Exploring the pPb ridge effect with CMS: Azimuthal correlations with identified hadrons and pseudorapidity dependence

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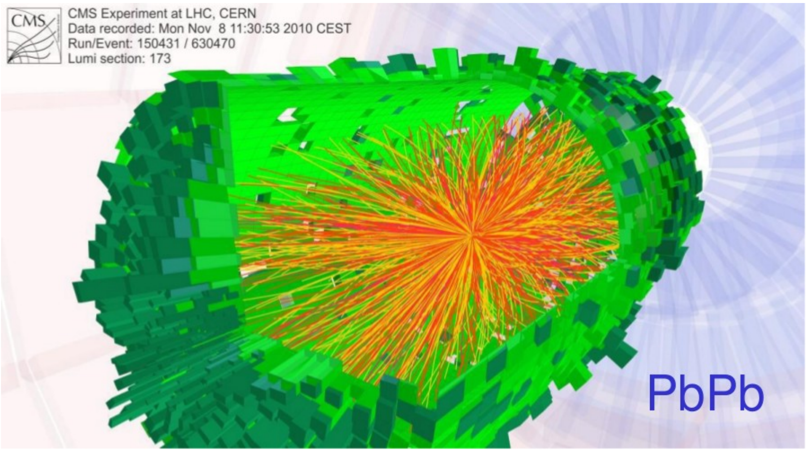
Two particle angular correlations

Perfect tool for examining:

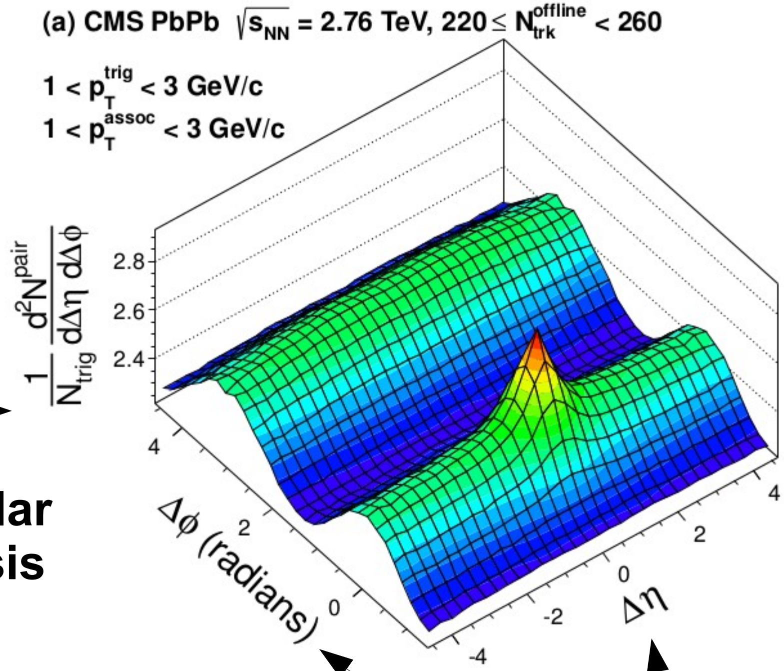
- geometry of the particle production process
- the initial-state of the medium that is created in the collision.

One of the techniques to extract single particle v_n



PbPb event in CMS

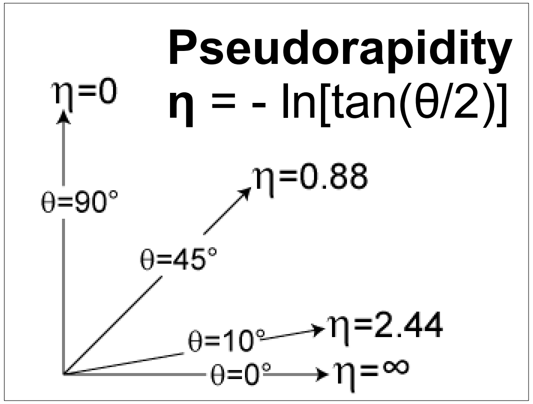
Two particle angular correlation analysis



dependence on **ΔΦ** and **Δη**

2D Correlation function

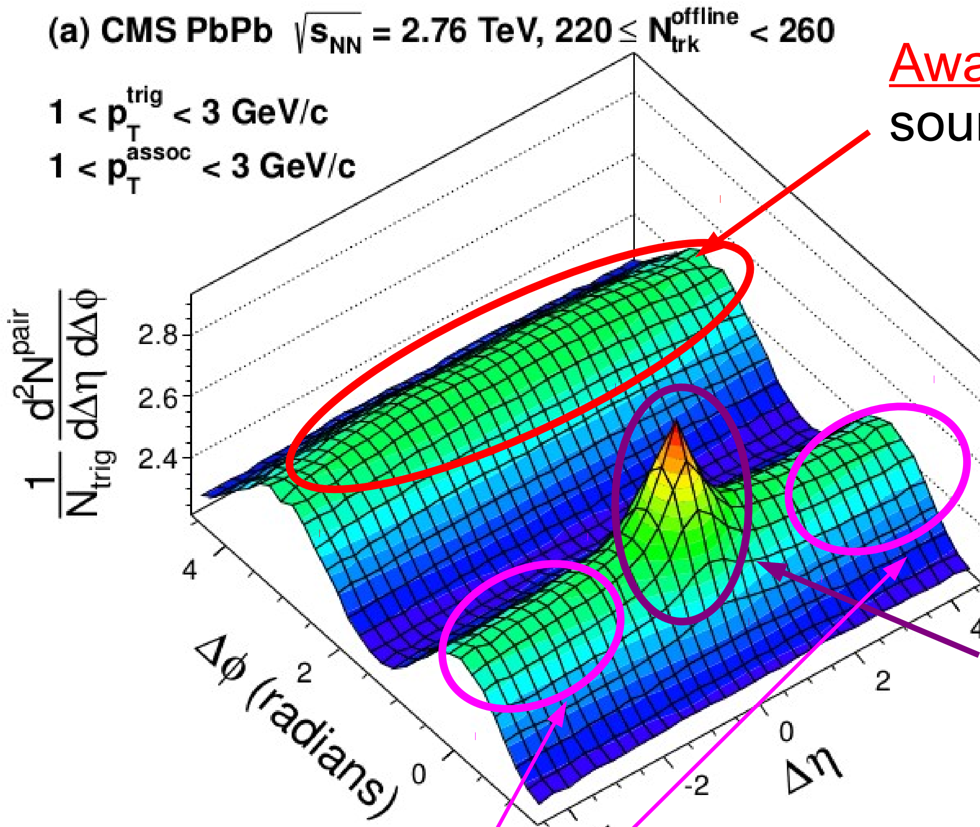
PLB 724 (2013) 213



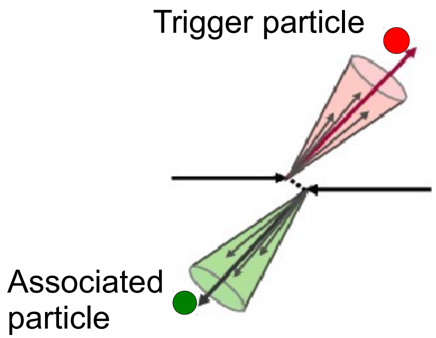
θ – polar angle

Φ – azimuthal angle

Understanding two particle angular correlations – specific regions and the physics behind it

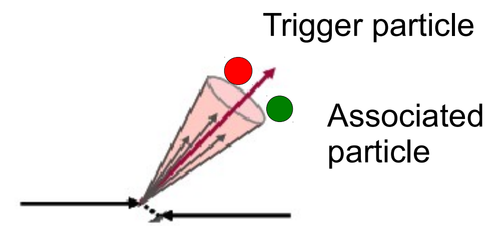


<u>Away side structure</u> (wide Δη, ΔΦ ~ π)
sources: - momentum conservation: minijets, jets
- flow



back-to-back jet

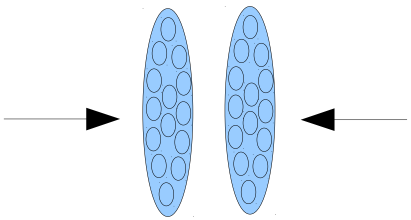
<u>Near side peak</u> (Δη ~ 0, ΔΦ ~ 0)
sources: - minijets, jets
- resonances
- quantum correlations



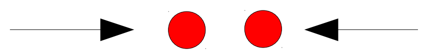
particles emerging from the same jet

Near side ridge (wide Δη, ΔΦ ~ 0)
sources: - flow
- ?

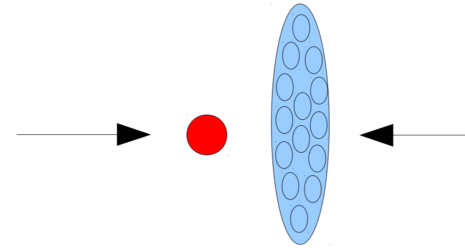
Ridge effect in different collision systems



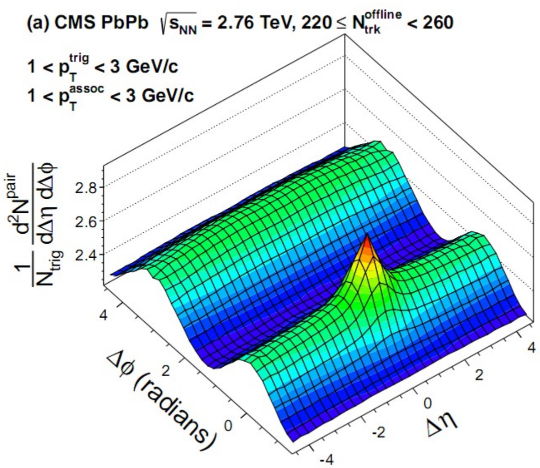
A - A



p - p



p - A



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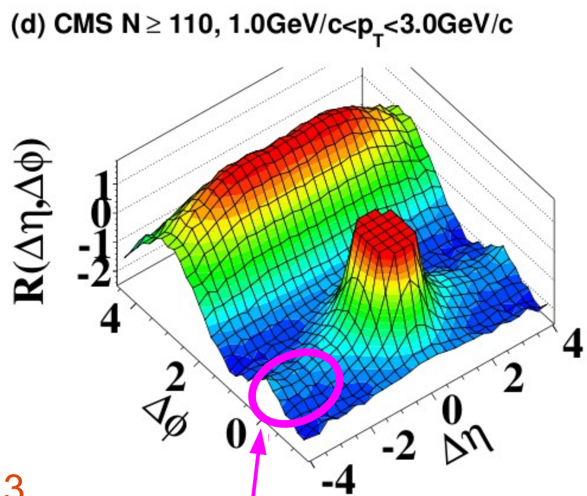
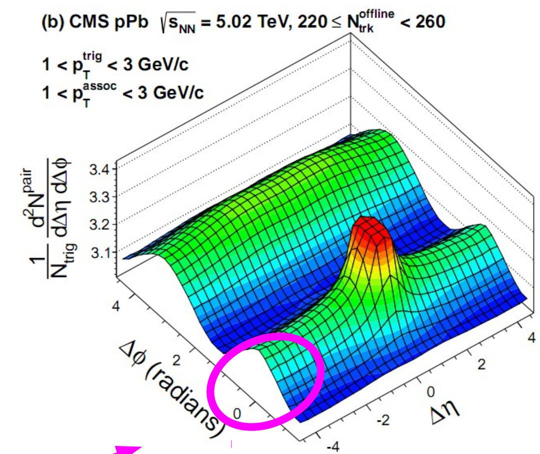


