XXth International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2012)

Bethe Centre for Theoretical Physics, University of Bonn

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Low-x Physics in ep and eA scattering at an LHeC (I)

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

Contents:

1. Introduction.

2. Kinematical coverage of an LHeC.

3. Inclusive measurements and small-x glue.

4. Final states.

5. Summary.

See the EIC and LHeC talks, plus many many others, here.

I focus on inclusive and final state observables. See A. Stasto's talk for diffractive observables at the LHeC.

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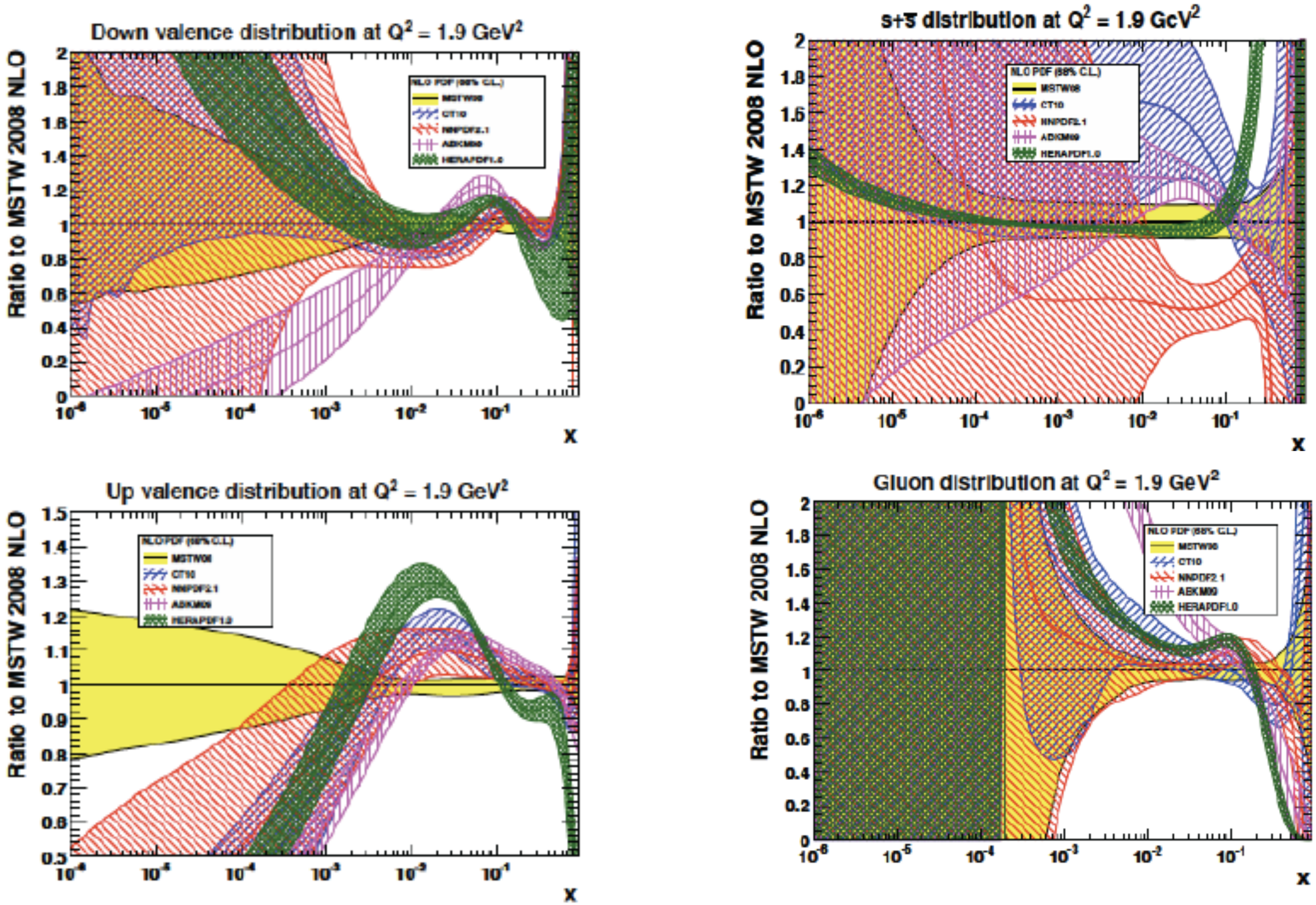
Results from Design Study Report as close to final as possible.

See the EIC and LHeC talks, plus many many others, here.

I focus on inclusive and final state observables. See A. Stasto's talk for diffractive observables at the LHeC.

Motivation:

- **HERA**: successful but unfinished QCD program - eA, eD, high and small x, new concepts (TMDs,...), instantons, odderon,...



Preliminary; LHeC Design Study Report, CERN 2012

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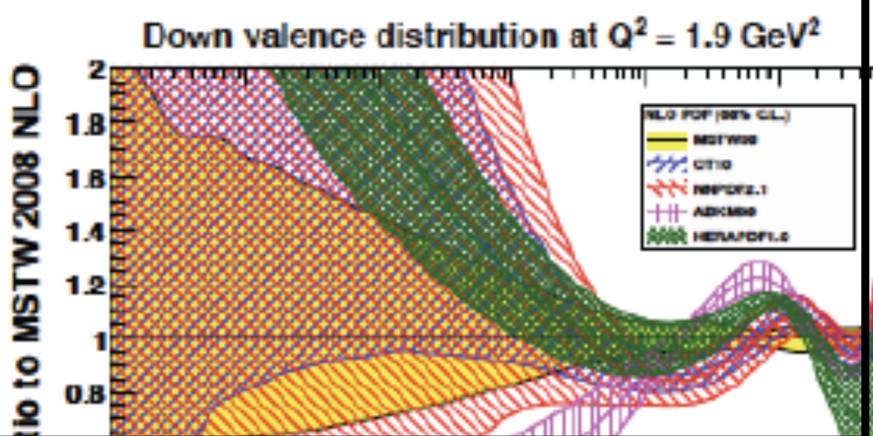
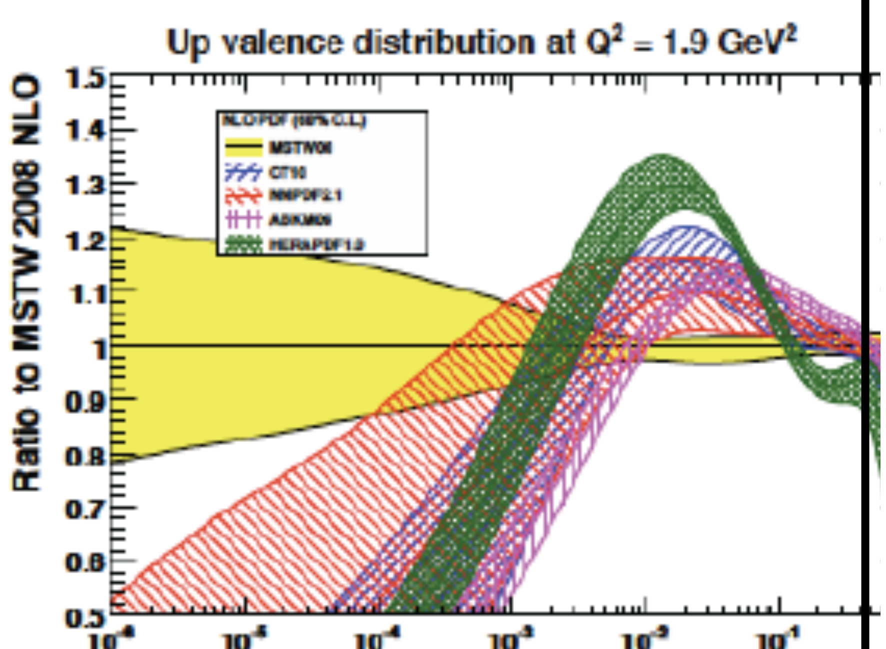
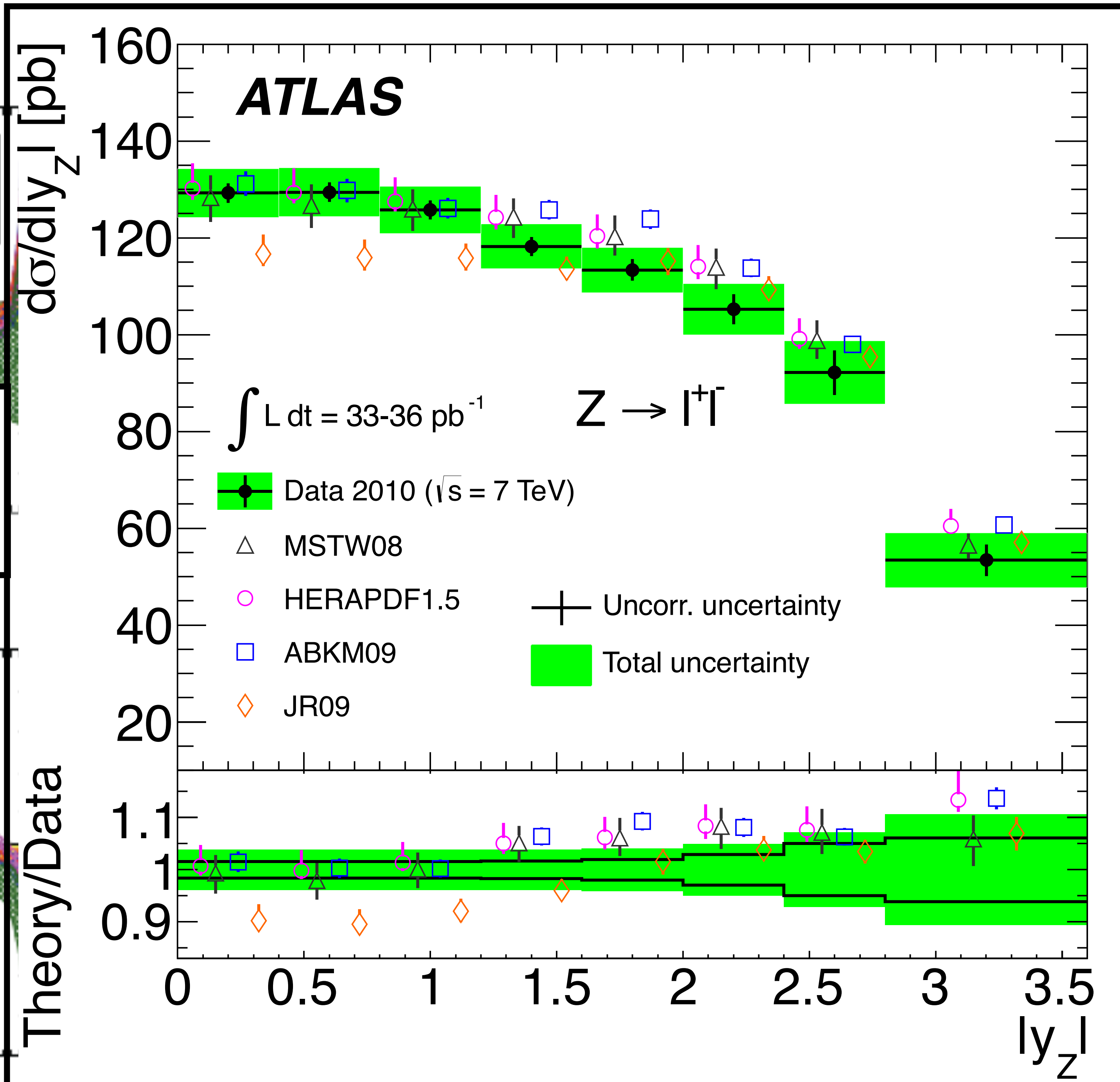


LHC starts to be sensitive to differences in pdfs!!!



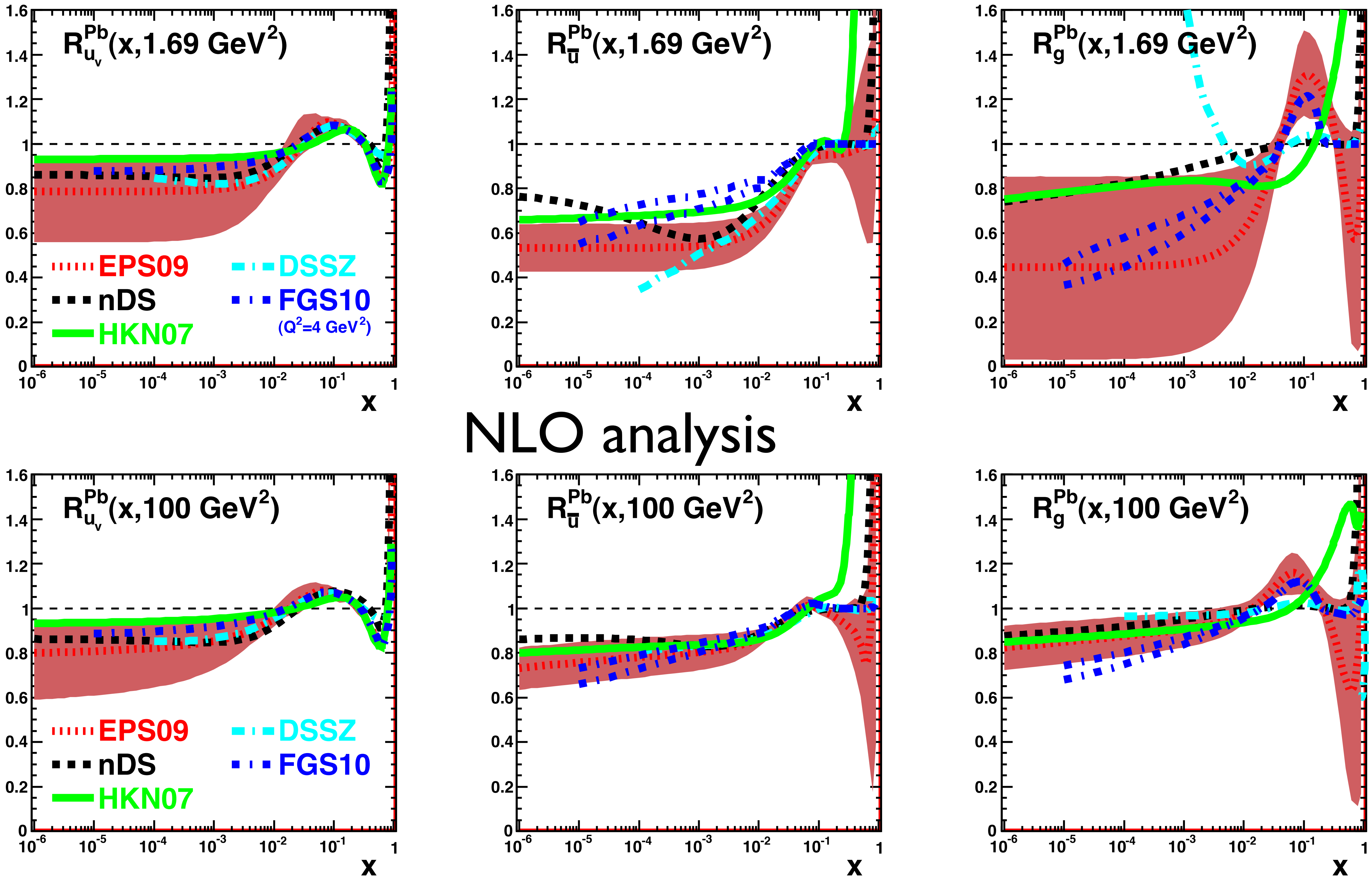


Preliminary; LHeC Design Study Report, CERN 2012

Uncertainties in DGLAP npdf's:

$$R_{F_2}^{A}(x,Q^2) = \frac{F_2^A(x,Q^2)}{A F_2^{\rm nucleon}(x,Q^2)}$$

Problem for benchmarking in hard probes!!!



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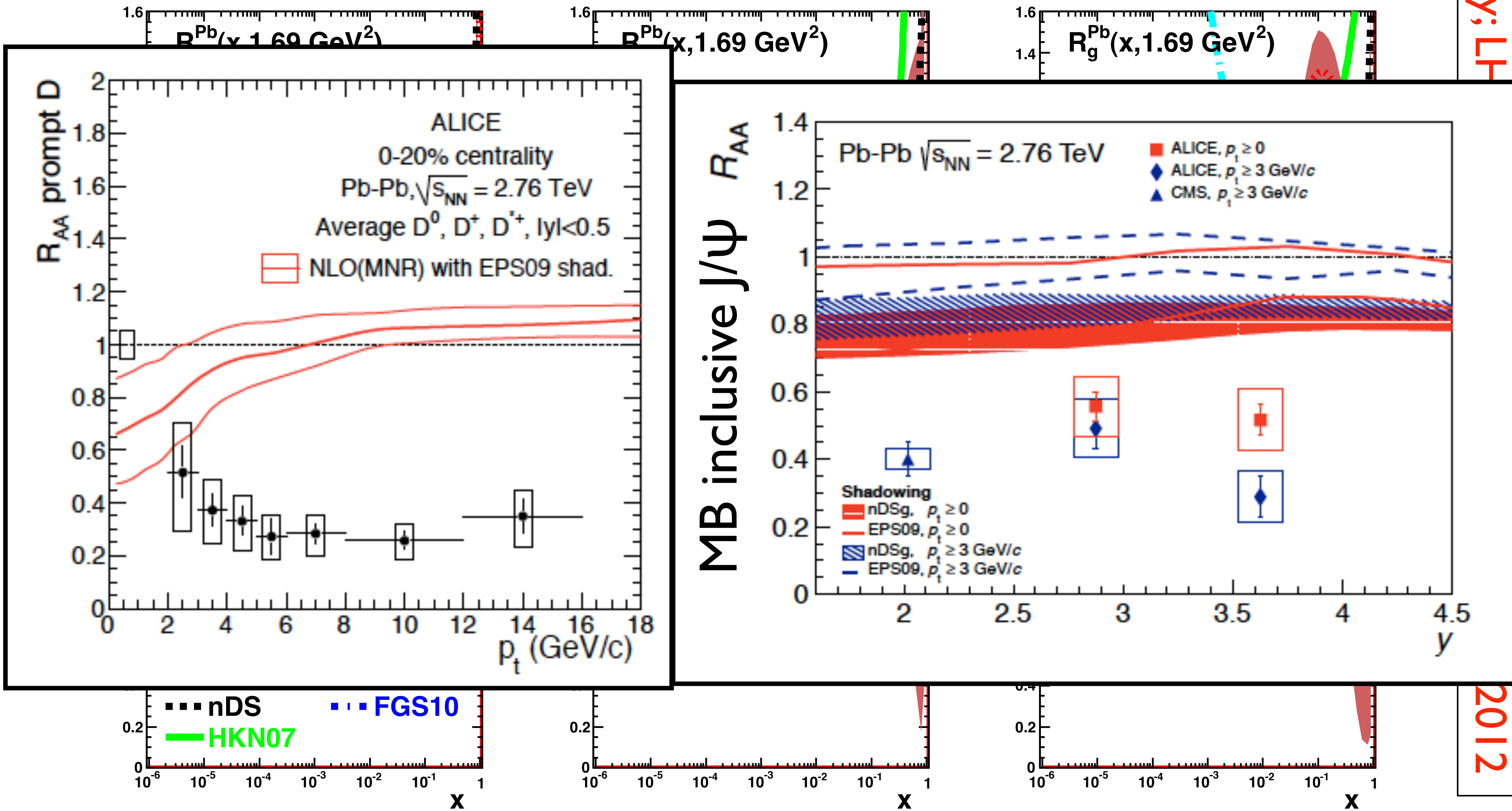


Theory:

- Three pQCD-based alternatives (plus several models) to describe small-x ep and eA data:

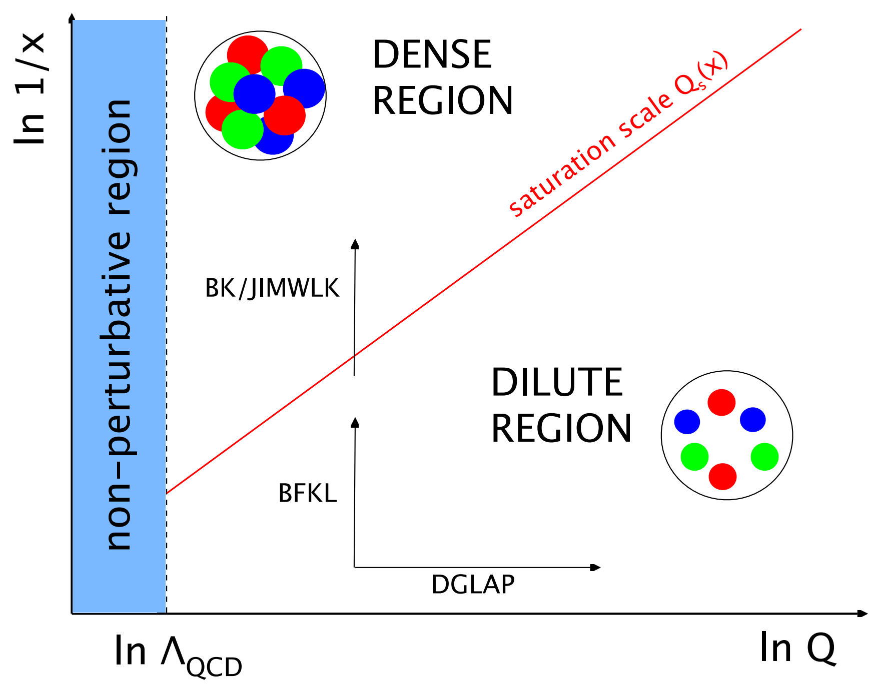
→ DGLAP evolution (fixed order PT).

→ Resummation schemes.

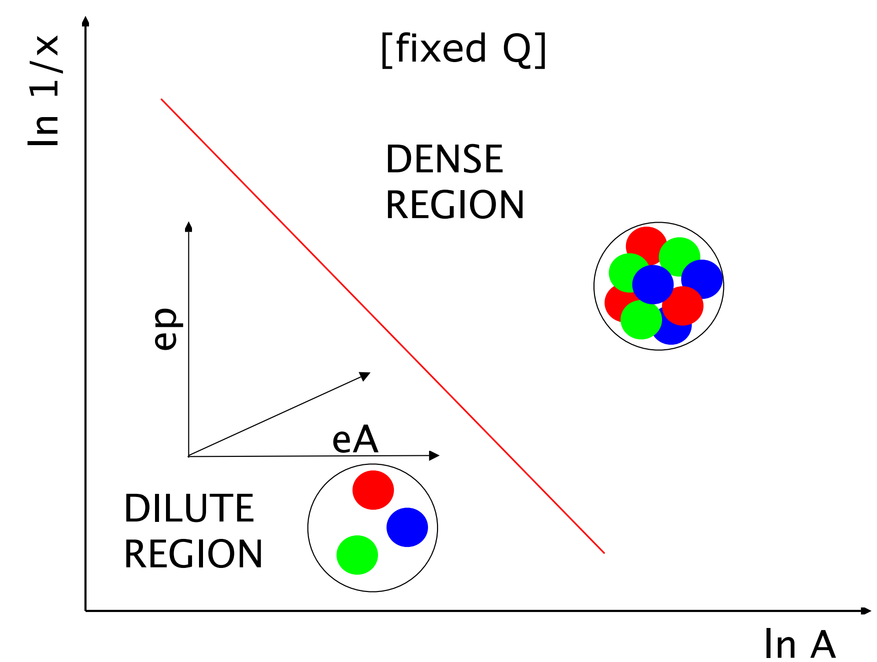
→ CGC (dipole models and rcBK).

Differences lie at moderate $Q^2 (>\Lambda^2_{QCD})$ and small x. Hints of deviations from NLO DGLAP (Caola et al '09, Albacete et al '12).

- **Unitarity** (non-linear effects): where?



Two-pronged approach at the LHeC:
↓ x / ↑ A. **eA**:
test/enhance
density effects.



