2014 LHeC Workshop
Chavannes-de-Bogis, January 20th 2014

# Heavy Ion Physics in e-A and p/A-A


Néstor Armesto
*Departamento de Física de Partículas and IGFAE*
*Universidade de Santiago de Compostela*
nestor.armesto@usc.es

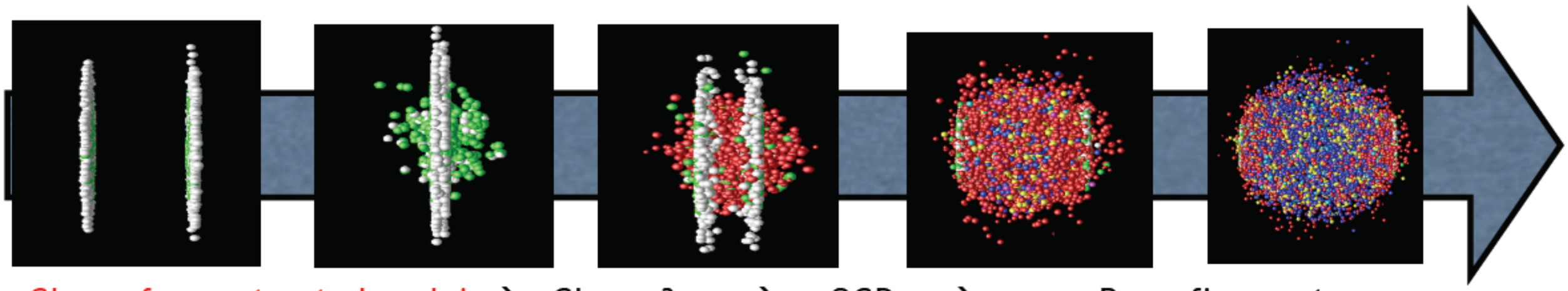

for the LHeC Study group, http://cern.ch/lhec

# Contents:



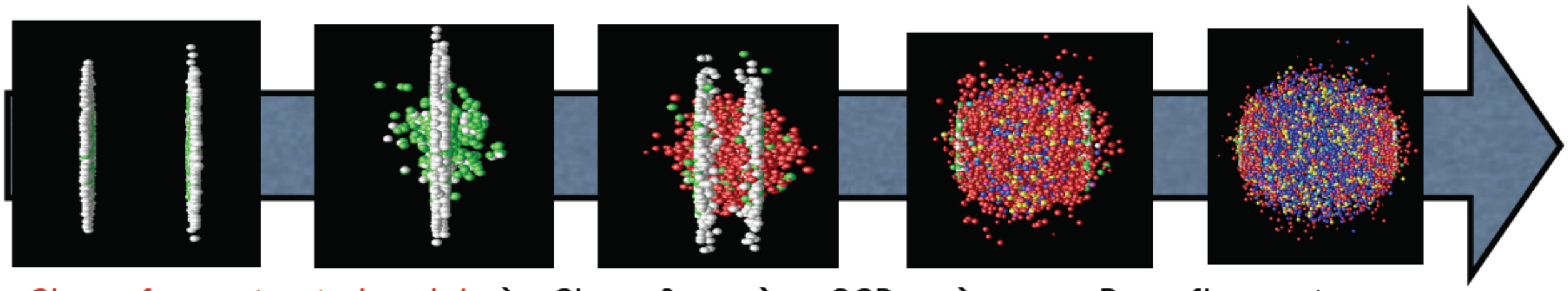
CDR, arXiv:1206.2913, J. Phys. G 39 (2012) 075001;
arXiv:1211.4831; arXiv:1211.5102.
See the talks by Jansova, Newman and Paukunnen this afternoon.

# Relevance for the HI program:



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

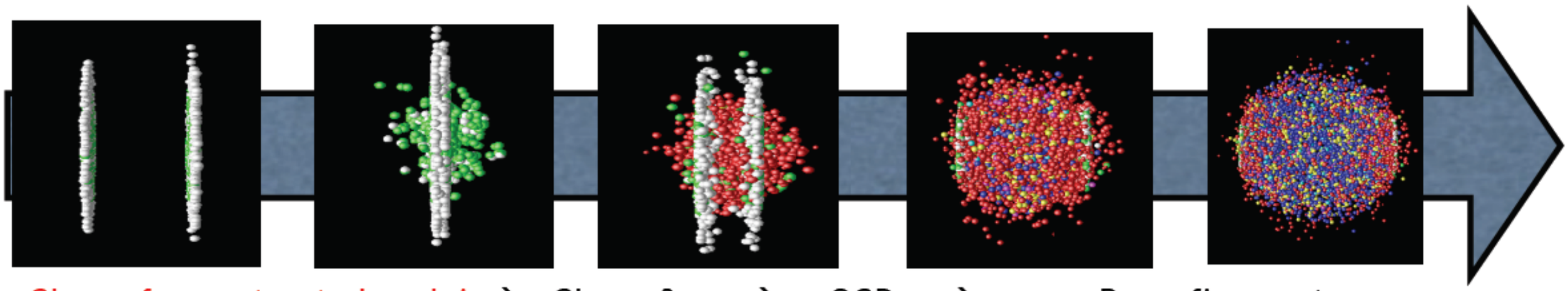
# LHeC Relevance for the HI program:



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

- Nuclear wave function at small x: nuclear structure functions.

# Relevance for the HI program:



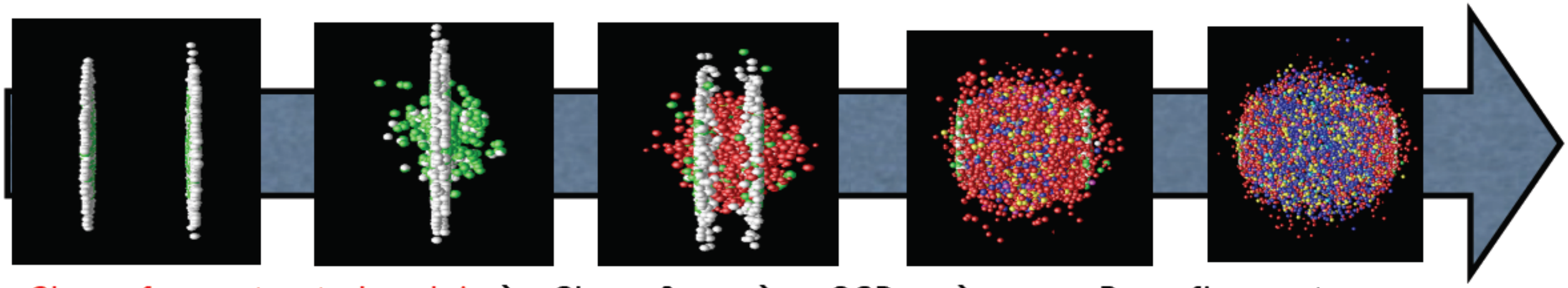
Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

- Nuclear wave function at small x: nuclear structure functions.

- Particle production at the very beginning: which factorisation in eA?

- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

# Relevance for the HI program:



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

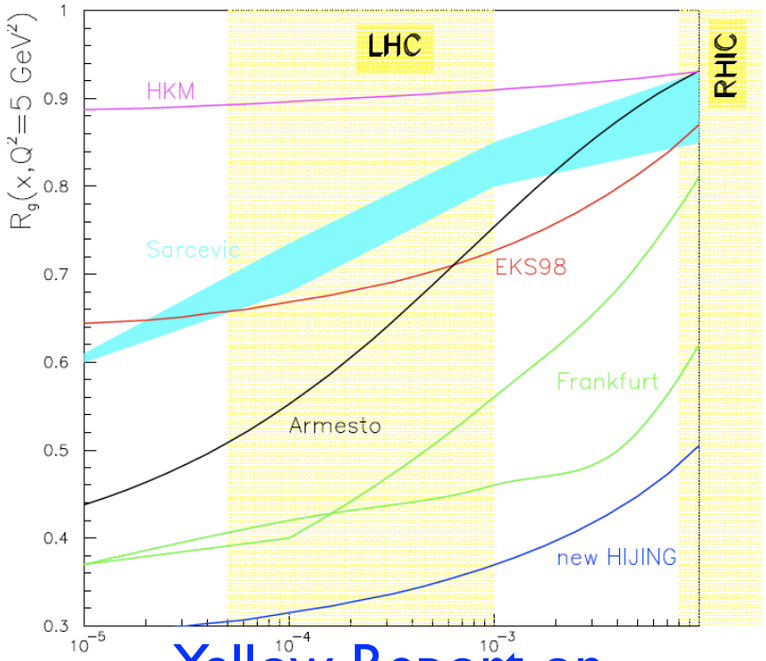
- Nuclear wave function at small x: nuclear structure functions.

- Particle production at the very beginning: which factorisation in eA?
- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronization in the nuclear medium.

# nPDFs:

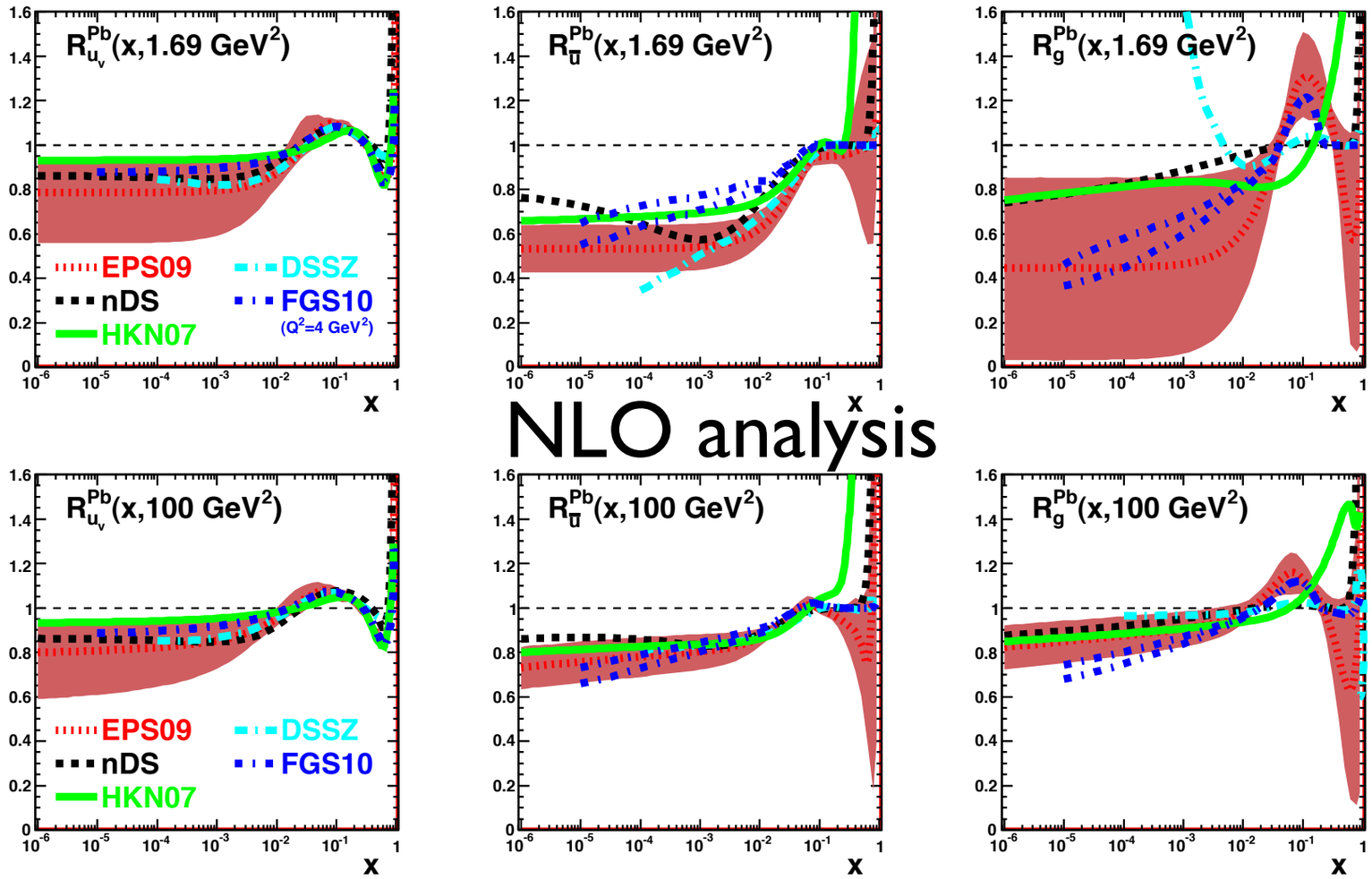
$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$




Yellow Report on Hard Probes, 2004

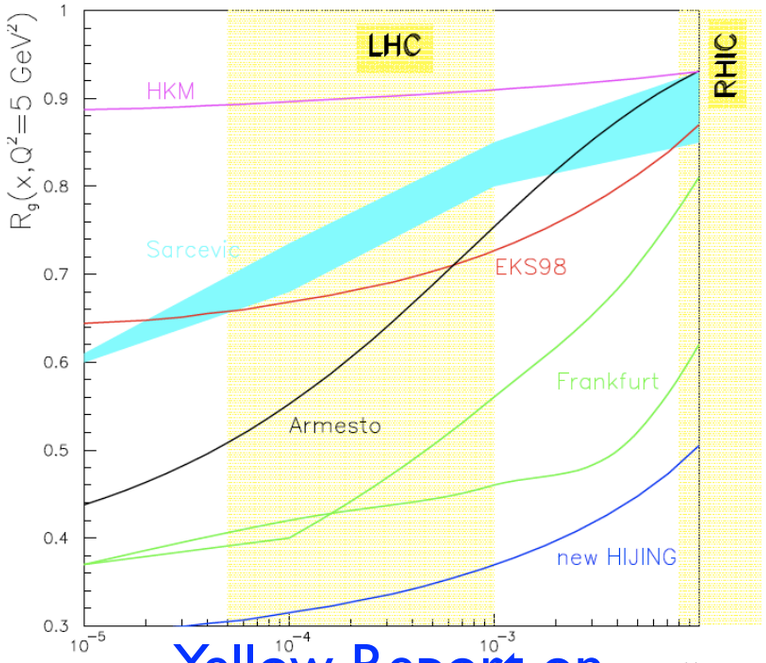
- Lack of data ⇒ models give vastly different results for the nuclear glue at small scales and x: problem for benchmarking in HIC.

- Available DGLAP analysis at NLO show large uncertainties at small scales and x.




NLO analysis

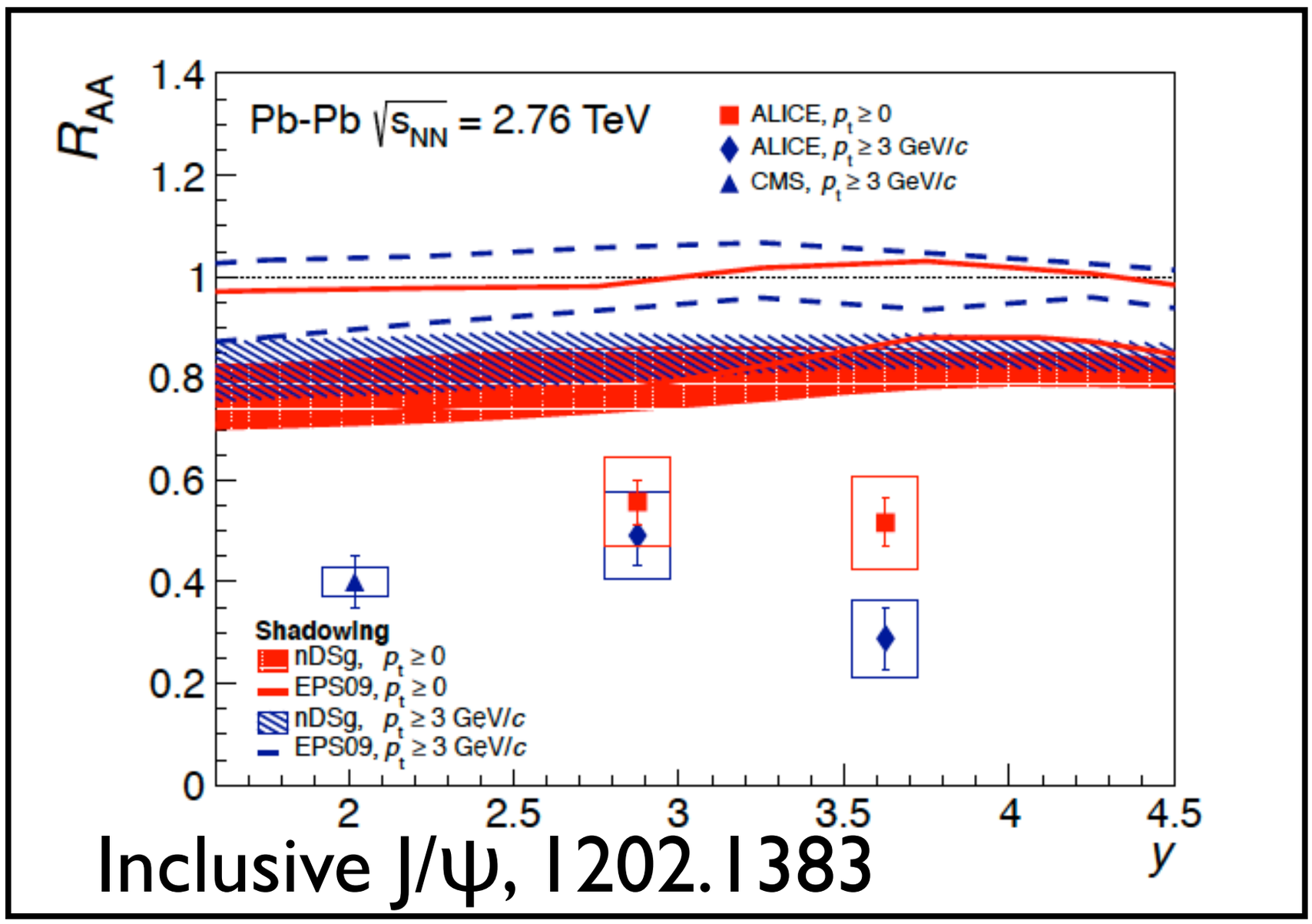
# nPDFs: $R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$




Yellow Report on Hard Probes, 2004

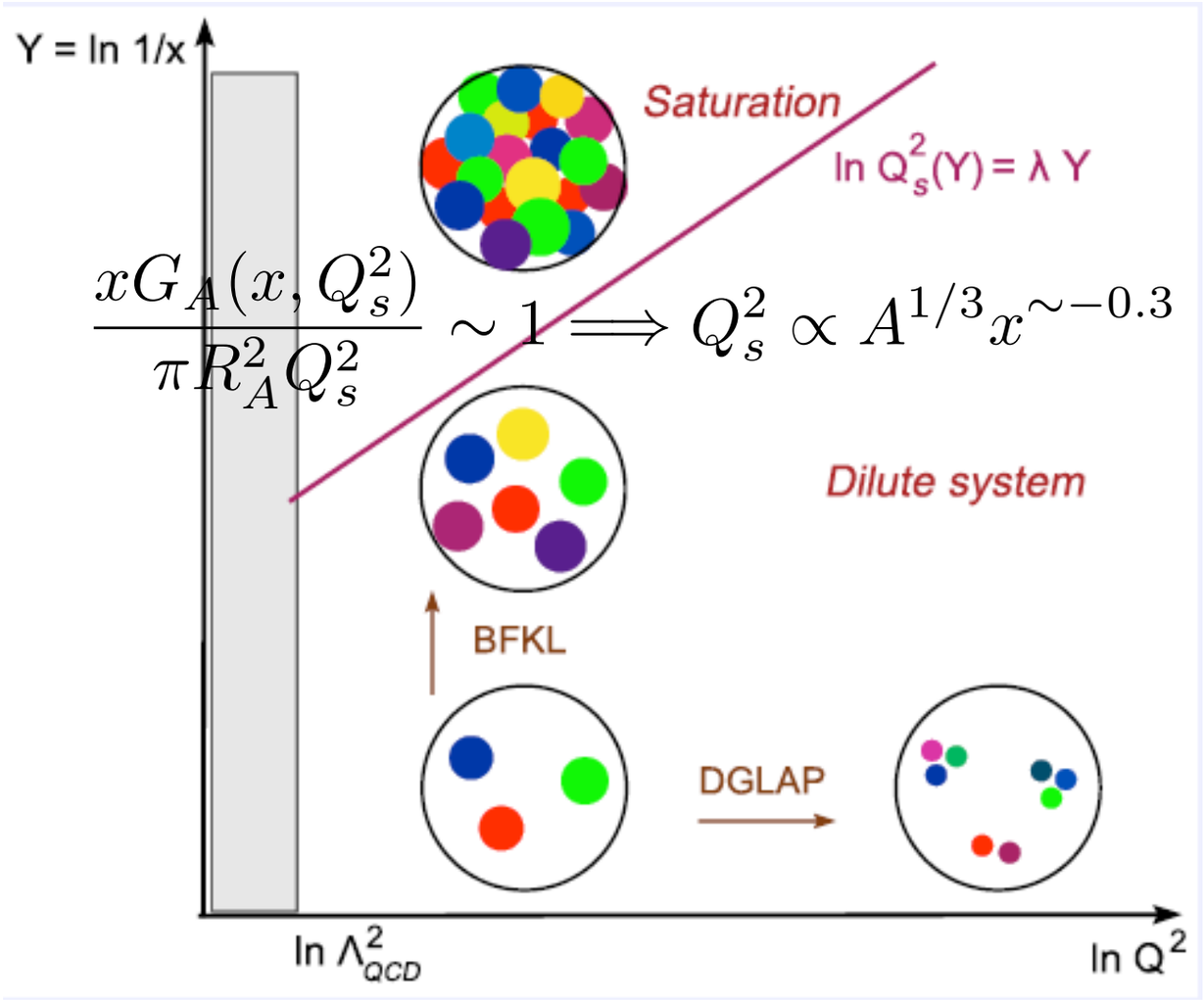
- Lack of data ⇒ models give vastly different results for the nuclear glue at small scales and x: problem for benchmarking in HIC.

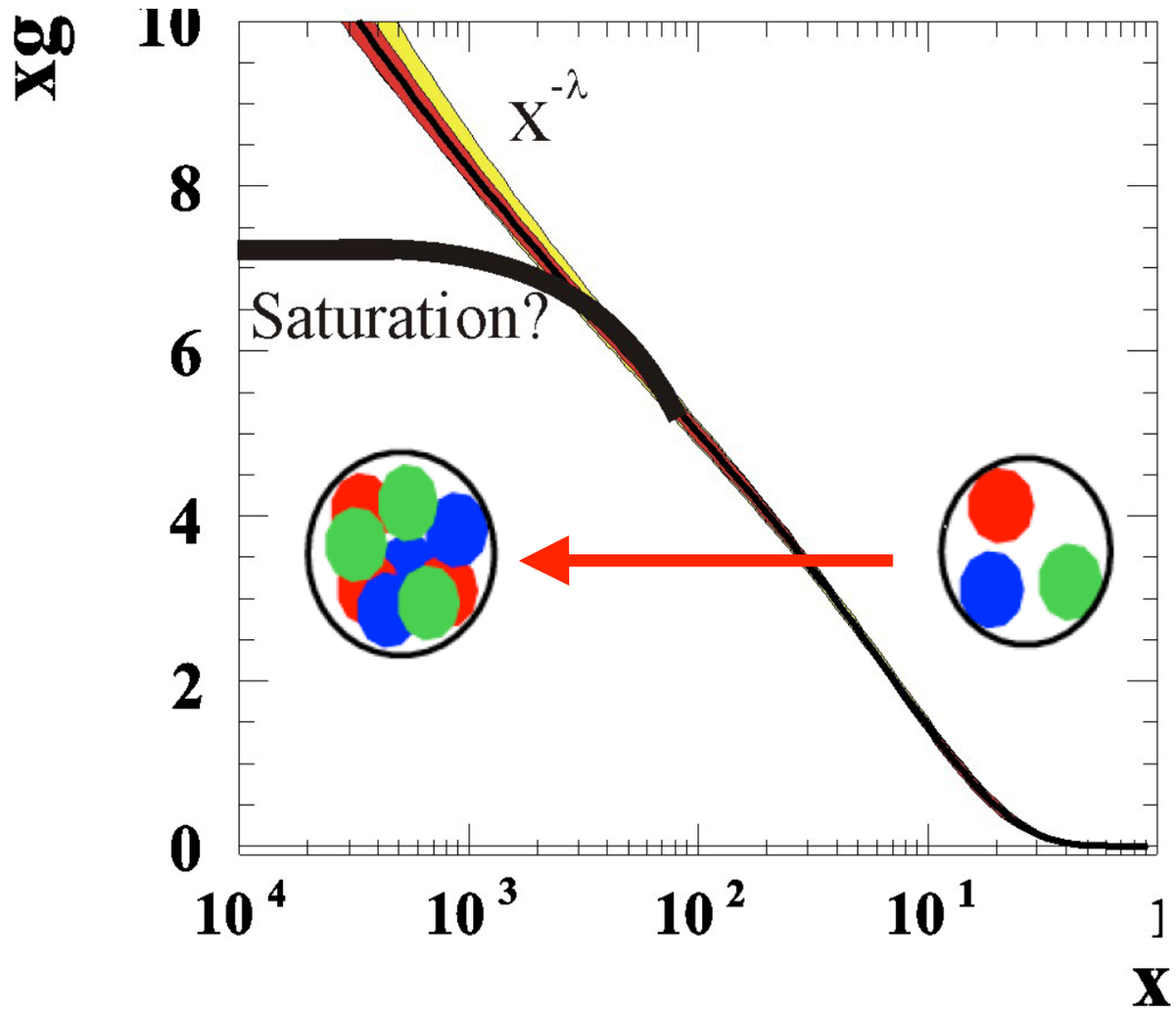
- Available DGLAP analysis at NLO show large uncertainties at small scales and x.




Inclusive J/ψ, 1202.1383

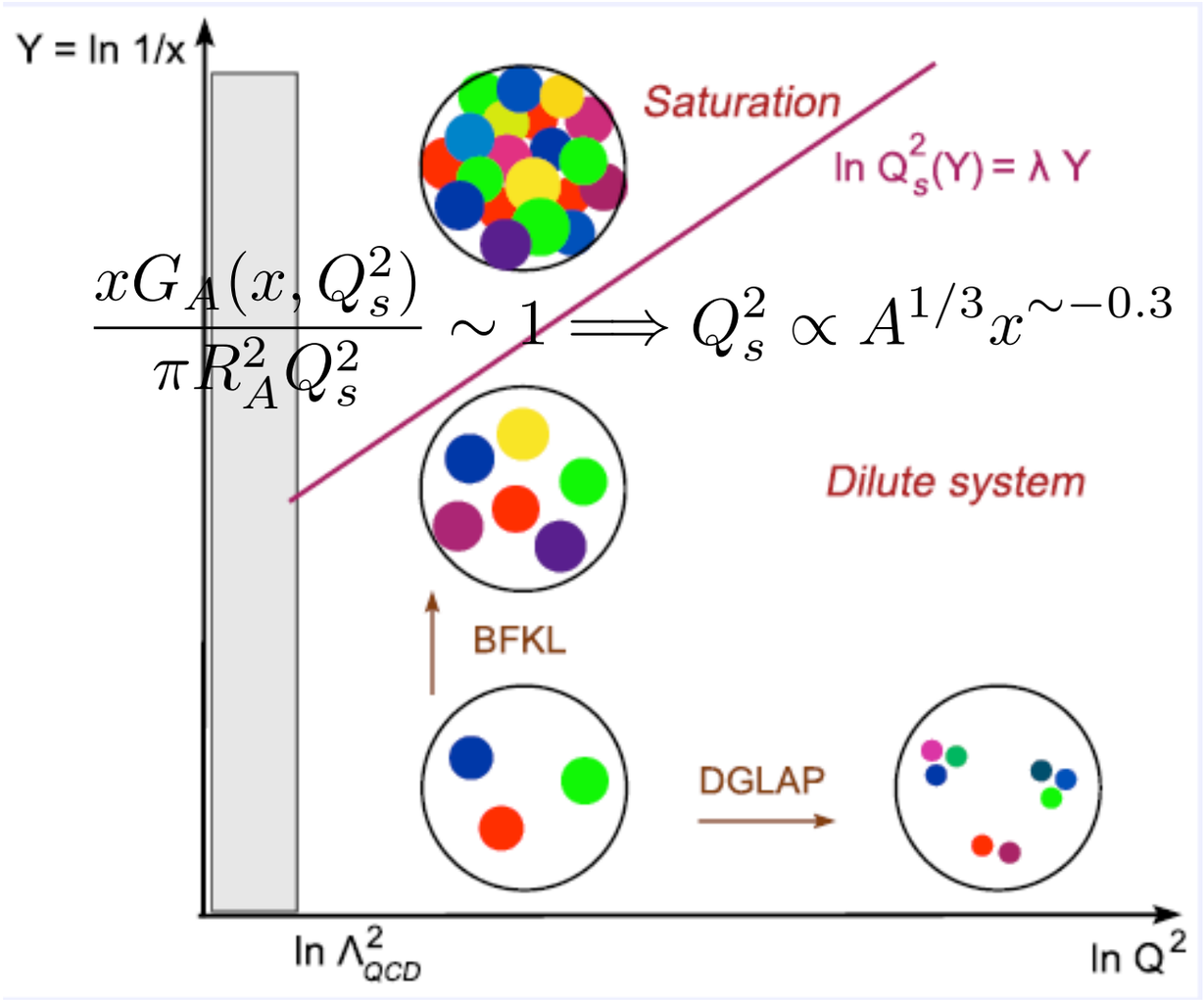
# Small x and saturation:

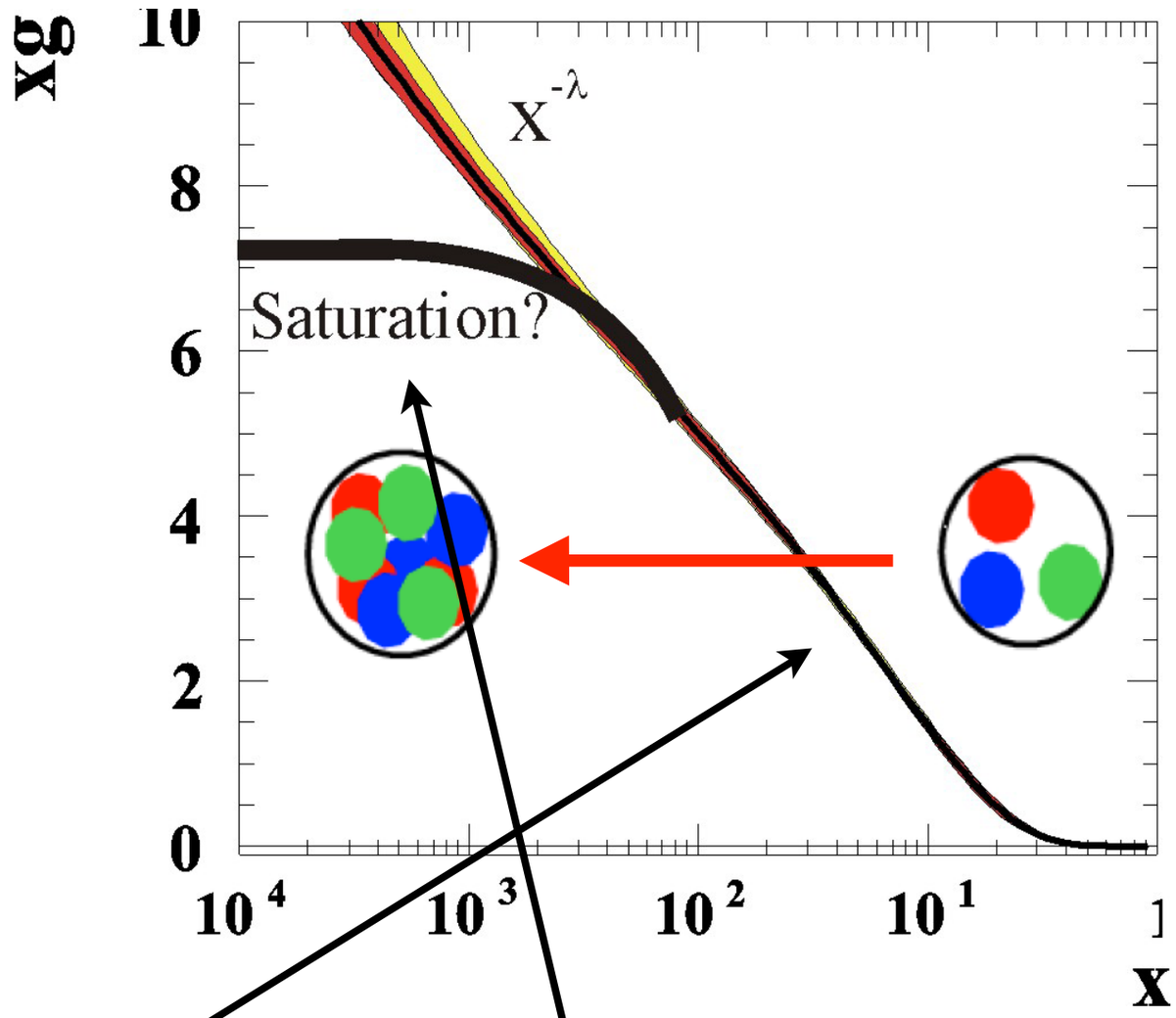



- QCD radiation of partons when x decreases leads to a large number of partons (gluons), provided each parton evolves independently (linearly, $\Delta[xg] \propto xg$).
- This independent evolution breaks at high densities (small x or high mass number A): non-linear effects ($gg \rightarrow g$, $\Delta[xg] \propto xg - k(xg)^2$).

# Small x and saturation:




- QCD radiation of partons when x decreases leads to a large number of partons (gluons), provided each parton evolves independently (linearly, $\Delta[xg] \propto xg$).
- This independent evolution breaks at high densities (small x or high mass number A): non-linear effects ($gg \rightarrow g$, $\Delta[xg] \propto xg - k(xg)^2$).

