

Future Heavy Ion Physics studies with EIC

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KPS focus session

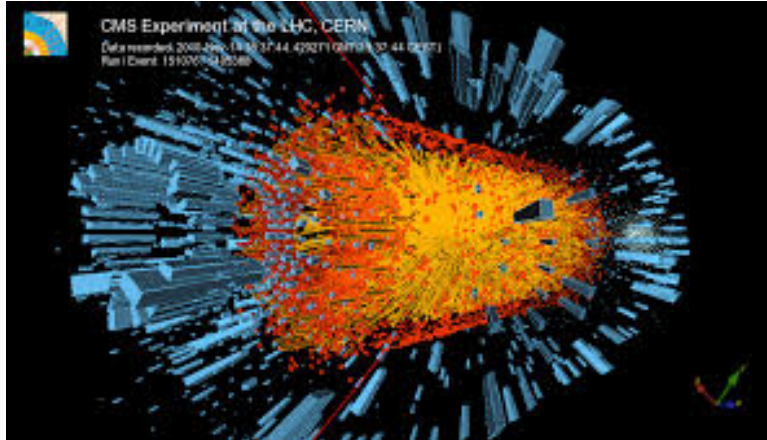
Cornerstone for future collider projects

2020.11.05



Nuclear experiments associated with Korean physicists

LHC - QGP



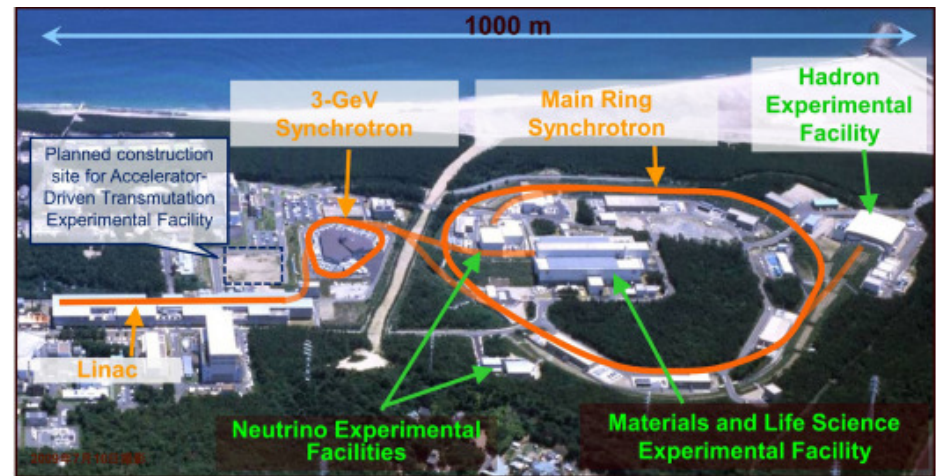
RHIC - QGP, spin



JLab - GPD, TMD

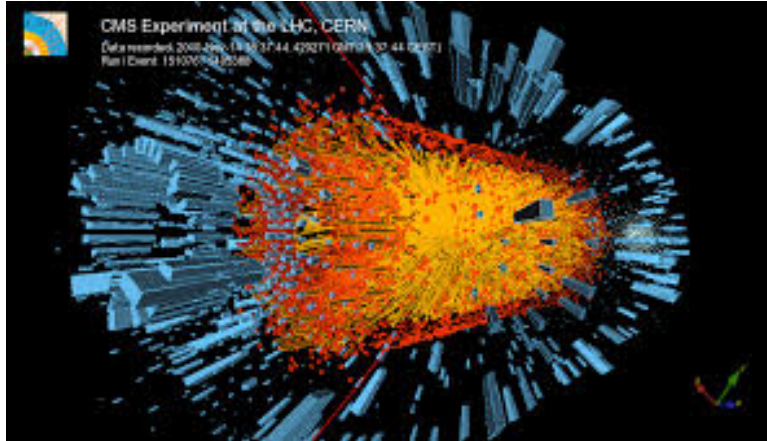


J-PARC - hadron physics



Nuclear experiments associated with K-physicists

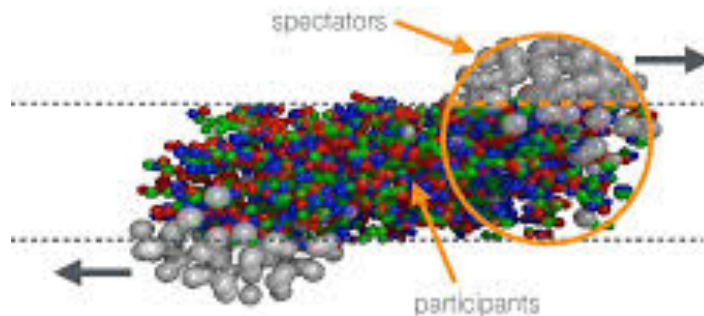
LHC - QGP



RHIC - QGP, spin



- * Today, we will discuss how to extend the relativistic heavy ion physics can be extended to EIC program
- * In particular, we will seek for the common physics observables in AA and eA



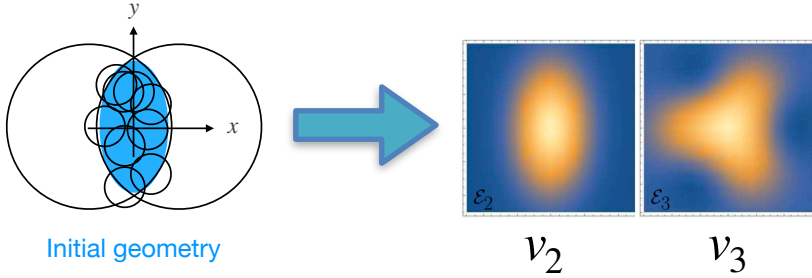
Ion-Ion collision



Electron-Ion collision

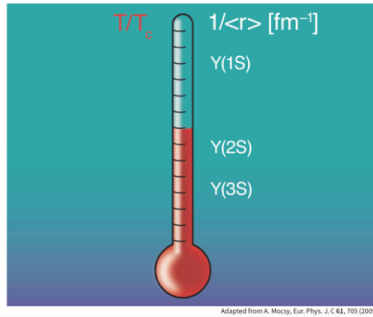
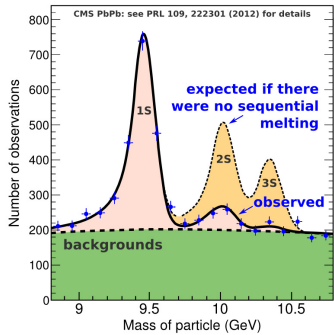
Mainstream Heavy Ion observables

Collective moment of particles in A+A, p+A and p+p



What is the collective motion in the very small system in e+A?

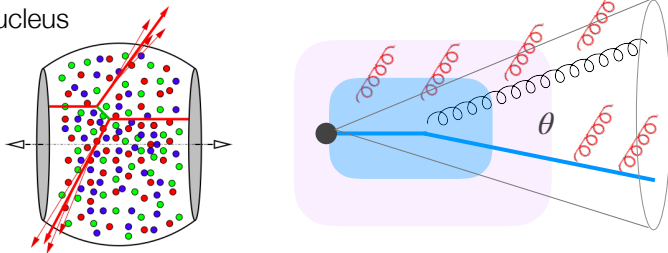
Disassociation of quarkonia by deconfined system



