



Measurement of Λ baryon balance function in pp collisions at $\sqrt{s} = 13.6$ TeV

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Outline of the talk

- Balance Function
- Analysis Details
 - ◆ Reconstruction of Λ baryon
 - ◆ Correction Factors (MC)
 - ◆ MC Closure Test
- Balance Function Results
- Conclusion

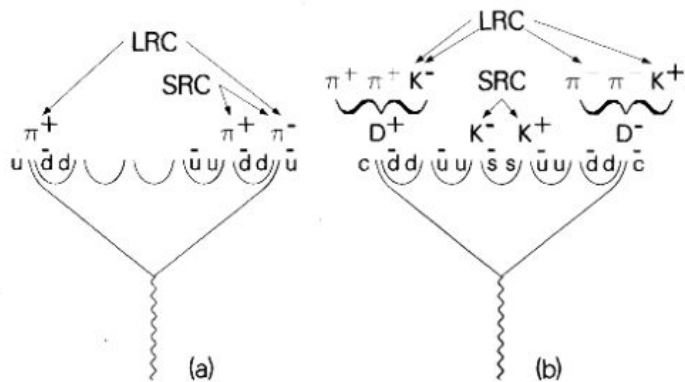
Introduction and Motivation

Balance Functions

- Balance functions are defined as the conditional probability density of finding a particle at momentum p_1 given that its antiparticle is produced at momentum p_2

Clocking Hadronization

- Delayed hadronization leads to decrease in the width of balance function in relative rapidity, therefore the width of the balance function will decrease with increasing collision centrality

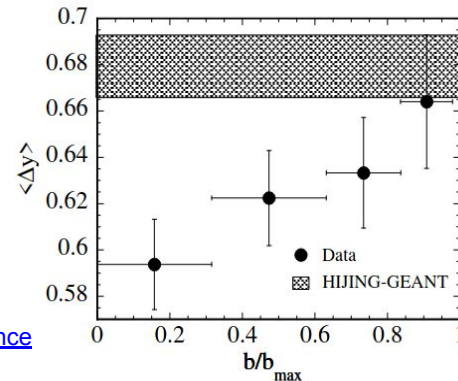
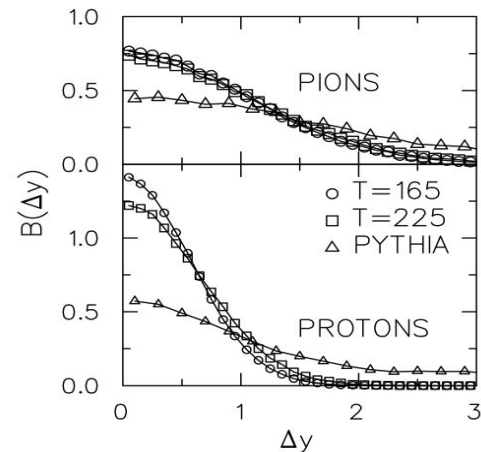


Width of balance function is sensitive to production of hadron pairs

Observation of Strangeness Correlations in e^+e^- Annihilation at $\sqrt{s} = 29$ GeV

TPC/Two Gamma Collaboration, H. Aihara et al., Phys. Rev. Lett. 53, 2199 (1984)

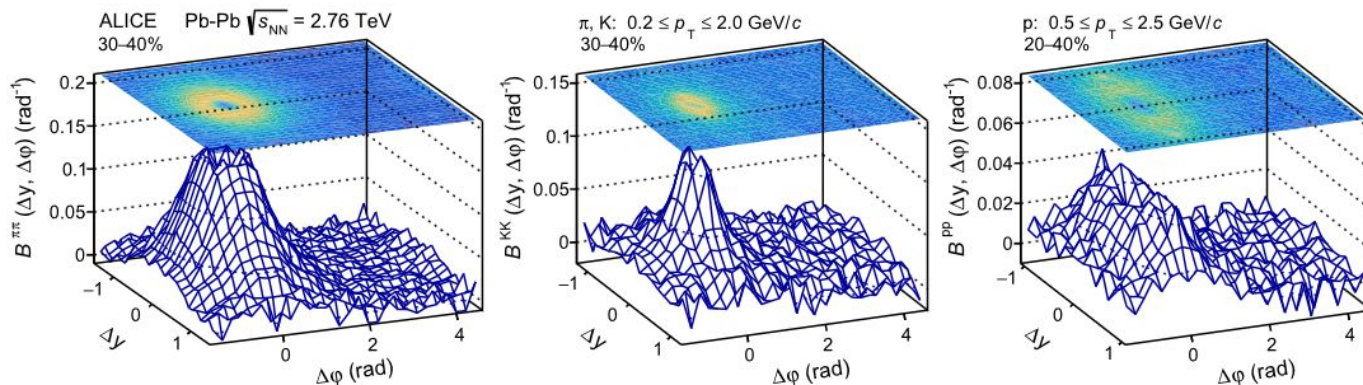
Clocking Hadronization in Relativistic Heavy Ion Collisions, S. Pratt et. al.



STAR

Pion Balance Function
Au-Au (200 GeV)

Previous Work



[ALICE Collaboration, Phys. Lett. B 833, 137338 \(2022\)](#)

Balance functions of identified hadrons were measured and their widths and integral have been studied as a function of collision centrality

[Balance function of \(un\)identified hadrons in PbPb, pPb and pp collisions.](#)
Jinjin Pan, for ALICE Collaboration, Nuclear Physics A, Volume 982, (2019)

We intend to measure **Λ Balance Function** and study the evolution of its width and integral as a function of collision centrality

Comparison with existing MC models would help us understand the hadron pair production mechanisms

Λ Balance Function ???

