
C. Muñoz

ePIC Collaboration Meeting

# Overview

Goal: coordinate French community and prioritize physics

- Location: IJCLab, Orsay
- Dates: 1–3 December 2025
- ~70 Participants: theorists, phenomenologists, detector experts
- Activities: presentations, discussions, ePIC software tutorial
- https://indico.in2p3.fr/e/EIC-FRANCE-2025

# Agenda

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|---|---|---|---|
| 14:00 | **Update of the national roadmap for research infrastructures**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *Stefano Matthias Panebianco*<br>14:00 - 14:25 | |
| | **ePIC and EIC project update**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *John Lajoie*<br>14:30 - 14:55 | |
| 15:00 | **Early physics running at EIC**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *Salvatore Fazio*<br>15:00 - 15:25 | |
| | **Group photo**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* 15:30 - 15:40 | | **Coffee break**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* 15:30 - 16:00 |
| 16:00 | **EIC-Canada**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *Wouter Deconinck*<br>16:00 - 16:15 | |
| | **Outreach**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *Silvia Niccolai*<br>16:20 - 16:30 | |
| | **Event generators for eA and ep**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | *Raphaël DUPRE*<br>16:35 - 17:00 | |
| 17:00 | **Discussion: the future EIC-France**<br>*Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* | <br>17:05 - 17:35 | |

# Agenda

09:00 **Inclusive physics** — *Ingo Schlenbeln* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 09:00 - 09:20

**Diffraction** — *Cyrille Marquet* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 09:30 - 09:50

10:00 **Semi-inclusive physics** — *Valerio Bertone* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 10:00 - 10:20

**Coffee break** — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 10:30 - 11:00

11:00 **Exclusive physics** — *Samuel Wallon* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 11:00 - 11:20

**Quarkonia and open heavy flavor** — *Jean-Philippe Lansberg* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 11:30 - 11:50

12:00 **Discussion** — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 12:00 - 12:30

14:00 **CyMBal: MPGDs for the ePIC detector** — *Audrey Francisco* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 14:00 - 14:20

**ePIC backward ECal** — *Afnan SHATAT* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 14:25 - 14:45

15:00 **The Longitudinal Forward Hadronic Calorimeter (LFHCal)** — *Friederike Bock* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 14:50 - 15:05

**CALOROC** — *Pedro Dumas Ziehlmann* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 15:10 - 15:30

**Coffee break** — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 15:35 - 16:00

16:00 **Roman Pots** — *Dominique Marchand* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 16:00 - 16:20

**Status of EICROC and future plans** — *Adrien Verplancke* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 16:25 - 16:45

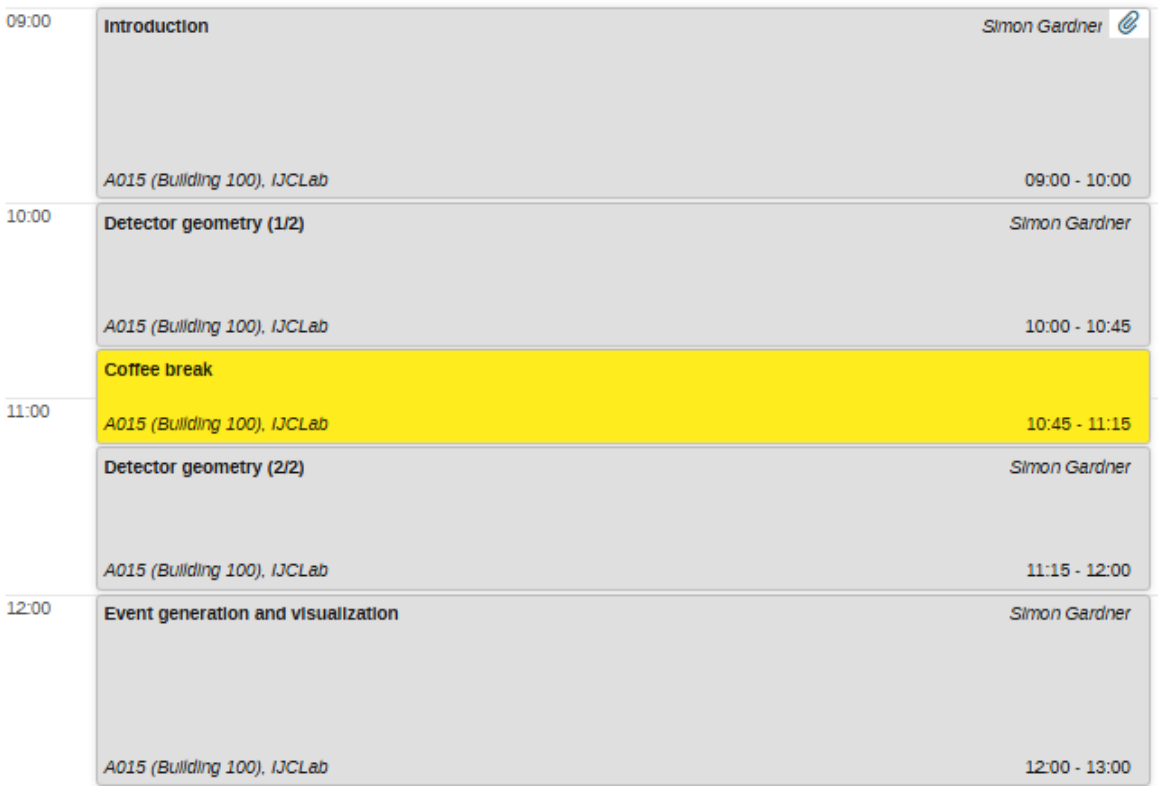
**Architecture proposal of the final 32x32 EICROC chip** — *Alexandre SOULIER* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 16:50 - 17:00

