# Strange hadron production in pp, pPb, and PbPb collisions at LHC energies

Hong Ni
Vanderbilt University
*for the CMS Collaboration*

Strangeness in Quark Matter, Utrecht
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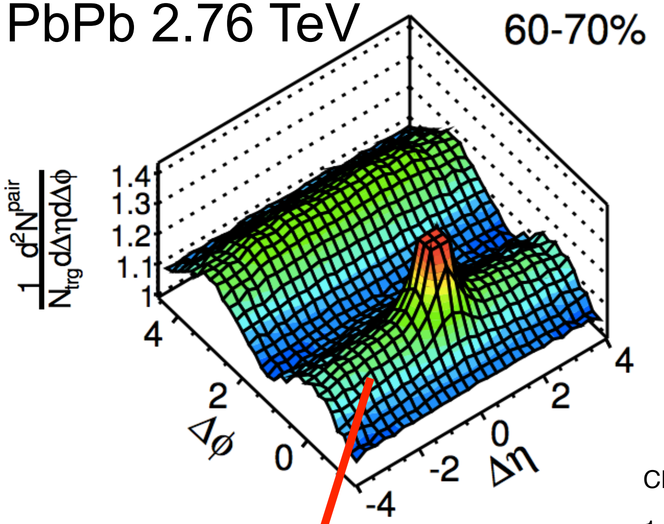
# "Ridge"

EPJC 72(2012)
JHEP 09(2010) 091
PLB 718(2013) 795

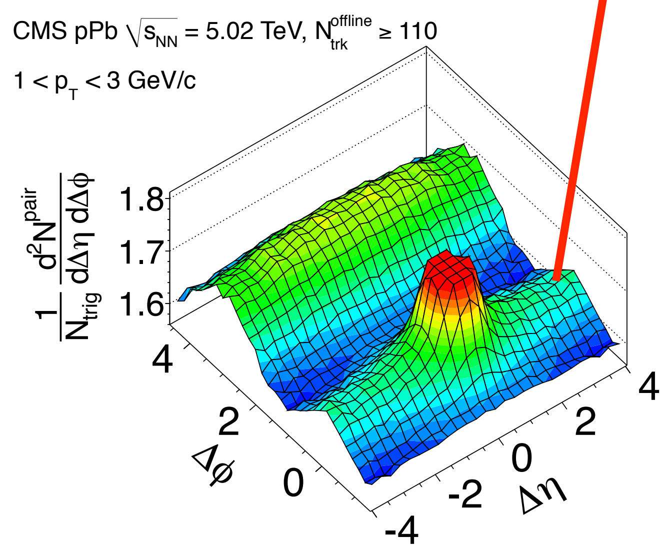
PbPb 2.76 TeV



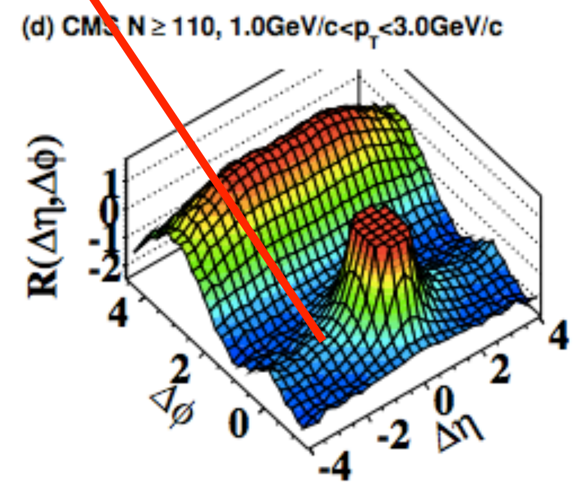

- Ridge-like structure
- Collective flow

In smaller systems with high multiplicity
- Similar ridge structure as in AA collisions
- Also related to collective flow?

pPb 5.02 TeV



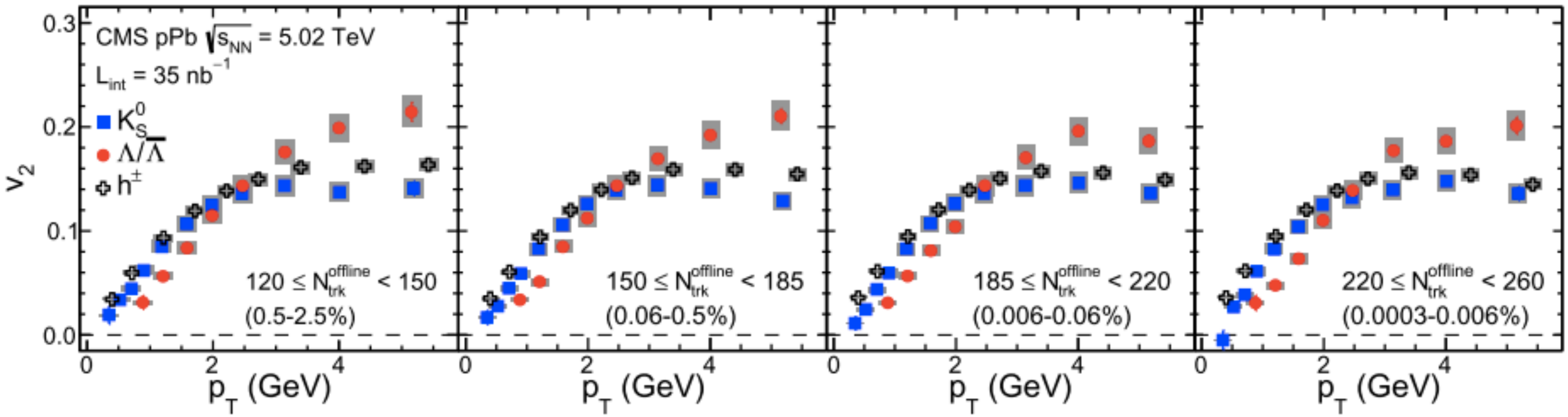

pp 7 TeV




If it is collective flow, can we see mass effect?

# Strange particle $v_2$

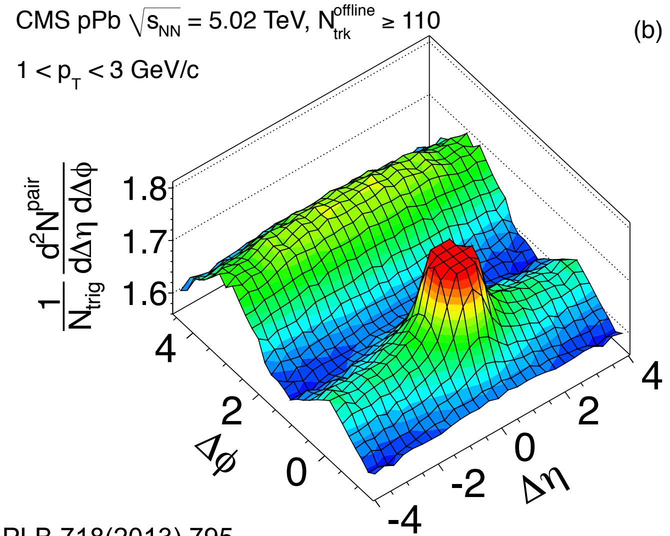
PLB 742 (2015) 200




CMS strange particle $v_2$ in high multiplicity pPb shows mass effect for $p_T$<2GeV: $v_2(h^{+/-}) > v_2(K_S) > v_2(\Lambda)$

What other measurements can be used to see the mass effect, if ridge in small system is due to radial flow?

