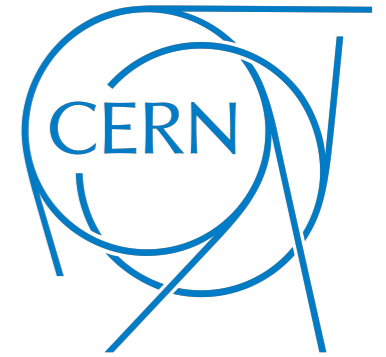




**ALICE**



# ALICE STATUS REPORT

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**Deepa Thomas**  
for the ALICE Collaboration

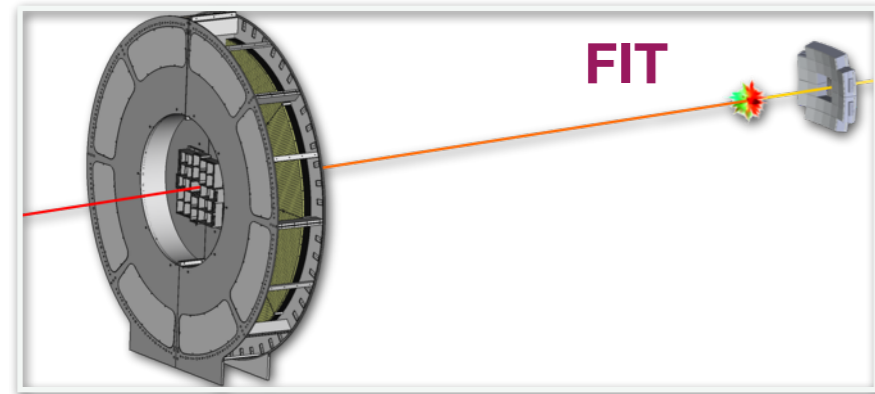
**142<sup>nd</sup> LHCC meeting**  
4<sup>th</sup> June 2020



The University of Texas at Austin

# LS2 activities

# ALICE Upgrades for Run 3



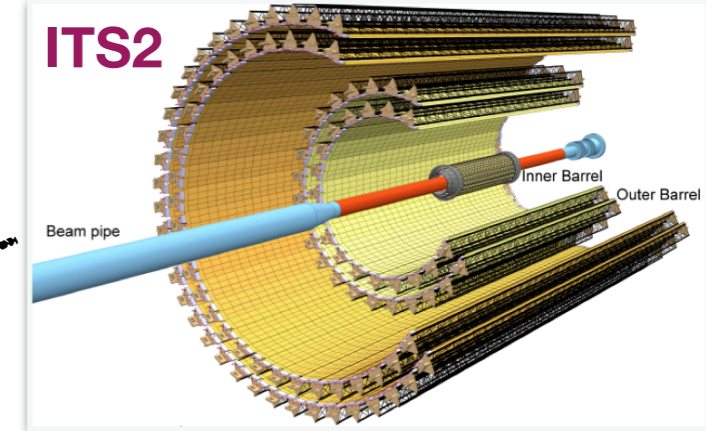
**FIT**

## New Fast Interaction Trigger (FIT) Detector

- Centrality, event plane, luminosity, interaction time

## New Inner Tracking System (ITS 2)

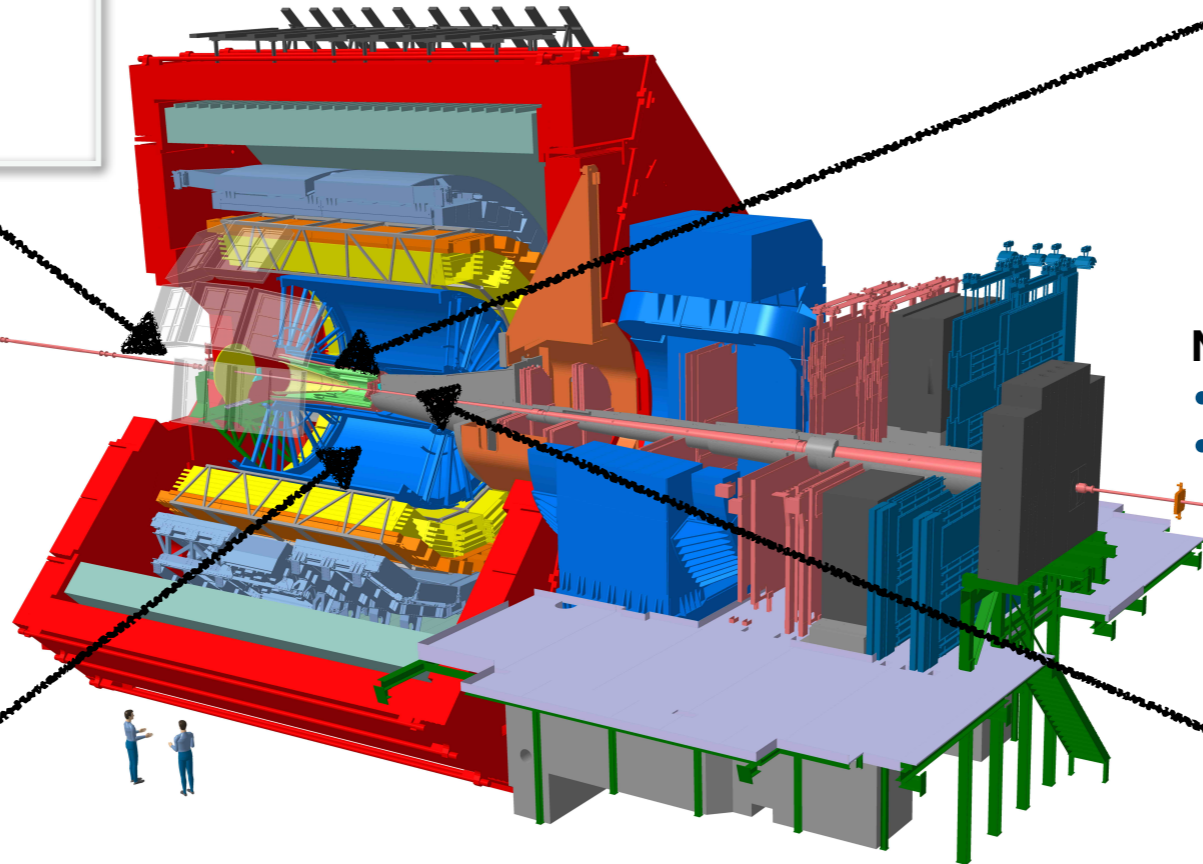
- CMOS pixel, MAPS technology
- Improved resolution, less material, faster readout



**ITS2**

## New Muon Forward Tracker (MFT)

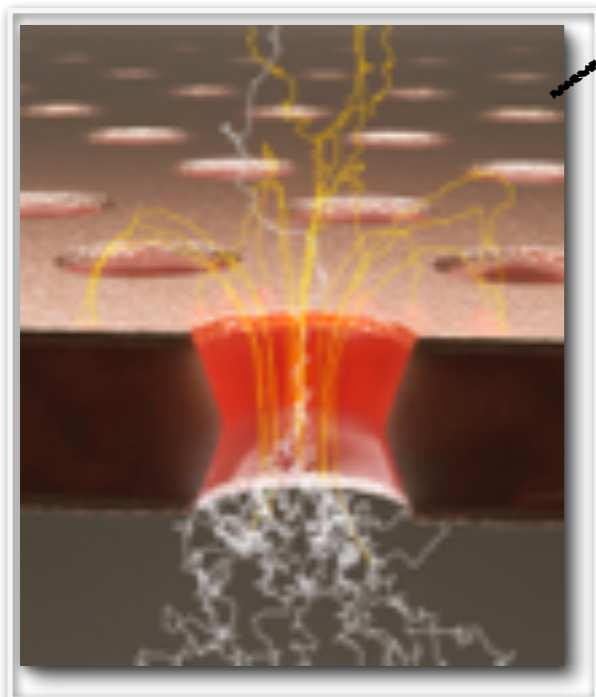
- CMOS Pixels, MAPS technology
- Vertex tracker at forward rapidity



**TPC**

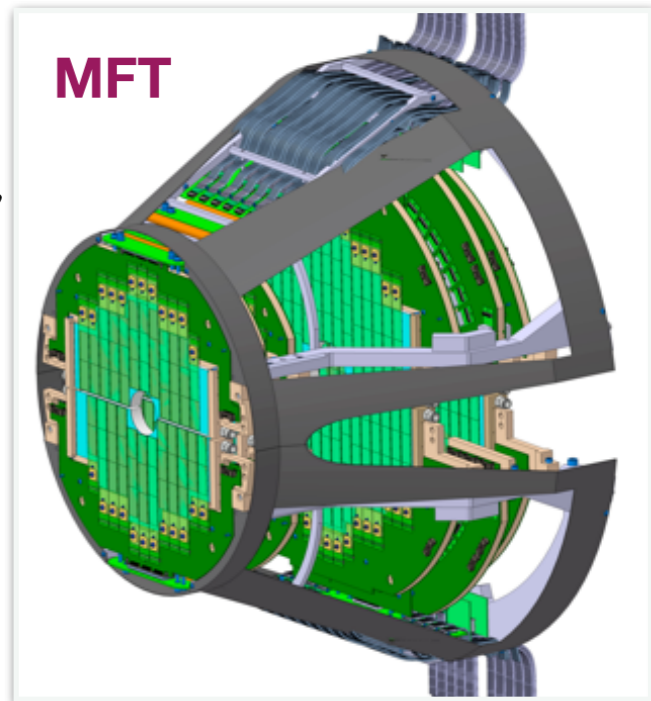
## New TPC Readout Chambers (ROCs)

- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPAs), continuous readout



## Readout upgrade

- TOF, TRD, MUON, HMPID, ZDC, Calorimeters



**MFT**

## Integrated Online-Offline system (O<sup>2</sup>)

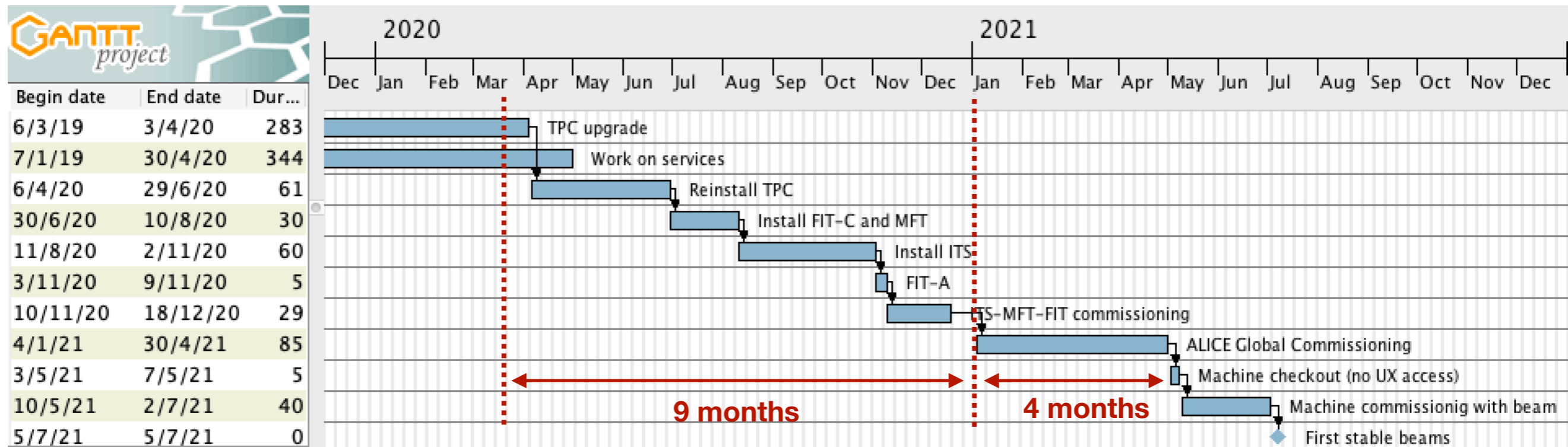
- Record Pb-Pb data at 50 kHz



# Original ALICE LS2 schedule

- ALICE entered the safe mode on March 13<sup>th</sup> → TPC was in the cleanroom and **3 weeks away** from moving TPC to the cavern
- **Installation of the TPC starting April 6<sup>th</sup> 2020**
- **Need 9 months to complete installation sequence (TPC, ITS, MFT and FIT) → mid March 2020 to end 2020**
- **Following the installation we had planned 4 months global commissioning → January to end April 2021**

## Original LS2 plan



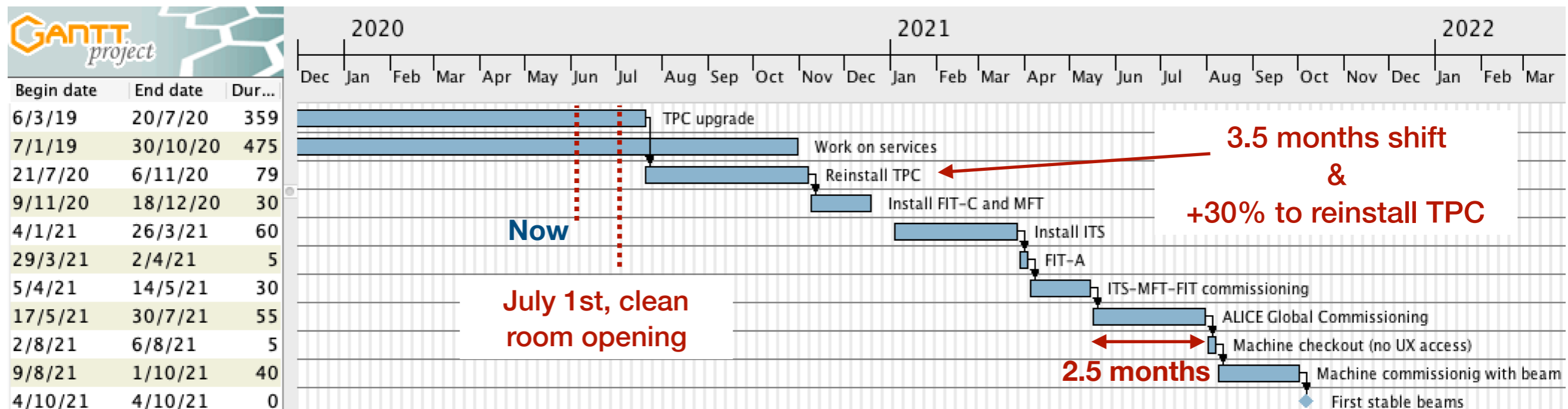
**March 13th → ALICE in safe mode (last LHCC Feb. 17th)**

# New ALICE LS2 schedule

- Restart the detector installation sequence on **July 1<sup>st</sup>** i.e. **+3 and ½ months**
- **30% additional time** to reinstall the TPC i.e. **+1 month**
- Assumption that from November we can move according to the original schedule
- **Start of global commissioning shifts moved from Jan. 4<sup>th</sup> 2021 → May 17<sup>th</sup> 2021.**
- Assuming the LHC schedule is delayed by 3 months → 1.5 of 4 months of global commissioning take place in parallel with LHC commissioning
  - Global commissioning: mid-May to end of August 2021 (16 weeks)
  - ALICE cavern closure **August 1, 2021 is feasible**

**Total of 4.5 months delay**

## New LS2 plan



# ALICE publications since last LHCC

## 21 papers submitted since last LHCC

pp

1. Search for a common baryon source in high-multiplicity pp collisions at the LHC - **arXiv:2004.08018**
2. A new laboratory to study hadron-hadron interactions - **arXiv:2005.11495**
3. (Anti)Deuteron production in pp collisions at  $\sqrt{s}=13$  TeV - **arXiv:2003.03184**
4. Multiplicity dependence of  $\pi$ , K, and p production in pp collisions at  $\sqrt{s} =13$  TeV - **arXiv:2003.02394**
5. Observation of a low- $p_T$  excess in low-mass dielectrons in 13 TeV pp - **arXiv:2005.14522**
6.  $J/\psi$  production as a function of charged-particle pseudorapidity density in pp collisions at  $\sqrt{s} = 13$  TeV - **arXiv:2005.11123**
7. Production of light flavor hadrons in pp collisions at 7 and 13TeV - **arXiv:2005.11120**

p-Pb, Pb-Pb

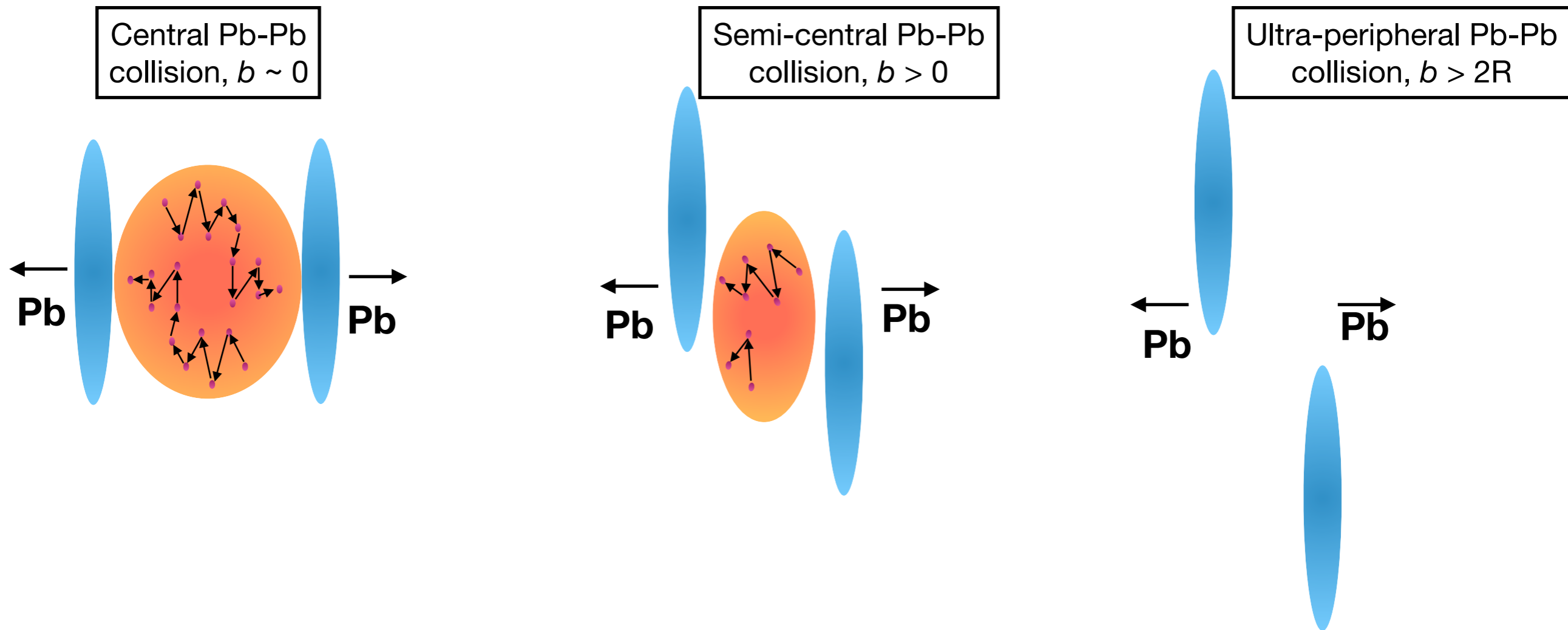
1. Measurement of low-energy anti-deuteron inelastic cross section - **arXiv:2005.11122**
2.  $J/\psi$  production as a function of charged-particle multiplicity in p-Pb collisions at  $\sqrt{s_{NN}} = 8.16$  TeV - **arXiv:2004.12673**
3. Measurement of nuclear effects on  $\psi(2S)$  production in p-Pb collisions at  $\sqrt{s_{NN}} =8.16$  TeV - **arXiv:2003.06053**
4. Measurement of isolated photon-hadron correlations in 5 TeV pp and p-Pb data - **arXiv:2005.14637**
5. Dielectron production in proton-proton and proton-lead collisions at  $\sqrt{s_{NN}} = 5.02$  TeV - **arXiv:2005.11995**
6. Coherent photoproduction of  $\rho^0$  vector mesons in ultra-peripheral Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV - **arXiv: 2002.10897**
7. Z boson production in p-Pb collisions at  $\sqrt{s_{NN}}$  TeV and Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV - **arXiv:2005.11126**
8. Elliptic flow of electrons from beauty-hadron decays in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV - **arXiv:2005.11130**
9. First measurement of quarkonium polarization in nuclear collisions at the LHC - **arXiv:2005.11128**
10. Constraining the Chiral Magnetic Effect with charge-dependent azimuthal correlations in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  and 5.02 TeV - **arXiv:2005.14640**
11.  $J/\Psi$  elliptic and triangular flow in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV - **arXiv:2005.14518**
12. Lambda-Kaon femtoscopy in Pb-Pb collisions at 2.76 TeV - **arXiv:2005.11124**
13. Transverse-momentum and event-shape dependence of D-meson flow harmonics in Pb-Pb at 5.02 TeV - **arXiv:2005.11131**
14. Elliptic and triangular flow of (anti)deuterons in Pb-Pb collisions at - **arXiv:2005.14639**

Several new and exciting results prepared for the recent/ongoing conferences (> 30 new preliminary results):

LHCP:  
19 ALICE speakers and 10 posters

Hard Probes:  
21 ALICE talks and 16 posters

# Results in Pb-Pb



- ❖ Coherent photoproduction of  $\rho^0$  in UPC
- ❖ First  $J/\psi$  polarization measurement in Pb-Pb collisions
- ❖ Accessing properties of QGP using hard probes - heavy flavor and jets

