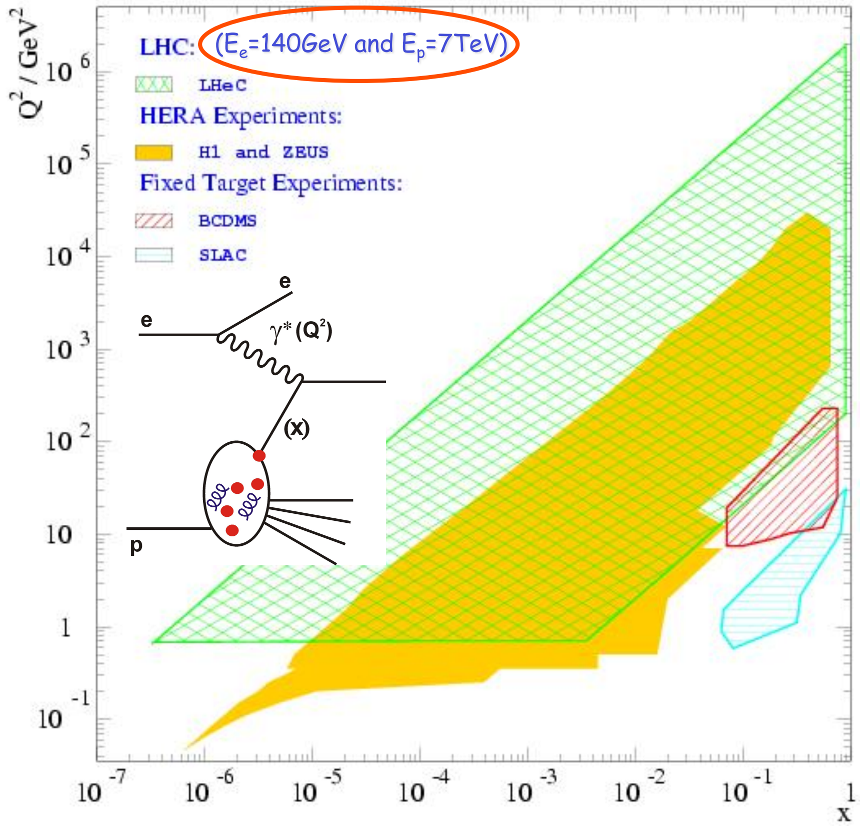
http://cern.ch/lhec



LHeC proposal

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

27/06/2012 *Low x Workshop*, *Paphos, Cyprus*

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: Large Hadron electron Collider

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 50-150 GeV accelerated in LEP-like ring or linac.
Precision experiment at high luminosity.
Parallel operation with the LHC.

Project Development

2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)
3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)
NuPECC puts LHeC to its Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
refereed and being updated

2012: Discussion of LHeC at LHC Machine Workshop (Chamonix)
Publication of CDR – European Strategy
New workshop (June14-15, 2012)

LHeC has some history already ..

Conceptual Design Report

arXiv:1206.2913v1 [physics.acc-ph] 13 Jun 2012

CERN-OPEN-2012-015
LHeC-Note-2012-001 GEN
Geneva, June 14, 2012

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

Submitted to J.Phys. G

LHeC Study Group

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], V.Cetinkaya[01], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

arXiv:1206.2913

193 authors
631 pages
947 references
5 chapters
14 sections

performance targets

e- energy ≥60 GeV

luminosity ~10^{33} $cm^{-2}s^{-1}$

total electrical power for e-: ≤100 MW

e^+p collisions with similar luminosity

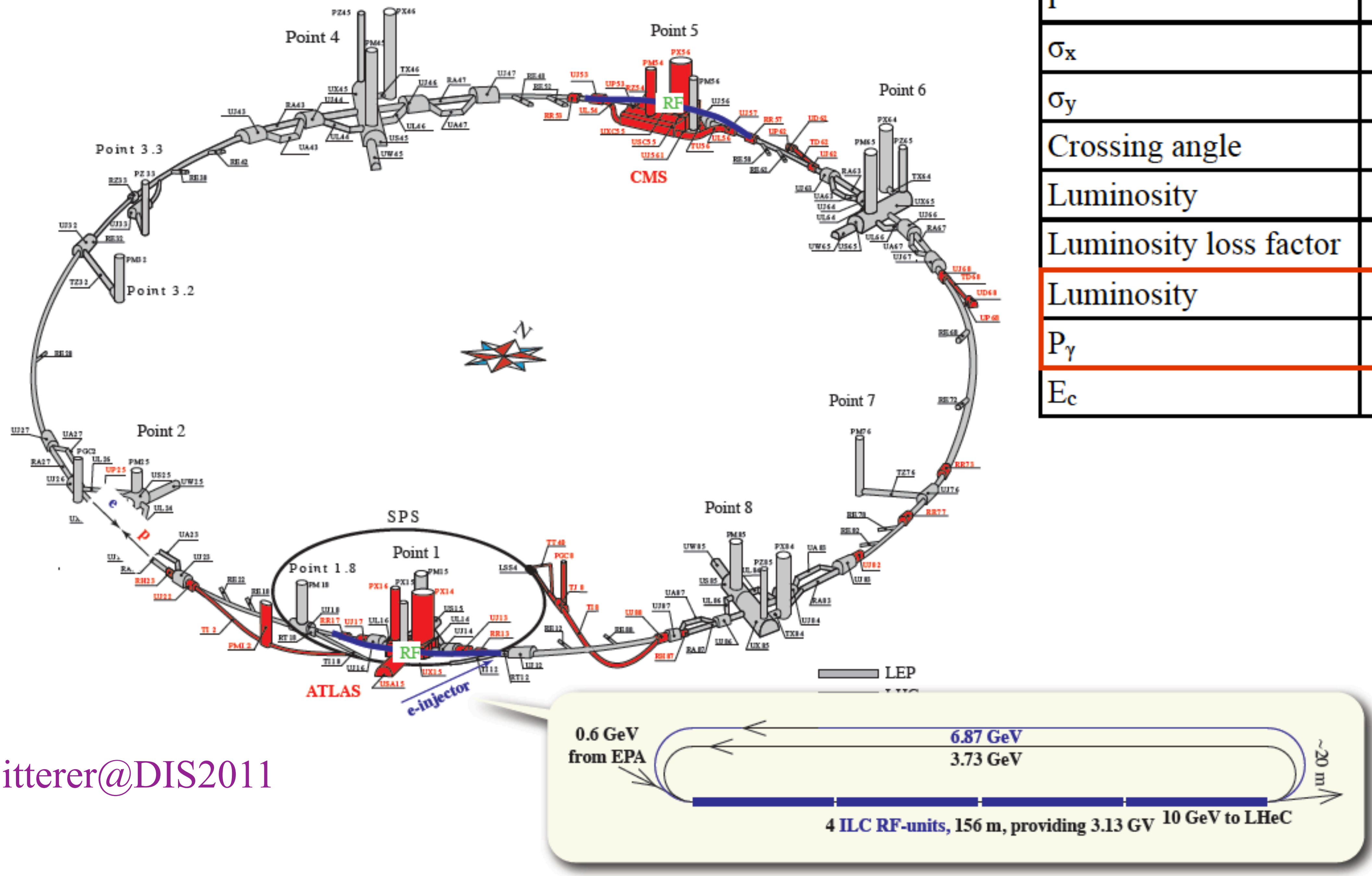
simultaneous with LHC *pp* physics

e^-/e^+ polarization

detector acceptance down to 1^o

Machine design

Ring-ring scenario



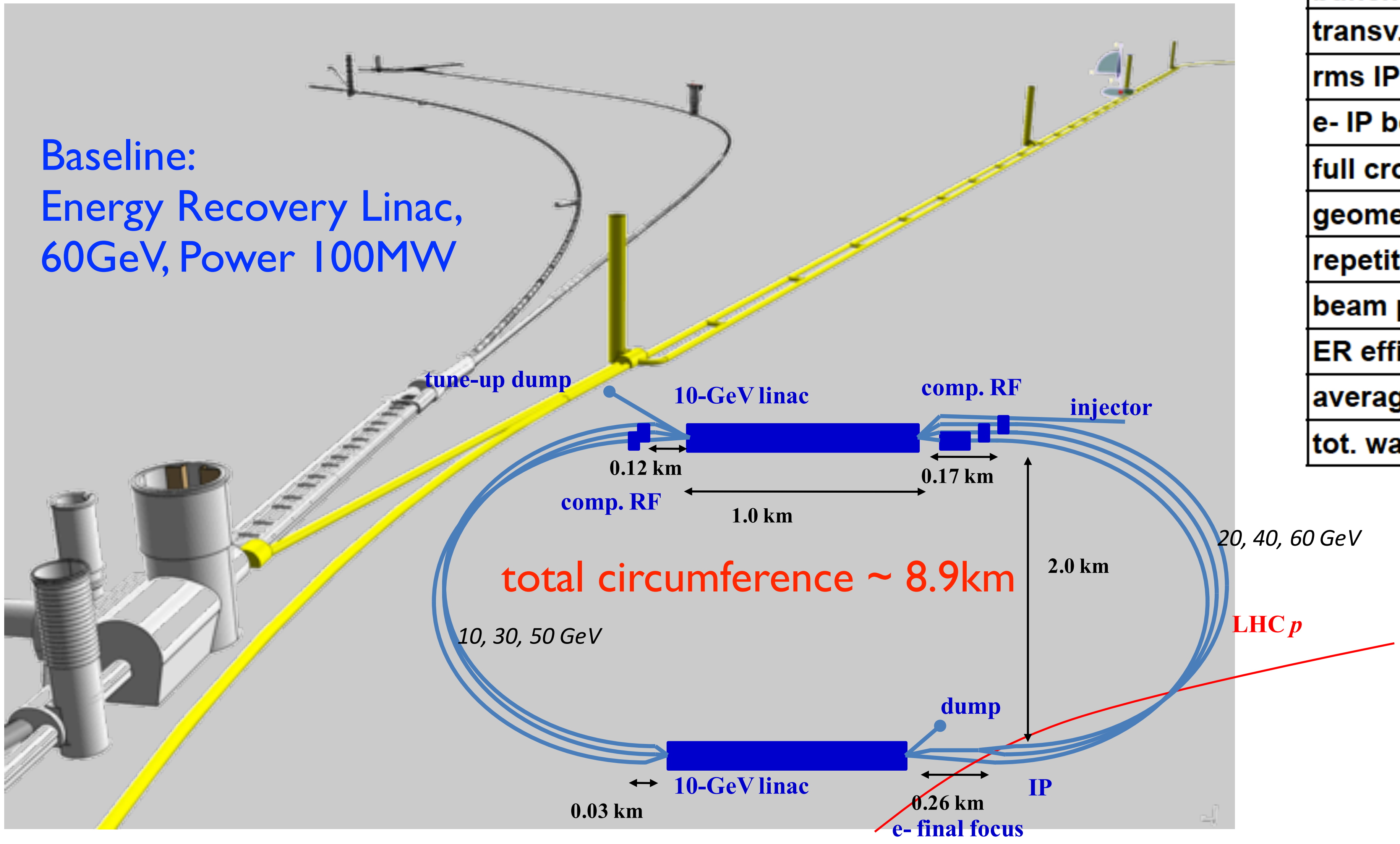
	Electrons	Protons
β_x	0.4 m	4.05 m
β_y	0.2 m	0.97 m
l*	6 m	22.96 m
σ_x	45 µm	
σ_y	22 µm	
Crossing angle	1 mrad	
Luminosity	$8.54\ 10^{32}$ cm^{-2} s^{-1}	
Luminosity loss factor	86%	
Luminosity	$7.33\ 10^{32}$ cm^{-2} s^{-1}	
P_γ	51 kW	
E_c	163 keV	

Fitterer@DIS2011

Machine design

Linac-ring scenario

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



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

total circumference ~ 8.9km

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.

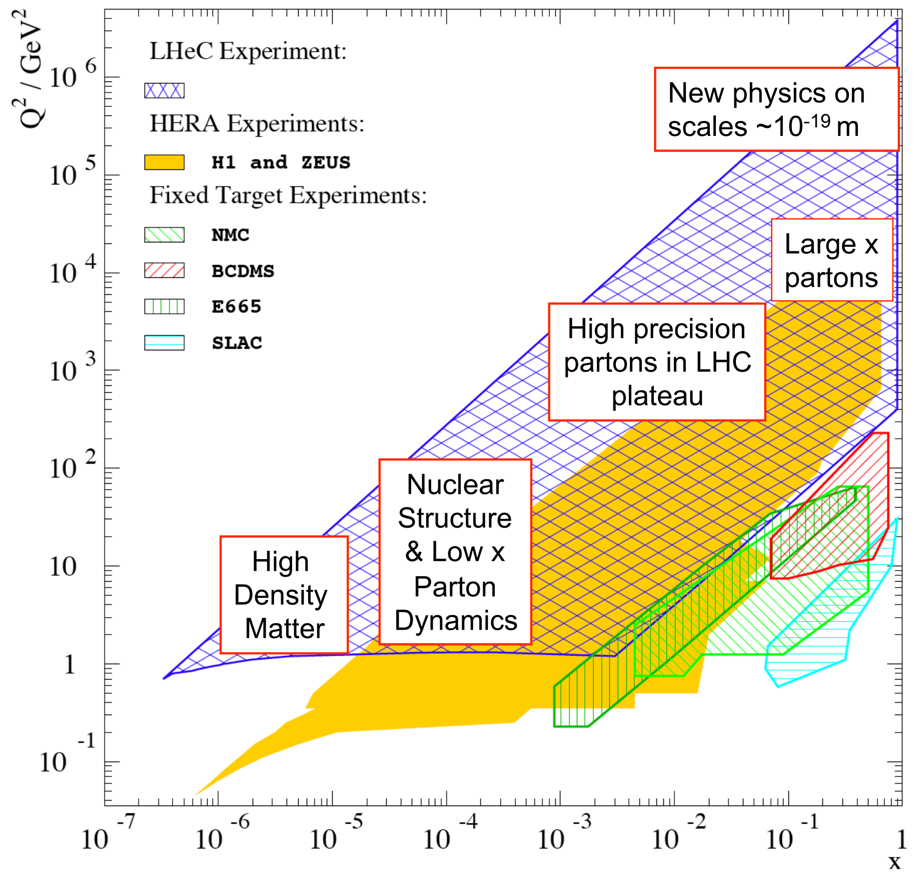
* EMCAL calibration to 0.1 %.

* HCAL calibration to 0.5 %.

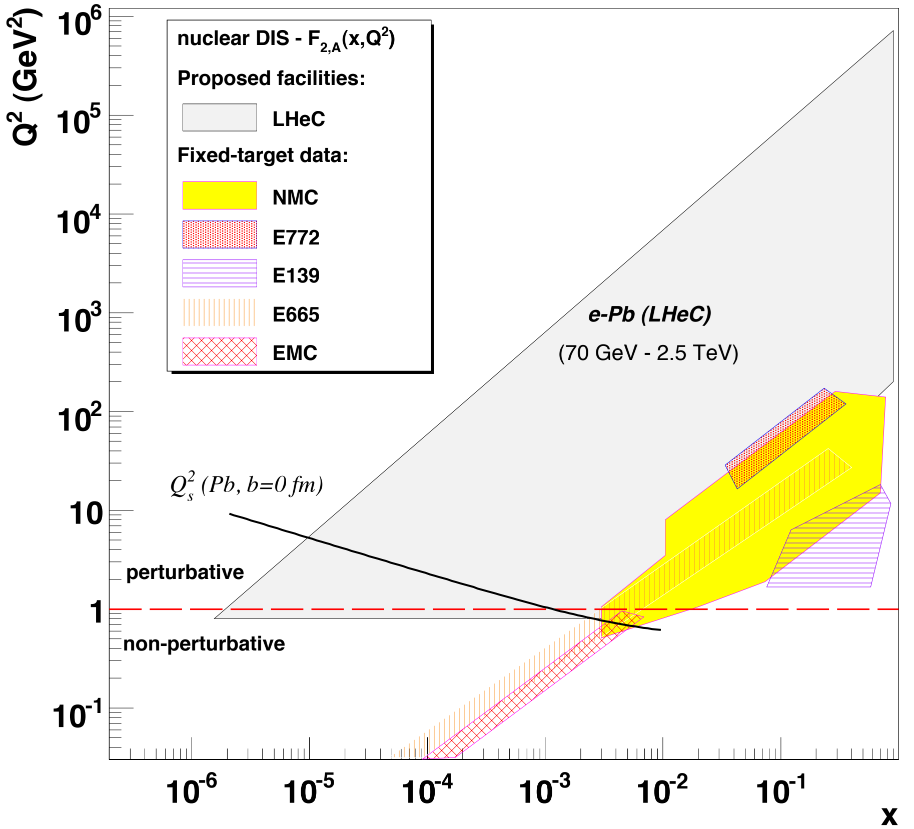
* Luminosity determination to 1 %.

