Forward-backward correlations in Pb–Pb collisions at $\sqrt{s_{NN}}$=2.76 and 5.02 TeV with ALICE

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ICPPA-2017
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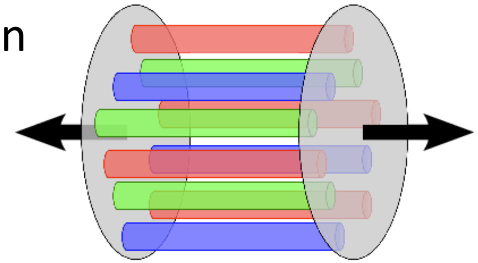
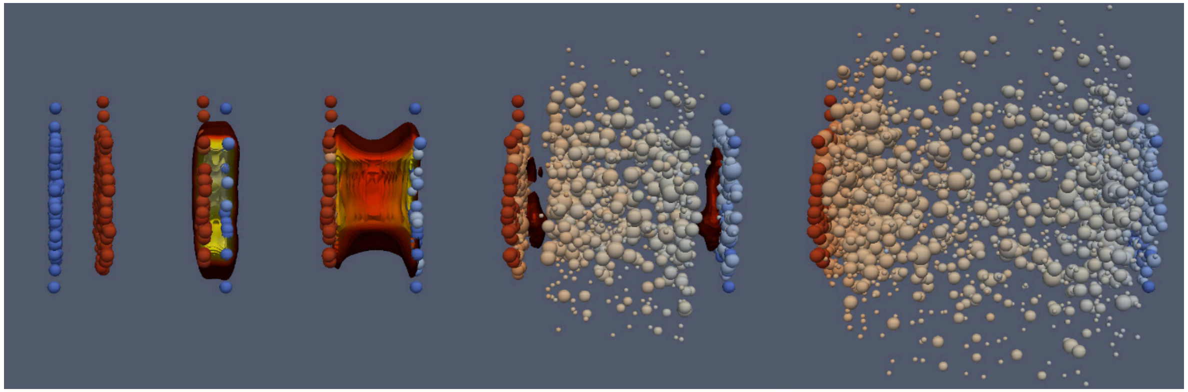
What are the sources of long-range correlations?

Long-range correlations (LRC) – can be explored with correlations between particles separated by pseudorapidity gap.
Typically: $|\Delta\eta| > 1.0$ → suppress contribution from resonances and (mini) jets



- LRC can be created predominantly at early stages of the collision
  - geometry, interactions between strings
- can be modified by medium and final state interactions
  - hydrodynamic expansion
  - energy loss in medium
  - conservation laws

Pb-Pb, p-Pb and pp collisions are under investigation at the LHC.



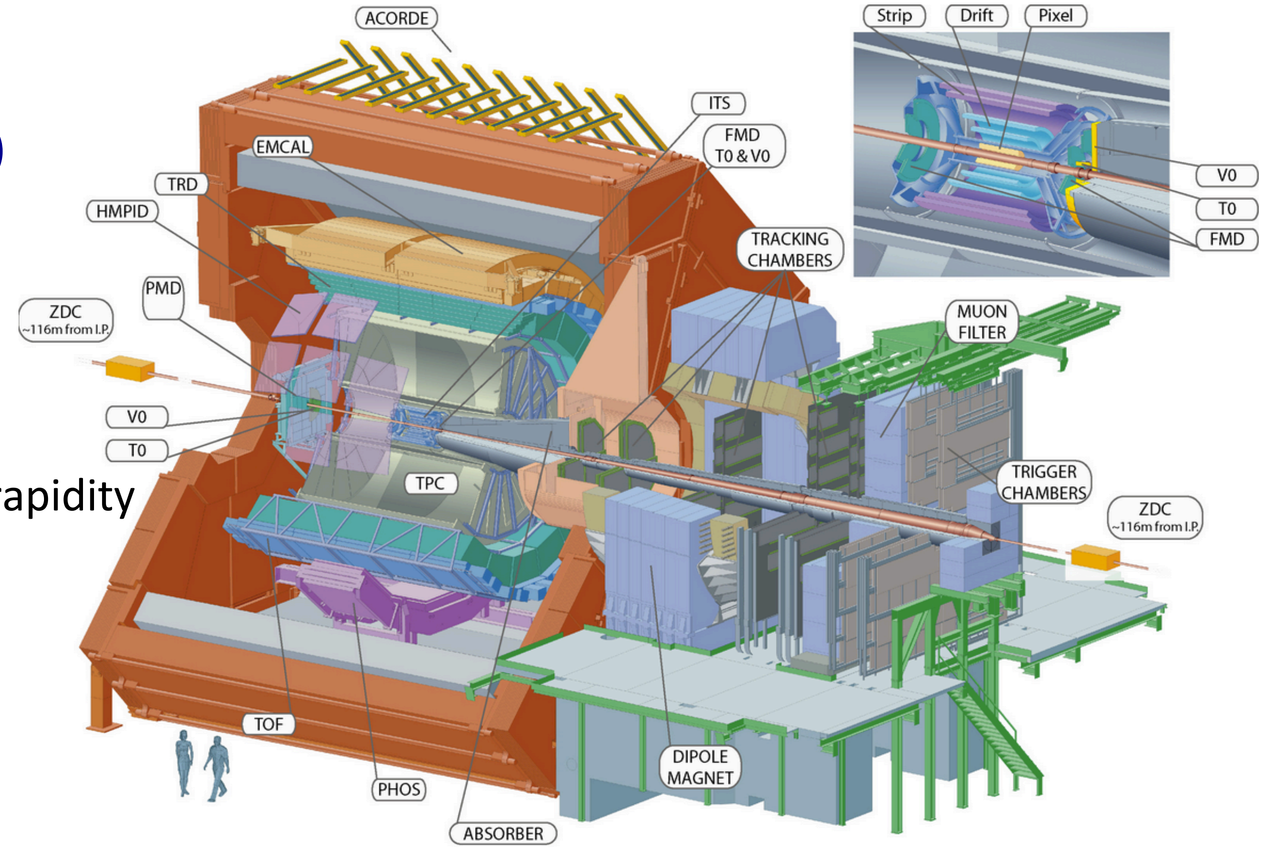
ALICE experiment

Inner Tracking System (ITS)
tracking + triggering

Time Projection Chamber (TPC)
tracking

V0 detector
Two forward scintillator arrays
($-3.7<\eta<-1.7$, $2.8<\eta<5.1$)
centrality: particles at forward rapidity

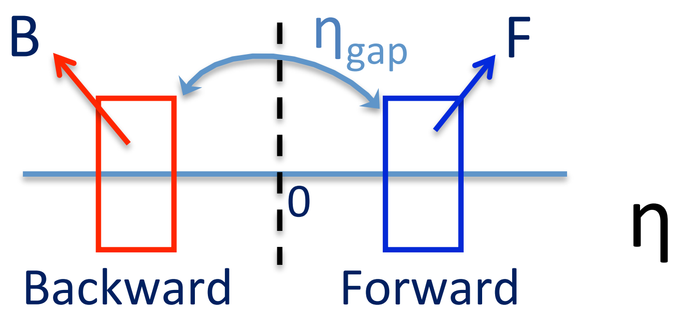
Zero-Degree Calorimeters
centrality: spectators



- *Number of min. bias Pb-Pb events:* ≈**11×10^6**@2.76 TeV, ≈**50×10^6**@5.02 TeV
- *Tracks:* **$-0.8<\eta<0.8$, $0.2<p_T<2.0$ GeV/c**
- *Centrality estimators:* **V0, ZDC**

Forward-Backward correlations: **the observables**

Event-by-event calculation: choose some **F** and **B** quantities from separated η windows and assess correlation strength:



Correlation coefficient: $$b_{\rm corr} = \frac{\langle FB\rangle - \langle F\rangle\langle B\rangle}{\langle F^2\rangle - \langle F\rangle^2}$$

