U.S. DEPARTMENT OF ENERGY

Office of Science

Selected recent results on UPCs

Daniel Tapia Takaki

Latin American Symposium on Nuclear Physics and Applications (LASNPA)

Facultad de Ciencias, UNAM CDMX

June 21, 2024

KU THE UNIVERSITY OF KANSAS

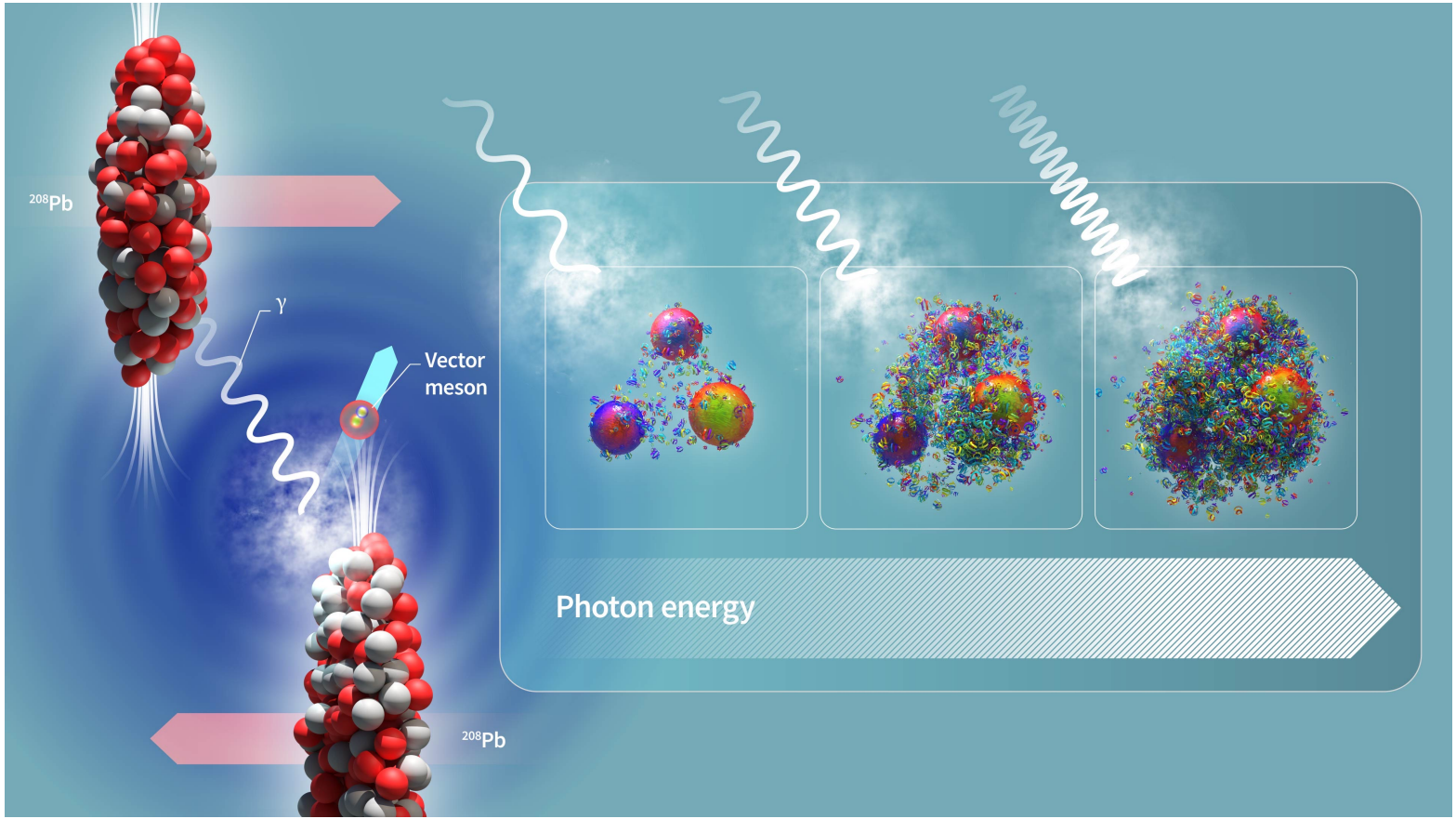
CERNCOURIER | Reporting on international high-energy physics

STRONG INTERACTIONS | MEETING REPORT

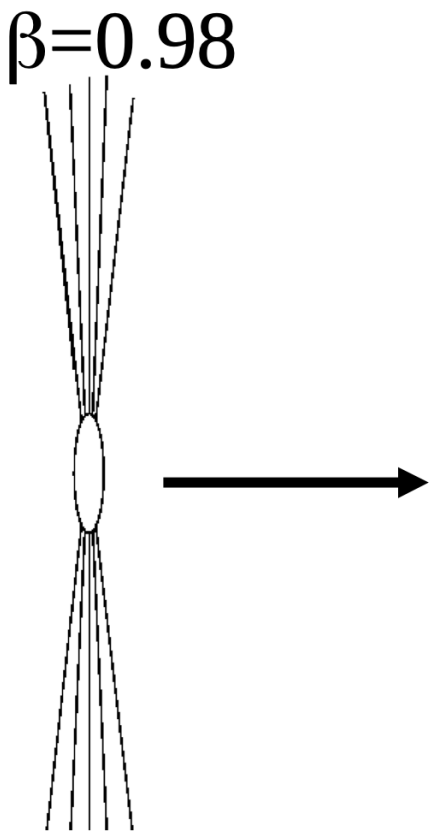
Ultra-peripheral conference debuts in Mexico

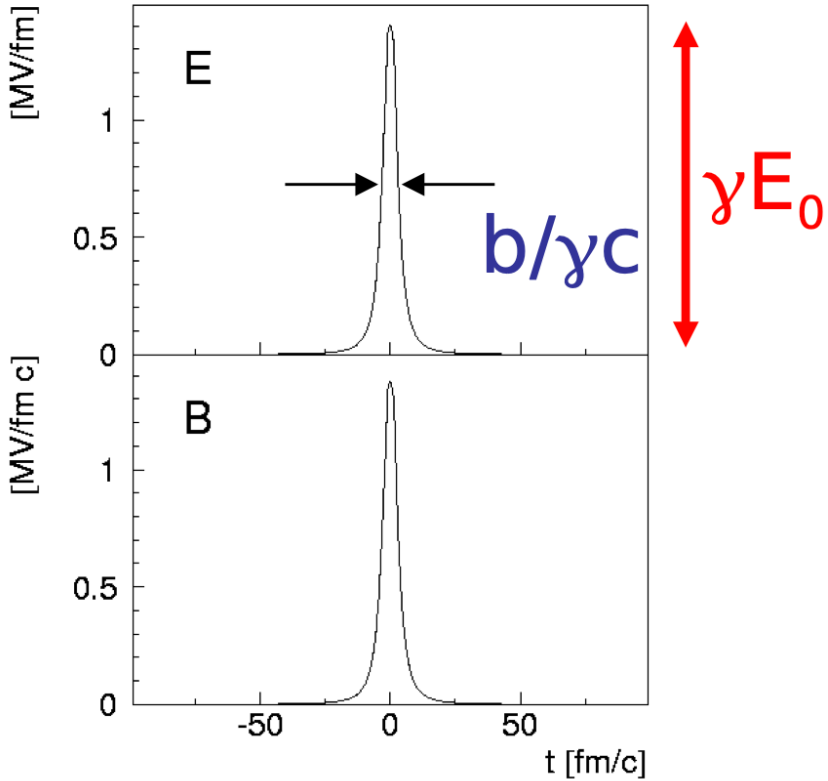
4 May 2024

Ultra peripheral collisions (UPC)



EM fields of a charged particle





Pulse width

The photon flux can be computed through a Fourier transform

Weizsäcker-Williams method (1934)

RHIC and LHC as Photon Colliders

- **Ultra Peripheral Collisions (UPC)** can explore a wide range of energies using almost real photons

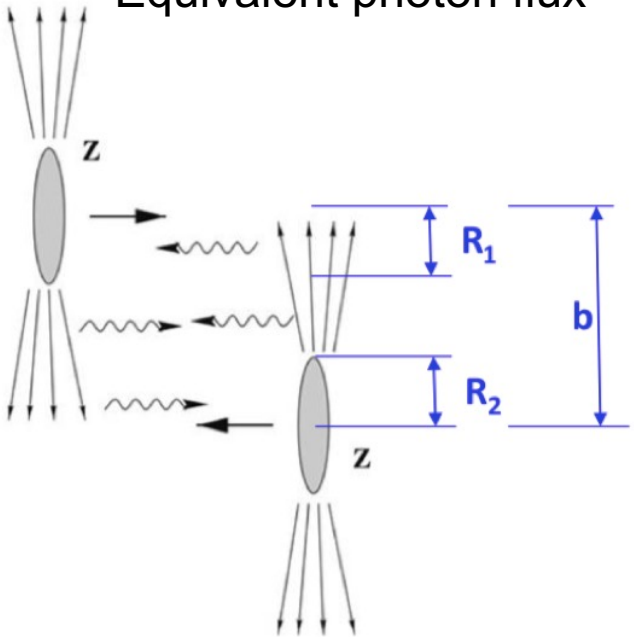
  $k = \gamma M_V \exp(\pm,y)$
  Up to several TeV in γp
  Up to ~ 700 GeV/nucleon in γA
  Up to ~ 150 GeV in $\gamma\gamma$ using UPC PbPb,
  ~ 4 TeV in in $\gamma\gamma$ using UPC pp

- UPCs at the LHC probe the hadronic structure over a broad and unique Bjoren *x* region, yet the precision not compatible to DIS machines like the EIC

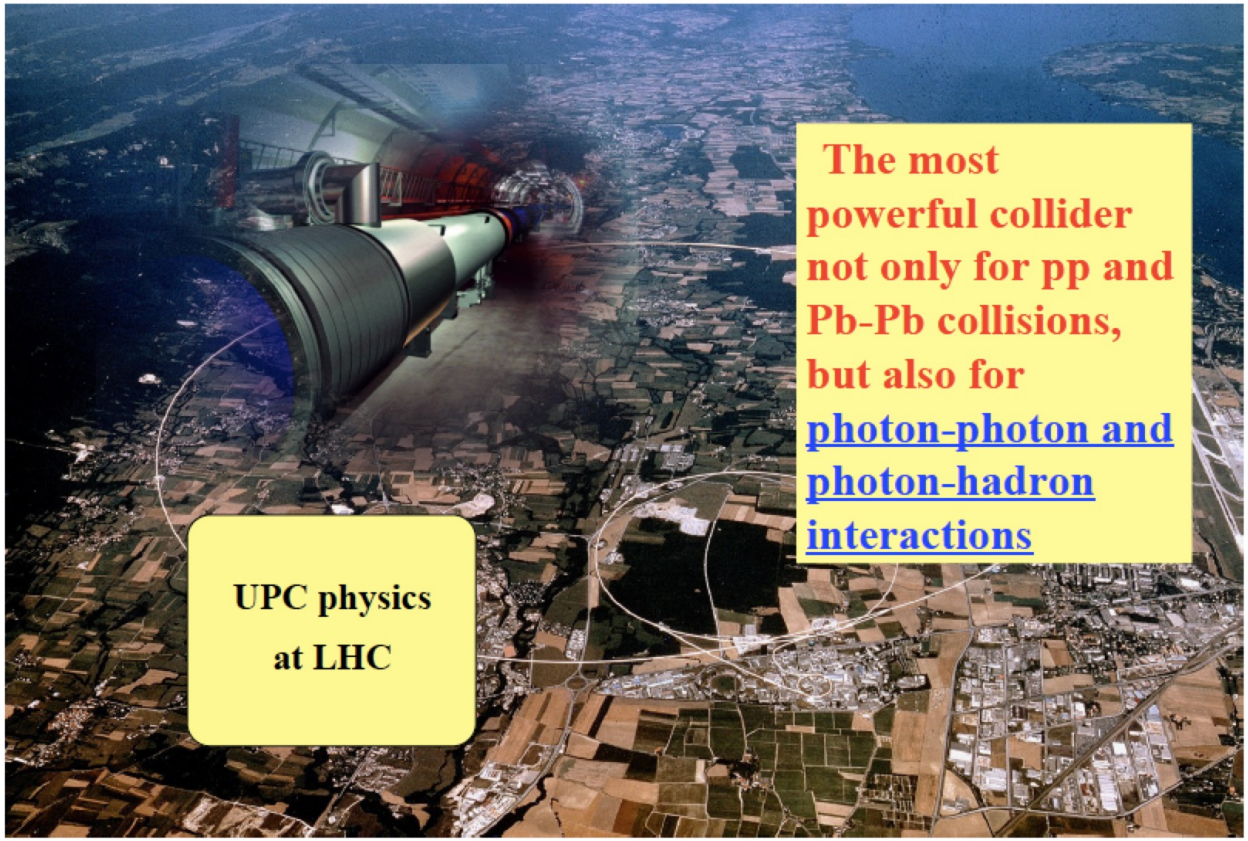
  $x = M_V/\gamma m_p \exp(\pm,y)$

Interactions mediated by the EM interactions

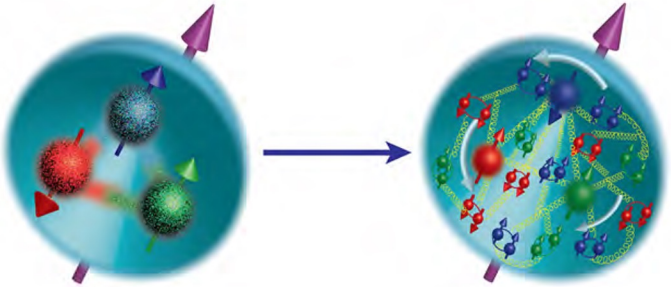
Equivalent photon flux



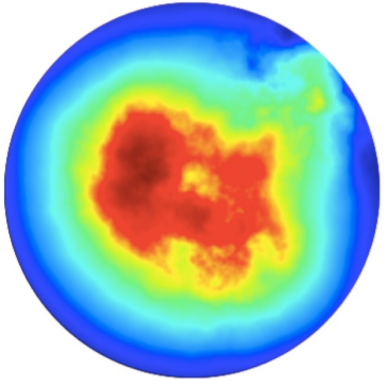
The LHC as Photon Collider

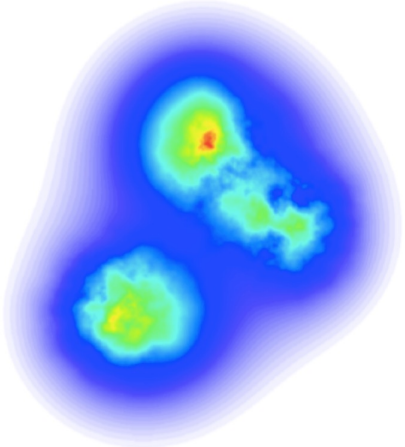


The structure and dynamics of hadrons



What does the proton look like?

