5th International Conference on the Initial Stages in High-Energy Nuclear Collisions IS2019
Columbia University, New York City, June 28th 2019

CERN perspective

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Unión Europea
Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
EXCELENCIA MARÍA DE MAEZTU

Contents:

1. Proposals.

2. Partonic structure of the nucleus.

3. New dynamics at small x.

4. Pre-equilibrium dynamics and small systems.

5. Summary.

References:

- *1812.06772 (HL-LHC with ions);*
- *Future Circular Collider: Vol. 1 Physics opportunities, CERN-ACC-2018-0056 (Eur. Phys. J. C79 (2019) no.6, 474), and 1605.01389;*
- *1901.09076 (diffraction in ep and eA);*
- *LHeC CDR, 1206.2913;*
- *2018 LHeC and FCC-eh workshop, https://indico.cern.ch/event/698368/;*
- *LHeC talks at DIS 2019, https://indico.cern.ch/event/749003/.*
- *Fixed target program at the HL-LHC, 1807.00603.*

Talks by J. Lajoie and E. Sichtermann.

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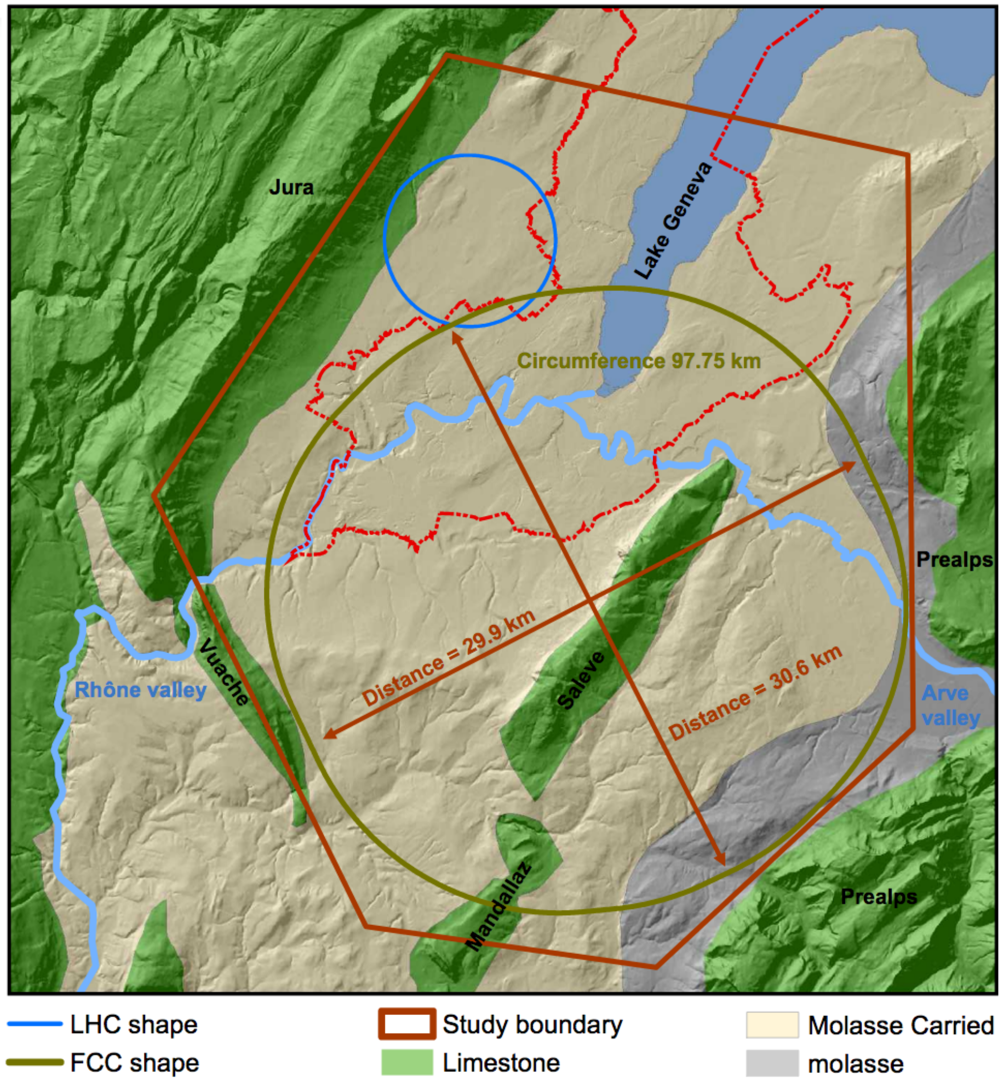
Warnings:

- *Although the focus was asked to be on what goes beyond LS4, I will also be talking about the perspectives at Runs 3 and 4.*
- *This is a personal review, my apologies to those who find their work misrepresented.*
- *I am not giving a full review of the heavy-ion topics at energies higher that LHC, just focus on those aspects that I find more closely related to initial stages.*
- *Even with these restrictions, it is too much material…*

pp/pA/AA colliders:

✦ FCC parameters for PbPb and pPb collisions:

	Unit	FCC Injection	FCC Collision	
Operation mode		Pb	Pb–Pb	p–Pb
Beam energy	[TeV]	270	4100	50
$\sqrt{s_{NN}}$	[TeV]	-	39.4	62.8
No. of bunches per LHC injection	-	518	518	518
No. of bunches in the FCC	-	2072	2072	2072
No. of particles per bunch	$[10^8]$	2.0	2.0	164
Transv. norm. emittance	[μm]	1.5	1.5	3.75
Number of IPs in collision	-	-	1	1
Crossing-angle	[μrad]	-	0	
Initial luminosity	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	-	24.5	2052
Peak luminosity	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	-	57.8	9918
Integrated luminosity per fill	$[\mu b^{-1}]$	-	553	158630
Average luminosity	$[\mu b^{-1}]$	-	92	20736
Time in collision	[h]	-	3	6
Assumed turnaround time	[h]	-	1.65	1.65
Integrated luminosity/run	$[nb^{-1}]$	-	33	8000



- **FCC-hh as representative:**

other ideas around like

➜ HE-LHC (16 T magnets): 27 TeV pp.

➜ 6 T magnets in the FCC tunnel: 37.5 TeV pp.

M. Benedikt at FCC Week 2019

parameter	FCC-hh	FCC-hh-6T	HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100	37.5	27	14	14
dipole field [T]	16	6	16	8.33	8.33
beam current [A]	0.5	0.6	1.1	1.1	0.58
synchr. rad. power/ring [kW]	2400	57	101	7.3	3.6
peak luminosity $[10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	5 30	10 (lev.)	16	5 (lev.)	1
events/bunch crossing	170 1000	~300	460	132	27
stored energy/beam [GJ]	8.4	3.75	1.4	0.7	0.36

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vs LHC: 5.5 (PbPb) and 8.8 (pPb)

vs LHC (total):
PbPb: ~1 (Run2); ~4 (Run3); ~4 (Run4)
pPb: 50-400 (2 weeks)

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AA

Isotope	^{40}Ar^{18+}	^{40}Ca^{20+}	^{78}Kr^{36+}	^{129}Xe^{54+}	^{208}Pb^{82+}
Number of particles [10^8]	19.4	16.6	6.9	3.7	2.0
Integrated $\mathcal{L}_{AA}$ [nb^{-1}/run]	28381	25074	3286	560	62
Integrated $\mathcal{L}_{NN}$ [fb^{-1}/run]	45.4	40.1	20.0	9.3	2.7

M. Schaumann at FCC Week 2019

pPb

Including a **performance efficiency factor** of 50%

	Baseline:	Ultimate:
1 exp. L_{int}/run:	**8pb^{-1}**	**29pb^{-1}**
2 exp. L_{int}/run:	**6pb^{-1}**	**18pb^{-1}**

vs LHC (total):
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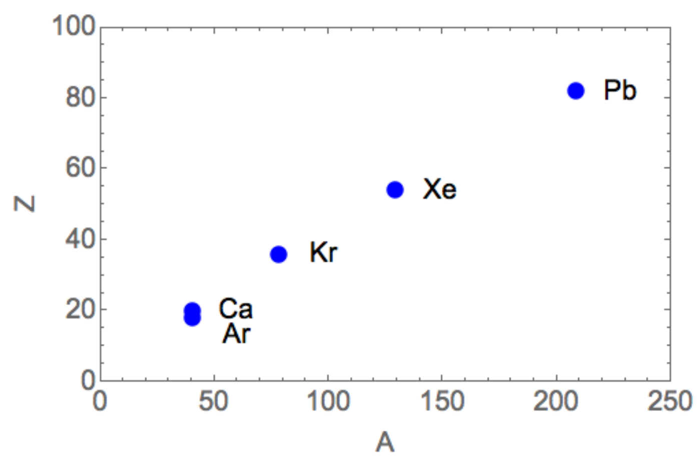
Timelines…

- **Pb–Pb at $\sqrt{s_{\rm NN}} = 5.5$ TeV**, $L_{\rm int} = 13\ {\rm nb}^{-1}$ (ALICE, ATLAS, CMS), $2\ {\rm nb}^{-1}$ (LHCb)
- **pp at $\sqrt{s} = 5.5$ TeV**, $L_{\rm int} = 600\ {\rm pb}^{-1}$ (ATLAS, CMS), $6\ {\rm pb}^{-1}$ (ALICE), $50\ {\rm pb}^{-1}$ (LHCb)
- **pp at $\sqrt{s} = 14$ TeV**, $L_{\rm int} = 200\ {\rm pb}^{-1}$ with low pileup (ALICE, ATLAS, CMS)
- **p–Pb at $\sqrt{s_{\rm NN}} = 8.8$ TeV**, $L_{\rm int} = 1.2\ {\rm pb}^{-1}$ (ATLAS, CMS), $0.6\ {\rm pb}^{-1}$ (ALICE, LHCb)
- **pp at $\sqrt{s} = 8.8$ TeV**, $L_{\rm int} = 200\ {\rm pb}^{-1}$ (ATLAS, CMS, LHCb), $3\ {\rm pb}^{-1}$ (ALICE)
- **O–O at $\sqrt{s_{\rm NN}} = 7$ TeV**, $L_{\rm int} = 500\ \mu{\rm b}^{-1}$ (ALICE, ATLAS, CMS, LHCb)
- **p–O at $\sqrt{s_{\rm NN}} = 9.9$ TeV**, $L_{\rm int} = 200\ \mu{\rm b}^{-1}$ (ALICE, ATLAS, CMS, LHCb)
- **Intermediate AA**, e.g. $L_{\rm int}^{\rm Ar-Ar} = 3$–$9\ {\rm pb}^{-1}$ (about 3 months) gives NN luminosity equivalent to Pb–Pb with $L_{\rm int} = 75$–$250\ {\rm nb}^{-1}$

Considered species

^{40}Ar^{18+}	^{40}Ca^{20+}	^{78}Kr^{36+}	^{129}Xe^{54+}	^{208}Pb^{82+}



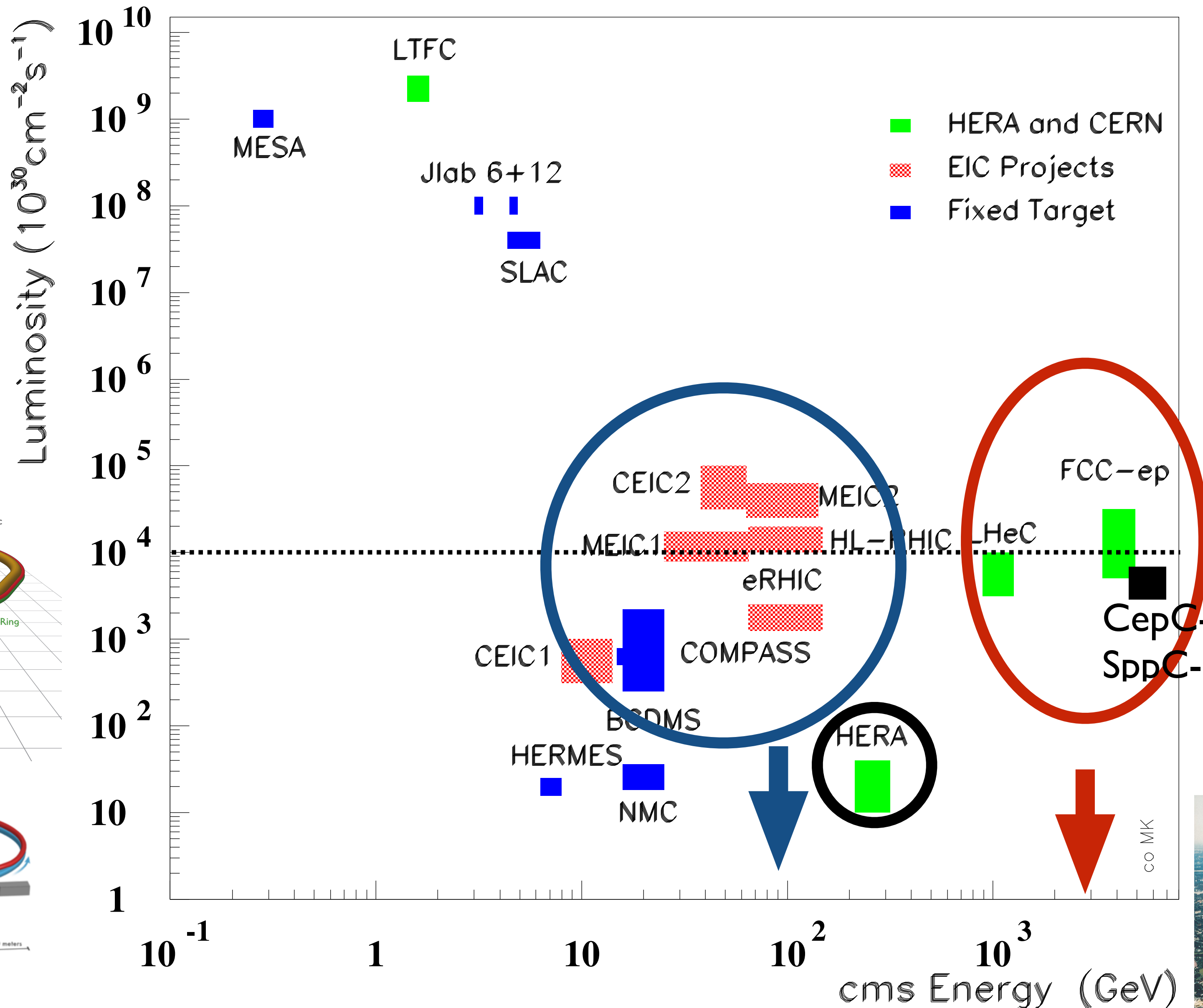
1812.06772

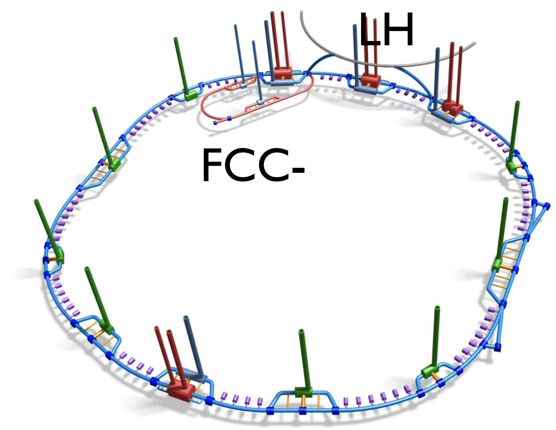
Year	Systems, $\sqrt{s_{\rm NN}}$	Time	$L_{\rm int}$
2021	Pb–Pb 5.5 TeV	3 weeks	$2.3\ {\rm nb}^{-1}$
	pp 5.5 TeV	1 week	$3\ {\rm pb}^{-1}$ (ALICE), $300\ {\rm pb}^{-1}$ (ATLAS, CMS), $25\ {\rm pb}^{-1}$ (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	$3.9\ {\rm nb}^{-1}$
	O–O, p–O	1 week	$500\ \mu{\rm b}^{-1}$ and $200\ \mu{\rm b}^{-1}$
2023	p–Pb 8.8 TeV	3 weeks	$0.6\ {\rm pb}^{-1}$ (ATLAS, CMS), $0.3\ {\rm pb}^{-1}$ (ALICE, LHCb)
	pp 8.8 TeV	few days	$1.5\ {\rm pb}^{-1}$ (ALICE), $100\ {\rm pb}^{-1}$ (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	$3.8\ {\rm nb}^{-1}$
	pp 5.5 TeV	1 week	$3\ {\rm pb}^{-1}$ (ALICE), $300\ {\rm pb}^{-1}$ (ATLAS, CMS), $25\ {\rm pb}^{-1}$ (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	$0.6\ {\rm pb}^{-1}$ (ATLAS, CMS), $0.3\ {\rm pb}^{-1}$ (ALICE, LHCb)
	pp 8.8 TeV	few days	$1.5\ {\rm pb}^{-1}$ (ALICE), $100\ {\rm pb}^{-1}$ (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	$3\ {\rm nb}^{-1}$
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 ${\rm pb}^{-1}$ (optimal species to be defined)
	pp reference	1 week	

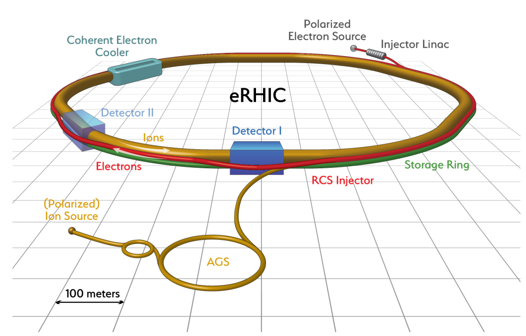
ep/eA colliders:

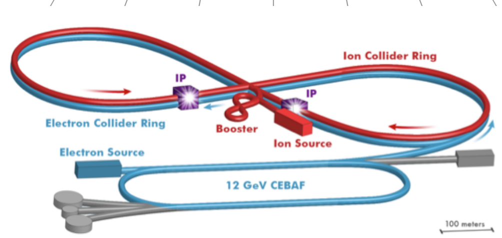
- Projects of ep/eA colliders with $E_{cm} \sim \mathcal{O}(0.1)$ TeV/A (EICs at US and China) and $\mathcal{O}(1)$ TeV/A (LHeC and FCC-eh at CERN) addressing different physics.

Lepton-proton/nucleus scattering facilities



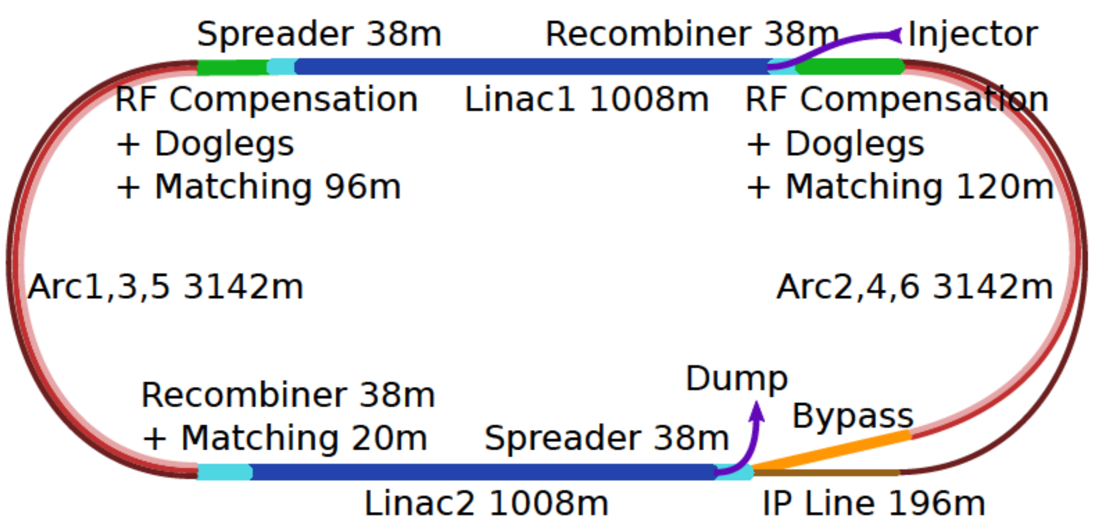






See M.Wing's talk for PEPIC and VHEeP, and 1812.08110.

ep/eA colliders:



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

eD at LHeC:
$L_{eN}=AL_{eA}\sim 5\times 10^{32}$ cm^{-2}s^{-1}

See M.Wing's talk for PEPIC and VHEeP, and 1812.08110.

ep

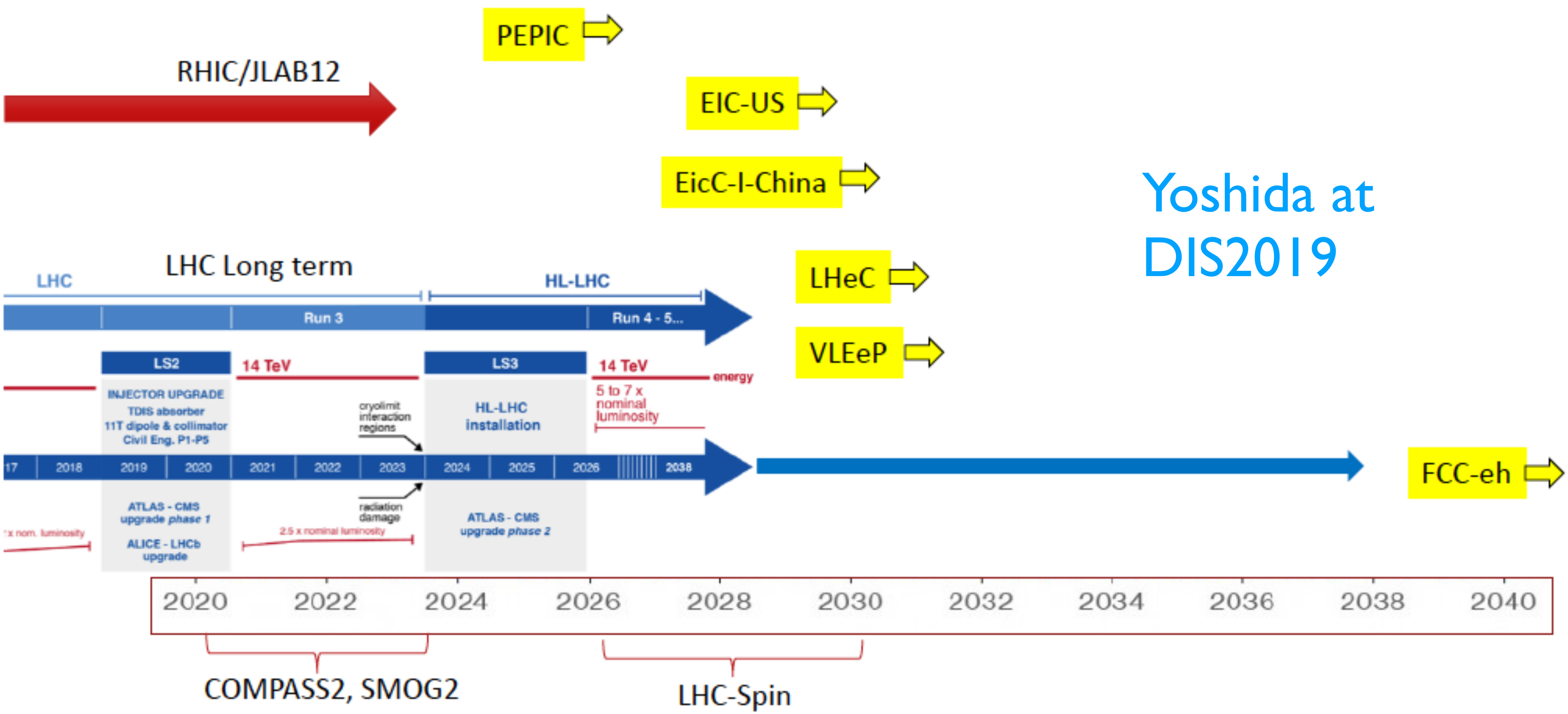
Parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	13.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
Bunch spacing [ns]	25	25	25	25
Protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
Electrons per bunch [10^9]	1	2.3	3.0	3.0
Electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
Hourglass factor H_{geom}	0.9	0.9	0.9	0.9
Pinch factor H_{b-b}	1.3	1.3	1.3	1.3
Proton filling H_{coll}	0.8	0.8	0.8	0.8
Luminosity [10^{33} cm^{-2}s^{-1}]	1	8	12	15

ePb

CERN-ACC-2017-0019

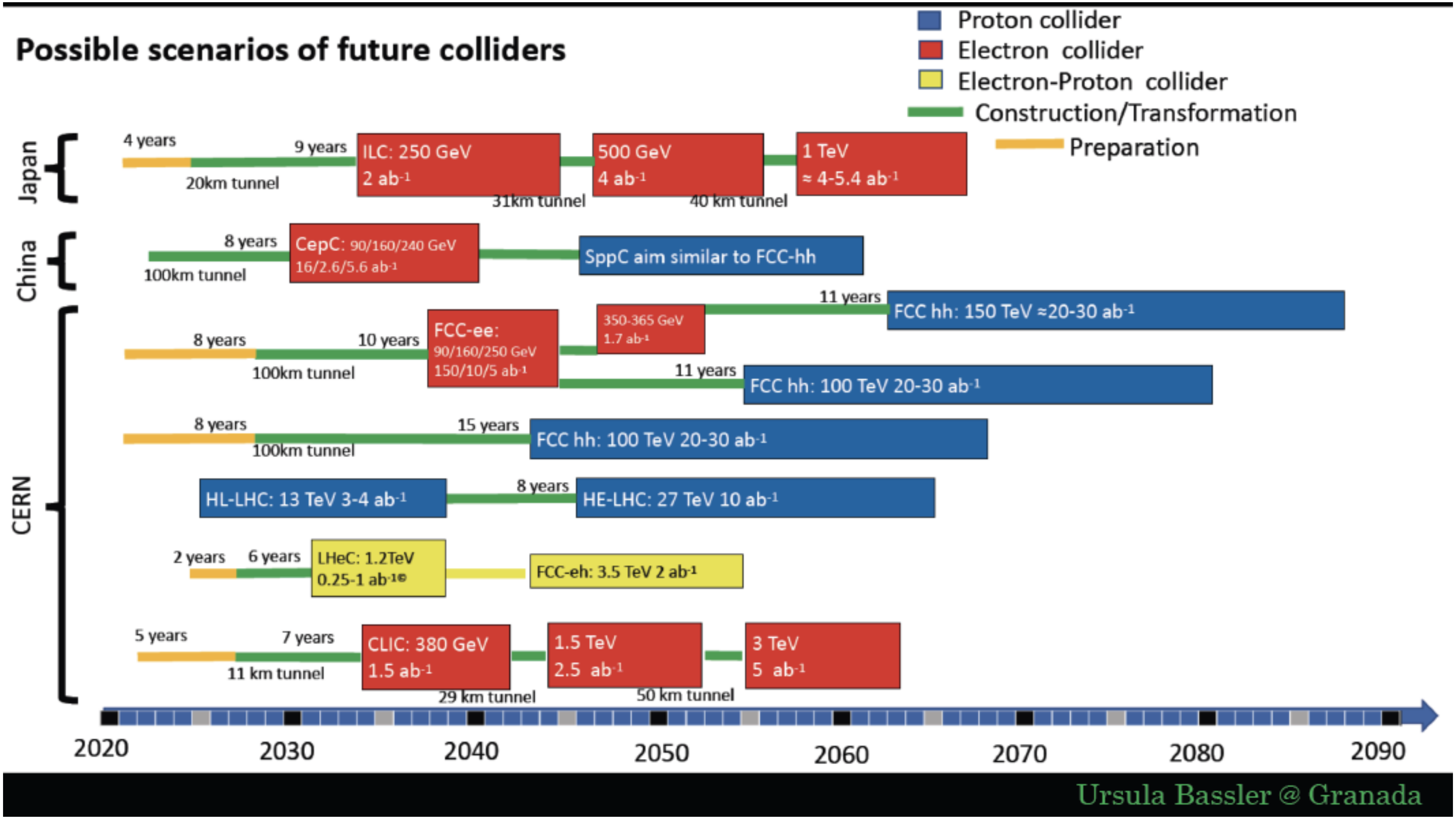
parameter [unit]	LHeC (HL-LHC)	eA at HE-LHC	FCC-he
E_{Pb} [PeV]	0.574	1.03	4.1
E_e [GeV]	60	60	60
$\sqrt{s_{eN}}$ electron-nucleon [TeV]	0.8	1.1	2.2
bunch spacing [ns]	50	50	100
no. of bunches	1200	1200	2072
ions per bunch [10^8]	1.8	1.8	1.8
$\gamma\epsilon_A$ [μm]	1.5	1.0	0.9
electrons per bunch [10^9]	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}cm^{-2}s^{-1}]	7	18	54
Integrated lumi. in 10 y. (fb^{-1}) ~~	6	15	45

Timelines…



Yoshida at DIS2019

Timelines…



Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation
Preparation
Japan
4 years
9 years
20km tunnel
ILC: 250 GeV
2 ab-1
31km tunnel
500 GeV
4 ab-1
40 km tunnel
1 TeV
≈ 4-5.4 ab-1
China
8 years
100km tunnel
CepC: 90/160/240 GeV
16/2.6/5.6 ab-1
SppC aim similar to FCC-hh
CERN
8 years
10 years
100km tunnel
FCC-ee:
90/160/250 GeV
150/10/5 ab-1
350-365 GeV
1.7 ab-1
11 years
FCC hh: 150 TeV ≈20-30 ab-1
11 years
FCC hh: 100 TeV 20-30 ab-1
8 years
15 years
100km tunnel
FCC hh: 100 TeV 20-30 ab-1
HL-LHC: 13 TeV 3-4 ab-1
8 years
HE-LHC: 27 TeV 10 ab-1
2 years
6 years
LHeC: 1.2TeV
0.25-1 ab-1
FCC-eh: 3.5 TeV 2 ab-1
5 years
7 years
11 km tunnel
CLIC: 380 GeV
1.5 ab-1
29 km tunnel
1.5 TeV
2.5 ab-1
50 km tunnel
3 TeV
5 ab-1
2020
2030
2040
2050
2060
2070
2080
2090
Ursula Bassler @ Granada

Kinematics:

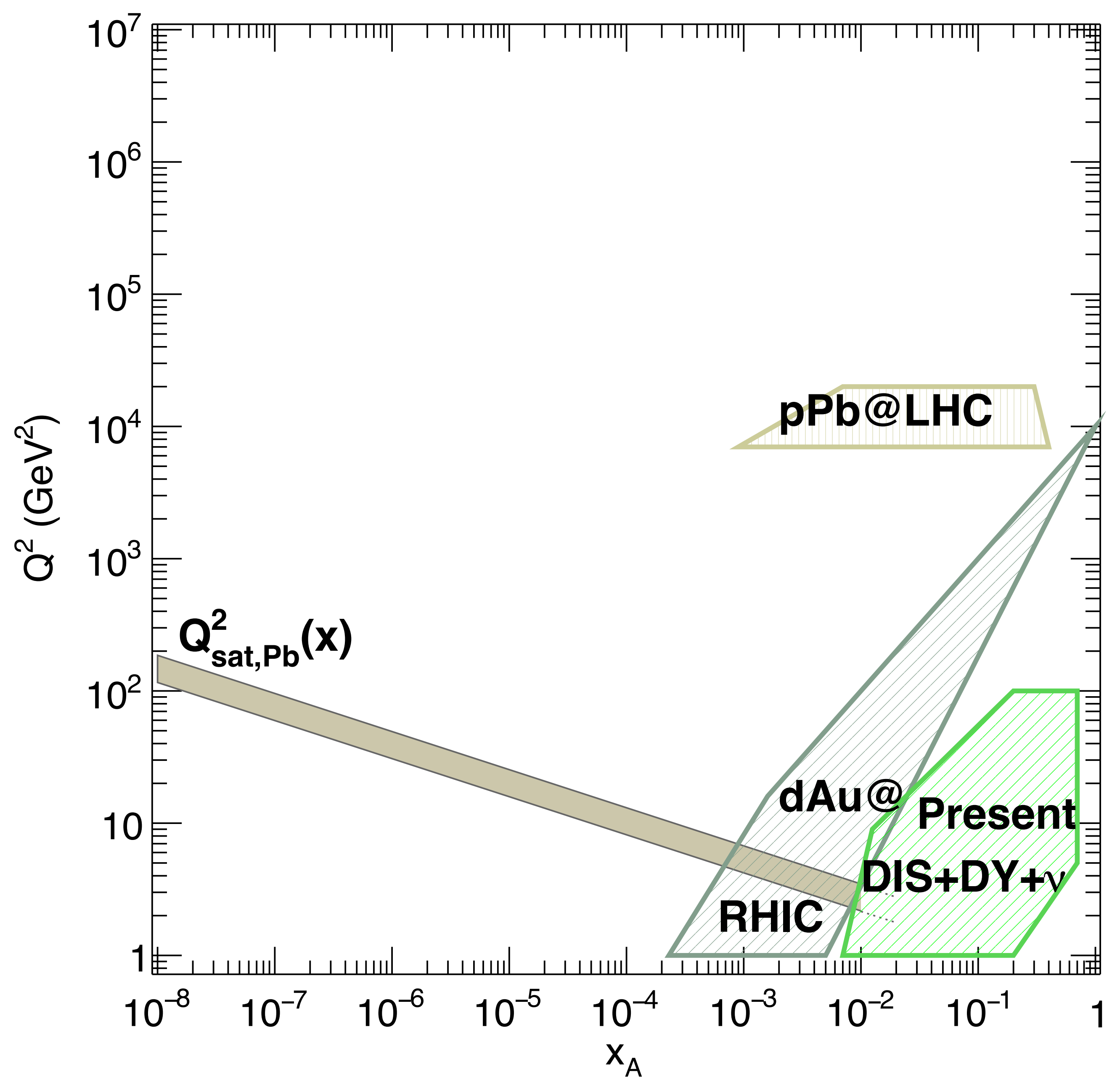
- Extension of several orders of magnitude in x and Q^2 w.r.t. existing DIS data.
- **DIS versus hh**:

➜ pA/AA covers largest range in kinematics.

