NATIONAL SCIENCE CENTRE

Overview of two-particle angular correlations

Małgorzata Janik

Faculty of Physics
Warsaw University
of Technology

International Conference on New Frontiers in Physics 2015
28.08.2015

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Selected highlights *from experimentalist*

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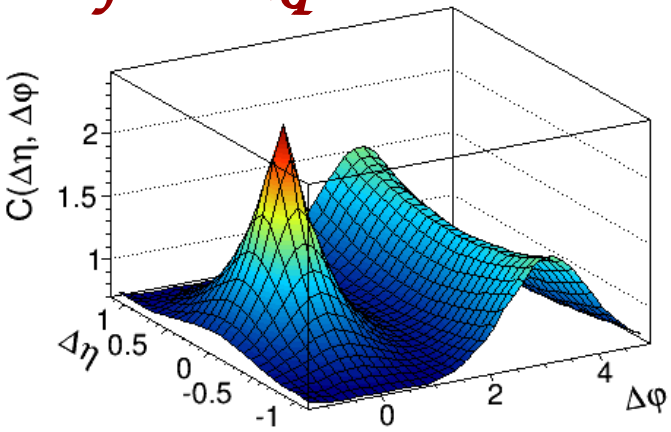

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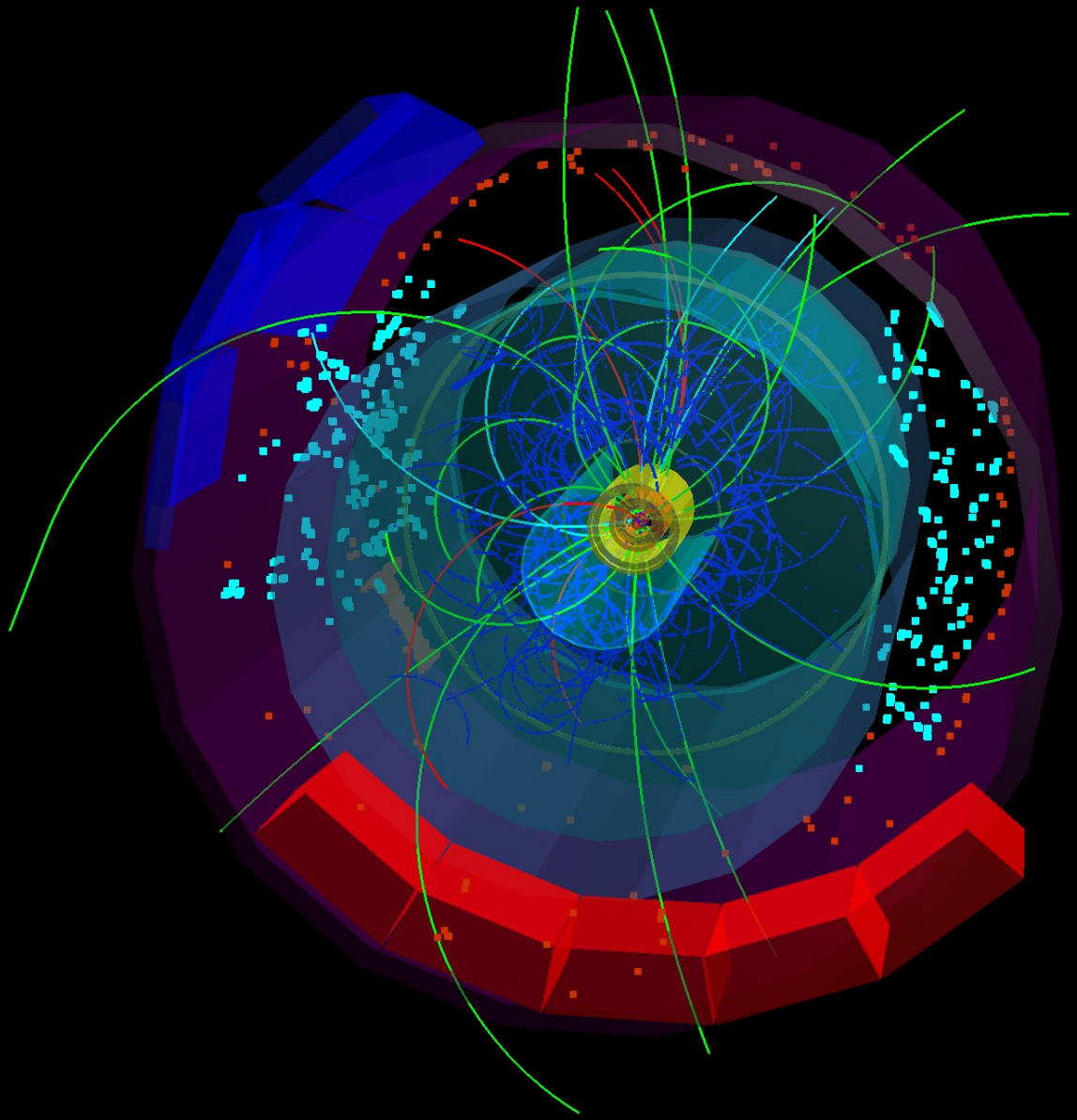
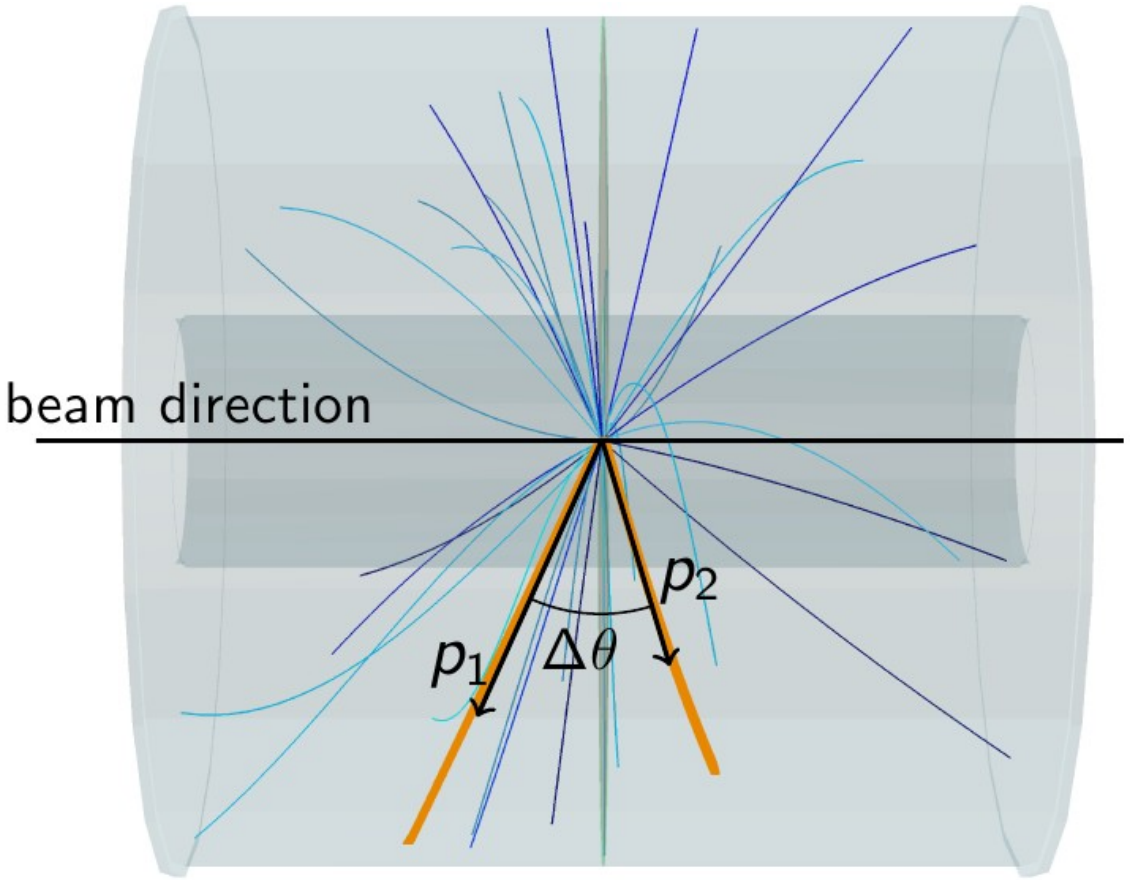
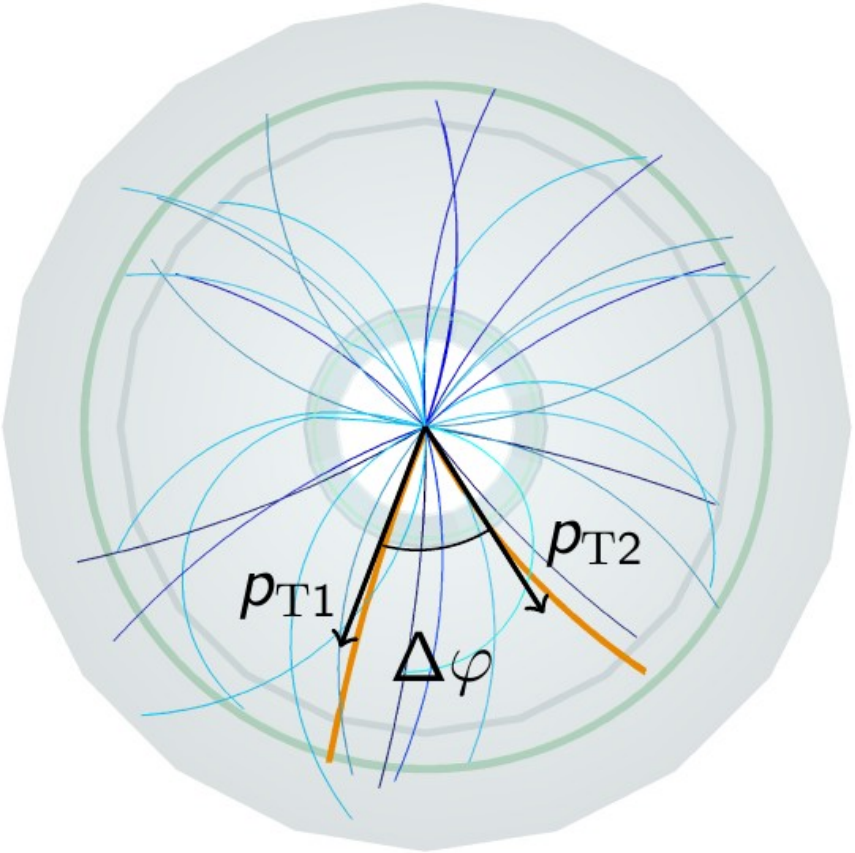
Two-particle ΔηΔφ angular correlations