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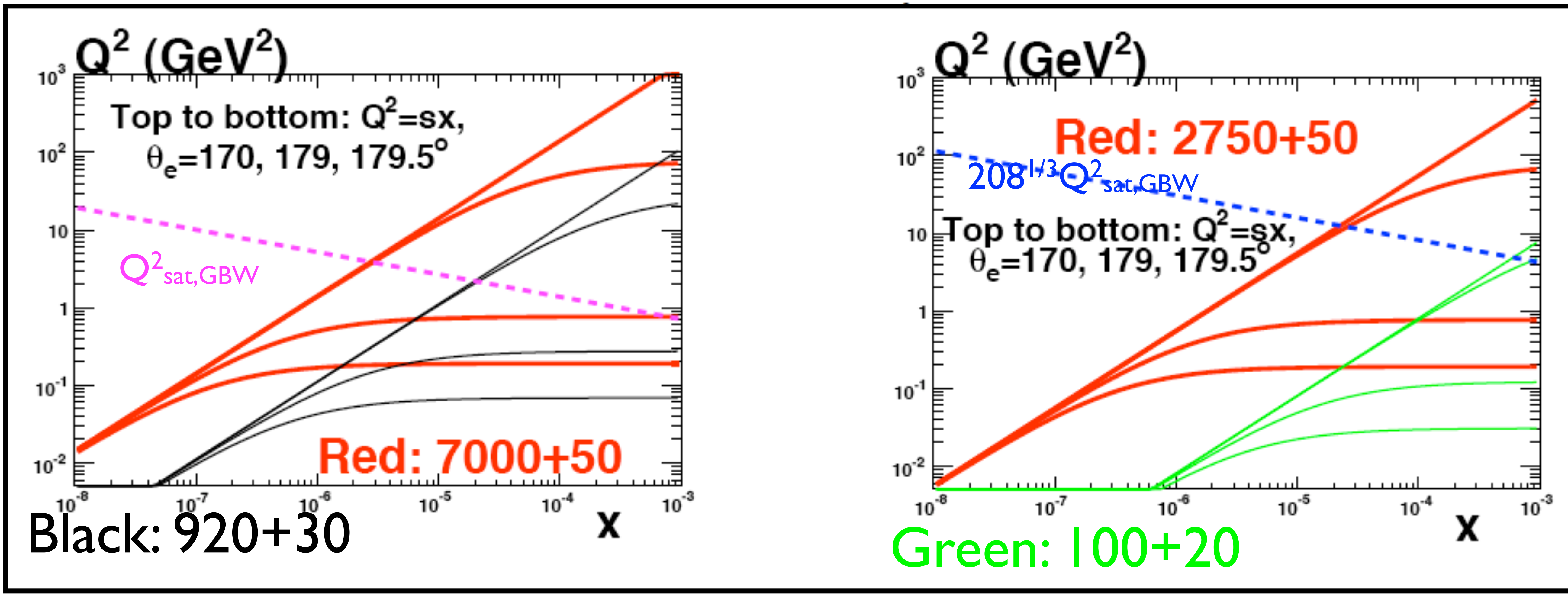
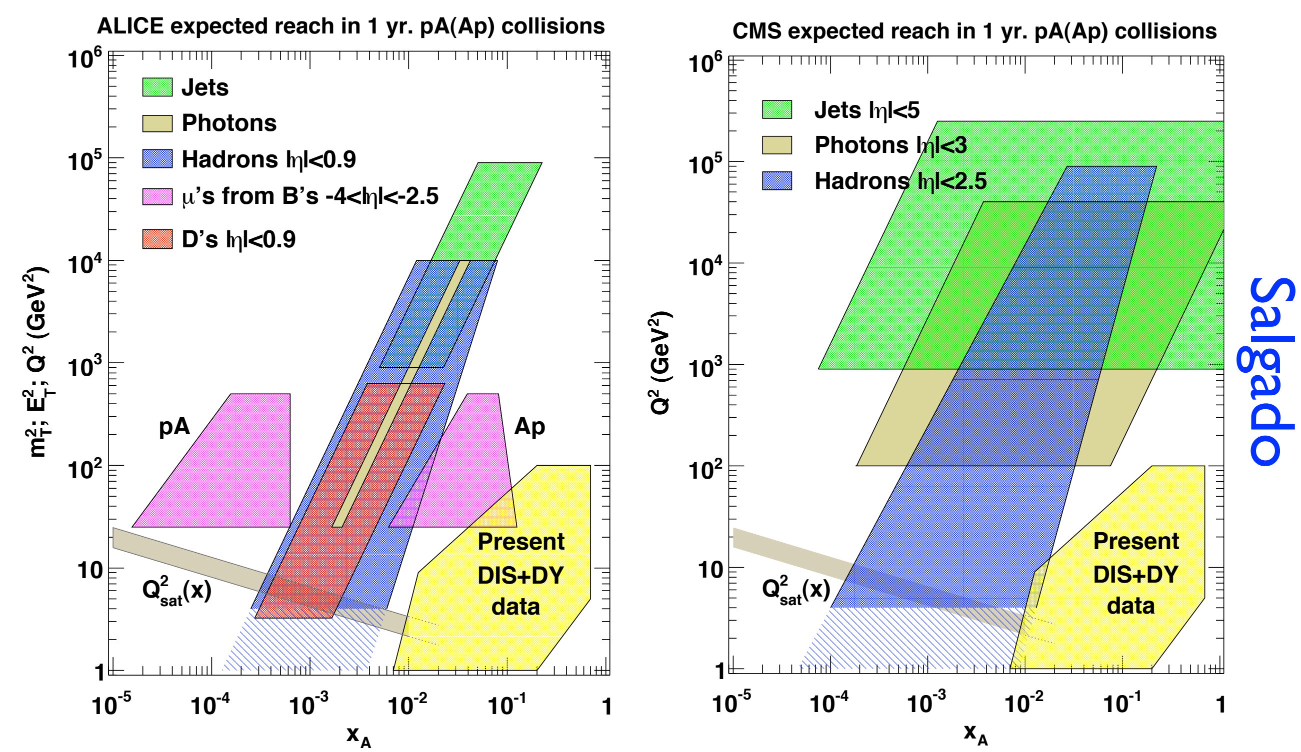
Kinematics:



- ep: access to the perturbative region beLow-x ~ a few 10^{-5}.
- eA: new realm.
- No small-x physics without ~ 1 degree acceptance.



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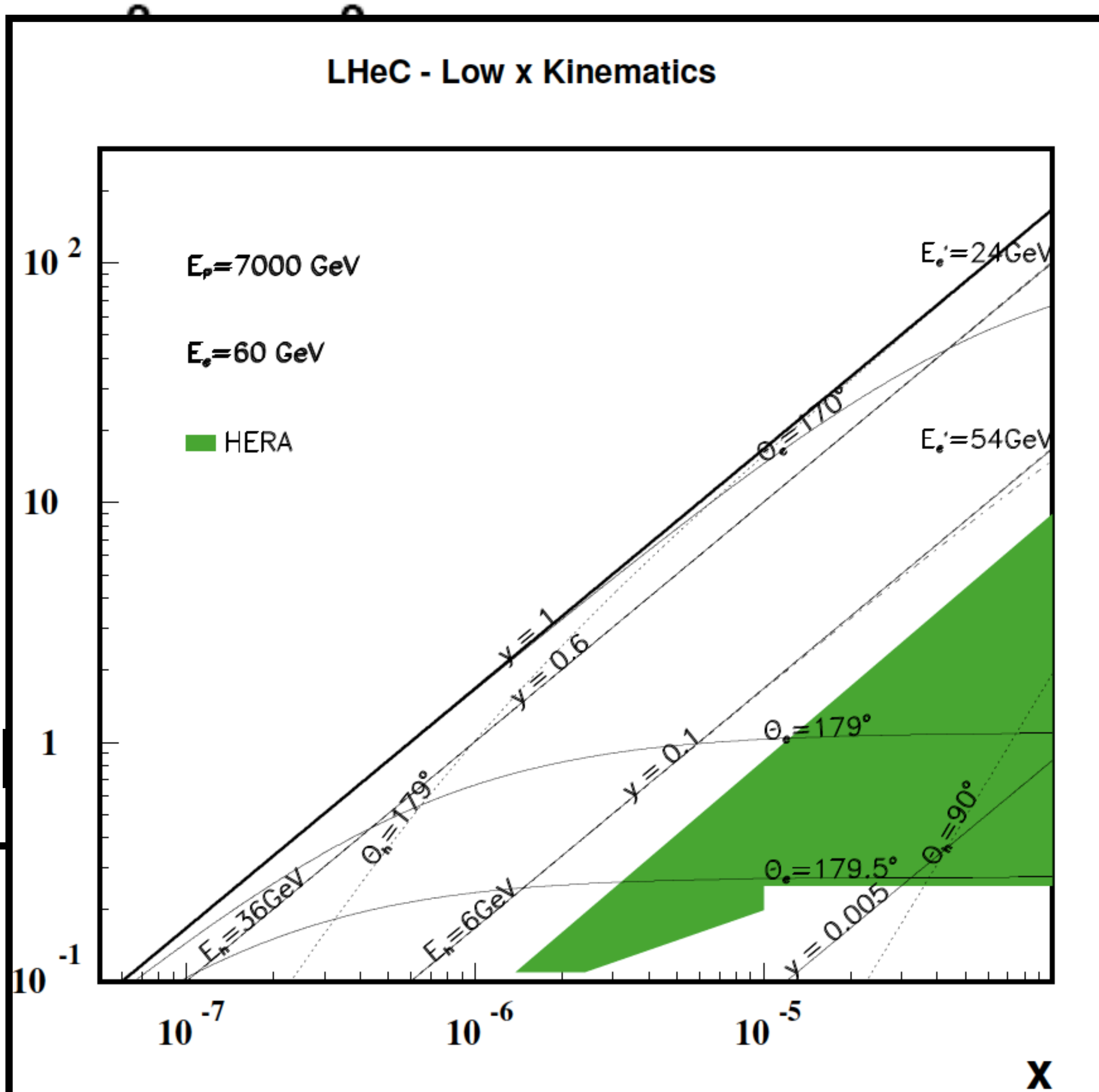
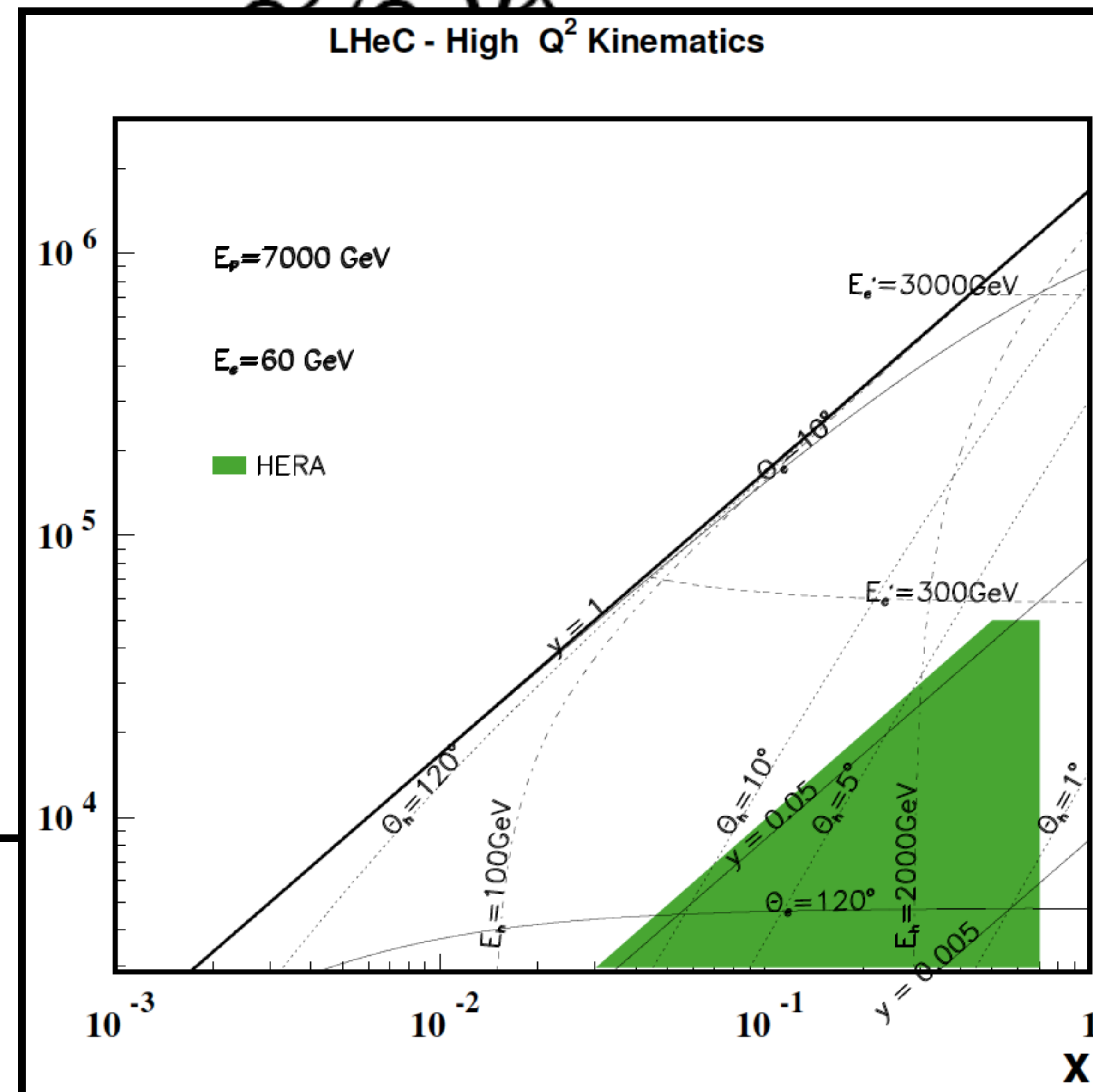
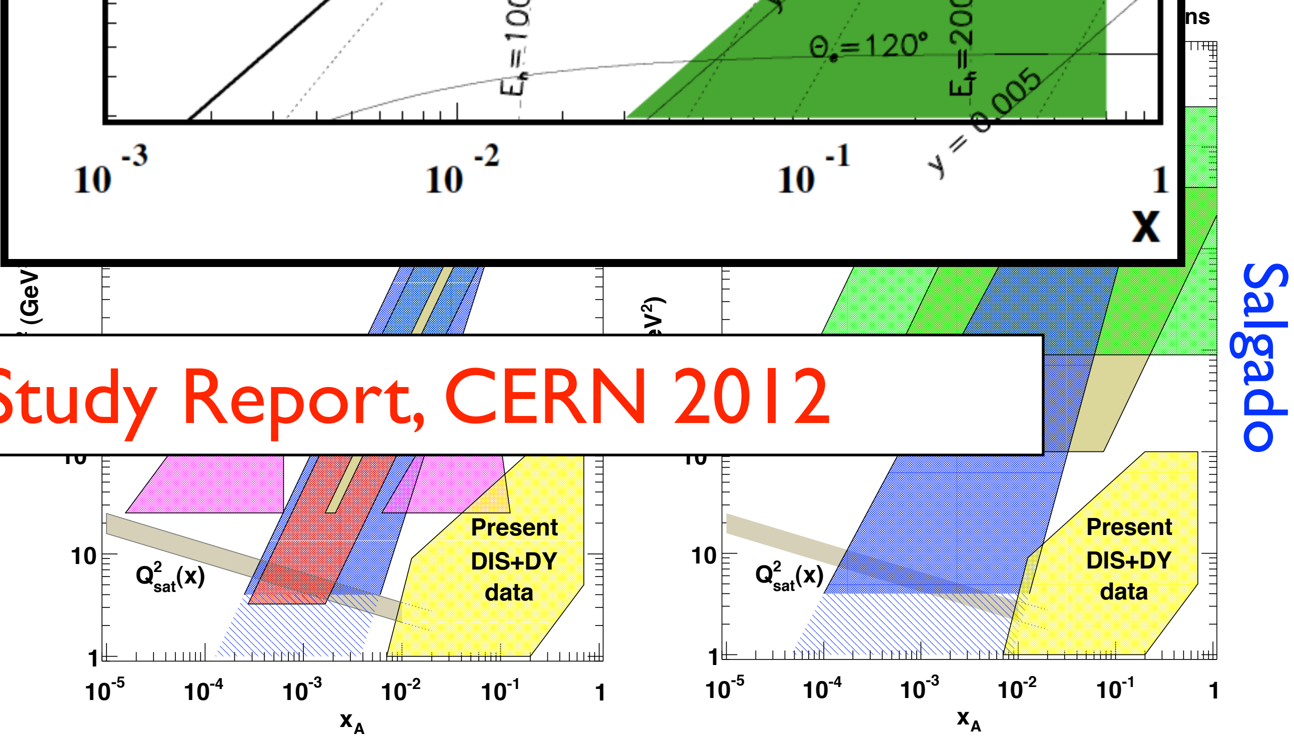






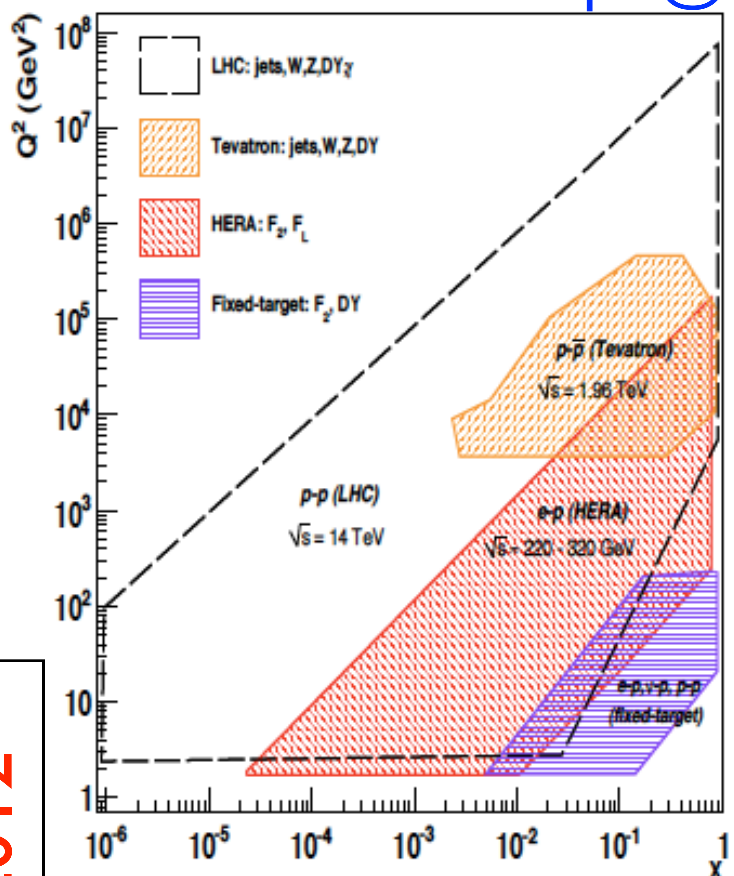
- eA

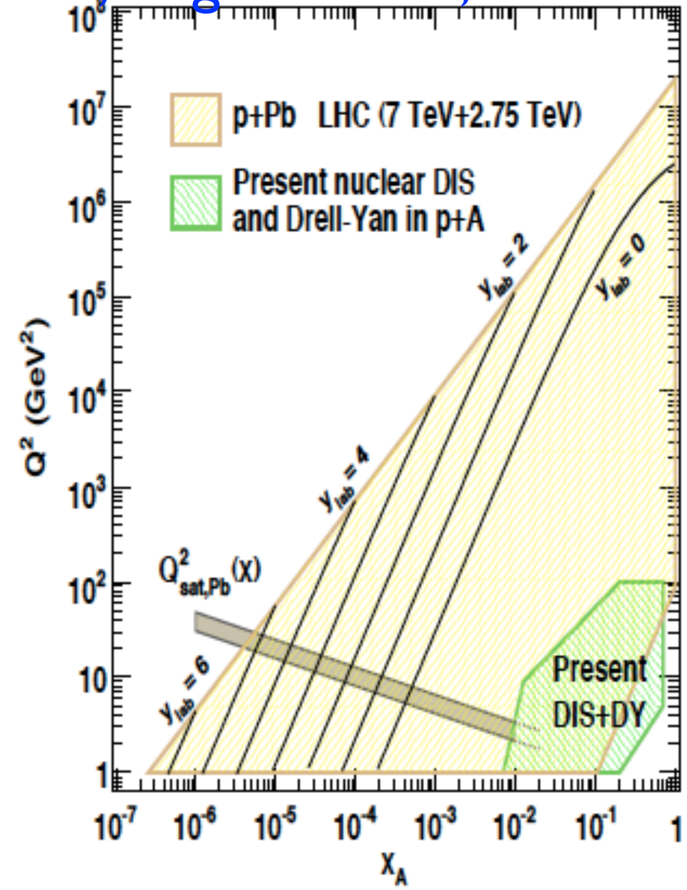
Preliminary; LHeC Design Study Report, CERN 2012

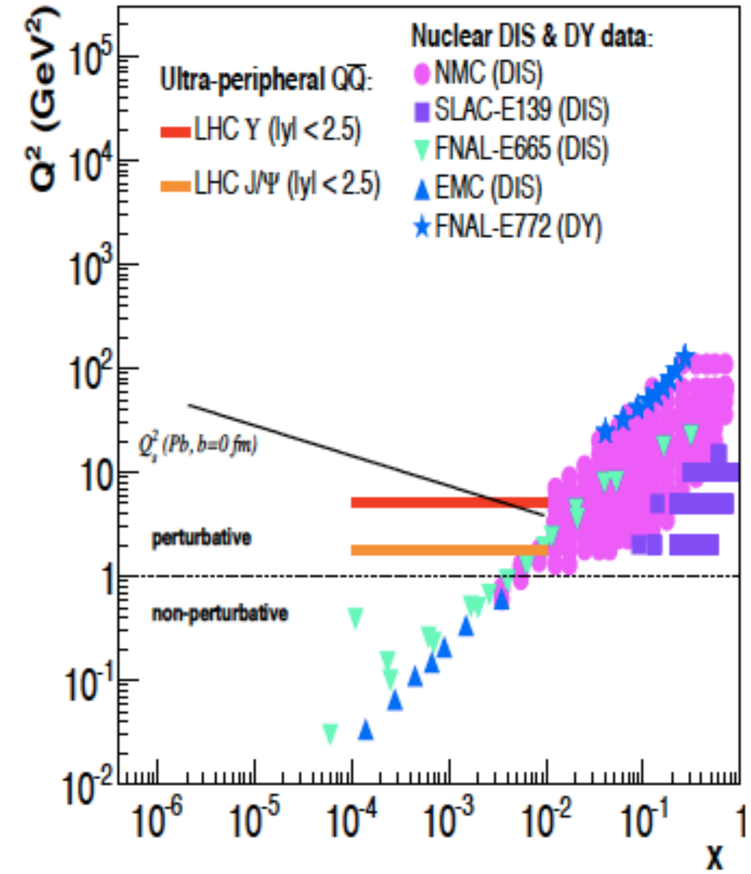
- No small-x physics without ~ 1 degree acceptance.

