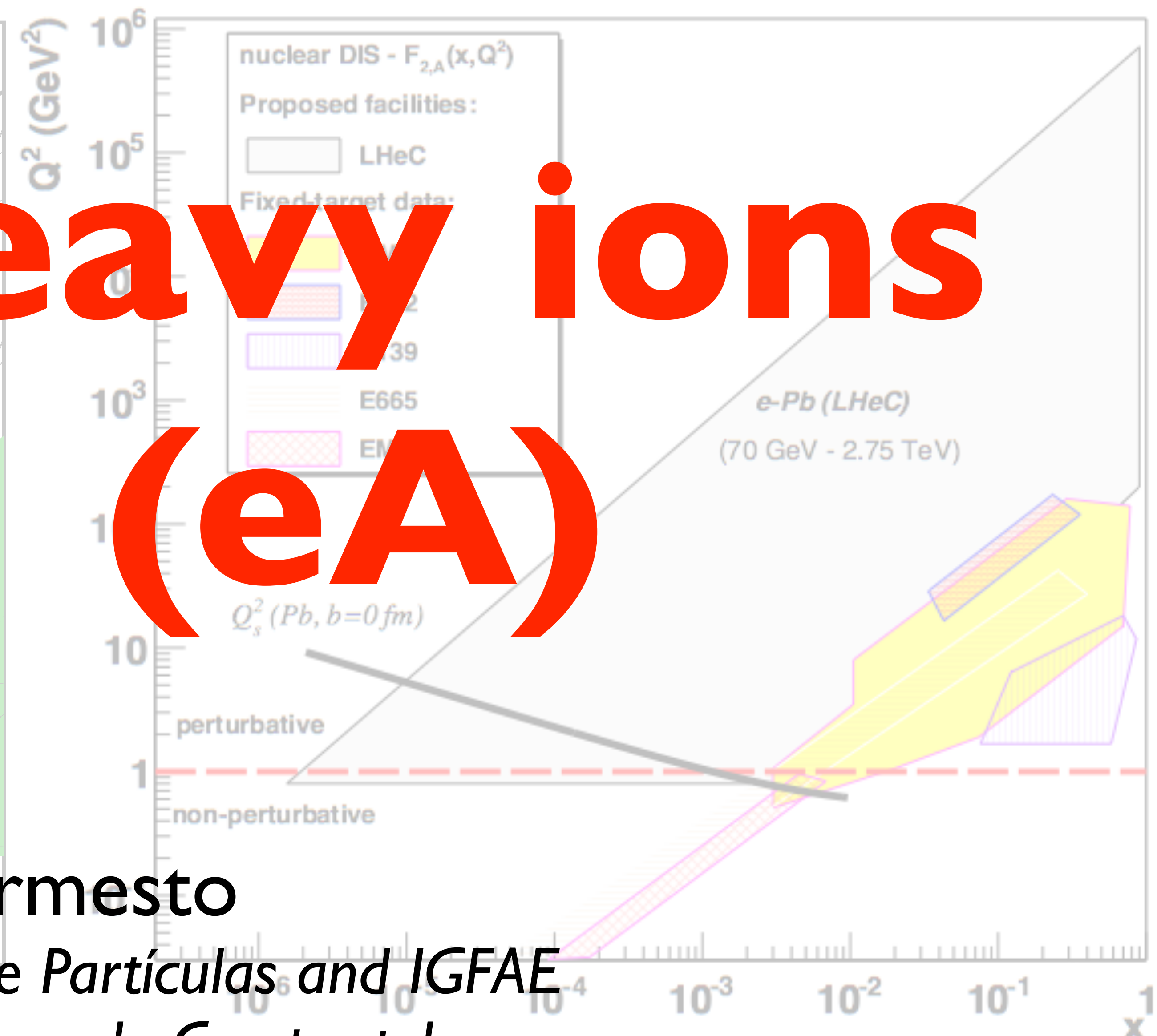
Meeting of the Physics Study Convenors of the LHeC
CERN, November 4th 2014

Heavy ions (eA)



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coordinated with small x: Paul Newman and Anna Stasto

Contents:

1. Brief review as in CDR.

2. Ongoing plans.

3. FCC-he.

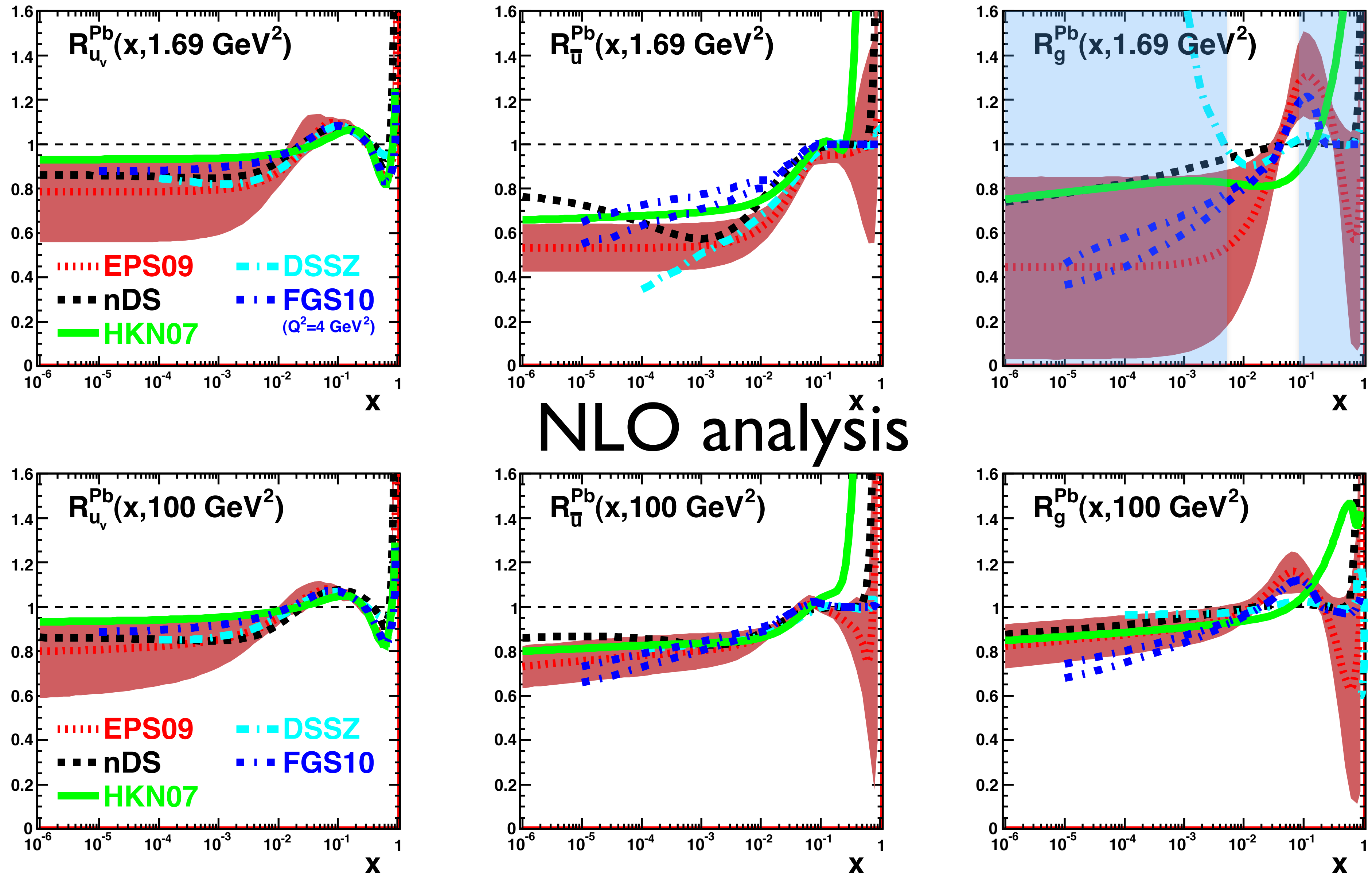
4. Activities at the LHC.

5. How to attract manpower.

Motivation: nPDFs

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

- Lack of data ⇒ models and DGLAP analysis (up to NLO) give vastly different results at small scales and all x: problem for benchmarking in HIC.
- Glue unconstrained for $x<10^{-2}$.



NLO analysis

Motivation: eA for small x

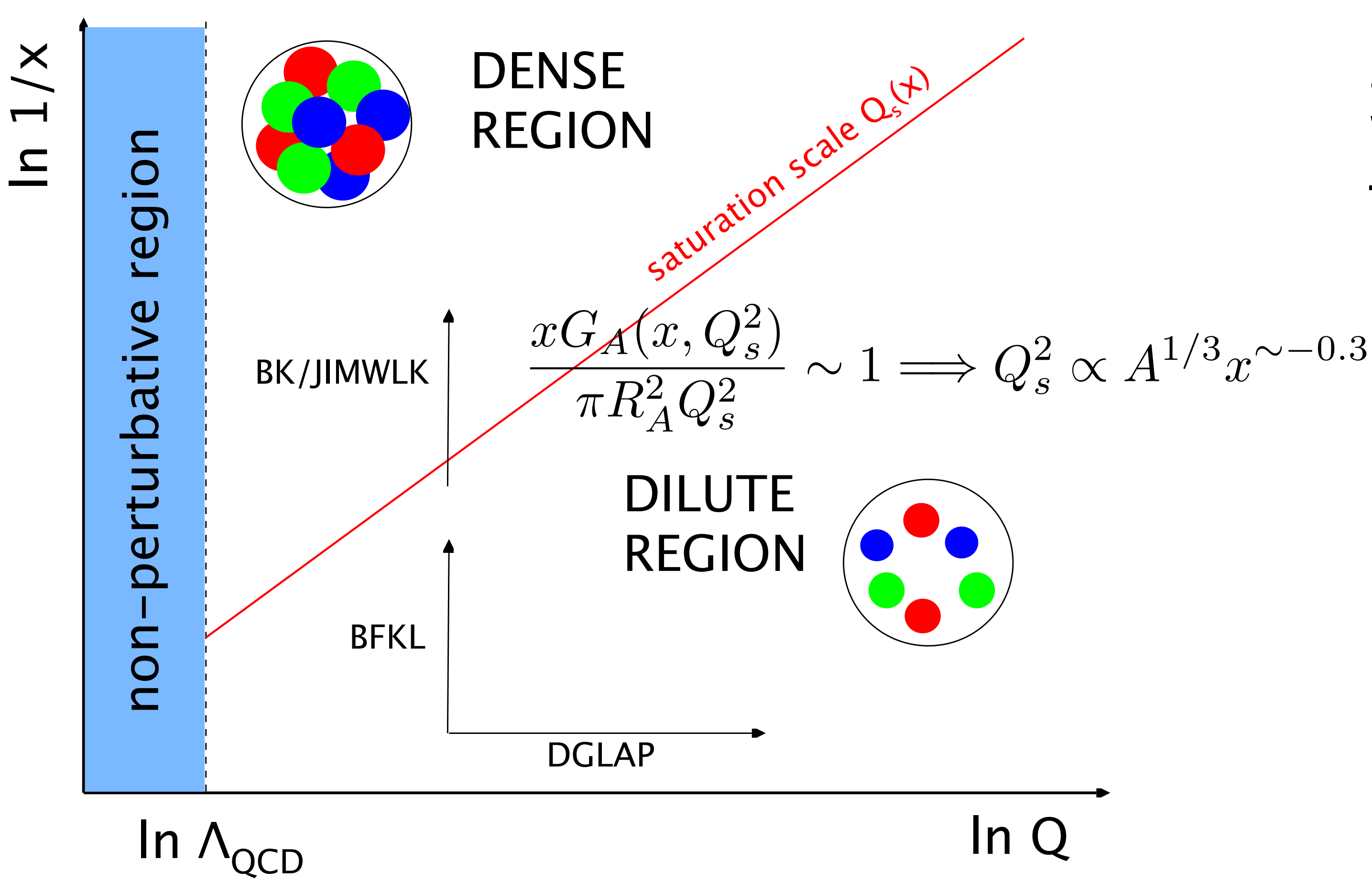
- Three pQCD-based alternatives to describe small-x ep and eA data (differences at moderate $Q^2(>\Lambda^2_{QCD})$ and small x):

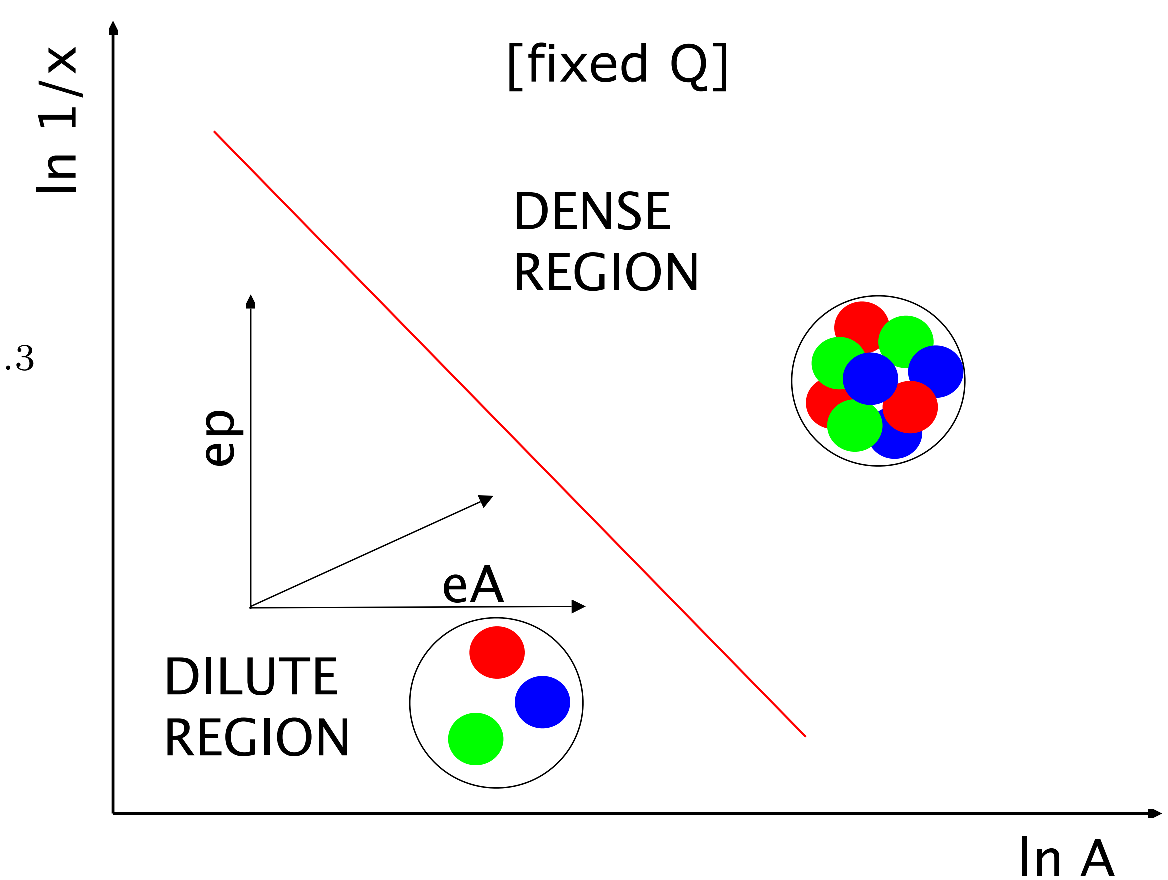
→ DGLAP evolution (fixed order perturbation theory).

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

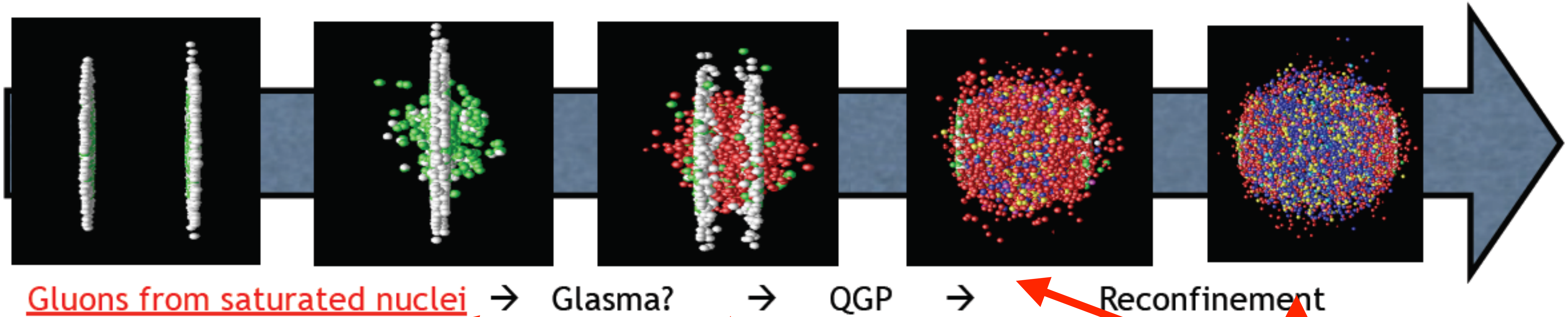
→ Saturation (CGC, dipole models).

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





Motivation: HI program



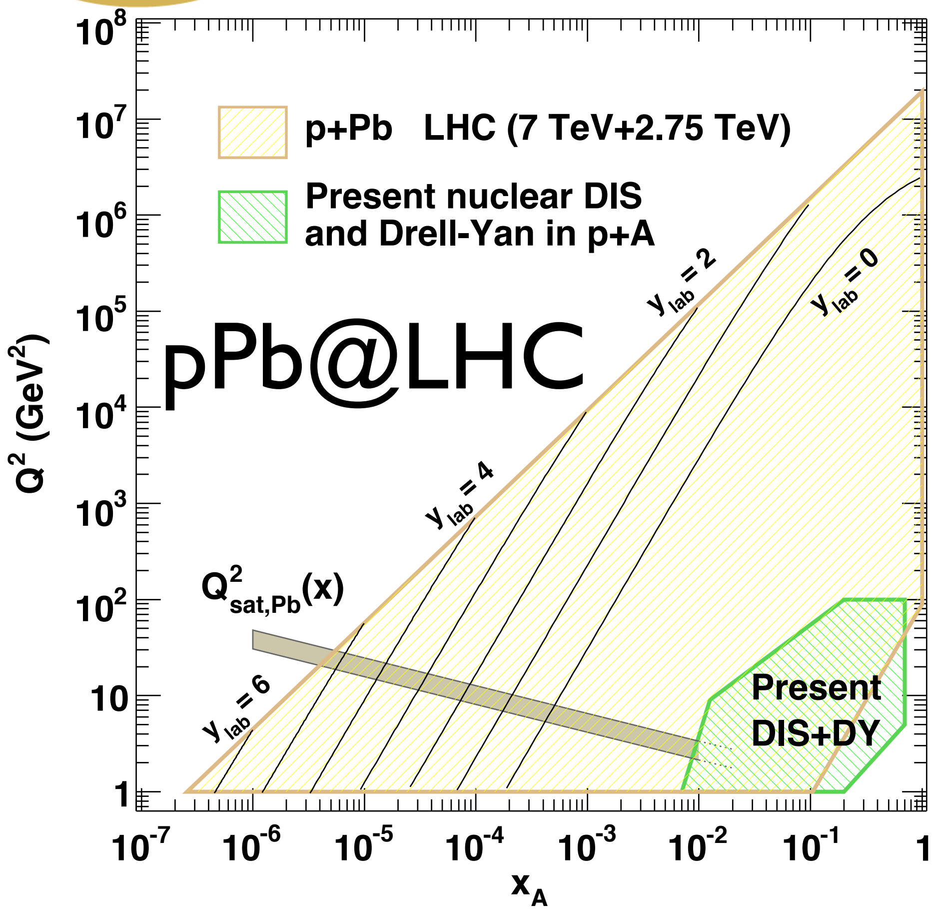
• Nuclear wave function at small x: nuclear structure functions.