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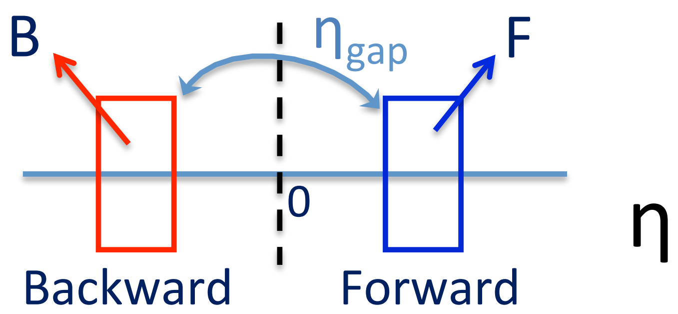

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n_B-n_F – between multiplicities in F and B

a "classical" measurement, done in many experiments

Phys.Rev.Lett.103:172301, JHEP 1505 (2015) 097

$\overline{p}_{tB}$-$\overline{p}_{tF}$ – between event-mean transverse momenta in F and B

$\overline{p}_{tB}$-n_F – between event-mean transverse momentum in B and multiplicity in F

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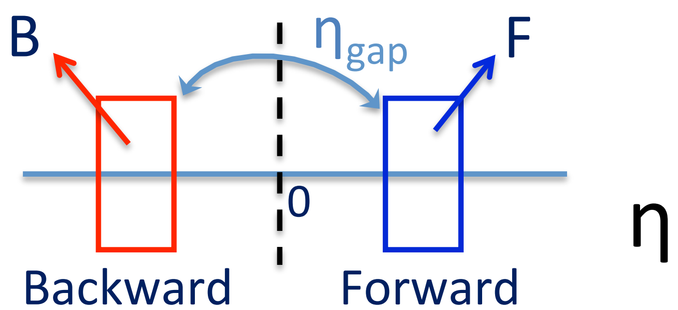

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n_B-n_F – between multiplicities in F and B ← **a "classical" measurement, done in many experiments**

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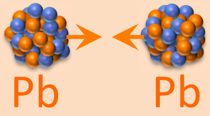
$\overline{p}_{tB}$-$\overline{p}_{tF}$ – between event-mean transverse momenta in F and B ← **this talk**

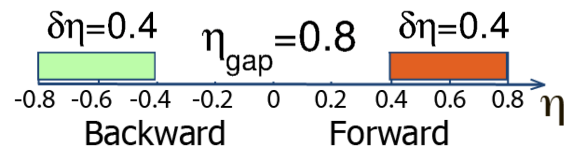
$\overline{p}_{tB}$-n_F – between event-mean transverse momentum in B and multiplicity in F



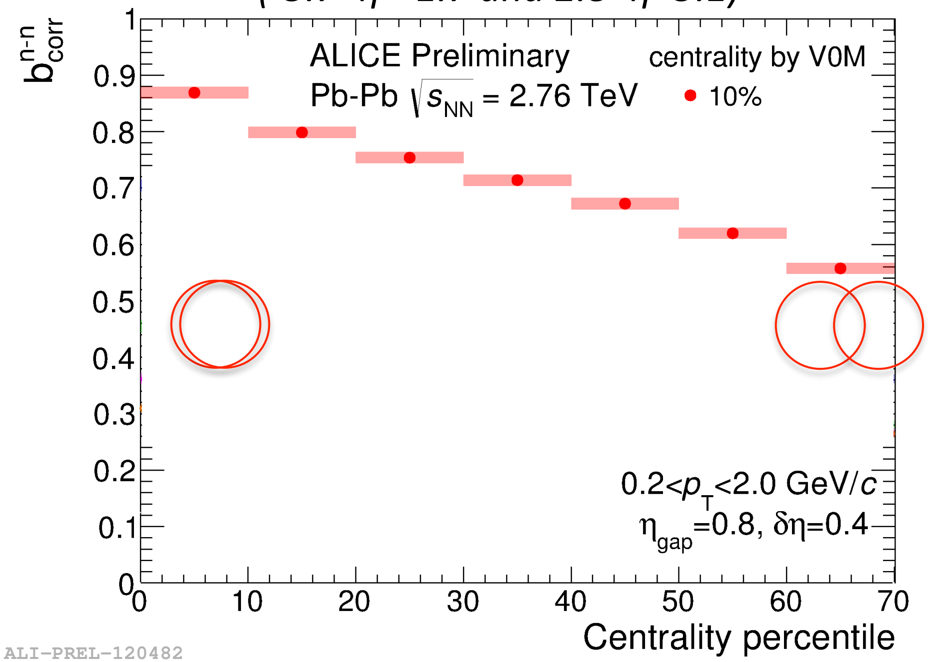
FB multiplicity correlations in Pb-Pb: centrality dependence

- Predictions for Pb-Pb from CGC, DPM, …

Nucl.Phys.A781:201-208
Phys.Rept. 236 (1994) 225-329



Centrality classes by **V0 detector:**
(-3.7<η<-1.7 and 2.8<η<5.1)



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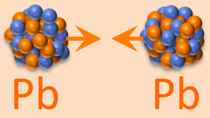

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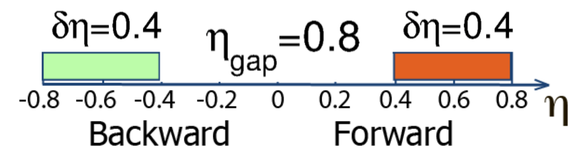

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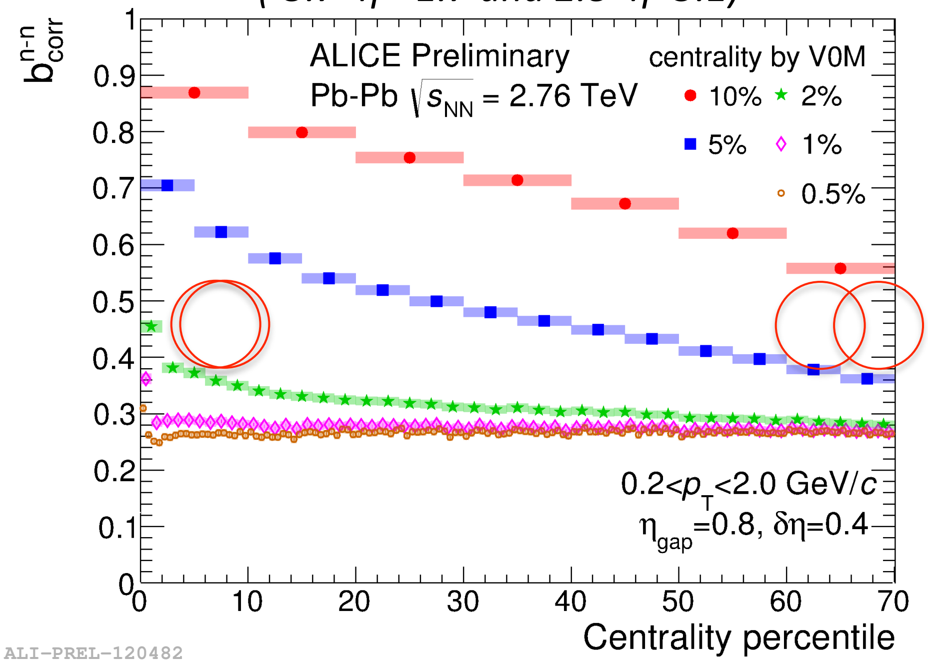
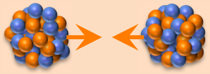


$$b_{\mathrm{corr}} = \frac{\langle n_{\mathrm{B}} n_{\mathrm{F}} \rangle - \langle n_{\mathrm{B}} \rangle \langle n_{\mathrm{F}} \rangle}{\langle n_{\mathrm{F}}^2 \rangle - \langle n_{\mathrm{F}} \rangle^2}$$