Kinematics: LHC vs. LHeC

pA@LHC, Salgado et al., 1105.3919







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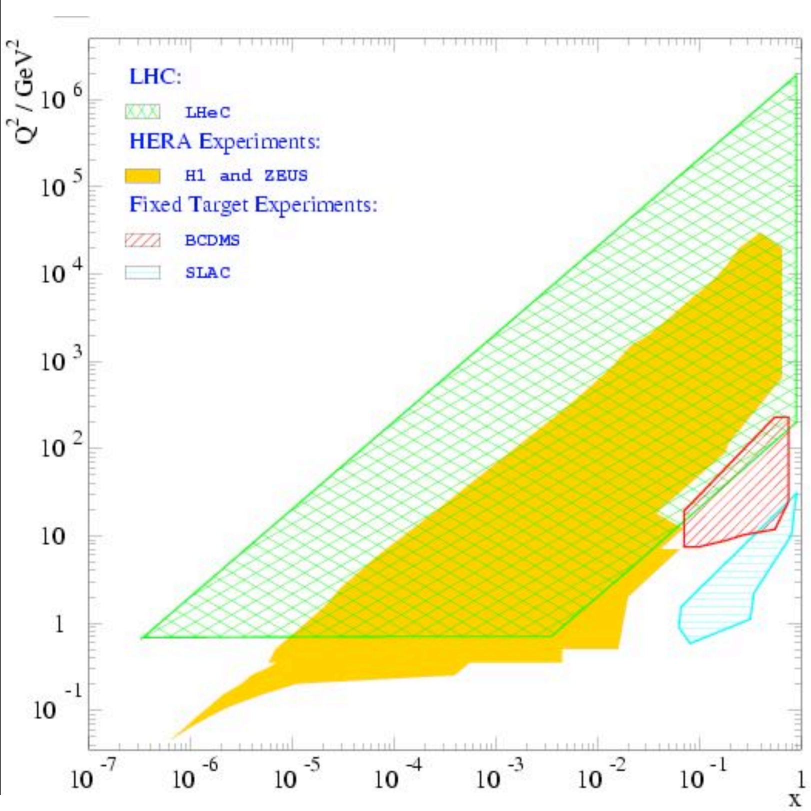
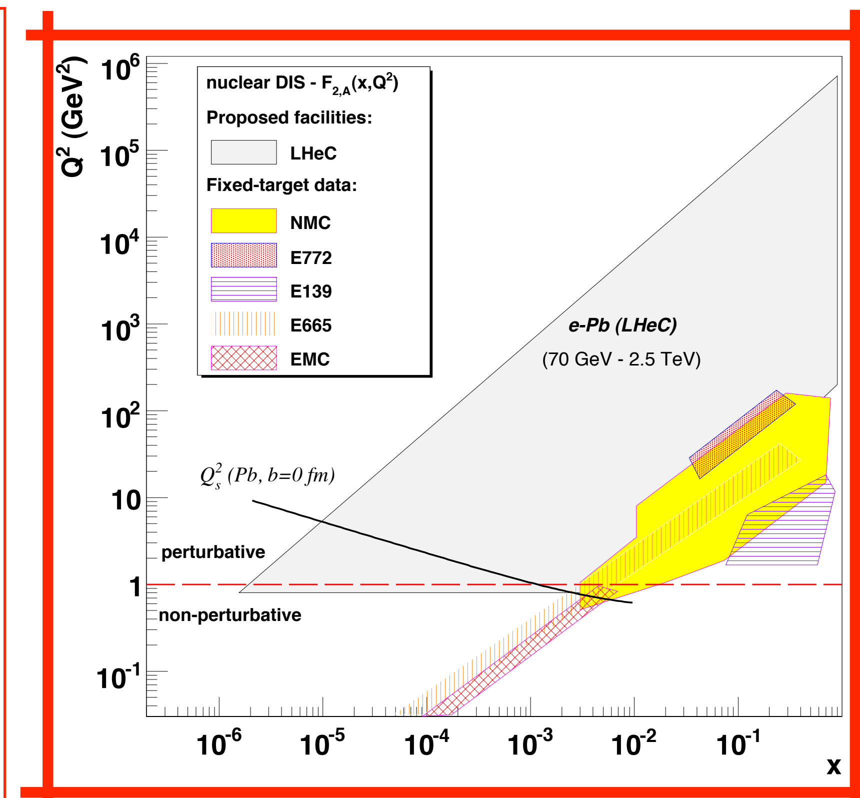


- Existing ep: pp@LHC at y=0; eA: not even dAu@RHIC.
- LHeC: clean scan of the LHC x-Q^2 domain.



Contents:

LHeC scenarios:

For F_2

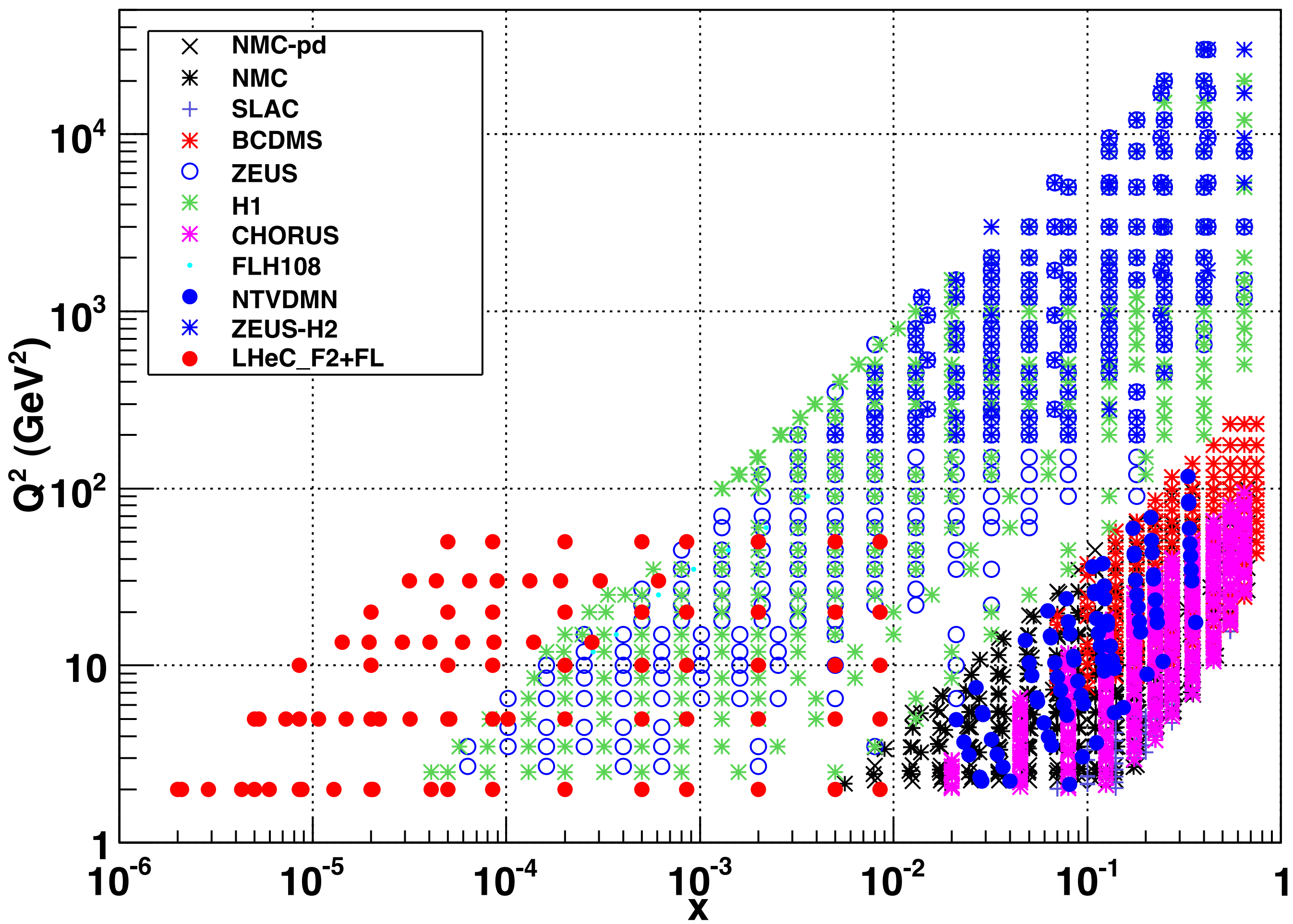
config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	10^{-4}	10^{-4}	0.4	10^{-3}	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp
I	50	3.5	Ca	$5 \cdot 10^{-4}$		?	$5 \cdot 10^{-3}$	?	?	eCa

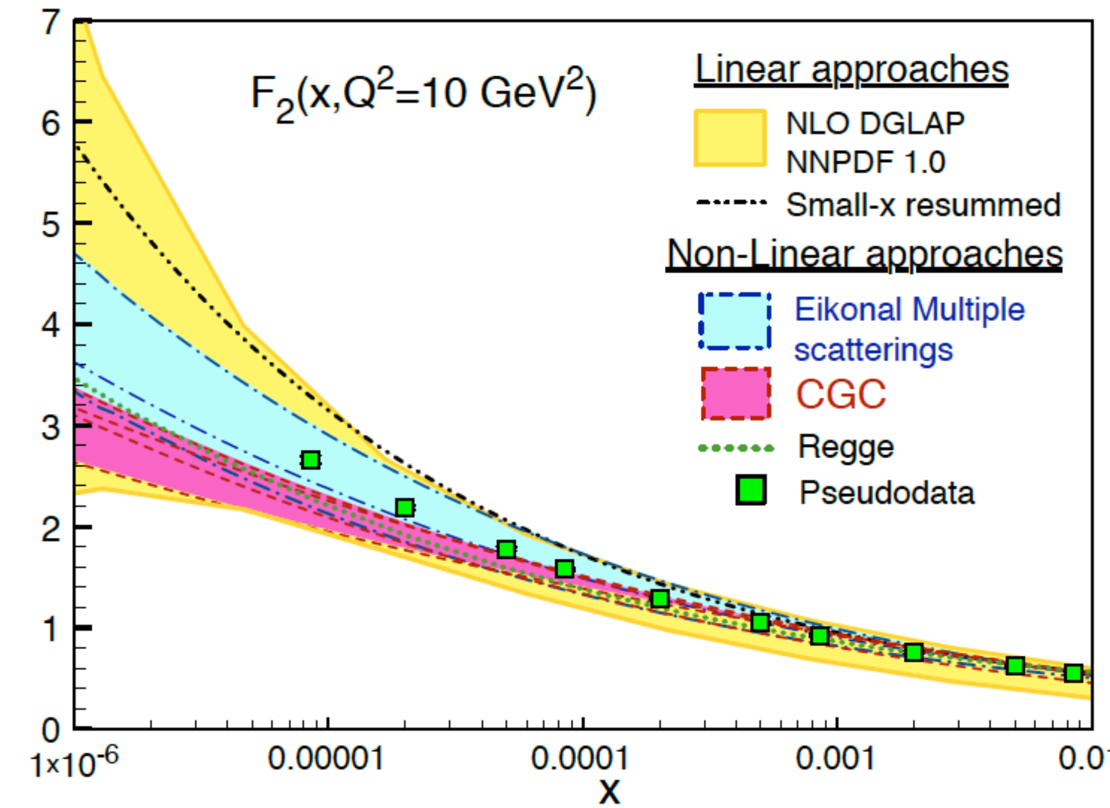
- For F_L: 10, 25, 50 + 2750 (7000); $Q^2 \leq sx$; Lumi=5,10,100 pb^{-1} respectively; charm and beauty: same efficiencies in ep and eA.

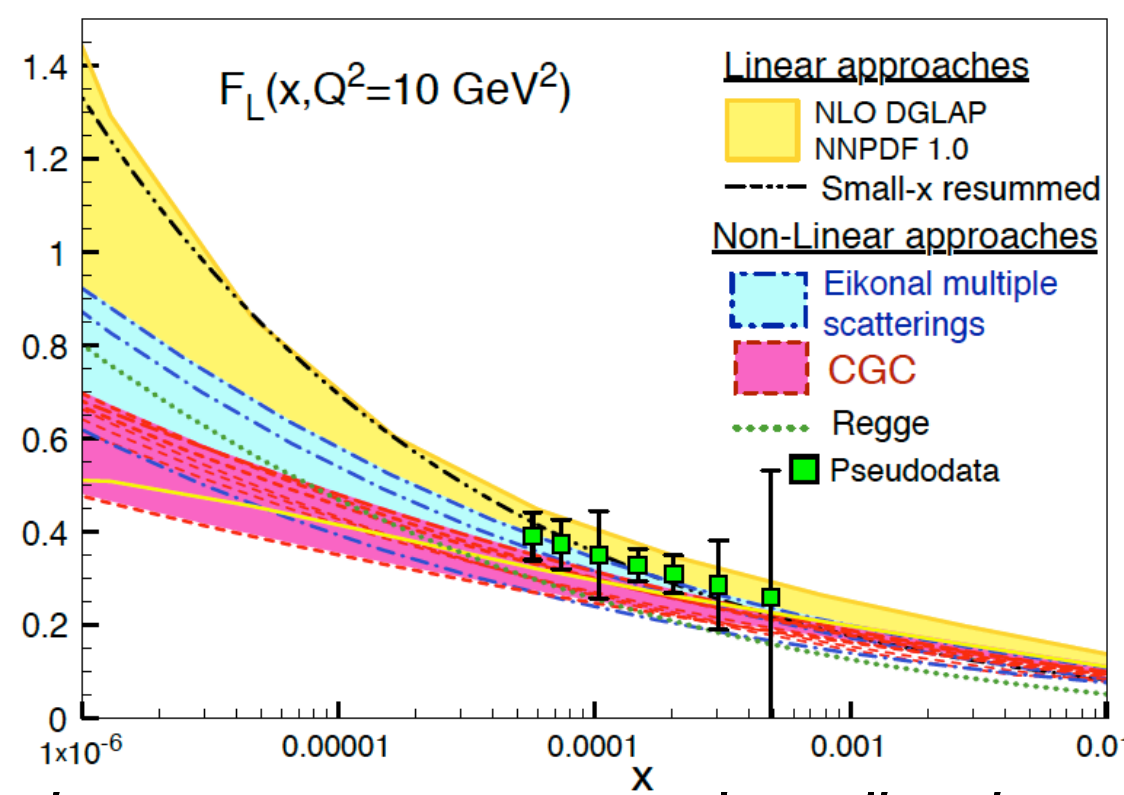
Preliminary; LHeC Design Study Report, CERN 2012

ep inclusive: comparison

- Extensive model comparison: LHeC will have discriminative power.
- Note: size of radiative corrections pending.



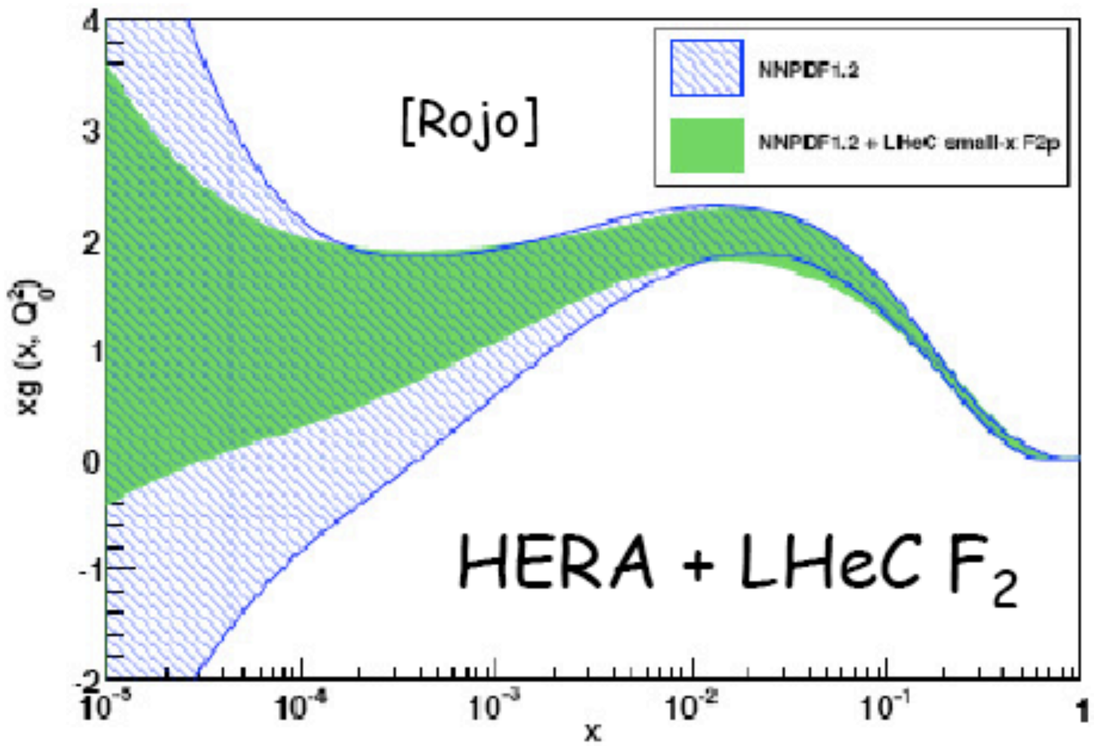


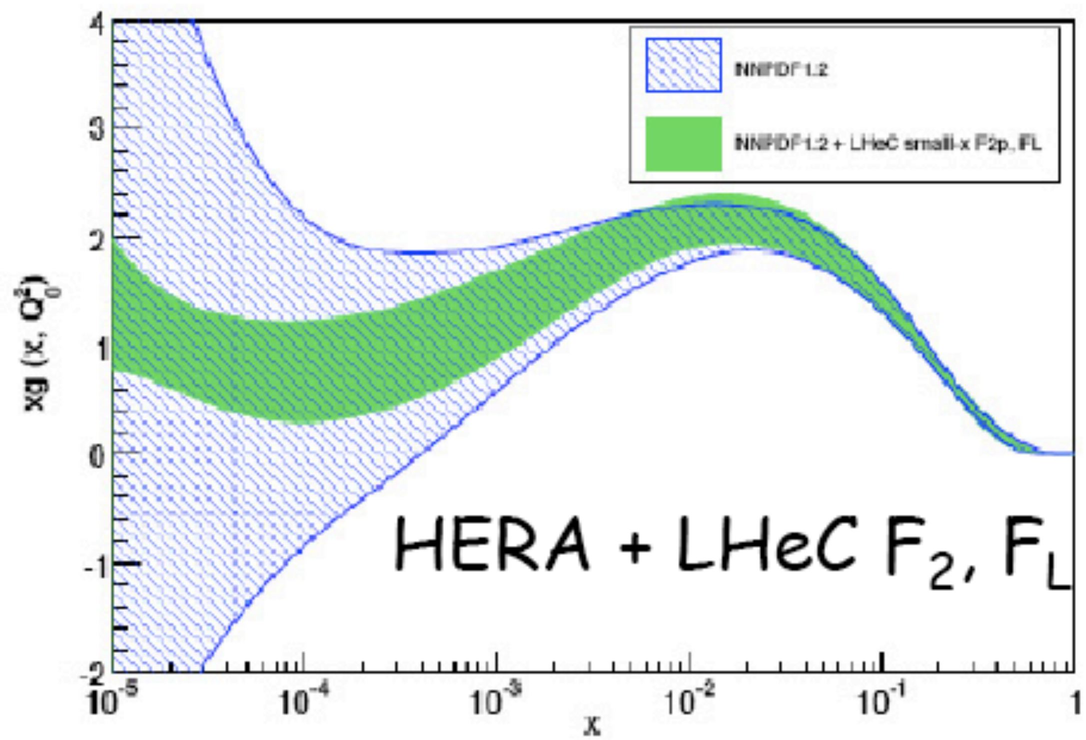


Preliminary; LHeC Design Study Report, CERN 2012

ep inclusive: extracting the glue

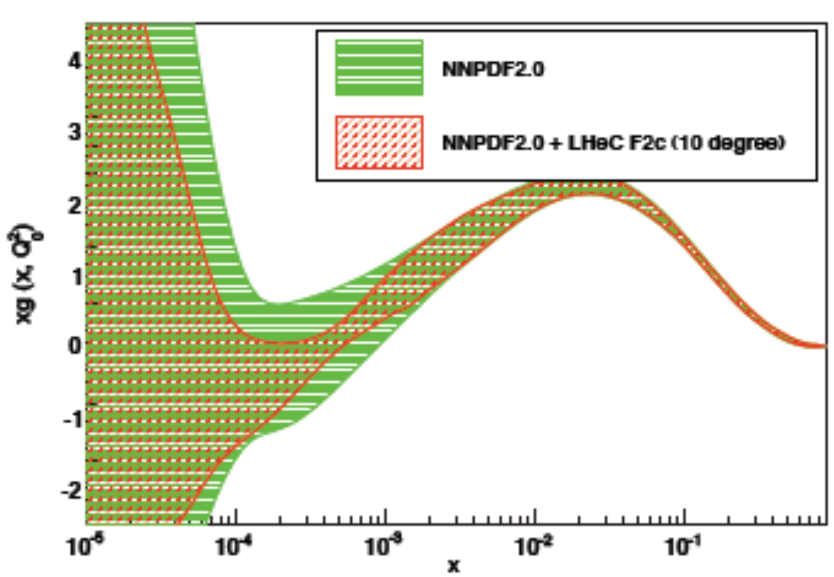
Preliminary; LHeC Design Study Report, CERN 2012

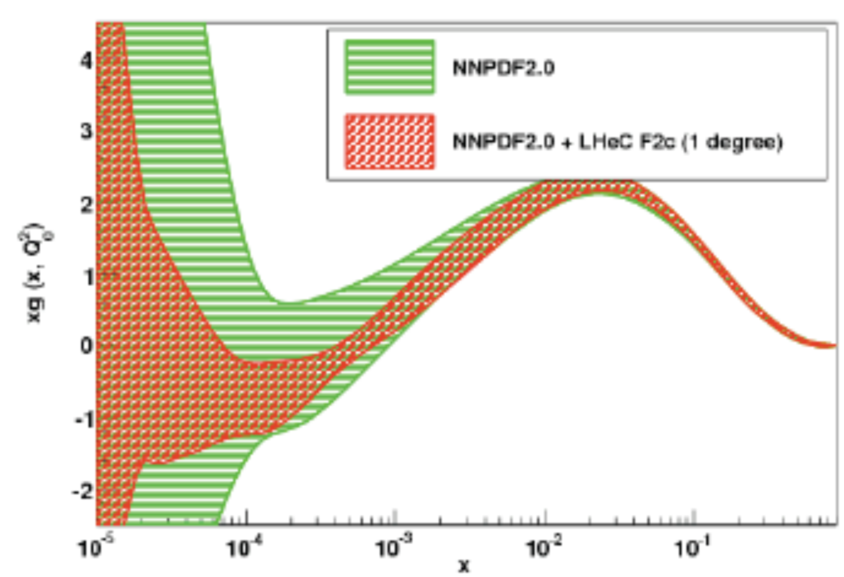




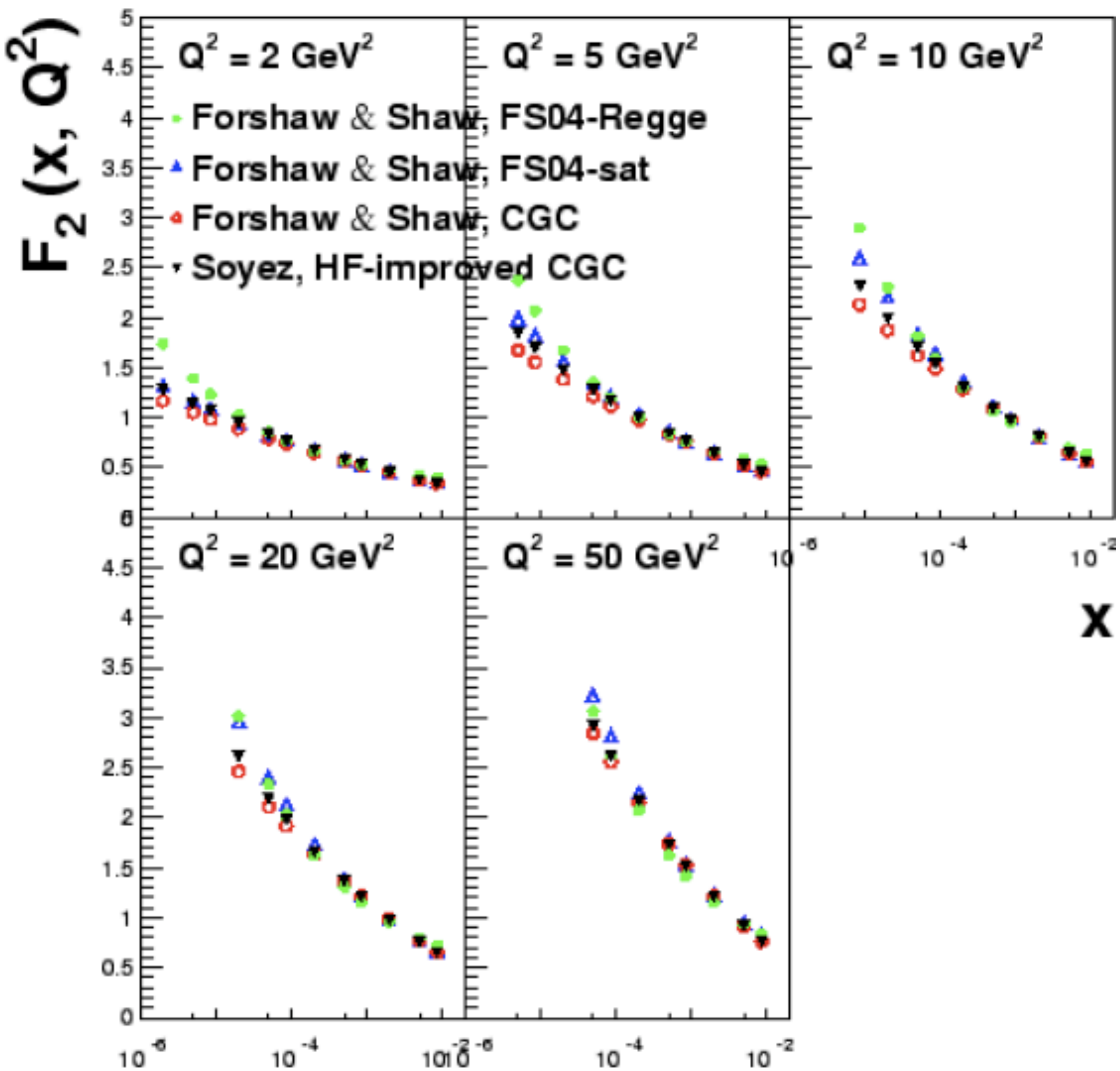
($Q^2 = 2\ GeV^2$)

- LHeC substantially reduces the uncertainties in global fits: F_L and heavy flavor decomposition most useful.