➜ **DIS offers**:

➤ A clean experimental environment - low multiplicity, no pileup, fully constrained kinematics x, Q^2;

➤ A more controlled theoretical setup - many first-principles calculations, factorisation tests.



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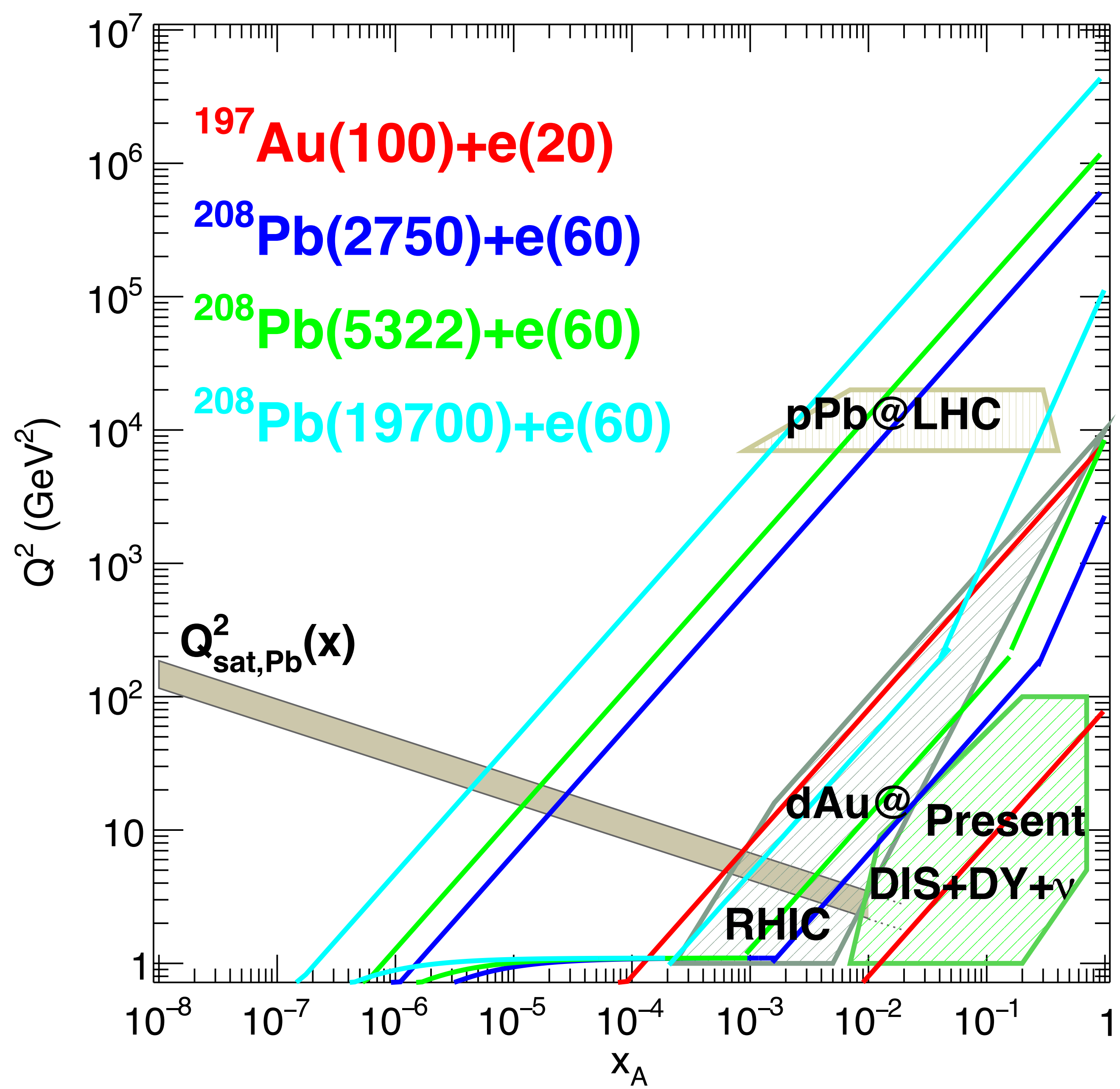

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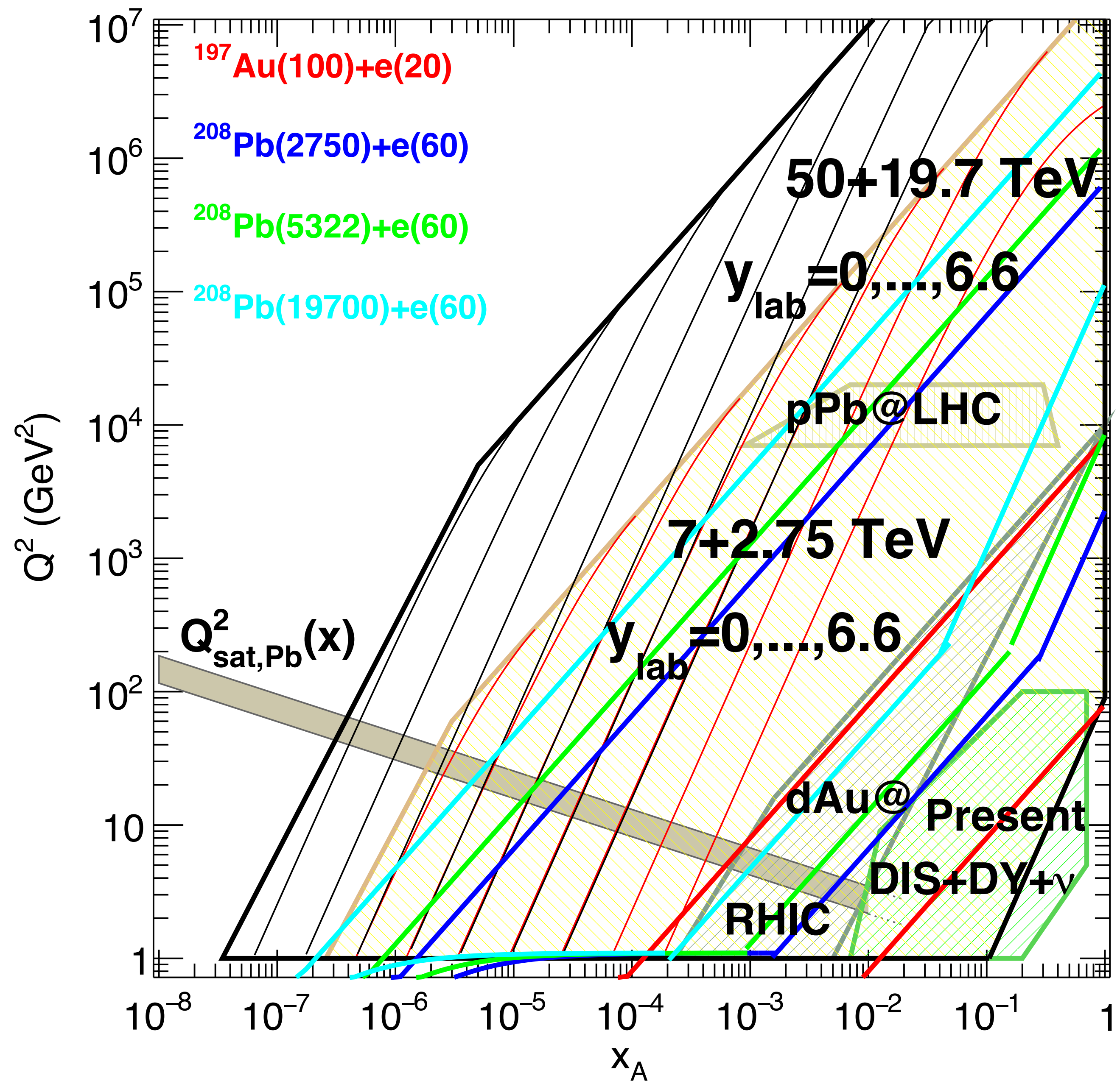

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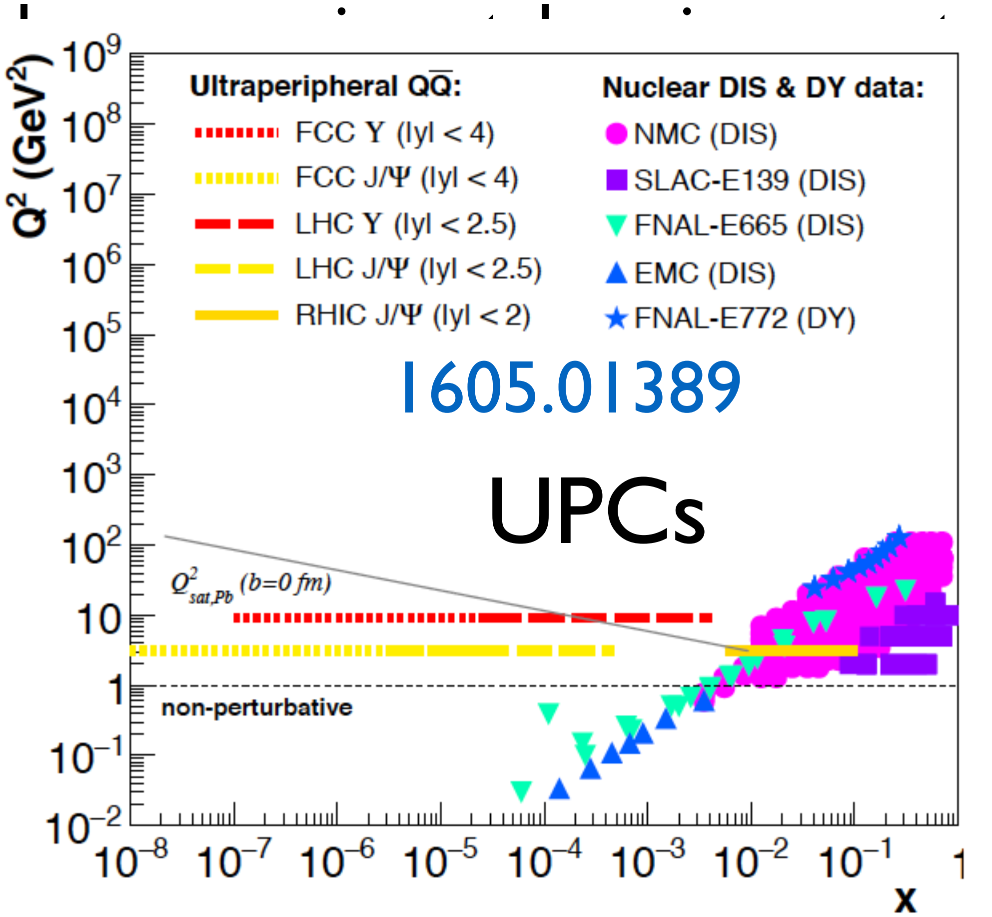

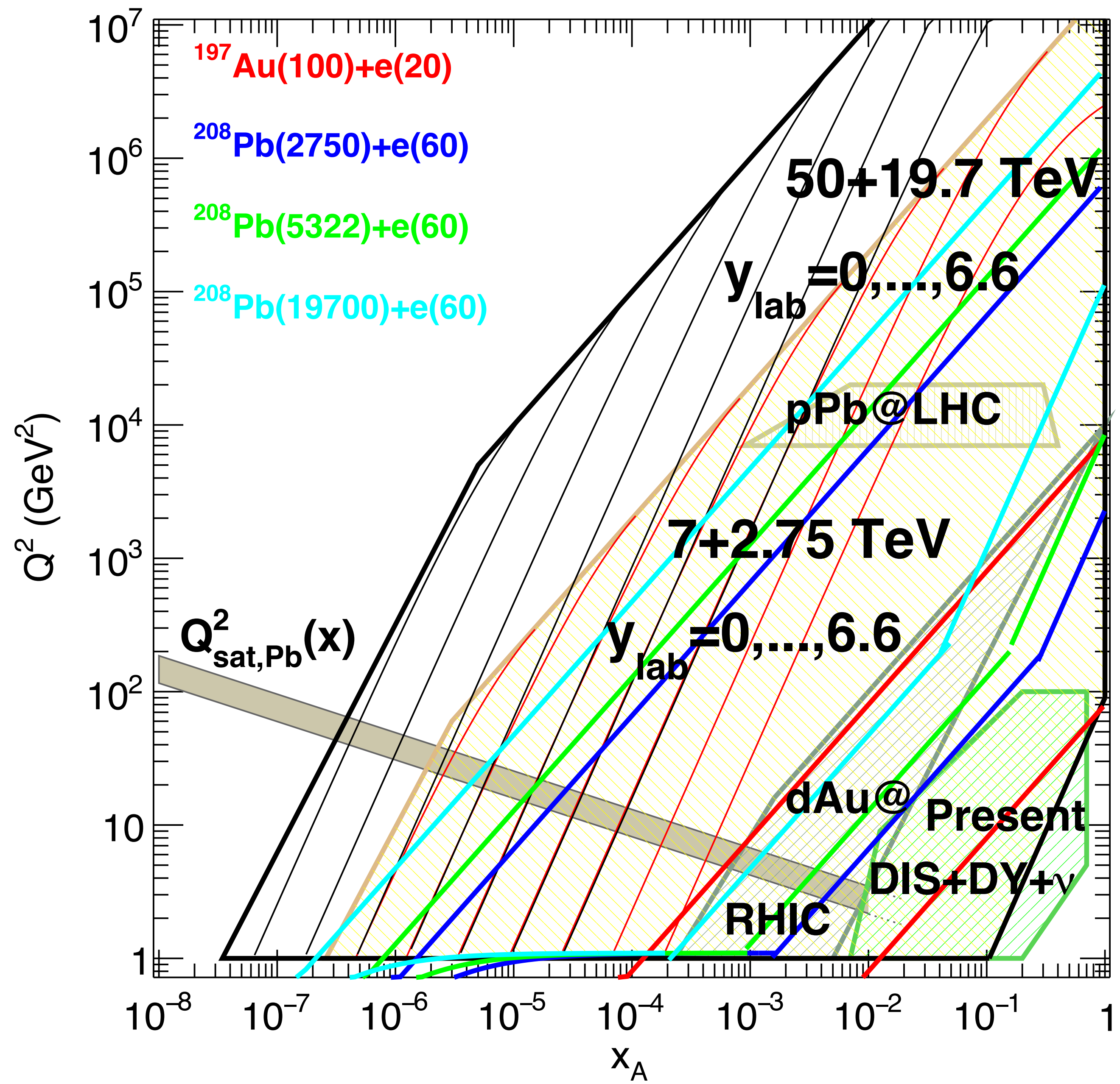

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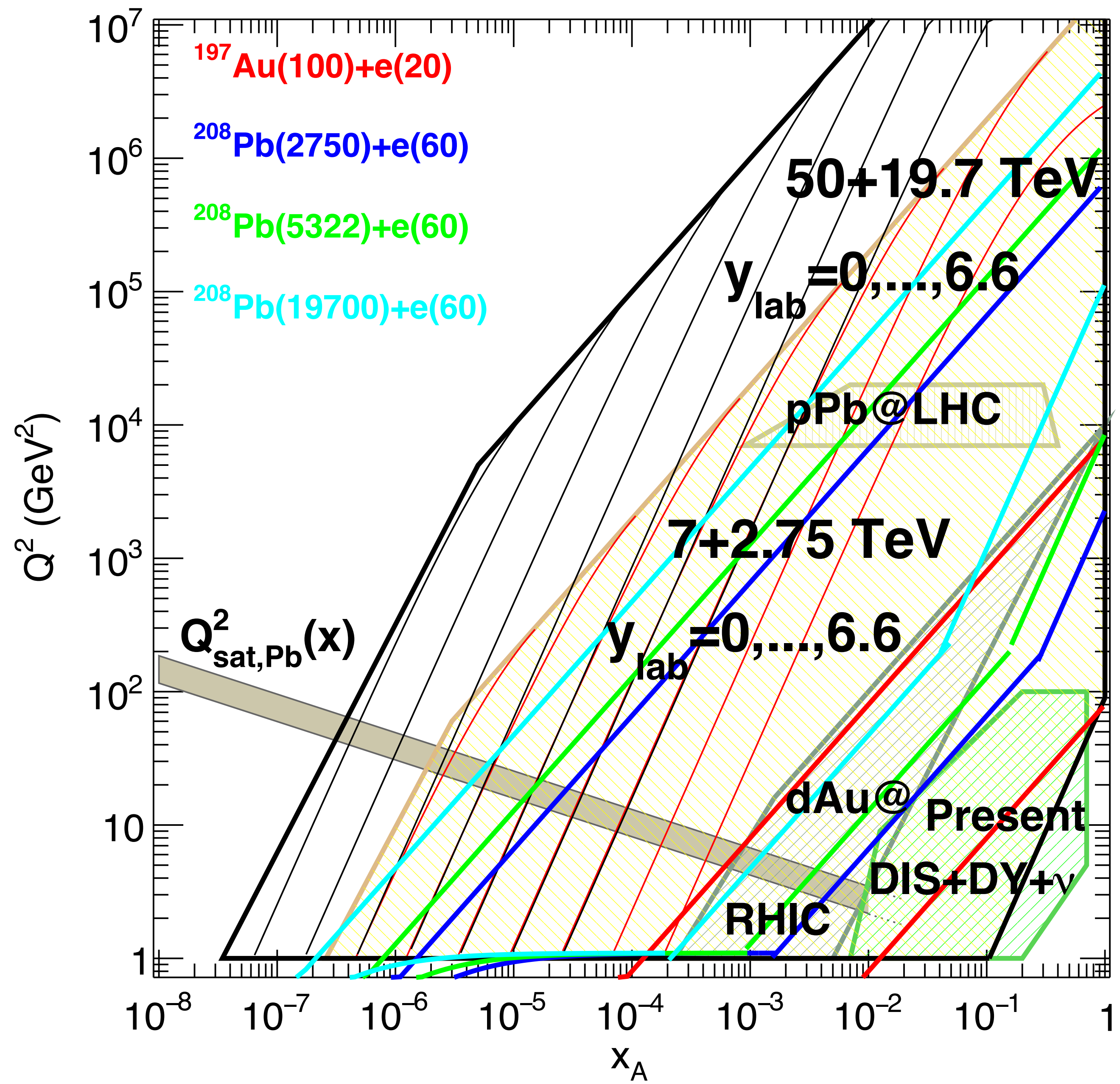

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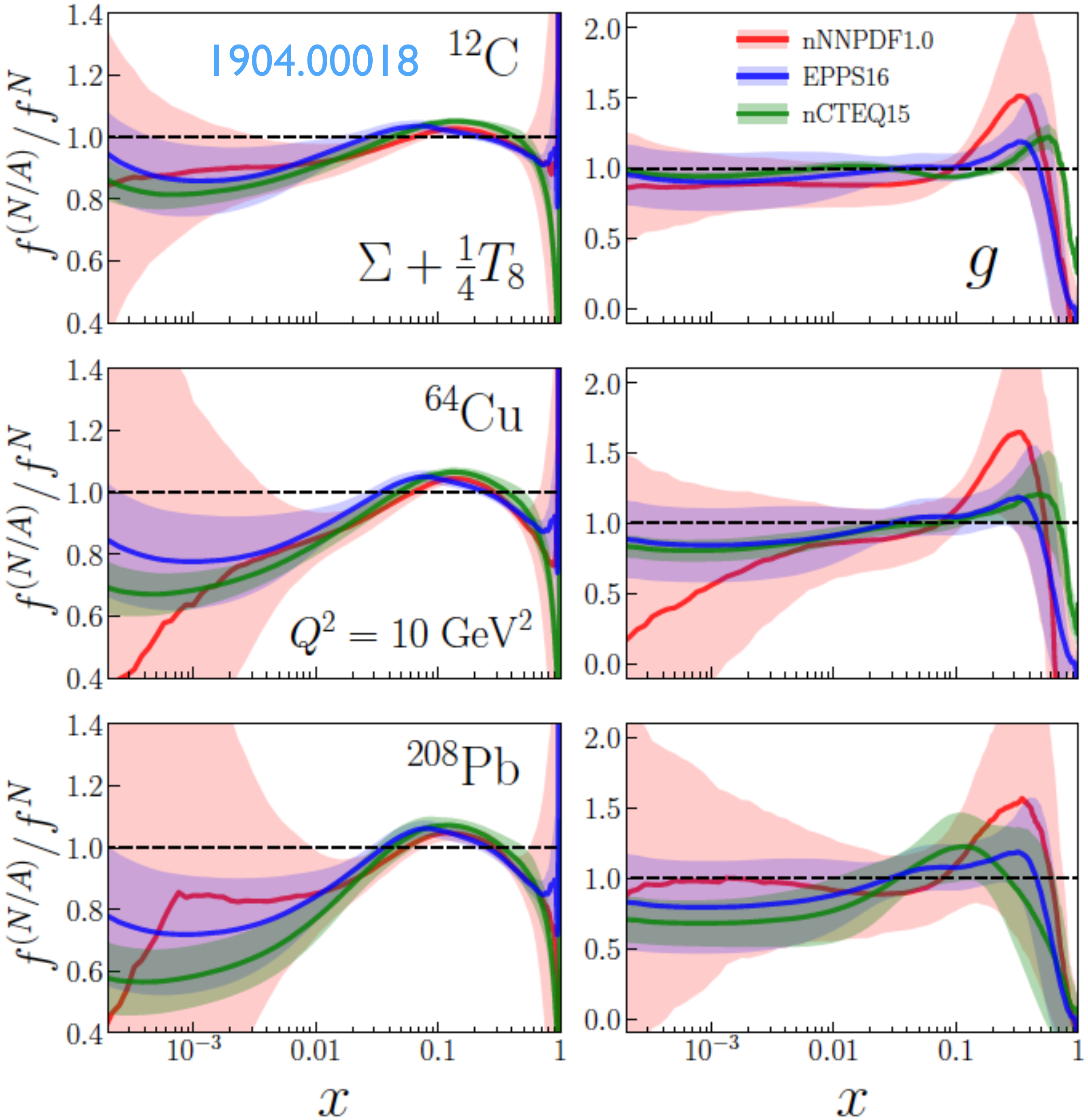
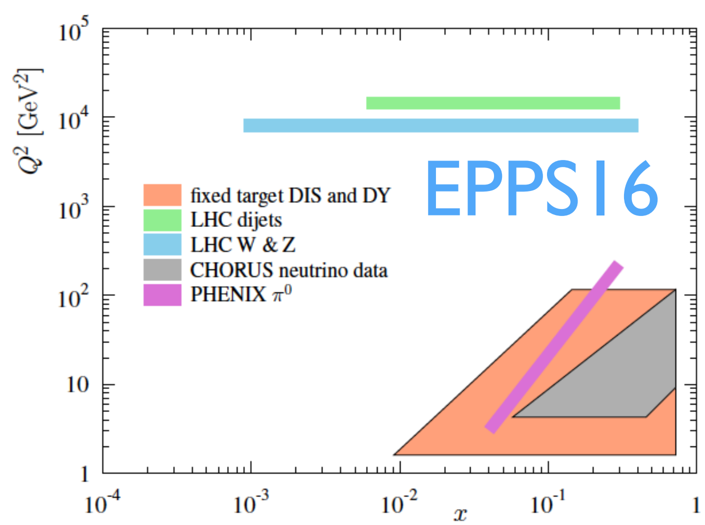
- *LHeC talks at DIS 2019, https://indico.cern.ch/event/749003/.*
- *Fixed target program at the HL-LHC, 1807.00603.*

Talks by J. Lajoie and E. Sichtermann.

Status of nPDFs:

- Large uncertainties for x<0.01 and for large x glue (parametrisation biases); small impact of LHC data (large-x glue).
- Few data for any single A e.g. Pb (15 DIS+30 pPb+νA): A-dependence of I.C. mandatory; flavour decomposition weakly constrained (~ isoscalarity).
- Impact parameter dependence modelled.

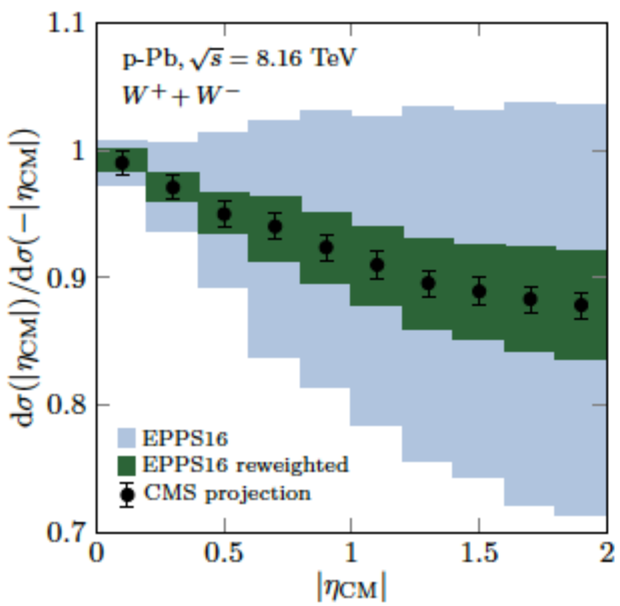


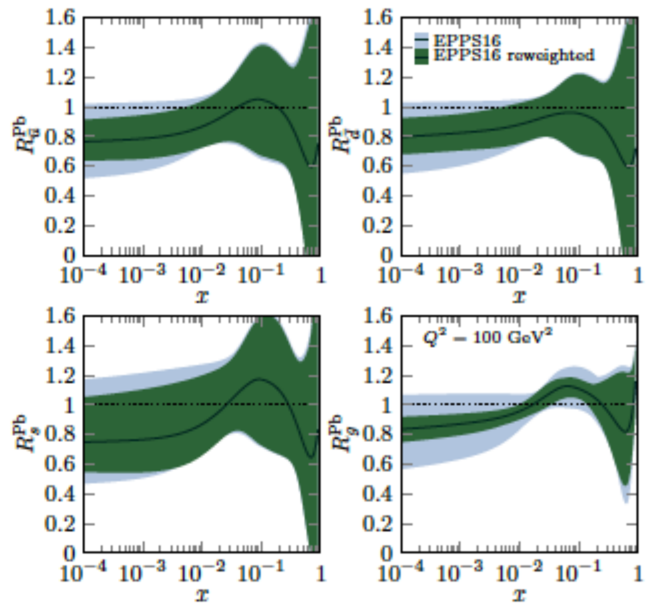


Talks by P. Zurita and C. Keppel; N. Valle, M. Dumancic, E. Chapon, S. Hayashi, M. Faggin, A. Bylinkin, I. B. Sanjuan, Y. Kim, N. Fomin, M. Rybar, S. Yang, Z. Chen,…

nPDFs @ HL-LHC (I):

W

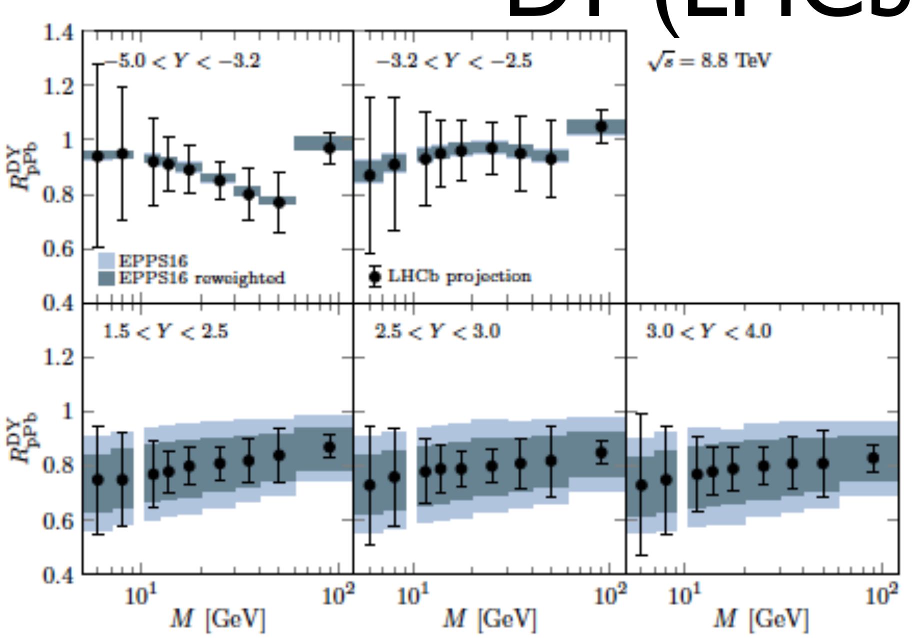


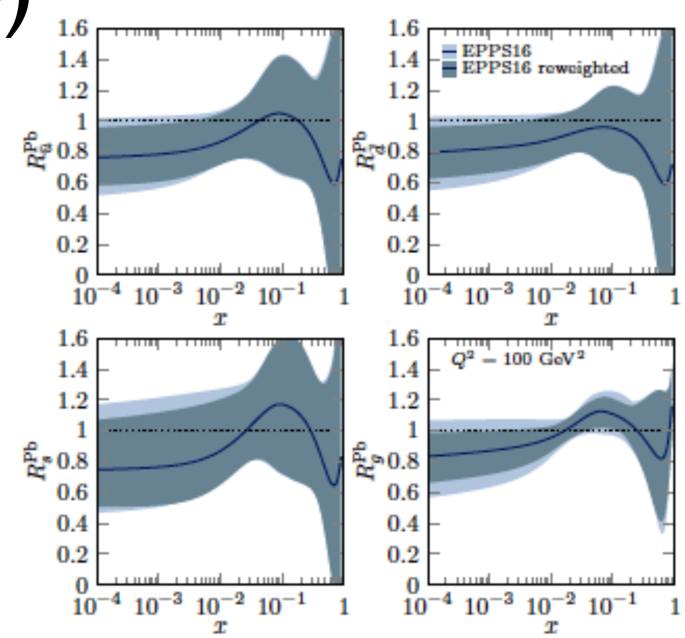


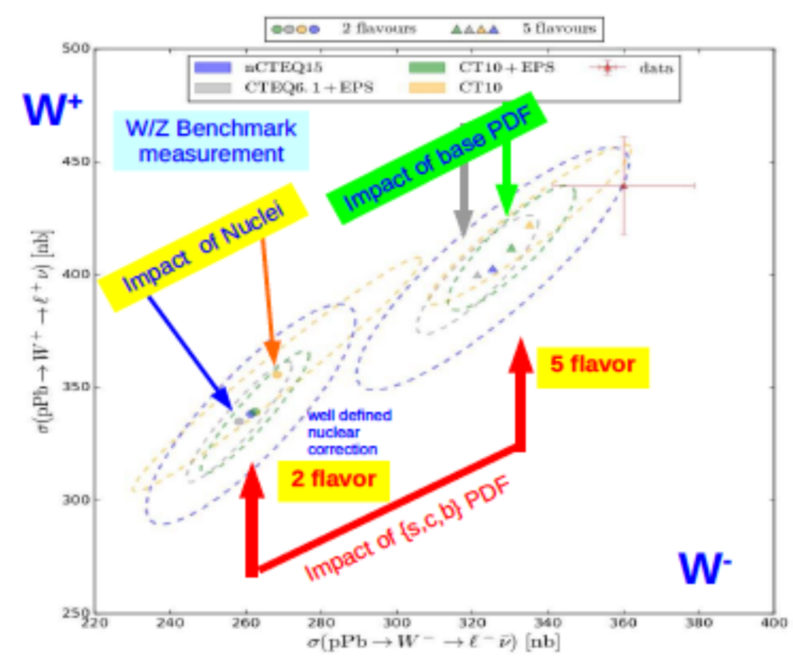
1812.06772

- Inclusive W for s/u.
- W asymmetries for gluon (evolution).
- Low mass forward DY for sea and gluon.
- Dijets for glue.
- Z and γ at forward rapidity (glue).
- UPCs will also contribute: quarkonium, inclusive dijets (1902.05126).
- Top requires higher statistics: lighter ions in the 30's?

