Workshop: Low-x gluon structure of nuclei
and signals of saturation at LHC
CERN, March 27th 2018

Lessons from EIC: how to determine the gluon density

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Unión Europea
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"Una manera de hacer Europa"

EXCELENCIA
MARÍA
DE MAEZTU

GOBIERNO
DE ESPAÑA

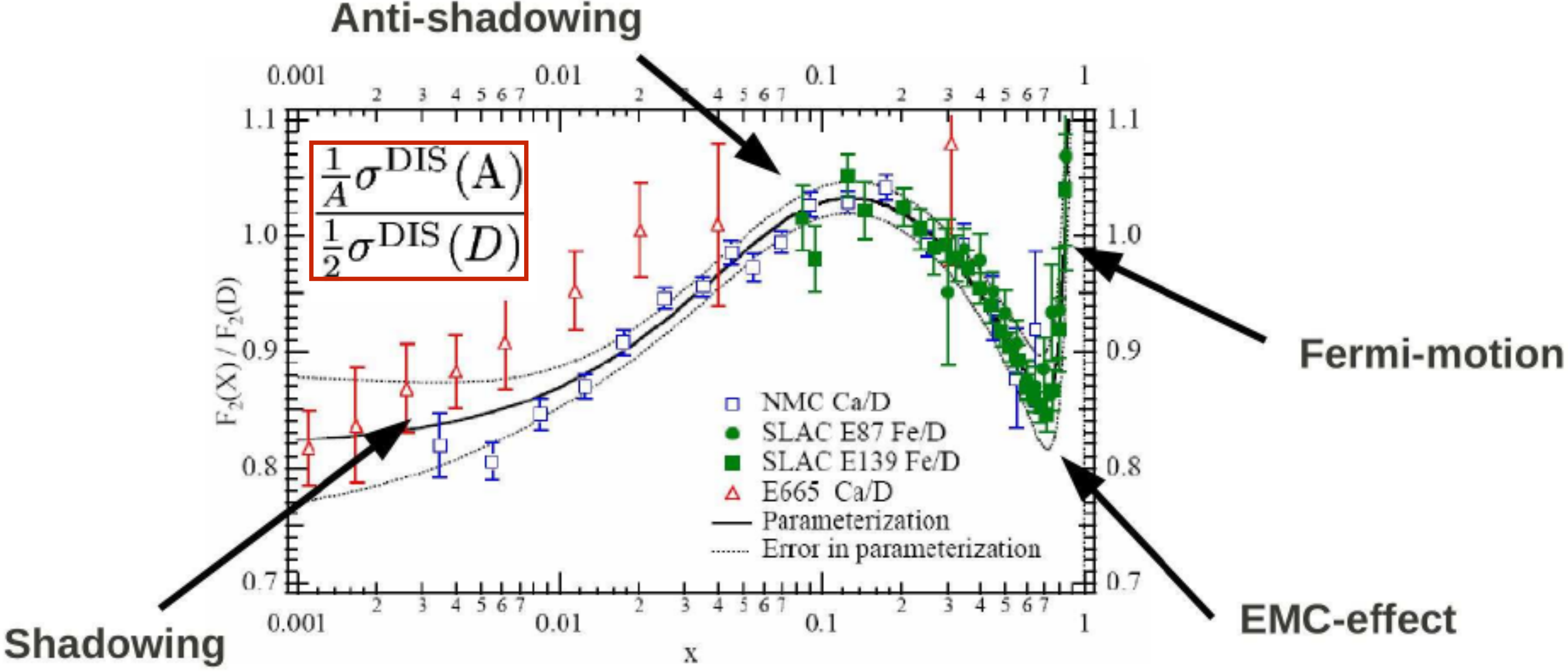
MINISTERIO
DE ECONOMIA
Y COMPETITIVIDAD

XUNTA
DE GALICIA

Contents:

See the talks by Vadim Guzey, Juan Rojo and Ilkka Helenius.

Collinear approach:



- Bound nucleon$\neq$free nucleon: search for process independent nPDFs that realise this condition, assuming collinear factorisation.

$$\sigma_{\rm DIS}^{\ell+A\to\ell+X} = \sum_{i=q,\overline{q},g} \underbrace{f_i^A(\mu^2)}_{\text{Nuclear PDFs, obeying the standard DGLAP}} \otimes \underbrace{\hat{\sigma}_{\rm DIS}^{\ell+i\to\ell+X}(\mu^2)}_{\text{Usual perturbative coefficient functions}}$$

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

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

Collinear approach:

Anti-shadowing

- At an ep/eA collider:
  - ➜ PDF of a single nucleus possible, no need of ratios that would be obtained a posteriori.
  - ➜ Same method of extraction in both ep and eA.
  - ➜ Physics beyond standard collinear factorisation can be studied in a single setup, with size effects disentangled from energy effects and a large lever arm in x at perturbative Q².
- Bound nucleon ≠ free nucleon: search for process independent nPDFs that realise this condition, assuming collinear factorisation.

$$\sigma_{\rm DIS}^{\ell+A\to\ell+X} = \sum_{i=q,\bar{q},g} \underbrace{f_i^A(\mu^2)}_{\text{Nuclear PDFs, obeying the standard DGLAP}} \otimes \underbrace{\hat{\sigma}_{\rm DIS}^{\ell+i\to\ell+X}(\mu^2)}_{\text{Usual perturbative coefficient functions}}$$

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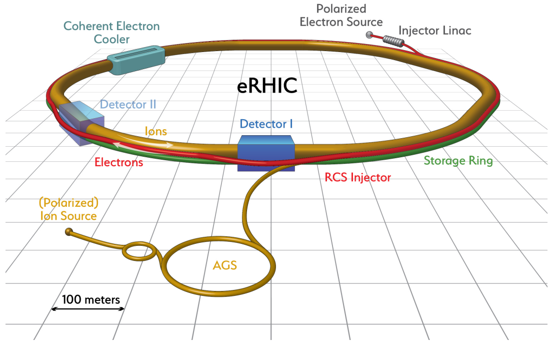
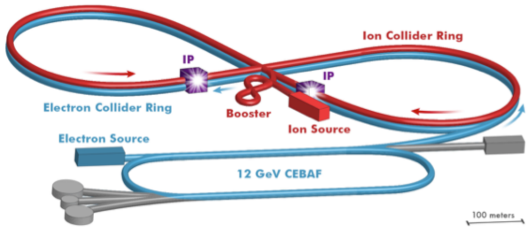
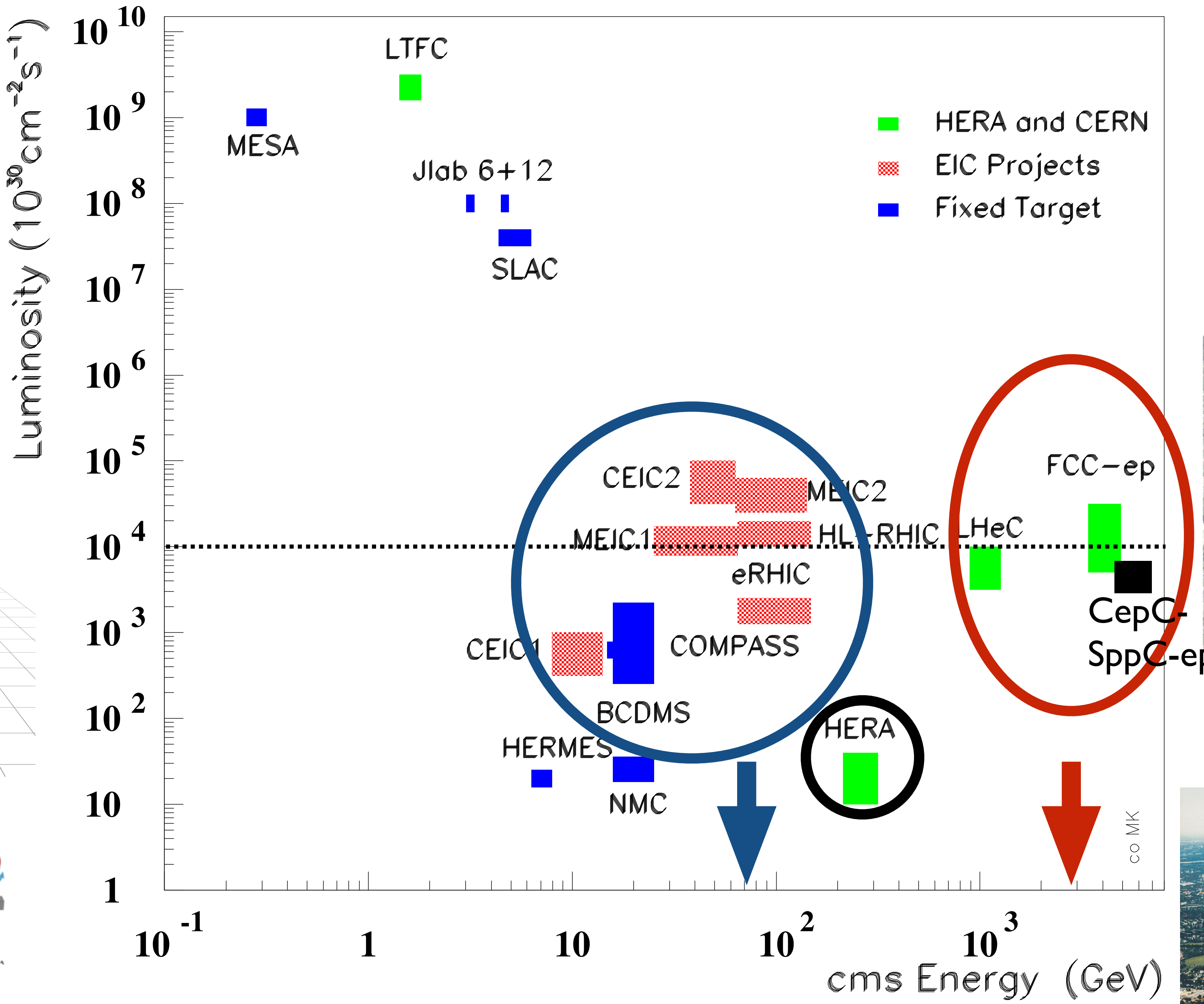
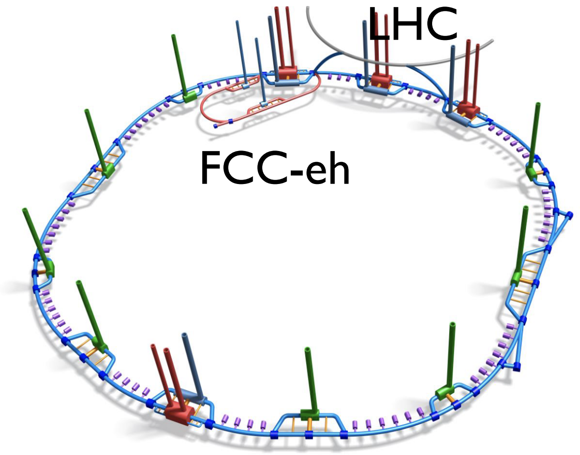
Summary of machines:

Lepton-proton/nucleus scattering facilities









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Available sets:

SET		**HKN07** PRC76 (2007) 065207	**EPS09** JHEP 0904 (2009) 065	**DSSZ** PRD85 (2012) 074028	**nCTEQ15** PRD93 (2016) 085037	**KA15** PRD93 (2016) 014036	**EPPS16** EPJC C77 (2017)163
data	eDIS	✔	✔	✔	✔	✔	✔
	DY	✔	✔	✔	✔	✔	✔
	π^0	✘	✔	✔	✔	✘	✔
	νDIS	✘	✘	✔	✘	✘	✔
	pPb	✘	✘	✘	✘	✘	✔
# data		1241	929	1579	740	1479	1811
order		NLO	NLO	NLO	NLO	NNLO	NLO
proton PDF		MRST98	CTEQ6.1	MSTW2008	~CTEQ6.1	JR09	CT14NLO
mass scheme		ZM-VFNS	ZM-VFNS	GM-VFNS	GM-VFNS	ZM-VFNS	GM-VFNS
comments		$\Delta\chi^2=13.7$, ratios, no EMC for gluons	$\Delta\chi^2=50$, ratios, huge shadowing-antishadowing	$\Delta\chi^2=30$, ratios, medium-modified FFs for π^0	$\Delta\chi^2=35$, PDFs, valence flavour sep., not enough sensitivity	PDFs, deuteron data included	$\Delta\chi^2=52$ flavour sep., ratios, LHC pPb data

Available sets:

- Centrality dependence (EPS09s) not from data but from the A-dependence of the parameters.
- Several models provide it: Vogt et al., FGS, Ferreiro et al.,…

SET	**HKN07** PRC76 (2007)	**EPS09** JHEP 0904	**DSSZ** PRD85 (2012) 074028	**nCTEQ15** PRD93 (2016) 085037	**KA15** PRD93 (2016) 014036	**EPPS16** EPJC C77 (2017)163
			✔	✔	✔	✔
			✔	✔	✔	✔
			✔	✔	✘	✔
			✔	✘	✘	✔
			✘	✘	✘	✔
			1579	740	1479	1811
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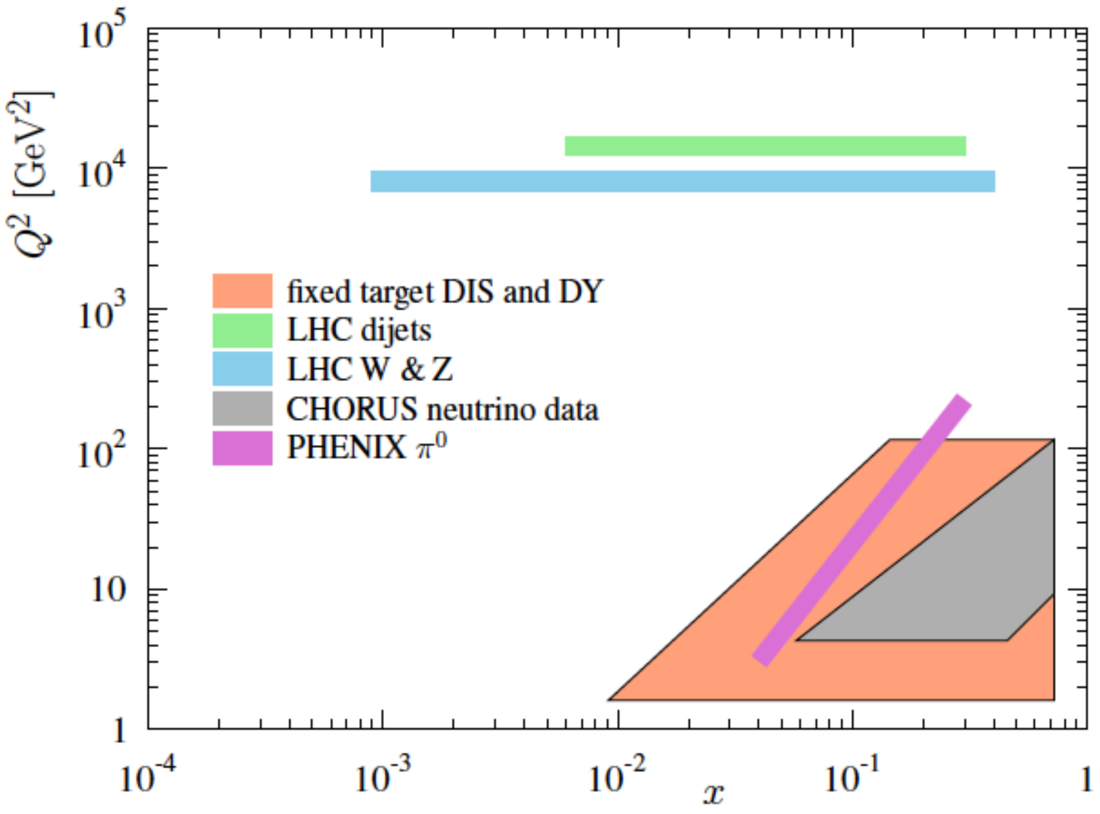
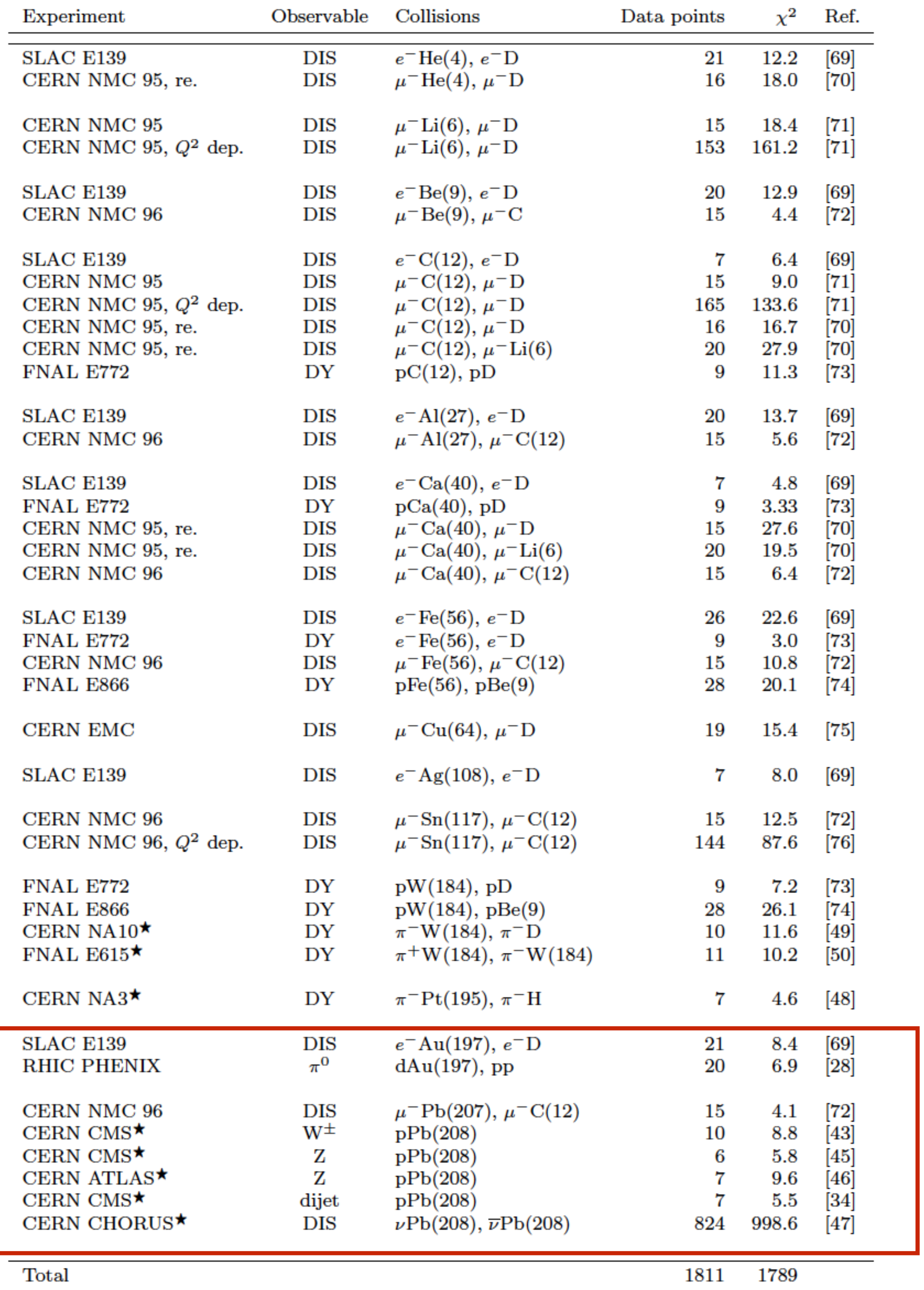
EPPS16:



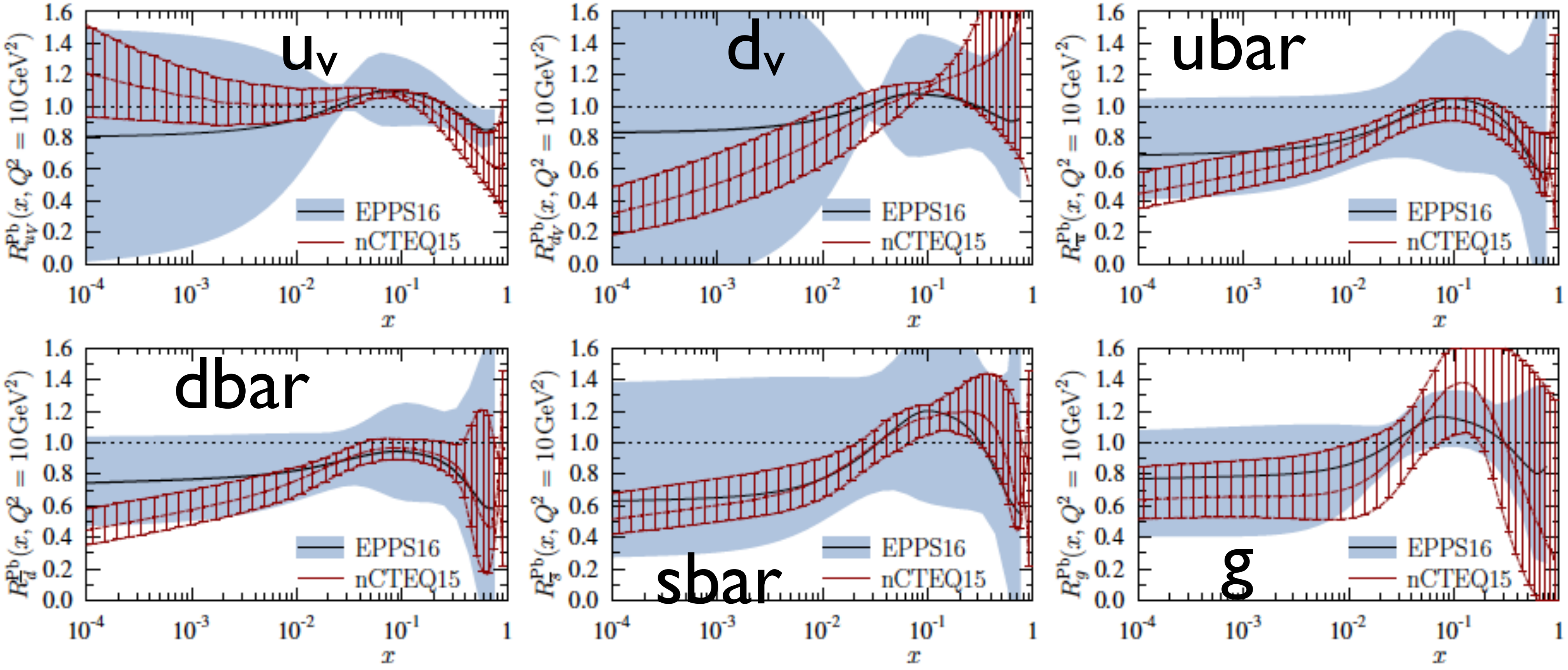
- Most Pb data from CHORUS, 30 Pb points from pPb@LHC: fit for a single nucleus not possible.



Experiment	Observable	Collisions	Data points	χ^2	Ref.
SLAC E139	DIS	e^-He(4), e^-D	21	12.2	[69]
CERN NMC 95, re.	DIS	μ^-He(4), μ^-D	16	18.0	[70]
CERN NMC 95	DIS	μ^-Li(6), μ^-D	15	18.4	[71]
CERN NMC 95, Q^2 dep.	DIS	μ^-Li(6), μ^-D	153	161.2	[71]
SLAC E139	DIS	e^-Be(9), e^-D	20	12.9	[69]
CERN NMC 96	DIS	μ^-Be(9), μ^-C	15	4.4	[72]
SLAC E139	DIS	e^-C(12), e^-D	7	6.4	[69]
CERN NMC 95	DIS	μ^-C(12), μ^-D	15	9.0	[71]
CERN NMC 95, Q^2 dep.	DIS	μ^-C(12), μ^-D	165	133.6	[71]
CERN NMC 95, re.	DIS	μ^-C(12), μ^-D	16	16.7	[70]
CERN NMC 95, re.	DIS	μ^-C(12), μ^-Li(6)	20	27.9	[70]
FNAL E772	DY	pC(12), pD	9	11.3	[73]
SLAC E139	DIS	e^-Al(27), e^-D	20	13.7	[69]
CERN NMC 96	DIS	μ^-Al(27), μ^-C(12)	15	5.6	[72]
SLAC E139	DIS	e^-Ca(40), e^-D	7	4.8	[69]
FNAL E772	DY	pCa(40), pD	9	3.33	[73]
CERN NMC 95, re.	DIS	μ^-Ca(40), μ^-D	15	27.6	[70]
CERN NMC 95, re.	DIS	μ^-Ca(40), μ^-Li(6)	20	19.5	[70]
CERN NMC 96	DIS	μ^-Ca(40), μ^-C(12)	15	6.4	[72]
SLAC E139	DIS	e^-Fe(56), e^-D	26	22.6	[69]
FNAL E772	DY	e^-Fe(56), e^-D	9	3.0	[73]
CERN NMC 96	DIS	μ^-Fe(56), μ^-C(12)	15	10.8	[72]
FNAL E866	DY	pFe(56), pBe(9)	28	20.1	[74]
CERN EMC	DIS	μ^-Cu(64), μ^-D	19	15.4	[75]
SLAC E139	DIS	e^-Ag(108), e^-D	7	8.0	[69]
CERN NMC 96	DIS	μ^-Sn(117), μ^-C(12)	15	12.5	[72]
CERN NMC 96, Q^2 dep.	DIS	μ^-Sn(117), μ^-C(12)	144	87.6	[76]
FNAL E772	DY	pW(184), pD	9	7.2	[73]
FNAL E866	DY	pW(184), pBe(9)	28	26.1	[74]
CERN NA10*	DY	π^-W(184), π^-D	10	11.6	[49]
FNAL E615*	DY	π^+W(184), π^-W(184)	11	10.2	[50]
CERN NA3*	DY	π^-Pt(195), π^-H	7	4.6	[48]
SLAC E139	DIS	e^-Au(197), e^-D	21	8.4	[69]
RHIC PHENIX	π^0	dAu(197), pp	20	6.9	[28]
CERN NMC 96	DIS	μ^-Pb(207), μ^-C(12)	15	4.1	[72]
CERN CMS*	$W^\pm$	pPb(208)	10	8.8	[43]
CERN CMS*	Z	pPb(208)	6	5.8	[45]
CERN ATLAS*	Z	pPb(208)	7	9.6	[46]
CERN CMS*	dijet	pPb(208)	7	5.5	[34]
CERN CHORUS*	DIS	νPb(208), $\overline{\nu}$Pb(208)	824	998.6	[47]
Total			1811	1789	

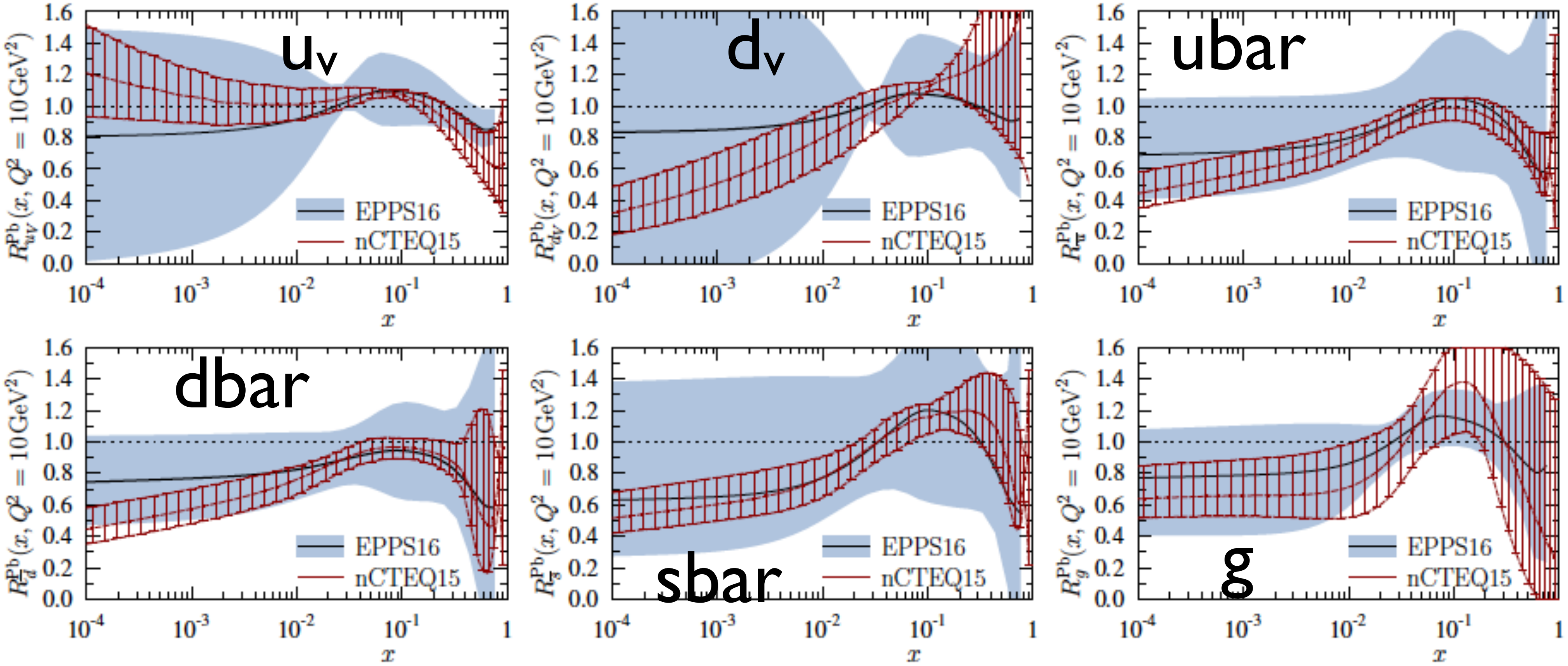
EPPS16:

- nCTEQ15 vs. EPPS16: note the parametrisation bias.