# Ridge: radial flow?

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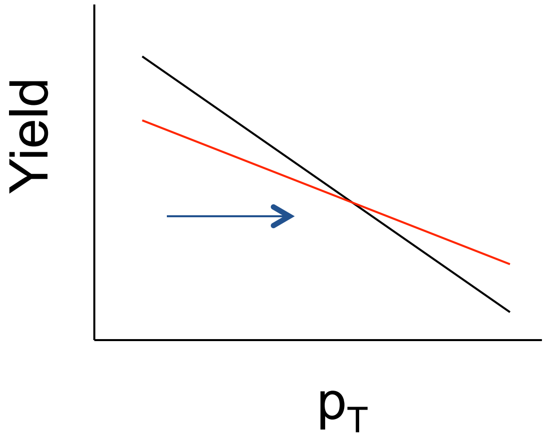
radial flow driven by pressure gradient?

if yes, flatten spectra, mass effect can be seen

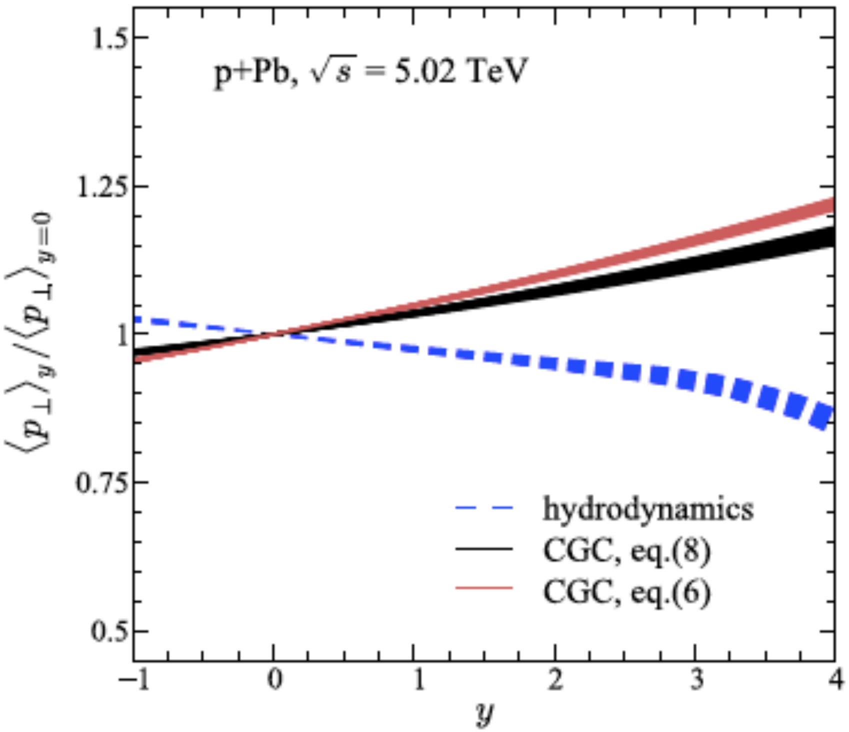



If the ridge is due to collective flow, then radial flow must be present
→ flattened spectra→ dependence on the mass of hadrons

Can we see flattened spectra with the measurement of identified strange particle spectra?

# CGC or Hydro?

PLB 728 (2014) 662





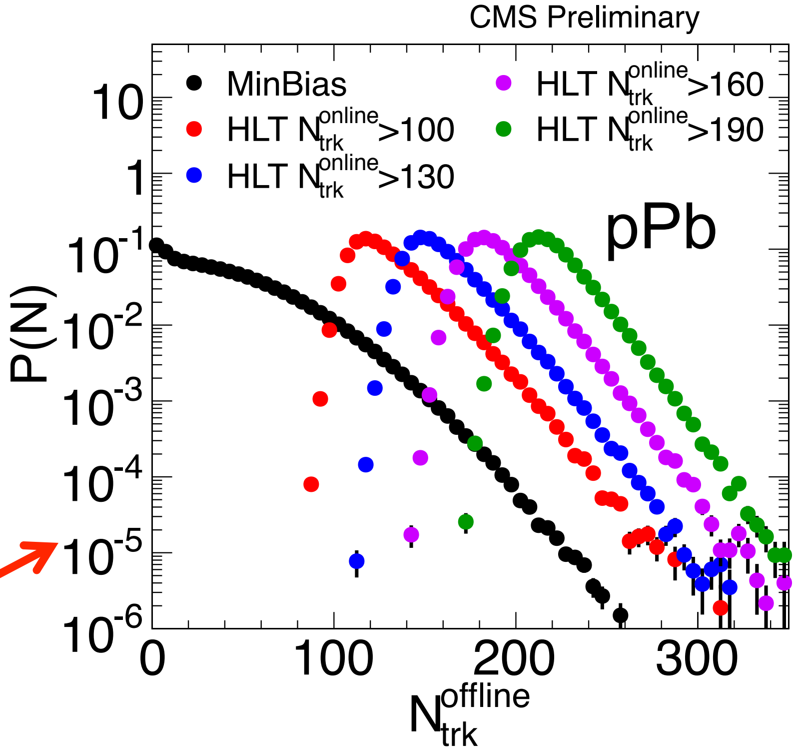
From Pb-going side to p-going side:

- In hydrodynamics, <$p_T$> gets smaller
  - Number of particles decreases
- Opposite trend in CGC (only) model.
  - Saturation momentum increases

With the large acceptance of CMS detector, what will we see in our result?

# Data sample

- pp
  - Data set: 2010 7 TeV
  - Event Selection:
    - Minimum bias trigger
    - High multiplicity triggers
- pPb
  - Data set: 2013 5.02 TeV
  - Event Selection:
    - Minimum bias trigger
    - High multiplicity triggers
- PbPb (50-100% Centrality)
  - Data set: 2011 2.76 TeV
  - Event Selection:
    - Minimum bias trigger




Track multiplicity distribution for different triggers in pPb

# $V_0$ and $\Xi$ ($\Xi^- + \Xi^+$) Reconstruction

## Decay Channel:

$K_s \rightarrow \pi^+ \pi^-$

$\Lambda^0 \rightarrow \pi^- p$

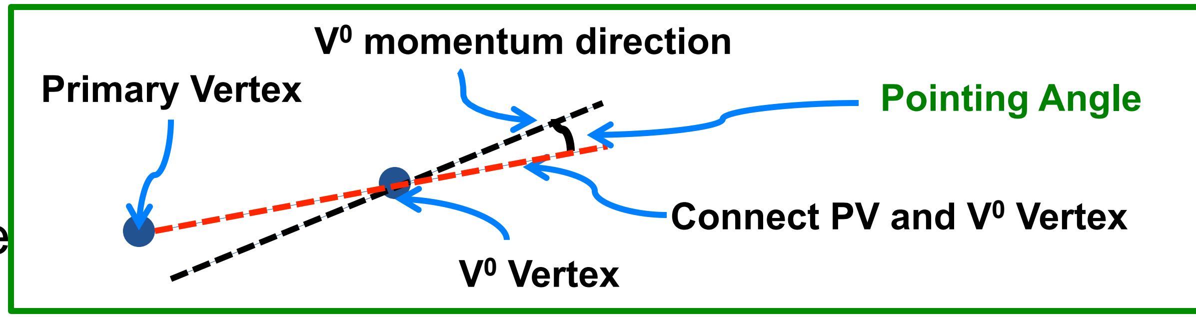
→ $V^0$

$\Xi^- \rightarrow \Lambda^0 \pi^-$

$V^0$s are reconstructed via combining a pair of oppositely charged tracks

$\Xi^-$ candidates are reconstructed via combining $\Lambda^0$ candidate with an additional charged track with the proper sign

## Candidates Selection:



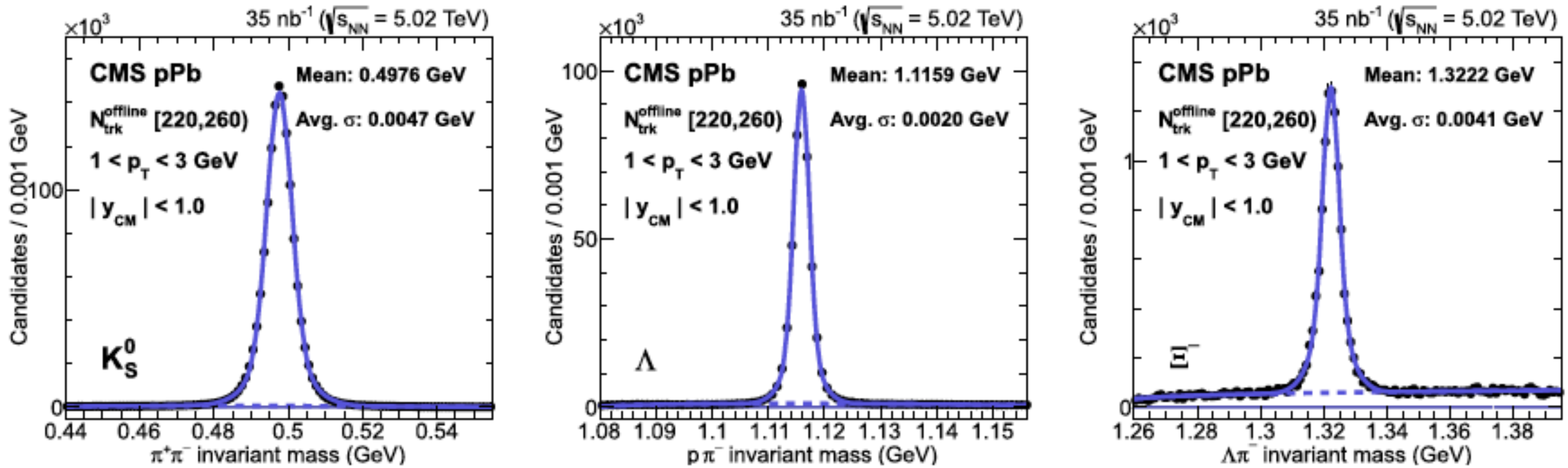

For $V^0$s

- Decay length significance
- Cos(pointing angle)
- 2D impact parameter significance of daughter tracks wrt PV

