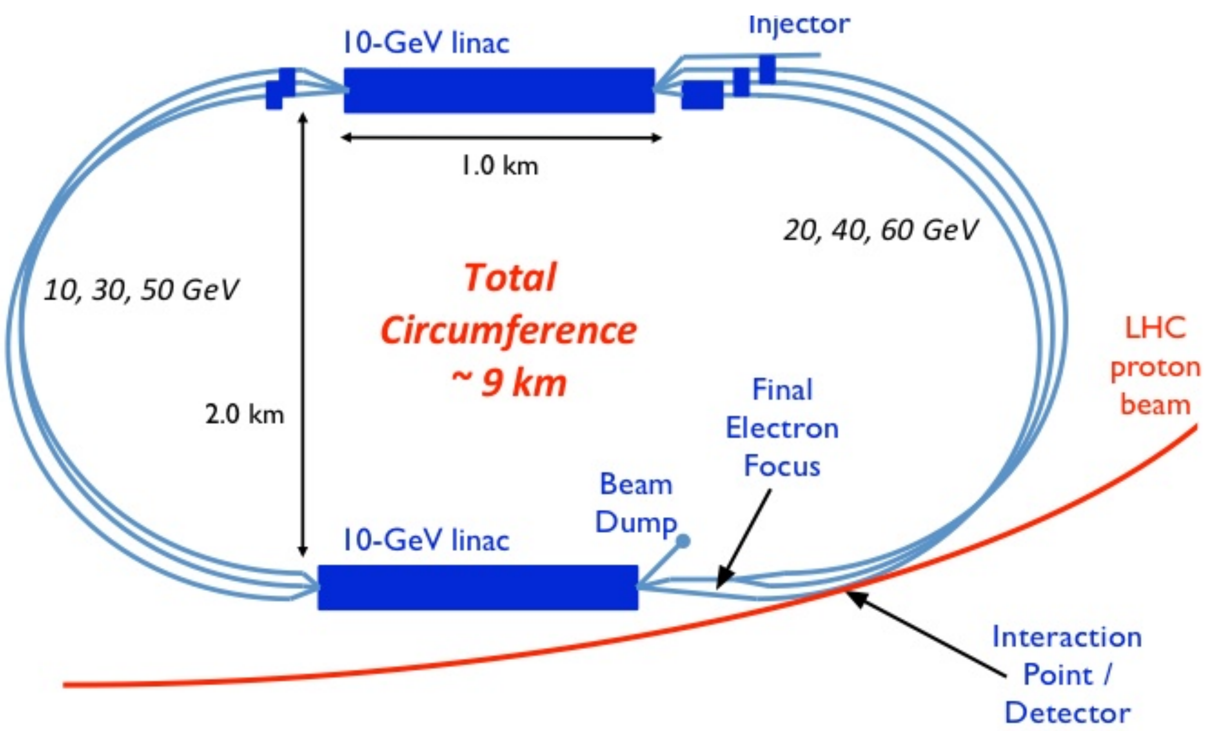
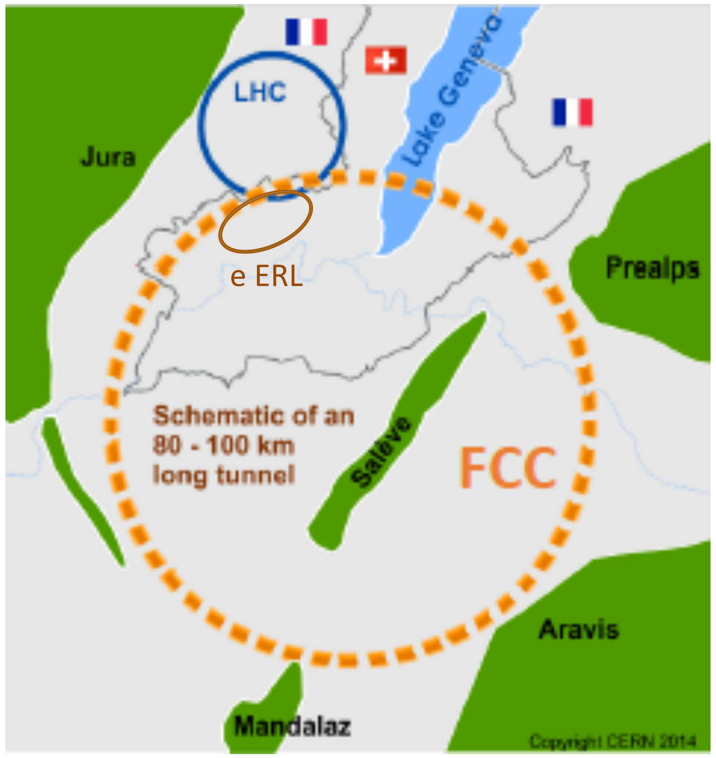




eA collisions at LHeC and nuclear parton densities

Anna Staśto

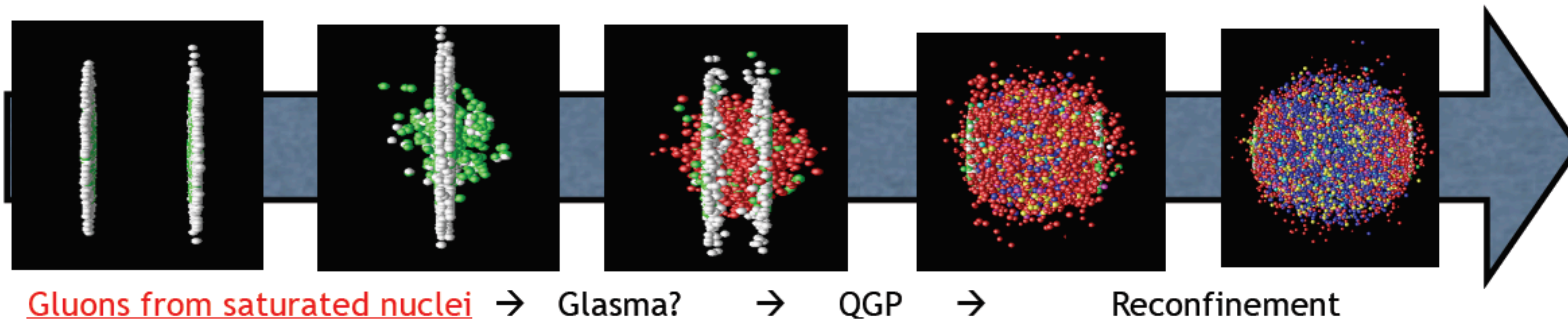
PennState
Eberly College of Science

Outline

- Motivation for eA Deep Inelastic Scattering in TeV range
- LHeC and FCC-eh kinematics
- Example of simulations for eA in TeV range:
  - Constraints on nuclear Parton Distribution Functions (nPDFs)
  - Heavy Flavors
  - Exclusive vector meson production
  - Inclusive diffraction

More talks/posters on LHeC/FCC-eh: Amanda Sarkar (Precision QCD), Uta Klein (Higgs), Christian Schwanenberger (top & EW), Max Klein (Detector R&D, poster), Anna Stasto(Diffraction ,poster)

Nuclear physics in eA complementarity to pA, AA at LHC



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.

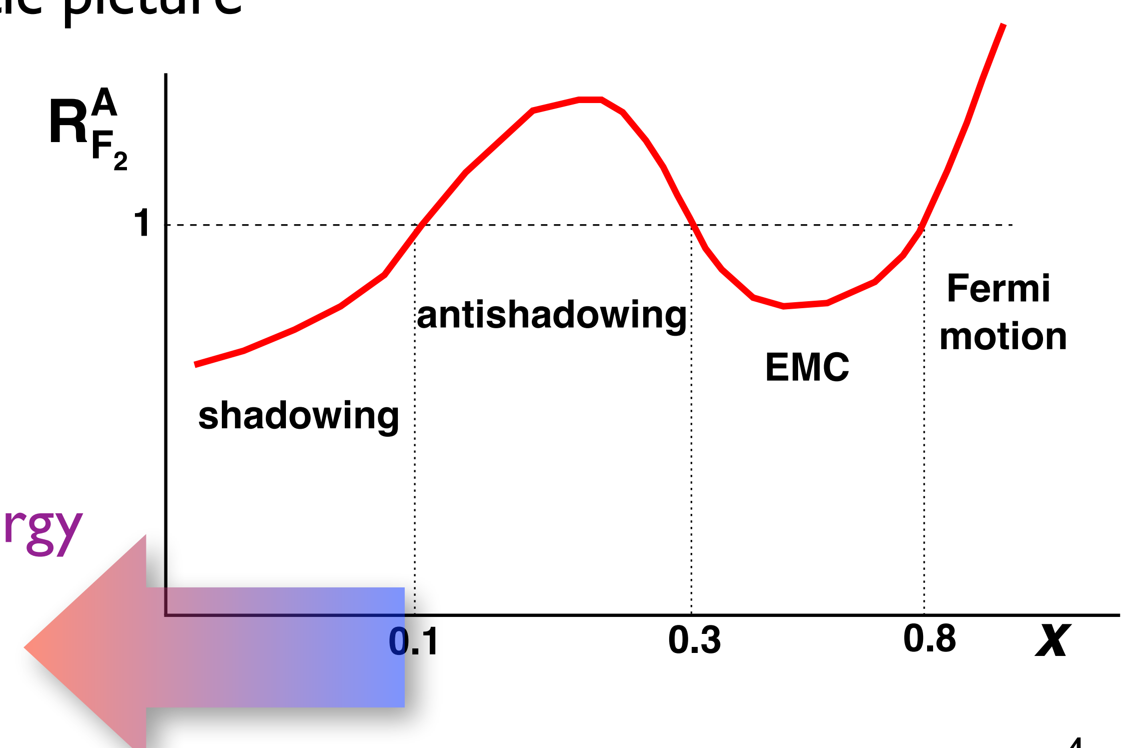
Nuclear structure

Deep Inelastic Scattering:
$$\frac{d^2\sigma^{ep\to eX}}{dxdQ^2} = \frac{4\pi\alpha_{e.m.}^2}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

Nuclear ratio for structure function
$$R_{F_2}^A(x,Q^2) = \frac{F_2^A(x,Q^2)}{A\,F_2^{\text{nucleon}}(x,Q^2)}$$

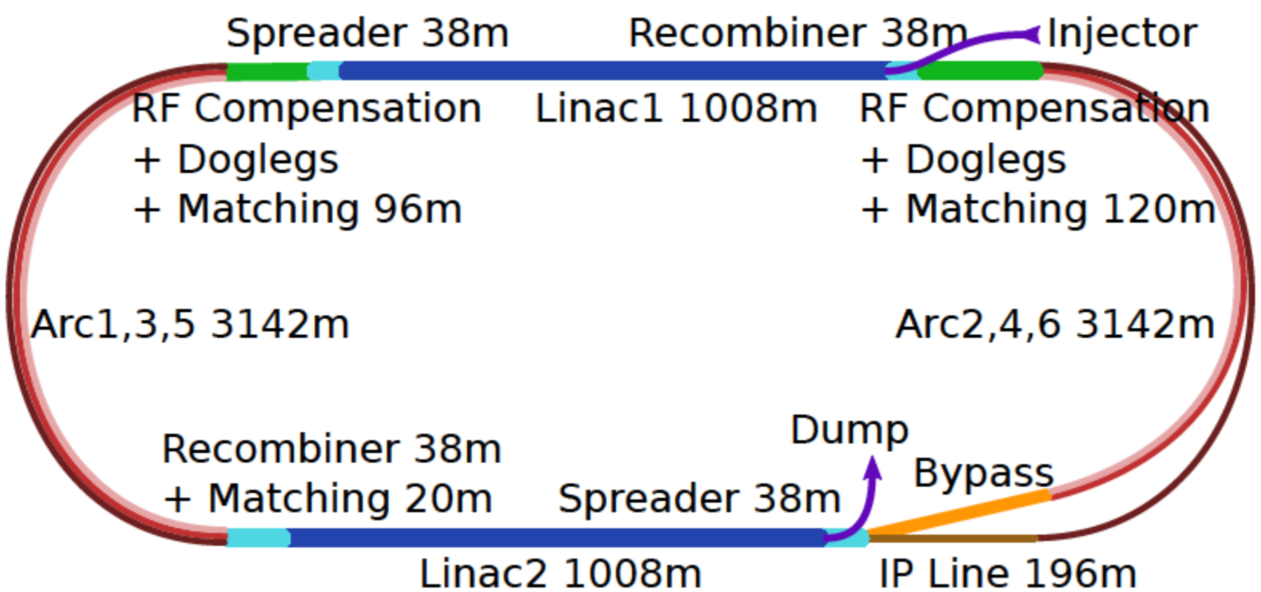
Nuclear effects $R^A \neq 1$

Schematic picture

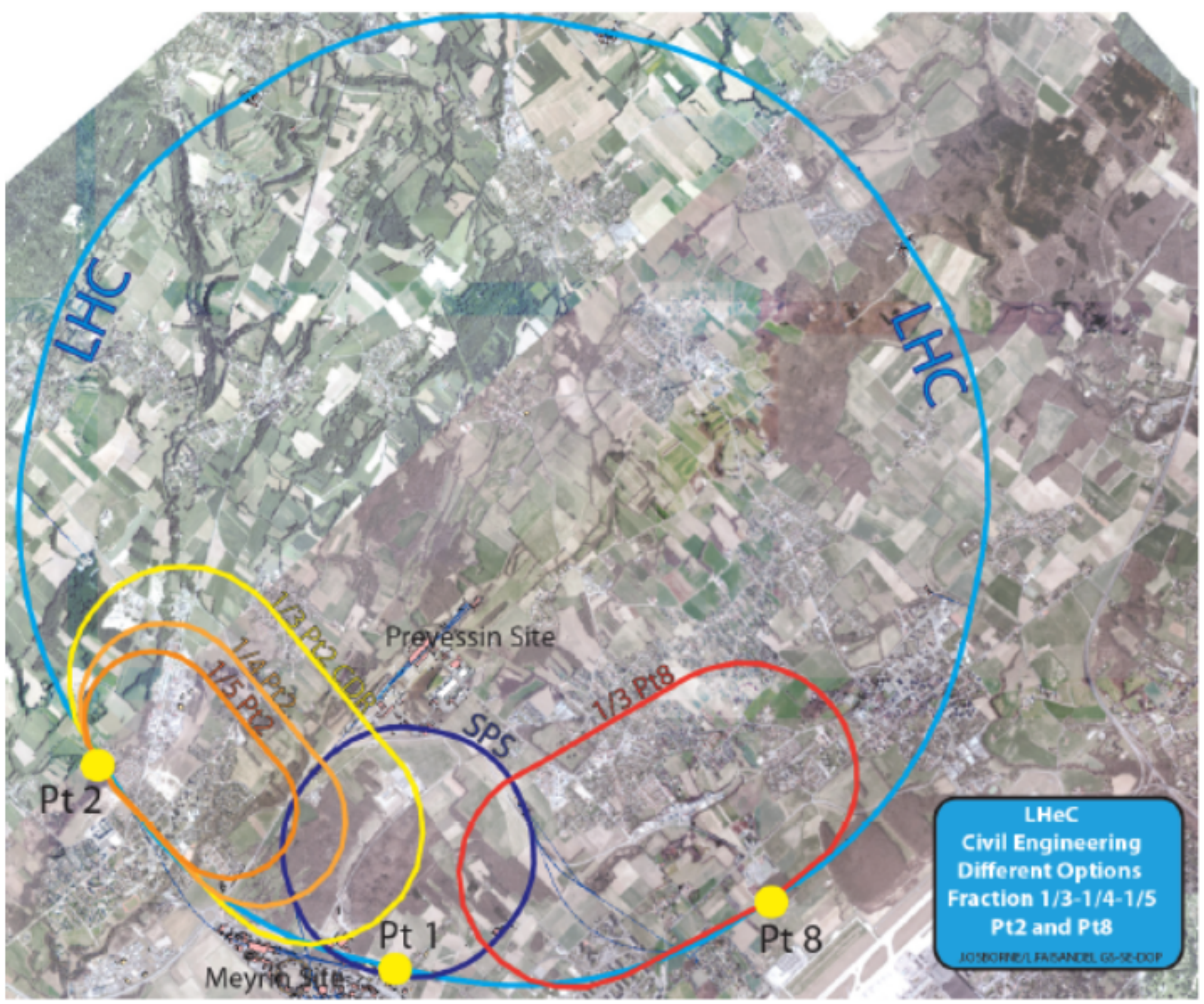


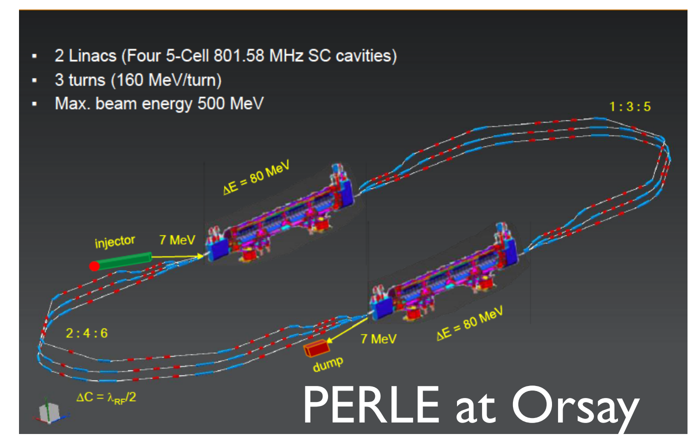
- Fermi motion $x \geq 0.8$
- EMC region $0.25-0.3 \leq x \leq 0.8$
- Antishadowing region $0.1 \leq x \leq 0.25-0.3$
- Shadowing region $x \leq 0.1$

