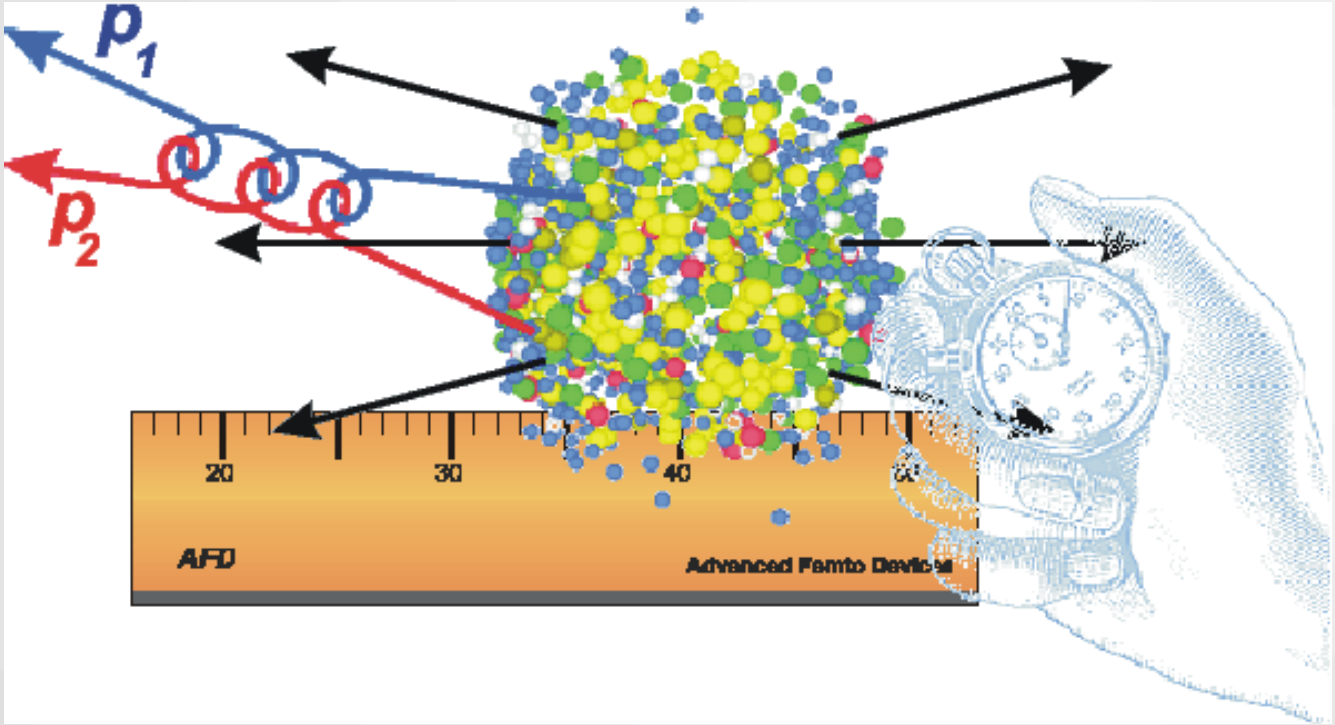
# Multiplicity Evolution of PID Balance Functions in Pb-Pb, p-Pb and pp Collisions with ALICE




| | Charged | π |
|---|---|---|
| Pb-Pb 2.76 TeV | ✔ | ✔ |
| p-Pb 5.02 TeV | ✔ | |
| pp 7 TeV | ✔ | |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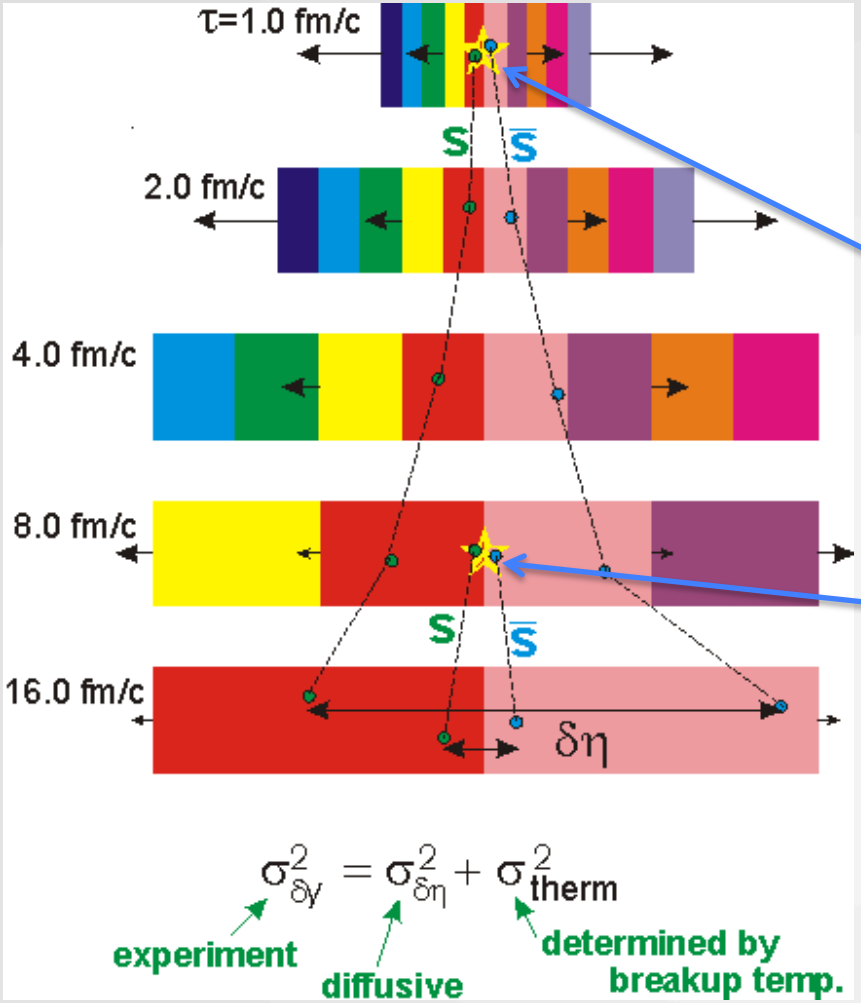
On Behalf of the ALICE Collaboration


