LHC and EIC synergies

19 December 2023

Michael Pitt

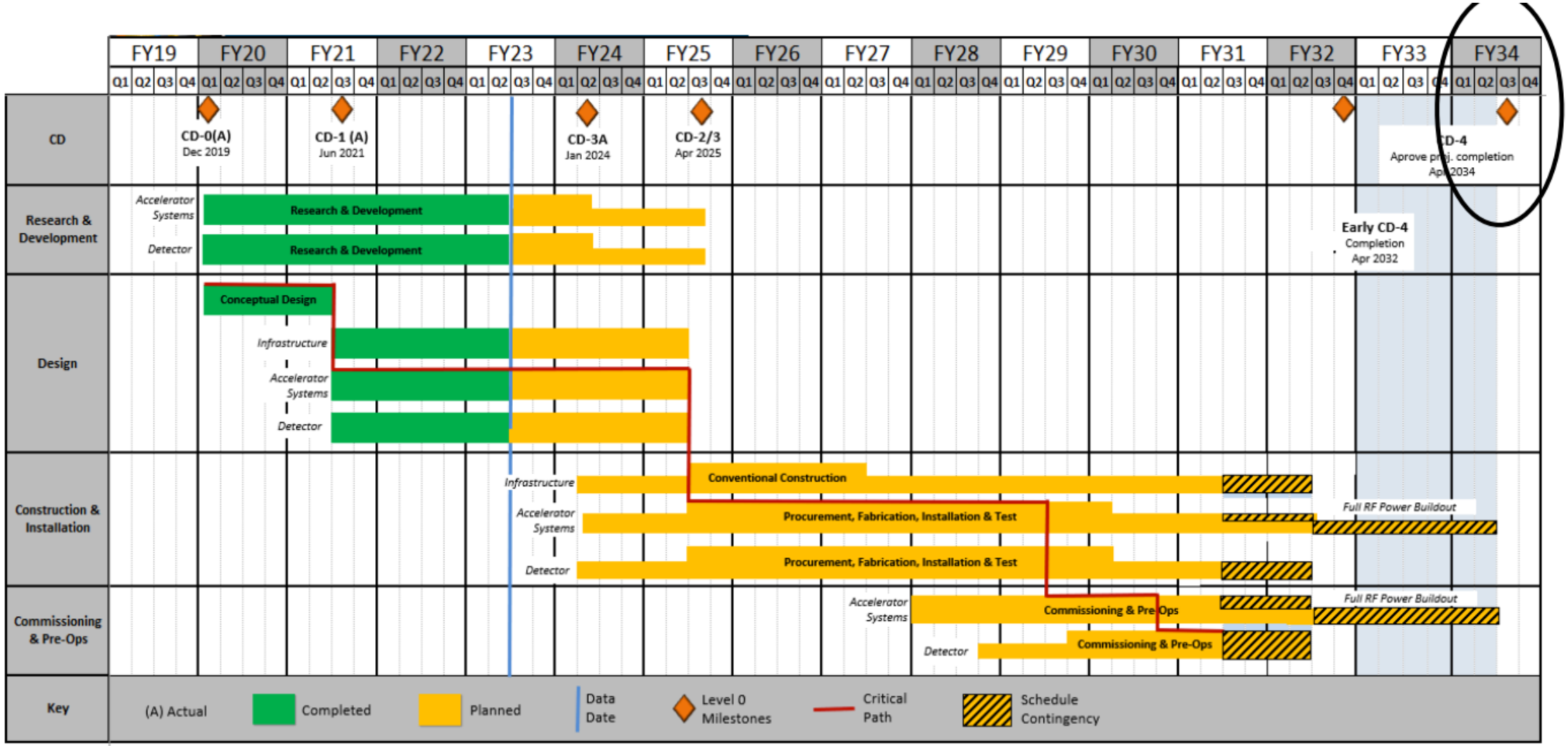
Based on the material form a dedicated workshop:
Join ECFA-NuPECC-APPEC Activity workshop "Synergies between the EIC and the LHC"
Dec 14-15, 2023, DESY, Hamburg (https://indico.desy.de/event/41404/)

Outline

Several common topics were discussed at the WS, I will mention a few selected:

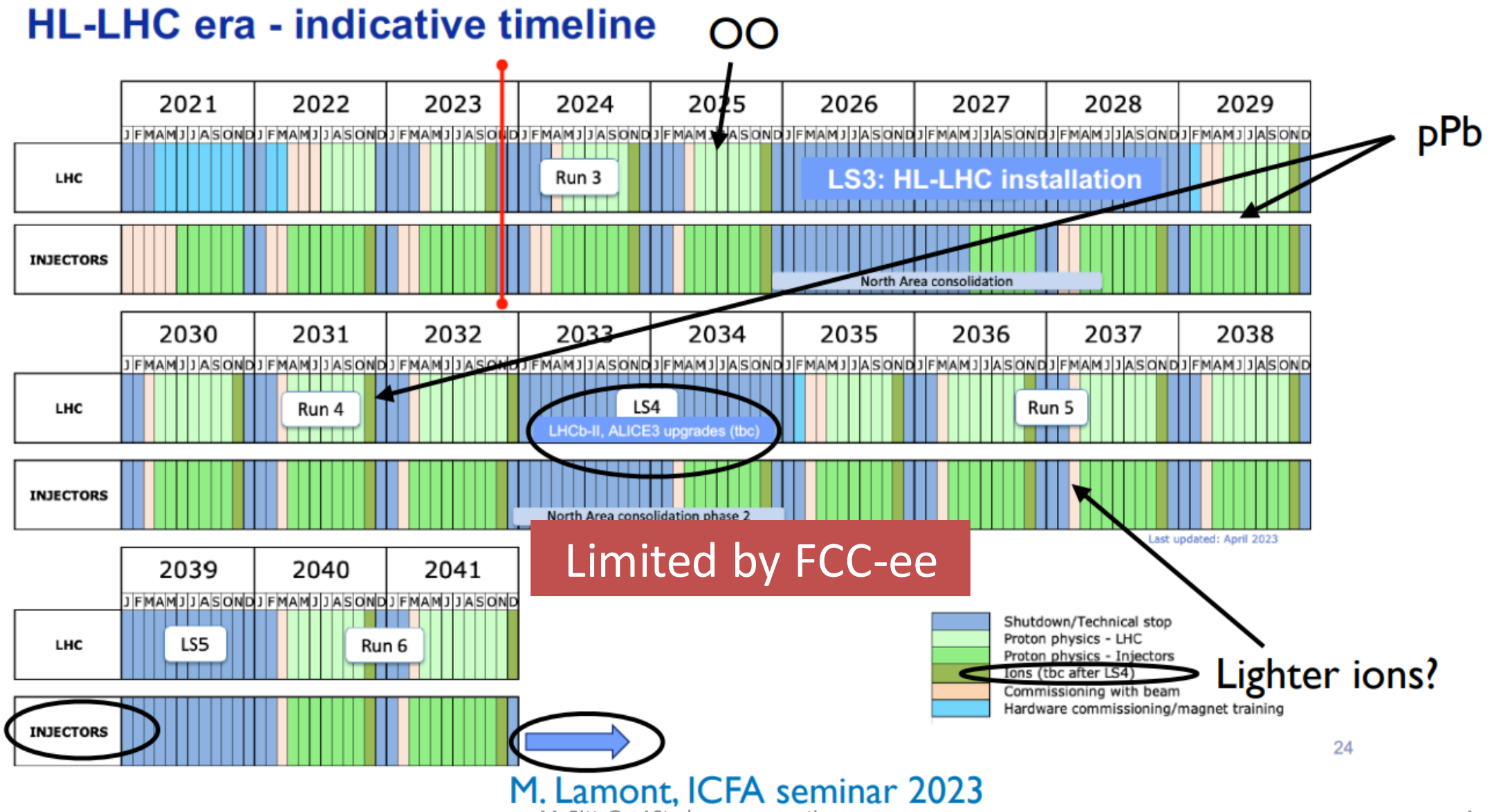
- Timelines
- Proton PDFs
- Energy-energy correlators
- 3D structure and diffraction
- ~~Impact of diffractive processes: from accelerator experiments to UHECRs~~
- ~~BSM physics~~

