AA-pA-eA complementarity

[also some ep complementarity]

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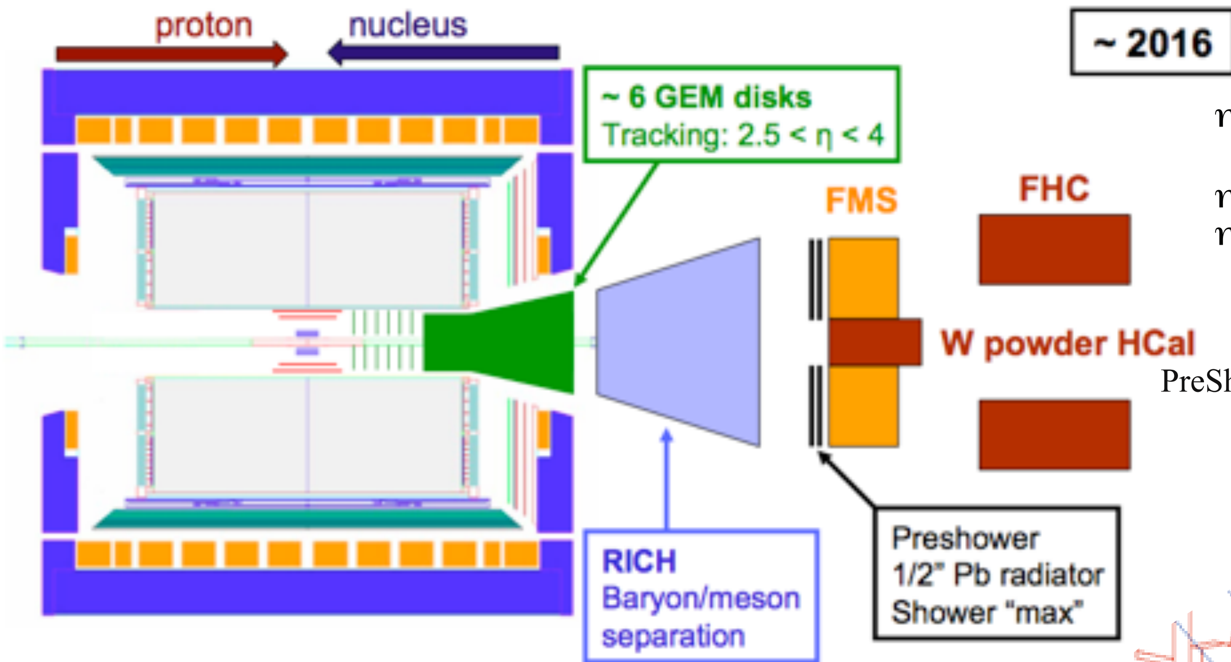
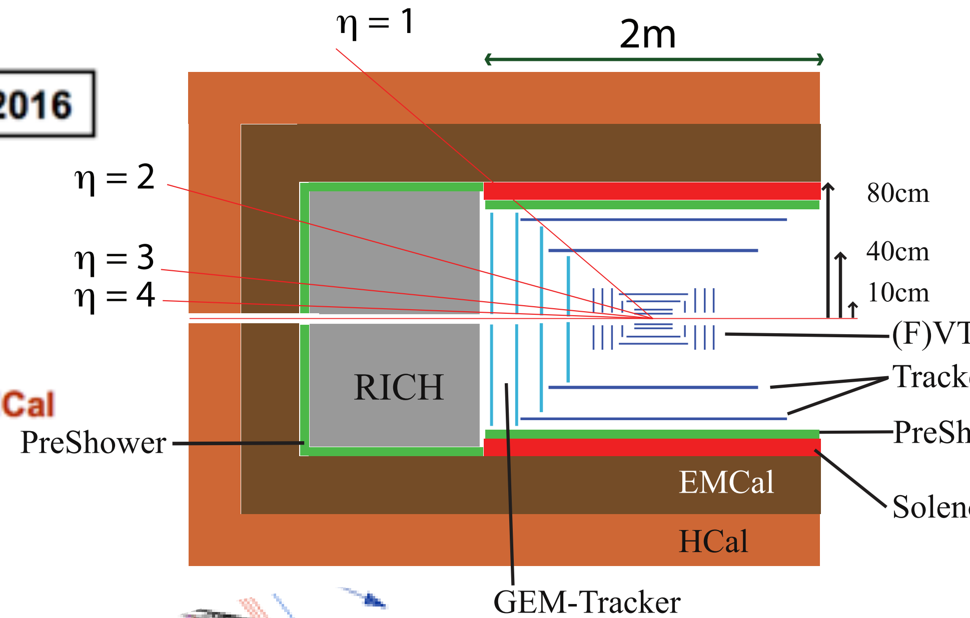
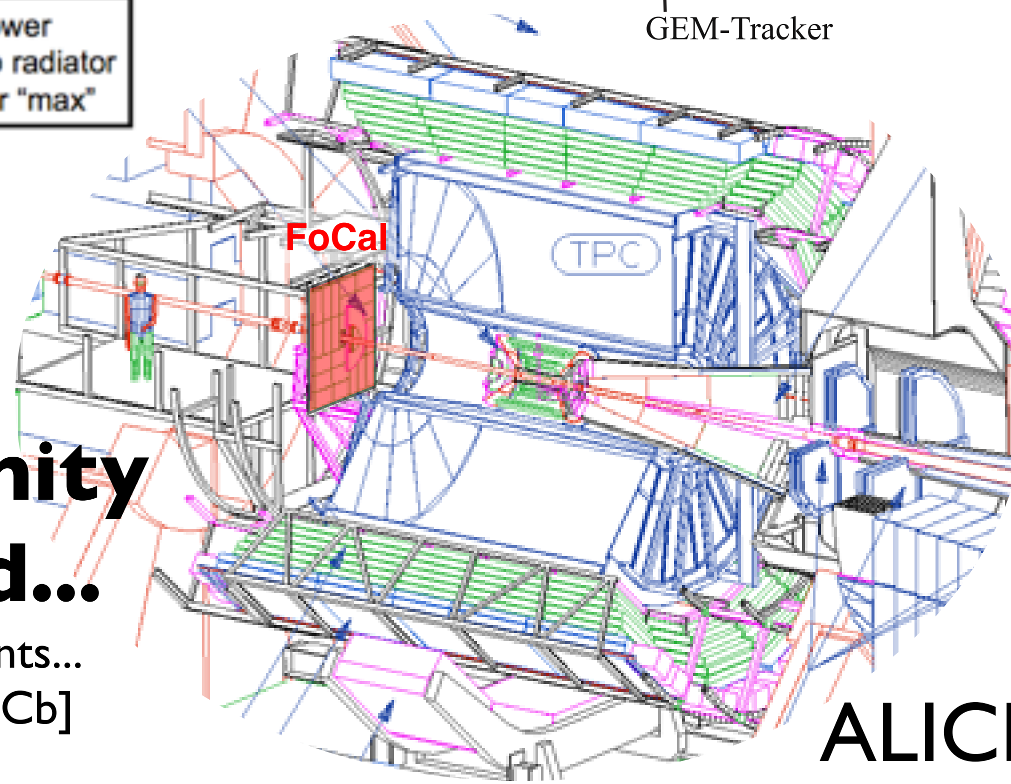
STAR



PHENIX





ALICE

The heavy-ion community plans to move forward...

[for the more nuclear/QCD oriented experiments... Interesting upgades also in ATLAS, CMS and LHCb]

New lepton-proton/nucleus colliders being planned

BROOKHAVEN NATIONAL LABORATORY

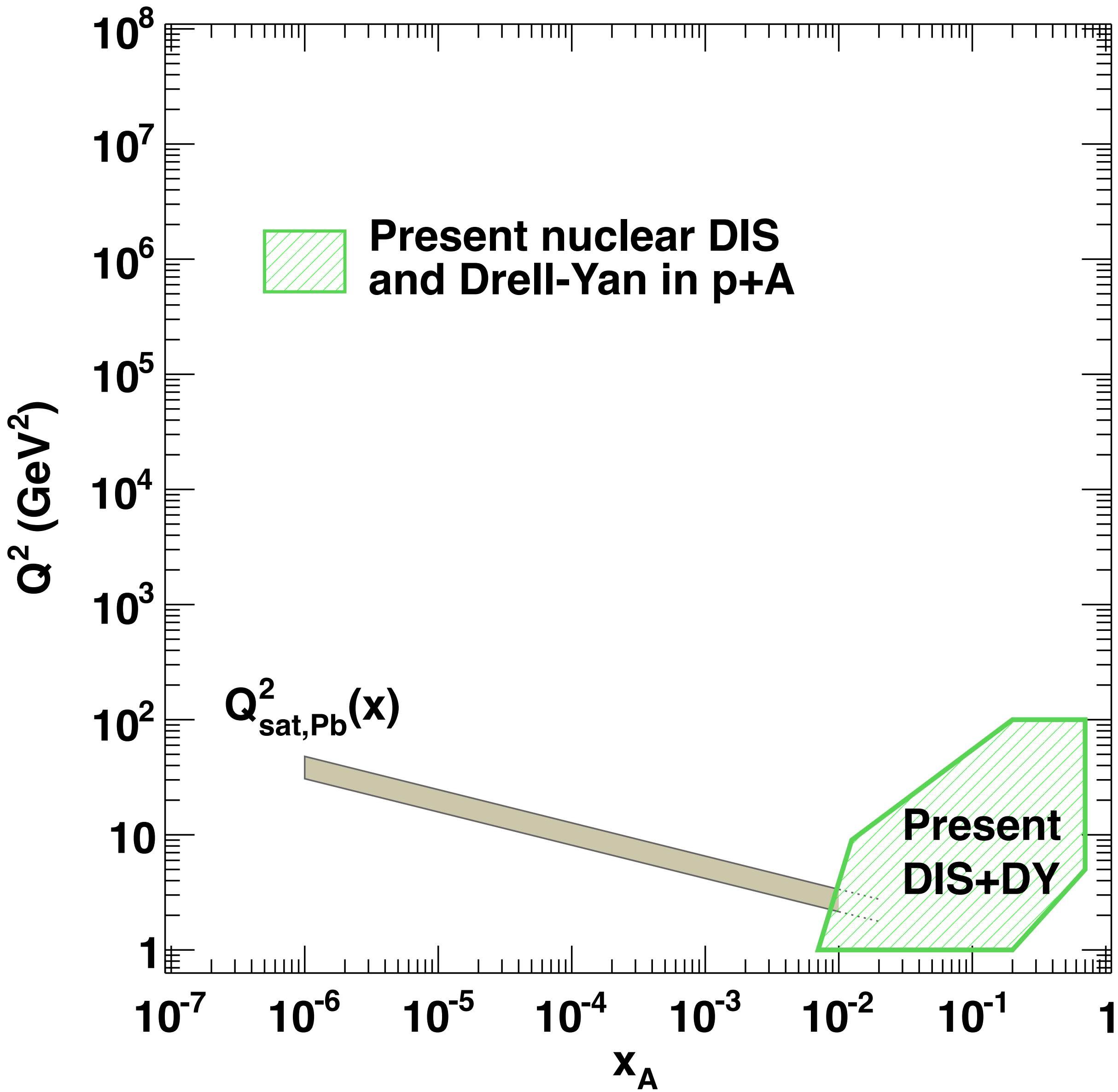
Jefferson Lab

LHeC

CERN European Organization for Nuclear Research

LHC and RHIC experiment upgrades will precede the (eventual) operation of LHeC and/or EIC - **Complementarity**

Kinematical reach in nuclear collisions



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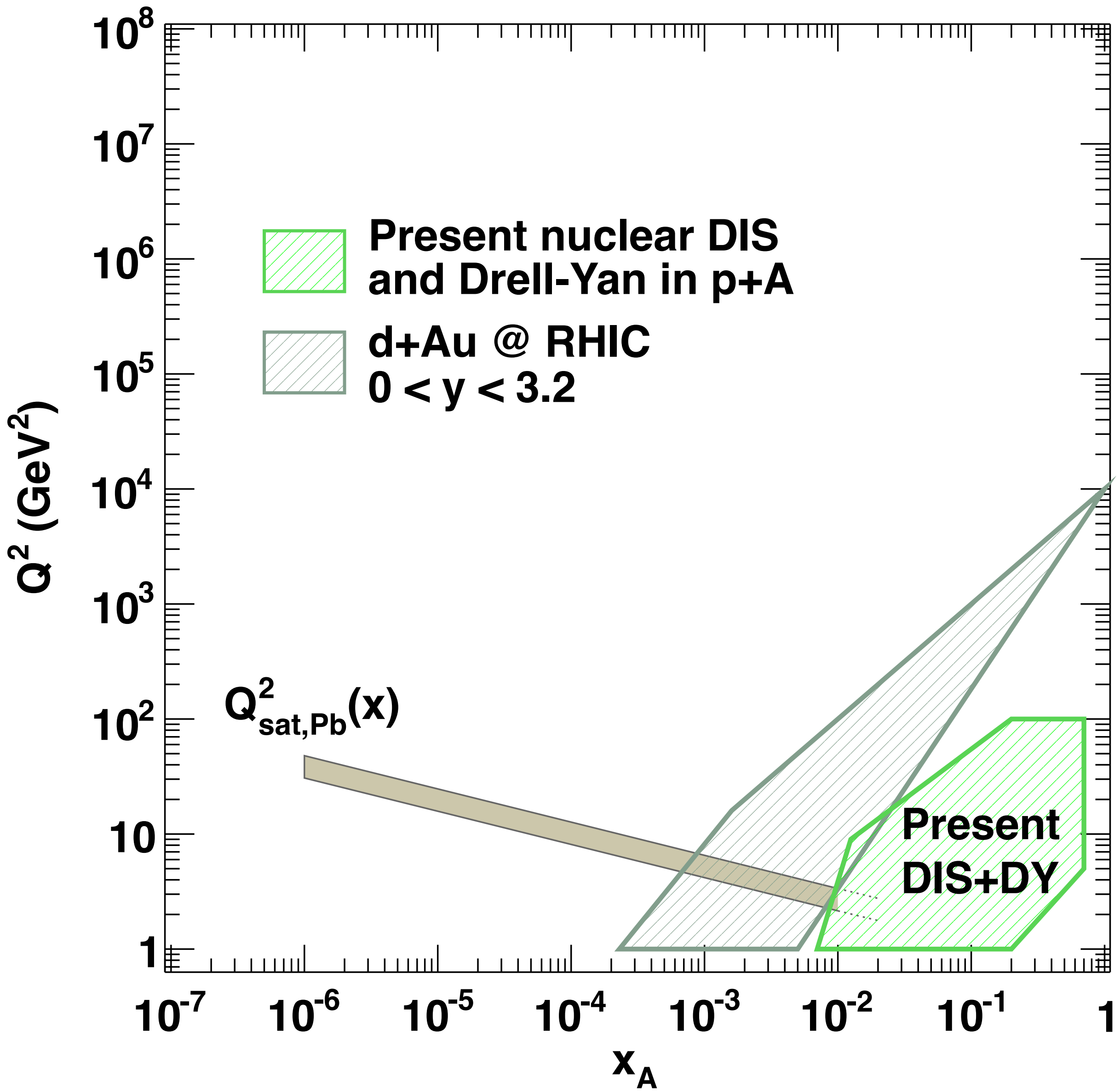

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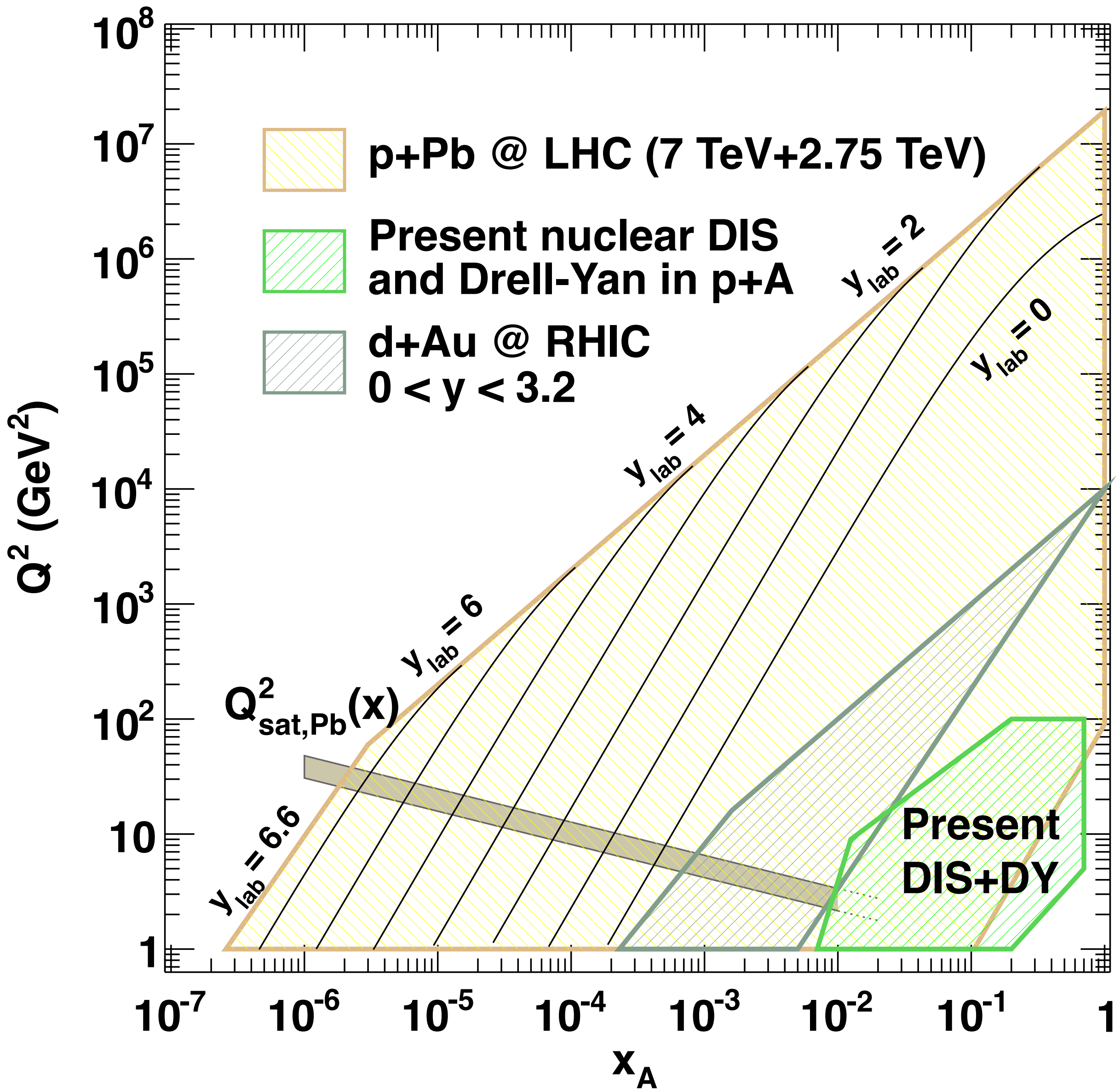

