

Probing nPDF at LHC using electromagnetic processes and quarkonium production

General assembly of GDR QCD
Oct 2026-Nantes

Djessy Bourgeais
with François Arleo, Paul Caucal and Greg Jackson

- 1. Motivations**
- 2. Fully coherent energy loss**
- 3. Prompt photons**
- 4. Quarkonium production**
- 5. Conclusion**

1. Motivations

2. Fully coherent energy loss

3. Prompt photons

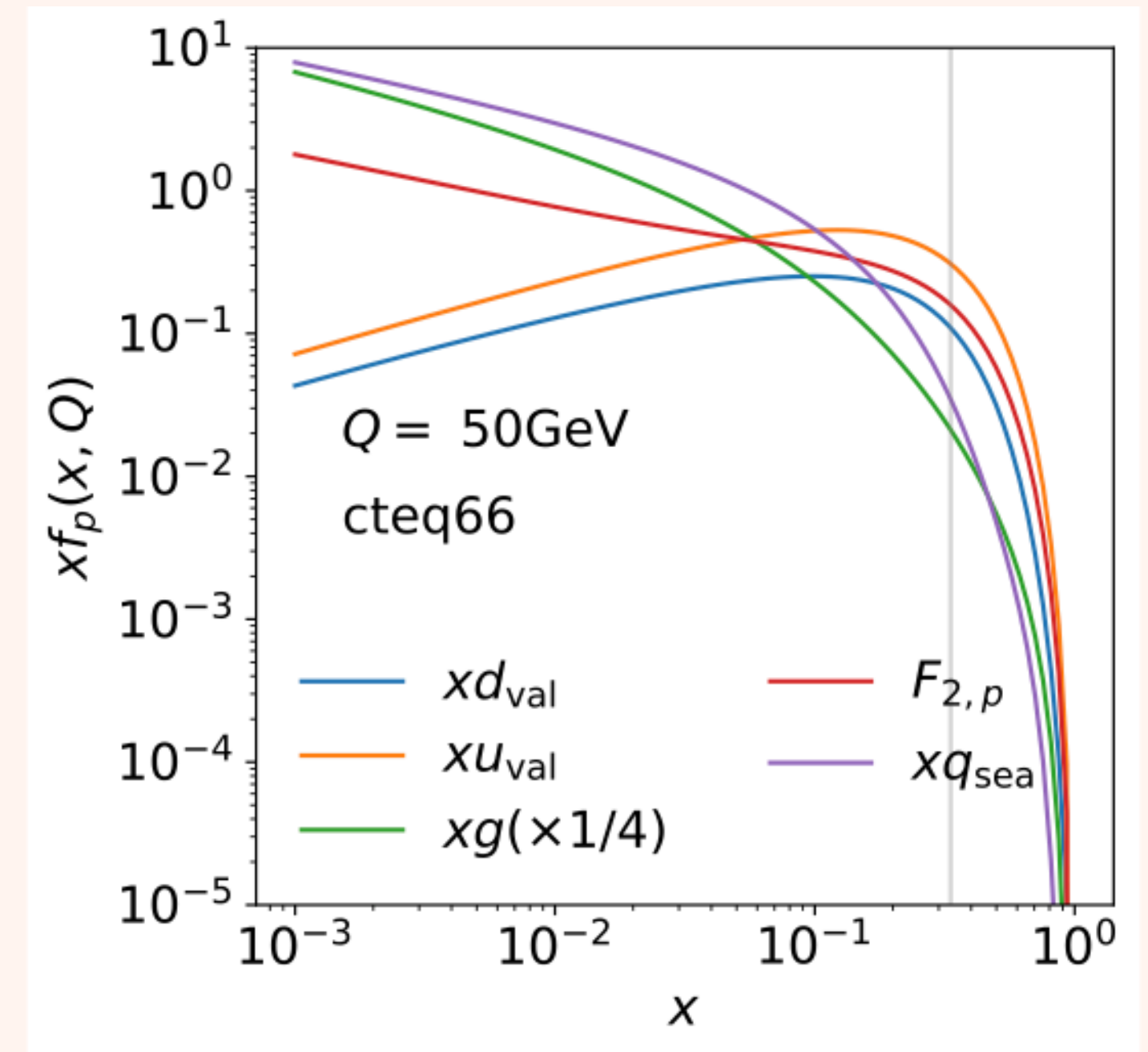
4. Quarkonium production

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Motivations

Parton distribution functions (PDFs)

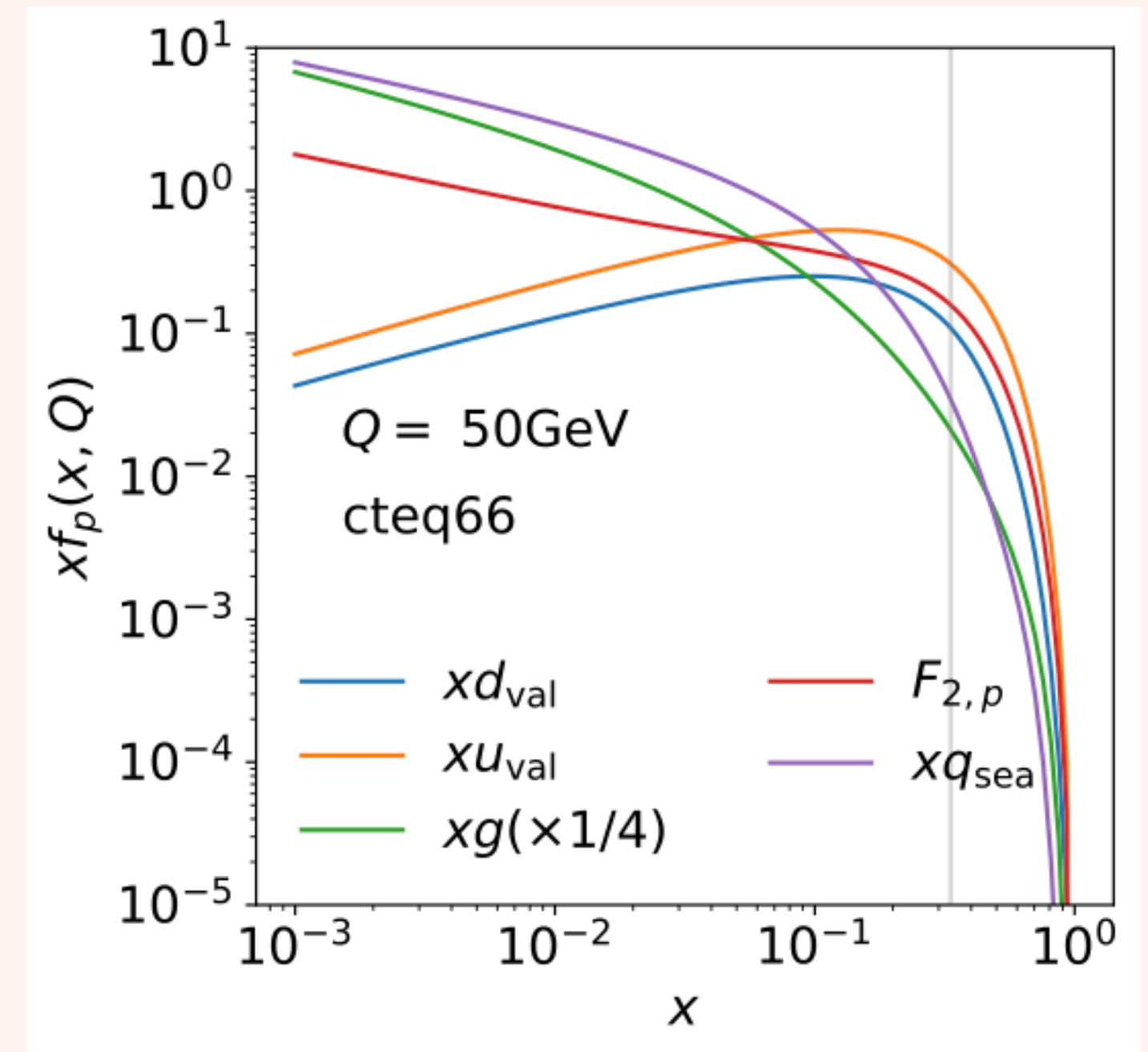
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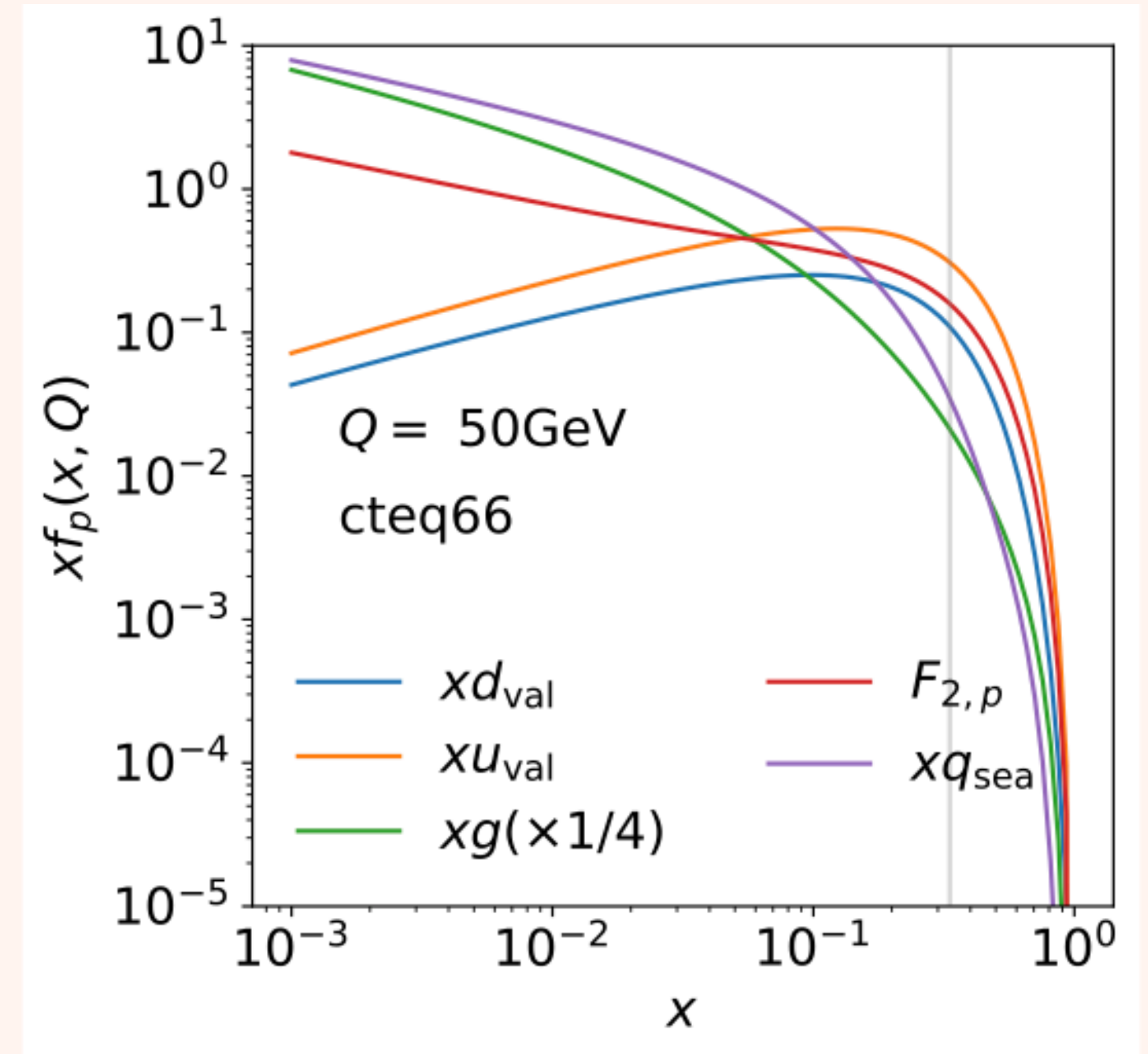
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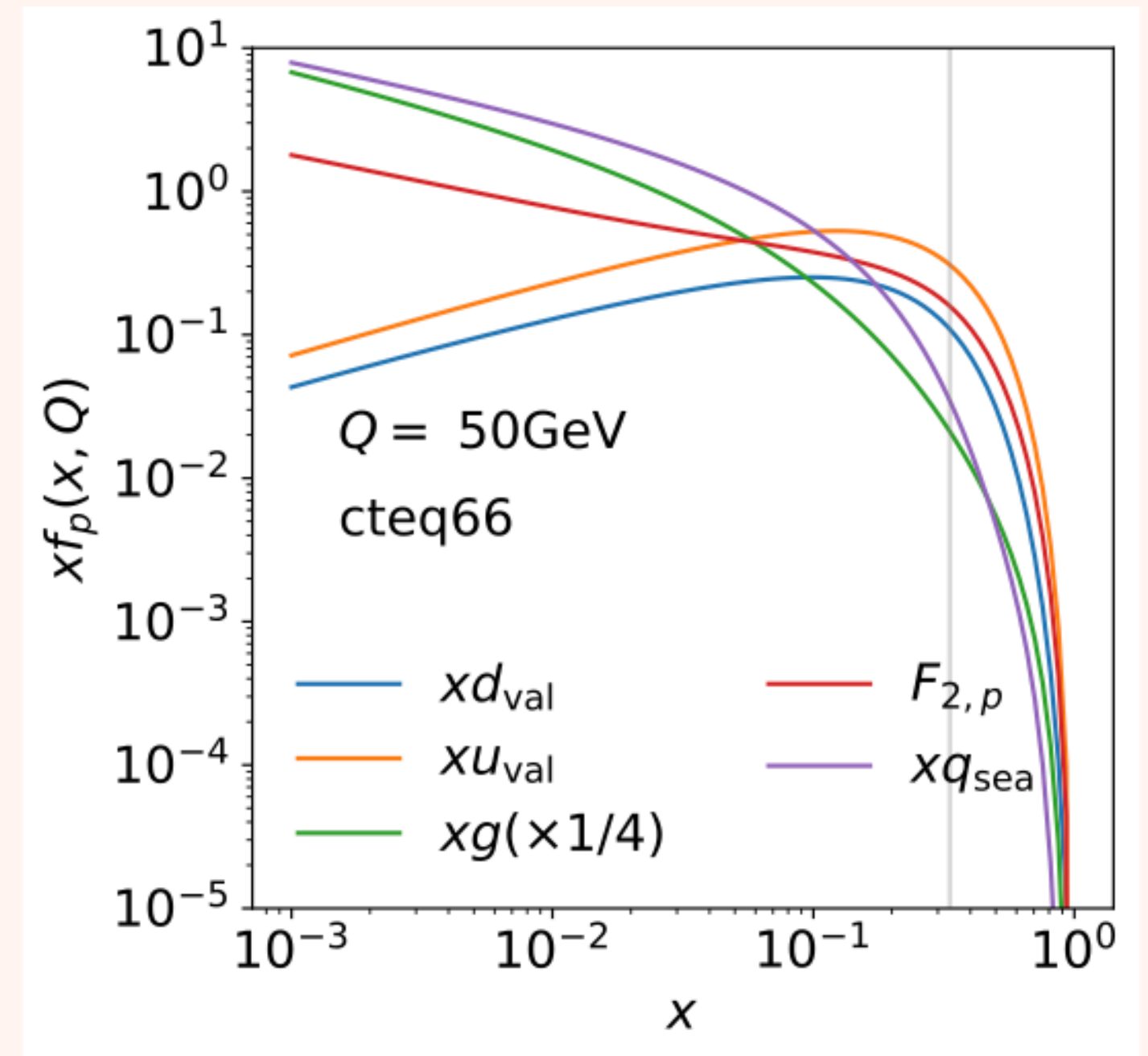
- Universal objects in pQCD
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- Not directly computable
 - Extracted from global fits on data



Motivations

Parton distribution functions (PDFs)

- Universal objects in pQCD
 - Independent of the collision system
 - Describes the presence of partons
- Not directly computable
 - Extracted from global fits on data
- Several collaborations extract PDFs using different processes
 - F_2 in DIS, Drell-Yan, Jets, ...

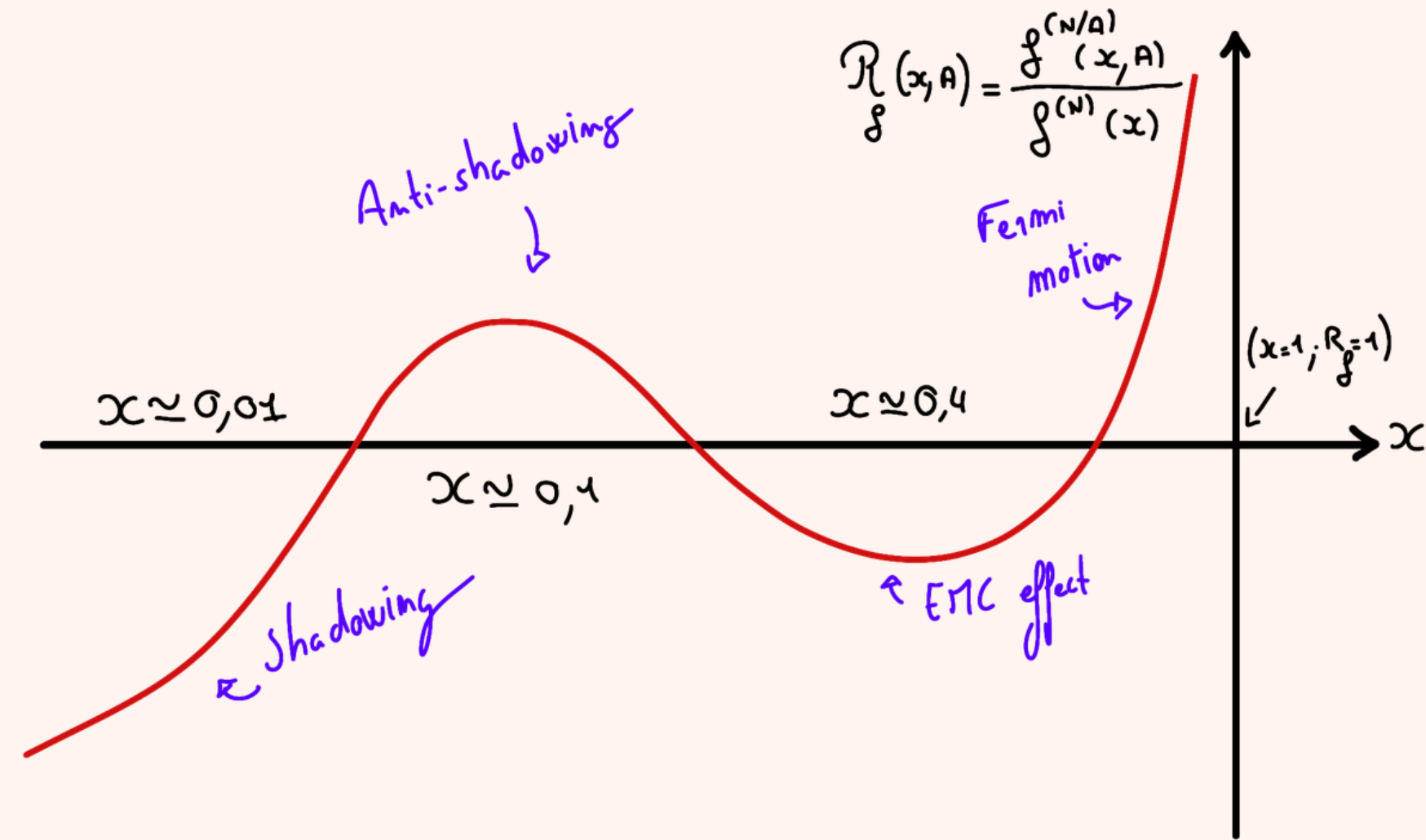


Motivations

Nuclear PDFs (nPDFs)

