# A Potpourri of p-Pb Results from ALICE

ALICE

**pot·pour·ri** *noun* \ˌpō-pu̇-ˈrē\ : a mixture of flowers, herbs, and spices usually kept in a jar and used for good fragrance

John Harris (Yale) for ALICE

RANP 2013, Rio de Janeiro, Brazil, 9/23–27/2013

# Happy Birthday on the Occasion of Takeshi's $70^{th}$ Birthday Celebration

ALICE

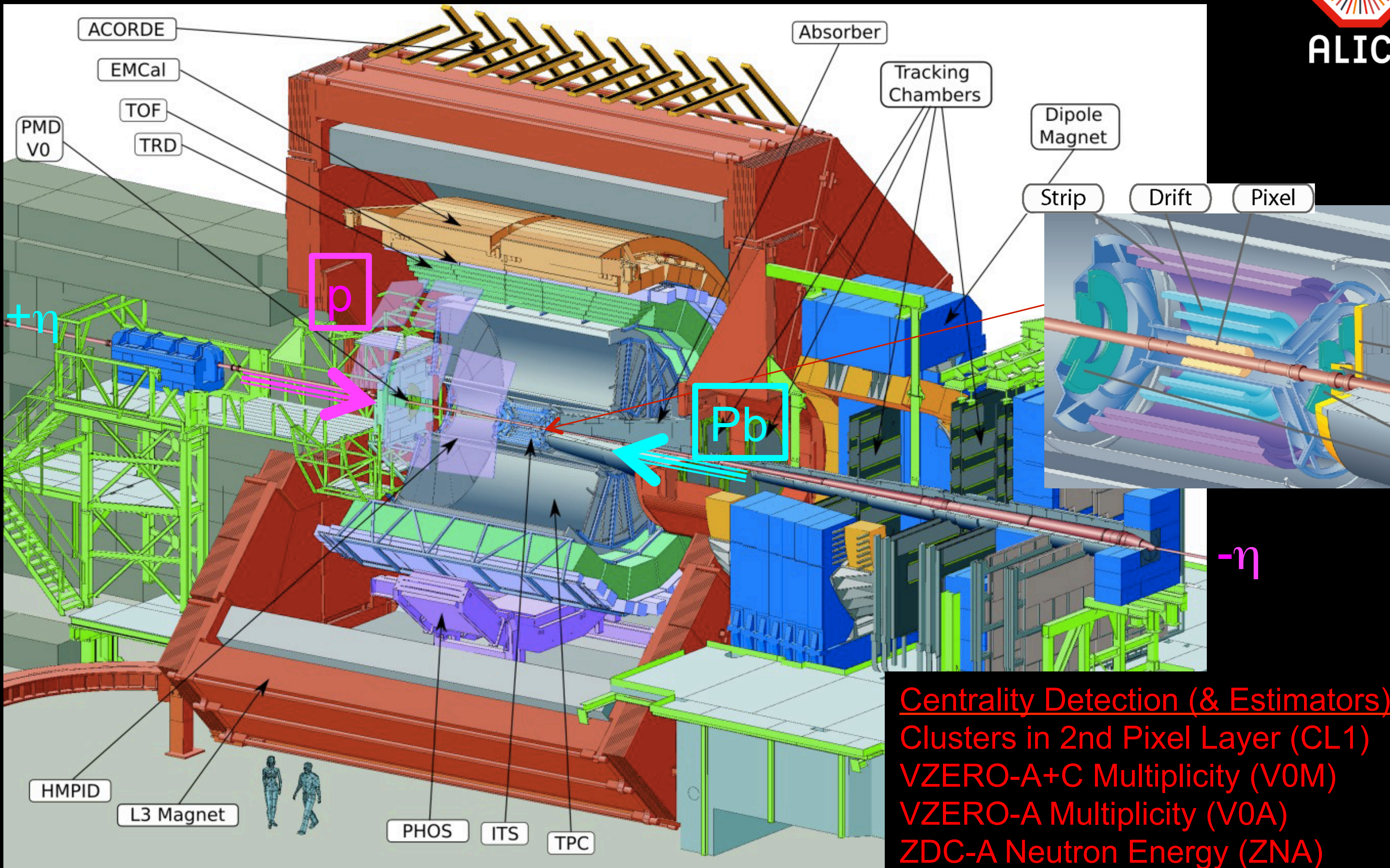
# *Why Study p-A Collisions?*

ALICE

Can pp, p-A and A-A all be described in a consistent framework?

- Can we separate the initial state from final state? (Is it even possible?)
  - Is the initial state composed of gluon fields?
  - Is it saturated?
  - Is it a CGC?
- What is the effect of cold nuclear matter (on final state observables)?
- Can we understand multiplicity and energy dependence of p-A & A-A?
  - e.g. compare high mult p-A at LHC & same mult A-A at LHC & RHIC

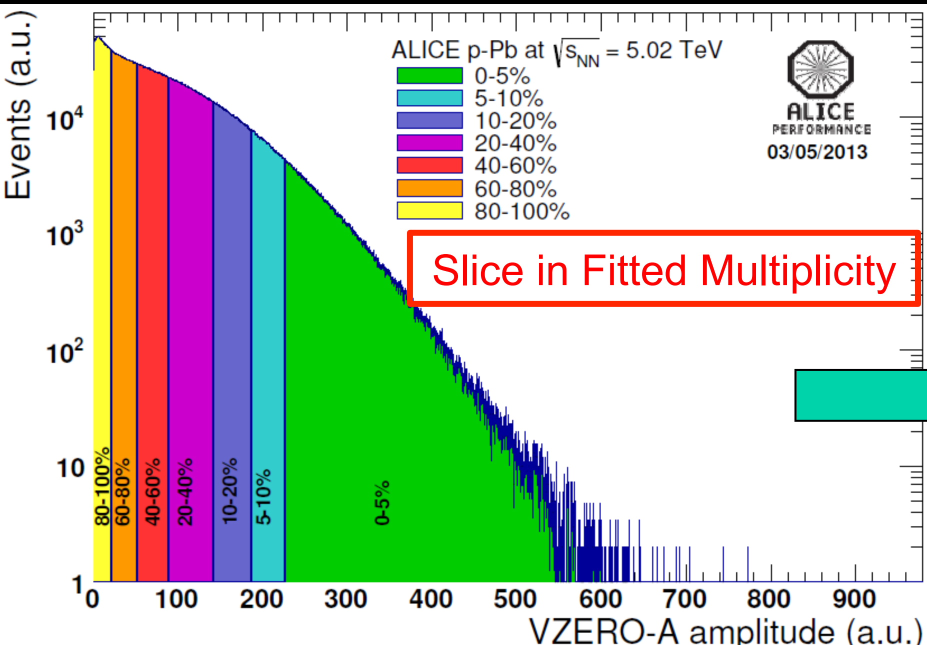
# p-Pb in ALICE

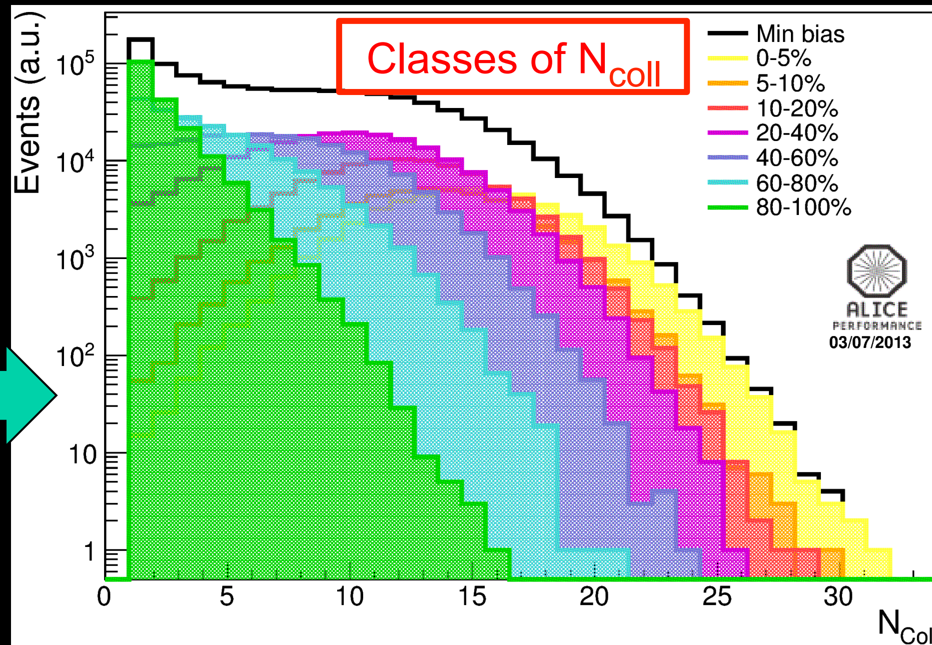



Centrality Detection (& Estimators):
Clusters in 2nd Pixel Layer (CL1)
VZERO-A+C Multiplicity (V0M)
VZERO-A Multiplicity (V0A)
ZDC-A Neutron Energy (ZNA)

4 TeV protons ⊖⟶ ✳ ⟵⊕ 1.58 A-TeV Pb    $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb  $\Delta y_{NN}$=0.465 in p-dir

# Multiplicity in ALICE



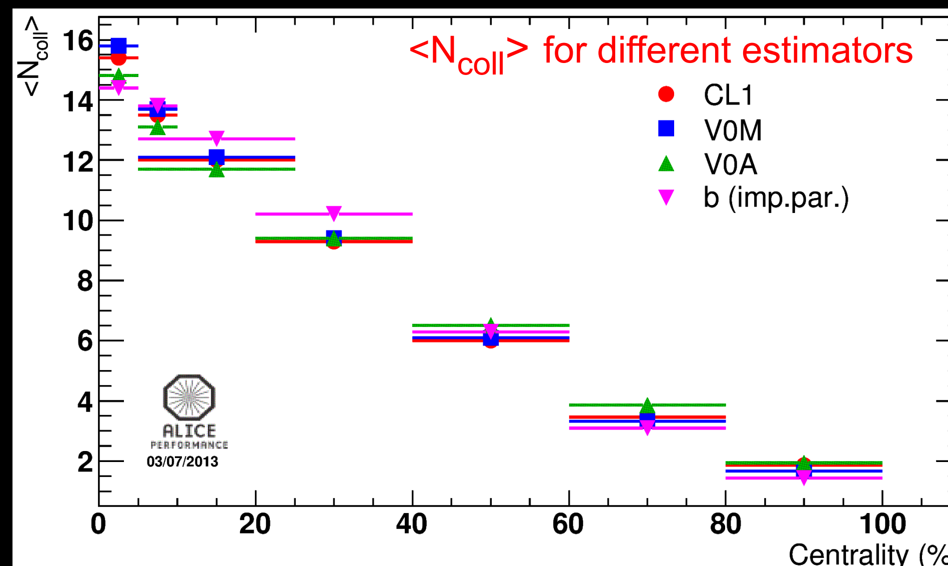




Same ALICE procedure as in Pb-Pb (arXiv:1301.4361)

Use Glauber + Negative Binomial

Fit multiplicity data, slice into bins of % $\sigma$

Extract $N_{coll}$



# ALICE p-Pb: $dN_{ch}/d\eta$ Distribution vs Models

Most Model Predictions within 20% of data.

Saturation Models:

Rise too steeply

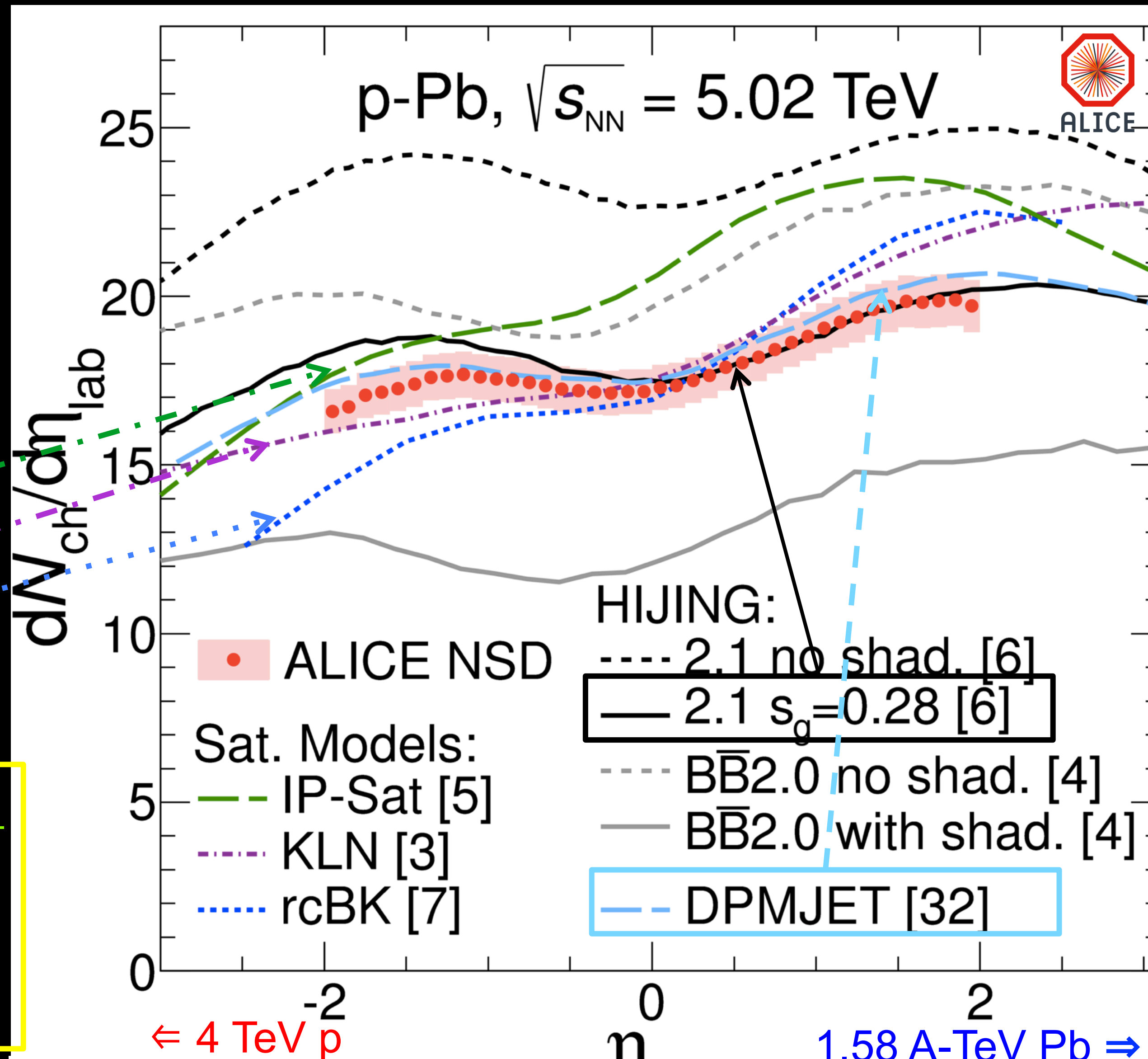
with $\eta_{lab}$ !