U.S. DEPARTMENT OF ENERGY | Office of Science

*US–LHC* | 11/02/2017

# Balance Functions – A Signal of Late Hadronization




*S. Bass, P. Danielewicz and S.Pratt. PRL 85, 2689 (2000)*

**$q\bar{q}$ pair creation in a rapidly expanding system**

**Early stage creation: larger final separation, wider balance function distributions**

**Late stage creation(Most $q\bar{q}$ pairs created at hadronization): pairs more correlated, narrower balance function distributions**

***Balance Functions identify balancing charges on a statistical basis.***

$$B(\Delta\vec{p}) = \frac{1}{2}\left\{\frac{\langle N_{+-}(\Delta\vec{p})\rangle - \langle N_{++}(\Delta\vec{p})\rangle}{\langle N_{+}\rangle} + \frac{\langle N_{-+}(\Delta\vec{p})\rangle - \langle N_{--}(\Delta\vec{p})\rangle}{\langle N_{-}\rangle}\right\}$$

$\Delta\vec{p}$

momentum difference

# Balance Functions of Unidentified Charged Particles

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$0.2<p_{T,assoc}<p_{T,trig}<2.0$ GeV/c

Pb-Pb → p-Pb → pp

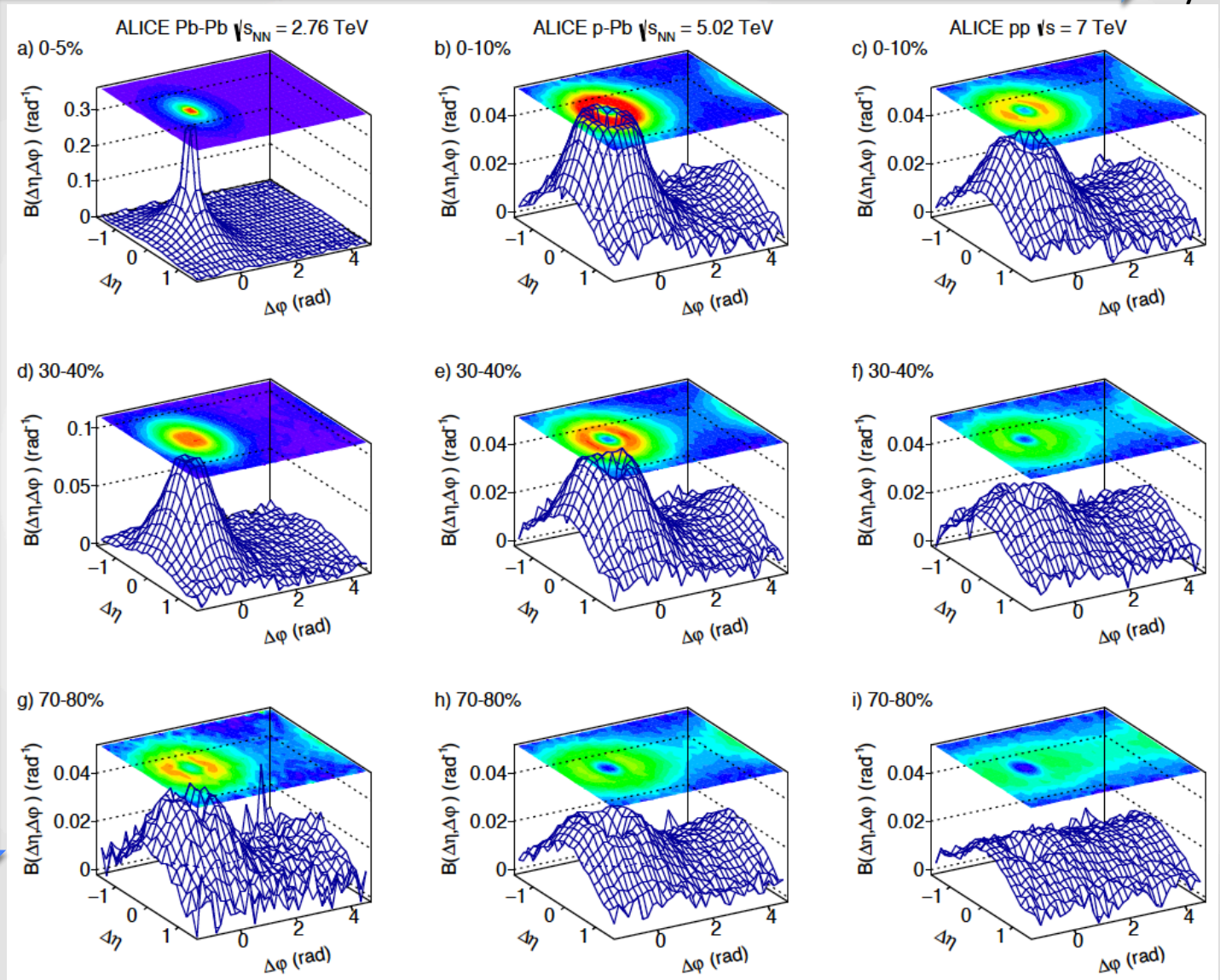
Collision Systems

Central

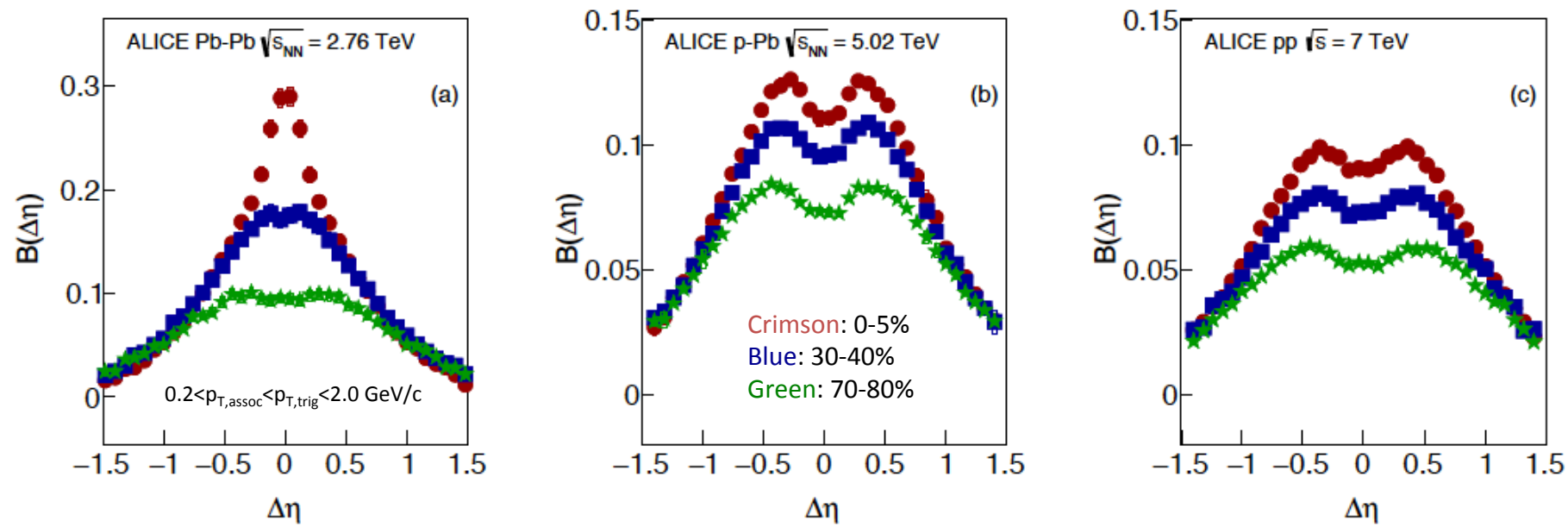
Mid-Central

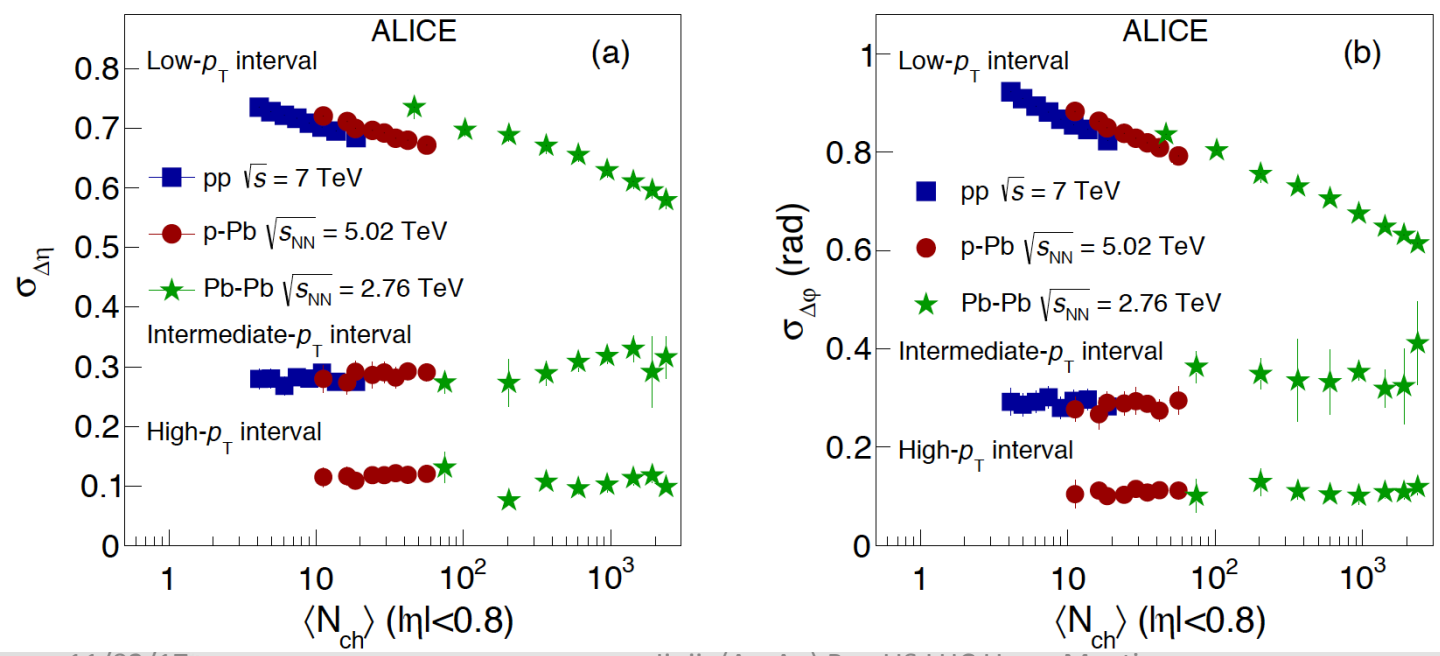
Peripheral

Multiplicity Classes