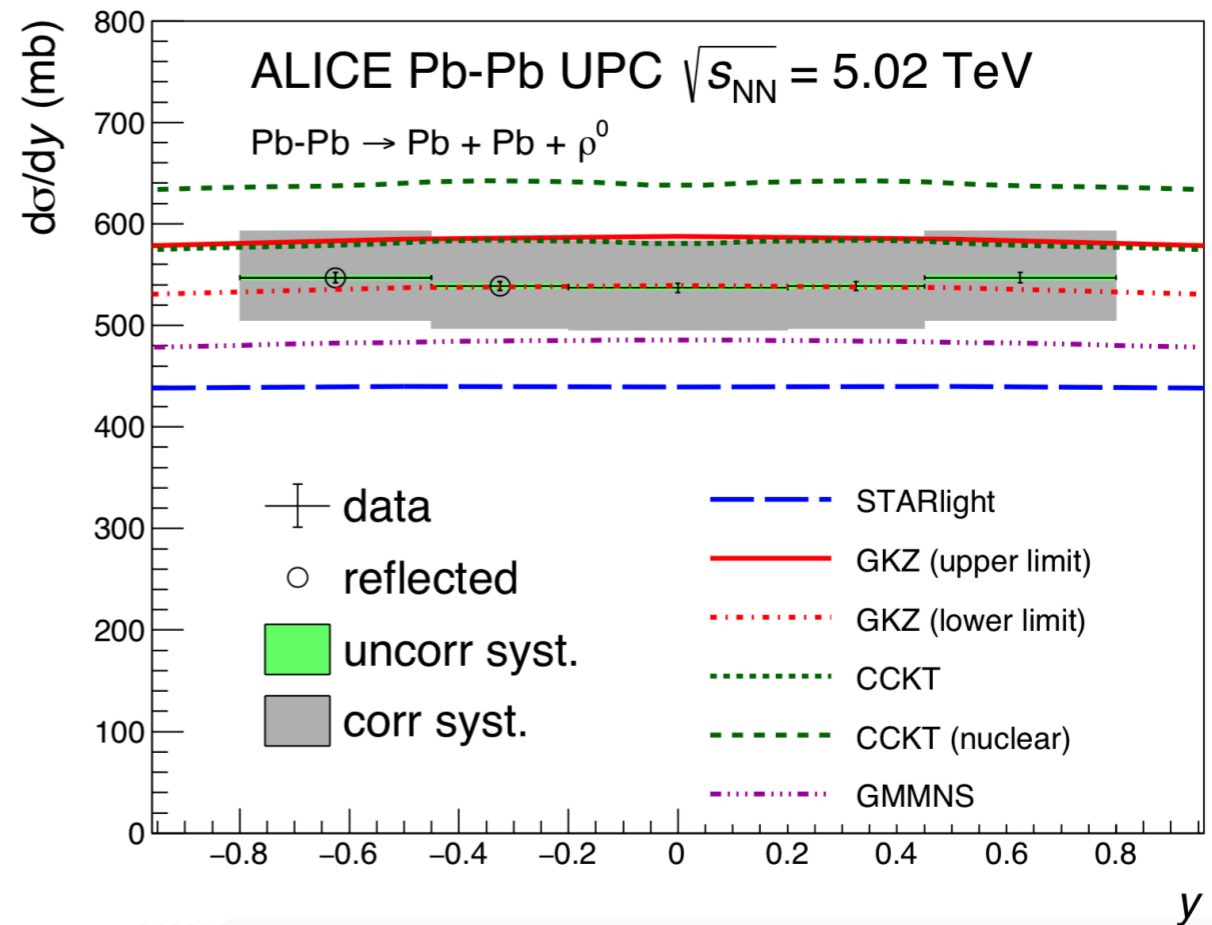
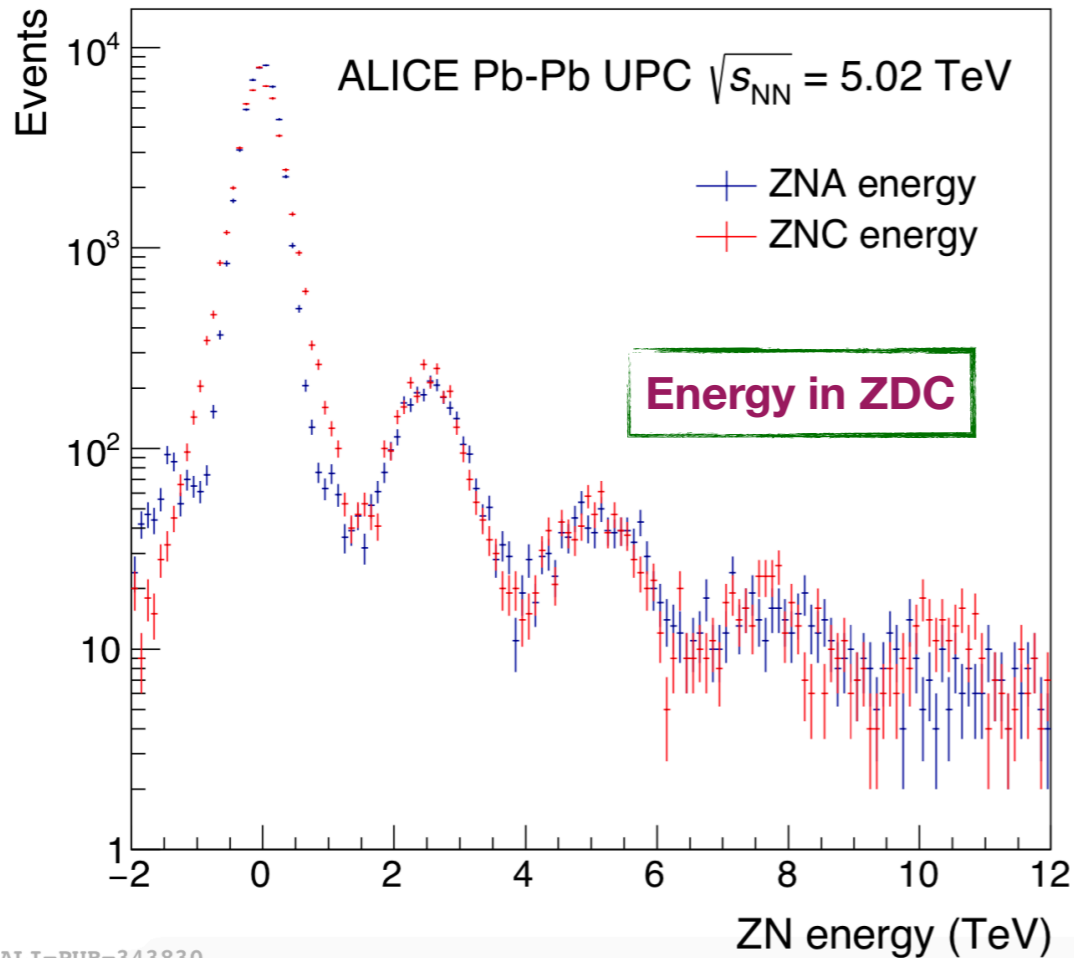
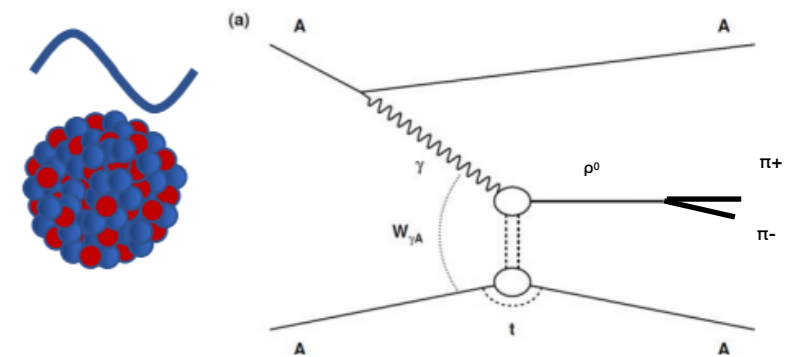
Few selected results presented here → Check out LHC Seminar on June 30th

# Photoproduction of $\rho^0$ in Pb-Pb

## Coherent photoproduction of $\rho^0$ in ultra-peripheral Pb-Pb collisions (UPC)

arXiv: 2002.10897

- Hadronic interactions strongly suppressed and electromagnetic events dominant
- EM field of relativistic particle act as beam of quasi-real photons  
—> interacts with Pb nucleus
- Secondary photon interactions causing EM excitation of nuclei  
—> produces neutrons in beam rapidity



- **First measurement of cross sections for events accompanied by EM dissociation of Pb nuclei**
- **Data consistent with theoretical models of nuclear shadowing within  $2\sigma$**



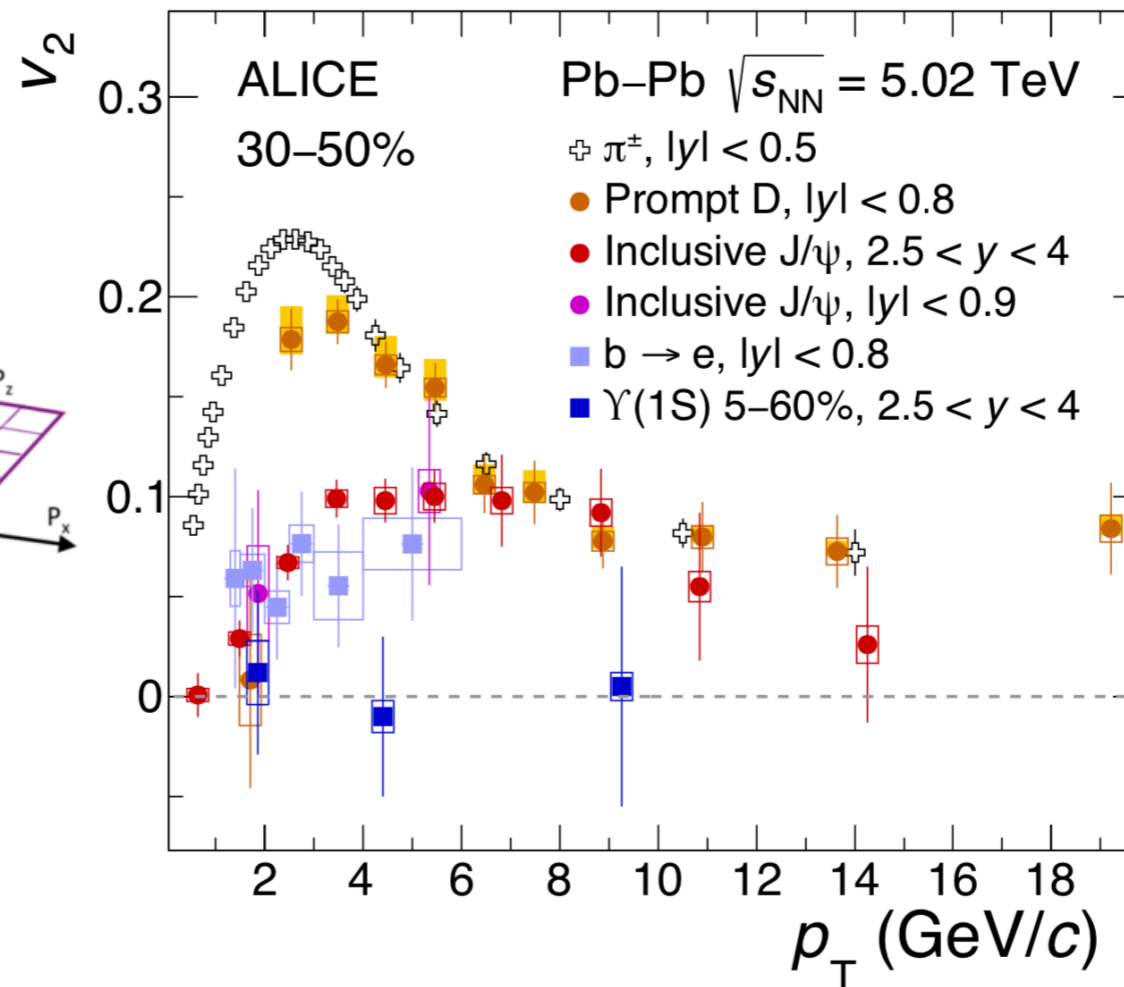
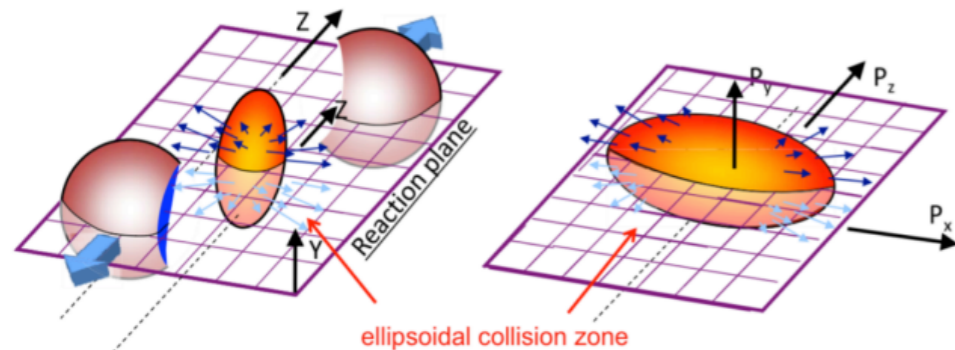
# Azimuthal anisotropy of heavy quarks

## $v_2$ of heavy-flavor particles

$v_n$  measurement allows to quantify HQ interaction strength at low  $p_T$  and constrain its path length dependent energy loss at high  $p_T$

JHEP 09 (2018) 006  
 PRL 123 (2019) 192301  
 arXiv:2005.11130  
 arXiv:2005.11131  
 arXiv:2005.14518

$$v_2 = \langle \cos[2(\phi - \Psi_2)] \rangle$$



$\pi^{\pm}$   
 D mesons  
 J/ψ  
 b→e  
 Y(1S)

- $v_2(\pi^{\pm}) > v_2(\text{D}) > v_2(\text{J}/\psi)$ 
  - D-meson  $v_2$  possibly from charm quark flow + recombination with the light-flavor quark
- **Charm quarks interact strongly with the medium and participate in its collective expansion**
- **Positive  $v_2$  for b→e**
- $v_2$  for Y(1S)  $\sim 0$  → consistent with large mass and negligible  $b\bar{b}$  recombination

# J/ψ polarization

## First measurement of J/ψ polarization in Pb-Pb collisions

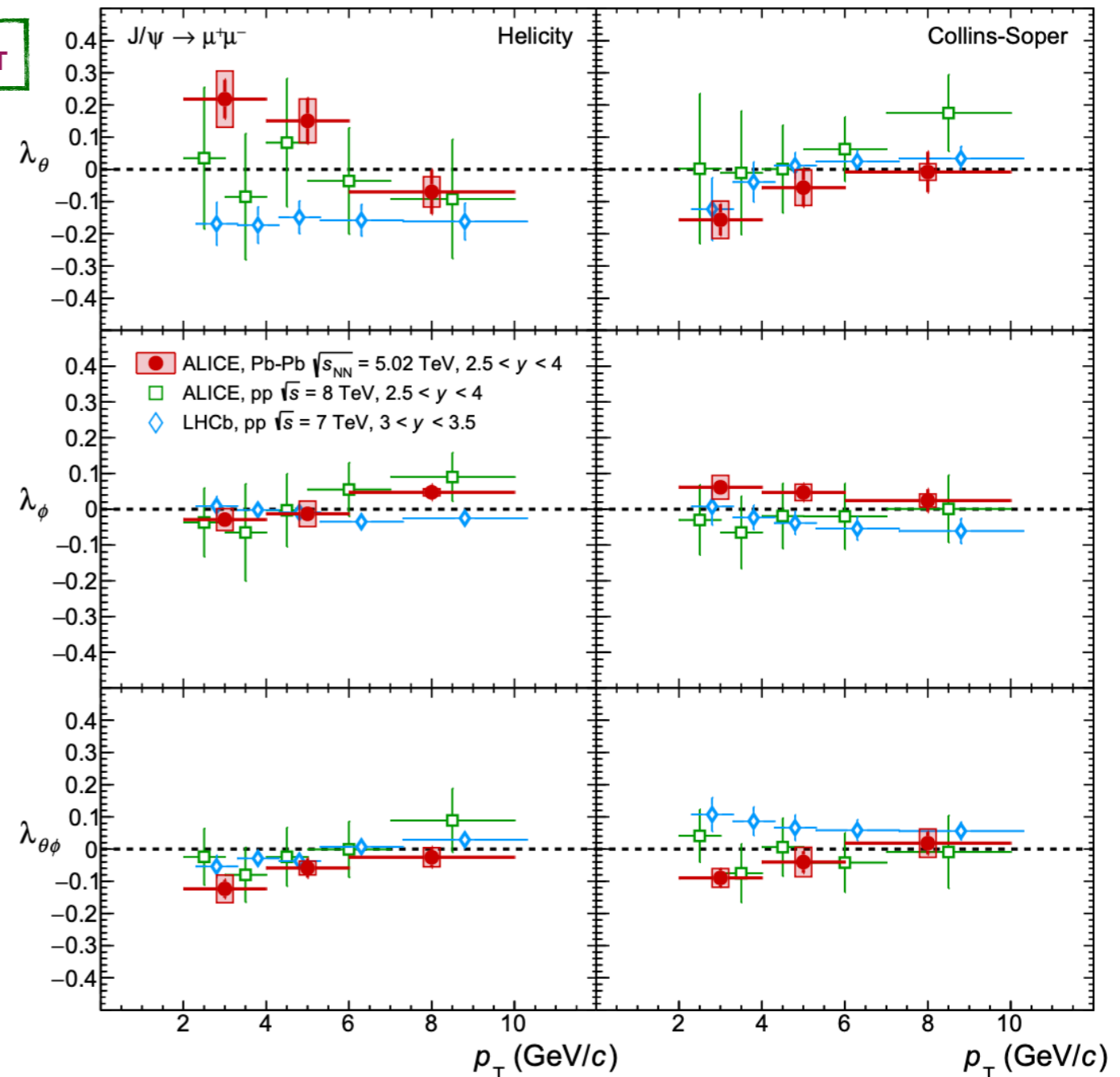
arXiv: 2005.11128

- Polarization accessed via angular distribution of decay muons
- In Pb-Pb collisions -> presence of QGP could affect J/ψ polarization
  - Different suppression effects on higher mass charmonium states and regeneration mechanism

- $\lambda_\theta$  deviates from zero ( $2\sigma$ ) at low  $p_T$  in Pb-Pb  
—> very interesting in view of higher luminosity in Run 3

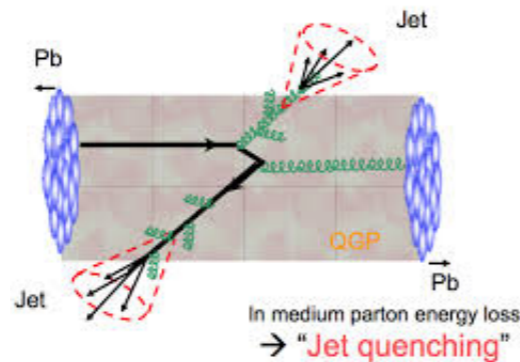
- $\lambda_\theta$  independent of centrality

