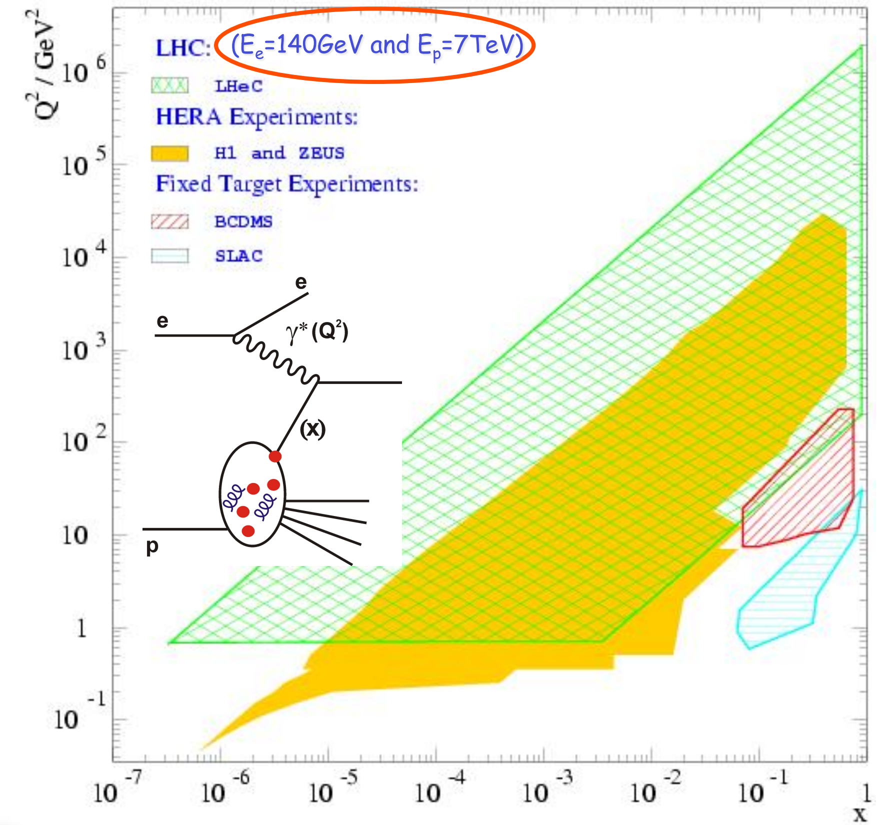
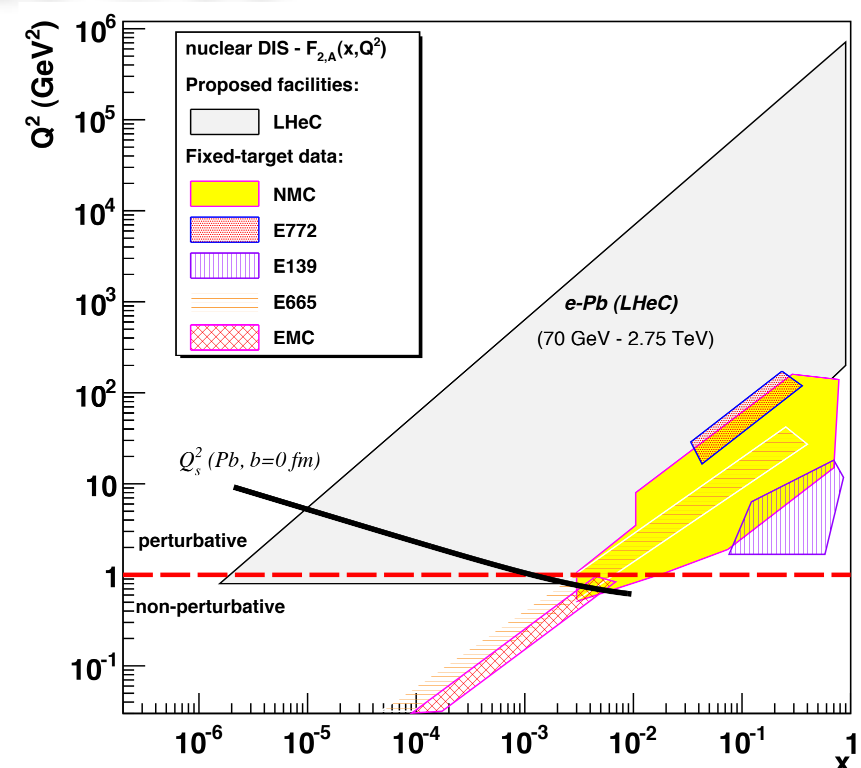
http://cern.ch/lhec



The Large Hadron electron Collider at CERN

Anna Stasto (Penn State & RIKEN BNL & Krakow INP)



08/17/2012 Quark Matter 2012, Washington DC

Conceptual Design Report

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LHeC-Note-2012-001 GEN
Geneva, June 14, 2012

All the results presented here are published in CDR

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

LHeC Study Group

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14 sections

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Physics Motivation for ep/eA in TeV range

- Details of parton structure of the nucleon (from ep,ed/eA), full unfolding of PDFs. Measurement of GPDs and unintegrated PDFs.
- Mapping the gluon field down to very low x. Saturation physics.
- Heavy quarks, factorization, diffraction, electroweak processes.
- Properties of Higgs. Very good sensitivity to: H to bbar, H to WW coupling in the 120-130 GeV mass range.
- Searches and understanding of new physics. Very precise measurement of the coupling constant. Leptoquarks, excited leptons...
- Deep inelastic scattering off nuclei. Nuclear parton distributions. Pinning down the initial state for heavy ion collisions.
- Understanding nuclear effects of QCD radiation and hadronization.

LHeC kinematics

ep/eA collisions

$$E_p = 7 \text{ TeV}$$

$$E_A = 2.75 \text{ TeV/nucleon}$$

$$E_e = 50 - 150 \text{ GeV}$$

$$\sqrt{s} \simeq 1 - 2 \text{ TeV}$$

- **Requirements**:

* Luminosity~10^{33} $cm^{-2}s^{-1}$. eA: L_{en}~10^{32} $cm^{-2}s^{-1}$

* Acceptance: 1-179 degrees (low-x ep/eA).

* Tracking to 1 mrad.

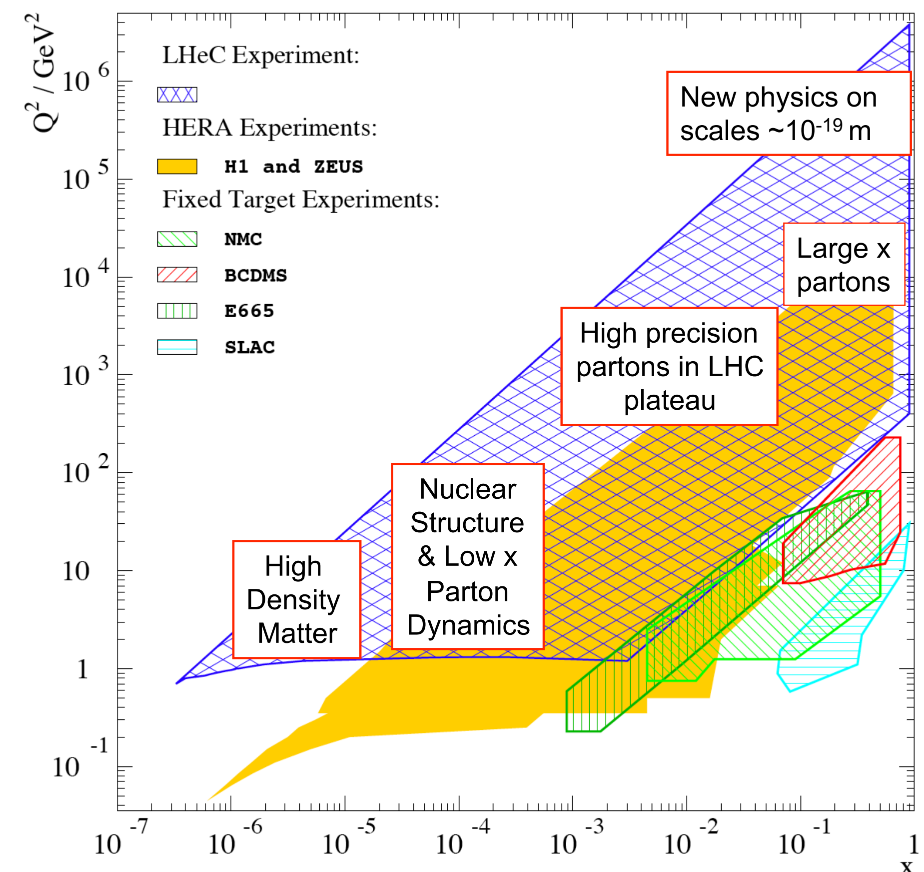
* EMCAL calibration to 0.1 %.

* HCAL calibration to 0.5 %.

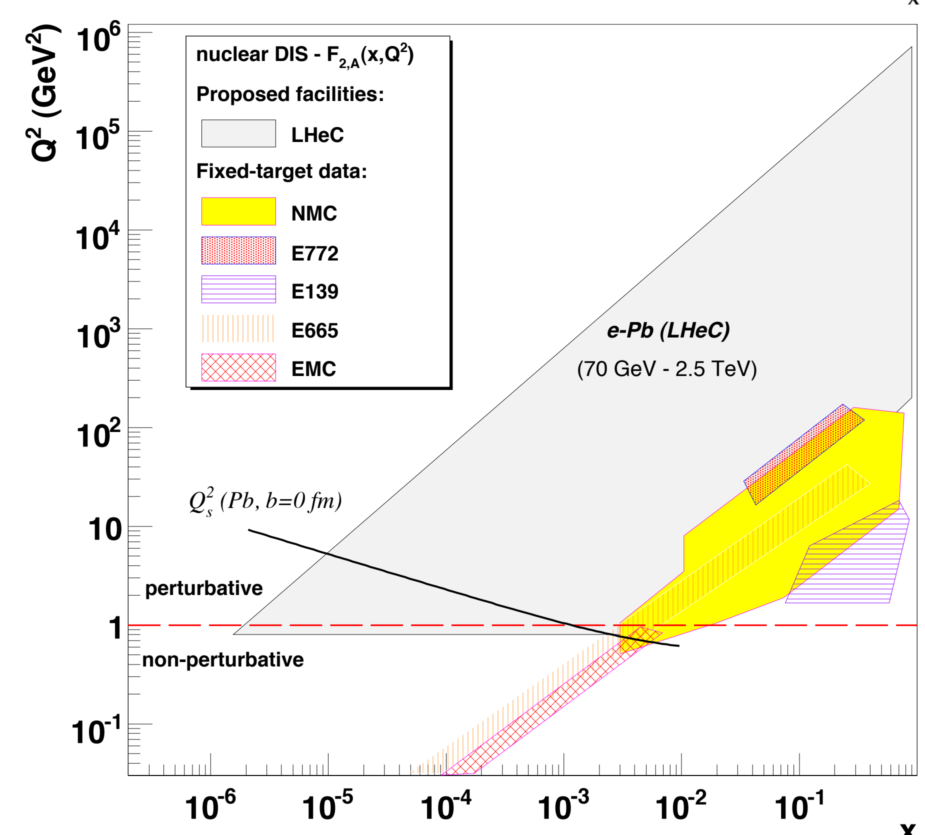
* Luminosity determination to 1 %.

* Compatible with LHC operation.