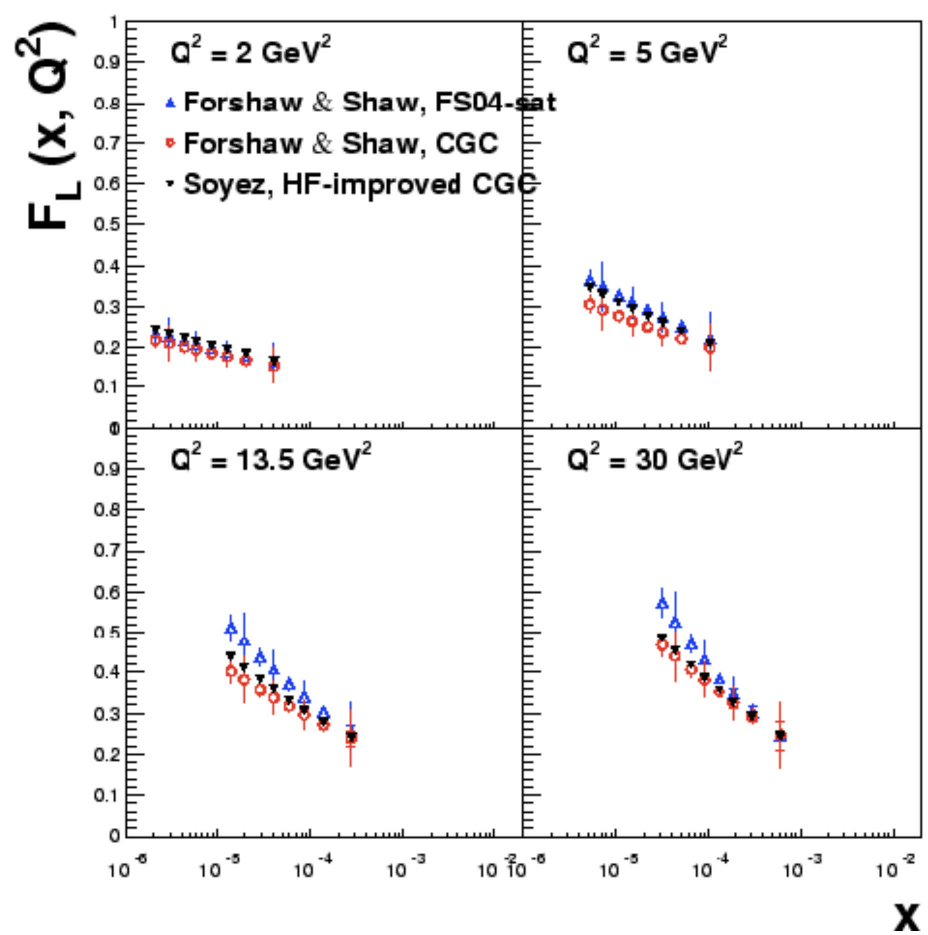




ep inclusive: searching



- Tension between F_2 and F_L in DGLAP fits as a sign of physics beyond standard DGLAP (GBW and CGC models).



Preliminary; LHeC Design Study Report, CERN 2012

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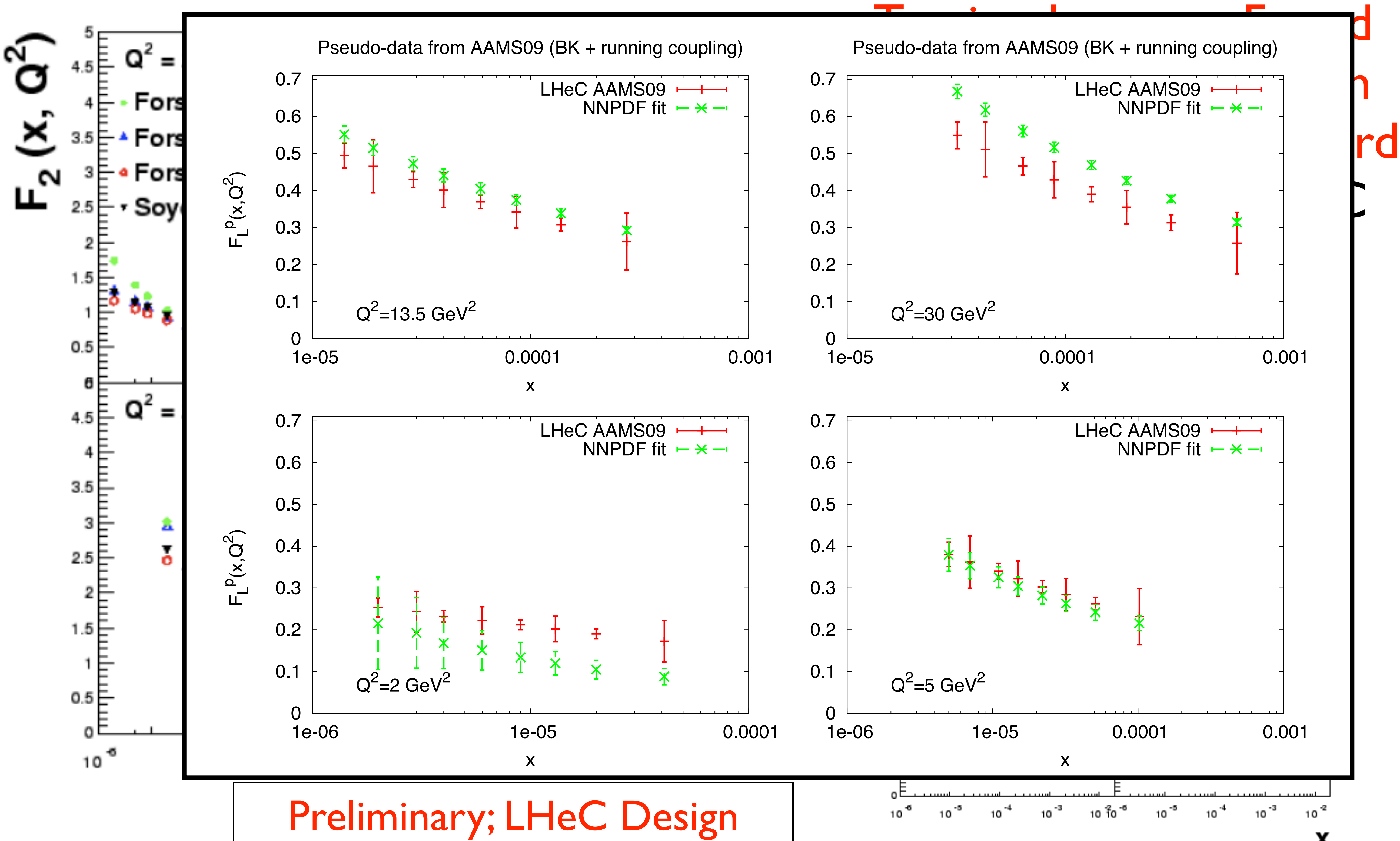


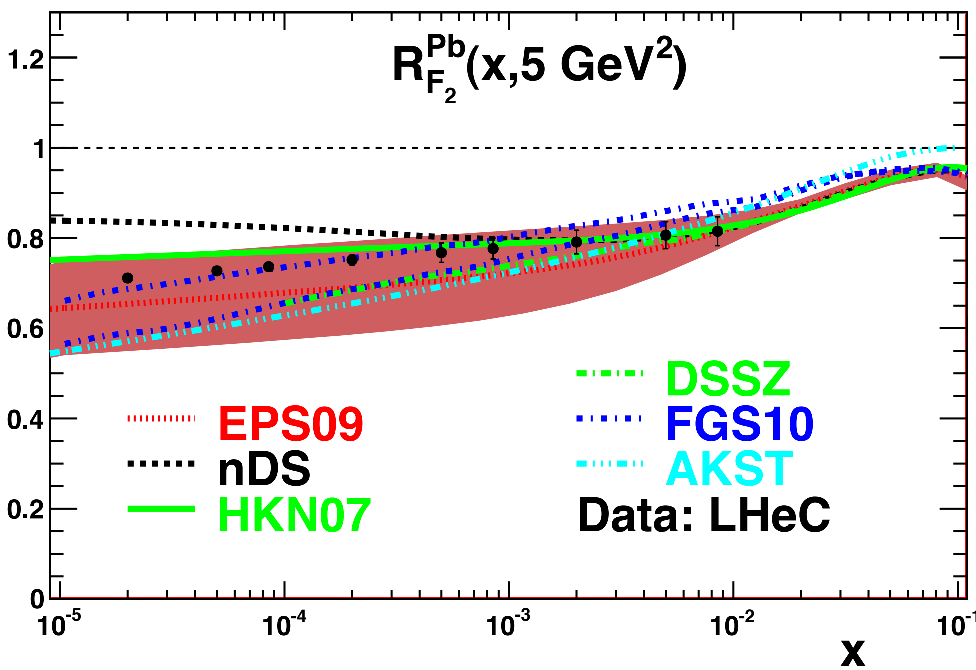
Preliminary; LHeC Design Study Report, CERN 2012

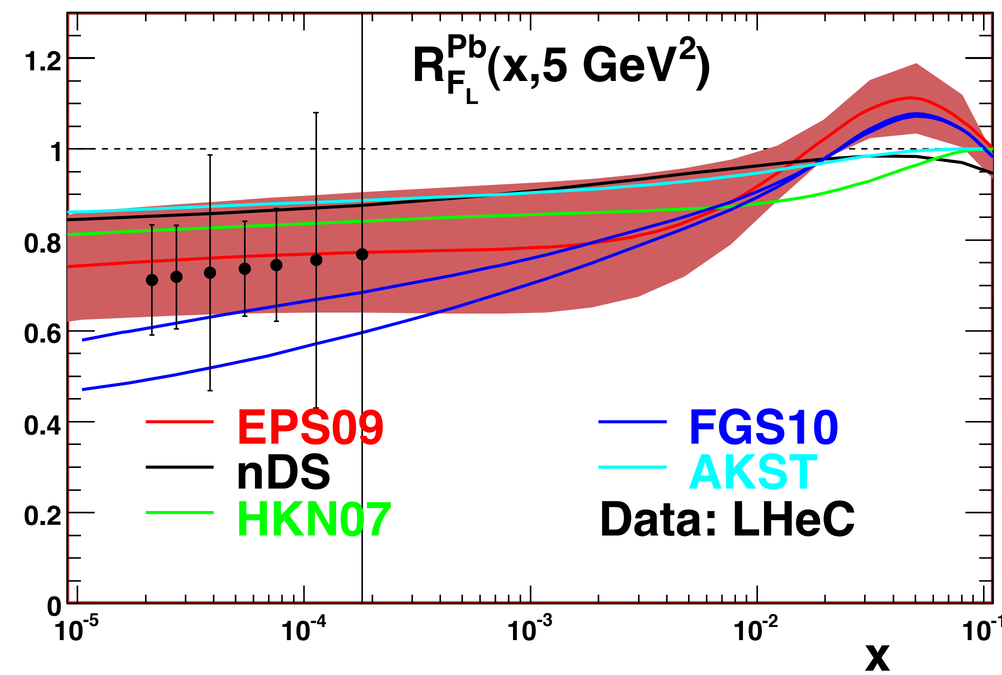
eA inclusive: comparison

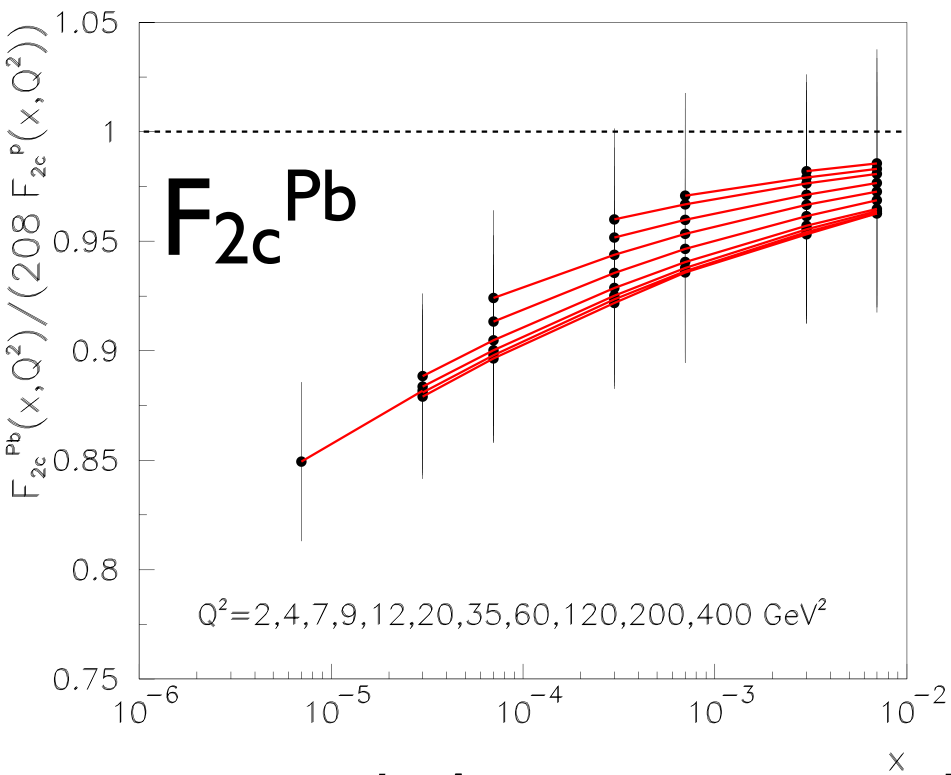
- Good precision can be obtained for $F_{2(c,b)}$ and F_L at small x

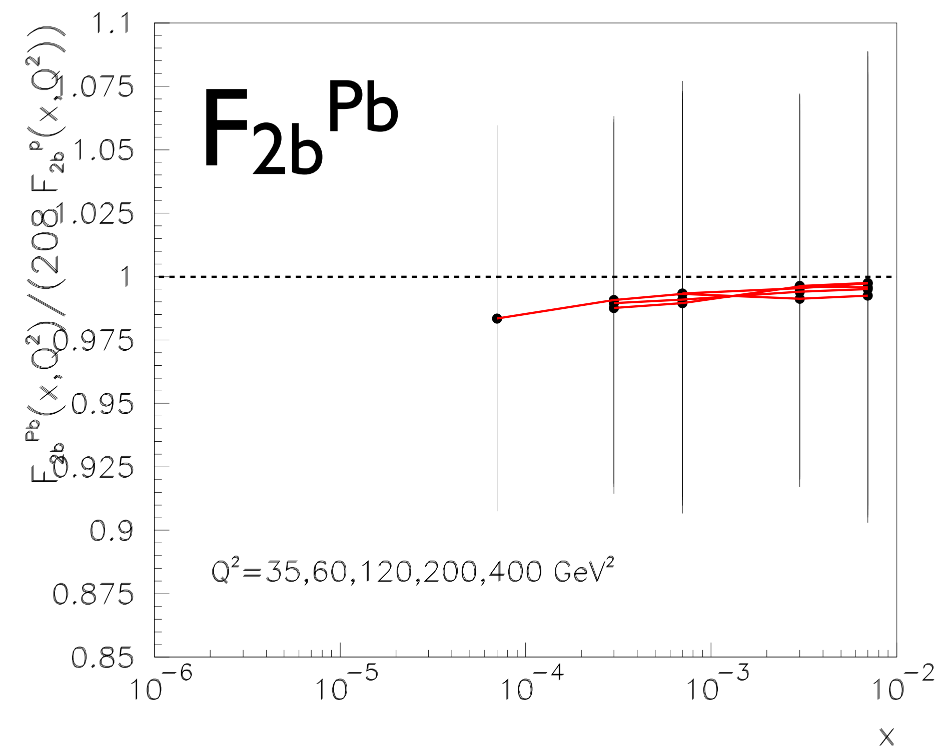
(Glauberized 3-5 flavor GBW model, NA '02).

Preliminary; LHeC Design Study Report, CERN 2012



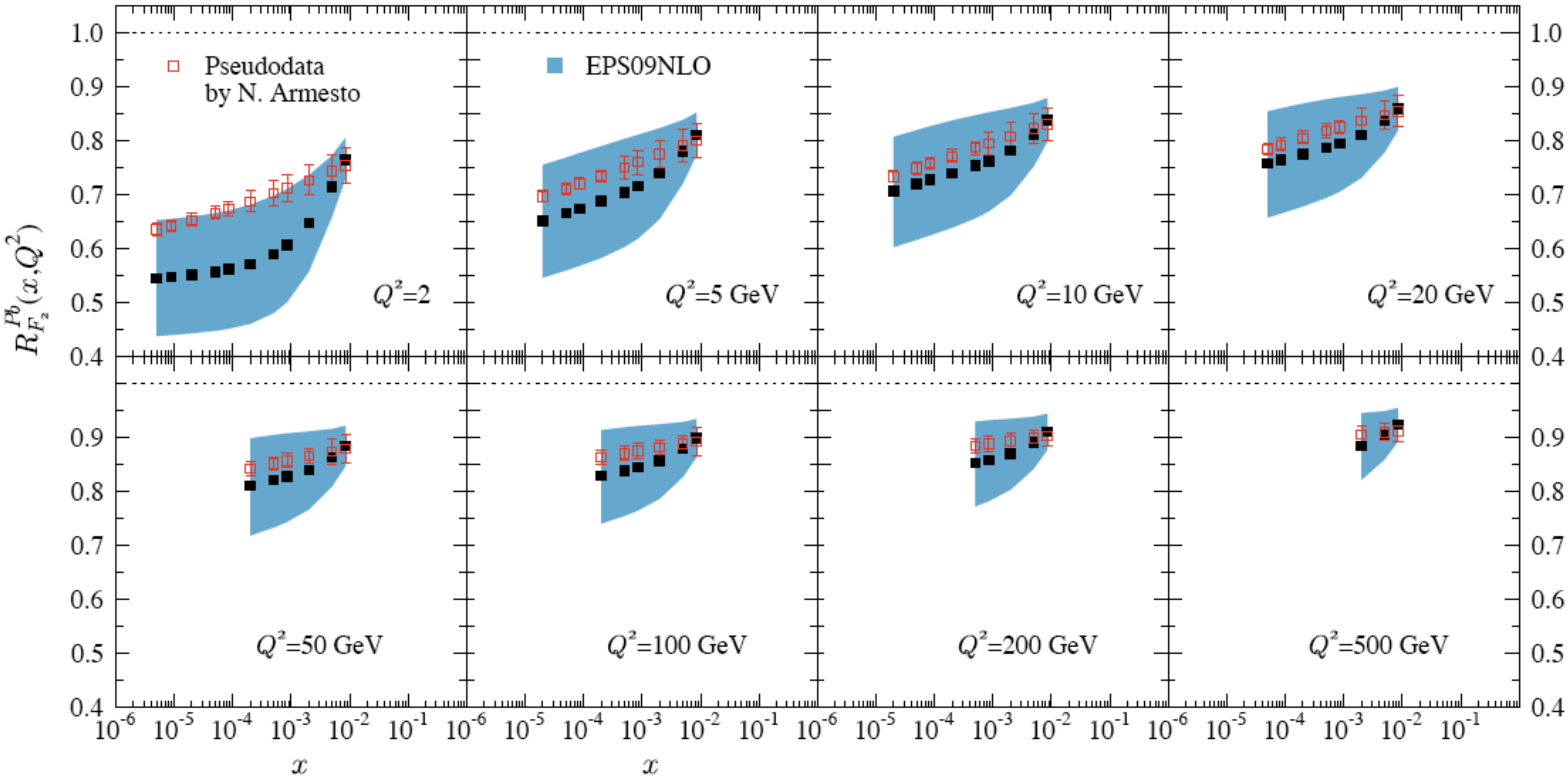






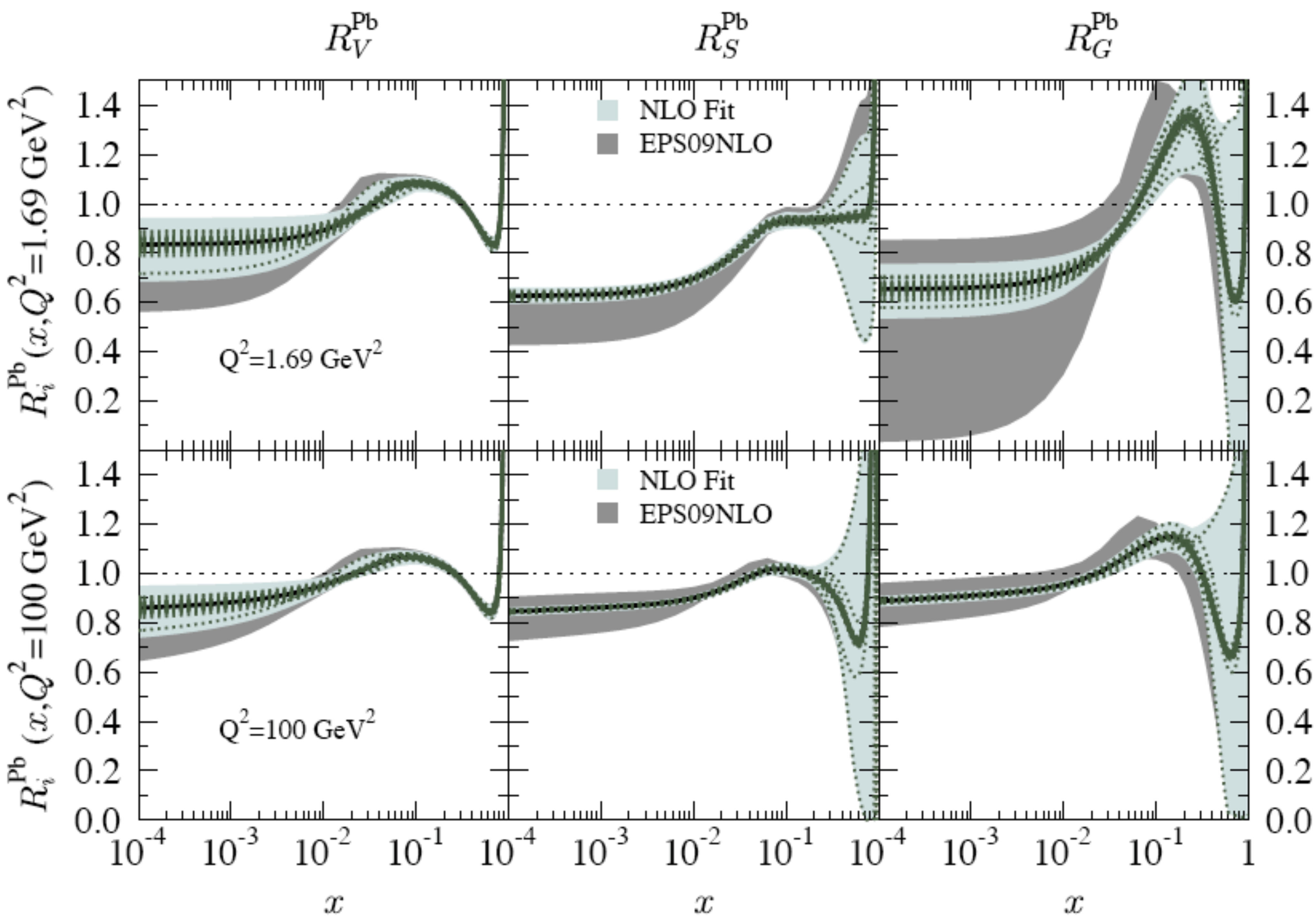
eA inclusive: constraining pdfs

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



eA inclusive: constraining pdfs

- F_2 data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty and F_L produce minor improvements.



