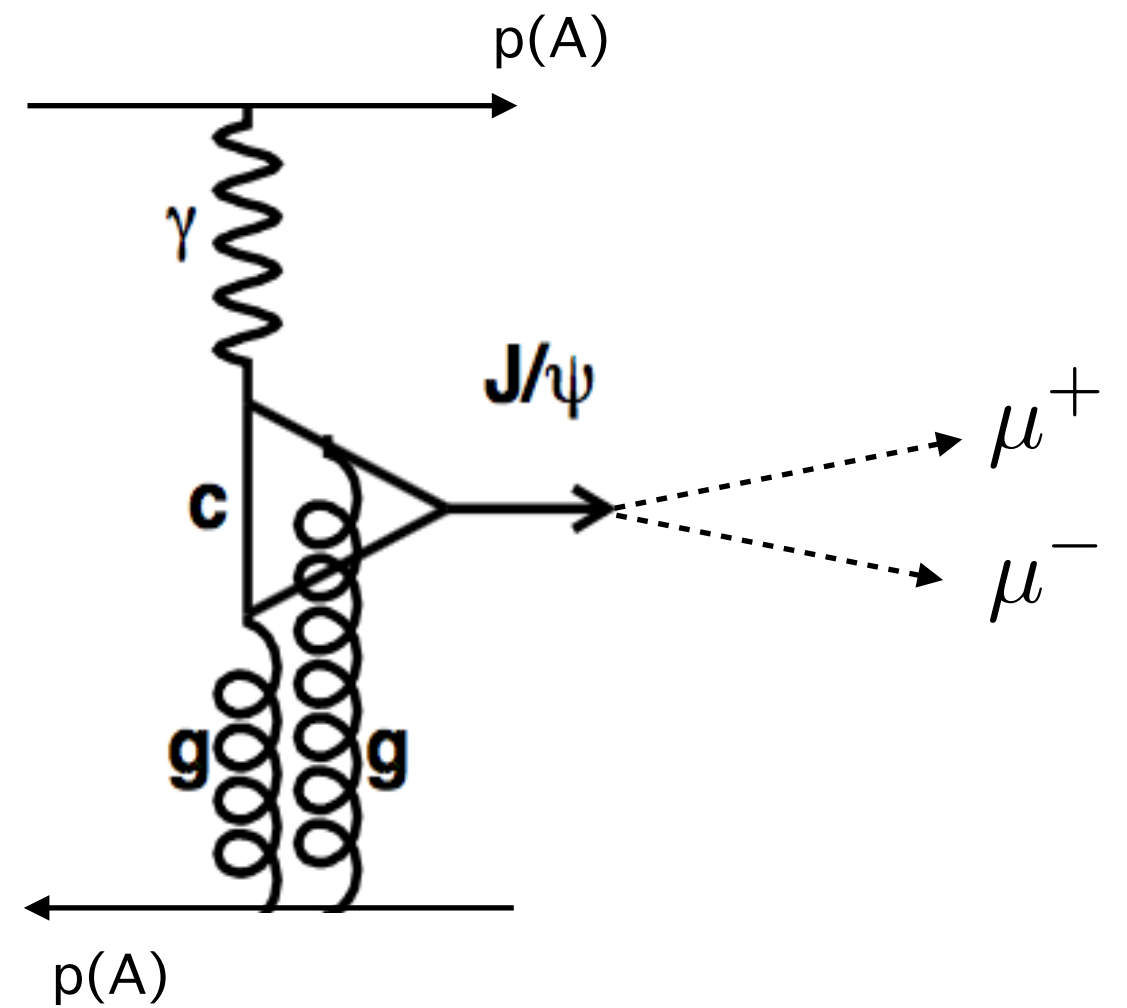
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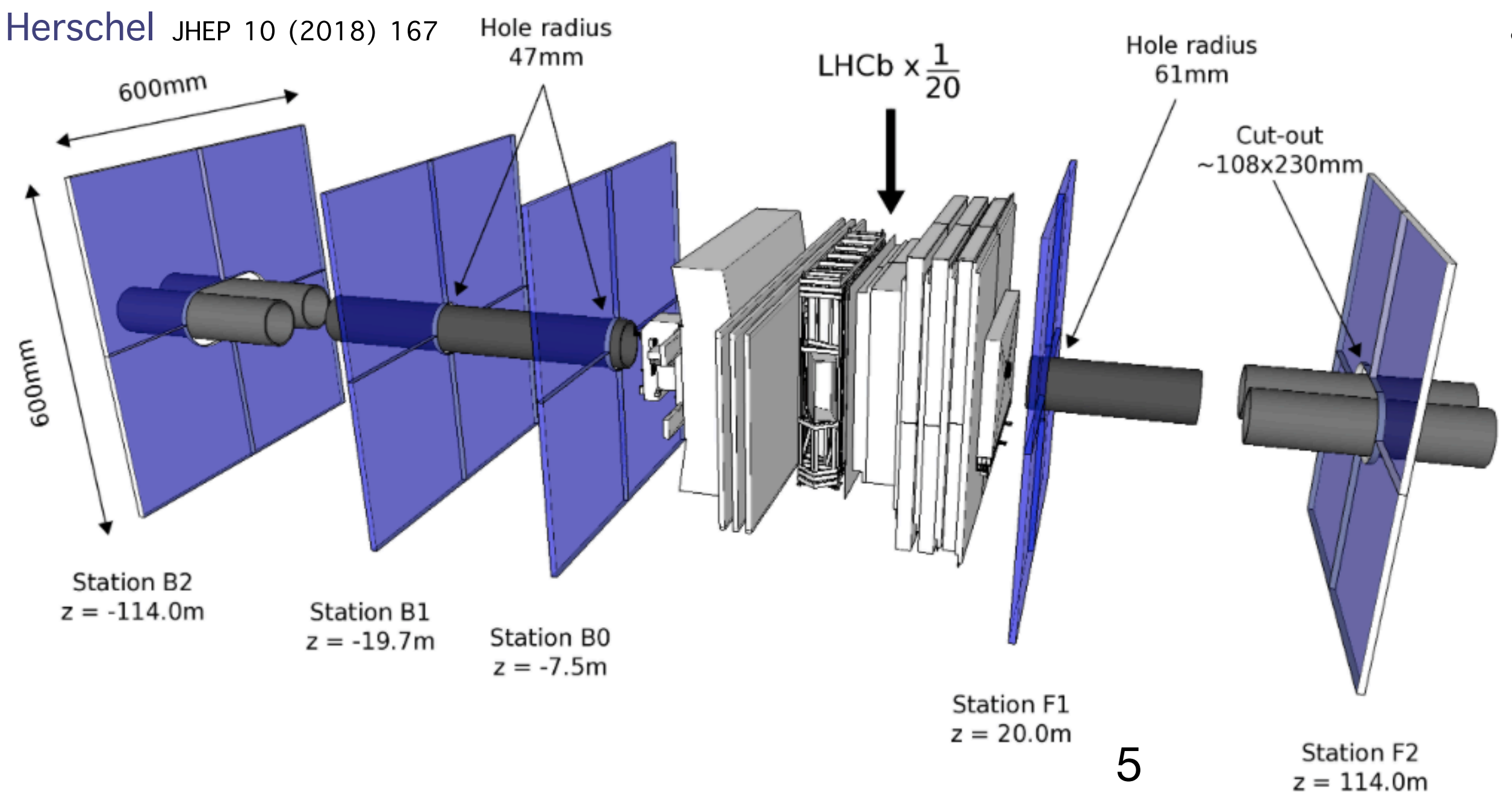
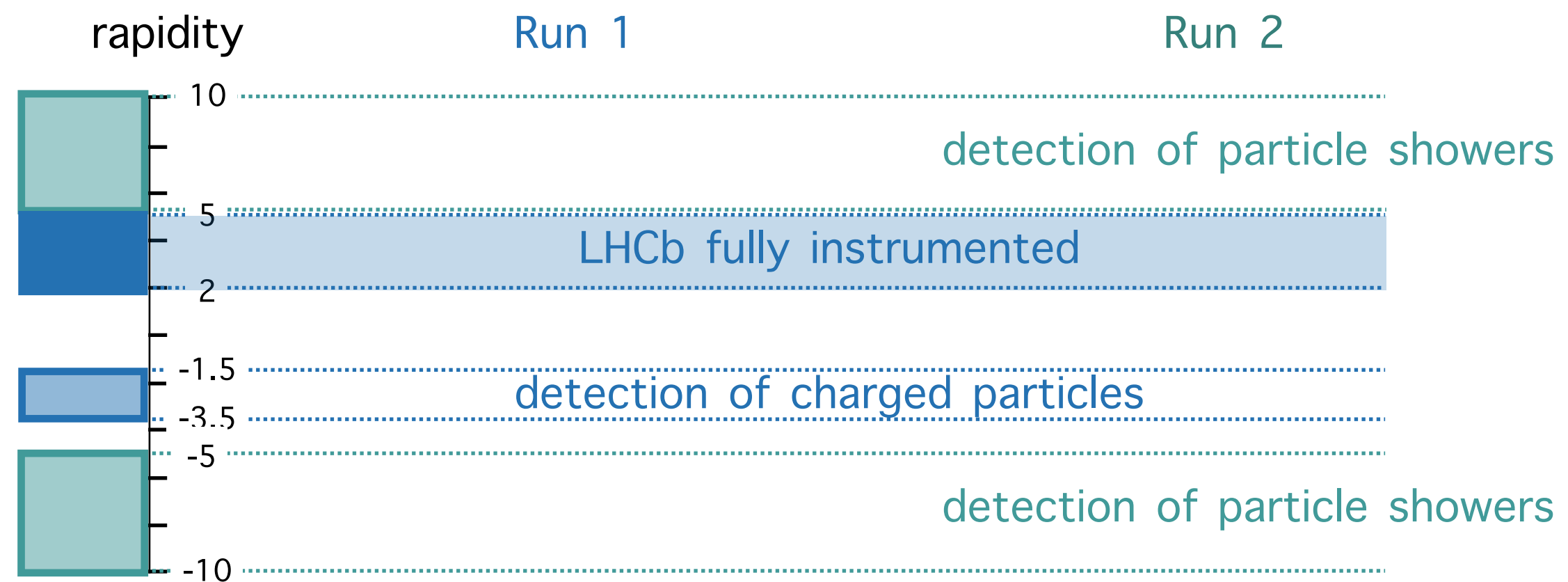
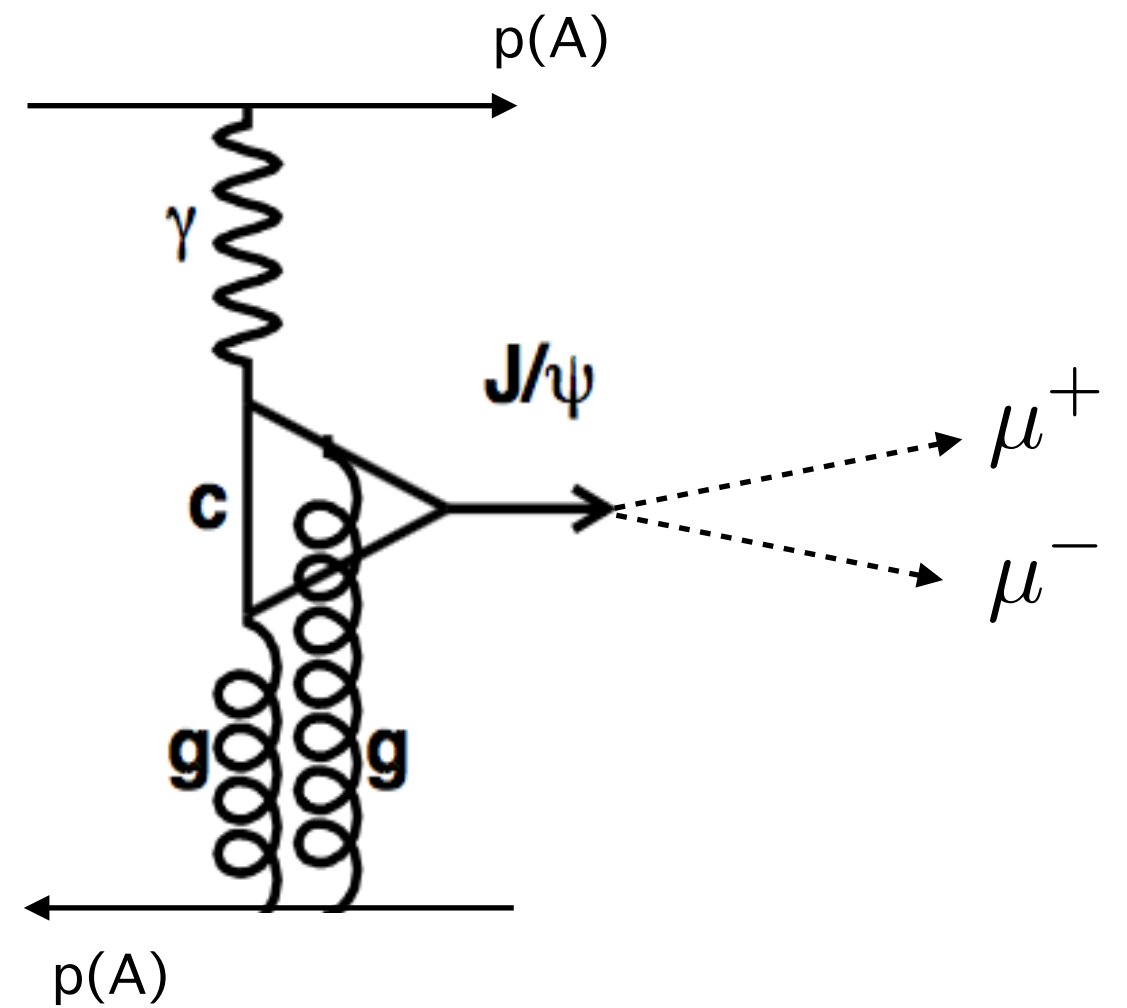
# Measurement of exclusive production at LHCb



- 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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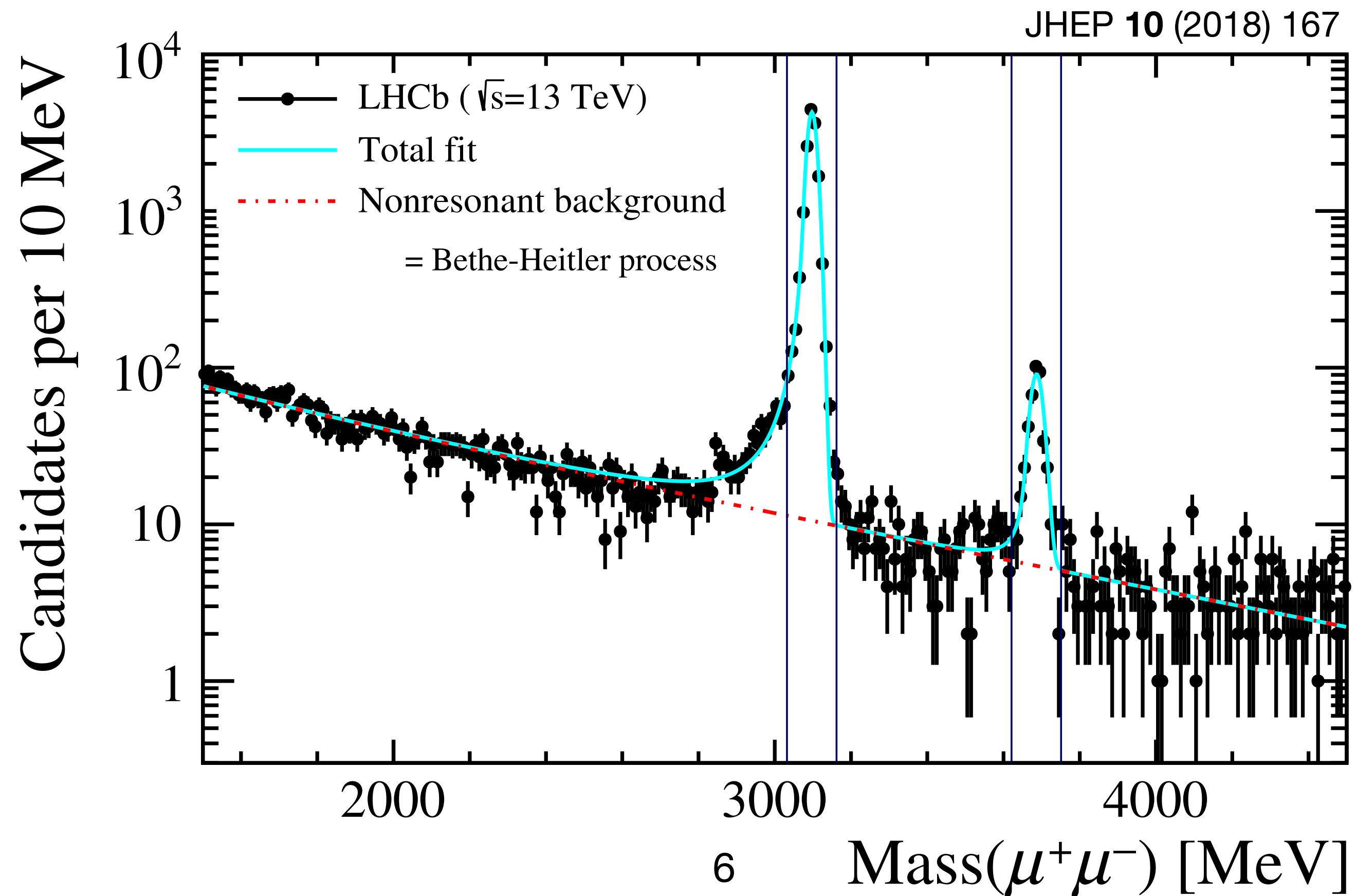
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# Exclusive single $\psi$ production in pp collisions

- Exclusive  $J/\psi$  and  $\psi(2S)$ :  $\sqrt{s} = 7$  TeV and part of  $\sqrt{s} = 13$  TeV data (from 2015)
  - $x_B$  down to  $2 \times 10^{-6}$
- Reconstruction via dimuon decay, with  $2 < \eta < 4.5$ .
- No other detector activity.
- Quarkonia  $J/\psi$  and  $\psi(2S)$ :  $2 < y < 4.5$  and  $p_T^2 < 0.8 \text{ GeV}^2$

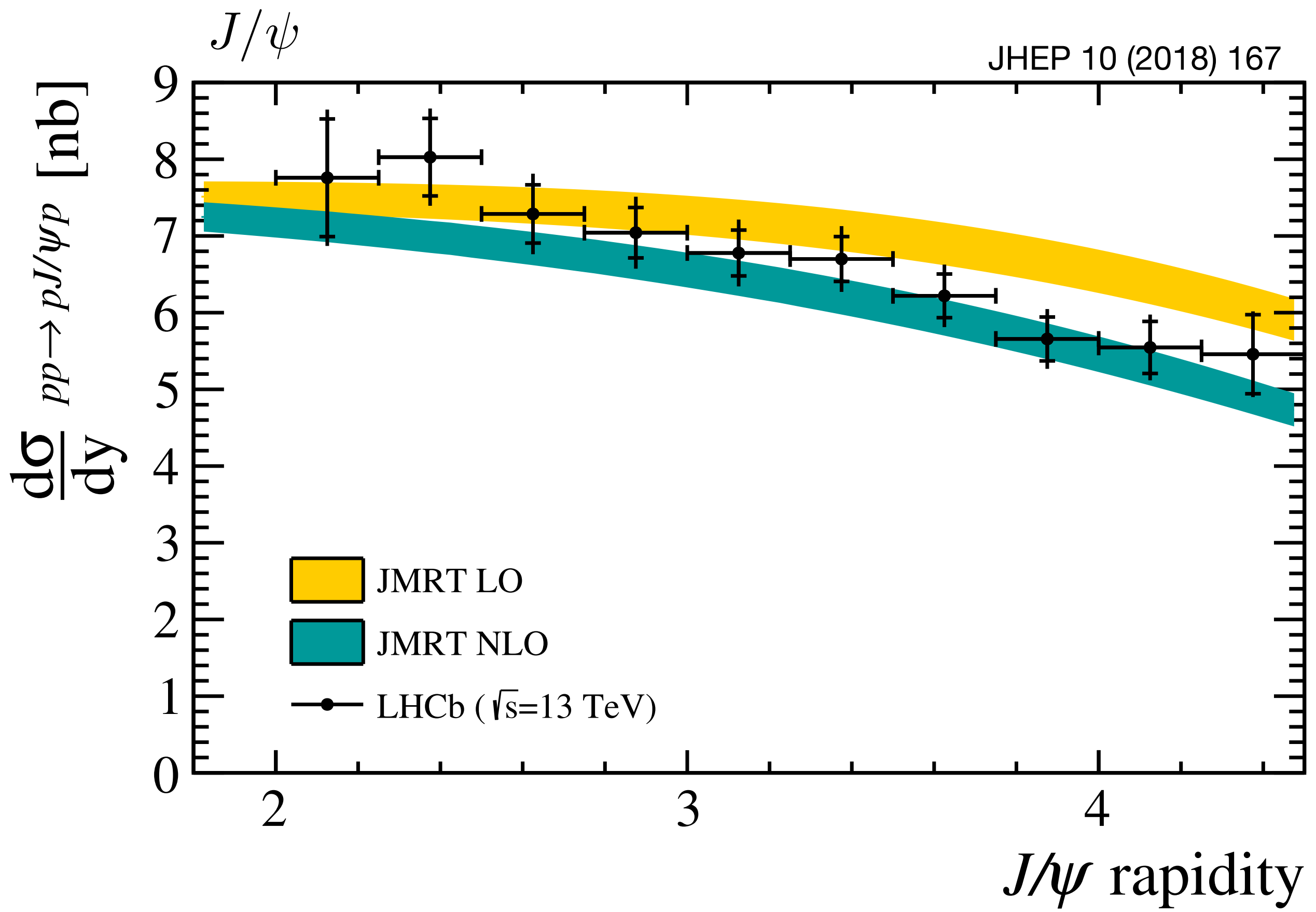
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# pp cross section



