Study of collective phenomena in pPb collisions by the CMS experiment

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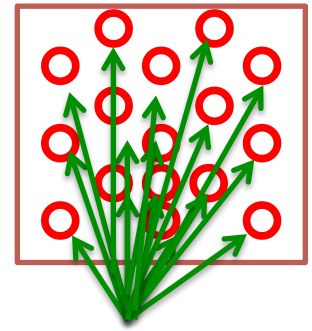
Outline

(I): Multiparticle correlations in pPb

Charged particles: $v_2\{6\}$, $v_2\{8\}$ and $v_2\{LYZ\}$

→ All particle correlations, collective flow?

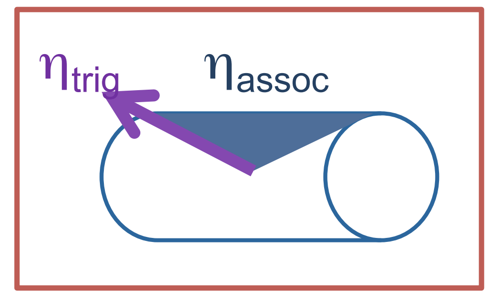


$$g(ir) \equiv e^{irQ_2} \equiv e^{ir\sum_{j=1}^{M}\left(\cos(2\phi_j)+\sin(2\phi_j)\right)}$$

(II): Pseudorapidity dependence

Charged particles: $v_2(\eta)/v_2(0)$ and $v_3(\eta)/v_3(0)$

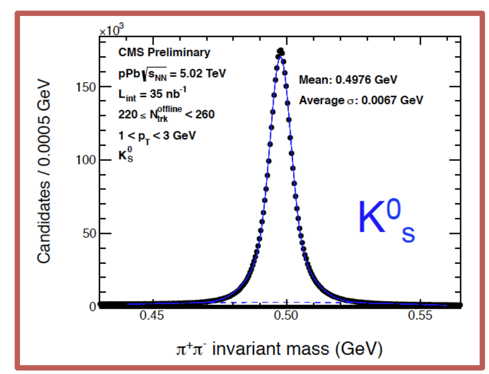
→ More insights, more constraints to models



(III): Identified particles

K^0_S and Λ: v_2 and v_3 vs p_T and multiplicity

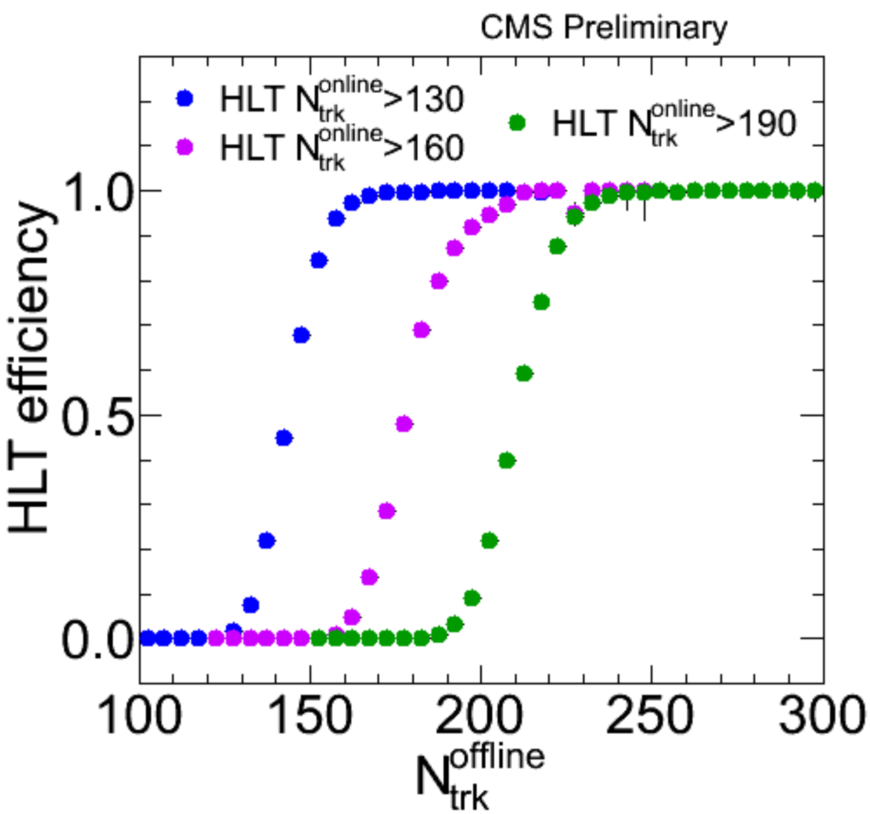
→ Partonic level flow in pPb?

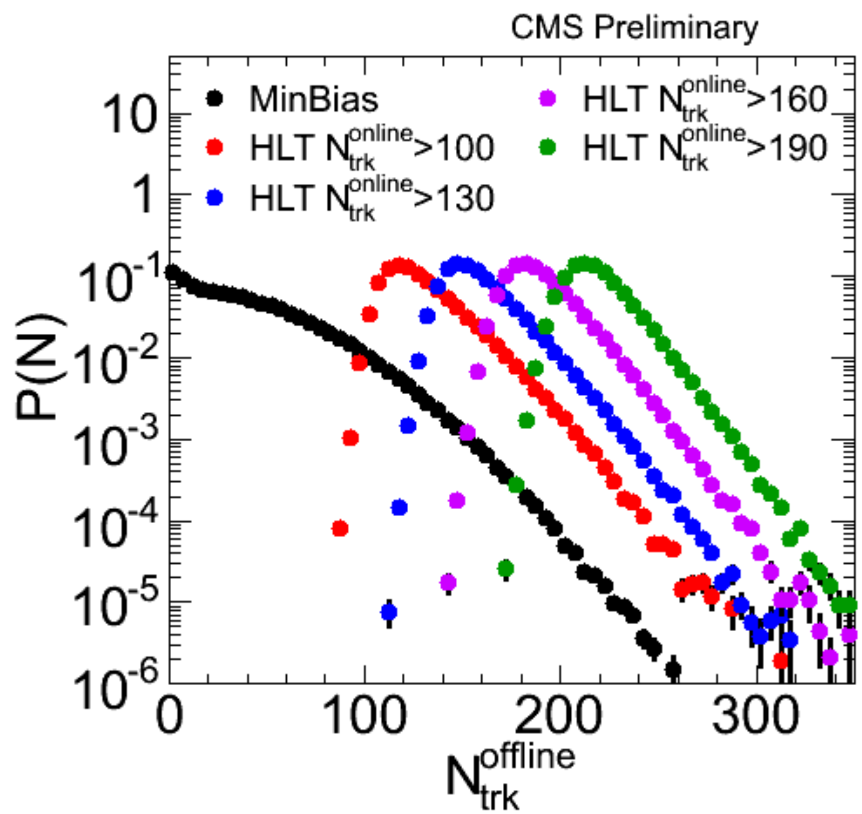


Data sets, triggers and multiplicity distributions

- Data sets
  - 2013 pPb, 35 nb^{-1}
  - 2011 PbPb, 2.3μb^{-1} (50-100%)
- Triggers
  - Minimum bias trigger
  - High multiplicity triggers in 2013

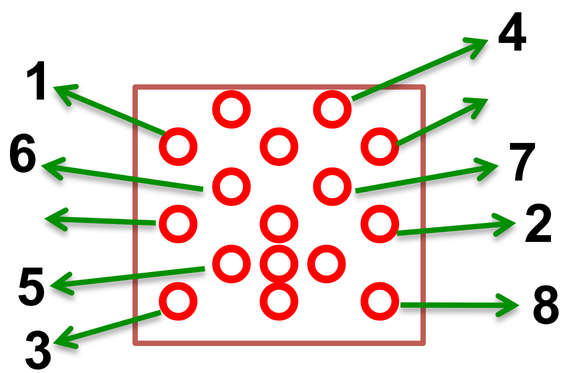
Track ($p_T > 0.4$ GeV/c, $|\eta| < 2.4$) multiplicity distribution in pPb for different triggers