* Compatible with LHC operation.

ep



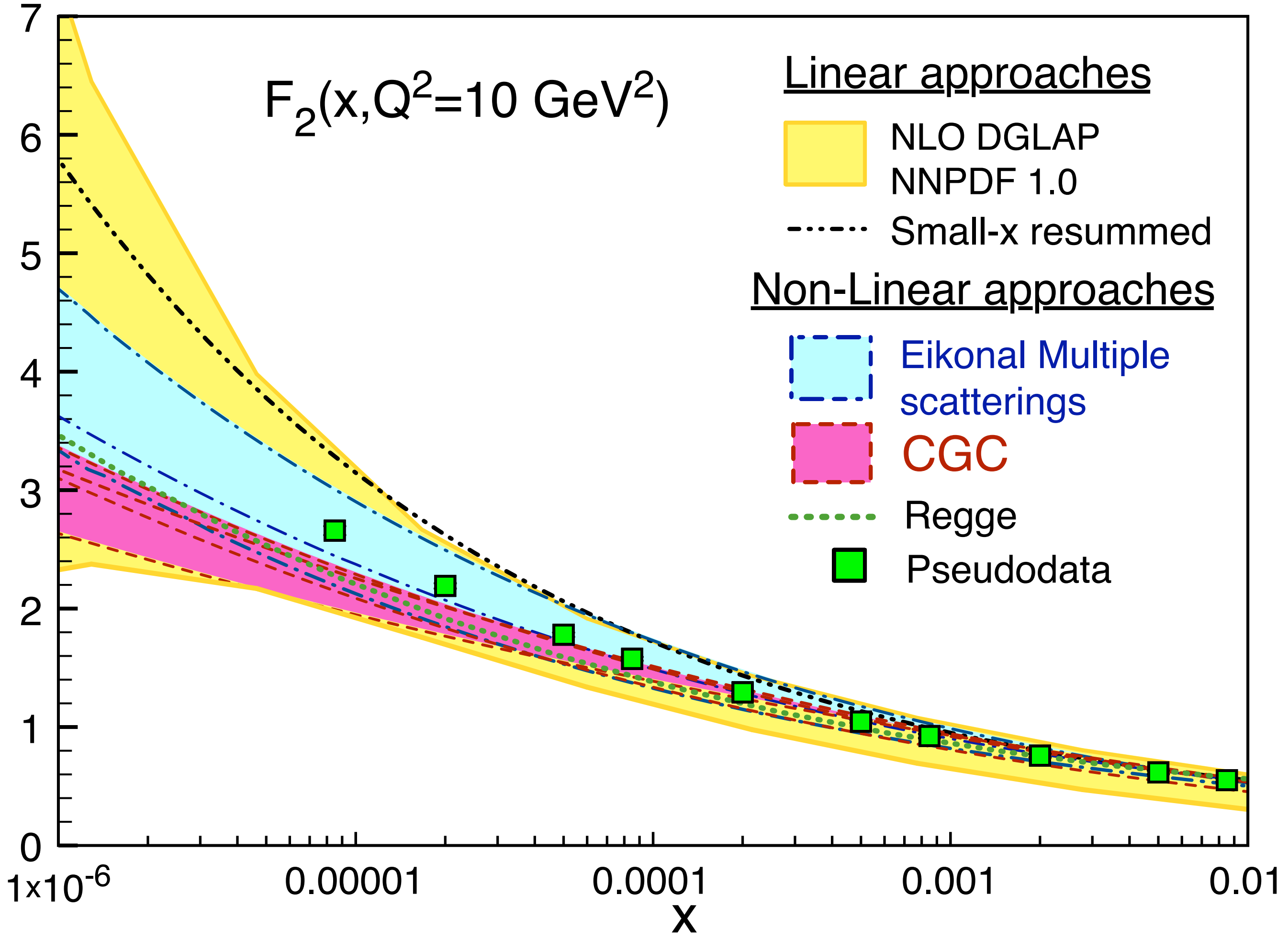
eA

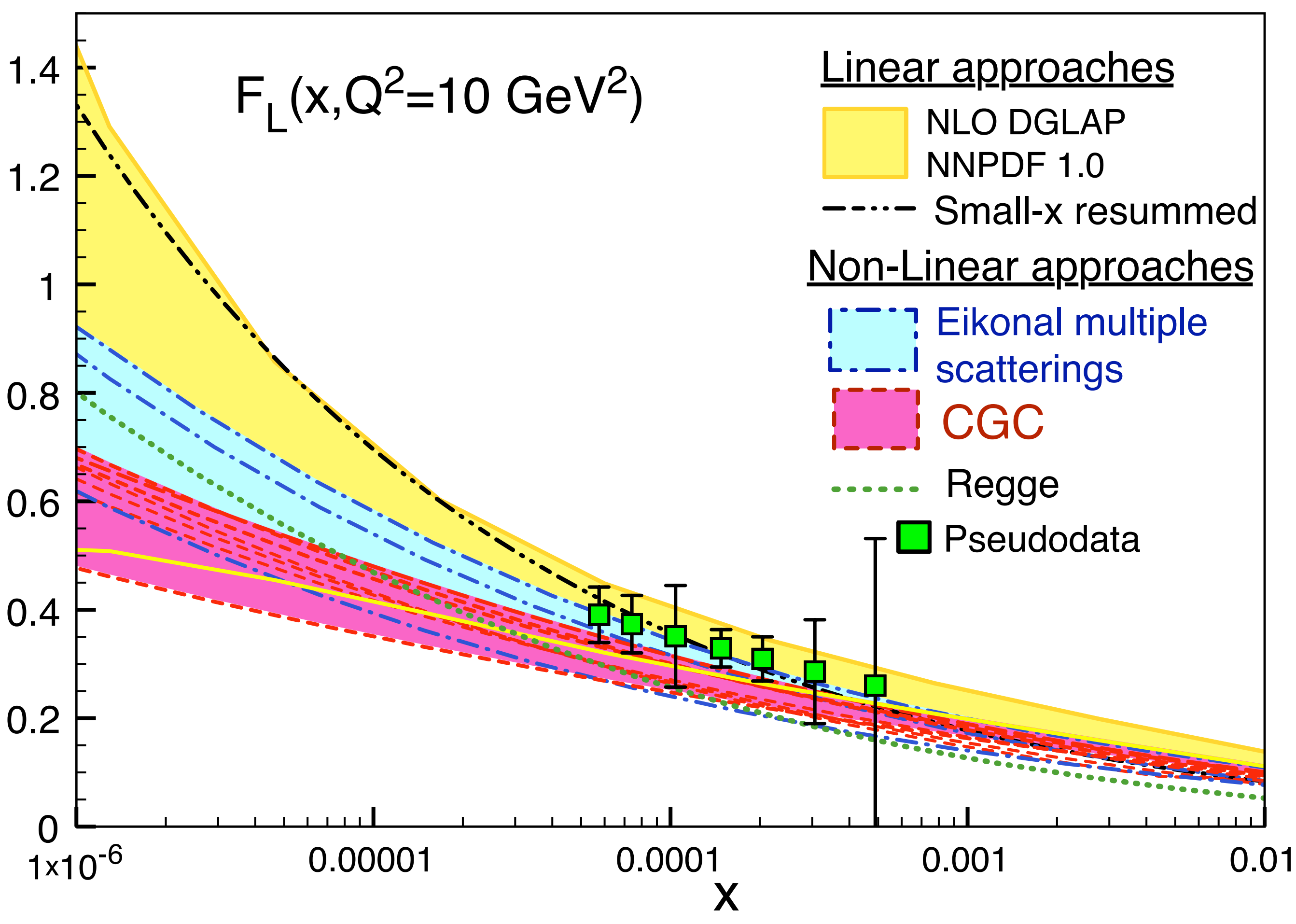


Physics chapter of the CDR

F_2,F_L structure functions and pdfs

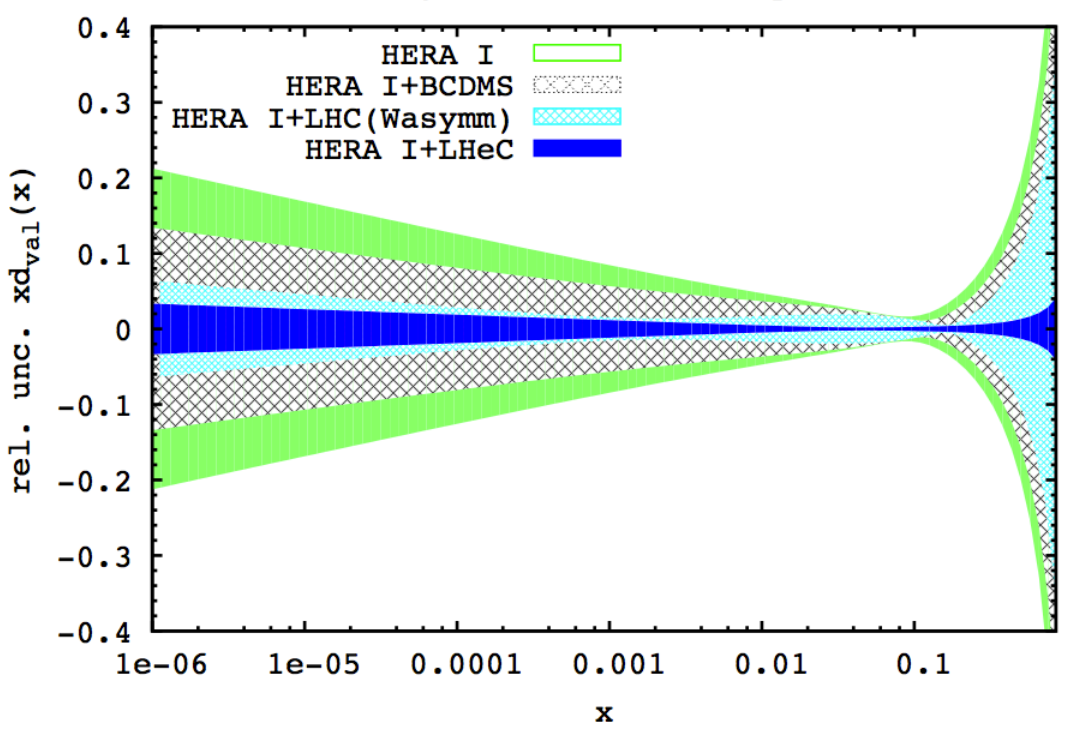
Precision measurements of structure functions at very low x: test DGLAP, small x, saturation inspired approaches.