pQCD-based MC models:

HIJING

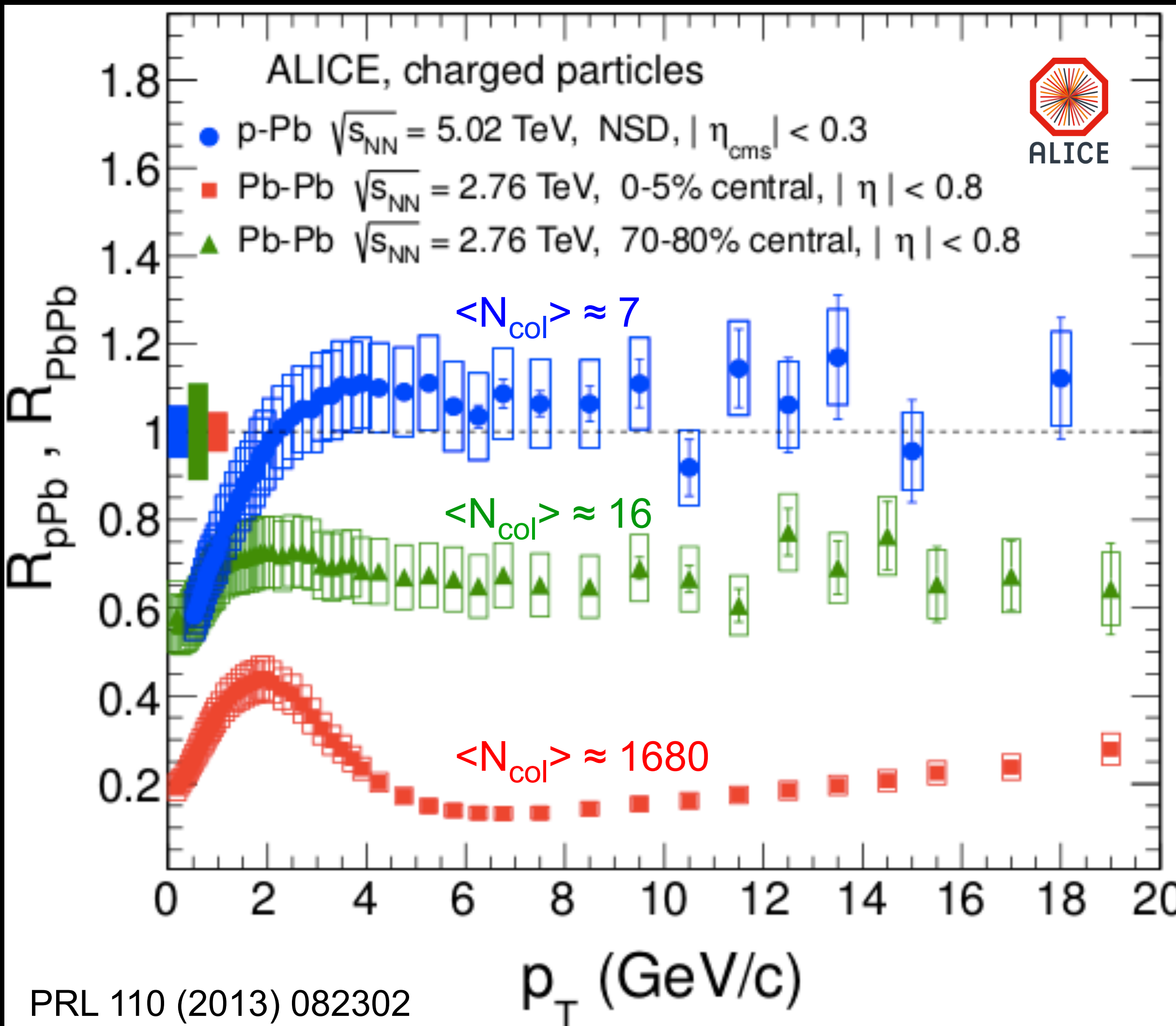
DPMJET

Describe $dn_{ch} / d\eta_{lab}$



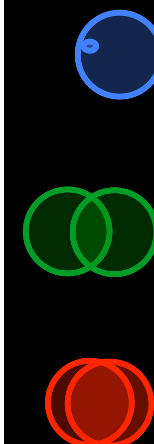

Phys. Rev. Lett. 110, 032301 (2013)

# Charged Particles: $R_{pPb}$ and $R_{PbPb}$




PRL 110 (2013) 082302

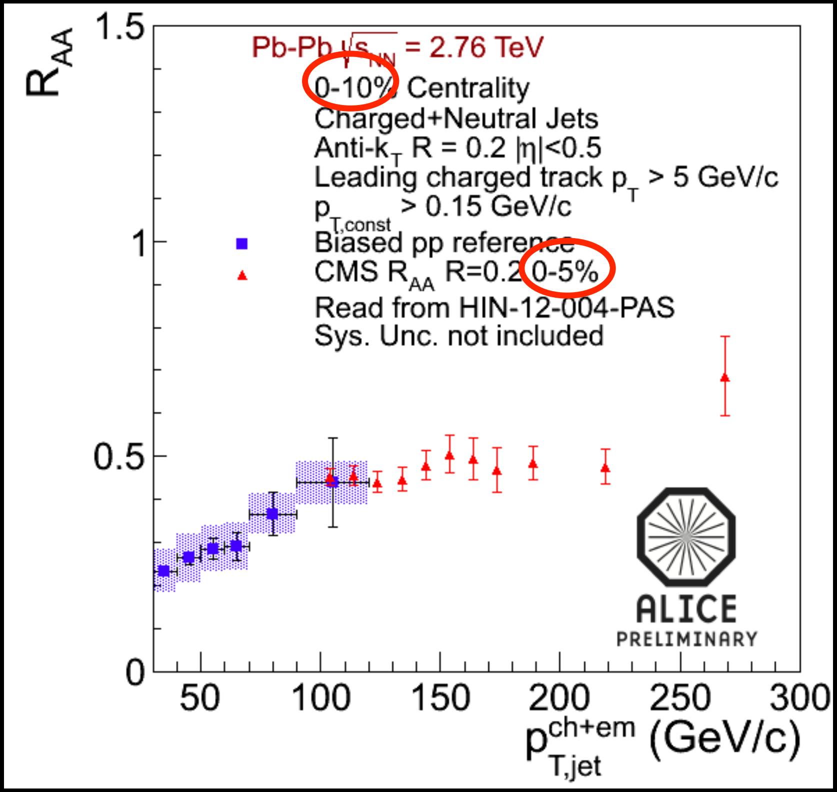
$$R_{AA} = \frac{N_{AA}^{particle}}{N_{coll} N_{pp}^{particle}}$$

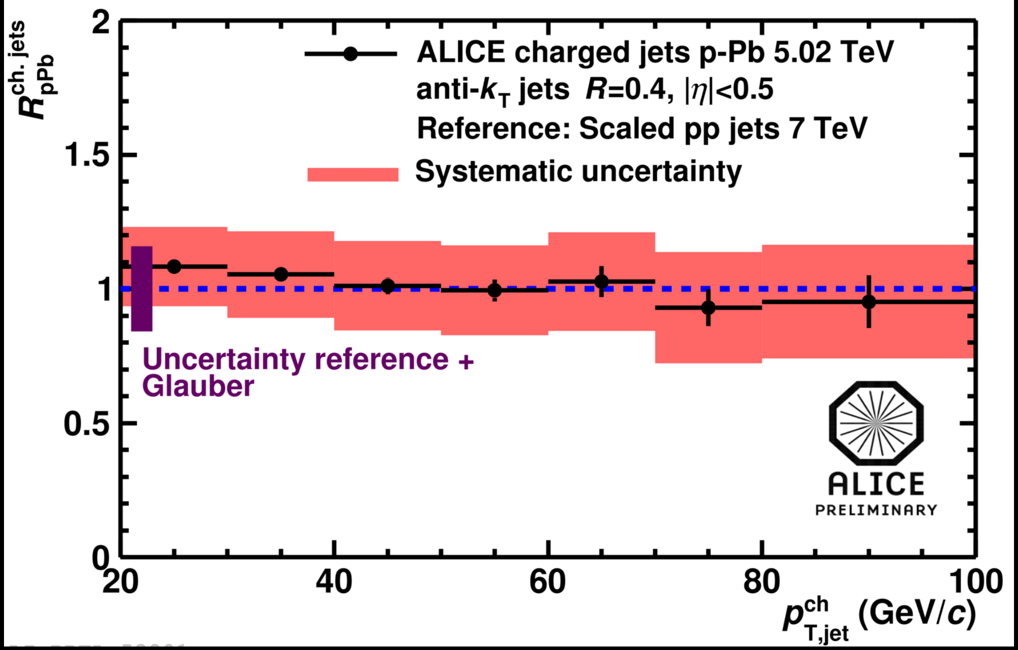


**p-Pb ($p_T$ > 2 GeV/c)**
- Binary scaling ($R_{pPb}$ ~ 1)
- Absence of Nuclear Modification
- Initial state effects small

**Pb-Pb – Suppression!**
- Increases with centrality
- Not initial state
- Final state effect (hot QCD matter)

# Hard Probe: Jet $R_{PbPb}$ and Jet $R_{pPb}$

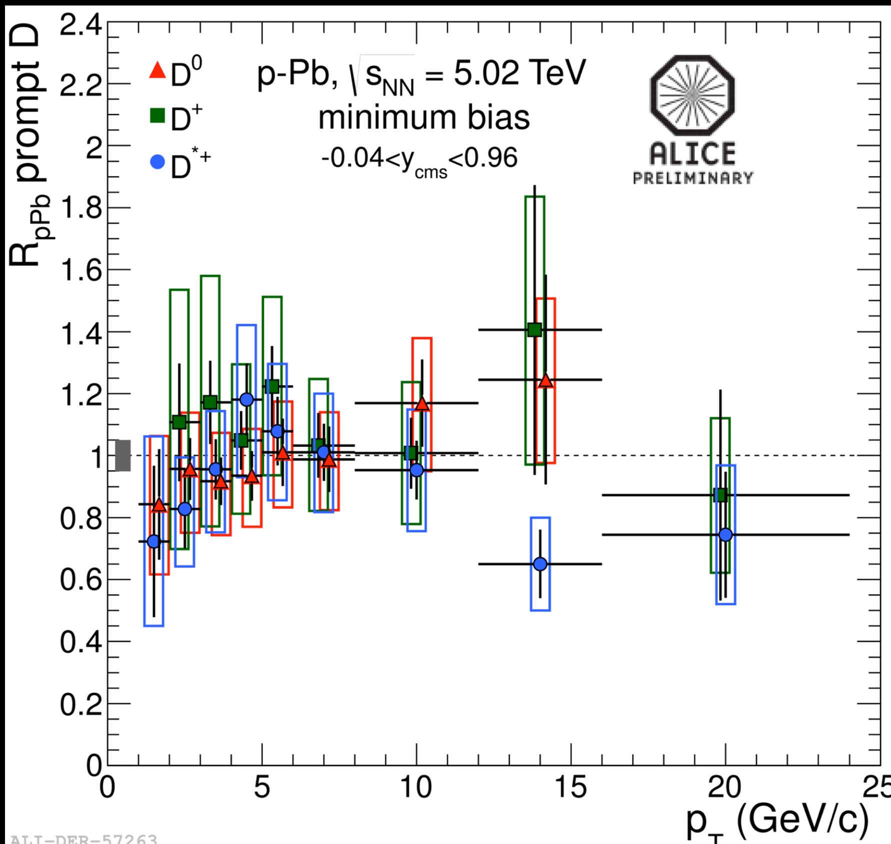


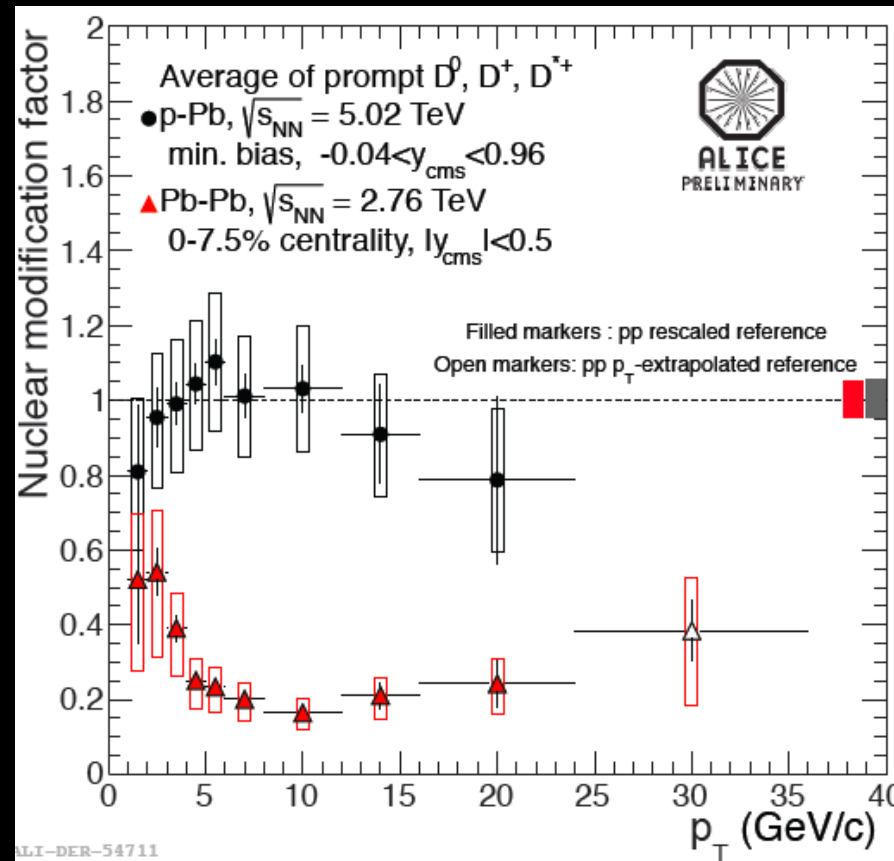




*Pb-Pb (full jets from central collisions)*
- Strong suppression ($R_{PbPb}$ ≤ 0.5)