- PDFs are modified in nuclei

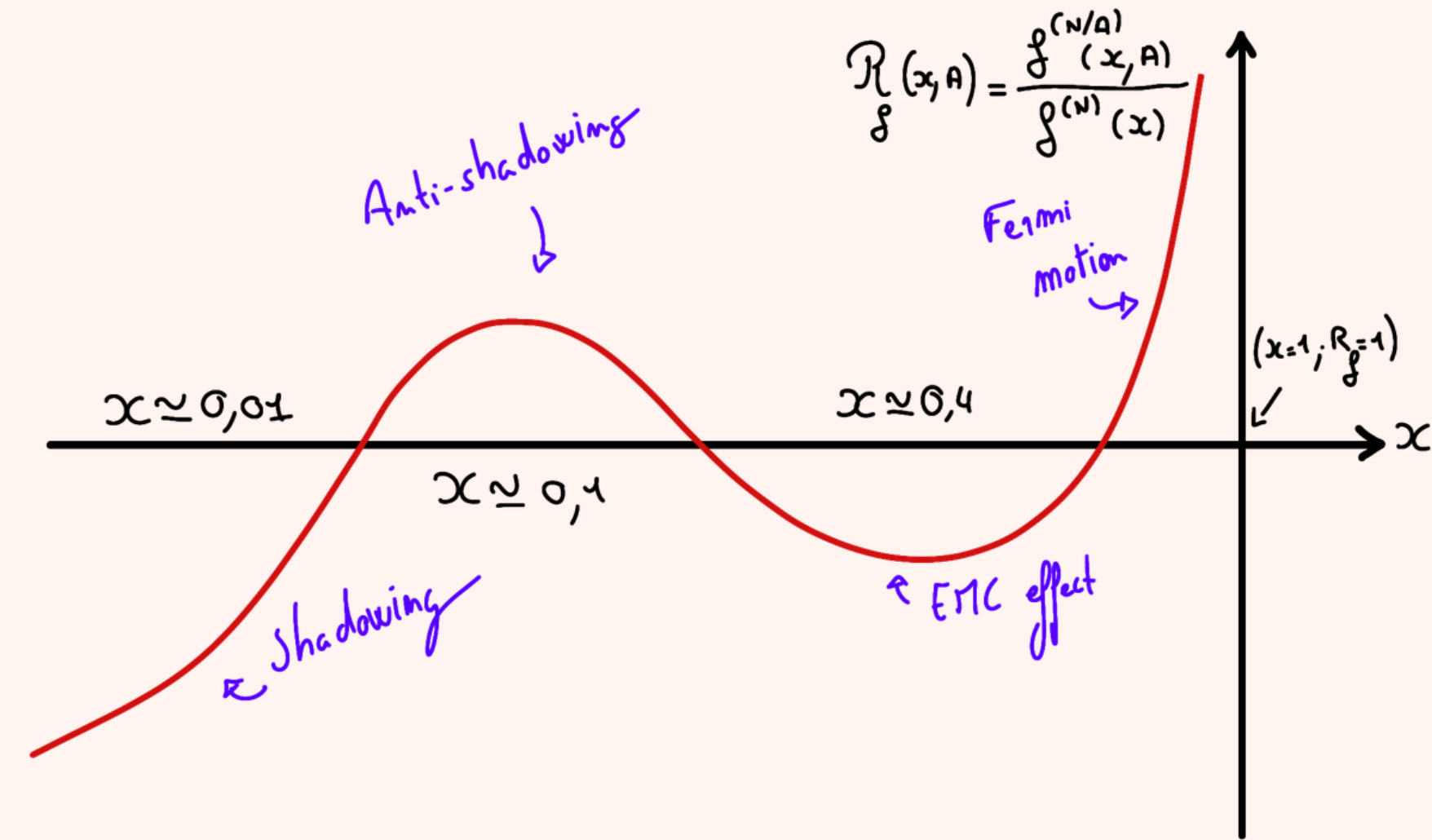
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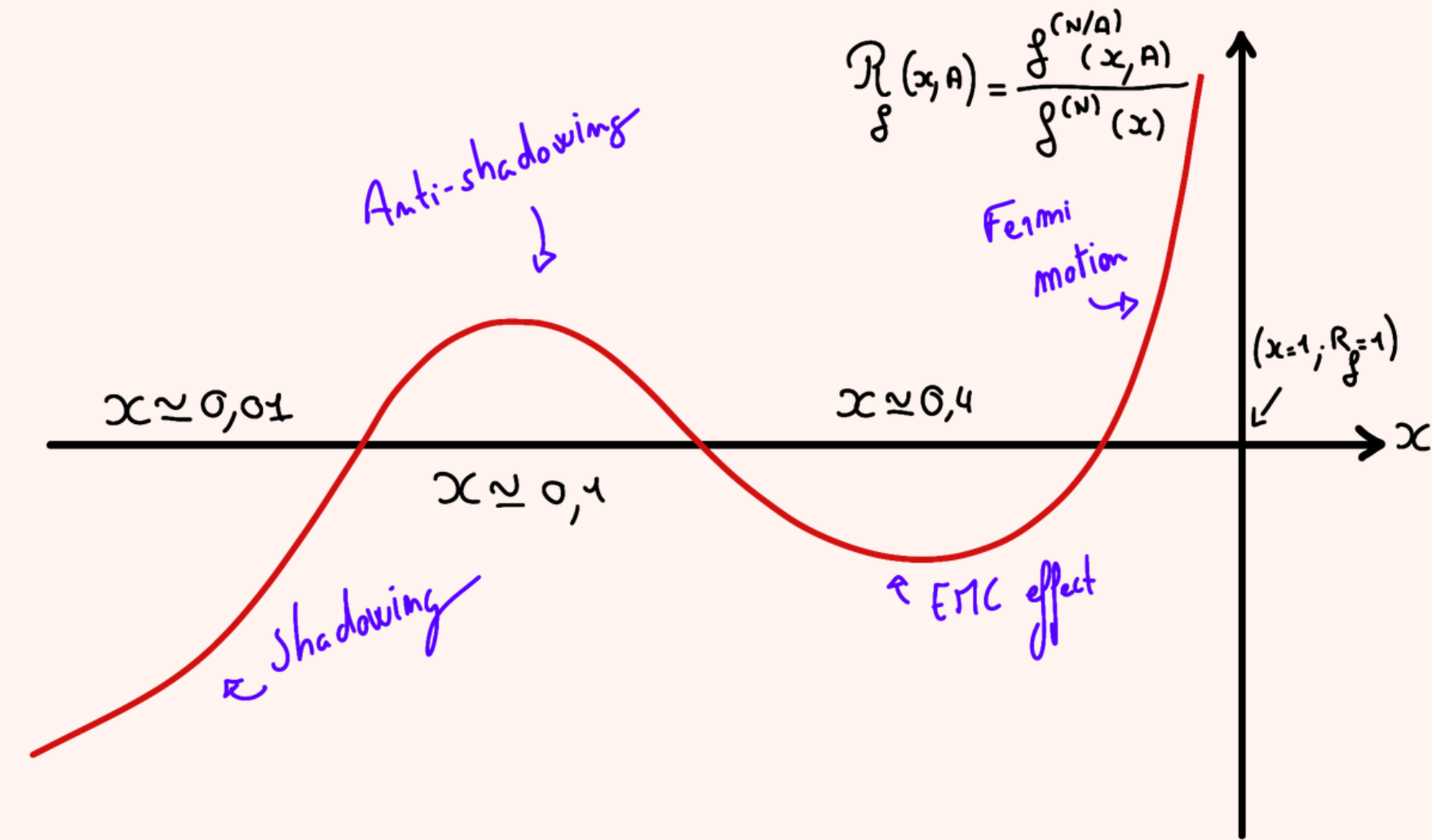
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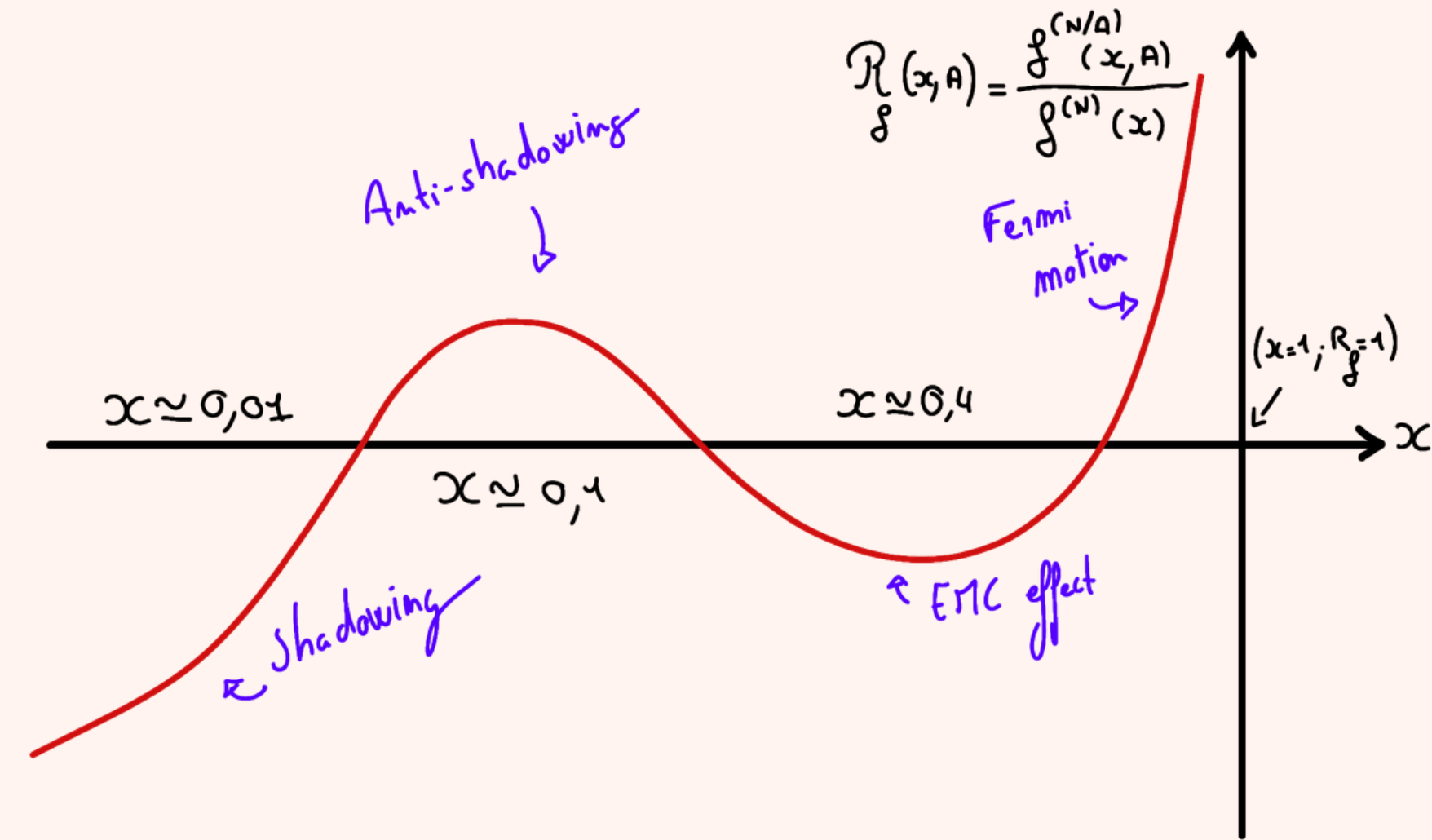
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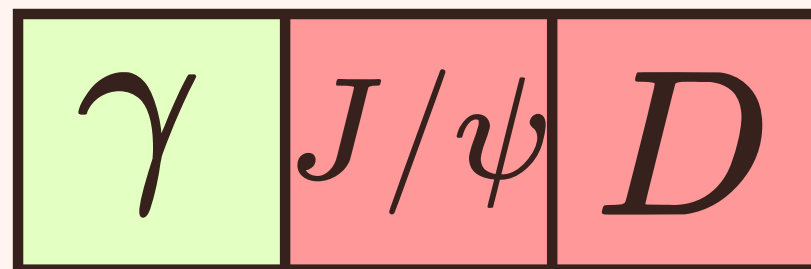
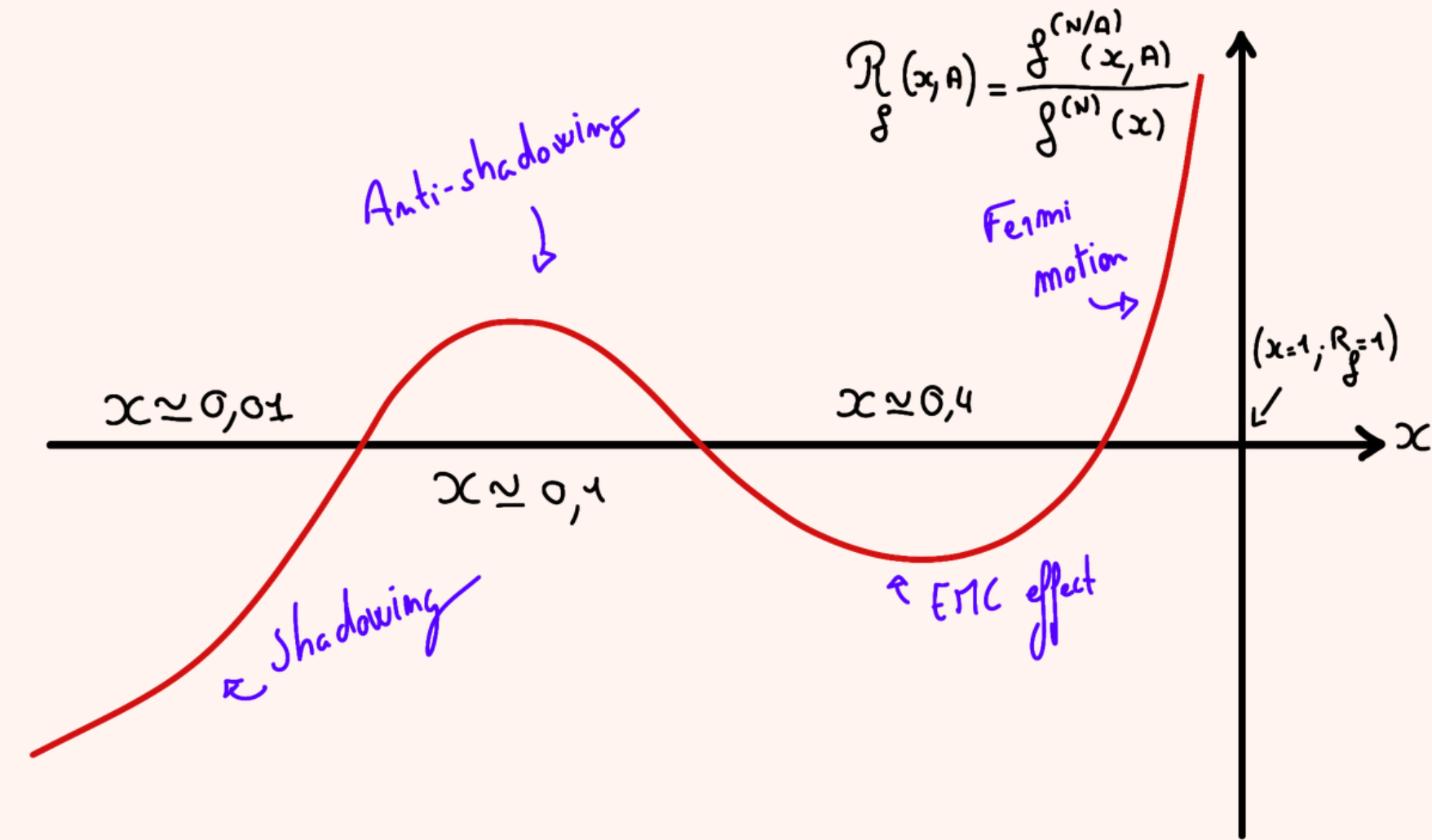
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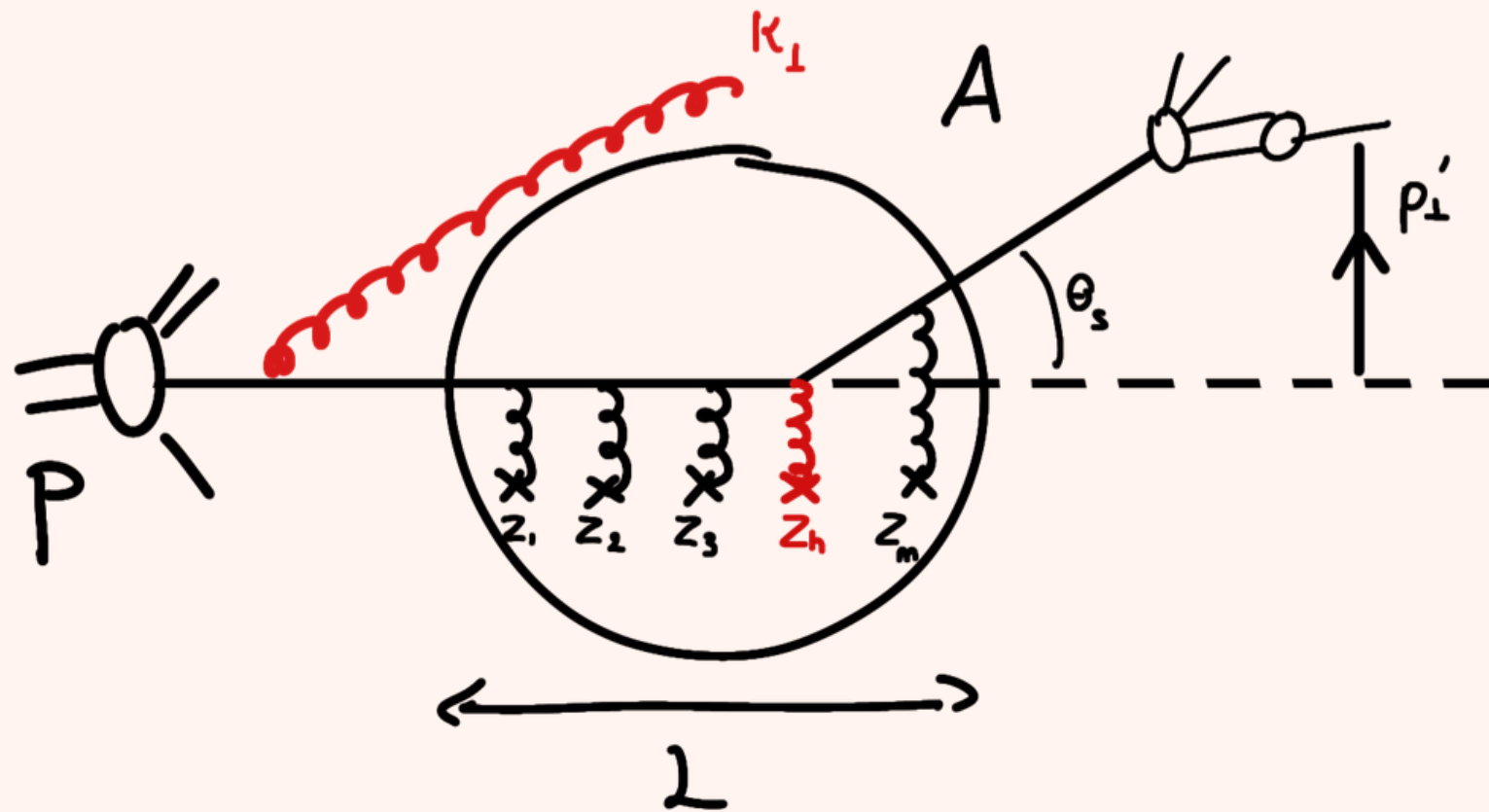
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- Solution: include more constraining data



... but sensitive to another nuclear effect

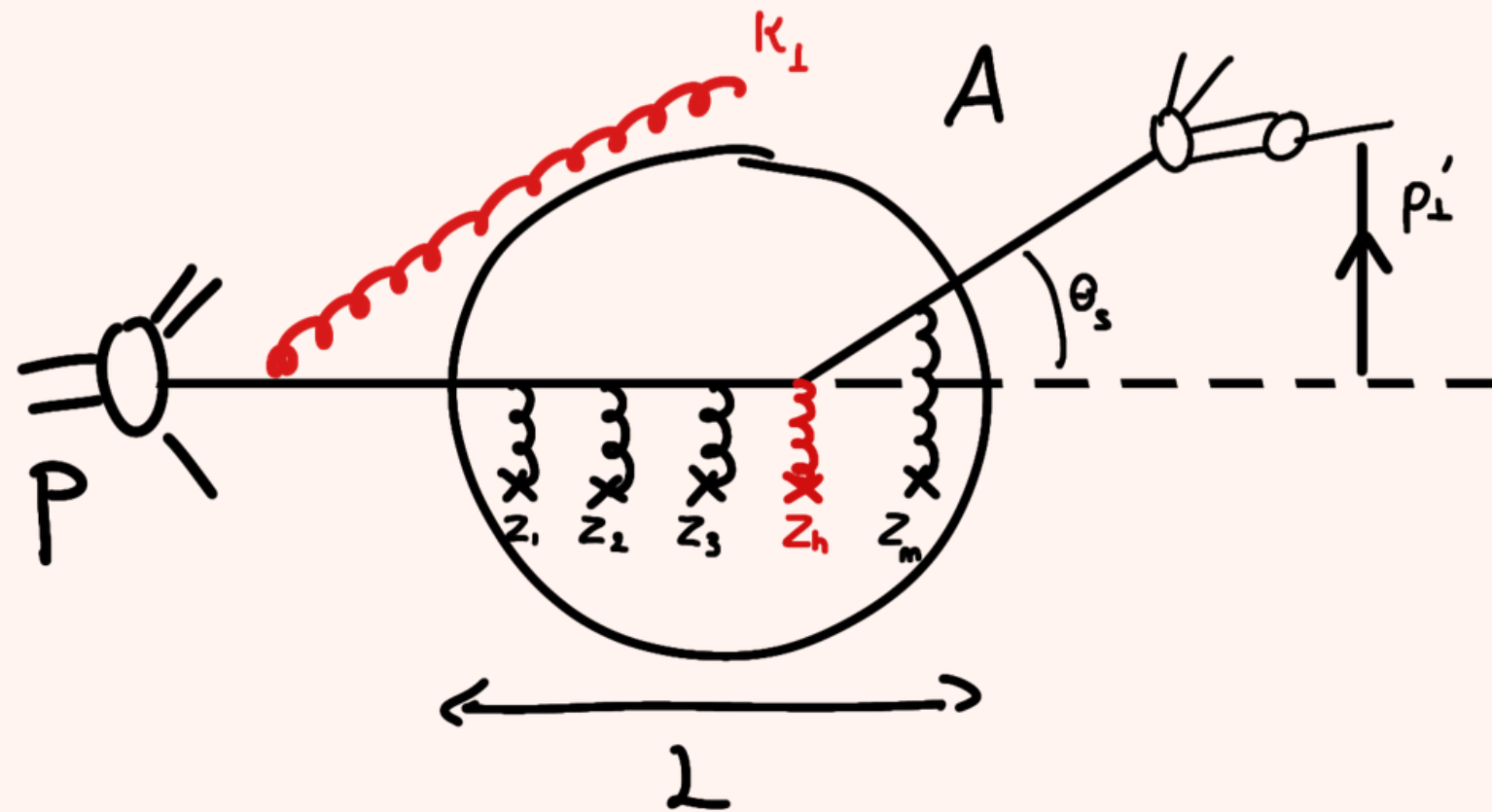
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Fully coherent energy loss (FCEL)