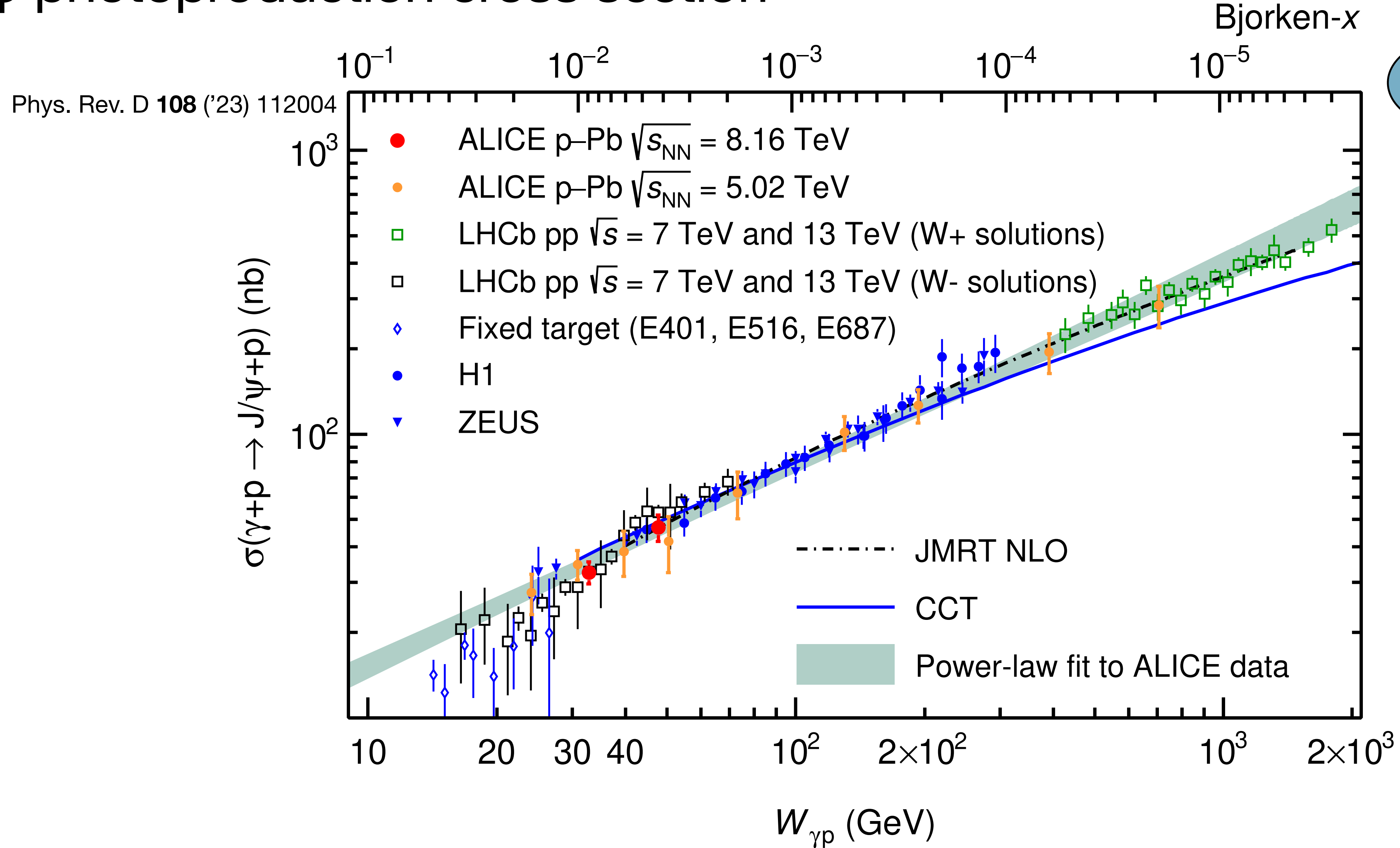
JMRT prediction, based on gluon PDF:

At low  $x_B$ , approximate GPD to gluon PDF

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

Z. Phys. C57 ('93) 89–92;  
arXiv:1609.09738

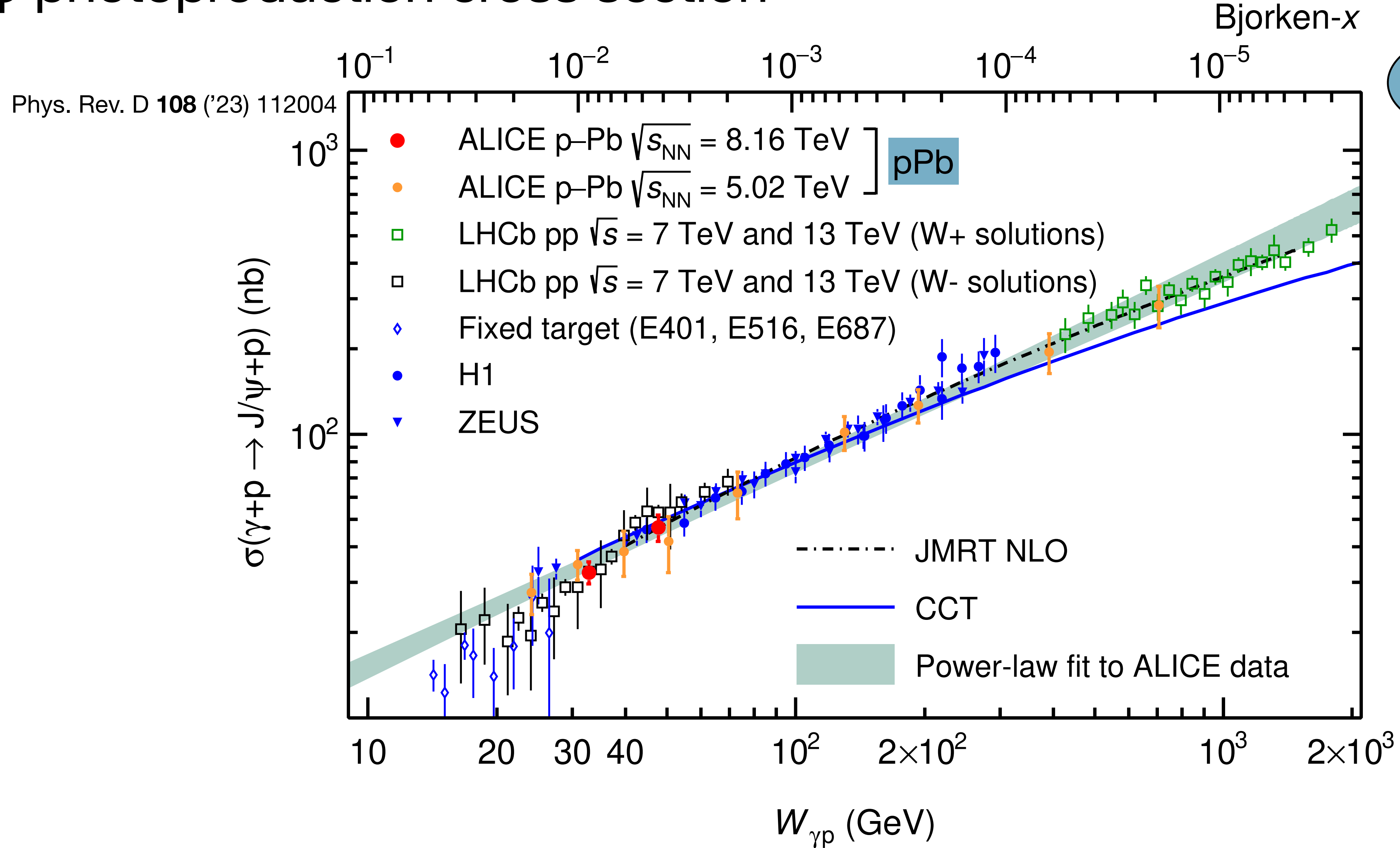
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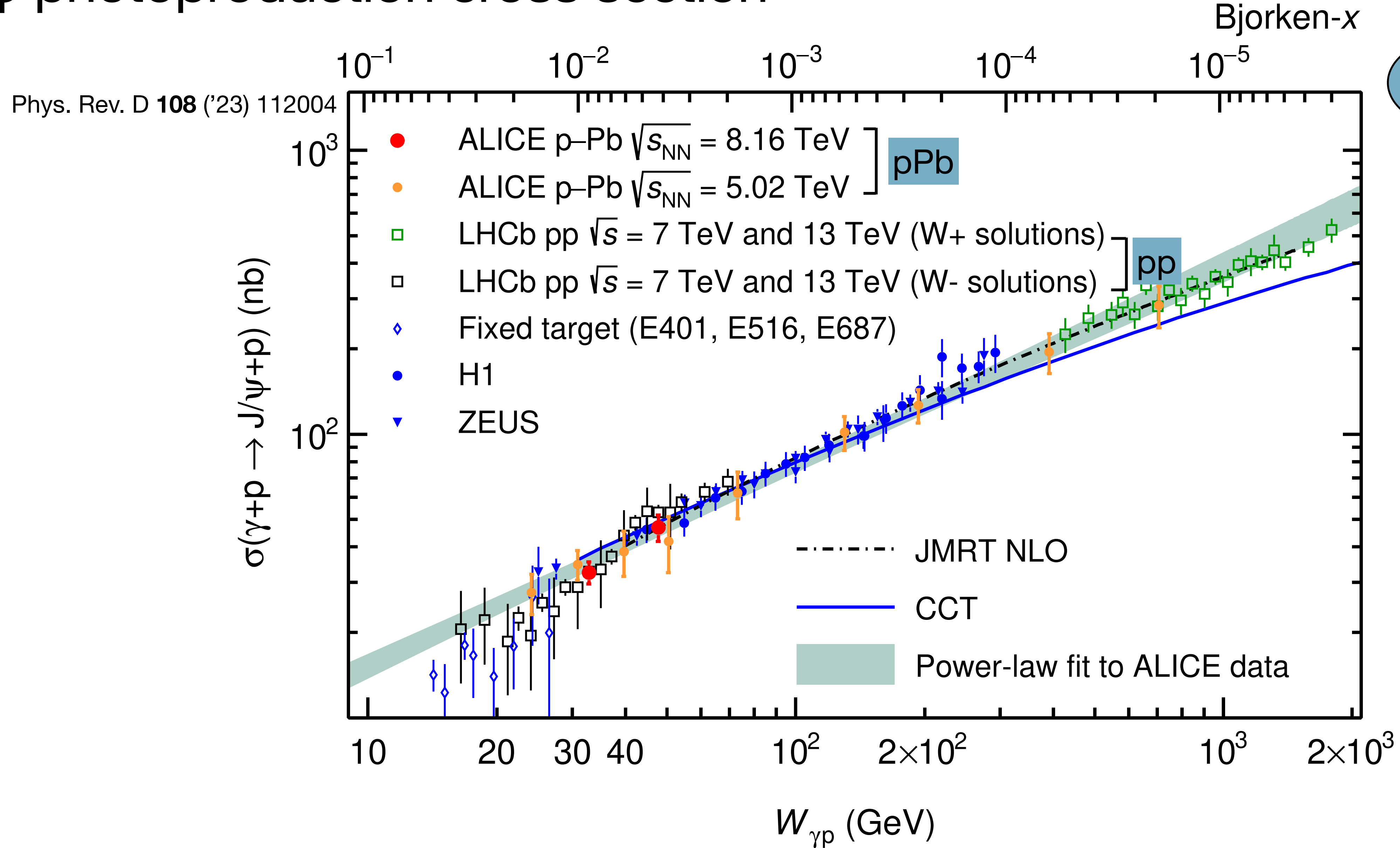
GPD H