*p-Pb (charged jets from min bias collisions)*
- $R_{pPb}$ consistent with unity

# Heavy Flavor – D-Mesons: $R_{pPb}$ & $R_{PbPb}$

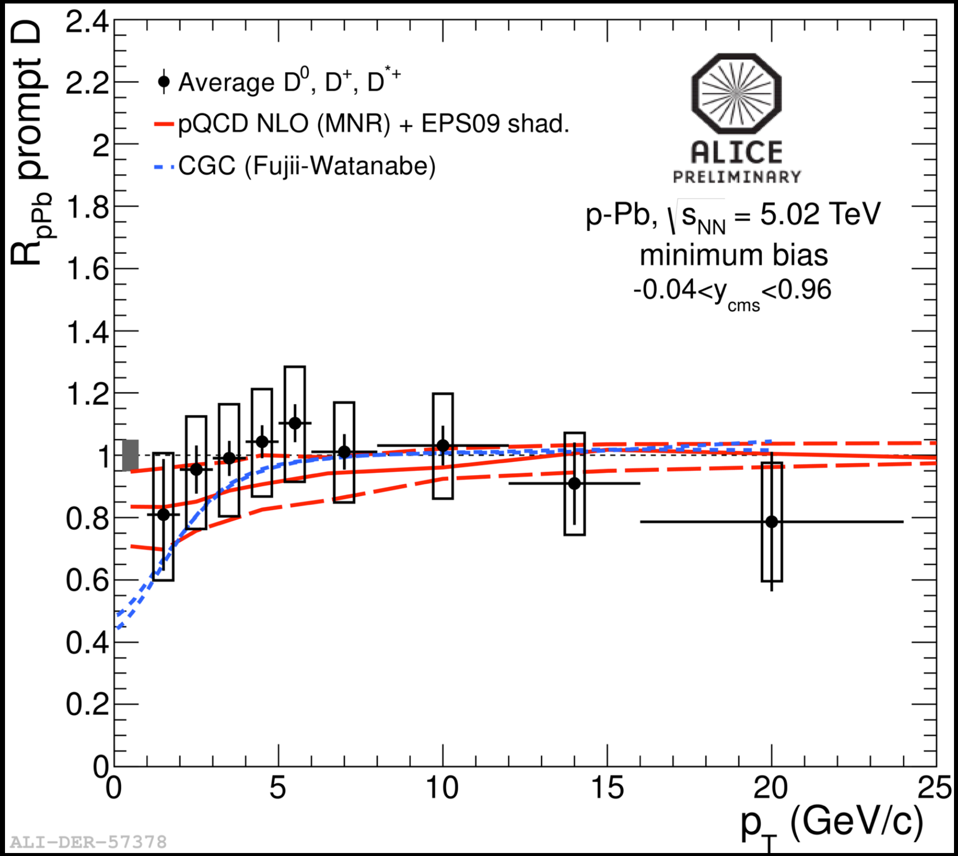



D-meson $R_{pPb}$ consistent with ≈1
Initial state effects small!

D-meson central $R_{PbPb}$ suppressed!
($p_T \gtrsim$ 4 GeV/c)
Not initial state effect!

# Heavy Flavor – D-Mesons: $R_{pPb}$ & Models




D-meson $R_{pPb}$ consistent with ≈1

Initial state effects small!

Cannot distinguish between models yet!

NLO+EPS09: M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B373 (1992) 295
K. J. Eskola, H. Paukkunen and C. A. Salgado, JHEP 0904 (2009) 065

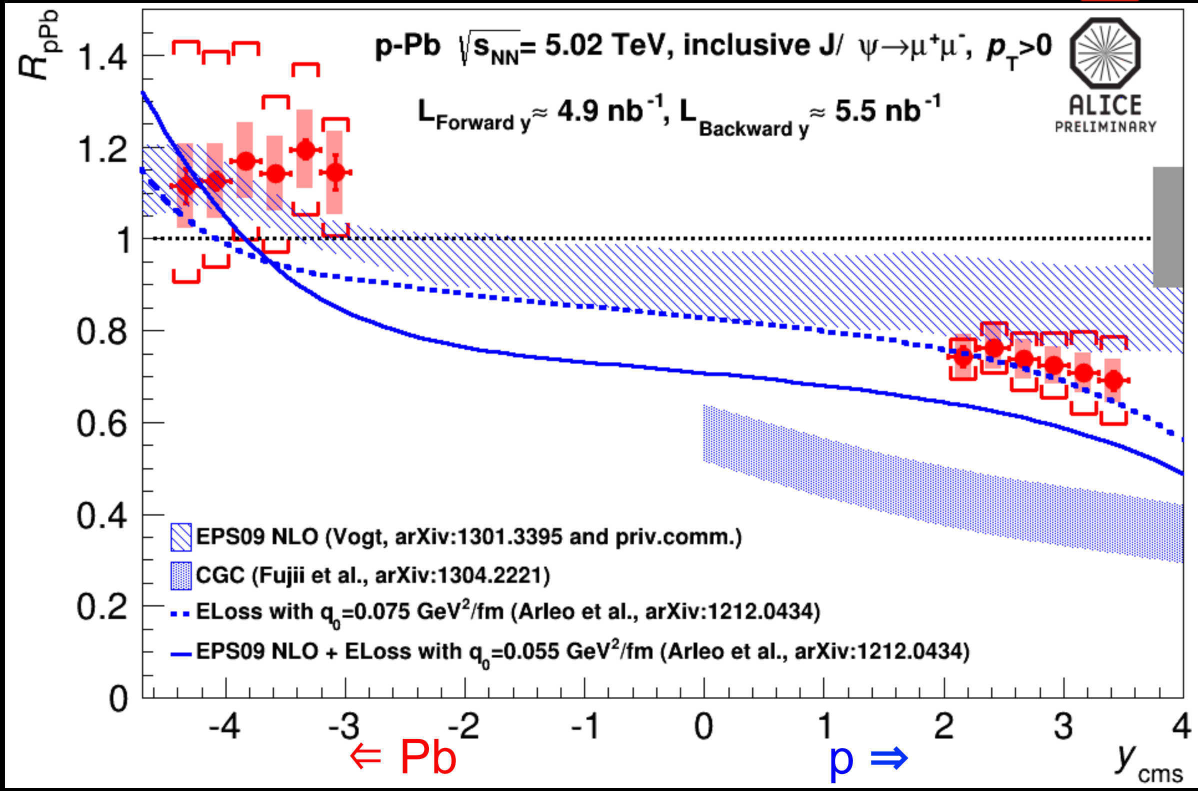
CGC: H. Fujii and K. Watanabe, arXiv:1308.1258v1

# Heavy Flavor – J/ψ $R_{pPb}$ & Models

$R_{pA}$ decreases at forward y

Dominant source of error is the normalization to pp

No apparent rapidity dependence in backward region




## Comparison with models:

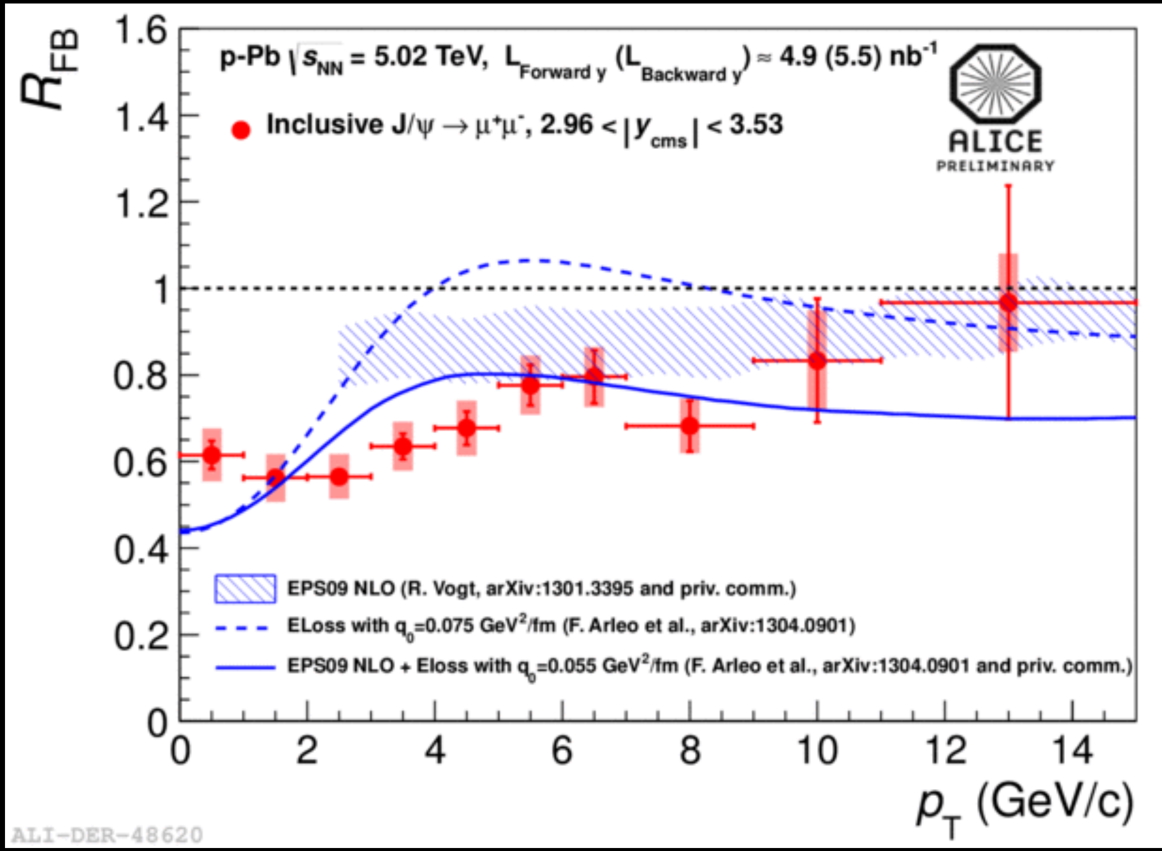
- Good agreement with models incorporating shadowing (EPS09 NLO) and/or a contribution of coherent parton energy loss (F. Arleo et al).

- CGC description (H. Fujii et al) appears disfavored
- Better measurement of any rapidity dependence in backward region may provide additional constraints

# $J/\psi$: Forward-backward Asymmetry vs. $p_T$

$$R_{FB} = \frac{R_{pPb}\,(2.96 < y_{cms} < 3.53)}{R_{pPb}\,(-3.53 < y_{cms} < -2.96)}$$

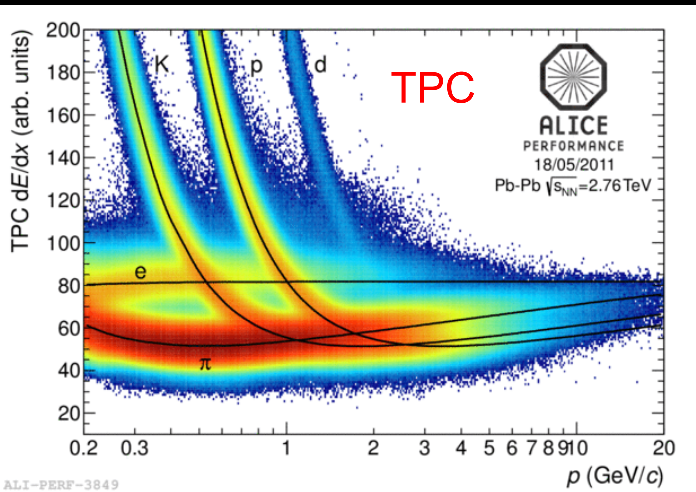
i.e. over $2.96 < |y_{cms}| < 3.53$

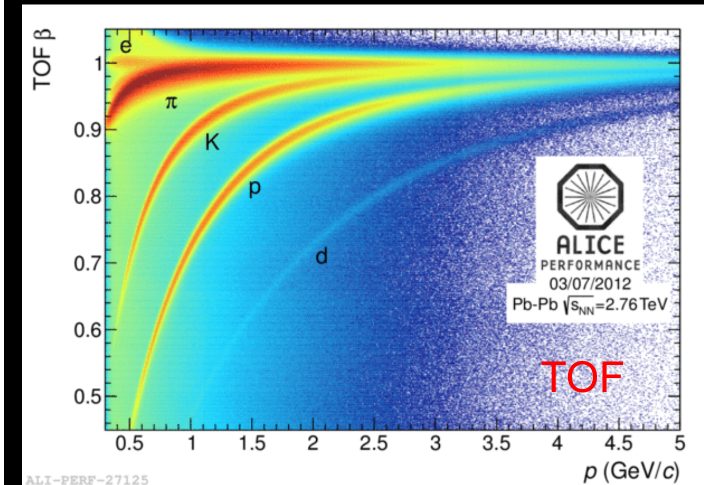


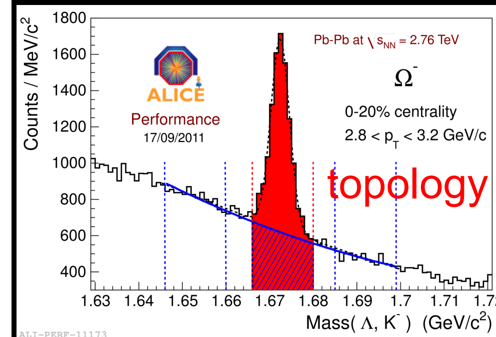

Stronger suppression of $R_{FB}$ at low $p_T$ .