DY (LHCb)

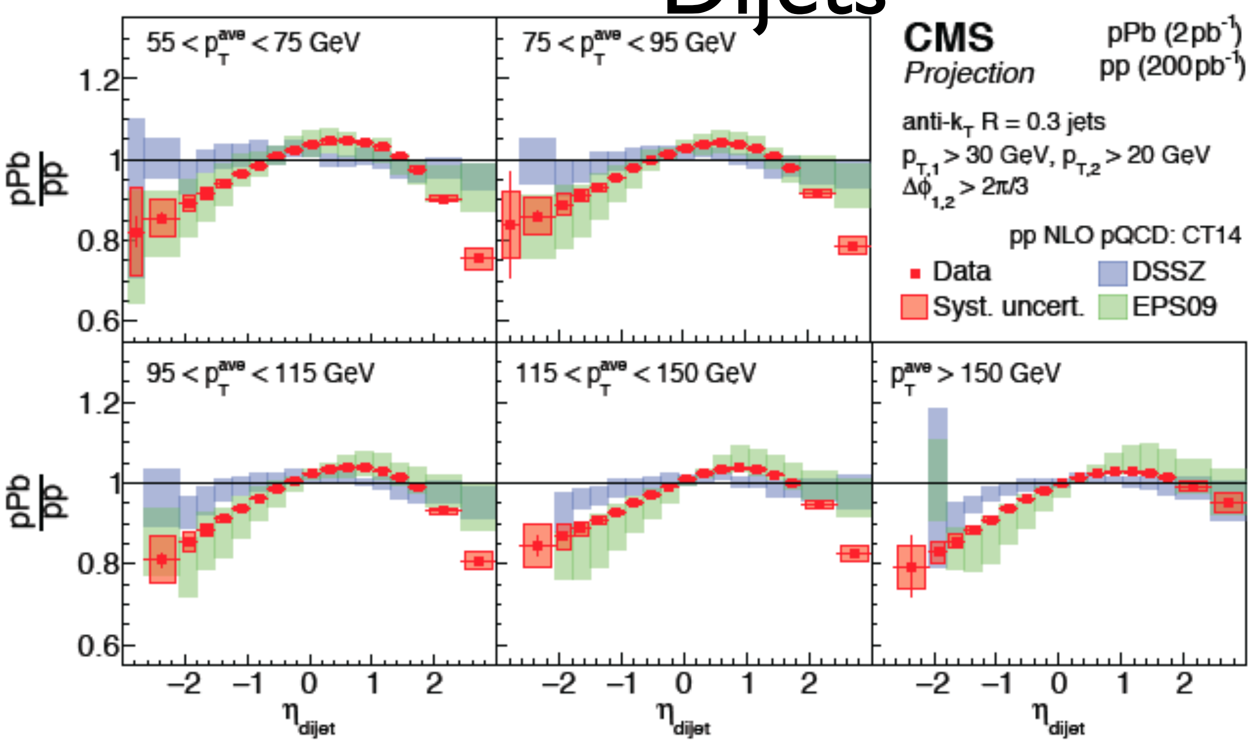






nPDFs @ HL-LHC (II):

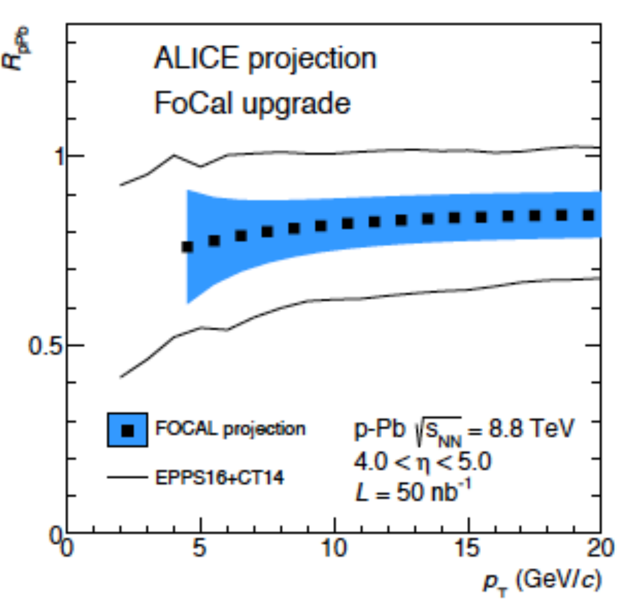
Dijets

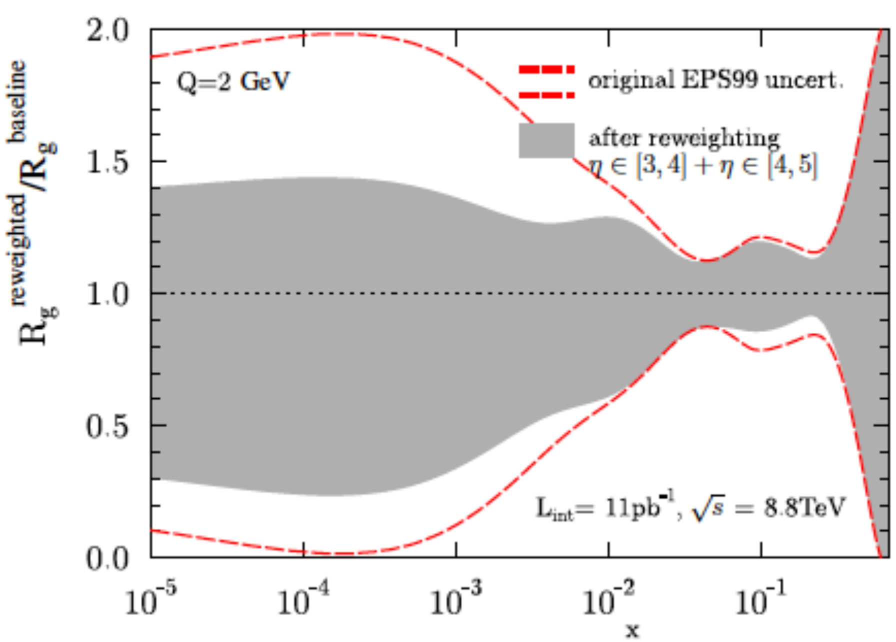


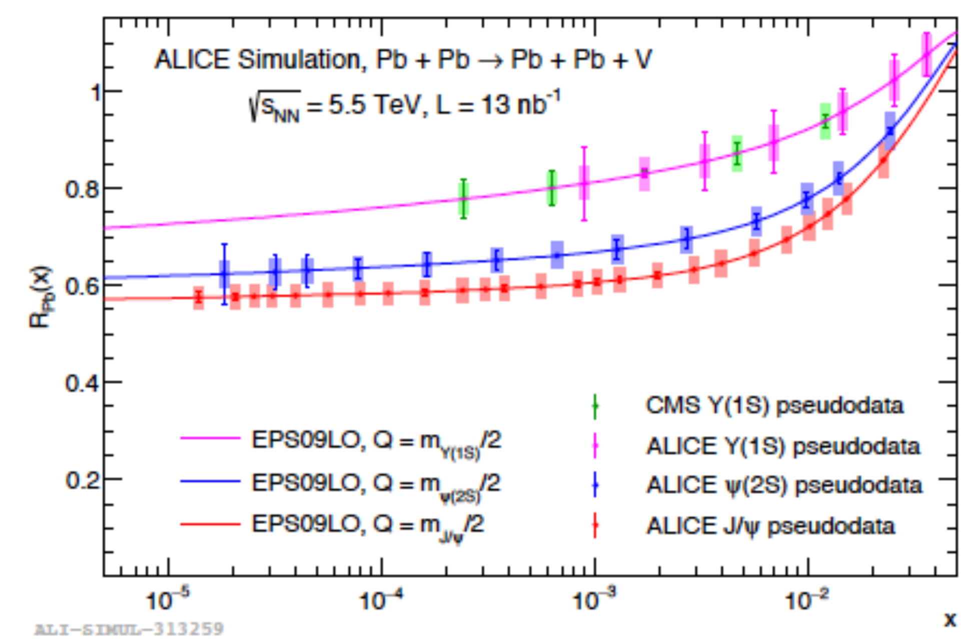
1812.06772

- Inclusive W for s/u.
- W asymmetries for gluon (evolution).
- Low mass forward DY for sea and gluon.
- Dijets for glue.
- Z and γ at forward rapidity (glue).
- UPCs will also contribute: quarkonium, inclusive dijets (1902.05126).
- Top requires higher statistics: lighter ions in the 30's?

Photons







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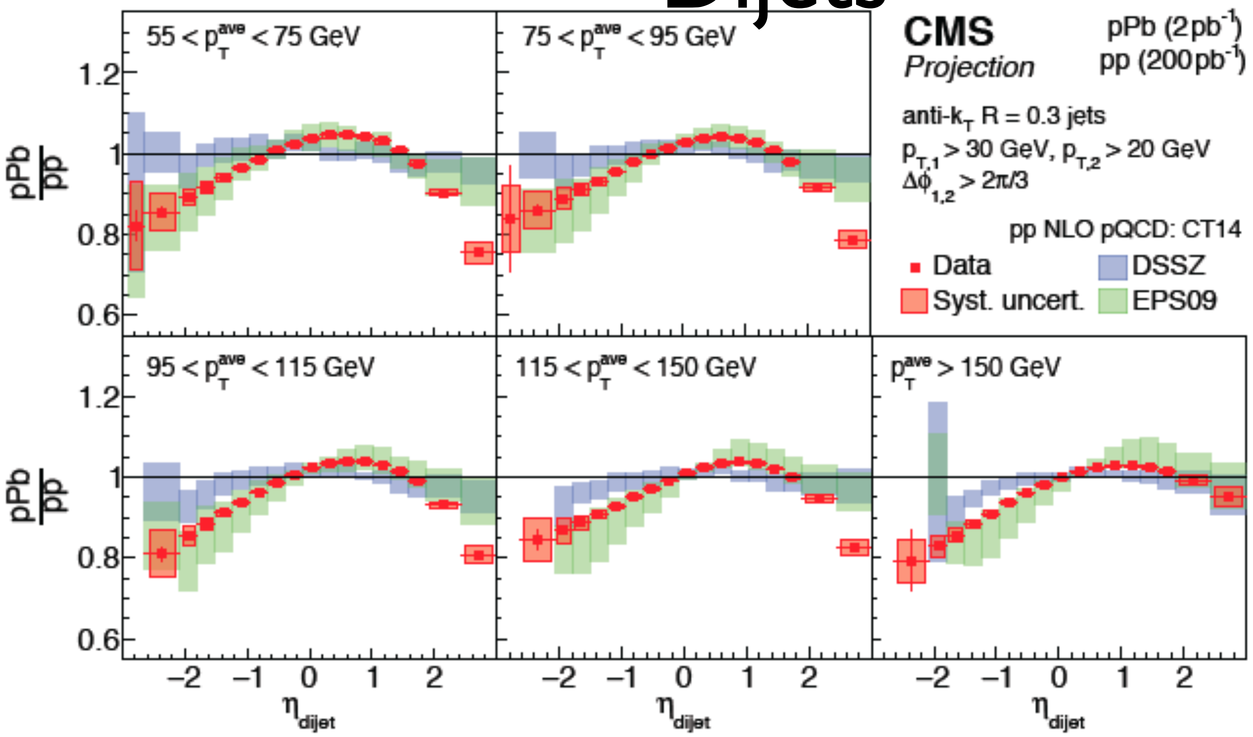
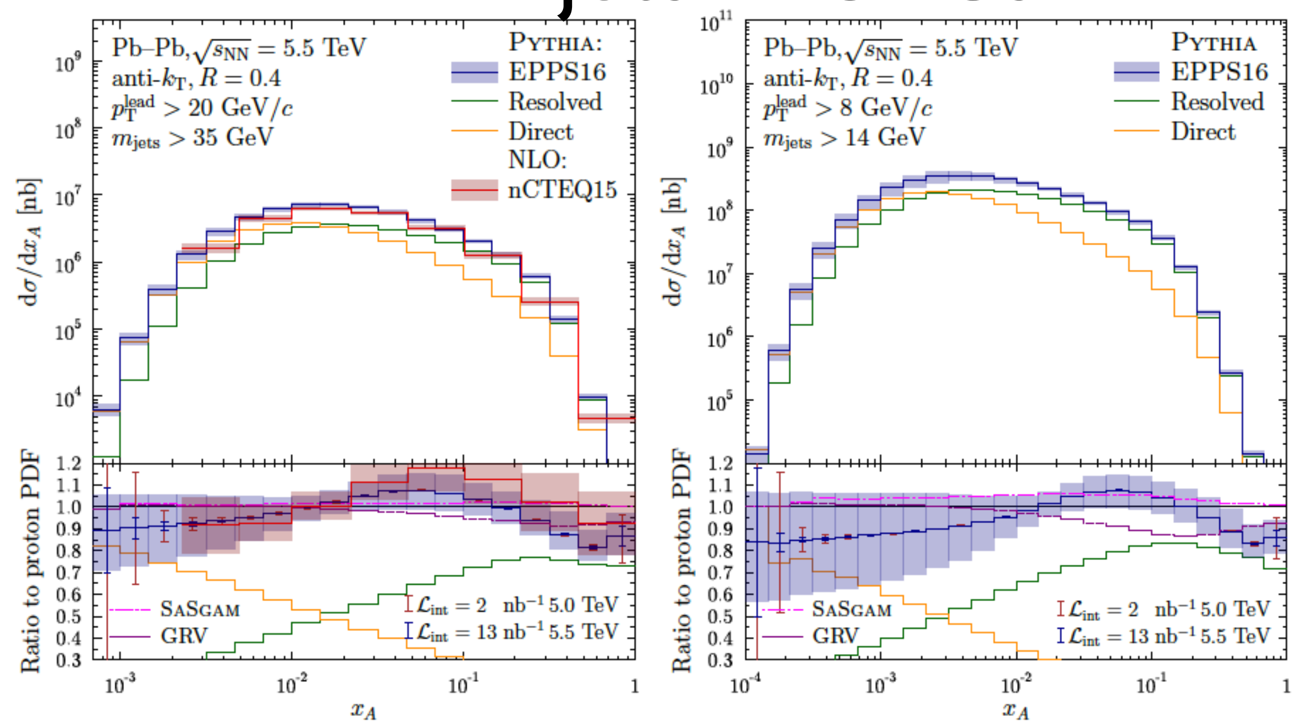
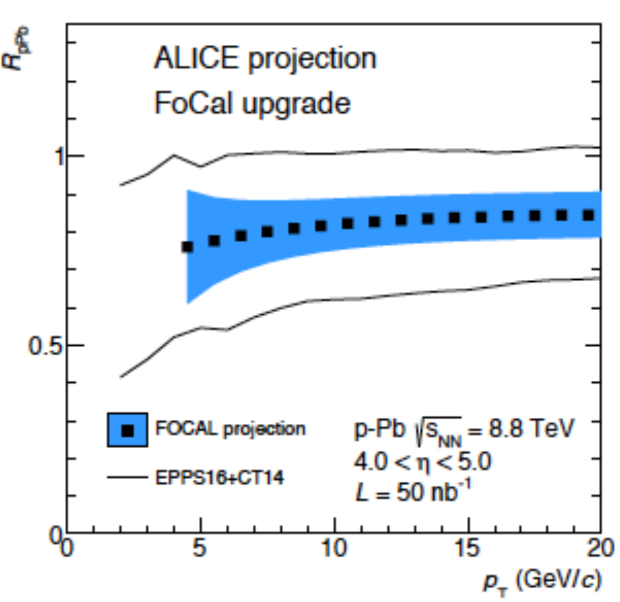


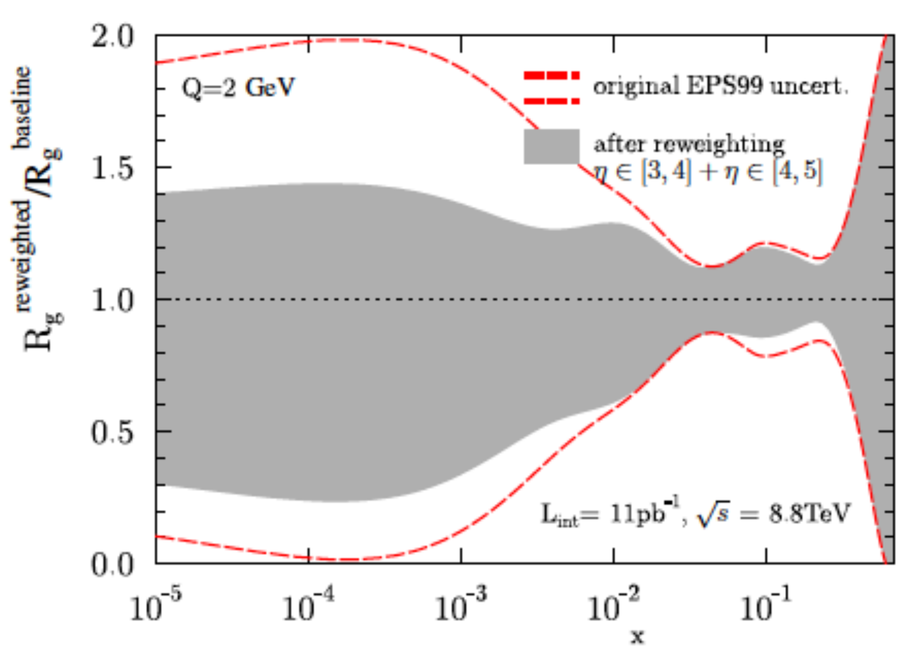
Dijets in UPCs

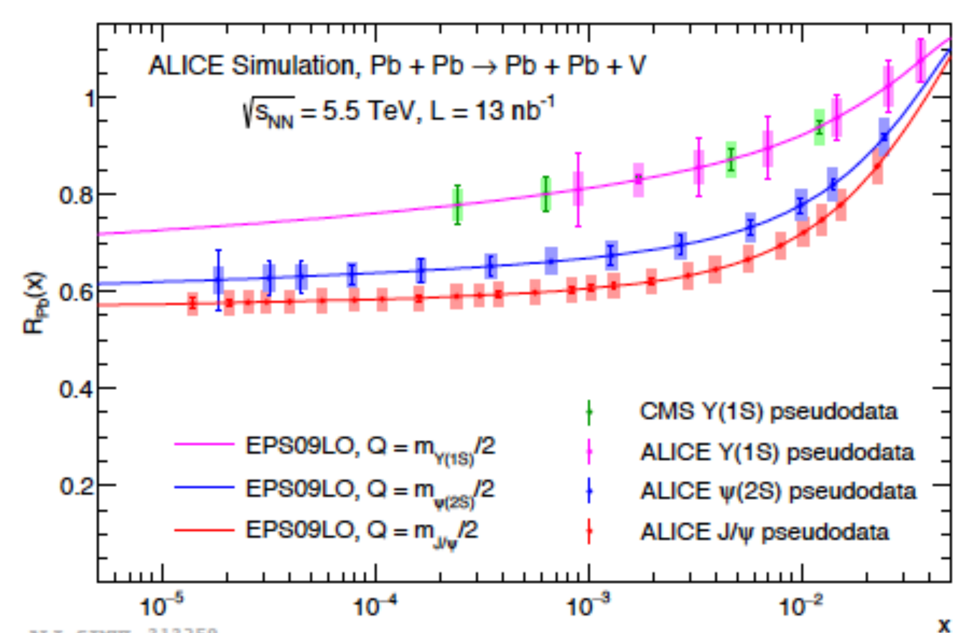


1812.06772

Photons



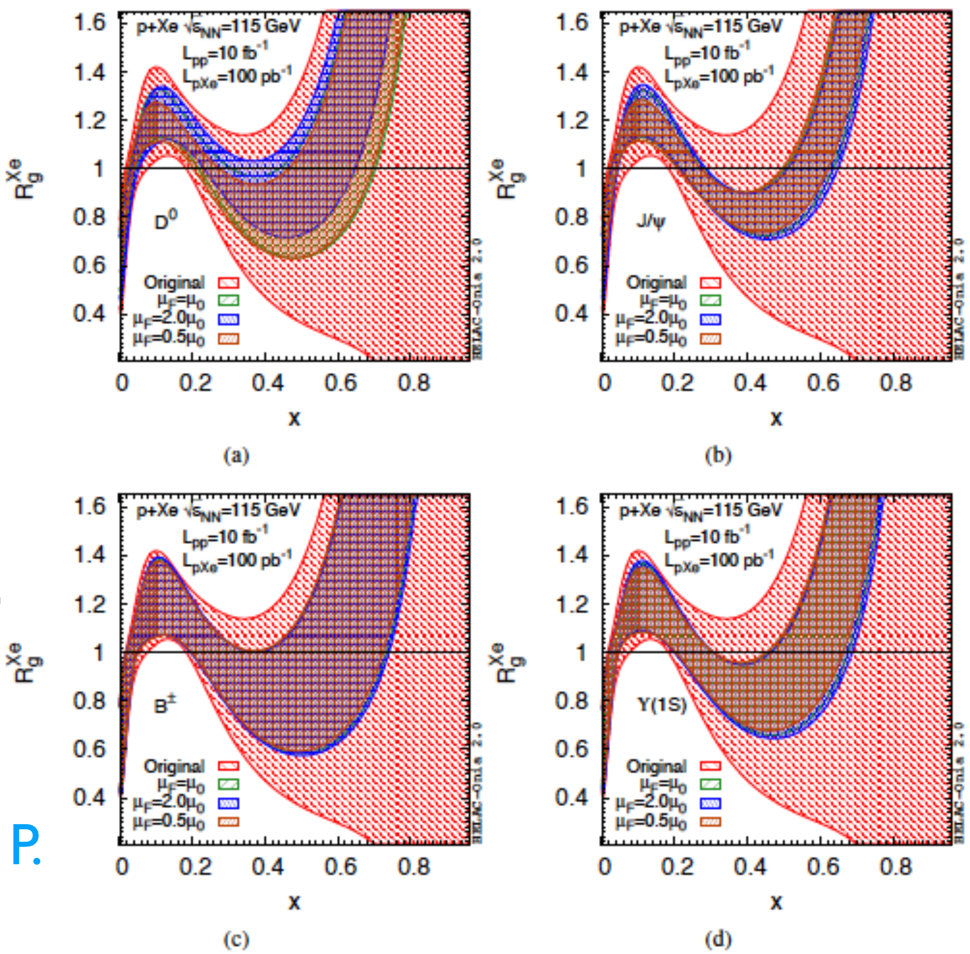




nPDFs beyond HL-LHC:

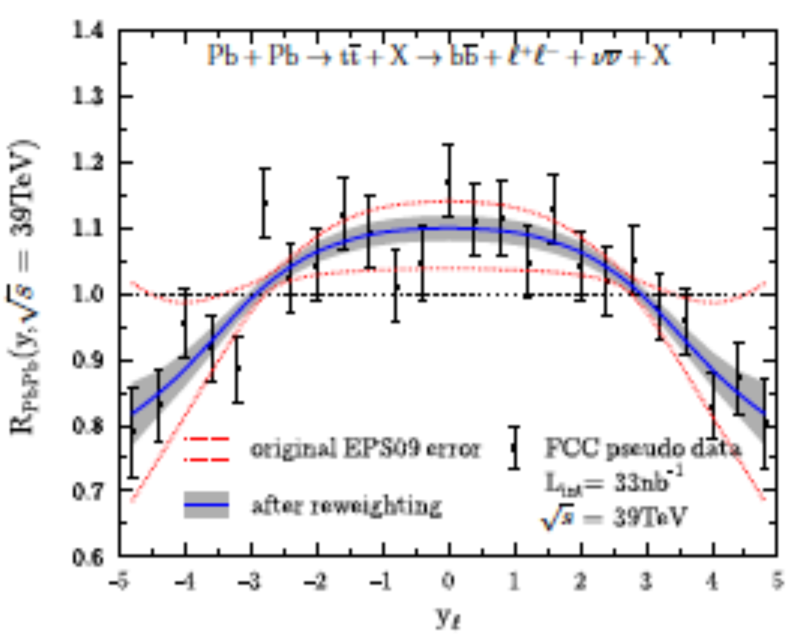
D, B mesons and quarkonia in pXe in fixed target mode

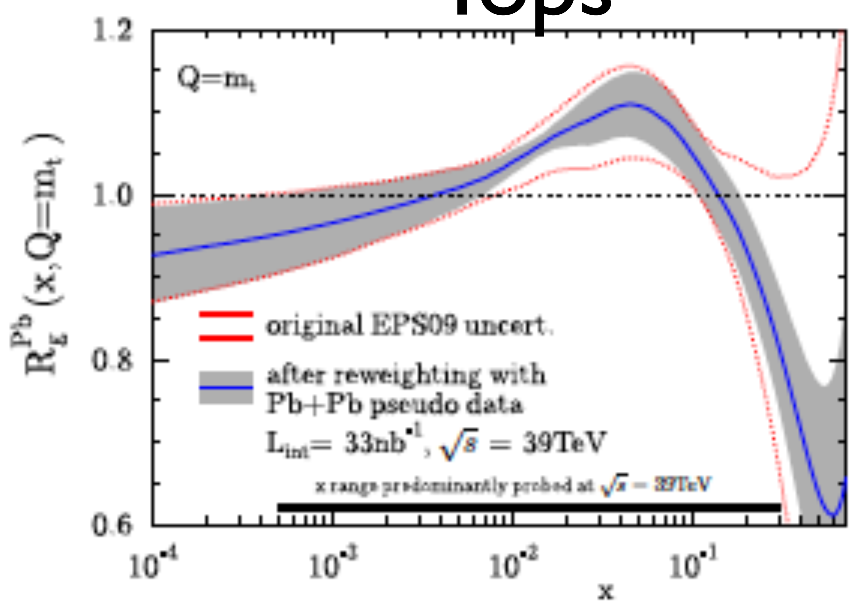
1807.00603, see the talk by P. Di Nezza.

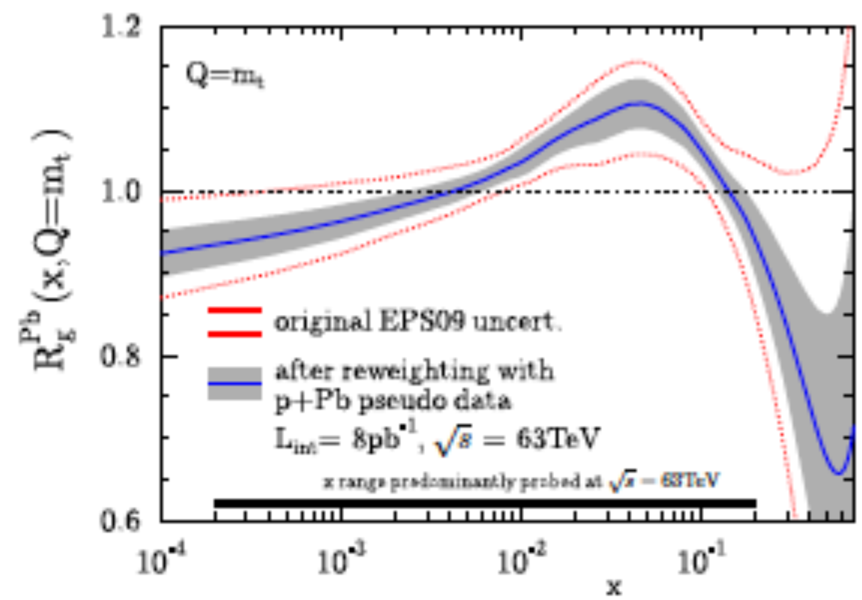


- Top studies become feasible at the HL-LHC (lighter ions) and the FCC: gluon in pPb.
- UPCs will also contribute: quarkonium, inclusive dijets (1902.05126).
- Fixed target mode to constrain the high-x glue.

Tops



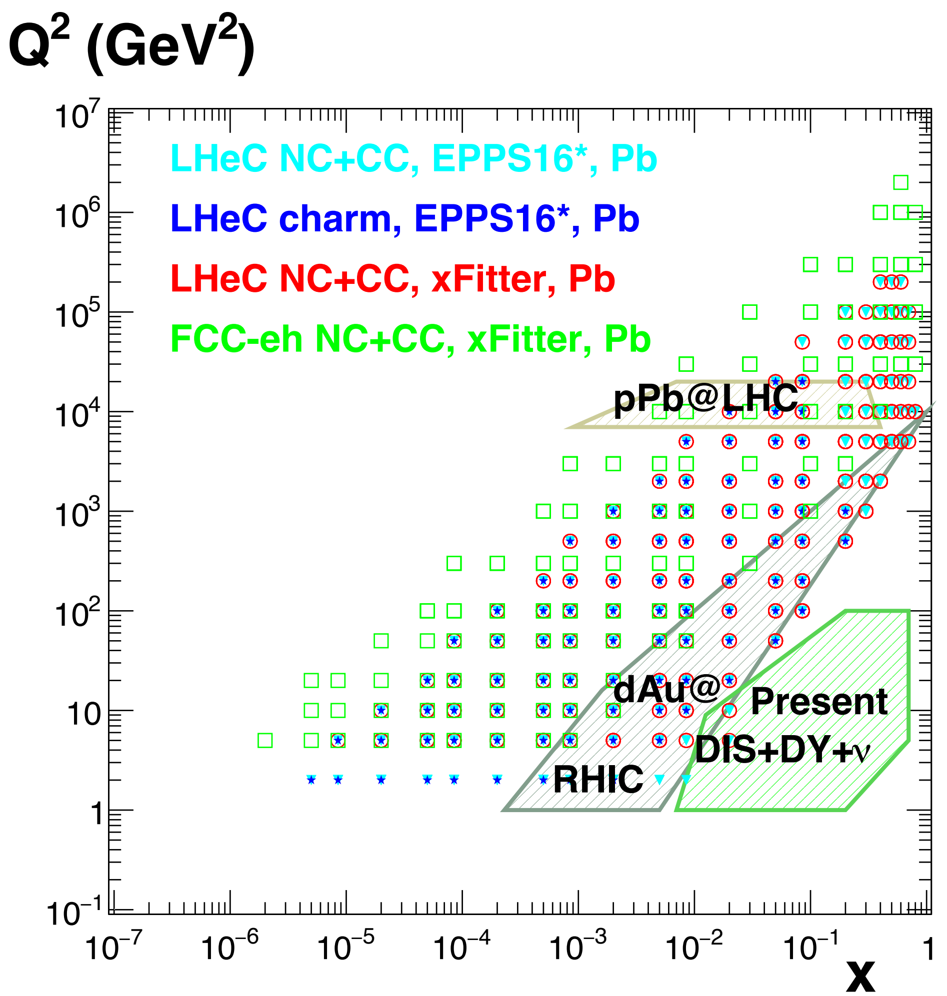


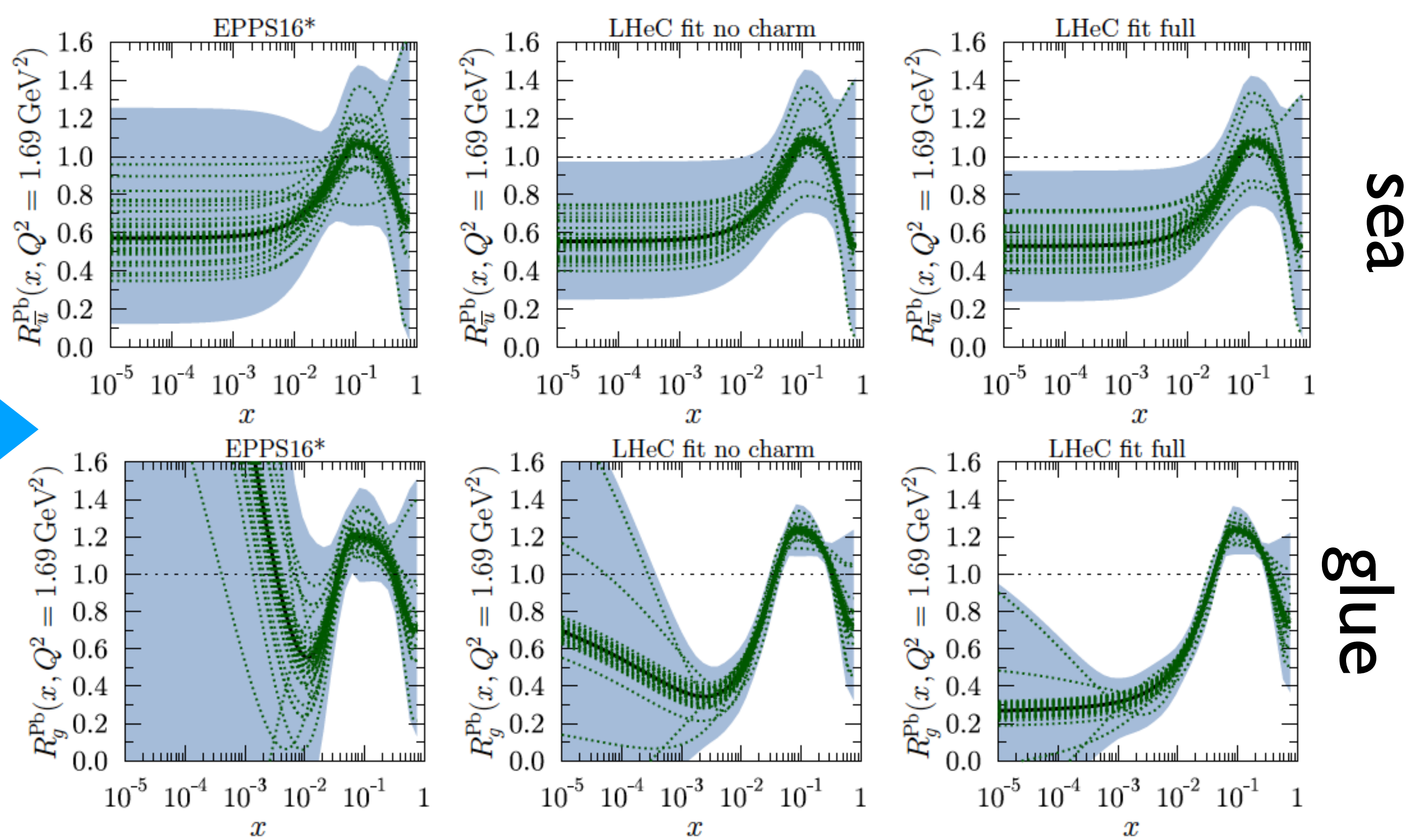


nPDFs @ LHeC/FCC-eh:

- ePb pseudodata included in EPPS16* global fits and HERAPDF DIS-only fits: large impact.