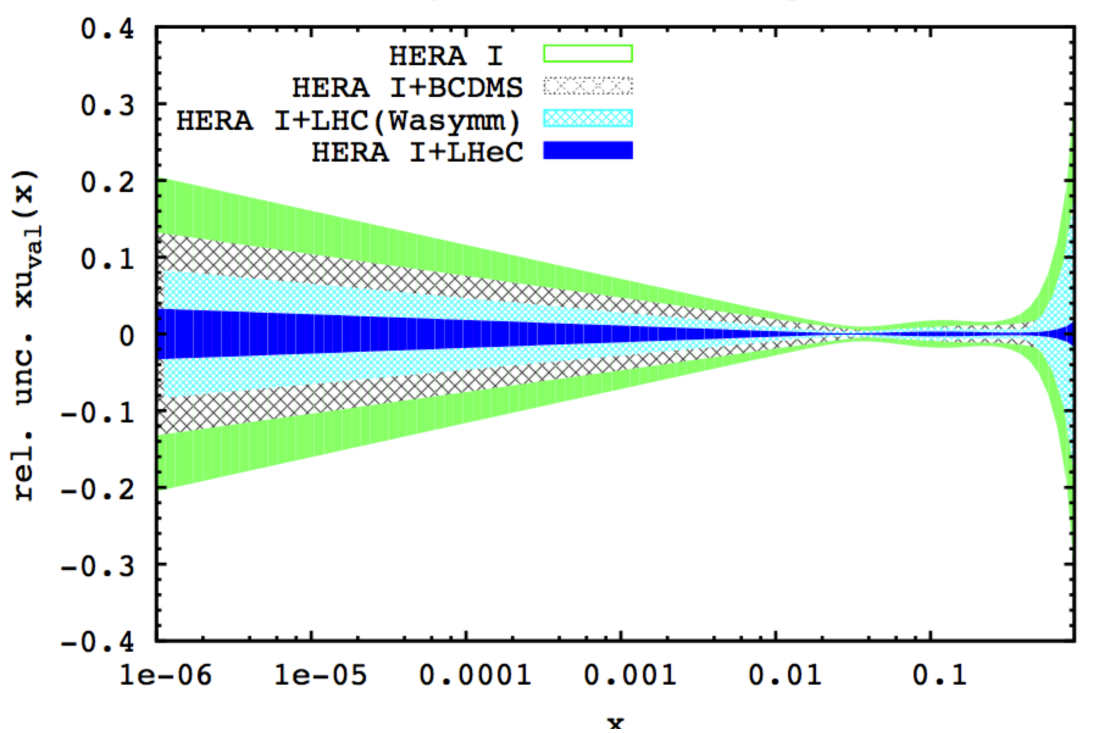


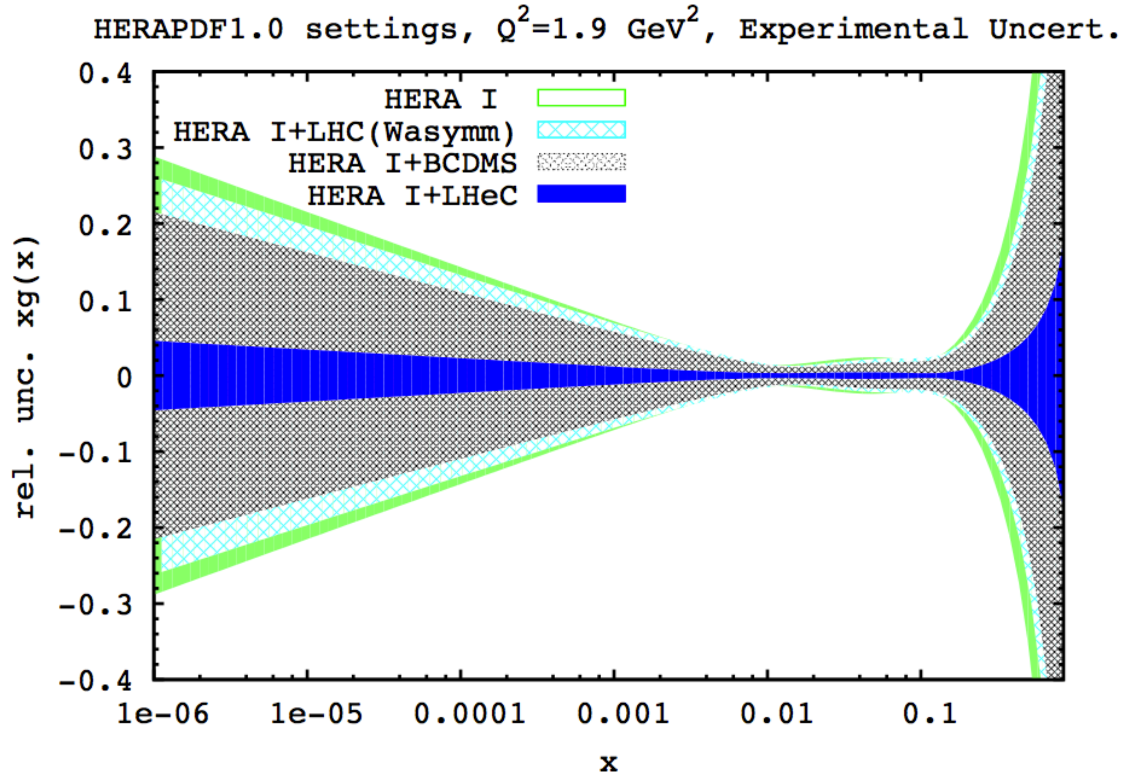


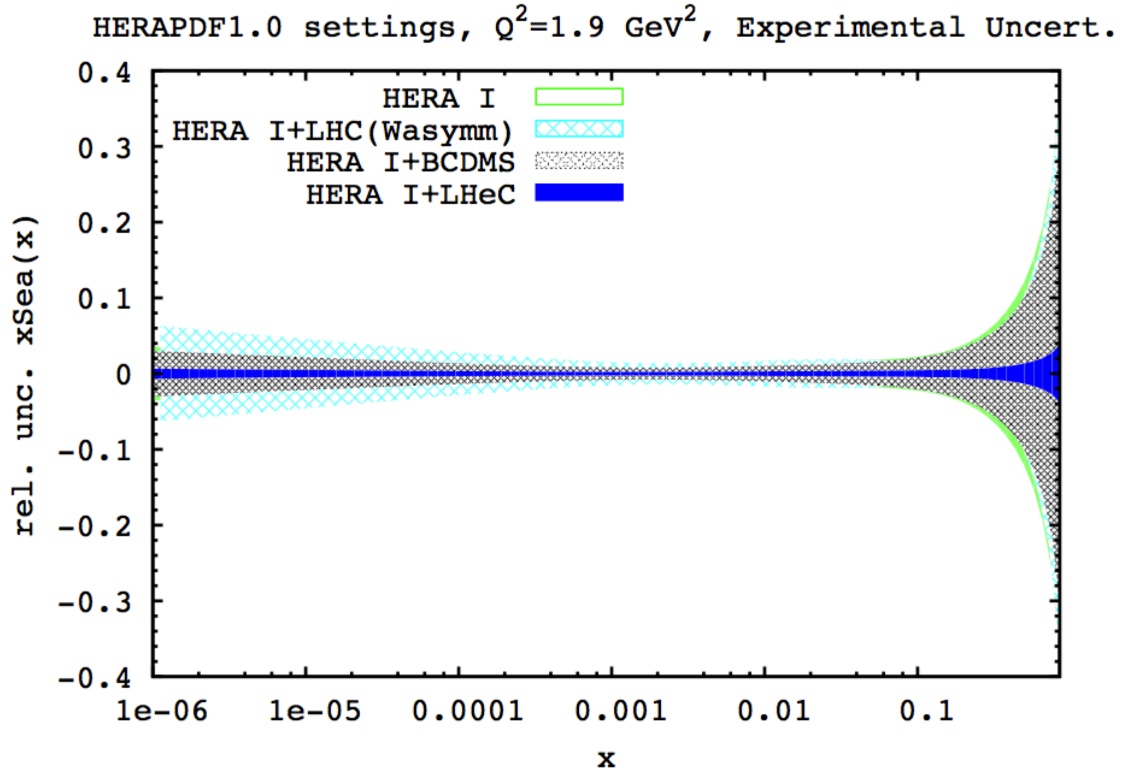
Impact of LHeC on PDFs: zoom on low x

* Experimental uncertainties are shown at the starting scale $Q^2=1.9\ \mathrm{GeV}^2$









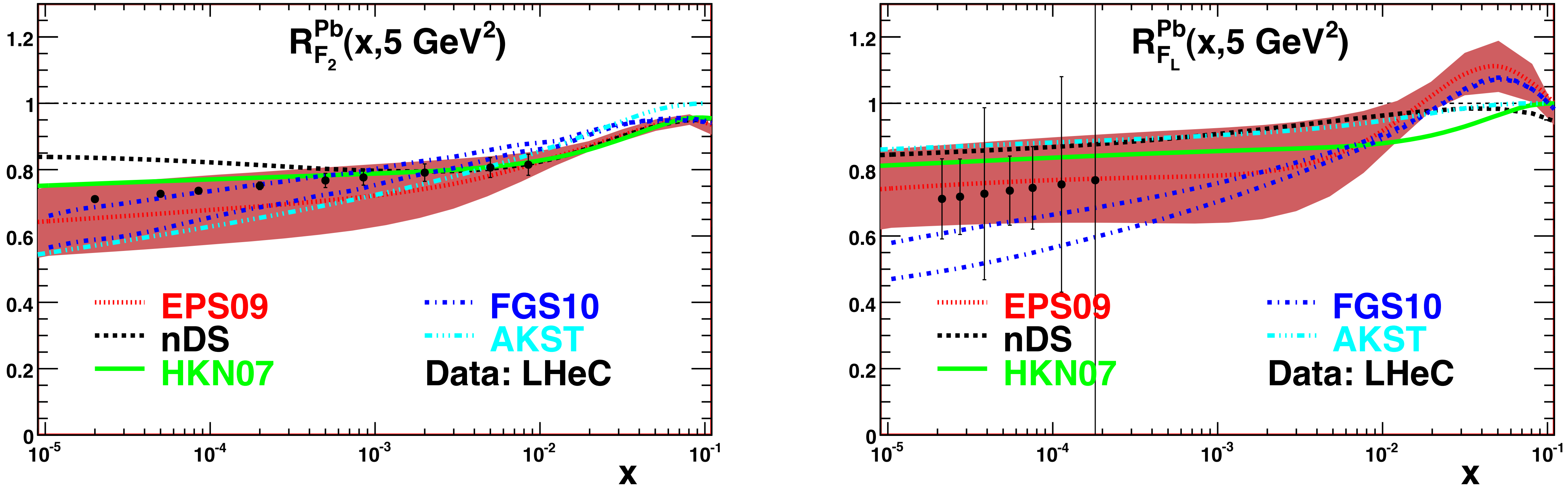
Nuclear structure functions at LHeC

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 $R^A \neq 1$

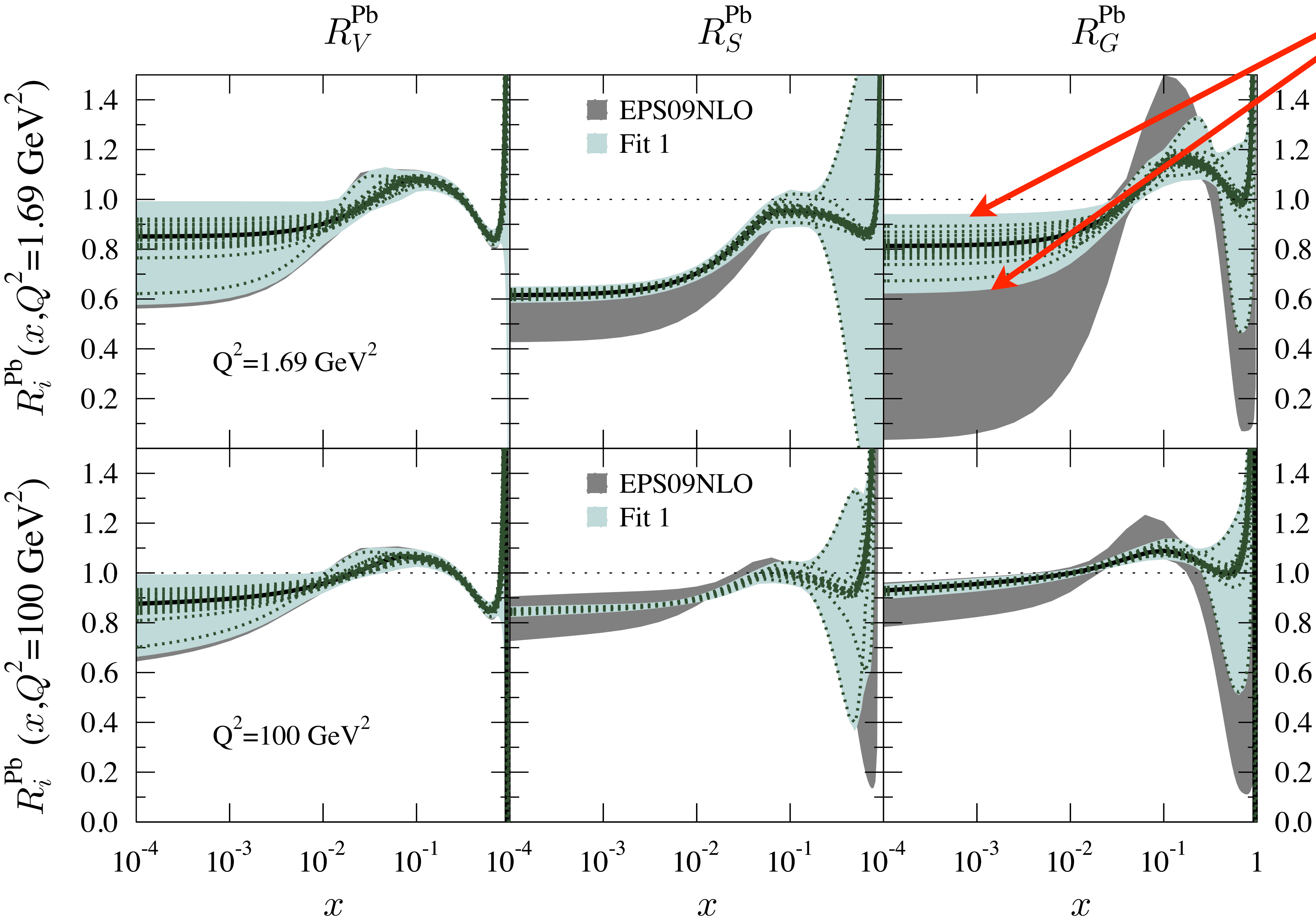
LHeC potential: precisely measure partonic structure of the nuclei at small x.



Nuclear structure functions measured with very high accuracy.

Nuclear parton distributions at LHeC

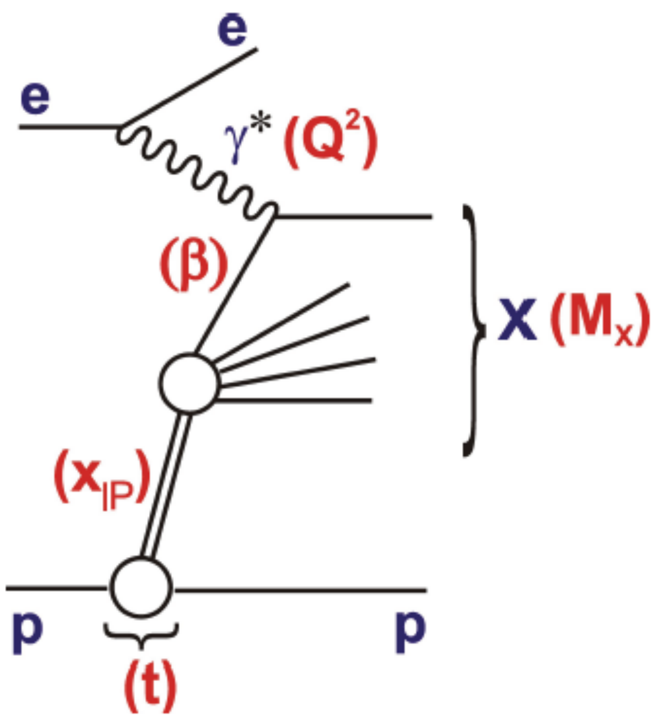
Global NLO fit with the LHeC pseudodata included



Much smaller uncertainties.

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

Diffraction



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

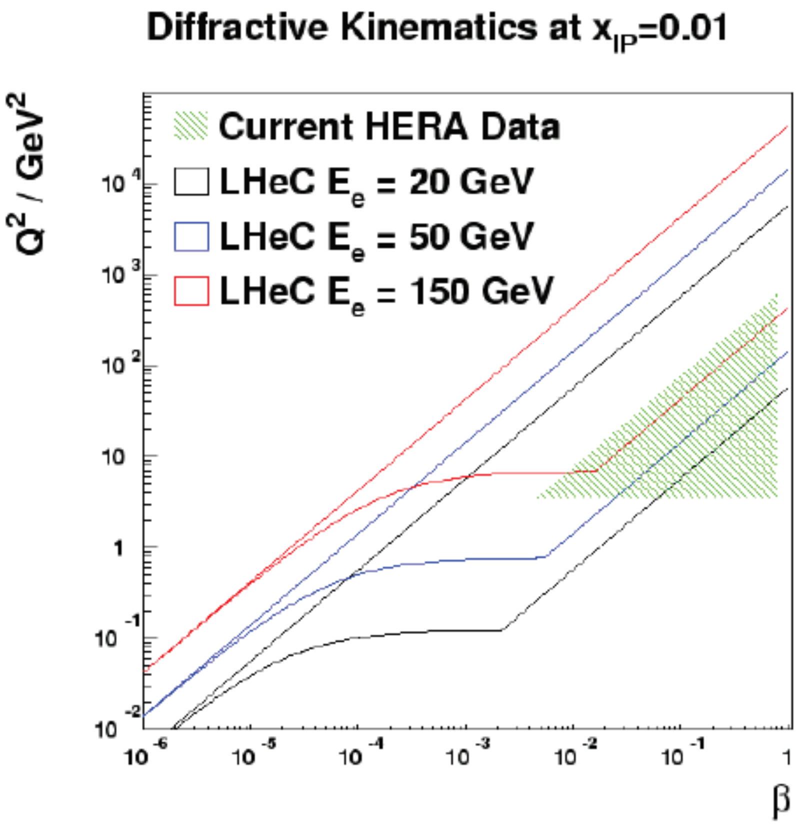
momentum fraction of the Pomeron w.r.t hadron

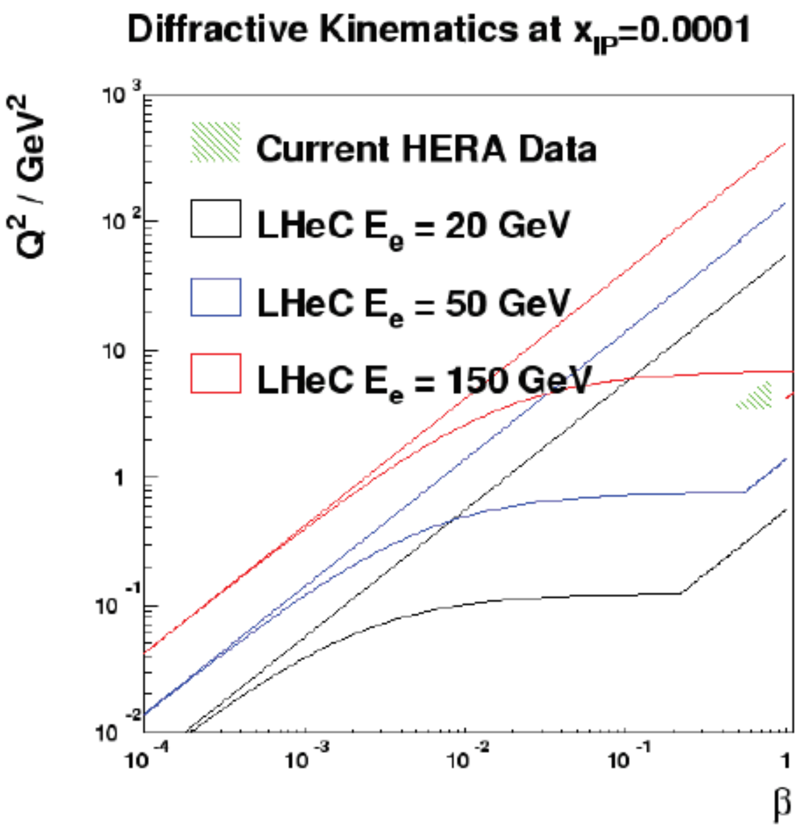
$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