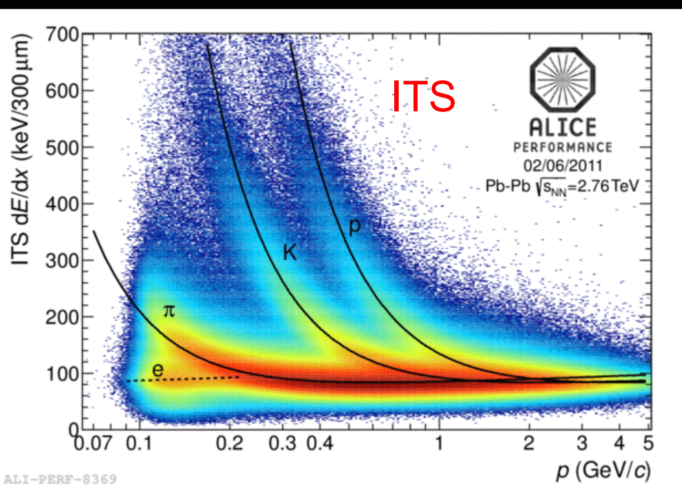
- Models including energy loss show strong nuclear effects at low $p_T$
  Reasonable agreement with the data.
- F/B $p_T$ dependence is smoother than expected from coherent energy loss models.

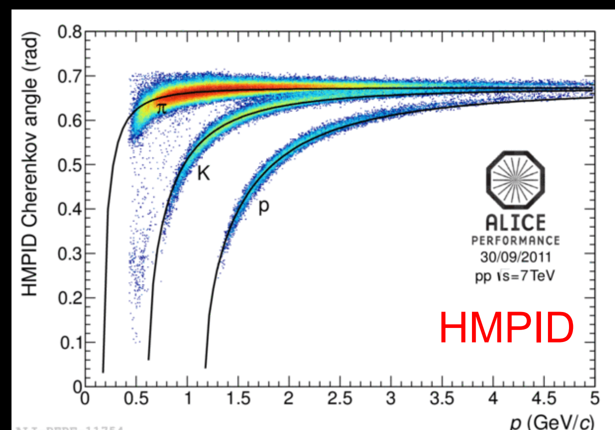
# ALICE Particle IDentification Capabilities

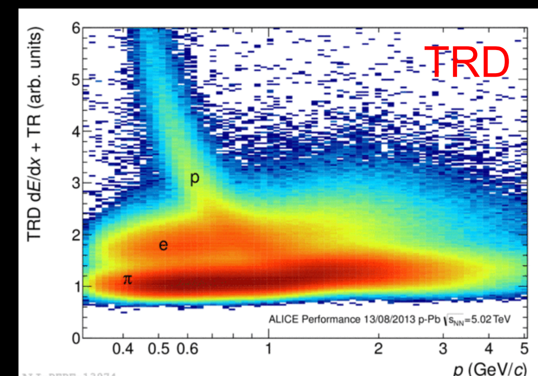


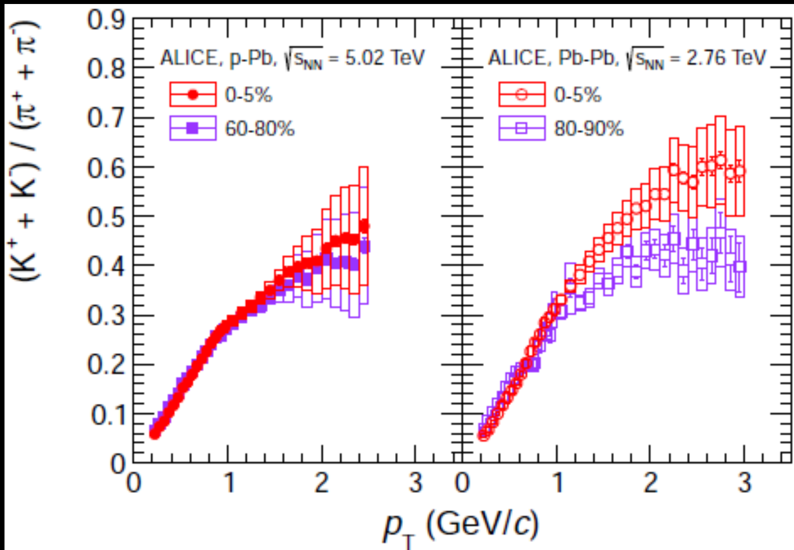



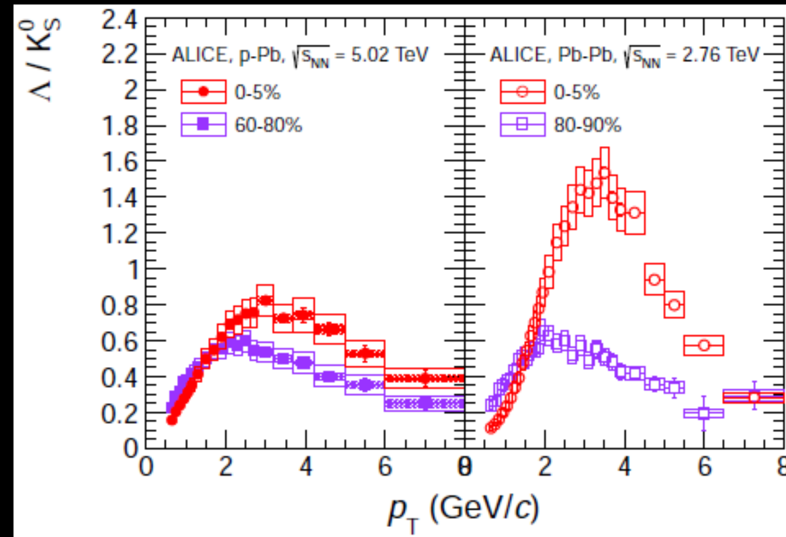



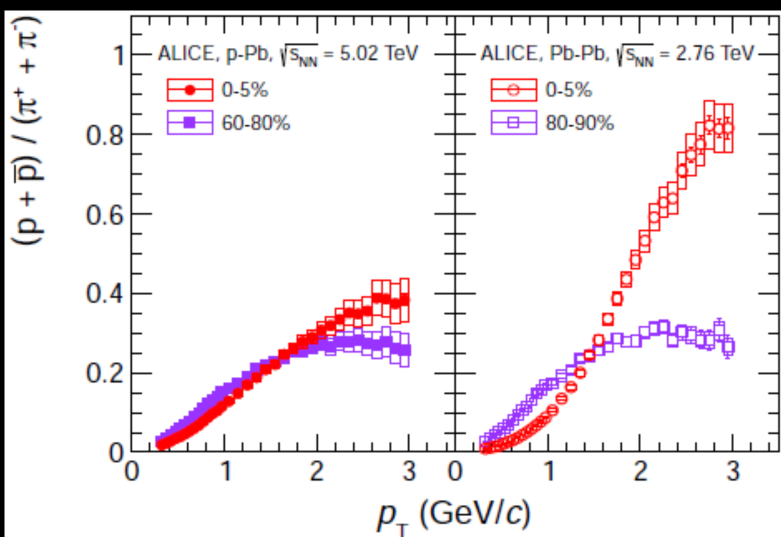




ALICE incorporates many PID techniques:
dE/dx; time of flight; EM, Cerenkov and transition radiations; topological reconstruction

# Identified Particle Ratios vs $p_T$ in pPb & PbPb



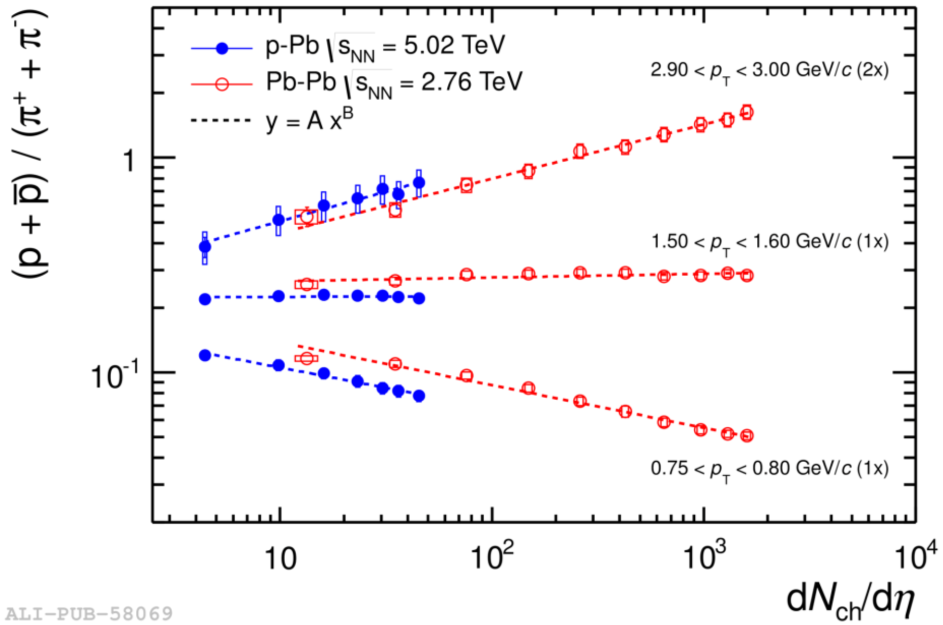




p-Pb similar behavior & pattern to Pb-Pb
- increase with $p_T$, peak near $p_T$ = 3 GeV/c
- increased enhancement: $\Lambda$/K > p/$\pi$ > K/$\pi$

p-Pb ratios increase not as strongly as in Pb-Pb

ALICE, arXiv:1307.6796

# $p/\pi$ Ratio vs $dN_{ch}/d\eta$ & $p_T$



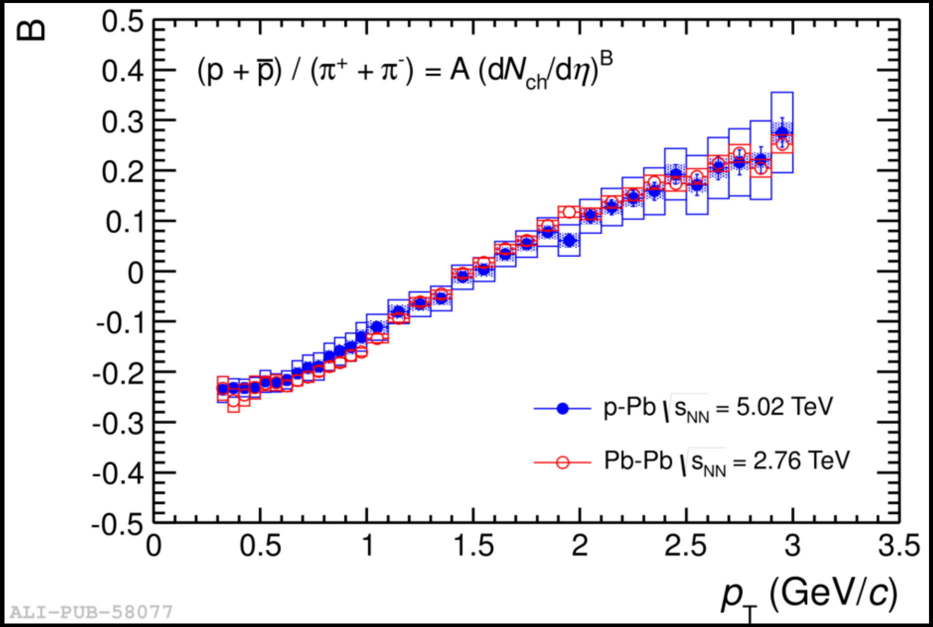

$p/\pi$ ratio follows power law behavior with $dN_{ch}/d\eta$

In each $p_T$ interval:

$$\text{Ratio}(p_T) = A(p_T) \cdot [dN_{ch}/d\eta]^{B(p_T)}$$

i.e.

$$p/\pi = A\ [dN_{ch}/d\eta]^{B}$$



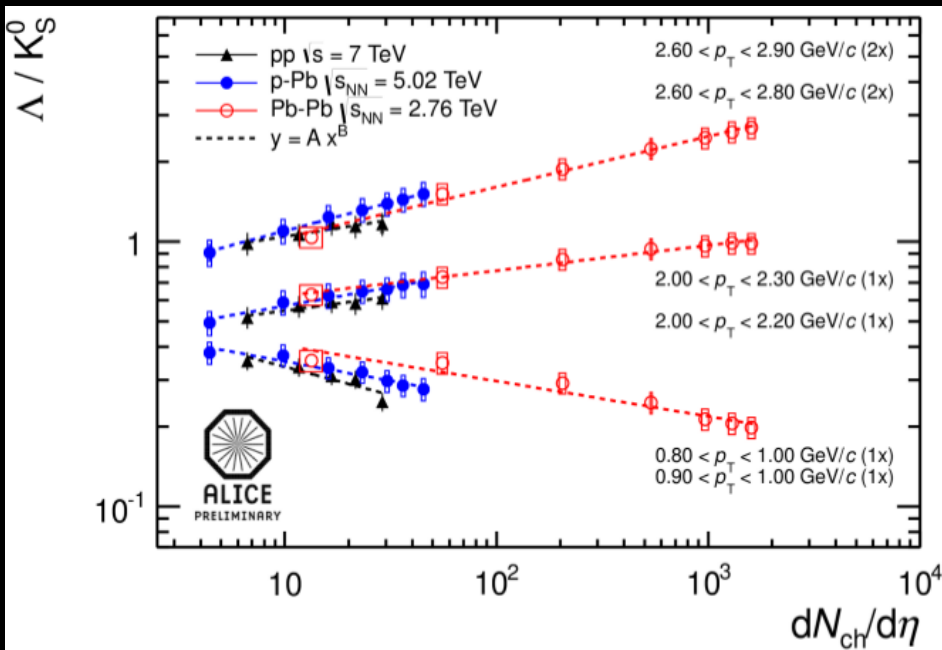

Evolution of $p/\pi$ ratio with $dN_{ch}/d\eta$

Identical in p-Pb as in Pb-Pb!

