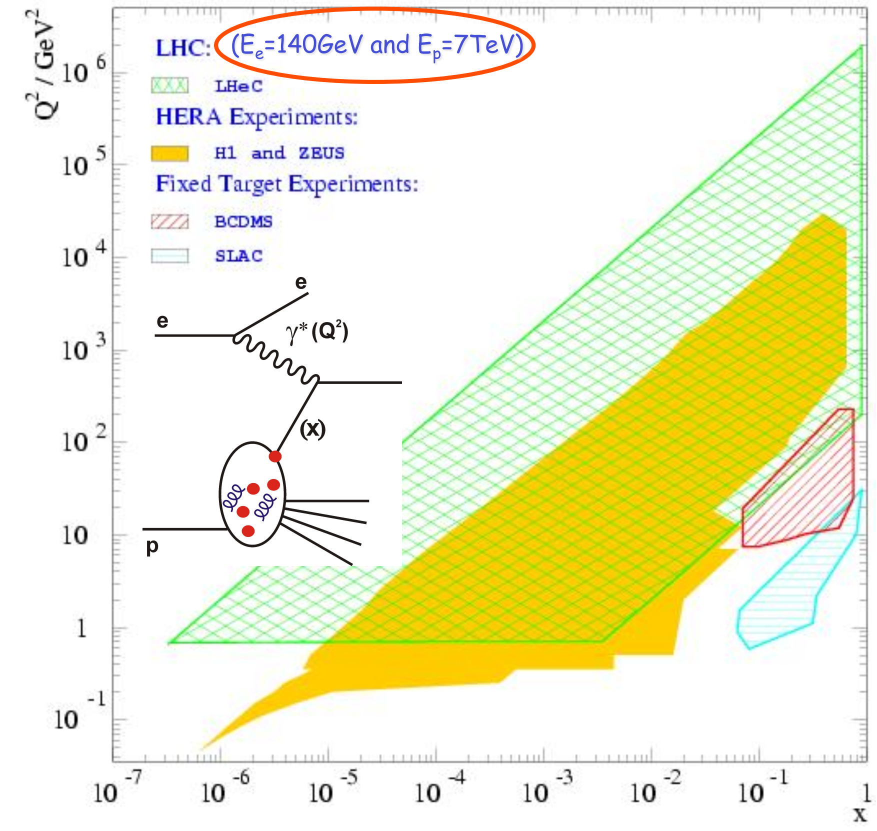
http://cern.ch/lhec



Small x physics at the LHeC

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

for the LHeC working group on

Physics at high parton densities (ep and eA)

Nestor Armesto(Santiago de Compostela), Brian Cole(Columbia Univ.), Paul Newman(Birmingham Univ.)

03/06/2011 Low x Workshop, Santiago de Compostela

Exploring the nucleon structure

A classic way to measure the hadron and nuclear structure and quark/gluon distributions is through deep inelastic scattering.

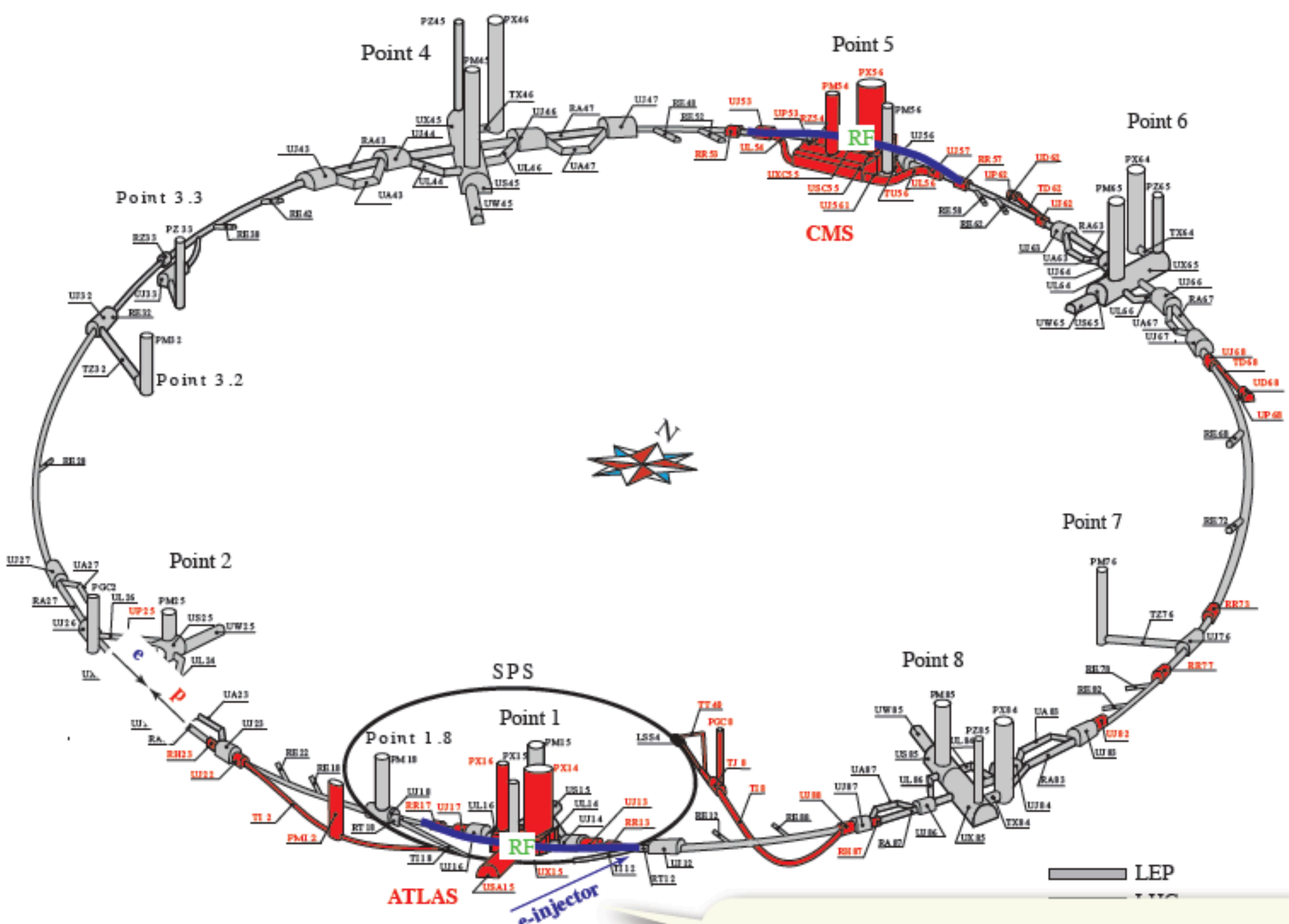
Timeline of experiments:

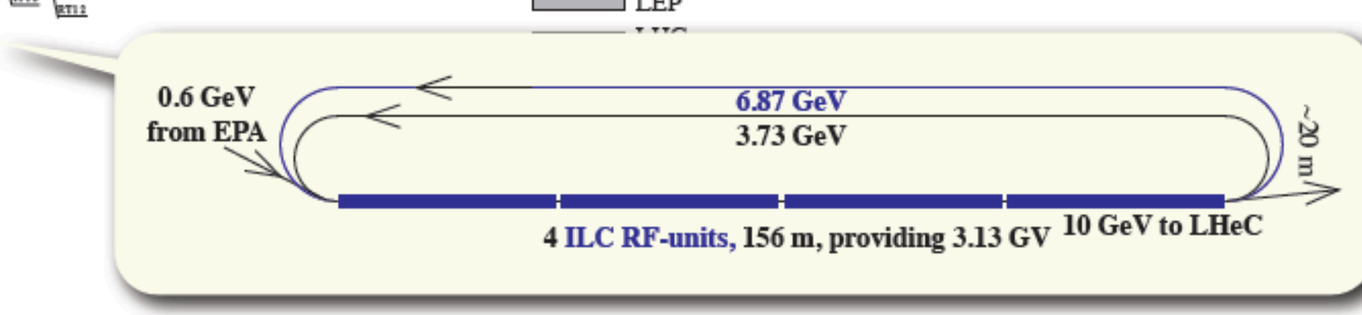
Rutherford 1911 → SLAC 1967 → HERA 2007 → future facilities?

LHeC is a proposed deep inelastic scattering experiment at CERN.
The goal is to scatter electrons with the LHC proton and lead beams.
Beam of high energy electrons 50-150GeV accelerated in LEP-like ring or linac.
Precision experiment at high luminosity.
Parallel operation with the LHC.

Machine design

Ring-ring scenario





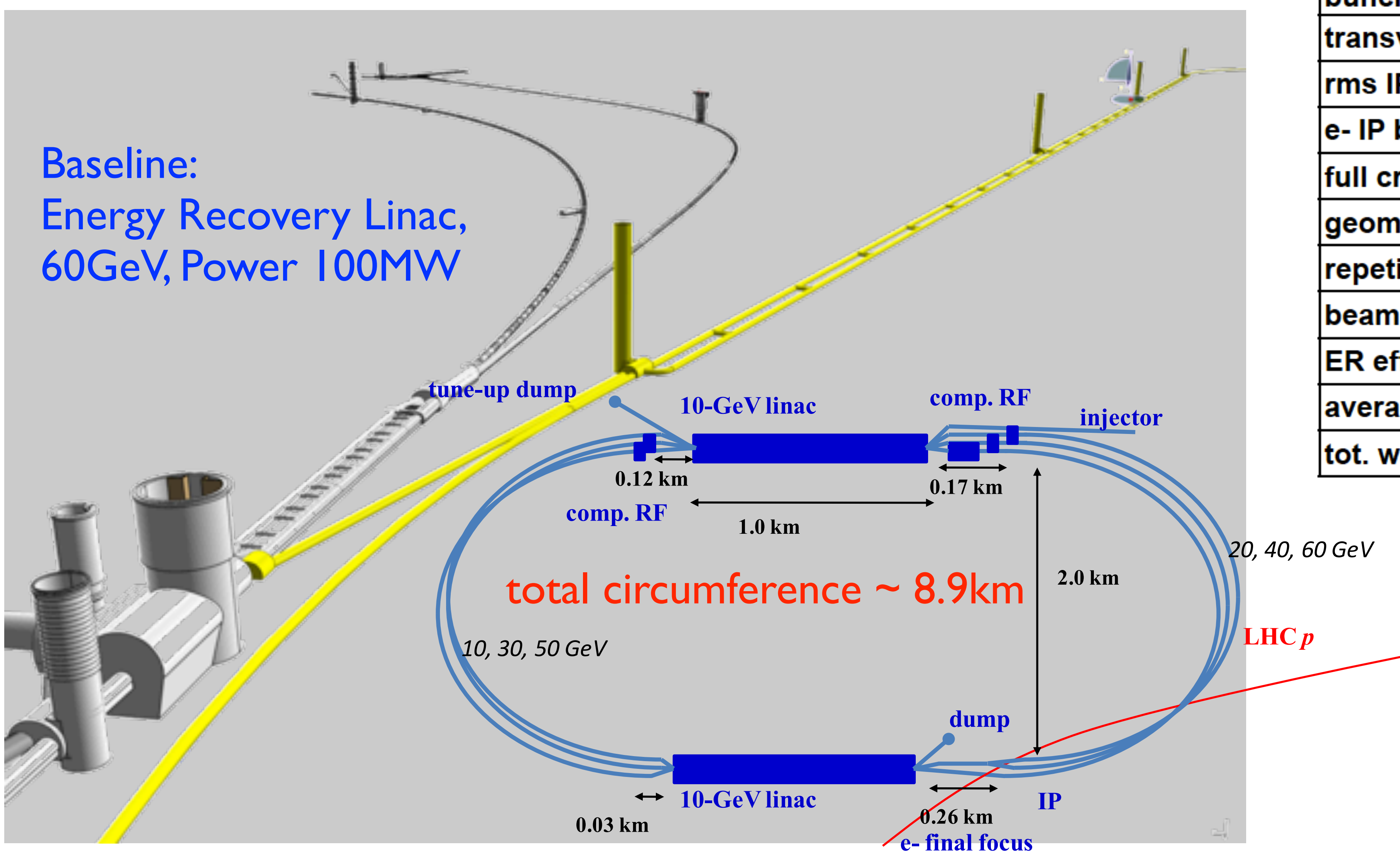
	Electrons	Protons
β_x	0.4 m	4.05 m
β_y	0.2 m	0.97 m
l*	6 m	22.96 m
σ_x	45 µm	
σ_y	22 µm	
Crossing angle	1 mrad	
Luminosity	8.54 10^{32} cm^{-2} s^{-1}	
Luminosity loss factor	86%	
Luminosity	7.33 10^{32} cm^{-2} s^{-1}	
P_γ	51 kW	
E_c	163 keV	

Fitterer@DIS2011

Machine design

Linac-ring scenario

Baseline:
Energy Recovery Linac,
60GeV, Power 100MW



electron beam	LR ERL	LR
e- energy at IP[GeV]	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	10	0.44
polarization [%]	90	90
bunch population [10^9]	2.0	1.6
e- bunch length [mm]	0.3	0.3
bunch interval [ns]	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.12	0.14
full crossing angle [mrad]	0	0
geometric reduction H_{hg}	0.91	0.94
repetition rate [Hz]	N/A	10
beam pulse length [ms]	N/A	5
ER efficiency	94%	N/A
average current [mA]	6.6	5.4
tot. wall plug power[MW]	100	100

Bogacz@DIS2011

LHeC kinematics

ep/ea collisions

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

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

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

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

- 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.

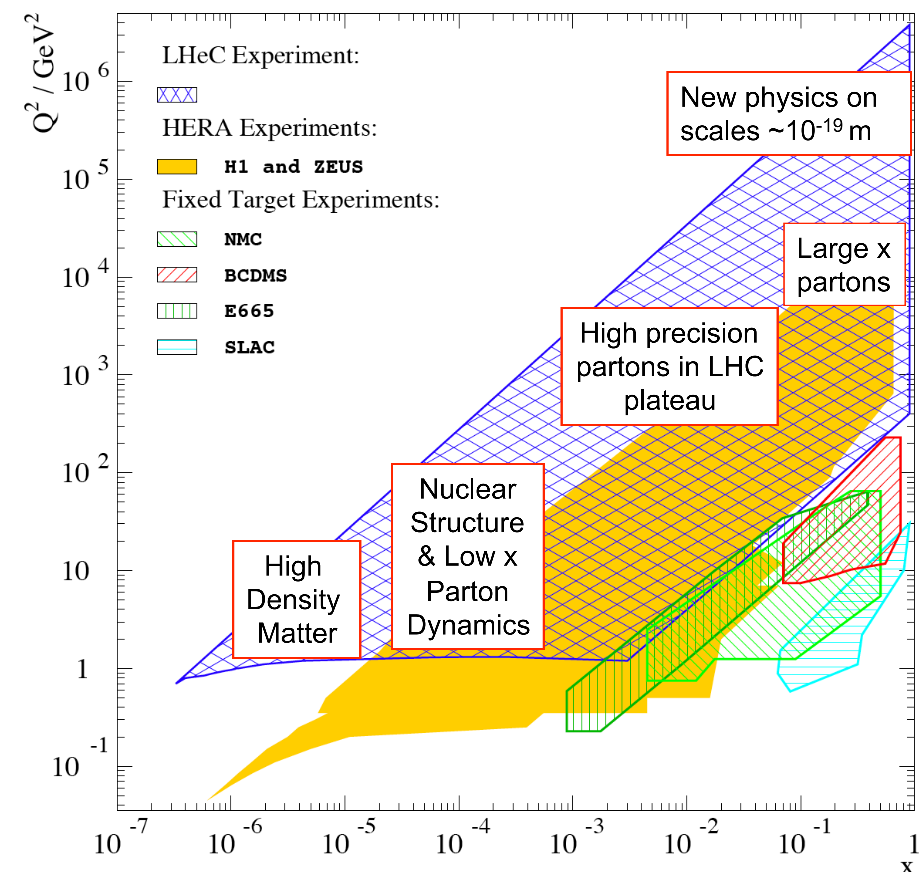
* EMCAL calibration to 0.1 %.