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- F₂ data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty and F_L produce minor improvements.

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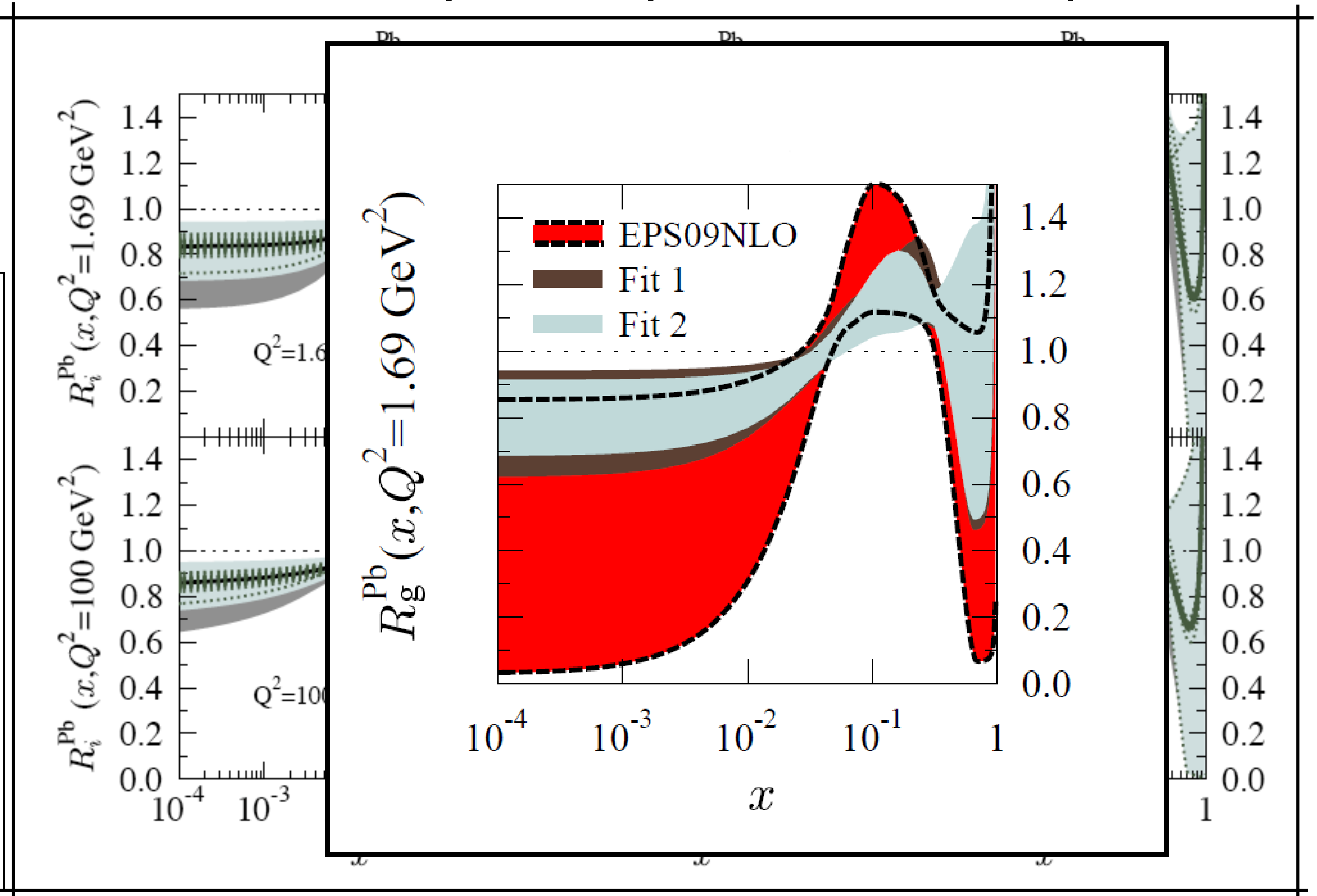


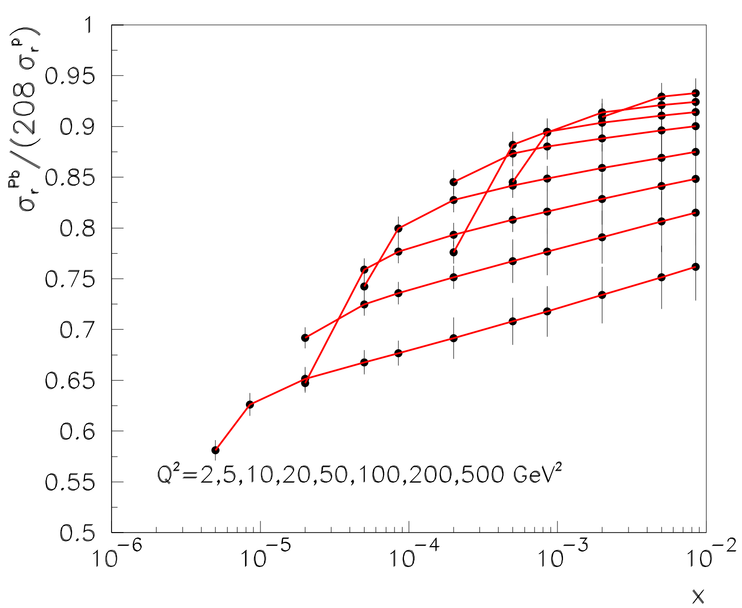
Note: F_L in eA

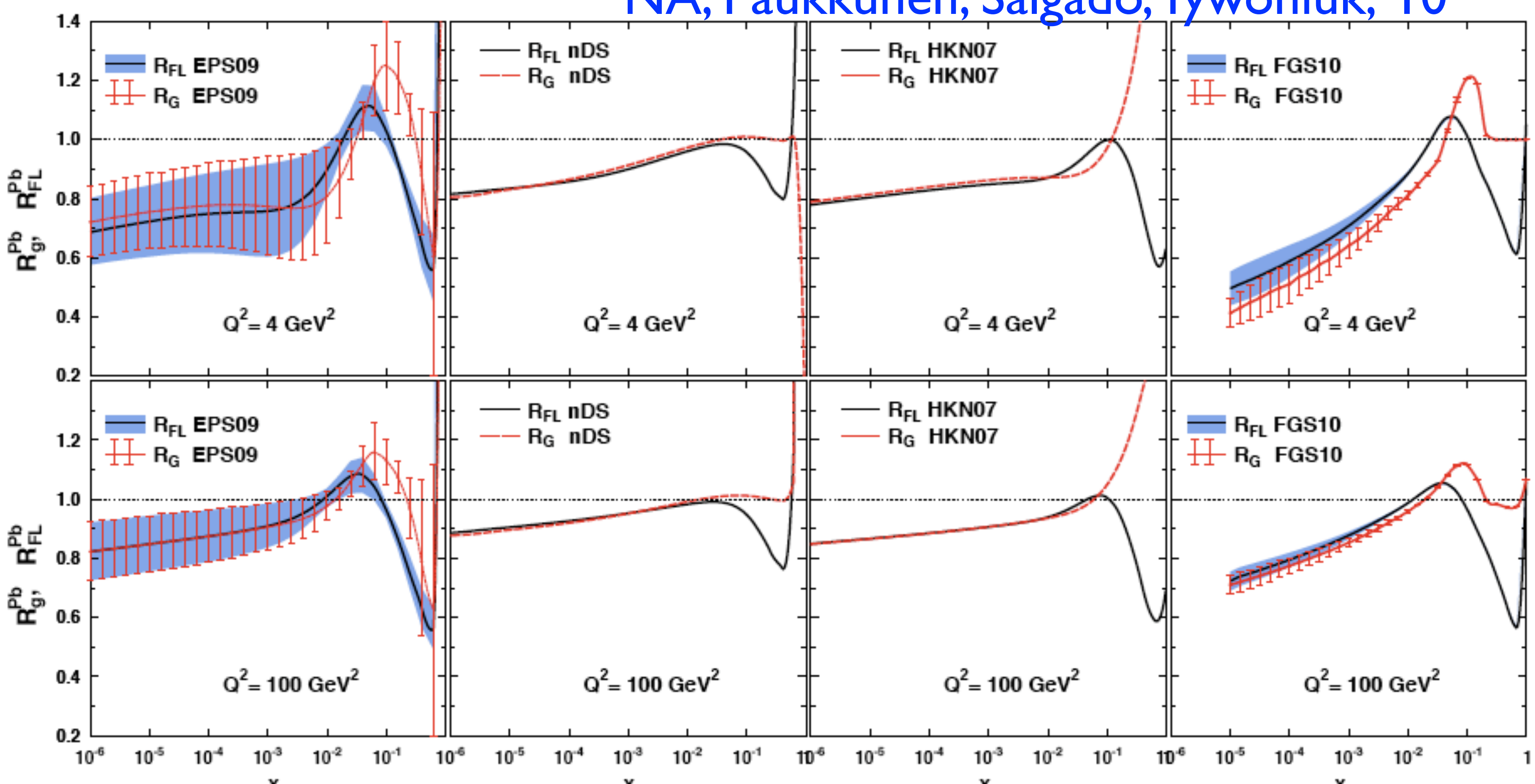
$$\sigma_r^{NC} = \frac{Q^4 x}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^{NC}}{dx dQ^2} = F_2 \left[1 - \frac{y^2}{Y_+}\frac{F_L}{F_2}\right], \qquad Y_+ = 1 + (1-y)^2$$

- 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

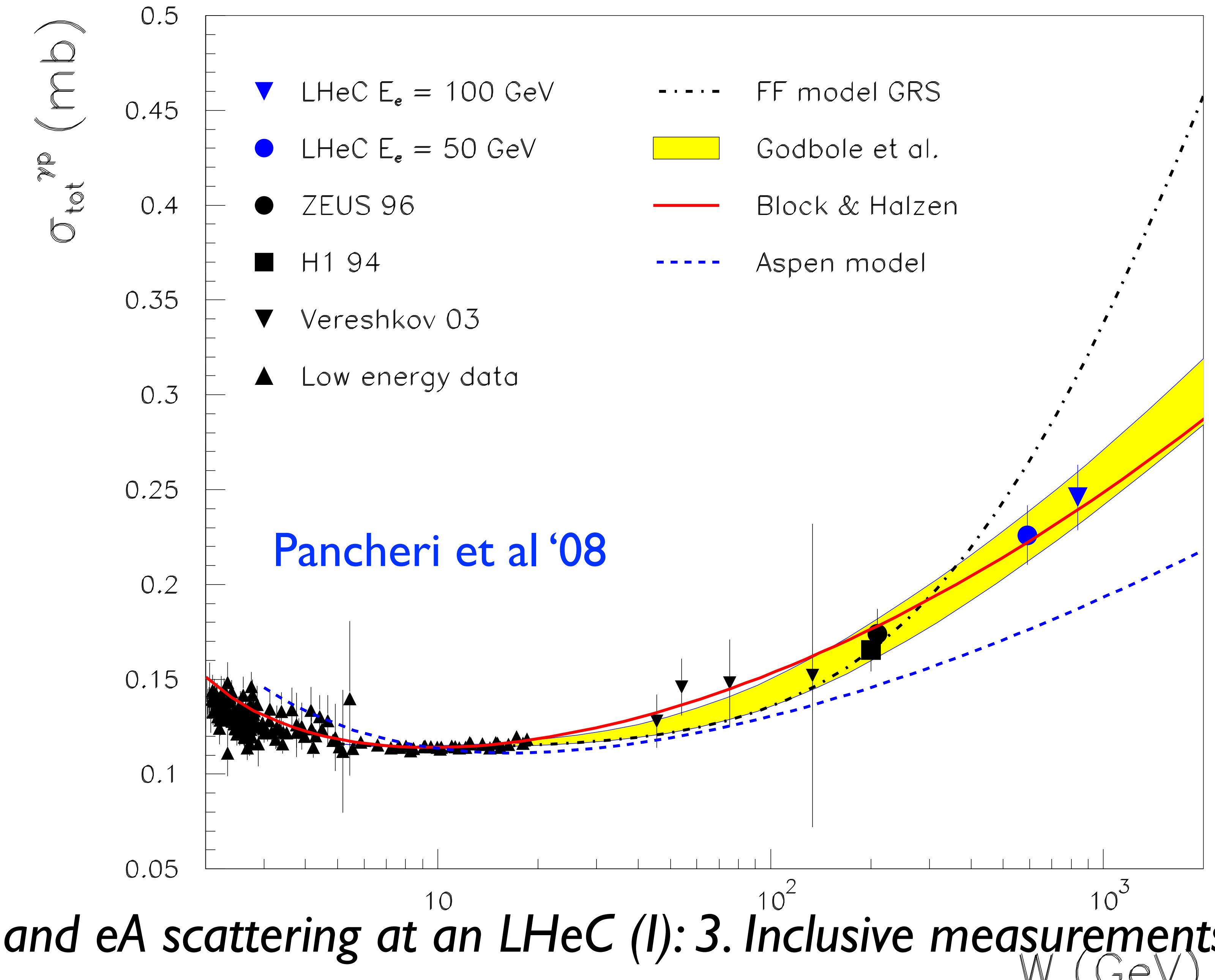




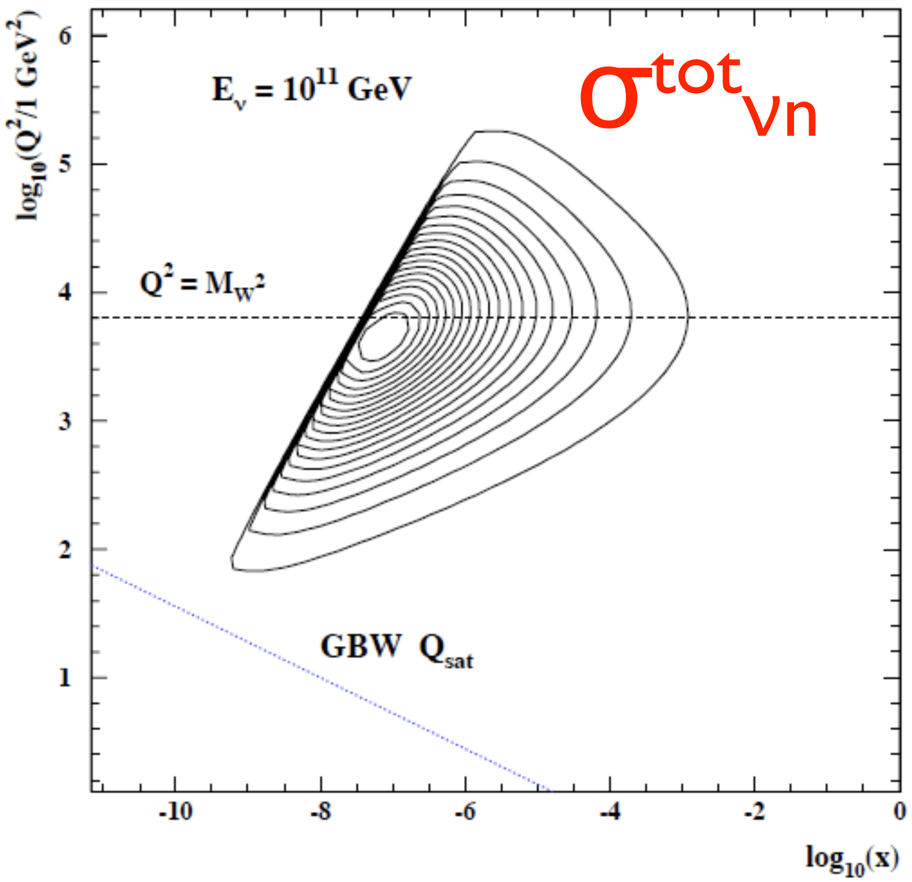
Photoproduction cross section:

- Small angle electron detector 62 m far from the interaction point: $Q^2<0.01$ GeV, $y \sim 0.3 \Rightarrow W \sim 0.5 \sqrt{s}$.

- Substantial enlarging of the lever arm in W.

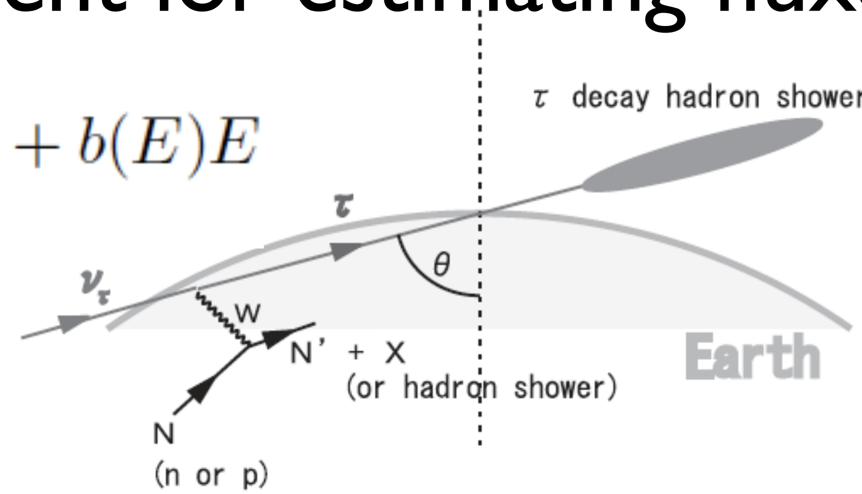


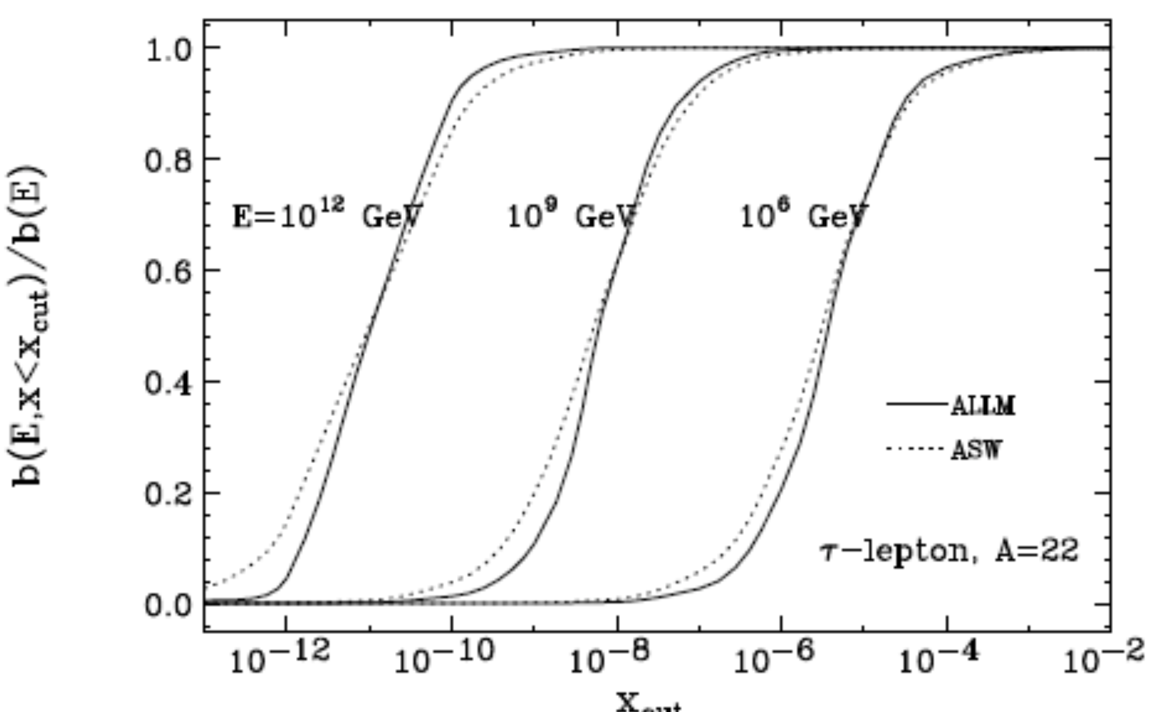
Implications for UHEν's:

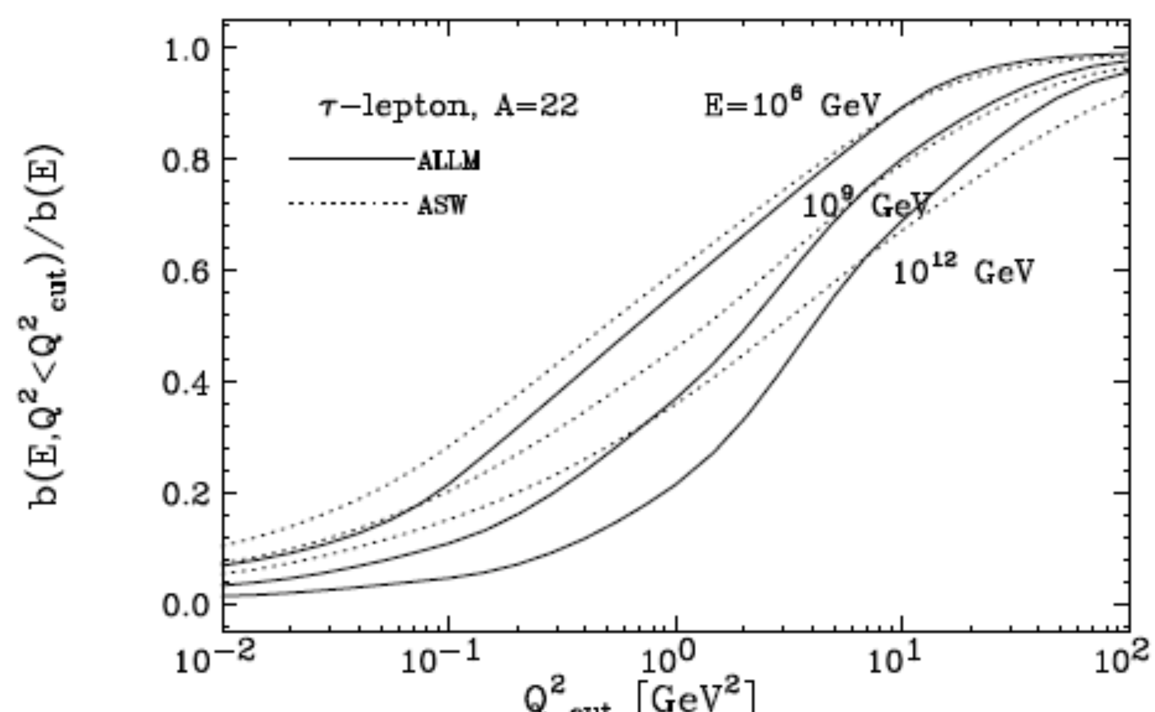


- ν-n/A cross section (τ energy loss) dominated by DIS structure functions / (n)pdfs at small-x and large (small) Q^2.
- Key ingredient for estimating fluxes.

$$-\left\langle \frac{dE}{dX} \right\rangle = a(E) + b(E)E$$







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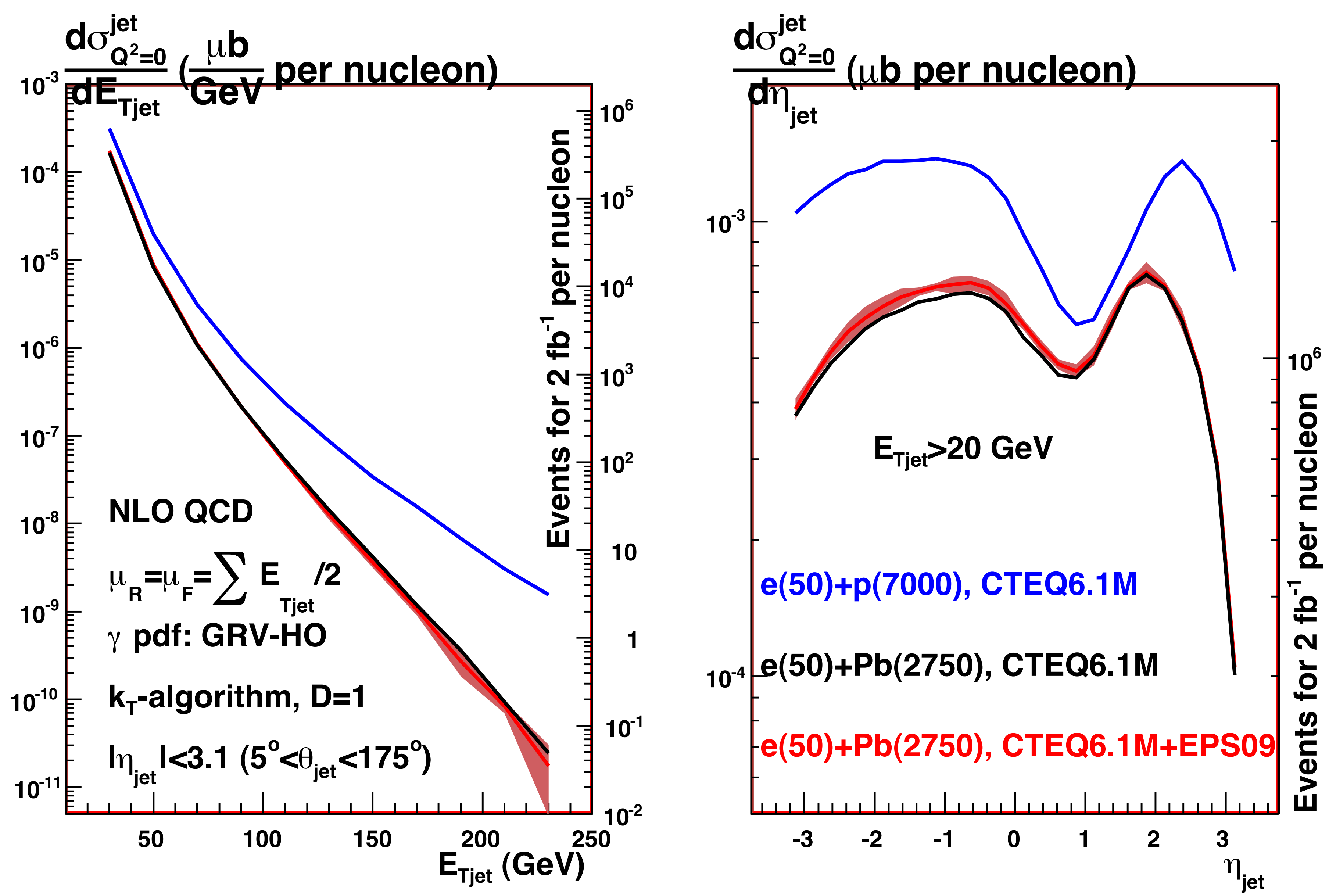
Jet photoproduction:



- 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.