For $\Xi^-$ Candidates

- 3D impact parameter significance of daughter tracks wrt PV
- 3D separation significance between $\Xi^-$ or $\Lambda^0$ vertex wrt PV
- 3D impact parameter significance of $\Xi^-$ candidate wrt PV

# Invariant Mass Peaks

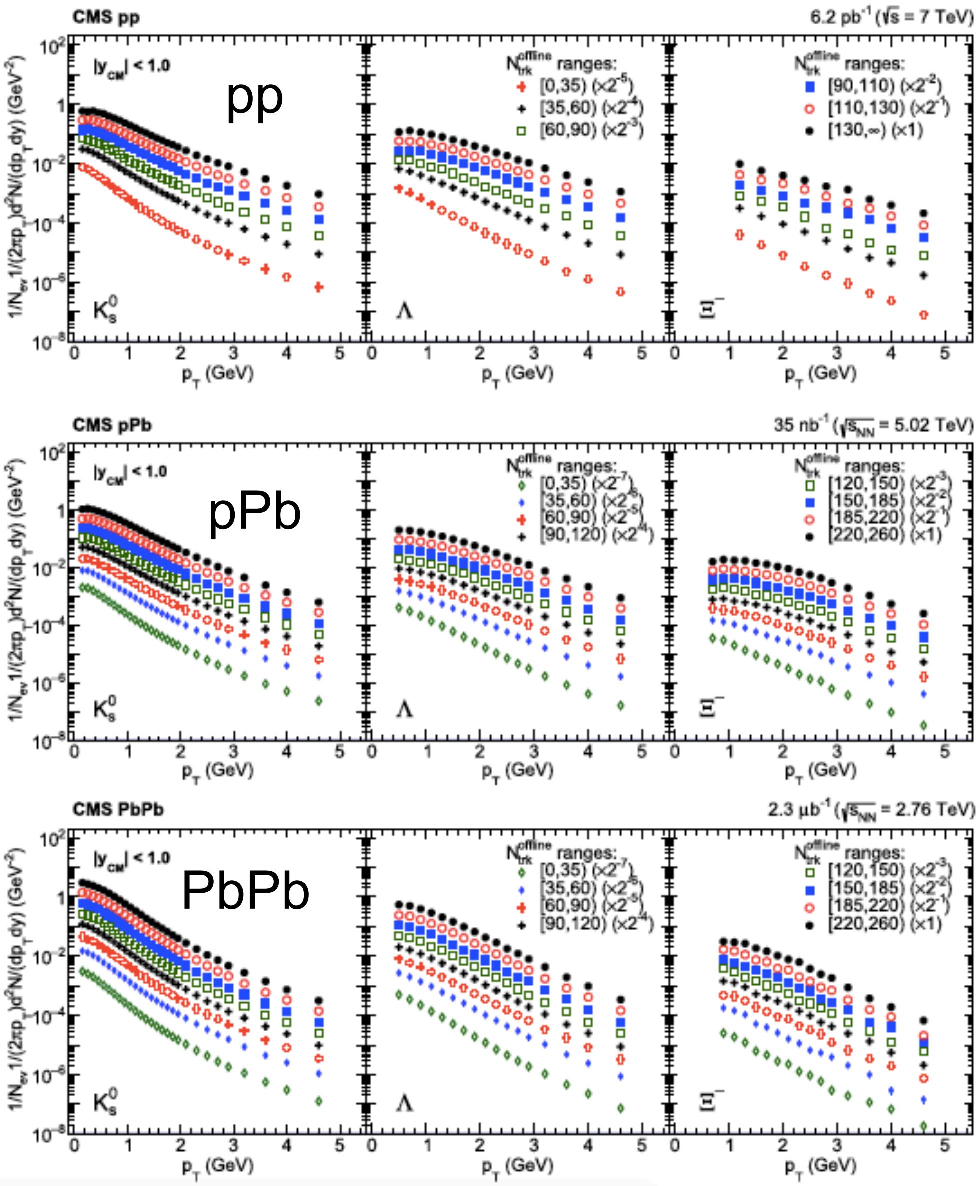



- Signal Function: Double Gaussian(with a common mean)
- Background Function:
  - quadratic function for $K_s$
  - $Aq^{3/2}+Bq^{1/2}$ for Λ, where $q = m – (M_p + M_\pi)$
  - $Aq^B$ for Ξ, where $q = m – (M_\Lambda + M_\pi)$

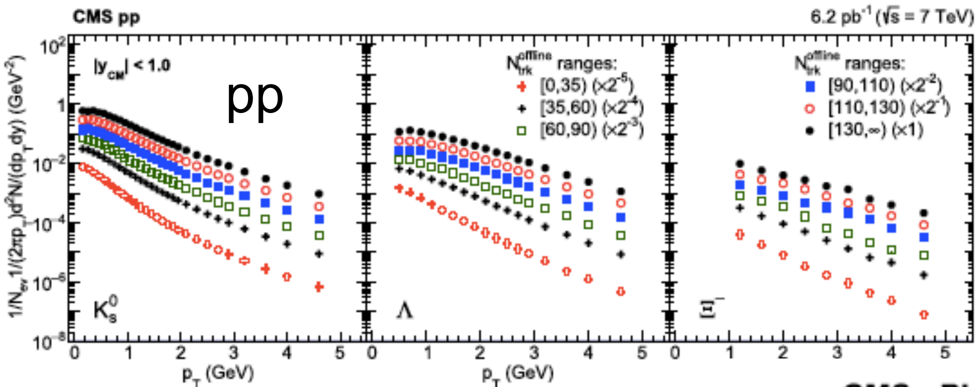
Yield Extraction

1. Implement Signal Fitting Function → Signal Counts * PDF
2. Obtain signal counts and statistical error from fitting parameters