H. Paukkunen at DIS18





- HF separation → glue.
- Missing: beauty, c-tagged CC for strange.

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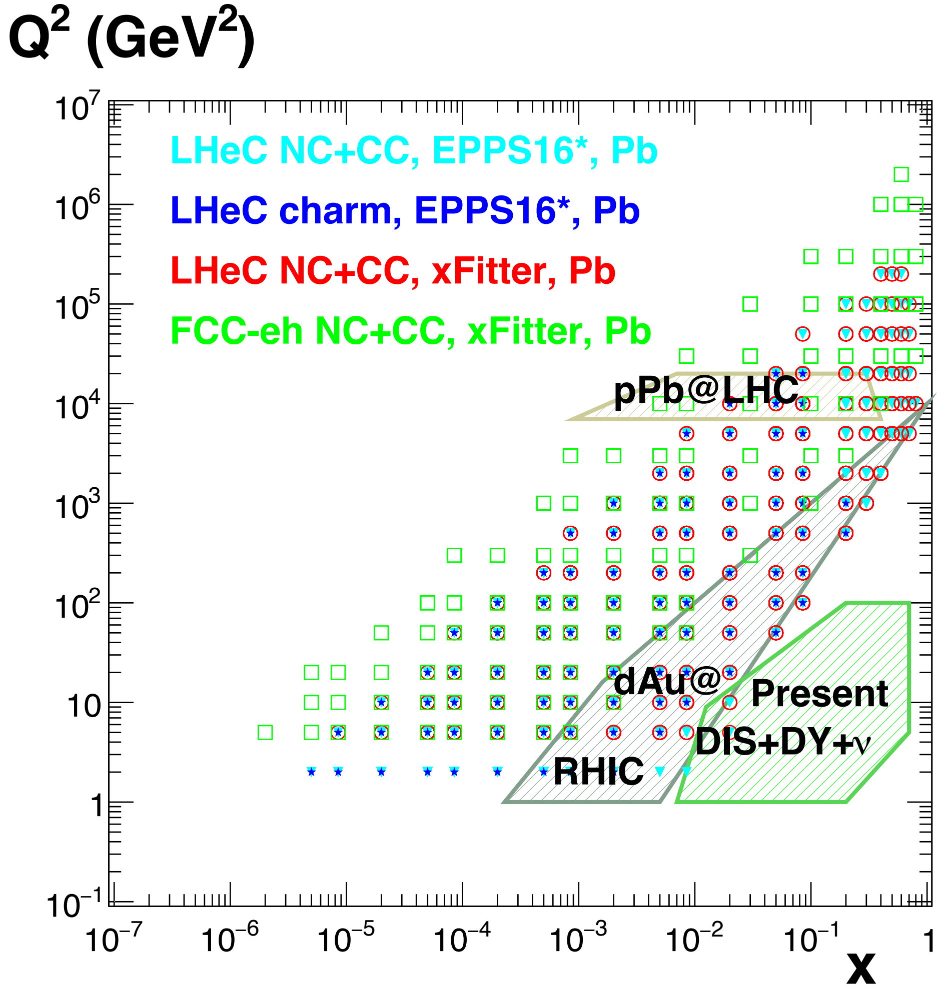
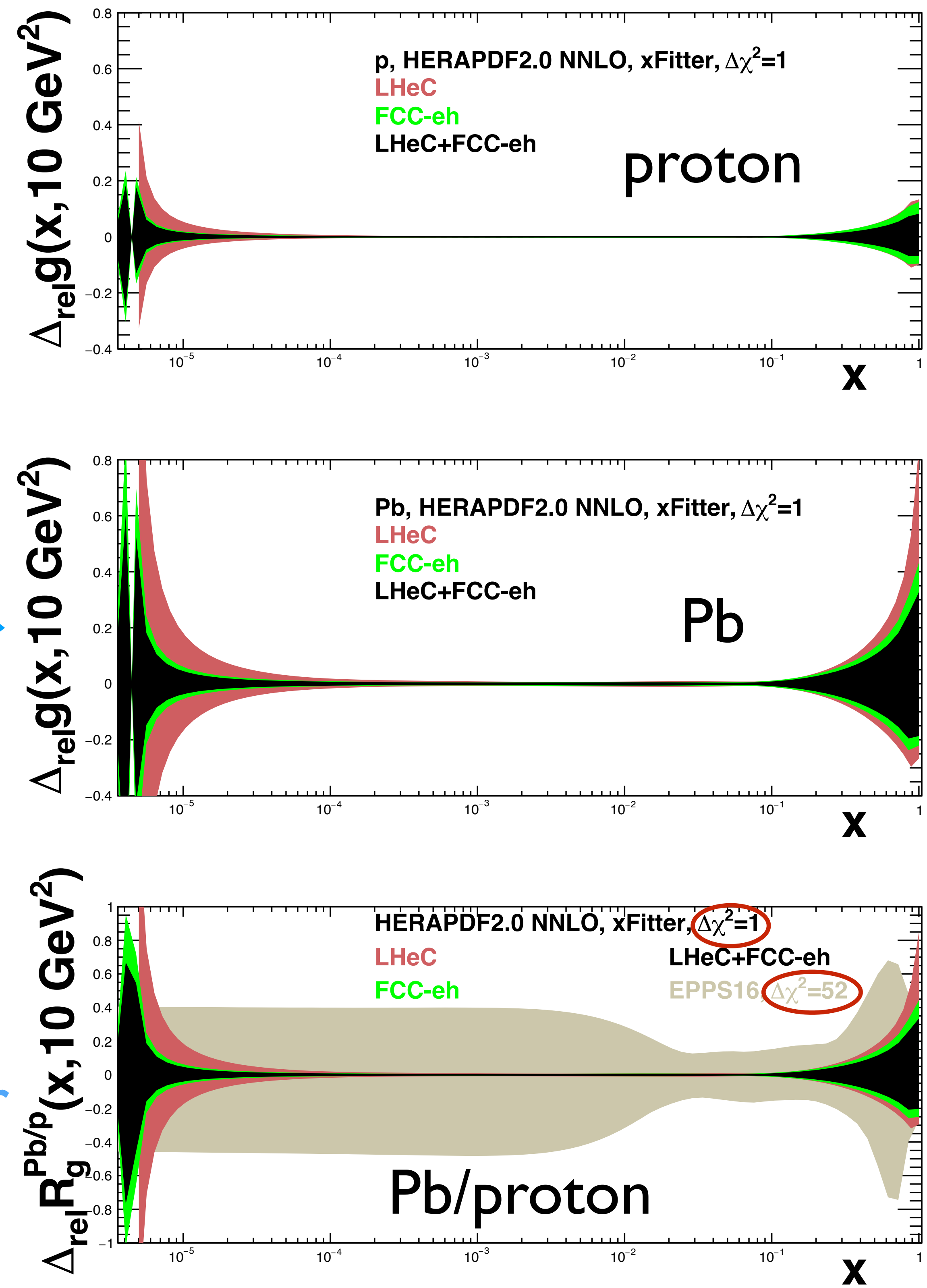


NA at DIS18 and DIS19

Ultimate *experimental* precision (poster by F. Olness and 1906.10127 for ep)



- HF separation → glue.
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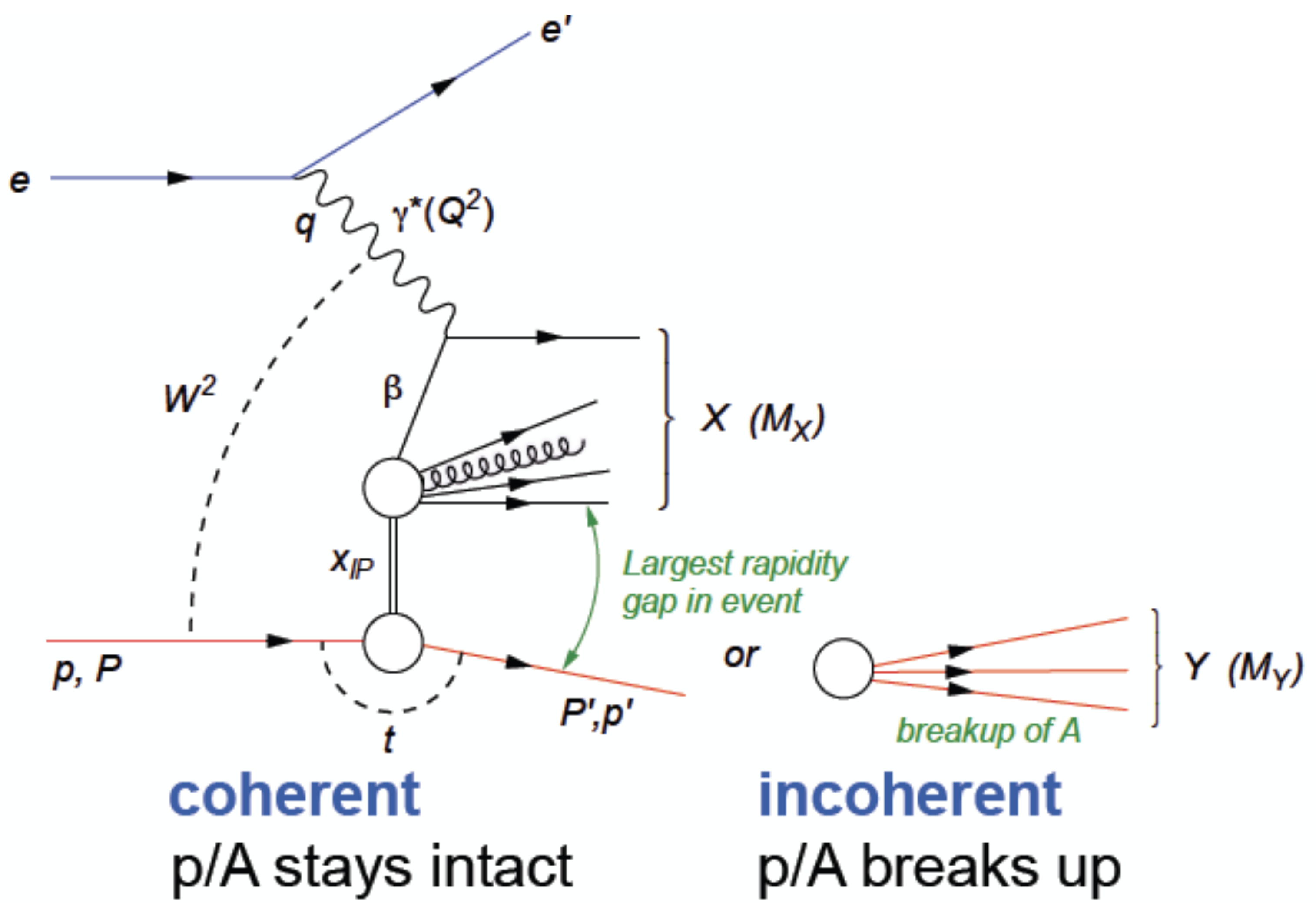
Beyond collinear factorization (I):

- The extraction of 3D-structure (GPDs and TMDs and their evolution equations) is a huge undergoing program: scarcely known in the proton, **mostly unknown in nuclei**.

Talks by R. Boussarie, A. Dumitru and J. H. Lee



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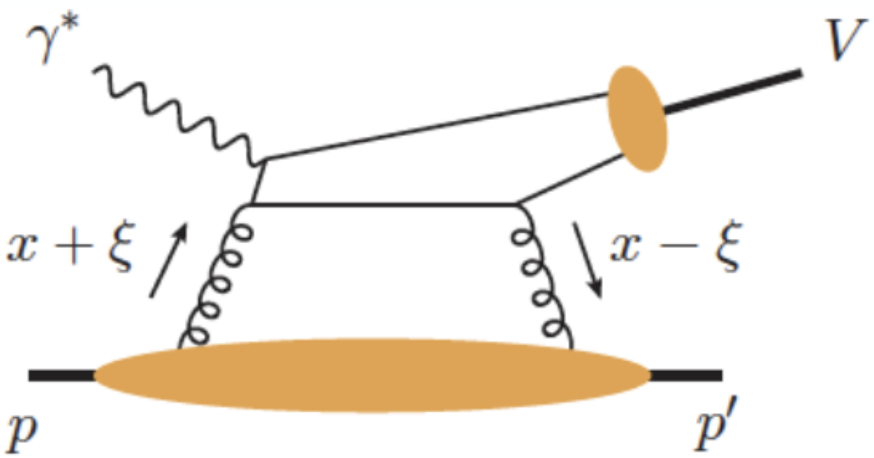
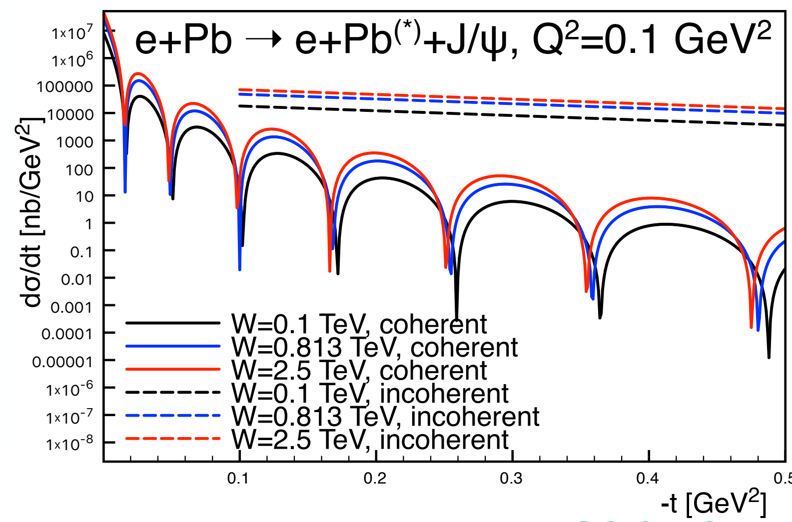
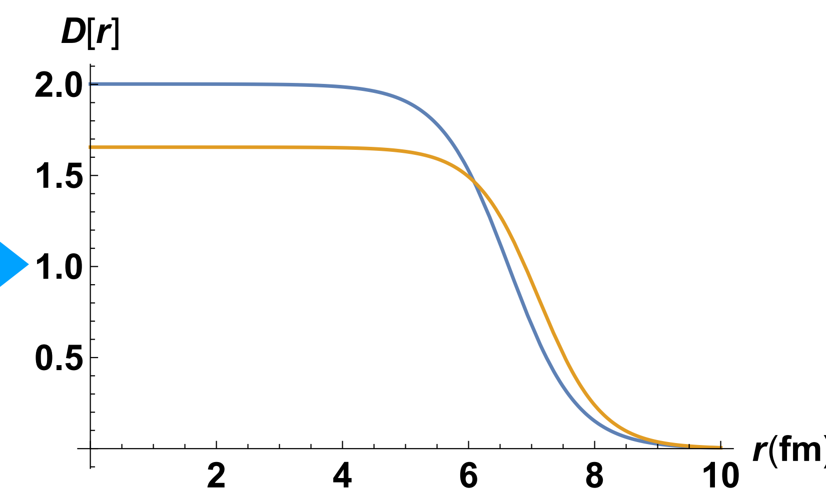
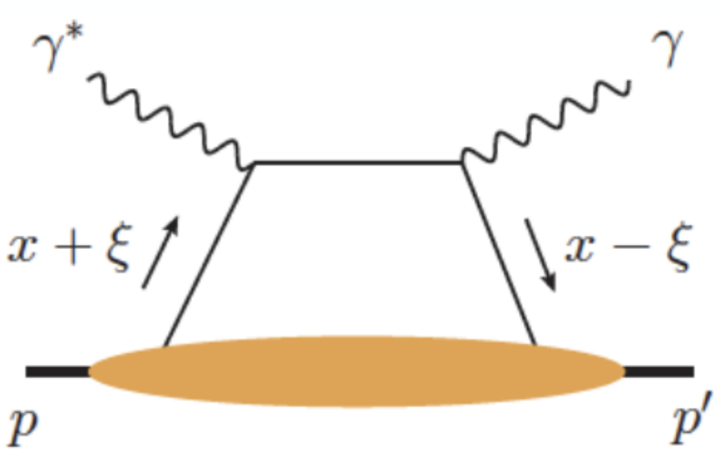
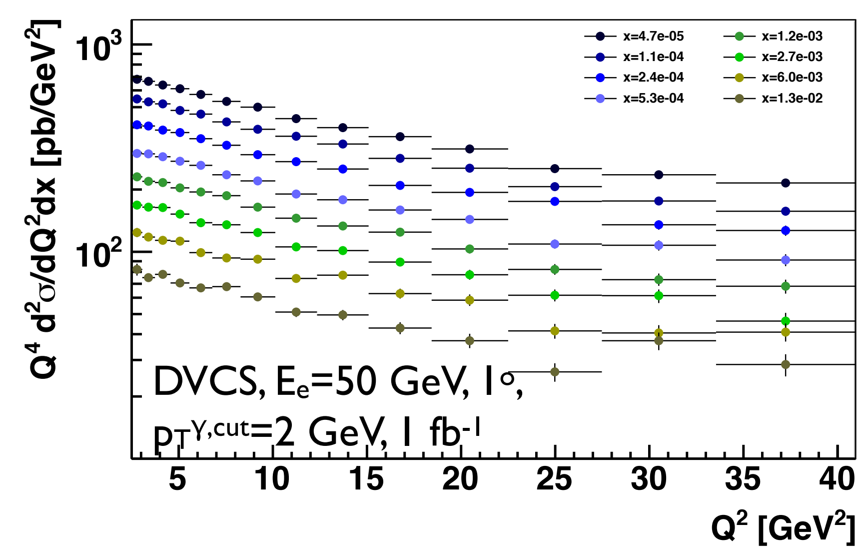






Mantysaari in DIS2018; LHeC CDR update to appear





LHeC 1206.2913

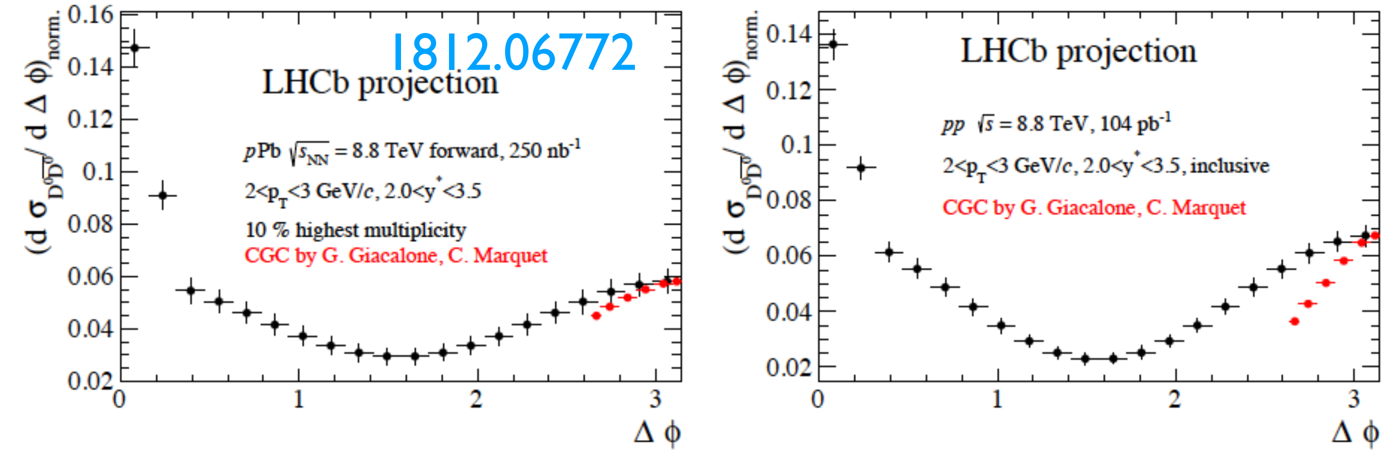
- LHeC/FCC-eh: large range of x and Q^2 ⇒ evolution.

Beyond collinear factorization (II):

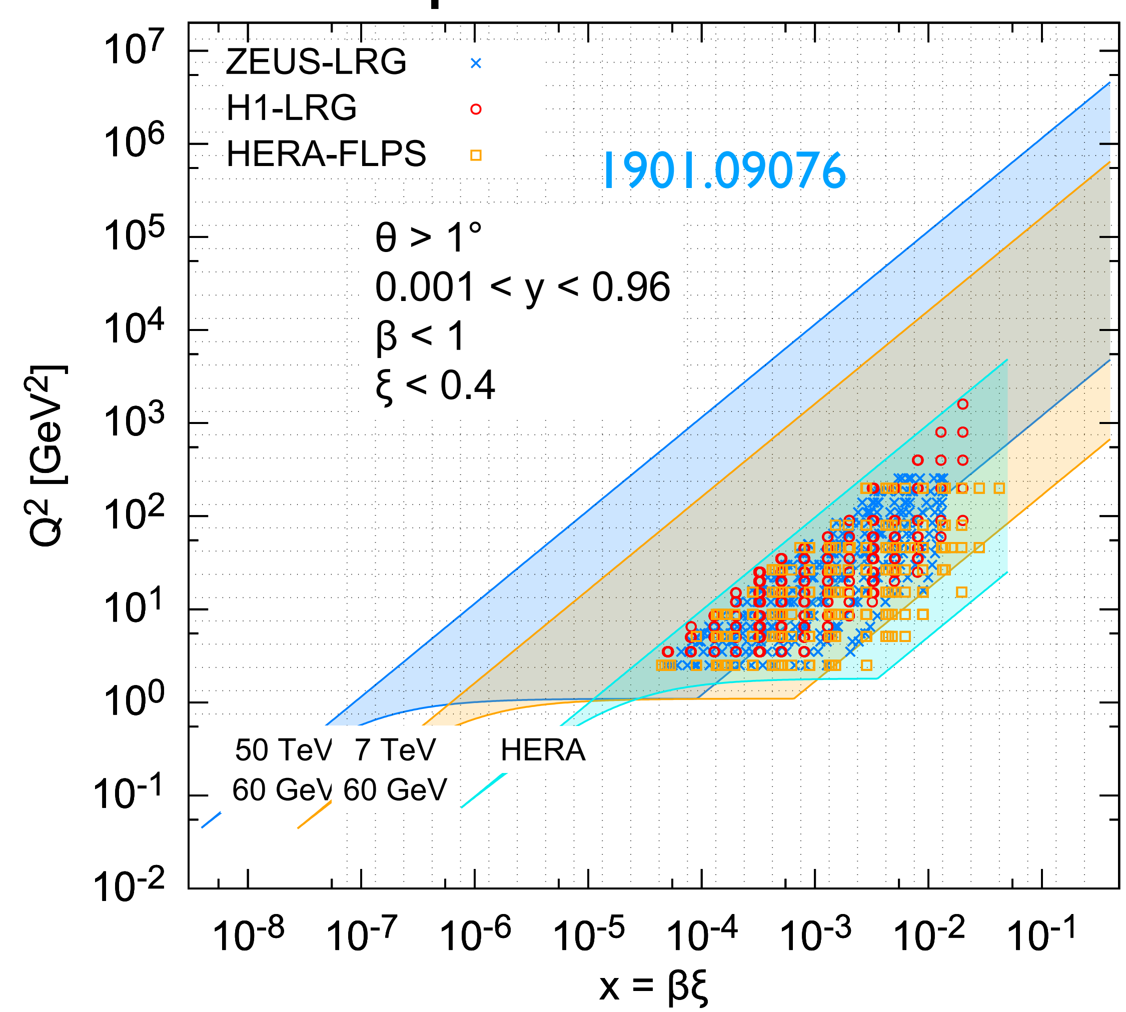
- Incoherent diffraction sensitive to fluctuations: hot spots? that determine the initial stage of HIC, the distribution of MPIs,… (Talk by H. Mantyssari)
- Exclusive dijet production sensitive to the gluon Wigner distribution, forward DDbar to g TMDs.
- UPCs, even for larger energies, but for photoproduction (1702.07705, 1902.01339).
- Also extensive studies in fixed target mode (1807.00603), main focus on spin.

- Diffractive PDFs on A never measured. (Talk by M. Walczak, pPb)

DDbar correlations at HL-LHC



Diffractive plane at LHeC/FCC-eh



Contents:

1. Proposals.
2. Partonic structure of the nucleus.
3. New dynamics at small x. (Talks by T. Altinoluk, M. Sievert and B. Xiao)
4. Pre-equilibrium dynamics and small systems.
5. Summary.

References:

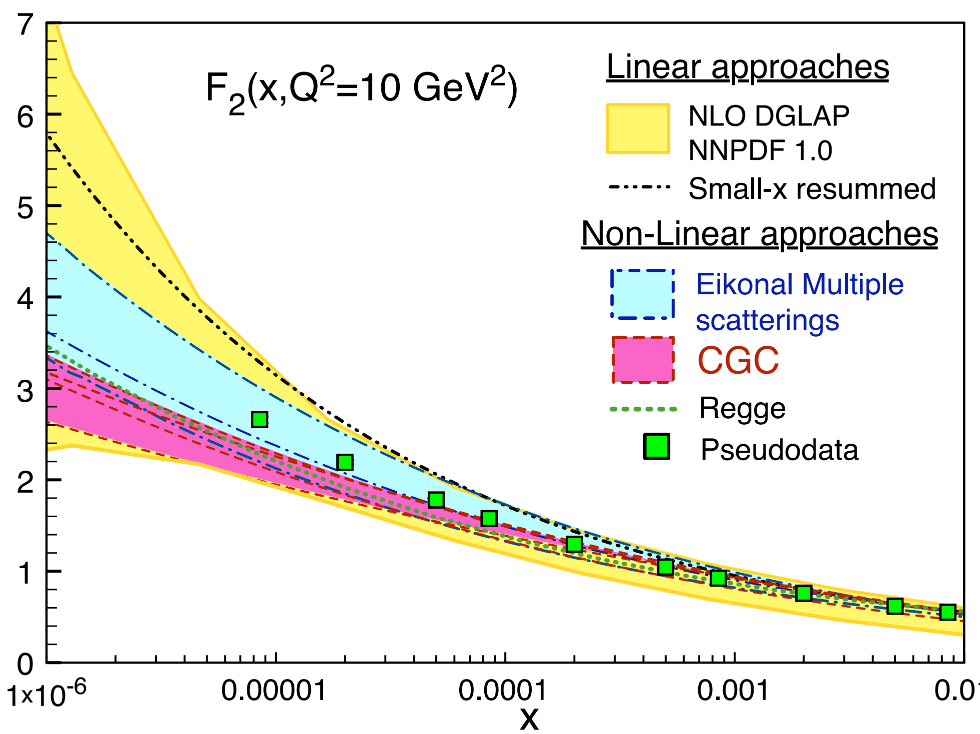
- *1812.06772 (HL-LHC with ions);*
- *Future Circular Collider: Vol. 1 Physics opportunities, CERN-ACC-2018-0056 (Eur. Phys. J. C79 (2019) no.6, 474), and 1605.01389;*
- *1901.09076 (diffraction in ep and eA);*
- *LHeC CDR, 1206.2913;*
- *2018 LHeC and FCC-eh workshop, https://indico.cern.ch/event/698368/;*
- *LHeC talks at DIS 2019, https://indico.cern.ch/event/749003/.*
- *Fixed target program at the HL-LHC, 1807.00603.*

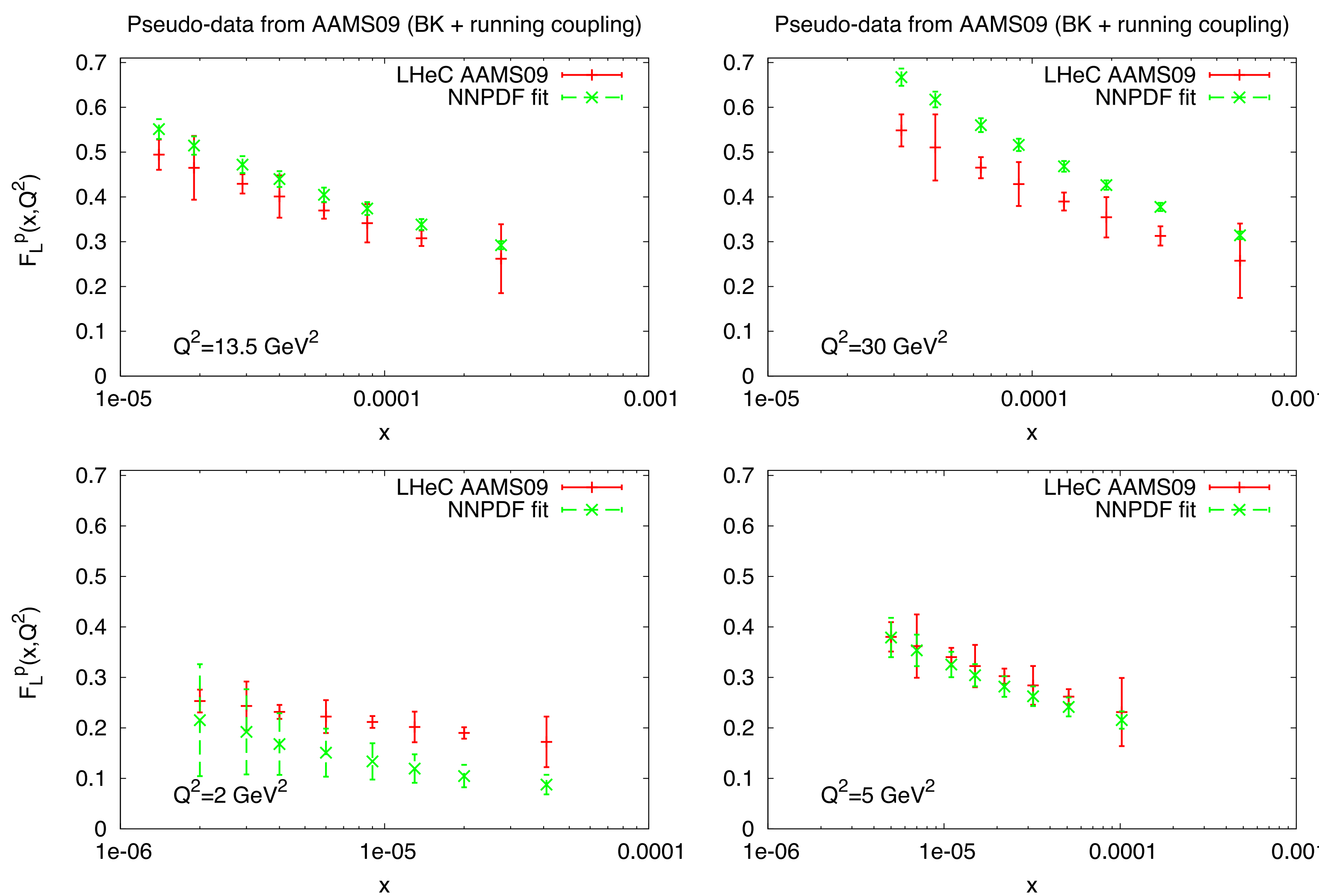
Talks by J. Lajoie and E. Sichtermann.

Search in ep/eA:

- **Saturation modifies evolution**: tension between the description in DGLAP analyses of different inclusive observables (with different sensitivities to glue and sea, e.g. F_2 and F_L or σ_r^{HQ}), **if enough lever arm in Q^2 at small x available**. (1702.00839)

ep@LHeC





- High scales → small x @ FCC-AA: e.g. tops in pPb sensitive to x ~ 0.02-0.2 at HL-LHC and 0.0002-0.2 at the FCC-hh (1501.05879).