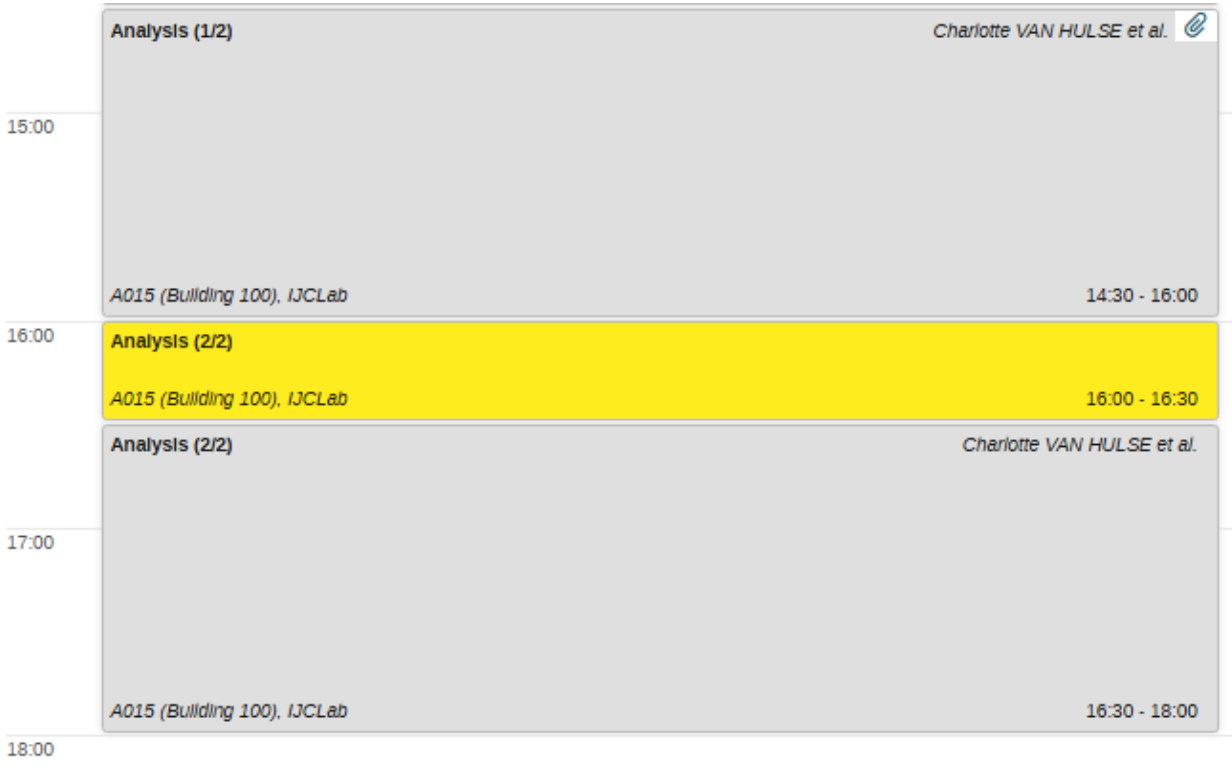
17:00 **SALSA** — *Beatrice Guenego* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 17:05 - 17:25

**Magnets** — *Valerio Calvelli* — *Auditorium Joliot Curie, Bât. 100, IJCLab, Orsay* — 17:30 - 17:55

# Agenda :sofware tutorial

Led by S. Gardner (Glasgow) and C. Van Hulsen (Alcala)