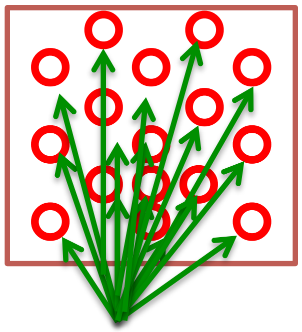


Multiparticle correlations analysis techniques

6- and 8-particle cumulant



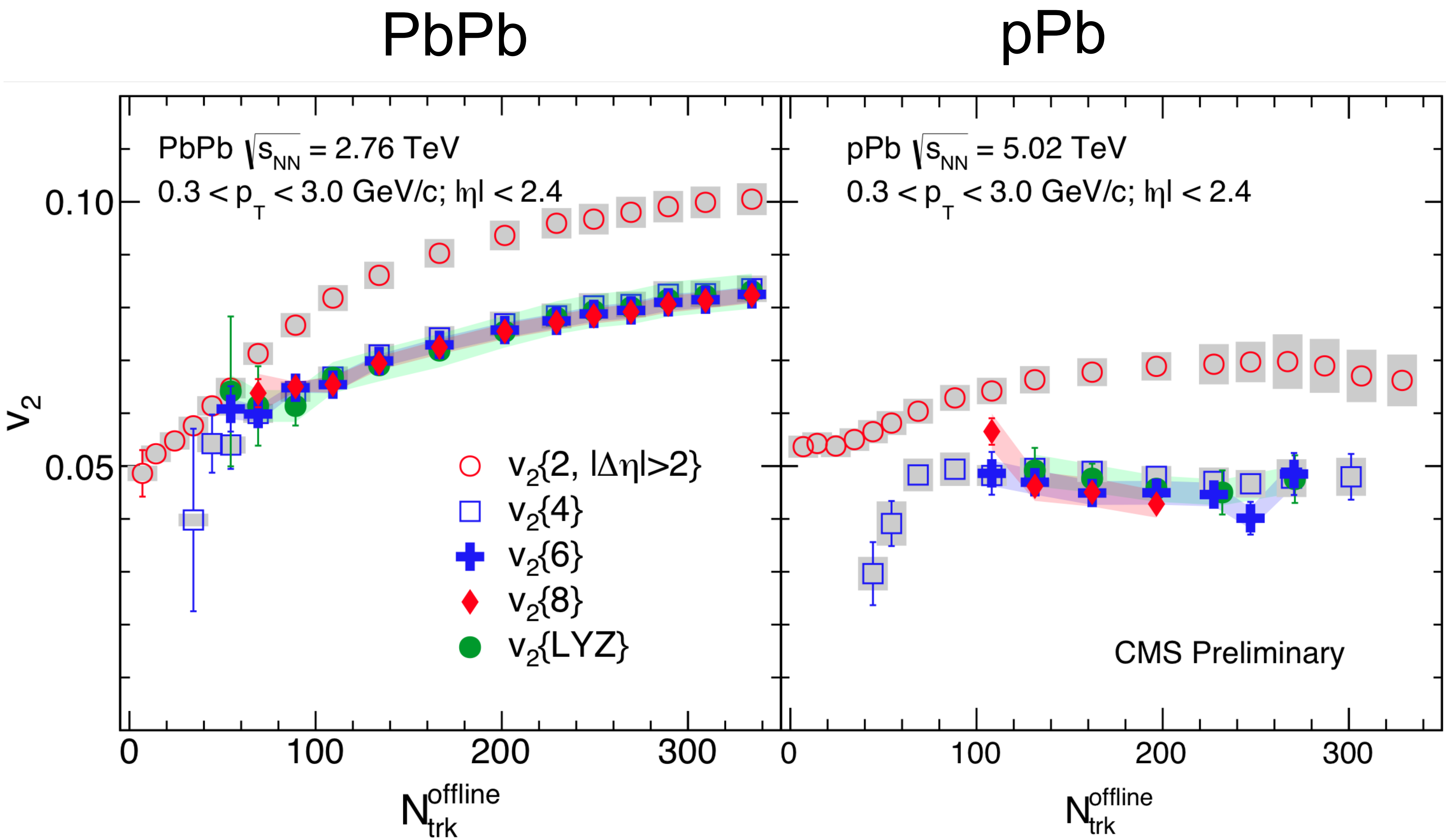
Lee-Yang Zeros



- ➢ Genuine 6- and 8-particle correlations
- ➢ Insensitive to non-flow contributions from less than 6 and 8 particle correlations

- ➢ Genuine all-particle correlations
- ➢ Remove most of the non-flow contributions

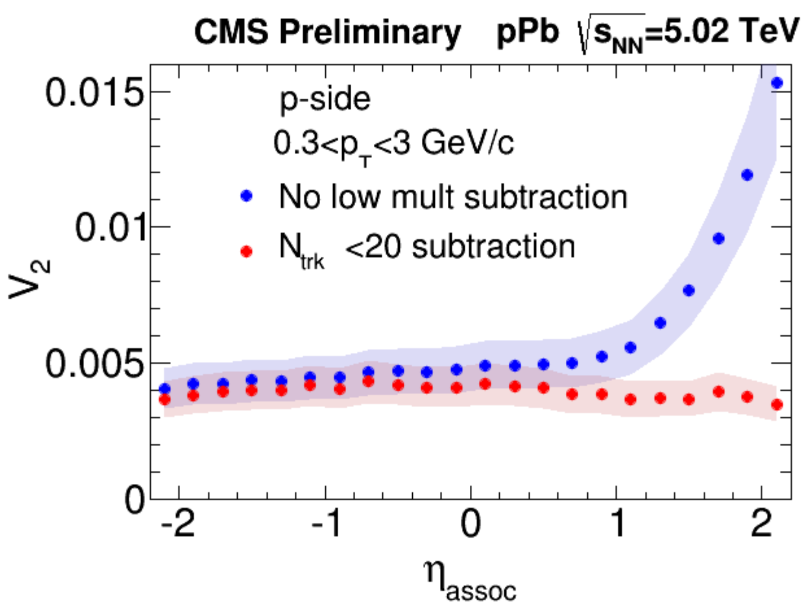
Results: v_2 vs multiplicity



- $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$ and $v_2\{LYZ\}$ agree within 10%

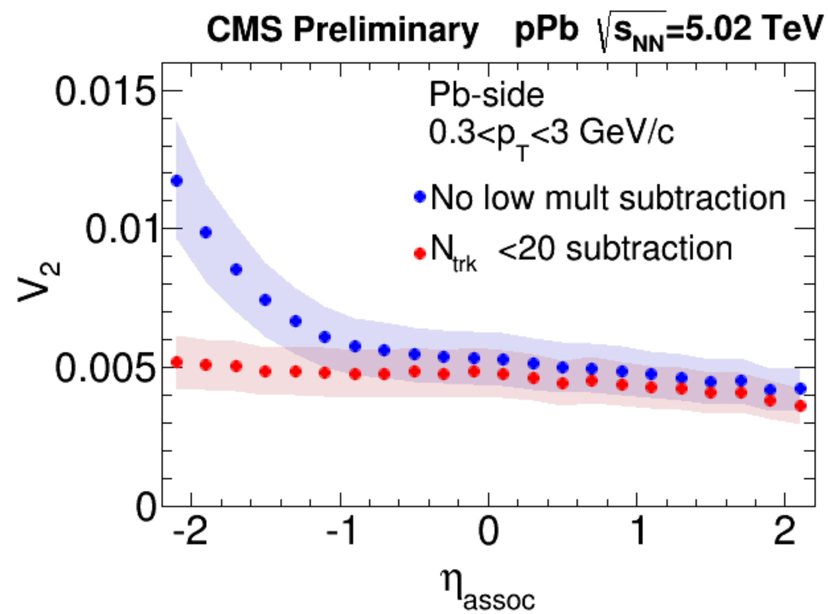
Fourier coefficients V_2 vs η

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



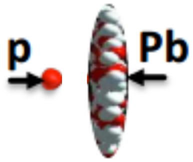
Blue: no jet Subtraction

Red: with jet subtraction

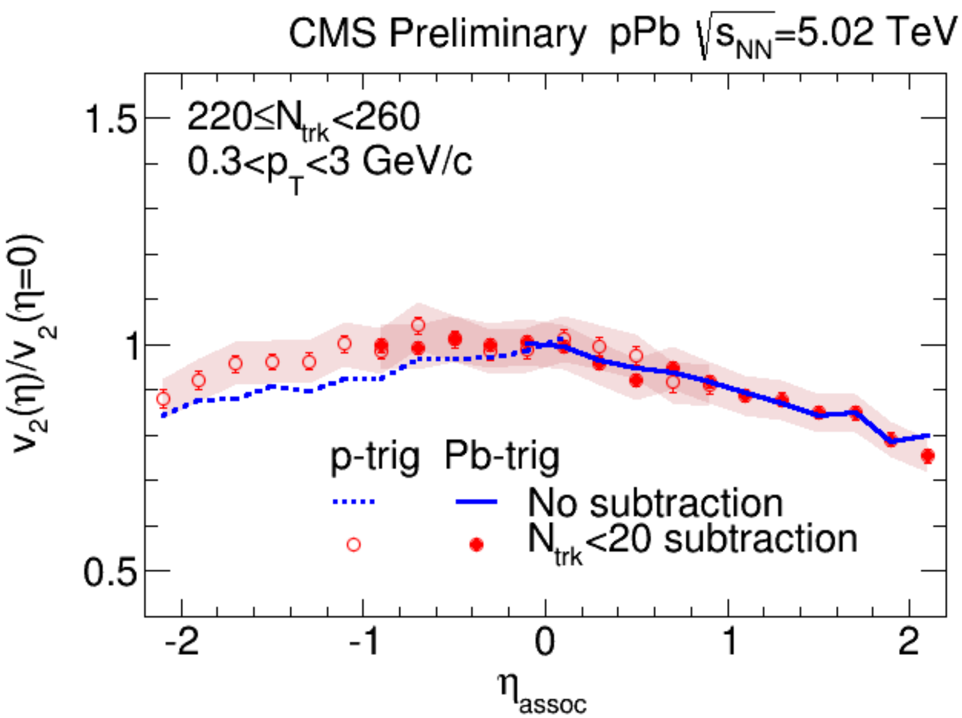


- Jet contribution mostly removed at short range
- Small difference at long range: away side jet contribution is small

