Nuclear Dynamics probed in Electron-Ion Scattering at TeV Energies

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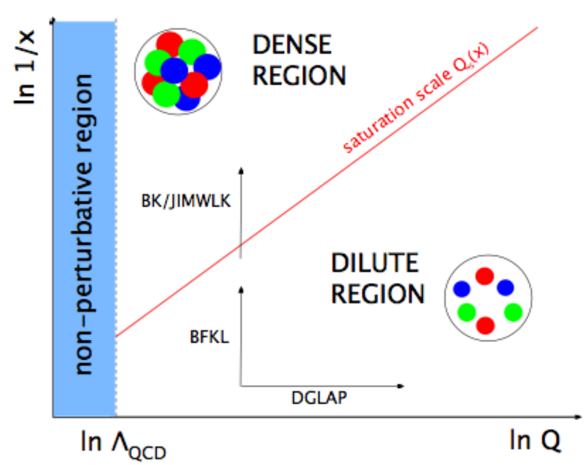
High-energy nuclear collisions

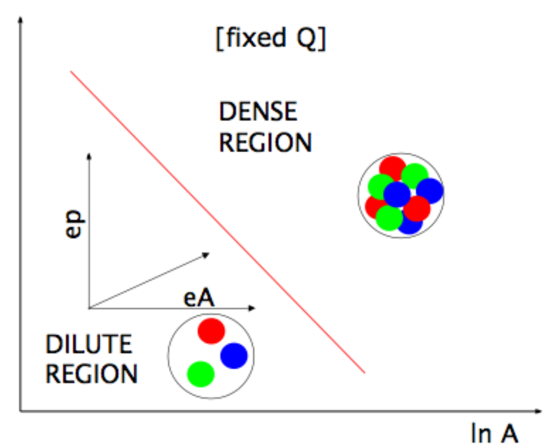
Several open issues can be addressed and, may be, fixed at *high density*.

Due to the large partonic density per unit transverse area, effects are enhanced in nuclei:
- non-linear QCD dynamics (gluon recombination, multiple scattering, …)
- saturation: partonic densities from power-like to logarithmic
- breakdown of collinear factorization: dynamical generation of transverse momentum scale

Density effects and not different physical mechanisms

$$\frac{xG_A(x,Q_s^2)}{\pi R_A^2 Q_s^2} \sim 1 \Longrightarrow Q_s^2 \propto \underline{A^{1/3}} x^{\sim -0.3}$$





LHC data show several similarities and a smooth transition between physics in pp, pPb and PbPb

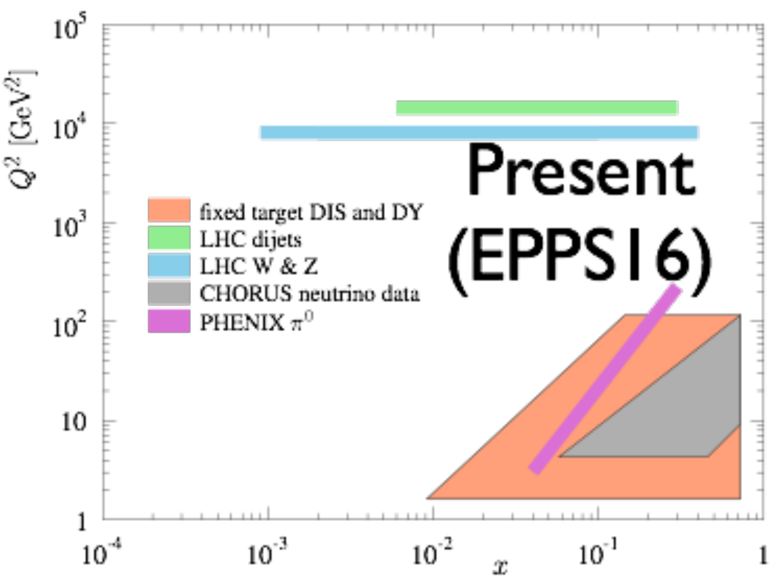
Why ep/eA colliders

DIS offers a clean experimental environment:

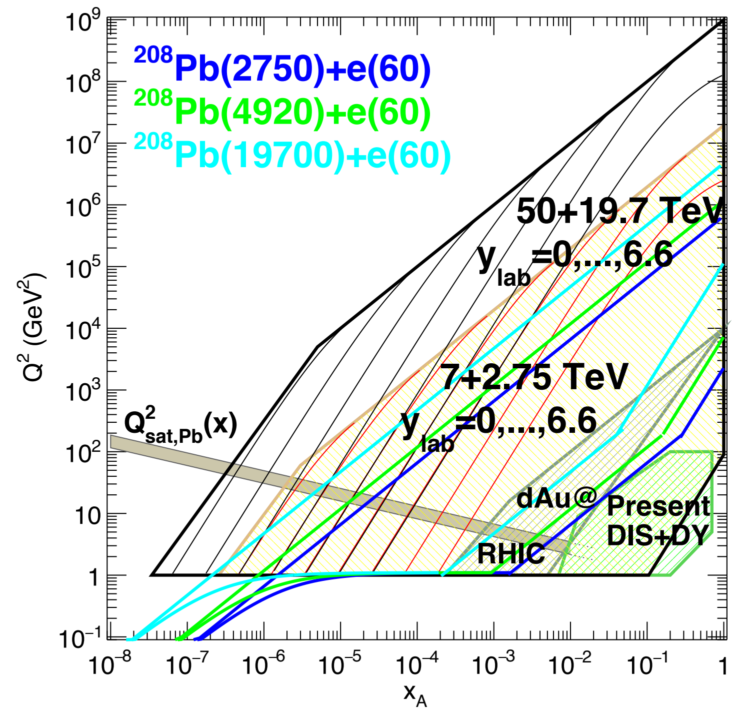
- Lower multiplicity, no pileups, fully constrained kinematics
- More controlled theoretical setup: most of the existing computations in dilute-dilute and dilute-dense regime