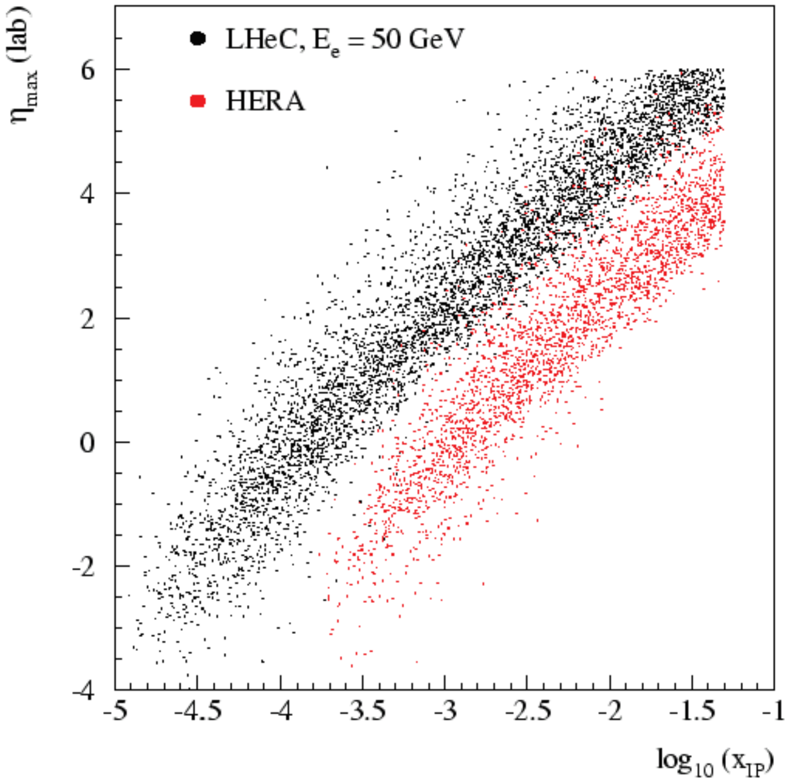
$$x_{Bj} = x_{IP}\beta$$

Methods: Leading proton tagging, large rapidity gap selection

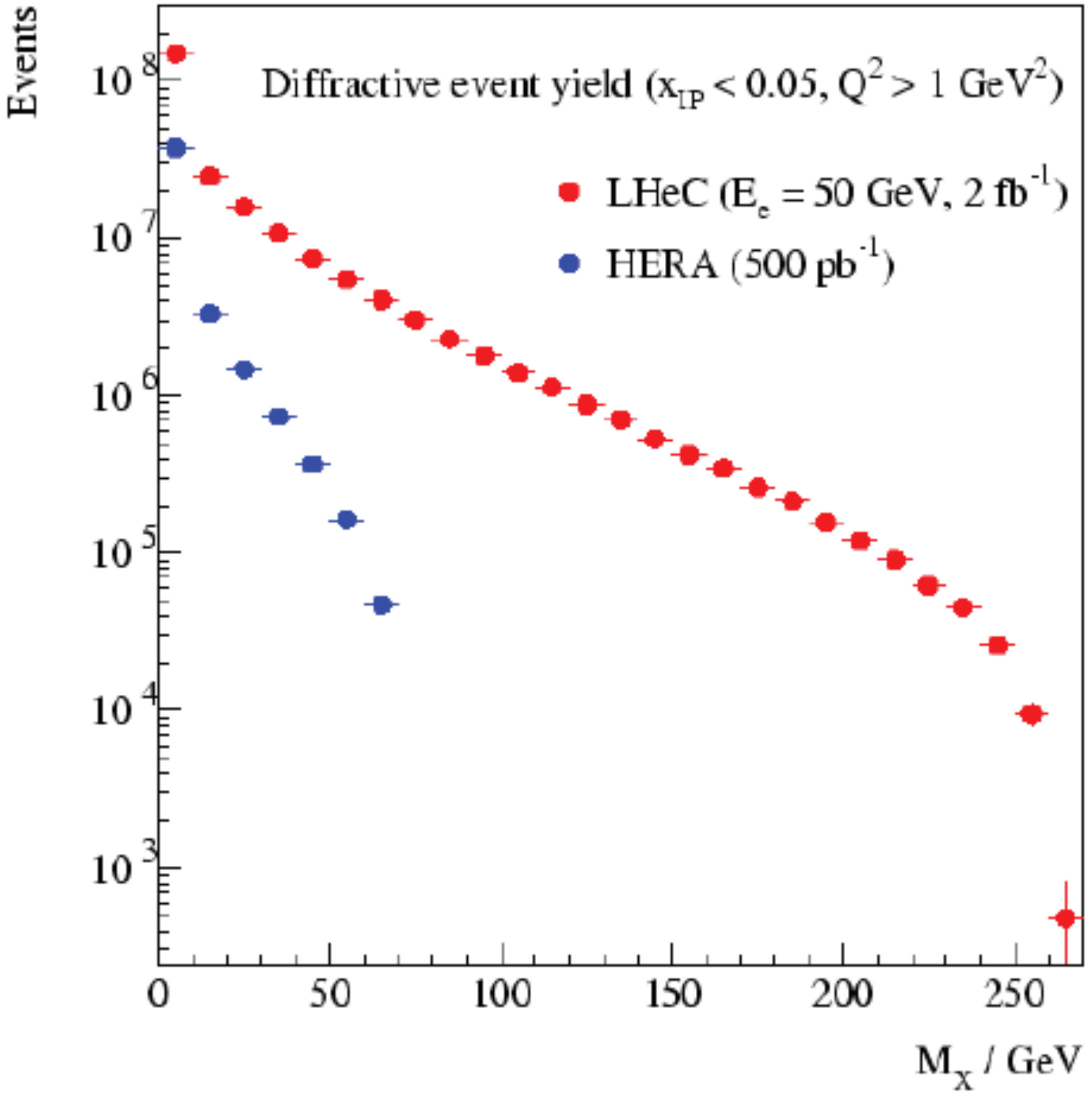

Diffractive Kinematics at x_{IP}=0.01

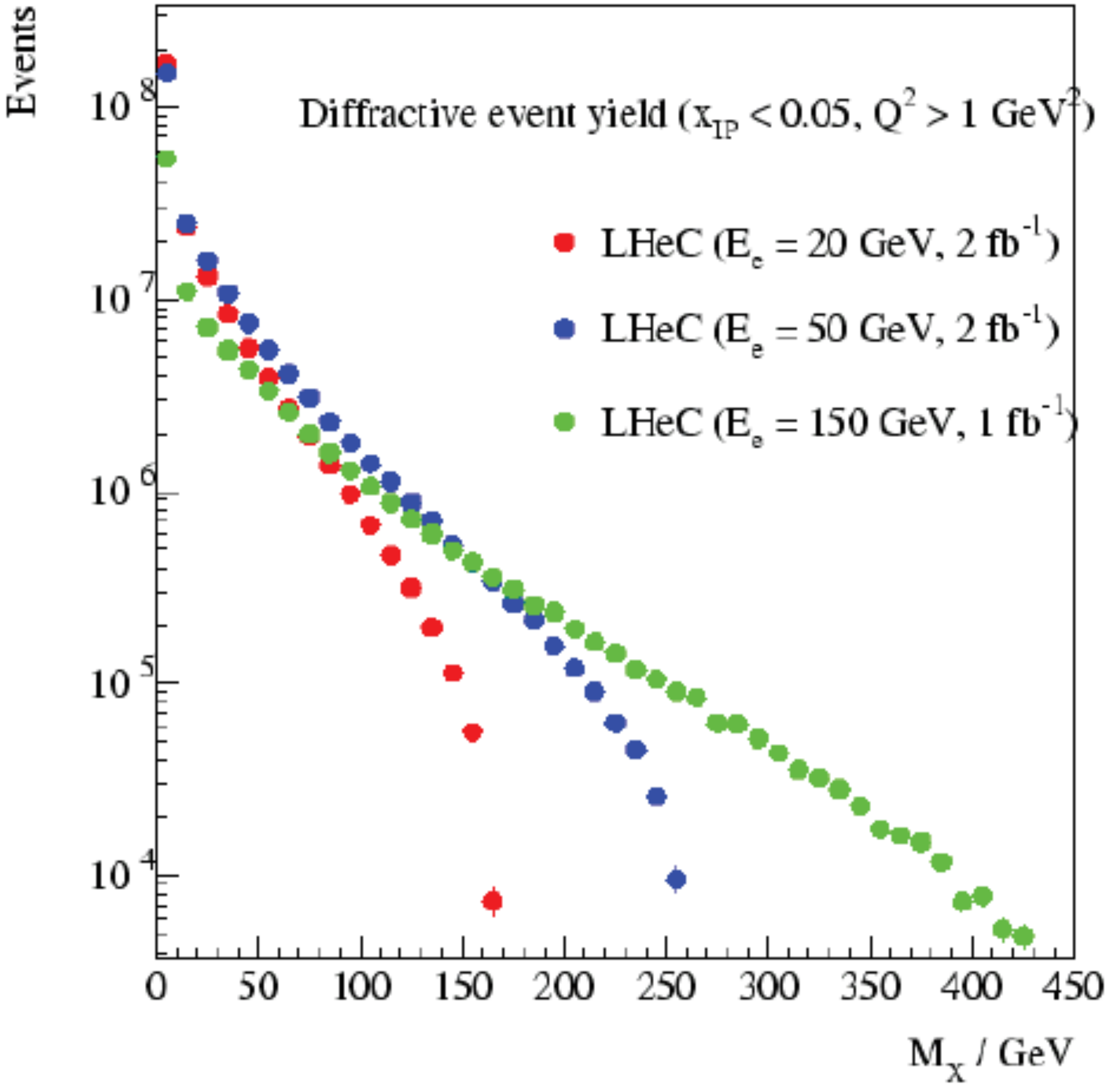

Diffractive Kinematics at x_{IP}=0.0001

η_{max} from LRG selection ...



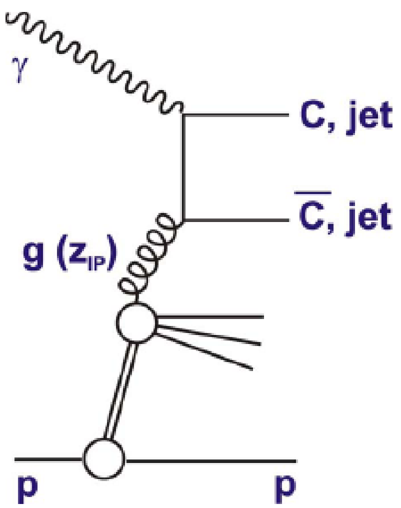
Diffractive mass distribution





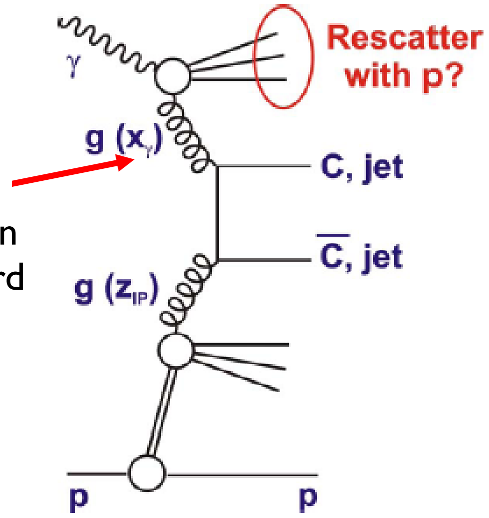
New domain of diffractive masses.
M_X can include W/Z/beauty

Diffractive dijets



direct

fraction of photon momentum in hard subprocess



resolved

Factorization in diffraction breaks down at hadron collider.

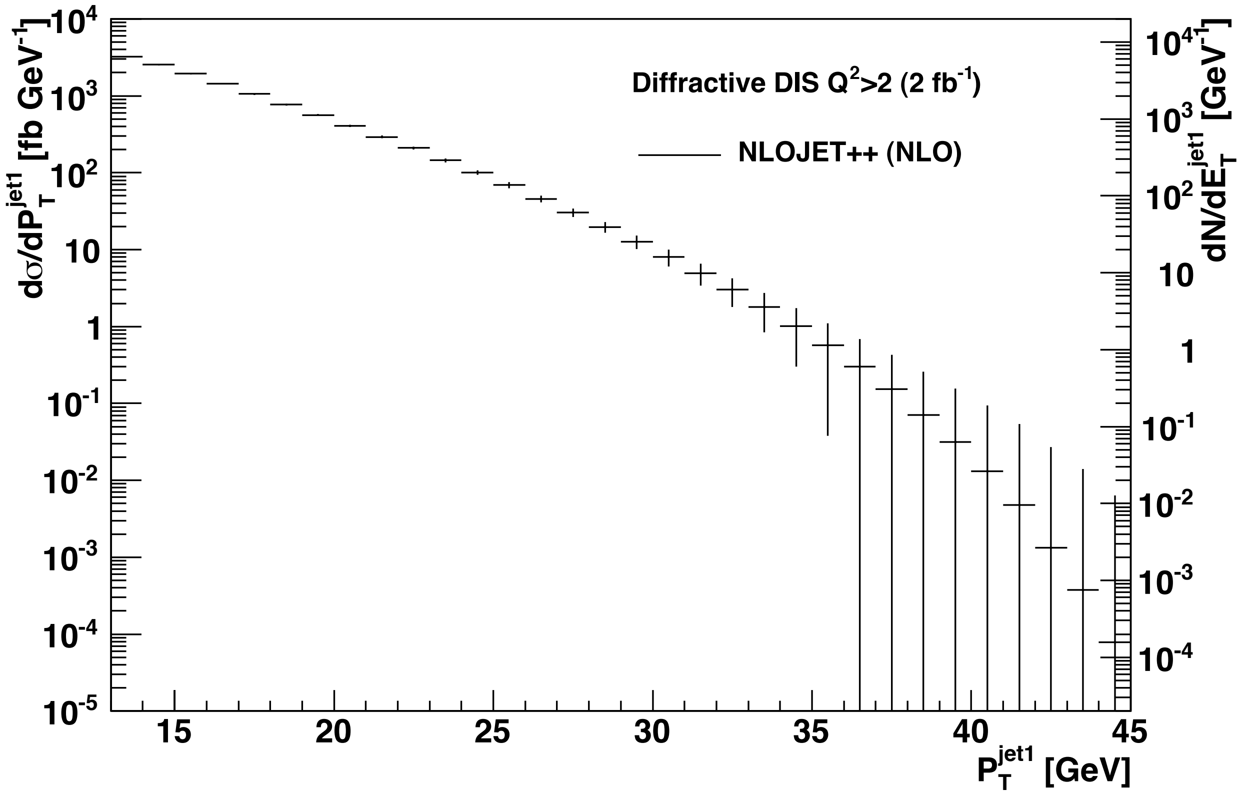
Is factorization valid for dijet production?