EIC Timeline



F. Willeke, ICFA seminar 2023

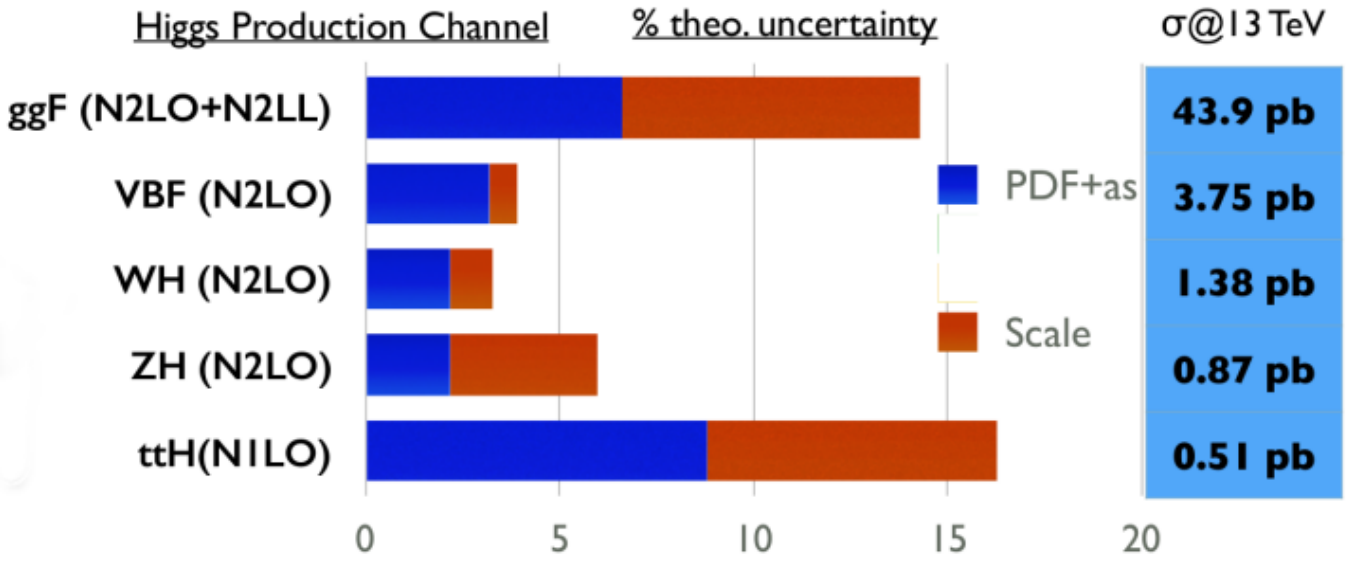
LHC Timeline



Proton PDF

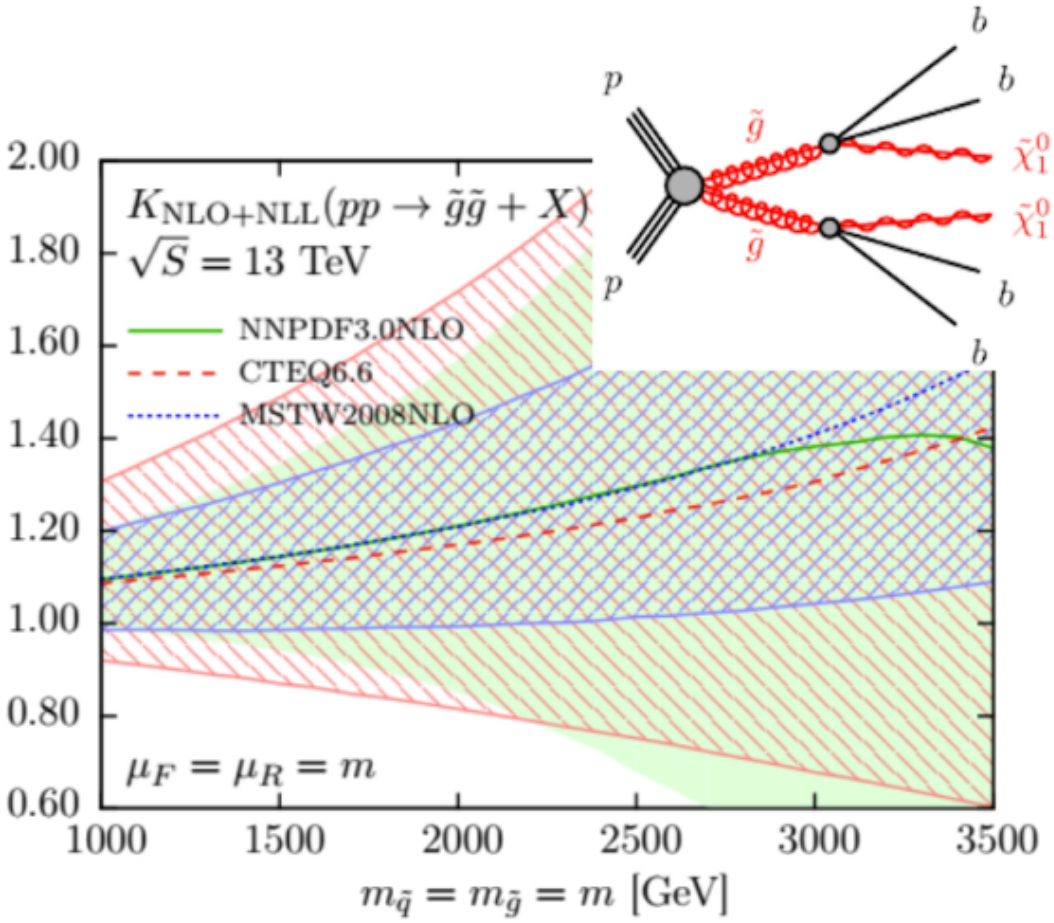
Motivation (LHC perspective):

Precision



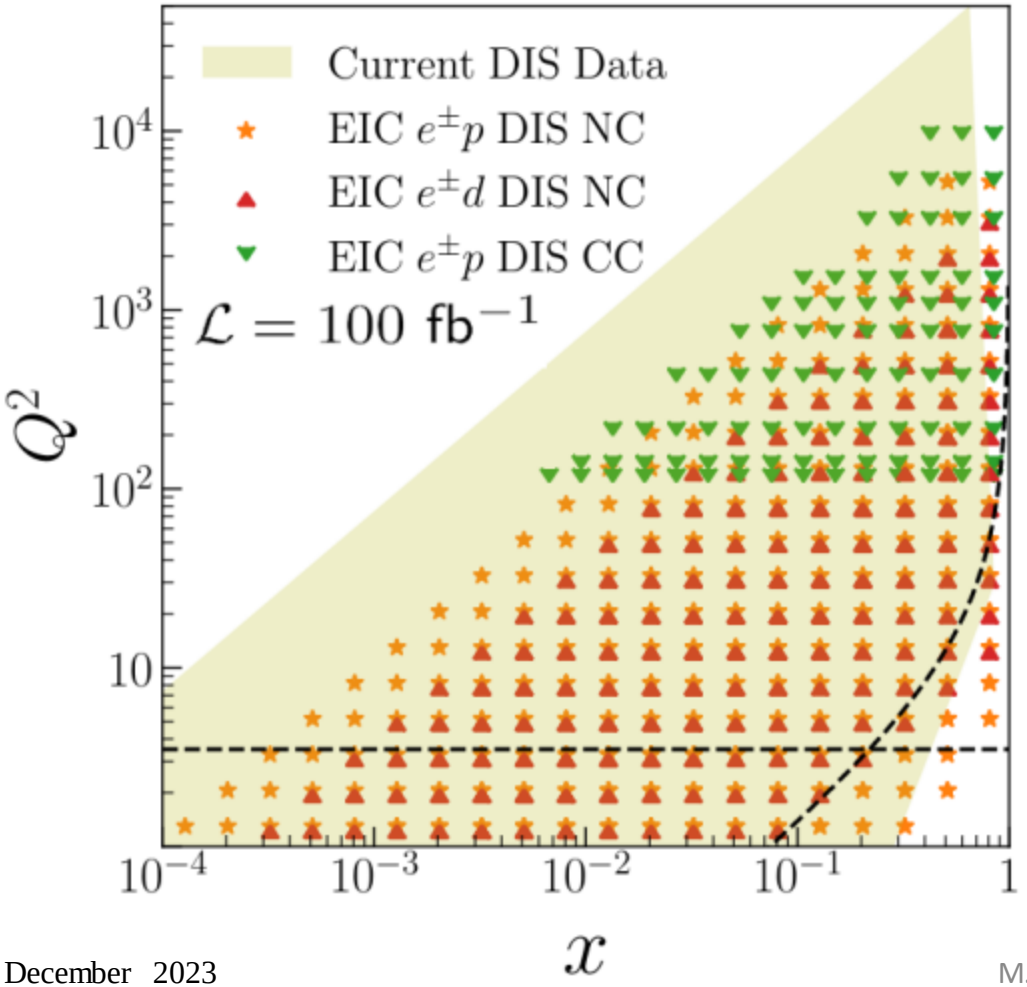
Channel	$m_{W^+} - m_{W^-}$ [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W \to e\nu$	−29.7	17.5	0.0	4.9	0.9	5.4	0.5	0.0	24.1	30.7
$W \to \mu\nu$	−28.6	16.3	11.7	0.0	1.1	5.0	0.4	0.0	26.0	33.2
Combined	−29.2	12.8	3.3	4.1	1.0	4.5	0.4	0.0	23.9	28.0

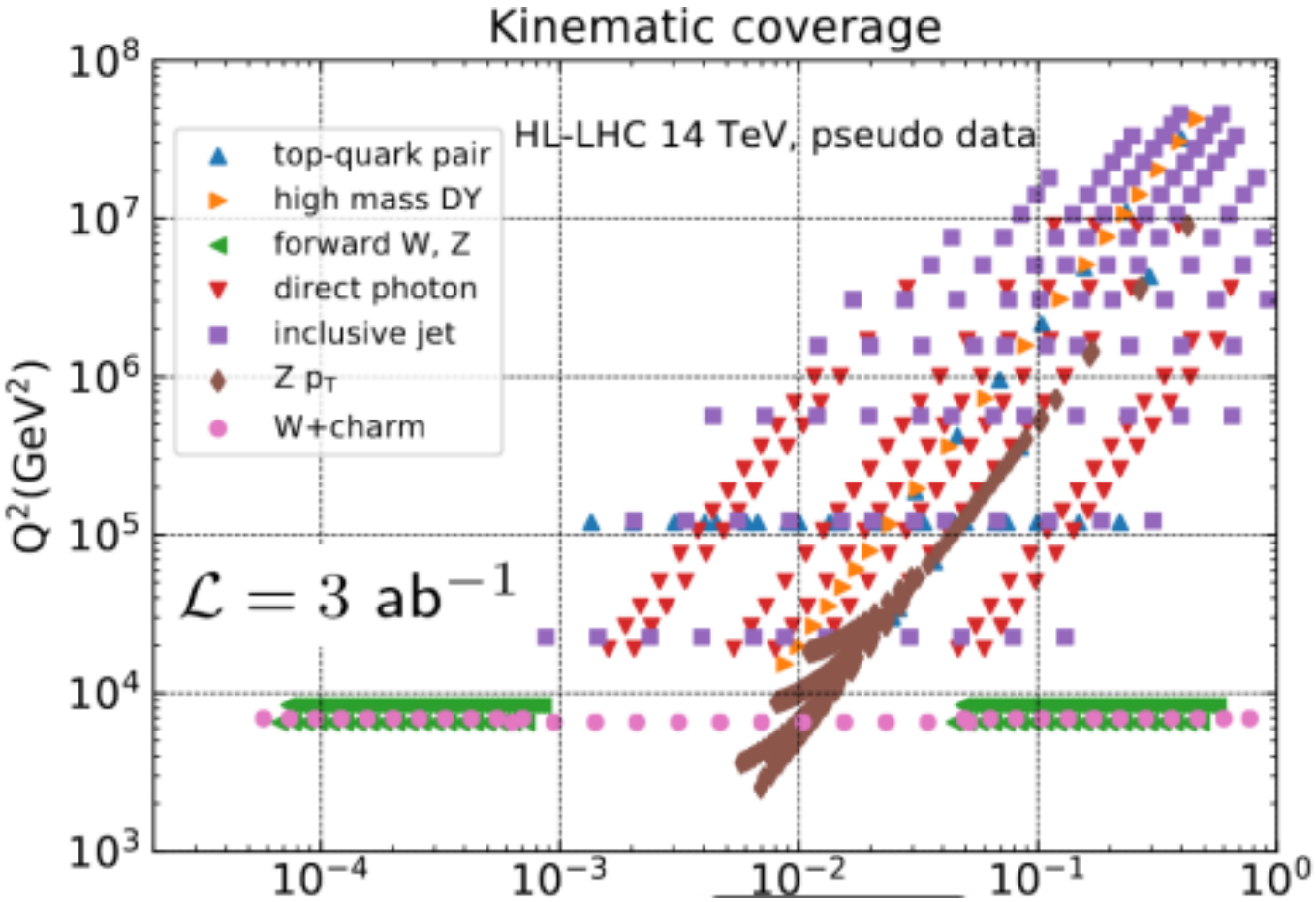
Discovery



Proton PDF (future)

- aN^{3}LO QCD corrections for PDF within the NNPDF framework was discussed.
- Projections for EIC and HL-LHC were shown