Two-particle ΔηΔφ angular correlations





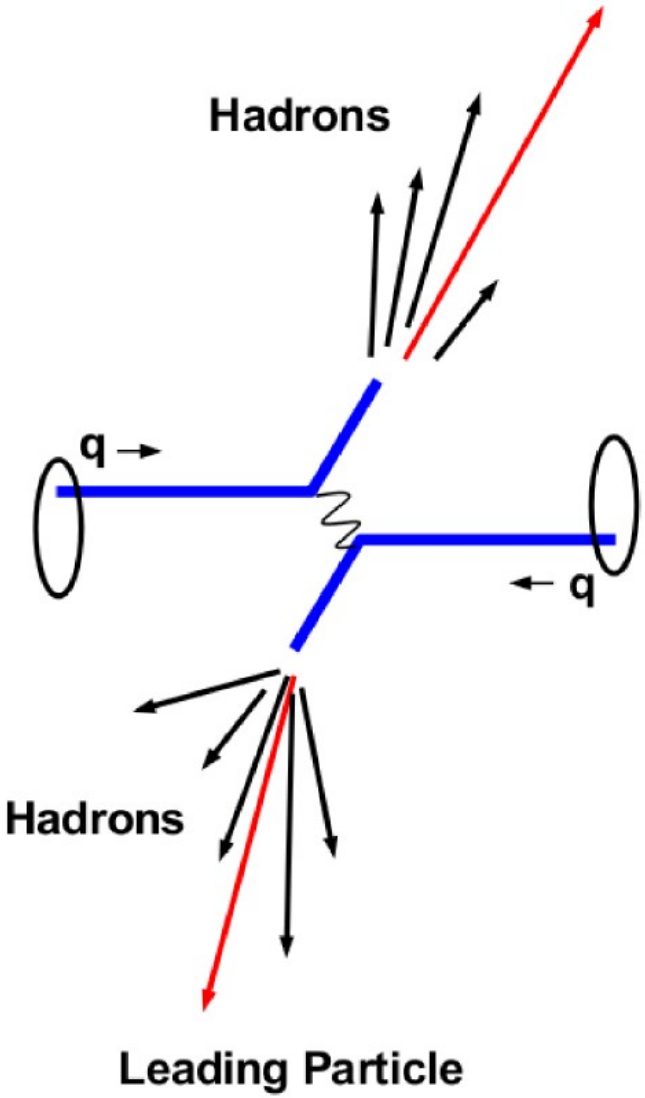
p - particle momentum;
θ - polar angle;
η - pseudorapidity:

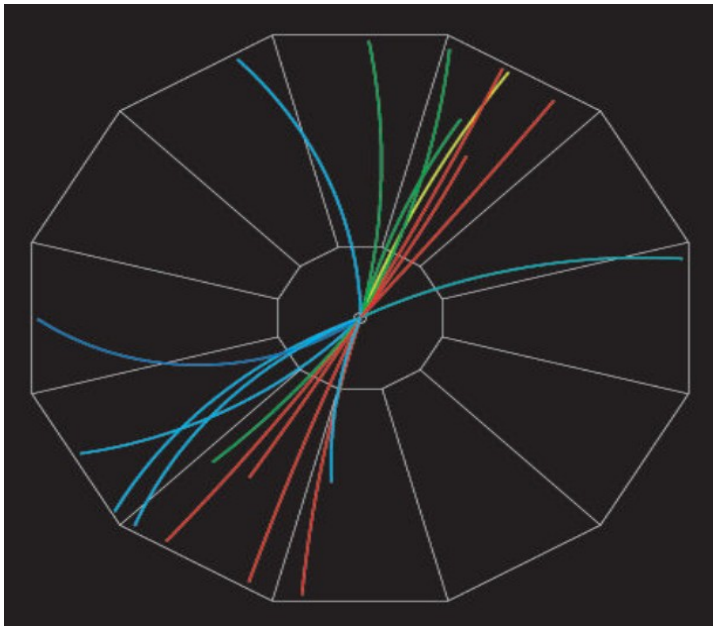
$$\eta = -\ln\left|\mathrm{tg}\frac{\theta}{2}\right|$$

p_T - transverse momentum;
φ - azimuthal angle;