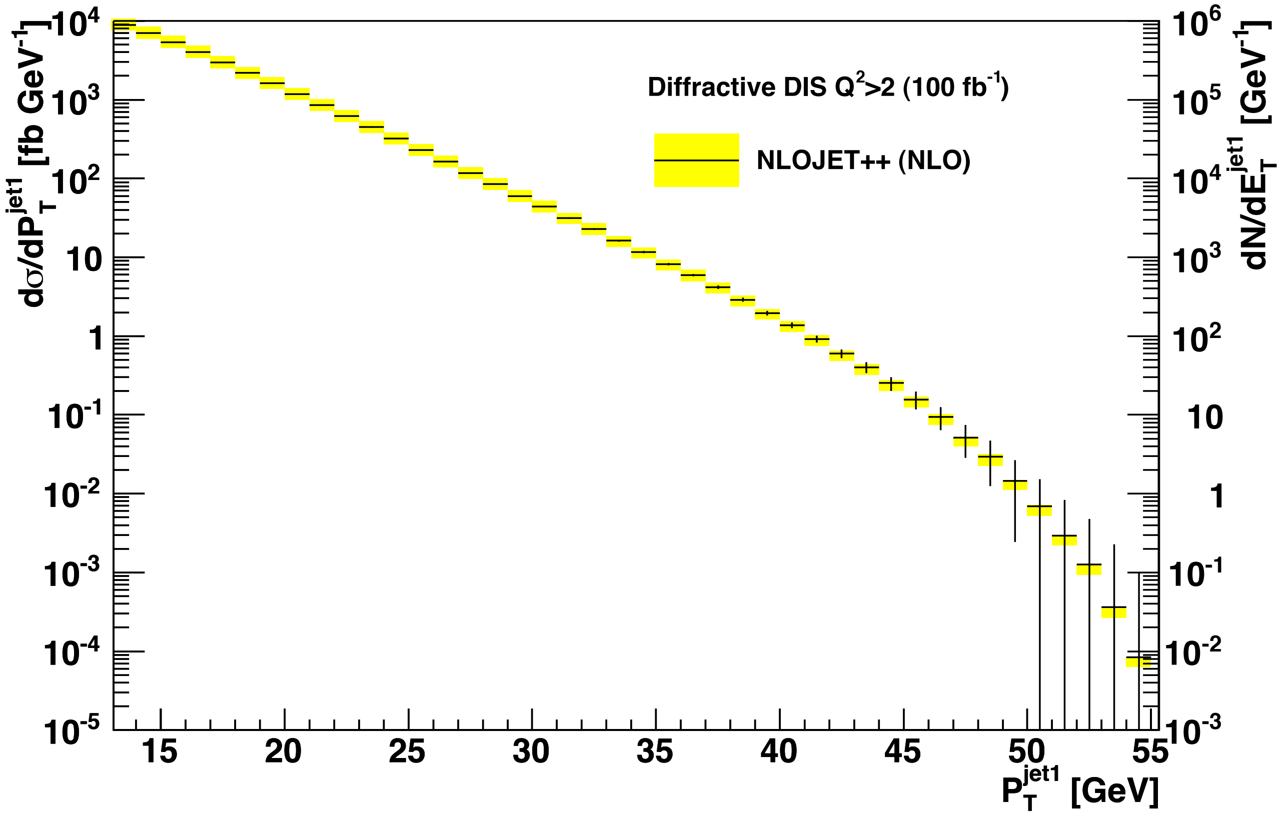
$0.2 < y < 0.4$

$x_{IP} < 0.01$

scale uncertainties $0.5\mu, 2\mu$

$0.1 < y < 0.7$

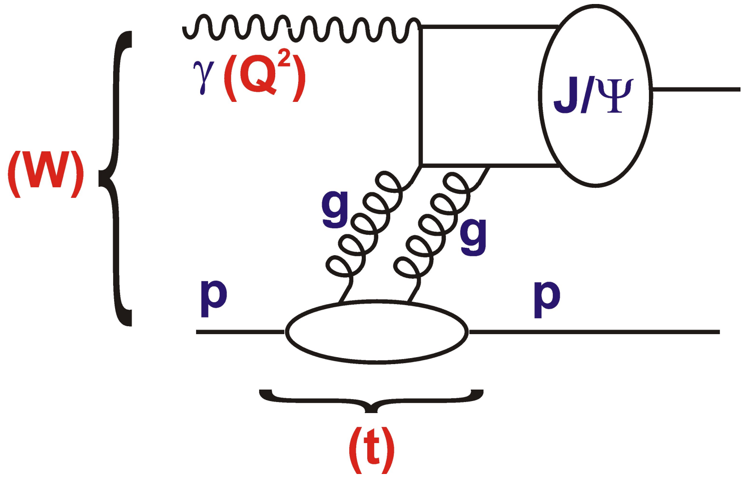


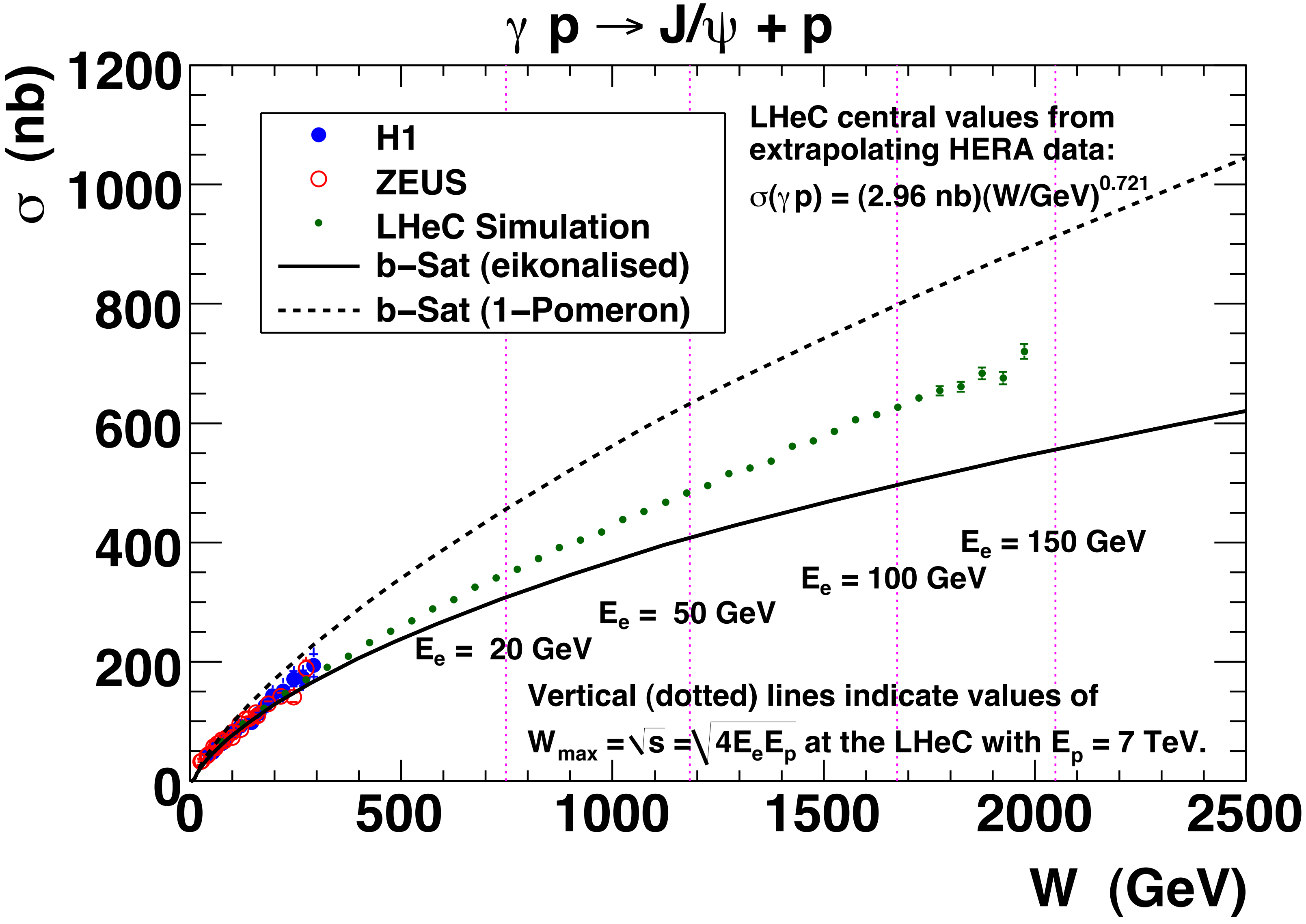


Exclusive diffraction: predictions

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

- 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.

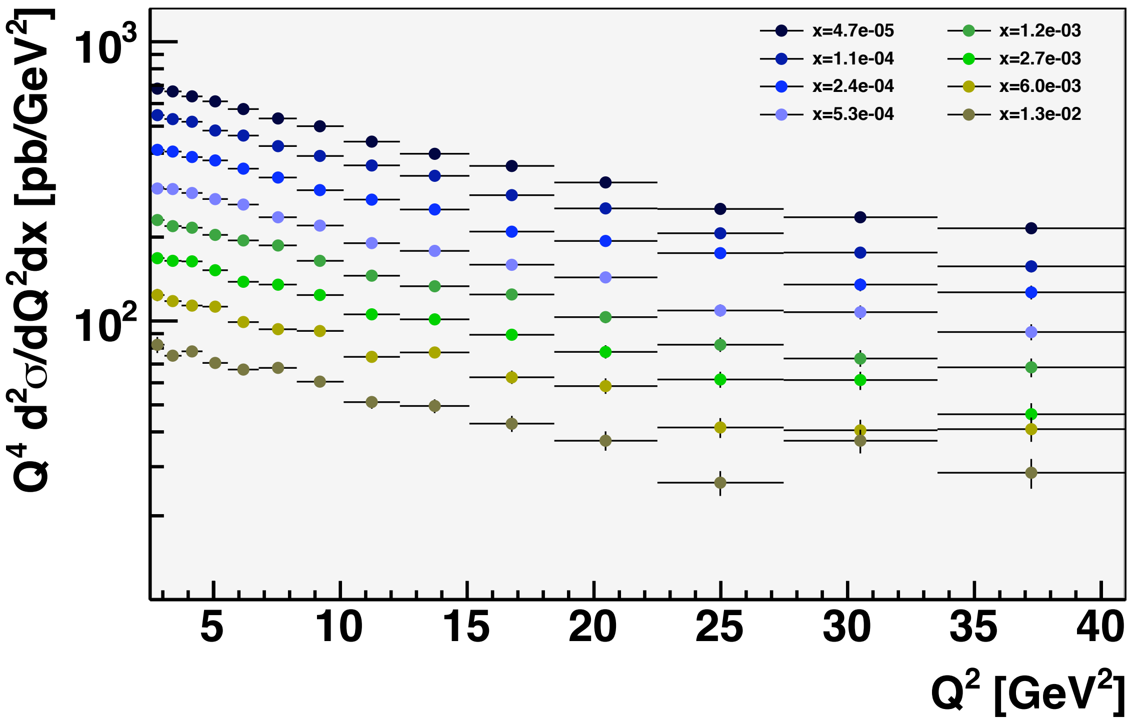
Different W behavior depending whether saturation is included or not.

Simulated data are from extrapolated fit to HERA data

LHeC can distinguish between the different scenarios.

Exclusive processes: DVCS

MILOU generator using Frankfurt, Freund, Strikman model.



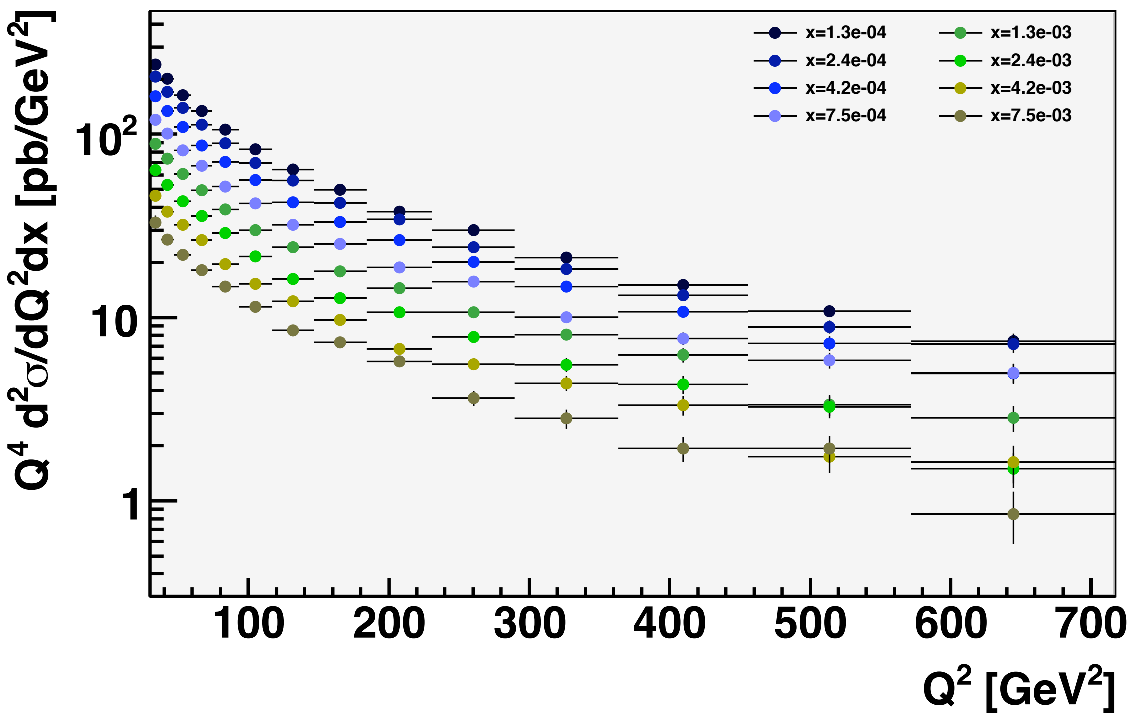
$$\mathcal{L} = 1\ \mathrm{fb}^{-1}$$

$$\theta = 1^o$$

$$p_T^\gamma = 2\ \mathrm{GeV}$$

$$2.5 < Q^2 < 40\ \mathrm{GeV}^2$$

low x



$$\mathcal{L} = 100\ \mathrm{fb}^{-1}$$

$$\theta = 10^o$$

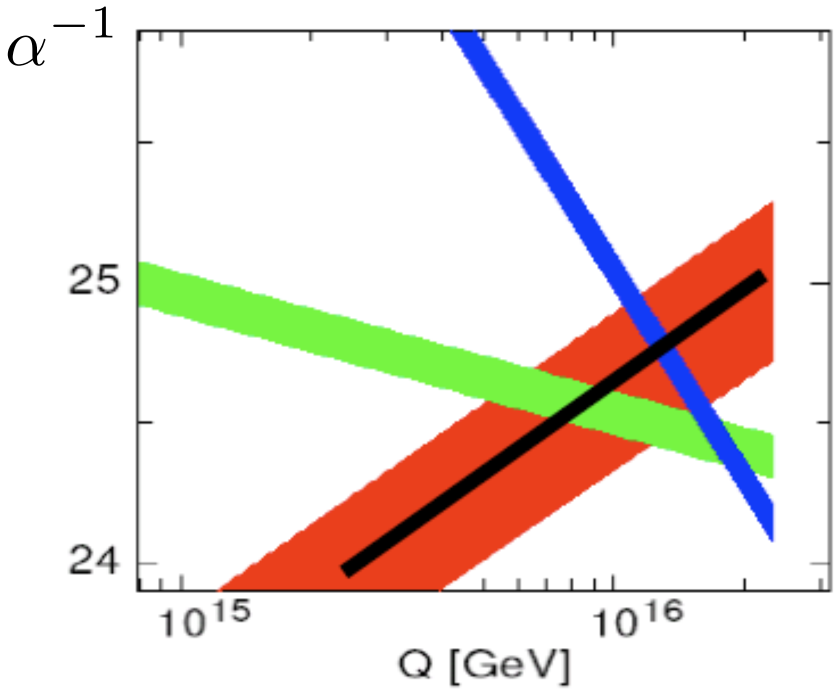
$$p_T^\gamma = 5\ \mathrm{GeV}$$

$$50 < Q^2 \simeq 500\ \mathrm{GeV}^2$$

large scales

Measurement of strong coupling

Unification of coupling constants?



case	cut [Q^2 in GeV^2]	α_S	±uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.12203	0.000995	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.11680	0.000180	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.11796	0.000199	0.17
LHeC only (14p)	$Q^2 > 20.$	0.11602	0.000292	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11769	0.000132	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.11831	0.000238	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.11839	0.000304	0.26

