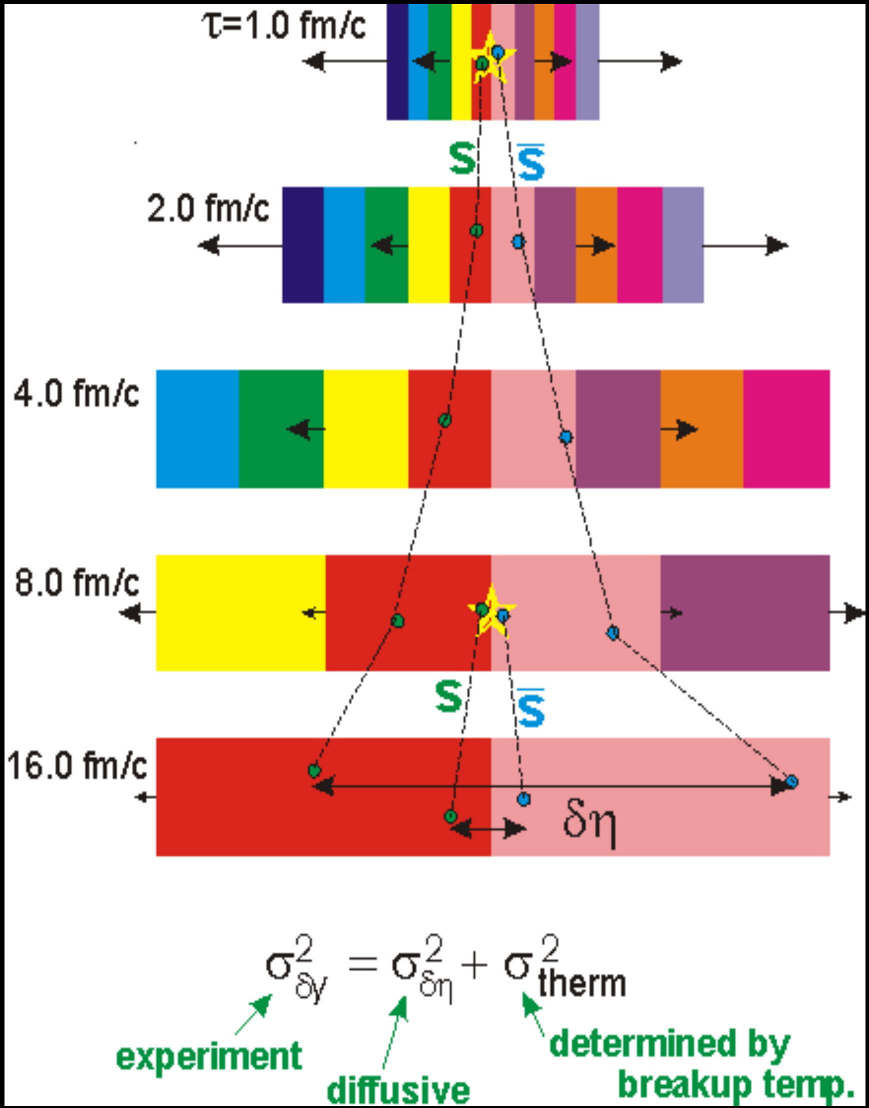
Charge correlations and balance functions at the LHC

Panos Christakoglou[1] (for the ALICE Collaboration)

[1]Nikhef

Correlation length vs time

q-qbar pair creation in a rapidly expanding medium



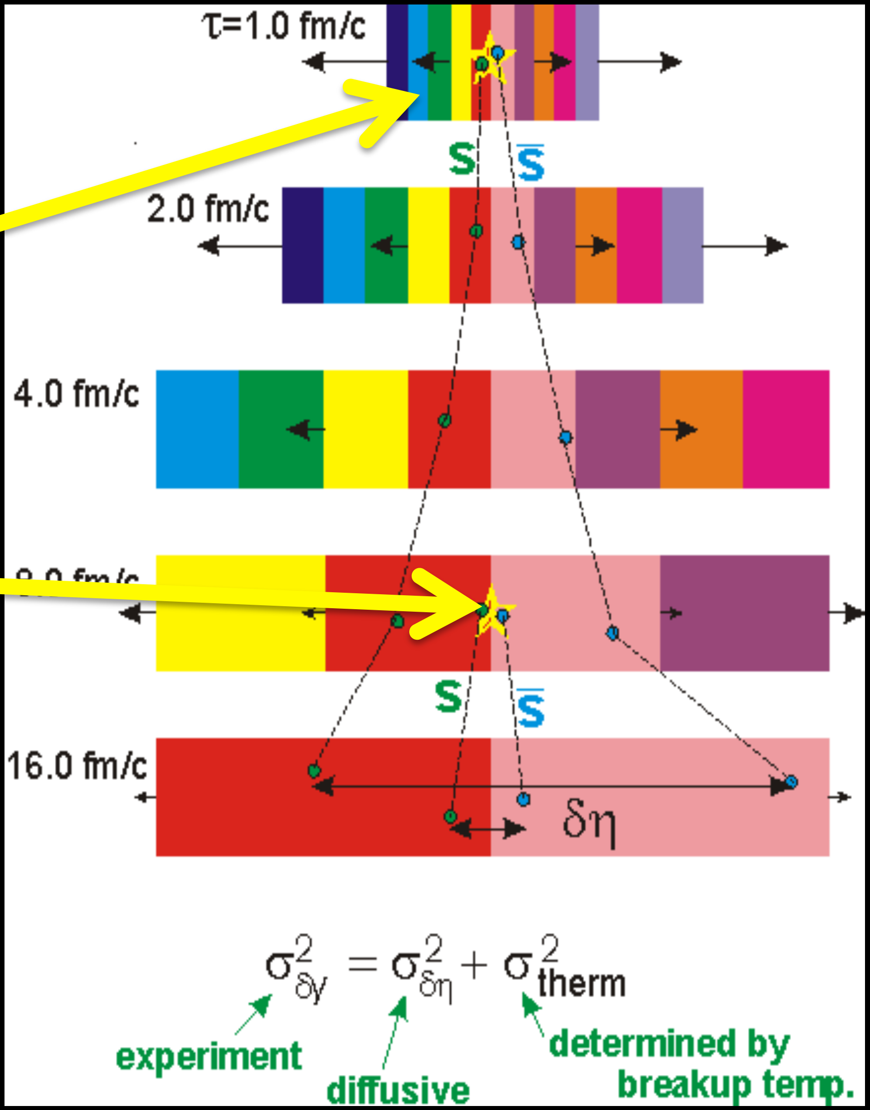
- S. Bass, P. Danielewicz and S.Pratt , Phys. Rev. Lett. **85**, (2000) 2689.
- S. Pratt, Phys. Rev. **C85**, (2012) 014904.

Correlation length vs time

q-qbar pair creation in a rapidly expanding medium

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

Late stage creation: pairs more correlated, narrower balance function distributions



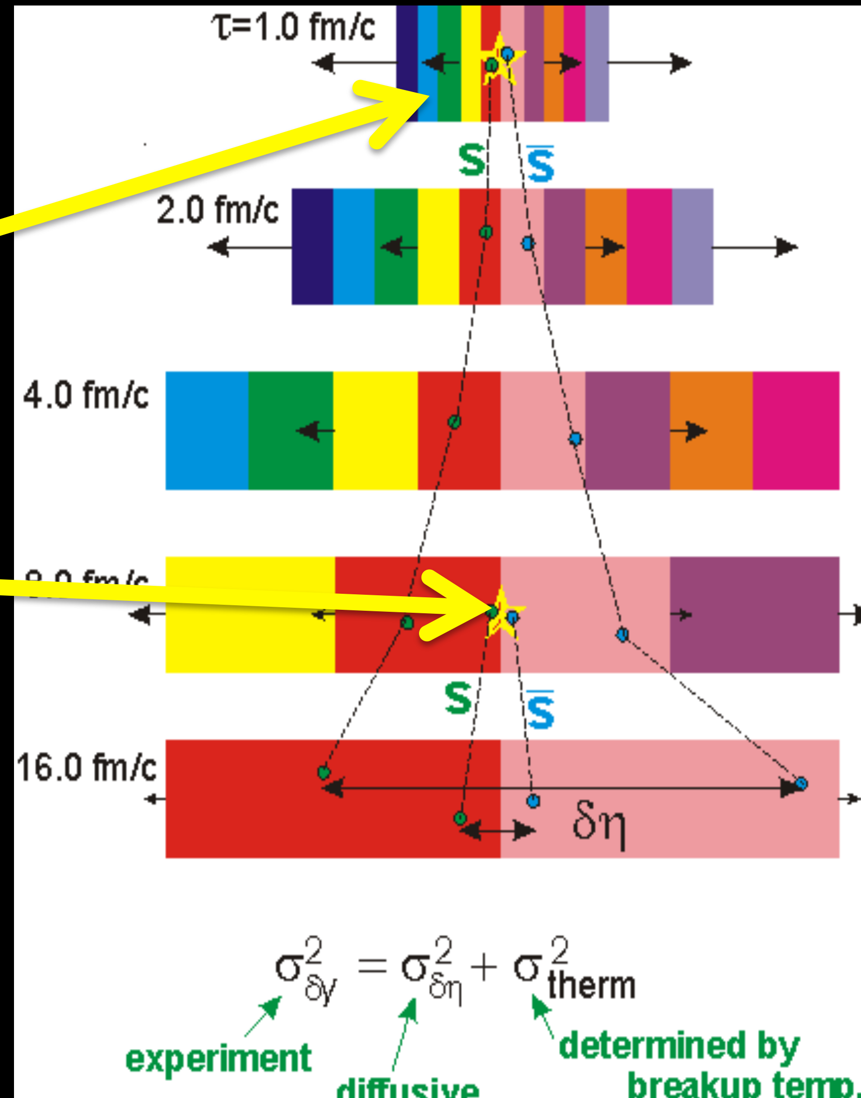
- S. Bass, P. Danielewicz and S.Pratt , Phys. Rev. Lett. **85**, (2000) 2689.
- S. Pratt, Phys. Rev. **C85**, (2012) 014904.

Correlation length vs time

q-qbar pair creation in a rapidly expanding medium

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

Late stage creation: pairs more correlated, narrower balance function distributions

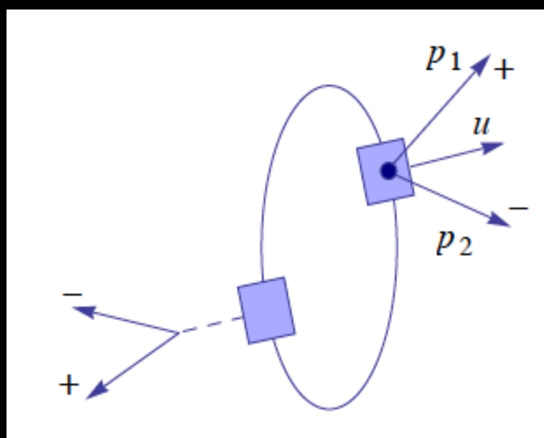


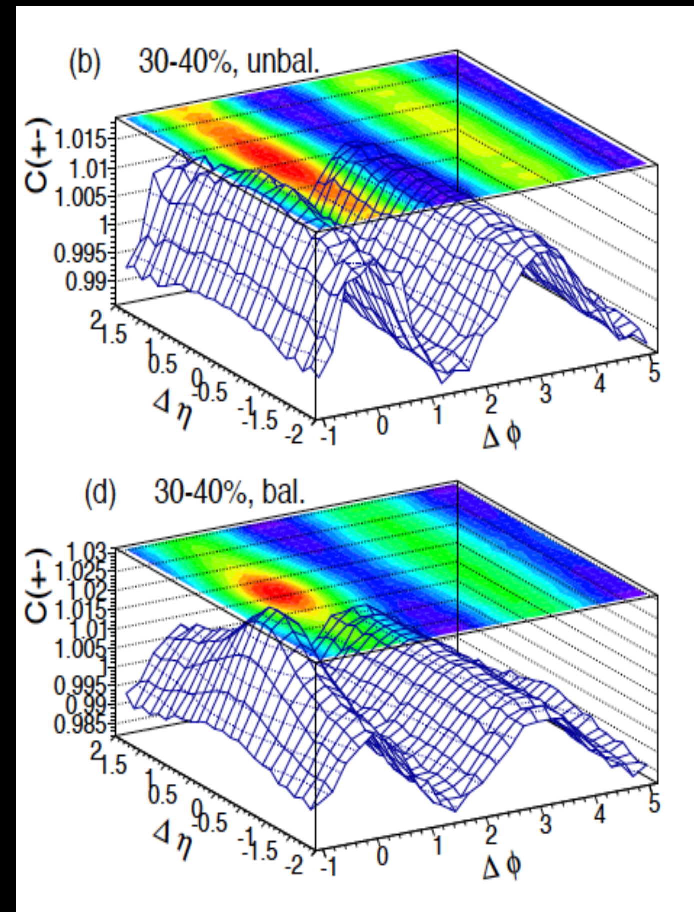
- ❑ What is the time ordering of the collision?
- ❑ Can we detect different stages where charges are created?

- ❑ S. Bass, P. Danielewicz and S.Pratt , Phys. Rev. Lett. **85**, (2000) 2689.
- ❑ S. Pratt, Phys. Rev. **C85**, (2012) 014904.