# Mid-rapidity Spectra

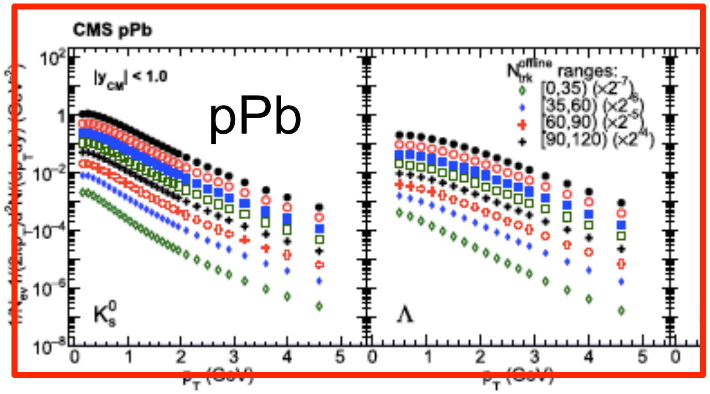


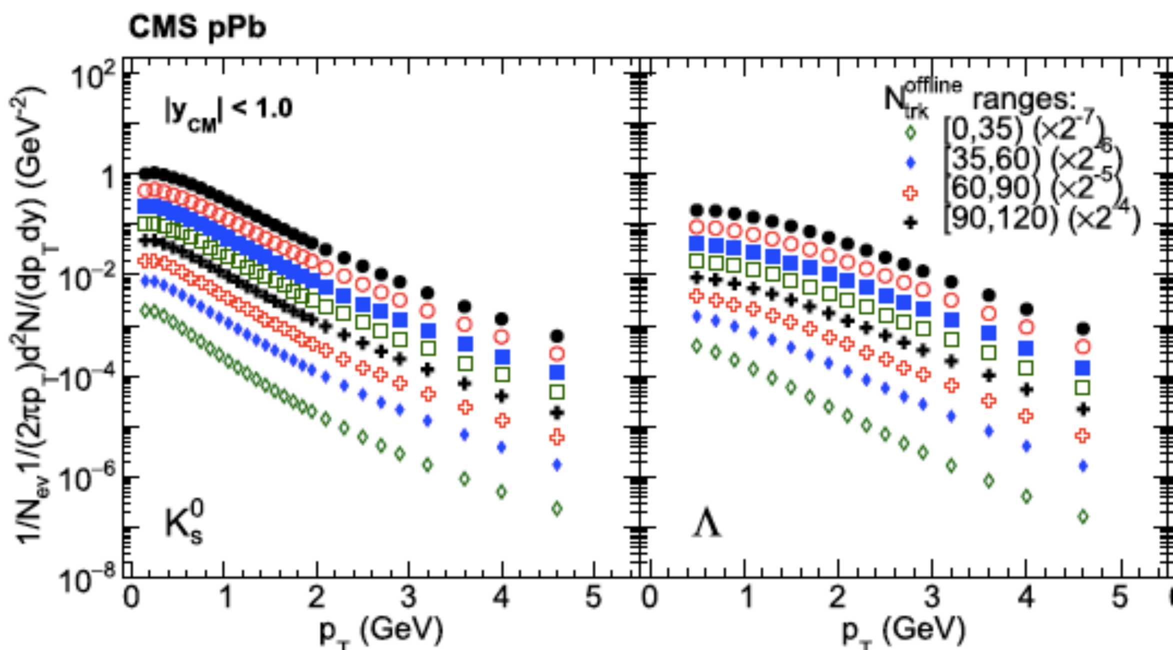
# Mid-rapidity Spectra

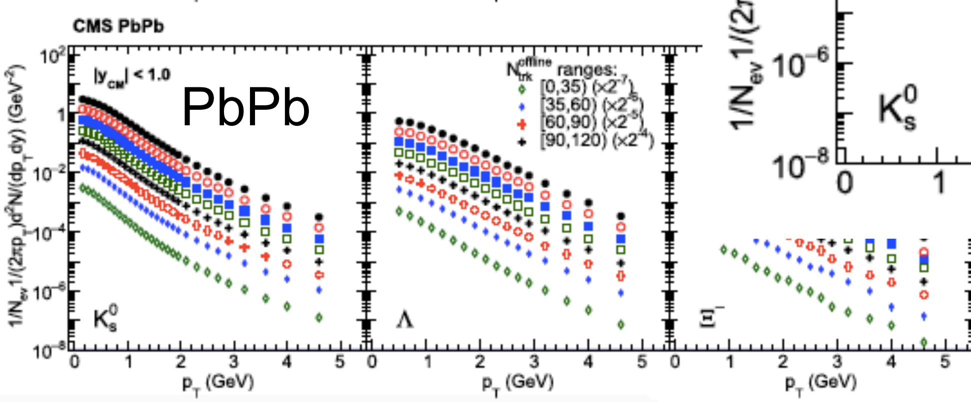



Evolution of Spectra Shape:

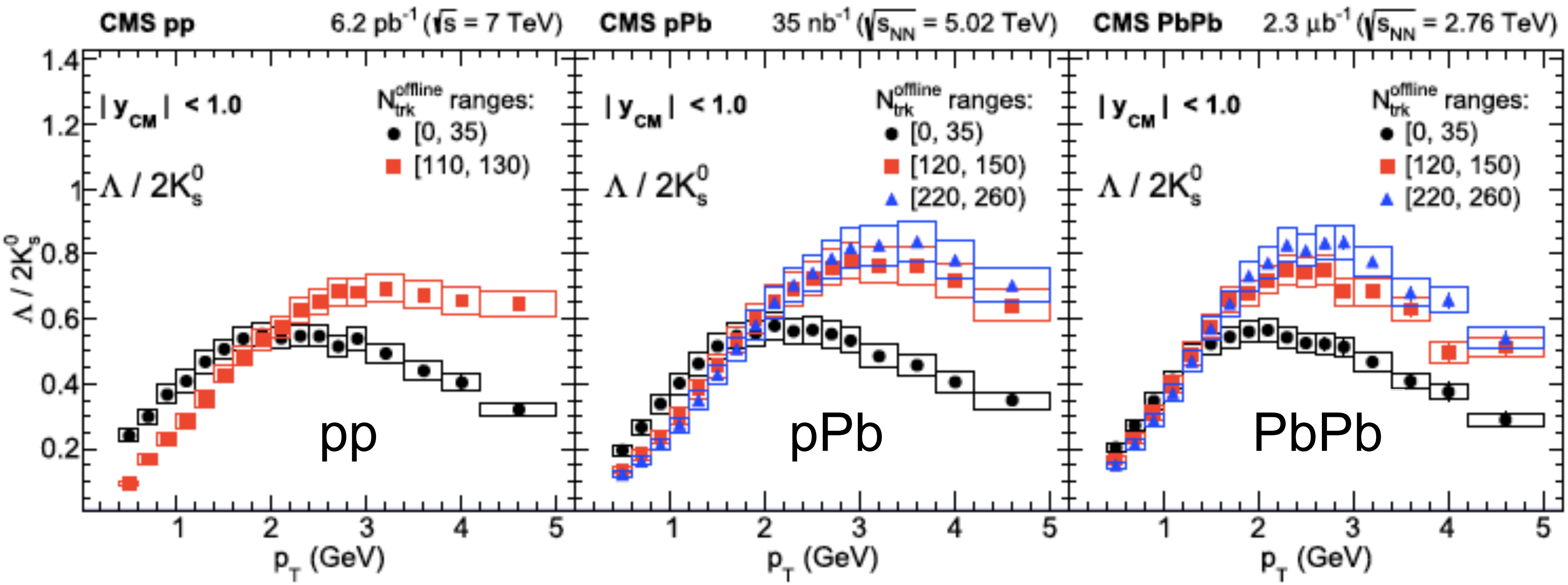
1. Spectra become harder as multiplicity increases
2. Heavier particles have harder spectra