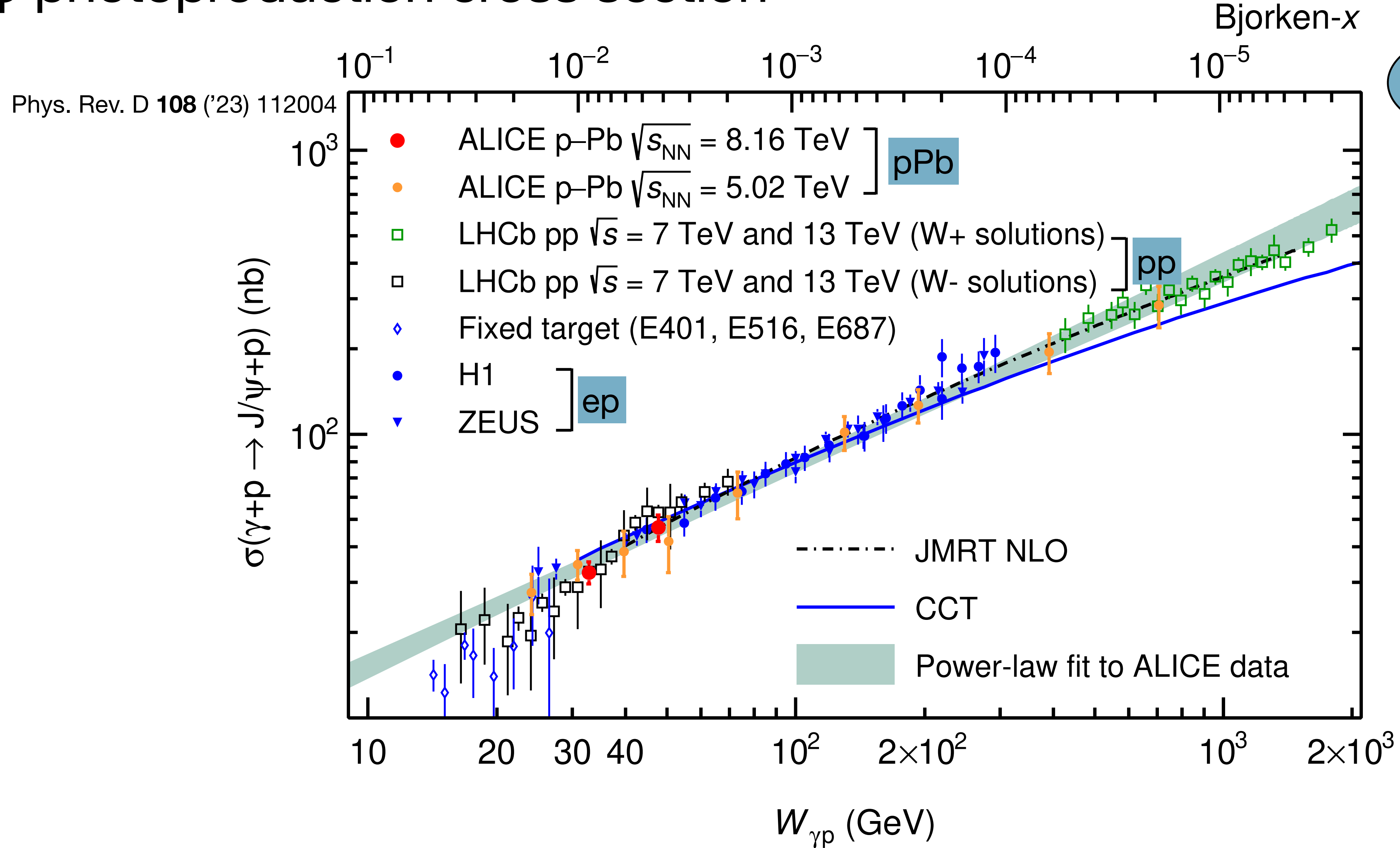
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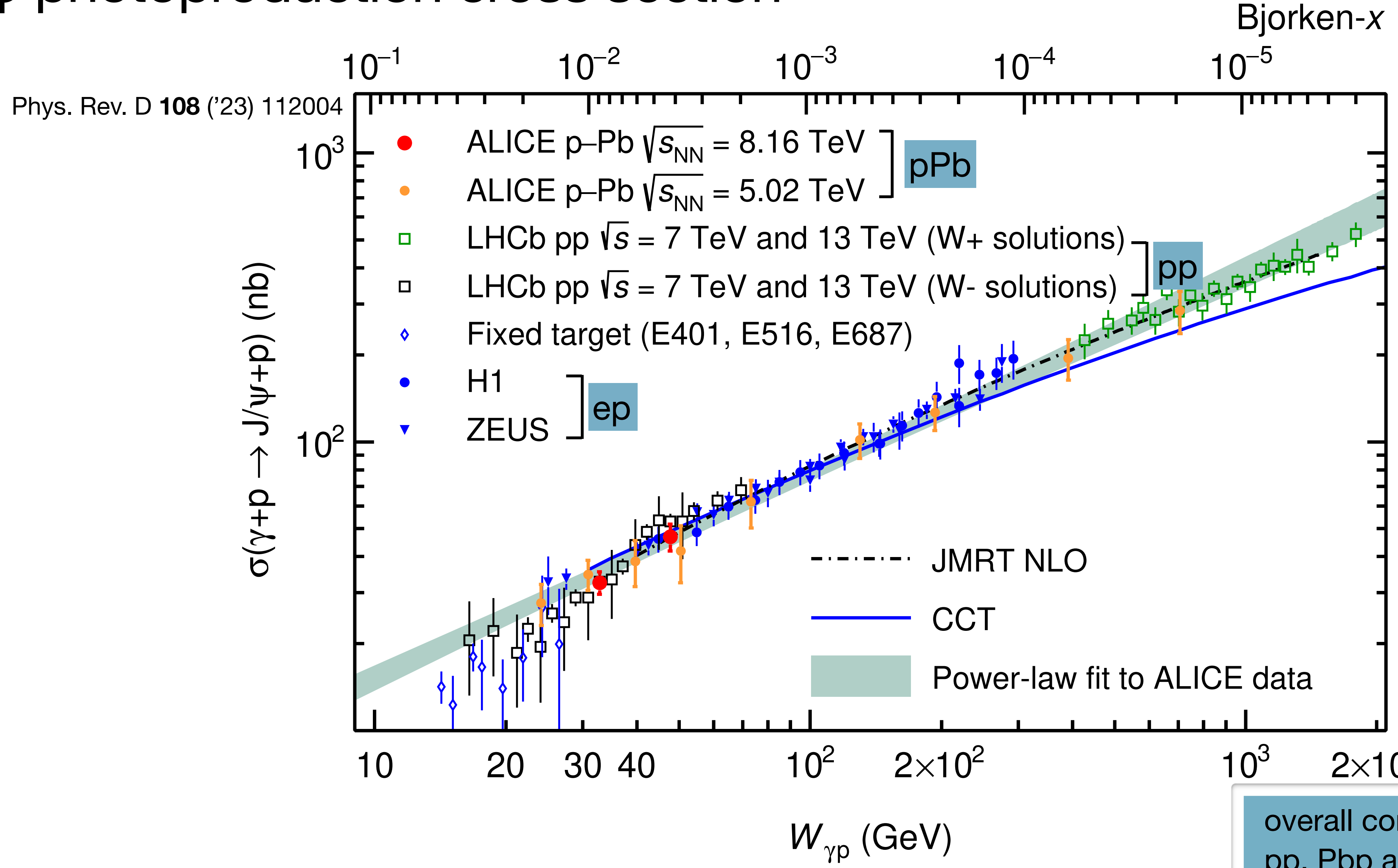
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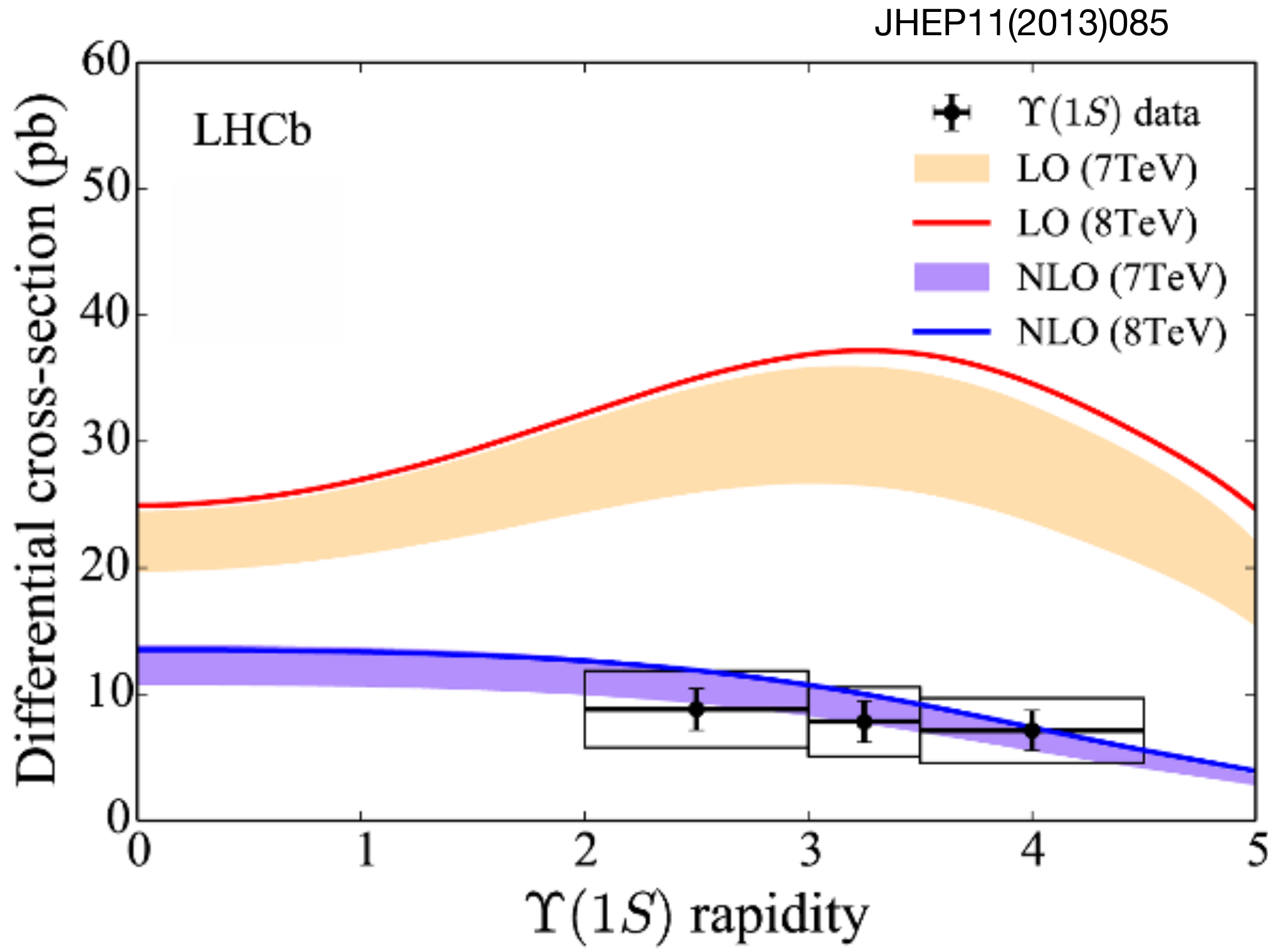
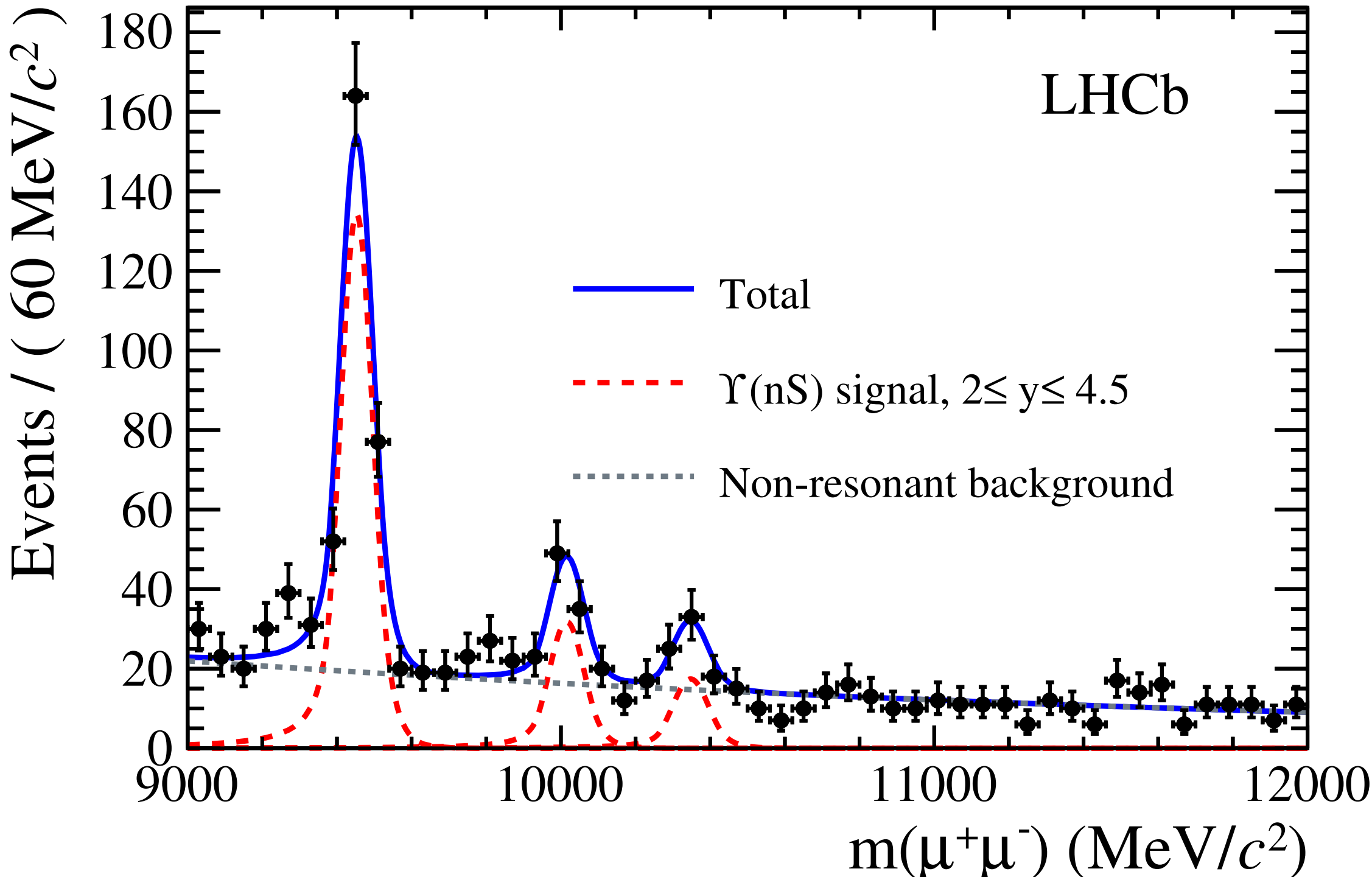
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GPD H

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

# Exclusive single $\Upsilon$ production in pp collisions



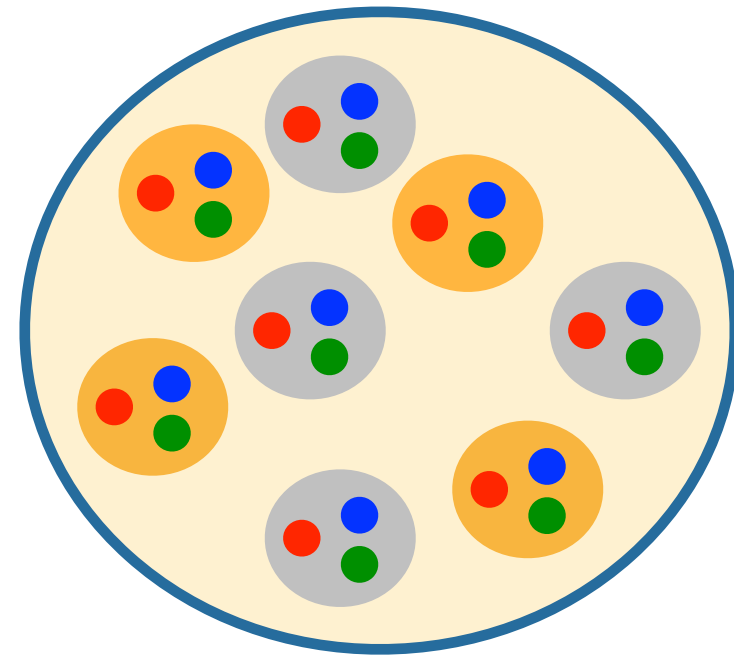
higher Q<sup>2</sup> scale

# Ultra-peripheral PbPb collisions

What object are we probing?

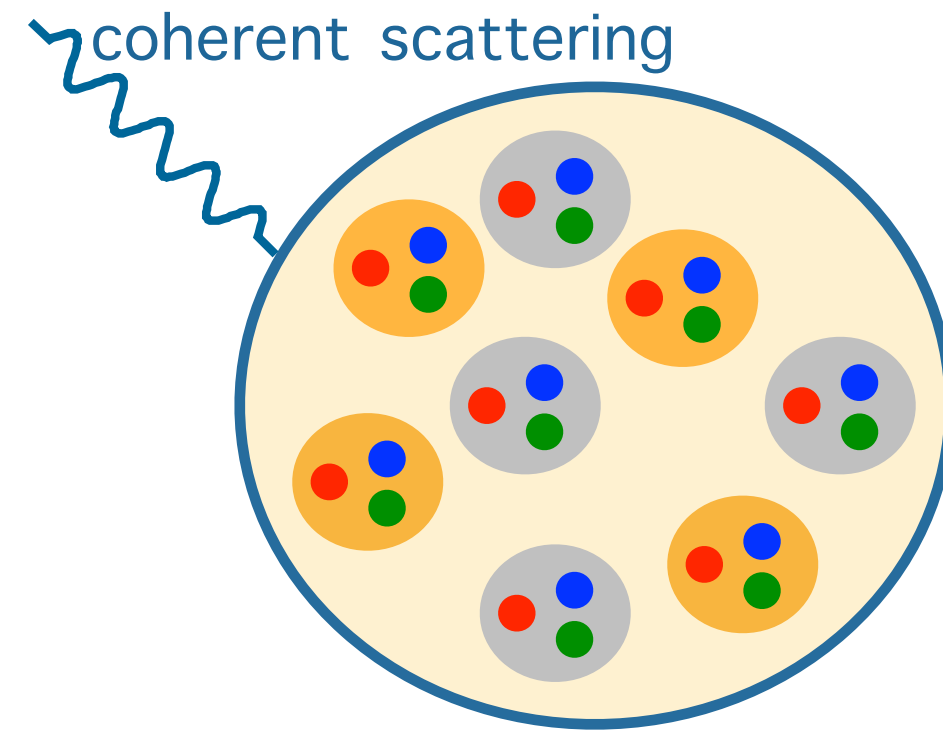
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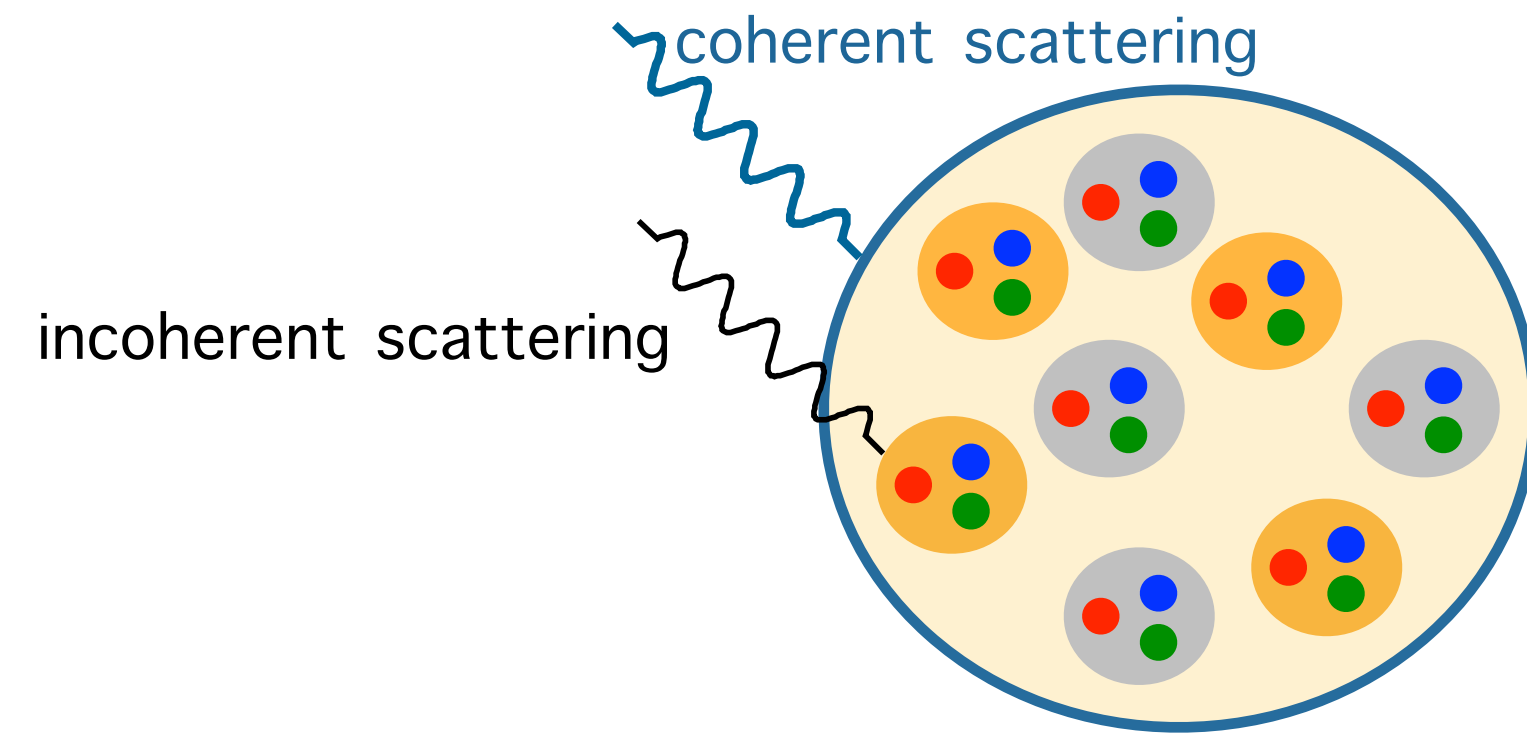


Coherent interaction: interaction with target as a whole.  
~ target remains in same quantum state.



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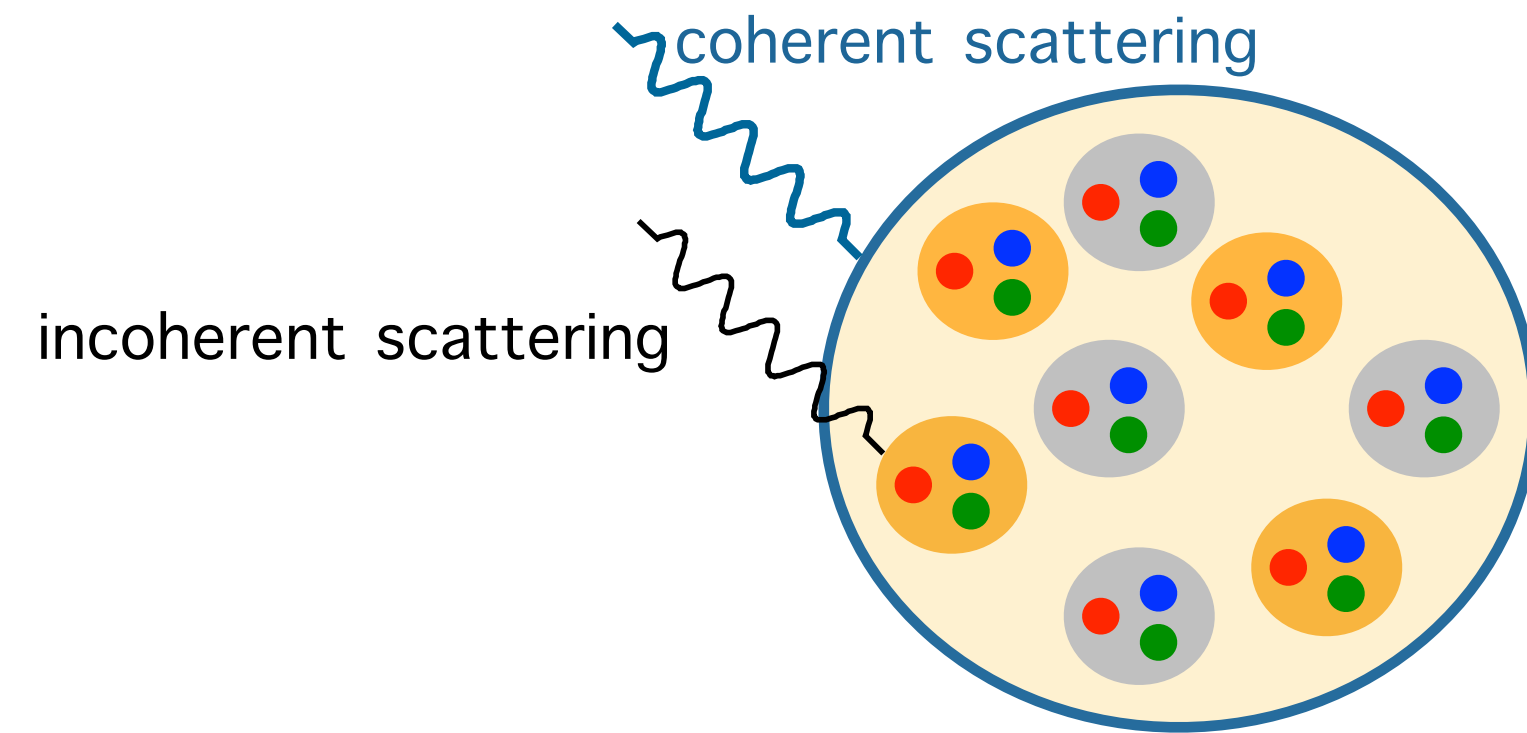


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Incoherent interaction: interaction with constituents inside target.  
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Ex.: target dissociation, excitation