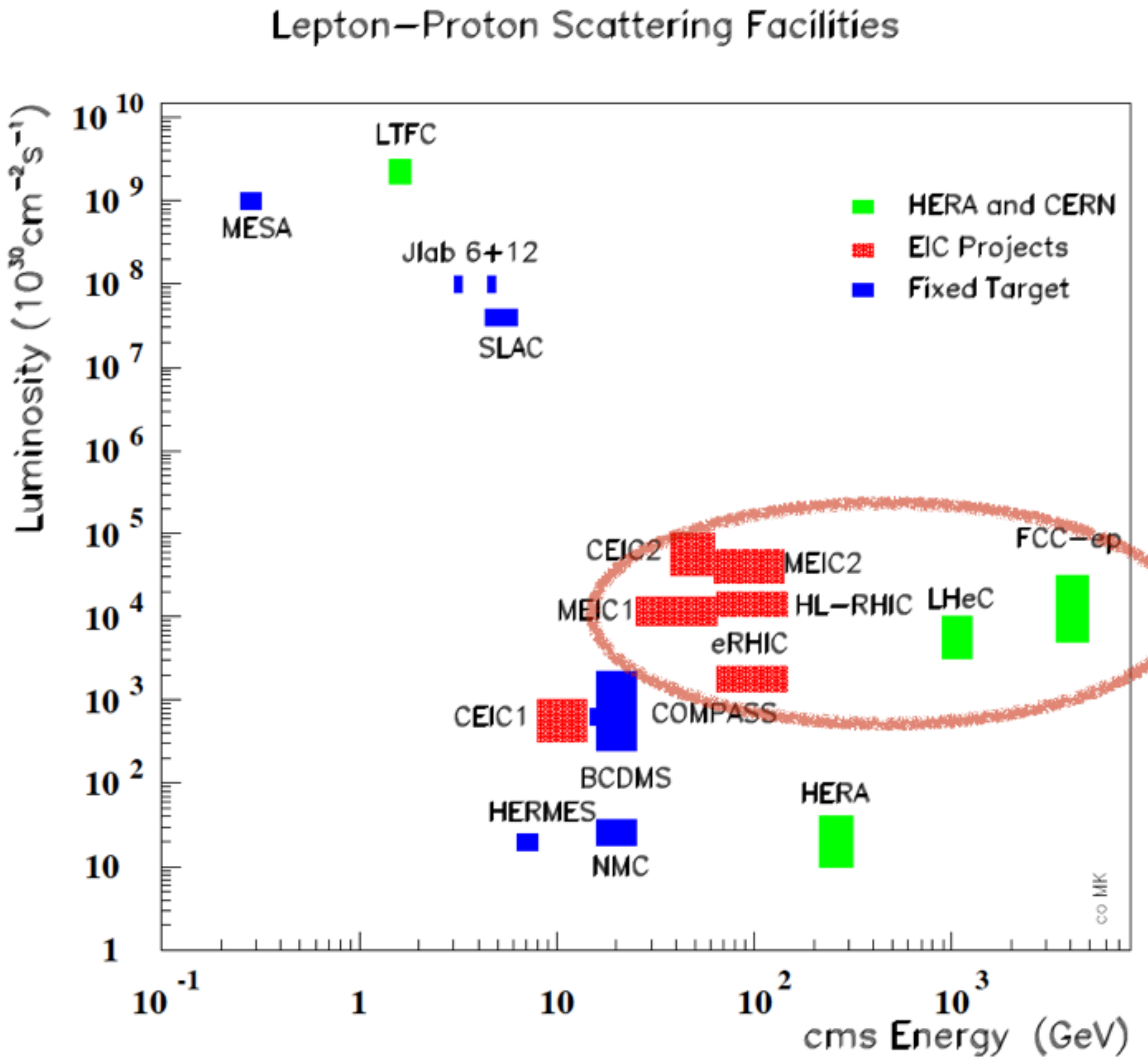
- Stringent tests of collinear factorization: constraint on small-x nPDFs
- Transverse structure by diffraction events
- Essential input for heavy-ion programmes (initial conditions, hadronization)