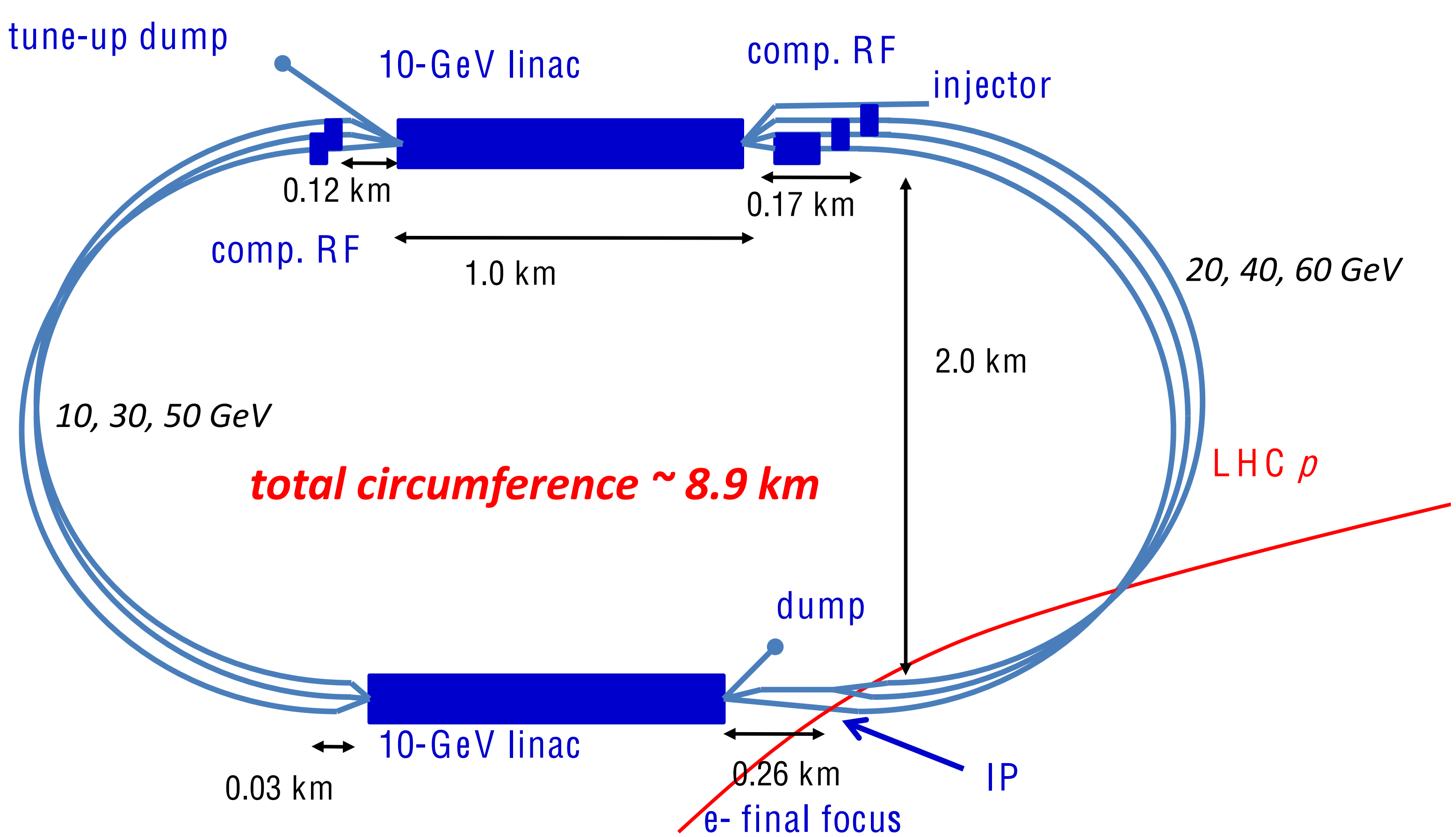
ep



eA



Accelerator design in linac-ring scenario



500 MeV injection
3 turns
2 linacs, 10 GeV
energy recovery
90% polarisation

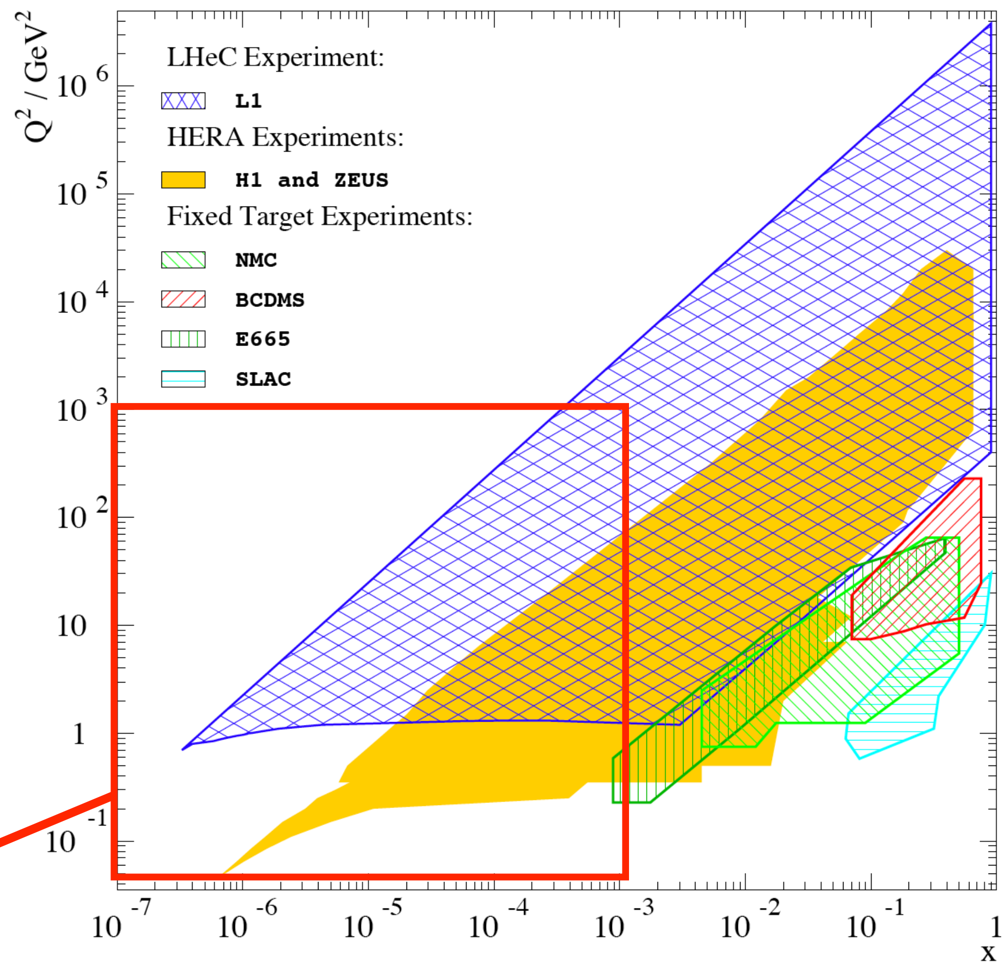
$$L = 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

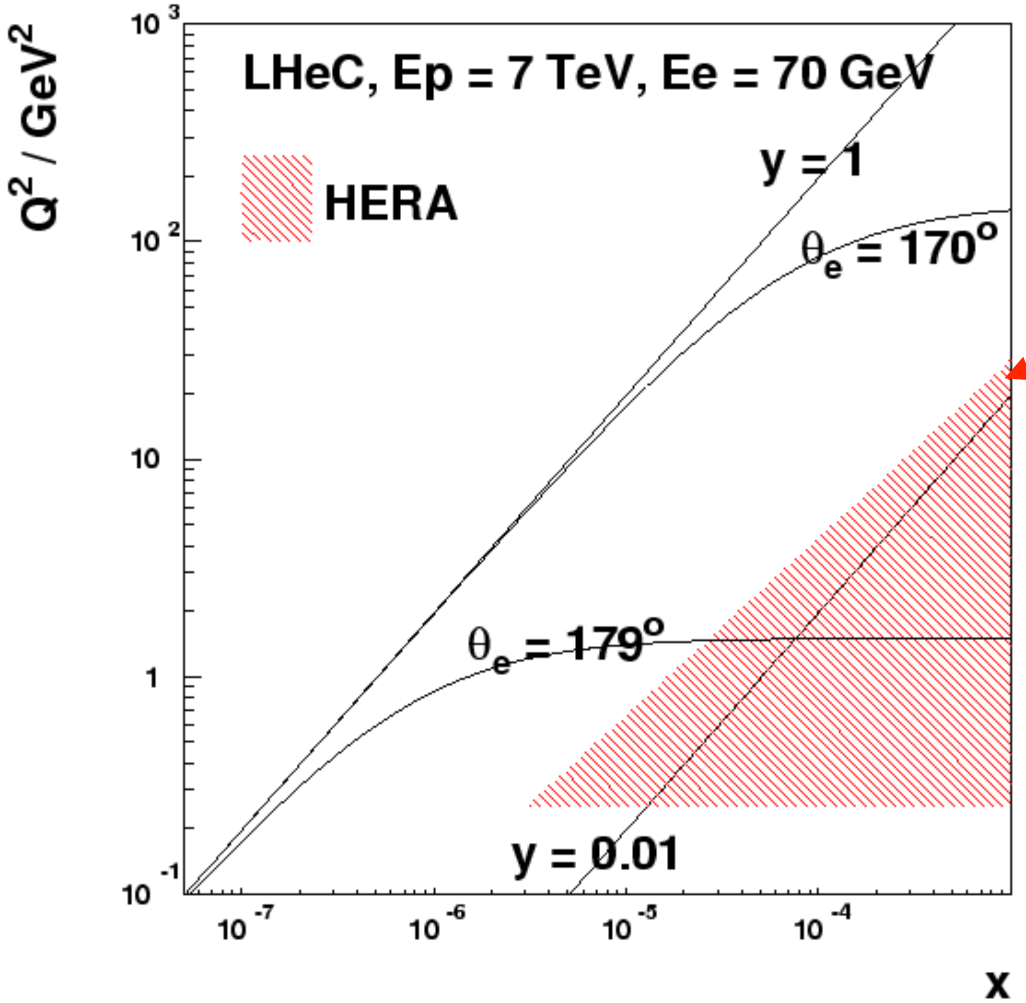
preferred option

Higher energy:
140 GeV linac
ILC type
31.5 MV/m
without energy recovery
lower luminosity

Detector Acceptance Requirements

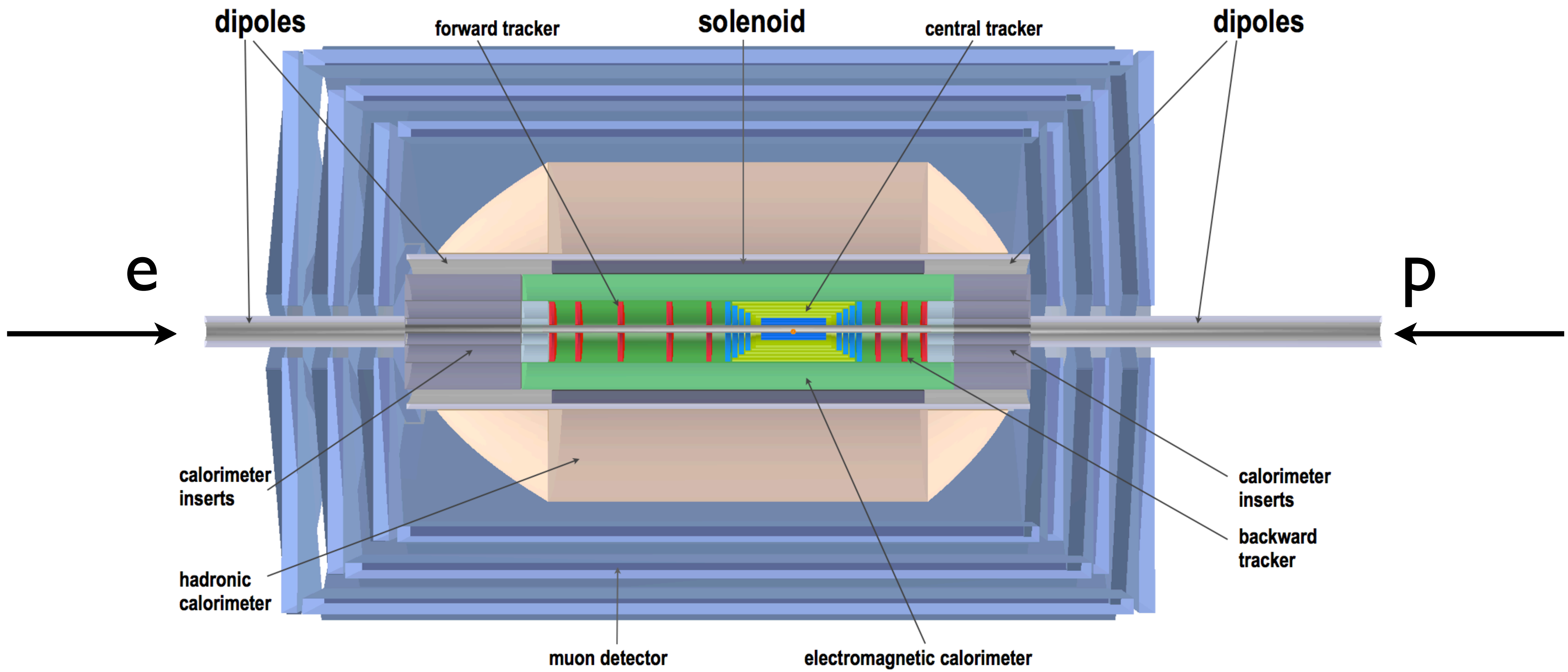
Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°





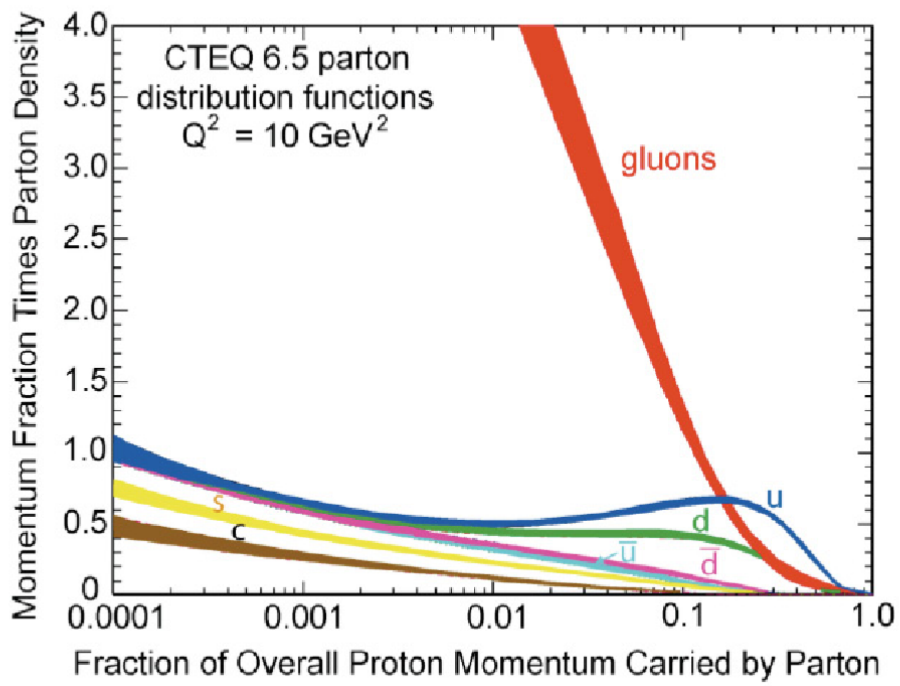
Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x (essential for good kinematic reconstruction)

Detector design



Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

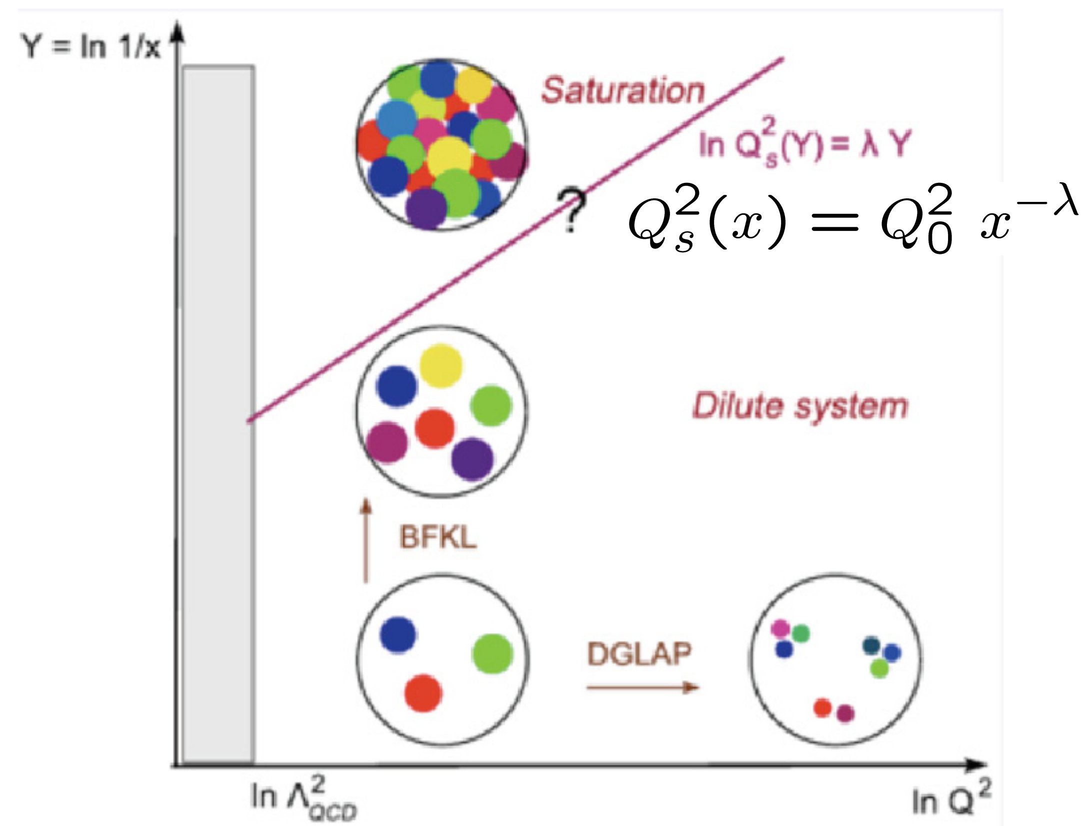
Low x and saturation



HERA established strong growth of the gluon density towards small x

Parton saturation: recombination of gluons at sufficiently high densities leading to nonlinear modification of the evolution equations.

