Two- and four-particle correlations in pPb collisions from CMS

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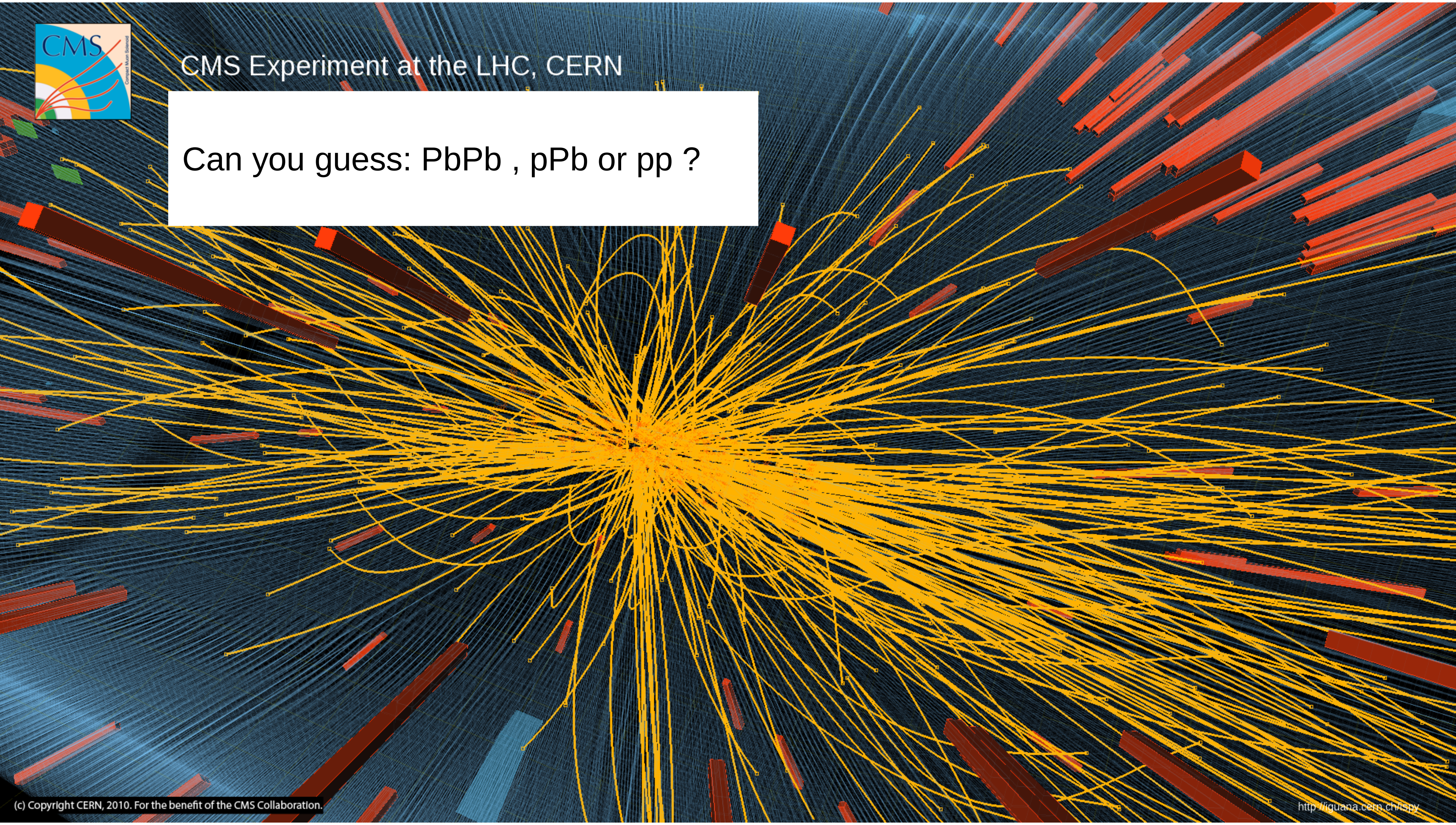
for the CMS Collaboration

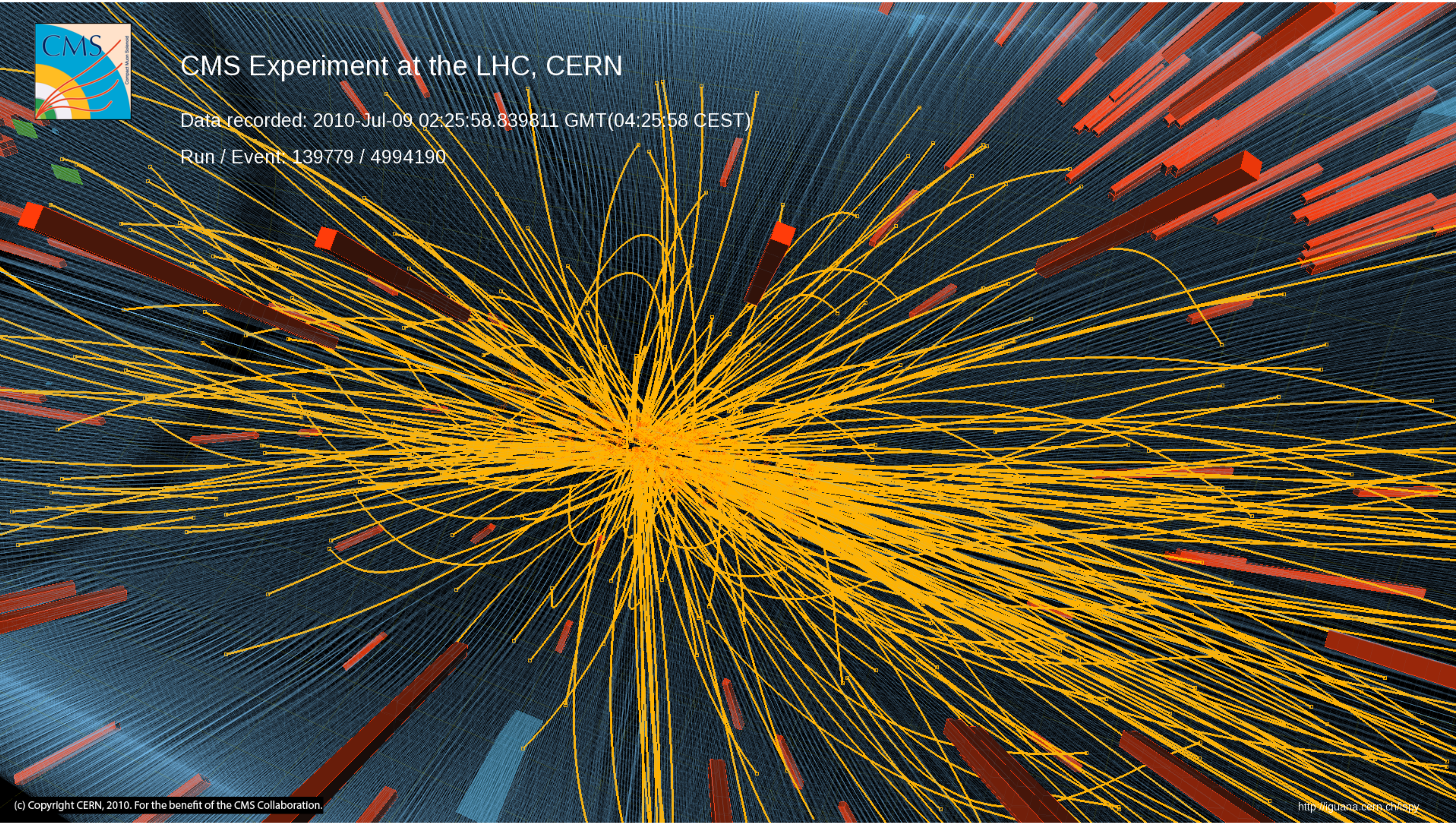
Motivation



CMS Experiment at the LHC, CERN
Can you guess: PbPb , pPb or pp ?
(c) Copyright CERN, 2010. For the benefit of the CMS Collaboration.
http://iguana.cern.ch/ispy