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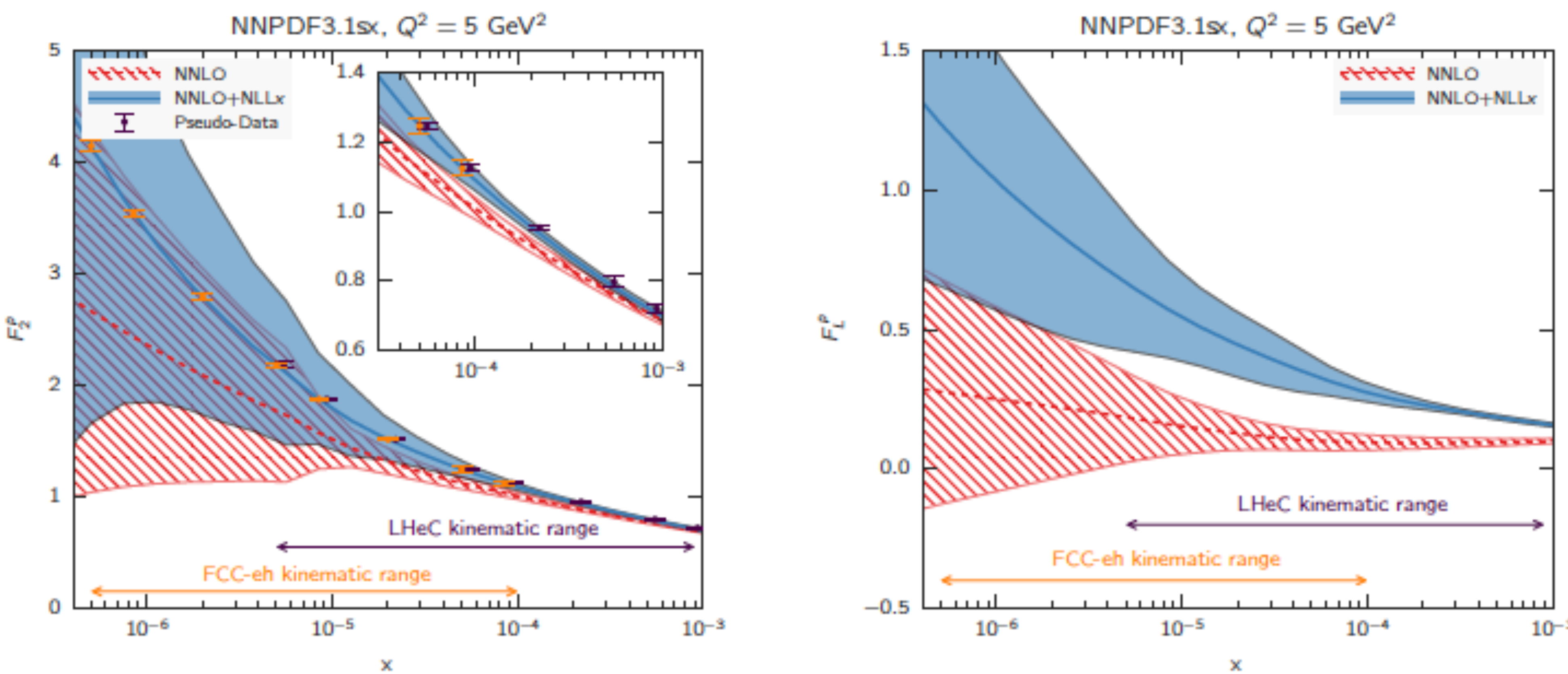
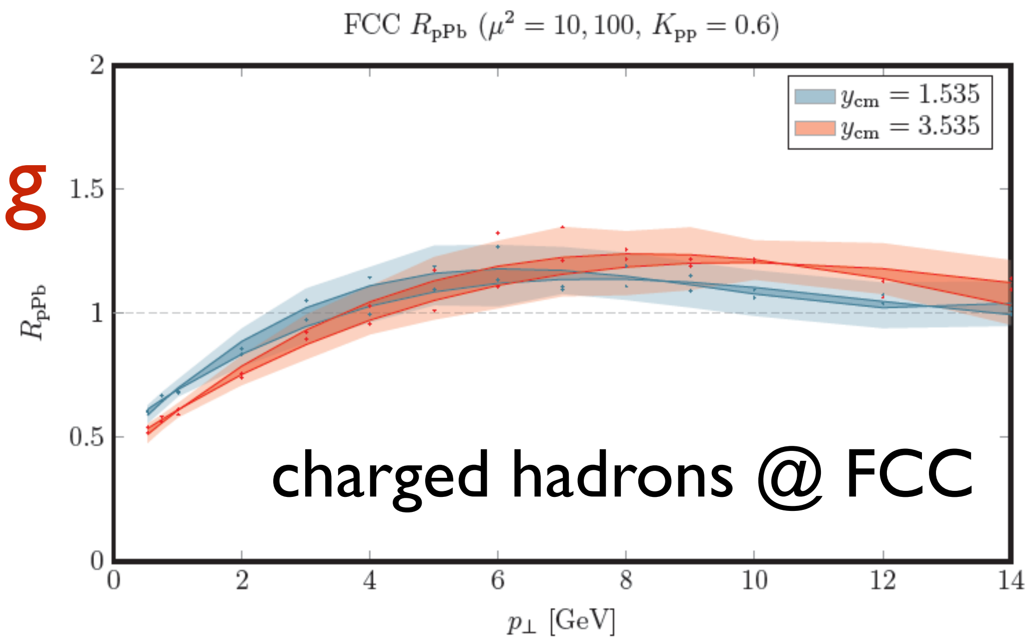
- Resummation becomes very sizeable (1710.05935 and talk by M. Bonvini.).

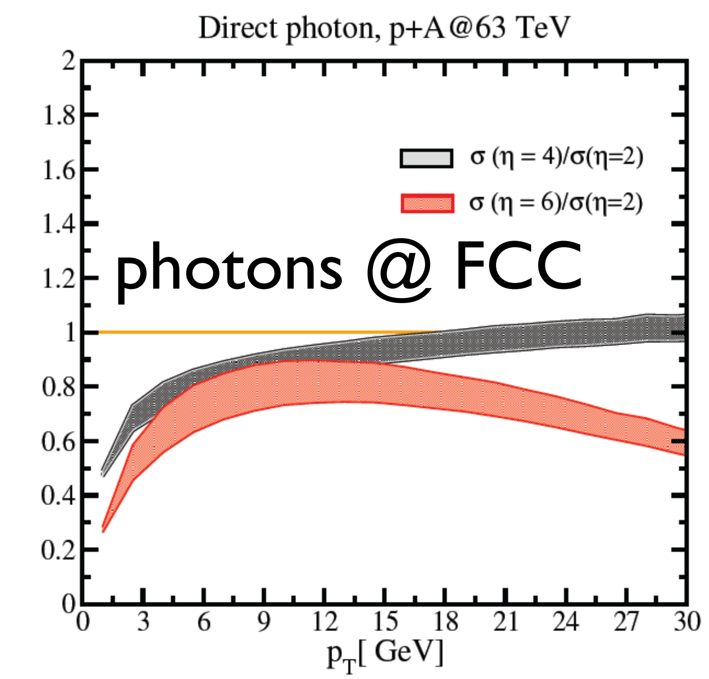


- High scales → small x @ FCC-AA: e.g. tops in pPb sensitive to x ~ 0.02-0.2 at HL-LHC and 0.0002-0.2 at the FCC-hh (1501.05879).

Search in pA:

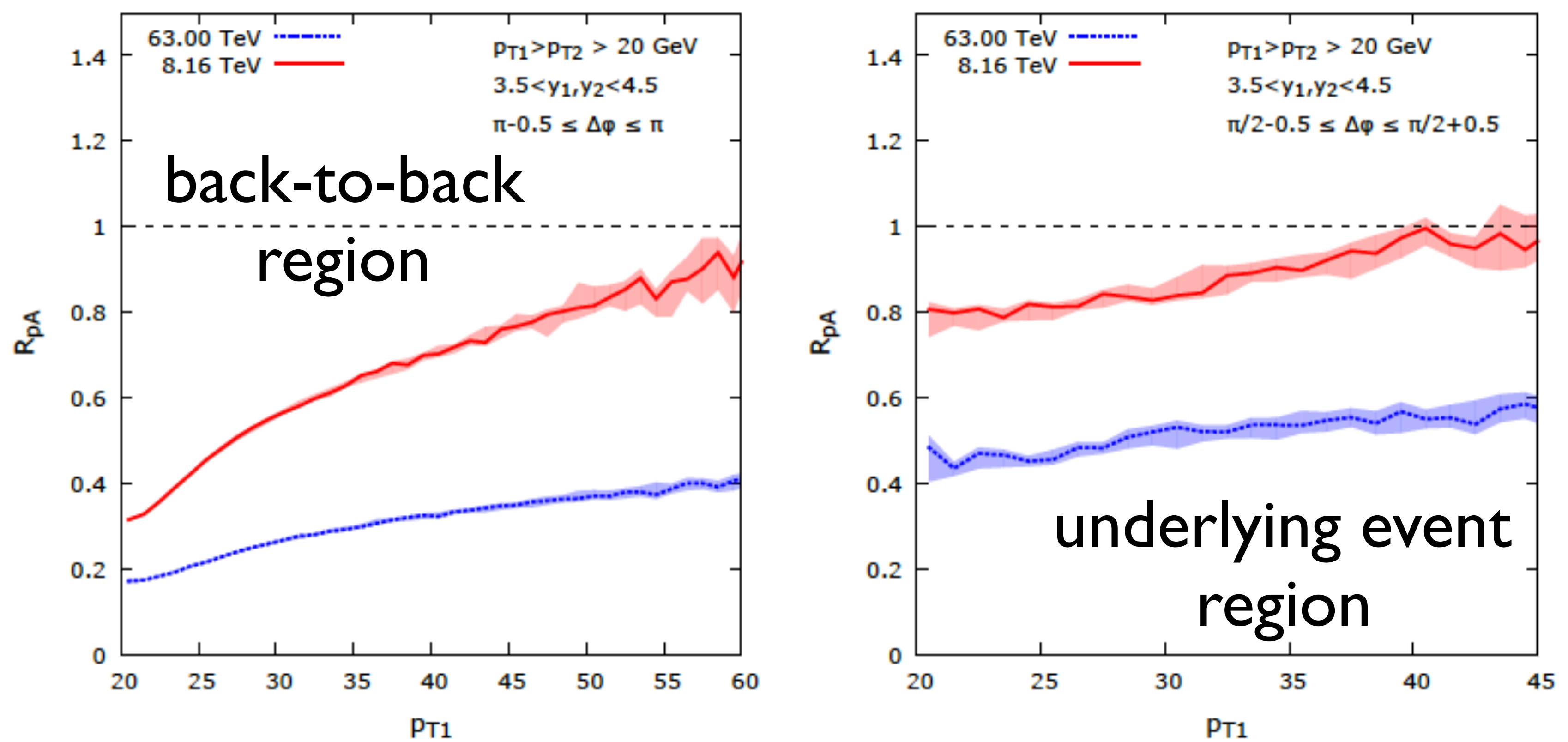
- Single particle suppression increasing with rapidity was proposed as a signal of saturation.





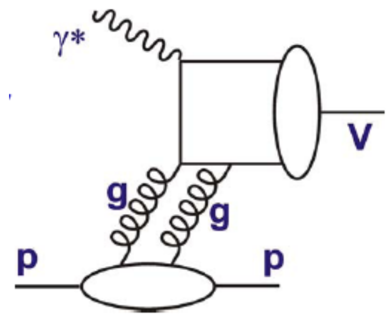
- Suppression observed up to large transverse momenta.

- Search for tensions between different observables in collinear factorisation.

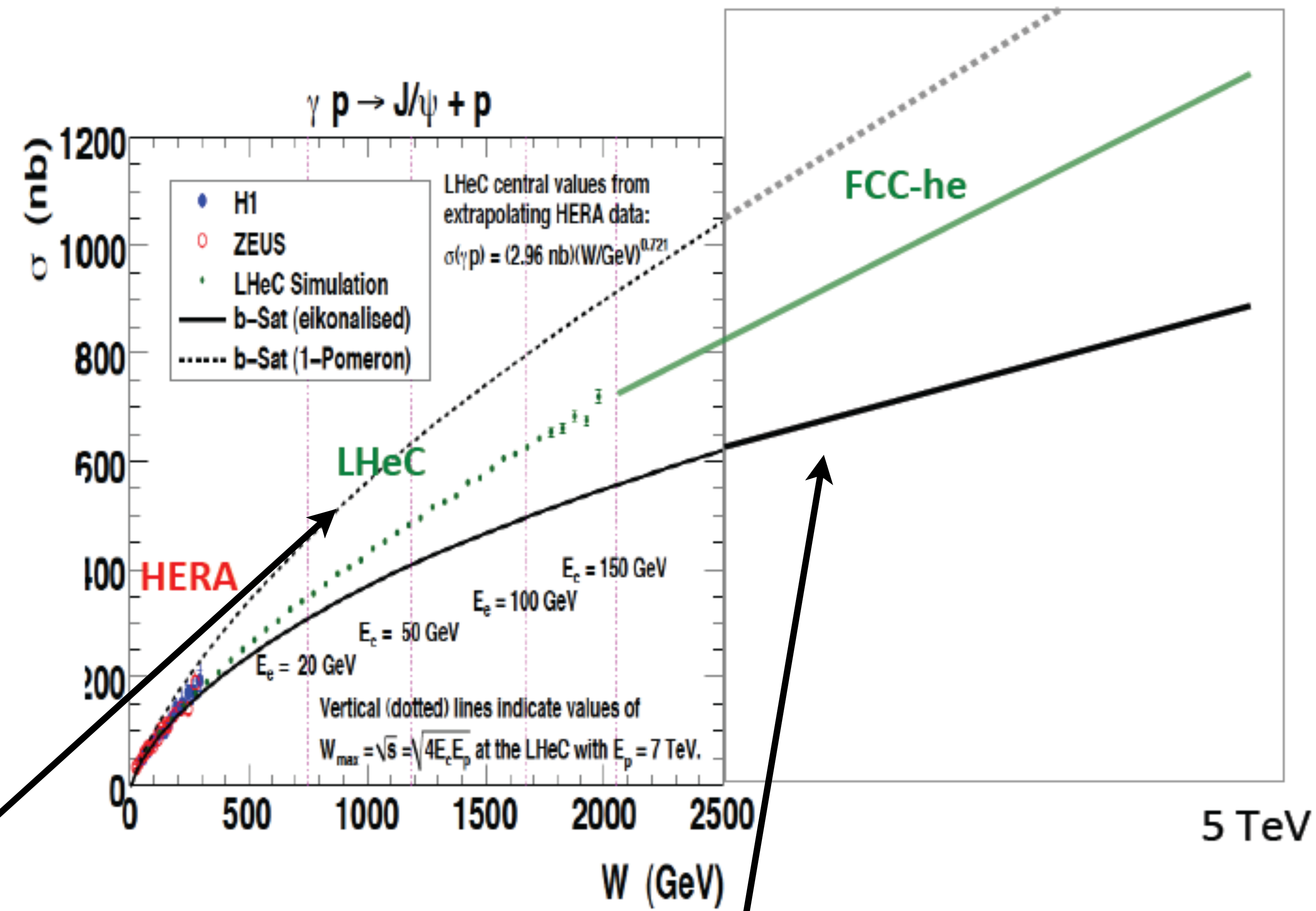


dijet yield modification pPb/pp @ FCC, anti-k_T, R=0.5

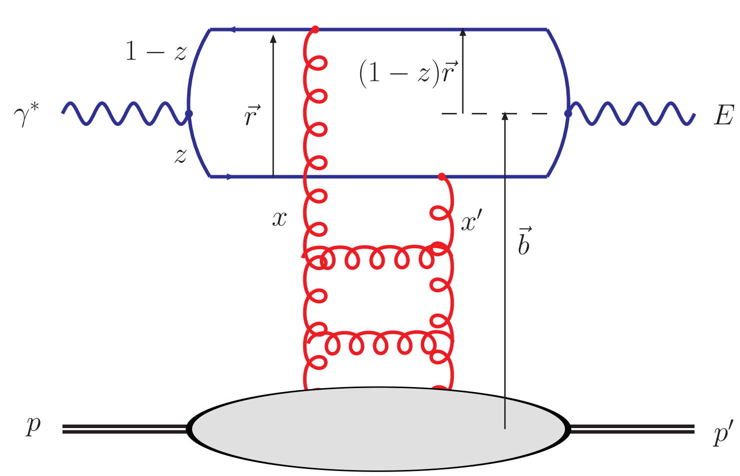
Elastic VM production on p:

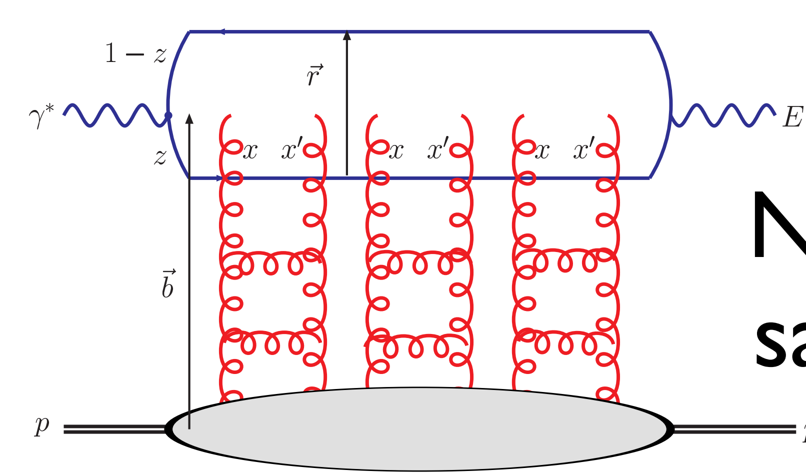


- Elastic J/ψ production may be a candidate to signal saturation effects at work.



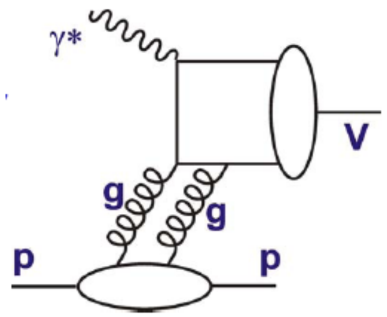
Linear, sensitivity to $(xg)^2$.





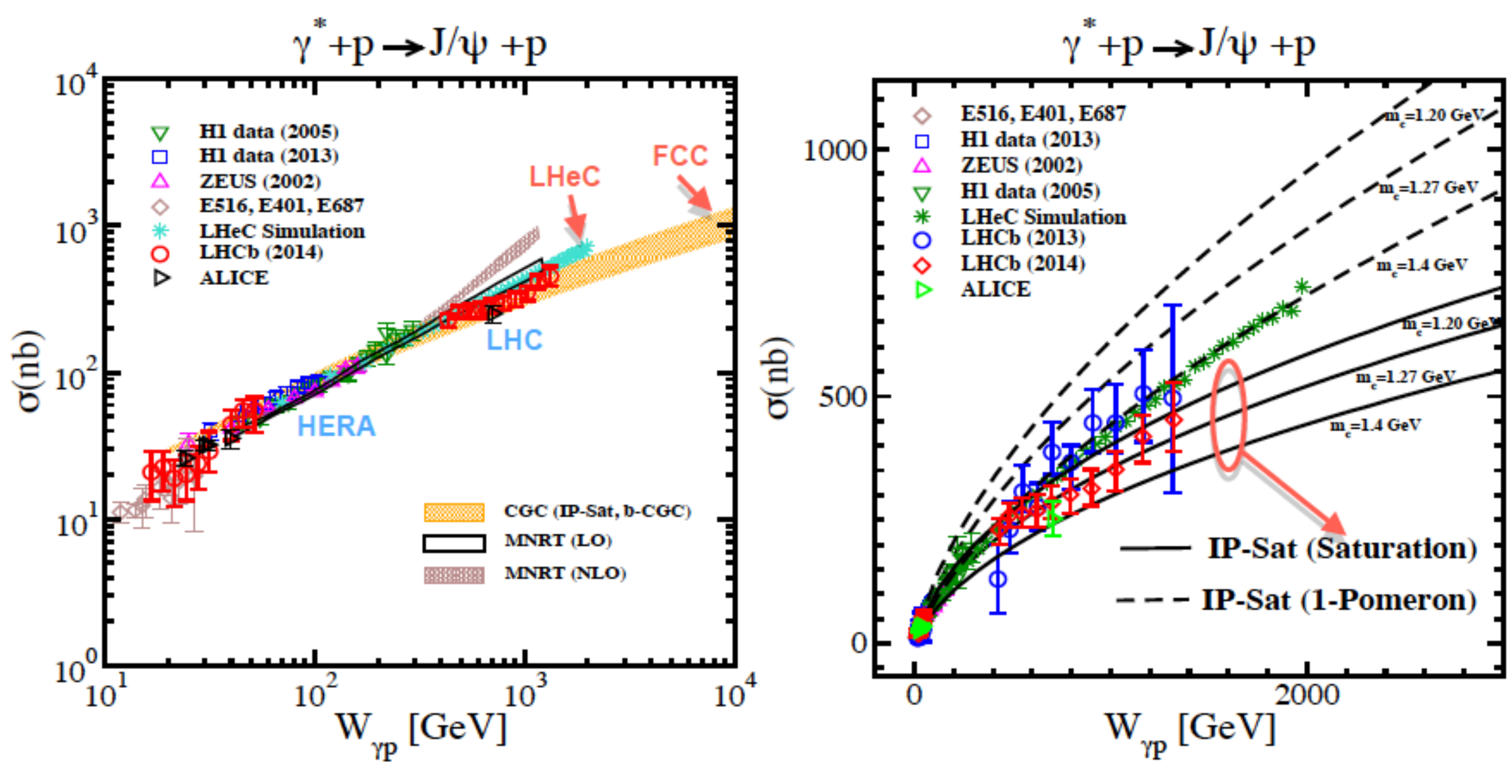
Non-linear, saturation.

Elastic VM production on p:



- Large uncertainties, e.g. charm mass (1402.4831).
- UPCs are an alternative.

Armesto and Rezaeian, arXiv:1402.4831



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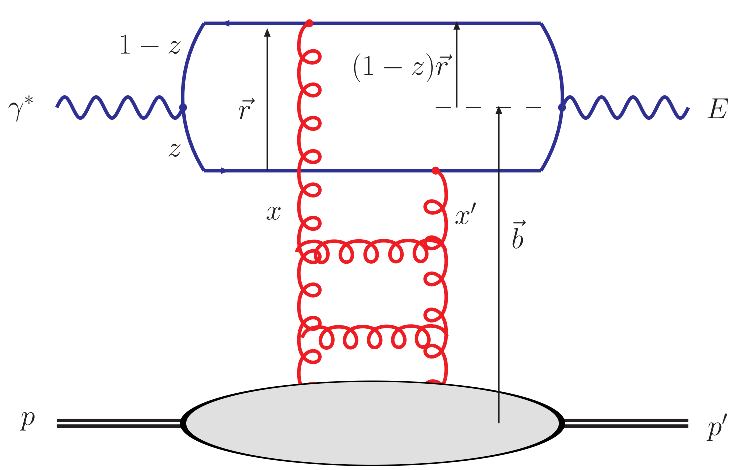
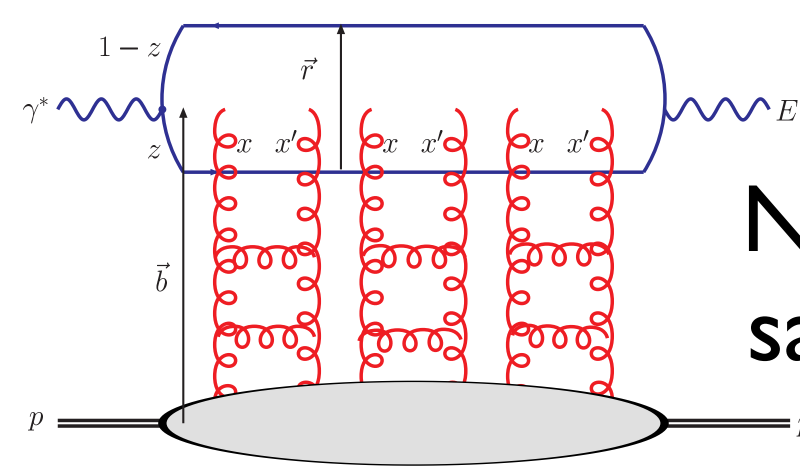
W (GeV)

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

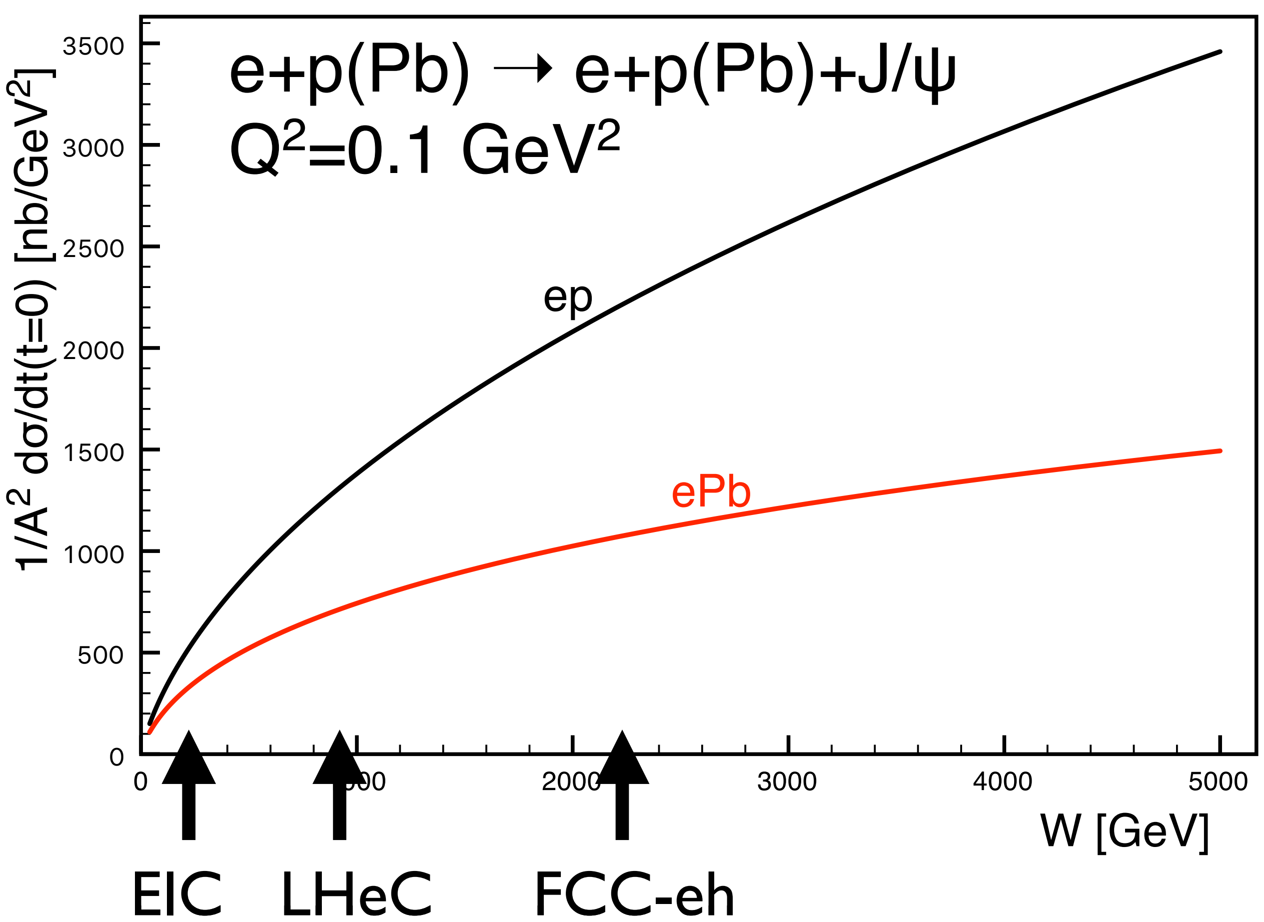


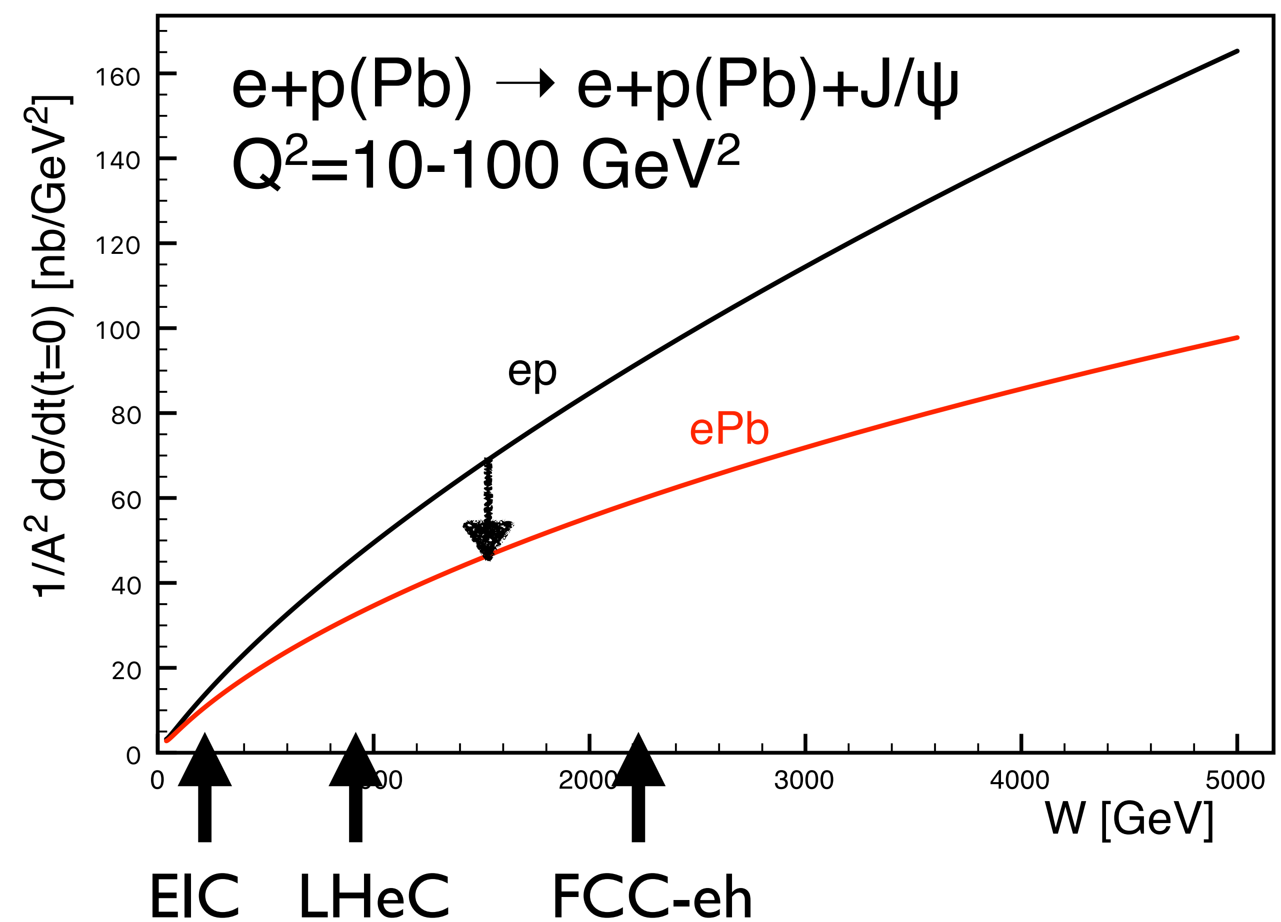


Non-linear, saturation.

Elastic VM production on A:

- Saturation (approach to the black disk limit) affects both energy and t (impact parameter) dependences of coherent exclusive VM production: softer energy dependence, shrinking of diffractive peak.
- Saturation results in a larger diffractive over inclusive cross section (Nikolaev et al., Z.Phys. A351 (1995) 435): interplay between non-linear phenomena and survival probability.





