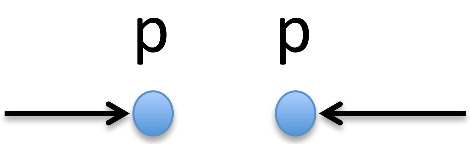
First two-particle correlation results in proton-lead collisions from CMS

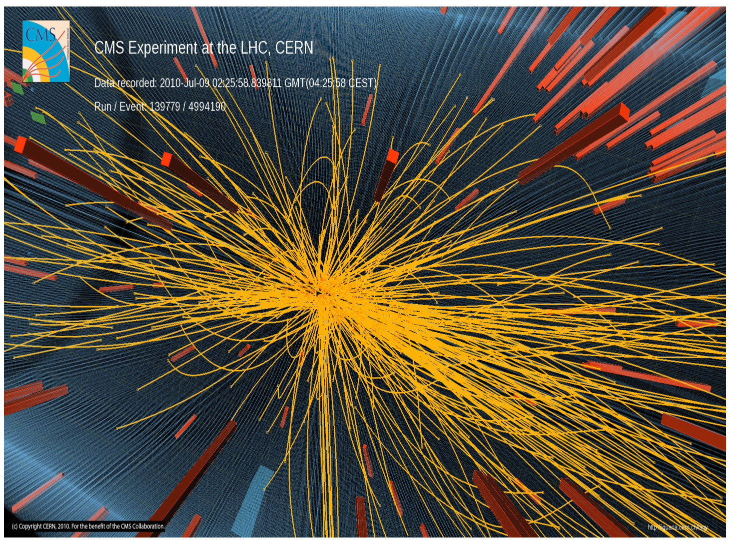
Wei Li (Rice University)
for the CMS collaboration

The “ridge” in pp collisions

Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC

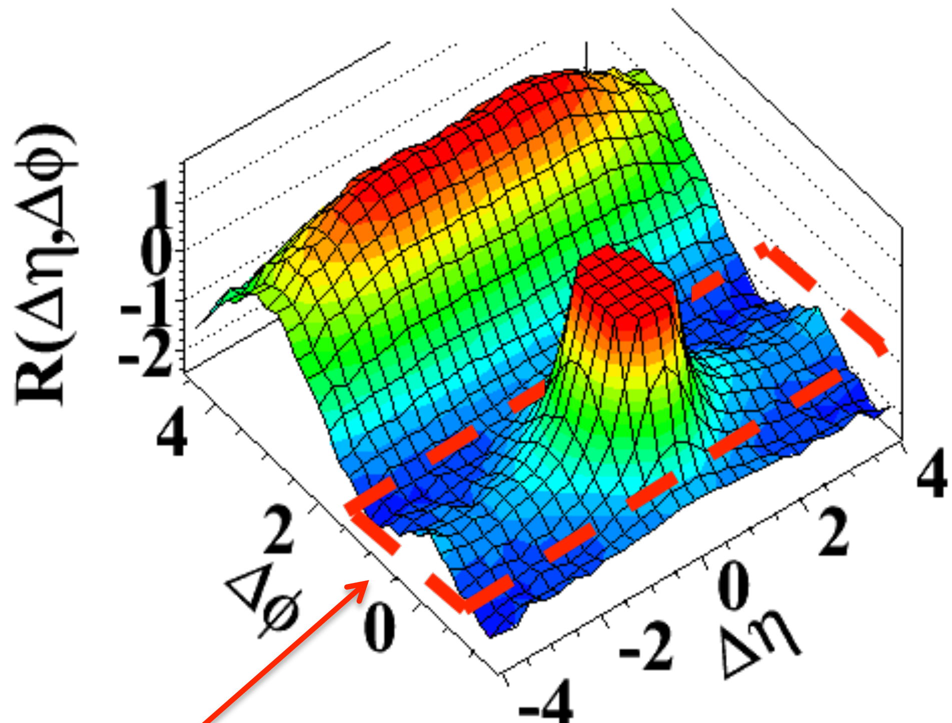
CMS collaboration, JHEP 09 (2010) 091





Event with more than 200 charged particles

pp N>110, $1<p_T<3$ GeV/c



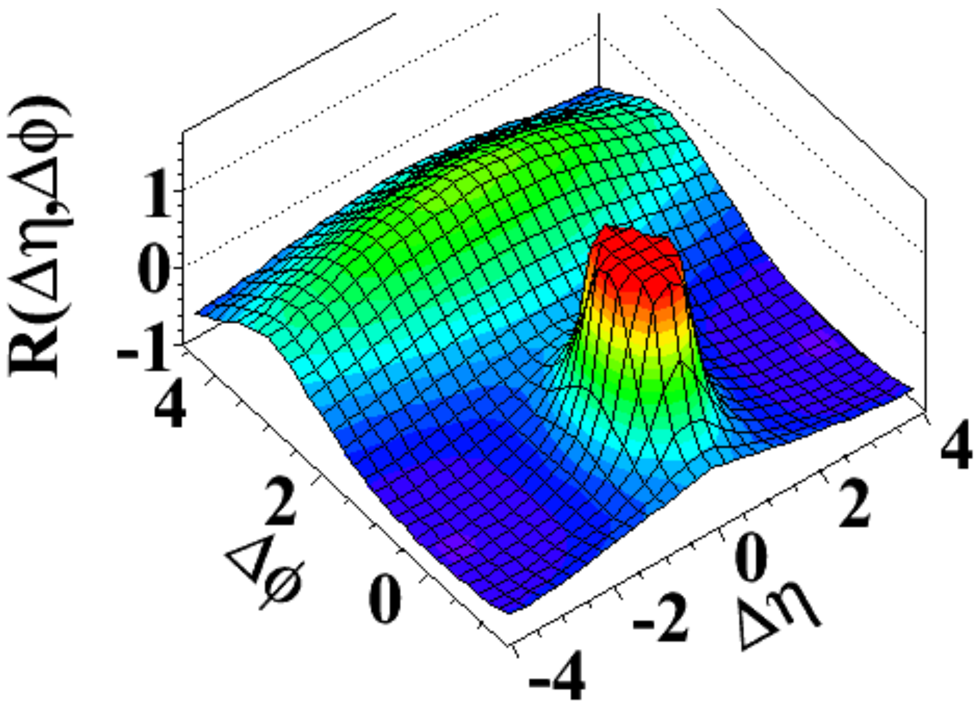
A surprise: near-side (Δϕ~0) “ridge” in high multiplicity pp!

The “ridge” in pp collisions

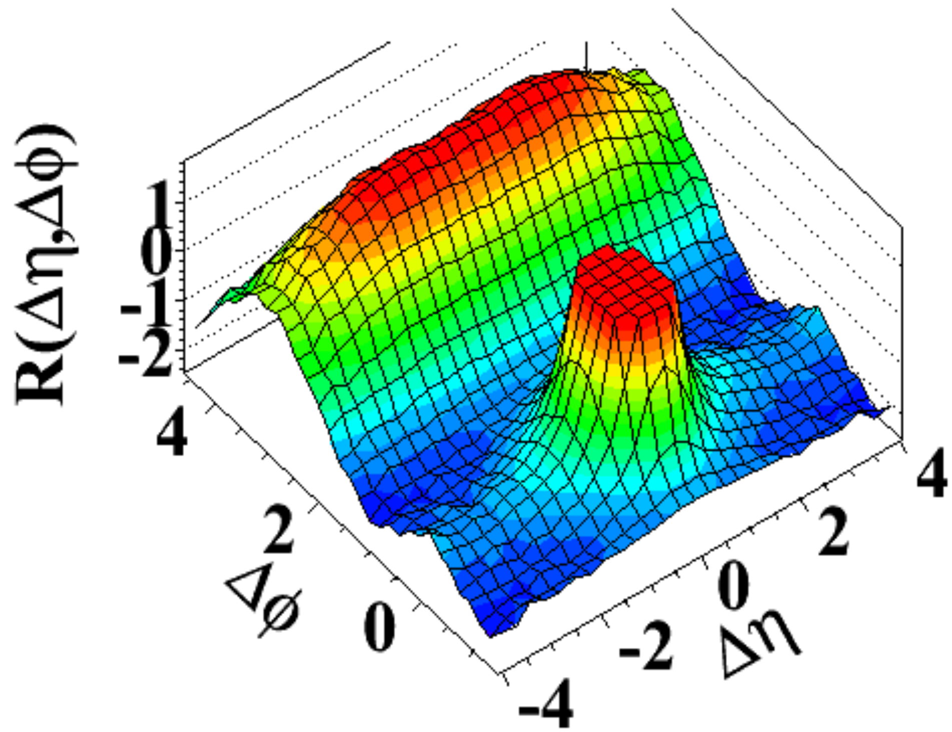
Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC

CMS collaboration, JHEP 09 (2010) 091

pp <N>~15, $1<p_T<3$ GeV/c



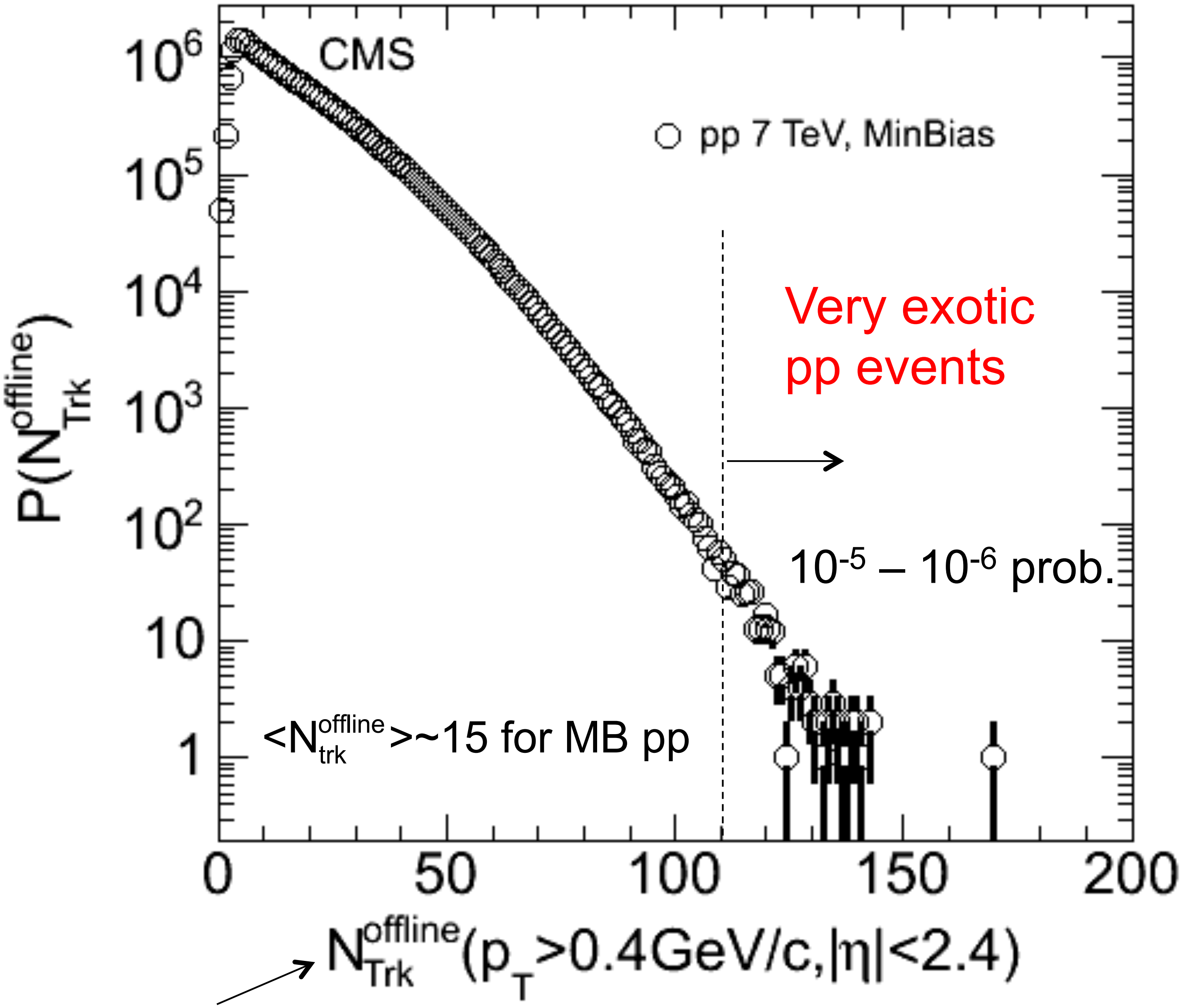
pp N>110, $1<p_T<3$ GeV/c



No ridge observed in minimum bias pp or any pp MC generators

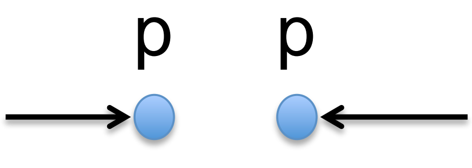
Very high multiplicity pp collisions

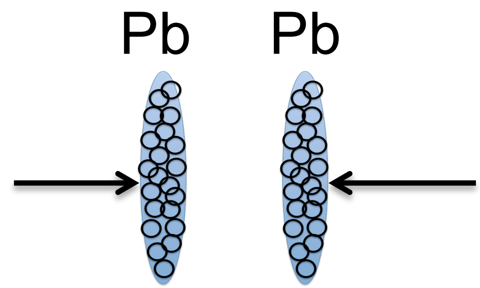
Very high-multiplicity pp events are rare in nature

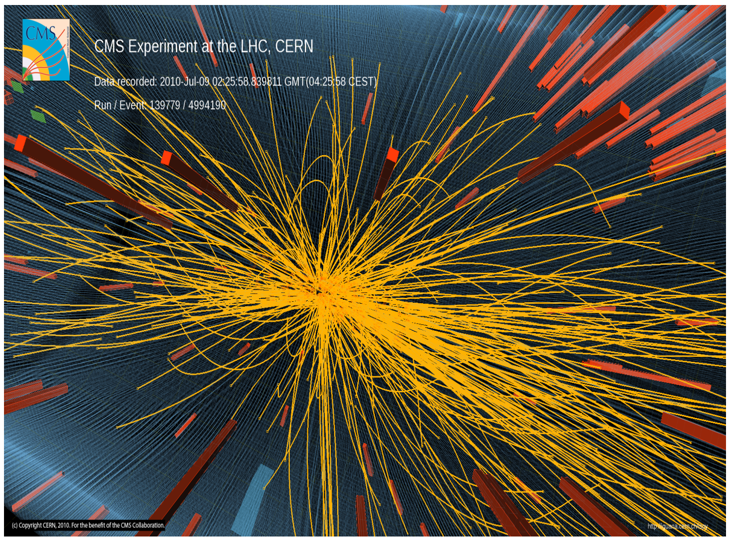


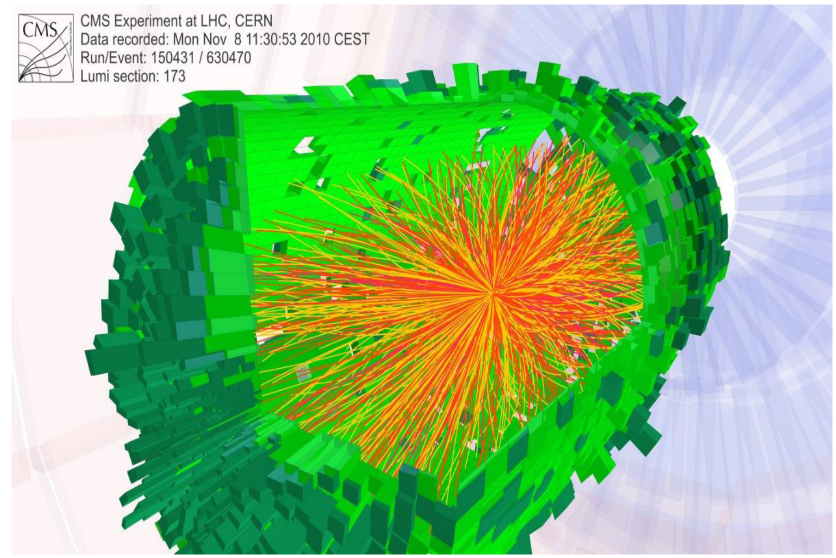
Raw counts of tracks!

proton-proton and nucleus-nucleus collisions

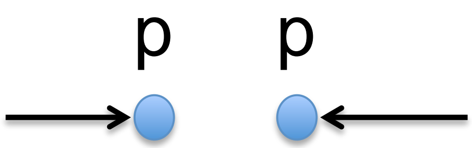




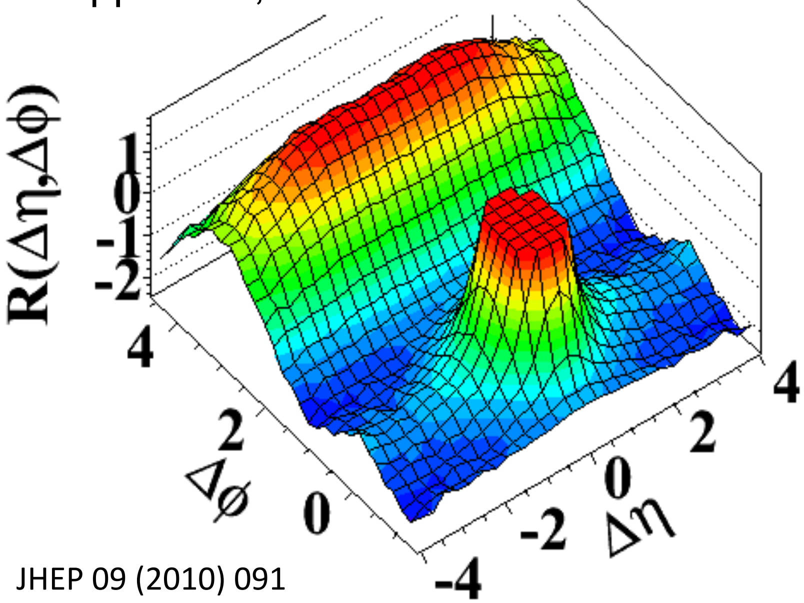




The "ridge" in pp and AA collisions



pp 7 TeV, N>110



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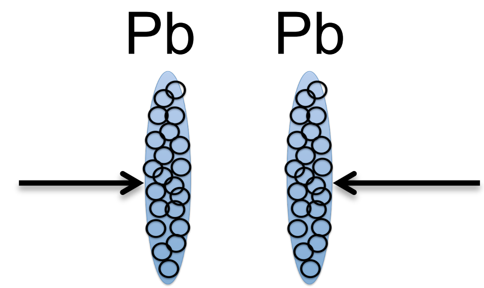
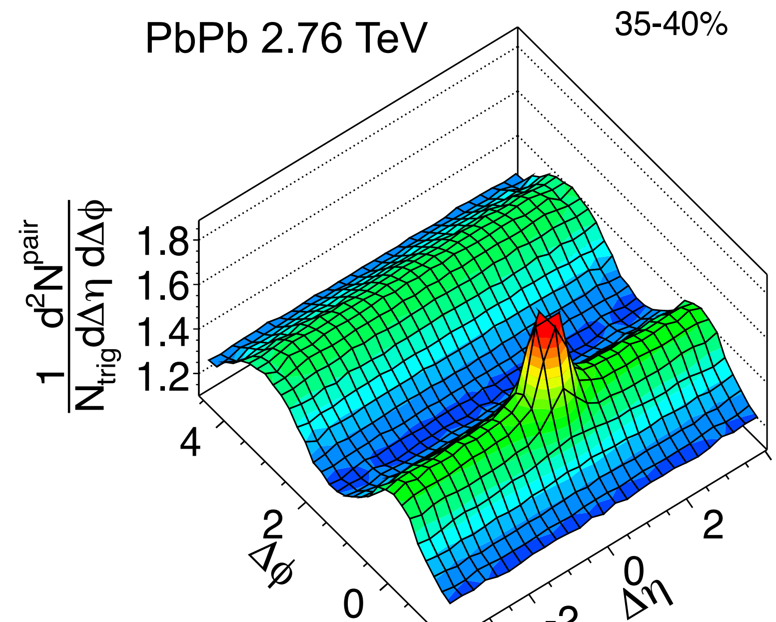


PbPb 2.76 TeV



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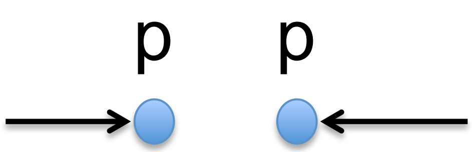
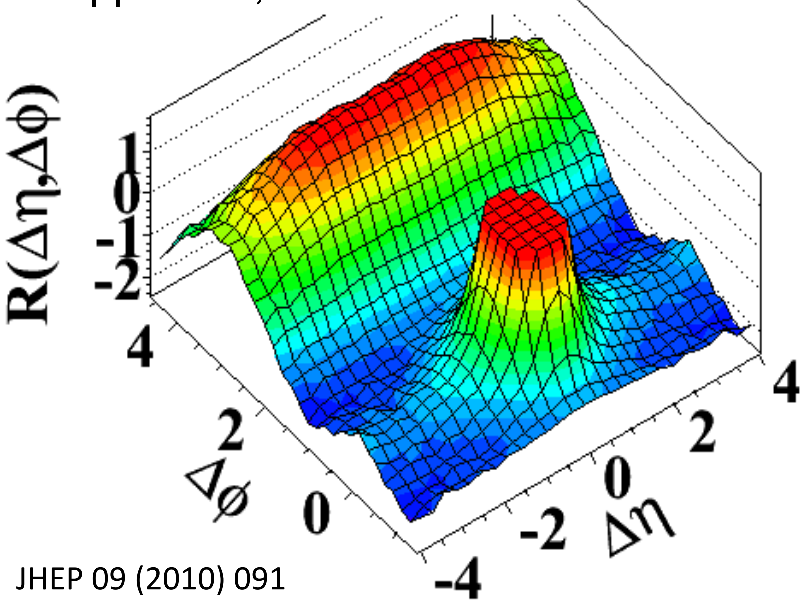
EPJC 72 (2012) 2012

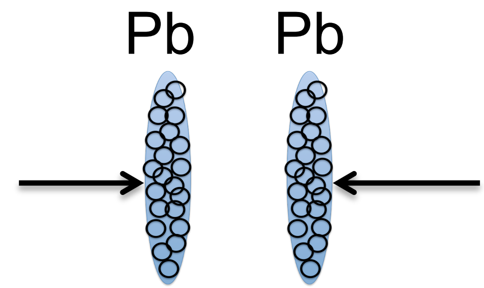
The “ridge” in pp and AA collisions



pp 7 TeV, N>110



JHEP 09 (2010) 091



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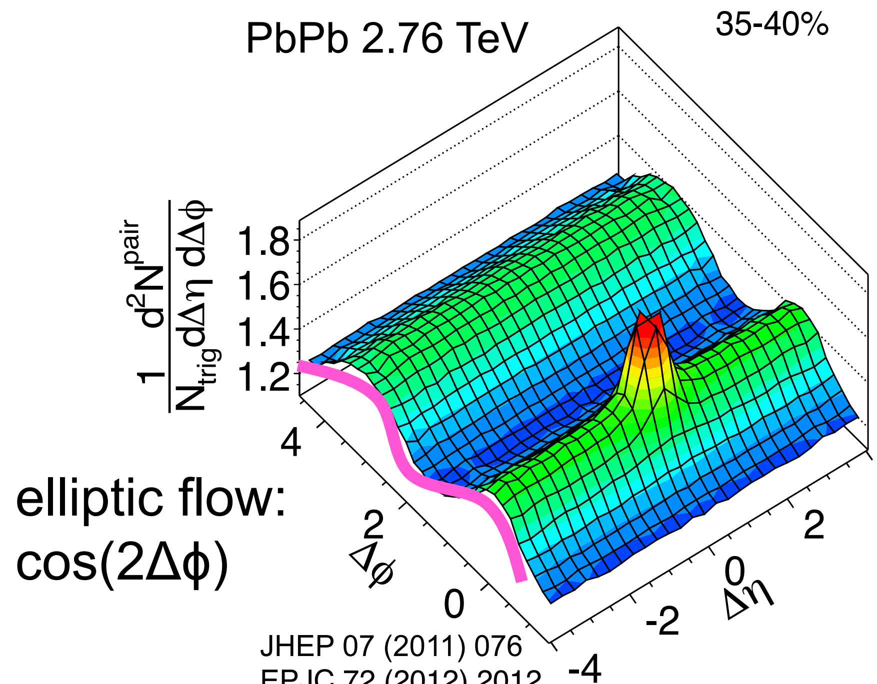