Local charge conservation in 2-particle correlations

- Hydro calculations with the inclusion of the local charge conservation after the hydro evolution give a quantitative description of the
  - Near side ridge in Δη,
  - difference in the correlation function between unlike and like sign pairs



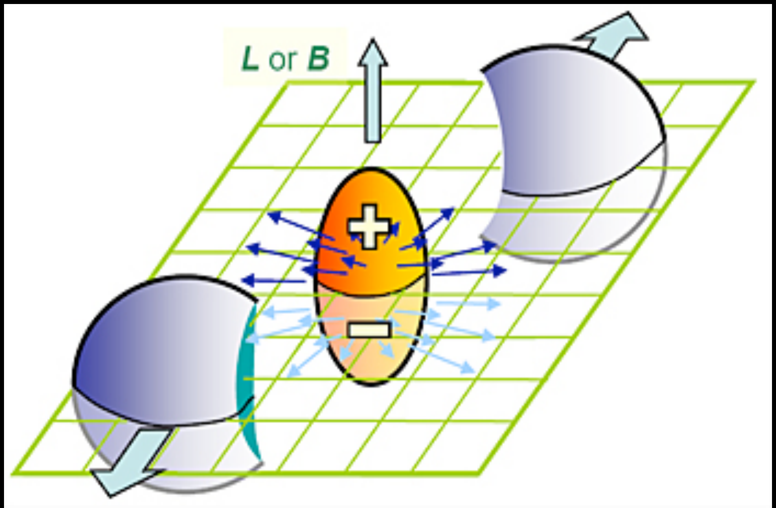


See talk from W. Broniowksi

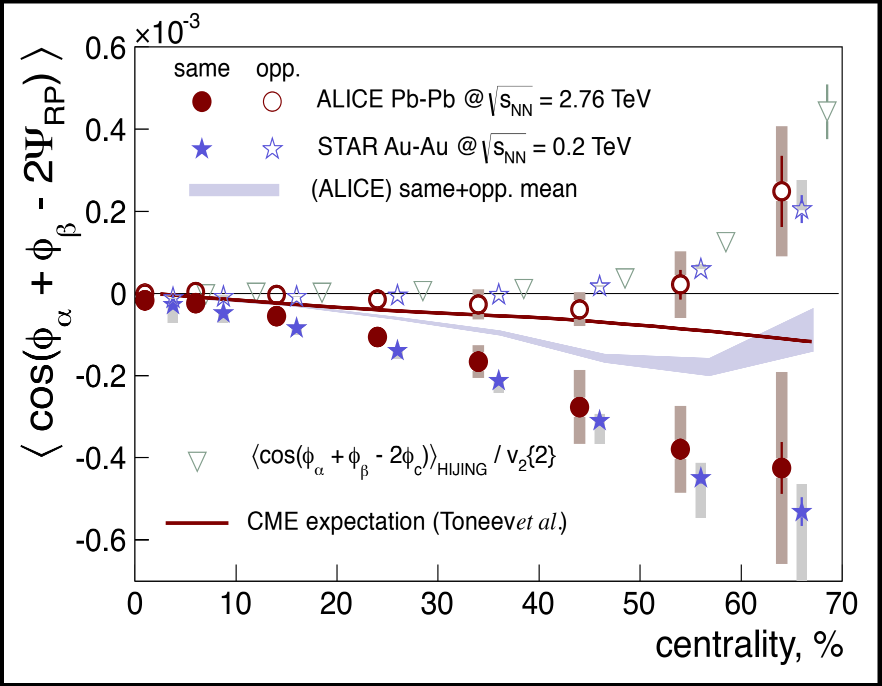
P. Bozek and W. Broniowski, Phys.Rev.Lett. **109**, (2012) 062301

Local charge conservation and the chiral magnetic effect

- Chiral magnetic effect:
  - topological domains where the parity symmetry is locally violated in the strong interaction
  - interaction of quarks of different charge with the strong magnetic field ➔ quarks change helicity, direction ➔ creation of electromagnetic current along the axis of the magnetic field
  - charge separation wrt the reaction plane

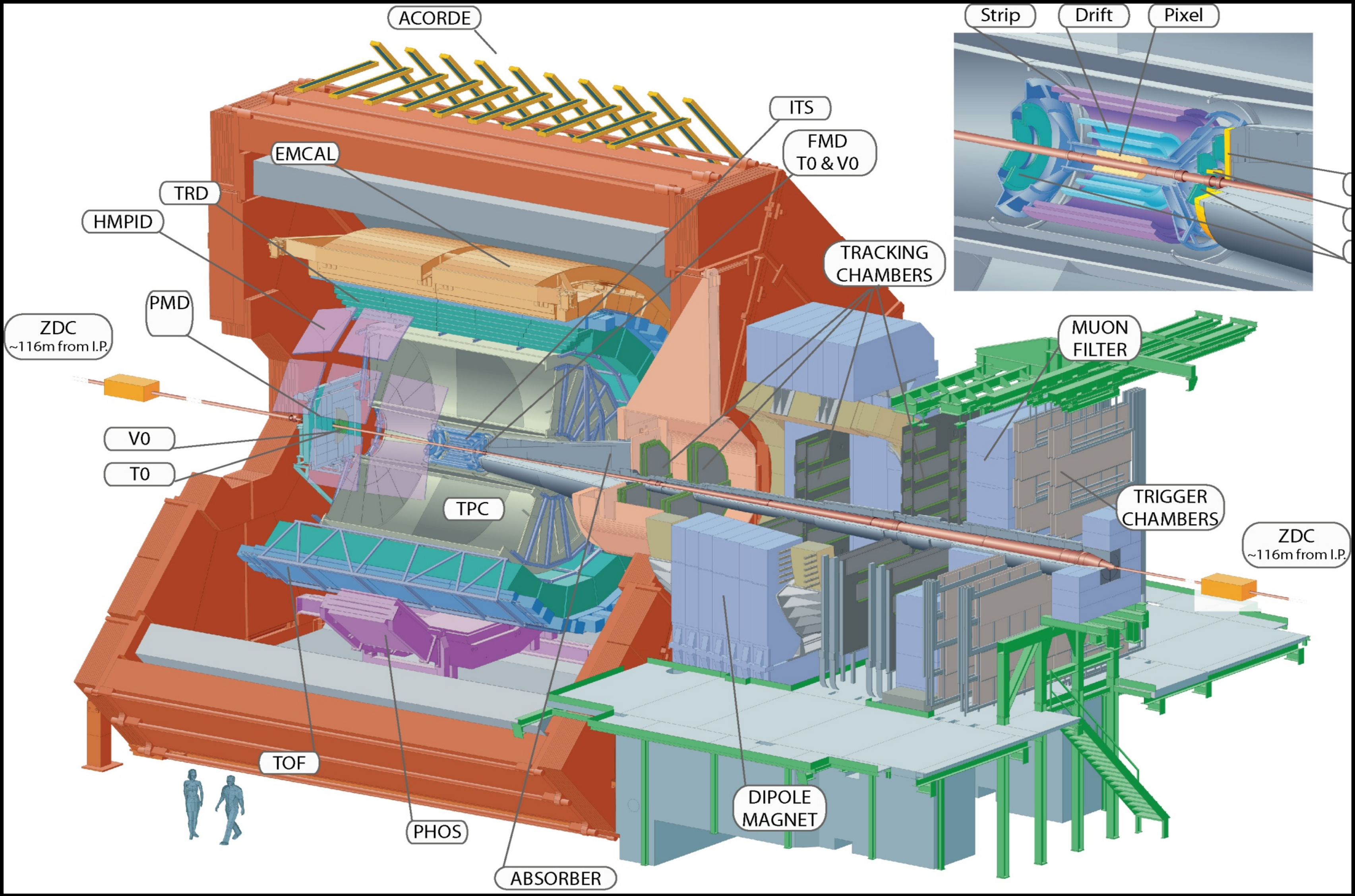


- Connection to the chiral magnetic effect studies
  - Local charge conservation and the CME are two competing physics effects



(ALICE Collaboration) arXiv:1207.0900 (accepted in PRL)

Experimental setup



Analysis details

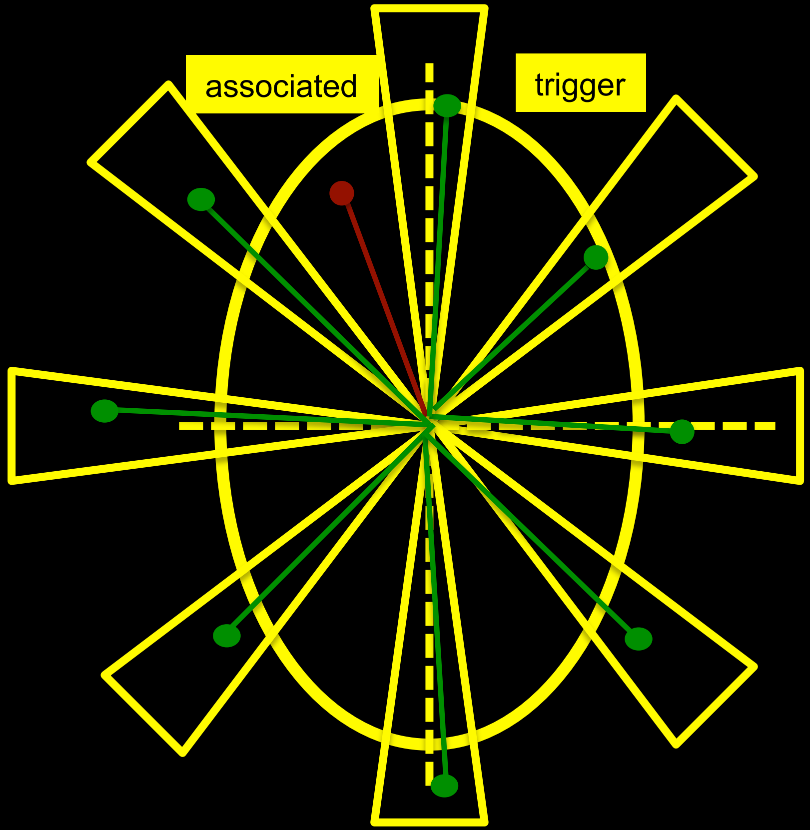
- Pb-Pb collisions @ $\sqrt{s_{NN}}$= 2.76TeV from the 2010 and 2011 periods
- Trigger conditions
  - Min-bias for 2010
  - Min-bias, semi-central (i.e. ~20-50%), central (i.e. 0-10%)
- Clean events:
  - Centrality 0-80% (no E/M contamination)
  - Good reconstructed vertex
- Centrality:
  - Estimated from the amplitude (~multiplicity) measured by the VZERO detectors
  - Cross-check results with other centrality estimators (e.g. TPC tracks, SPD clusters)
- Uniform acceptance
  - Tracks reconstructed by the TPC
- Track cuts
  - Reduce the contamination from secondaries (i.e. apply cuts on the distance of closest approach)
  - Good track quality (e.g. long tracks, good momentum resolution)
- Phase space:
  - $0.2 < p_T < 20.0$ GeV/c
  - $|\eta| < 0.8$

Definition – analysis method

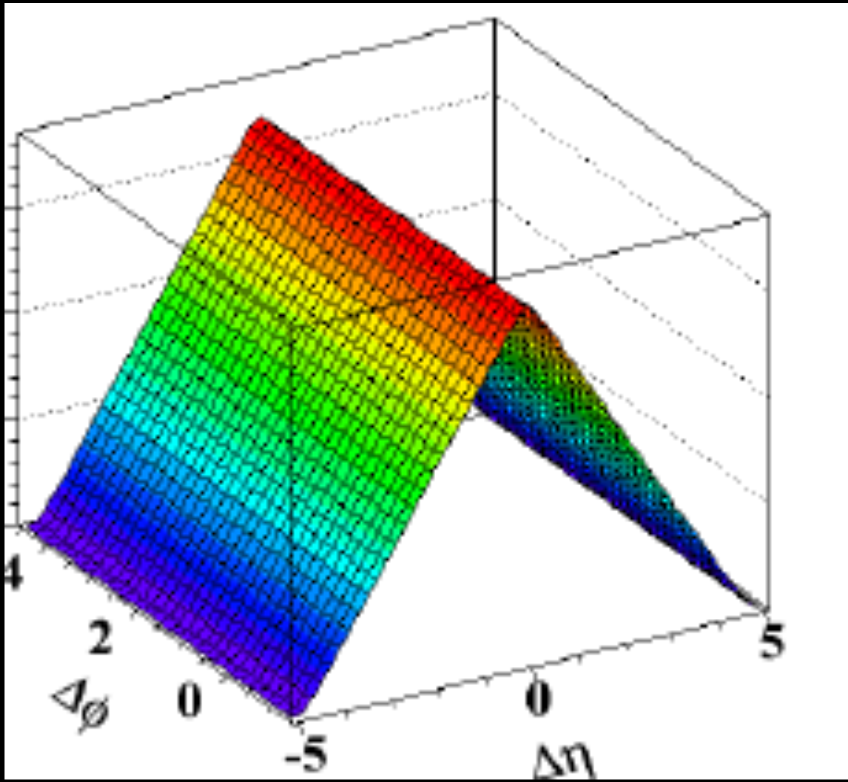
$$B(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}) = C_{+-} + C_{-+} - C_{++} - C_{--}$$

$$C_{+-}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}) = \frac{\langle N_{+-}\rangle_{\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}}}{\langle N_{+}\rangle_{\eta,\varphi,p_T^{trig.}}}$$

- Select a "trigger" particle with a given η, φ and $p_T^{trig.}$
- Calculate the distributions between (un)like-sign pairs
  - Second (associated) particle $p_T^{assoc.}$ and within $\Delta\varphi = \varphi^{trig.} - \varphi^{assoc.}$ and $\Delta\eta = \eta^{trig.} - \eta^{assoc.}$
  - Normalize to the number of "trigger" particles
- Calculate the balance functions for mixed events
- Correct the "raw" balance functions with the ones from mixed events
- Apply corrections resulting in fully corrected correlation functions