nPDFs



LHeC
FCC-eh





Lepton−Proton Scattering Facilities
Luminosity $(10^{30}cm^{-2}s^{-1})$
cms Energy (GeV)
HERA and CERN
EIC Projects
Fixed Target
LTFC
MESA
Jlab 6+12
SLAC
CEIC2
MEIC2
MEIC1
HL−RHIC
LHeC
FCC−ep
eRHIC
CEIC1
COMPASS
BCDMS
HERMES
NMC
HERA
co MK

nPDFs in heavy ion data

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

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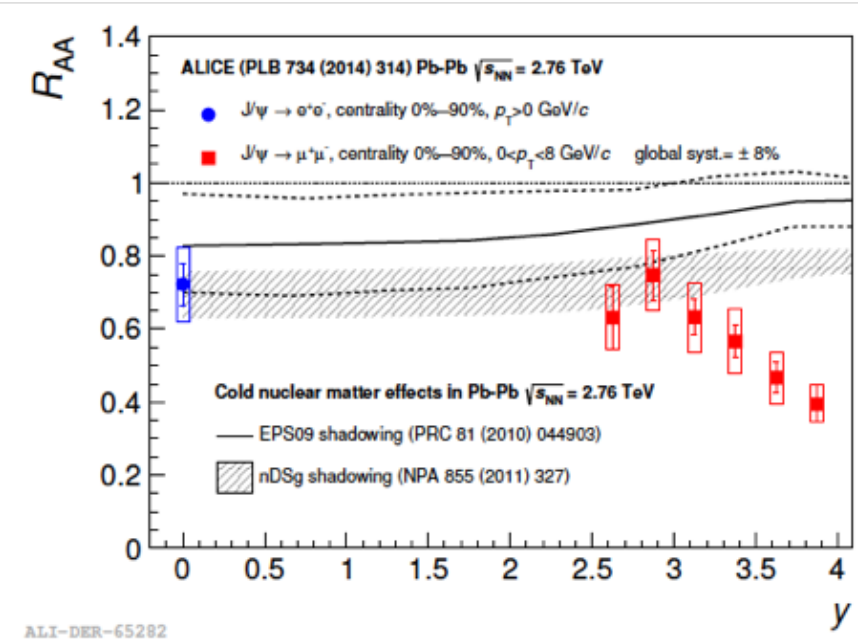
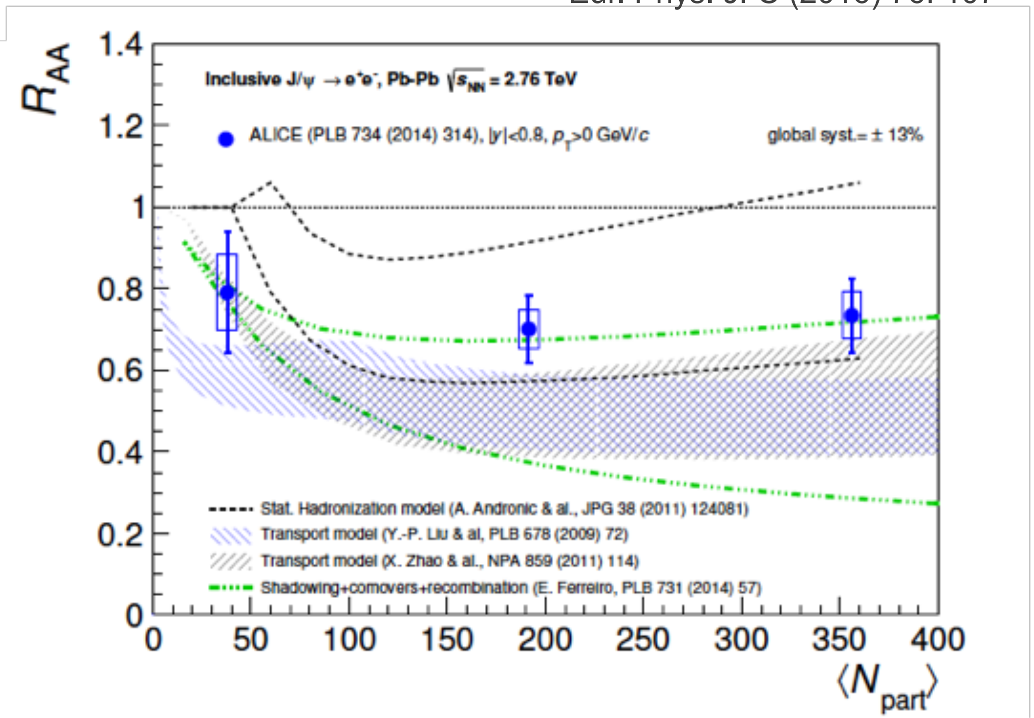




- Large lack of data
- Large uncertainties for the nuclear PDFs → major limitation for extraction of QGP parameters