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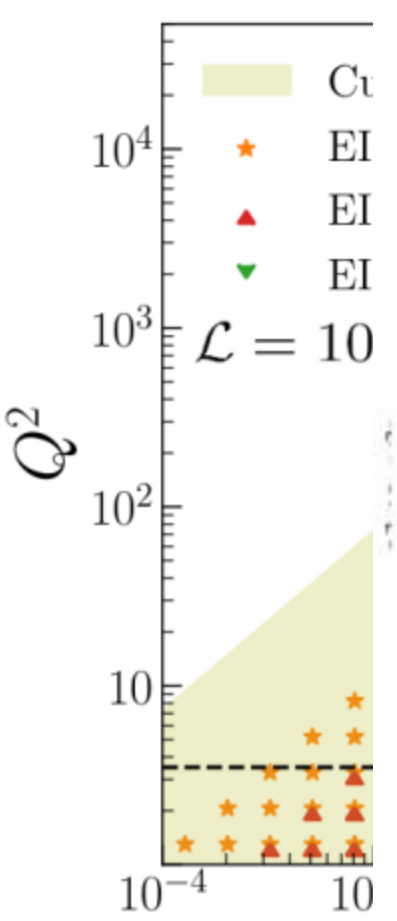
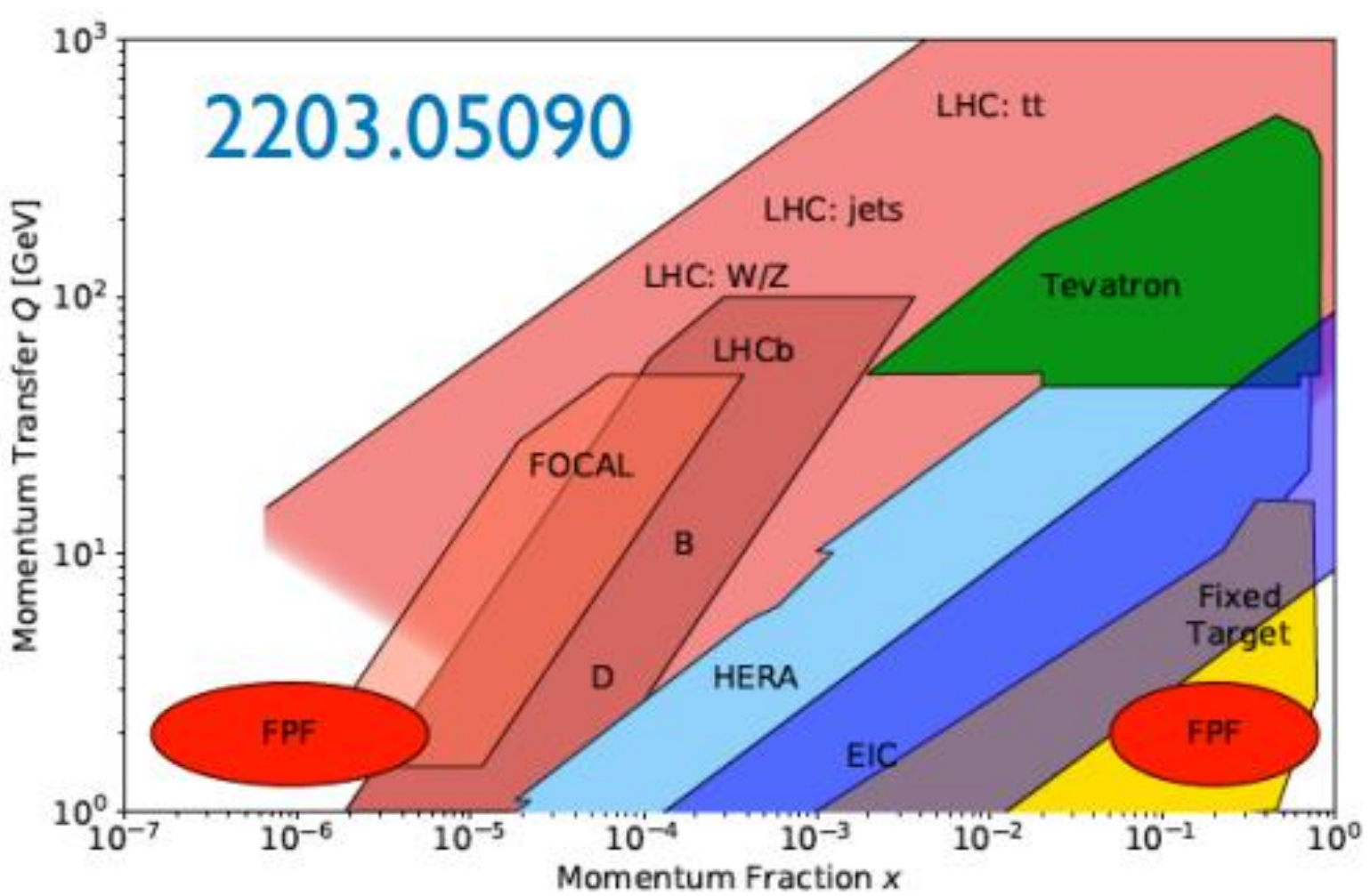
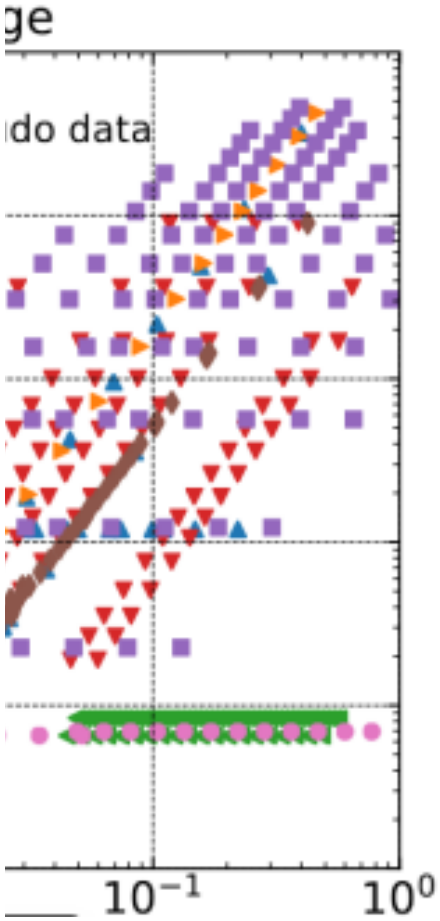
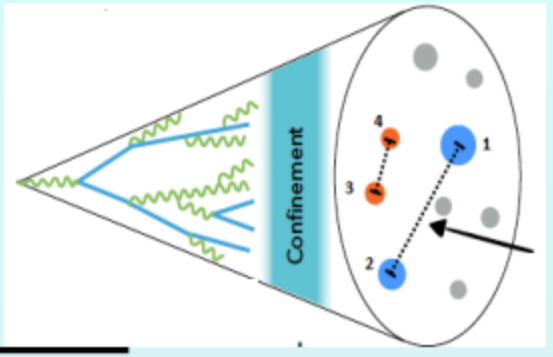






Energy-energy correlators

- QCD shower evolution, used to extract αS
- First measured in LEP (proposed in 1978)



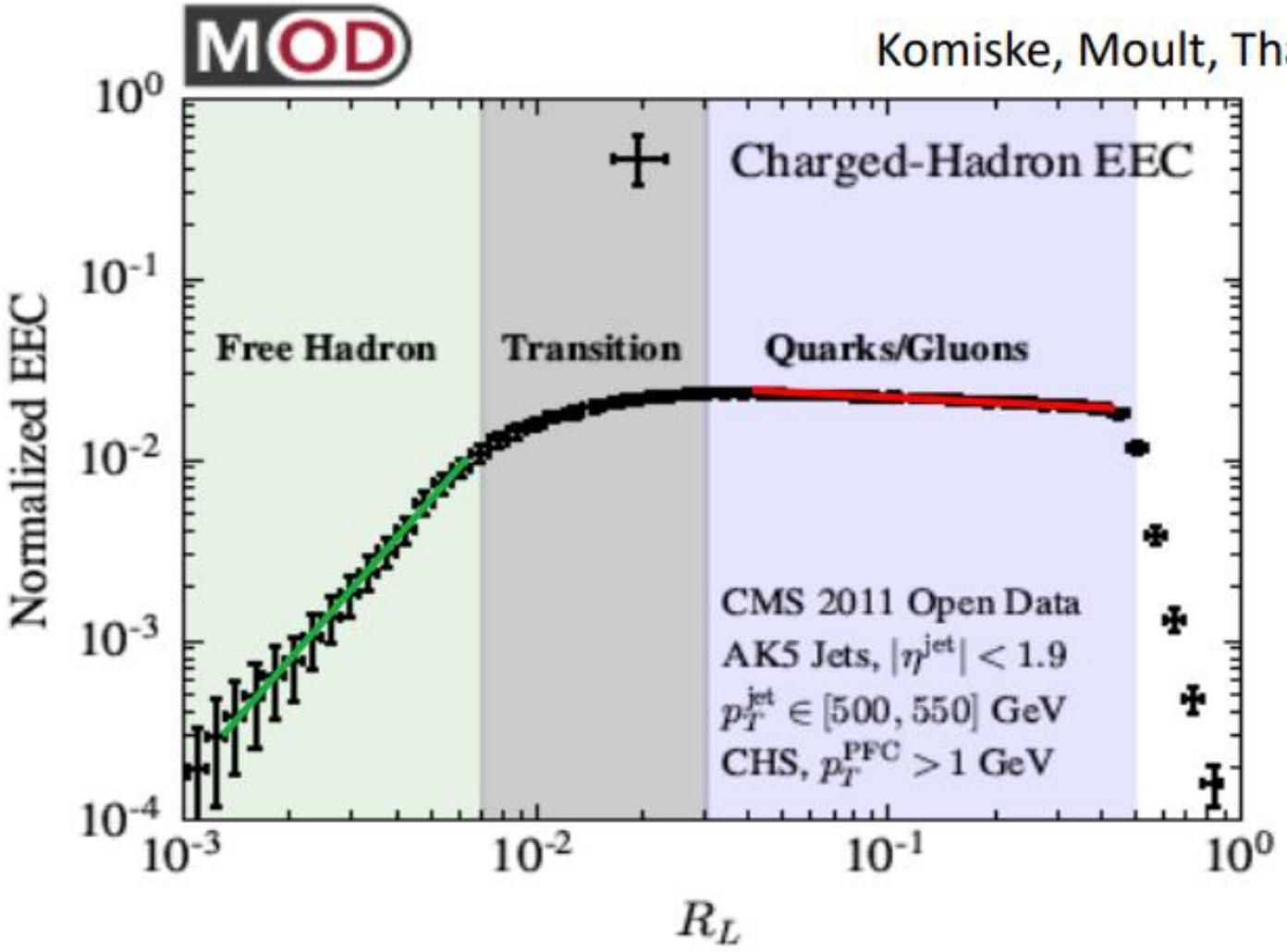
- **Experimentally, sum over all hadron pairs in jet:**

$$EEC(R_L) = \sum_{pairs} \frac{p_{T1}\, p_{T2}}{p_{T,jet}^2} \text{ with } R_L = \sqrt[2]{\Delta\varphi^2 + \Delta\eta^2}$$

- **Two-particle correlation function, weighted by $p_{T,\,hadron}/p_{T,jet}$; plot vs. angular distance, R_L**

Energy-energy correlators

- CMS open data used in EEC analysis



Exchanged $p_T \sim p_{Tjet} \times R_L$ (Q of hard process)