Induced gluon radiation due to
multiple parton scattering

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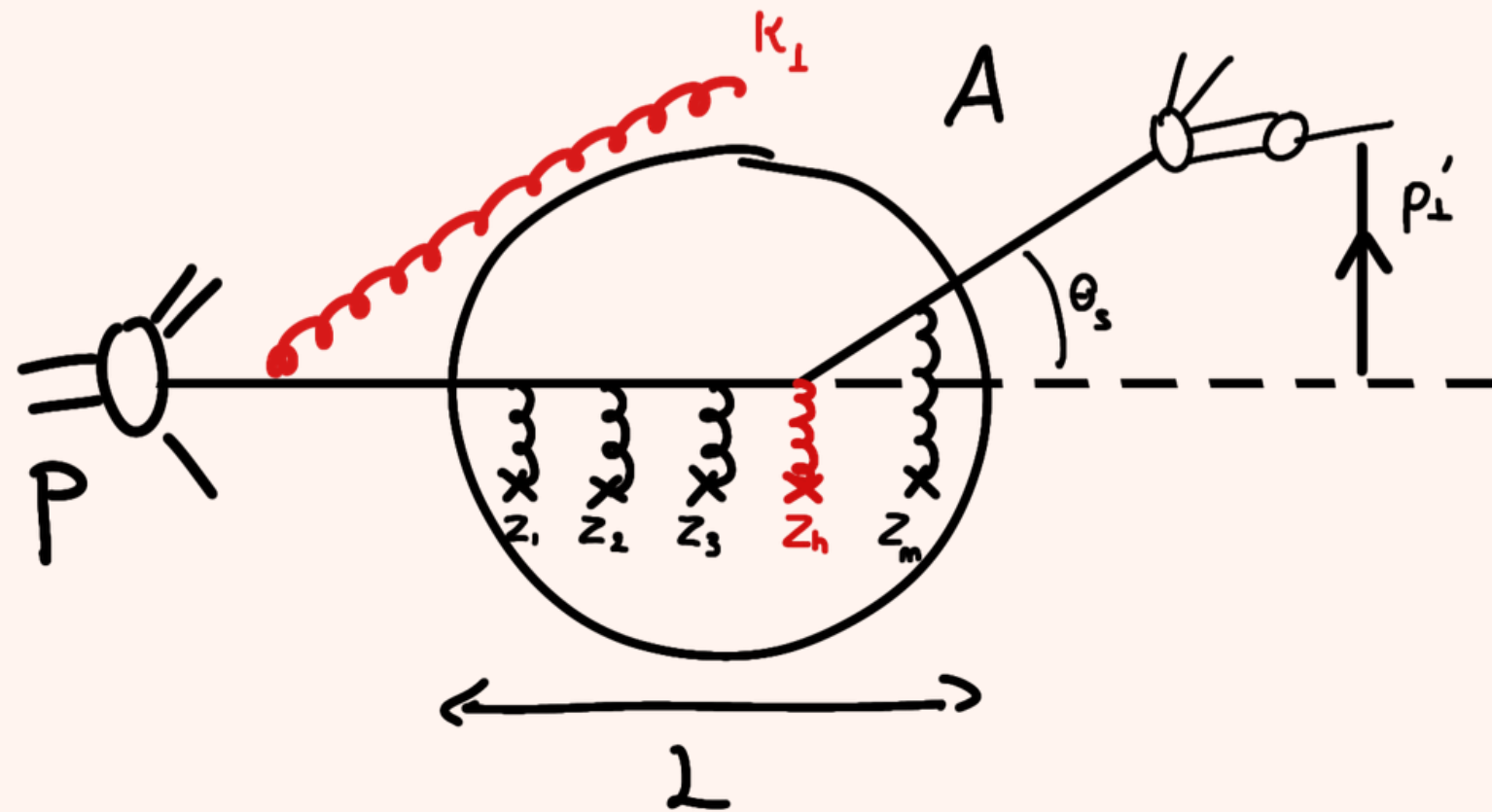


Average energy loss

$$\Delta E_{\text{FCEL}} \propto \alpha_s (Q_s / M_\perp) E$$

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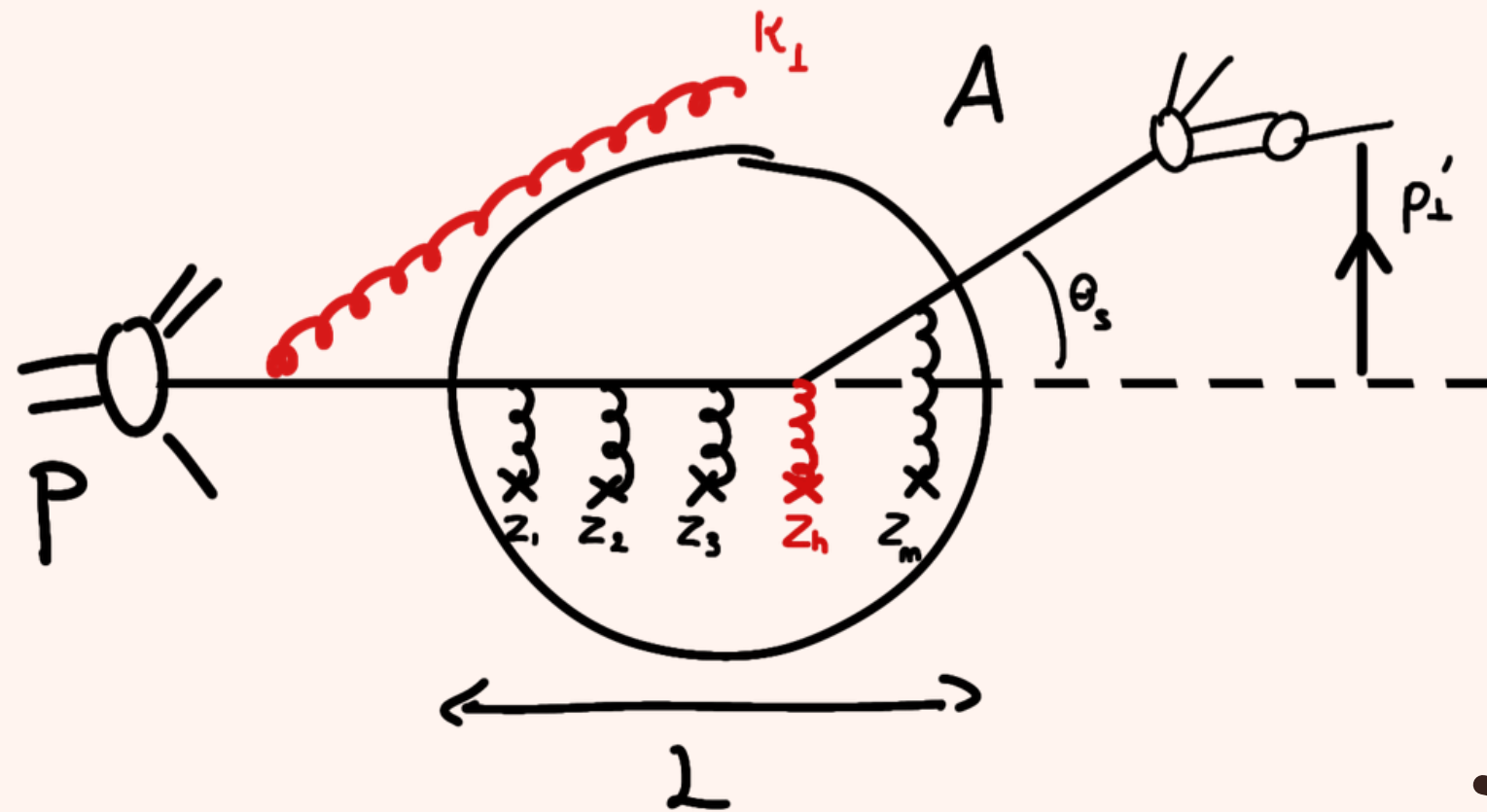
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Needs **color** in both initial and final states

→ No effect in DIS nor DY at LO

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Applied to a **variety of processes** in pA collisions

quarkonia, open heavy flavour, light hadrons, atmospheric neutrinos

Fully coherent energy loss (FCEL)

Considering a generic process in pA collision: $ab \rightarrow [cd]_R$  Color irrep

$$\frac{d\sigma_{\text{pA,FCEL}}^R}{dE d\xi}(E) = \int_0^{\epsilon_{\text{max}}} d\epsilon \mathcal{P}^R(\epsilon, E, |F|, \xi) \frac{d\sigma_{\text{pA}}^R}{dE d\xi}(E + \text{sgn}(F) \epsilon)$$

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To a first approximation, FCEL effects are **sensitive to the slope** (in E or y) of the cross section

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(first part of this talk)

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Include FCEL in pQCD calculations and
then **extract nPDFs**

 Stronger constraints from
all measurements available

 First attempt using J/ψ data
(second part of this talk)

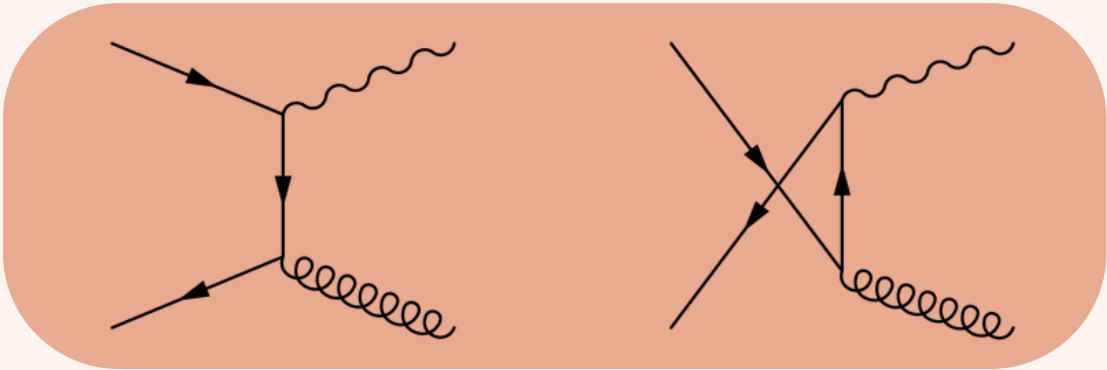
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Prompt photons

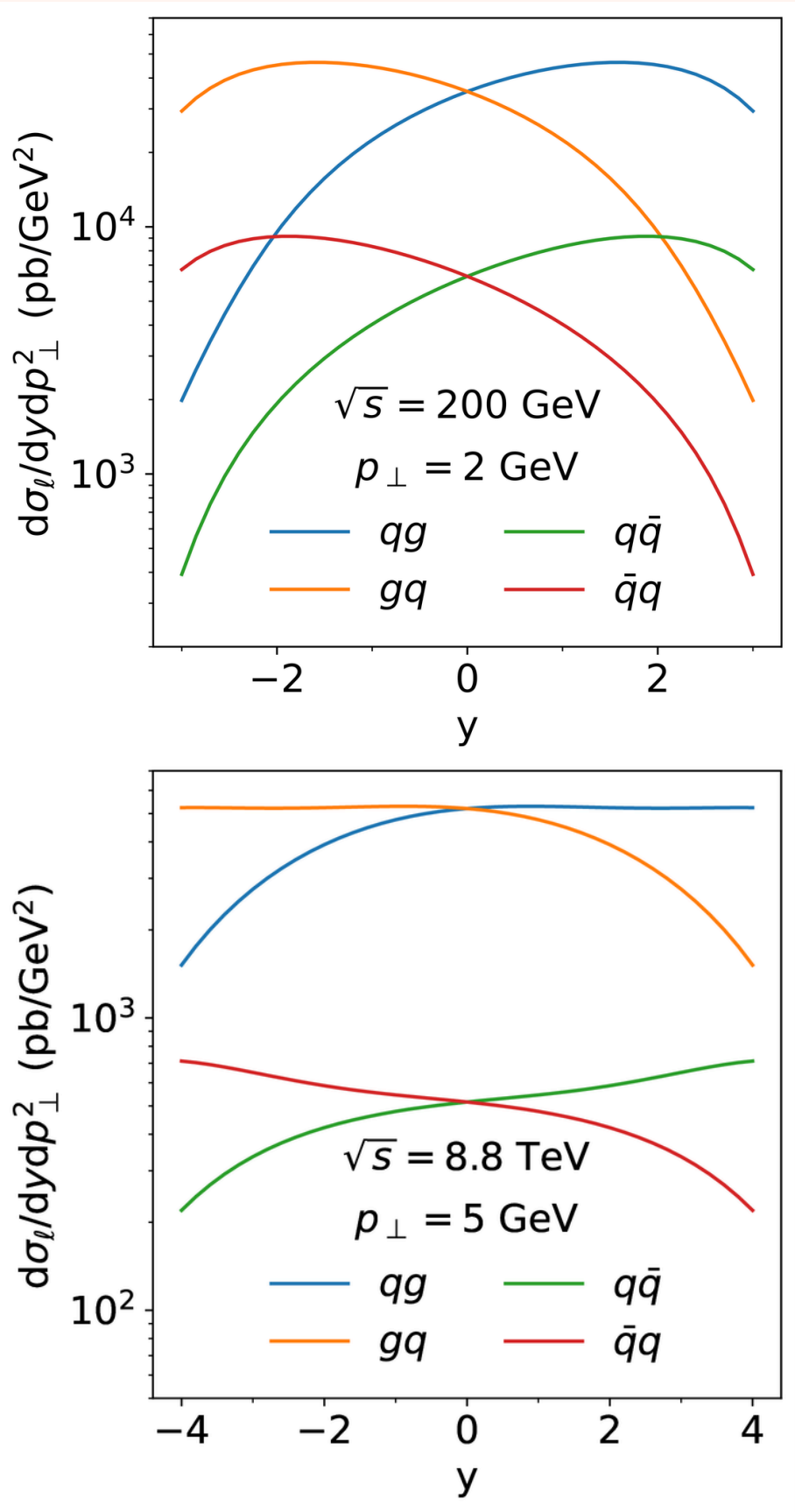
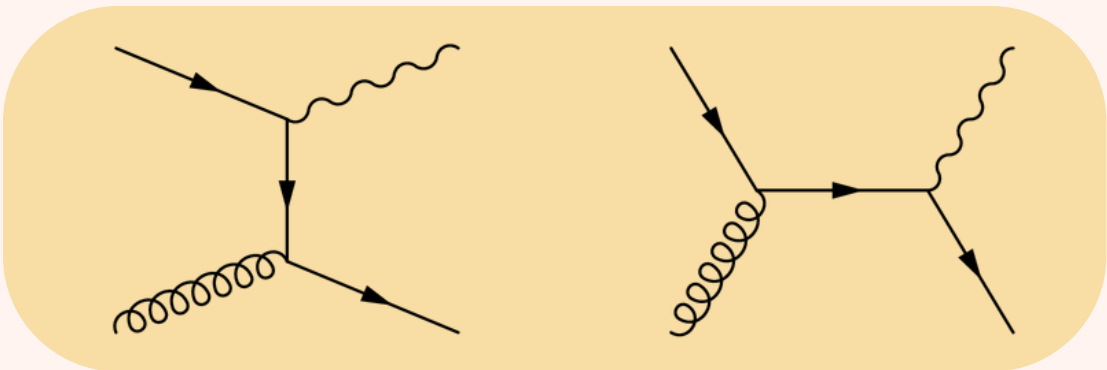
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Annihilation



Compton



RHIC

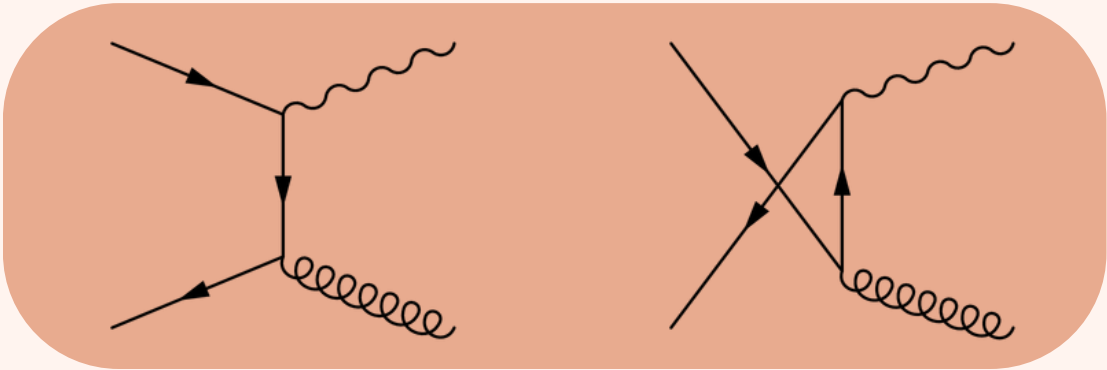
LHC

Prompt photons

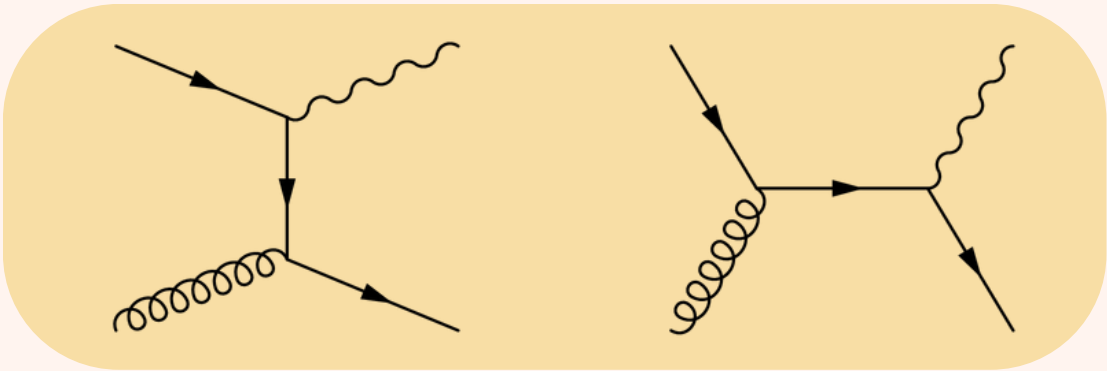
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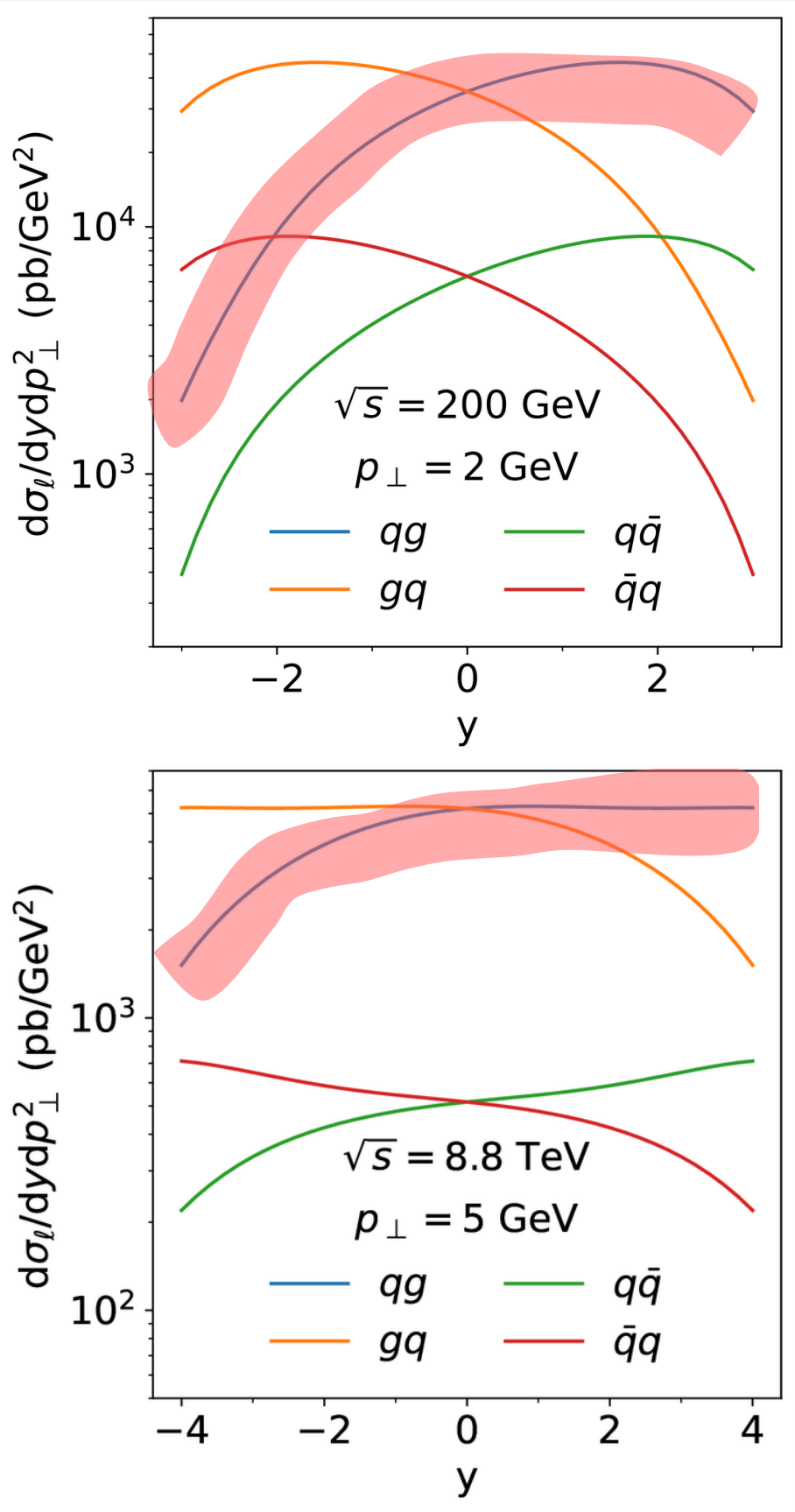
Annihilation