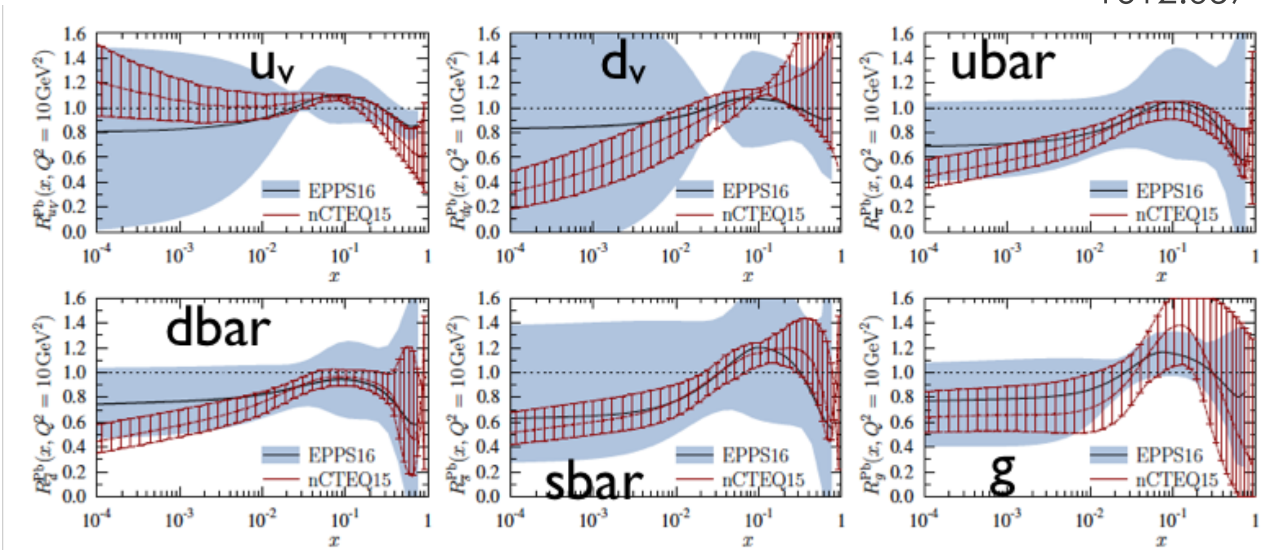
nPDFs at present

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

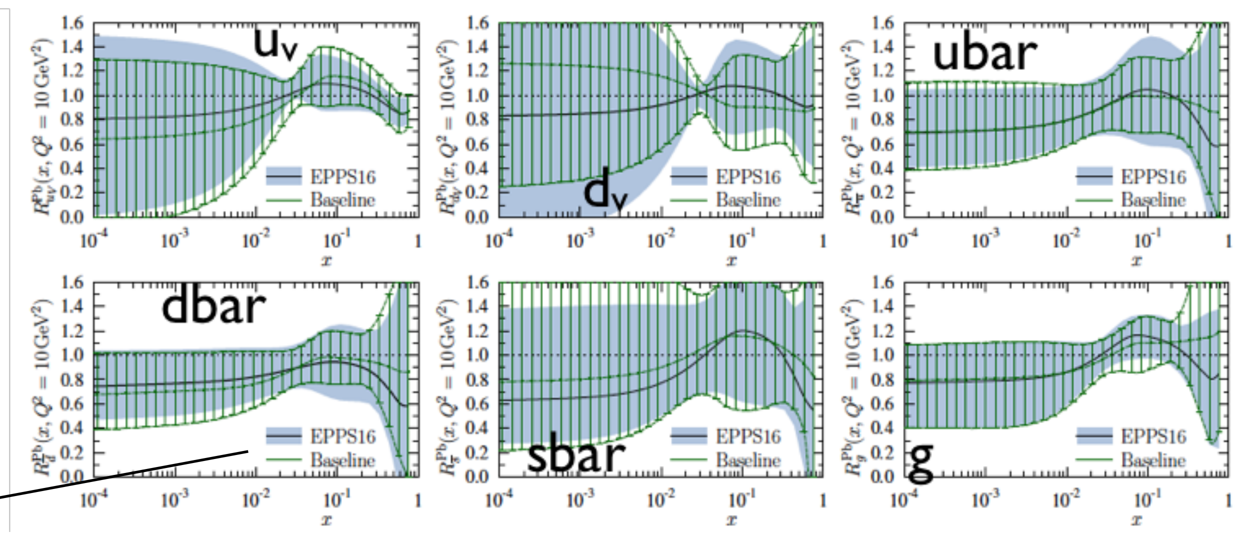
1612.05741

nCTEQ15 no neutrino data included, different functional form than EPPS16