# Status of small-x physics:

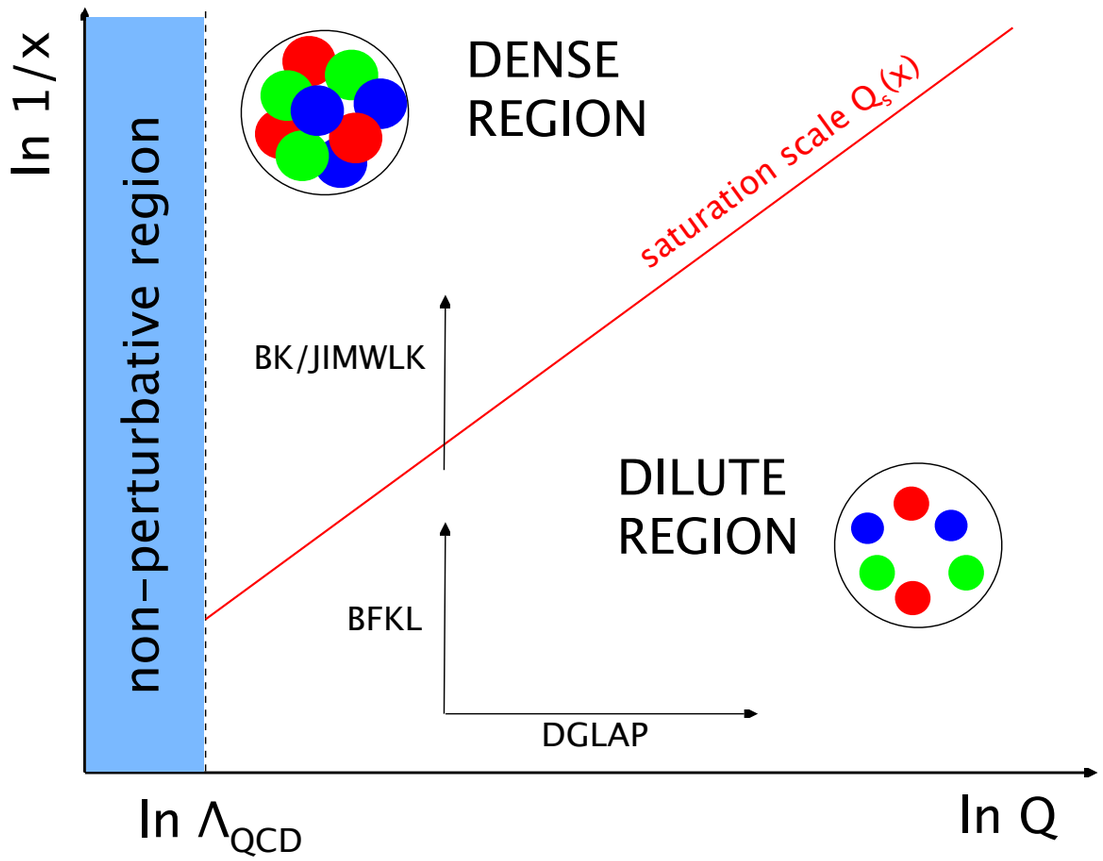
- Three pQCD-based alternatives to describe small-x ep and eA data (differences at moderate $Q^2(>\Lambda^2_{QCD})$ and small x):

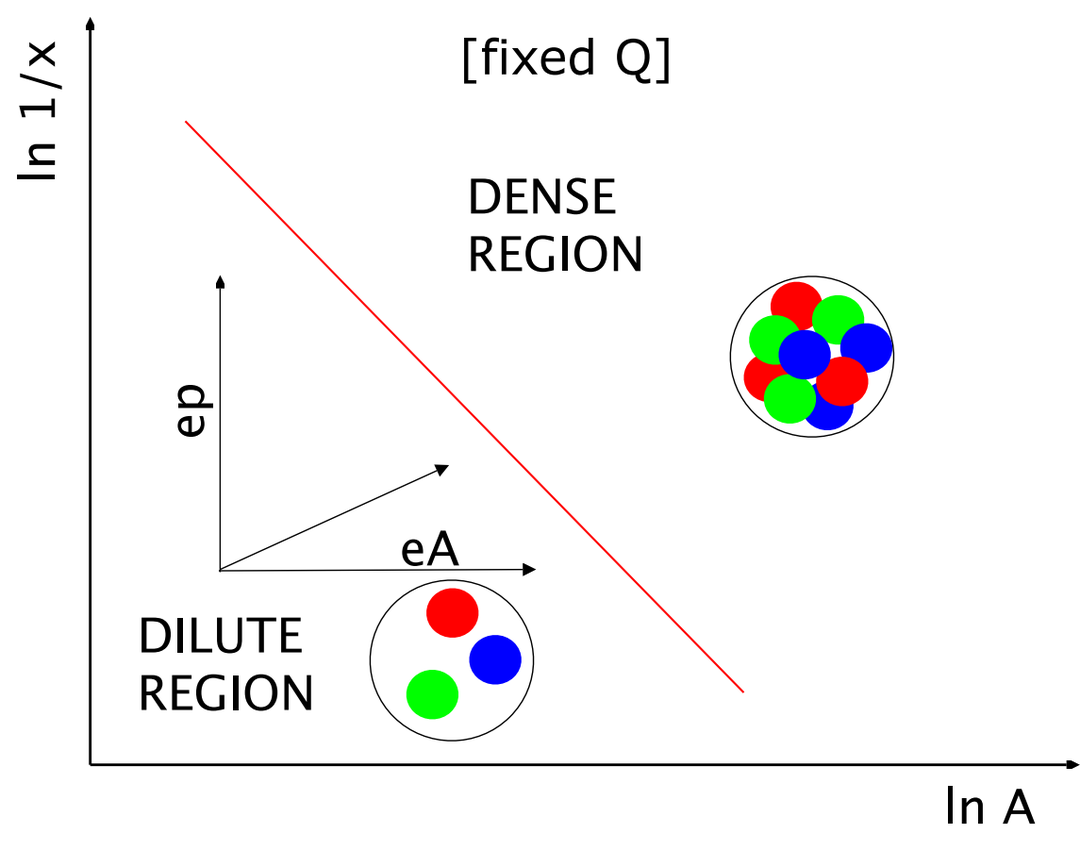
→ DGLAP evolution (fixed order perturbation theory).

→ Resummation schemes: BFKL, CCFM, ABF, CCSS.

→ Saturation (CGC, dipole models).

- **Non-linear effects** (unitarity constraints) are density effects: where? ⇒ **two-pronged approach at the LHeC**: ↓ x / ↑ A.



# Contents:

1. Introduction.

2. eA at the LHeC and comparison to the LHC.

3. Physics case in eA:
   - Inclusive measurements and nuclear PDFs.
   - Diffraction.
   - Final states: dynamics of QCD radiation and hadronization.

4. Summary and outlook.

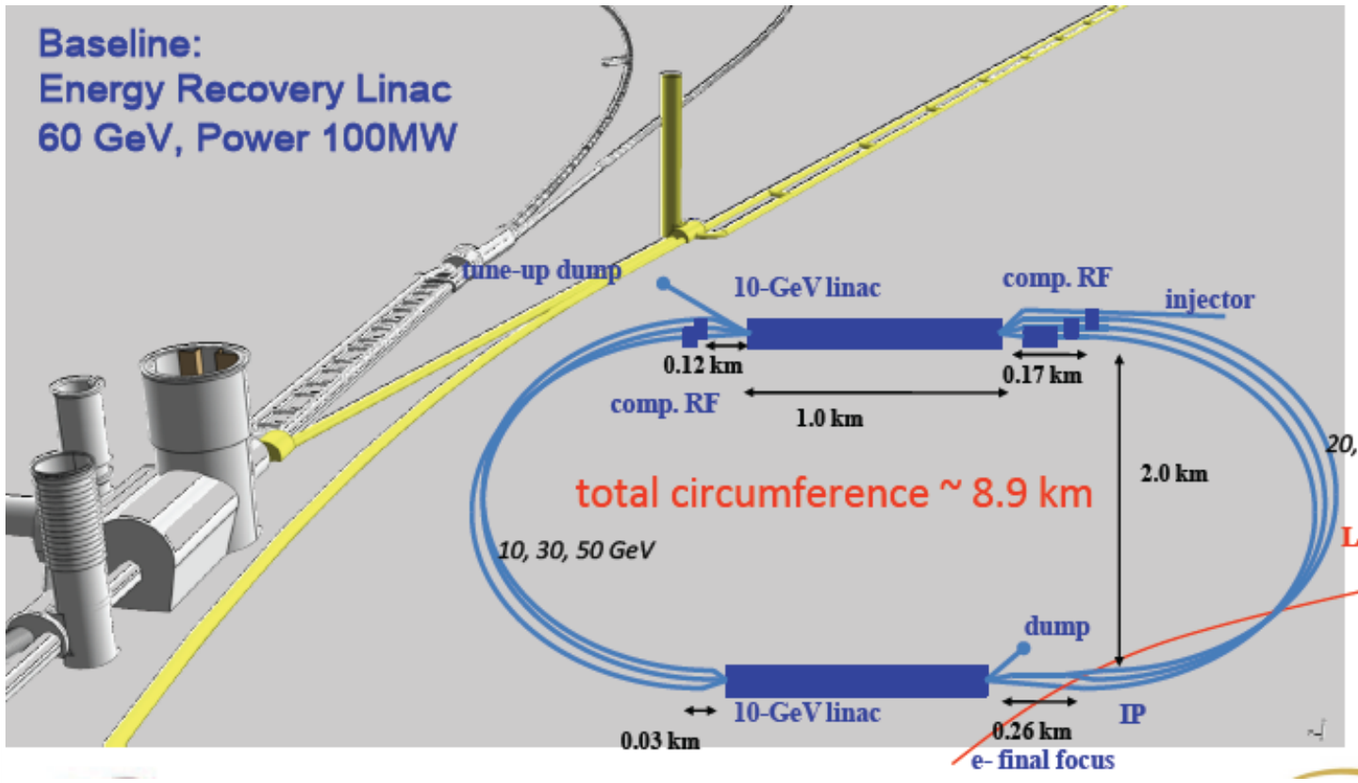
CDR, arXiv:1206.2913, J. Phys. G 39 (2012) 075001;
arXiv:1211.4831; arXiv:1211.5102.
See the talks by Jansova, Newman and Paukunnen this afternoon.

# Accelerator:

$\sqrt{s} \simeq 0.8$ TeV/nucleon

| electron beam | LR ERL | LR |
|---|---|---|
| e- energy at IP[GeV] | 60 | 140 |
| luminosity [$10^{32}$ cm$^{-2}$s$^{-1}$] | 10 | 0.44 |
| polarization [%] | 90 | 90 |
| bunch population [$10^9$] | 2.0 | 1.6 |
| e- bunch length [mm] | 0.3 | 0.3 |
| bunch interval [ns] | 50 | 50 |
| transv. emit. $\gamma\varepsilon_{x,y}$ [mm] | 0.05 | 0.1 |
| rms IP beam size $\sigma_{x,y}$ [μm] | 7 | 7 |
| e- IP beta funct. $\beta^*_{x,y}$ [m] | 0.12 | 0.14 |
| full crossing angle [mrad] | 0 | 0 |
| geometric reduction $H_{hg}$ | 0.91 | 0.94 |
| repetition rate [Hz] | N/A | 10 |
| beam pulse length [ms] | N/A | 5 |
| ER efficiency | 94% | N/A |
| average current [mA] | 6.6 | 5.4 |
| tot. wall plug power[MW] | 100 | 100 |

CDR numbers for luminosity, to be considered now as lower bounds.

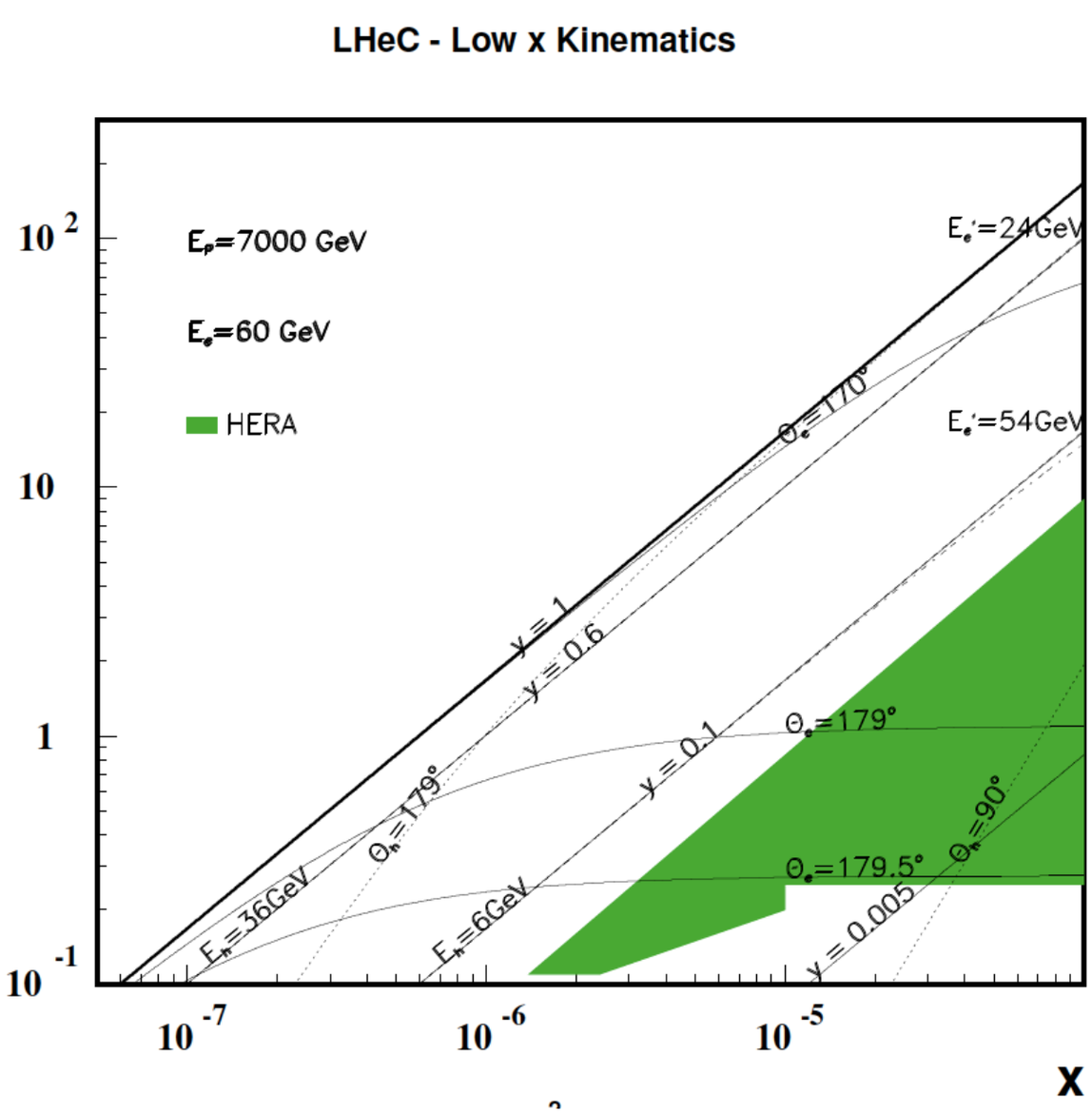


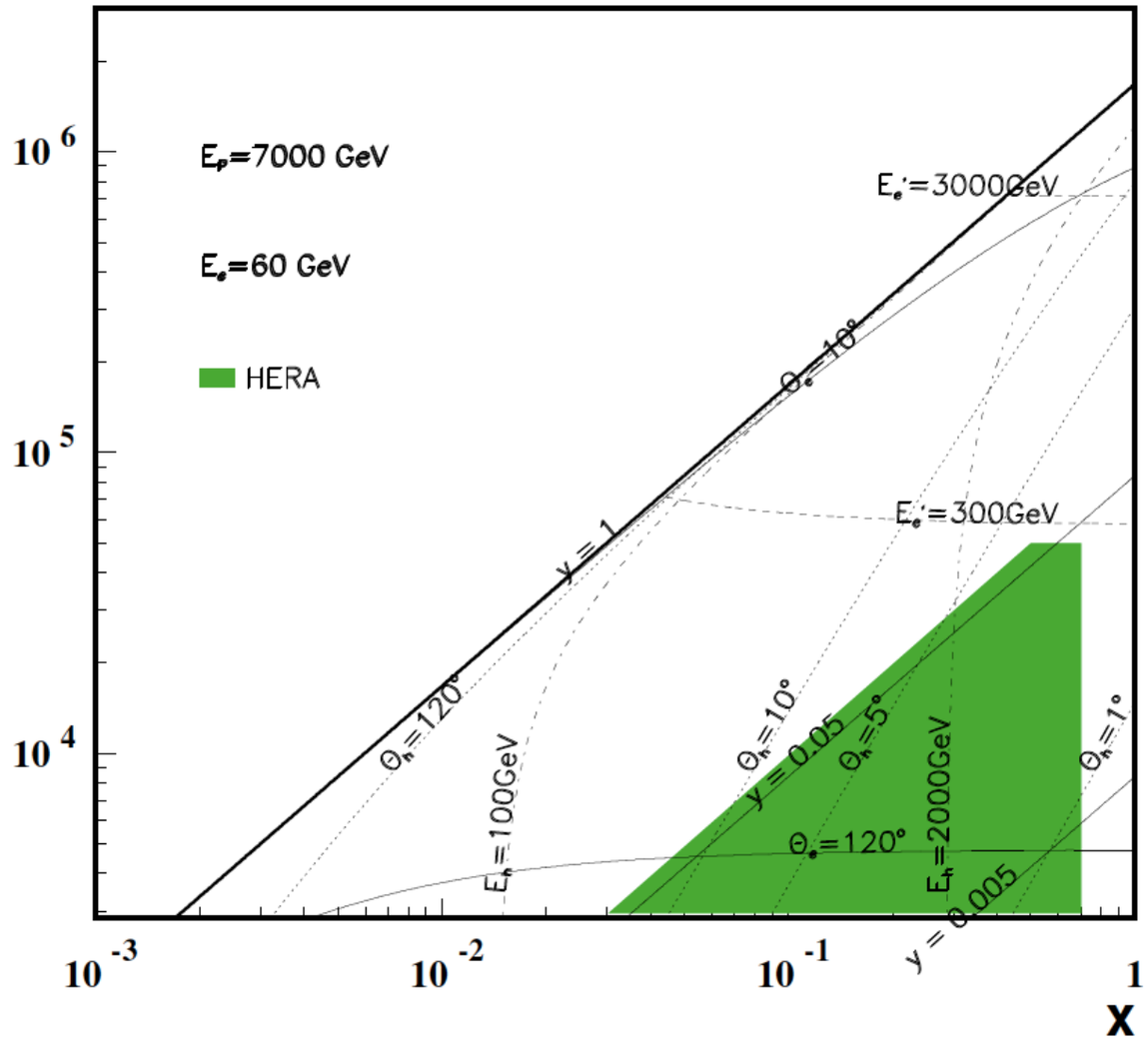

Luminosity per nucleon

$$L_{eN} = \begin{cases} 9 \times 10^{31}\ \mathrm{cm^{-2}s^{-1}} & \text{(Nominal Pb)} \\ 1.6 \times 10^{32}\ \mathrm{cm^{-2}s^{-1}} & \text{(Ultimate Pb)} \end{cases}$$

eD: $L_{eN} = A L_{eA} > \sim 3 \times 10^{31}$ cm$^{-2}$s$^{-1}$

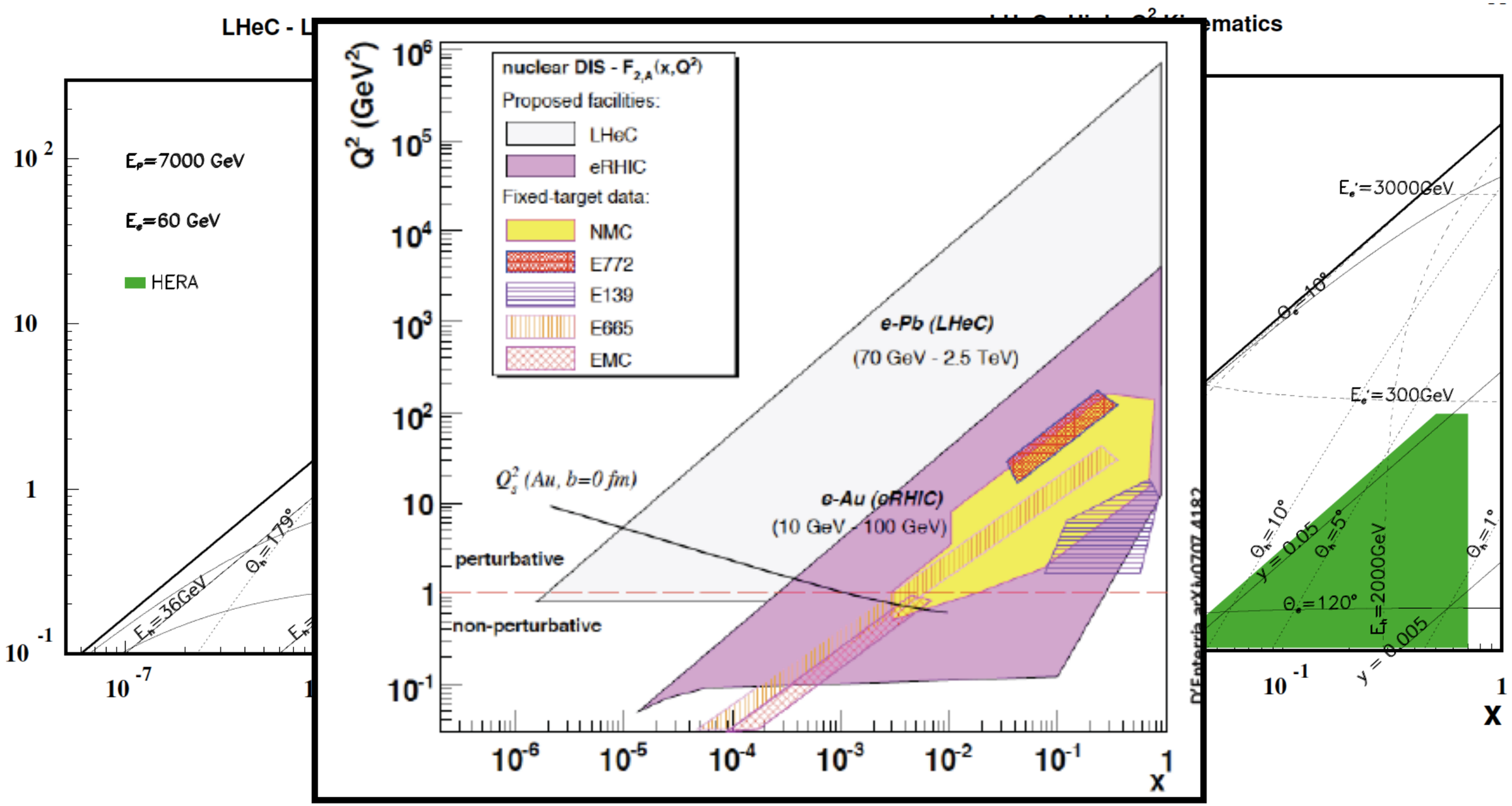
# Kinematics:



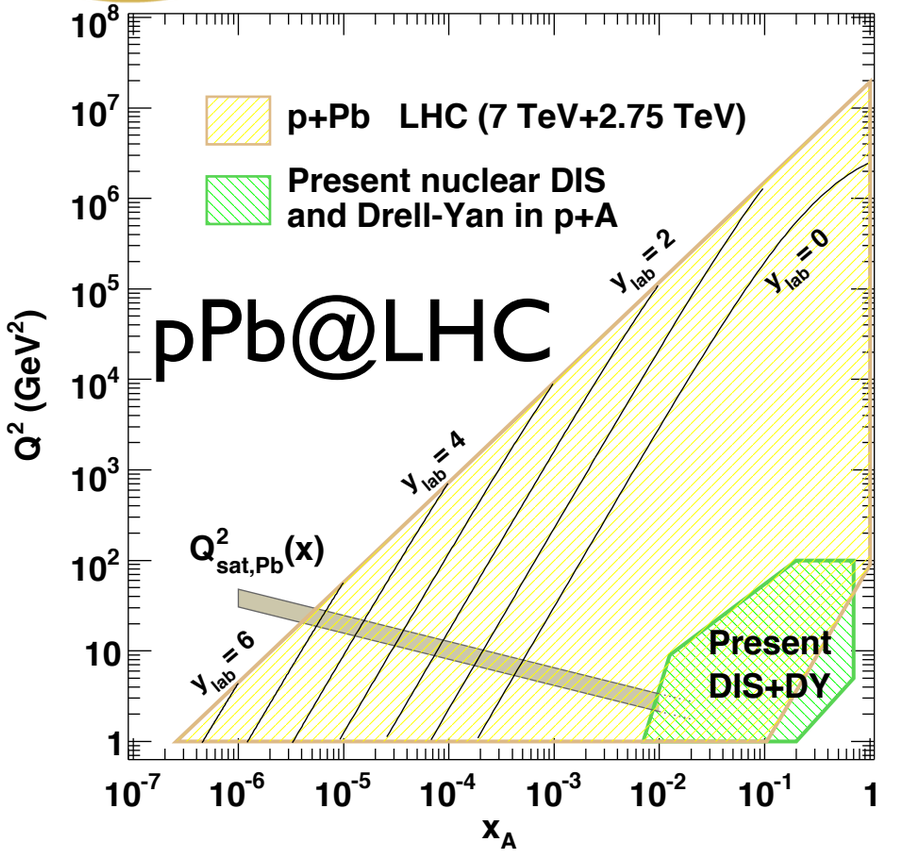

- Small-x demands 1 degree acceptance.
- Higher luminosity would benefit high-x and $Q^2$ studies.

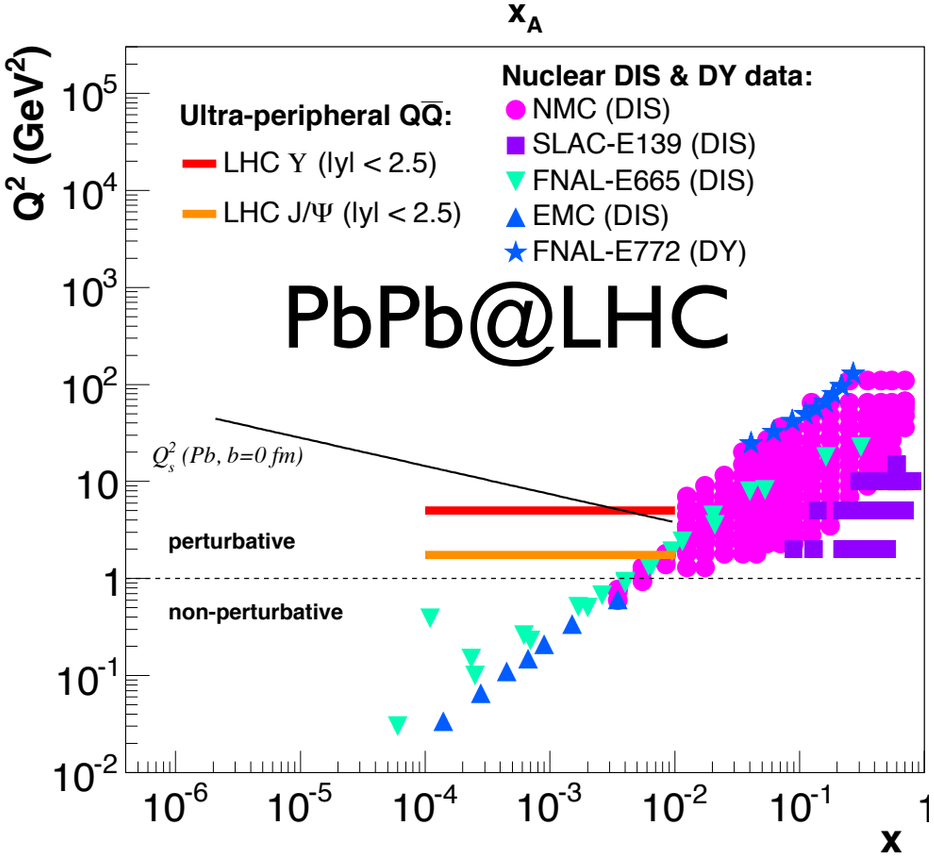
# Kinematics:

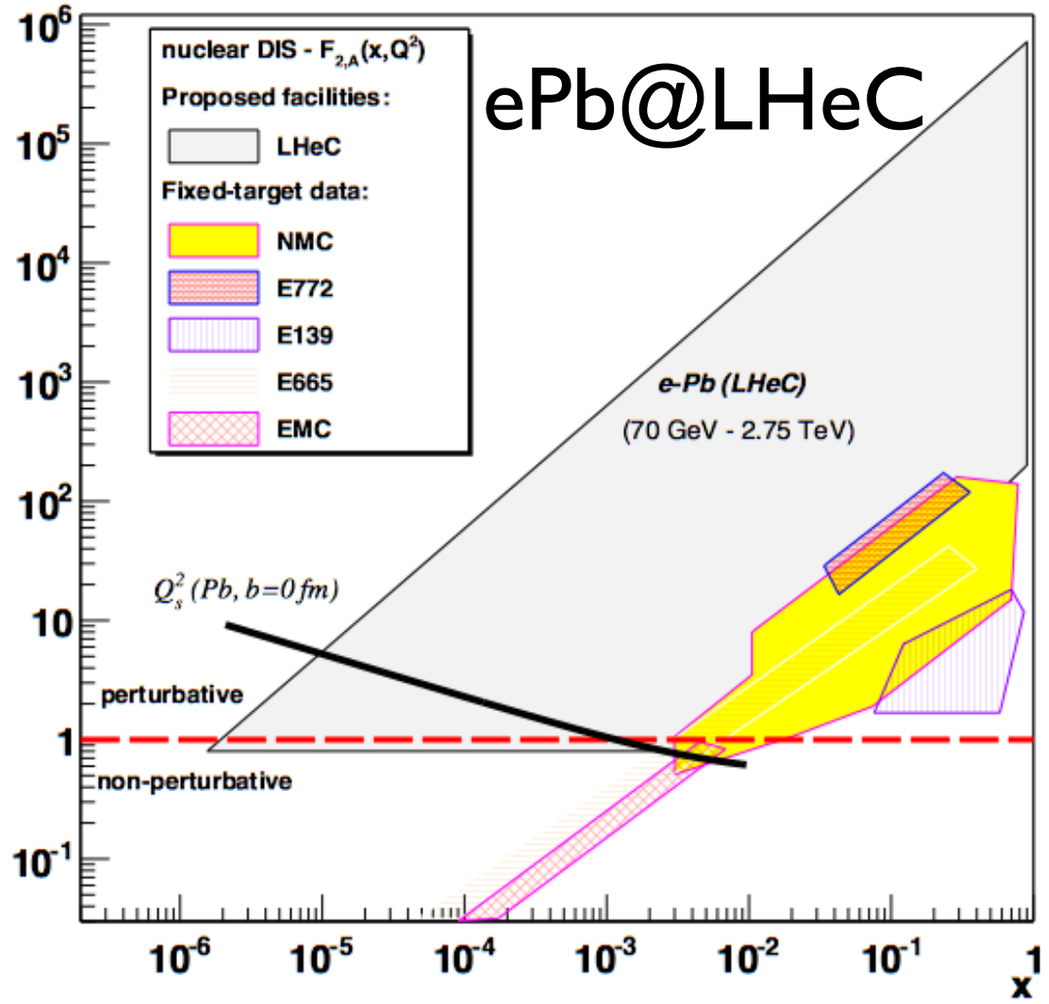



- Small-x demands 1 degree acceptance.
- Higher luminosity would benefit high-x and $Q^2$ studies.

# LHC vs. LHeC:

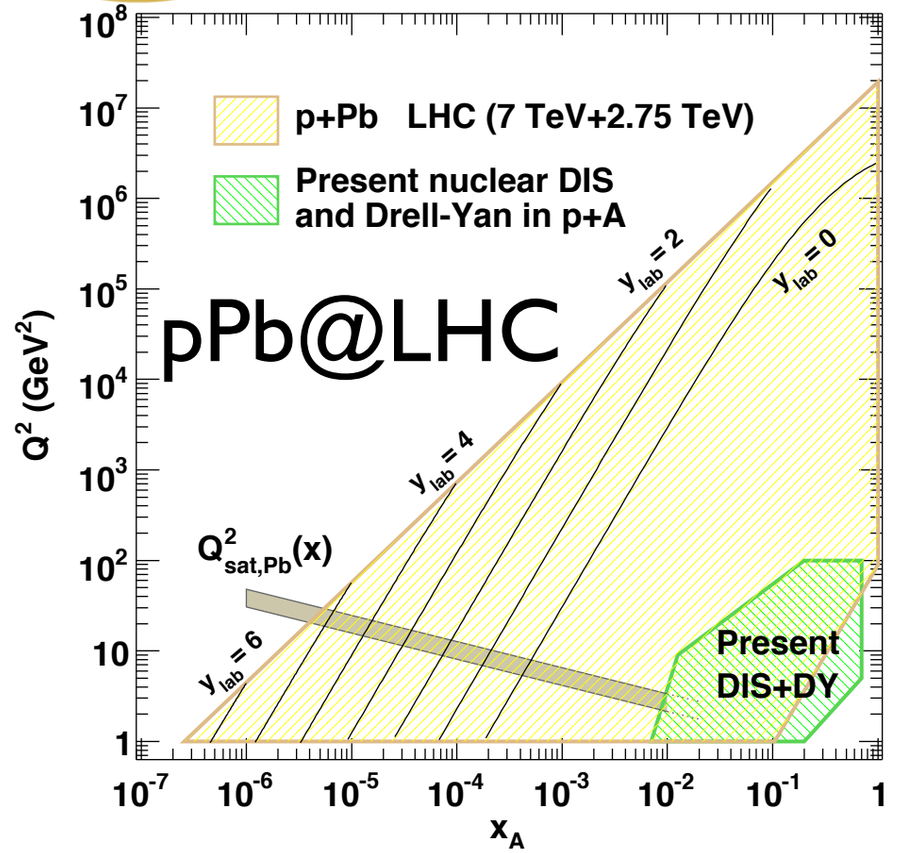


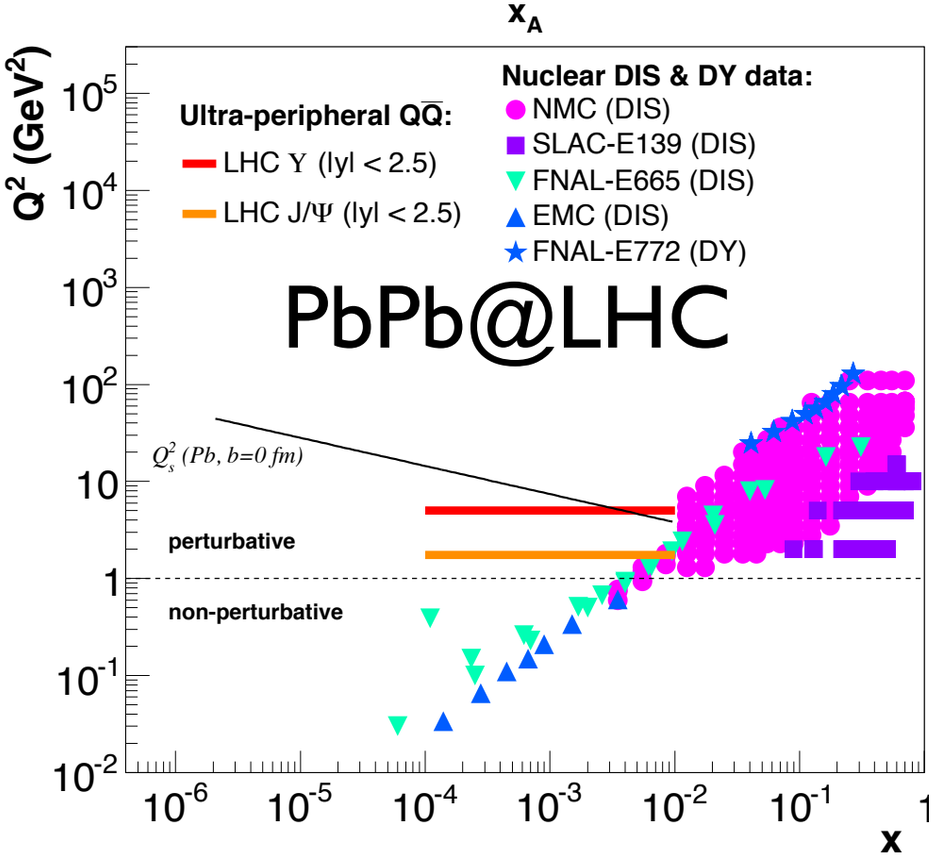



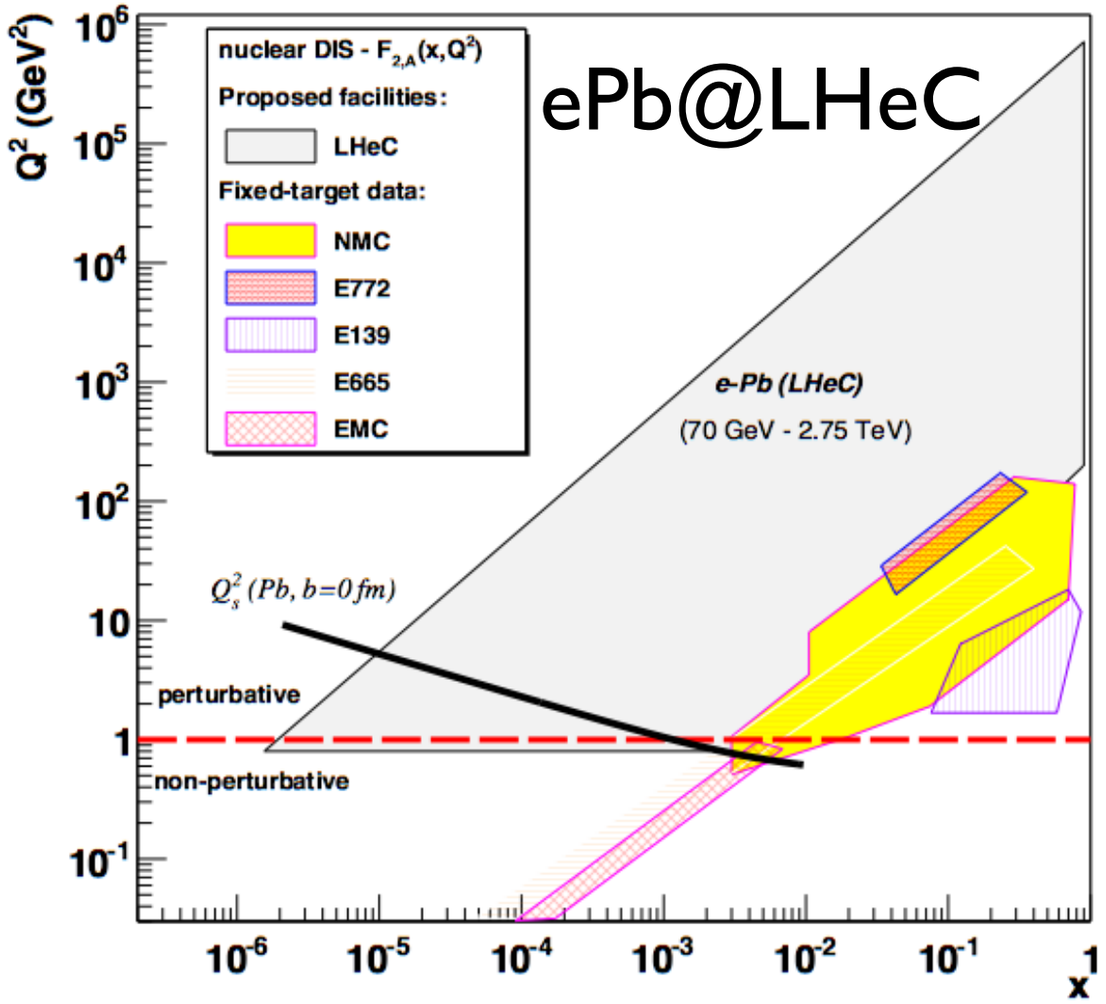




*Heavy Ion Physics in e-A and p/A-A: 2. eA at the LHeC and comparison to the LHC.*