Mantysaari in DIS2018; LHeC CDR update to appear

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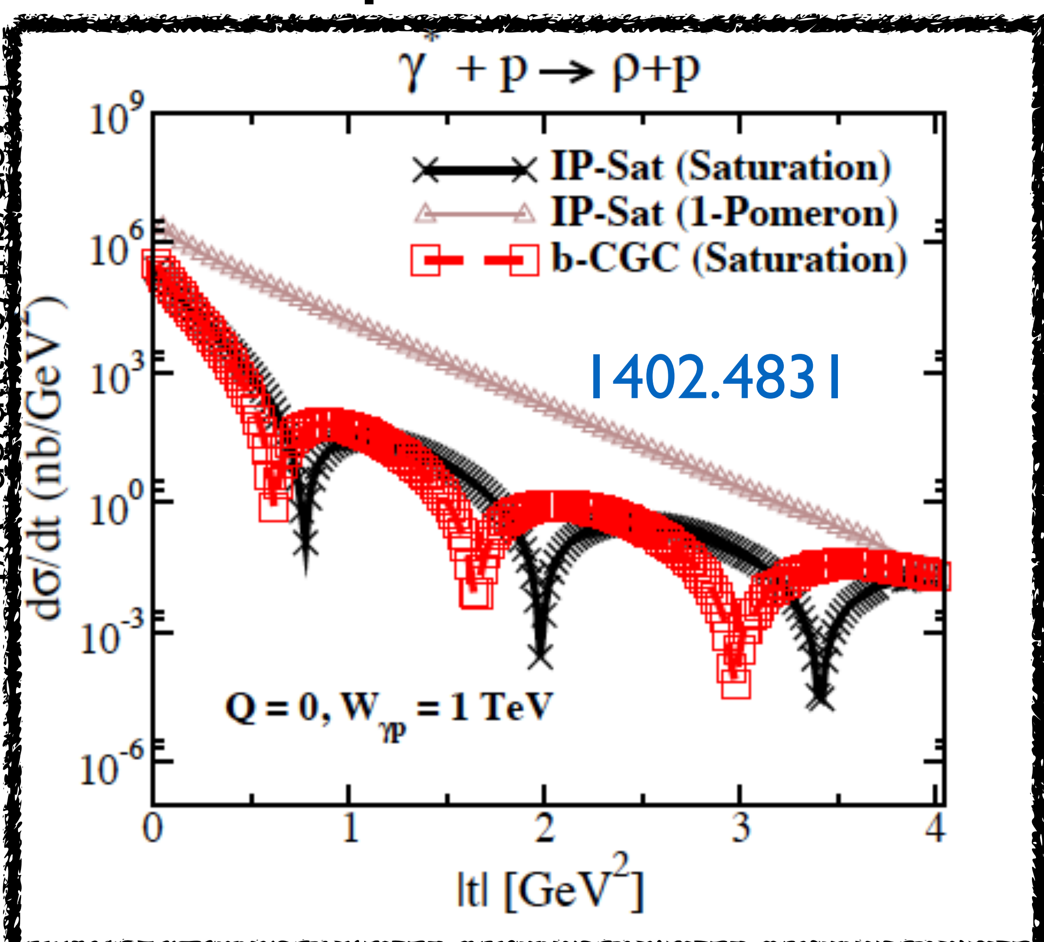
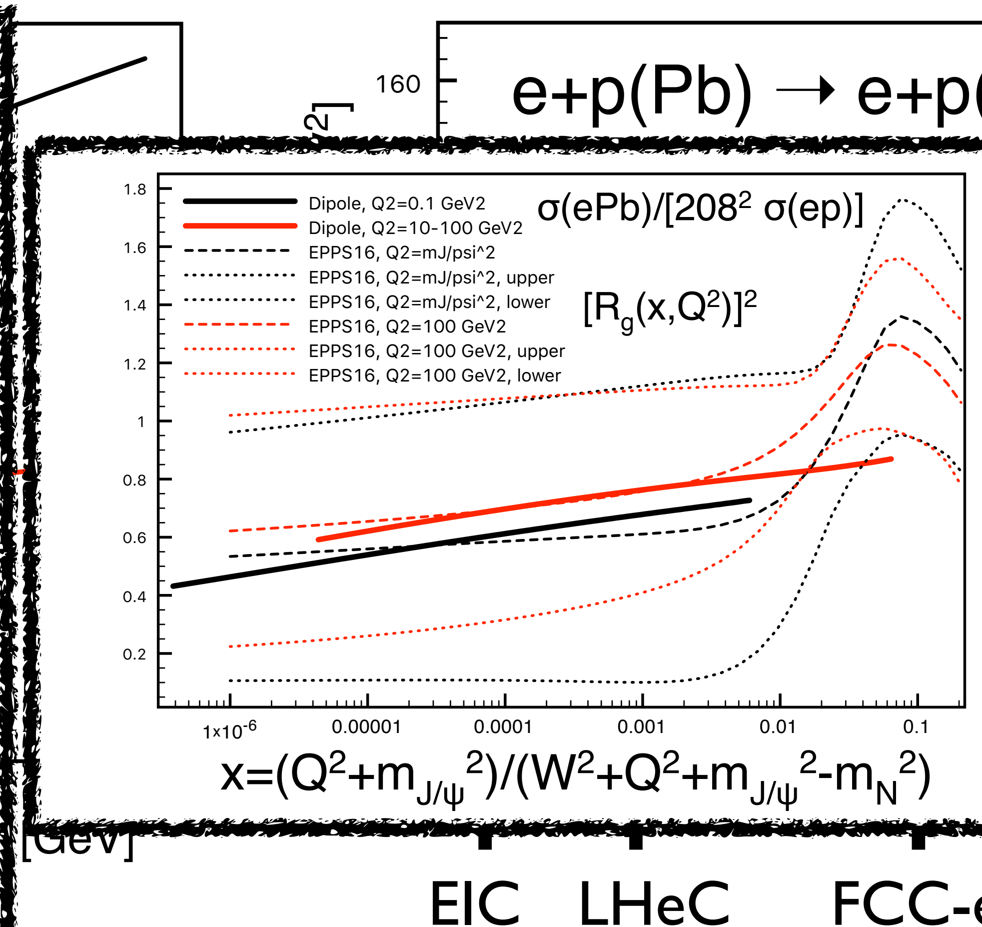




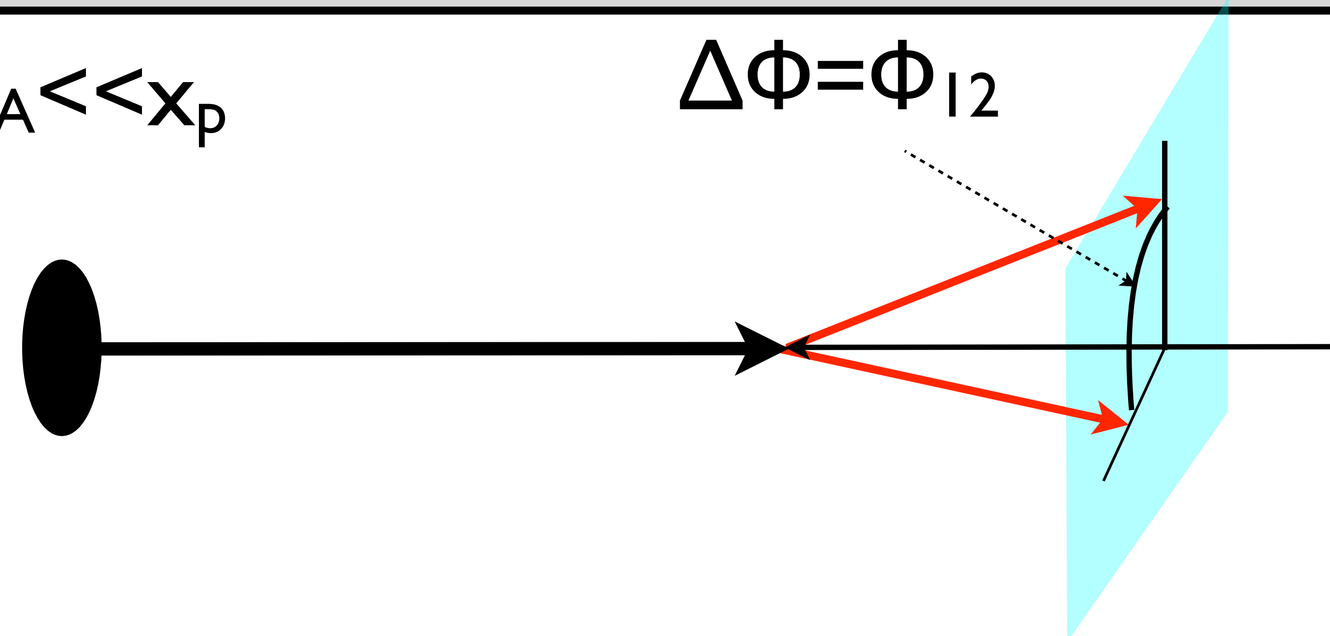
- Nuclear dependence may not be a signal of saturation by itself…
- Nuclear effects on quarkonium can be studied.

Mantysaari in DIS2018; LHeC CDR update to appear

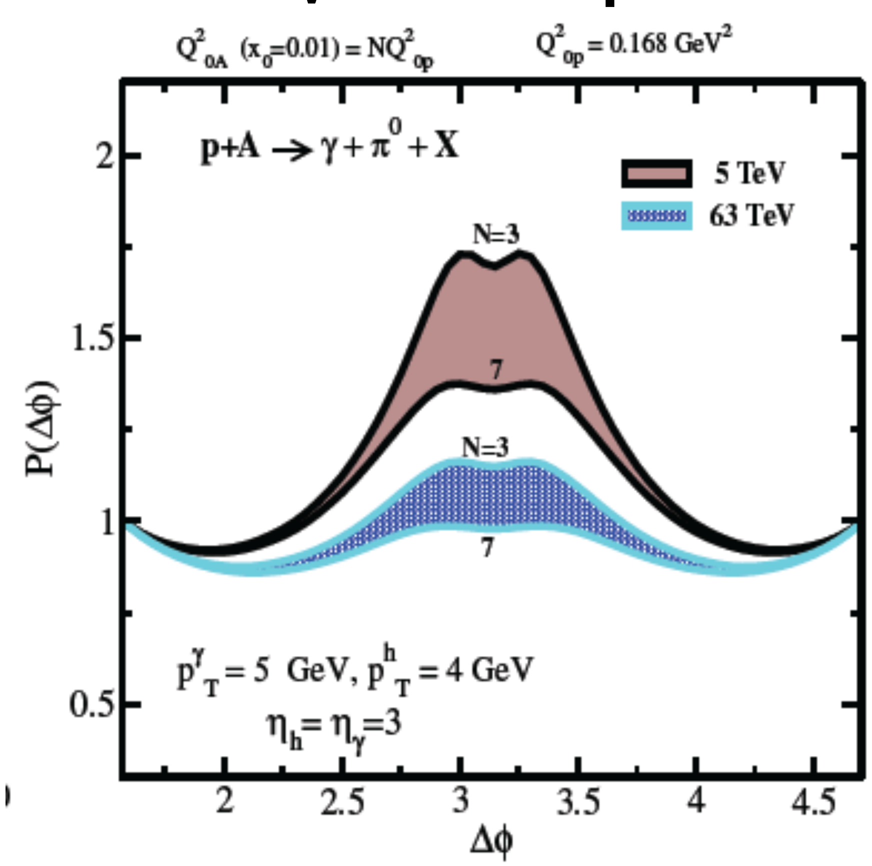
Correlations in eA/pA:

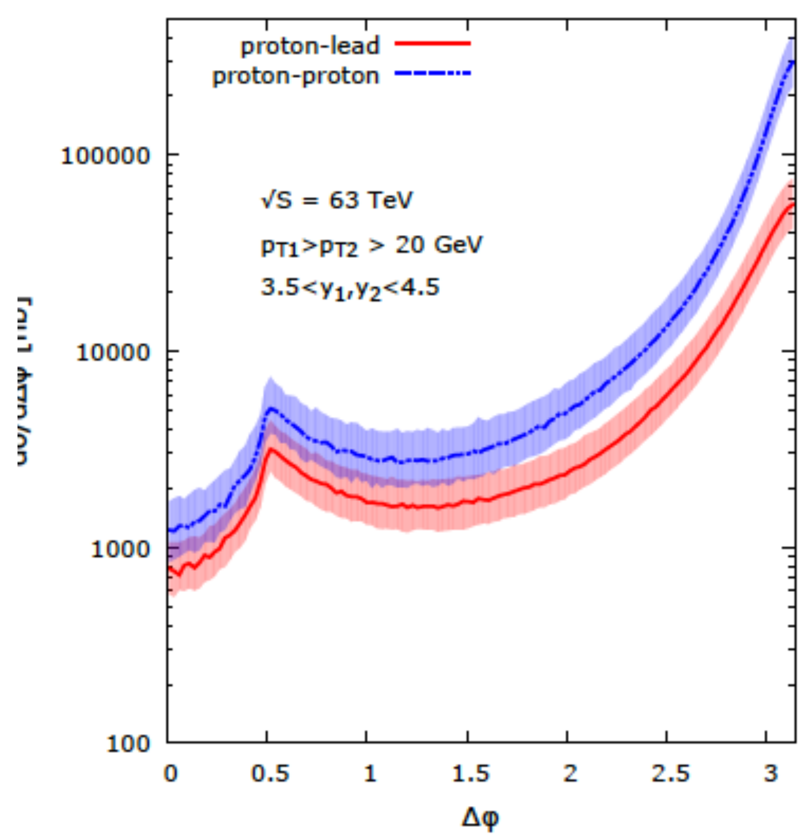
- Dihadron azimuthal decorrelation: discussed at RHIC as suggestive of saturation.
- To be studied far from kinematical limits.

Talk by D. Perepelitsa



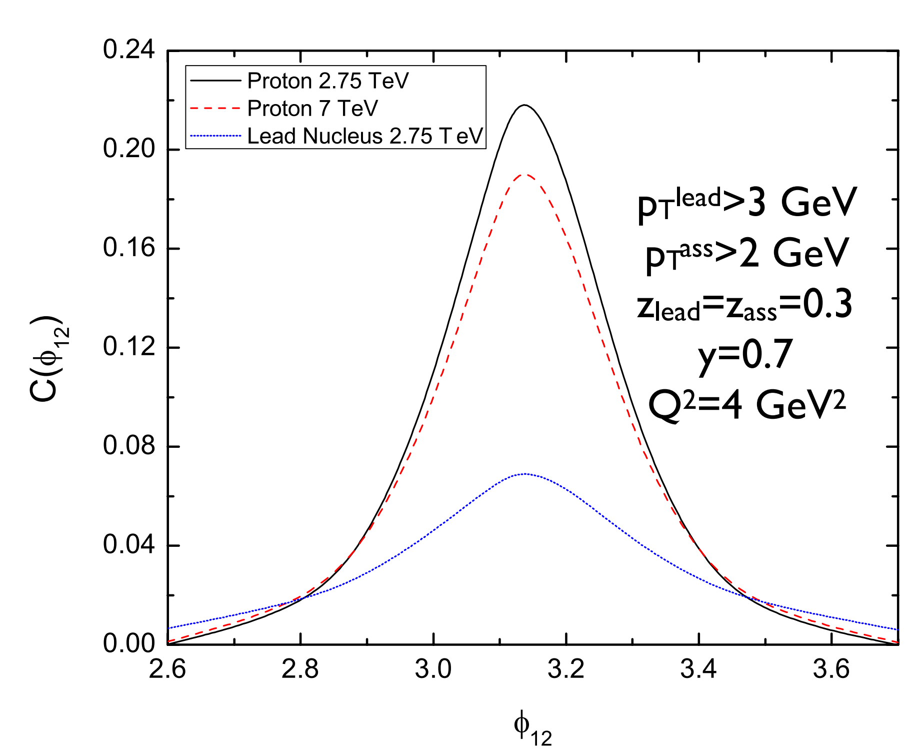
γ-π⁰ in pPb





jet-jet in pPb

$$C(\phi_{12}) = \frac{1}{\frac{d\sigma(\gamma^* N \to h_1 X)}{dz_{h1}}} \frac{d\sigma^{\gamma^* N \to h_1 h_2 + X}}{dz_{h1} dz_{h2} d\phi_{12}}$$



h-h in ePb

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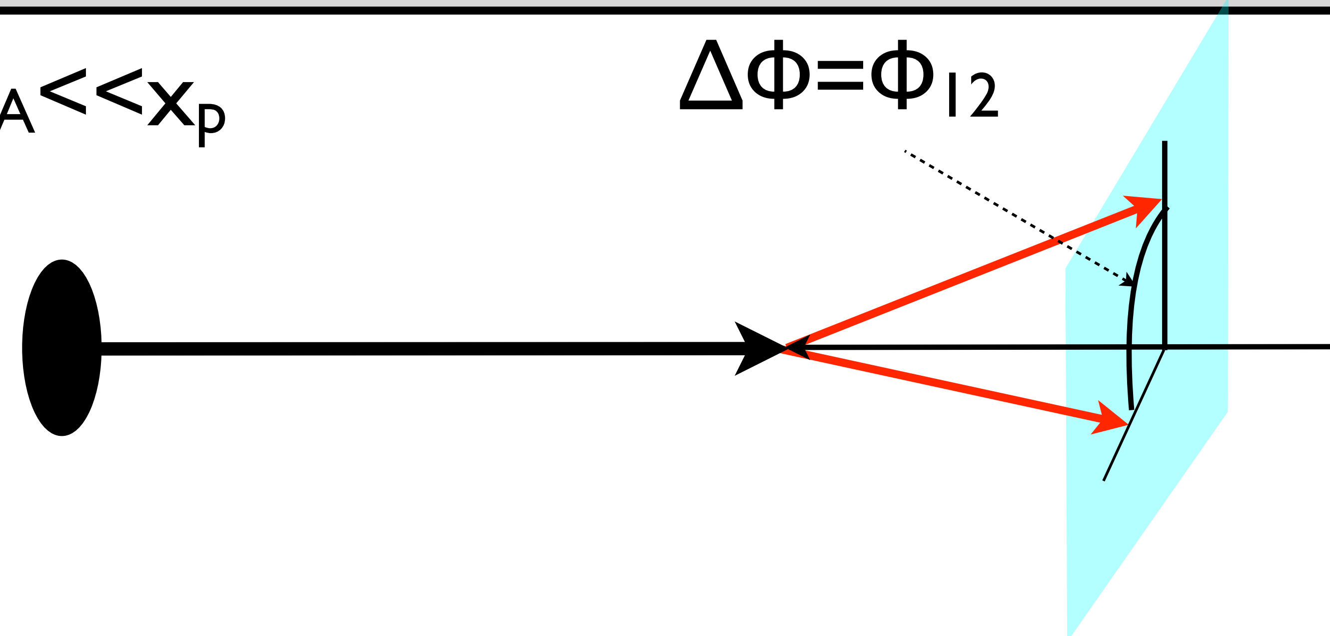
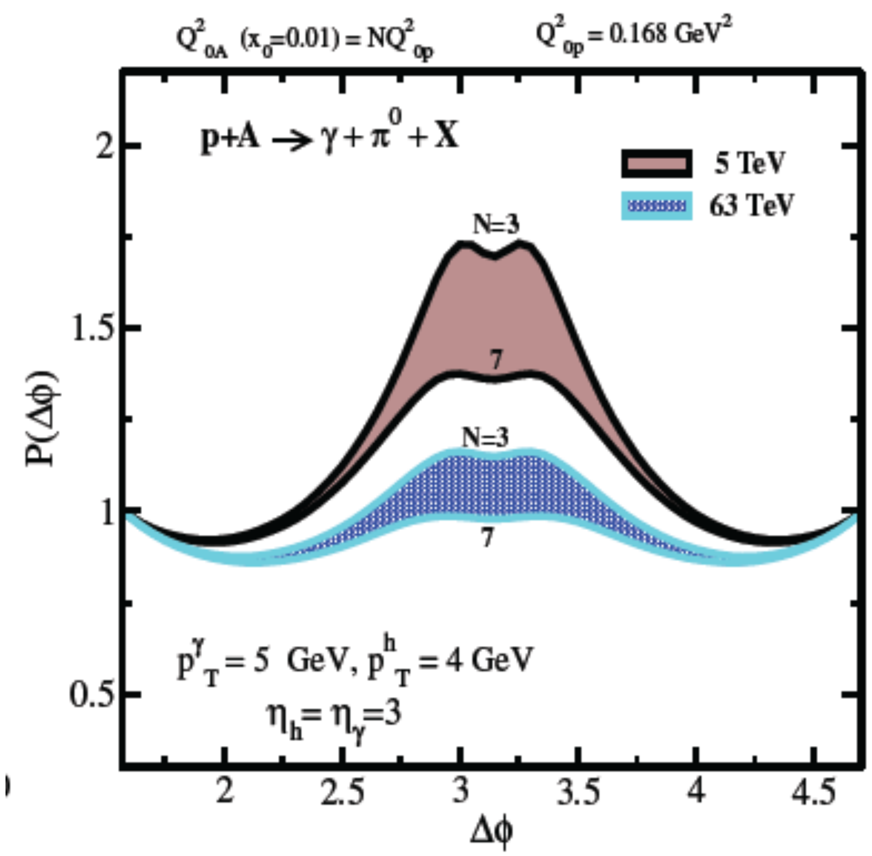
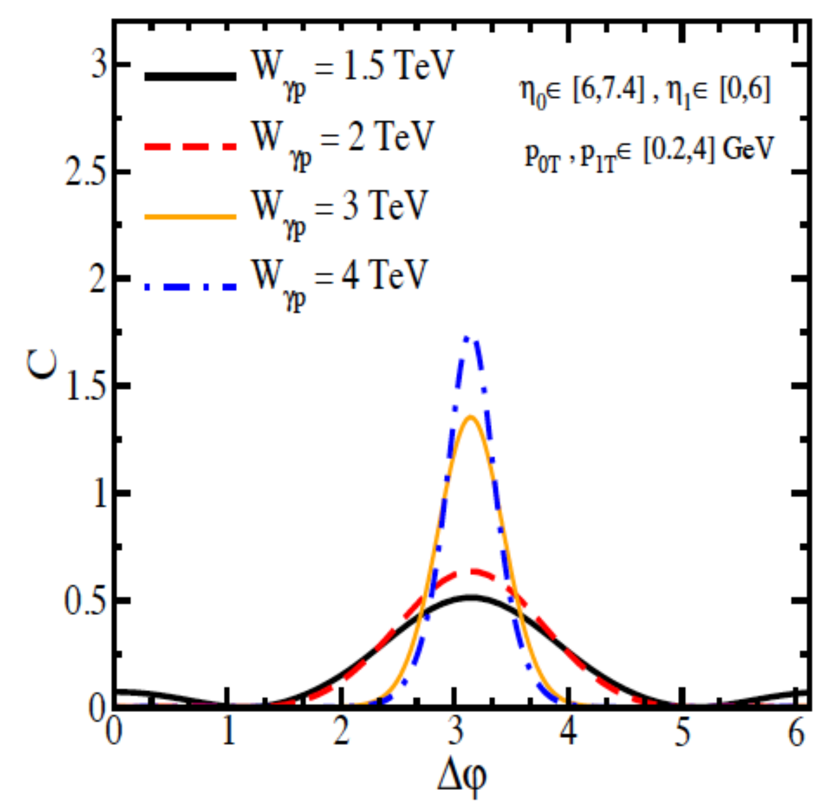


Talk by D. Perepelitsa

γ-π^0 in pPb



central-forward exclusive dijets in ep/eA, 1511.07452



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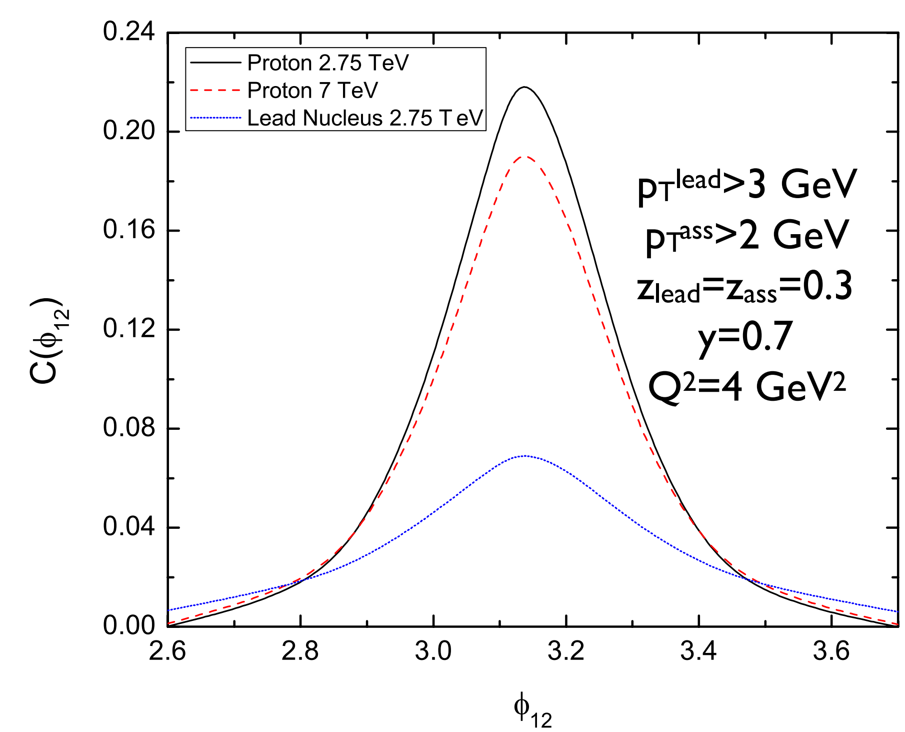

h-h in ePb

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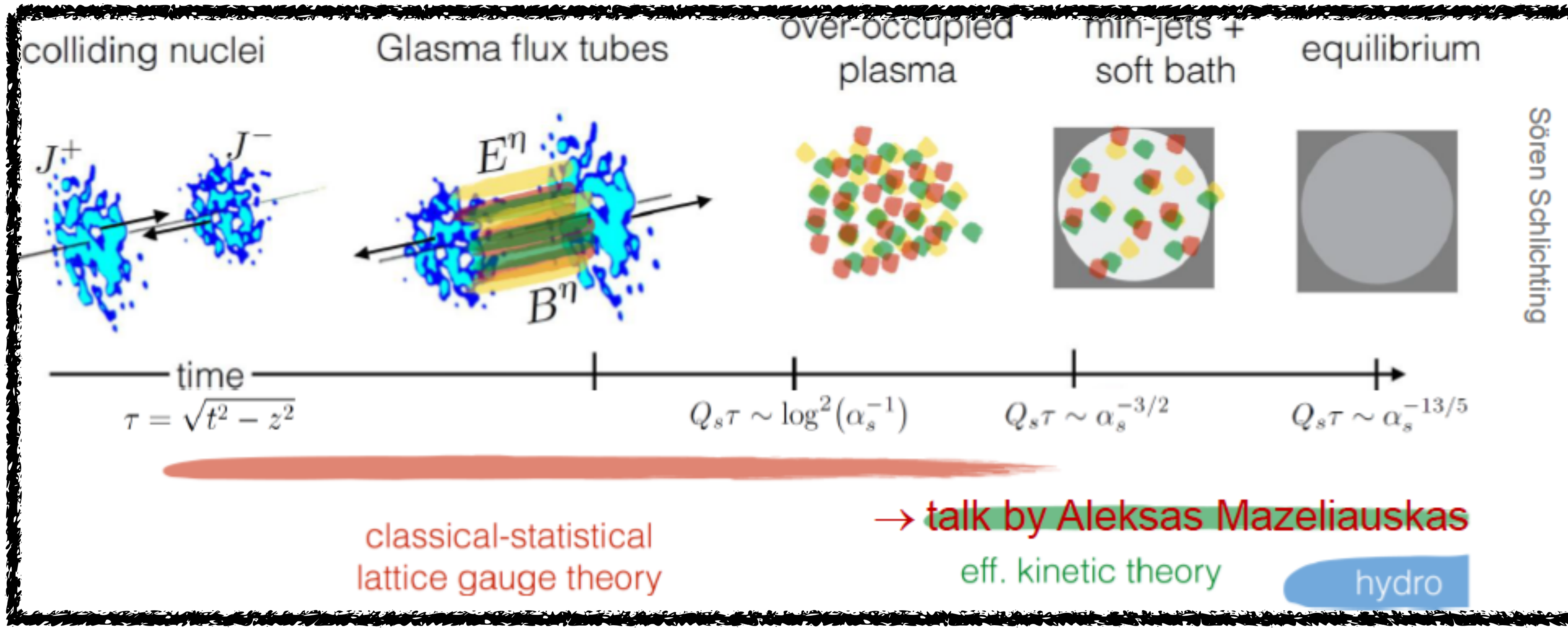
- *LHeC CDR, 1206.2913;*
- *2018 LHeC and FCC-eh workshop, https://indico.cern.ch/event/698368/;*
- *LHeC talks at DIS 2019, https://indico.cern.ch/event/749003/.*
- *Fixed target program at the HL-LHC, 1807.00603.*

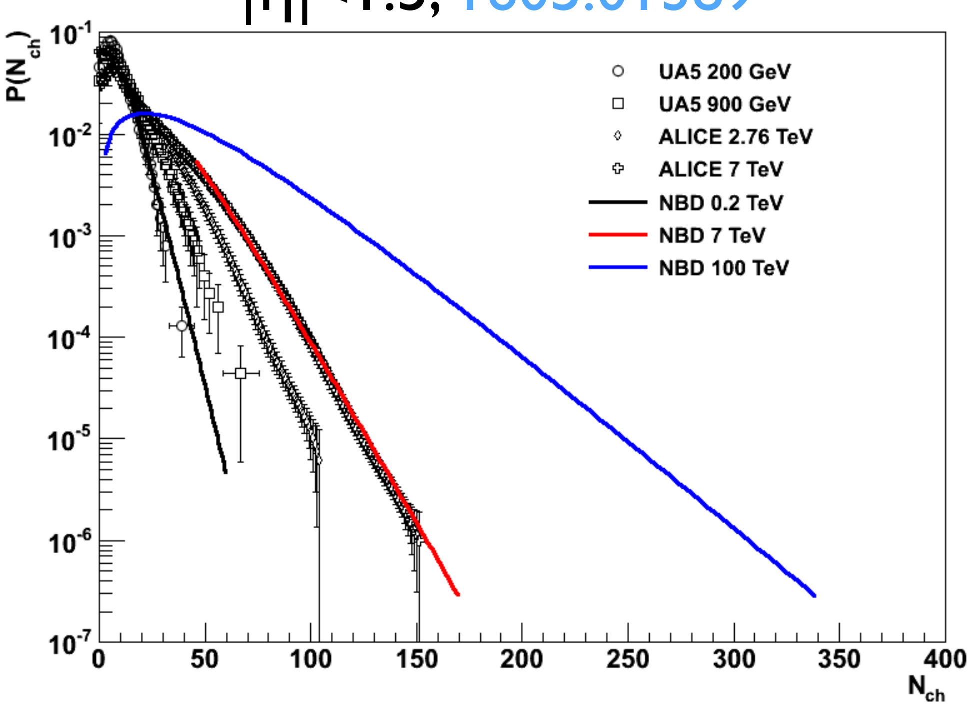
Talks by J. Lajoie and E. Sichtermann.

Pre-equilibrium dynamics:

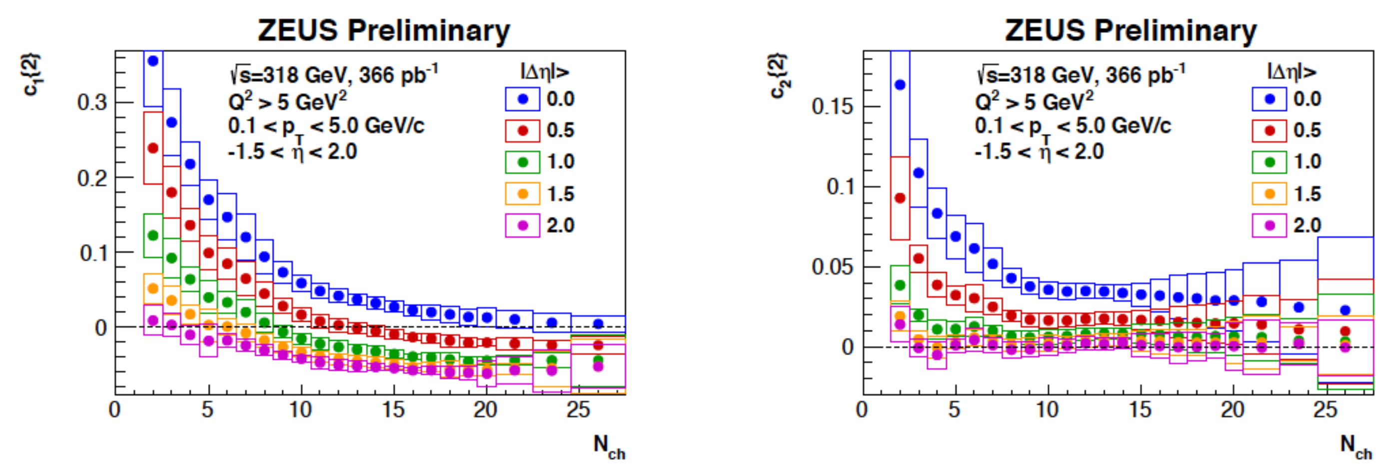


Talk by J. Berges

Charged multiplicity distribution $|\eta|<1.5$, 1605.01389



Multiplicity-dependent $c_1\{2\}$ and $c_2\{2\}$ with increasing η-separation



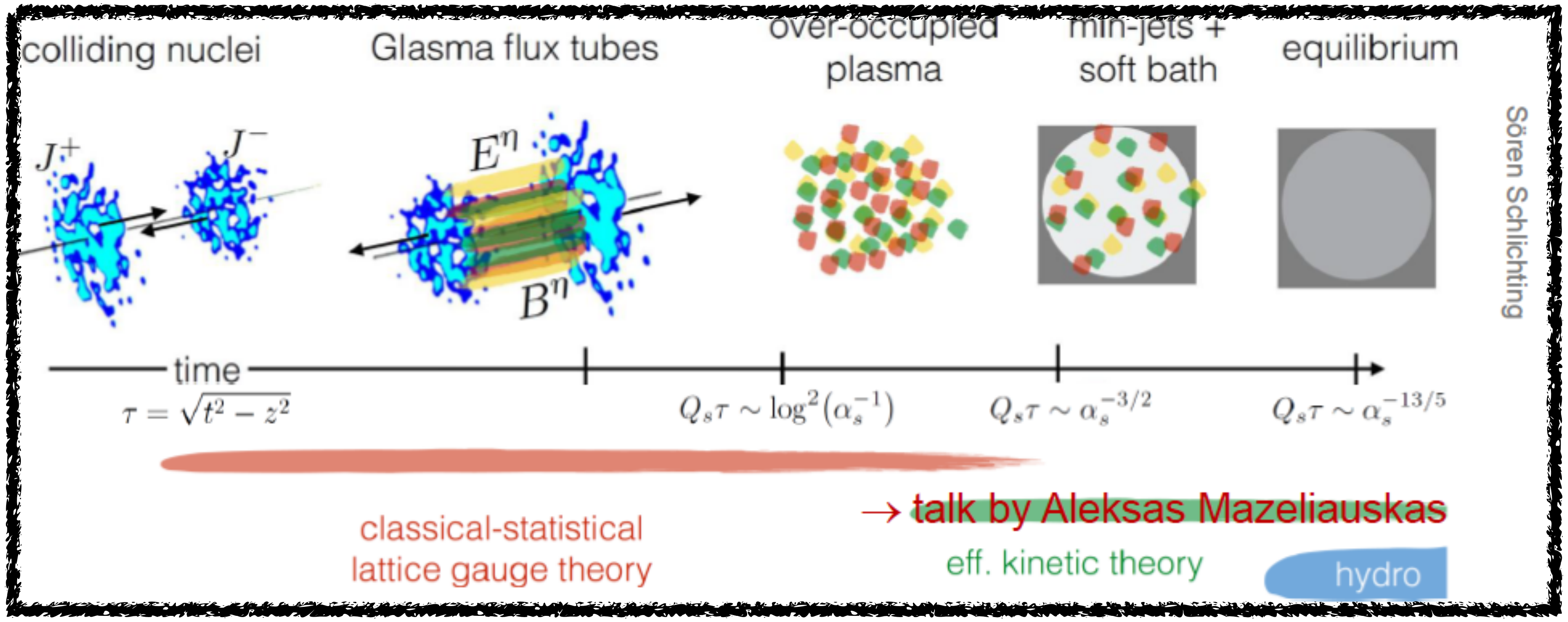
$|\Delta\eta| > 2.0$: $c_1\{2\}$ changes sign → consistent with momentum conservation.