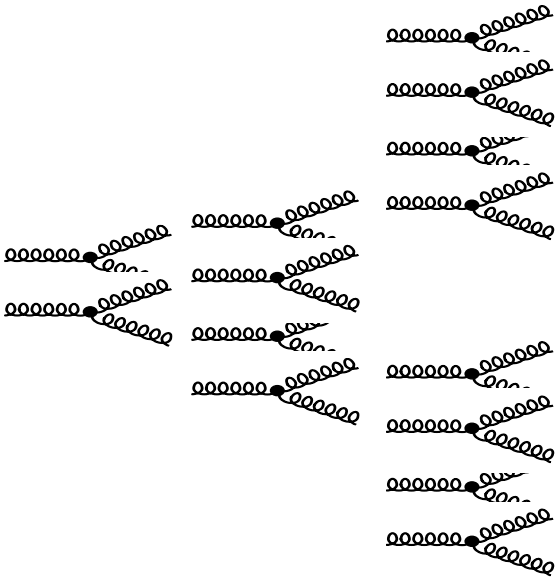




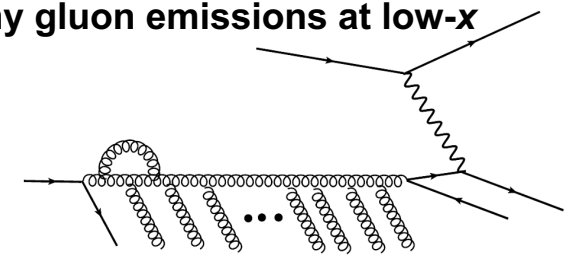
Gluons matter

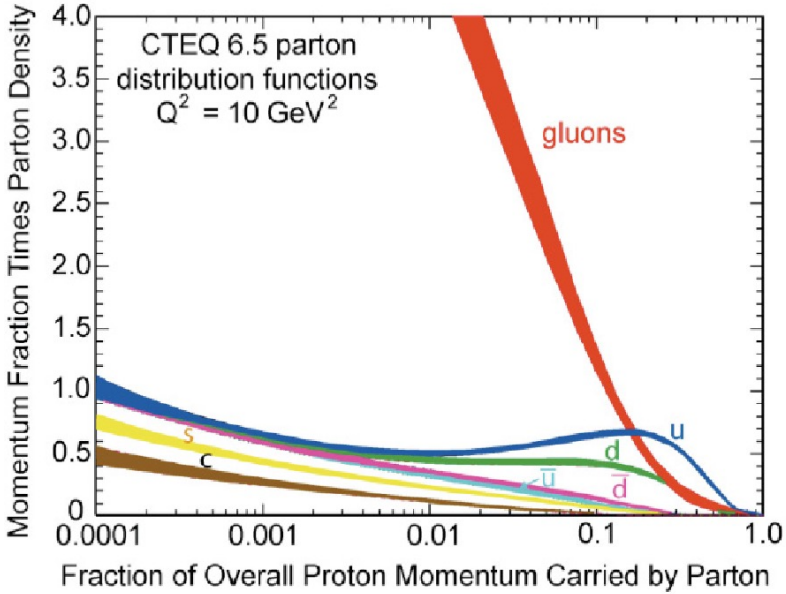
Quarks and gluons dynamics described by QCD

Gluons carry color, thus self-gluon interactions



Many gluon emissions at low-*x*





Gluon saturation

At high energies, or for heavy nuclei at lower energies, gluon saturation is predicted

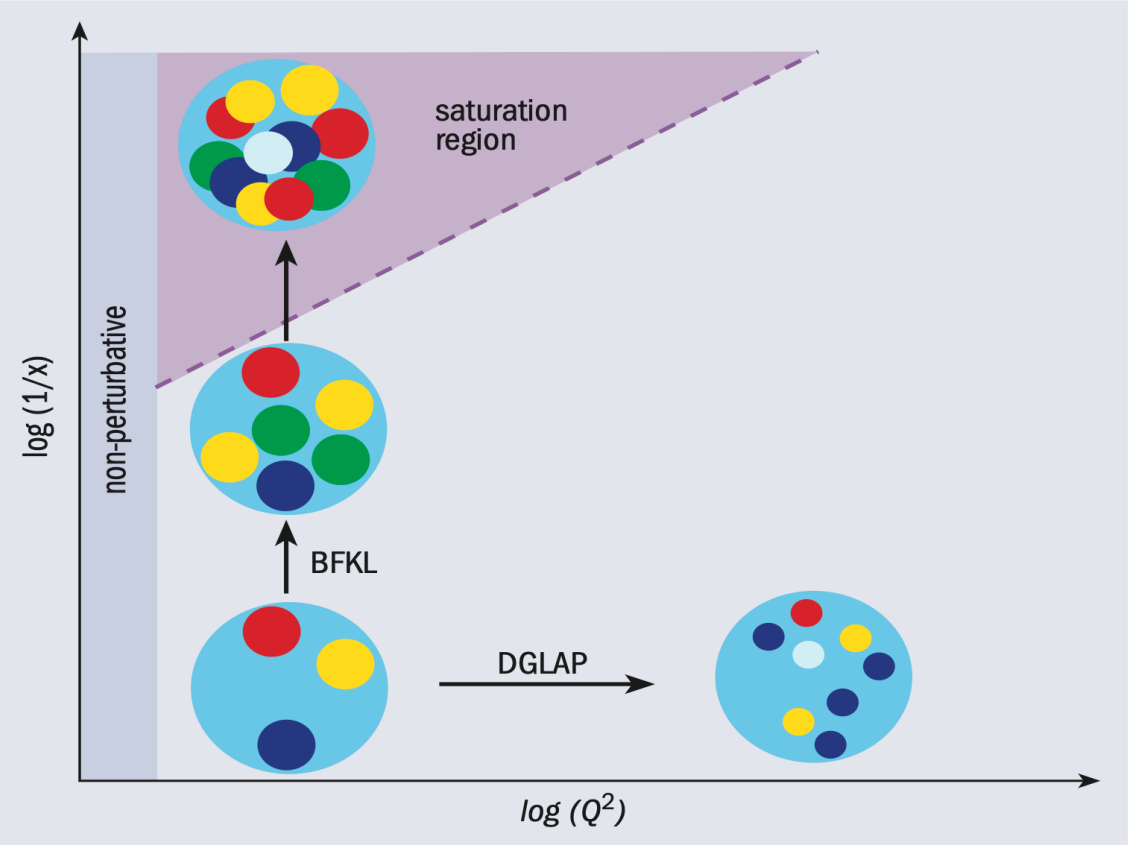
gluon emission

gluon recombination

Dynamical equilibrium of gluon saturation state reached

- Non-linear QCD evolution equations introduced, but how is gluon saturation triggered?
- Can we determine experimentally the saturation scale (Q_S)?
- Is there a state of matter formed by gluon saturated matter with universal properties?

Evolution of the hadronic structure with Bjorken-x and Q^2

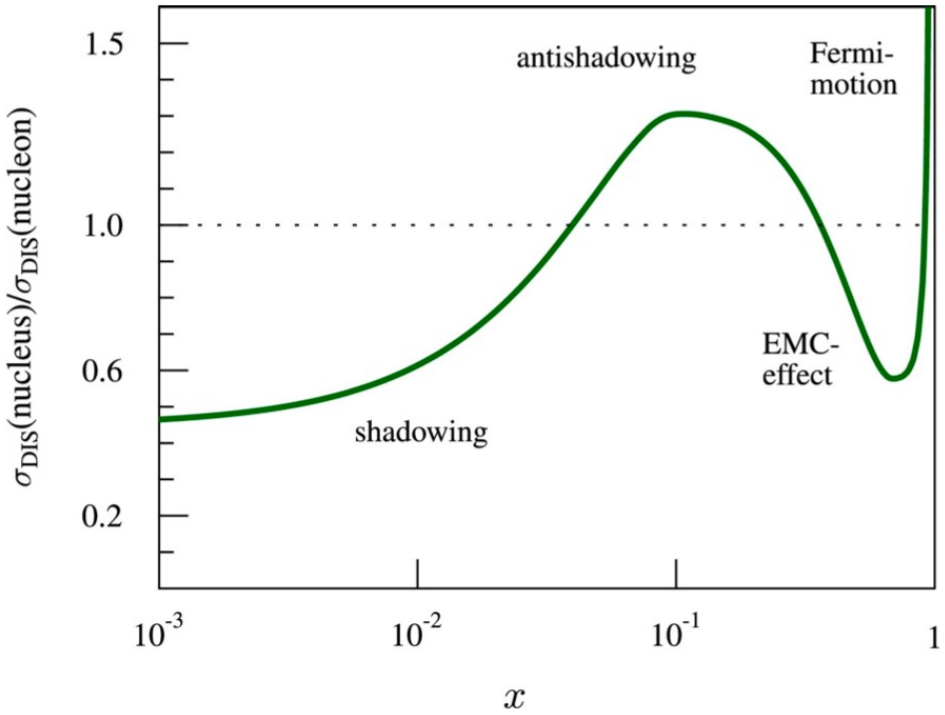


- Experimental observables needed to map out the transition between the dilute and saturation regimes
- For nuclei, the saturation scale is enhanced by a $A^{1/3}$ factor

$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

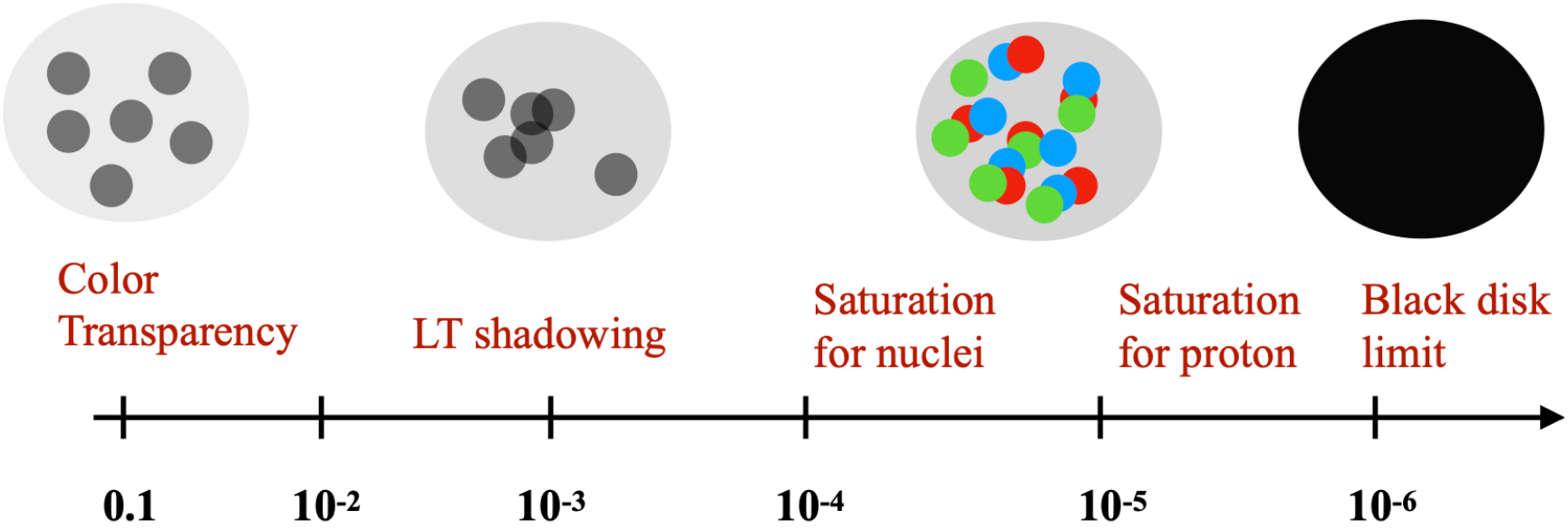
Nuclear shadowing experimentally confirmed, but not fully understood

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



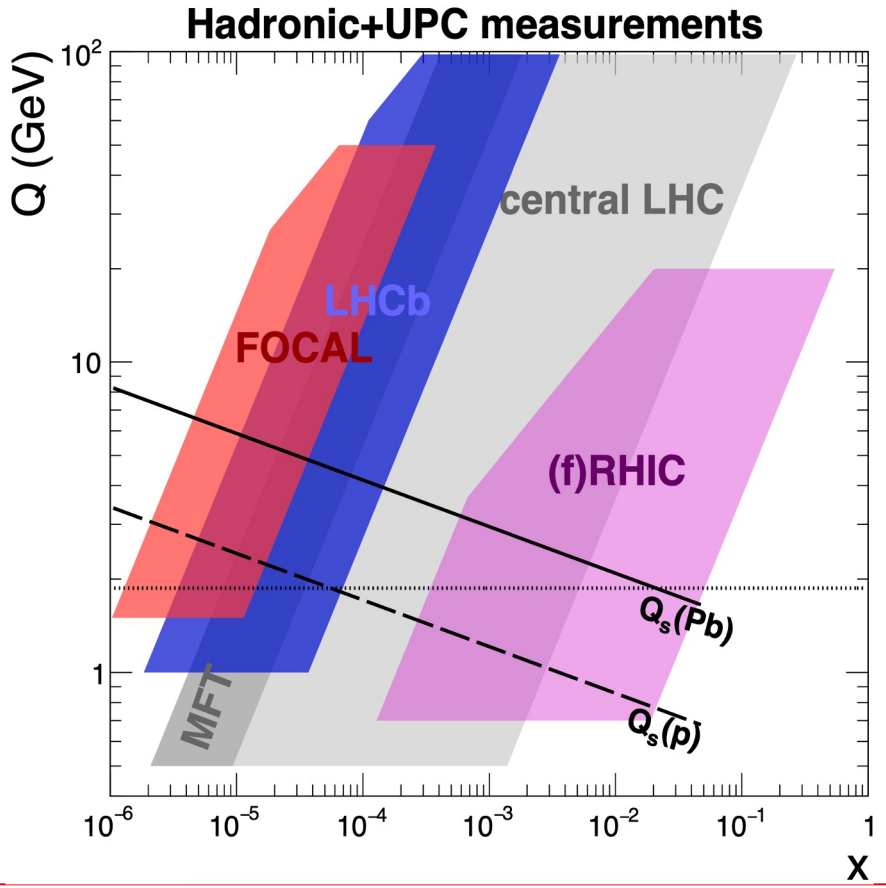
- Experimental observation that parton distributions are different for protons and nuclei
- What's the mechanism responsible for shadowing? How is gluon saturation related?
- The knowledge of the initial state of nuclei also needed for understanding the QGP evolution

Possible stages?