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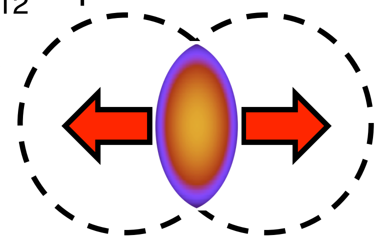
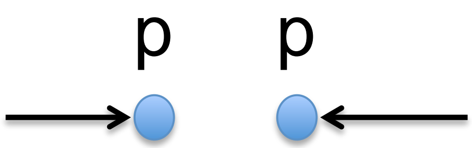
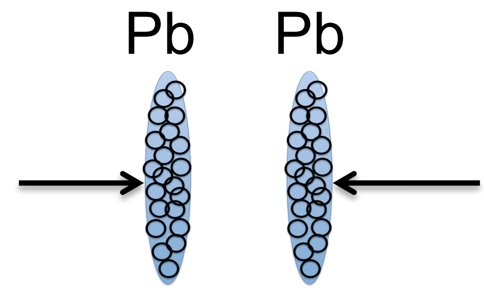
Initial-state geometry
+
collective expansion



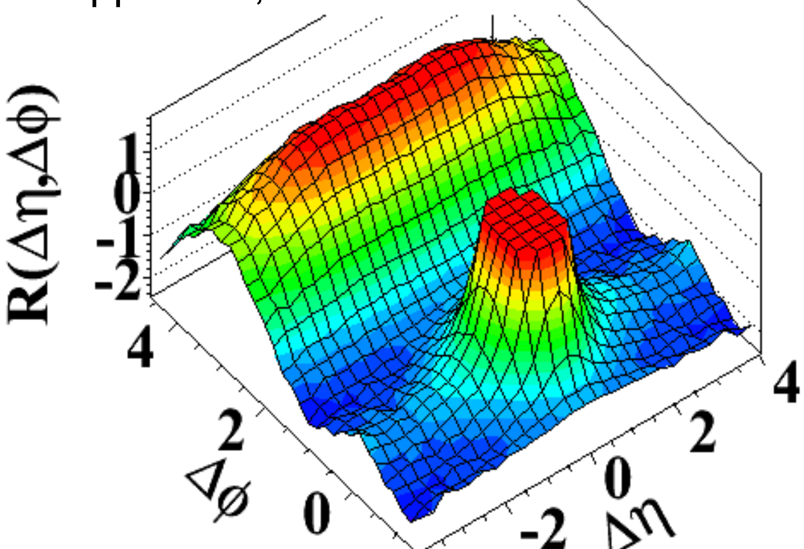
“Smoking gun” of a strongly interacting QGP liquid!

The "ridge" in pp and AA collisions

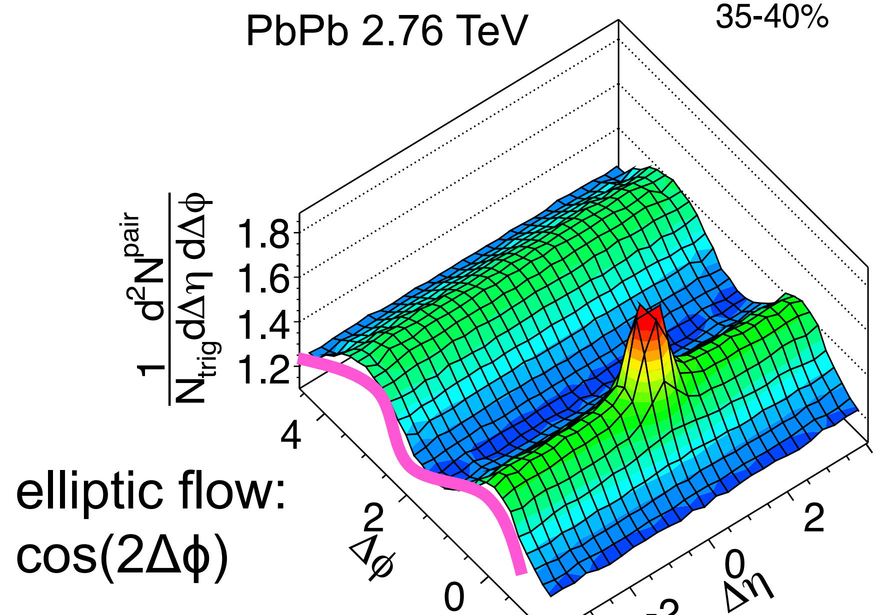




pp 7 TeV, N>110



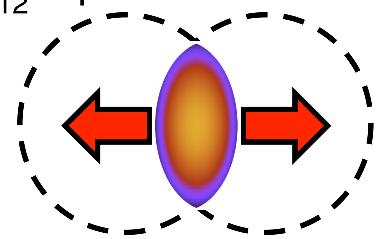
JHEP 09 (2010) 091



JHEP 07 (2011) 076
EPJC 72 (2012) 2012

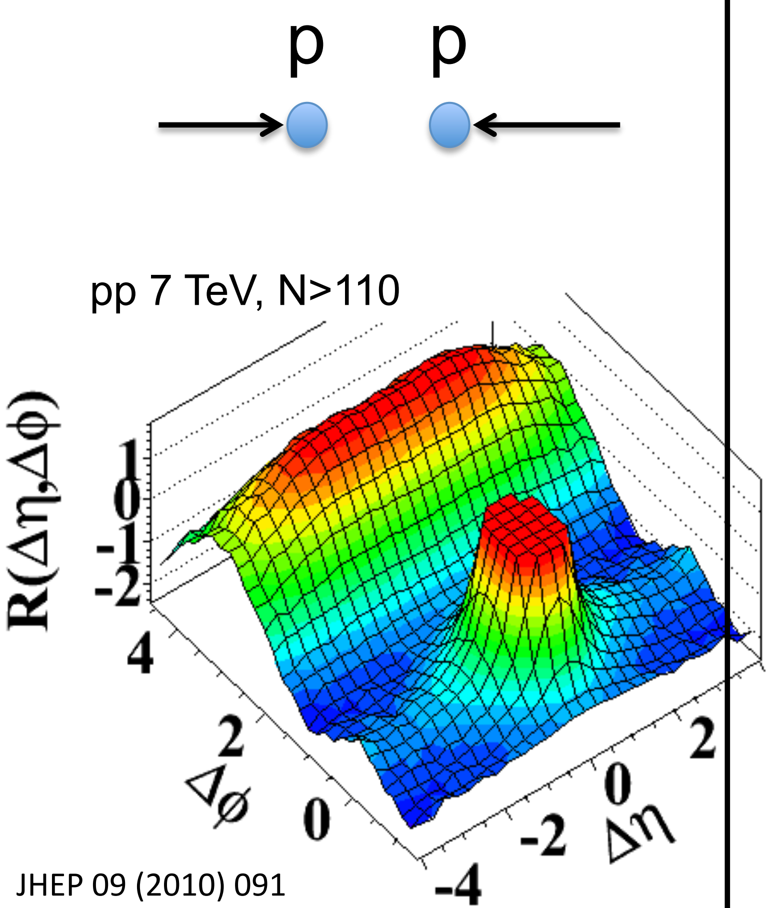
Physical origin of pp ridge is still not completely explained

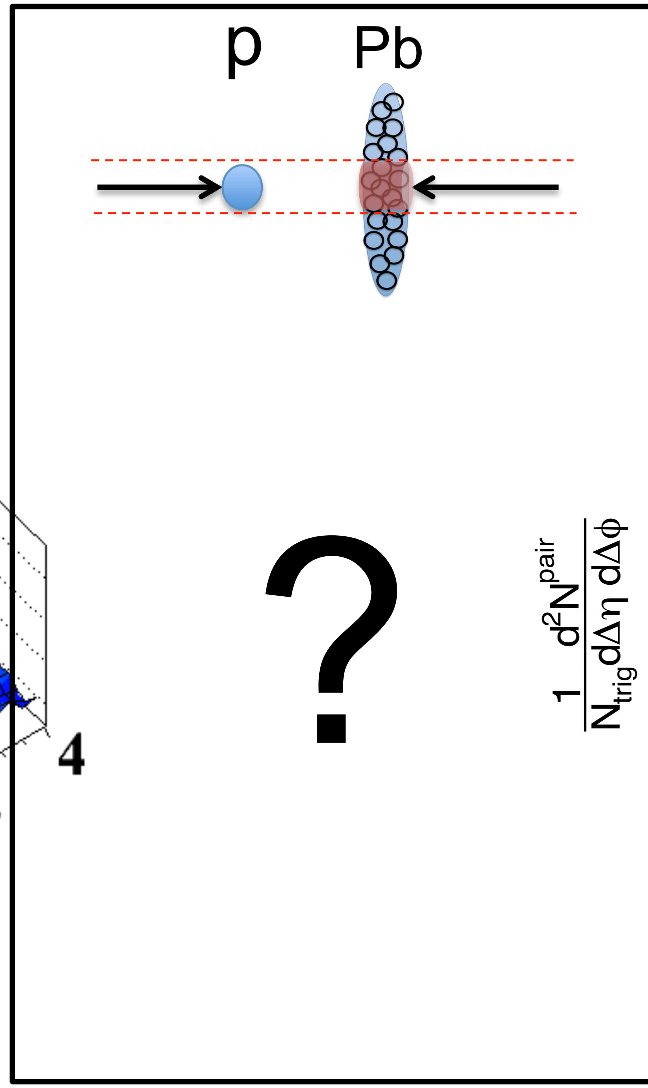
Initial-state geometry
+
collective expansion

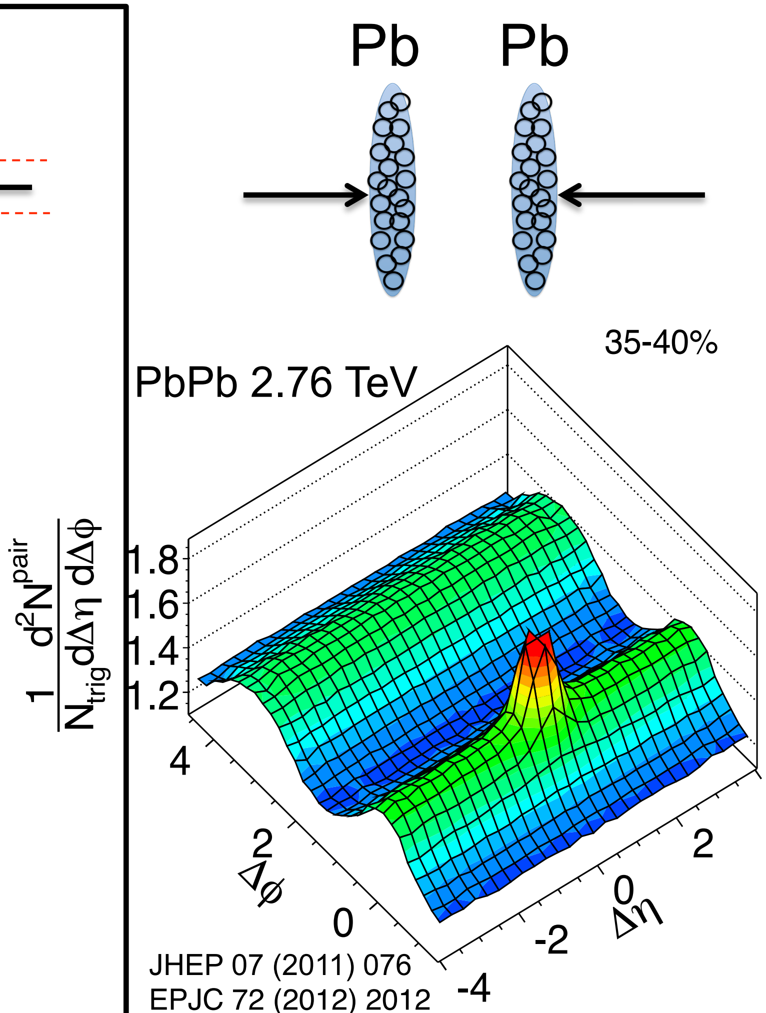


"Smoking gun" of a strongly interacting QGP liquid!

The “ridge” in pp, pA and AA collisions?





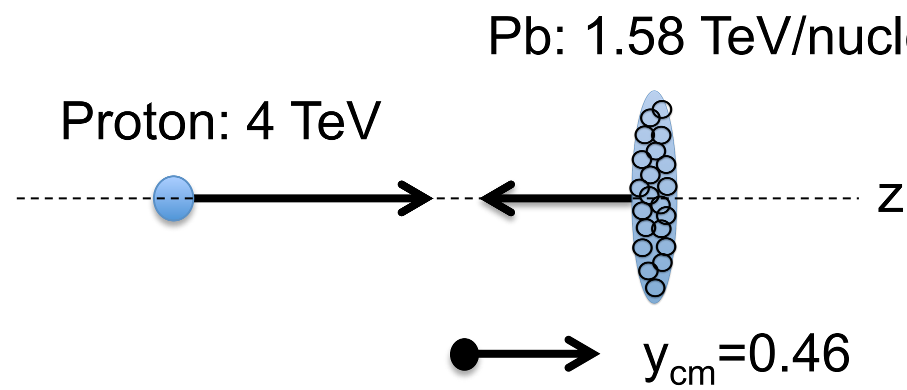


What if colliding a proton and a nucleus?

Is there a ridge and how big is it?

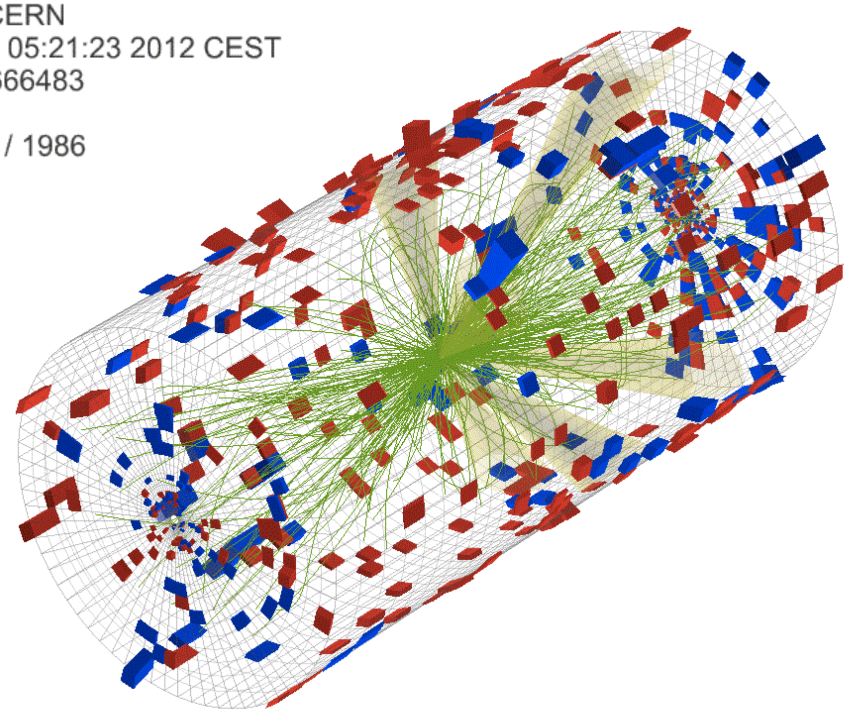
Proton-nucleus collisions at the LHC

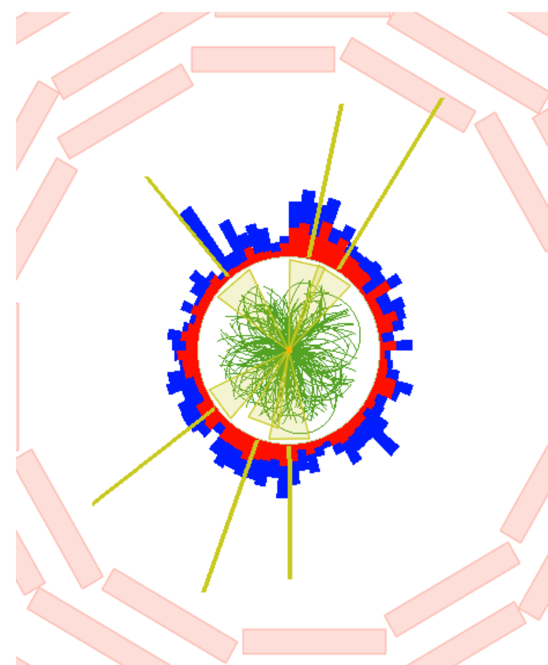
pPb pilot run at the LHC on September 13, for ~ 8 hours



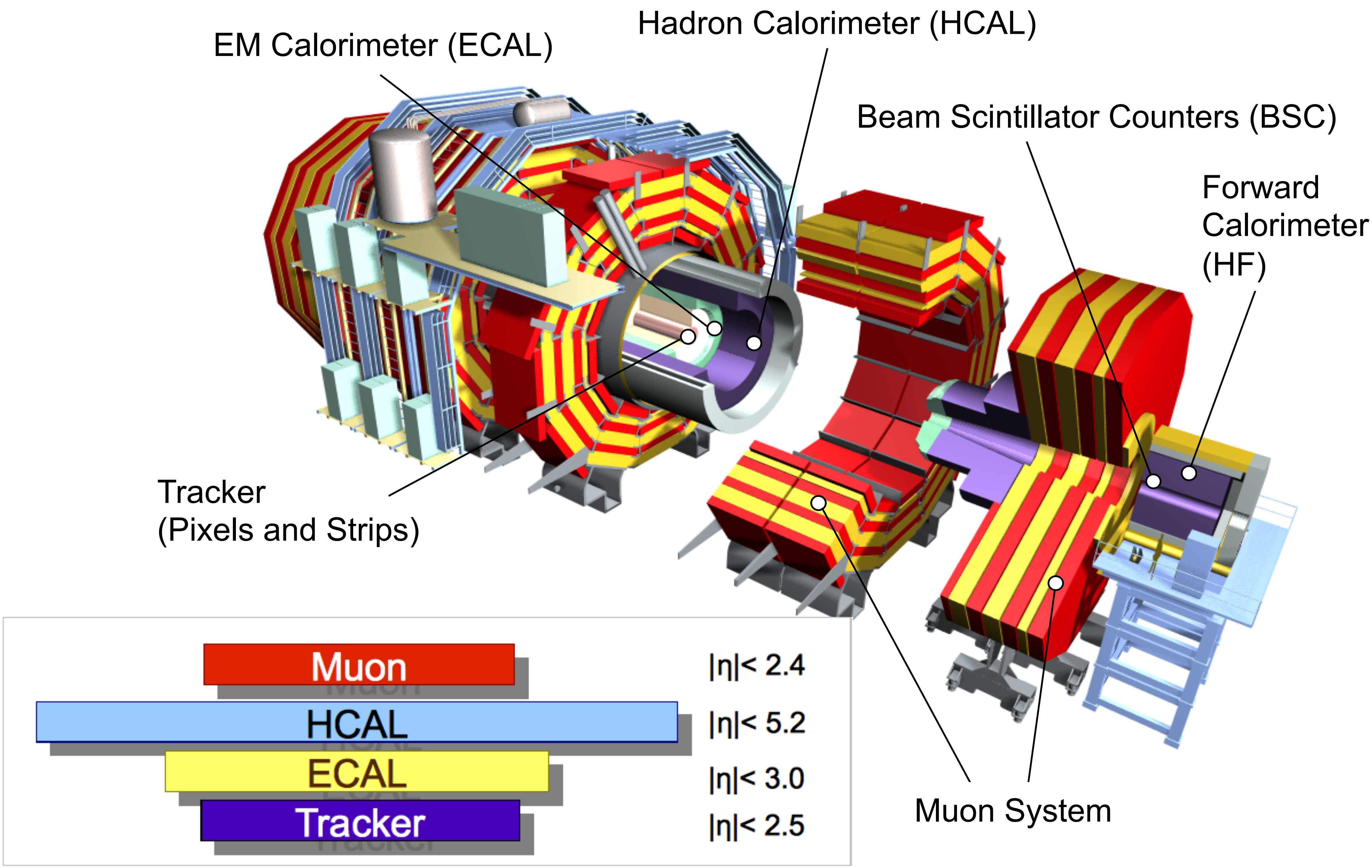
Center-of-mass energy: $\sqrt{s_{NN}}$ = 5.02 TeV

CMS Experiment at LHC, CERN
Data recorded: Thu Sep 13 05:21:23 2012 CEST
Run/Event: 202792 / 1737666483
Lumi section: 918
Orbit/Crossing: 240400935 / 1986





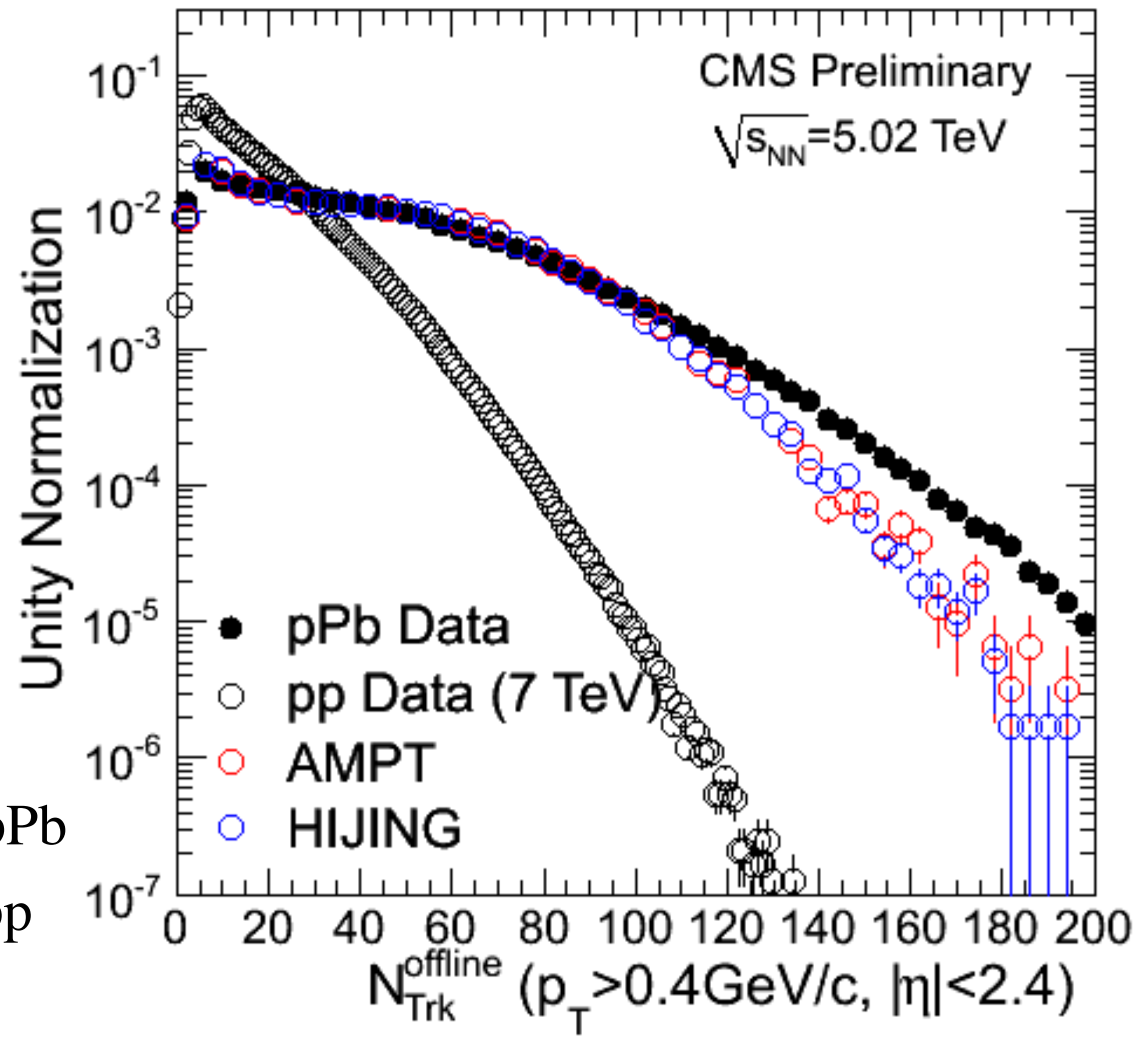
CMS experiment at the LHC



Unprecedented kinematic range and acceptance

Multiplicity distribution in pPb

~ 2 million minimum bias pPb events were collected (1 μb^{-1})