* HCAL calibration to 0.5 %.

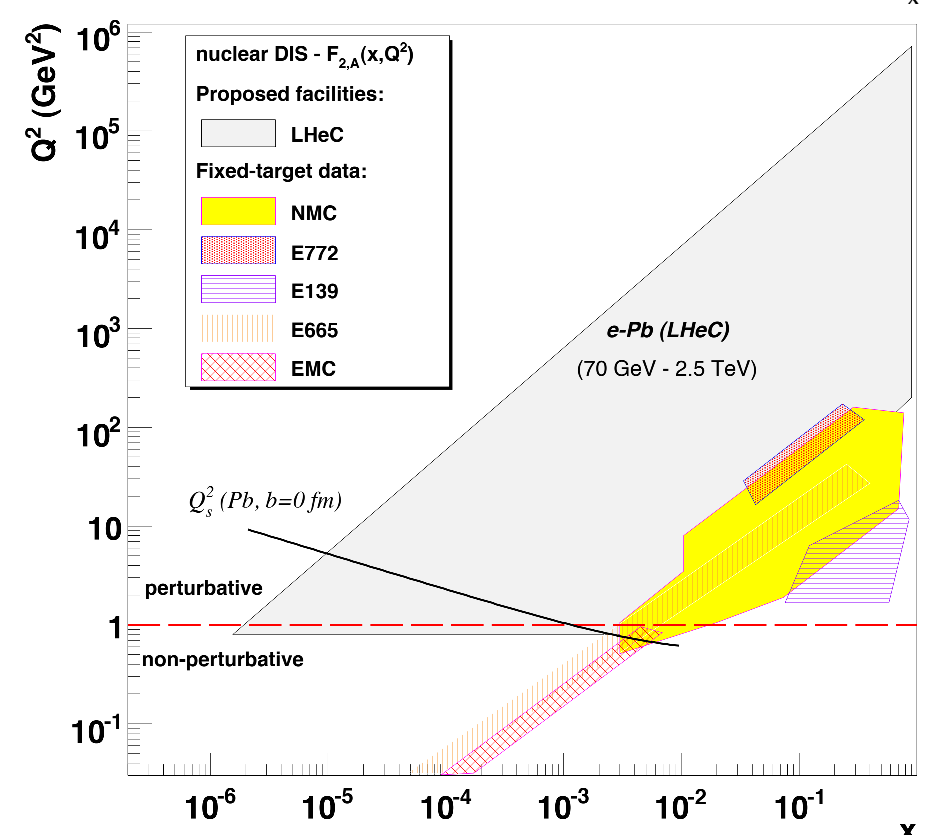
* Luminosity determination to 1 %.

* Compatible with LHC operation.

ep



eA



Physics possibilities at the LHeC

Beyond Standard Model

Leptoquarks
Contact Interactions
Excited Fermions
Higgs in MSSM
Heavy Leptons
4th generation quarks
Z'
SUSY
???

QCD and EW precision physics

Structure functions
Quark distributions from direct measurements
Strong coupling constant to high accuracy
Higgs in SM
Gluon distribution in extended x range to unprecedented accuracy
Single top and anti-top production
Electroweak couplings
Heavy quark fragmentation functions
Heavy flavor production with high accuracy
Jets and QCD in photoproduction
Partonic structure of the photon
...

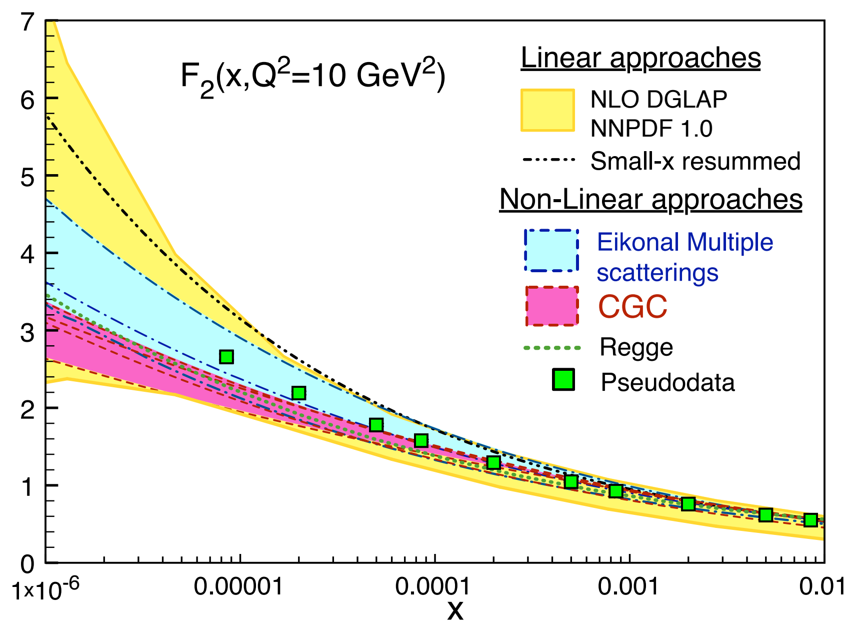
Small x and high parton densities

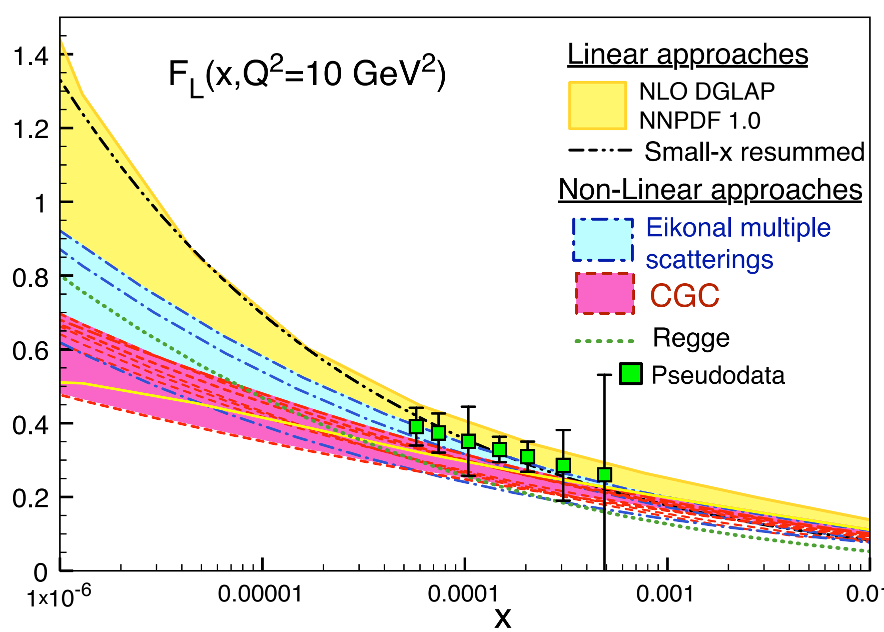
New regime at low x
Saturation
Diffraction
Vector Mesons
Deeply Virtual Compoton Scattering
Forward jets and parton dynamics
DIS on nuclei
Generalized/unintegrated parton distribution functions

All the results shown are from preliminary CDR draft

F_2, F_L structure functions and pdfs

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

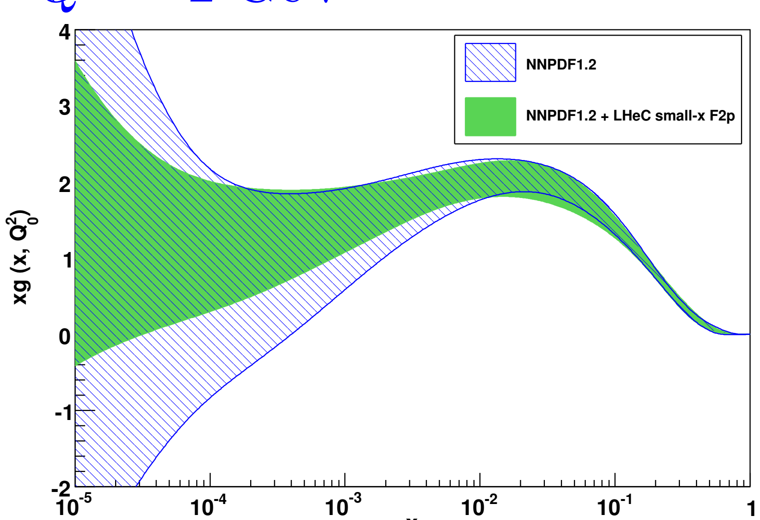




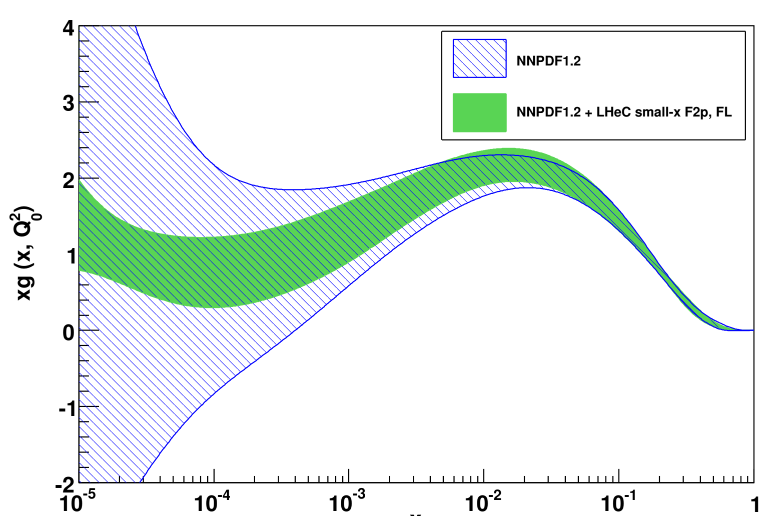
Inclusion of LHeC pseudodata for F_2, F_L or F_{2c} in DGLAP fits improves the determination of the glue at small x.