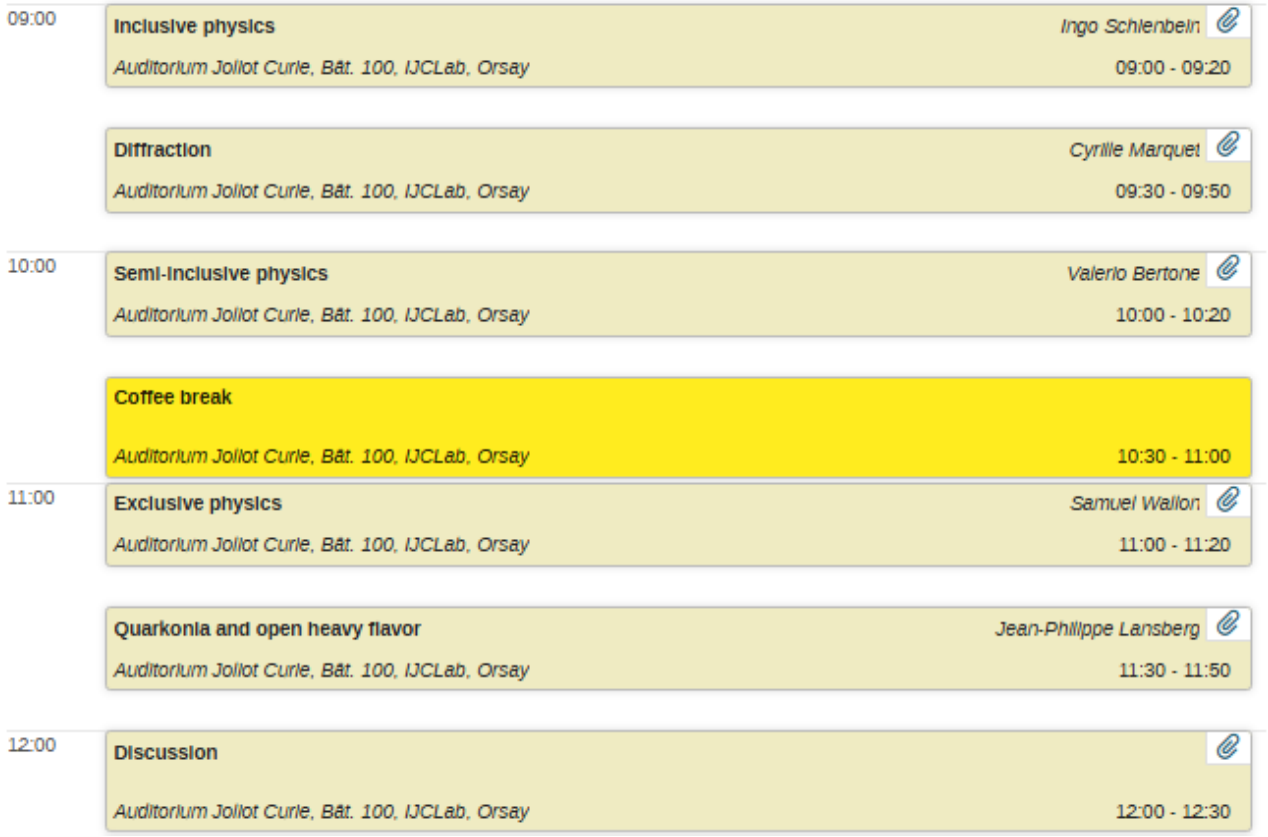



10 participants, mostly PhD students and postdocs

# Theory/physics session

- 5 overview talks: Inclusive DIS, small-x physics, SIDIS, exclusive processes, heavy flavor
- Highlights of flagships/golden measurements
- Focus on expertise/interest by the French community (theory/exp)
- Priority to early-physics opportunities and long-term measurements

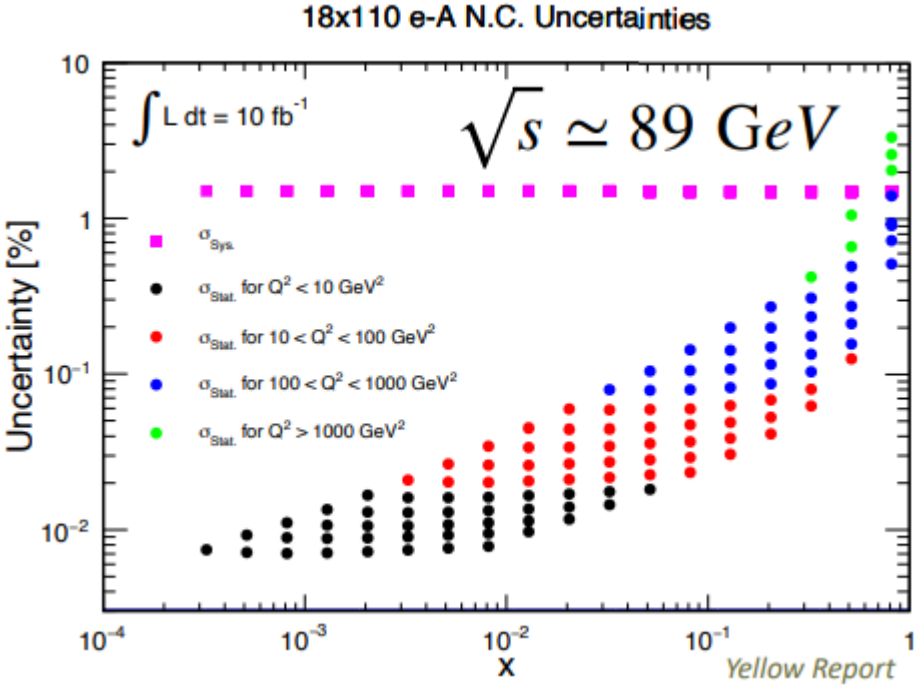



**Lively discussion:**

- Cross-checking with ongoing analysis in the ePIC collaboration
- Identifying impactful, yet under-study channels/measurements