$\langle N_{trk}^{offline} \rangle$~40 for MB pPb

$\langle N_{trk}^{offline} \rangle$~15 for MB pp

Much easier to reach high multiplicity in pPb, as expected

Two-particle correlations at CMS

Pair of two primary reconstructed tracks within $|\eta|<2.4$

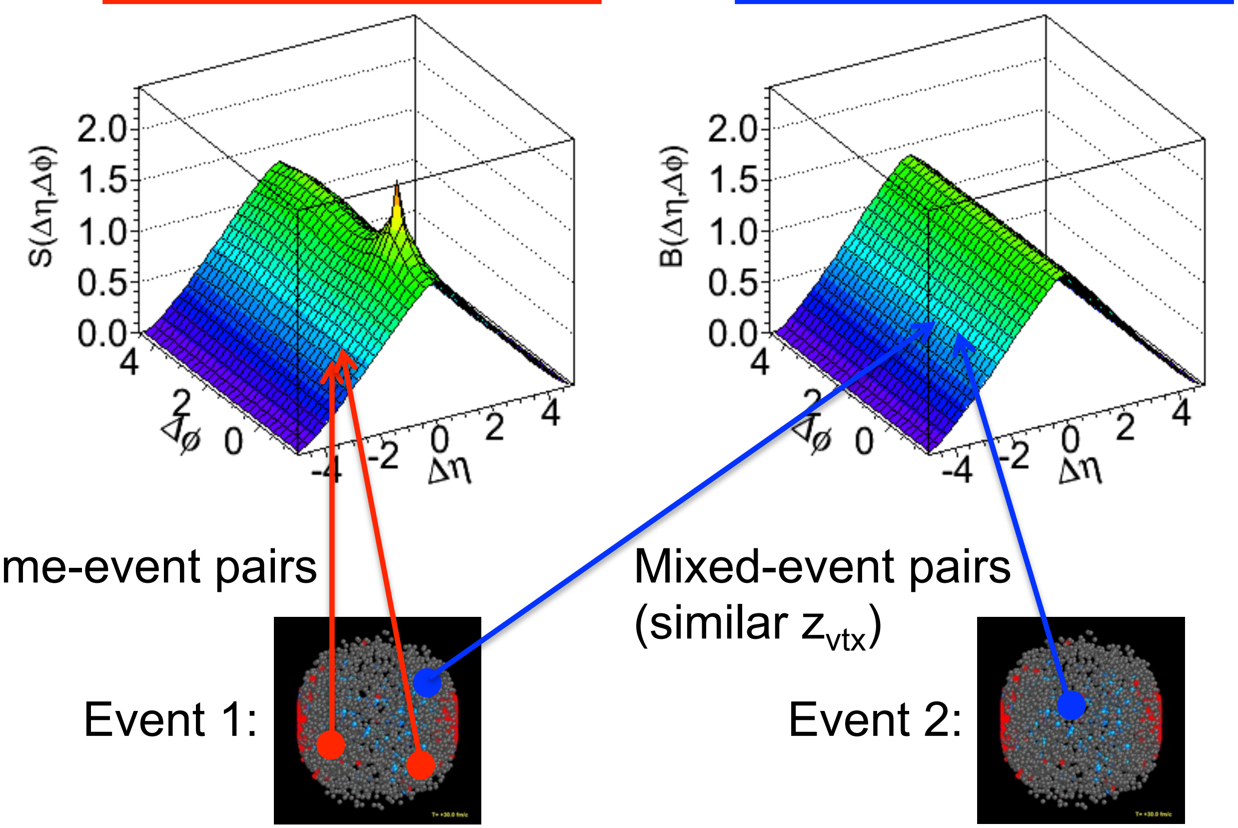
- Trigger particle from a p_T^{trig} interval
- Associated particle from a p_T^{assoc} interval

Signal-pair distribution

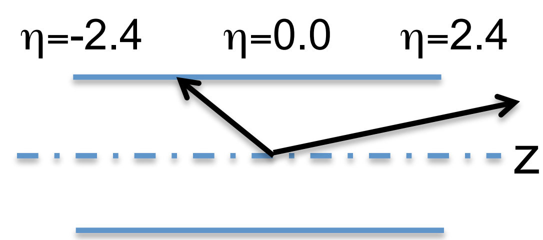
$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$

Background-pair distribution

$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$



Triangular shape in Δη due to limited acceptance



$$\Delta\eta = \eta^{assoc} - \eta^{trig}$$
$$\Delta\phi = \phi^{assoc} - \phi^{trig}$$

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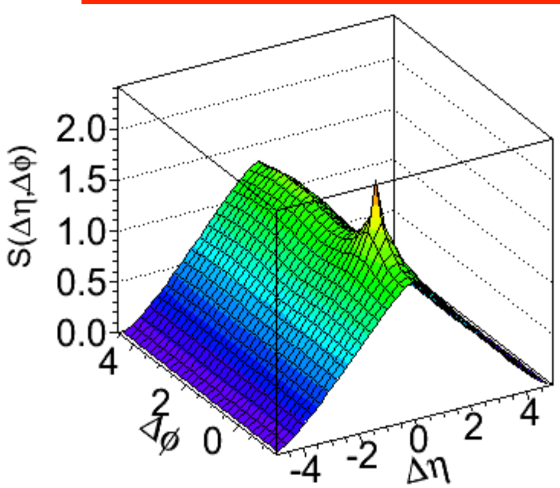

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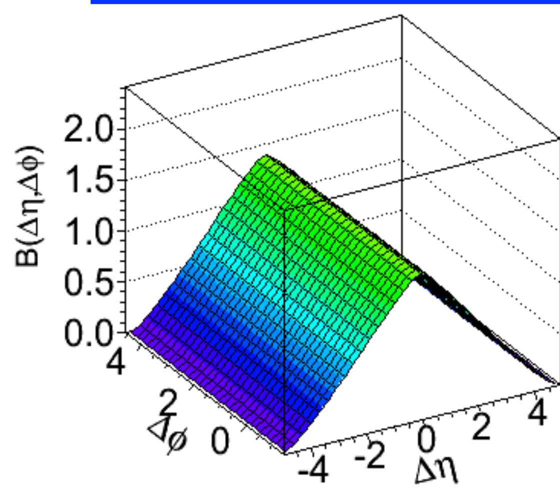
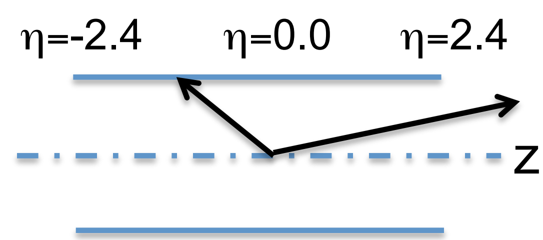


Triangular shape in $\Delta\eta$ due to limited acceptance



$\Delta\eta = \eta^{assoc} - \eta^{trig}$
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

Pair yield per trigger particle:

$$\frac{1}{N_{trg}} \frac{d^2N}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

Two-particle correlations at CMS

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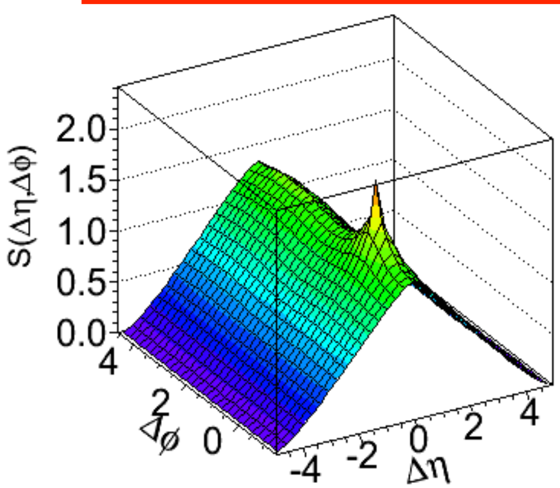

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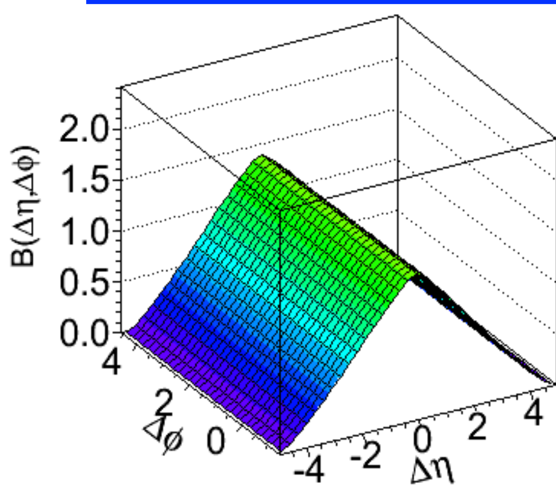

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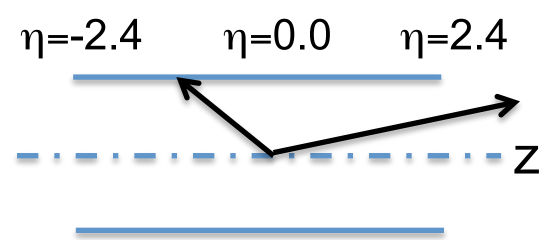

$\Delta\eta = \eta^{assoc} - \eta^{trig}$
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

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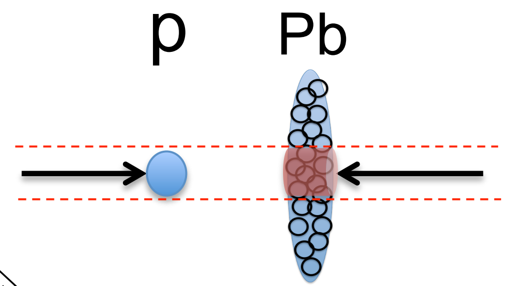
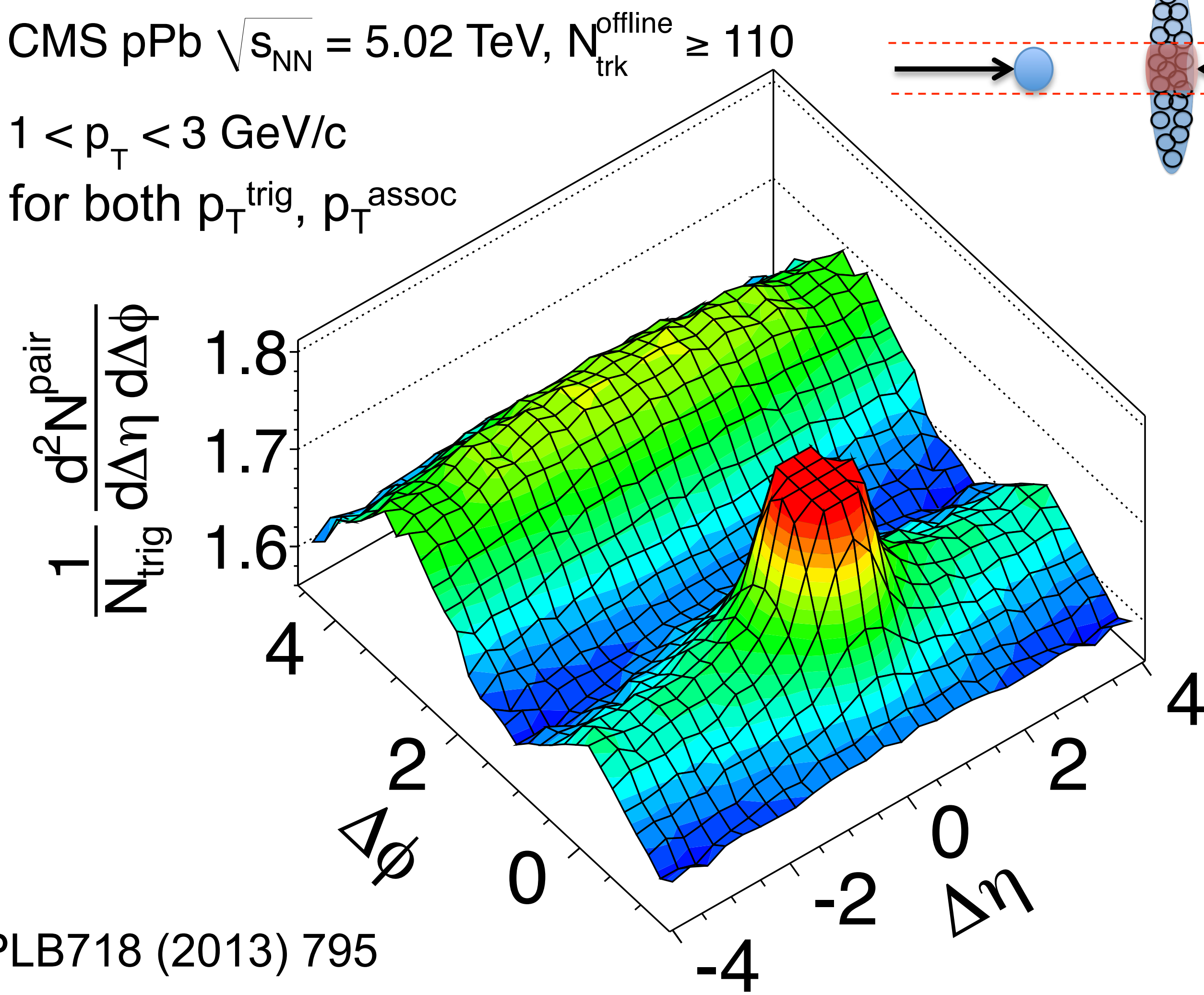
acceptance correction

First two-particle correlation result in pPb

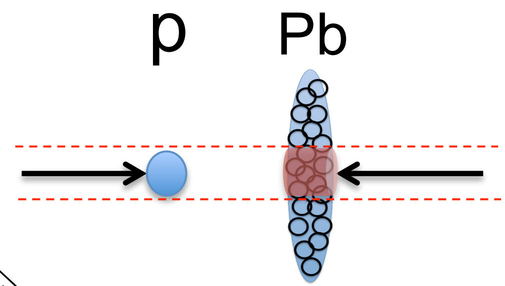


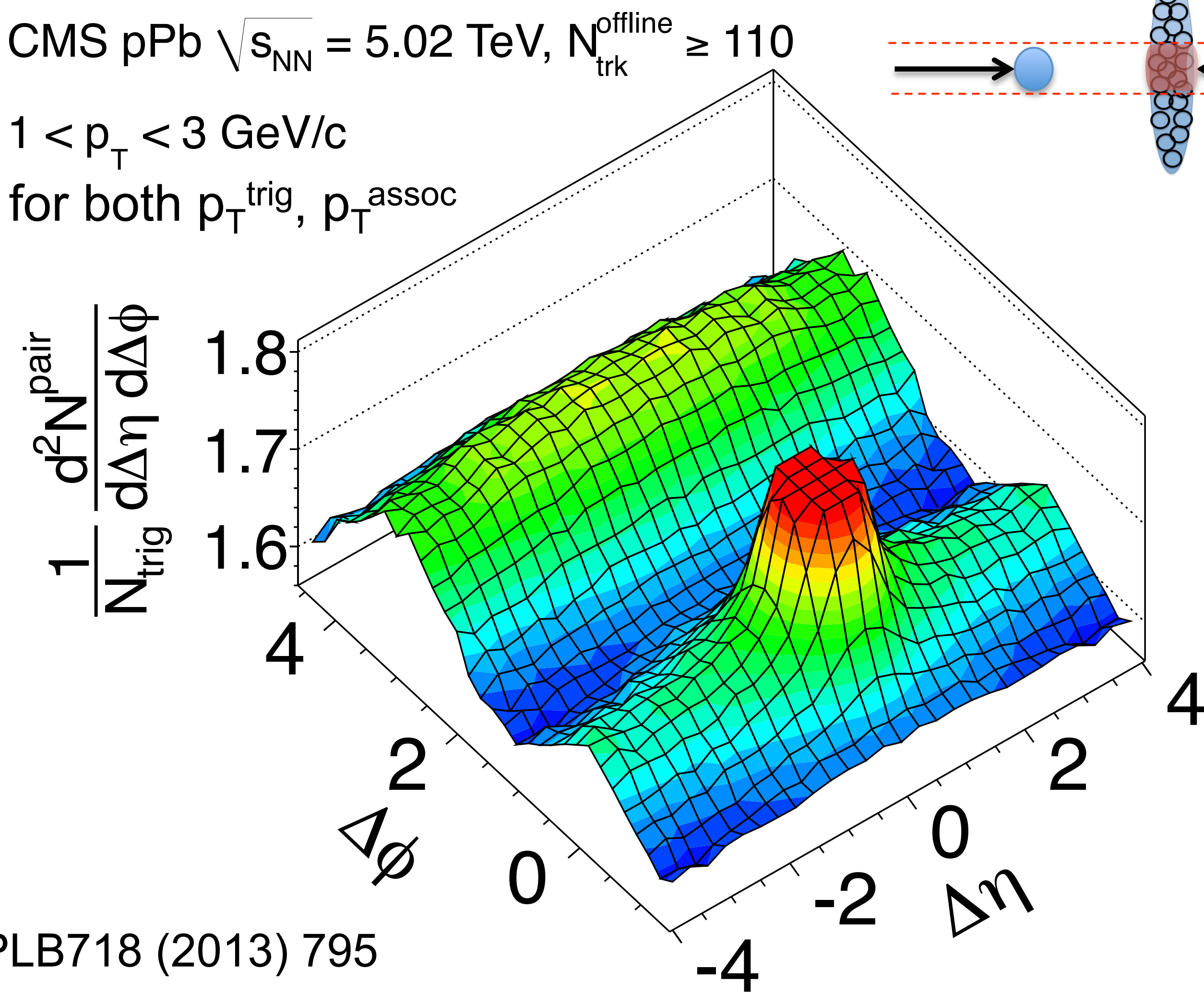


PLB718 (2013) 795

A significant near-side ridge in high multiplicity pPb!

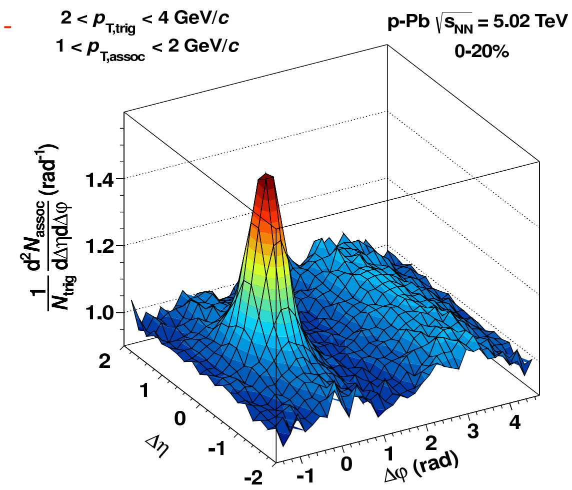
First two-particle correlation result in pPb



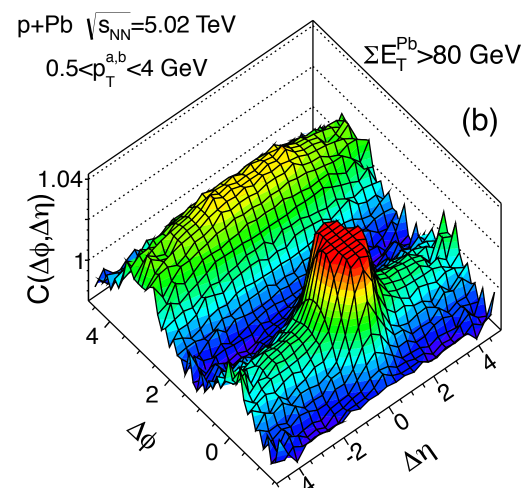


PLB718 (2013) 795

ALICE (arXiv:1212.2001)



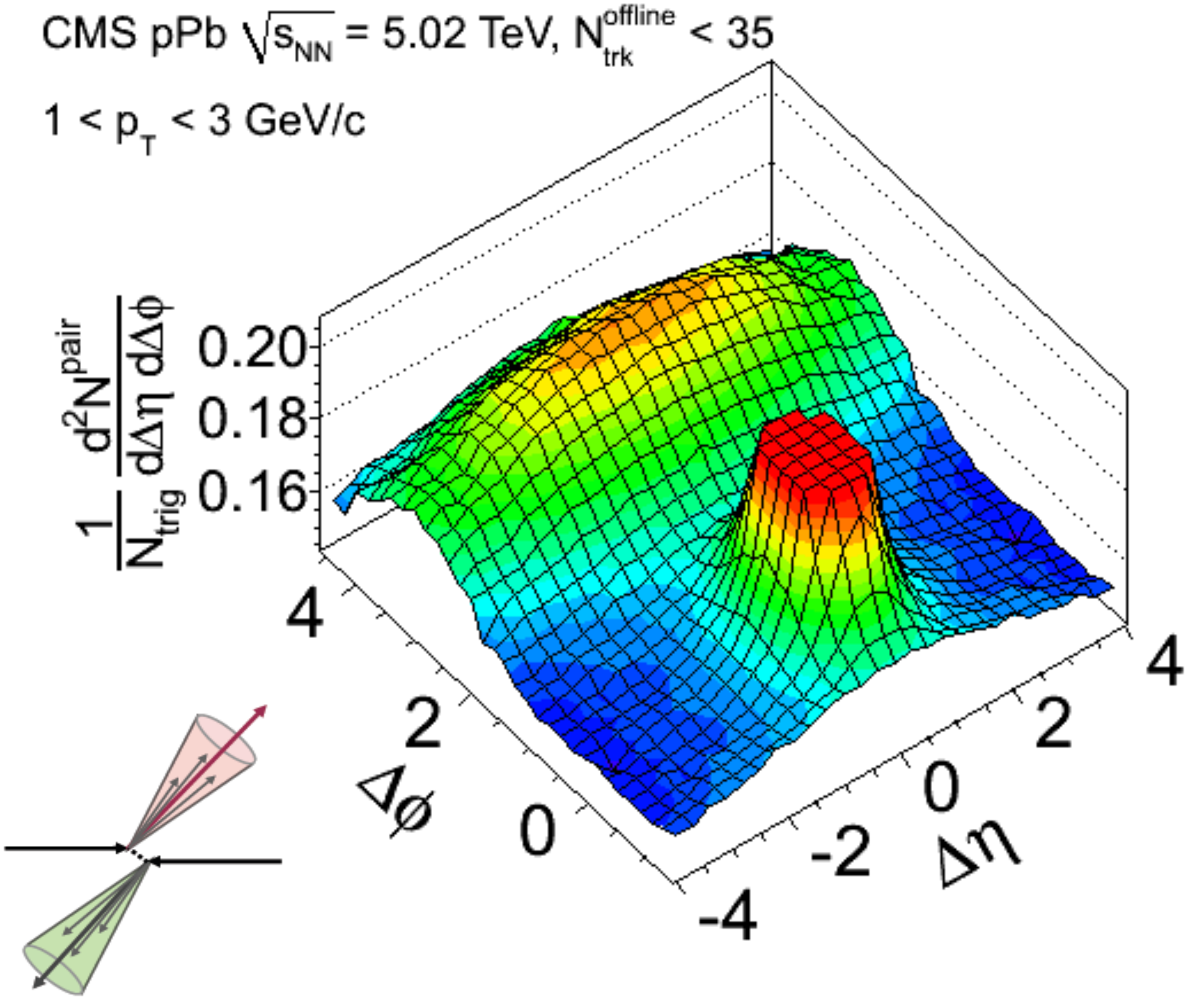
ATLAS (arXiv:1212.5198)