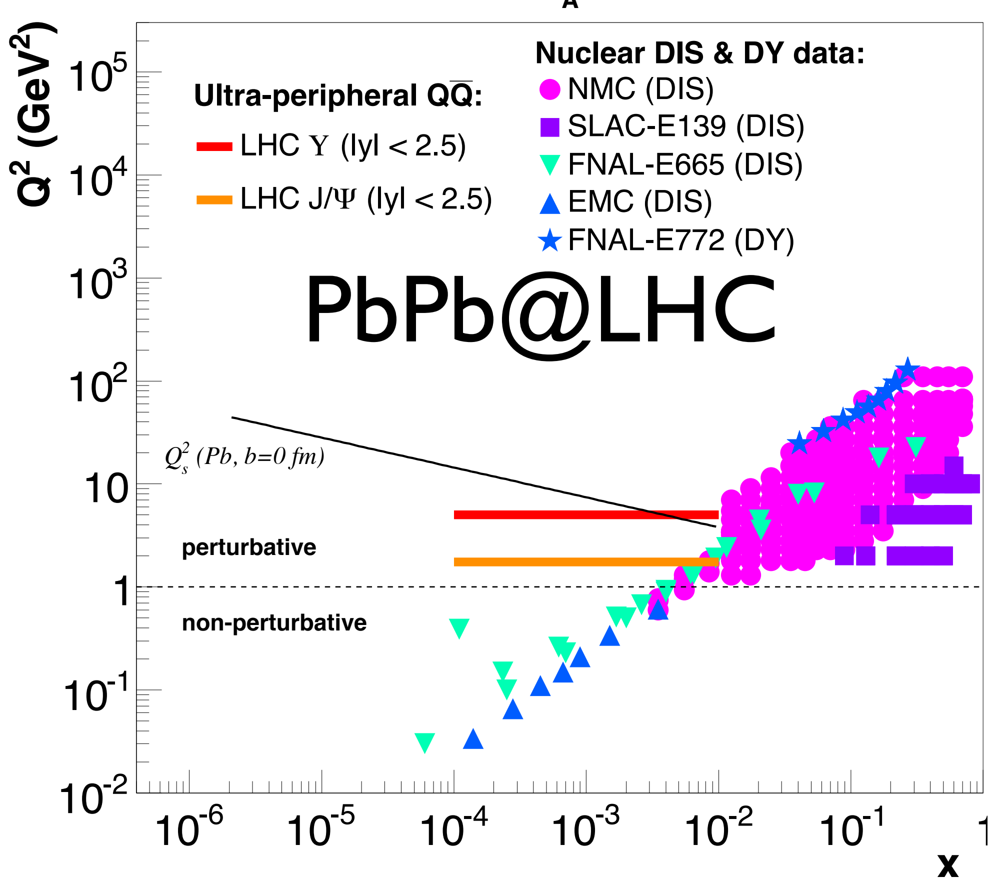
• Particle production at the very beginning: which factorisation in eA?

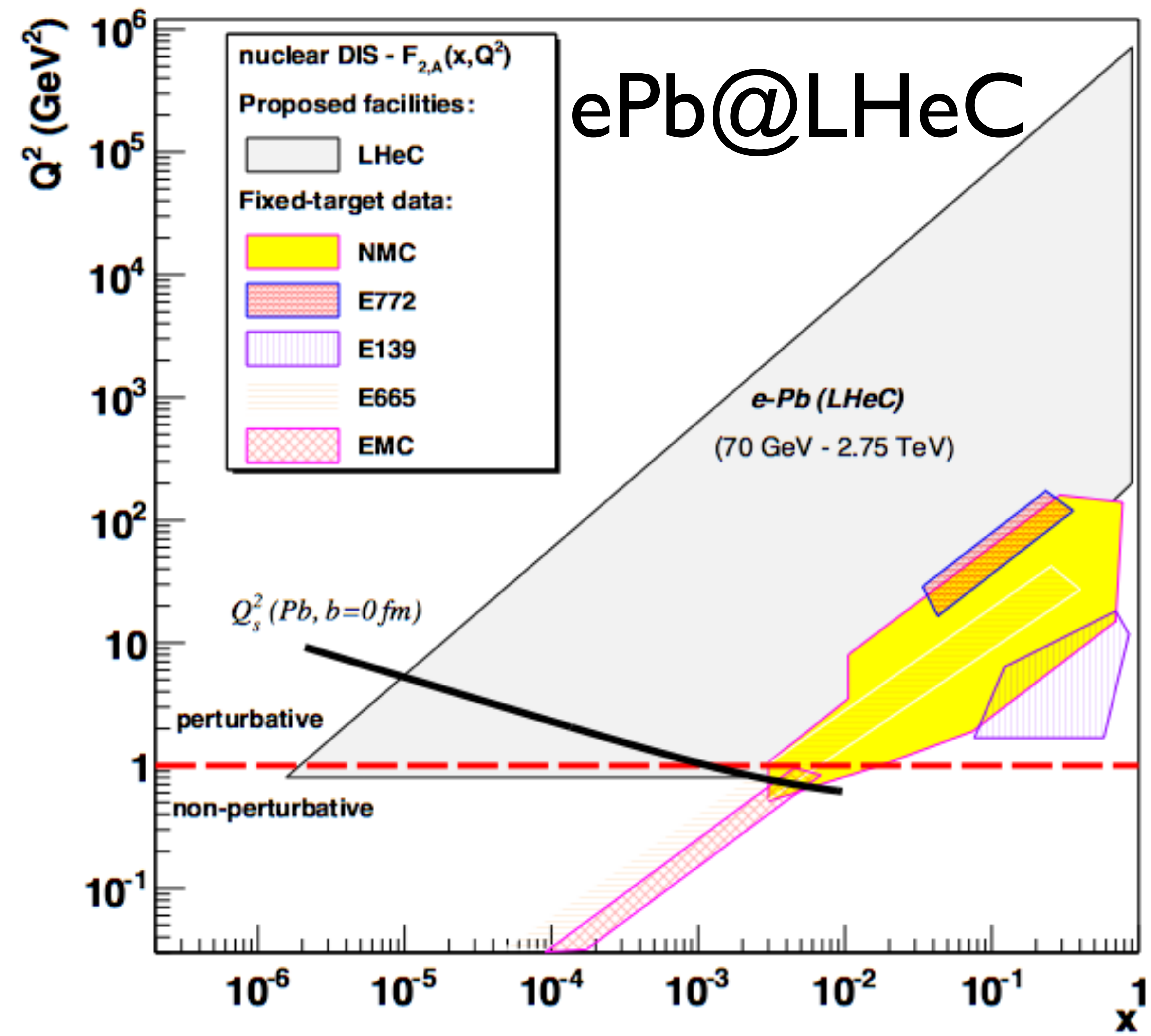
• How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

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

Motivation: LHC vs. LHeC







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

➜ in a cleaner experimental setup;

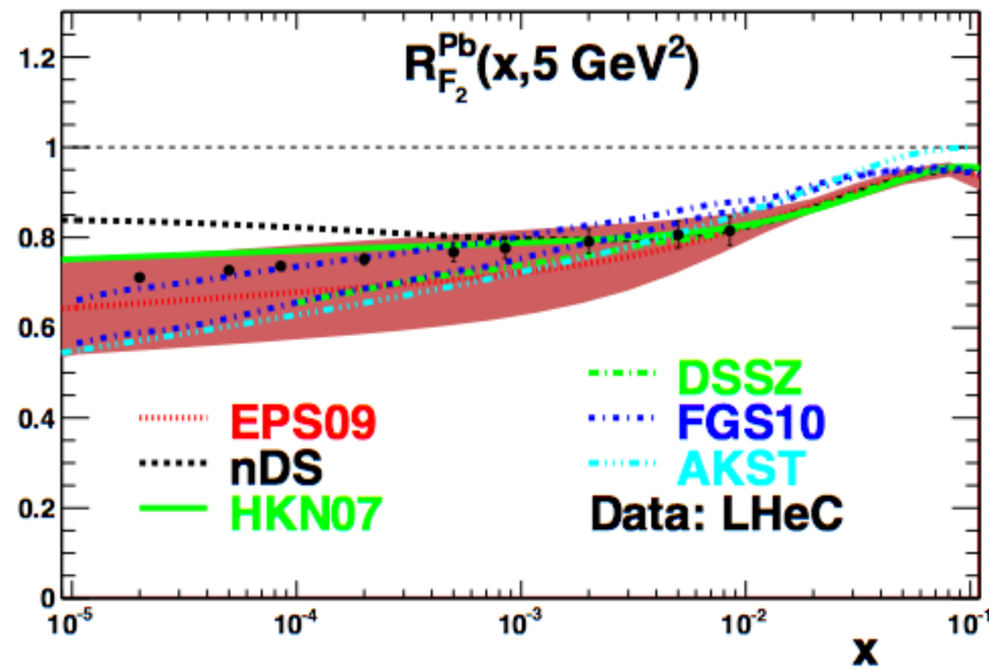
➜ on firmer theoretical grounds.

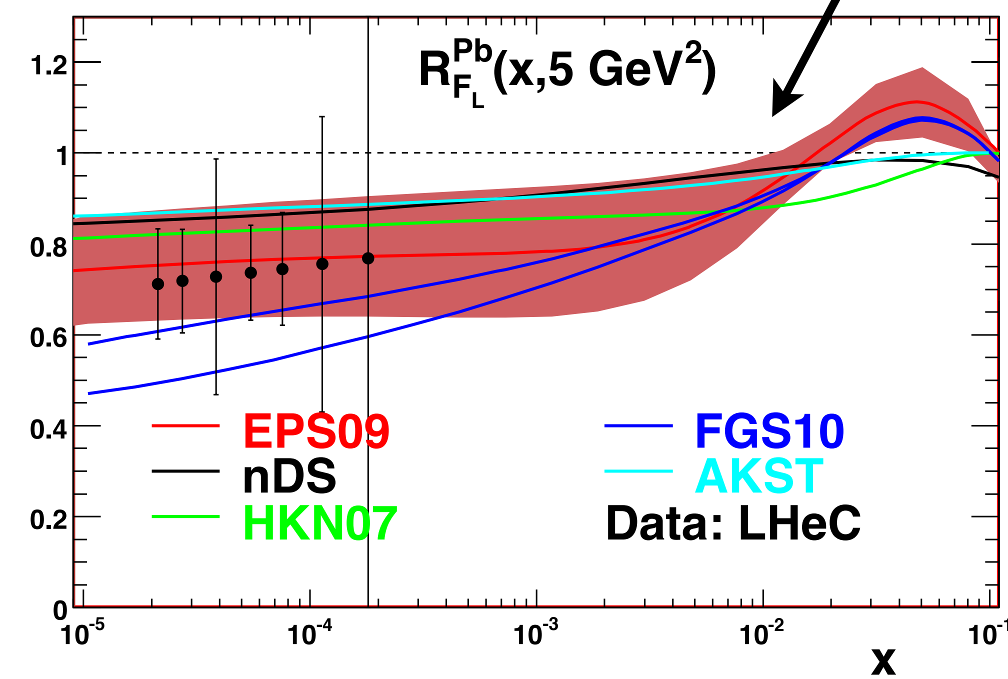
Inclusive studies

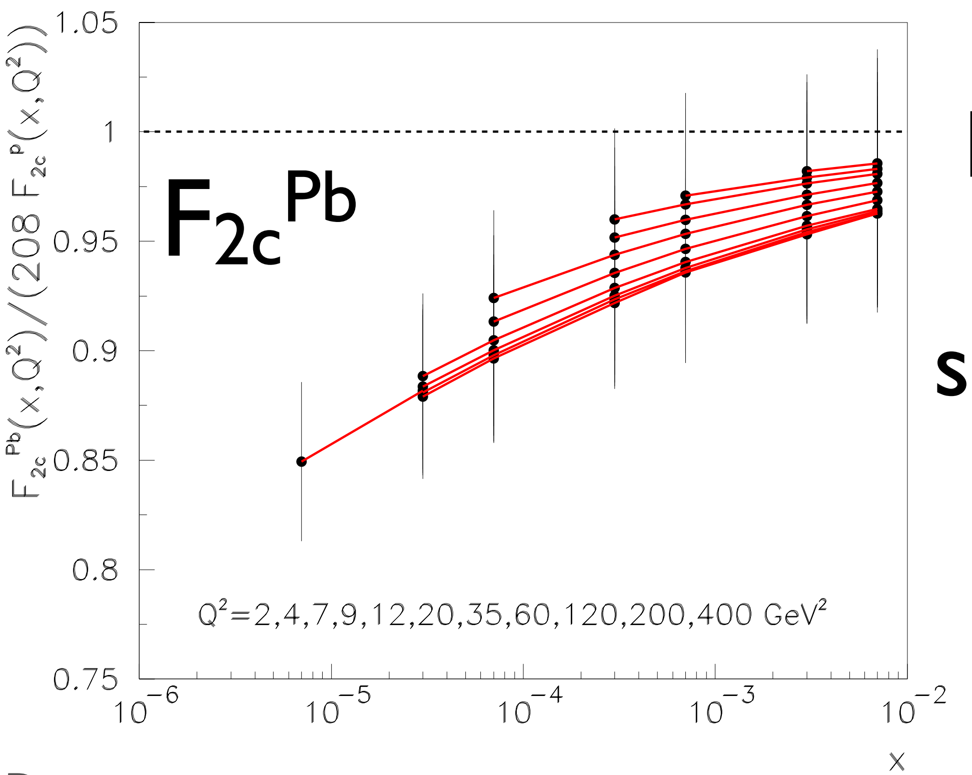
- Good precision can be obtained for $F_{2(c,b)}$ and F_L at small x

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

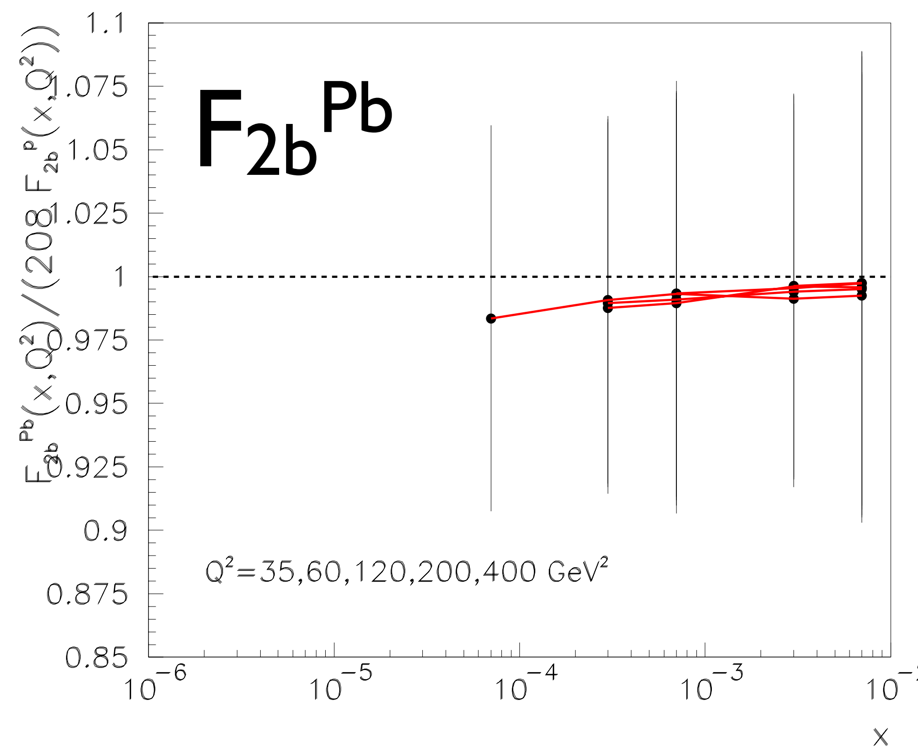
Not optimized!



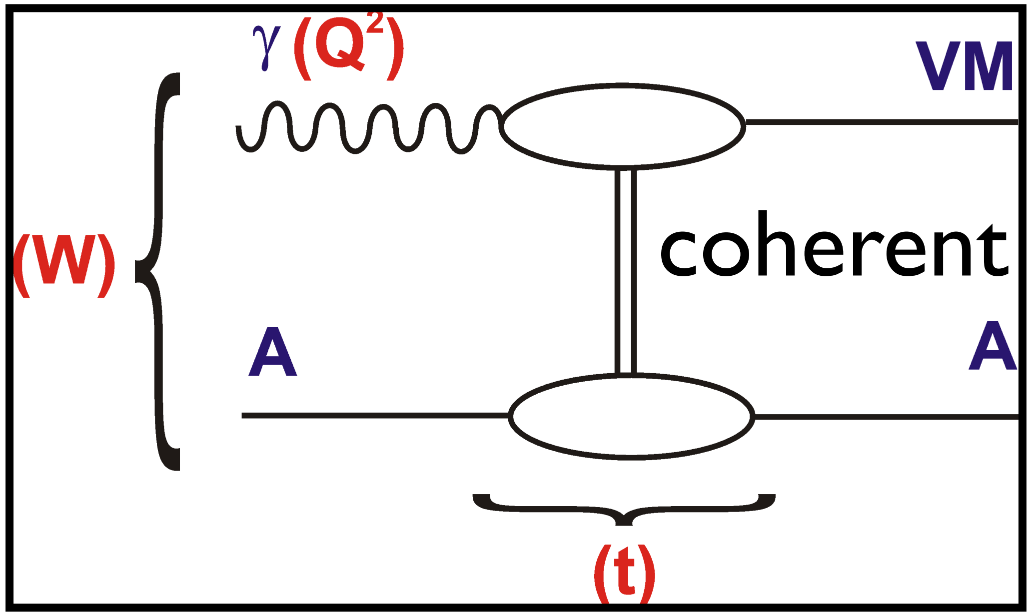




Note the scale!!!

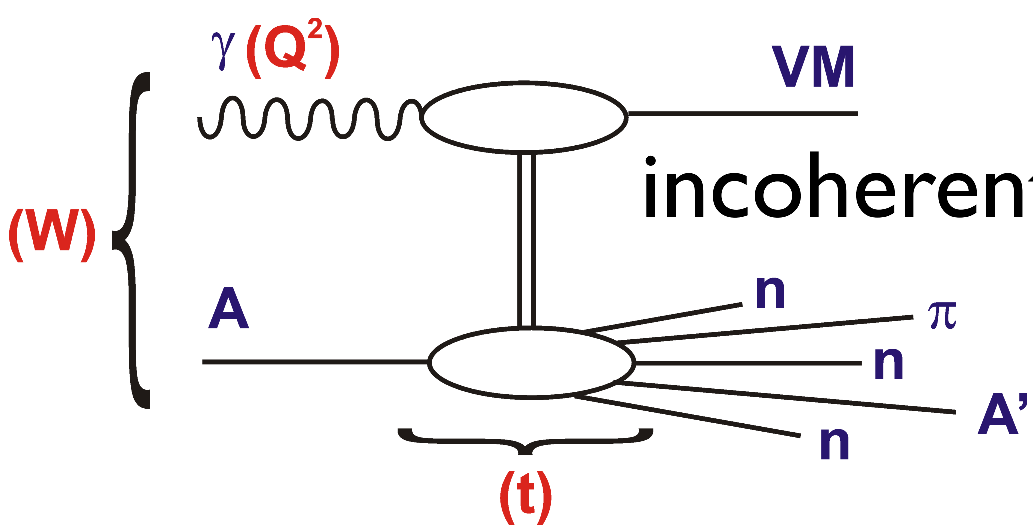


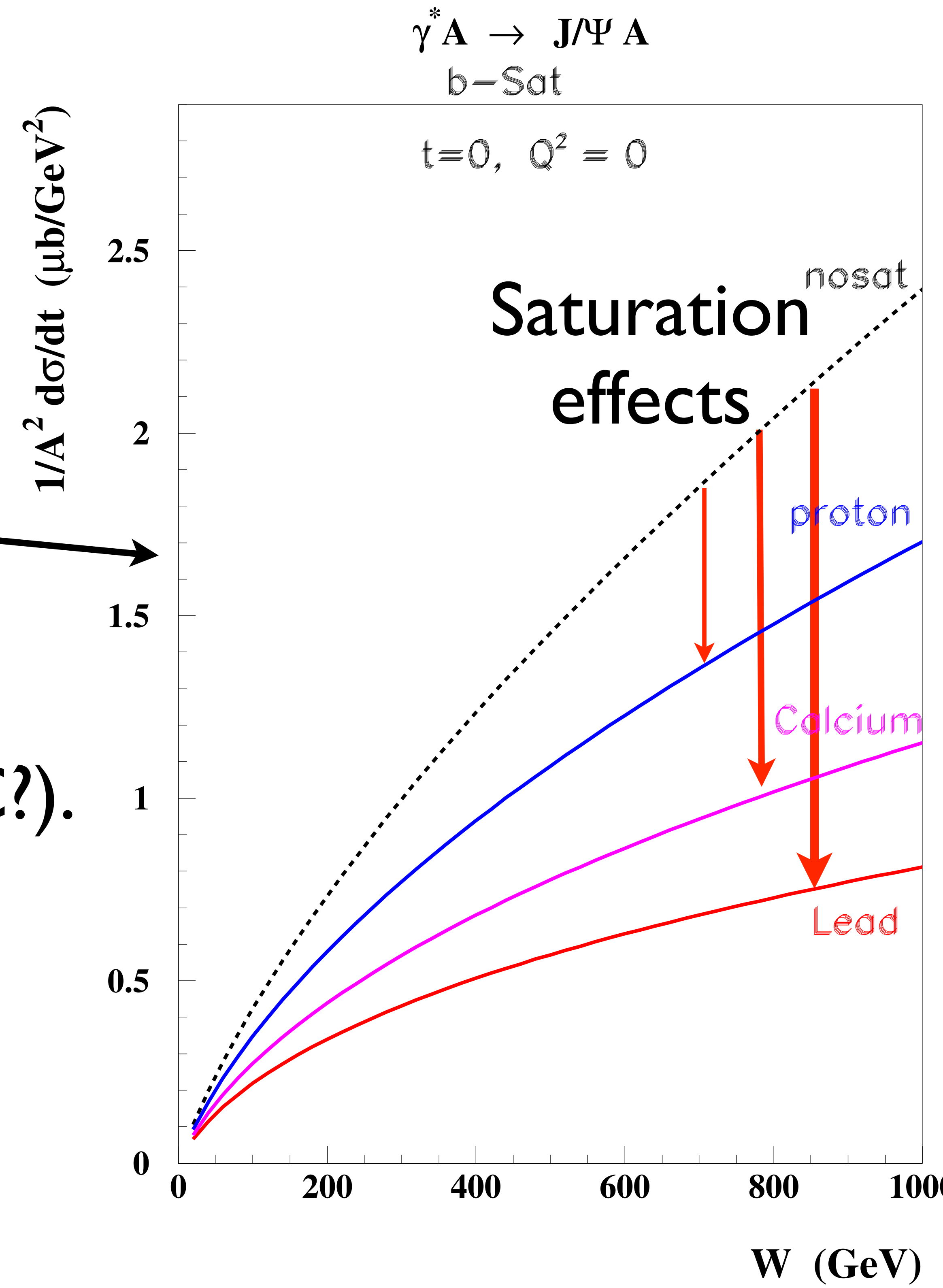
Elastic VM production in eA:



- For the coherent case, predictions available.