The uncertainties are artificially smaller

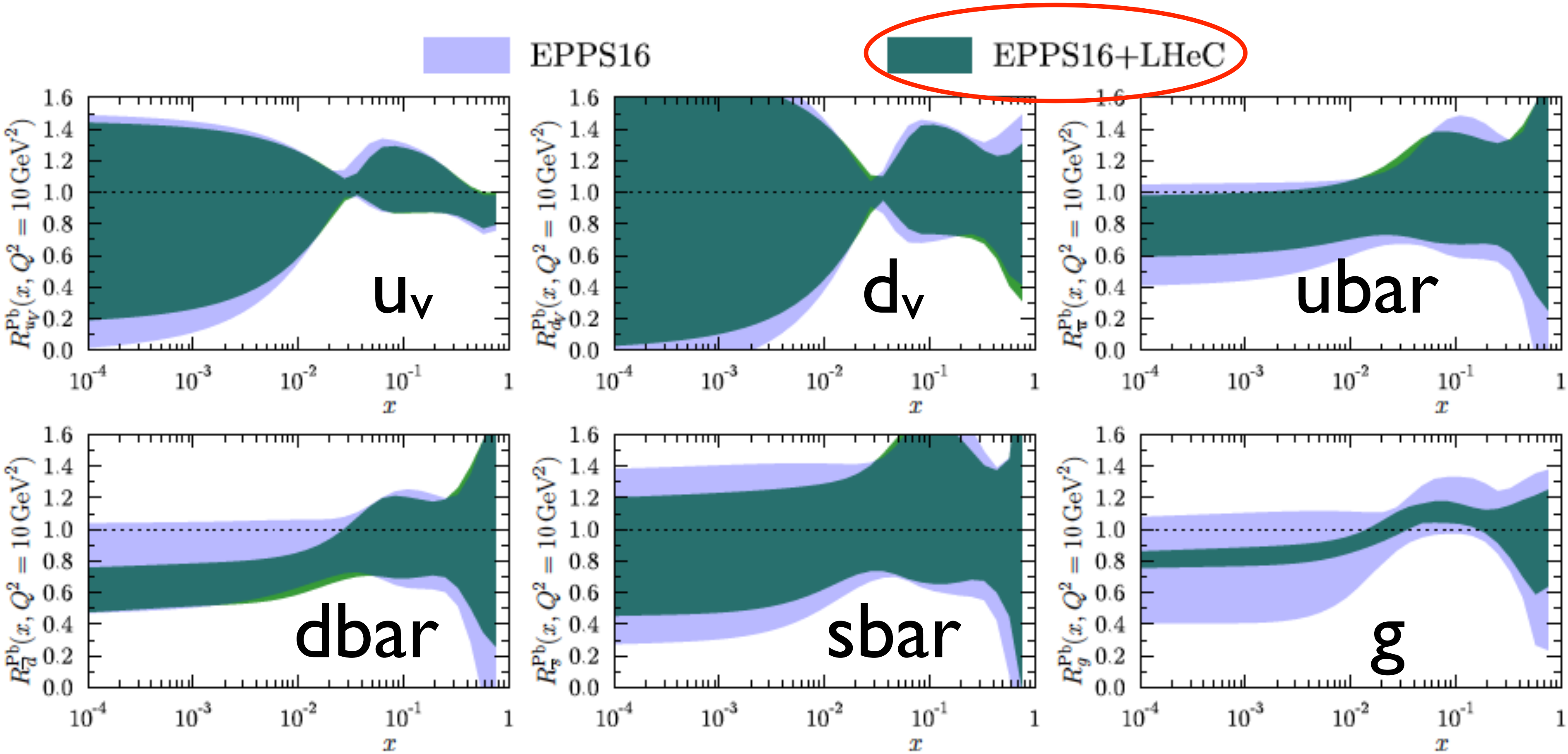


Presently available LHC data don't seem to have a large effect



Baseline includes EPS09 (fixed targets DIS, DY, RHIC)
EPPS16: baseline + Chorus data + LHC (dijet, W, Z) pPb