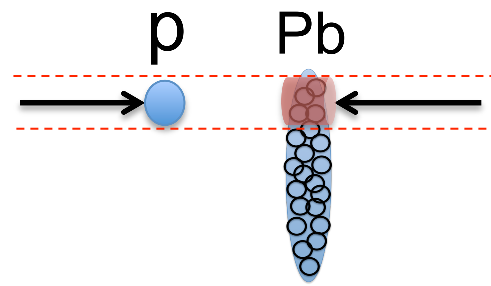


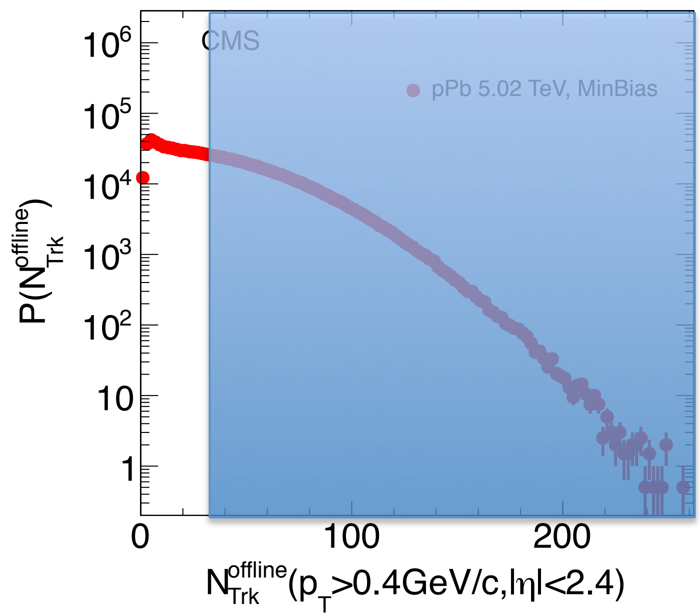
A significant near-side ridge in high multiplicity pPb!

First two-particle correlation result in pPb

$N_{trk}^{offline} < 35$





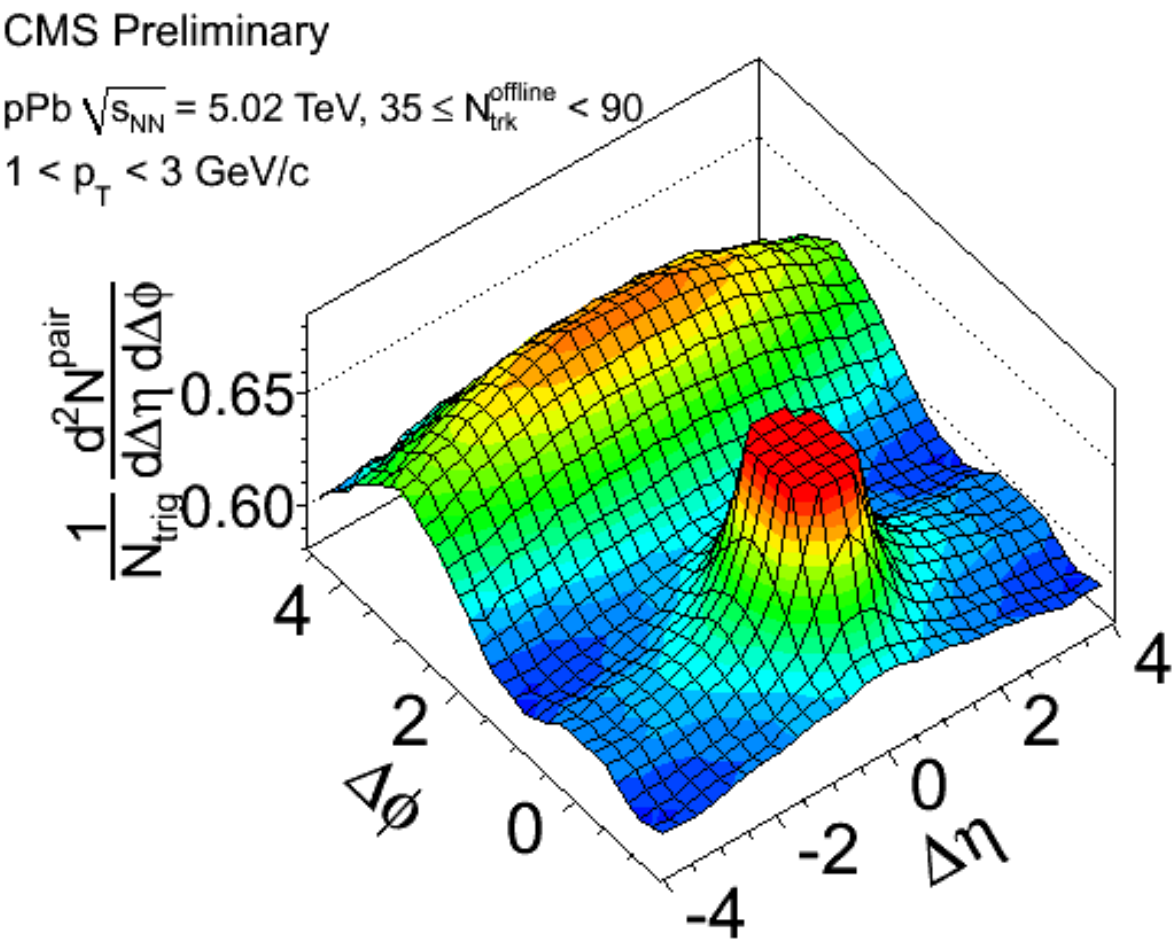


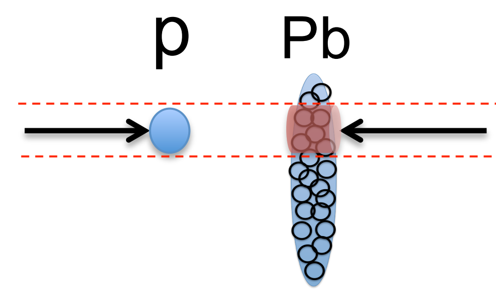
Fraction of cross section: **50.4%**

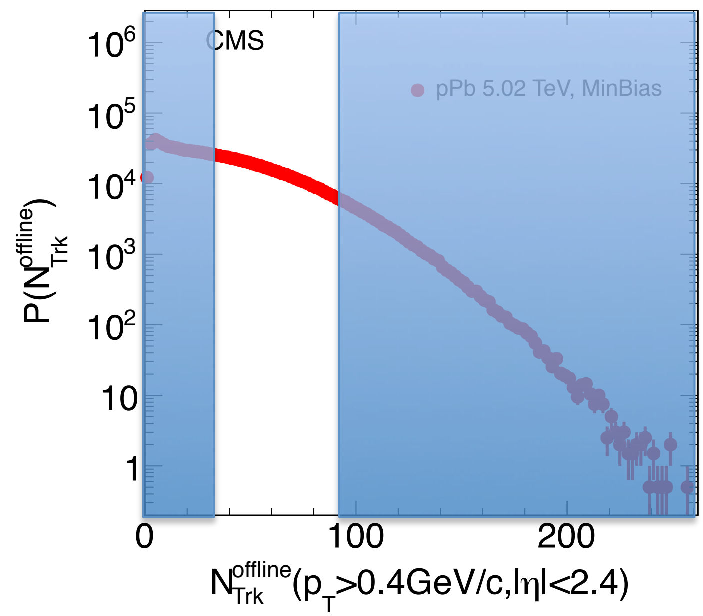
Dijet-like correlations in low multiplicity (or peripheral) pPb!

First two-particle correlation result in pPb

$35 \le N_{trk}^{offline} < 90$





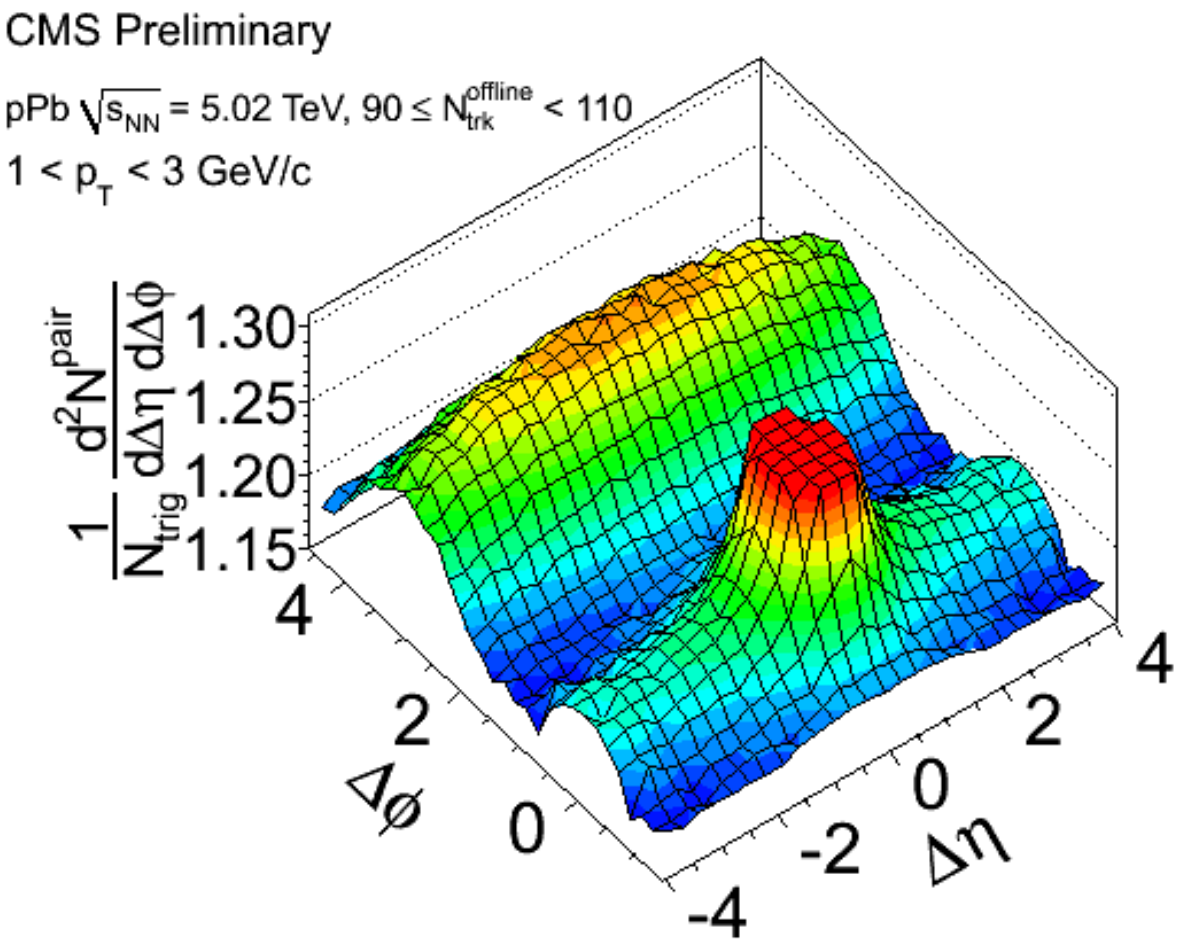


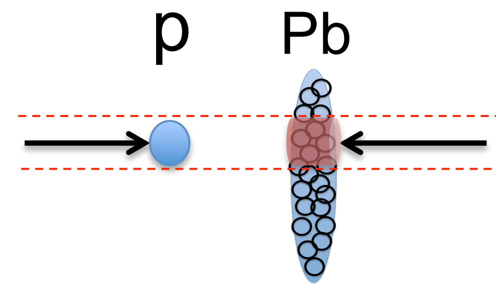
Fraction of cross section: **41.9%**

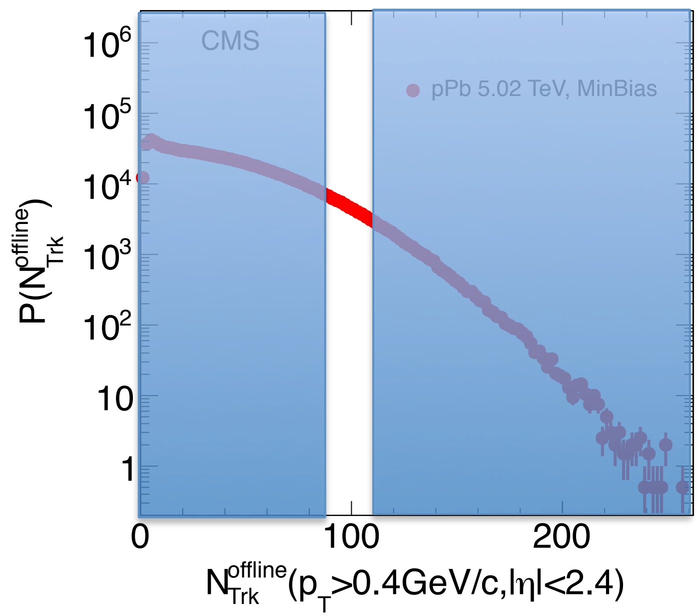
Near-side (Δφ~0) ridge structure turns on as multiplicity increases

First two-particle correlation result in pPb

$90 \leq N_{trk}^{offline} < 110$





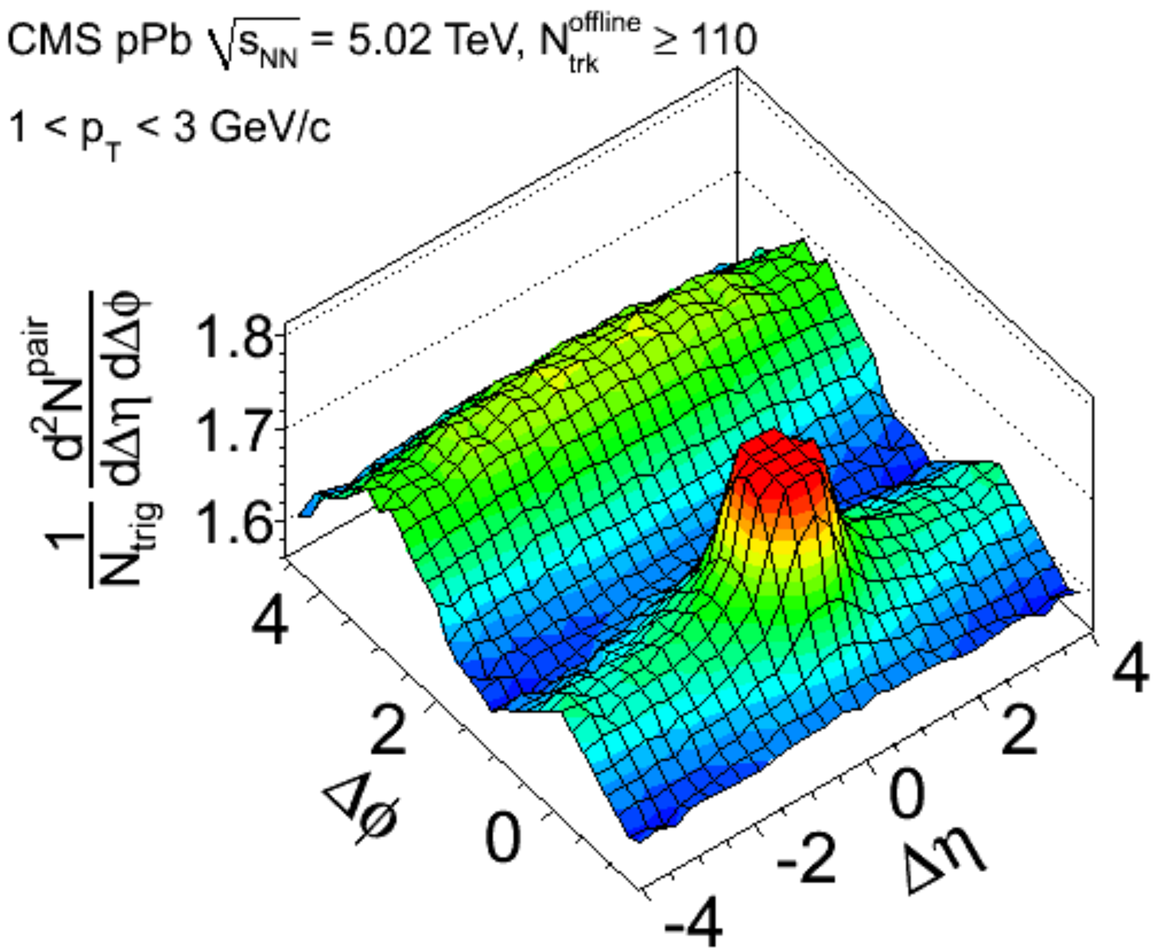


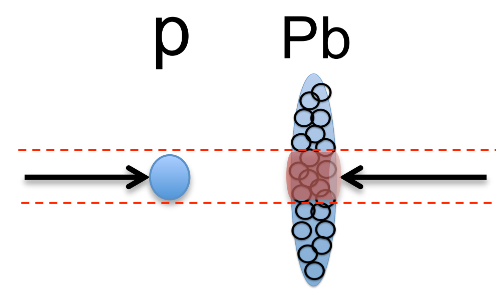
Fraction of cross section: **4.6%**

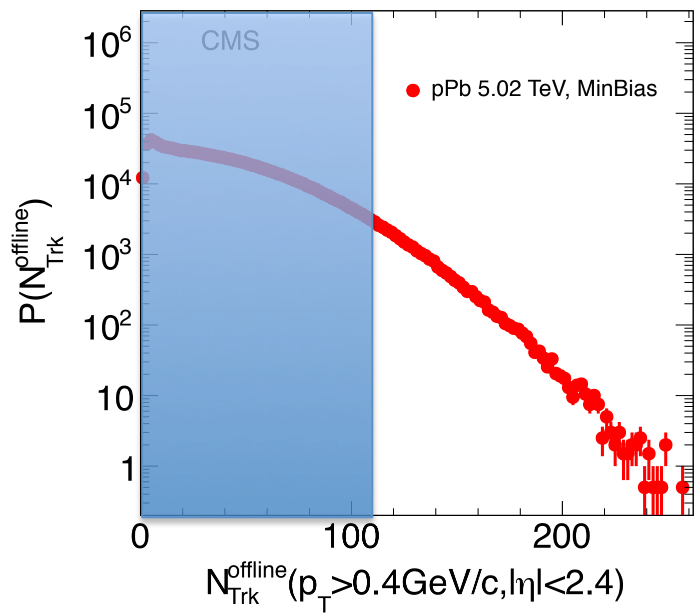
Near-side ($\Delta\phi$~0) ridge structure turns on as multiplicity increases

First two-particle correlation result in pPb

$N_{trk}^{offline} \geq 110$





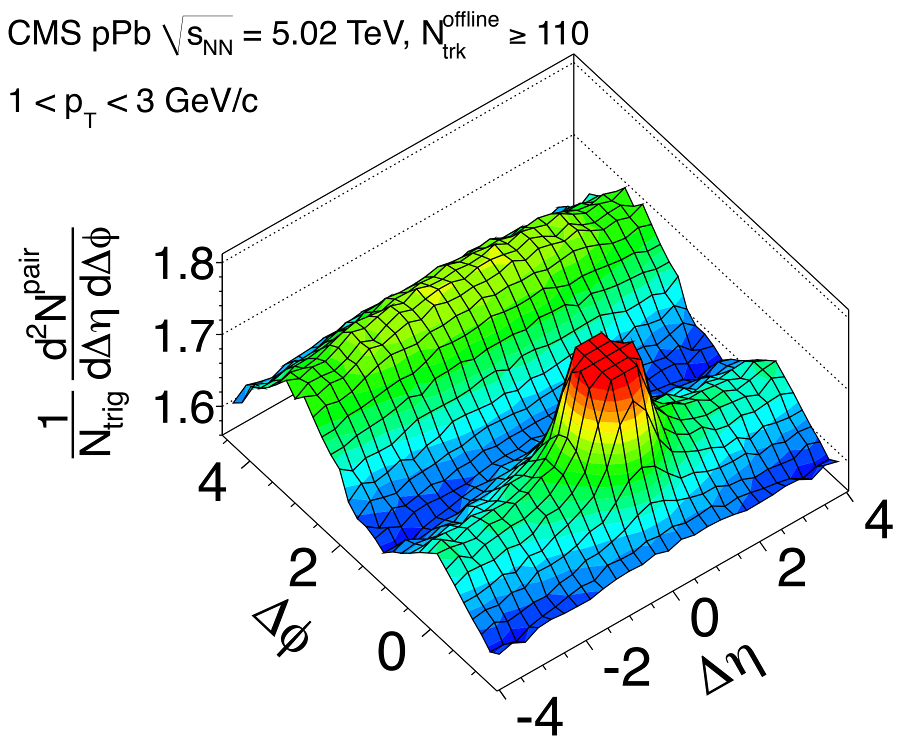


Fraction of cross section: **3.1%**

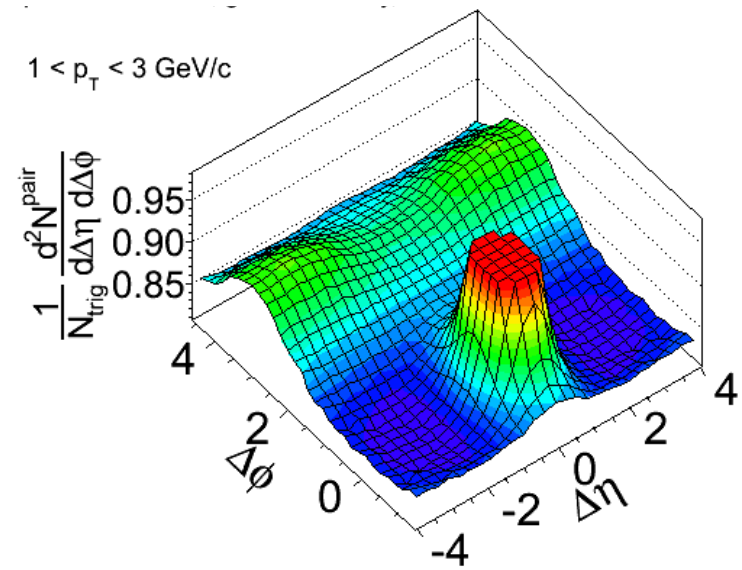
Near-side (Δϕ~0) ridge structure turns on as multiplicity increases