$Q^2 = 2\ GeV^2$

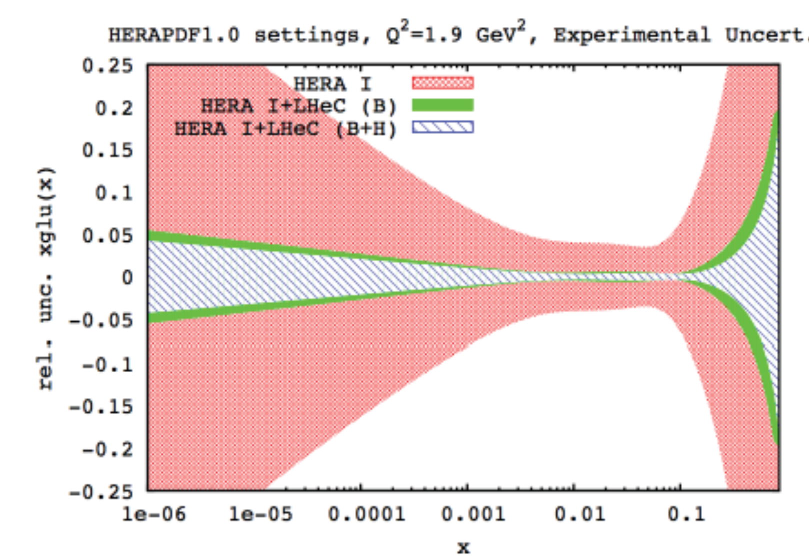
Radescu@DIS2011



F_2



$F_2 + F_L$



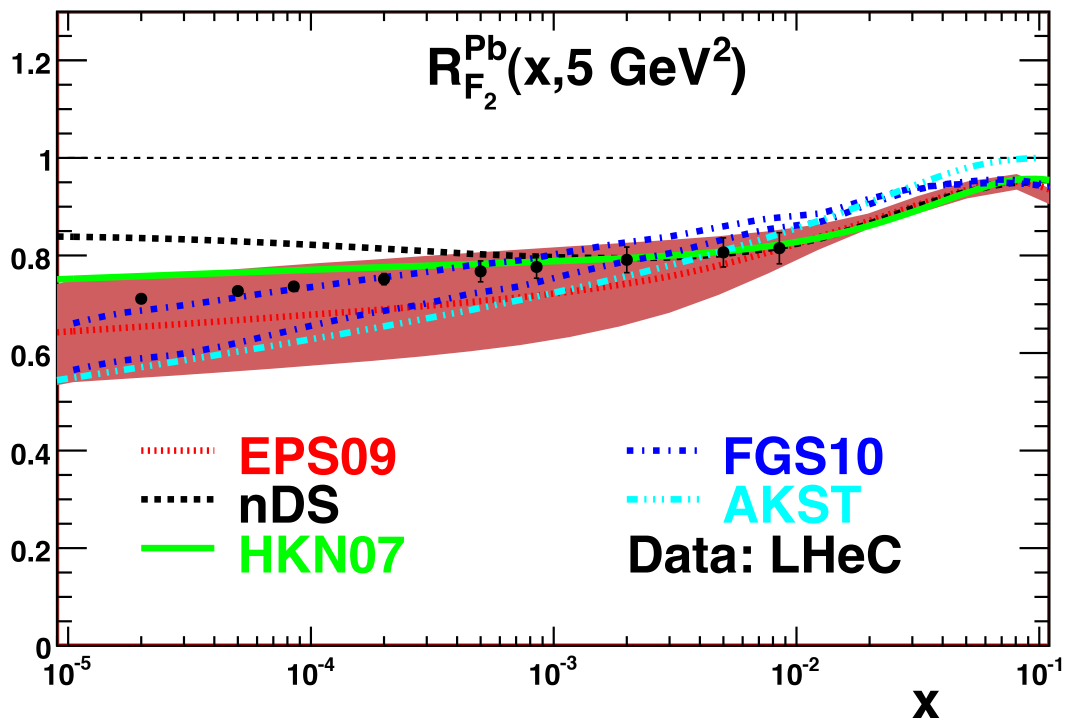
Nuclear structure functions at LHeC

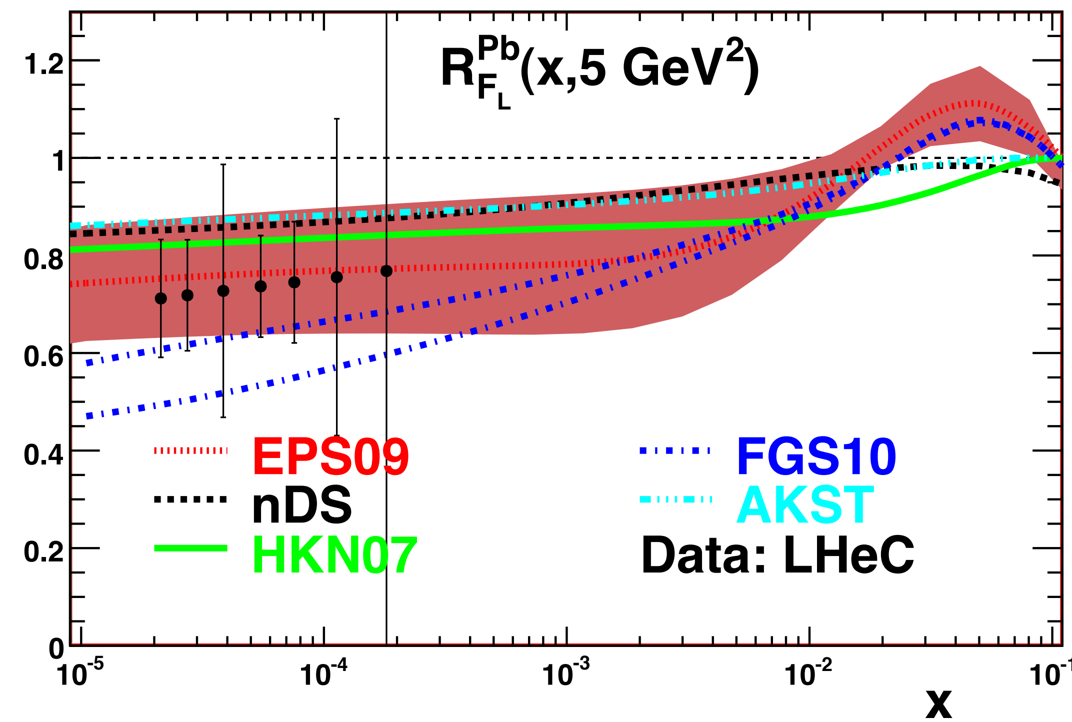
Nuclear ratio for structure function or a parton density:

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

Nuclear effects $R^A \neq 1$

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

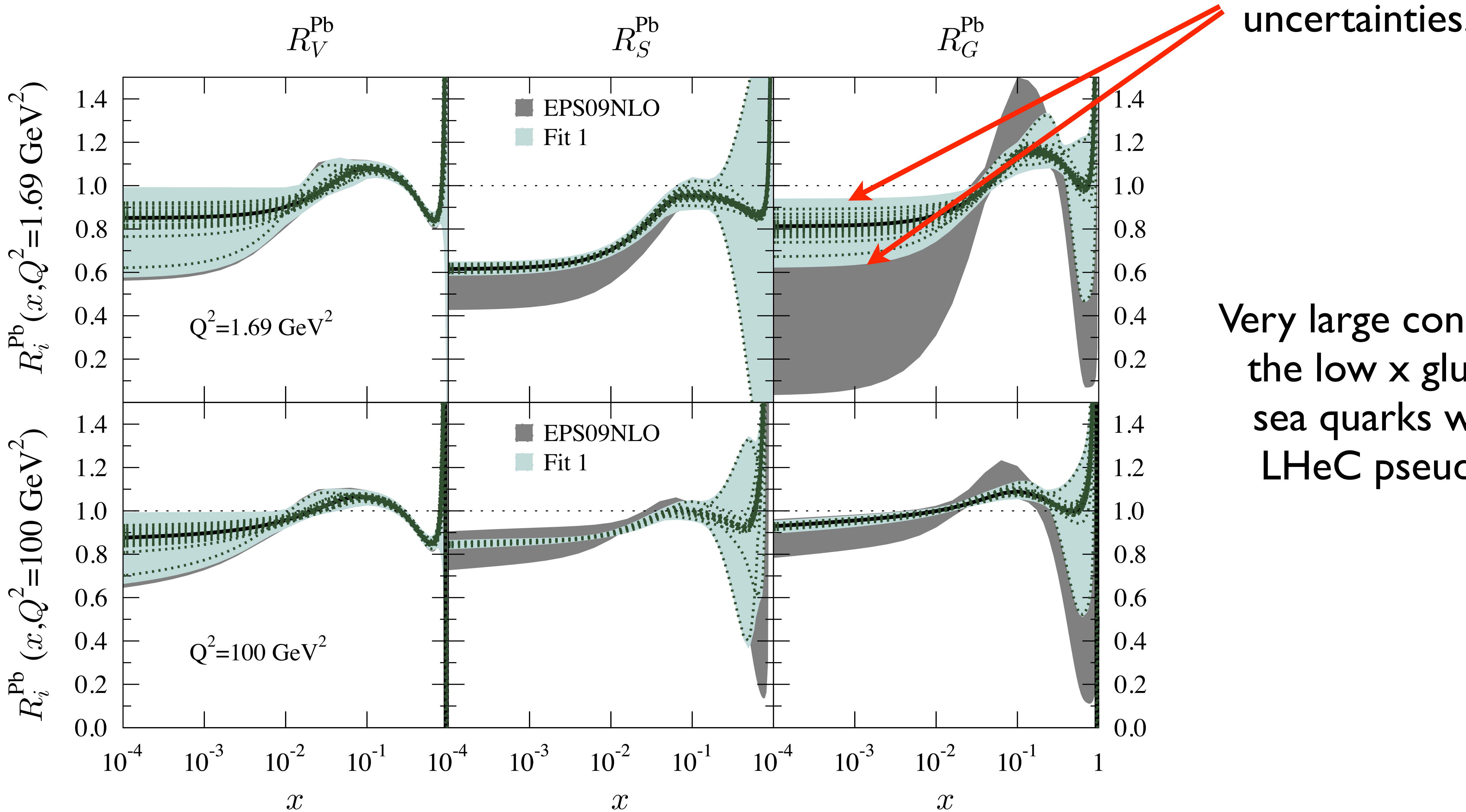




Nuclear structure functions measured with very high accuracy.

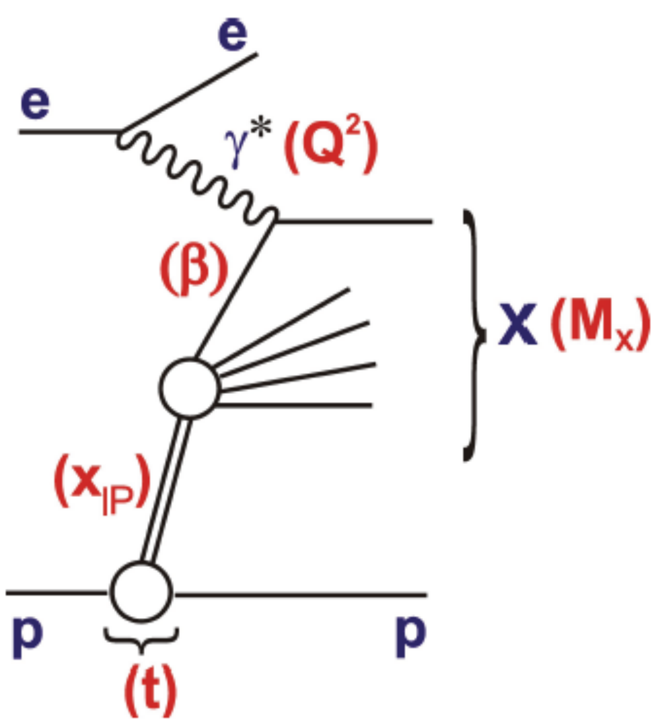
Nuclear parton distributions at LHeC

Global NLO fit with the LHeC pseudodata included



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

Diffraction



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

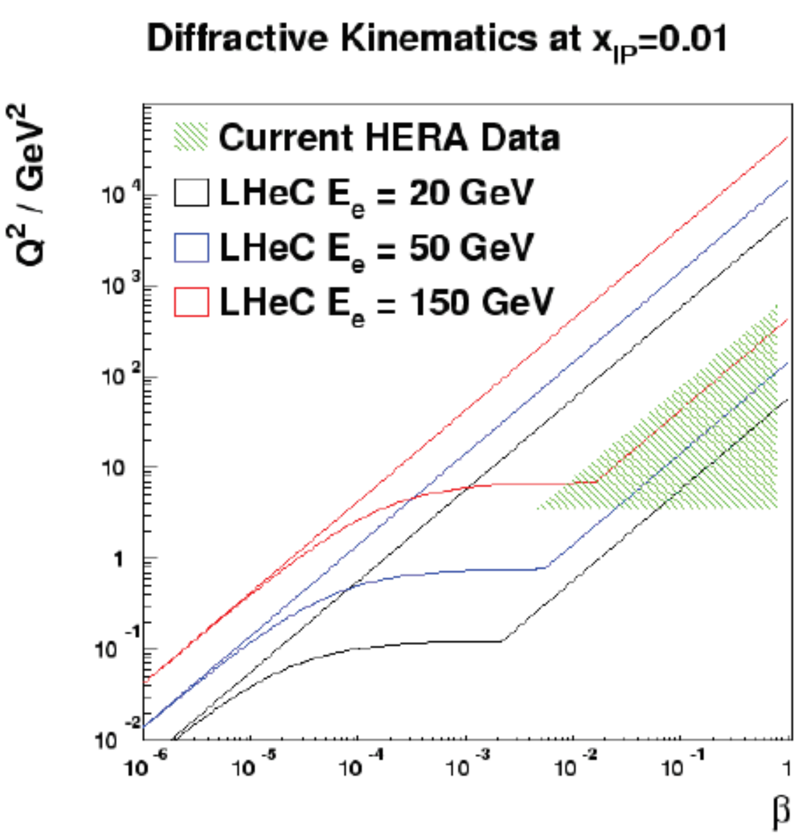
momentum fraction of the Pomeron w.r.t hadron

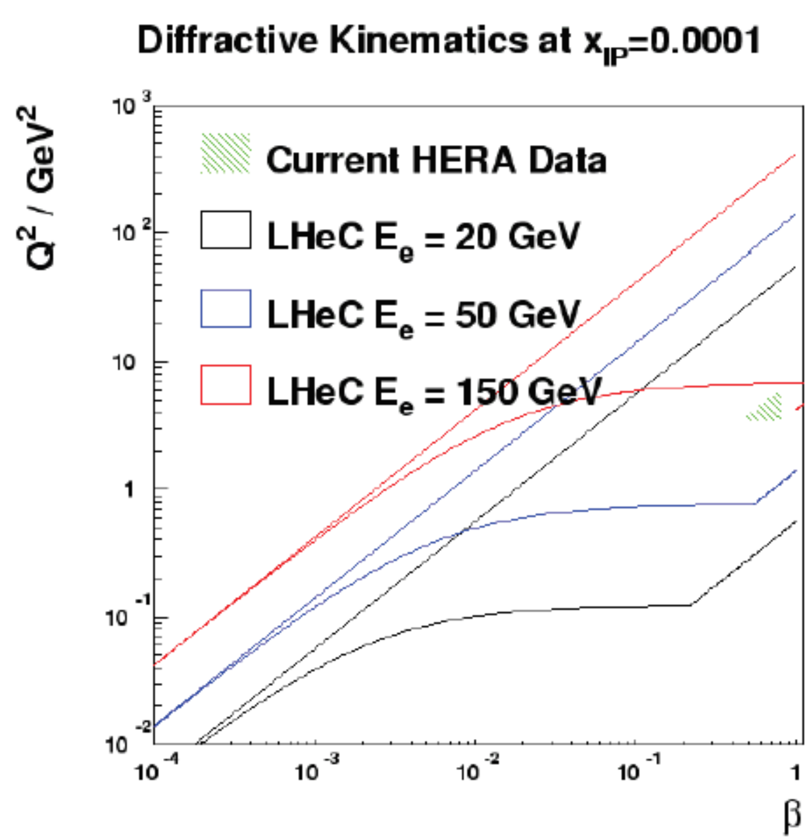
$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