# LHC vs. LHeC:



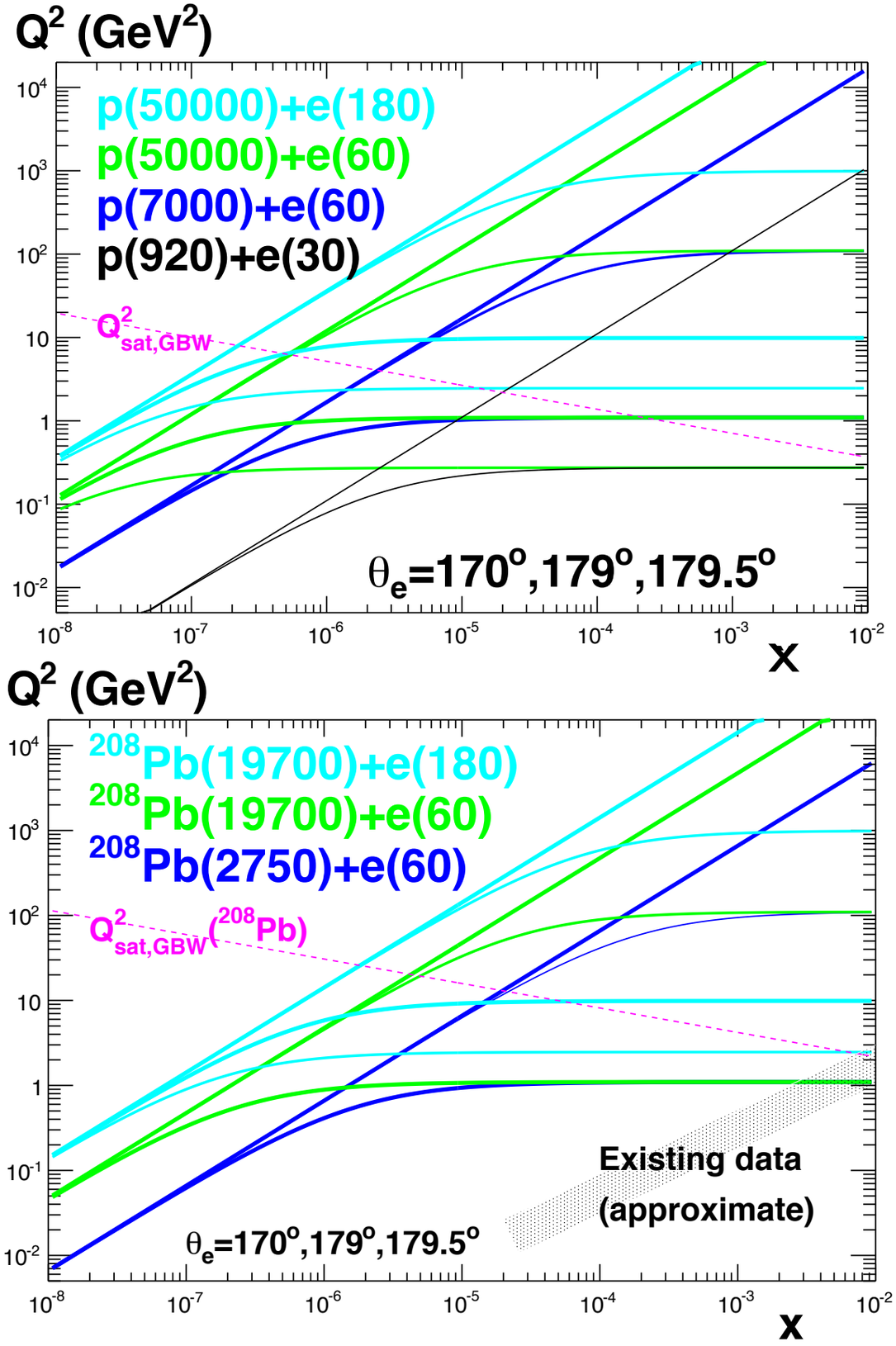




- The LHeC will explore a region overlapping with the LHC:

➜ in a cleaner experimental setup;

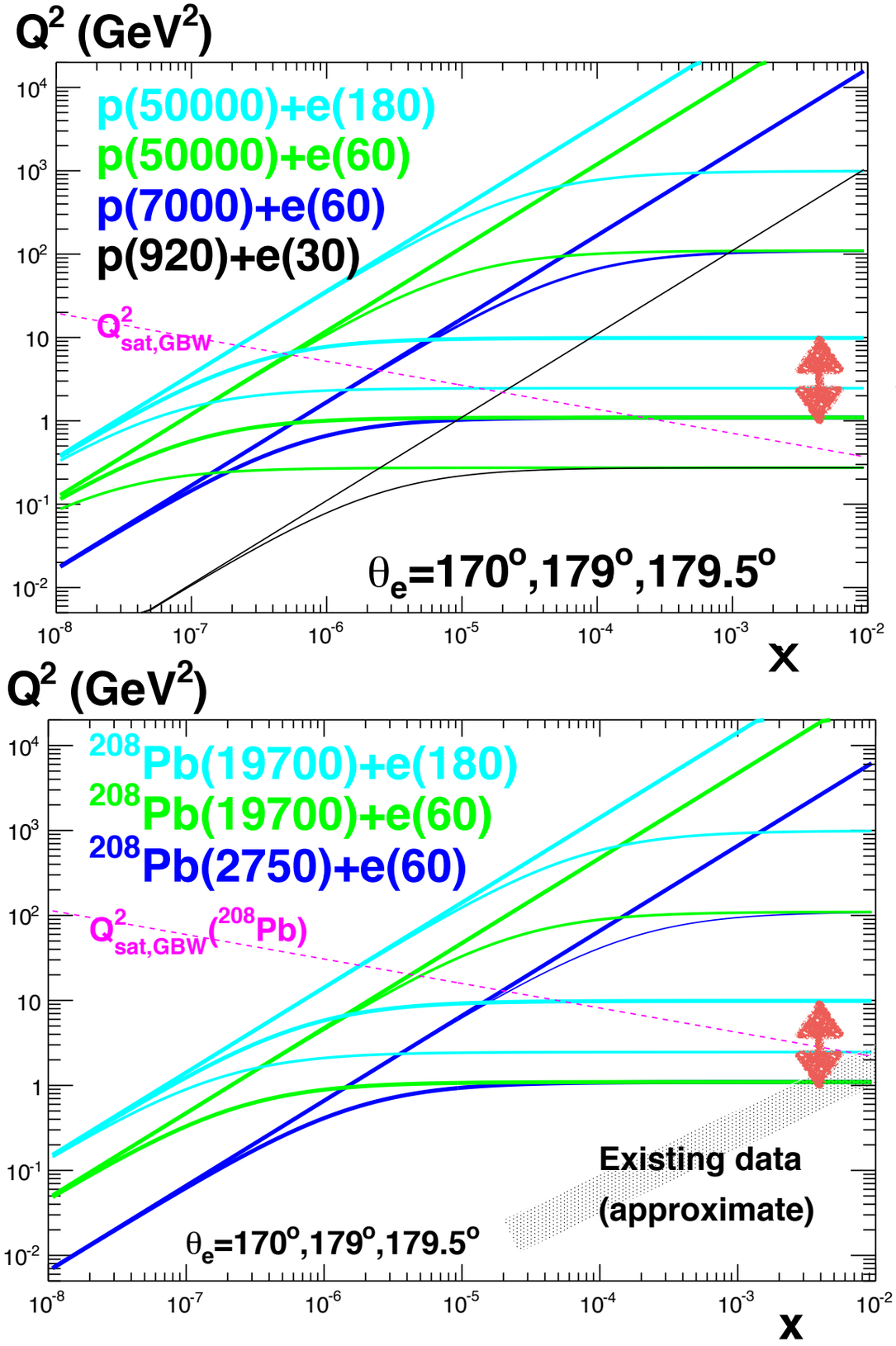
➜ on firmer theoretical grounds.

# Kinematics for FHeC:




- Obvious extension of the kinematics.
- Larger electron energy drastically compromises small-x unless we can enlarge substantially the acceptance for e.

# Kinematics for FHeC:



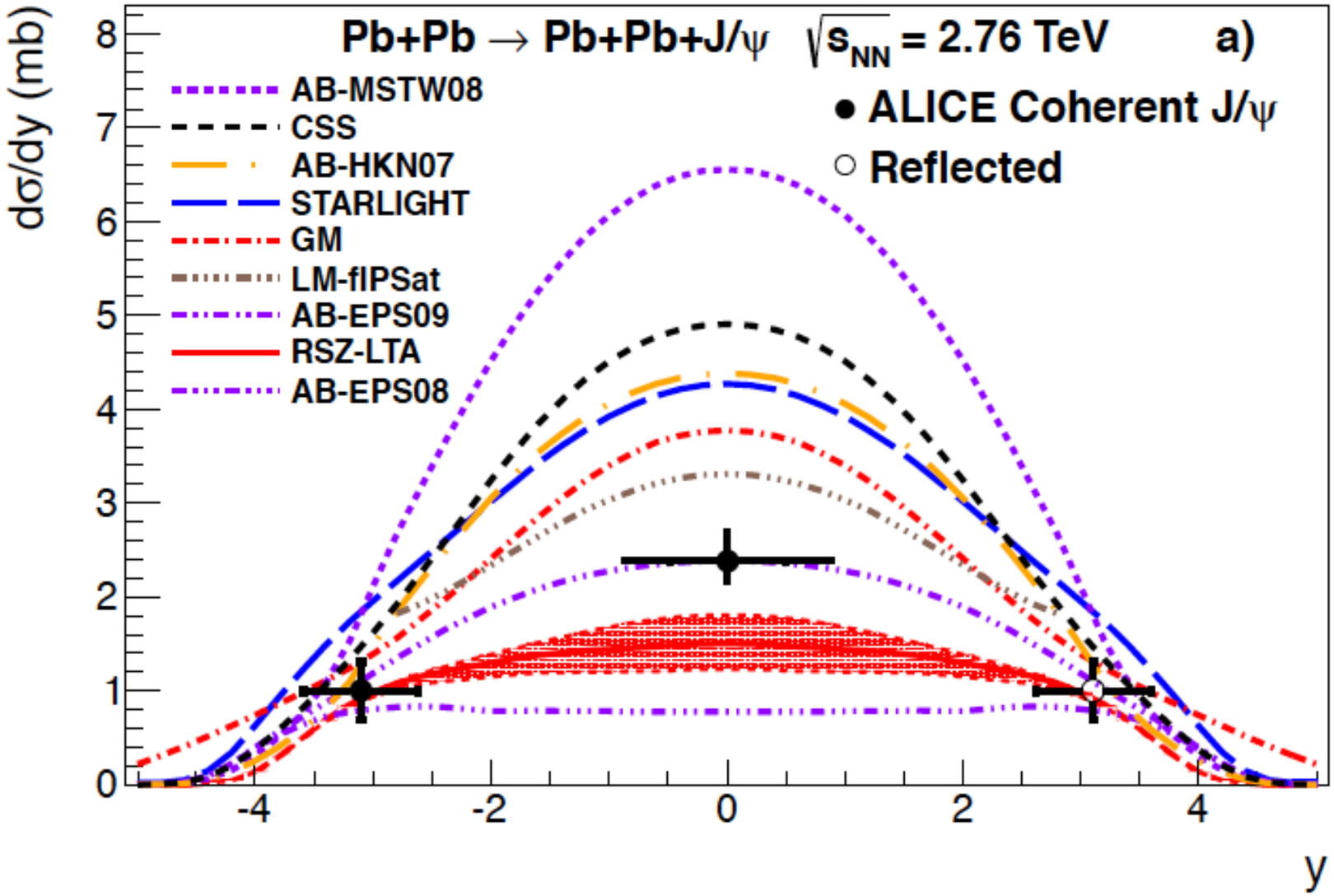

- Obvious extension of the kinematics.
- Larger electron energy drastically compromises small-x unless we can enlarge substantially the acceptance for e.

# LHC studies: PbPb

➜ Benchmarking: EW bosons or VM production in UPCs, both sensitive to nPDFs.

➜ Search for 'non-standard' physics like saturation: multiplicities, the ridge,…

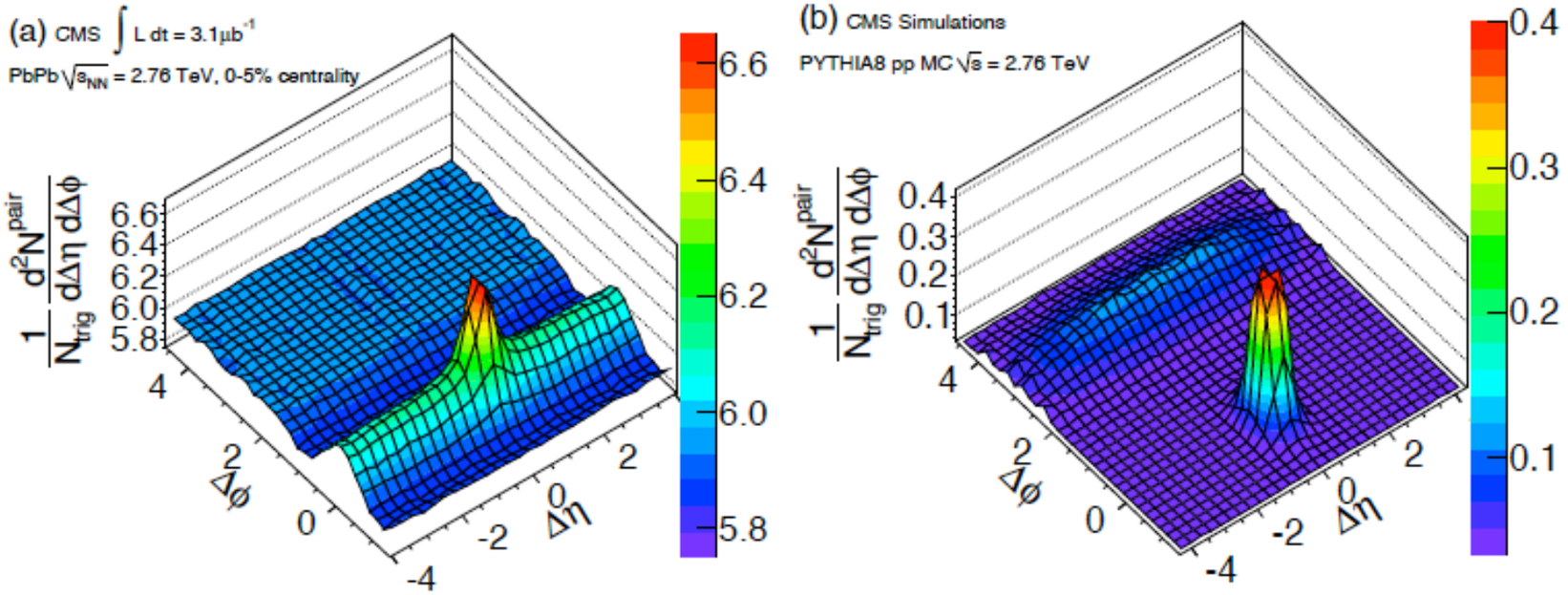
ALICE, 1305.1467



# LHC studies: PbPb

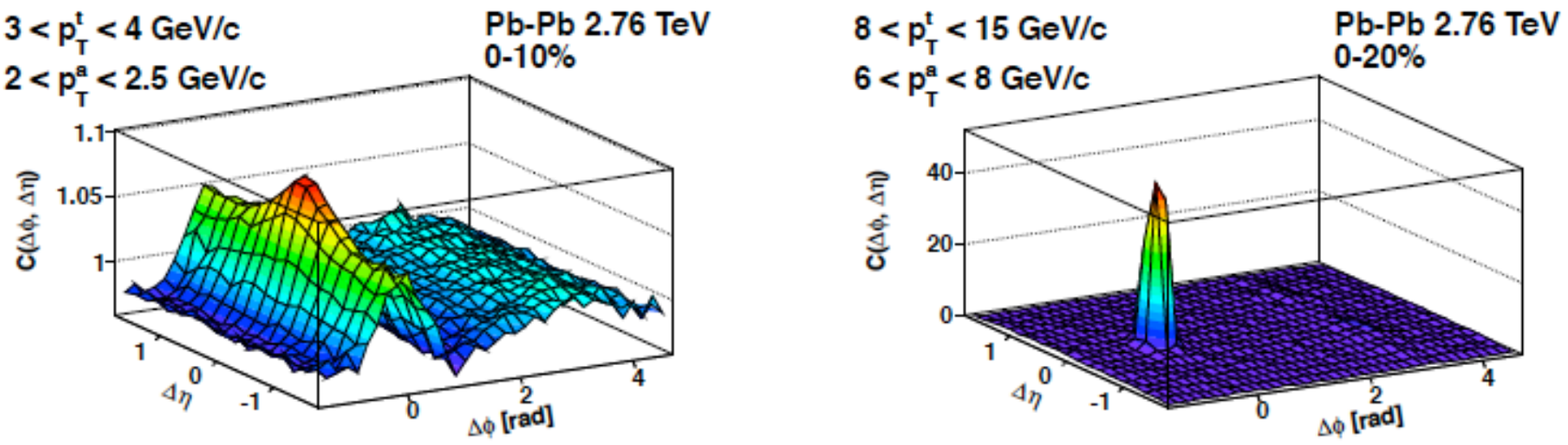
➜ Benchmarking: EW bosons or VM production in UPCs, both sensitive to nPDFs.

CMS, 1105.2438



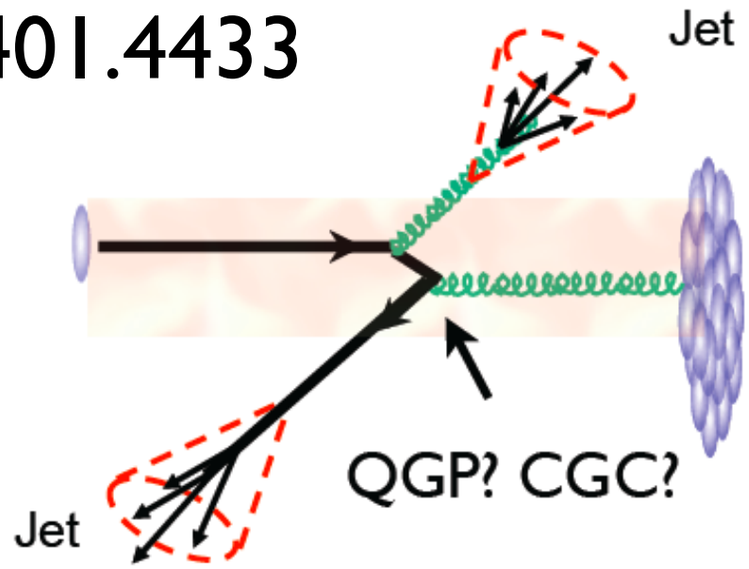

➜ Search for ‘non-standard’ physics like saturation: multiplicities, the ridge,…

ALICE, 1109.2501



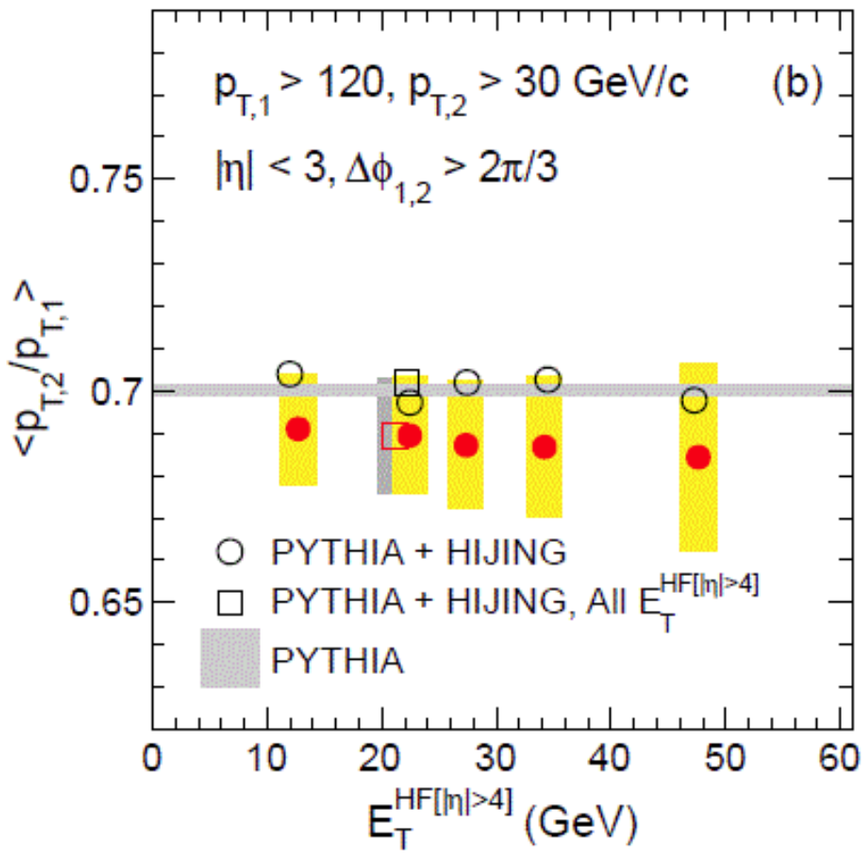
# LHC studies: pPb

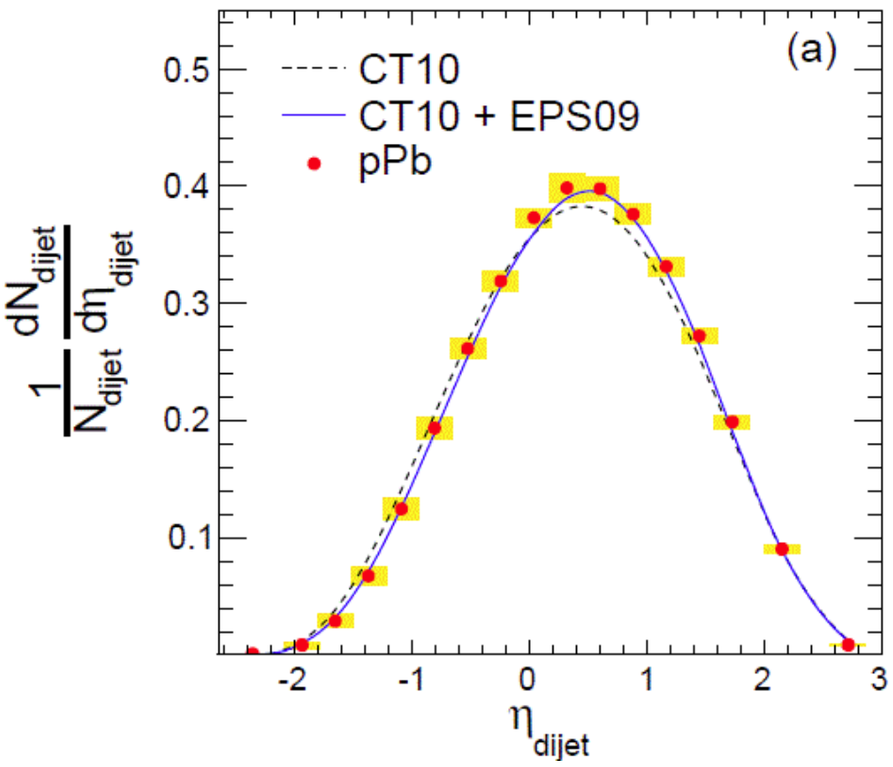
CMS, 1401.4433




➜ Benchmarking: jets, quarkonia and heavy flavours.

➜ Search for 'non-standard' physics like saturation: multiplicities and $p_T$ distributions, flow, ridge.

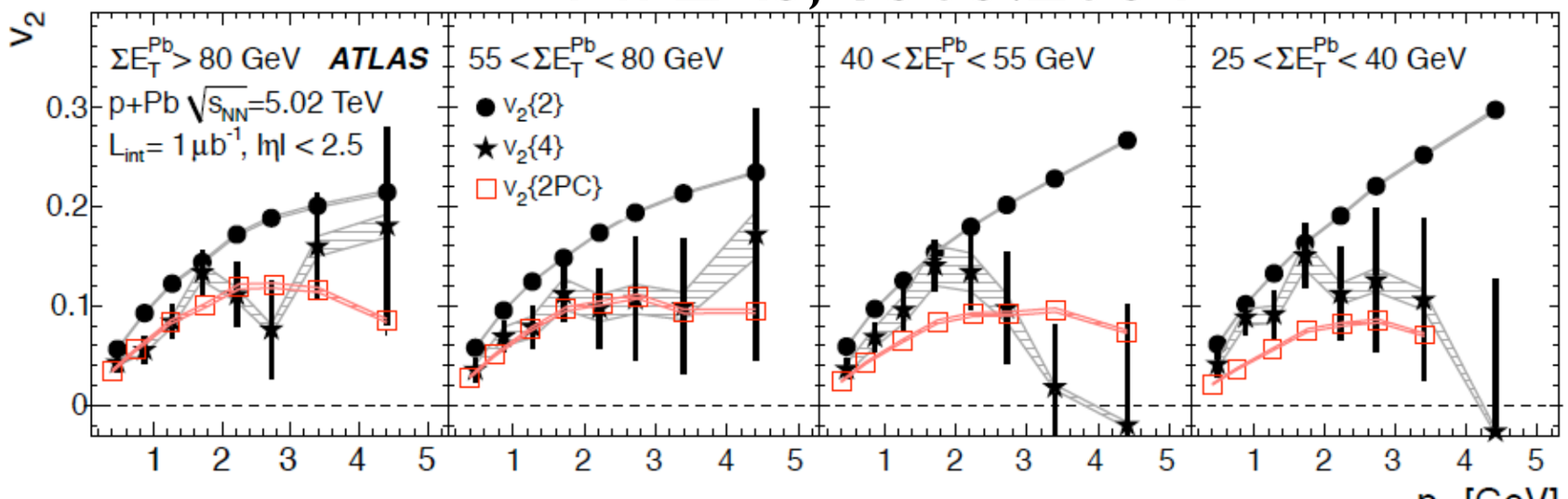


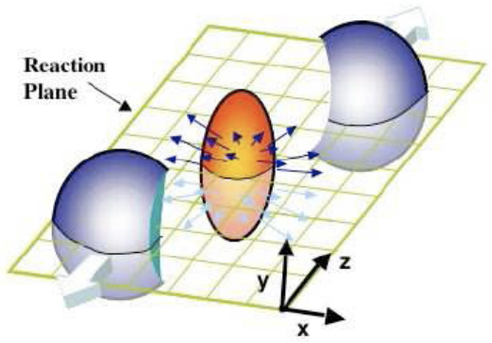
# LHC studies: pPb

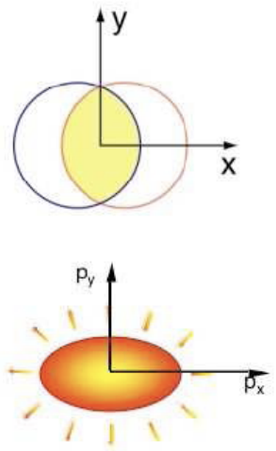
➜ Benchmarking: jets, quarkonia and heavy flavours.

ATLAS, 1303.2084

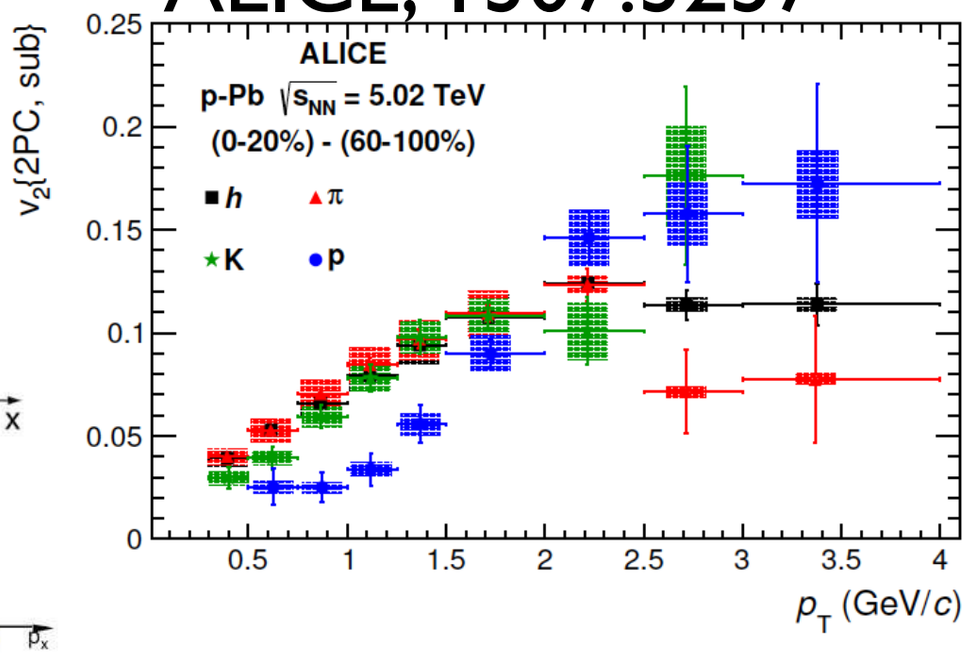



➜ Search for 'non-standard' physics like saturation: multiplicities and $p_T$ distributions, flow, ridge.




ALICE, 1307.3237

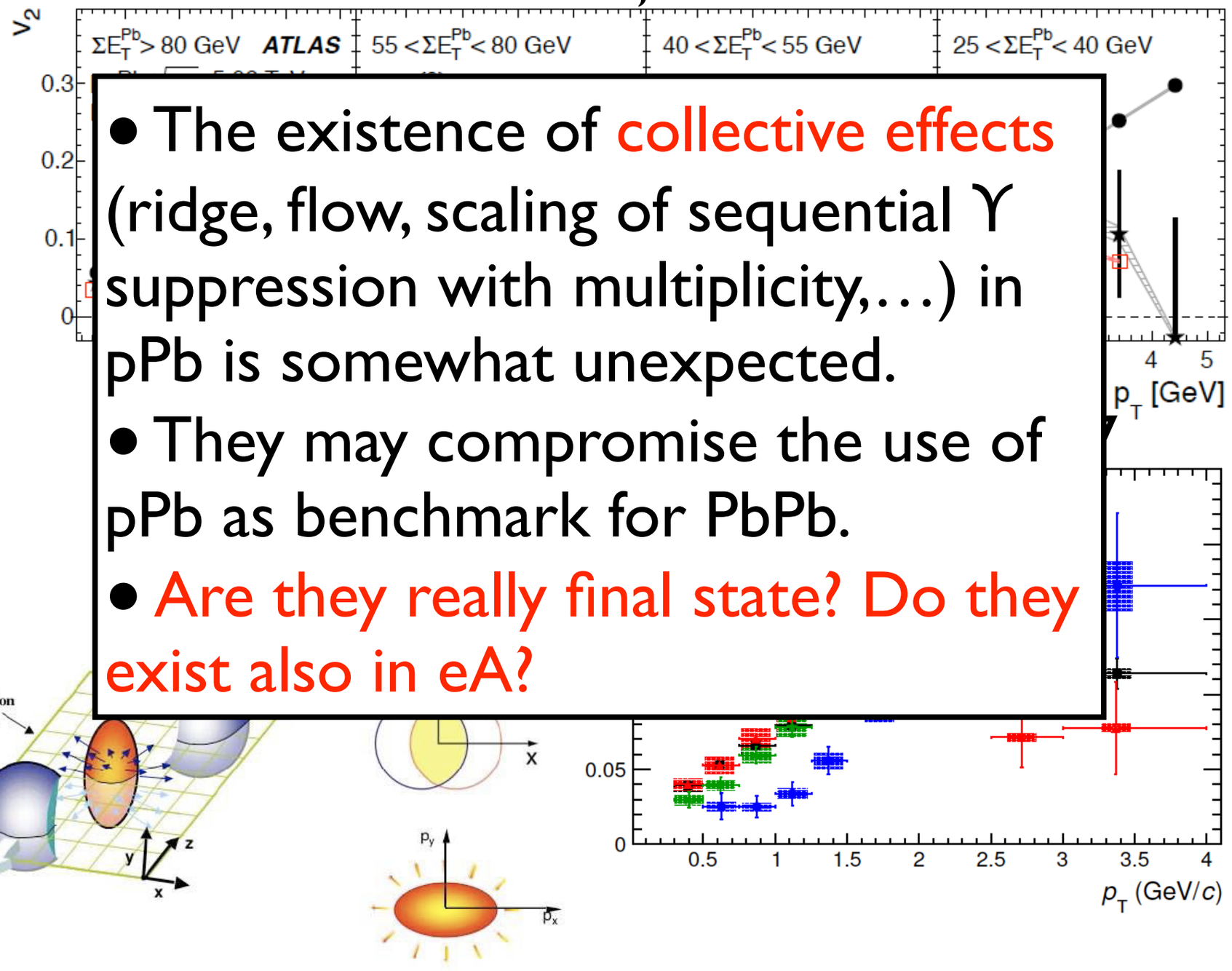


# LHC studies: pPb

➜ Benchmarking: jets, quarkonia and heavy flavours.

➜ Search for 'non-standard' physics like saturation: multiplicities and $p_T$ distributions, flow, ridge.

ATLAS, 1303.2084




- The existence of collective effects (ridge, flow, scaling of sequential $\Upsilon$ suppression with multiplicity,…) in pPb is somewhat unexpected.
- They may compromise the use of pPb as benchmark for PbPb.
- Are they really final state? Do they exist also in eA?

# Contents:

1. Introduction.

2. eA at the LHeC and comparison to the LHC.

3. Physics case in eA:
   - Inclusive measurements and nuclear PDFs.
   - Diffraction.
   - Final states: dynamics of QCD radiation and hadronization.

4. Summary and outlook.

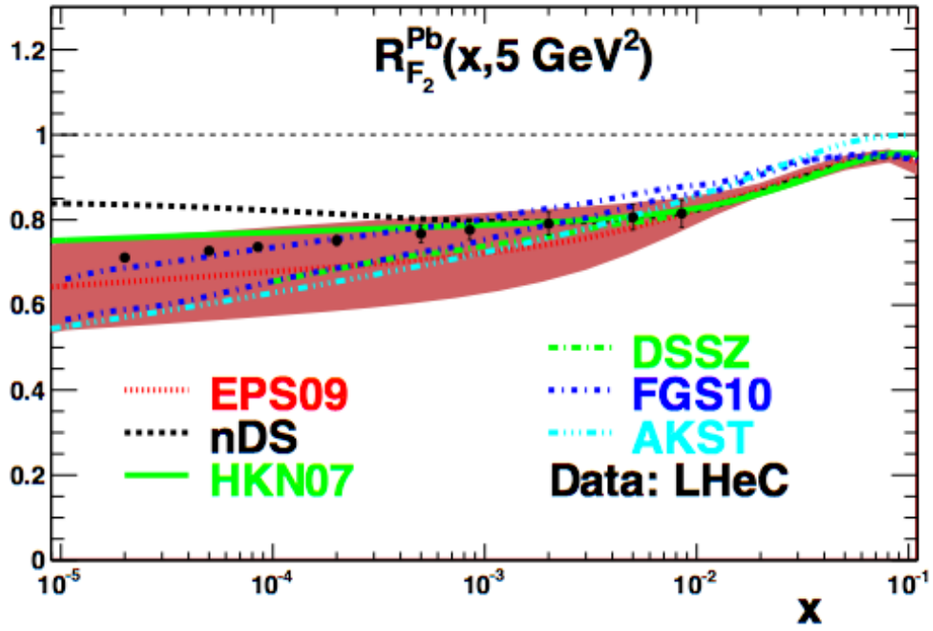
CDR, arXiv:1206.2913, J. Phys. G 39 (2012) 075001;
arXiv:1211.4831; arXiv:1211.5102.
See the talks by Jansova, Newman and Paukunnen this afternoon.