$\lambda_\theta$  vs  $p_T$   
Pb-Pb



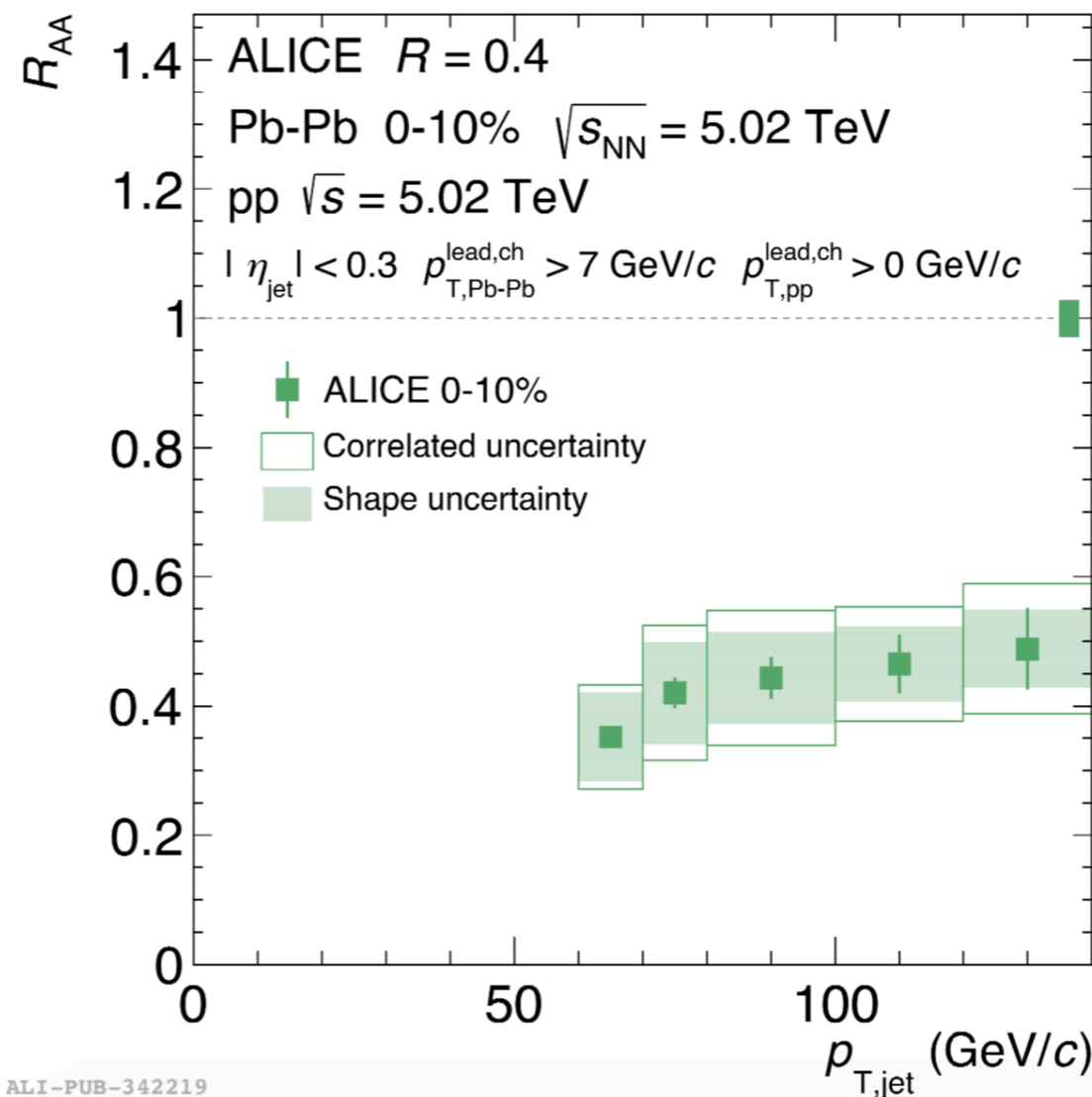
# Probing QGP with jets

## Jet quenching in Pb-Pb



$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{Y_{AA}}{Y_{pp}}$$

PRC 101 (2020) 034911



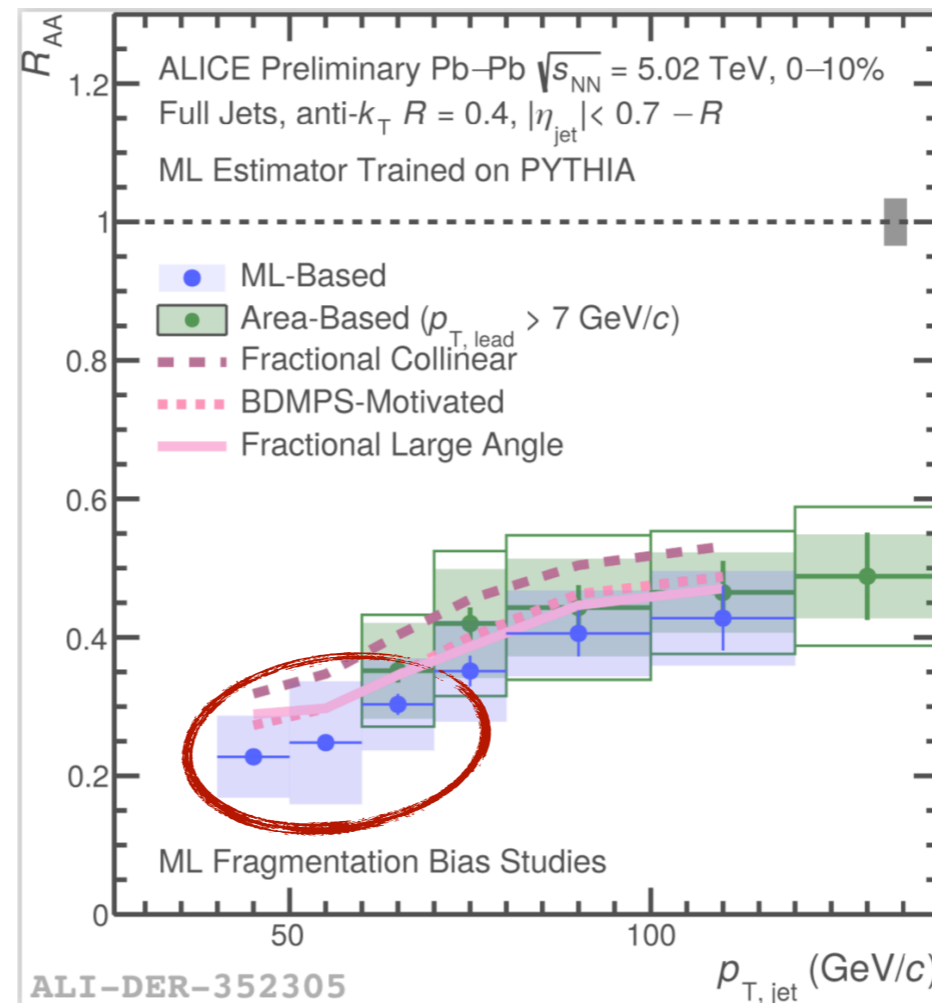
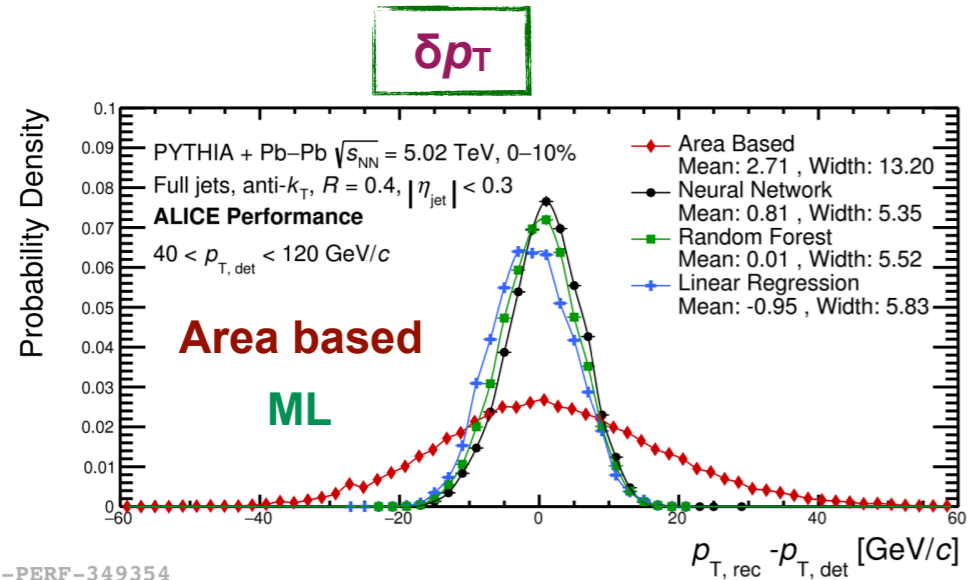
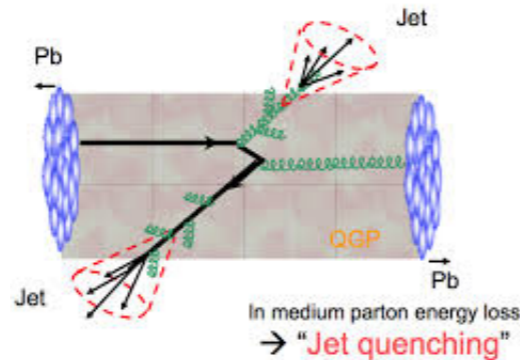
- Challenging to measure jets at low  $p_T$  due to large underlying background in heavy-ion collisions
- **Published measurement down to 60 GeV/c for  $R = 0.4$  → Strong suppression of jet yield**

# Probing QGP with jets

## Jet quenching in Pb-Pb

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{Y_{AA}}{Y_{pp}}$$

PRC 101 (2020) 034911  
New preliminary



ML  
Area based

Bias due to PYTHIA-trained  
ML studied in detail

- Challenging to measure jets at low  $p_T$  due to large underlying background in heavy-ion collisions
- **Published measurement down to 60 GeV/c for  $R = 0.4$  → Strong suppression of jet yield**
- Machine learning techniques used to reduce impact of background fluctuations and improve resolution  
→ allows measurement of large  $R$  jets to low  $p_T$
- **Full jet  $R_{AA}$  for  $R = 0.2, 0.4$  measured at low jet  $p_T$  down to 40 GeV/c**

# Jet substructure

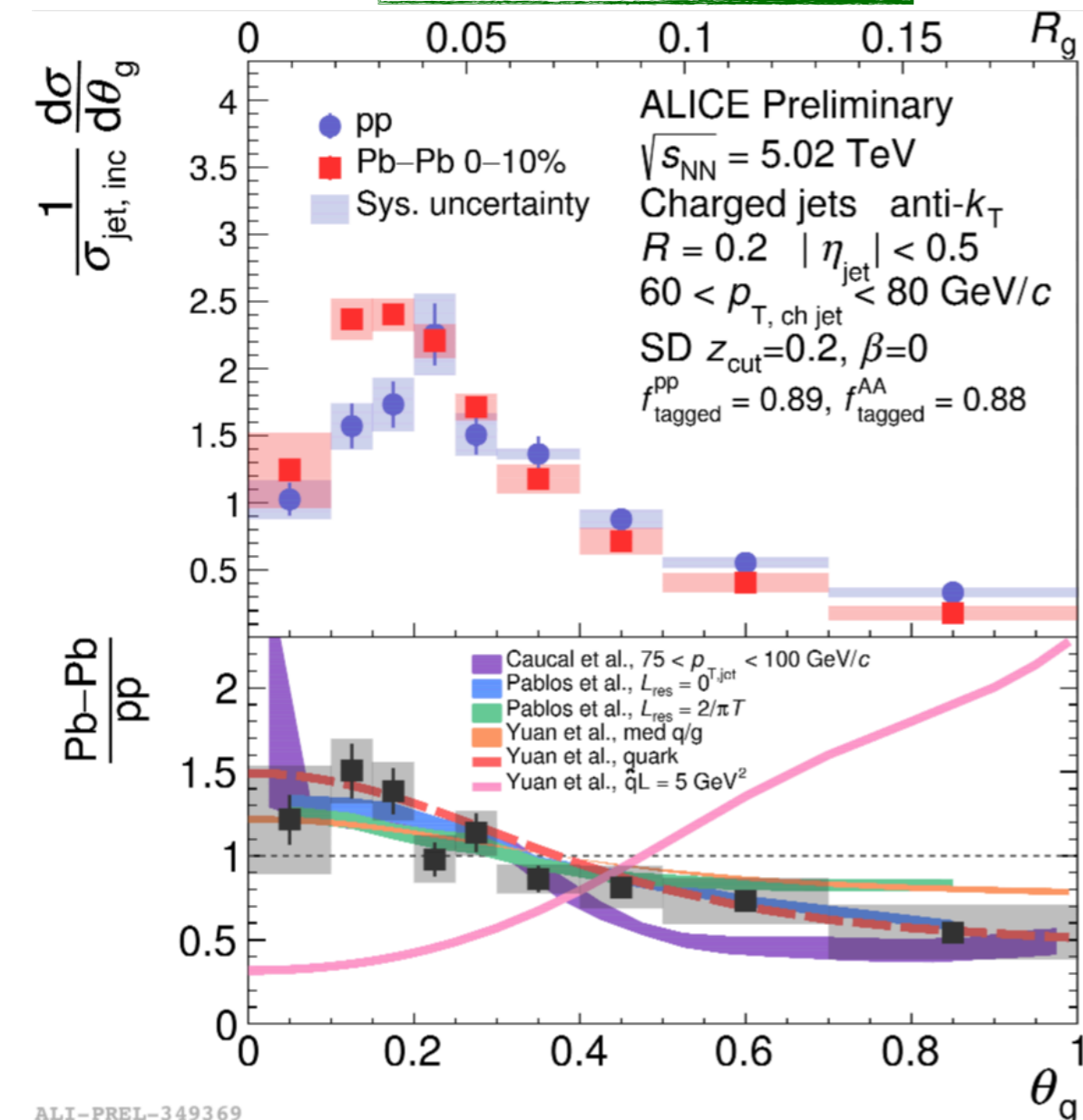
## Jet substructure sensitive to modifications in the medium

New preliminary

Grooming jets with SoftDrop algorithm and Dynamic grooming technique

- Extract the hard components of a jet by recursively removing large-angle soft radiation
- Groomed splitting characterized by **groomed jet radius ( $\theta_g$ )** and **groomed momentum fraction ( $z_g$ )**

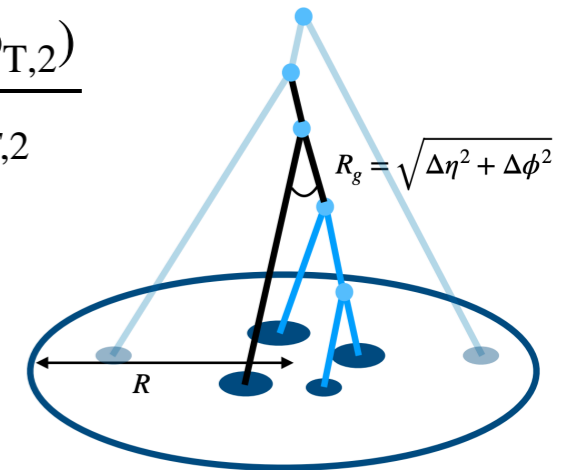
$\theta_g$  distribution for  $Z_g > 0.2$



pp  
 Pb-Pb, 0-10%

$$Z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

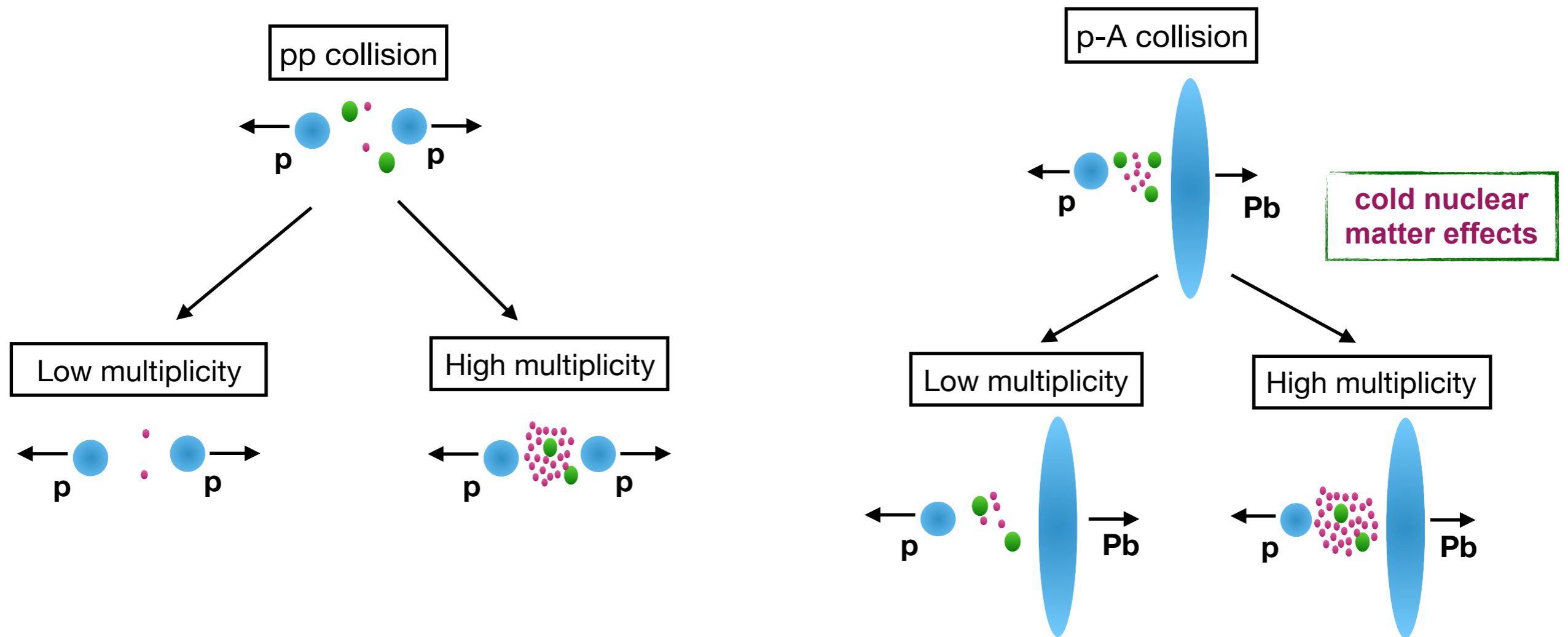
$$\theta_g = \frac{R_g}{R}$$



Fully corrected to particle level (including unfolding for detector and background effects)

- **Modification of  $\theta_g$  in central Pb-Pb collisions w.r.t vacuum**
  - **Jets more narrower in Pb-Pb than in pp**

# Results in pp and p-Pb



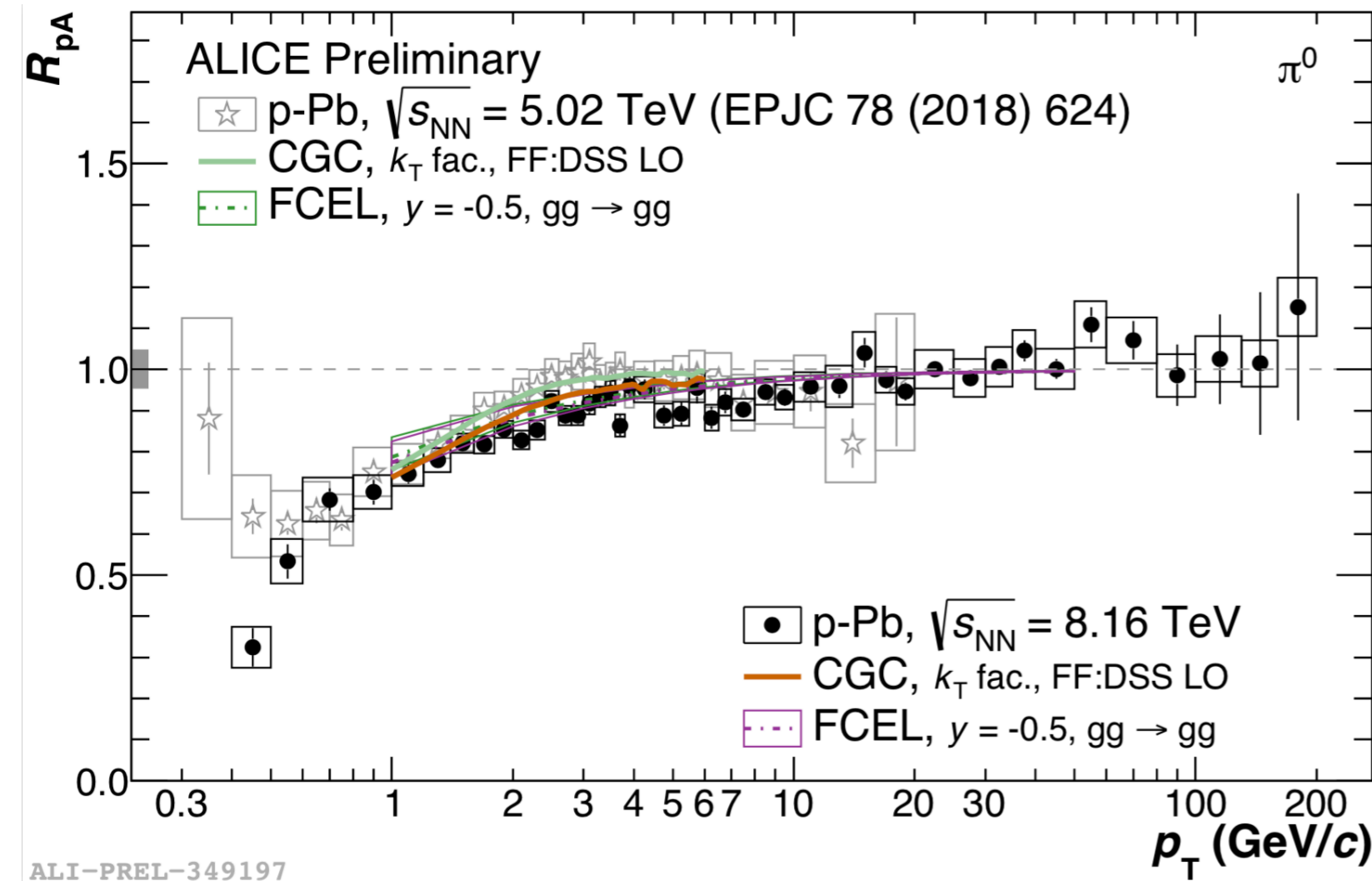
- ❖ pp and p-Pb collisions → baseline measurements to access non-QGP signals
- ❖ Multiplicity dependent studies → more differential and a bridge to Pb-Pb collisions
  - Several signals similar to the one in Pb-Pb observed → new measurements to gain insight
- ❖ Hadron physics and inputs to other fields

# Nuclear modification of $\pi^0$ in p-Pb

$R_{pA}$  probes cold nuclear matter effects in initial and final state

- $\pi^0 R_{pPb}$  measured at  $\sqrt{s_{NN}} = 8.16$  TeV

$$R_{pA} = \frac{1}{\langle N_{coll} \rangle} \frac{Y_{pA}}{Y_{pp}}$$

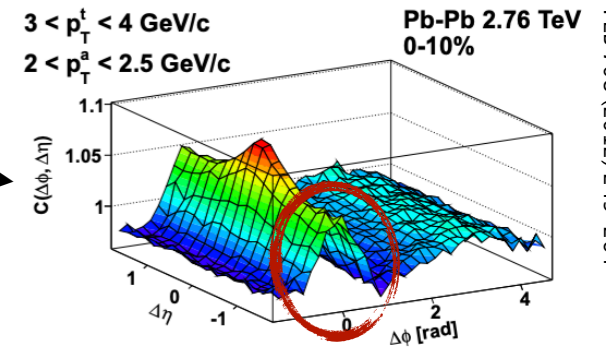


- Cross section and  $R_{pPb}$  of  $\pi^0$  measured up to 200 GeV/c
- $R_{pPb} < 1$  for  $2 < p_T < 4$  GeV/c described by initial state effects.
- $R_{pPb} \sim 1$  for  $p_T > 10$  GeV/c