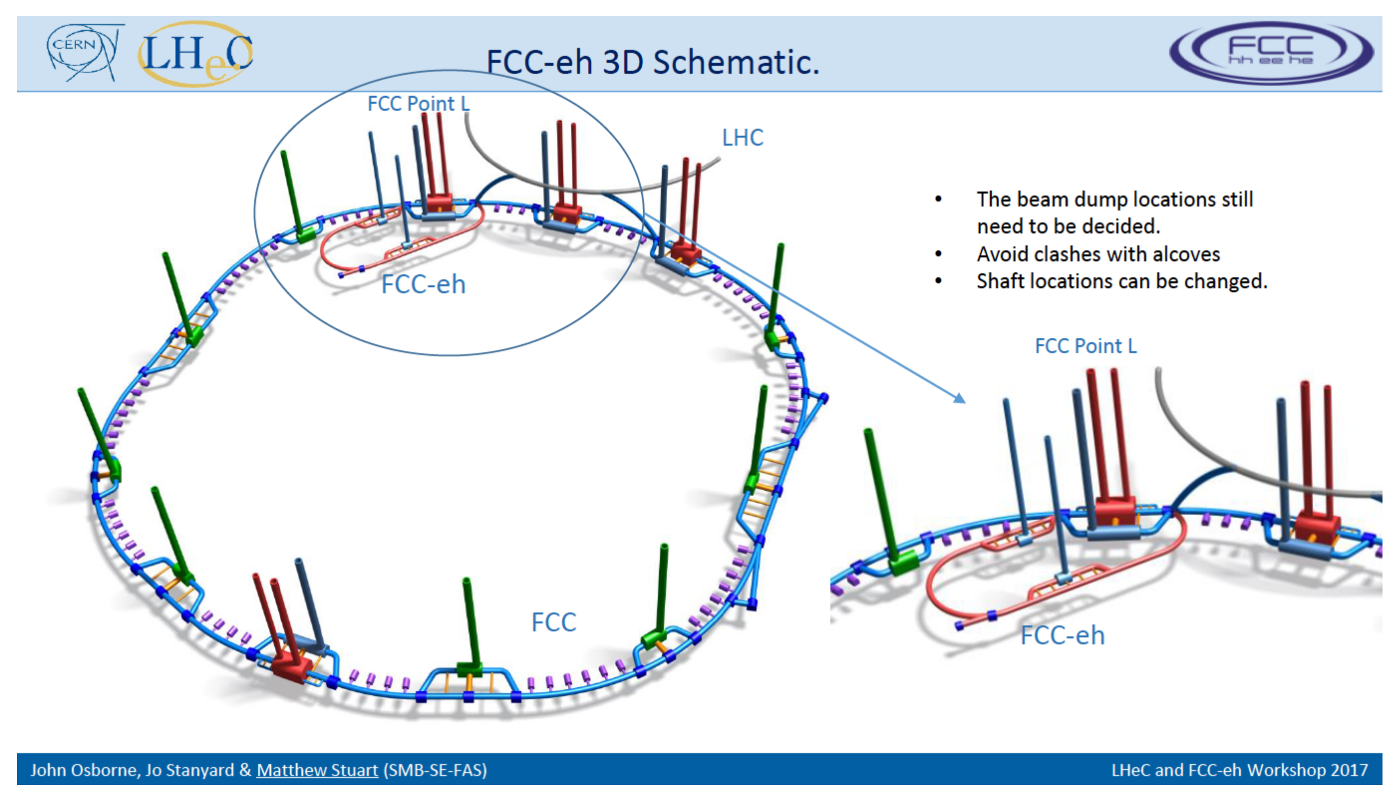
Machines:



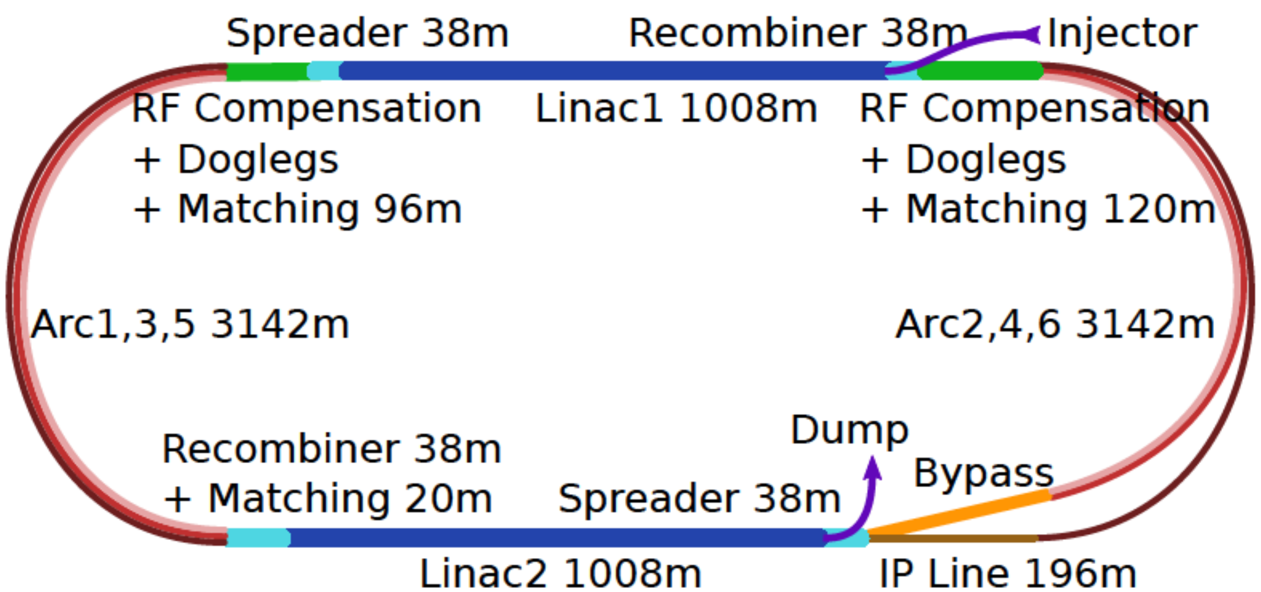
- 60 GeV e⁻ (ERL) against the (HL/HE-)LHC/FCC hadron beams: eA to run either concurrently with pA/AA or in dedicated mode.







Machines:



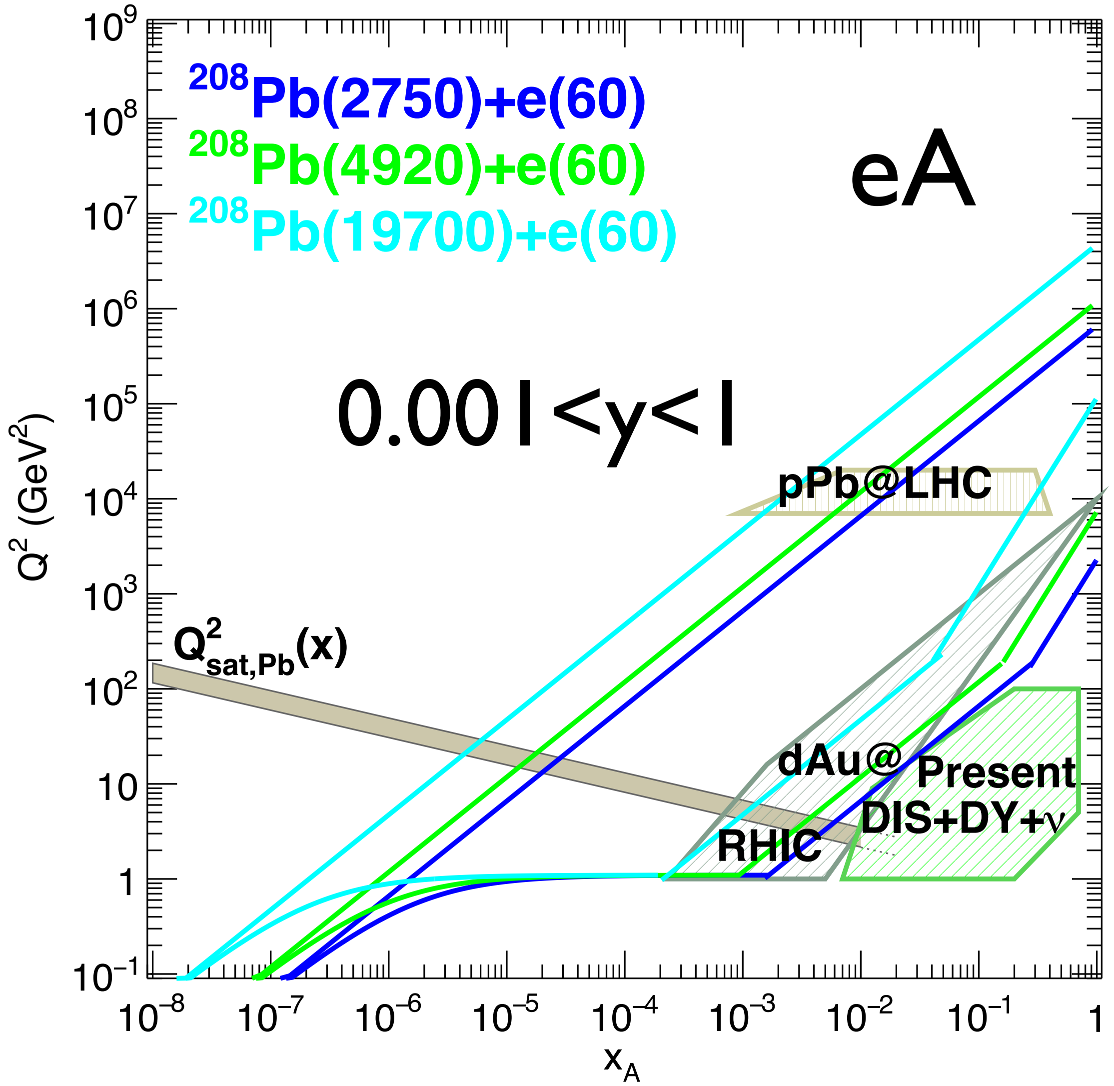
- 60 GeV e$^-$ (ERL) against the (HL/HE-)LHC/FCC hadron beams: eA to run either concurrently with pA/AA or in dedicated mode.

CERN-ACC-2017-0019

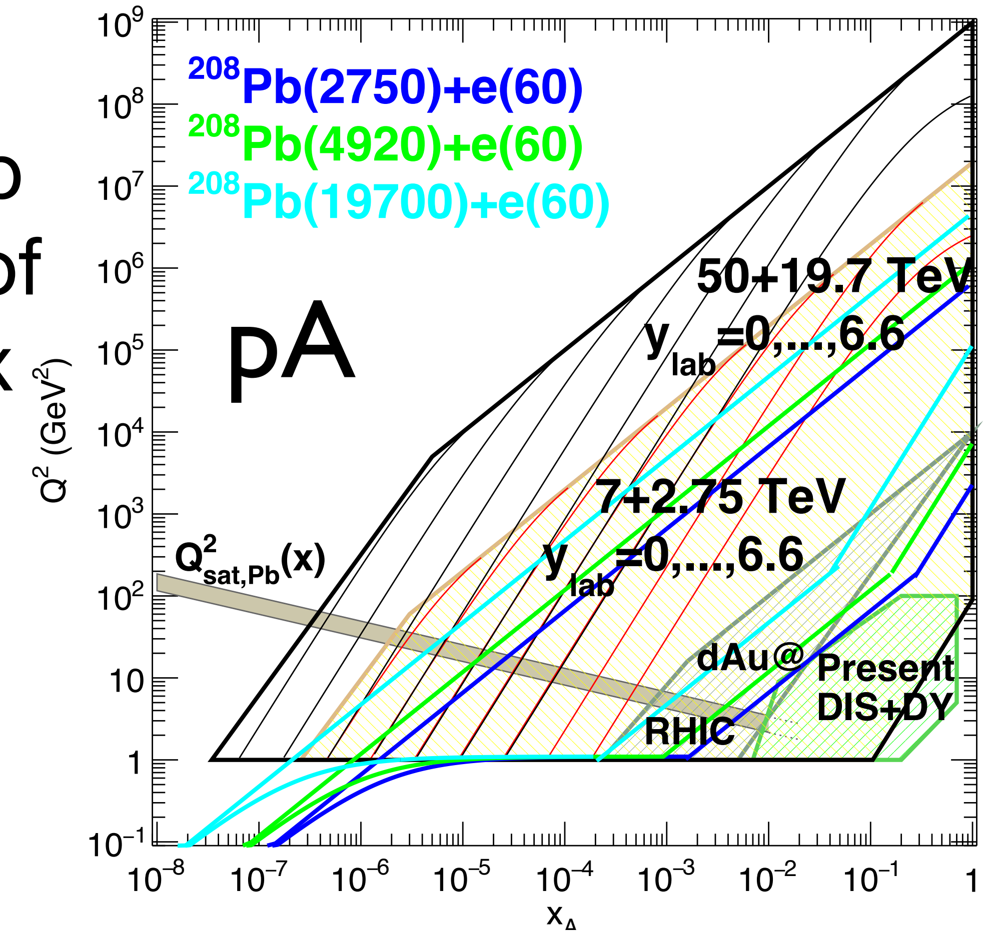
parameter [unit]	LHeC (HL-LHC)	eA at HE-LHC	FCC-he
$E_{\rm Pb}$ [PeV]	0.574	1.03	4.1
E_e [GeV]	60	60	60
$\sqrt{s_{eN}}$ electron-nucleon [TeV]	0.8	1.1	2.2
bunch spacing [ns]	50	50	100
no. of bunches	1200	1200	2072
ions per bunch [10^8]	1.8	1.8	1.8
$\gamma\epsilon_A$ [μm]	1.5	1.0	0.9
electrons per bunch [10^9]	4.67	6.2	12.5
electron current [mA]	15	20	20
IP beta function β^*_A [cm]	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3
bunch filling H_{coll}	0.8	0.8	0.8
luminosity [10^{32}cm^{-2}s^{-1}]	7	18	54
Integrated lumi. in 10 y. (fb^{-1}) ~~	6	15	45

- 100 times larger luminosity than HERA, full HERA integrated luminosity in less than a month.

DIS eA: kinematics



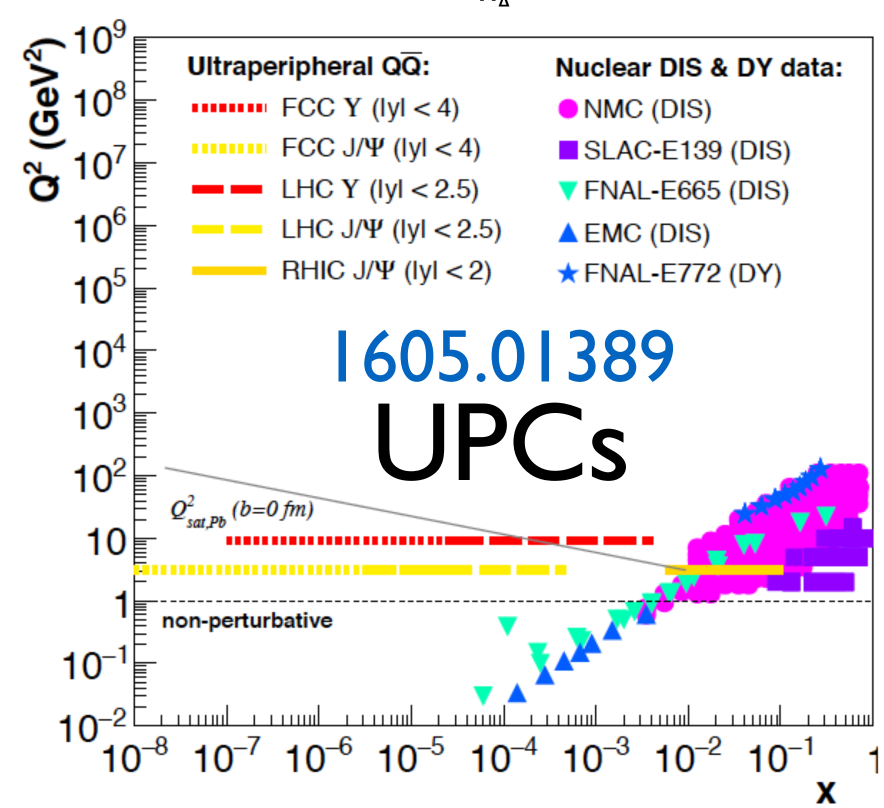
- Extension up to 4-5 orders of magnitude in x and Q² wrt. existing DIS data, ~3 wrt JLEIC/eRHIC.