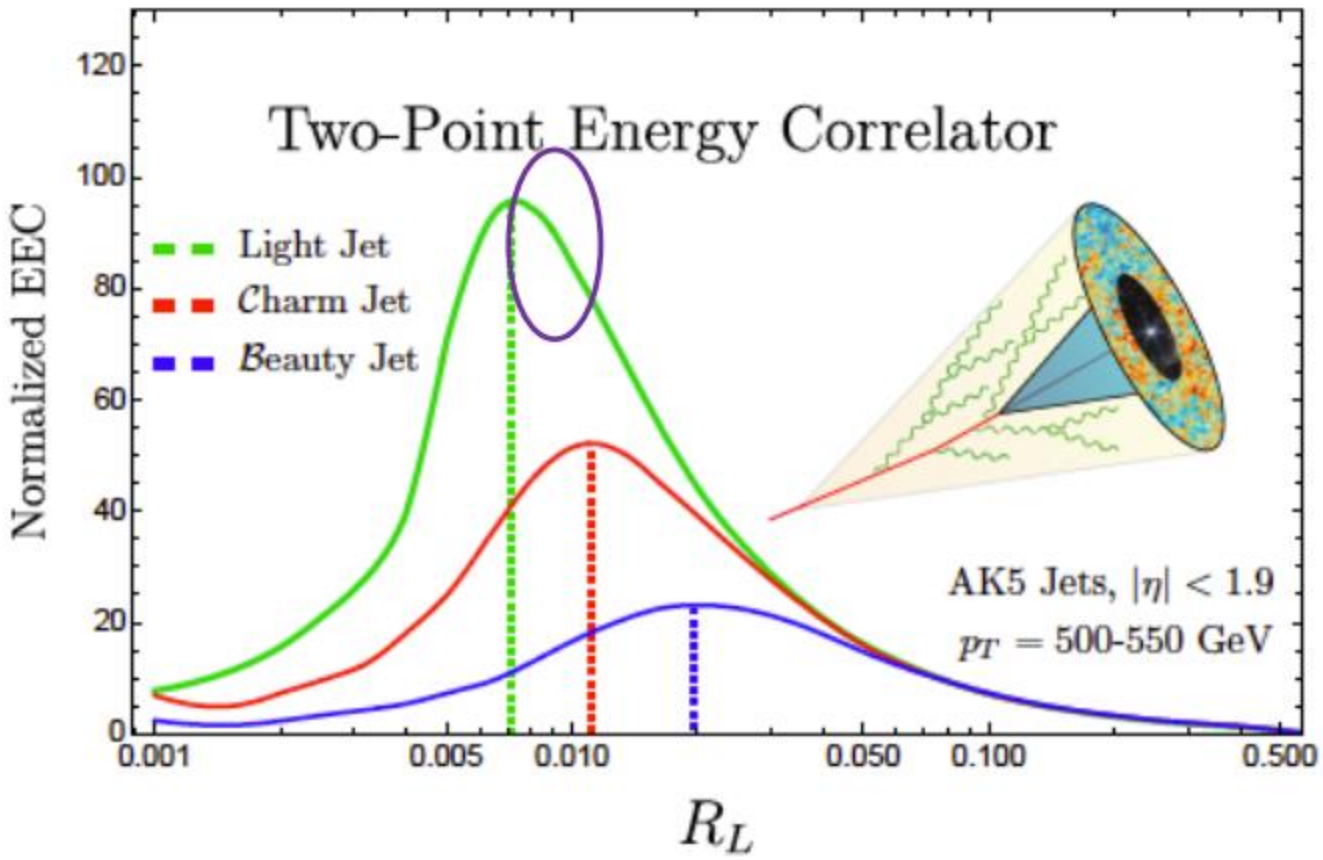
$$R_L = \sqrt[2]{\Delta\varphi^2 + \Delta\eta^2}$$

500 GeV jets

Energy-energy correlators

- "Dead" phasespace cone angle (dead cone)

Craft, Lee, Mecaj, Moult arXiv:2210.09311



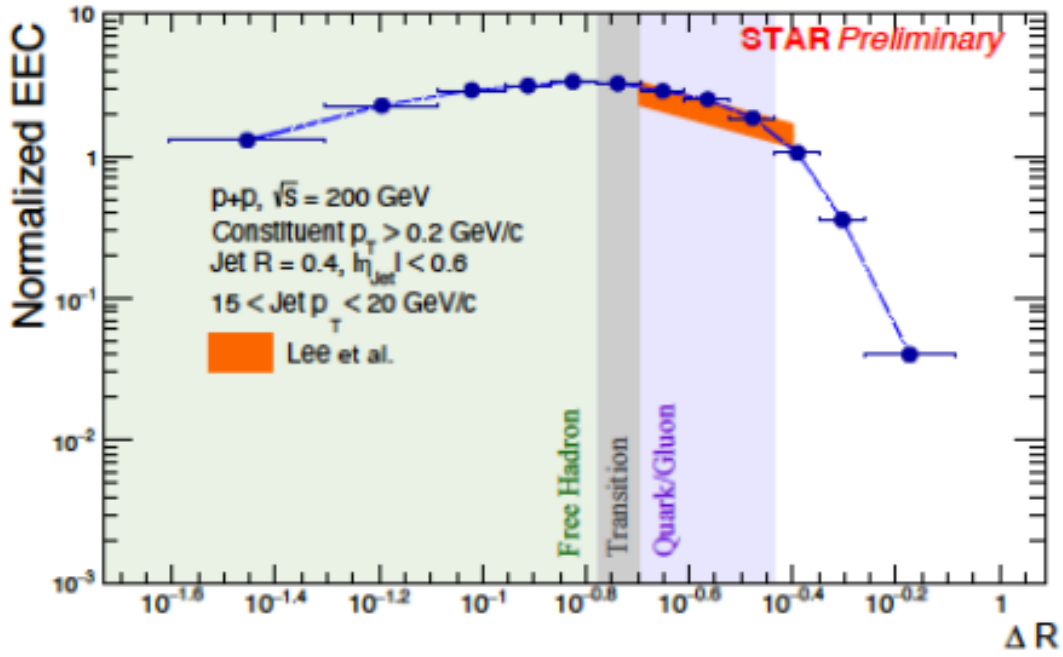
Small angle partonic splittings should be missing

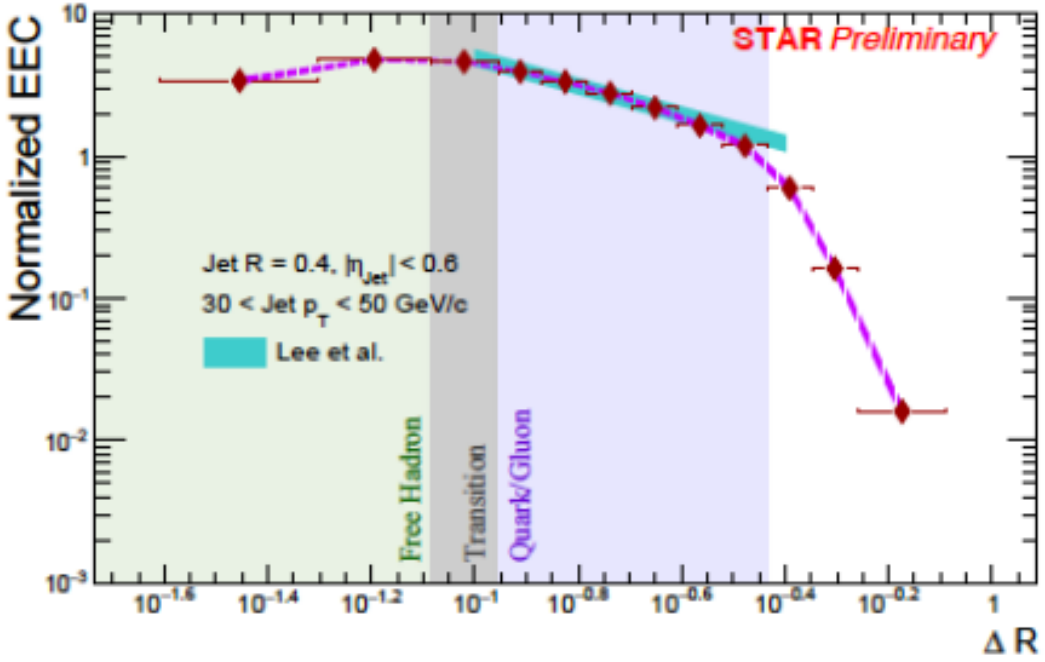
Energy-energy correlators

- Measured in RHIC

Similar results in 200 GeV pp at RHIC

arXiv:2309.05761

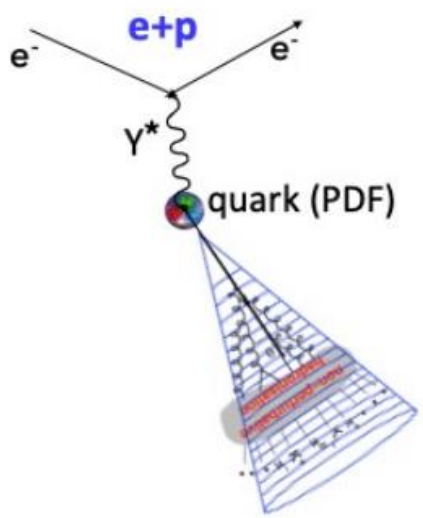


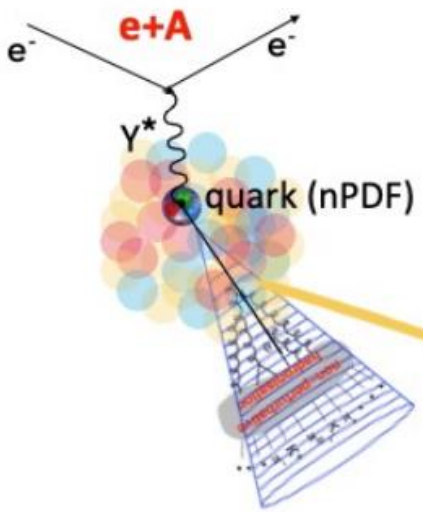


Energy-energy correlators

Study e+p and e+A collisions with eHIJING event generator

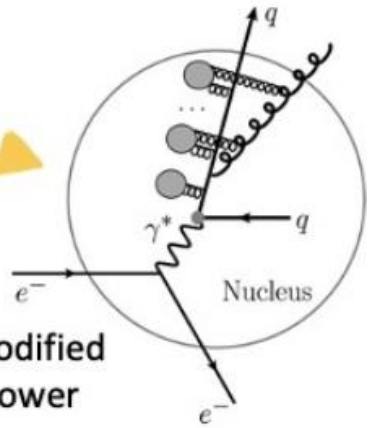
- eHIJING: developed to study nuclear-modified jet evolution in DIS events
  - e+p: equivalent to Pythia 8
  - e+A: initial DIS process via Pythia 8 + medium modified parton shower (p_T broadening via multiple collisions and medium induced parton splitting)
  - Default setup benchmarked to HERMES results





HIJING

arXiv:2304.10779 (W. Ke, Y. He, X-N Wang, H-X Xing, Y Zhang)