Nuclear modification by cold nuclear matter

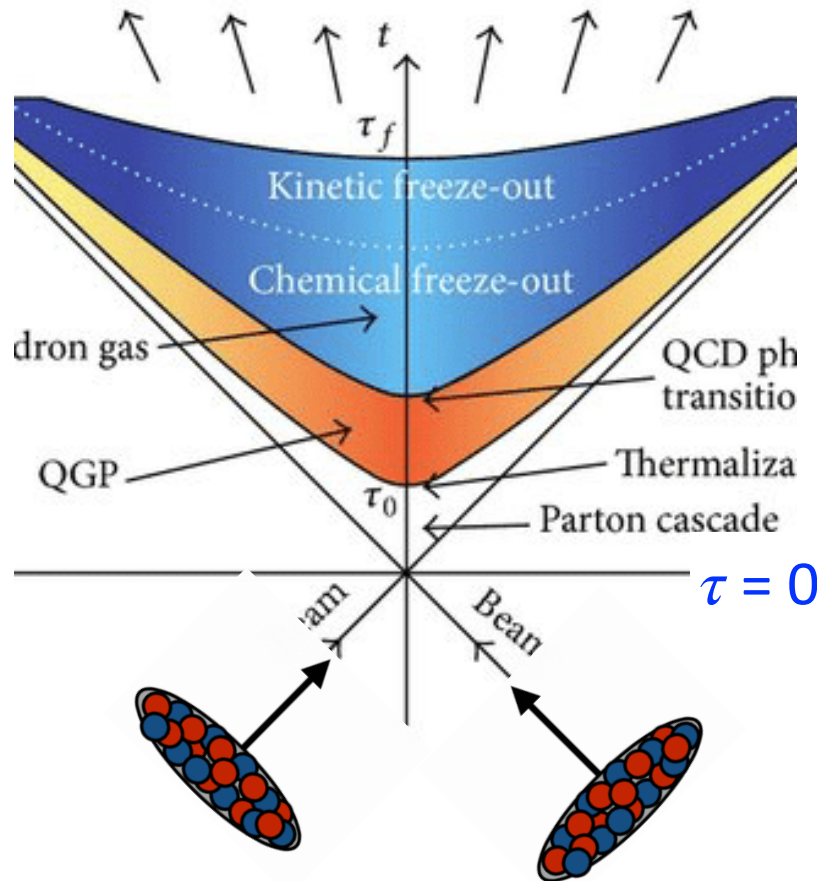
Jet quenching

nucleus



Energy loss and modification of constituent of jet by cold nuclear matter

Initial stage vs final stage



Final state effects

by medium, either cold or hot

- Jet quenching
- Debye screening
- Recombination
- Comover effect
- Elastic collision inside nucleus

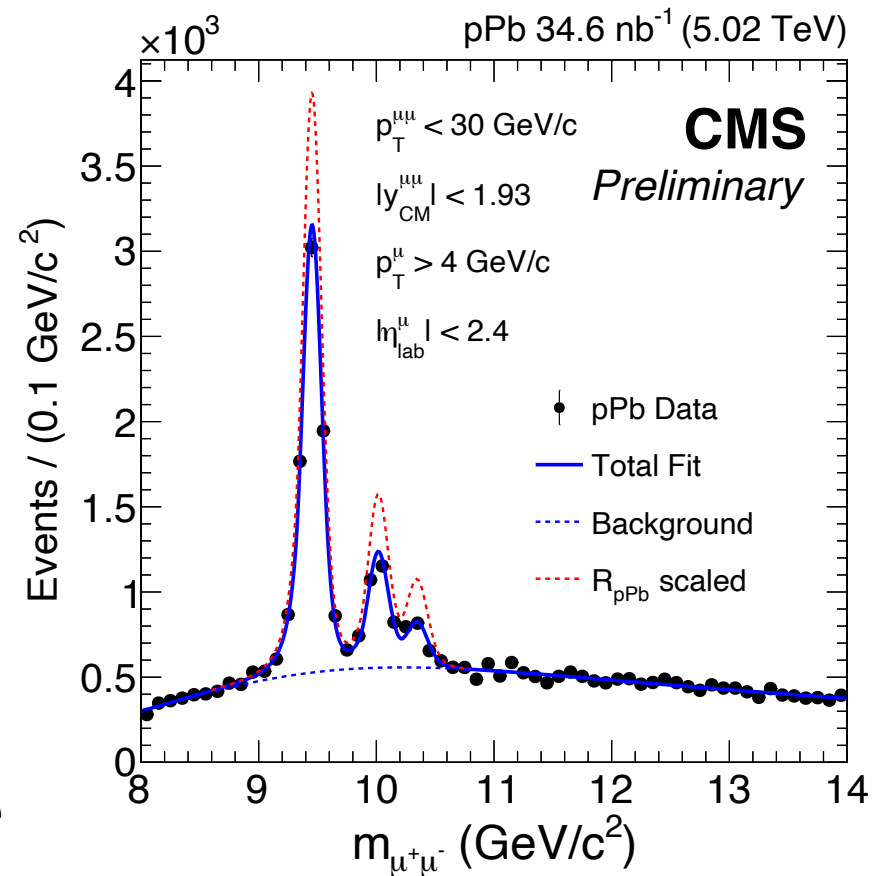
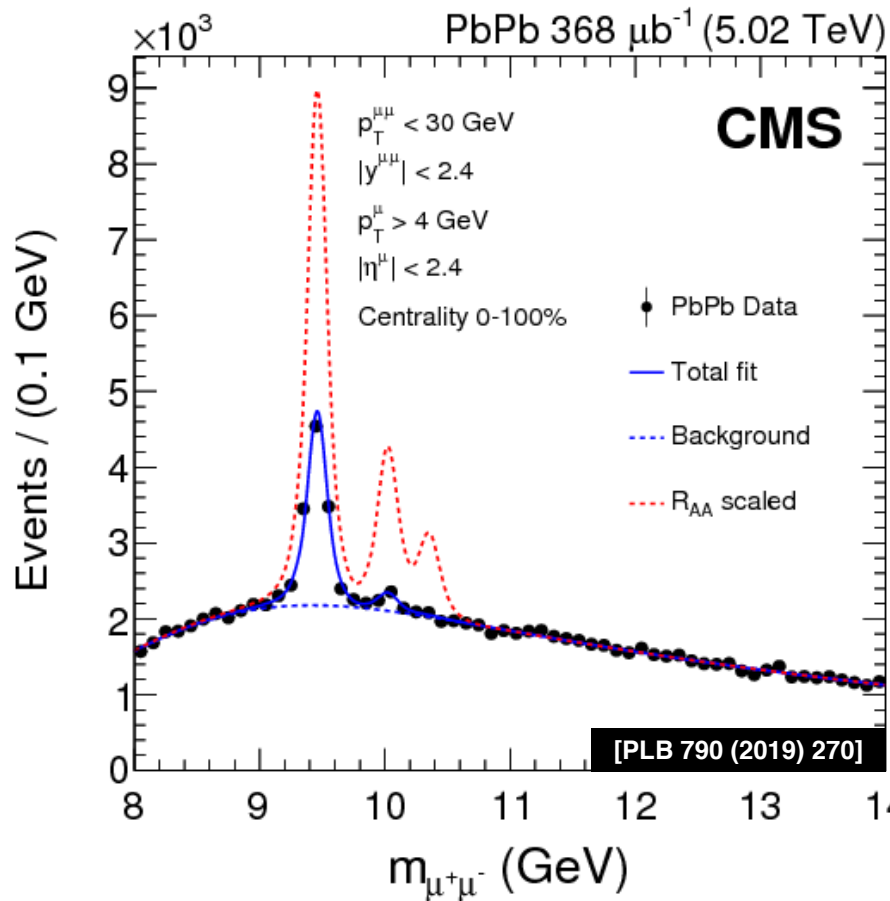
Initial state effects

Inherent to the nucleus

- nPDF
- Isospin effect

- At the LHC, the QGP signatures has been shown by comparing PbPb, pPb and pp
 - (a) PbPb : hot medium
 - (b) pPb : cold medium
 - (c) pp : vacuum environment