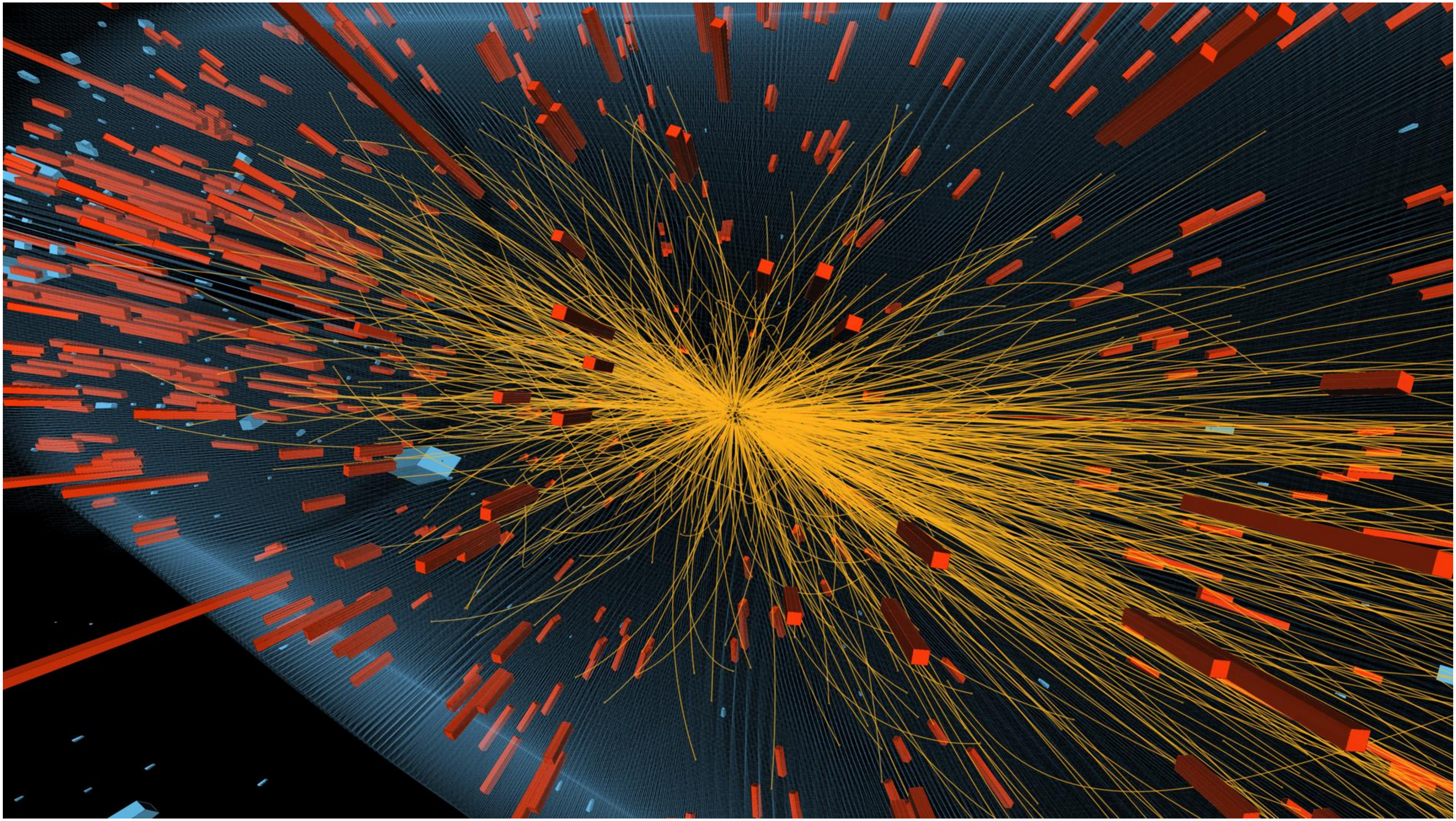
Motivation

High-multiplicity pp collisions at $\sqrt{s}$ = 7 TeV **JHEP 1009 (2010) 091**

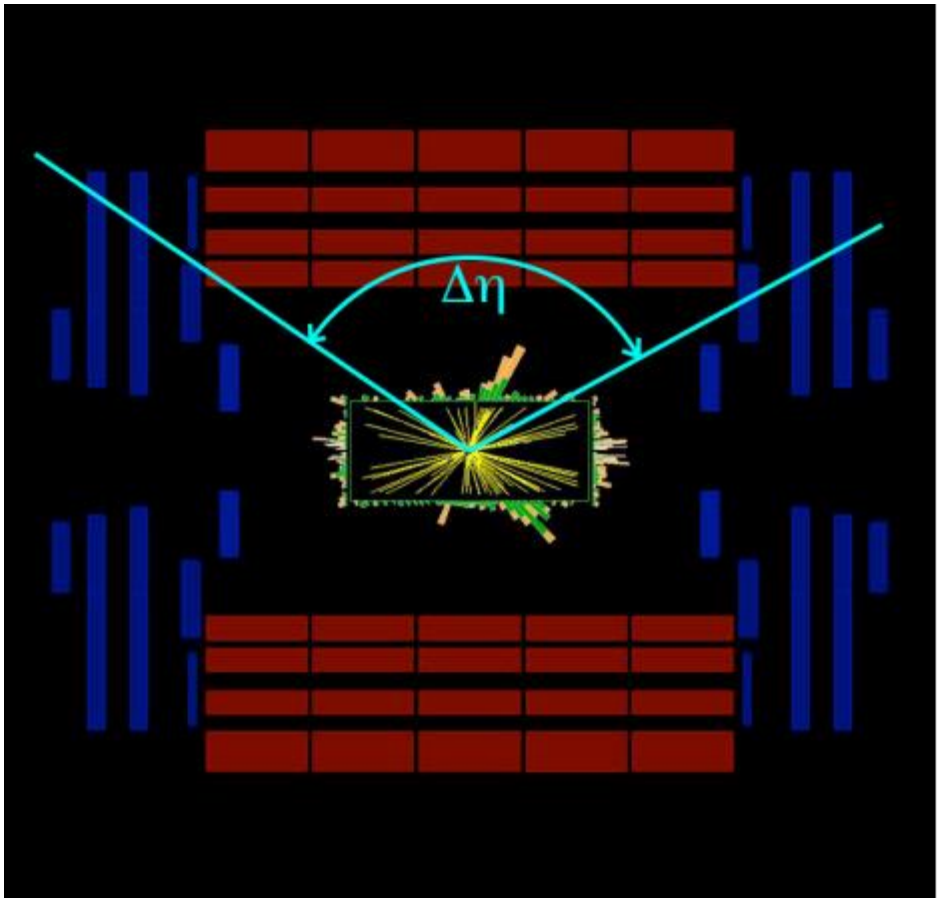


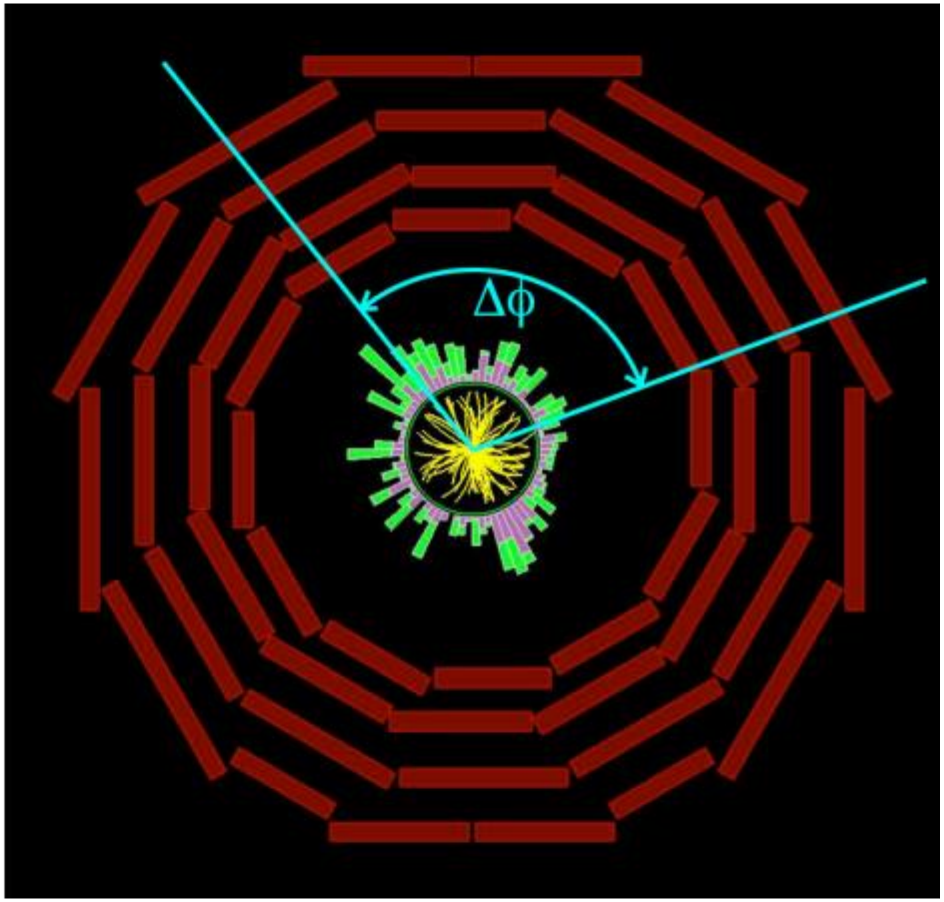
pPb collisions could be even more violent !

- 418 charged particles detected !

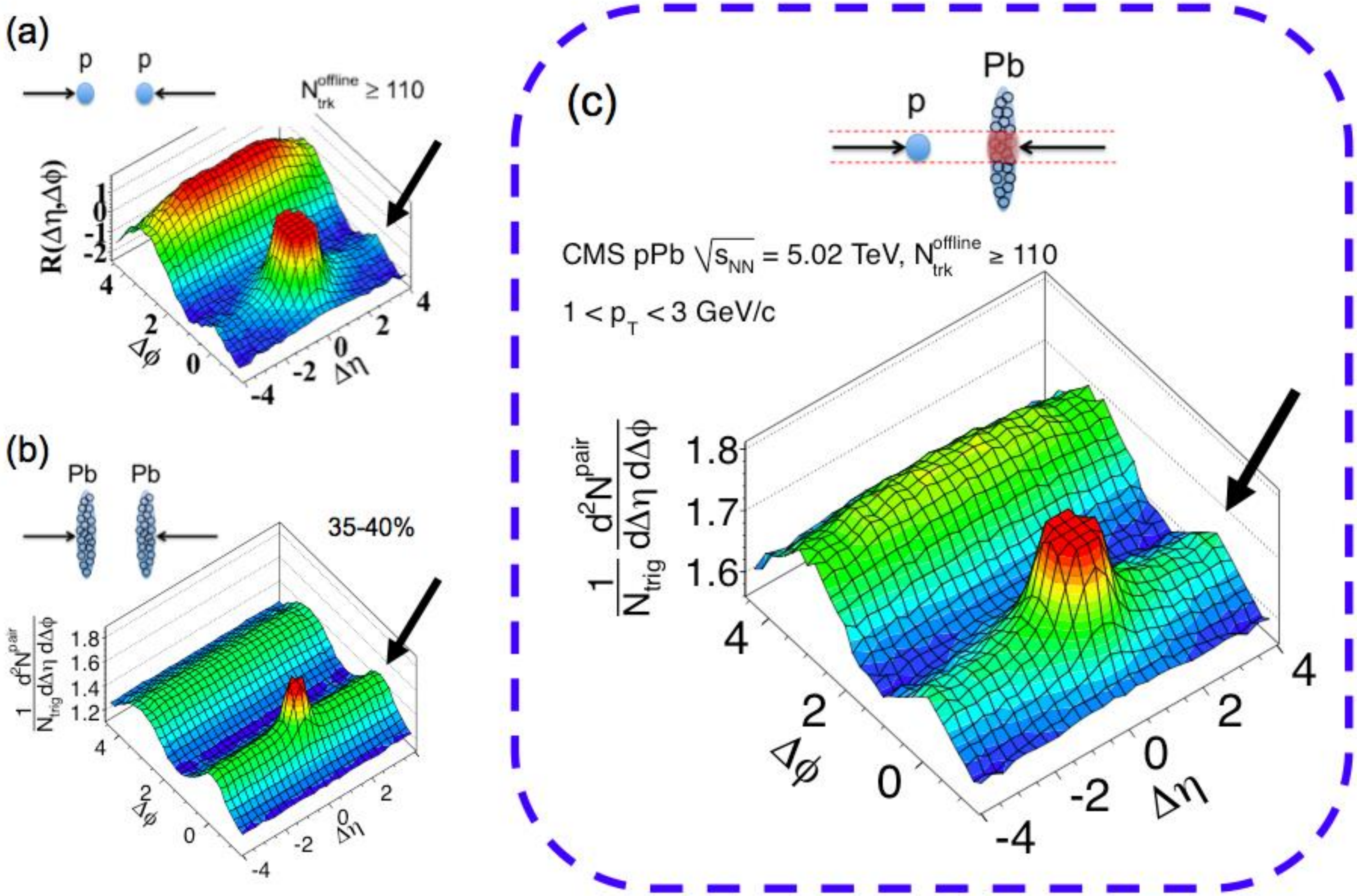


We study 2-particle correlations





To find ….ridges everywhere …



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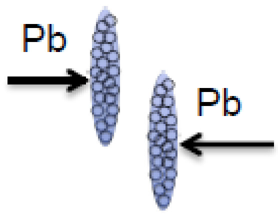
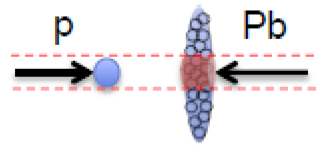
2013 pPb data: match the multiplicity in PbPb

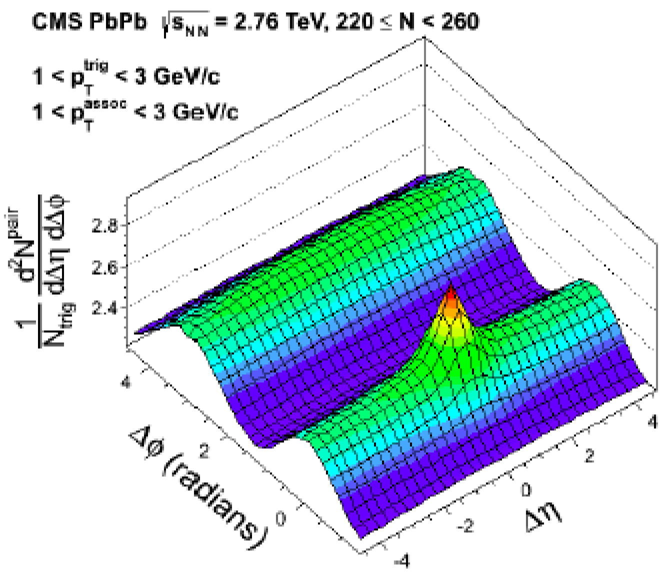


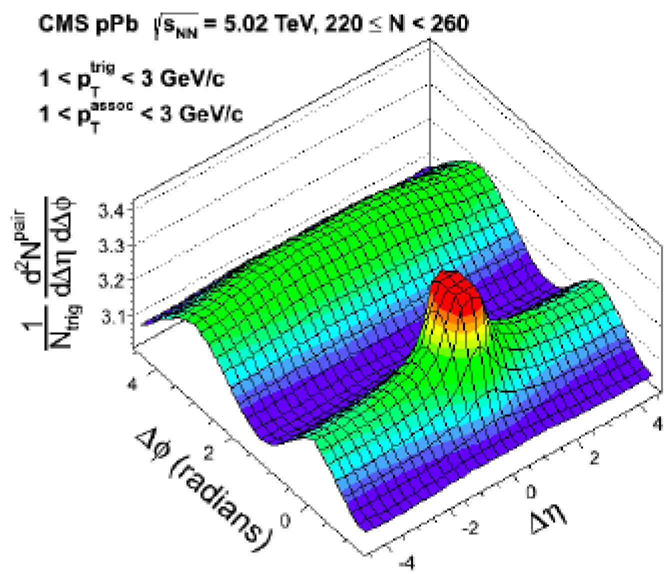


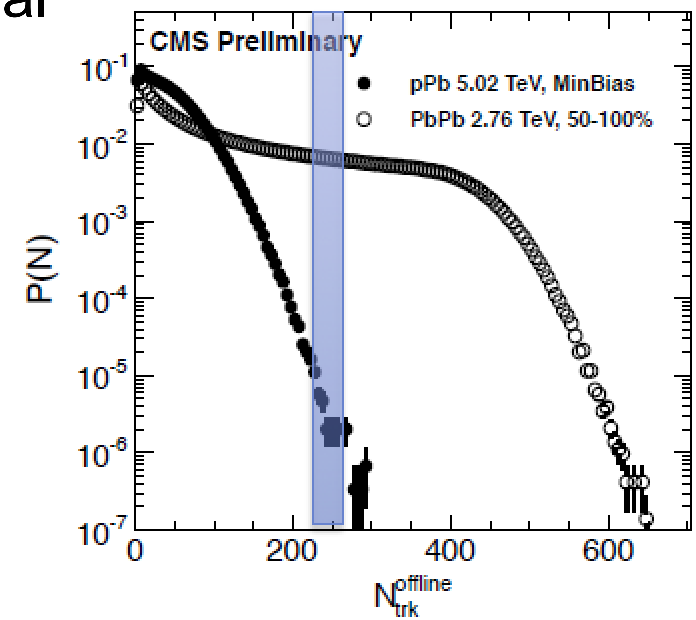
[PLB 724 (2013) 213]

~ 55-60% centrality

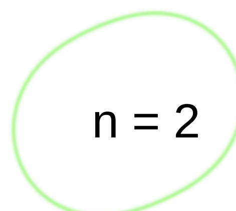
0-0.0003% “most central”

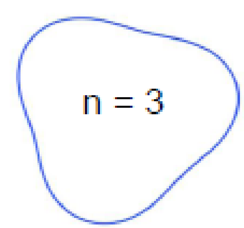






- Extend the multiplicity range in pPb
- Study Fourier harmonics
- 4-particle correlations
- Revisit PbPb