(as observed by same B vs $p_T$ slice)

ALICE, arXiv:1307.6796

# $\Lambda$/K Ratio vs $dN_{ch}/d\eta$ & $p_T$




Extended $p_T$ range possible for $\Lambda$/K (inc. peak)

$\Lambda$/K ratio vs. $dN_{ch}/d\eta$

Note:

$\Lambda/K \sim [dN_{ch}/d\eta]^B$

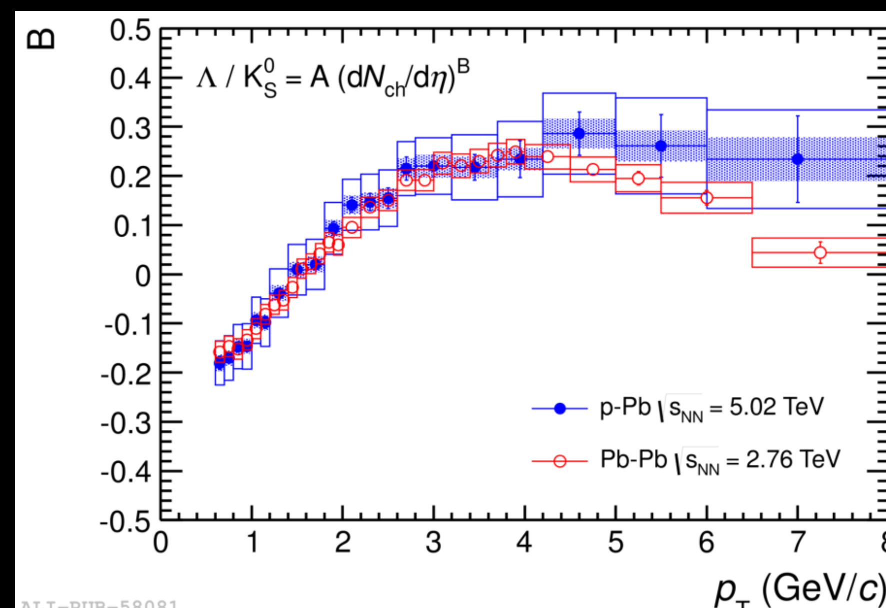
Behavior similar for pp, p-Pb, Pb-Pb

~ Same B values for pp, p-Pb, Pb-Pb!

Is there a common mechanism for the ratio evolution in pp, p-Pb, Pb-Pb???

Similar physics?

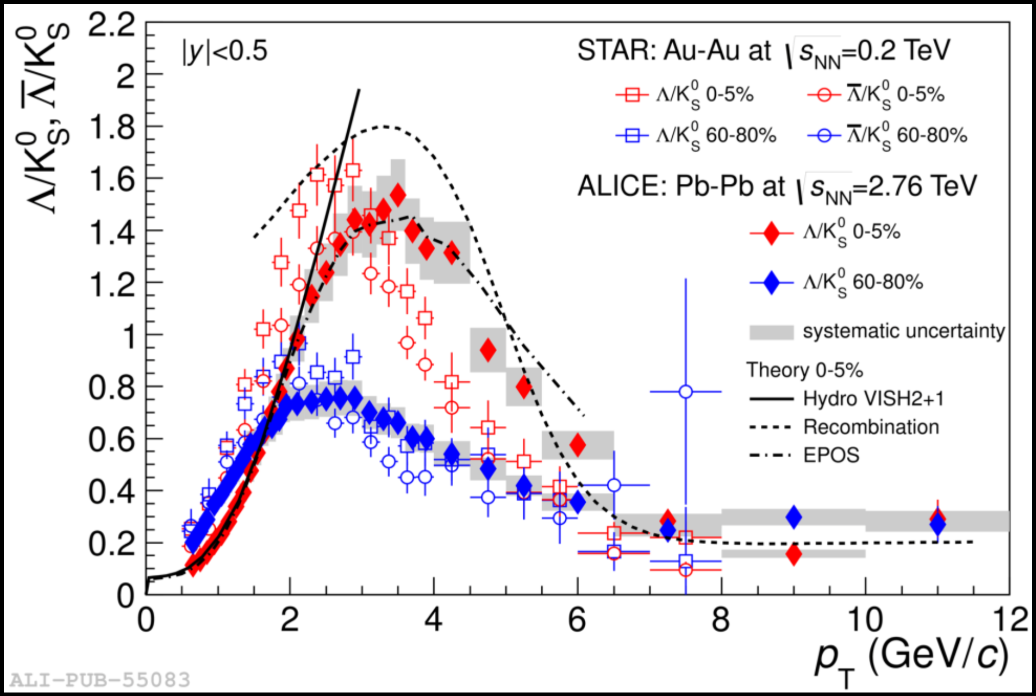
Across systems, sizes/geometries, energies?




ALICE, arXiv:1307.6796

# $\Lambda$/K Ratios in AA vs $p_T$ at RHIC & LHC

ALICE




RHIC and LHC:

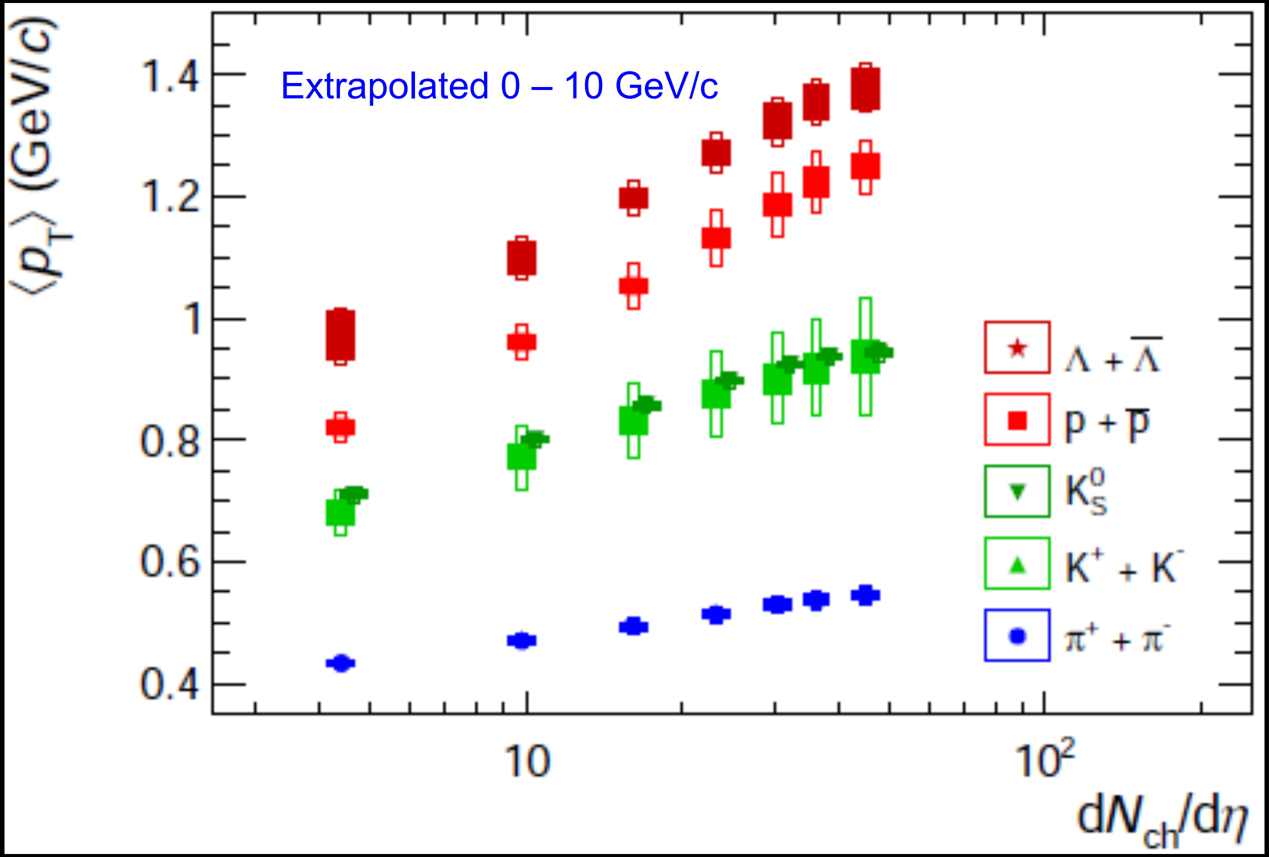
- Ratios similar for peripheral events.
- Ratios differ for central events.

- Since $\mu_B$ << T, RHIC & LHC ratios should be similar.

Can this centrality dependence of ratios at RHIC and LHC be explained by hydro?

ALICE, arXiv:1307.5530

# <$p_T$> vs Multiplicity in p-Pb for $\Lambda$, p, K, $\pi$




<$p_T$> increases strongly with particle mass

increases with multiplicity

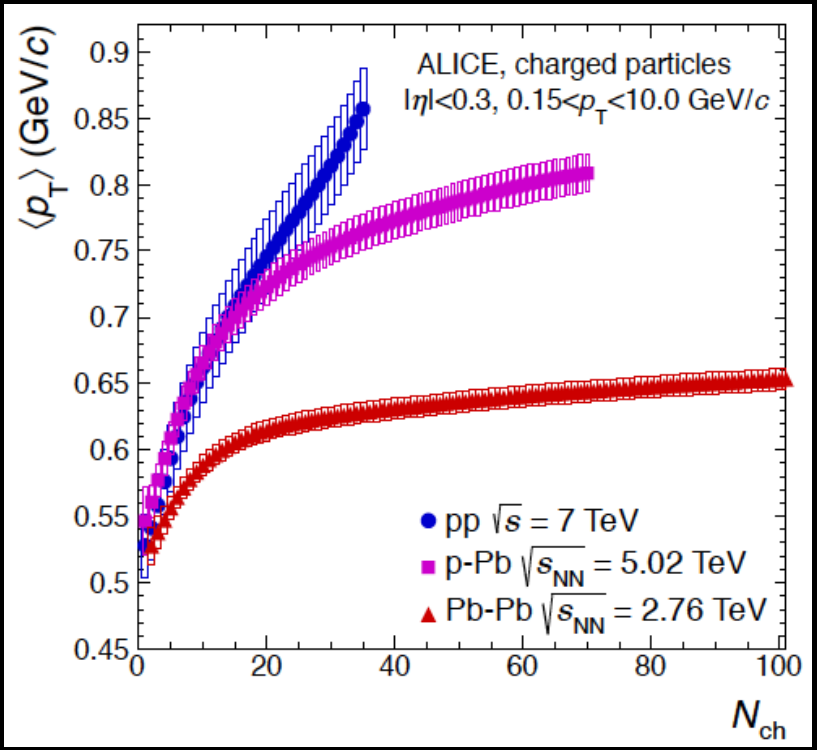
(stronger for heavier particles)

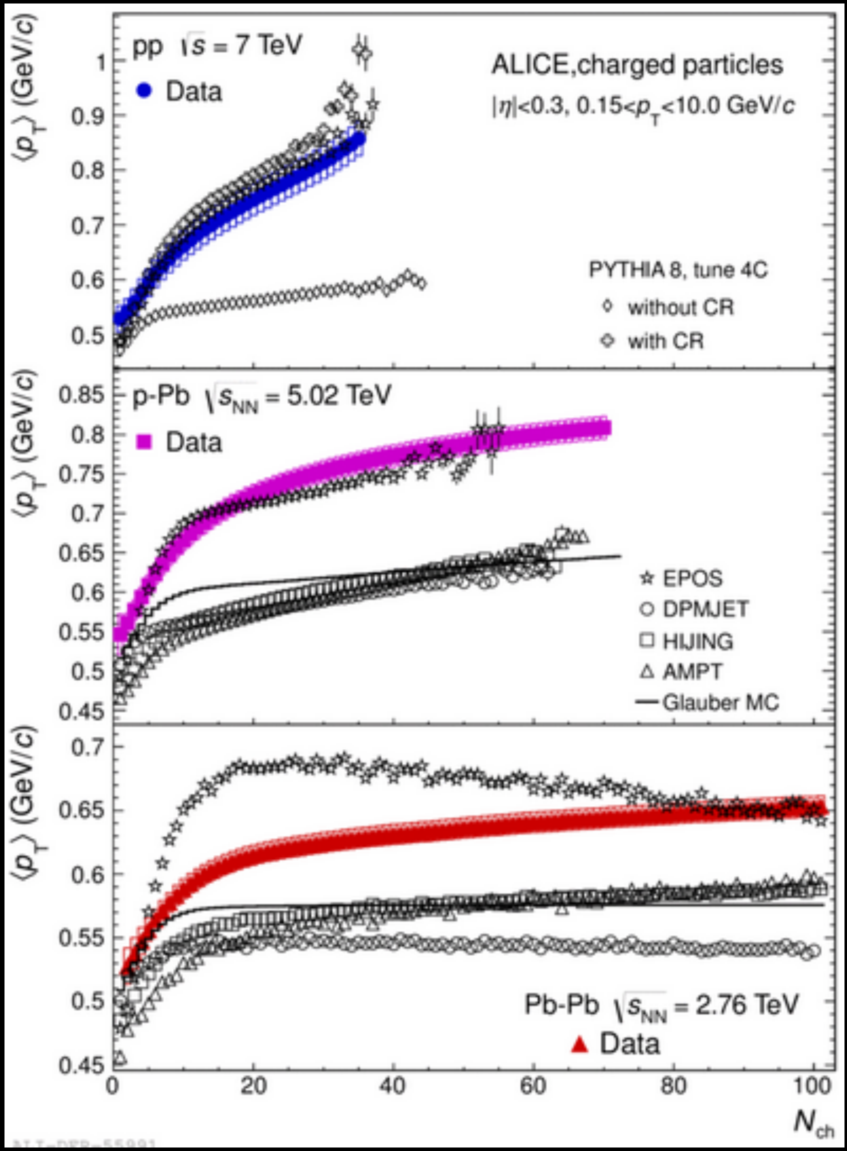
Same <$p_T$> trends observed in Pb-Pb

ALICE, arXiv:1307.6796

# Charged Particle $<p_T>$ vs Multiplicity

ALICE, arXiv:1307.1094




$<p_T>$ increases sharply at low multiplicity

Increases to higher values for pp & p-Pb.