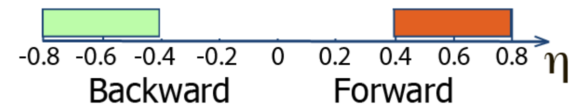
- Strong dependence on centrality class width (volume fluctuations)



Pb Pb

FB **multiplicity** correlations **in Pb-Pb**: centrality dependence

ALICE



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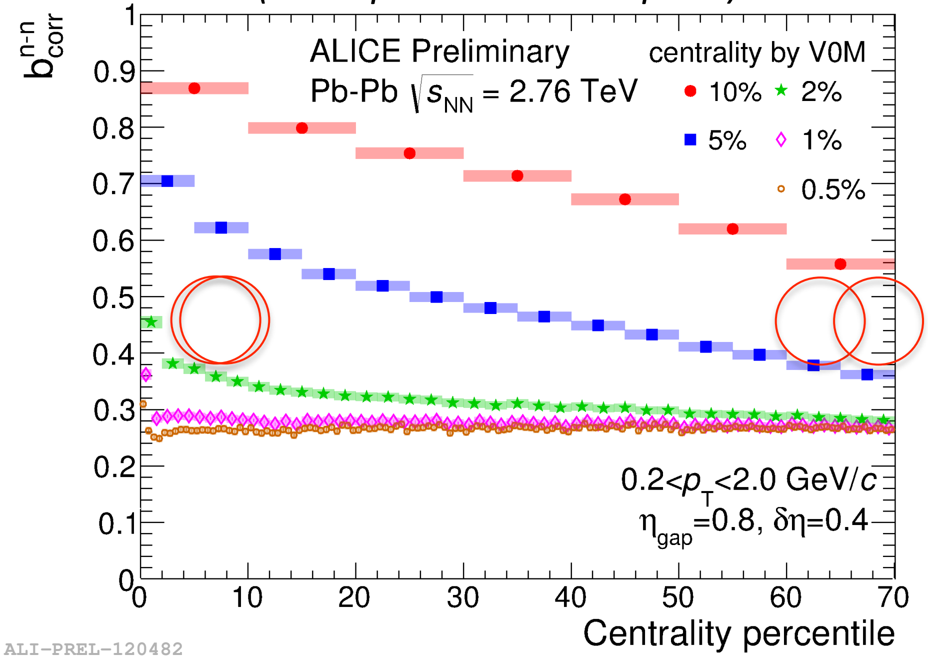
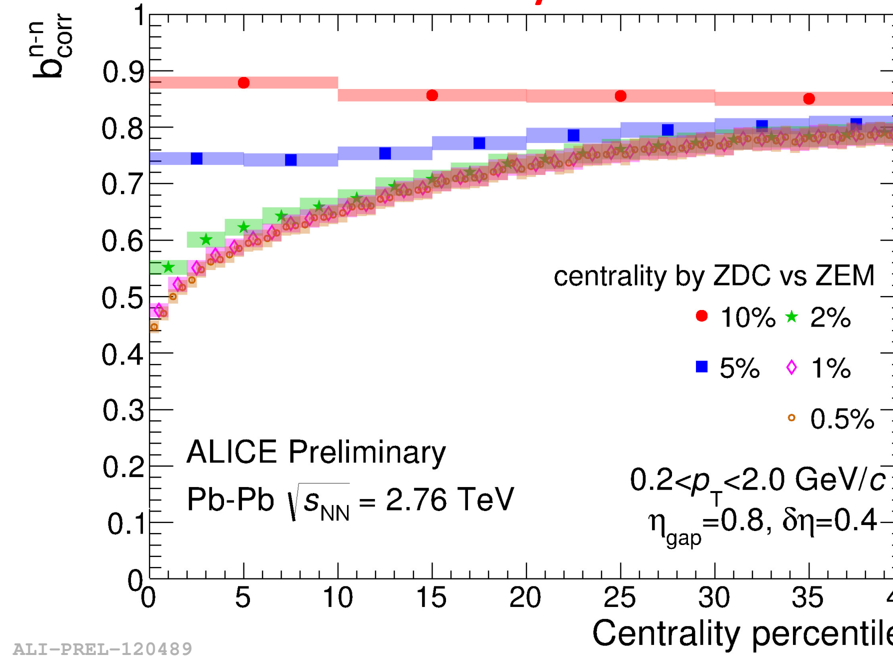


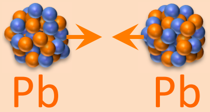
... but if by ZDC:



- Strong dependence on centrality class width (volume fluctuations)
- Dramatic dependence on centrality estimator (acceptance and resolution)

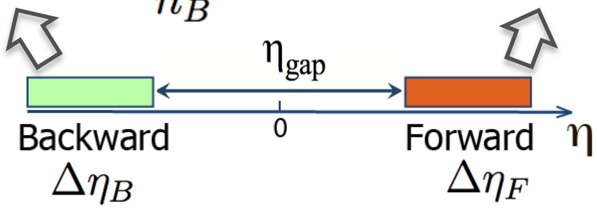
Details of centrality selection are crucial for FB **multiplicity** correlation studies in A-A.

- STAR claims "growth with centrality" – this should be taken with care.
  Phys.Rev.Lett.103:172301, 2009



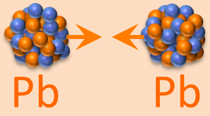
FB correlations between intensive observables: take event-mean transverse momentum

$$B \equiv \overline{p_{\rm T}}_B = \frac{\sum_{i=1}^{n_B} p_{\rm T}^{(i)}}{n_B} \qquad F \equiv \overline{p_{\rm T}}_F = \frac{\sum_{j=1}^{n_F} p_{\rm T}^{(j)}}{n_F}$$



Correlation coefficient:

$$b_{\rm corr}^{p_T - p_T} = \frac{\langle \overline{p_{\rm F}}\,\overline{p_{\rm B}} \rangle - \langle \overline{p_{\rm F}} \rangle \langle \overline{p_{\rm B}} \rangle}{\langle \overline{p_{\rm F}}^2 \rangle - \langle \overline{p_{\rm F}} \rangle^2}$$



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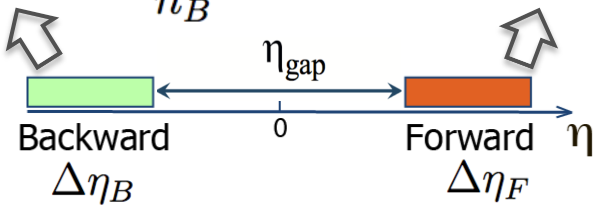

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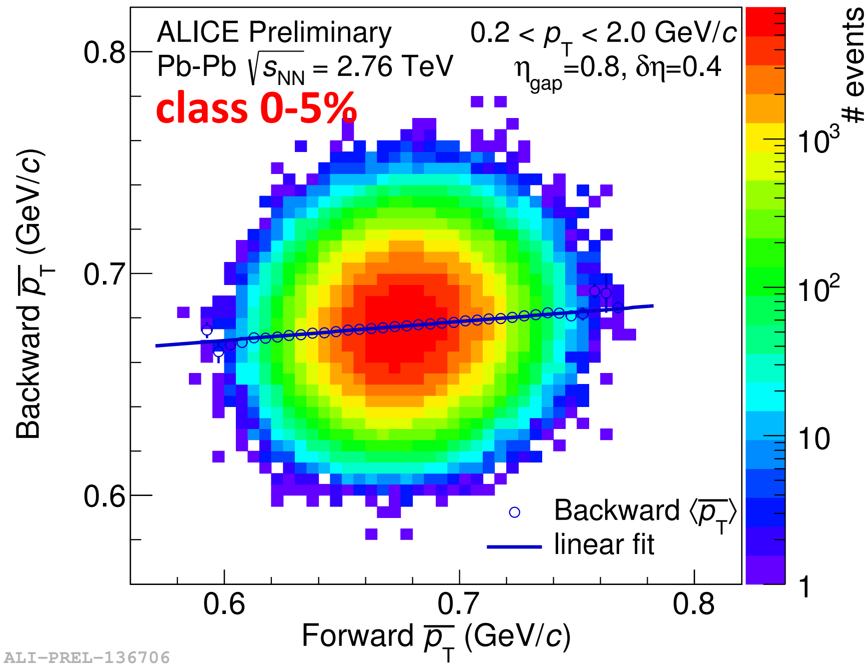

→ Traditional b_{corr} is related to slope of the linear fit.