Strong coupling is least known of all couplings

Grand unification predictions suffer from uncertainty

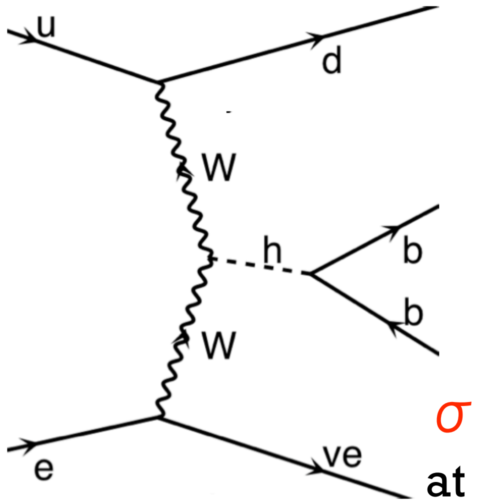
LHeC: per mille accuracy

Verify at large values of photon virtuality, smaller influence of HT effects

Higgs at the LHeC

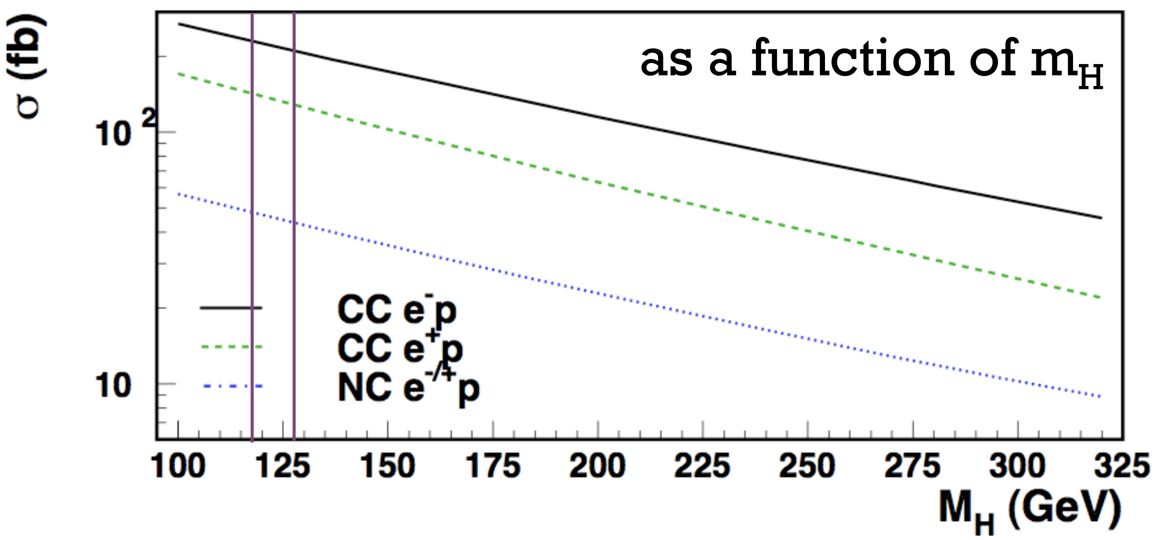
Signal

CC: H → $b\bar{b}$ (BR ~ 0.7 at M_H=120GeV)



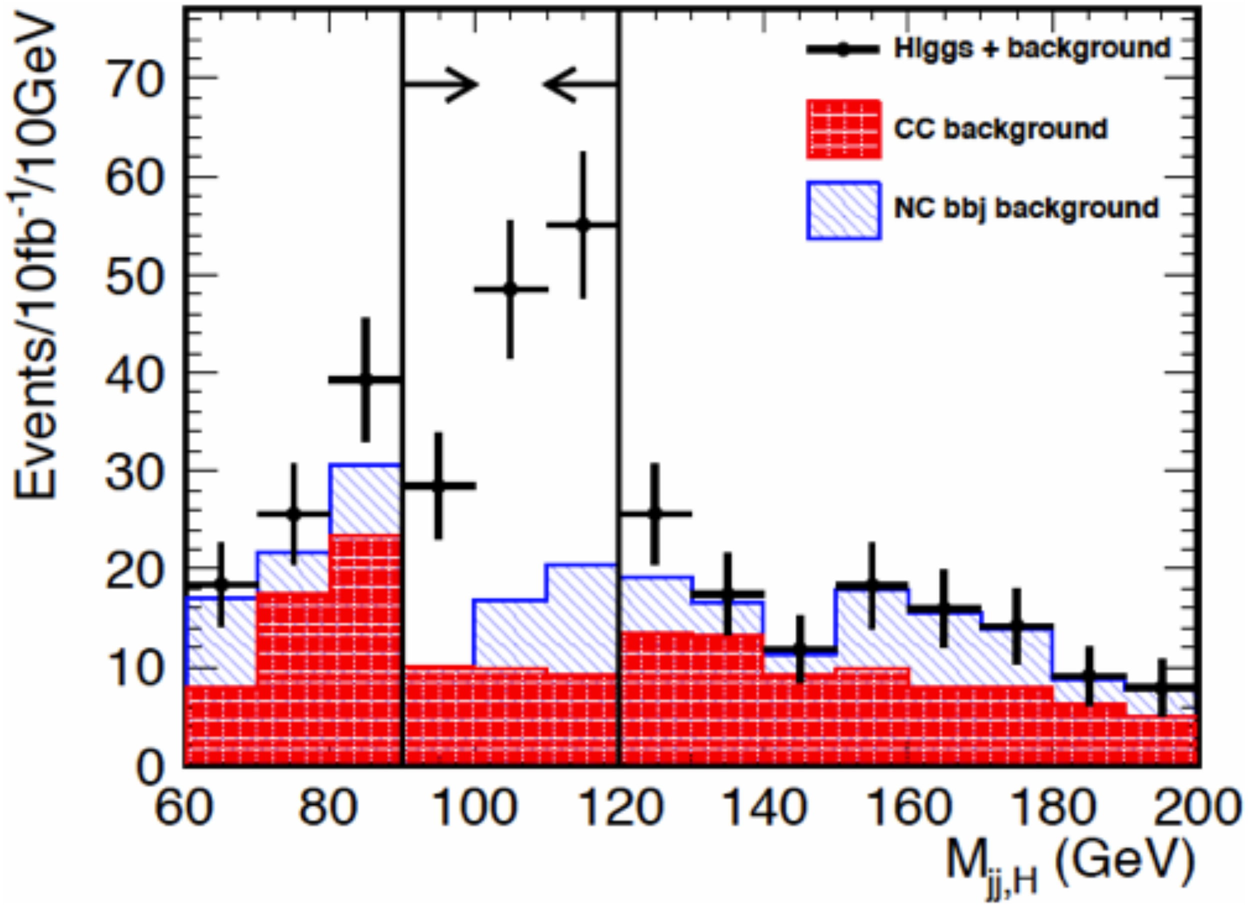
σ ~ 0.16 pb
at √s=2.05TeV

Higgs production cross-section
at √s = 1.98TeV (E_e=140GeV, E_p=7TeV)



CC Higgs production cross-section
(M_H = 120 GeV)

Electron beam energy	50 GeV	100 GeV	150 GeV
cross-section (fb)	81	165	239



Higs can be studied at the LHeC.
High rates in CC interactions.
bbar channel cleaner at the LHeC.
Necessary to confirm the SM Higgs.

Higgs at the LHeC

Talk by Masaki Ishitsuka at Chavannes-de-Bogis

Beam energy:	
Electron beam	150 GeV
Proton beam	7 TeV
SM Higgs mass	120 GeV
Luminosity	$10\ \text{fb}^{-1}$

Signal and background cut flow

	H→bb	**CC DIS**	**NC bbj**	**S/N**	**$S/\sqrt{N}$**
NC rejection	816	123000	4630	6.38×10^{-3}	2.28
+ b-tag requirement **+ Higgs invariant mass**	178	1620	179	9.92×10^{-2}	4.21
All cuts	84.6	29.1	18.3	1.79	12.3

Beam energy:	
Electron beam	150 GeV ⇒ 60 GeV
Proton beam	7 TeV
SM Higgs mass	120 GeV
Luminosity	$10\ \text{fb}^{-1} \Rightarrow 100\ \text{fb}^{-1}$

	E_e = 150 GeV ($10\ \text{fb}^{-1}$)	**E_e = 60 GeV ($100\ \text{fb}^{-1}$)**
H → bb signal	84.6	248
S/N	1.79	1.05
$S/\sqrt{N}$	12.3	16.1

- We can explore other channels
  - NC Higgs production in ZZ fusion
  - Other light Higgs decay channels

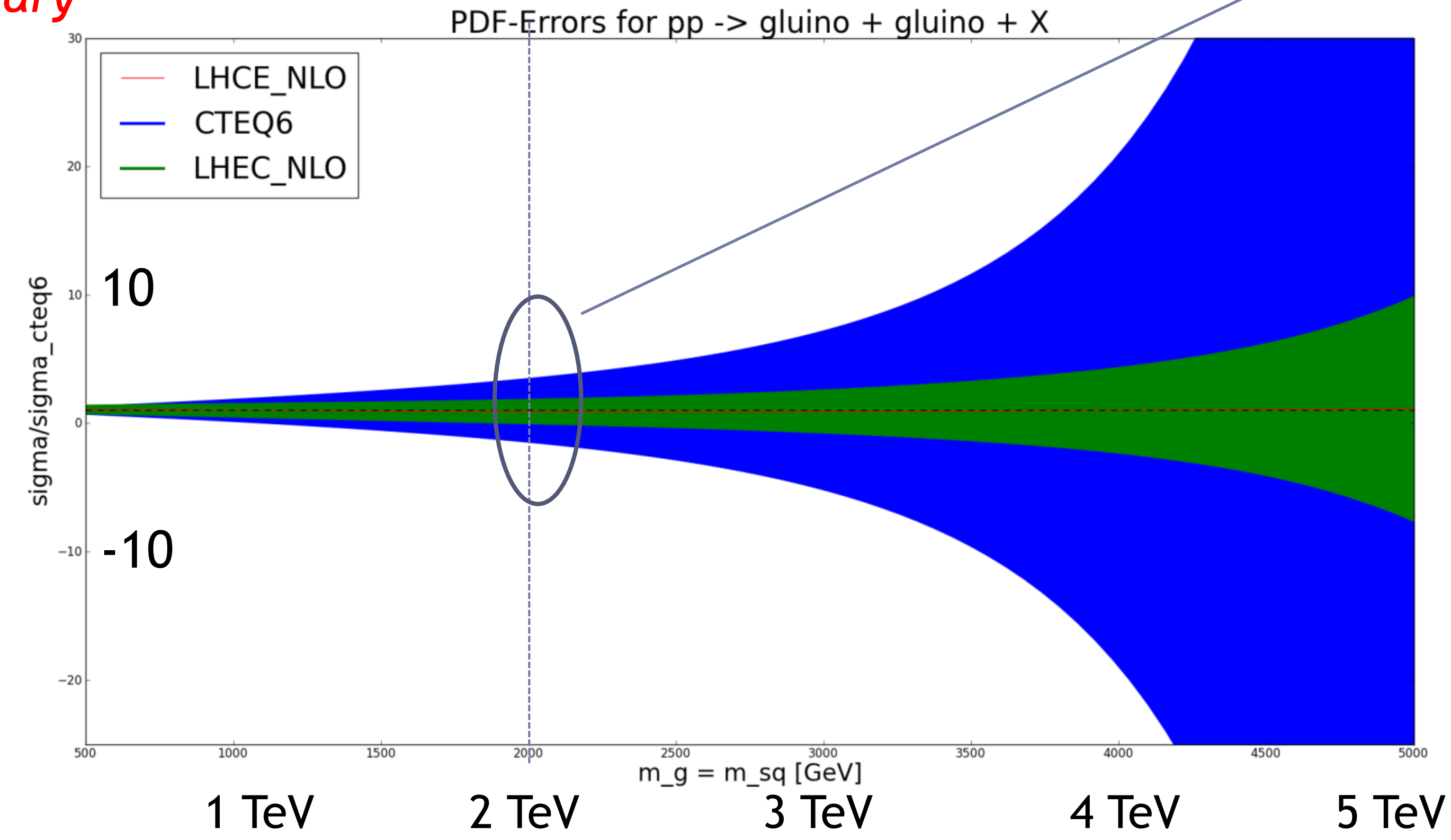
Monica d’Onofrio talk at Chavannes-de-Bogis

Impact of LHeC on searches for New Physics

- M.Kramer and R.Klees working on impact of improved PDF fits on theoretical predictions for SUSY process:
  - Example: gl-gl production (assuming m_gl = m_sq)
  - without(blue, CTEQ6) and with (green) LHeC PDF

Improve of
factor of 2-3 @ 2 TeV
factor of 10 at 3.5 TeV

preliminary



Precise determination of the PDFs at higher scales absolutely necessary for searches of New Physics.

Summary

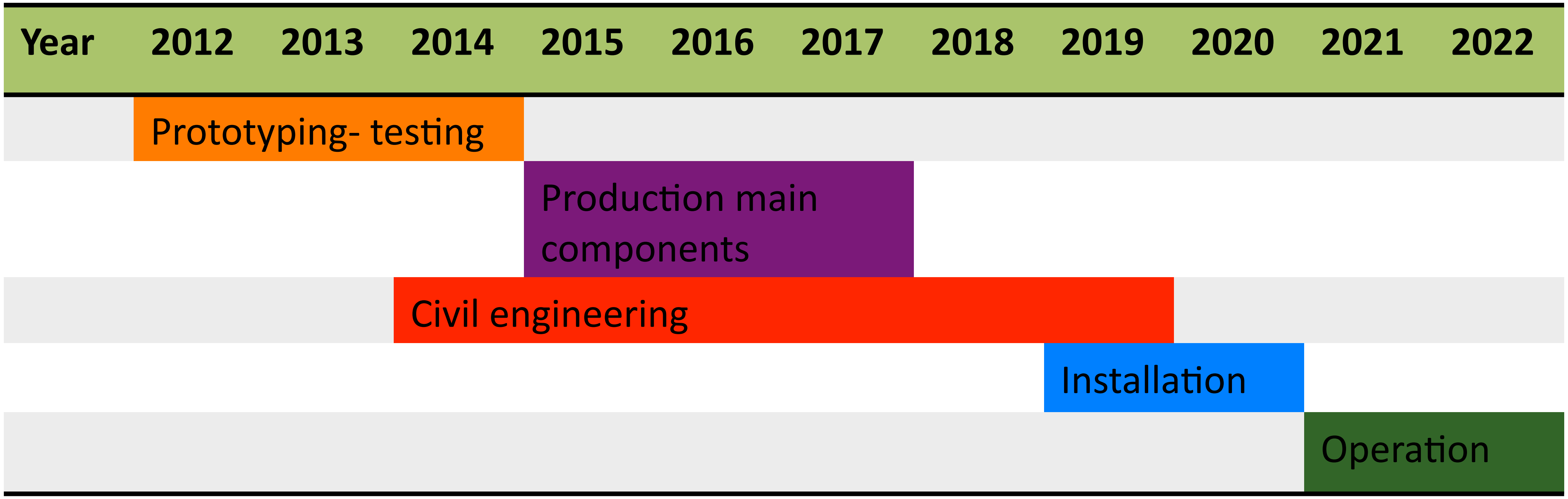
- LHeC has an unprecedented potential as a high luminosity, high energy DIS machine. Offering a unique window for small x physics and high parton density regime.
- Precision DIS measurements: constraining and unfolding PDFs, heavy flavor physics, precision strong coupling , precision electroweak measurements.
- Wide range of possible BSM searches. Essential for precision evaluation of the cross sections for new particles.
- eA at high energy essential to untangle the complex nuclear structure at low x and constrain the initial conditions for AA at the LHC. Complementary to pp/pA/AA.
- CDR for the project is complete: arXiv:1206.2913
- Next steps in the near future:
  - Reorganization of the working groups. Forming a collaboration.
  - First steps towards Technical Design Report.

http://cern.ch/lhec

Backup

LHeC Draft Timeline

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



Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Prototyping- testing	■	■								
				Production main components	■	■					
			Civil engineering	■	■	■	■	■			
								Installation	■		
										Operation	■

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]

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
...