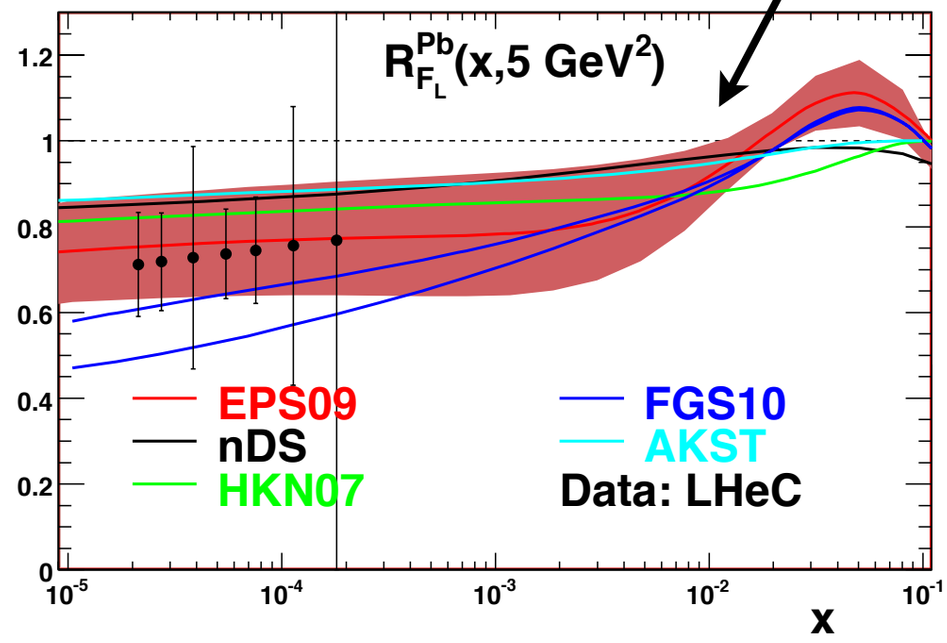
# eA inclusive: comparison

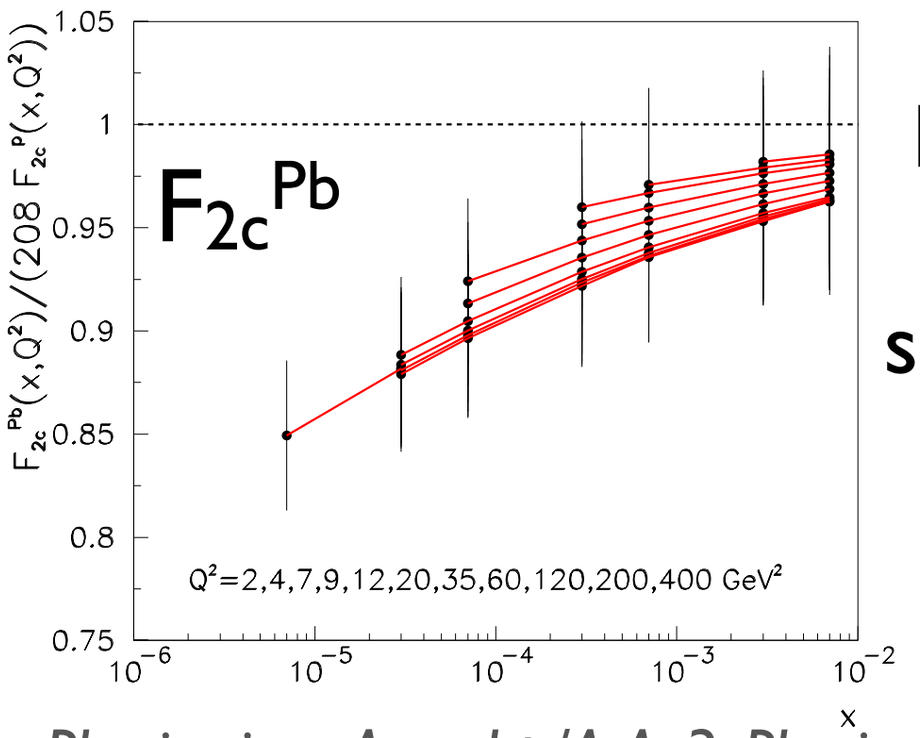
- Good precision can be obtained for $F_{2(c,b)}$ and $F_L$ at small x

(Glauberized 3-5 flavor GBW model, NA '02).

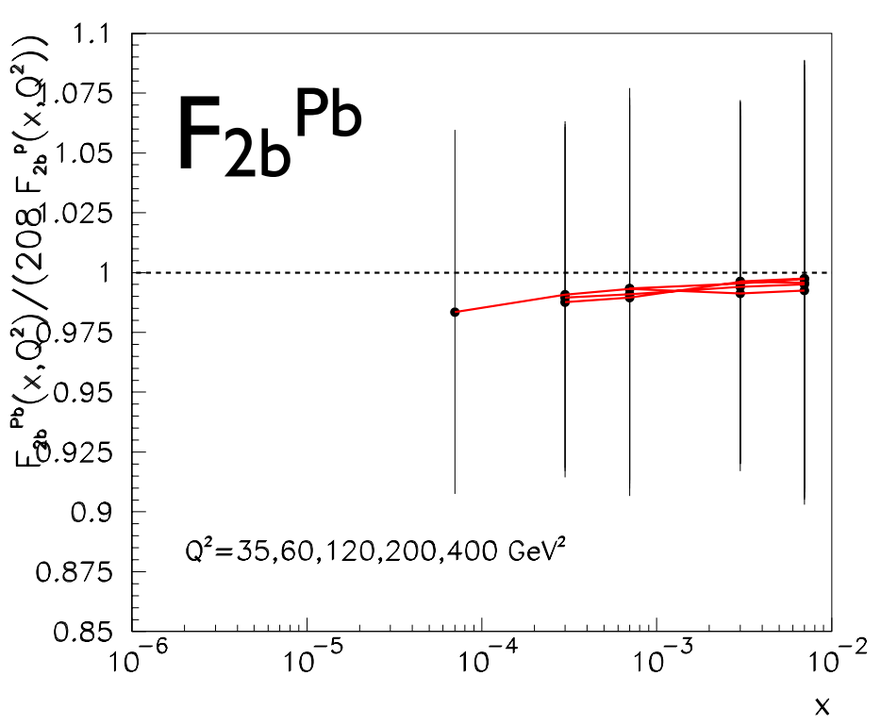
Not optimized!




Note the scale!!!



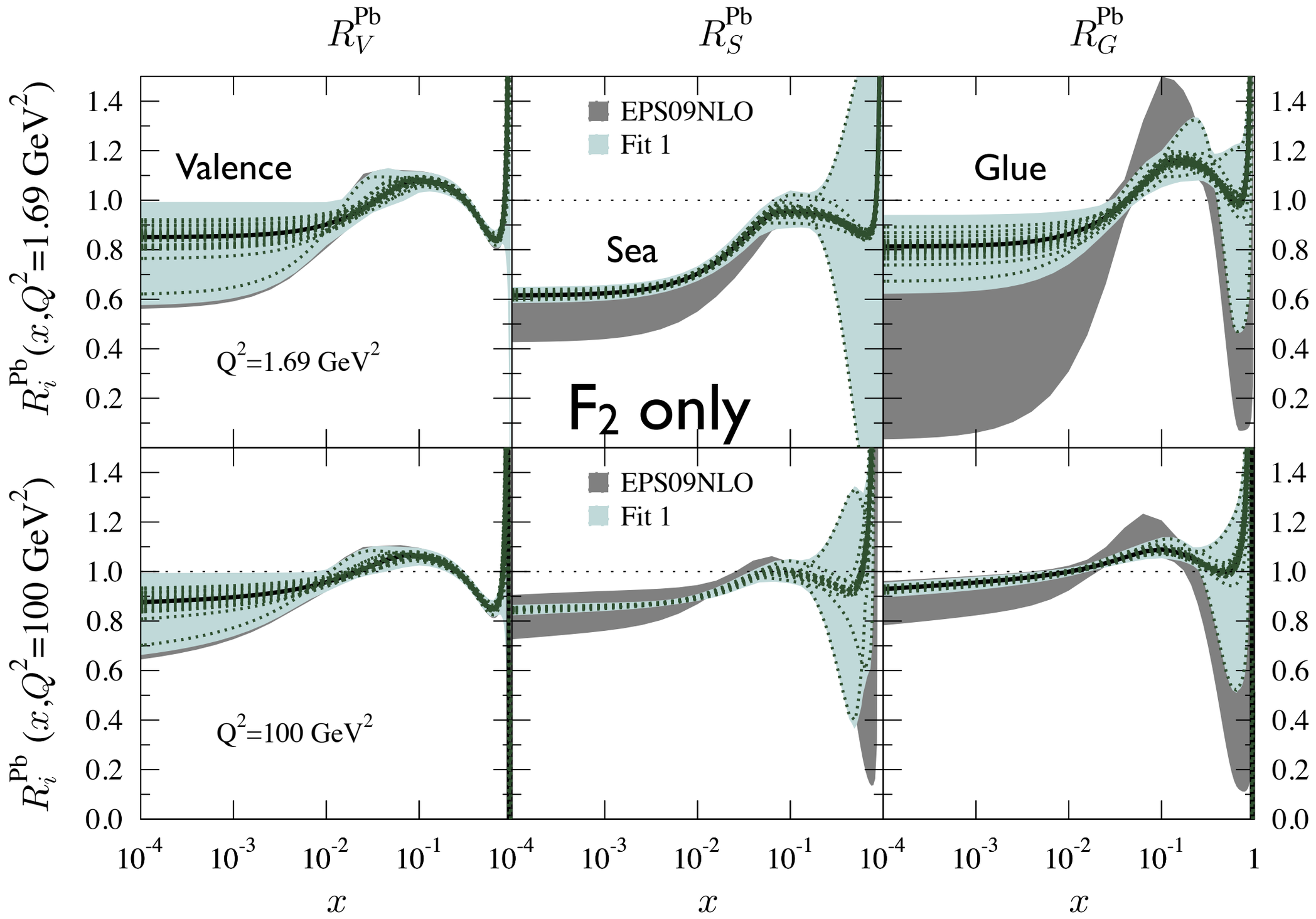
# Nuclear PDFs at small x:

- $F_2$ data substantially reduce the uncertainties in DGLAP analysis;

inclusion of charm, beauty; and $F_L$ also give constraints.

# Nuclear PDFs at small x:

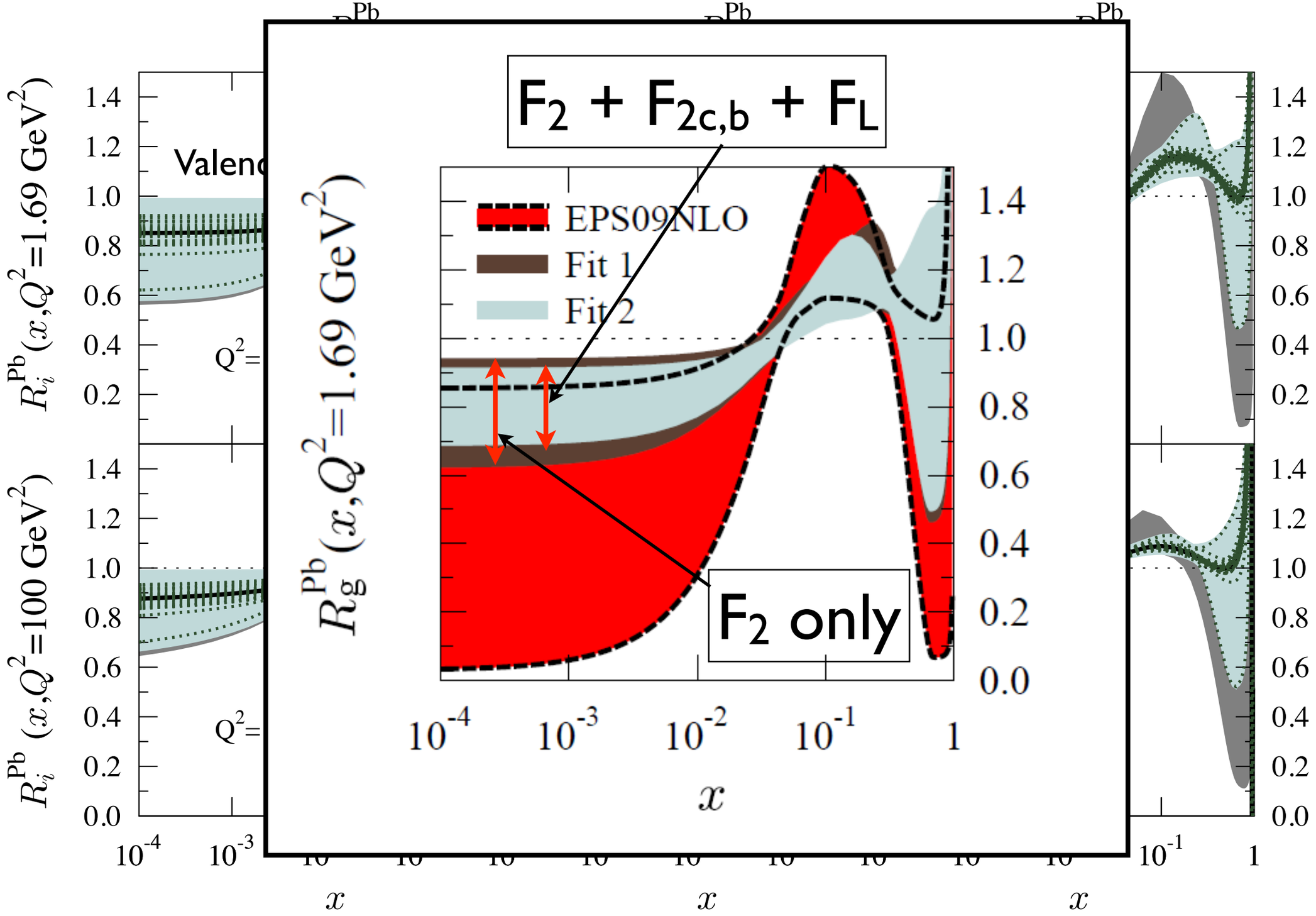
- $F_2$ data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty; and $F_L$ also give constraints.



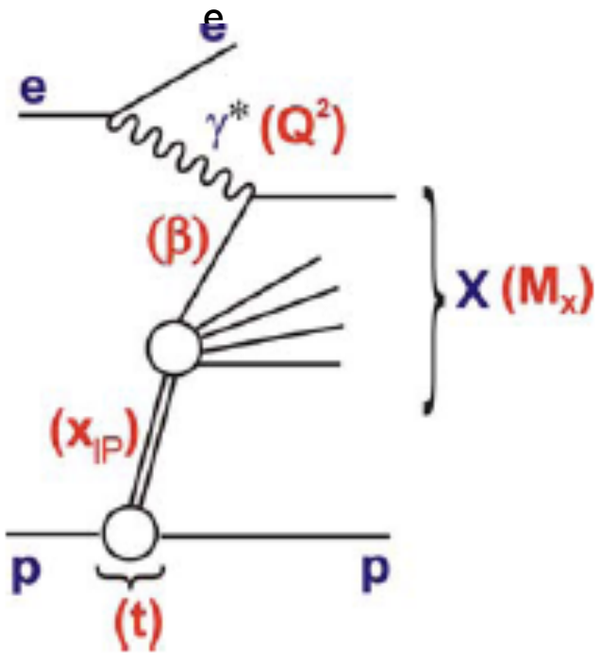
# Nuclear PDFs at small x:

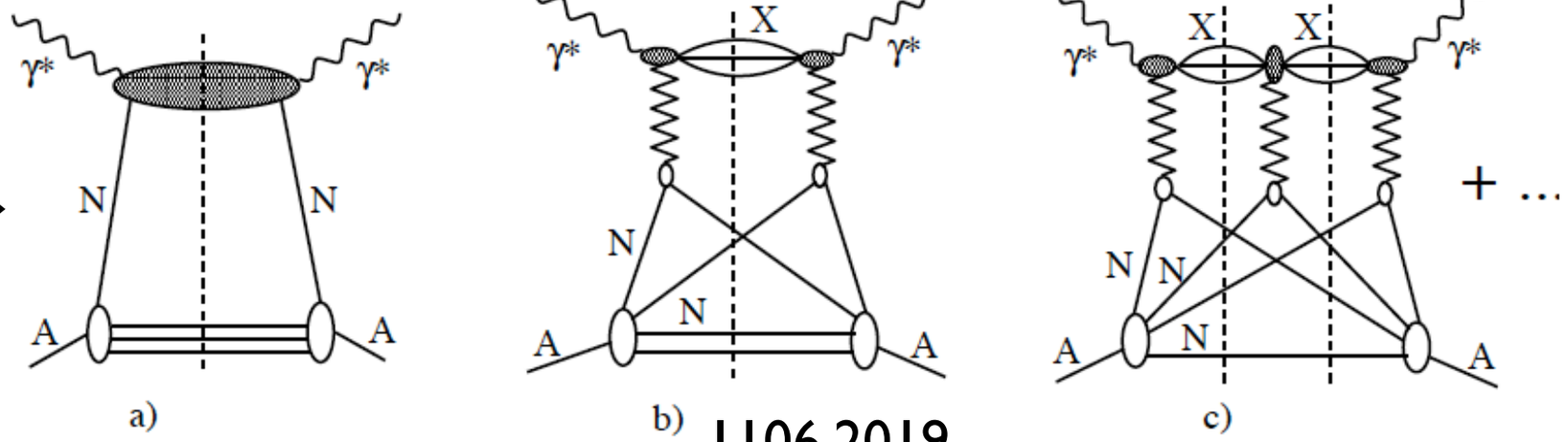
- $F_2$ data substantially reduce the uncertainties in DGLAP analysis;

inclusion of charm, beauty; and $F_L$ also give constraints.



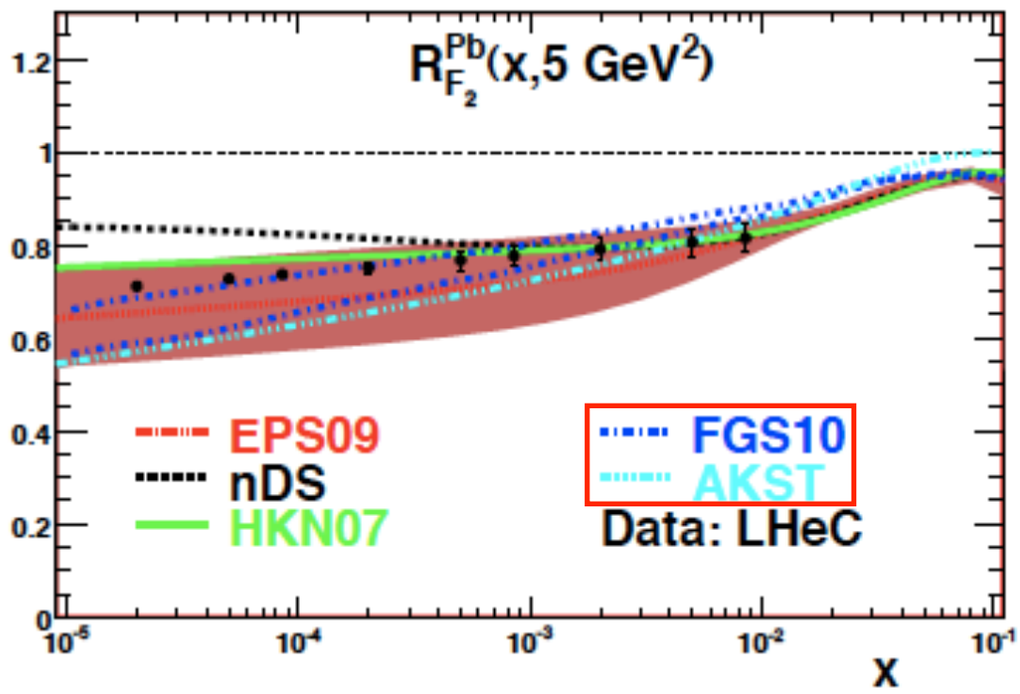
# Diffraction in ep and shadowing:

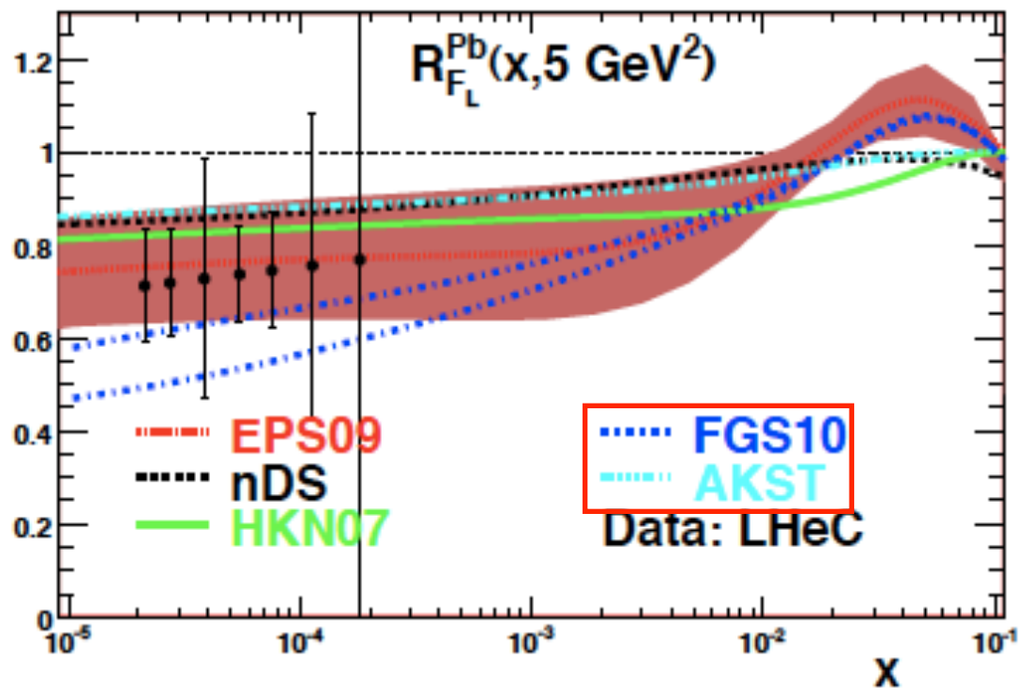


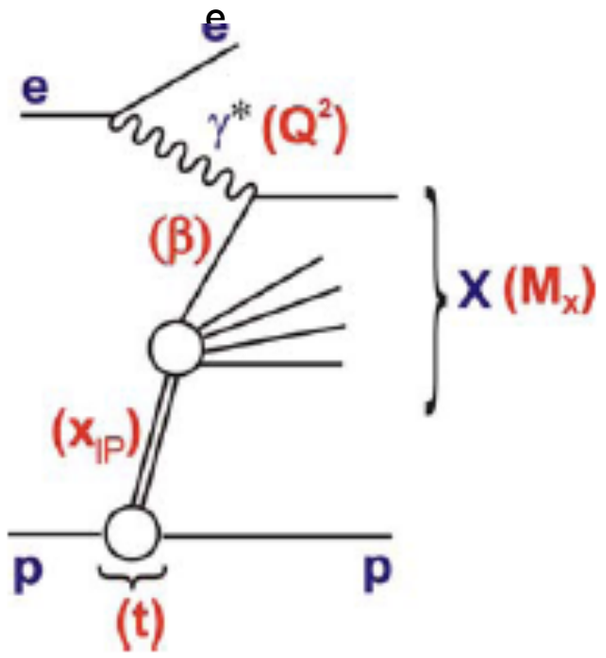

1106.2019

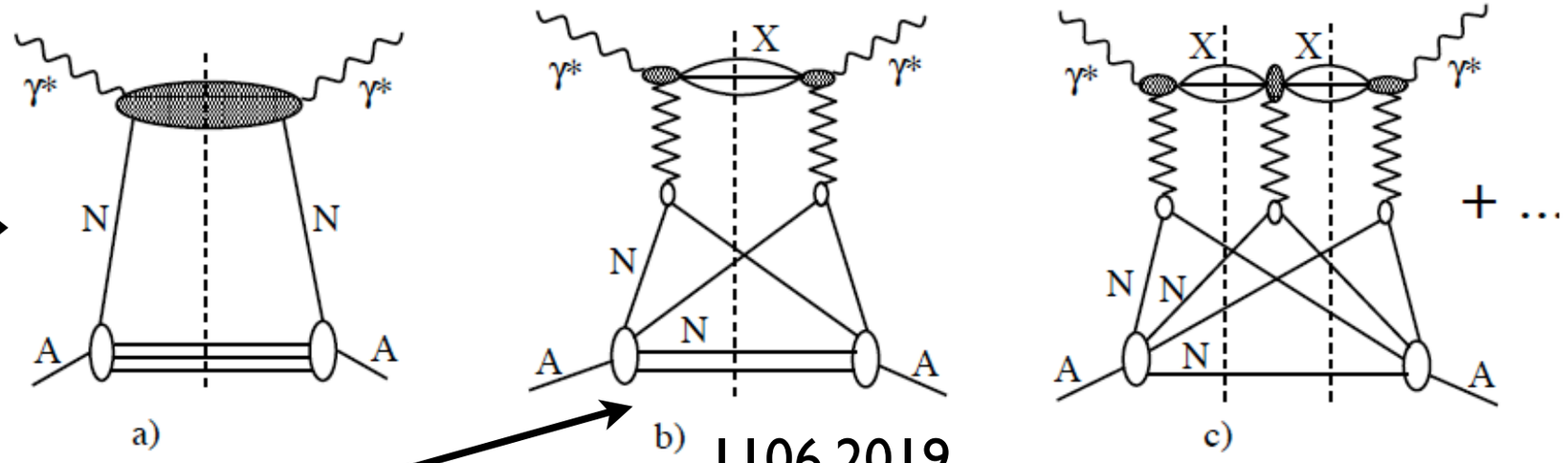
- Diffraction is linked to nuclear shadowing through basic QFT (Gribov): eD to test and set the 'benchmark' for new effects.



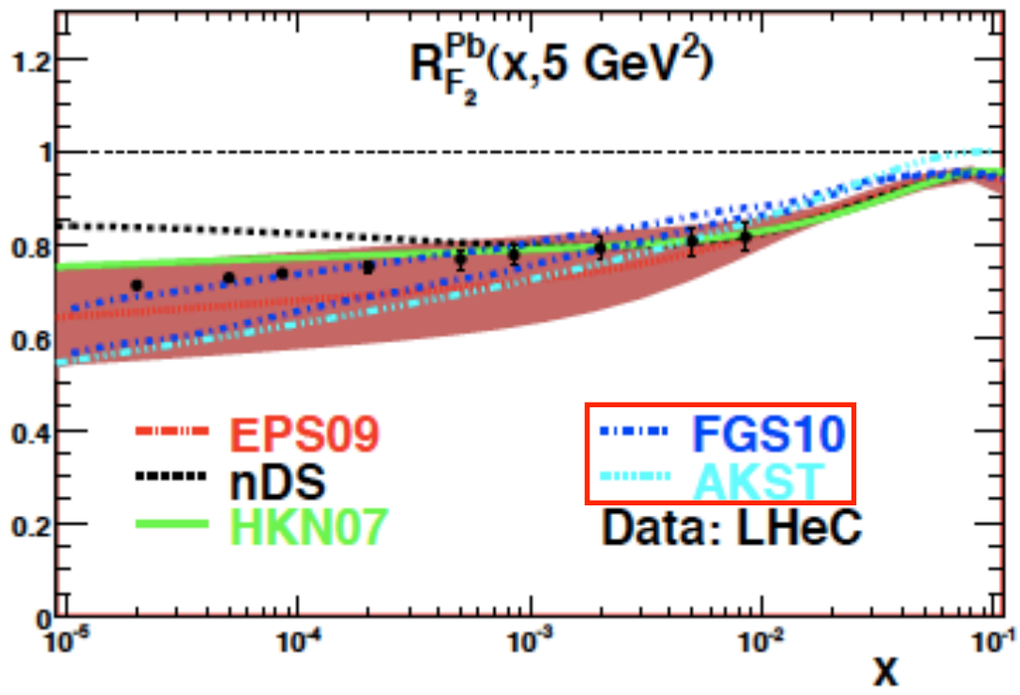
# Diffraction in ep and shadowing:

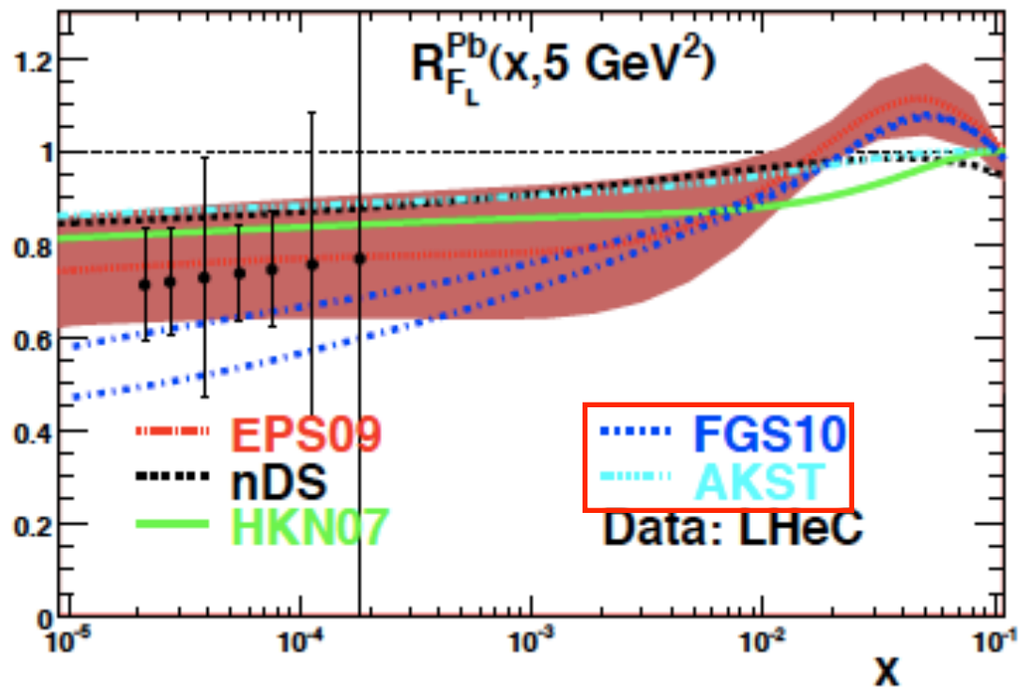


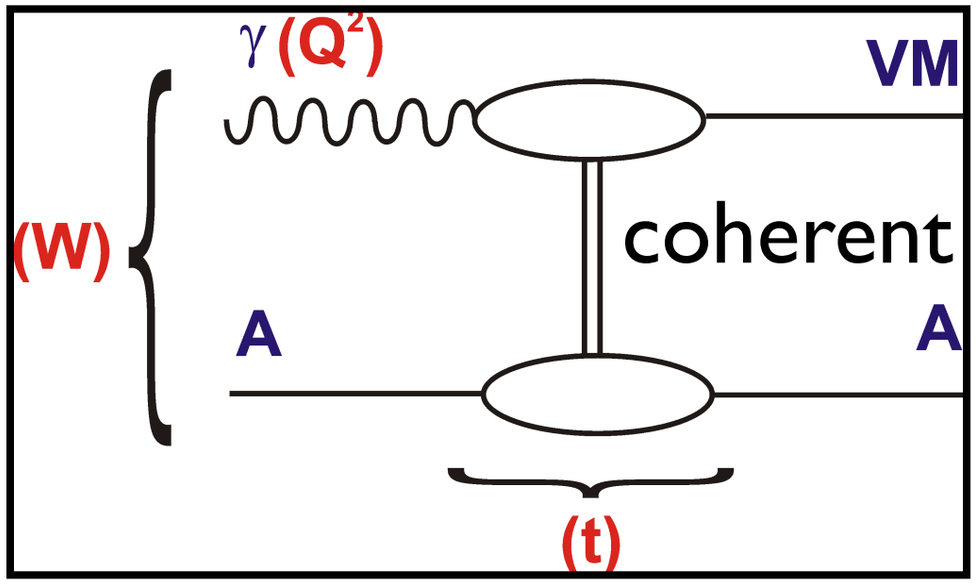

1106.2019

- Diffraction is linked to nuclear shadowing through basic QFT (Gribov): eD to test and set the 'benchmark' for new effects.



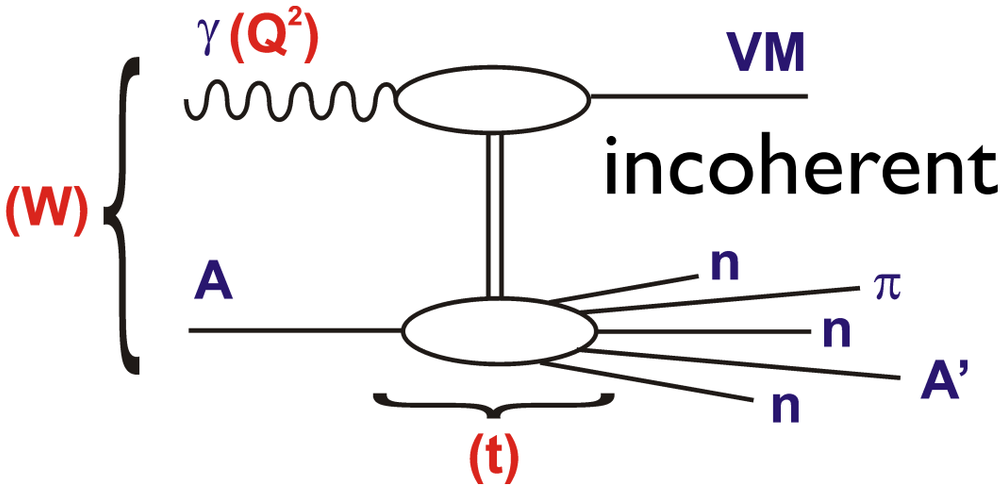



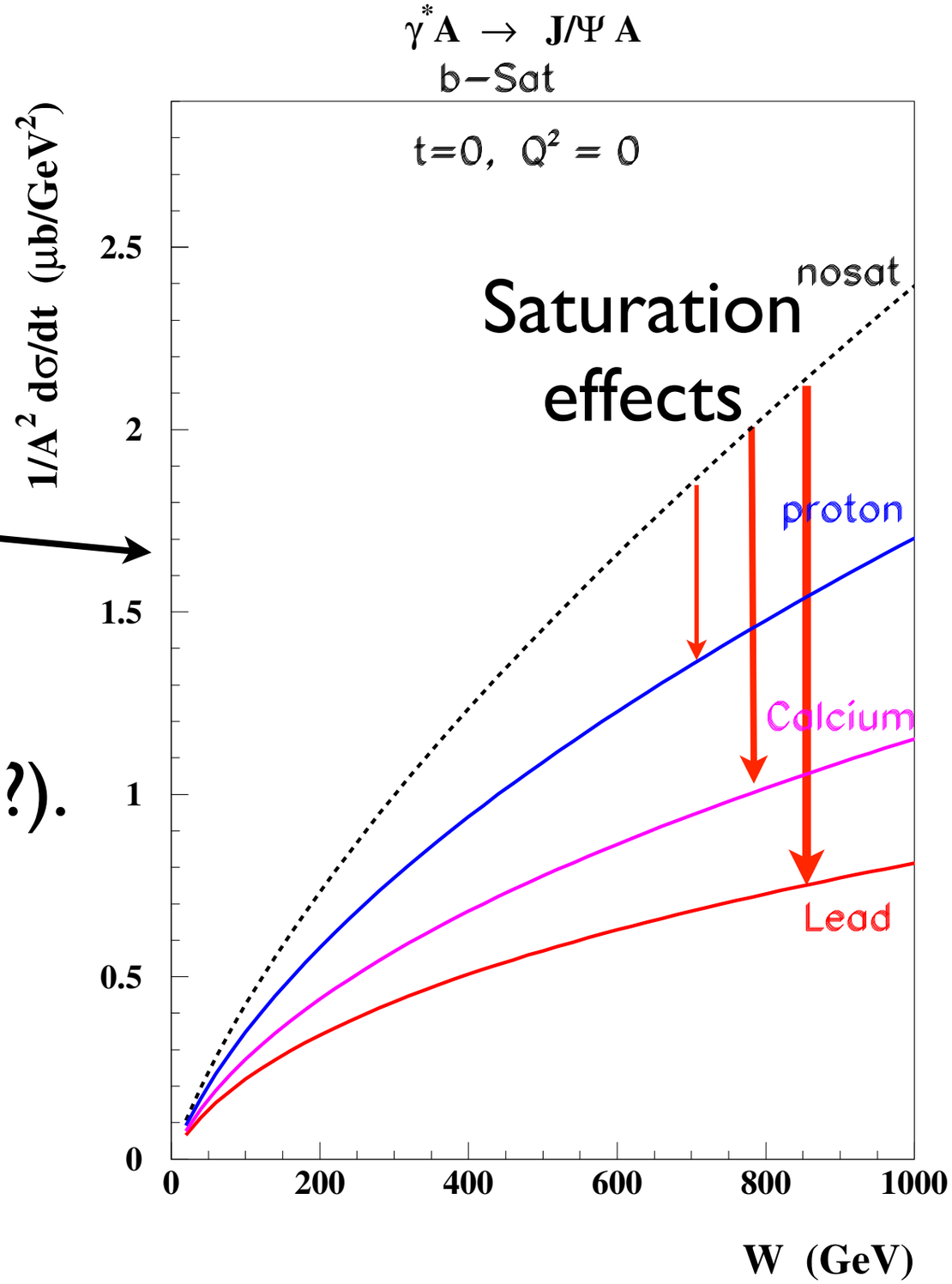
# Elastic VM production in eA:




- For the coherent case, predictions available.