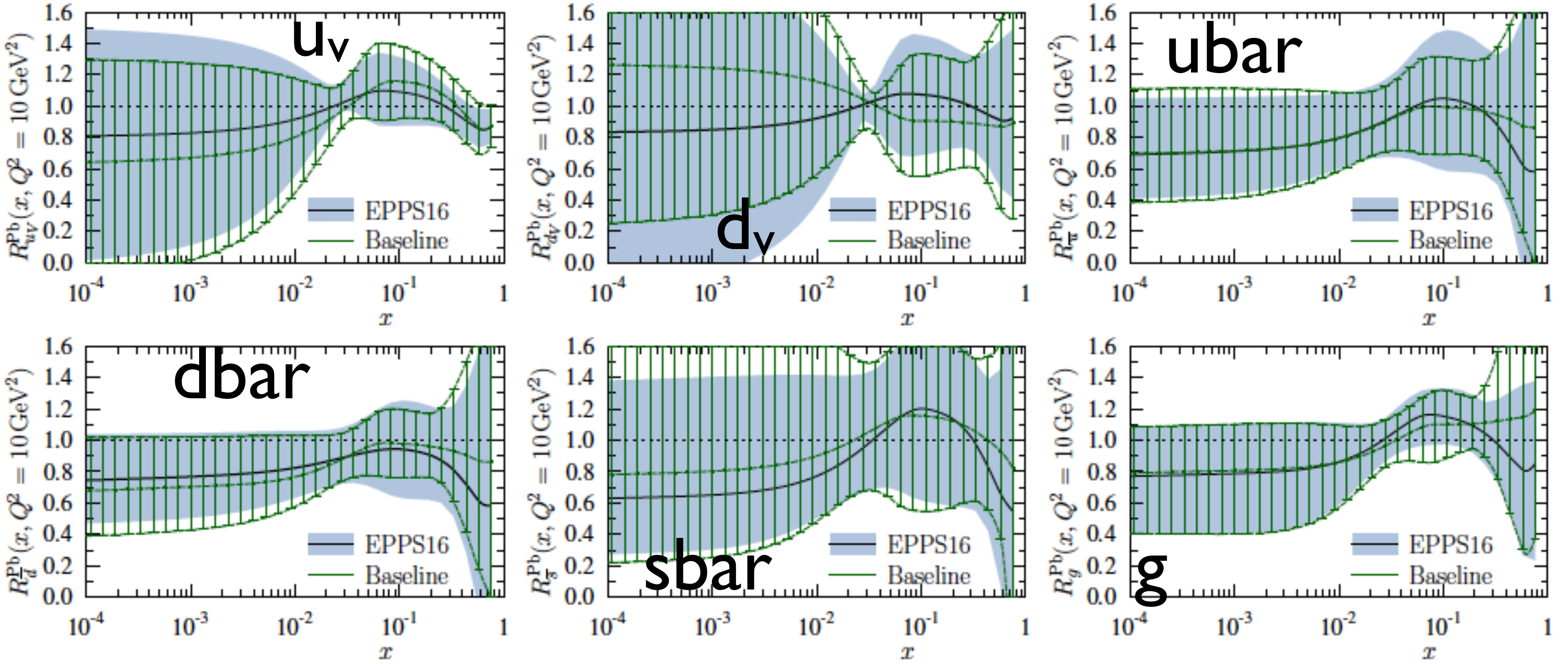


EPPS16:

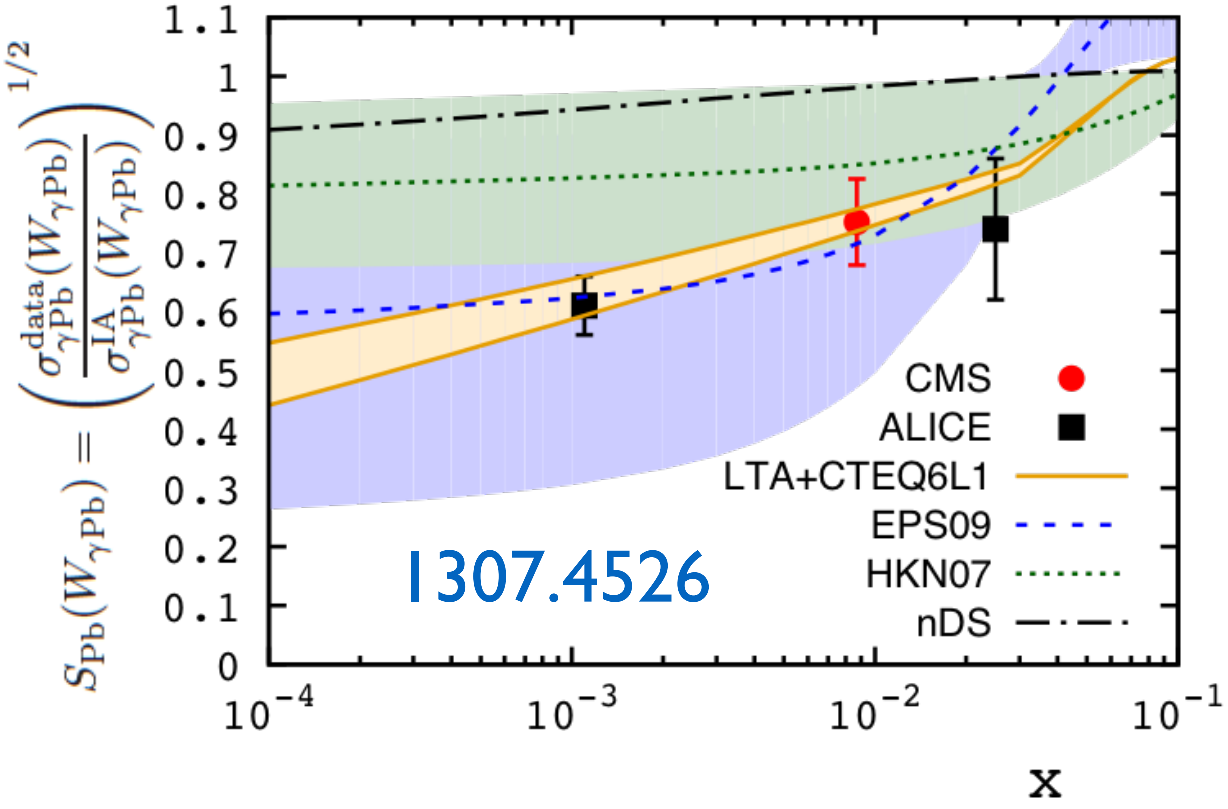
- nCTEQ15 vs. EPPS16: note the parametrisation bias.



- Presently available LHC data seem not to have a large effect: large-x glue (baseline=no ν, no LHC data).

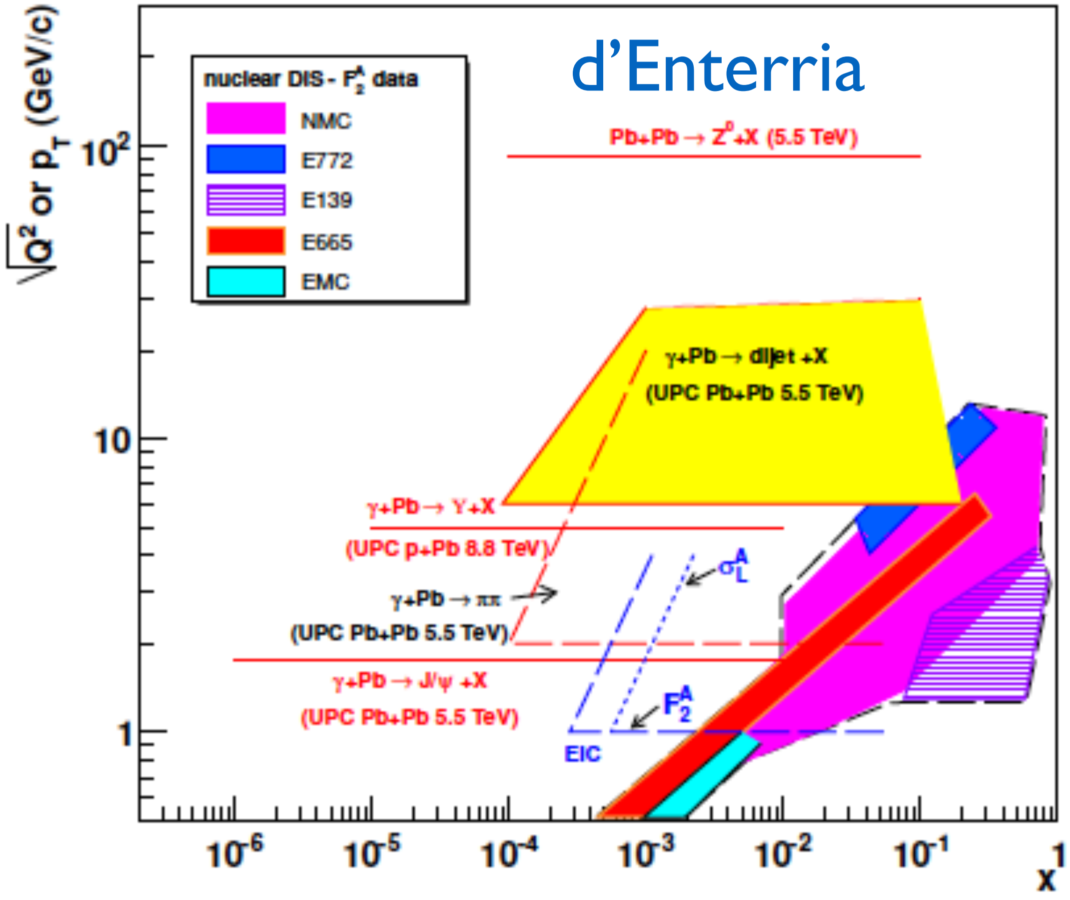


UPCs:



1307.4526

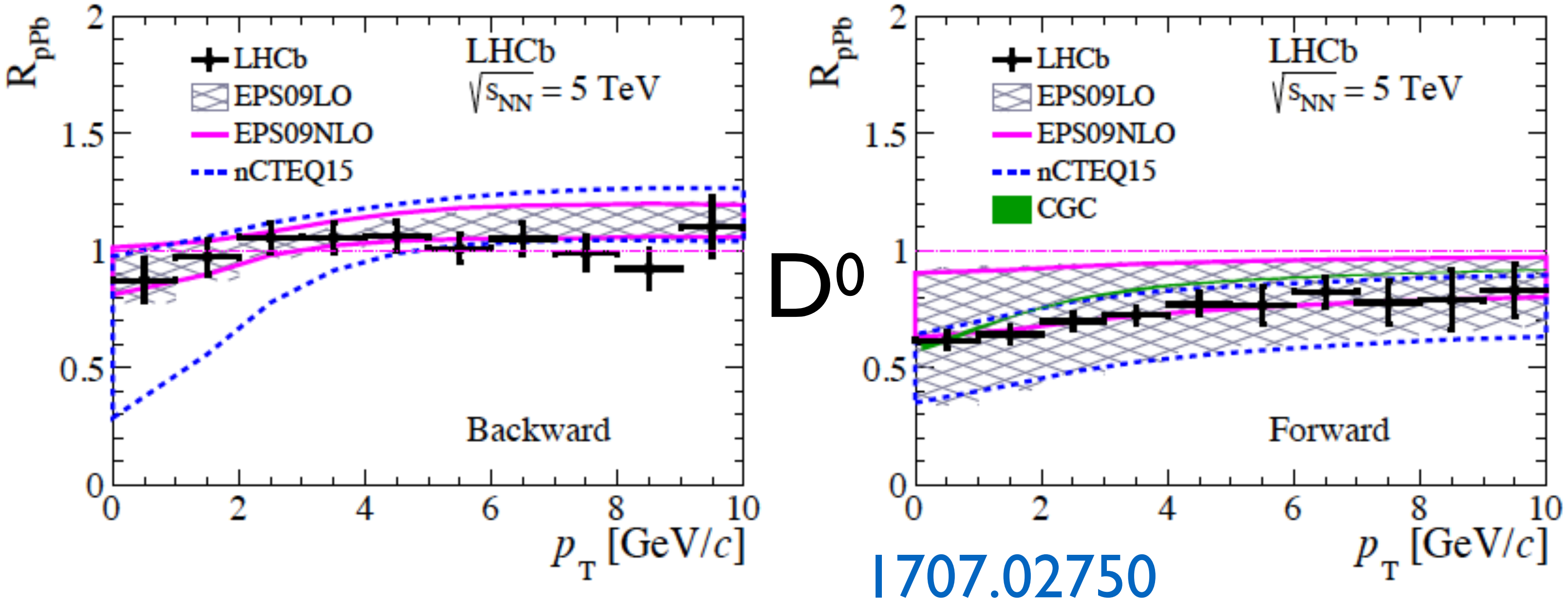
- UPCs offer possibilities for constraining both nPDFs: they were the first indication of nuclear shadowing.



d’Enterria

- Uncertainties on the precision and applicability of standard collinear factorisation exist for many of the processes currently studied e.g. exclusive VM production: work still required for this data to be included in global fits.

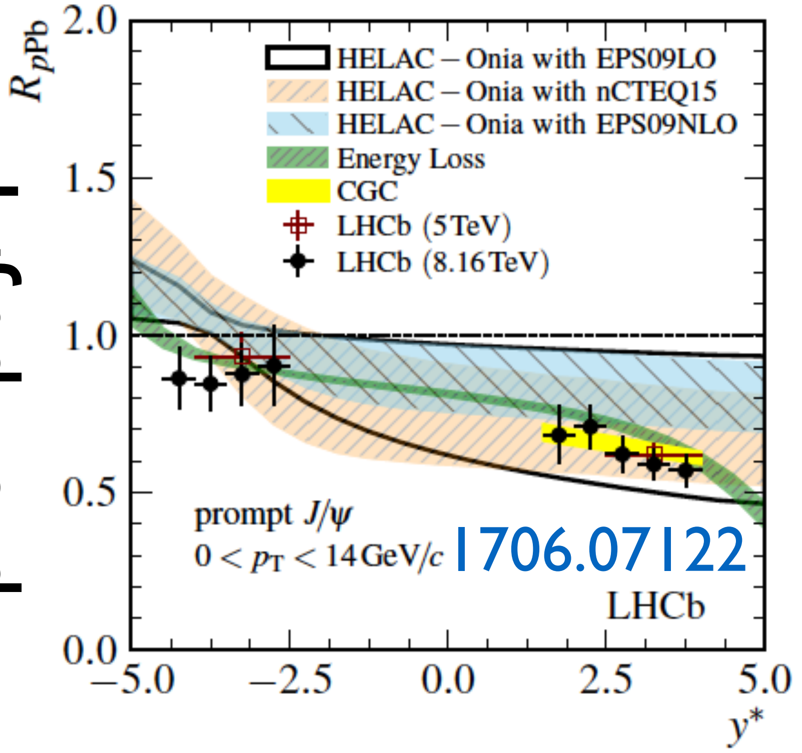
Open charm and J/ψ:



D^0

1707.02750

prompt J/ψ



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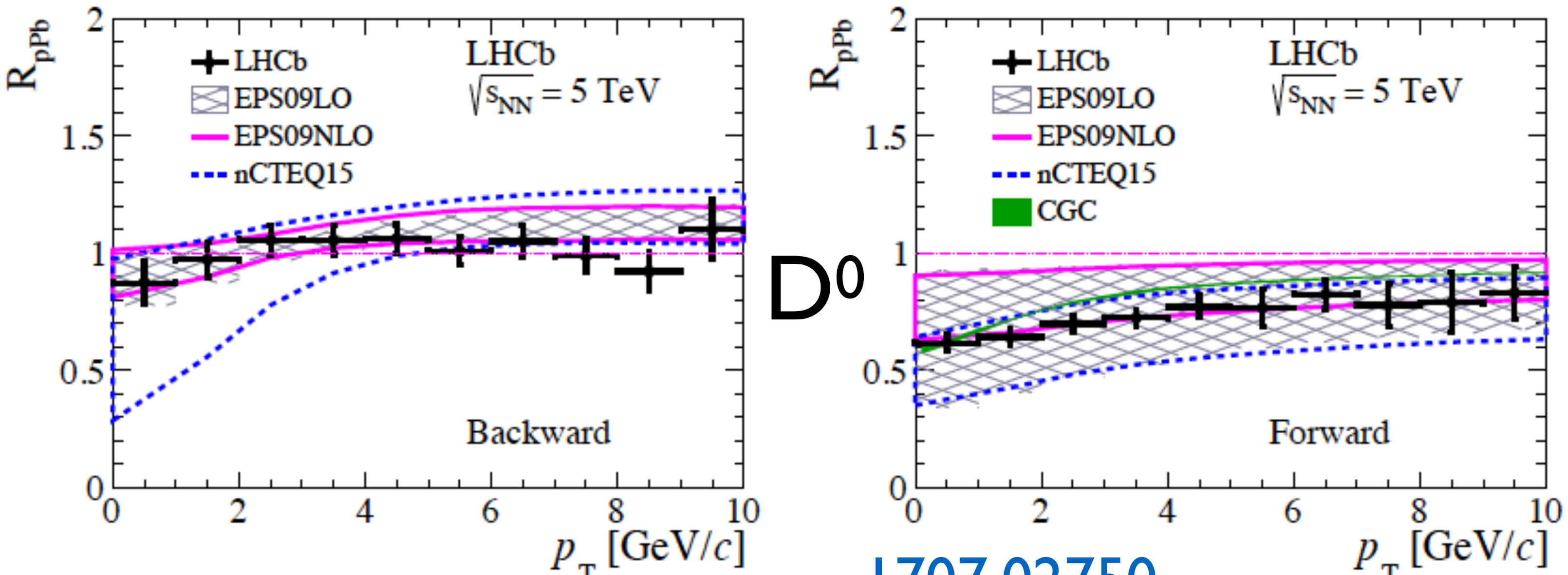
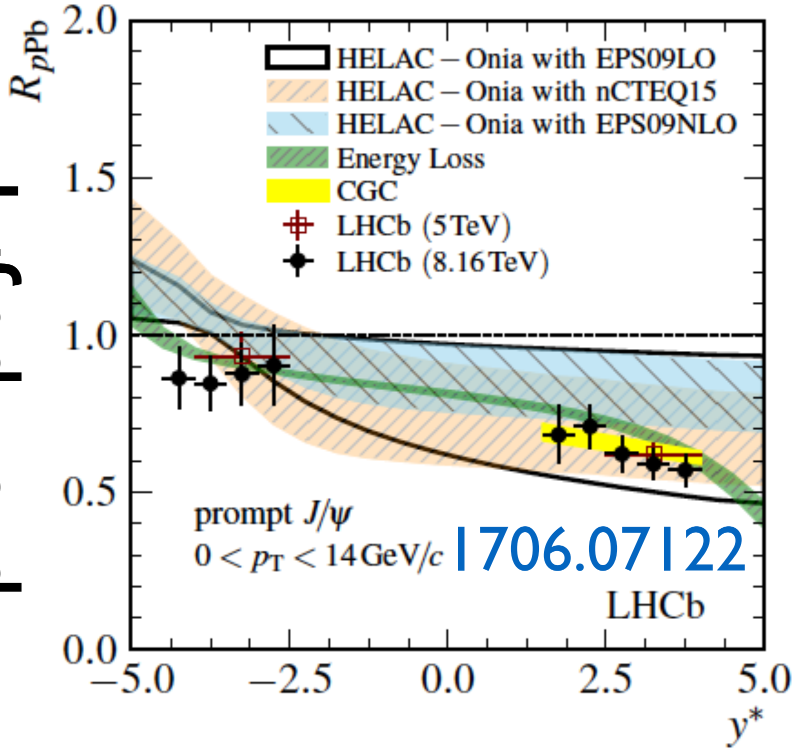
Open charm and J/ψ:



D^0

1707.02750

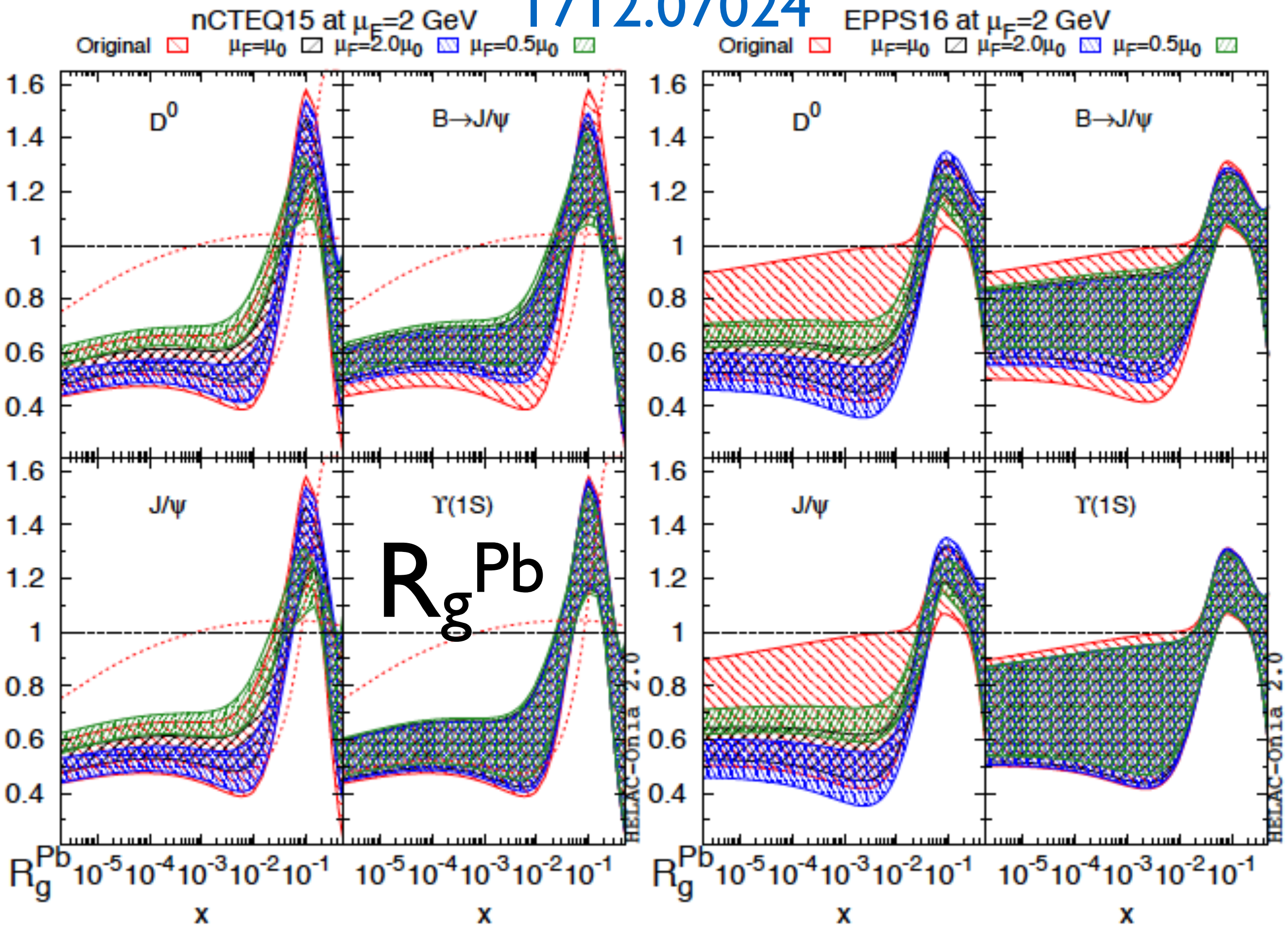
prompt J/ψ



1706.07122

- Theoretical control in PT over forward D or J/ψ under debate, even in pp: scales, DPS, non-linear dynamics, …, see 1610.09373 vs. 1710.05935.
- E.g. quarkonium: superposition of nPDFs + eloss/absorption + comovers for ψ' + …
- Collectivity (flow for D in pPb as for charged hadrons in pPb and PbPb?) would limit the use of low p_T data for extraction of nPDFs.