FB correlations between intensive observables: take event-mean transverse momentum

Pb Pb

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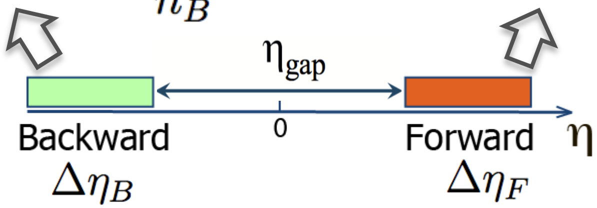

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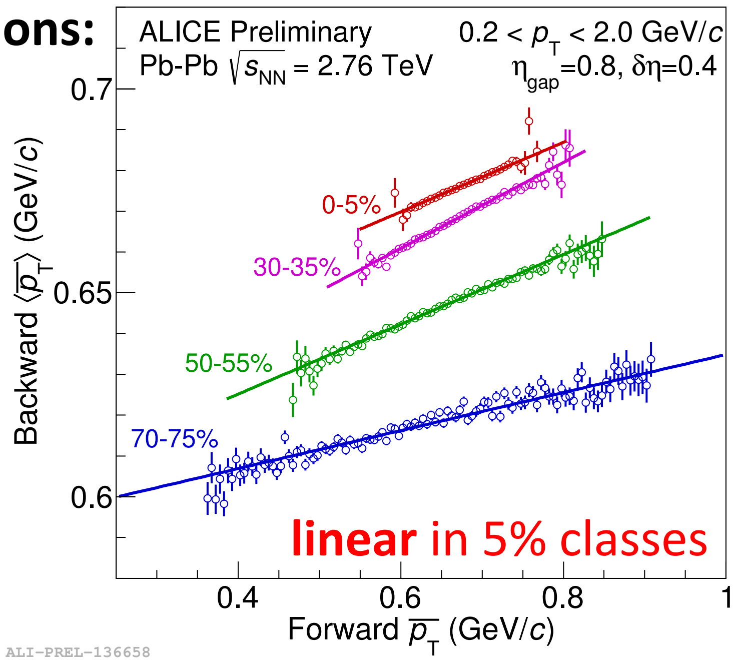
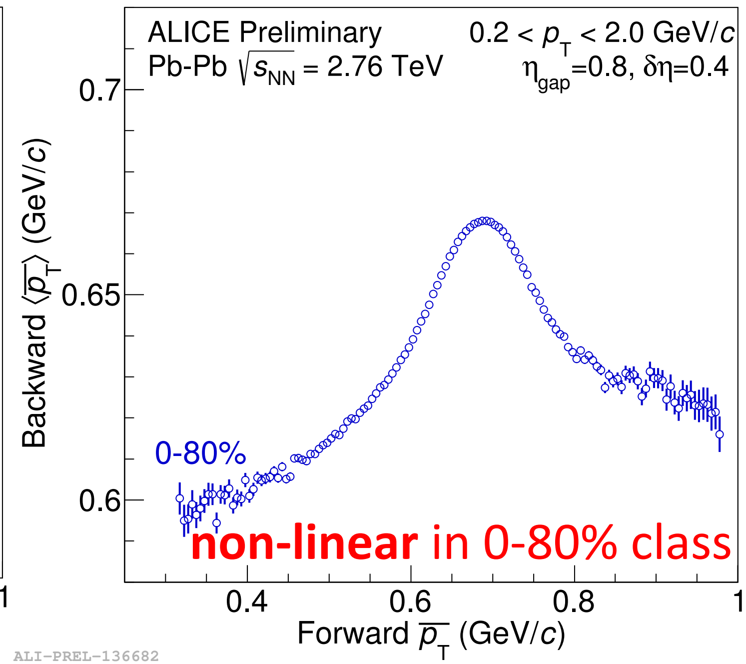
Correlation functions:

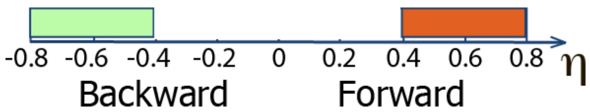




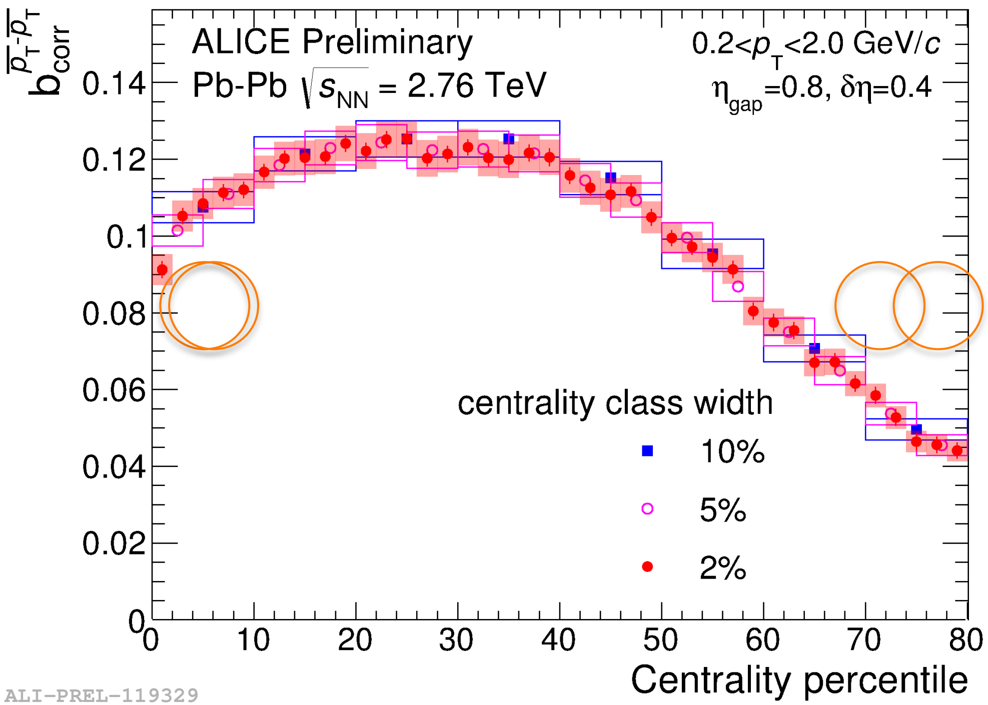
→ Traditional b_{corr} is related to slope of the linear fit.