Analysis Details

Balance Function Definition

The balance function is defined as,

$$B^{\alpha\bar{\beta}} = \frac{1}{2} \left(\rho_1^{\bar{\beta}} (R_2^{\alpha\bar{\beta}} - R_2^{\bar{\alpha}\bar{\beta}}) + \rho_1^{\beta} (R_2^{\bar{\alpha}\beta} - R_2^{\alpha\beta}) \right)$$

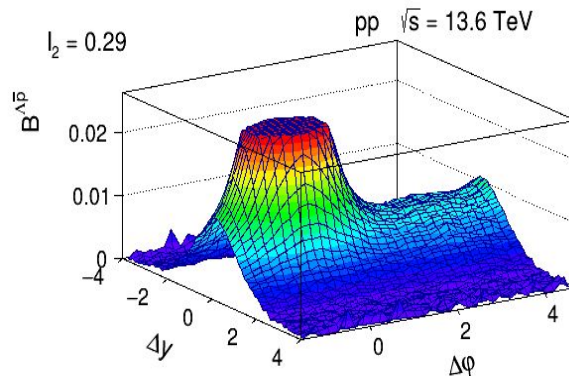
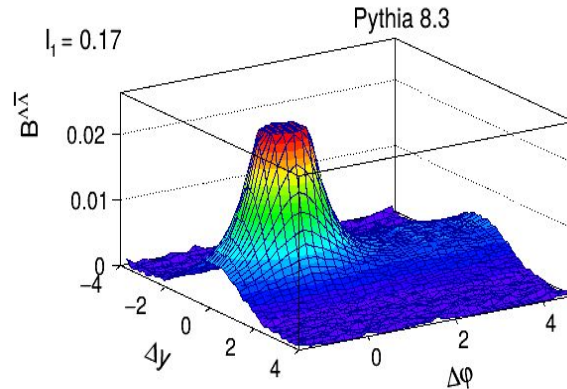
where, R_2 is the two-particle number cumulant,

$$R_2^{\alpha\beta}(\vec{p}_\alpha, \vec{p}_\beta) = \frac{\rho_2^{\alpha\beta}(\vec{p}_\alpha, \vec{p}_\beta)}{\rho_1^\alpha \otimes \rho_1^\beta(\vec{p}_\alpha, \vec{p}_\beta)} - 1$$

and ρ_1 and ρ_2 are single and pair densities

In an ideal case of full acceptance, the integral of the balance function Λ with its balancing partners p , Σ , Ξ , Ω , etc should tend to unity

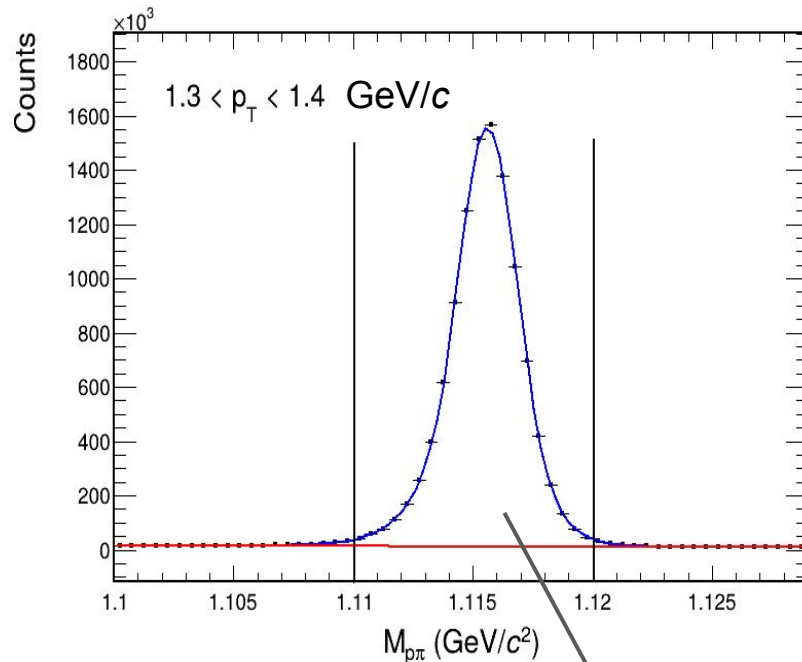
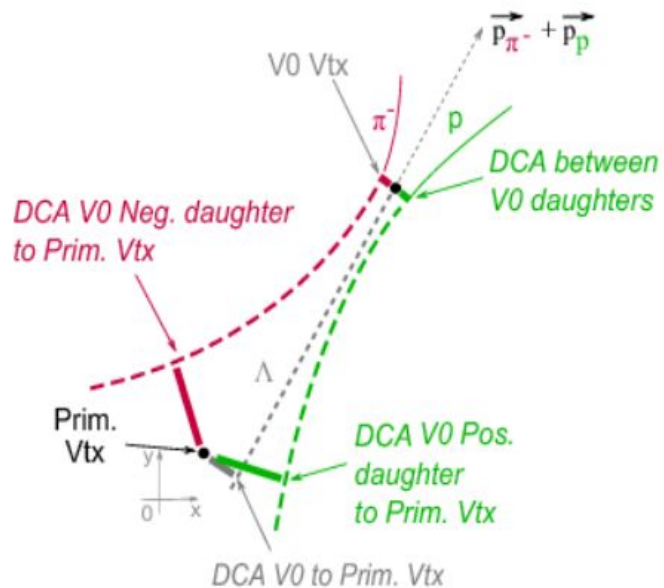
Pythia simulation study to verify the balance function calculation



Decay Topology and Invariant Mass Spectra

CERN-DOC-ALICE

LHC22o_pass7_minBias_small



Mass : 1.115 GeV/c²

Decay Length : 7.89 cm

BR (%) : $\Lambda \rightarrow p\pi^-$: 64.1 ± 0.5 (%)