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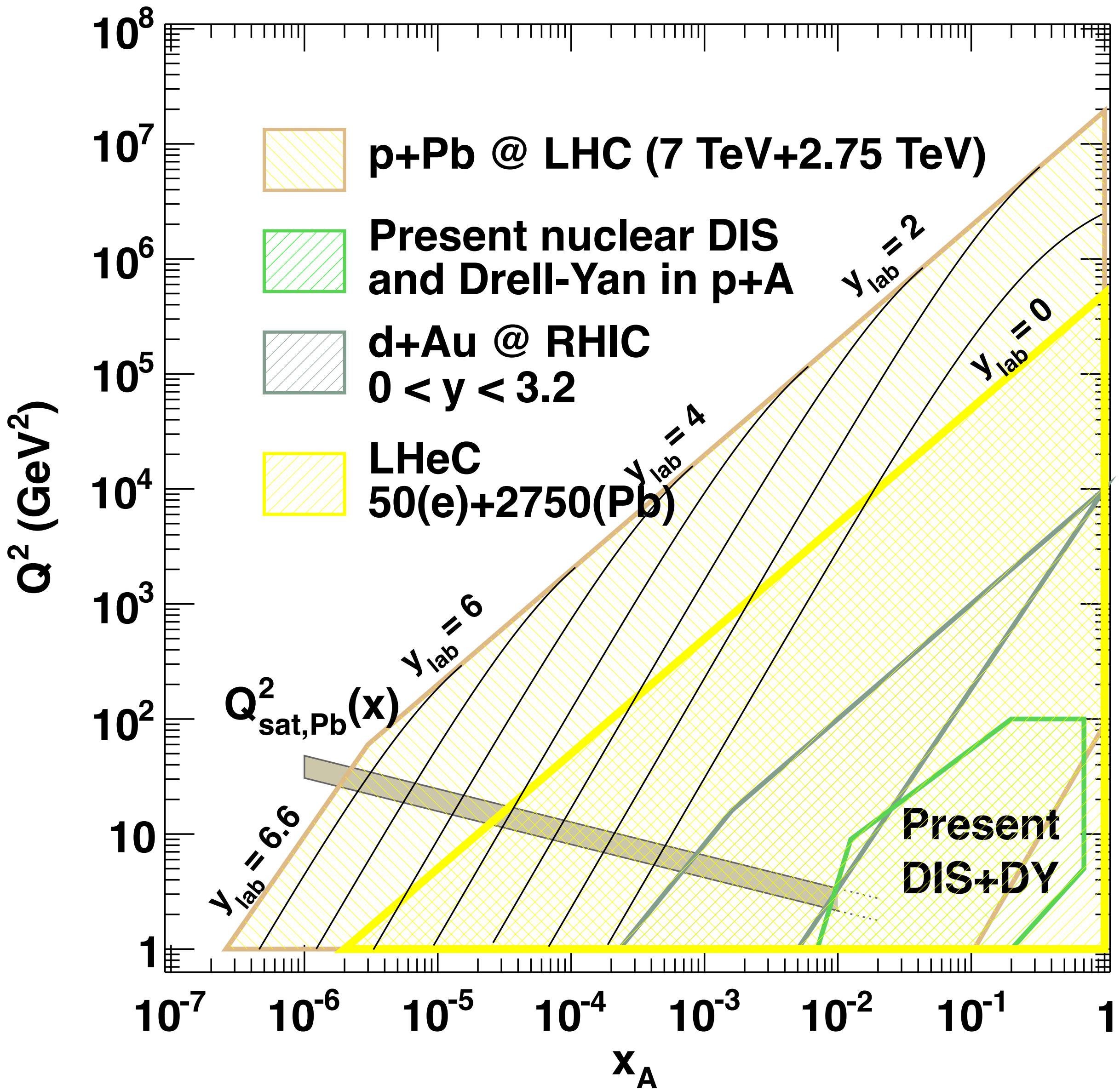
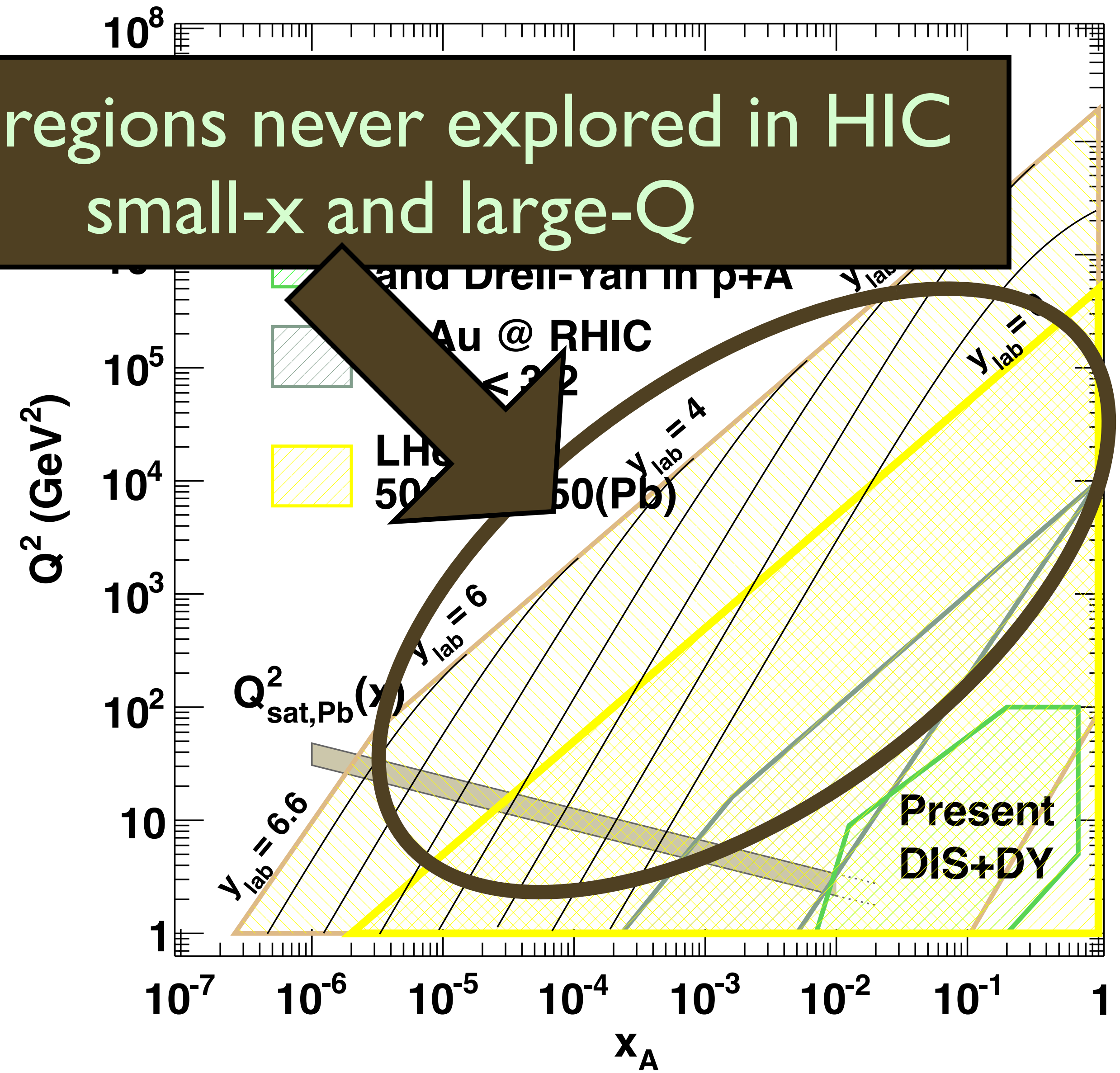


Kinematical reach in nuclear collisions

New regions never explored in HIC
small-x and large-Q



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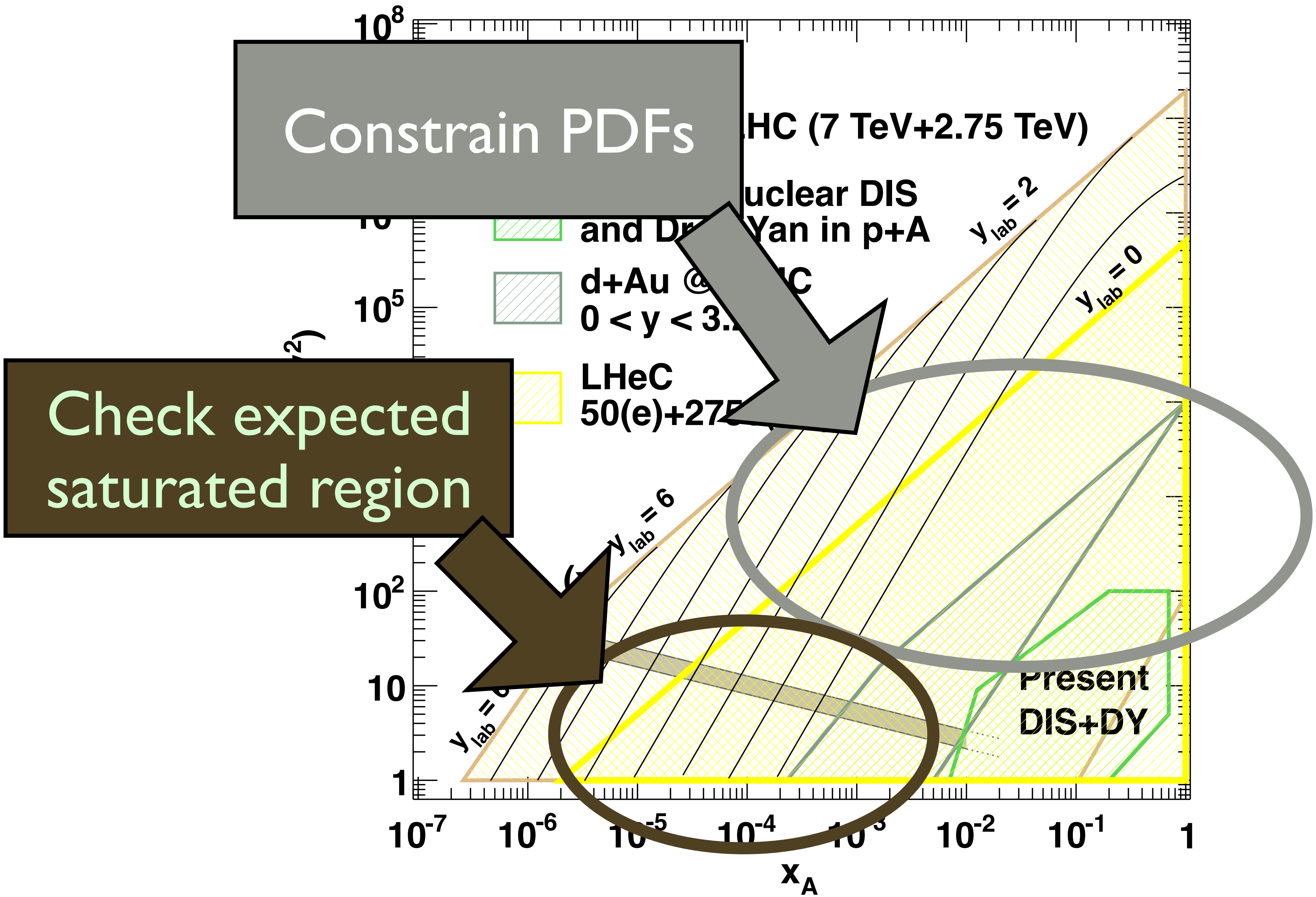


Proton-nucleus at the LHC

Feasibility checks performed - estimate luminosity

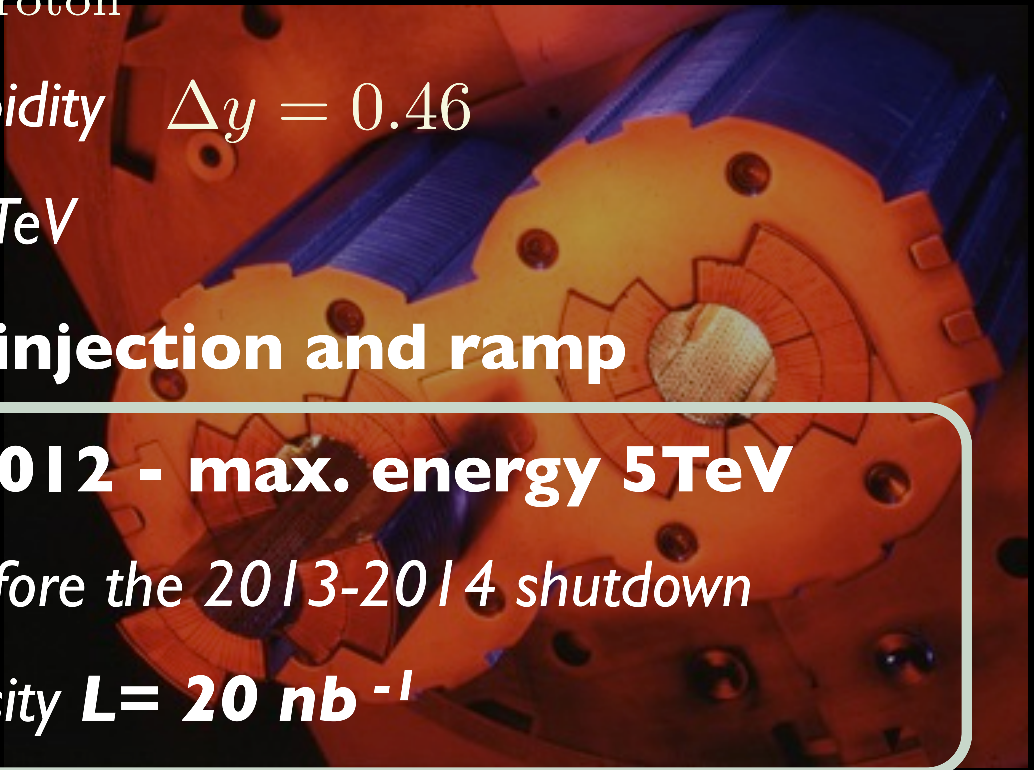
L=10^{29} cm^{-2} s^{-1} (full energy) *[Integrated in 10^{6} s : **L= 100 nb^{-1}**]*

LHC two-in-one magnet

— *Equal rigidity ::* $p_{\rm Pb} = Z\, p_{\rm proton}$

— *Center of mass shifted in rapidity* $\Delta y = 0.46$

— *Top LHC energy for pPb: 8.8 TeV*



Unequal revolution freq. at injection and ramp

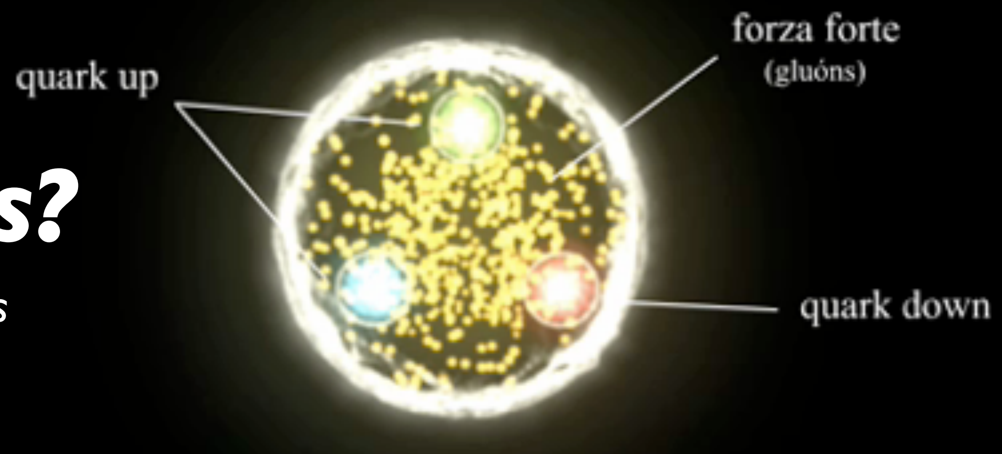
First pPb run scheduled in 2012 - max. energy 5TeV

— *A new physics system just before the 2013-2014 shutdown*

— *Estimated integrated luminosity **L= 20 nb^{-1}***

Why proton-nucleus?