→ Always important to look at *correlation functions themselves.*

FB **mean-p_T** correlations *vs* centrality



Centrality classes by **V0:** *class widths **10%, 5%, 2%***



- Mean-p_T is an *intensive* observable

→ **robust against volume fluctuations**

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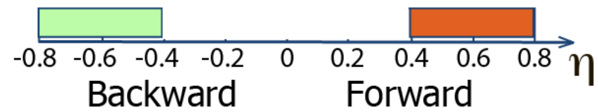

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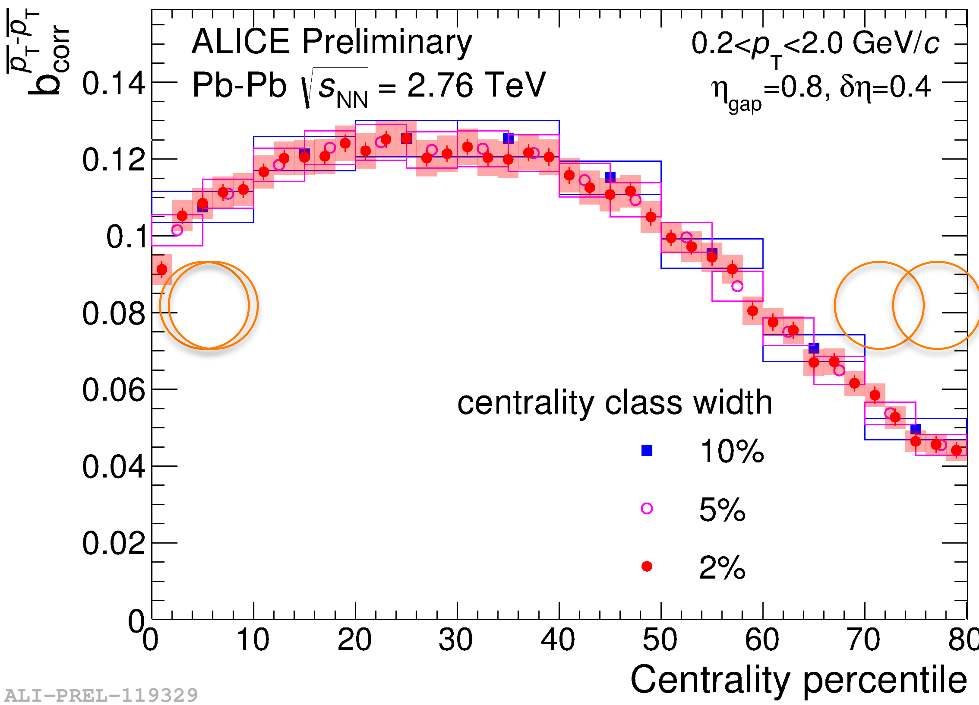

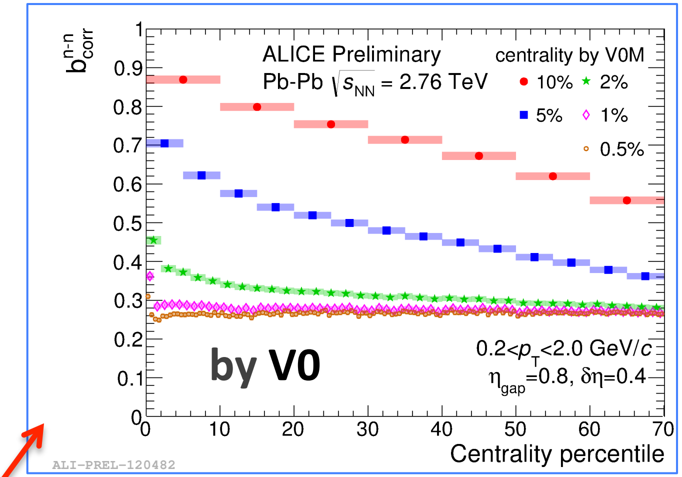

Compare with FB **multiplicity** correlations

- Mean-p_T is an *intensive* observable

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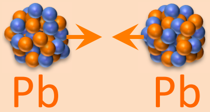
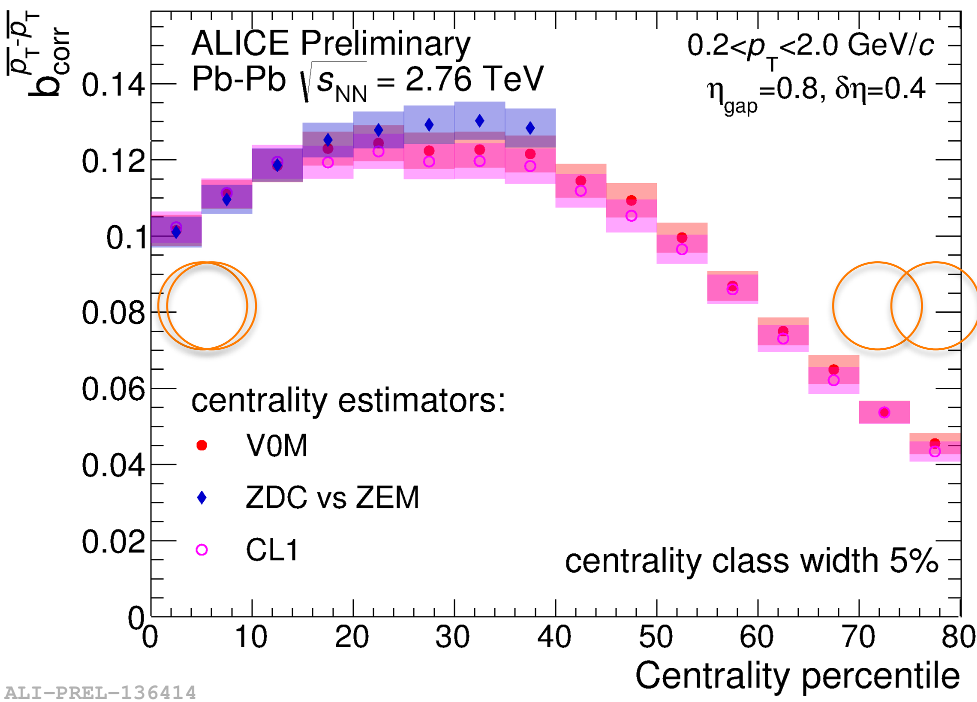
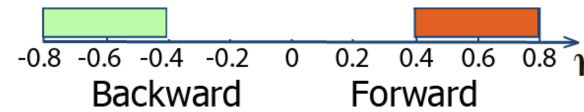
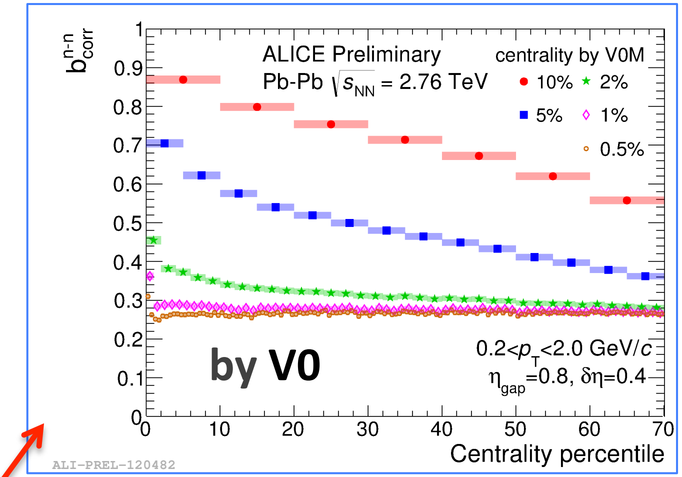