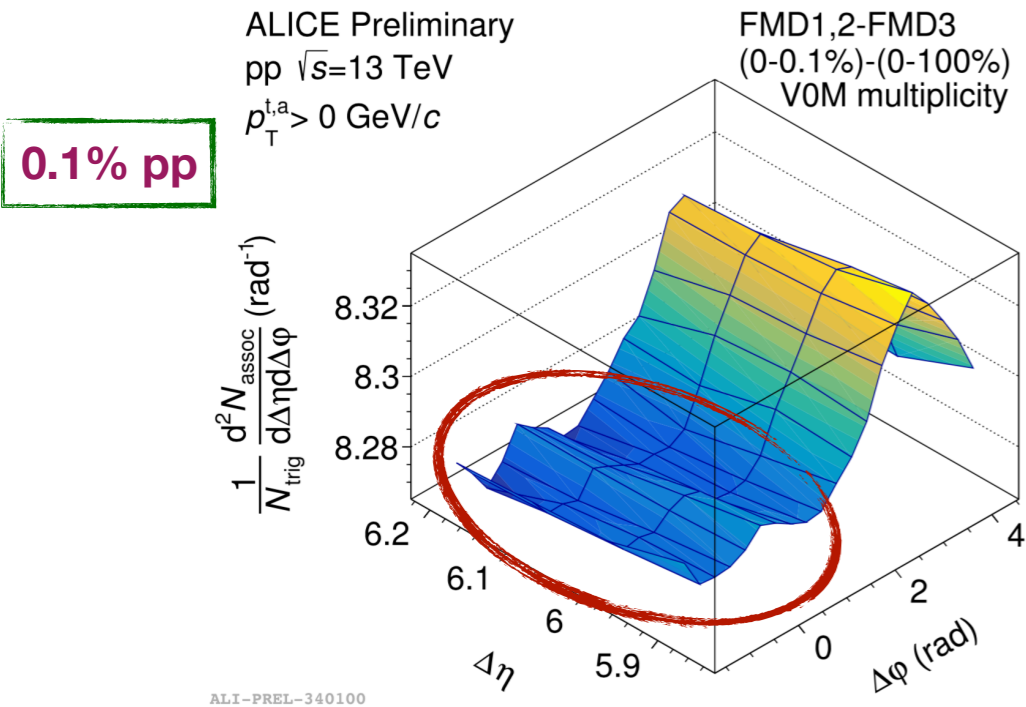
# Long range correlations at large $\Delta\eta$ in pp

## $v_2$ in high multiplicity pp events at large rapidity

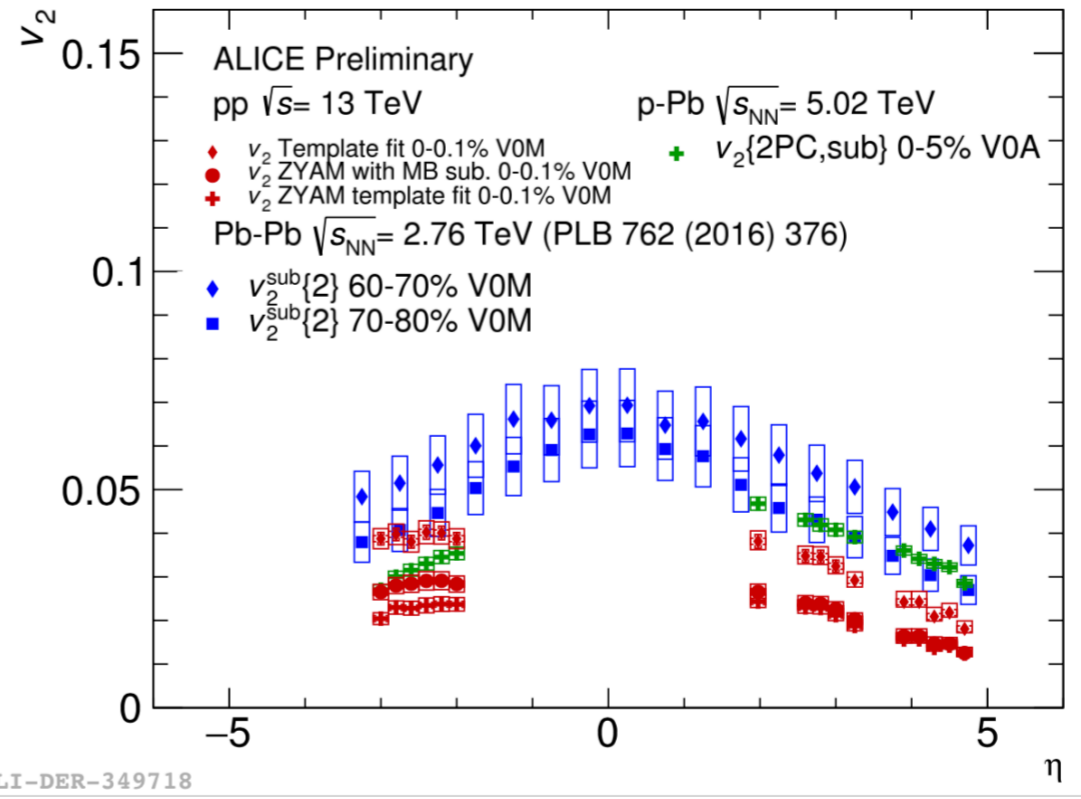
- Positive  $v_2$  in Pb-Pb  $\rightarrow$  described by hydrodynamic models
- Positive  $v_2$  in high multiplicity p-Pb and pp  $\rightarrow$  similar origin for collectivity?
  - Explore the extent and evolution of the correlations in rapidity



PLB 708 (2012) 249-264



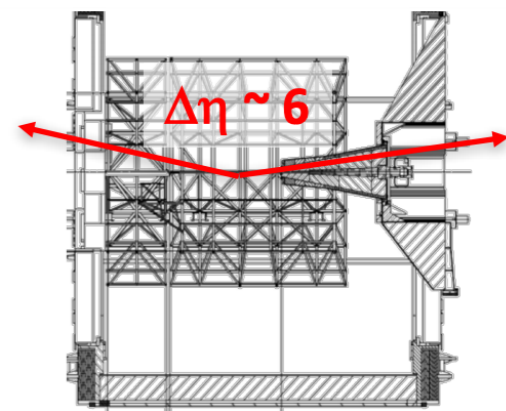
0.1% pp



New preliminary

pp  
p-Pb  
Pb-Pb

- Study of correlations up to  $\Delta\eta \sim 6$  with ALICE Forward Multiplicity Detector (FMD)
  - **Unique capability at the LHC**
- **Ridge in high multiplicity pp (0-0.1%) up to  $\Delta\eta \sim 6.2$**
- **Positive  $v_2$  values measured to large  $\eta$  in pp collisions at 13 TeV**





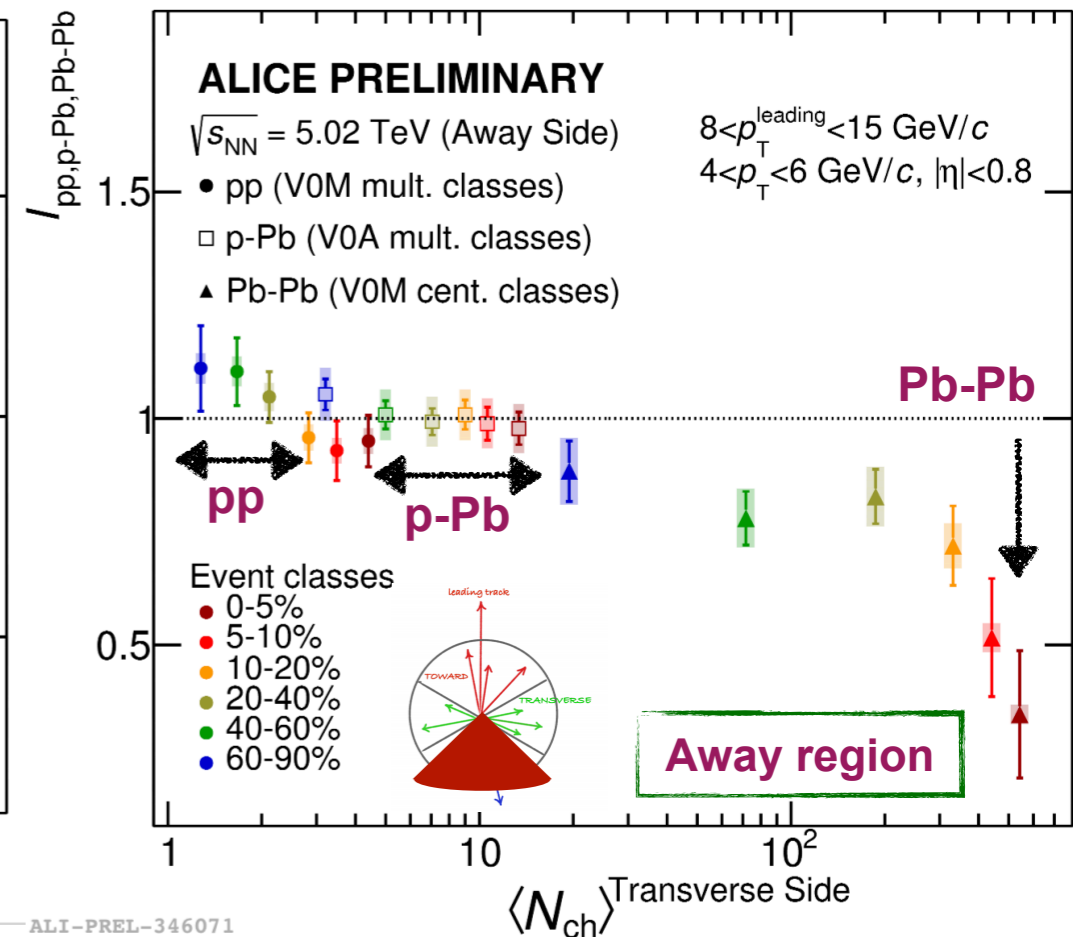
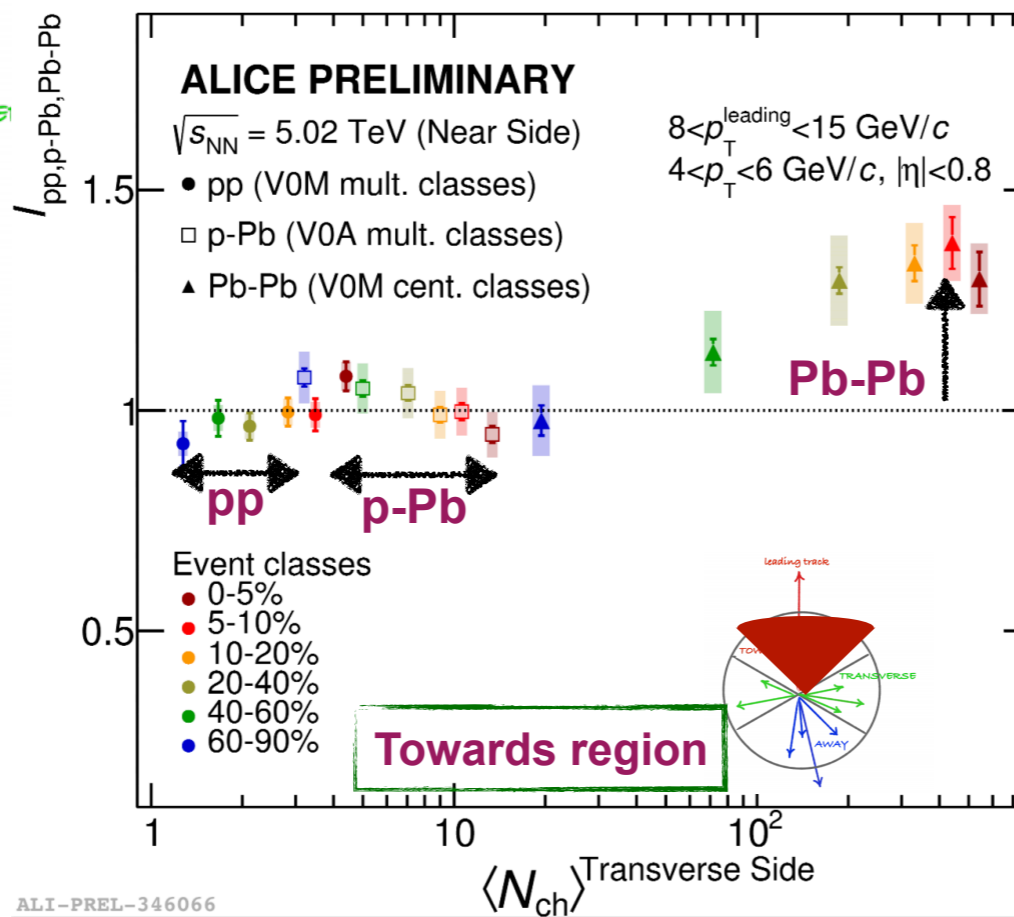
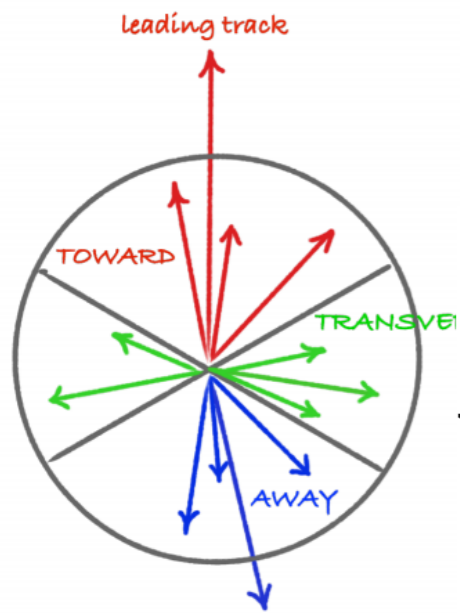
# Jet quenching in pp and p-Pb?

## Near- and away-side yield vs multiplicity

New preliminary

Leading particle:  $8 < p_T < 15$  GeV/c  
 Associated particle:  $4 < p_T < 6$  GeV/c

$$I_{AA} = \frac{Y_{pp,pA,AA}}{Y_{pp}^{MinBias}}$$



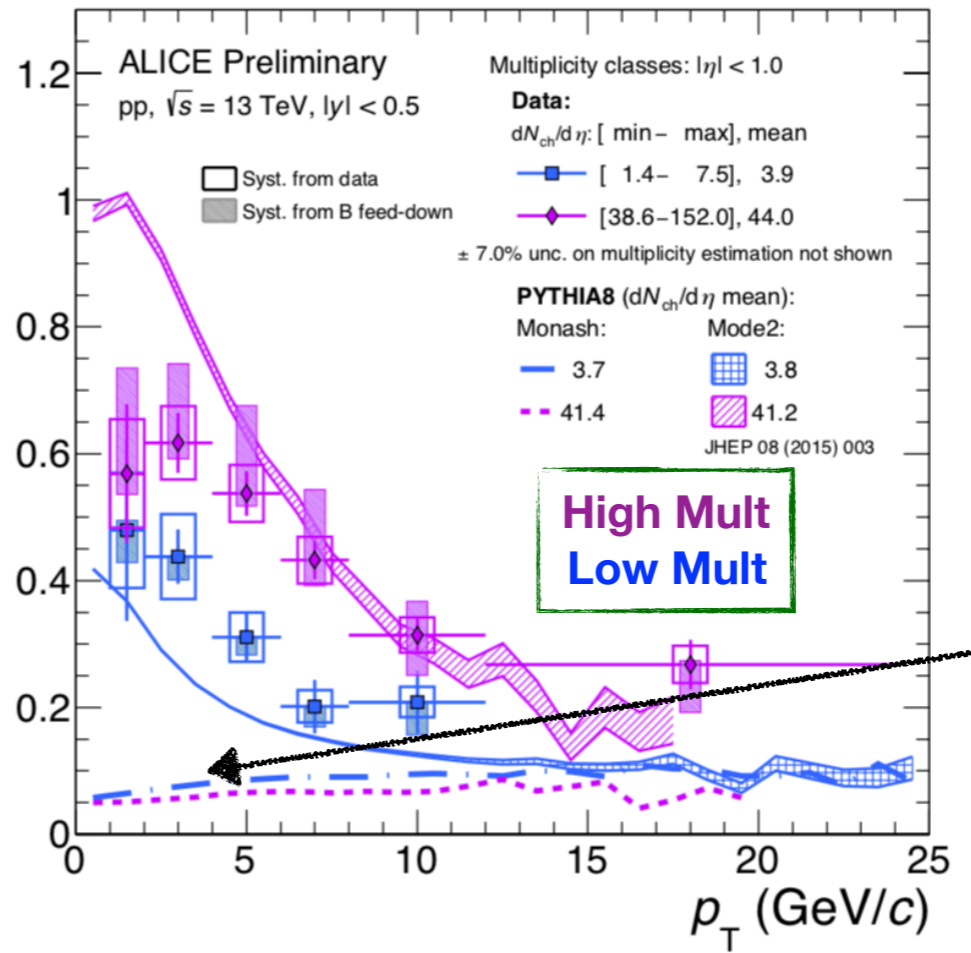
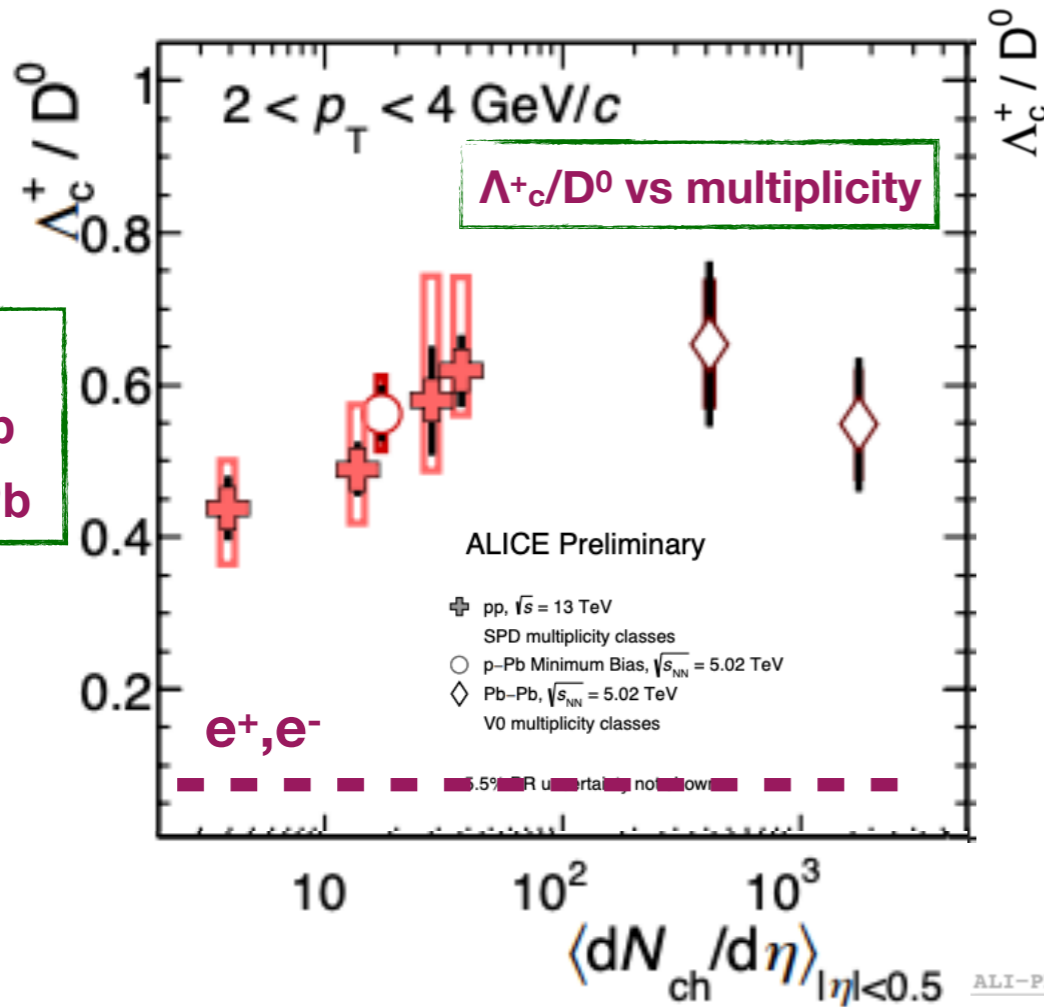
- Enhancement and suppression in the Towards and Away region respectively in Pb-Pb → due to medium effects
- **No indication of jet quenching in small systems in the measured multiplicity region**

# Multiplicity dependent heavy-flavor production

## Study hadronisation with heavy-flavor baryons

- Enhancement of baryon over meson yield in heavy-ion collisions → supports hypothesis of charm recombination/coalescence in QGP
- Investigate hadronisation vs multiplicity pp collisions