[To study the structure of a large object make collisions with smaller objects (Rutherford experiment...)]



The proton structure is constrained by DIS + other data

— *HERA data of utmost importance*

Need pA to study the high-energy nuclear structure

— *DIS data is old (90's) short number and with limited range*

— *pA@LHC is the only experimental condition available before an eventual lepton-A collider (LHeC, eRHIC?)*

— *Needed as benchmark for the AA program*

— *High-density effects (saturation) enhanced in nuclei*

Low-x Physics with electrons, protons and nuclei

One of the basic questions:

Low-x Physics with electrons, protons and nuclei

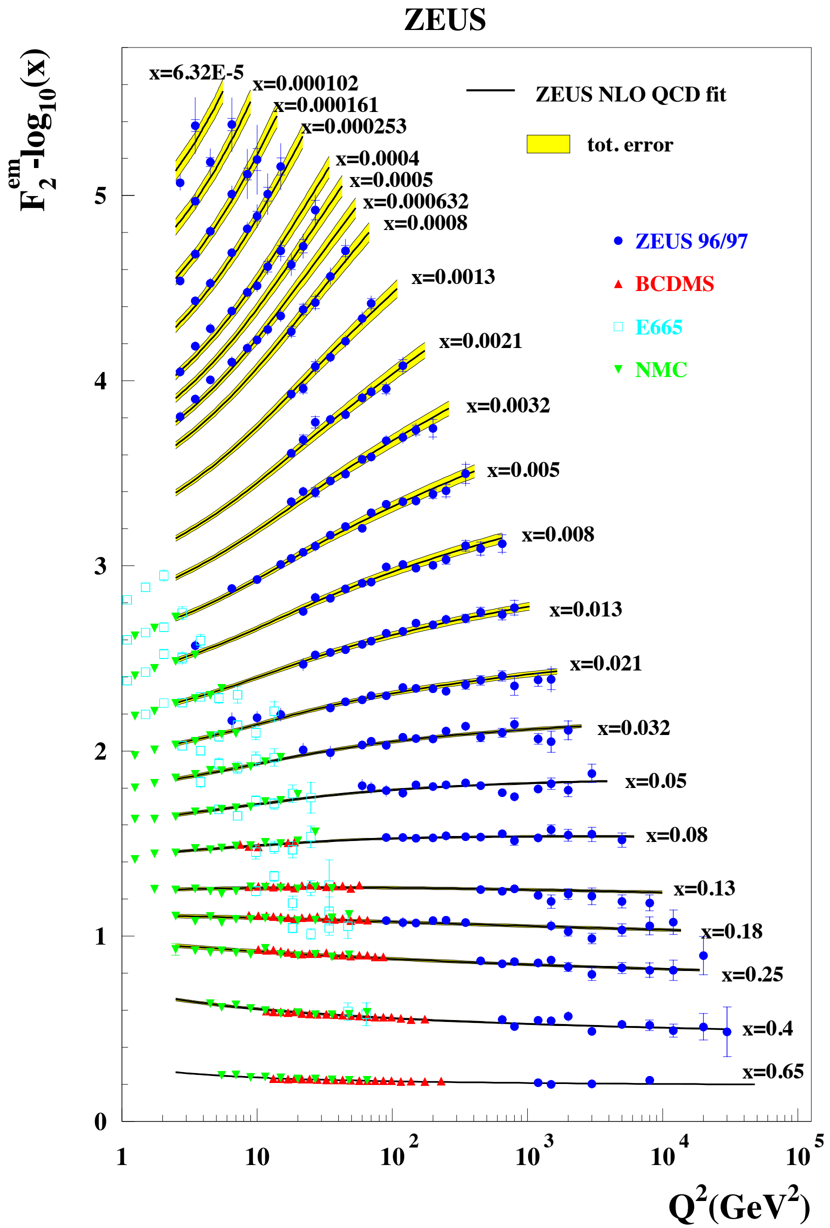
One of the basic questions:

DGLAP or not DGLAP

- *Saturation of partonic densities*
- *Resummation*
- *Signs of BFKL*
- *Violations of DGLAP expected to be larger in nuclei*

[For hot QCD studies this is an essential question: Initial state of the system]

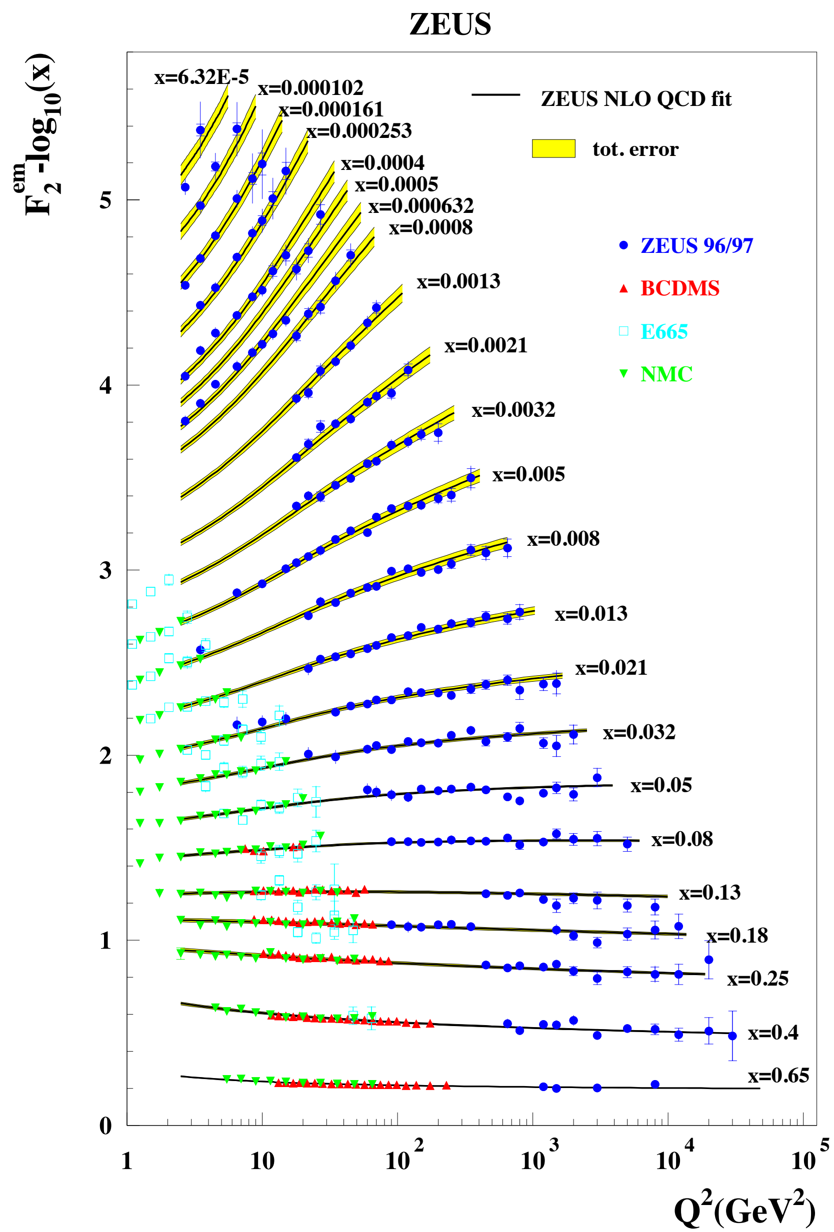
Some historical perspective



Global DGLAP fits work

- Essential for the phenomenology
- In particular LHC

Some historical perspective



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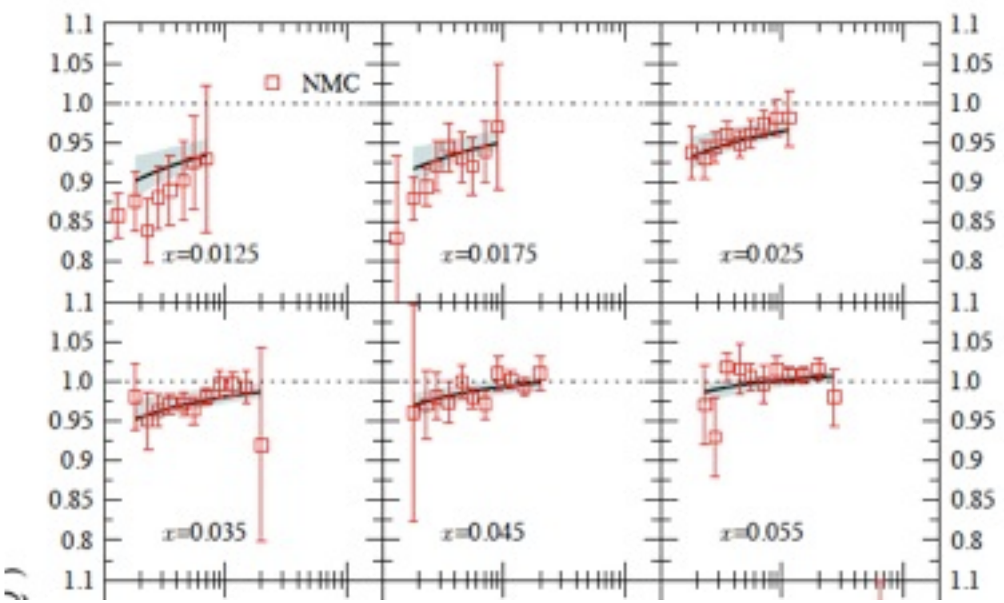


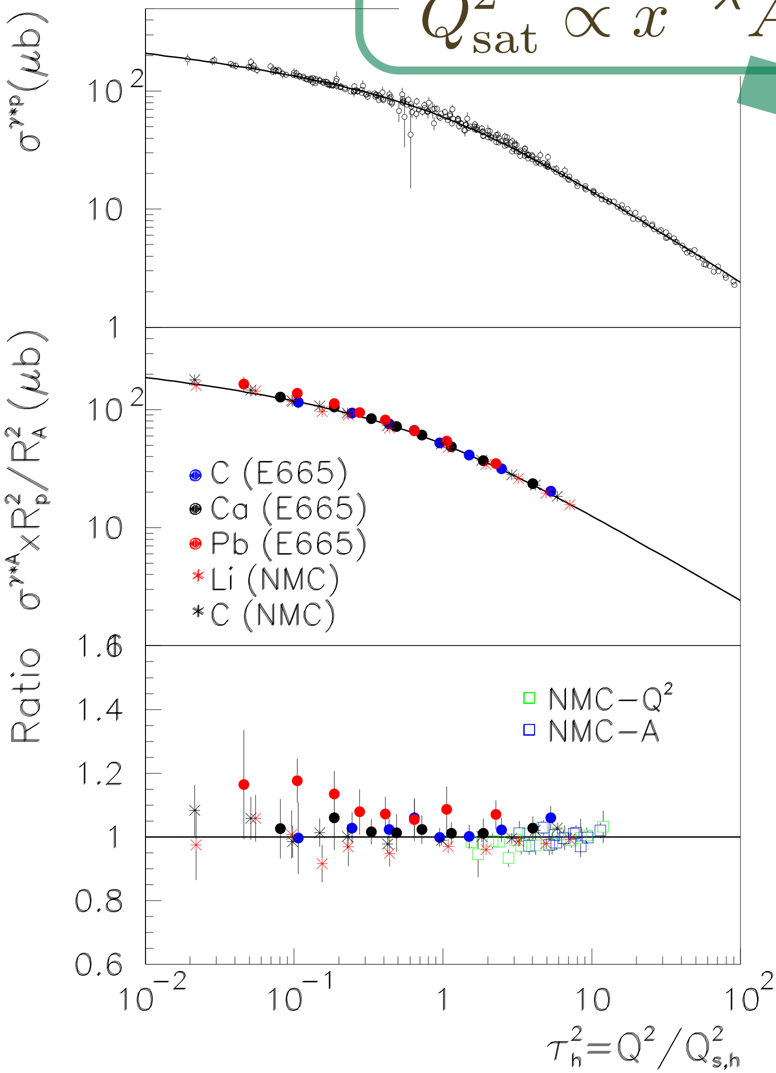
Also for nuclei [talk by P. Zurita]

- Reduced amount of data

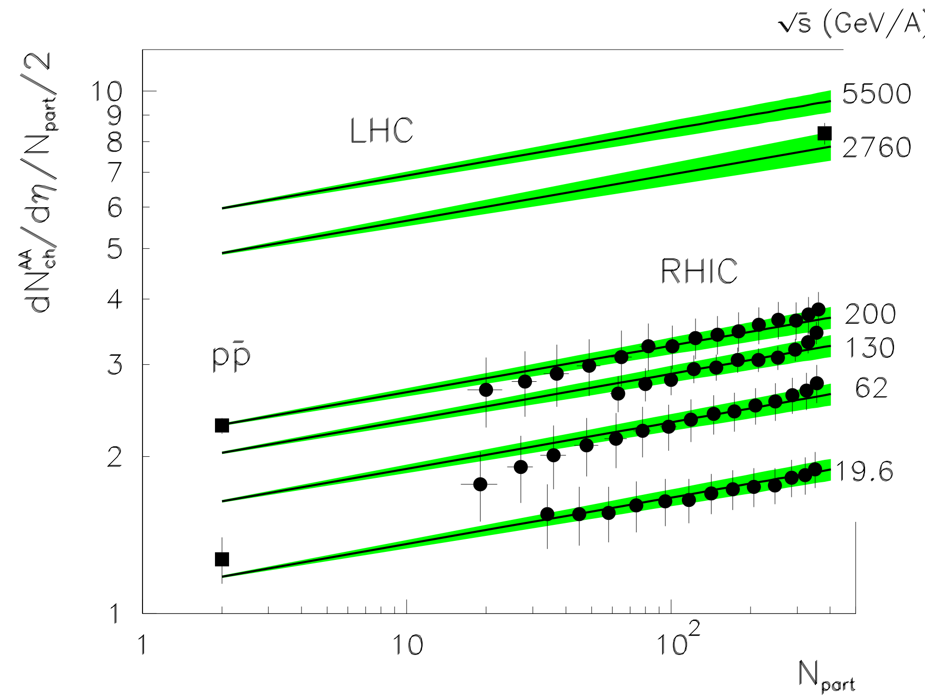
Geometric scaling as a qualitative signature

$$Q^2_{\rm sat} \propto x^{-\lambda} A^{1/3\delta}$$

$$\frac{2}{N_{\rm part}}\frac{dN^{AA}}{d\eta}\bigg|_{\eta\sim 0} = N_0 \sqrt{s}^{\lambda} N_{\rm part}^{\frac{1-\delta}{3\delta}}$$

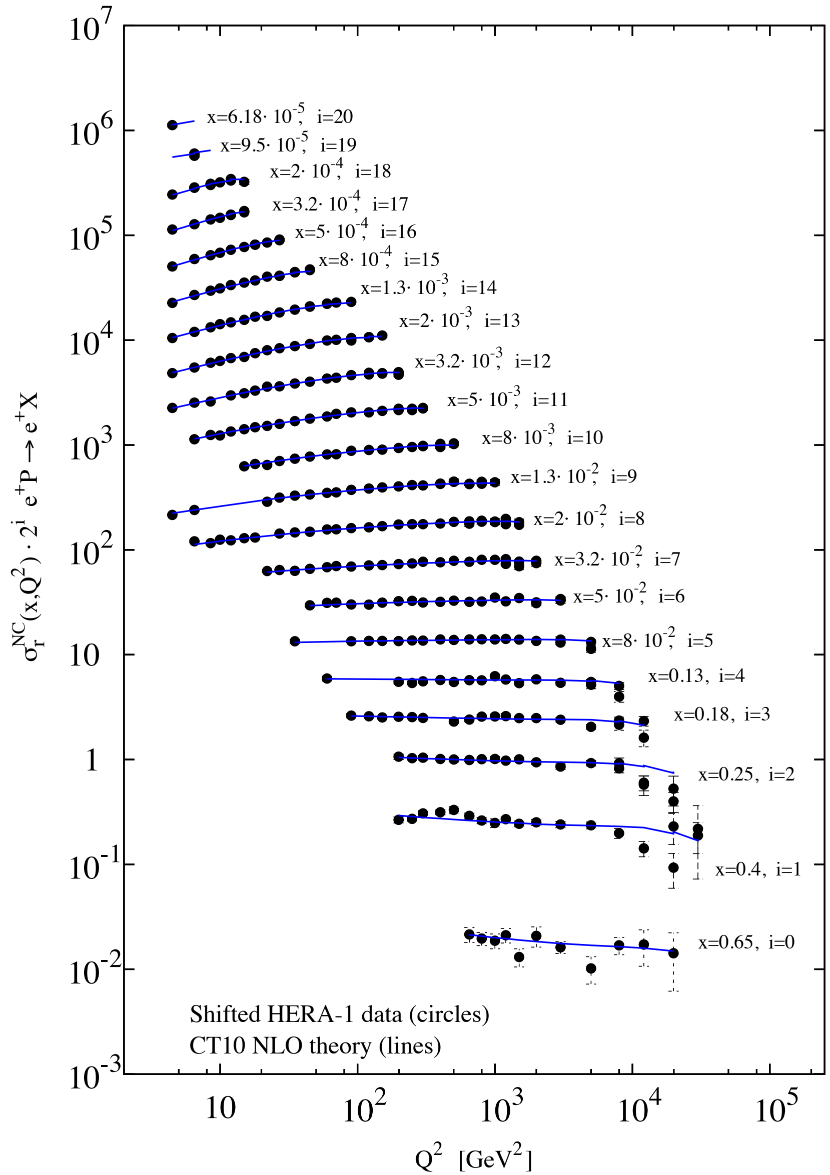


[Stasto, Golec-Biernat, Kwiecinski 2001; Armesto, Salgado, Wiedemann 2004]