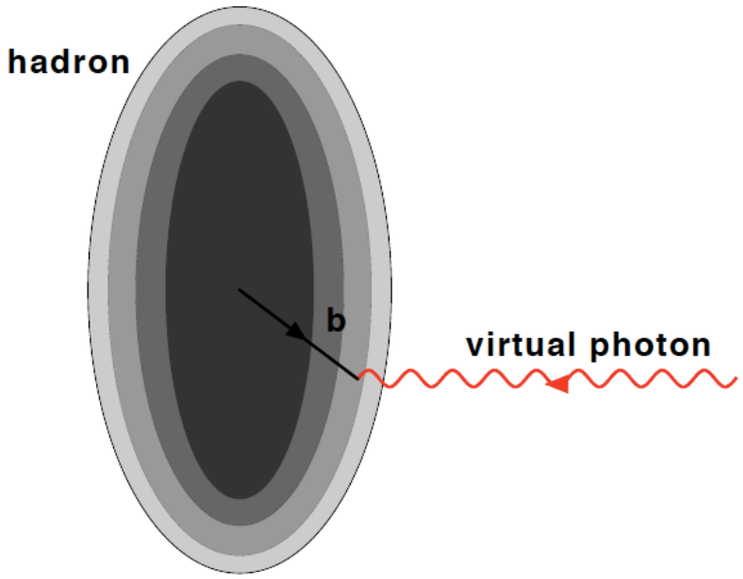
- Challenging experimental problem (neutron tagging in ZDC?).

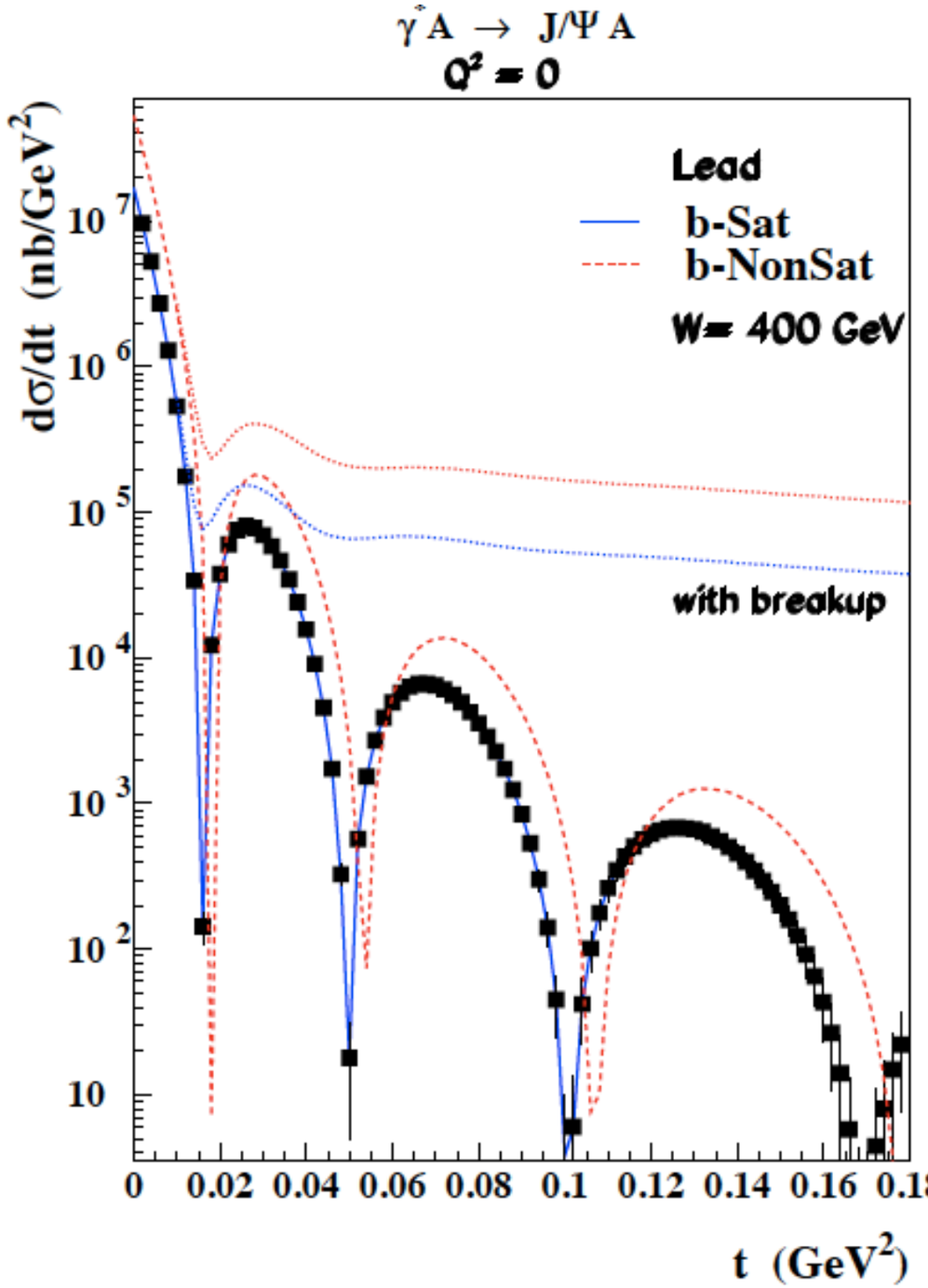


# Transverse scan: elastic VM

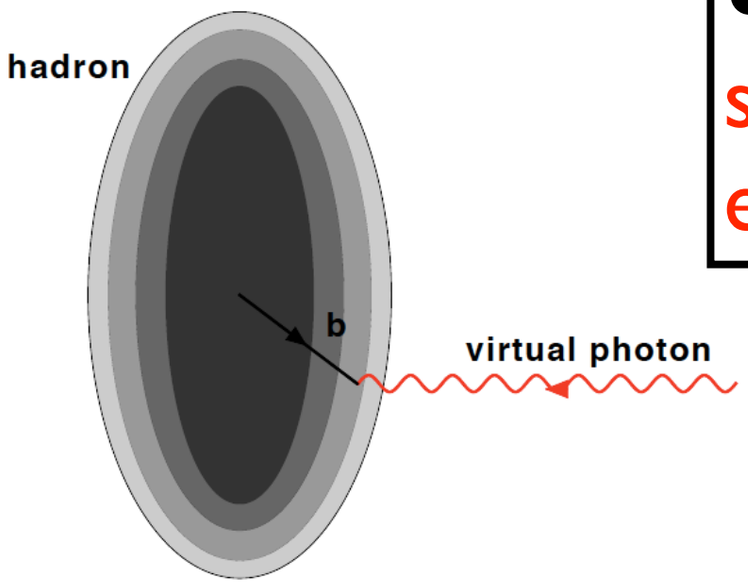
- t-differential measurements give a gluon tranverse mapping of the hadron/nucleus.



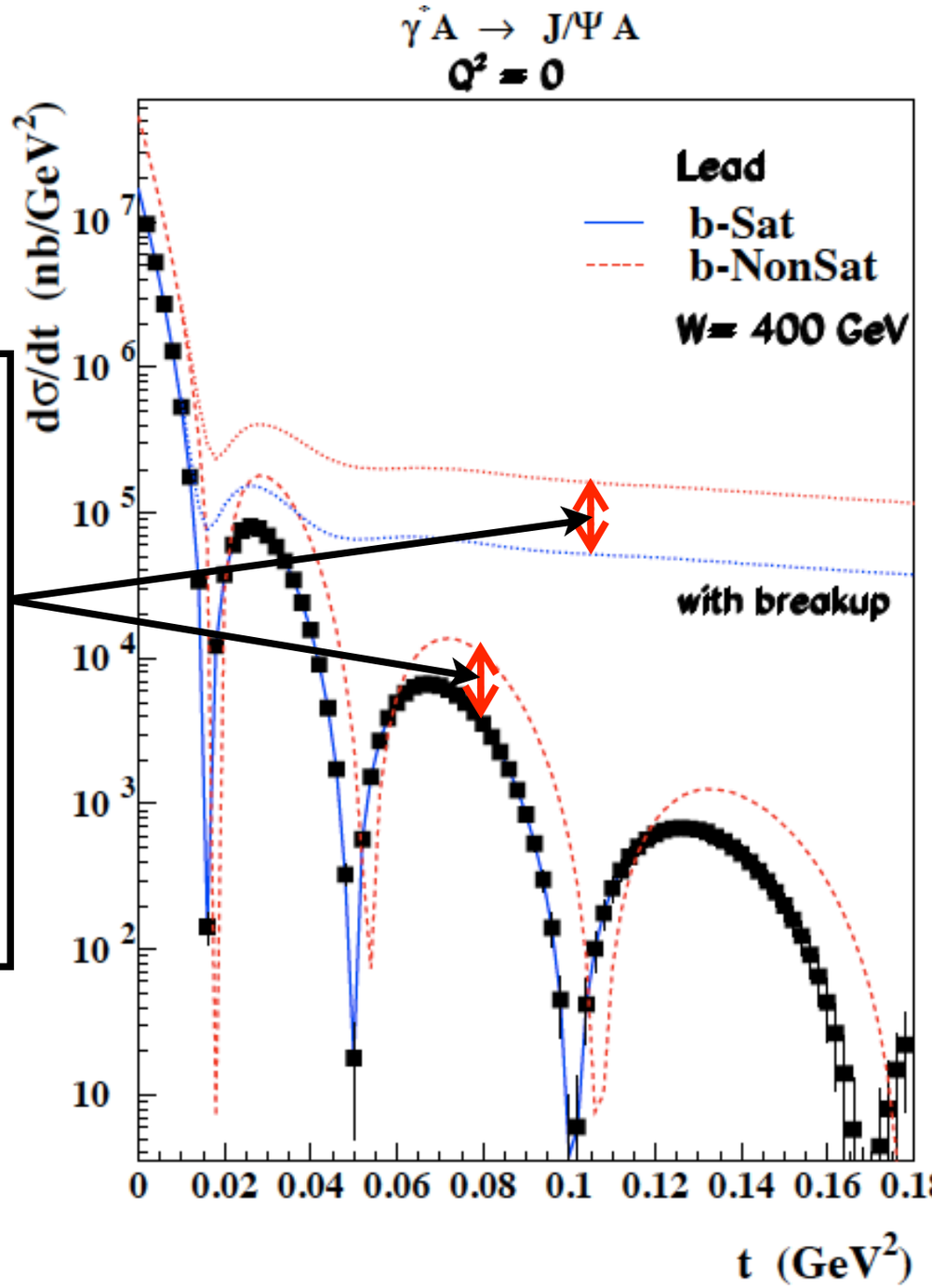



# Transverse scan: elastic VM

- t-differential measurements give a gluon tranverse mapping of the hadron/nucleus.

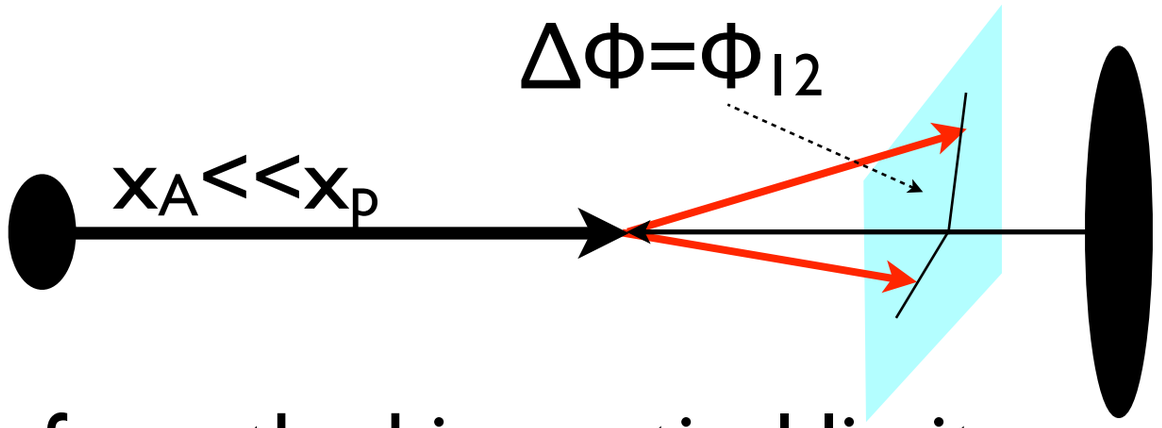


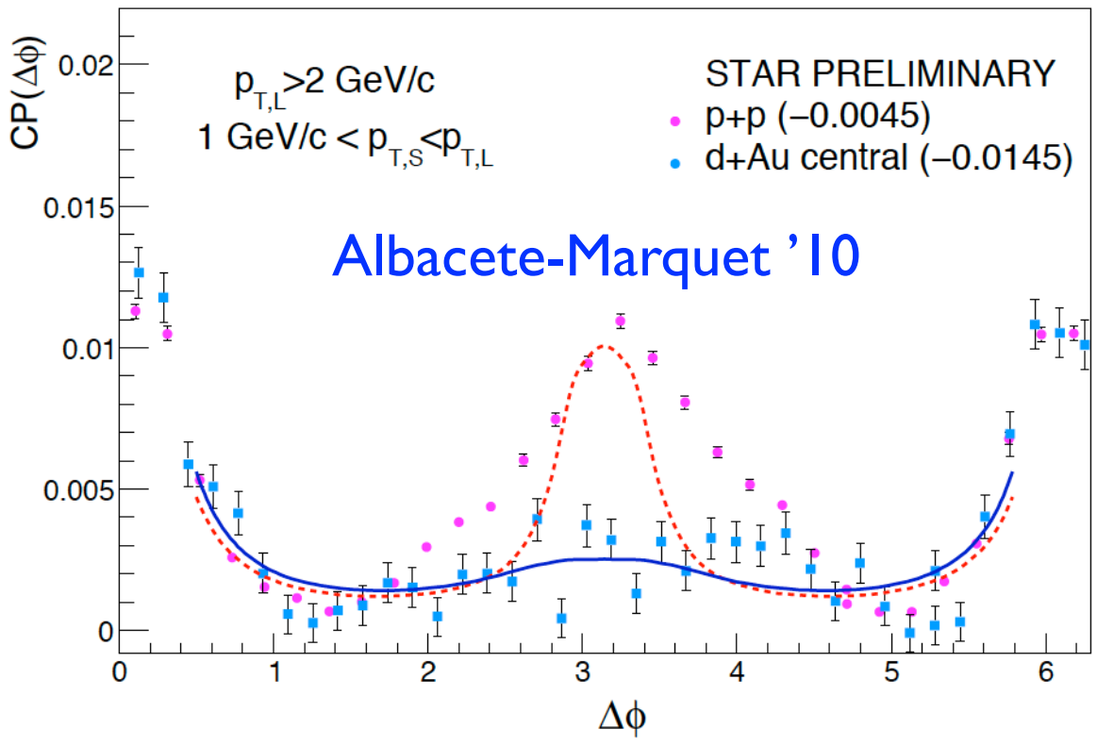

- Large extent in t with good precision.
- Sizable saturation effects expected.



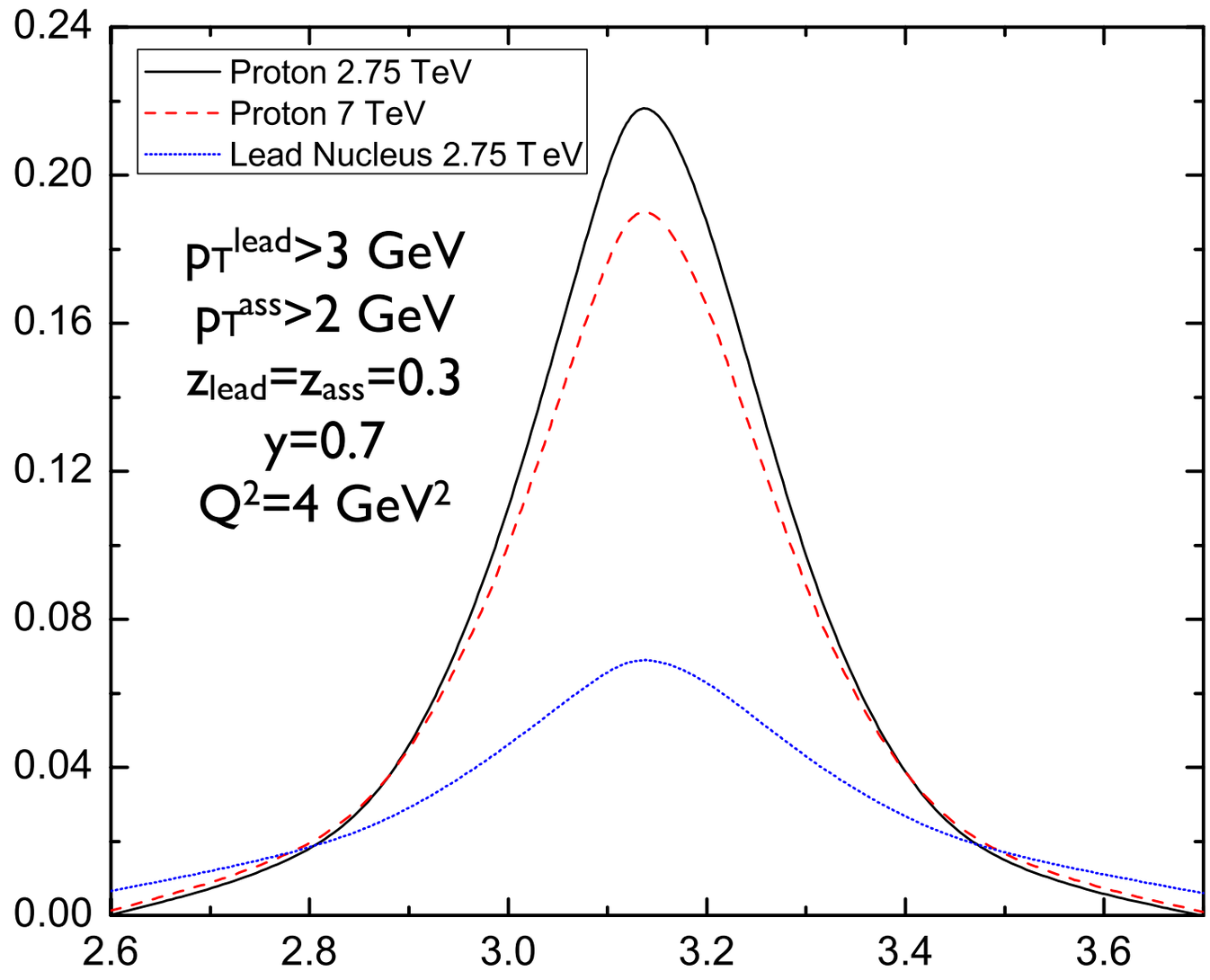
# Dihadron azimuthal decorrelation:

- Dihadron azimuthal decorrelation: currently discussed at RHIC as suggestive of saturation.
- At the LHeC it could be studied far from the kinematical limits.




$$C(\phi_{12}) = \frac{1}{\frac{d\sigma(\gamma^* N \to h_1 X)}{dz_{h1}}} \frac{d\sigma^{\gamma^* N \to h_1 h_2 + X}}{dz_{h1} dz_{h2} d\phi_{12}}$$

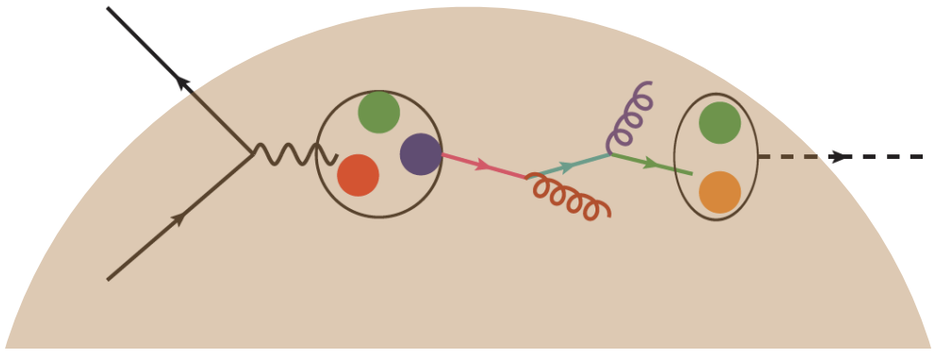


# Radiation and hadronization:

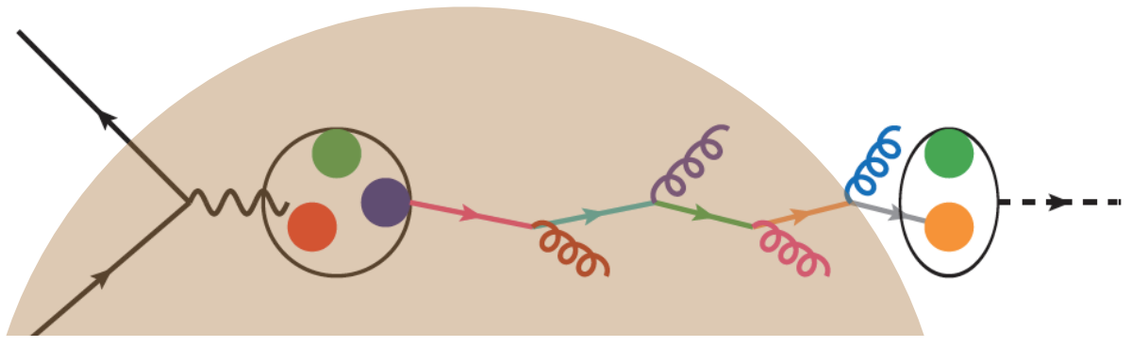
- LHeC: dynamics of QCD radiation and hadronization.
- Most relevant for particle production off nuclei and for QGP analysis in HIC.

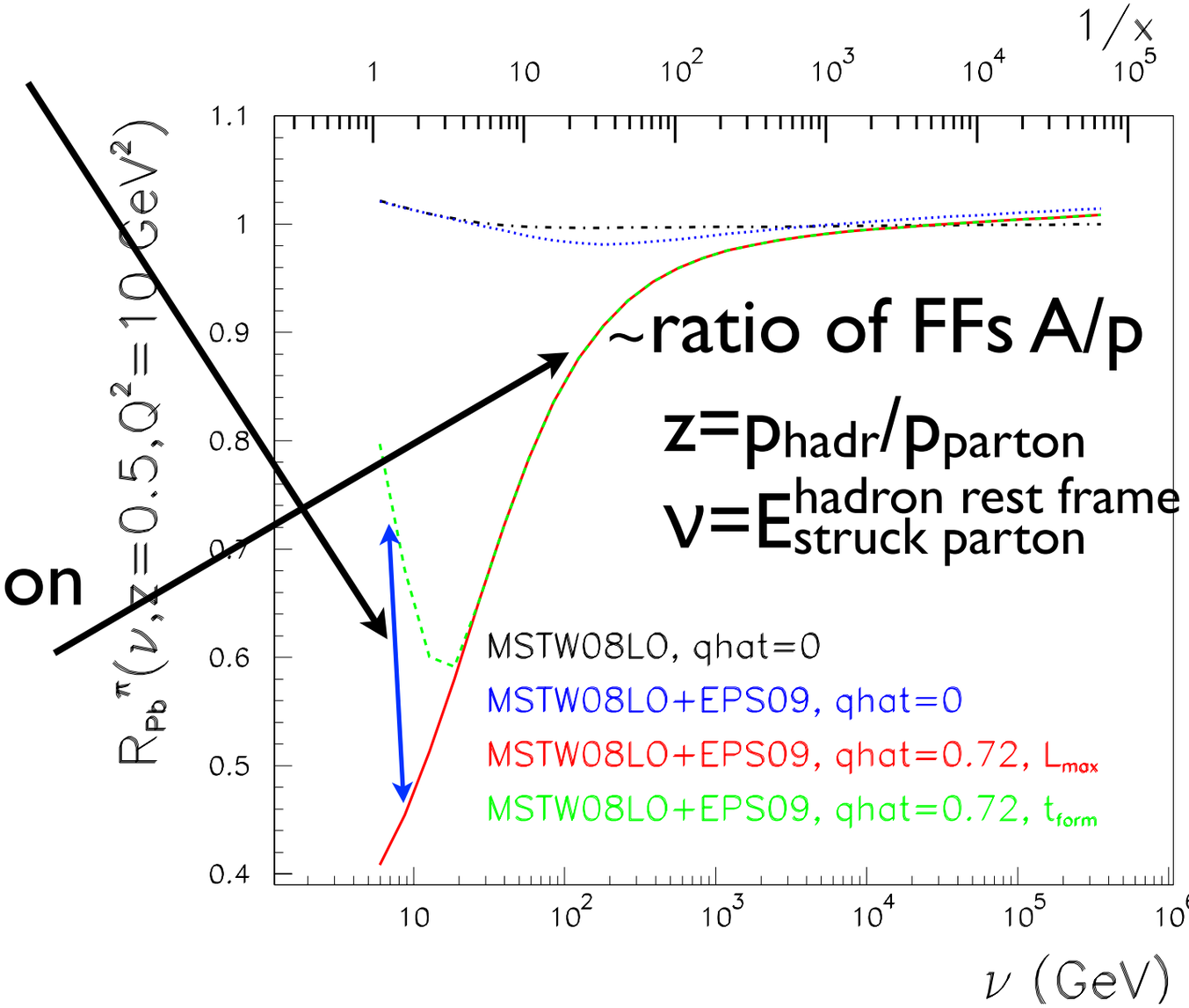
$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{\mathrm{d}N_A^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z} \Big/ \frac{1}{N_D^e}\frac{\mathrm{d}N_D^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z}$$

- Low energy: hadronization inside → formation time, (pre-)hadronic absorption,...



- High energy: partonic evolution altered in the nuclear medium.



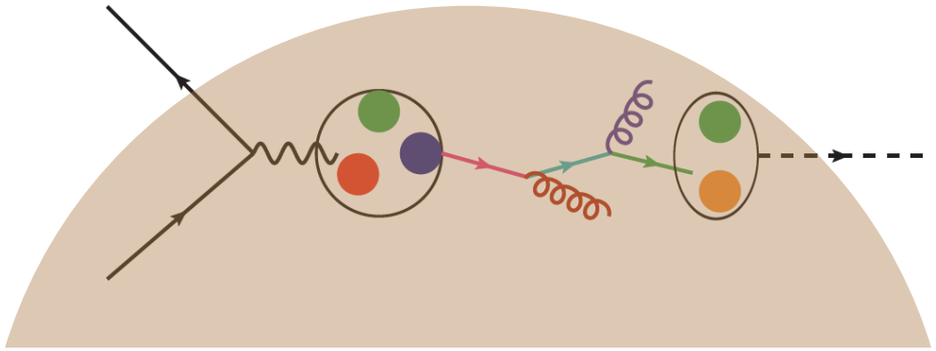


# Radiation and hadronization:

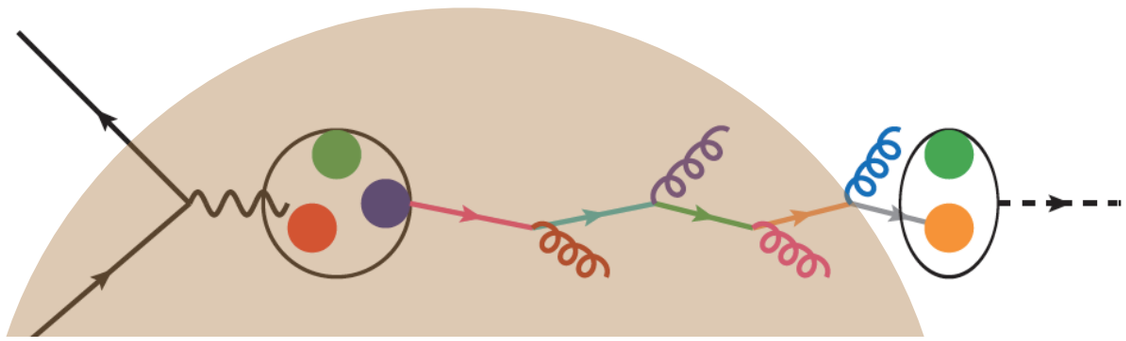
- LHeC: dynamics of QCD radiation and hadronization.
- Most relevant for particle production off nuclei and for QGP analysis in HIC.

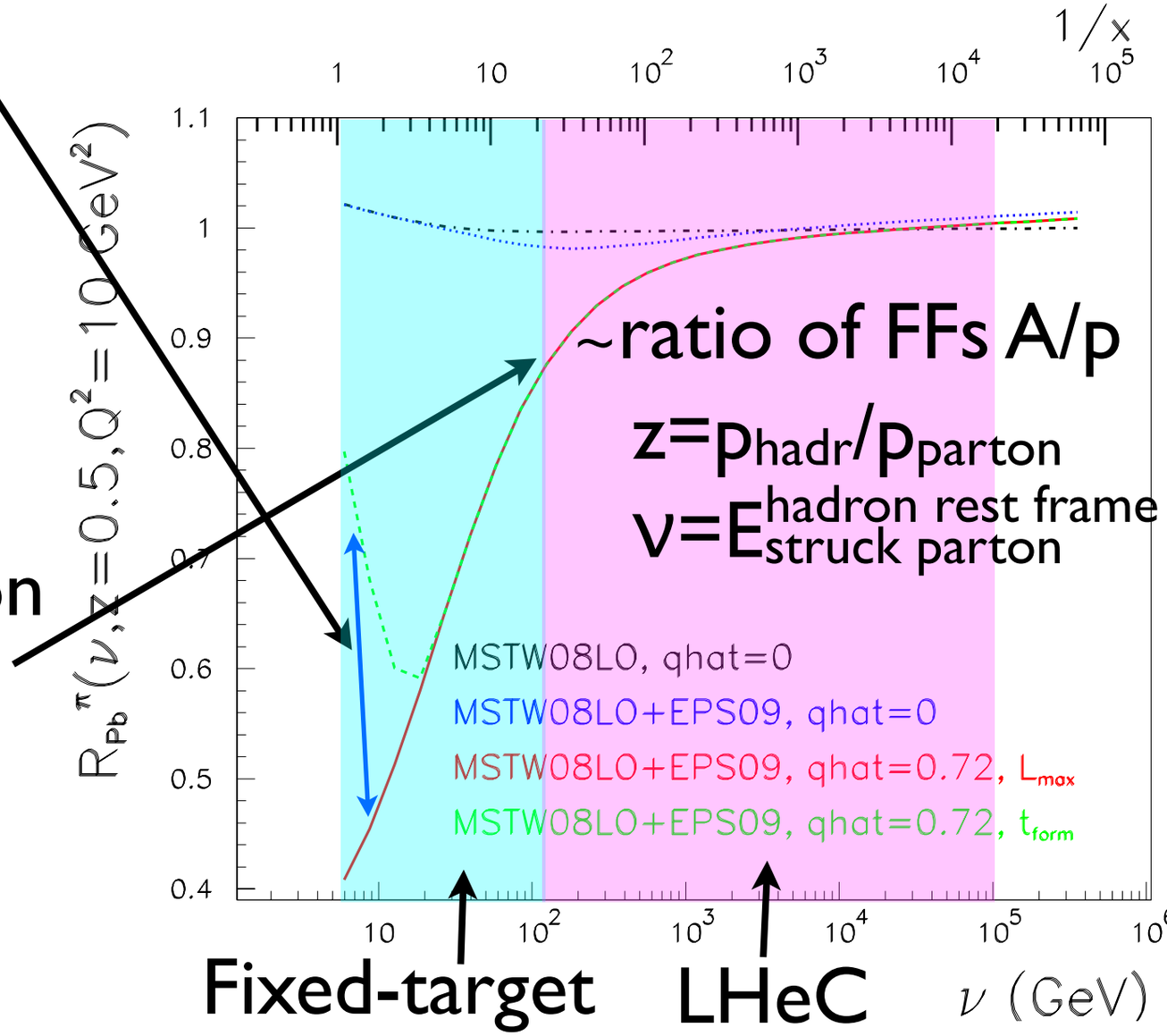
$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{\mathrm{d}N_A^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z} \Big/ \frac{1}{N_D^e}\frac{\mathrm{d}N_D^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z}$$

- Low energy: hadronization inside → formation time, (pre-)hadronic absorption,...

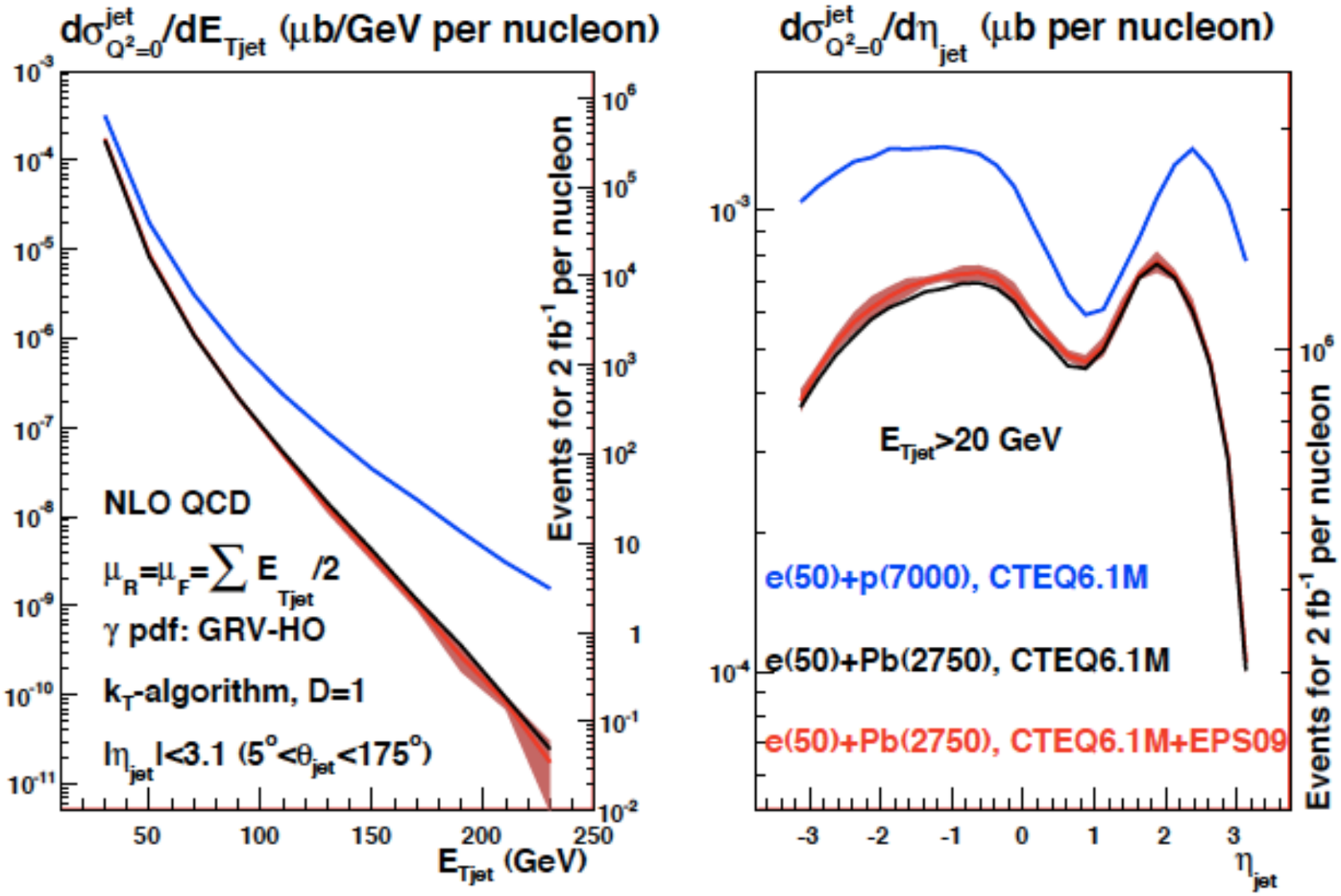


- High energy: partonic evolution altered in the nuclear medium.