# Balance Functions of Unidentified Charged Particles

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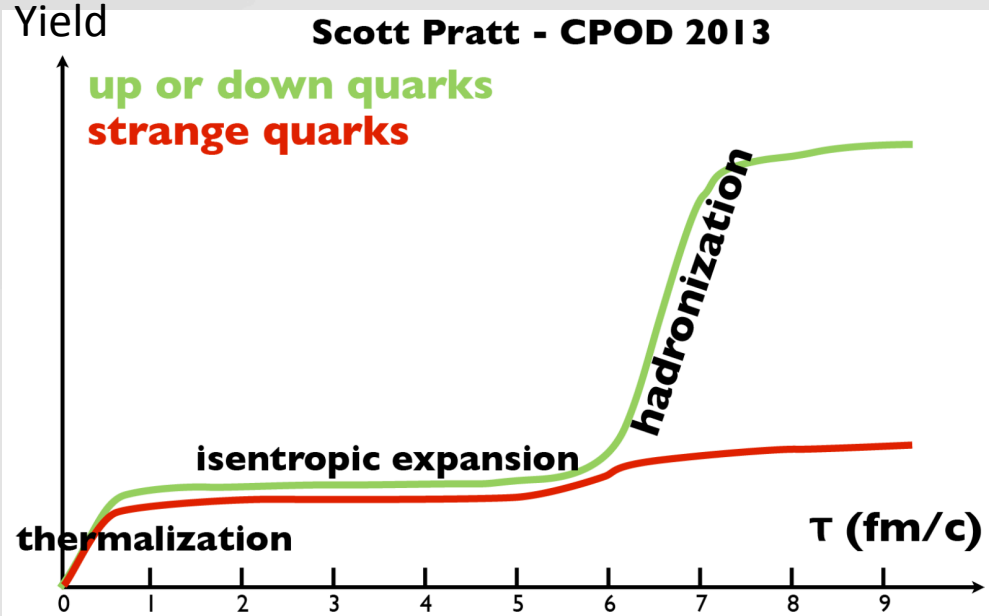
By the ALICE Collaboration

Low-$p_T$ interval
$0.2<p_{T,assoc}<p_{T,trig}<2$ GeV/c

Intermediate-$p_T$ interval
$2<p_{T,assoc}<3<p_{T,trig}<4$ GeV/c

High-$p_T$ interval
$3<p_{T,assoc}<8<p_{T,trig}<15$ GeV/c

# PID Balance Functions – How They Work




Two-wave scenario of quark production

1st wave – flat production rate over time

– main source of s-quark

2nd wave – rapid increase around hadronization

– main source of u,d-quarks

Scott Pratt PRL. 108, 212301 (2012)