Corrections

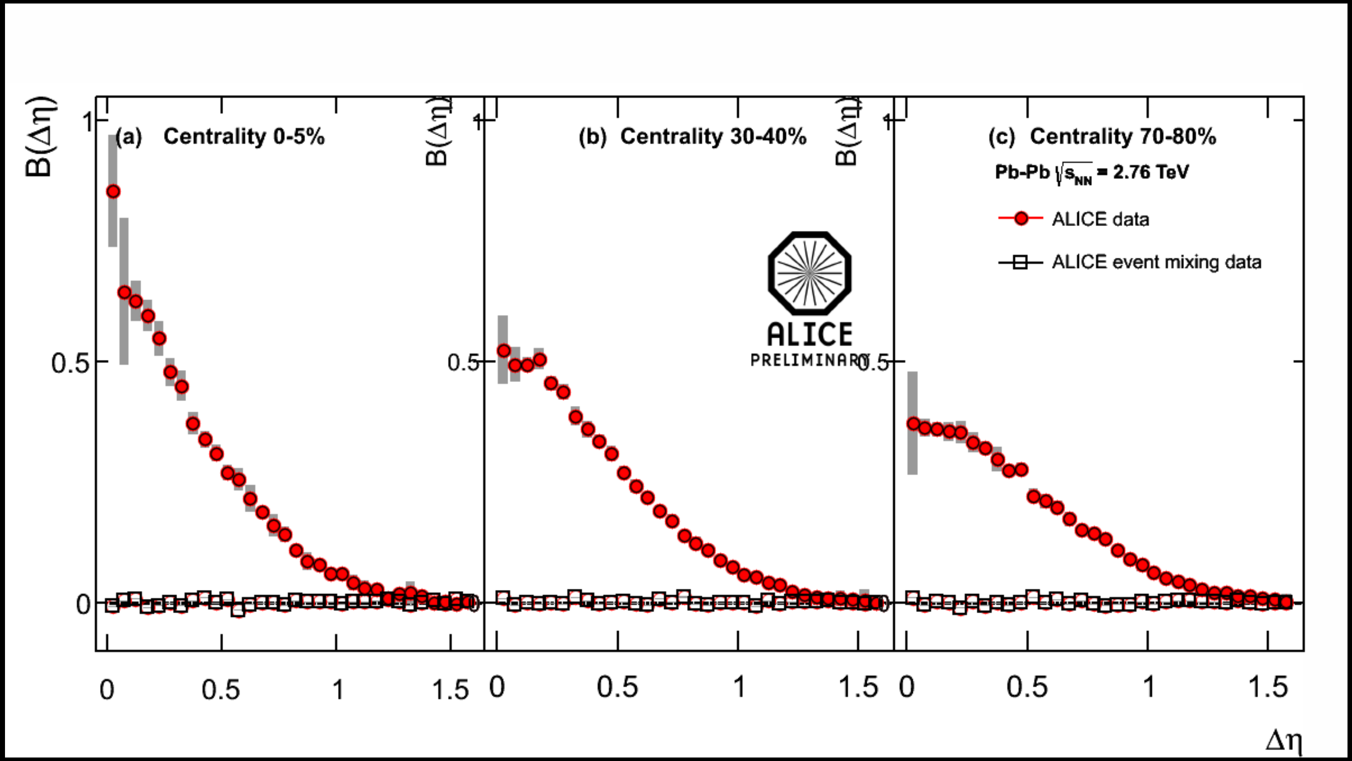


- Accounts for the probability that given a trigger particle falls in our acceptance and is detected, the associated is also reconstructed
- In $\Delta\eta$ no charge dependence
  - balance functions from mixed events around 0
- In $\Delta\varphi$ residual charge dependent acceptance effects
  - balance functions from mixed events around 0 but exhibiting modulations due to the TPC sectors

$$B(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}) = C_{+-} + C_{-+} - C_{++} - C_{--}$$

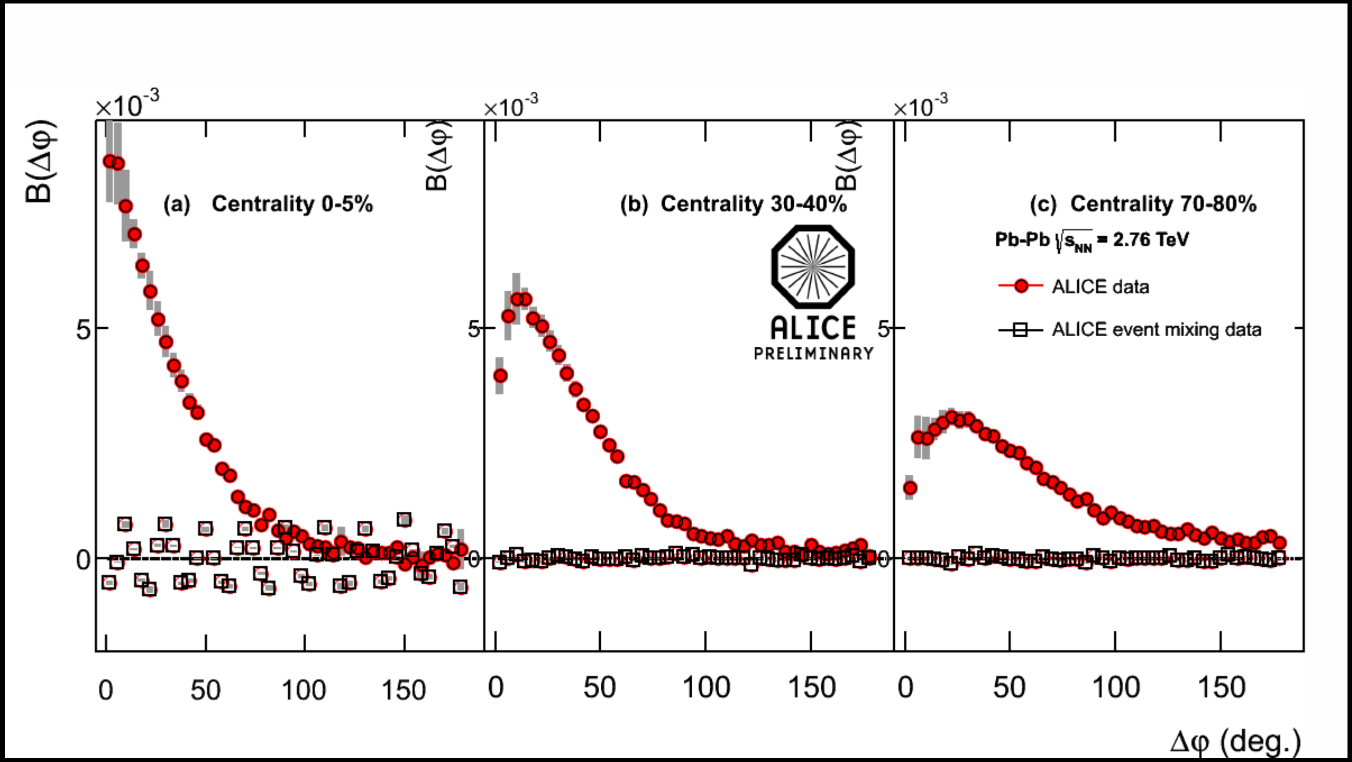
$$C_{+-}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}) = \frac{C_{+-}^{raw}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.})}{f_{+-}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.})}$$

Balance function in $\Delta\eta$ (low p_T)



- Event mixing: uncorrelated sample, used to remove residual detector effects (see next slide)
- Narrower distributions in central events

Balance function in Δφ (low p_T)



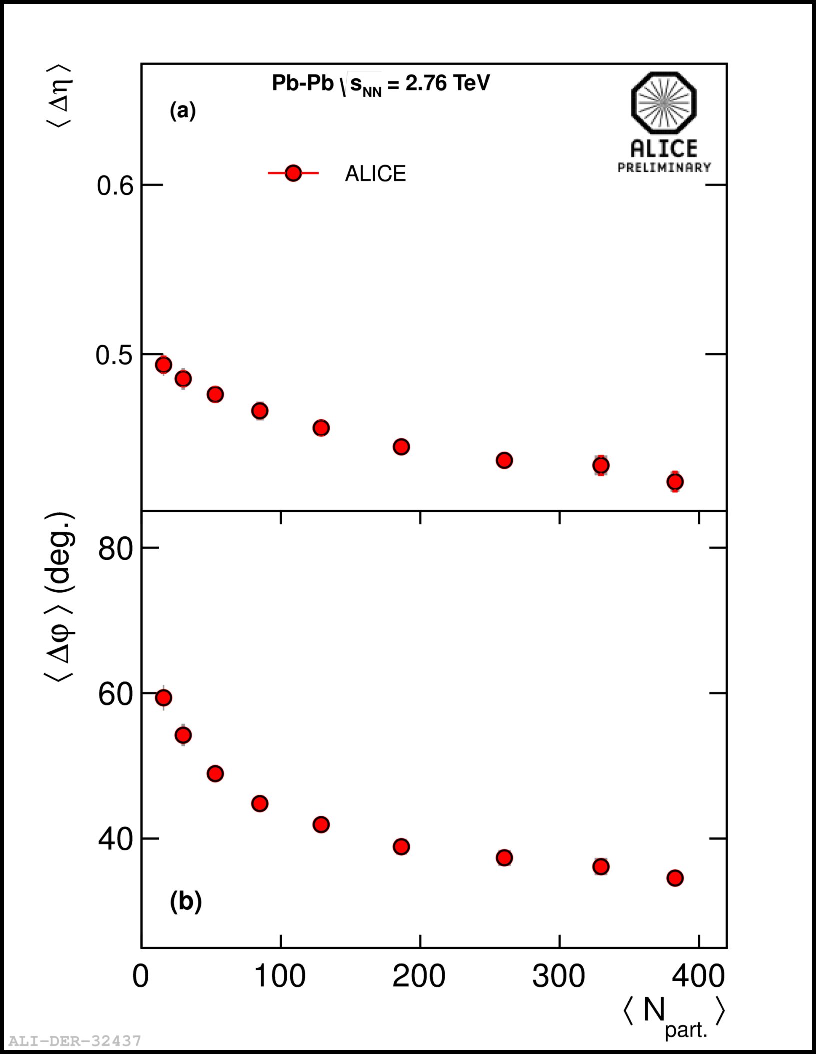
- Periodic structure in the raw balance function reproduced by event mixing
  - TPC sector boundaries ➔ removed
- Drop in the B(Δφ) for small angles: short range correlations
- Narrower distributions in central events

Centrality dependence of the width

$$\langle \Delta\eta \rangle = \frac{\sum_{\Delta\eta=0.1}^{\Delta\eta_{max}} B(\Delta\eta_i)\cdot\Delta\eta_i}{\sum_{\Delta\eta=0.1}^{\Delta\eta_{max}} B(\Delta\eta_i)}$$

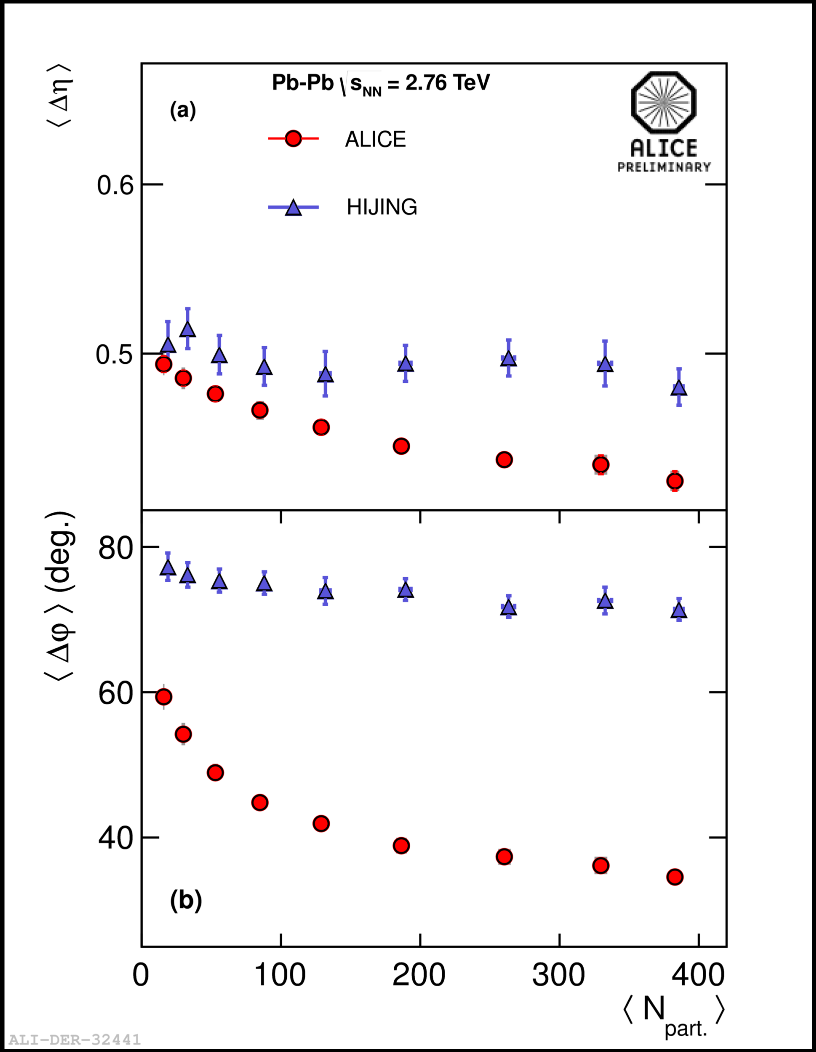
$$\langle \Delta\varphi \rangle = \frac{\sum_{\Delta\varphi=4^o}^{\Delta\varphi_{max}} B(\Delta\varphi_i)\cdot\Delta\varphi_i}{\sum_{\Delta\varphi=4^o}^{\Delta\eta_{max}} B(\Delta\varphi_i)}$$

- Width calculated by the weighted average
- Strong centrality dependence of the width in both Δη and Δφ