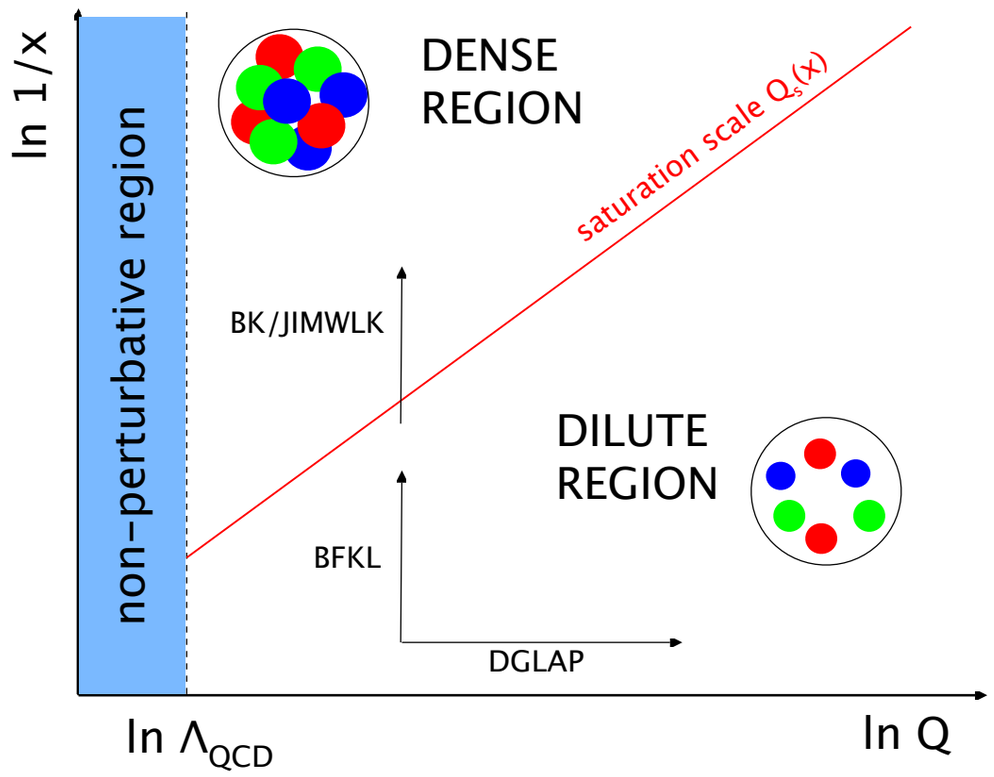
# Jets:

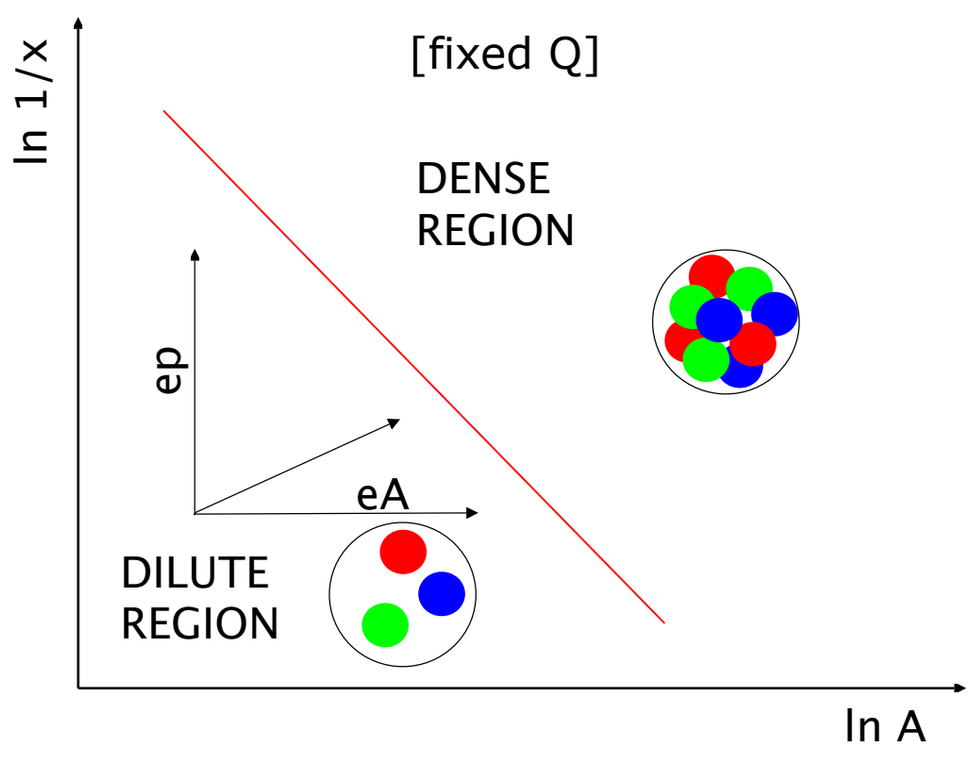



- Jets: large $E_T$ even in eA.
- Useful for studies of parton dynamics in nuclei (hard probes), and for photon structure.
- Background subtraction, detailed reconstruction pending.

# Summary:

- ***At an LHeC@CERN***:
  - ➜ High-precision tests of collinear factorization(s) and determination of PDFs.
  - ➜ Unprecedented access to small x in p and A.
  - ➜ Novel sensitivity to physics beyond standard pQCD.
  - ➜ Stringent tests of QCD radiation and hadronization.
  - ➜ Transverse scan of the hadron/nucleus at small x.
  - ➜ ... with implications on our understanding of QGP.
- **The LHeC will answer the question of saturation/ non-linear dynamics. For that, ep AND eA essential!!!**



# Outlook:

- With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, several items have to be done/improved:

➜ Refine DGLAP fits with flavour decomposition (include neutrino data, relax assumptions) and optimized $F_L$ scenarios, and LHC data.
➜ Monte Carlo generators!!!
➜ Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets,...
➜ Large x, EW bosons.
➜ Nuclear GPDs: nuclear DVCS etc.
➜ eD.
➜ Jet reconstruction, angular decorrelation,...
➜ ...

→ Synergies with EIC in some of these items exist.

# Outlook:

- With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, several items have to be done/improved:

➜ Refine DGLAP fits with flavour decomposition (include neutrino data, relax assumptions) and optimized $F_L$ scenarios, and LHC data.
➜ Monte Carlo generators!!!
➜ Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets,...
➜ Large x, EW bosons.
➜ Nuclear GPDs: nuclear DVCS etc.
➜ eD.
➜ Jet reconstruction, angular decorrelation,...
➜ ...

*Thanks for your attention!*

→ Synergies with EIC in some of these items exist.

# Backup:

# LHC studies: PbPb

➜ EW bosons: nPDFs.
➜ VMs in UPCs: nPDFs.

Benchmarking

Searches

➜ Multiplicities: particle production.
➜ Ridge: particle production.

➜ ...

# LHC studies: PbPb

➜ EW bosons: nPDFs.
➜ VMs in UPCs: nPDFs.

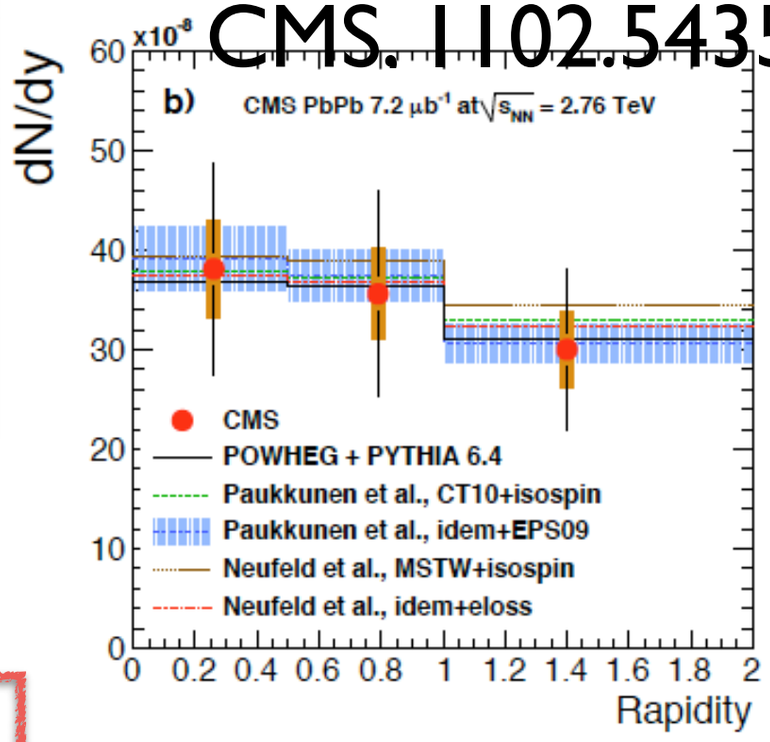
Benchmarking

Searches

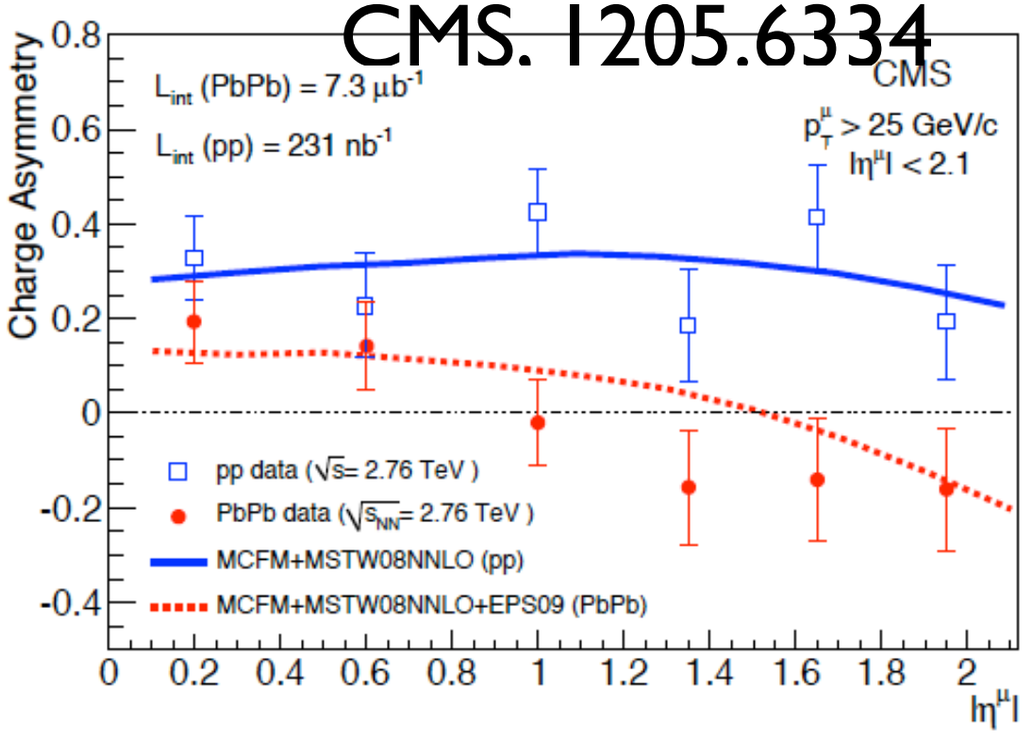
➜ Multiplicities: particle production.
➜ Ridge: particle production.

➜ ...

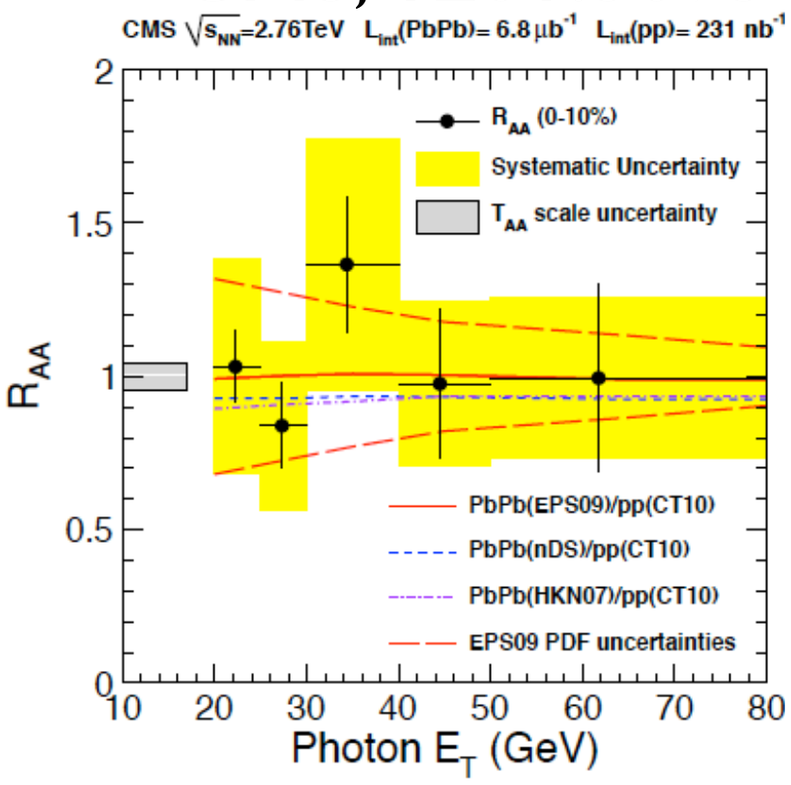
CMS, 1102.5435



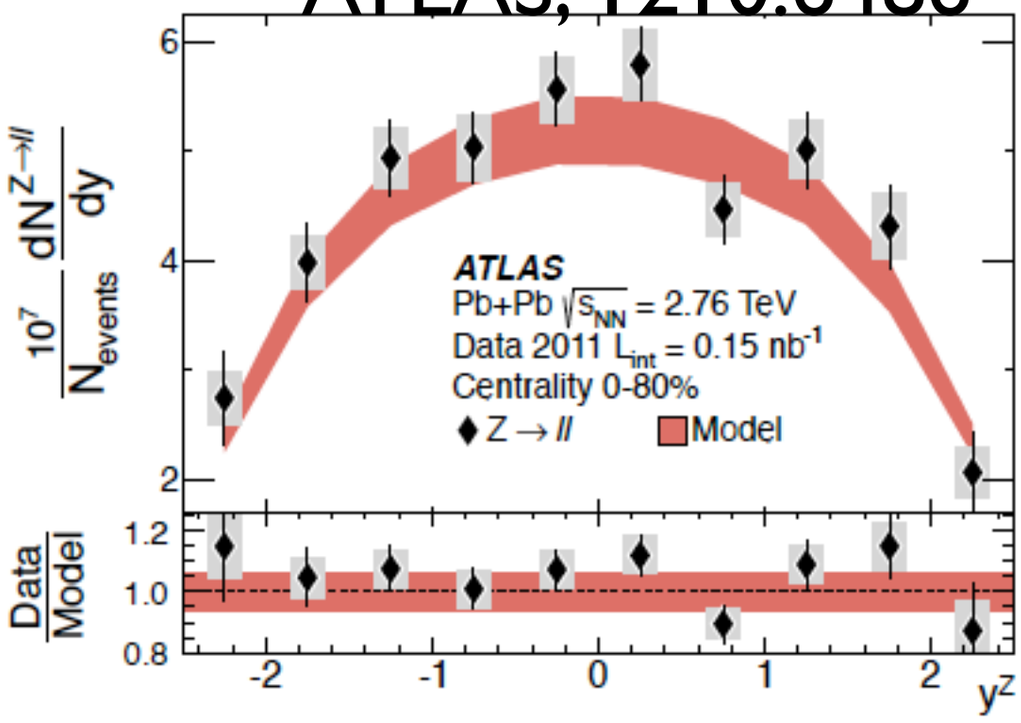

CMS, 1205.6334




CMS, 1201.3093




ATLAS, 1210.6486



# LHC studies: PbPb

➜ EW bosons: nPDFs.
➜ VMs in UPCs: nPDFs.

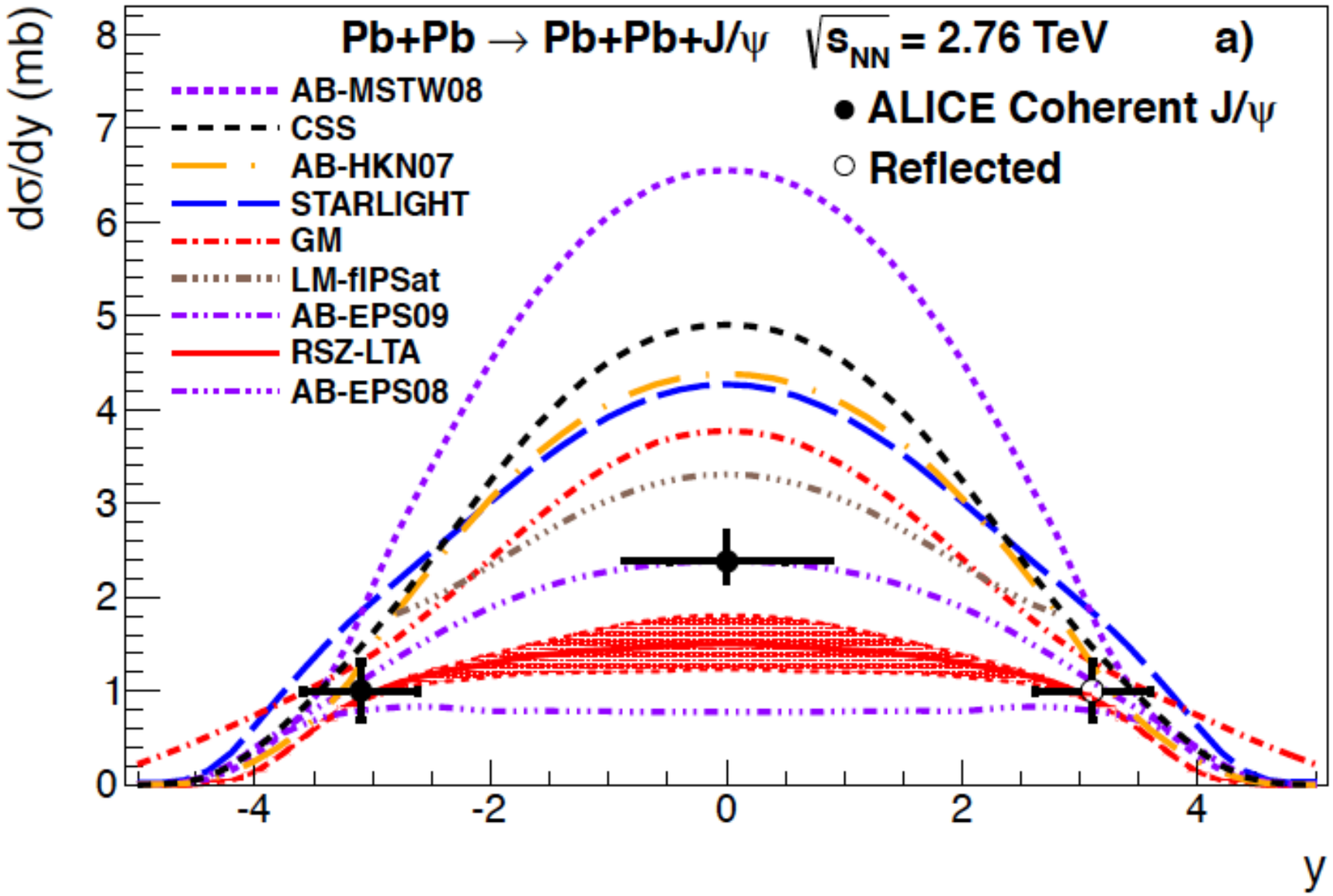
Benchmarking

Searches

➜ Multiplicities: particle production.
➜ Ridge: particle production.

➜ ...

ALICE, 1305.1467



# LHC studies: PbPb

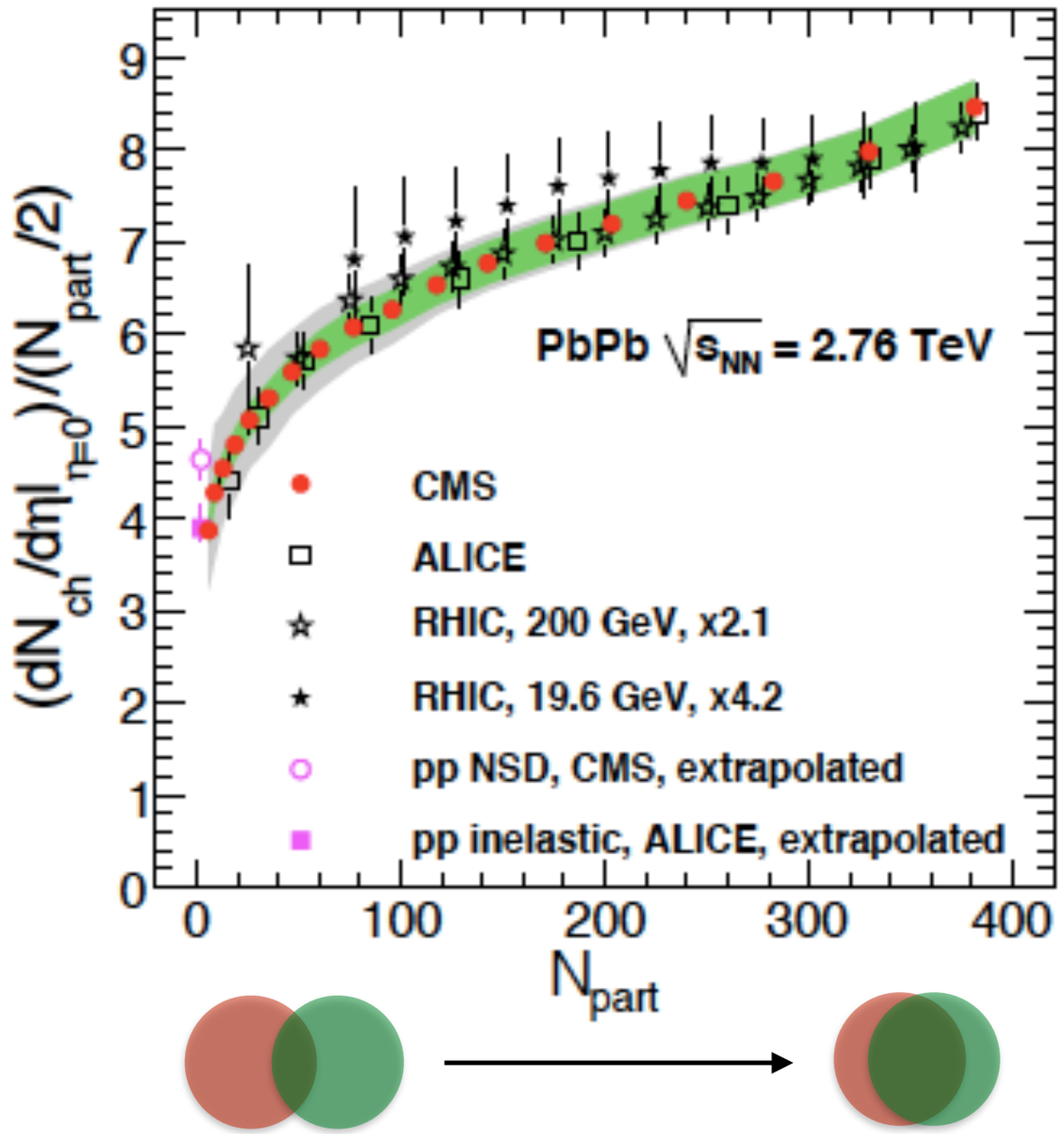
➜ EW bosons: nPDFs.
➜ VMs in UPCs: nPDFs.

Benchmarking

Searches

➜ Multiplicities: particle production.
➜ Ridge: particle production.

➜ ...



# LHC studies: PbPb

➜ EW bosons: nPDFs.
➜ VMs in UPCs: nPDFs.

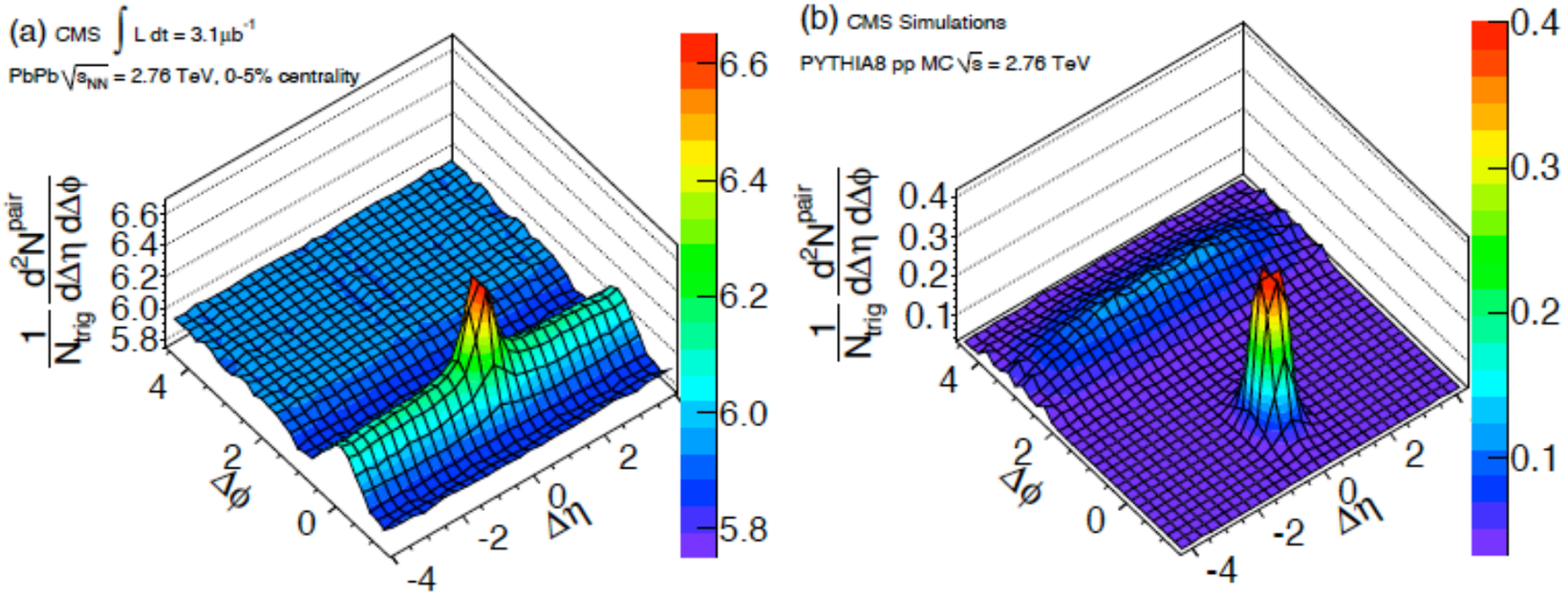
Benchmarking

Searches

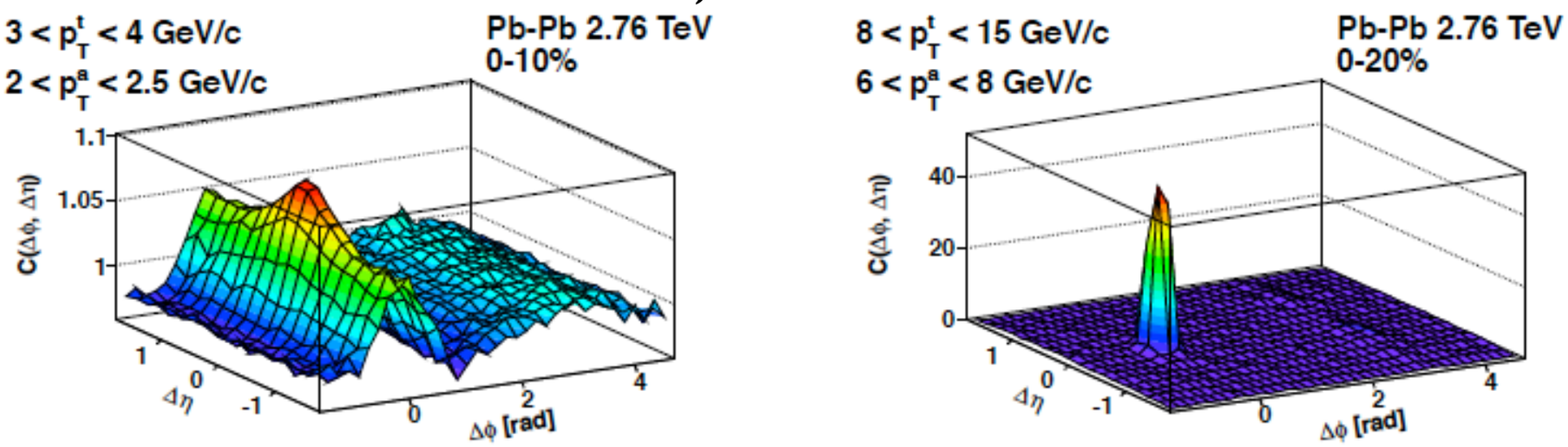
➜ Multiplicities: particle production.
➜ Ridge: particle production.

➜ ...

CMS, 1105.2438




ALICE, 1109.2501



# LHC studies: pPb

Searches

➜ Ridge.
➜ Flow.
➜ Charged particles.

➜ Jets and interjet activity.
➜ VMs, HF.

Benchmarking

➜ Back-to-back correlations, central/forward?
➜ EW bosons, DY?
➜ UPCs?
➜ ...

# LHC studies: pPb

Searches

➜ Ridge.

➜ Flow.

➜ Charged particles.

➜ Jets and interjet activity.

➜ VMs, HF.

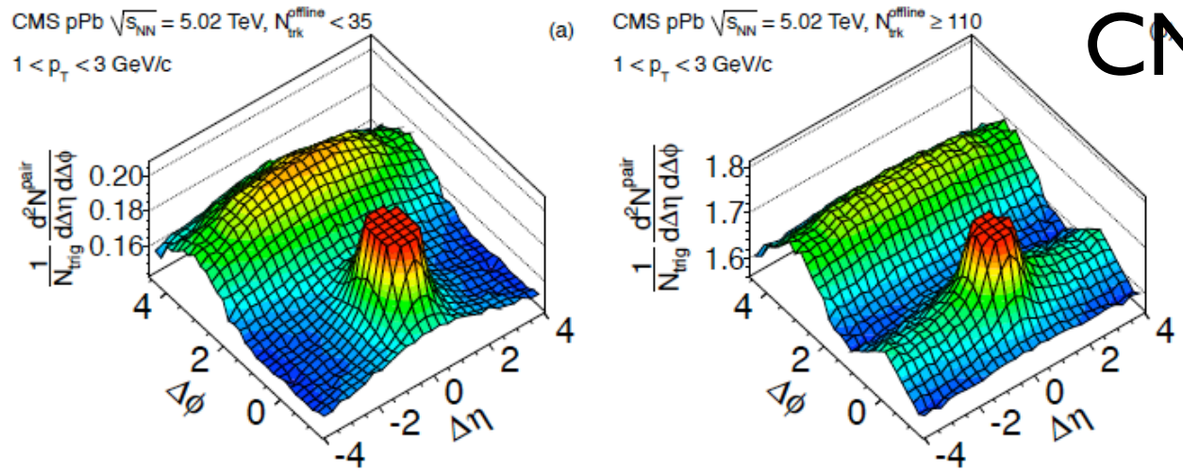
Benchmarking

➜ Back-to-back correlations, central/forward?

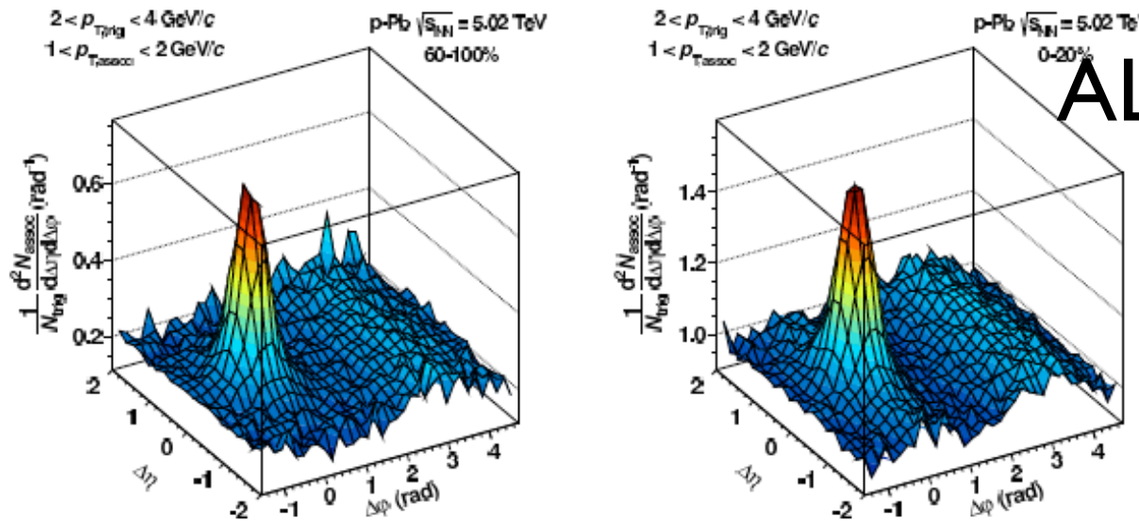
➜ EW bosons, DY?

➜ UPCs?

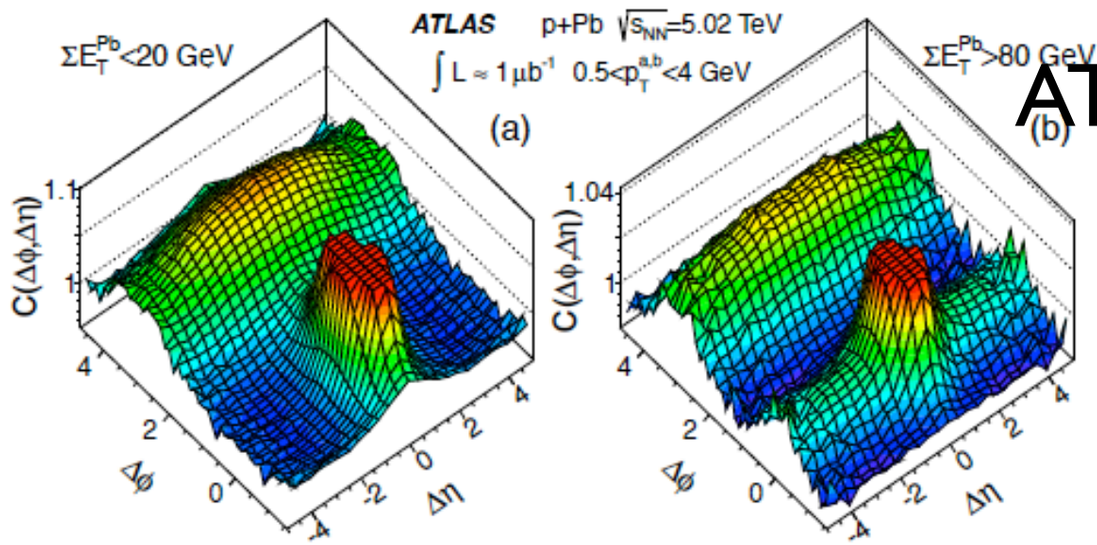
➜ ...




CMS, 1210.5482




ALICE, 1212.2001




ATLAS, 1212.5198

# LHC studies: pPb

Searches

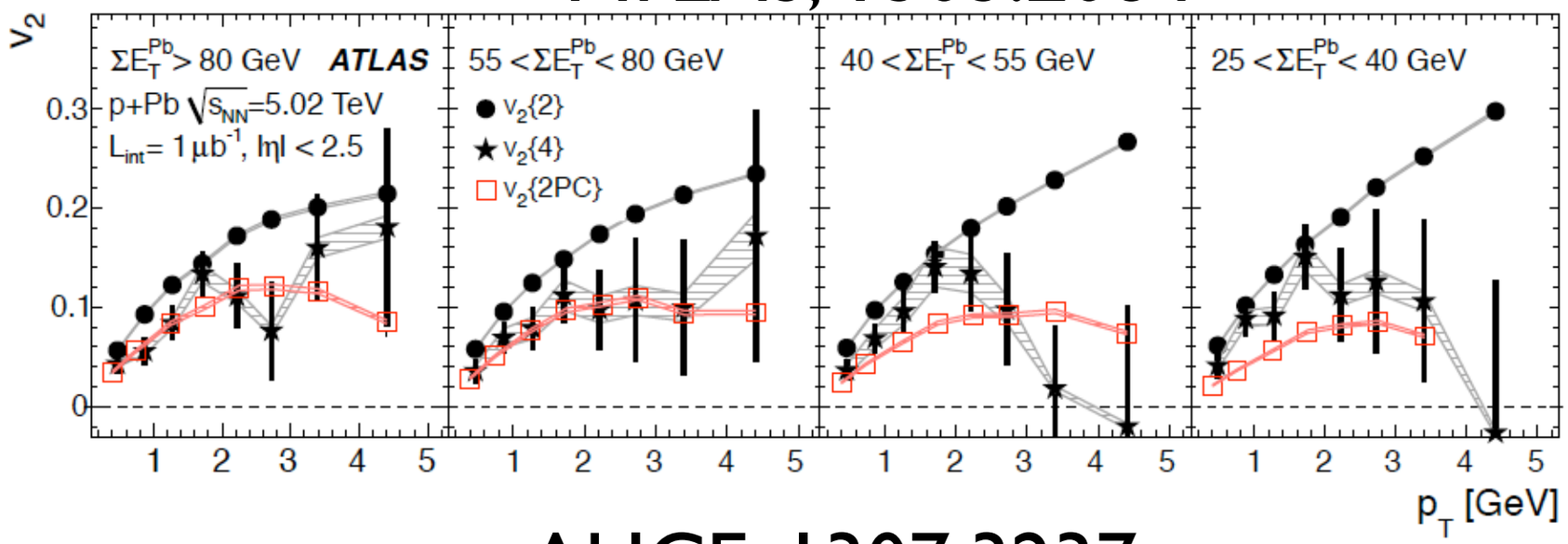
➜ Ridge.
➜ Flow.
➜ Charged particles.

➜ Jets and interjet activity.
➜ VMs, HF.