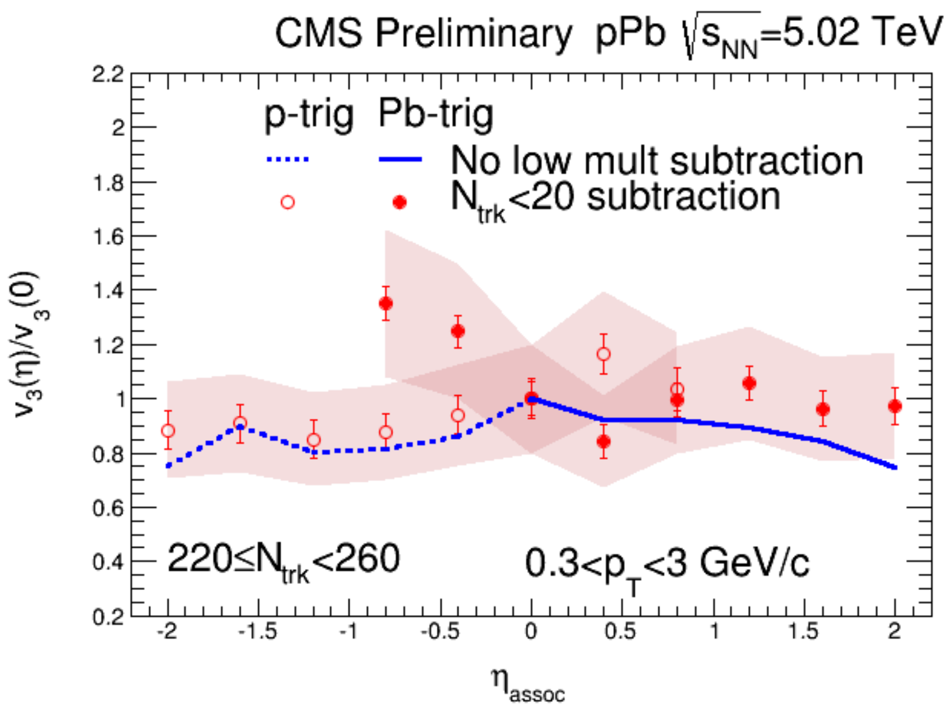
Extract $v_n(\eta)/v_n(0)$ from Fourier coefficient



$v_2(\eta)/v_2(0)$:

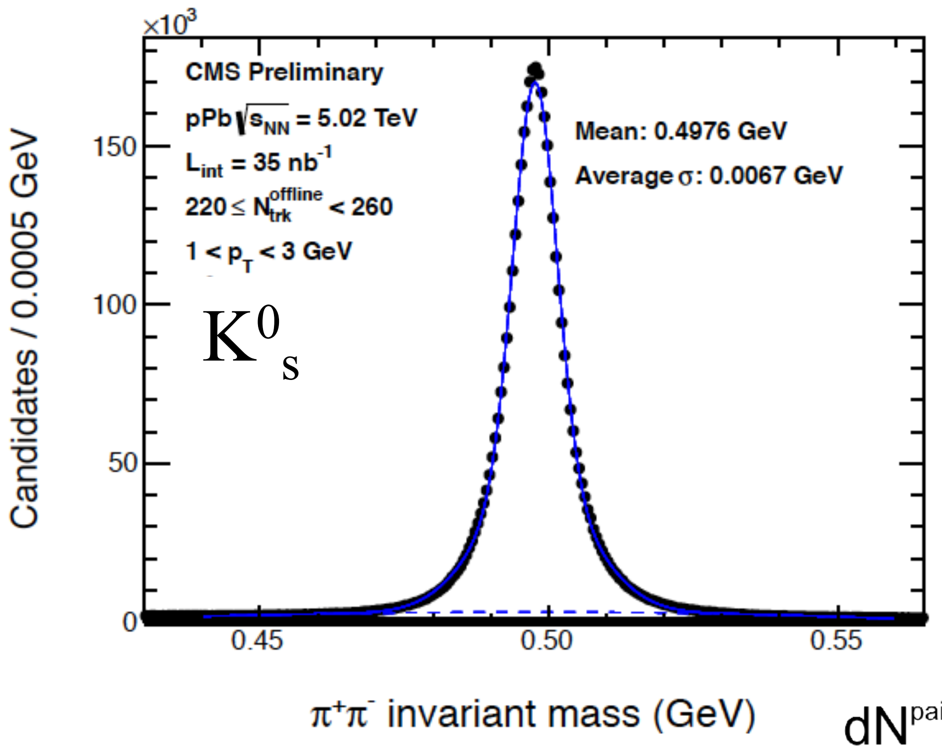


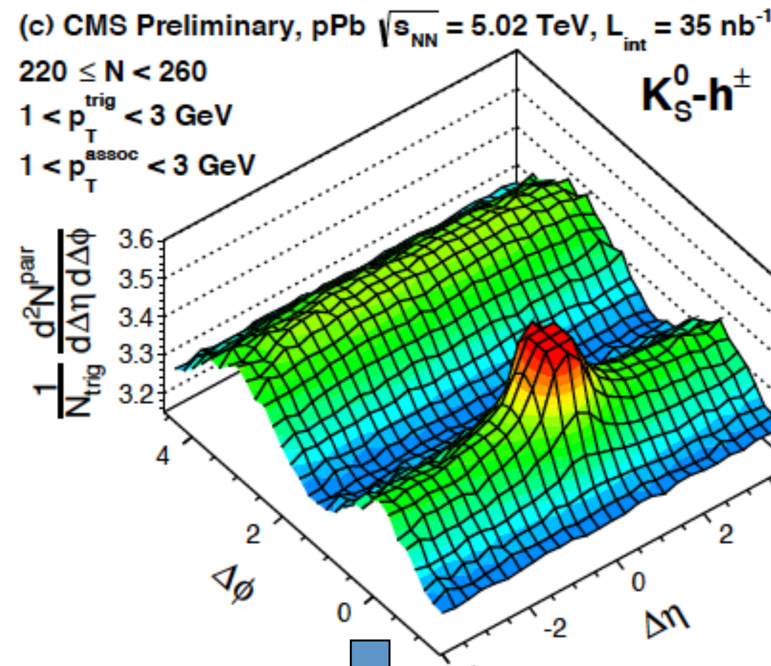
$v_3(\eta)/v_3(0)$:



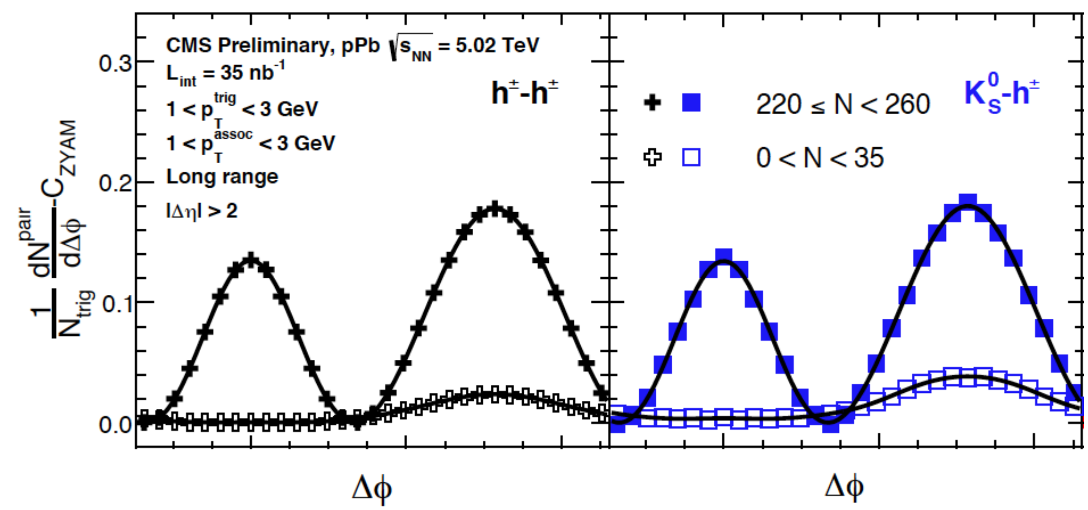
- Pb going side v_2 is larger than proton going side v_2
- Not easy to conclude for v_3

V^0 reconstruction and analysis method





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



Assuming Factorization:

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

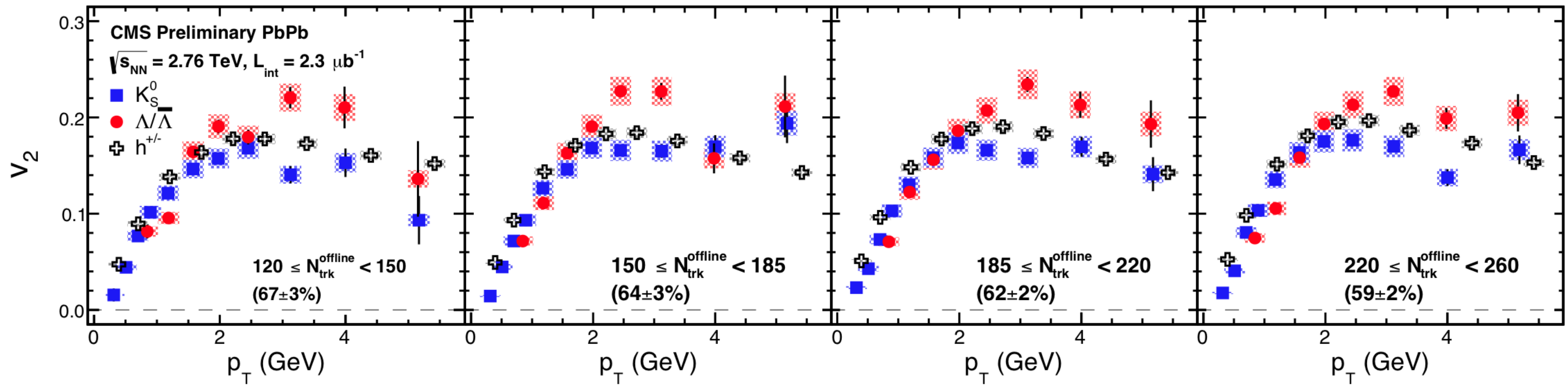
$$v_n(p_T^{V^0}) = \frac{V_{n\Delta}(p_T^{V^0}, p_T^{ref})}{\sqrt{V_{n\Delta}(p_T^{ref}, p_T^{ref})}}$$