- DIS offers:

➜ A clean experimental environment: low multiplicity, no pileup, fully constrained kinematics;

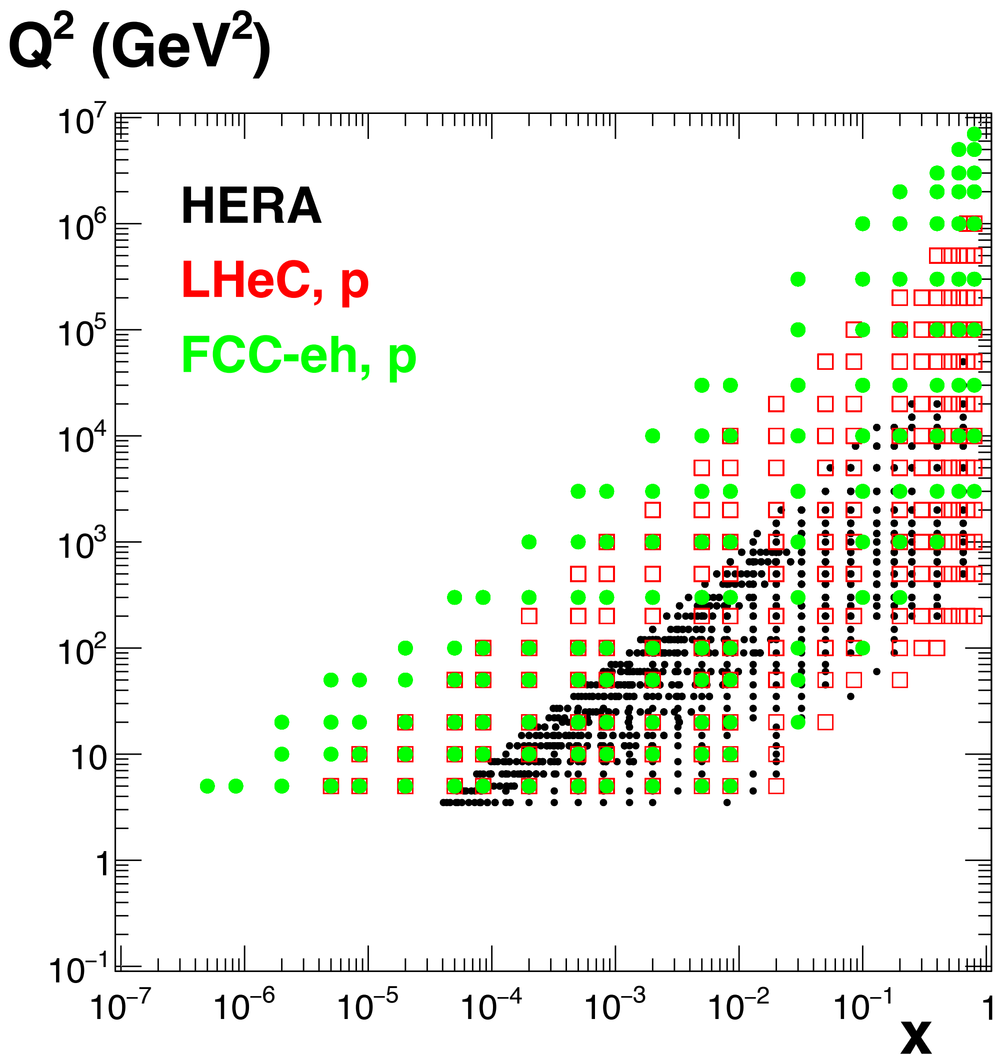
➜ A more controlled theoretical setup: many first-principles calculations in collinear and non-collinear frameworks.

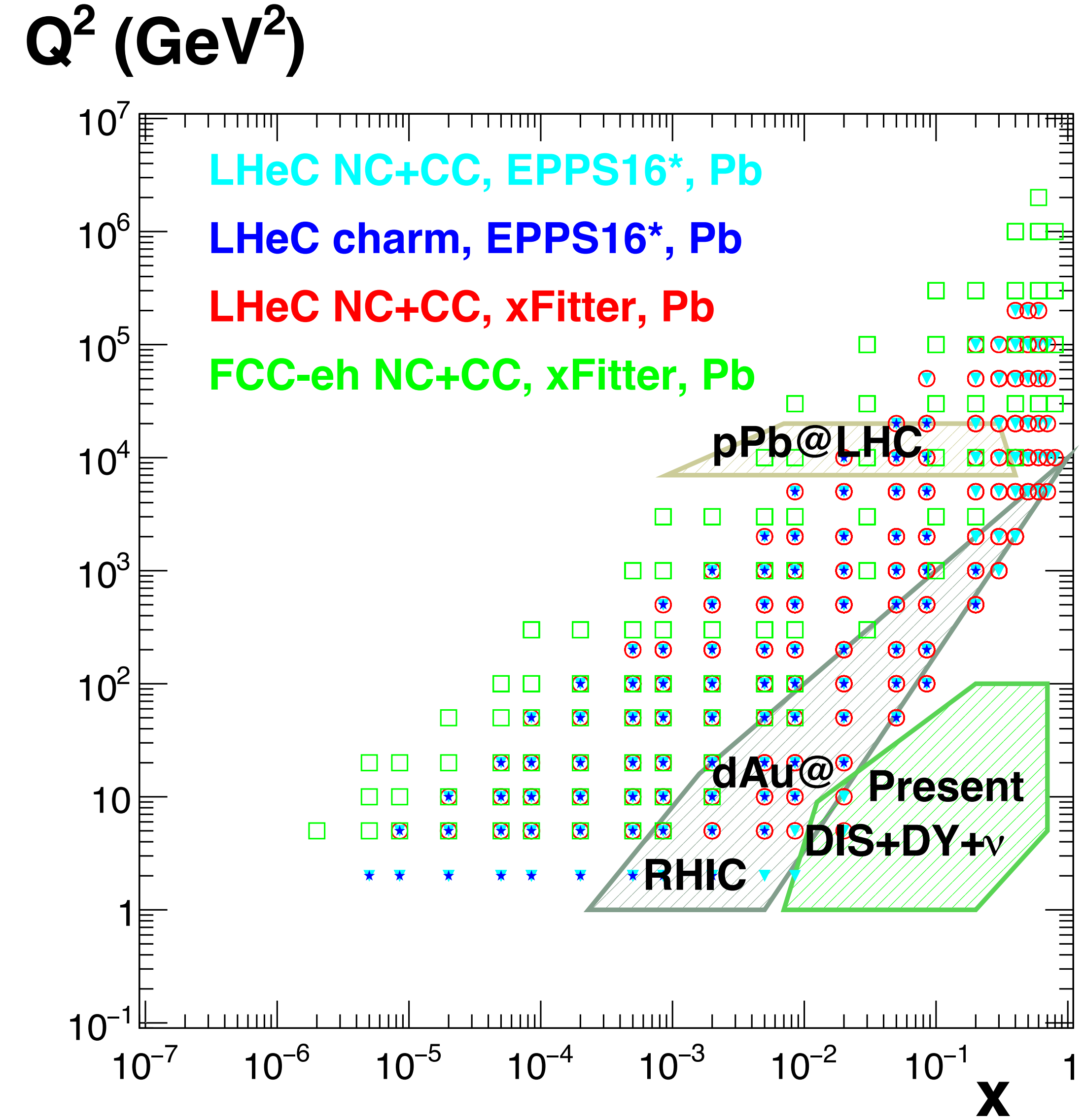


Pseudodata:

	E_e (GeV)	E_h (TeV/nucleon)	Polarisation	Luminosity (fb^{-1})	NC/CC	# data
ep@LHeC, 1005 data points for $Q^2 \geq 3.5$ GeV^2	60 (e^-)	1 (p)	0	100	CC	93
	60 (e^-)	1 (p)	0	100	NC	136
	60 (e^-)	7 (p)	-0.8	1000	CC	114
	60 (e^-)	7 (p)	0.8	300	CC	113
	60 (e^+)	7 (p)	0	100	CC	109
	60 (e^-)	7 (p)	-0.8	1000	NC	159
	60 (e^-)	7 (p)	0.8	300	NC	159
	60 (e^+)	7 (p)	0	100	NC	157
ePb@LHeC, 484 data points for $Q^2 \geq 3.5$ GeV^2	20 (e^-)	2.75 (Pb)	-0.8	0.03	CC	51
	20 (e^-)	2.75 (Pb)	-0.8	0.03	NC	93
	26.9 (e^-)	2.75 (Pb)	-0.8	0.02	CC	55
	26.9 (e^-)	2.75 (Pb)	-0.8	0.02	NC	98
	60 (e^-)	2.75 (Pb)	-0.8	1	CC	85
	60 (e^-)	2.75 (Pb)	-0.8	1	NC	129
ep@FCC-eh, 619 data points for $Q^2 \geq 3.5$ GeV^2	20 (e^-)	7 (p)	0	100	CC	46
	20 (e^-)	7 (p)	0	100	NC	89
	60 (e^-)	50 (p)	-0.8	1000	CC	67
	60 (e^-)	50 (p)	0.8	300	CC	65
	60 (e^+)	50 (p)	0	100	CC	60
	60 (e^-)	50 (p)	-0.8	1000	NC	111
	60 (e^-)	50 (p)	0.8	300	NC	110
	60 (e^+)	50 (p)	0	100	NC	107
ePb@FCC-eh, 150 data points for $Q^2 \geq 3.5$ GeV^2	60 (e^-)	20 (Pb)	-0.8	10	CC	58
	60 (e^-)	20 (Pb)	-0.8	10	NC	101

Pseudodata:

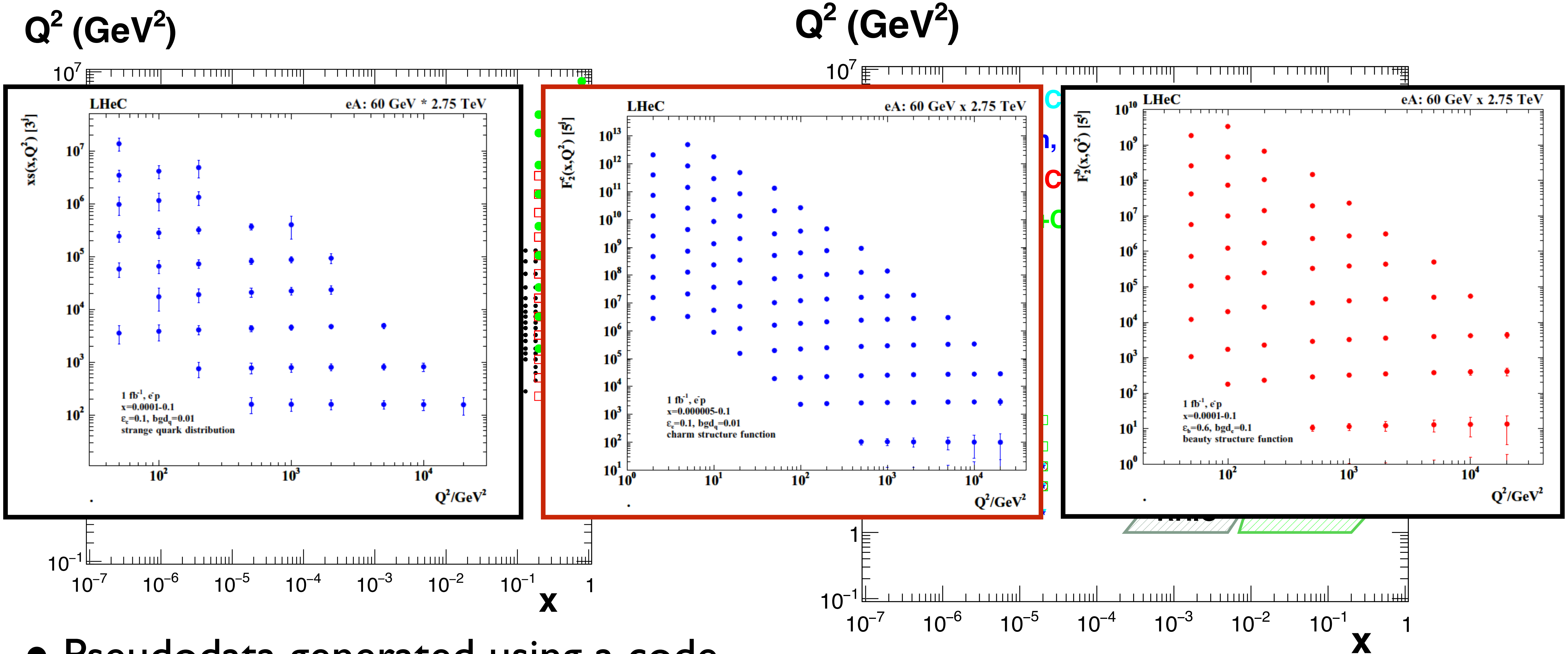




- Pseudodata generated using a code (Max Klein) validated with the H1 MC.
- Cuts: $|\eta_{max}|$=5, 0.95< y< 0.001.
- Error assumptions ~ factor 2 better than at HERA (luminosity uncertainty kept aside).

Source of uncertainty	Error on the source or cross section
scattered electron energy scale	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale	0.5 %
calorimeter noise ($y < 0.01$)	1-3 %
radiative corrections	1-2 %
photoproduction background	1 %
global efficiency error	0.7 %

Pseudodata:



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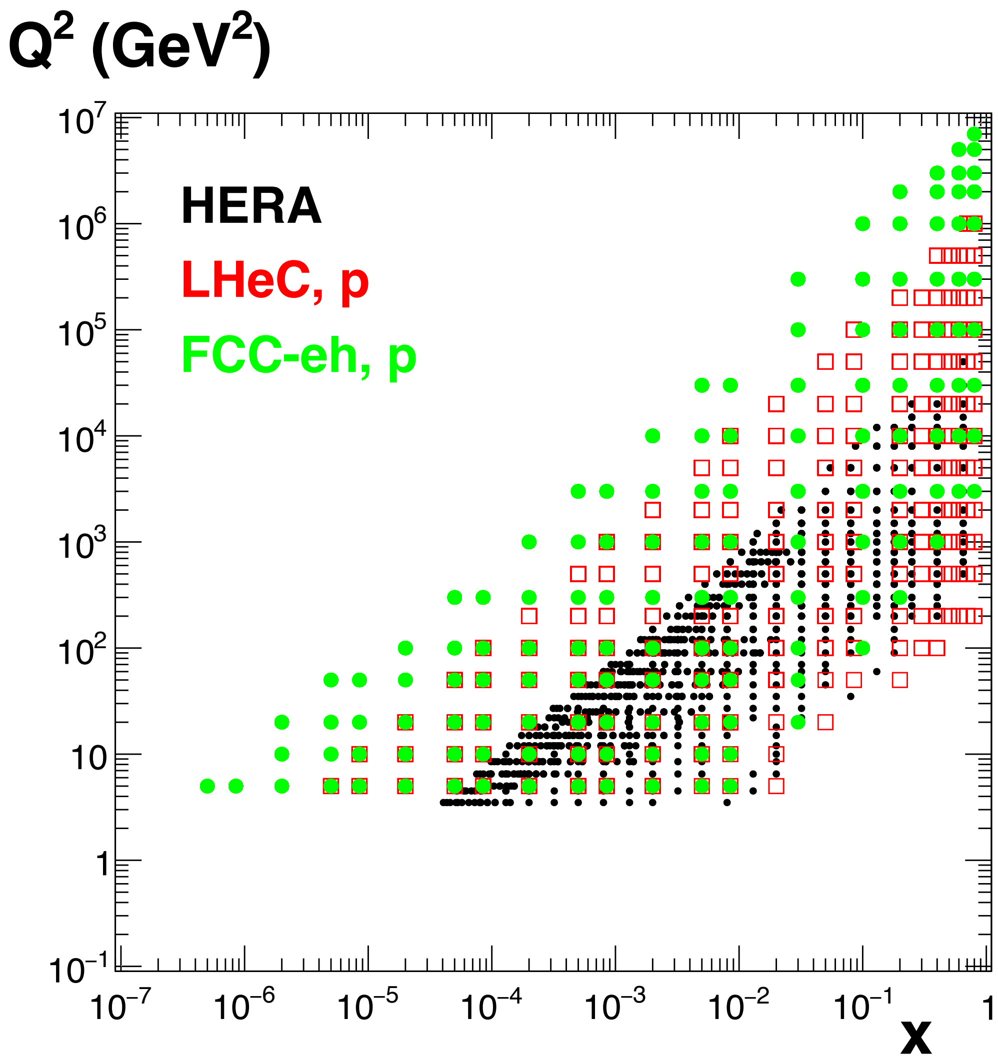