1712.07024



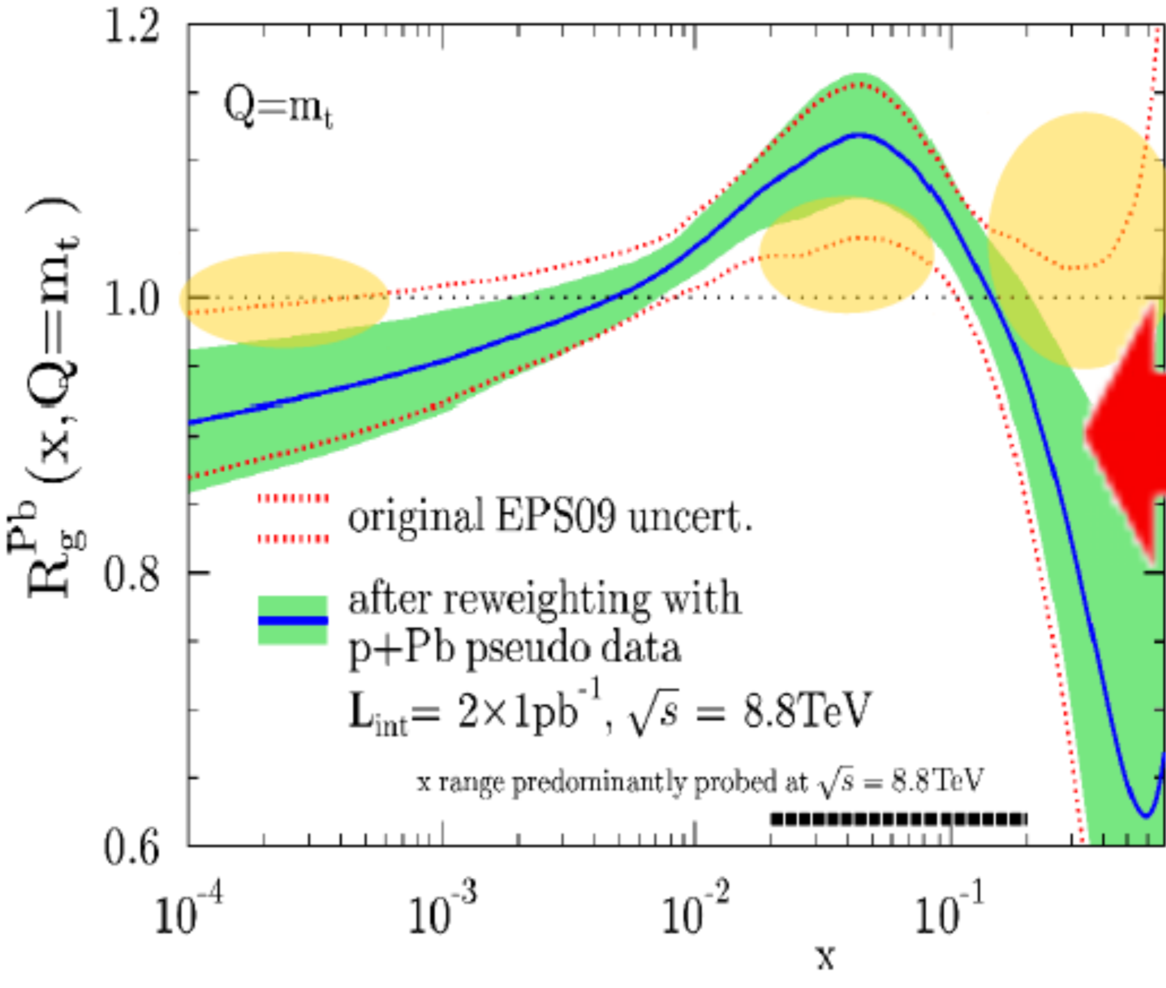
R_g^{Pb}

N. Armesto, 27.03.2018 - Lessons from EIC: 2. Present status of nPDFs.

Tops at HL-LHC:

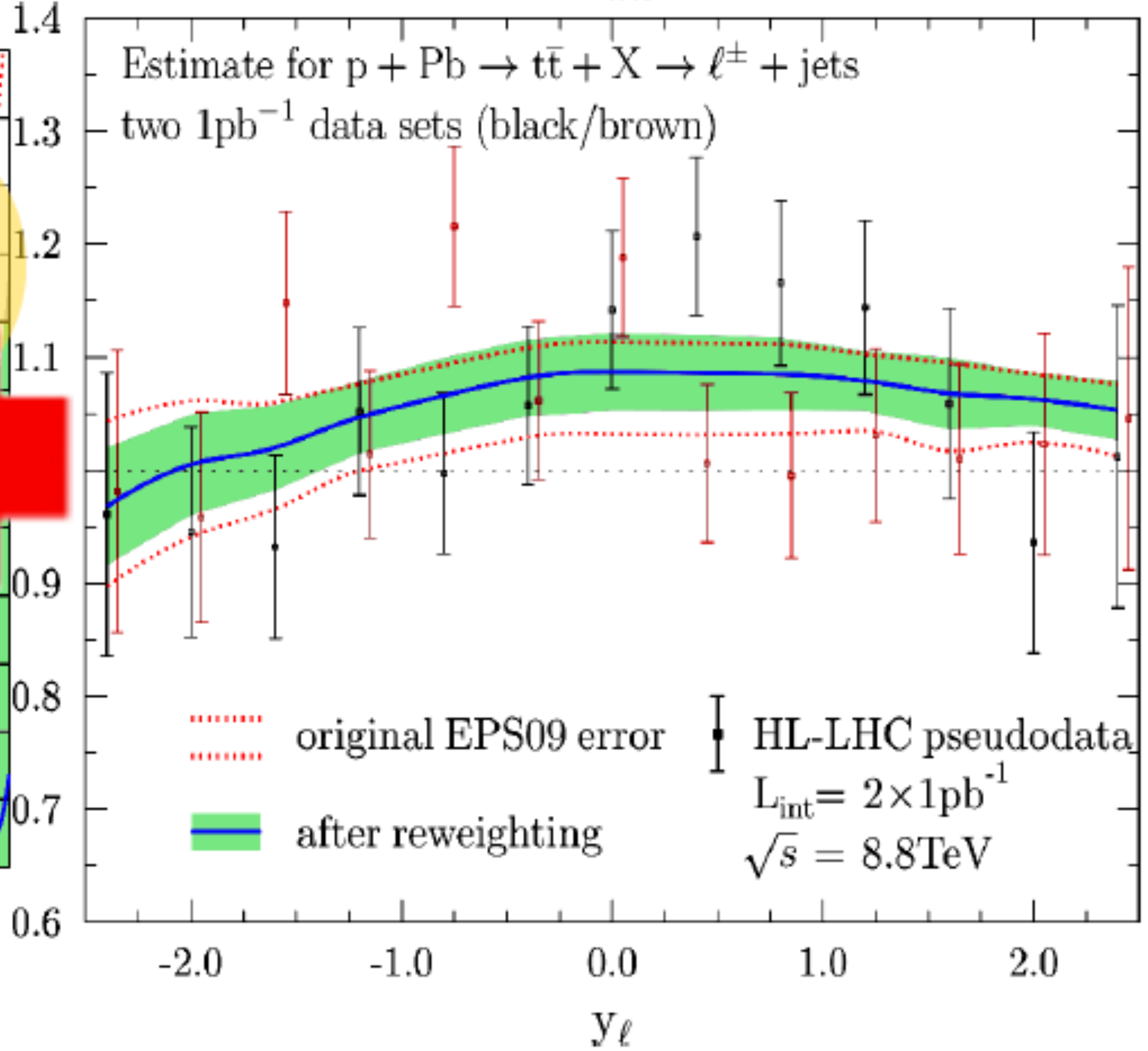
pPb→ttbar+X (8.8 TeV): Gluon density constraints

- Improved gluon density via Hessian PDF reweighting



- ~50% reduction in uncertainties at antishadowing (x~0.05) and EMC (x~0.4) regions.

- Isolated lepton y-distrib. after cuts: (Pseudodata for L_{int}= 1 pb^{-1})

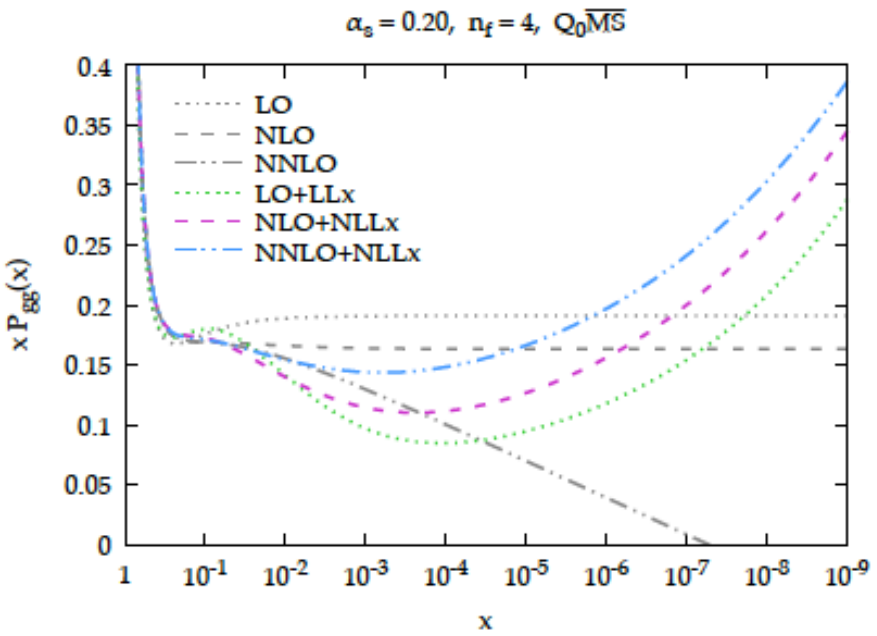


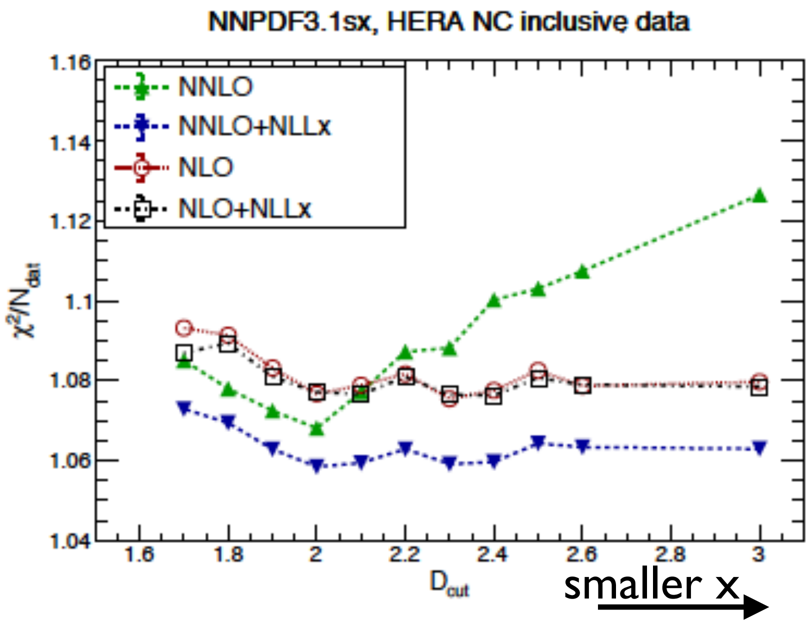
(5% syst. uncertainties dominate now)

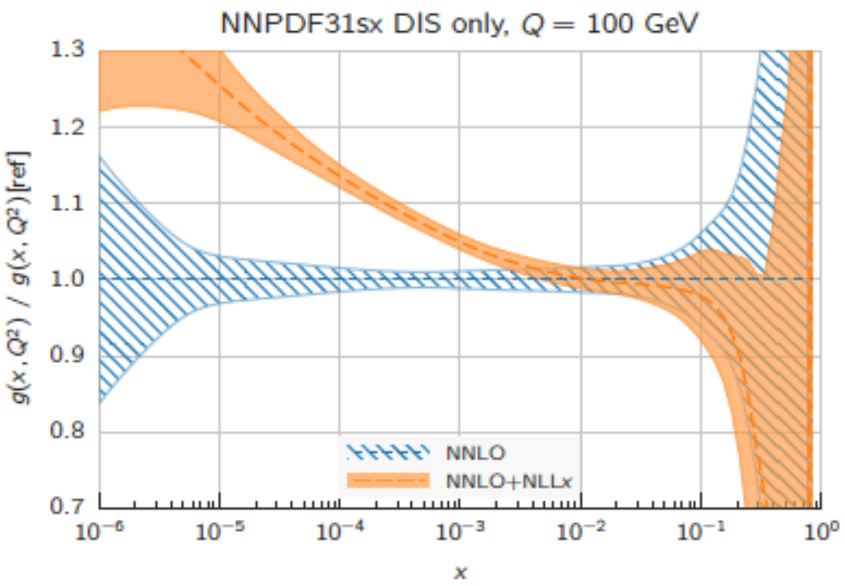
- nPDF R_{pPb} effects (lepton): ±10%
  L_{int}=2x1 pb^{-1}: ~35% constraining power

Resummation:

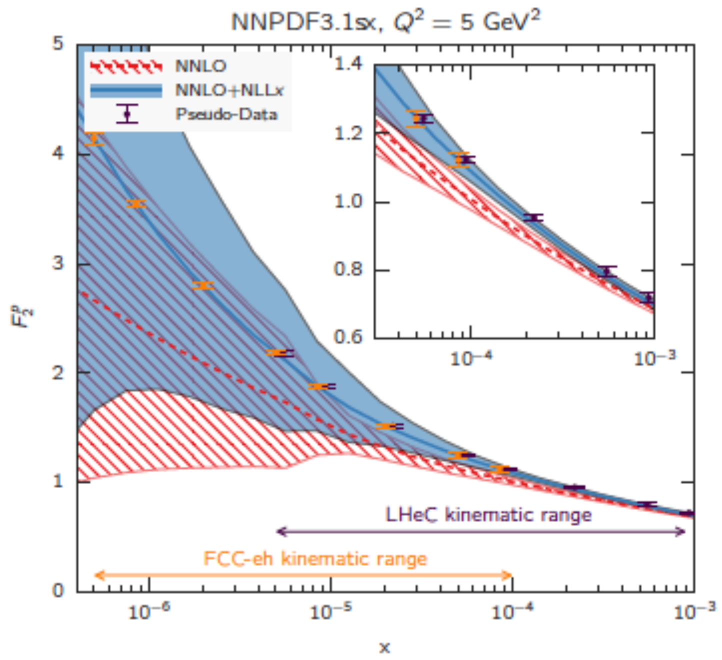
- Resummation has been suggested (1710.05935) to cure the problem seen in HERA data of a worsening of the PDF fit quality with decreasing x and Q^2: the problem lies in F_L.

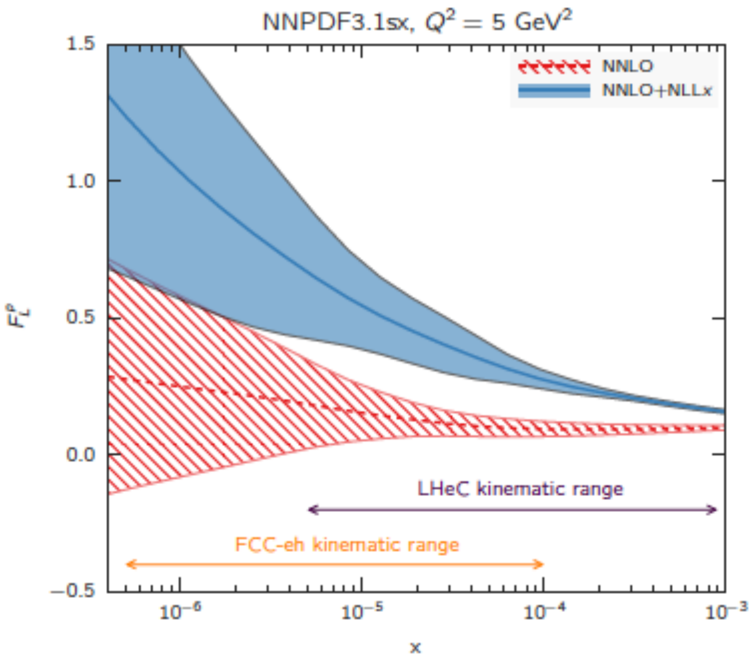






- This approach, and saturation, can be checked at smaller x through the tension between observables: F_2, F_L, σ_r^{HQ}.





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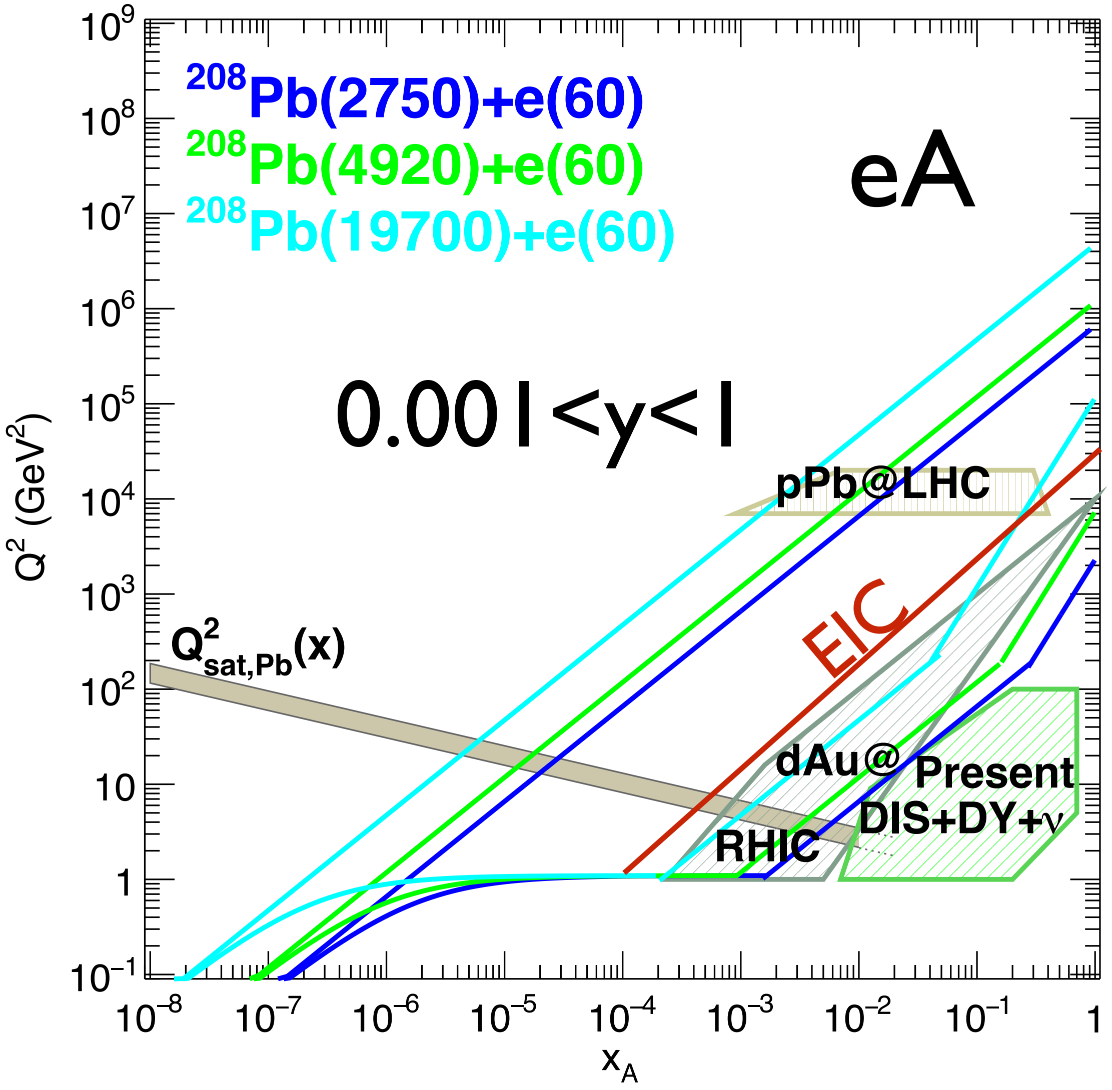
   - ➜ Further constrains from the LHC.

3. Nuclear PDFs from EICs:
   - ➜ Kinematics.
   - ➜ The method.
   - ➜ Constraints on nPDFs.

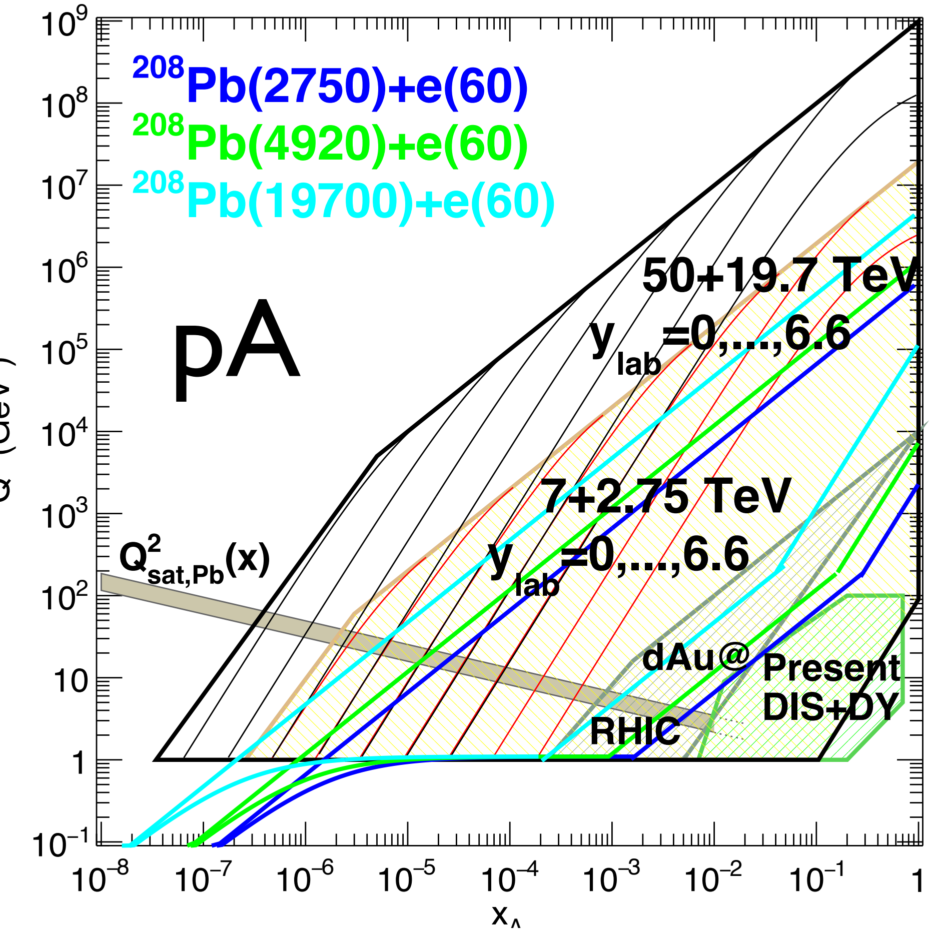
4. Summary.

See the talks by Vadim Guzey, Juan Rojo and Ilkka Helenius.

EICs versus pA:



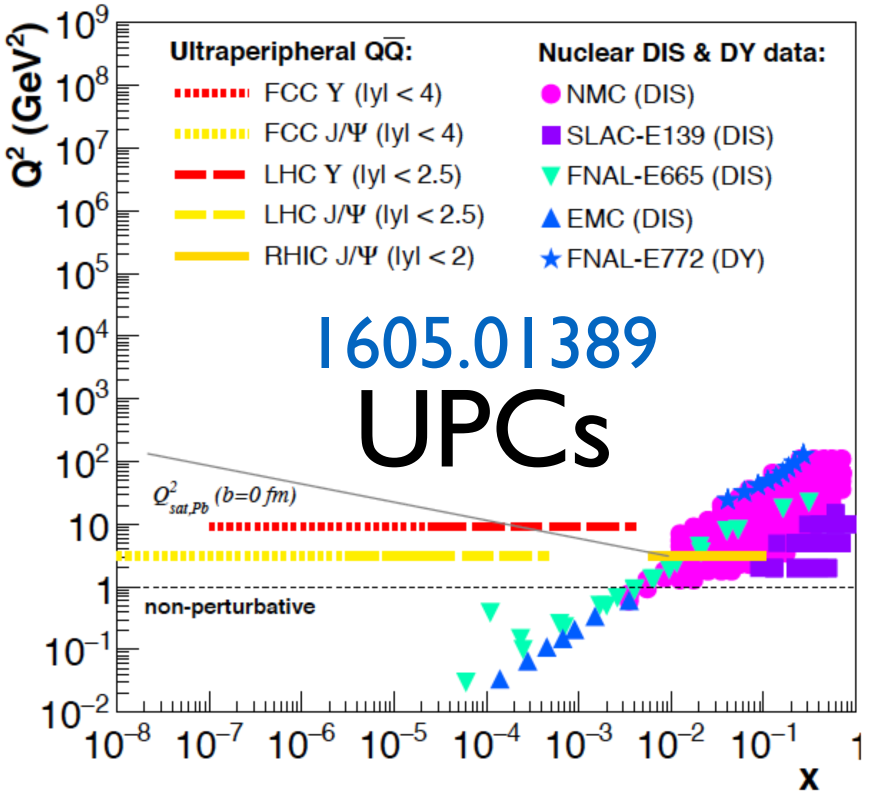
- Extension of 4-5 orders of magnitude in x and Q² wrt existing DIS data.



- DIS offers:

➜ A clean experimental environment: low multiplicity, no pileup, fully constrained kinematics x,Q² by reconstructing the outgoing lepton;

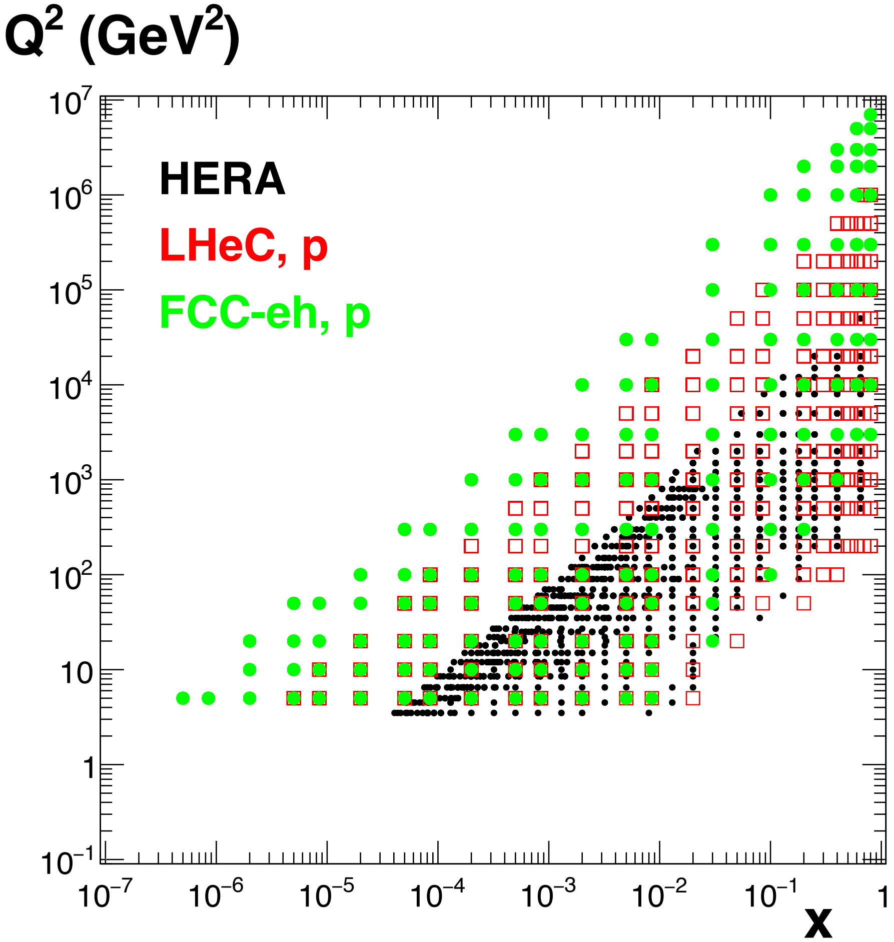
➜ A more controlled theoretical setup: many 1st-principles calculations.