$|\Delta\eta| > 2.0$: $c_2\{2\}$ consistent with zero.

ZEUS at DIS2019, talk by A. Baty

12/17

Pre-equilibrium dynamics:



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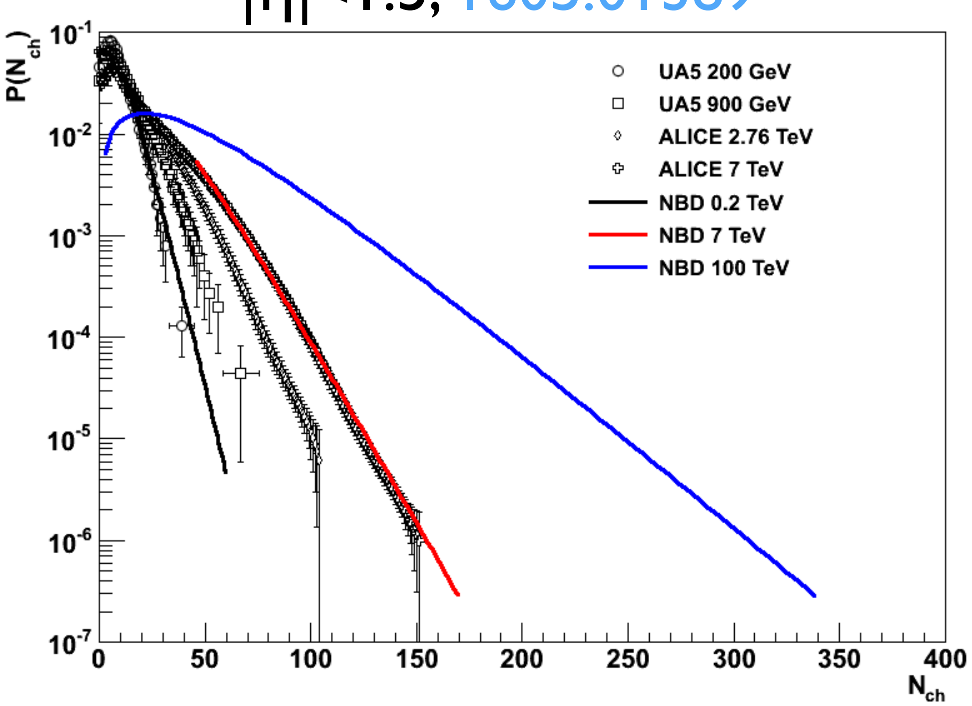
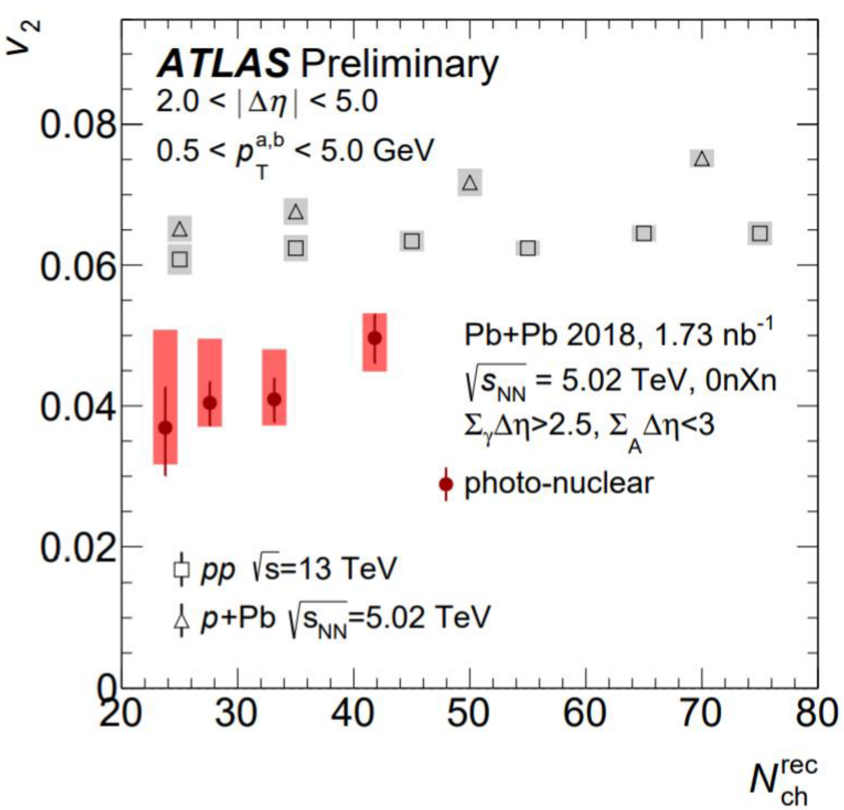
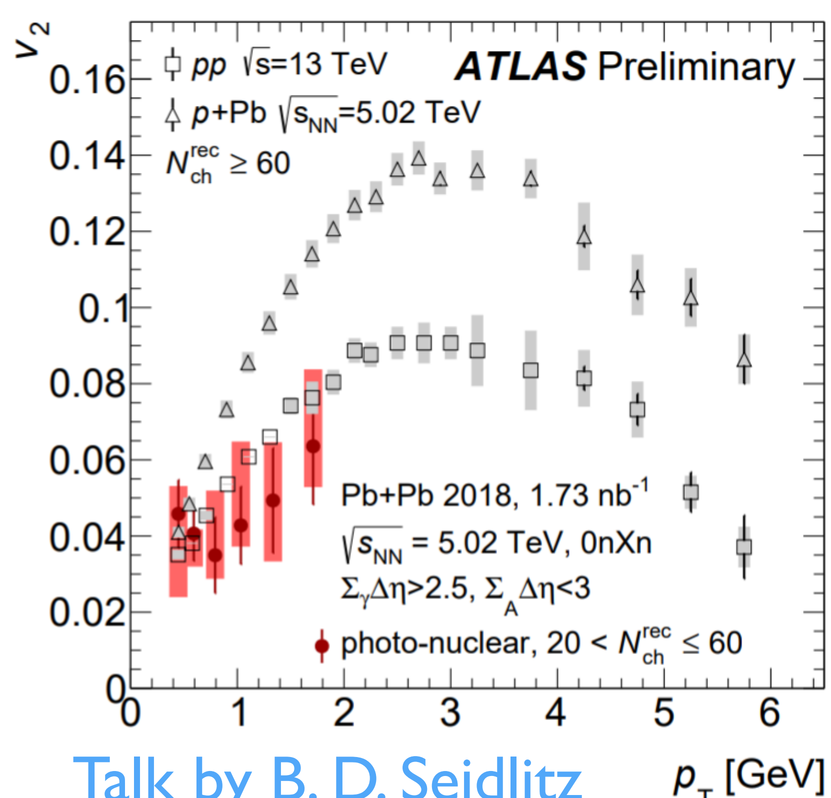
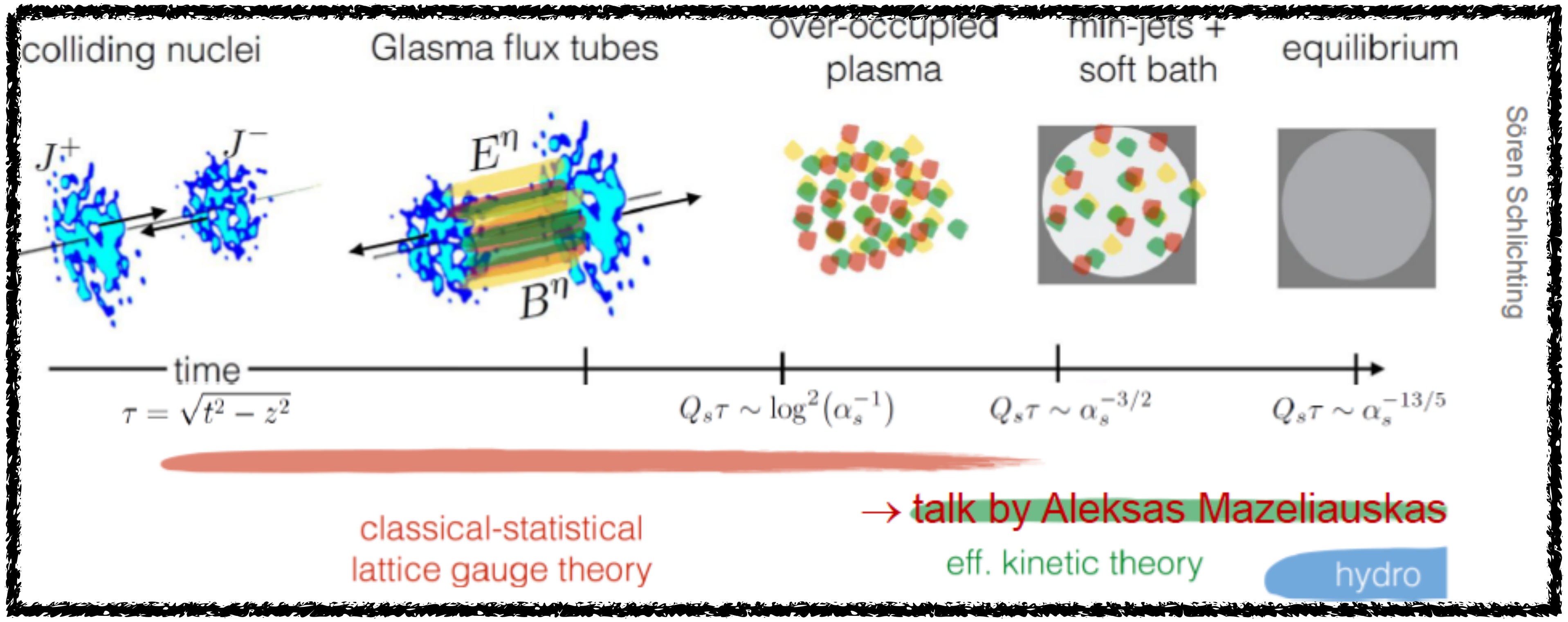




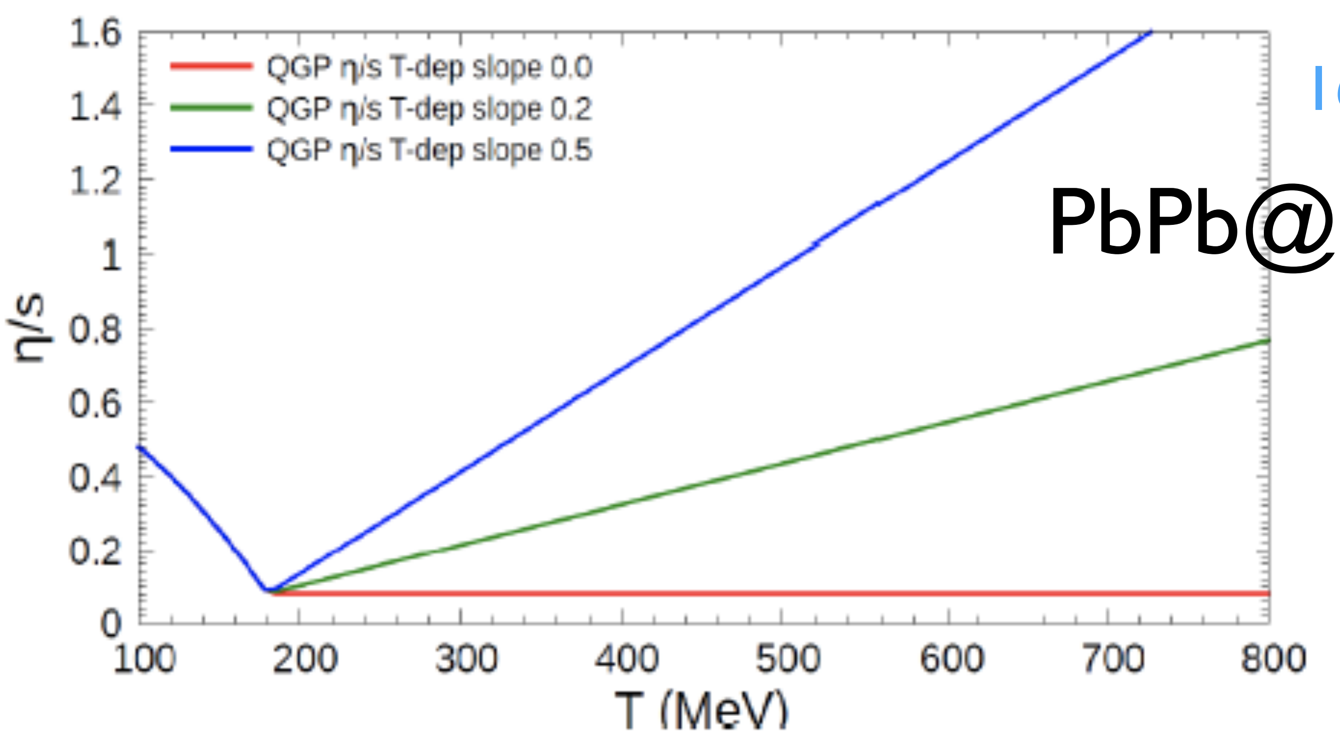


Talk by B. D. Seidlitz

Pre-equilibrium dynamics:

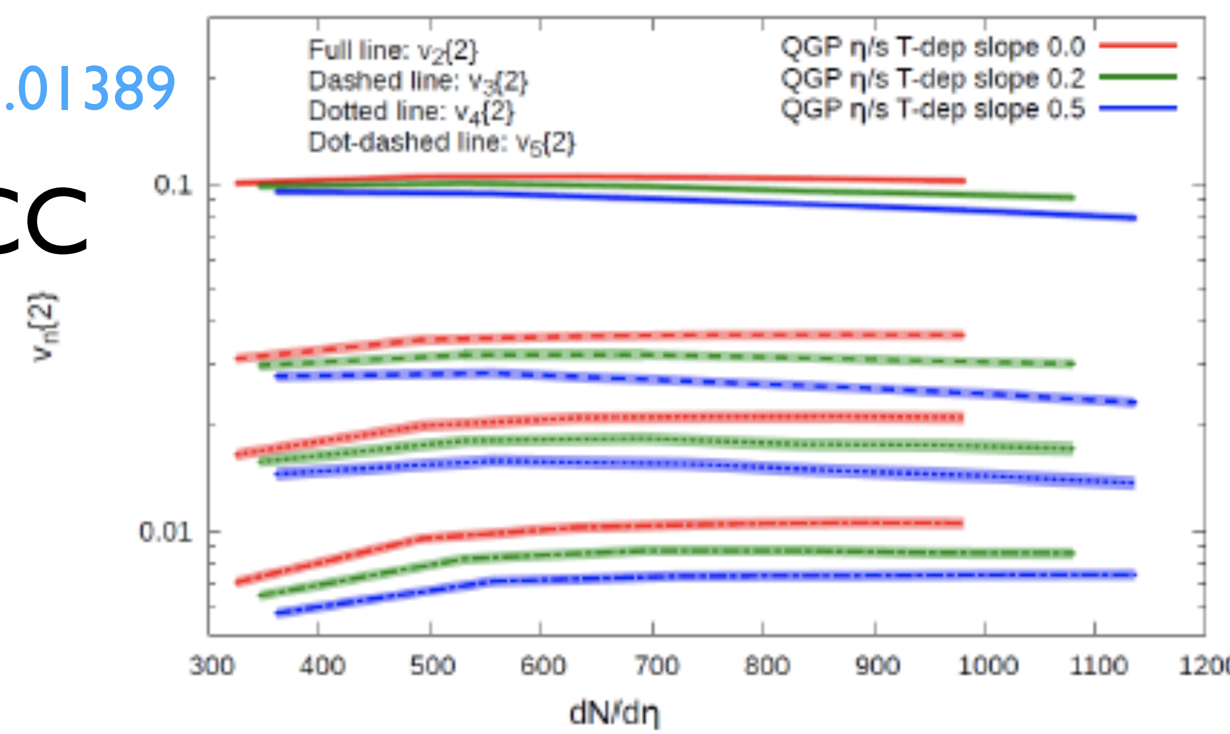


Talk by J. Berges



1605.01389

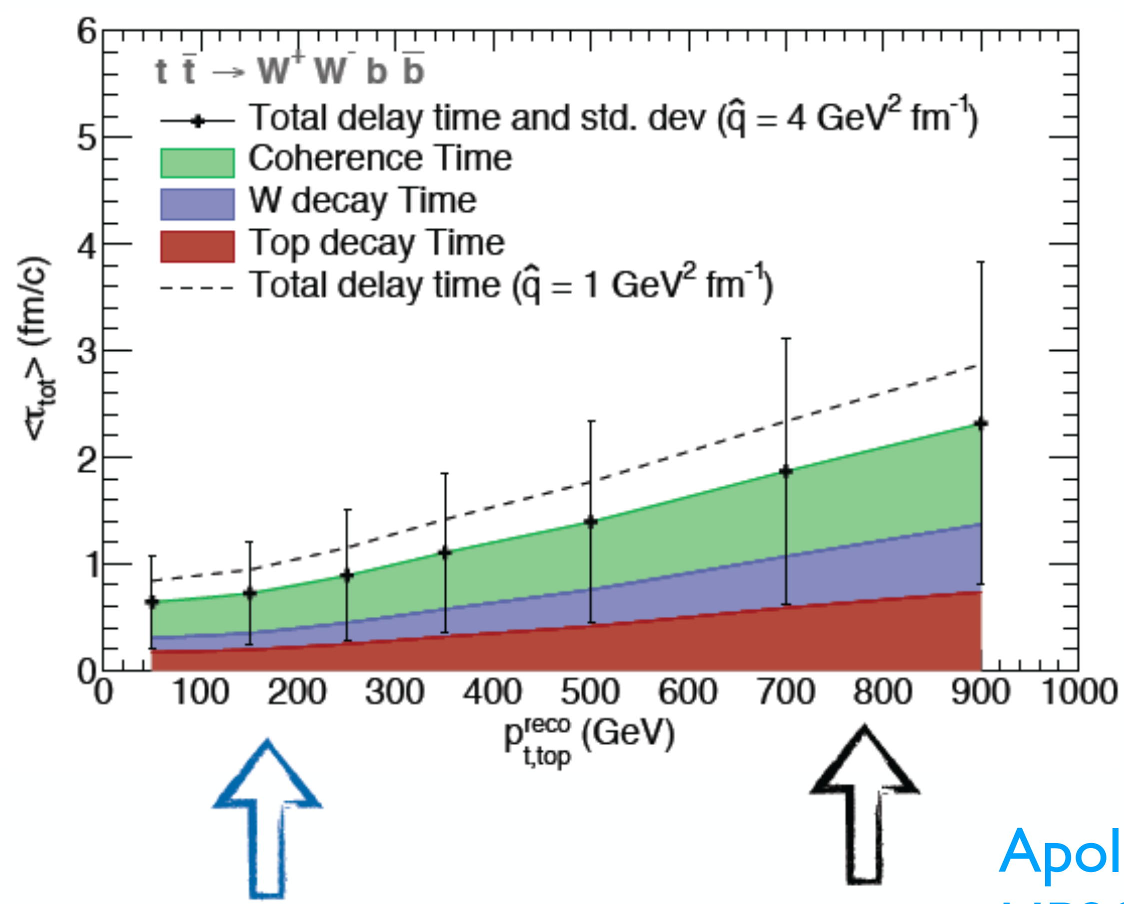
PbPb@FCC

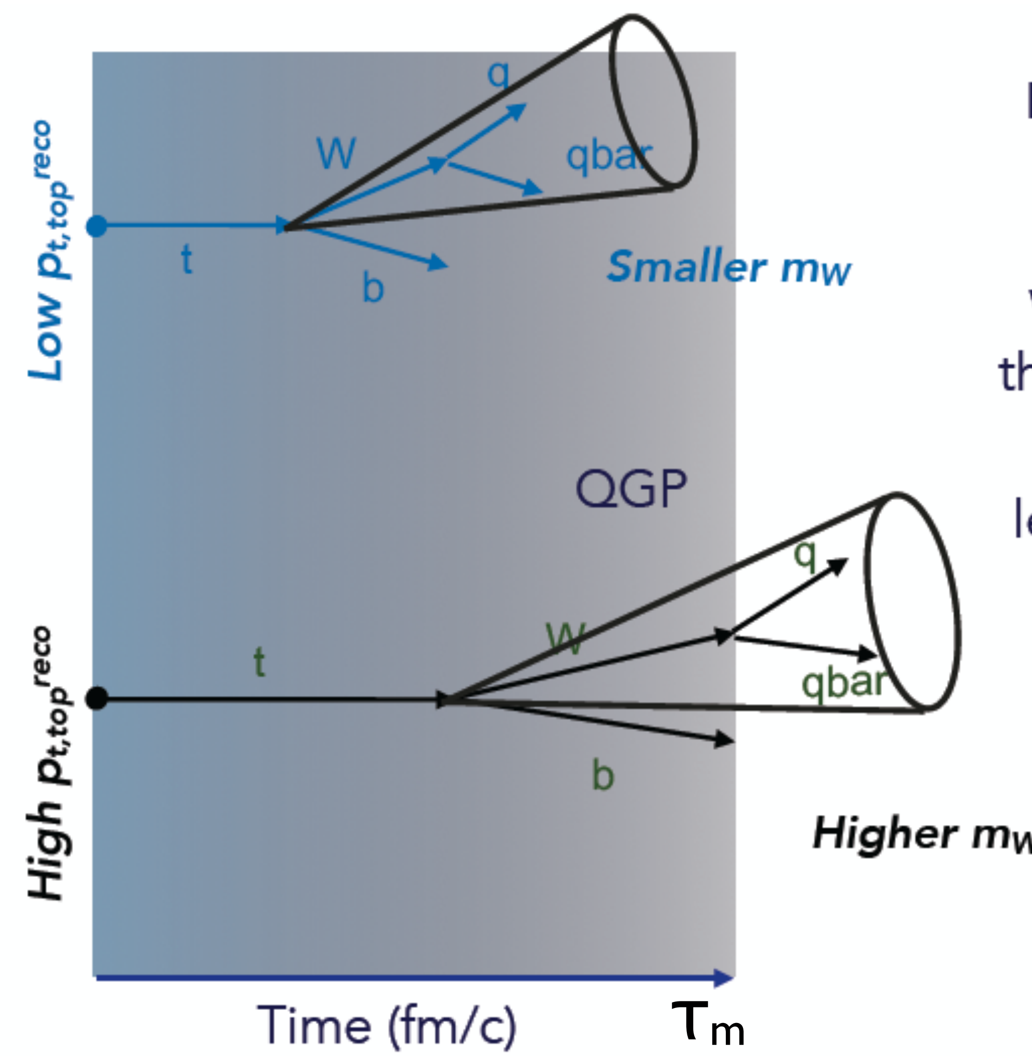


Hard probes:

- Recent activity on the use of hard probes to study the initial stages of hadronic collisions (1902.03231, talk by C. Andres).
- Large energies and statistics (lighter ions at HL-LHC; FCC-AA) make boosted tops available (1711.03105).

✦ Semi-leptonic decay of tt events produce jets that start interacting with the QGP only at later times





Reconstructed W mass: mw

will depend on the energy that is lost (medium length that jet is able to "see")

Apolinario at HP2018

$$\langle \tau_{\rm tot} \rangle = \gamma_{t,{\rm top}}\tau_{\rm top} + \gamma_{t,W}\tau_W + \tau_d$$

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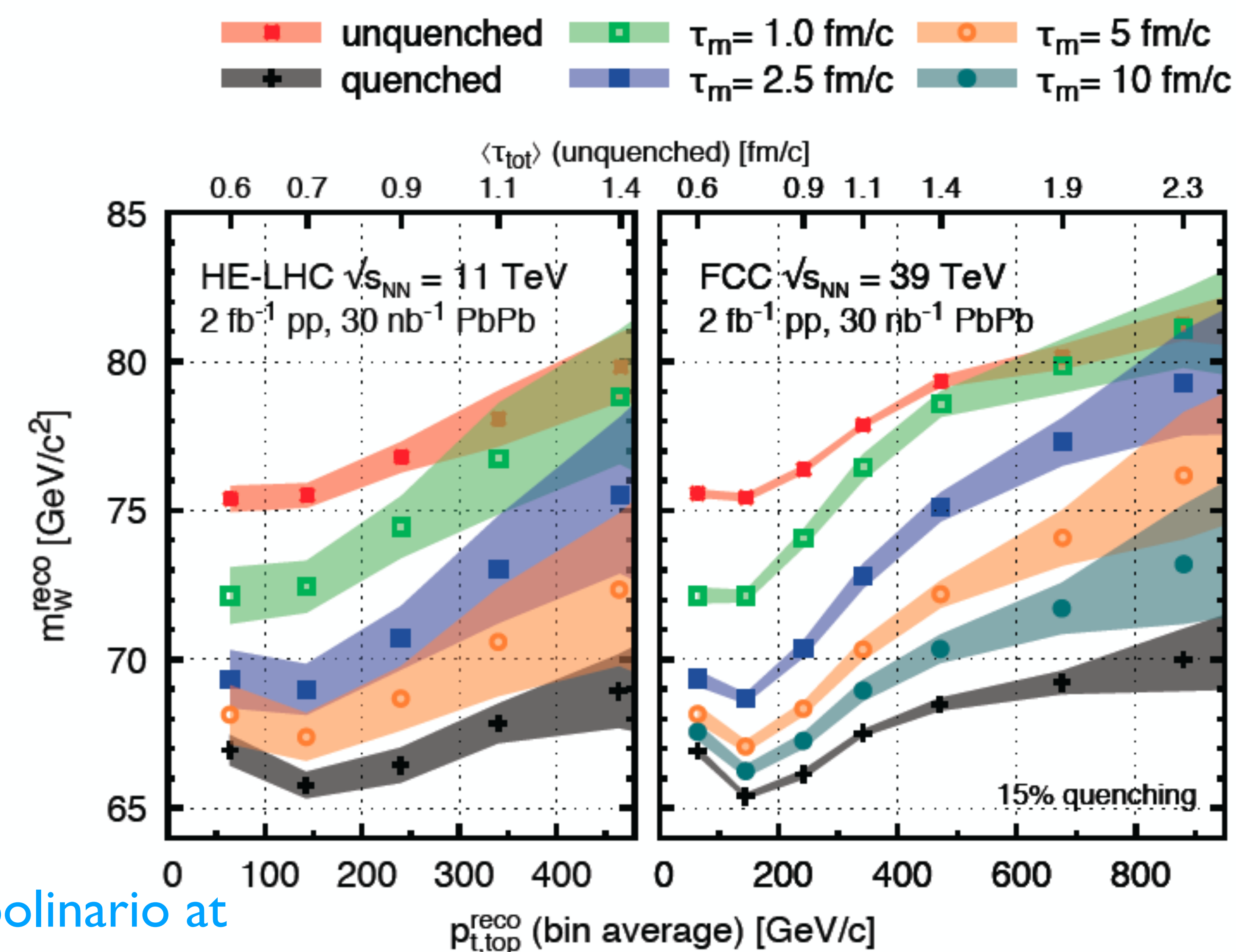
- Recent activity on the use of hard probes to study the initial stages of hadronic collisions (1902.03231, talk by C. Andres).
- Large energies and statistics (lighter ions at HL-LHC; FCC-AA) make boosted tops available (1711.03105).

- Reconstructed W Mass as a function of the top p_T:
  - Useful probe of the QGP density evolution
- QGP tomography:
  - HE-LHC: Some discrimination between short vs long lived medium
  - ✓ FCC: able to scan entire QGP lifetime!



Apolinario at HP2018

Lighter ions beyond LS4:

• There has been a proposal to collide lighter ions in Runs 5 to:

➜ Get larger statistics: gains of factors 2 (Xe) to 10 (Ar), for e.g. top studies, Z+jet,…

➜ Test size dependences of QGP properties and dynamics, without centrality definitions (strong biases in peripheral collisions and pA) → link to small systems.

➜ Get rid of centrality dependence for nPDFs, ridge, etc., that introduce additional correlations.

See also M. Schaumann at FCC Week 2019 for lighter ions at FCC.