Similar studies for Λ

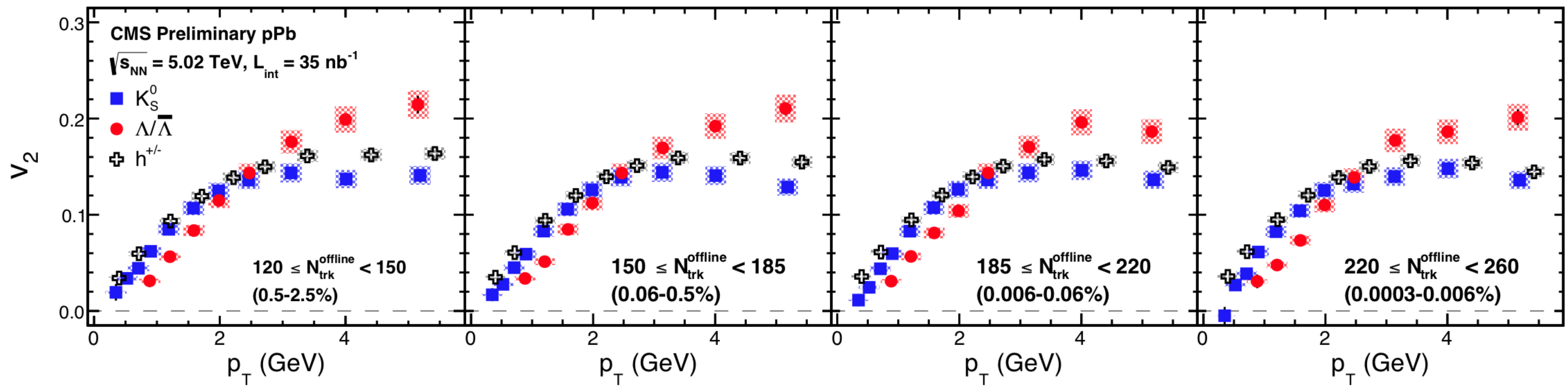
$v_2(p_T)$ in PbPb and pPb

PbPb

Multiplicity →



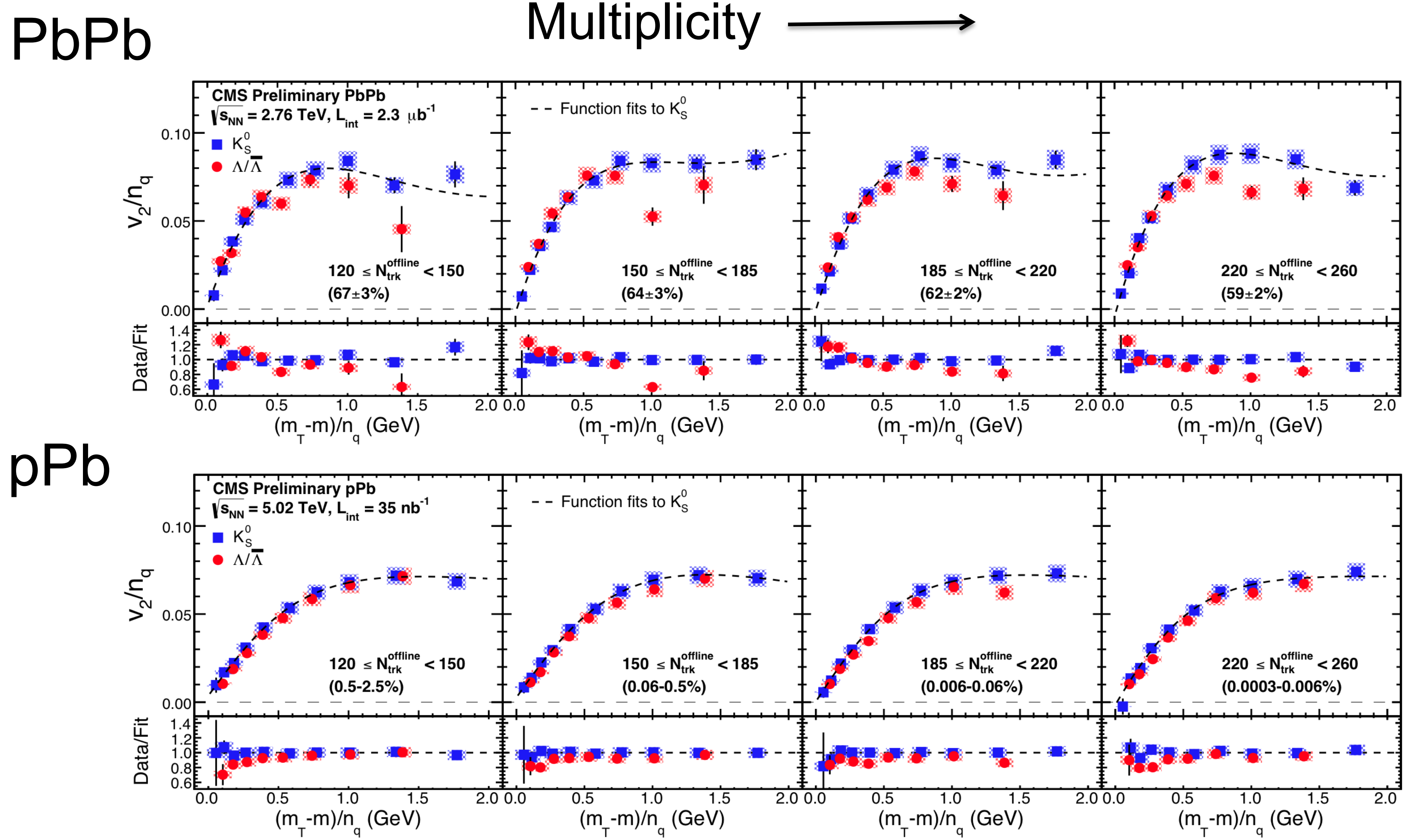
pPb



- Mass ordering more clear in pPb than in peripheral PbPb

Number of constituent quark scaling for v_2

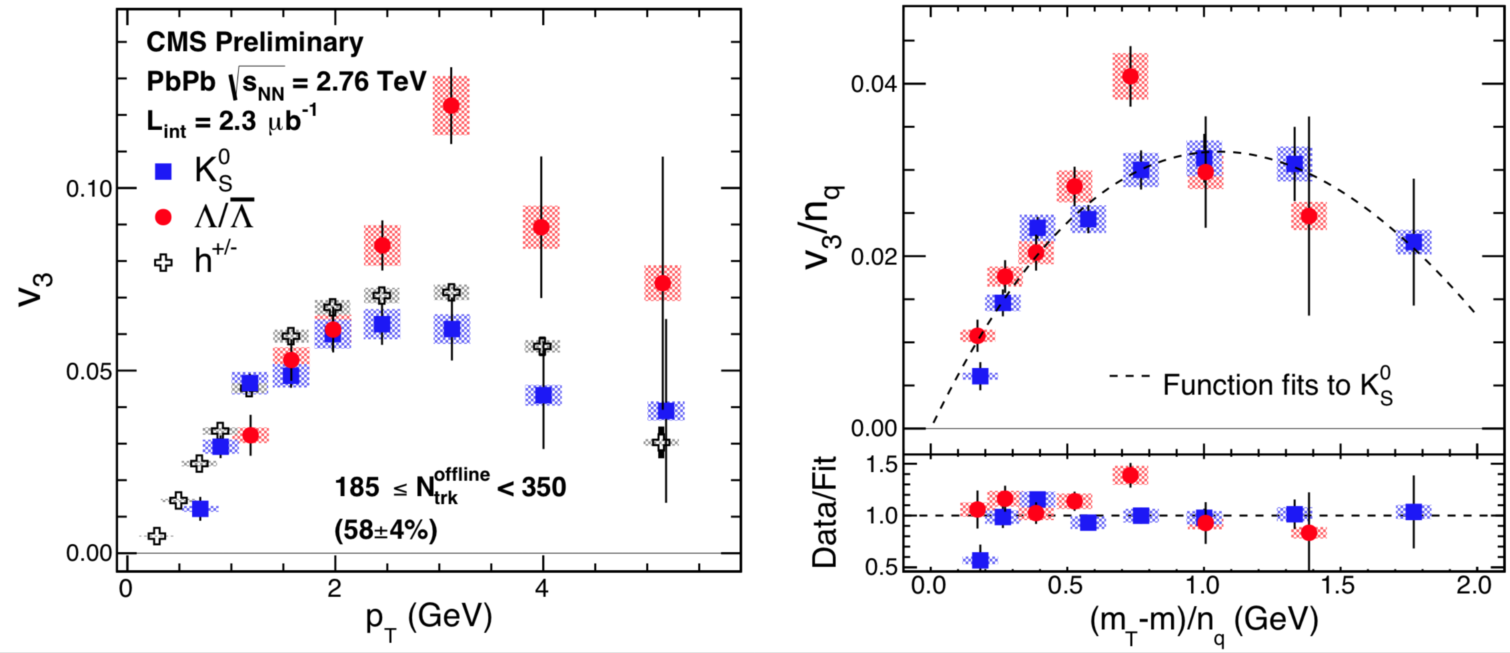
Multiplicity →



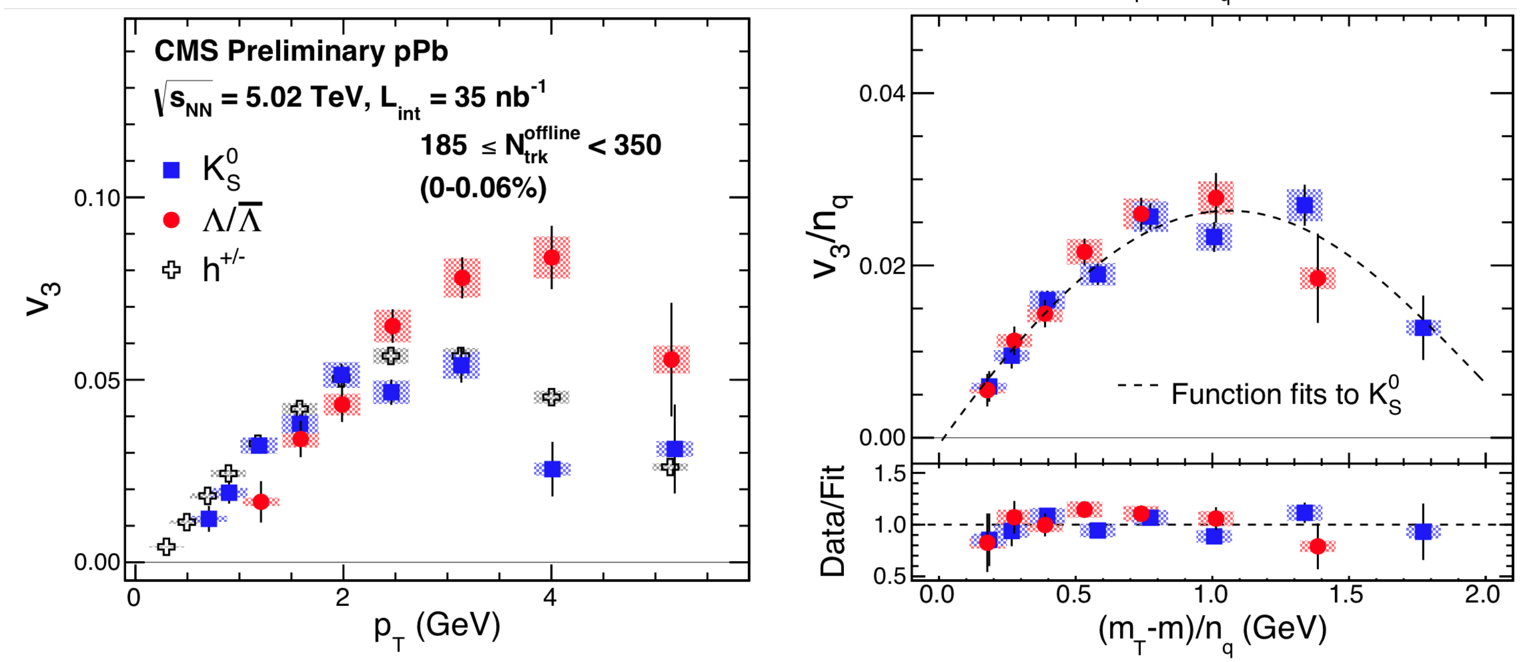
- NCQ scaling holds better in pPb than in peripheral PbPb

Results for v_3

PbPb

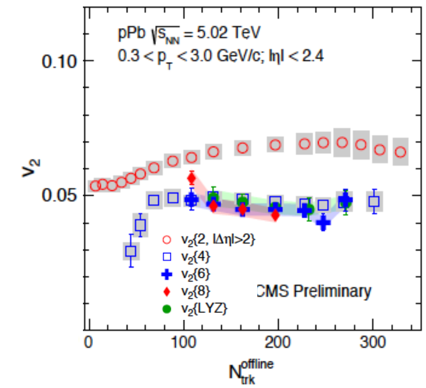


pPb



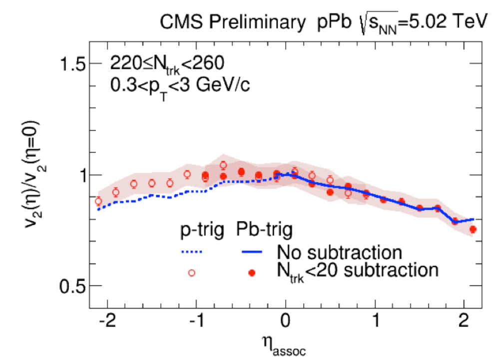
- NCQ scaling holds within 20%

Comprehensive measurements of flow phenomena in pPb and PbPb by CMS



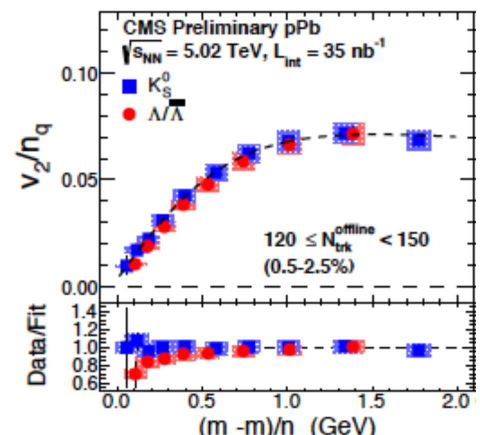
I. Multiparticle correlations in pPb and PbPb

- $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$ and $v_2\{LYZ\}$ agree within 10%



II. Pseudorapidity dependence of v_2 and v_3

- v_2 of Pb going side larger than proton going side



III. v_2 and v_3 from K^0_s and Λ

- NCQ scaling holds better in pPb than in peripheral PbPb

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Backup

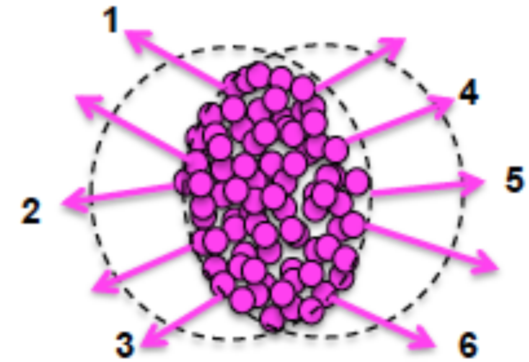
Multiparticle Cumulant

- 6-particle correlator, per event

$$\langle 6 \rangle \equiv \left\langle e^{in(\phi_1+\phi_2+\phi_3-\phi_4-\phi_5-\phi_6)} \right\rangle$$

$$\equiv \frac{1}{P_{M,6}} \sum_{\substack{i\neq j\neq k \\ \neq l\neq m\neq n}}^{M} e^{in(\phi_i+\phi_j+\phi_k-\phi_l-\phi_m-\phi_n)}$$

Distinctive 6-particle combinations



- 6-particle cumulant, all events

$$c_n\{6\} = \langle\langle 6 \rangle\rangle - 9 \bullet \langle\langle 4 \rangle\rangle \langle\langle 2 \rangle\rangle + 12 \bullet \langle\langle 2 \rangle\rangle^3$$