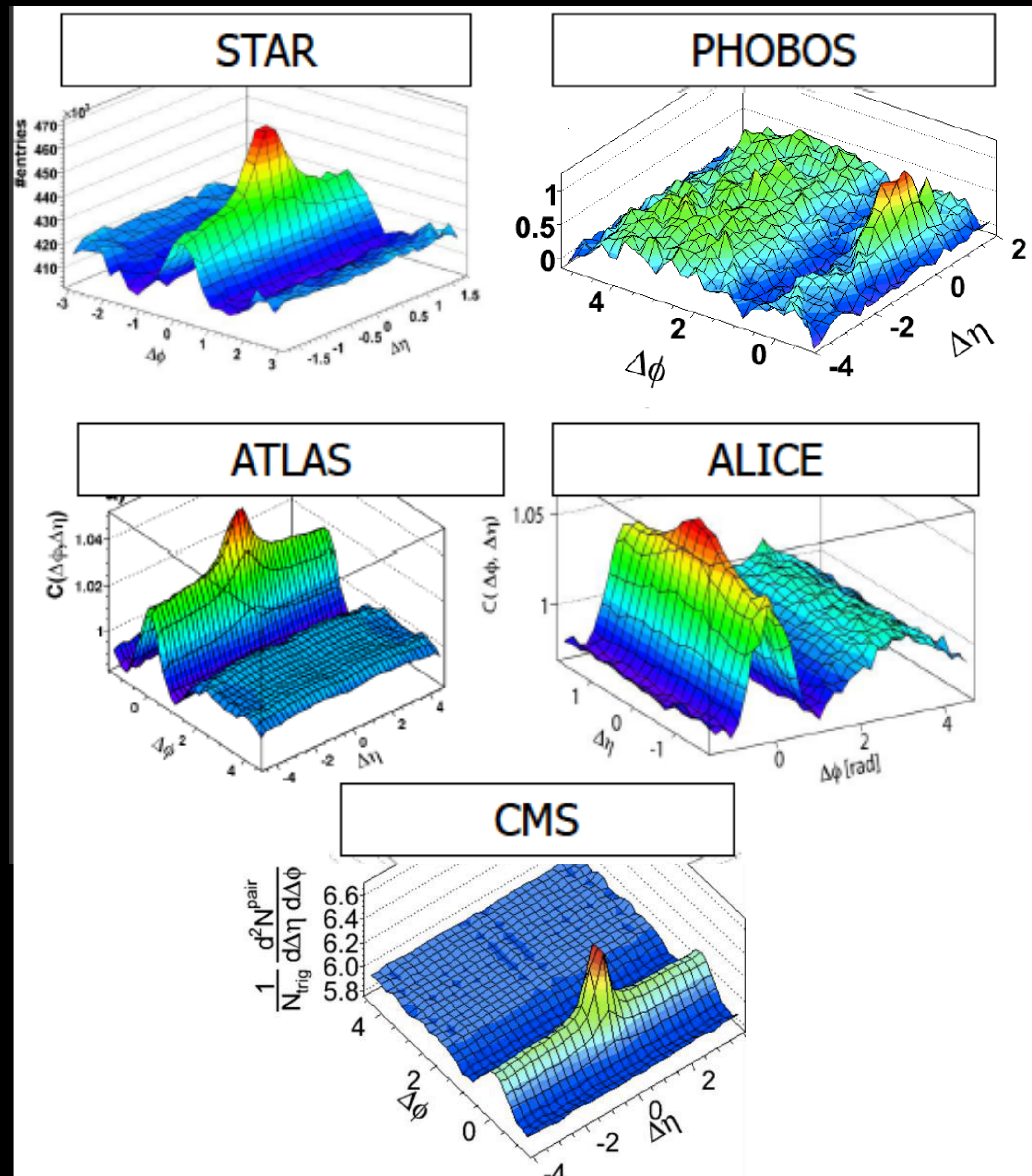
- pp fit by PYTHIA with color reconnections
- p-Pb described by EPOS with collective effects
- Pb-Pb not described by any models

# Long-range Di-hadron Correlations in A-A

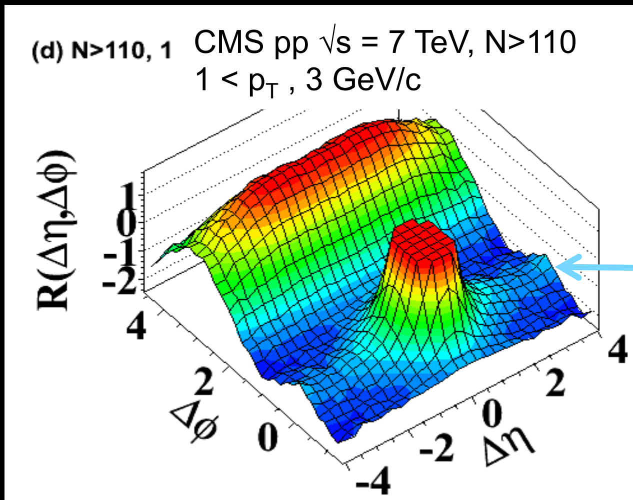
$\sqrt{s_{NN}}$ = 0.2 TeV Au-Au
Near-side Ridge
(2005-2008)

$\sqrt{s_{NN}}$ = 2.76 TeV Pb-Pb
Near-side Ridge
(2010-2012)

Possible interpretations
involve
Collective effects



# Long-range Di-hadron Correlations in pp, p-A

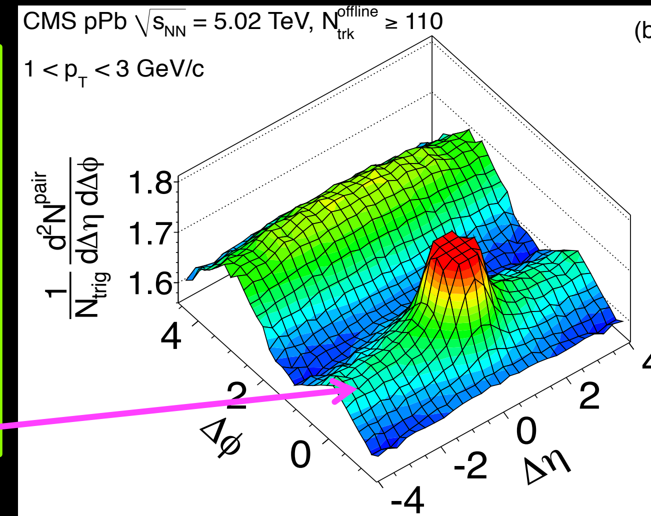



CMS, JHEP 09 (2010) 091

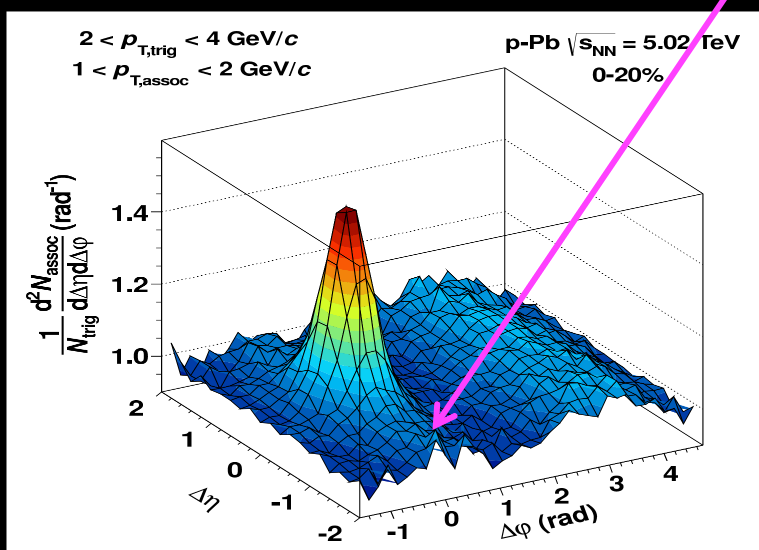
LHC near-side ridge
for $\sqrt{s_{NN}}$ =

7 TeV pp

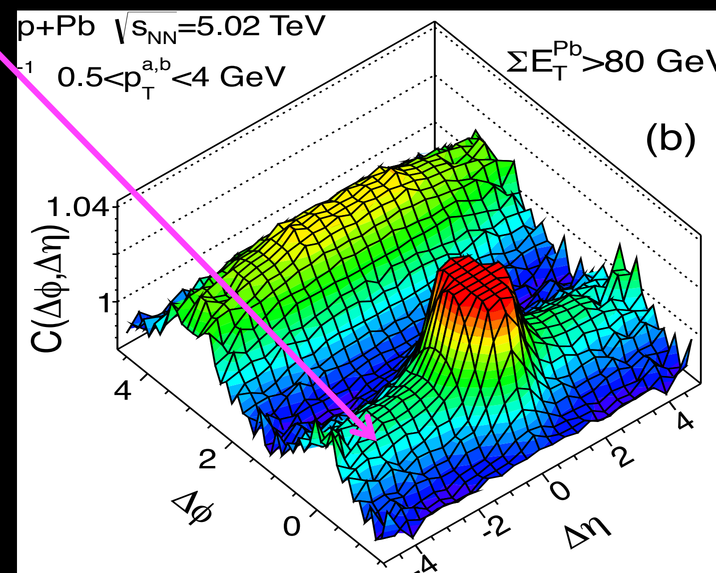
5.02 TeV p-Pb




CMS, PLB 718 (2013) 795




ALICE, PLB 719 (2013) 29



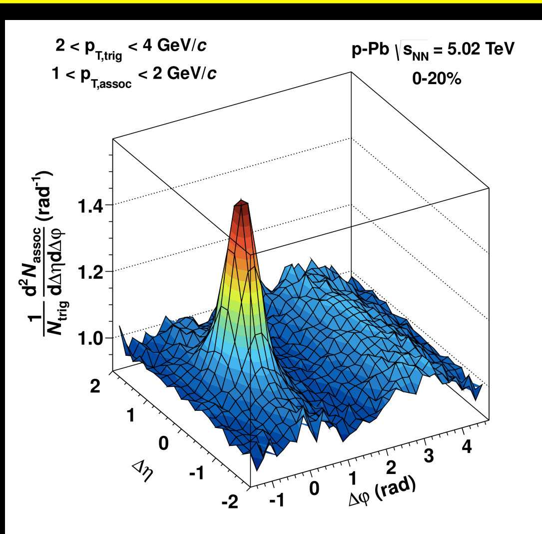

ATLAS, Phys. Rev. Lett. 110, 182302 (2013)

Potential interpretations include CGC, long-range color correlations……, hydro??

# Long-range Di-hadron Correlations in p-Pb

ALICE, Physics Letters B 719 (2013) 29

Hi Mult. 0-20% Event Class – Lo Mult. 60-100% Event Class = Excess correlation yield from subtraction of event classes

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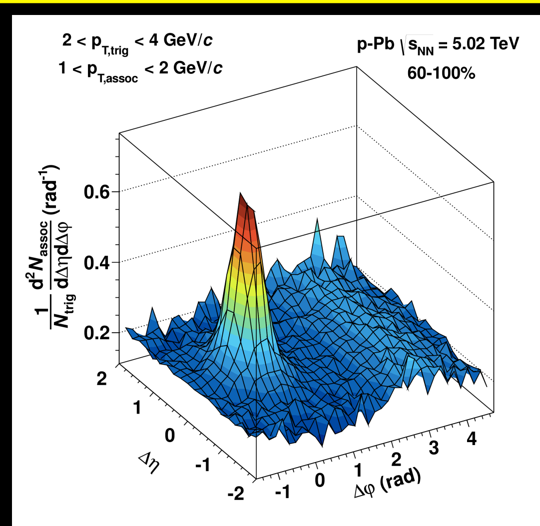


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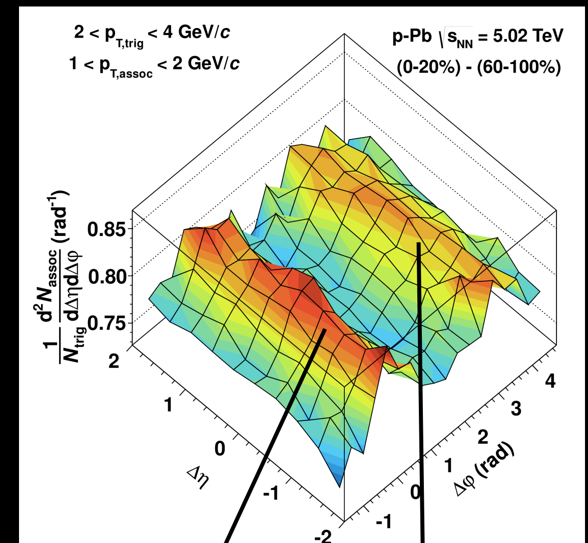
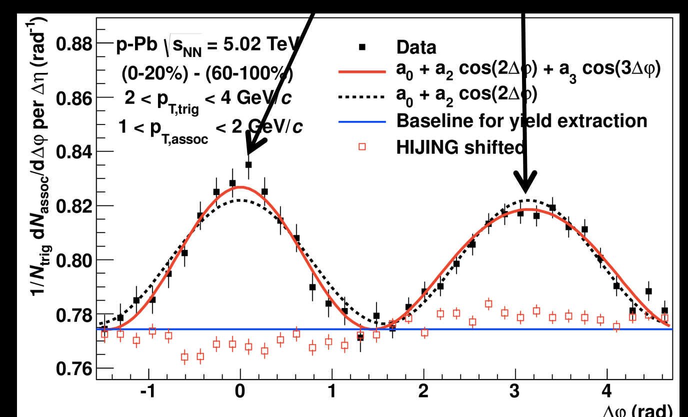



Per trigger yield exhibits two nearly identical ridges back-to-back extended in $\eta$.