	$^{16}O^{8+}$	$^{40}Ar^{18+}$	$^{40}Ca^{20+}$	$^{78}Kr^{36+}$	$^{129}Xe^{54+}$	$^{208}Pb^{82+}$
γ	3760.	3390.	3760.	3470.	3150.	2960.
$\sqrt{s_{NN}}$/TeV	7.	6.3	7.	6.46	5.86	5.52
σ_{had}/b	1.41	2.6	2.6	4.06	5.67	7.8
σ_{BFPP}/b	2.36×10^{-5}	0.00688	0.0144	0.88	15.	280.
σ_{EMD}/b	0.0738	1.24	1.57	12.2	51.8	220.
σ_{tot}/b	1.48	3.85	4.18	17.1	72.5	508.
N_b	6.24×10^9	1.85×10^9	1.58×10^9	6.53×10^8	3.56×10^8	1.9×10^8
ϵ_{xn}/μm	2.	1.8	2.	1.85	1.67	1.58
f_{IBS}/(m Hz)	0.0662	0.0894	0.105	0.13	0.144	0.167
W_b/MJ	68.9	45.9	43.6	32.5	26.5	21.5
$L_{AA0}/\text{cm}^{-2}s^{-1}$	1.46×10^{31}	1.29×10^{30}	9.38×10^{29}	1.61×10^{29}	4.76×10^{28}	1.36×10^{28}
$L_{NN0}/\text{cm}^{-2}s^{-1}$	3.75×10^{33}	2.06×10^{33}	1.5×10^{33}	9.79×10^{32}	7.93×10^{32}	5.88×10^{32}
P_{BFPP}/W	0.0031	0.179	0.303	5.72	43.4	350.
P_{EMD1}/W	4.98	16.5	16.9	40.5	76.7	141.
τ_{L0}/h	16.4	21.3	23.	13.5	5.87	1.57
T_{opt}/h	9.04	10.3	10.7	8.23	5.42	2.8
$\langle L_{AA}\rangle$ cm^{-2}s^{-1}	8.99×10^{30}	8.34×10^{29}	6.17×10^{29}	9.46×10^{28}	2.23×10^{28}	3.8×10^{27}
$\langle L_{NN}\rangle$ cm^{-2}s^{-1}	2.3×10^{33}	1.33×10^{33}	9.87×10^{32}	5.76×10^{32}	3.71×10^{32}	1.64×10^{32}
$\int_{month} L_{AA}$ dt/nb^{-1}	1.17×10^4	1080.	799.	123.	28.9	4.92
$\int_{month} L_{NN}$ dt/pb^{-1}	2980.	1730.	1280.	746.	481.	213.
R_{had}/kHz	2.07×10^4	3340.	2440.	653.	270.	106.
μ	1.64	0.266	0.194	0.0518	0.0215	0.00842

1812.06772, p=1.5

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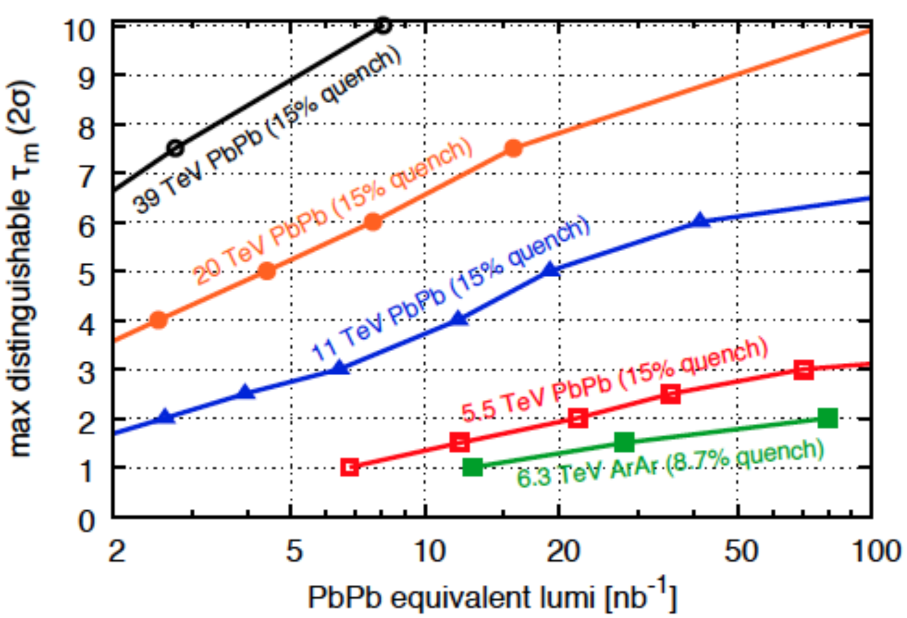
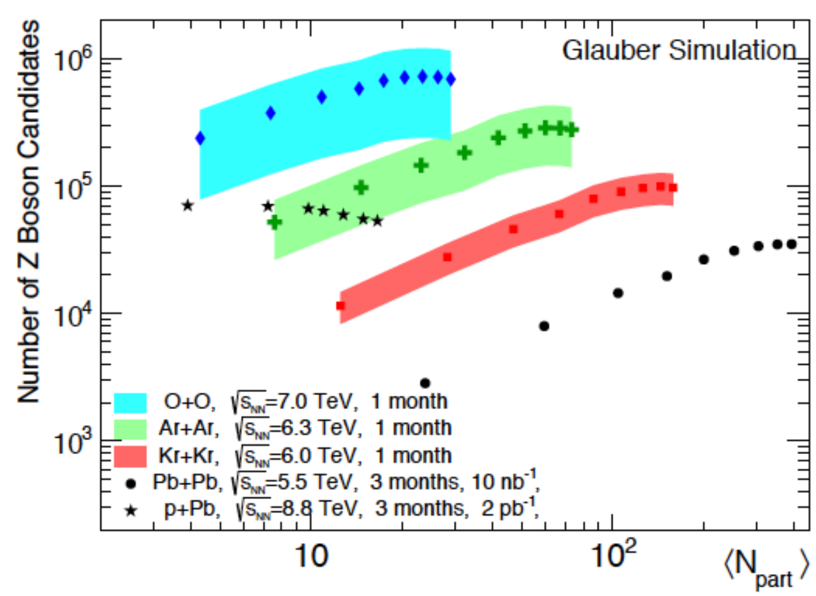
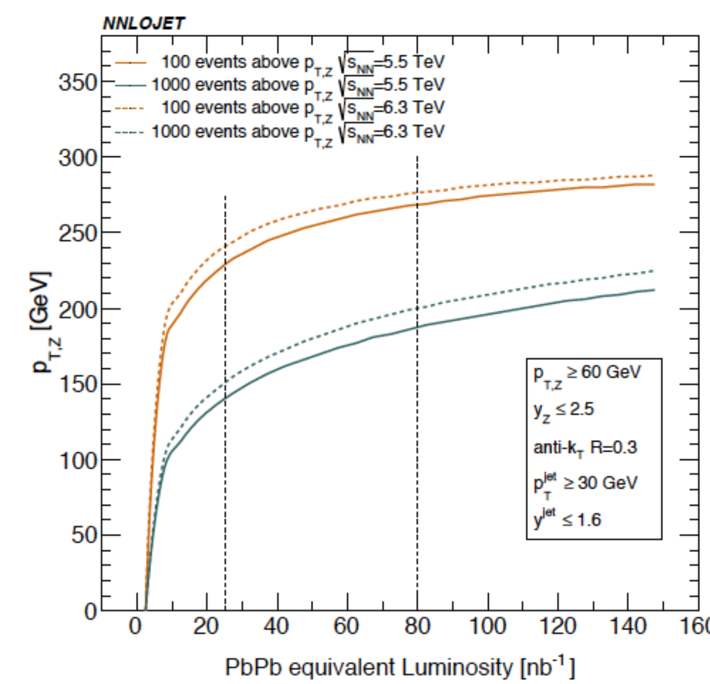
1812.06772







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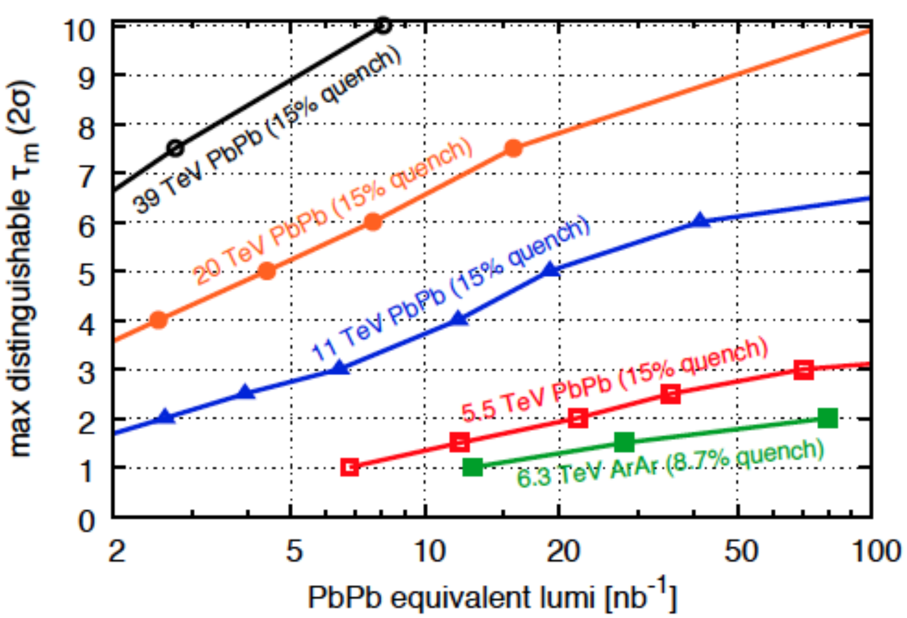
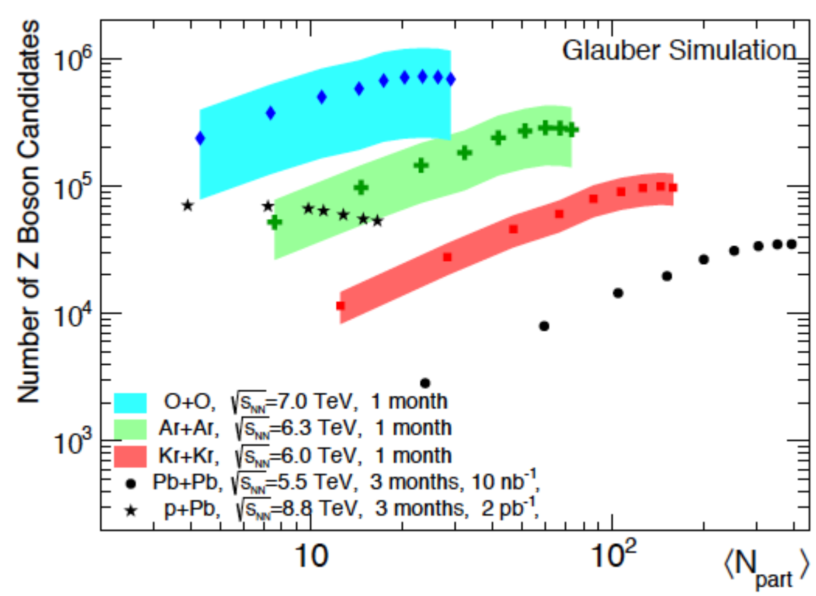
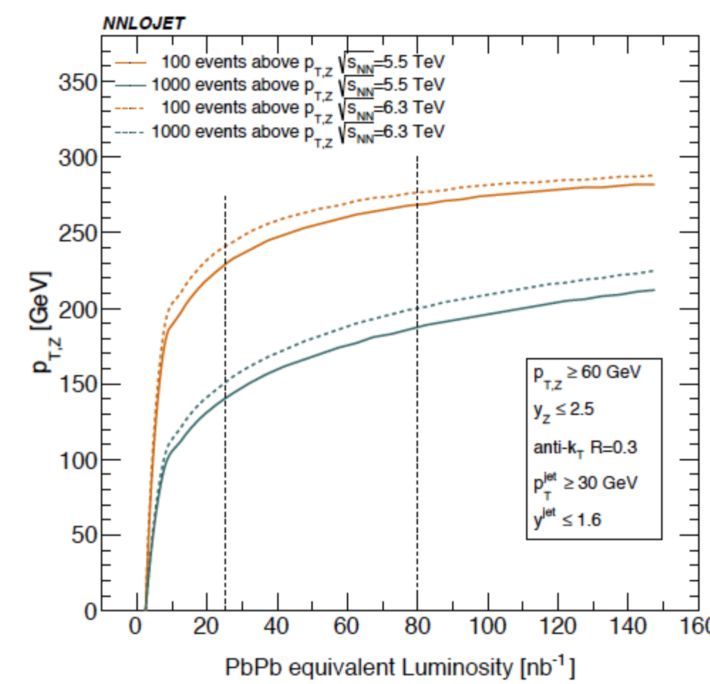






- We may have new detectors/experiments there: LHCb Upgrade II, new detector in IP2 (heavy-ion detector focused on thermal radiation, rare c,b hadrons, ultrasoft particles (1902.01211), or LHeC offering ep/eA at the same time as pp/pA/AA).

Announcements:

https://conferences.lbl.gov/event/196/

POETIC 2019

16-21 September 2019
LBL-Hill
US/Pacific timezone

- Overview
- Scientific Programme
- Code of conduct
- Registration
- Call for Abstracts
  - View my Abstracts
  - Submit Abstract
- Timetable
- Contribution List
- Author List
- Committees
- Logistics

9th International Conference on Physics Opportunities at an ElecTron-Ion-Collider

POETIC 9, the Ninth International Conference on the 'Physics Opportunities at an ElecTron-Ion Collider', will take place at Lawrence Berkeley National Laboratory, Berkeley, USA, from Monday, September 16 to Saturday, September 21, 2019. The primary goal of the conference is to continue the advancement of the field of electron-ion collider physics.

The first three days, from Monday to Wednesday, we plan to arrange focus meetings on various aspects of our program (in parallel). The formal POETIC workshop starts on Thursday and ends on Saturday.

The program will consist of invited and contributed talks. We strongly encourage the submission of abstracts. Postdocs and students are especially encouraged to attend the conference.

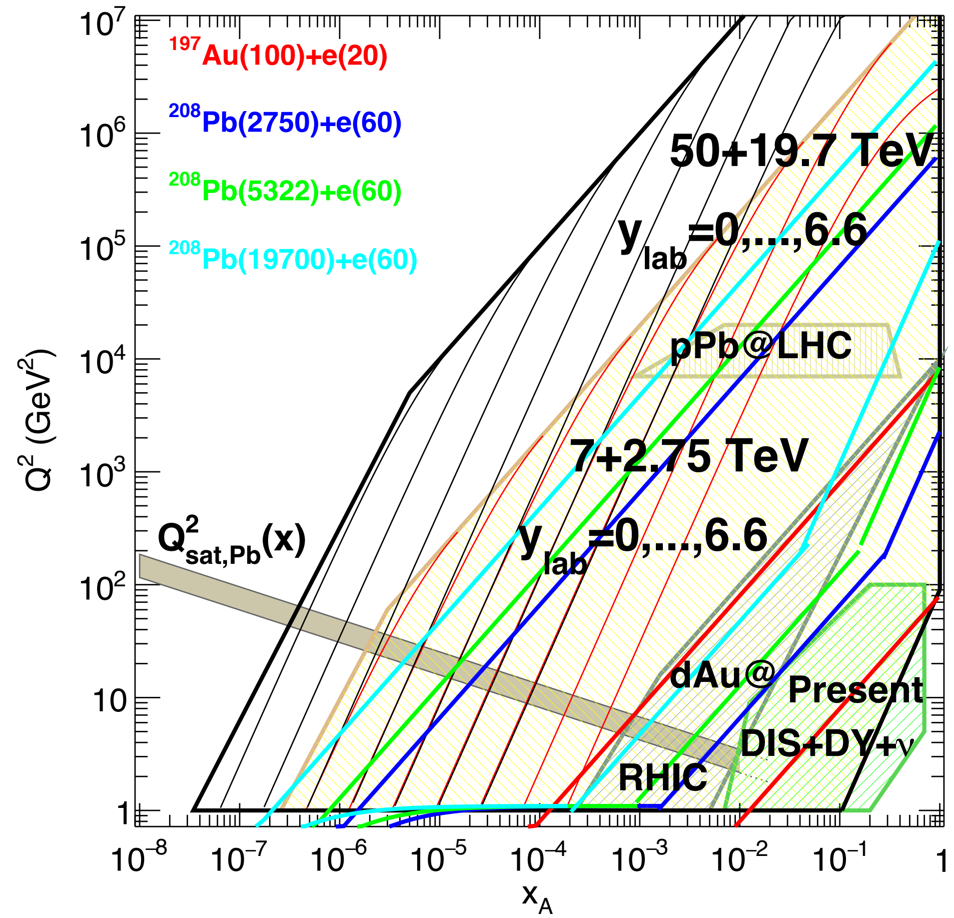
Conference Topics:

Structure of hadrons: (nuclear) parton distribuition functions (PDFs nPDFs), transverse momentum dependent (TMDs) and generalized parton distributions (GPDs), Distribution Amplitudes (DAs) , Double Distributions (DDs).
QCD at high parton densities and small-x: saturation, evolution, Color Glass Condensate
Fragmentation functions and Jet properties
Complementarity and connections of EIC physics with p+p, p+A and A+A collisions: high-pt processes, diffraction, multi-parton interactions, quark-gluon plasma and colored probes in hot nuclear matter.
Physics beyond the Standard Model and connections to other areas in physics.
Future DIS facilities: accelerator and detector developments.

- **LHeC/FCC-eh 2019 Workshop, October 24th-25th 2019 in Chavannes-de-Bogis near CERN.**

Summary:

- I have done an incomplete, **personal** overview of the future possibilities for initial stages at CERN: FCC as representative of AA colliders, ep/eA and fixed target programmes.
  - ➜ Partonic structure of the nucleus, in the collinear framework and beyond.
  - ➜ New dynamics at small x.
  - ➜ Pre-equilibrium and small systems.



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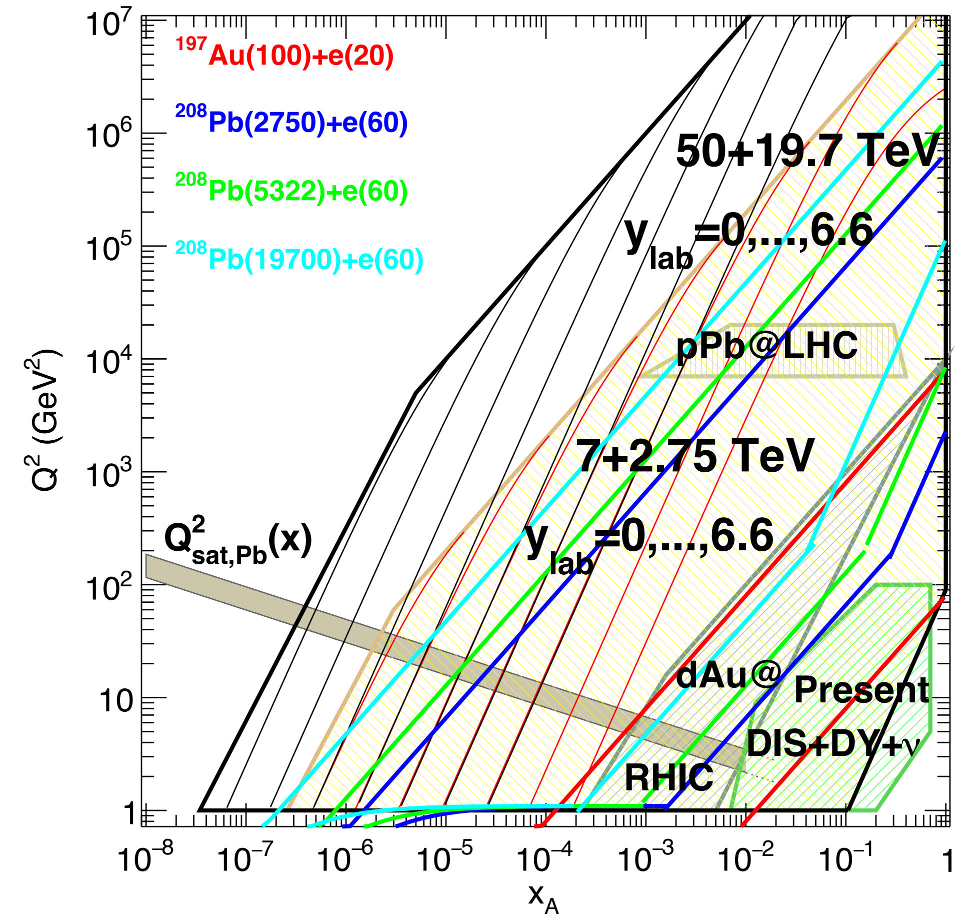

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Personal view!!!

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Timelines:

➜ Disclaimer: train timelines are written only to show how late trains arrive (Herwig Schopper);

➜ Warning: they may contain traces of politics.

Q^2 (GeV^2)

x_A

2019 → LS4 (2030)	LS4 → End of the LHC (2037)		Beyond LHC
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		pp/pA/AA, lighter ions?, & ep/eA?	

Personal view!!!

Summary:

Many thanks to:

➜ My HL-LHC, FCC-AA, LHeC/FCC-eh (and EIC) colleagues for discussions and the opportunity to work with them;

➜ A. Dainese, M. Klein, G. Milhano, C.A. Salgado and M.Winn for comments;

➜ The organisers for the invitation to provide this talk;

➜ You all for your attention.

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Personal view!!!

Backup:

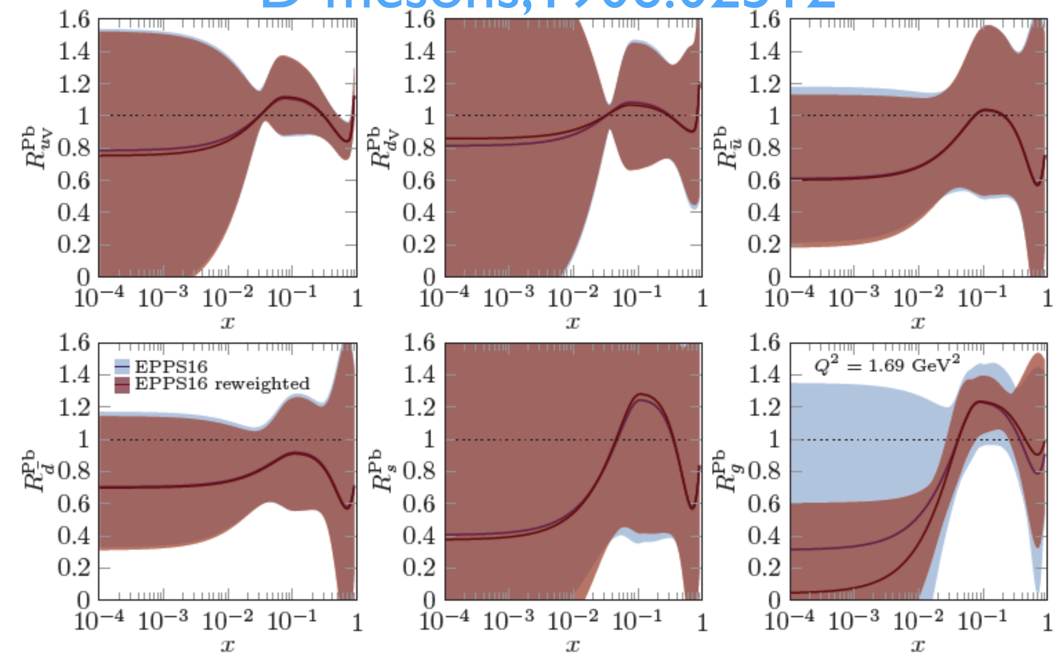
Status of nPDFs:

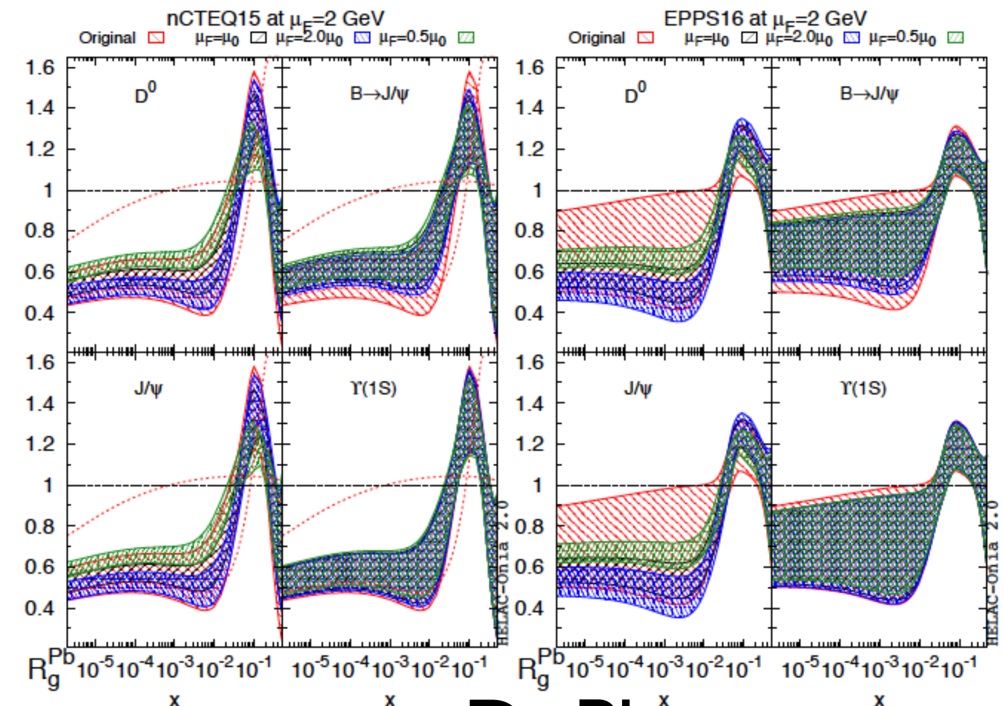
SET		EPS09 JHEP 0904 (2009) 065	DSSZ PRD85 (2012) 074028	nCTEQ15 PRD93 (2016) 085037	KA15 PRD93 (2016) 014036	EPPS16 EPJC77 (2017)163	nNNPDF1.0 EPJC79 (2019) 471
data	eDIS	✔	✔	✔	✔	✔	✔
	DY	✔	✔	✔	✔	✔	✘
	π^0	✔	✔	✔	✘	✔	✘
	νDIS	✘	✔	✘	✘	✔	✘
	pPb	✘	✘	✘	✘	✔	✘
# data		929	1579	740	1479	1811	451
order		NLO	NLO	NLO	NNLO	NLO	NNLO
proton PDF		CTEQ6.1	MSTW2008	~CTEQ6.1	JR09	CT14NLO	NNPDF3.1
mass scheme		ZM-VFNS	GM-VFNS	GM-VFNS	ZM-VFNS	GM-VFNS	FONLL-B
comments		$\Delta\chi^2$=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	NNPDF methodology, isoscalarity assumed

nPDF studies now:

- Theoretical control in PT over forward D or J/ψ under debate: scales, DPS, non-linear dynamics,… E.g. quarkonium: superposition of nPDFs + eloss/absorption + comovers for ψ', …
- Collectivity (flow for D and J/ψ as in charged hadrons in pPb and PbPb) would limit the use of low p_T data for extraction of nPDFs.
- UPCs offer possibilities for constraining both nPDFs: first indication of nuclear shadowing (talk by J. Seger).

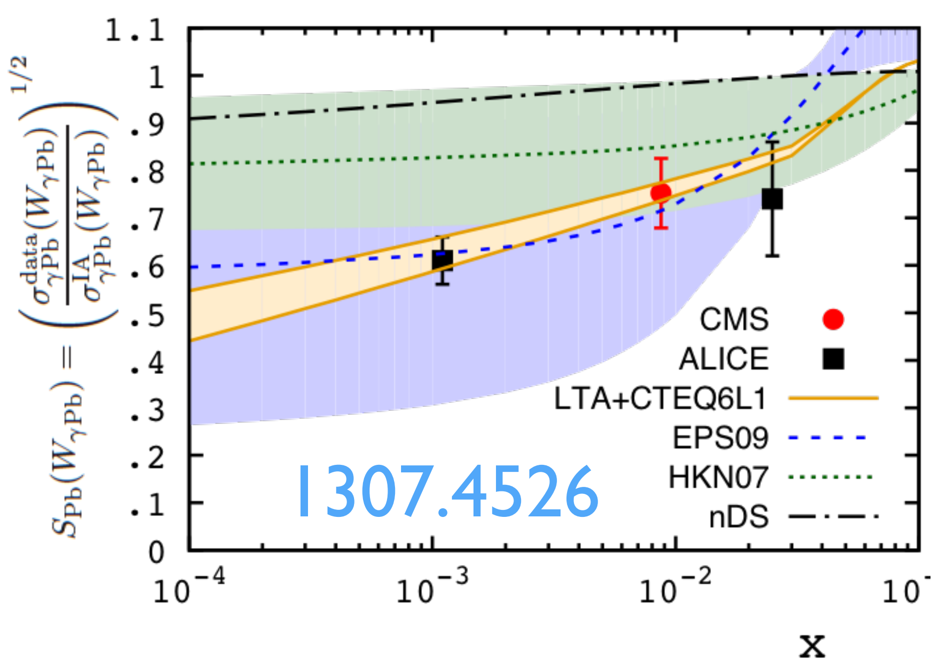
D mesons, 1906.02512

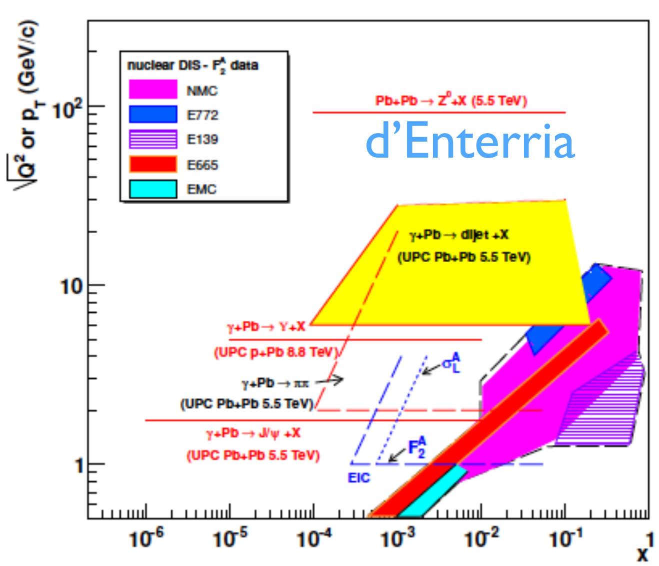




1712.07024

R_g^{Pb}





Talks by N. Valle, M. Dumancic, E. Chapon, S. Hayashi, M. Faggin, A. Bylinkin, I. B. Sanjuan, Y. Kim, N. Fomin, M. Rybar, S. Yang, Z. Chen,…

Correlations in eA/pA (II):

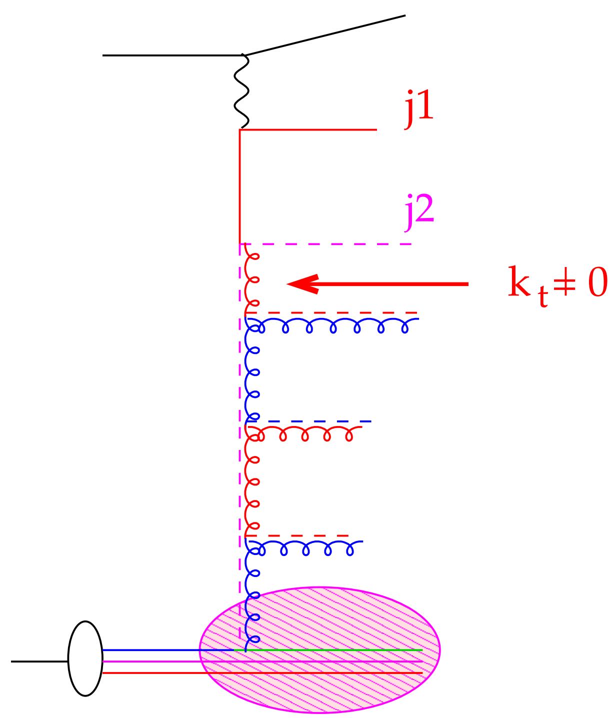
- Studying dijet azimuthal decorrelation or forward jets ($p_T \sim Q$) in ep/eA/pp/pAwould allow to understand the mechanism of radiation:

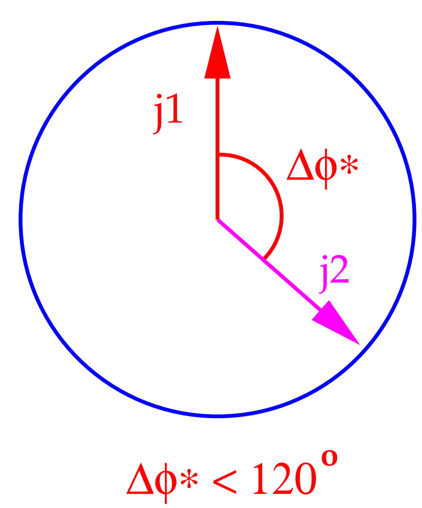
➜ k_T-ordered: DGLAP.

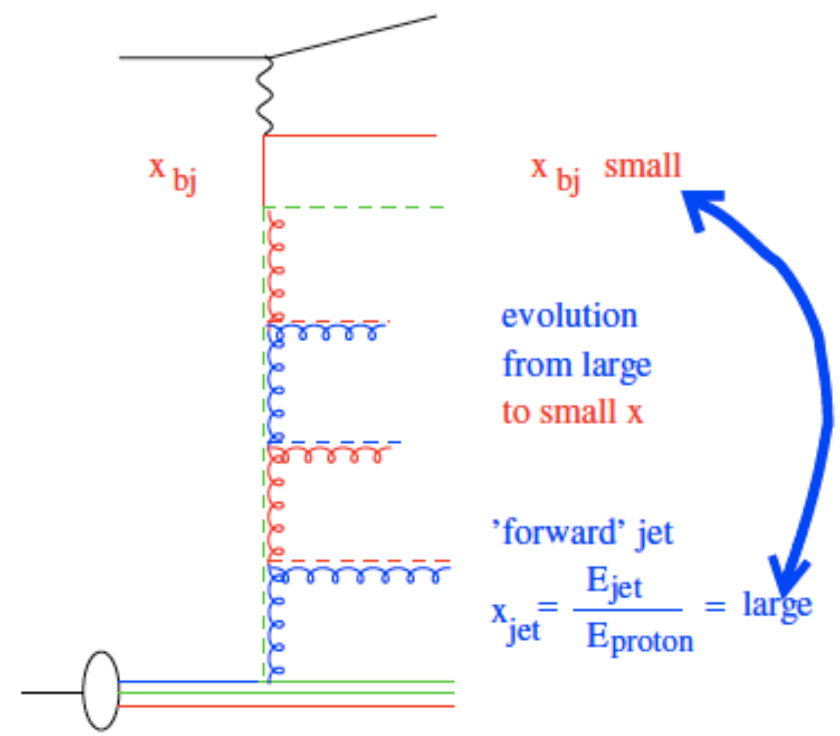
➜ k_T-disordered: BFKL.

➜ Saturation?

- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.







- **Nuclear and saturation effects on usual BFKL signals** (e.g. dijet azimuthal decorrelation, Mueller-Navelet jets) has not been extensively addressed: A-dependence contrary to linear resummation?