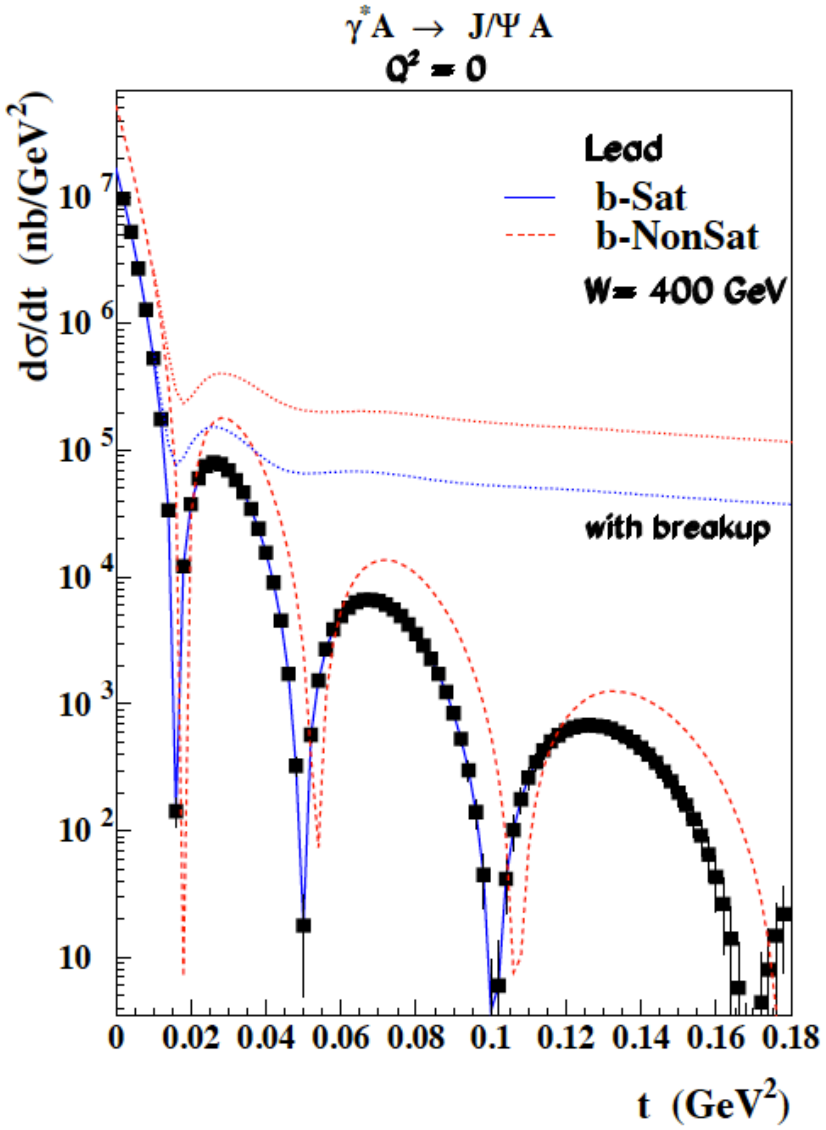
Small x and high parton densities

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

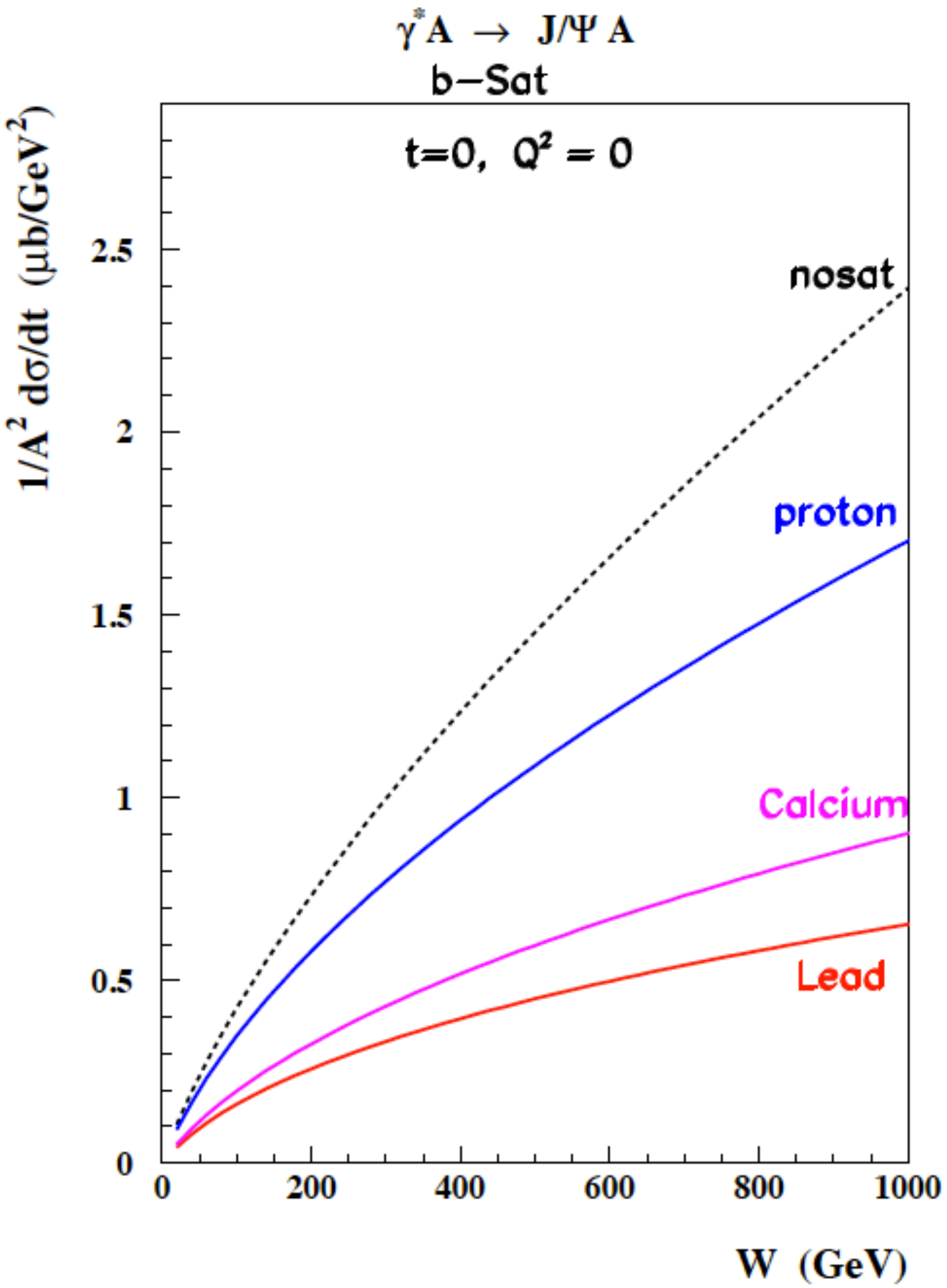
All the results shown are from the CDR draft or have been shown in the workshop at Chavannes-de-Bogis

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.

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

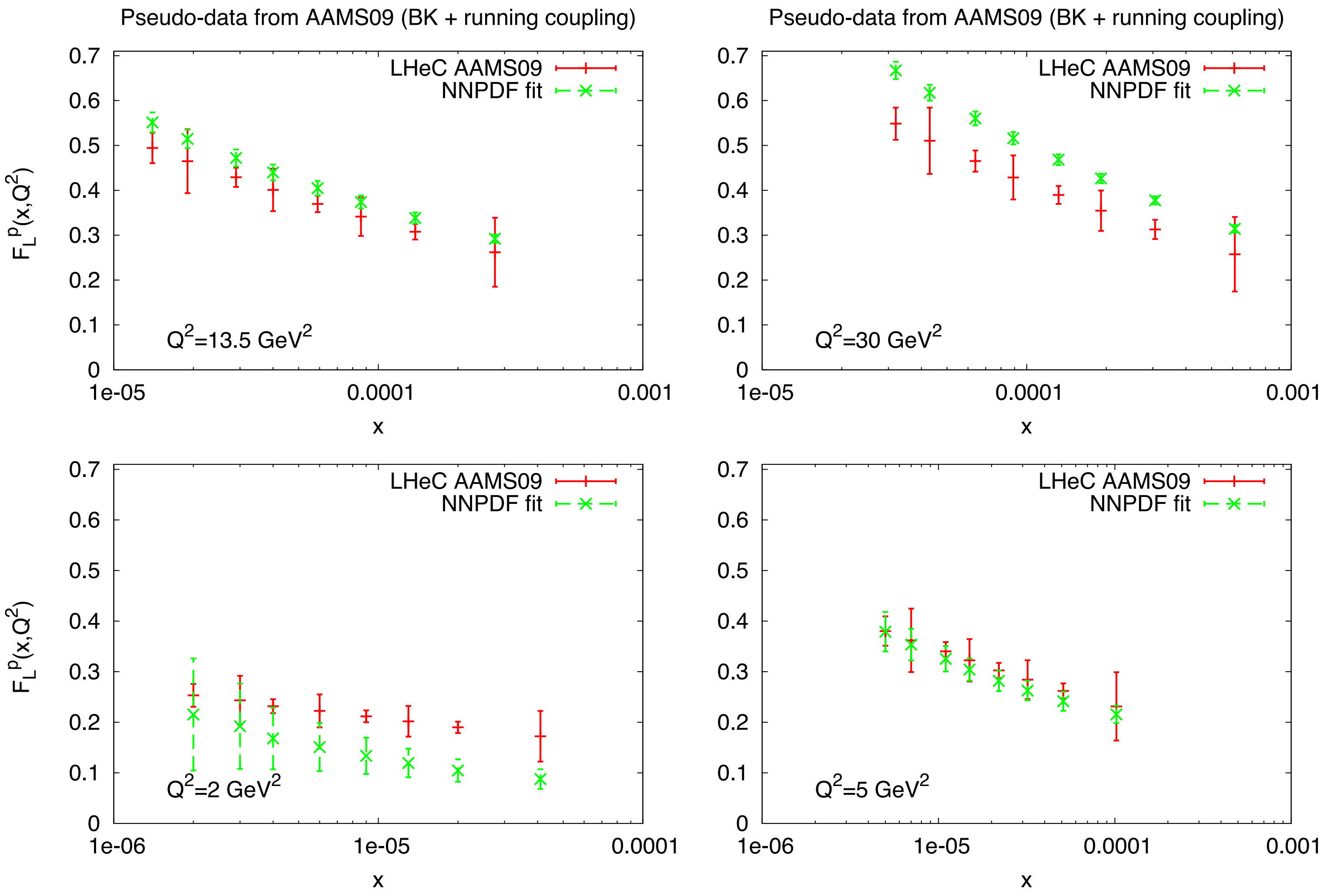
Magnets
Neil Marx, Martin Wilson

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.

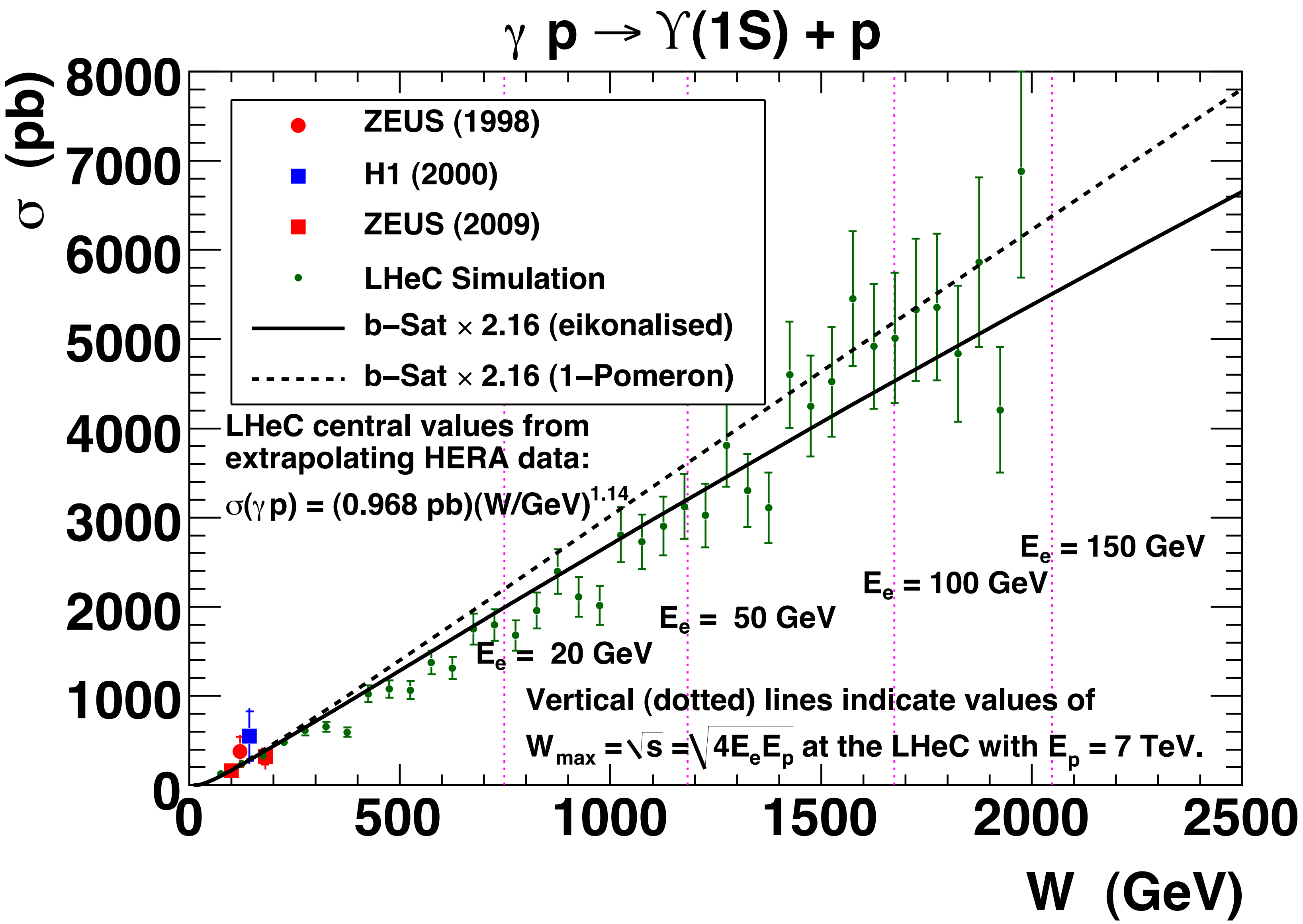


Albacete,Rojo

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

Exclusive diffraction: predictions

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



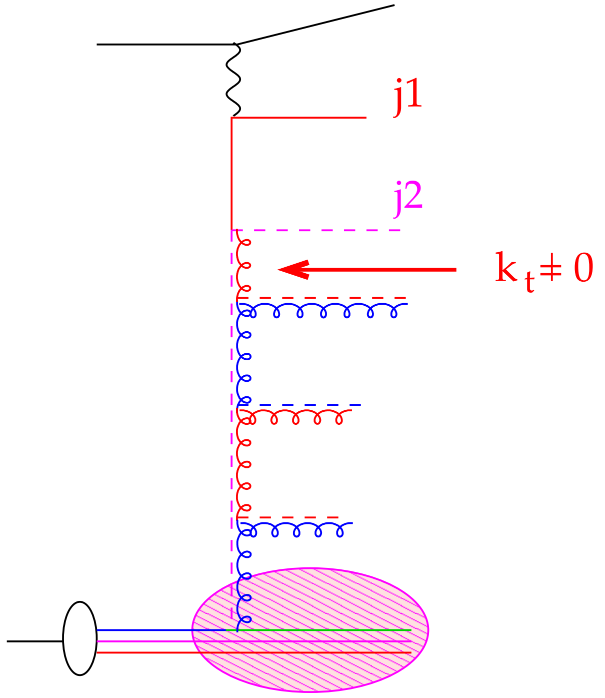
Similar analysis for heavier states.

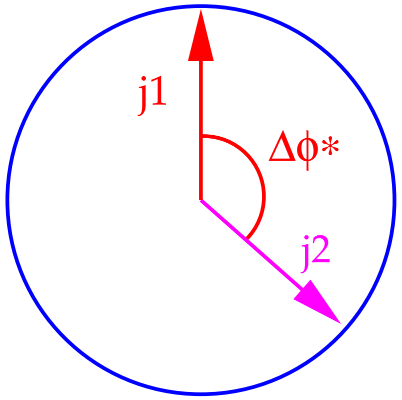
Smaller sensitivity to the saturation effects.

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





$\Delta\phi^* < 120^{\circ}$

- 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).