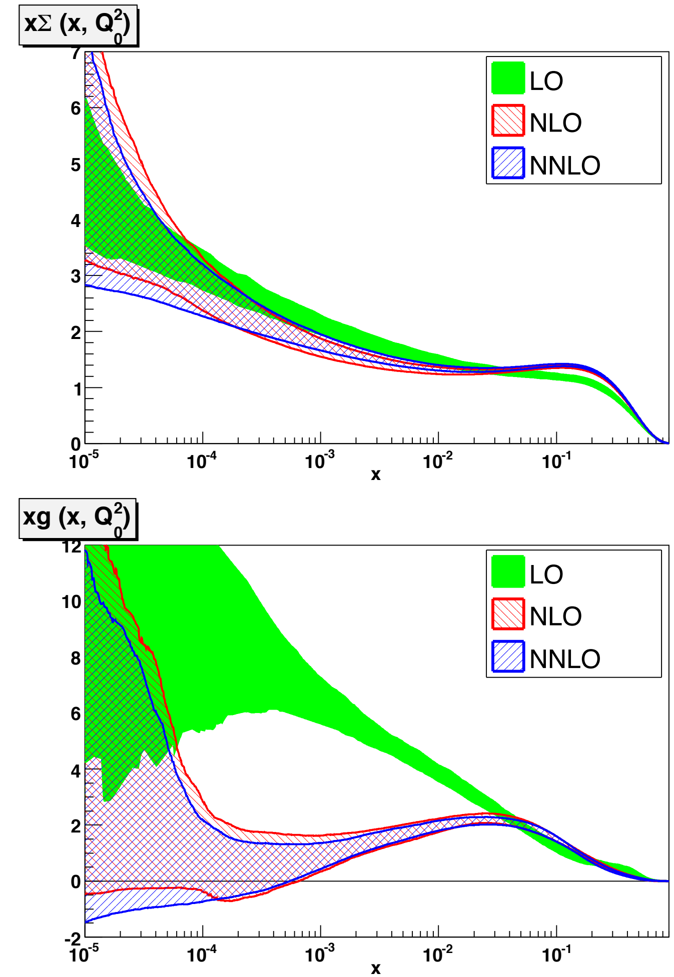


Energy and centrality dependences fixed by lepton-nucleus data

Combined HERA data: unprecedented precision



[CT10 arXiv:1007.2241[hep-ph]]

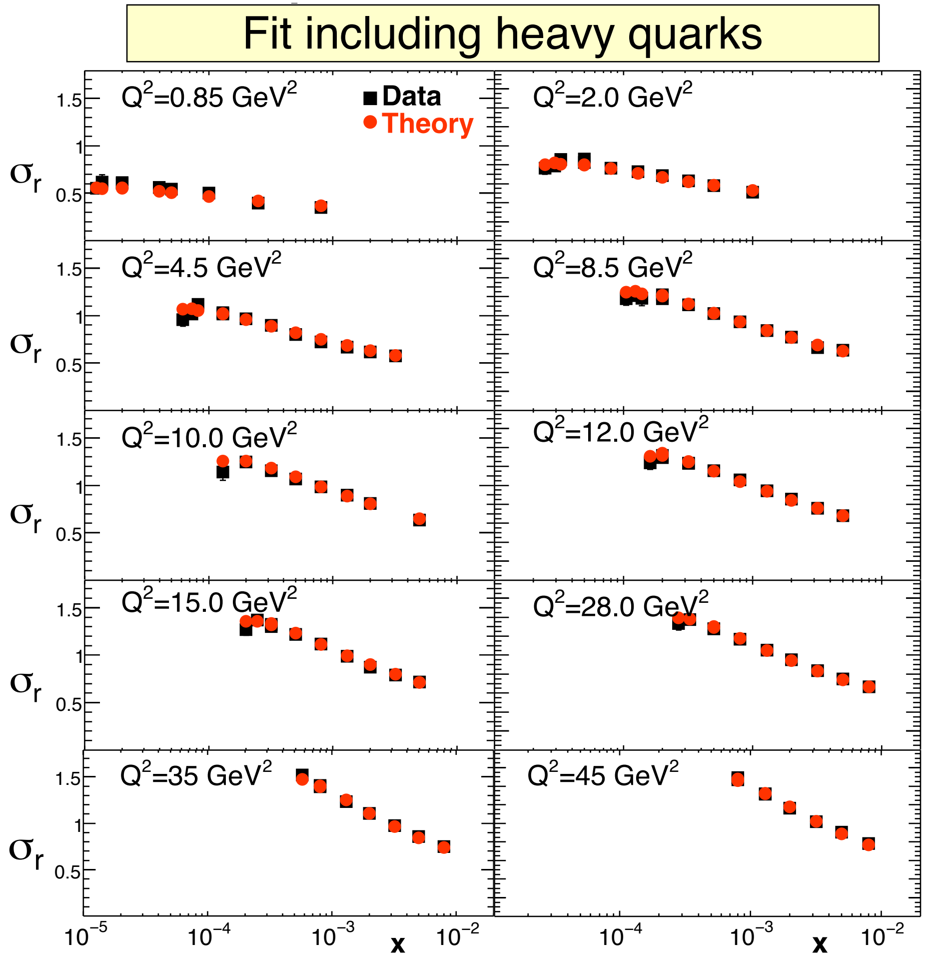


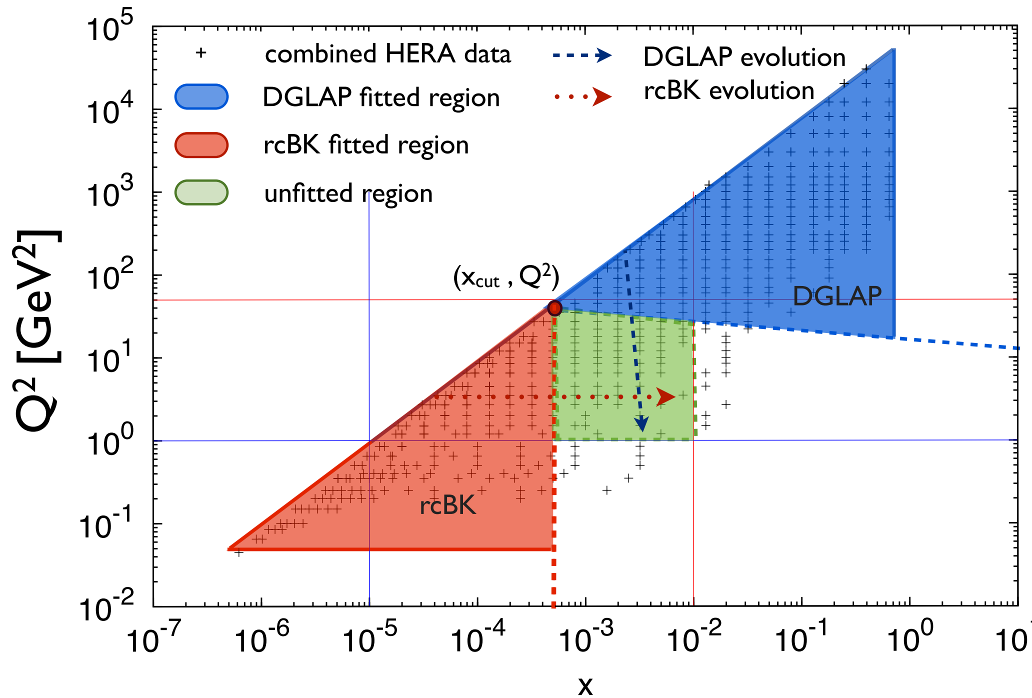
[NNPDF arXiv:1107.2652 [hep-ph]]

Still, uncertainties large at small-x

Non-linear BK equations also fit small-x

[AAMQs 2010]





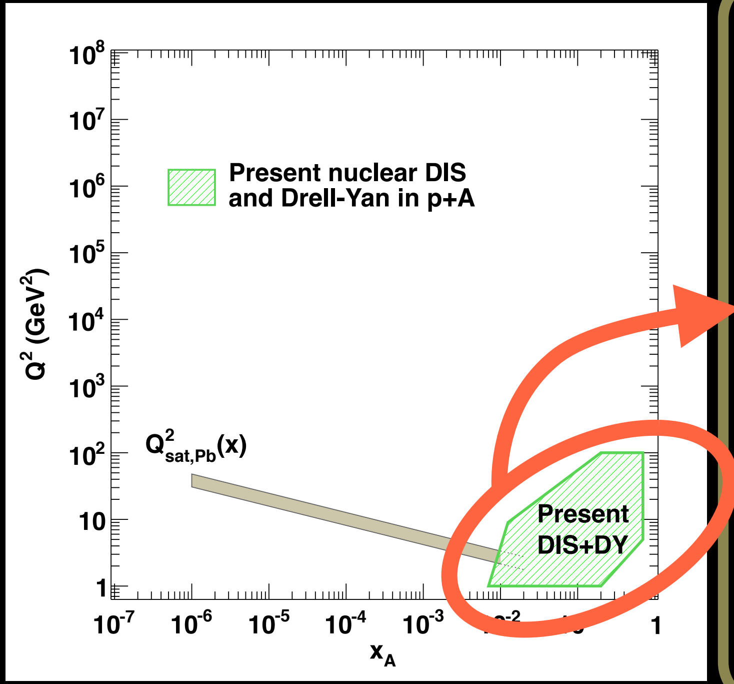
[Albacete, Milhano, Quiroga, Rojo 2012]

Excluding the small-x data from the fits would result in larger uncertainties at the LHC

nPDFs: global analyses. Status

Main goals

- Check the factorization of nPDFs for hard processes
- Fix the benchmark for HI hot matter or saturation



EKS98 [Eskola, Kolhinen, Ruuskanen, Salgado 1998]

HKM [Hirai, Kumano, Miyama, 2001]

nDS [de Florian, Sassot, 2003]

HKN [Hirai, Kumano, Nagai, 2004; 2007]

EPS08, EPS09 [Eskola, Paukkunen, Salgado, 2008; 2009]

nCTEQ [Kovarik et al, 2011]

DSSZ [de Florian, Sassot, Stratmann, Zurita, 2011]

Included data

[EPS09]

DIS: (484 points)

SLAC-E-139

NMC 95, 95re, 96 + EMC

- leave E665 out

DY in p+A (92 points)

E772 & E866

RHIC inclusive dAu (51 points)

PHENIX/STAR: midrapidity

BRAHMS: forward

Include only $p_T > 2\,\mathrm{GeV}$

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NMC 95, reanalysis	DIS	C/Li	20	36.4	1	[26]
FNAL-E772	DY	C/D	9	8.9	10	[29]
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CERN EMC	DIS	Cu(64)/D	19	12.3	1	[31]
SLAC E-139	DIS	Ag(108)/D	7	2.3	1	[25]
NMC 96	DIS	Sn(117)/C	15	10.9	1	[28]
NMC 96, Q^2 dep. $x \leq 0.025$	DIS	Sn/C	24	9.4	10	[32]
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Sea quarks

Gluons

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Sea quarks

Not possible to fit one single nucleus:
use proton as reference and A-dependence

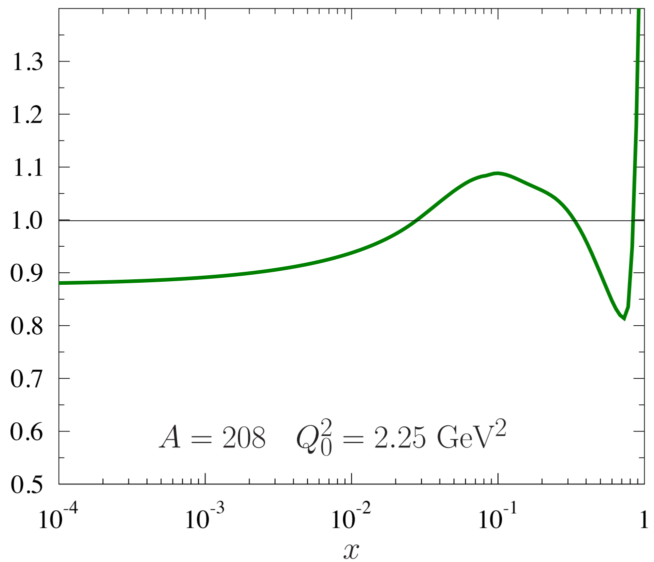
$$R_i^A(x,Q^2) = \frac{f_i^A(x,Q^2)}{f_i^p(x,Q^2)}$$

$$\left\{R_i^A(x,\{a_i\})\right\} \text{ at } Q_0^2$$

A fit for (say) Pb alone would be most welcome

Approximate ranges and constrains in EPS09

Valence



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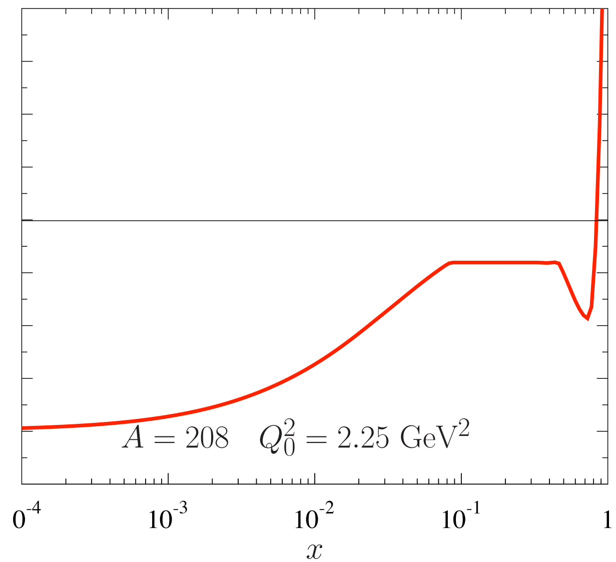
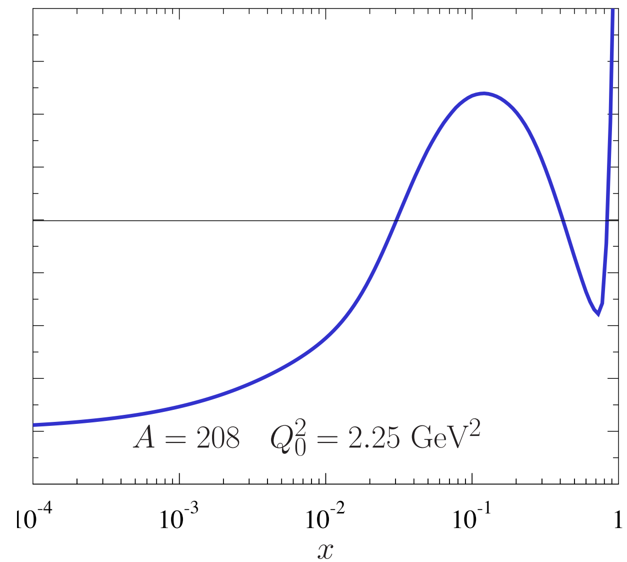


Gluons



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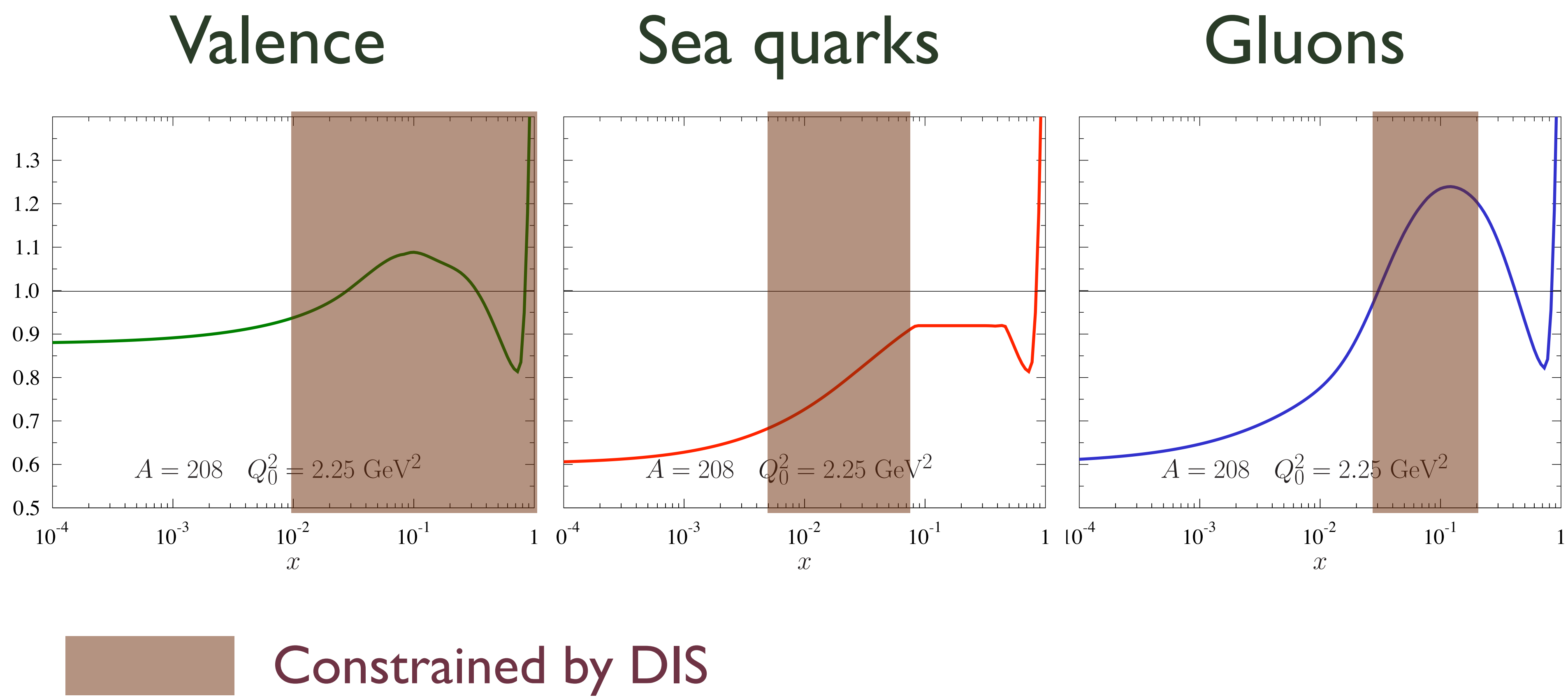