FB **mean-p_T** correlations *vs* centrality

Centrality classes by **V0, ZDC and CL1 estimators:**







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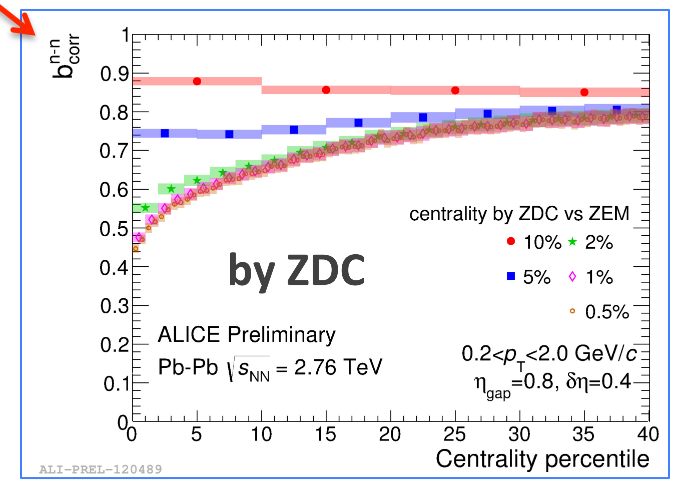
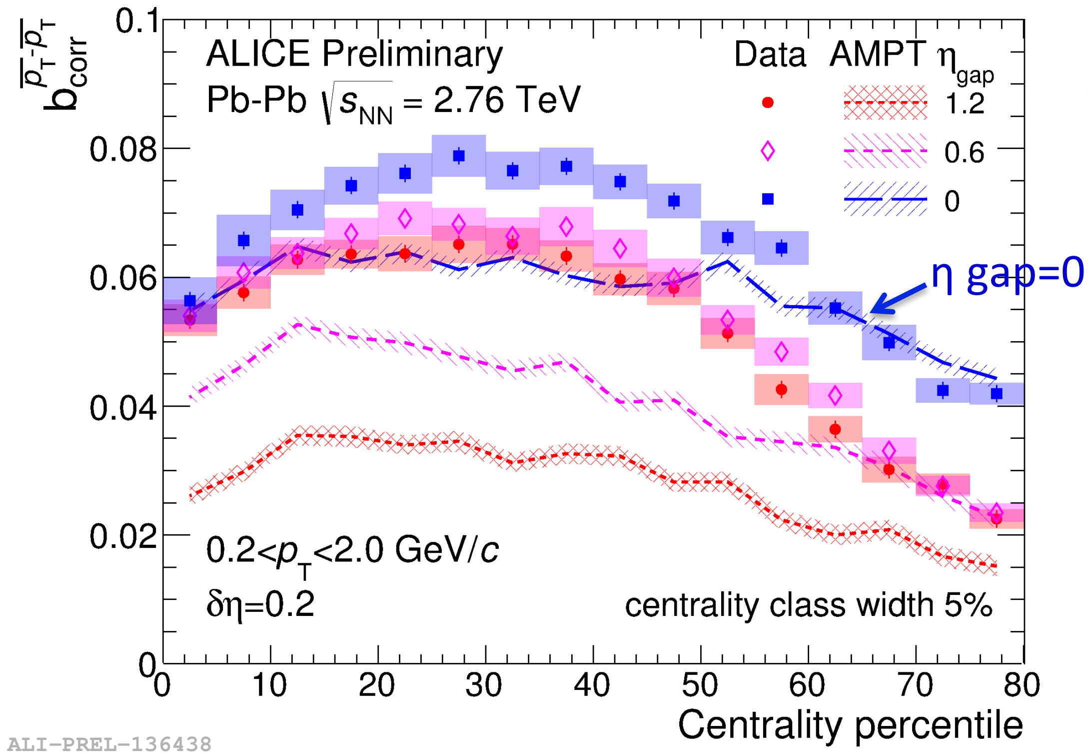


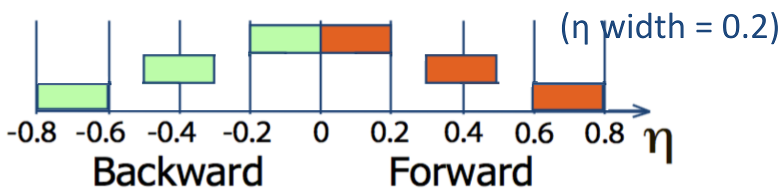
- Mean-p_T is an *intensive* observable

→ **robust against volume fluctuations**

… and thus the centrality determination methods

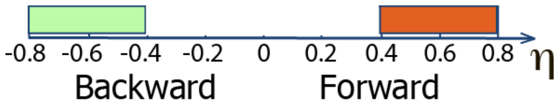
FB **mean-p_T** correlations for **several η-gaps**

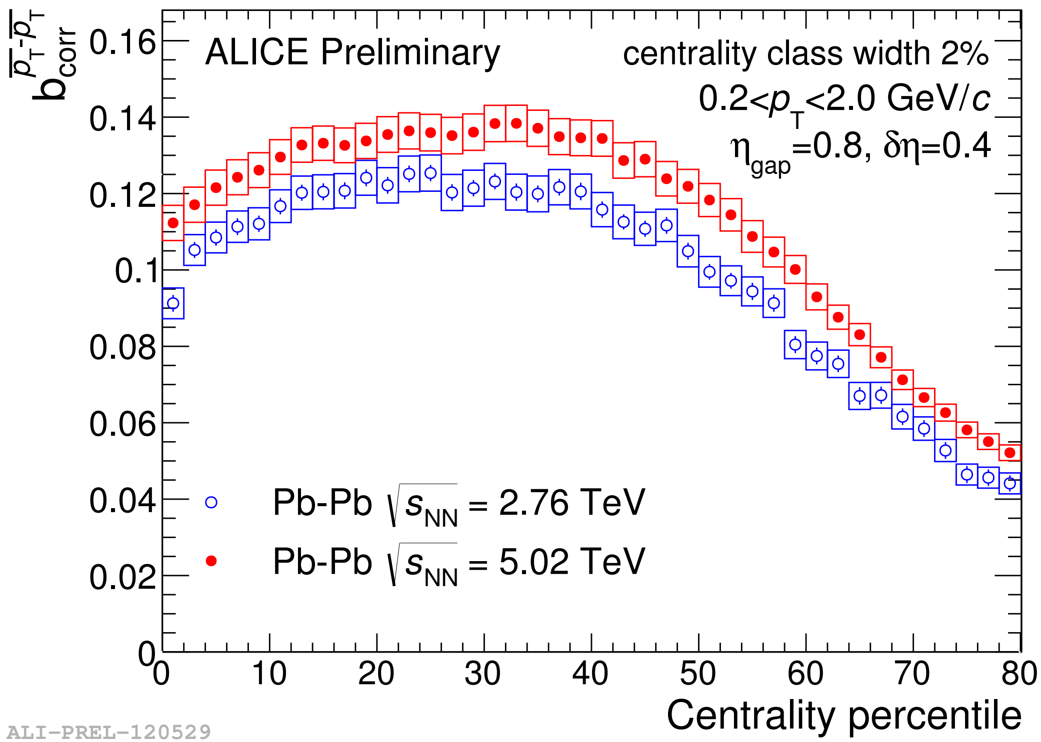




- at all η gaps, **same shape of the centrality dependence**
- **higher values at η gap=0** due to short-range contributions

FB **mean-p_T** correlations at **2.76** and **5.02** TeV

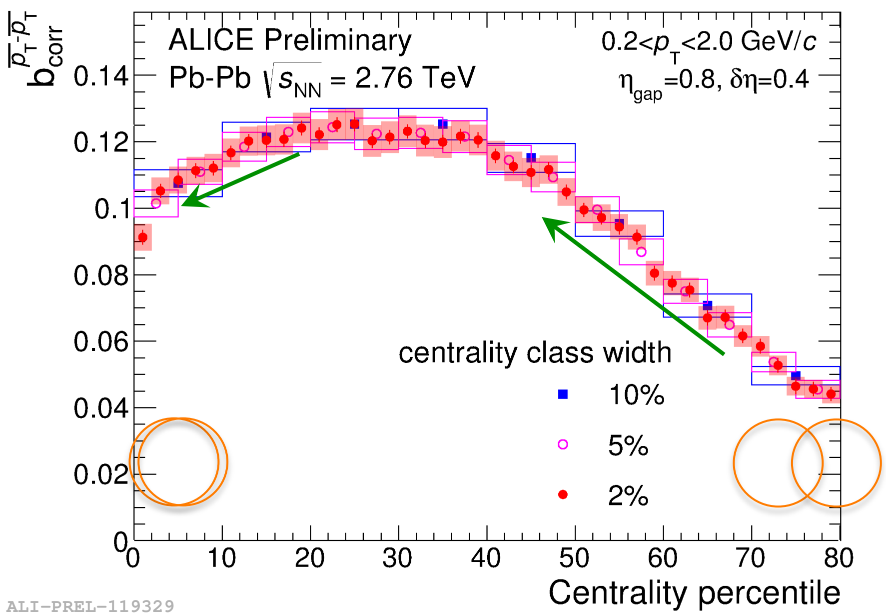




- Similar behavior with centrality at both energies
- Higher b_{corr} values at 5.02 TeV (by 10-20%)

FB mean-p_T correlations: interpretations

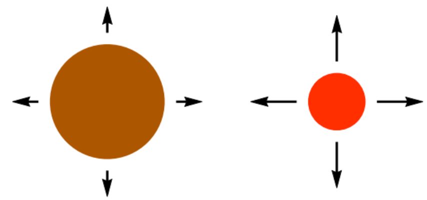
Pb Pb



What can cause mean-p_T FB correlations?