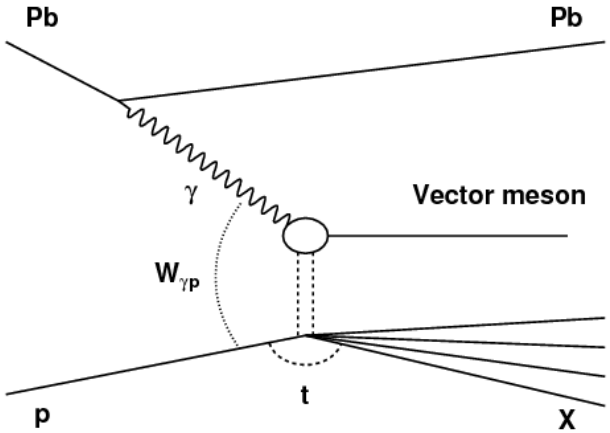
Experimental program

- The Electron-Ion Collider will be a dedicated QCD machine with the precision and control capabilities for studying gluon saturation and shadowing in a systematic way like never before.
- The LHC explores the high energy domain for both hadronic and photon-induced reactions
- FoCal at ALICE will explore a unique low-*x* regime reaching $x \sim 10^{-6}$



Vector meson (VM) photoproduction in UPCs

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

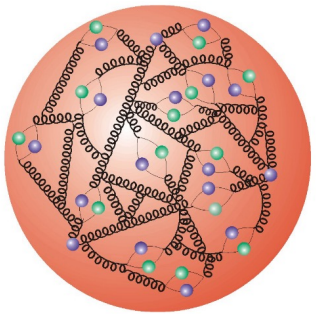


- As in DIS, several reactions are possible in UPCs:

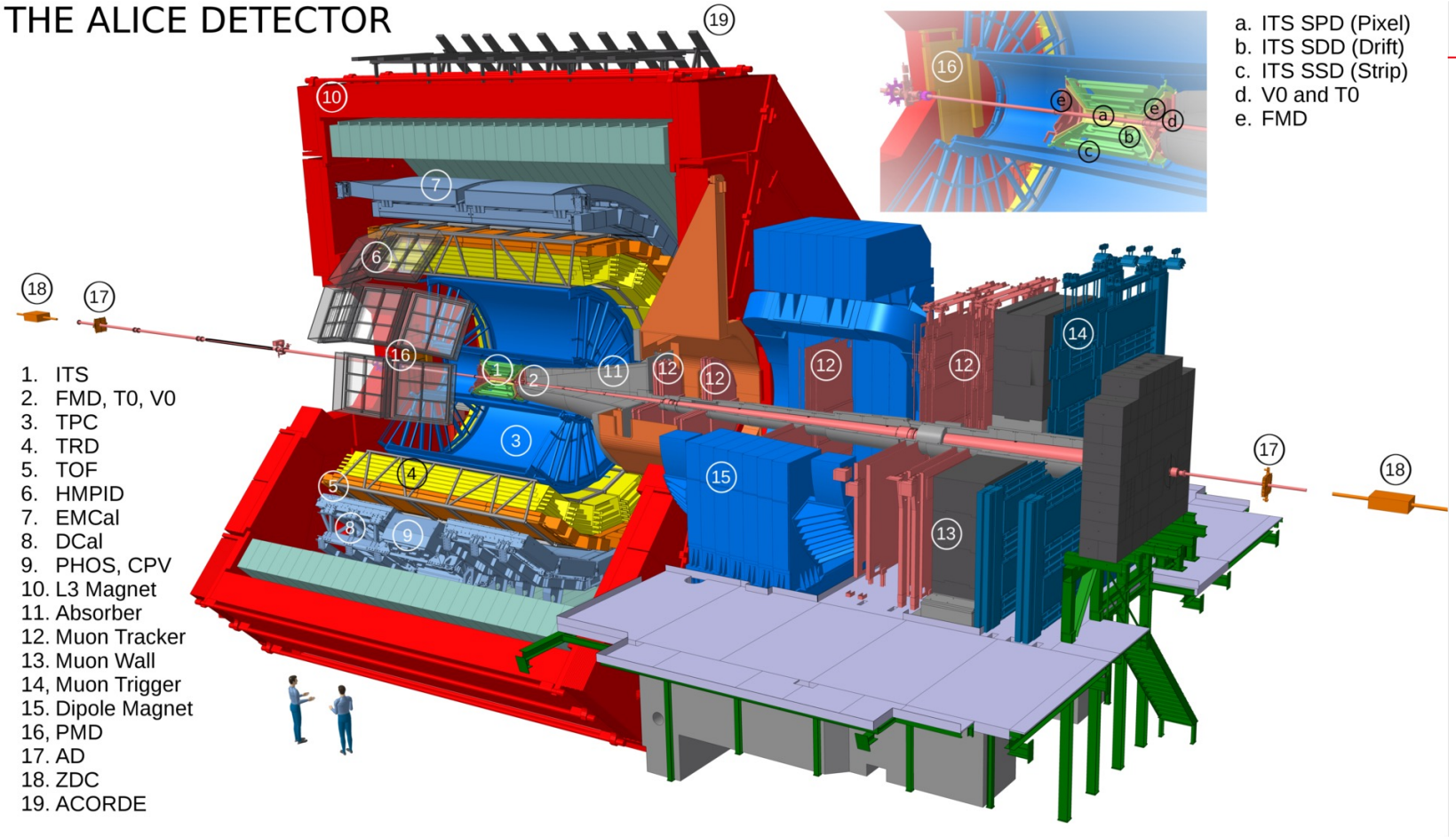
  -Exclusive photoproduction
  -Semi-exclusive photoproduction
  -Inclusive photoproduction

- By studying various VMs, it is possible to study the Q^2 dependence

- In the dipole approach, the light VMs (ϕ, ρ^0) are more sensitive to saturation because of the larger dipole, but pQCD methods not applicable

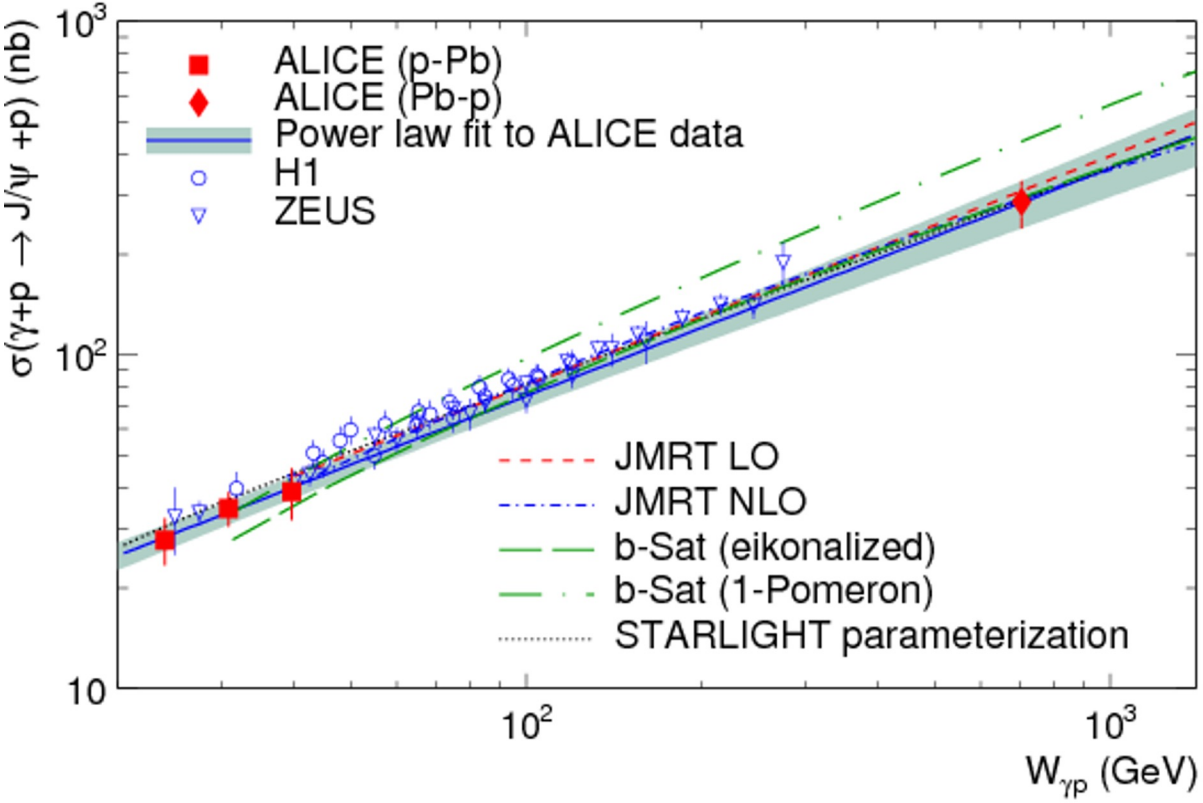


THE ALICE DETECTOR



First exclusive J/ψ measurements by ALICE using Run 1 (2013)

Phys. Rev. Lett. 113 (2014) 23, 232504



- No change with respect to HERA power-law growth observed at low energies up to 700 GeV
- UPC pPb collisions have no ambiguity on the photon energy

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

Coherent J/ψ in UPC Pb-Pb

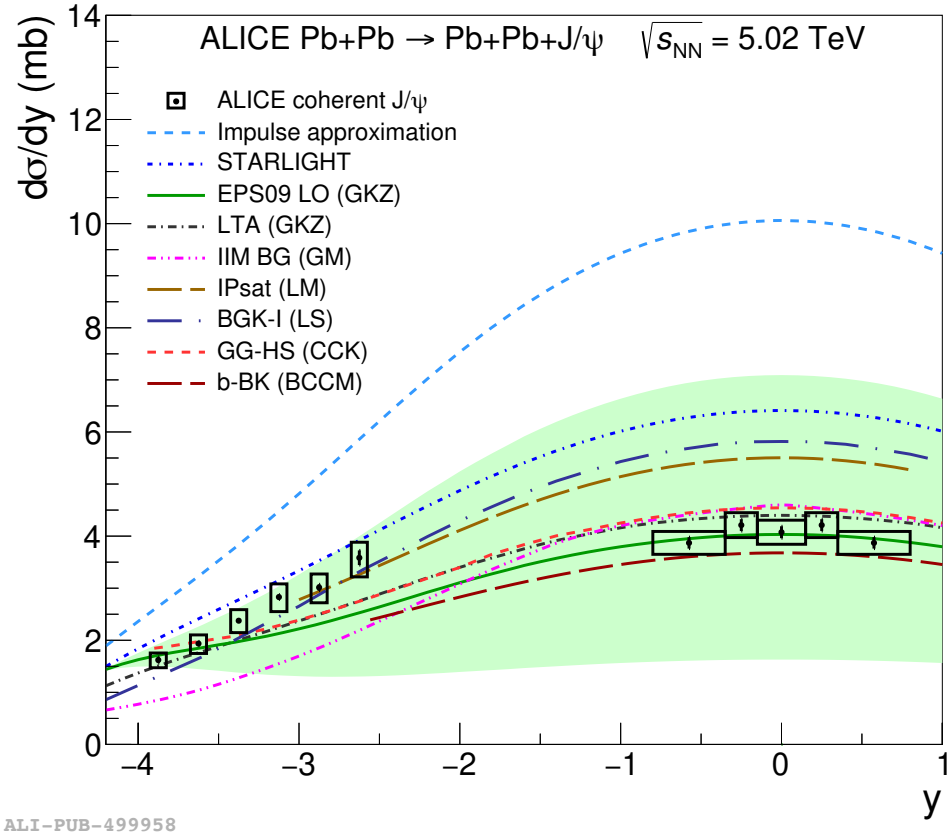
Eur. Phys. J. C 81 (2021) 712

- Confirmation of nuclear shadowing with Run 2 data
- No model can describe the rapidity dependence

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

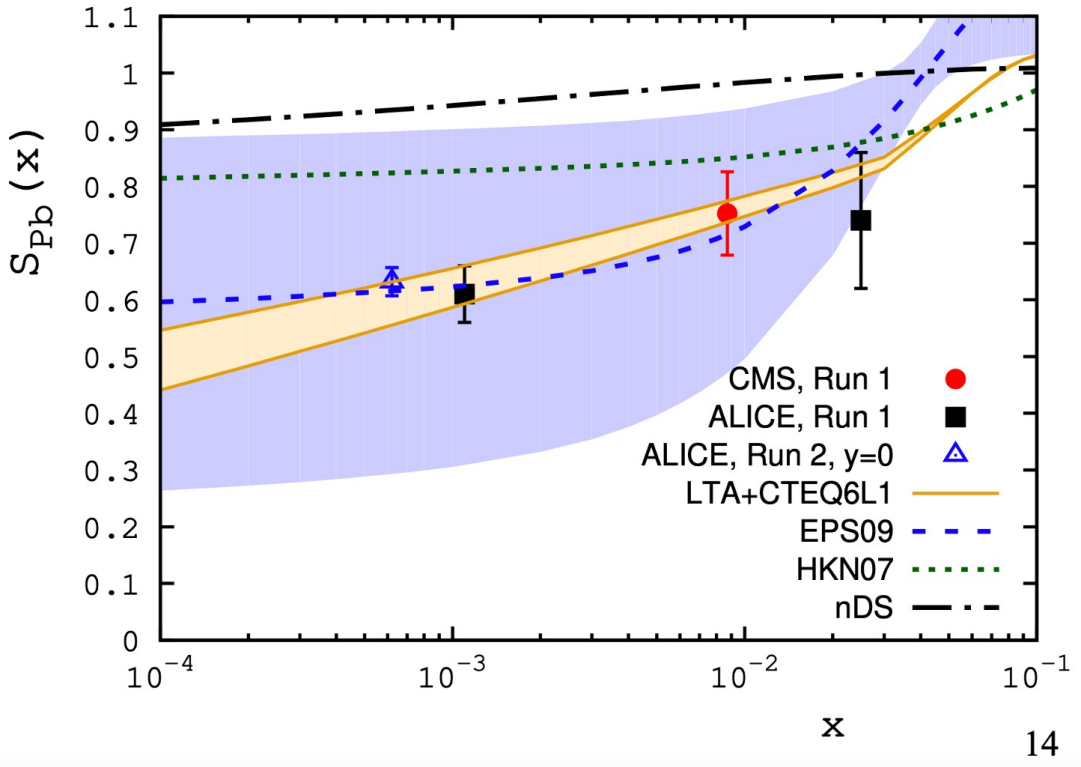
Mid-rapidity x ~10^{-3}

Forward rapidity 95% at x ~ 10^{-2}
5% at x ~ 10^{-5}



Nuclear suppression factor for UPC J/ψ: Comparing γPb to γp

V. Guzey et al. PLB 726 (2013)



An experimental definition, which can be linked to PDFs at LO

$$S_{Pb}(x) = \sqrt{\frac{\sigma_{\gamma A \to J/\psi A}(W_{\gamma p})}{\sigma^{\mathrm{IA}}_{\gamma A \to J/\psi A}(W_{\gamma p})}} = \kappa_{A/N} \frac{x g_A(x,\mu^2)}{A x g_N(x,\mu^2)}$$

Run 1 data from ALICE was the first at indicating nuclear gluon shadowing at x ~ 10^{-3}

Large scale NLO uncertainties should cancel in the $S_{Pb}(x)$ ratio

ALICE results at y=0 have no ambiguity on the photon energy

Two-fold ambiguity on the photon direction in symmetric systems

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

Symmetric systems (pp, A-A) suffer from the two-fold ambiguity on the photon direction