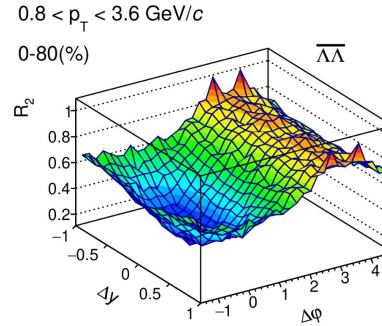
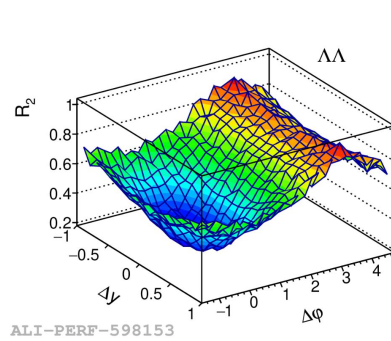
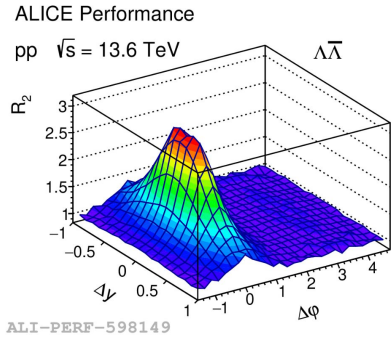
Details of fit in backup !!!

Signal Region

Two-particle cumulants Balance Function

Uncorrected for efficiency

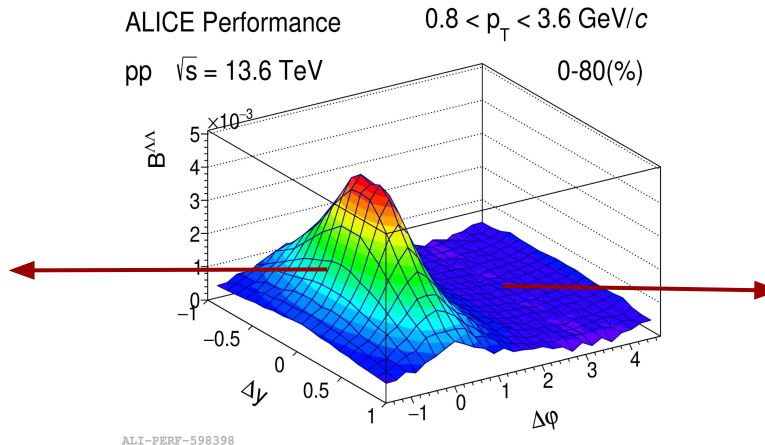
First look at run 3 data results [Uncorrected for efficiency]



**Correlated near-side peak
in baryon-antibaryon pair
 R_2 correlation function**

**Anti-correlation on the
near-side in baryon-baryon pair
 R_2 correlation function**

**The balance
function shows
a wide
correlated
near-side peak
along $\Delta\psi$**



**The away-side is slightly
anti-correlated**

MC Analysis

Correcting for efficiency and secondary contamination

Reconstruction efficiency and fraction of primary (Monte Carlo)

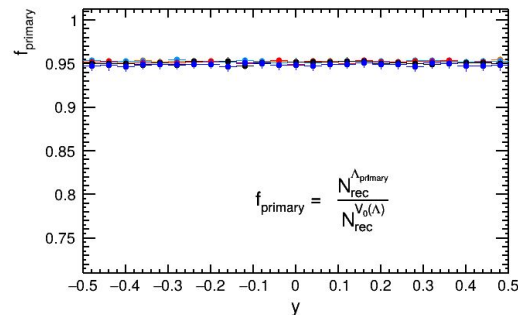
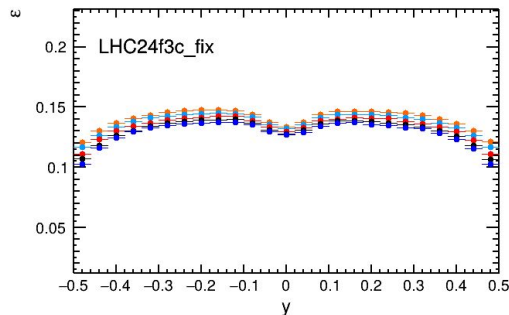
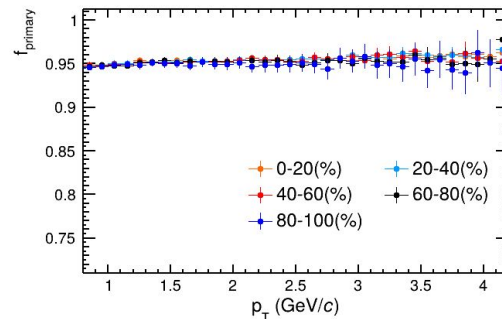
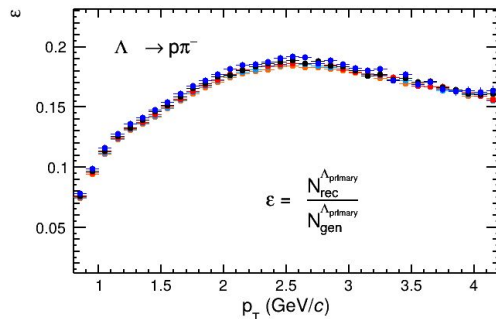
Efficiency as a function of rapidity account for the losses at the edges of the detector

The efficiencies are estimated as function of p_T and rapidity

$$\varepsilon = \frac{N_{rec}^{\Lambda Primary}}{N_{gen}^{\Lambda Primary}}$$

$$f_{Primary} = \frac{N_{rec}^{\Lambda Primary}}{N_{rec}^{V_0}}$$

$$N_{rec}^{V_0} = N_{rec}^{\Lambda Primary} + N_{rec}^{\Lambda Secondary} + N_{rec}^{contamination}$$