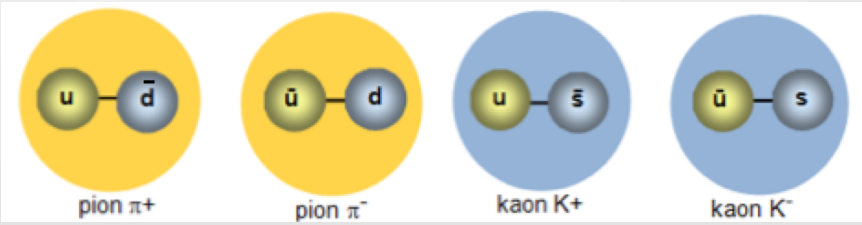
$$B(\Delta\vec{p}) = \frac{1}{2}\left\{\frac{\langle N_{+-}(\Delta\vec{p})\rangle - \langle N_{++}(\Delta\vec{p})\rangle}{\langle N_{+}\rangle} + \frac{\langle N_{-+}(\Delta\vec{p})\rangle - \langle N_{--}(\Delta\vec{p})\rangle}{\langle N_{-}\rangle}\right\}$$

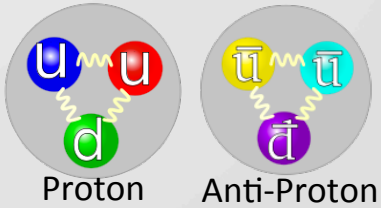
$\Delta\vec{p}$

momentum difference

Two-wave quark creation can be studied with balance functions of **identified particle pairs**

- Charged π pairs
- Charged K pairs
- π/K pairs
- Proton Anti-Proton pairs



# Measuring Balance Functions - the Observable

$$x \equiv \{y, \varphi, p_T\}$$

$$\rho(x) = \frac{1}{\sigma}\frac{d\sigma}{dx}$$

*Cumulant* $$C_2(x_1, x_2) = \rho_2(x_1, x_2) - \rho_1(x_1)\rho_1(x_2)$$

*Normalized Cumulant* $$R_2(x_1, x_2) = \frac{C_2(x_1, x_2)}{\rho_1(x_1)\rho_1(x_2)}$$

***$R_2$ is a robust observable!***
Single track efficiencies cancel out of the ratio

4 different charge combinations for $R_2$: (+ -), (- +), (+ +), and (- -)