Compton



Energy gain



RHIC

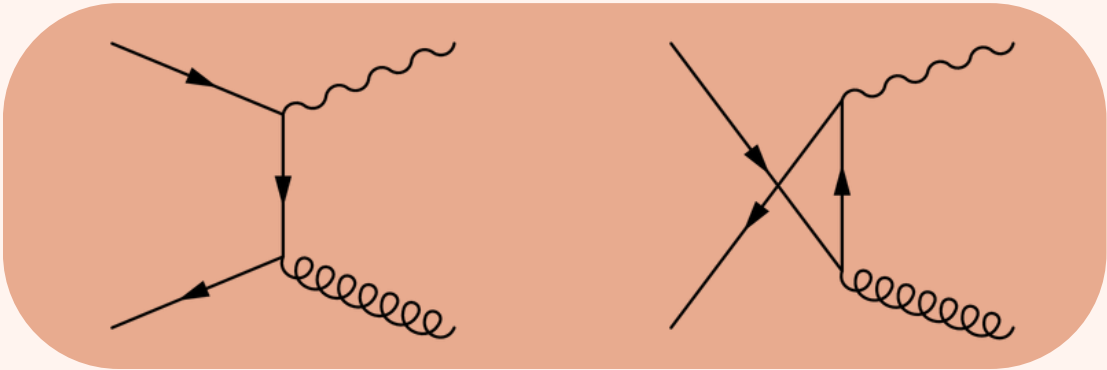
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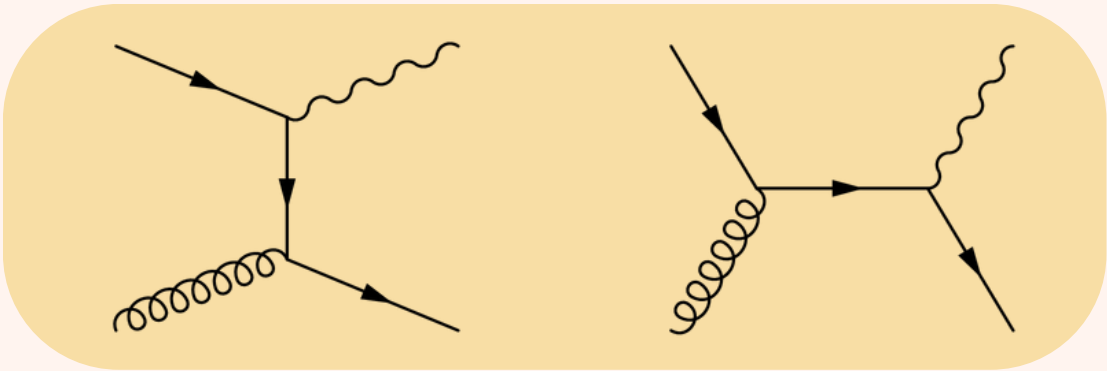
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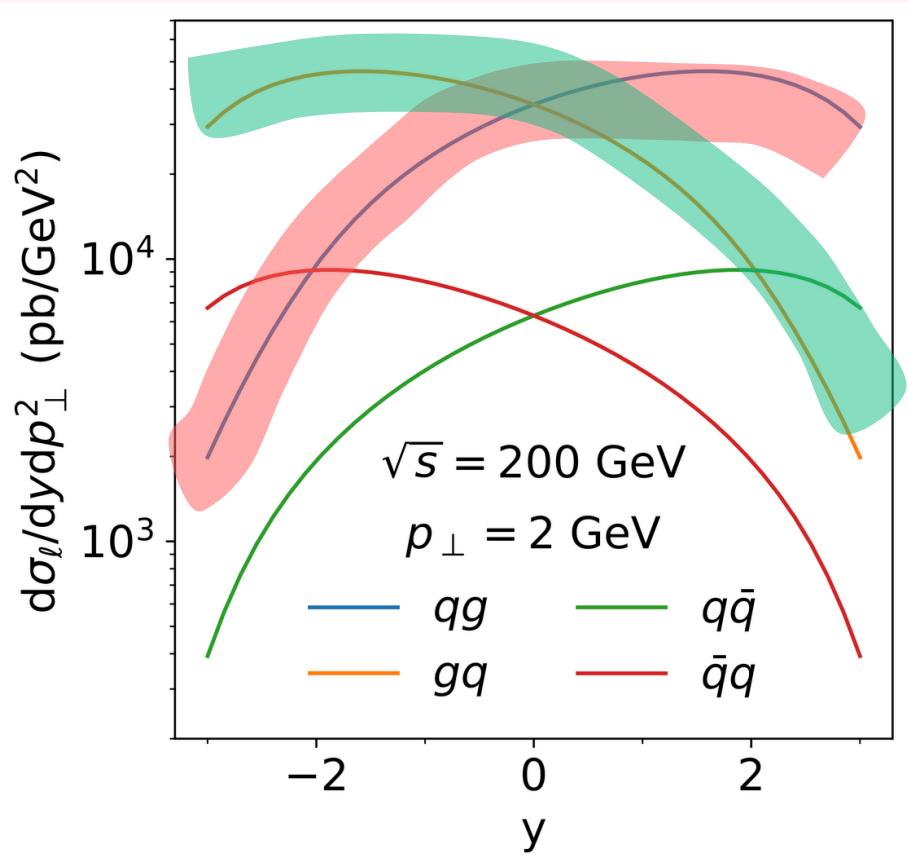
Annihilation



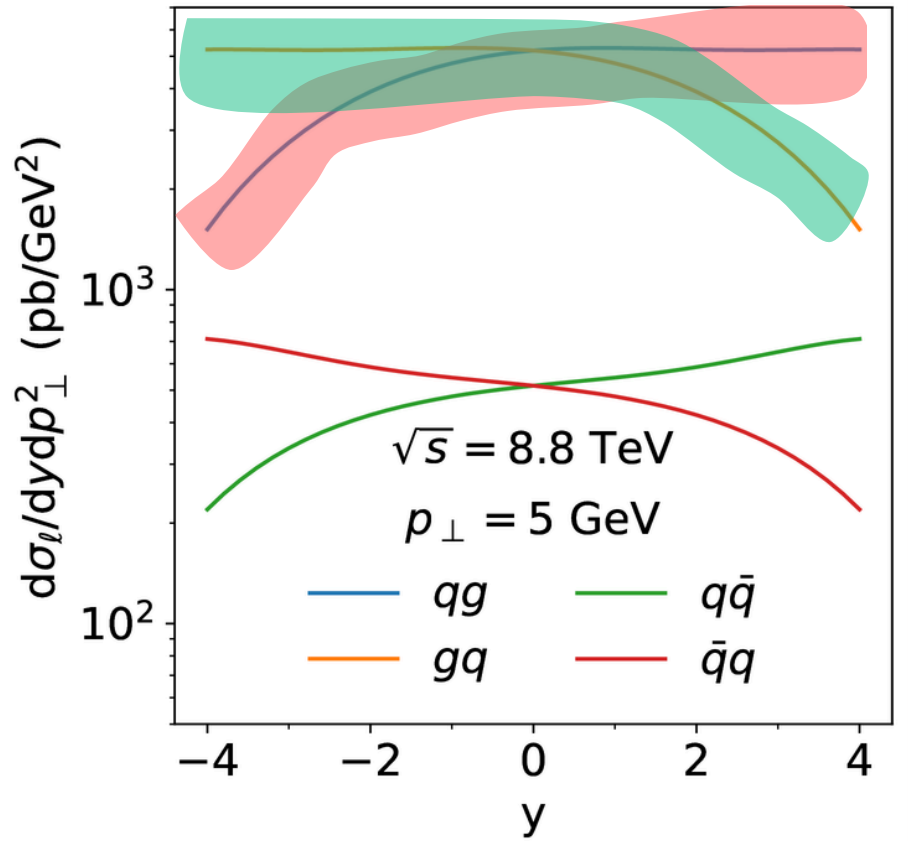
Compton



Energy gain
Energy loss



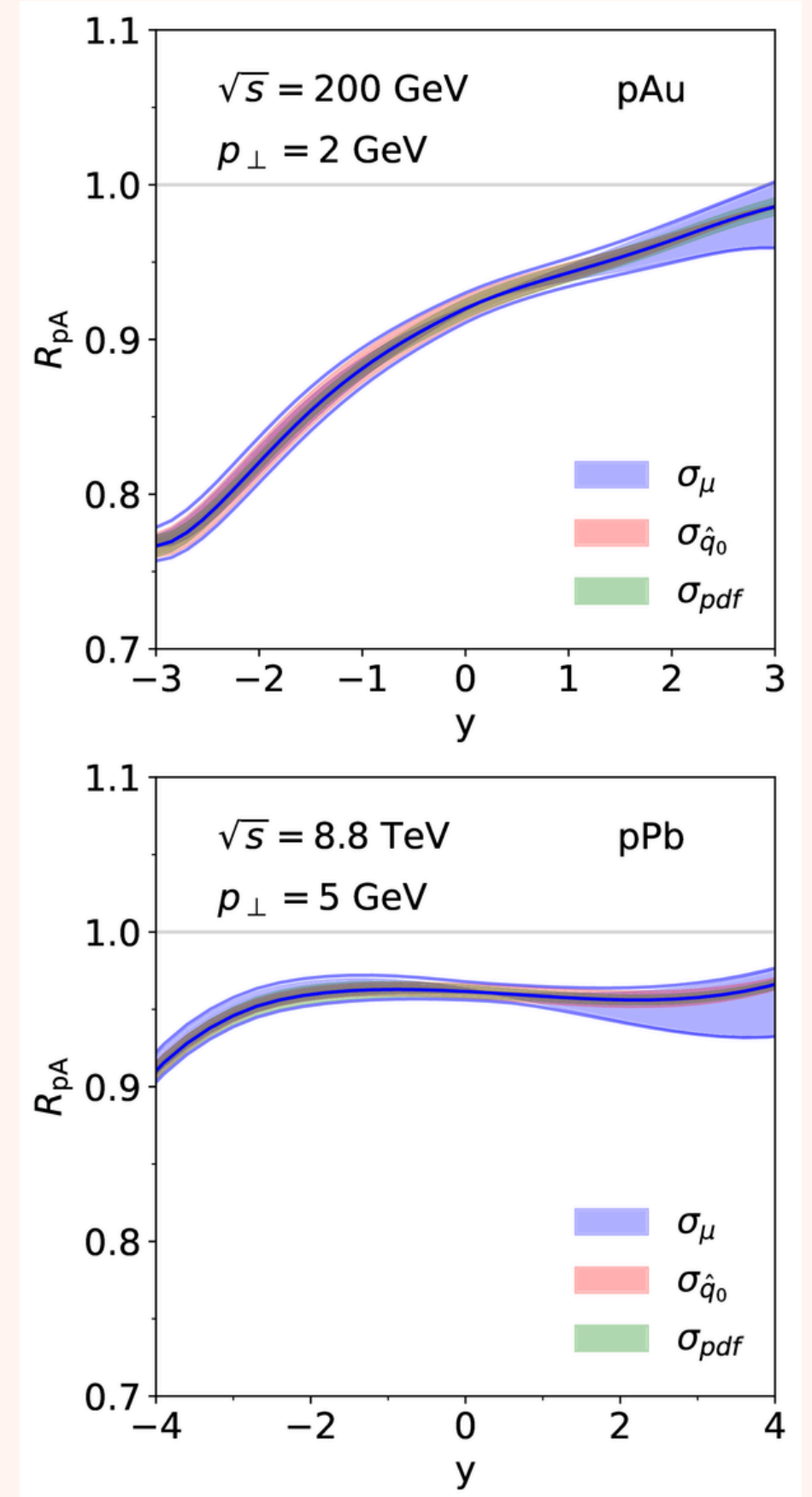
RHC



LHC

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Computing R_{pA} **without** nPDF effects $R_{pA} = \frac{1}{A} \frac{d\sigma^{pA}}{d\sigma^{pp}}$



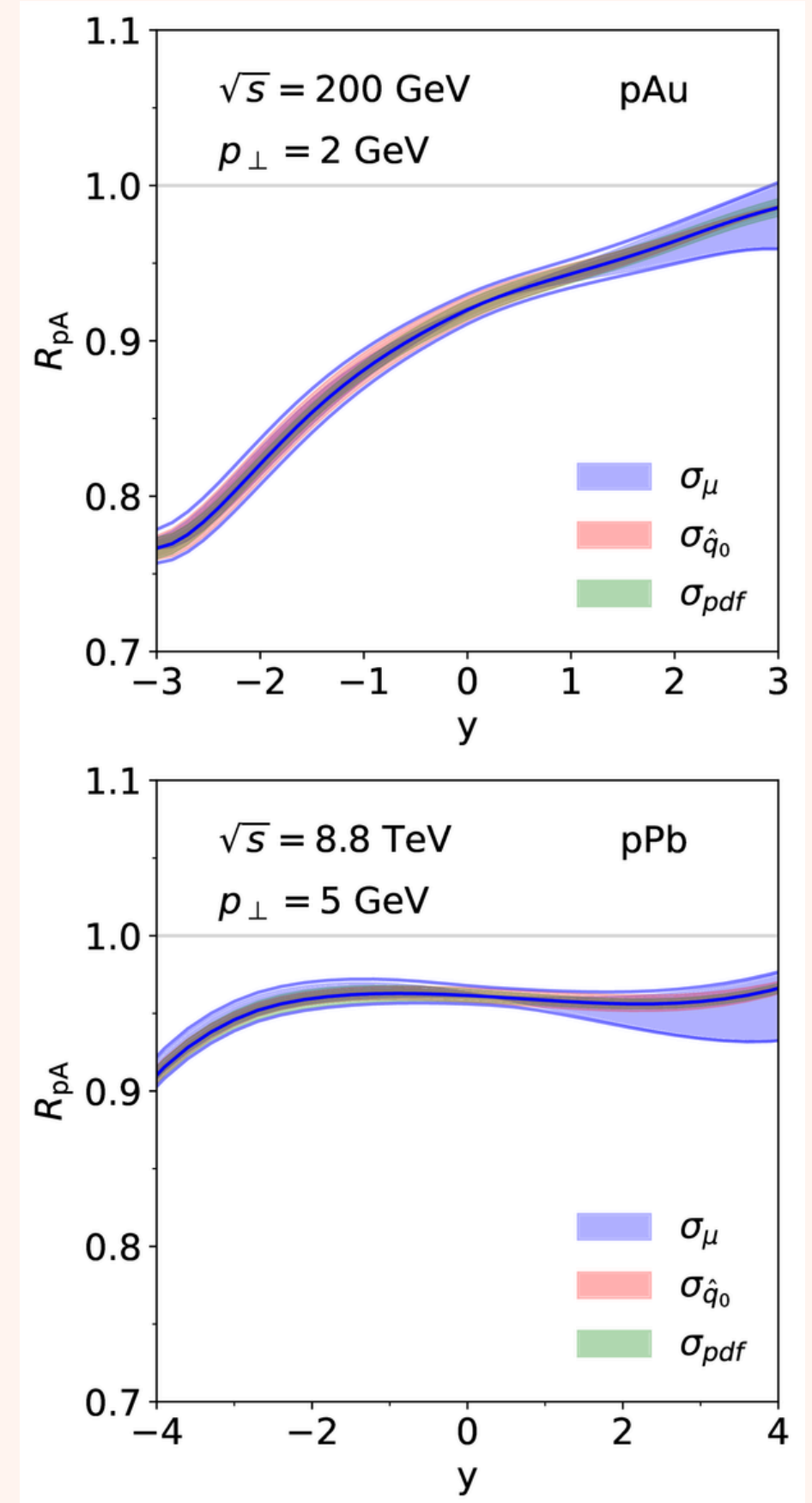
RHIC

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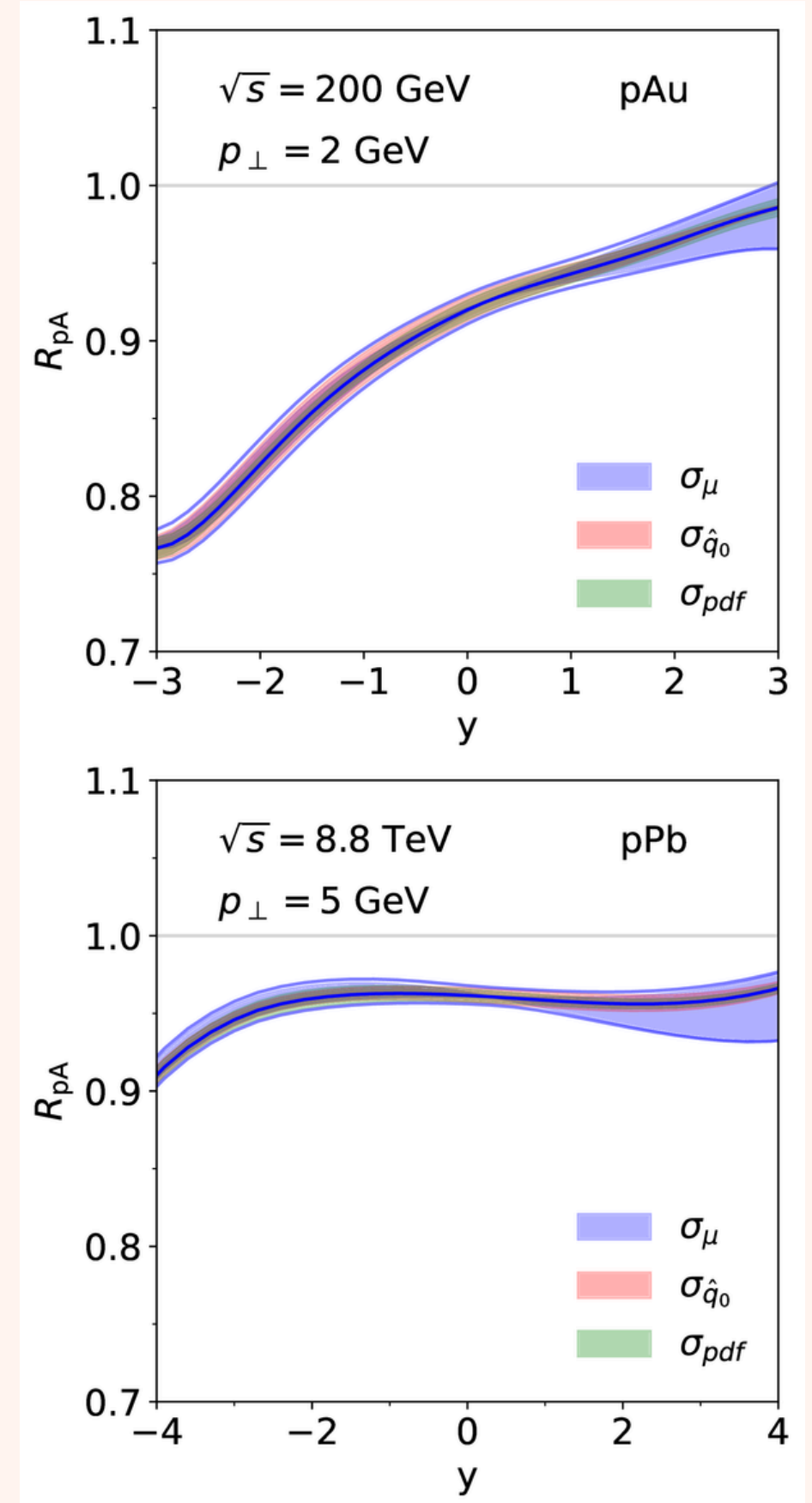
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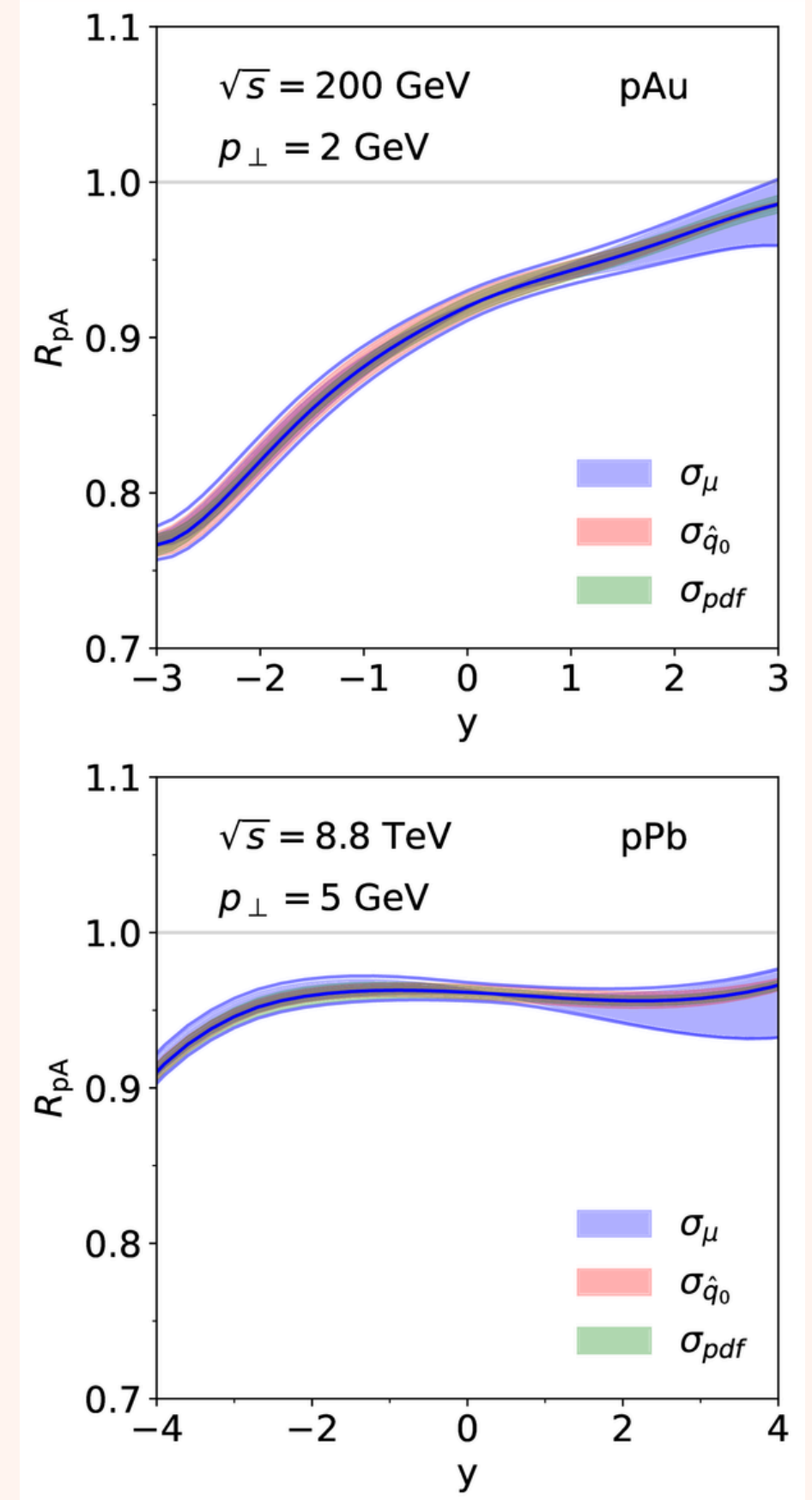
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LHC