Emergence of a dynamical scale: saturation scale dependent on energy.



What we learned from HERA about saturation?

Linear DGLAP evolution works well at HERA.

Hints of saturation at low Q and low x: deterioration of the global fit in that region.

Large diffractive component.

Success of the dipole models in the description of the data.

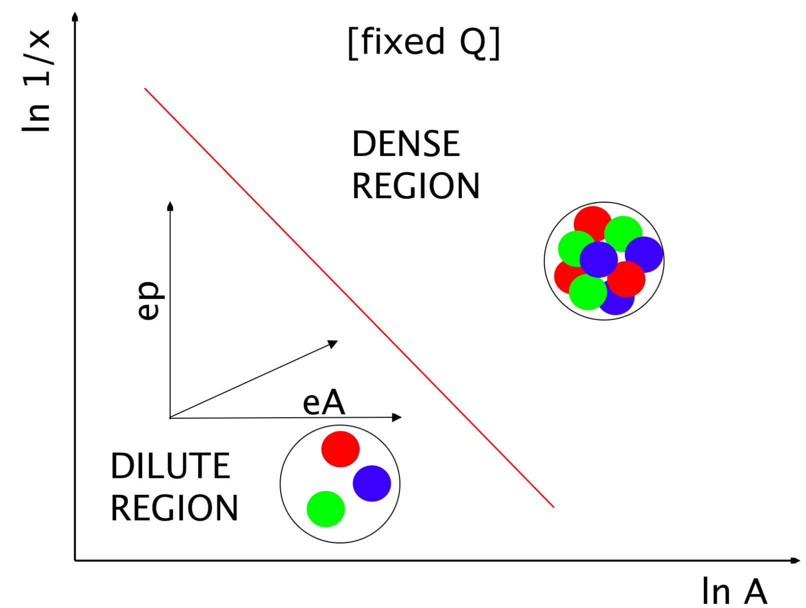
The models point at the low value of the saturation scale

LHeC would provide an access to a kinematic regime where the saturation scale is perturbative

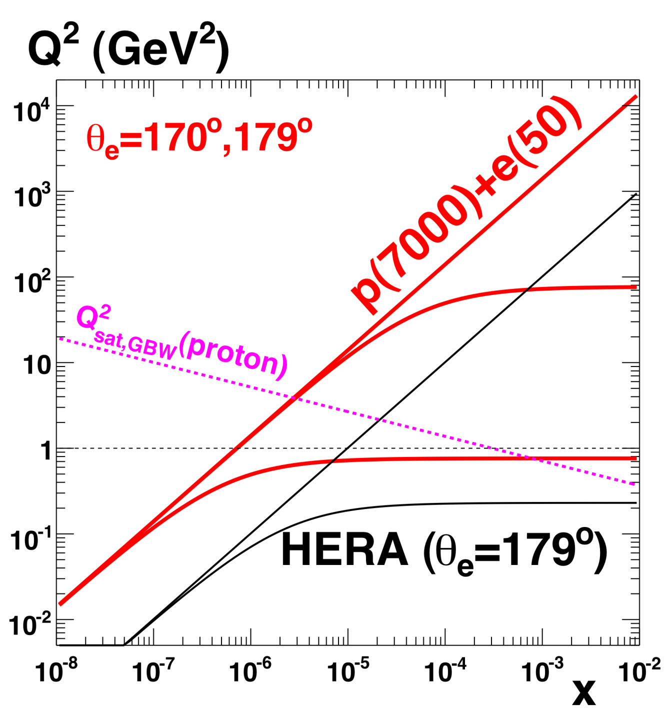
Strategy for making target more 'black'

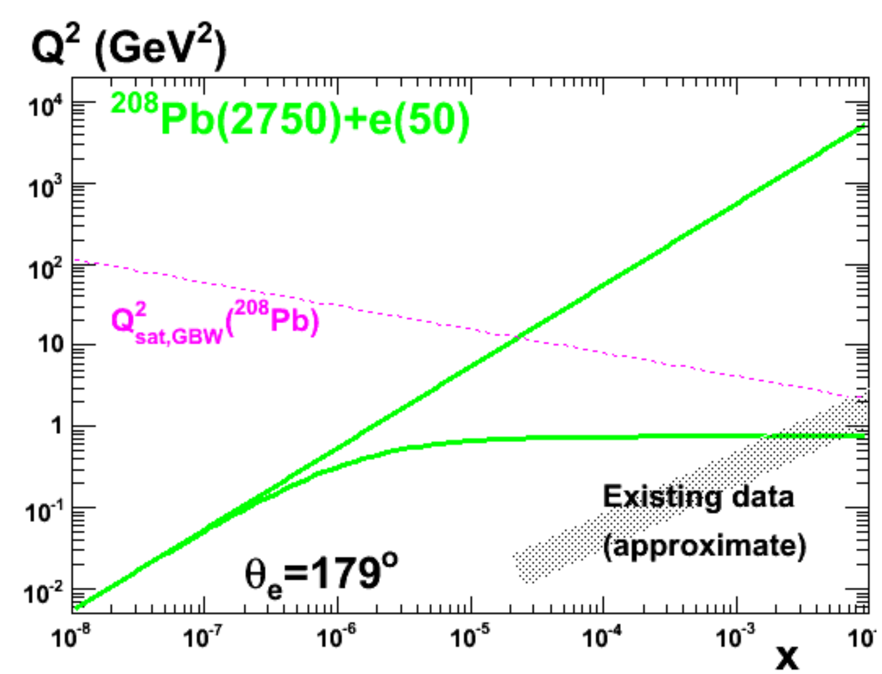
LHeC would deliver a two-pronged approach:

Probing lower x in ep. Evolution of a single source

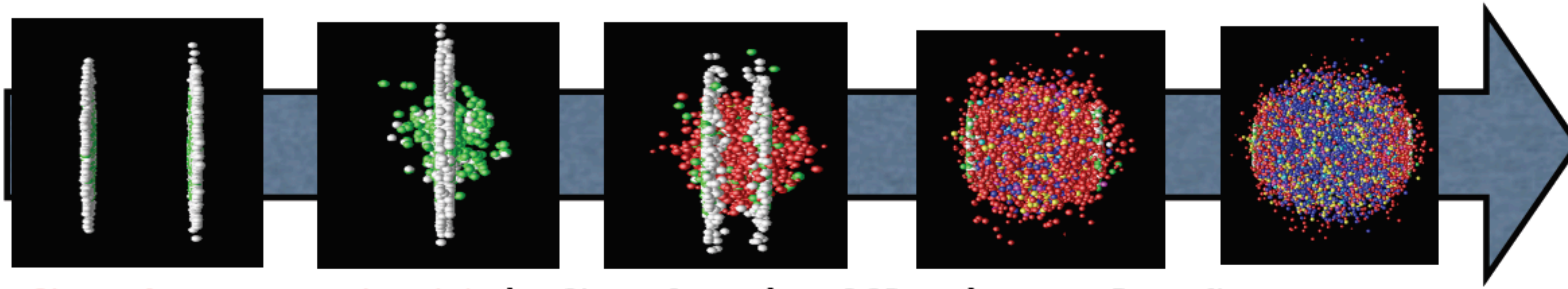


More nucleons: eA scattering. Many sources overlapping in impact parameter .





Nuclear physics in eA complementarity to pA, AA at LHC



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

Precision measurement of the initial state.

Nuclear structure functions.

Particle production in the early stages.

Factorization eA/pA/AA.

Modification of the QCD radiation and hadronization in the nuclear medium.

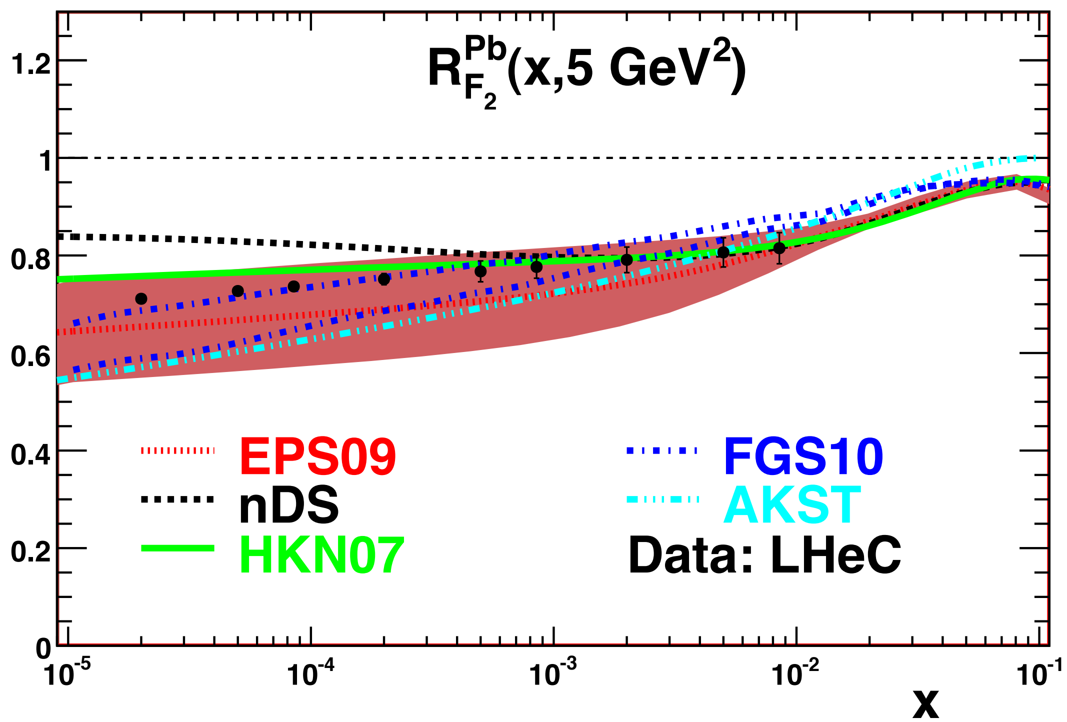
Nuclear structure functions at LHeC

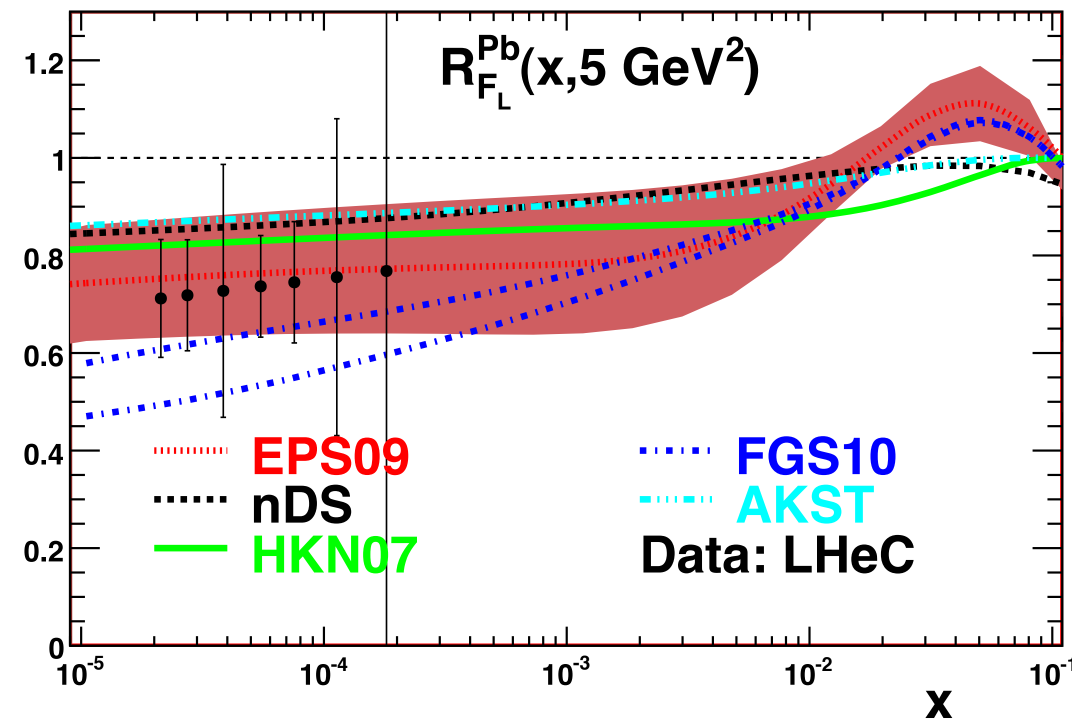
Nuclear ratio for structure function or a parton density:

$$R_f^A(x,Q^2) = \frac{f^A(x,Q^2)}{A \times f^N(x,Q^2)}$$

Nuclear effects $R^A \neq 1$

LHeC potential: precisely measure partonic structure of the nuclei at small x.