nPDFs in eA colliders



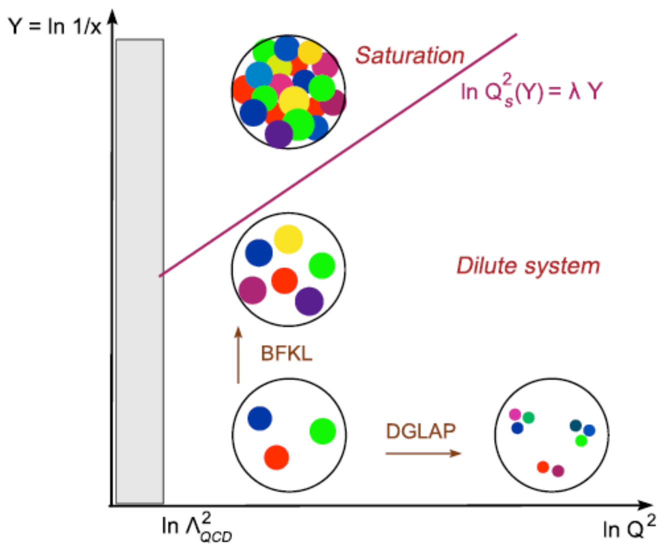
Large reduction of uncertainties

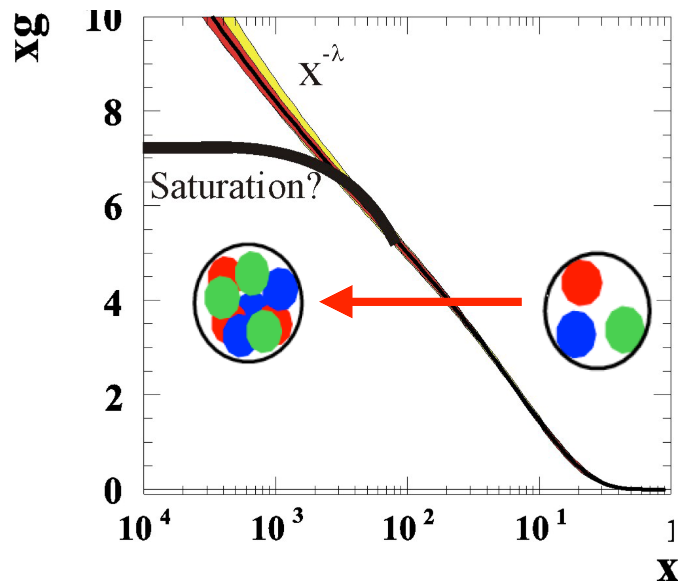
Small x and non-linear dynamics

1702.00839

Determining the dynamics at small x has been a major subject at HERA, RHIC and the LHC both in pp, pA and AA

Smoking gun for breakdown of the collinear factorization





Several approaches have been developed to address small-x/high density dynamics

Simultaneous description of different inclusive observables (with different sensitivities to the gluon and the sea) in DGLAP may show tensions e.g. F2 and FL

Small x and non-linear dynamics

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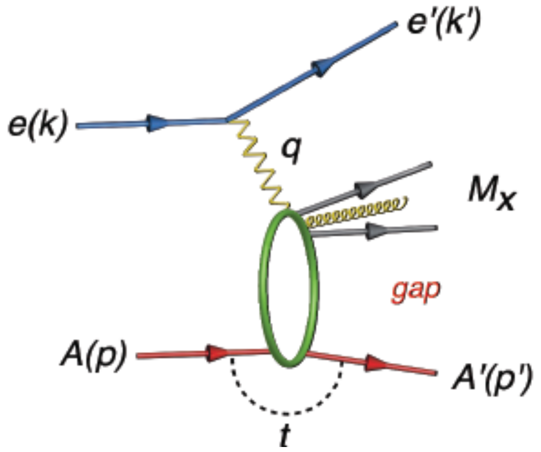
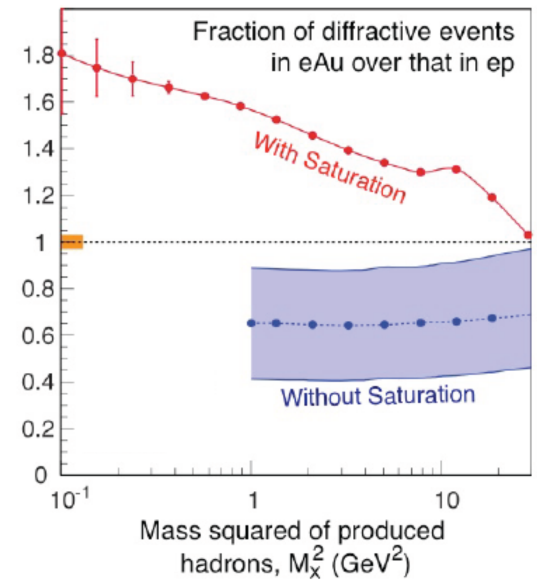
Smoking gun for breakdown of the collinear factorization

Diffractive events may be quite sensitive:





One would expect naively that suppression effects are larger when going from p to A in saturation than in collinear approaches

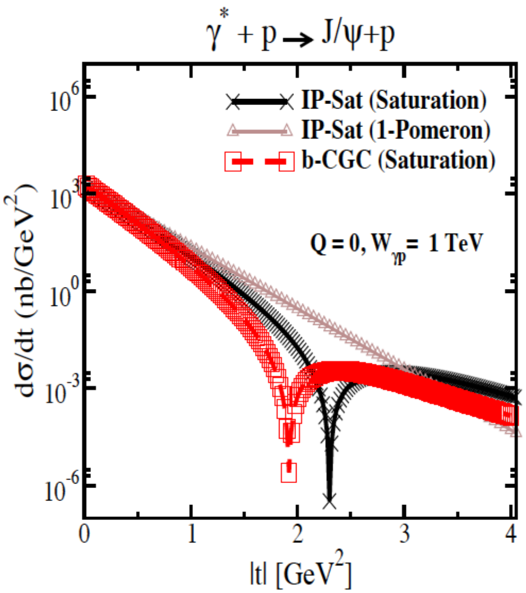
This is not generically so because the saturation due to the increase of density when going from p to A could be smaller for an already saturated proton input

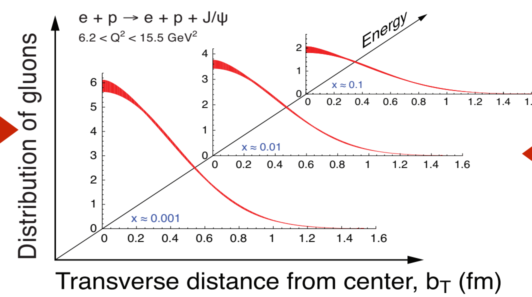
both ep and eA are essential!!!