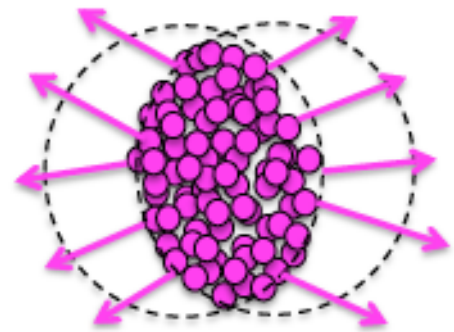
- Q-Cumulant: decompose ➔ flow vector $Q_n \equiv \sum_{i=1}^{M} w_i e^{in\varphi_i}$

- Cumulant v_n ➔ $\boxed{v_n\{4\} = \sqrt[4]{-c_n\{4\}}, v_n\{6\} = \sqrt[6]{\frac{1}{4}c_n\{6\}}, v_n\{8\} = \sqrt[8]{-\frac{1}{33}c_n\{8\}}}$

Lee-Yang Zeros Method

- All-particle correlation, per event

$$g(ir) \equiv \prod_{j=1}^{M}\left[1 + i \cdot r \cdot w_j \cos\left(n(\phi_j - \theta)\right)\right]$$



- Generating function, all events

$$G(ir) = \langle g(ir) \rangle = \frac{1}{N_{evt}} \sum_{events} g(ir)$$

Decompose

Flow vector:

$$Q_n = (Q_{nx}, Q_{ny})$$

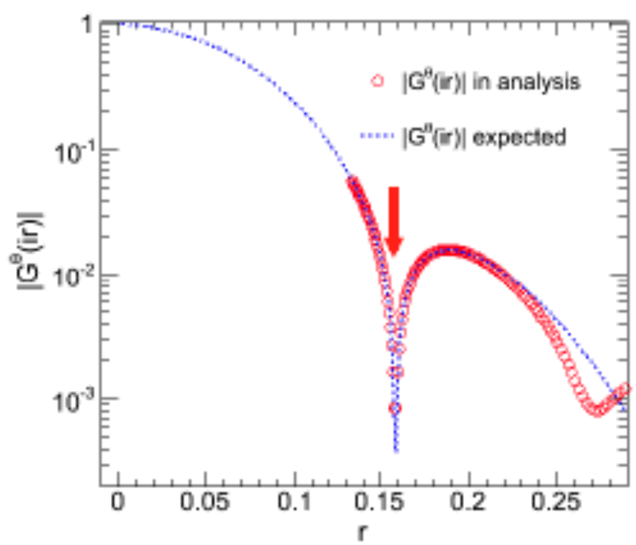
$$Q_{nx} = \sum_{j=1}^{M} w_j \cos(n\phi_j)$$