# Inclusive physics

- Precision mapping of **nuclear PDFs** over wide $x$–$Q^2$ range
- Sensitivity to shadowing, antishadowing, EMC effect, and small-$x$ dynamics
- Structure functions $F_2$ and $F_L$ provide direct access to nuclear gluons
- Heavy-flavor production probes gluons via photon–gluon fusion
- Strong reduction of uncertainties on nuclear gluons and sea quarks
- Tests of nPDF universality and essential input for RHIC and LHC heavy-ion physics
- Polarized DIS enables precision measurements of $g_1$ and $A_1$
- Access to polarized gluons and sea quarks at small $x$
- Improved understanding of the **proton spin decomposition**



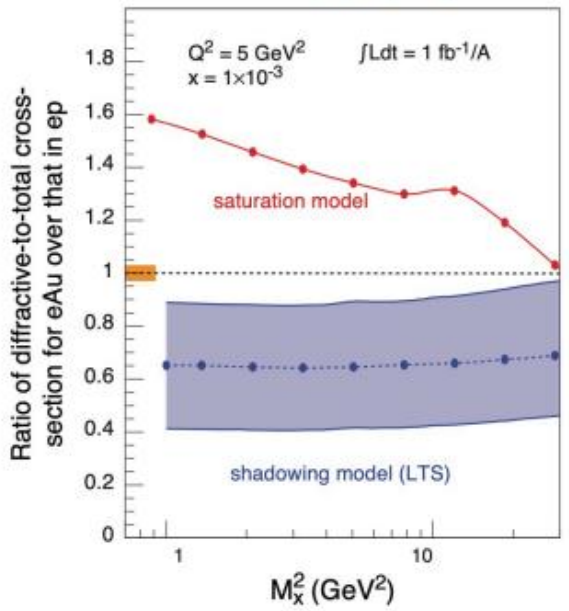

French community working on these topics is relatively small

# Small-x physics and diffraction

## The golden measurement

- Small-$x$ physics and gluon saturation are core objectives of EIC
- Rapid growth of gluon densities at low $x$ requires non-linear QCD descriptions
- The Color Glass Condensate provides an effective theory framework
- Inclusive, diffractive, and exclusive measurements probe saturation dynamics
- Key signatures: geometric scaling and **modified diffractive observables**
- Sensitivity to transverse spatial gluon distributions
- Strong recent theoretical progress in small-$x$ evolution
- EIC will establish the existence and properties of gluon saturation
- Mapping of the transition from dilute to dense QCD matter

EIC White paper (2016)




clean and unambiguous signal of saturation

Strong expertise and *theory* interest in France

# Semi-inclusive physics

- SIDIS at the EIC: single identified hadrons probe PDFs and FFs
- $q_T \ll Q$ region allows access to TMD distributions
- Enables **3D imaging of partons** inside nucleons
- Absolute cross sections improve normalization and reduce uncertainties
- EIC broad kinematics supports **precision tests of TMD factorization**

## Proposal for the EIC

- In order to shed light on this puzzle, the proposal is that the EIC measures **SIDIS absolute cross sections**, *i.e.*:

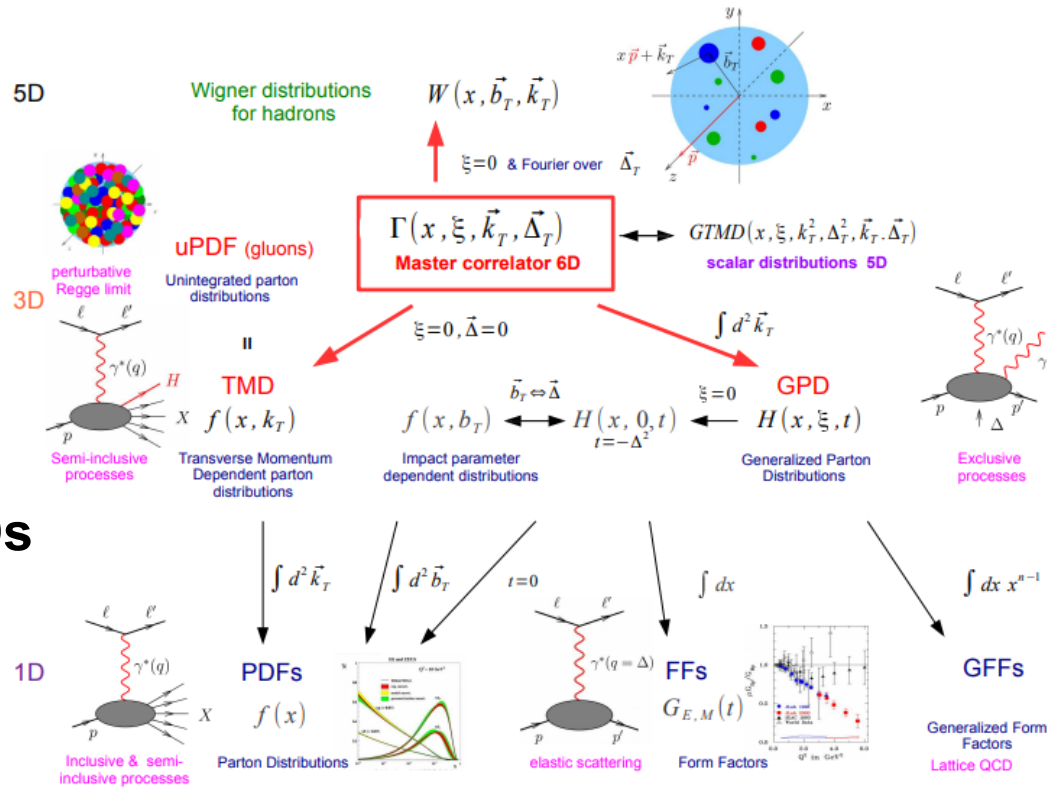
$$\frac{d\sigma^{\ell P\to \ell h X}}{dx dQ^2 dz dq_T} \quad \text{or} \quad \frac{d\sigma^{\ell P\to \ell h X}}{dx dy dz dq_T}$$

- This observable would greatly benefit TMD extractions towards a more solid determination of **TMD FFs**:
  - more direct handle on TMD distributions than multiplicities,
  - it would help us pin down the normalisation problem.
  - cross sections differential in $q_T$ (vector-boson transverse momentum), rather than $P_{hT}$ (produced hadron transverse momentum), better match TMD factorisation helping us devise better cut strategies.

Some expertise/interest in France from both theory/experiment

# Exclusive physics

- Exclusive processes at the EIC probe **GPDs**
- DVCS and exclusive vector-meson production as benchmarks
- **Two-body final states connect PDFs, TMDs, and GPDs**
- High luminosity + variable energies separate longitudinal/transverse contributions
- Angular modulations provide 3D nucleon imaging
- Precision measurements reduce uncertainties at small/intermediate *x*

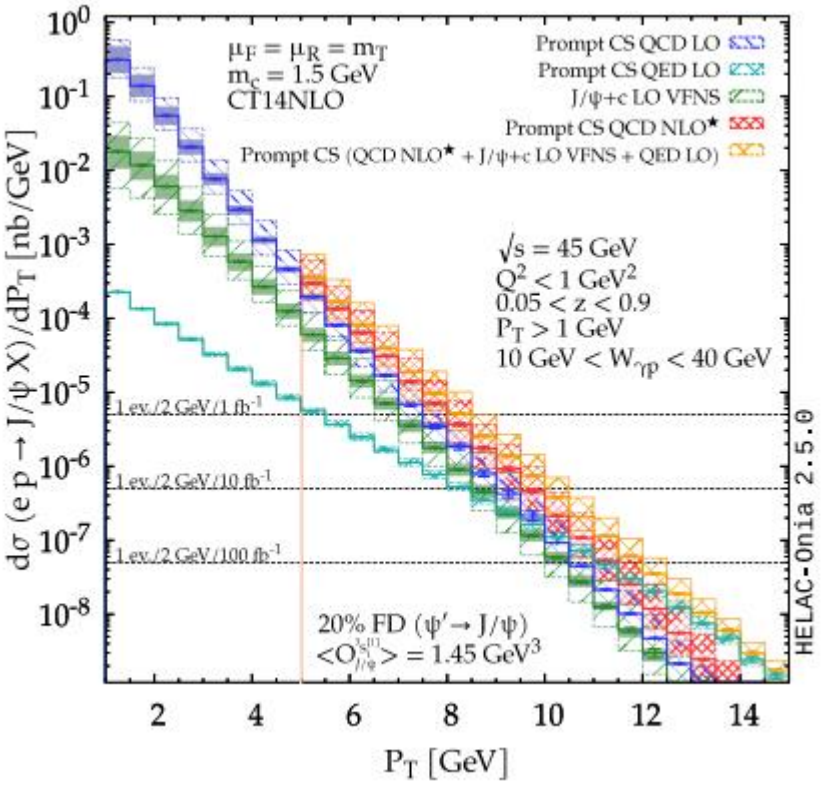



Strong expertise/interest in France from both theory/experiment

# Heavy flavor

- Quarkonia ($J/\psi$, $\Upsilon$) probe gluon dynamics across wide $x$
- Photon–gluon fusion dominates production at the EIC
- Precise measurements in photo- and electroproduction
- Channels include $J/\psi + c$and C-even states ($\eta_c$ ,$\chi_c$)
- Constrains **nuclear gluons, intrinsic charm, gluon GPDs, TMDs, and GTMDs**
- Complementary to LHC ultra-peripheral collisions