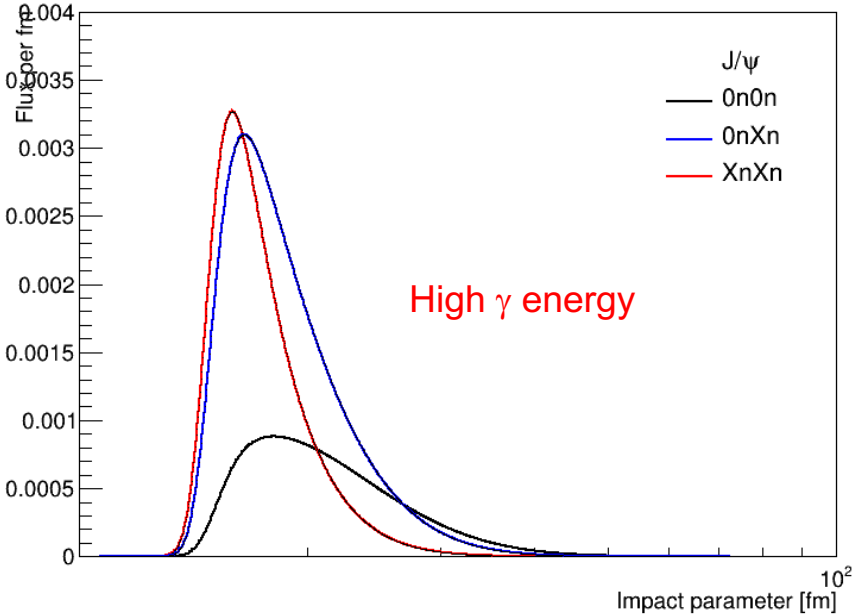
Positive rapidity Negative rapidity

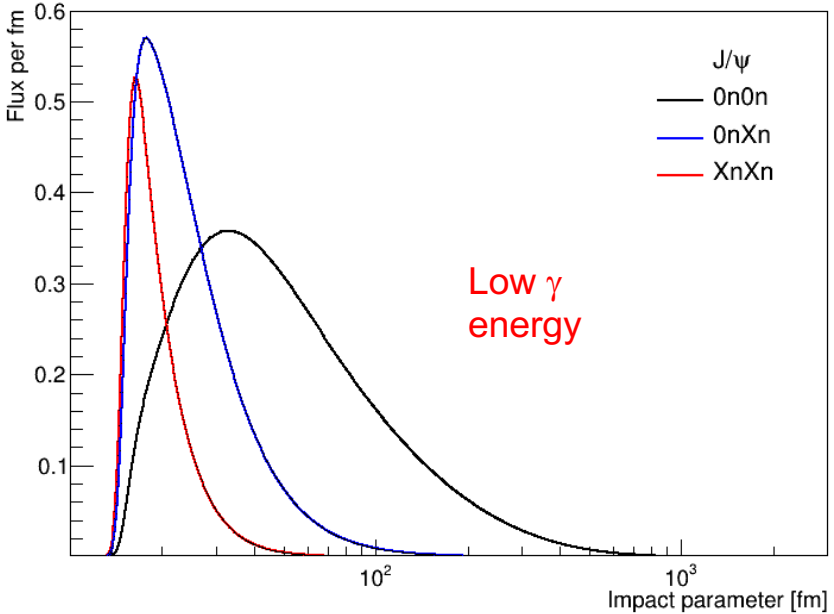
$$\frac{d\sigma}{dy} = n(+y)\sigma(\gamma p, +y) + n(-y)\sigma(\gamma p, -y)$$

Analyses of UPC asymmetric systems (p-Pb) provide a model independent way to study the energy dependence of $\sigma(\gamma p)$

Impact parameter flux profile

Broz, Contreras and DTT, CPC 235 (2020) 107181





Neutron-dependence of coherent J/ψ in UPC Pb-Pb

The photon flux (n) depends on the impact parameter

Decomposed in terms of neutron configurations emitted in the forward region

$$\frac{d\sigma}{dy} = \frac{d\sigma(0\mathrm{n}0\mathrm{n})}{dy} + 2\frac{d\sigma(0\mathrm{n}\mathrm{X}\mathrm{n})}{dy} + \frac{d\sigma(\mathrm{X}\mathrm{n}\mathrm{X}\mathrm{n})}{dy}$$

Solving the linear equations resolves the two-fold ambiguity for VMs at y ≠ 0

Positive rapidity Negative rapidity

$$\frac{d\sigma}{dy} = n(+y)\sigma(\gamma\mathrm{p}, +\mathrm{y}) + \mathrm{n}(-\mathrm{y})\sigma(\gamma\mathrm{p}, -\mathrm{y})$$

Guzey, Strikman, Zhalov, EPJC 74 (2014) 7, 2942

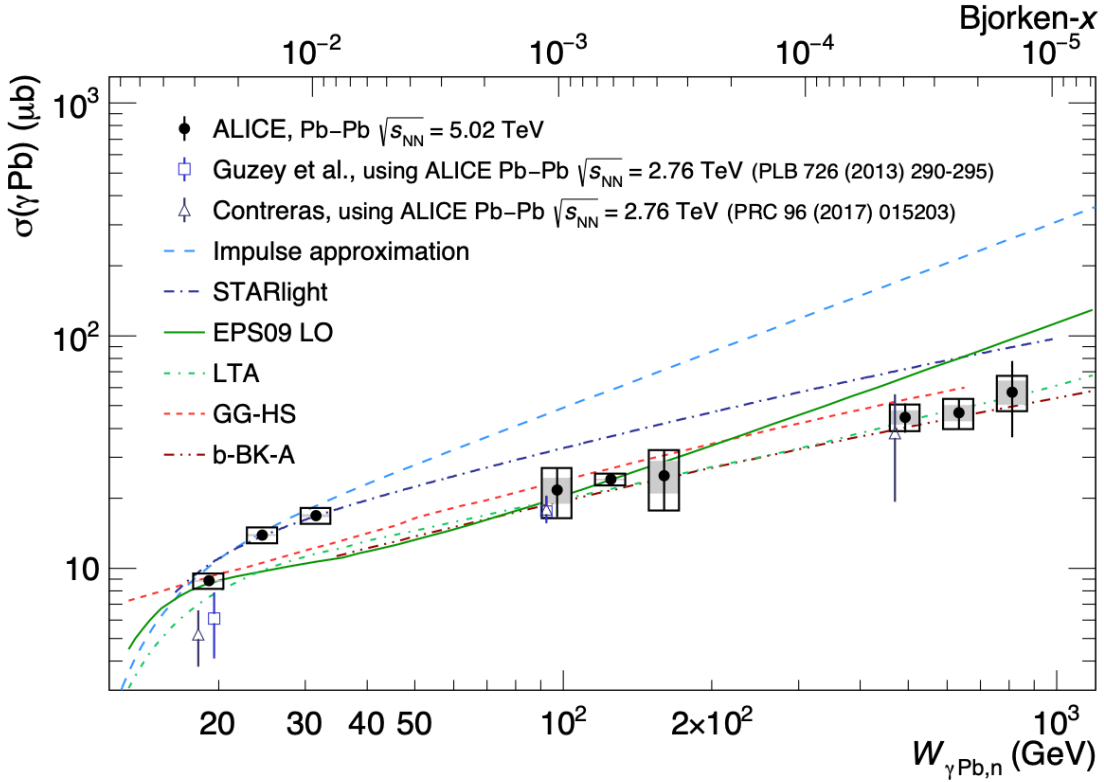
Energy dependence of coherent J/ψ in γPb – ALICE Run 1 and Run 2 data

Confirmed Run 1 results. At low x, both shadowing and saturation models describe the data

Energy dependence across the whole range not described by models

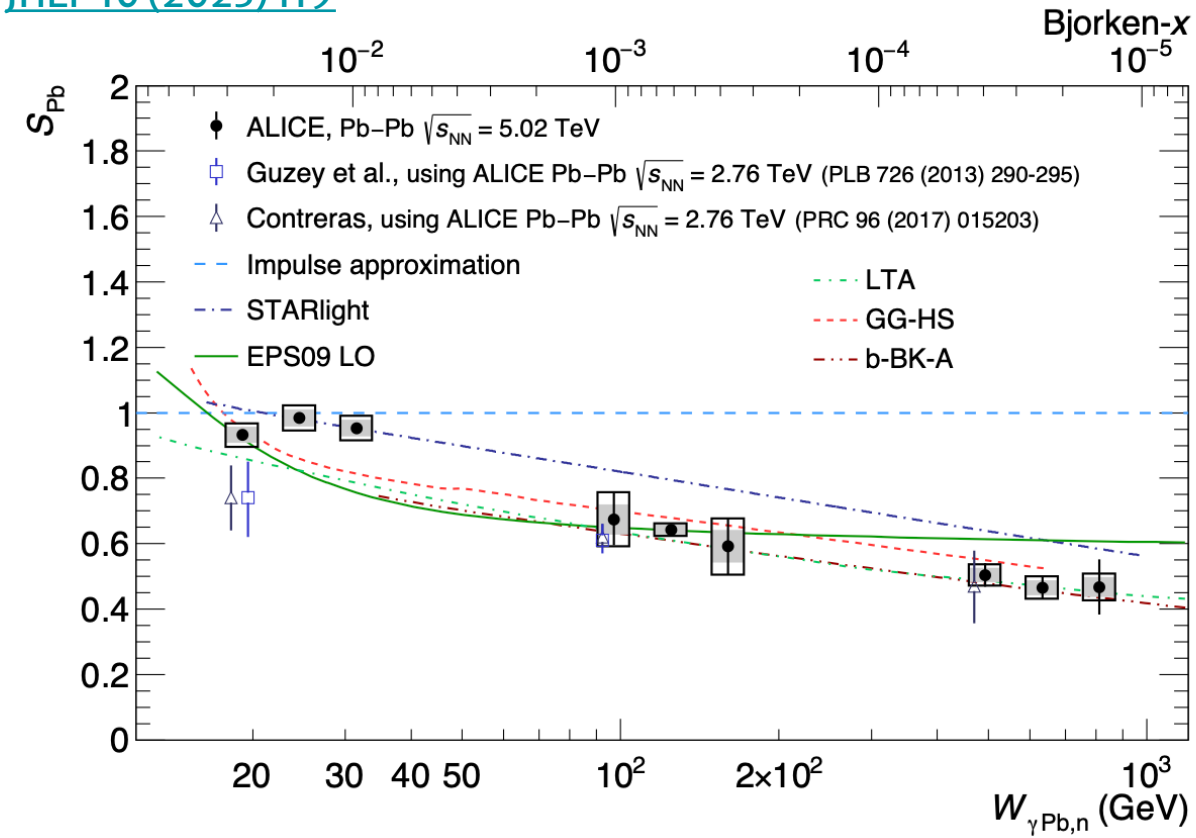
In a single experiment exploring (20,800) GeV in $W_{\gamma Pb}$ and x from 10^{-2} to 10^{-5}

JHEP 10 (2023) 119



Nuclear suppression factor – ALICE Run 1 and Run 2 data

JHEP 10 (2023) 119

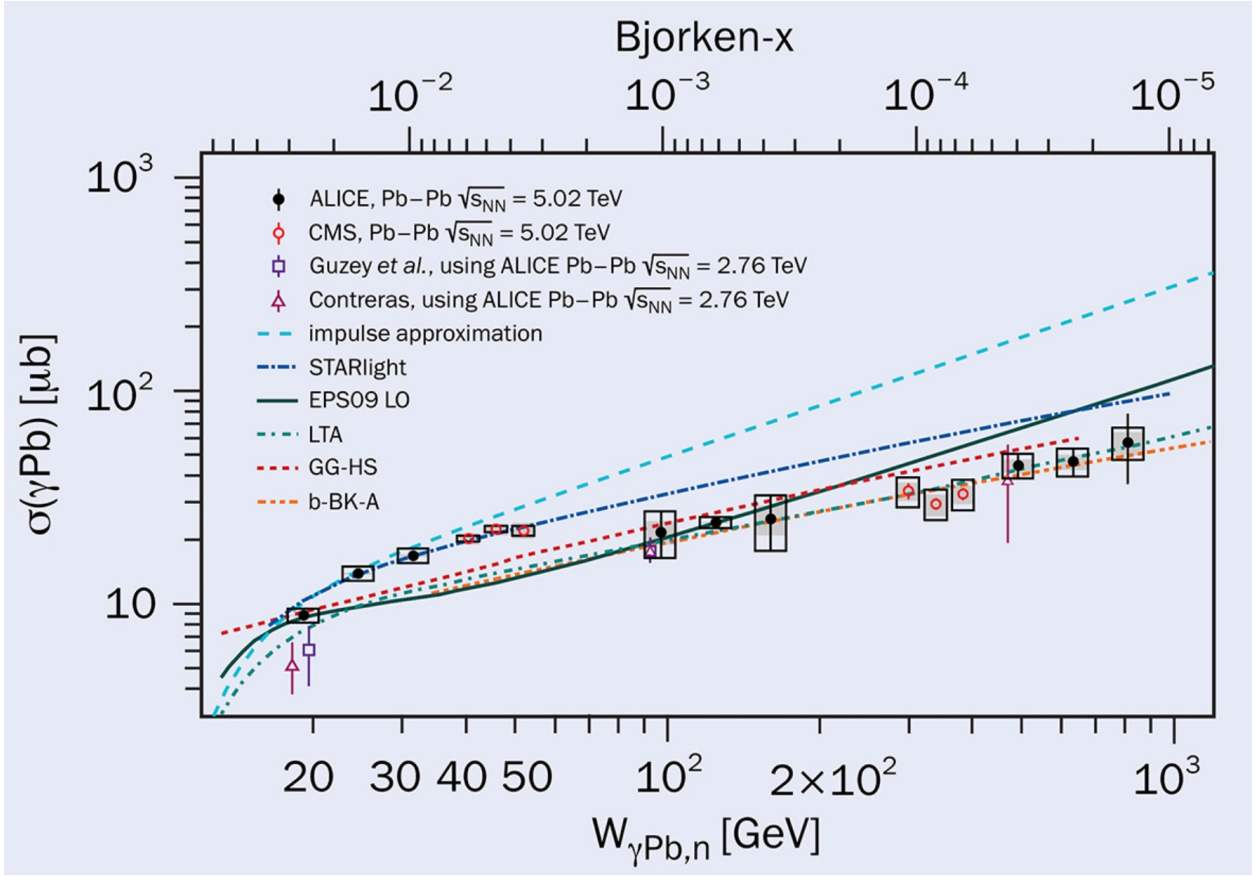


At low x, both shadowing and saturation models describe the data

Confirmation that peripheral hadronic events can be used to extract the energy dependence. Already explored down to $x = 4.4 \times 10^{-5}$ using Run 1 data

With the neutron-dependent analysis using Run 2 data, down to $x = 1.1 \times 10^{-5}$, Run 2

Energy dependence of coherent J/ψ in γPb

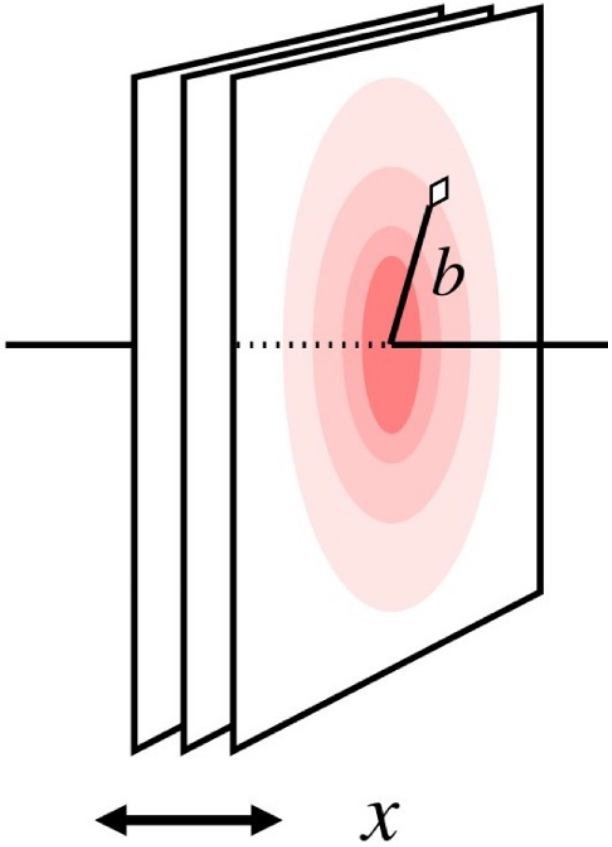


JHEP 10 (2023) 119

Both gluon saturation and shadowing describe the data at high energies

At low energies the data cannot be described by these models

Transverse profile of the target

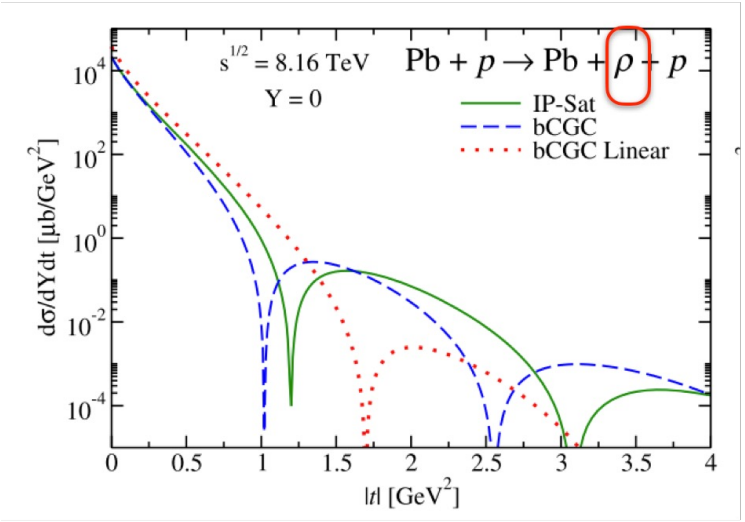


UPCs can probe the transverse profile of the target!