Example: R_{AA} and R_{pA} of $Y(nS)$



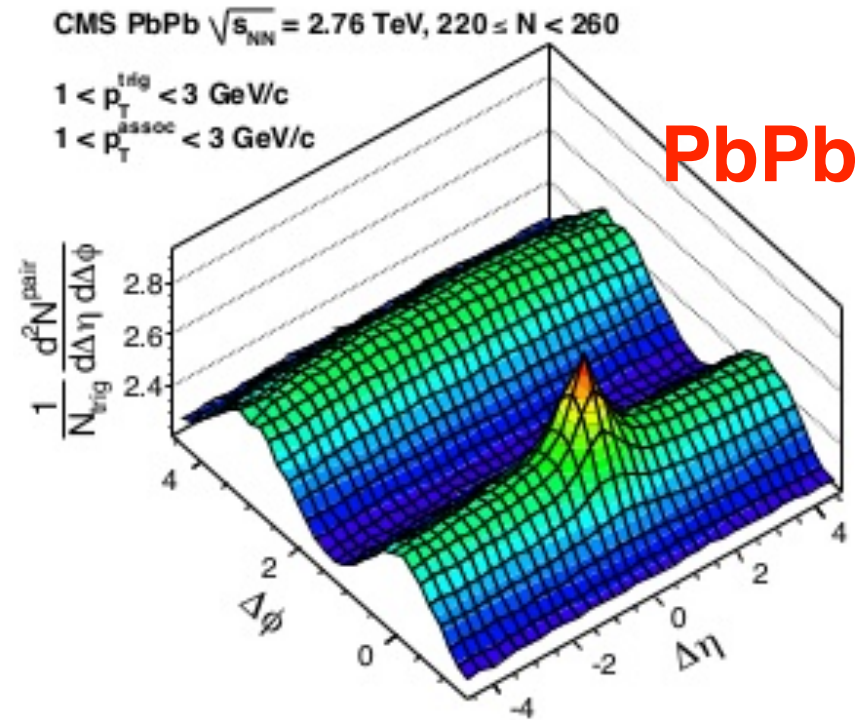
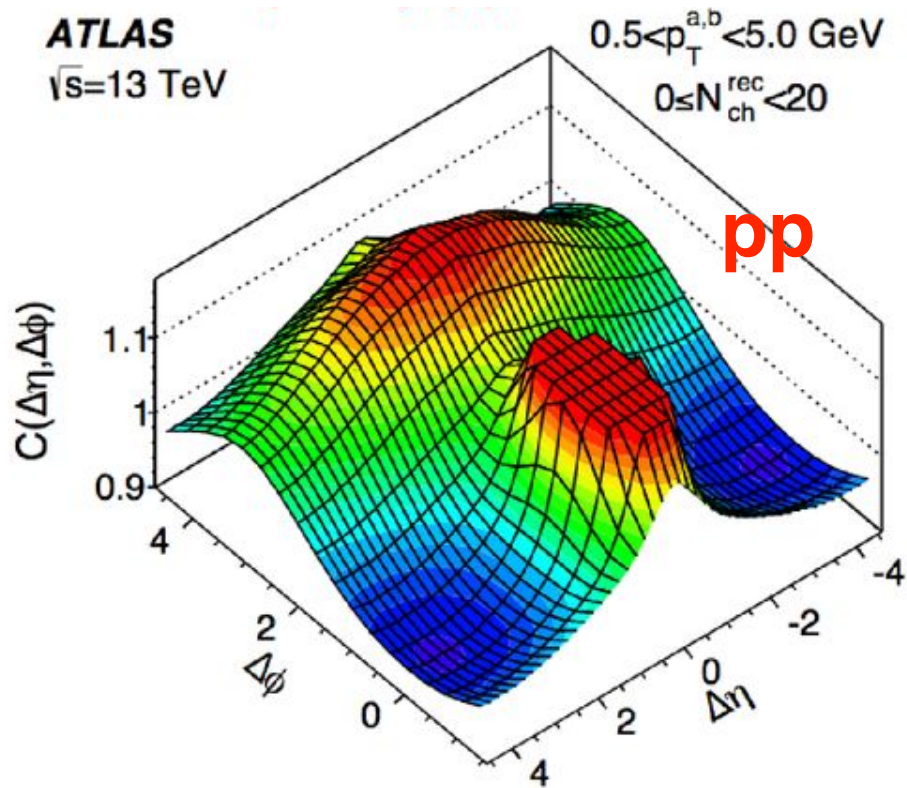
- Sequential melting of Upsilon states were quantified by comparing $Y(nS)$ yields in PbPb (hot and cold matter), in pPb (cold matter) and in pp (vacuum)

...AND UNFORTUNATELY...

PbPb = hot medium?
pPb = cold medium?
pp = vacuum?

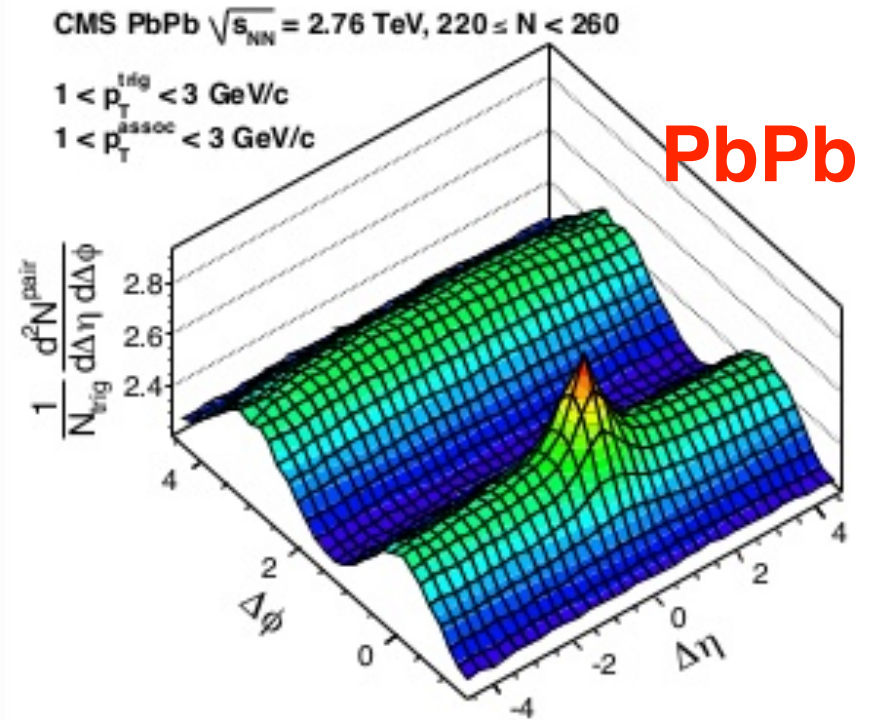
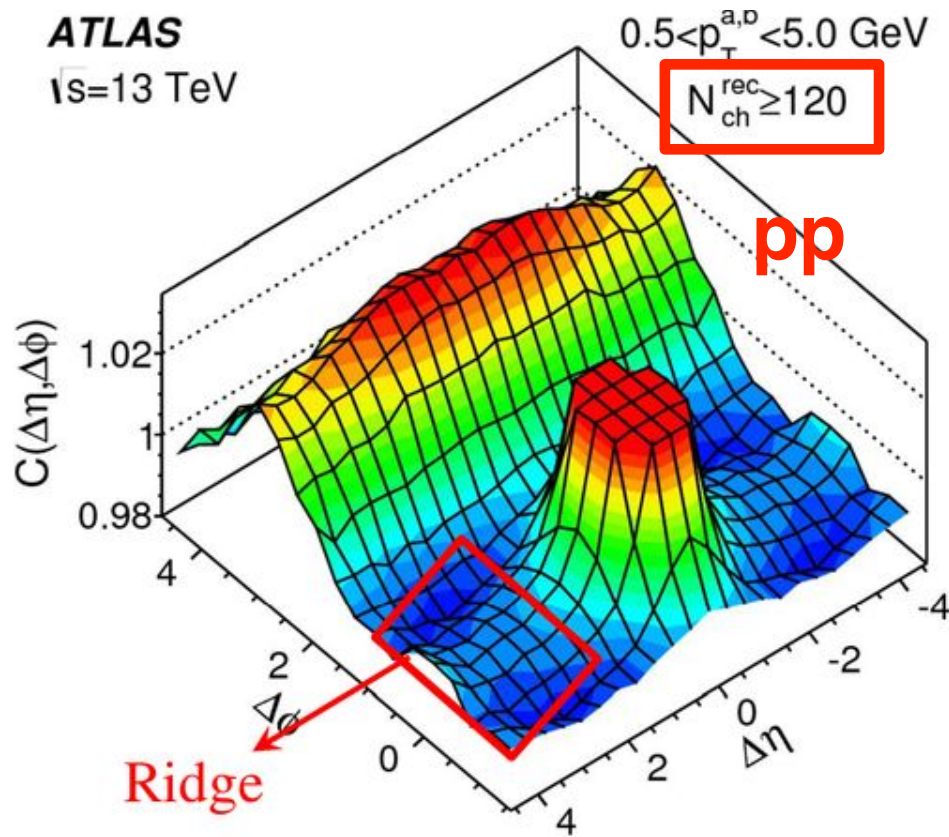
...IT'S NOT SO SIMPLE!