JHEP 1009:091,2010



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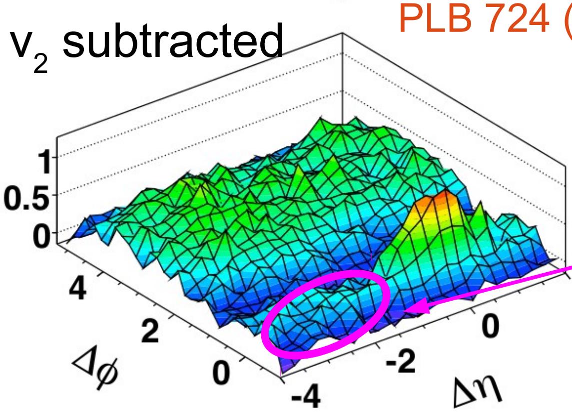
v_2 subtracted



(b) Au+Au 0-30% (PHOBOS)

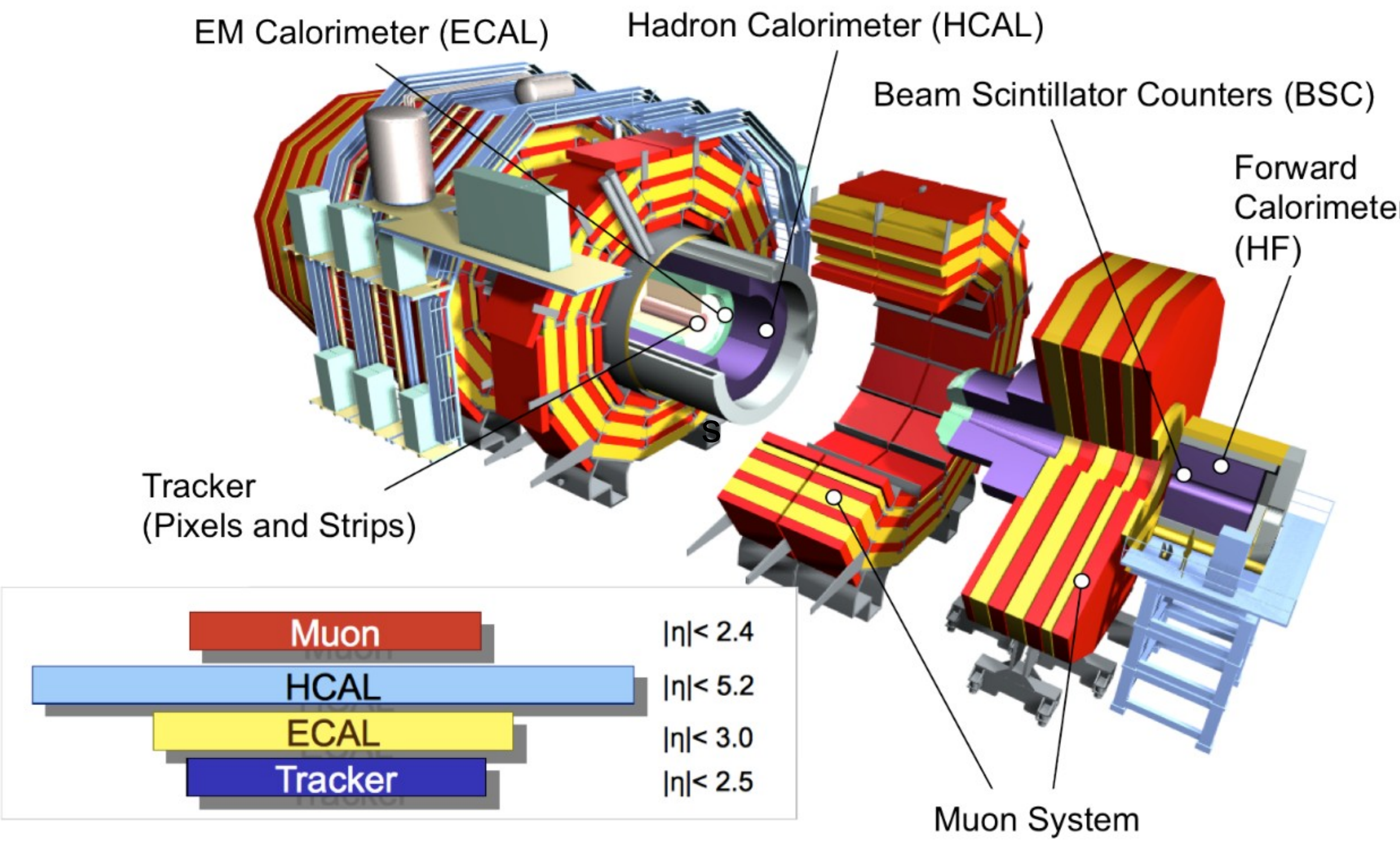
Phys. Rev. Lett. 104, 062301

Near side ridge (wide Δη, ΔΦ ~ 0)

Necessary: High multiplicity

Results from **p-Pb** & **Pb-Pb** are shown in this talk

CMS detector



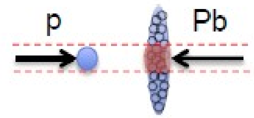
Full acceptance in Φ and large acceptance in η
→ provides wide domain for correlation analysis

Subdetectors used for flow studies

- Tracker |Δη| up to 5 (charged hadrons)
- HF (Event plane and centrality determination)

Exploring the ridge

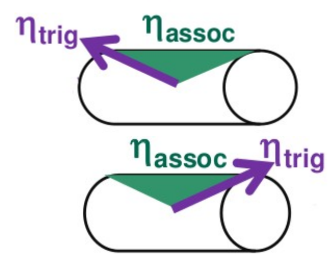
Fixed trigger η, unidentified charged particles

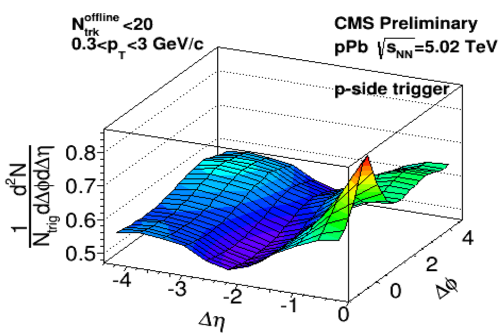


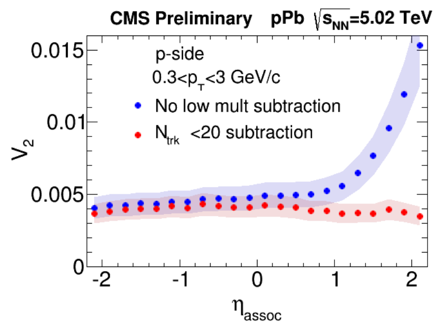
HIN-14-008

$$-2.4 < \eta_{trig} < -2.0$$

$$2.0 < \eta_{trig} < 2.4$$





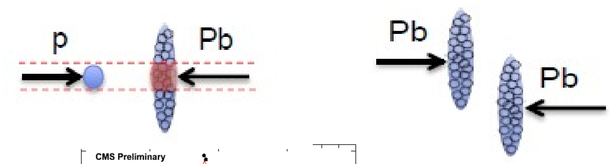


$v_2(\eta_{assoc})$

η dependence of the ridge

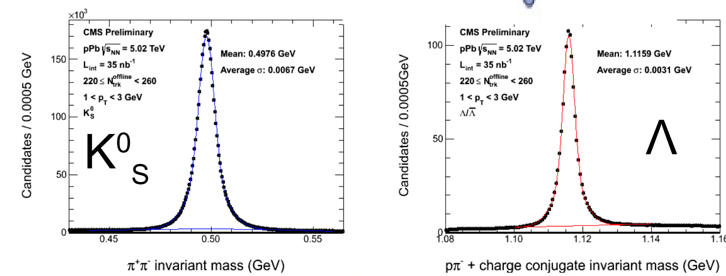
Examining $v_2(\eta)$ and v_3 (η) anisotropy parameters.

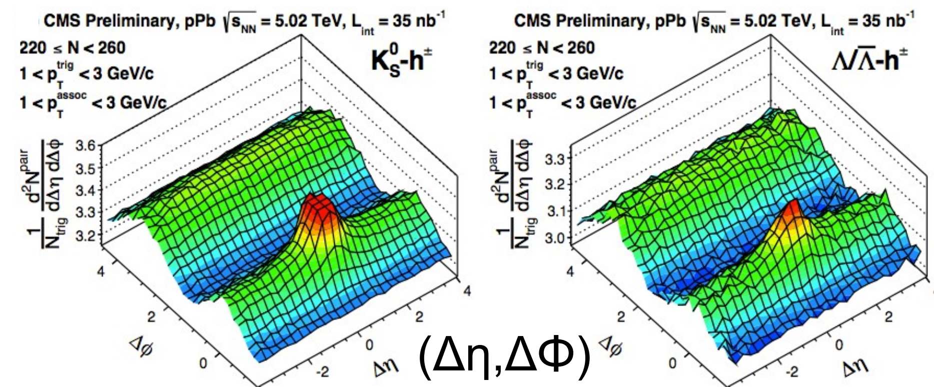
Integrated trigger η, identified particles (K^0_S and Λ)



HIN-14-002

PID





$(\Delta\eta, \Delta\Phi)$ Correlation functions

(K^0_S) - (charged) and **(Λ) – (charged)** correlations

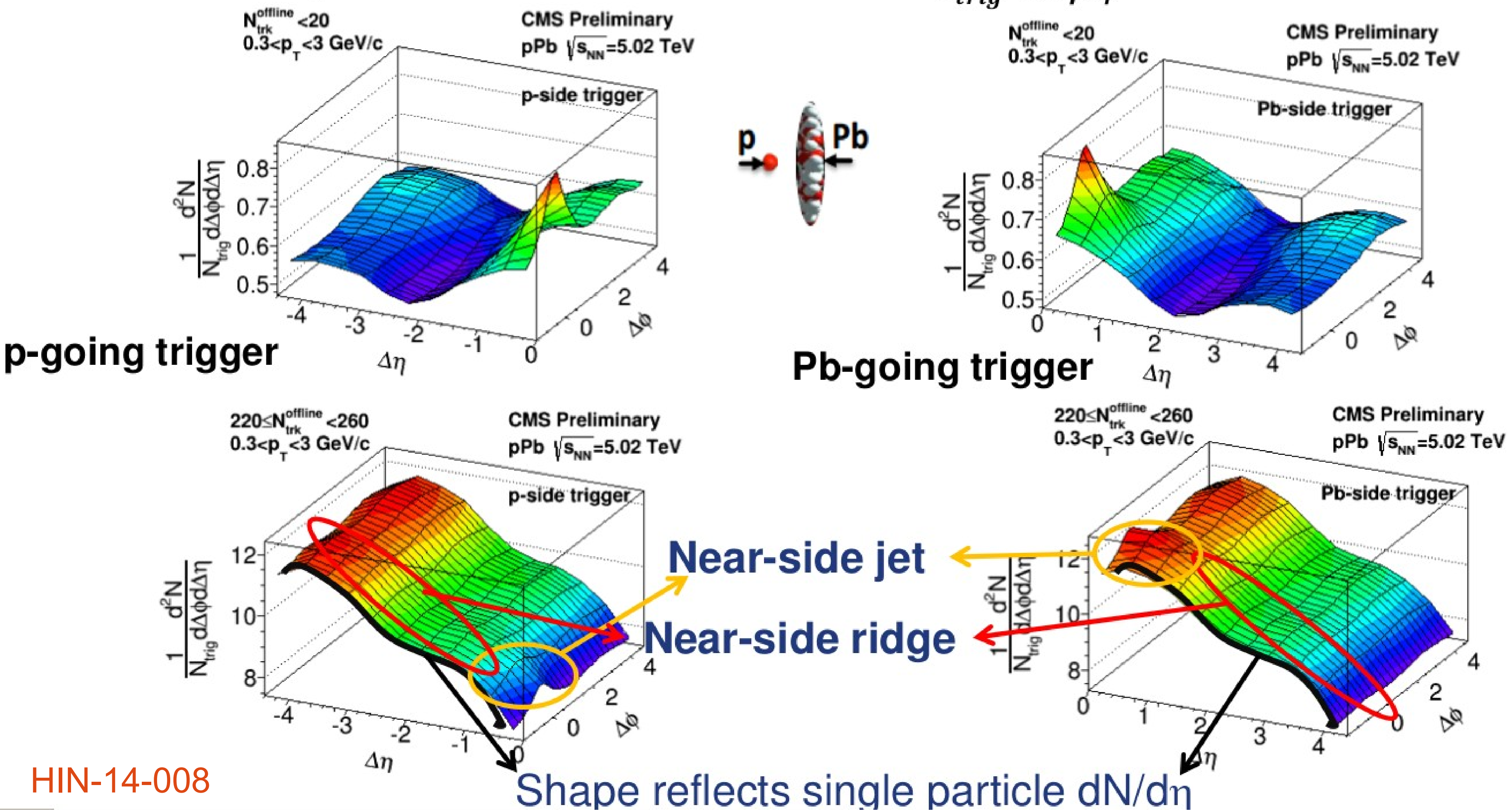
Examining v_2 and v_3 anisotropy parameters: mass ordering, v_2 crossing and quark number scaling