Appearance and location of diffractive dips can be signatures of gluon saturation

Transverse profile of the target

V. Goncalves, et al.
Phys. Lett. B791 (2019) 299-304

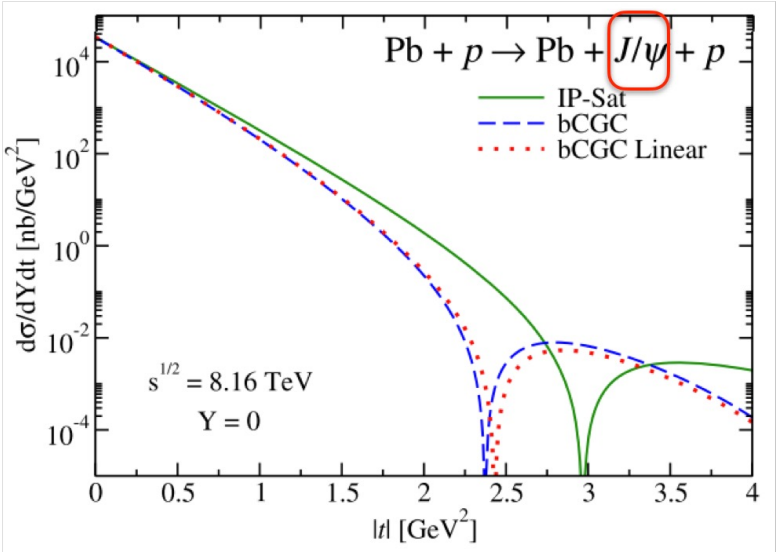


Location of the Diffractive dips:
Different for IP-Sat and bCGC

Energy dependence of the t-distribution: onset of gluon saturation

Signature of gluon saturation

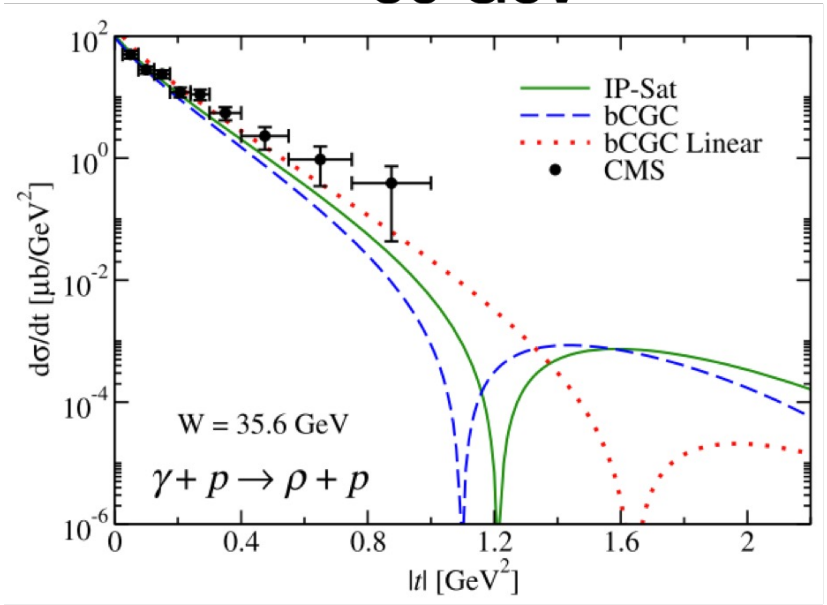
Study of ρ^0 is very promising since diffractive dips expected at lower t values



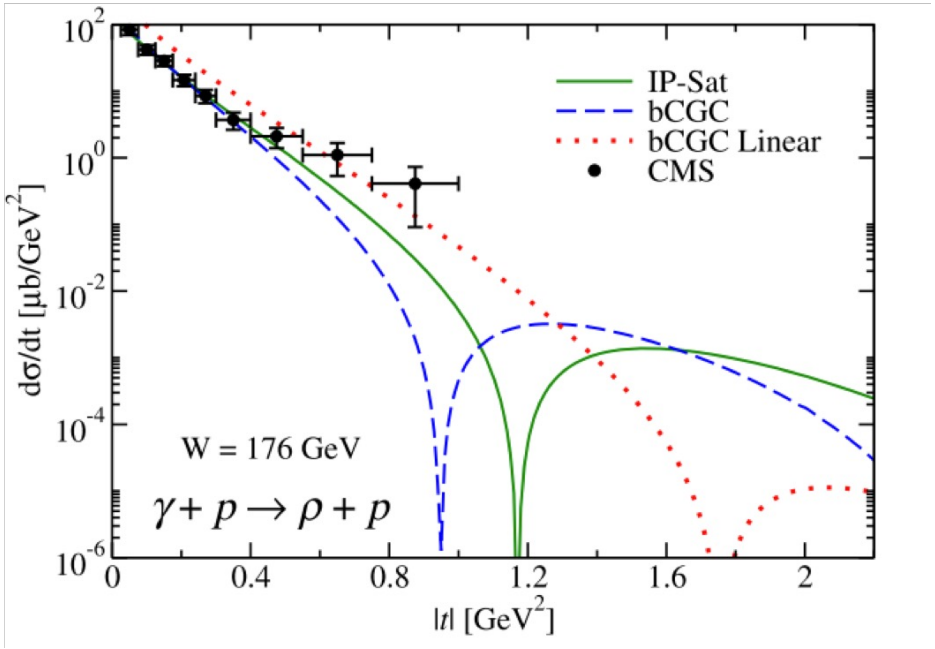
t-dependence measurement of UPC ρ^0

V. Goncalves, et al.
Phys. Lett. B791 (2019) 299-304

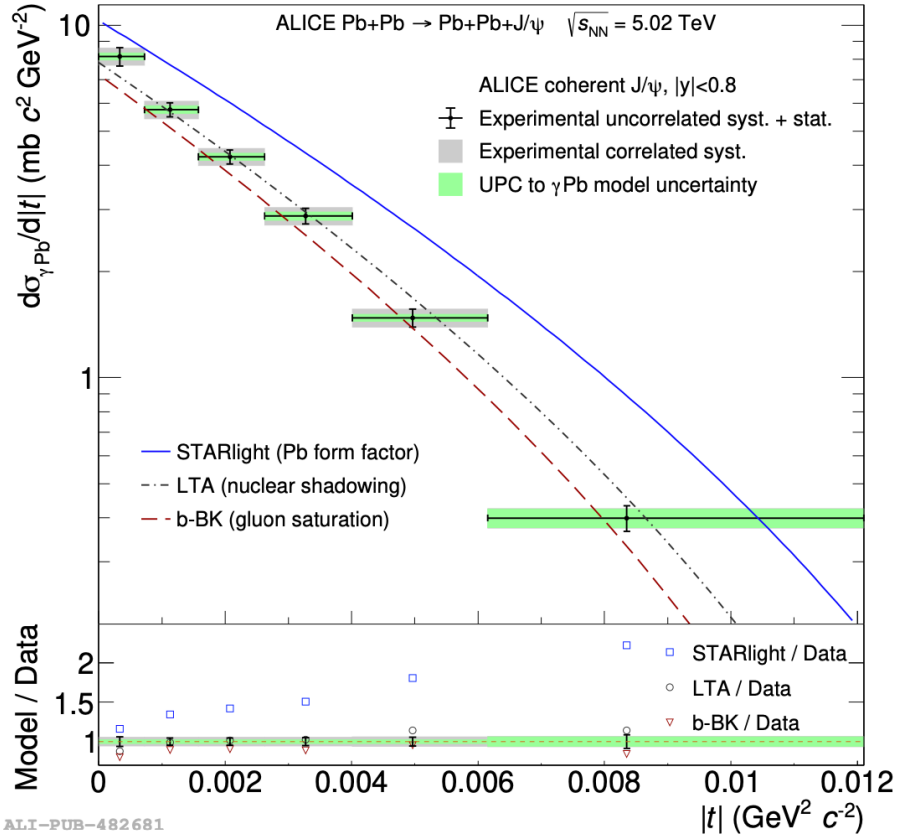
36 Gev



176 Gev

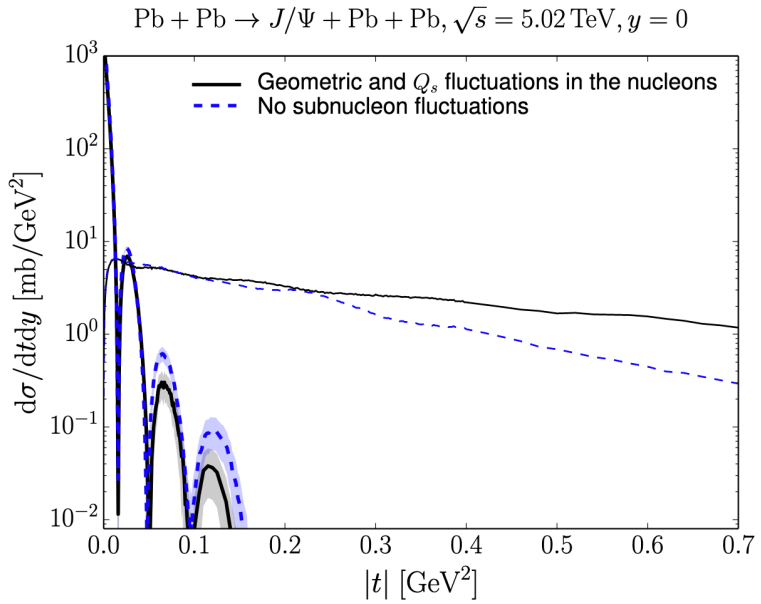


t-dependence measurement of UPC J/ψ



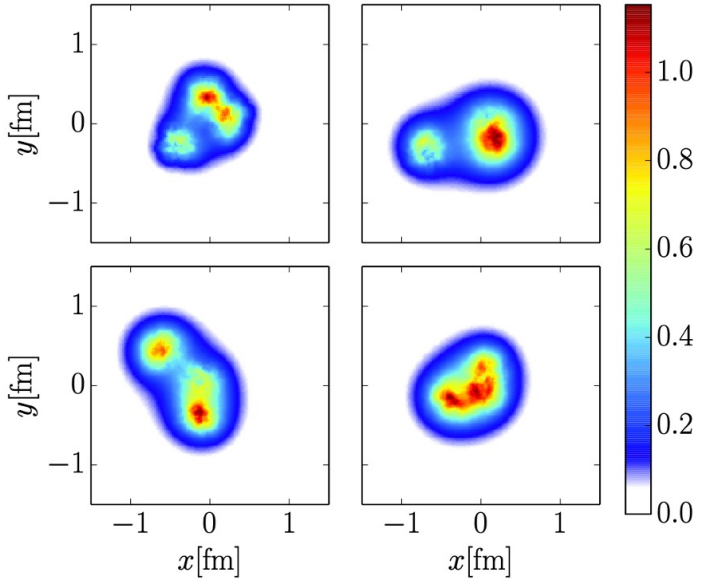
Dissociative/incoherent J/ψ in γp

H. Mantysaari and B. Schenke,
Phys. Lett. B772 (2017) 832



J. Cepilia, J.G. Contreras and DTT
Phys. Lett. B 766 (2017) 186-191

Event-by-event fluctuations



Mantysaari and Schenk, PRD 94, 034042 (2016)
S. Klein arXiv:2301.014018

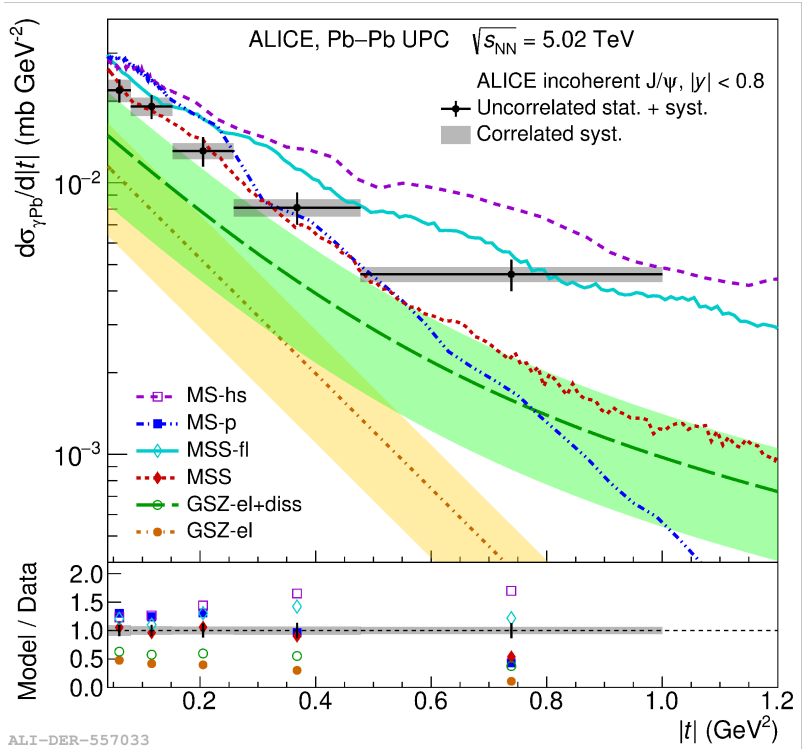
In the Good-Walker approach, sensitive to subnucleonic fluctuations of the gluon density