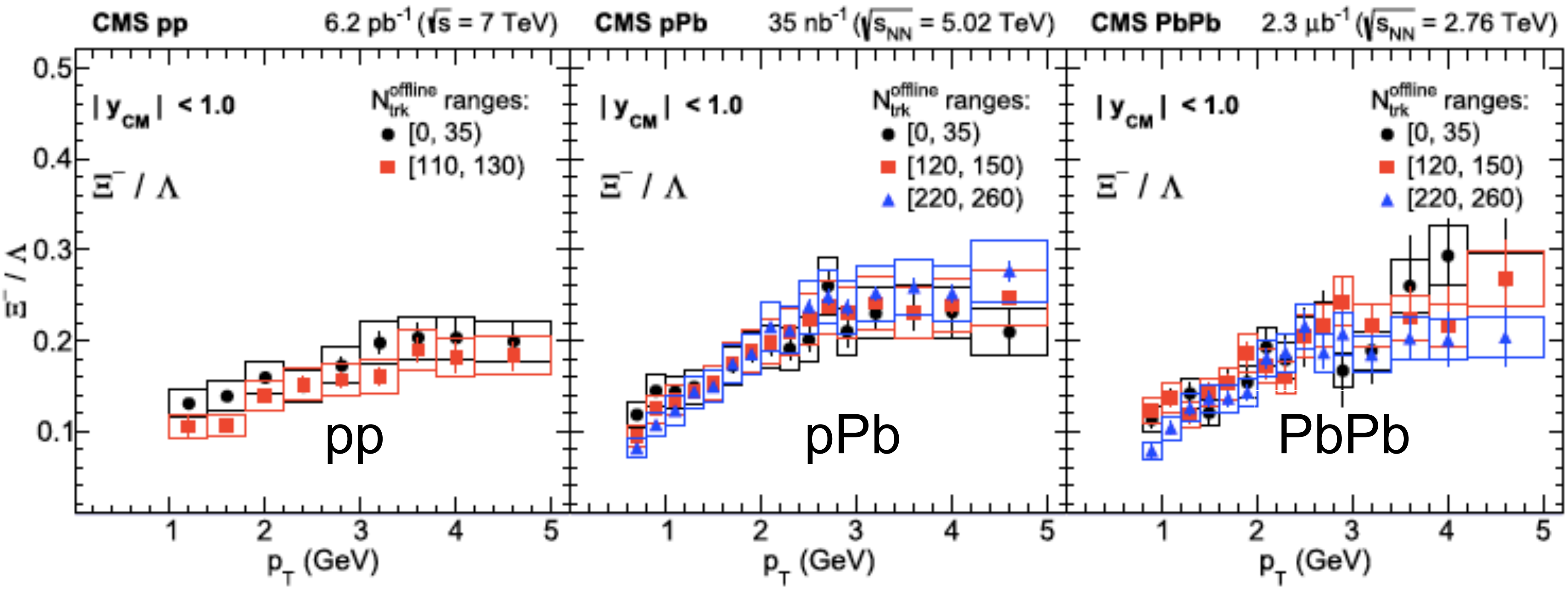



# $\Lambda$ / $K_s$ Ratio



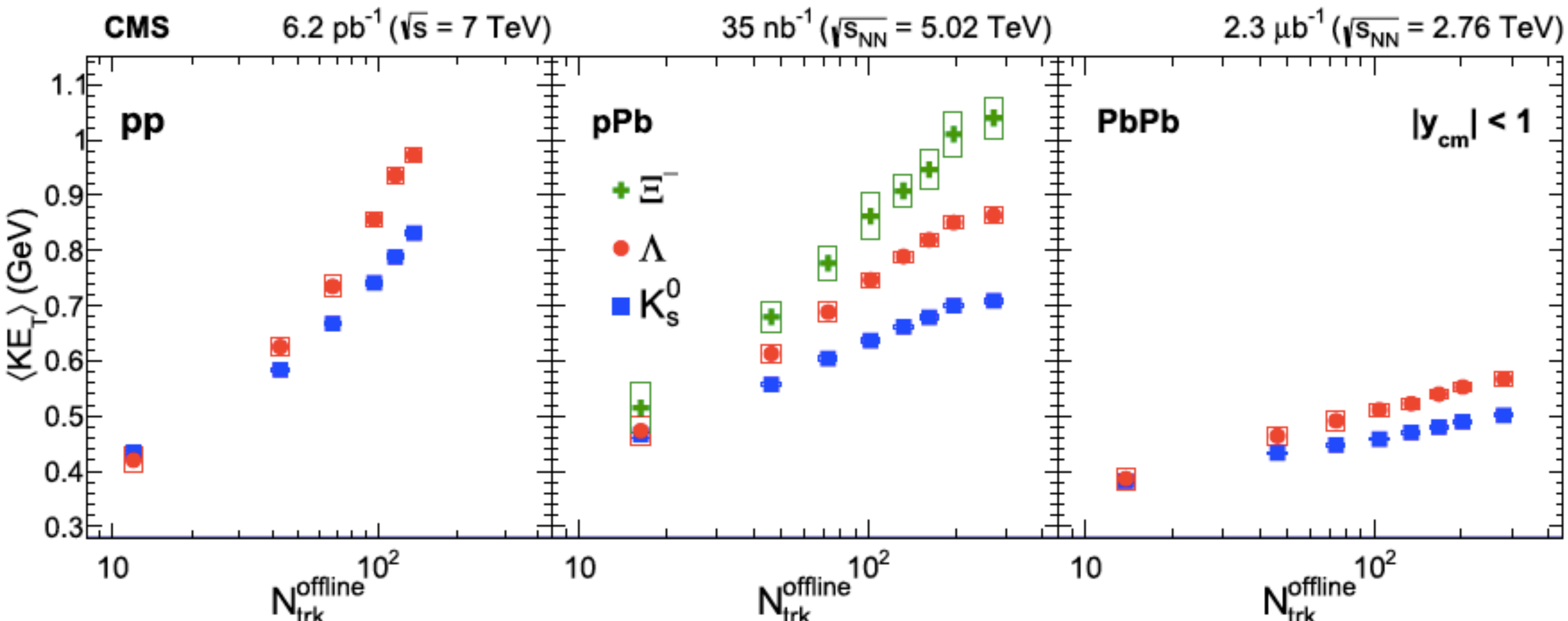

- For all multiplicity classes
  - $\Lambda$ / $K_s$ ratio reaches a maximum and then declines at higher $p_T$
  - Location of the maximum in $p_T$ increases with multiplicity
- At low $p_T$ region
  - In each system, at a given $p_T$, $\Lambda$ / $K_s$ ratio is smaller in higher multiplicity events
  - Difference between high and low multiplicity events is larger for smaller system

# Ξ / Λ Ratio




- For all multiplicity classes
  - Ξ / Λ ratio increases with $p_T$ and then reaches a plateau at around 3 GeV
- At low $p_T$ region
  - Don't expect a large difference between high and low multiplicity events, because of small mass difference

# <KE$_T$> versus Multiplicity

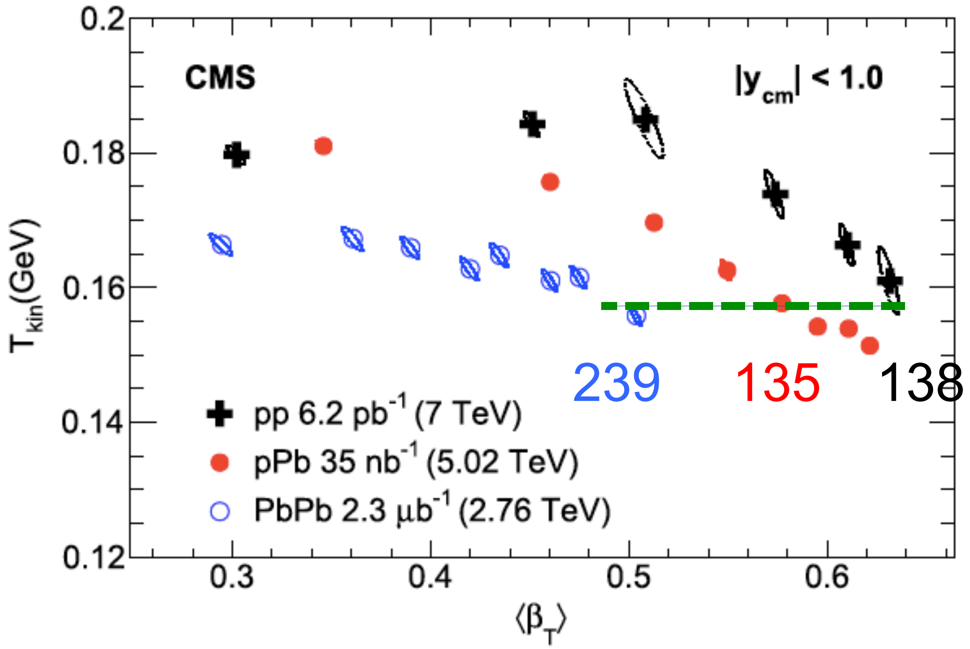



$KE_T = m_T – m_0 = \sqrt{(p_T^2 + m_0^2)} – m_0$

- At the lowest multiplicity bin, <KE$_T$> for all particles are similar ($m_T$ scaling)
- For all particles, <KE$_T$> increases as multiplicity increases
- For each system, <KE$_T$> of heavier particle species increases faster with multiplicity
  - In PbPb collisions, $m_T$-scaling breaking is the effect of radial flow.
- At similar multiplicities, larger separation for pp / pPb than PbPb

# Simultaneous Blast Wave Fit

multiplicity increases ➔




Simultaneous fit for $K_s$ and Λ

$T_{kin}$:
kinetic freeze-out temperature
$<\beta_T>$:
average radial flow velocity

Simultaneous Blast-wave model assumes:

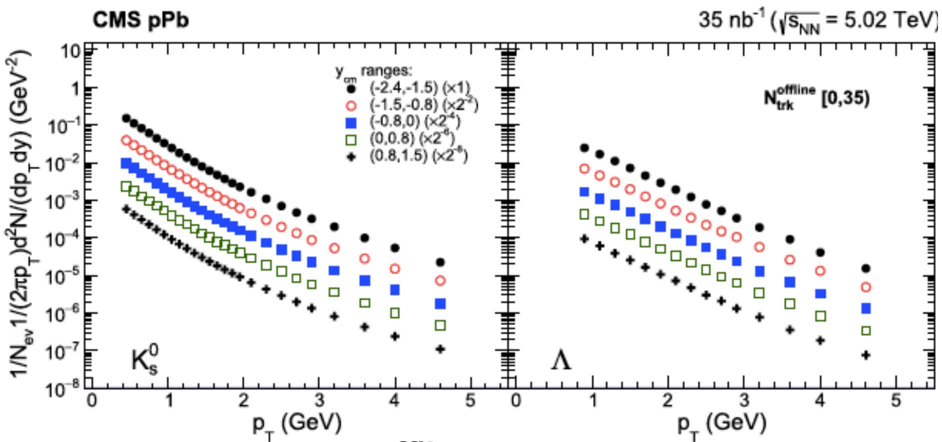
- common $T_{kin}$
- common $<\beta_T>$

for all particle species

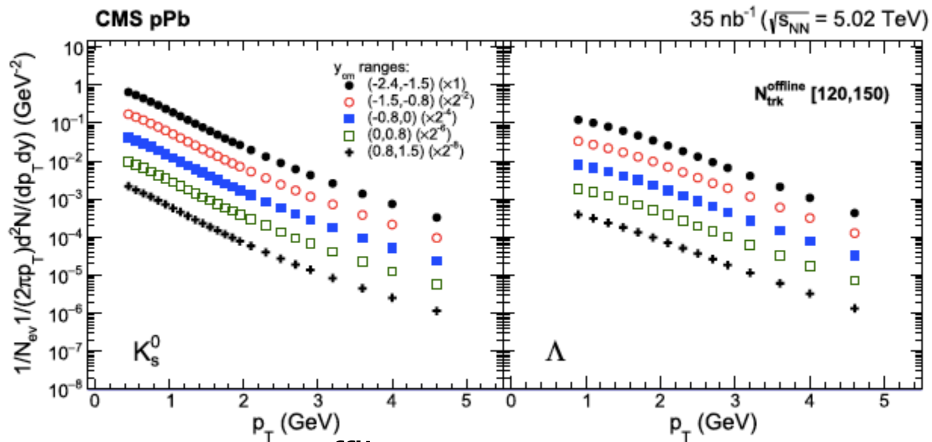
- Meaning of $T_{kin}$ and $<\beta_T>$ are model-dependent
- Provide a qualitative comparison of the spectra shape among three systems

Larger radial flow velocity for smaller system

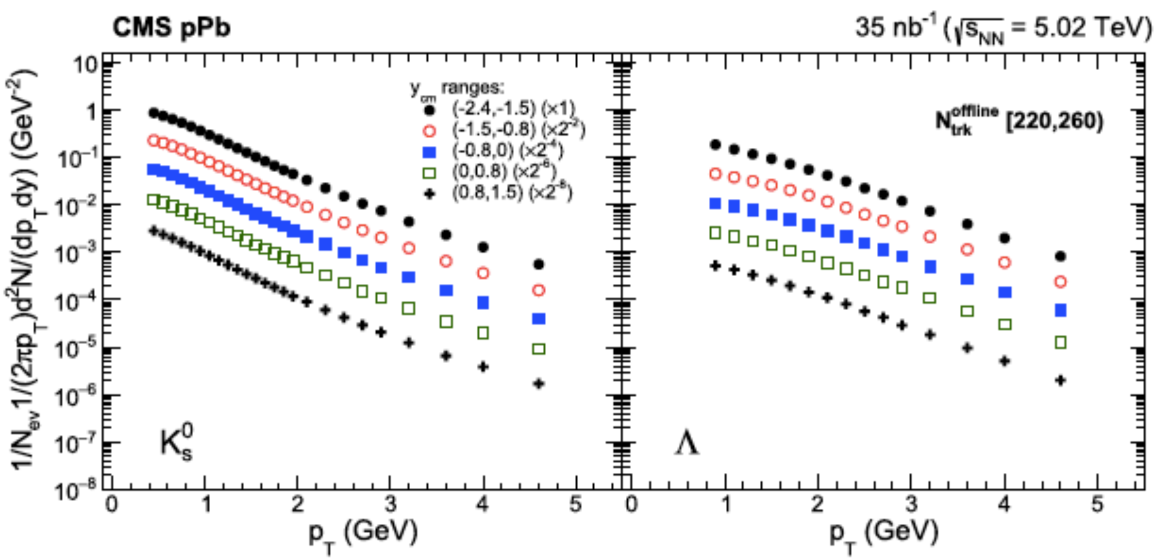
# pPb Spectra in Different Rapidity Range

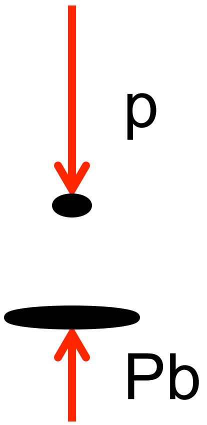



$N_{trk}^{offline}$ [0,35)



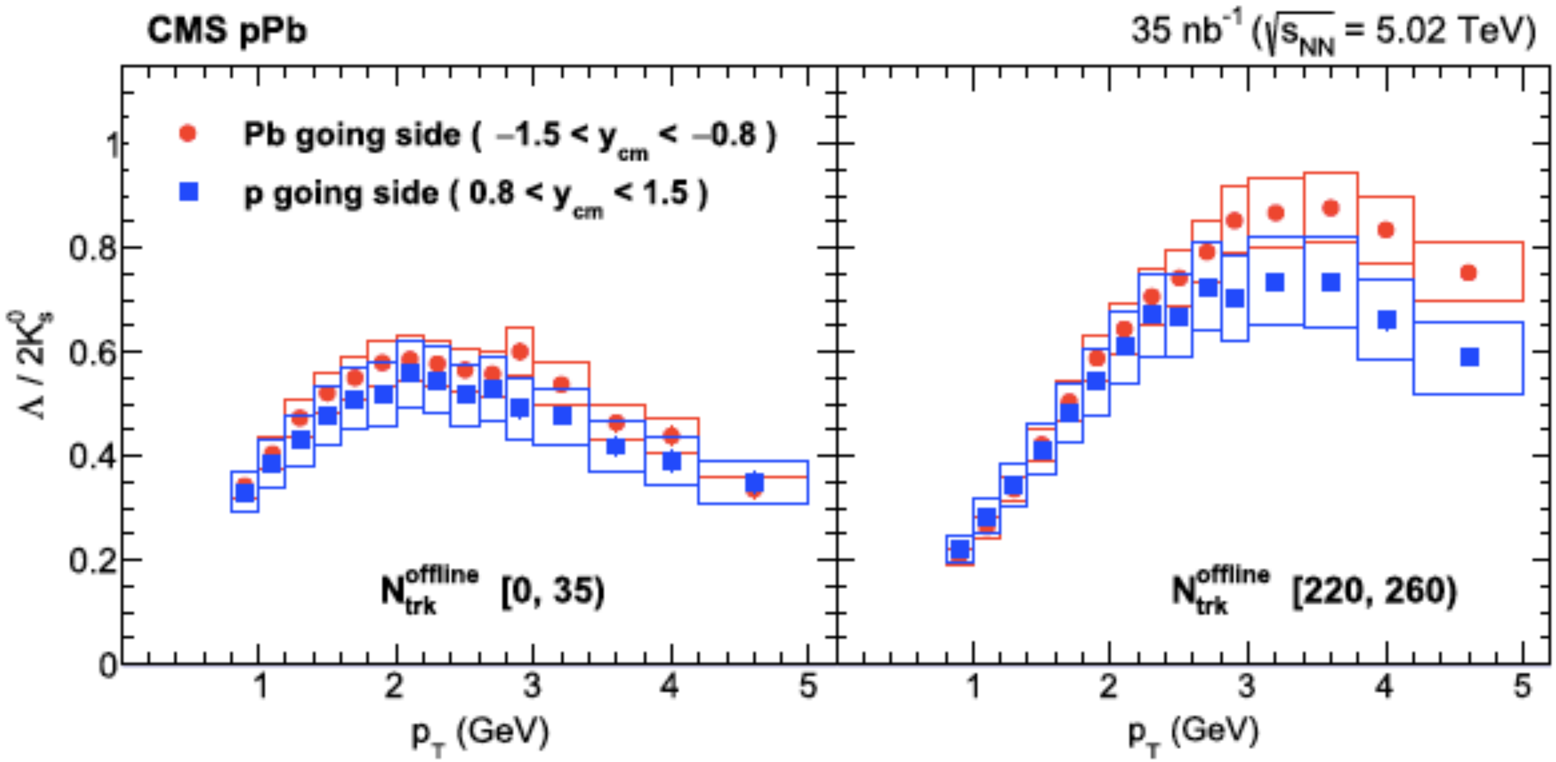

$N_{trk}^{offline}$ [120,150)