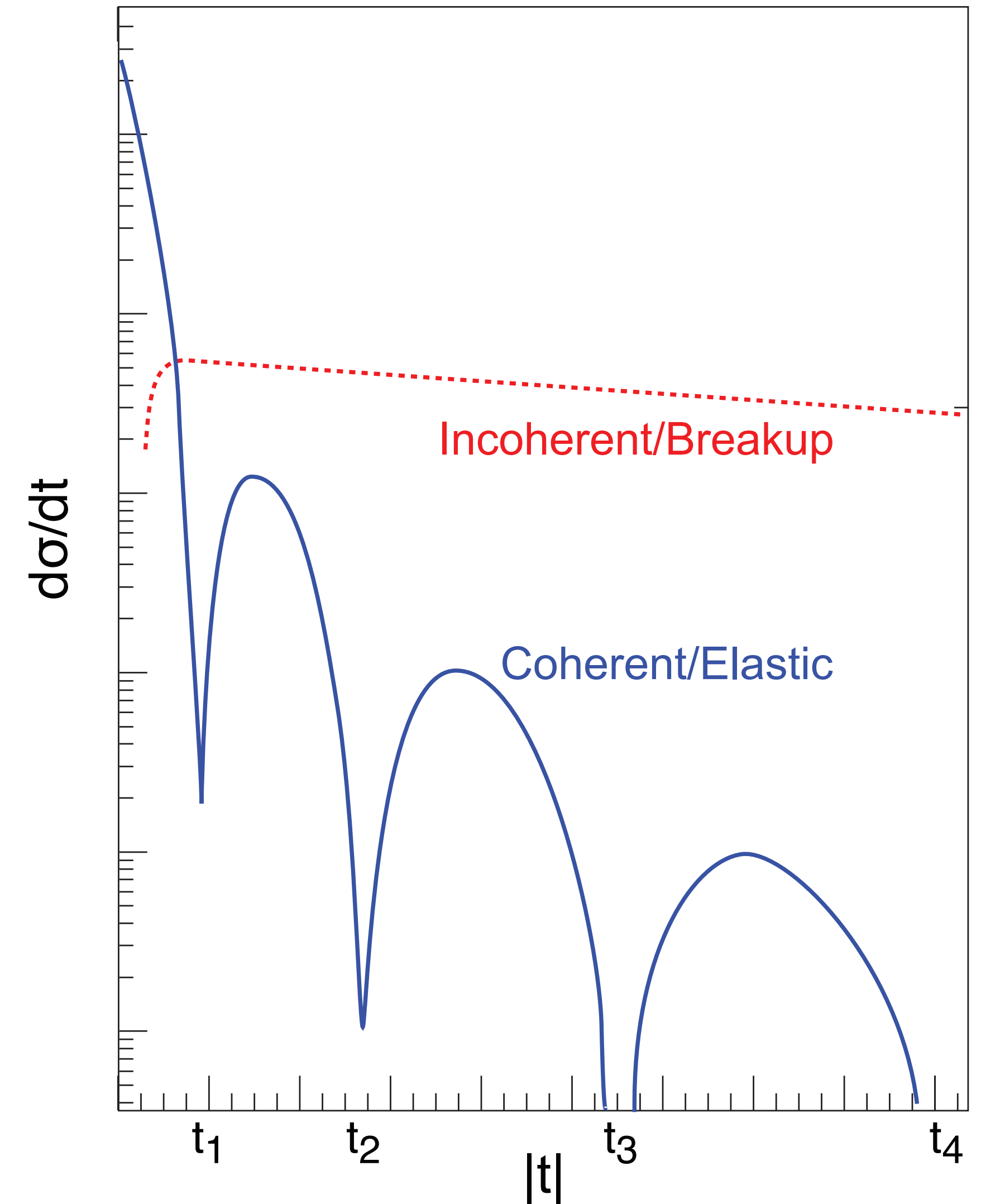
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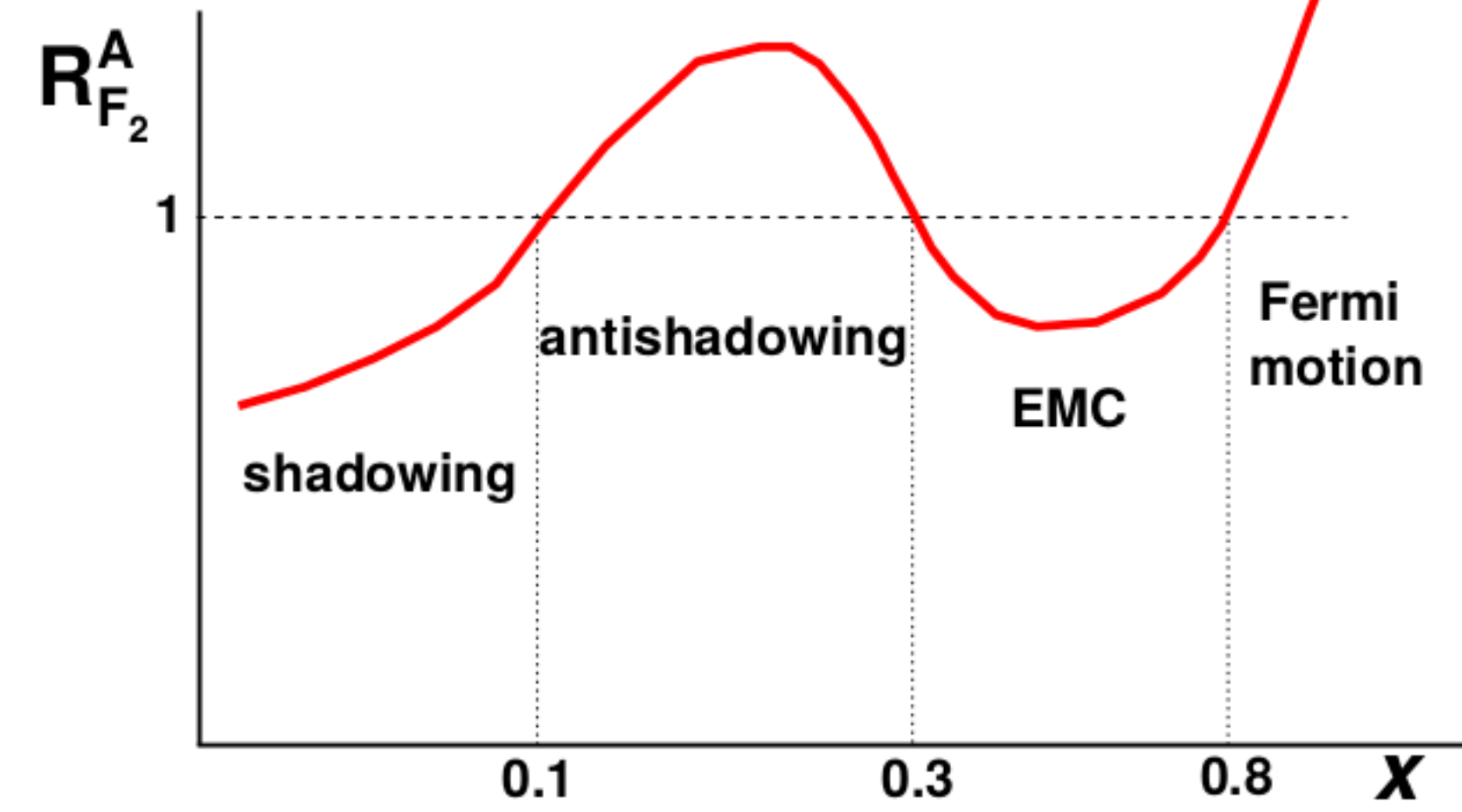
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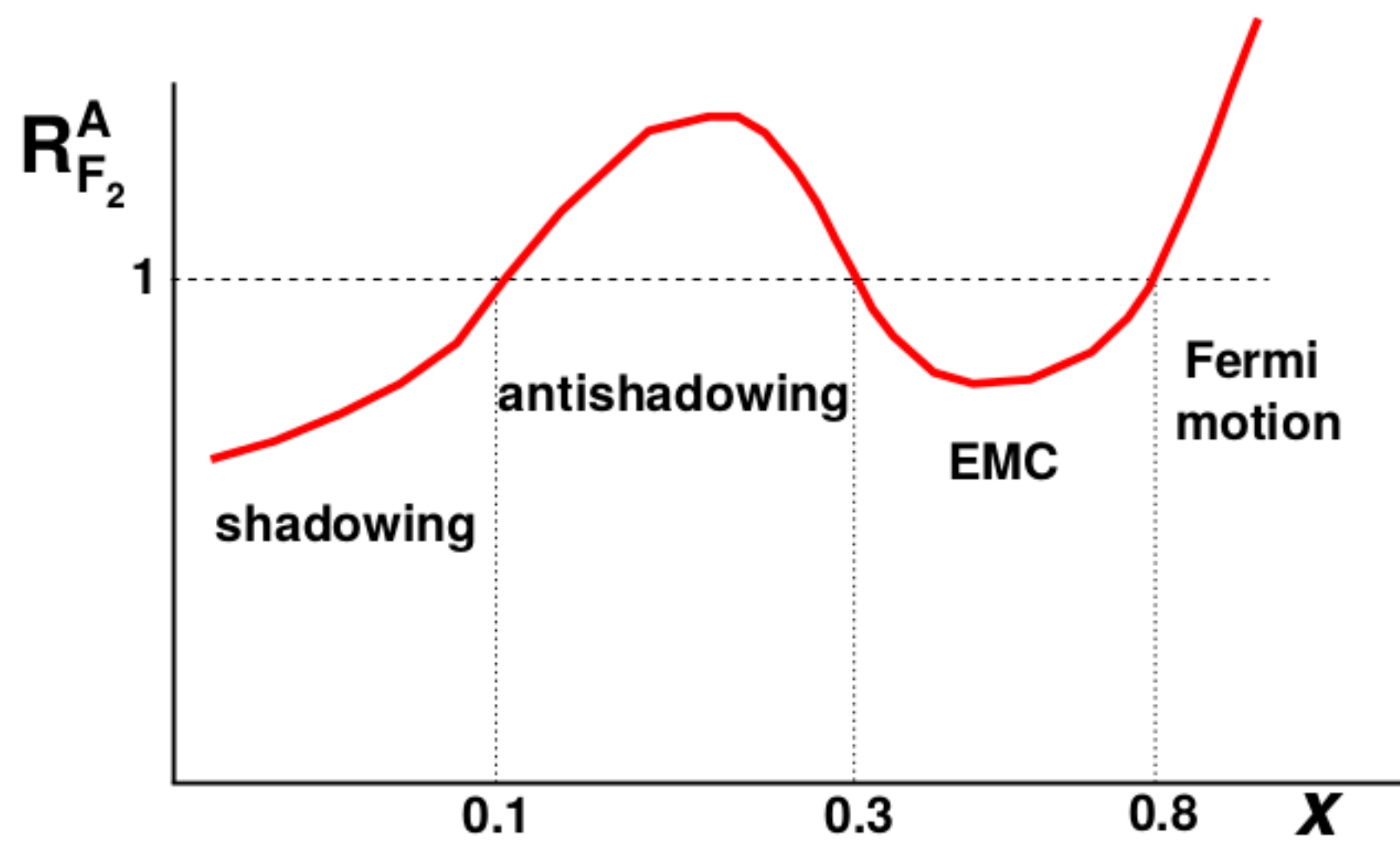
# Coherent production

Nuclear GPDs (PDFs at low  $x_B$ )

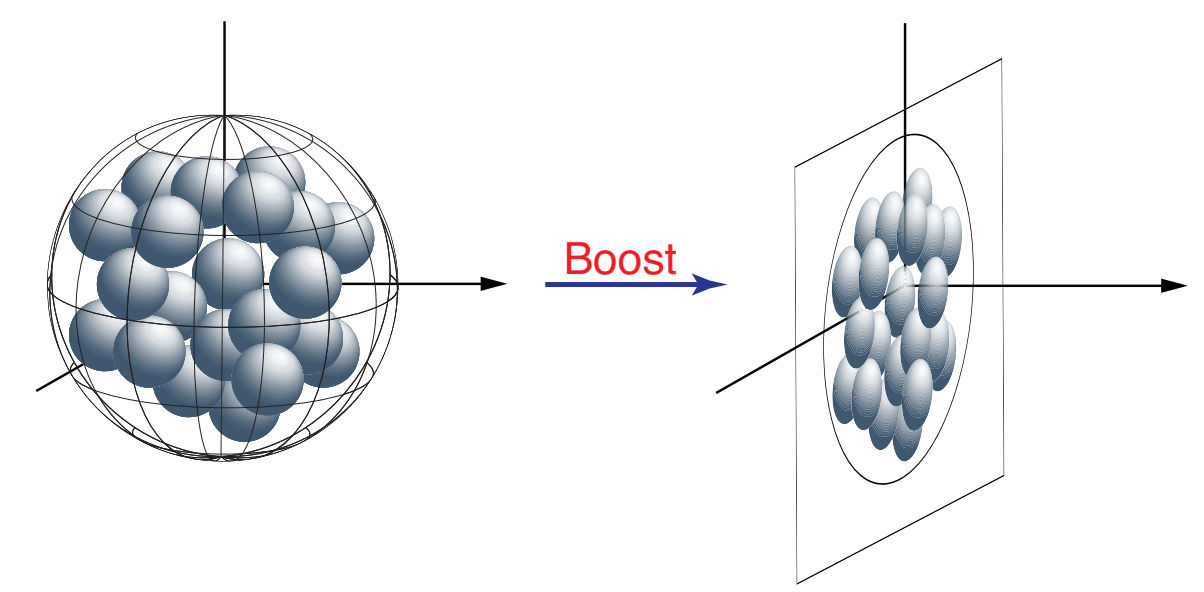
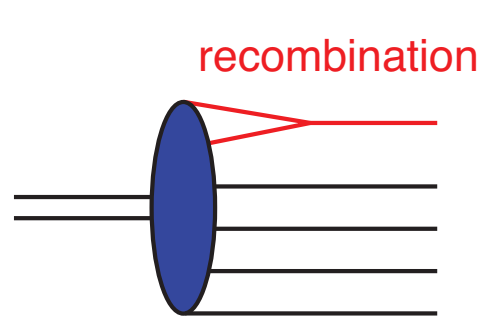
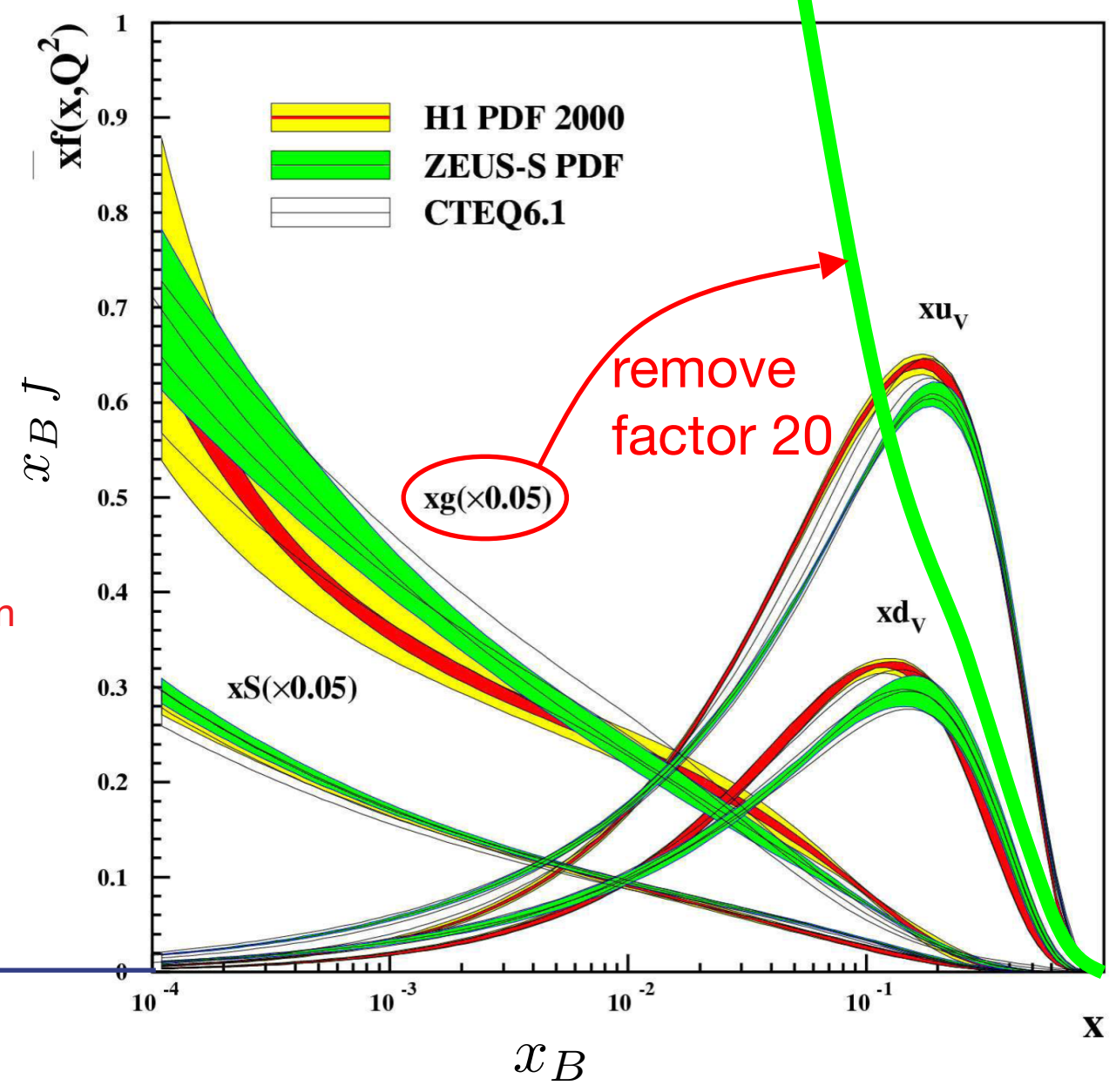
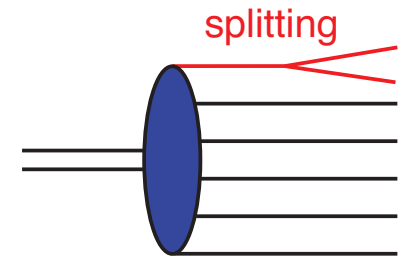


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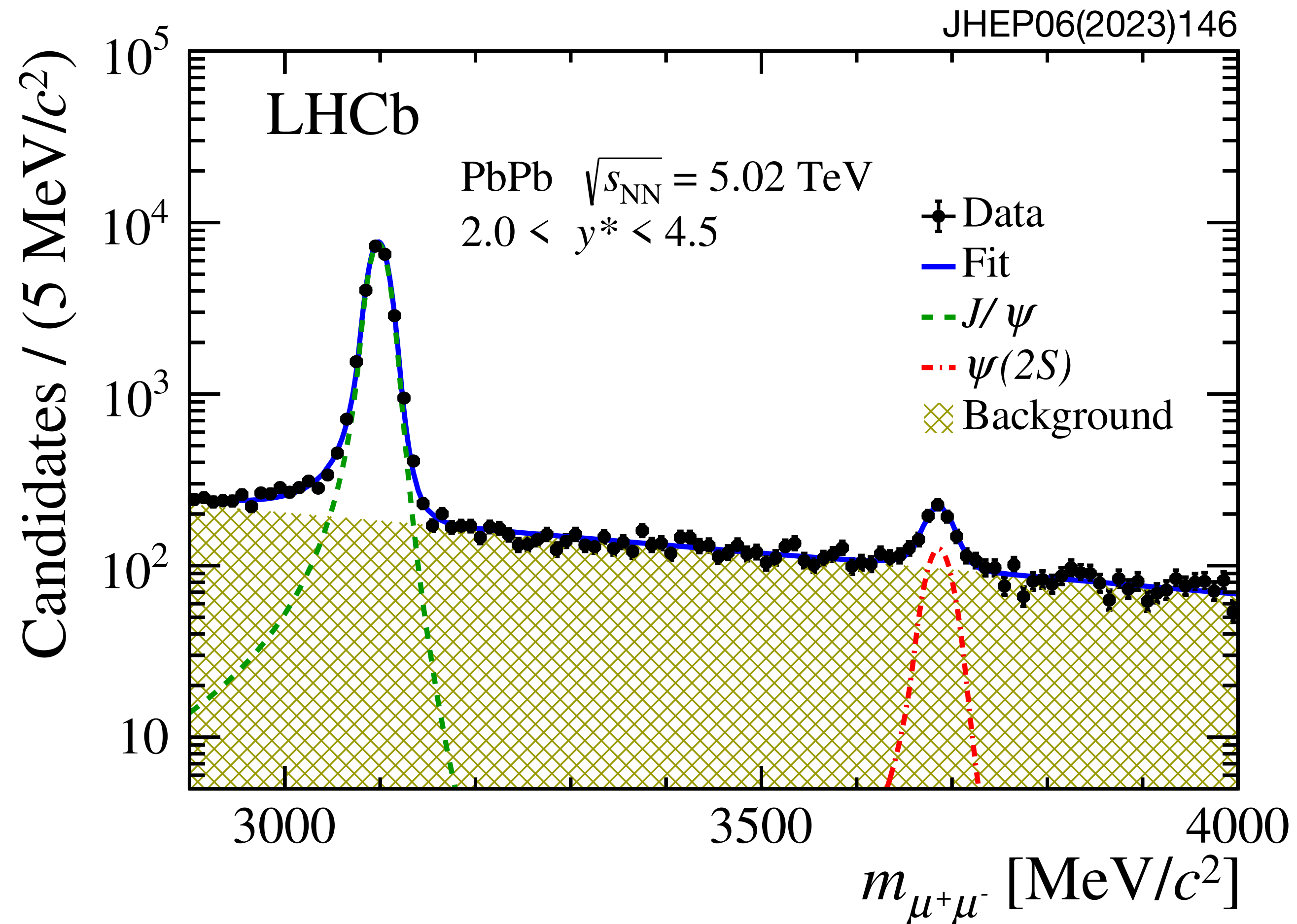
## Probing saturation