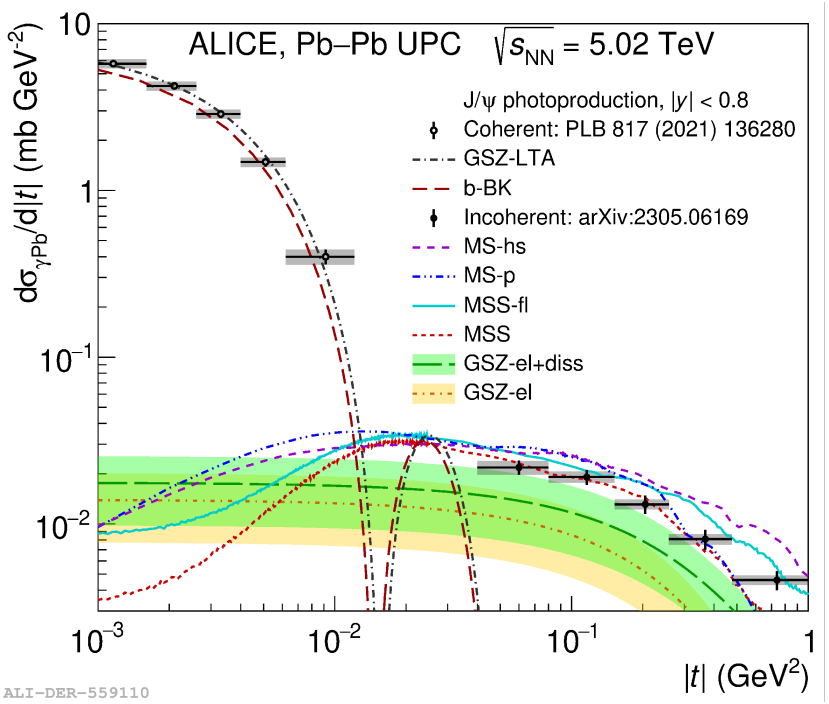
$$\frac{d\sigma(\gamma p\to \mathrm{J}/\psi Y)}{dt}=\frac{R_g^2}{16\pi}\left(\left\langle\left|A(x,Q^2,\vec{\Delta})\right|^2\right\rangle-\left|\left\langle A(x,Q^2,\vec{\Delta})\right\rangle\right|^2\right)$$

t-dependence of coherent and incoherent J/ψ in UPC PbPb

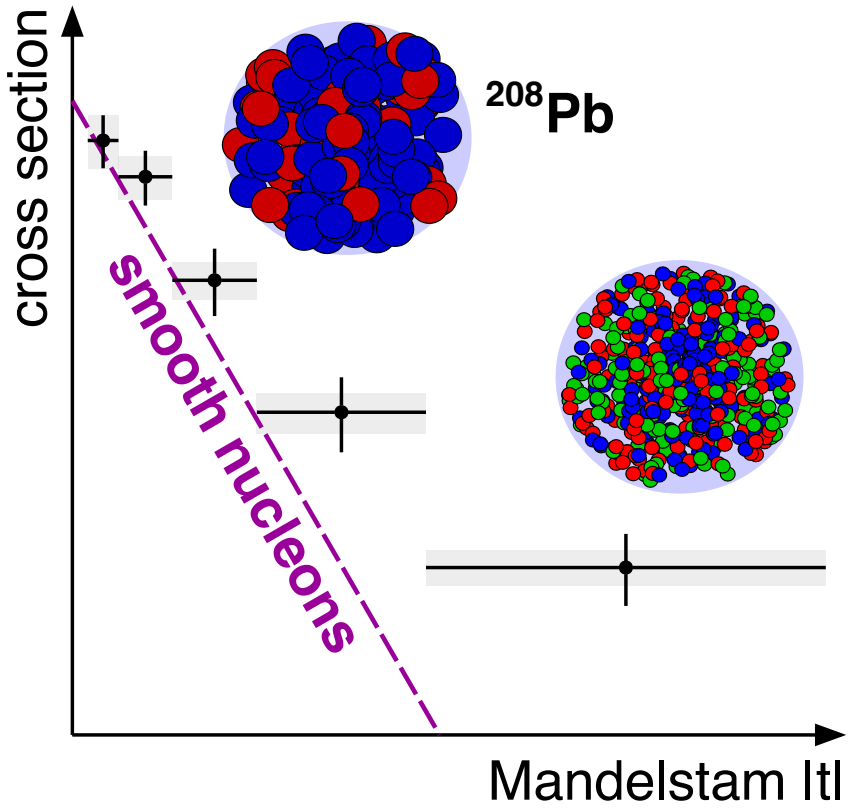
First measurement of the |t|-dependence of incoherent J/ψ photonuclear production
https://arxiv.org/abs/2305.06169

Probing for gluonic ”hot spots” in Pb using UPCs for the first time!





t-dependence of incoherent J/ψ in UPC PbPb

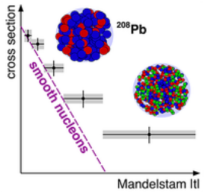


Editors' Suggestion

First Measurement of the $|t|$ Dependence of Incoherent J/ψ Photonuclear Production

S. Acharya *et al.* (ALICE Collaboration)

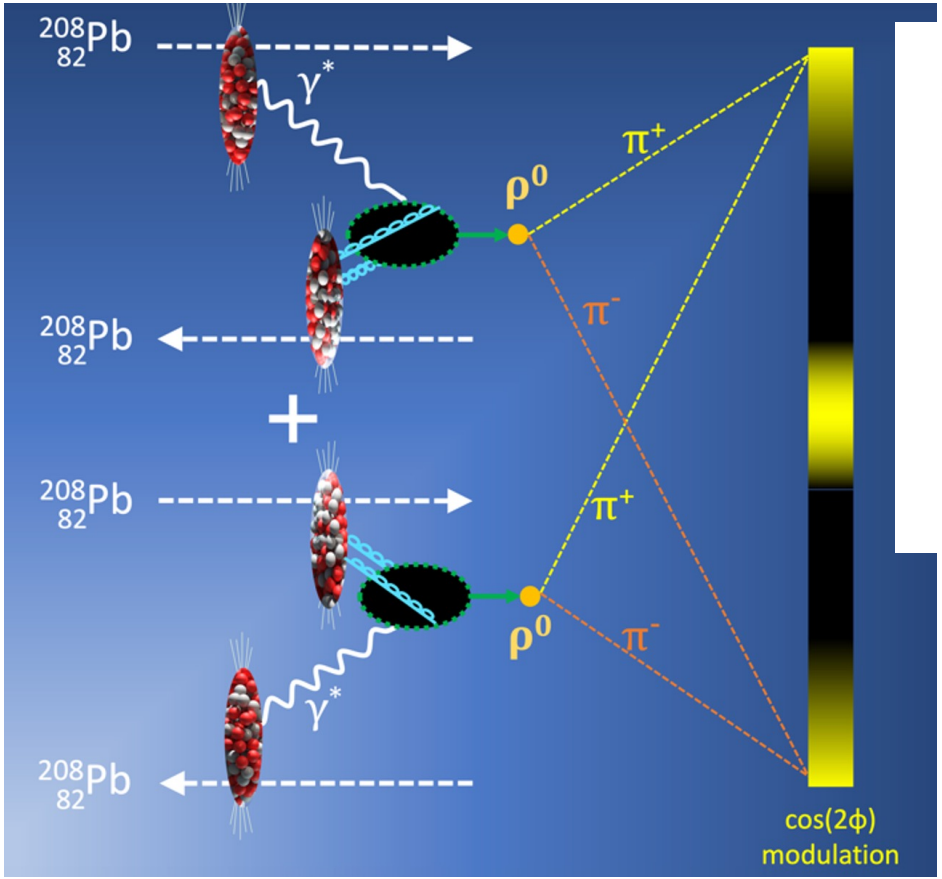
Phys. Rev. Lett. **132**, 162302 (2024) – Published 19 April 2024

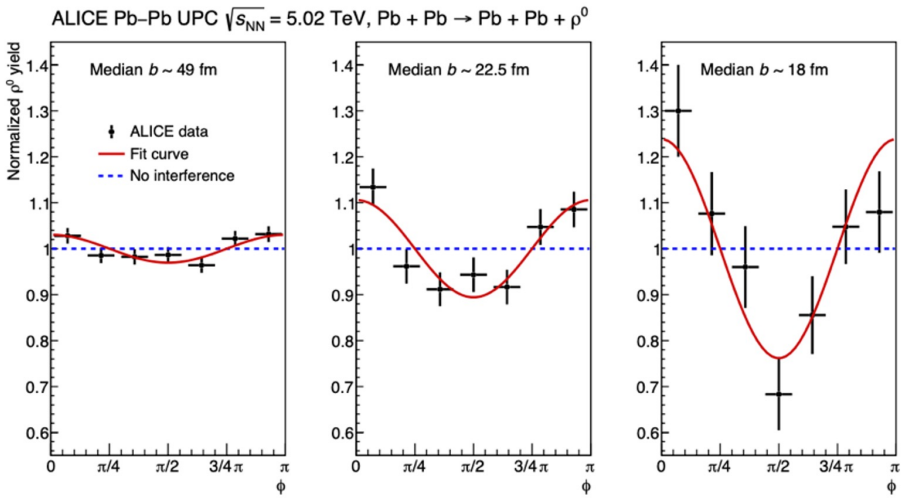


The first experimental measurement of the incoherent photonuclear production of J/ψ in ultraperipheral heavy-ion collisions is better explained by the presence of subnuclear quantum fluctuations of the gluon field.

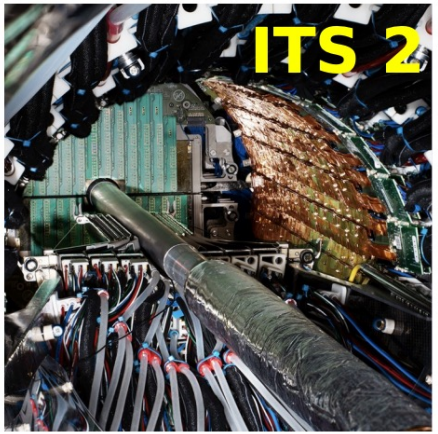
Show Abstract +

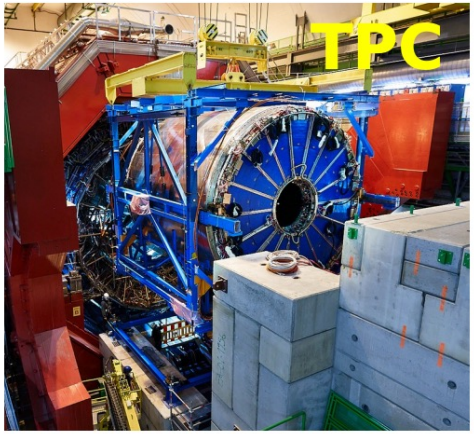
A femtometer-scale double-slit experiment with ALICE

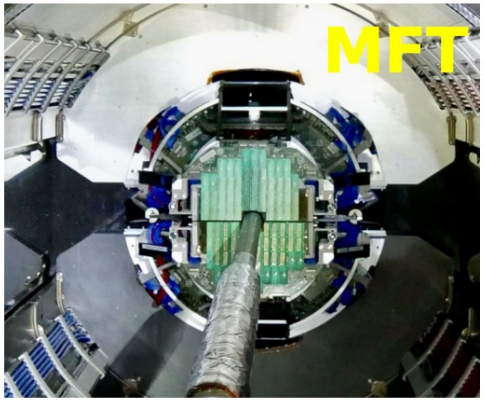


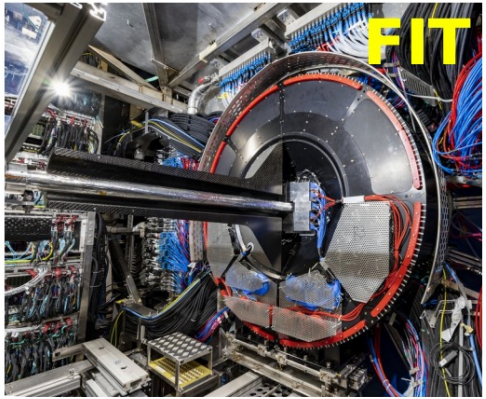


ALICE in Run 3: A major upgrade



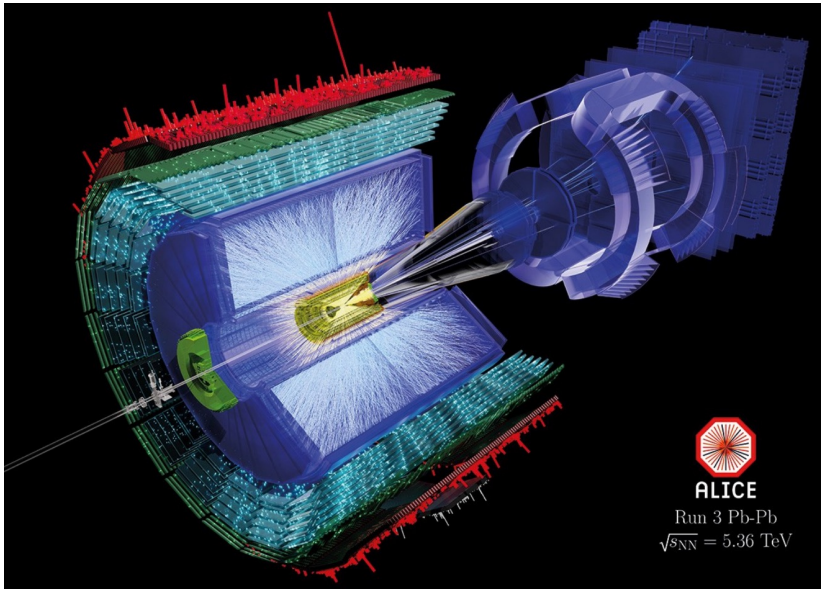


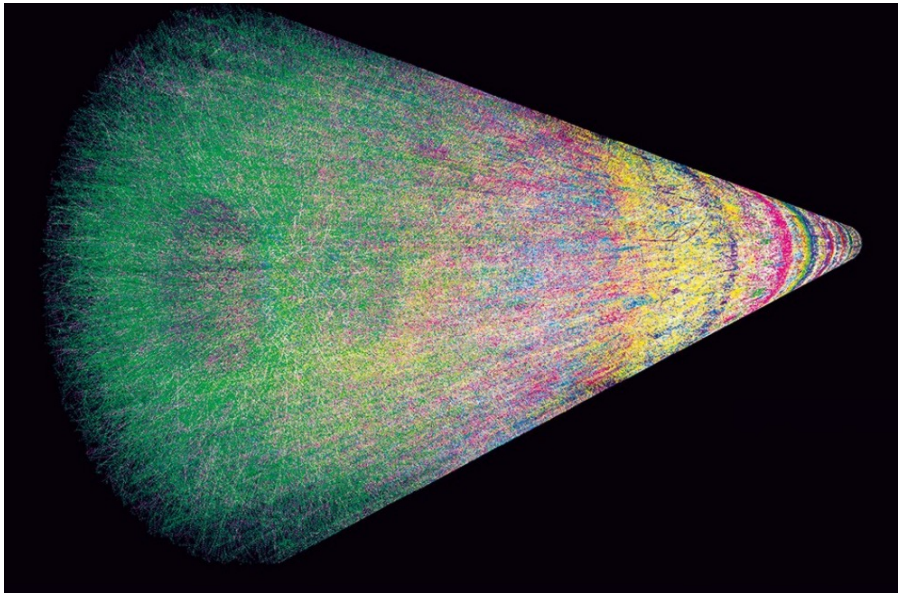




- 50 times increase in the readout rate
- 3 to 6x improvement in pointing resolution
- Secondary vertexing for forward muons