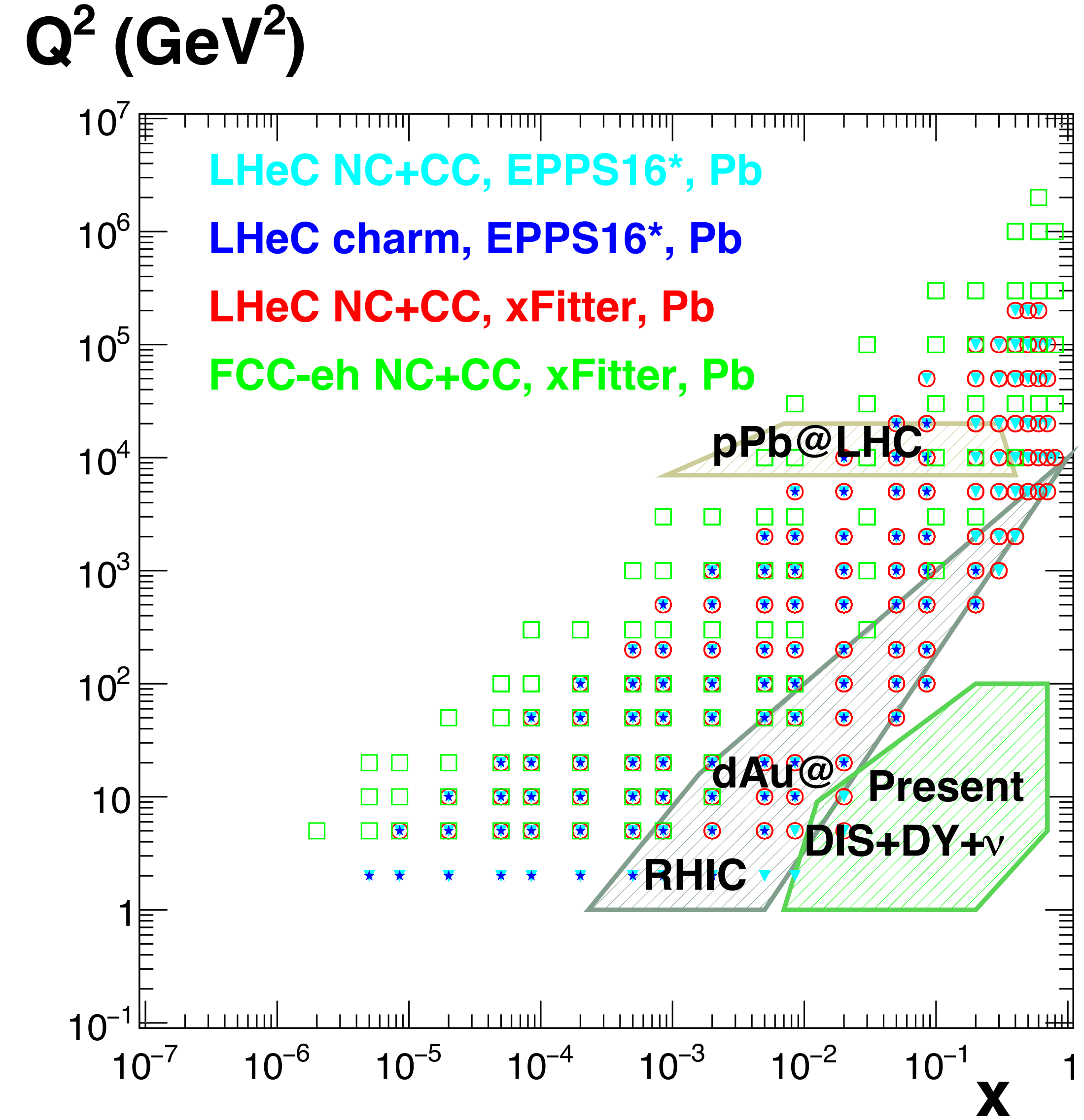

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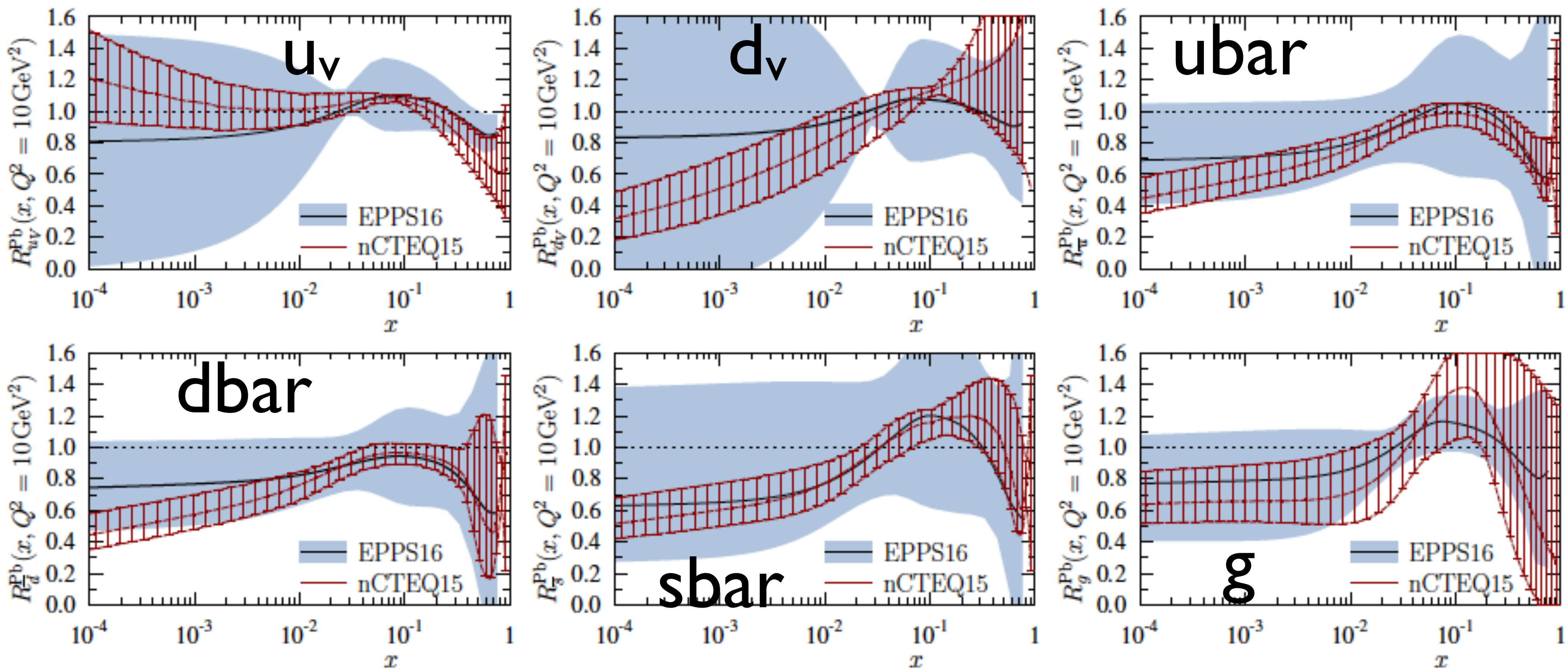
EPPS16*: simulation

EPPS16* setup

- EPPS16-like analysis updated, with the same data sets plus LHeC NC, CC and charm reduced cross sections.
- Central values generated using EPS09.
- Same methods and tolerance as in EPPS16, but more flexible functional form at small x.

EPPS16*: simulation

• nCTEQ15 vs. EPPS16: note the parametrisation bias.



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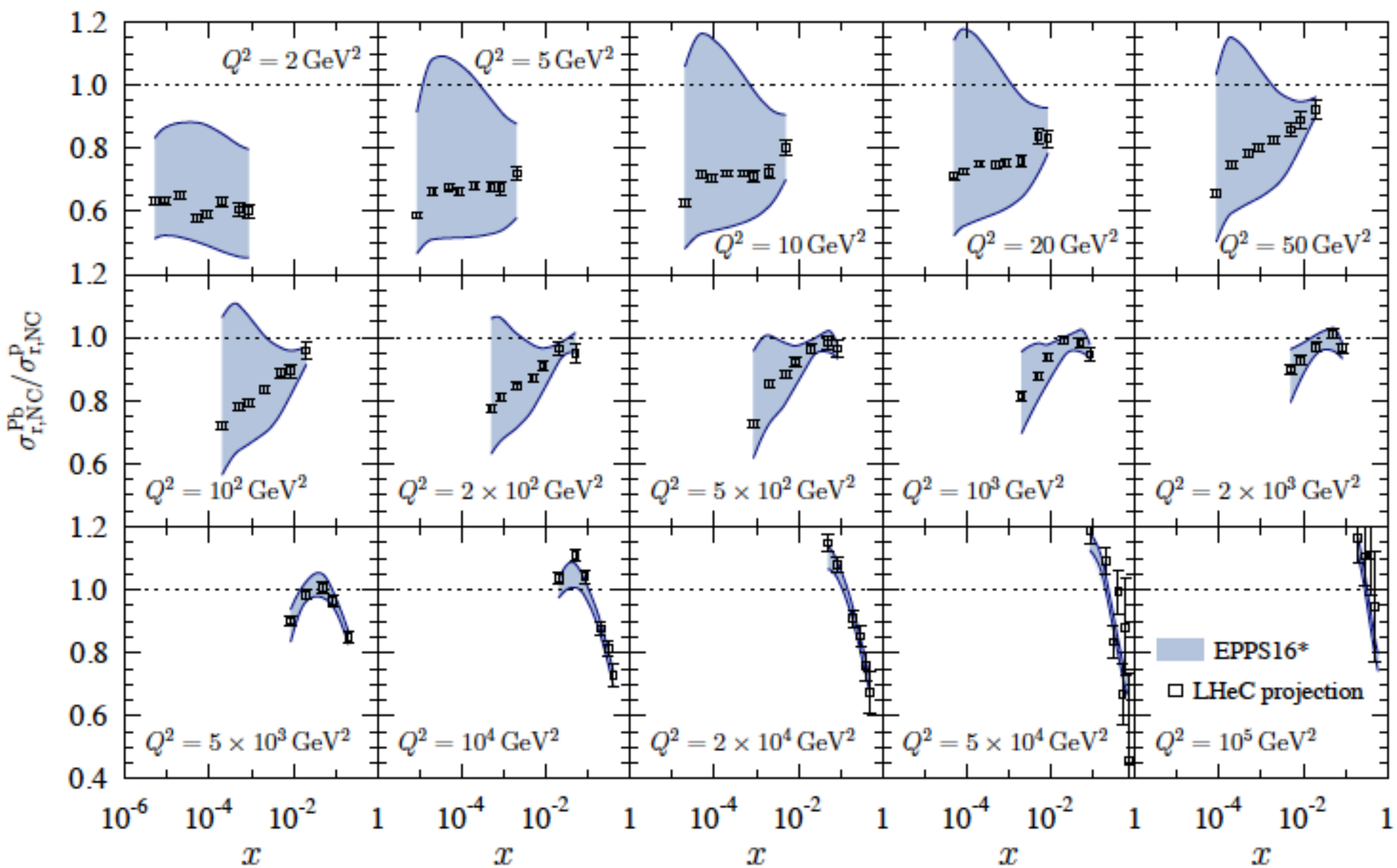
EPPS16*: results

- Large effect of NC+CC LHeC pseudodata, and of charm on the glue at small x.
- Limitation on u/d decomposition inherent to almost isospin symmetric nuclei (u/d difference suppressed by 2Z/A-1).



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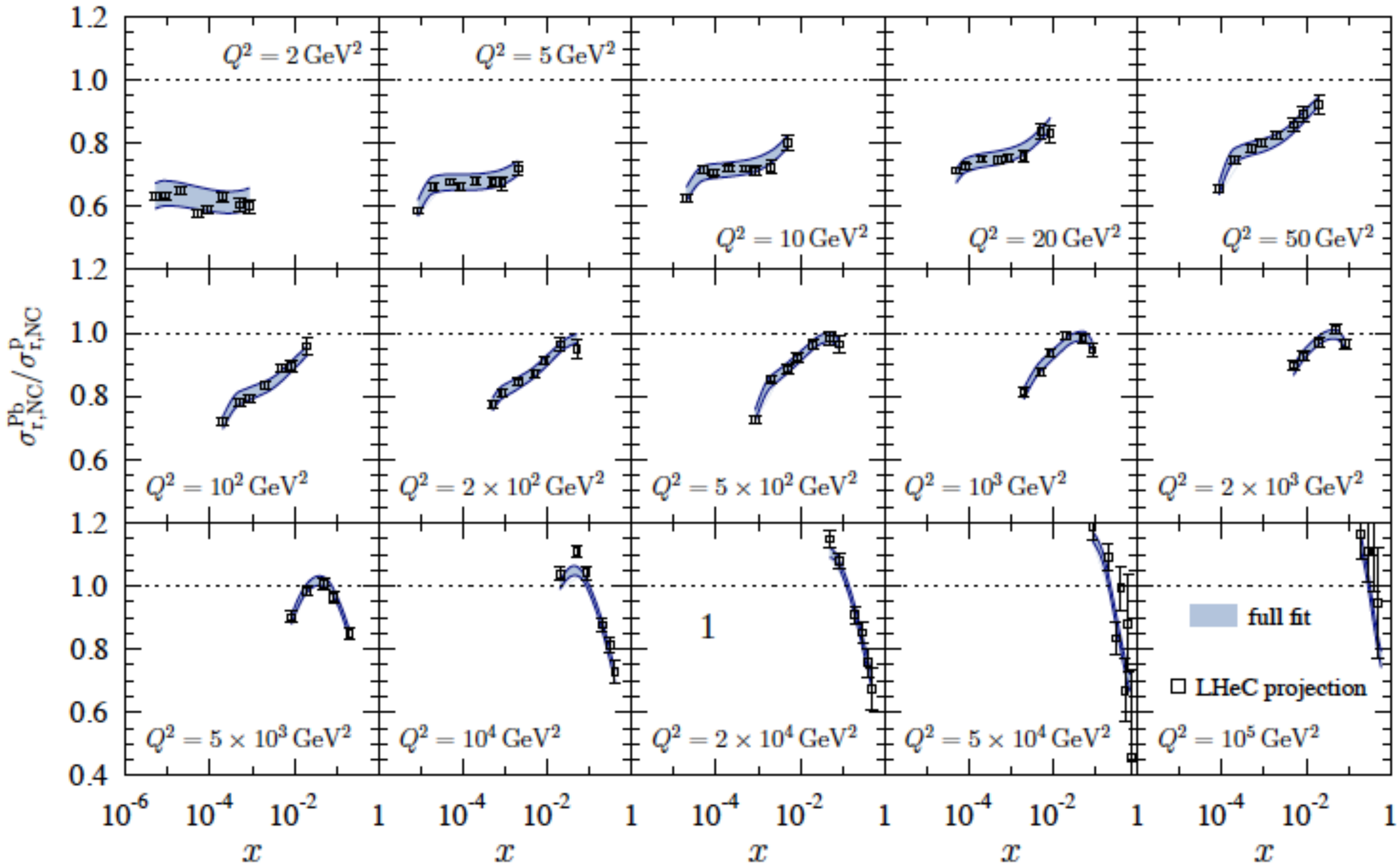