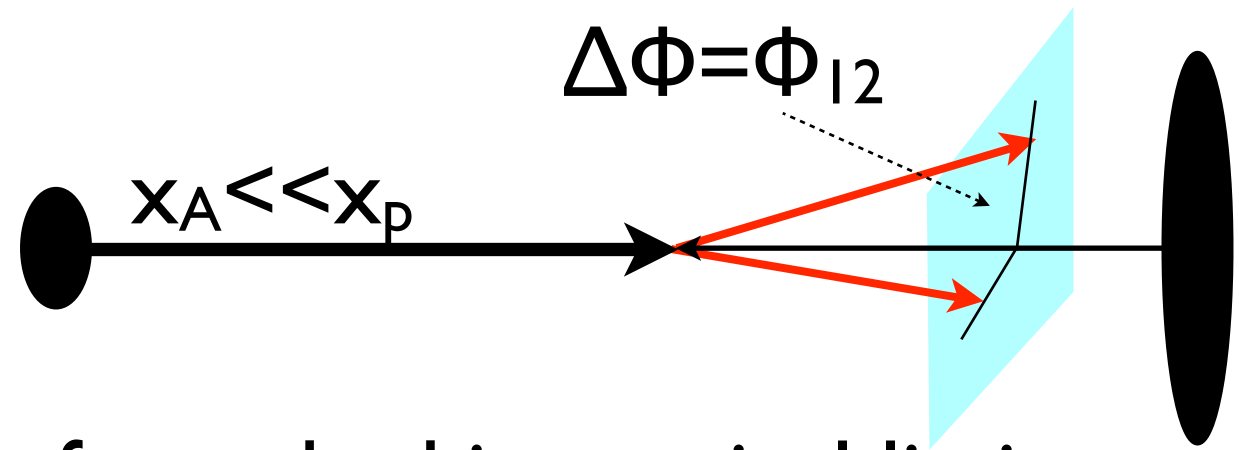
- Challenging experimental problem (neutron tagging in ZDC?).



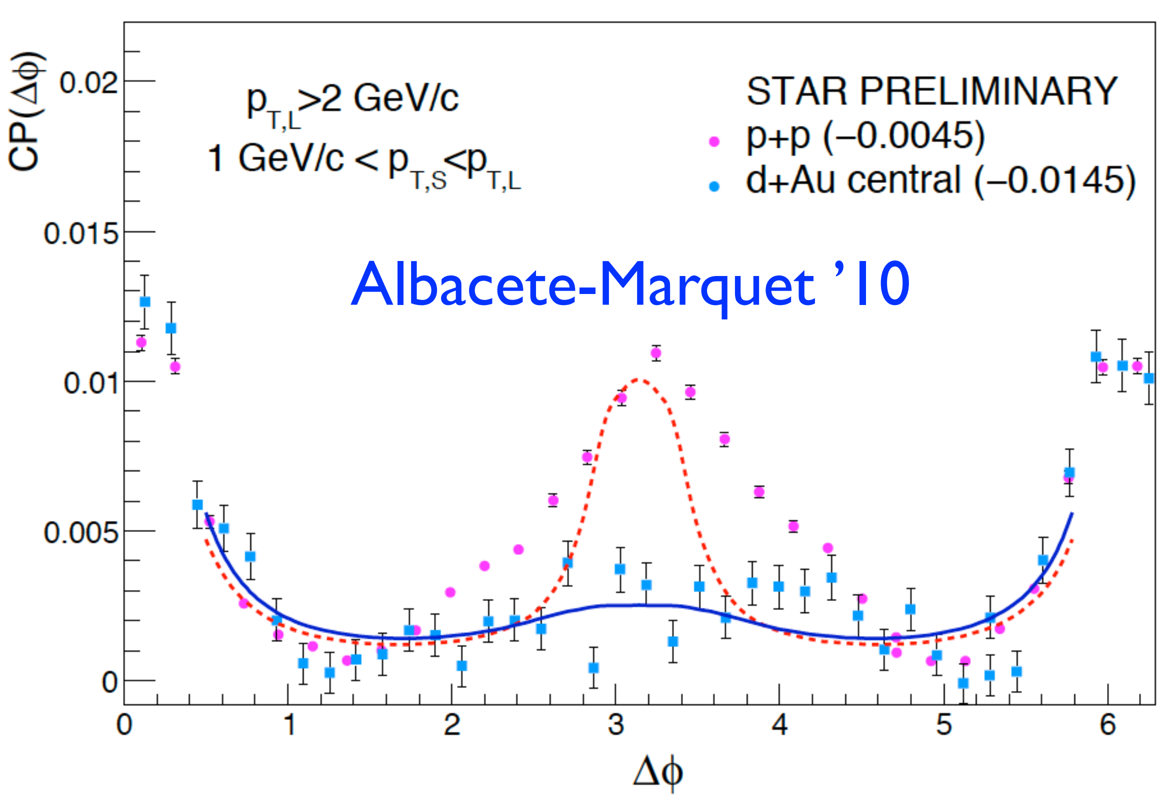


Dihadron azimuthal decorrelation:

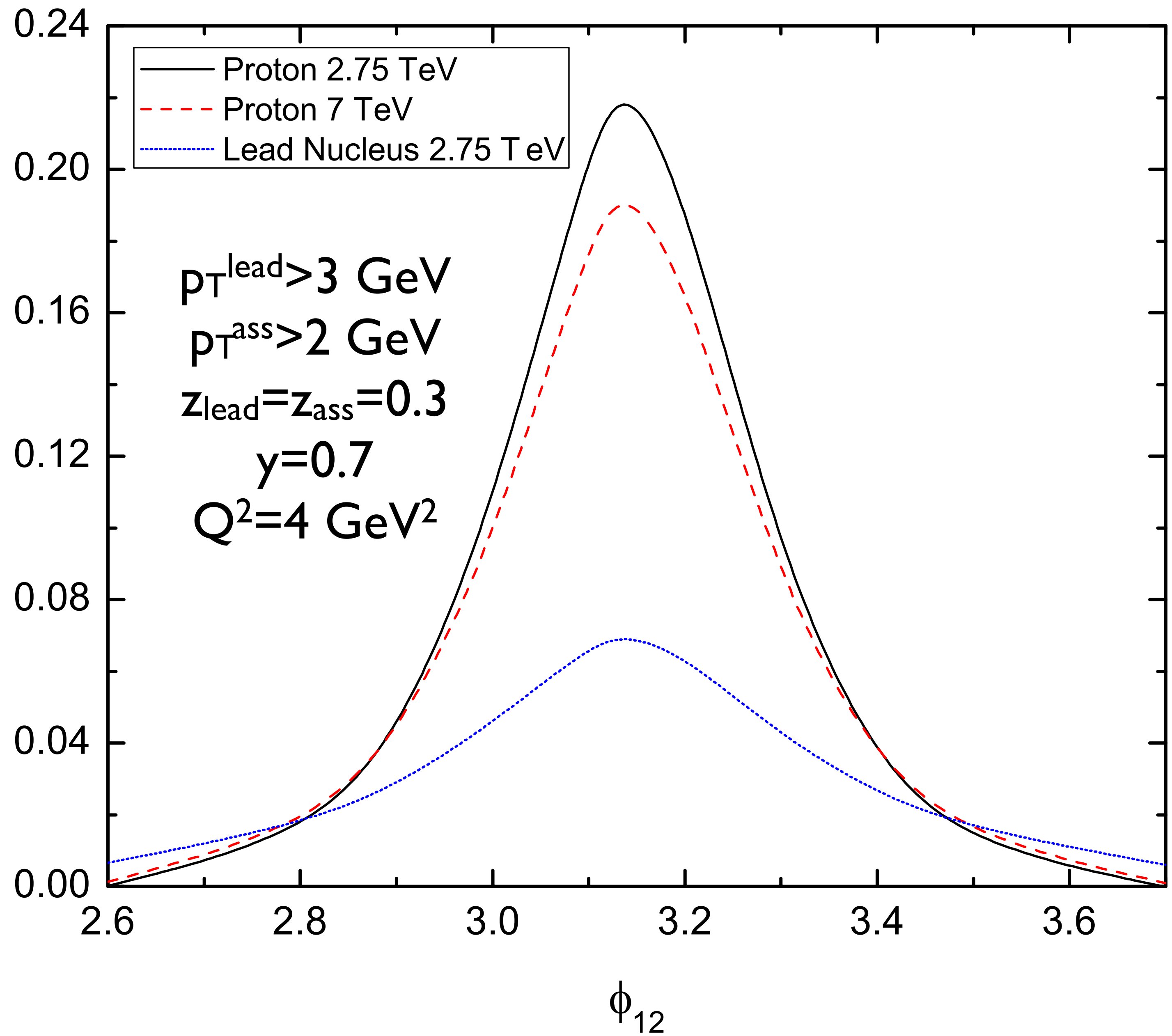
- Dihadron azimuthal decorrelation: currently discussed at RHIC as suggestive of saturation.



- At the LHeC it could be studied far from the kinematical limits.



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



Other aspects:

- Relation of diffraction and shadowing.
- t-differential studies in exclusive VM production.
- Jets in photoproduction.
- Hadronization and QCD radiation inside the nuclear medium.

Contents:

New nPDF studies:

- New pseudo data for $10^{-5}<x<1$, $2<Q^2<10^5$ GeV^2, P=-0.8, as reduced cross sections: new fits done (Hannu Paukkunen, Max and NA).

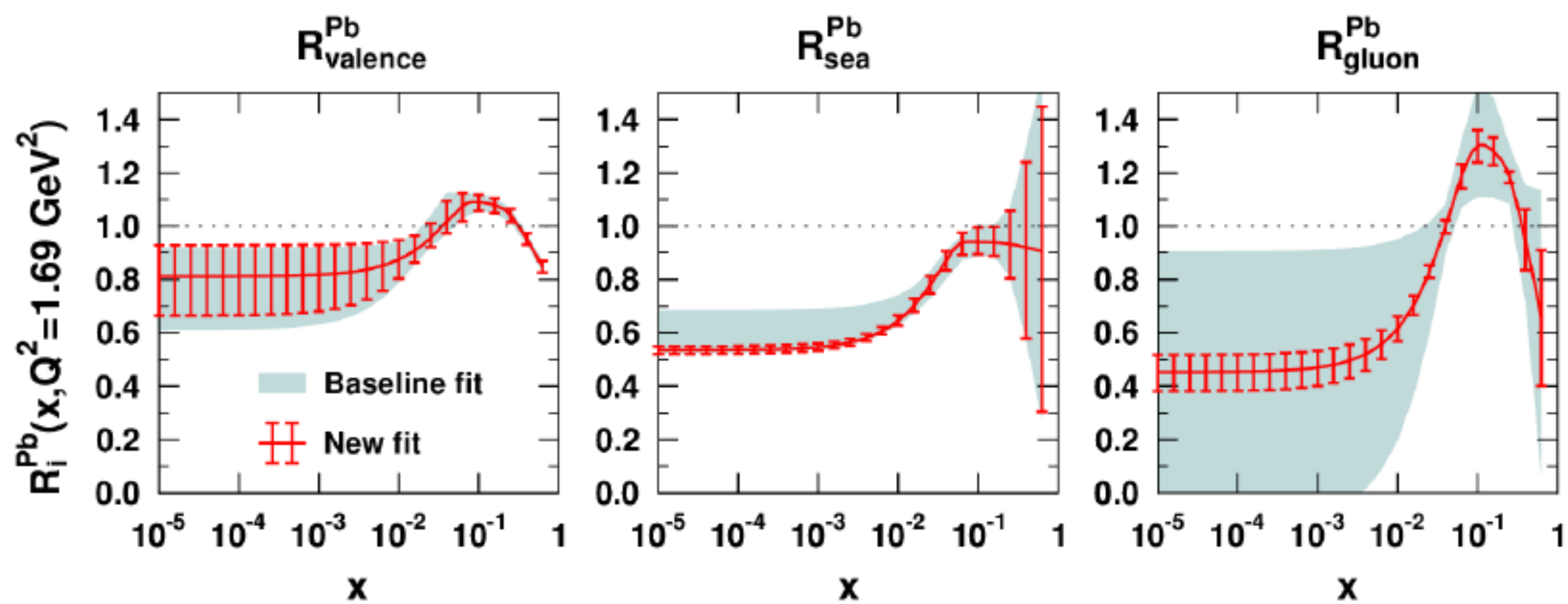
Ee (GeV)	Pol	Lumi (fb^{-1}) in ep		Lumi (fb^{-1}) in ePb	
		NC	CC	NC	CC
20	-0.8	0.03	0.03	0.03	0.03
26.9	-0.8	0.02	0.02	0.02	0.02
60	-0.8	1	1	1	1

- SACOT scheme → GM-VFNS.
- Only NC → CC+NC.
- Same parametrisation as in CDR → relax assumptions.
- No flavour decomposition → add it.
- Errors in quadrature → separate correlated ones.

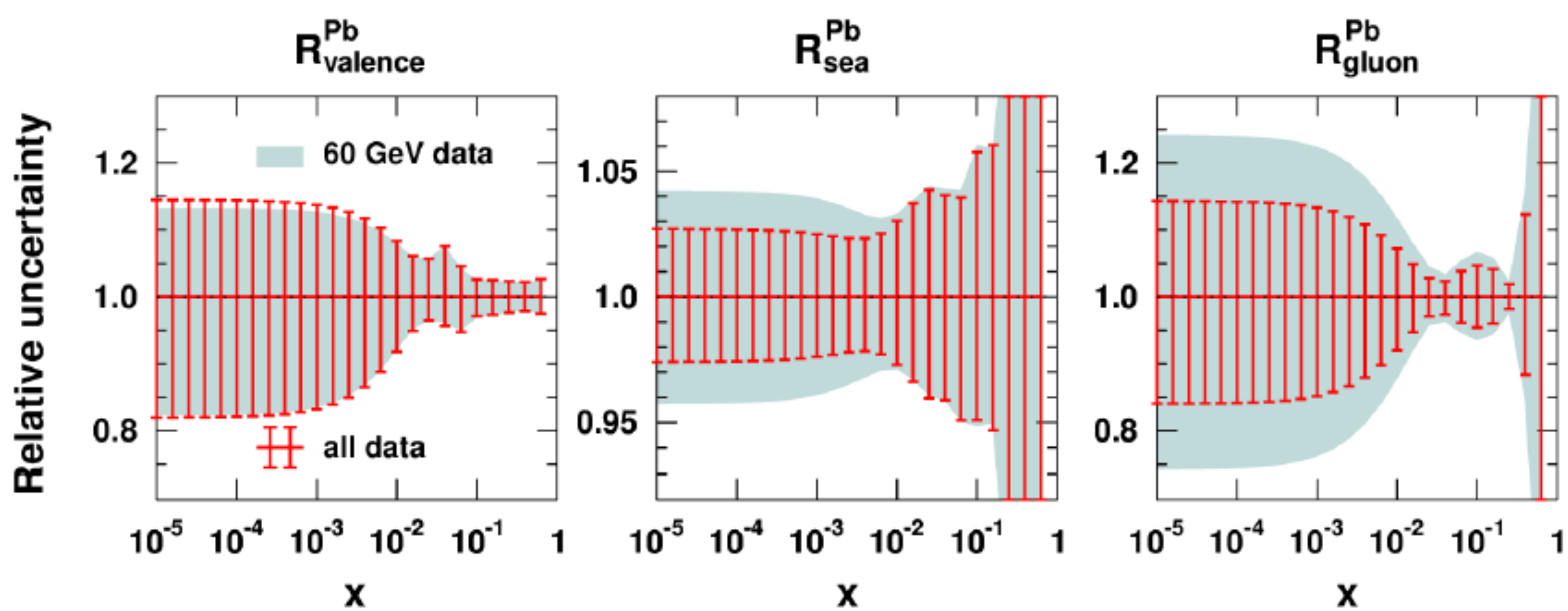
Part of this is doable for March 2015.

New nPDF studies:

- Include also the data from the E_{lepton} = 20GeV and E_{lepton} = 26.9GeV runs



- Relative uncertainties compared to the case with E_{lepton} = 60GeV data only



- Even larger reduction in the small-x uncertainties – though not dramatic

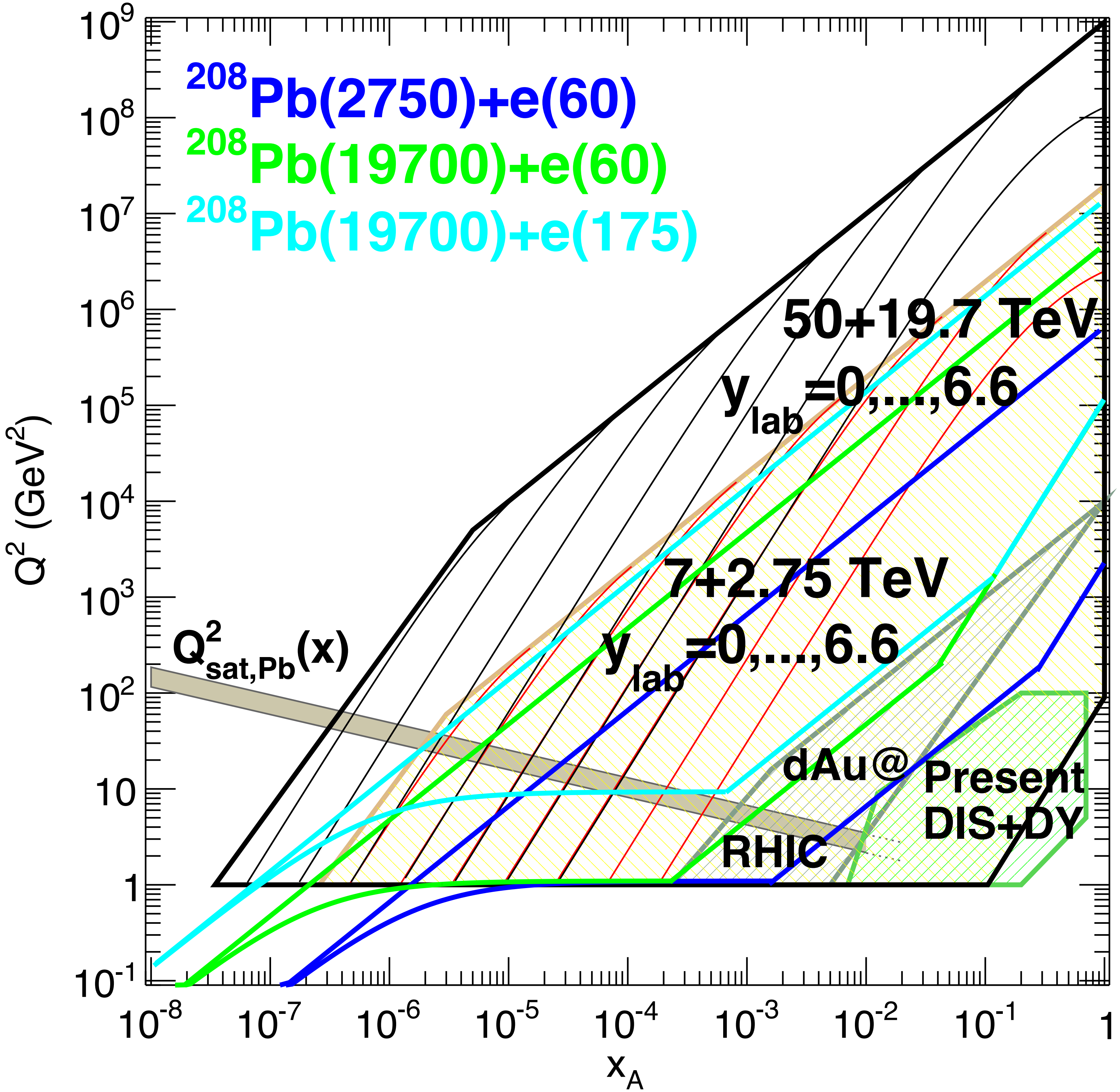
Longer term plans:

- Study the possibility of accommodating saturation effects (in ep and eA) within DGLAP fits using reweighting: with Hannu Paukkunen and a master student. It might be possible to have something for the white paper.