charged = all charged particles

Fixed trigger η technique

Dihadron techinique: $\Delta\phi = \phi_{assoc} - \phi_{trig}, \Delta\eta = \eta_{assoc} - \eta_{trig}$

Not divided by mixed events: $S(\Delta\eta,\Delta\phi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta\Delta\phi}$



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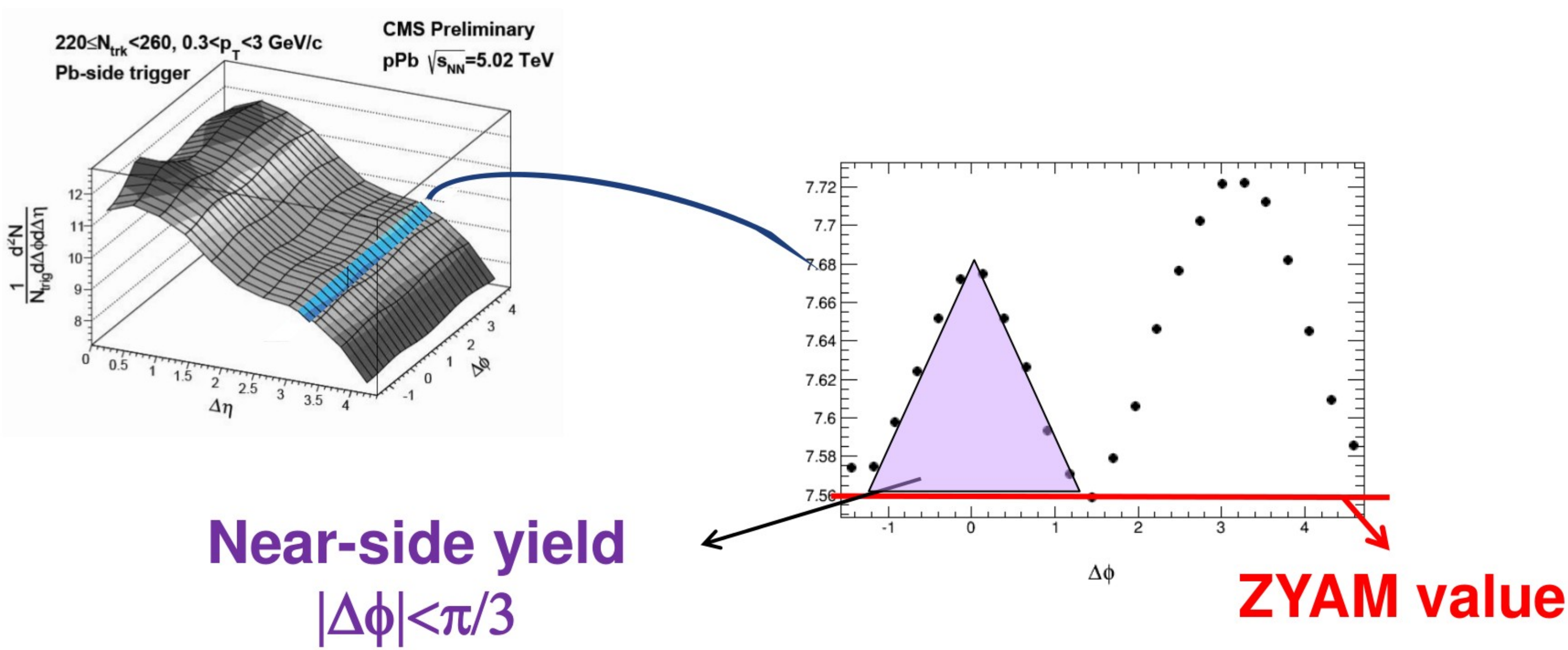
ZYAM method

- For each $\Delta\eta$ slice, step through the $\Delta\phi$ range with $\Delta\phi$ width of 0.26 to find the minimum value.
- After ZYAM subtraction, near-side yield is calculated by integrating over $|\Delta\phi|<\pi/3$



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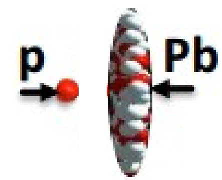
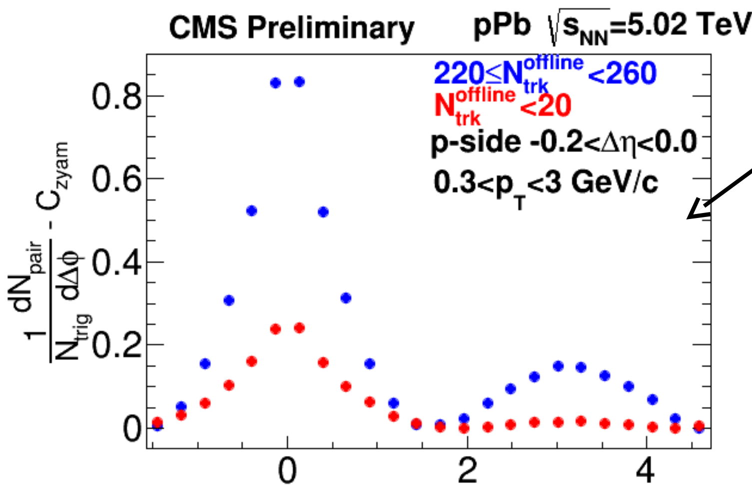
ΔΦ distribution of correlated yield after ZYAM subtraction

p-going trigger

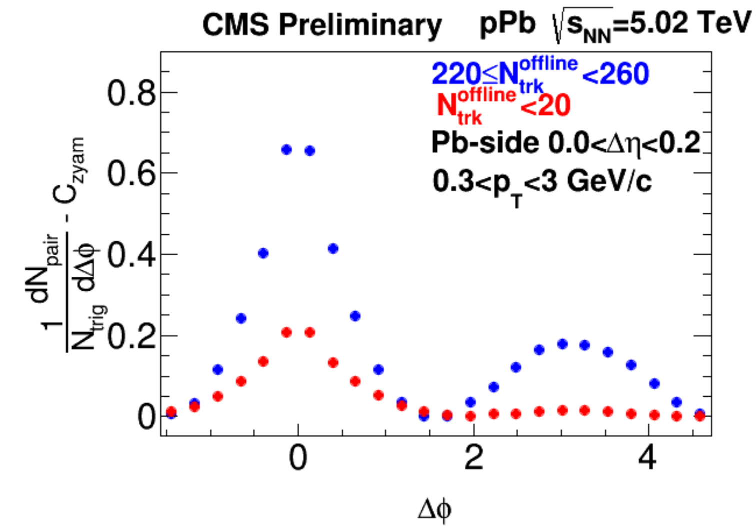


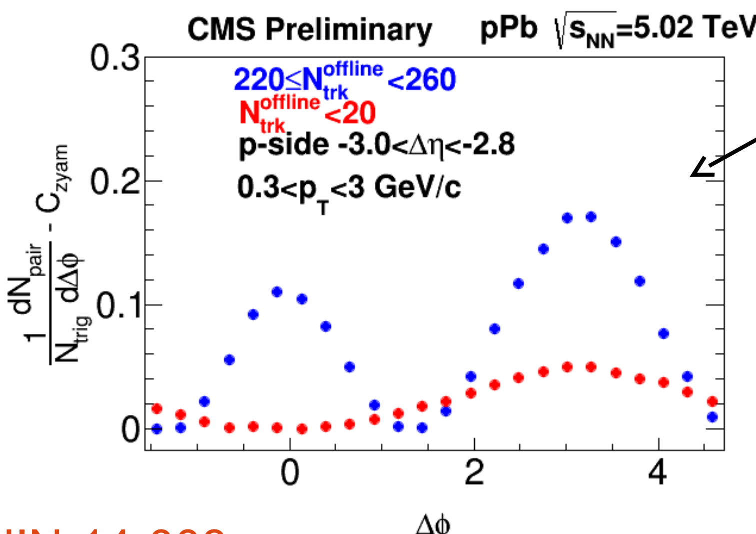
Pb-going trigger



Jet region

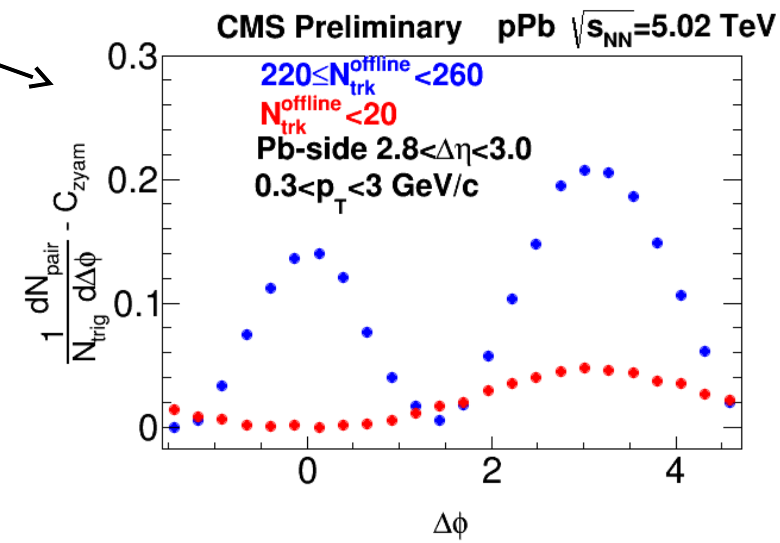
$|\Delta\eta| < 0.2$





Ridge region

$2.8 < |\Delta\eta| < 3.0$



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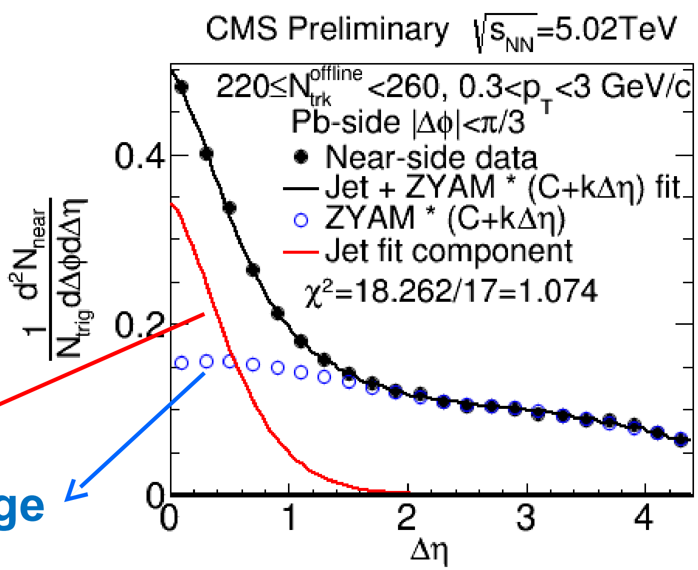
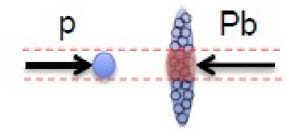
Near-side jet and ridge decomposition