Size fluctuations ↔ p_T fluctuations

Phys. Rev. C 96, 014904 (2017)

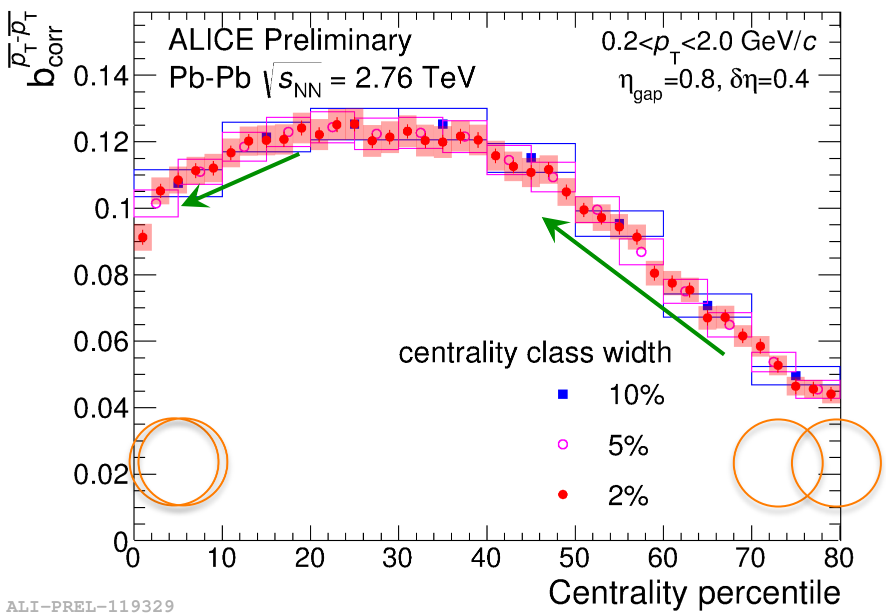


– pressure gradients in the fireball reflect the fluctuations of the density in the fireball.

Correlation strength:

- rises from peripheral to mid-central
- **drops towards central collisions.**

FB mean-p_T correlations: interpretations



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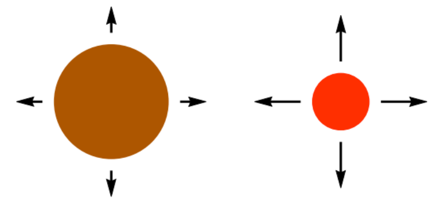

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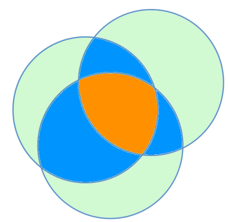
String fusion model

Nucl. Phys. B 390 542–558 (1993)



strings overlap
→ modification of string tension
→ increased p_T of particles from the fused strings

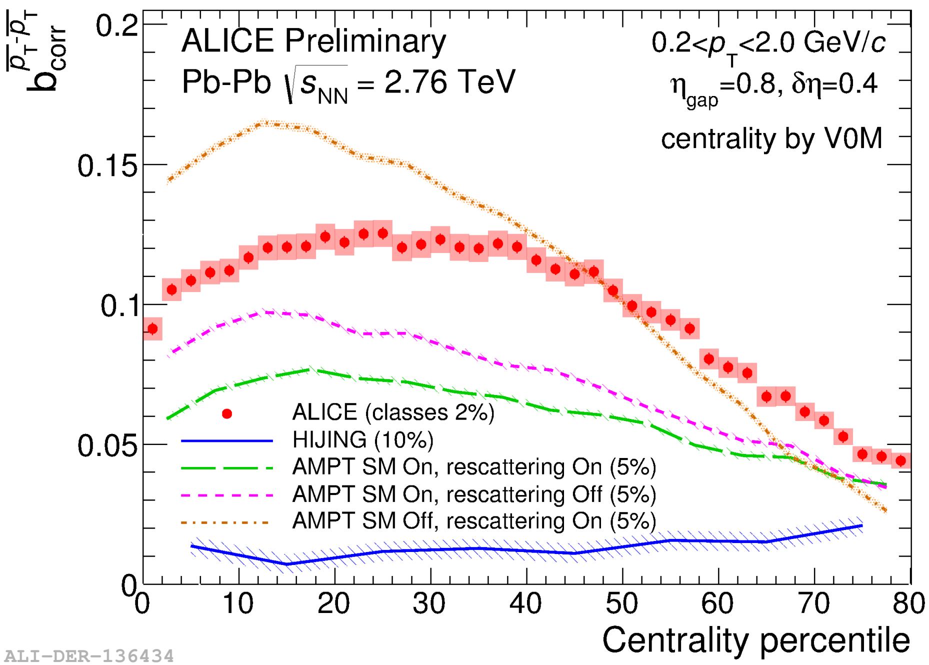
MC realization: arXiv:1308.6618

What is important for models to capture:
pattern of mean-p_T correlations *vs* centrality.

FB **mean-p_T** correlations: what can we learn from comparison with models?

Pb Pb

ALICE



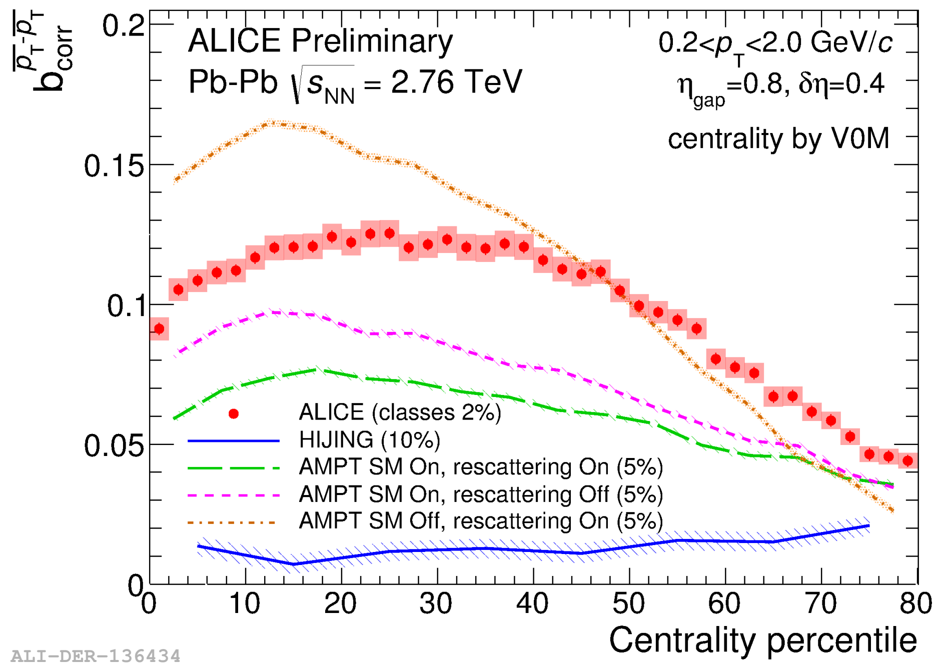
- **HIJING:** weak correlations, no dependence on centrality
- **AMPT:** generally reproduces the shapes, not the magnitude in detail
  - Rescattering *off* → rise of b_{corr}
  - String melting *off* → large "jump" of b_{corr}

Role of quark coalescence?..