- Elastic VM production in eA: refined predictions (with Amir Rezaeian) possibilities for distinguishing coherent from incoherent diffraction (detector, EIC people).

- Monte Carlo for eA (with Paul, HPH2020 proposal - little money).

FCC-he:



- Repeat LHeC studies for larger energy: no major surprises to be expected.

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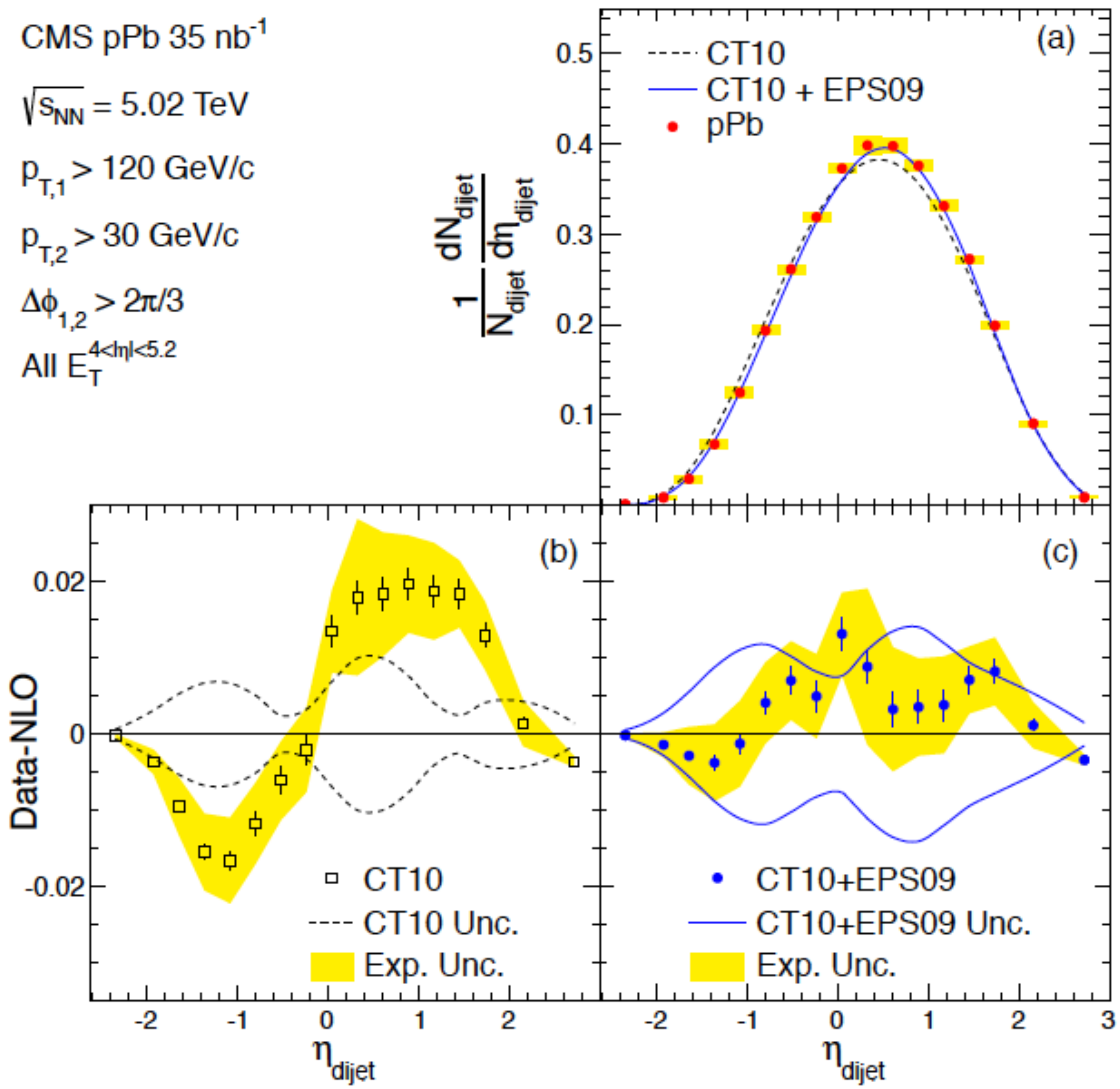
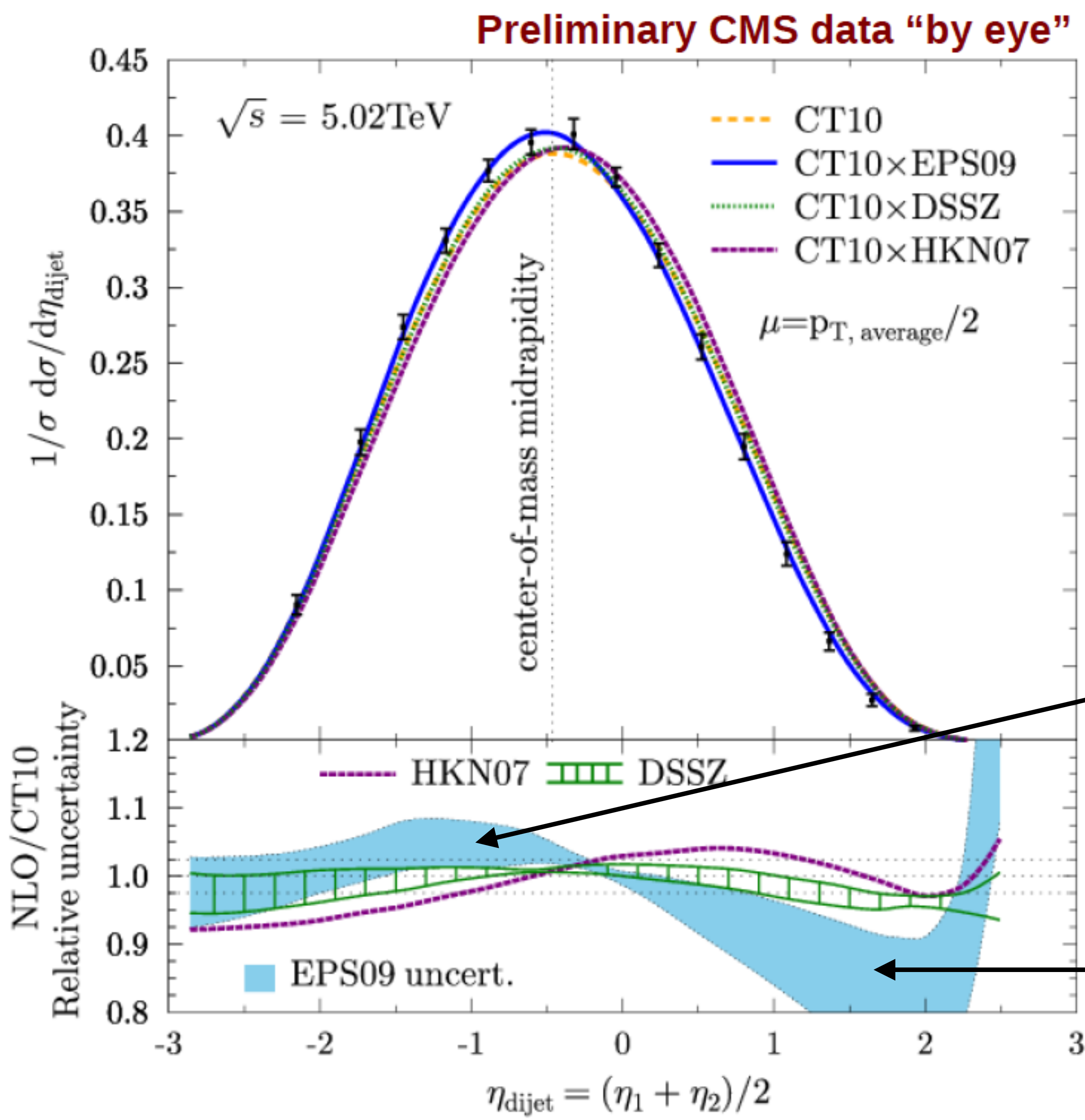
nPDFs:

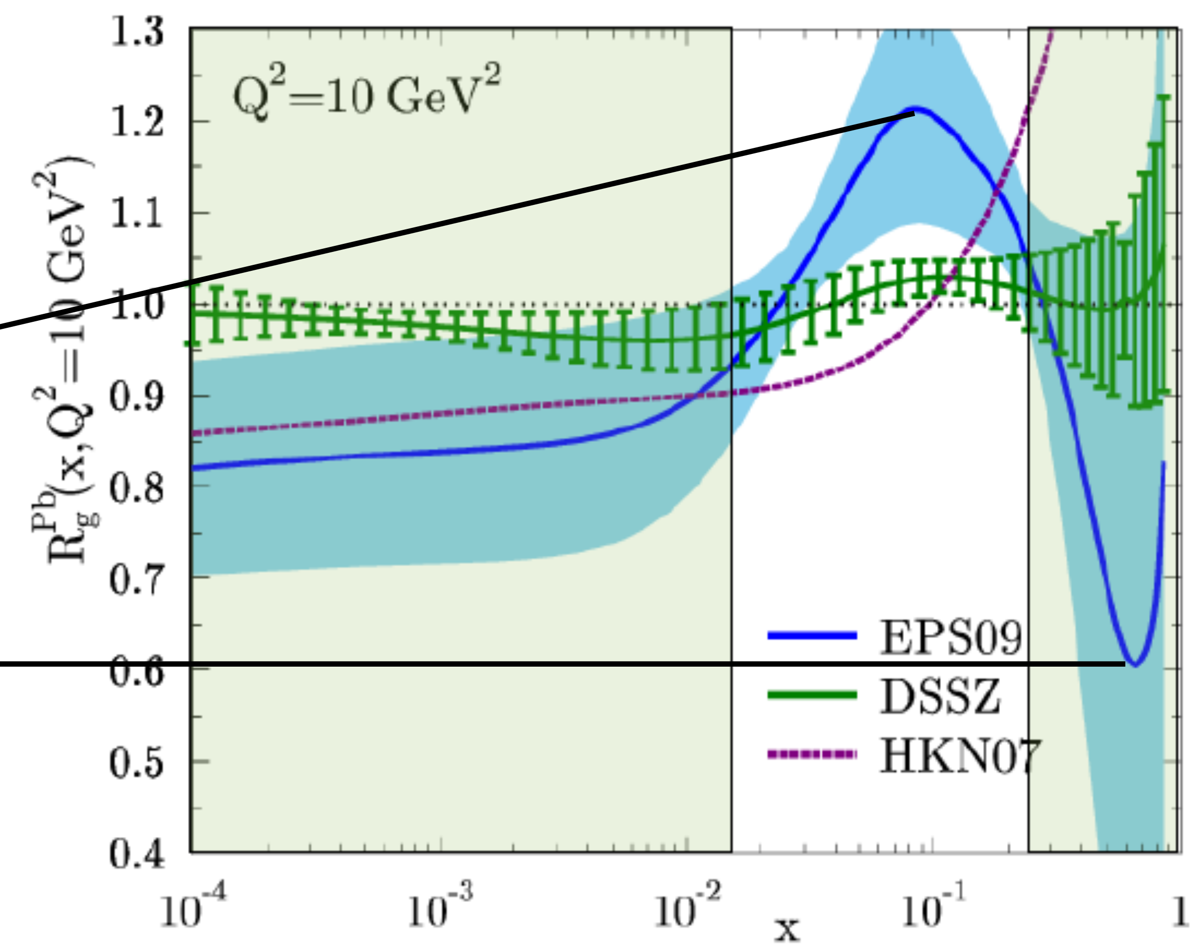


- CMS dijets to substitute neutral pion data from RHIC (which may contain hadronisation effects).

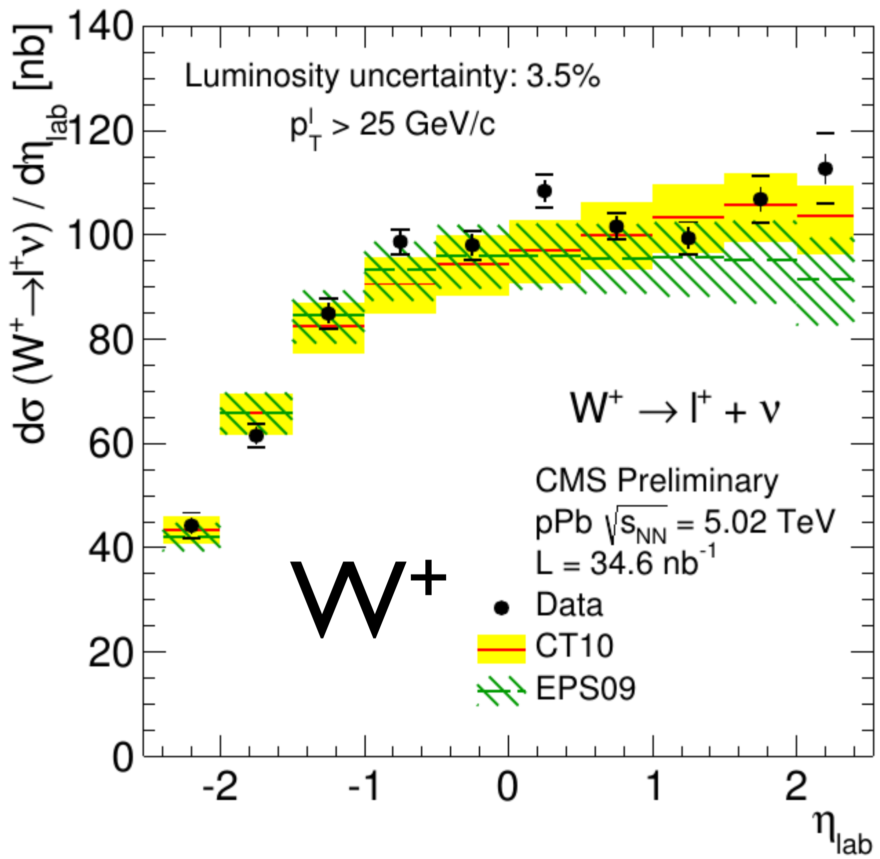
nPDFs: dijets

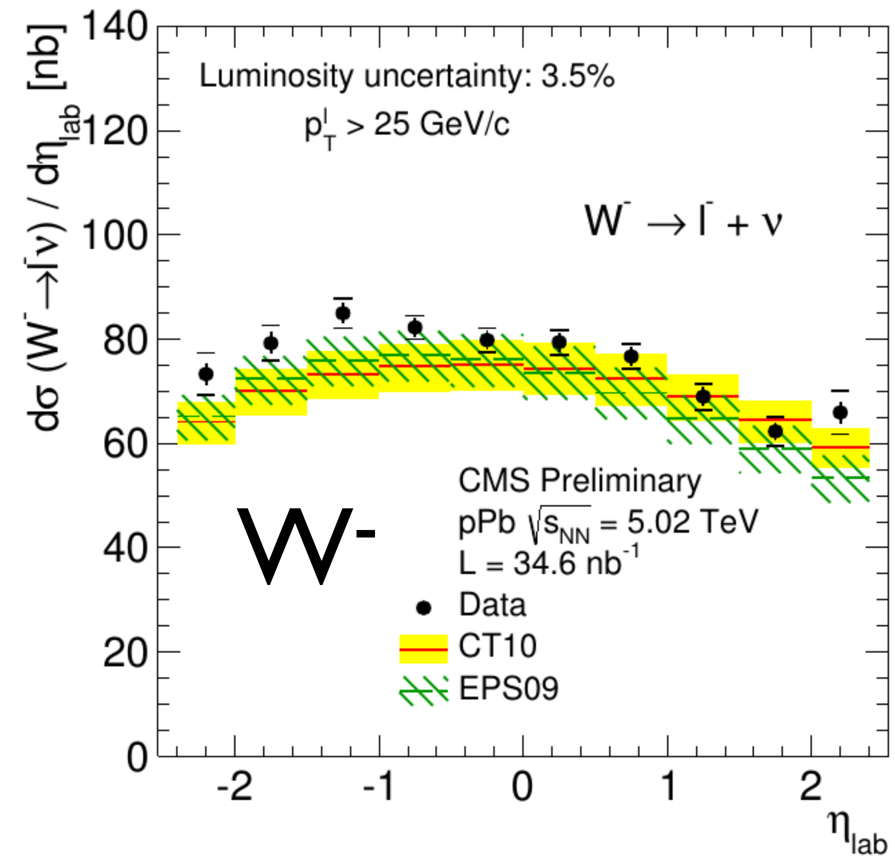


- CMS dijets to substitute neutral pion data from RHIC (which may contain hadronisation effects).