Δη distribution of correlated yield after ZYAM subtraction $|\Delta\phi|<\pi/3$





Pb-going trigger

Use a fit function representing jet + ridge structure:

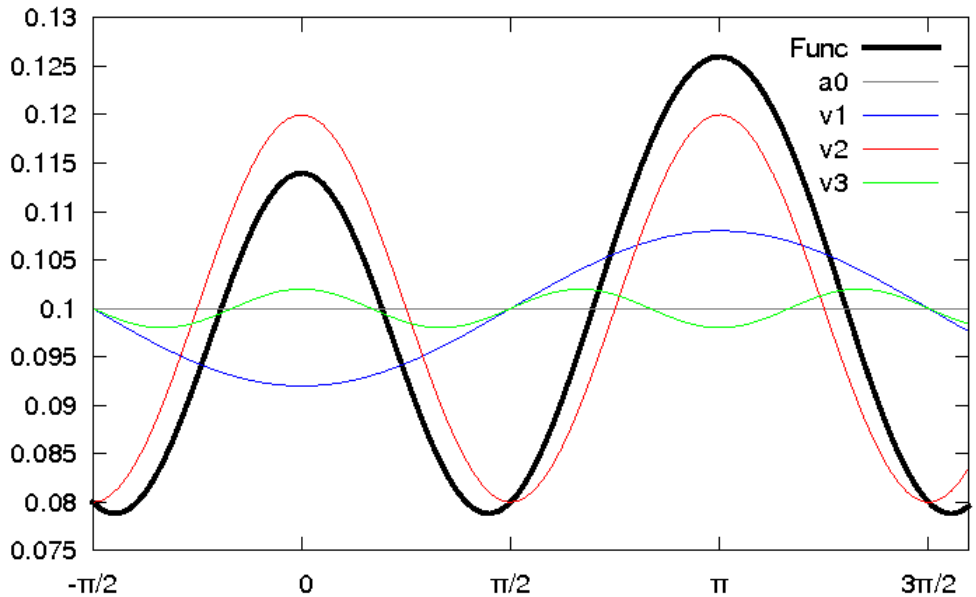
$$\frac{1}{N_{trig}}\frac{dN_{near}(\Delta\eta)}{d\Delta\eta} = \frac{Y\beta}{\sqrt{2}\sigma\Gamma(1/2\beta)}\exp[-(\frac{\Delta\eta^2}{2\sigma^2})^{\beta}] + (C+k\,\Delta\eta)\times ZYAM(\Delta\eta)$$

Jet yield high-multiplicity/low-multiplicity ratio:

$$\frac{Y_{jet}(220 \le N_{trk}^{offline} < 260)}{Y_{jet}(N_{trk}^{offline} < 20)} = \begin{cases} 3.08 \pm 0.11 \text{ (p-side trigger)} \\ 3.13 \pm 0.09 \text{ (Pb-side trigger)} \end{cases}$$

HIN-14-008

Fourier coefficients V_N from two-particle angular correlations



Fourier decomposition:

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

Factorization assumption:

$$V_n(\eta^{trig},\eta^{assoc}) = v_n(\eta^{trig})\, v_n(\eta^{assoc})$$

$$v_n(\eta^{assoc}) = \frac{V_n(\eta^{trig},\eta^{assoc})}{v_n(\eta^{trig})}$$

$v_n(0)$ normalized anisotropy:

$$\frac{v_n(\eta^{assoc})}{v_n(0)} = \frac{V_n(\eta^{trig},\eta^{assoc})}{V_n(\eta^{trig},0)}$$

V_n two-particle anisotropy harmonic

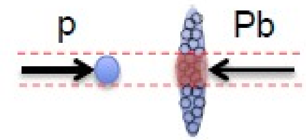
v_n single-particle anisotropy harmonic

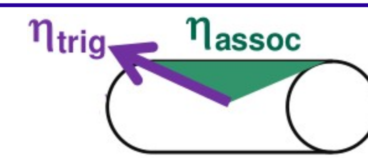
Low-multiplicity subtraction to minimize jet contributions:

$$V_n^{sub} = V_n - V_n(N_{trk}^{offline}<20)\times\frac{N_{assoc}(N_{trk}^{offline}<20)}{N_{assoc}}\times\frac{Y_{jet}}{Y_{jet}(N_{trk}^{offline}<20)}$$