$A^{1/3}$  enhancement of saturation effect for ions

# Coherent J/ψ in PbPb UPCs – selection

- $\sqrt{s_{NN}} = 5.02$  TeV data.
- $L_{\text{int}} = 228 \pm 10 \mu\text{b}^{-1}$
- Reconstruction via dimuon decay, with offline selection:  $2 < \eta_{\mu} < 4.5$  and  $p_{T,\mu} > 700$  MeV
- $2 < y_{J/\psi} < 4.5 \rightarrow x_B$  down to  $10^{-5}$
- $p_T < 1$  GeV





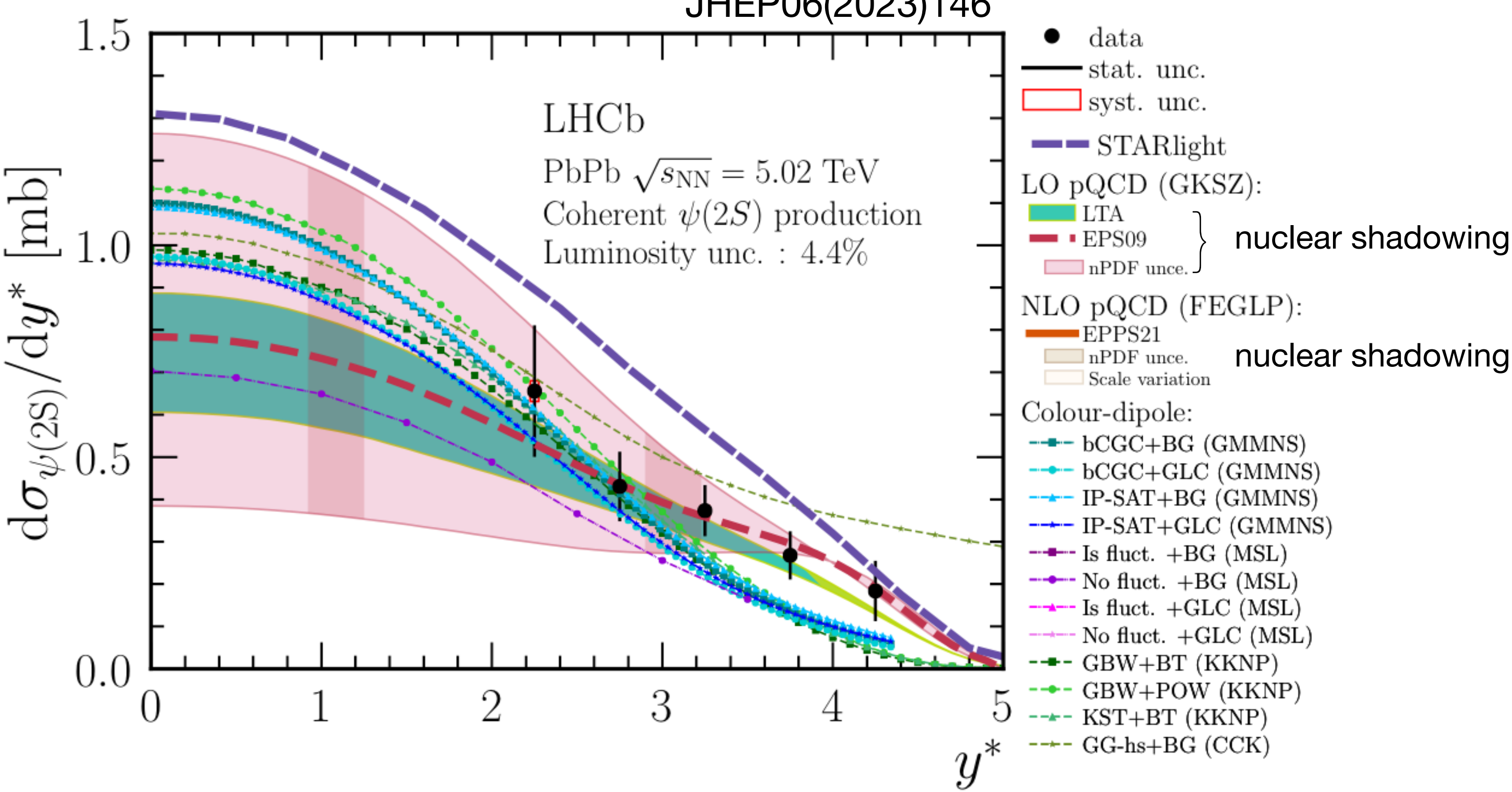
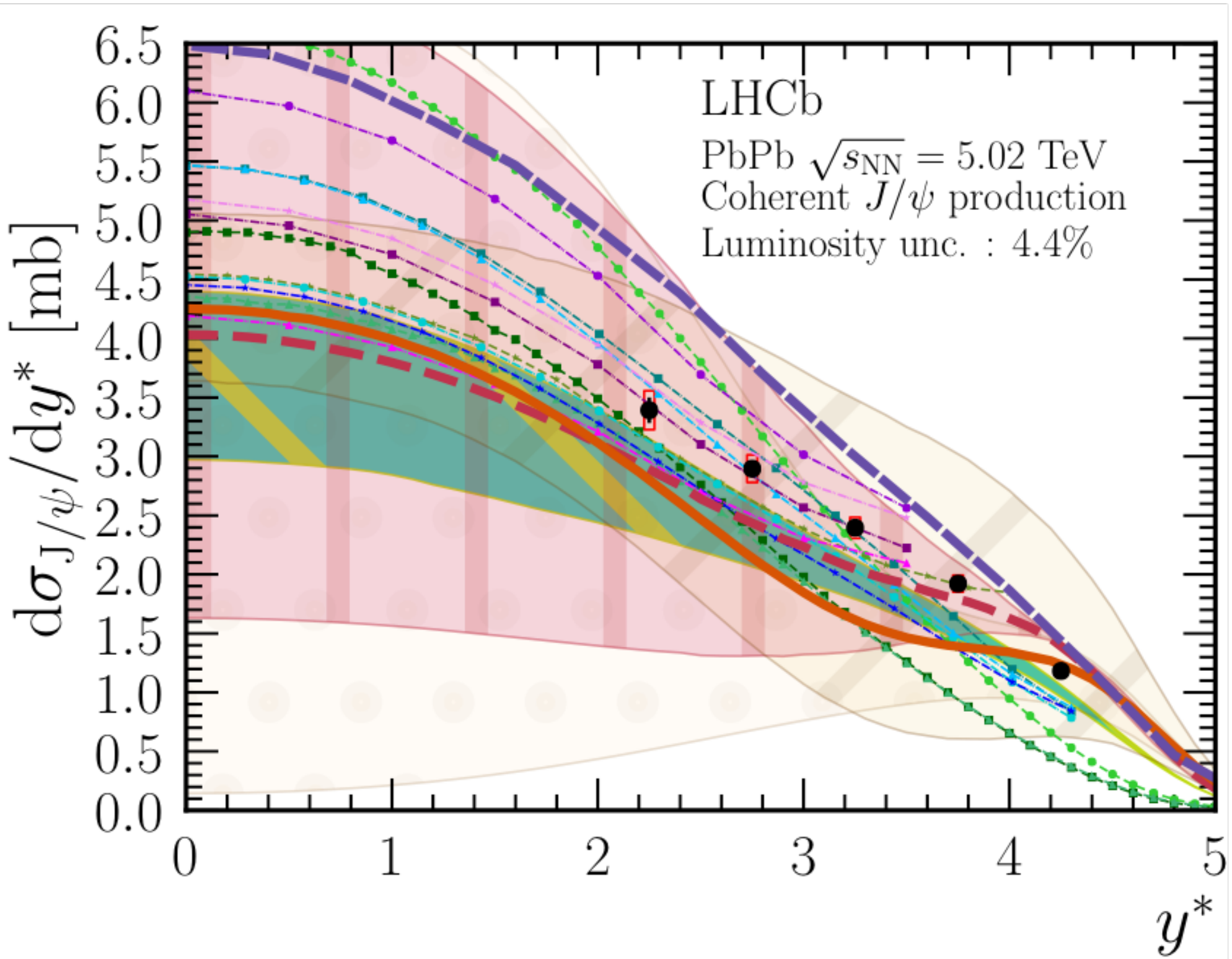
# Coherent photoproduction in PbPb: $y$ dependence

$$\sigma_{J/\psi}^{\text{coh}} = 5.965 \pm 0.059 \pm 0.232 \pm 0.262 \text{ mb}$$

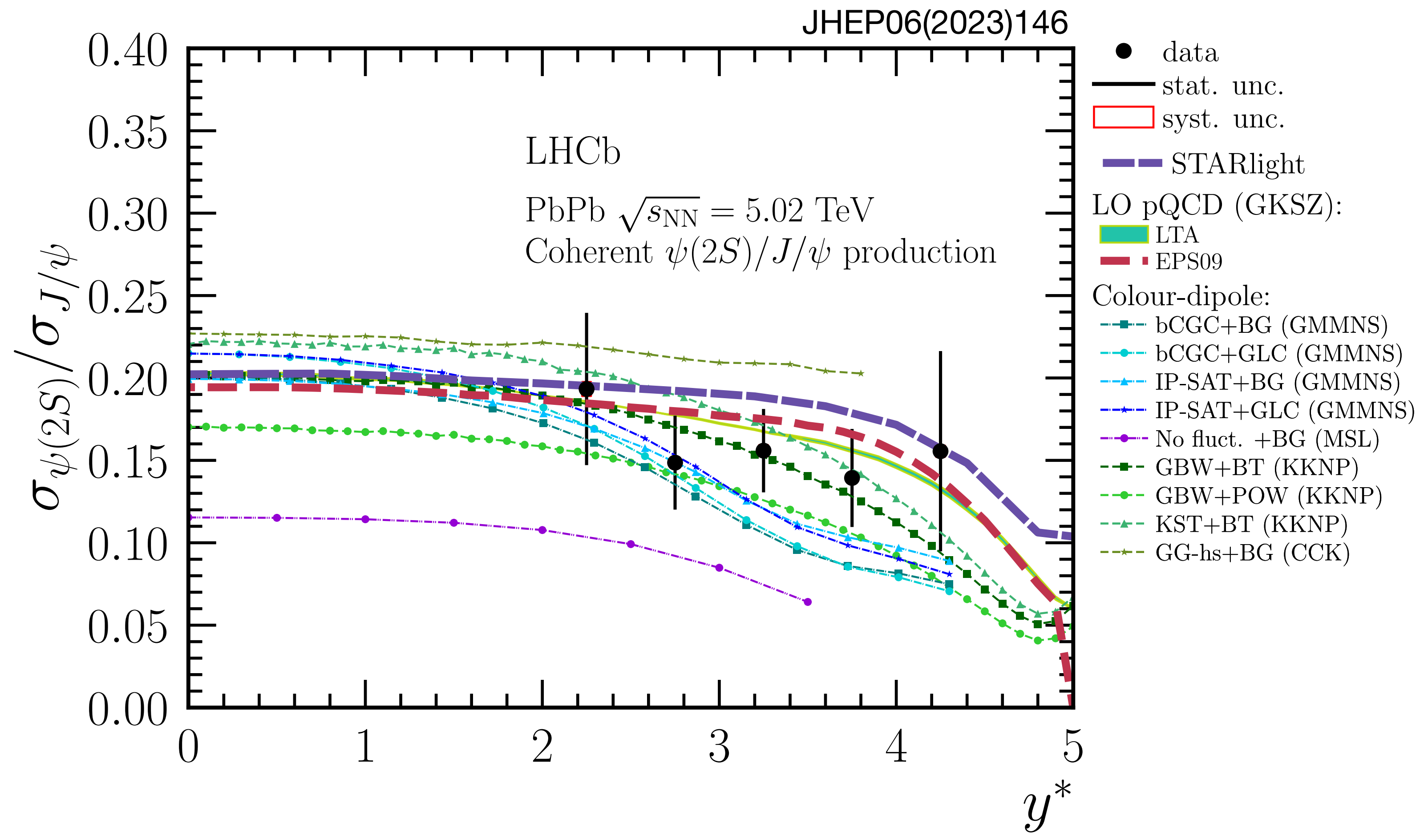
$$\sigma_{\psi(2S)}^{\text{coh}} = 0.923 \pm 0.086 \pm 0.028 \pm 0.040 \text{ mb}$$

Pb + Pb  $\rightarrow$  Pb + Pb +  $\psi$

JHEP06(2023)146



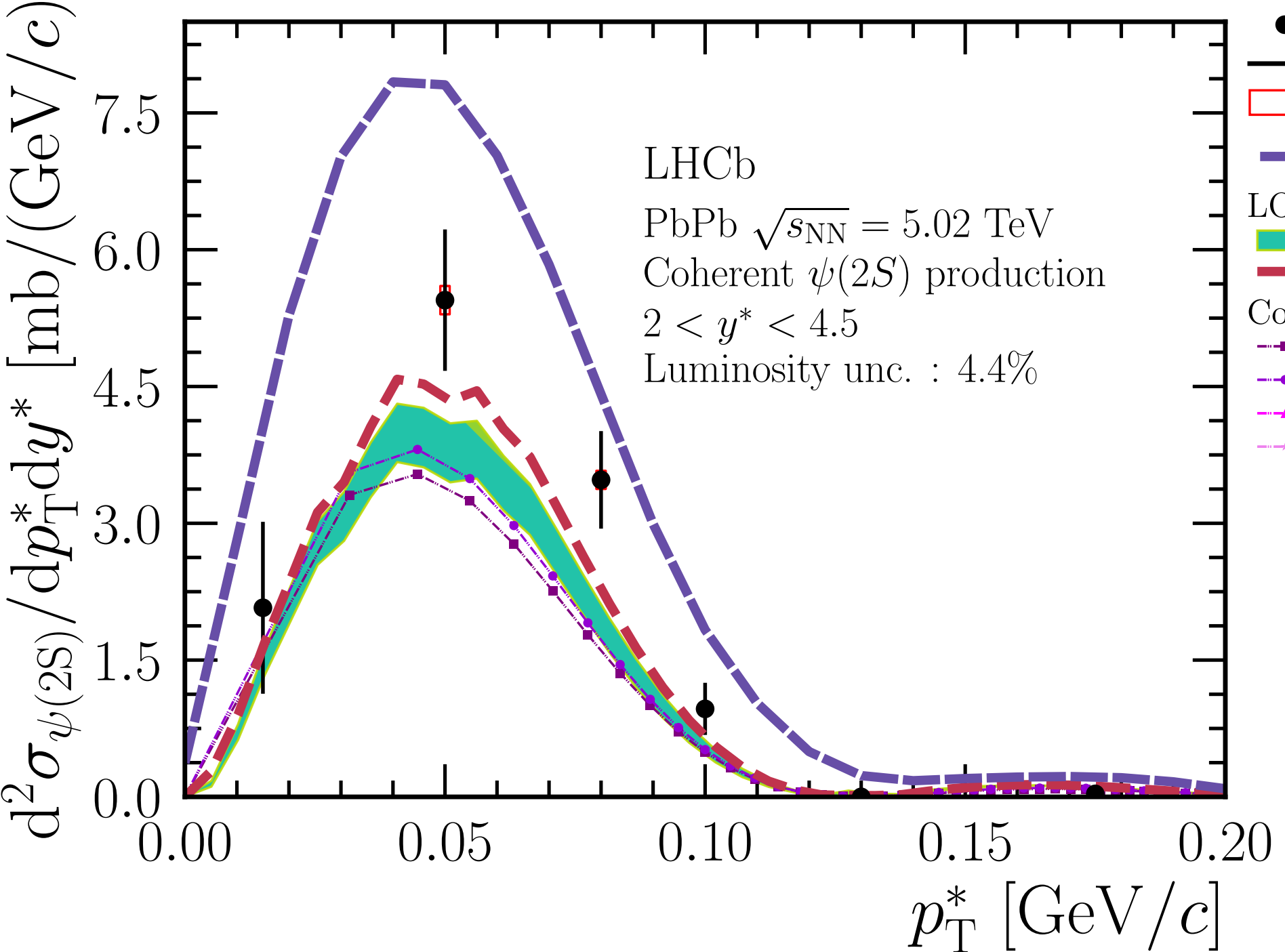
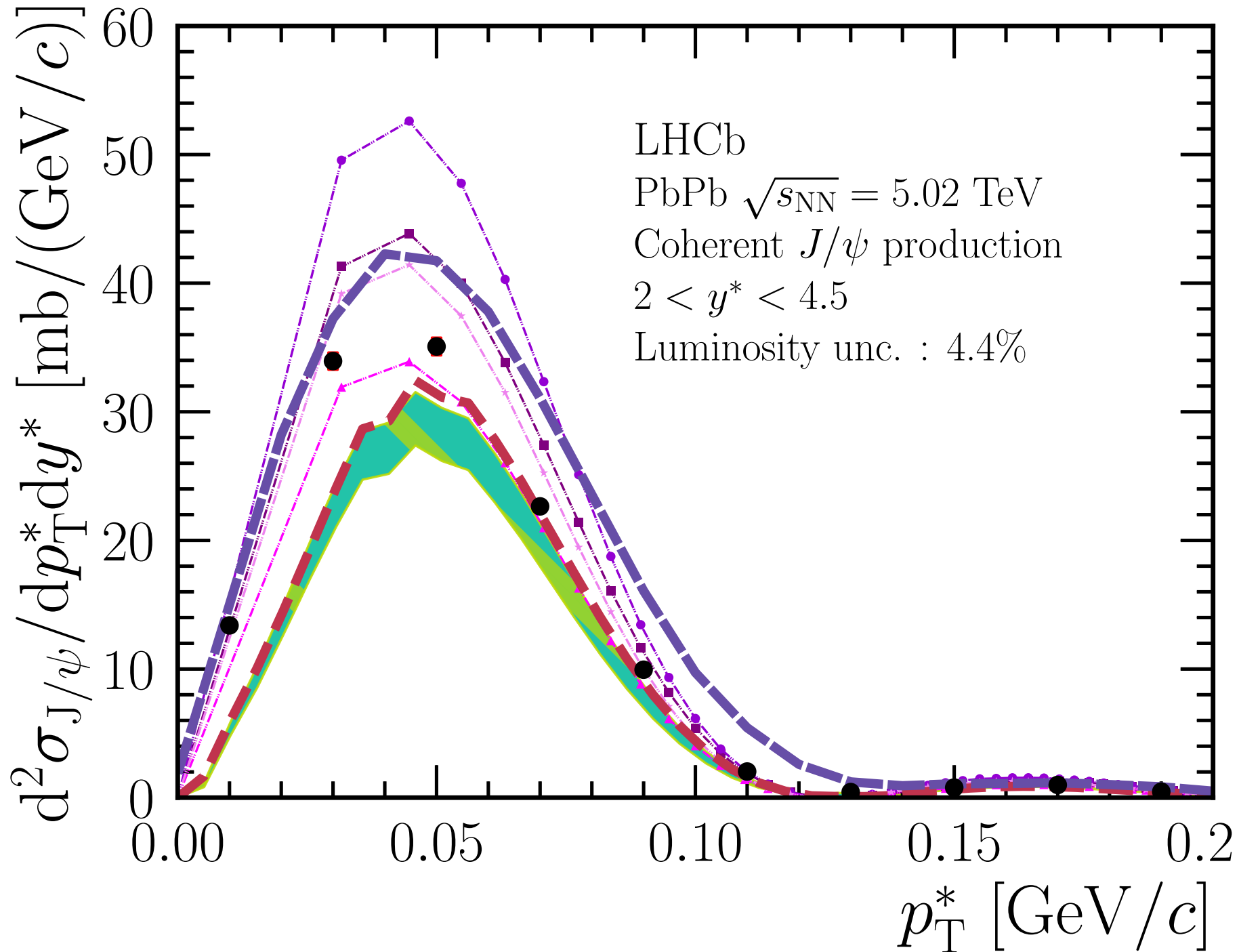
# Coherent photoproduction in PbPb: $\psi(2S)/J/\psi$