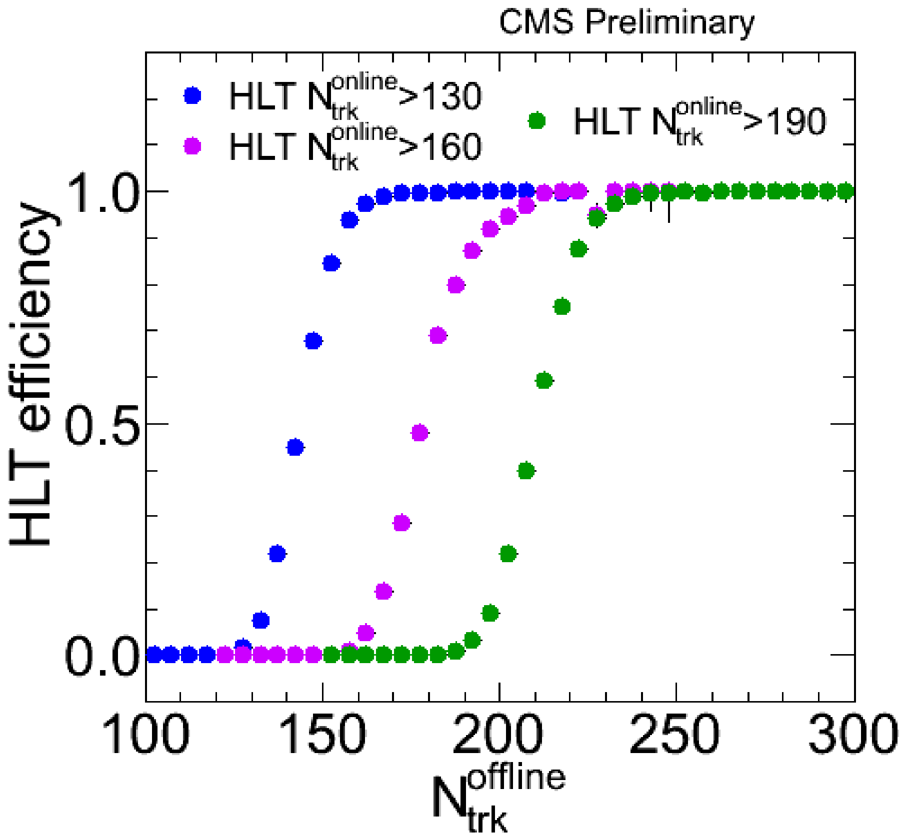
Questions to address

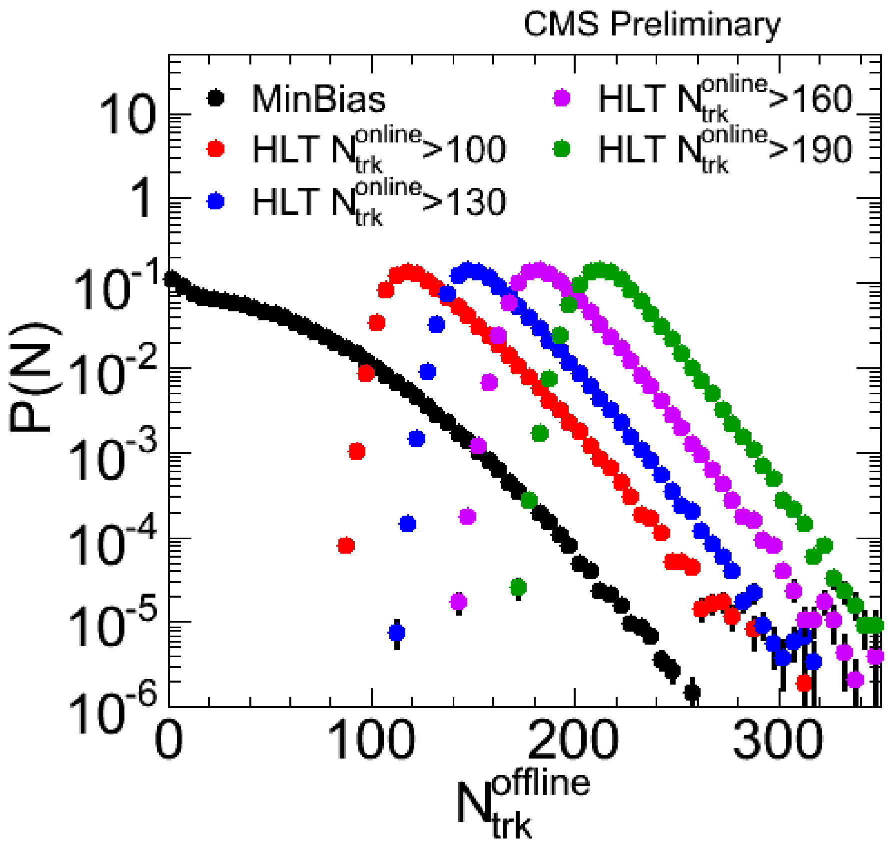
- What is the origin of the ridge in small systems ?
  - Collective flow ?
  - Quantum interference of gluons (CGC) ?
  - … or something else ?
- What are the initial state fluctuations ?

- Methods:
  - Compare 2- and 4-particle correlations in different collision systems
  - Study high-order harmonics
  - multiplicity dependence

EXPERIMENTAL DETAILS

Data sets and triggers





- Start with a L1 trigger “seed” : total transverse energy > 20,40 GeV
- 4 High-Multiplicity HLT trigger thresholds based on tracking
- Each recorded 20 M events in 3 weeks run
- pPb integrated luminosity: $31 nb^{-1}$
- PbPb data from 2011: 50-100% , 2.3 μb^{-1} reanalyzed

2-particle correlations

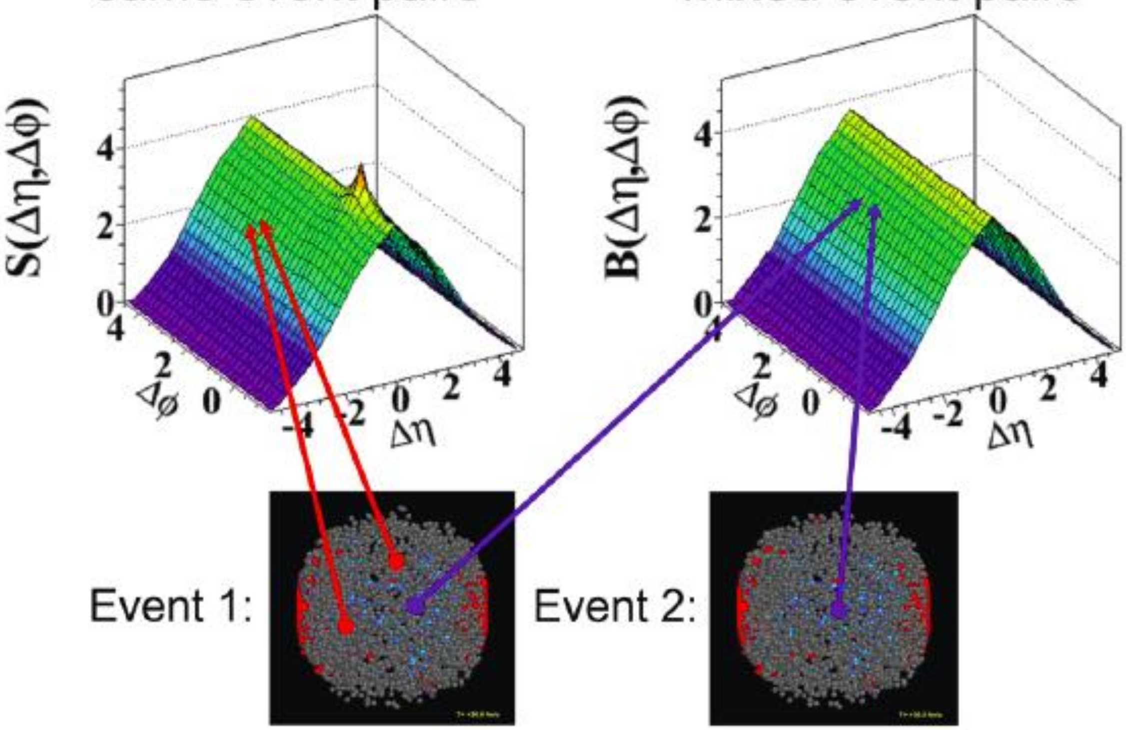
Signal pair distribution:

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

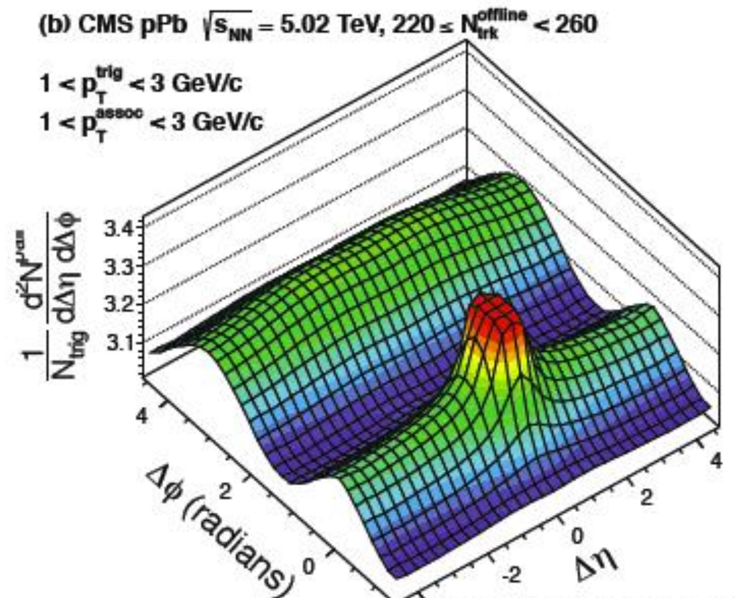
Background pair distribution:

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

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



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



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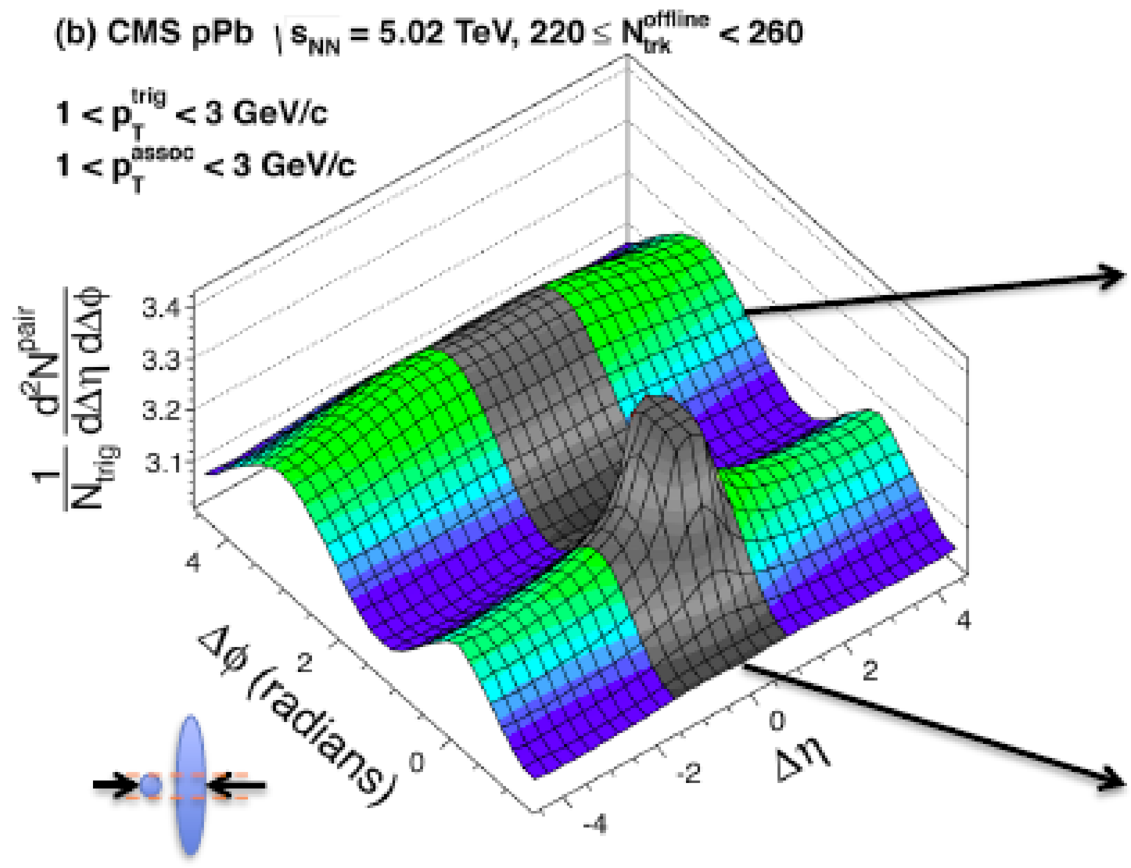
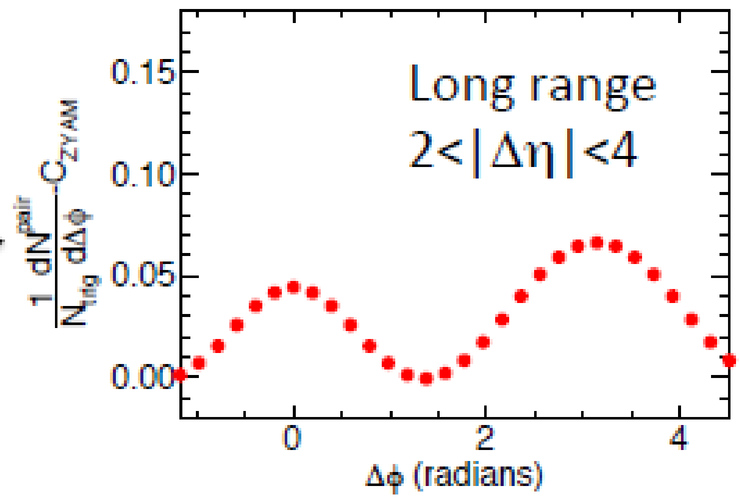
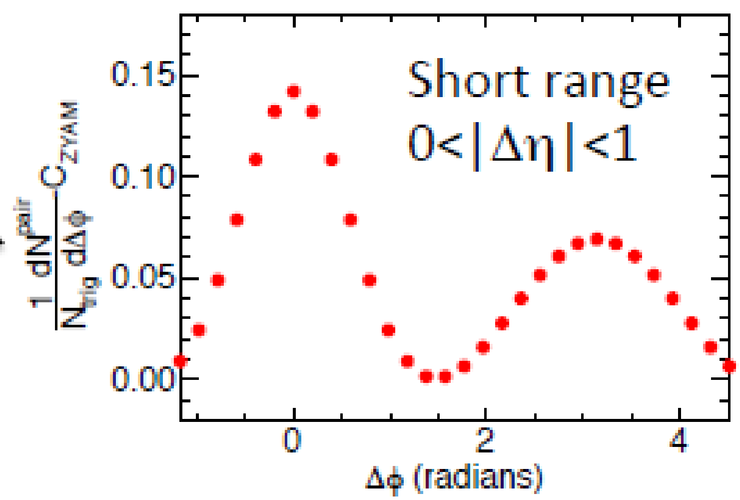
Long and short range correlations