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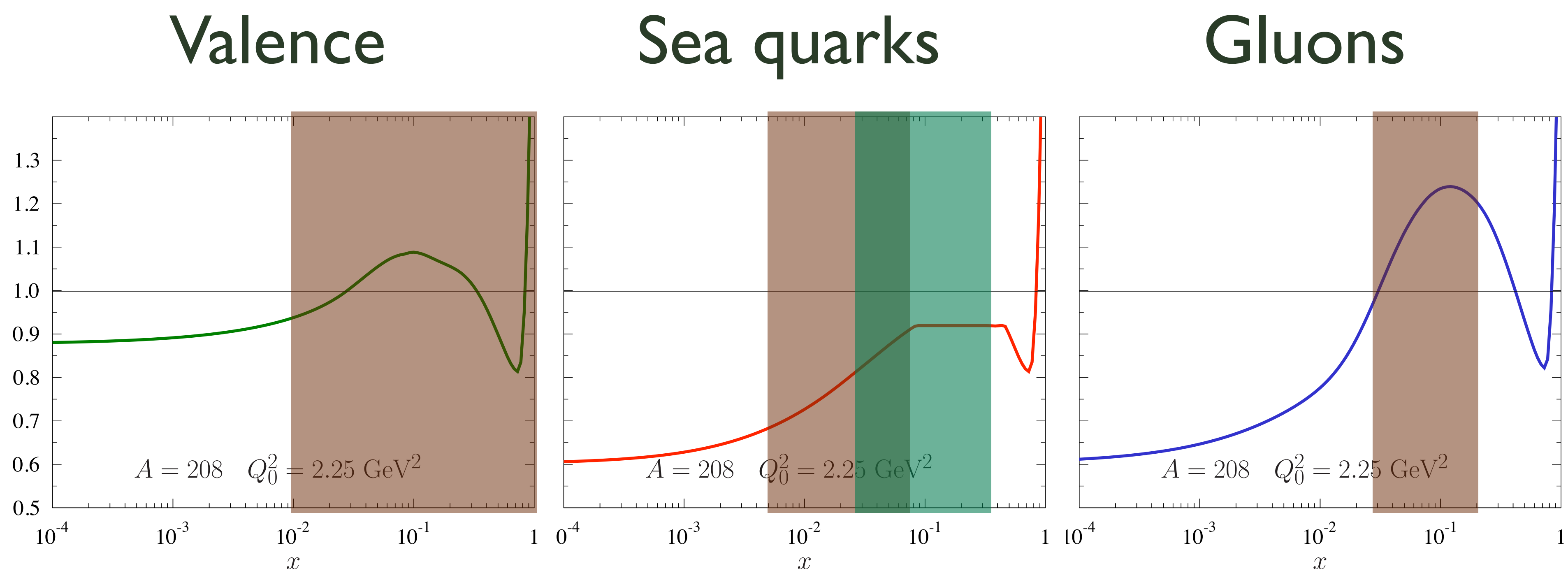
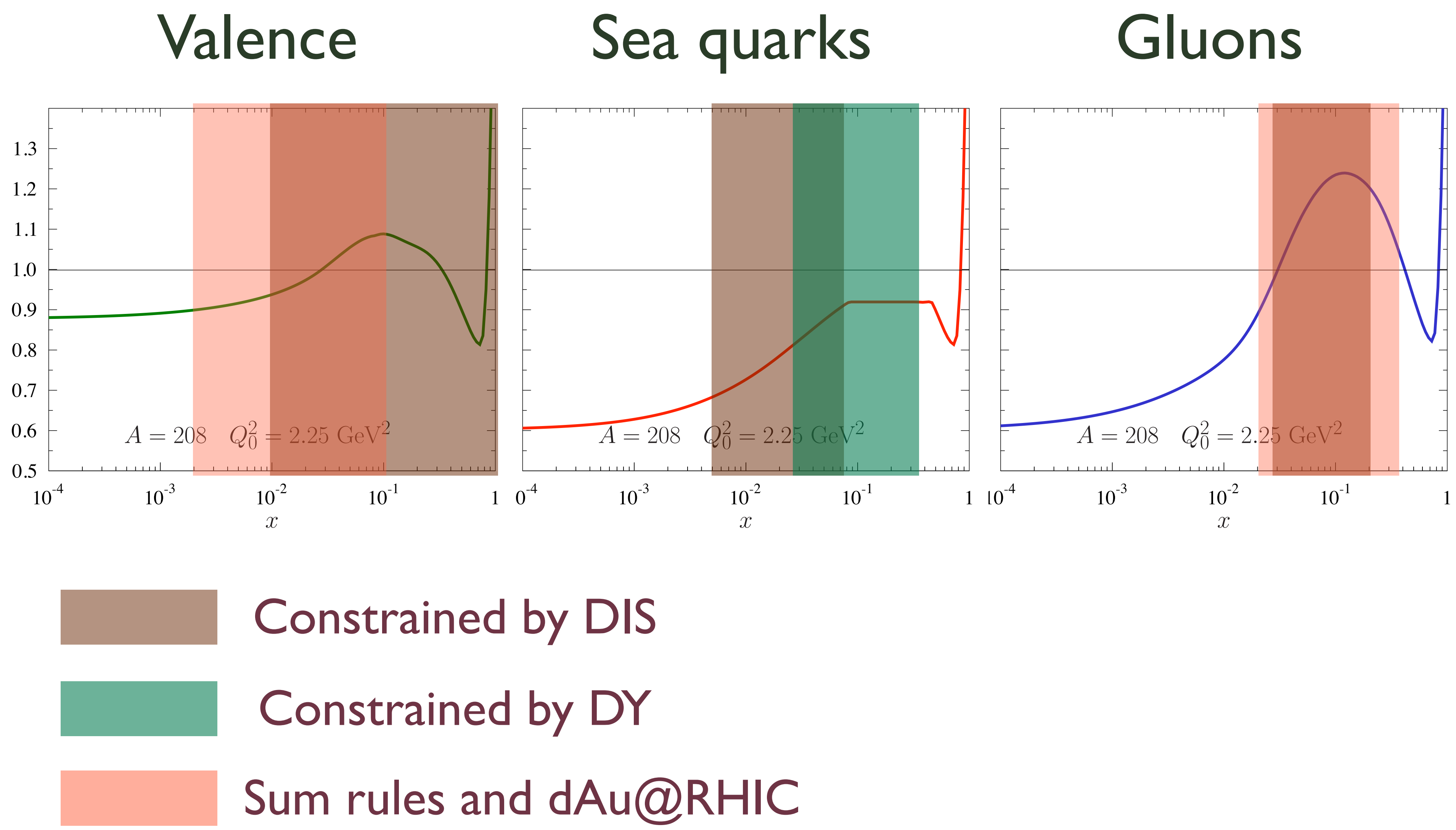


Constrained by DIS

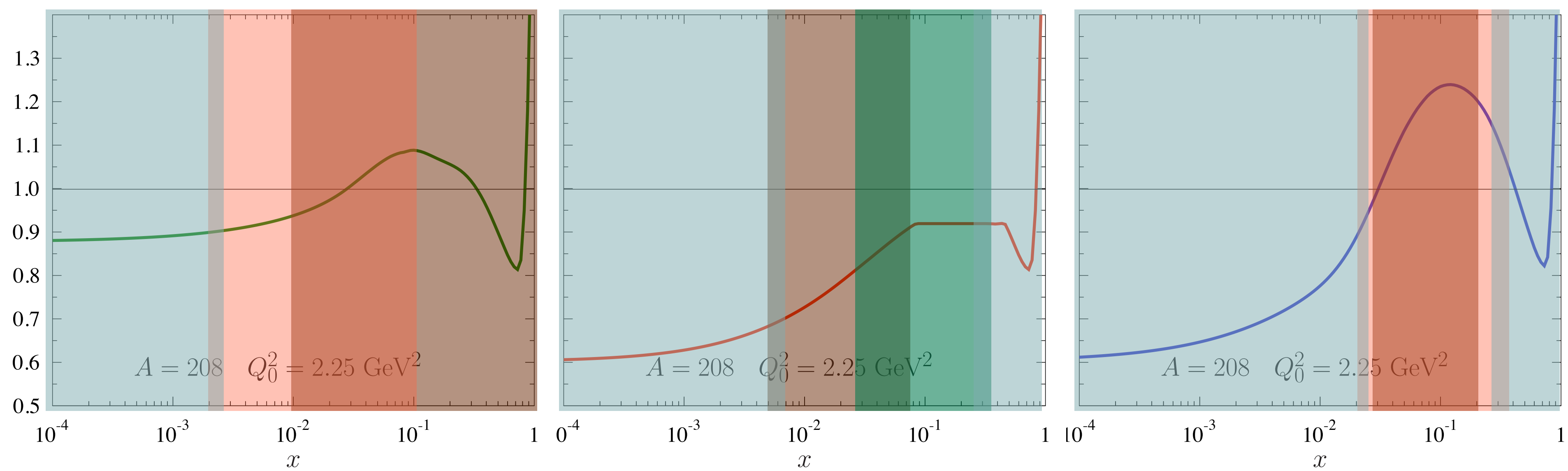
Constrained by DY

Approximate ranges and constrains in EPS09



Approximate ranges and constrains in EPS09

Valence | Sea quarks | Gluons



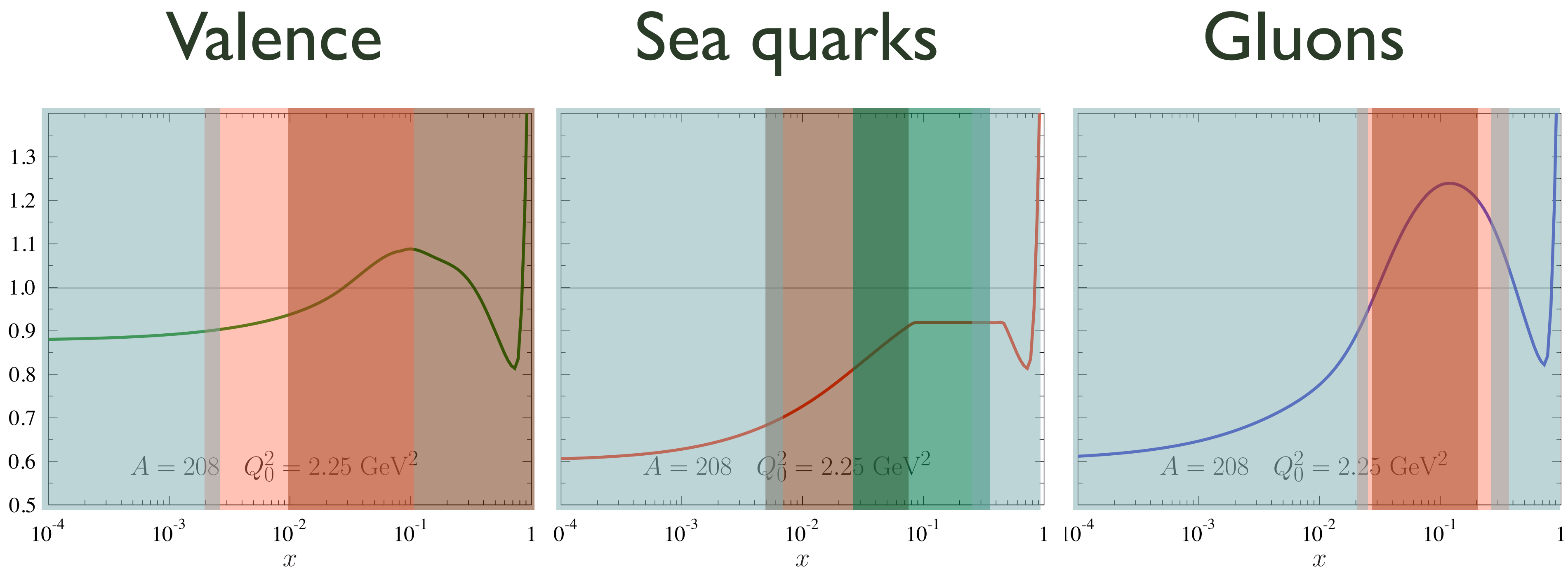
Constrained by DIS

Constrained by DY

Sum rules and dAu@RHIC

Unconstrained

Approximate ranges and constrains in EPS09



Constrained by DIS

Constrained by DY

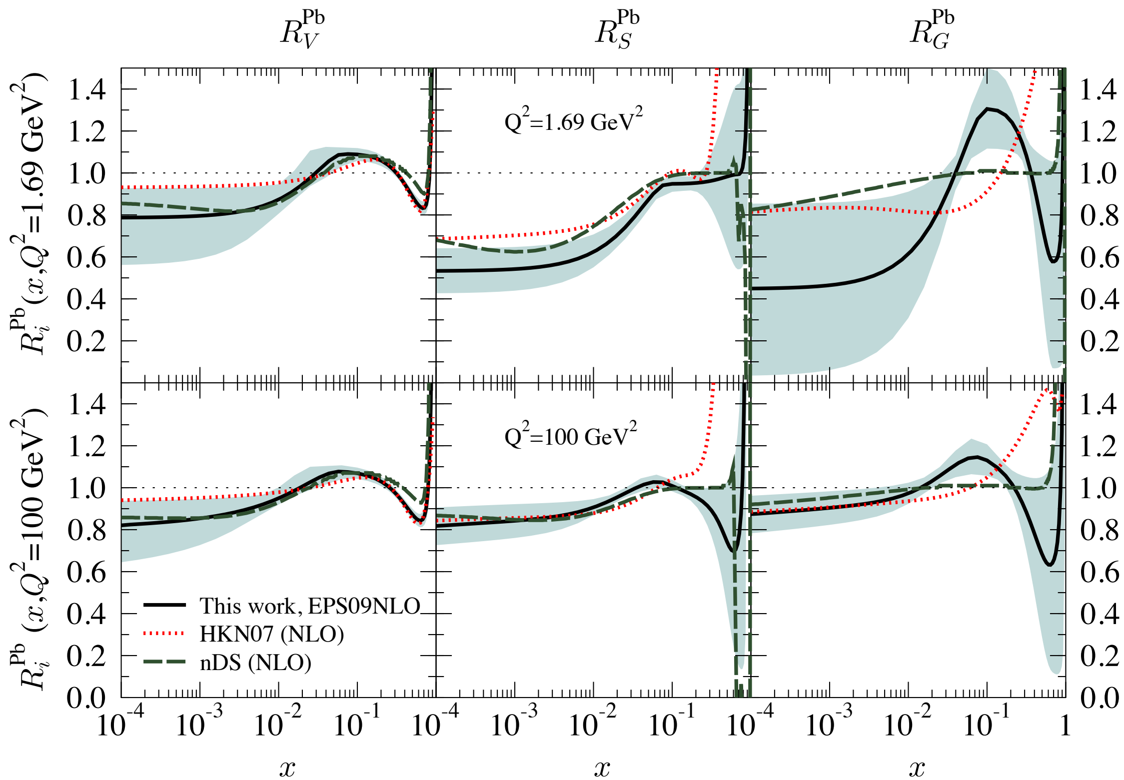
Sum rules and dAu@RHIC

Unconstrained

[these ranges are very approximative... but valid in general for other analyses]

Nuclear PDFs

⇛ Initial conditions and error analysis for different NLO sets



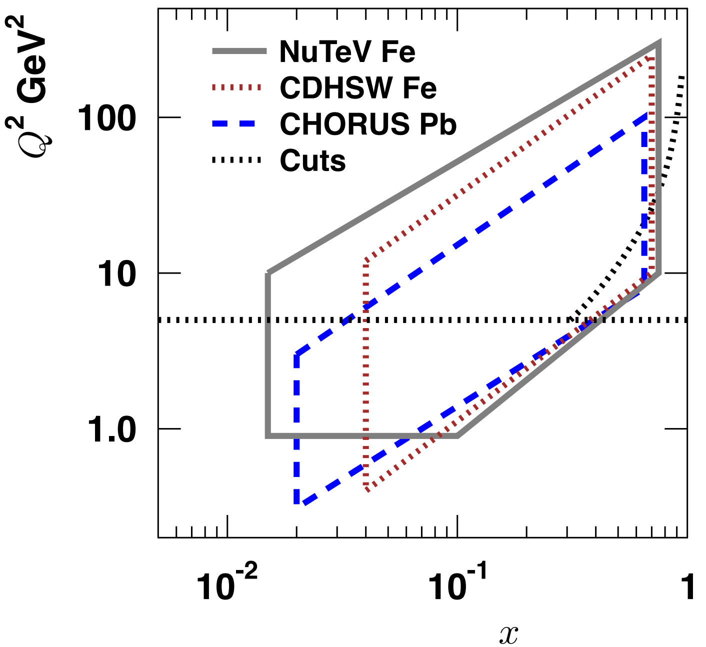
	Chi²/dof
EPS09	0.79
HKN	1.58
nCTEQ	0.89
DSSZ	0.99