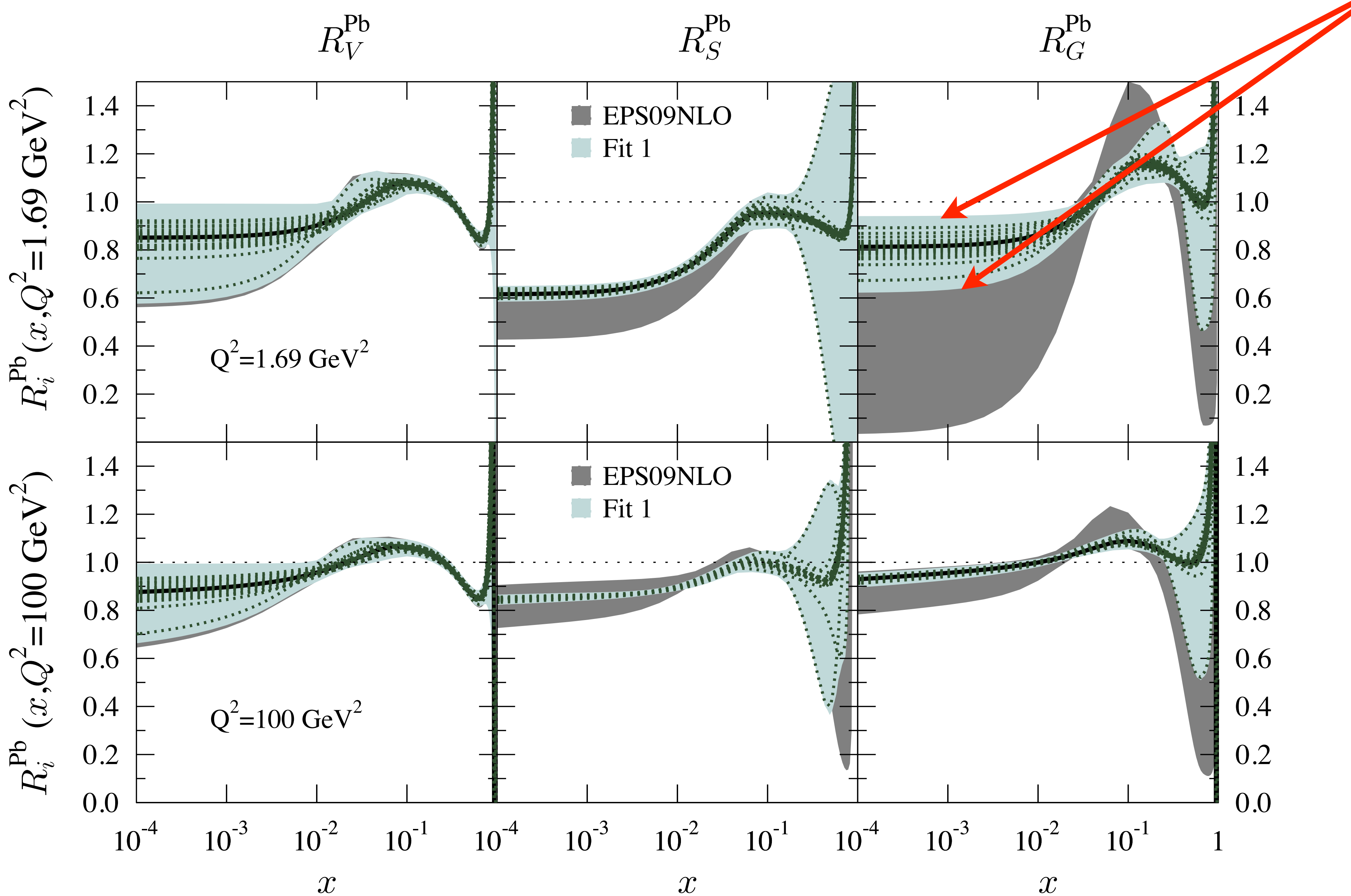




Nuclear structure functions measured with very high accuracy.

Nuclear parton distributions at LHeC

Global NLO fit of nuclear PDFs with the LHeC pseudodata included



Much smaller uncertainties.

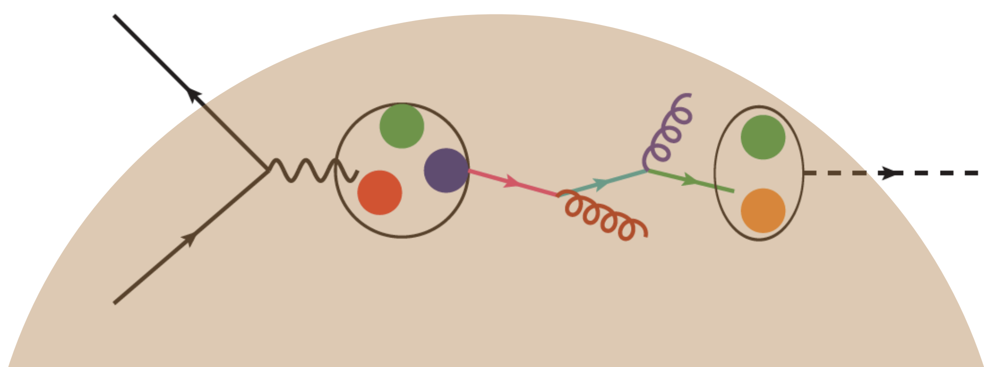
Very large constraint on the low x gluons and sea quarks with the LHeC pseudodata .

Radiation and Hadronization

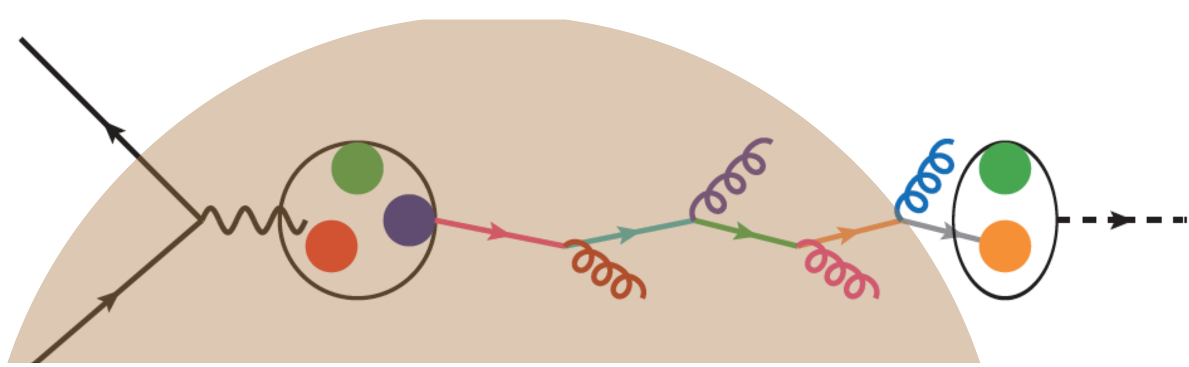
- LHeC can provide information on radiation and hadronization.
- Large lever arm in energy allows probing different timescales.
- Important for HI collisions .

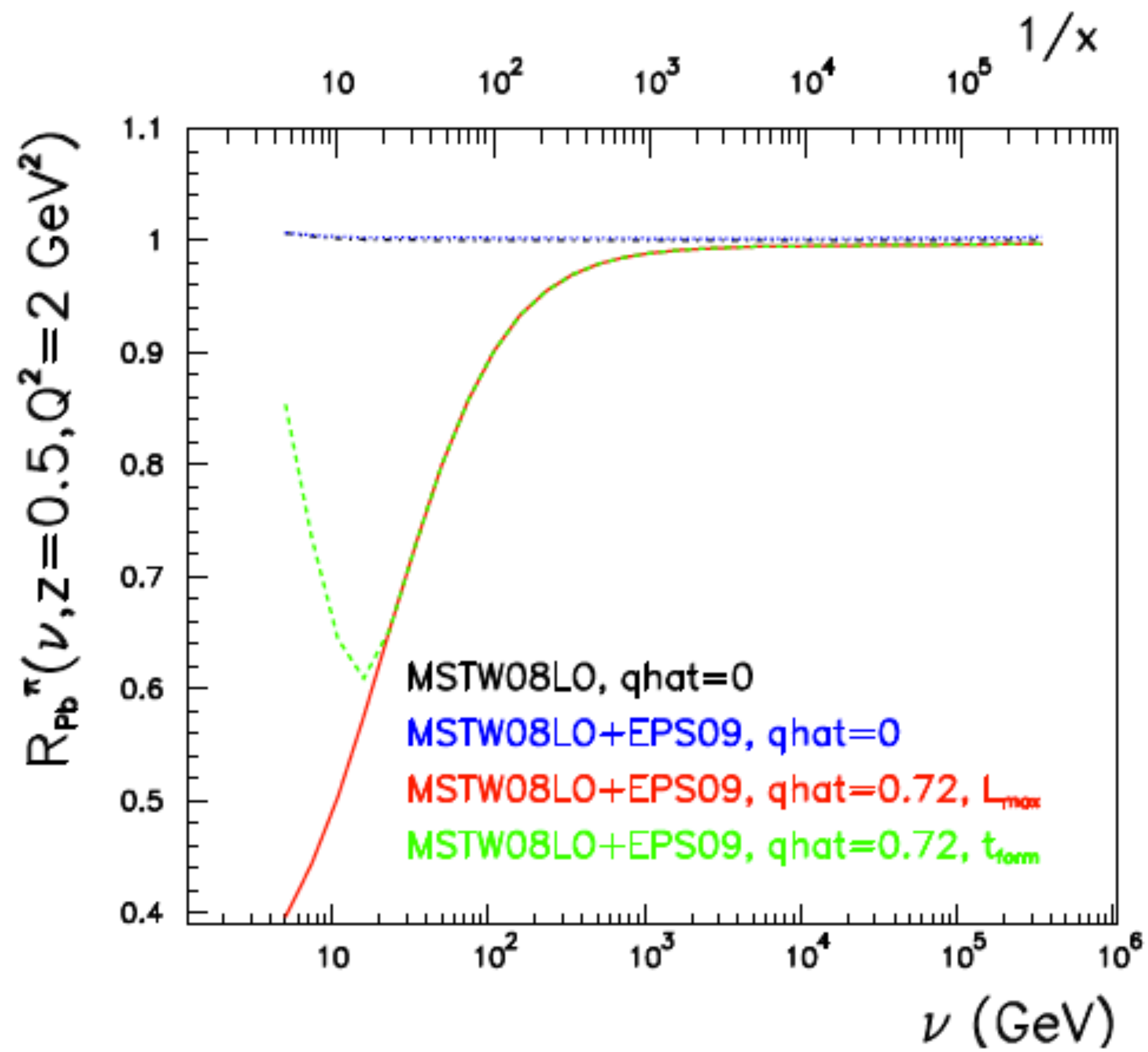
$$R_A^k(\nu, z, Q^2) = \frac{1}{N_A^e} \frac{dN_A^k}{d\nu dz} \Bigg/ \frac{1}{N_p^e} \frac{dN_p^k}{d\nu dz}$$

Low energy: hadronization inside

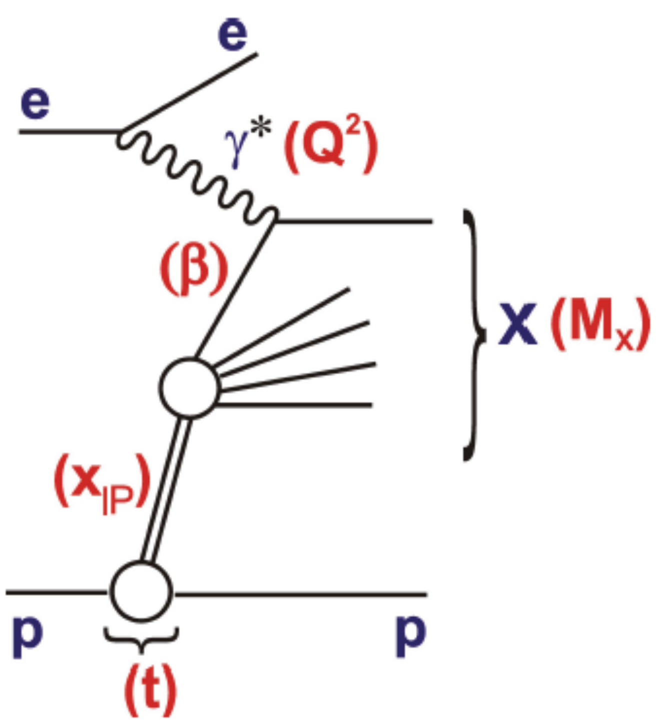


High energy: partonic evolution altered in nuclear medium





Diffraction



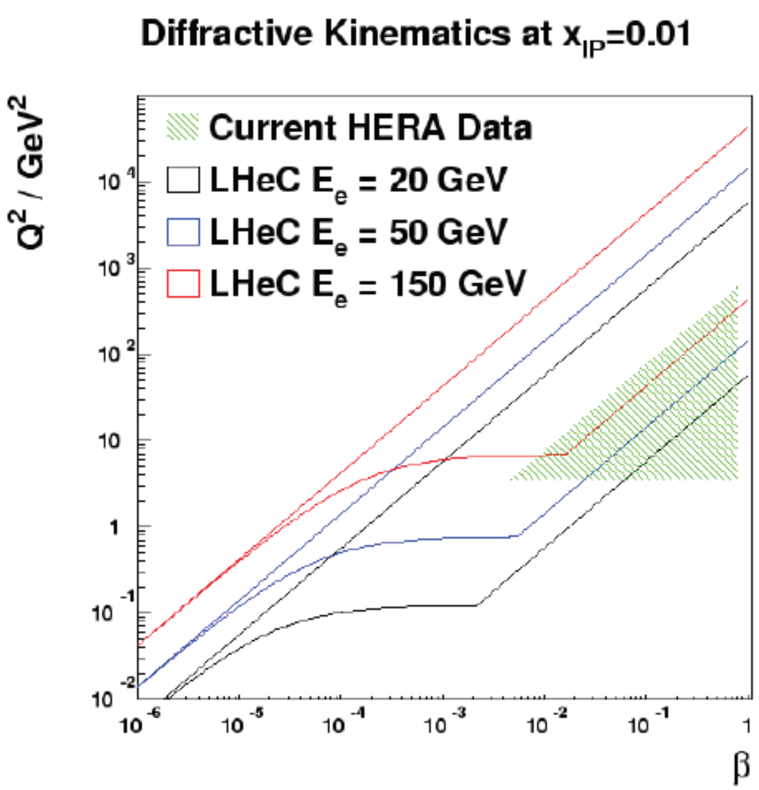
$$x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