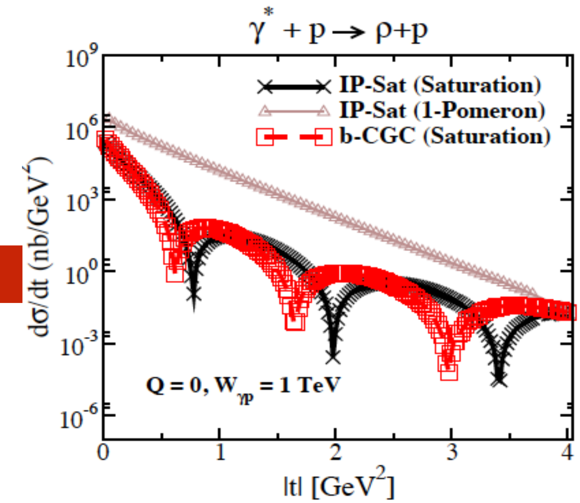
VM production

- Exclusive VM production ←→ DVCS provides a transverse scan of the partonic structure of the hadron

1402.4831







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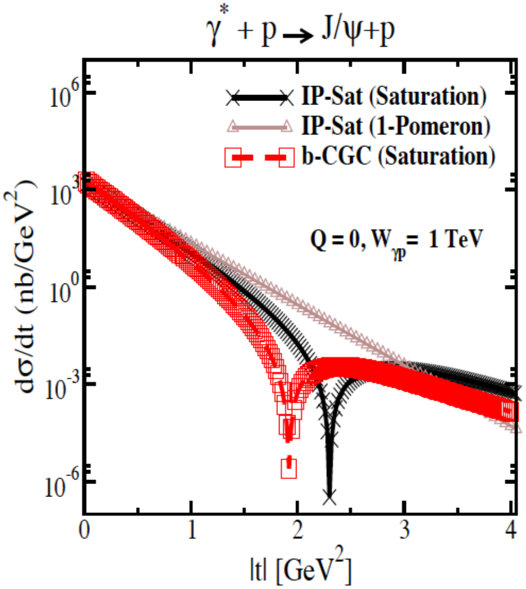
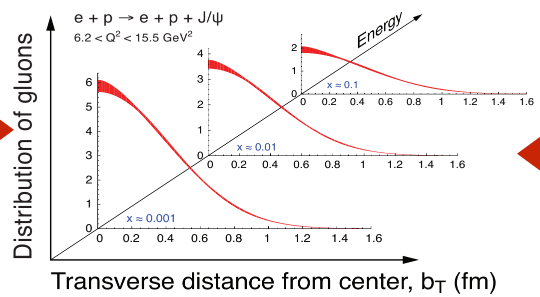
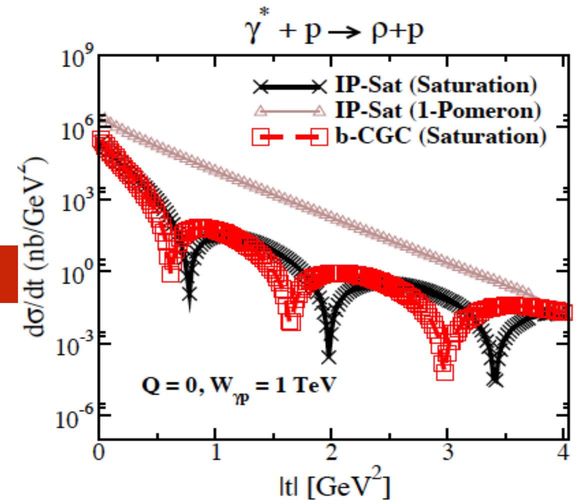
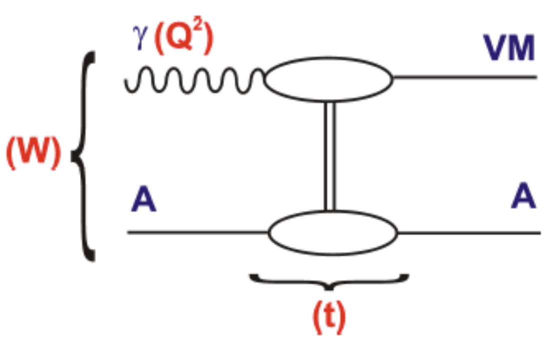
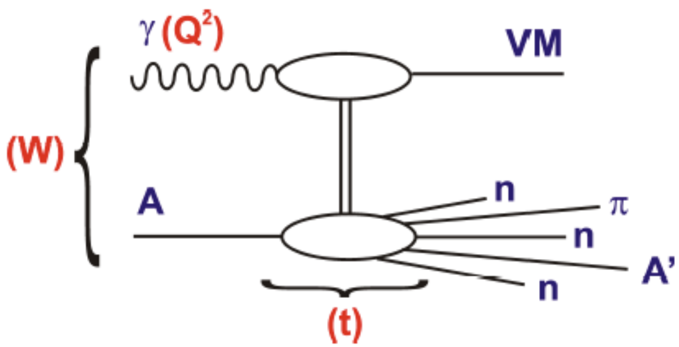






- Coherent vs incoherent diffraction can solve the issue that the gluonic density of the proton in the transverse plane is distributed around the constituent quarks (hot spots) relevant for fluctuations, azimuthal asym, definition of MPIs...