Predictions for the $J/\psi p_T$distribution in inclusive quarkonium production at the EIC




https://arxiv.org/pdf/2009.08264

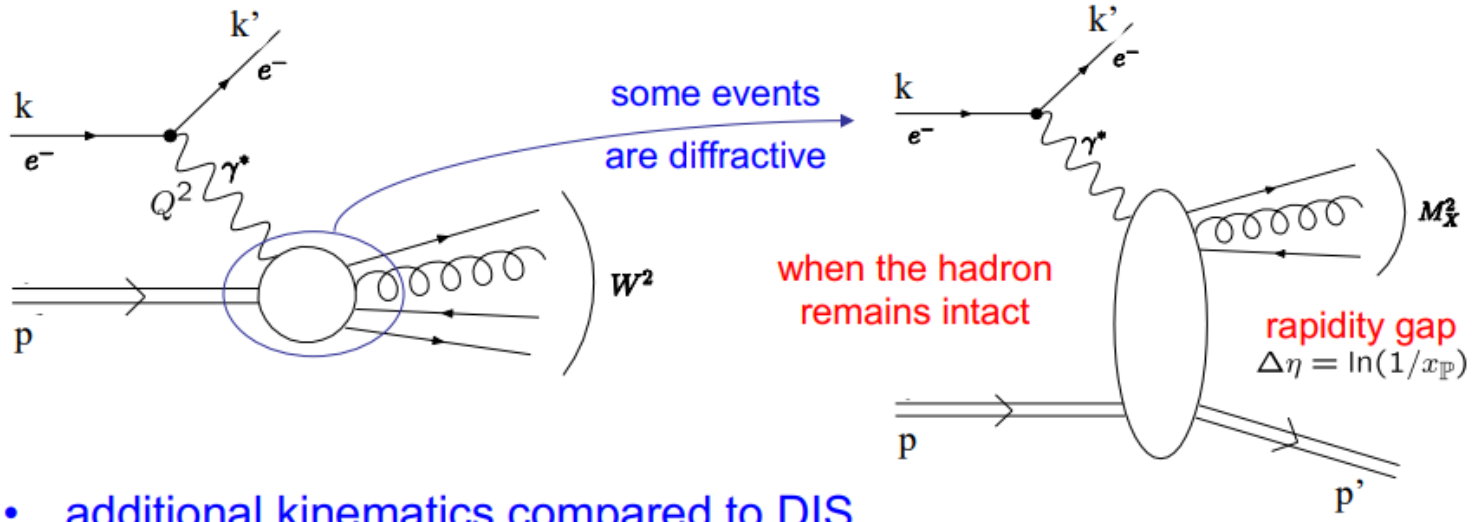
Some expertise/interest in France from the theory side

# Theory discussion

- Workshop participants identified **two particularly promising early measurements** at the EIC:
  - **Inclusive diffraction**
  - **Inclusive quarkonium production**
- These channels have **clean experimental signatures** and are theoretically well understood
- They directly address central EIC goals:
  - Mapping **gluon dynamics at small-$x$**
  - Probing the **onset of non-linear QCD / saturation effects**
- They also constrain **heavy-quark production mechanisms**
- Both measurements align with areas of **French theoretical expertise**, including:
  - small-$x$ physics and gluon saturation (CGC)
  - quarkonium production theory and heavy-flavour phenomenology
- This theoretical strength, combined with physics relevance, positions the French community to:
  - contribute predictive frameworks
  - develop simulation tools
  - design analysis strategies
- As a result, these topics were **prioritized for early French involvement** in the EIC program

# Inclusive diffraction

- Inclusive diffraction at small $x\rightarrow$ probe of **gluon saturation**
- Large rapidity gap signals diffractive DIS (target intact or low-mass dissociation)
- Significant fraction of small-$x$ DIS cross section
- **EIC advantages:** precision measurement on **protons & nuclei**, rapidity gap detection, leading hadron measurement
- Test **CGC predictions** and map **gluon transverse spatial distributions**




- additional kinematics compared to DIS

diffractive mass $M_X^2 = (q+p-p')^2$

momentum transfer $t = (p-p')^2 < 0$

$$\beta = \frac{Q^2}{2(p-p')\cdot q} = \frac{Q^2}{M_X^2 - t + Q^2}$$

~ momentum fraction of the struck parton with respect to the exchanged object (Pomeron)

$$x_{\mathbb{P}} = x/\beta$$

momentum fraction of the Pomeron with respect to the hadron

# Inclusive quarkonia

- Inclusive $J/\psi$ & Υ → probe **gluon PDFs** via photon–gluon fusion
- EIC advantages: high **luminosity, heavy-flavor tagging**, photoproduction & electroproduction
- Explore **perturbative vs. non-perturbative mechanisms** (color-singlet vs. octet, feed-down)
- Nuclear targets → constrain **gluon shadowing** & intrinsic heavy quarks
- Connect **pQCD dynamics** to **quarkonium formation**