Centrality dependence of the width: HIJING

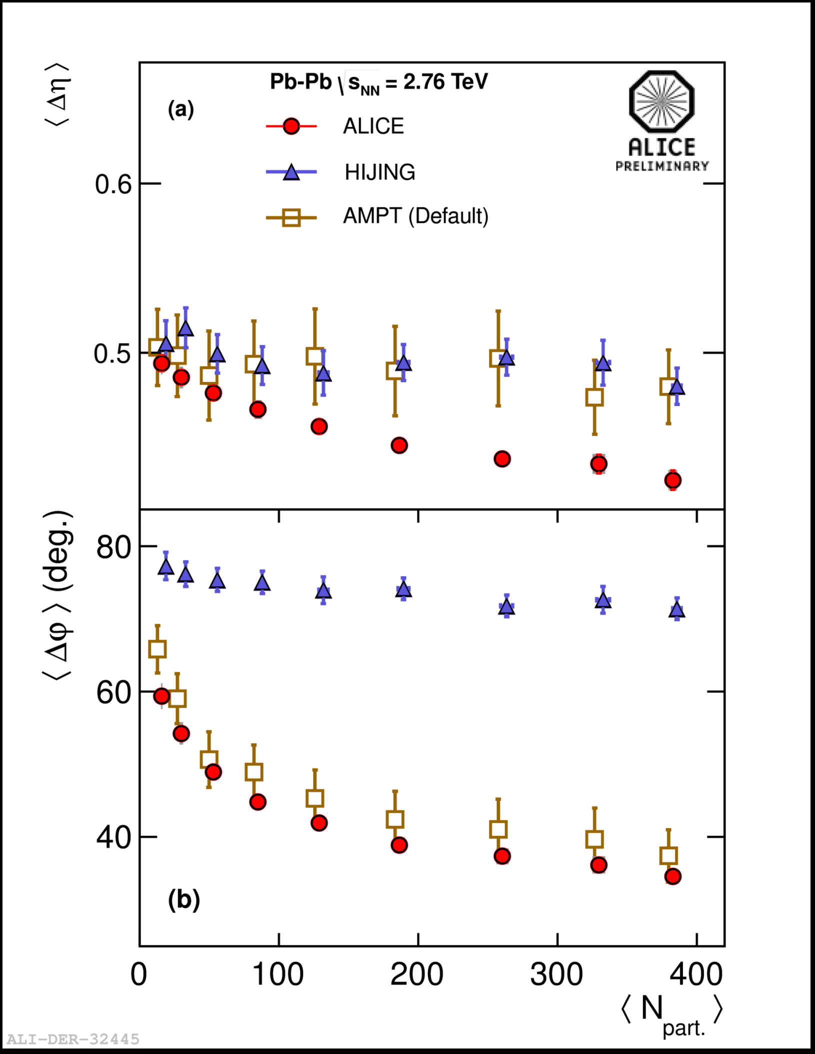
- Collision data:
  - Strong centrality dependence of the width in both $\Delta\eta$ and $\Delta\varphi$
- HIJING:
  - superposition of independent pp collisions
  - no collective effects
  - very mild centrality dependence



- M. Gyulassy and X. N. Wang, Comput. Phys. Commun. **83**, 307 (1994).
- X. N. Wang and M. Gyulassy, Phys. Rev. **D44**, 3501 (1991).

Centrality dependence of the width: AMPT

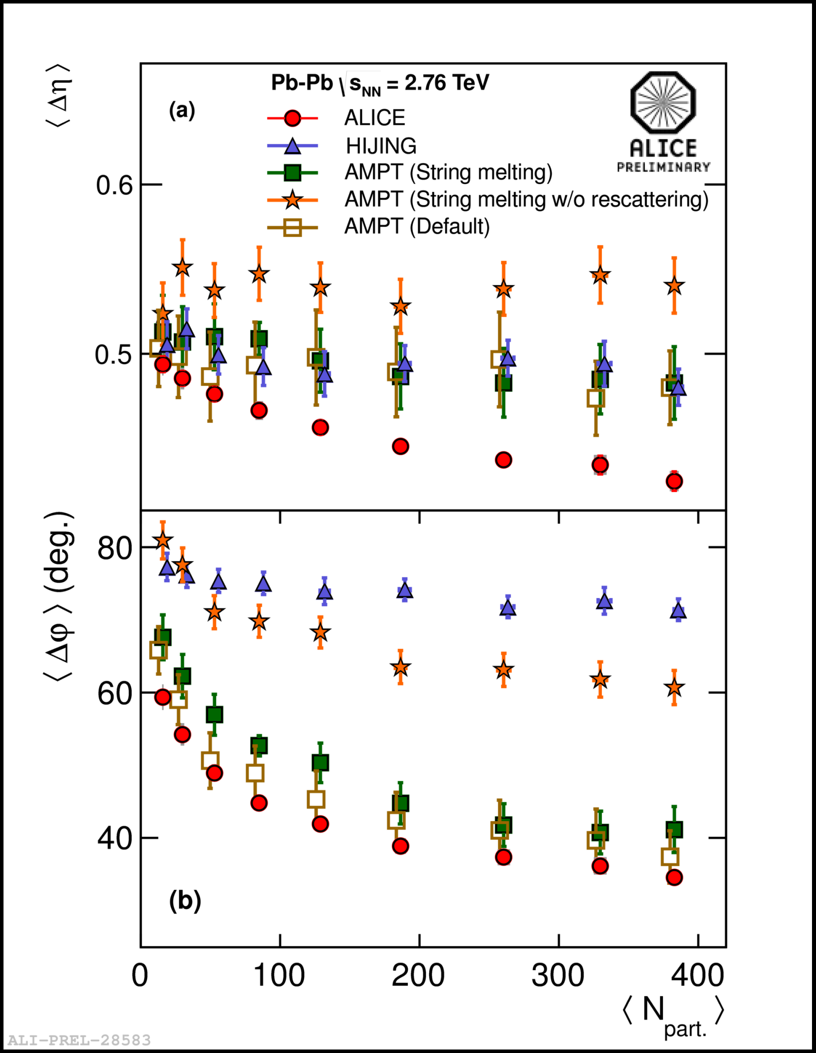
- ❑ Collision data:
  - Strong centrality dependence of the width in both Δη and Δφ
- ❑ HIJING:
  - very mild centrality dependence
- ❑ AMPT default:
  - initial conditions from HIJING
  - partonic rescattering via ZPC + Lund fragmentation
  - hadronic rescattering and resonance decays (i.e. ART)
  - Similar centrality dependence of radial flow as in data
  - Smaller centrality dependence of elliptic flow compared to data



❑ B. Zhang *et al.*, Phys. Rev. **C61**, (2000) 067901.
❑ Z. W. Lin *et al.*, Phys.Rev. **C64**, (2001) 011902. 72}, (2005) 064901.

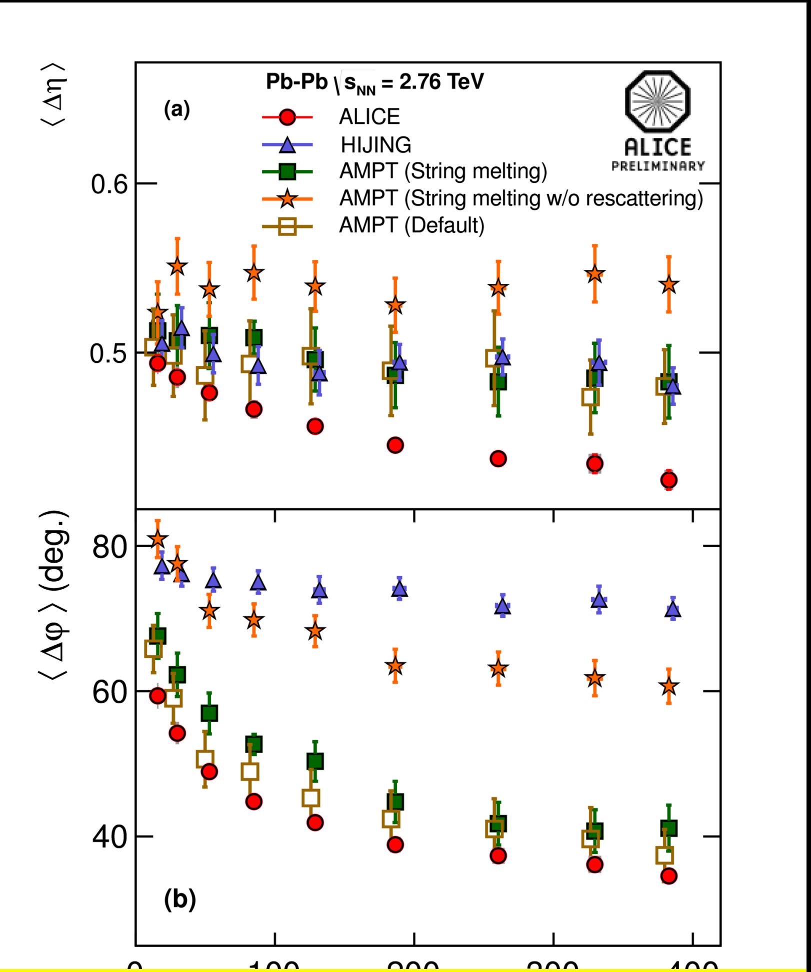
Centrality dependence of the width: more AMPT

- **Collision data:**
  - Strong centrality dependence of the width in both $\Delta\eta$ and $\Delta\varphi$
- **HIJING:**
  - very mild centrality dependence
- **AMPT default:**
  - very mild centrality dependence in $\Delta\eta$
  - in agreement with data in $\Delta\varphi$
- **AMPT string melting**
  - partonic rescattering via ZPC + coalescence
  - hadronic rescattering and resonance decays (i.e. ART)
  - Slightly smaller centrality dependence of radial flow compared to the default
  - Similar centrality dependence of elliptic flow compared to data



Centrality dependence of the width: more AMPT

- **Collision data:**
  - Strong centrality dependence of the width in both Δη and Δφ
- **HIJING:**
  - very mild centrality dependence
- **AMPT default:**
  - very mild centrality dependence in Δη
  - in agreement with data in Δφ
- **AMPT string melting**
  - partonic rescattering via ZPC + coalescence
  - hadronic rescattering and resonance decays (i.e. ART)
  - Slightly smaller centrality dependence of radial flow compared to the default
  - Similar centrality dependence of elliptic flow compared to data

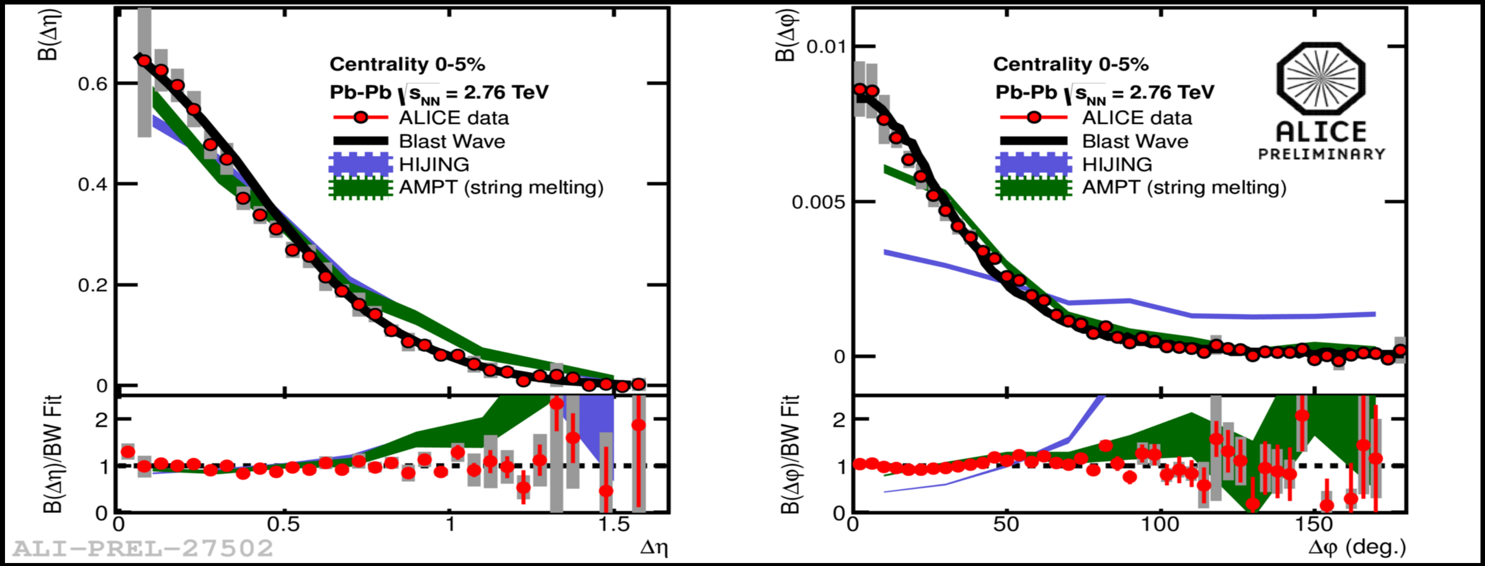


However we recently confirmed that the charge is not conserved in AMPT→ we should put the proper weight to the conclusion

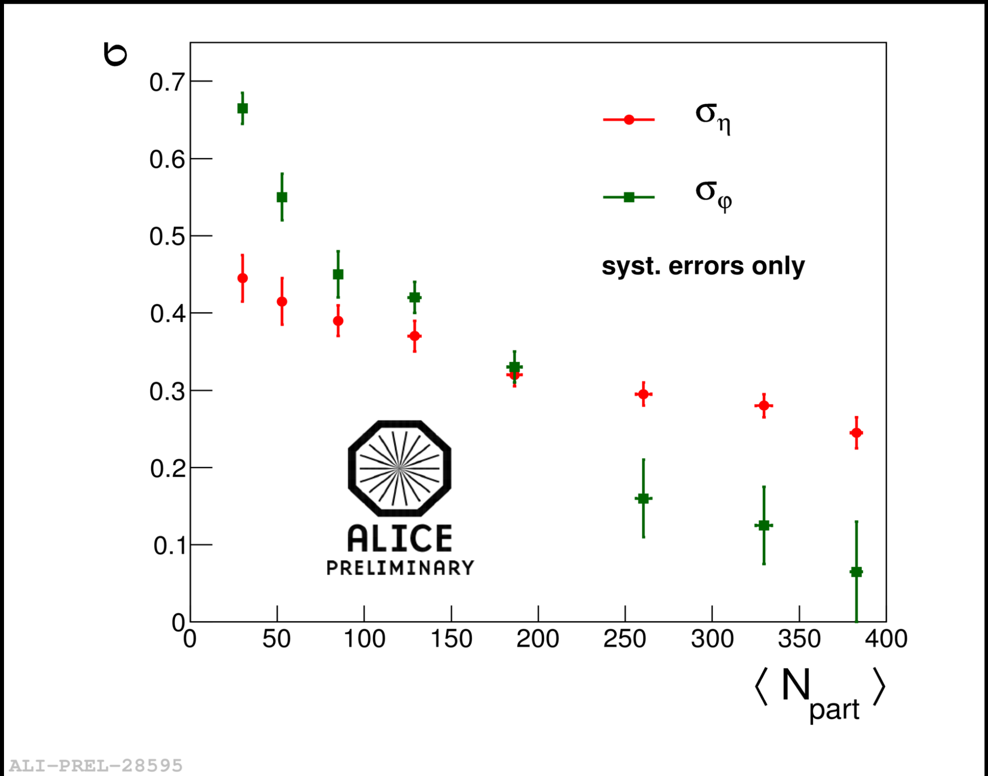
Comparison to blast wave

- Parameterization including radial and elliptic flow
- Implementation of local charge conservation by emitting particle pairs with an "initial separation" at the freeze-out surface
  - initial separation indicated by σ_η and σ_φ
- Model parameters tuned to fit the
  - identified particle spectra
  - v_2 for all charges
- Fit the centrality dependence of the width of the balance function in $\Delta\eta$ and $\Delta\varphi$ to get σ_η and σ_φ

- S. Pratt, Phys. Rev. **C85**, (2012) 014904.
- S. Pratt, Phys. Rev. Lett. **108**, (2012) 212301.