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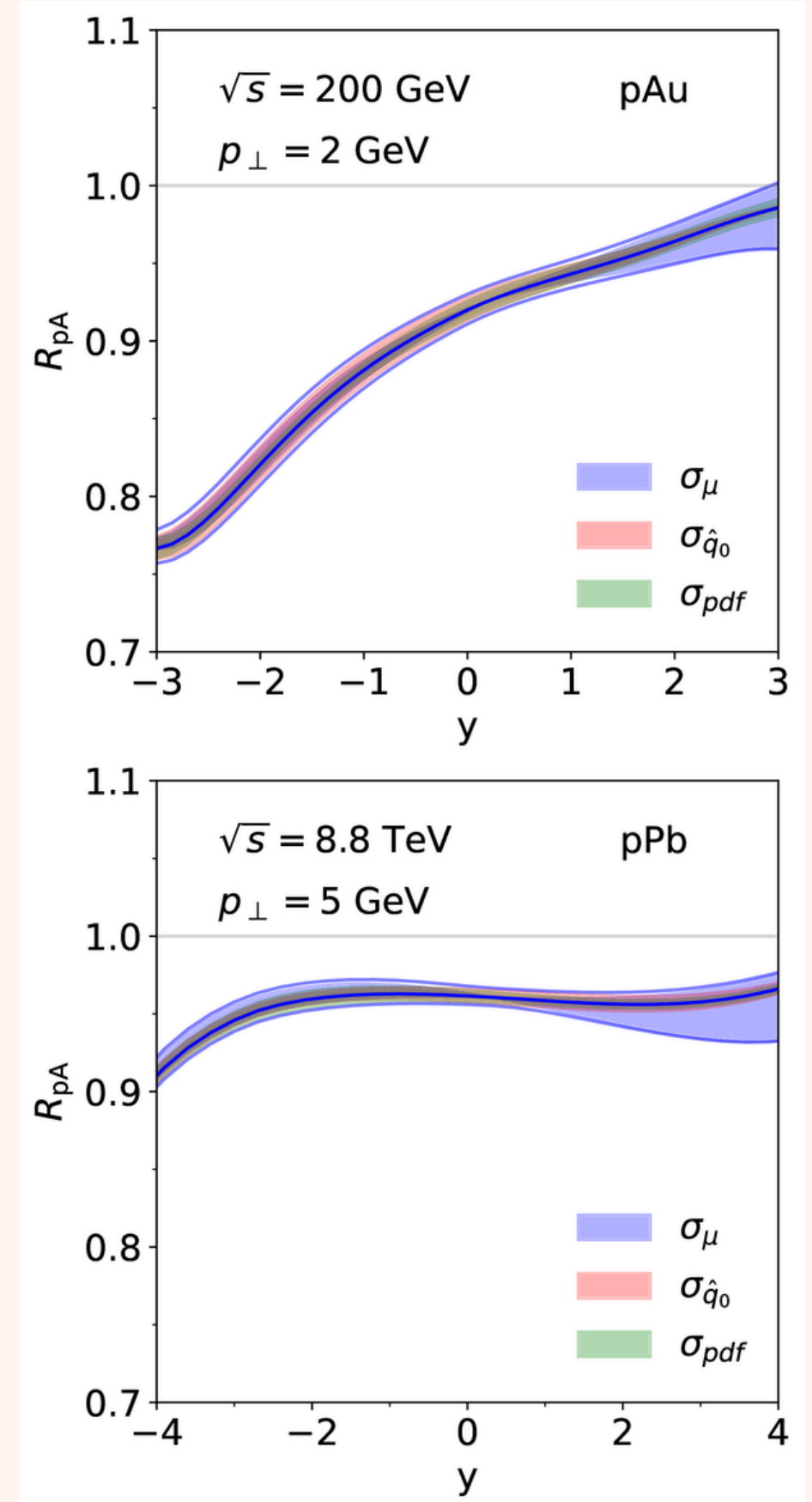
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→ Fragmentation photons have a negligible effect

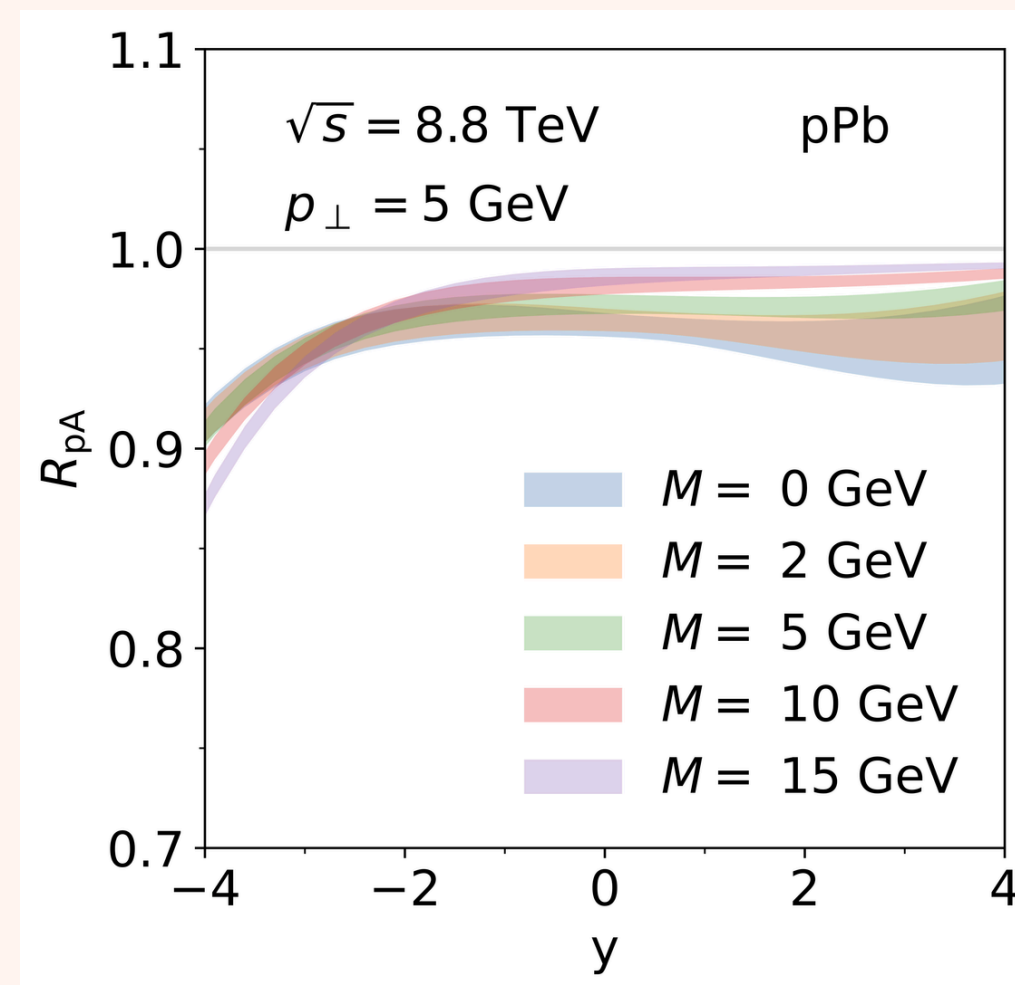
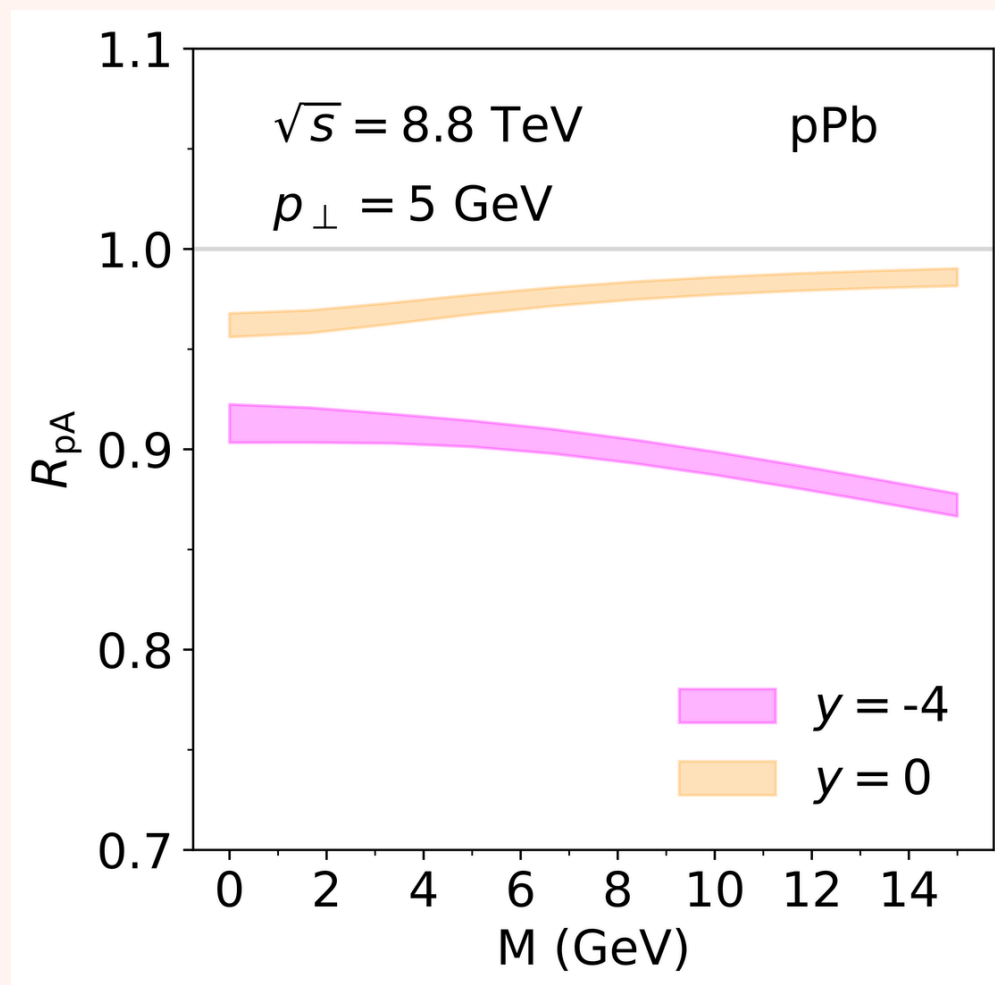


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LHC

Virtual photons

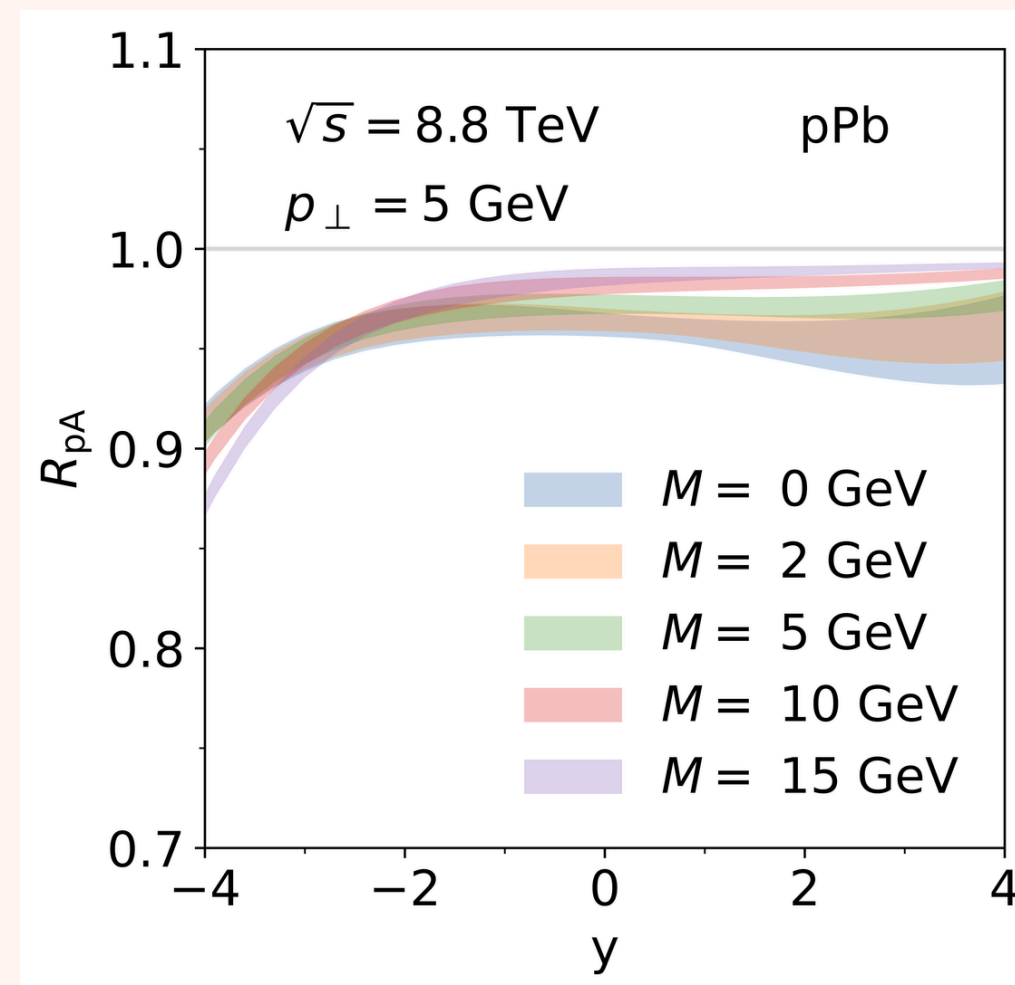
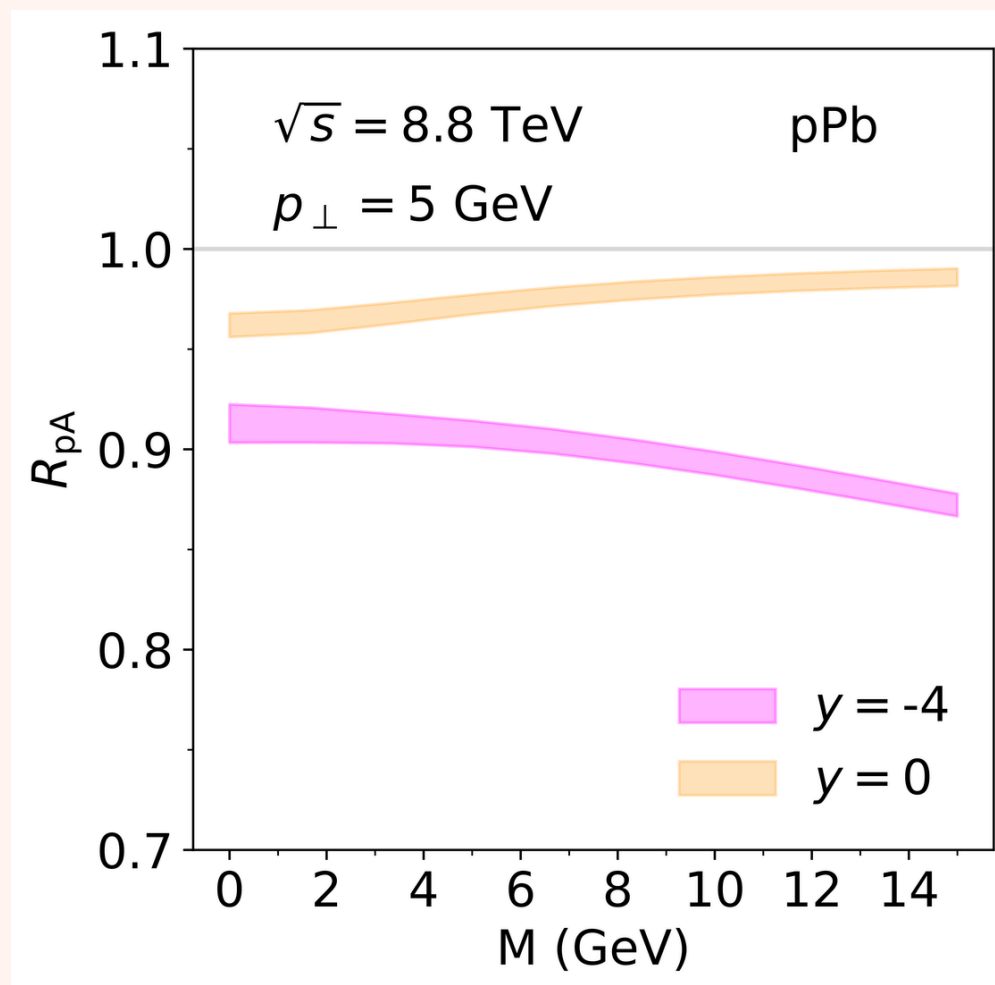
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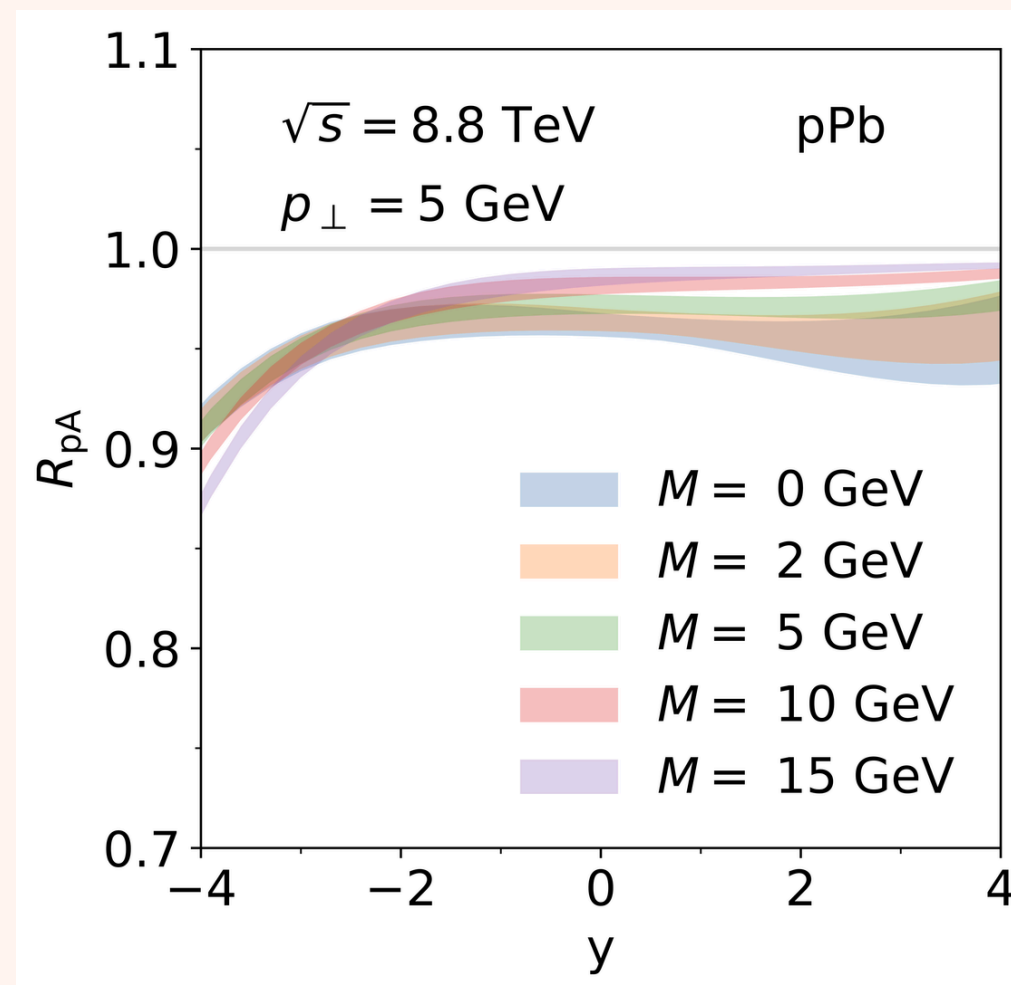
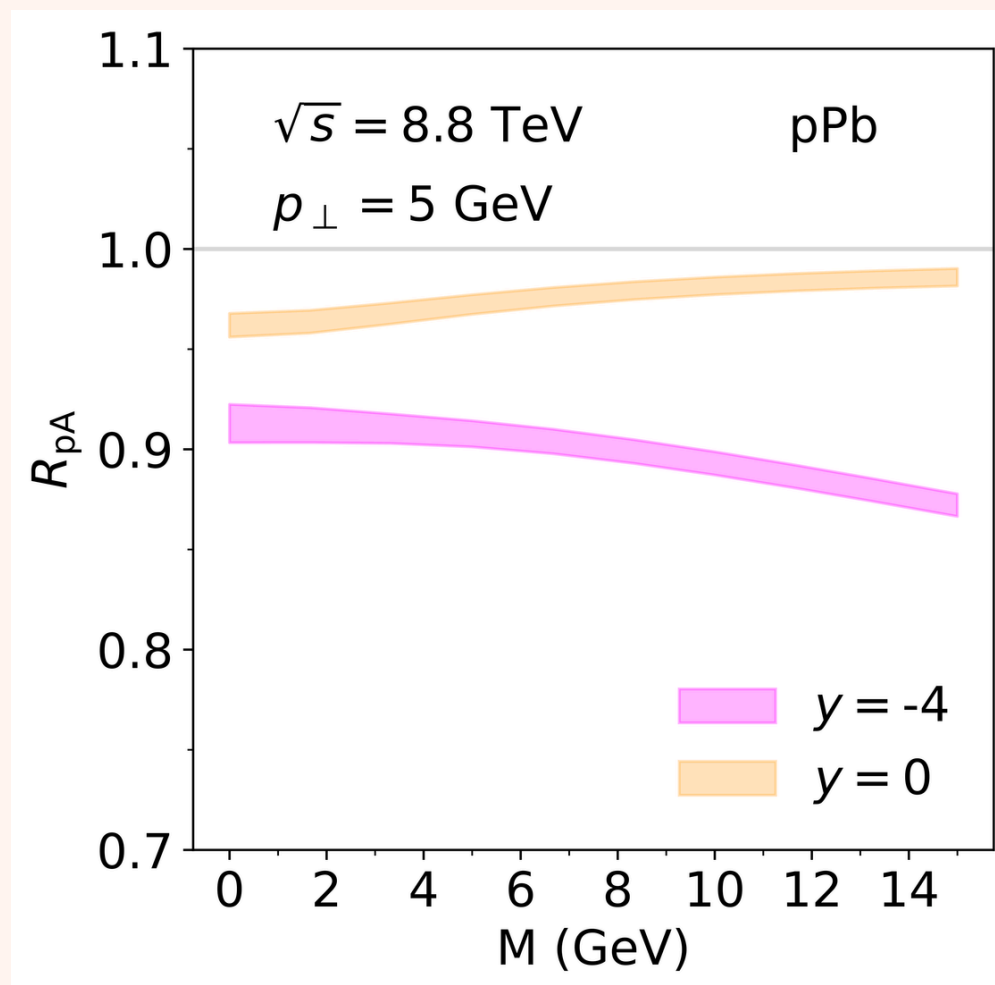
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Drell-Yan one of the **best** processes to **probe** nPDF at LHC