⇛ Large uncertainties especially for gluons - smaller at large virtuality

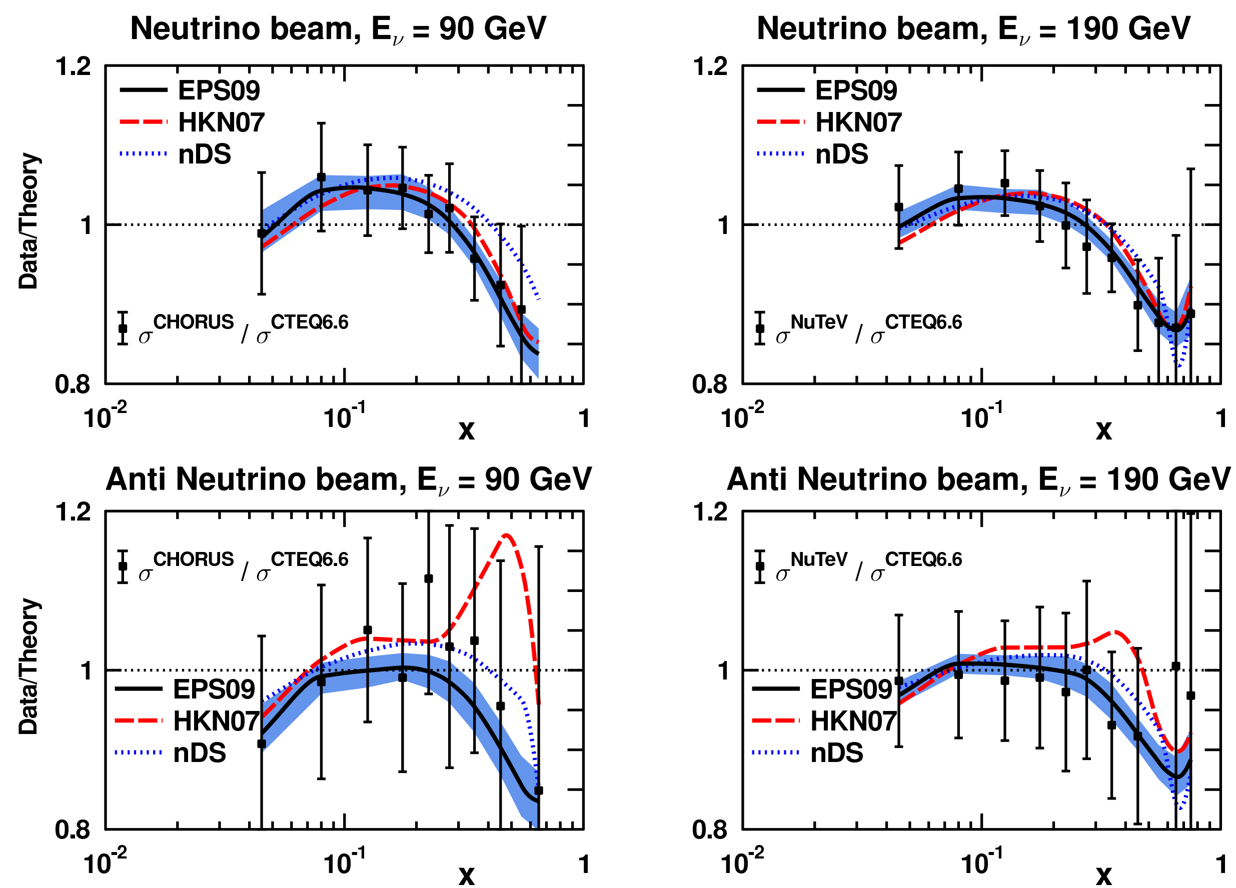
⇛ Notice that parametrization bias effects are present

- Bands to be considered as lower bounds

Additional checks of factorization: neutrino DIS



NuTeV: 2618 data
CDHSW: 1533 data
CHORUS: 1214 data



[Paukkunen, Salgado, 2010]

⇛ Non-trivial check (neutrino data not included in the fit)

Result agrees with DSSZ (data included in the fit)

CONCLUSIONS

[Slide stolen from K. Kovari's talk at DIS 2012]

- Incompatibility of neutrino DIS with charged lepton DIS (?)
  - conclusions heavily rely on only NuTeV data - most precise
  - incompatibility a "precision" effect - the result changes e.g. when using uncorrelated errors
  - tension in NuTeV data → high χ^2 of the fit to NuTeV alone → problem of NuTeV data ?
  - NOMAD data can help decide

- The impact of nuclear PDF from neutrino DIS on proton PDF
  - how does the incompatibility of neutrino DIS impact the uncertainty of strange quark PDF ?

Karlsruhe Institute of Technology

CONCLUSIONS

[Slide stolen from K. Kovari's talk at DIS 2012]

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- The impact of nuclear PDF from neutrino DIS on proton PDF
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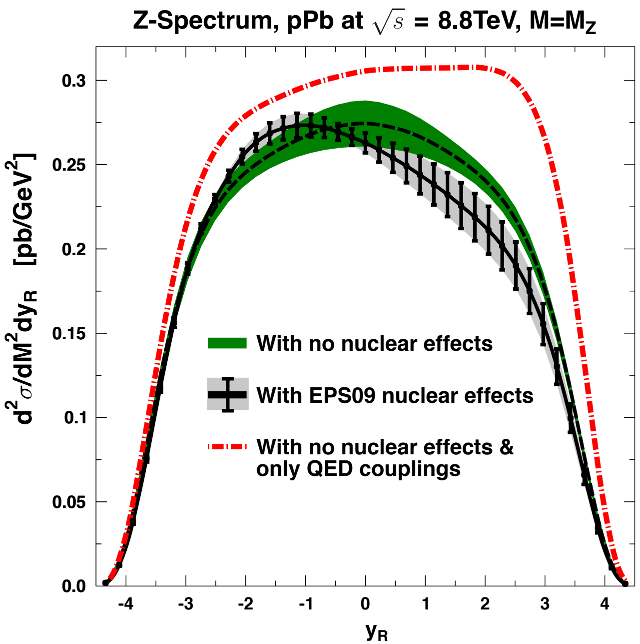
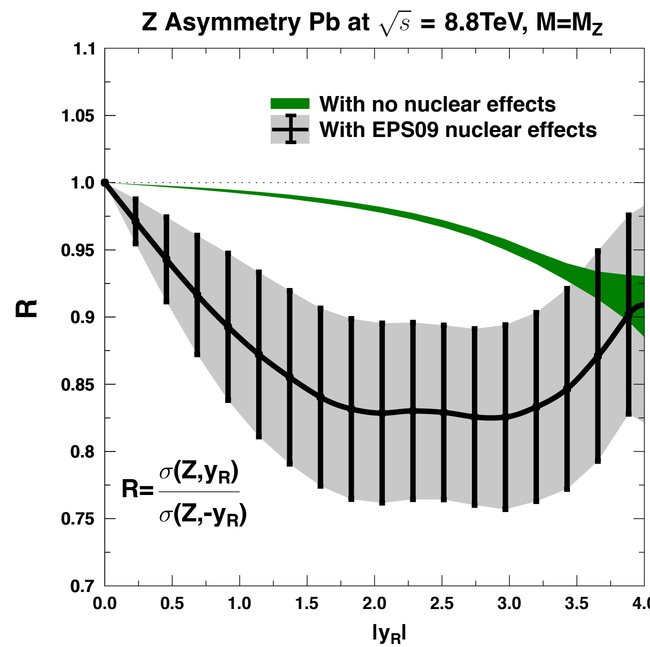
More precise neutrino data, but also better pA or nuclear-DIS data would indeed solve the problem
Relevant for proton PDFs

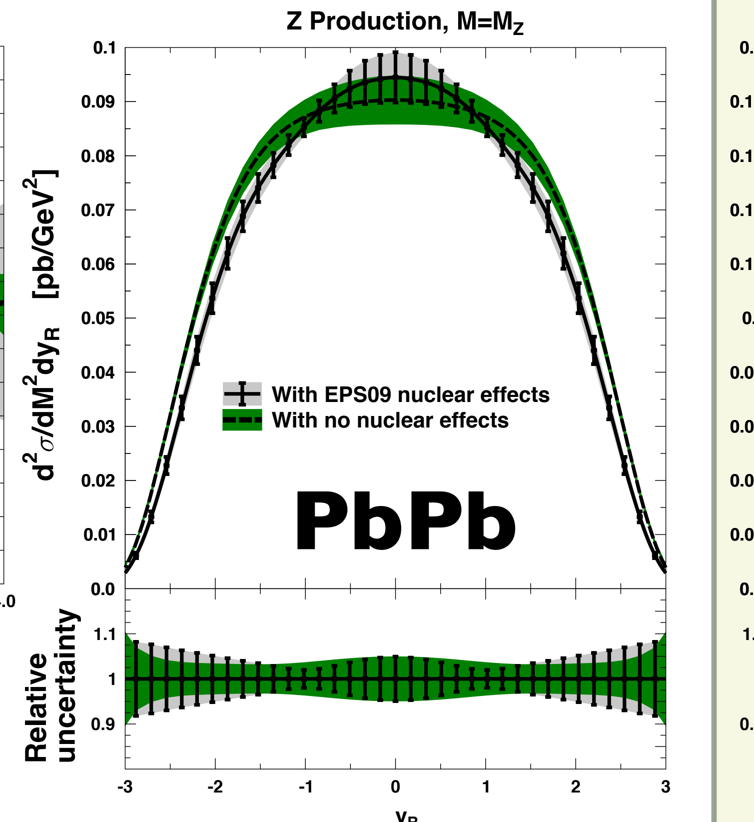
Karlsruhe Institute of Technology

W/Z bosons in pA: a very promising tool

- The rapidity asymmetry in pA can be exploited for nPDF studies



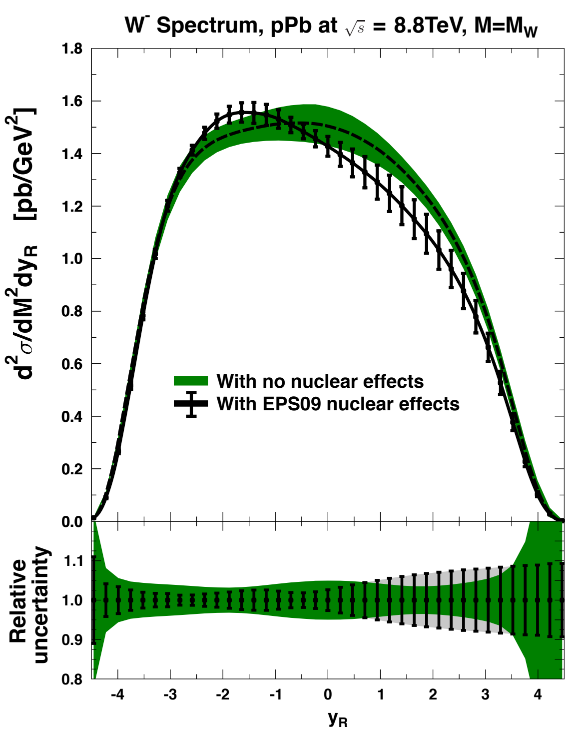


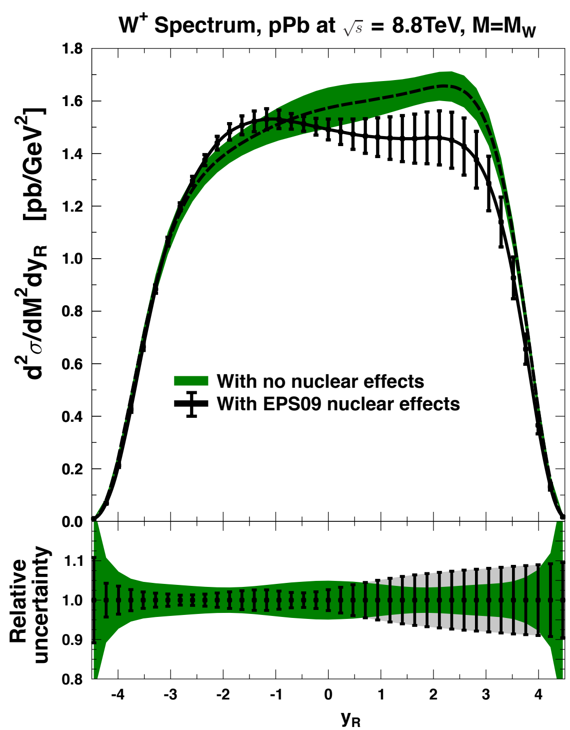


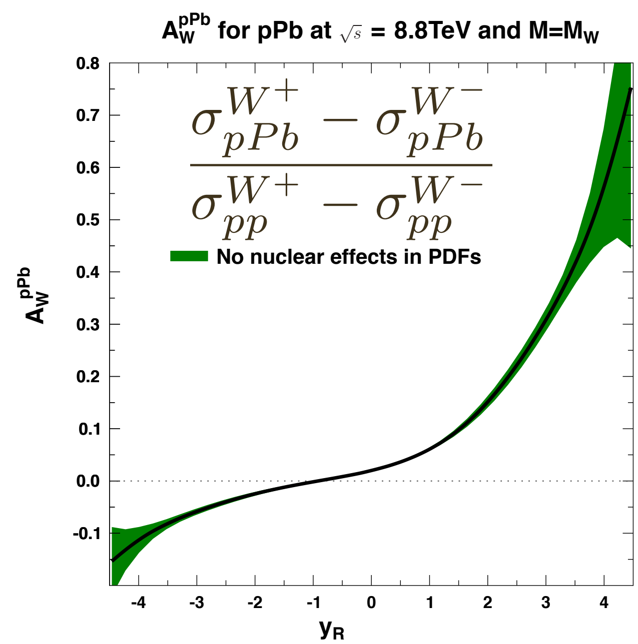
[Paukkunen, Salgado 2011]

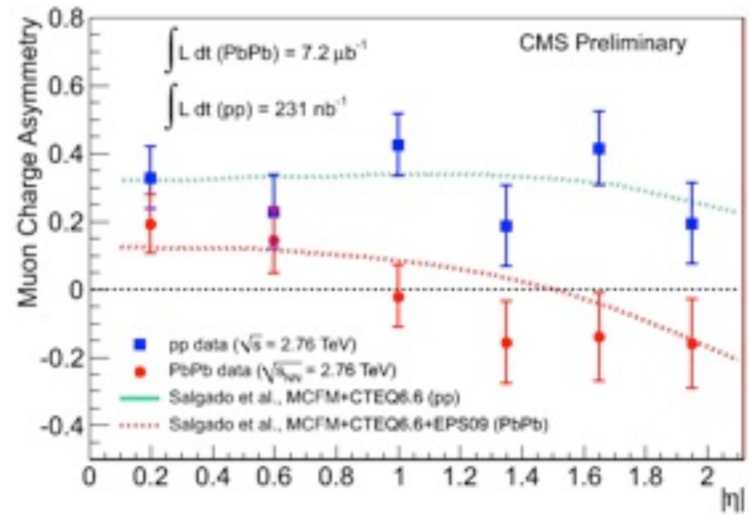
- Small isospin effects on Z production
  - Asymmetry provides constraints **without pp reference**
  - PbPb much less constraining

W/Z bosons in pA: a very promising tool









Isospin effects important in W production

pA useful for proton PDFs fits?