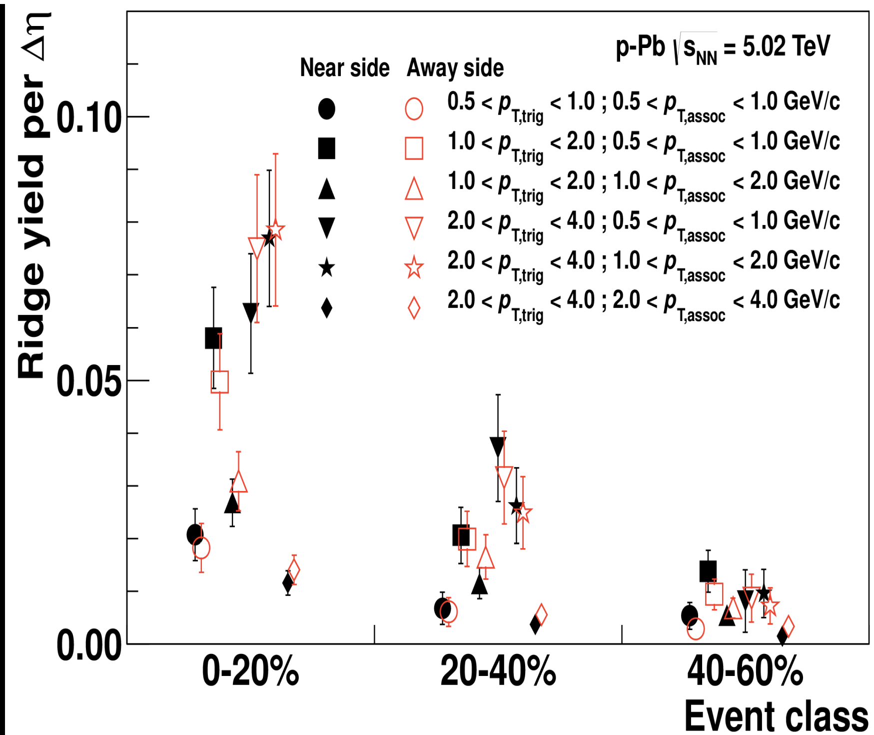

near-side: $0.8<|\Delta\eta|<1.8$ away-side: $|\Delta\eta|<1.8$

# Compare Ridge Yields & Resulting $v_2$ & $v_3$

ALICE

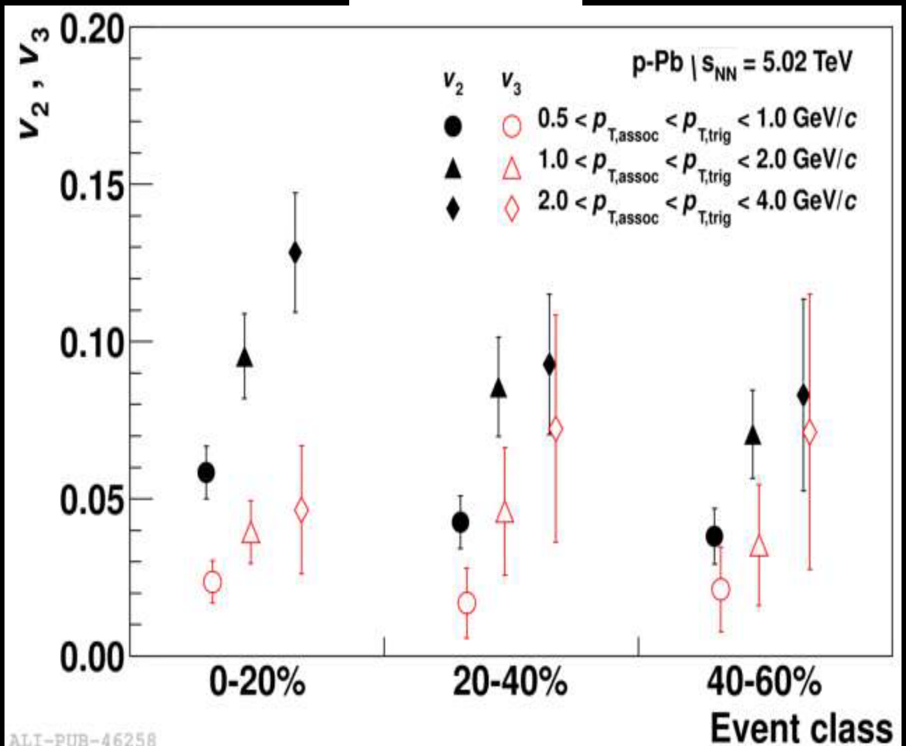
Integrate two ridge yields

near-side: $|\Delta\varphi|<\pi/2$ away-side: $\pi/2<|\Delta\varphi|<3\pi/2$




Extract

v2 and v3




Near- and away-side yields:
vary over a large range
agree for each $p_T$ & event class
(multiplicity range)

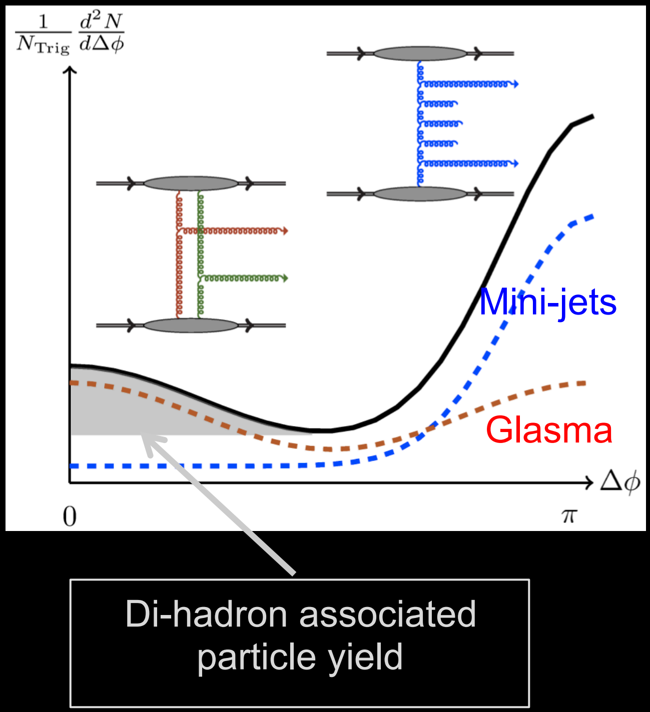
$v_2 > v_3$ in each $p_T$ range in an event class
higher order harmonics negligible
$v_2$ & $v_3$ increase with $p_T$ (studied) & mult.

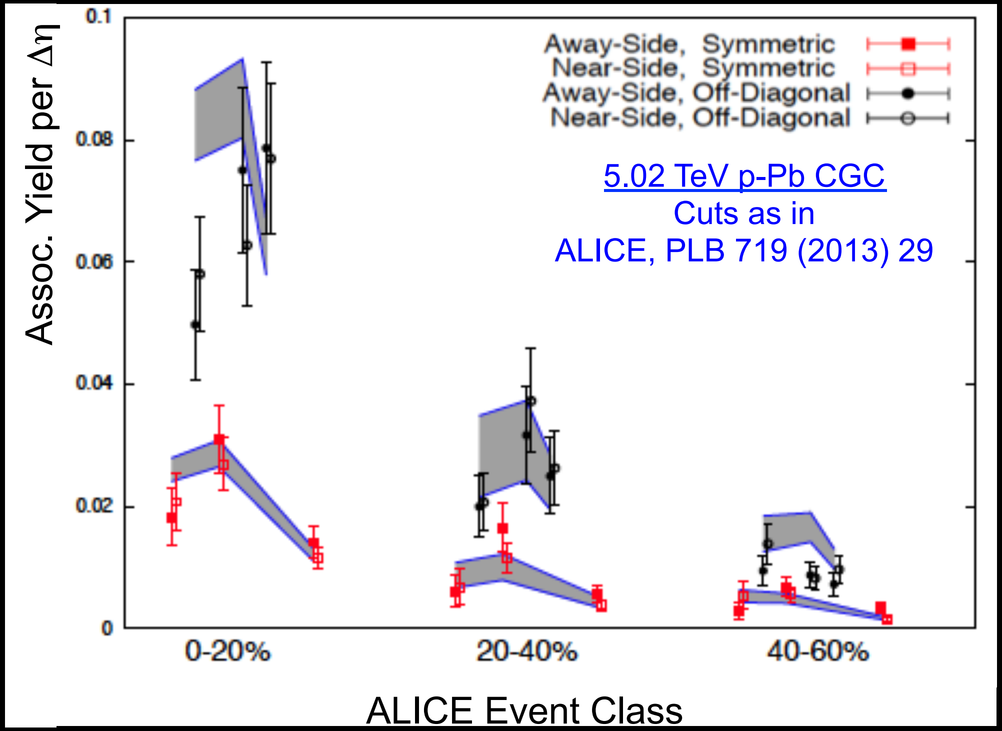
Common Underlying Process?

ALICE, PLB 719 (2013) 29

# Comparison – Ridge Yields and CGC!

Two p-Pb ridges predicted by CGC (Dusling & Venugopalan arXiv:1302.7018):




CGC

Subtract mini-jets→ Glasma graph with near & away-side correlations

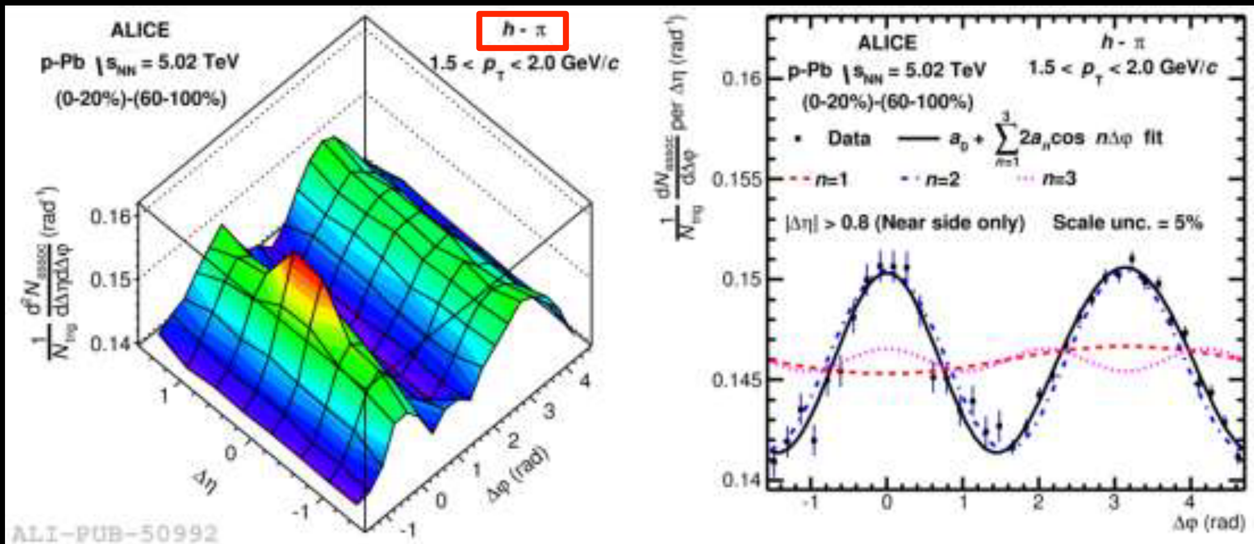
→ comparable to ALICE results

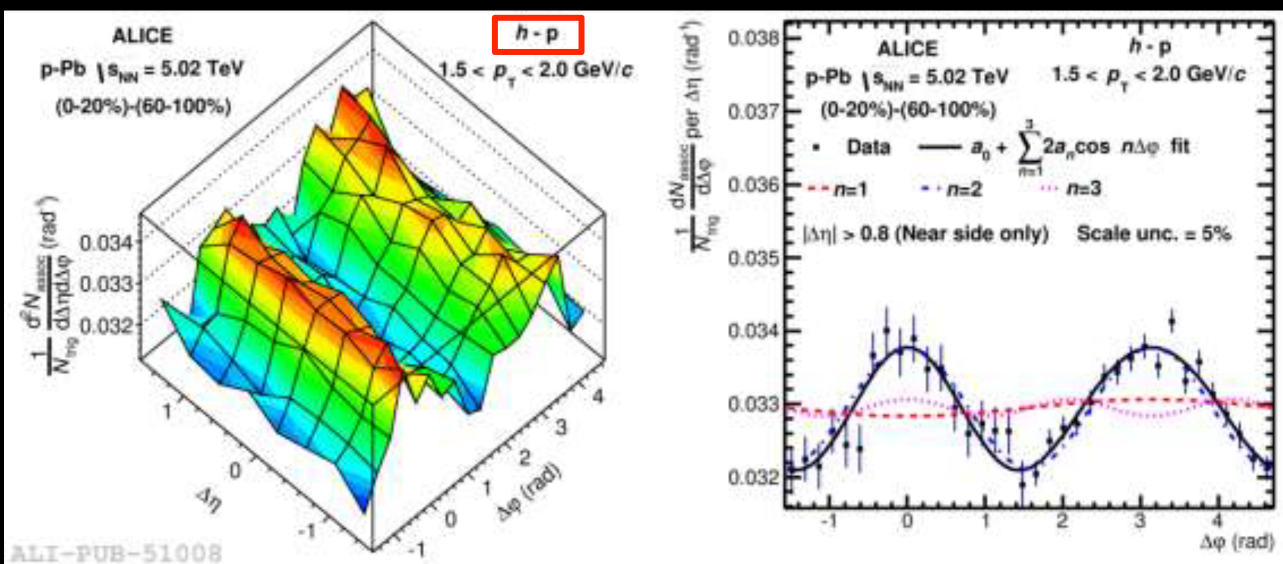
Extract event classes by matching Ntracks in ALICE to CGC charge multiplicities.

Note - ALICE 0-20% corresponds ~ to CMS with Nch ~ 85.

ALICE, CMS, ATLAS results (in different acceptances) are consistent.

# Investigate p-Pb Double Ridge with PID




After subtraction

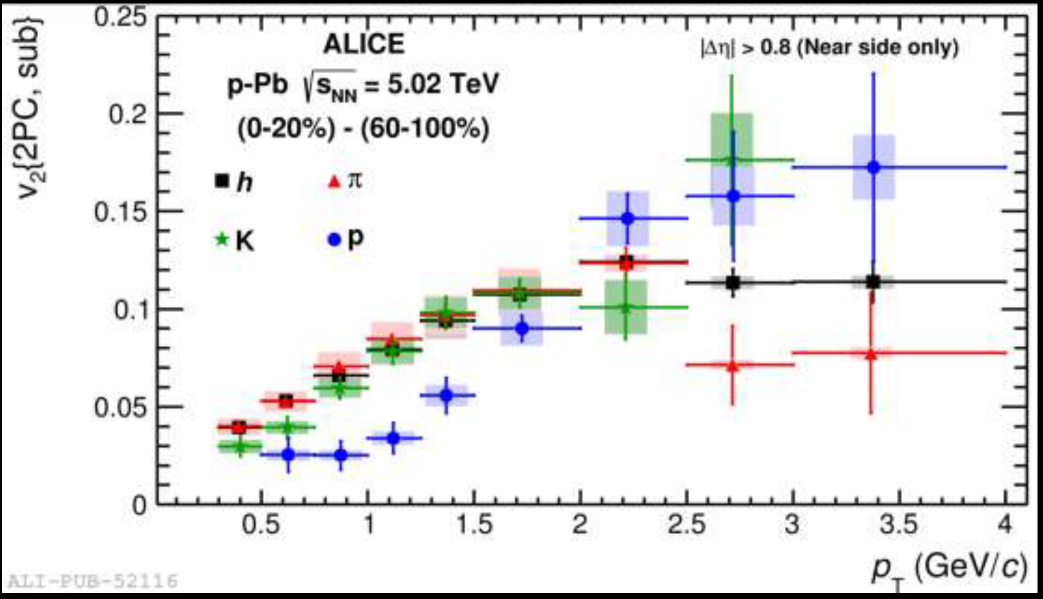
Fourier decomposition

Components shown as dotted/dashed curves

Subtraction procedure as with charged di-hadrons

ALICE, arXiv:1307.3237

# Fourier Decomposition of p-Pb Double Ridge




After subtraction Fourier coefficient $v_2$ (2PC, sub)

Observe ordering in mass!