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Quarkonium production

Production cross section in the **color evaporation model** at LO

e.g. hadronisation of J/ψ :
$$\frac{d\sigma^{J/\psi}}{dy dm^2} = F_{J/\psi} \int_{4m_c^2}^{4m_D^2} dm^2 \frac{d\sigma^{c\bar{c}}}{dy dm^2}$$

Quarkonium production

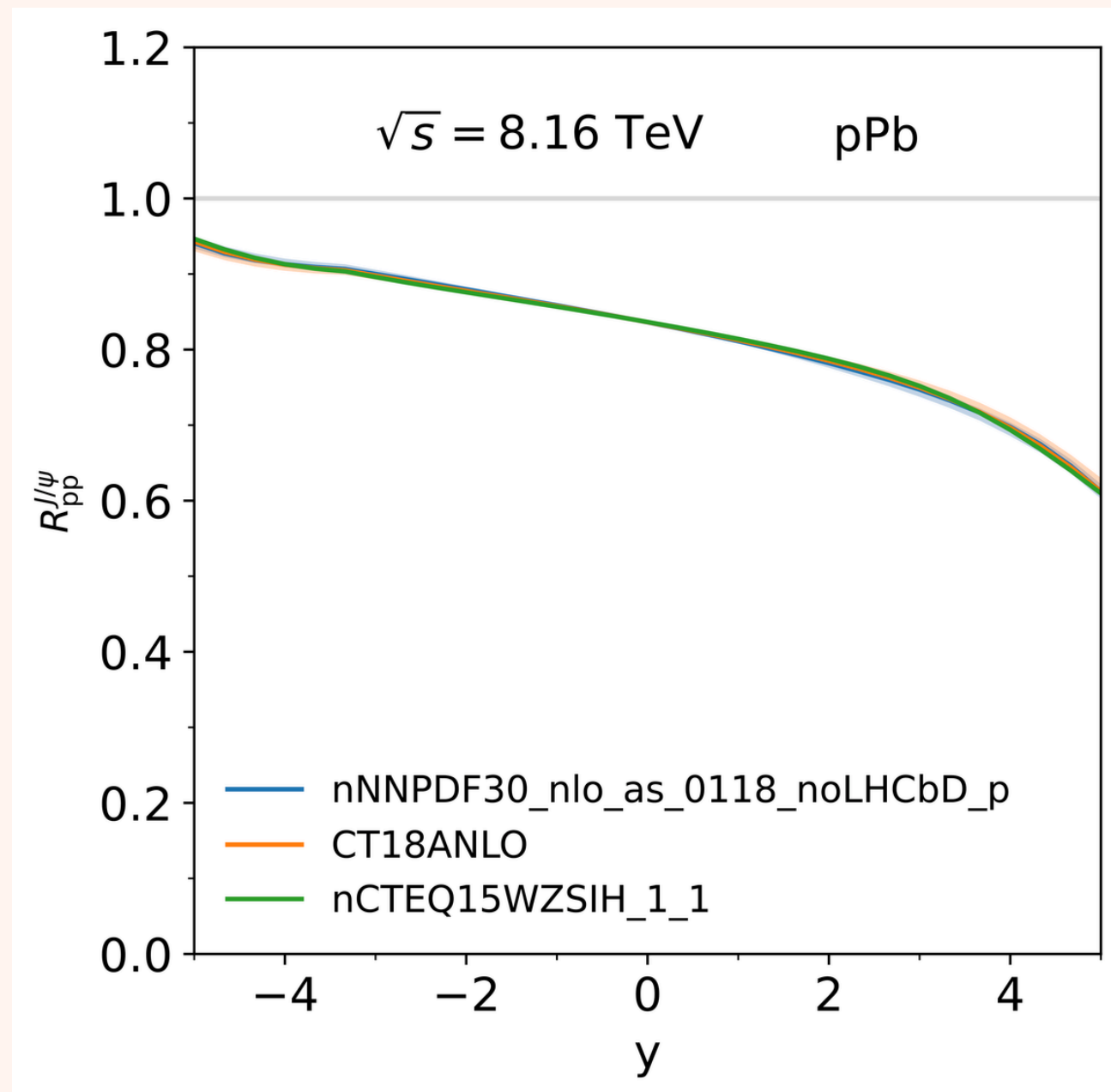
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We will investigate the impact of FCEL and nPDFs on R_{pA}

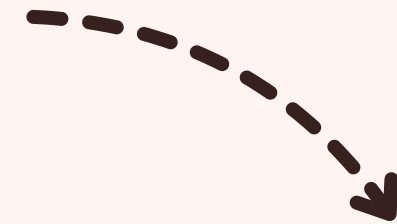
First results (FCEL only)

Significant suppression especially at large rapidity

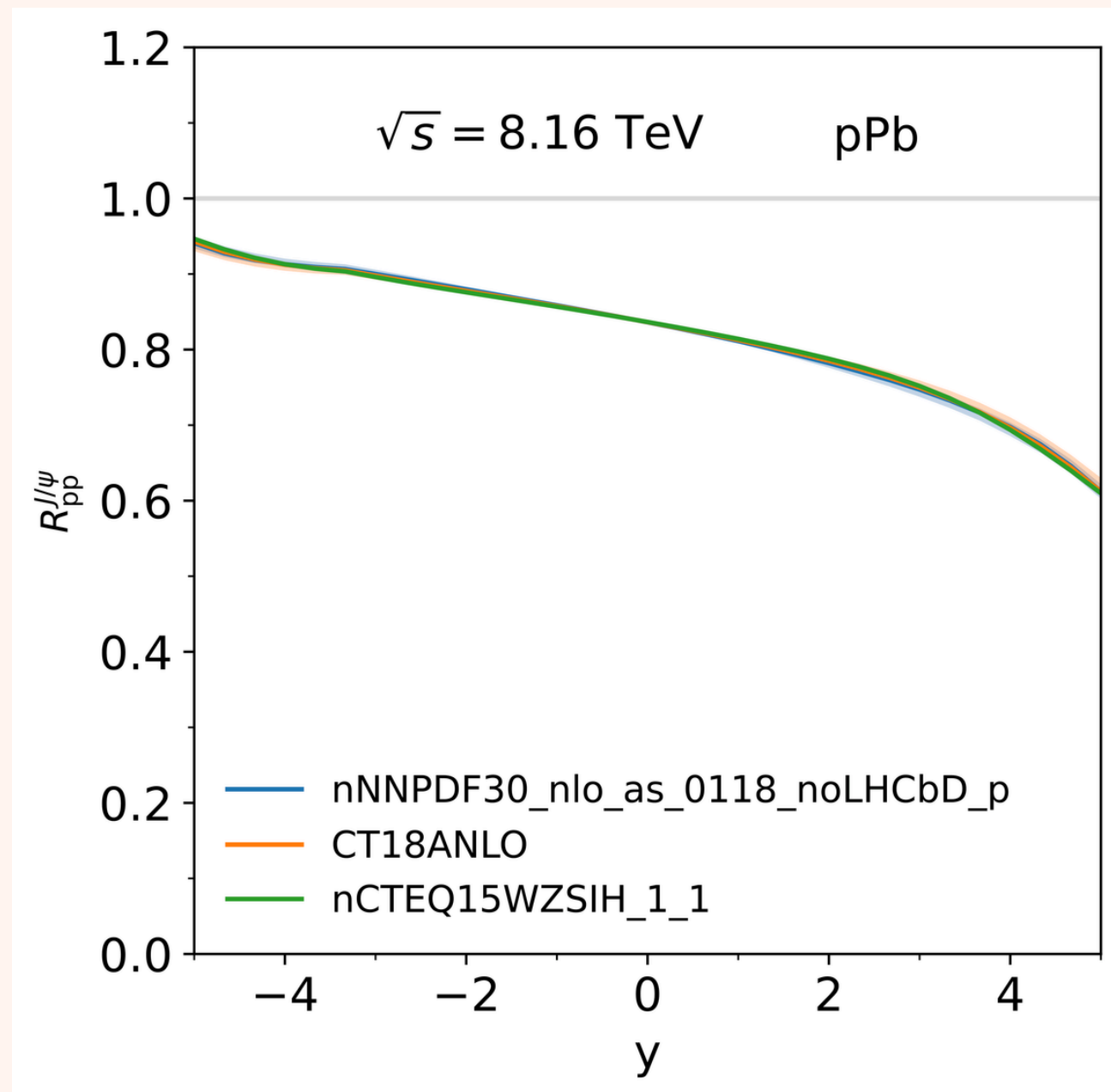


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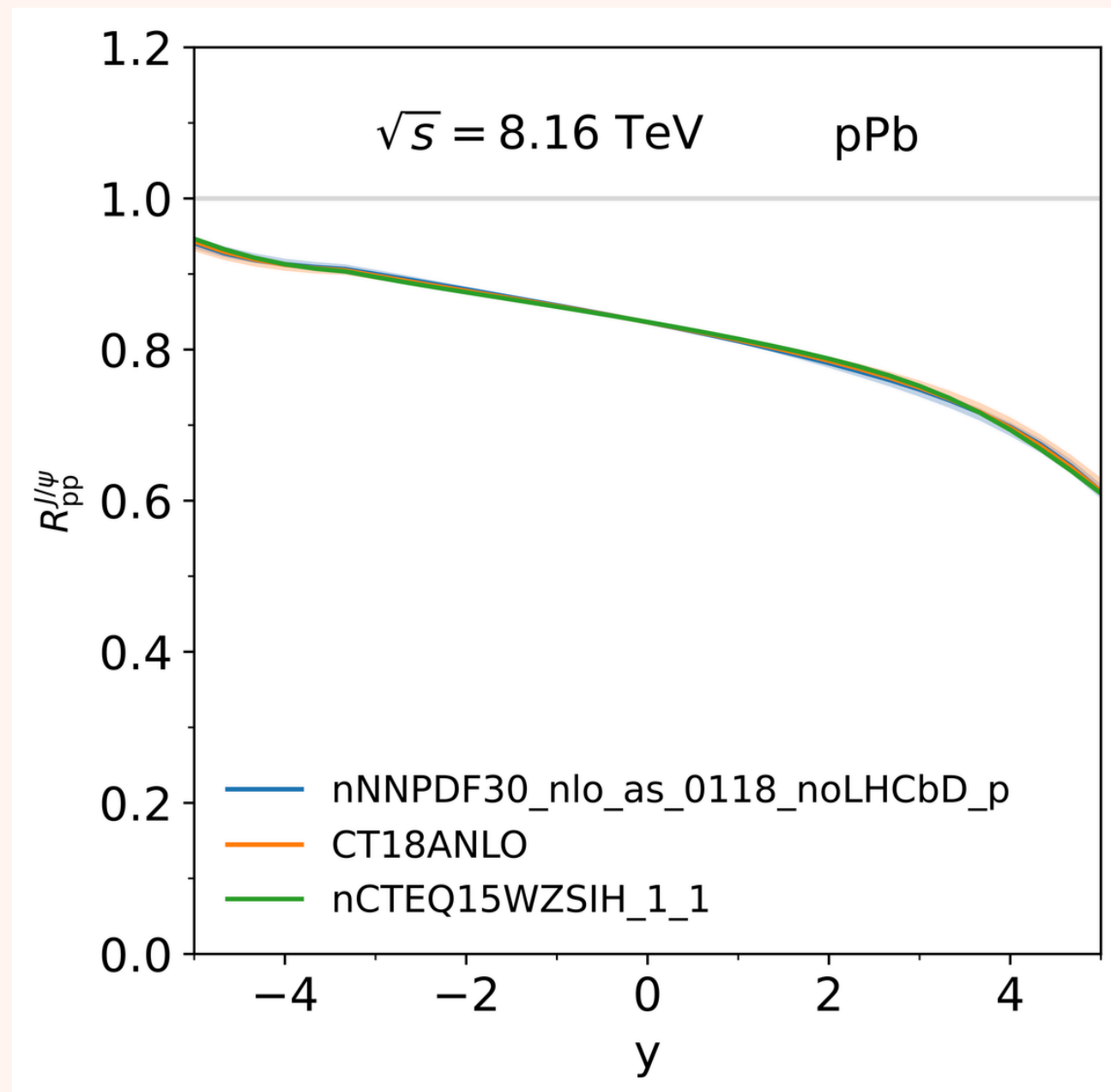


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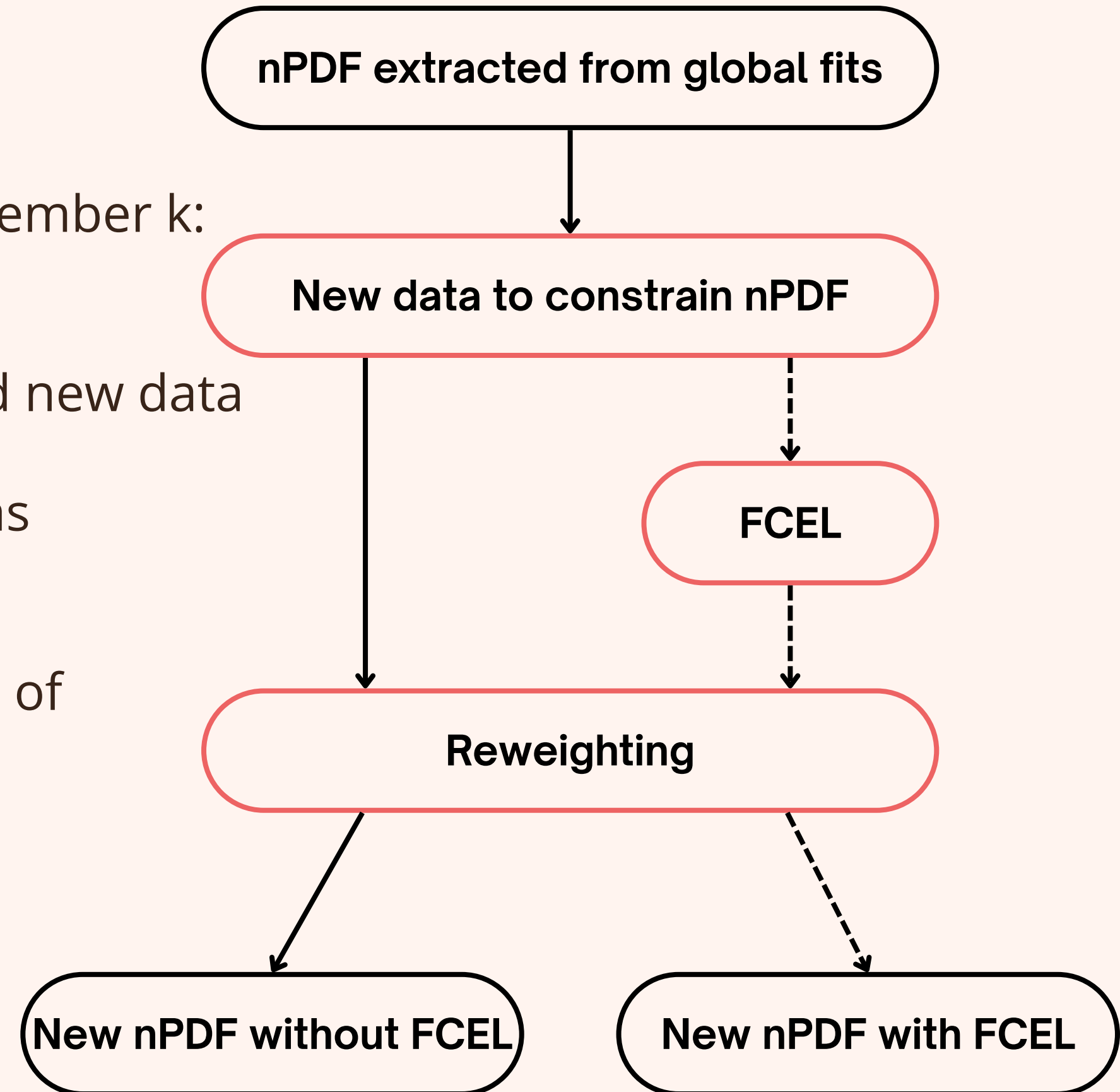
Reweighting techniques

Reweighting techniques

- Reweighting associate a **weight** for each set member k:

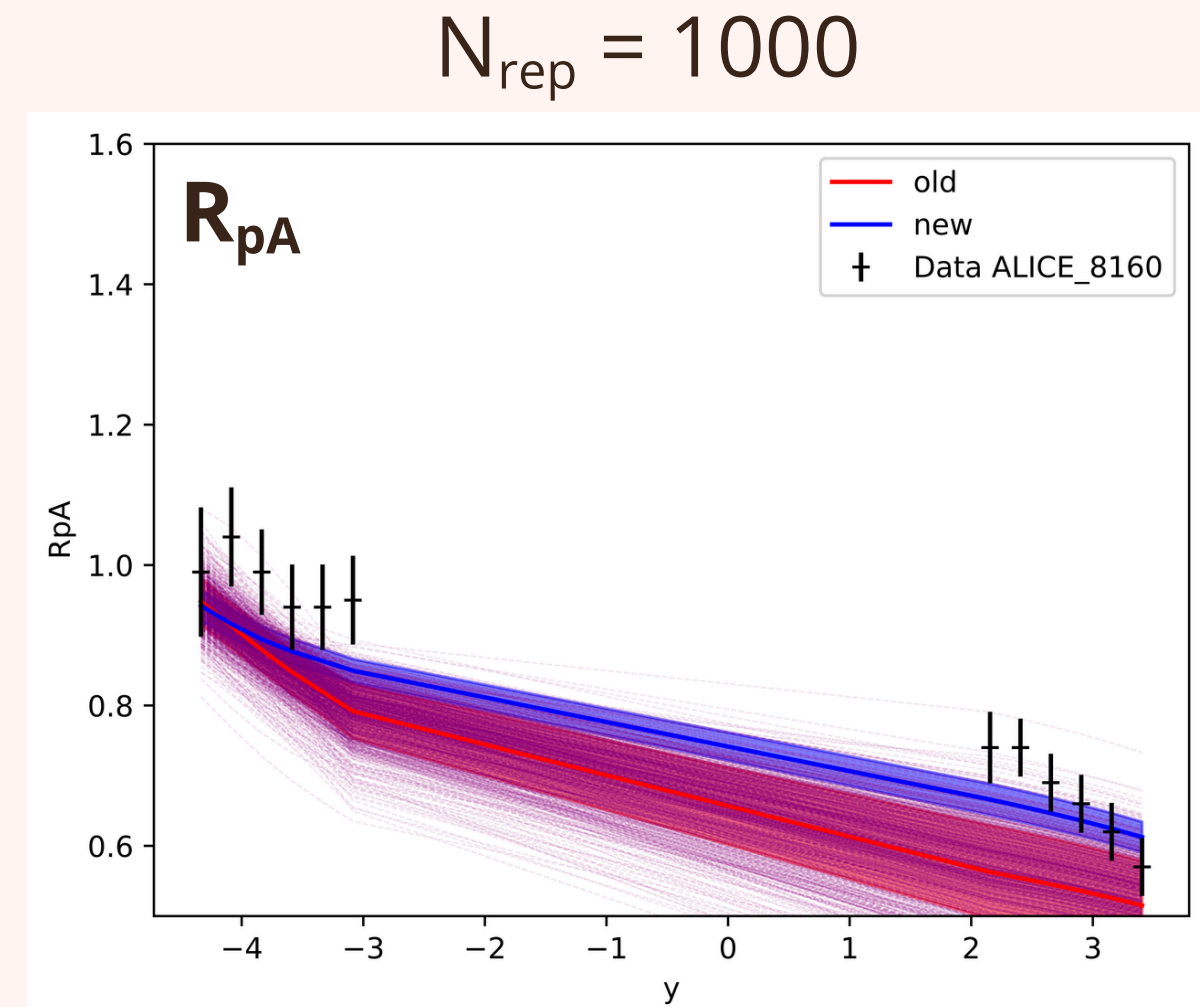
$$\omega_k = f(\chi_k^2)$$

- χ^2 computed on the new member set k and new data
- The weights give an effective number of replicas
- Possibility to unweight a set (reduced members of equal weight)