Dependence on centrality

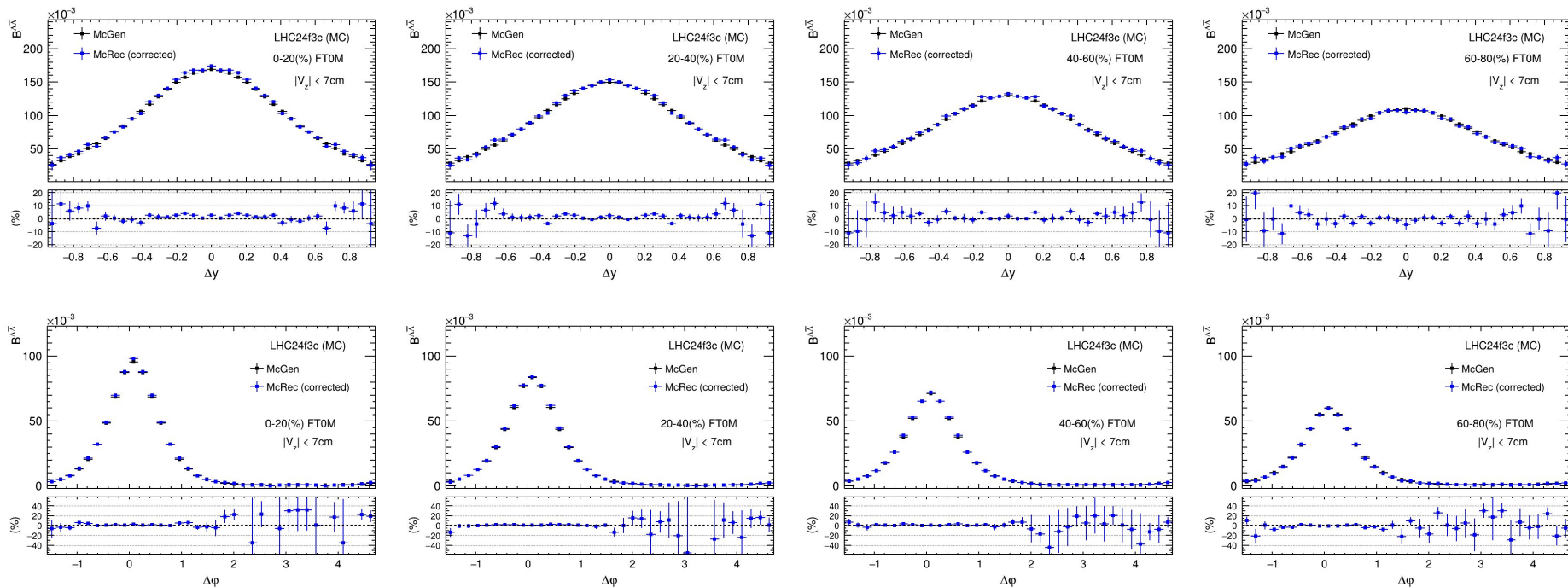
MC Closure Tests

Validation of correction procedure

Weighting the single- and pair-densities in balance function with the correction factor (F)

$$F = \frac{f_{Primary}}{\varepsilon}$$

Multiplicity Dependent Study (MC Closure Tests)



These closure tests verifies the validity of the correction procedure and the selection criteria to estimate Λ balance function

Balance Function

Back to ALICE data

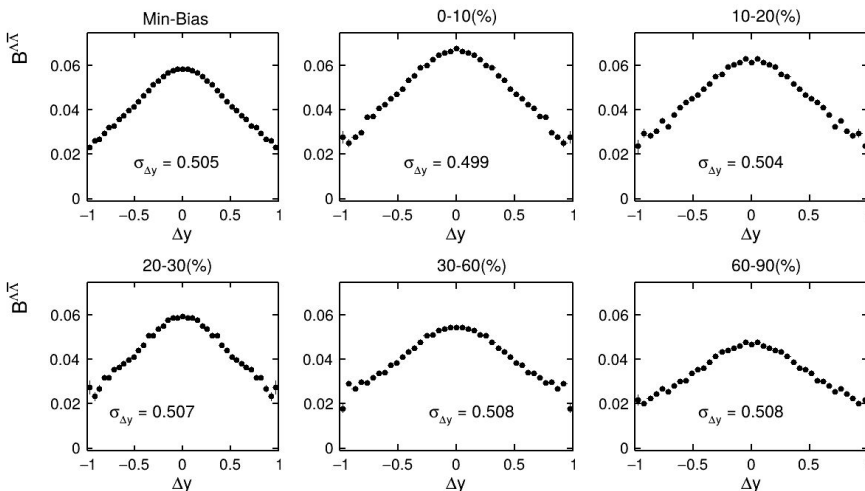
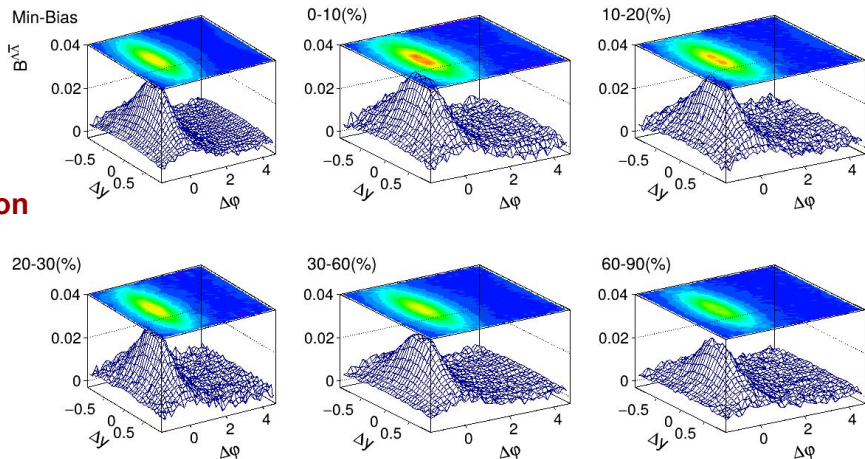
Λ balance function in different multiplicity classes