Fourier coefficients V_n from two-particle correlations

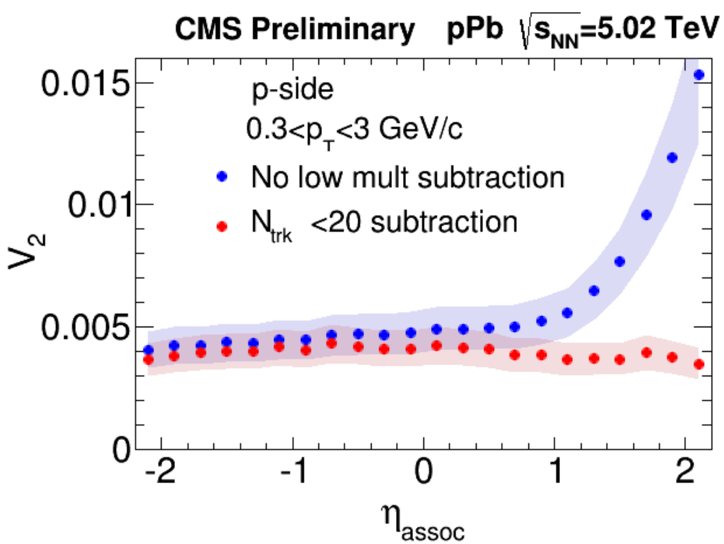
p-going trigger

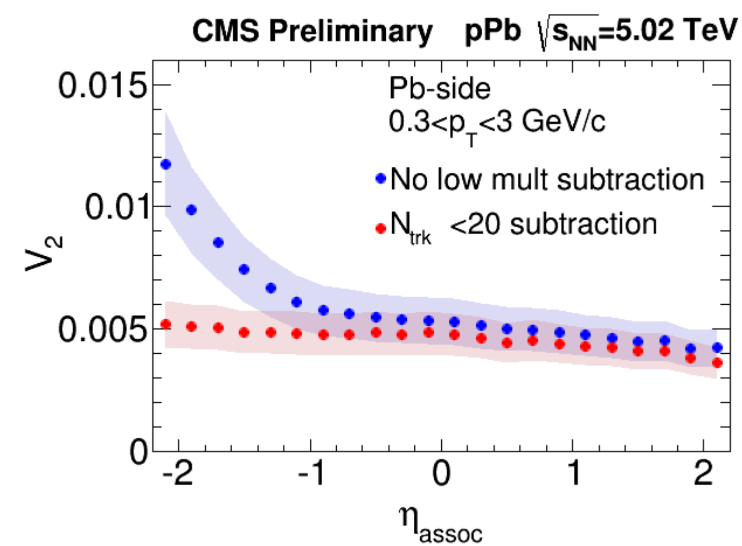




Pb-going trigger

V2

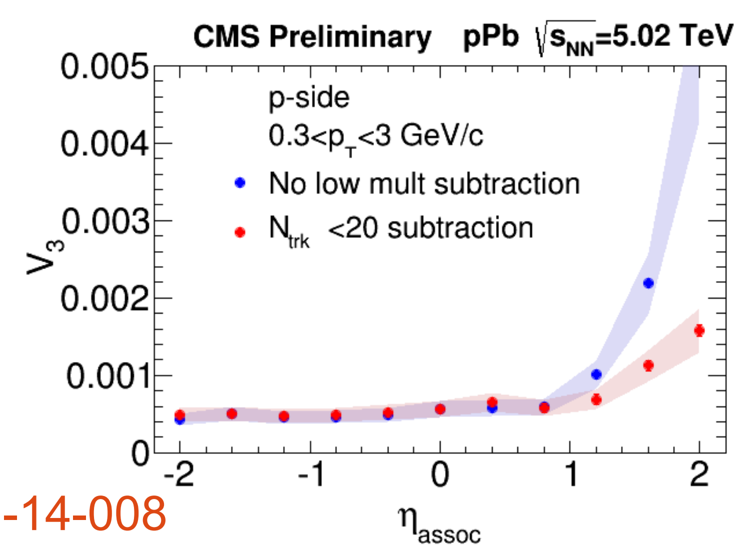


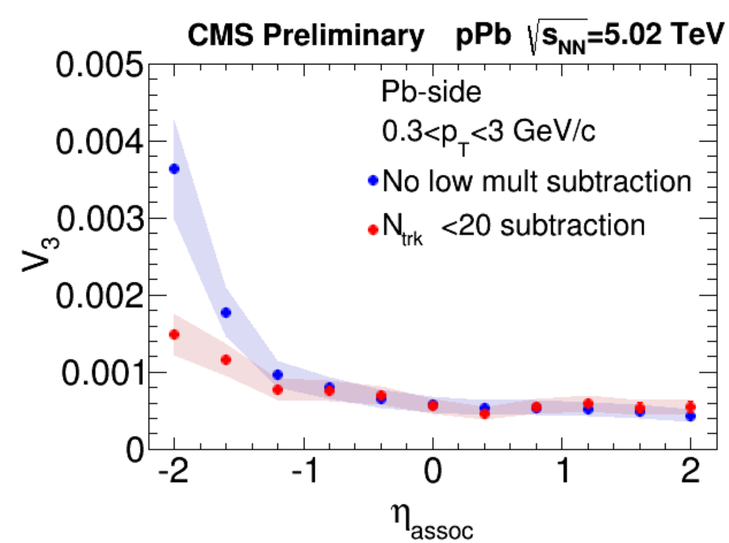


Blue: no jet Subtraction

Red: with jet subtraction

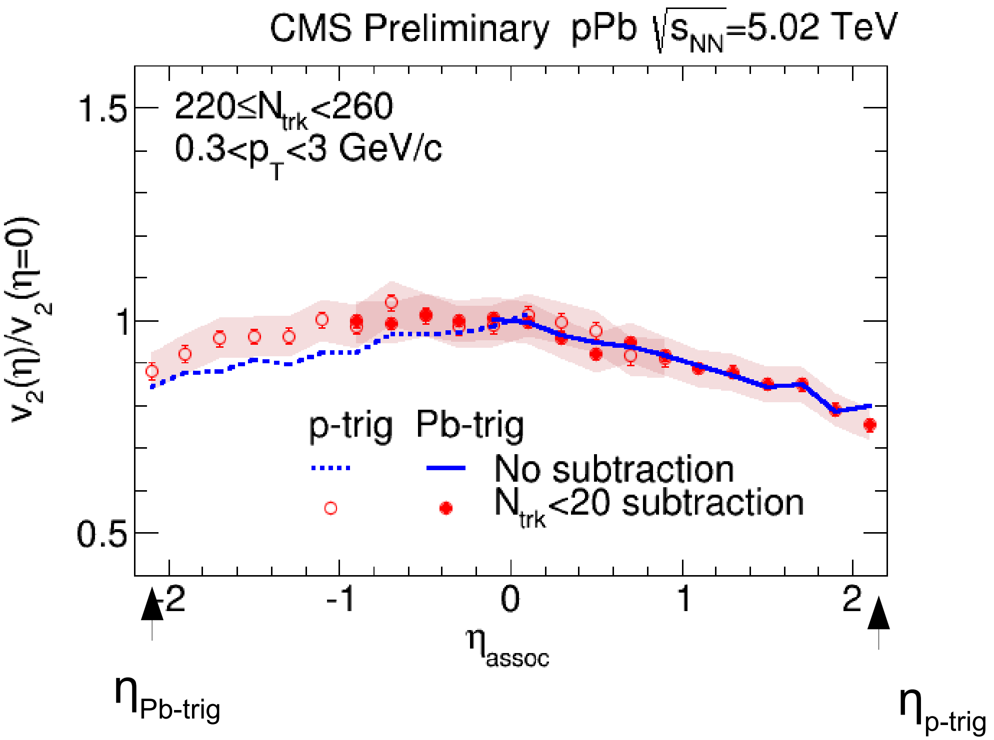
V3

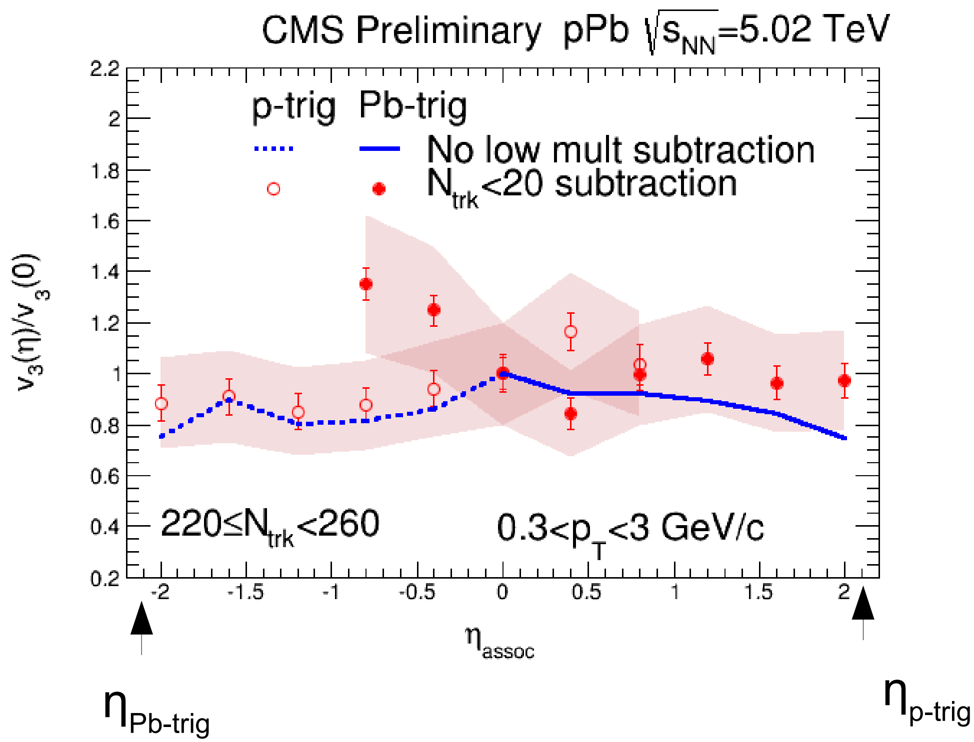




HIN-14-008

$v_n(0)$ normalized anisotropy $= v_n(\eta)/v_n(0)$





- v_2 shape is η dependent !
- v_2 from low-mult. subtraction: asymmetric about mid-rapidity
- With large errors, cannot draw conclusion for v_3

HIN-14-008

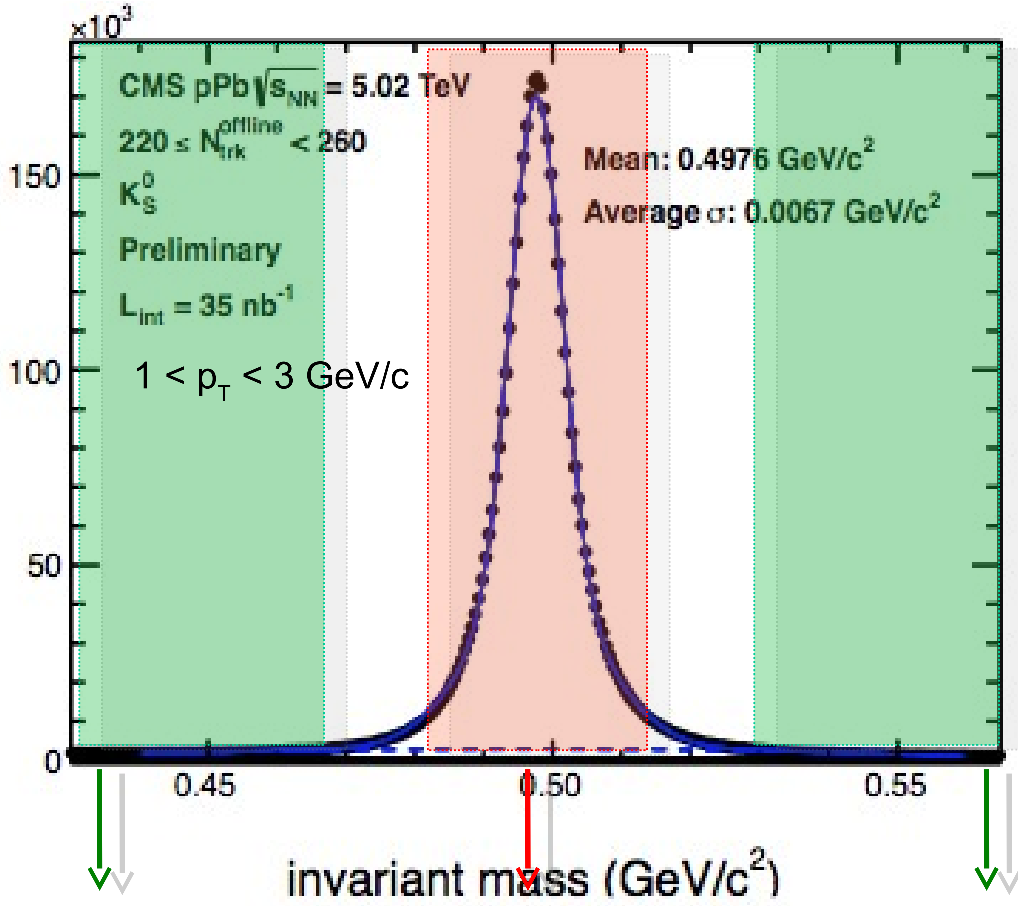
Moving to identified K^0_s and Λ and unidentified charged particle correlations with integrated η

Extraction of the v_2 signal for K^0_S and Λ

$K^0_S \rightarrow \pi^+ + \pi^-$

$\Lambda\ (\bar{\Lambda}) \rightarrow p + \pi^-\ (\bar{p} + \pi^+)$

V^0 reconstruction mass assumption



Peak region:
Background + signal candidates,
Extraction of v_n^{obs},
Calculation of signal fraction
f = signal yield/total yield = S/(S+B)

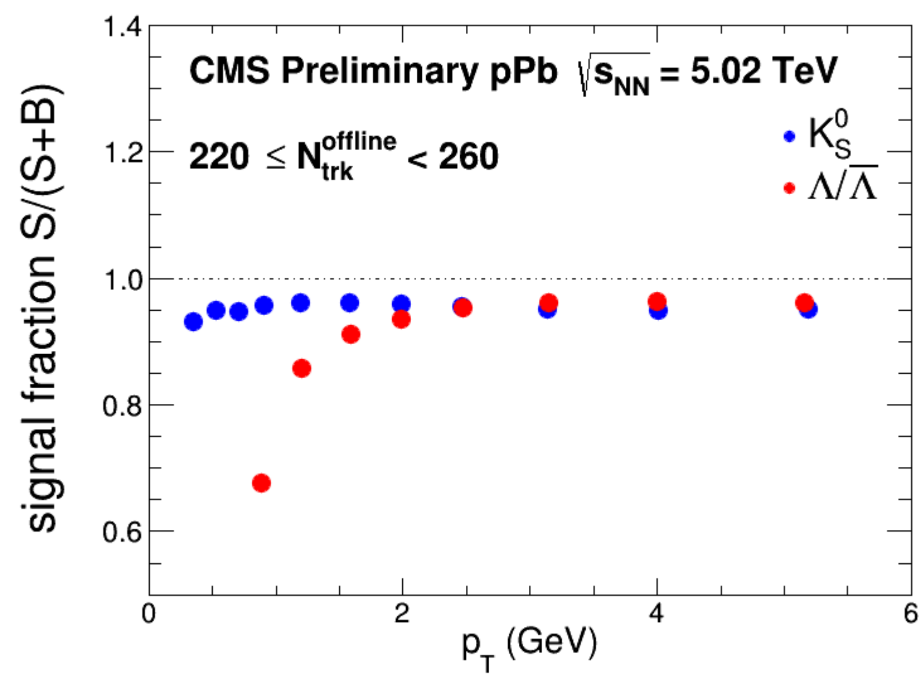
Sideband background region:
Only background candidates,
Extraction of v_n^{bkg}