Counter-example: Long range correlation



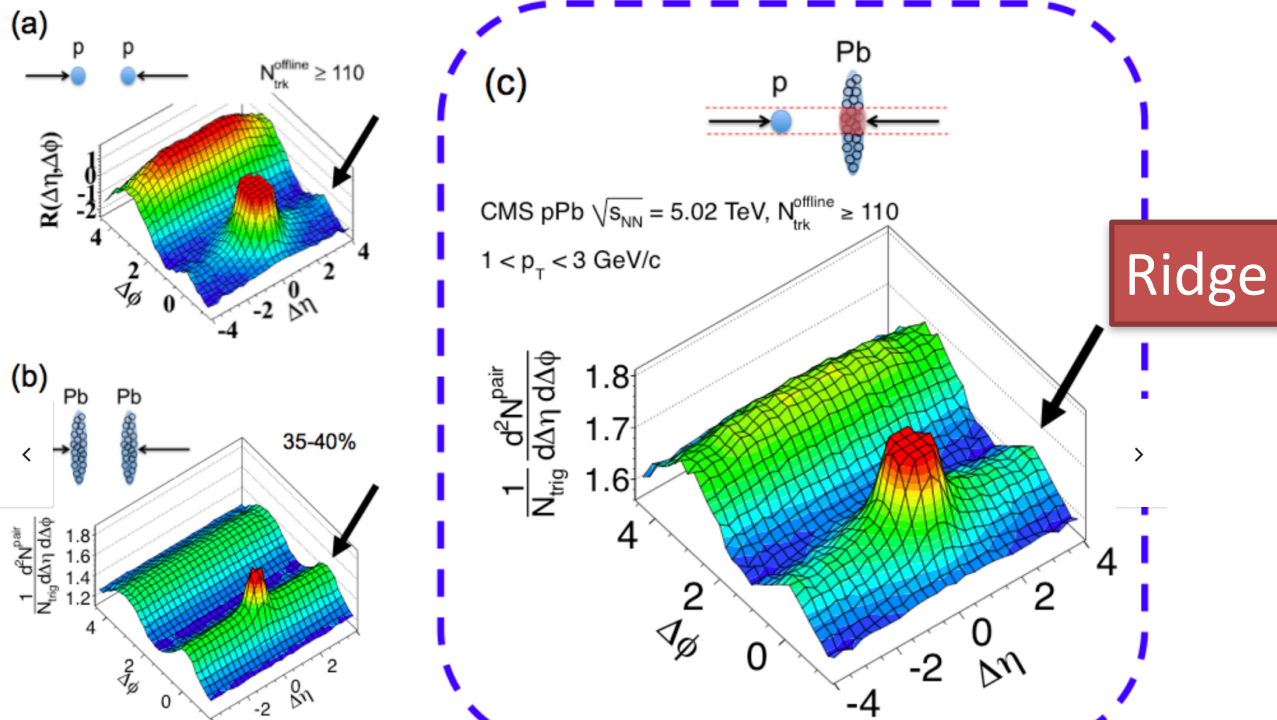
- Collective motion of particles = thermalization of system
- Correlation between large $\Delta\eta$ particles (aka, *ridge*) is the evidence of early time thermalization
- Known to be the signature of QGP production in heavy ion collision

Long-range correlation



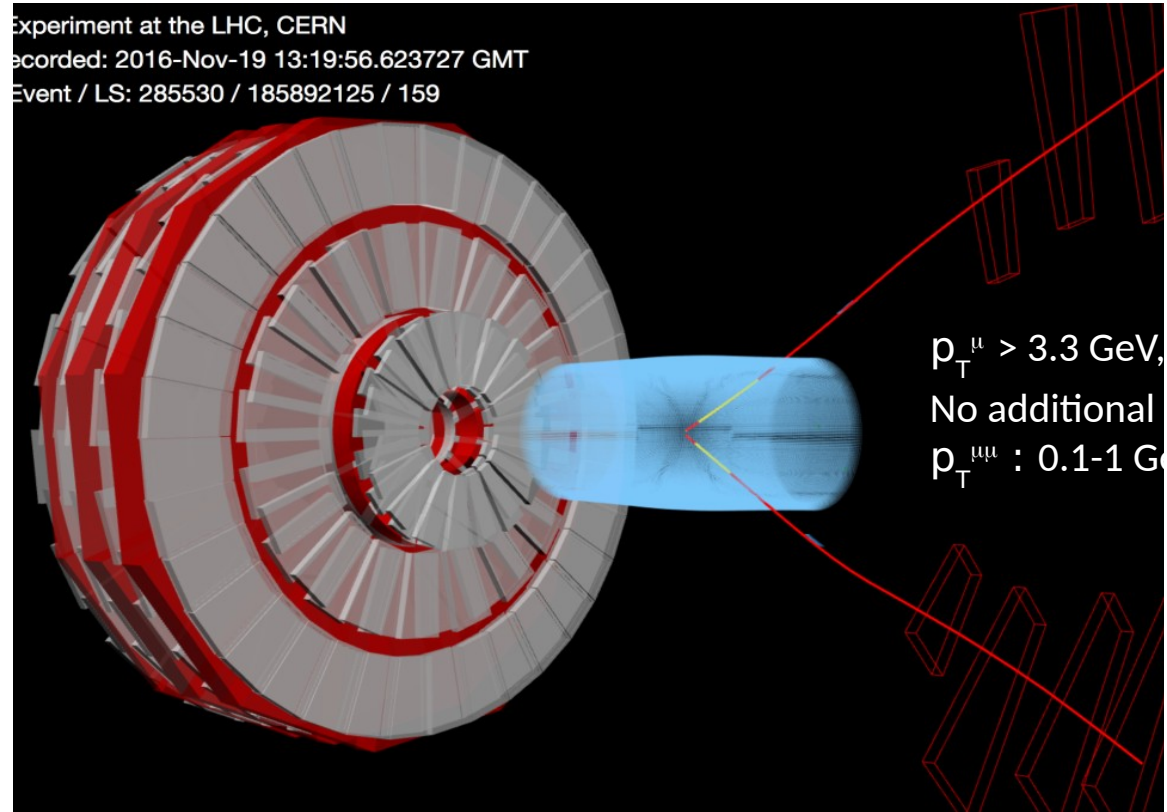
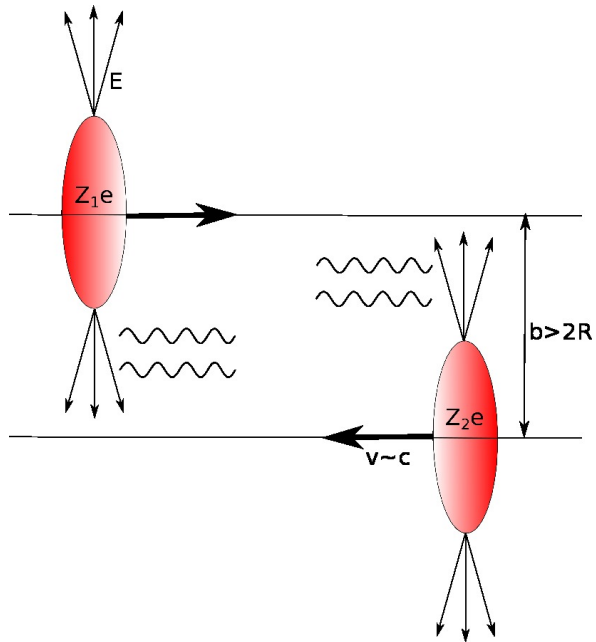
- Long-range correlation also observed in pp collision for high multiplicity event