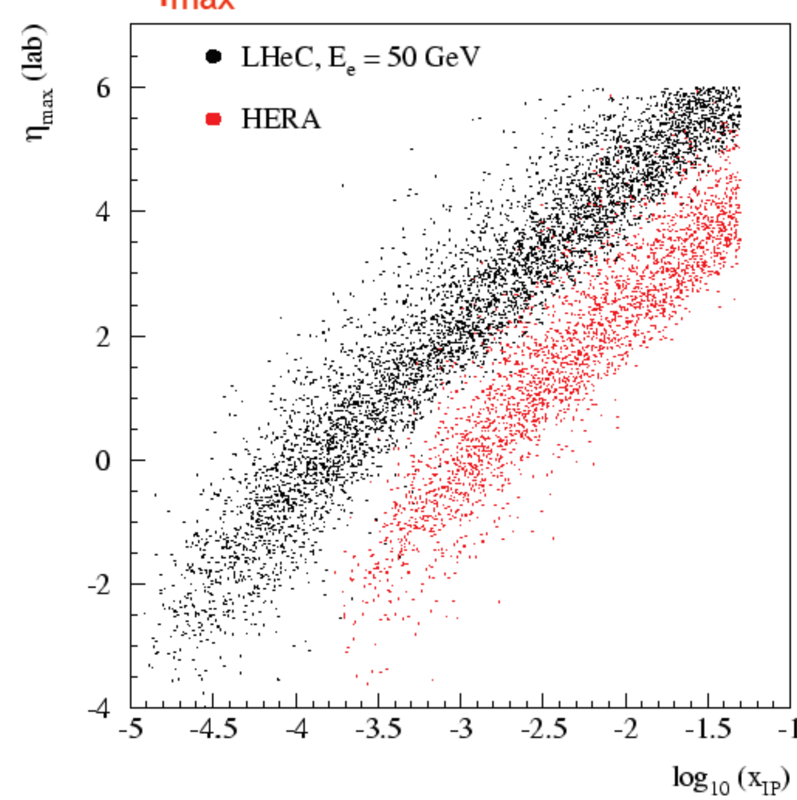
$$x_{Bj} = x_{IP}\beta$$

Methods: Leading proton tagging, large rapidity gap selection

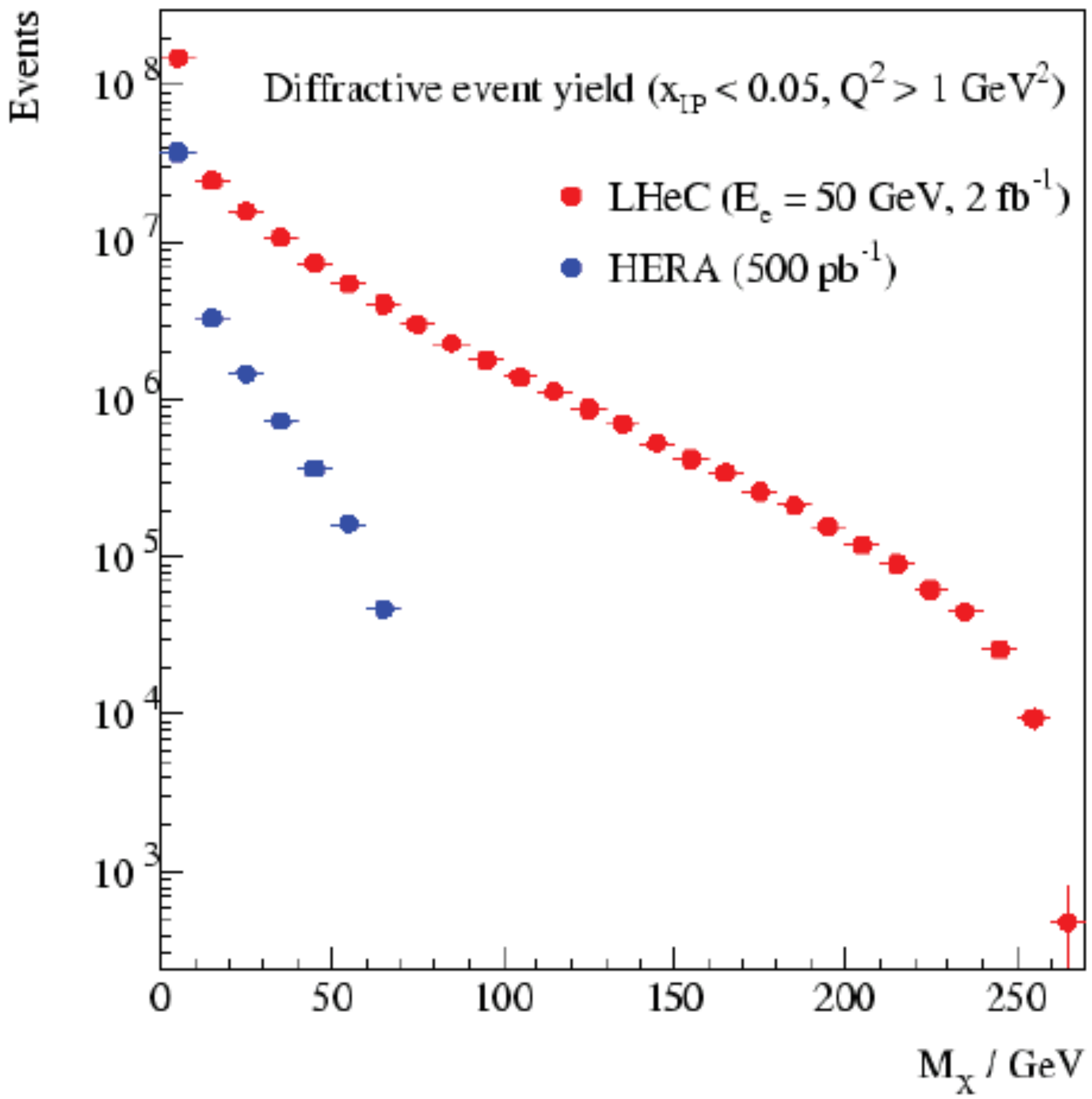


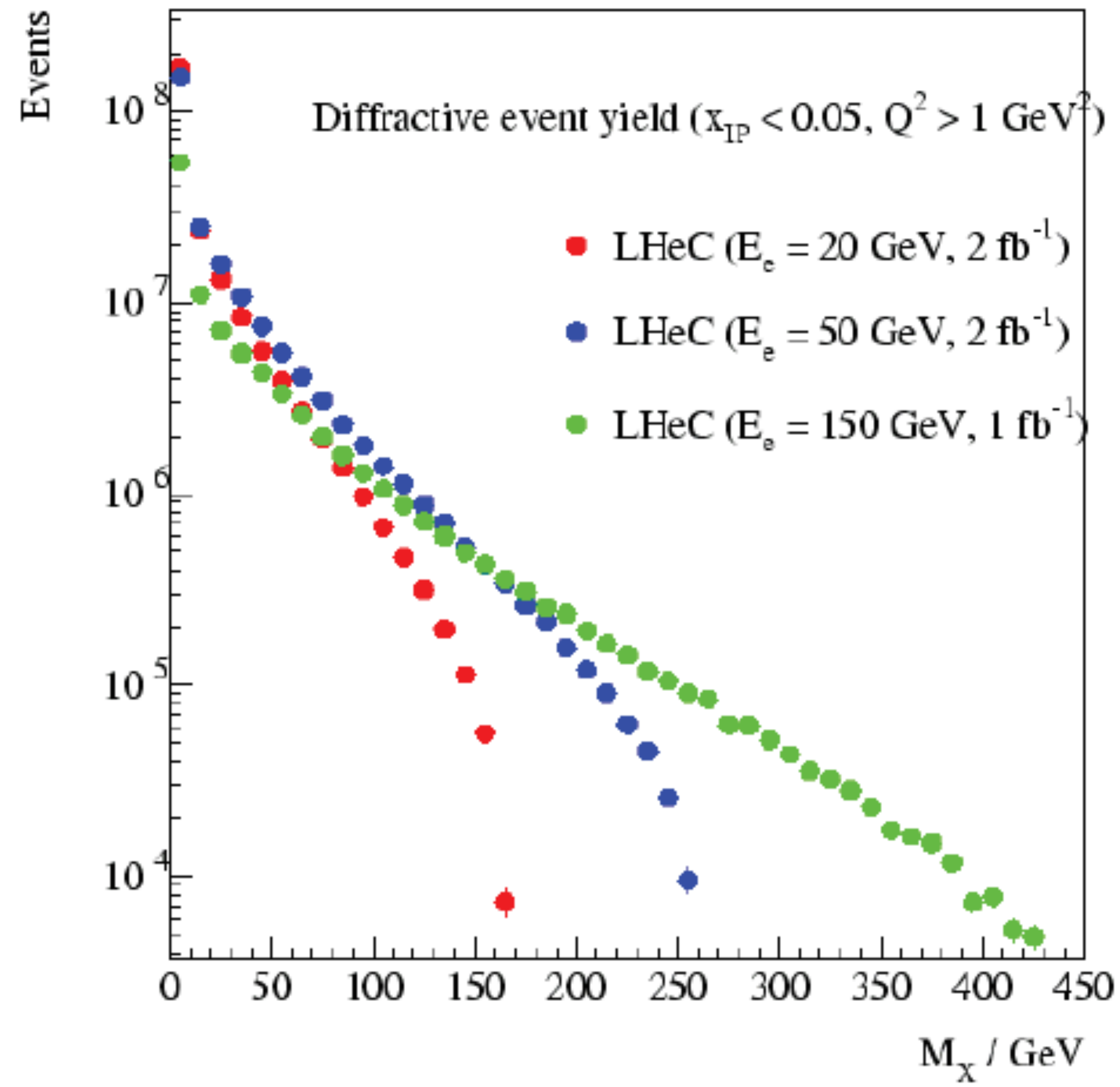


η_{max} from LRG selection ...



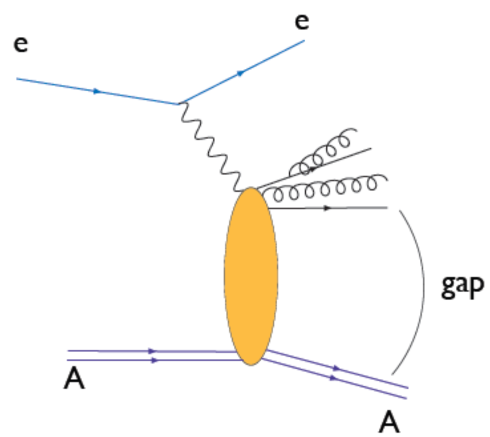
Diffractive mass distribution



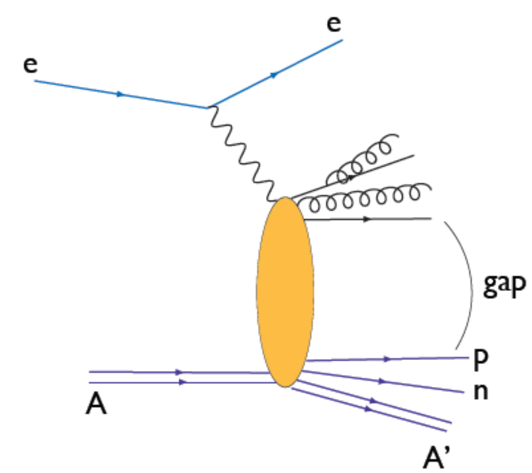


New domain of diffractive masses.
M_X can include W/Z/beauty

Inclusive diffraction in eA

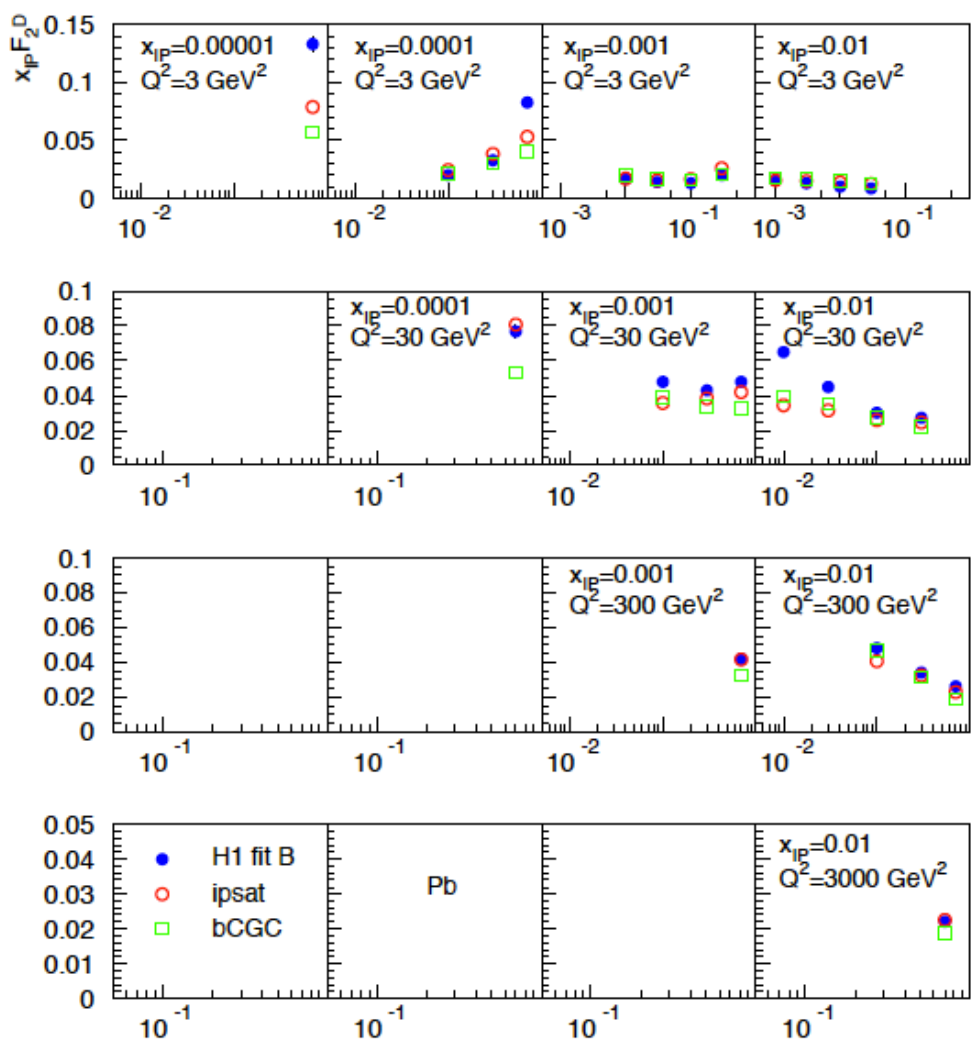


coherent

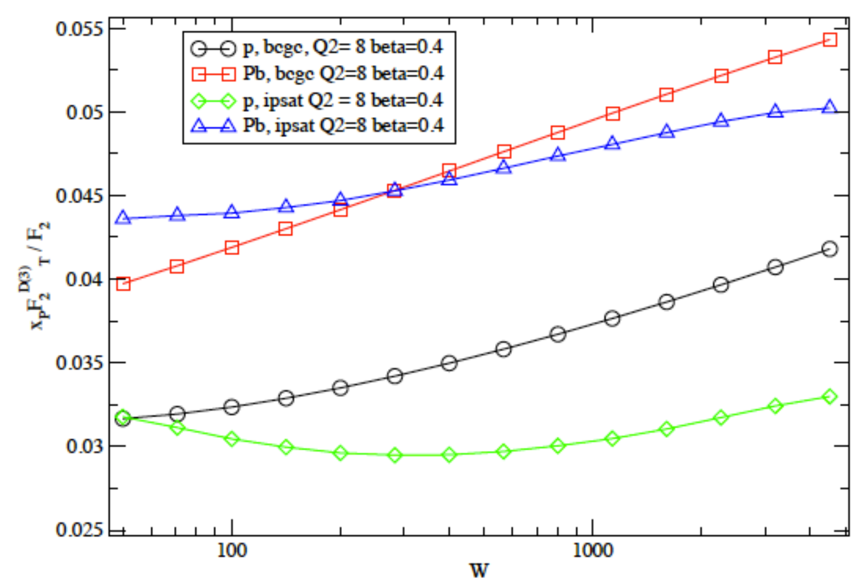


incoherent

Diffractive structure function for Pb



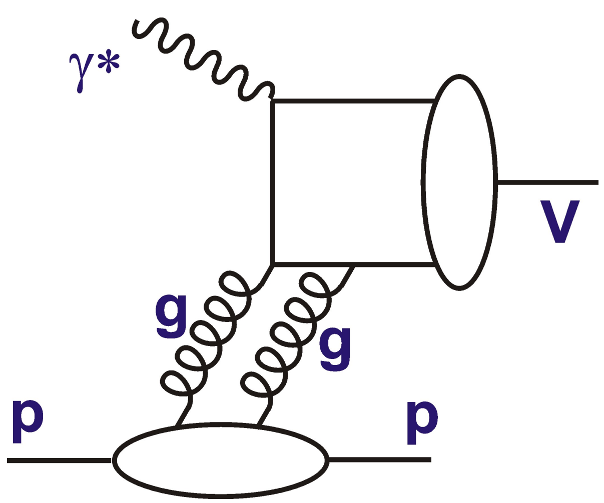
Diffractive to inclusive ratio for protons and Pb