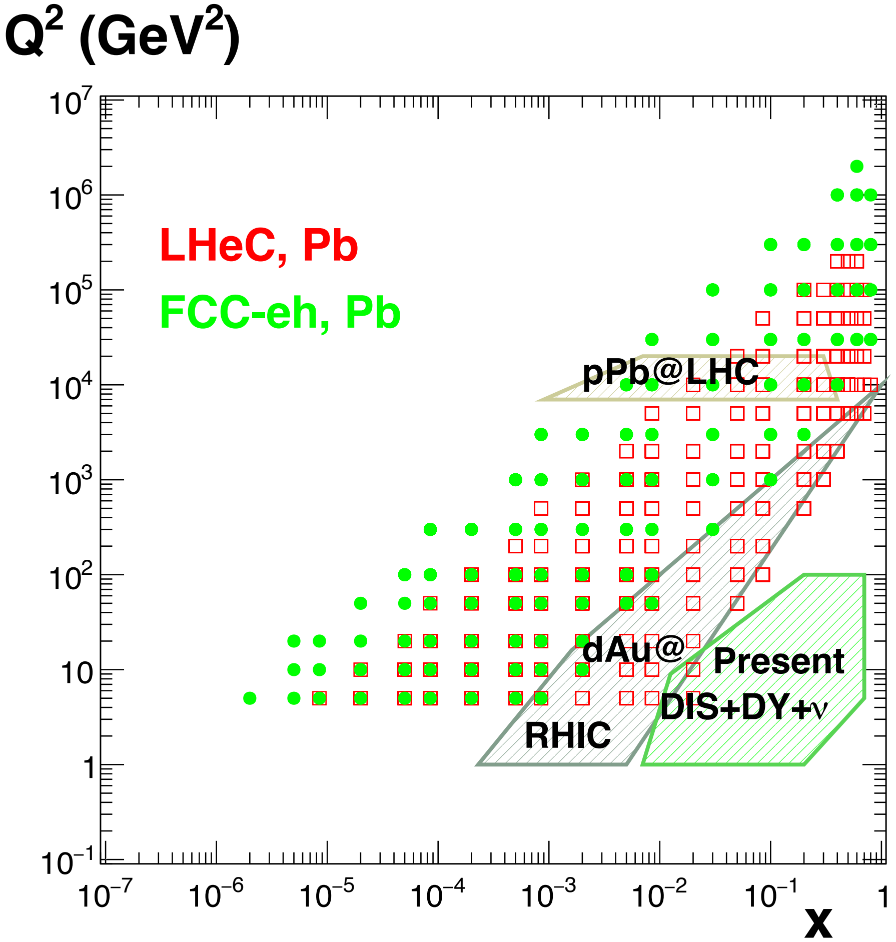


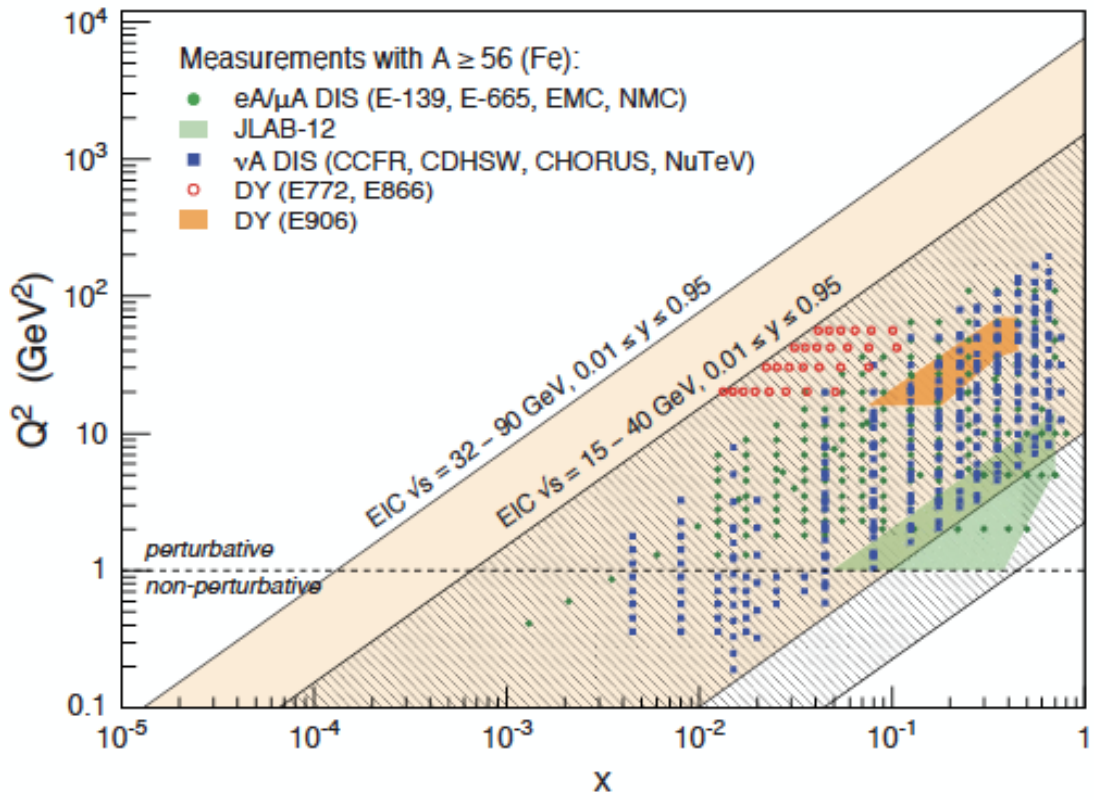
1605.01389

UPCs

LHeC/FCC-eh vs. EIC:

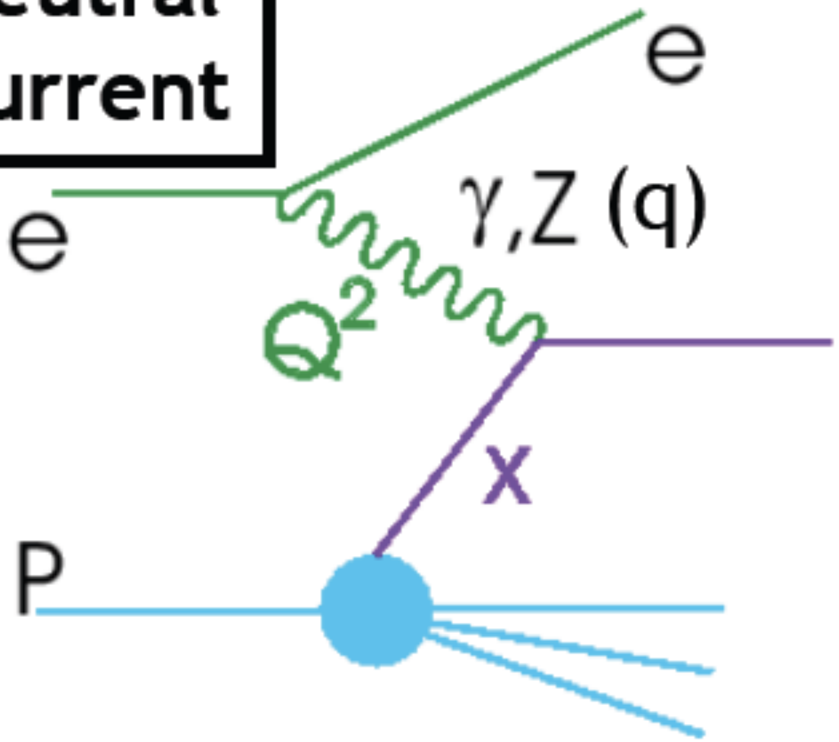






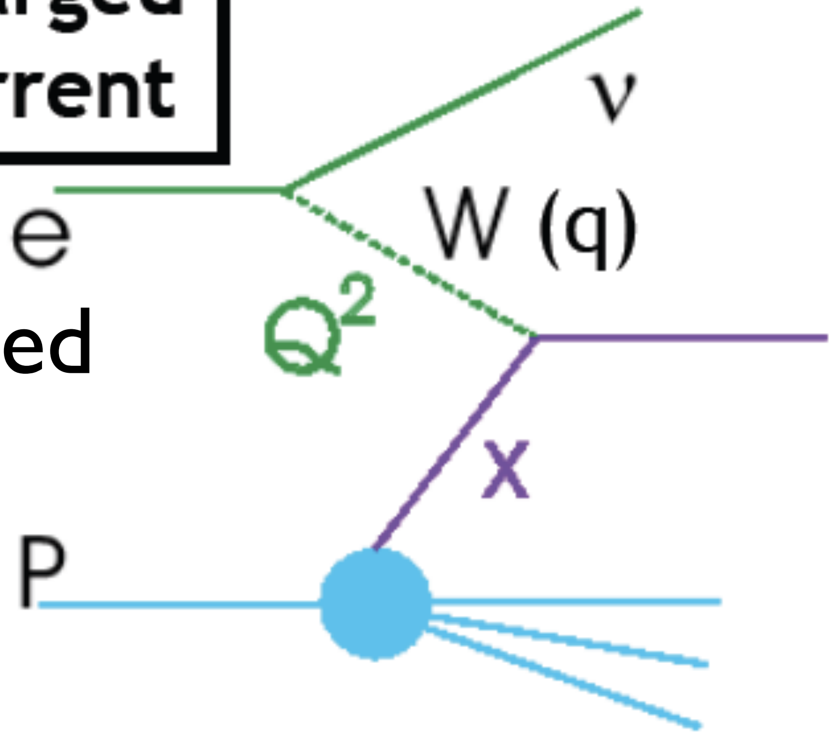
Some relations:

Neutral Current



Fully constrained kinematics!

Charged Current



$$\boxed{\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\cdot\sigma_{r,NC}}$$

$$\boxed{\frac{\mathrm{d}^2\sigma^{\pm}_{CC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{1\pm P}{2}\cdot\frac{G_F^2}{2\pi x}\cdot\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 Y_+\cdot\sigma_{r,CC}}$$

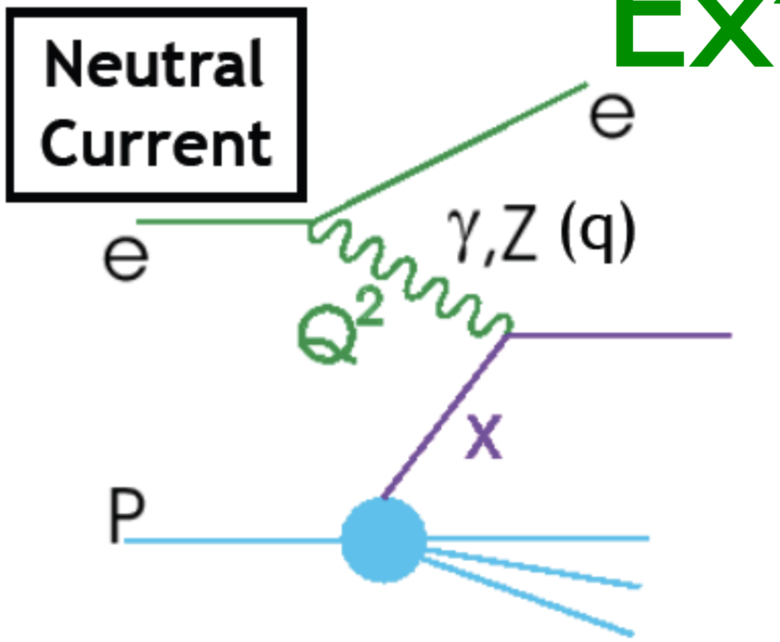
$$\sigma_{r,NC} = \mathbf{F_2} + \frac{Y_-}{Y_+}\mathbf{xF_3} - \frac{y^2}{Y_+}\mathbf{F_L},$$

$$Y_\pm = 1 \pm (1-y)^2$$

$$\sigma^{\pm}_{r,CC} = W_2^{\pm} \mp \frac{Y_-}{Y_+}xW_3^{\pm} - \frac{y^2}{Y_+}W_L^{\pm}$$

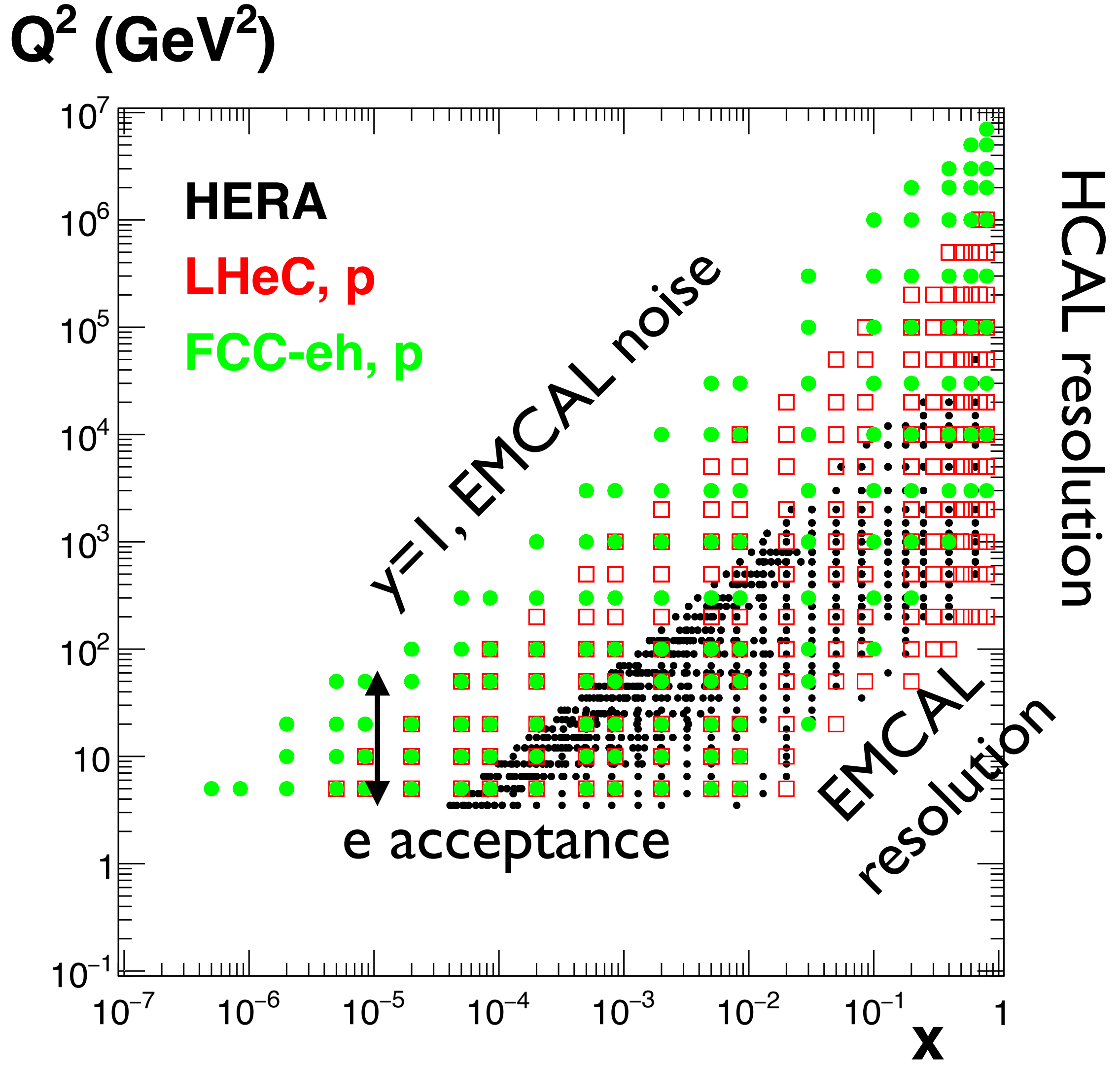
$$\begin{aligned}
\mathbf{F_2^{\pm}} &= F_2 + \kappa_Z(-v_e \mp Pa_e)\cdot F_2^{\gamma Z} + \kappa_Z^2(v_e^2 + a_e^2 \pm 2Pv_e a_e)\cdot F_2^Z \\
\mathbf{xF_3^{\pm}} &= \kappa_Z(\pm a_e + Pv_e)\cdot xF_3^{\gamma Z} + \kappa_Z^2(\mp 2v_e a_e - P(v_e^2 + a_e^2))\cdot xF_3^Z
\end{aligned}$$

Extraction of PDFs:



$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x} \cdot \sigma_{r,NC}$$

$$\sigma_{r,NC} = \mathbf{F_2} + \frac{Y_-}{Y_+}\mathbf{xF_3} - \frac{y^2}{Y_+}\mathbf{F_L},$$



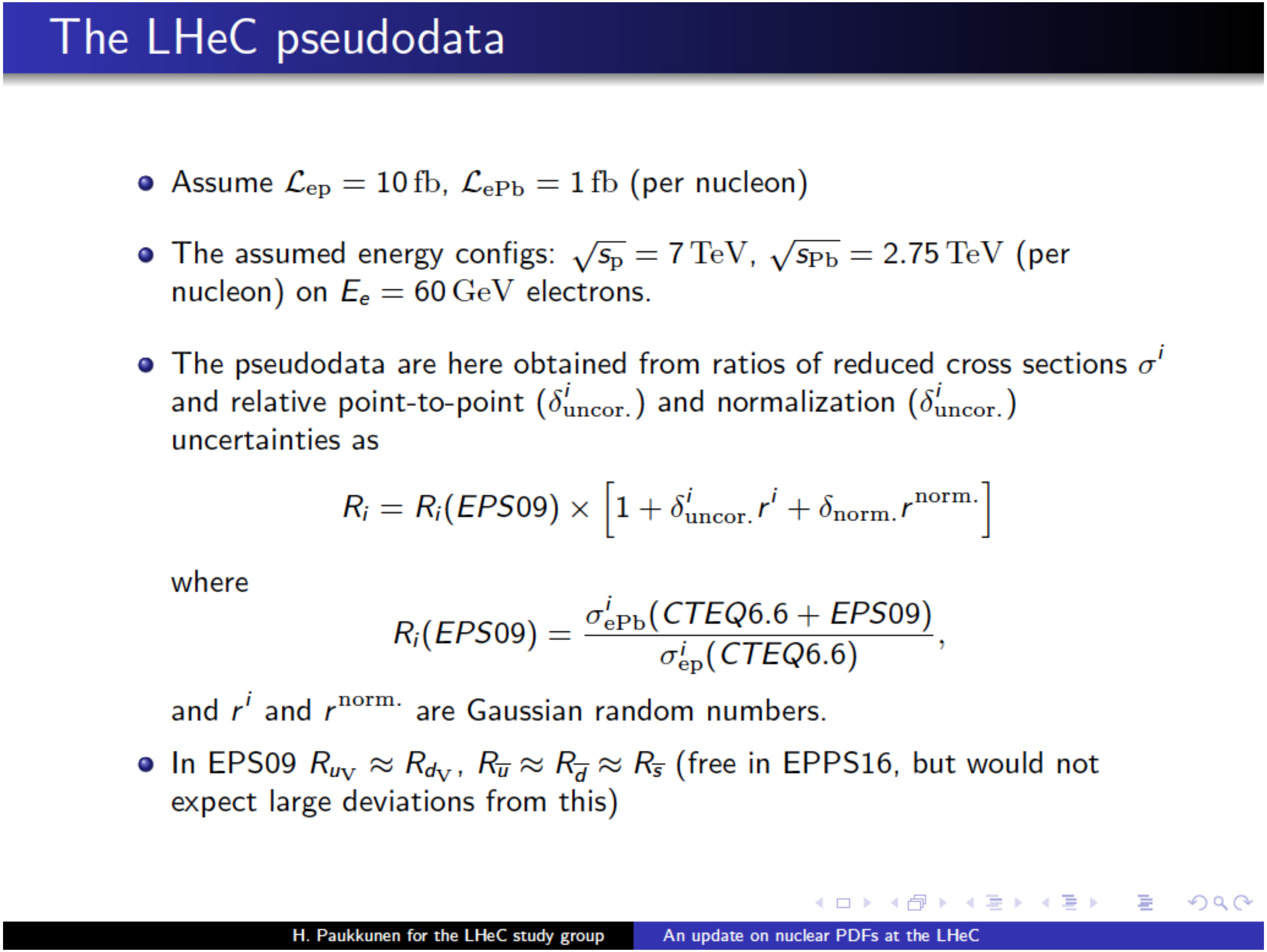
- Ignoring EW contributions:

$$F_2(x,Q^2) \propto \sum xq(x,Q^2)$$ Sensitive to the sea.

$$\frac{\partial F_2(x,Q^2)}{\partial \log Q^2} \propto xg(x,Q^2)$$ Via DGLAP: requires lever arm in Q^2.

$$F_L(x,Q^2) \propto xg(x,Q^2) - F_2(x,Q^2)$$ Via DGLAP: requires lever arm in s (different y at fixed x,Q^2): better σ_{red}.

EPPS16@LHeC (I):



The LHeC pseudodata

- Assume $\mathcal{L}_{\mathrm{ep}} = 10\,\mathrm{fb}$, $\mathcal{L}_{\mathrm{ePb}} = 1\,\mathrm{fb}$ (per nucleon)
- The assumed energy configs: $\sqrt{s_{\mathrm{p}}} = 7\,\mathrm{TeV}$, $\sqrt{s_{\mathrm{Pb}}} = 2.75\,\mathrm{TeV}$ (per nucleon) on $E_e = 60\,\mathrm{GeV}$ electrons.
- The pseudodata are here obtained from ratios of reduced cross sections σ^i and relative point-to-point ($\delta^i_{\mathrm{uncor.}}$) and normalization ($\delta^i_{\mathrm{uncor.}}$) uncertainties as

  $$R_i = R_i(EPS09) \times \left[1 + \delta^i_{\mathrm{uncor.}} r^i + \delta_{\mathrm{norm.}} r^{\mathrm{norm.}}\right]$$

  where

  $$R_i(EPS09) = \frac{\sigma^i_{\mathrm{ePb}}(CTEQ6.6 + EPS09)}{\sigma^i_{\mathrm{ep}}(CTEQ6.6)},$$

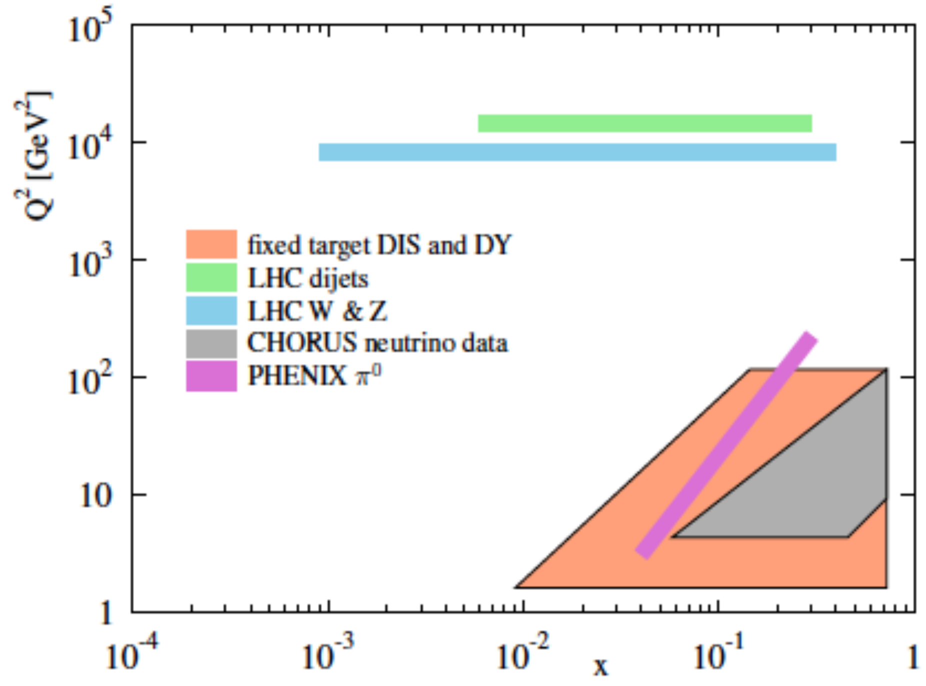
  and r^i and $r^{\mathrm{norm.}}$ are Gaussian random numbers.
- In EPS09 $R_{u_{\mathrm{V}}} \approx R_{d_{\mathrm{V}}}$, $R_{\overline{u}} \approx R_{\overline{d}} \approx R_{\overline{s}}$ (free in EPPS16, but would not expect large deviations from this)

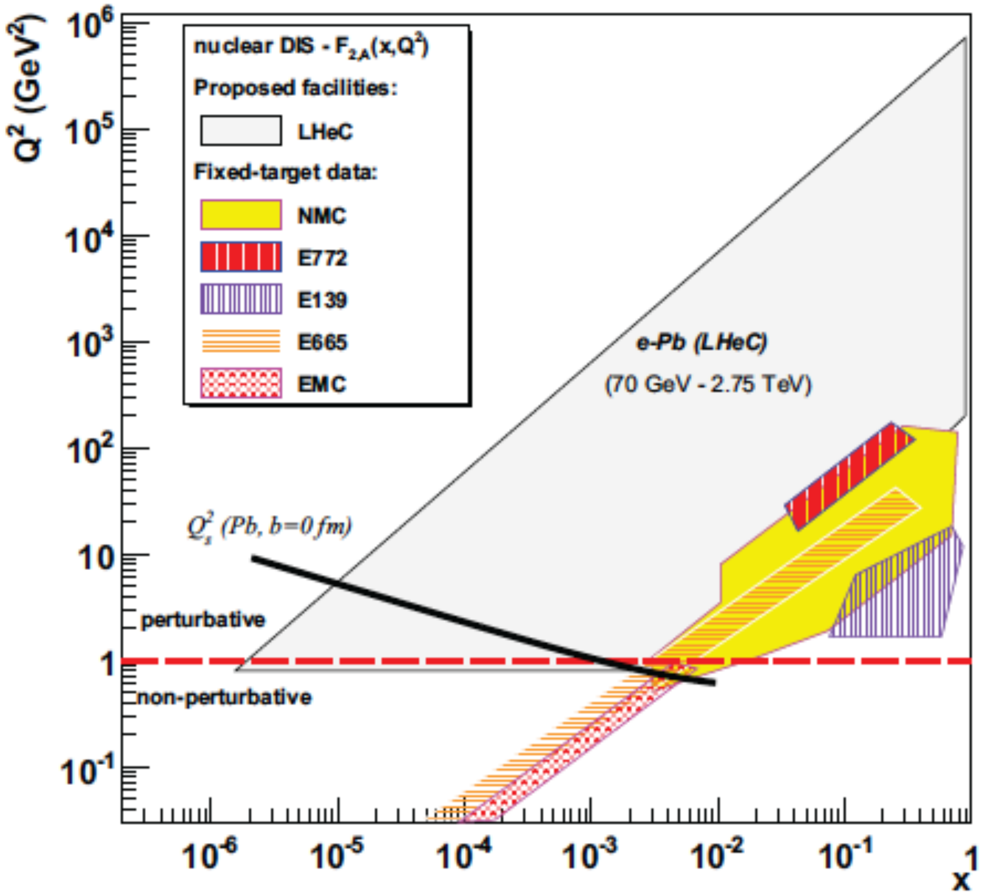
H. Paukkunen for the LHeC study group | An update on nuclear PDFs at the LHeC

EPPS16@LHeC (I):

The analysis framework

- The fit framework same as in the EPPS16 analysis [EPJ C77, 163]
- Include the same data as in EPPS16 plus LHeC (NC and CC) pseudo data.
- Hessian uncertainty analysis with $\Delta\chi^2 = 52$ (as in EPPS16)

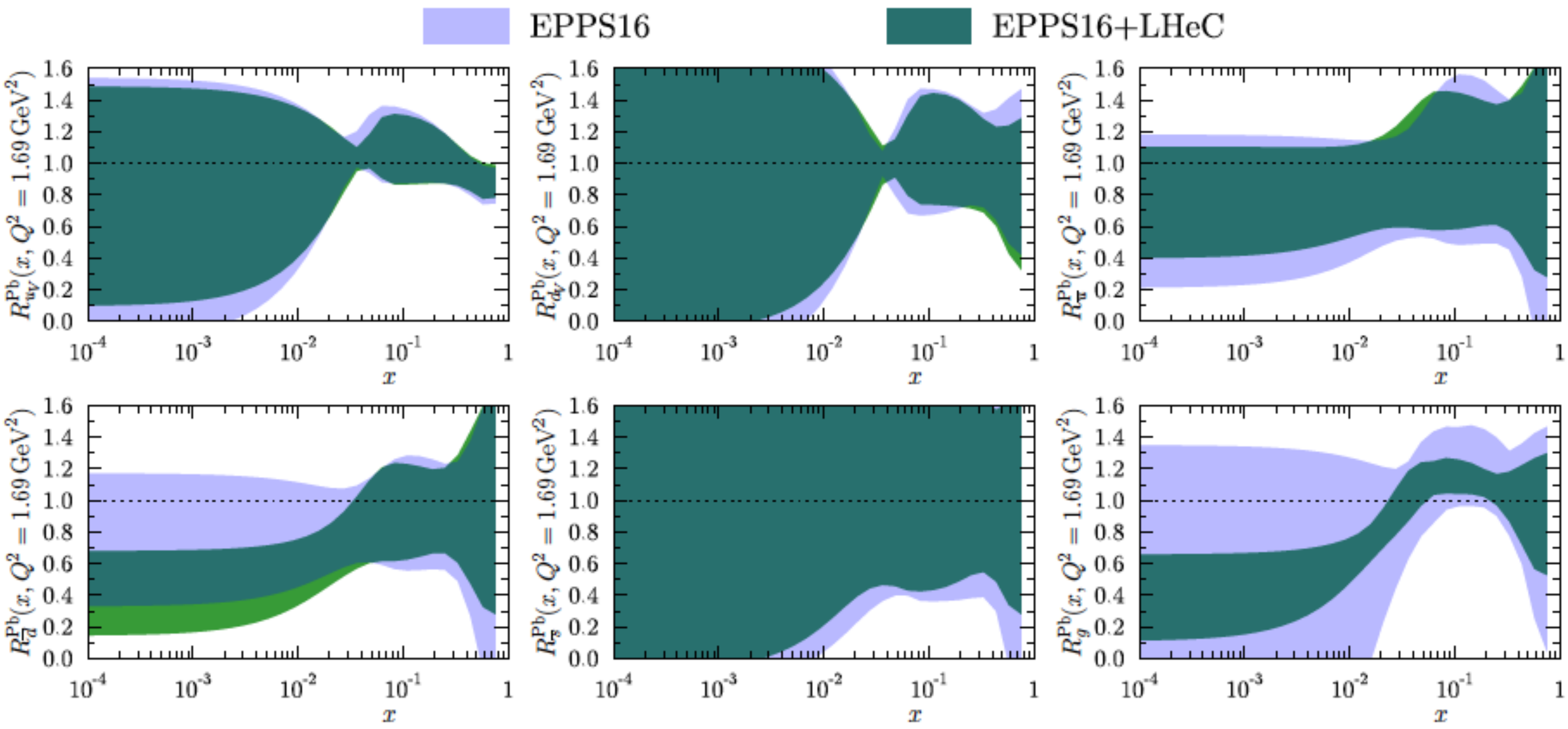




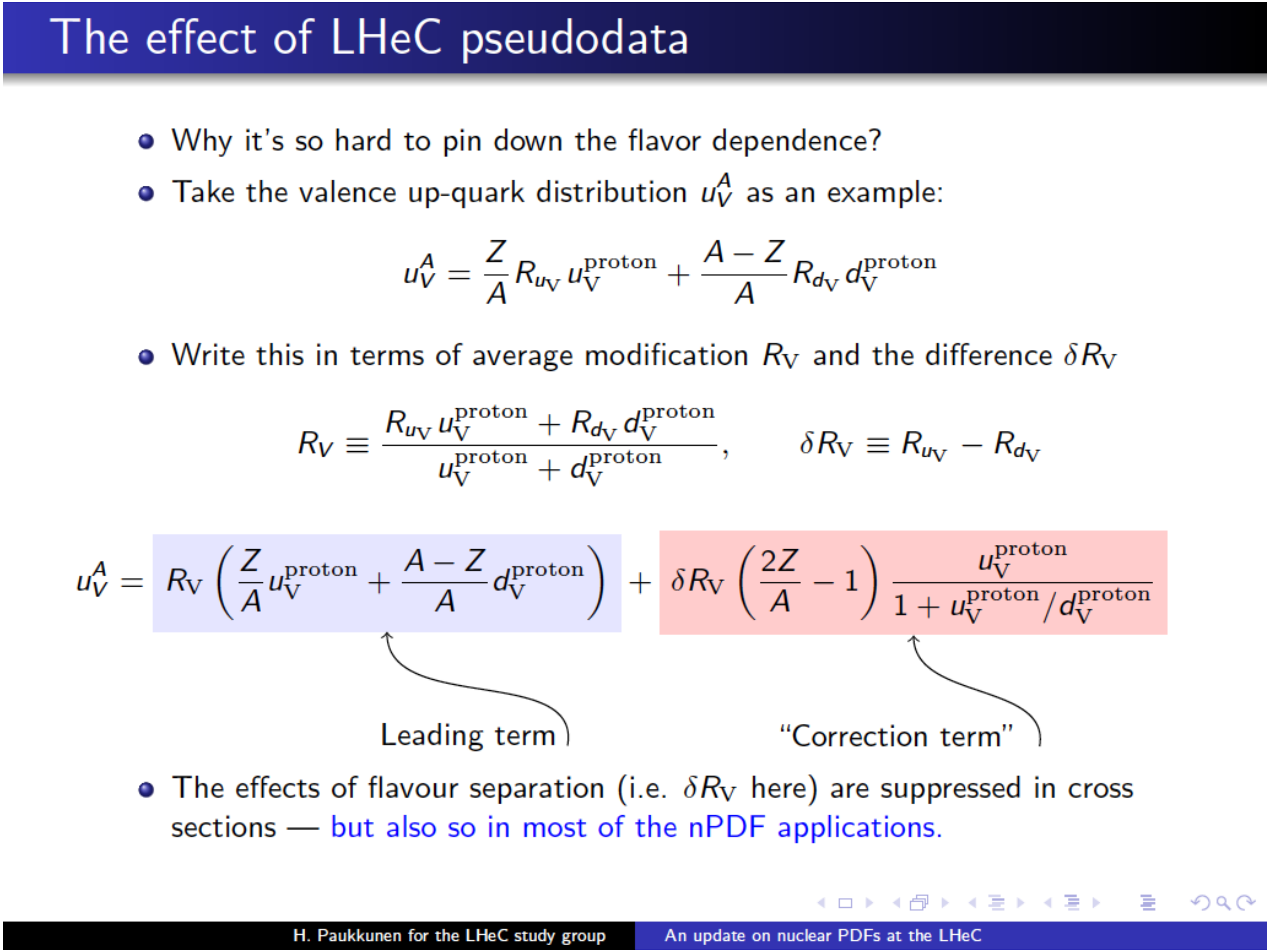
EPPS16@LHeC (I):