Long-range correlation

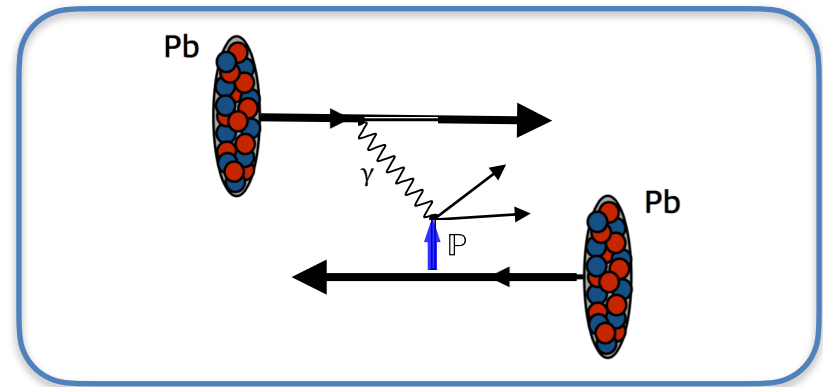
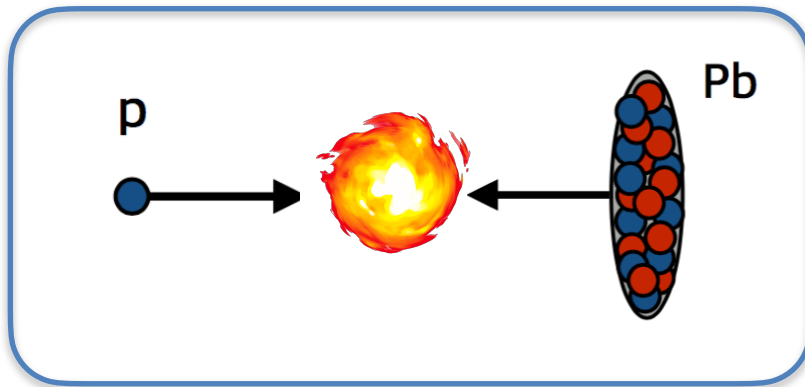
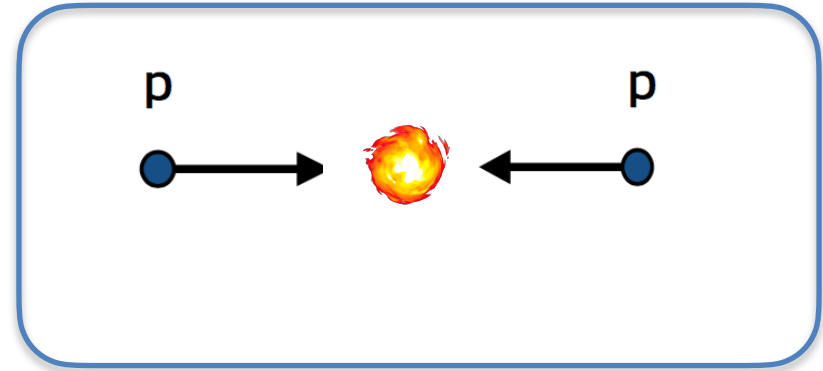
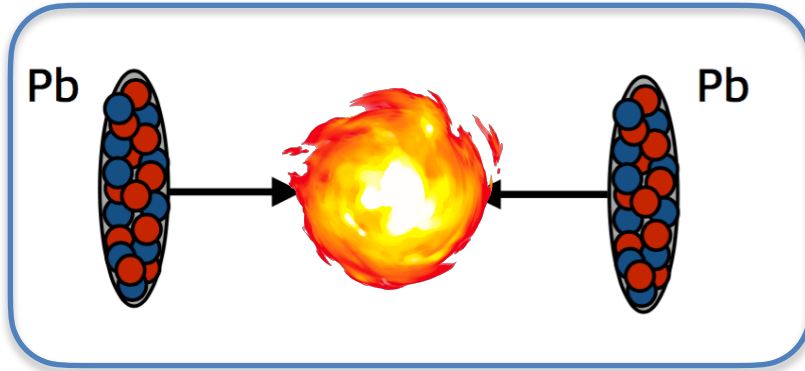


- Later, it turned out that ridge is made for high-multiplicity events for all collision systems
- Naturally arising question
 - What will be the smallest system to make collective motion?
 - Can we make a system that can clearly separate the *initial* and *final* state effects?

Ultra-Peripheral Collision



Ultra-peripheral collision (UPC)

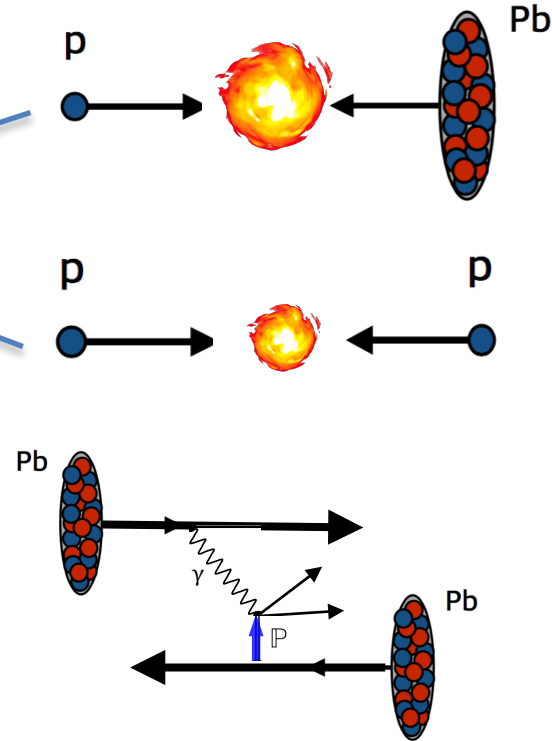
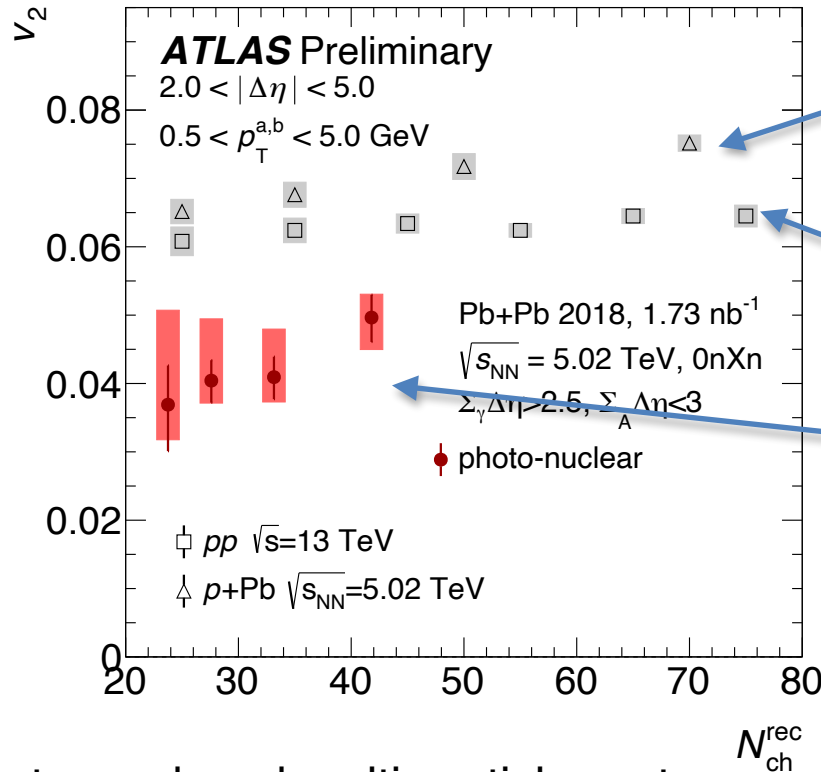


Ultra-Peripheral Collision (UPC)

- The smallest QCD system made by hadronic collision
- Vector meson and di-jet production are sensitive to the gluon distribution and polarization in the nucleus