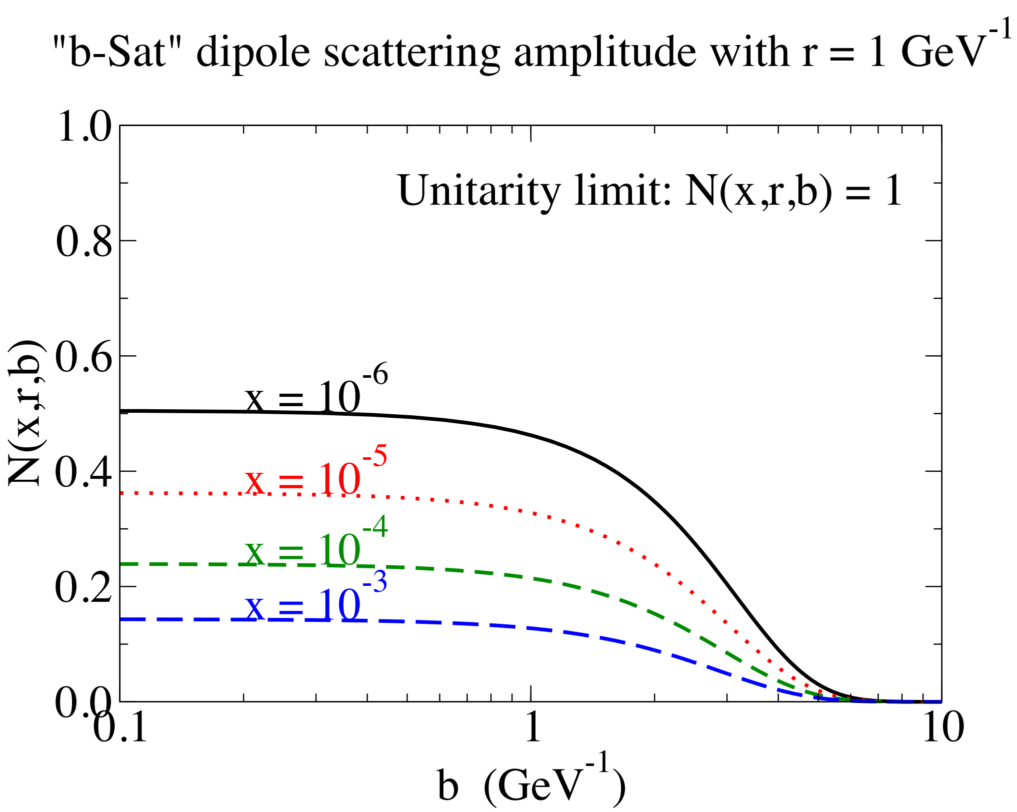
Enhanced diffraction in the nuclear case

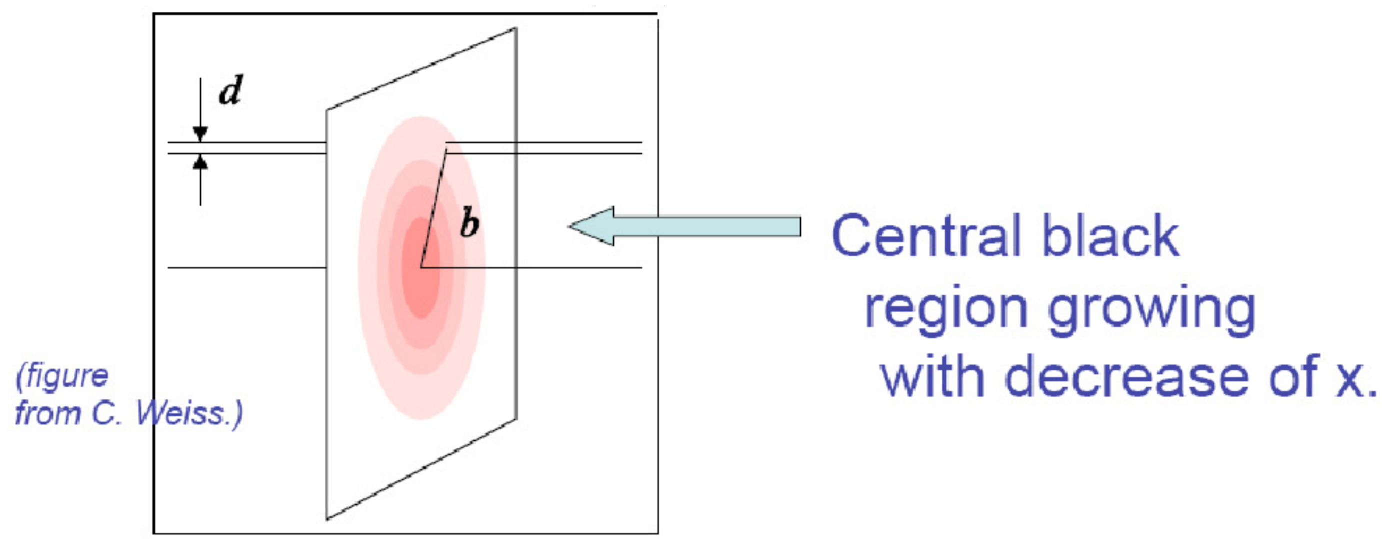
Study of diffractive dijets, heavy quarks for the factorization tests

Exclusive diffraction



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



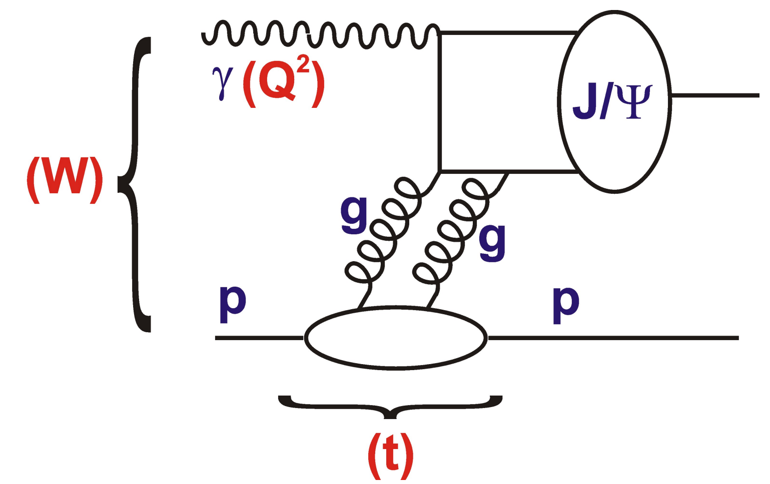


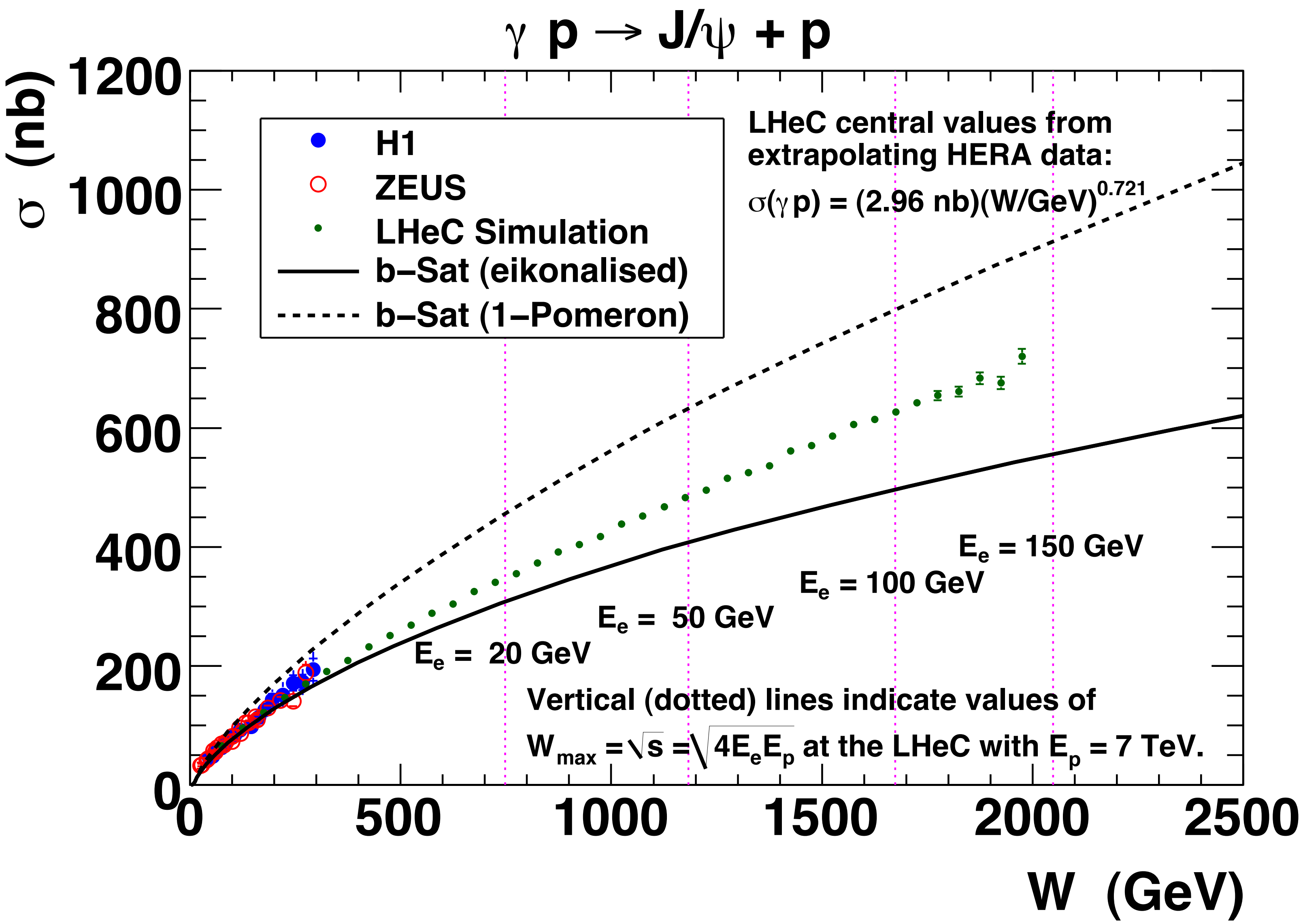
Large momentum transfer t probes small impact parameter where the density of interaction region is most dense.

Exclusive diffraction: predictions

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

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





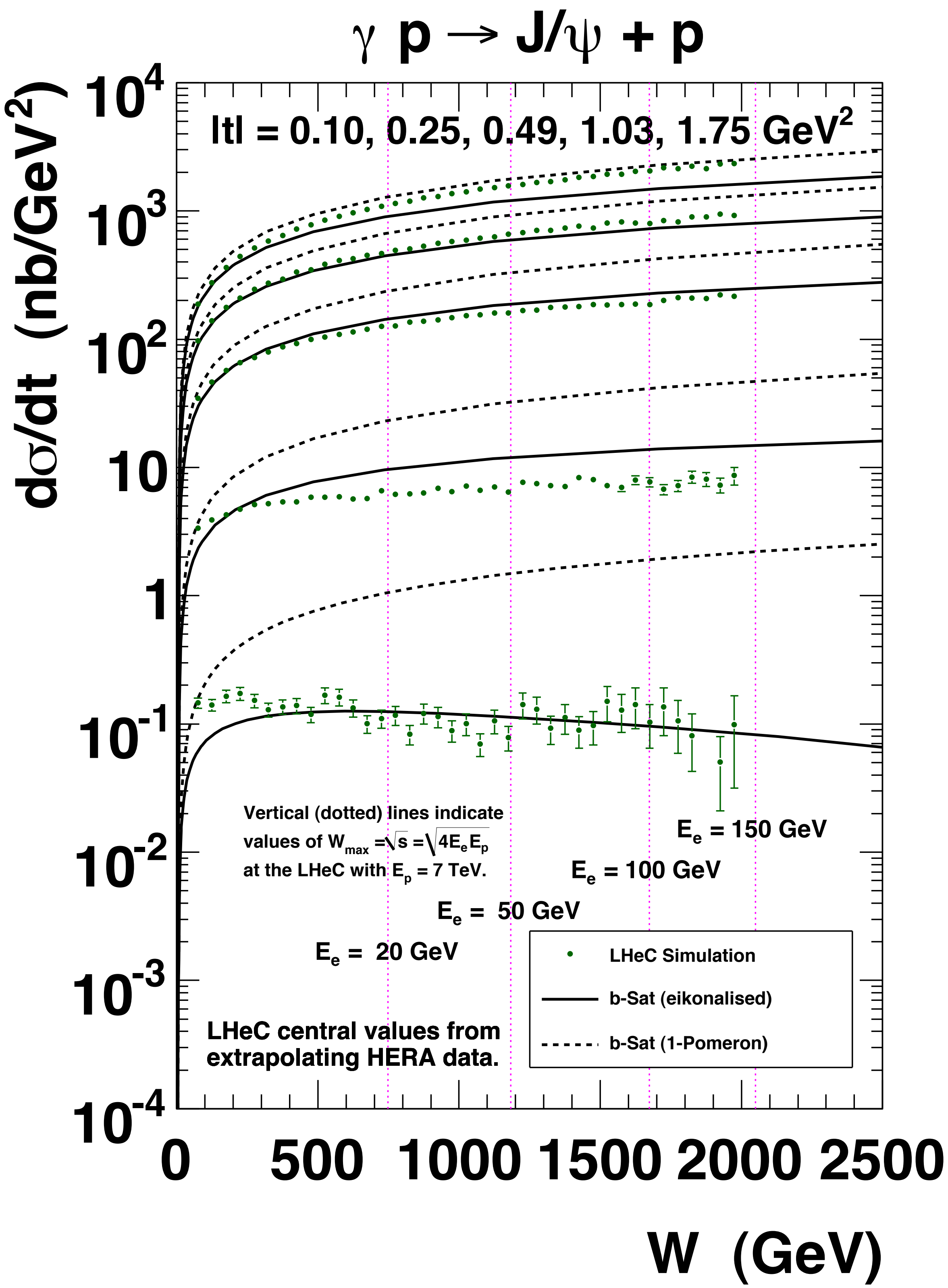
Large effects even for the t-integrated observable.

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: t-dependence

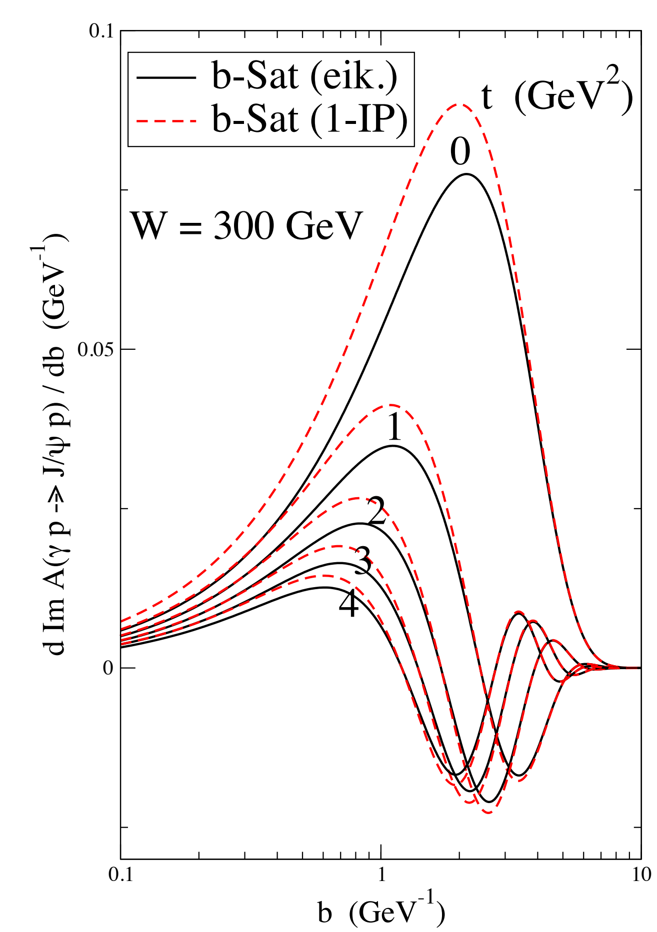


Photoproduction in bins of W and t.