FB mean-p_T correlations: what can we learn from comparison with models?

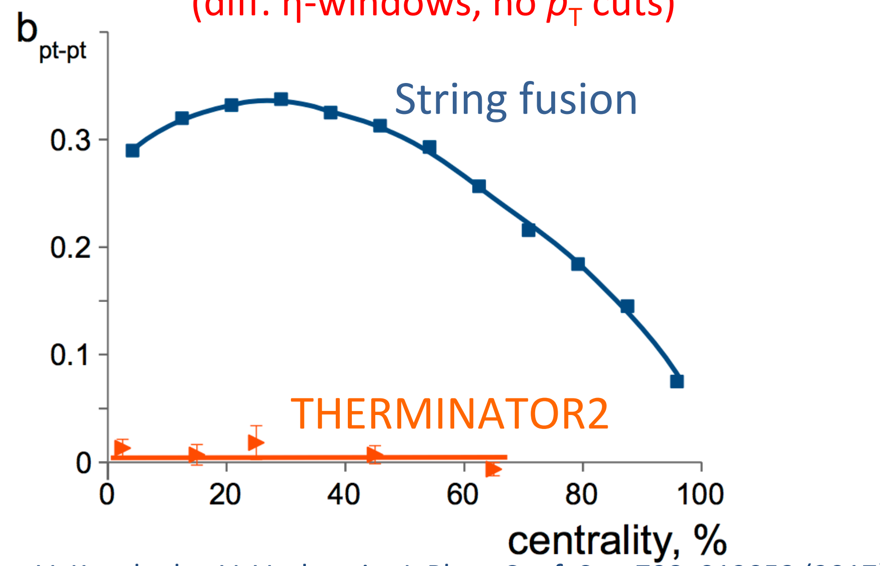
Pb Pb

ALICE



Compare to other MC generators:

(diff. η-windows, no p_T cuts)



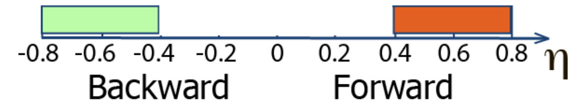
V. Kovalenko, V. Vechernin, J. Phys. Conf. Ser. 798, 012053 (2017) arXiv:1611.07274

- **HIJING:** weak correlations, no dependence on centrality
- **AMPT:** generally reproduces the shapes, not the magnitude in detail

- **THERMINATOR:** freeze-out hypersurface, Cooper-Frye + decays
  → no mean-p_T correlations due to absence of e-by-e fluctuations
- **String fusion** → qualitatively describes behaviour with centrality

Mean-p_T correlations provide higher sensitivity to the properties of the initial state and evolution of the medium created in A-A collisions.

Summary



Forward-backward **multiplicity** correlations:

✧ Correlation strength heavily depends on centrality selection (type of estimator, class width)

→ any physical conclusions should be made very carefully.

Forward-backward **mean-p_T** correlations:

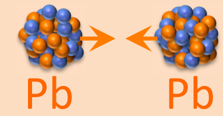
✧ Measured for the first time in ALICE in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 and 5.02 TeV.

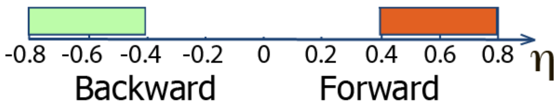
✧ Evolution with centrality: described by some models qualitatively, but not quantitatively.

✧ Robust against volume fluctuations and thus the centrality determination methods

→ **higher sensitivity to the properties of the initial state and medium evolution.**

Summary





Forward-backward **multiplicity** correlations:

- ✧ Correlation strength heavily depends on centrality selection (type of estimator, class width)
  - → any physical conclusions should be made very carefully.

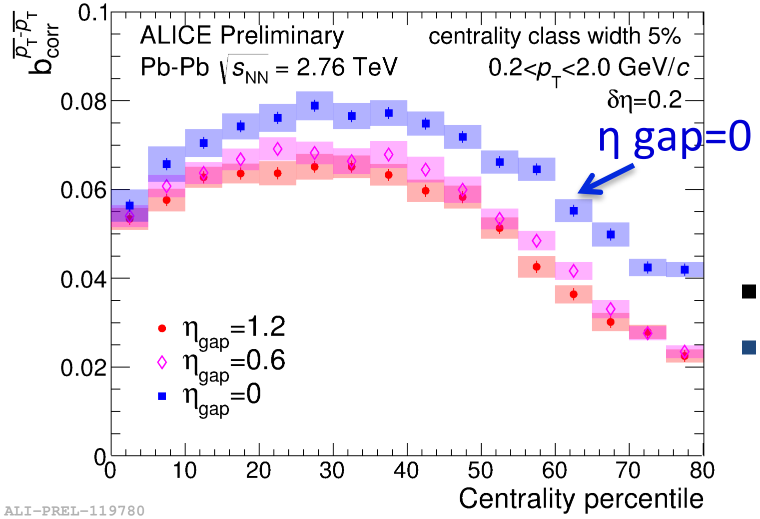
Forward-backward **mean-p_T** correlations:

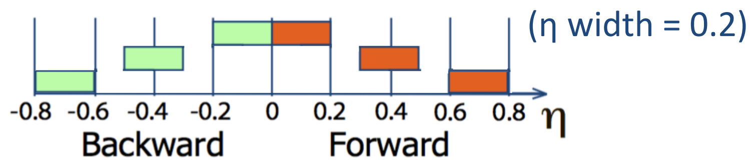
- ✧ Measured for the first time in ALICE in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 and 5.02 TeV.
- ✧ Evolution with centrality: described by some models qualitatively, but not quantitatively.
- ✧ Robust against volume fluctuations and thus the centrality determination methods
  - → **higher sensitivity to the properties of the initial state and medium evolution.**

Thank you for your attention!

Backup

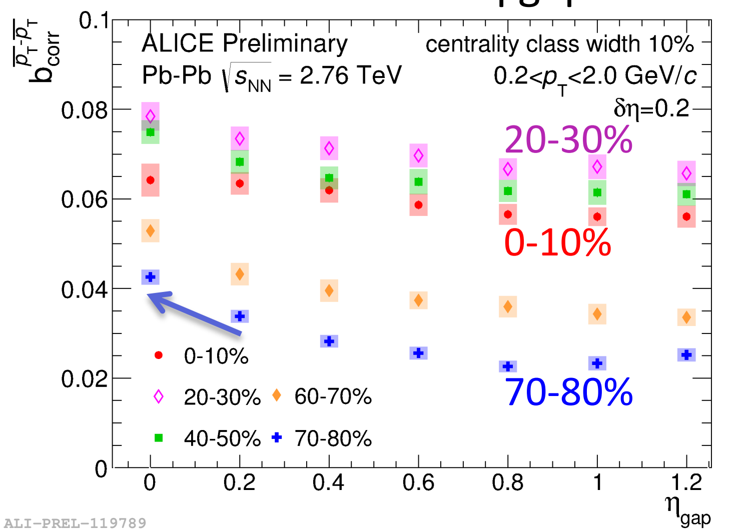
FB **mean-p_T** correlations for **several η-gaps**

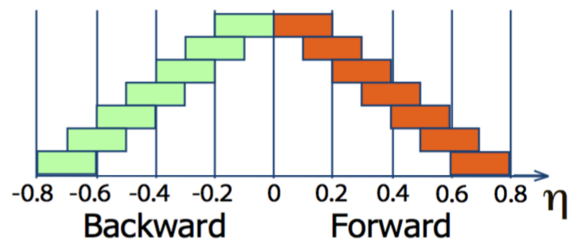




- at all η gaps, **same shape of the centrality dependence**
- **higher values at η gap=0** due to SR contributions

As a function of η gap:





- Peripheral events: **steeper rise for smaller η gaps**

FB mean-p_T correlations *vs* N_{ch} density: compare with AMPT