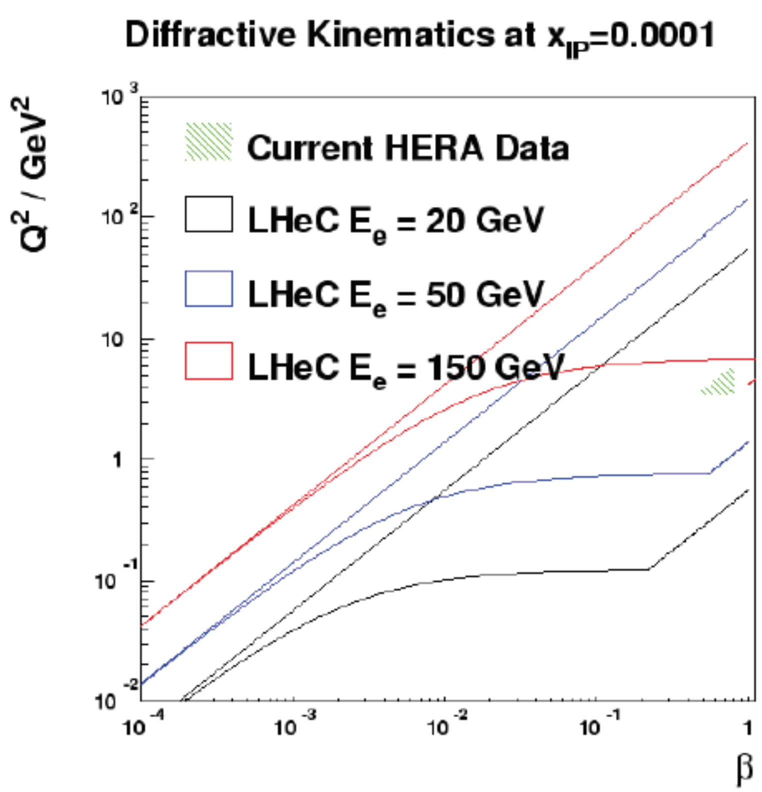
momentum fraction of the Pomeron w.r.t hadron

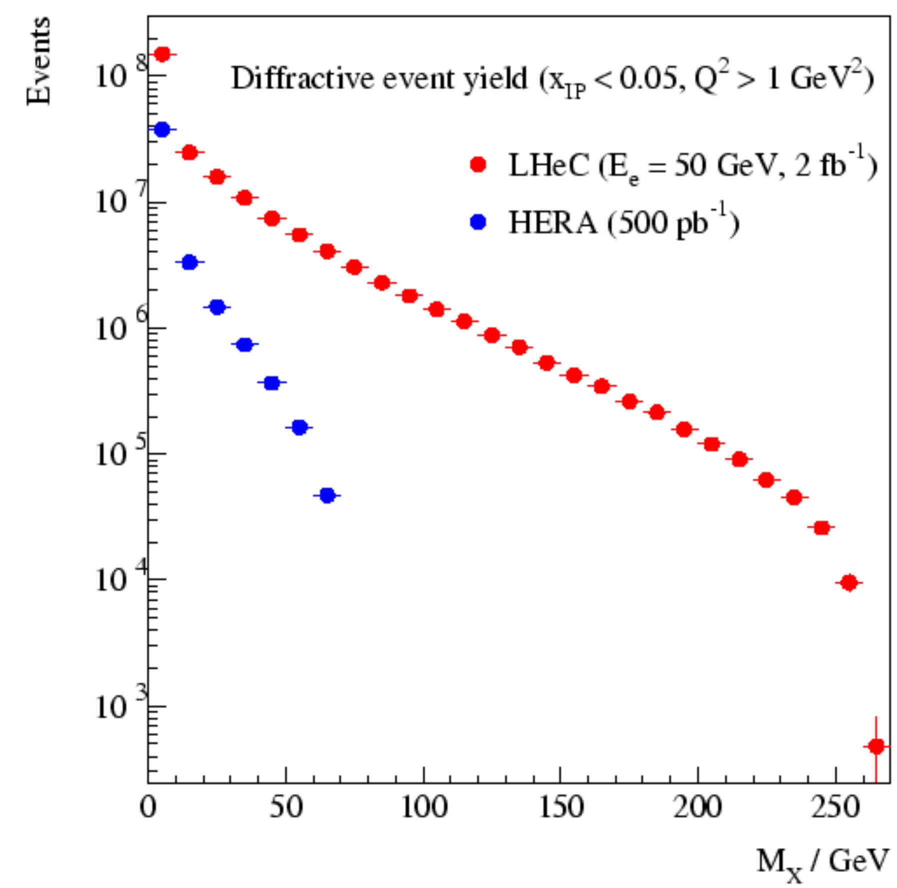
$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

$$x_{Bj} = x_{IP}\beta$$



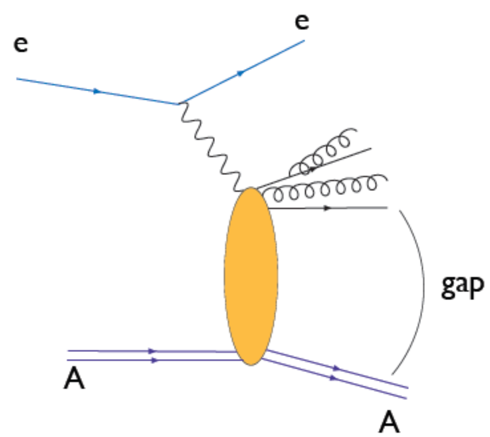




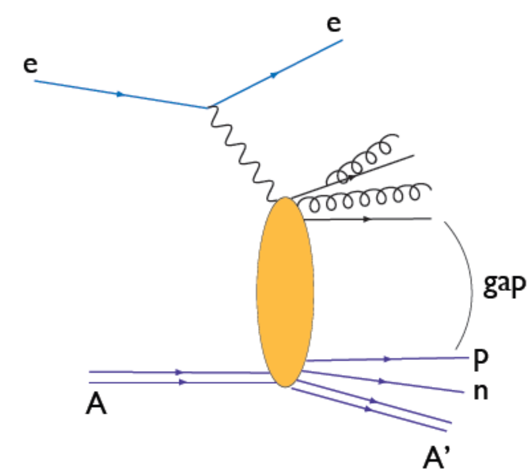
Methods: Leading proton tagging, large rapidity gap selection

New domain of diffractive masses M_X can include W/Z/beauty

Inclusive diffraction in eA

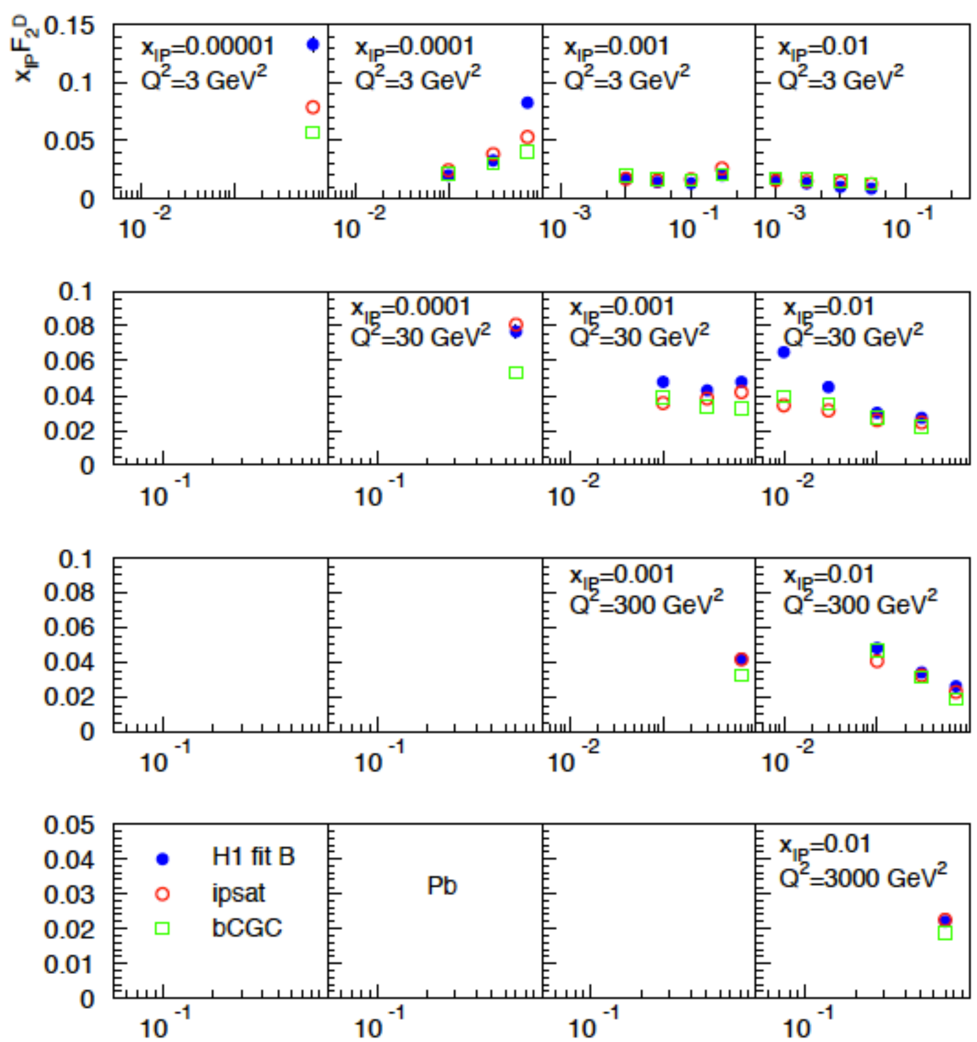


coherent

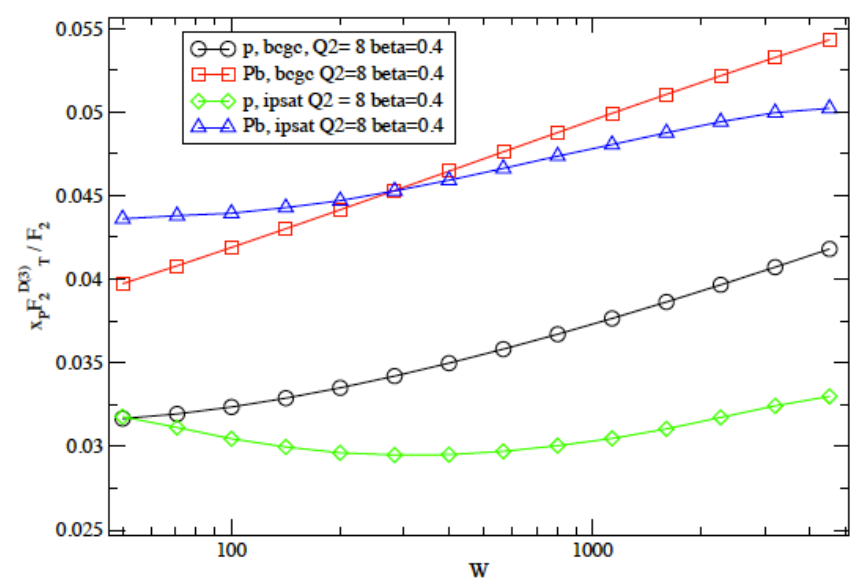


incoherent

Diffractive structure function for Pb



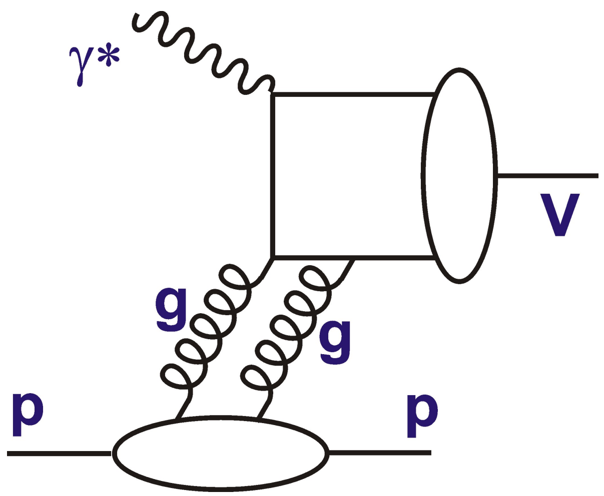
Diffractive to inclusive ratio for protons and Pb



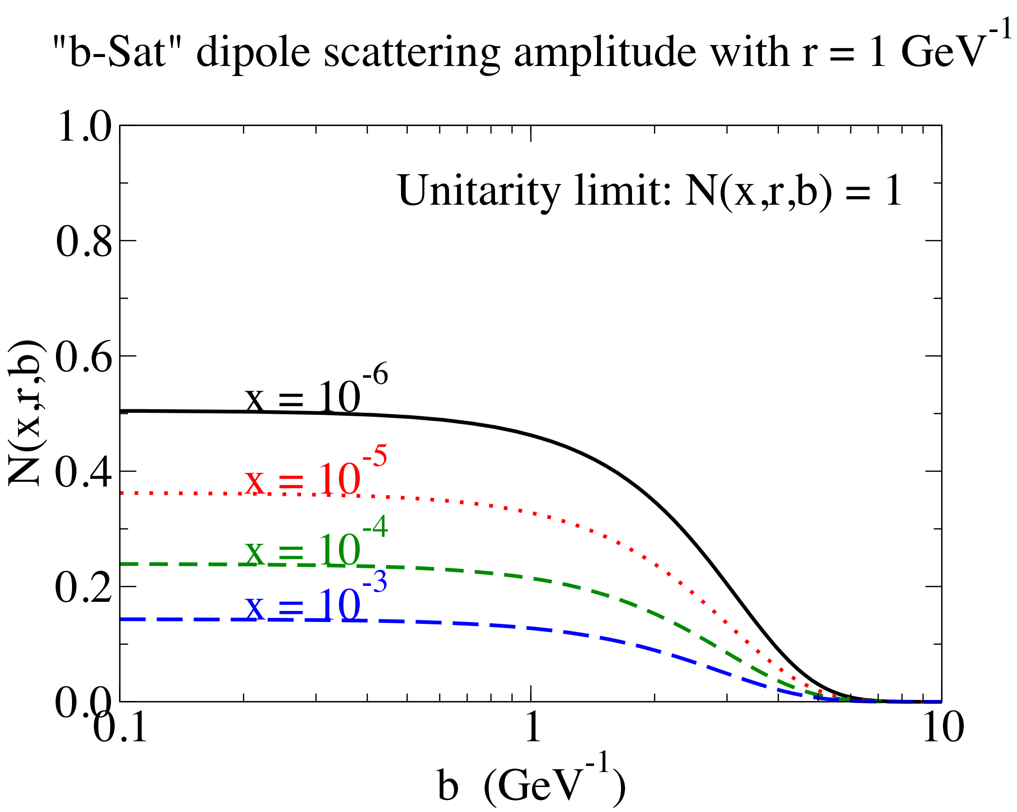
Enhanced diffraction in the nuclear case