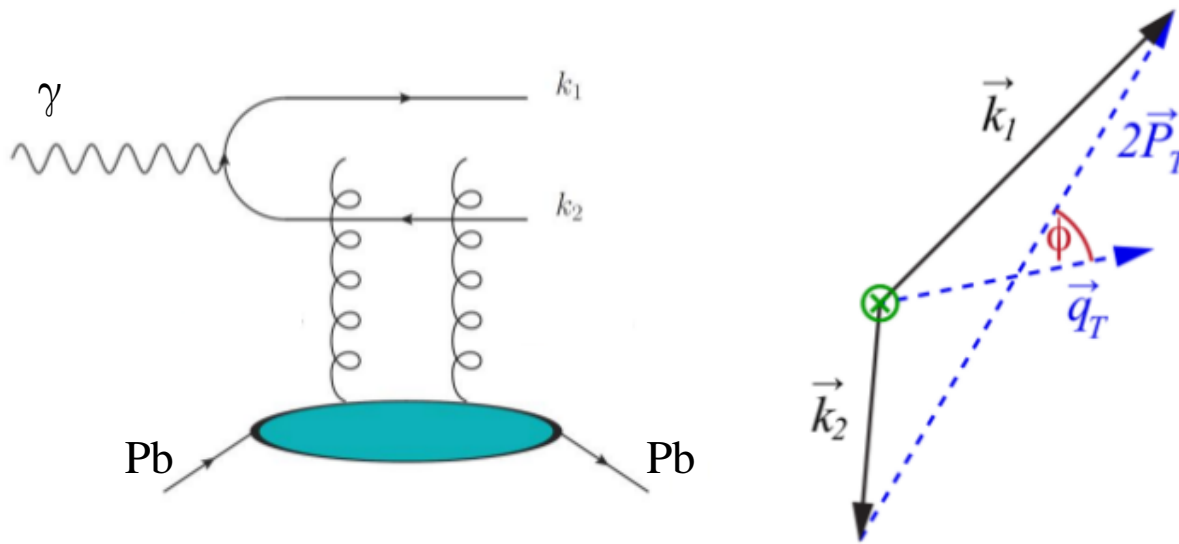
Elliptic flow observed in UPC

ATLAS-CONF-2019-022



- Photo-produced multi-particle system can produce flow in high multiplicity events
- Quantitatively smaller correlation than in hadronic collision, but have the same N dependence
- UPC is an important reference as a control experiment for the study of medium

Exclusive di-jet correlation



Vector sum of 2 jets:

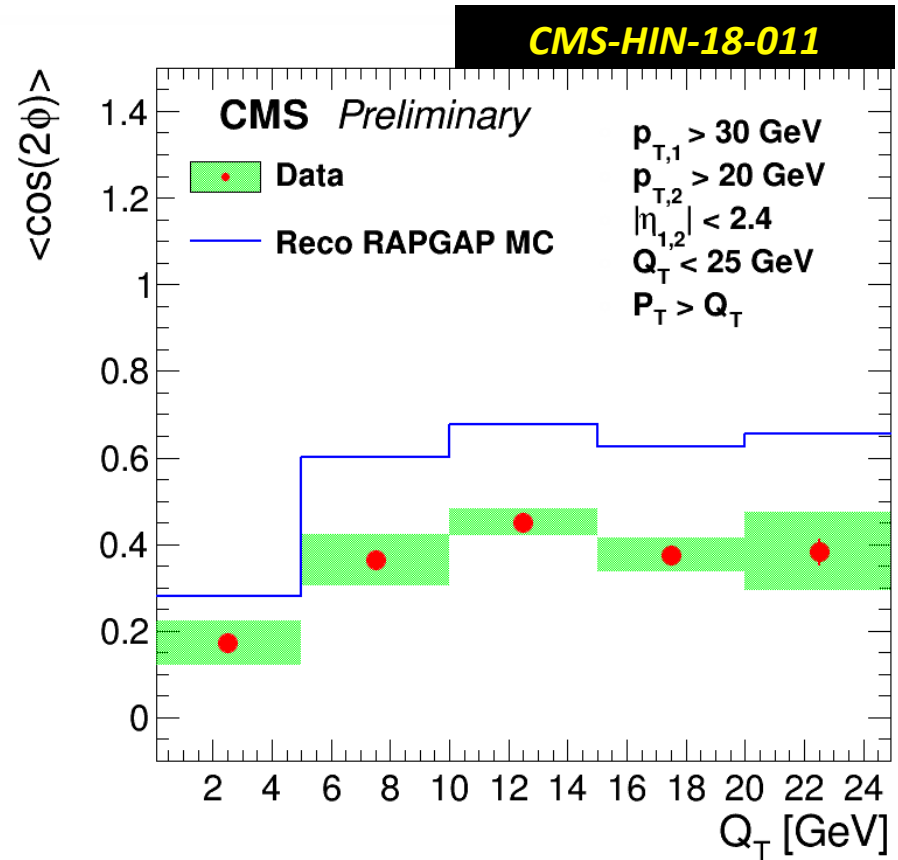
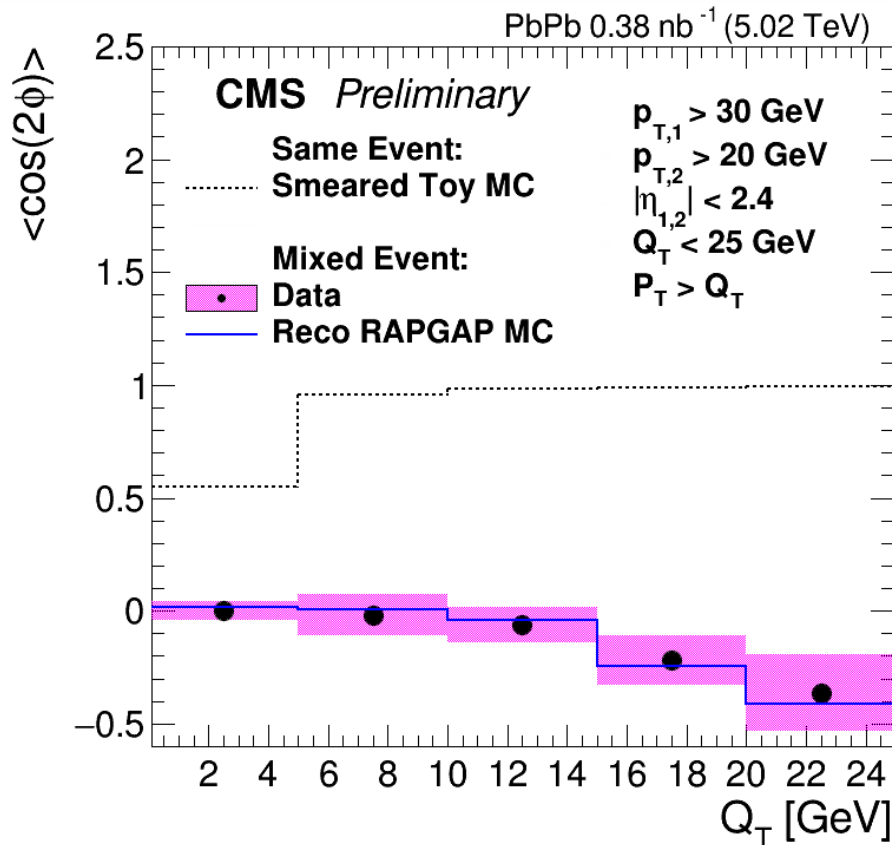
$$\vec{Q}_T = \vec{k}_1 + \vec{k}_2$$

Vector difference of 2 jets:

$$\vec{P}_T = \frac{1}{2}(\vec{k}_1 - \vec{k}_2)$$

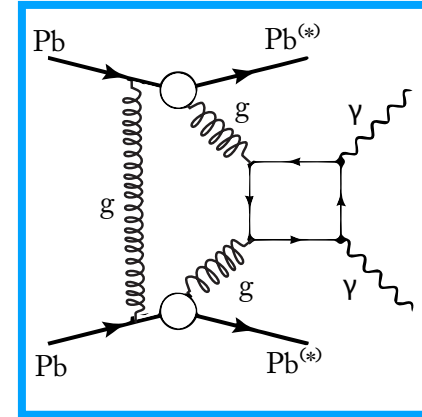
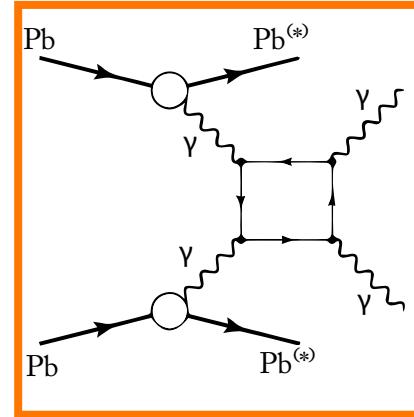
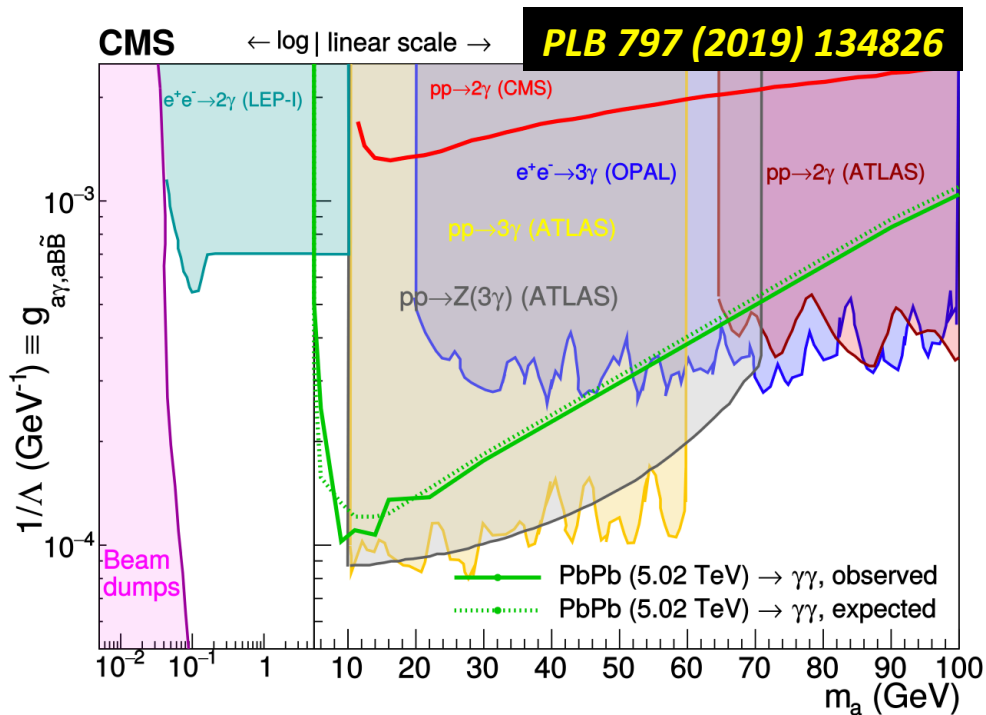
- The only process which can directly access to the Wigner gluon distribution [*PRL* 116, 202301 (2016)]
- Correlation between gluon and impact parameter vector due to dipole scattering amplitude in the small- x , so called “elliptic gluon” distribution
- Jets were used as the proxy of quarks decayed from the gluon
 - $|\ln|_{\text{lab}}| < 2.4$, $p_{T,1} > 30$ GeV, $p_{T,2} > 20$ GeV
- Observable: $v_2 = \langle \cos(2\phi) \rangle$

Exclusive di-jet correlation



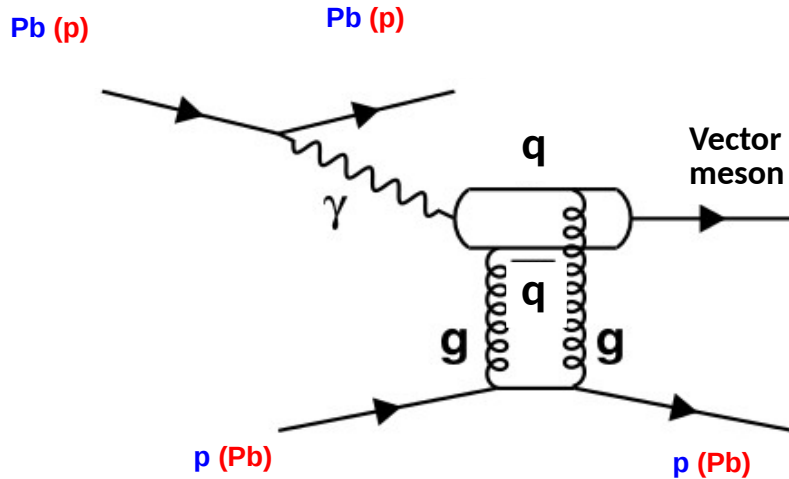
- Result is compared with the RAPGAP simulation and toyMC models
- $\langle \cos(2\phi) \rangle$ in data is lower than in RAPGAP prediction by 20-30%, which provides input to the theory community
- Mixed jet events were used for control dataset

Limitation of axion-like particles (ALP)

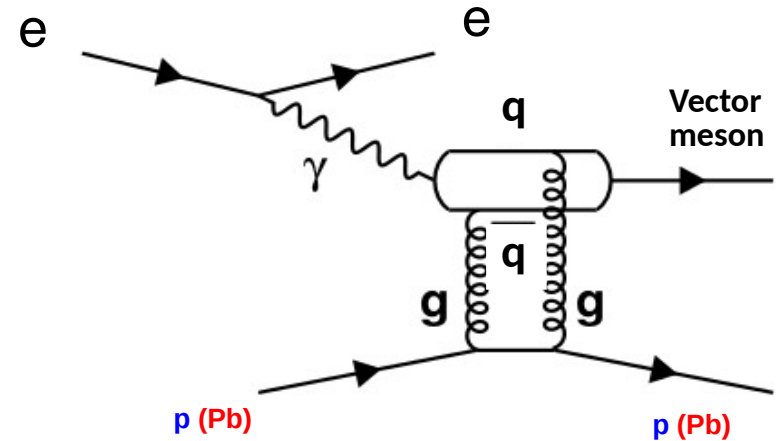


- light-by-light scattering
 - $\sigma(\text{PbPb}) = 82^4 \sigma(pp)$
 - Contains the loop of charged SM particles
 - Provides test for charged SUSY particles or spin-even resonances, e.g. axions and monopoles

UPC and EIC



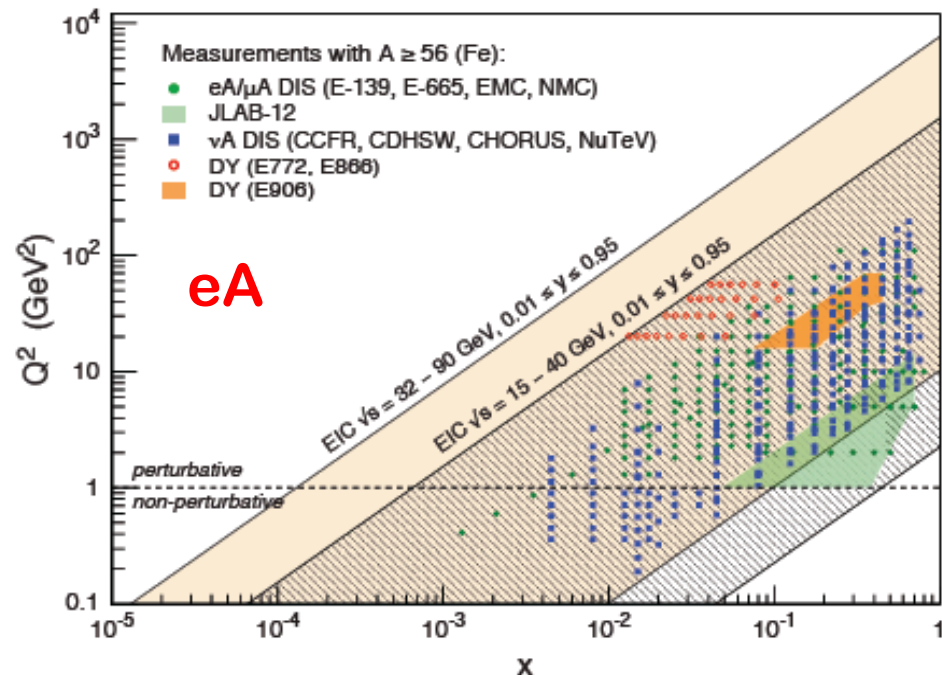
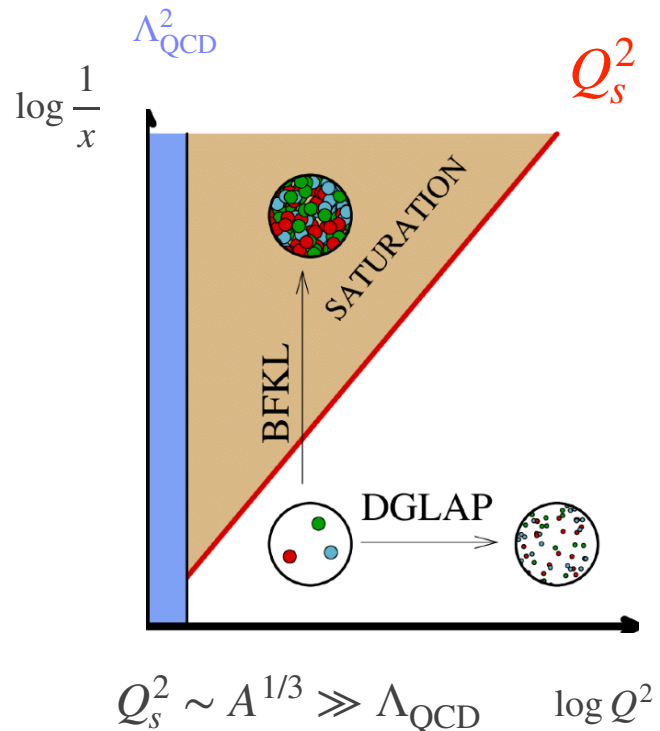
UPC at LHC