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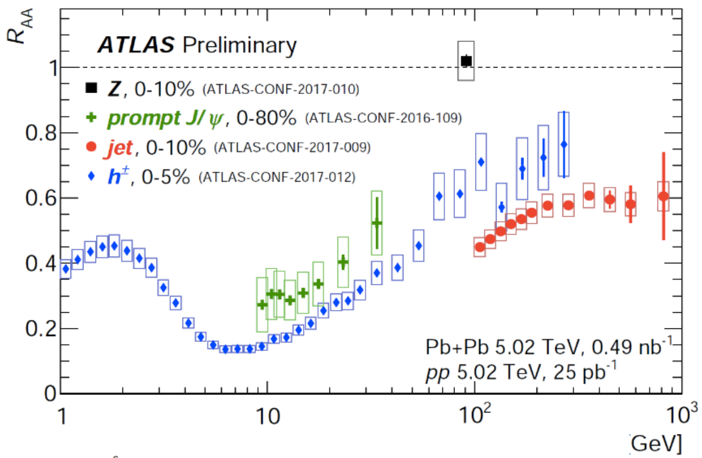
1011.1988
1703.09256

Hard probes

Extremely successful *self generated* probes for QGP and pQCD in AA collisions, but with a lot of issues to be understood, e.g.:

- The traditional picture of semihard large angle gluon radiation (interference with several scattering centres) could be replaced by the interplay between the medium resolving power and the jet scale (radiation off from total to individual color charge)
- Hadronisation is *assumed* to happen outside the medium, except for QQbar



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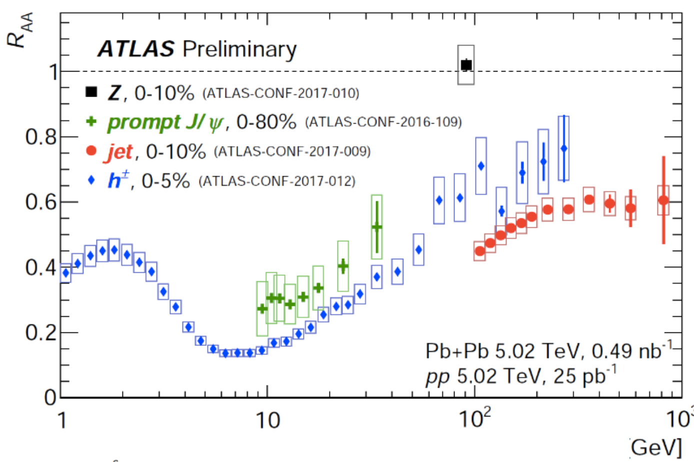
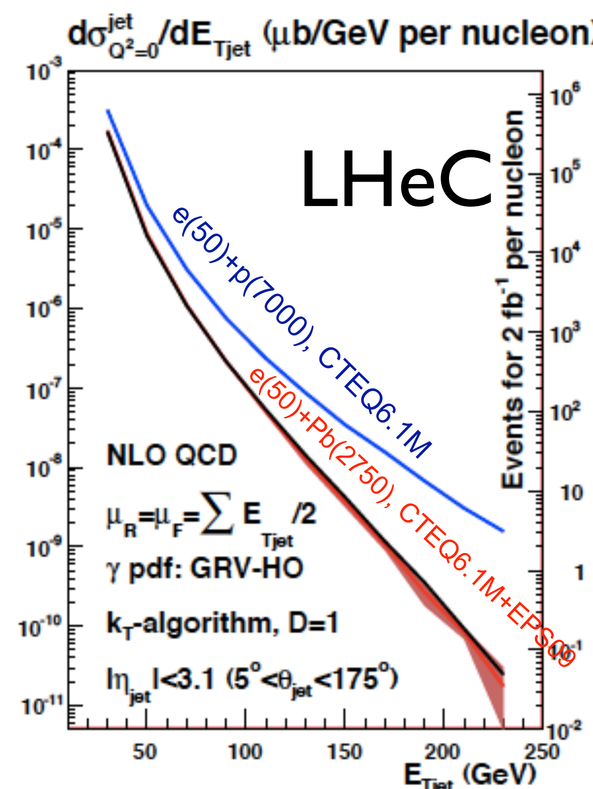


HP will be abundantly produced in eA colliders up to sizable E_T.

They can be used to test factorisation and for precision studies QCD radiation in the nuclear environment.



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Conclusions

ep/eA colliders at the TeV scale offer huge possibilities, not yet fully exploited:

- To provide most interesting information about QCD on their own:
  - partonic structure
  - new regimes of QCD
  - transverse structure of hadrons and nuclei
  - particle production and correlations

- To clarify aspects of pp, pA and AA collisions at high energy:
  - initial conditions for macroscopic descriptions
  - nature of collectivity
  - uncertainties in the extraction of parameters of the QCD

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For these and other reasons, ep and eA colliders would be highly desirable