$$Q_{ny} = \sum_{j=1}^{M} w_j \sin(n\phi_j)$$

- Integrated v_n\{LYZ\}

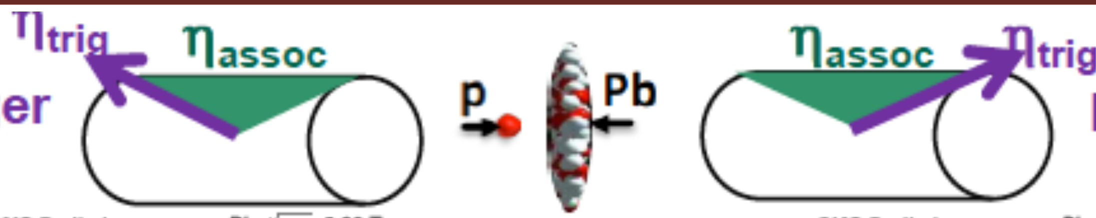
$$V_2\{LYZ\} = \frac{j_{01}}{r_0}$$

j_{01}=2.40483
r_0 is the first zero of |G(ir)|



ΔΦ distribution of correlated yield after ZYAM subtraction

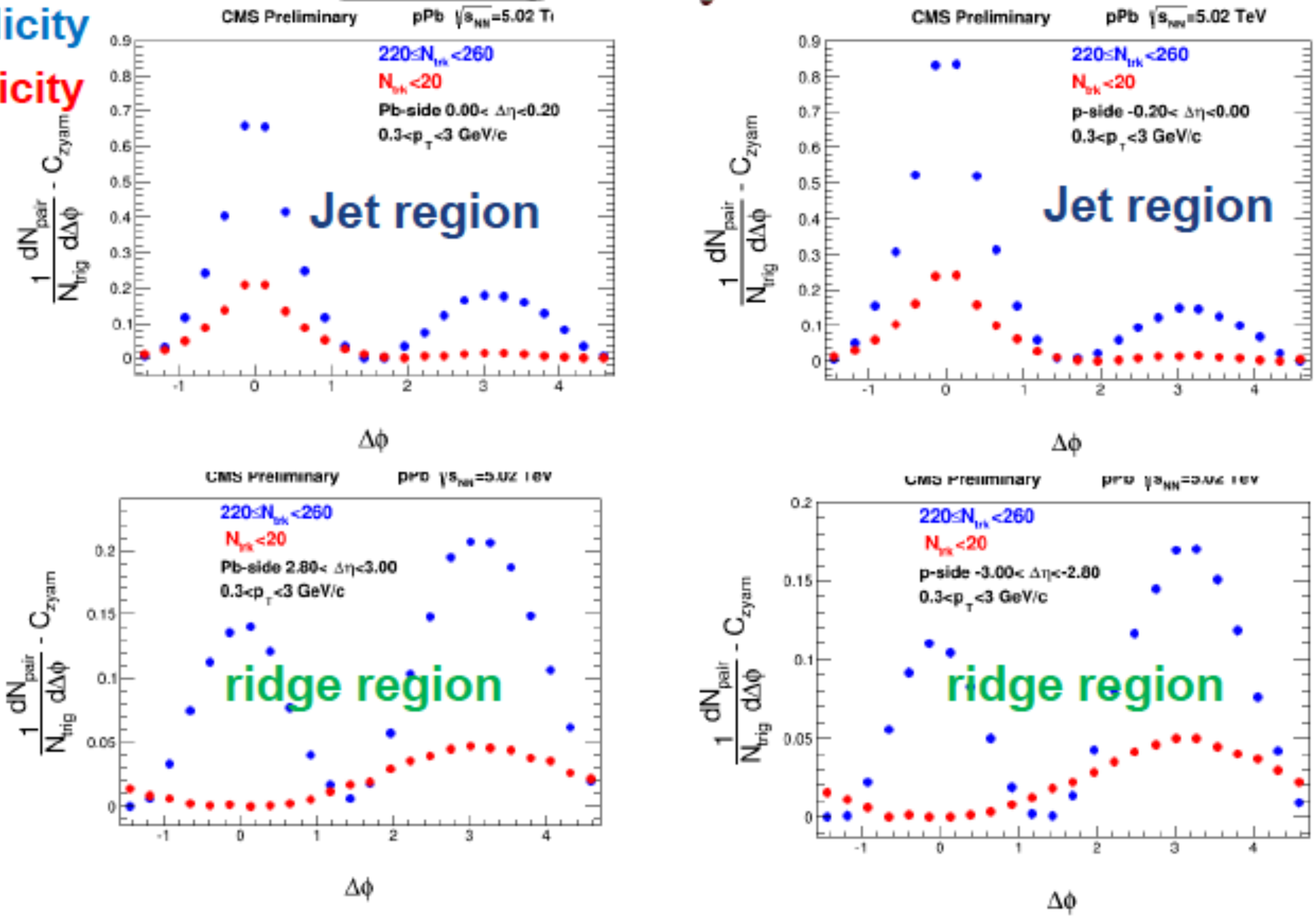
Pb-going trigger



p-going trigger

High multiplicity

Low multiplicity



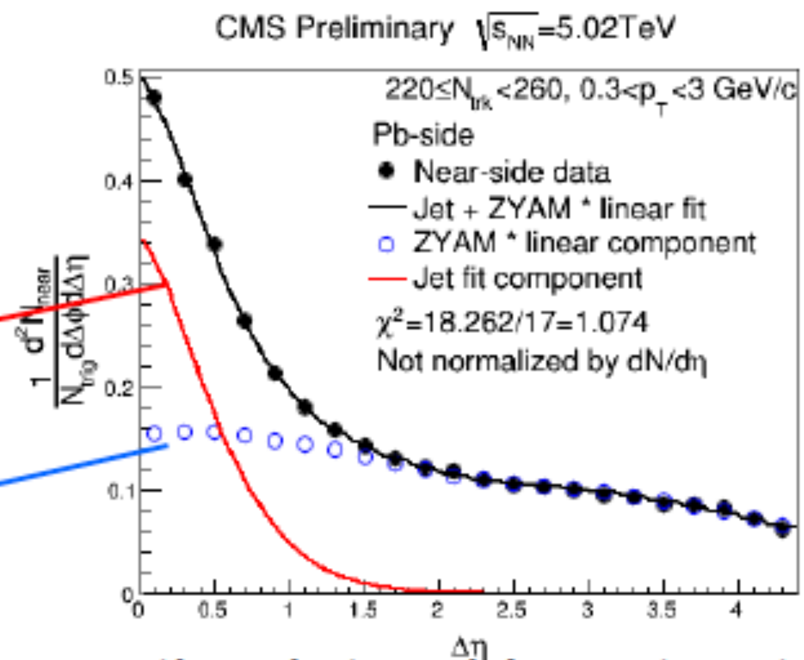
Near-side jet and ridge decomposition

$\Delta\eta$ distribution of correlated yield after ZYAM subtraction

$|\Delta\phi|<\pi/3$

Jet

Ridge



Pb-going trigger

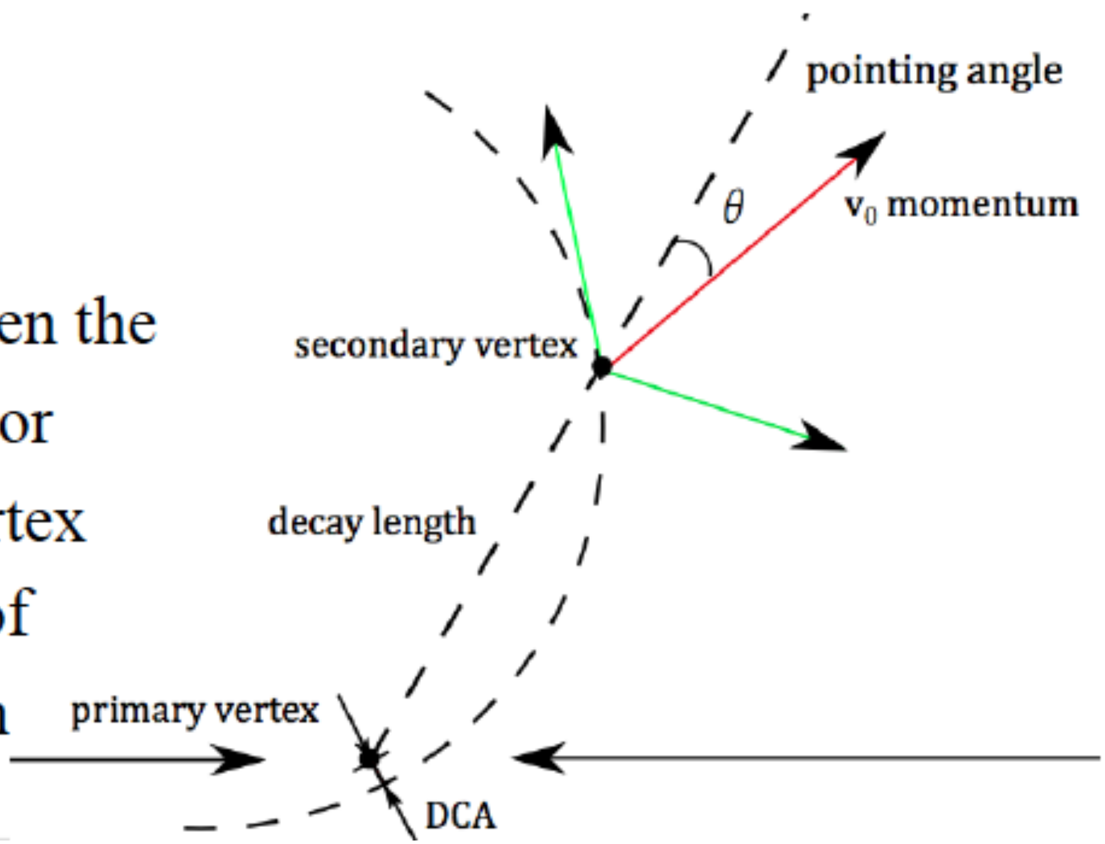
Use a fit function representing jet + ridge structure:

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

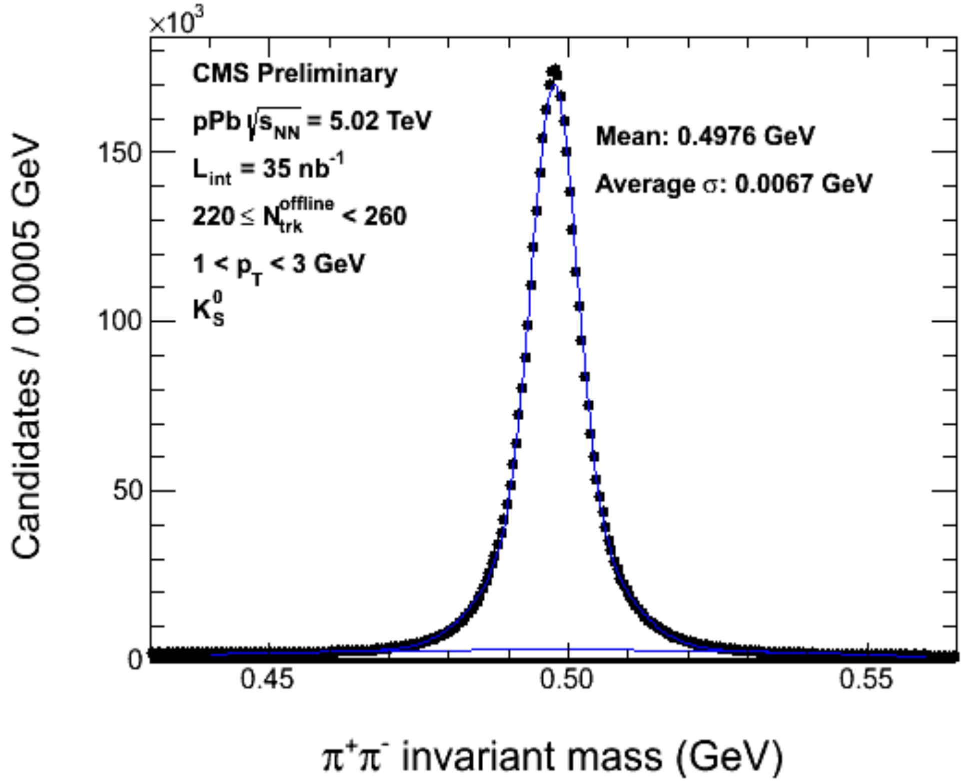
- Jet yield ratio of $Y_{jet}(220\leq N_{trk}^{offline}<260)/Y_{jet}(N_{trk}^{offline}<20)$:
  3.13 ± 0.09 (Pb-side trigger) and 3.08 ± 0.11(p-side trigger)

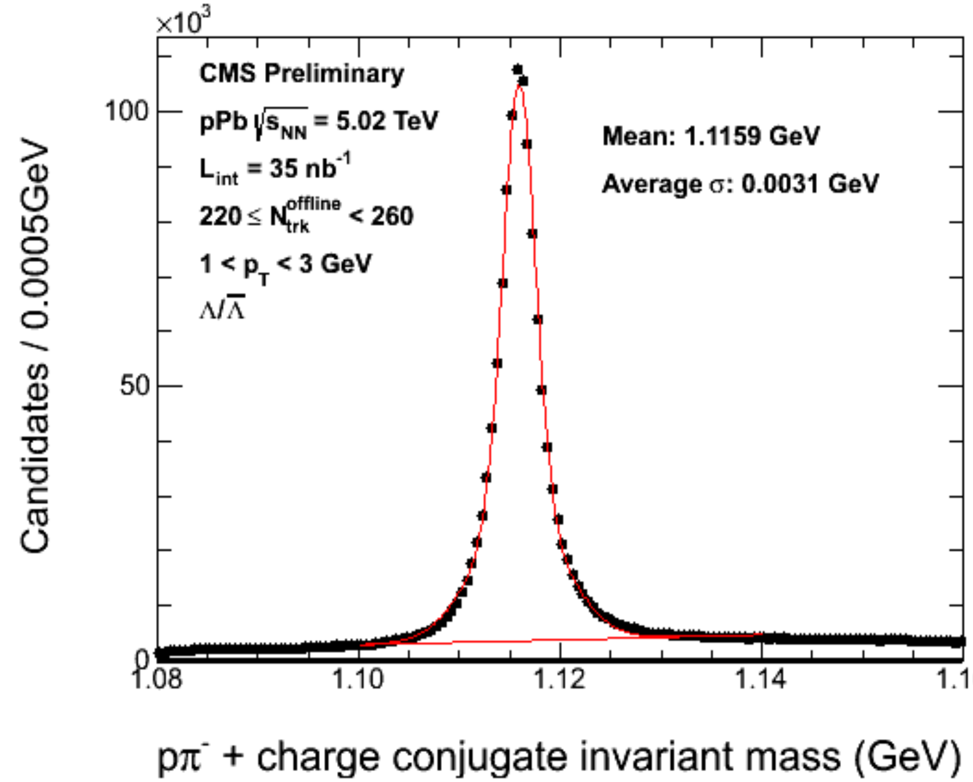
V^0 candidate reconstruction

- The K^0_s and Λ candidates (referred to as V^0) reconstructed by combining pairs of oppositely charged tracks which are detached from the primary vertex and form a good secondary vertex with an appropriate invariant mass
- $K^0_s \rightarrow \pi^+\pi^-$, $c\tau = 2.68$ cm
- $\Lambda \rightarrow p^+\pi^-$, $c\tau = 7.89$ cm
- Daughter track # of hits > 3
- $\mathrm{Cos}(\theta^{point}) > 0.99$, angle between the V^0 momentum vector and vector connecting primary and V^0 vertex
- Distance-of-closest approach of V^0 momentum vector < 0.5 cm