Corrected Balance Function

Dataset:

LHC22o_pass7_minBias_medium

→ It can be observed that the peak amplitude of the balance function at $(\Delta y, \Delta\phi) = (0, 0)$ increases from least to most central collision



Conclusion and future work

- The first measurement of balance function of Λ baryons with ALICE detector is presented as function of different multiplicity classes
- Measurement of the width and integral of the balance function is under progress
- The systematics is also under progress

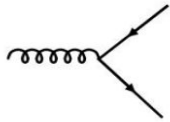
Thank You

Backup

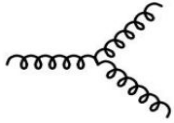
General picture of hadron collisions

The interactions at the collision vertex is governed by QCD

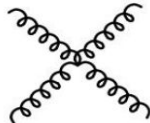
$$\mathcal{L}_{QCD} = \bar{\psi}_f (i\gamma^\mu \partial_\mu + ig \frac{\lambda_a}{2} A_\mu^a) \psi_f - m \bar{\psi}_f \psi_f - \frac{1}{4} G_{\mu\nu}^a G_a^{\mu\nu}$$



Analogous to photon exchange of QED



3-gluon vertex



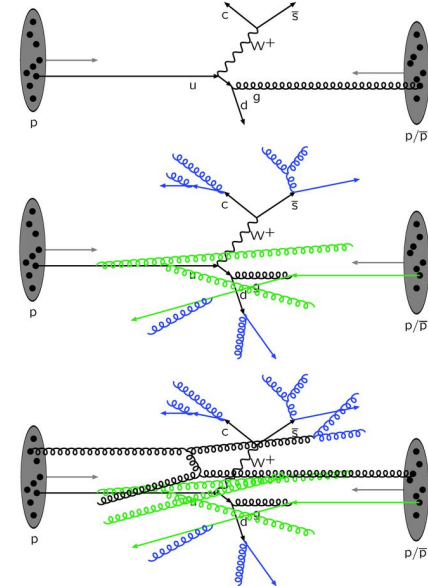
4-gluon vertex

Conserved Quantities at Interaction Vertex:

- Charge
- Flavor
- Color
- Energy and momentum

Interaction vertex in QCD

In addition to this there will also be electroweak interactions governed by photon, W and Z bosons



Charge conserving processes



Correlated pairs of hadrons

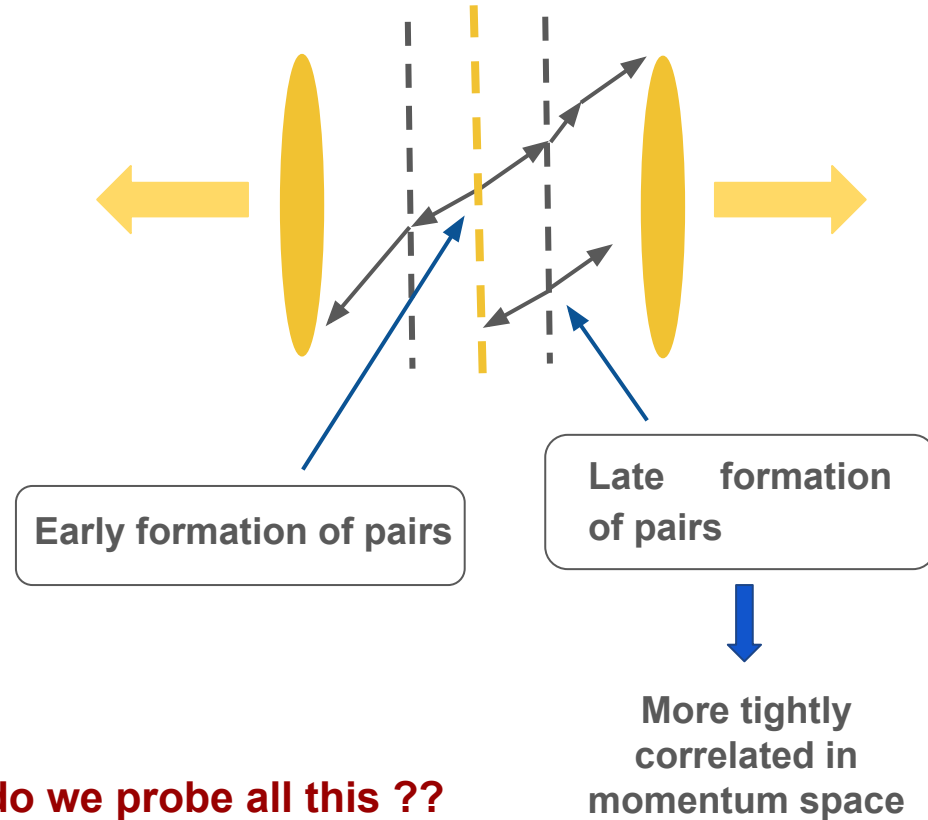
Correlated hadrons, balancing partners and delayed hadronization

Charge conserving processes → Correlated pairs of hadrons

→ Hadrons that are correlated in momentum space are formed in pairs of opposite charge at a spacetime point, such pairs are called balancing partners

Globally conserved quantities

- Electric charge
- Strangeness
- Baryon number



Event Selection Cuts

S.N.	Variable	Cut Value
1.	$ V_z $	< 7 cm
2.	Minimum Bias Trigger	Sel8 (FT0A + FT0C)
3.	FT0M Multiplicity Selection	0-100%