# Coherent photoproduction in PbPb: $p_T$ dependence

$$\text{Pb} + \text{Pb} \rightarrow \text{Pb} + \text{Pb} + \psi$$

JHEP06(2023)146

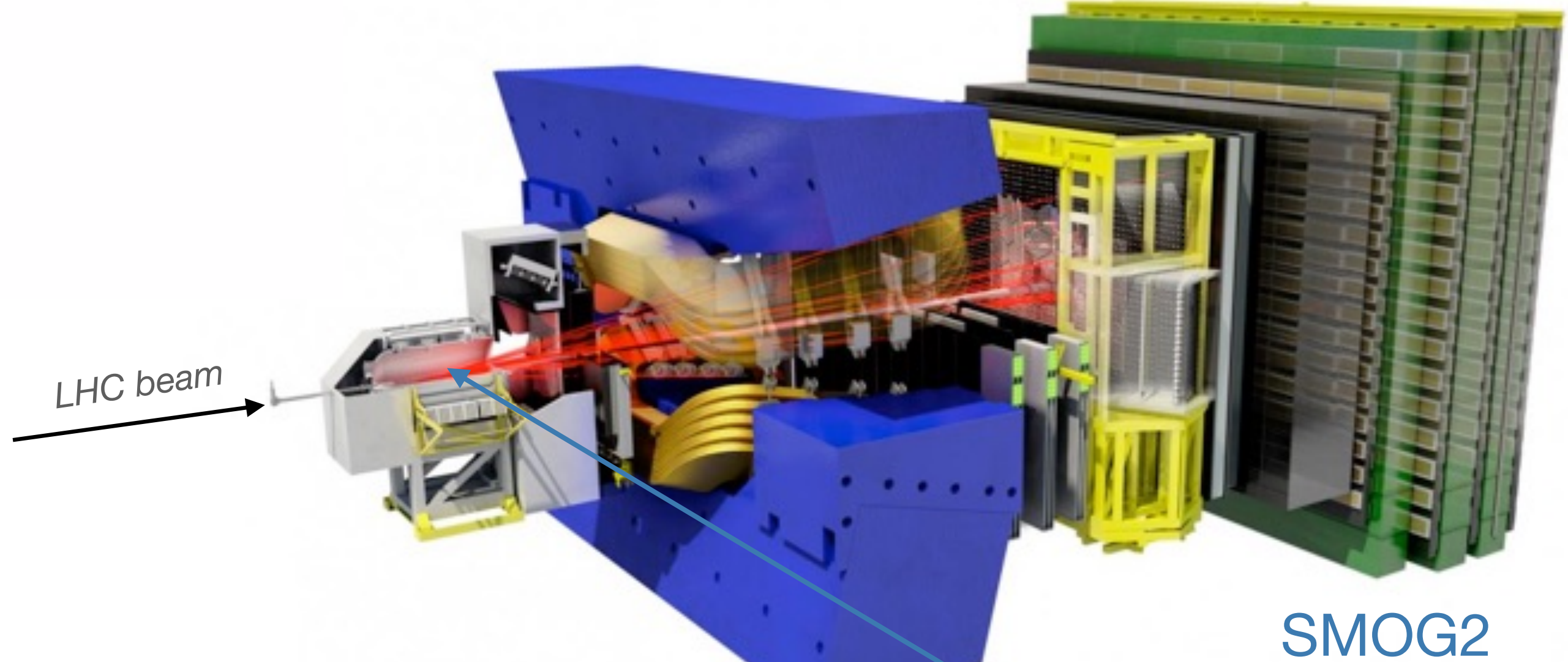


- data
- stat. unc.
- syst. unc.
- STARlight
- LO pQCD (GKSZ):
- LTA
- EPS09
- } nuclear shadowing
- Colour-dipole:
- Is fluct. +BG (MSL)
- No fluct. +BG (MSL)
- Is fluct. +GLC (MSL)
- No fluct. +GLC (MSL)

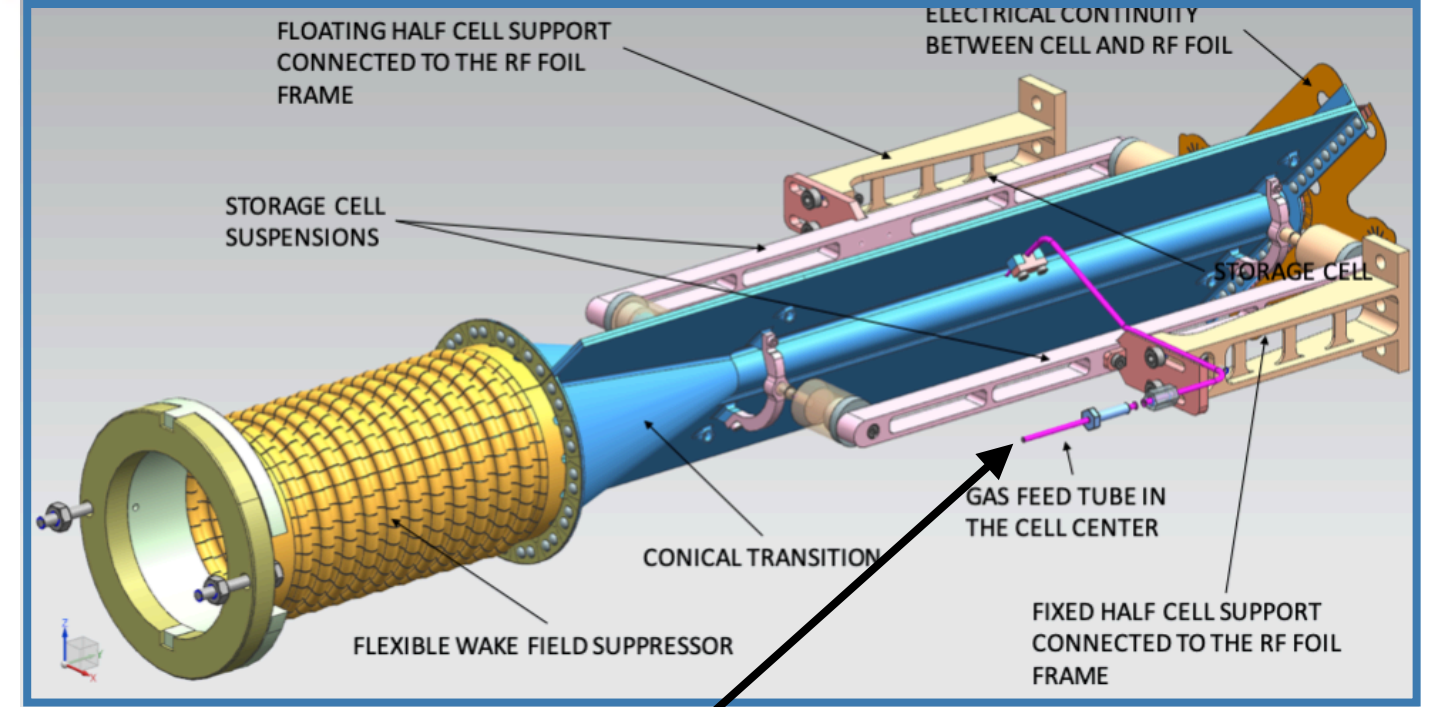
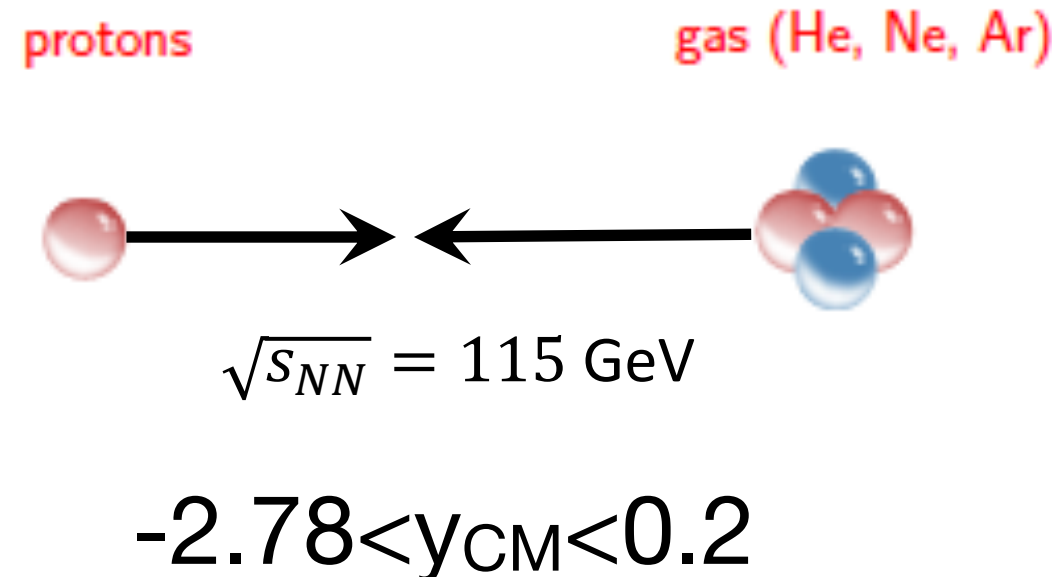


# Fixed target at LHCb

RUN3



SMOG2

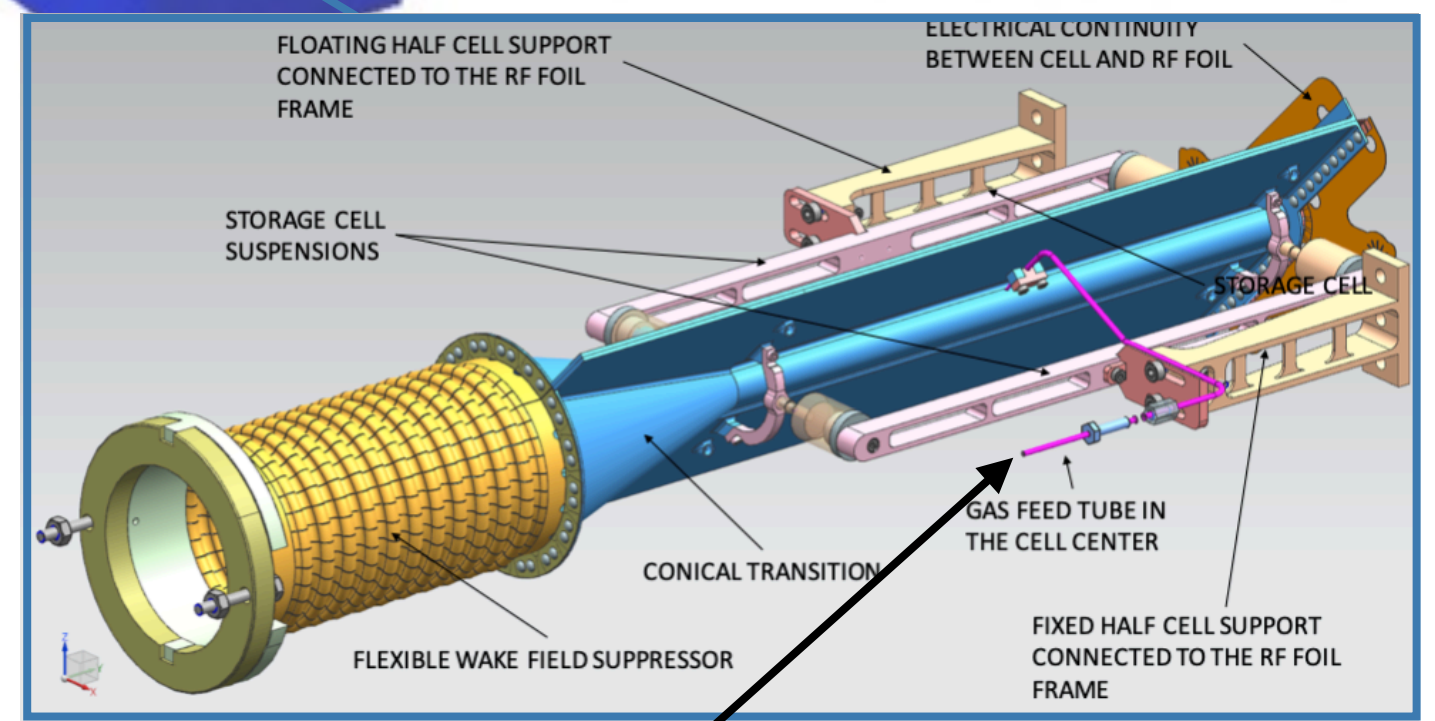
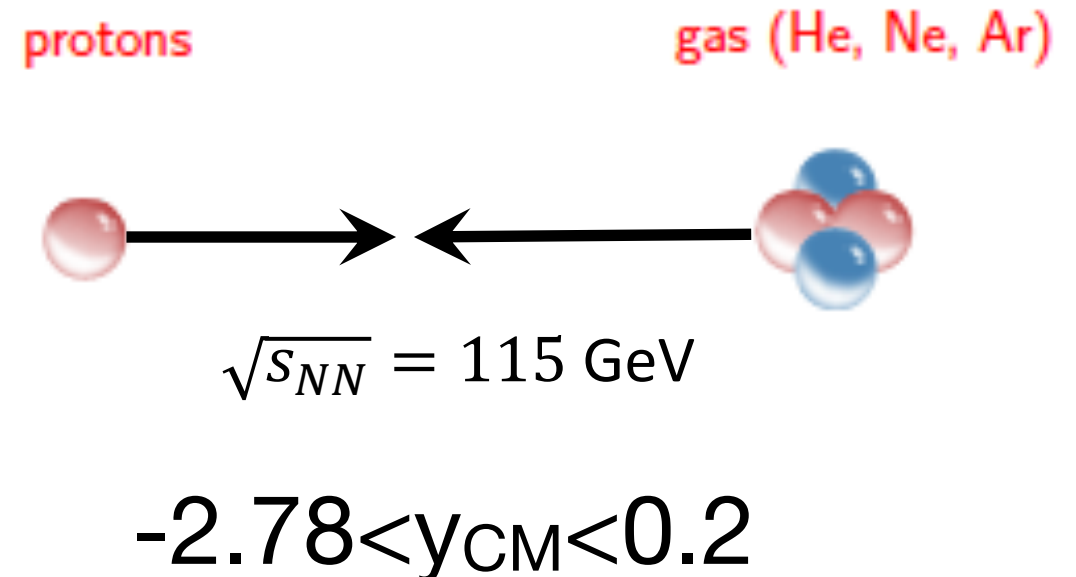
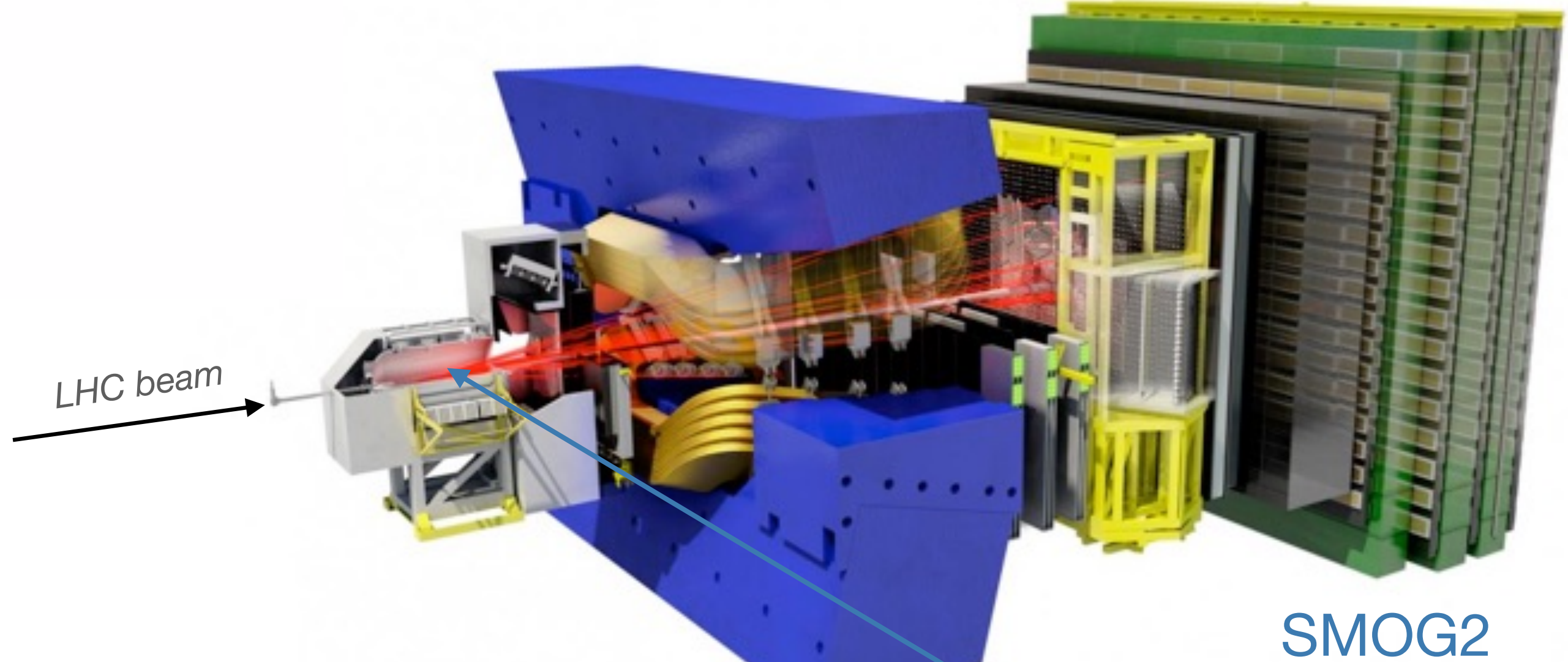