***Charge Independent (CI)*** combinations $$CI = \frac{1}{2}\{LS + US\}$$

***Charge Dependent (CD)*** combinations $$CD = \frac{1}{2}\{US - LS\}$$

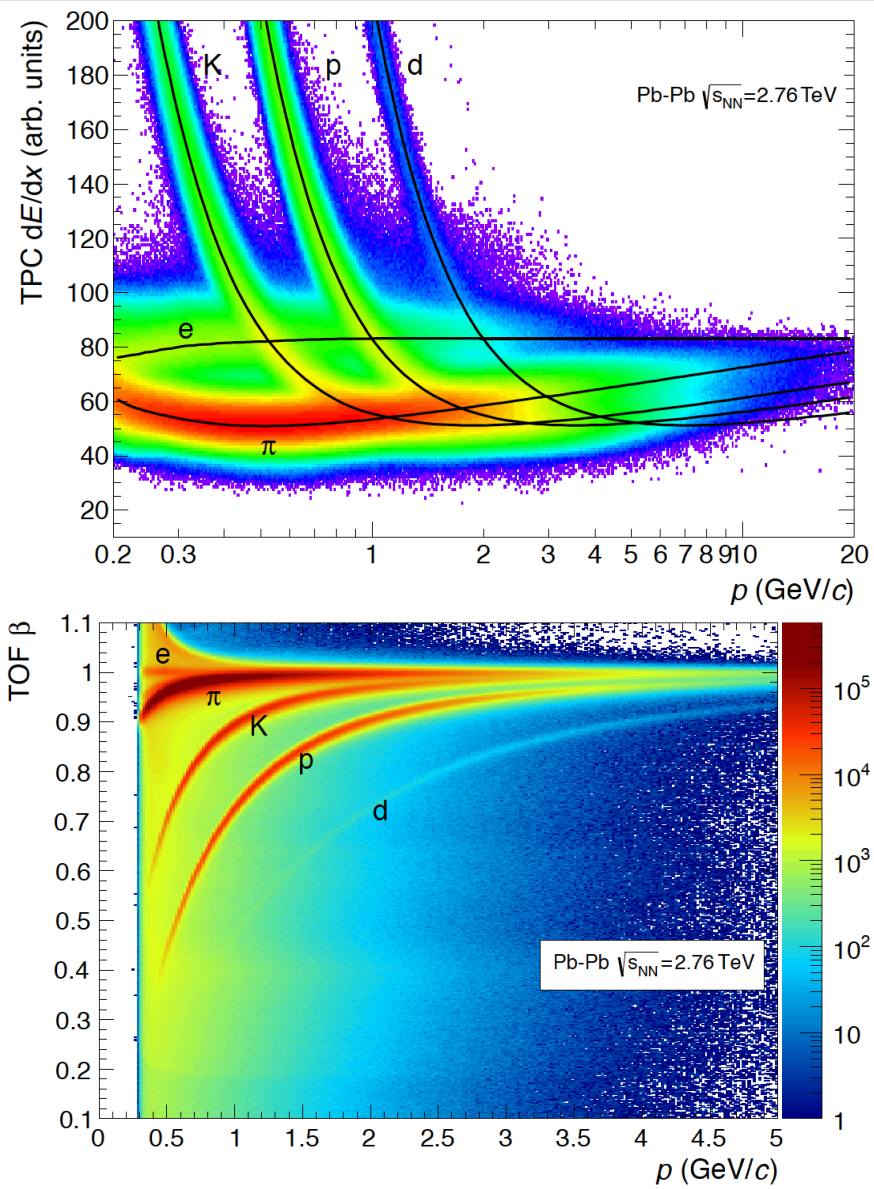
$$LS = \frac{1}{2}\{(++) + (--)\}$$

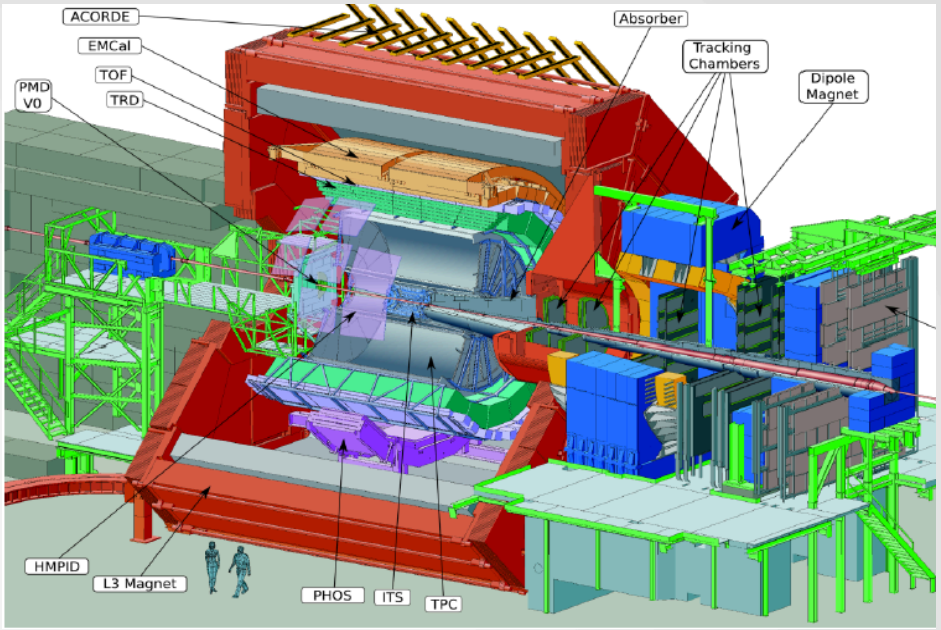
$$US = \frac{1}{2}\{(+-) + (-+)\}$$

***CD is proportional to the Balance Function***

$$B(\Delta x) \approx \frac{dN_{ch}}{dx} R_2^{CD} = \frac{dN_{ch}}{dx}\frac{1}{2}\left[R_2^{+-} - R_2^{++} + R_2^{-+} - R_2^{--}\right]$$