V0 Daughters Track Cuts

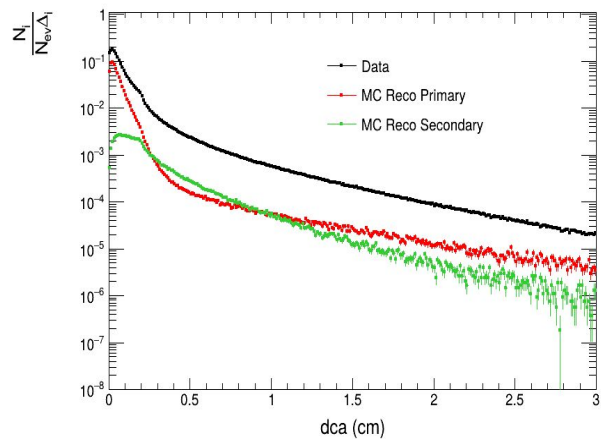
S.N.	Variable	Cut Value
1.	p_T (GeV/c)	> 0.15
2.	$ \eta $	< 0.8
3.	# of crossed rows TPC	> 70
4.	$ \sigma_{\text{TPC}} $ (TPC only)	< 3

V0 Selection Cuts for Λ

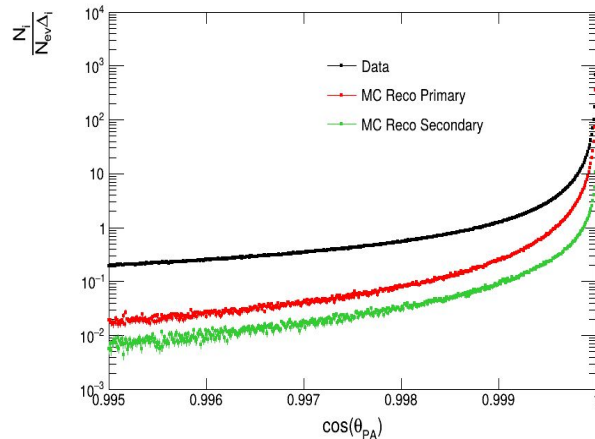
S.N.	Variable	Cut Value
1.	DCA V_0 Daughters	< 1 cm
2.	DCA V_0 to PV	< 0.1 cm
3.	DCA Proton to PV	> 0.02 cm
4.	DCA Pion to PV	> 0.06 cm
5.	Transverse Decay Radius (r_{XY})	> 0.5 cm
6.	$c\tau$	< 30 cm
7.	$\cos(\theta_{PA})$	> 0.995
8.	K_S Mass Rejection	$ M_{K_S} - M_{PDG} > 12$ MeV/ c^2
9.	Λ Mass Window	1.108 - 1.122 (GeV/ c^2)
10.	p_T (GeV/ c)	0.8 - 3.8
11.	$ y $	< 0.5

Quality Assurance

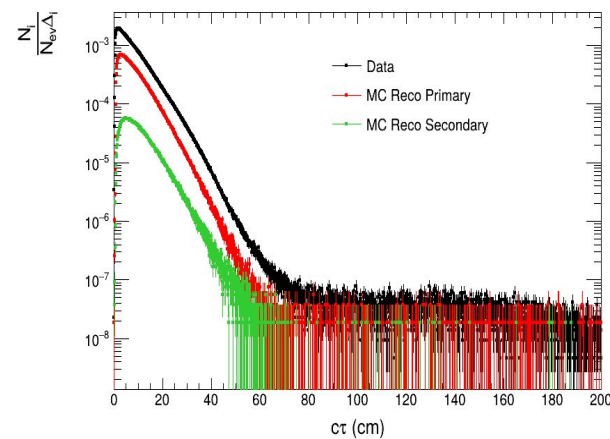
DCA V0 to PV



$\cos(\theta_{pA})$



$V_0 \tau$



Controls purity and fraction of primary and secondary Λ

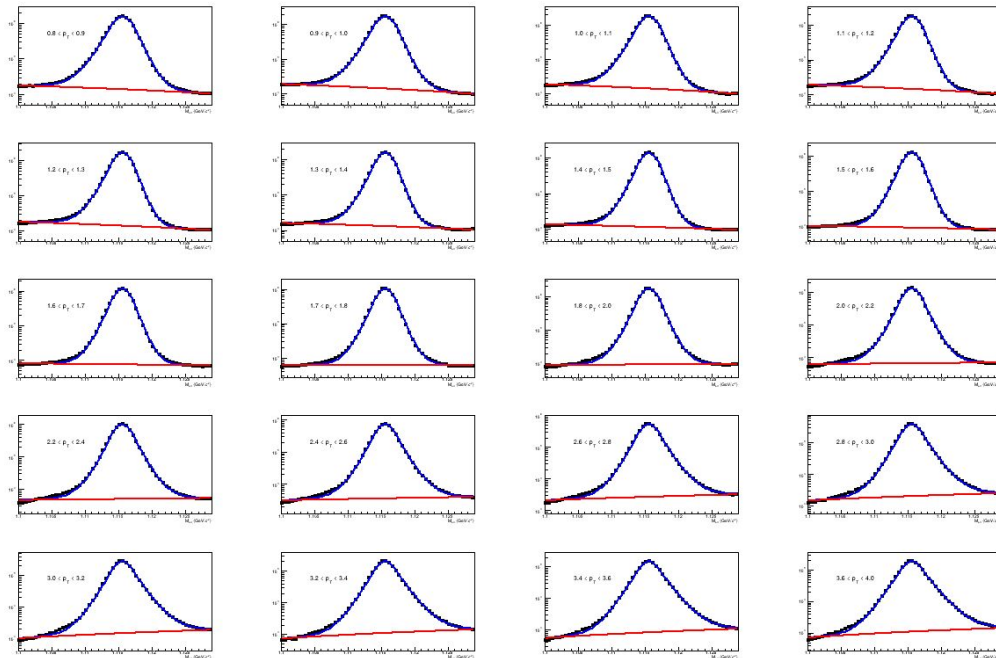
Invariant mass fits

Crystal Ball Function

$$f(x) = \begin{cases} N \cdot A_L \cdot \left(B_L - \frac{x-\mu}{\sigma}\right)^{-n_L} & t \leq -\alpha_L \\ N \cdot A_R \cdot \left(B_R + \frac{x-\mu}{\sigma}\right)^{n_R} & t \geq \alpha_R \\ N \cdot \exp\left(-\frac{1}{2} \frac{(x-\mu)^2}{\sigma^2}\right) & \text{otherwise} \end{cases}$$