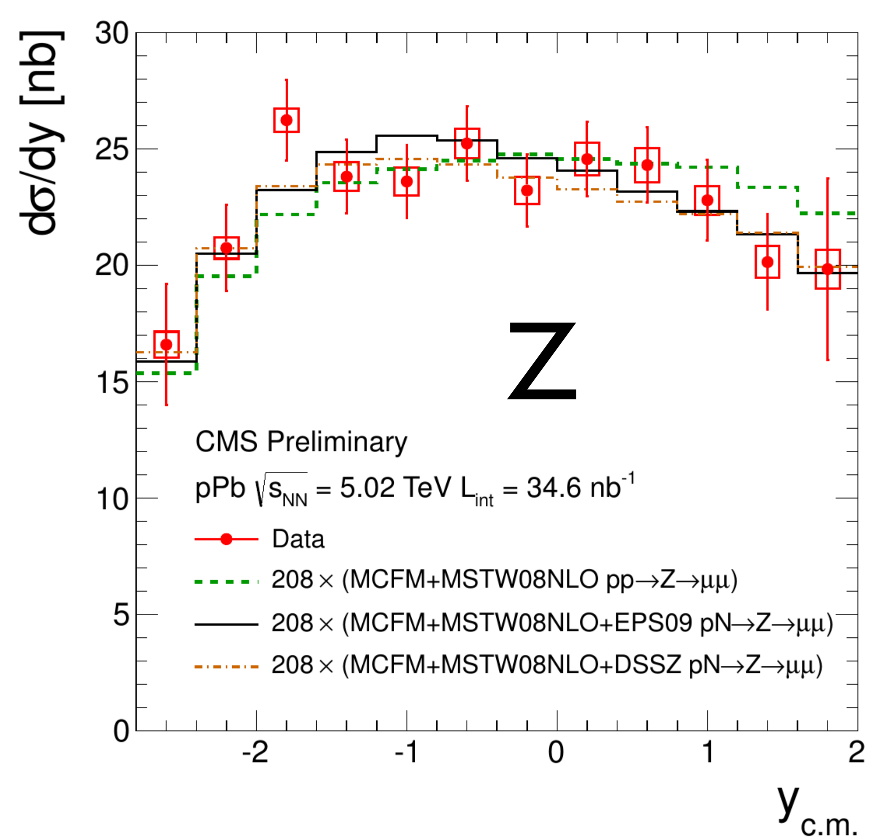
nPDFs: EW bosons



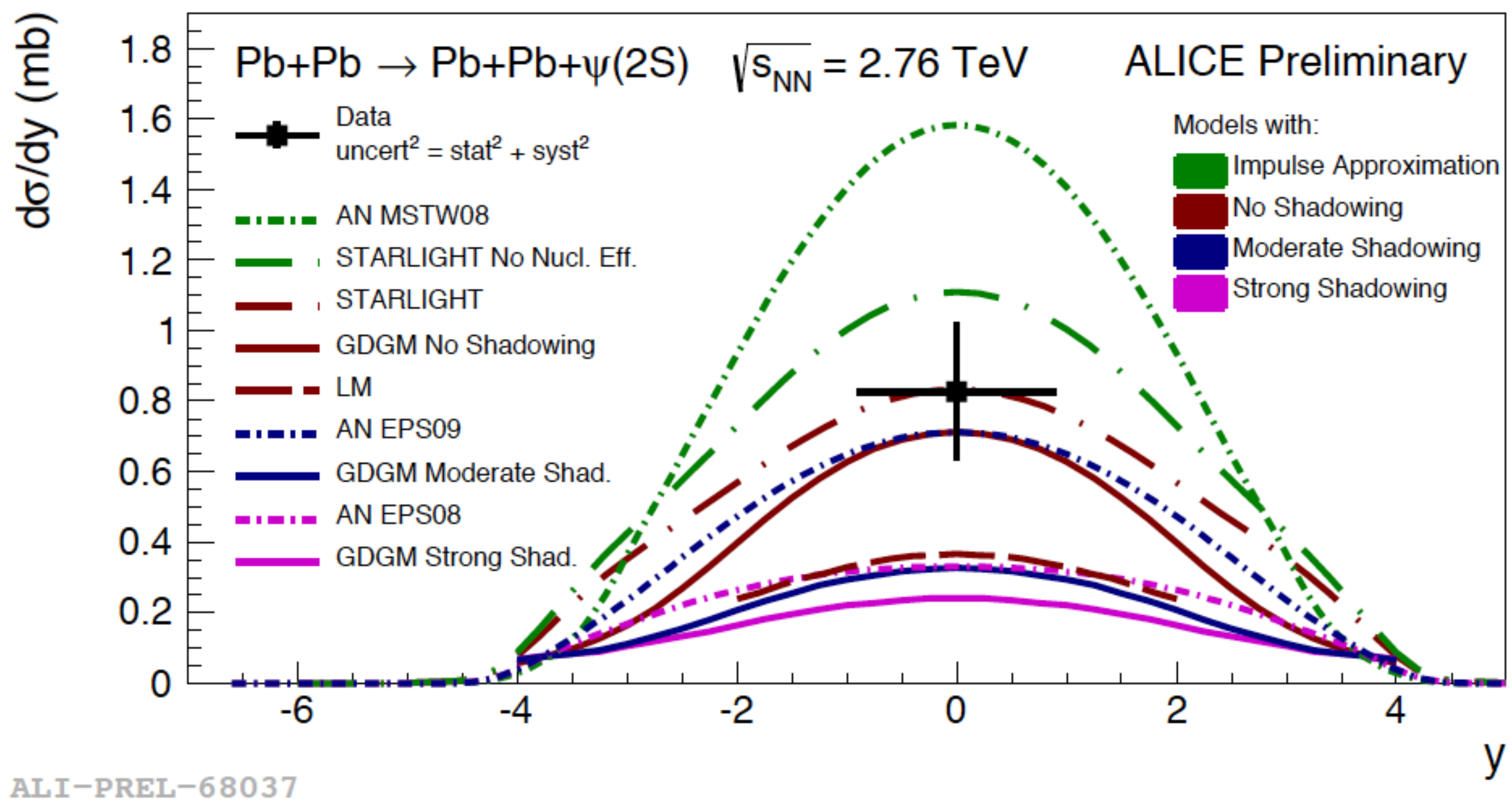


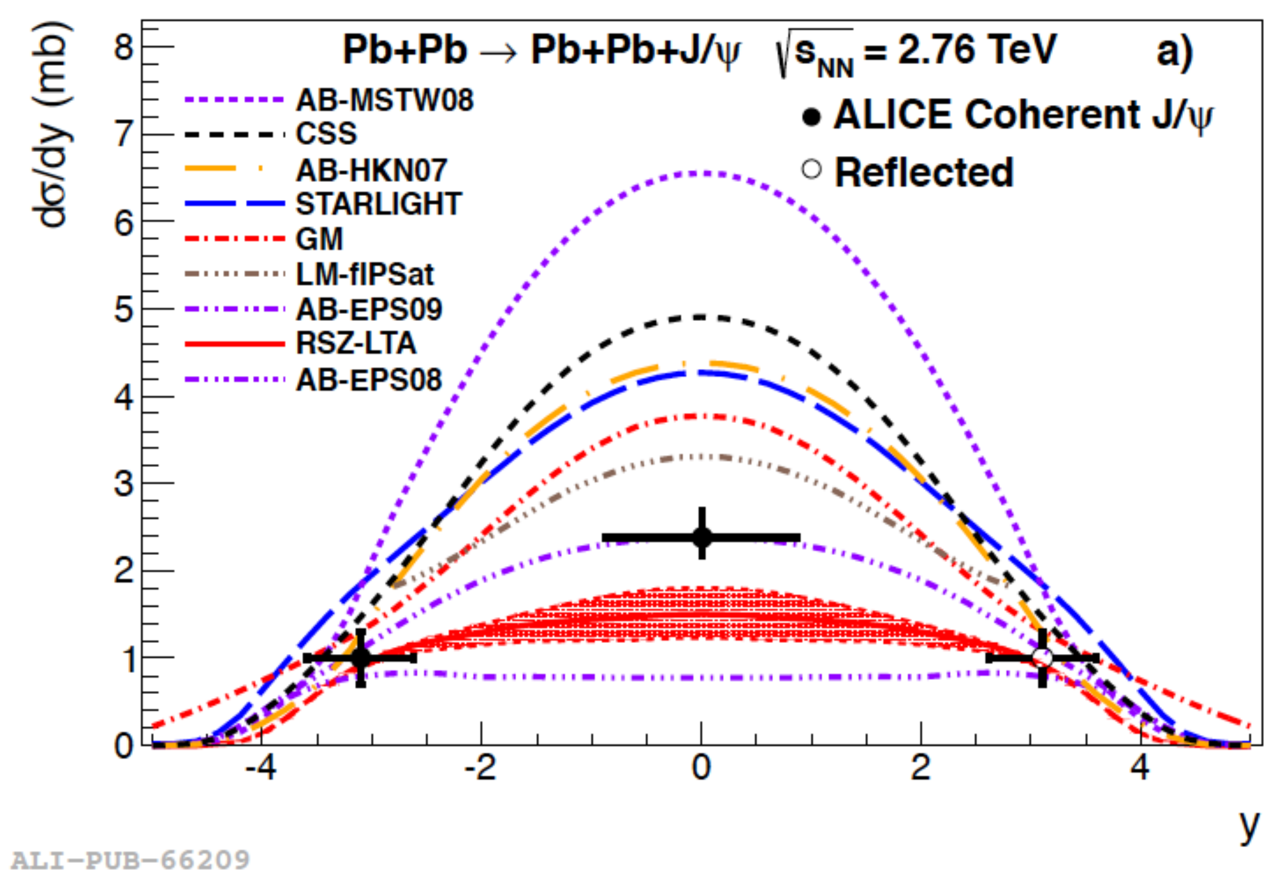
- EW bosons used to test factorisation in pA/AA, and offer some constrain to nPDFs (e.g. u/d).

- Statistics is crucial.



nPDFs: UPCs in PbPb

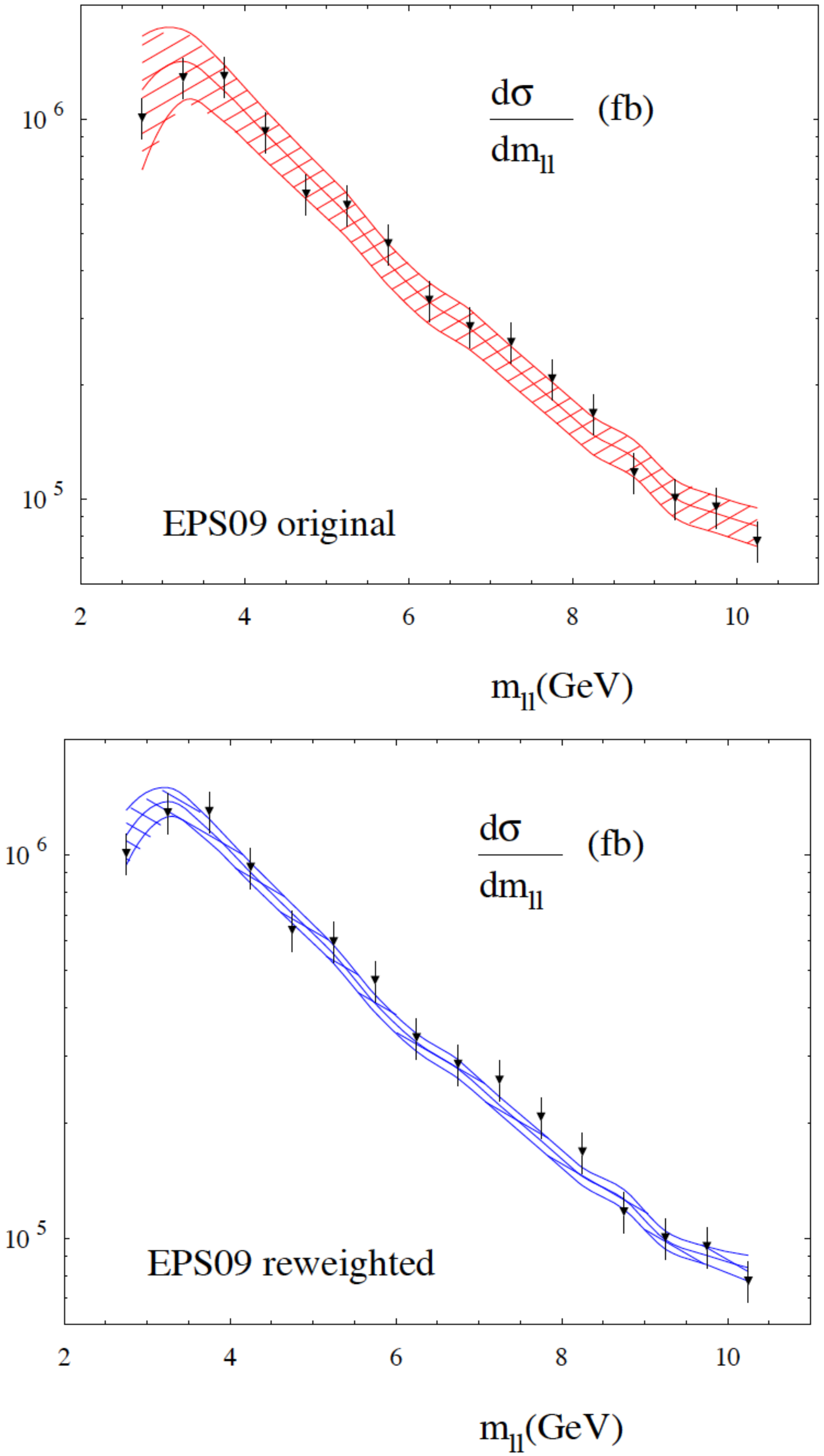


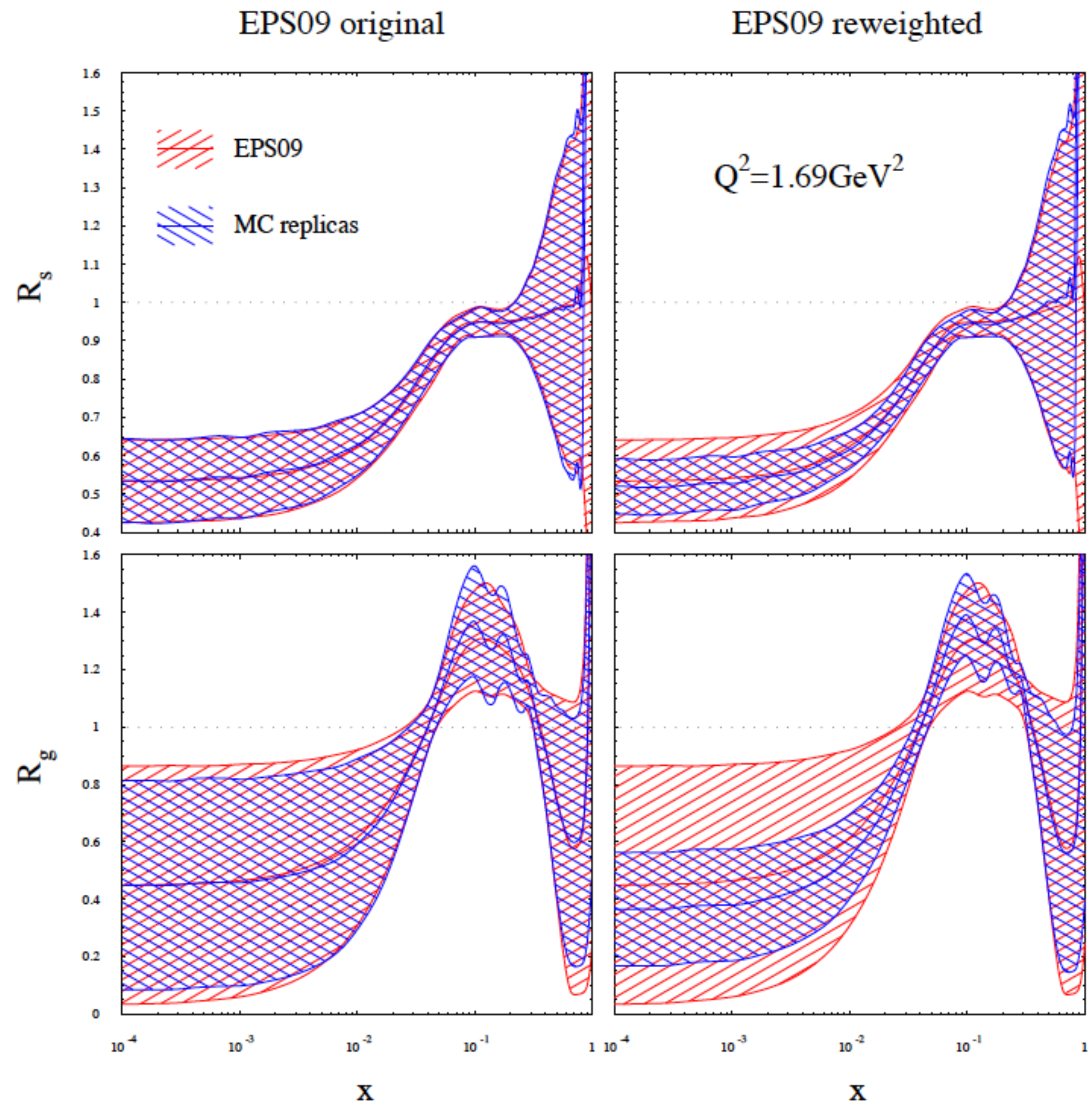


- Photon flux from on Pb can be used to study nPDFs on the other Pb.

- Large modelling inside - as for the proton.

nPDFs: DY in pPb@LHC





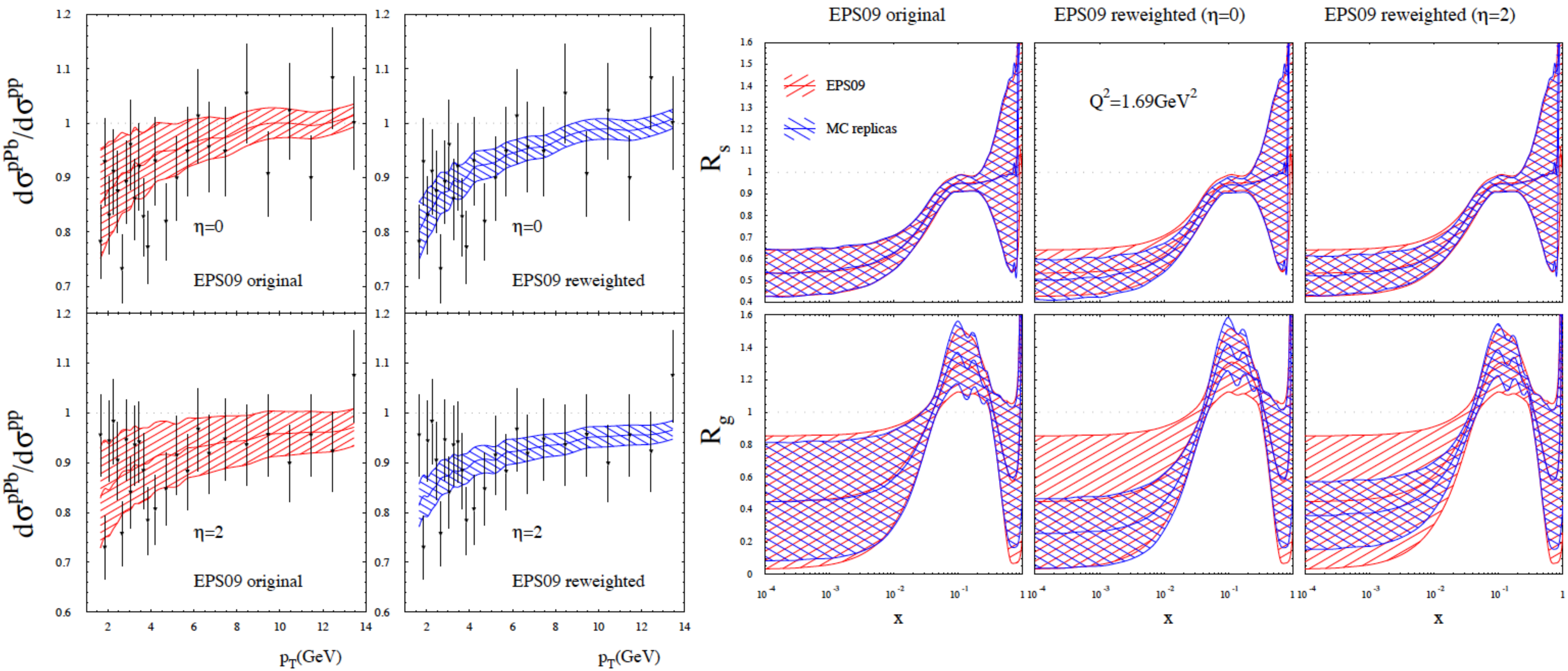
- Note: this is constrained by the shape of the nPDFs. And we were optimistic about data.
- Effect on sea and glue.