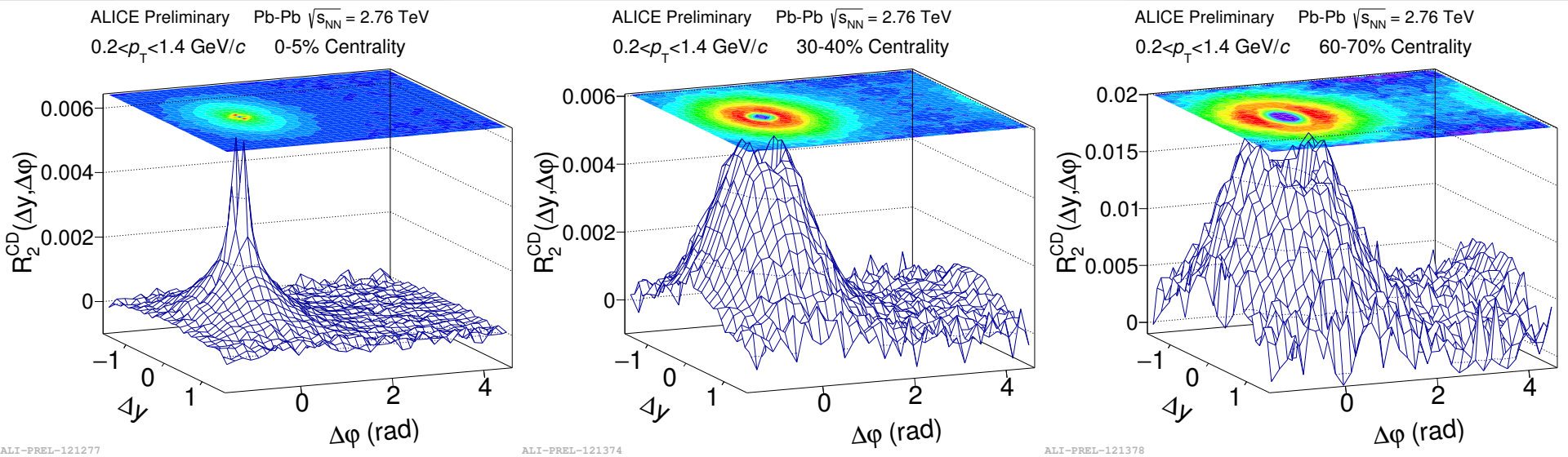
# Experimental Method - PID




| | Pion | Kaon |
|---|---|---|
| TPC | $0.2<p_T<0.6$ GeV<br>$n\sigma_\pi<2$<br>$n\sigma_{K,p}>2$, $n\sigma_e>1$ | $0.2<p_T<0.5$ GeV<br>$n\sigma_K<2$<br>$n\sigma_{\pi,p}>3$, $n\sigma_e>1$ |
| TOF | $0.6<p_T<1.4$ GeV<br>$n\sigma_\pi<2$, $n\sigma_{K,p}>2$ | |
| TPC + TOF | | $0.5<p_T<2.5$ GeV<br>$n\sigma_K<2$, $n\sigma_{\pi,p}>3$ |

# Pion 2D $R_2^{CD}(\Delta y,\Delta\phi)$ in 2.76 TeV Pb-Pb




*Centrality*

0-5%

30-40%

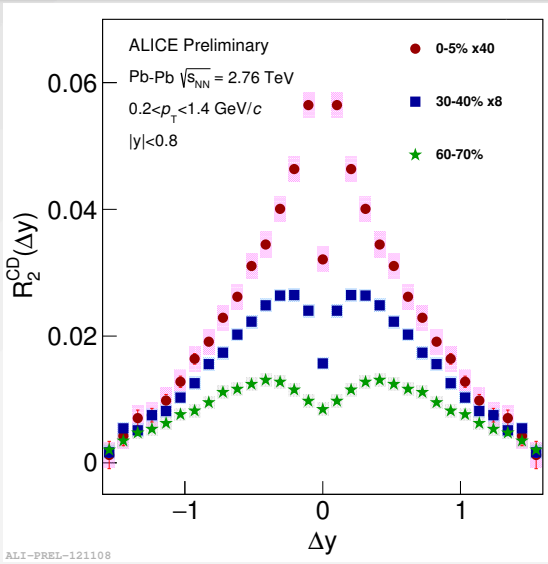
60-70%

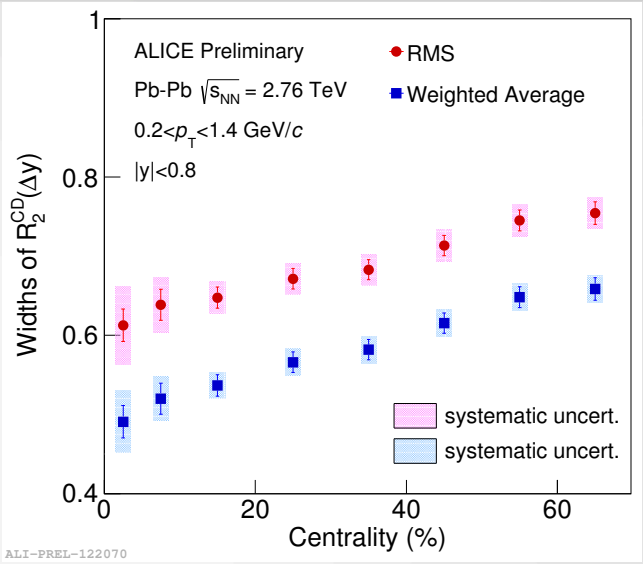
# Pion 1D $R_2^{CD}$ Projections & Widths