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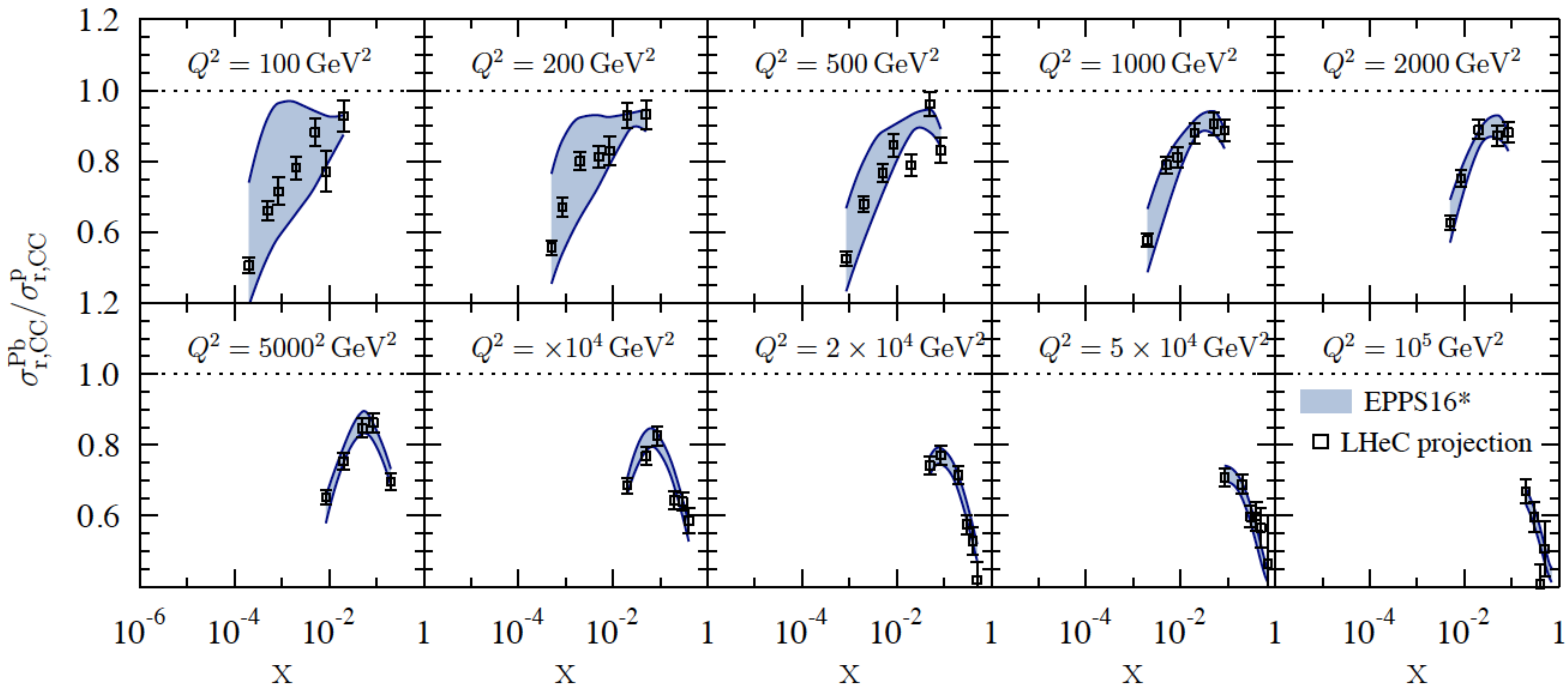

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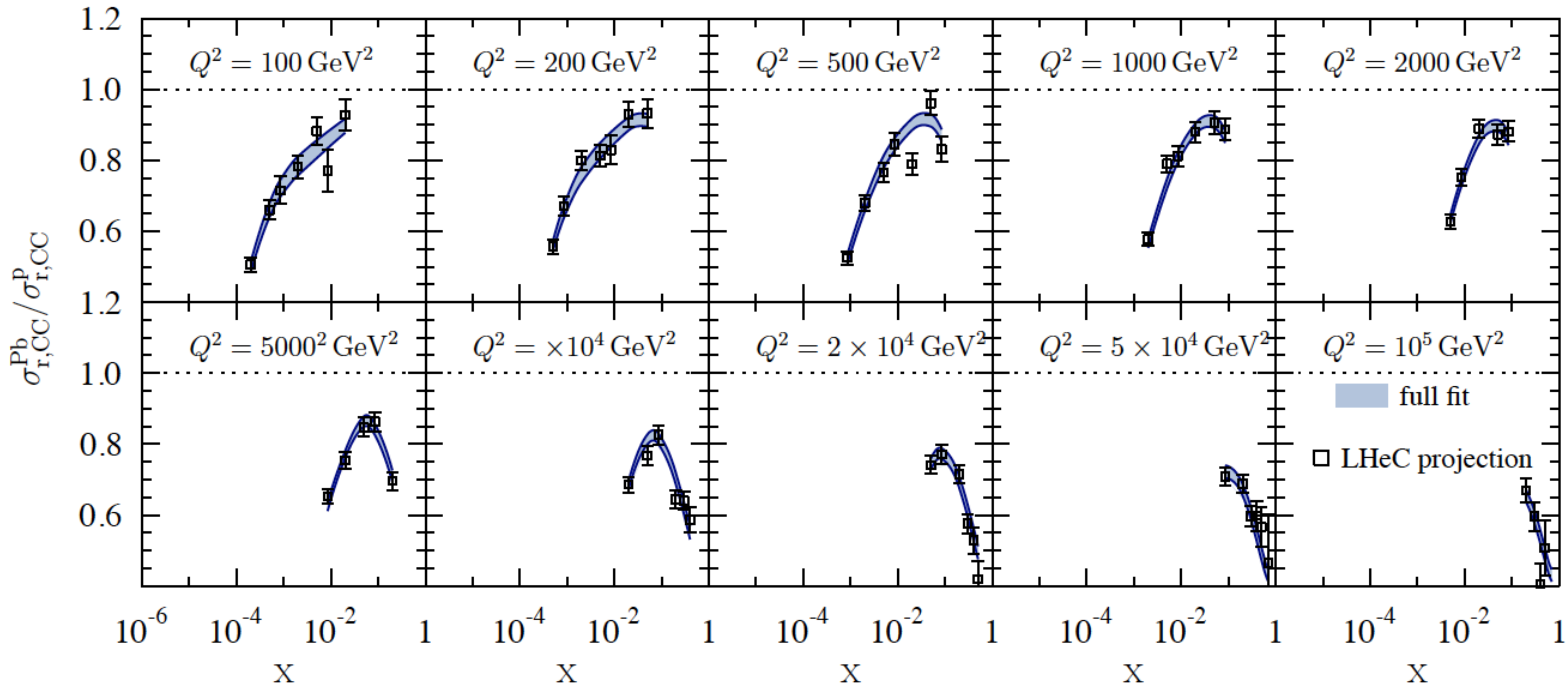

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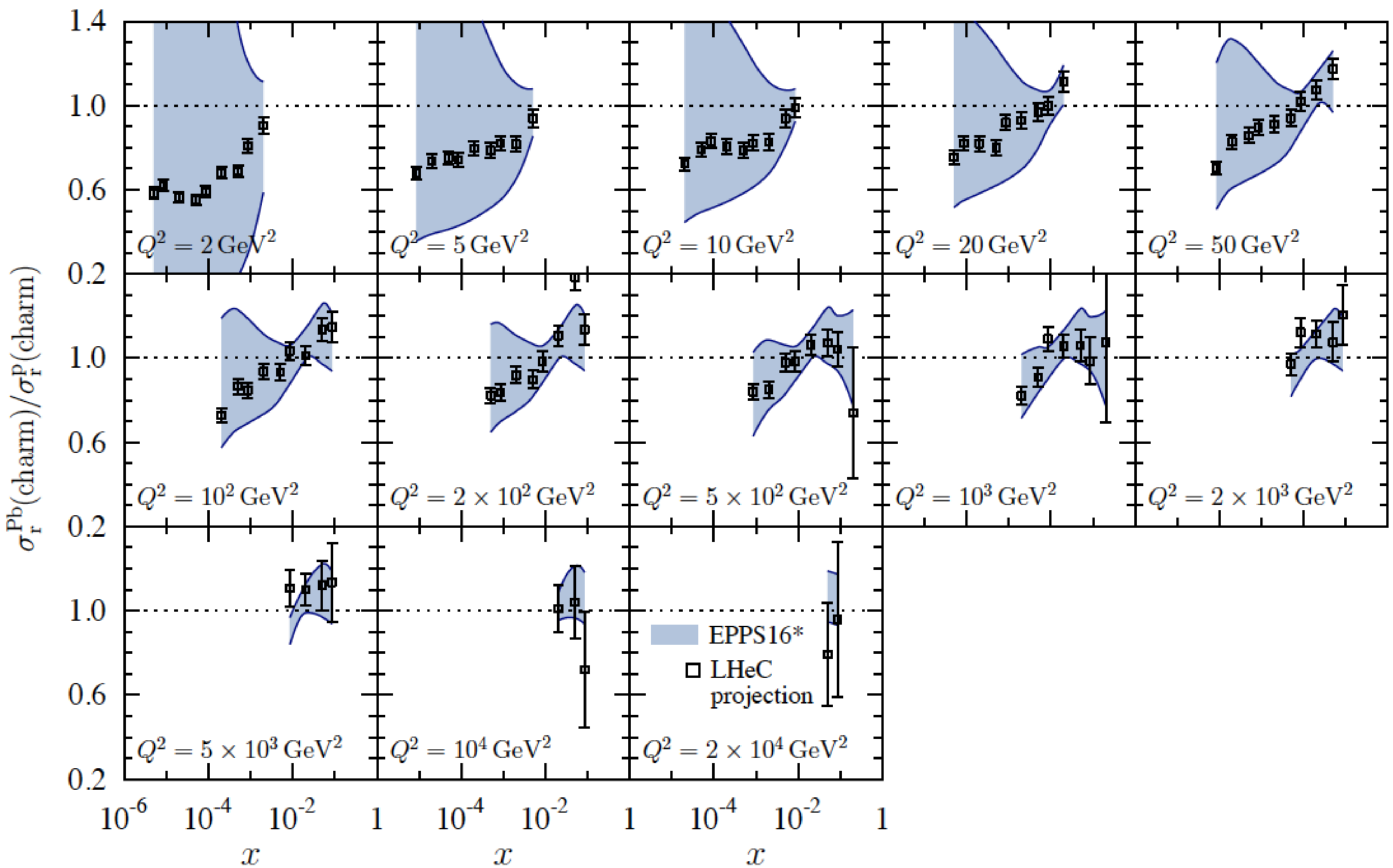

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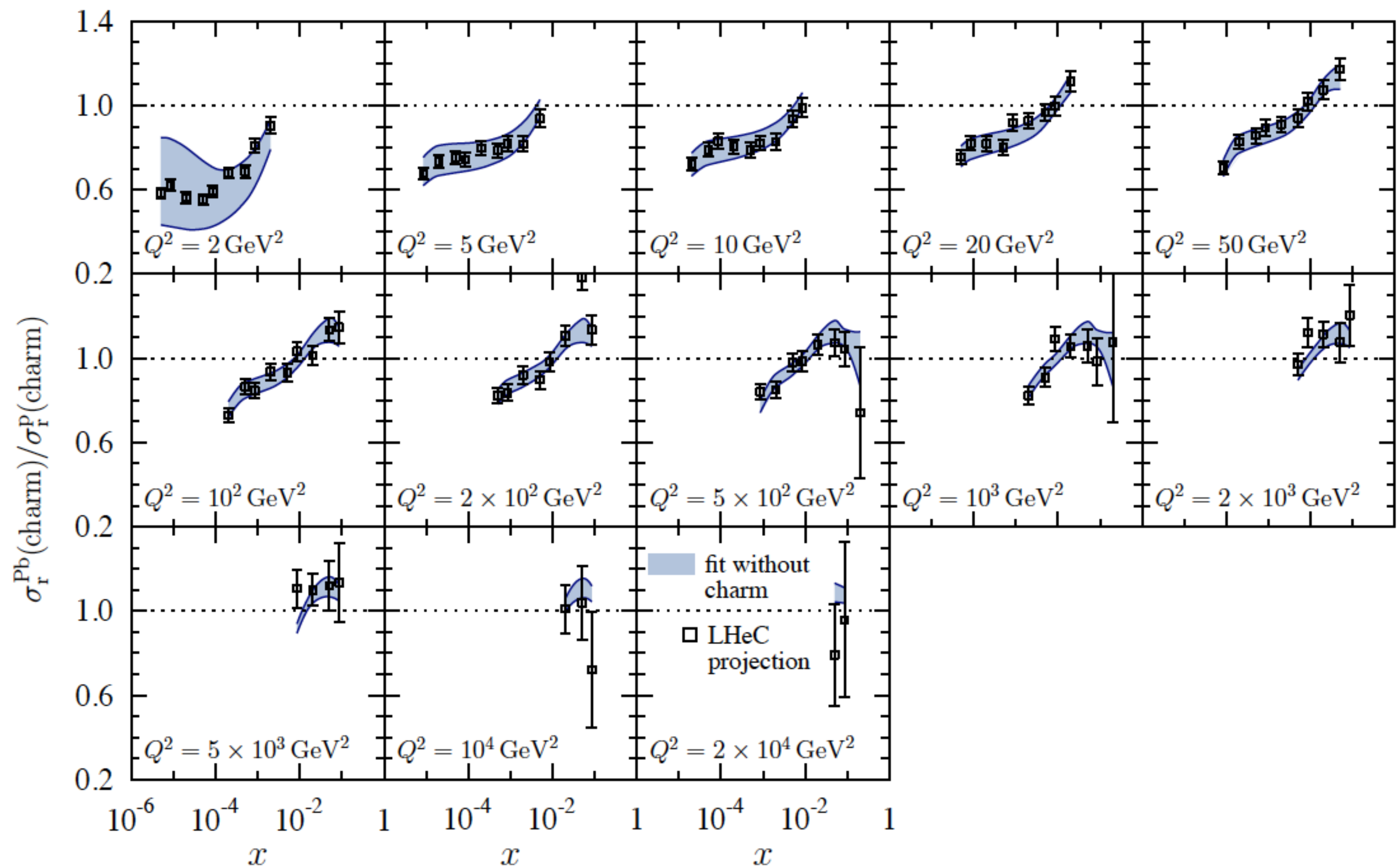