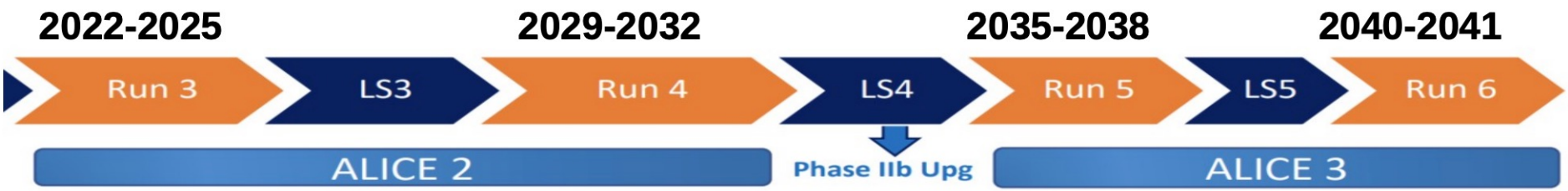
ALICE in Run 3: Trigger-less mode

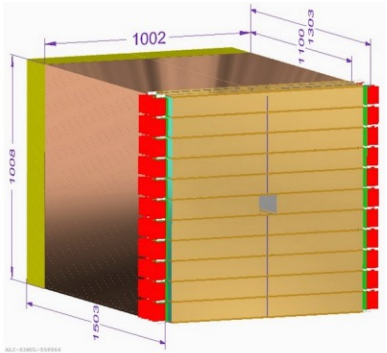


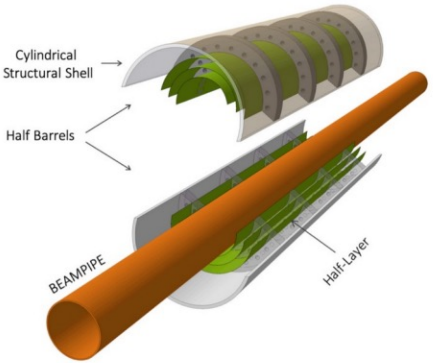


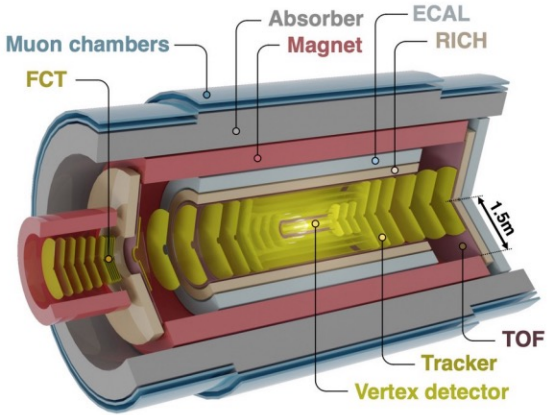
2 msec time frame of Pb-Pb collisions at a 50 kHz interaction rate in the TPC

ALICE timeline









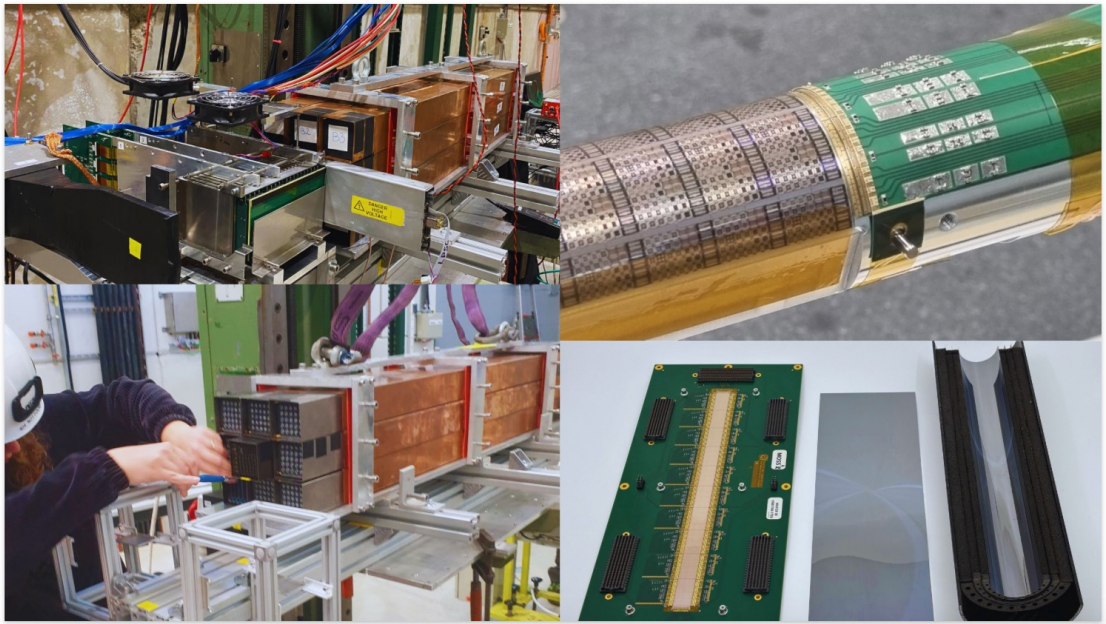
FoCal and ITS3

ALICE3

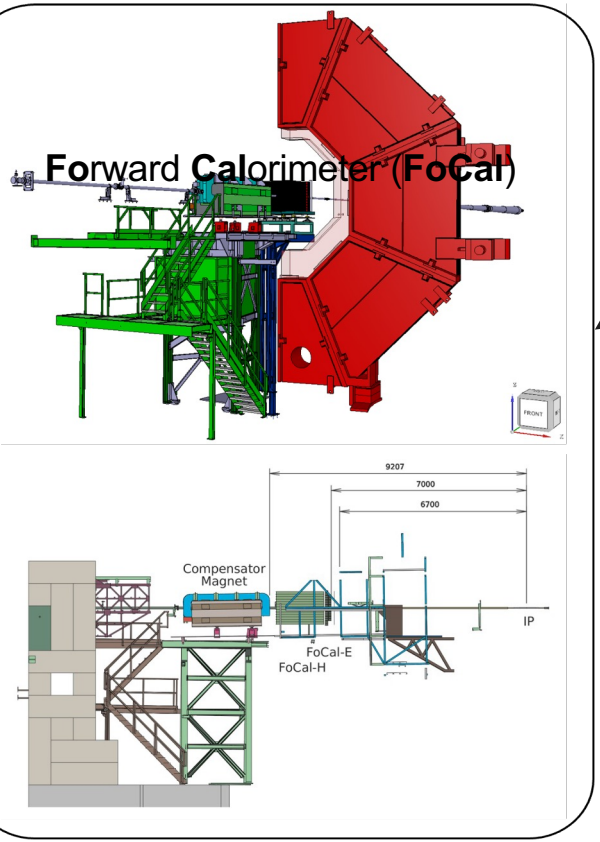
ALICE gets the green light for new subdetectors

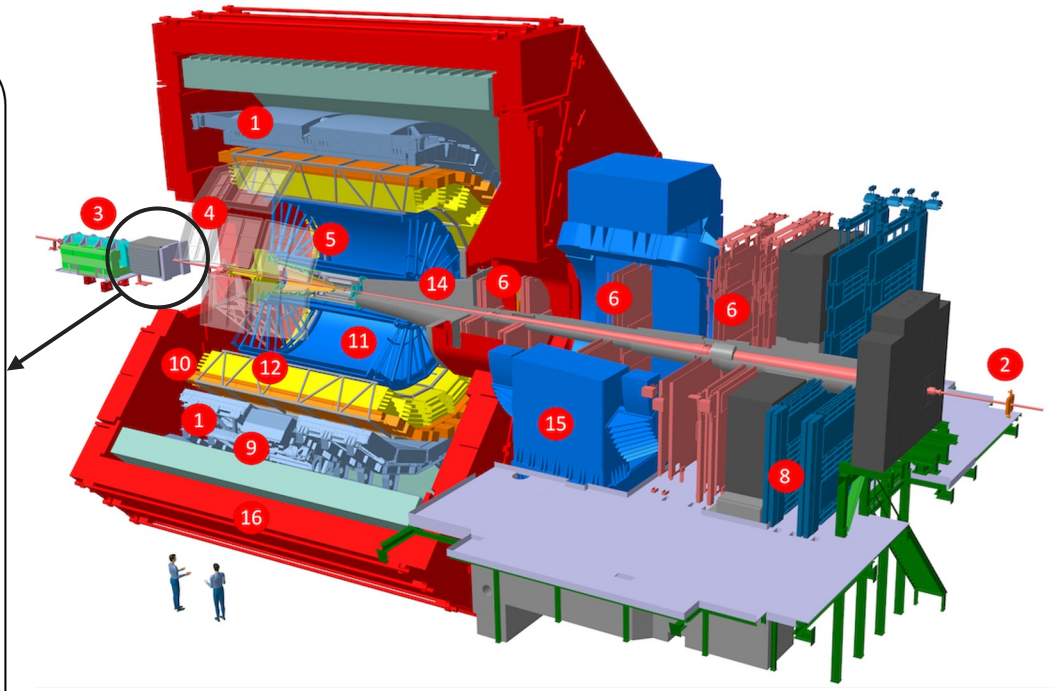
CERN's dedicated heavy-ion physics experiment, ALICE, is upgrading its Inner Tracking System and adding a forward calorimeter for the next phase of the LHC upgrade

25 APRIL, 2024 | By ALICE collaboration



The FoCal experiment at ALICE



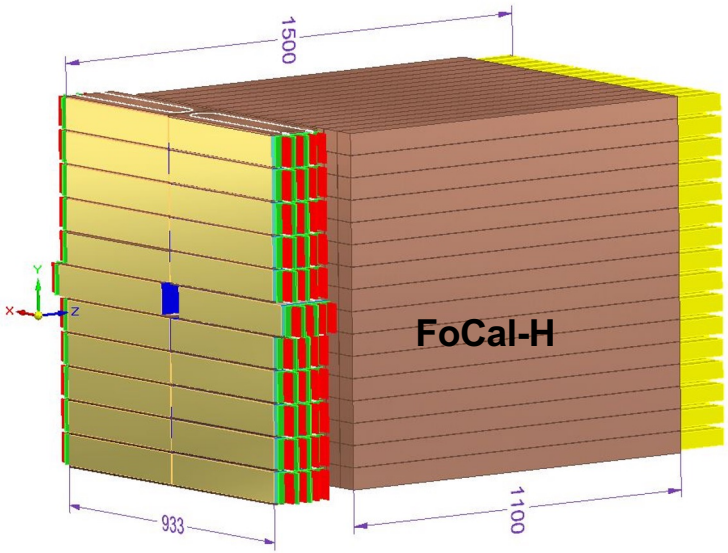


| Part of the ALICE upgrade for Run 4 (starting from 2029)

| Positioned 7 m from IP2 (A-side)

| covering $3.4 < \eta < 5.8$

The FoCal detector at ALICE



FoCal-E

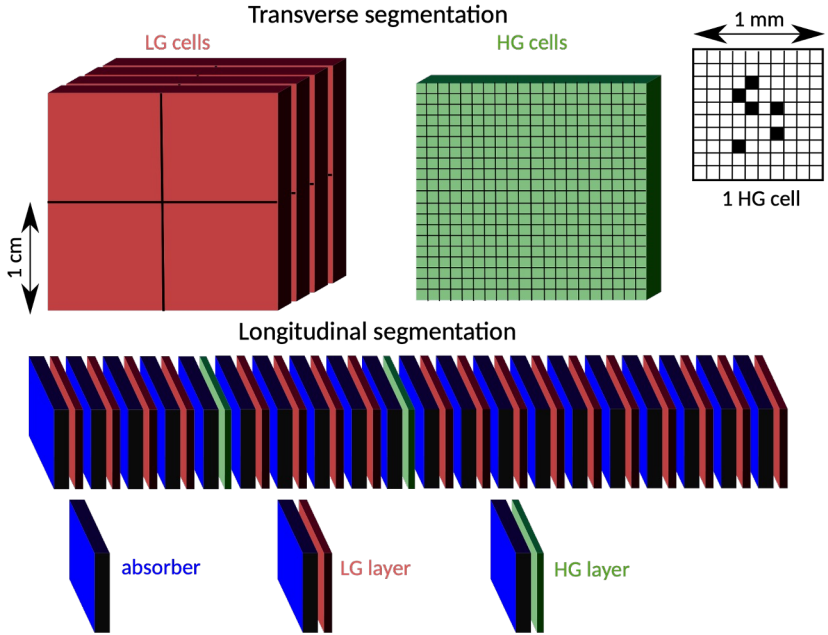
FoCal-E

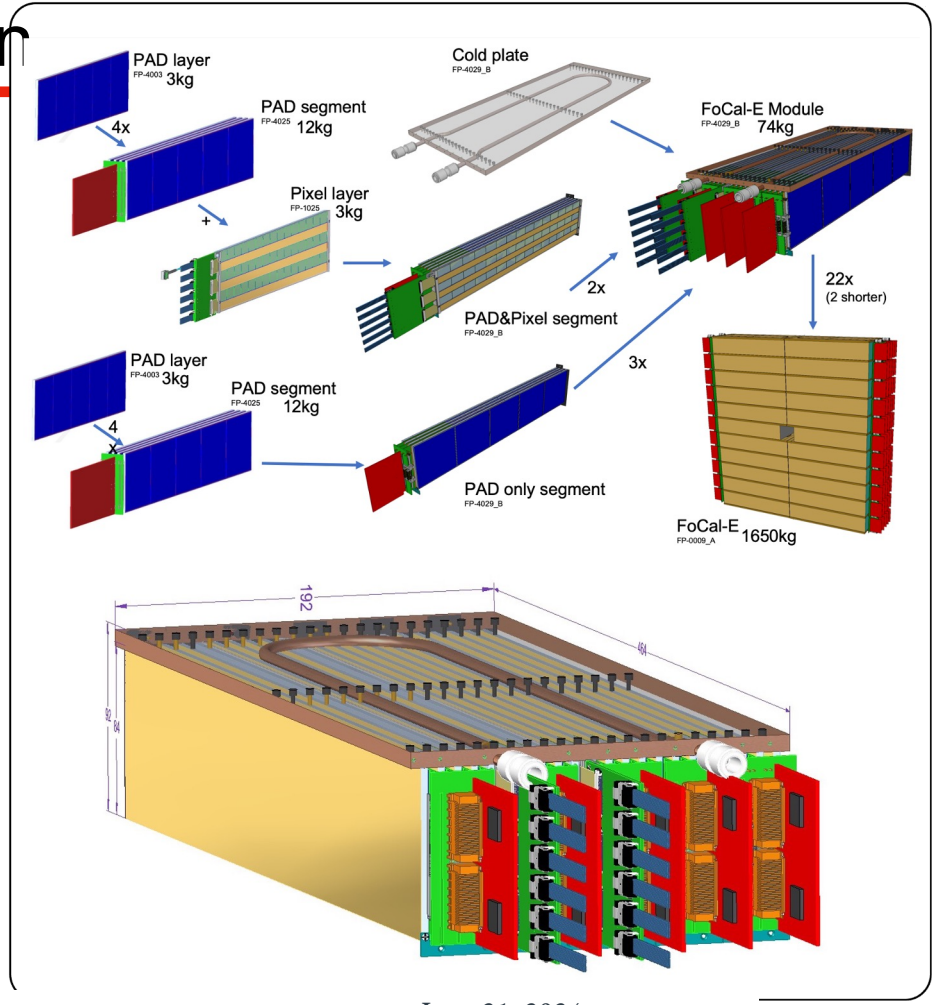
- 20 Layers (LG + HG Si detectors + W absorbers). Tot (~ 20 X0)
- Dimensions ~ 90cm x 98cm x 20cm
- Designed for:
  - measurement of direct photons
  - Measurement of high pt neutral pions (Pb-Pb vs p-p)
  - Granularity optimized to enable photons separation (~ 5mm distance)

FoCal-H

- Transversally segmented calorimeter Tot thickness ~ 6 λhad
- located behind FoCal-E (reduce shower blow-up)
- Designed for:
  - Studying the dynamics of hadronic matter with photons and jets (isolation capabilities (single hadron res ~ 20-25%))

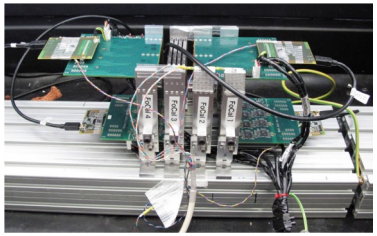
The FoCal-E detector design





FoCal prototypes

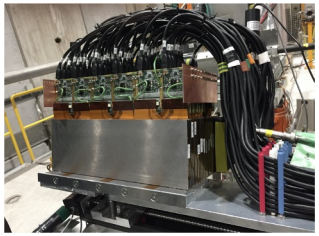
2010-2015



ORNL / Japan prototype:
- NIM A 988 (2021) 164796

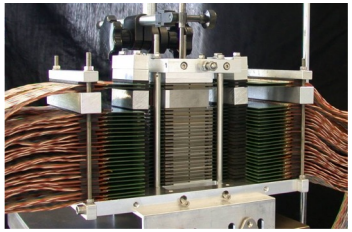
Indian prototypes:
- NIM A 764 (2014) 24
- JINST 15 (2020) 03, P03015