The effect of LHeC pseudodata

- The improvement after adding the LHeC data ($Q^2 = 1.69\,\mathrm{GeV}^2$)



nPDFs@LHeC (II):



The effect of LHeC pseudodata

- Why it's so hard to pin down the flavor dependence?
- Take the valence up-quark distribution u_V^A as an example:

$$u_V^A = \frac{Z}{A} R_{u_V} u_V^{\rm proton} + \frac{A-Z}{A} R_{d_V} d_V^{\rm proton}$$

- Write this in terms of average modification R_V and the difference δR_V

$$R_V \equiv \frac{R_{u_V} u_V^{\rm proton} + R_{d_V} d_V^{\rm proton}}{u_V^{\rm proton} + d_V^{\rm proton}}, \qquad \delta R_V \equiv R_{u_V} - R_{d_V}$$

$$u_V^A = \underbrace{R_V \left(\frac{Z}{A} u_V^{\rm proton} + \frac{A-Z}{A} d_V^{\rm proton} \right)}_{\text{Leading term}} + \underbrace{\delta R_V \left(\frac{2Z}{A} - 1 \right) \frac{u_V^{\rm proton}}{1 + u_V^{\rm proton} / d_V^{\rm proton}}}_{\text{“Correction term”}}$$

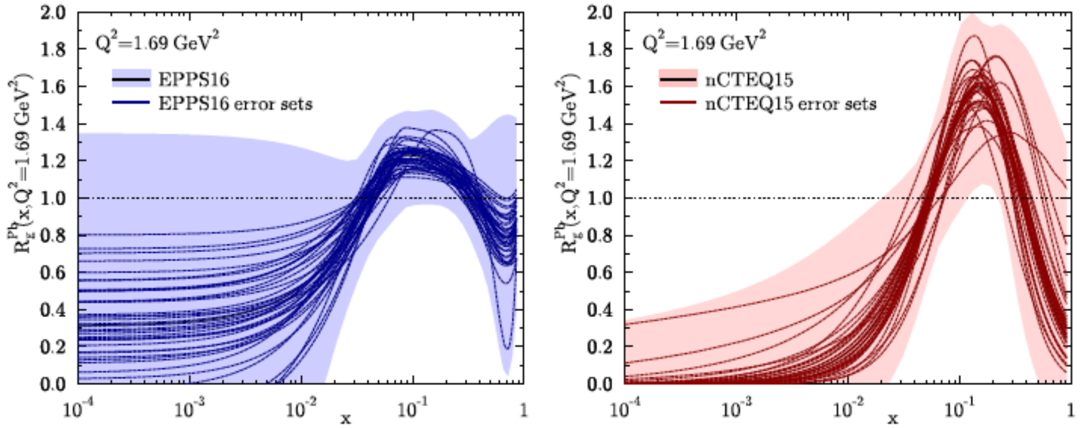
- The effects of flavour separation (i.e. δR_V here) are suppressed in cross sections — but also so in most of the nPDF applications.

H. Paukkunen for the LHeC study group | An update on nuclear PDFs at the LHeC

nPDFs@LHeC (II):

$$R^{\mathrm{EPS09}}(x) = \begin{cases} a_0 + a_1 (x - x_a)^2 & x \le x_a \\ b_0 + b_1 x^{\alpha} + b_2 x^{2\alpha} + b_3 x^{3\alpha} & x_a \le x \le x_e \\ c_0 + (c_1 - c_2 x)(1 - x)^{-\beta} & x_e \le x \le 1 \end{cases}$$

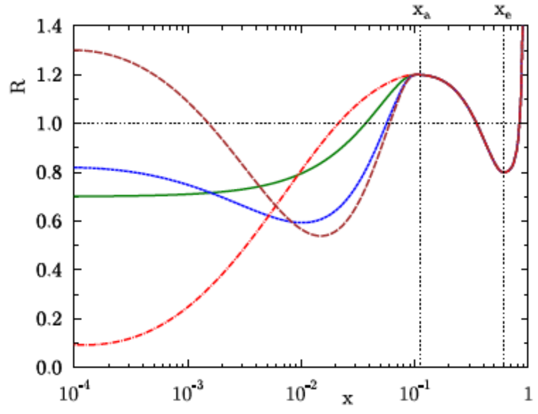
$$R^{\mathrm{nCTEQ15}}(x) = \left[c_0 x^{c_1} (1-x)^{c_2} e^{c_3 x} (1 + e^{c_4} x)^{c_5}\right] / f^p(x)$$



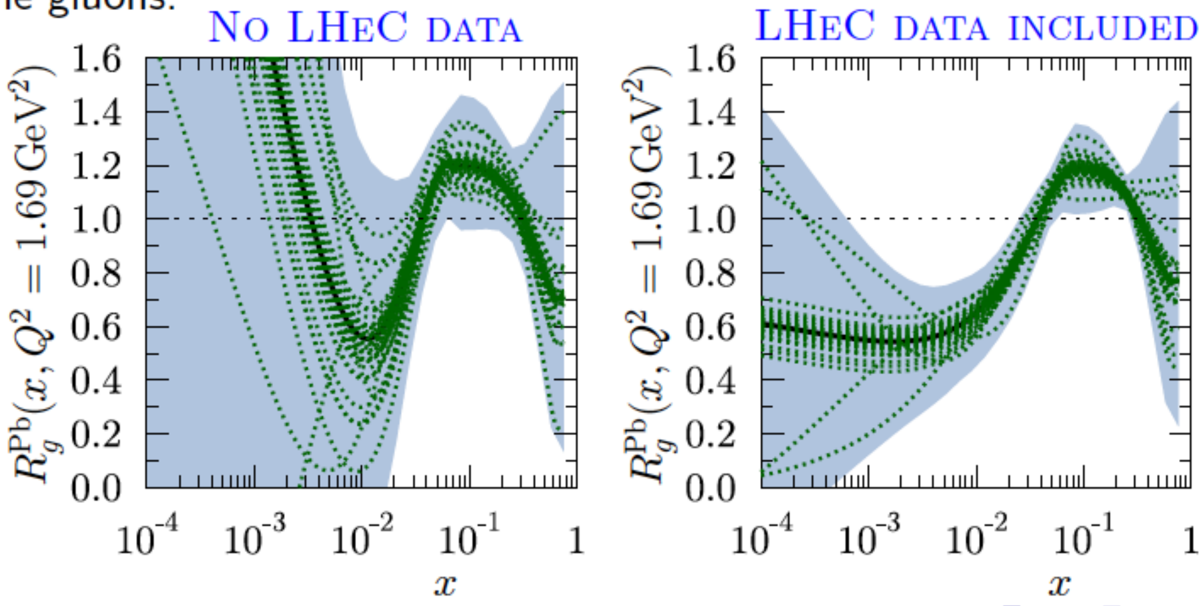
$$\begin{aligned} R(x \le x_a) \;&=\; a_0 + a_1 (x - x_a)^2 \\ &+\; \sqrt{x}(x_a - x)\left[a_2 \log\left(\frac{x}{x_a}\right) + a_3 \log^2\left(\frac{x}{x_a}\right) + a_4 \log^3\left(\frac{x}{x_a}\right) + \ldots\right] \end{aligned}$$

or

$$R(x \le x_a) \;=\; a_0 + (x - x_a)^2 \left[a_1 + a_2 x^{\alpha} + a_3 x^{2\alpha} + a_4 x^{3\alpha} + \ldots\right], \; \alpha \ll 1$$



- Would need Monte-Carlo methods to more reliably map the uncertainties
  $\Longrightarrow$ Further work needed
- Despite all the shortcomings, a typical result using a more flexible form for the gluons:



xFitter:

- Extraction of Pb-only PDFs by fitting pseudodata, using xFitter (1410.4412) 1.2.2 to estimate the 'ultimate' precision that could be achieved (P. Agostini, NA):

➜ HERAPDF2.0-type parametrisation (1506.06042, 14 parameters), NNLO evolution, RTOPT mass scheme, α_s=0.118.

$$\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\left(1+D_{\bar{U}}x\right), \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}$$

$$xU = xu + xc\,, \qquad x\bar{U} = x\bar{u} + x\bar{c}\,, \qquad xD = xd + xs\,, \qquad x\bar{D} = x\bar{d} + x\bar{s}$$

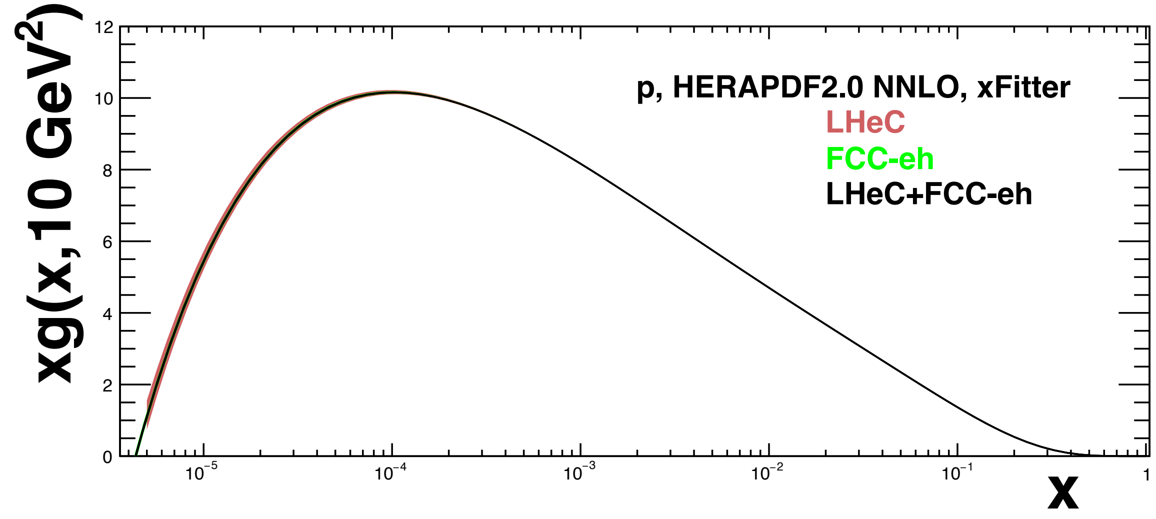
➜ Central pseudodata values from HERAPDF2.0: no parametrisation bias.

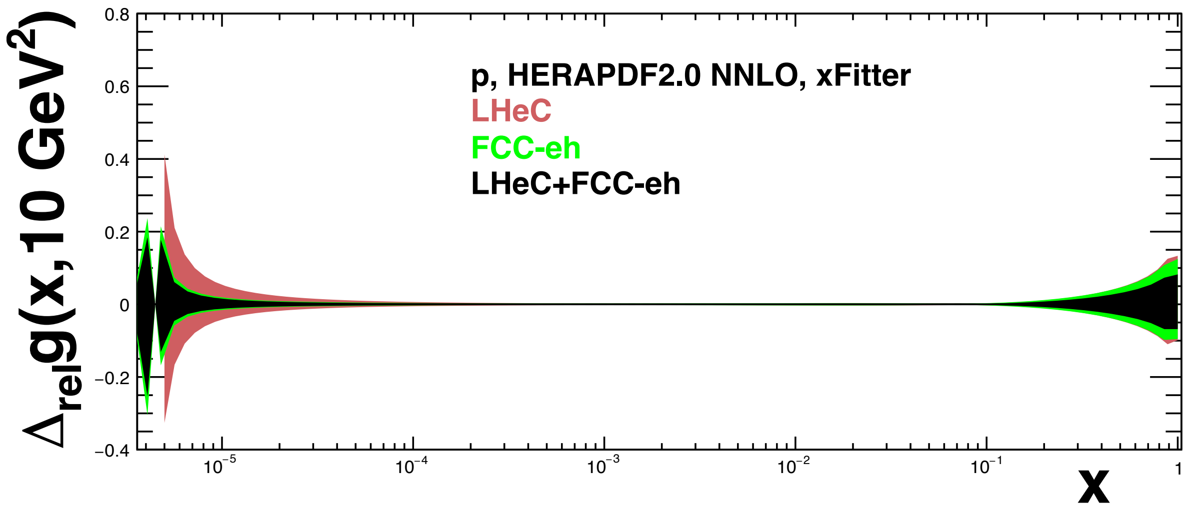
➜ Standard xFitter/HERAPDF treatment of correlated/uncorrelated systematics.

➜ Only data with $Q^2 \geq 3.5$ GeV^2, initial evolution scale 1.9 GeV^2.

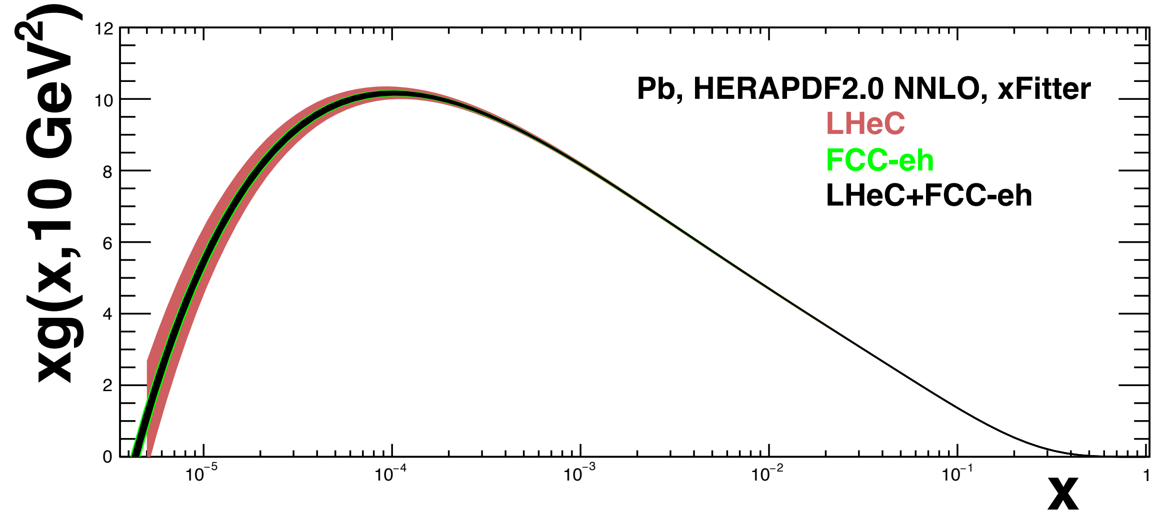
➜ Proton PDFs extracted in the same setup for consistency.

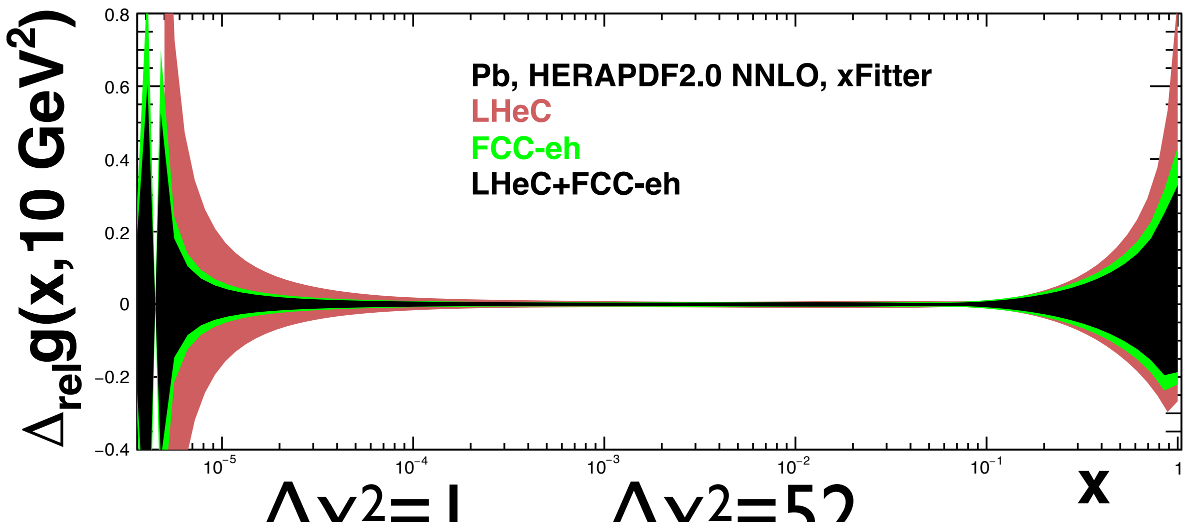
Results: gluon



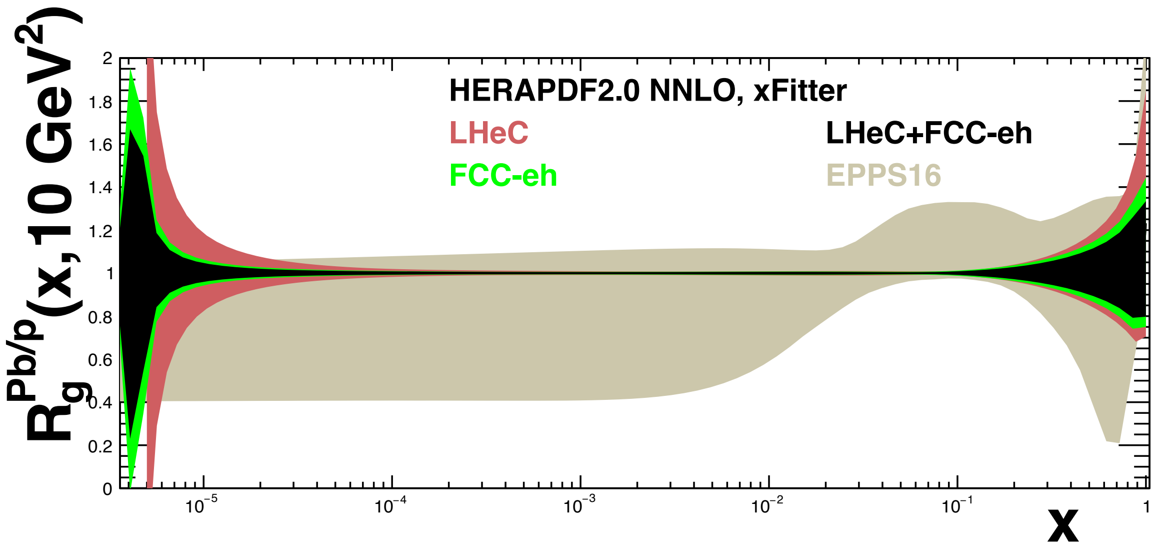


p

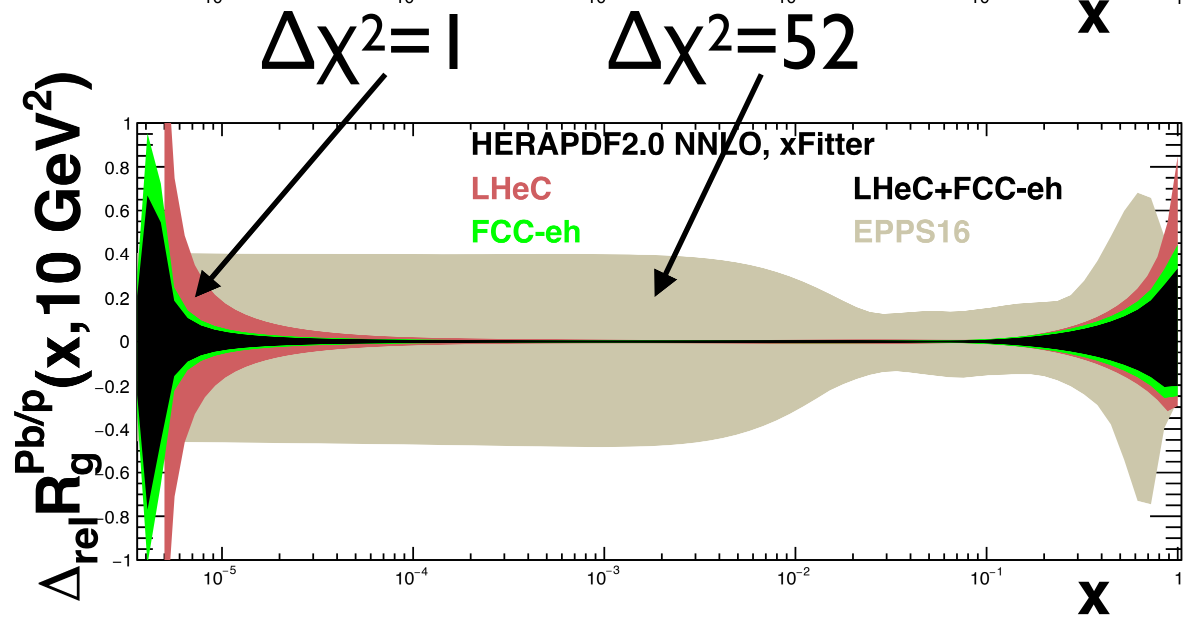




Pb



Pb/p



$\Delta\chi^2=1$

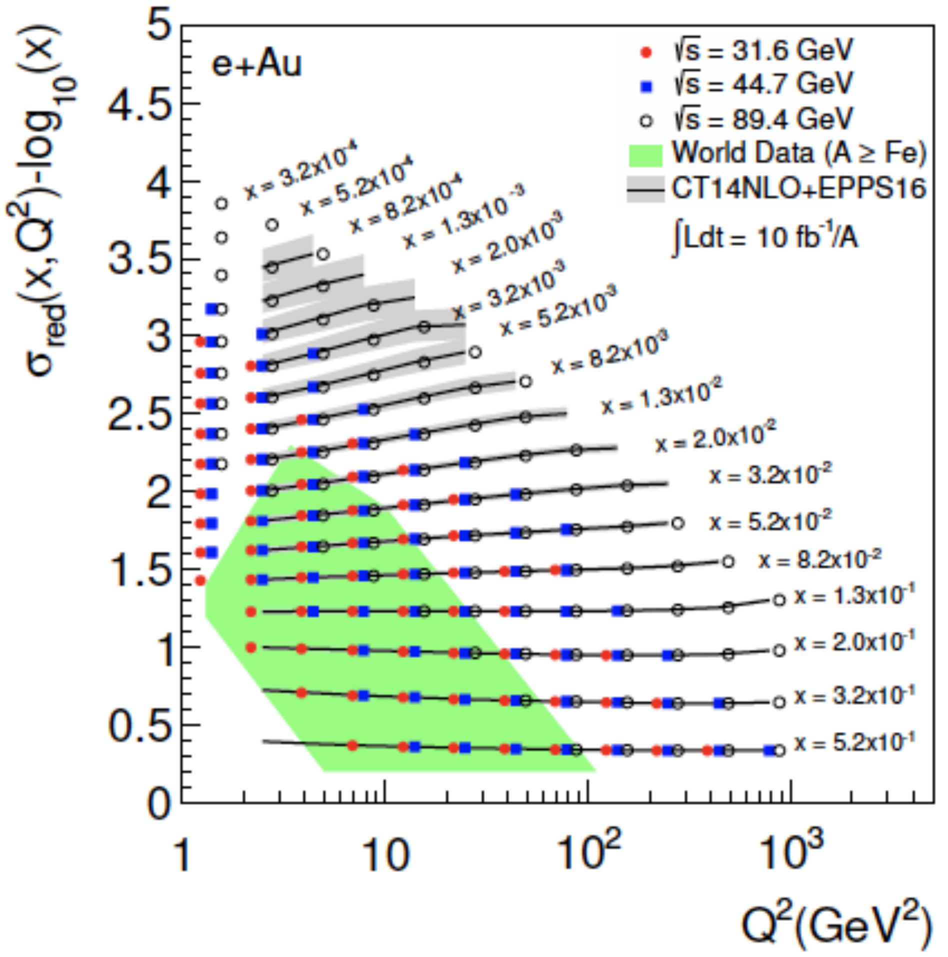
$\Delta\chi^2=52$

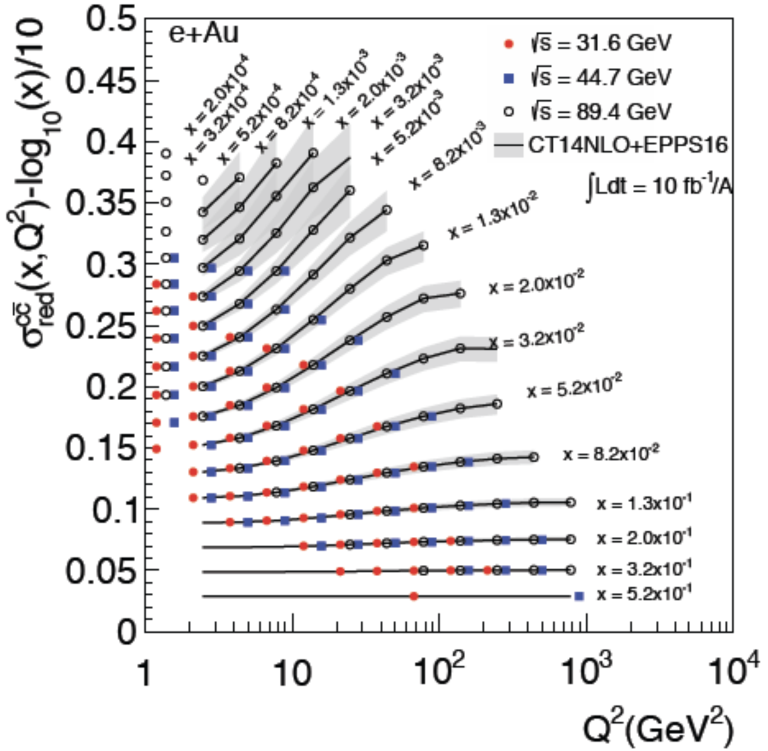
EPPS16@EIC:

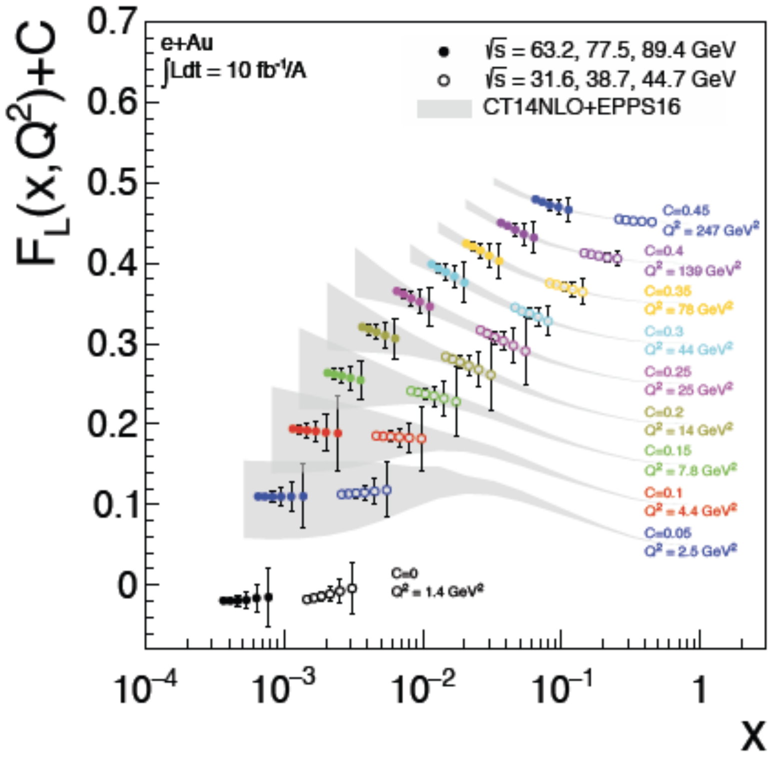
- Following a very similar approach to that shown for the LHeC (1708.05654):

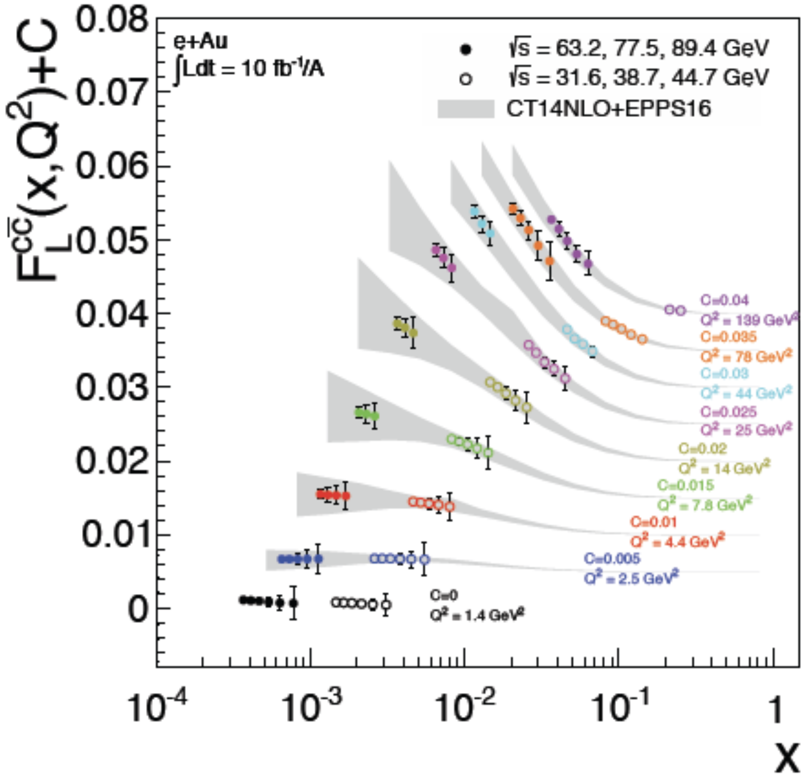
➜ Pseudodata generated with EPS09, uncertainties as achieved at HERA.