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

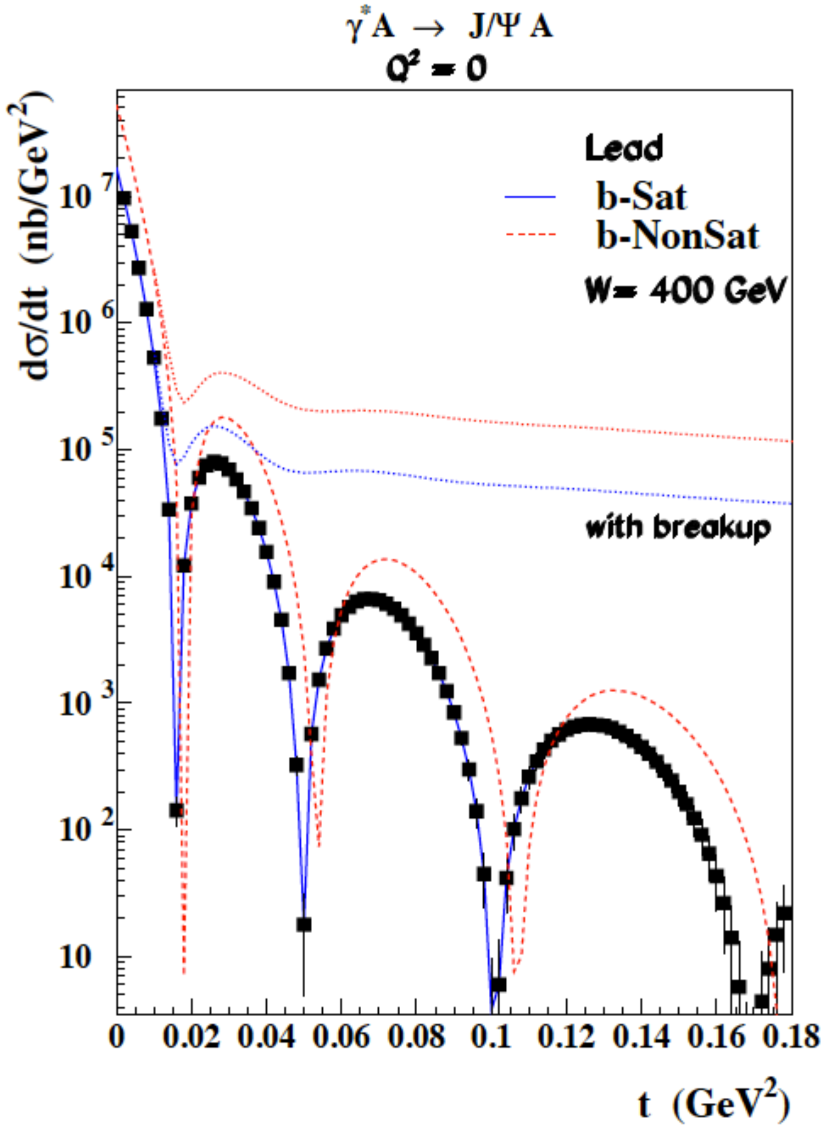
Large values of t : increased sensitivity to small impact parameters.

Amplitude as a function of the impact parameter.

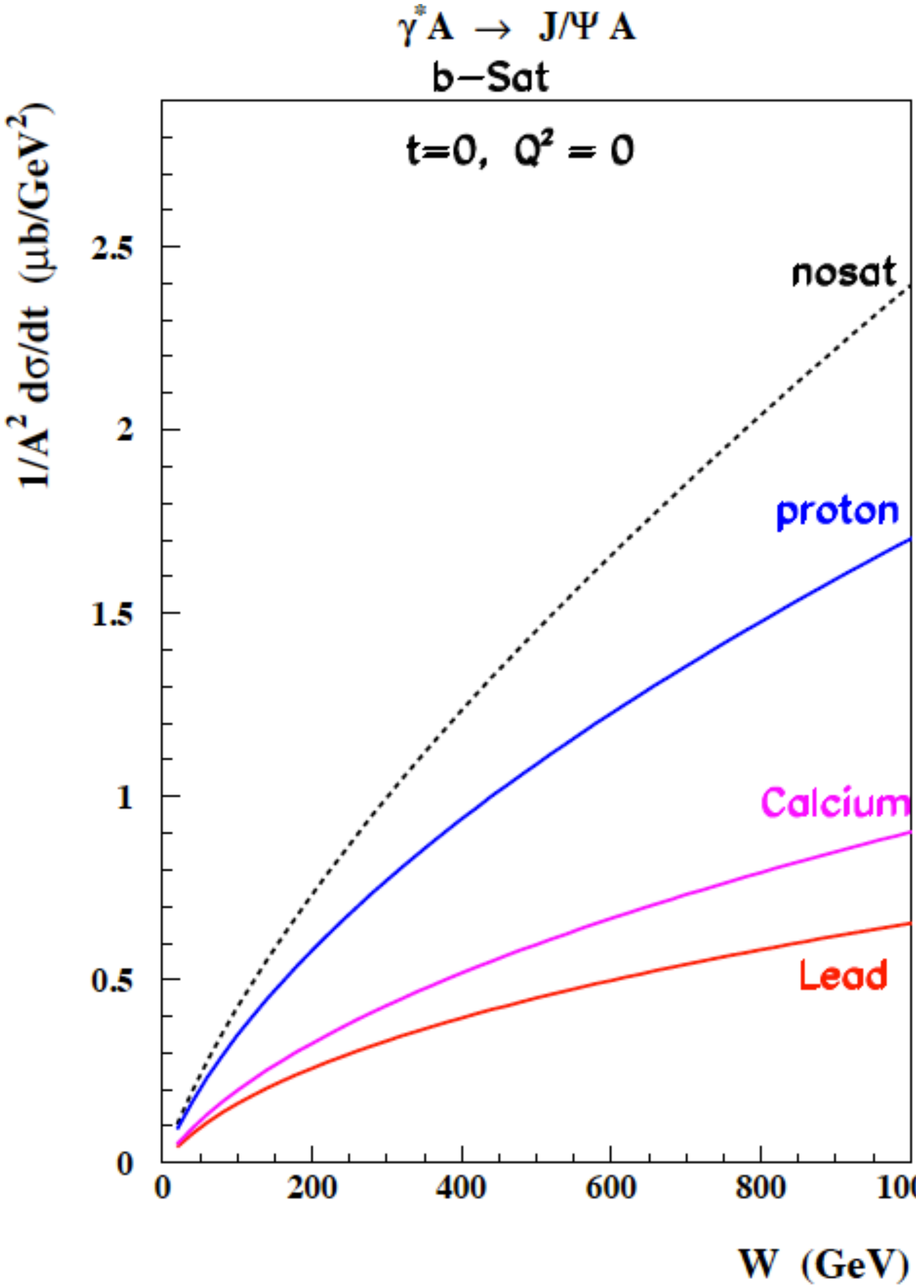


Exclusive diffraction on nuclei

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.

Photoproduction cross section

Explore dual nature of the photon: pointlike interactions or hadronic behavior.

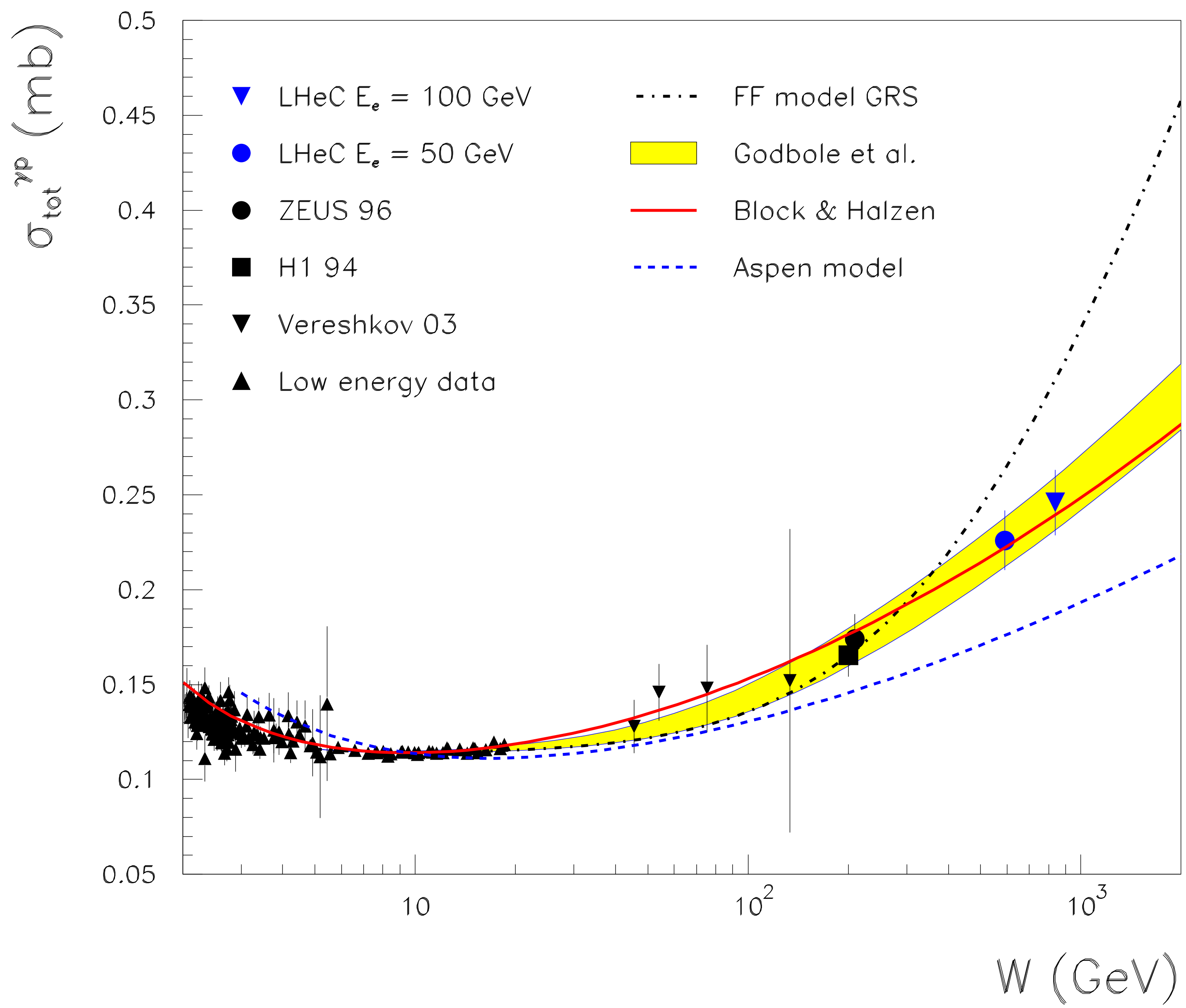
Tests of universality of hadronic cross sections, unitarity, transition between perturbative and nonperturbative regimes.

Dedicated detectors for small angle scattered electrons at 62m from the interaction point.

Kinematics of events:

$$Q^2 \sim 0.01$$

$$y \sim 0.3$$



Systematics is the limiting factor here. Assumed 7% for the simulated data as in H1 and ZEUS.

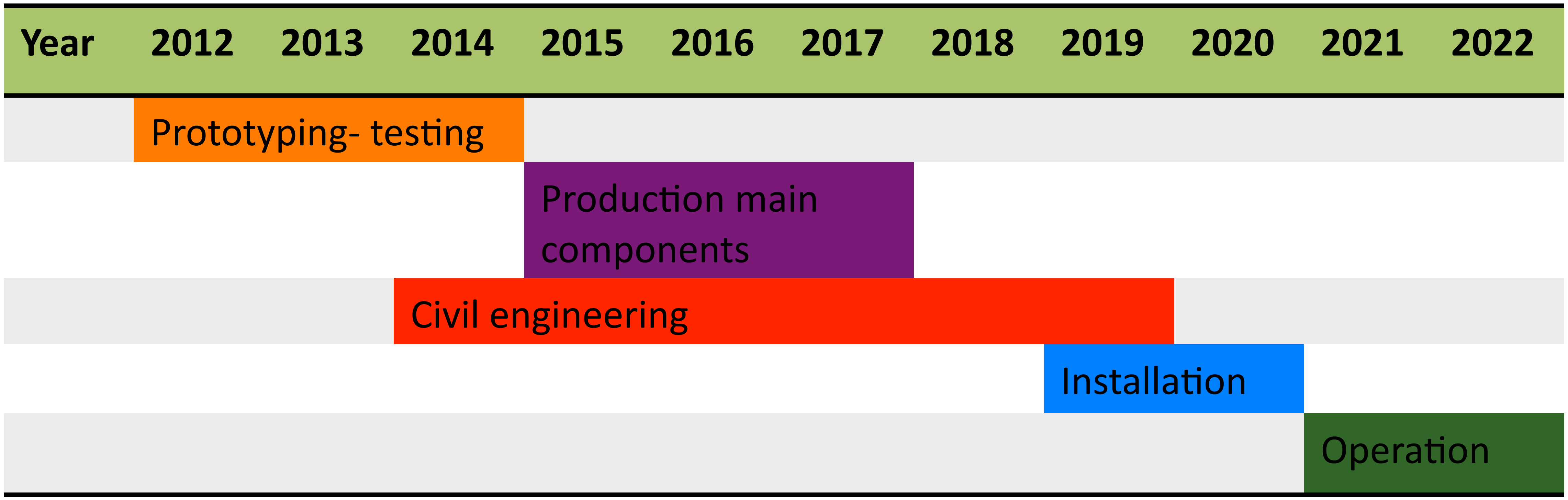
Summary

- LHeC has an unprecedented potential as a high luminosity, high energy DIS machine. Offering a unique window for small x physics and high parton density regime.
- Precision DIS measurements complementary to pp/pA/AA.
- eA at high energy essential to untangle the complex nuclear structure at low x and constrain the initial conditions for AA at the LHC.
- CDR for the project is almost complete.
- Next steps in the near future:
  - Referee process 6-9/11
  - Update of the CDR.
  - Workshop on Linac vs Ring in Fall 2011

http://cern.ch/lhec

LHeC Draft Timeline

Based on LHC constraints, ep/A programme, series production, civil engineering etc



Variations on timeline:

- ➔ production of main components can overlap with civil engineering
- ➔ Installation can overlap with civil engineering
- ➔ Additional constraints from LHC operation not considered here
- ➔ in any variation, a start by 2020 requires launch of prototyping of key components by 2012

[shown to ECFA 11/2010: mandate to 2012]

It would be a waste not to exploit the 7 TeV beams for eP and eA physics at some stage during the LHC time

G. Altarelli
Divonne 08

It would be a waste not to exploit the 7 TeV beams for eP and eA physics at some stage during the LHC time

G. Altarelli
Divonne 08

Thank you!