Collective effects :
decompose in Fourier components



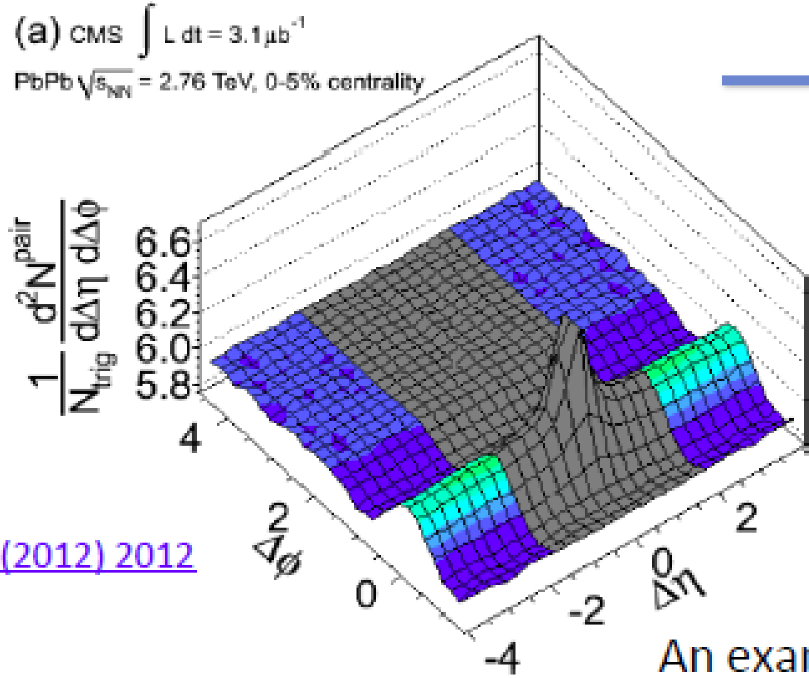




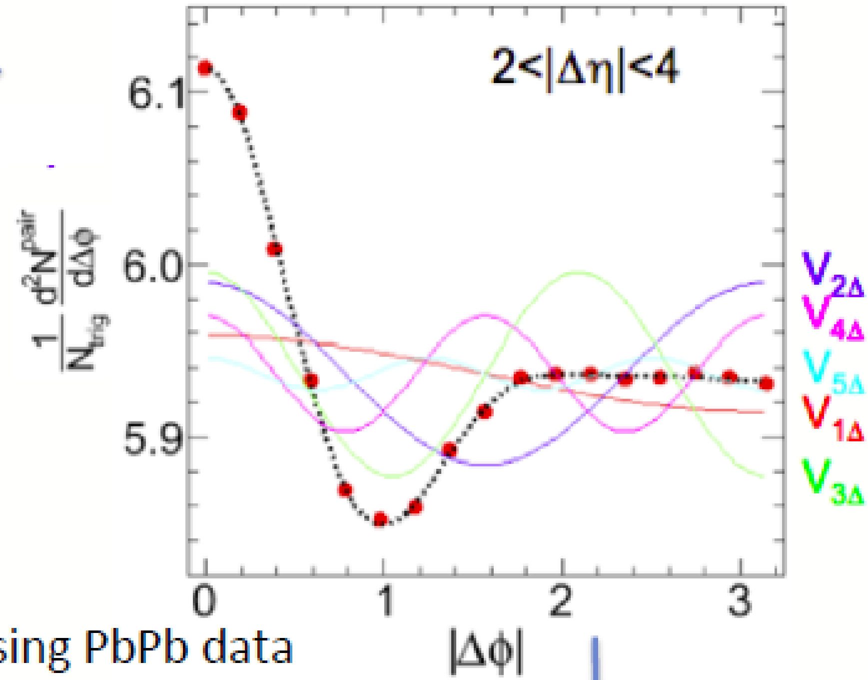
- Long range $2<|\Delta\eta|<4$
- Short range $0 < |\Delta\eta|<1$

Jet-like correlations

Fourier decomposition



EPJC 72 (2012) 2012



An example using PbPb data

Fourier decomposition:

$$\frac{dN^{pair}}{d\Delta\phi} \sim 1 + 2\sum_{n=1} V_{n\Delta}\cos(n\Delta\phi)$$

Assuming factorization:

$$V_{n\Delta} = v_n(p_T^{trig}) \times v_n(p_T^{assoc})$$

$$v_n\{2, |\Delta\eta| > 2\}(p_T) = \frac{V_{n\Delta}(p_T, p_T^{ref})}{\sqrt{V_{n\Delta}(p_T^{ref}, p_T^{ref})}}$$

Take low reference p_T bin (0.3-3 GeV/c)

pPb: Subtraction of peripheral correlations

- Away-side:
  - non-flow correlations

$$\frac{1}{N_{\rm trig}}\frac{dN^{\rm pair}}{d\Delta\phi} = \frac{N_{\rm assoc}}{2\pi}\left\{1+\sum_n 2V_{n\Delta}\cos(n\Delta\phi)\right\}$$

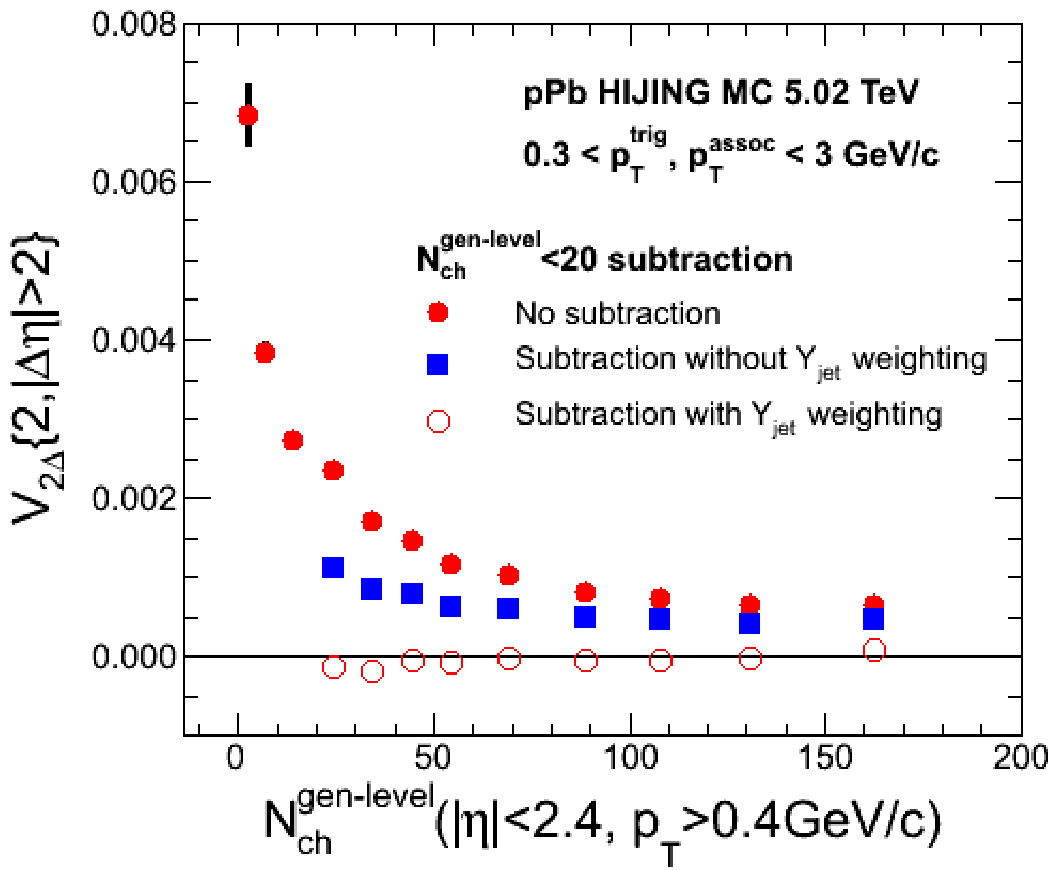
- Subtract peripheral

$N_{trk}^{offline}<20$

  - to get v_2, v_3

$$V_{n\Delta}(\text{cent}) - V_{n\Delta}(\text{peri}) \times \frac{N_{\text{assoc}}(\text{peri})}{N_{\text{assoc}}(\text{cent})} \times \frac{Y^{\text{jet}}(\text{cent})}{Y^{\text{jet}}(\text{peri})}$$

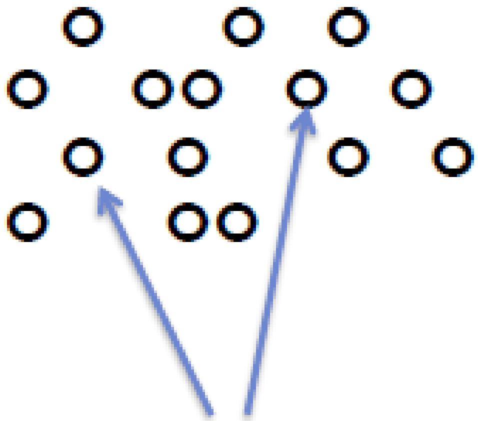
Account for the fact that jet correlation increases with multiplicity



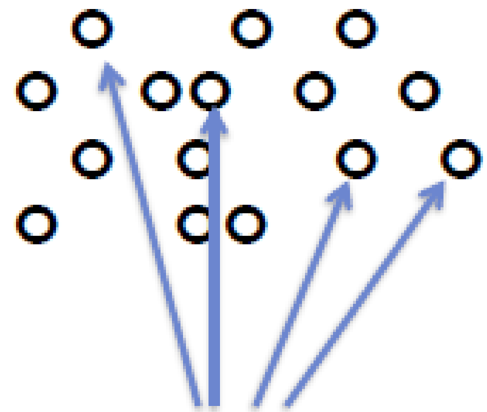
Test in HIJING

Note: Results are obtained with or without peripheral subtraction

multi-particle correlations

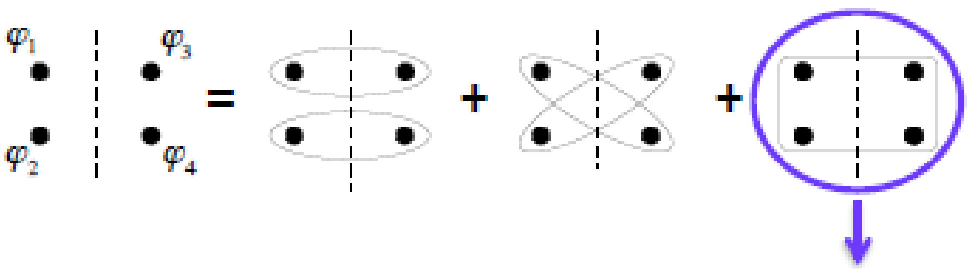


$$\left\langle e^{in(\varphi_1-\varphi_2)} \right\rangle$$



$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle$$

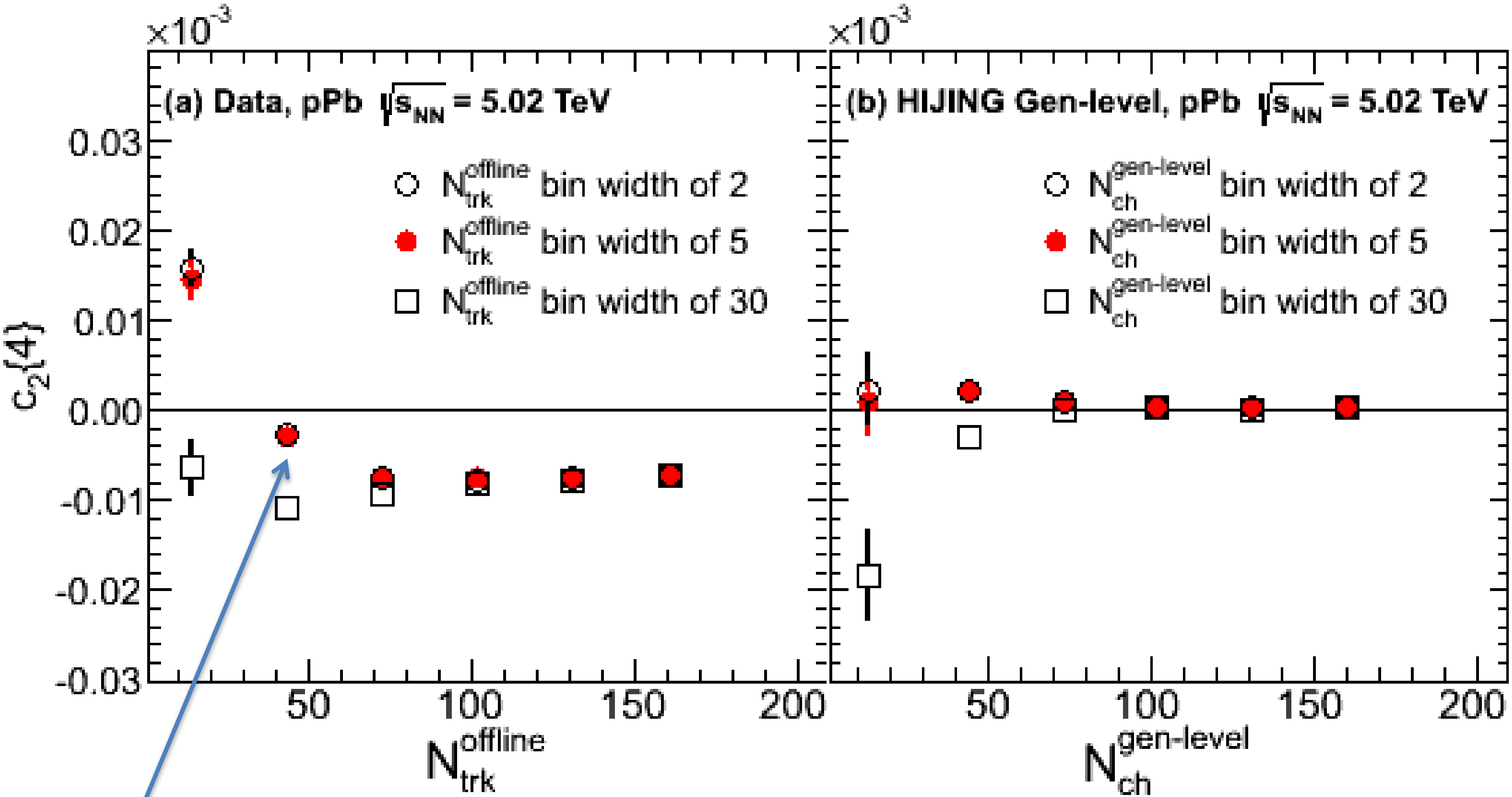
Four particle correlations (Q-cumulant method):



$$c_n\{4\} = \langle\langle 4\rangle\rangle - 2\cdot\langle\langle 2\rangle\rangle^2$$