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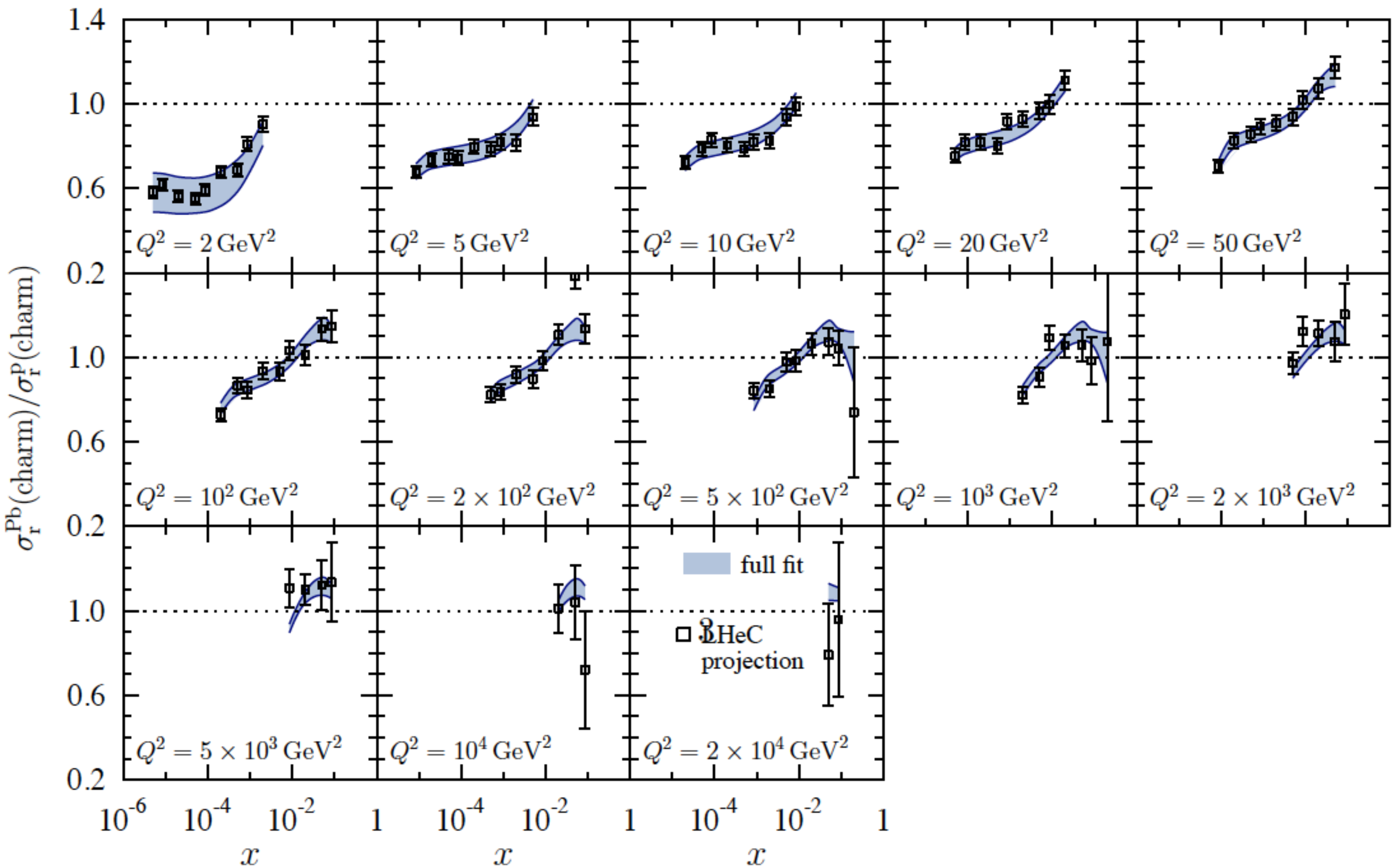
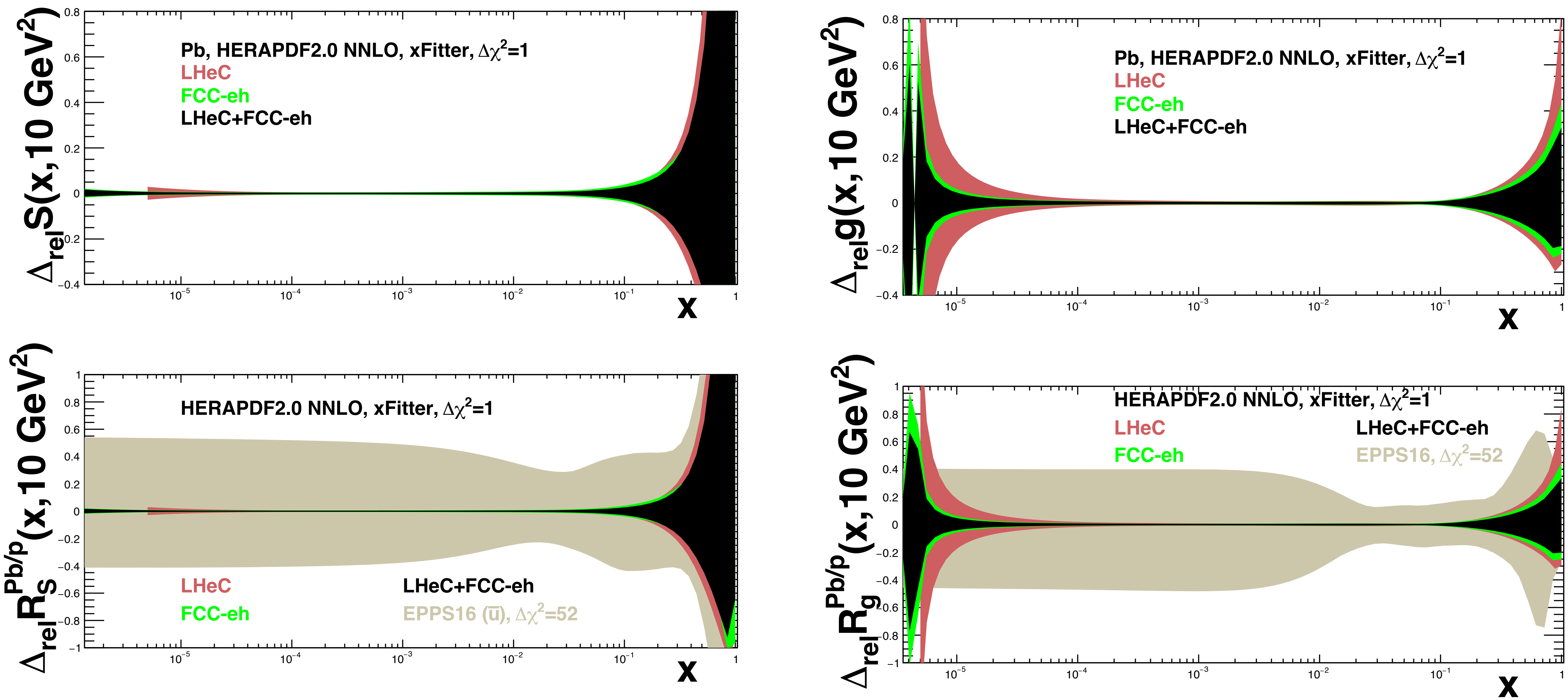


xFitter simulation

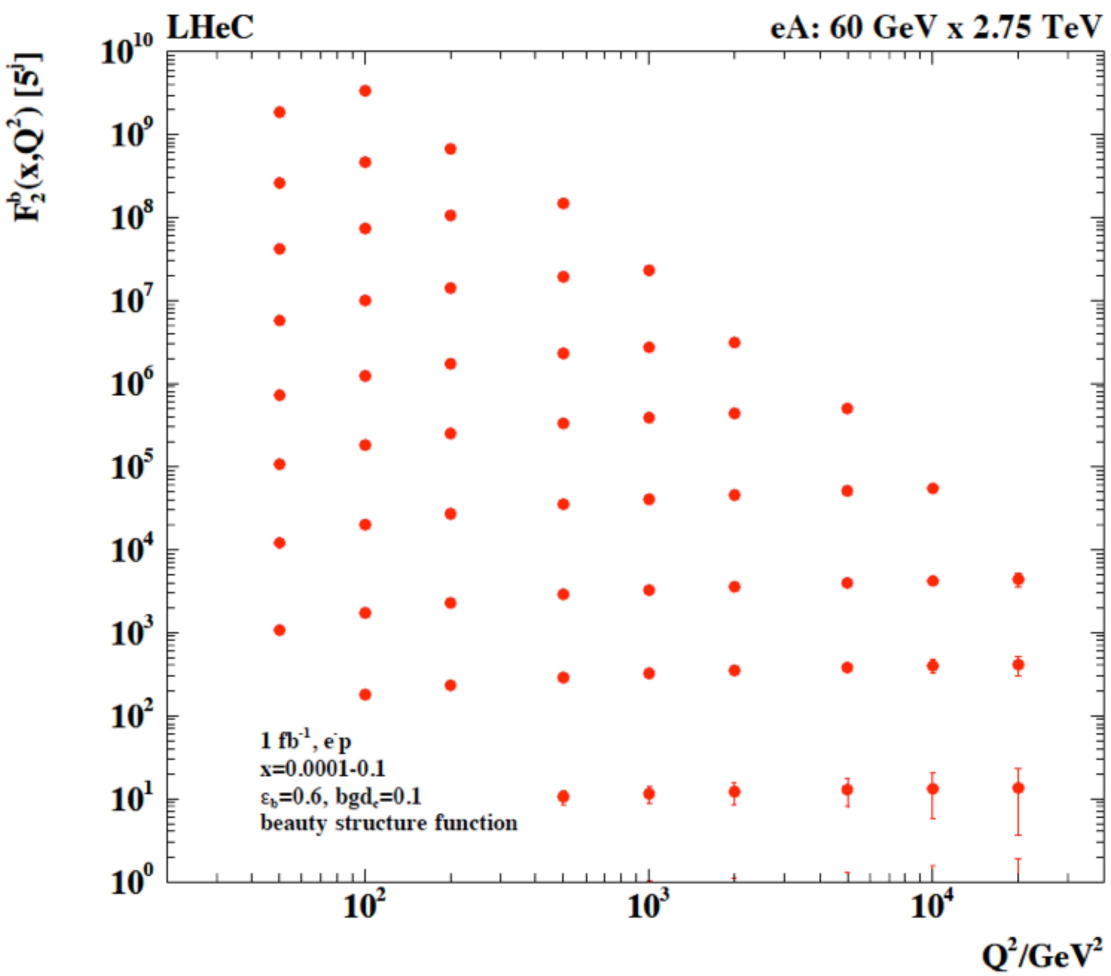
Extraction of Pb PDFs by fitting NC+CC pseudodata using xFitter
Uncertainties coming only from experimental precision
No parametrisation or theory uncertainties
Only data with $Q^2 \geq 3.5$ GeV^2, initial evolution scale 1.9 GeV^2.



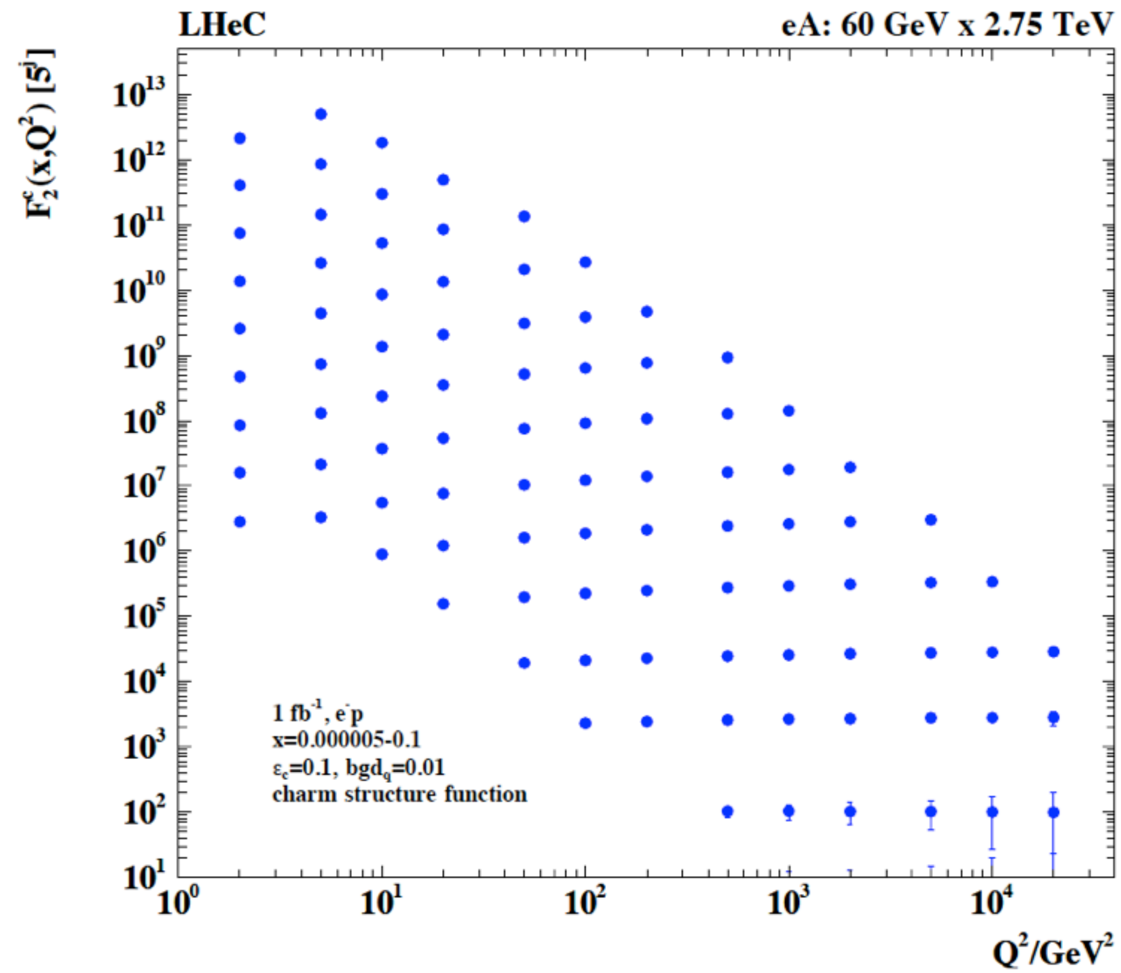
Large reduction of uncertainty at all x.
Possible further improvements : charm, beauty, CC with tagged charm for strange Distribution

Heavy flavors: LHeC simulation

Heavy Flavour – Beauty in ePb - from NC



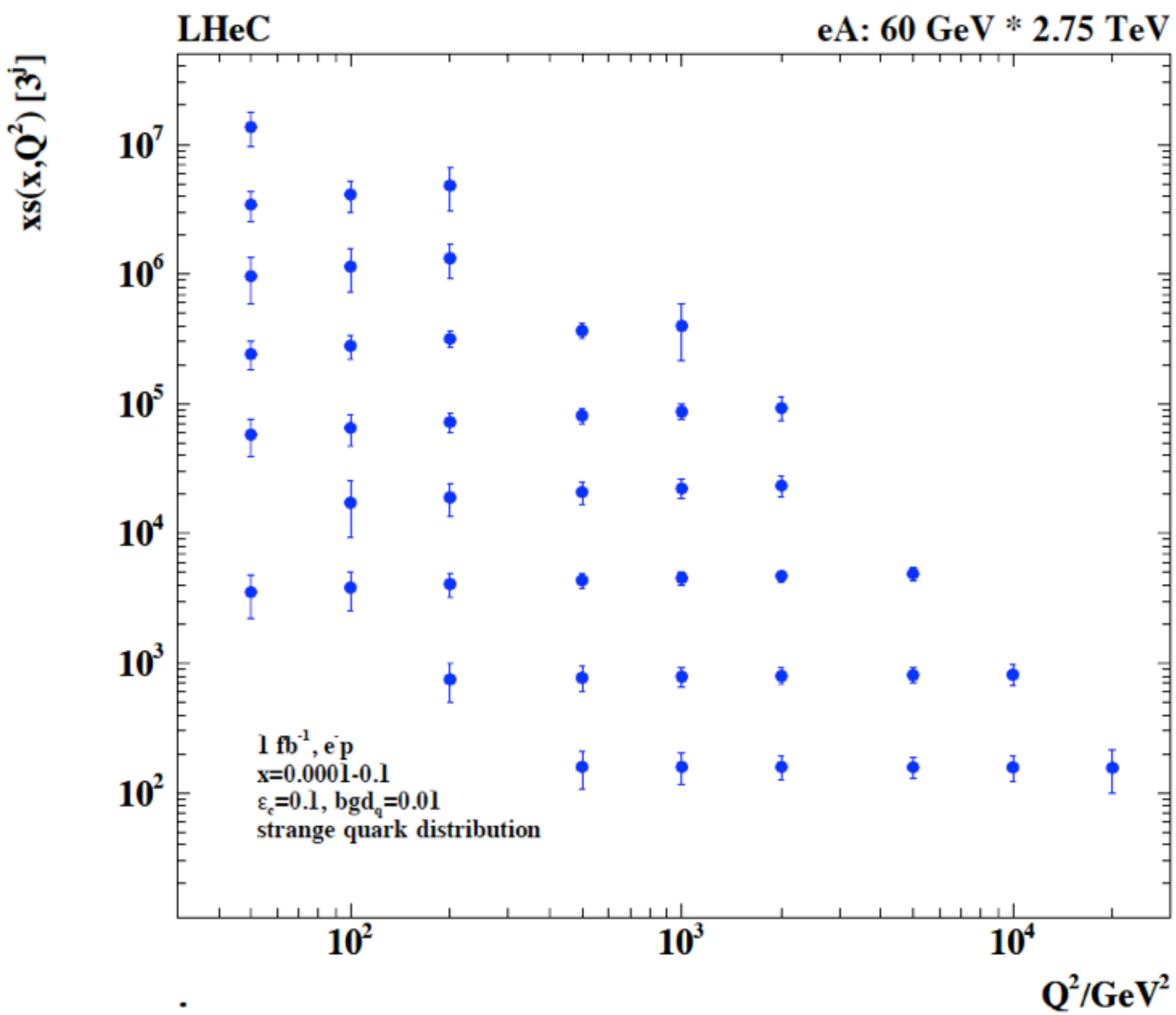
Heavy Flavour – Charm in eA - from NC



Possibility of precision measurements of heavy flavors in eA DIS at LHeC.

Heavy flavors: LHeC simulation

Heavy Flavour – Strange in ePb - from CC



Max Klein nPDFs with LHeC 10.9.2015 POETIC a PARIS

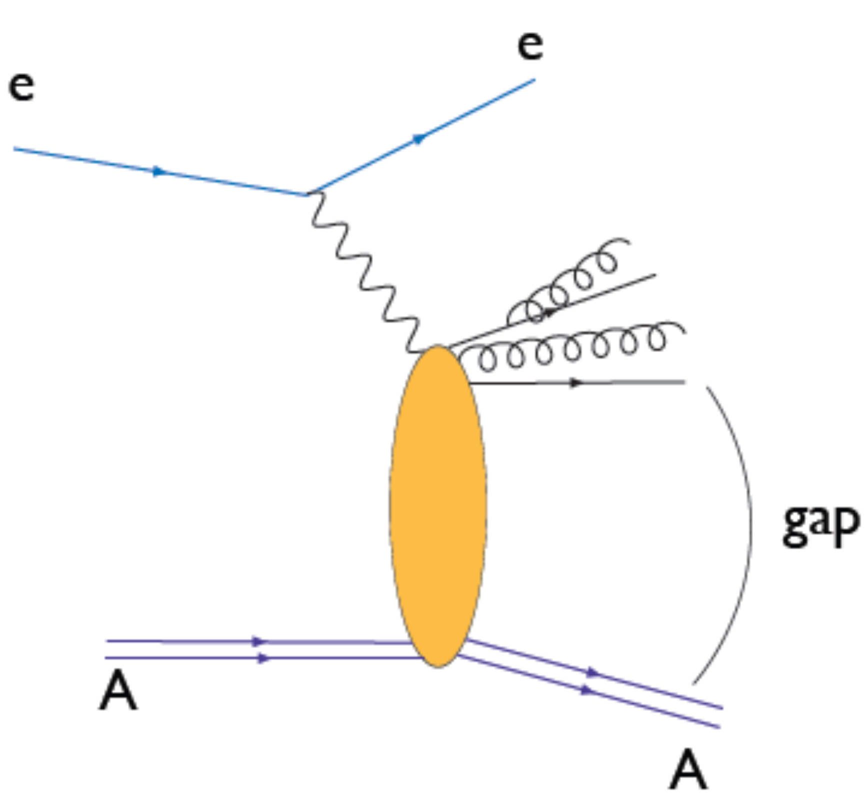
Extraction of strange quark distribution in eA through CC interaction.