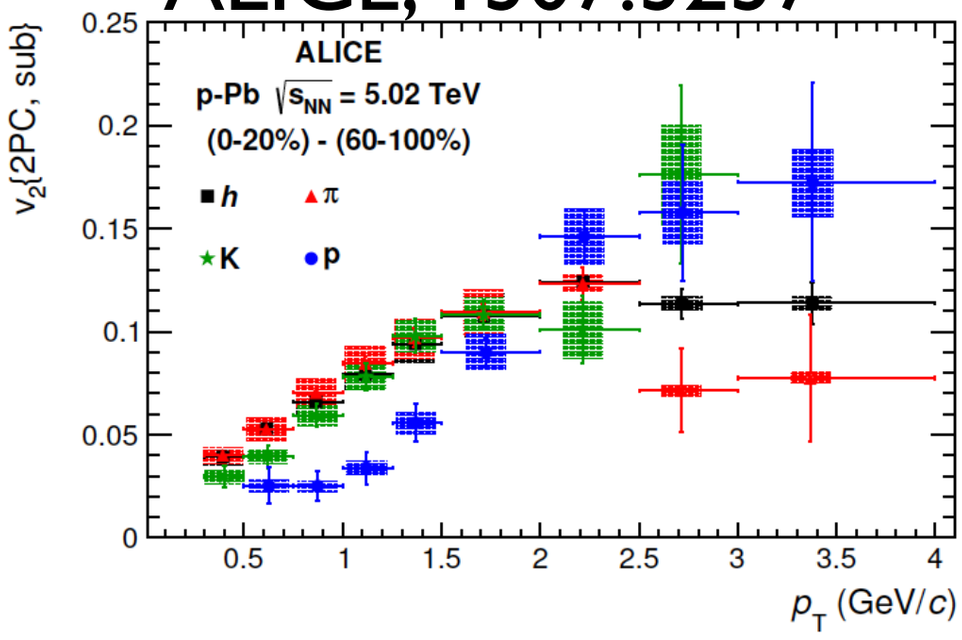
Benchmarking

➜ Back-to-back correlations, central/forward?
➜ EW bosons, DY?
➜ UPCs?
➜ ...

ATLAS, 1303.2084




ALICE, 1307.3237



# LHC studies: pPb

Searches

➜ Ridge.

➜ Flow.

➜ Charged particles.

➜ Jets and interjet activity.

➜ VMs, HF.

Benchmarking

➜ Back-to-back correlations, central/forward?

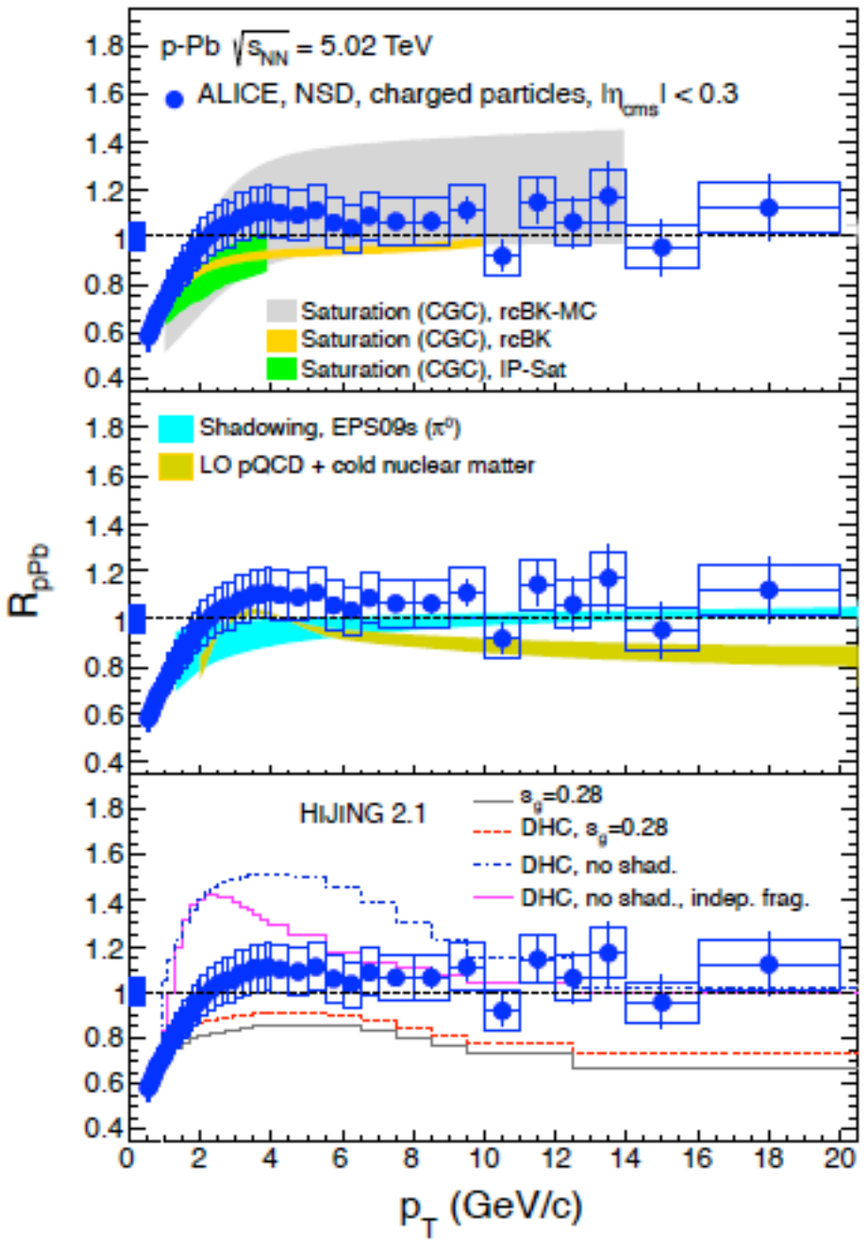
➜ EW bosons, DY?

➜ UPCs?

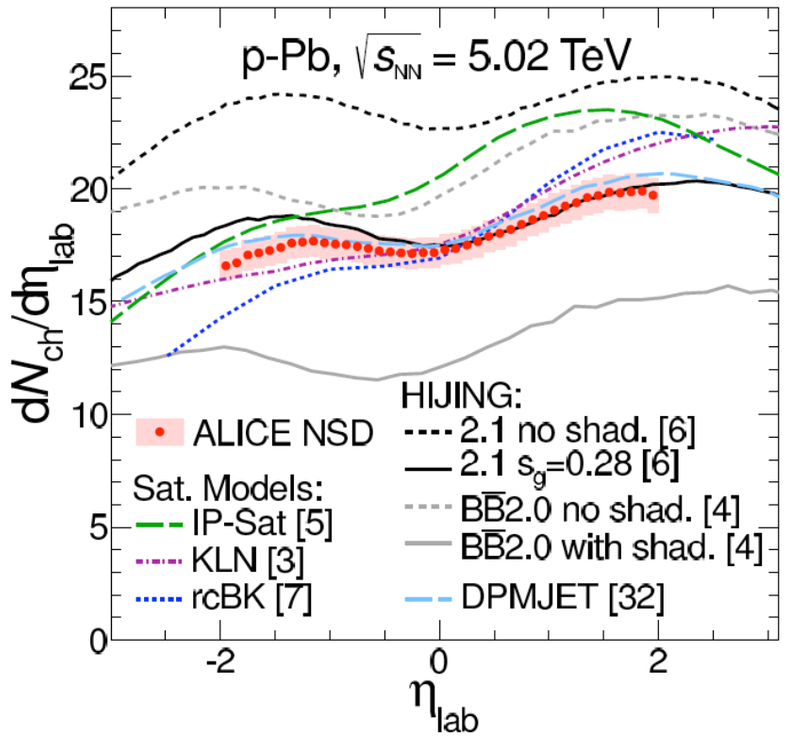
➜ ...

$$R_{AA}(y,p_T) = \frac{\frac{dN_k^{AA}}{dydp_T}}{\langle N_{coll}\rangle \frac{dN_k^{NN}}{dydp_T}}$$

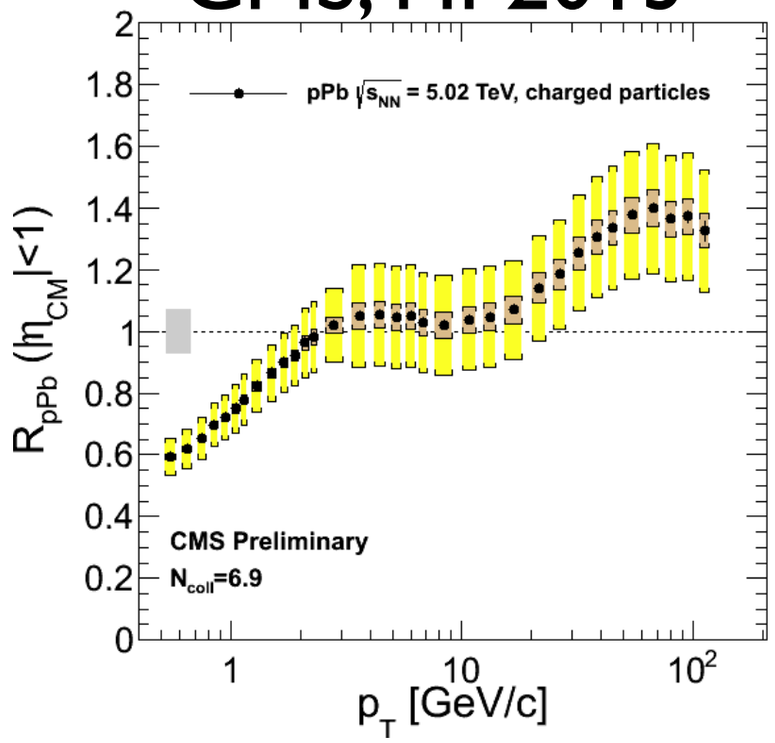
ALICE, 1210.4520




ALICE, 1210.3615




CMS, HP2013



# LHC studies: pPb

Searches

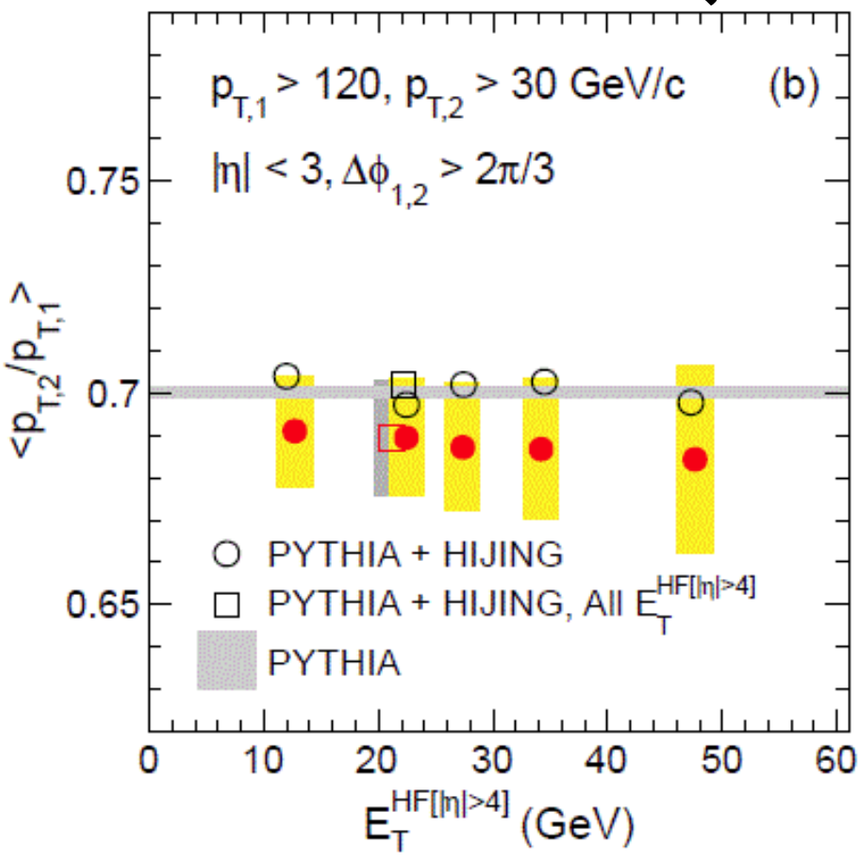
➜ Ridge.
➜ Flow.
➜ Charged particles.

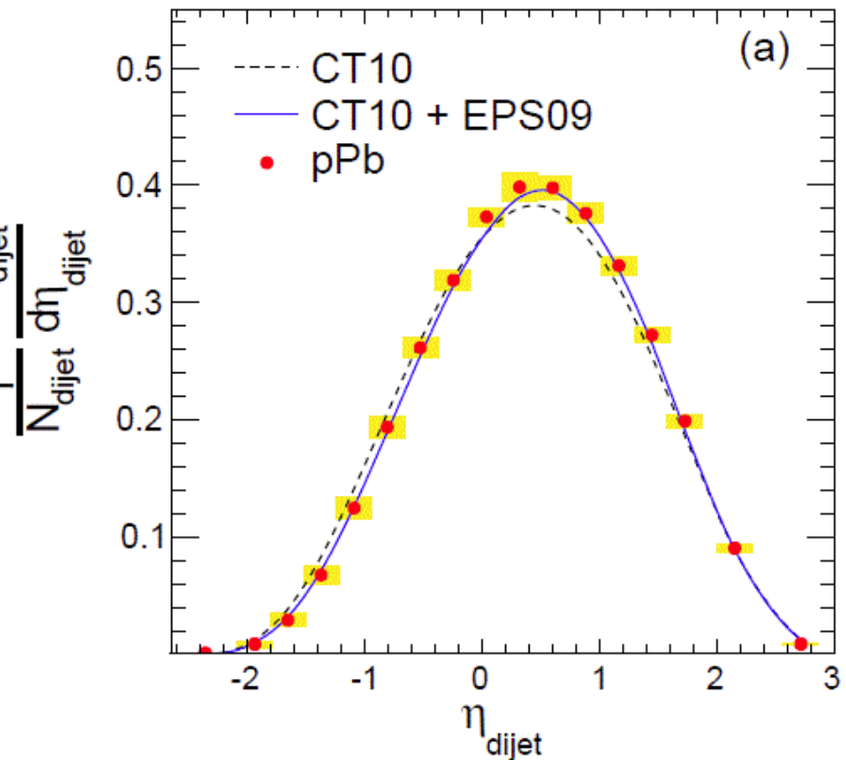
➜ Jets and interjet activity.
➜ VMs, HF.

Benchmarking

➜ Back-to-back correlations, central/forward?
➜ EW bosons, DY?
➜ UPCs?
➜ ...

Dijets, CMS, HP2013



# LHC studies: pPb

Searches

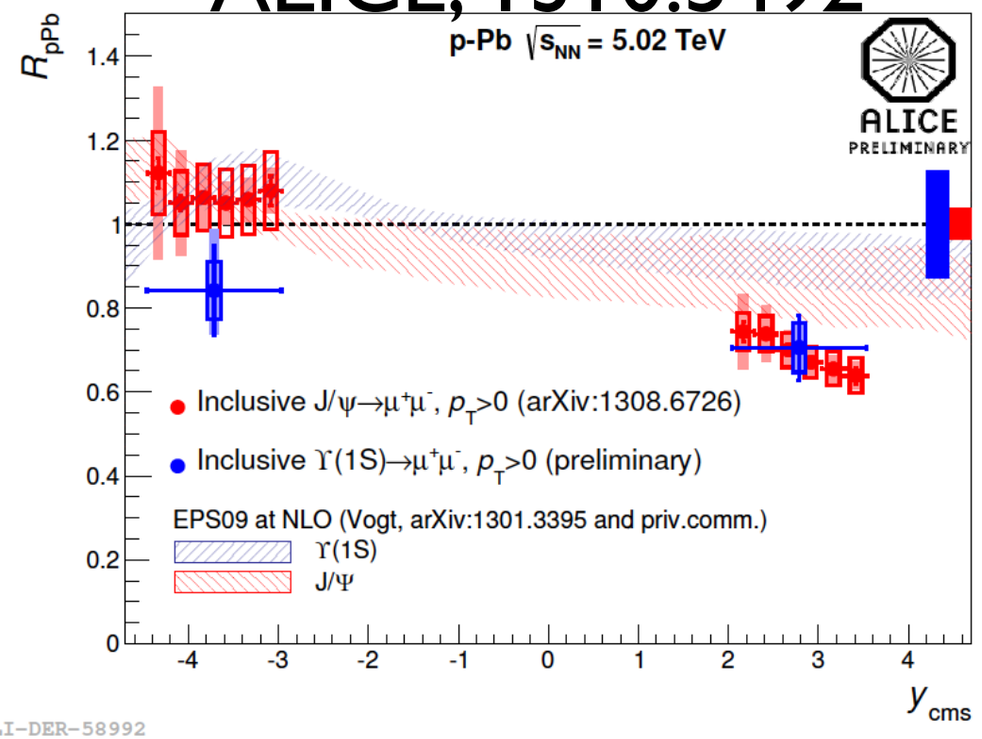
➜ Ridge.
➜ Flow.
➜ Charged particles.

➜ Jets and interjet activity.
➜ VMs, HF.

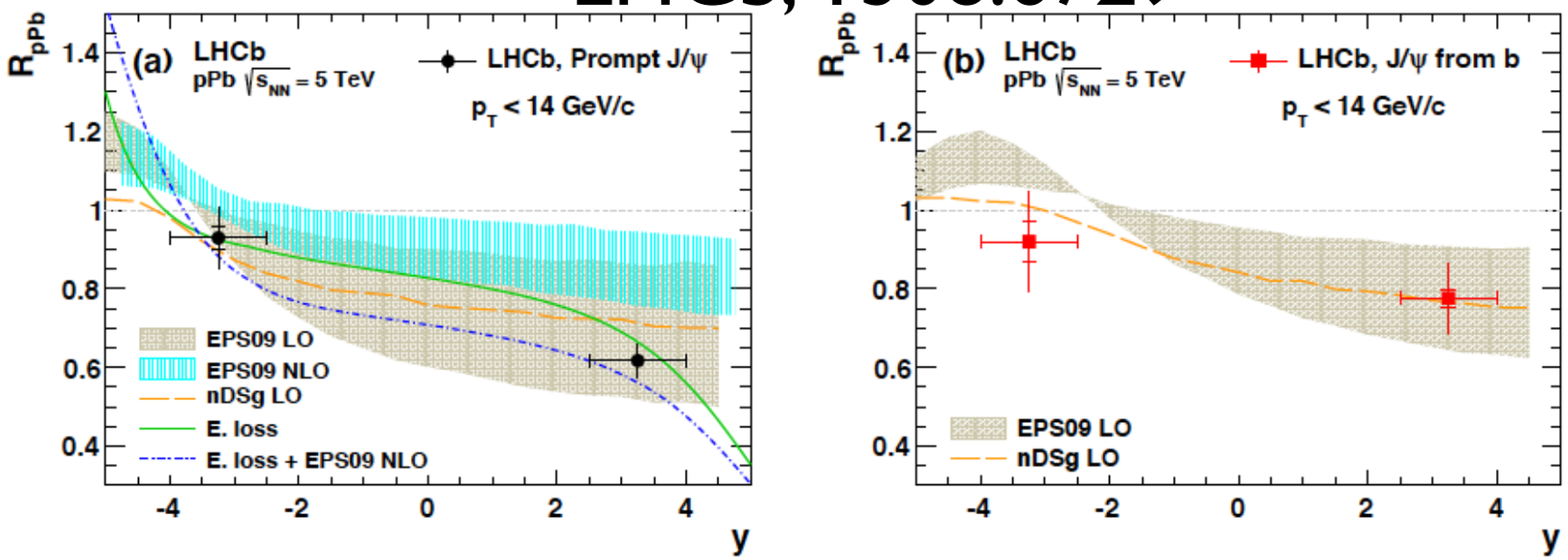
Benchmarking

➜ Back-to-back correlations, central/forward?
➜ EW bosons, DY?
➜ UPCs?
➜ ...

ALICE, 1310.5492




LHCb, 1308.6729



# LHC studies: pPb

Searches

➜ Ridge.
➜ Flow.
➜ Charged particles.

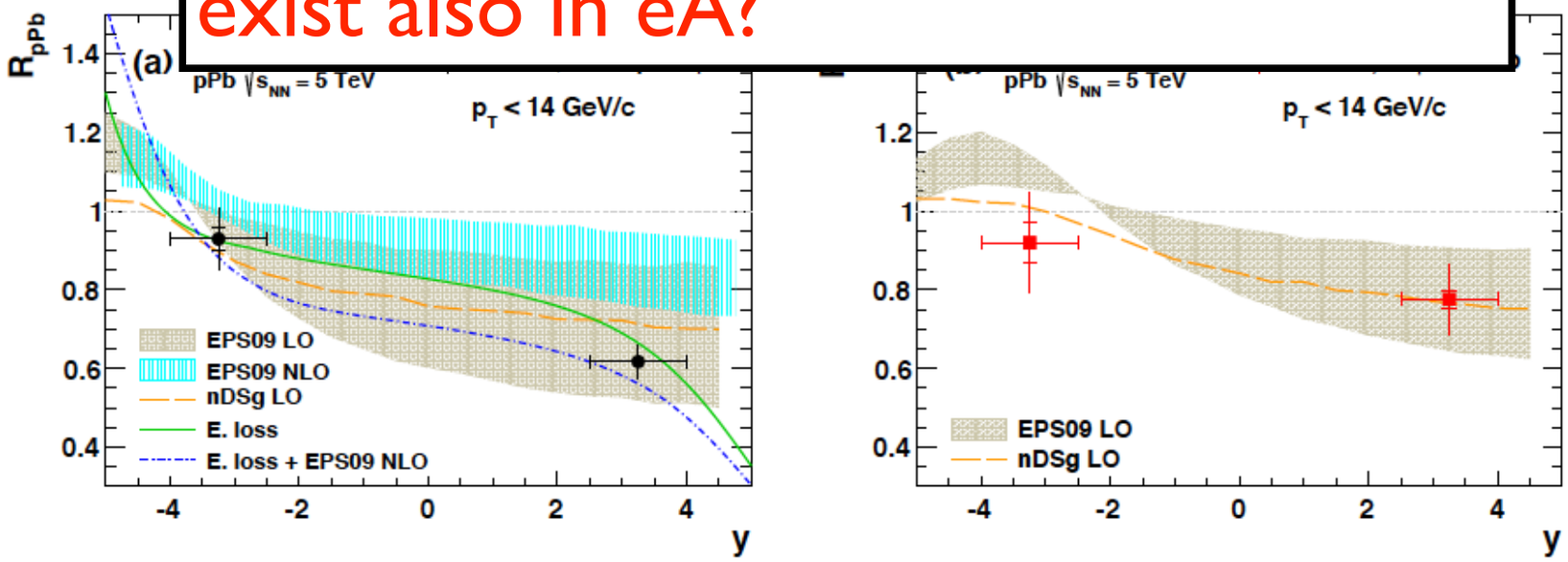
➜ Jets and interjet activity.
➜ VMs, HF.

Benchmarking

➜ Back-to-back correlations, central/forward?
➜ EW bosons, DY?
➜ UPCs?
➜ ...

ALICE, 1310.5492

- The existence of collective effects (ridge, flow, scaling of sequential $\Upsilon$ suppression with multiplicity,…) in pPb is somewhat unexpected.
- They may compromise the use of pPb as benchmark for PbPb.
- Are they really final state? Do they exist also in eA?



# LHeC scenarios:

| config. | E(e) | E(N) | N | $\int L(e^+)$ | $\int L(e^-)$ | \|Pol\| | $L/10^{32}$ | P/MW | years | type |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | For $F_2$ | | | | | | |
| A | 20 | 7 | p | 1 | 1 | - | 1 | 10 | 1 | SPL |
| B | 50 | 7 | p | 50 | 50 | 0.4 | 25 | 30 | 2 | RR hi$Q^2$ |
| C | 50 | 7 | p | 1 | 1 | 0.4 | 1 | 30 | 1 | RR lo x |
| D | 100 | 7 | p | 5 | 10 | 0.9 | 2.5 | 40 | 2 | LR |
| E | 150 | 7 | p | 3 | 6 | 0.9 | 1.8 | 40 | 2 | LR |
| F | 50 | 3.5 | D | 1 | 1 | -- | 0.5 | 30 | 1 | eD |
| G | 50 | 2.7 | Pb | $10^{-3}$ | $10^{-3}$ | 0.4 | $10^{-3}$ | 30 | 1 | ePb |
| H | 50 | 1 | p | -- | 1 | -- | 25 | 30 | 1 | lowEp |
| I | 50 | 3.5 | Ca | $5 \cdot 10^{-3}$ | | ? | $5 \cdot 10^{-3}$ | ? | ? | eCa |

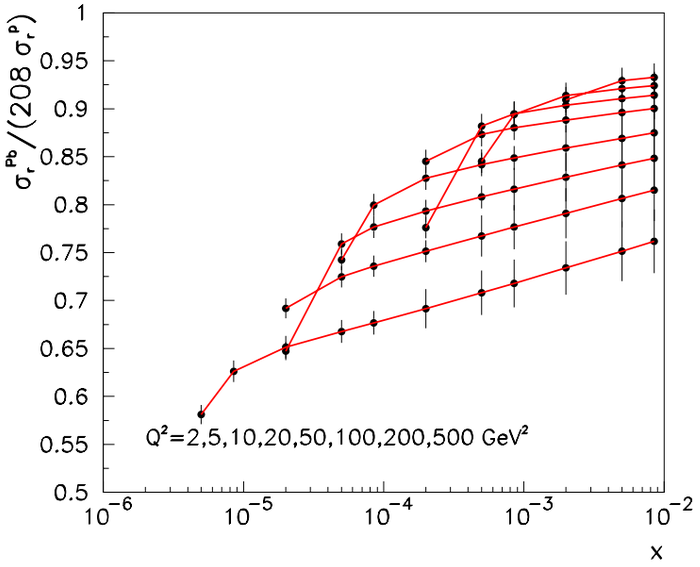
- For $F_L$: 10, 25, 50 + 2750 (7000); $Q^2 \leq sx$; Lumi=5,10,100 $pb^{-1}$ respectively; charm and beauty: same efficiencies in ep and eA.

# Note: $F_L$ in eA

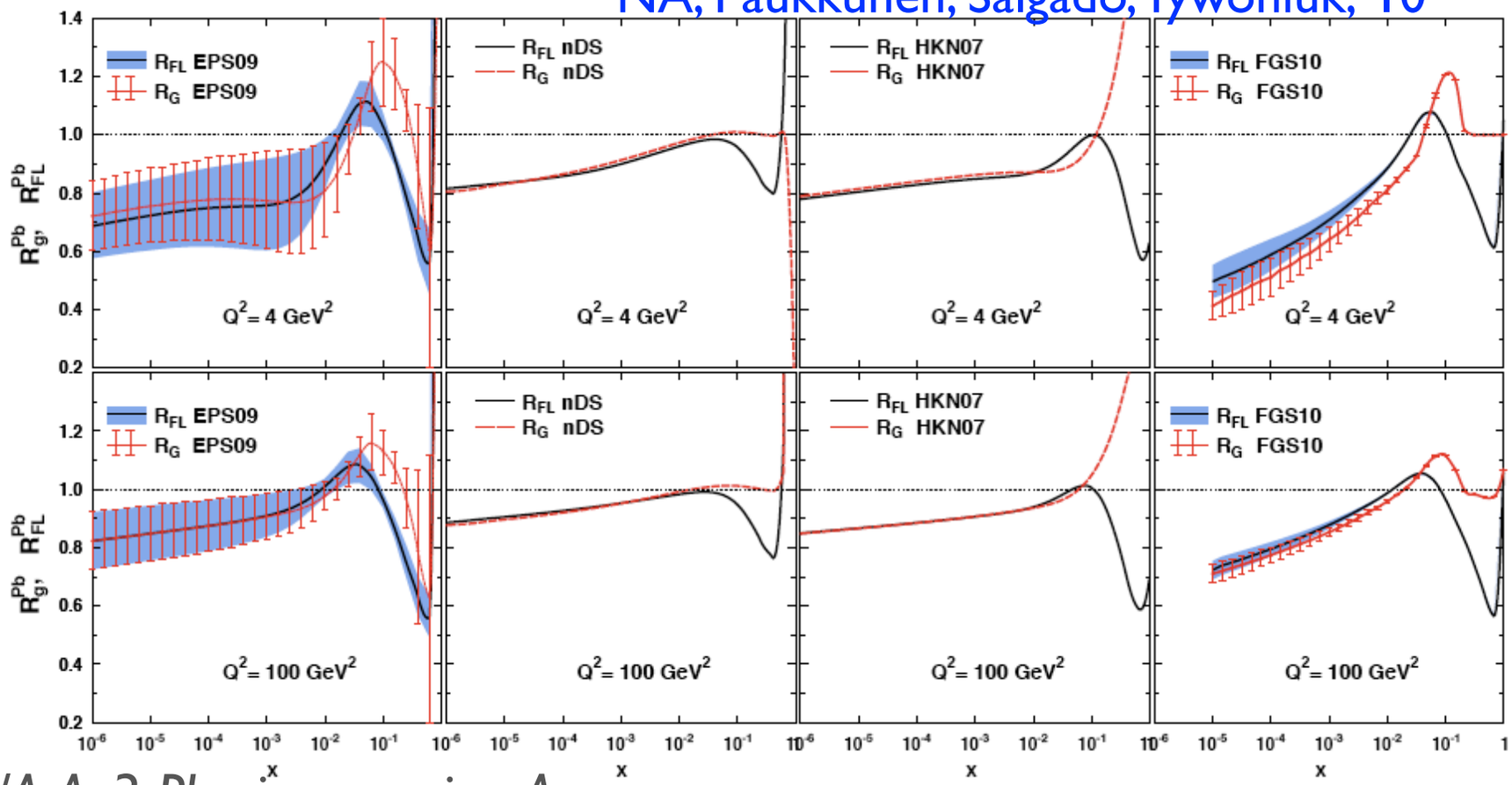
$$\sigma_r^{NC} = \frac{Q^4 x}{2\pi\alpha^2 Y_+}\frac{d^2\sigma^{NC}}{dxdQ^2} = F_2\left[1 - \frac{y^2}{Y_+}\frac{F_L}{F_2}\right], \qquad Y_+ = 1 + (1-y)^2$$

- $F_L$ traces the nuclear effects on the glue (Cazarotto et al '08).
- Uncertainties in the extraction of $F_2$ due to the unknown nuclear effects on $F_L$ of order 5 % (larger than expected stat.+syst.) ⇒

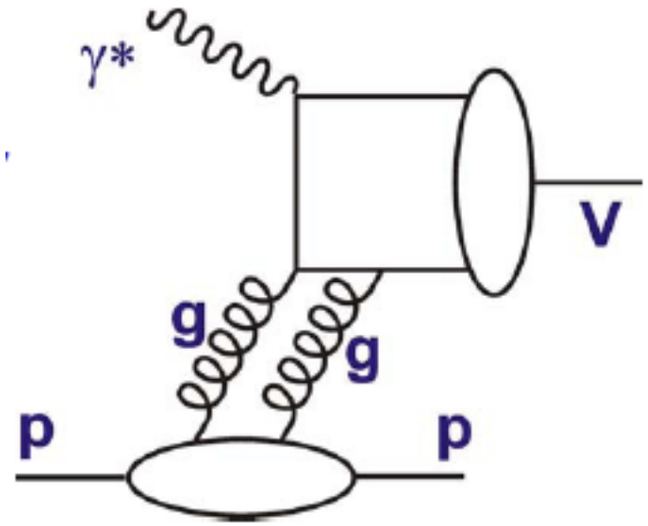
measure $F_L$ or use the reduced cross section (but then ratios at two energies...).



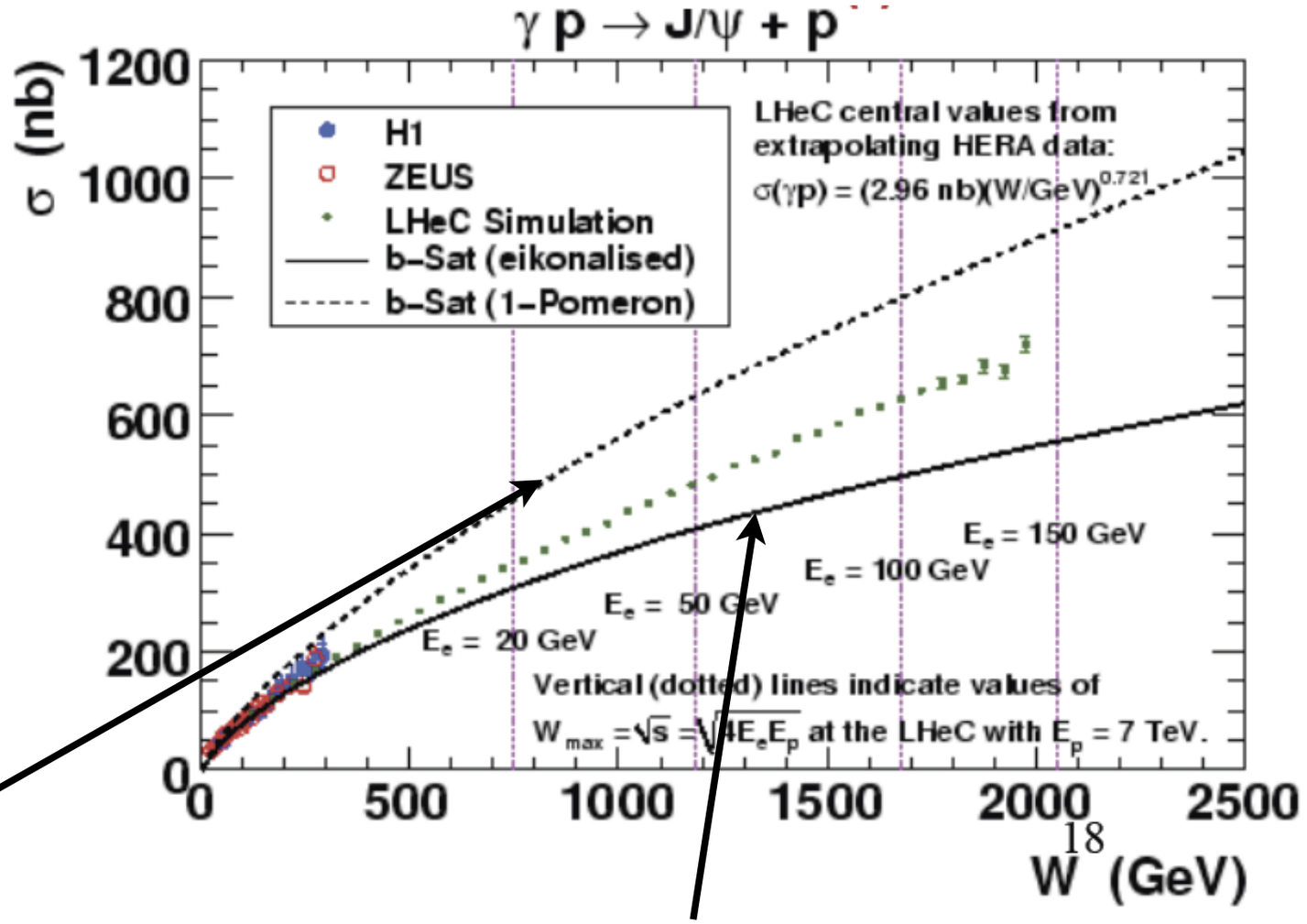

NA, Paukkunen, Salgado, Tywoniuk, '10

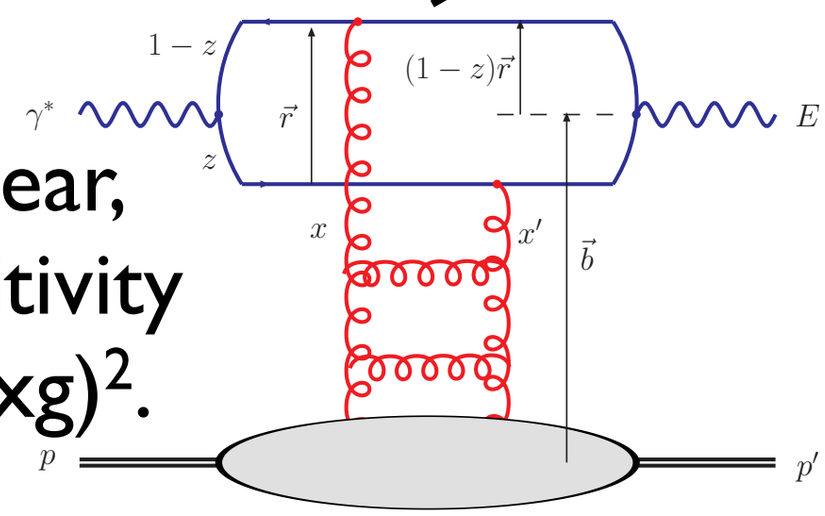


# Elastic VM production in ep:

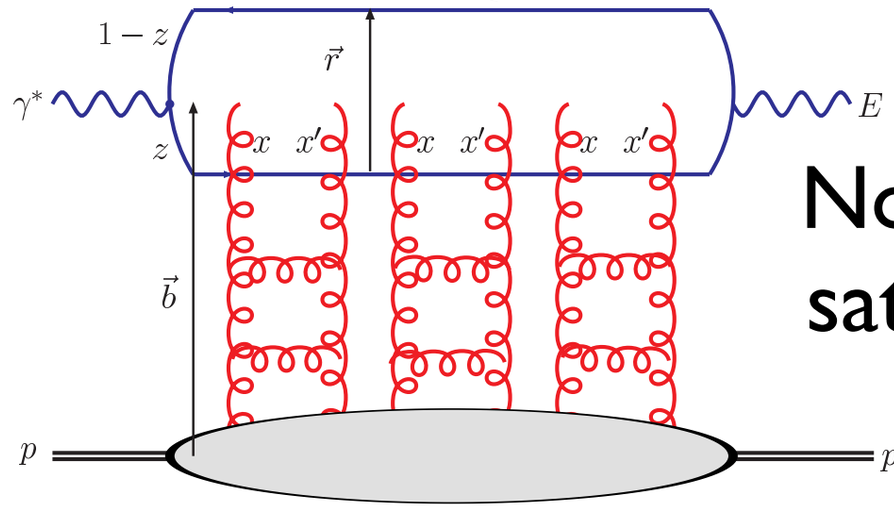



- Elastic J/ψ production appears as a candidate to signal saturation effects at work!!!