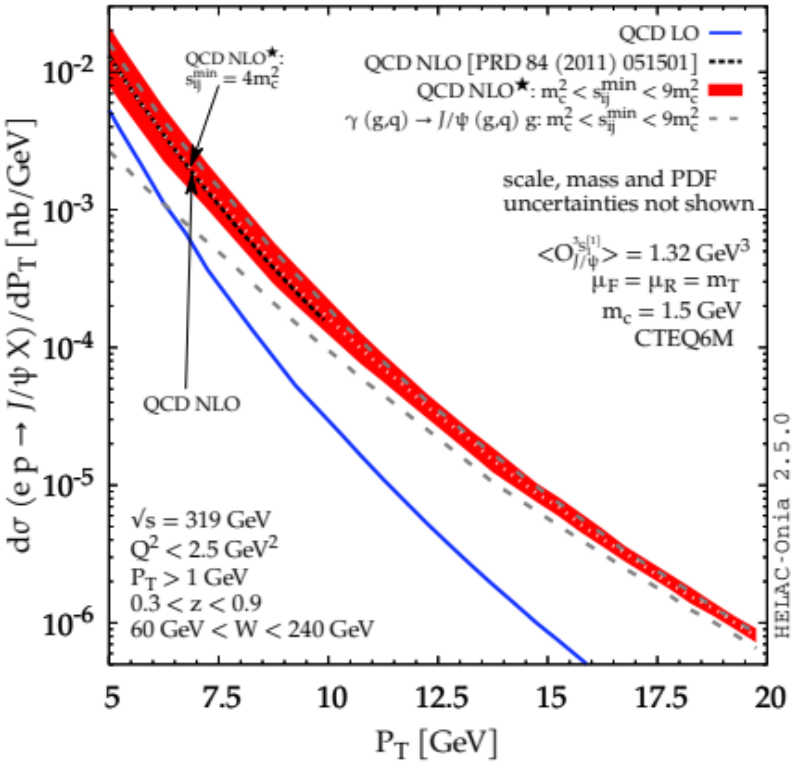



Figure 2: Comparison between our NLO★ (red band) and a complete NLO [43] (dashed black line) calculations. The red band results from a variation of the IR cut-off, $s_{ij}^{min}$, specific to the NLO★ approximation. The dashed grey curves refers to the contributions appearing at $\alpha\alpha_s^3$ for a similar variation of $s_{ij}^{min}$ and the blue at $\alpha\alpha_s^2$ (LO).

https://arxiv.org/pdf/2009.08264

# Longer-term physics opportunities

- Beyond early-phase measurements, the EIC enables a rich longer-term physics program
- Focus on processes requiring full EIC performance and maturity
- Depend on extended forward detector coverage
- Require high integrated luminosity
- Exploit the flexibility of beam energies and species
- Offer strong synergies with French theory expertise
- Two main directions highlighted by the workshop:
  - **Sullivan process:** access to the pion's three-dimensional structure
  - **Exclusive three-body final states:** new probes of QCD dynamics

# Pion Structure Through the Sullivan Process

- Unique long-term opportunity at the EIC to study the pion's internal structure
- Access provided via the **Sullivan process**, where the electron scatters from the nucleon's meson cloud
- Pion exchange effectively creates a **virtual pion target**
- Technique previously used to measure the pion form factor and structure function
- EIC enables extension to **exclusive processes**, such as DVCS off virtual pions
- Provides access to **pion GPDs**
- Broad kinematic reach opens regimes inaccessible to previous experiments
- State-of-the-art theory predicts measurable cross sections and asymmetries at the EIC
- Sensitivity to both **quark and gluon contributions** in the pion