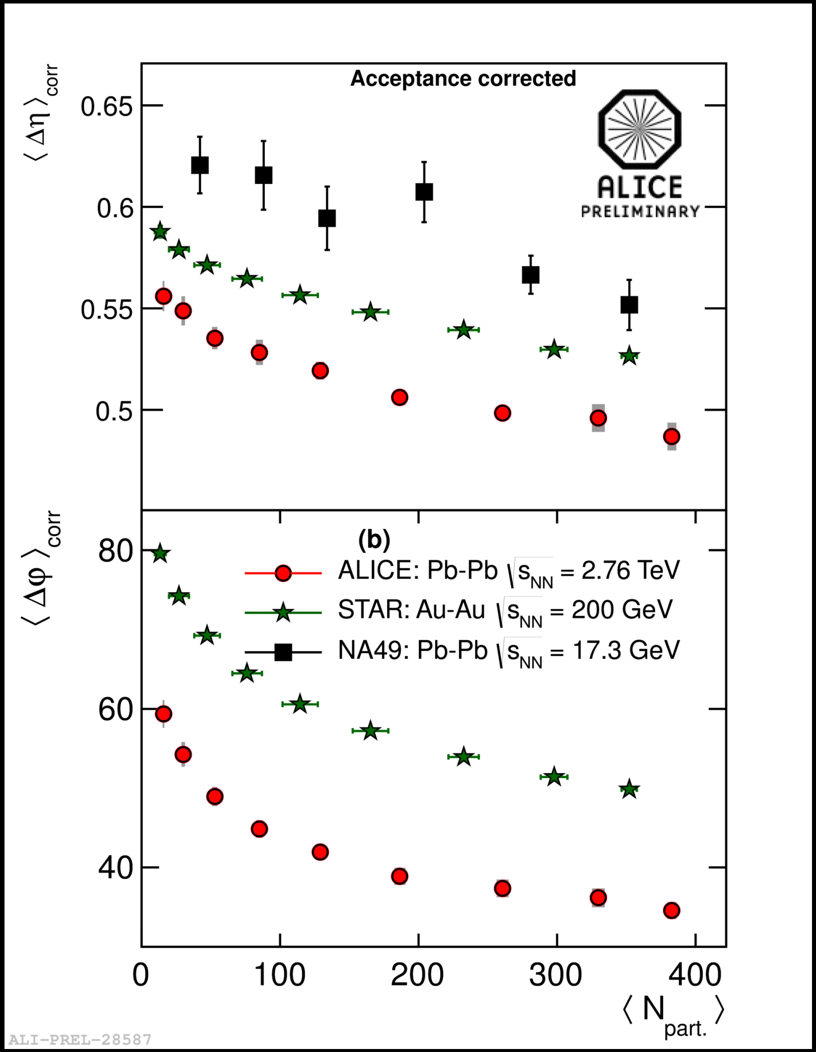
Centrality dependence of σ_η and σ_φ



- The two representations could probe different sensitivity to two contributions
  - radial flow
  - late stage creation of charges

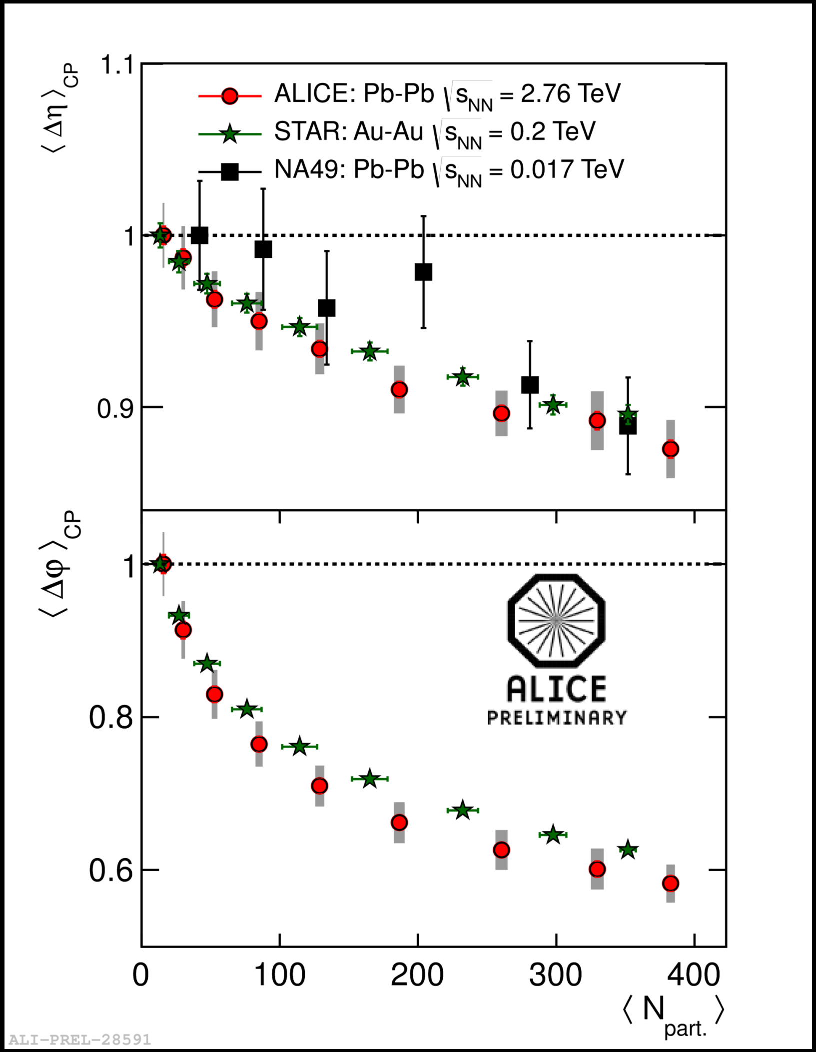
Energy dependence

- Comparison between experiments at SPS, RHIC and LHC
- Nice ordering with energy, consistent with the idea of
  - having a system exhibiting larger radial flow at the LHC
  - spending more time in the QGP phase
- However…



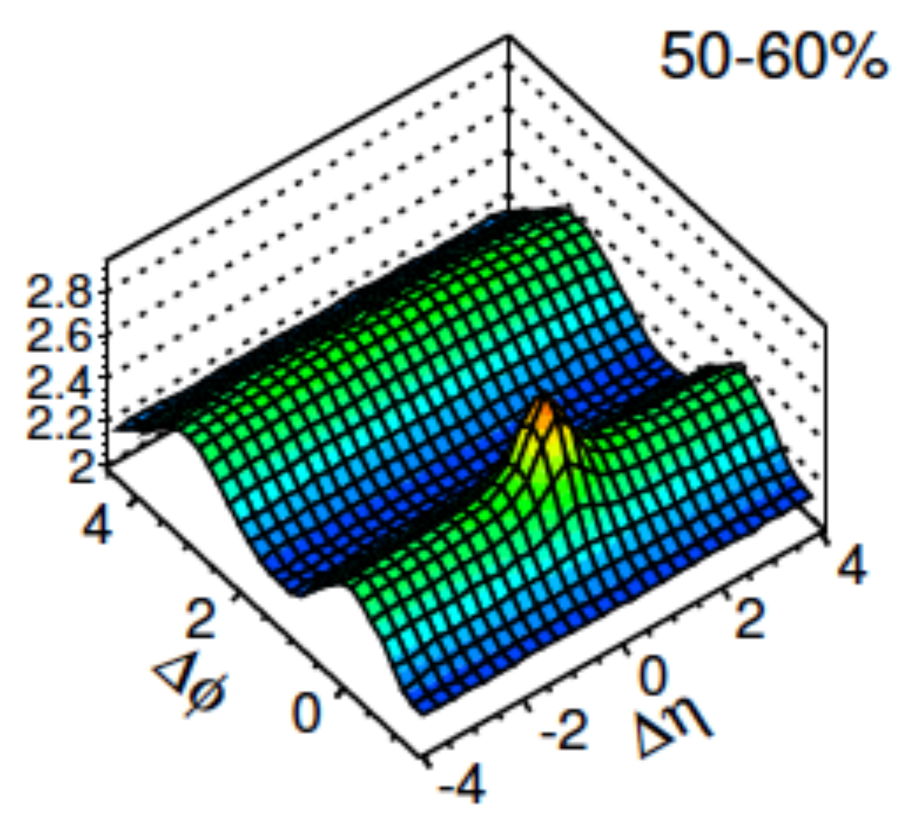
Energy dependence: relative decrease

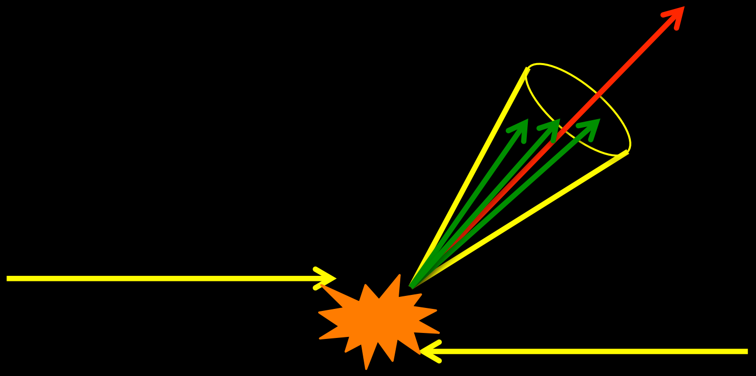
- The centrality dependence of $<\Delta\varphi>_{CP}$ shows an additional decrease between STAR and ALICE
  - consistent with the picture of having an additional increase of radial flow between central and peripheral collisions at the LHC wrt RHIC
- The centrality dependence of $<\Delta\eta>_{CP}$ seems to fall (unexpectedly?) on the same curve
  - hard to explain solely it in terms of late stage creation of charges



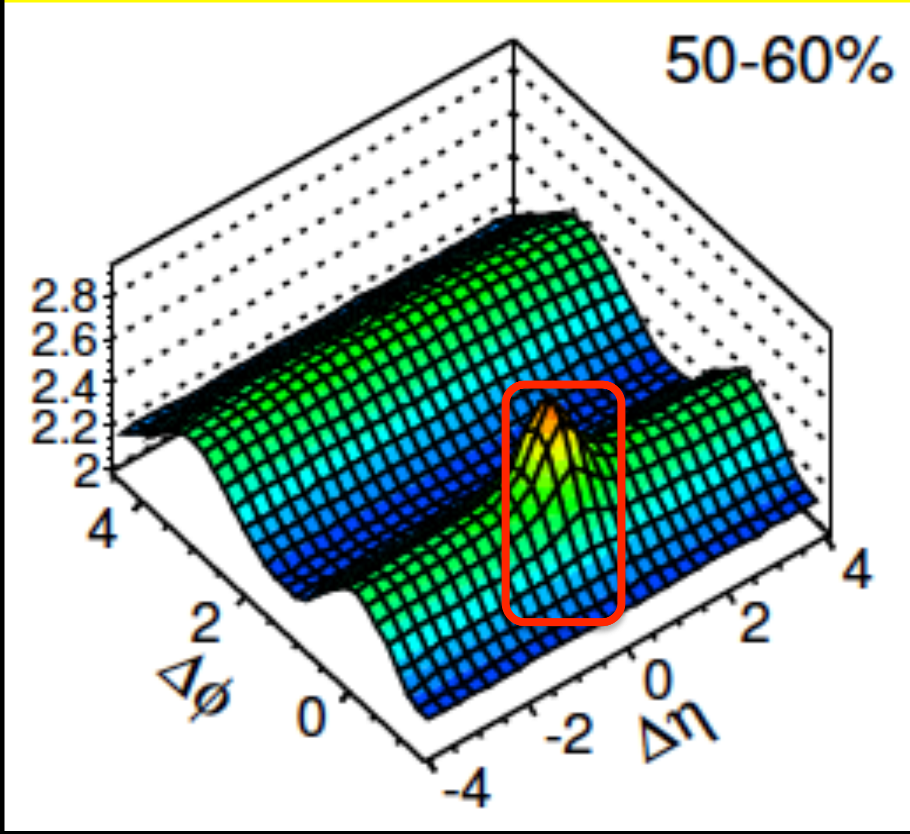
Dihadron correlations and balance functions

CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012

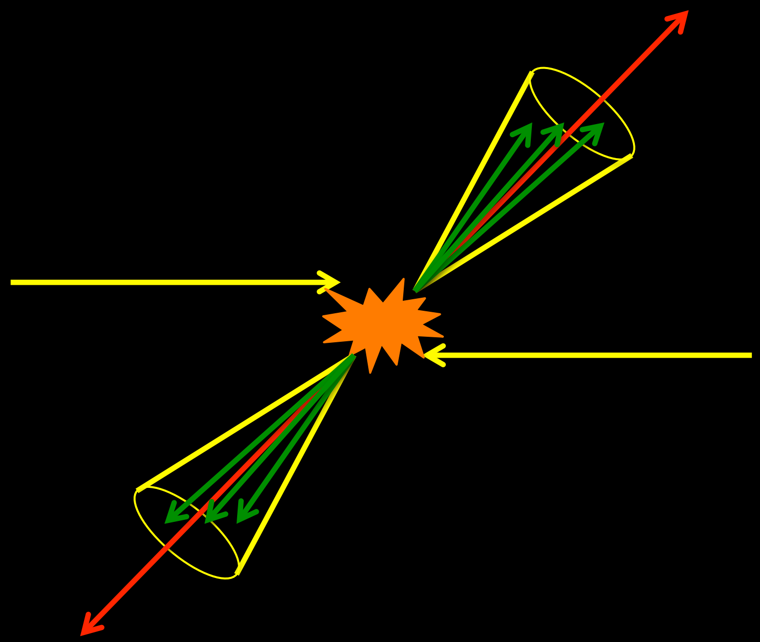




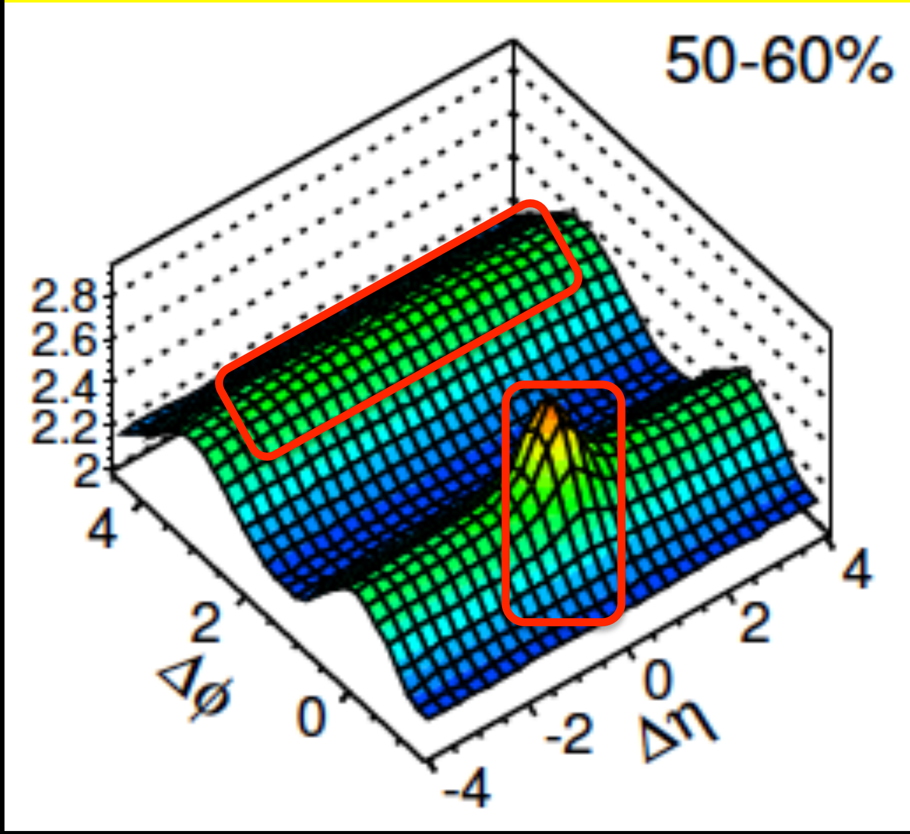
CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012



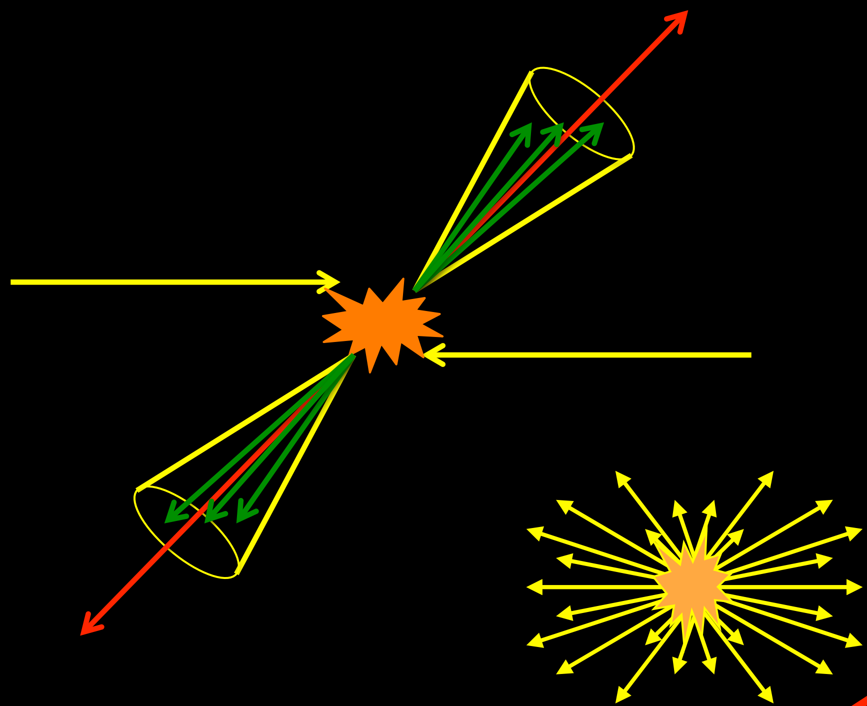
Dihadron correlations and balance functions

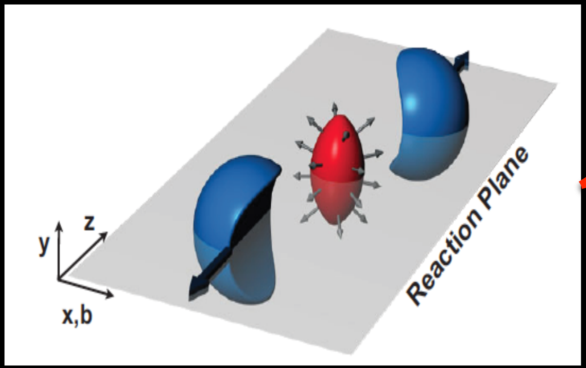


CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012

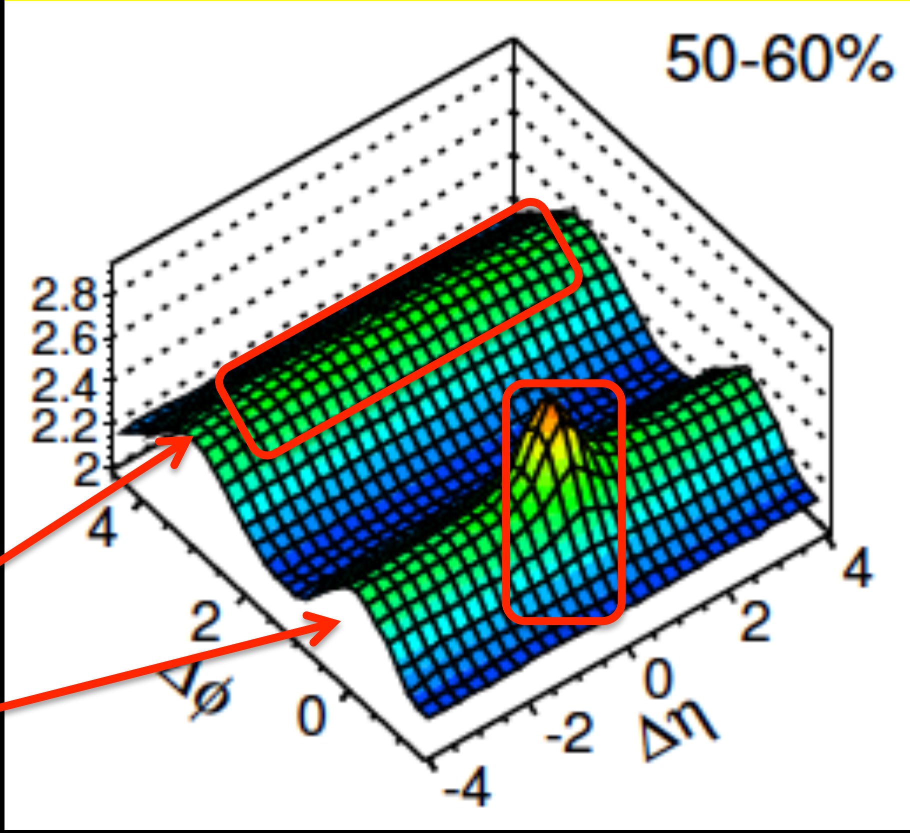


Dihadron correlations and balance functions

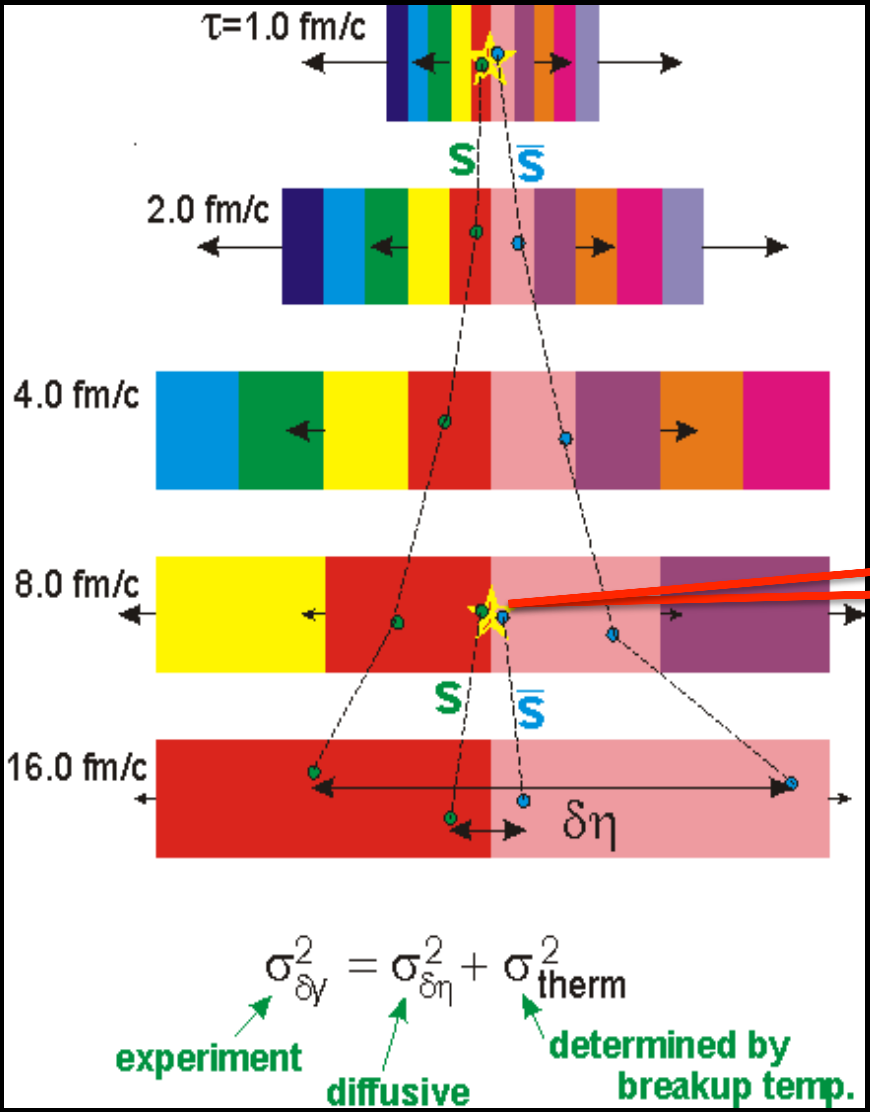




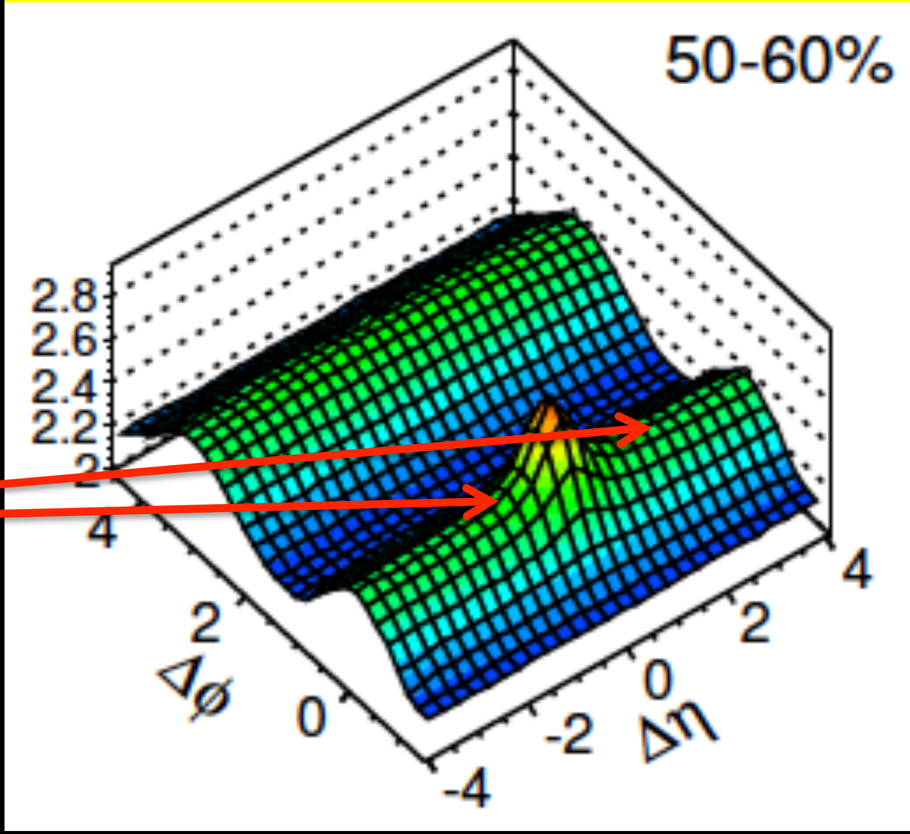
CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012