2014-2018



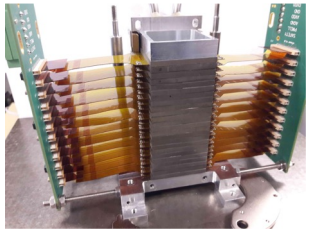
Mini-FoCal (PADs only) in beam at P2

2014-2016



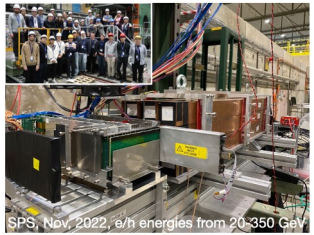
MIMOSA pixel tower (EPICAL)
JINST 13 (2018) P01014

2018-2021



ALPIDE pixel tower (EPICAL-2)
NIM A1045 (2023) 167539
arXiv:2209.02511

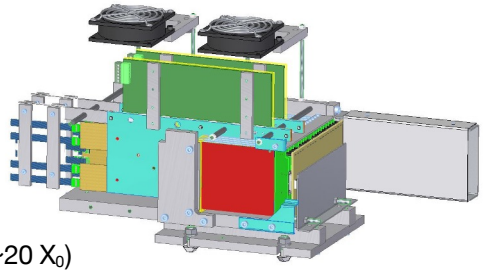
2019-2022



FoCal-E and H prototypes
- final sensors and chips close-to-final readout

Current state of the TB prototypes:

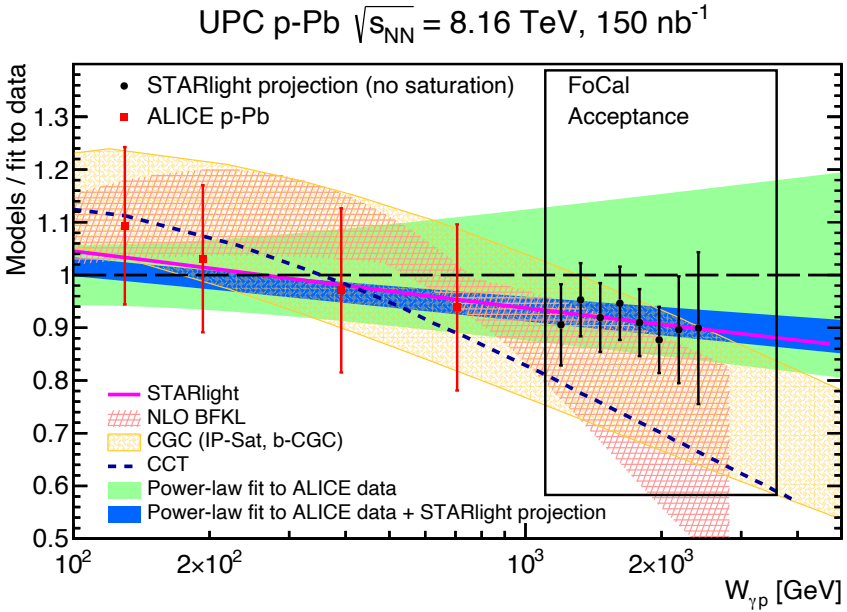
FoCal-E
- 18 LG Layers (Si Pads)
  - 9x8 array
  - 1cm2 resolution
- 2 HG Layers (Si Pixels)
  - L5 and L10
  - 6 OB ITS HICs, 2 IB
  - ~ 30 um2 res
  - 20 Tungsten layers (~20 X_0)



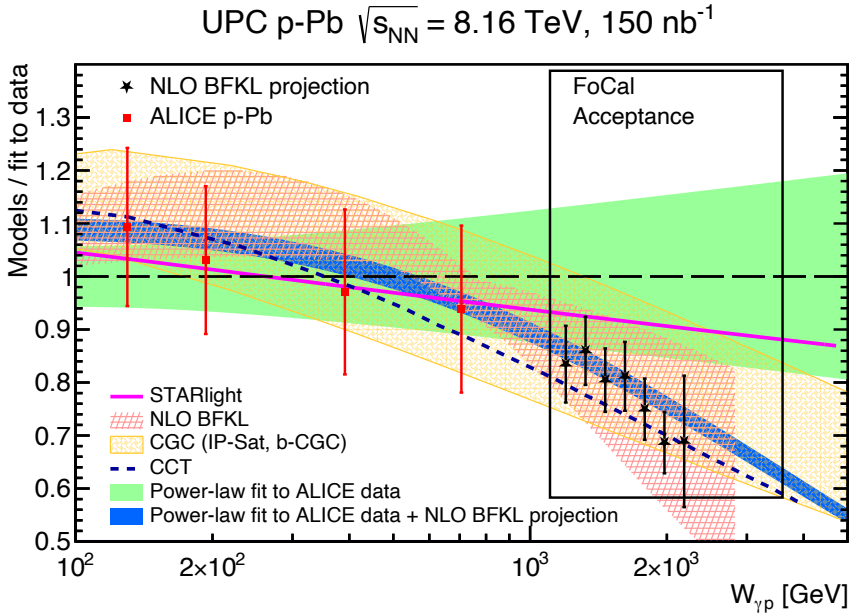
FoCal-H
- 6.5 cm x 6.5 cm x 110 cm
- BCF12 scintillating fiber
  49 (central), 25 (sides)
- SiPMs
  2/3 CAEN DT5202 boards

Projections for exclusive J/ψ off protons

Power-law behavior (STARlight)

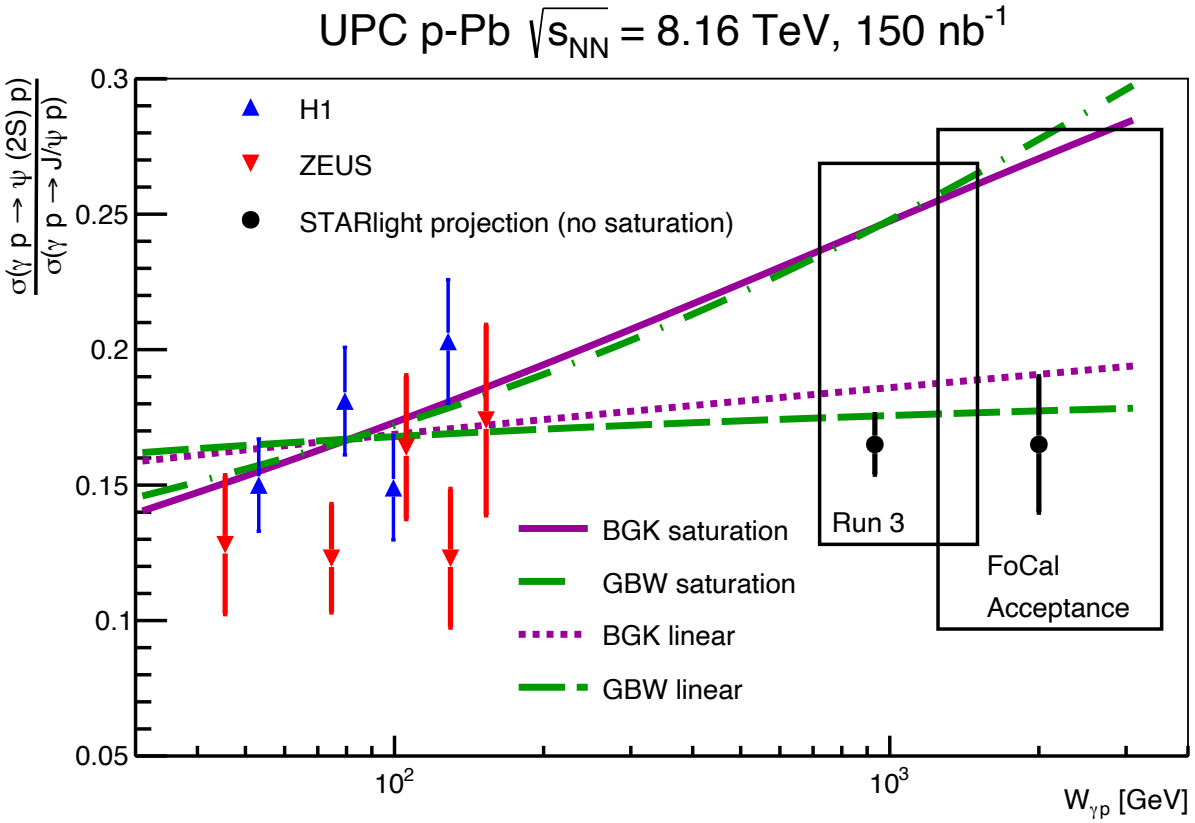


Broken power-law behavior (NLO BFKL)



FoCal measurement would be sufficient to observe a deviation from a power law behavior, if exists

Projections for exclusive ψ(2S) and J/ψ cross section ratio in γp



- Different wave functions and dipole sizes evolution result in great sensitivity to non-linear QCD effects
- No sensitivity at HERA, but expected at the LHC
- Projections here based on STARlight


I·AN
Network of Networks
Inter-American
QCD


NSF


NSF
EPSCoR

I·AN Inter-American Network of Networks QCD

Program goals

(1) Develop strategic partnerships across the various physics research networks in the Americas to tackle QCD challenges;

(2) Identify the needs, strengths and synergies of network partners for developing large scale science projects in the US;

(3) Design activities for researchers in the U.S., Canada, and Latin America that will facilitate leveraging complementary resources for QCD research, and

(4) Enhance the training of the next generation of researchers in a novel set of skills that include international multi-team experience.

I·AN Inter-American Network of Networks QCD

Research areas related to QCD

- Accelerator technologies
- Theory
- High performance computing
- Particle detectors, instrumentation and electronics
- Real-time event selection
- Software development, and development of Monte Carlo simulation
- AI and QIS tools

Kick-off meeting at CFNS on Dec 16, 2021

120 participants

https://indico.bnl.gov/event/13562/

I·AN Inter-American Network of Networks QCD

List of invited networks

We are an open network: future networks can also participate

- Electron-Ion Collider User Group
- Jefferson Lab Users Association
- RHIC and AGS User's Group
- US LHC Users Association
- Association of Latin American Nuclear Physics and Applications (ALAFNA),
- Southeastern Universities Research Association (SURA)
- Latin American Association for High Energy, Cosmology and AstroParticle Physics
- Nuclear Physics and Applications (INCT-FNA)
- Rede Nacional de Física de Altas Energias (RENAFAE)
- Mexican Particle Accelerator Community (CMAP)
- EIC-Canada Collaboration
- California EIC Consortium

I·AN Inter-American Network of Networks QCD

List of invited network partners

We are an open network: future networks can also participate

- Center for Frontiers in Nuclear Physics (CFNS) at Stony Brook University & Brookhaven National Laboratory
- The Electron-Ion Collider Center at Jefferson Lab
- Center for Accelerator Science at Old Dominion University
- The ICTP South American Institute for Fundamental Research (ICTP-SAIFR)
- Canadian Institute of Nuclear Physics
- TRIUMF. Canada's Particle Accelerator Center
- The Institute of Nuclear Theory
- Center for Nuclear Femtography

I·AN Inter-American Network of Networks QCD

Community-led program

Some examples of activities of interest

- Support to organize workshop, conference, summer schools
- Support for research visits
- Mobility
  - US person → to Canada or Latin America
  - Canadian or Latin American person → to US
- Support White Papers or community-led documents preparations
- Young scientists-led events
- Projects that promote development of early-career researchers
- Activities that promote better communication channels

I·AN Inter-American Network of Networks QCD

Examples of supported proposals related to EIC so far - Full list will be published soon

- **Accelerators:**
  - EIC acceleration exchange visits between Mexican and TRIUMF at BNL and JLab
- **Experimental:**
  - Research visit of student from Chile and Mexico in the US (both ways)
- **Theory**
  - Research visits of US-Mexican students (both ways)
  - Research visits of Brazilian students in Tennessee, Illinois and Texas

Open for initiatives –

Go to http://www.iann-qcd.org

- For this call, IANN-QCD is interested in supporting the following types of activities:

Activity 1: Exchange visit programs

Activity 2: Early-stage research projects

Activity 3: Participation or organization of scientific meetings

Activity 4: Strategic partnerships

We also welcome any inquires

I·ANN Inter-American Network of Networks QCD

https://indico.ku.edu/event/416/

I.ANN QCD Summit 2024: Empowering New Talents and Building Global Networks

Jun 13 – 14, 2024
Washington DC
America/New_York timezone

Enter your search term

The I.ANN QCD Summit 2024: "The Future of QCD: Empowering New Talents and Building Global Networks" took place at the Hall of States in Washington, D.C. June 13 and 14.

The summit brought together key figures from government and diplomacy, network representatives, experts, scientists and early career researchers to discuss how research partnerships in strong interaction physics across the Americas can be accelerated, within the wider international community.

Useful links

Please help us advertising this program and get engaged !

Website:
https://www.iann-qcd.org

Join the IANN-QCD Mailing list
https://www.iann-qcd.org/mailing-list

Thanks!

The amplitude in the dipole picture

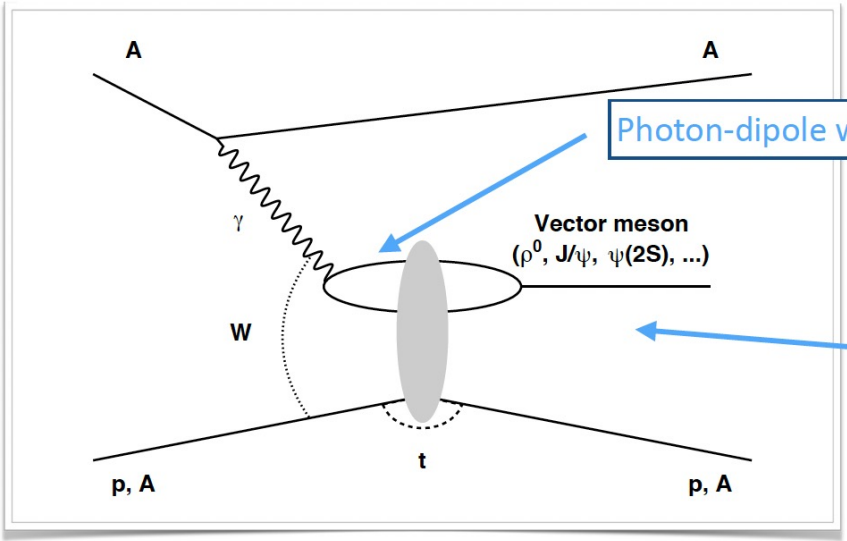
$$A(x,Q^2,\vec{\Delta})_{T,L} = i\int d\vec{r}\int_0^1 \frac{dz}{4\pi}(\Psi^*\Psi_V)_{T,L}\int d\vec{b}\, e^{-i(\vec{b}-(1-z)\vec{r})\cdot\vec{\Delta}}\frac{d\sigma_{\rm dip}}{d\vec{b}}$$

$\Delta^2=-t$

Dipole size

Quark energy fraction

Impact parameter



Photon-dipole wave function

Vector meson wave function

Dipole-Target cross section
pQCD physics gets here!