DVCS at EIC

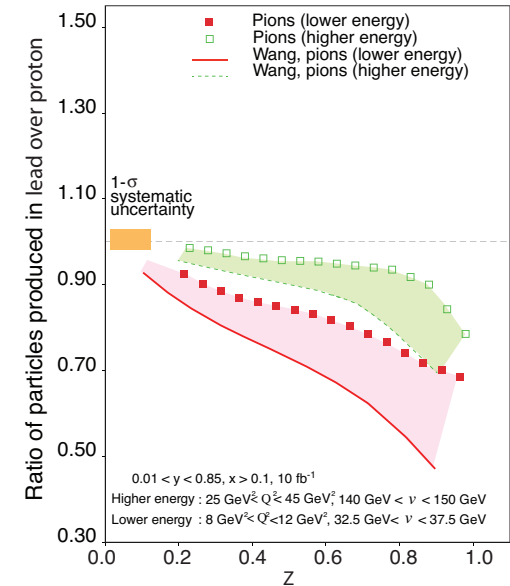
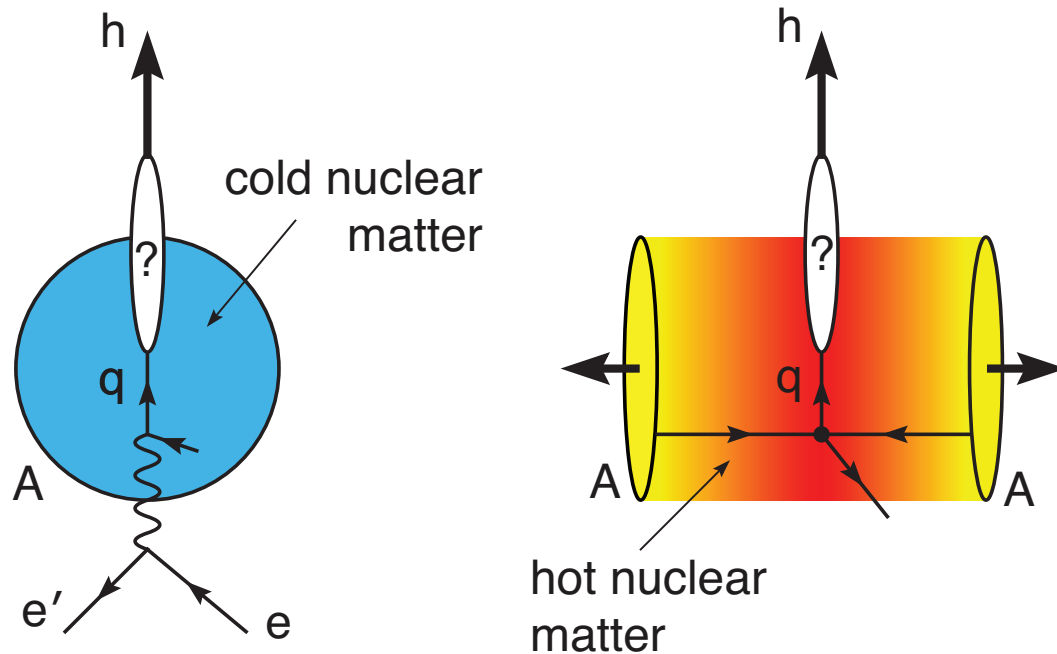
- * The photo-production channel in UPC is identical to DVCS in EIC
- * EIC will provide lower photon energy with higher statistics

UPC and EIC



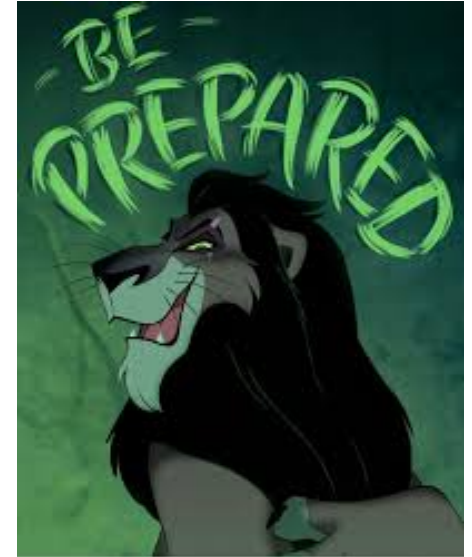
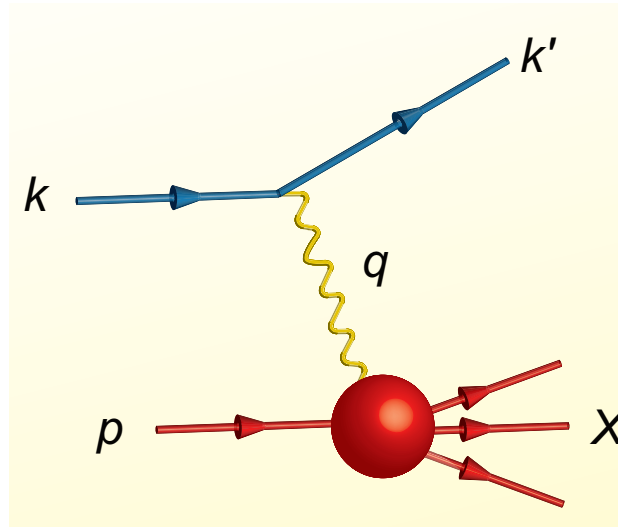
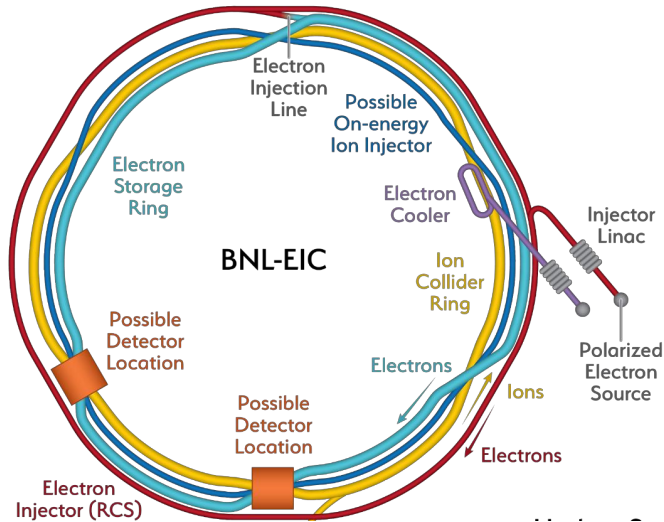
- * Great opportunity to access the new frontier of low- x regime where gluon saturation is enhanced
- * Observables developed for UPC can be used for EIC
 - * Vector mesons, jets and photons
 - * Require a hermetic detector with trackers and calorimeters, in particular in the **forward region**

, and hard probes!



- * Comparison of High- p_T probes in eA and ep allows the investigation of final state effects by cold nuclear matter
- * Much cleaner than comparison of pp and pA
- * Will provide useful constraints for various nuclear modification models, including jet quenching, Debye screening, coalescence models

Summary



- EIC is a great opportunity for new physics in nuclear
- In particular, most observables in UPC can be studied using EIC as well
 - Vector mesons, di-jet, two-particle correlation and rapidity gaps
 - Forward calorimeter would be useful to measure these
- It's time for Korean HI community to start extensive discussions on (a) what we can learn about QCD from EIC and (b) what we can contribute.

BACKUP