$$A_{L,R} = \left(\frac{n_{L,R}}{\alpha_{L,R}}\right)^{n_{L,R}} \cdot \exp\left(-\frac{\alpha_{L,R}^2}{2}\right)$$

$$B_{L,R} = \frac{n_{L,R}}{\alpha_{L,R}} - \alpha_{L,R}$$



Second order polynomial and fit function

$$p(x) = a + bx + cx^2$$

$$F(x) = f(x) + p(x)$$

Significance of Invariant Mass Signal in Data (Purity from MC)

Fit Function: **Crystal Ball + Polynomial (II order)**

Signal Region: **[1.11, 1.12] GeV/c²**

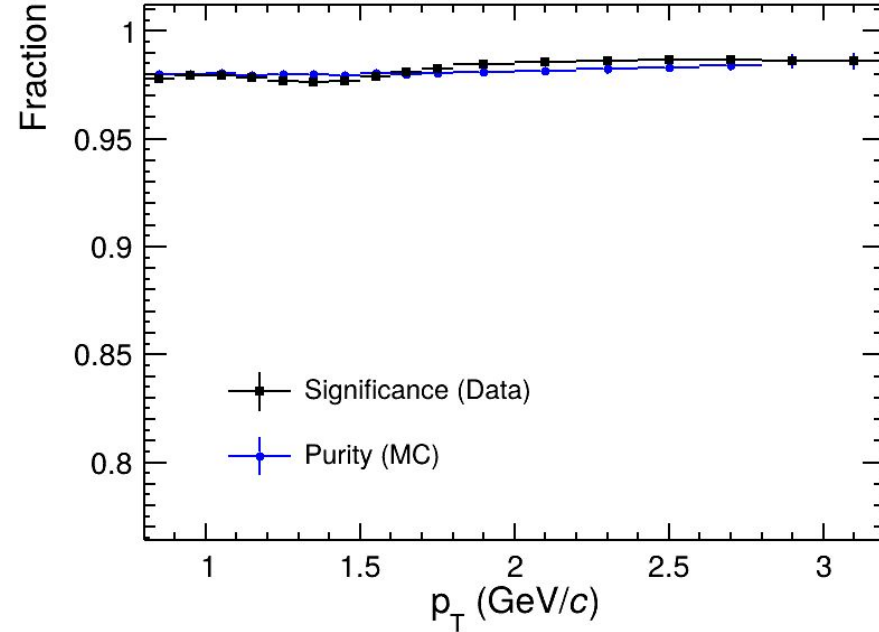
Fit Region: **[1.10, 1.13] GeV/c²**

$$S+B = \sum_{bin=x_{min}}^{x_{max}} H_{bin} \quad \{H : \text{Invariant Mass Histogram}\}$$

$$B = \int_{x_{min}}^{x_{max}} a + bx + cx^2$$

$$Fraction(Data) = \frac{S}{S+B}$$

$$Fraction(MC) = \frac{N_{rec}^{PDG|=3122}}{N_{rec}^{V_0}}$$



The purity in data and MC are consistent within 0.4%

Correction Factors

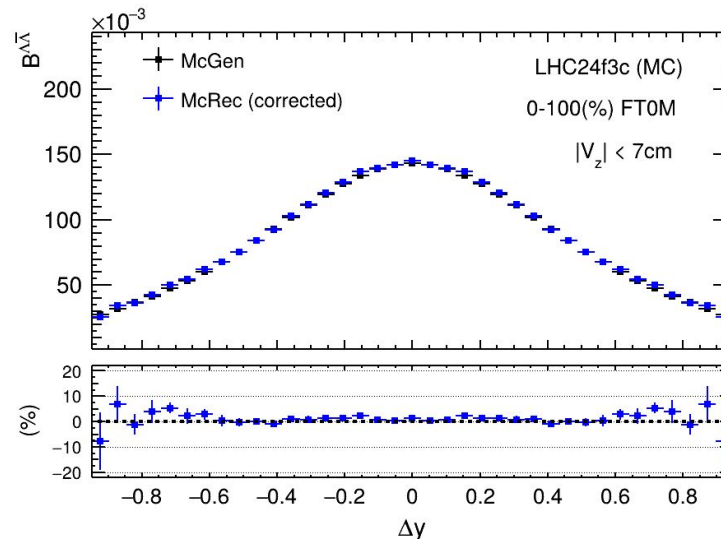
Reconstructed V_0 as Λ
$$N_{rec}^{V_0} = N_{rec}^{\Lambda_{Primary}} + N_{rec}^{\Lambda_{Secondary}} + N_{rec}^{contamination}$$

Reconstruction efficiency
$$\varepsilon = \frac{N_{rec}^{\Lambda_{Primary}}}{N_{gen}^{\Lambda_{Primary}}}$$

Fraction of primary
$$f_{Primary} = \frac{N_{rec}^{\Lambda_{Primary}}}{N_{rec}^{V_0}}$$