Preliminary; LHeC Design Study Report, CERN 2012

Dijet azimuthal decorrelation:

- Studying forward jets ($p_T \sim Q$) or dijet azimuthal decorrelation would allow to understand the mechanism of radiation:

→ k_T-ordered: DGLAP.

→ k_T-disordered: BFKL.

→ Saturation?

- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.

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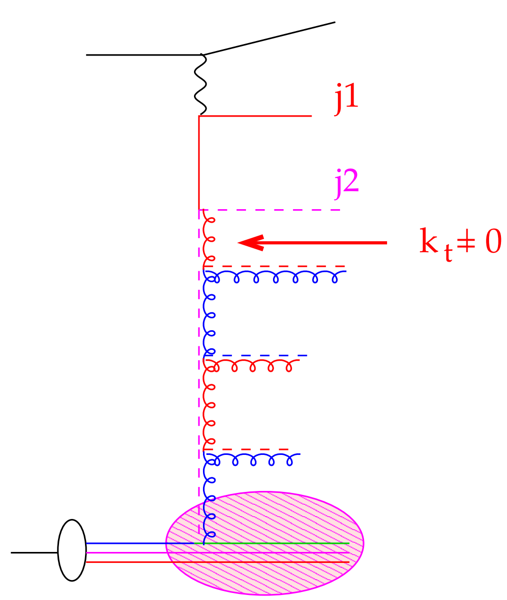
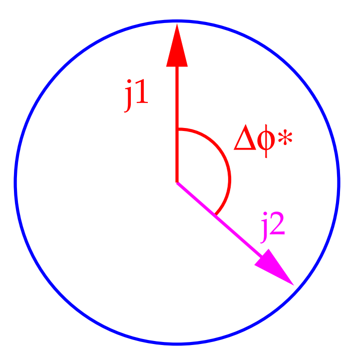
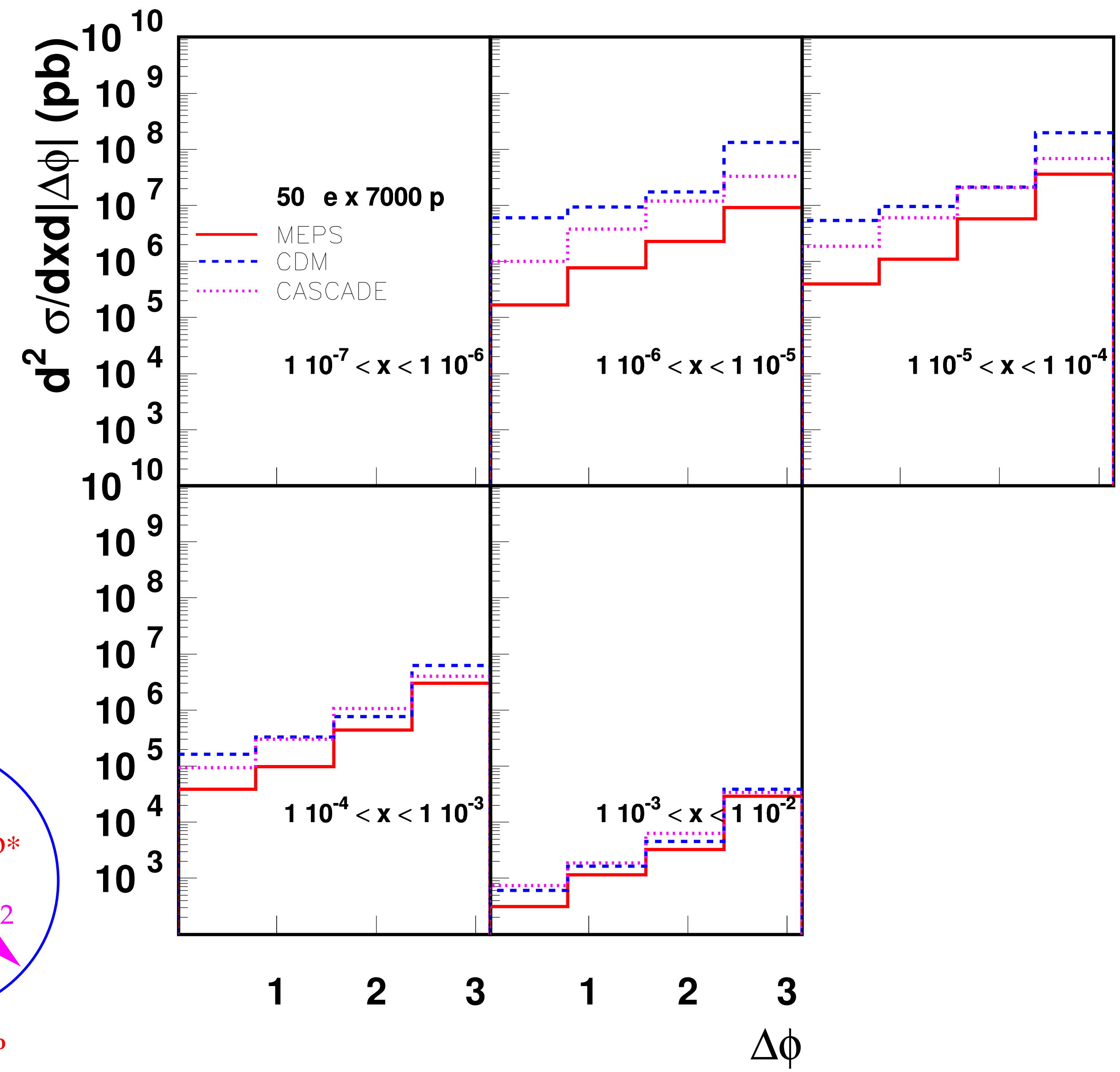




$\Delta\phi^* < 120^o$



Forward jets:

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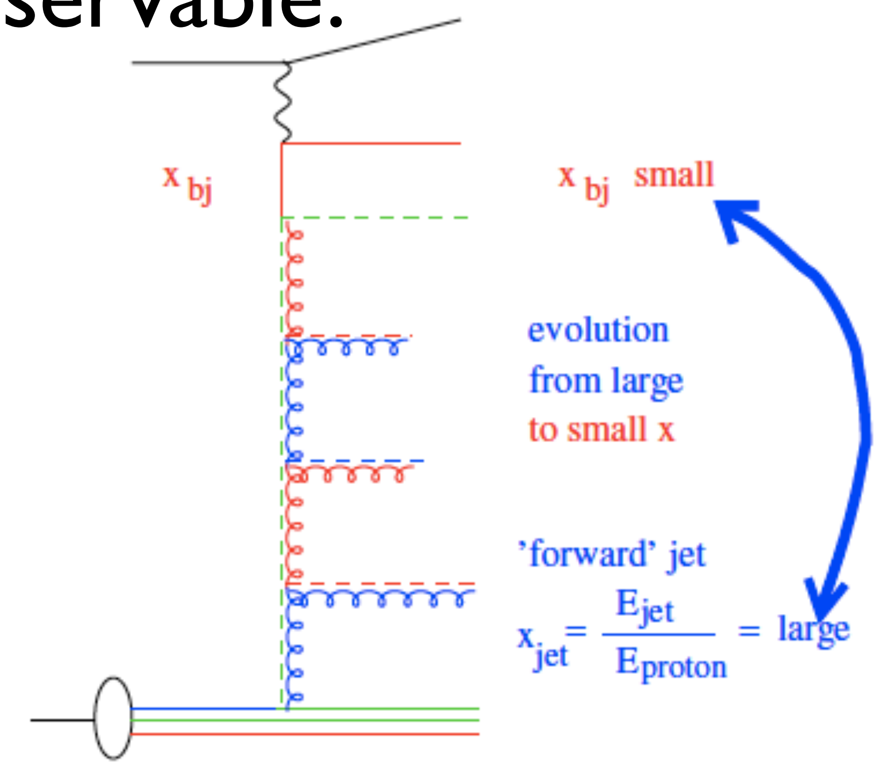
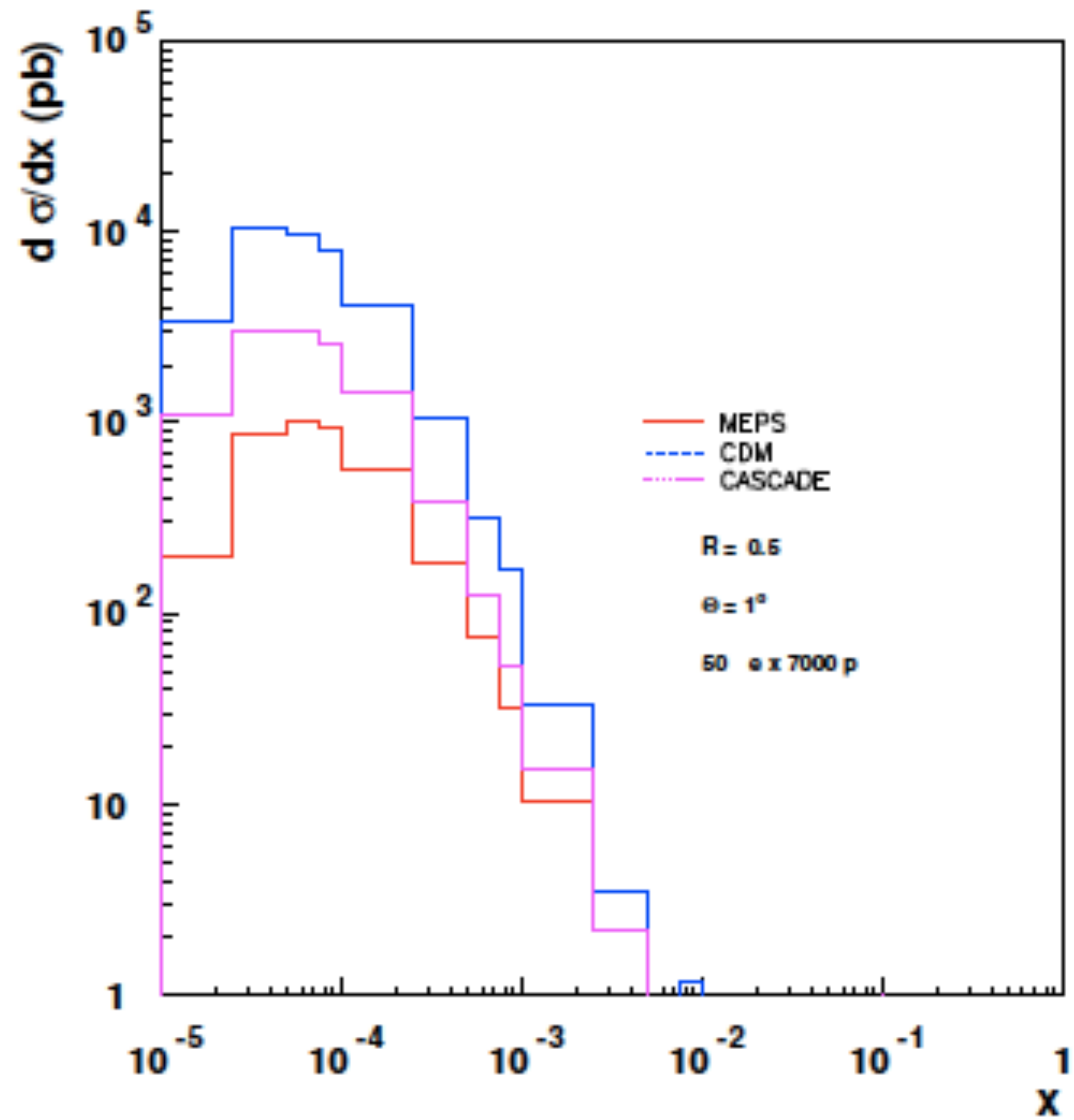
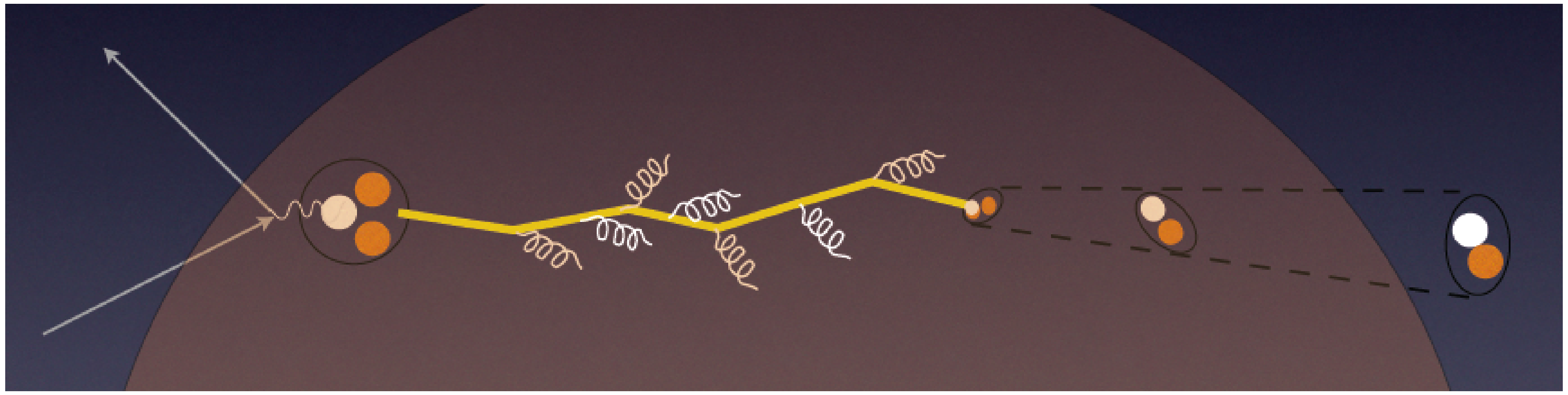




In-medium hadronization (I):

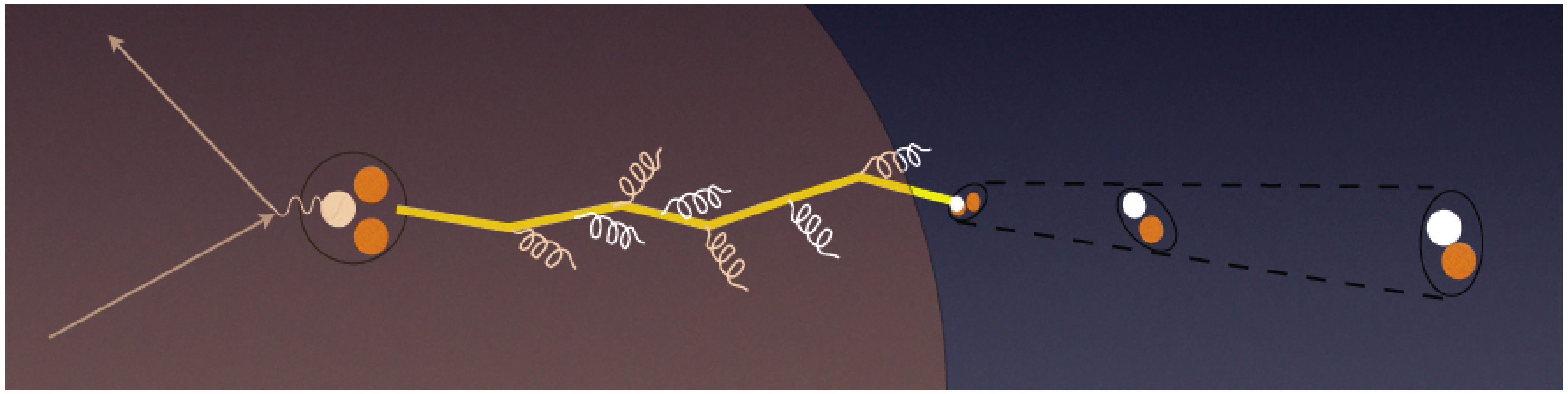
- The LHeC ($\nu_{max}\sim 10^5$ GeV) would allow to study the dynamics of hadronization, testing the parton/hadron eloss mechanism by introducing a length of colored material which would modify its pattern (length/nuclear size, chemical composition).

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



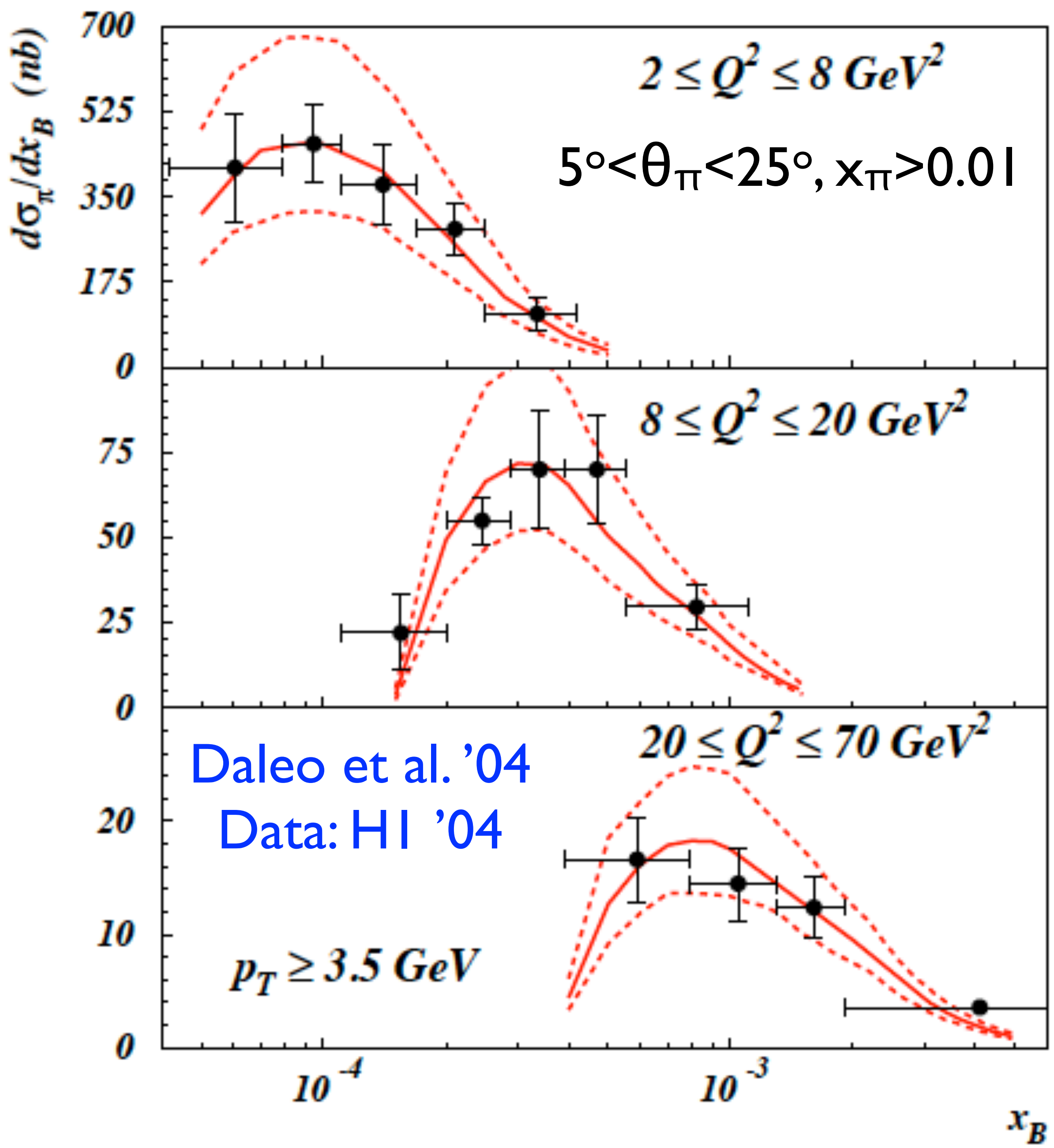
Brooks at Divonne'09

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

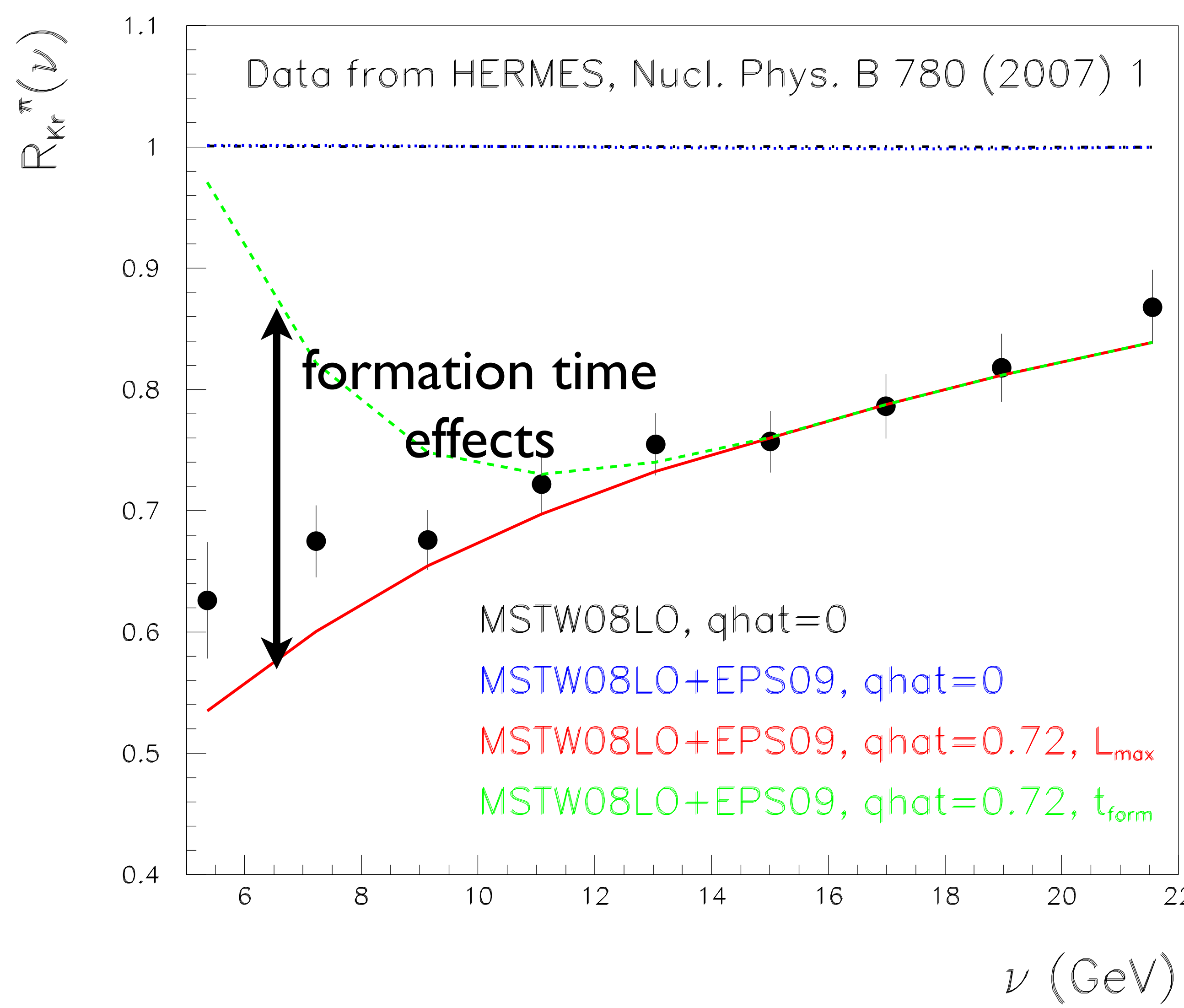


In-medium hadronization (II):

- 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).