Sideband background region > -3σ

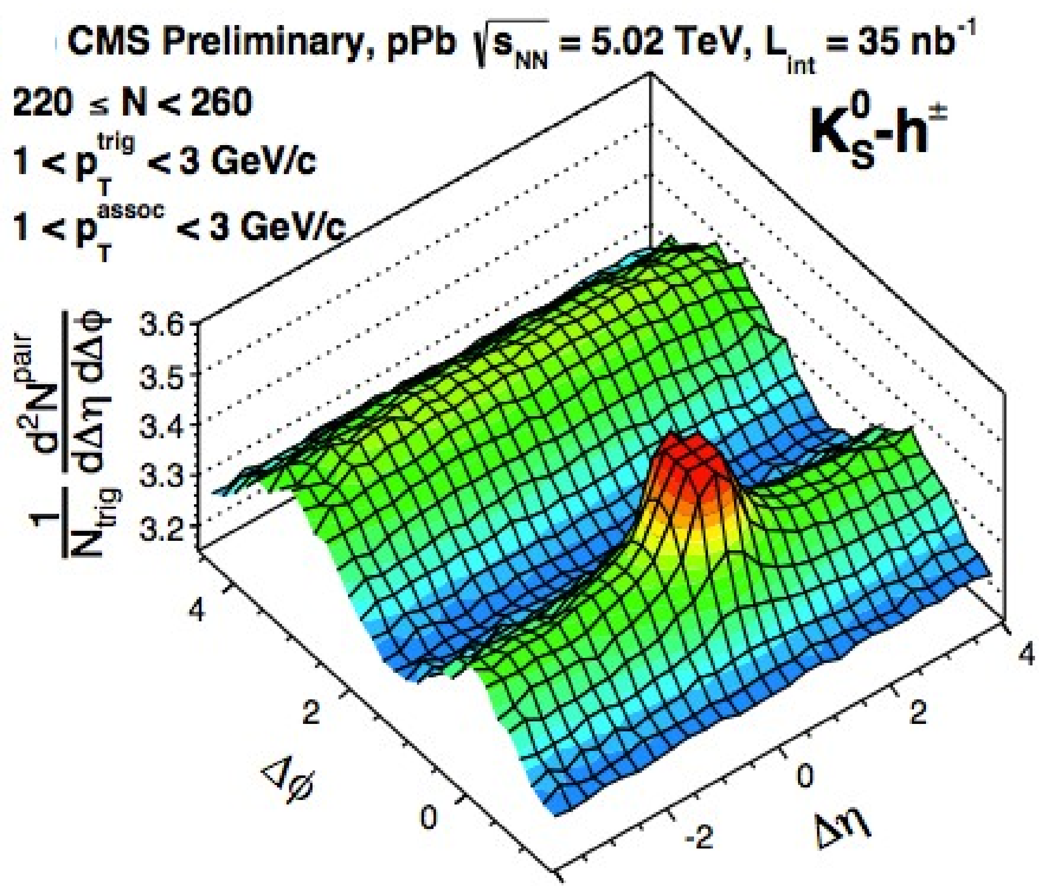
±2σ Peak region

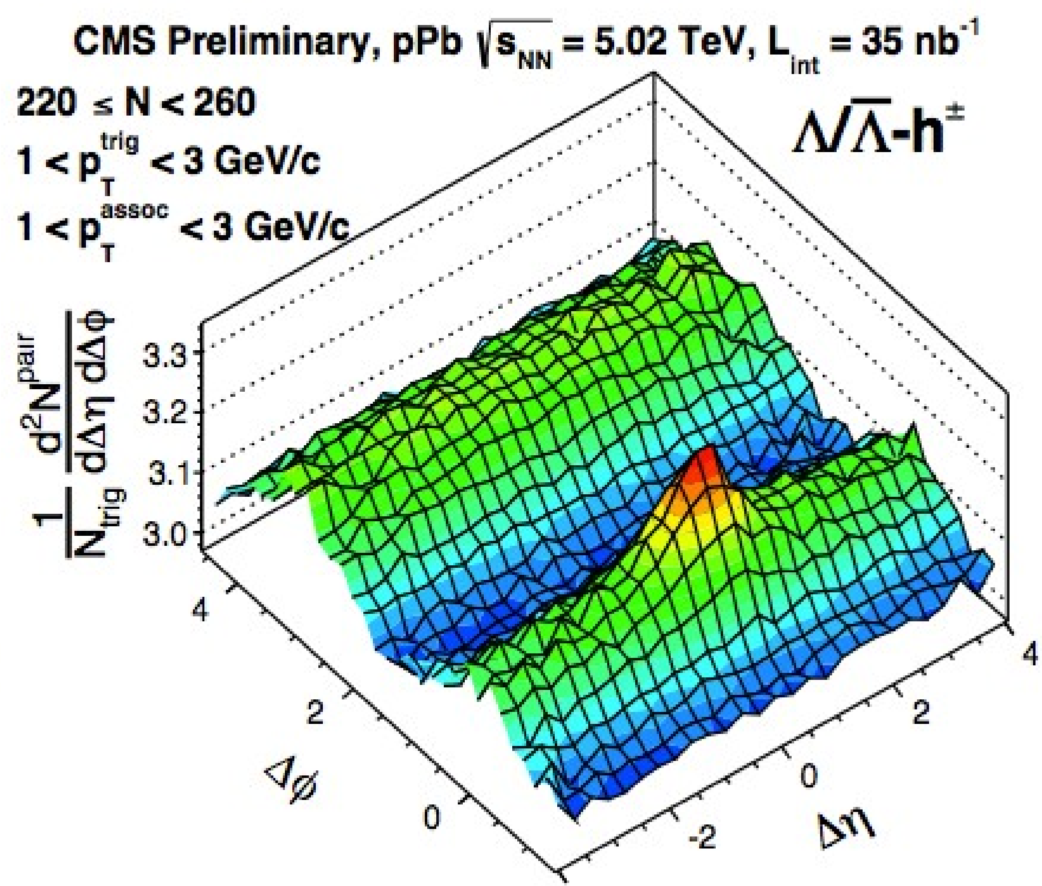
Sideband background region > 3σ

HIN-14-002



Two-particle correlation function





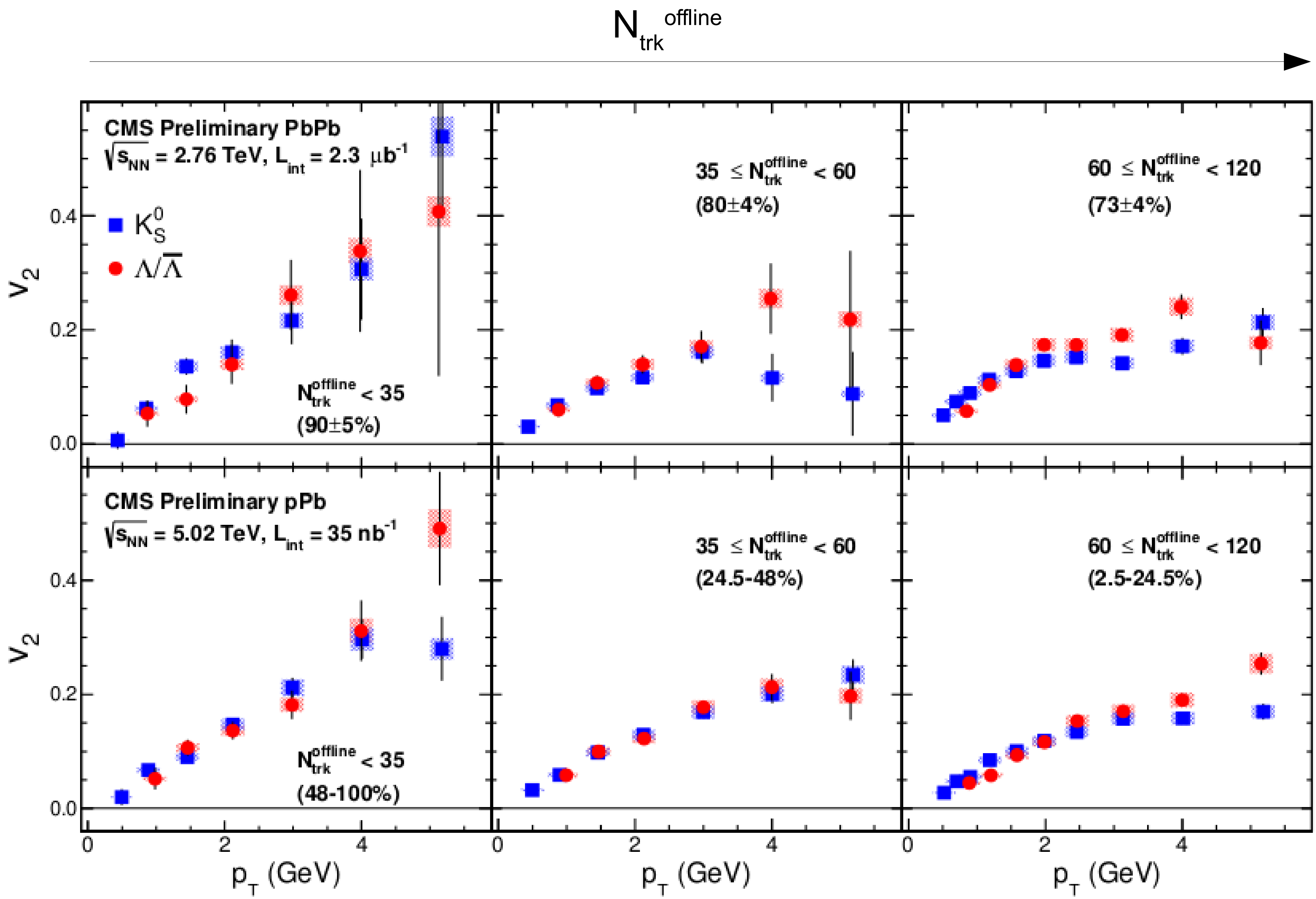
(K^0_S) – (charged) correlations
trigger associated