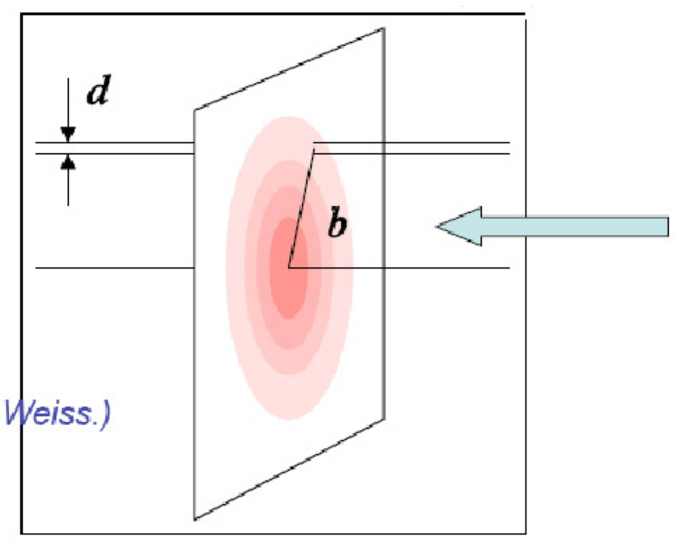
Study of diffractive dijets, heavy quarks for the factorization tests

Exclusive diffraction



- Exclusive diffractive production of VM is an excellent process for extracting the dipole amplitude and GPDs
- Suitable process for estimating the 'blackness' of the interaction.
- t-dependence provides an information about the impact parameter profile of the amplitude.





(figure from C. Weiss.)

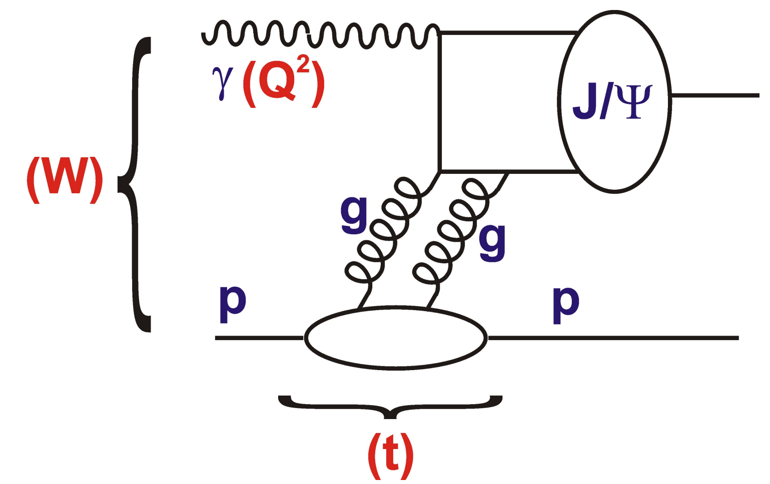
Central black region growing with decrease of x.

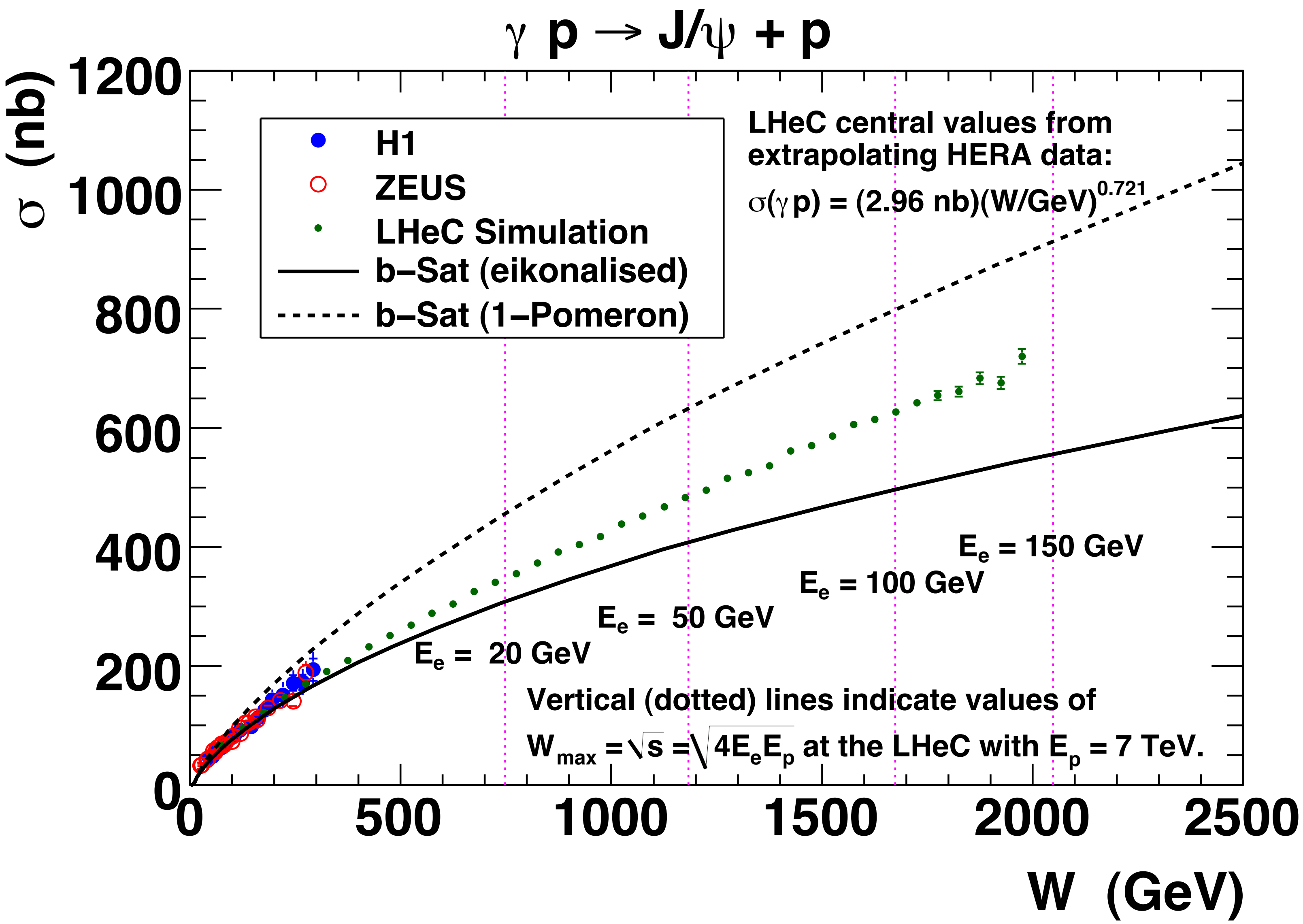
Large momentum transfer t probes small impact parameter where the density of interaction region is most dense.

Exclusive diffraction: predictions

$$\sigma^{\gamma p \to J/\Psi + p}(W)$$

- b-Sat dipole model (Golec-Biernat, Wuesthoff, Bartels, Motyka, Kowalski, Watt)
- eikonalised: with saturation
- 1-Pomeron: no saturation





Large effects even for the t-integrated observable.

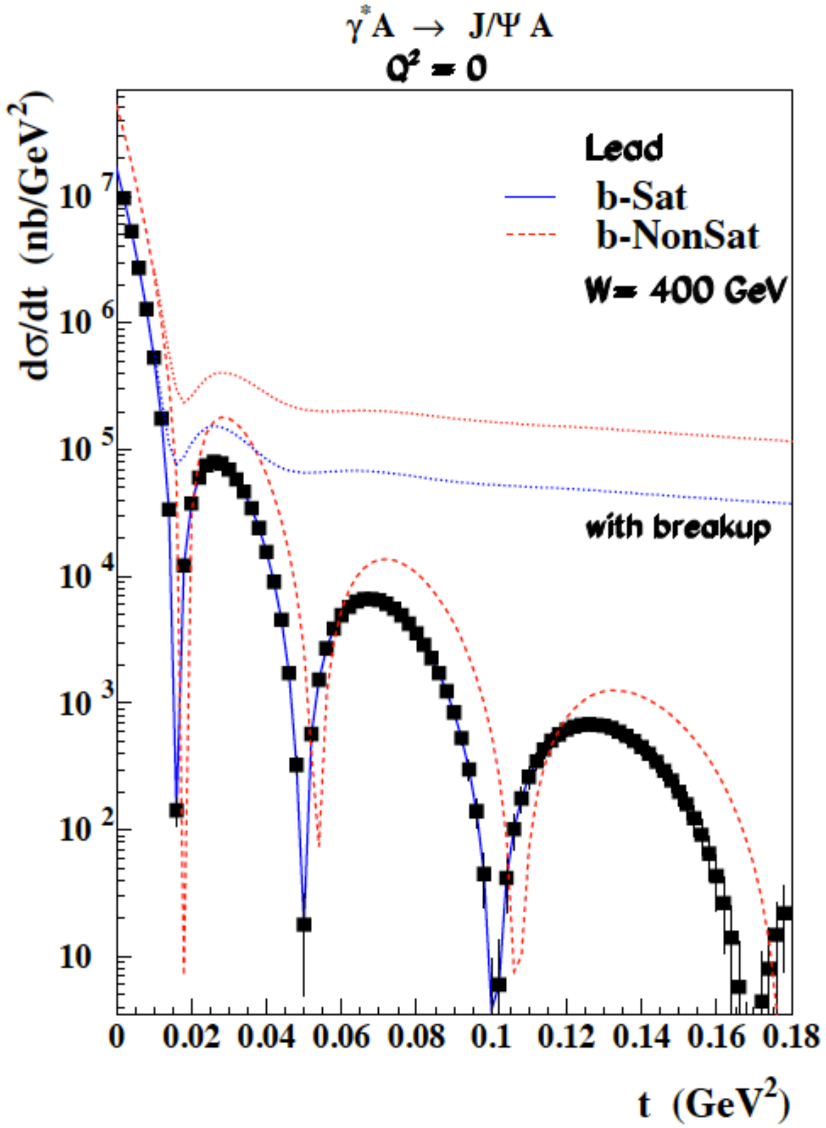
Different W behavior depending whether saturation is included or not.

Simulated data are from extrapolated fit to HERA data

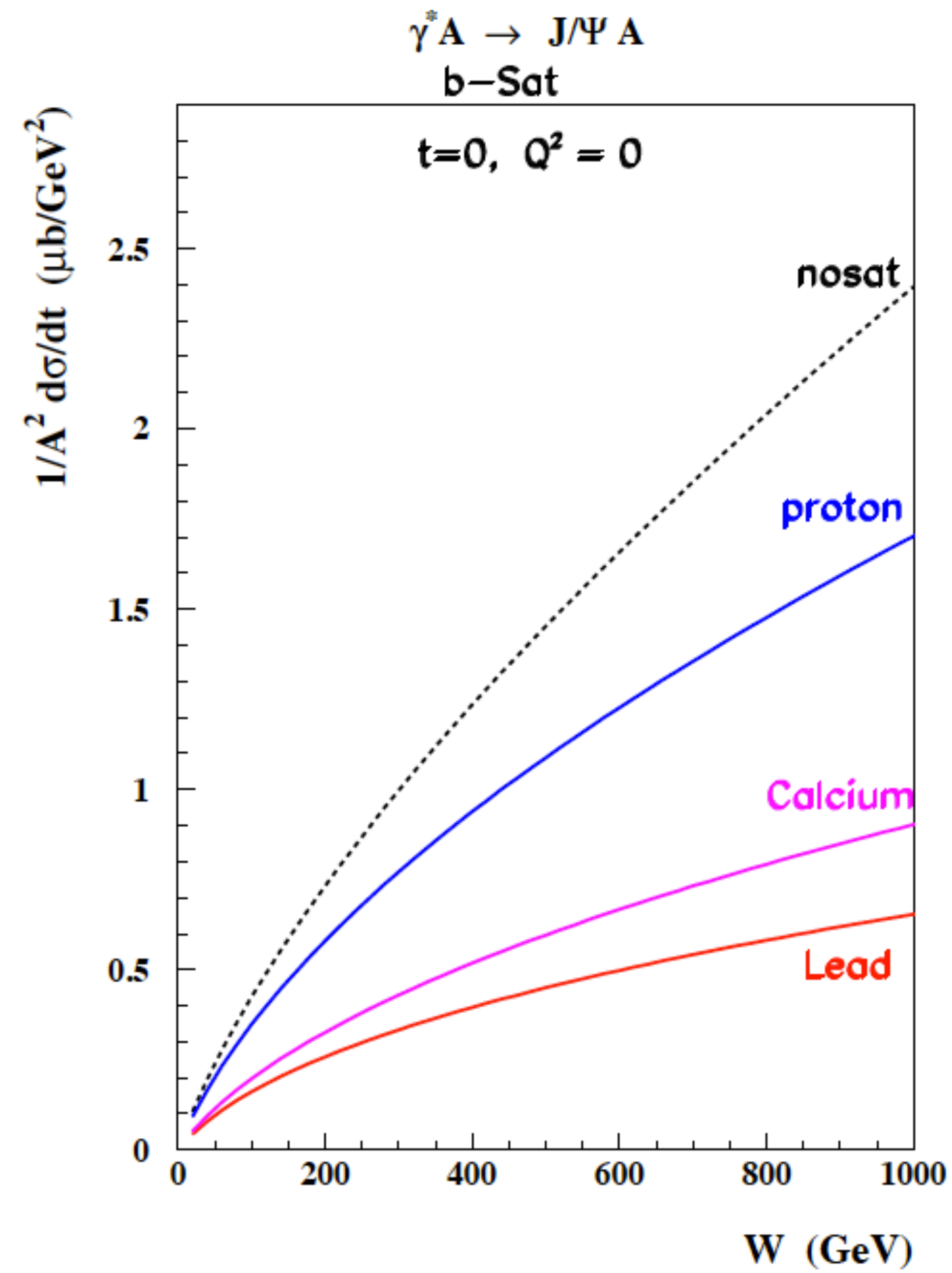
LHeC can distinguish between the different scenarios.