DGLAP global fits provide the technology

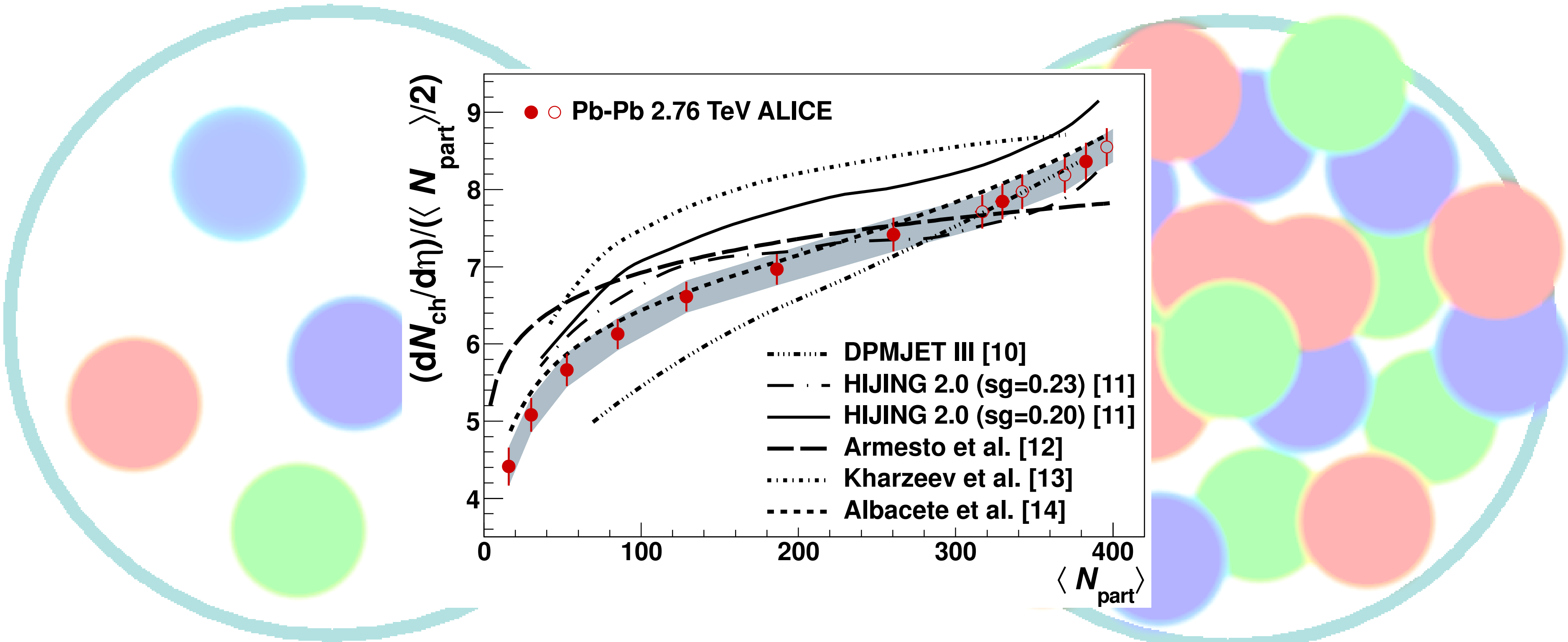
- *One of the most standardized methods in HEP*

Provide the data and checks of (collinear) factorization will be performed

- *(& sets of nPDF released)*

Saturation of partonic densities

(Color Glass Condensate)



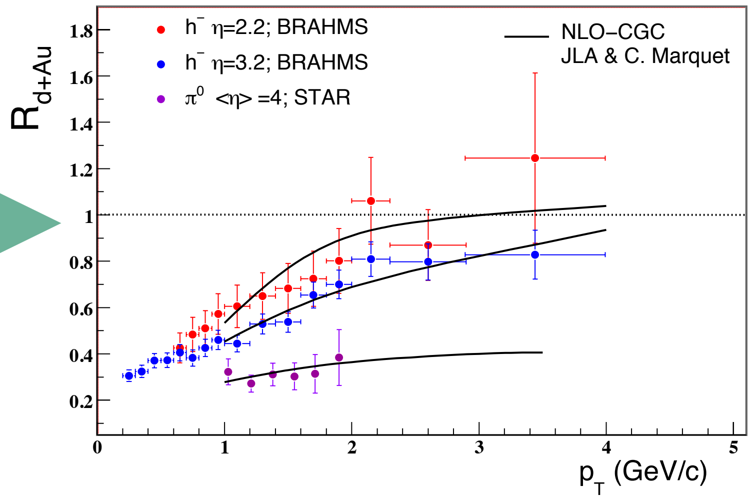
pA as a benchmark for the bulk particle production

Only theoretically controlled tool to compute the initial state of the system

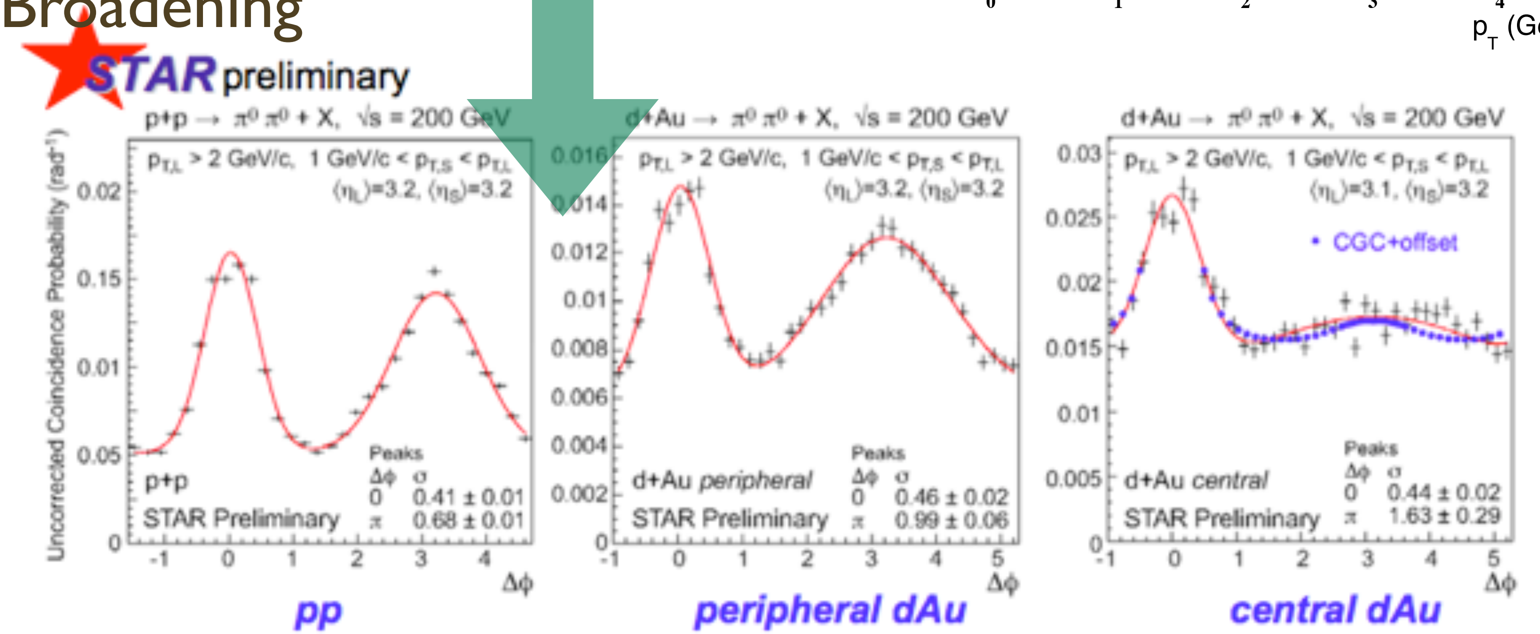
(essential for Hot QCD phenomenology)

Hits of saturation: RHIC@forward rapidities

- Suppression of yields
  - Small-x evolution

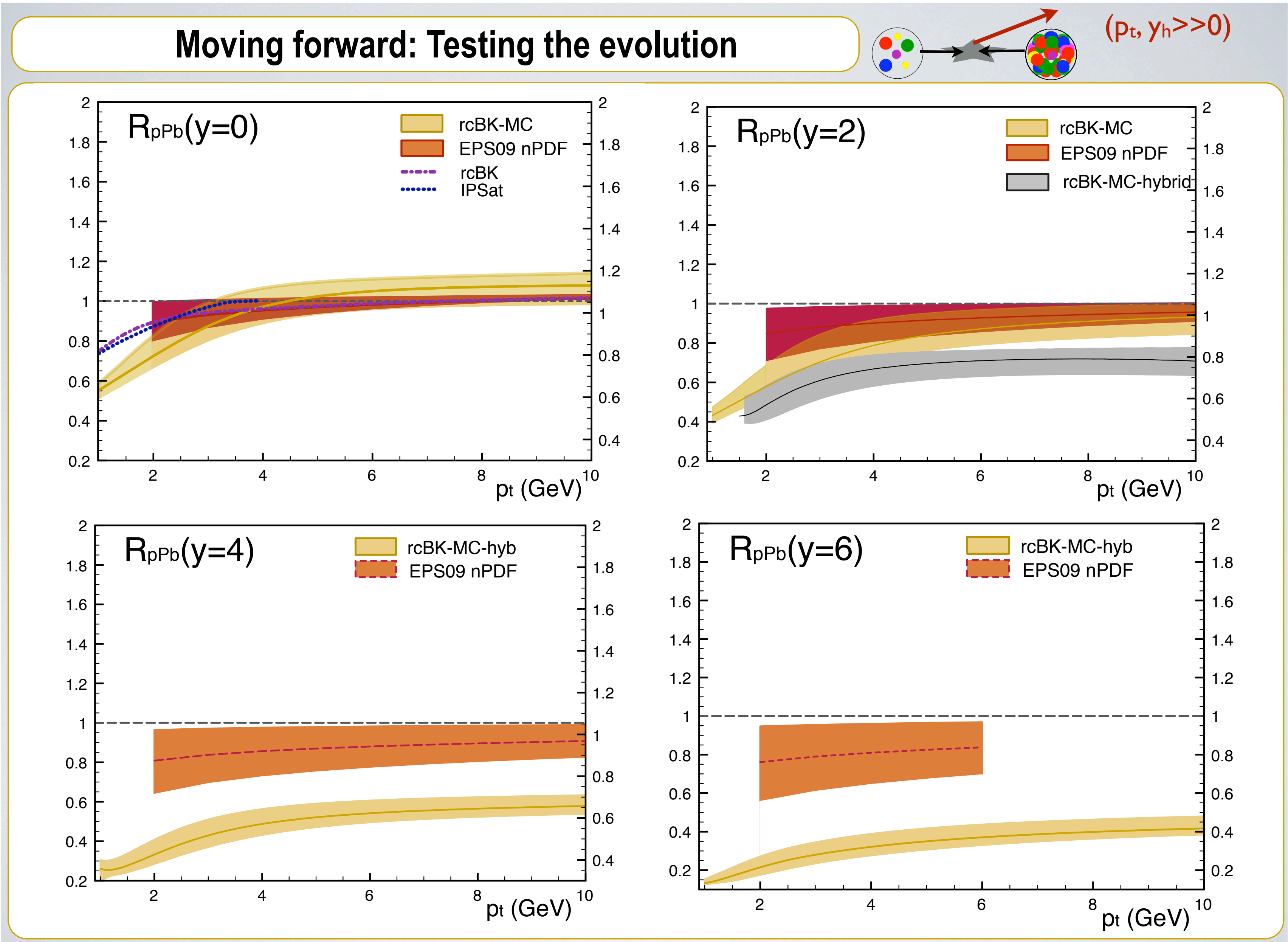


- Disappearance of back-to-back
  - Broadening



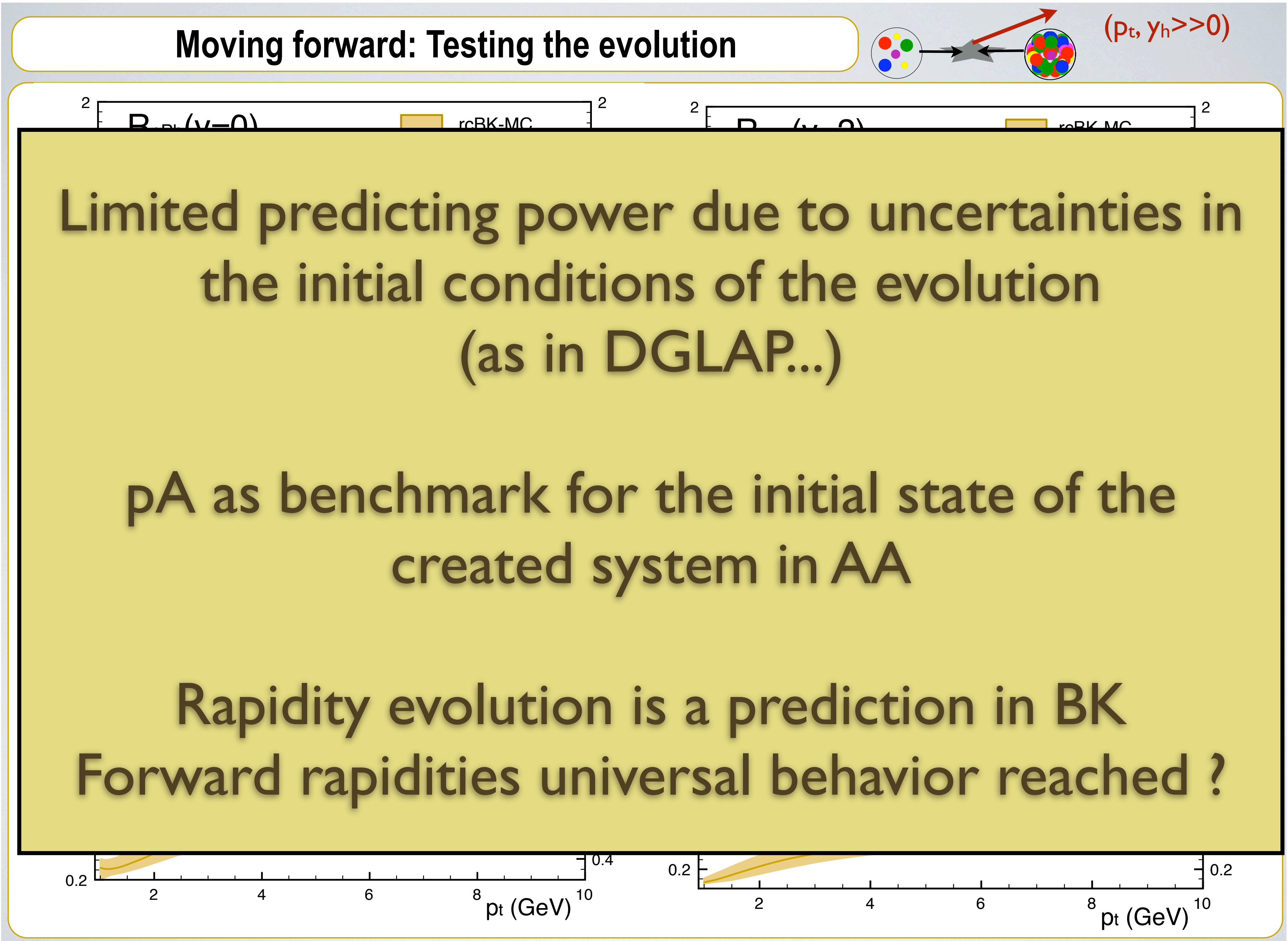
- PHENIX: forward-forward and central-forward studied

Extrapolation to pA@LHC



[Albacete, Hard Probes 2012 - May 2012]

Extrapolation to pA@LHC



Limited predicting power due to uncertainties in the initial conditions of the evolution
(as in DGLAP...)

pA as benchmark for the initial state of the created system in AA

Rapidity evolution is a prediction in BK
Forward rapidities universal behavior reached ?

[Albacete, Hard Probes 2012 - May 2012]

GGC: Short list of theoretical developments

Evolution Equations BK-JIMWLK: $\frac{\partial \phi(x,k)}{\partial \ln(1/x)} = \mathcal{K} \otimes \phi(x,k) - \phi^2(x,k)\ ; \quad \frac{\partial W[\rho]}{\partial Y} = ..$

- ✓ -Running coupling corrections [Balitsky, Kovchegov-Weigert, Gardi et at]
- ✗ -Full NLO kernel [Balitsky]
- ✗ -High-Q^2 effects (CCFM + saturation) [Avsar-Iancu]
- ✗ -Kinematic constraints & b-dependence in BK evolution [Berger-Stasto]
- ✗ - Subleading-N(c) corrections [kovchegov-Weigert]
- - ...

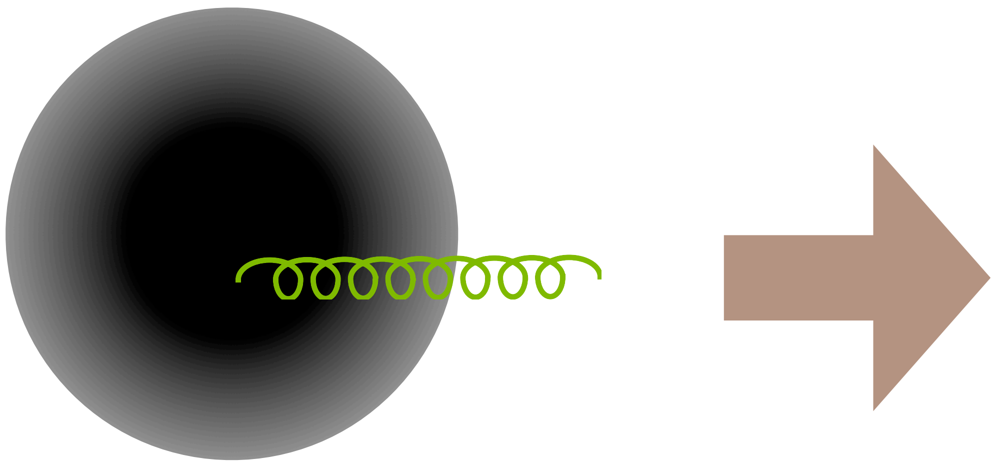
Slide shamelessly stolen from Albacete at QM11

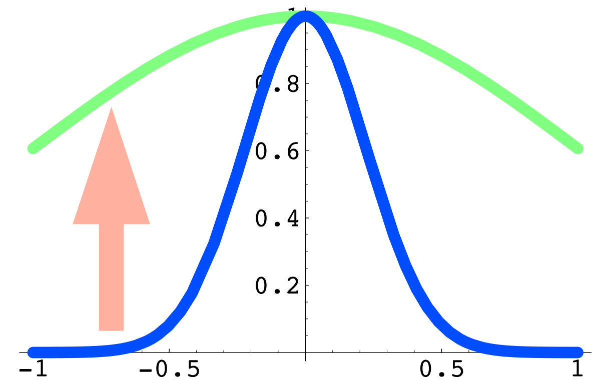
Production processes: $\frac{dN^{AB\to X}}{d^3p_1 \ldots}\left[\phi(x,k); W_Y[\rho]\right]$

- ✓ - Factorization of multiparticle production processes [Gelis-Lappi-Venugopalan]
- ✗ - Analytic solutions to Yang-Mills EOM [Blaizot-Mehtar Tani-Lappi]
- ✗ - Running coupling corrections to kt-factorization [Kovchegov-Horowitz]
- ✗ - DIS NLO photon impact factors [Balitsky-Chirilli]
- ✓ - Di-hadron correlations [Dumitru-Jalilian Marian, Dominguez et al]
- ✗ - Progress in the hybrid formalism (CGC+pdf's) [Altinoluk-Kovner]
- ✗ - New observables beyond the large-Nc limit [Marquet-Weigert]
- - ...

Used in phenomenological works? ✓ Yes ✗ No ✓A bit :)

The problem of impact parameter





Impact parameter

- The BK equations are perturbative
  - The gluon (dipole) can be emitted at arbitrary distances
  - Equivalent to Weizsacker-Williams photons in QED
- Tails grow too fast to describe experimental data

pPb central collisions - More clear signal of saturation?