No ridge in pPb MC models

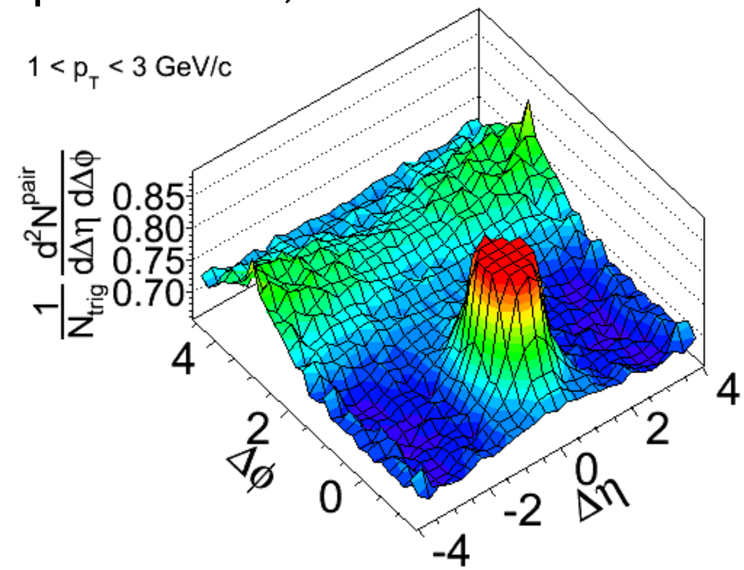
pPb data



pPb HIJING, N>120



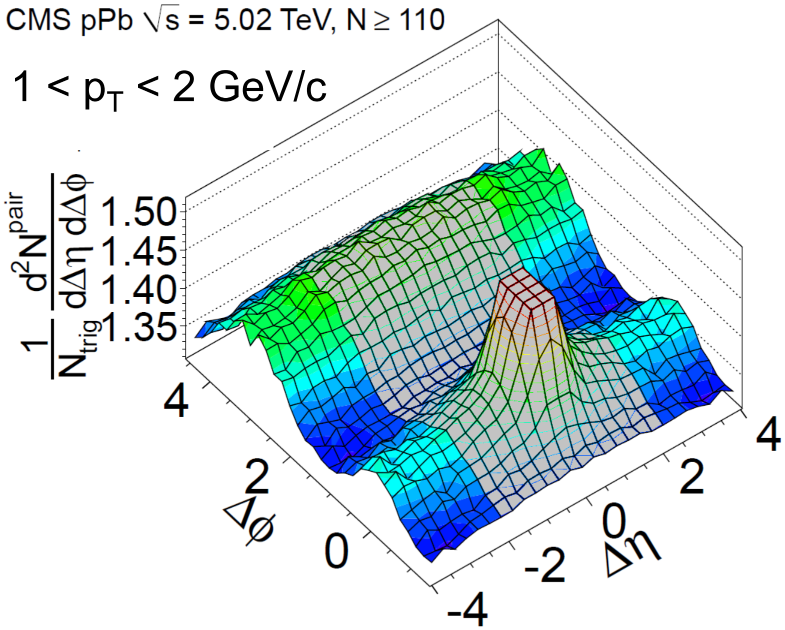
pPb AMPT, N>100



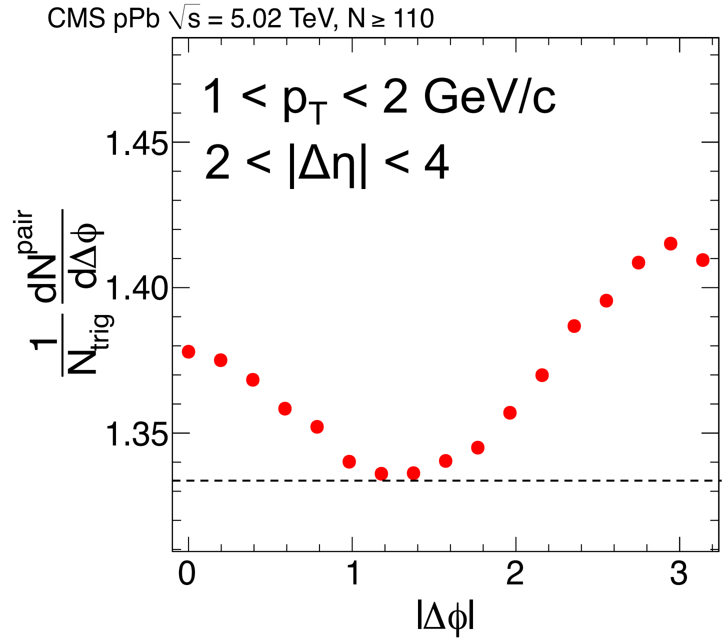
Ridge is not predicted by common pPb MC event generators, as in pp!

AMPT shows the ridge in AA collisions

Quantify the ridge correlations



Average over ridge region (2<|Δη|<4)



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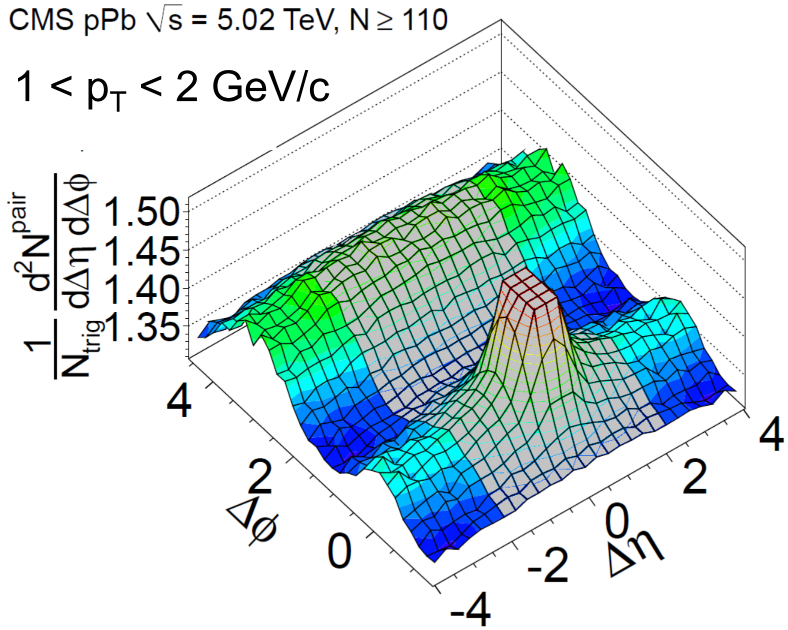

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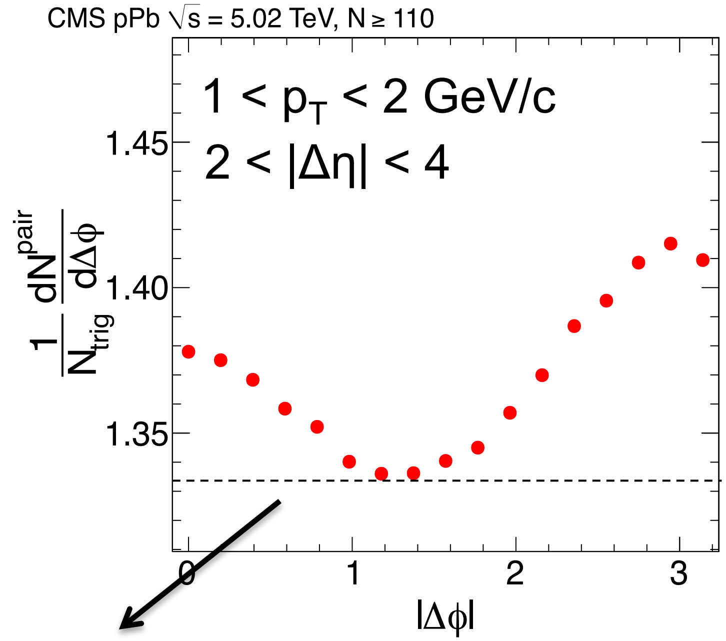
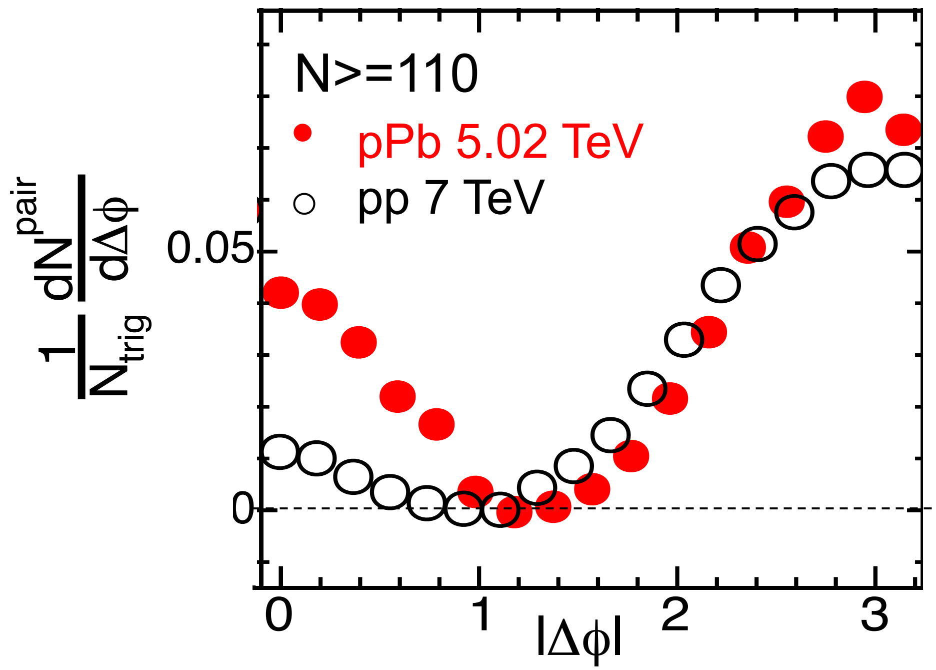


Shift the distribution to Zero Yield At Minimum (ZYAM)



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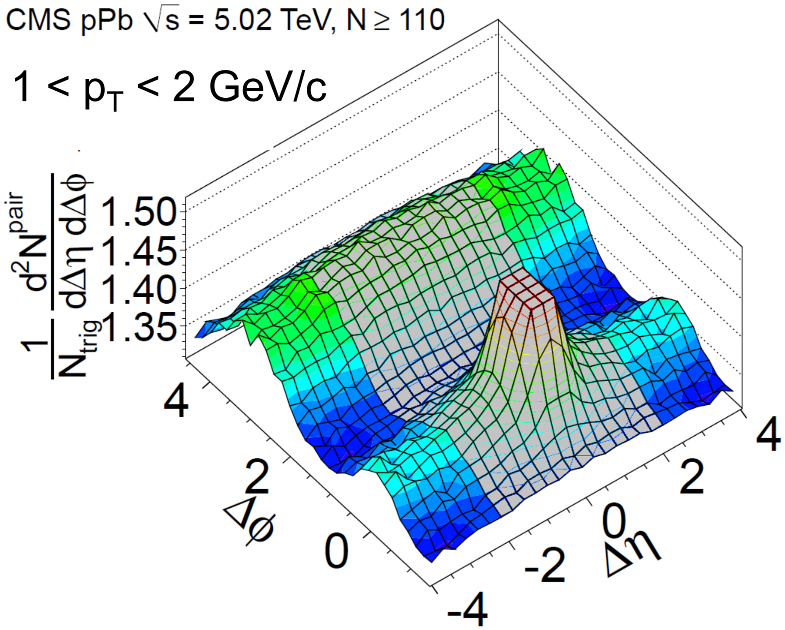

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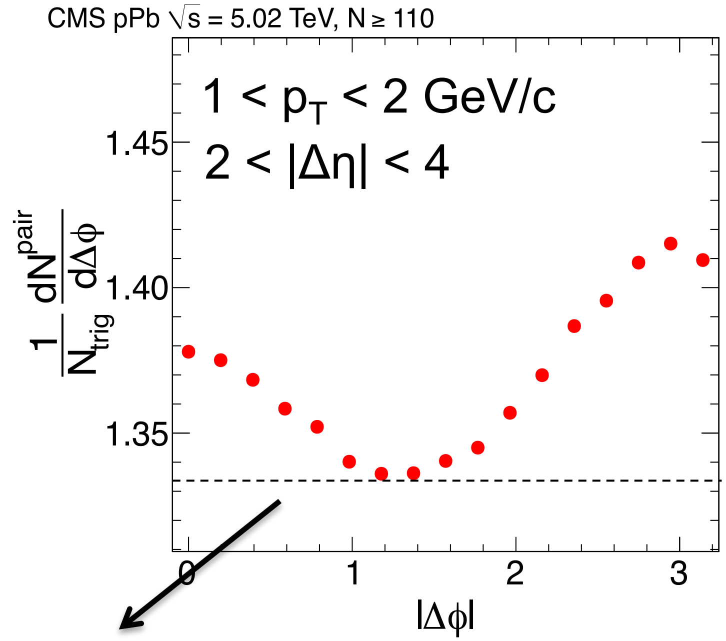

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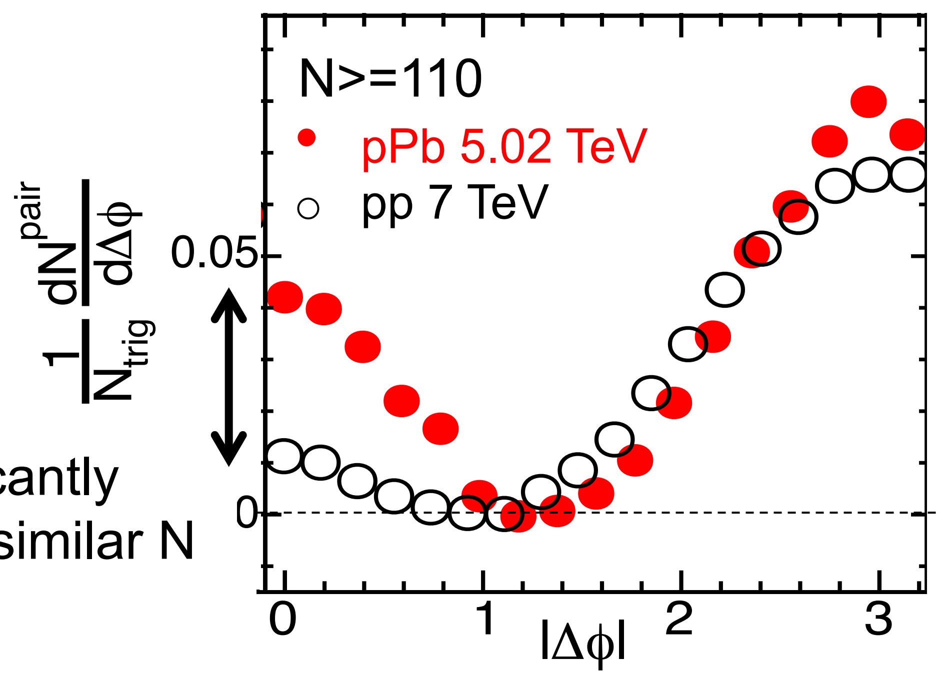
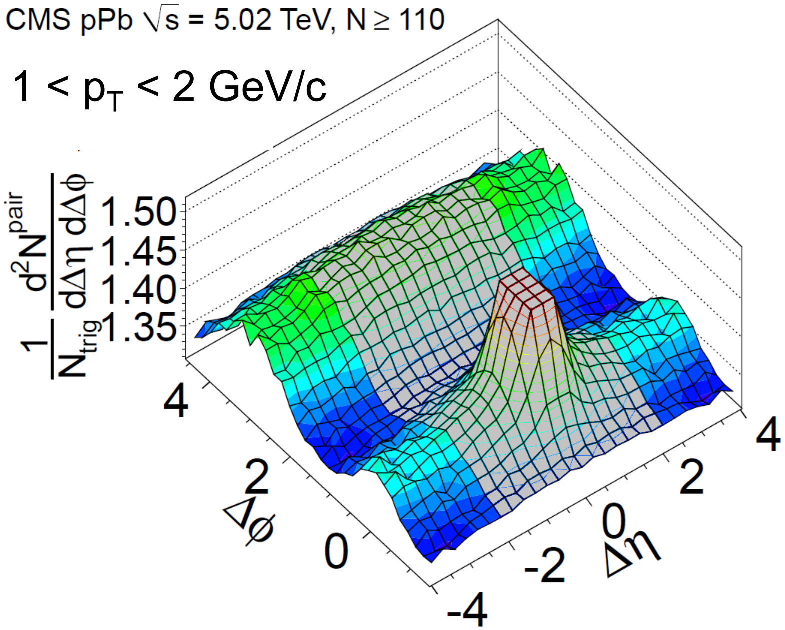


Ridge in pPb is significantly stronger than in pp at similar N

Quantify the ridge correlations



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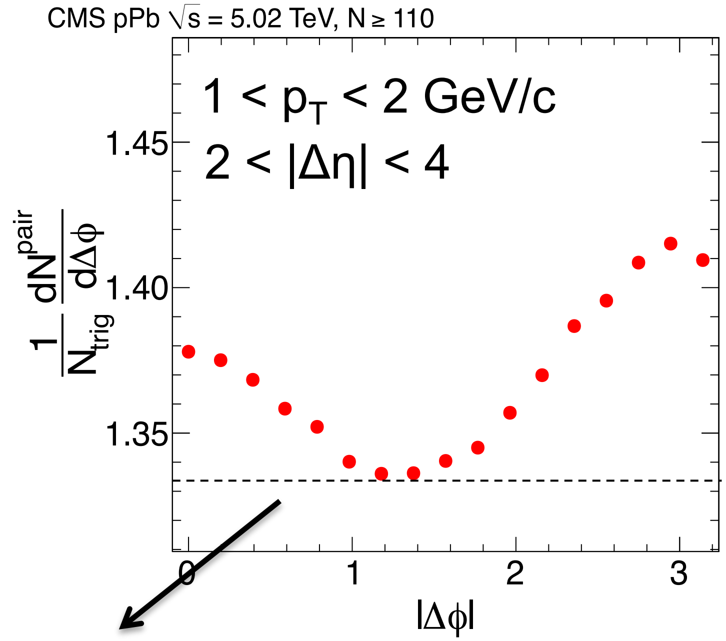

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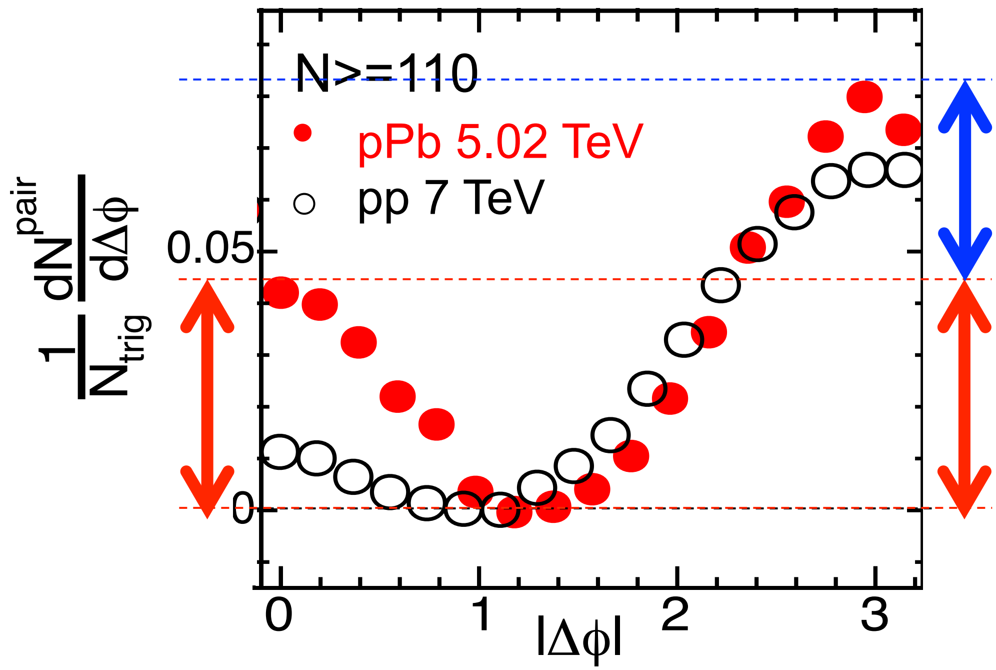

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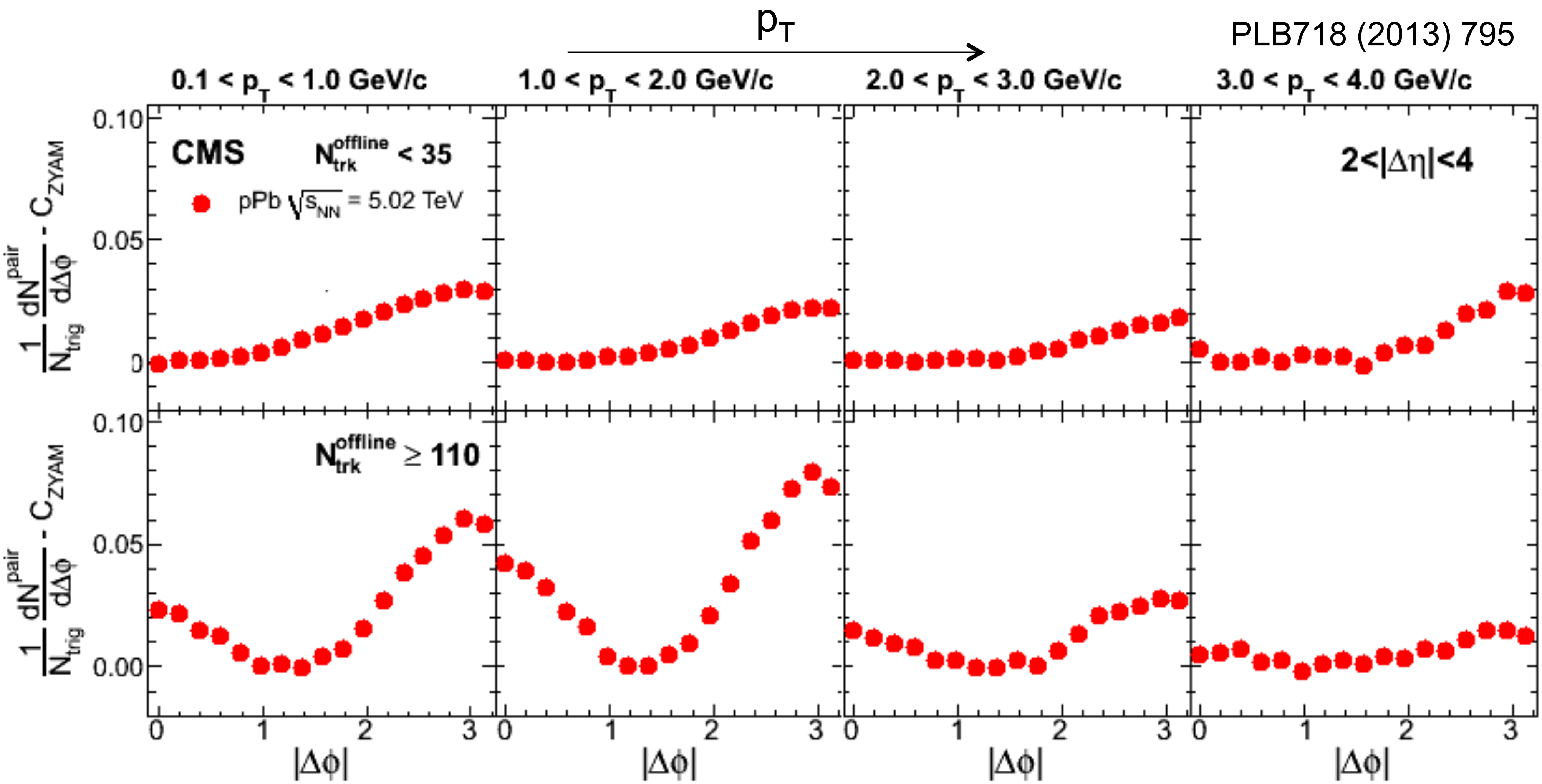