Backup

Organization of the CDR

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg)
Richard Milner (Bates)
Joachim Mnich (DESY)
Steven Myers, (CERN)
Tatsuya Nakada (Lausanne, ECFA)
Guenther Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Committee

Oliver Bruening (CERN)
John Dainton (Cockcroft)
Albert DeRoeck (CERN)
Stefano Forte (Milano)
Max Klein - chair (Liverpool)
Paul Laycock (secretary) (L'pool)
Paul Newman (Birmingham)
Emmanuelle Perez (CERN)
Wesley Smith (Wisconsin)
Bernd Surrow (MIT)
Katsuo Tokushuku (KEK)
Urs Wiedemann (CERN)
Frank Zimmermann (CERN)

Working Group Convenors

Accelerator Design [RR and LR]

Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),
Rainer Wallny (U Zurich),
Alessandro Polini (Bologna)

New Physics at Large Scales

George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)

Physics at High Parton Densities

Nestor Armesto (Santiago),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (PSU)

Referees invited by CERN

QCD/electroweak:
Guido Altarelli, Alan Martin, Vladimir Chekelyan

BSM:
Michelangelo Mangano, Gian Giudice, Cristinel Diaconu

eA/low x
Al Mueller, Raju Venugopalan, Michele Arneodo

Detector
Philipp Bloch, Roland Horisberger

Interaction Region Design
Daniel Pitzl, Mike Sullivan

Ring-Ring Design
Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

Linac-Ring Design
Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

Energy Recovery
Georg Hoffstatter, Ilan Ben Zvi

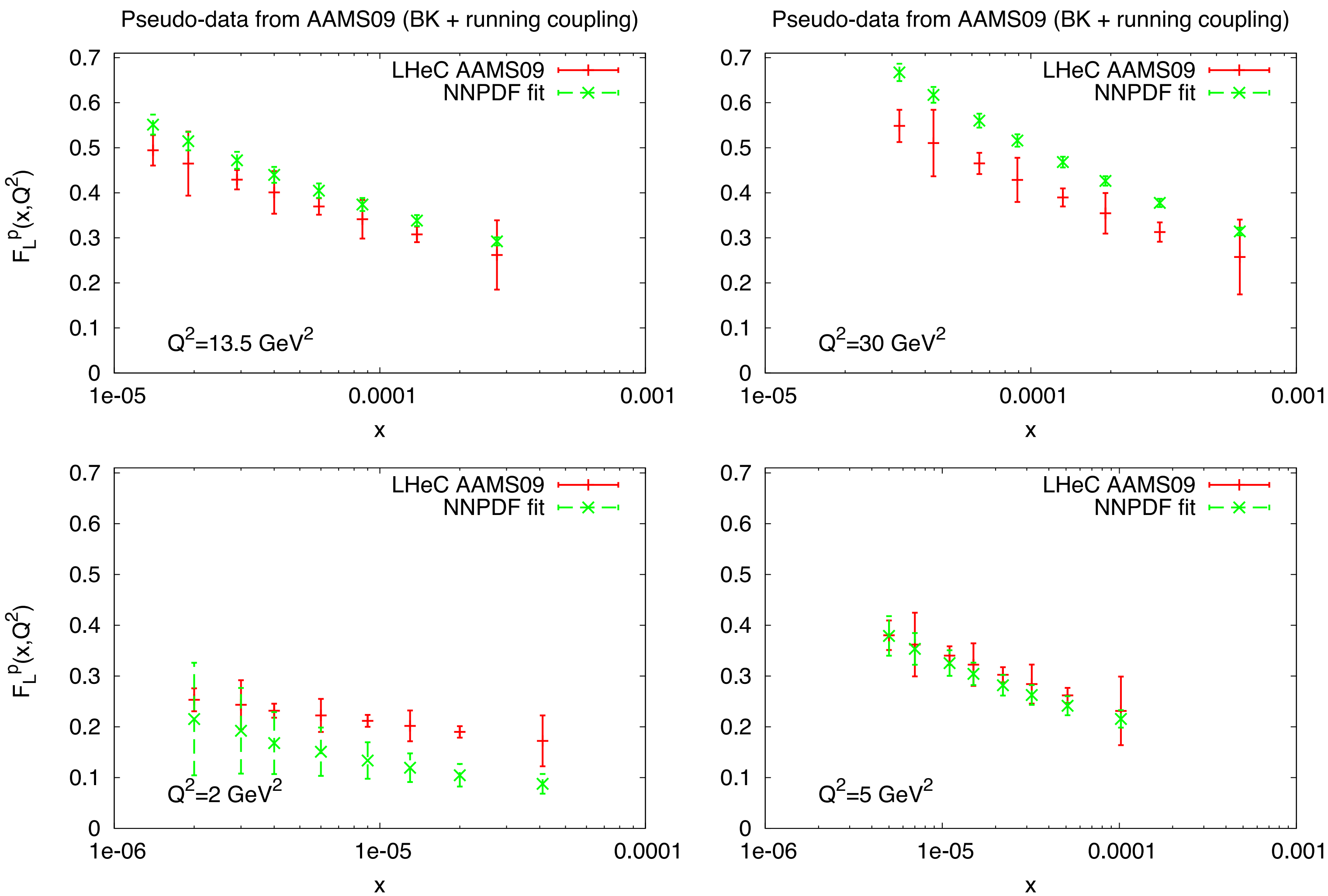
Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz

Testing nonlinear dynamics in ep

Simulated LHeC data using the nonlinear evolution which leads to the parton saturation at low x.

DGLAP fits (using the NNPDF) cannot accommodate the nonlinear effects if F2 and FL are simultaneously fitted.

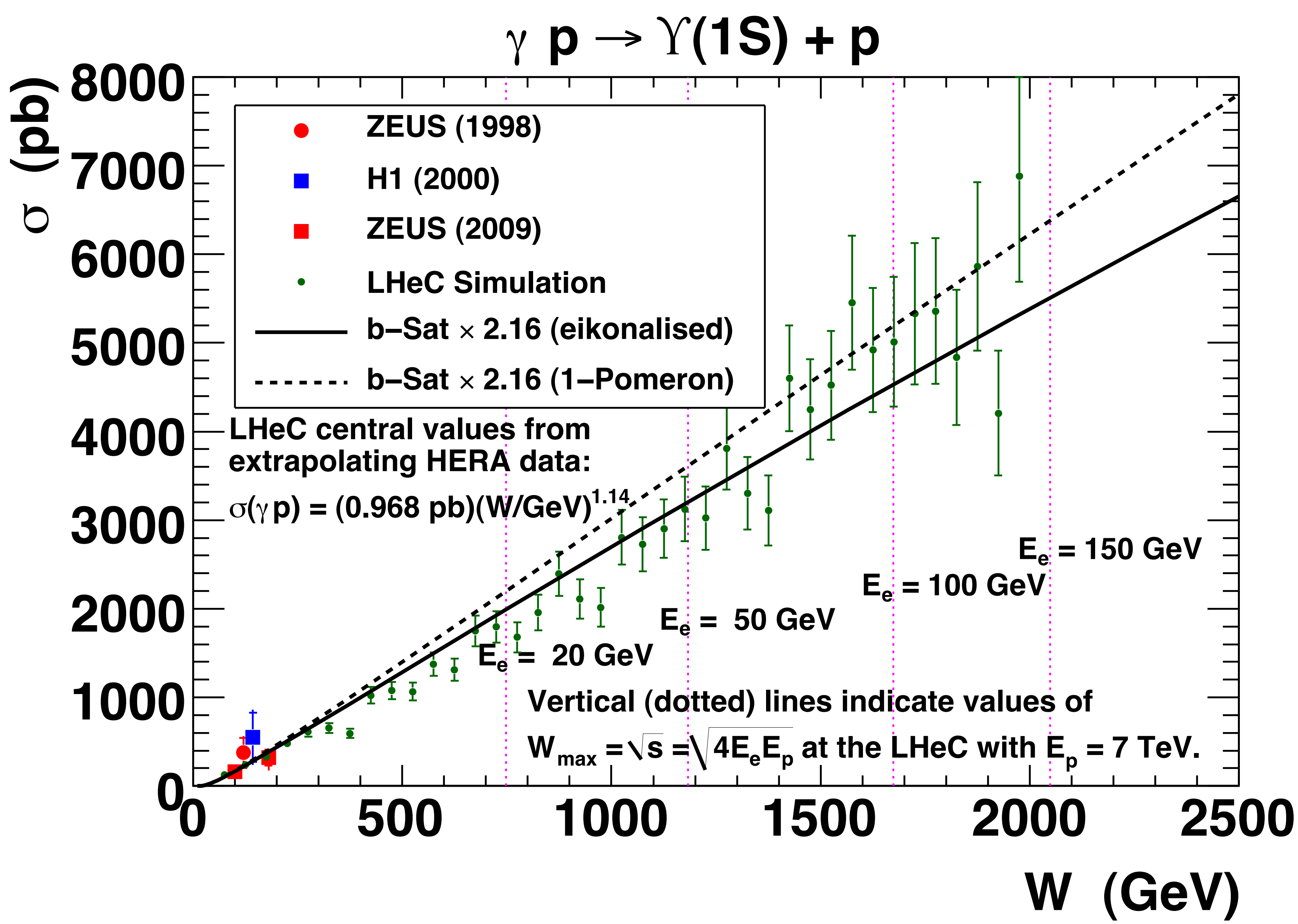


Albacete,Rojo

FL provides important constraint on the gluon density at low x.

Exclusive diffraction: predictions

$$\sigma^{\gamma p \to \Upsilon + p}(W)$$



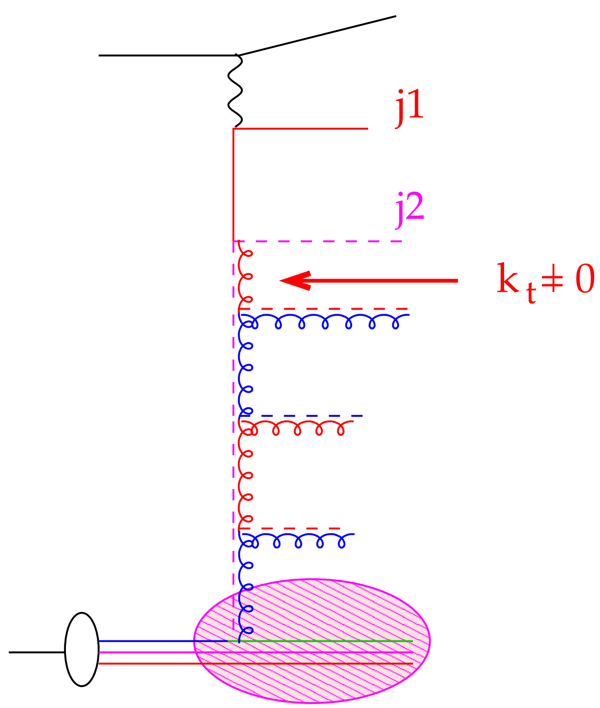
Similar analysis for heavier states.

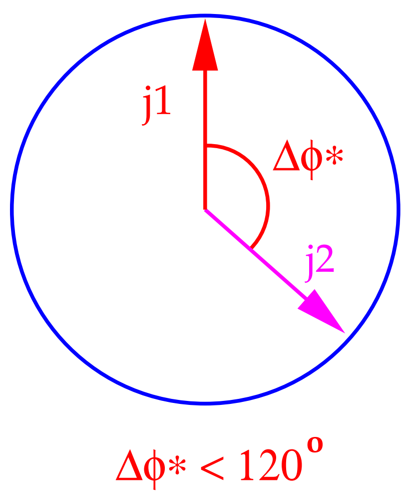
Smaller sensitivity to the saturation effects.

Models do have large uncertainty. Normalization needs to be adjusted to fit the current HERA data.

Precise measurements possible in the regime well beyond HERA kinematics.

Dijets in ep



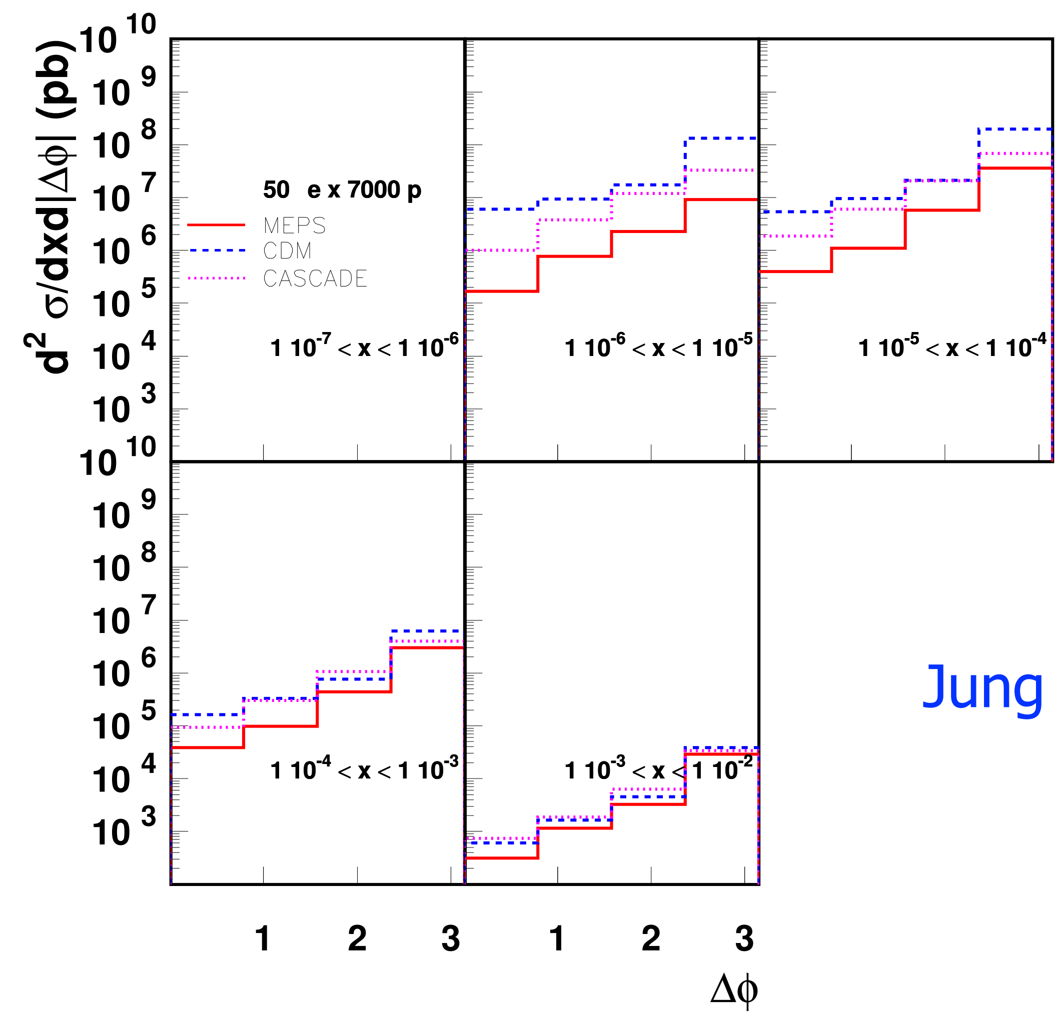


- Incoming gluon can have sizeable transverse momentum.
- Decorrelation of pairs of jets, which increases with decreasing value of x.
- Collinear approach typically produces narrow back-to-back configuration. Need to go to higher orders(NLO not sufficient).