Exclusive diffraction on nuclei

Possibility of using the same principle to learn about the gluon distribution in the nucleus.
Possible nuclear resonances at small t?

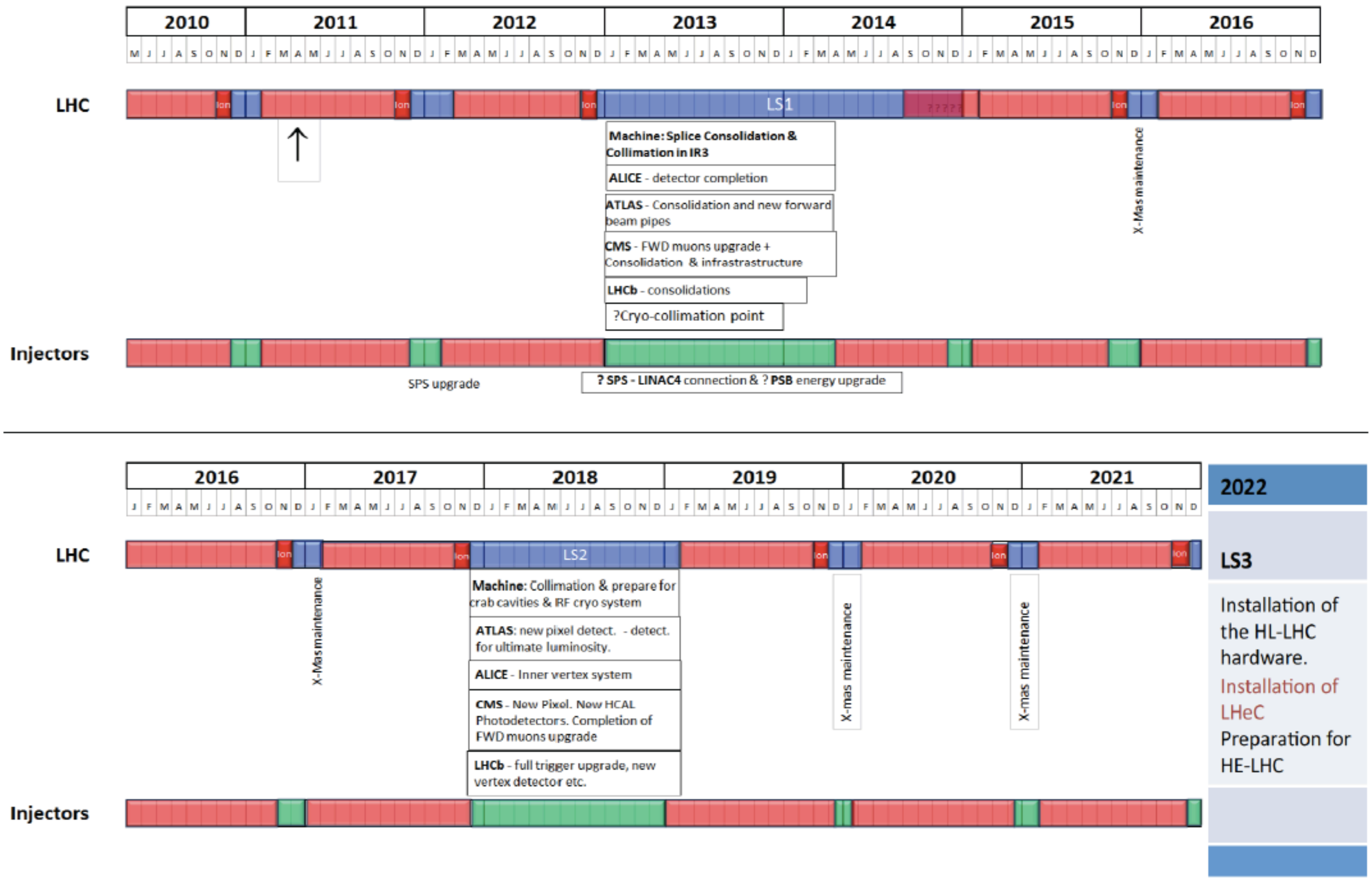


Energy dependence for different targets.



t-dependence: characteristic dips.
Challenges: need to distinguish between coherent and incoherent diffraction. Need dedicated instrumentation, zero degree calorimeter.

Draft LHC Schedule for the coming decade



as shown by S. Myers at EPS 2011 Grenoble

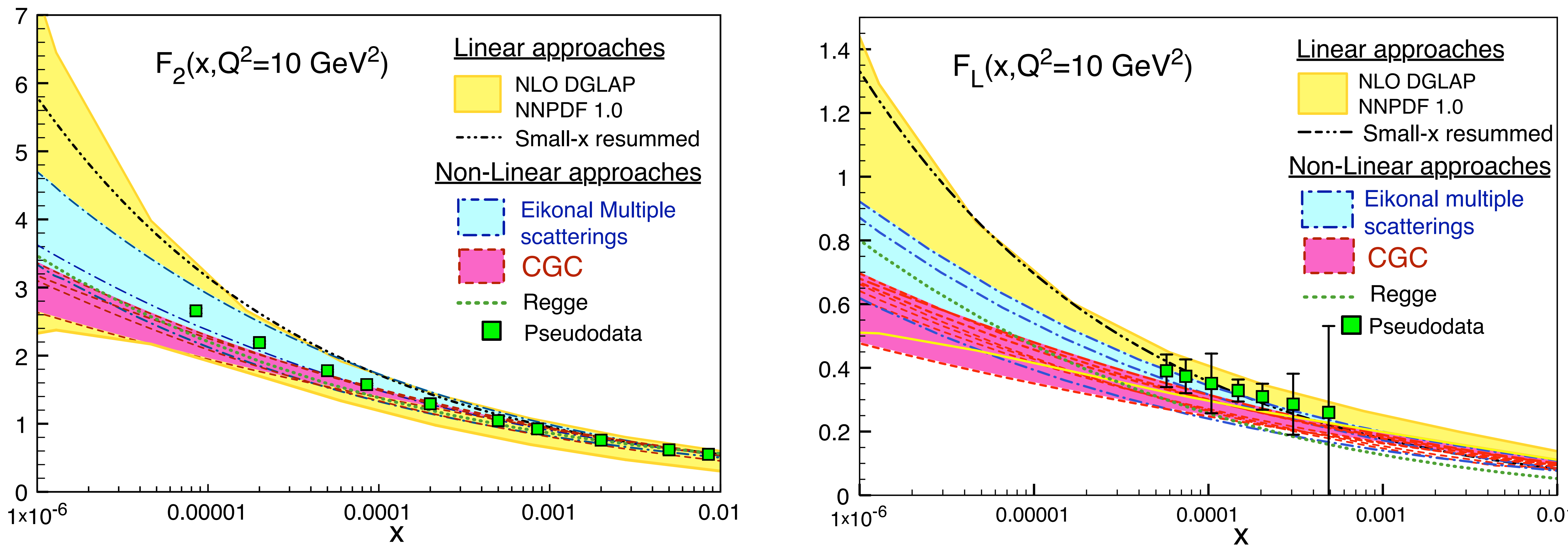
Summary

- LHeC has rich and unique physics program, DIS essential part of HEP.
- Precision QCD and Electroweak studies. Understanding the regime of small x.
- eA program has complementarity with pA and AA physics. Pinning down the initial state in nuclear collisions.
- Conceptual Design Report supported and monitored by CERN, ECFA and NuPECC, has been published.
- Next steps:
- Presentation in European Strategy for Particle Physics meeting in Cracow in September 2012.
- Collaborations are soon to be build for further design, machine and detector.
- CERN mandate for Technical Design Report in 2015.

Backup

F_2, F_L structure functions at low x

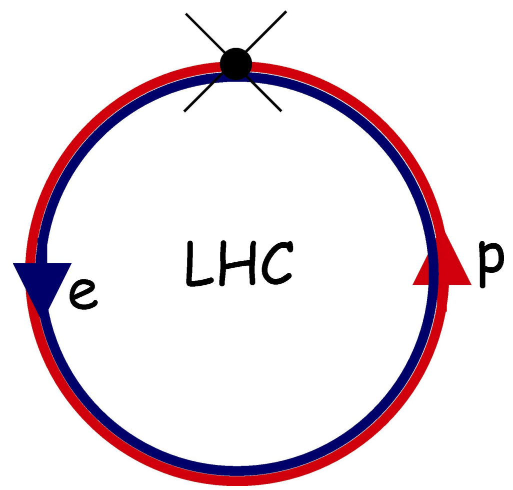
Precision measurements of structure functions at very low x: test DGLAP, small x, saturation inspired approaches.

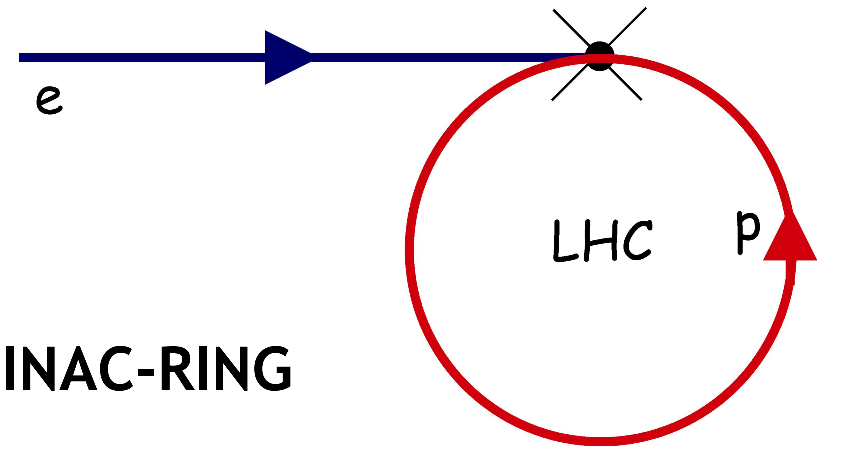


approx. 2% error on the F2 pseudodata, and 8% on the FL pseudodata ,should be able to distinguish between some of the scenarios.

How Could ep be Done using LHC?

… whilst allowing simultaneous ep and pp running …



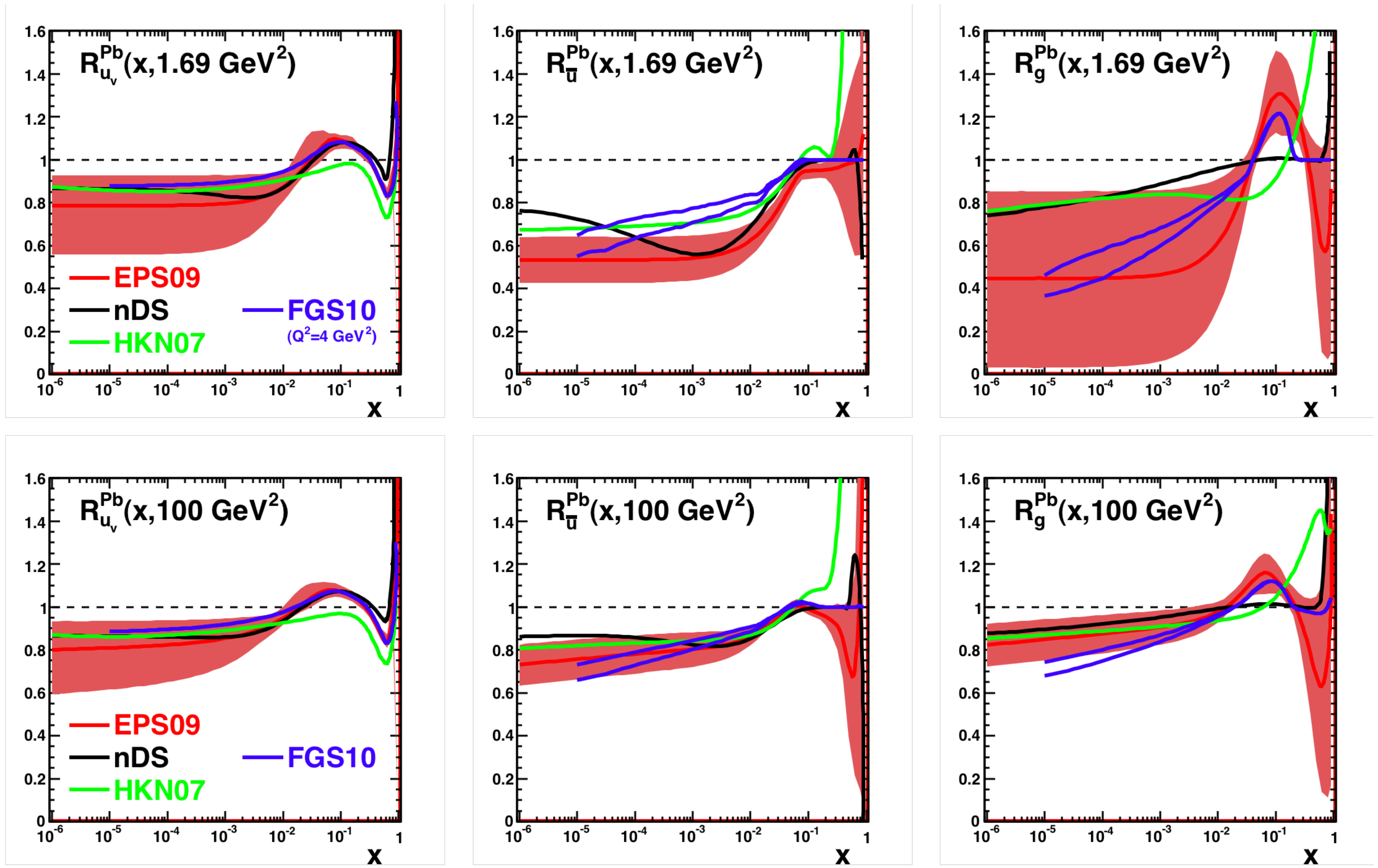


- First considered (as LEPxLHC) in 1984 ECFA workshop
- Main advantage: high peak lumi obtainable (~2.10^{33} cm^{-2} s^{-1})
- Main difficulties: building round existing LHC, e beam energy (60GeV?) and lifetime limited by synchrotron radiation