$N_{trk}^{offline}$ [220,260)

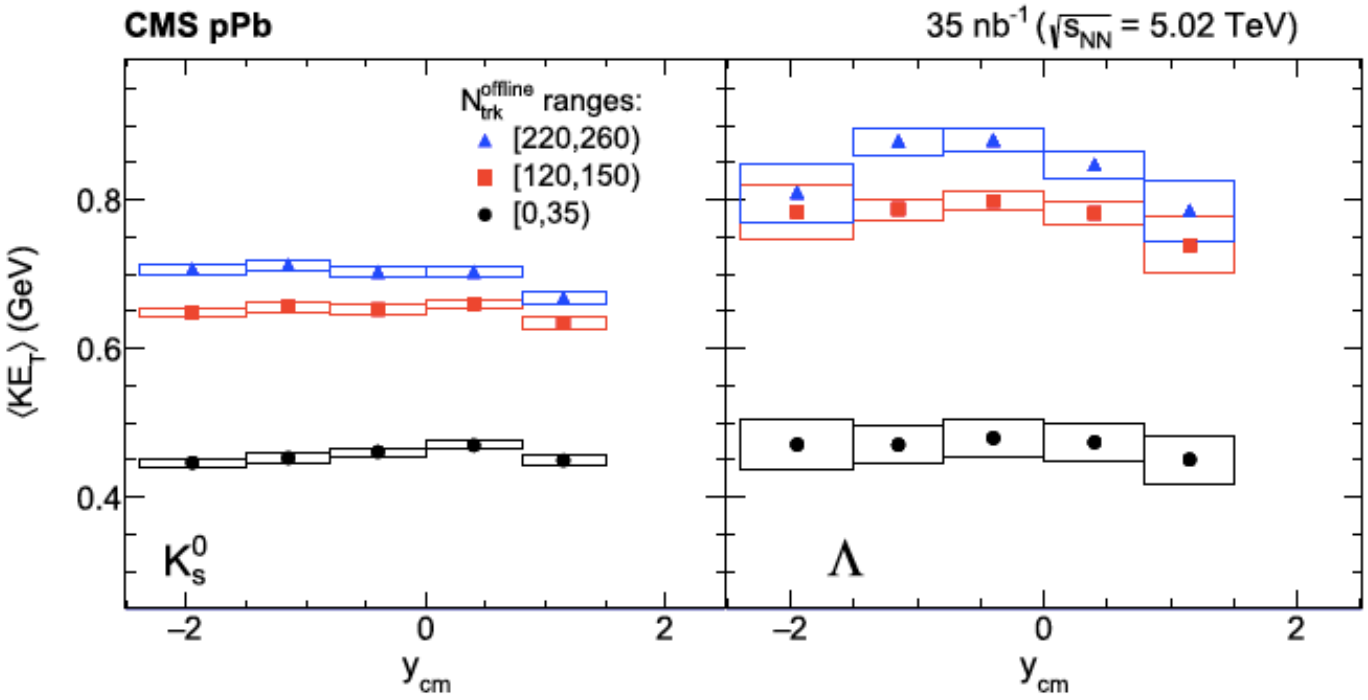
# Λ / $K_s$ Ratio in Pb-going Side versus p-going Side




Comparing Λ / $K_s$ ratio in Pb-going side and p-going side:

- For low multiplicity events, two ratios mostly overlap within systematic uncertainties
- For high multiplicity events, ratio in Pb-going side is larger at higher $p_T$

# <KE$_T$> versus $y_{cm}$



# $<KE_T>$ versus $y_{cm}$

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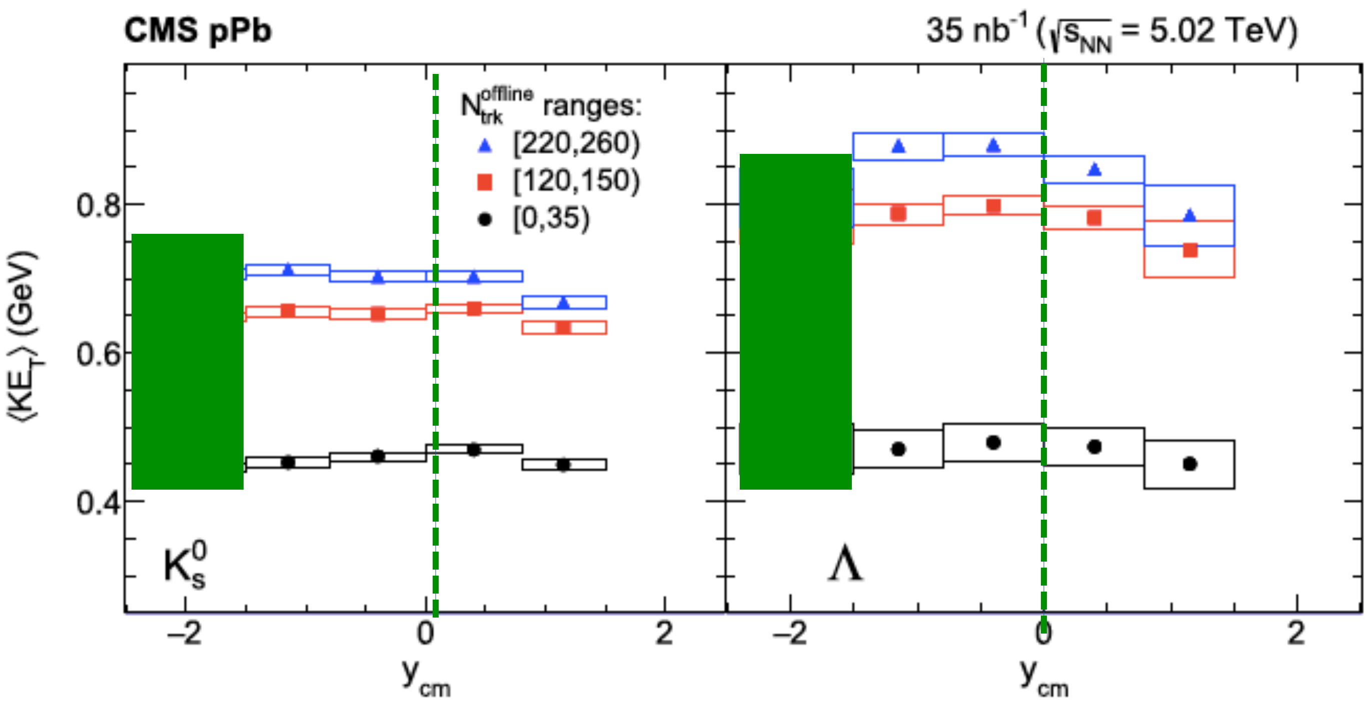
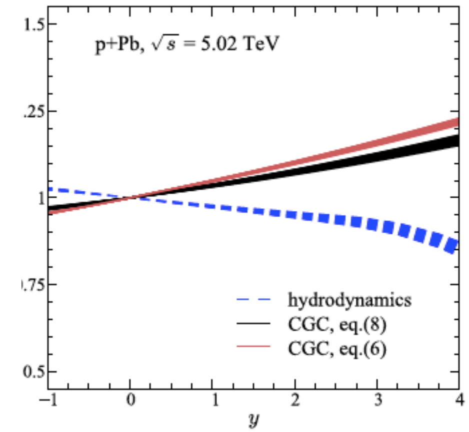



Comparing $<KE_T>$ in Pb-going side and p-going side:

- Asymmetry develops as event multiplicity increases(Pb-going side larger)
- Trend of asymmetry is more evident for heavier particle species

The trend of data is similar as hydrodynamic model predicted.