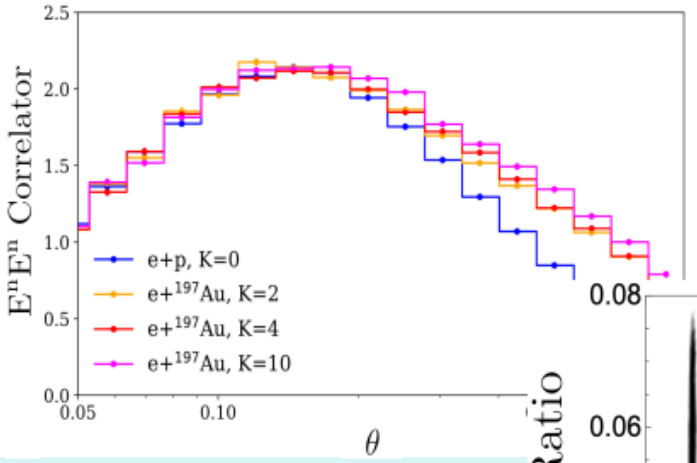
Medium modified parton shower

05/16/2023 Wenqing Fan — HIT seminar

Energy-energy correlators

Cold nuclear matter A-dependence

Increasing $\tau \sim 1/p_T\theta^2$



$\theta_L \sim 1/(p_T L)^{1/2} \sim 1/(p_T A^{1/3})^{1/2}$

$$\frac{\langle \mathcal{E}^n\mathcal{E}^n\rangle_{e+^{197}\mathrm{Au}} - \langle \mathcal{E}^n\mathcal{E}^n\rangle_{e+p}}{\langle \mathcal{E}^n\mathcal{E}^n\rangle_{e+p}}$$

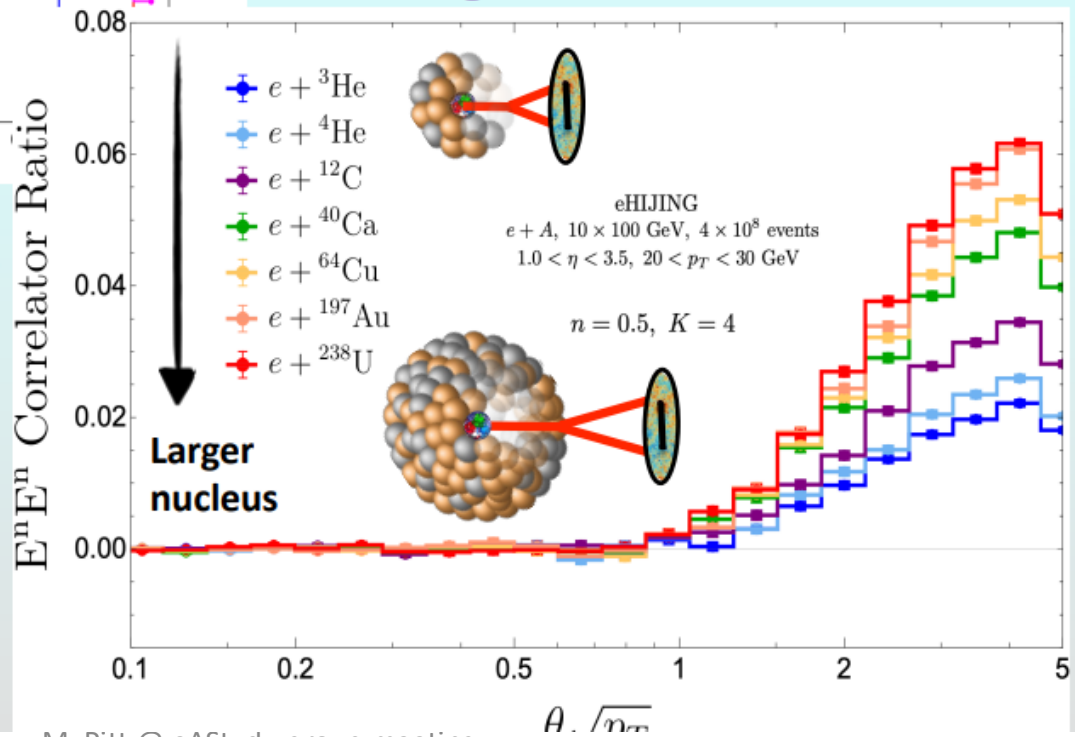
Again more early splittings induced by the medium

Devereaux, Fan, Ke, Lee, Moult arXiv:2303.08143

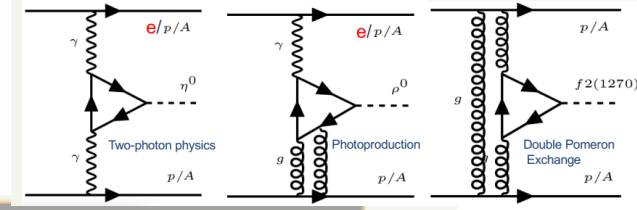
Jet R=1.0, as e+p/A is cleaner

Raise weight to power n=0.5 to enhance sensitivity to soft partons

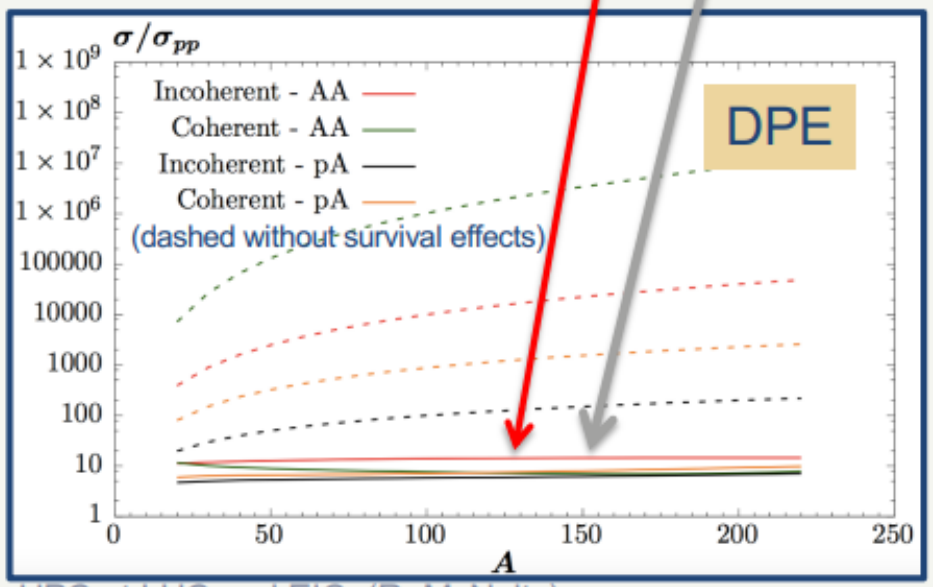
Medium-induced splitting & collisional broadening; little E loss

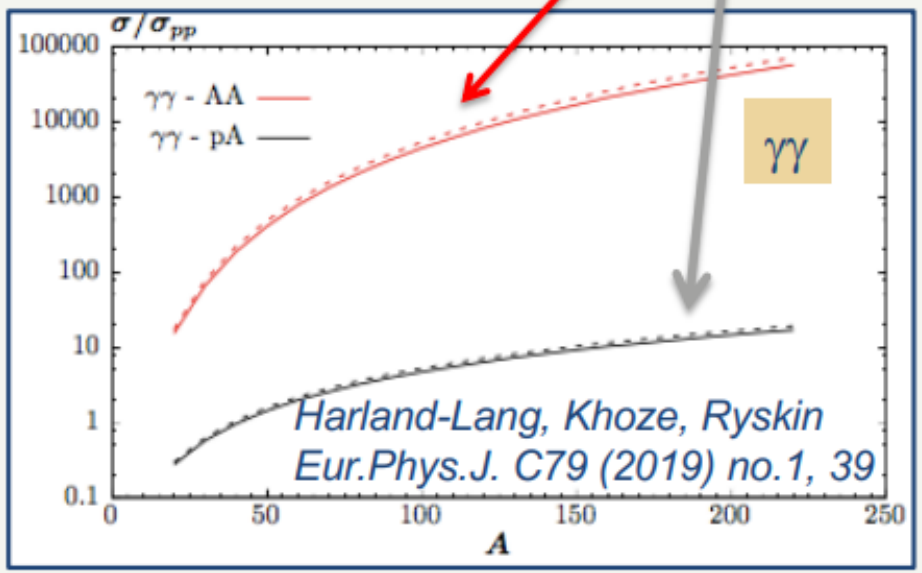


UPC at the LHC/EIC



Coherent	DPE (PP)	γP	γγ
pp	~100μb	~100μb	~0.0001μb
pA	x $A^{1/3}$	x Z^2	x Z^2
AA	x $A^{1/6}$	x AZ^2	x Z^4
eA	-	(A)	(AZ^2)