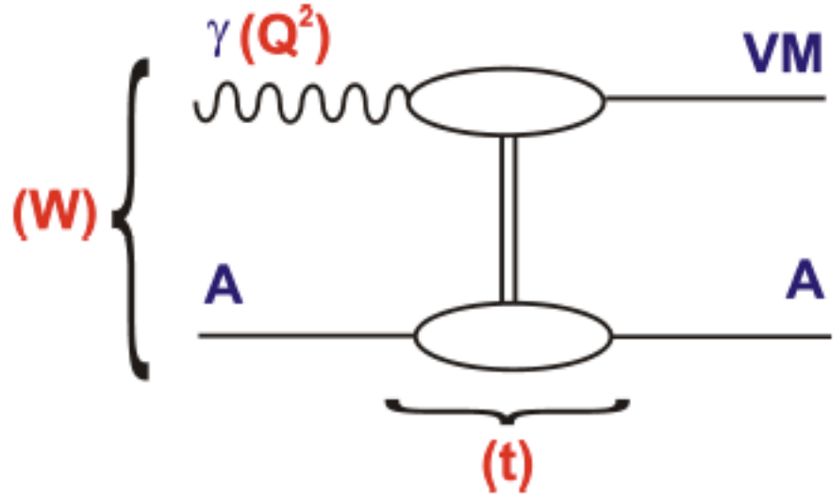



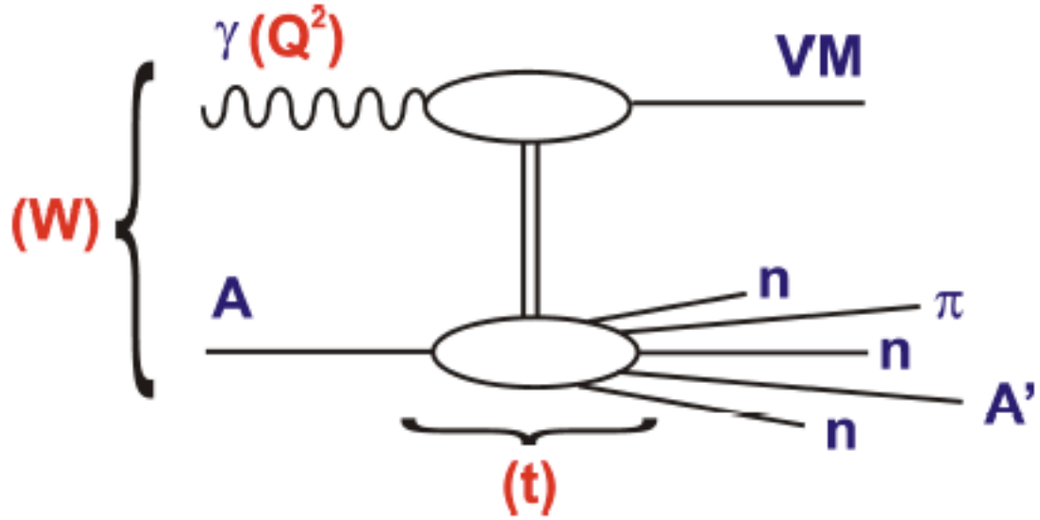

Linear, sensitivity to $(xg)^2$.




Non-linear, saturation.

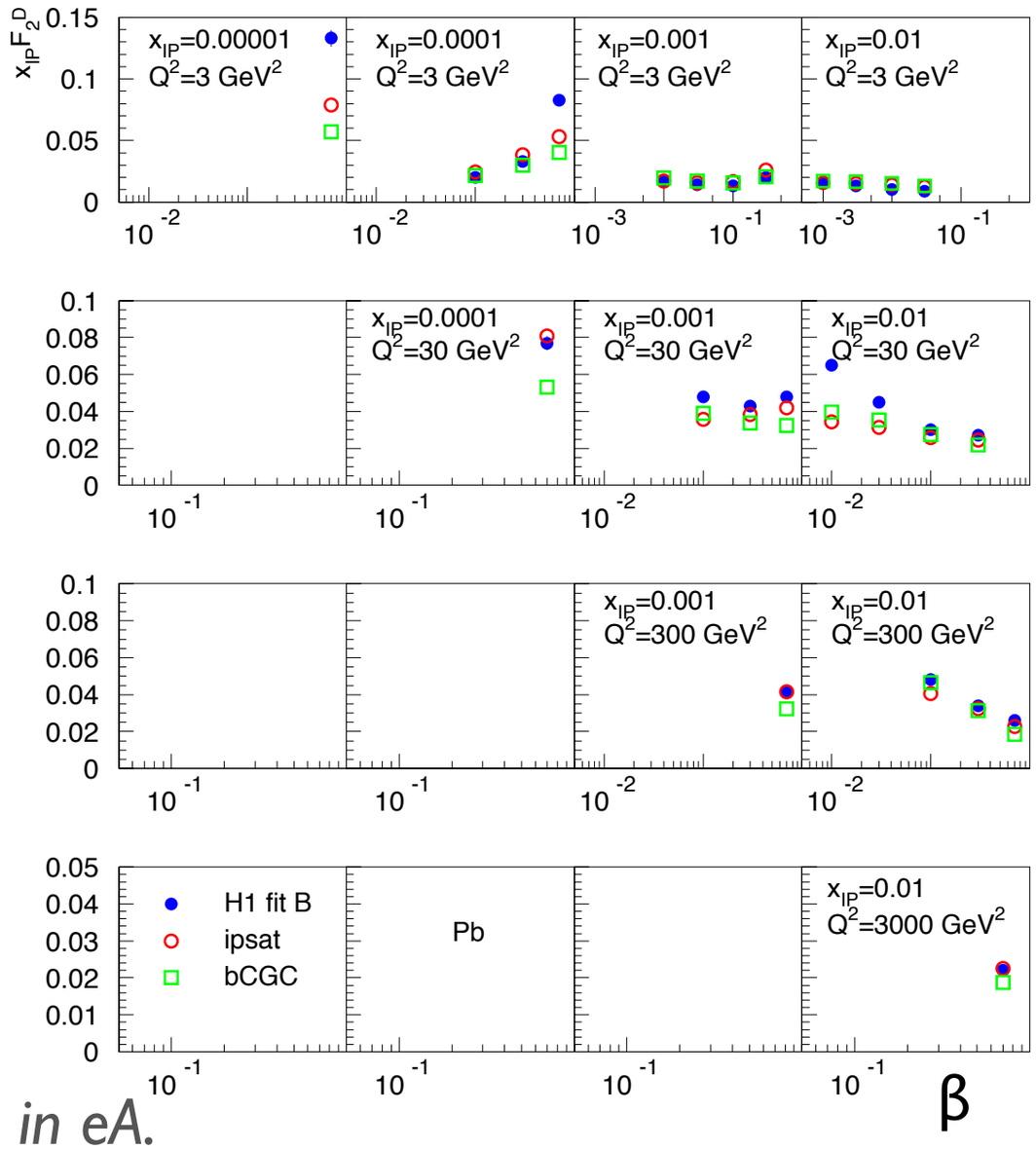
# Diffractive DIS on nuclear targets:



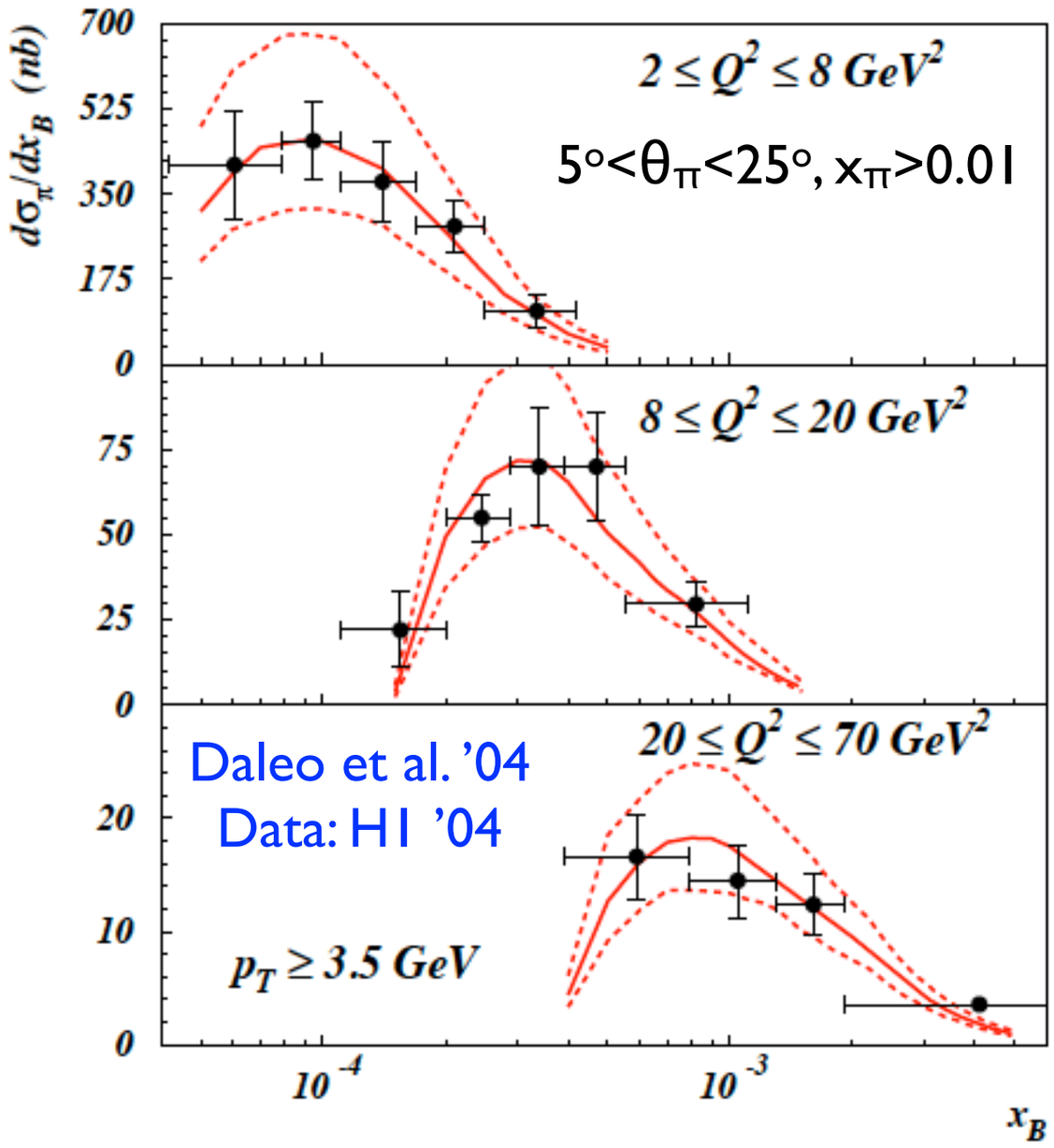

- Challenging experimental problem, requires Monte Carlo simulation with detailed understanding of the nuclear break-up.

- For the coherent case, predictions available.

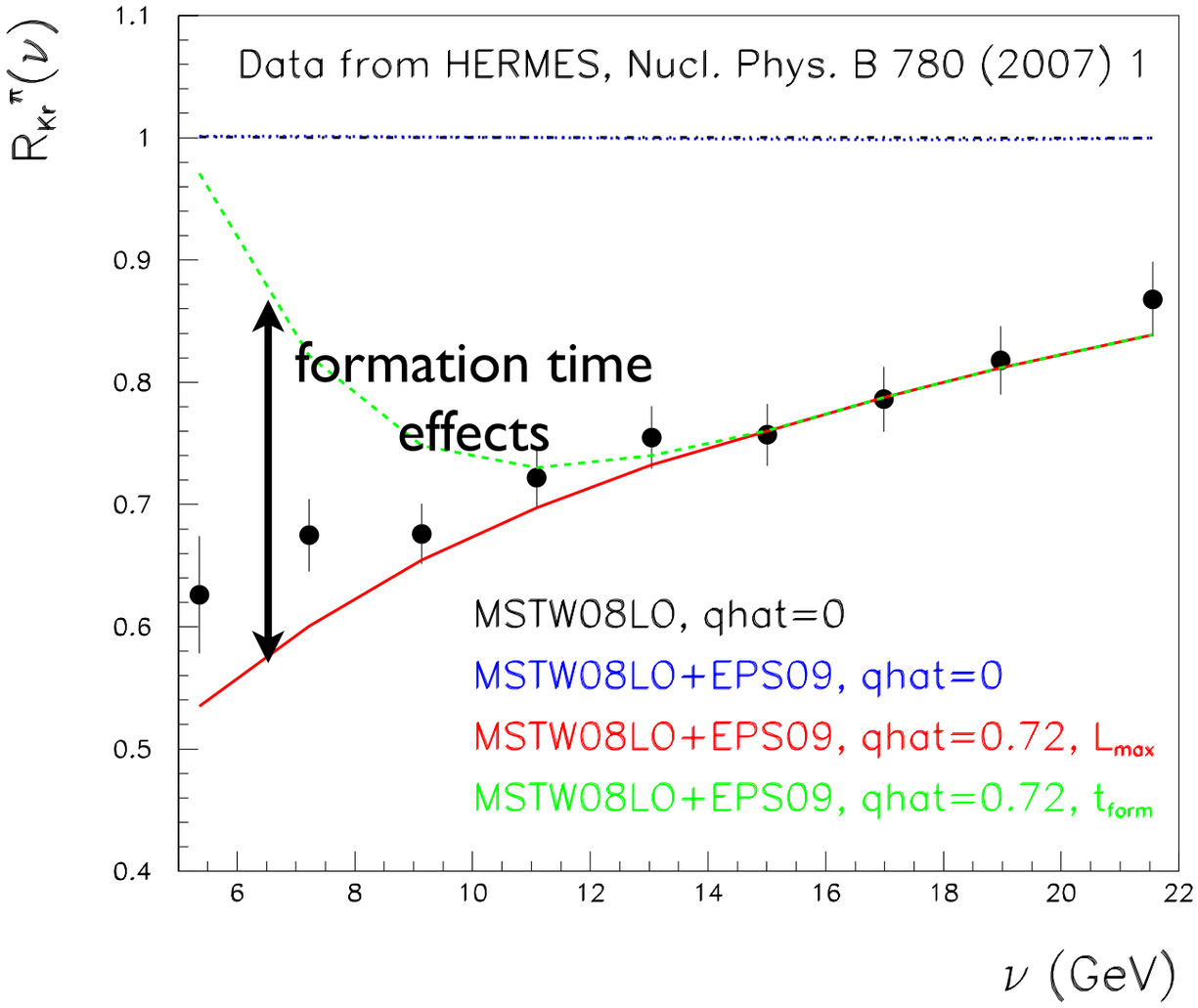


# Radiation and hadronization:

- Large (NLO) yields at small-x (H1 cuts, 3 times higher if relaxed).
- Nuclear effects in hadronization at small ν (LO plus QW, Arleo '03).

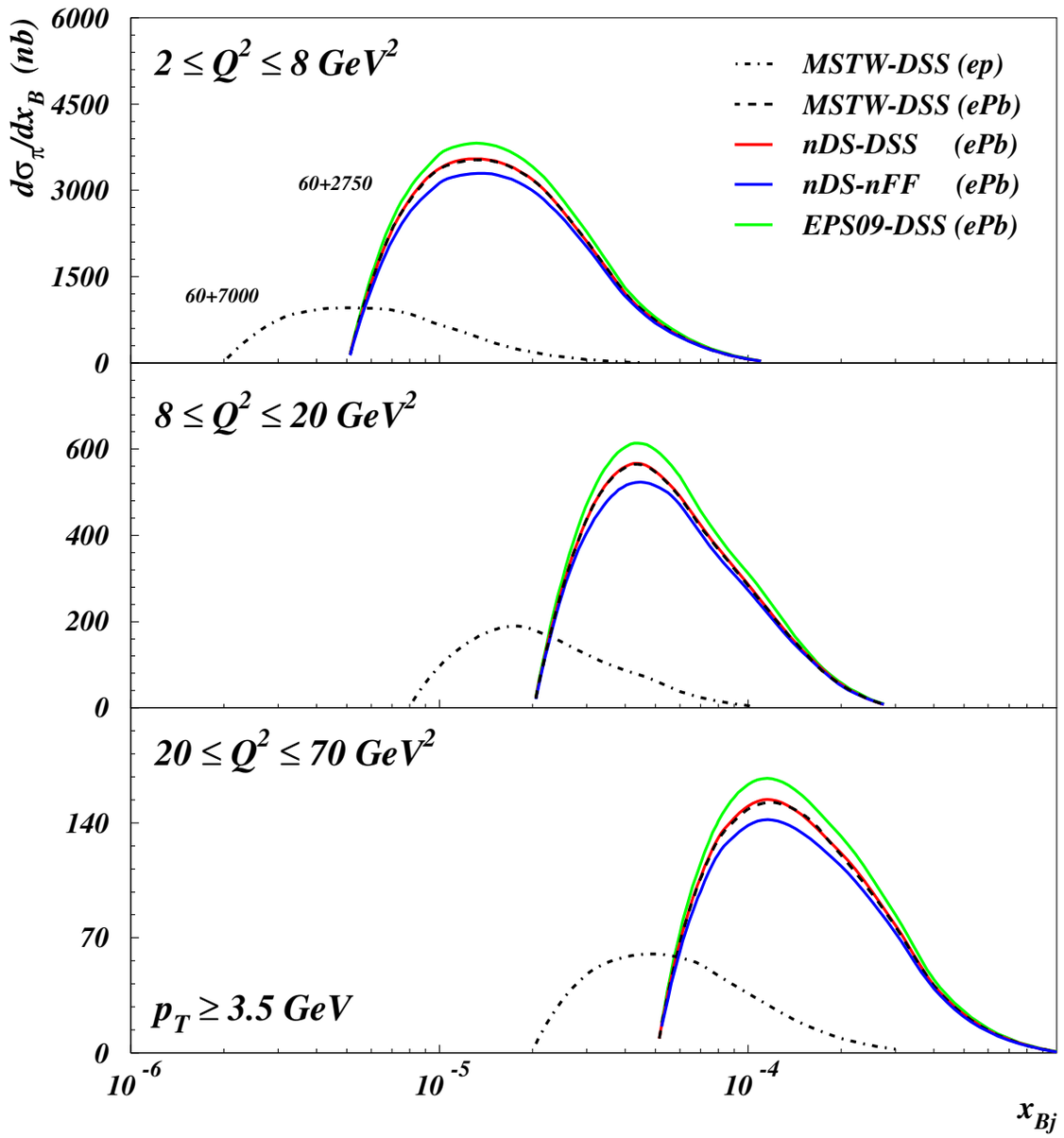


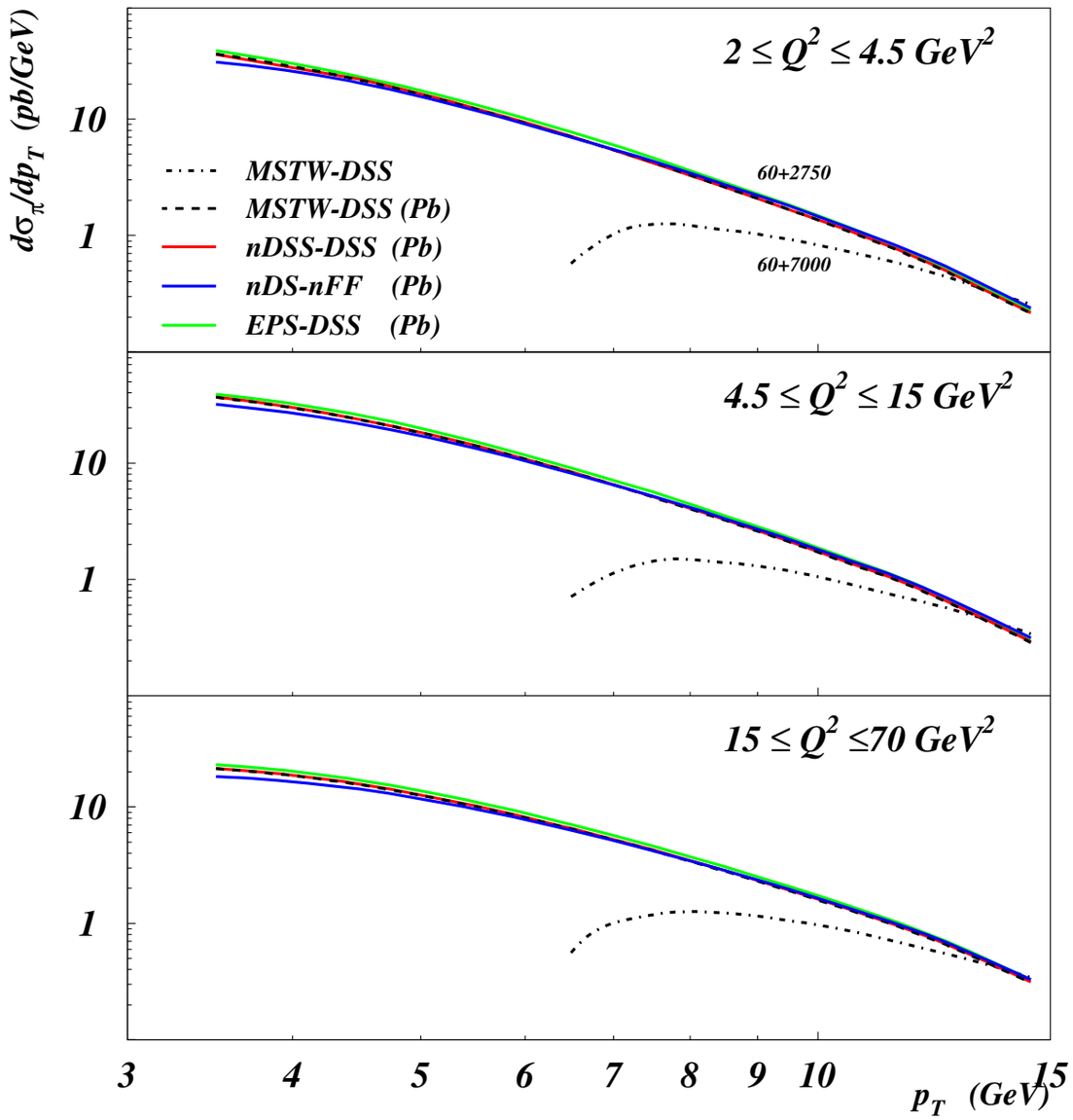

$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{\mathrm{d}N_A^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z} \Big/ \frac{1}{N_D^e}\frac{\mathrm{d}N_D^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z}$$



# Radiation and hadronization:

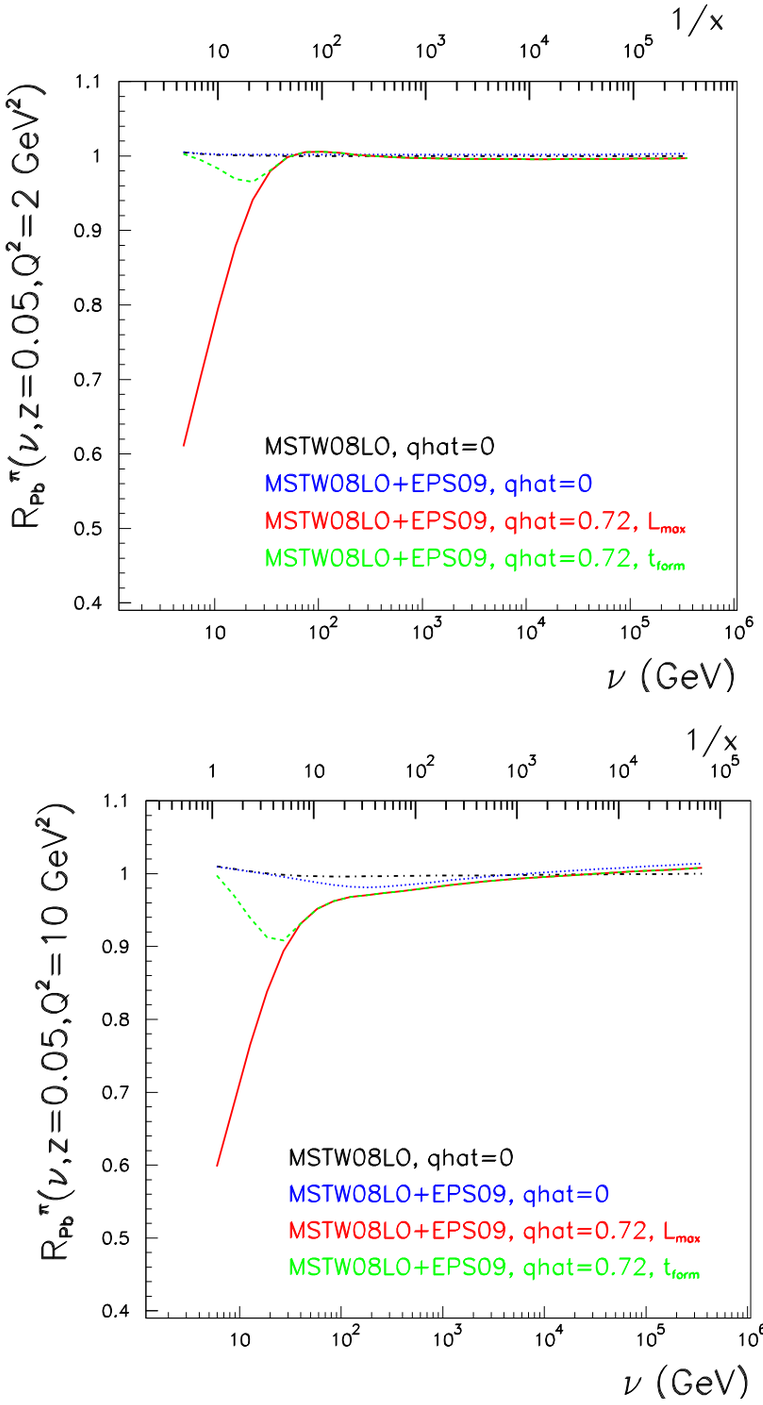
- Large (NLO) yields at small-x (H1 cuts, 3 times higher if relaxed).
- Nuclear effects in hadronization at small ν (LO plus QW, Arleo '03).



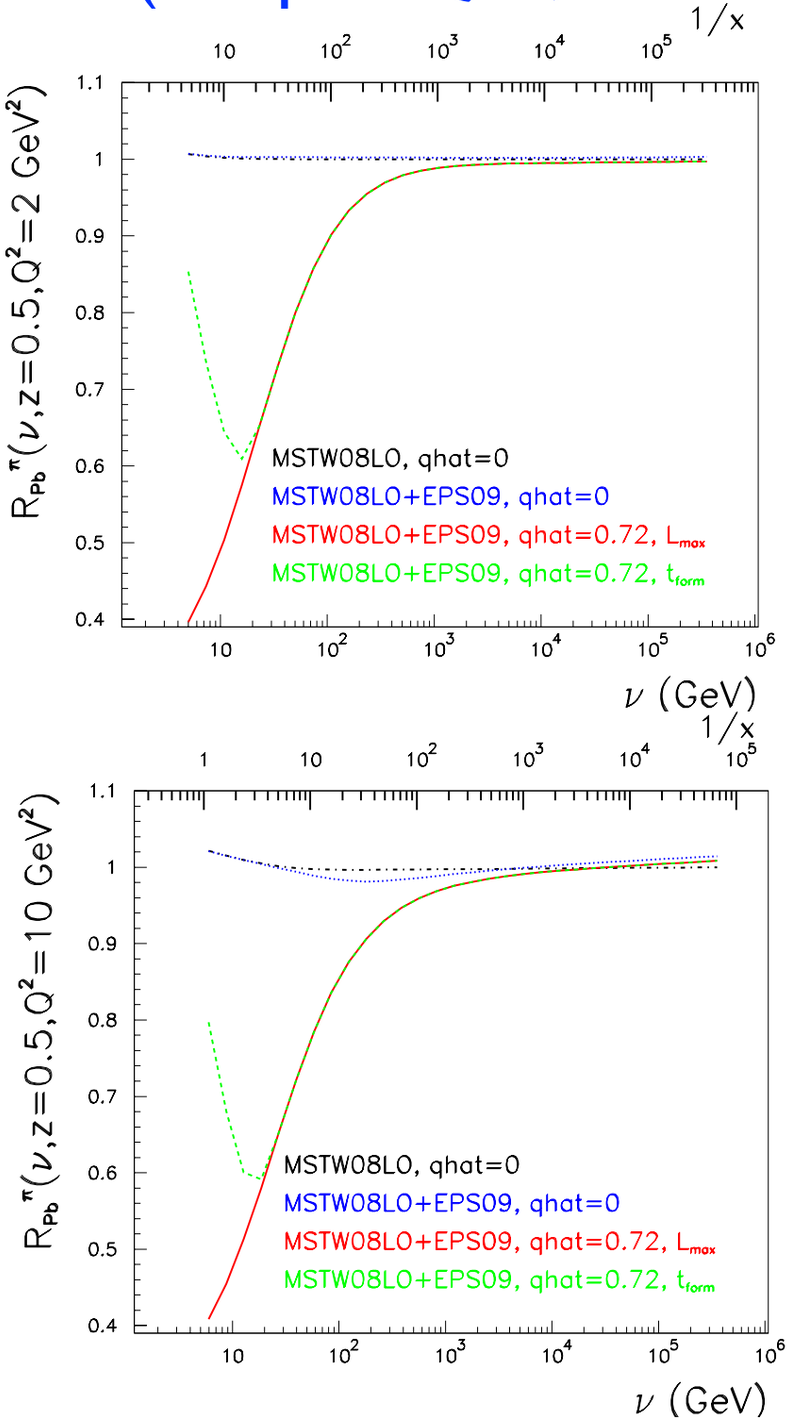



# Radiation and hadronization:

- Large (NLO) yields at small-x (H1 cuts, 3 times higher if relaxed).
- Nuclear effects in hadronization at small ν (LO plus QW, Arleo '03).




$$R_A^h(z,\nu) = \frac{\frac{1}{N_A^e}\frac{dN_A^h(z,\nu)}{d\nu\, dz}}{\frac{1}{N_D^e}\frac{dN_D^h(z,\nu)}{d\nu\, dz}}$$



# Outlook:

- With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, several items have to be done/improved:

➜ Refine DGLAP fits with flavour decomposition (include neutrino data, relax assumptions) and optimized $F_L$ scenarios, and LHC data.
➜ Monte Carlo generators!!!
➜ Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets,...
➜ Large x, EW bosons.
➜ Nuclear GPDs: nuclear DVCS etc.
➜ eD.
➜ Jet reconstruction, angular decorrelation...
➜ ...

→ Cooperation with EIC in some of these items desirable.

# Outlook:

- With CERN and NuPECC mar

physics case and produce a TDR

be done/improved:

➜ Refine DGLAP fits with flavou

data, relax assumptions) and opti

➜ Monte Carlo generators!!!

➜ Studies on diffraction: separat

ndPDFs, dijets,...

➜ Large x, EW bosons.

➜ Nuclear GPDs: nuclear DVCS

➜ eD.

➜ Jet reconstruction, angular de

➜ ...

→ Cooperation with EIC in som

*Heavy Ion Physics in e-A and p/A-A.*



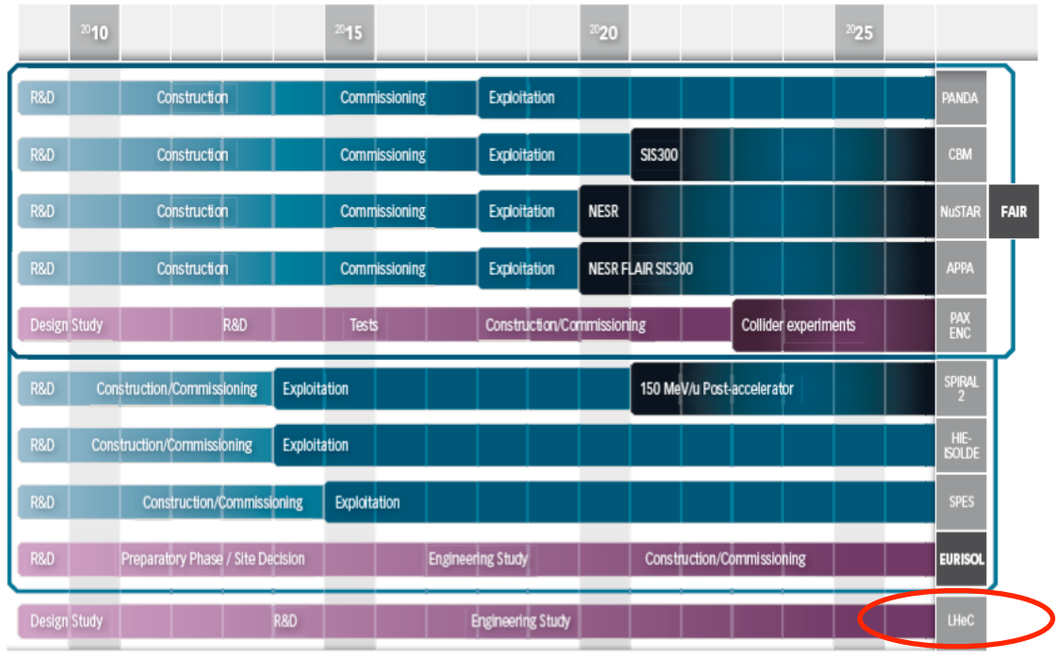
## NuPECC LRP

**EURISOL** in future updates of the ESFRI list, based on the successful EURISOL Design Study in FP6.

- The Technical Design Study for intense radioactive ion beams at **ISOL@MYRRHA**.
- The Technical Design Study for a polarised proton-antiproton, **PAX**, and an electron-nucleon/ion collider, **ENC**, at FAIR.
- The Technical Design Study for a high-energy electron-proton/ion collider, **LHeC**, at CERN.
- The inclusion of Nuclear Physics programmes at the multi-purpose facilities **ELI** and **ESS**.

### 2.2 Facilities Roadmap

We present below the roadmap for building new large-scale Nuclear Physics research infrastructures in Europe. The time span ranges until the middle of the next decade. Facilities whose first phases have already been approved are coloured in blue, future upgrades thereof in dark blue. The ISOL facilities SPIRAL 2, HIE-ISOLDE and SPES are designated to lead to EURISOL. PAX and the ENC at FAIR, EURISOL and the LHeC at CERN are still in the design or R&D phase. They are coloured in purple.




Roadmap for New Large Scale Facilities.

# Outlook:

- With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, several items have to be done/improved:

➜ Refine DGLAP fits with flavour decomposition (include neutrino data, relax assumptions) and optimized $F_L$ scenarios, and LHC data.
➜ Monte Carlo generators!!!
➜ Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets,...
➜ Large x, EW bosons.
➜ Nuclear GPDs: nuclear DVCS etc.
➜ eD.
➜ Jet reconstruction, angular decorrelation...
➜ ...

→ Cooperation with EIC in some of these items desirable.

# Outlook:

- With CERN and NuPECC mandate to further motivate the physics case and produce a TDR around 2015, several items have to be done/improved:

➜ Refine DGLAP fits with flavour decomposition (include neutrino data, relax assumptions) and optimized $F_L$ scenarios, and LHC data.
➜ Monte Carlo generators!!!
➜ Studies on diffraction: separation of coherent from incoherent, ndPDFs, dijets,...
➜ Large x, EW bosons.
➜ Nuclear GPDs: nuclear DVCS etc.
➜ eD.
➜ Jet reconstruction, angular decorrelation...
➜ ...

*Thanks for your attention!*

→ Cooperation with EIC in some of these items desirable.