$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_3)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_4)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_3)} \right\rangle$$

Effect of multiplicity fluctuations on $c_2\{4\}$



Turn-on of the signal in data

Narrow bins + averaging:**$c_2\{4\}>0$**

Wide bins: "generate" v_2 in HIJING

RESULTS

Long range 1 D correlation functions

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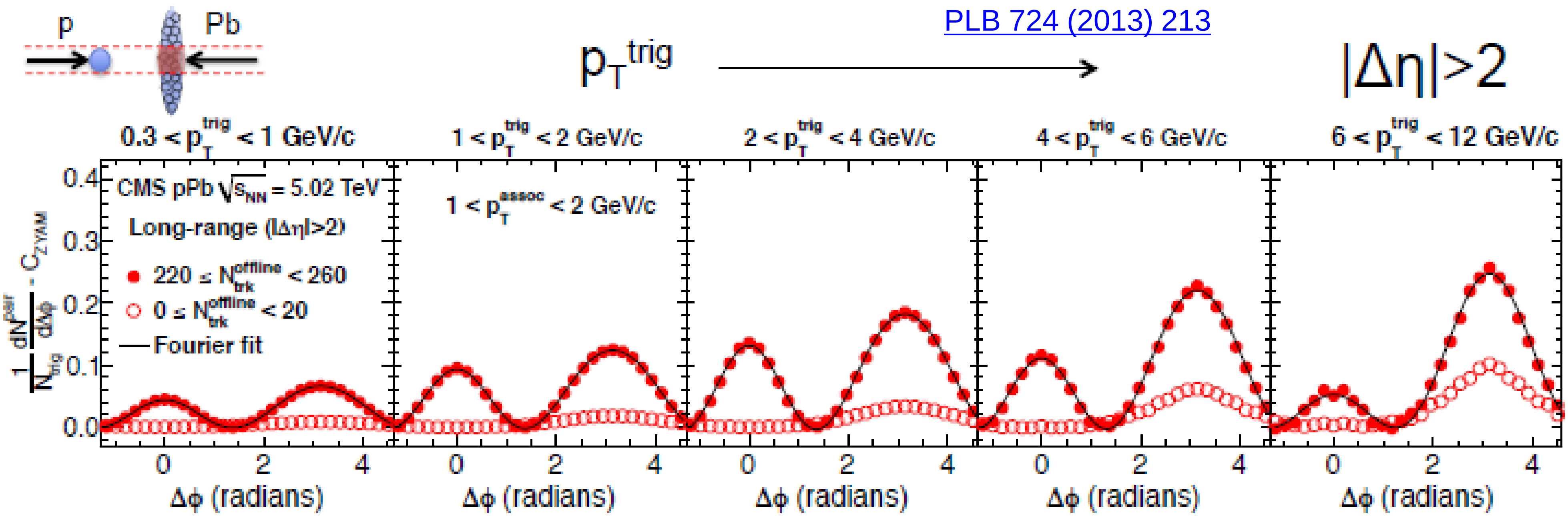

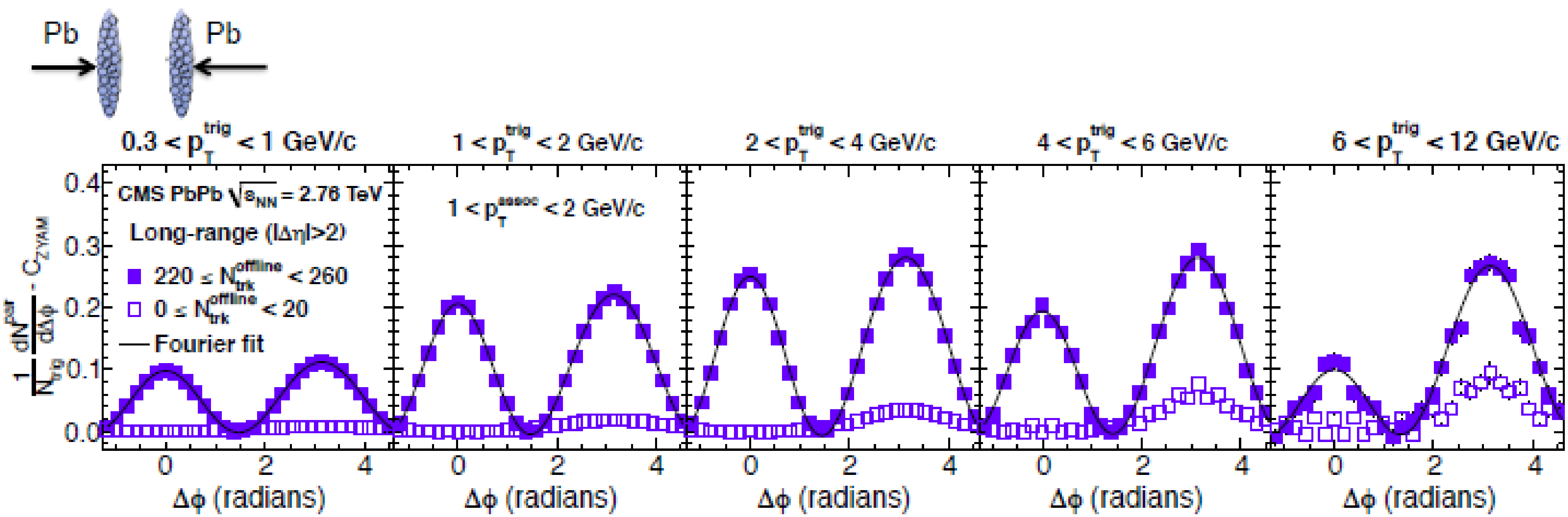

The ridge yield in different systems

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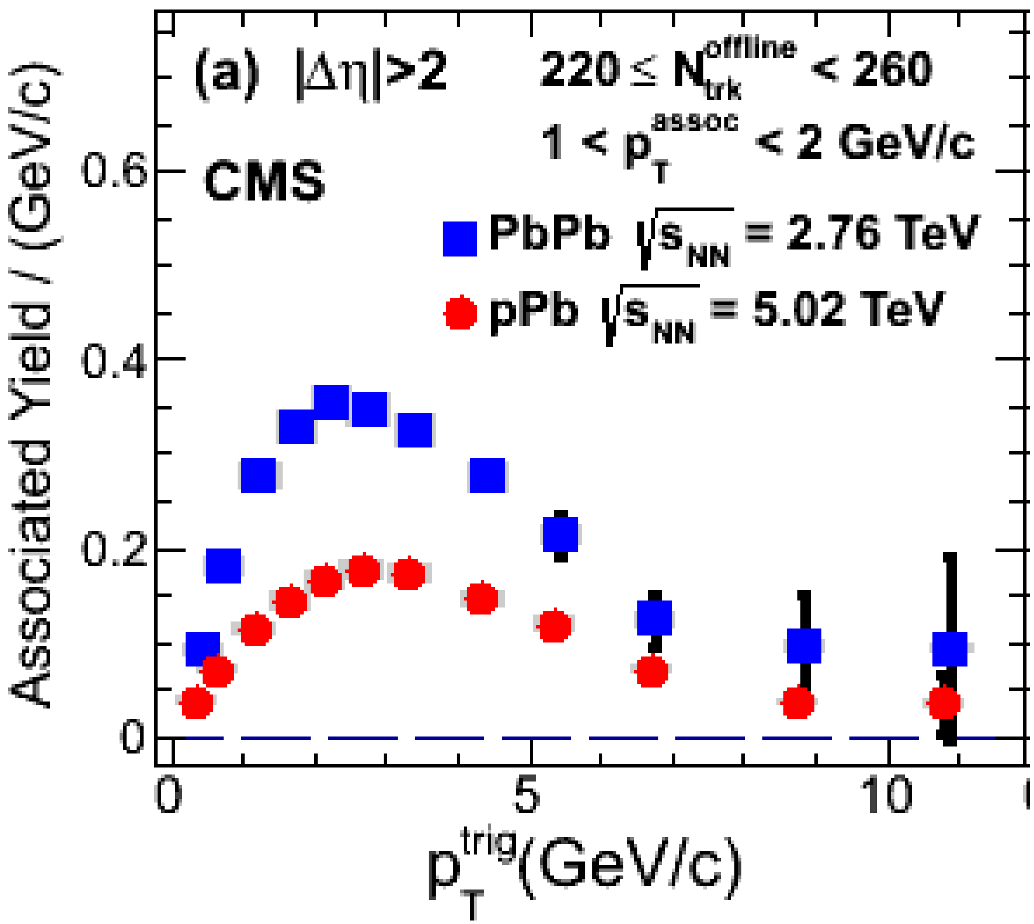
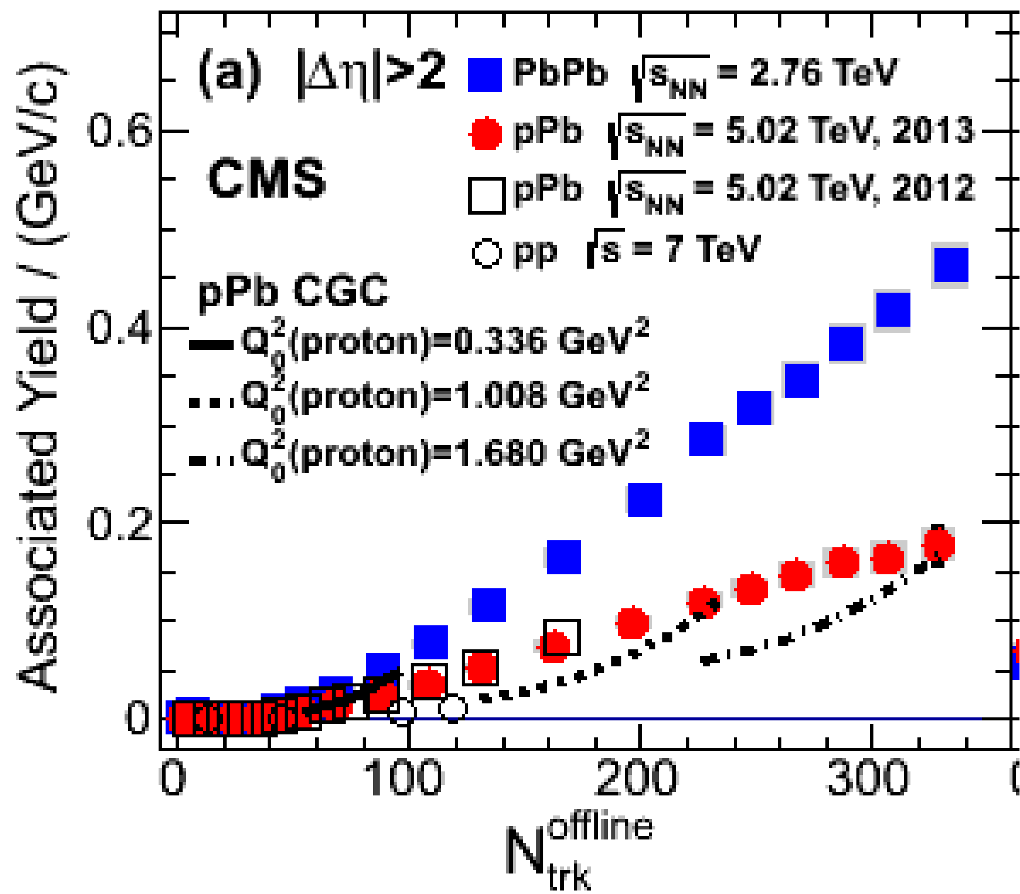
1 < p_T^{trig} < 2 GeV/c
1 < p_T^{assoc} < 2 GeV/c