1309.5371

nPDFs: charged in pPb@LHC

1309.5371

'DGLAP' (linear) pseudodata



- Note: this is constrained by the shape of the nPDFs.
- Reduction of uncertainties around a factor 2 for glue.
- Tension may appear for some scenarios.

nPDFs: charged in pPb@LHC

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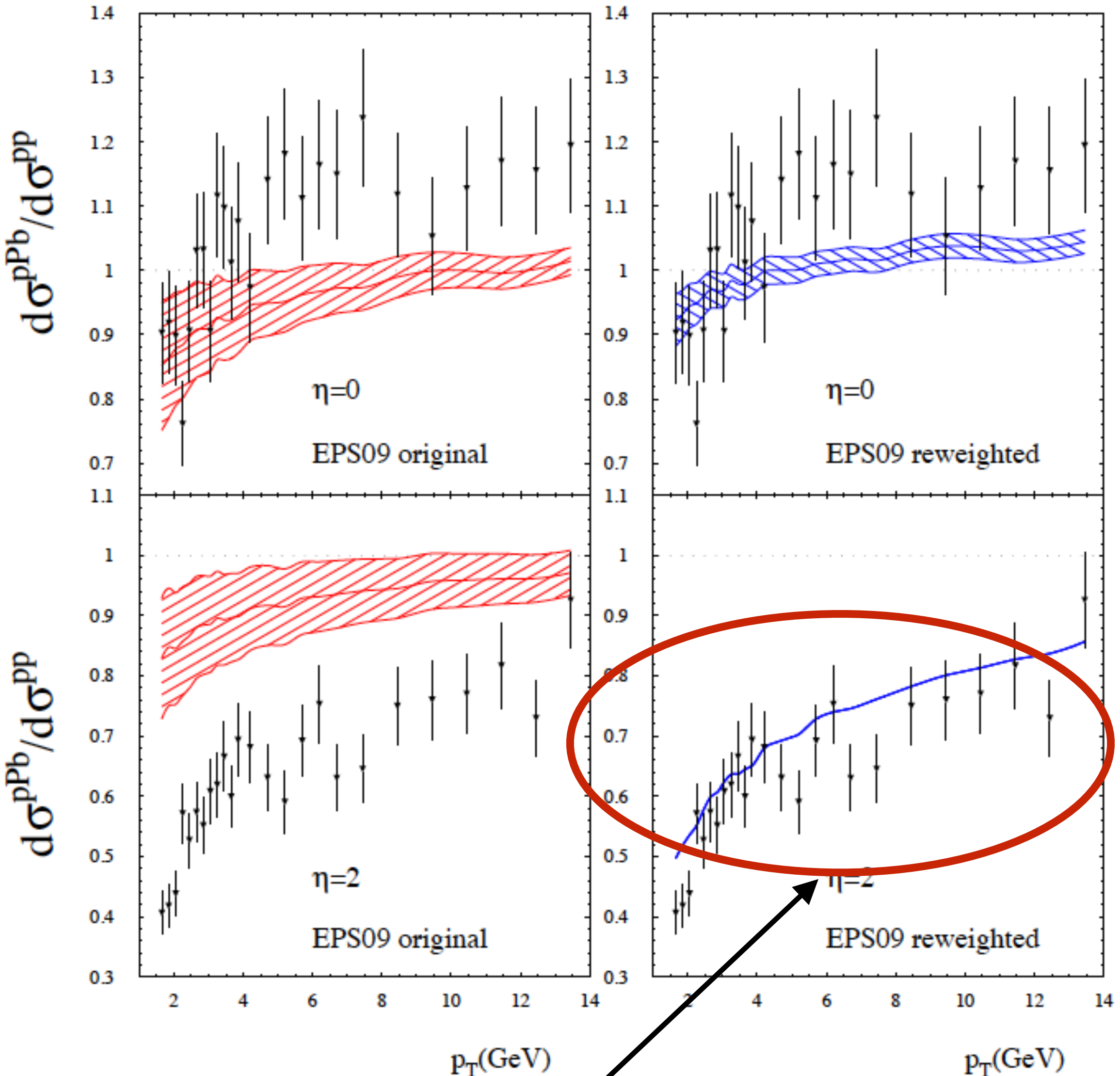
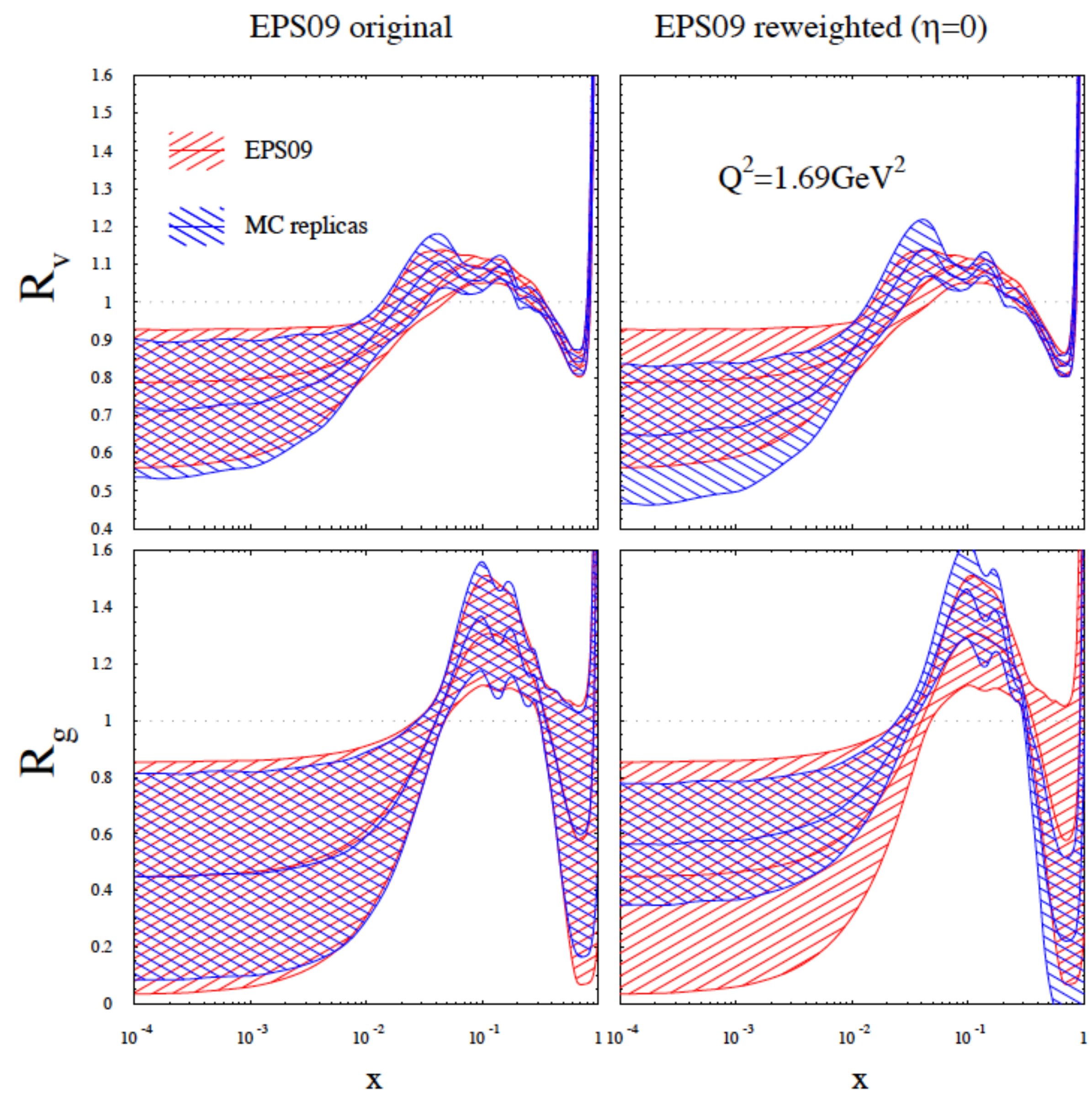
'CGC' (saturation) pseudodata





- Note: this is constrained by the shape of the nPDFs.
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nPDFs: charged in pPb@LHC

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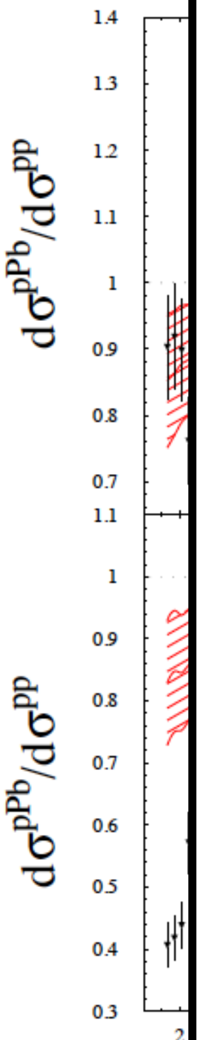


- Constrains to nPDFs at moderate /large x are to appear.

- Constrains to nPDFs at small x are problematic: use of small p_T data for benchmarking dubious as probably there are collective effects in pPb@LHC (breakdown of factorisation).

- The same holds for the search of non-linear dynamics at small x.

- UPC data will offer some constrains for nPDFs, but they are limited by statistics and, above all, for the theoretical modelling required.

- No
- Re
- Tension may appear for some scenarios.

Manpower:

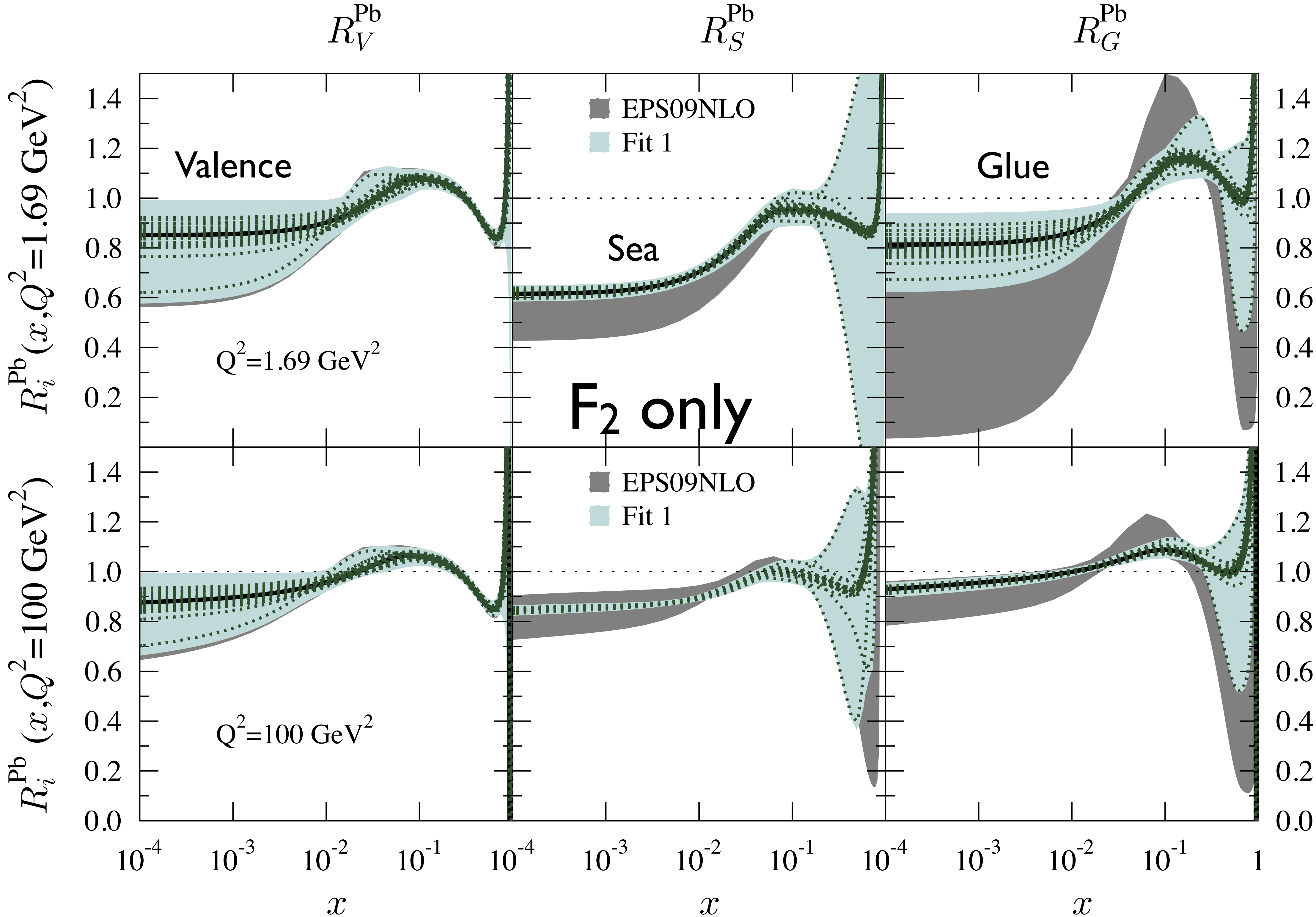
- The bottleneck of the plan is manpower, to linked to some extent to financial support but also to scientific policy.
- Manpower:
  - ➜ Hannu Paukkunen and some master student for nPDF/small x studies.
  - ➜ Amir Rezaeian for VM production.
  - ➜ Paul, master students for diffraction and eA Monte Carlo plus collaborations with EIC people.
- Financial resources:
  - ➜ 20 KEUR from HPH2020 (hopefully…) for a PhD student.
  - ➜ What we can take from our own grants, when possible.
  - ➜ Applications for ERC grants.
  - ➜ CERN?
- Some HI people has recent shown strong interest 👍, but probably not much to offer as they are really busy.
- ***Link LHeC studies to those at the LHC to attract people!!!***

Backup:

Nuclear PDFs at small x:

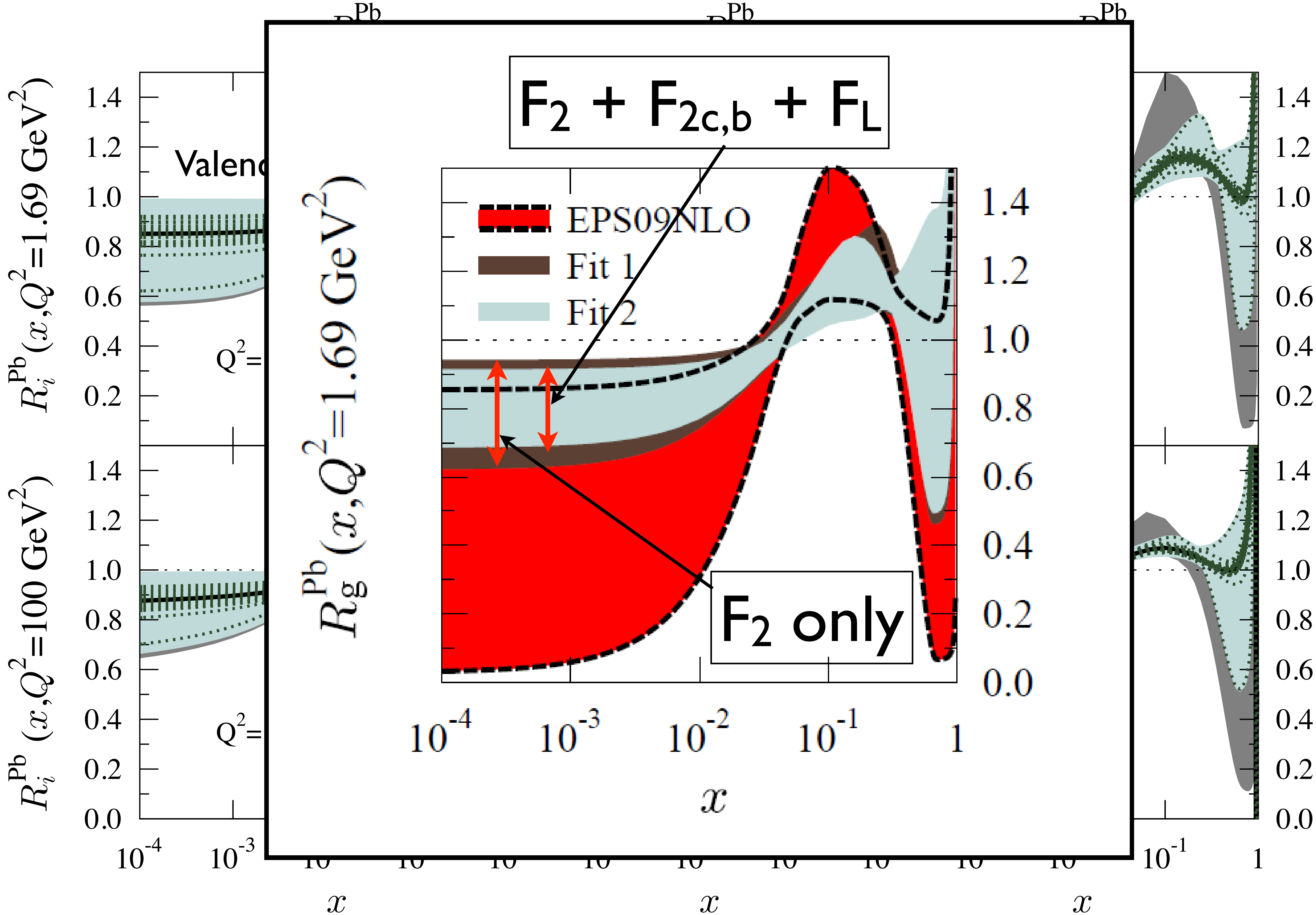
- F$_2$ data substantially reduce the uncertainties in DGLAP analysis;

inclusion of charm, beauty and F$_L$ also give constraints.

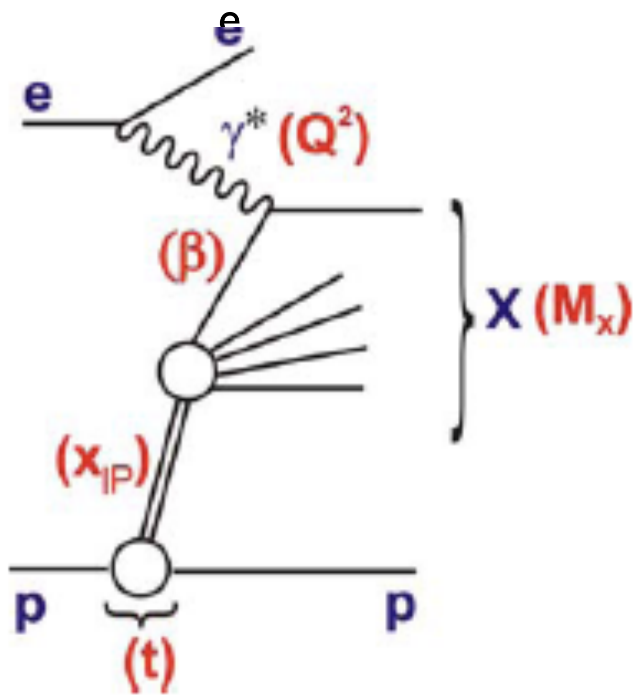


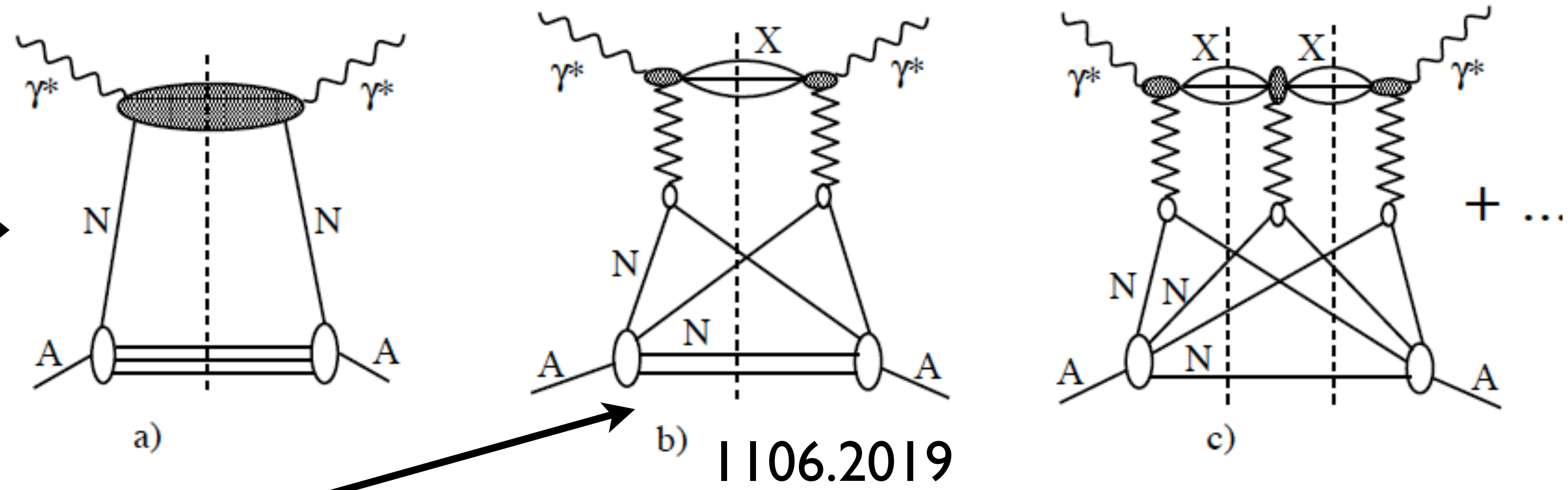
Nuclear PDFs at small x:

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

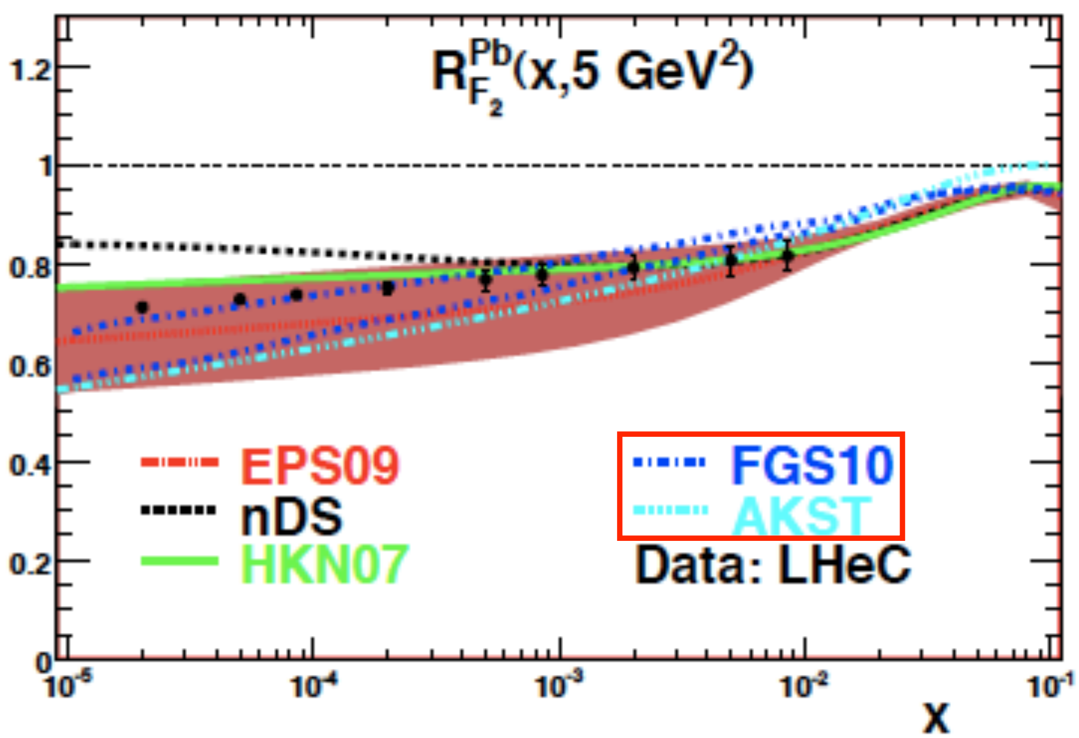


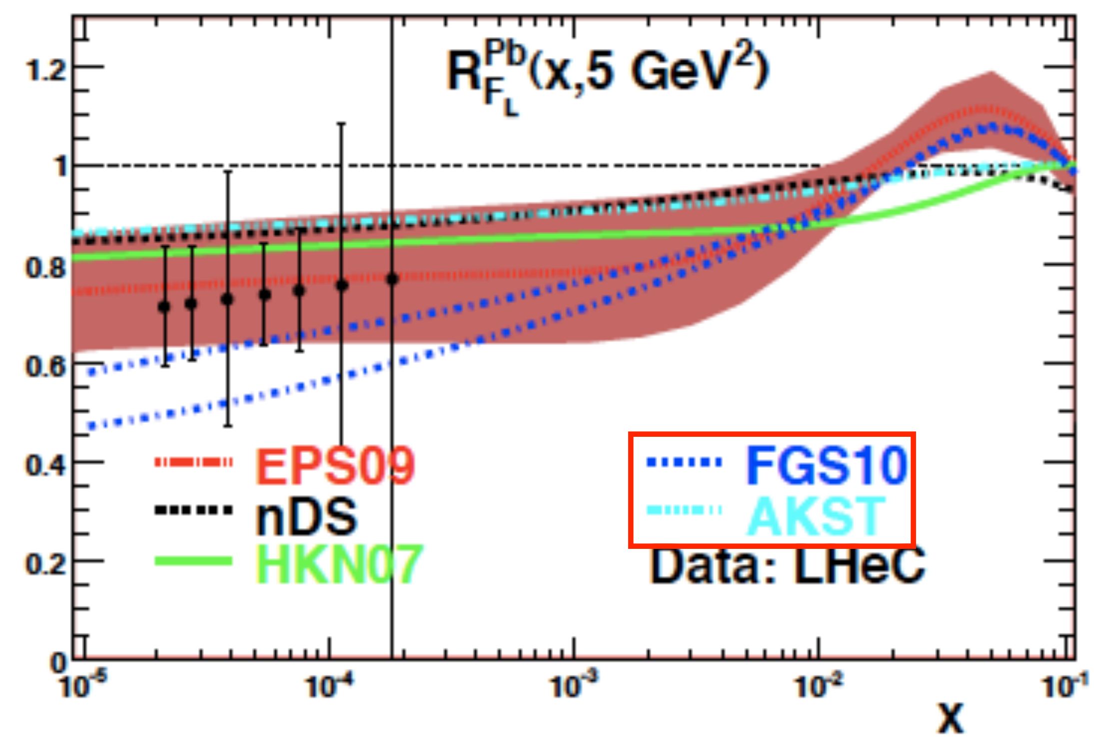
Diffraction in ep and shadowing:





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

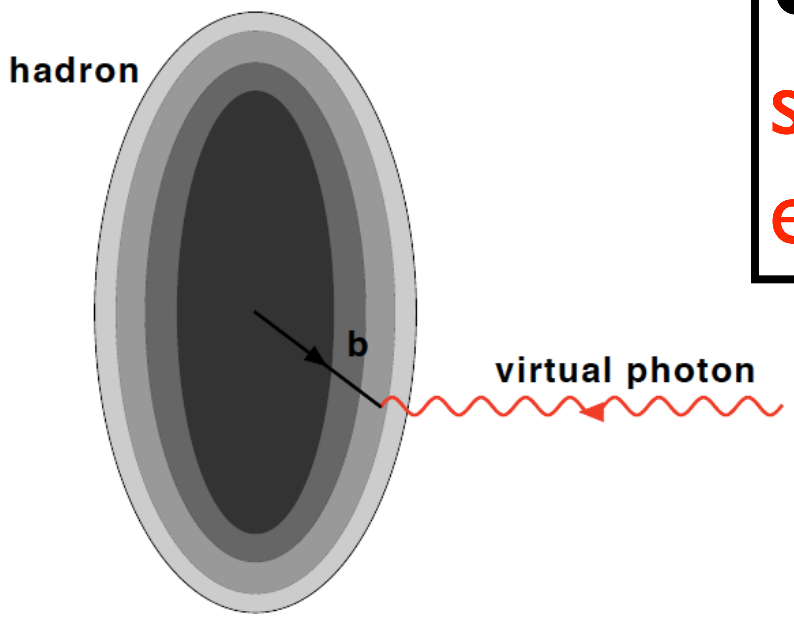




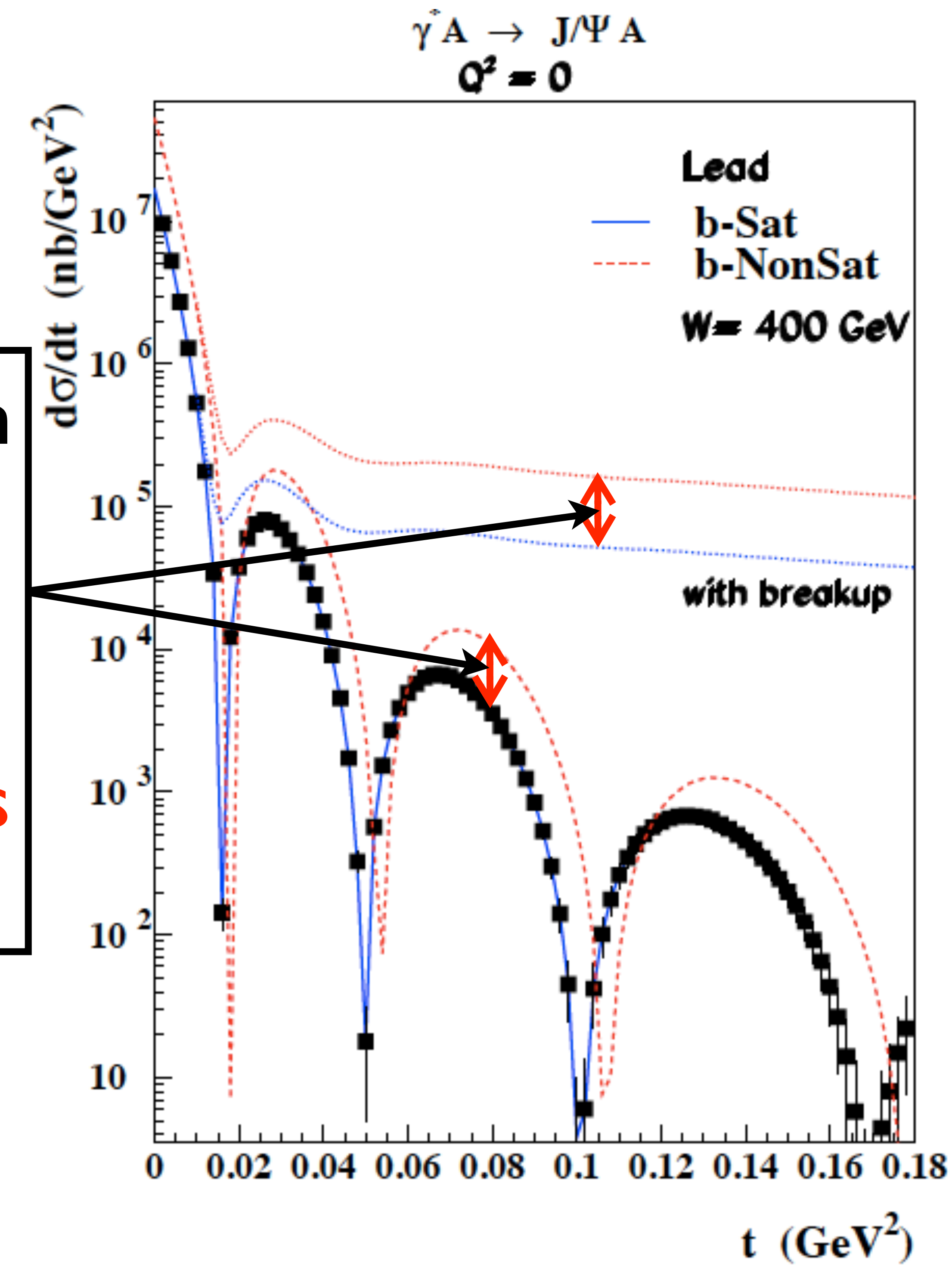
eA: 1. CDR.

Transverse scan: elastic VM

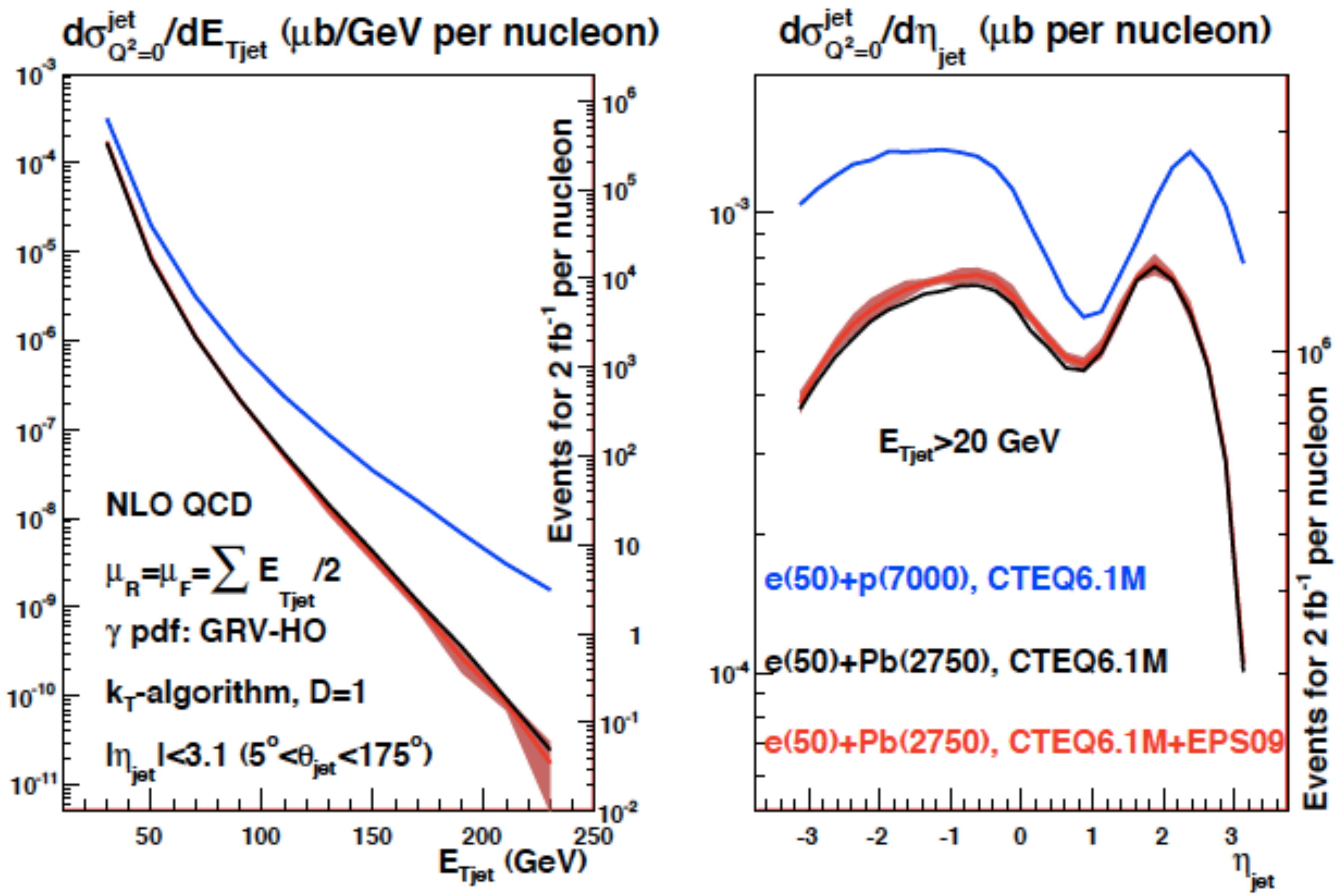
- t-differential measurements give a gluon tranverse mapping of the hadron/nucleus.



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



Jets:



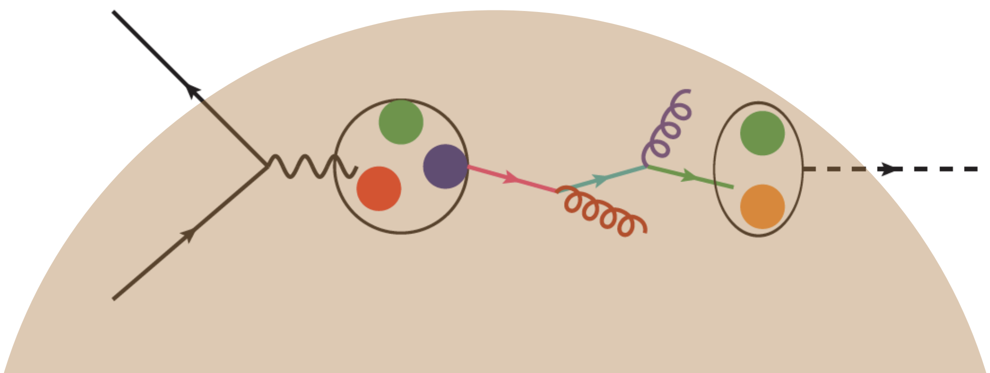
- Jets: large E_T even in eA.
- Useful for studies of parton dynamics in nuclei (hard probes), and for photon structure.
- Background subtraction, detailed reconstruction pending.

Radiation and hadronization:

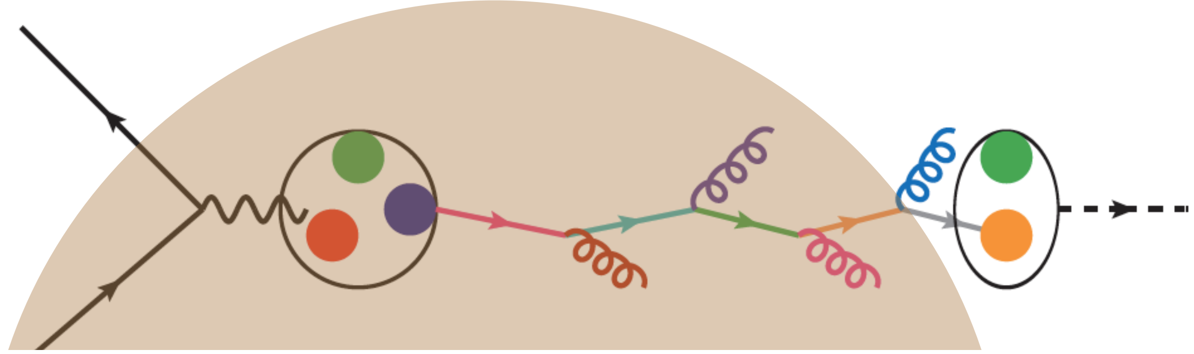
- LHeC: dynamics of QCD radiation and hadronization.
- Most relevant for particle production off nuclei and for QGP analysis in HIC.

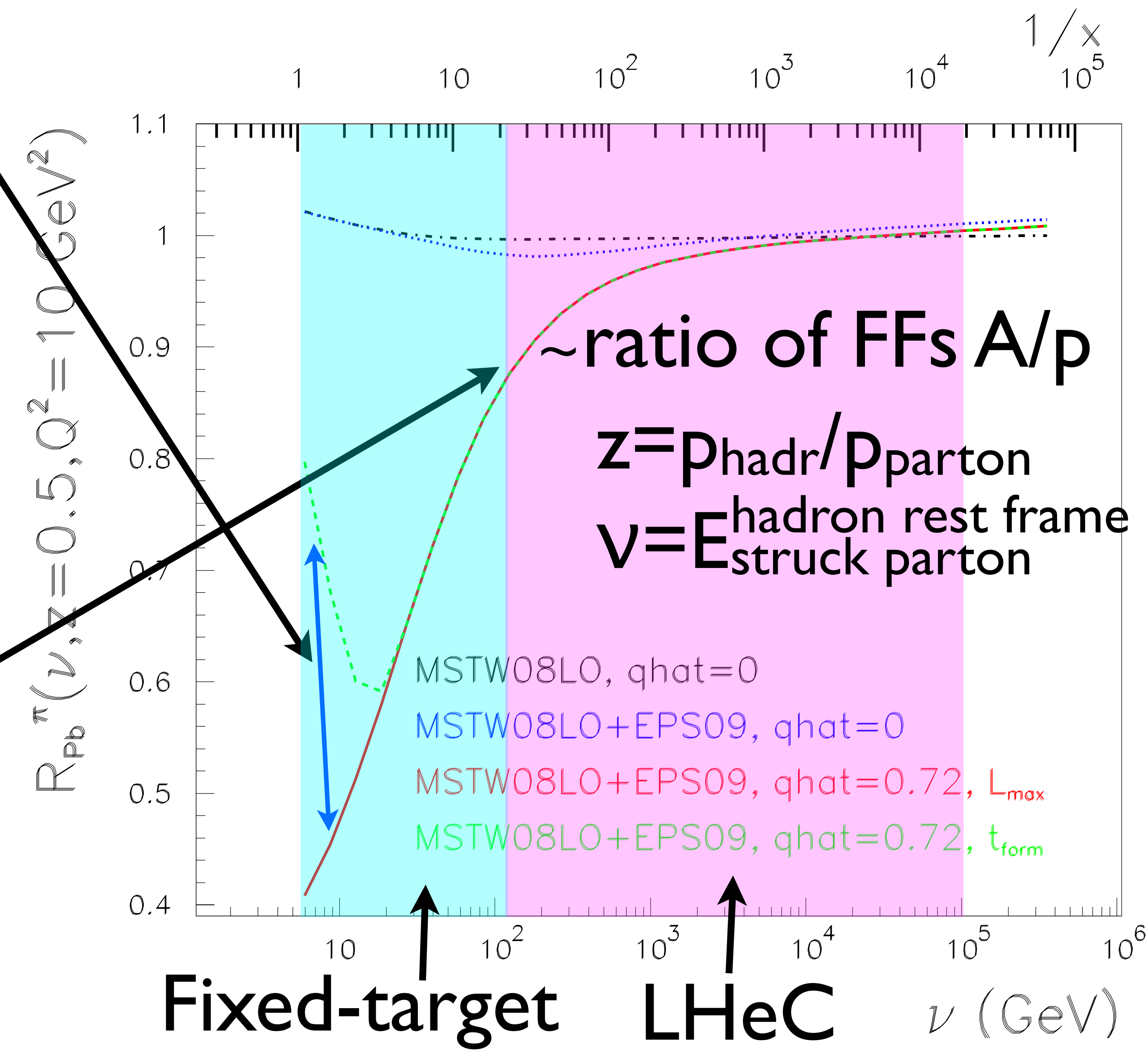
$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{dN_A^h(z,\nu)}{d\nu\, dz} \Bigg/ \frac{1}{N_D^e}\frac{dN_D^h(z,\nu)}{d\nu\, dz}$$