New preliminary



$\Lambda_c^+ / D^0$  vs  $p_T$   
pp,  $\sqrt{s} = 13$  TeV

- Smooth evolution of  $\Lambda_c / D^0$  with multiplicity across different systems. Common origin?
- $\Lambda_c / D^0$  in pp vs multiplicity:
  - Default PYTHIA tuned on  $e^+e^-$  data (Monash), underestimates the measurement
  - **PYTHIA with color reconnections describes multiplicity dependent data in pp**

# Higher charm baryon states

Extend charm baryon measurements using heavier baryonic states

pp,  $\sqrt{s}=13$  TeV

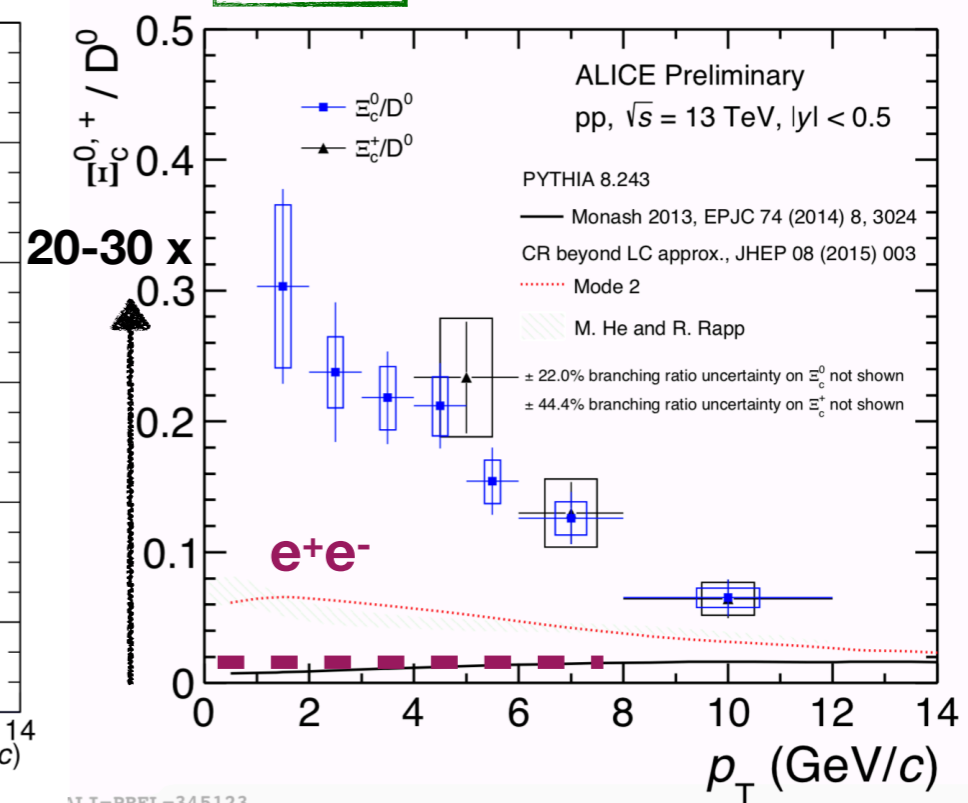
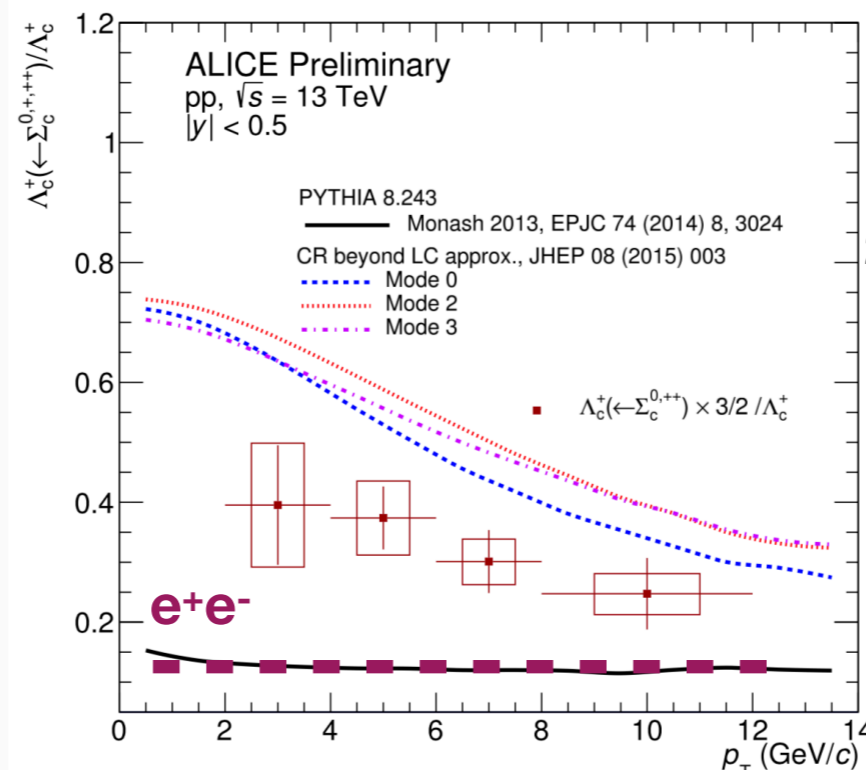
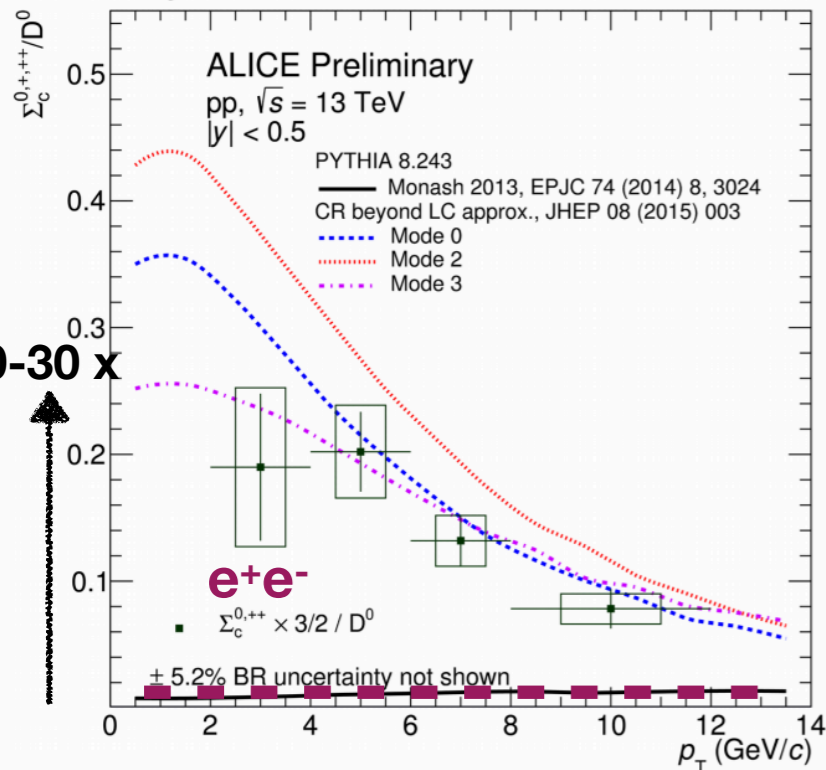
New preliminary

	mass	quark
$\Lambda_c$	2286	udc
$\Xi_c^+$	2567	usc
$\Xi_c^0$	2471	dsc
$\Sigma_c^{0,+,++}$	2455	ddc, uuc

$\Sigma_c^{0,+,++}/D^0$

$\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+$

$\Xi_c^{0,+}/D^0$



$\Sigma_c/D^0$ :

- PYTHIA with color reconnections beyond leading color approx. describes data

$\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+$ :

- Provides constraint on feed down contribution to  $\Lambda_c^+$
- Not described by available PYTHIA tunes/modes

$\Xi_c/D^0$ :

- Similar  $p_T$  dependence as  $\Lambda_c/D^0$ ,  $\Sigma_c/D^0$
- Not described by available PYTHIA tunes/modes

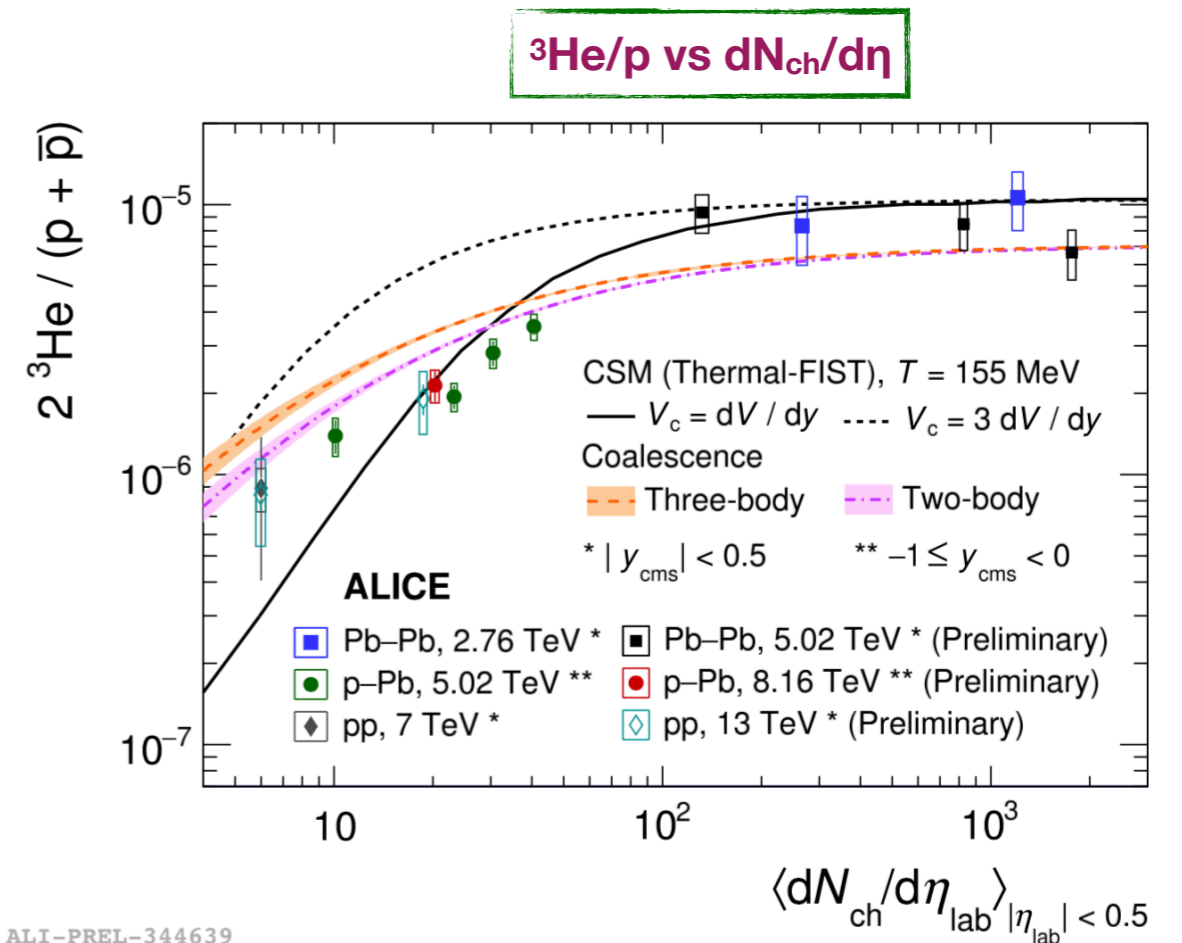
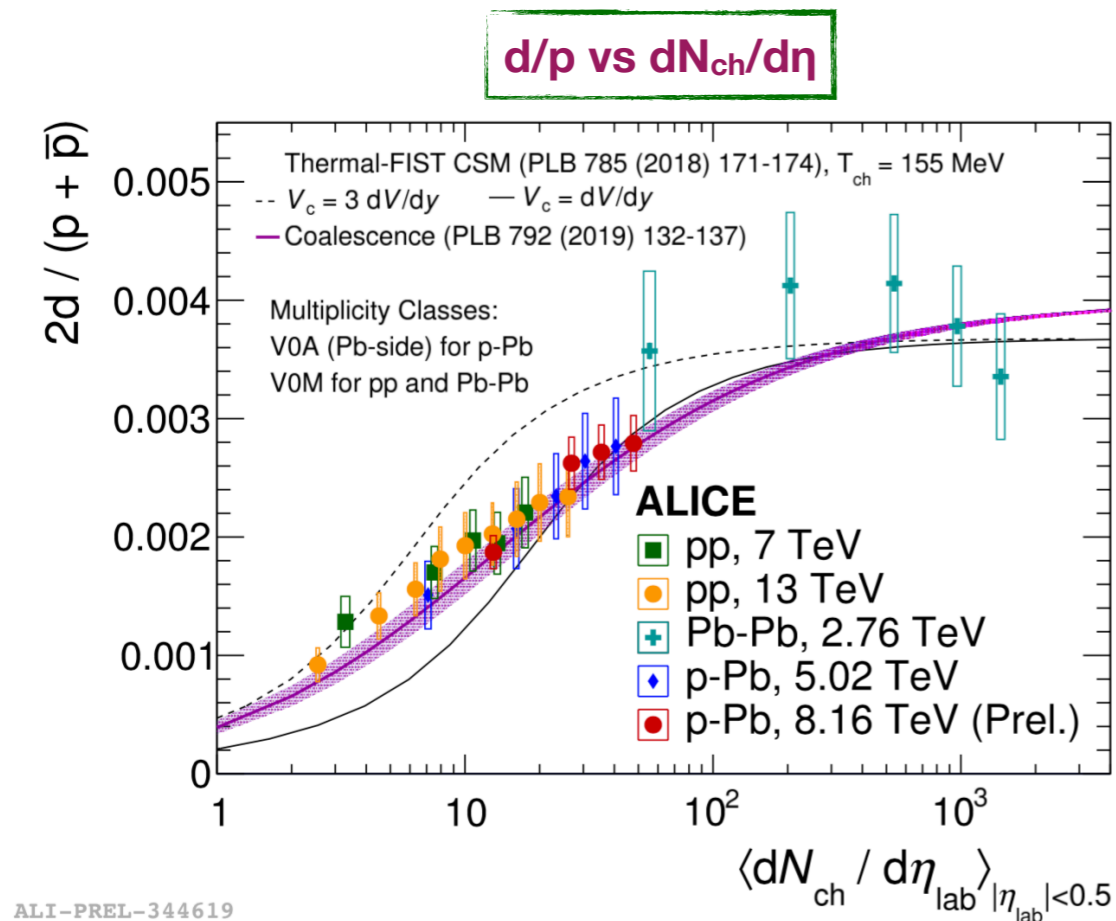
Better understanding of baryon production needed

# Multiplicity dependent nuclei production

## Studying production mechanism of light nuclei

- Measuring (anti)deuteron and (anti)helium production vs multiplicity

arXiv:2003.03184  
New preliminary



- Smooth evolution of light nuclei production with multiplicity across different collision systems similar to other light-flavored hadrons

- Suggests common physics process involved in nuclei production

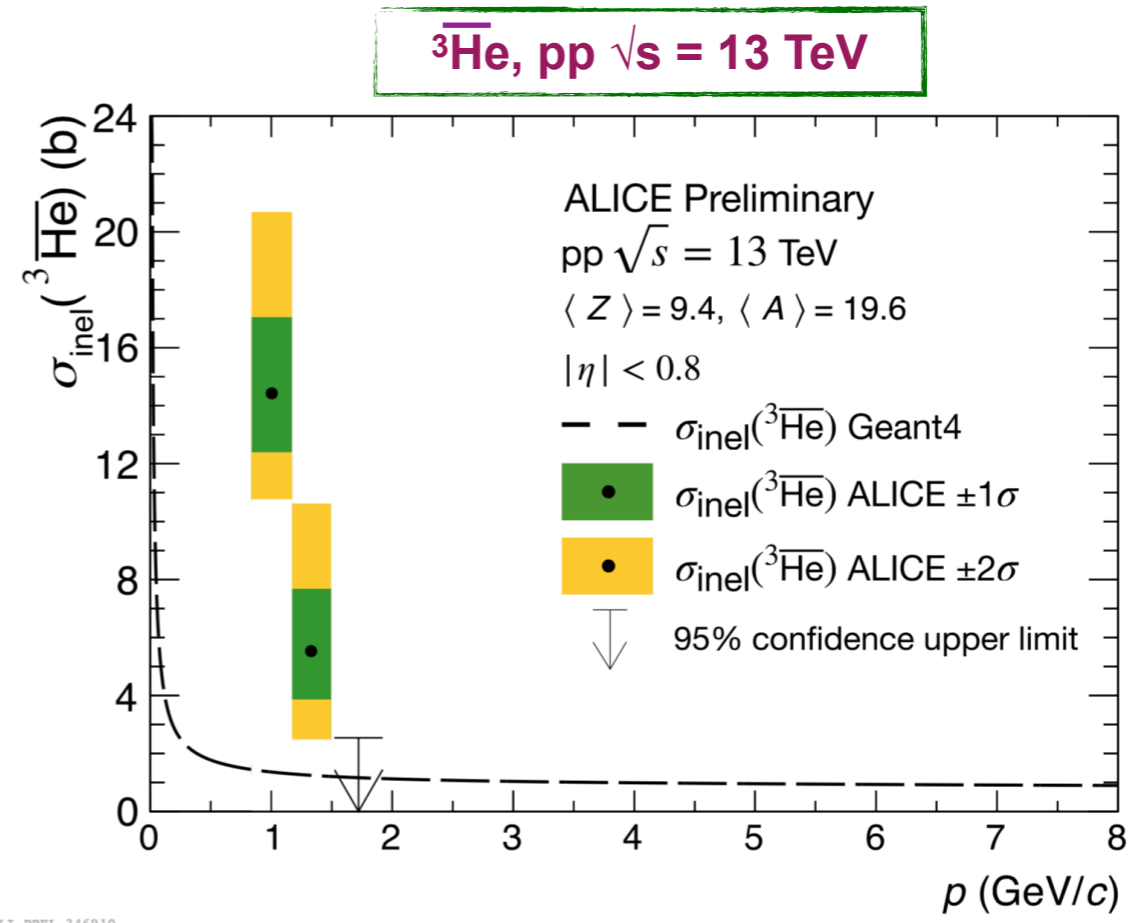
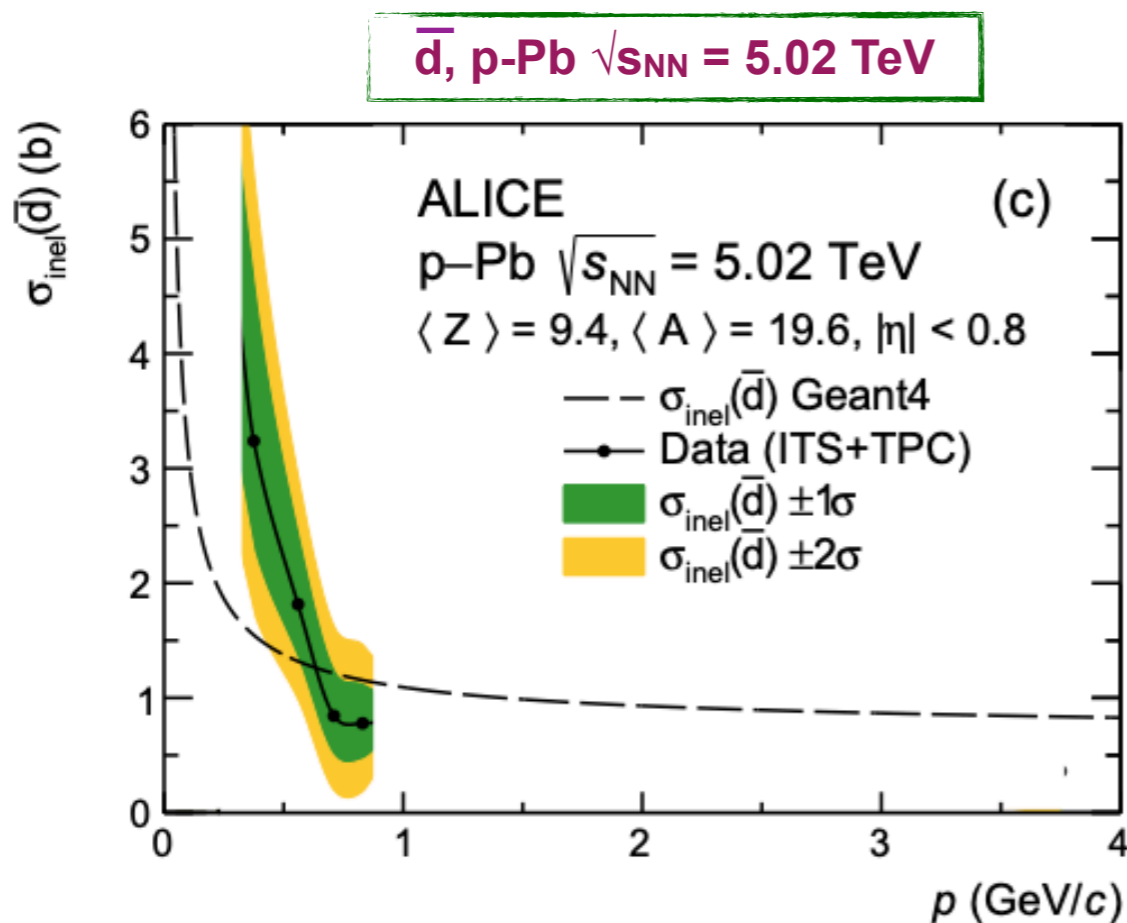
- Model comparisons:

- Nucleon coalescence model qualitatively describes data
- Statistical Model (CSM) struggles in small systems (also for  $p/\pi$ )

# $\overline{2}\text{H}$ , $\overline{3}\text{He}$ inelastic cross section

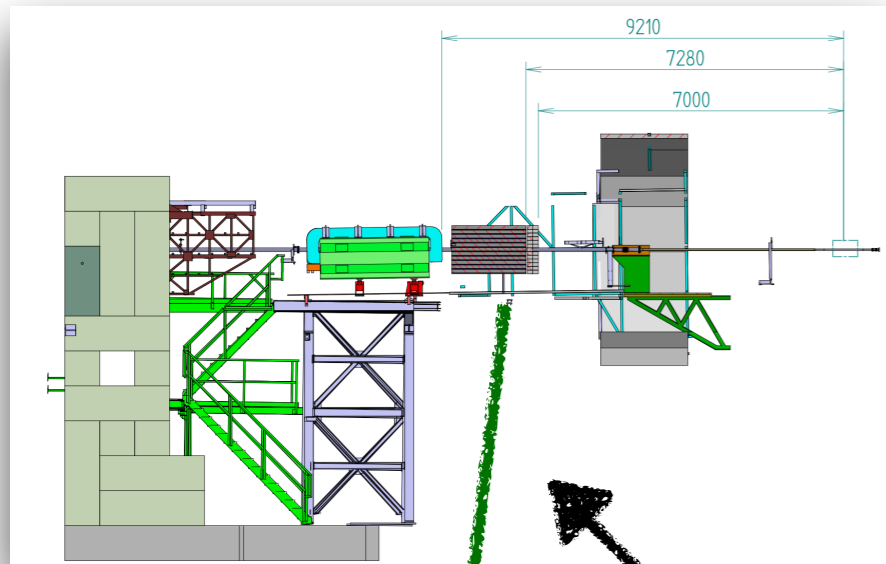
arXiv:2005.11122  
New preliminary

- Antimatter searches in space (AMS-02, GAPS, BESS...) as signatures for Dark Matter annihilation
  - Requires knowledge of antinuclei background from cosmics and absorption rate in interstellar medium
  - ALICE nuclei production and annihilation measurements provides input to both
- **First measurement of the inelastic scattering cross section of antinuclei at low  $p_T$**
- ALICE detector material used as an absorber

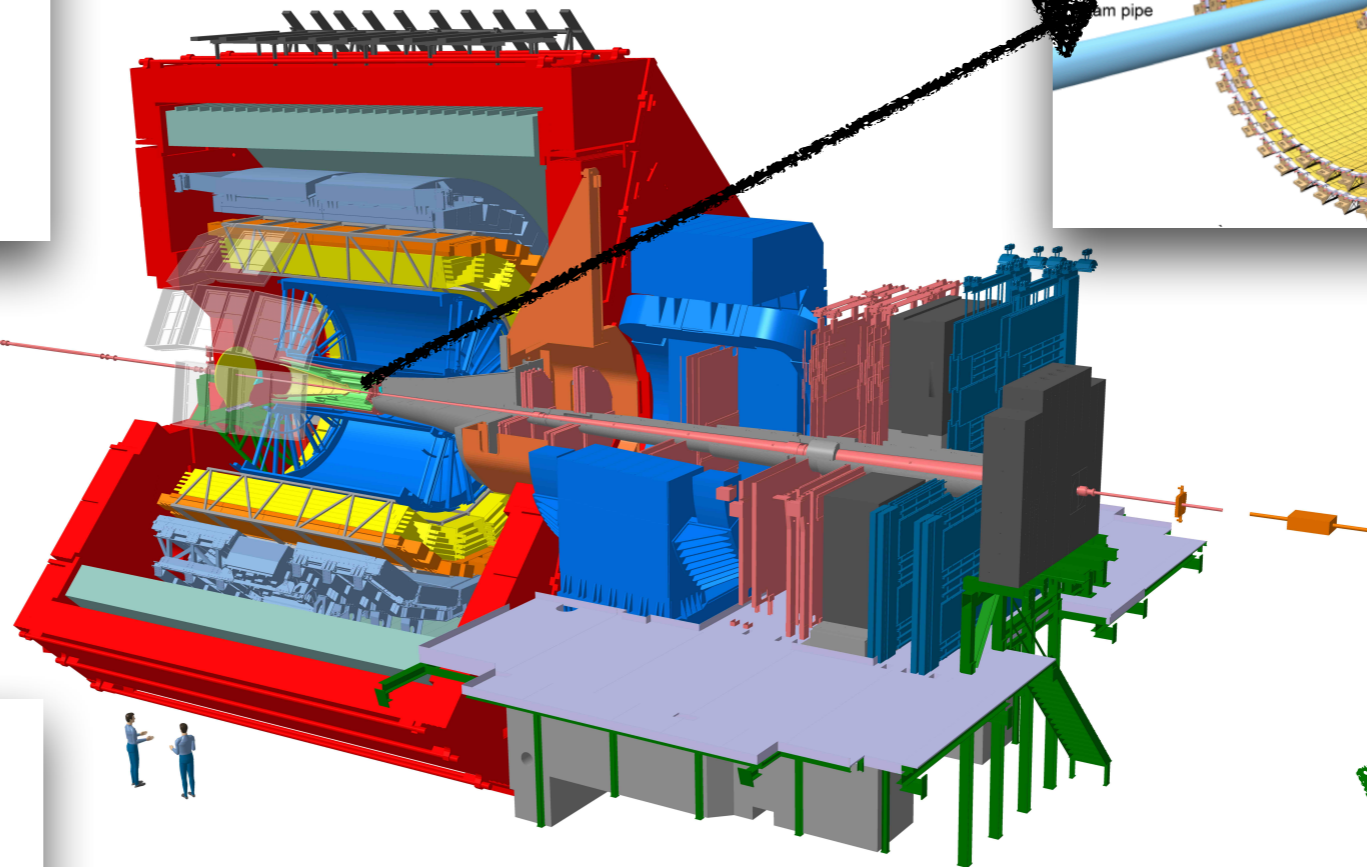
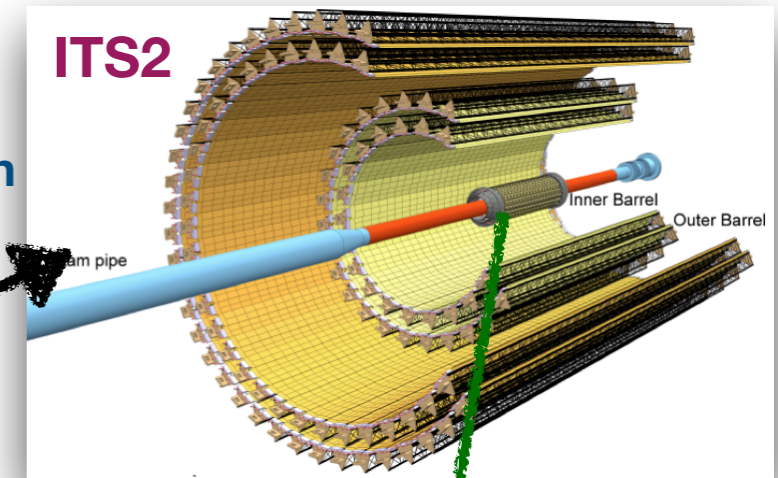


- State-of-the art GEANT4 parameterization agrees with measurement at high  $p_T$ ; increasing discrepancy at low  $p_T$

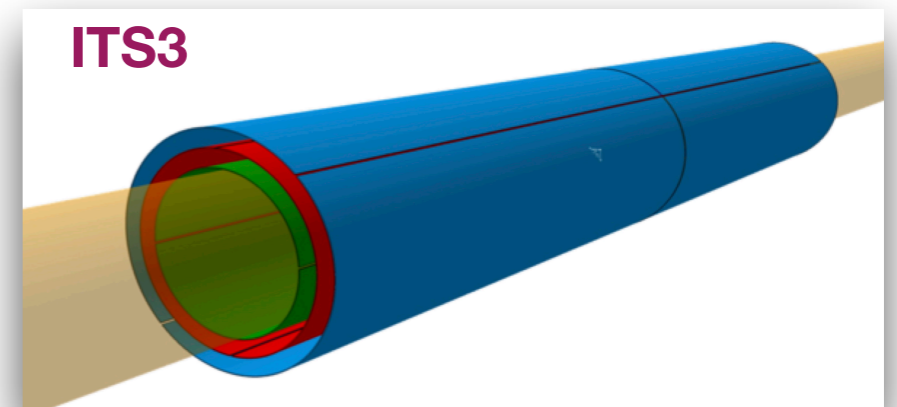
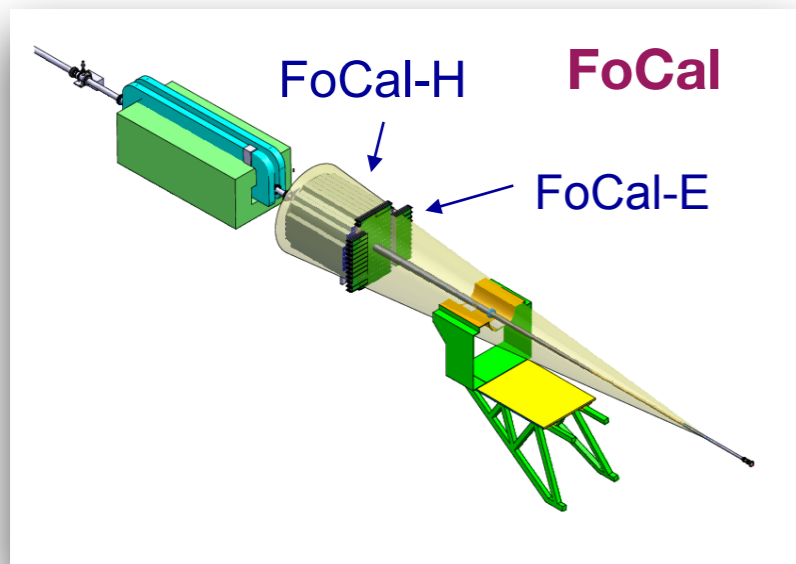
# ALICE upgrades for Run 4



Letter of Intent:  
 ITS 3 → Endorsed in September 2019  
 FoCal → Submitted in this LHCC session



Replace inner 3 layers



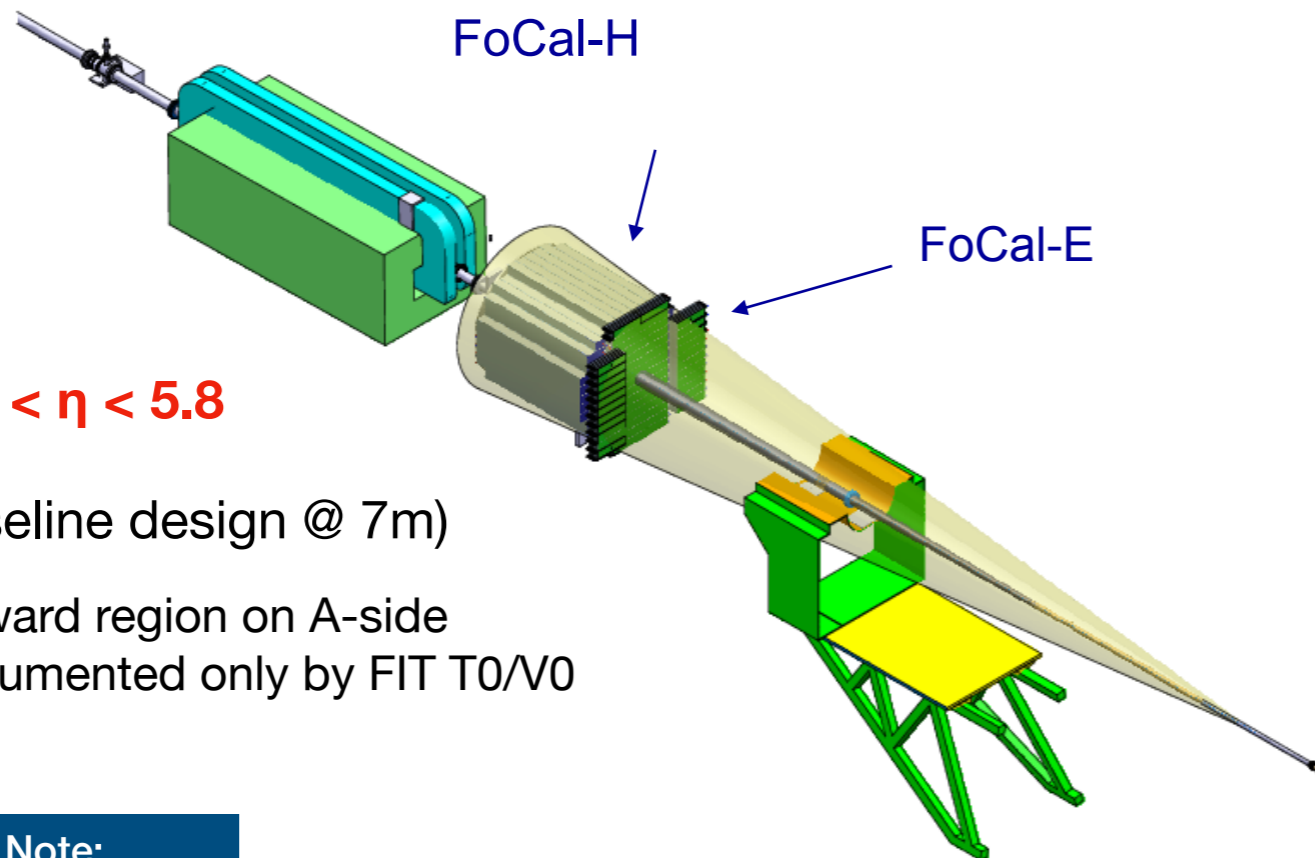
# The FoCal proposal

## The Forward Calorimeter:

- Study the nucleon structure at small  $x$ -scale and low  $Q$ 
  - Strong small- $x$  program at LHC together with LHCb; complementary fRHIC and EIC

**FoCal-E:** high-granularity Si-W sampling calorimeter for photons and  $\pi^0$

**FoCal-H:** Conventional absorber (Pb) - Sc sampling calorimeter for photon isolation and jets

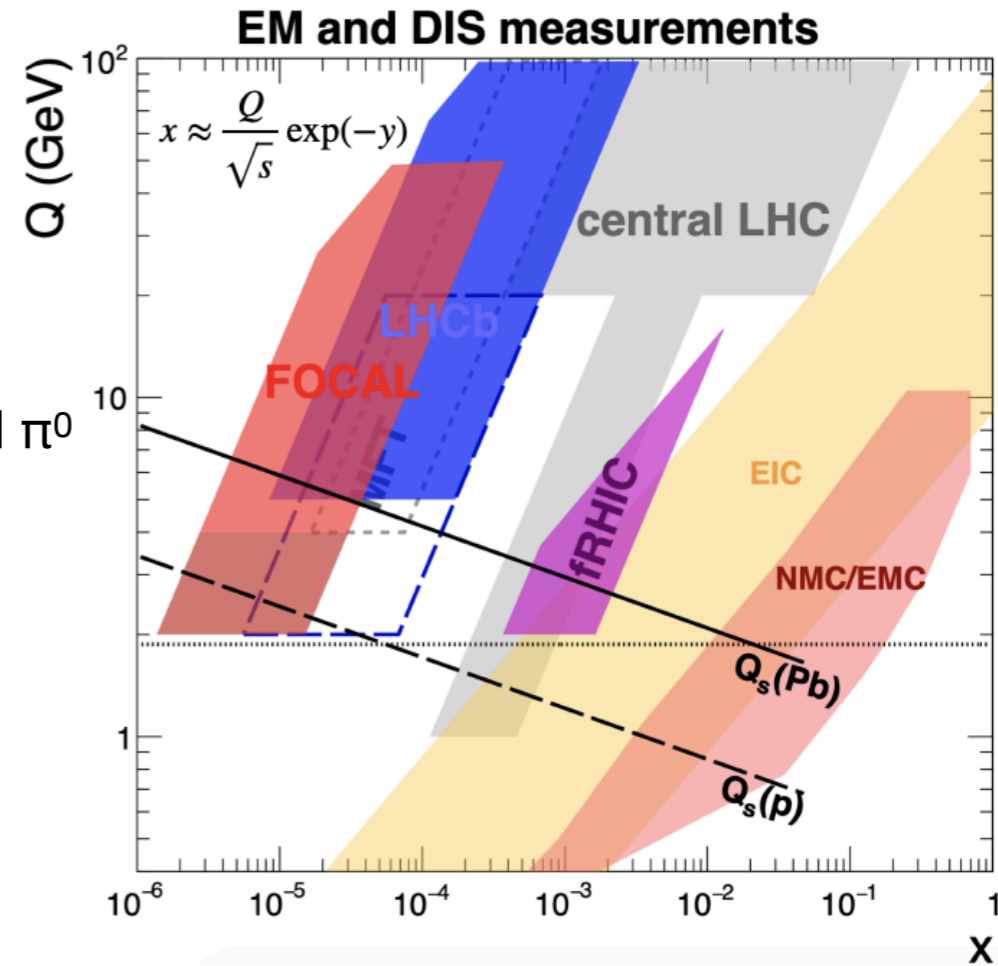


$$3.4 < \eta < 5.8$$

(baseline design @ 7m)

Forward region on A-side instrumented only by FIT T0/V0

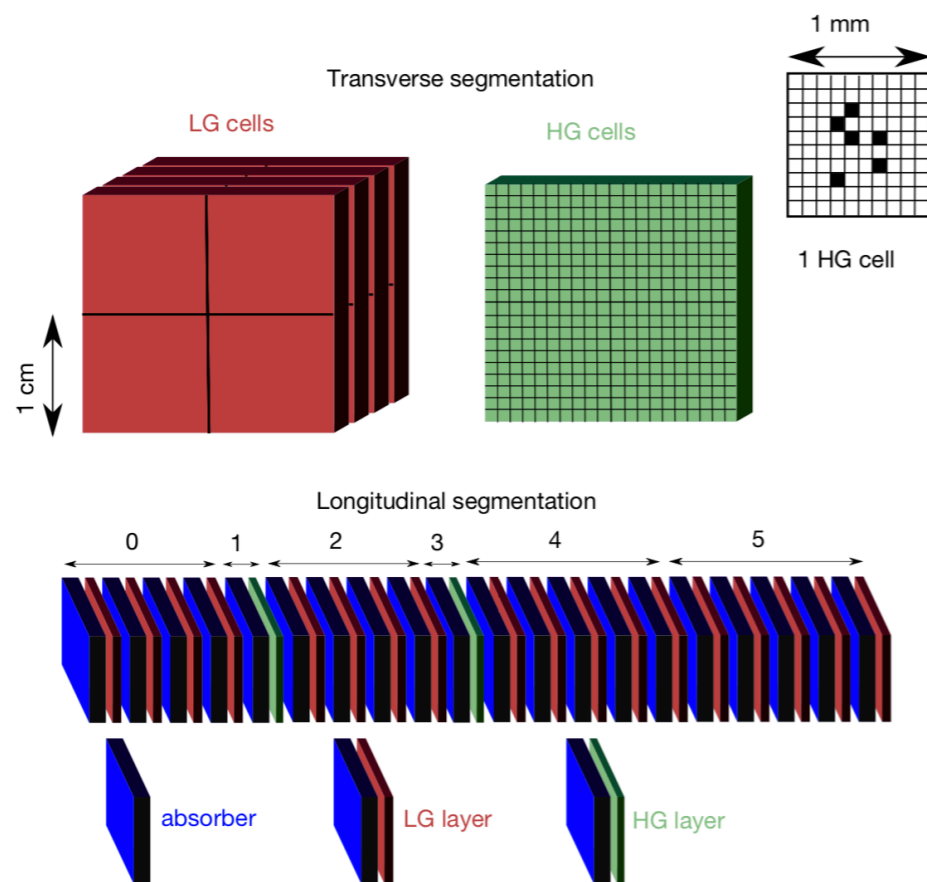
Public Note:  
ALICE-PUBLIC-2019-005



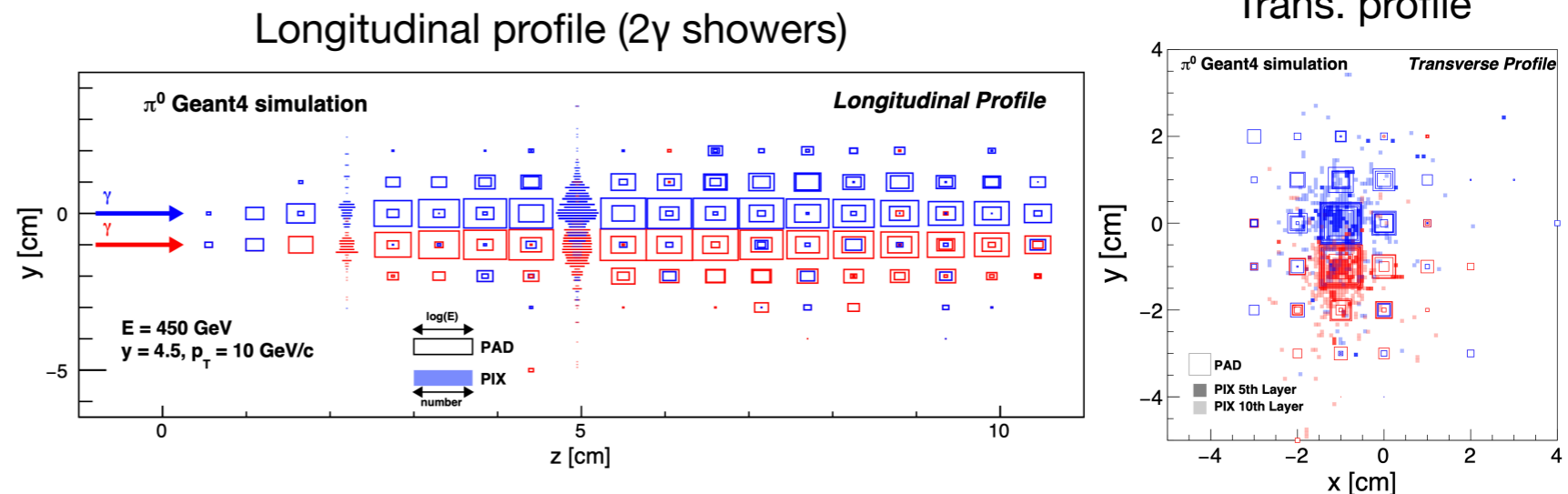
## Observables:

- $\pi^0$  (and other neutral mesons)
- Isolated (direct) photons
- Jets (and di-jets)
- $J/\psi$  ( $\Upsilon$ ) in UPC
- W, Z
- Event plane and centrality

# FoCal-E design



- **Main challenge: Separate  $\gamma/\pi^0$  at high energy**
  - Two photon separation from  $\pi^0$  decay ( $p_T=10$  GeV,  $\eta=4.5$ )  $\sim 5$  mm
  - Requires small Molière radius and high granularity readout
  - Si-W calorimeter with effective granularity  $\approx 1$  mm<sup>2</sup>



## Studied in simulations 20 layers:

W(3.5 mm  $\approx 1X_0$ ) + silicon sensors

Two types: **Pads (LG)** and **Pixels (HG)**

- Pad layers provide shower profile and total energy
- Pixel layers (ALPIDE) provide position resolution to resolve overlapping showers

## Further optimization left for TDR:

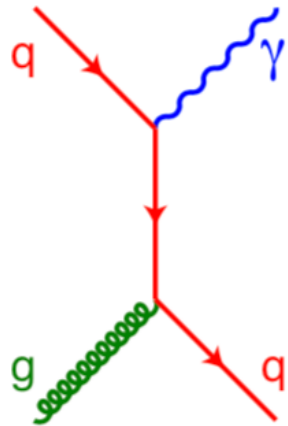
- Location of pixel layers
- Number of pad layers
- Sensitive area at front for CPV/eID



# Small-x program using forward isolated photons

## Goal

- Explore non-linear QCD evolution at small  $x$   $\rightarrow$  constrain nuclear PDFs at small  $x$

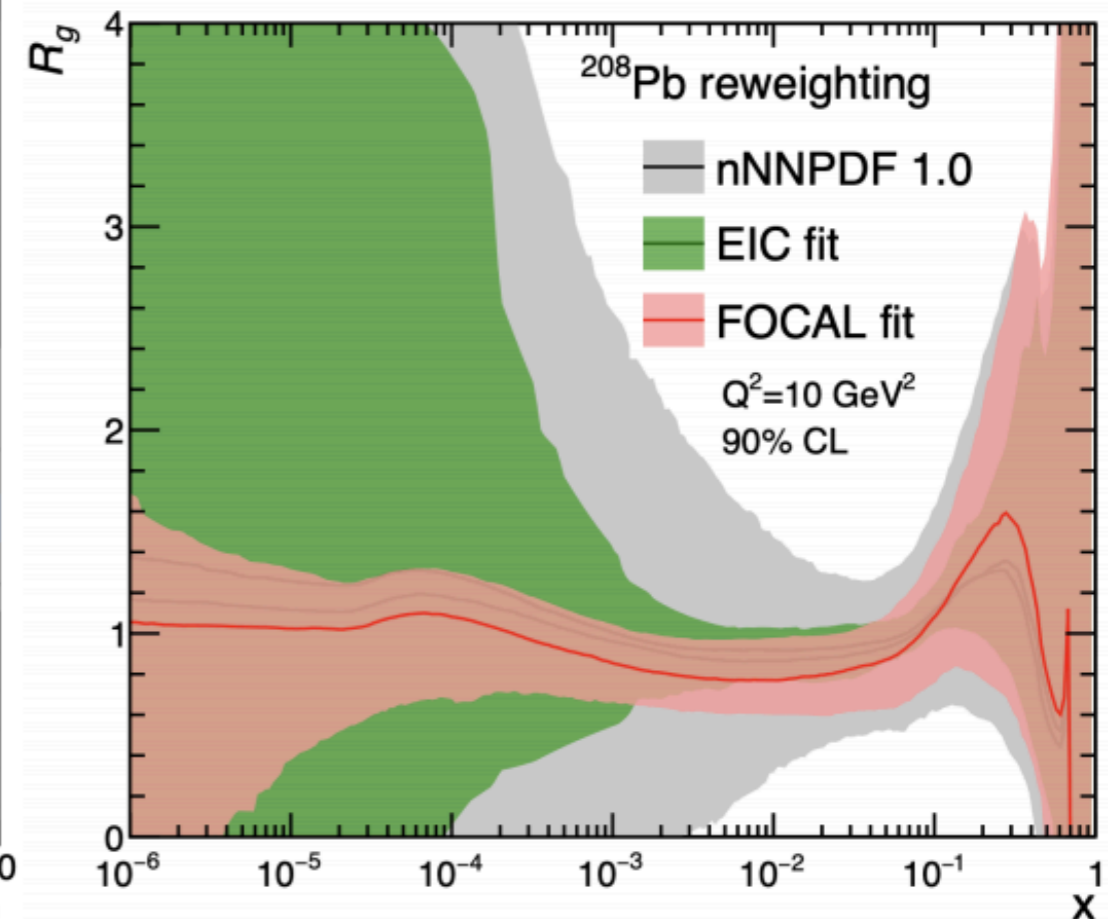
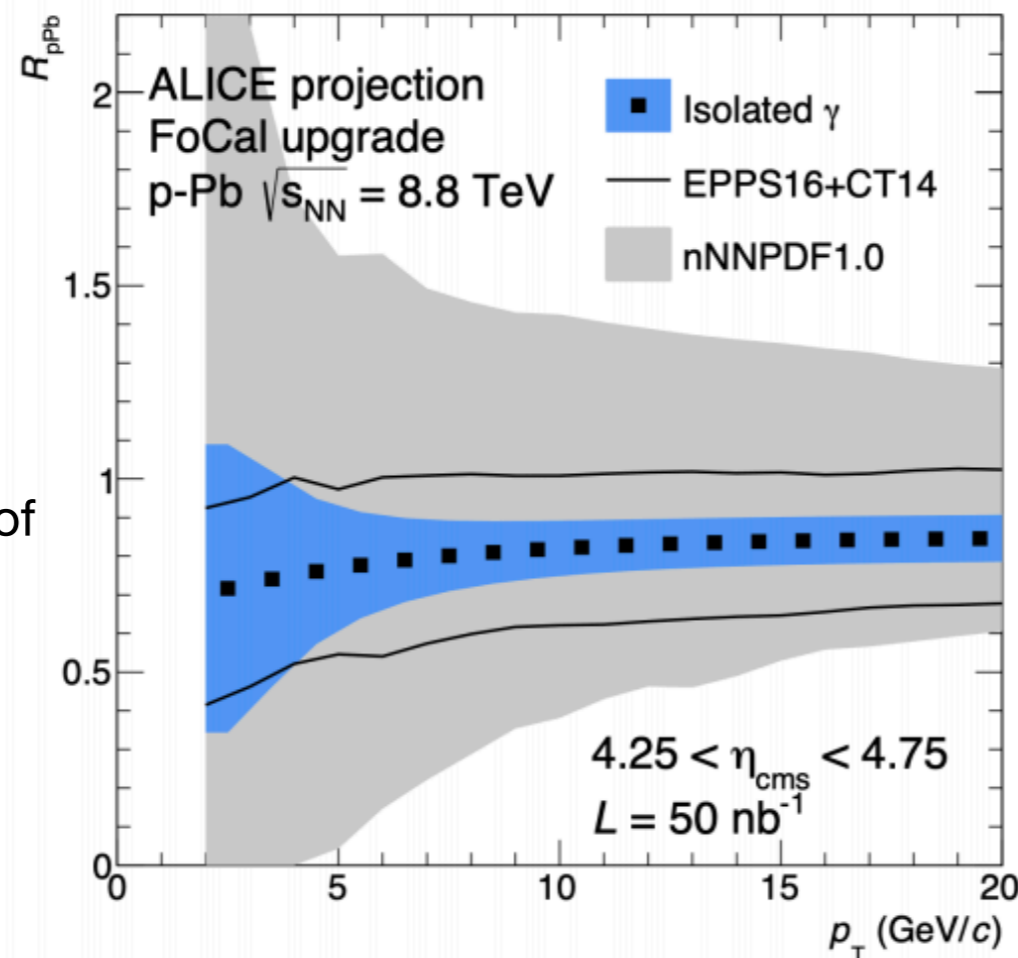


Compton

## Recent nuclear PDFs: nNNPDF from DIS experiments and minimal theoretical assumptions

- Unconstrained for  $x < 10^{-2}$
- **FOCAL provides significant constraints over a broad range:  $\sim 10^{-5} - 10^{-2}$** 
  - Measure isolated photons  $\rightarrow$  direct sensitivity to gluon density.
- Outperforming the EIC for  $x < 10^{-3}$

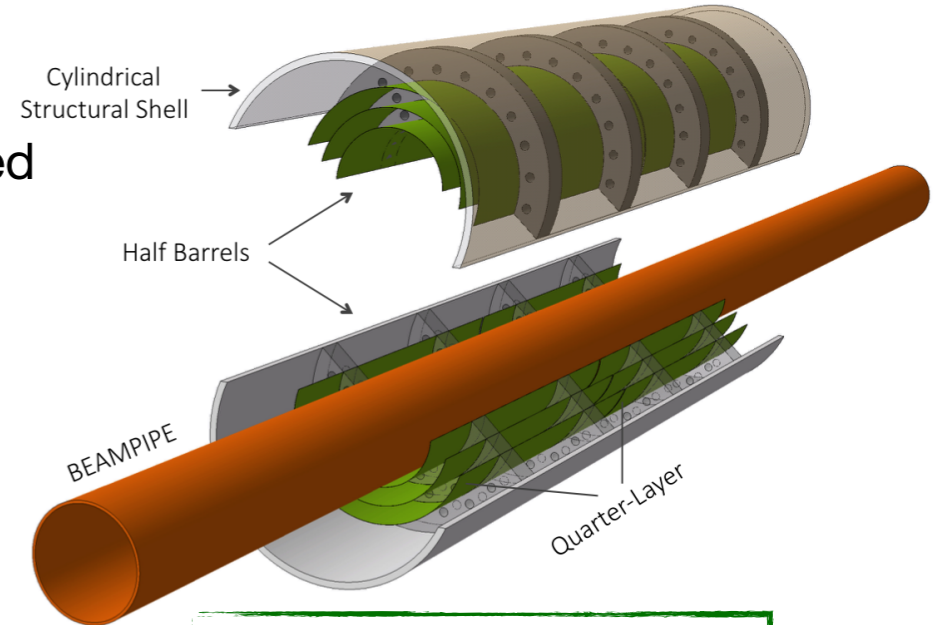
$R_{pPb}$  measurements used to obtain  $R_g$  (nuclear modification of gluon PDF)



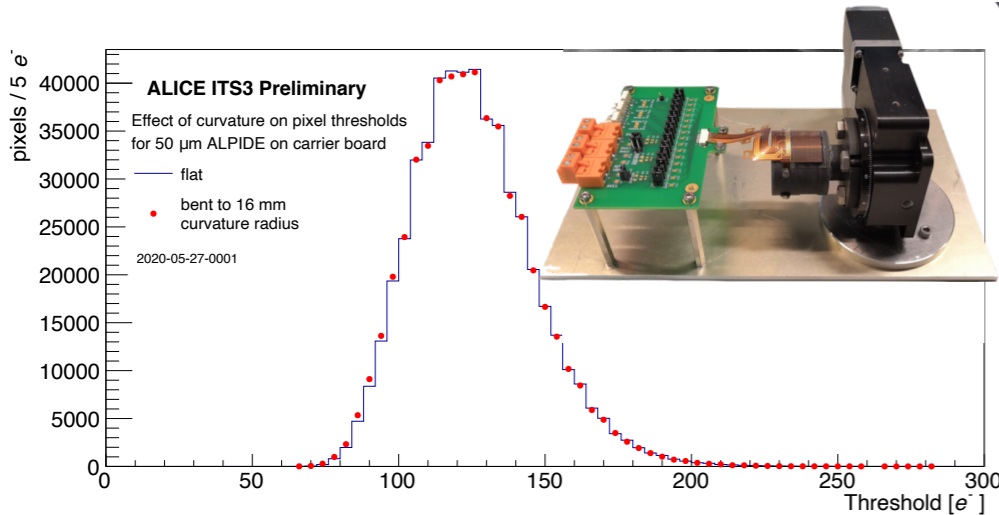
# Inner Tracking System-3

## Inner Tracking System 3: New detector technology

- Three fully-cylindrical Si-pixel layer based on ultra-thin wafer-sized curved sensors
  - Sensor thickness = 20-40  $\mu\text{m}$  (0.02-0.04%  $X_0$ )
- New beam pipe inner radius = 16 mm, thickness = 500  $\mu\text{m}$  (0.14%  $X_0$ )
- Material budget reduced to bare minimum



**Expected performance:**  
 $v_2$  of non-prompt  $D_s$



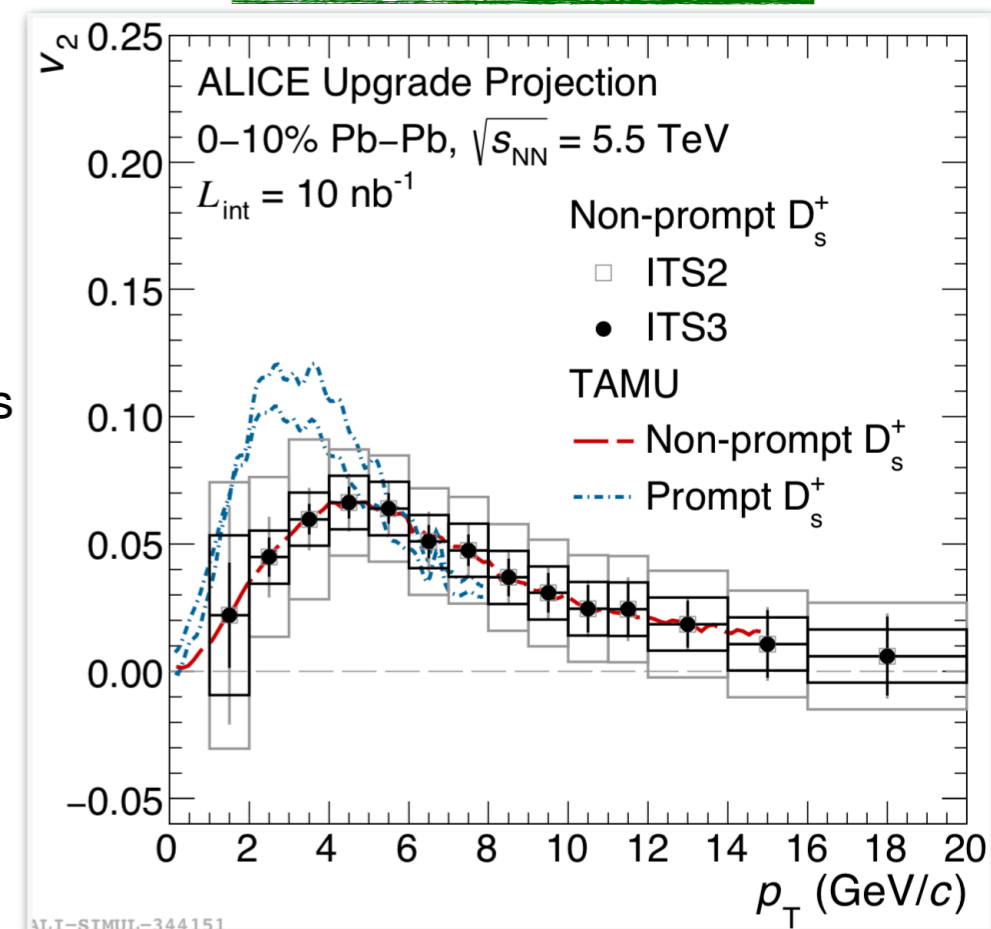
## Observables:

- Low-mass dielectrons
- Beauty baryons
- Charm-strange baryons
- Non-prompt  $D_s$  and  $\Lambda_c$
- c-deuteron search
- Charm correlations and jets

## R&D on bent MAPS:

- Effect of curvature on pixel thresholds for 50  $\mu\text{m}$  ALPIDE
  - No noticeable effect

Working on R&D and completing physics performance studies to enhance measurements



# Summary

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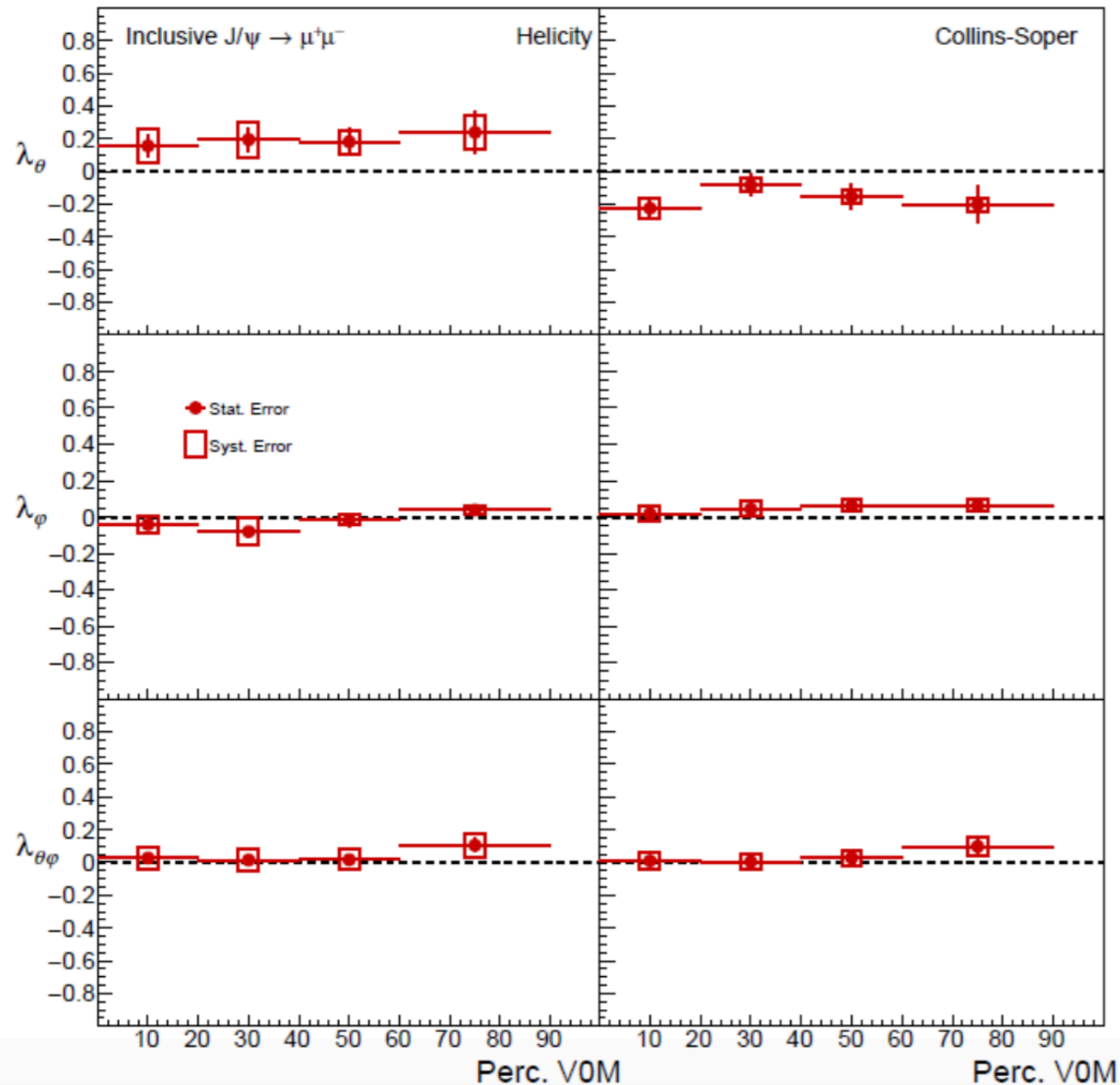
- Several new results in different collision systems prepared for the LHCP and HP conference
- Measurements in Pb-Pb collisions to continue investigating QGP properties
- Multiplicity dependent studies in pp and p-Pb open up new unexplored avenues
- ALICE preparations continuing for Run 3
  - **Ready for beam commissioning on Aug 1st**
- New upgrades (FoCal and ITS3) planned for Run 4