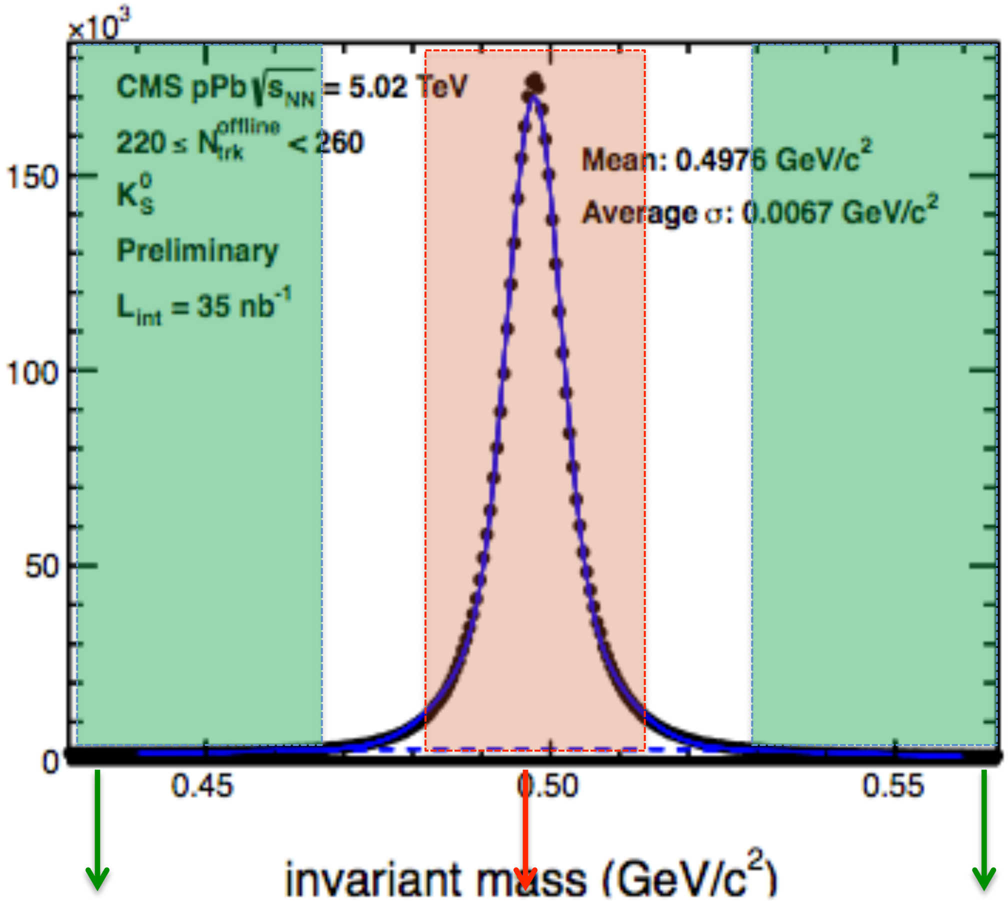


V^0 candidate reconstruction





Extraction of v_2 signal



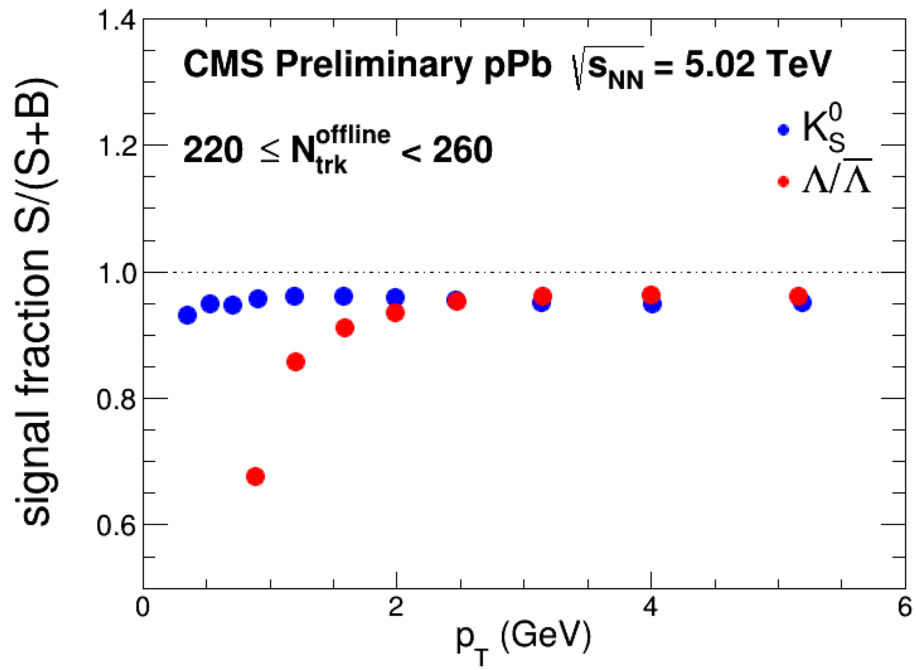
Sideband background region > -3σ

±2σ Peak region

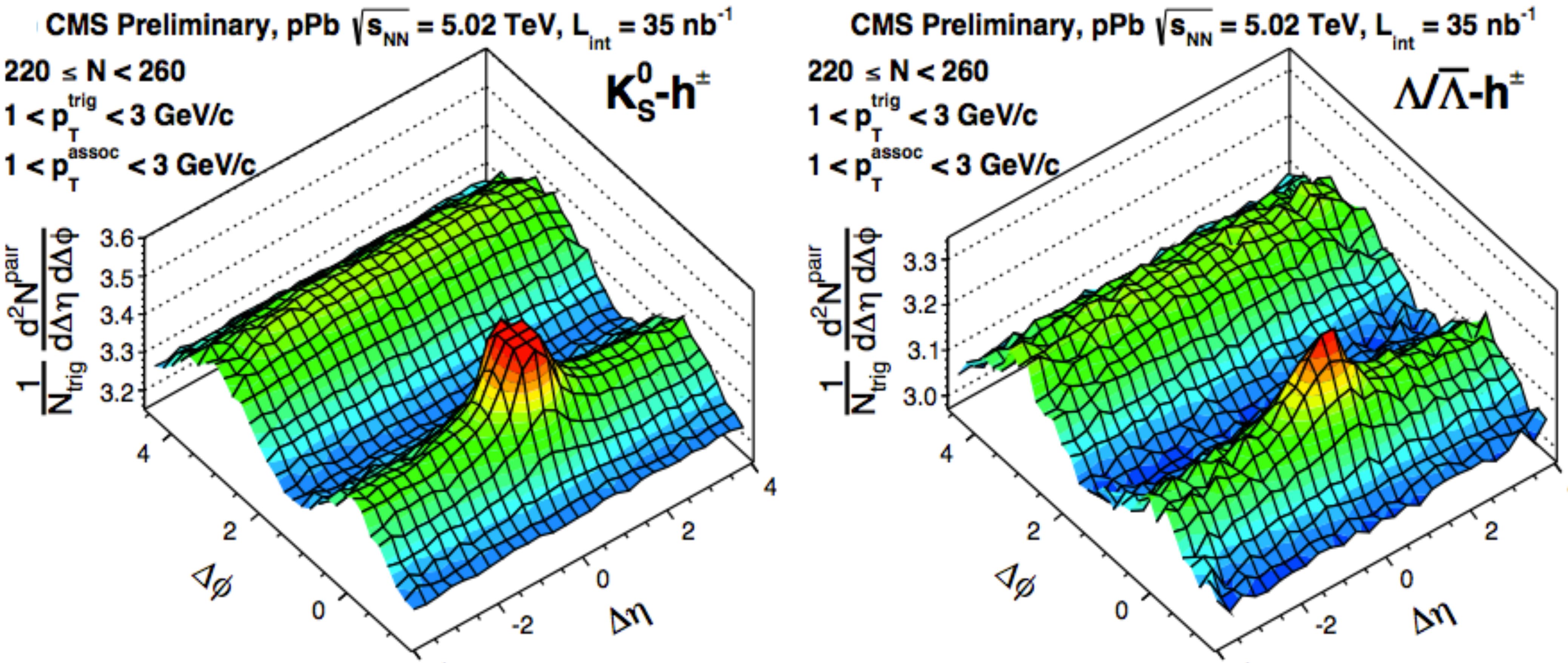
Sideband background region > 3σ

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}



Two-particle correlation function



- Two-particle correlation functions constructed for:
  - K^0_S as trigger, charged hadron as associated, K^0_S-h$^\pm$
  - Λ as trigger, charged hadron as associated, Λ-h$^\pm$