➜ Impact of low (5 GeV) and high (20 GeV) electron energies, and of charm.









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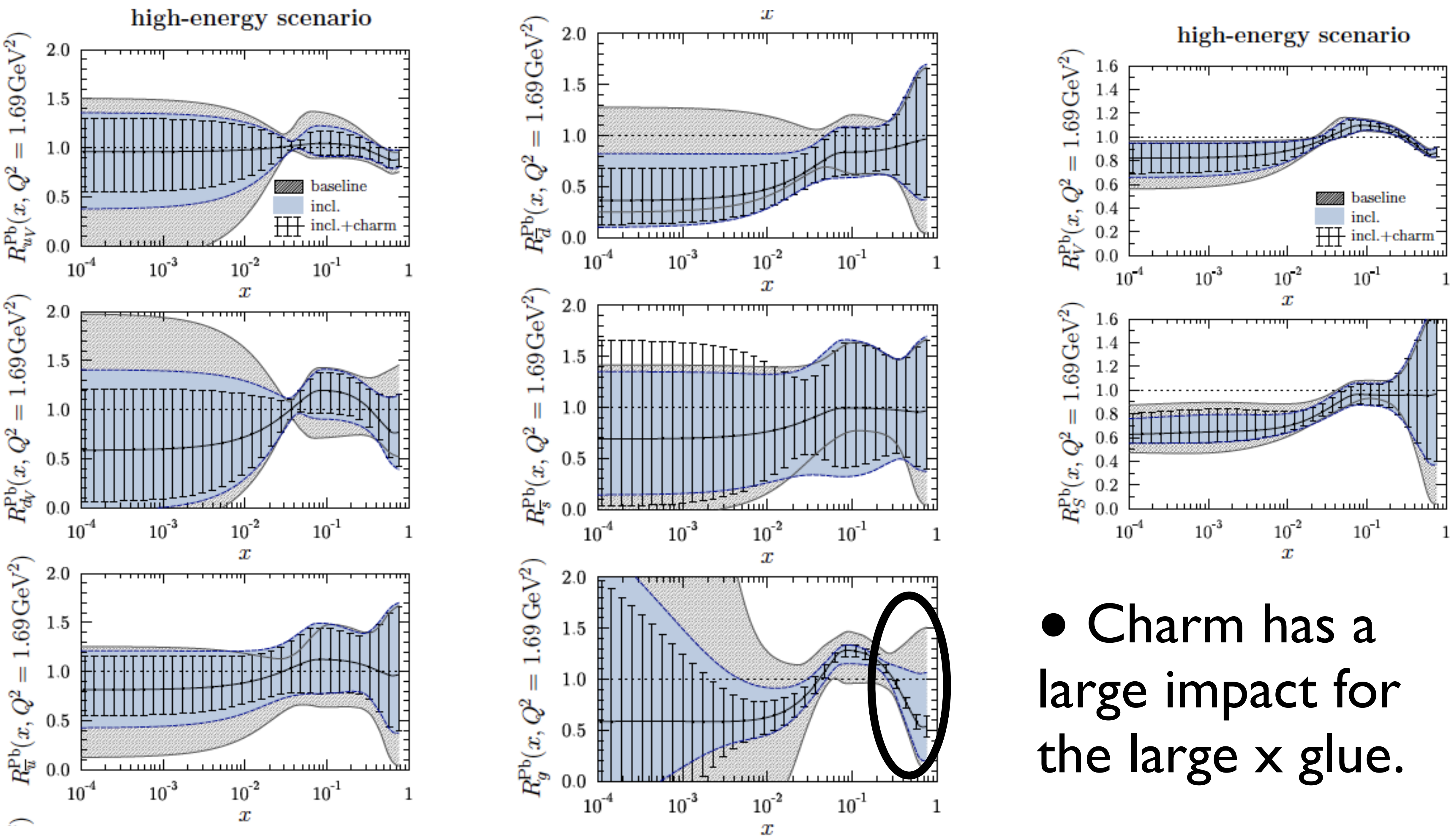
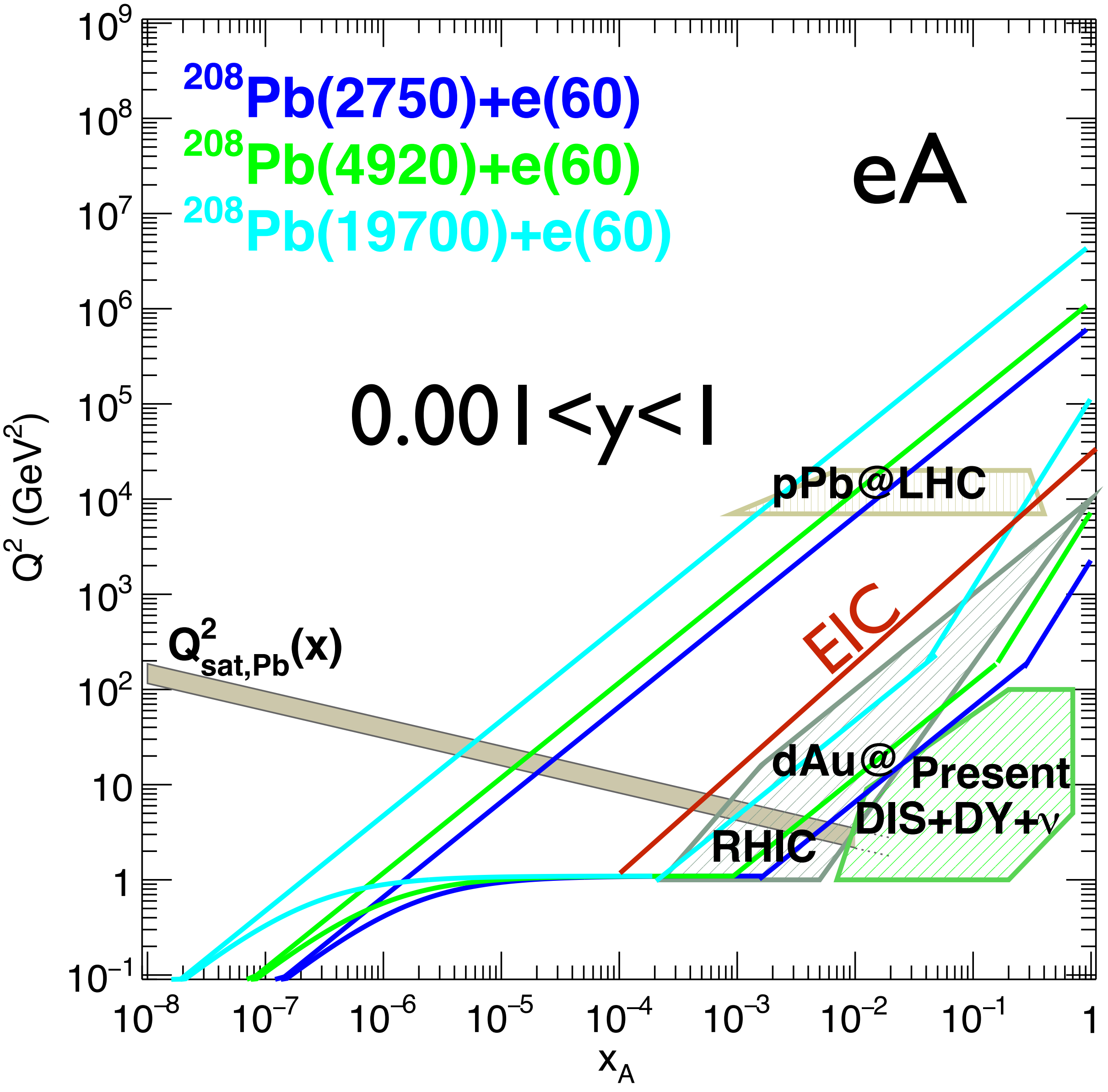


- Charm has a large impact for the large x glue.

N. Armesto, 27.03.2018 - Lessons from EIC: 3. nPDFs from EICs.

Summary:

- EICs are the ideal places to determine the nPDFs: fully constrained kinematics, well controlled th. & exp. setup.
- Limitation: do not cover as much as hadronic colliders, and luminosity may be important for quantitative studies e.g. impact of high x on low x.
- The EIC will not cover the kinematic region for the LHC or for future pA/AA machines.



- pA cannot be challenged in terms of kinematic reach: tests of collinear factorisation and its eventual breaking.
- Establishing the existence of a new regime of QCD will most probably be a quantitative issue demanding both ep/eA and pp/pA.

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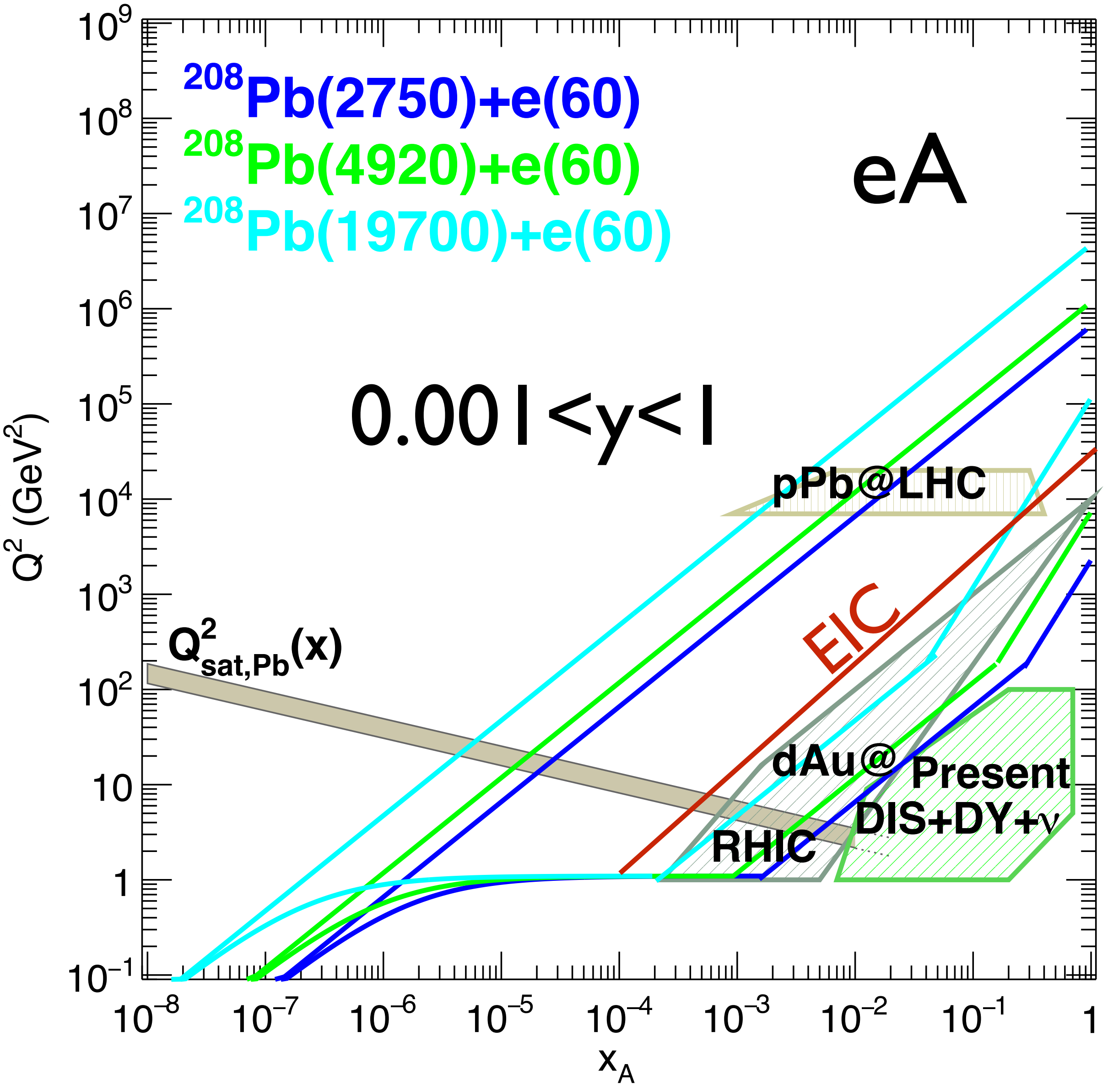

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Summary:

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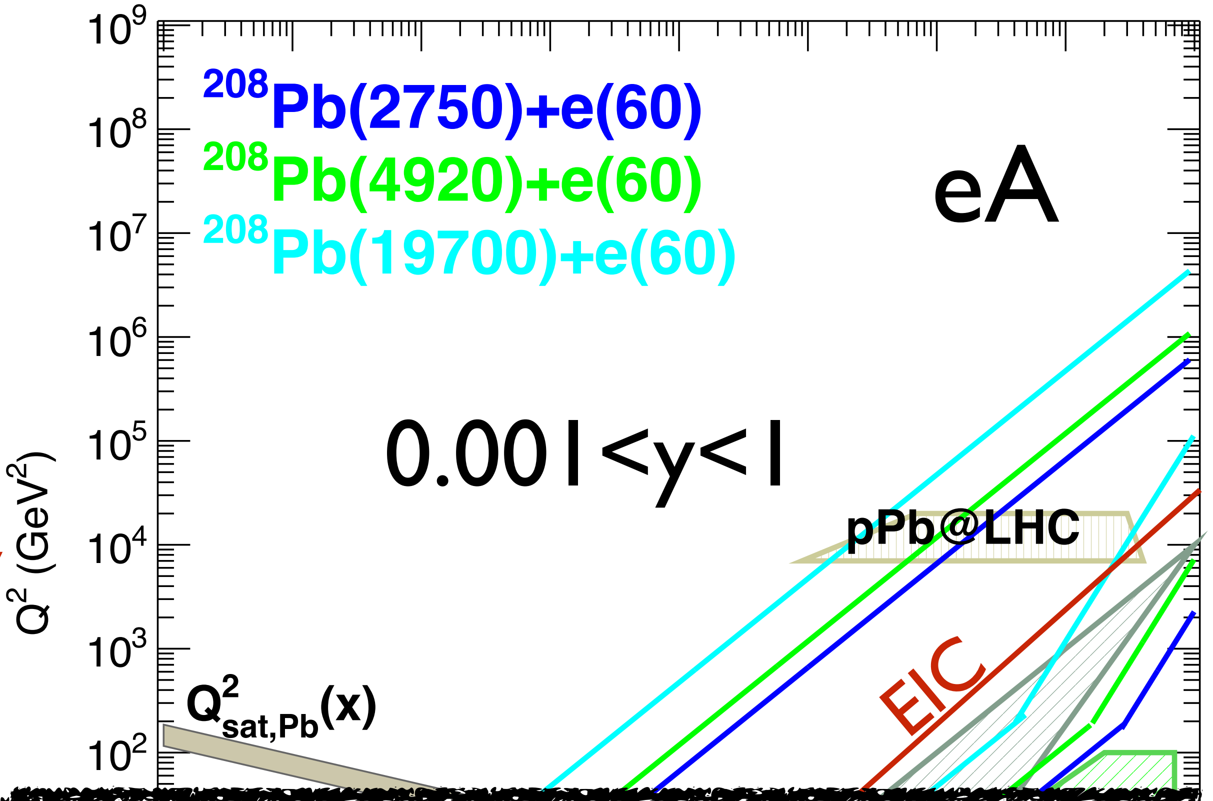


Many thanks to:

➜ Marco for his invitation.

➜ You all for your attention.

- pA cannot be challenged in terms of kinematic reach: tests of collinear factorisation and its eventual breaking.
- Establishing the existence of a new regime of QCD will most probably be a quantitative issue demanding both ep/eA and pp/pA.

Backup:

h/A wave function:

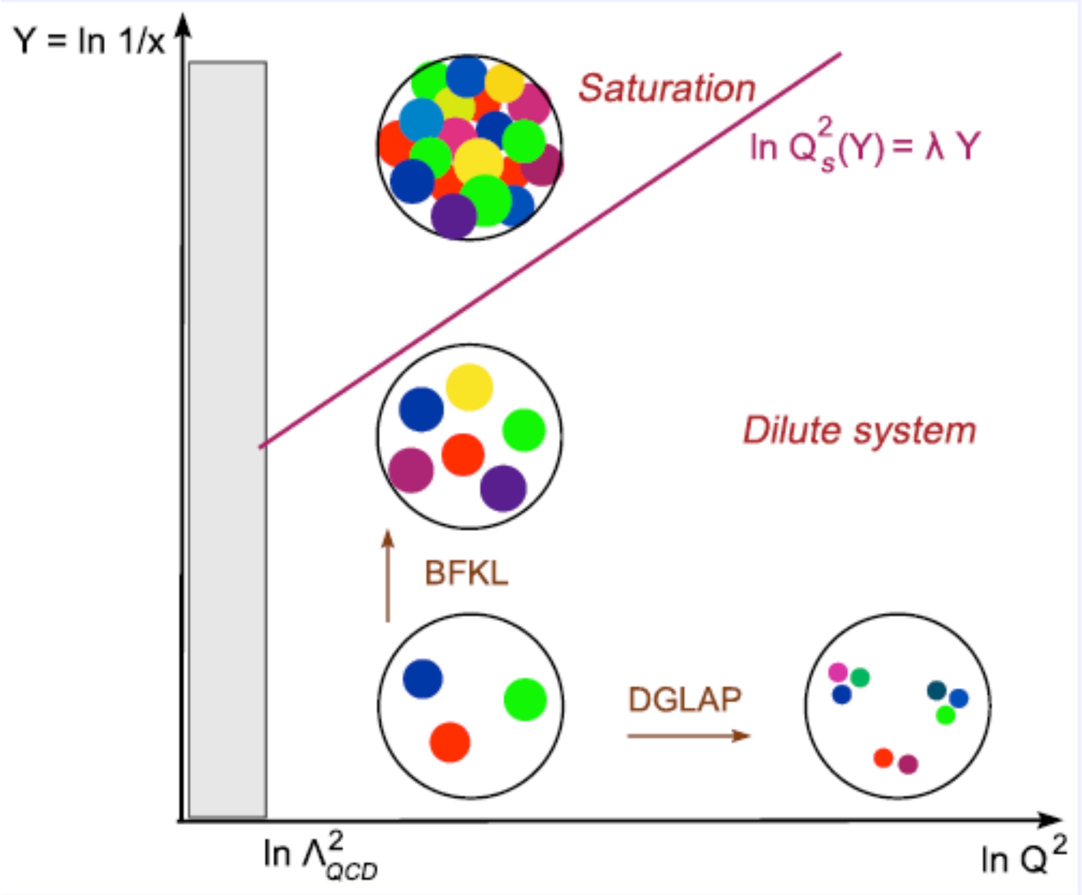
- Standard fixed-order perturbation theory (DGLAP, linear evolution) must eventually fail:

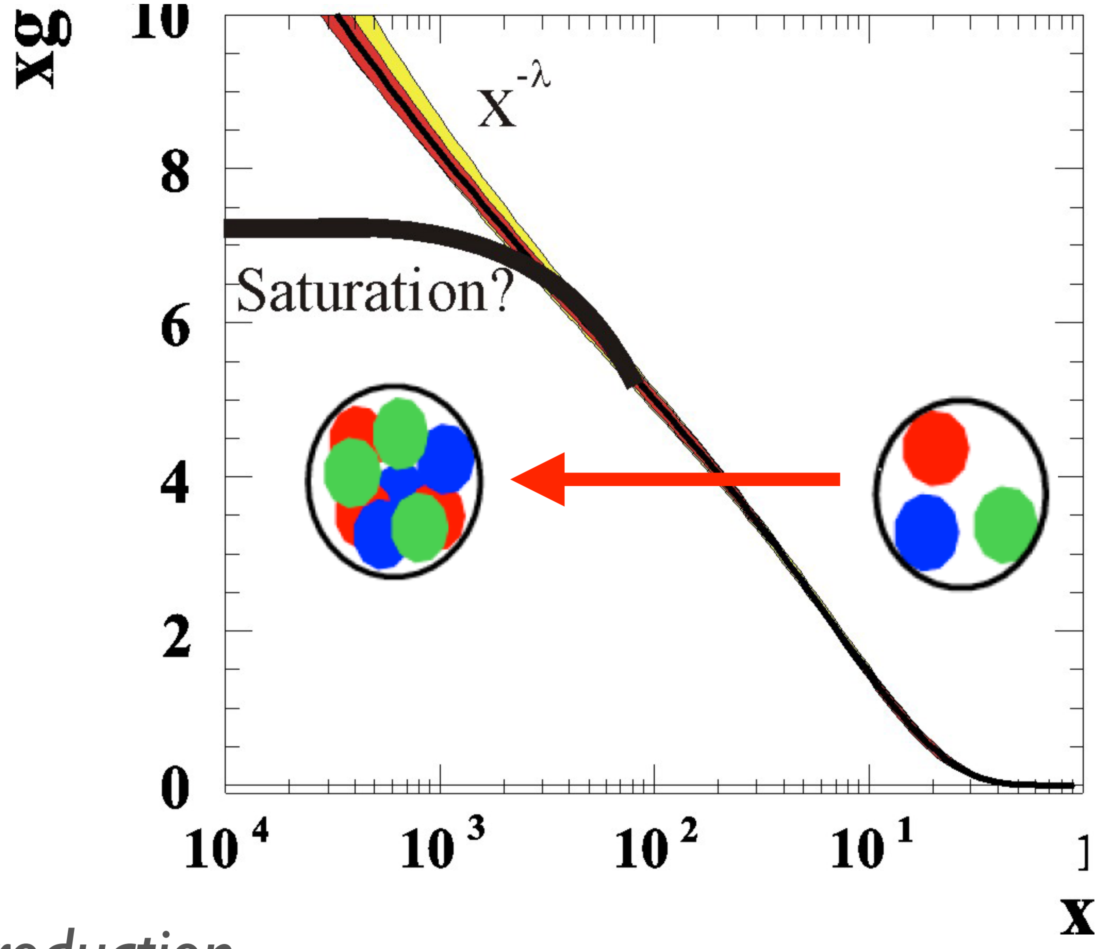
➜ Large logs e.g. $\alpha_s \ln(1/x) \sim 1$: resummation (BFKL,CCFM,ABF,CCSS).

➜ High-density: x↓, A↑ ⇒ non-linear regime, recombination

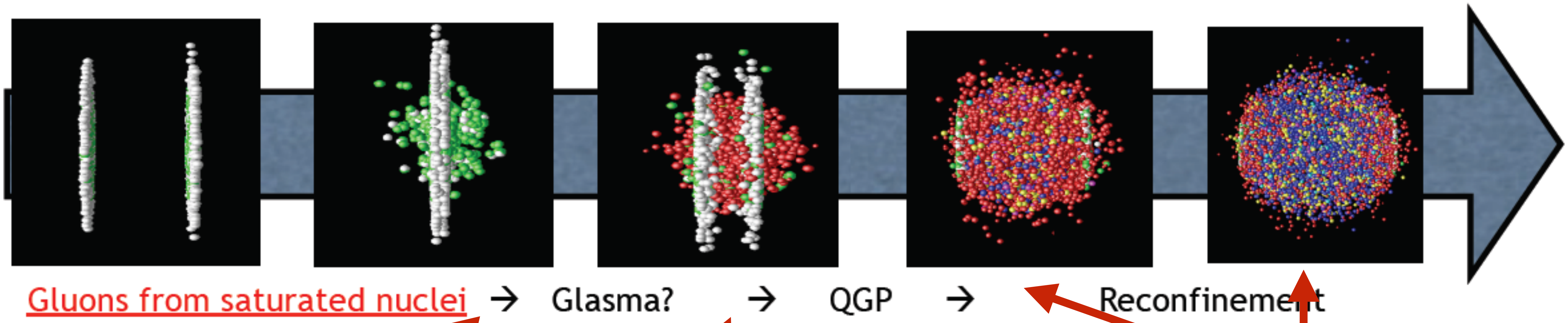
balancing splitting: saturation, perturbative (CGC) or non.

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





Relevance for HIC:



- Nuclear wave function at small x: **nuclear structure functions**.

- Particle production at the very beginning: which factorisation in eA?