$$-1 < \eta_{\rm jet} < 2.5 \qquad 0.1 < y < 0.6$$

$$E_{1T} > 7 \text{ GeV} \qquad Q^2 > 5 \text{ GeV}^2$$

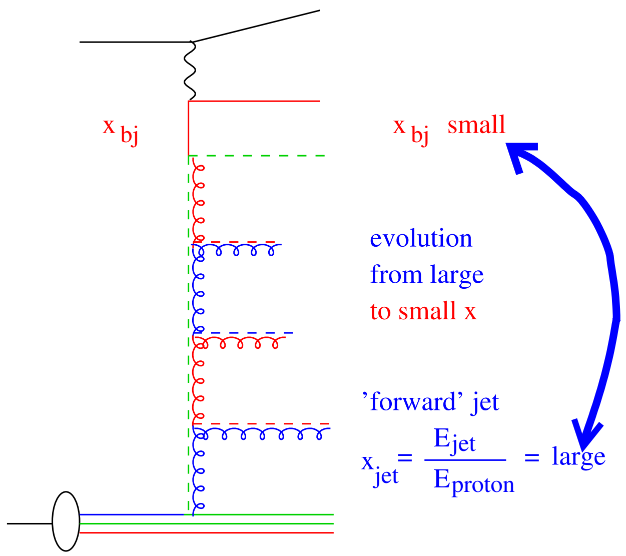
$$E_{2T} > 5 \text{ GeV}$$



Jung

- All simulations agree at large x.
- CDM, CASCADE give a flatter distribution at small x.

Forward jets



- Forward jet provides the second hard scale.
- By selecting it to be of the order of the photon virtuality, collinear configurations can be suppressed.
- Forward jet, large phase space for gluon emission.
- DGLAP typically underestimates the forward jet production.

Simulations for

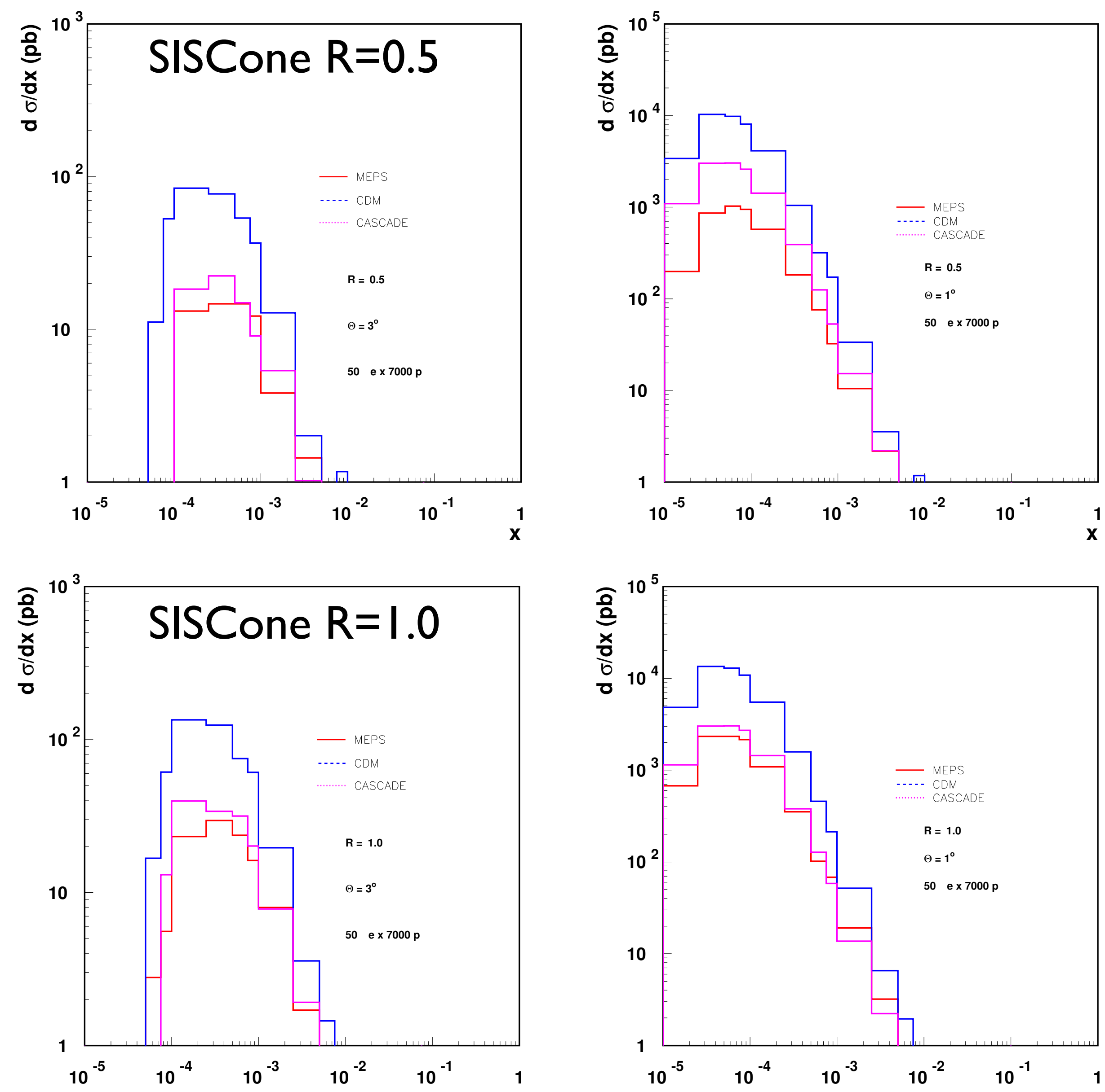
$\Theta > 3^o$ and $\Theta > 1^o$

Angular acceptance crucial for this measurement.

With $\Theta > 10^o$

all the signal for forward jets is lost.

Can explore also forward pions. Lower rates but no dependencies on the jet algorithms. Non-perturbative hadronisation effects included effectively in the fragmentation functions.



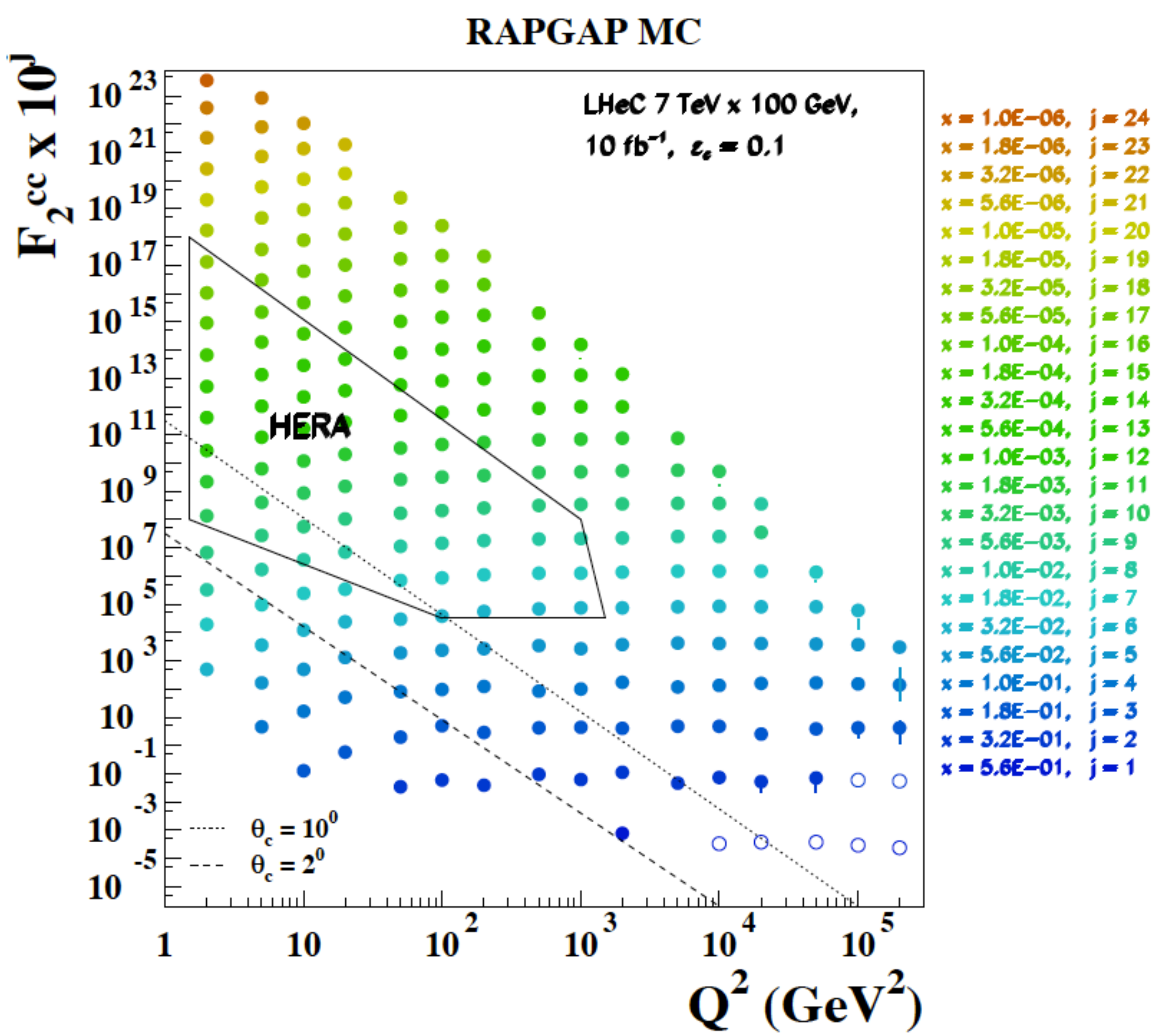
Jung

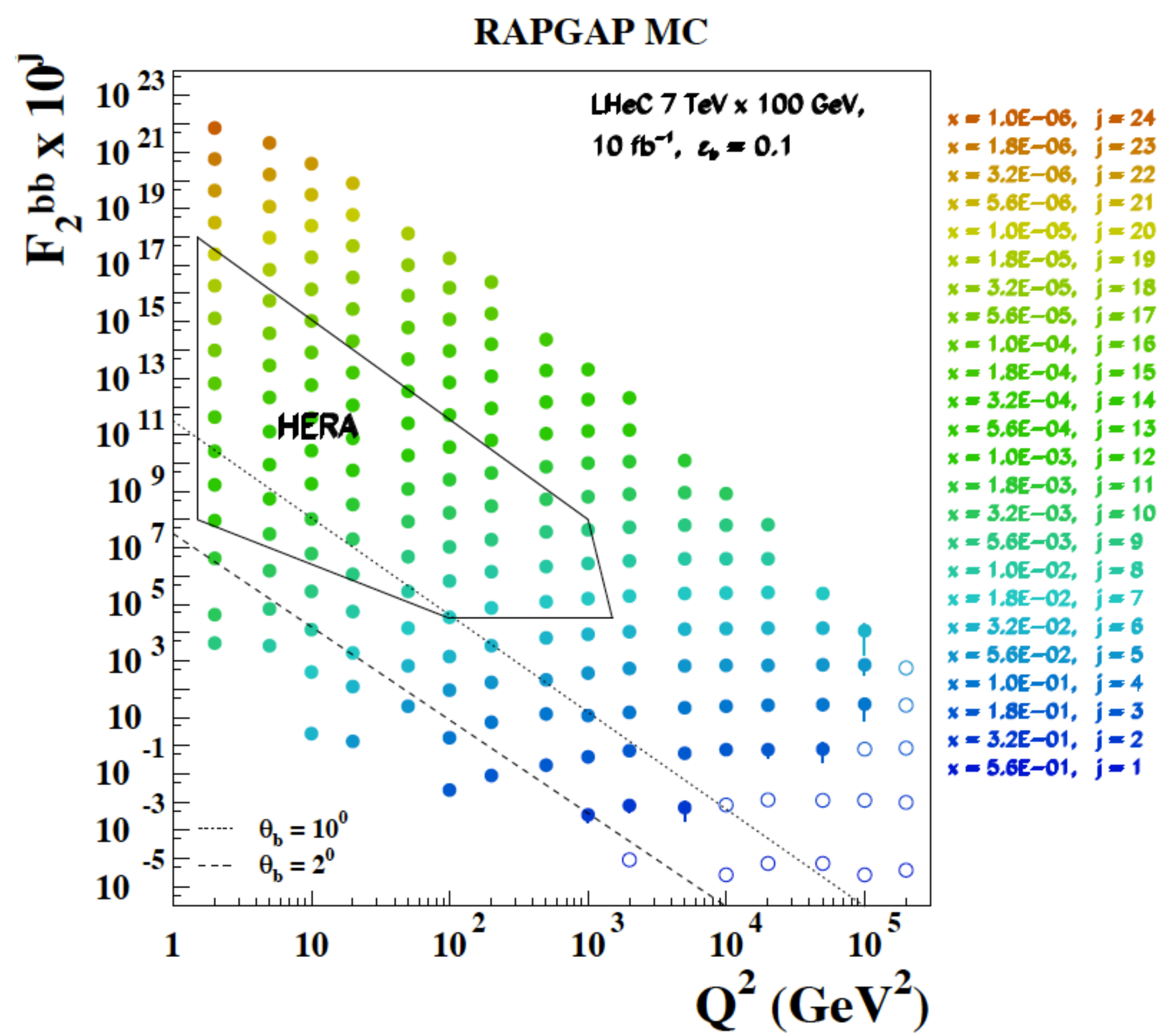
Heavy flavor in ep

Simulations with RAPGAP MC 3.1

QCD_WG@DIS2011

Impressive extension of the phase space.
Both small and large x.





Crucial as a benchmark for the heavy flavor production in nuclei. Can test thoroughly the nuclear effects of in heavy quark production.