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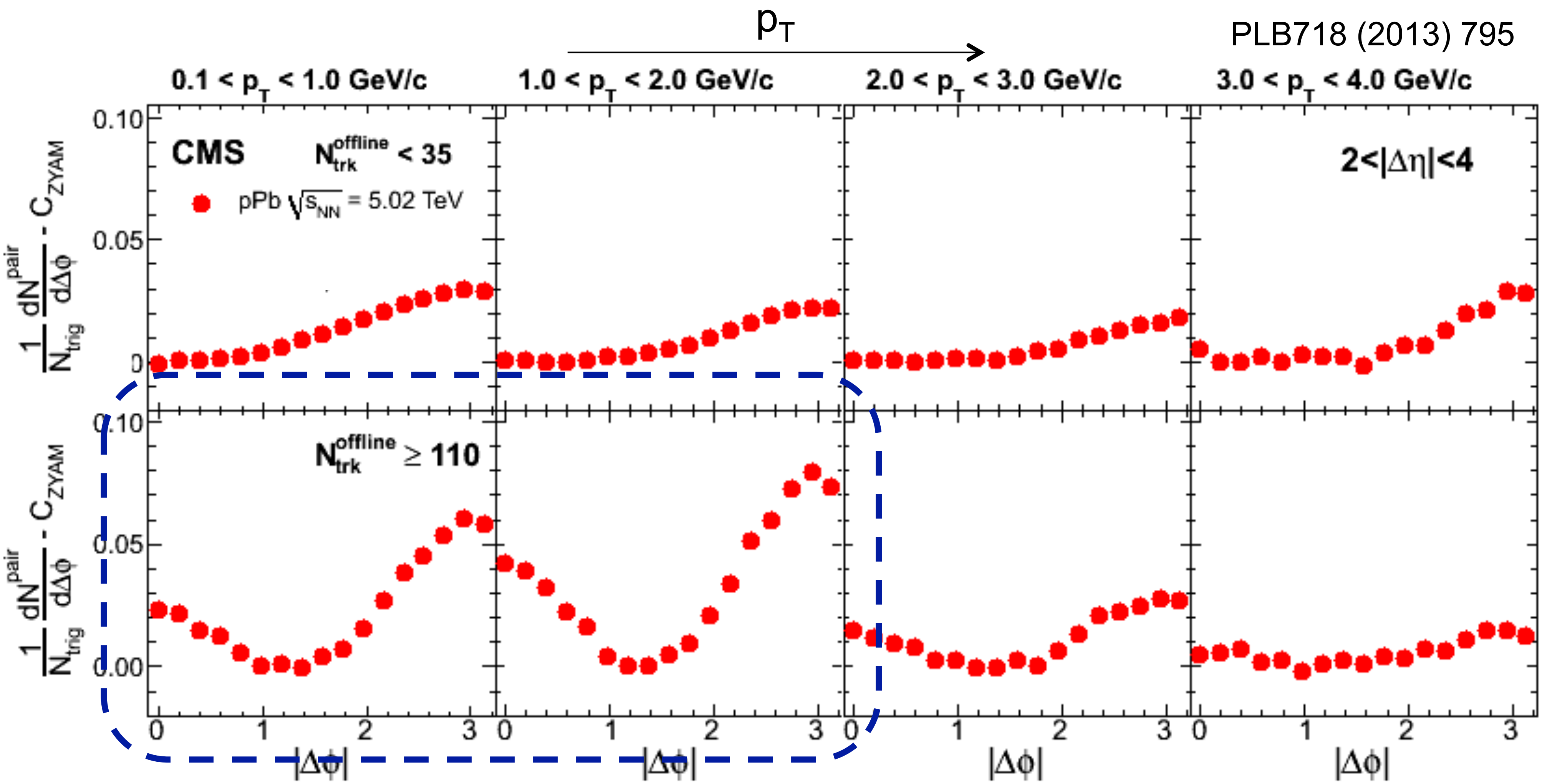
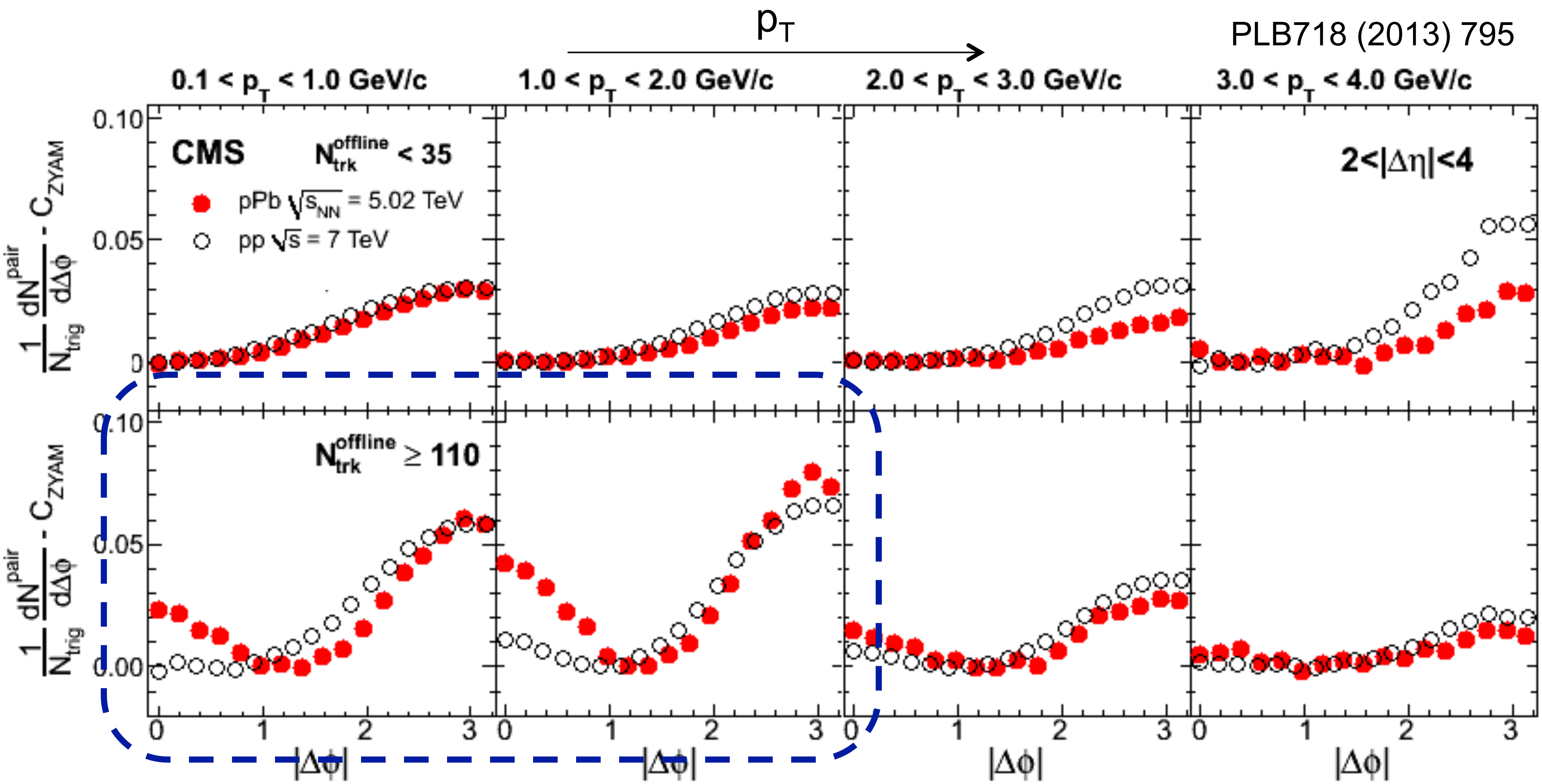


Ridge most prominently at:

- ➢ high multiplicity, N >= 110
- ➢ intermediate p_T ~ 1 GeV/c

Quantify the ridge correlations



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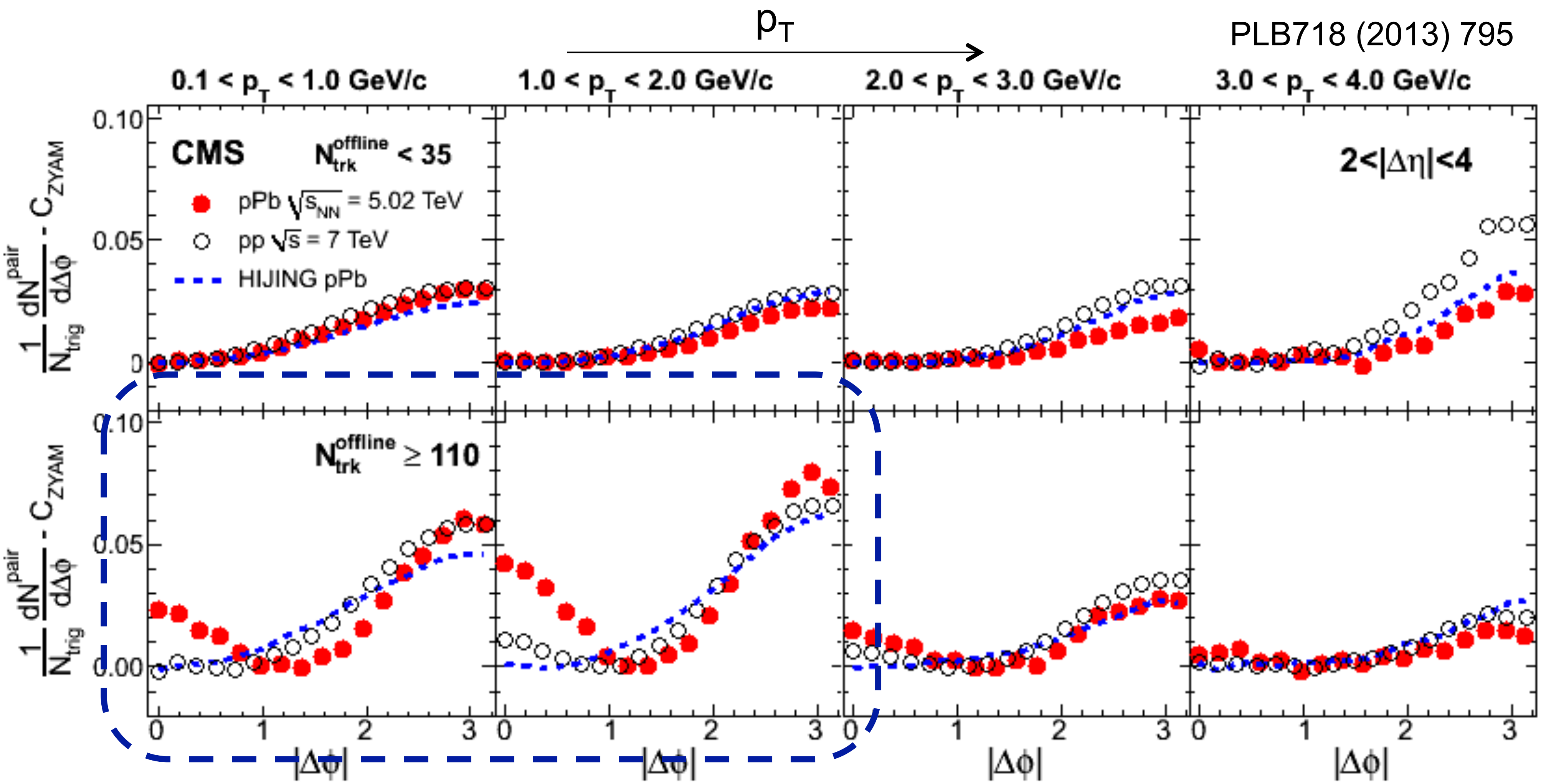
Stronger ridge in pPb than in pp at similar N!

Quantify the ridge correlations



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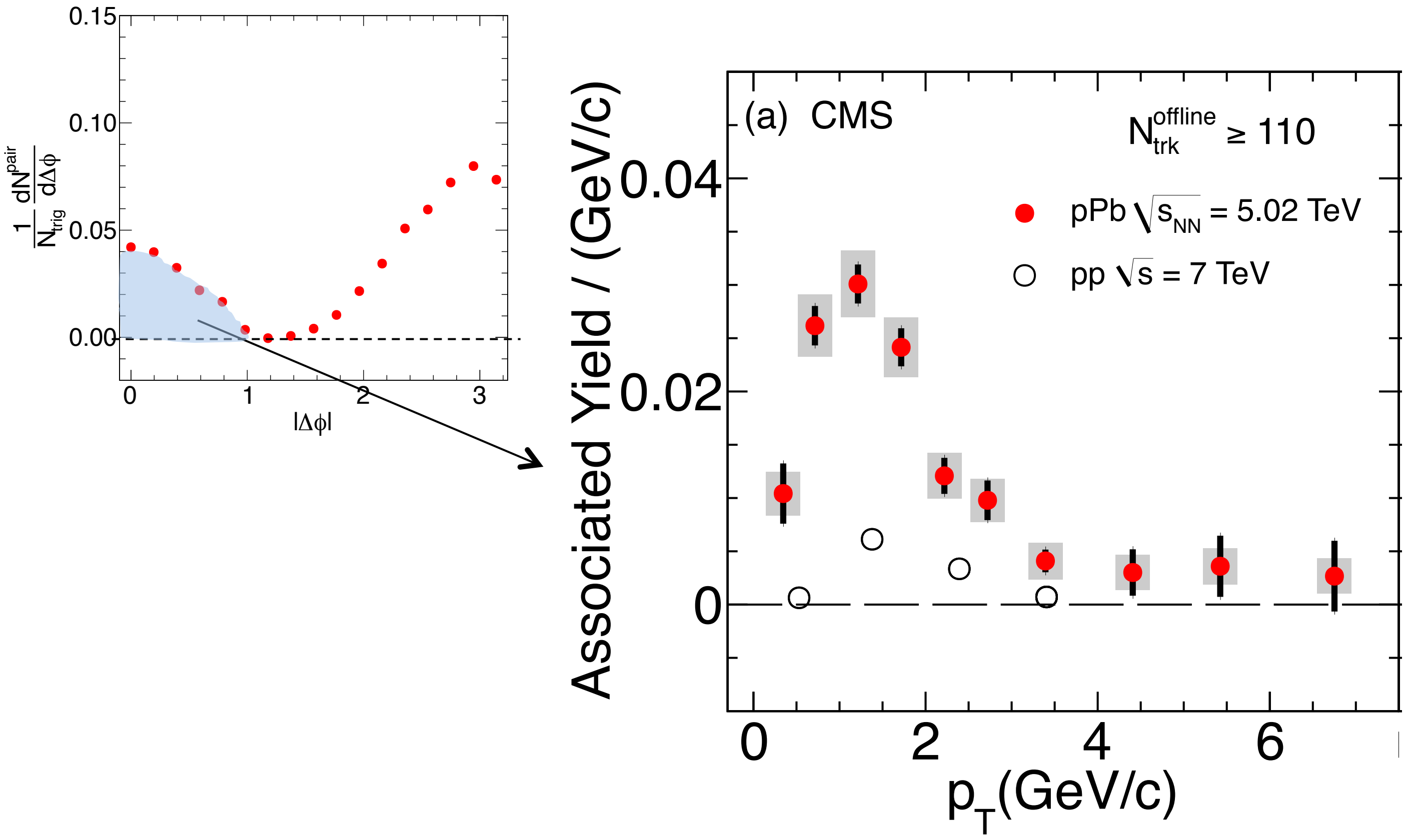
HIJING does not show any near-side ridge in all bins

Quantify the ridge correlations

Quantify the ridge

p_T and multiplicity dependence of ridge yield

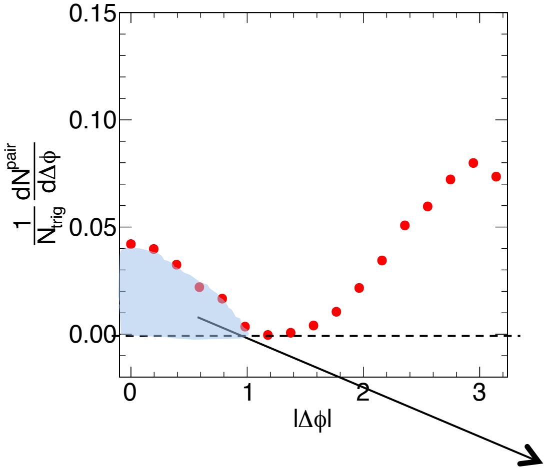
PLB718 (2013) 795



➢ "Rise and Fall" as a function of p_T, similar to pp (even PbPb)!

Quantify the ridge correlations

Quantify the ridge



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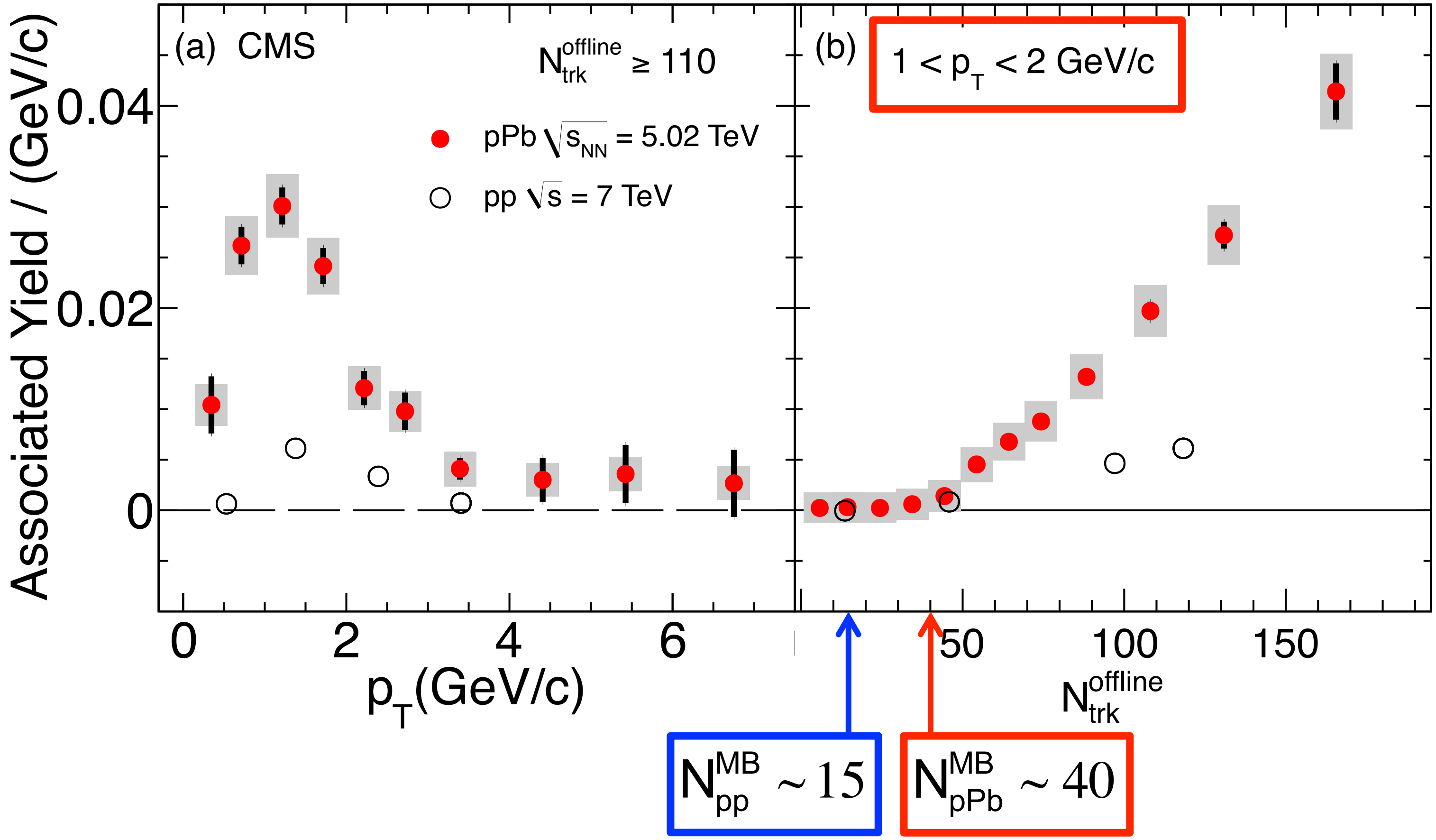
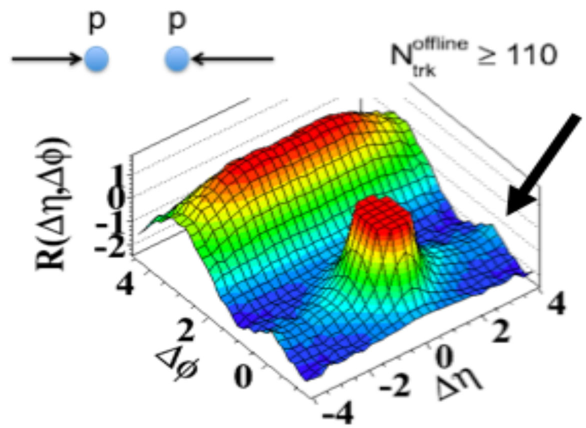
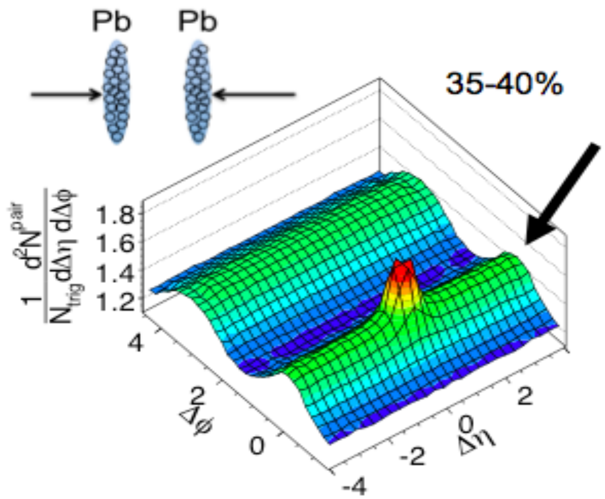
PLB718 (2013) 795

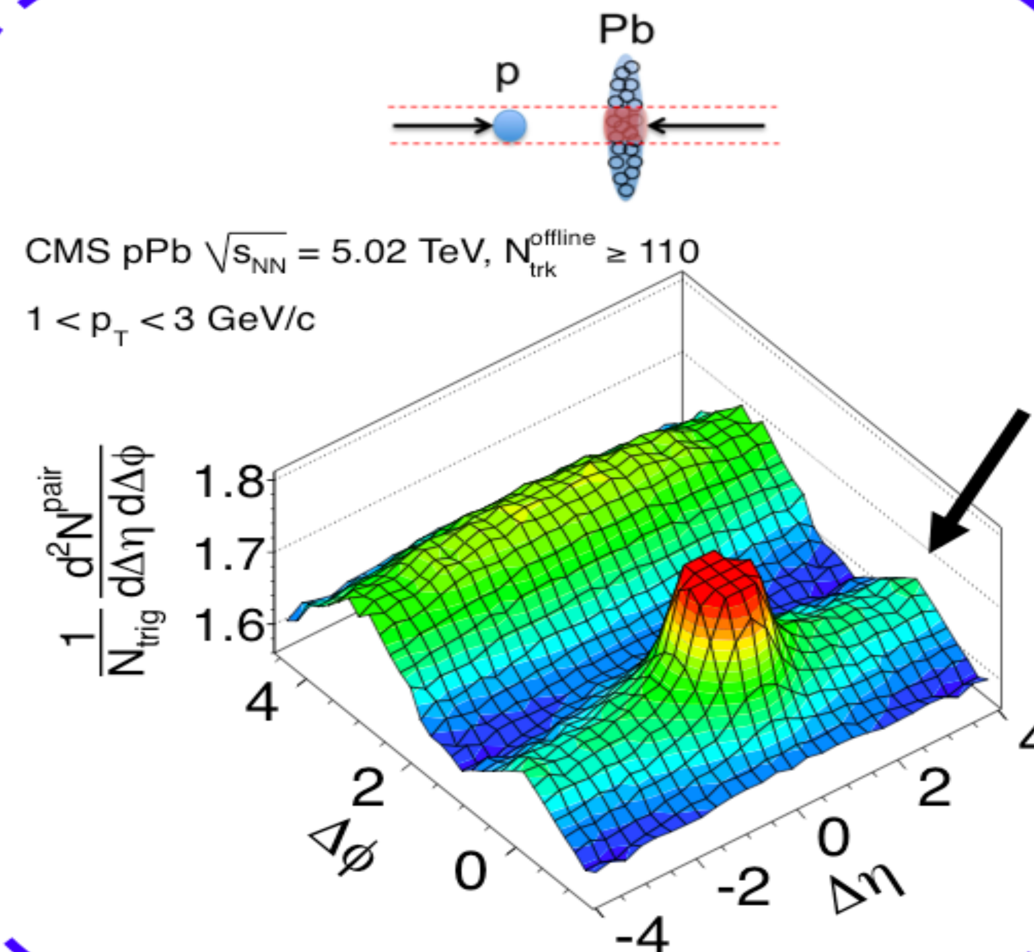


- "Rise and Fall" as a function of p_T, similar to pp (even PbPb)!
- Become significant at N ~ 40 and linearly increases, similar to pp!