Diffraction in eA

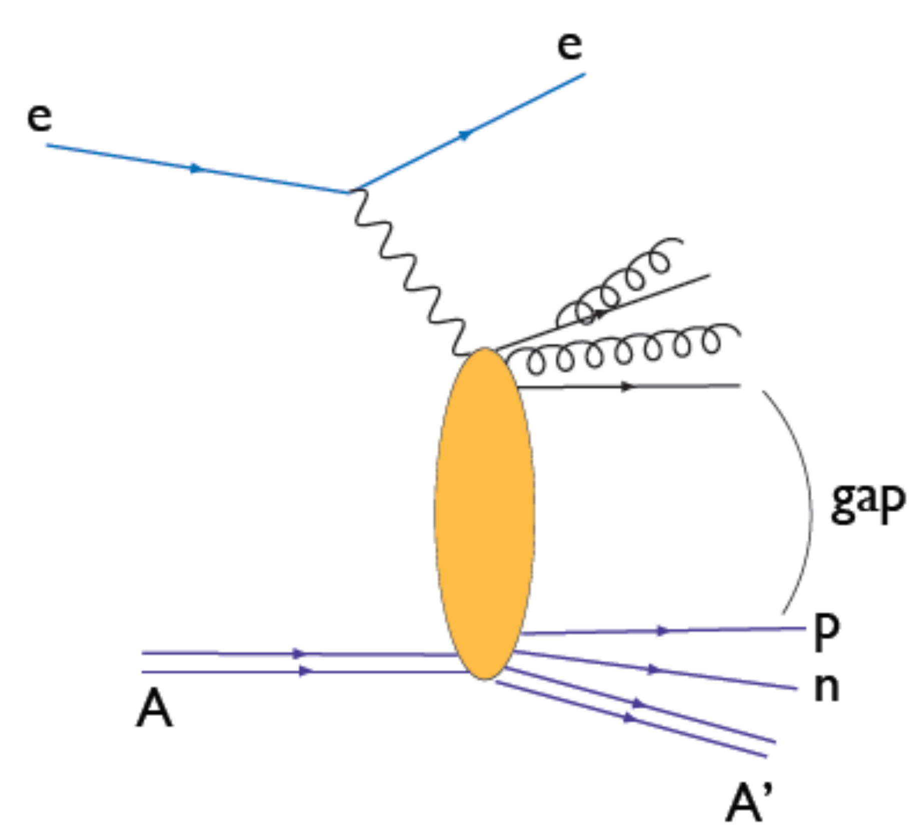
Diffraction: event in hadronic collisions characterized by the large rapidity gap, void of any activity

From theoretical perspective: requires exchange of colorless object in the t-channel

Diffraction on nuclei: possible coherent (nucleus stays intact) or incoherent (nucleus breaks but still rapidity gap present)



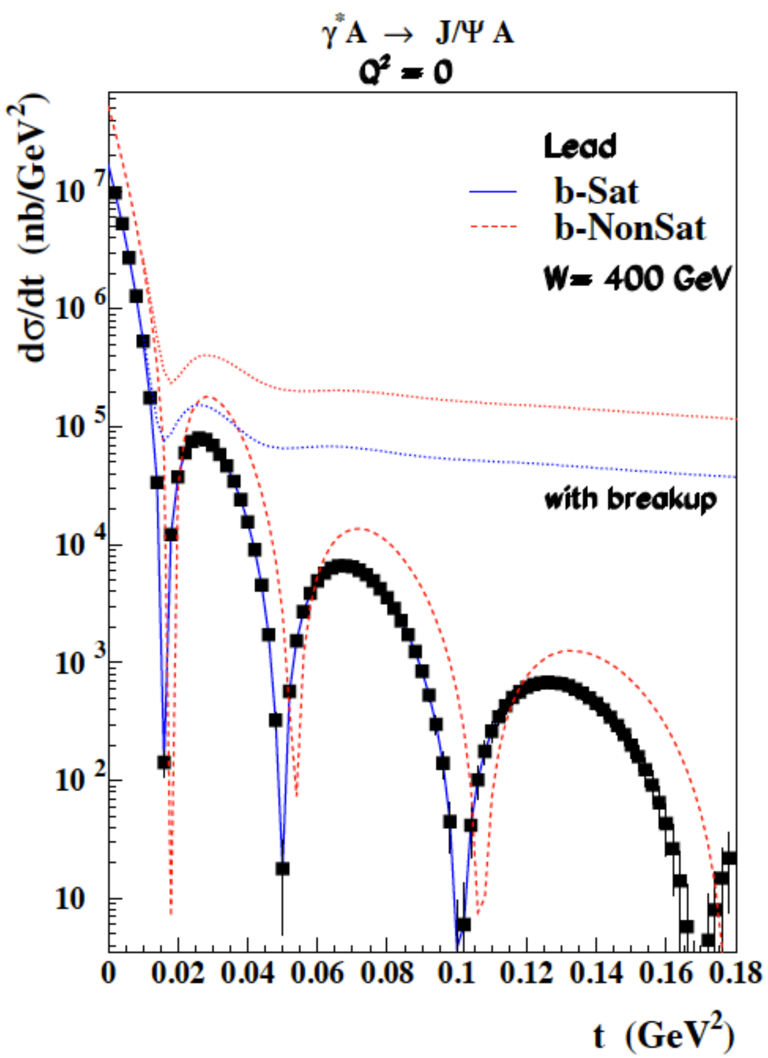
coherent



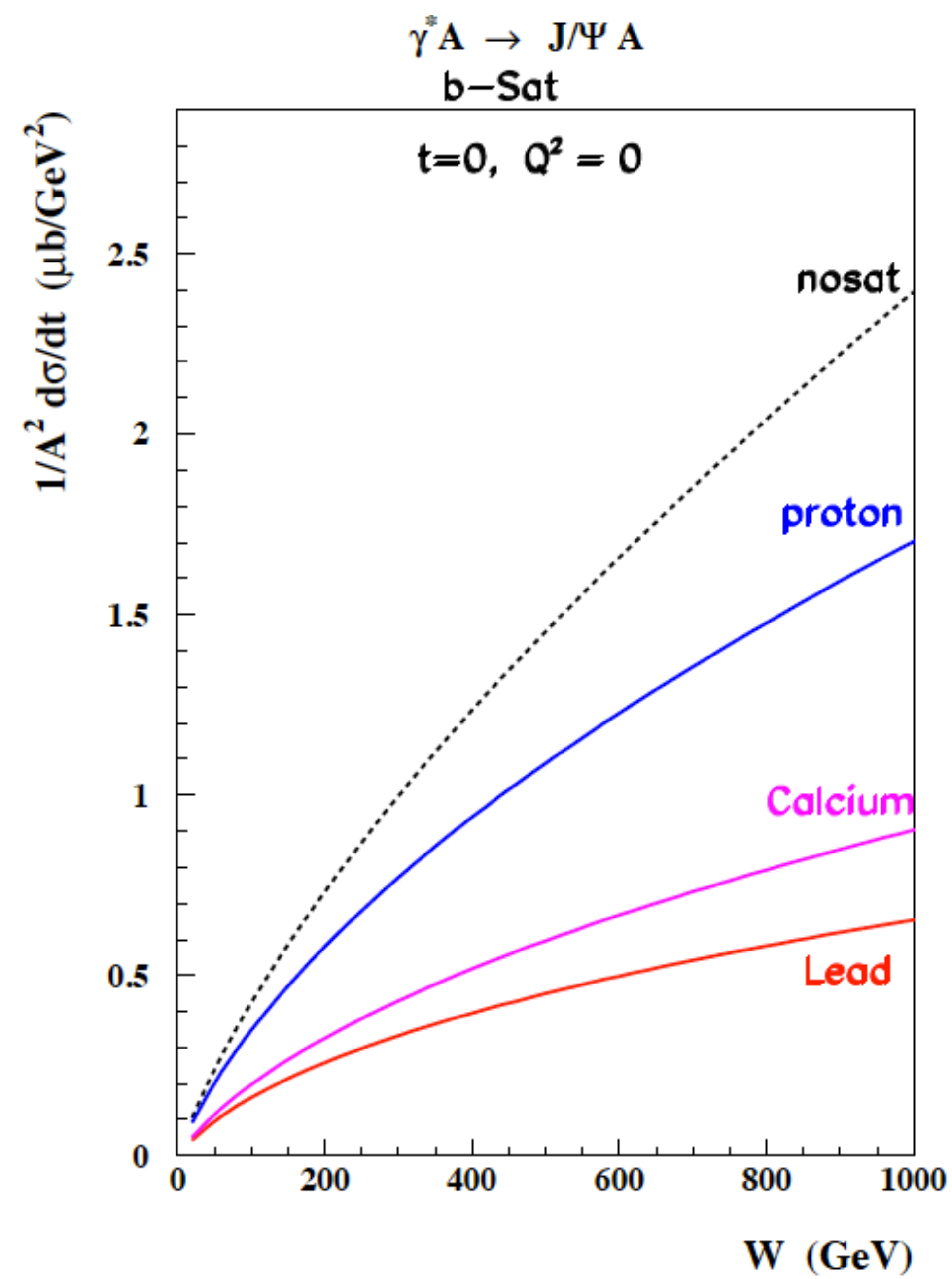
incoherent

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?

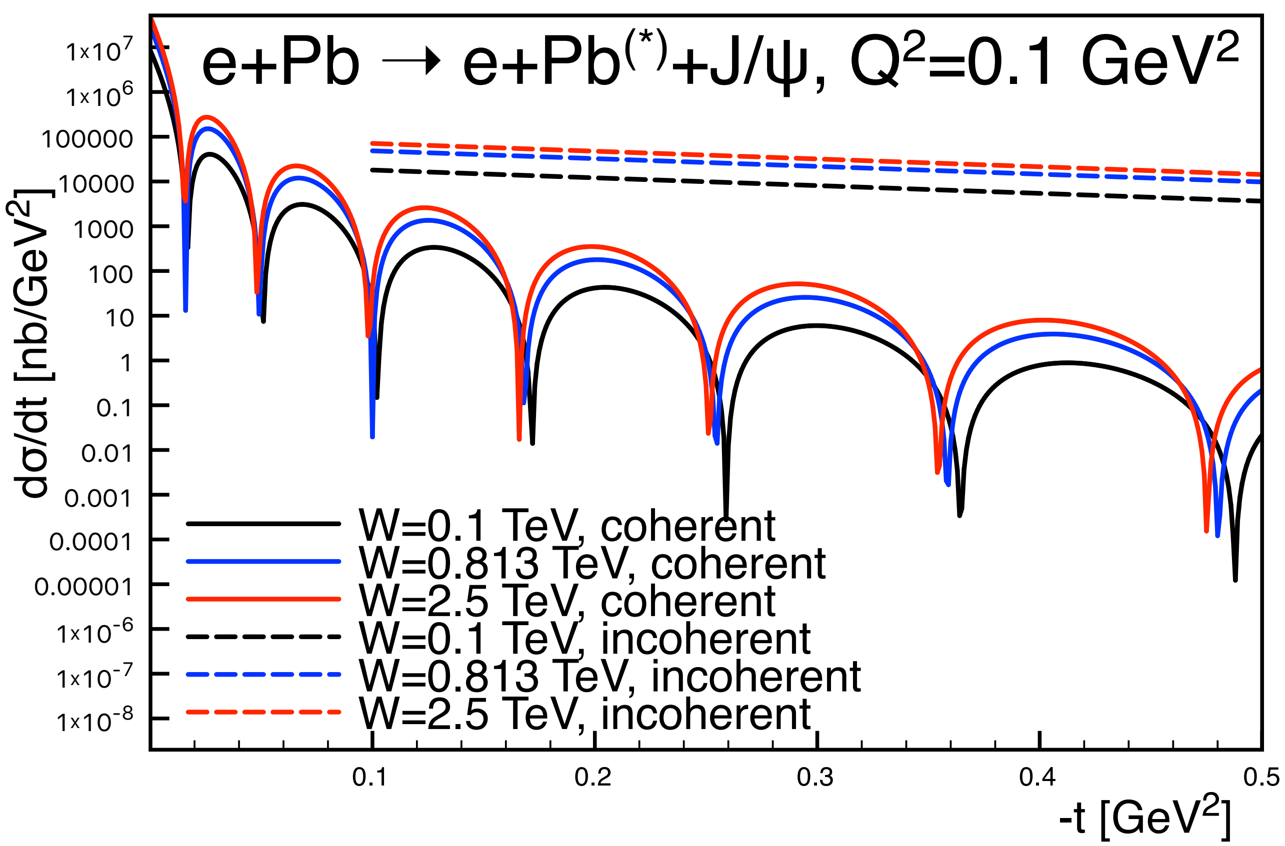


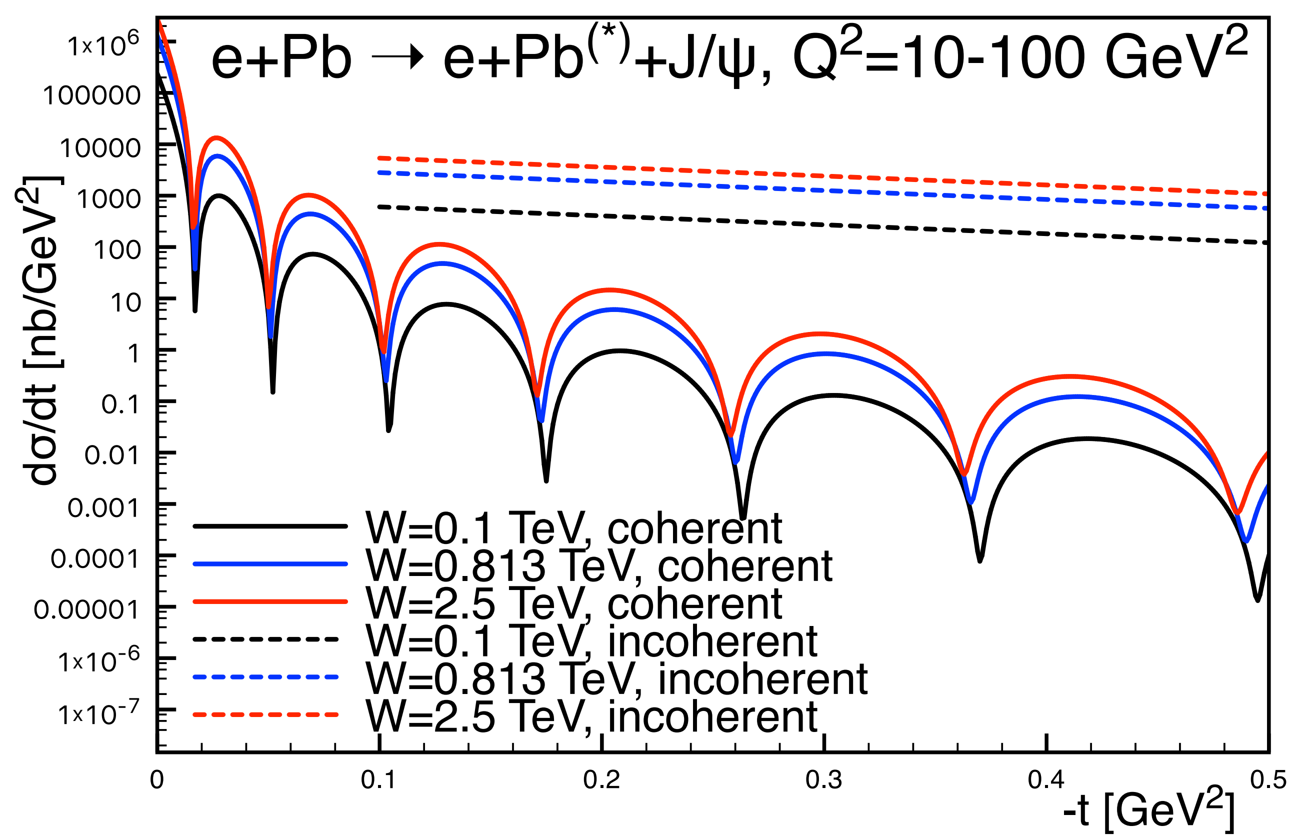
Energy dependence for different targets.