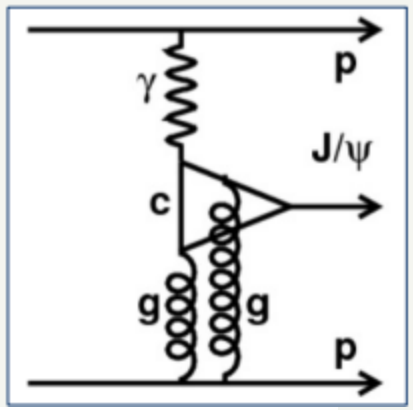


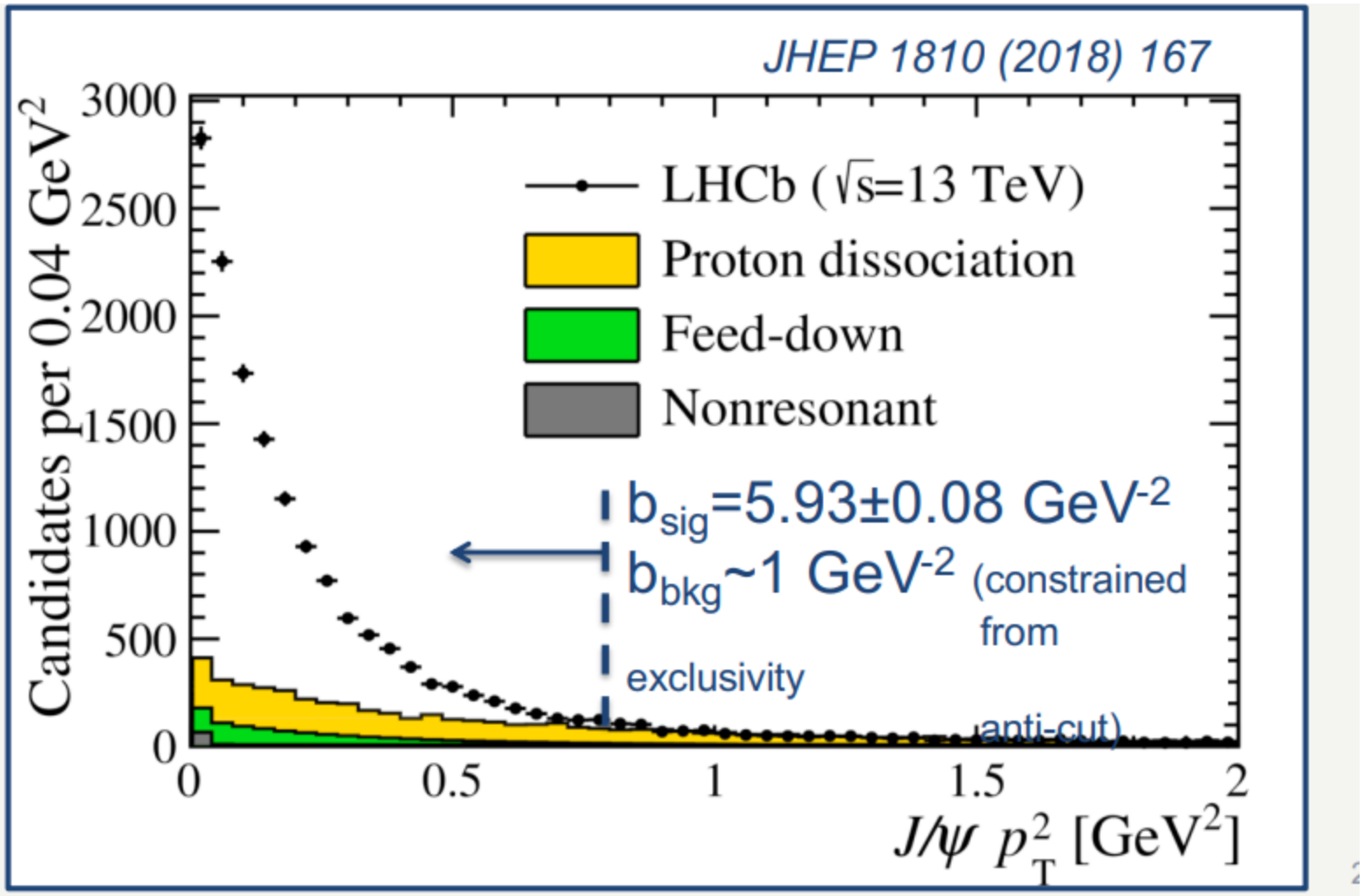
UPC at the LHC/EIC

- CEP of J/psi

Assume Signal and Background

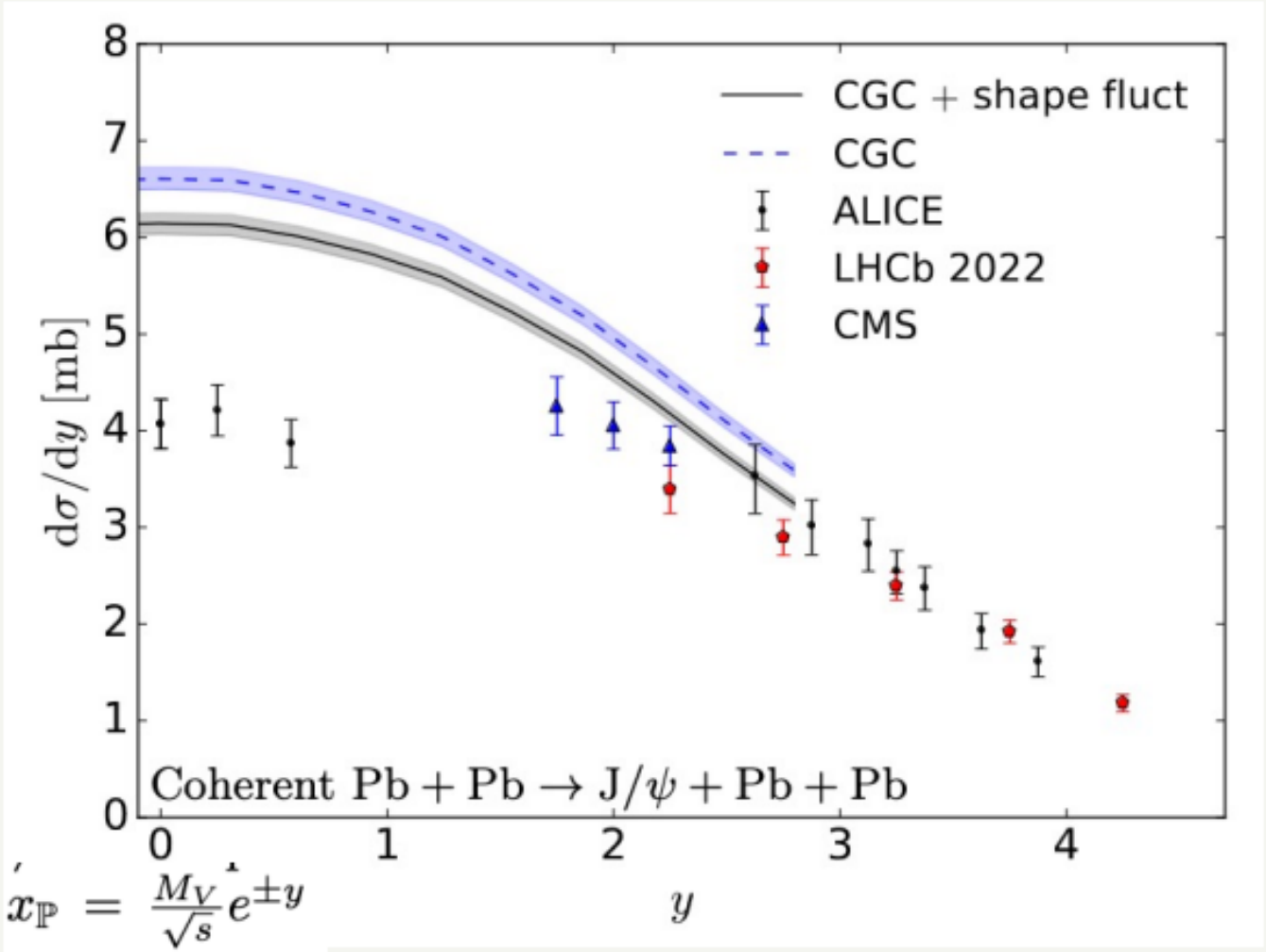
$$\frac{d\sigma}{dt} \sim e^{bt}$$





UPC at the LHC/EIC

- J/psi in PbPb

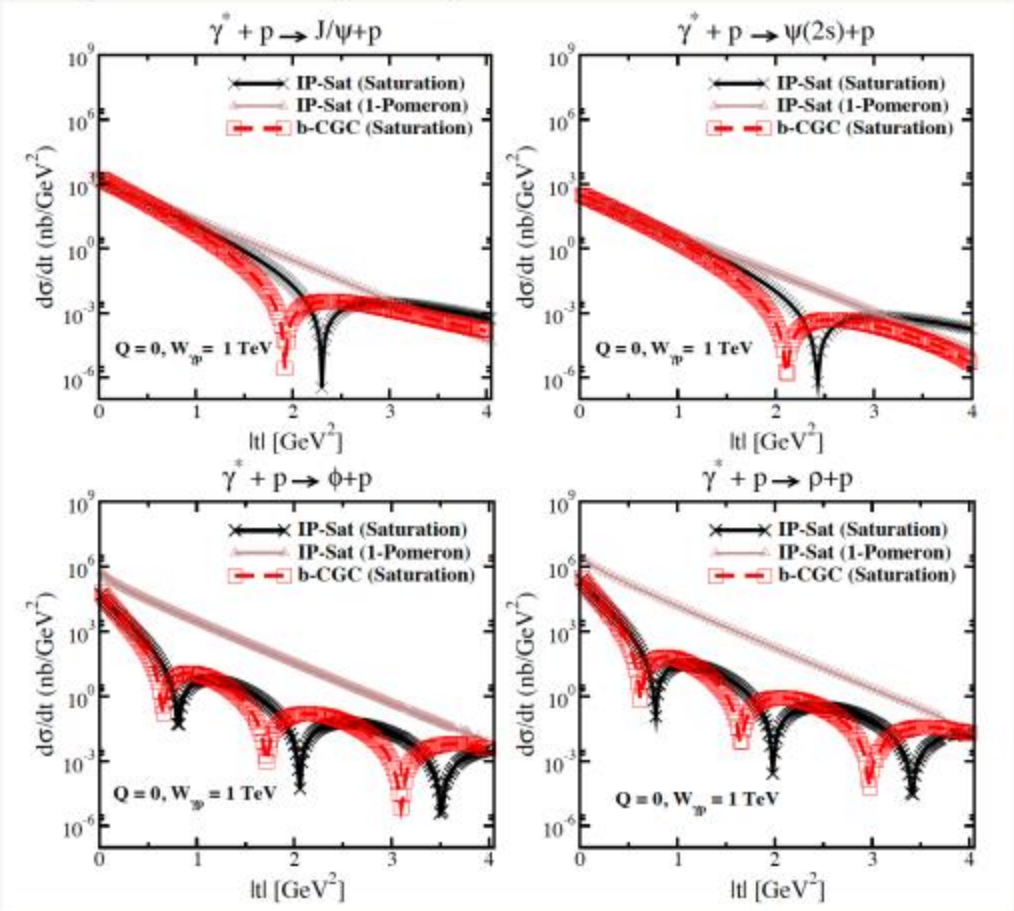


H. Mäntysaari, F. Salazar, B. Schenke: arXiv: 2312.04194

"We predict strong saturation-driven nuclear suppression at high energies, while LHC data prefers even stronger suppression."

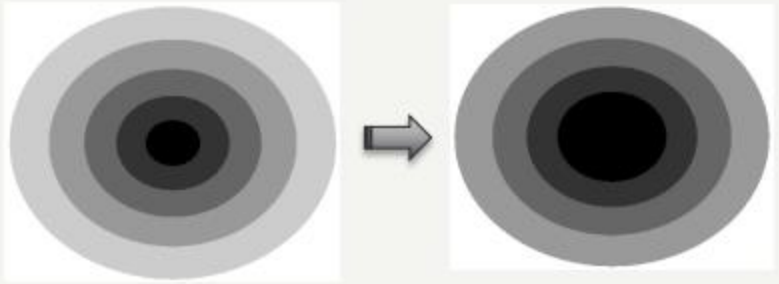
UPC at the LHC/EIC

N. Armesto & A. Rezaeien
Phys.Rev.D 90 (2014) 5, 054003



Experimentally tricky as incoherent reactions dominate at high-t

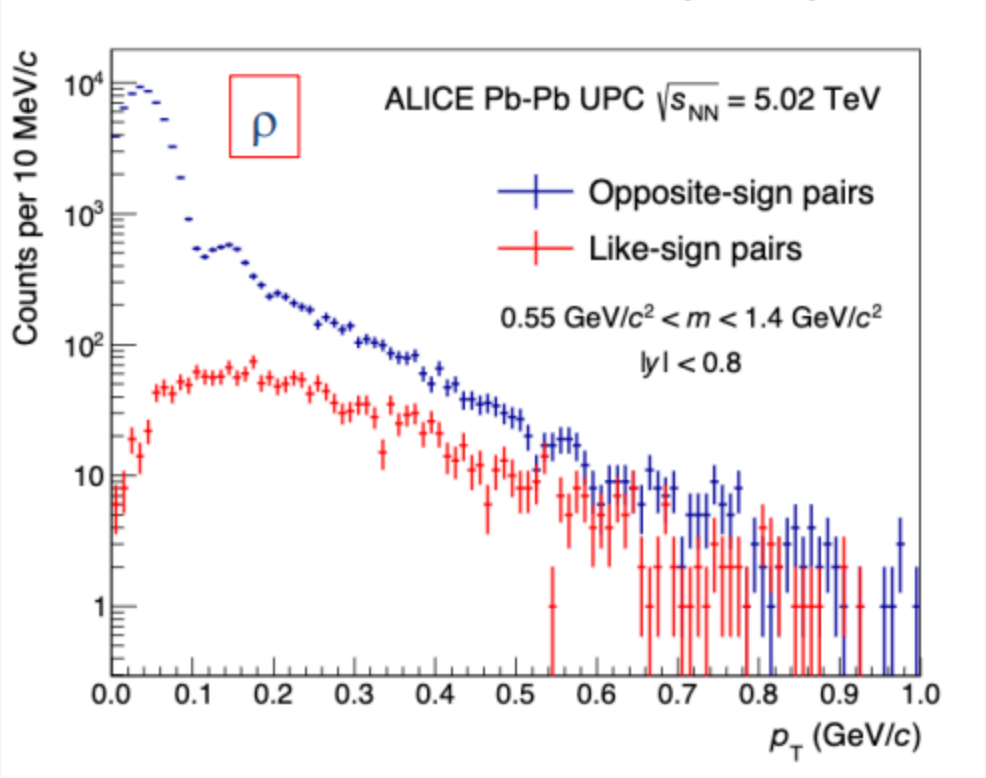
Presence of dips not necessarily evidence for saturation but non-linea models change dip position with W as you approach black-disk limit