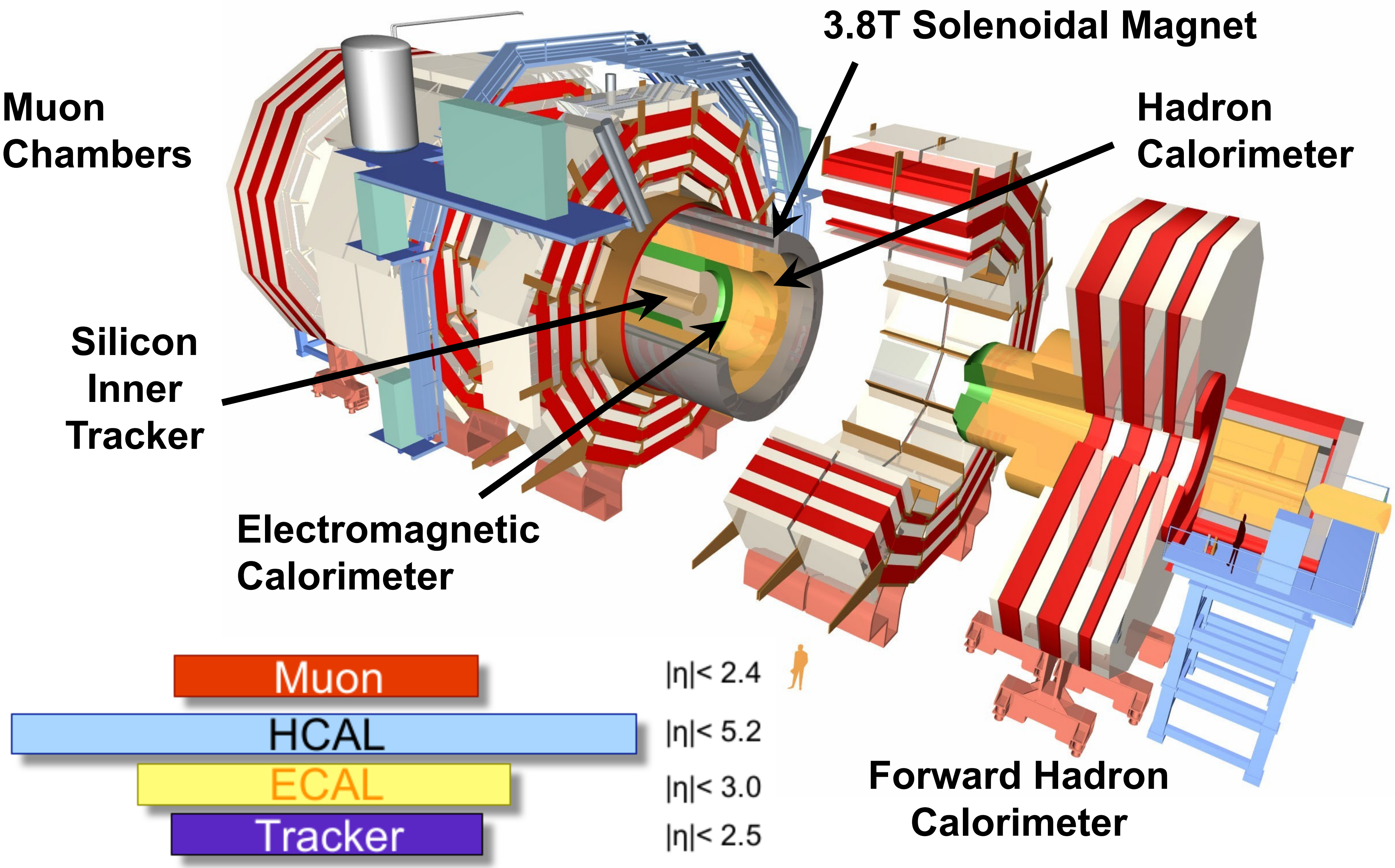
# Summary

- $K_s$, $\Lambda$, and $\Xi$ spectra are measured in three systems with high precision
- At similar multiplicities, particle ratios at low $p_T$ show a larger difference between high- and low-multiplicity events in smaller system
- At similar multiplicities, "$m_T$-scaling" breaking is more significant for smaller system
- <$KE_T$> asymmetry develops as multiplicity increases, with a larger value at Pb-going side, especially for heavier particles

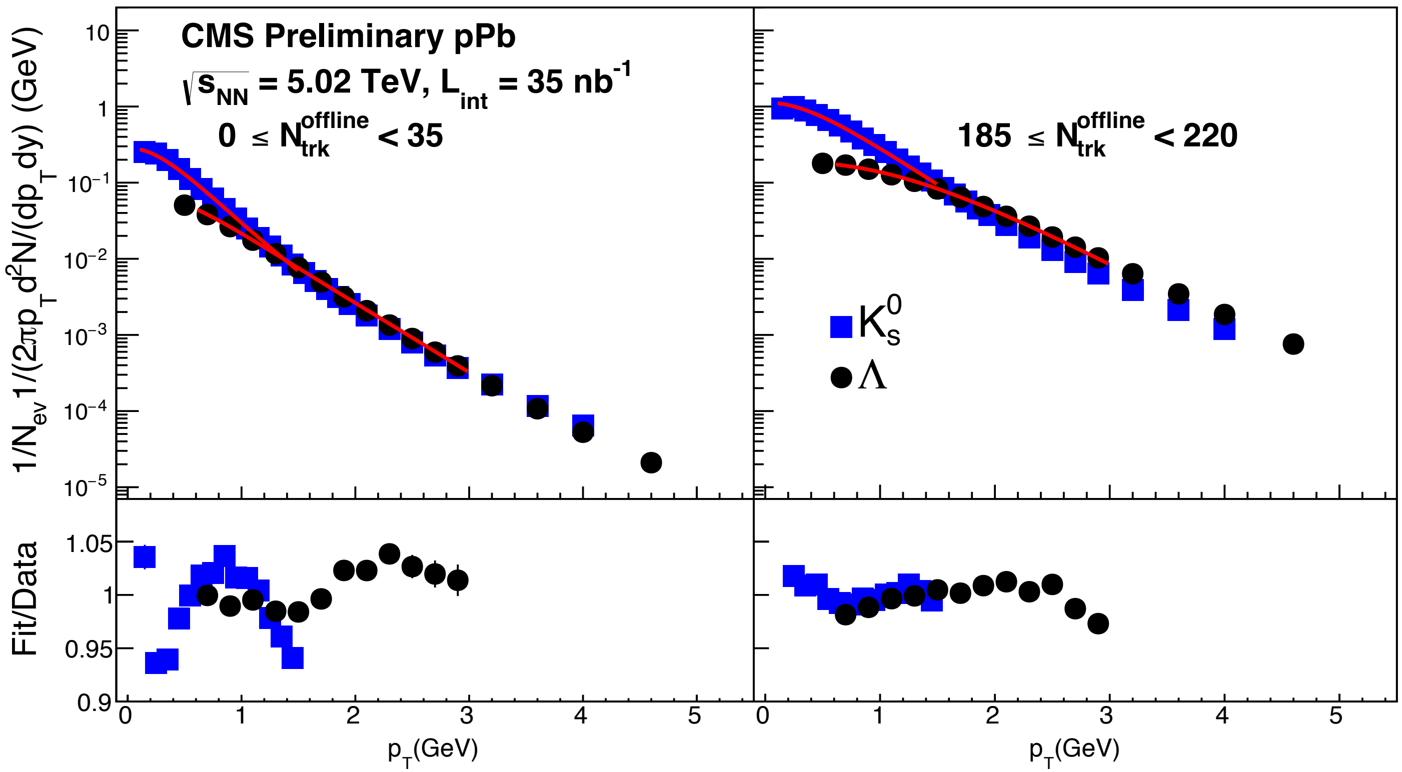
Thank you!

# Extra Slides

# CMS Detector



# Blast Wave Fit Quality




- Fit quality is good at high multiplicity events
- Fit quality is not so good at low multiplicity events (No “radial” flow effect)

Fitting Range:

$K_s$(0.1 to 1.5 GeV/c), Λ(0.6 to 3 GeV/c)