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



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





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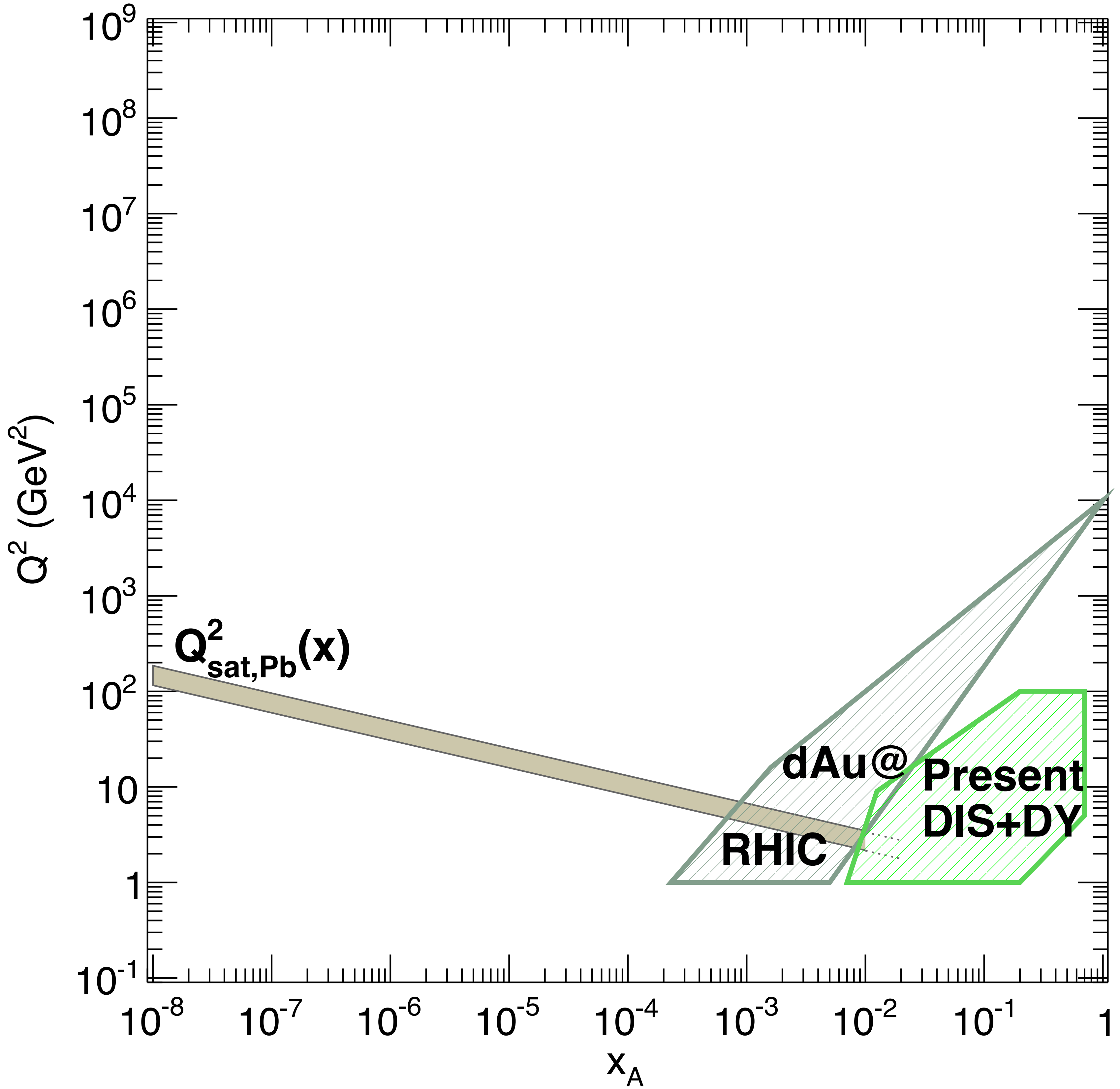
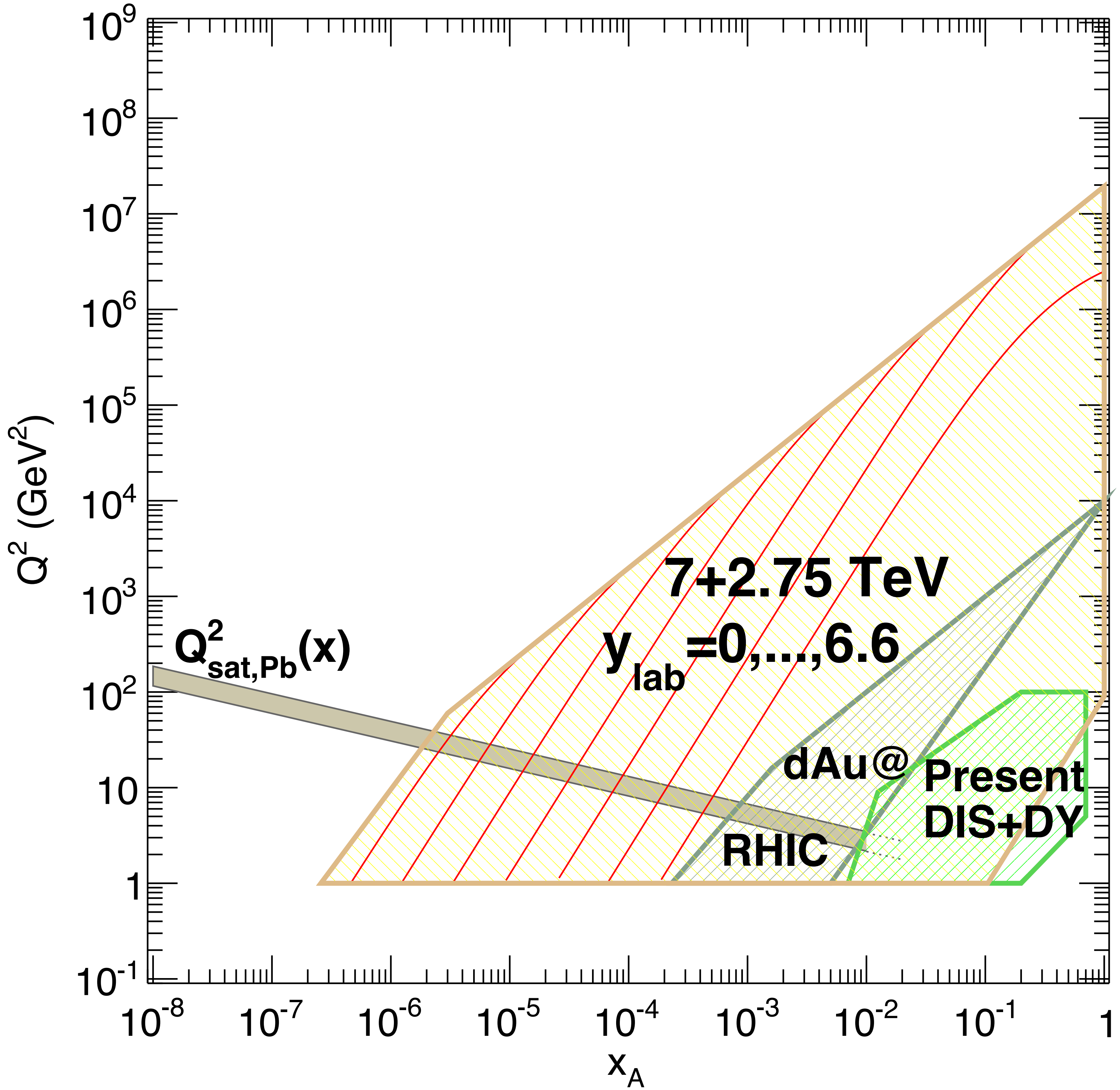
Kinematics:



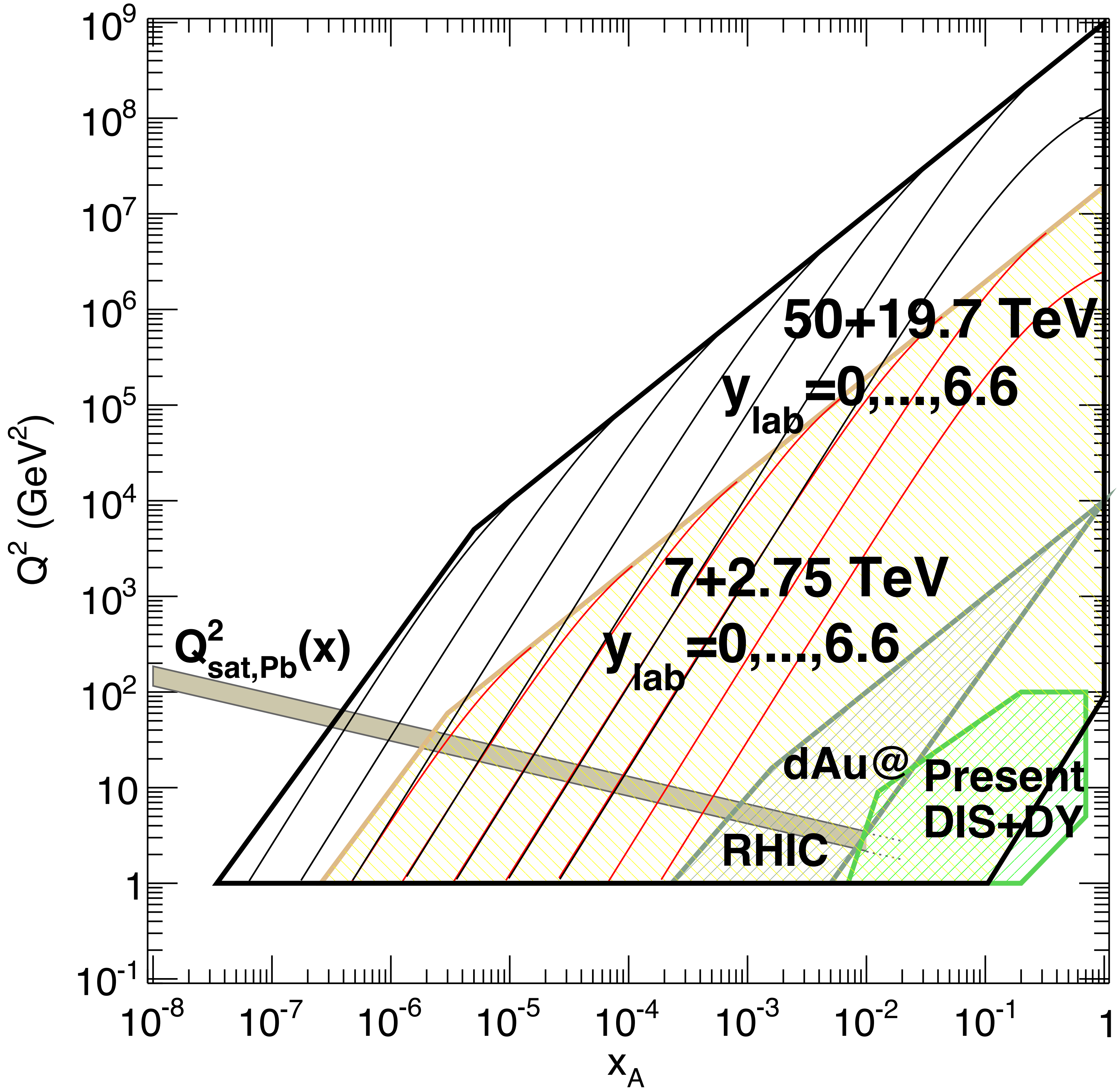
Q^2 (GeV^2)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x_A
$Q^2_{sat,Pb}(x)$
dAu@
RHIC
Present
DIS+DY

Kinematics:



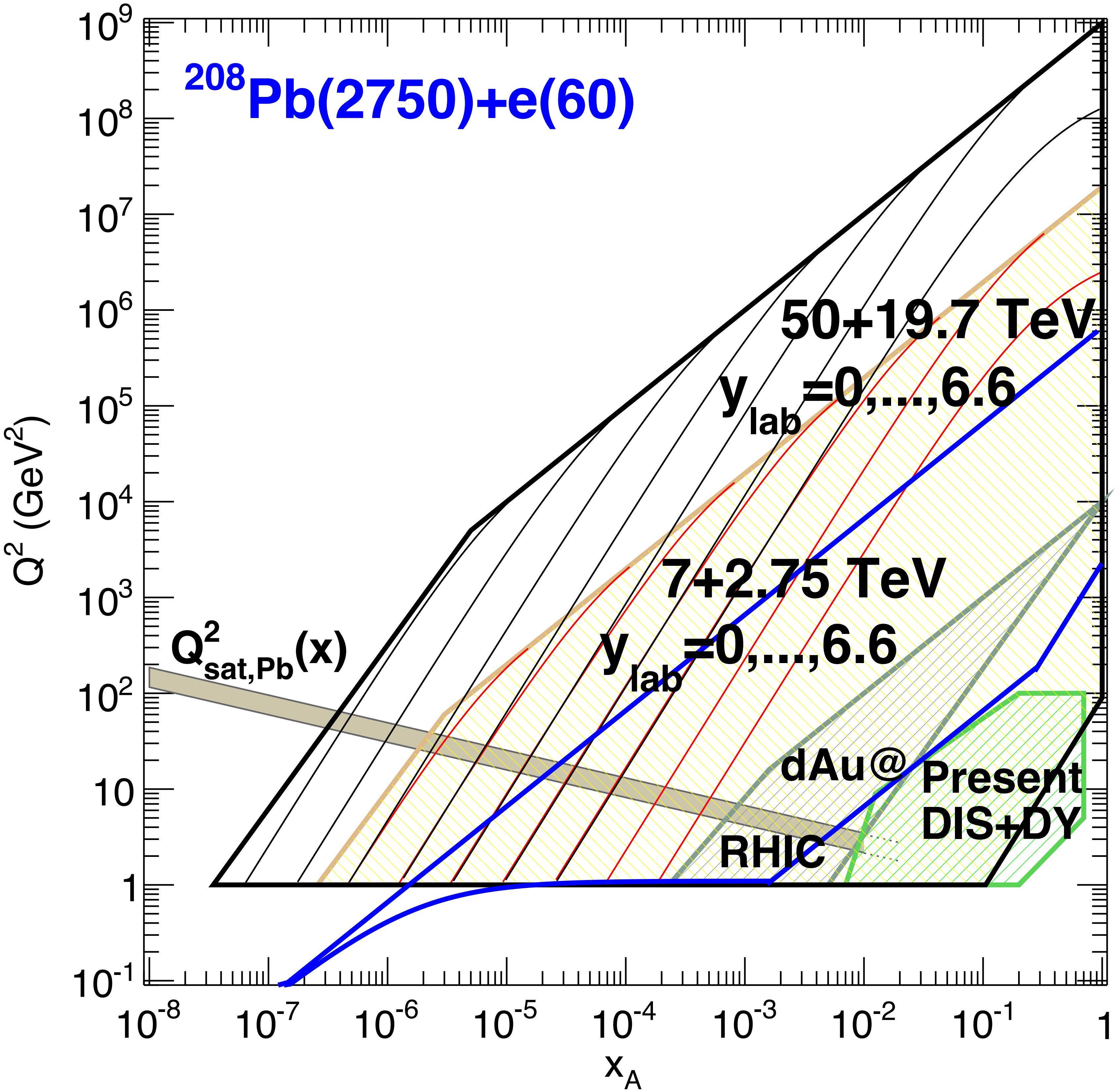
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
Q^2 (GeV^2)
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x_A
$Q^2_{sat,Pb}(x)$
7+2.75 TeV
y_{lab}=0,...,6.6
dAu@
RHIC
Present
DIS+DY

Kinematics:



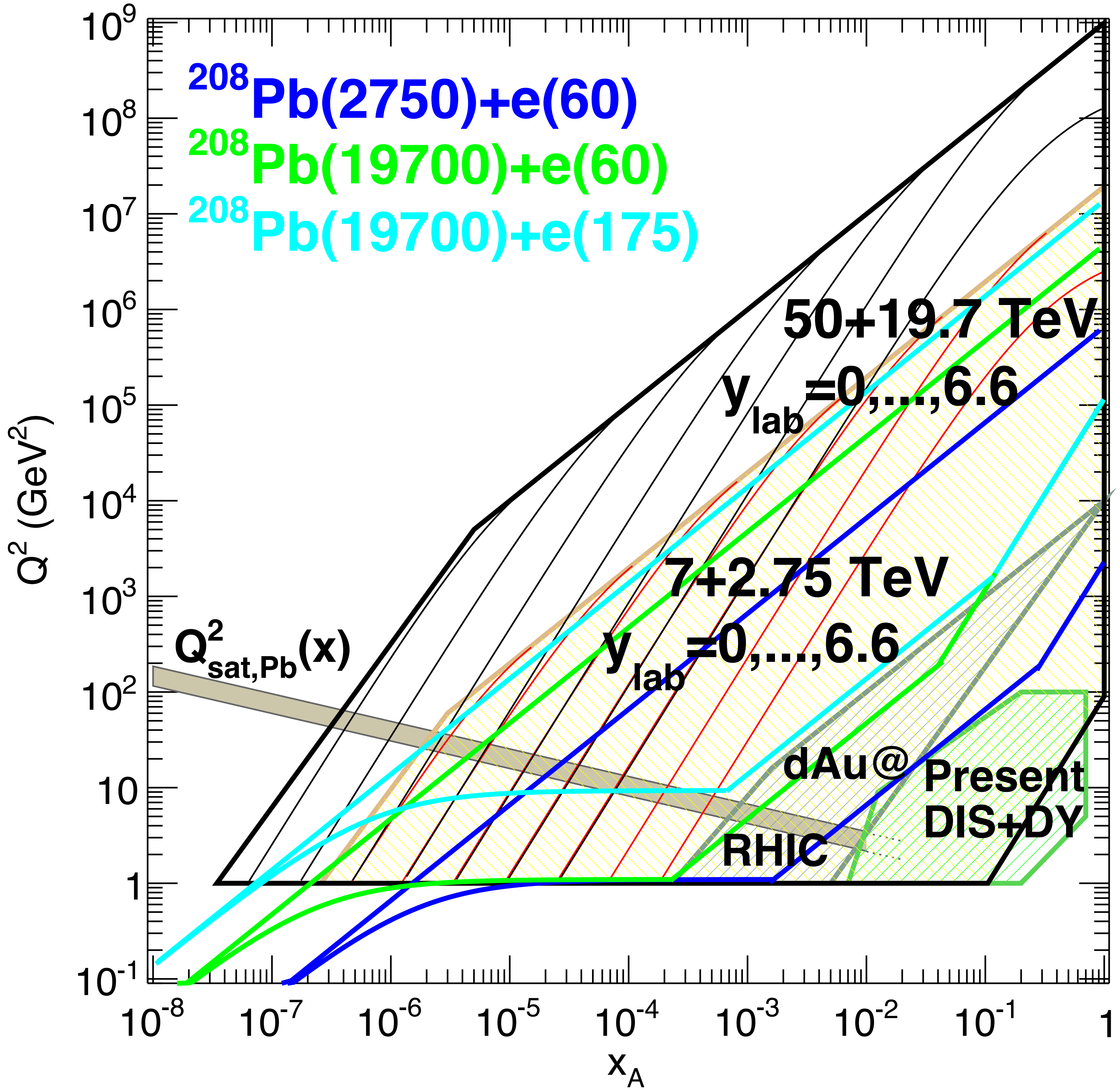
50+19.7 TeV
y_{lab}=0,...,6.6
7+2.75 TeV
y_{lab}=0,...,6.6
$Q^2_{sat,Pb}(x)$
dAu@
RHIC
Present
DIS+DY
Q^2 (GeV^2)
x_A

Kinematics:



^{208}Pb(2750)+e(60)
50+19.7 TeV
y_{lab}=0,...,6.6
7+2.75 TeV
y_{lab}=0,...,6.6
$Q^2_{sat,Pb}(x)$
dAu@
RHIC
Present
DIS+DY
Q^2 (GeV^2)
x_A

Kinematics:



^{208}Pb(2750)+e(60)
^{208}Pb(19700)+e(60)
^{208}Pb(19700)+e(175)
50+19.7 TeV
y_{lab}=0,...,6.6
7+2.75 TeV
y_{lab}=0,...,6.6
$Q^2_{sat,Pb}(x)$
dAu@
RHIC
Present
DIS+DY
Q^2 (GeV^2)
x_A