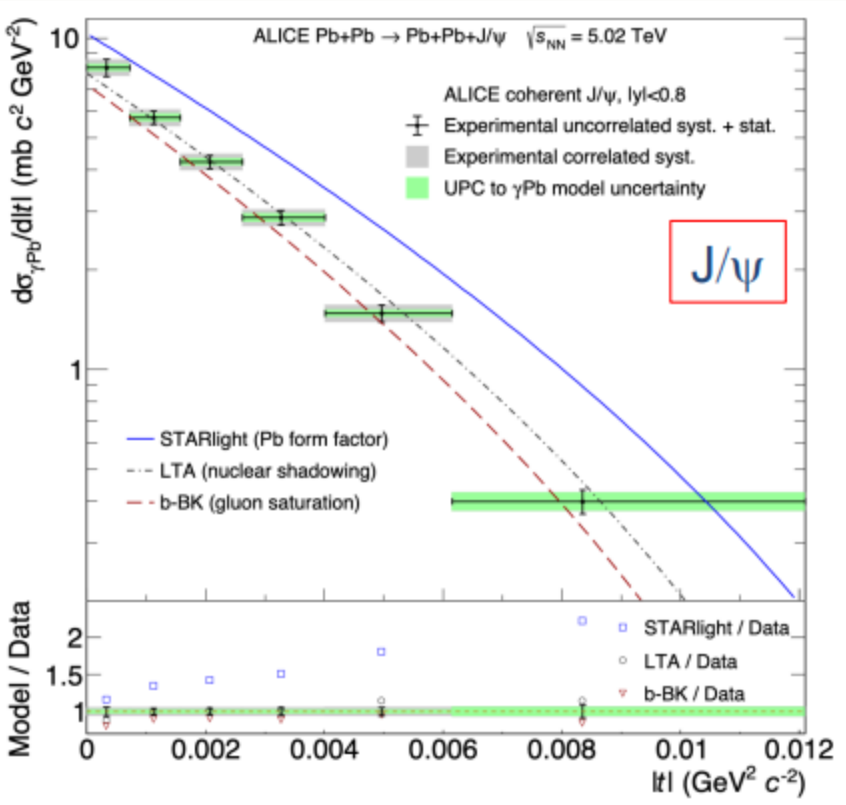
UPC at the LHC/EIC

First p_T measurements in UPC

JHEP 06 (2020) 035



Phys.Lett.B 817 (2021) 136280



coherent VM at the LHC/EIC

M. Pitt: https://indico.desy.de/event/41404/contributions/156398

Ongoing studies at EIC

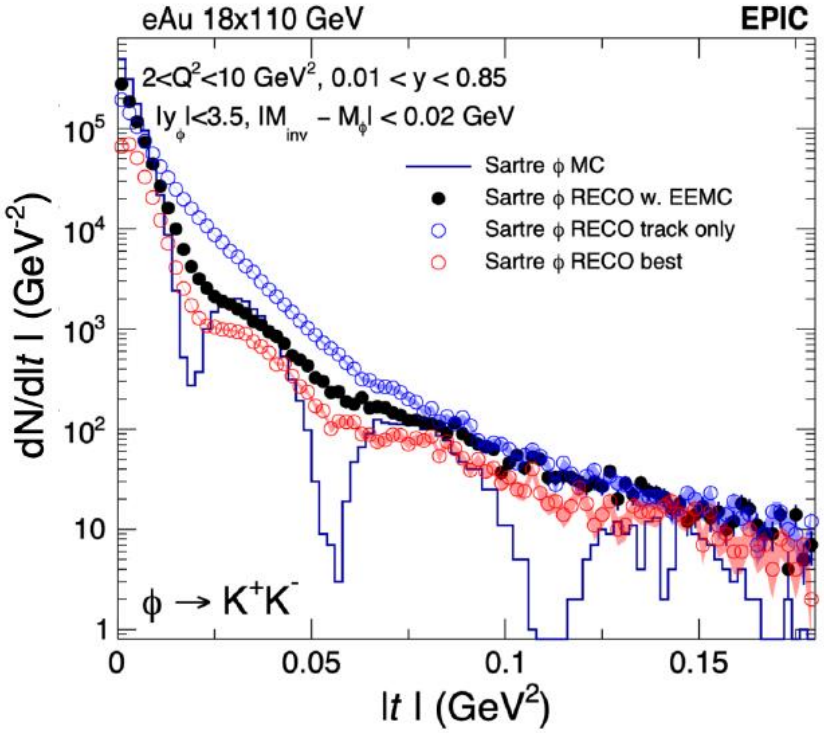
Nathaly Santiesteban @ First International Workshop on the Physics of UPC
https://indico.cern.ch/event/1263865/contributions/5667687/

- Challenges in measurements of exclusive J/ψ at the EIC

Main challenge is reconstructing the dips

Legend details:

- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (η, φ) K, from tracking
- Track only: all from tracking
- Best: average of 2 above



from S.Fazio talk

Other options:

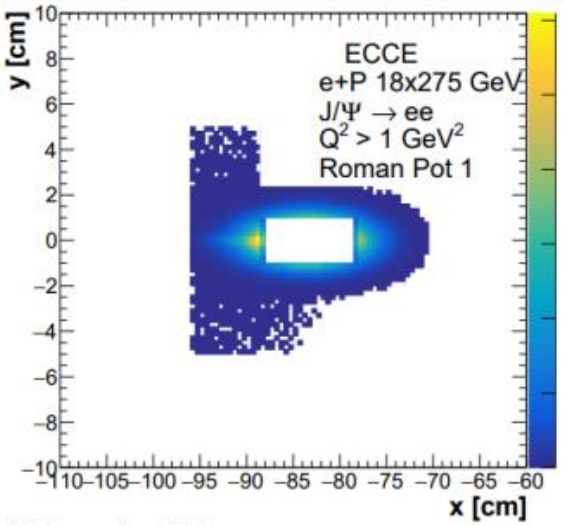
- Constrain electron kinematics using ion mass
- Low Q2 region

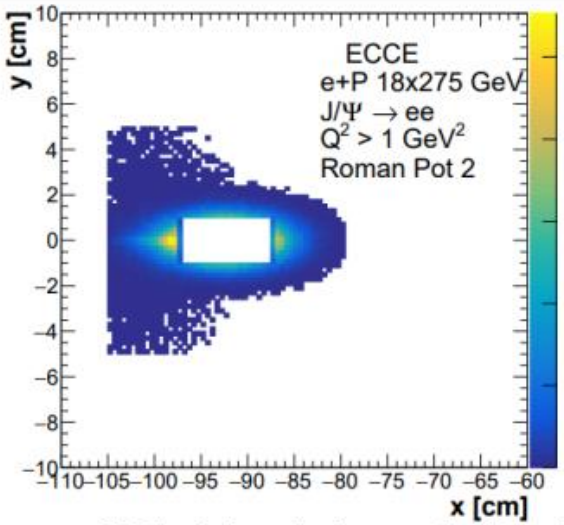
coherent VM at the LHC/EIC

M. Pitt: https://indico.desy.de/event/41404/contributions/156398

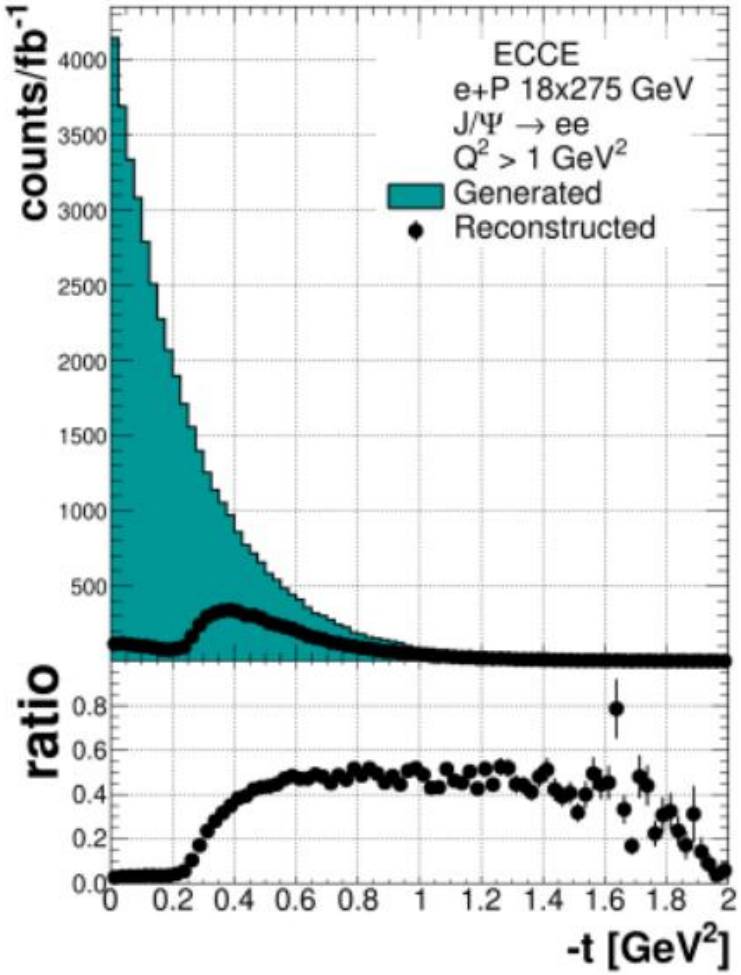
Exclusive VM production

- Q^2 is correlated with outgoing electron rapidity, and can be measured in the **central detector** for $Q^2 > 1$ GeV^2, ~~and using the low-Q taggers for $0.0001 < Q^2 < 0.01$~~
- Proton can be tagged by the Far-Forward detectors