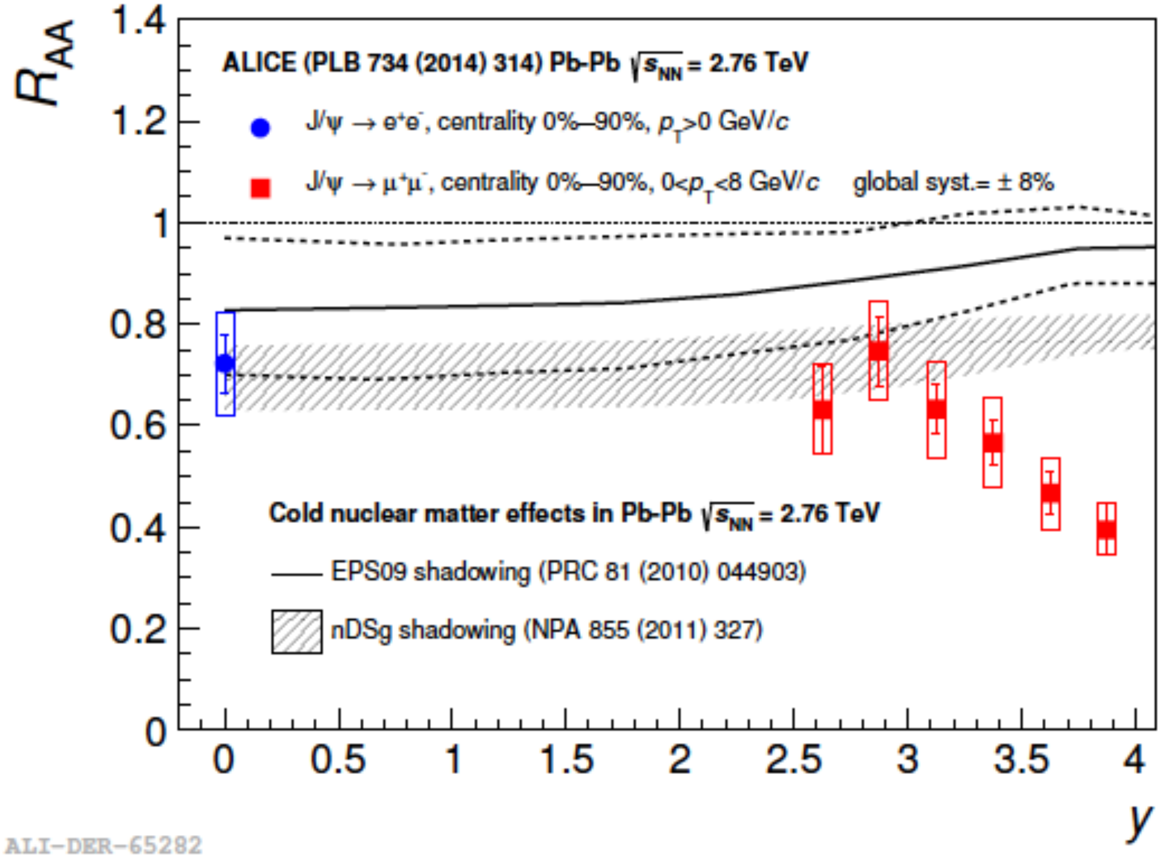
- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

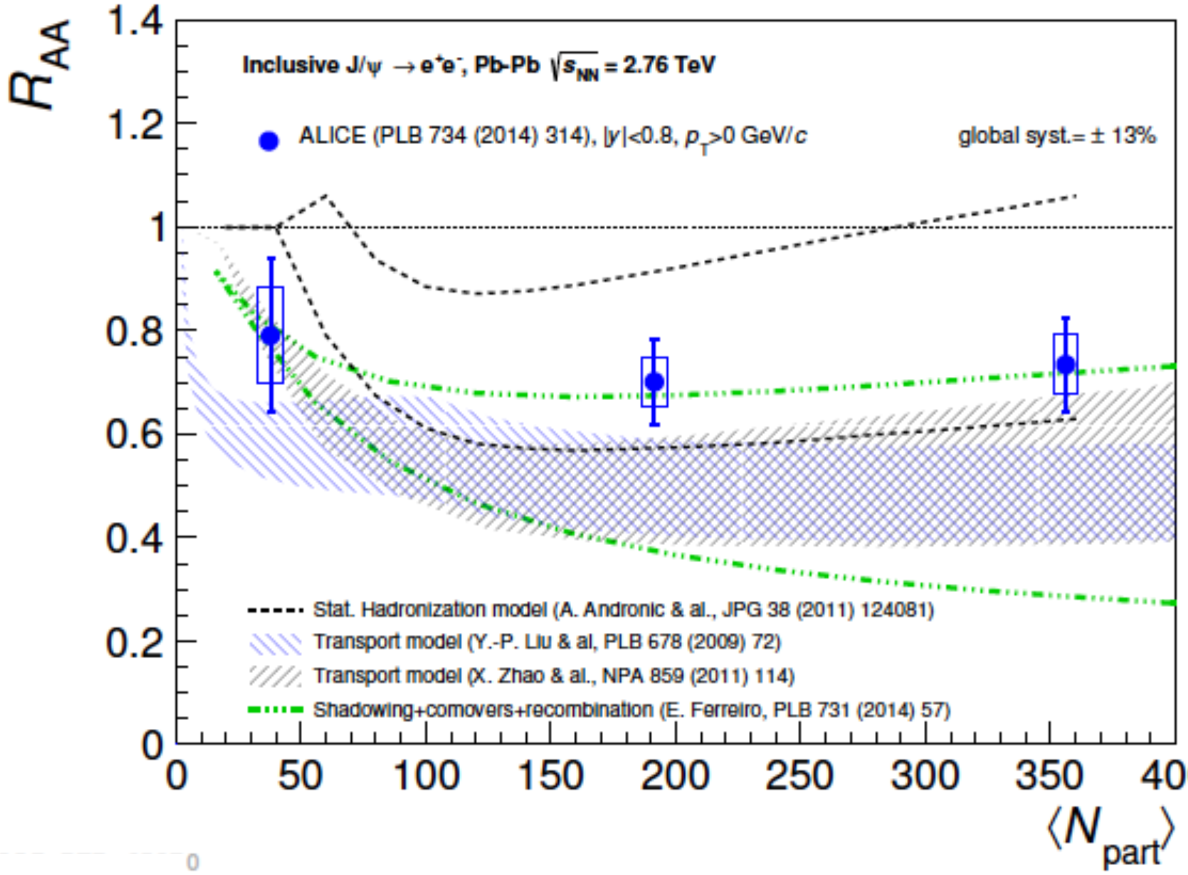
- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronization in the nuclear medium.

nPDFs for HIC:

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

- Lack of data ⇒ large uncertainties for the nuclear glue at small scales and x: problem for benchmarking in HIC in order to extract 'medium' parameters.





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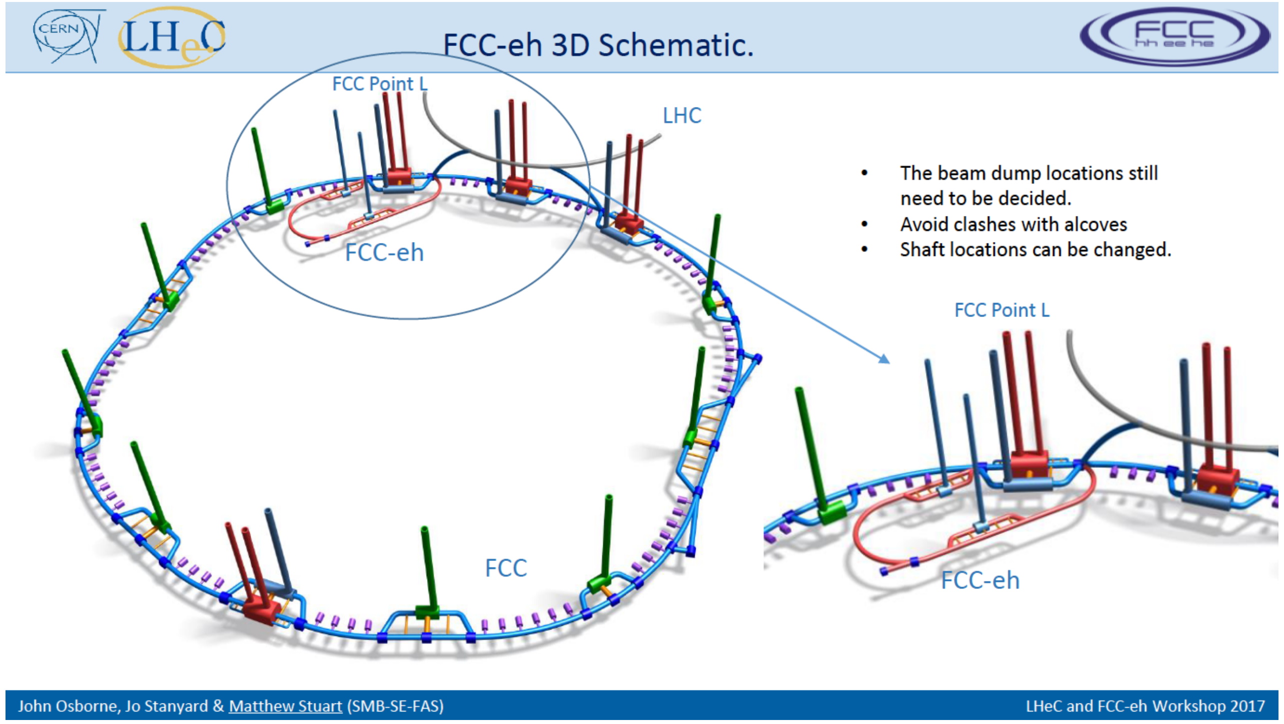
FCC-eh (I):



- The beam dump locations still need to be decided.
- Avoid clashes with alcoves.
- Shaft locations can be changed.

John Osborne, Jo Stanyard & Matthew Stuart (SMB-SE-FAS)

LHeC and FCC-eh Workshop 2017

- eA could 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_{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 [$10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	7	18	54
Integrated lumi. in 10 y. (fb^{-1}) ~~	6	15	45

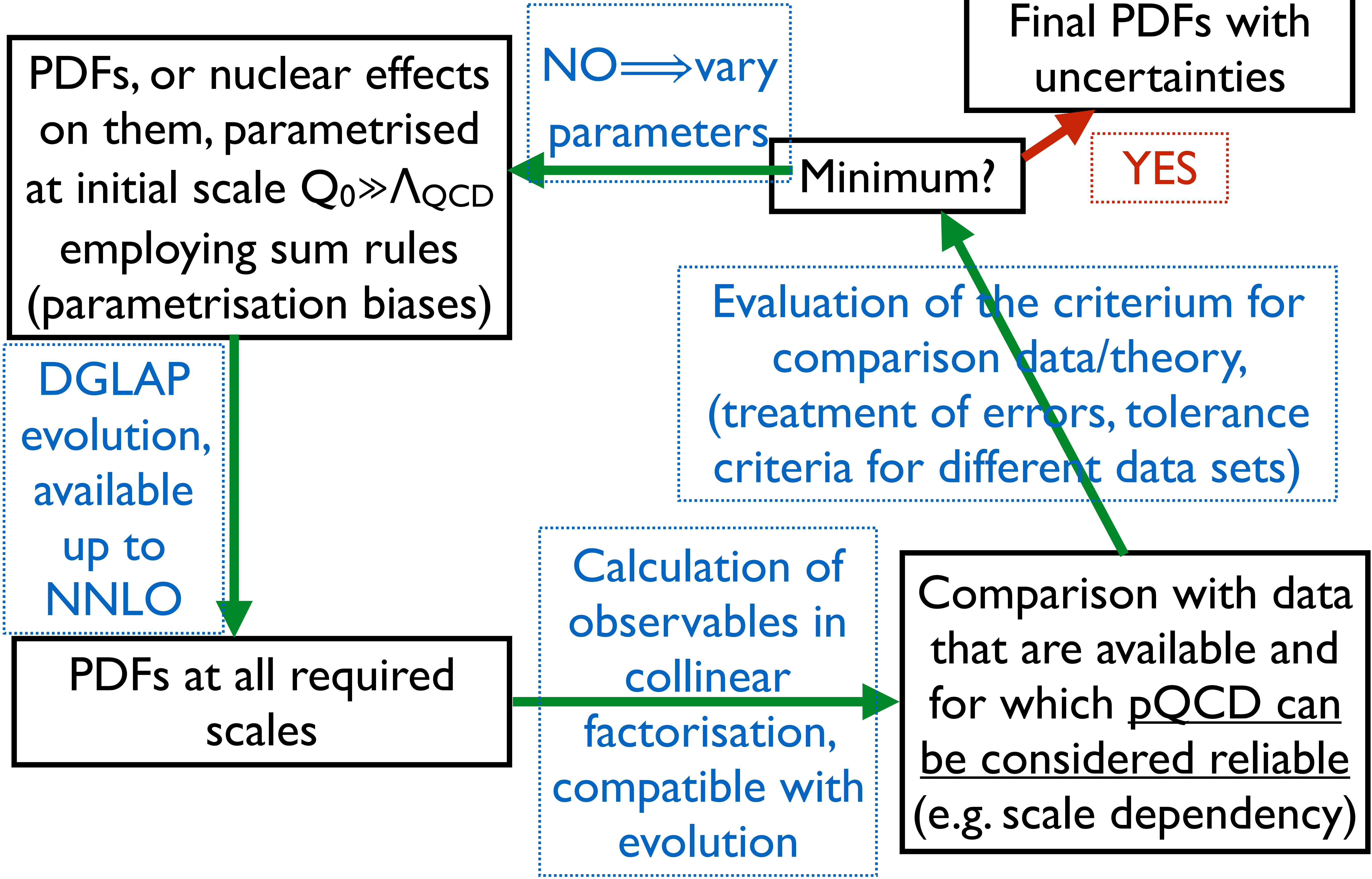
eD at LHEC:

$L_{eN}=AL_{eA}>\sim 3\times 10^{31}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$

(old CDR number)

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

Extracting PDFs:



PDFs, or nuclear effects on them, parametrised at initial scale $Q_0 \gg \Lambda_{QCD}$ employing sum rules (parametrisation biases)

DGLAP evolution, available up to NNLO

PDFs at all required scales

Calculation of observables in collinear factorisation, compatible with evolution

Comparison with data that are available and for which <u>pQCD can be considered reliable</u> (e.g. scale dependency)

Evaluation of the criterium for comparison data/theory, (treatment of errors, tolerance criteria for different data sets)

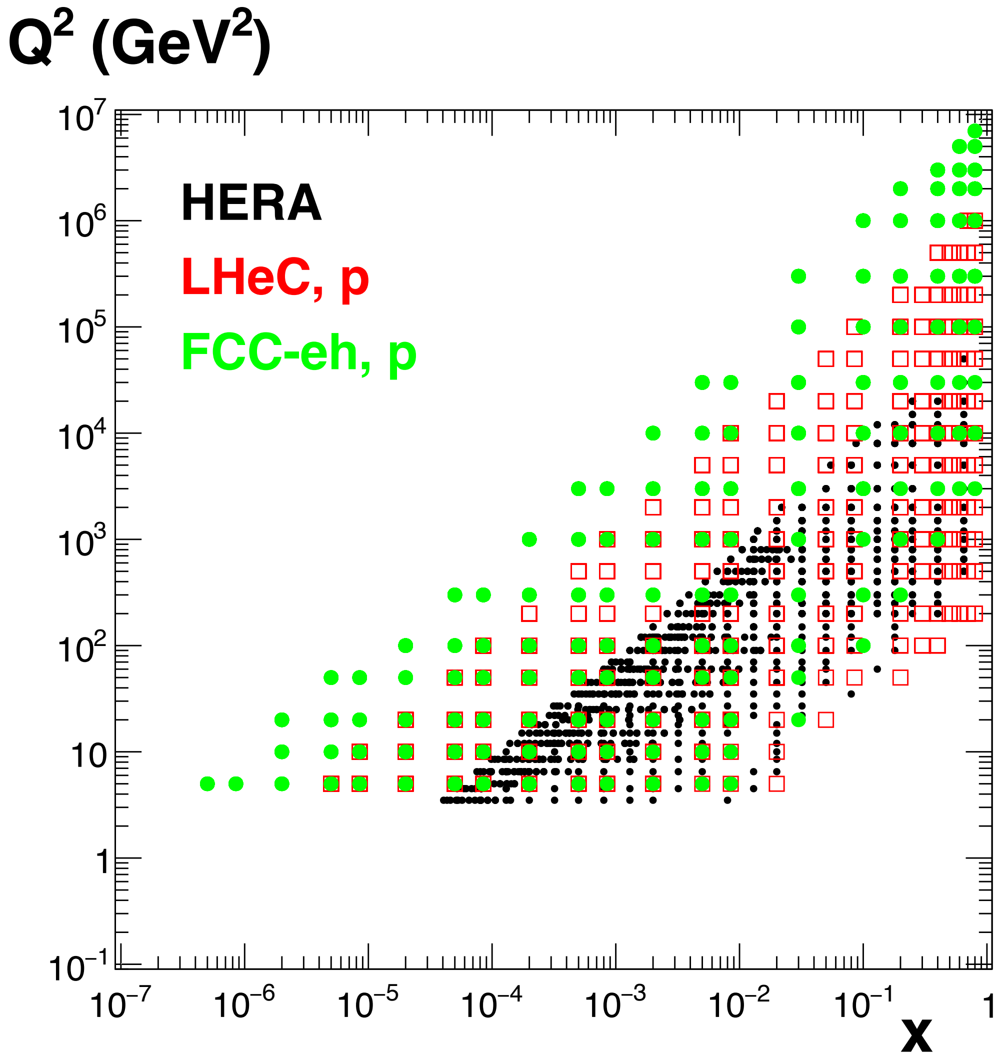
Minimum?

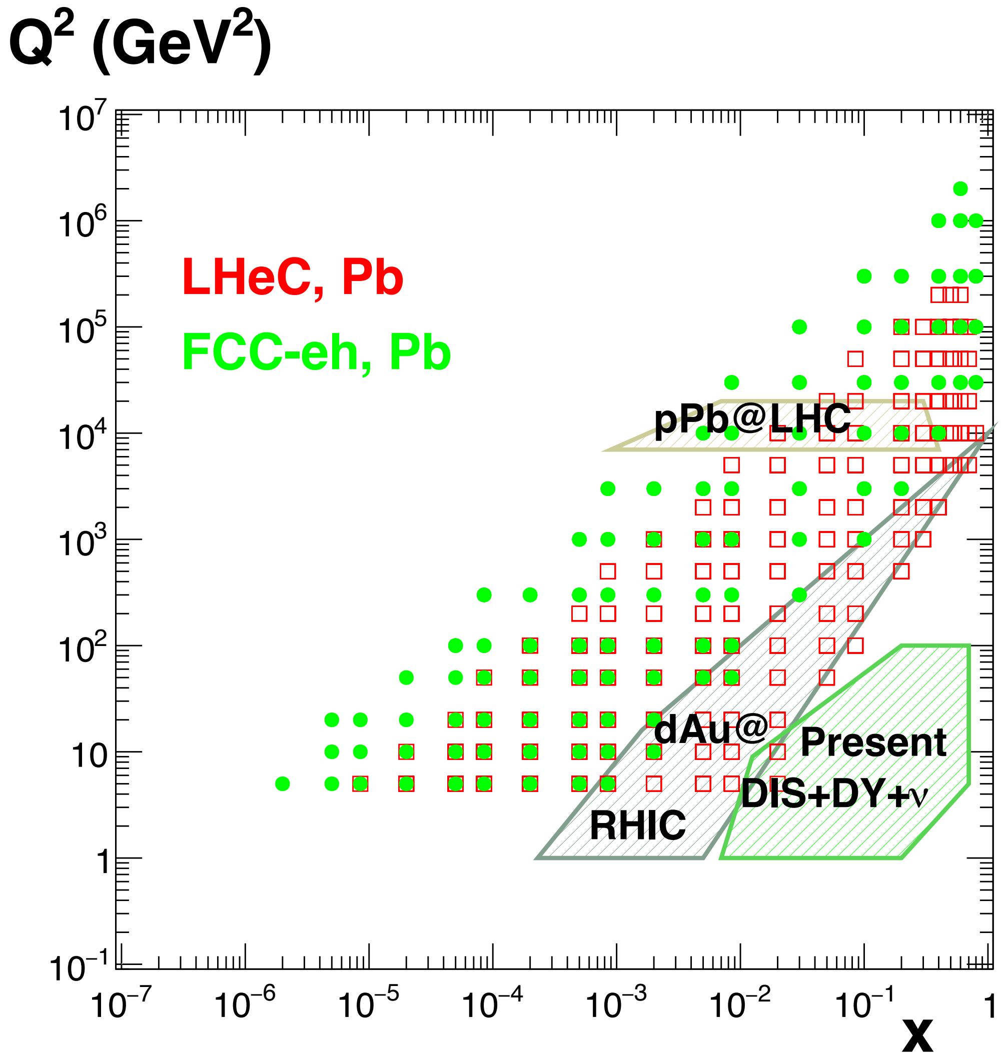
NO ⟹ vary parameters

YES

Final PDFs with uncertainties

Pseudodata:





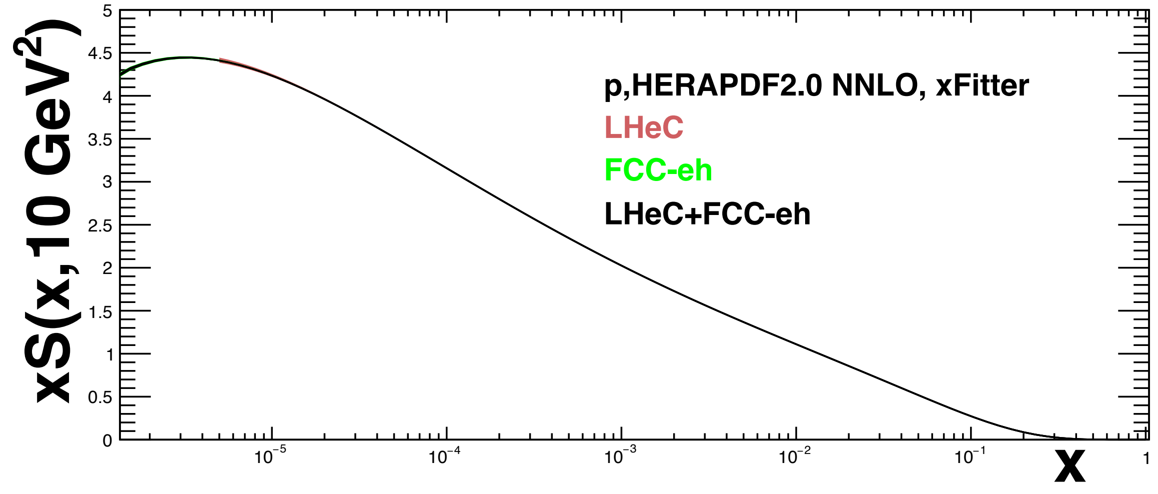
- Pseudodata generated using a code (Max Klein) validated with the H1 MC.
- Cuts: $|\eta_{max}|=5$, 0.95< y< 0.001.
- Error assumptions ~ factor 2 better than at HERA (luminosity uncertainty kept aside).
- Stat./syst. errors (ePb@FCC-eh) from 0.1/1.2% (small x, NC) to 37/6% (large x & Q^2, CC).

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:

	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

Results: sea



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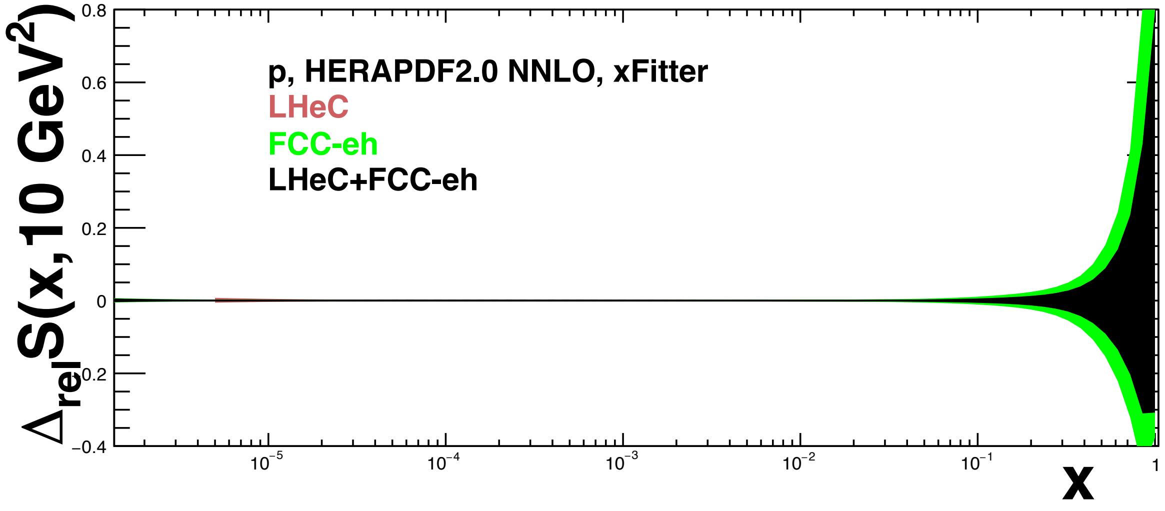

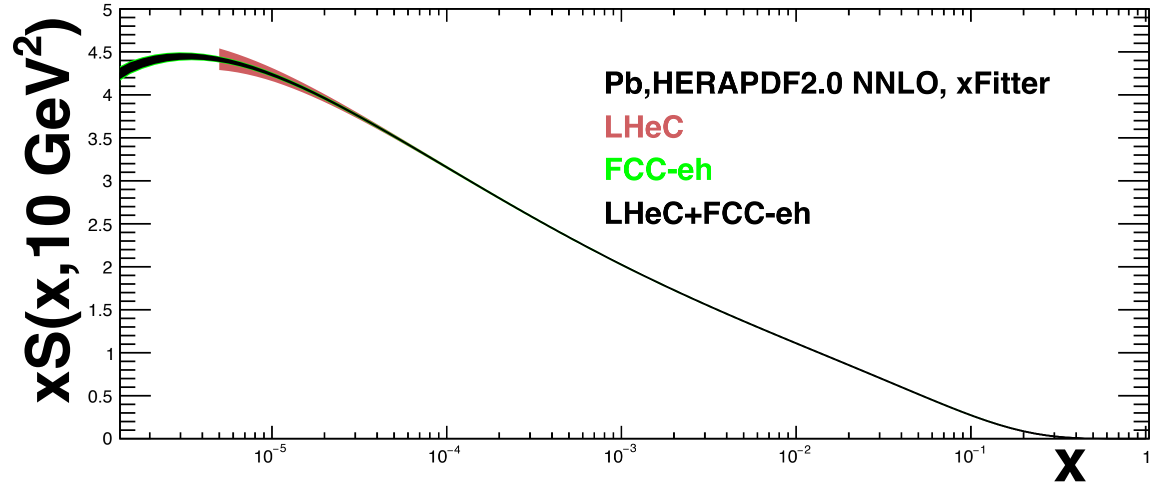

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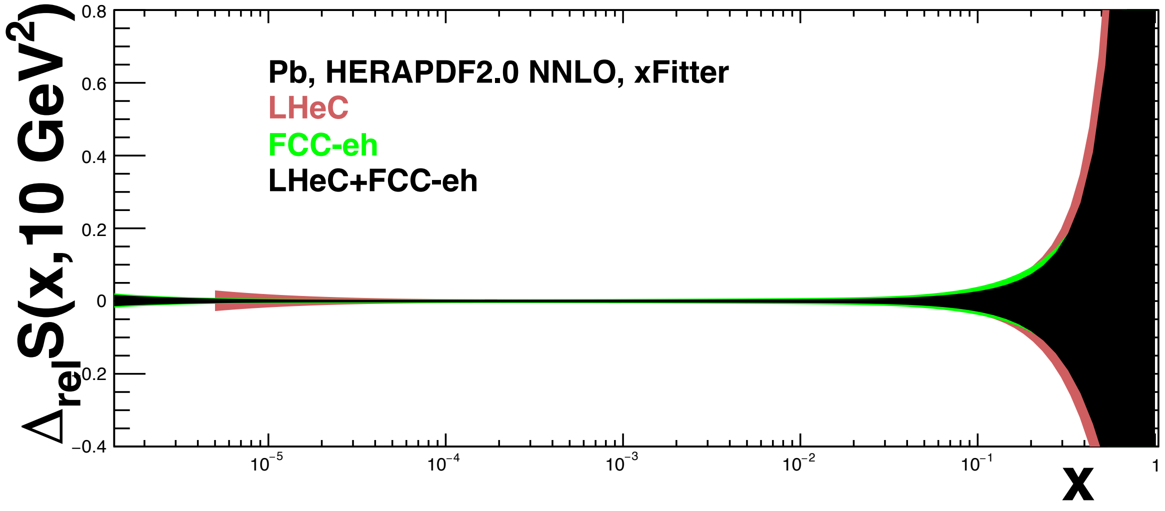