# Back-up

# J/ψ polarization

## J/ψ polarization vs centrality in Pb-Pb collisions

New preliminary



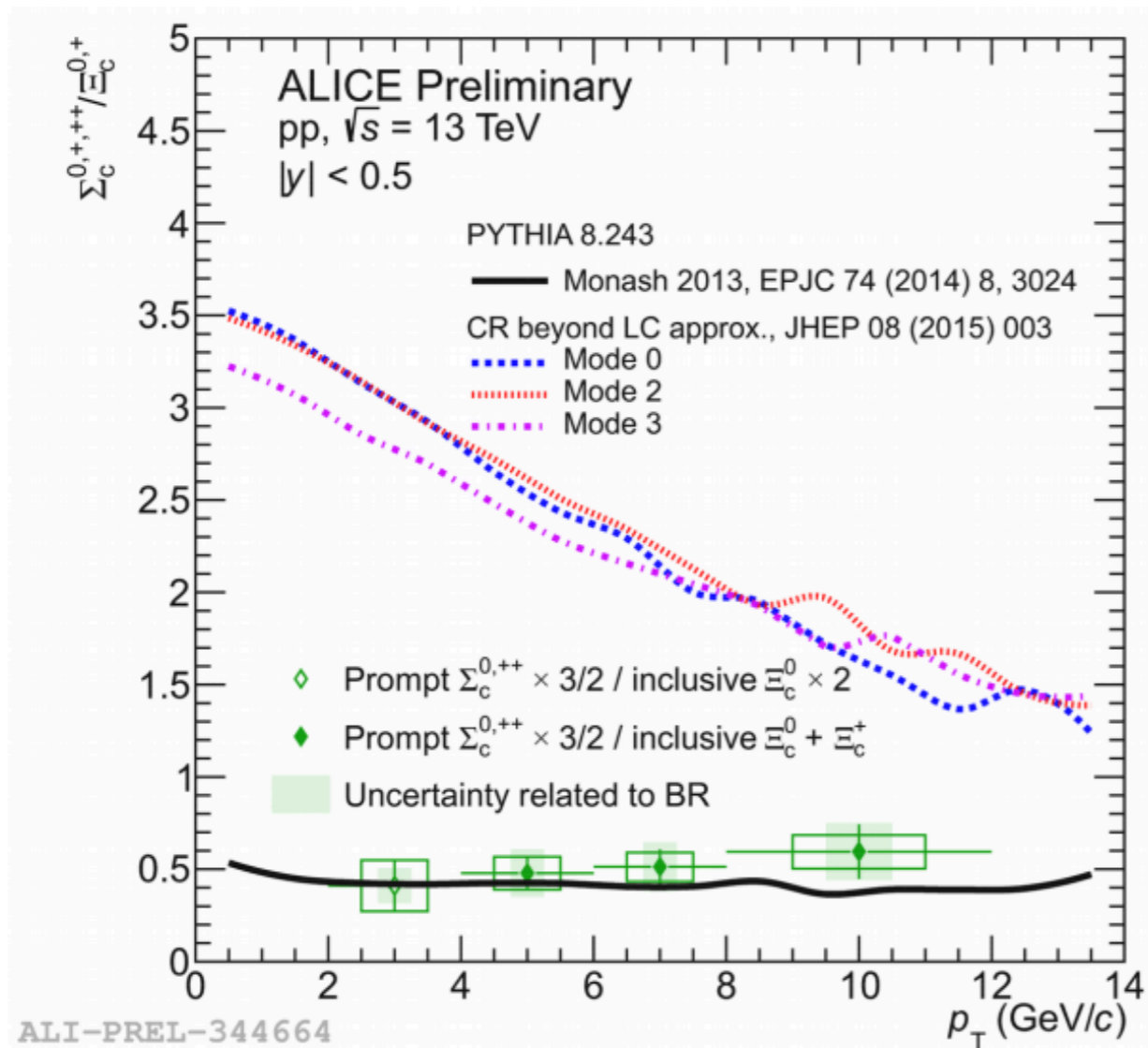
$2 < p_T < 4 \text{ GeV}/c$

- $\lambda_\theta$  independent of centrality
- Values consistent with centrality integrated measurement

# Higher charm baryon states

Extend charm baryon measurements using heavier baryonic states

New preliminary



- $\Sigma_c/\Xi_c$ :
  - Standard Pythia reproduces data.
  - Effect of similar mass?

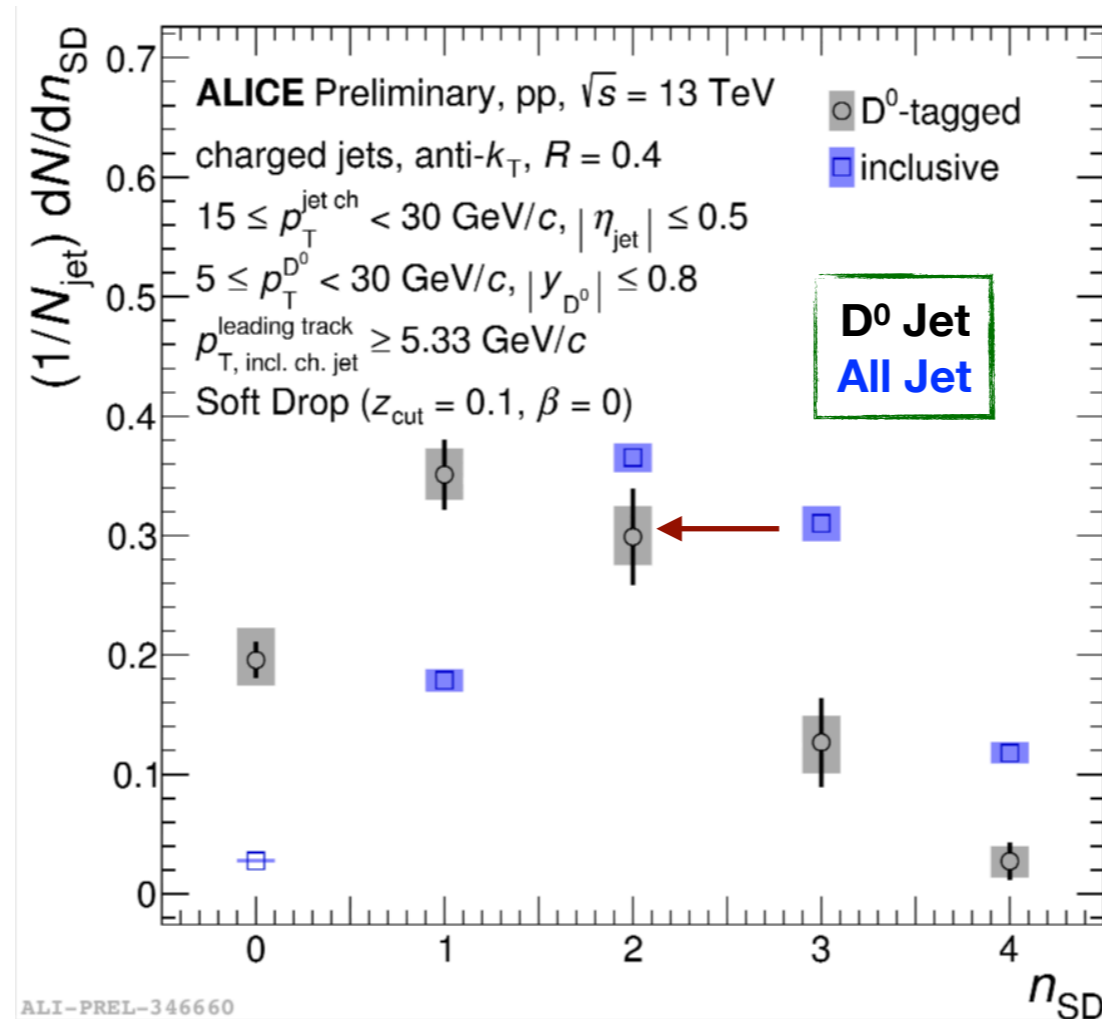
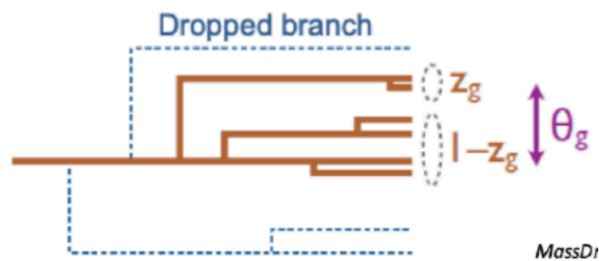
# Jet substructure of $D^0$ -tagged jets

## Measuring substructure of jets containing $D^0$ mesons in pp collision

New preliminary

Grooming jets with SoftDrop algorithm:

- Groomed splitting characterized by **N-splitting passing grooming condition ( $N_{sd}$ )** and **groomed momentum fraction ( $z_g$ )**



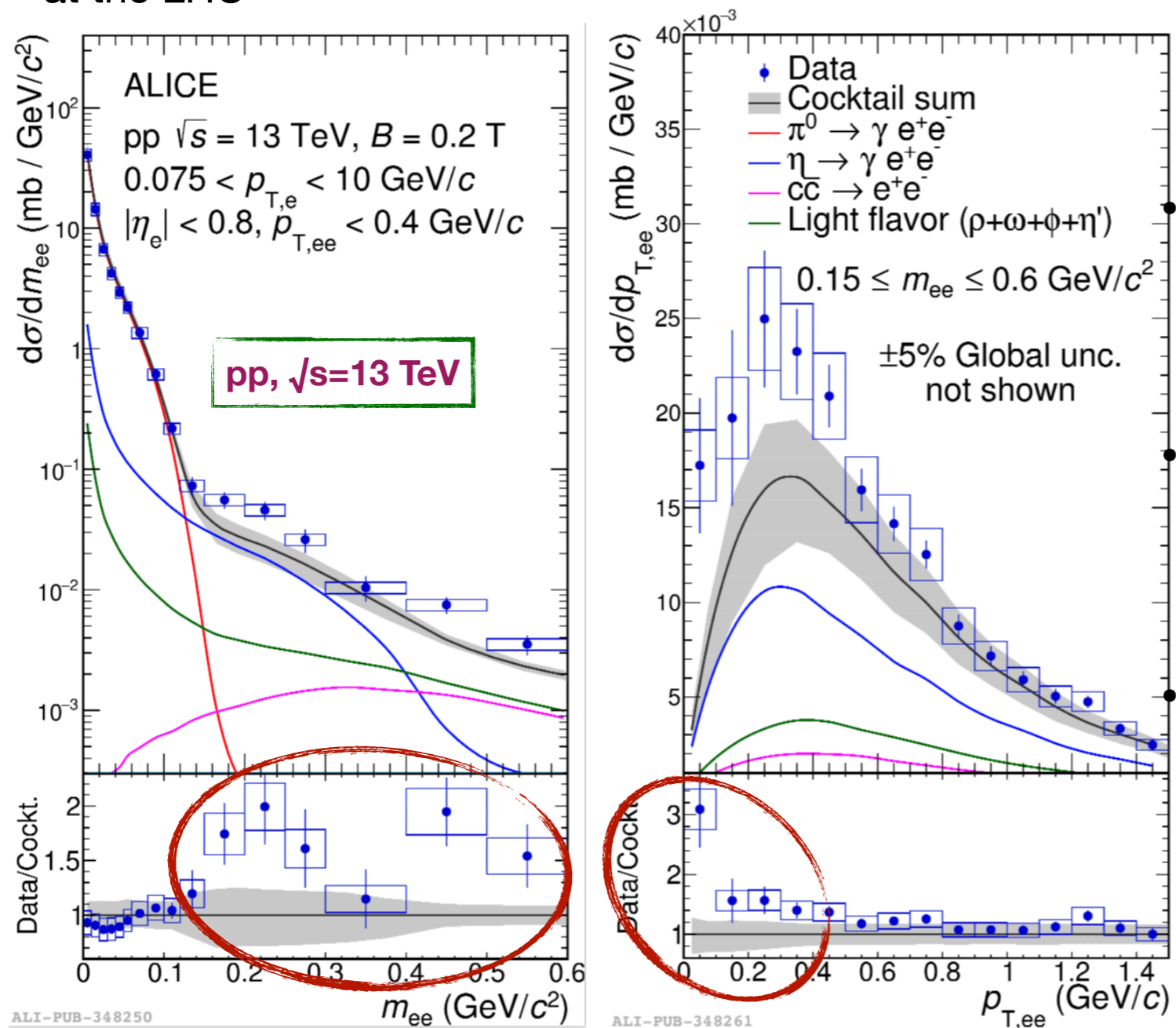
$N_{sd}$  distribution for  $Z_g > 0.1$   
 pp,  $\sqrt{s} = 13$  TeV

## Comparison of inclusive and charm jet using different grooming observables:

- Groomed momentum fraction similar and well described by Pythia
- $N_{sd}$  shows significant difference in the behavior**
  - Distribution shifted to smaller values for D-jet  $\rightarrow$  **fragmentation of HF has less prongs**

## Dielectron production in pp collisions

Using data collected with low B (0.2 T) to investigate low  $m_{ee}$  and  $p_{T,ee}$   $\rightarrow$  previously inaccessible at the LHC



Di-electron yield compared to hadronic cocktail at  $0.15 < m_{ee} < 0.6$  GeV/c<sup>2</sup> and for  $p_{T,ee} < 0.4$  GeV/c  $\rightarrow$  **enhancement of soft di-electrons (factor  $\sim 1.7$ )**

Soft-photon and soft-dielectron enhancement observed in low-energy fixed-target experiments and at ISR and SPS in 80's  $\rightarrow$  not fully understood

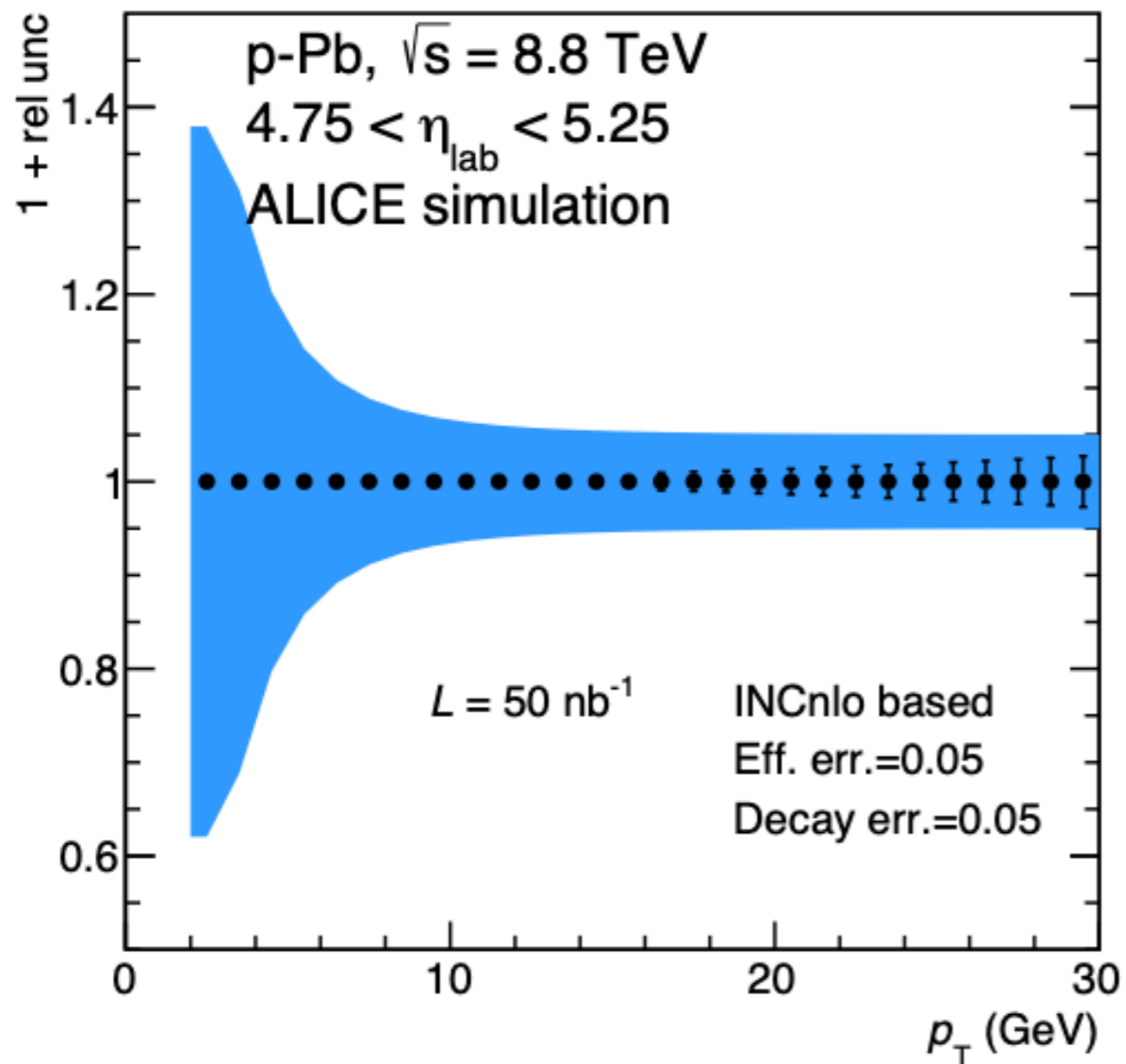
Different calculation fails to describe the data

- bremsstrahlung from initial- and final-state particles
- thermal di-electrons assuming a fireball

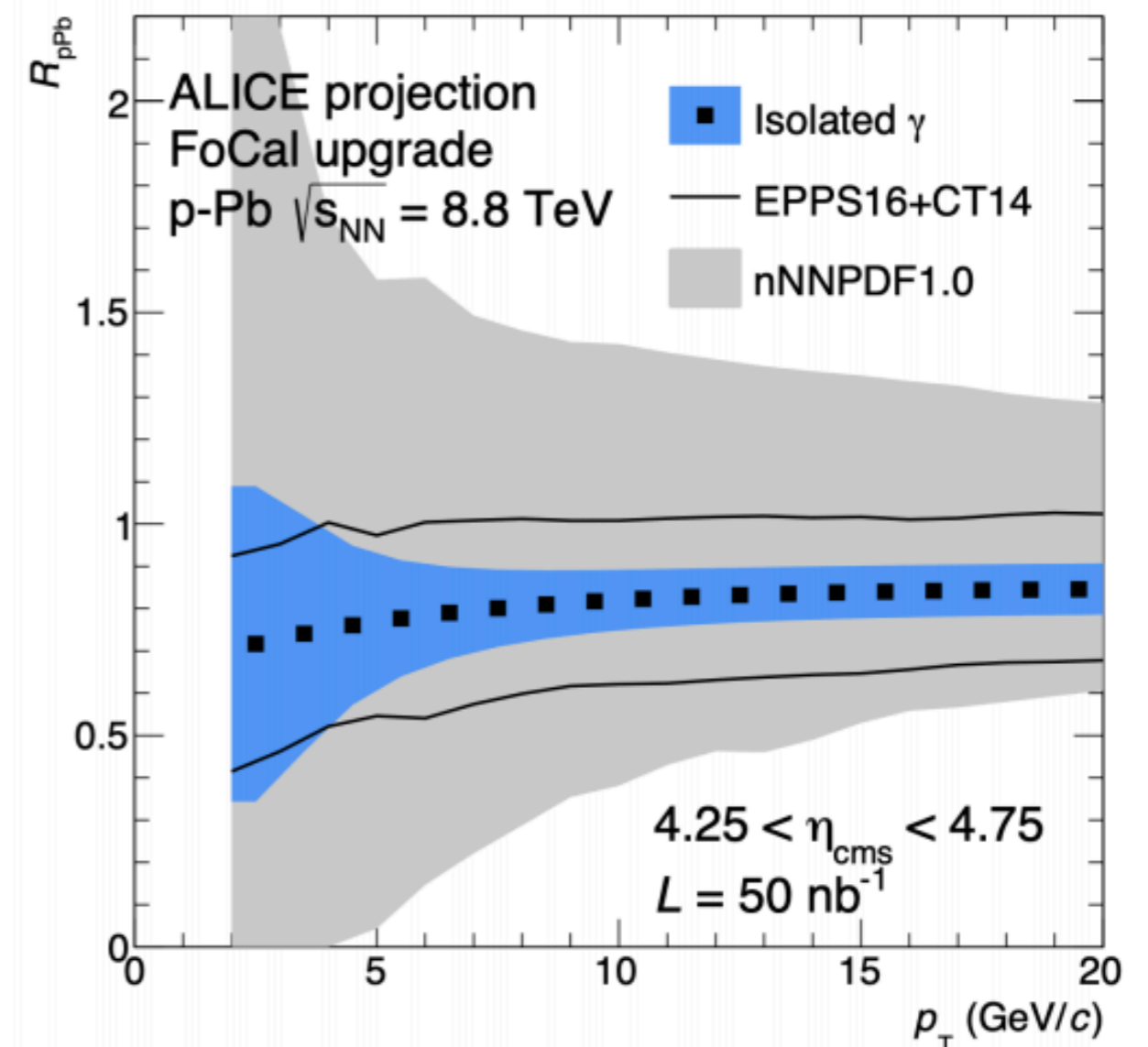
- **Further theoretical work encouraged to get more insight into this observation**



# FoCal - Expected performance



- Systematic uncertainty  $\sim 20\%$  at  $\sim 4 \text{ GeV}$
- Below  $\sim 6 \text{ GeV}$ , uncertainty rises due to remaining background



- Significant improvement (up to factor 2) on EPPS16 gluon PDF
- Similar improvement as from open charm
  - Test factorization/universality
- Below 4 GeV: challenging regime
  - Also measure direct photons by statistical subtraction