Needs good experimental control

Summary

Small-x physics interesting QCD testing ground

- *Departure from DGLAP? Nuclear vs proton case*
- *Potentially important phenomenological consequences (LHC)*
- *Precision of the data high, more to come from LHC*

Nuclear PDFs badly constrained at small-x

- *pA only possibility to reduce uncertainties*
- *Very standard technology but data needed*

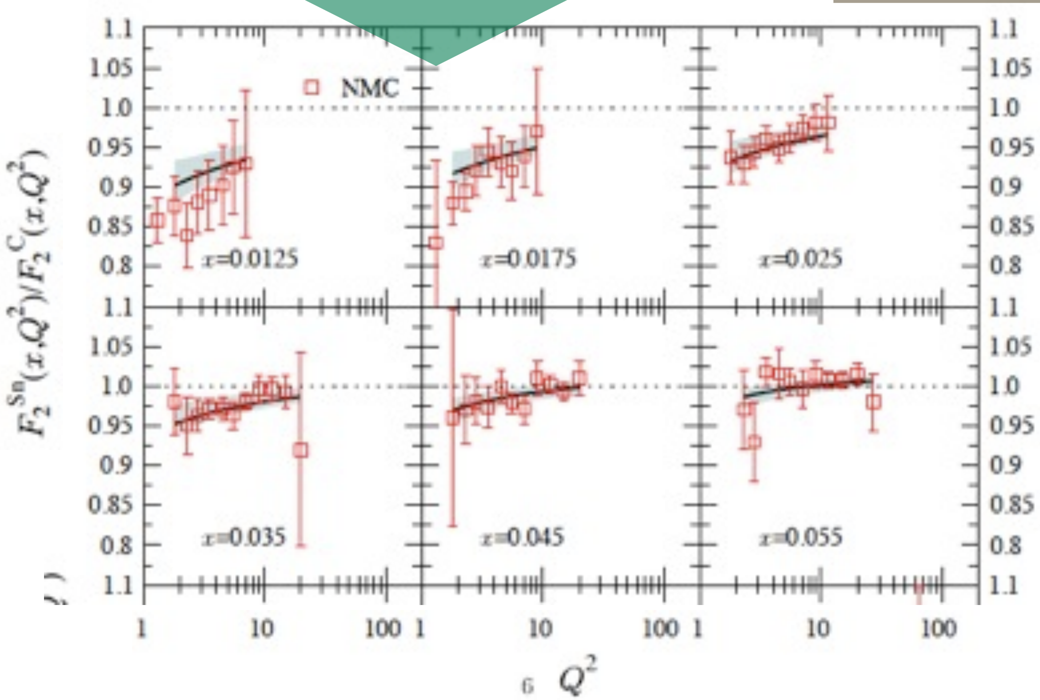
Saturation of partonic densities

- *pA@LHC arguably the best experimental option before LHeC, etc*
- *Phenomenology applicable to the proton case*
- *Only theoretical controlled way to compute IS in AA - hot matter*

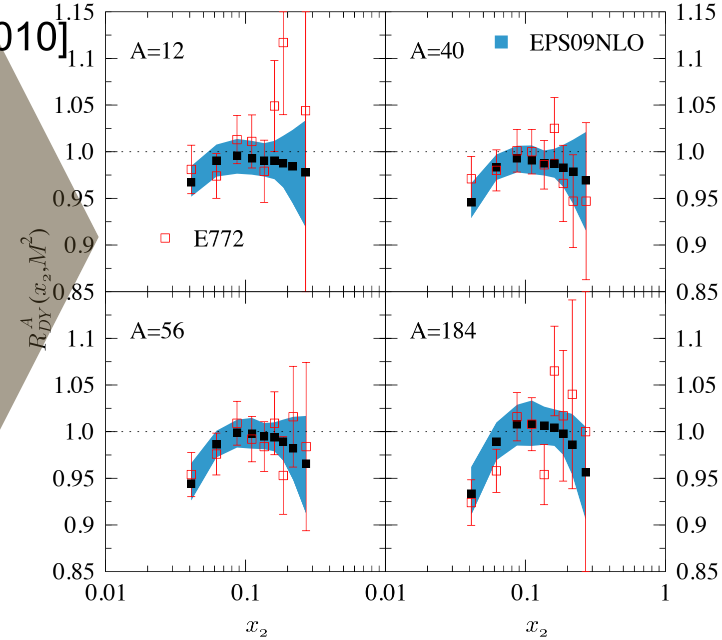
Comparison with data included in the fit

[Eskola, Paukkunen, Salgado, 2010]

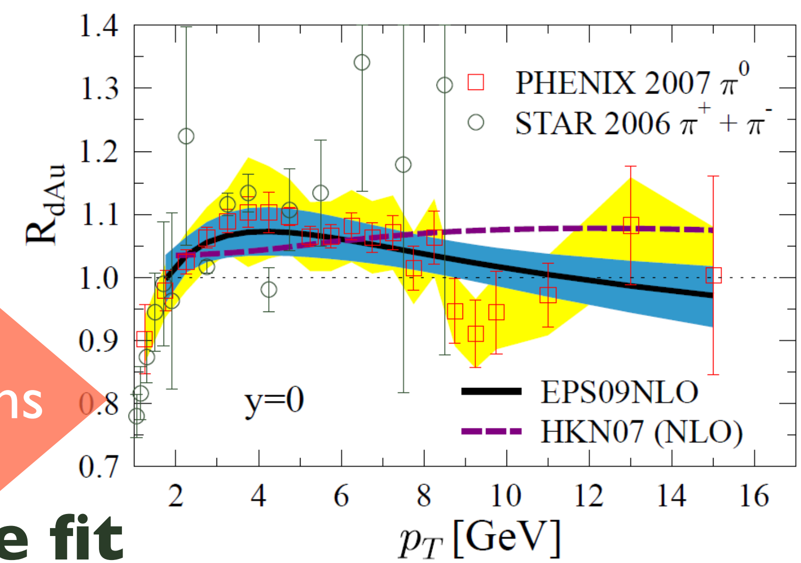
DIS
gluons



DY
sea quarks



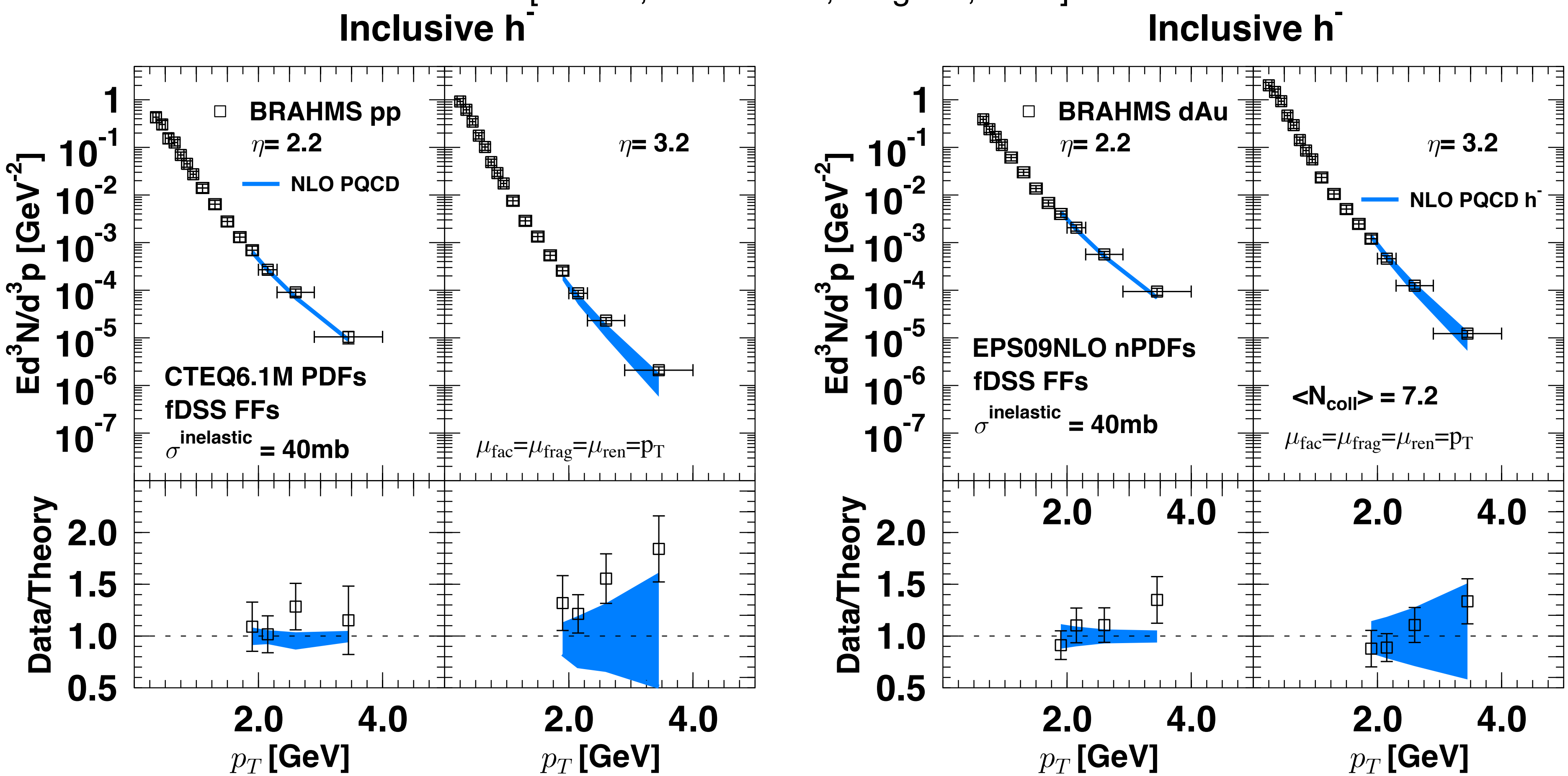
Inclusive pions. Constrain gluons



⇒ **No tension among data in the fit**

Checks of factorization: forward@RHIC

[Eskola, Paukkunen, Salgado, 2010]

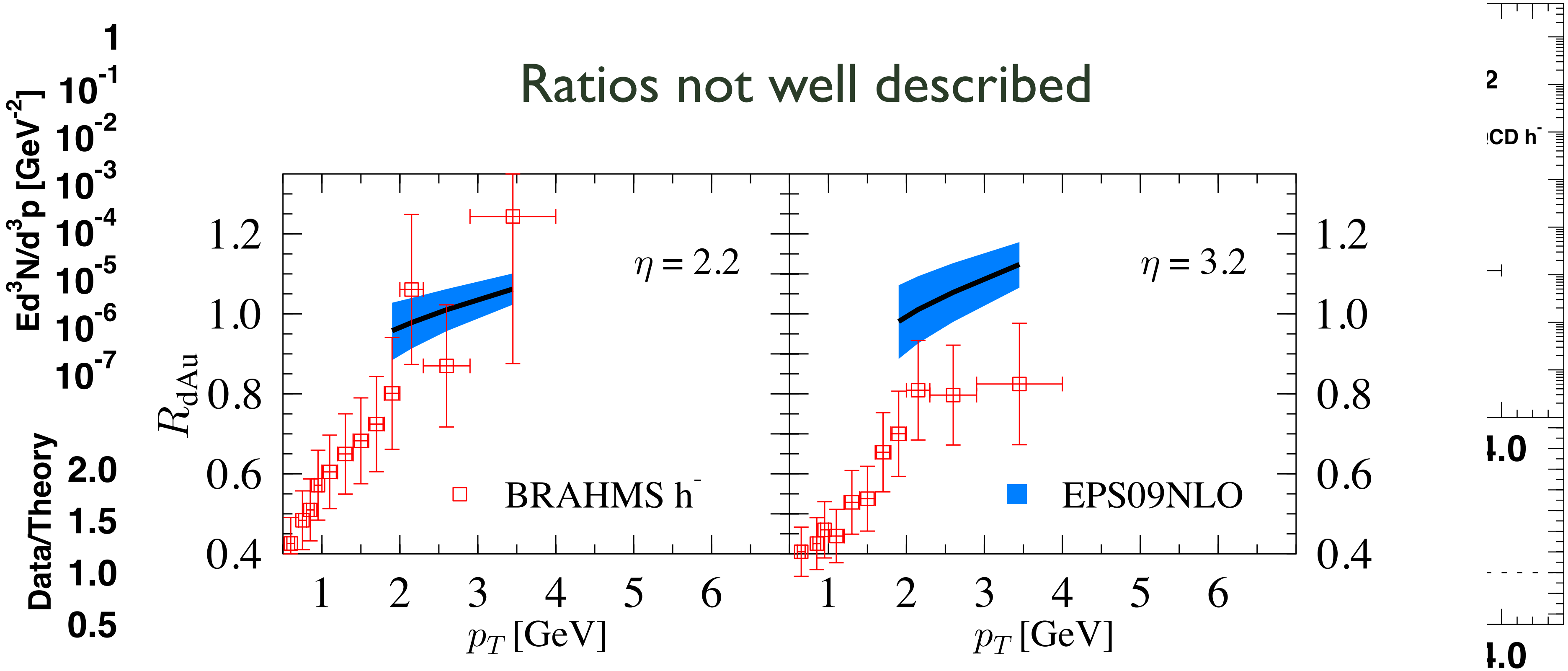


- ⇛ Good description except for pp @ y=3.2
- ⇛ Not conclusive, LHC will indeed help by reaching smaller-x

Checks of factorization: forward@RHIC

[Eskola, Paukkunen, Salgado, 2010]

Ratios not well described



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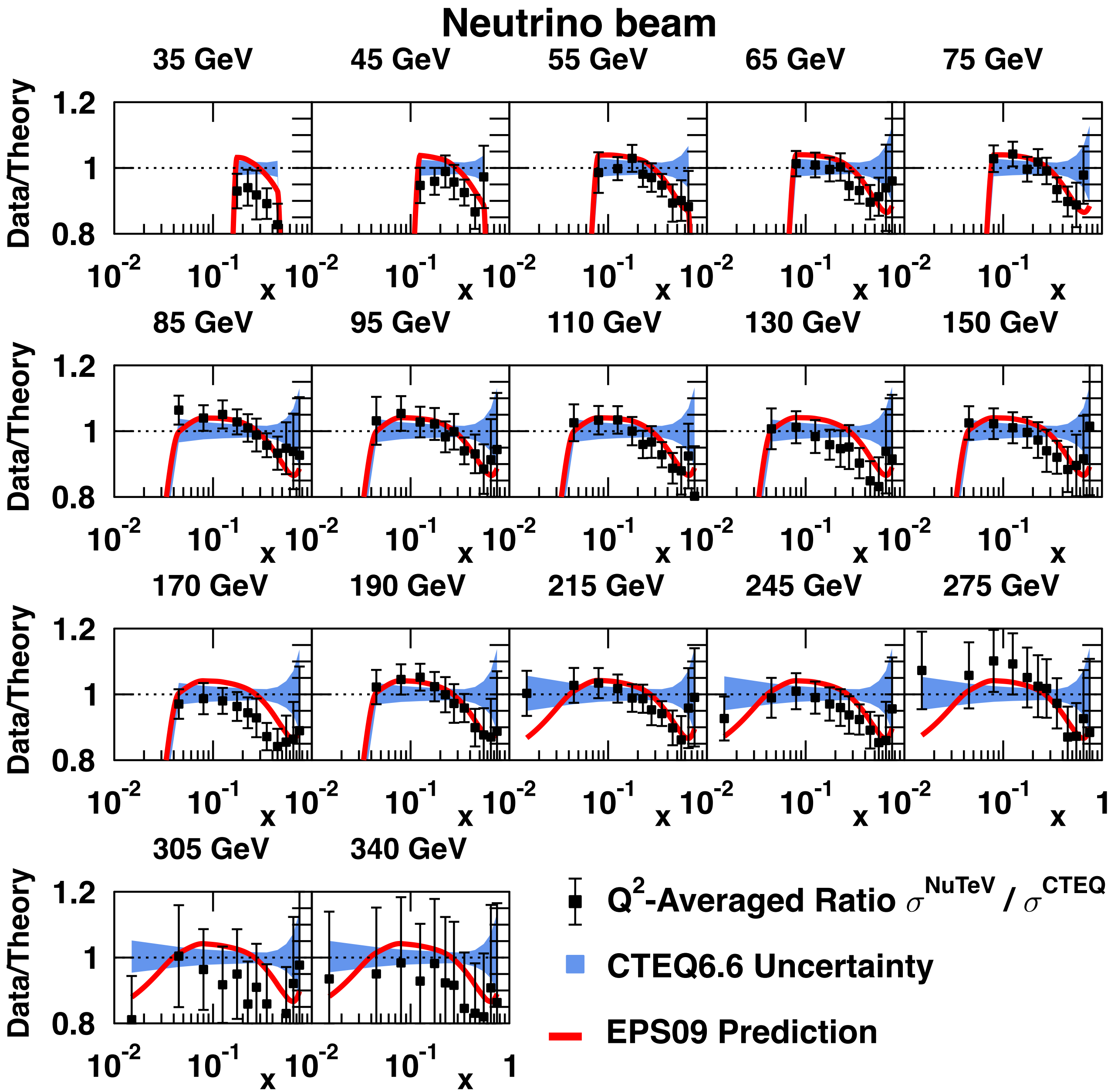
More on neutrino DIS: NuTeV



Our analysis points to systematic differences in NuTeV data as a function of the neutrino energy

[only present for neutrino and for NuTeV]

This cannot be fixed by nuclear PDFs

[Notice: ratios with **theoretical** proton DIS. CTEQ6.6 used here]