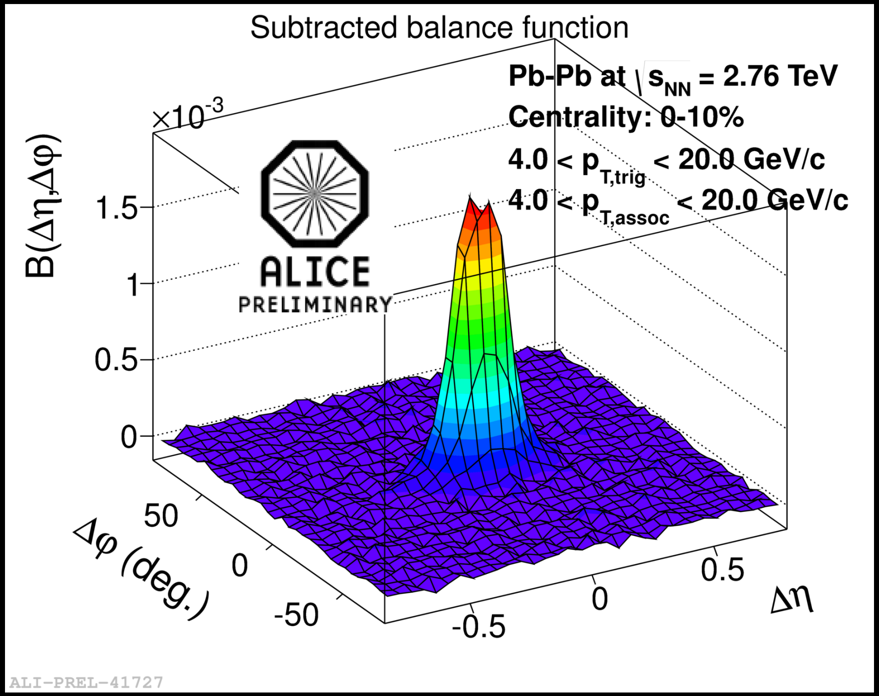
Dihadron correlations and balance functions

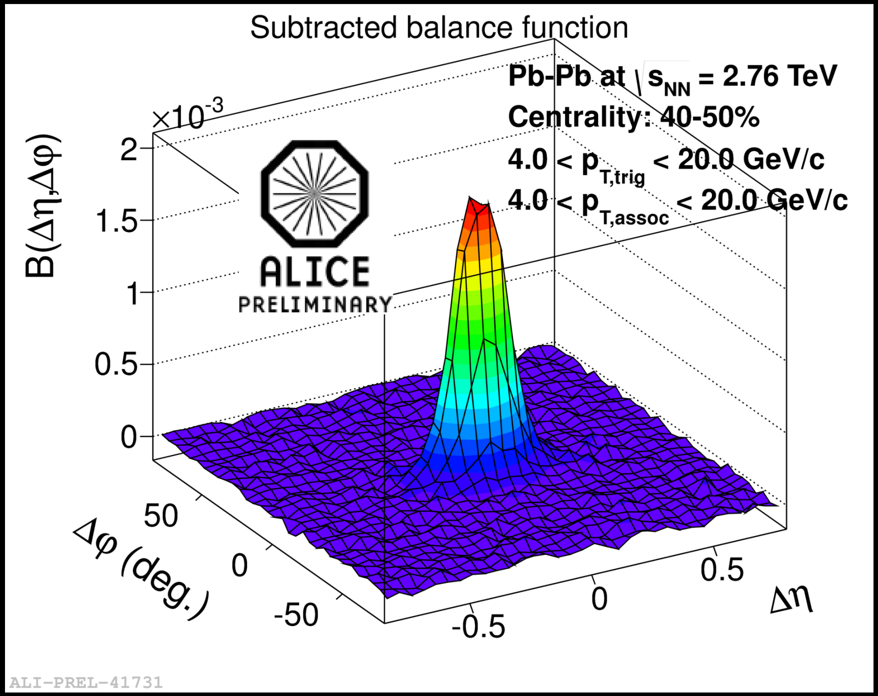


CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012



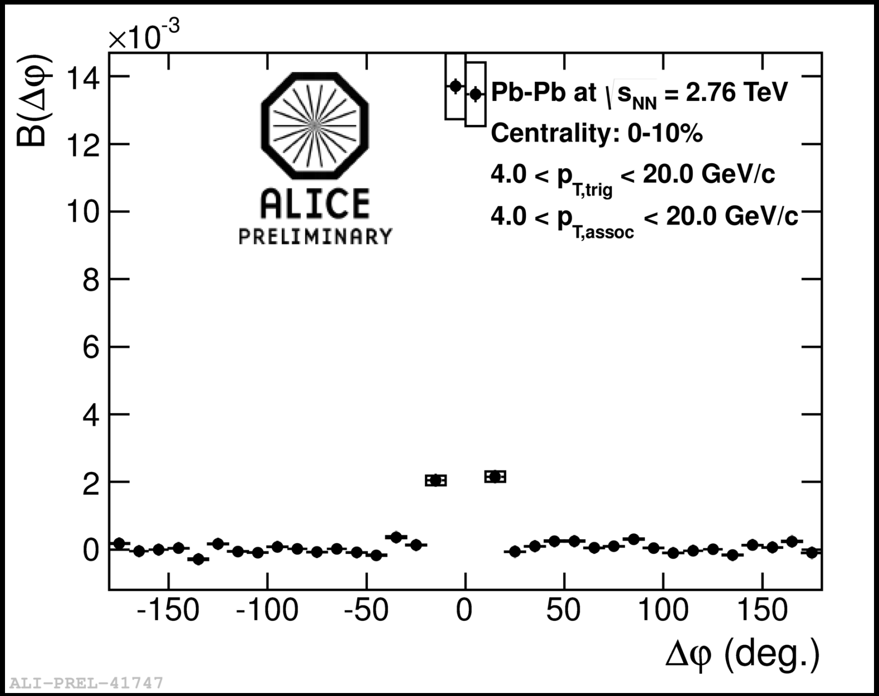
Balance function at higher transverse momenta

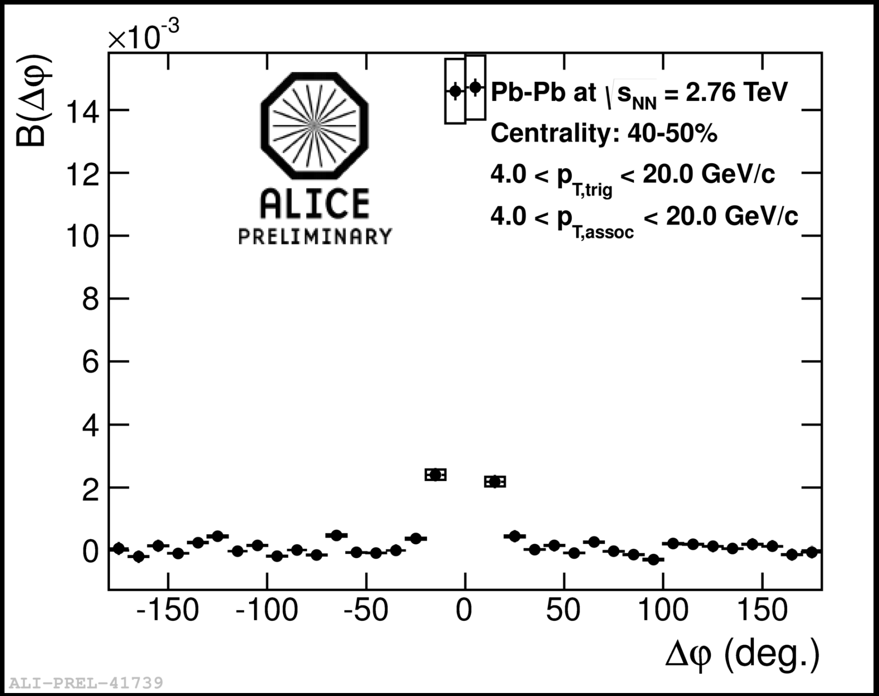




- ❑ Centrality evolution of the 2-dimensional balance function seems to be rather weak

Balance function at higher transverse momenta: Δφ





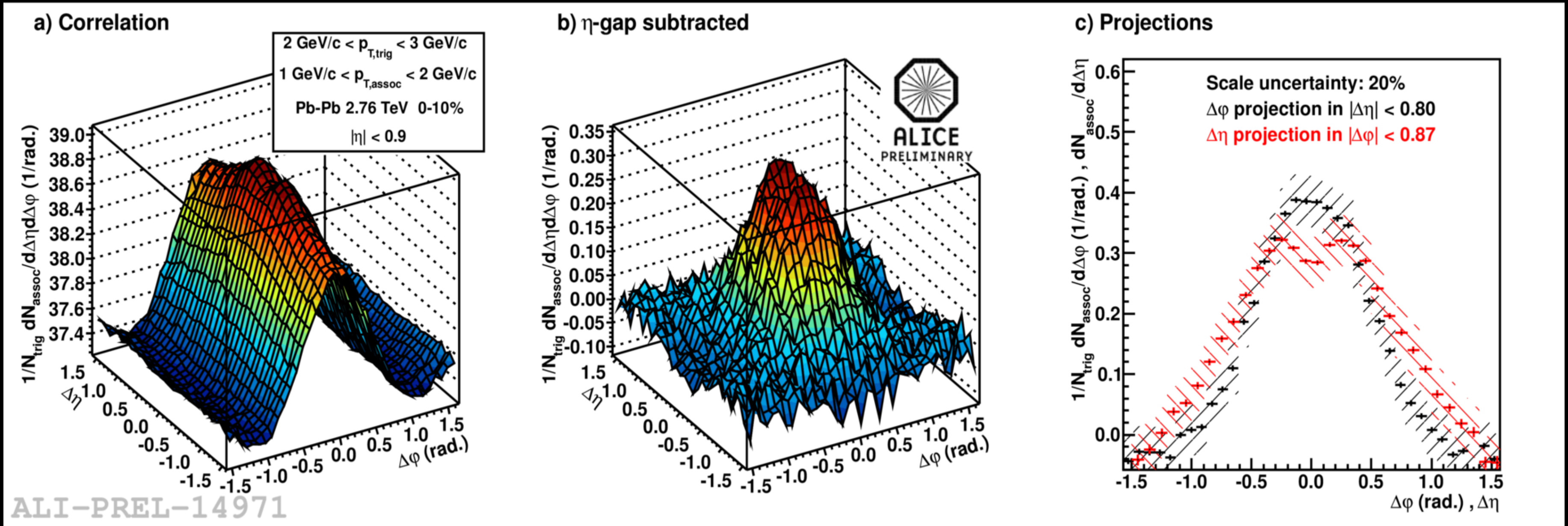
- ❑ Particles collimated in the transverse plane
- ❑ Centrality evolution very mild, seems to be restricted at low p_T

Summary

- Strong centrality dependence of the width of the balance functions in $\Delta\eta$ and $\Delta\varphi$
  - Can be reproduced in $\Delta\varphi$ by models that include collectivity
  - However it is fair to note that AMPT does not conserve charge
    - What the contribution of this effect to our observable is, is not known
- Qualitative similar behavior of the balance functions between RHIC and LHC
  - Reasonable ordering of the width with energy
  - Relative decrease of the width between peripheral and central collisions is hard to be understood by simply accounting for the late stage creation of balancing pairs.
- The strong centrality dependence seems to be restricted at low p_T