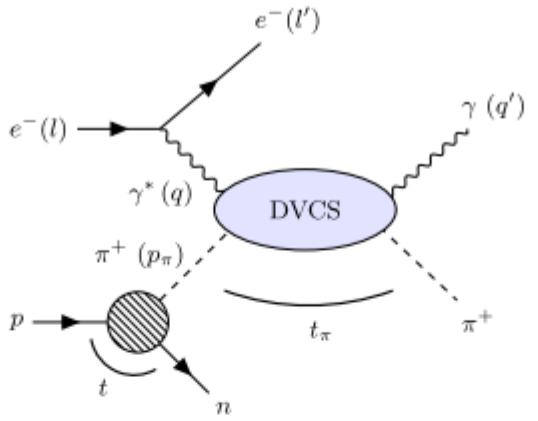
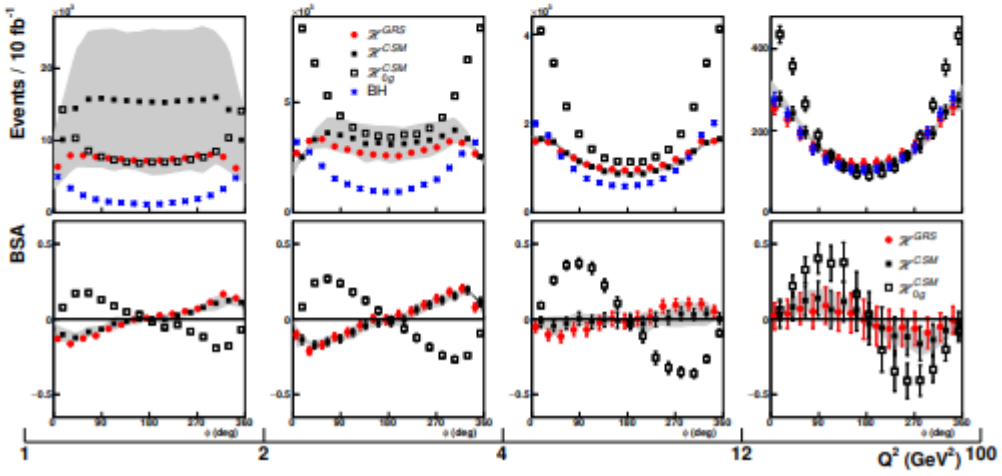
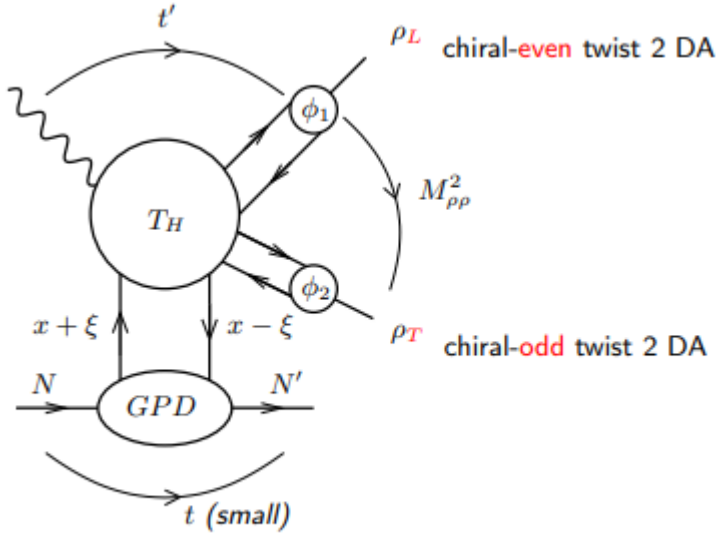



Figure 1: Diagrammatic representation of the Sullivan DVCS process.

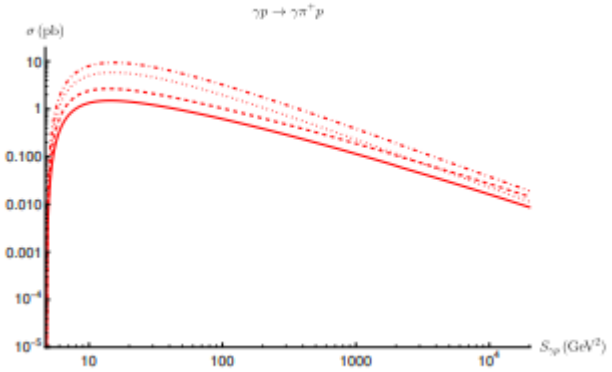


# Exclusive Three-Body Final States

- Involves processes such as:
  - Exclusive vector-meson pairs
  - Meson–baryon and two-hadron final states
- Provide a clean laboratory to study **QCD factorization mechanisms**
- Different theoretical descriptions depending on the channel:
  - **Collinear factorization** → GPDs (DVCS, DVMP)
  - **Transition distribution amplitudes (TDAs)** → meson–baryon production
  - $k_T$**-factorization** → very high-energy regime
- Sensitivity to **hard scales**, chiral-even and chiral-odd dynamics
- Enable multidimensional scans in:
  - photon virtuality $Q^2$
  - momentum transfer $t$
  - invariant mass of the produced hadron pair
- Connect partonic imaging, diffraction, and the emergence of hadronic degrees of freedom




chiral-odd twist 2 GPD



# Summary and conclusion

- The **2nd EIC–France Workshop** provided a coherent overview of French theory engagement in EIC physics
- Strong complementarity identified between early EIC capabilities and high-impact physics channels
- Inclusive diffraction and inclusive quarkonium production emerged as top priorities for early physics
  - Clean experimental signatures
  - Strong theoretical control
  - Unique sensitivity to small- $x$ gluon dynamics

- Longer-term opportunities will expand with full luminosity and detector performance
- Key examples include:
  - Pion structure via the Sullivan process
  - Exclusive multi-hadron final states

- These programs connect partonic imaging with emergent QCD phenomena
- They align closely with French leadership in small-$x$ physics, GPDs, TDAs, and non-perturbative QCD
- Overall, the French community shows strong readiness, motivation, and capability to play a leading role in the EIC physics program