- Previously considered as \`QCD explorer' (also THERA)
- Main advantages: low interference with LHC, high E_e (→ 150 GeV?) and lepton polarisation, LC relation
- Main difficulties: lower luminosity <10^{33} cm^{-2} s^{-1}? at reasonable power, no previous experience exists

preferred option

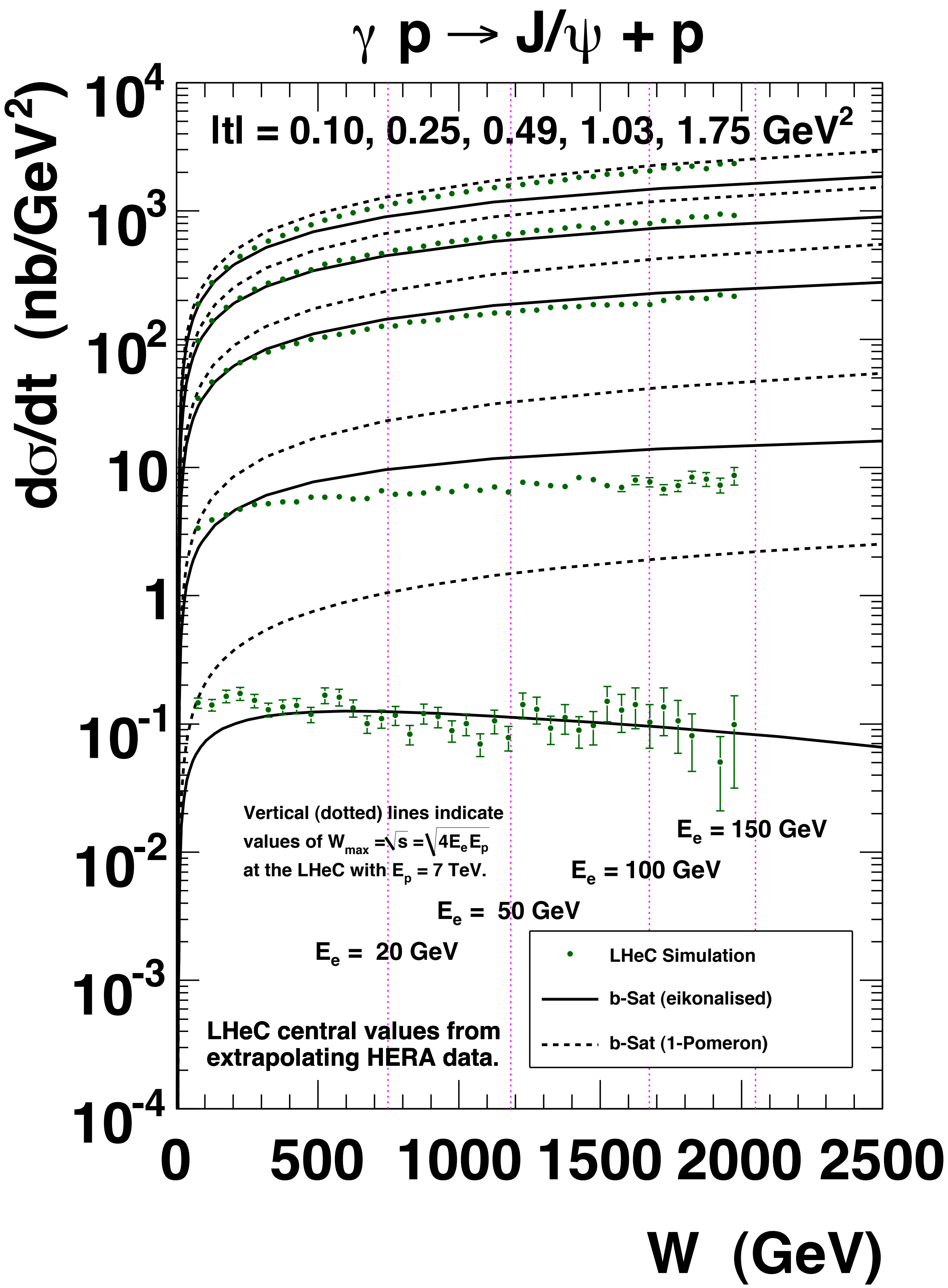
Nuclear parton distributions



R_i = Nuclear PDF i / (A * proton PDF i)

Current status: nuclear parton distribution functions are poorly known at small x. Especially gluon density, below x=0.01 can be anything between 0 and 1....

Exclusive diffraction: t-dependence

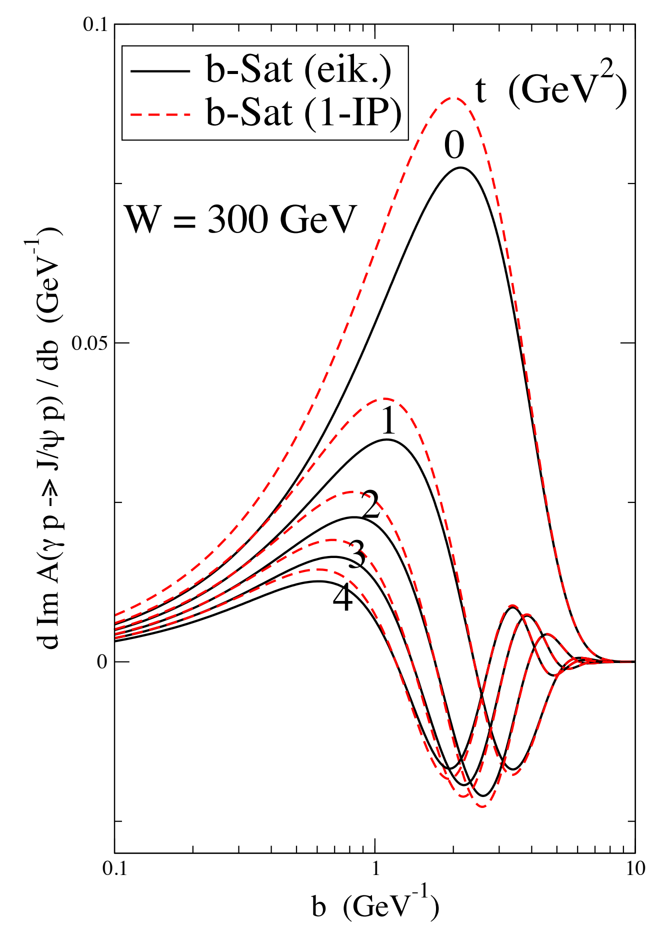


Photoproduction in bins of W and t.

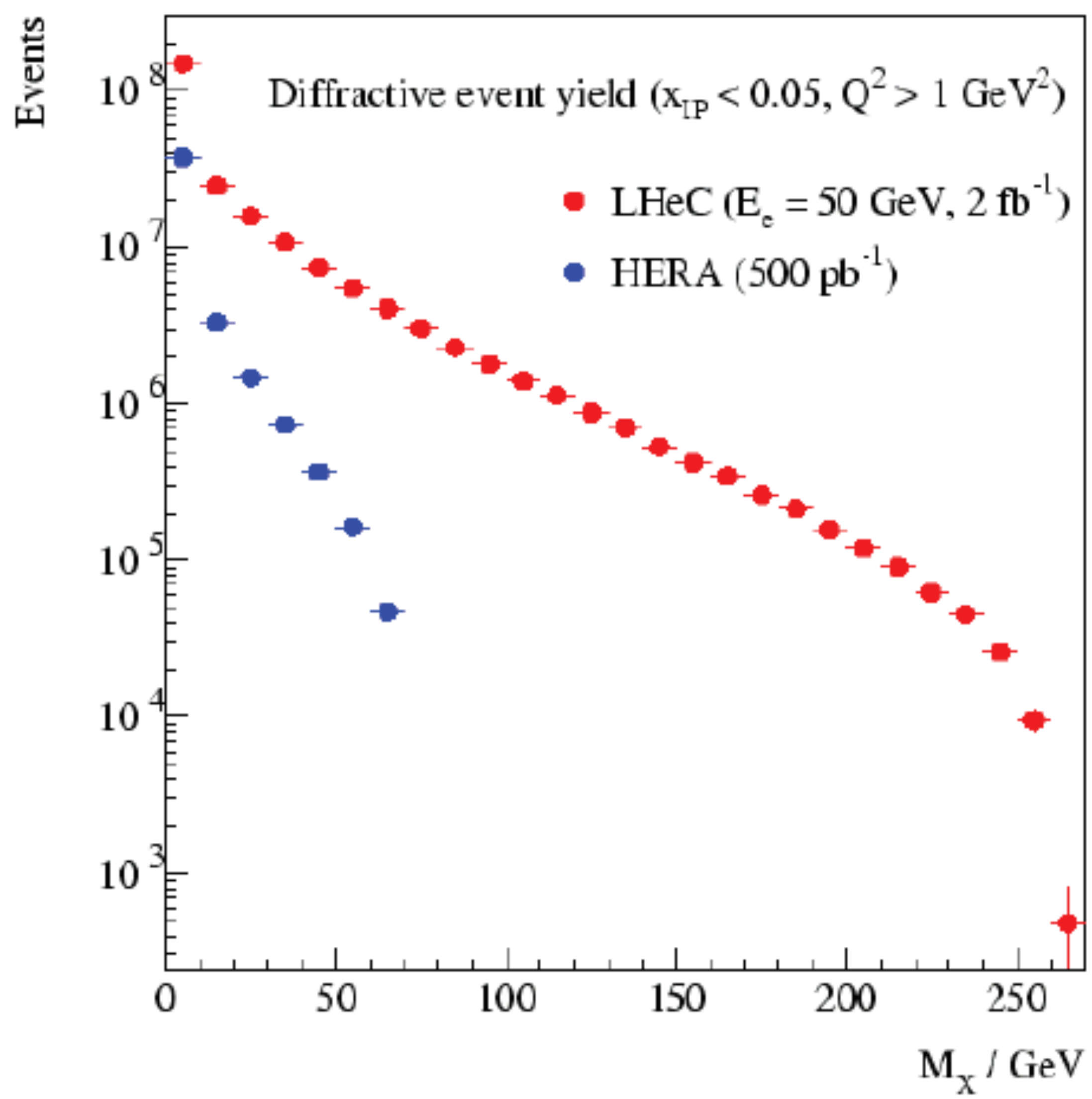
Already for small values of t and smallest energies large discrepancies between the models. LHeC can discriminate.

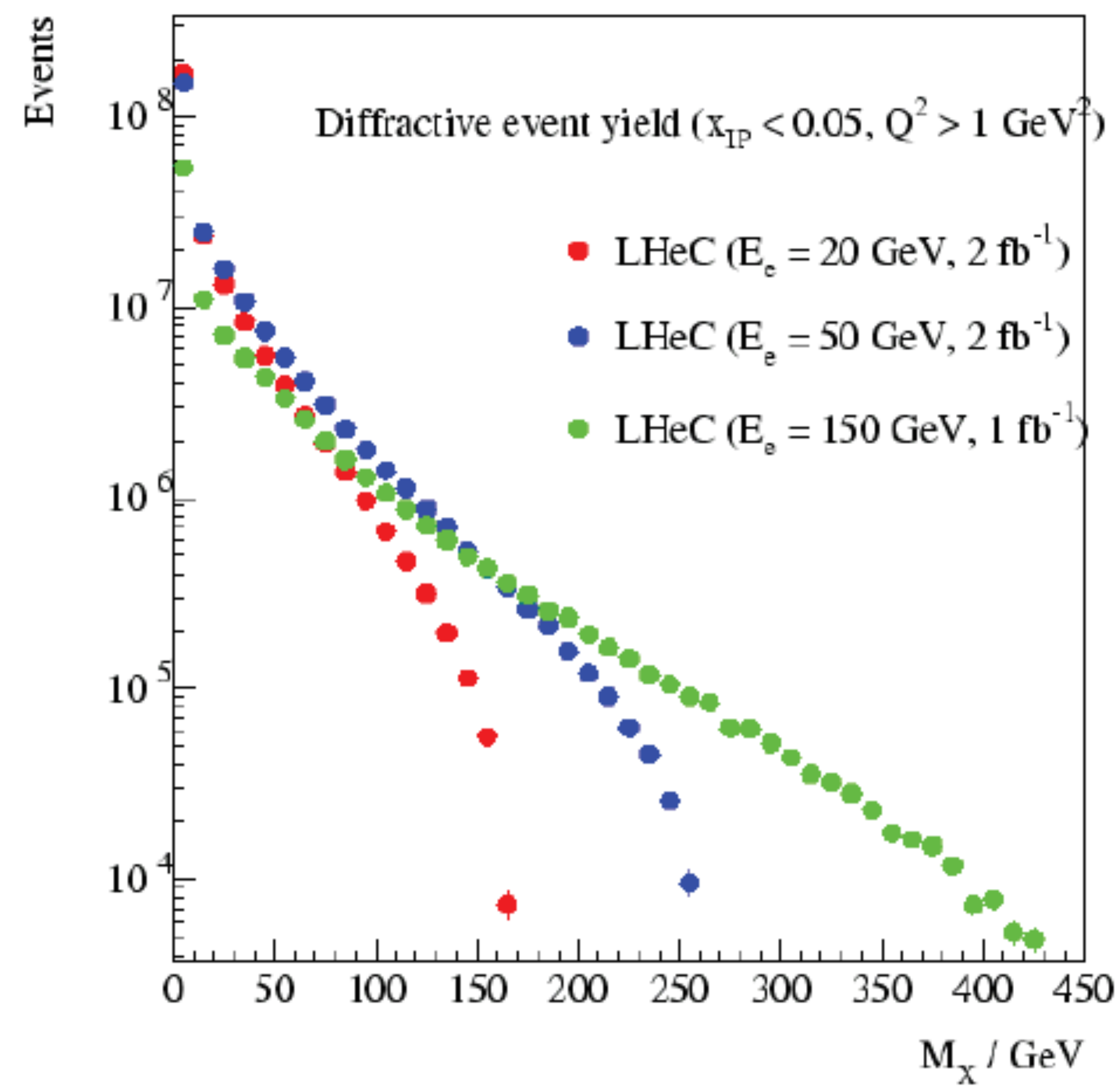
Large values of t : increased sensitivity to small impact parameters.

Amplitude as a function of the impact parameter.



Diffractive mass distribution





New domain of diffractive masses.
M_X can include W/Z/beauty