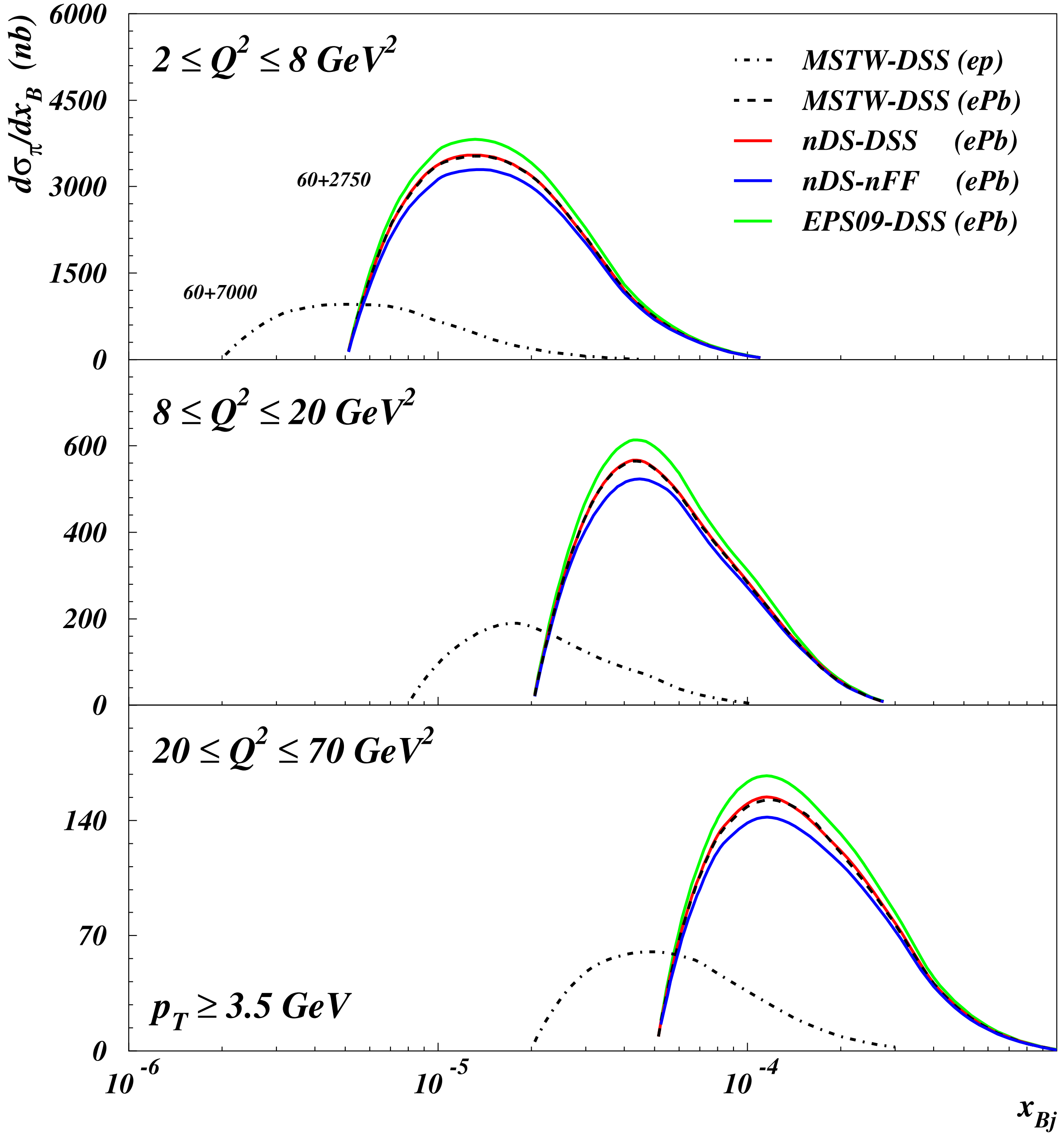


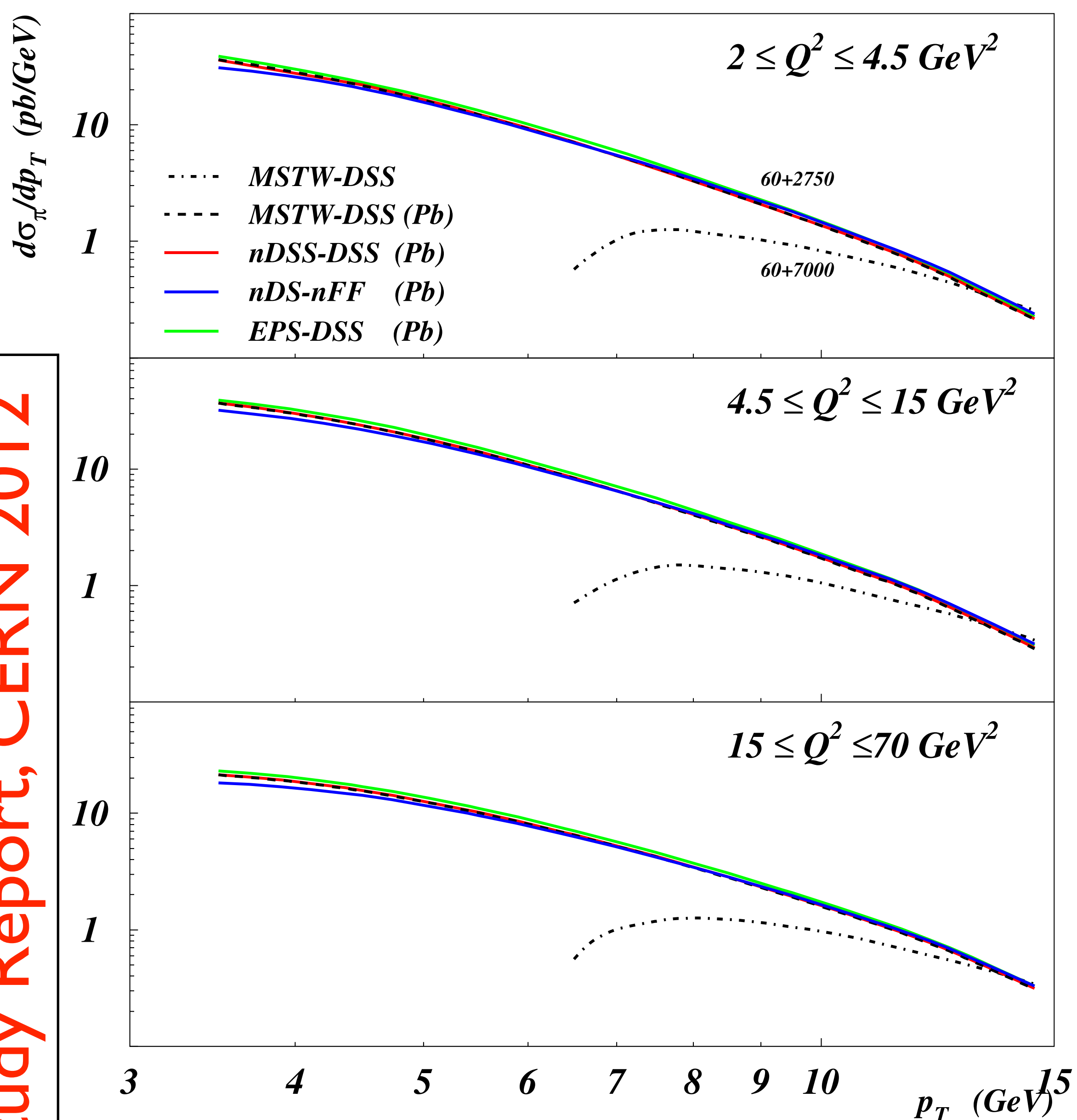
$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{dN_A^h(z,\nu)}{d\nu\, dz} \Bigg/ \frac{1}{N_D^e}\frac{dN_D^h(z,\nu)}{d\nu\, dz}$$



In-medium hadronization (II):

- 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).





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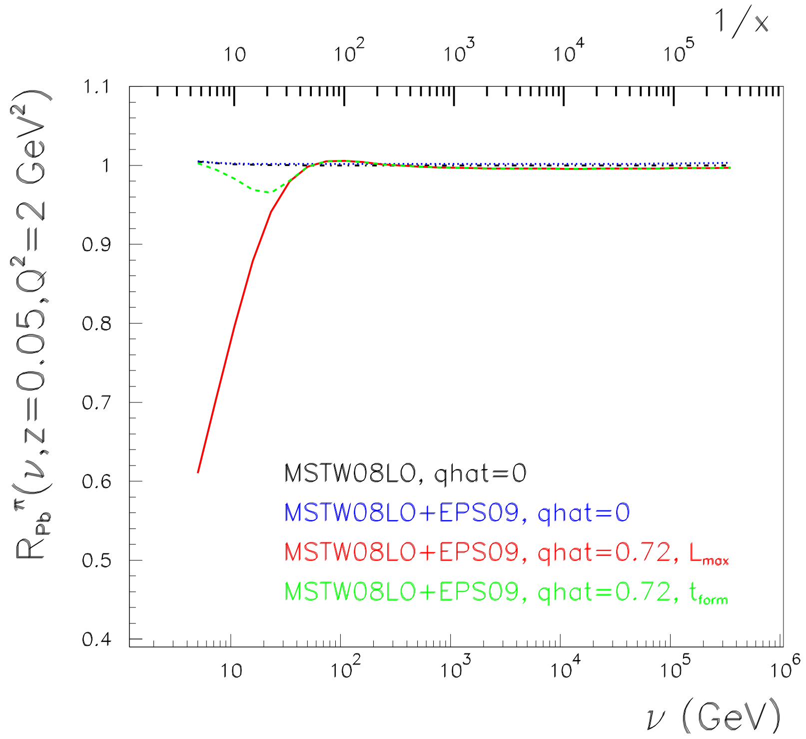

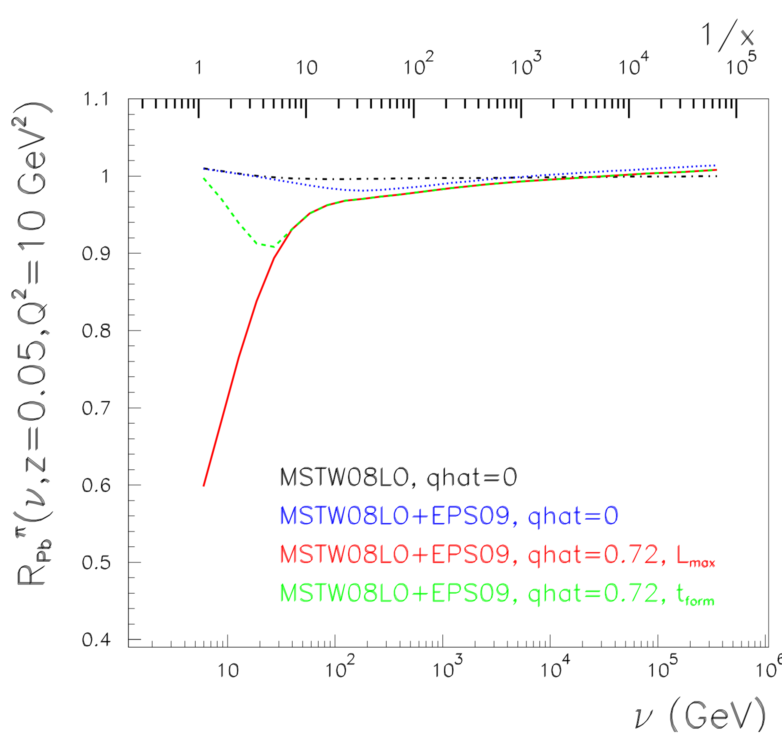

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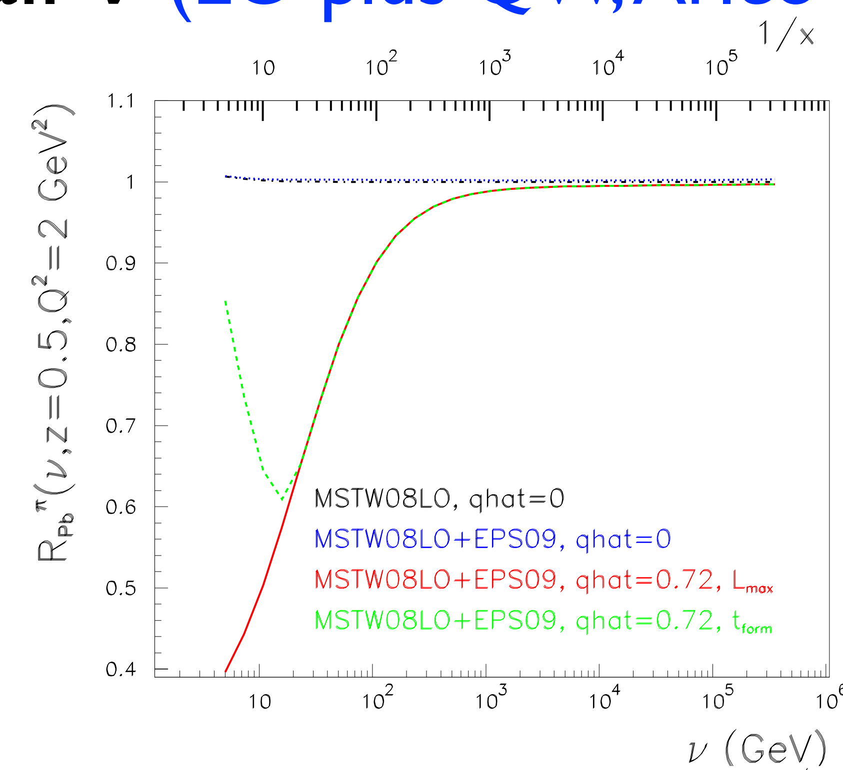

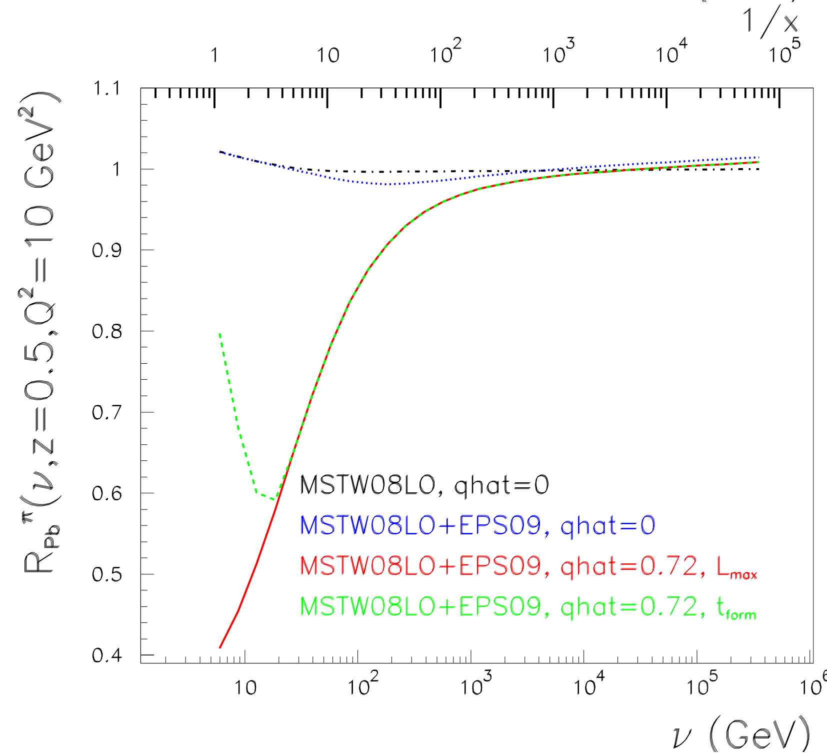

Summary:

- Many issues remain open about precision perturbative QCD and small-x physics.
- Pdfs: current ep experiments cover pp@LHC at y=0; in eA, not even dAu@RHIC is really constrained.
- An ep/eA collider offers huge possibilities to test our ideas about QCD: hadron structure, high-energy behavior, radiation,...
- **eA**: amplifier of density effects, implications on UrHIC complementary to pA@LHC.
- ***At an LHeC@CERN***:
  - ➜ Unprecedented access to small x in p and A for pdfs.
  - ➜ Novel sensitivity to physics beyond standard pQCD.
  - ➜ Stringent tests of the dynamics of QCD radiation.
  - ➜ ...

See A. Stasto's talk for diffractive observables @ LHeC.

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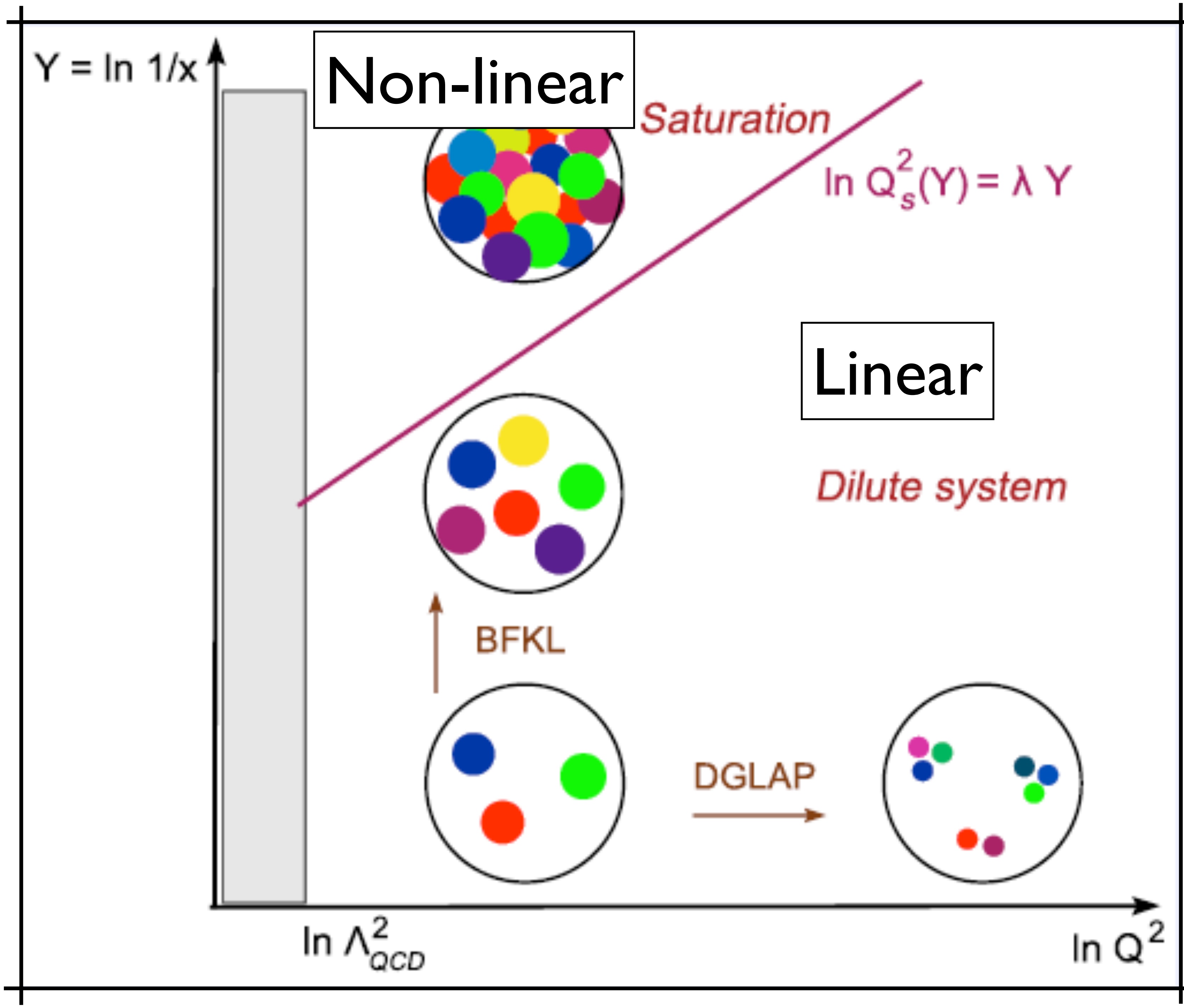
Backup:

High-energy QCD:

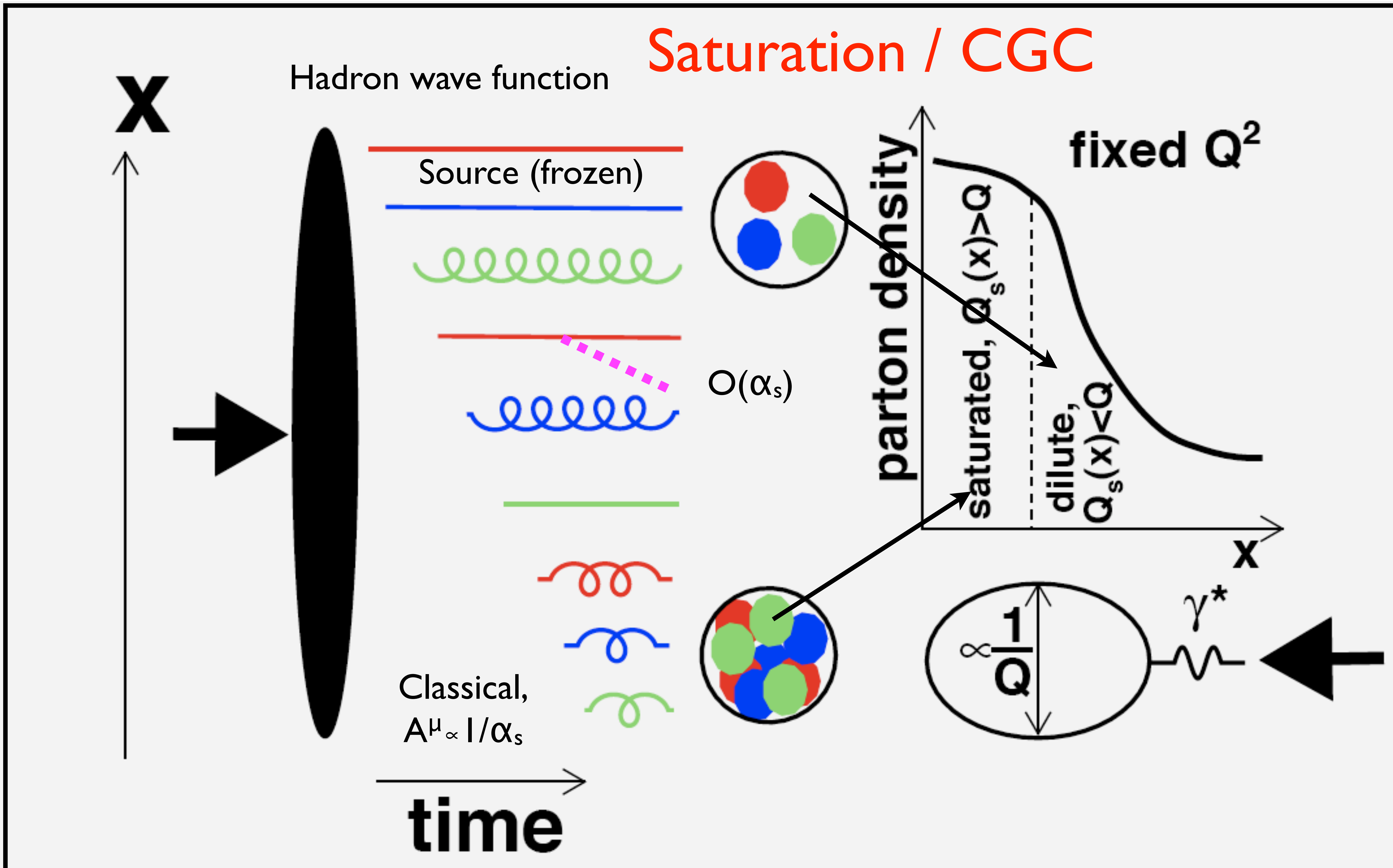


Where do the available experimental data lie?