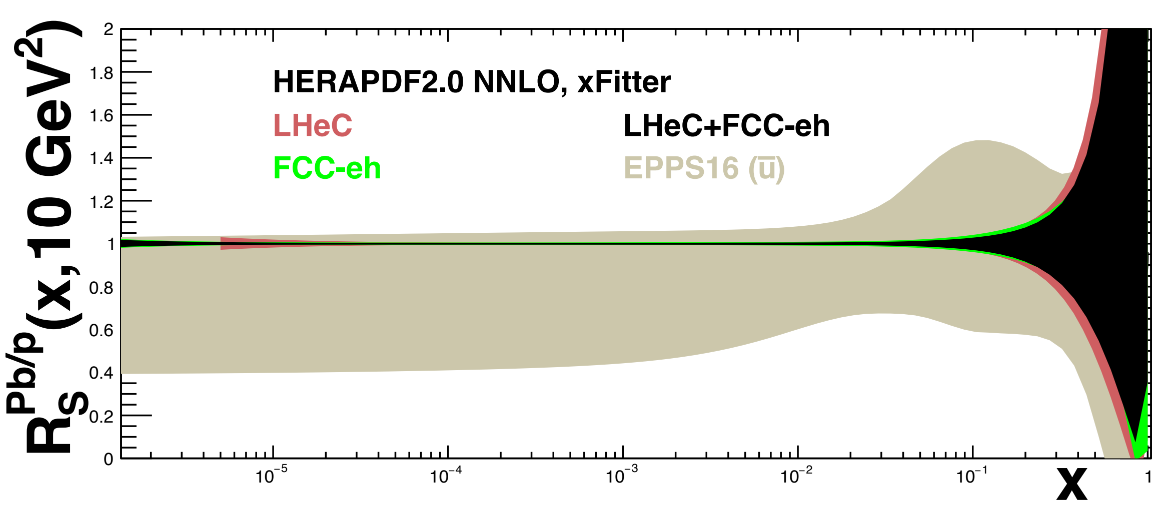

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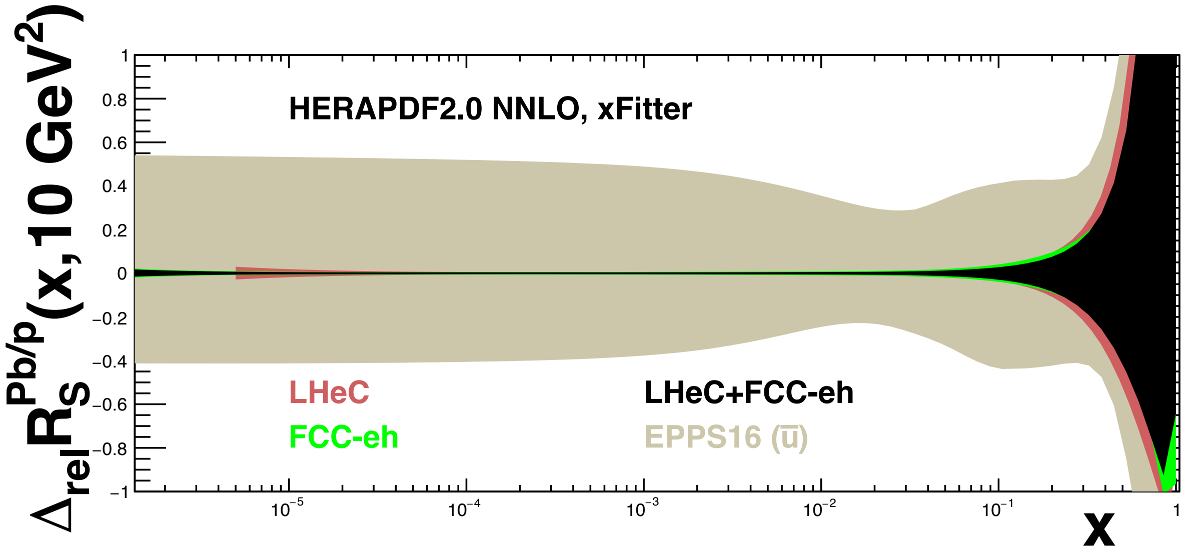
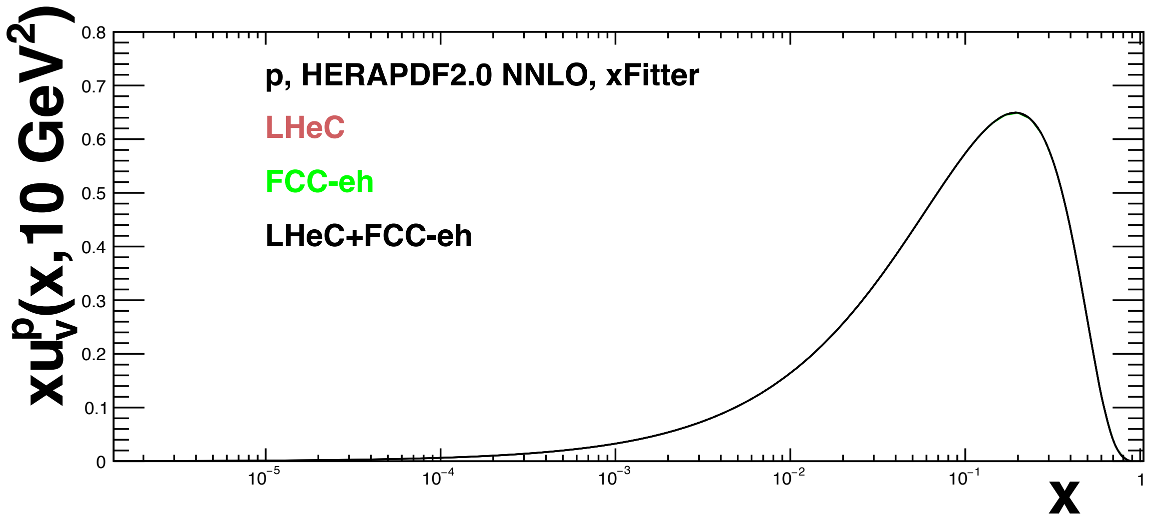
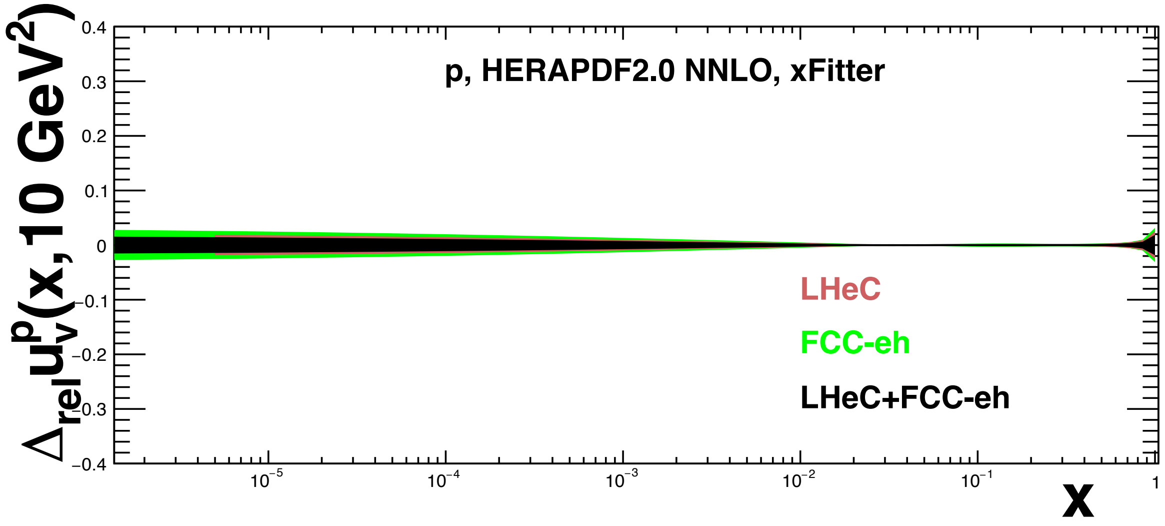


Results: valence





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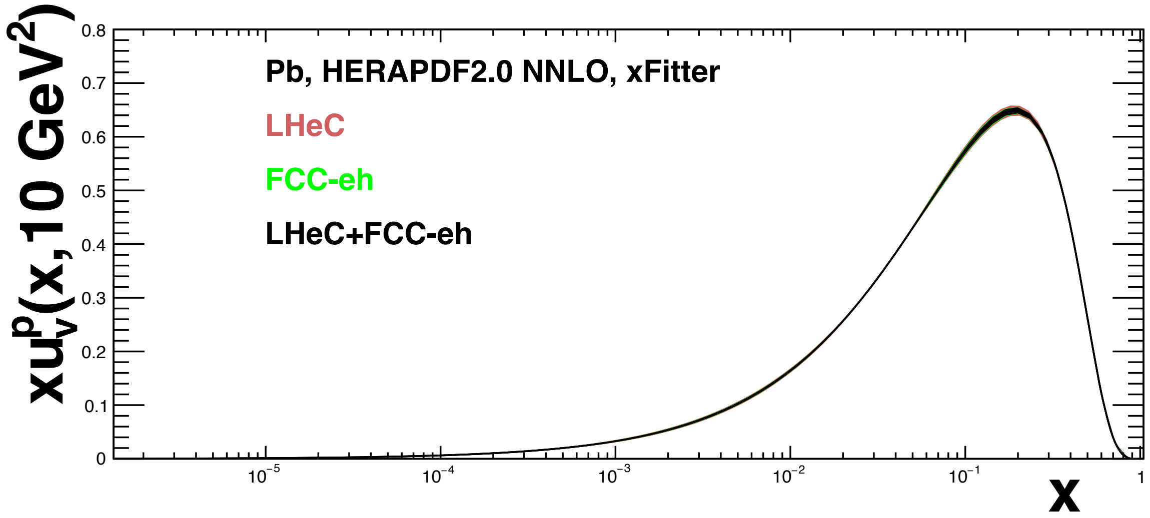

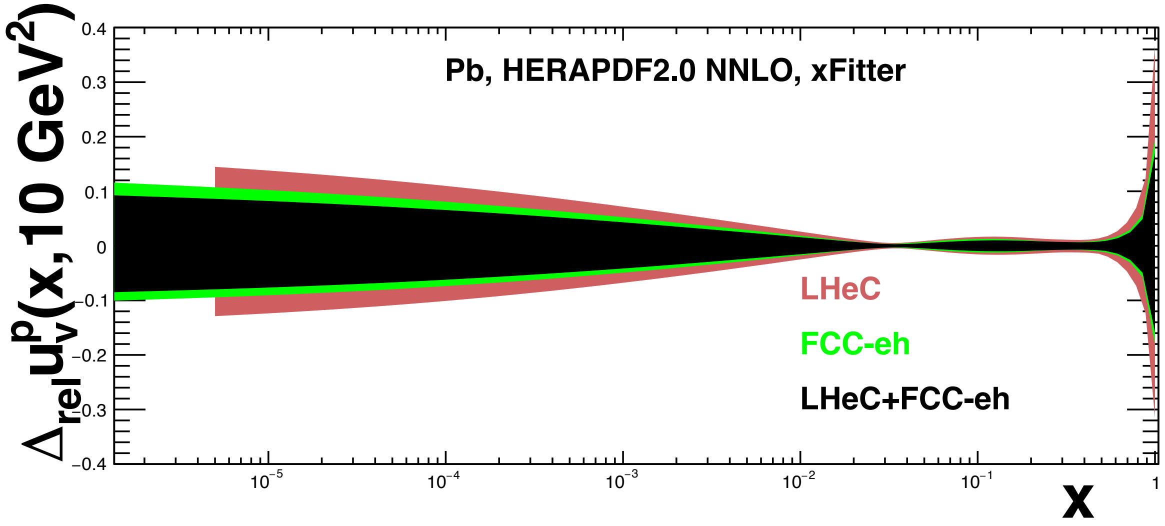

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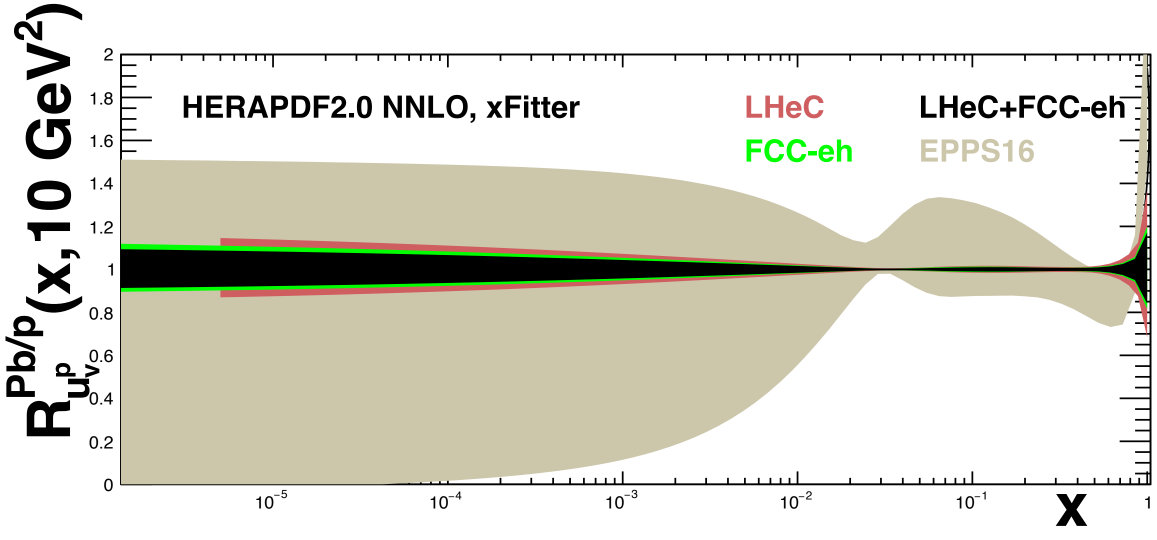
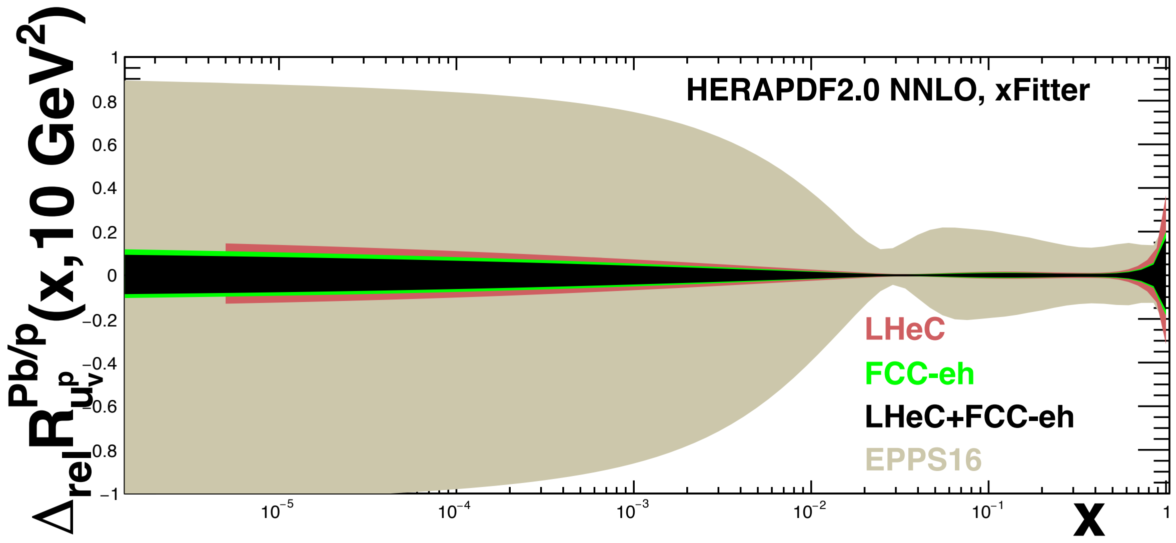
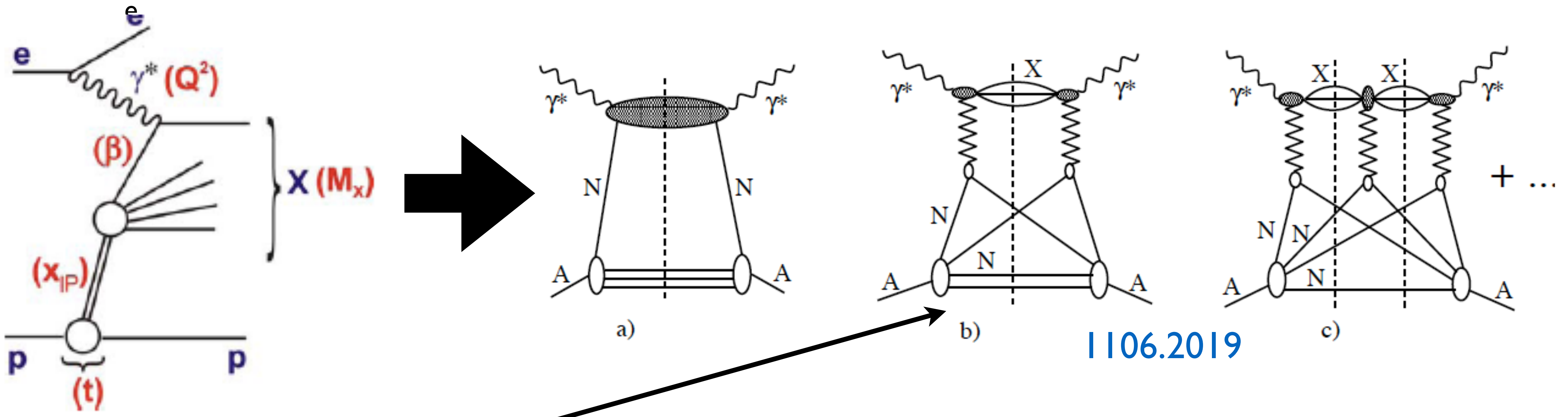




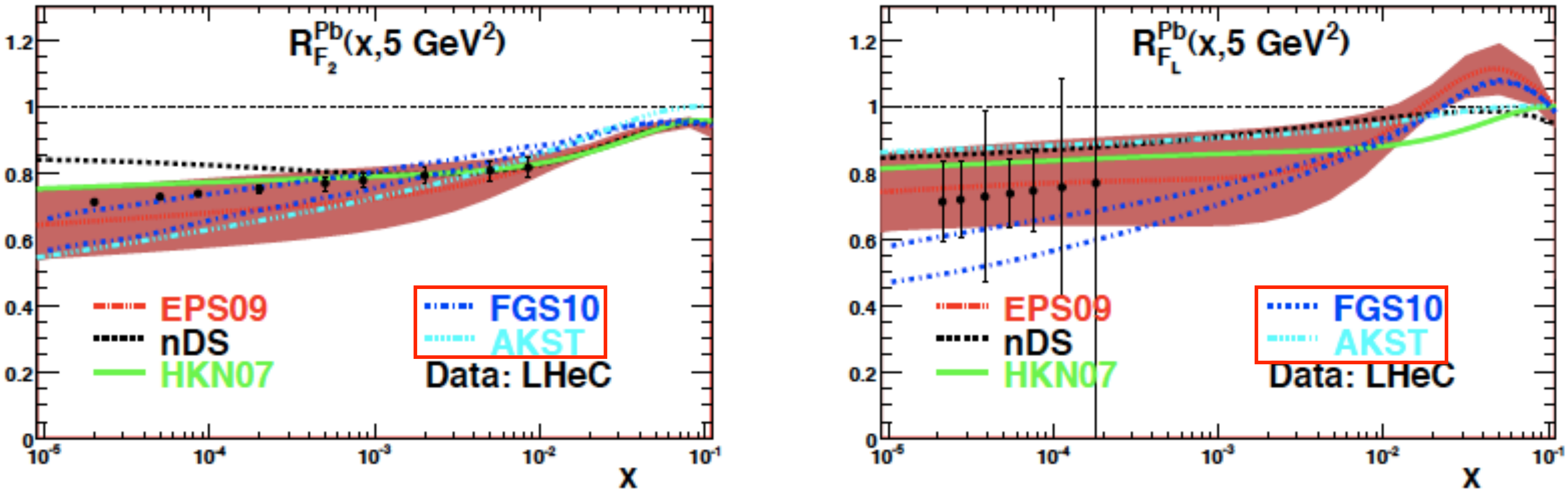
Pb/p

Diffraction in ep and shadowing:



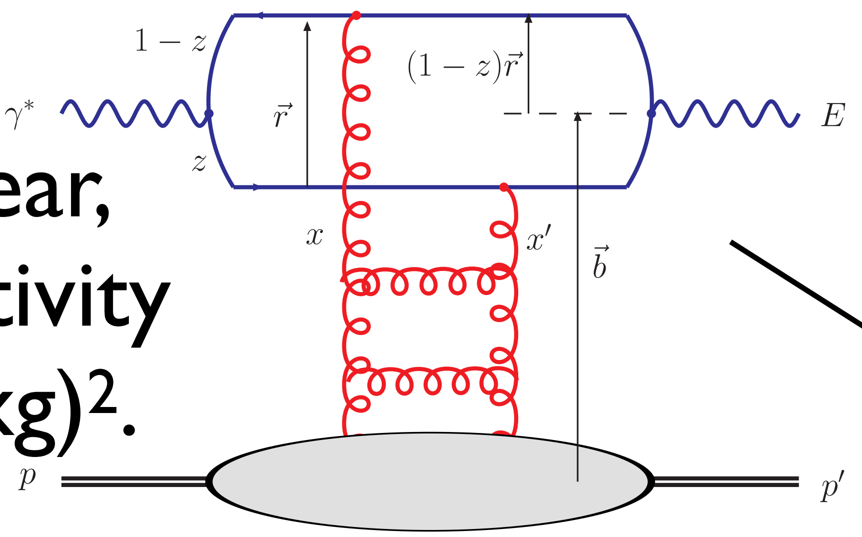
1106.2019

- Diffraction in ep is linked to nuclear shadowing through basic QFT (Gribov): eD to test and set the ‘benchmark’ for new effects.

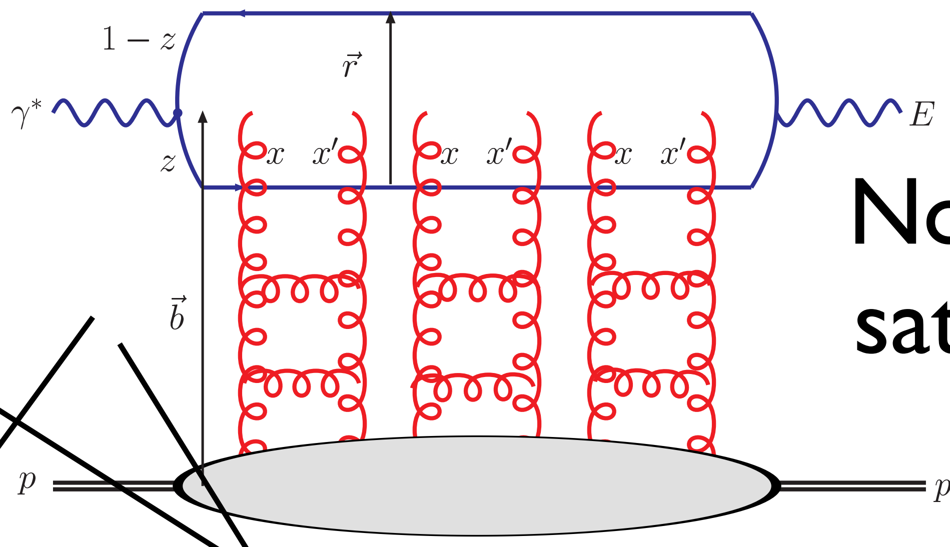


N. Armesto, 27.03.2018 - Lessons from EIC: 3. nPDFs from EICs.

Exclusive VMs:

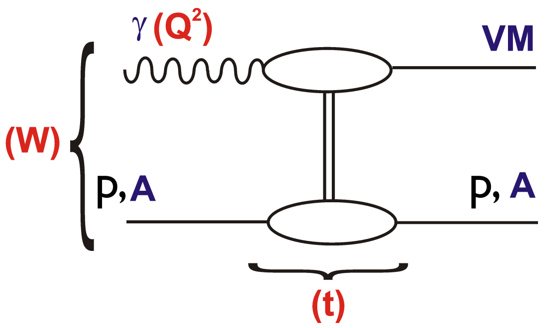


Linear, sensitivity to $(xg)^2$.

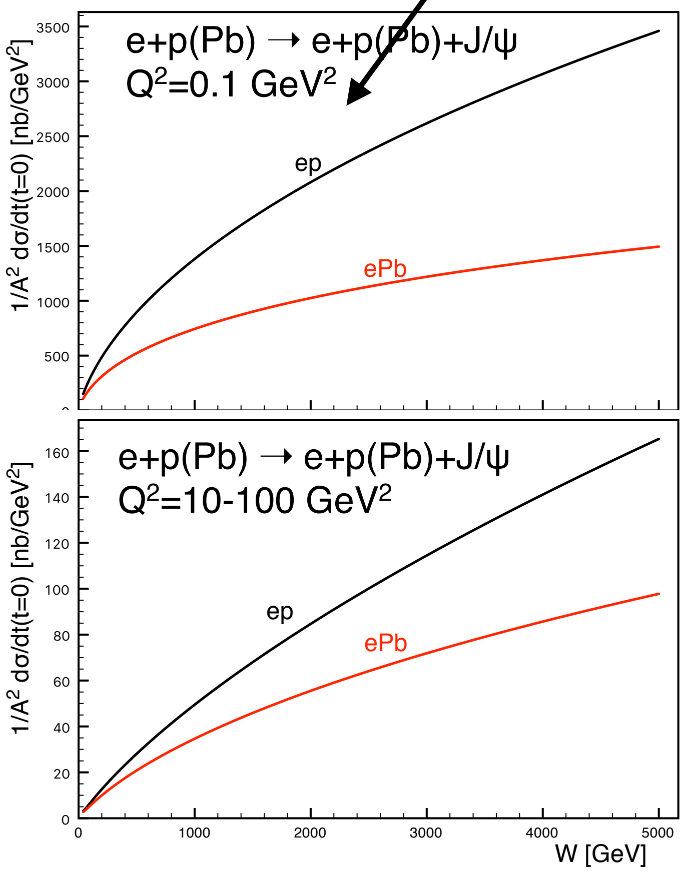


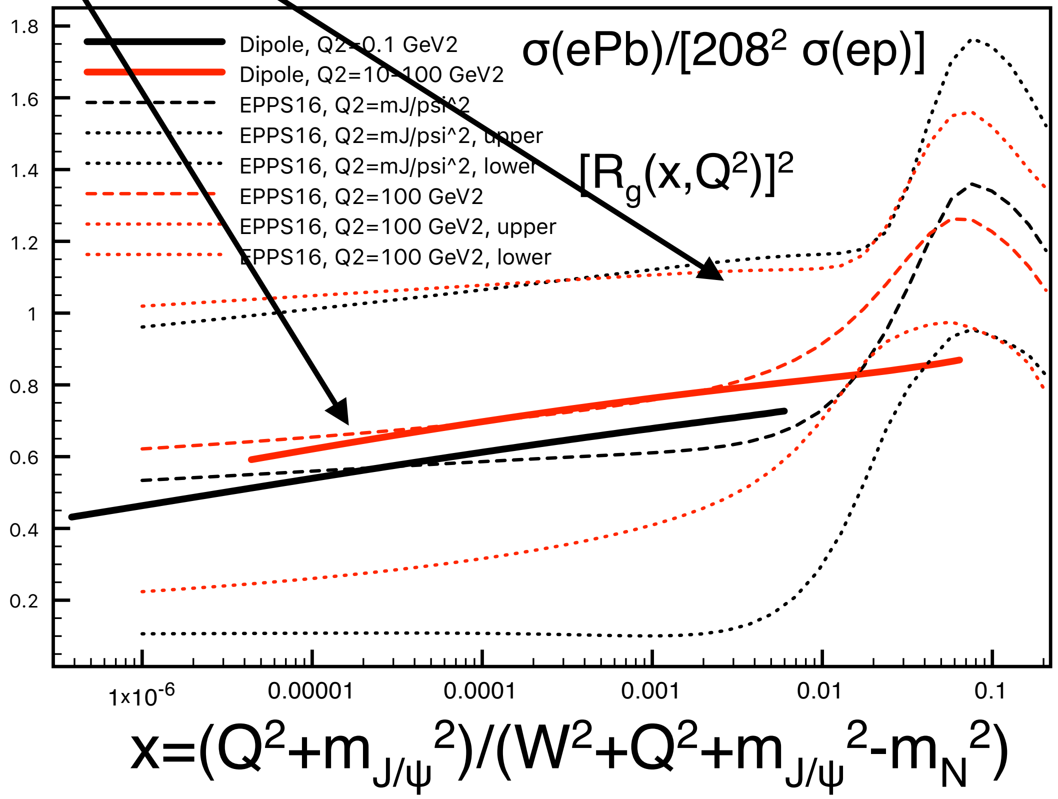
Non-linear, saturation.

- The magnitude of nuclear shadowing needs not be different in collinear and non-collinear approaches.



Coherent diffractive VM production





Mantysaari, Paukkunen