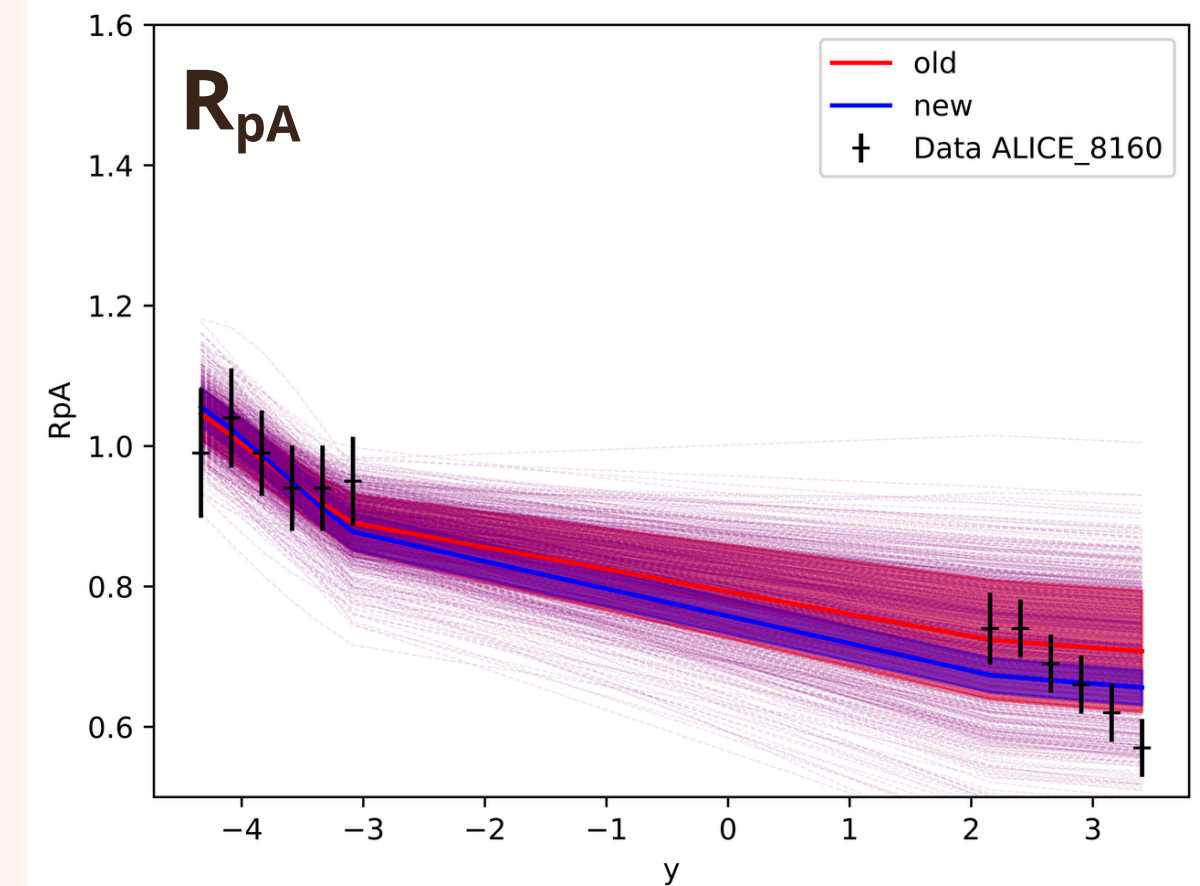


Preliminary results (with EPPS21)

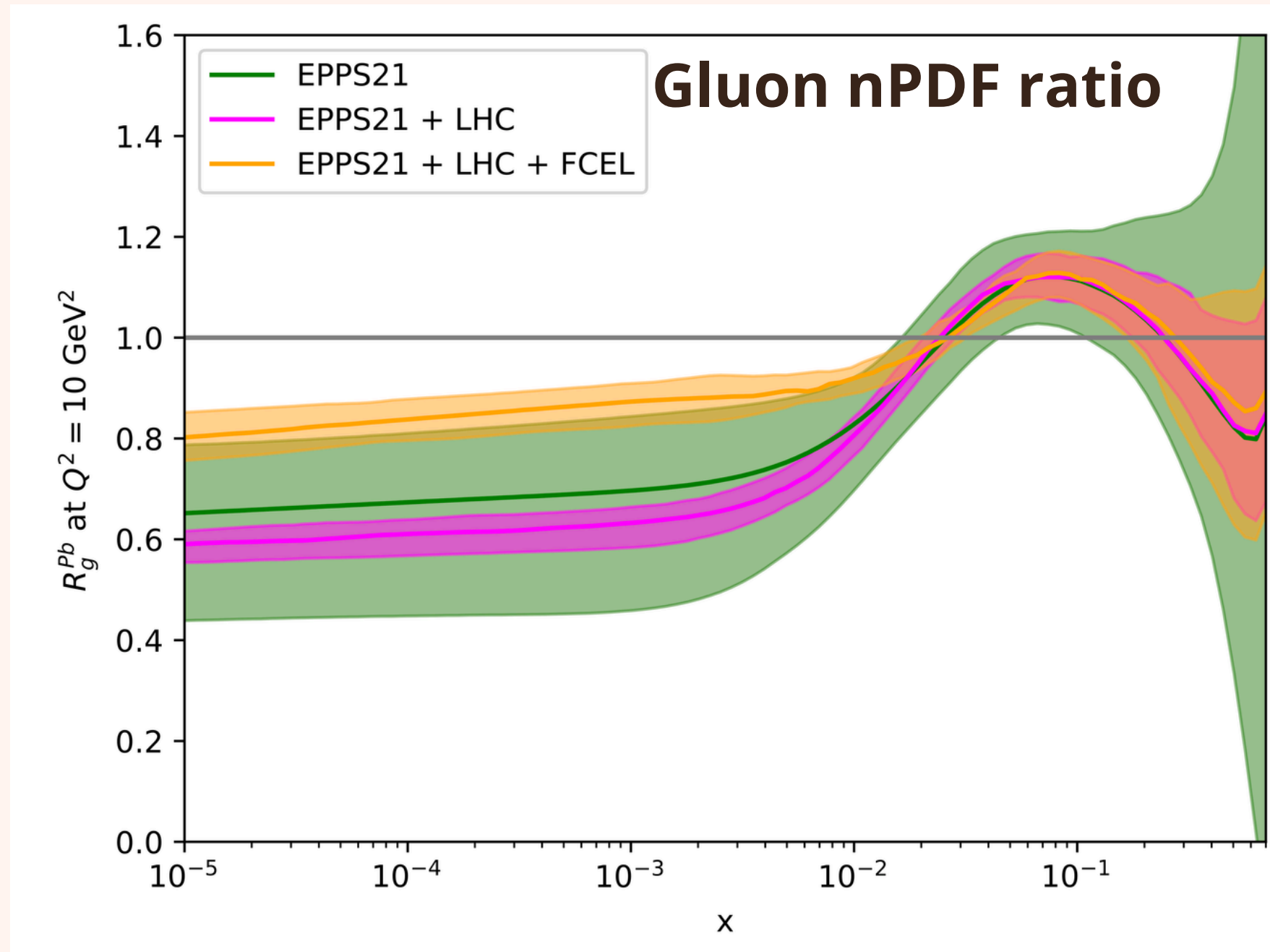
With FCEL
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Without FCEL
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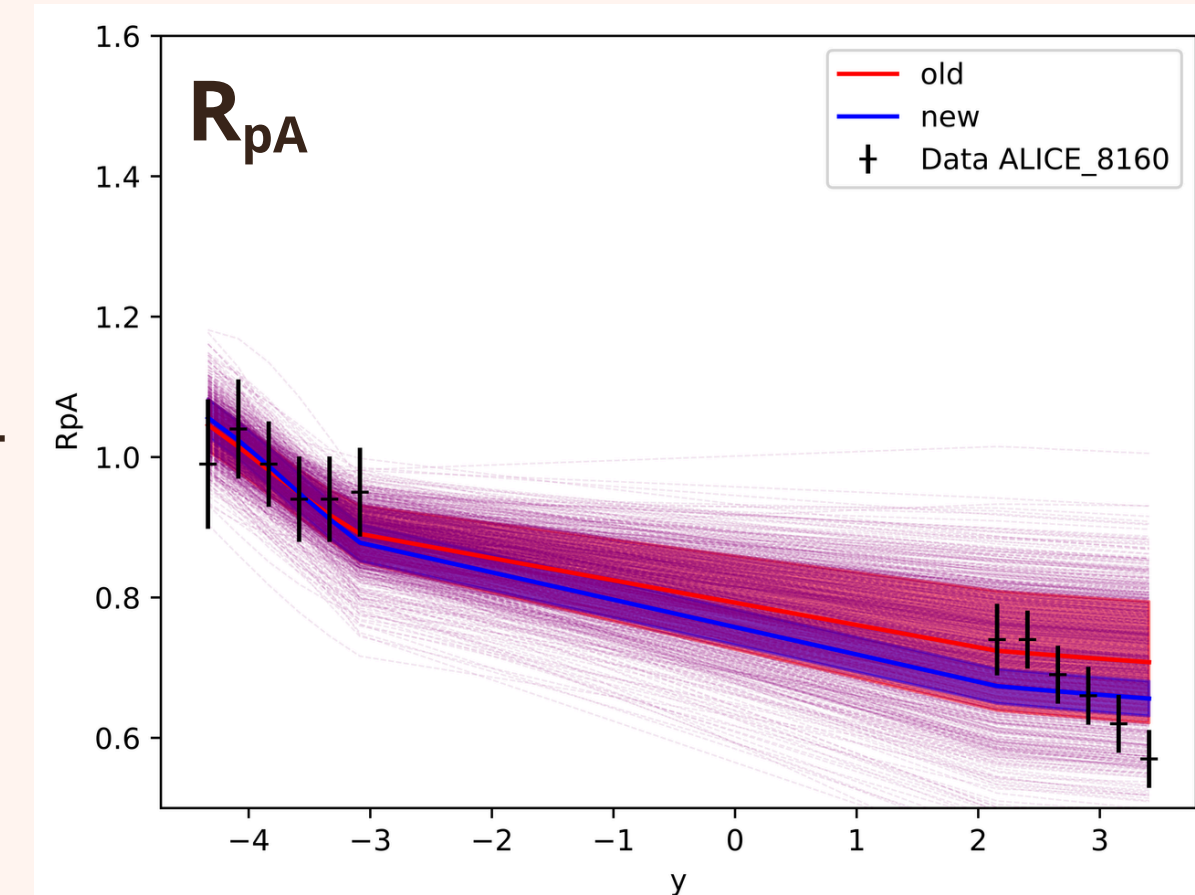
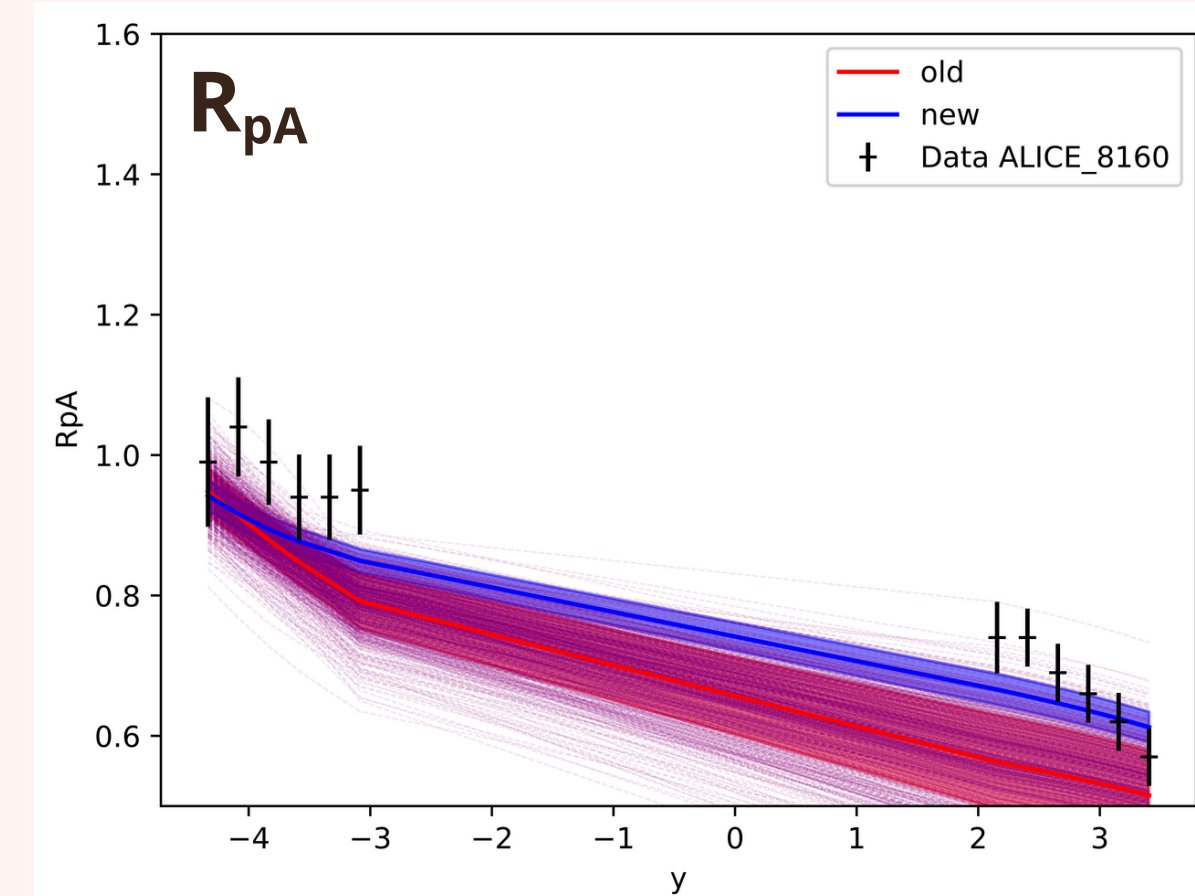
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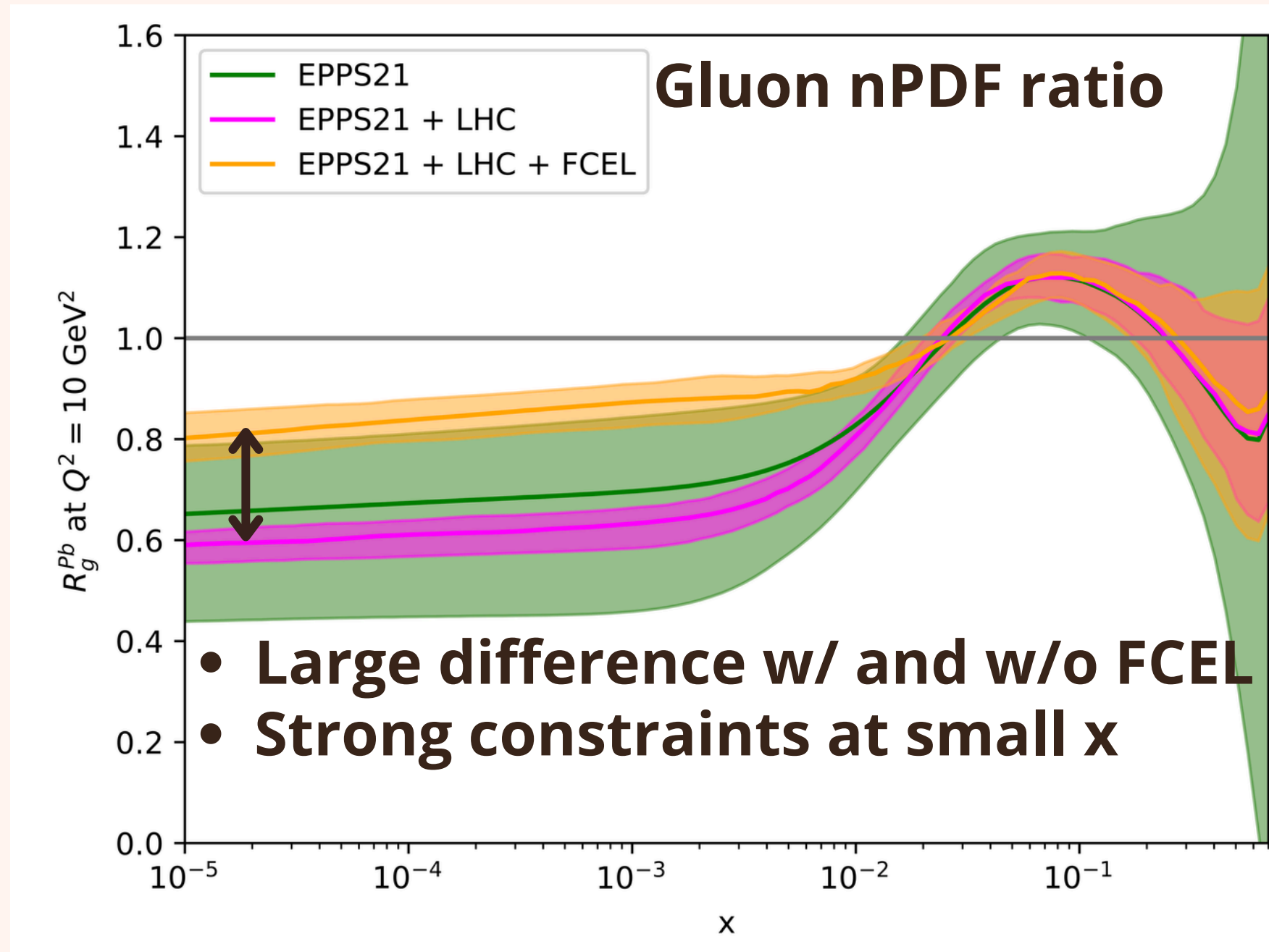
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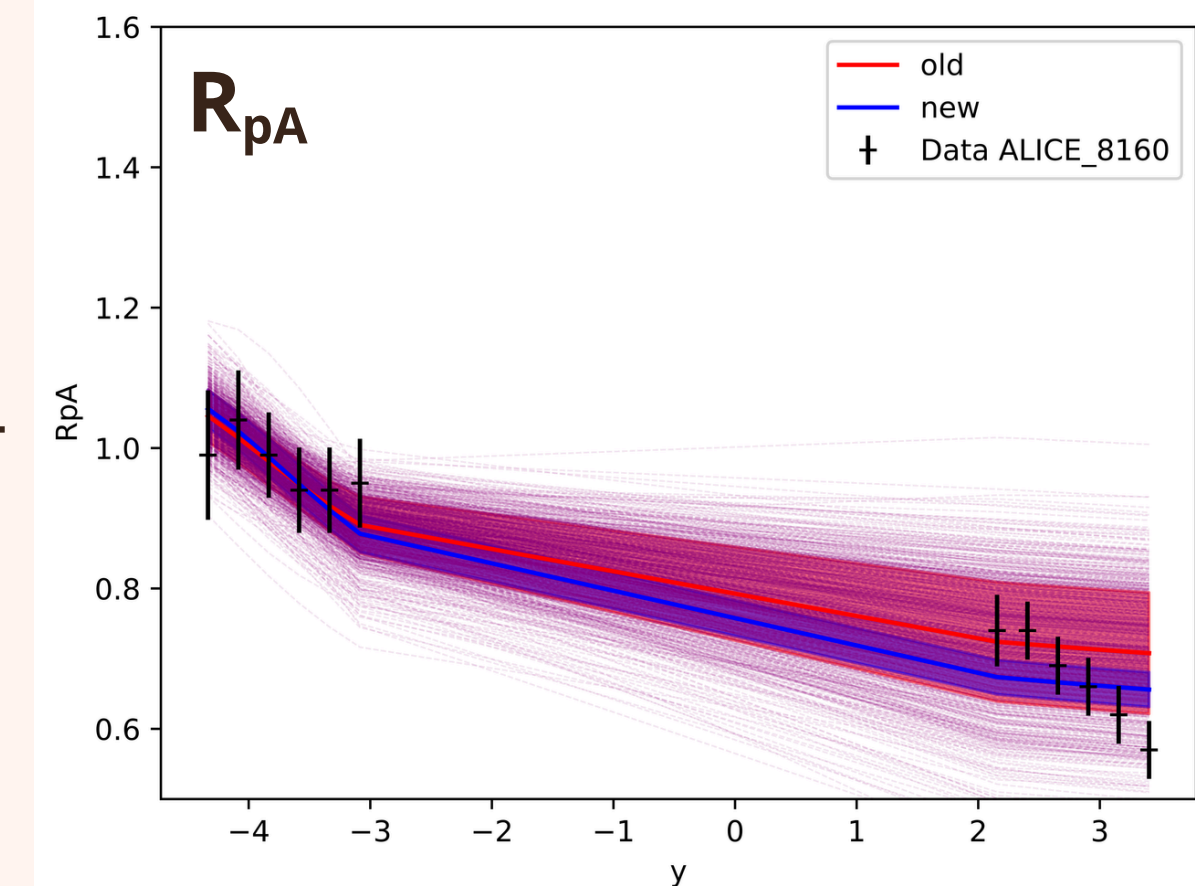
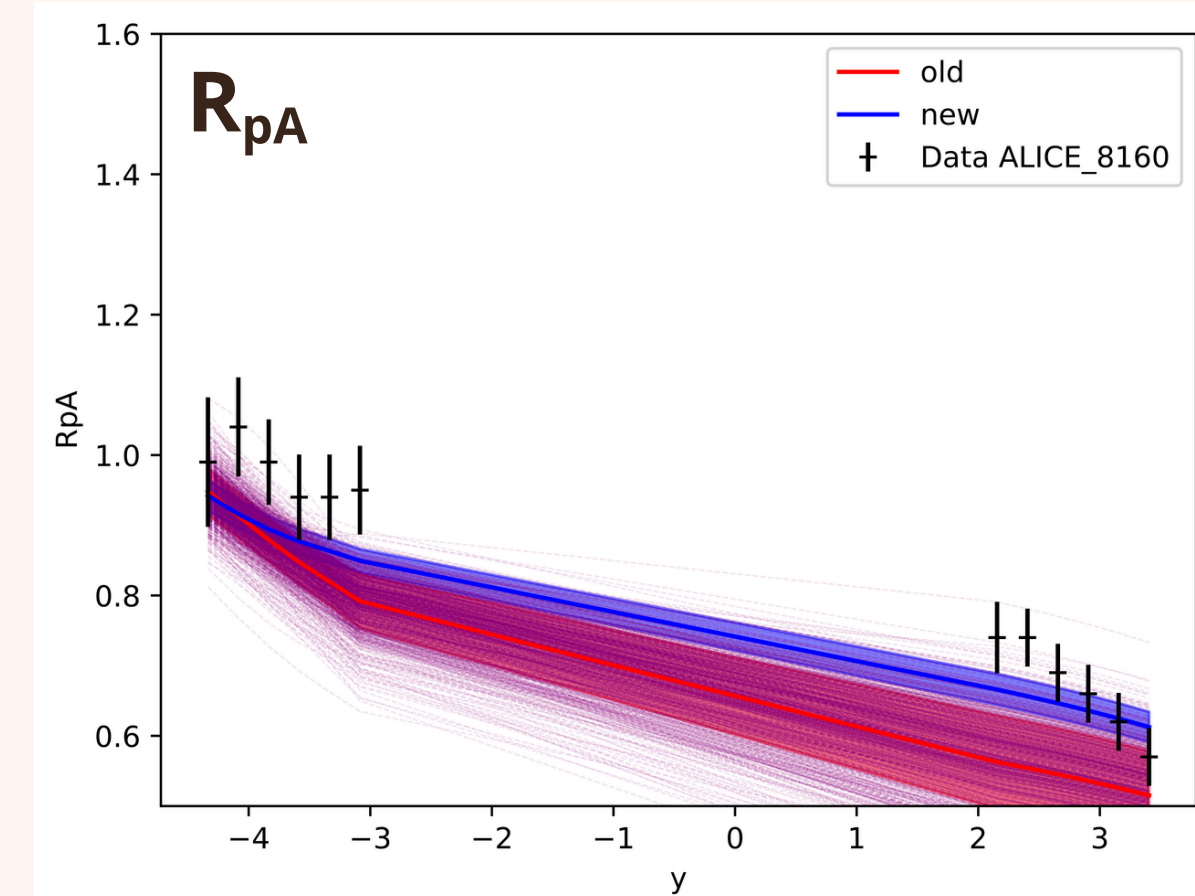
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Conclusion