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

Exclusive diffraction on nuclei

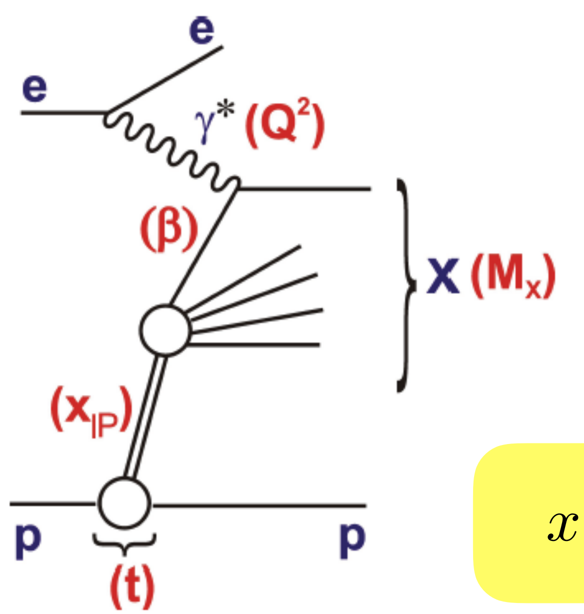




Mantysaari, 1011.1988, IPsat

Energy and scale dependence of the position of dips in |t|. Provides information about nuclear structure. Can perform similar measurements on proton target to estimate the saturation in proton vs nuclei. Challenging experimentally.

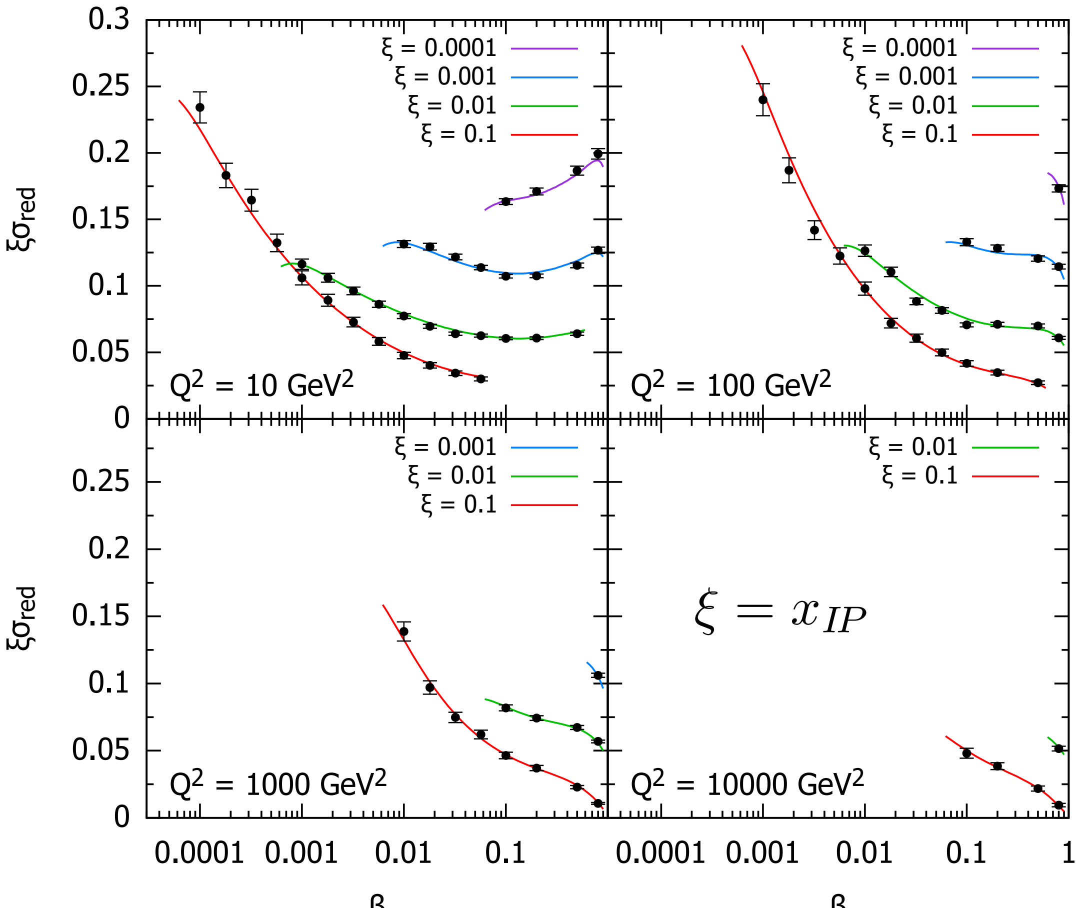
Inclusive diffraction



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

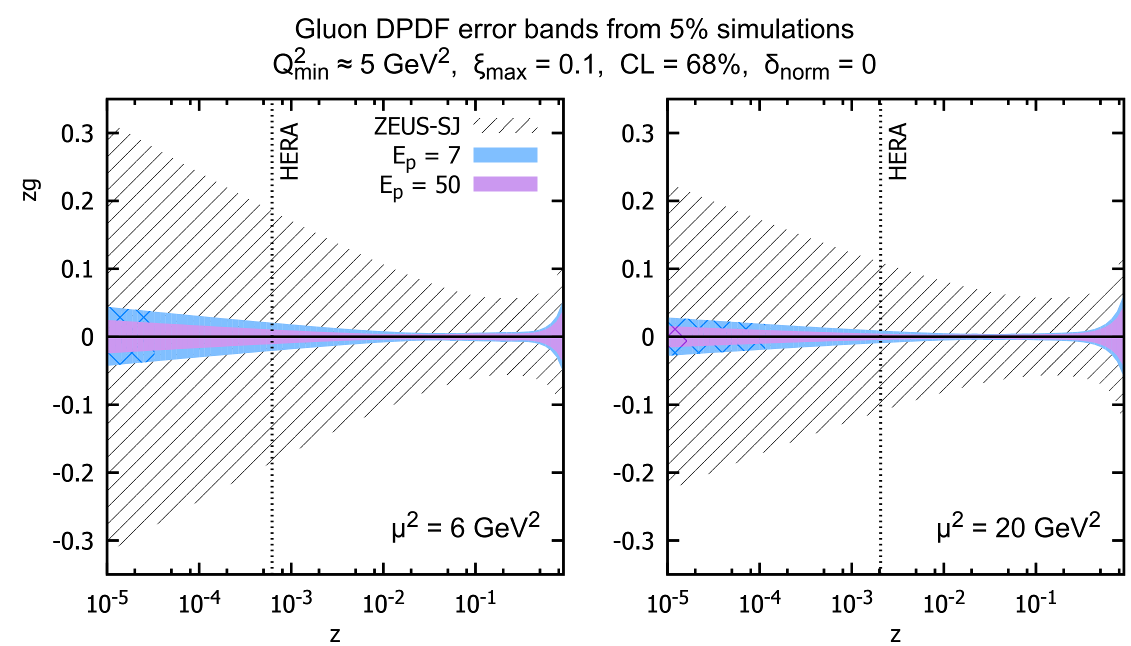
- Low x_{IP} → cleanly separate diffraction
- Low β → Novel low x effects
- High Q^2 → Lever-arm for gluon,flavour decomposition
- Large M_X → Jets, heavy flavours, W/Z …
- Large E_T → Precision QCD with jets …

e p E_p = 7 TeV, E_e = 60 GeV, L = 2 fb^{-1}



High quality data for inclusive diffraction

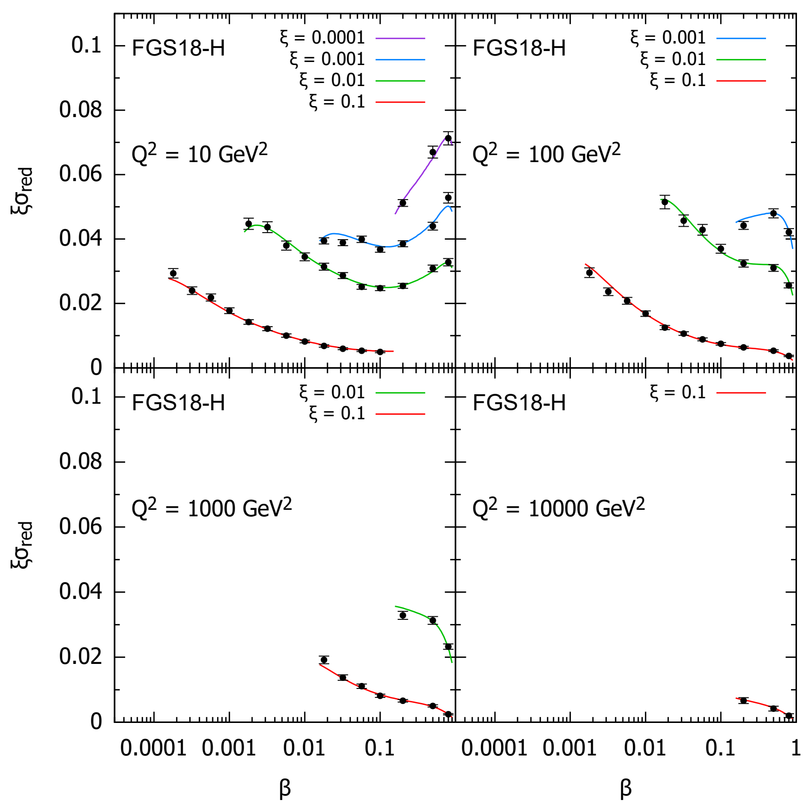
DPDFs uncertainty reduction by pseudodata of LHeC and FCC-eh



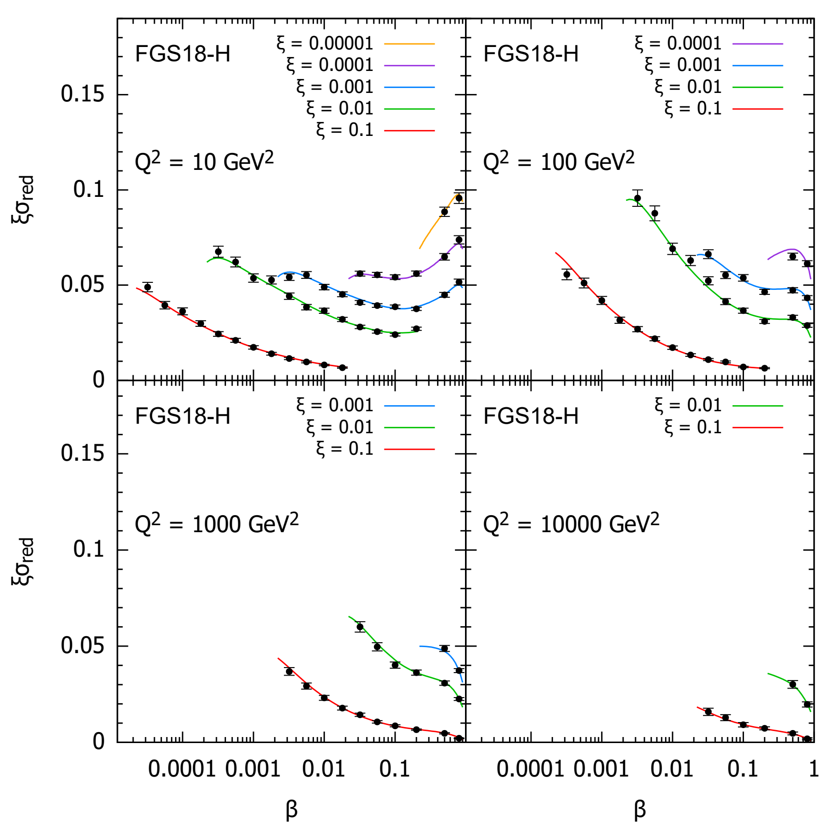
Precise extraction of diffractive PDFs
Tests of factorization in QCD

Inclusive diffraction: nuclei

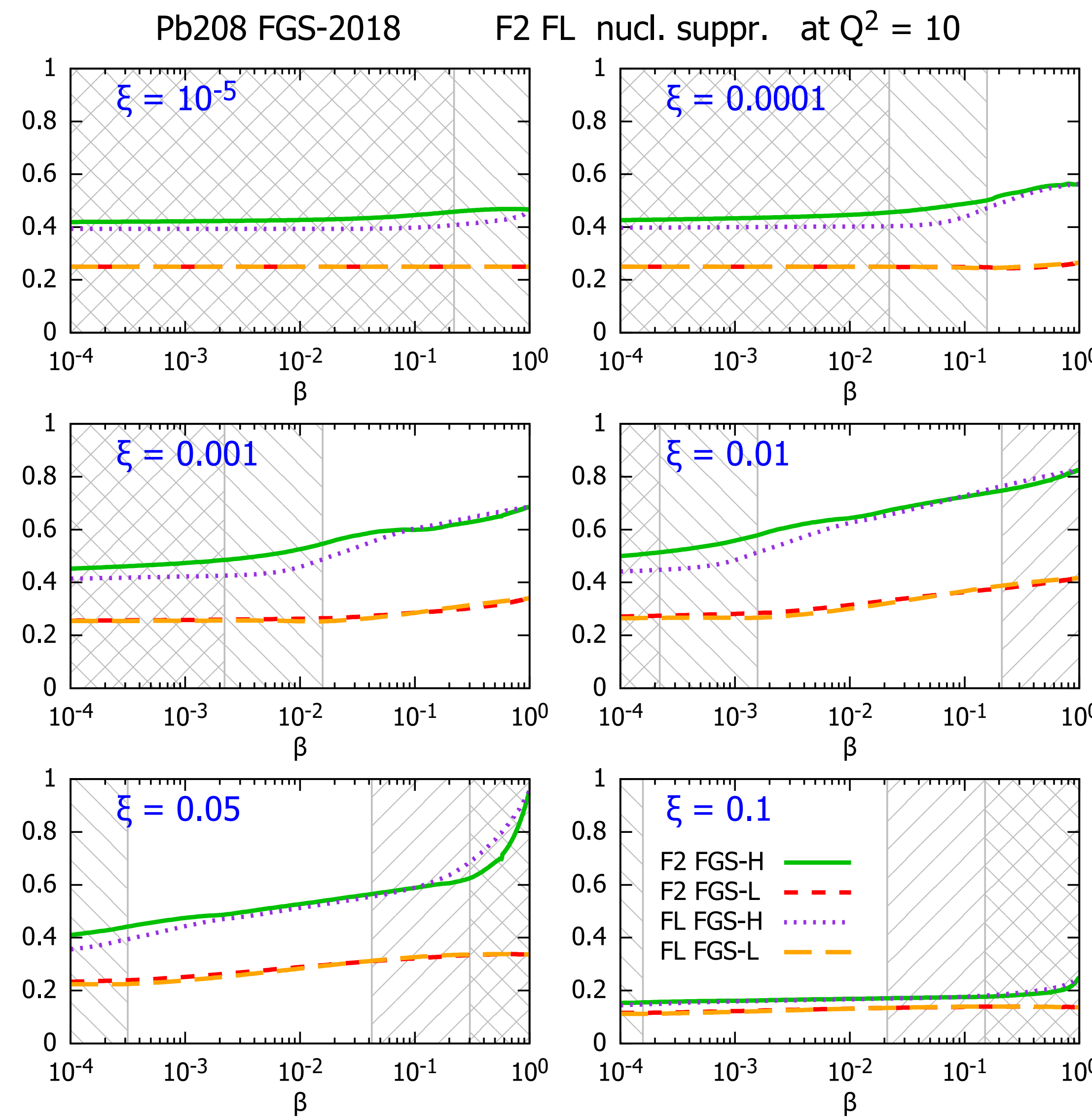
/A = 2.76 TeV, E_e = 60 GeV, L = 2 fb^{-1}



e Pb E_{Pb}/A = 19.7 TeV, E_e = 60 GeV, L = 2 fb^{-1}



Similar high quality data for diffraction in eA
Possible extraction of diffractive nuclear PDFs for the first time!



Examples of nuclear ratios for structure functions
In different scenarios for Frankfurt, Guzey, Strikman model.

Summary

- The LHeC and FCC-eh will explore a completely new region in (x,Q) for eA collisions. Enlarge the kinematic space by 4 orders of magnitude over what was previously measured in DIS.
- Precise determination of nuclear PDFs which cannot be matched at hadron colliders.
- Coupled with ep, would allow to test the saturation at low x and with different A dependence.
- Precise measurements of heavy flavors in eA.
- Exclusive VM diffractive production would allow to explore the nuclear structure in impact parameter.
- New possibilities for the inclusive diffraction: extraction of nuclear diffractive parton densities. Checks of QCD factorization and relation between diffraction in ep and shadowing in eA.
- Other processes studied: azimuthal decorrelations, radiation and hadronization.