Similar p_T dependence in PbPb and pPb

Turn on around N_{trk} ~ 50
Independent of system size

p_T dependence of v_n : PbPb vs pPb

Dashed-dotted curves
N<20 subtracted
Important for high-p_T

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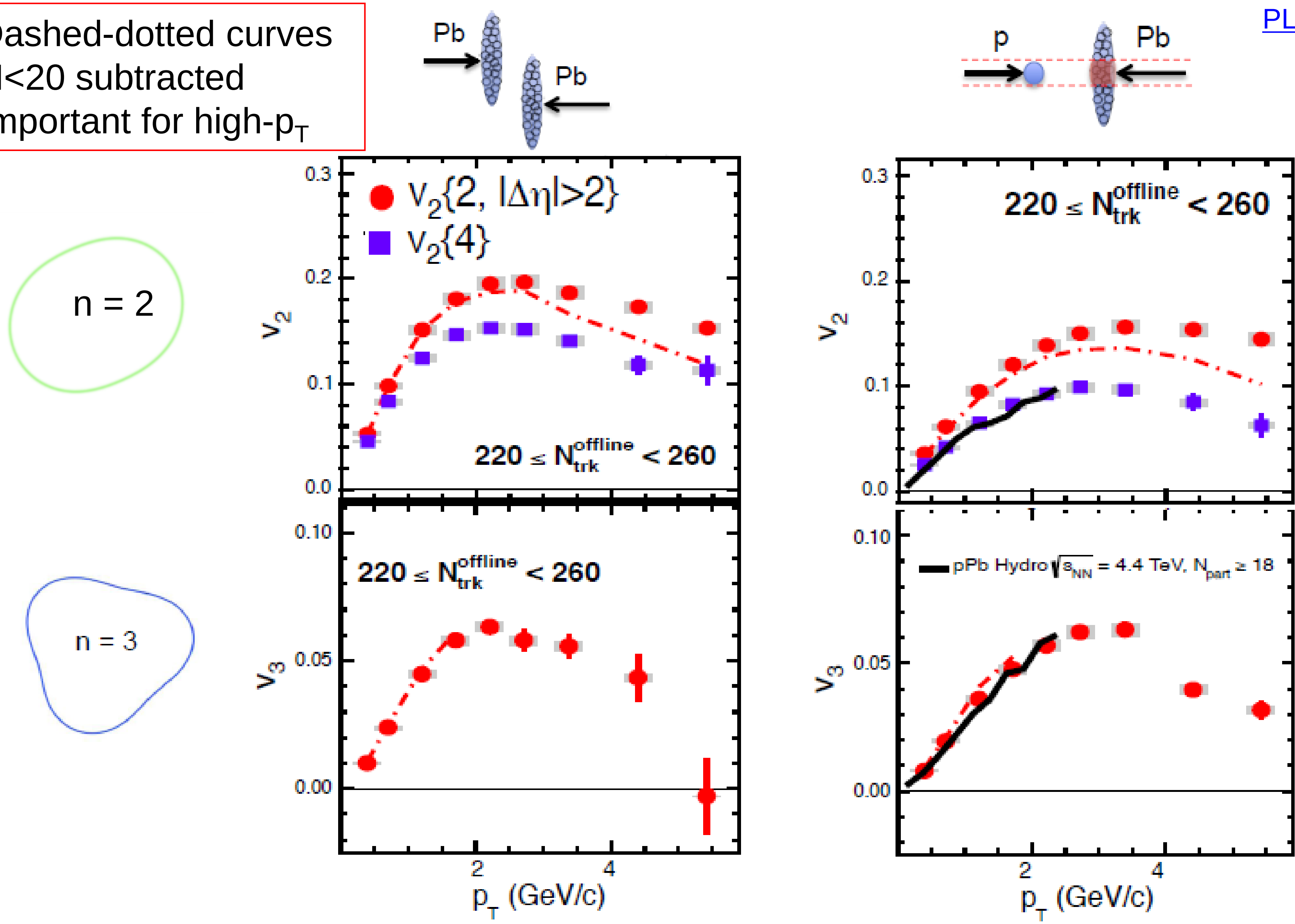

Remarkable similarity in PbPb and pPb for same multiplicity

Multiplicity dependence of v_2

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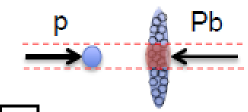
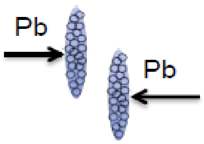
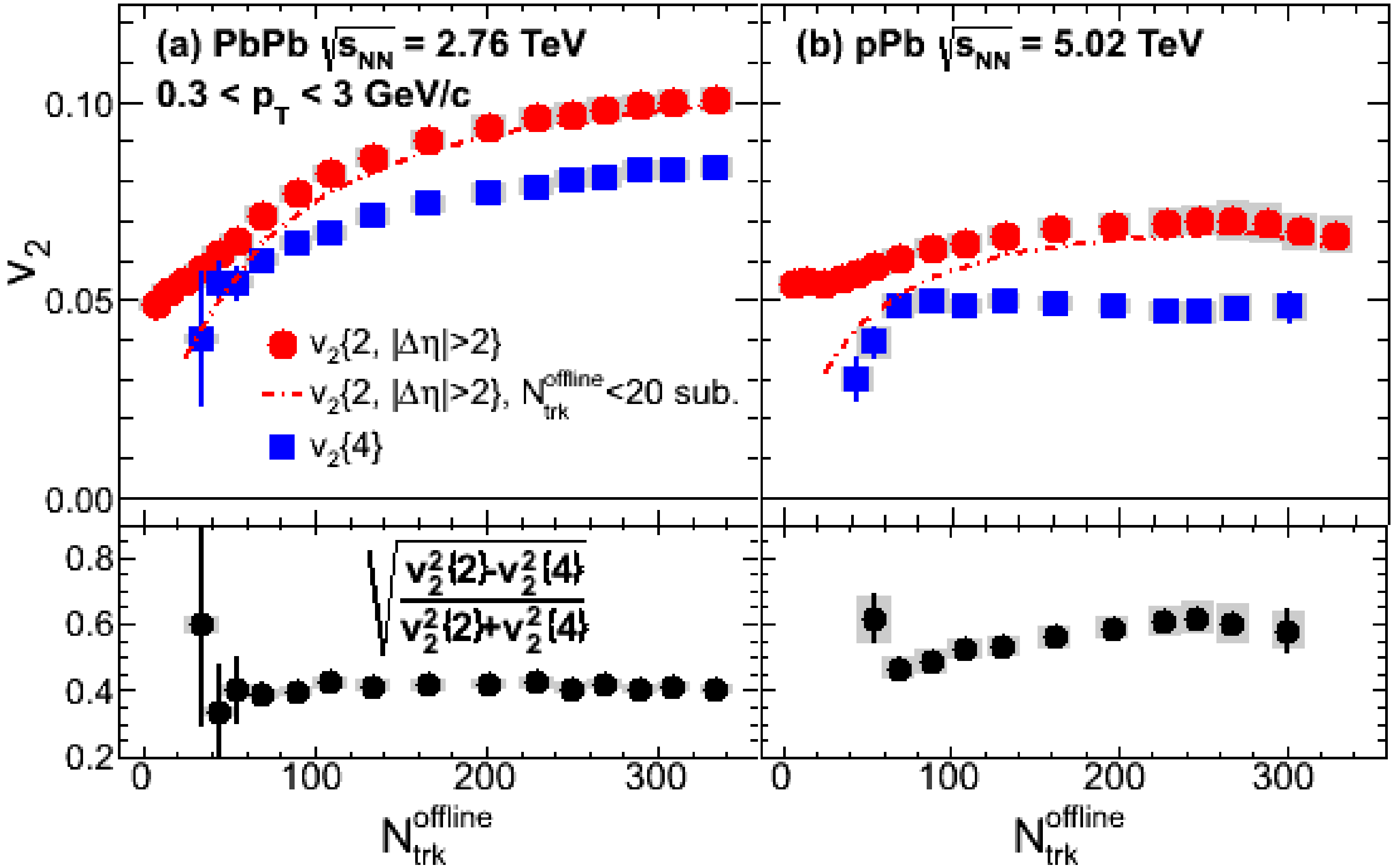




n = 2



$v_2\{4\}$ turn-on around N_{trk} ~ 50; weak multiplicity dependence

Multiplicity dependence of v_2

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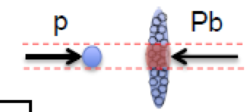
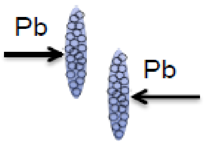
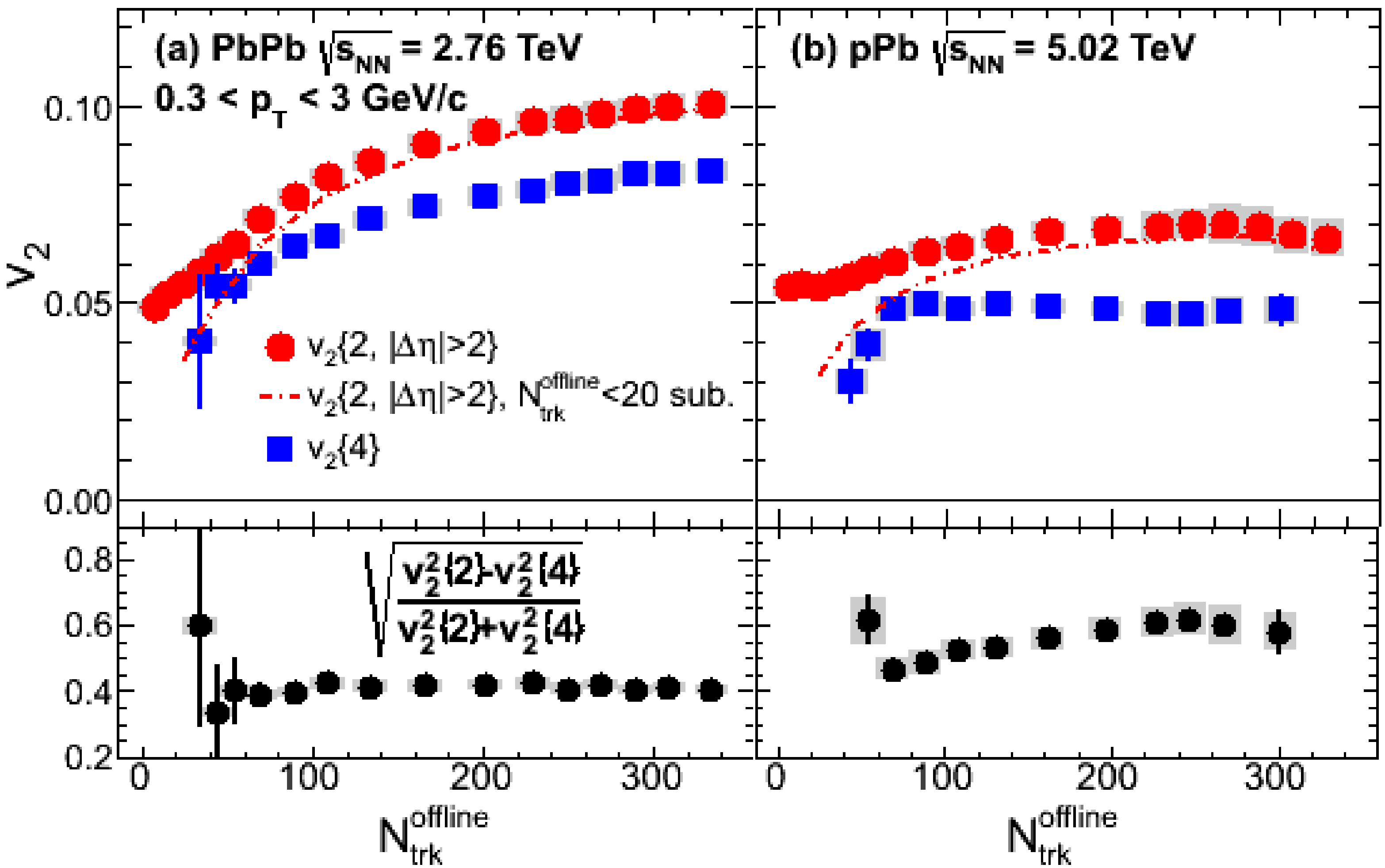






n = 2

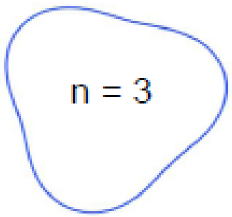
$$v_n\{2\} = \sqrt{\langle v_2 \rangle^2 + \sigma_{v_n}^2}$$

$$v_n\{4\} = \sqrt{\langle v_2 \rangle^2 - \sigma_{v_n}^2}$$

$$\frac{\sigma_{v_n}}{v_n} = \sqrt{\frac{v_n^2\{2\} - v_n^2\{4\}}{v_n^2\{2\} + v_n^2\{4\}}}$$