A complete picture of ridge correlations







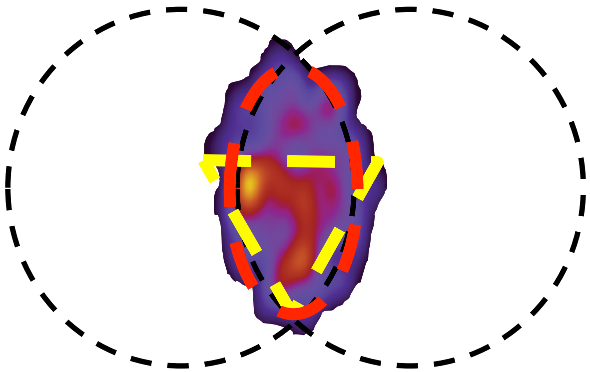
Is there a common origin of the ridge in all systems?

- Flow-like effect similar to PbPb? Final-state effect seen in pPb?
- Other QCD mechanisms in smaller systems?

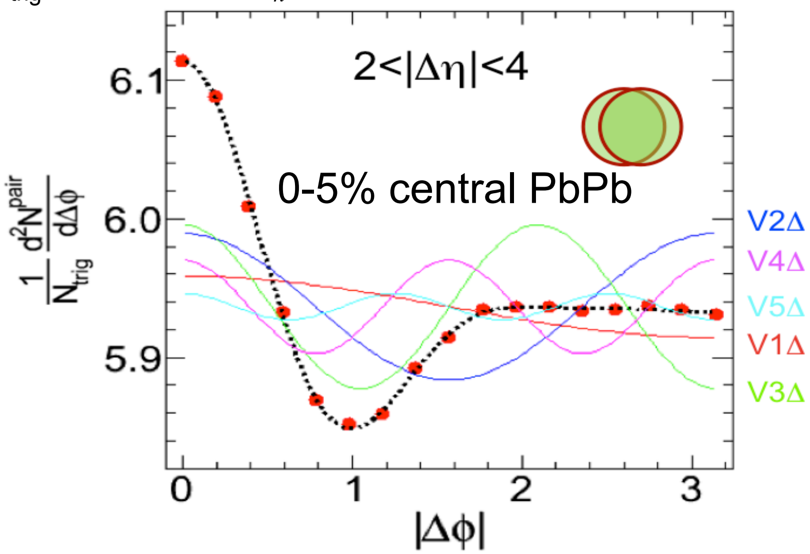
Understanding the origin of ridge

Hydrodynamics/final-state interactions

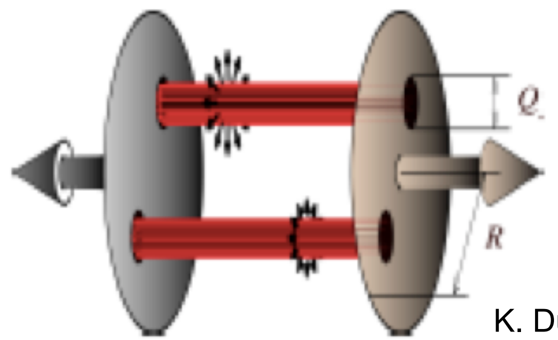
Initial-state asymmetry



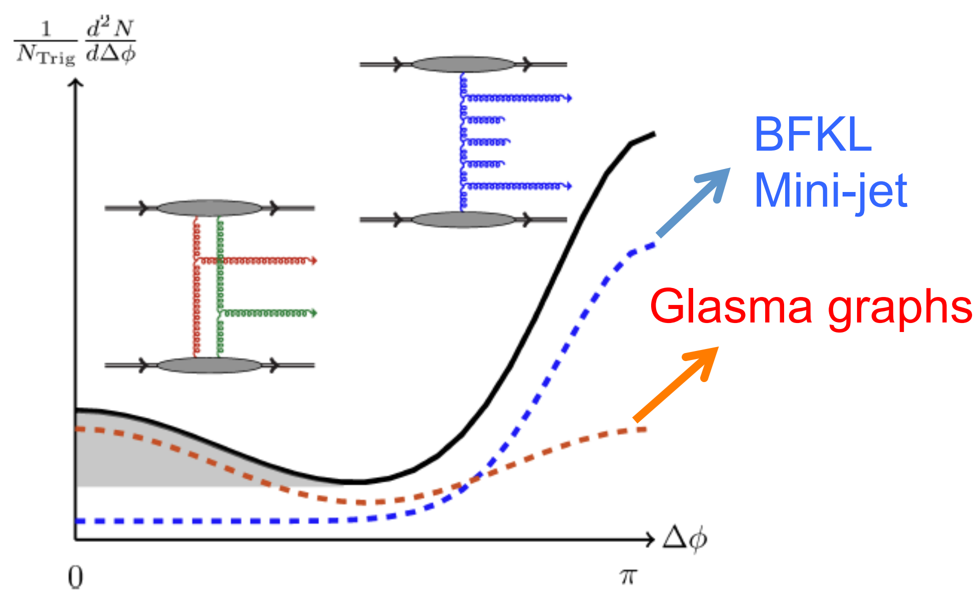
$$\frac{1}{N_{trig}}\frac{dN^{pair}}{d\Delta\phi} \sim 1 + 2\sum_n (v_n)^2 \cos(n\Delta\phi)$$



Intrinsic collimated gluon emission from glasma diagram (CGC)



K. Dusling, R. Venugopalan: arXiv:1210.3890



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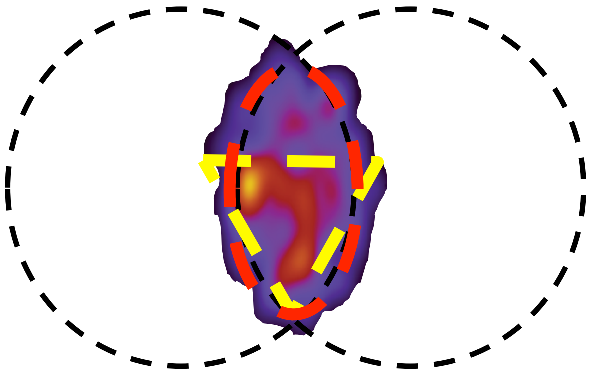

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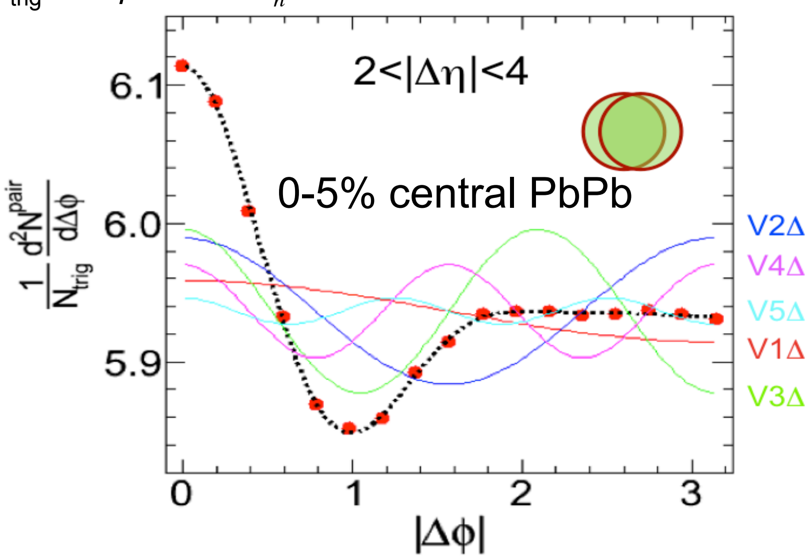

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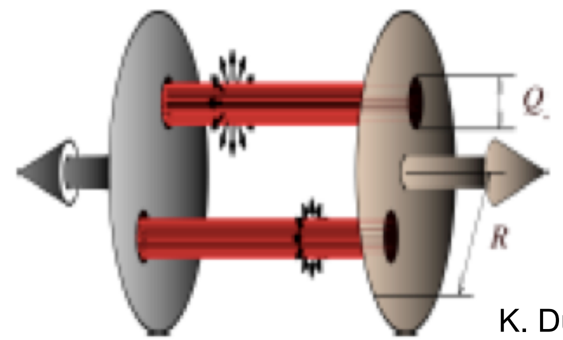

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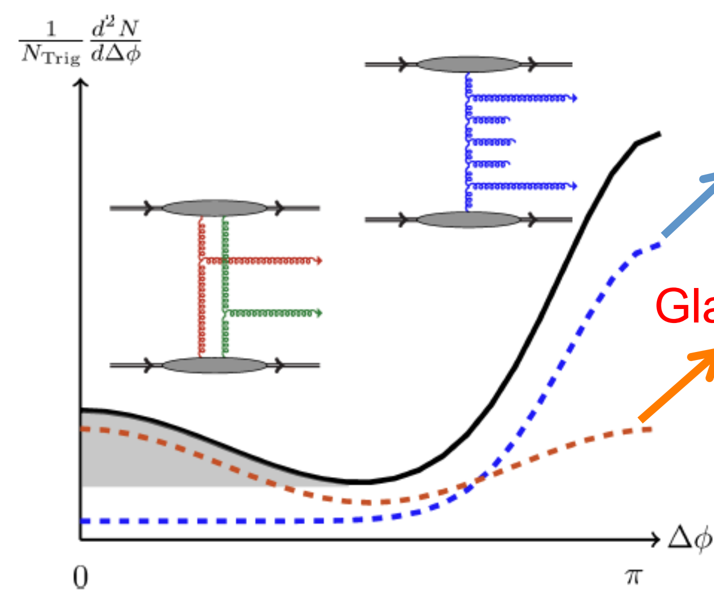
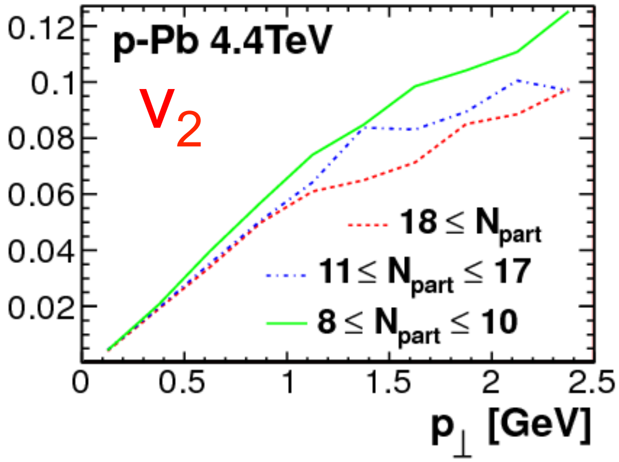


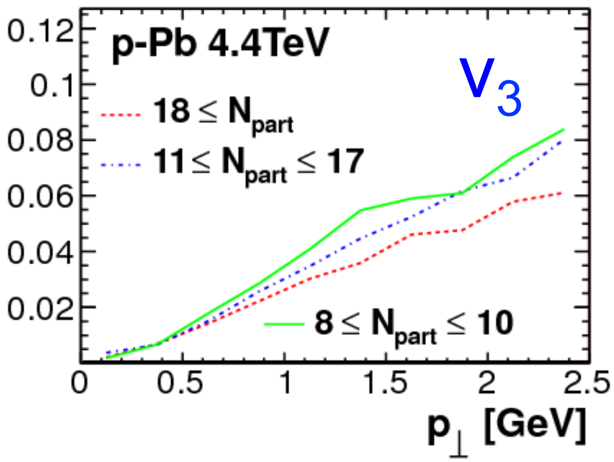
Key difference: initial-state "geometry" driven or not!

Hydrodynamics in pp and pA?

Viscous hydro calculation in pPb

P. Bozek, Phys.Rev. C85 (2012) 014911





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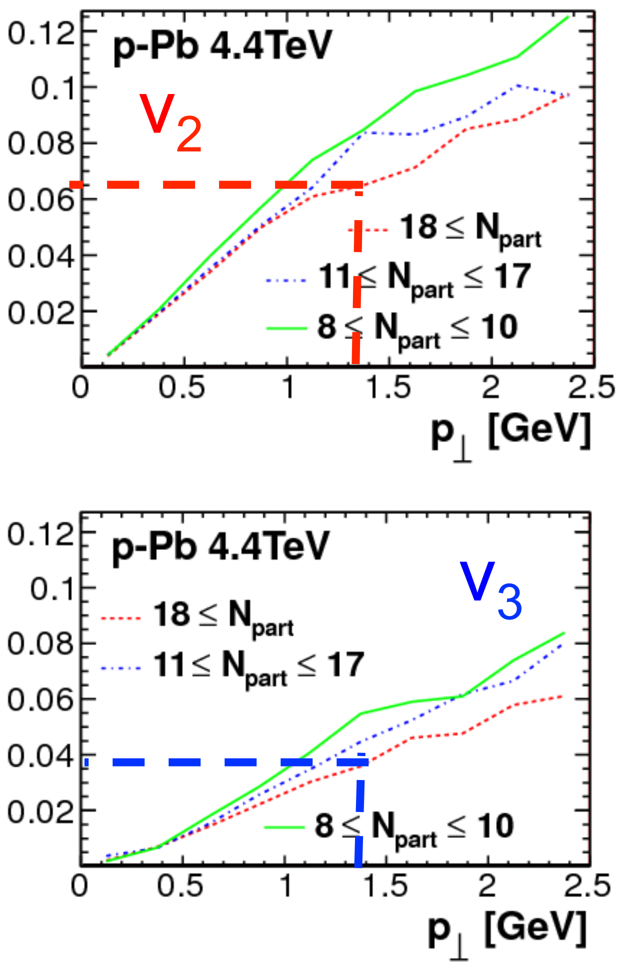

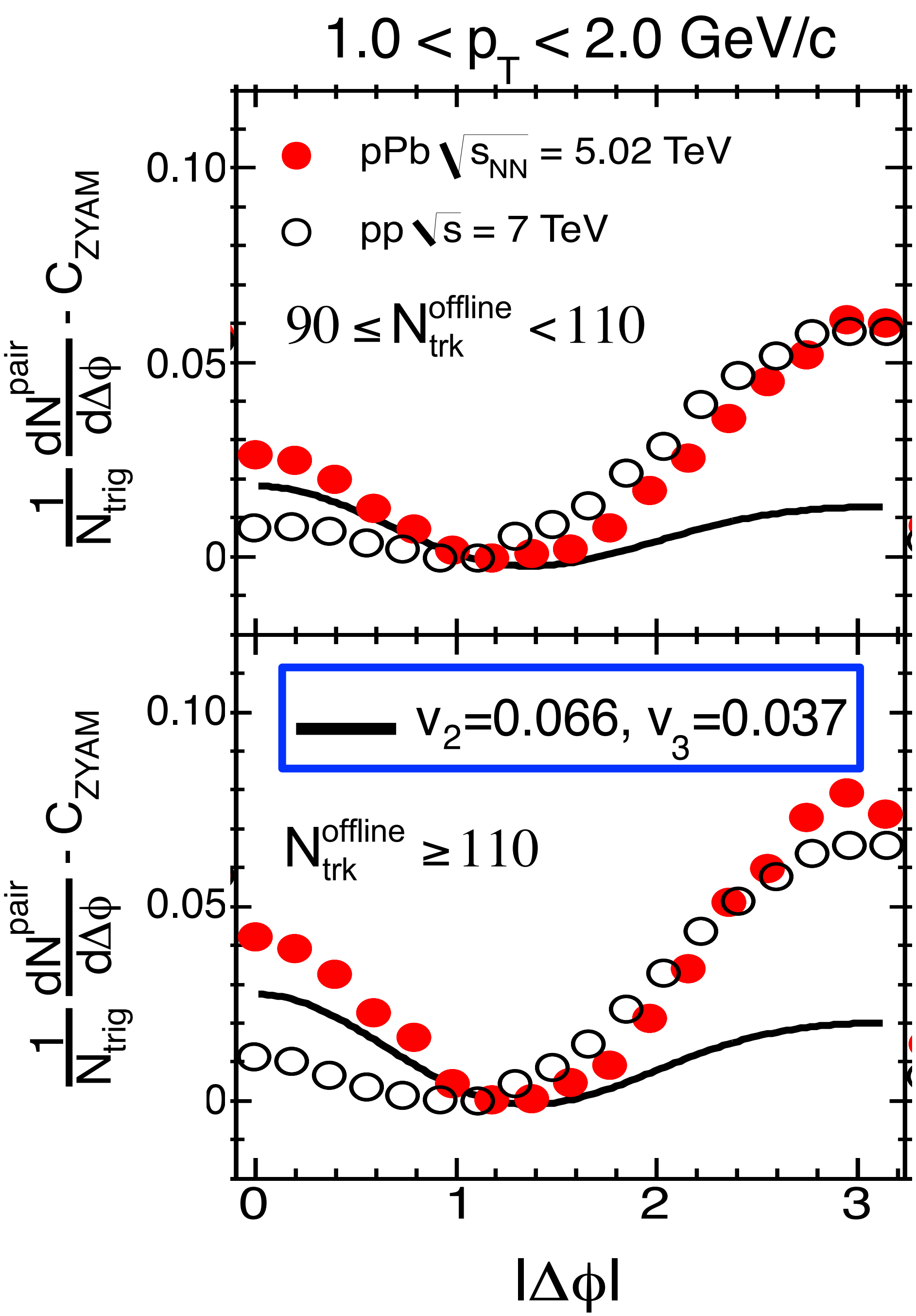

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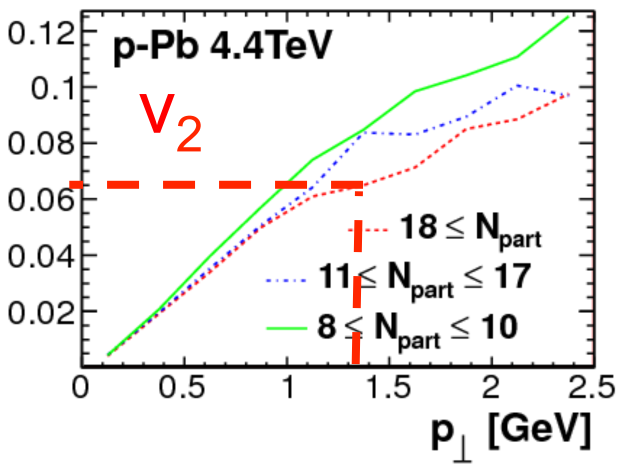
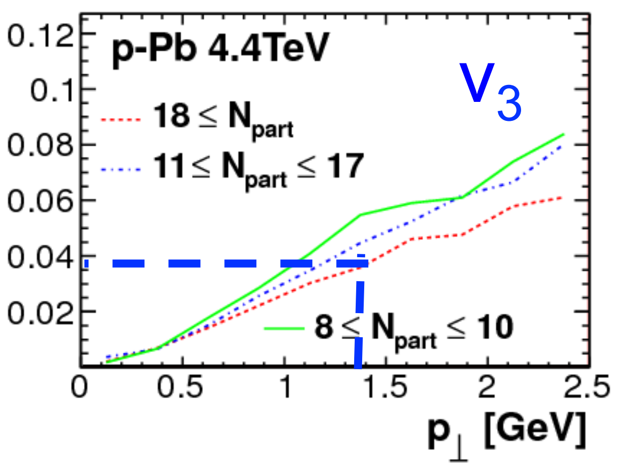
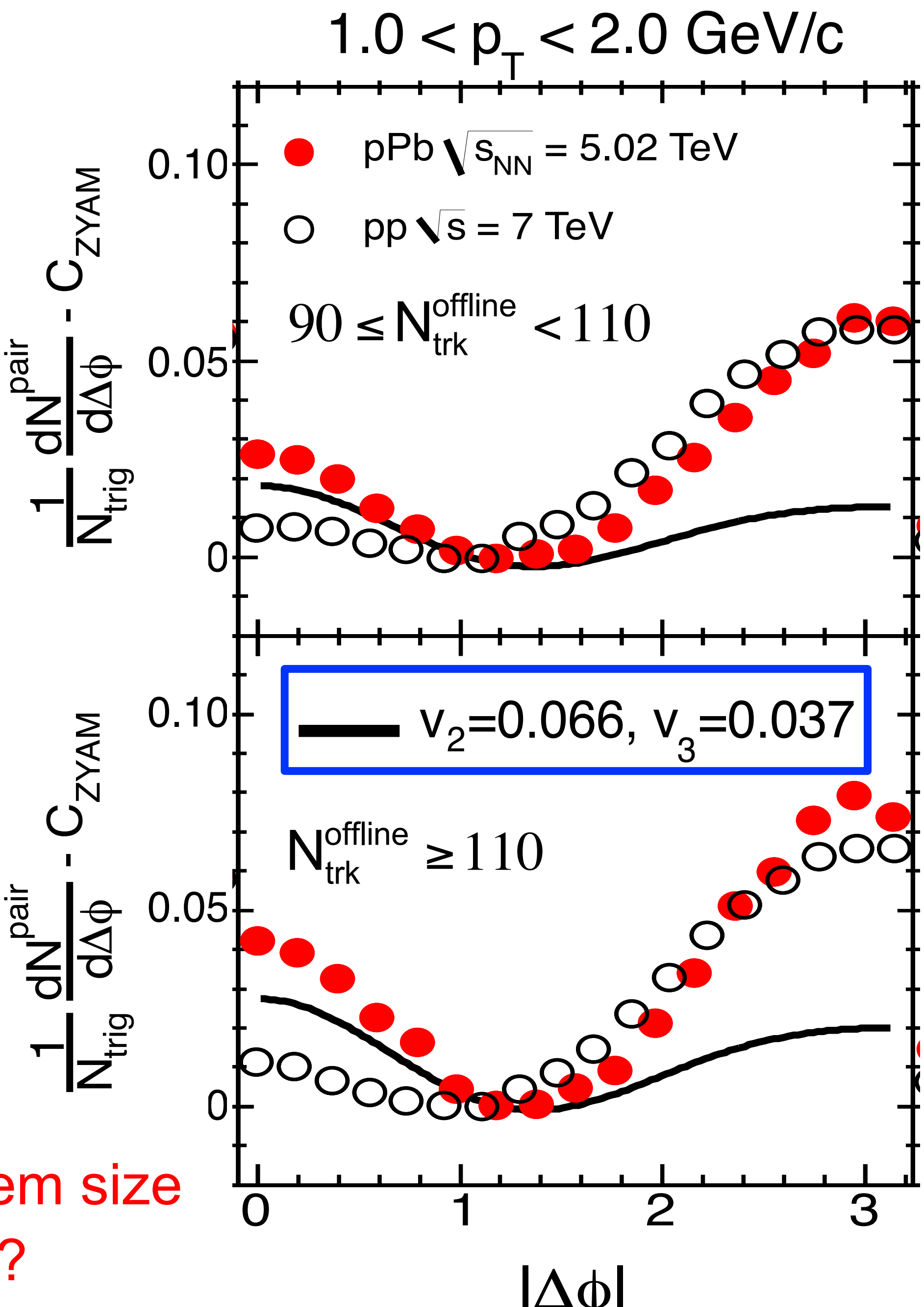