$-1 < \eta_{\rm jet} < 2.5$

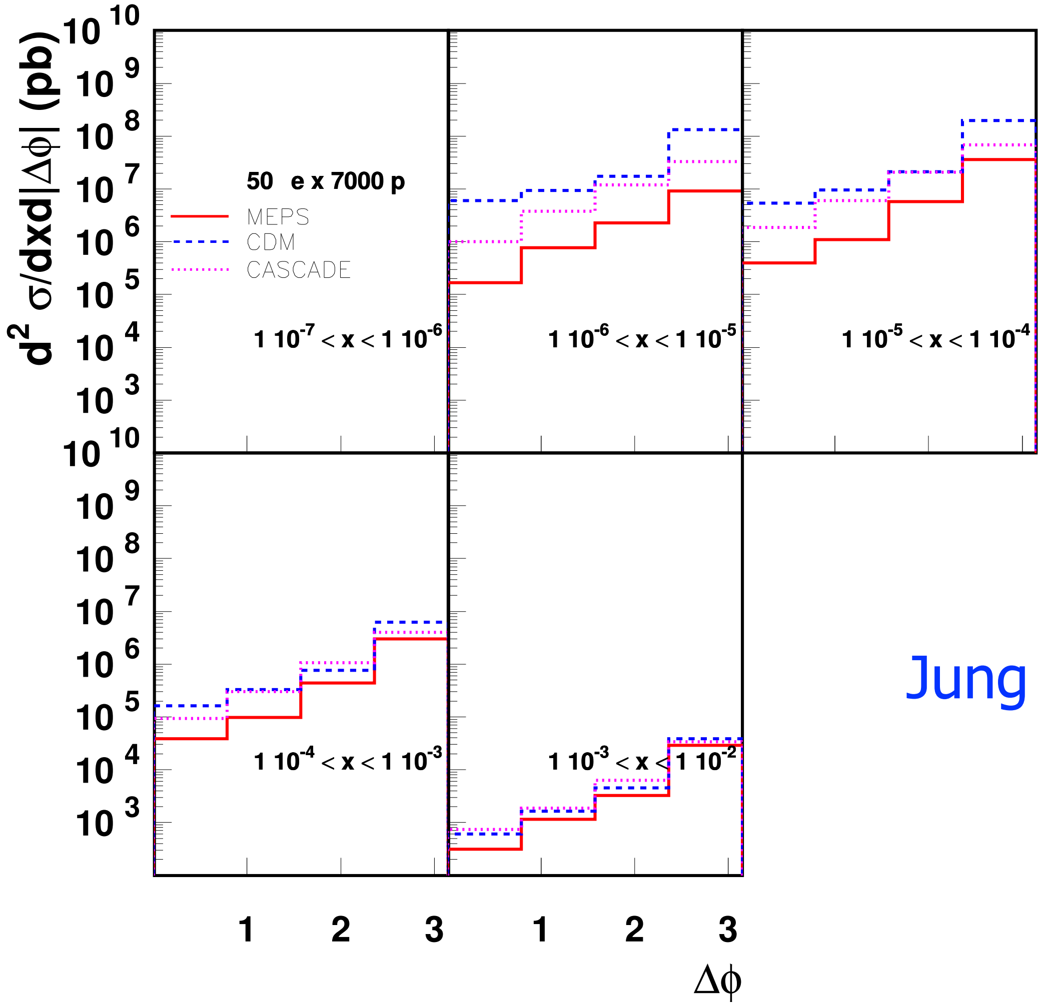
$0.1 < y < 0.6$

$E_{1T} > 7$ GeV

$Q^2 > 5$ GeV^2

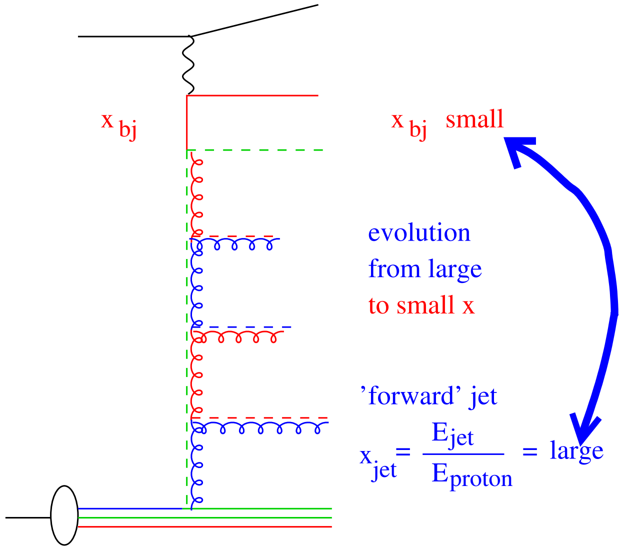
$E_{2T} > 5$ GeV

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



Jung

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

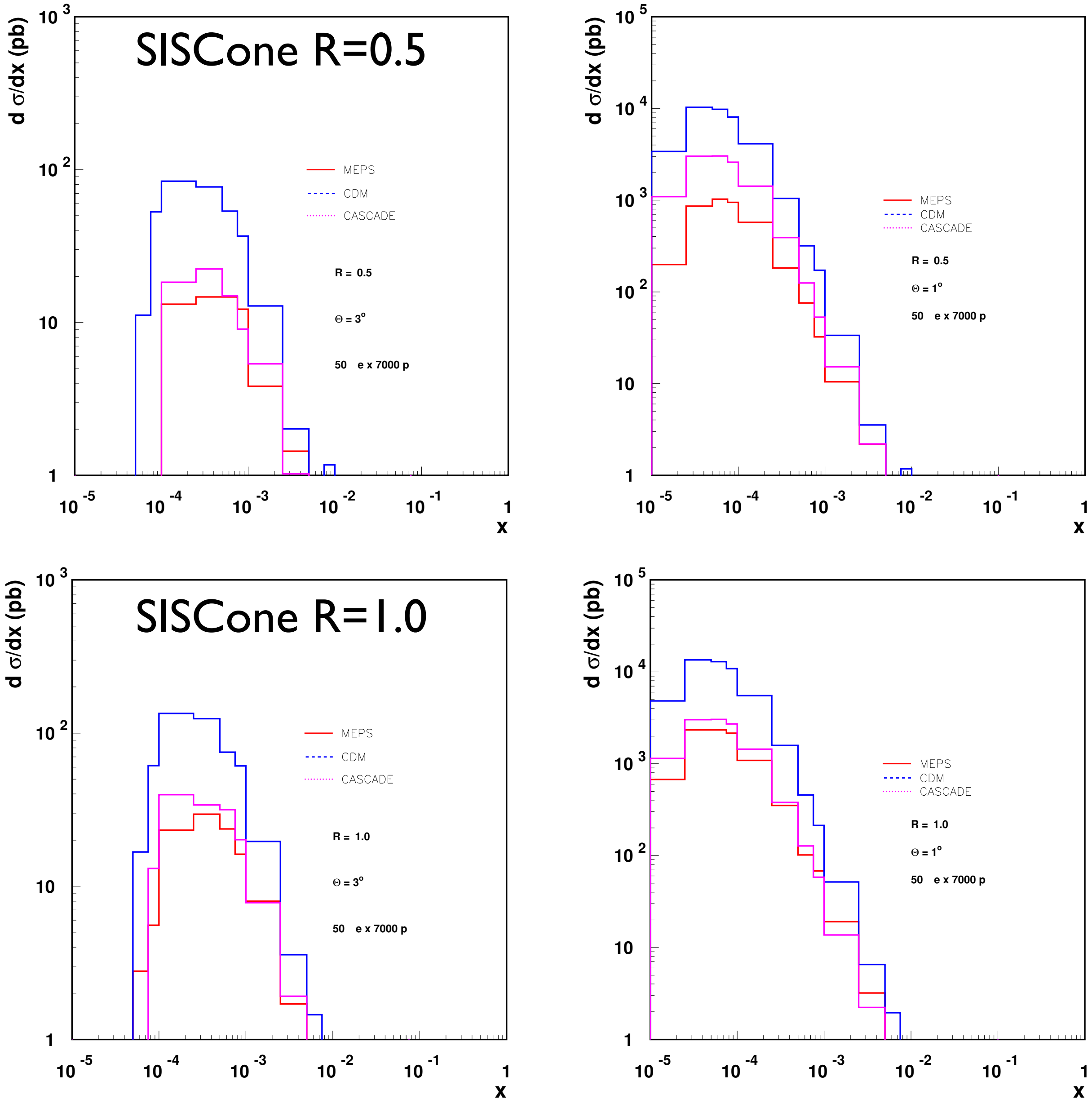
$\Theta > 3^o$ and $\Theta > 1^o$

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.


SISCone R=0.5

SISCone R=1.0

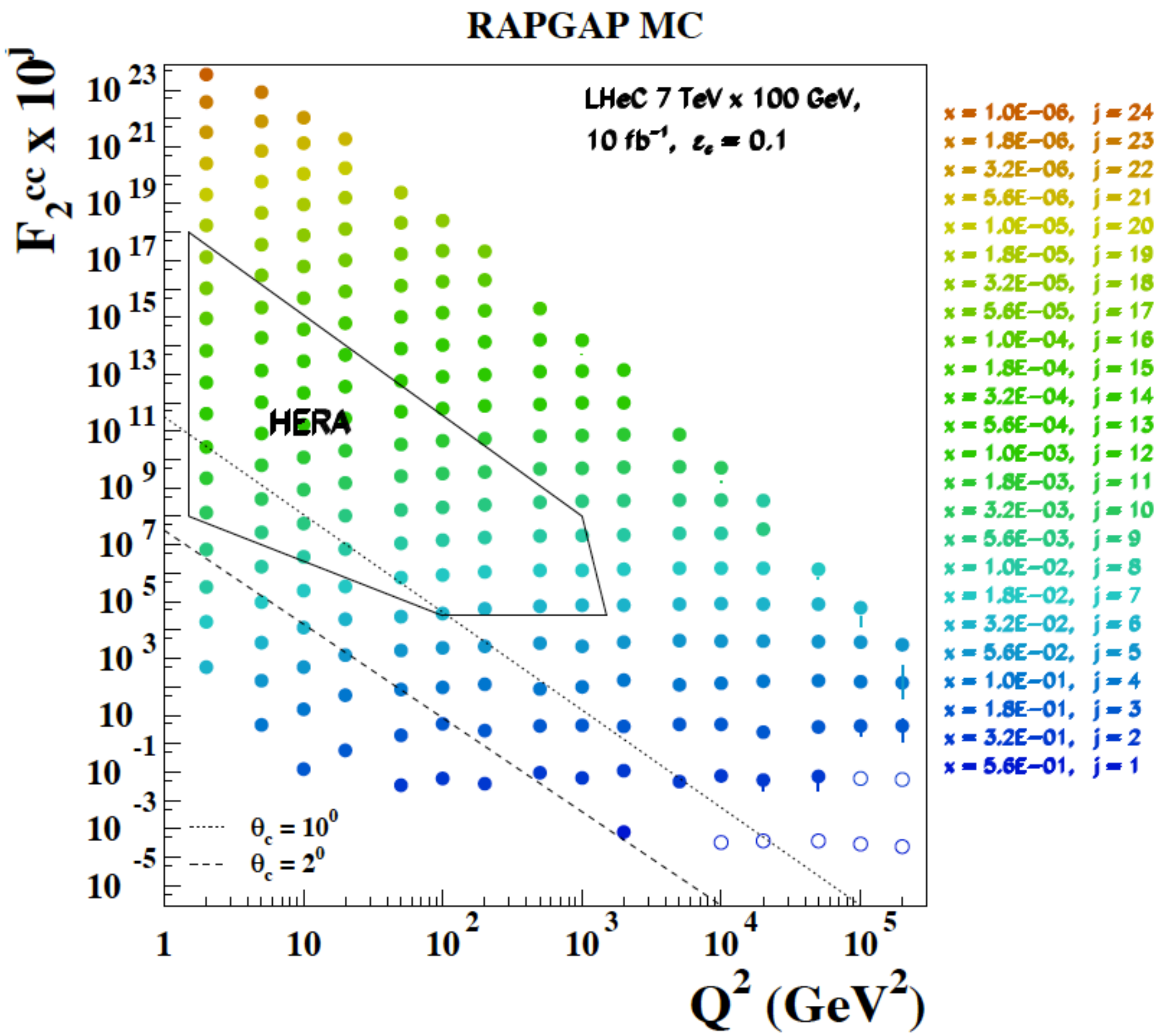
Jung

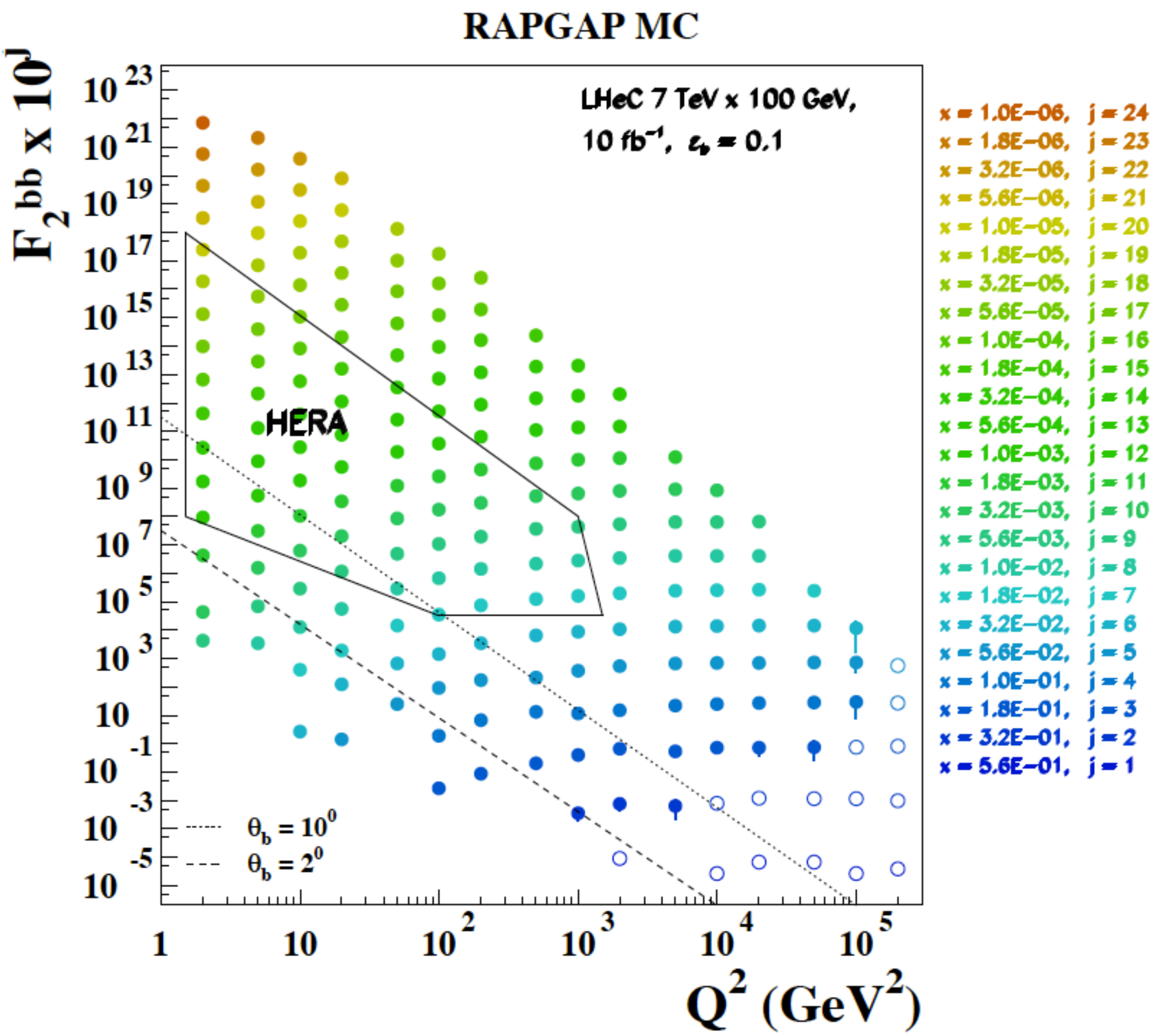
Heavy flavor in ep

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.