Larger fluctuation in pPb

Multiplicity dependence of v_3



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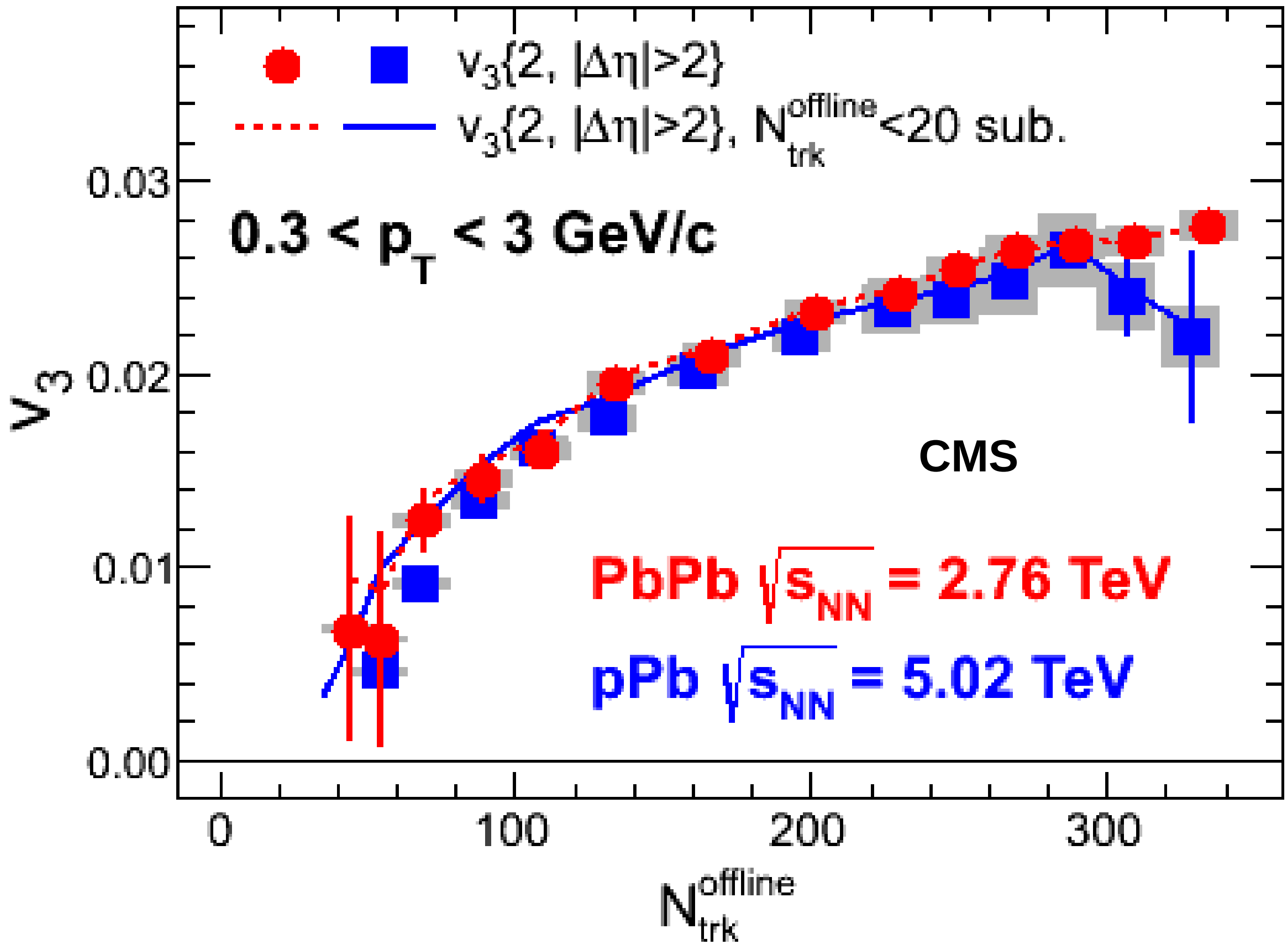
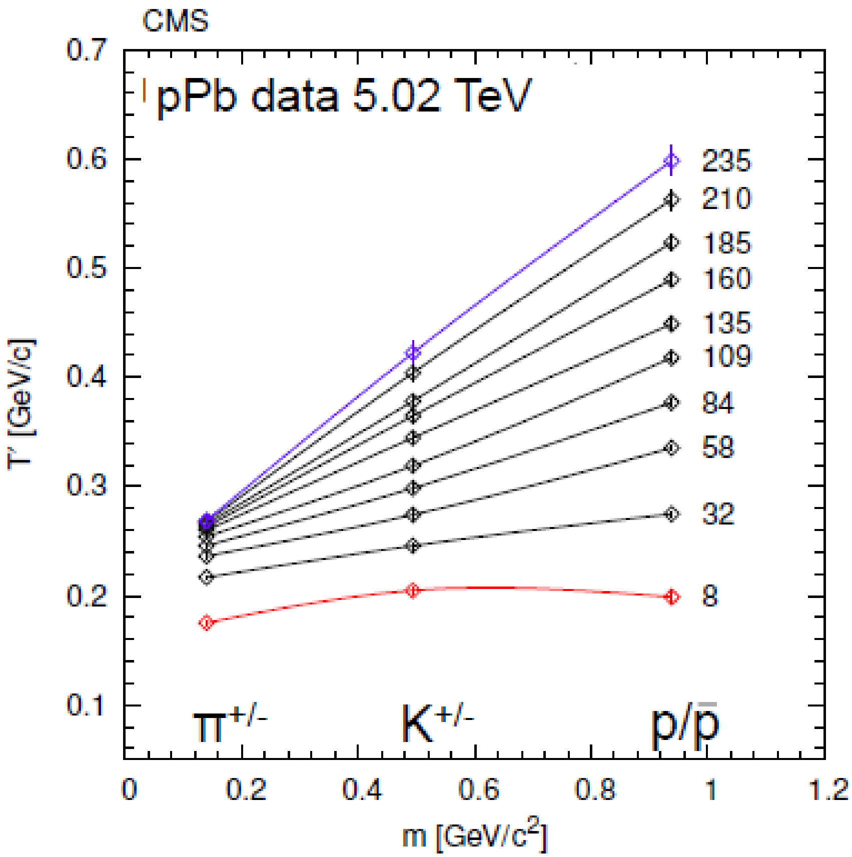


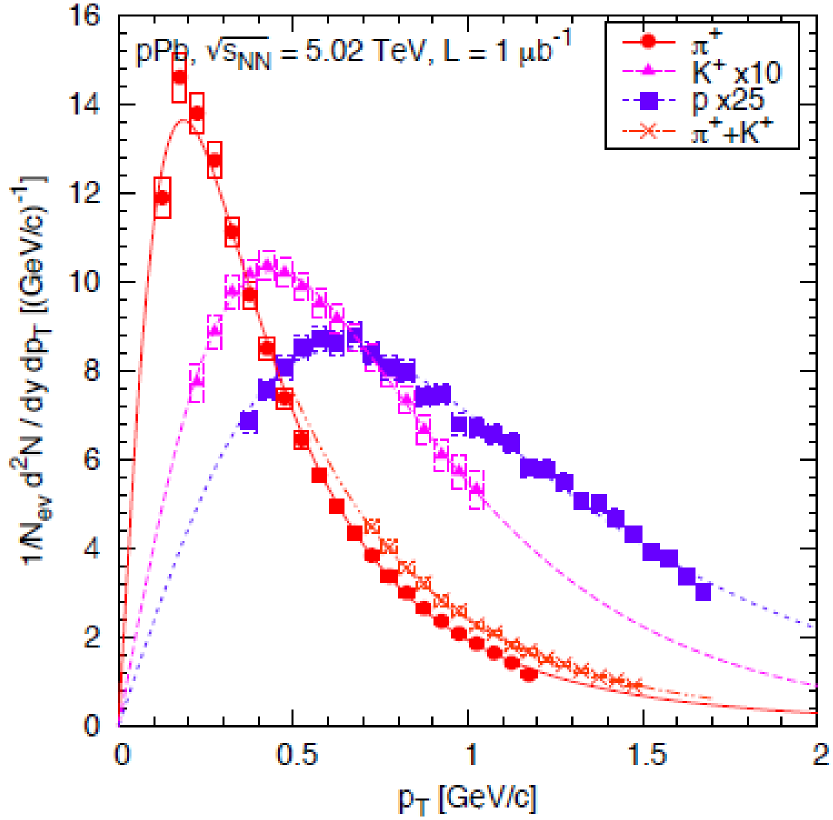
- Independent of system size
- Does not extrapolate to 0

Other hints of collective effects ?

Inverse slope of m_T distributions, T_{slope}: $$\frac{1}{m_T}\frac{dN}{dm_T} \sim \exp(-\frac{m_T}{T_{slope}})$$



arXiv:1307.3442



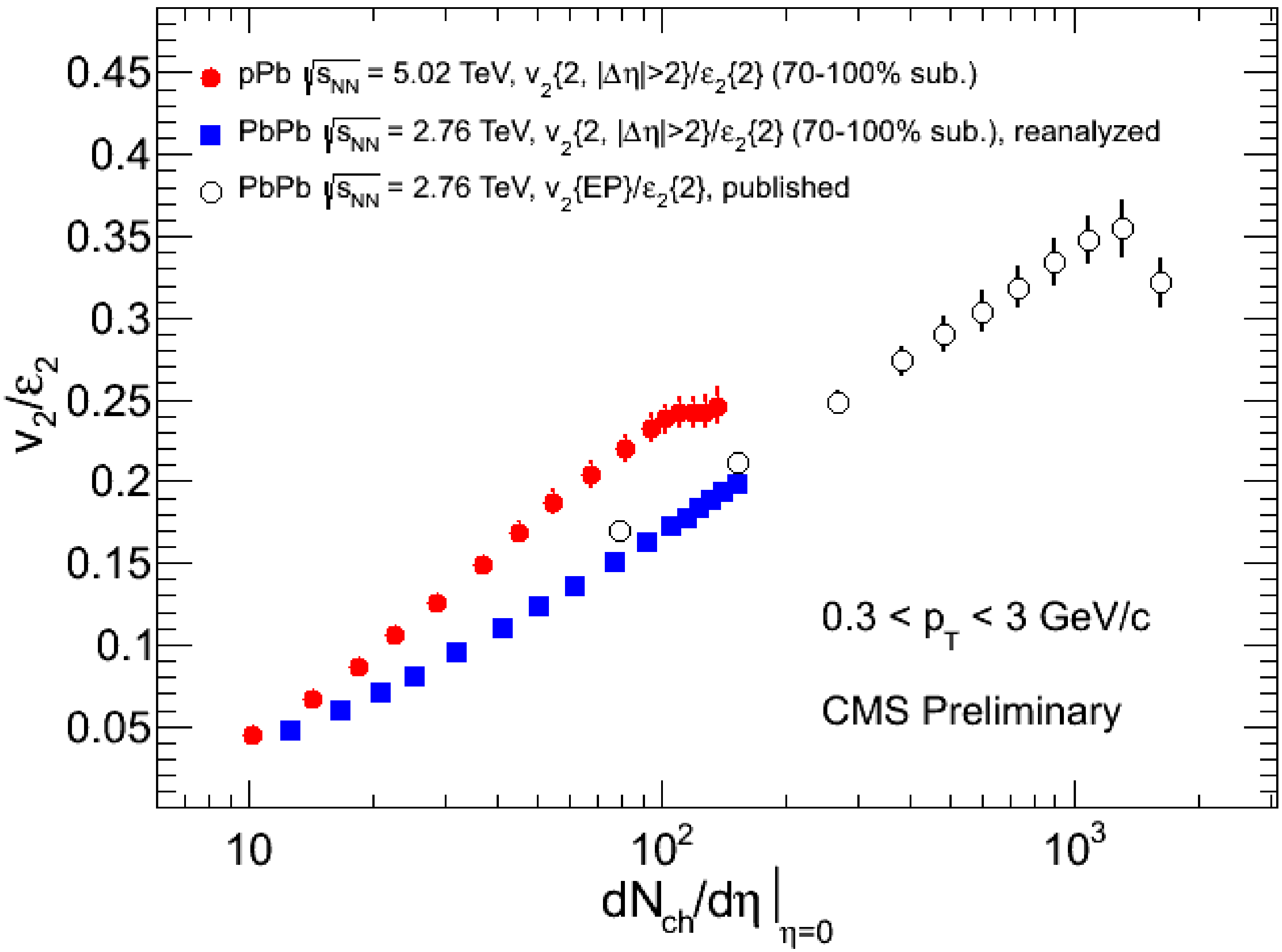
Inverse slope increases with particle mass and with multiplicity. Reminiscent of radial flow.

F.Sikler on Thursday

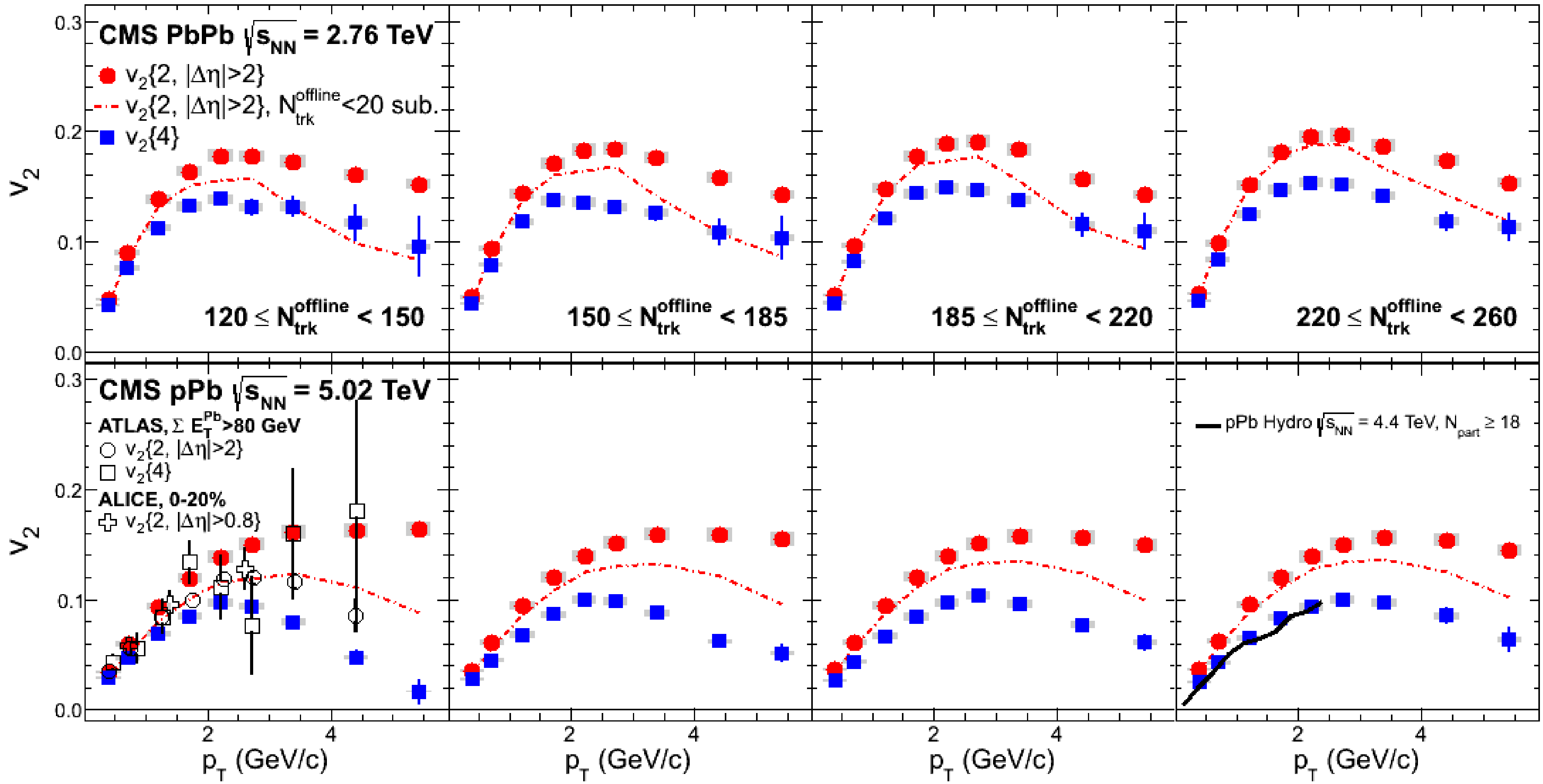
Conclusions

- CMS has measured elliptic and triangular flow coefficients in pPb and PbPb collisions
- Similar p_T and multiplicity dependence in different systems ; v_3 is identical in pPb and PbPb
- Four-particle correlations indicate a turn-on of multi-particle dynamics at ~ N_{trk} ~ 50
- The ridge becomes apparent at the same multiplicity independent of system size.
  - Are we probing the limits of hydrodynamics ?
- Hints of multiplicity dependent radial expansion
- pPb provides a testing ground for our “reference” ideas