(Λ) – (charged) correlations
trigger associated

charged = all charged particles

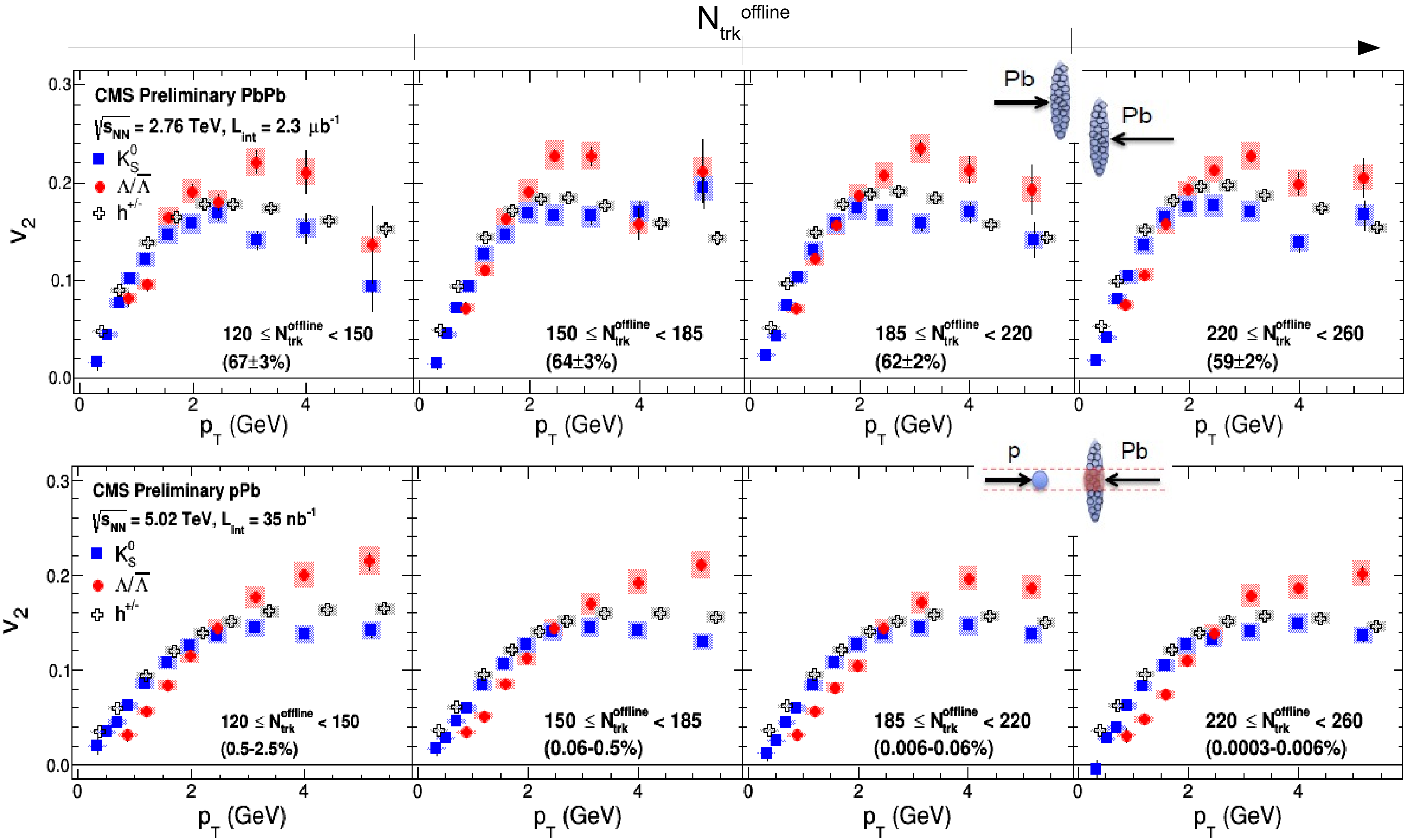
HIN-14-002

Low multiplicity: pPb and PbPb collisions



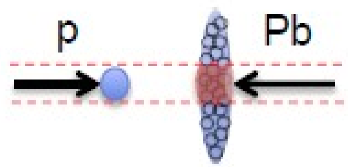
HIN-14-002

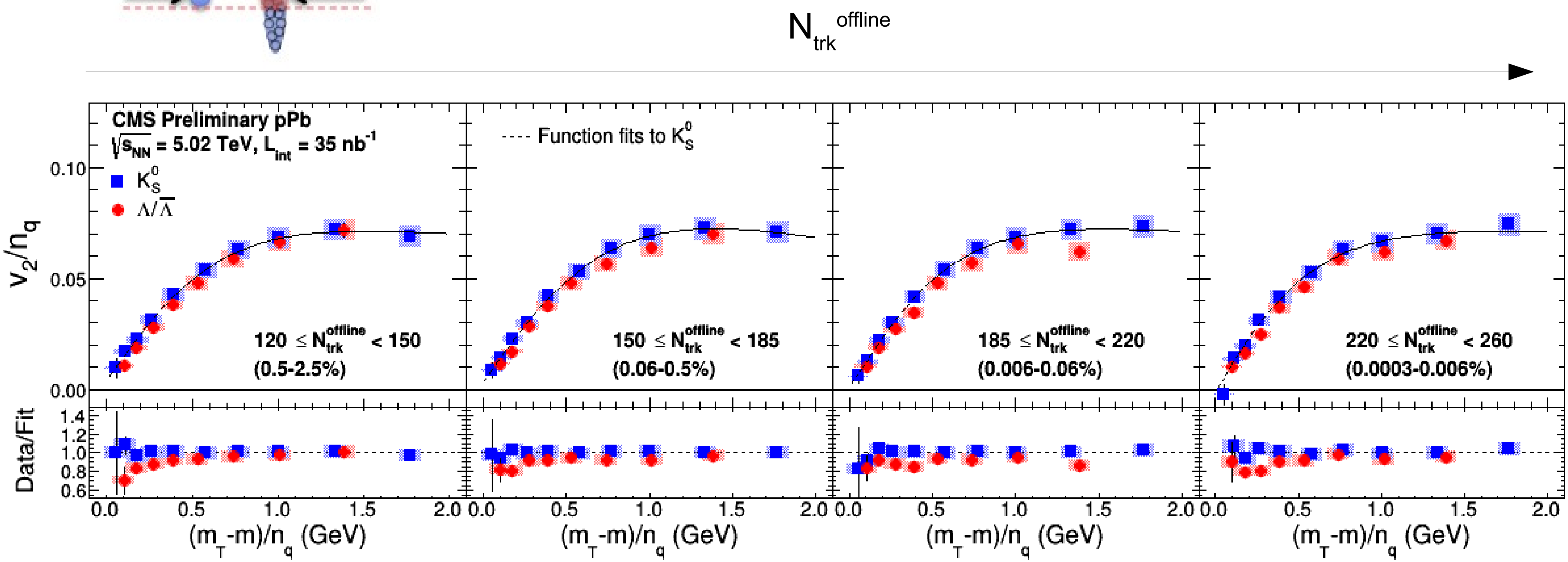
Higher multiplicity class: pPb and PbPb collisions



HIN-14-002

NCQ scaling in high multiplicity pPb collisions





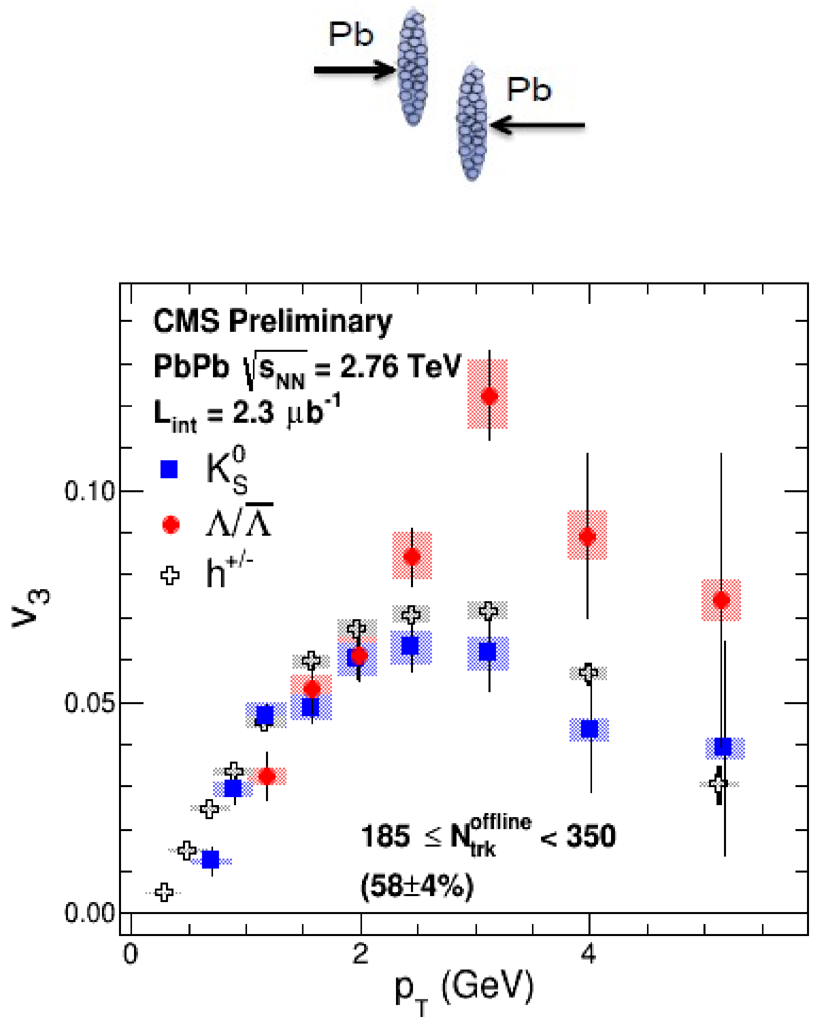
$KE_T = m_T - m$

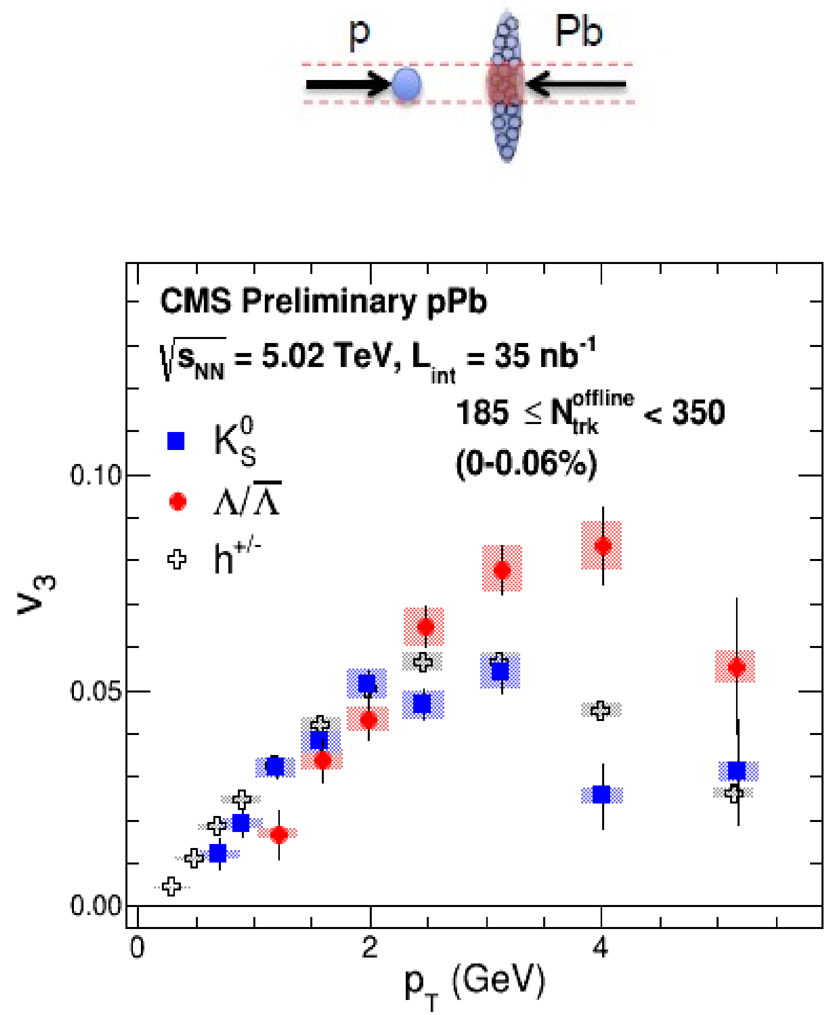
$$m_T = \sqrt{m^2 + p_T^2}$$

scaling holds better than 10% over most of the KE_T/n_q range, except for $KE_T/n_q < 0.2$ GeV where the deviation grows to about 20%.

HIN-14-002

v_3 in higher multiplicity





Cross-over (above ~ 2 GeV/c) observed

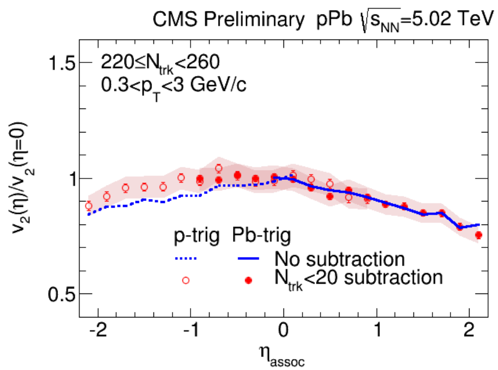
HIN-14-002

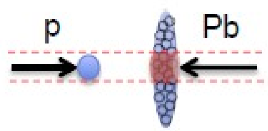
Summary

η dependence of the ridge

p-going trigger

Pb-going trigger

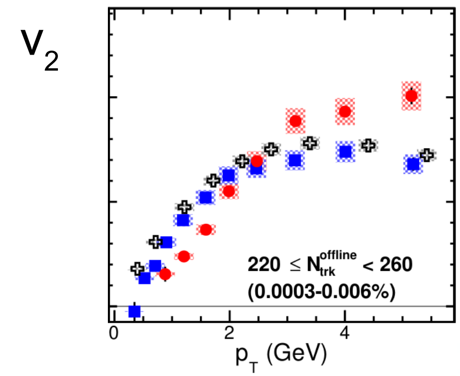




HIN-14-008

- Ridge yield depends on η
- Significant η dependence observed for v_2

(K^0_s) - (charged) and **(Λ) – (charged)** correlations



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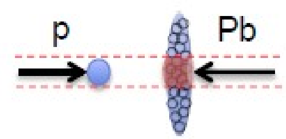
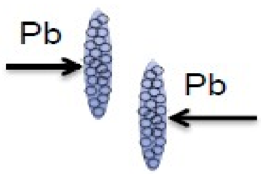


vs.



- Mass ordering $v_2(\Lambda) < v_2(K^0_S)$, is observed in pPb collisions and is more prominent compared to PbPb
- Approximate NCQ scaling of order 10% is observed for v_2 in pPb collisions

Thank you for your attention!