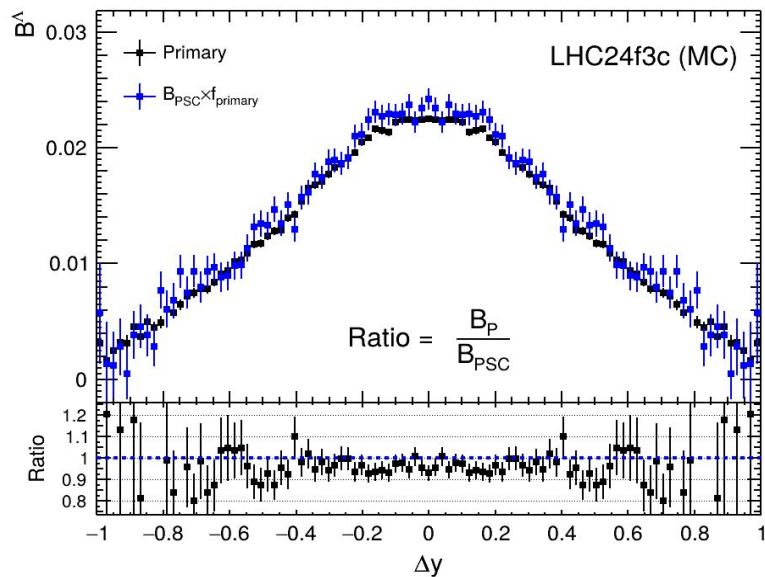
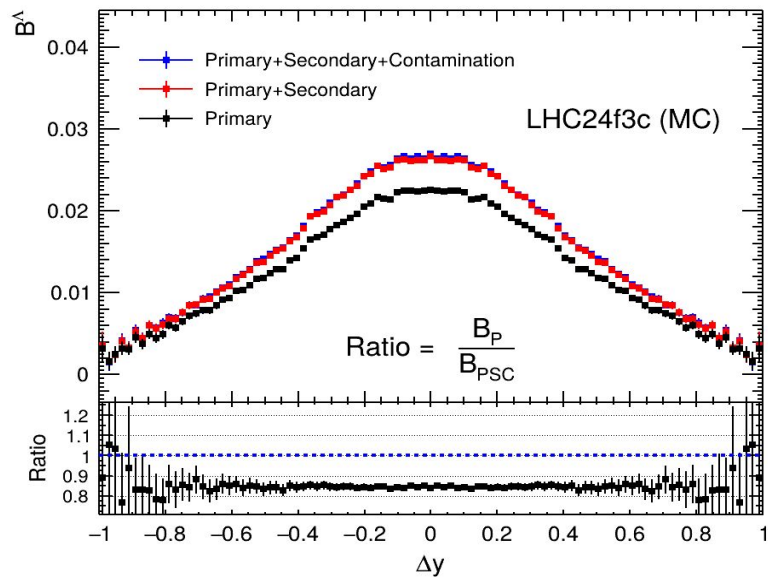
Correction Factor
$$F = \frac{f_{Primary}}{\varepsilon}$$

$$F = \frac{N_{gen}^{\Lambda_{Primary}}}{N_{rec}^{V_0}}$$



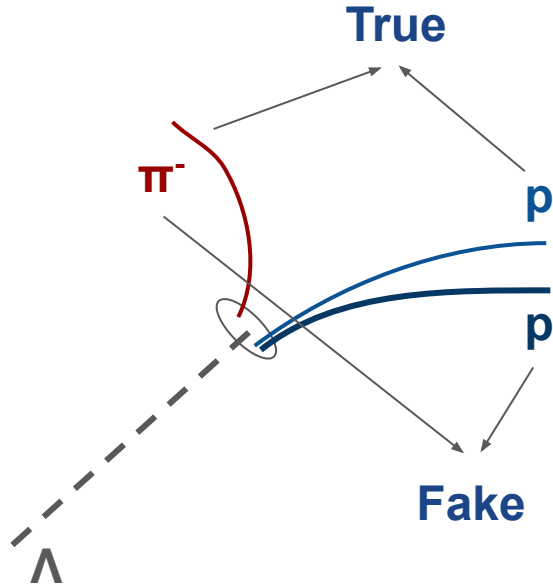
The closure test validates the estimation of correction factors and the correction procedure

MC Reconstructed BF (Uncorrected for efficiency)



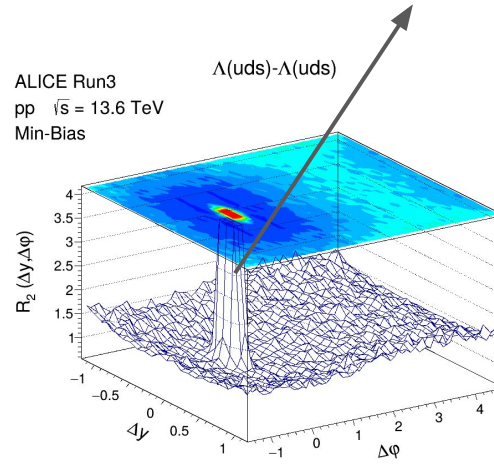
After applying **primary fraction correction**
the **BF of selected V0 candidates** coincides
with the **BF of primary Λ**

Effect of shared daughters



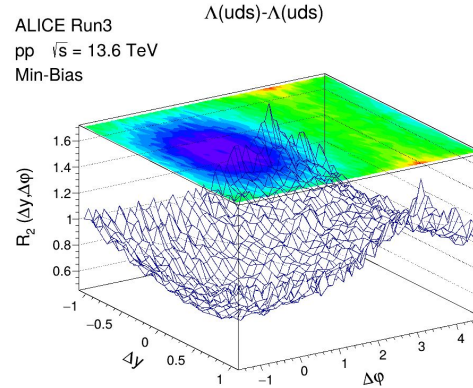
Huge autocorrelation

ALICE Run3
pp $\sqrt{s} = 13.6$ TeV
Min-Bias



**With
Shared
Daughters**

ALICE Run3
pp $\sqrt{s} = 13.6$ TeV
Min-Bias



**Without
Shared
Daughters**