Photons:

- FCEL **small** but non negligible
- Stronger effect at RHIC
- **Virtual** photons almost free from FCEL, so might be a **good nPDF probe**
- Paper to appear soon (already a PoS on direct photons: [2512.02640](#))

J/ψ :

- Constraining probe but FCEL is a **significant effect**
- **Reweighting techniques** to study the impact of FCEL on the nPDF extraction
- Consequence: **incompatibility** between simple reweighting and FCEL reweighting
- For later:
 - compare those results with other collaborations (nNNPDF, nCTEQ, ...)
 - include hyperparameters like the fraction of octets, the value of q hat...



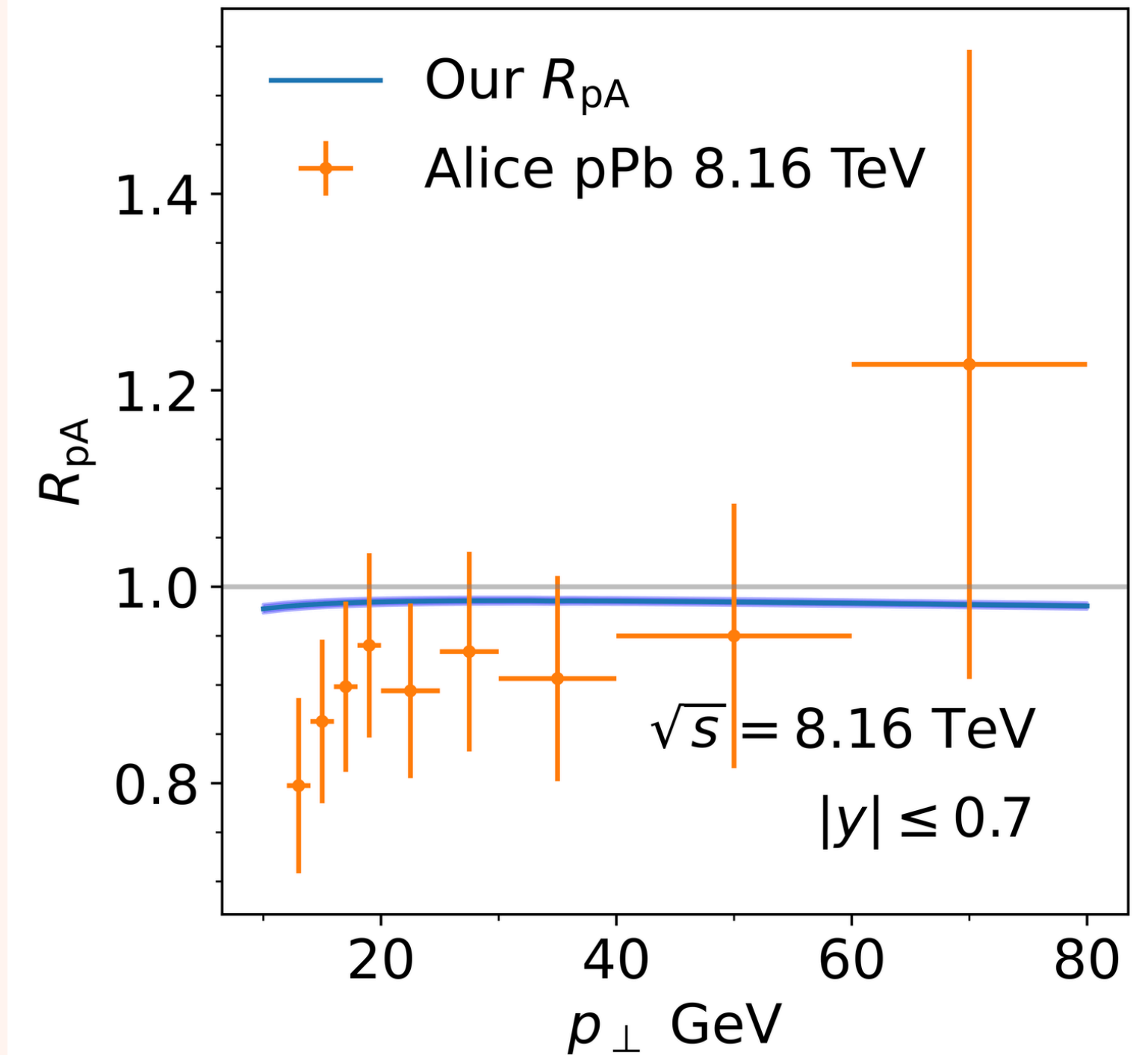
Merci!

General assembly of GDR QCD
Oct 2026-Nantes

Djessy Bourgeais
with François Arleo, Paul Caucal and Greg Jackson

Results direct photons

Comparison between ALICE data and our model

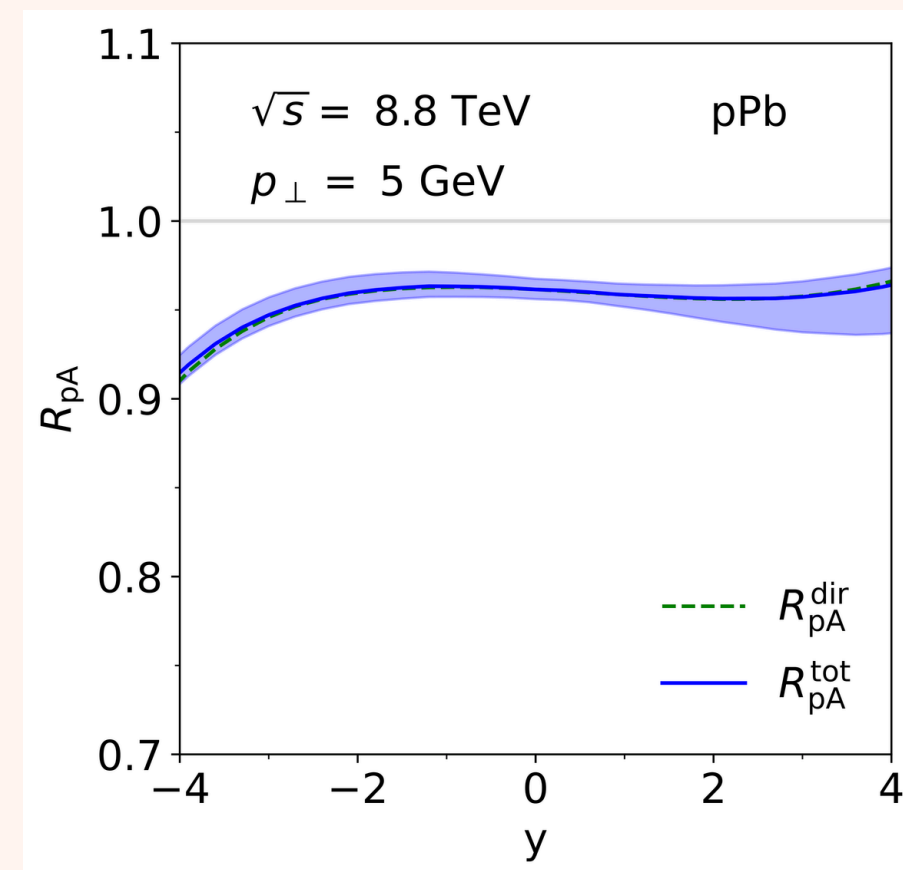
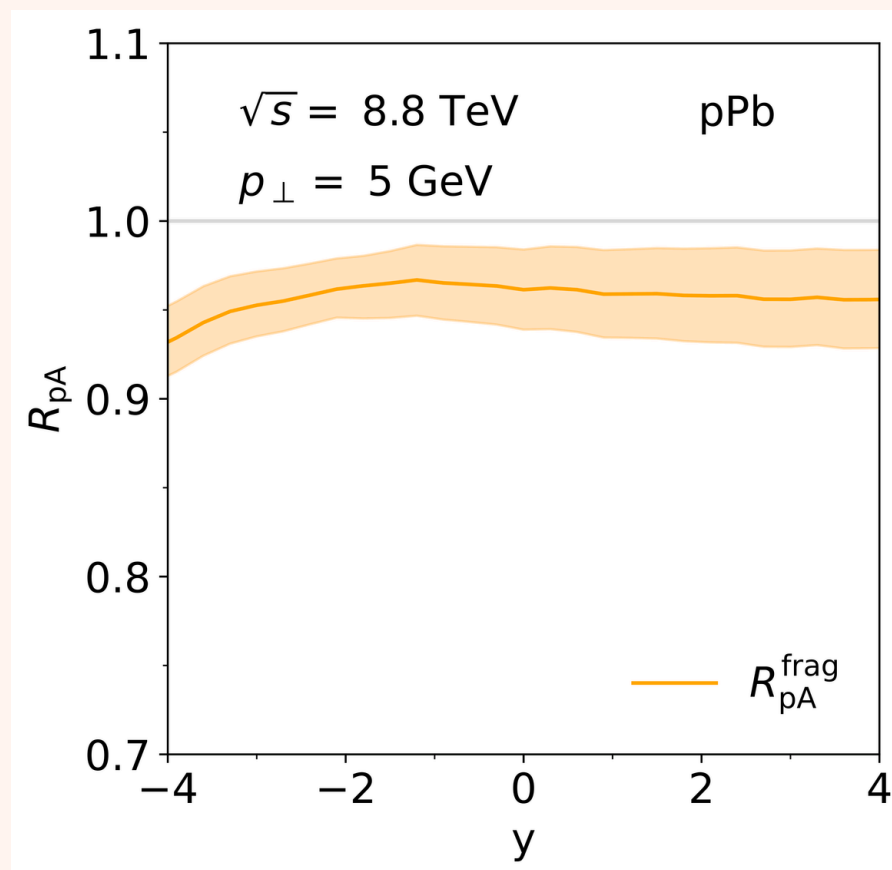


Fragmentation photons

LO frag processes $ab \rightarrow c(\rightarrow \gamma)d$ also affected by FCEL

Avoid some events with **isolation criteria**

close to experimental ones: $R = 0.4$, $E_{\text{th}} = 0.1 \times p_{\perp}^{\gamma}$



The R_{pA} resulting is really close to the direct photons one:
fragmentation computation can be avoided

FCEL in detail

$$\frac{d\sigma_{\text{pA,FCEL}}^R}{dE d\xi}(E) = \int_0^{\epsilon_{\text{max}}} d\epsilon \mathcal{P}^R(\epsilon, E, |F|) \frac{d\sigma_{\text{pA}}^R}{dE d\xi}(E + \text{sgn}(F) \epsilon) \quad F = C_a + C_R - C_b$$

Quenching weight

$$\mathcal{P}^R(\epsilon, E, |F|) \simeq \left. \frac{dI(\epsilon, E, |F|)}{d\epsilon} \right|_R \exp \left\{ - \int_{\epsilon}^{\infty} d\omega \left. \frac{dI(\omega, E, |F|)}{d\omega} \right|_R \right\}$$

Valid in the **pointlike dijet approximation** for which gluon radiation does not probe the dijet [cd]

Induced gluon spectrum

$$\omega \left. \frac{dI}{d\omega} \right|_R \simeq F \frac{\alpha_s}{\pi} \left[\ln \left(1 + \frac{l_{\perp A}^2 E^2}{M_{\perp}^2 \omega^2} \right) - \ln \left(1 + \frac{l_{\perp p}^2 E^2}{M_{\perp}^2 \omega^2} \right) \right] \Theta(l_{\perp A}^2 - l_{\perp p}^2)$$

Induced gluon spectrum computed **beyond** the pointlike approximation for a generic process

$$1\ 2 \rightarrow 3 \dots n$$

Transport coefficient

$$l_{\perp}^2 = \hat{q} L \quad \text{with } \hat{q}(x) = \hat{q}_0 \left(\frac{10^{-2}}{x} \right)^{0.3}$$

More about reweighting techniques

For a bayesian set:

$$\chi_k^2 = \sum_{i=1}^{N_{\text{data}}} \left[\frac{\mathcal{O}[f_k]_{\text{th}}^i - \mathcal{O}_{\text{data}}^i}{\delta_{\text{data}}^i} \right]^2 \Rightarrow \omega_k = \frac{1}{D} (\chi_k^2)^{\frac{N_{\text{data}}-1}{2}} e^{-\frac{\chi_k^2}{2}}, \quad D = \frac{1}{N_{\text{rep}}} \sum_{k=1}^{N_{\text{rep}}} (\chi_k^2)^{\frac{N_{\text{data}}-1}{2}} e^{-\frac{\chi_k^2}{2}}$$

For a Hessian set, bayesianisation first and then same as before:

$$\tilde{f}_k \equiv f_0 + \sum_{i=1}^{N_{\text{eig}}} \left(\frac{f(S_i^+) - f(S_i^-)}{2} \right) R_{ik}, \quad R_{ik} \sim \mathcal{N}(0, \sigma_R) \quad \text{1st order (classic method)}$$

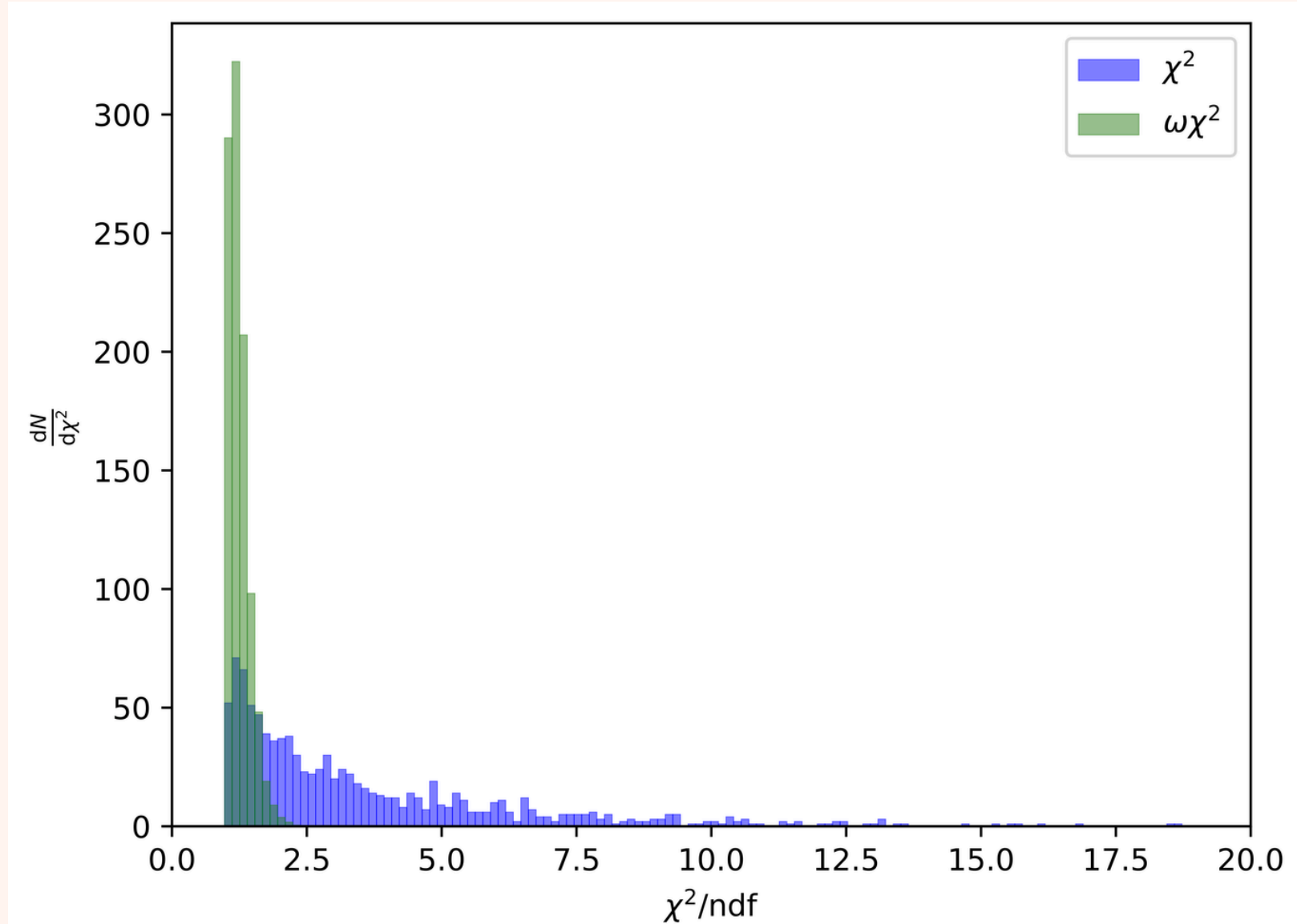
$$\tilde{f}_k = f_0 + d_k - \Delta,$$

$$d_k = \sum_{i=1}^{N_{\text{eig}}} \left(\frac{f_{S_i^+} - f_{S_i^-}}{2} R_{ik} + \frac{f_{S_i^+} + f_{S_i^-} - 2f_0}{2} R_{ik}^2 \right), \quad \text{2nd order (what we use)}$$

$$\Delta = \langle d_k \rangle \left(\Rightarrow \langle \tilde{f}_k \rangle = f_0 \right).$$

χ^2 distributions

w/o FCEL



w/ FCEL