inject gas: He, Ne, Ar, and H<sub>2</sub>, D<sub>2</sub>

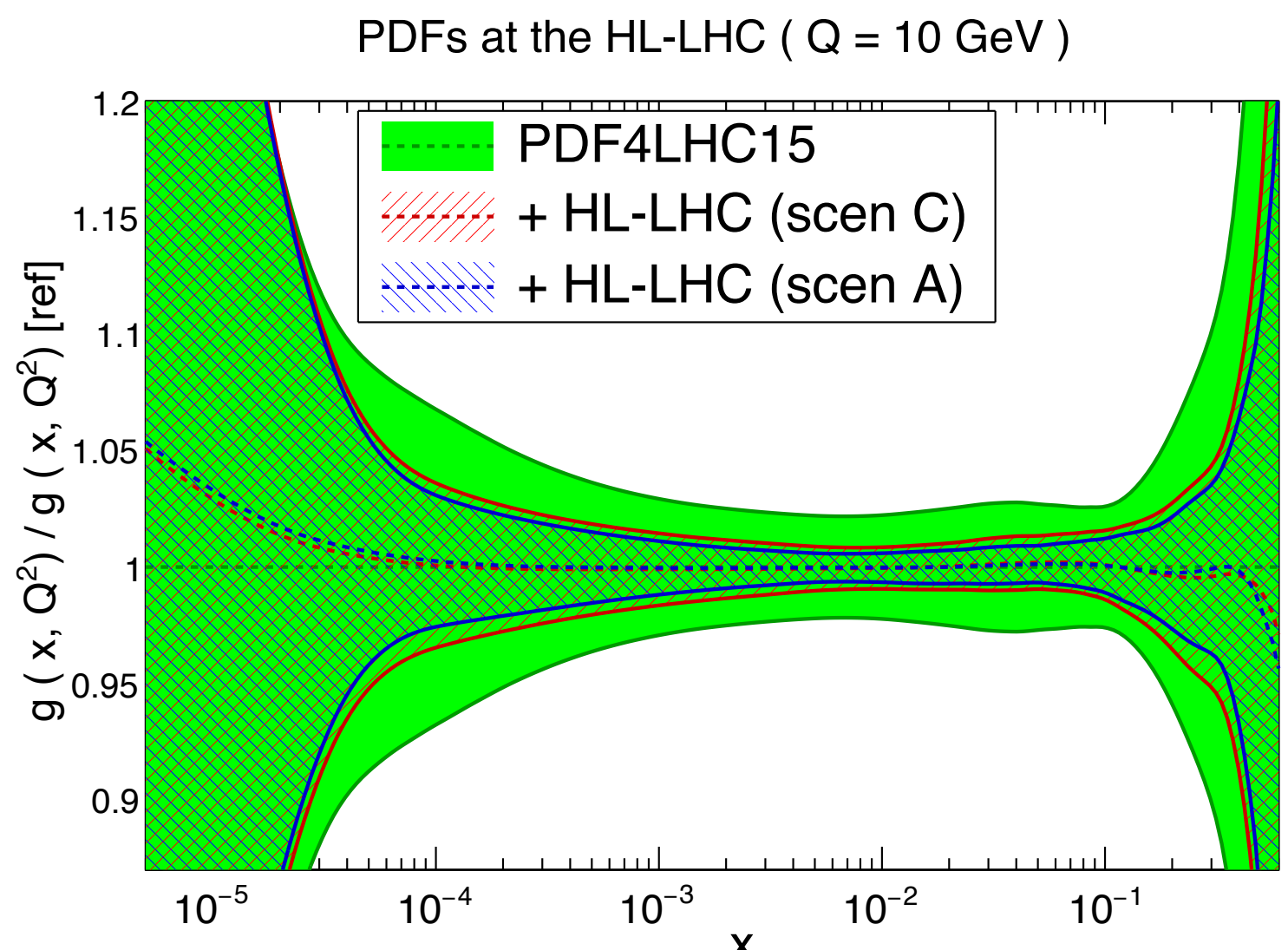
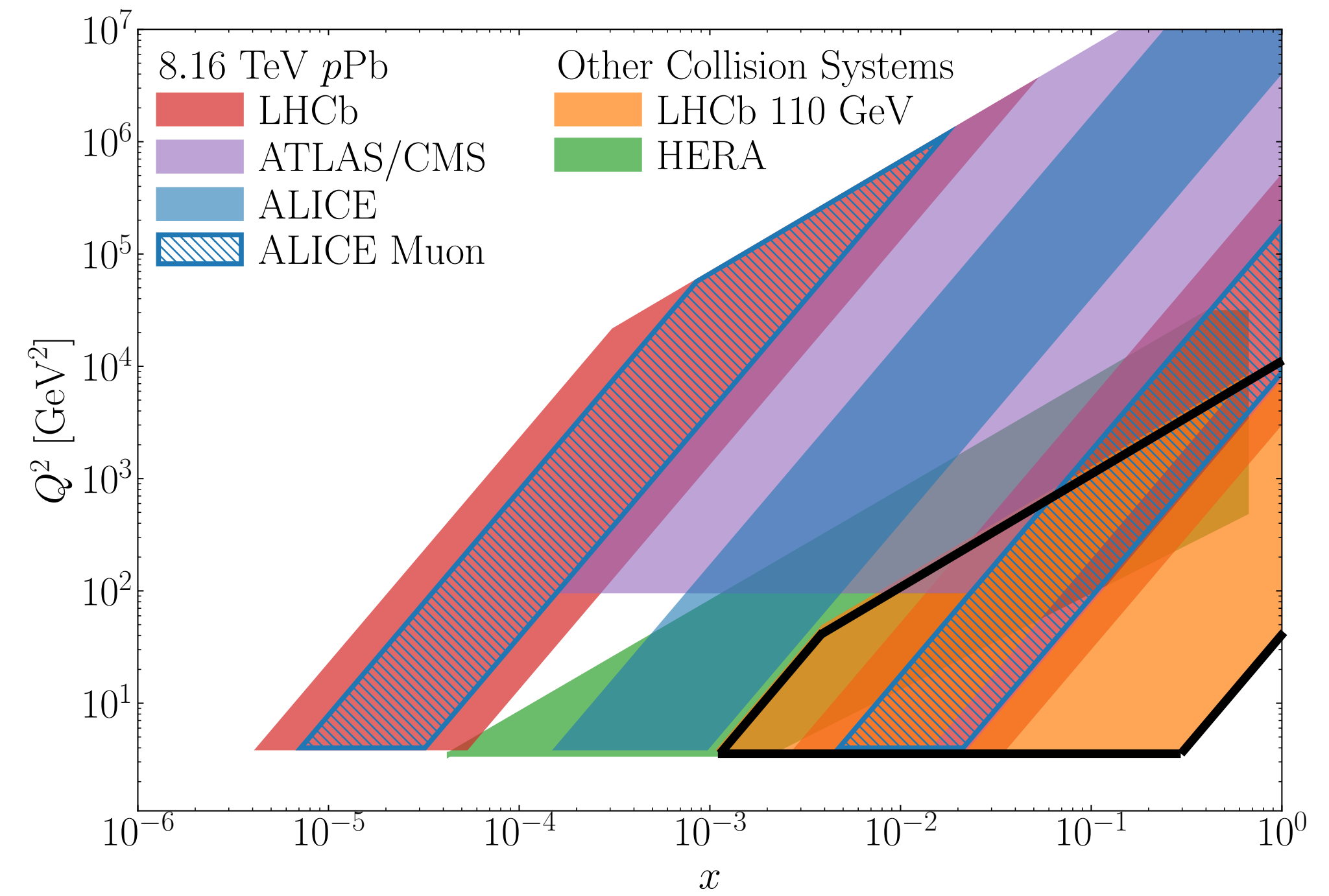


# Fixed target at LHCb

RUN3



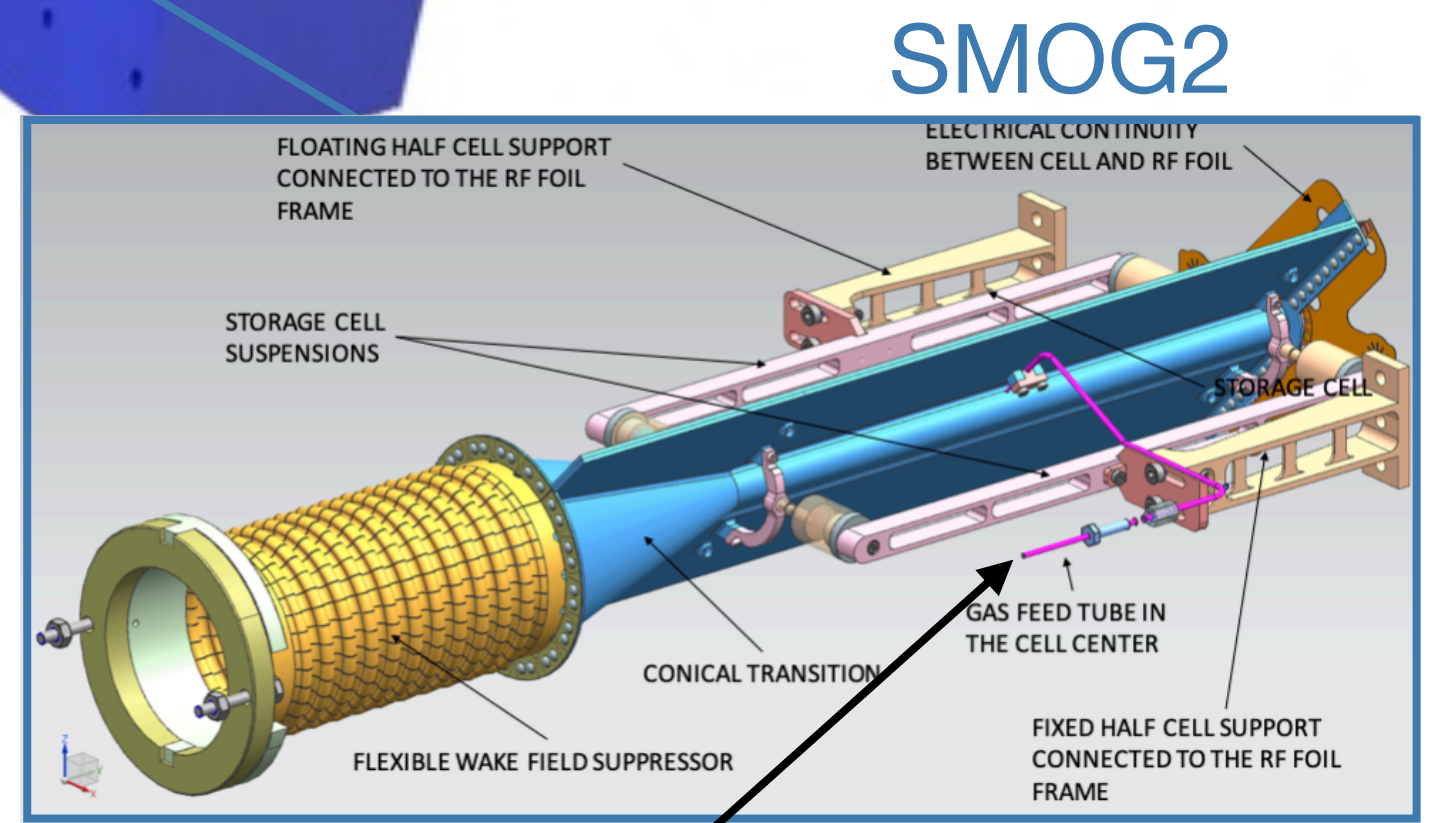
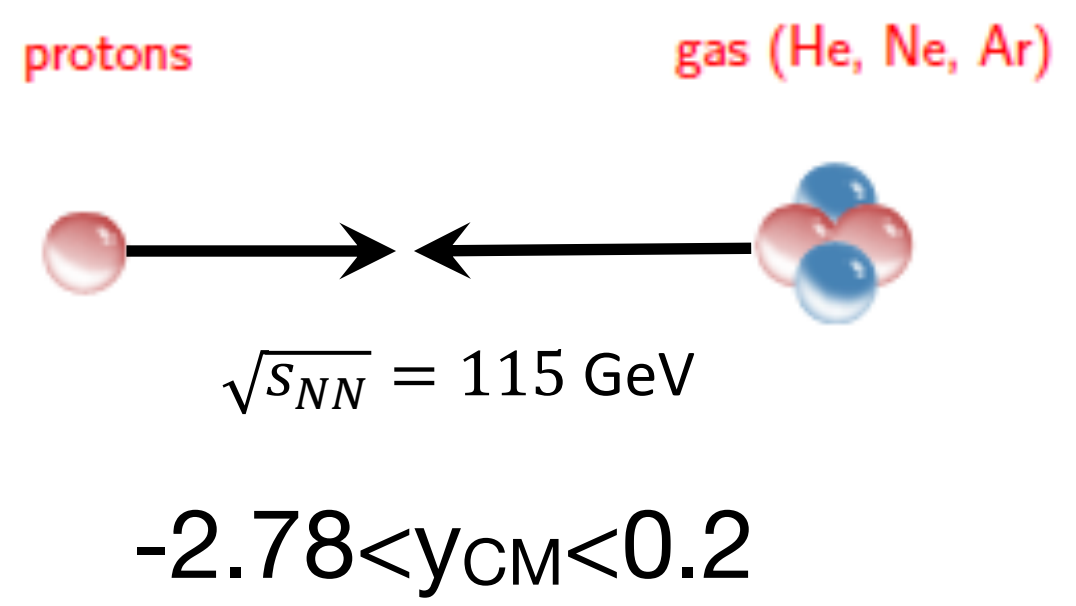
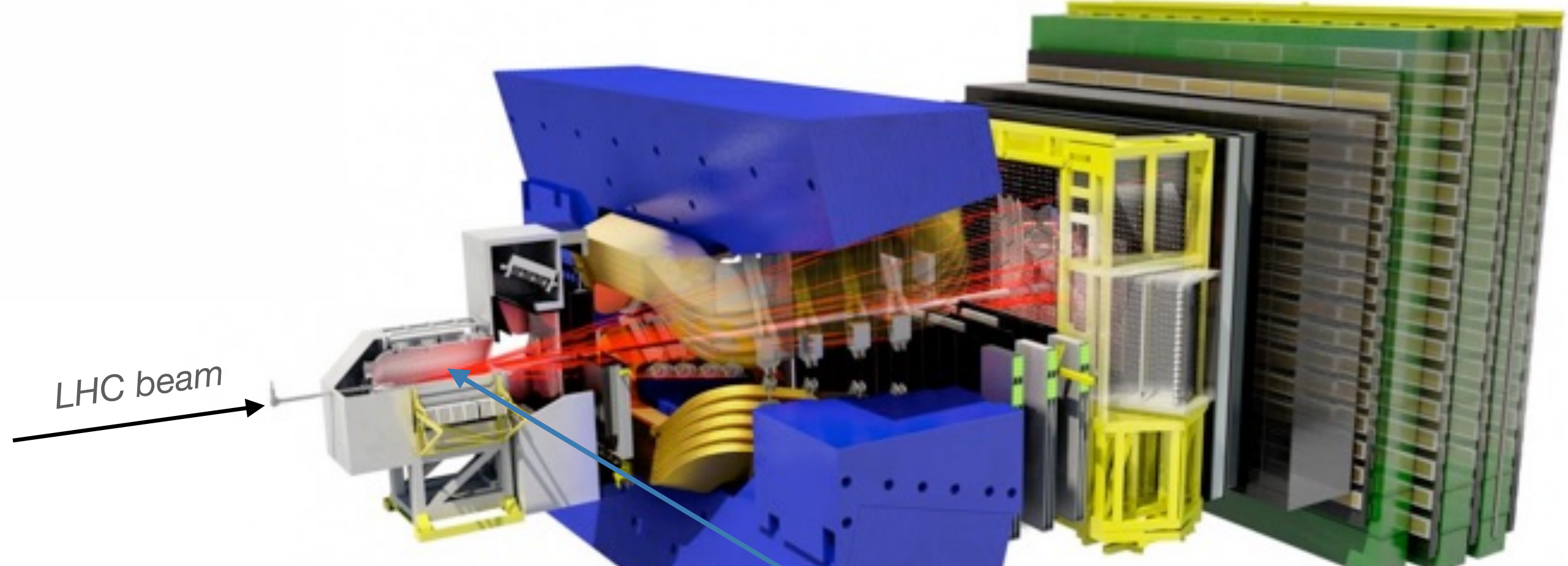
inject gas: He, Ne, Ar, and H<sub>2</sub>, D<sub>2</sub>



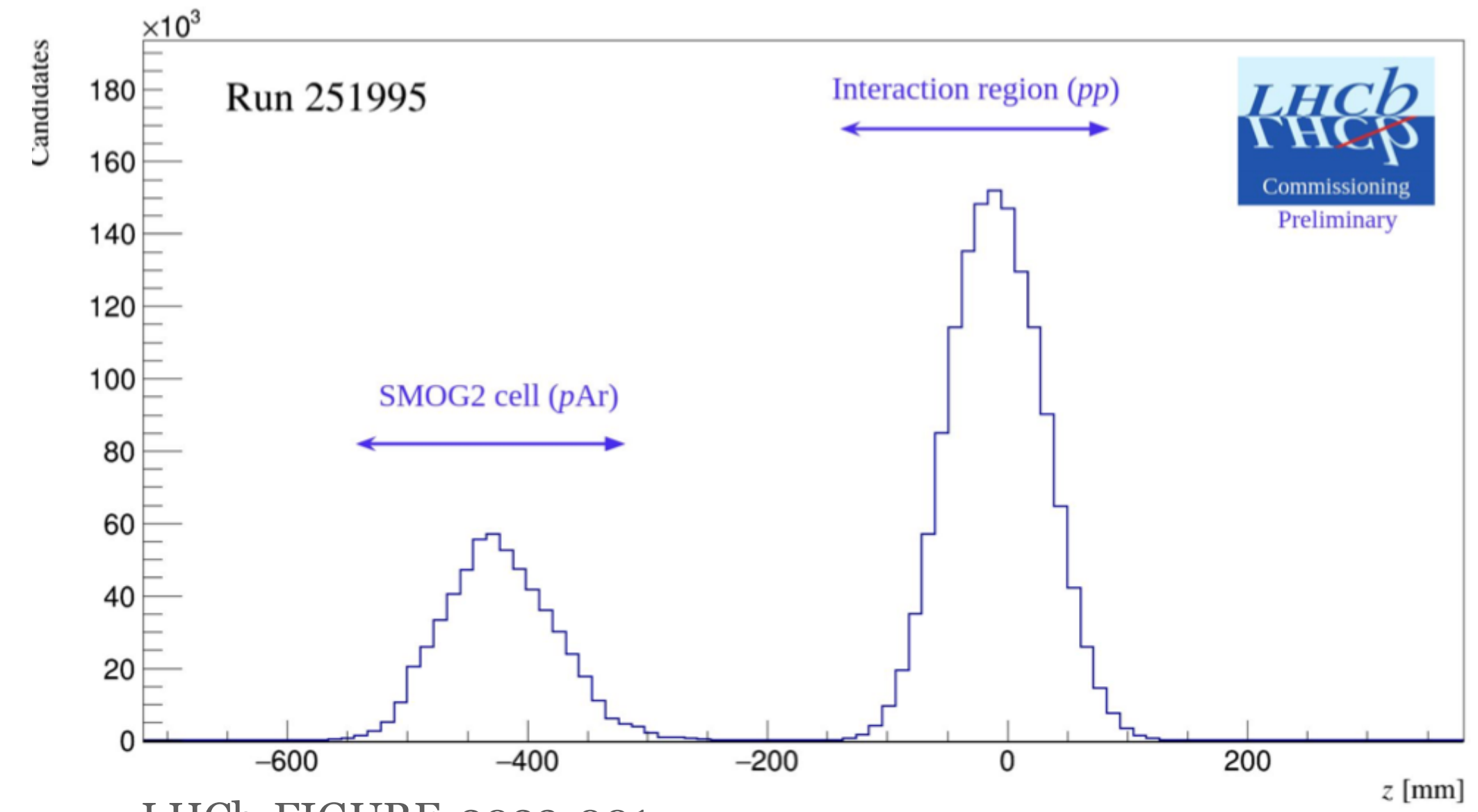


# Fixed target at LHCb

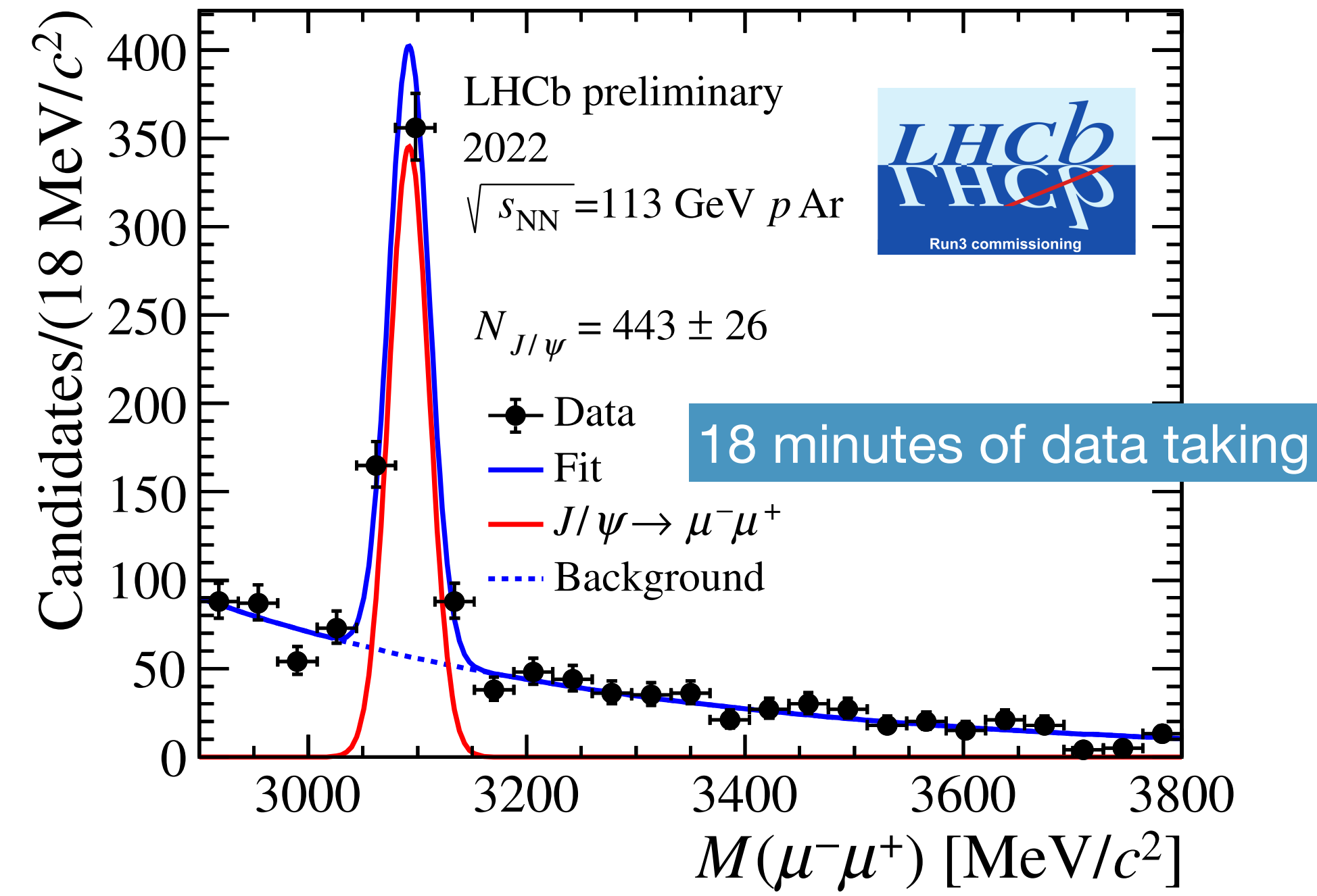
RUN3



inject gas: He, Ne, Ar, and H<sub>2</sub>, D<sub>2</sub>



LHCb-FIGURE-2023-001



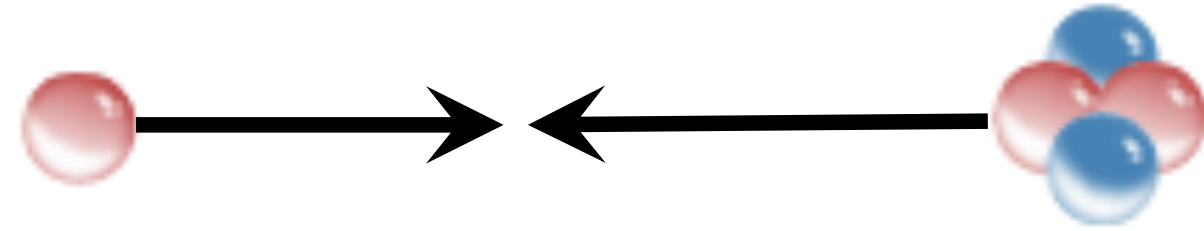
# Fixed target at LHCb

Proposal for Run 5:

SMOG2

protons

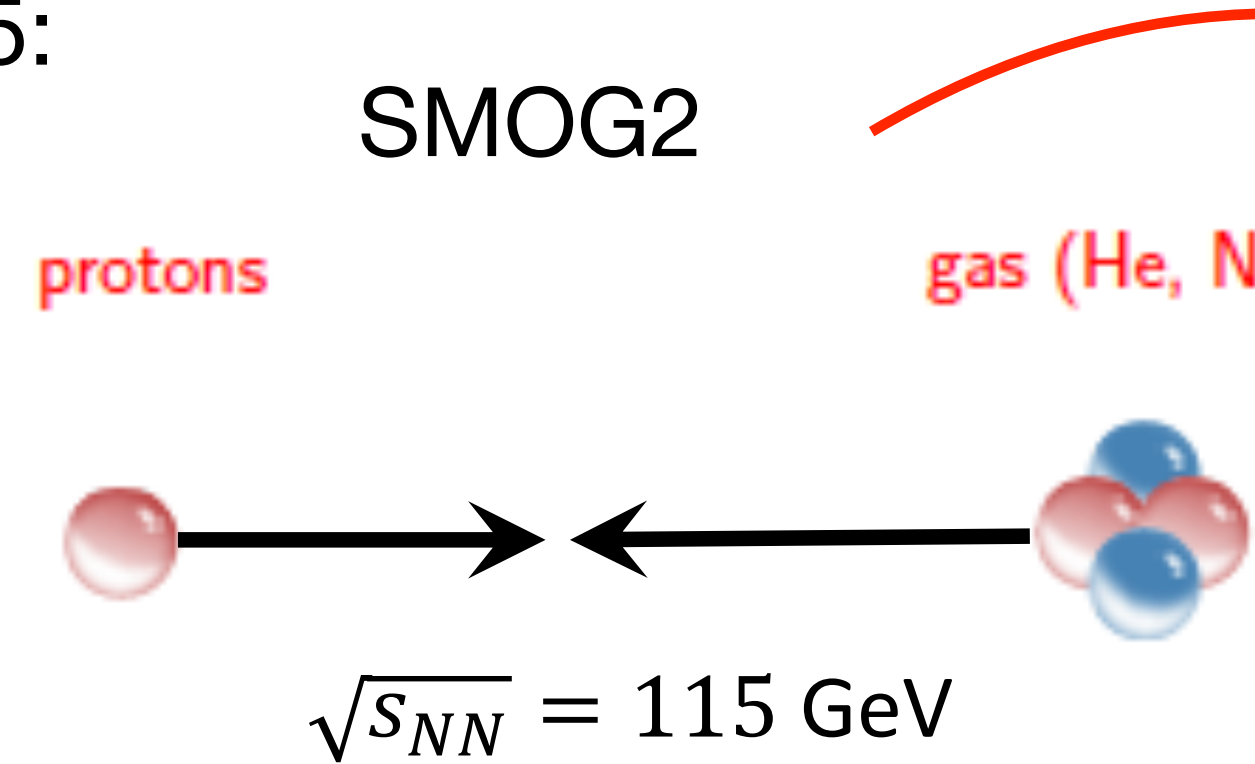
gas (He, Ne, Ar)



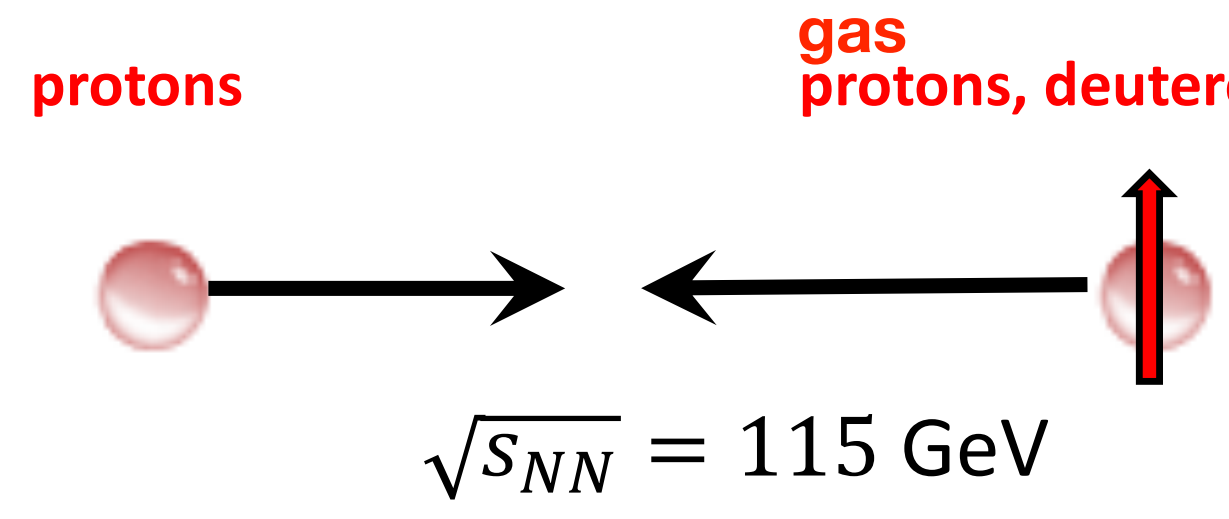
$$\sqrt{s_{NN}} = 115 \text{ GeV}$$

# Fixed target at LHCb

Proposal for Run 5:



LHCSPIN: transversely polarised gas target

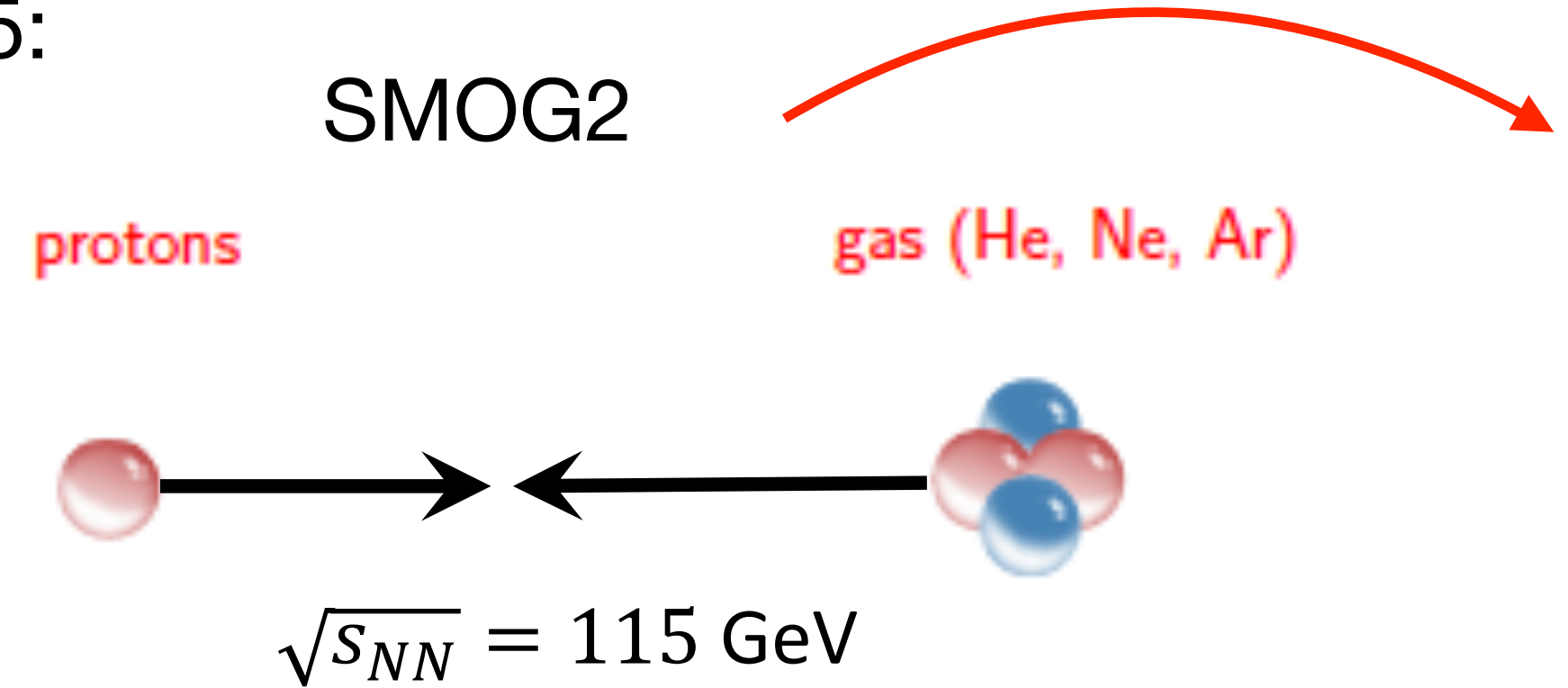


→ access to spin-dependent PDFs, TMD PDFs and GPDs at the LHC

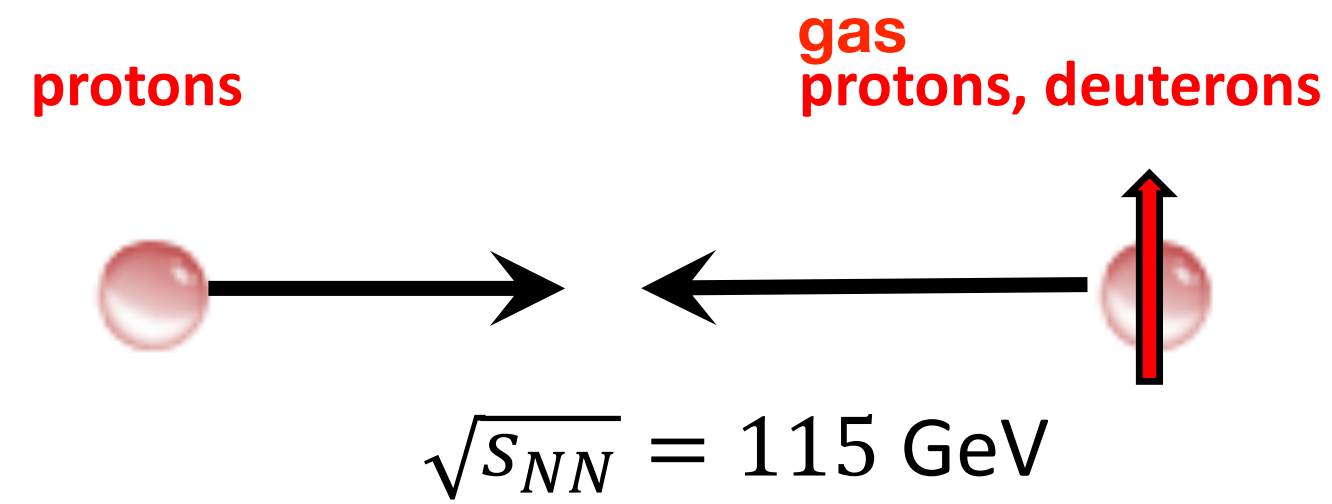


# Fixed target at LHCb

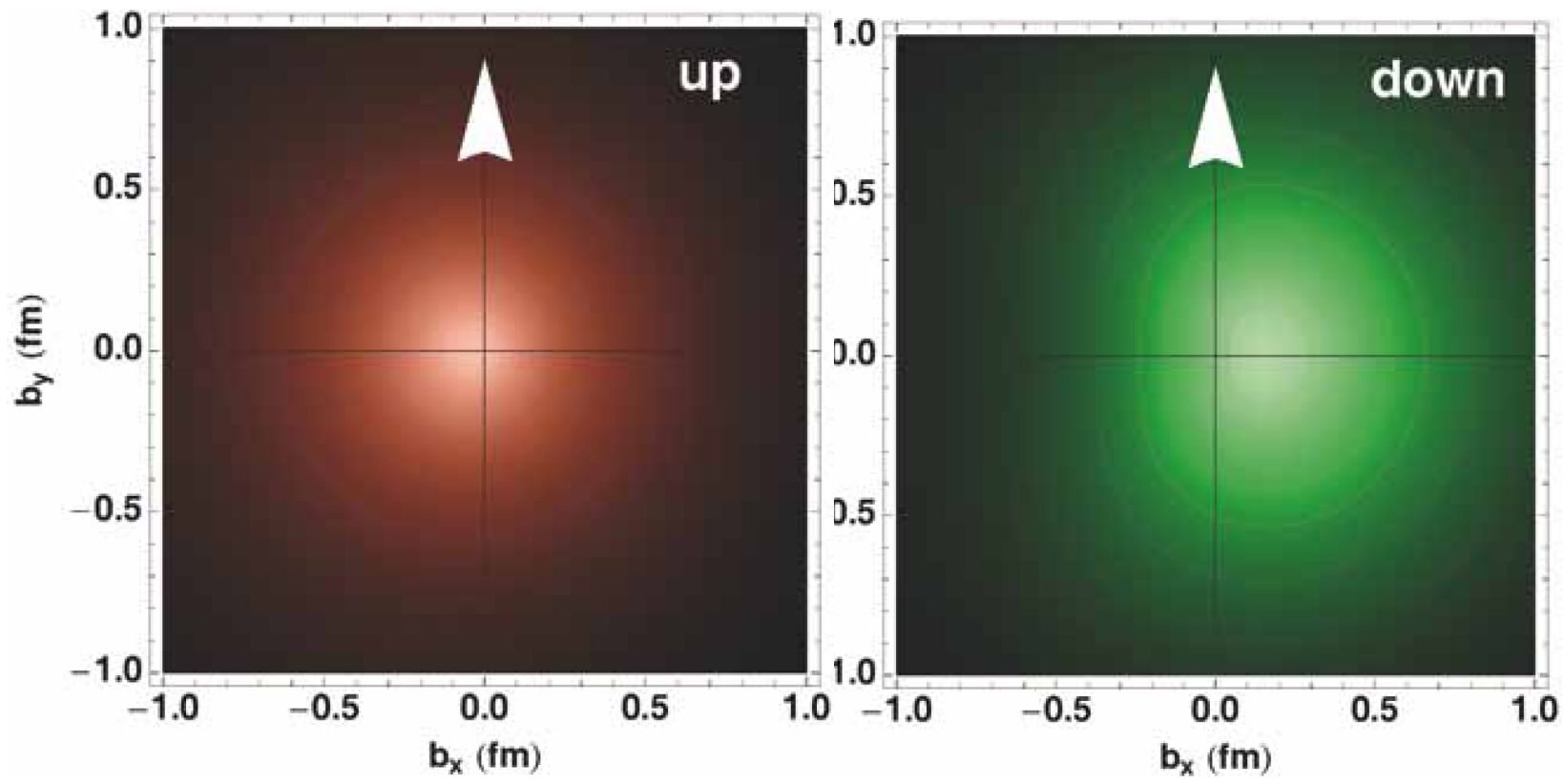
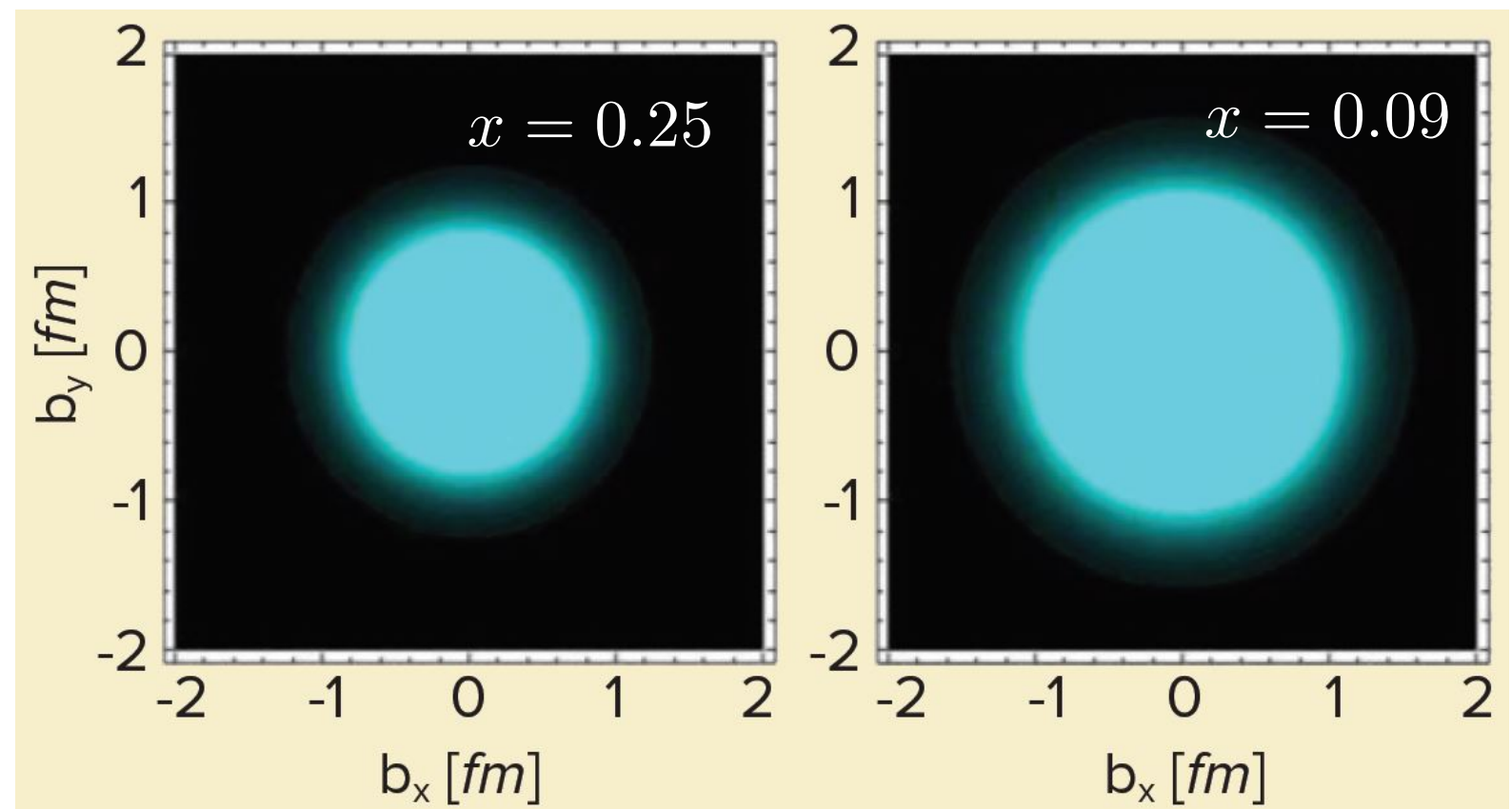
Proposal for Run 5:



LHCSPIN: transversely polarised gas target



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



# Summary

- Exclusive single-quarkonium production in pp:
  - unique potential to constrain GPDs at very low  $x_B$ , down to  $10^{-6}$
  - probe universality
- Exclusive single-quarkonium production in PbPb:
  - access to nuclear GPDs
  - potential to probe saturation effects
- Fixed target: potential to constrain GPDs in the poorly constrained high  $x_B$  region,