Our aims: understanding

- The implications of unitarity in a QFT.
- The behavior of QCD at large energies / hadron wave function at small x.
- The initial conditions for the creation of a dense medium in heavy-ion collisions: nuclear WF + initial stage.

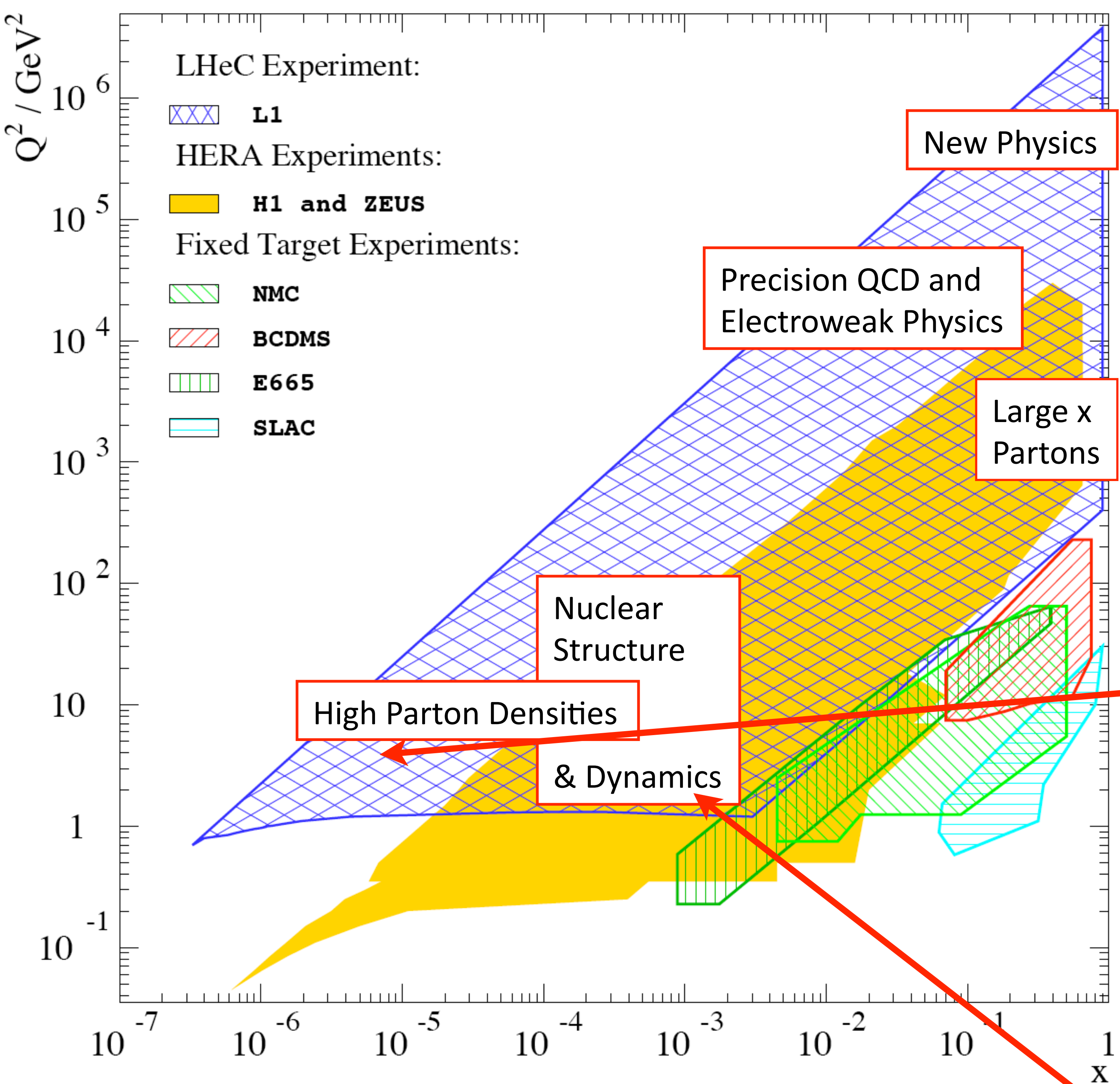
High-energy QCD:



experimental data lie?

initial stage.

Physics goals:

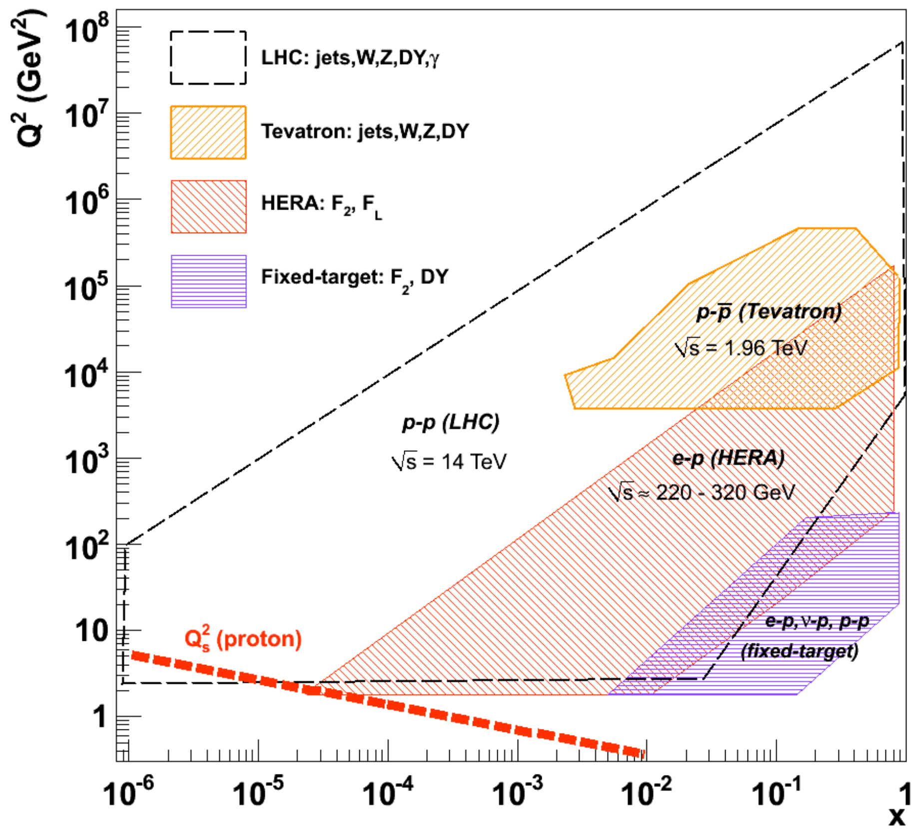


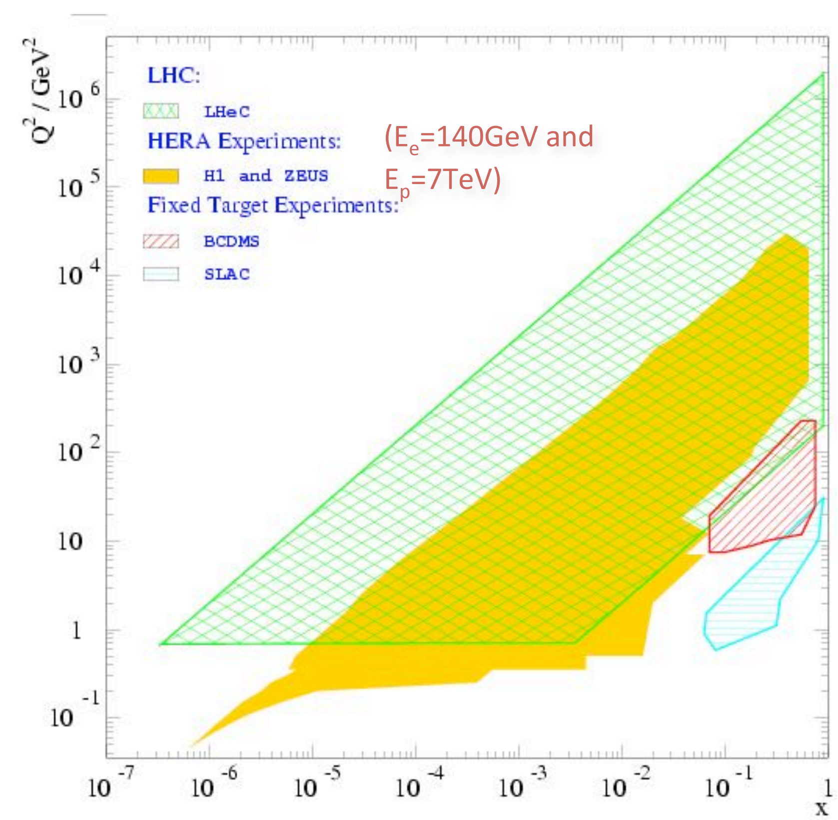
- Proton structure to a few 10^{-20} m: Q^2 lever arm.
- Precision QCD/EW physics.
- High-mass frontier (leptoquarks, excited fermions, contact interactions).
- Unambiguous access, in ep and eA, to a qualitatively novel regime of matter predicted by QCD.
- Substructure/parton dynamics inside nuclei with strong implications on QGP search.

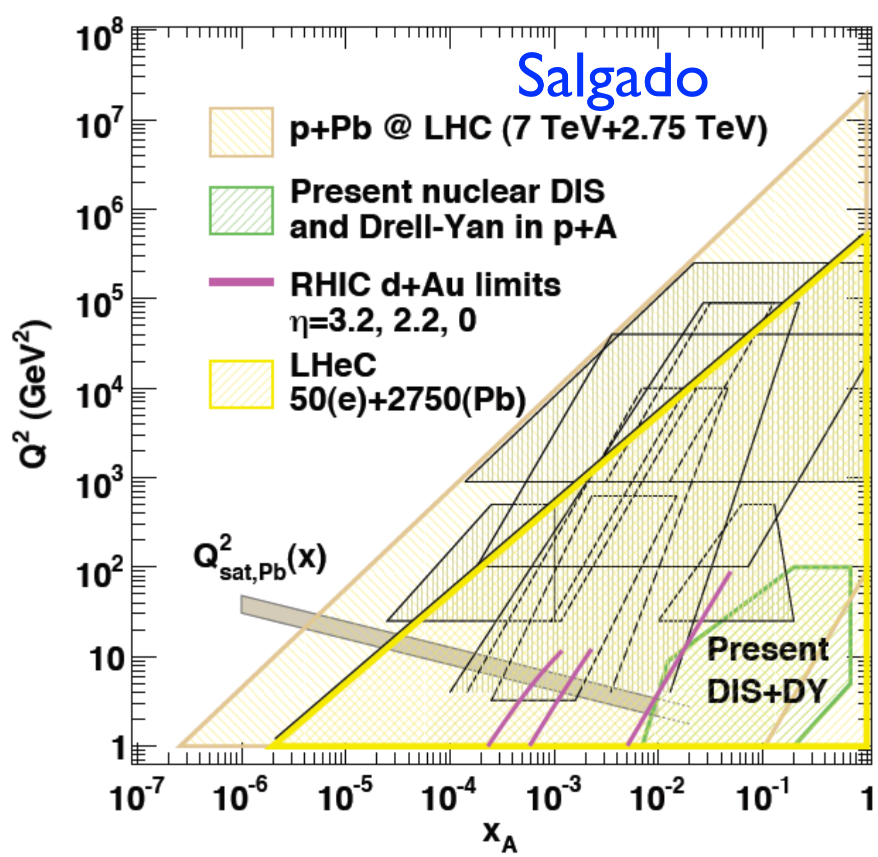
Low-x Physics in ep and eA scattering at an LHeC (I): 2. Kinematical coverage of an LHeC.

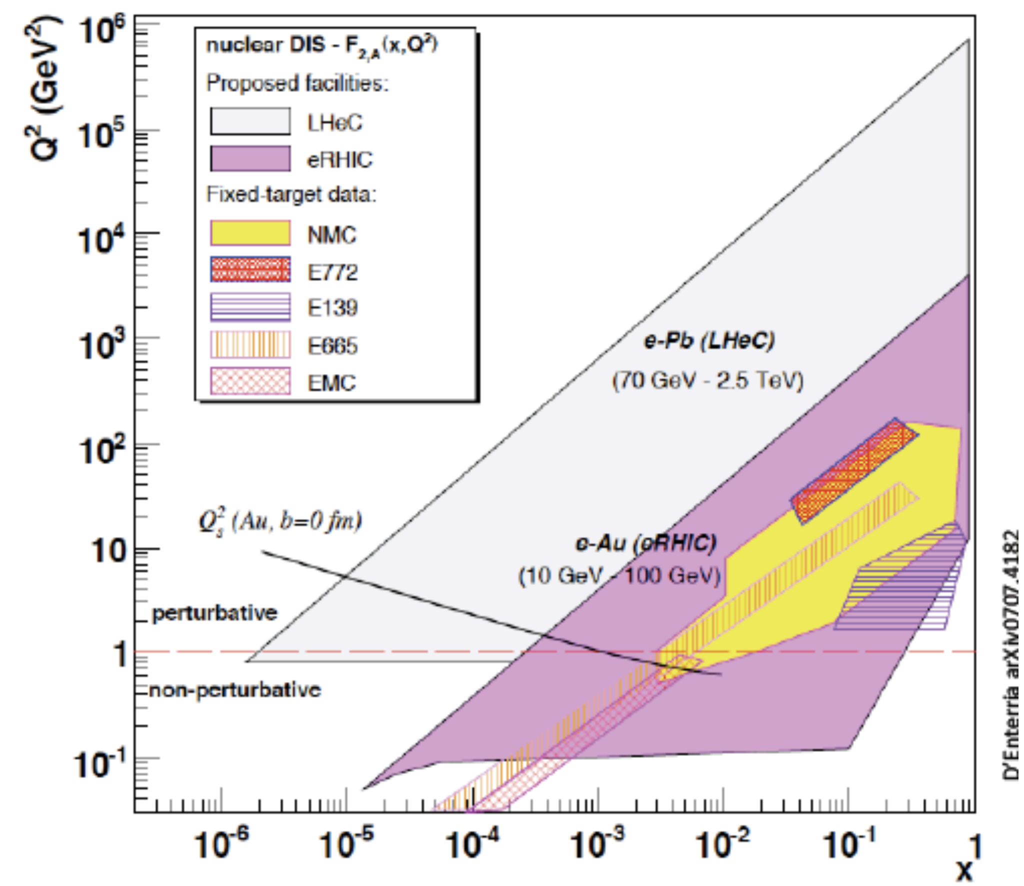
Kinematics: LHC vs. LHeC

d'Enterria





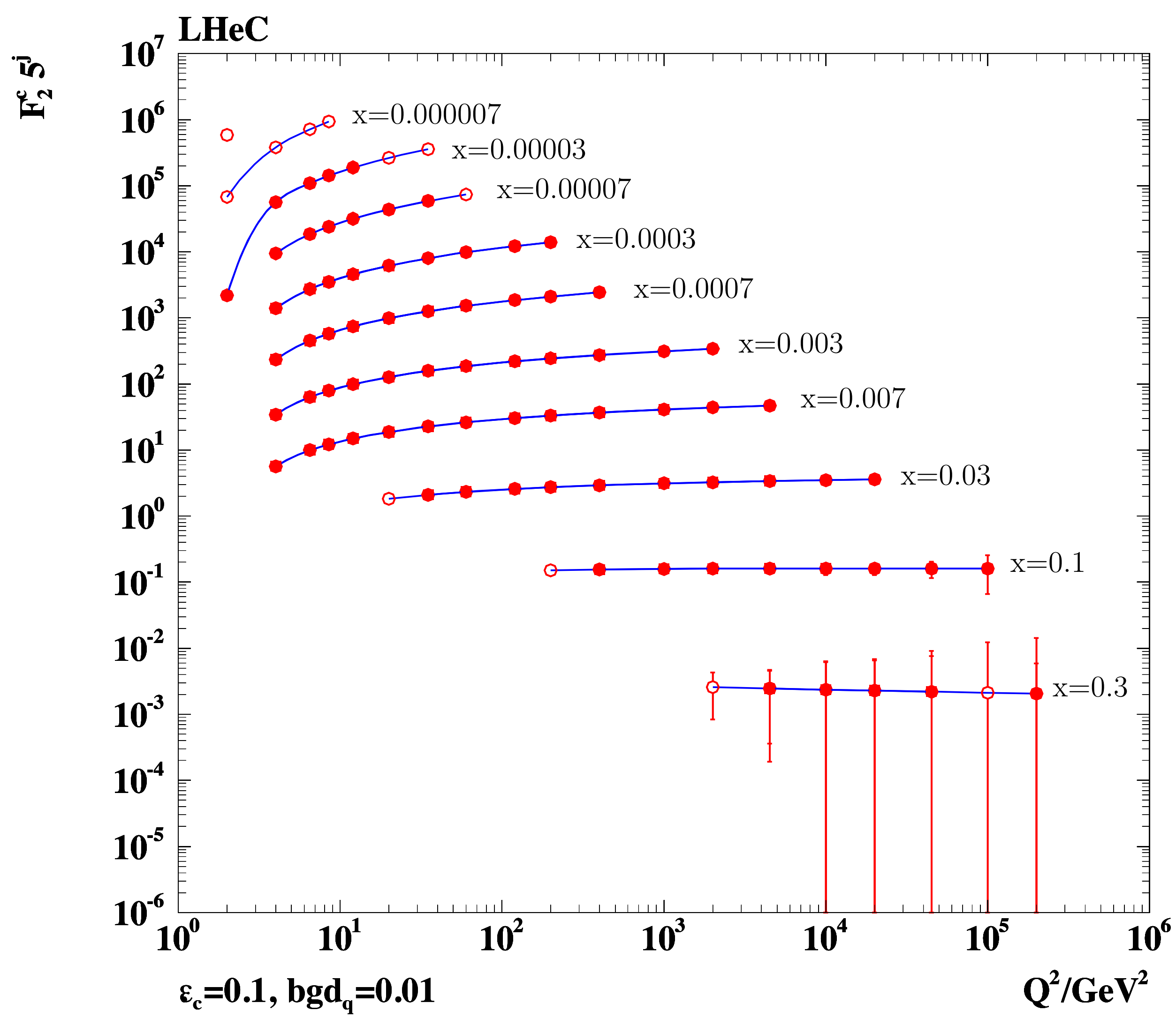


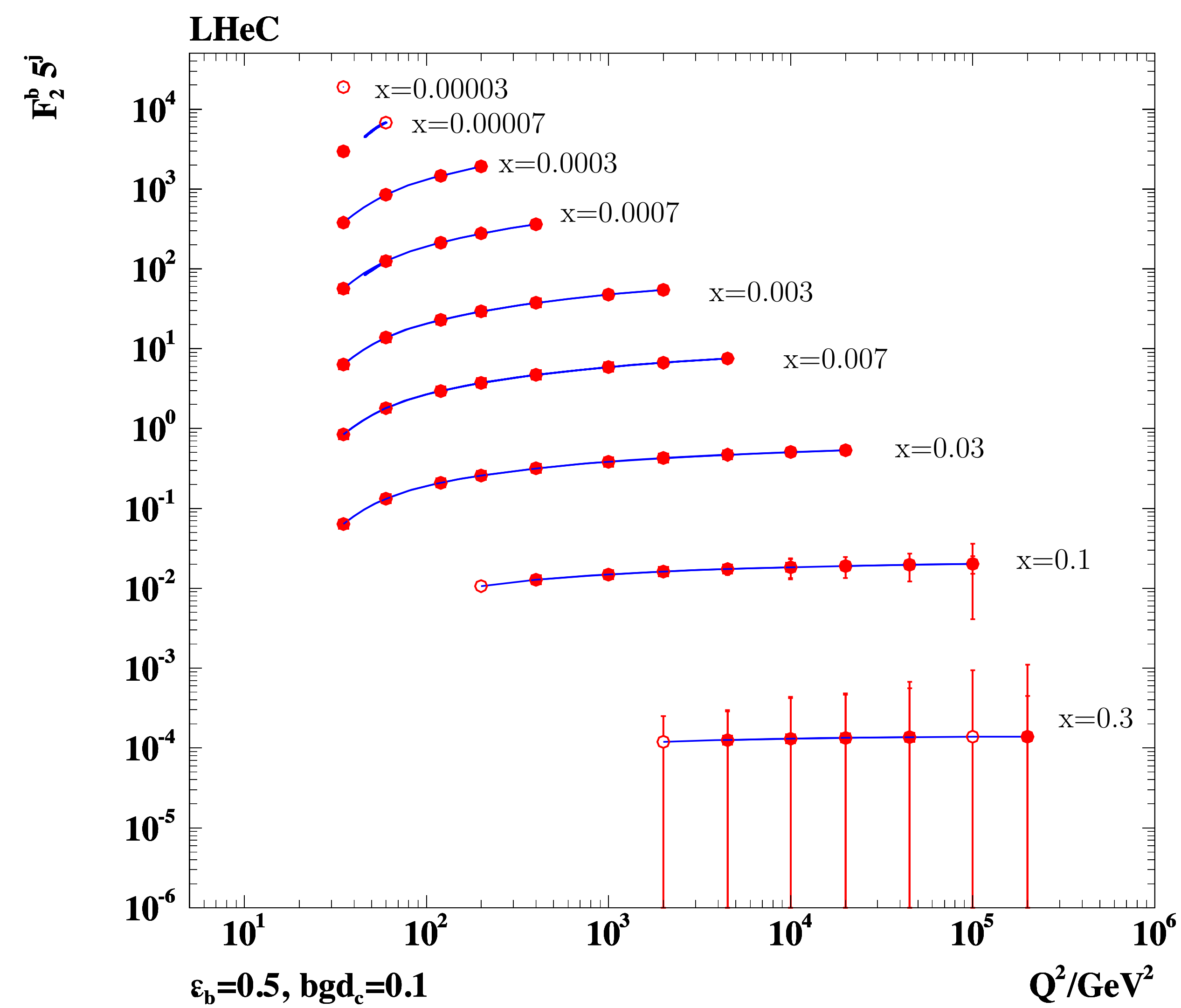


Low-x Physics in ep and eA scattering at an LHeC (I): 2. Kinematical coverage of an LHeC.

Charm and beauty:

- Charm and beauty most important (HERApdf; systematics half than at H1).





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