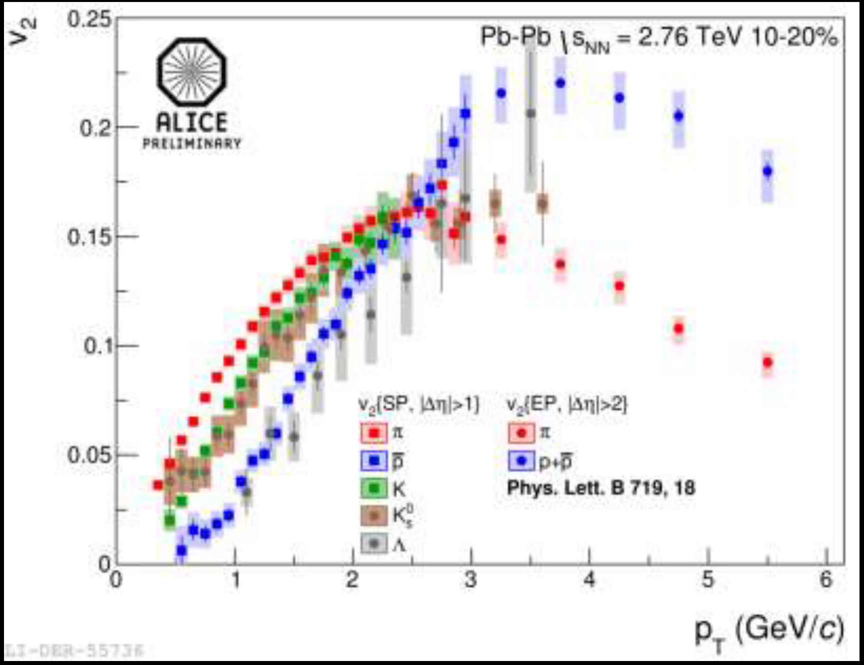
p-Pb ordering similar to Pb-Pb

$v_2$ (2PC, sub) mass hierarchy

~ described by

Hydro with Glauber initial conditions

ref: Bozek, Broniowski, Torrieri, arXiv:1307.5060




ALICE, arXiv:1307.3237

# $dn_{ch}/d\eta$ , $R_{pPb}$ Summary & Conclusions I

ALICE

ALICE $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb Results

- ALICE has measured $dn^{charged} / d\eta_{lab}$
  Described by pQCD-based MC models (HIJING, DPMJET)

- ALICE measures $R_{pPb}^{charged}$ ~ 1 for $p_T$ > 2 GeV/c, consistent with binary scaling
  Absence of nuclear modification → small initial state effects
  $R_{PbPb}$ suppression (previously measured) → a final state effect
  Described by Saturation (CGC) models, EPS09 with shadowing.

- ALICE has preliminary measurements of
  $R_{pPb}^{D\text{-mesons}}$ ~ 1 for $p_T$ = 1.5 - 20 GeV/c
  $R_{pPb}^{charged\ jet}$ ~ 1 for $p_T$ = 20 - 100 GeV/c
  Absence of nuclear modification → small initial state effects
  $R_{PbPb}$ suppression (previously measured) → a final state effect

- ALICE has measured $R_{pPb}^{J/\psi}$ (y)
  Observes suppression that increases towards forward rapidity (y)
  $R_{FB}^{J/\psi}$ ($p_T$) ratio decreases (more suppresssed) at low $p_T$
  In reasonable agreement with models including coherent energy loss
  Nuclear shadowing and/or energy loss describe the data, indicates that final state absorption may be negligible at LHC energies.

# Particle Ratios & Correlations: Summary & Conclusions

ALICE $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb Results

- ALICE has measured ratios of identified particles ($\pi$, K, p, $\Lambda$)

  p-Pb ratios similar behavior & pattern to Pb-Pb, do not increase as strongly as Pb-Pb

  Baryon/meson (B/M) ratios increase with $p_T$, peak near $p_T$ = 3 GeV/c

  Enhancement increases as $\Lambda$/K > p/$\pi$ > K/$\pi$

- ALICE has measured B/M ratio evolution with $p_T$ and event multiplicity

  p-Pb evolution identical to Pb-Pb!

  Similar physics with differing systems, sizes/geometries, energies?

- ALICE has measured $\langle p_T \rangle$ vs event multiplicity for $\pi$, K, p, $\Lambda$

  $\langle p_T \rangle$ increases strongly with particle mass, increases with multiplicity

  Same general $\langle p_T \rangle$ trends observed in Pb-Pb

- ALICE has measured $\langle p_T \rangle$ vs event multiplicity for charged particles

  $\langle p_T \rangle$ increases sharply at low multiplicity

  Increases to higher values for pp & p-Pb than Pb-Pb

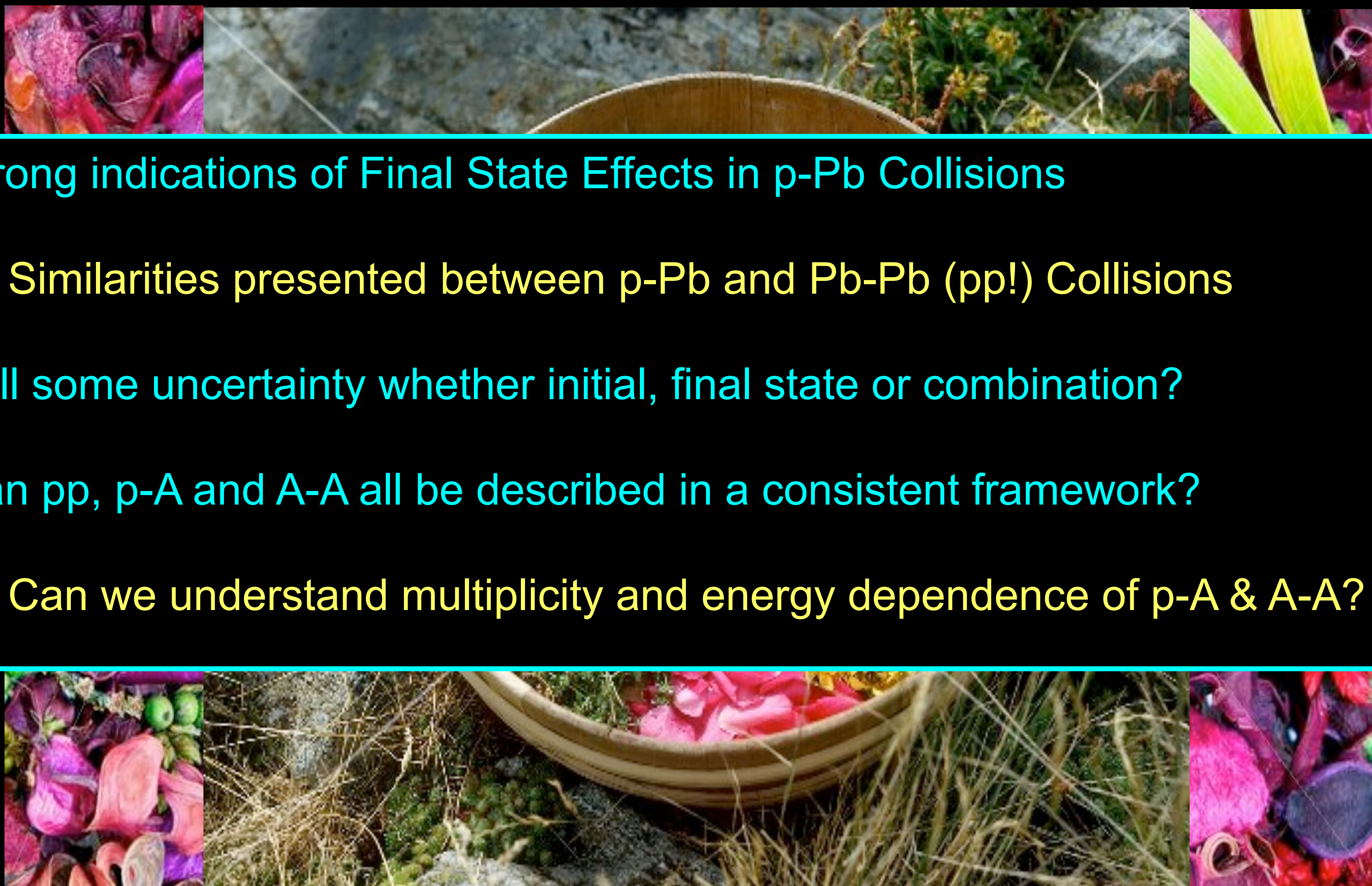
  Collective effects required (thus far) to fit p-Pb, no models fit Pb-Pb (so far)

- ALICE observes a double ridge structure in charged & identified particle correlations

  Identical identical back-to-back ($\Delta\phi = \pi$) ridges, extended in $\eta$ $\rightarrow$ CGC / hydro?

  $v_2$ (2PC, sub) exhibits mass ordering similar to $v_2$ in Pb-Pb $\rightarrow$ Hydro / CGC?

# *Bottomline for p-A Collisions*



Strong indications of Final State Effects in p-Pb Collisions

- Similarities presented between p-Pb and Pb-Pb (pp!) Collisions

Still some uncertainty whether initial, final state or combination?

Can pp, p-A and A-A all be described in a consistent framework?

- Can we understand multiplicity and energy dependence of p-A & A-A?

# Happy Birthday Takeshi

# on the Occasion of your 70th Birthday!

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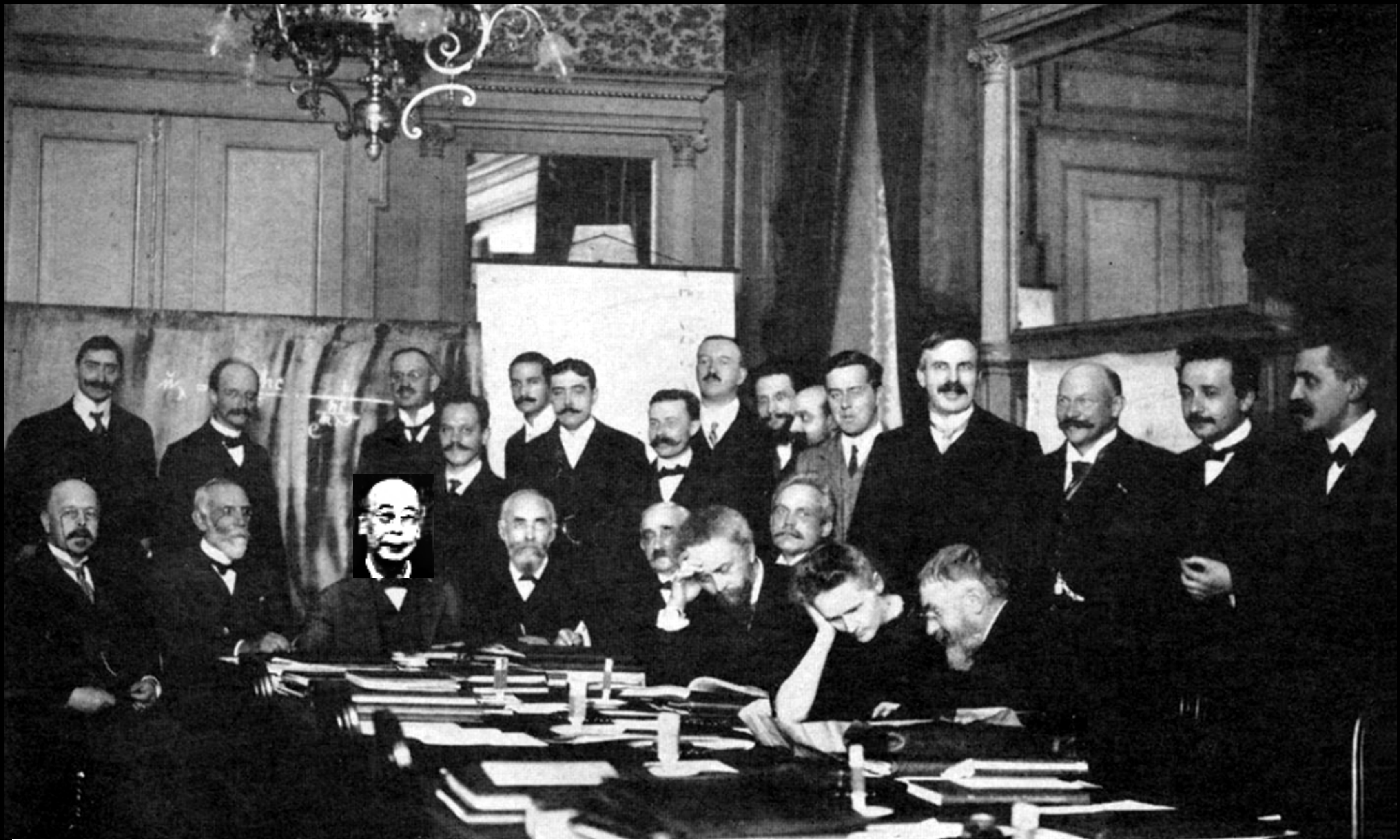
ALICE

Solvay Conference 1911

# Happy Birthday Takeshi
# on the Occasion of your 70th Birthday!



News Flash (Sept 26, 2013) - Solvay Conference 1911 – Mystery of Belgian Philanthropist Revealed

***Thanks for your attention***