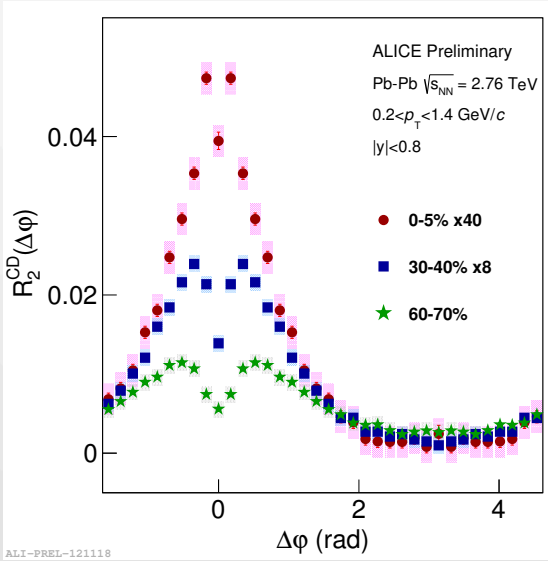
**Projection** **Width**

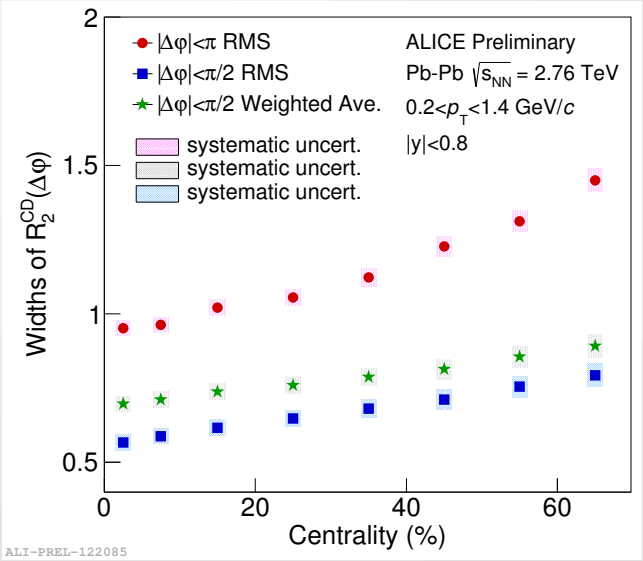
$R_2^{CD}(\Delta y)$

$R_2^{CD}(\Delta \phi)$



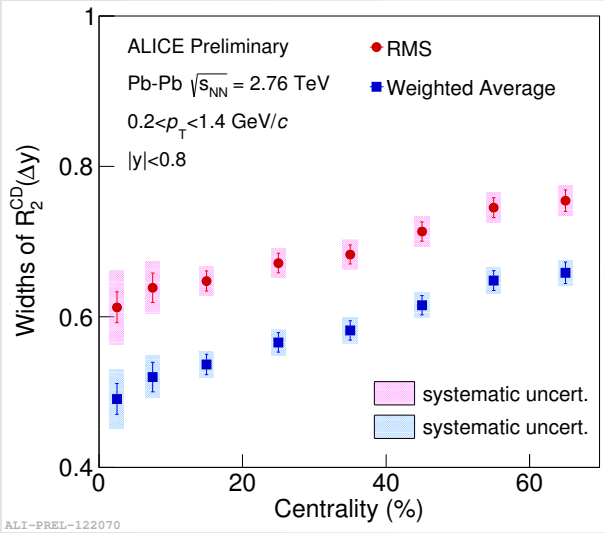



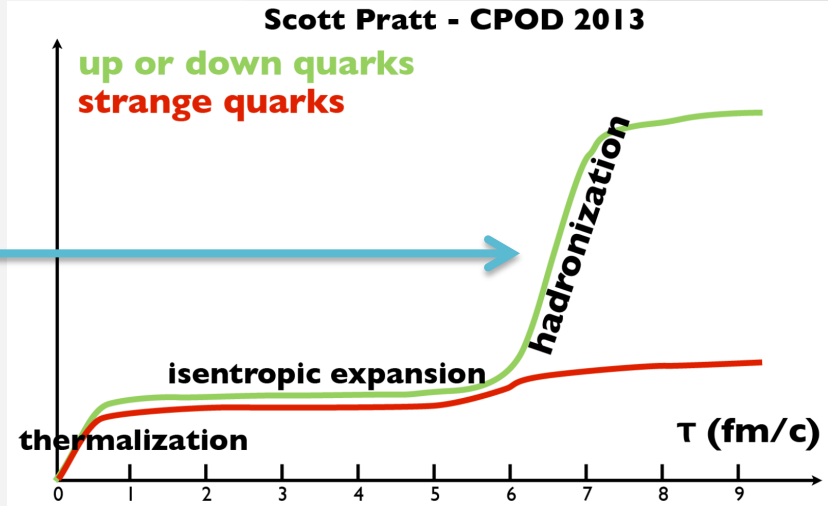



# Summary

- Pion $R_2^{CD}(\Delta y)$ and $R_2^{CD}(\Delta\phi)$ widths *narrowing* for more central events in Pb-Pb
- consistent with:
  - -> ALICE unidentified particle BF results
  - -> 2-wave quark production model
  - -> radial flow effect




## *Outlook*:

- Kaon BF
- Pion-Kaon BF
- BF w.r.t Event Plane

# *Thank you!*