15 December 2023 M. Pitt @ Synergies between the EIC and the LHC 12



coherent VM at the LHC/EIC

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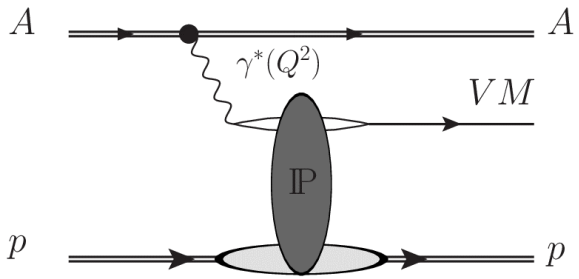
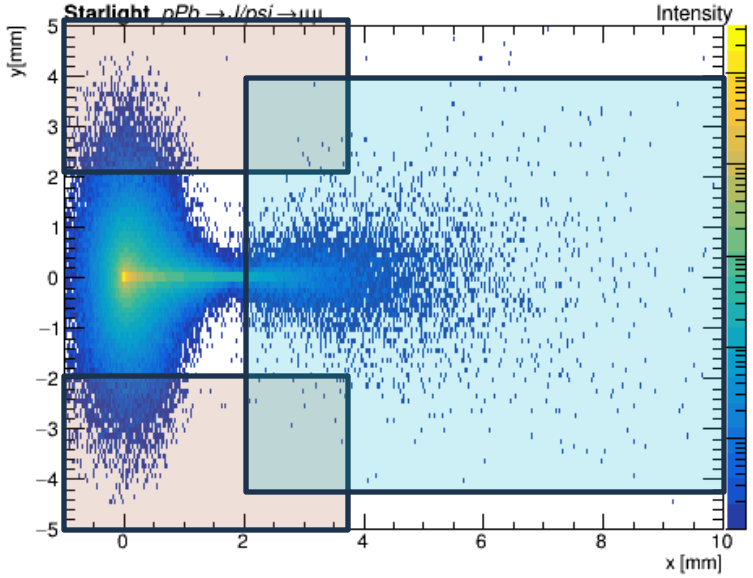
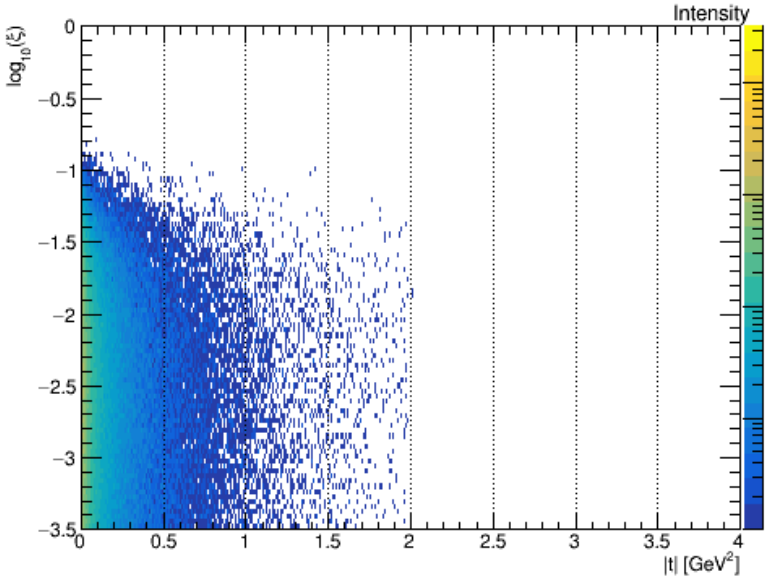
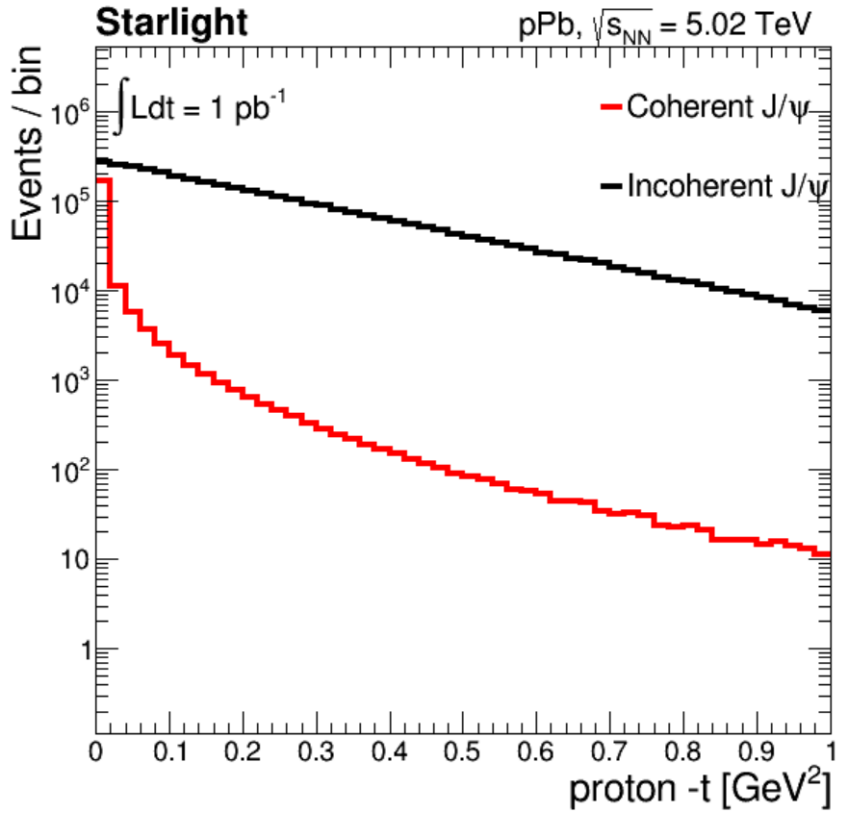


Exclusive VM production

- Vector mesons (Spin 1) are produced in $\gamma - IP$ interactions
- Ions emit a photon at Q2~0
- Incoherent cross-section dominates in the entire range







coherent VM at the LHC/EIC

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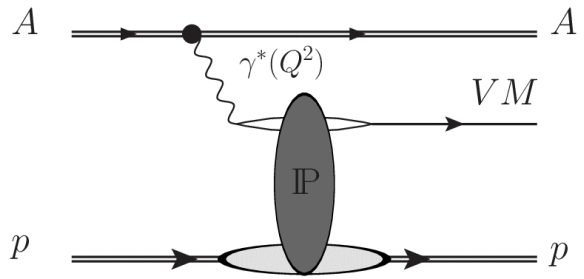

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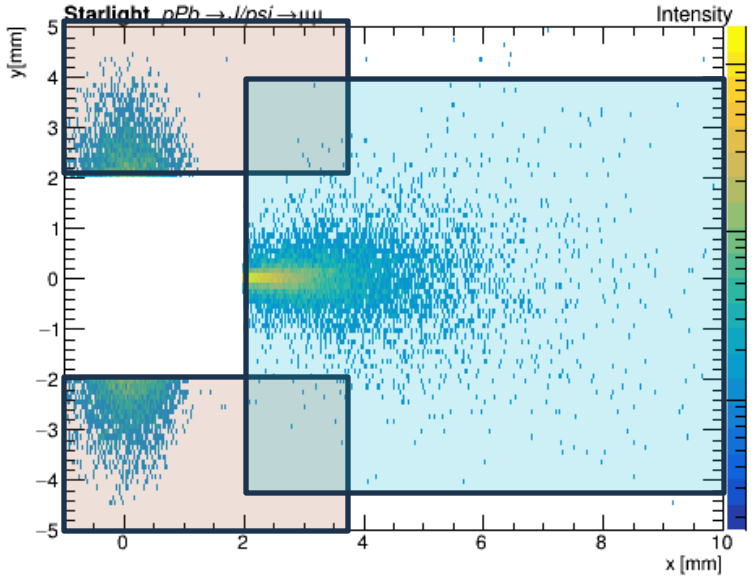

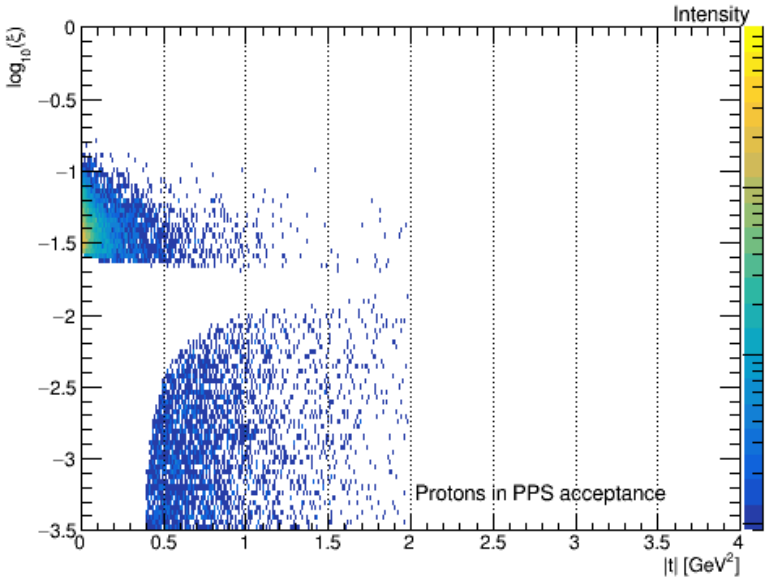

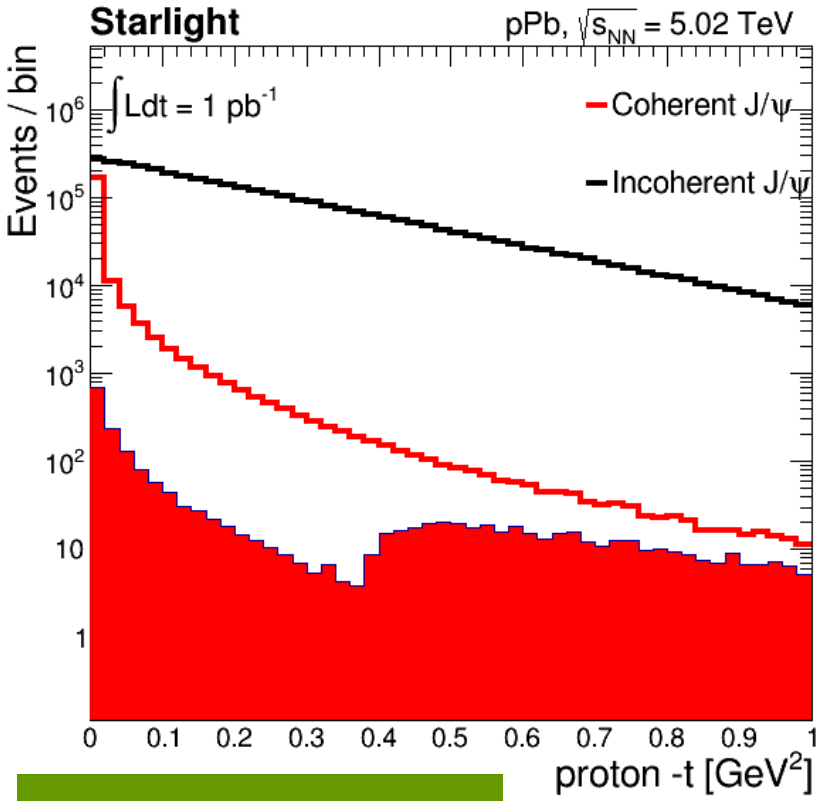

ε~1%

Summary

My summary

- *PDF and Jet substructure measurements have some synergies between EIC and LHC*
- *Coherent/Incoherent VM production seems to be an overlapping topic*
- *It was not clear to me how well we can model coherent production:*
  - *Saturation*
  - *VM type (J/psi pointlike vs rho or phi?)*
- *I would like to invest some time in ep collisions – while contrary to eA we veto, here we are tagging protons*