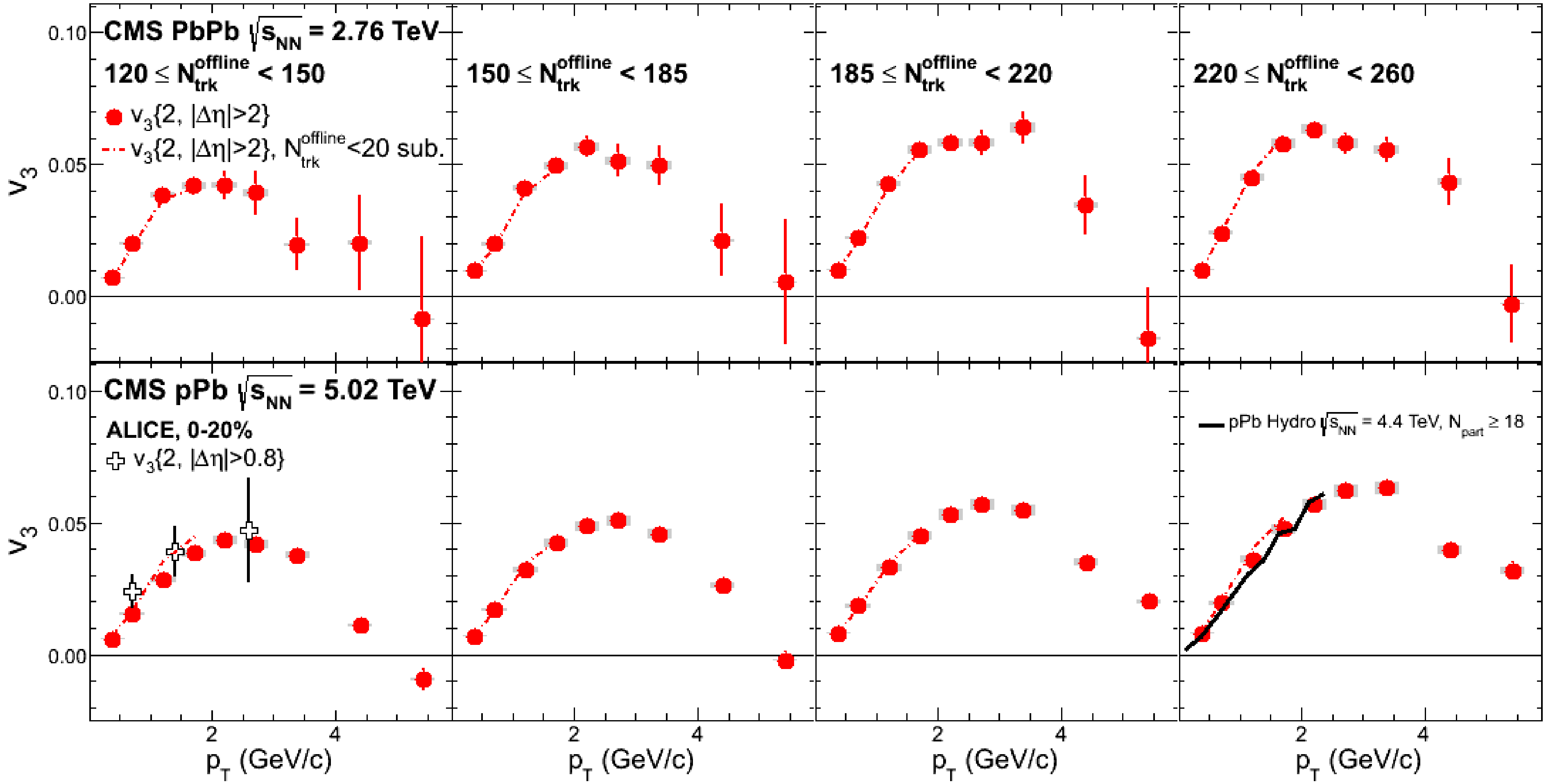
EXTRA

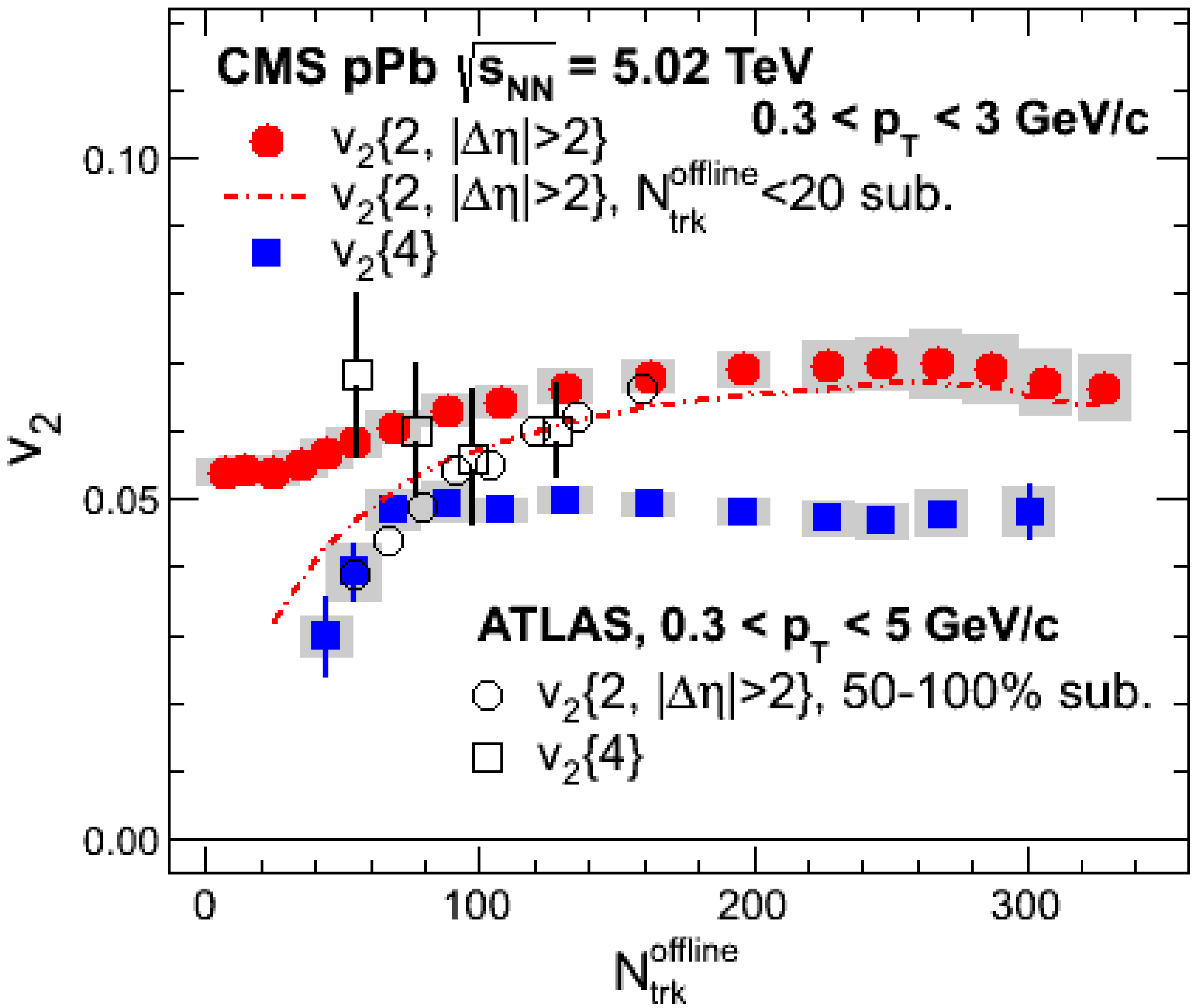

pPb $\sqrt{s_{NN}}$ = 5.02 TeV, $v_2\{2, |\Delta\eta|>2\}/\varepsilon_2\{2\}$ (70-100% sub.)
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV, $v_2\{2, |\Delta\eta|>2\}/\varepsilon_2\{2\}$ (70-100% sub.), reanalyzed
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV, $v_2\{EP\}/\varepsilon_2\{2\}$, published
0.3 < p_T < 3 GeV/c
CMS Preliminary
v_2/ε_2
$dN_{ch}/d\eta|_{\eta=0}$
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
10
10^2
10^3

	PbPb data			pPb data		
$N_{trk}^{offline}$ bin	$\langle$Centrality$\rangle$ $\pm$ RMS (%)	$\langle N_{trk}^{offline} \rangle$	$\langle N_{trk}^{corrected} \rangle$	Fraction	$\langle N_{trk}^{offline} \rangle$	$\langle N_{trk}^{corrected} \rangle$
$[0, \infty)$				1.00	40	50±2
$[0, 20)$	92±4	10	13±1	0.31	10	12±1
$[20, 30)$	86±4	24	30±1	0.14	25	30±1
$[30, 40)$	83±4	34	43±2	0.12	35	42±2
$[40, 50)$	80±4	44	55±2	0.10	45	54±2
$[50, 60)$	78±3	54	68±3	0.09	54	66±3
$[60, 80)$	75±3	69	87±4	0.12	69	84±4
$[80, 100)$	72±3	89	112±5	0.07	89	108±5
$[100, 120)$	70±3	109	137±6	0.03	109	132±6
$[120, 150)$	67±3	134	168±7	0.02	132	159±7
$[150, 185)$	64±3	167	210±9	4×10^{-3}	162	195±9
$[185, 220)$	62±2	202	253±11	5×10^{-4}	196	236±10
$[220, 260)$	59±2	239	299±13	6×10^{-5}	232	280±12
$[260, 300)$	57±2	279	350±15	3×10^{-6}	271	328±14
$[300, 350)$	55±2	324	405±18	1×10^{-7}	311	374±16



CMS PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
$v_2\{2, |\Delta\eta|>2\}$
$v_2\{2, |\Delta\eta|>2\}$, $N_{trk}^{offline}$<20 sub.
$v_2\{4\}$
$120 \leq N_{trk}^{offline} < 150$
$150 \leq N_{trk}^{offline} < 185$
$185 \leq N_{trk}^{offline} < 220$
$220 \leq N_{trk}^{offline} < 260$
CMS pPb $\sqrt{s_{NN}}$ = 5.02 TeV
ATLAS, ΣE_T^{Pb}>80 GeV
$v_2\{2, |\Delta\eta|>2\}$
$v_2\{4\}$
ALICE, 0-20%
$v_2\{2, |\Delta\eta|>0.8\}$
pPb Hydro $\sqrt{s_{NN}}$ = 4.4 TeV, $N_{part} \geq 18$
v_2
p_T (GeV/c)


CMS PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
120 ≤ $N_{trk}^{offline}$ < 150
$v_3\{2, |\Delta\eta|>2\}$
$v_3\{2, |\Delta\eta|>2\}$, $N_{trk}^{offline}$<20 sub.
150 ≤ $N_{trk}^{offline}$ < 185
185 ≤ $N_{trk}^{offline}$ < 220
220 ≤ $N_{trk}^{offline}$ < 260
CMS pPb $\sqrt{s_{NN}}$ = 5.02 TeV
ALICE, 0-20%
$v_3\{2, |\Delta\eta|>0.8\}$
pPb Hydro $\sqrt{s_{NN}}$ = 4.4 TeV, N_{part} ≥ 18
v_3
0.10
0.05
0.00
2
4
p_T (GeV/c)


CMS pPb $\sqrt{s_{NN}}$ = 5.02 TeV
0.3 < p_T < 3 GeV/c
$v_2\{2, |\Delta\eta|>2\}$
$v_2\{2, |\Delta\eta|>2\}$, $N_{trk}^{offline}$<20 sub.
$v_2\{4\}$
ATLAS, 0.3 < p_T < 5 GeV/c
$v_2\{2, |\Delta\eta|>2\}$, 50-100% sub.
$v_2\{4\}$
v_2
0.10
0.05
0.00
0
100
200
300
$N_{trk}^{offline}$