Outlook

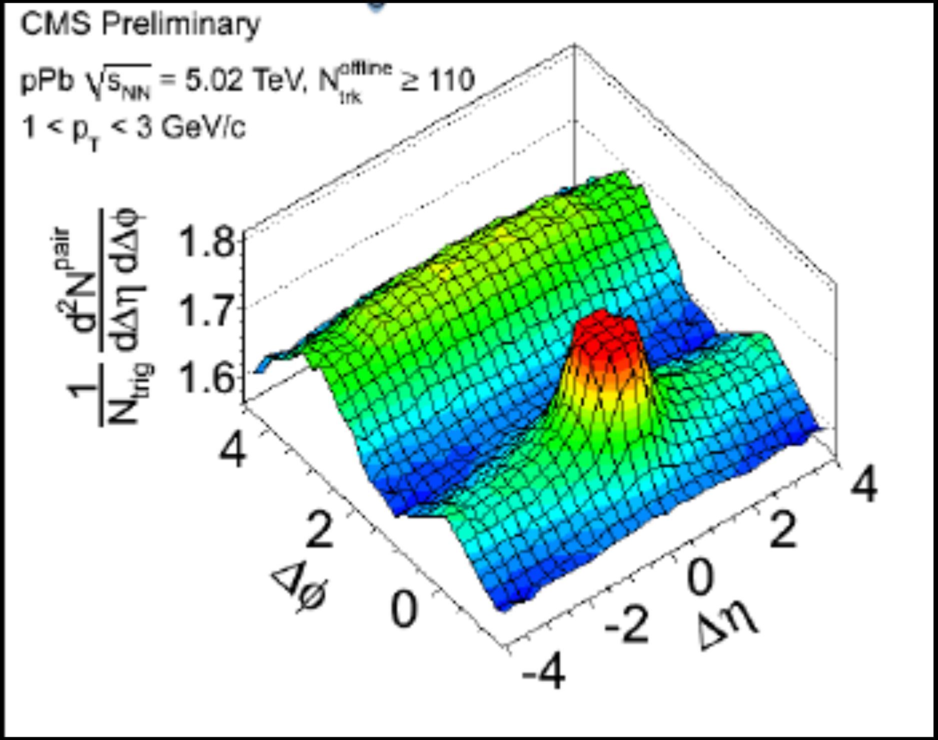
Near side jet-peak shapes



Jan-Fiete Grosse Oetringhaus @ Hard Probes 2012

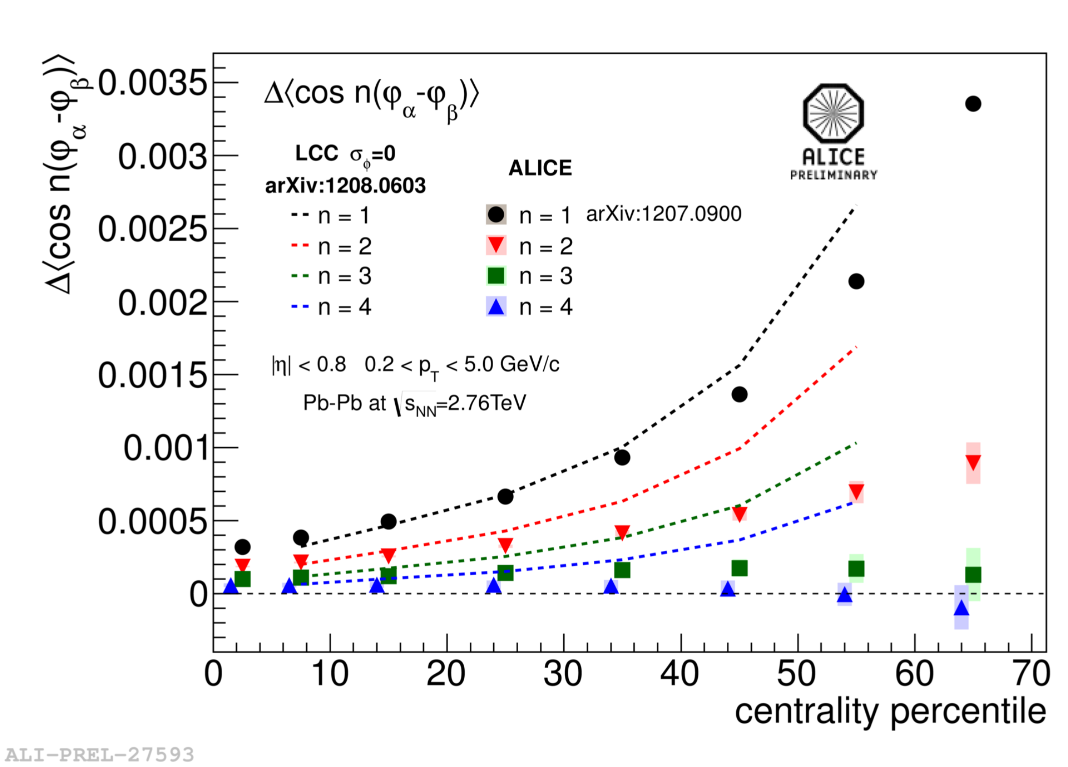
Outlook

p-Pb ridge-like structure



Outlook

Higher moments of the balance function (CME studies)



Yasuto Hori @ Quark Matter 2012

Backup

BF vs other charge dependent azimuthal correlations results

$$2\cdot\delta\left\langle\cos\left(\phi_a-\phi_\beta\right)\right\rangle=2\left\langle\cos\left(\phi_a-\phi_\beta\right)\right\rangle_{(+-)}-\left\langle\cos\left(\phi_a-\phi_\beta\right)\right\rangle_{(++)}-\left\langle\cos\left(\phi_a-\phi_\beta\right)\right\rangle_{(--)}$$

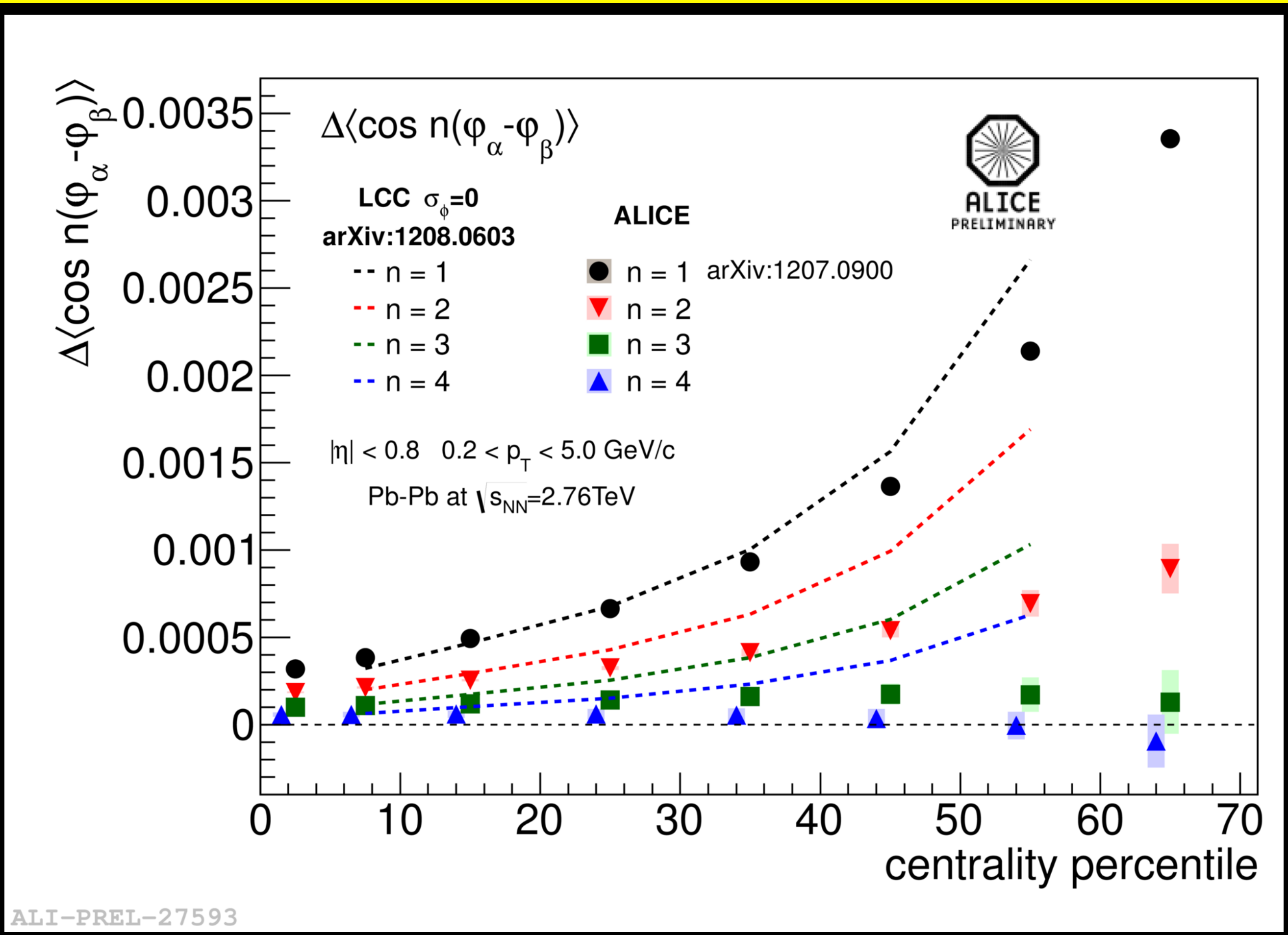
$$\frac{M}{2}\cdot\delta\left\langle\cos(\phi_a-\phi_\beta\right\rangle=\int_0^{2\pi}B(\Delta\phi)\cos\left(\Delta\phi\right)d\Delta\phi$$

$$2\cdot\delta\left\langle\cos\left(n\phi_a+m\phi_\beta-(n+m)\Psi_2\right)\right\rangle=2\left\langle\cos\left(n\phi_a+m\phi_\beta-(n+m)\Psi_2\right)\right\rangle_{(+-)}-\left\langle\cos\left(n\phi_a+m\phi_\beta-(n+m)\Psi_2\right)\right\rangle_{(++)}-\left\langle\cos\left(n\phi_a+m\phi_\beta-(n+m)\Psi_2\right)\right\rangle_{(--)}$$

$$\frac{M}{2}\cdot\delta\left\langle\cos\left(n\phi_a+m\phi_\beta-(n+m)\Psi_2\right)\right\rangle=$$

$$\int_0^{\pi}d(\varphi^{trig.}-\Psi_2)\int_0^{2\pi}d(\varphi^{trig.}-\varphi^{assoc.})\left\langle\frac{dN}{d(\varphi^{trig.}-\Psi_2)}\right\rangle B(\varphi^{trig.}-\Psi_2,\varphi^{trig.}-\varphi^{assoc.})\cos\left[(\varphi^{trig.}-\varphi^{assoc.})+2(\varphi^{trig.}-\Psi_2)\right]$$

Higher orders of charge dependent azimuthal correlations



- Good description of n=1 with an indication of a centrality dependence of σ_φ
- Model does not describe the higher orders.

Systematic uncertainties

Source	Action	Status
Run period	Repeat the same analysis over the good runs of LHC10h and LHC11h	DONE
Magnetic field polarities	Compare results from the 2011 sample for the (++) and (--) field configurations	DONE
Tracking modes	Compare different track cuts (e.g. bit 128 vs bit 1)	DONE
Centrality estimator	Repeat the analysis using TRK and CL1	DONE

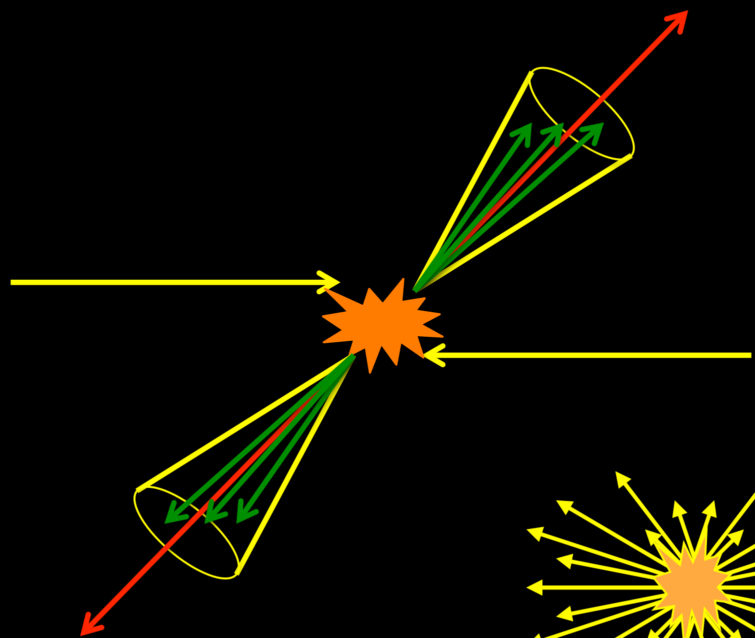
- Estimate corrections by analyzing MC

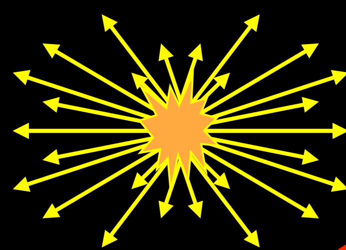
$$C_{+-}^{corr.}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}) = \frac{\left\langle N_{+-}\right\rangle^{corr.}_{\Delta\eta,\Delta\varphi,\varphi-\Psi_2,p_T^{trig.},p_T^{assoc.}}}{\left\langle N_{+}\right\rangle^{corr.}_{\eta,\varphi,p_T^{trig.}}}$$

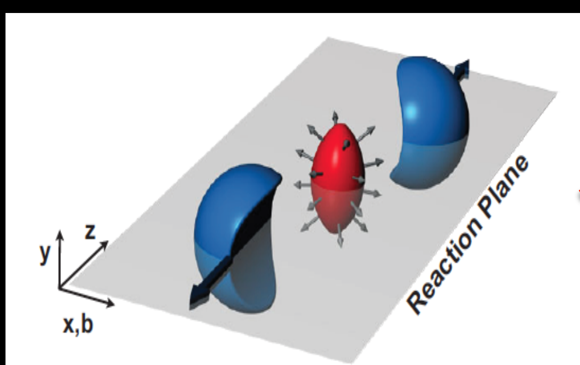
$$\left\langle N_{+-}\right\rangle^{corr.}_{\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}} = \frac{\left\langle N_{+-}\right\rangle^{raw}_{\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.}}}{\varepsilon_{+-}(\Delta\eta,\Delta\varphi,p_T^{trig.},p_T^{assoc.})}$$

$$\left\langle N_{+}\right\rangle^{corr.}_{\eta,\varphi,p_T^{trig.}} = \frac{\left\langle N_{+}\right\rangle^{corr.}_{\eta,\varphi,p_T^{trig.}}}{\varepsilon_{+}(\eta,\varphi,p_T^{trig.})}$$

Dihadron correlations and balance functions







CMS Collaboration, Eur. Phys. J. **C72**, (2012) 2012