CMS flow and correlations results

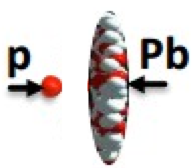
	Analysis	Type	Report	Publication
HIN-10-002	Elliptic flow and low-pt spectra	PbPb	arXiv:1204.1409	PRC 87(2013) 014902
HIN-11-001	Dihadron correlations	PbPb	arXiv:1105.2438	JHEP 07 (2011) 076
HIN-11-006	Dihadron correlations centrality dependence	PbPb	arXiv:1201.3158	EPJC 72 (2012) 2012
HIN-11-009	Neutral pion v_2 in PbPb collisions	PbPb	arXiv:1208.2470	PRL 110 (2013) 042301
HIN-11-012	Azimuthal anisotropy at high p_T	PbPb	arXiv:1204.1850	PRL 109 (2012) 022301
HIN-12-015	Ridge (2-particle correlations) in pPb	pPb	arXiv:1210.5482	PLB 718 (2013) 795
HIN-13-002	2- and 4-particle correlations in pPb	pPb	arXiv:1305.0609	PLB 724 (2013) 213
HIN-11-005	Higher order harmonics flow	PbPb	arXiv:1310.8651	PRC 89 (2014) 044906
HIN-12-011	v_n in ultra-central collisions	PbPb	arXiv:1312.1845	JHEP 02 (2014) 088
HIN-12-010	Very high p_T triggered correlations	PbPb	PAS	-
HIN-14-002	Correlations with K^0_S and Λ	pPb & PbPb	arXiv:1409.3392	Submitted to PLB
HIN-14-008	Ridge eta dependence	pPb	PAS	-
HIN-14-006	Multiparticle correlations in pPb	pPb	PAS	-
HIN-14-012	Factorization breaking	pPb & PbPb	PAS	-

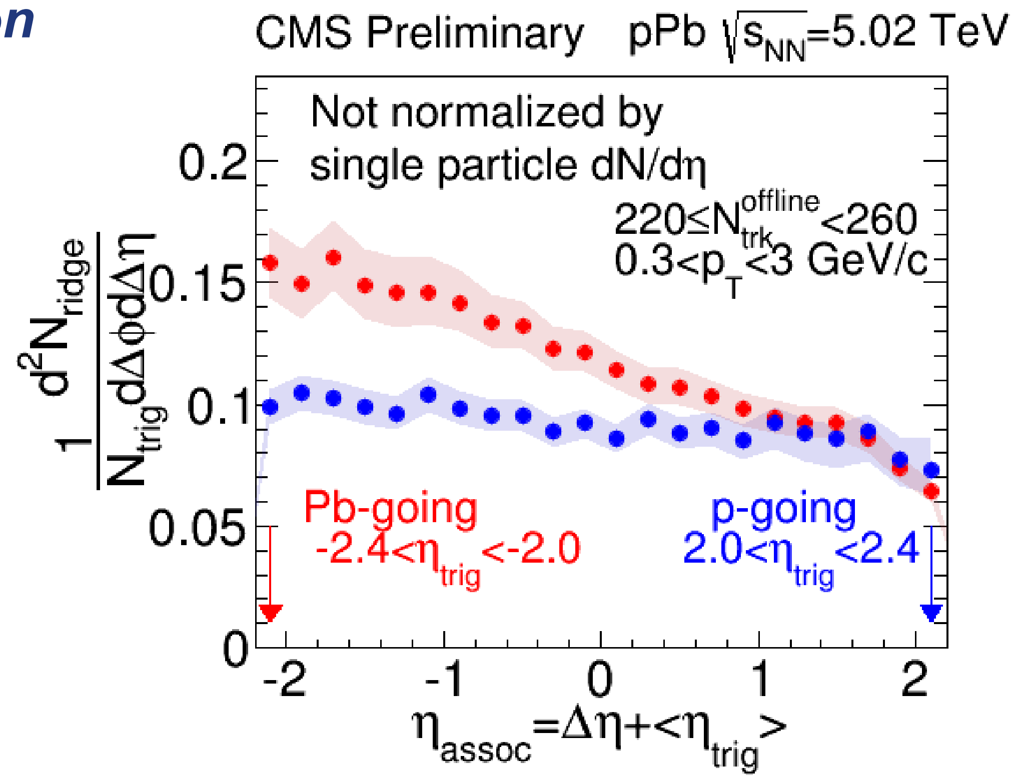
CMS Heavy-Ion Public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Backup

Ridge yield vs η^{assoc}

Near-side ridge after jet subtraction





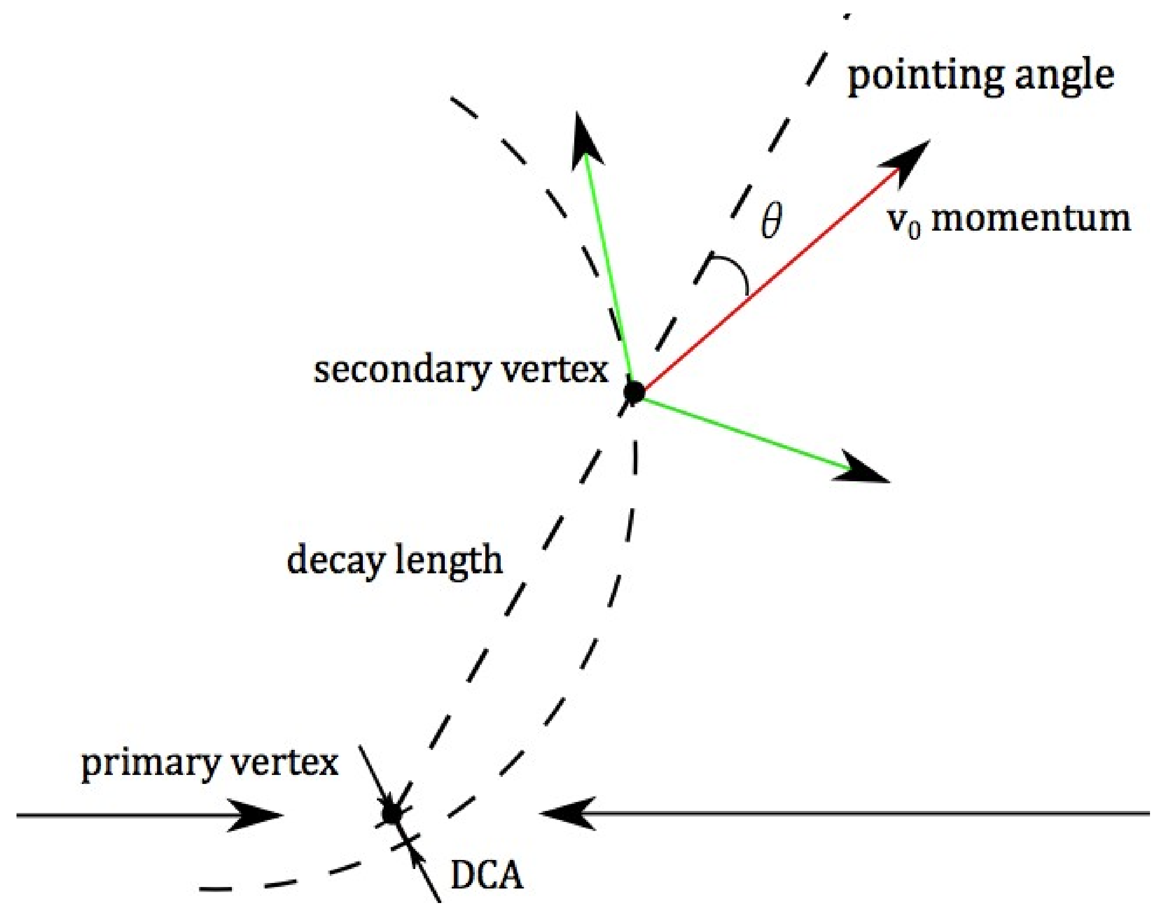
Near-side ridge yield: different η dependences observed for Pb-going trigger and p-going trigger

HIN-14-008

Reconstructing K^0_s and Λ candidates

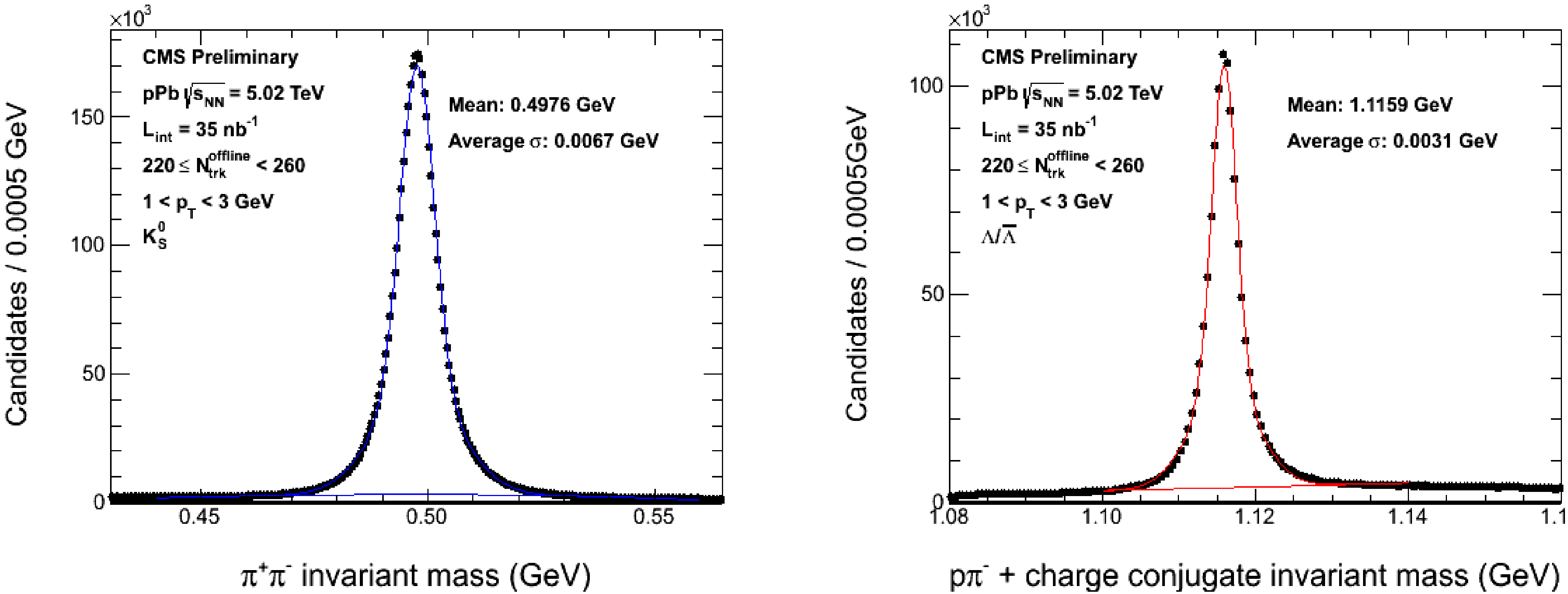
- The K^0_s and Λ candidates (referred to as V^0) reconstructed by combining oppositely charged pairs of tracks which are detached from the primary vertex and form a good secondary vertex with an appropriate invariant mass.

- K^0_S $\pi^+\pi^-$, $c\tau$ = 2.68 cm
- Λ $p^+\pi^-$, $c\tau$ = 7.89 cm
- $\cos(\theta^{point}) > 0.999$
- Distance-of-closest approach of V^0 momentum vector and primary vertex < 0.5 cm
- 3D separation between primary and V^0 vertex > 5σ



HIN-14-002

Reconstructing K^0_s and Λ candidates



HIN-14-002

- Clean signal of K^0_S and Λ reconstructed over a wide range of p_T and η
- Mass values very close to PDG numbers