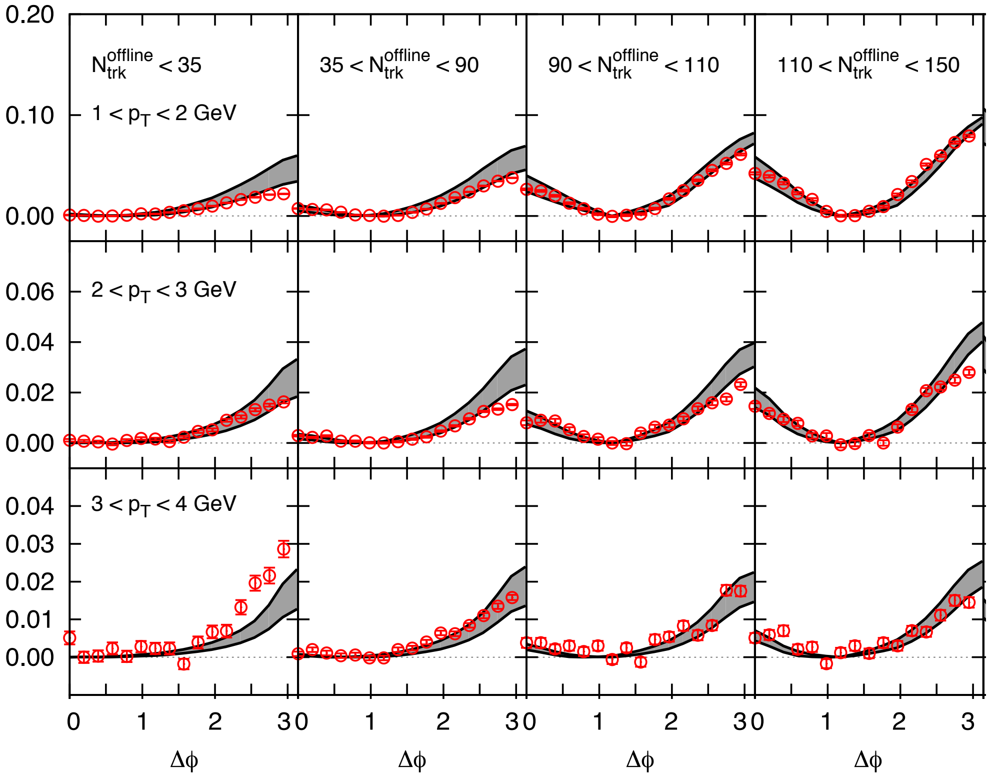
Is hydro still valid for such small system size and lifetime? Where is the limit?

Ridge arising from gluon saturation

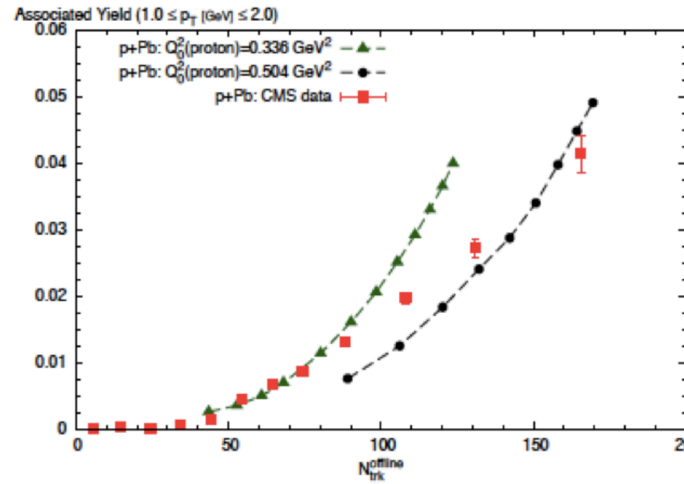
Calculations of ridge in pp and pPb from glasma mechanism

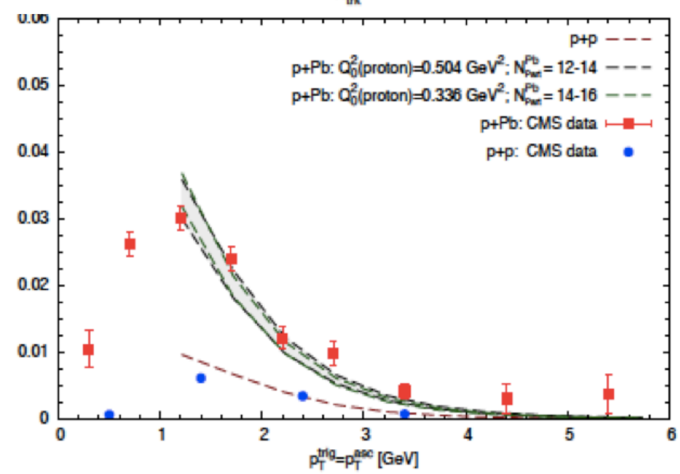
K. Dusling, R. Venugopalan: arXiv:1211.3701

Correlation functions



Integrated associated yield



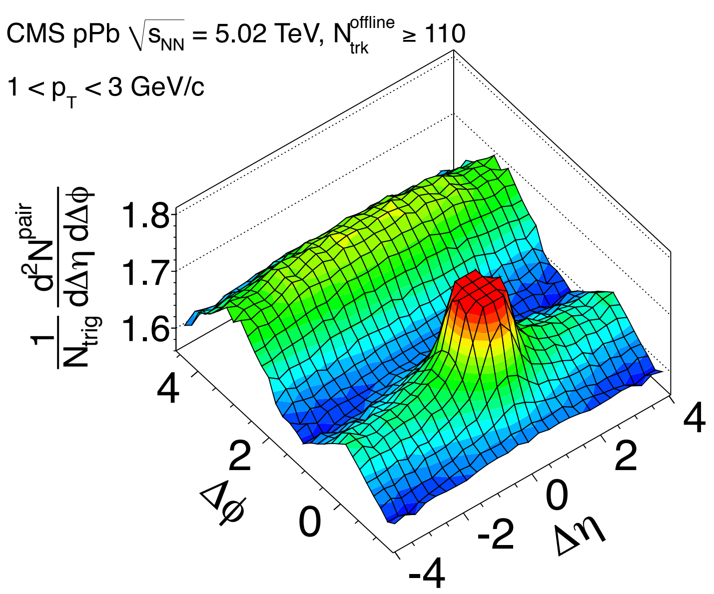


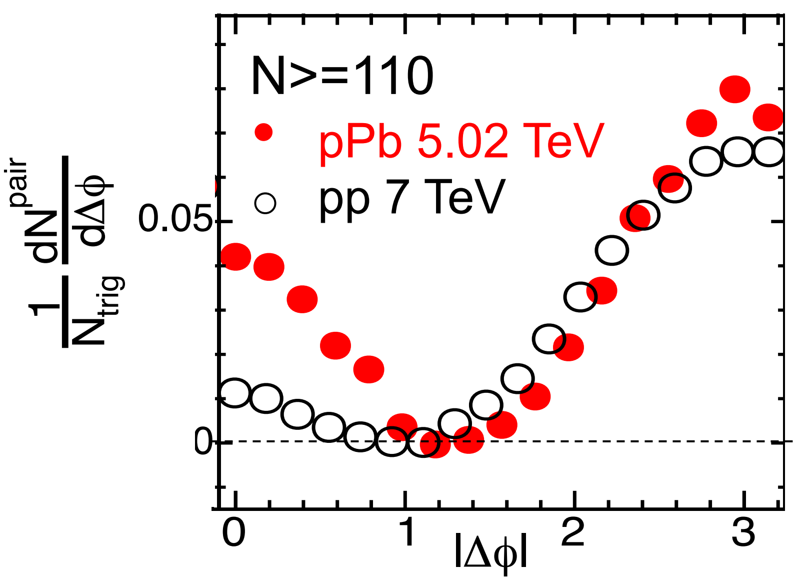
- Good description of the data
- No need of asymmetric initial geometry

Need qualitatively different predictions from two scenarios!

Summary

- First observation of a long-range near-side correlation ("ridge") in high multiplicity (central) pPb collisions at 5.02 TeV
  - much stronger than in pp
  - not in common pPb MC models
- Multiplicity and p_T dependence of the ridge in pPb have been investigated in detail:
  - turns on slightly above average MB multiplicity
  - rises and falls with p_T, similar trend as observed in PbPb and pp





Outlook

- Observation of the ridge in pp and pPb opens up a new testing ground of high-density, strongly interacting QCD system
  - Probing proton structure at very early timescale
  - Final-state effect also seen in pA?
  - Smoking gun of gluon saturation?

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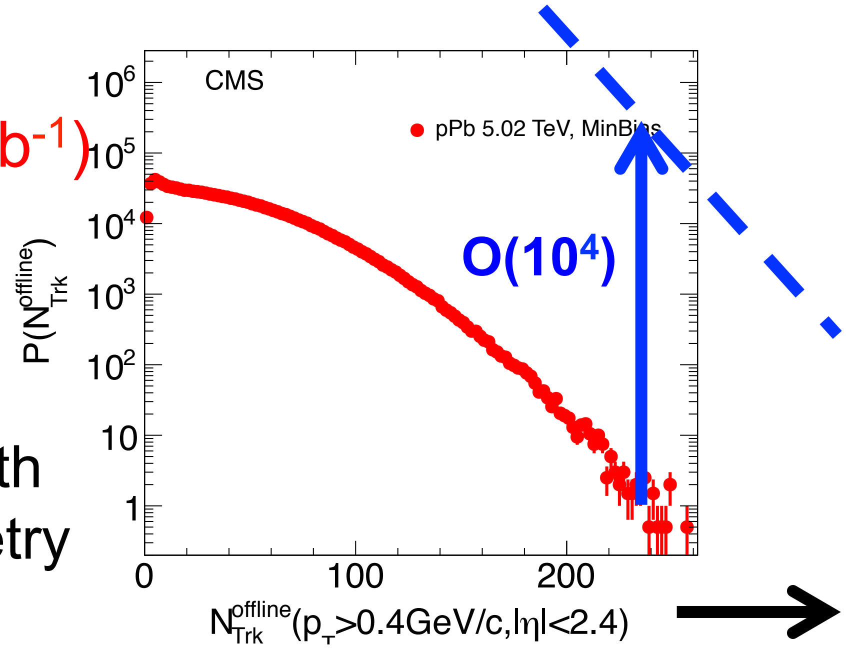
- 30,000-fold increase in luminosity (30 nb^{-1}) is expected in the nominal pPb run
  - Much wider reach in multiplicity
  - Access to a variety of observables
  - Direct comparison of pp, pPb, PbPb with drastically different system size, geometry



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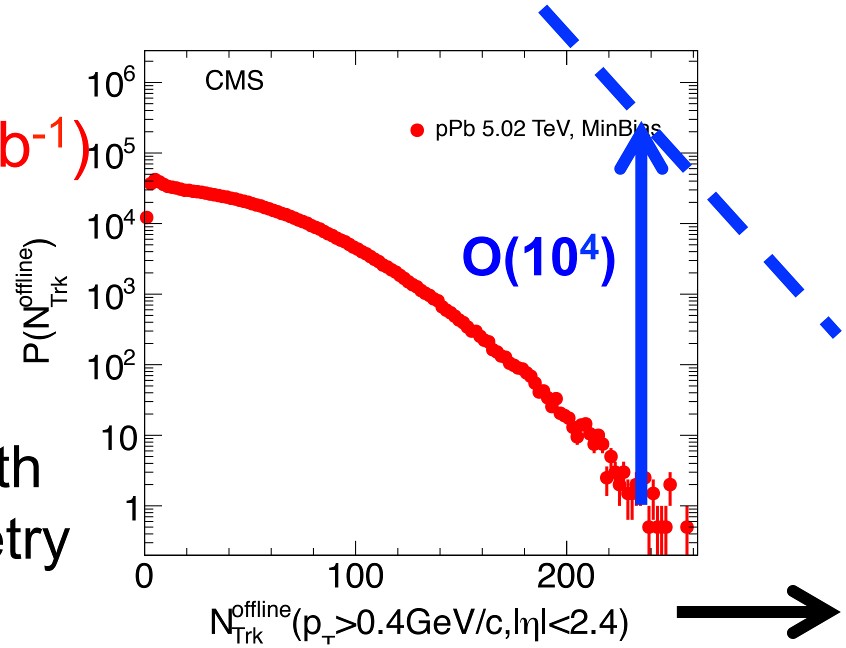

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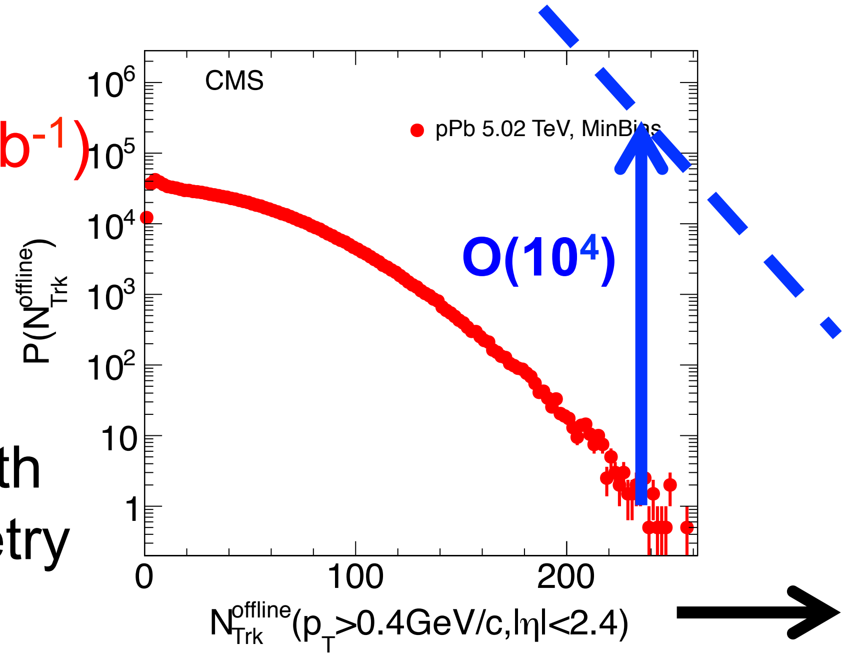
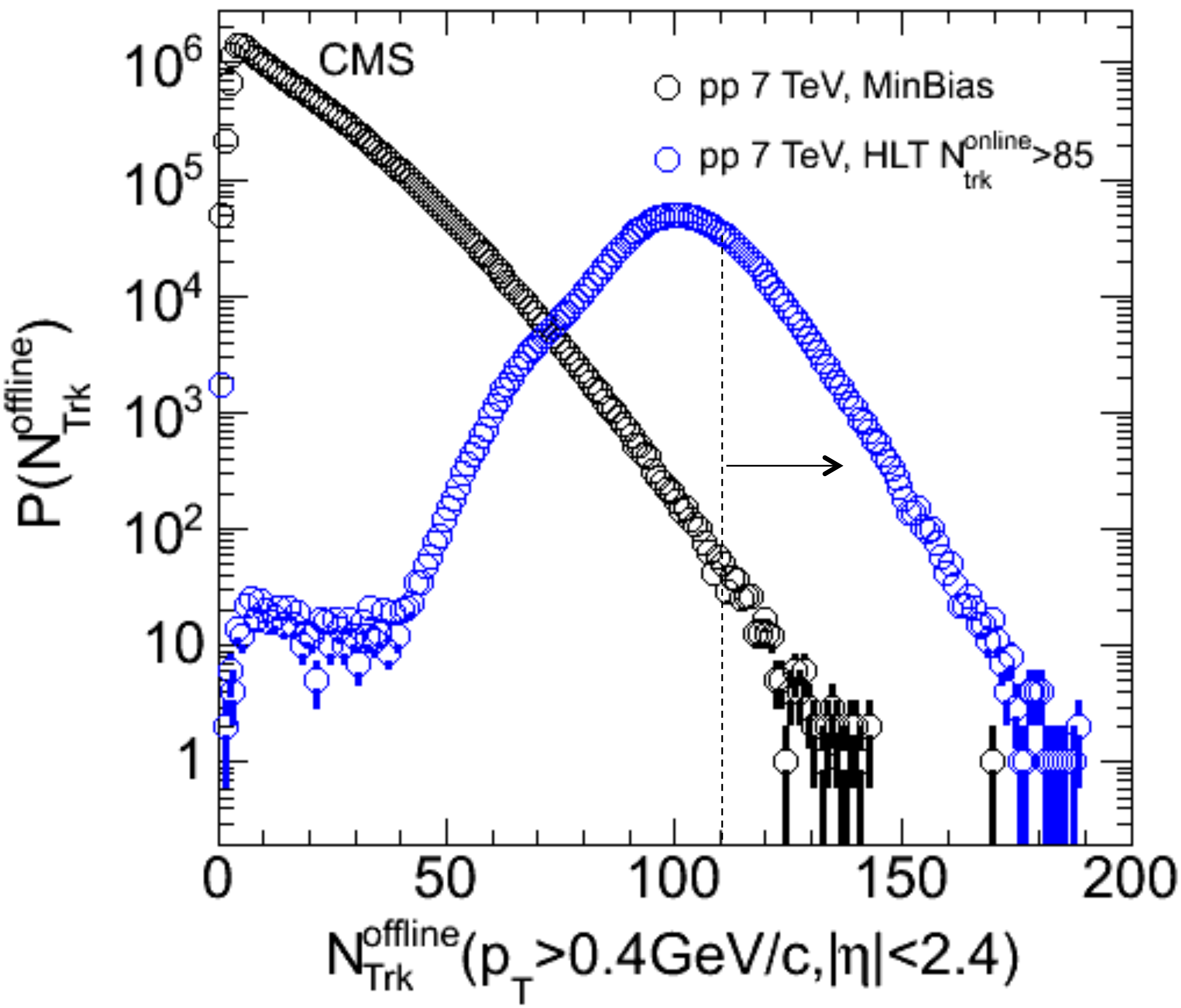


➢ With ~ 250 nb^{-1} projected luminosity, a pA program at RHIC can probe the same exciting physics and provide a new handle in the collision energy dependence

Backups

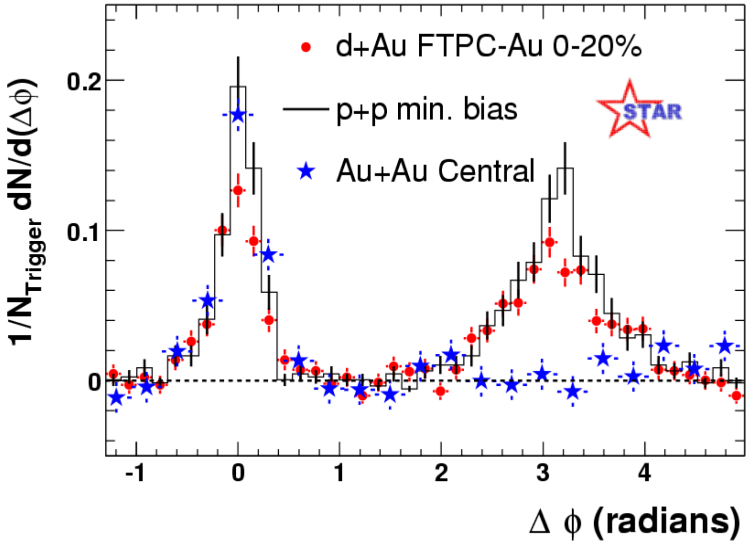
Very high multiplicity pp collisions

Dedicated online selection of high multiplicity events



Why studying pA collisions?

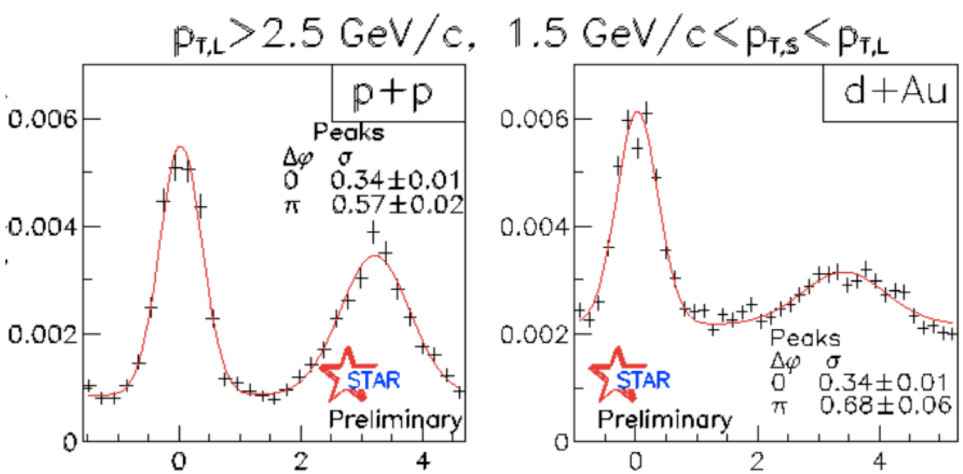
- Reference for nucleus-nucleus collisions: to address the issue of cold nuclear matter effects



Observation of jet quenching in AuAu but not in pp or dAu

➔Final-state effect

- Probe nucleus structure at extremely small-x regime



Modification of away side
In dAu at forward rapidity

➔Saturation of small-x gluons?