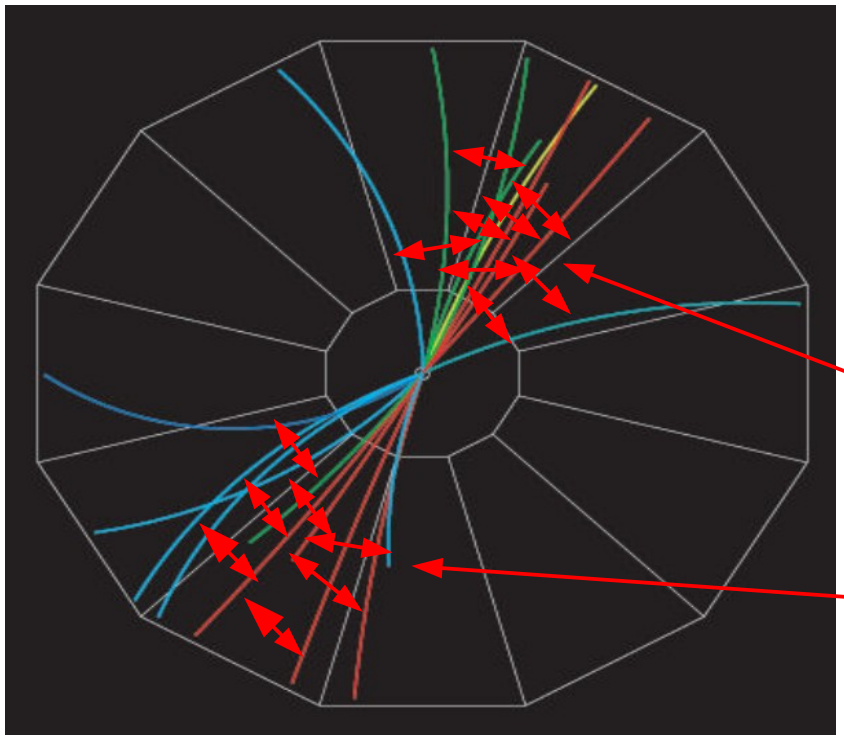
Fig. A. Zaborowska

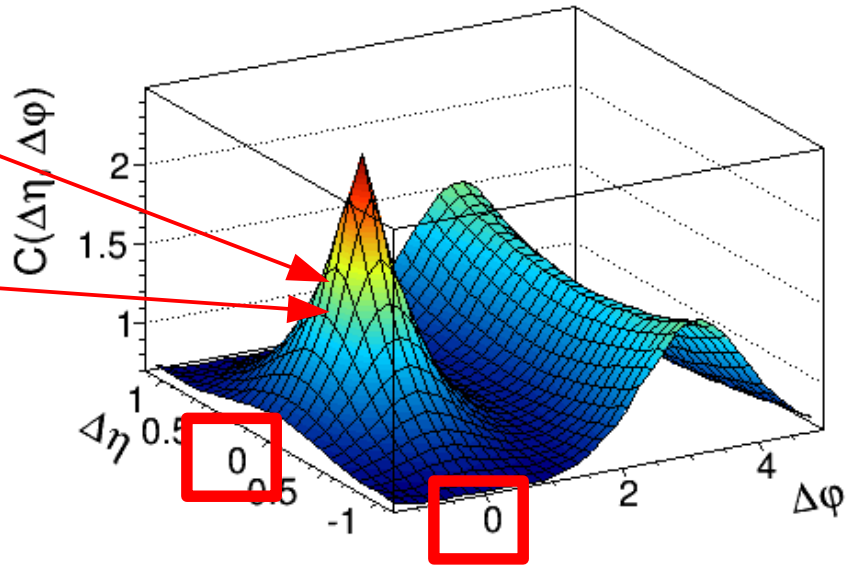
Creation of jets





ΔηΔφ two-particle angular correlations

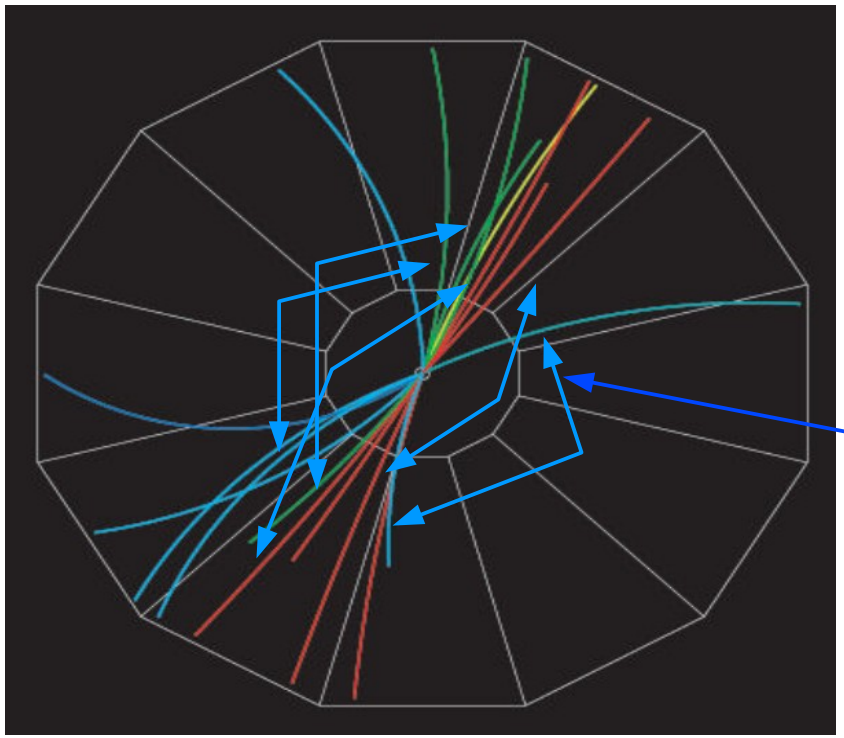


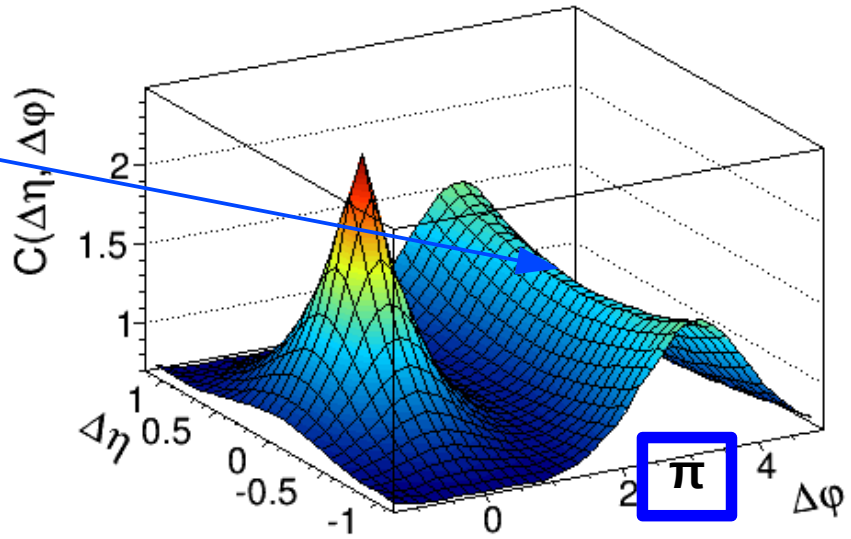


For particles from the same jet (red):

- **Δφ ~ 0**
- **Δη ~ 0**

ΔηΔφ angular correlations

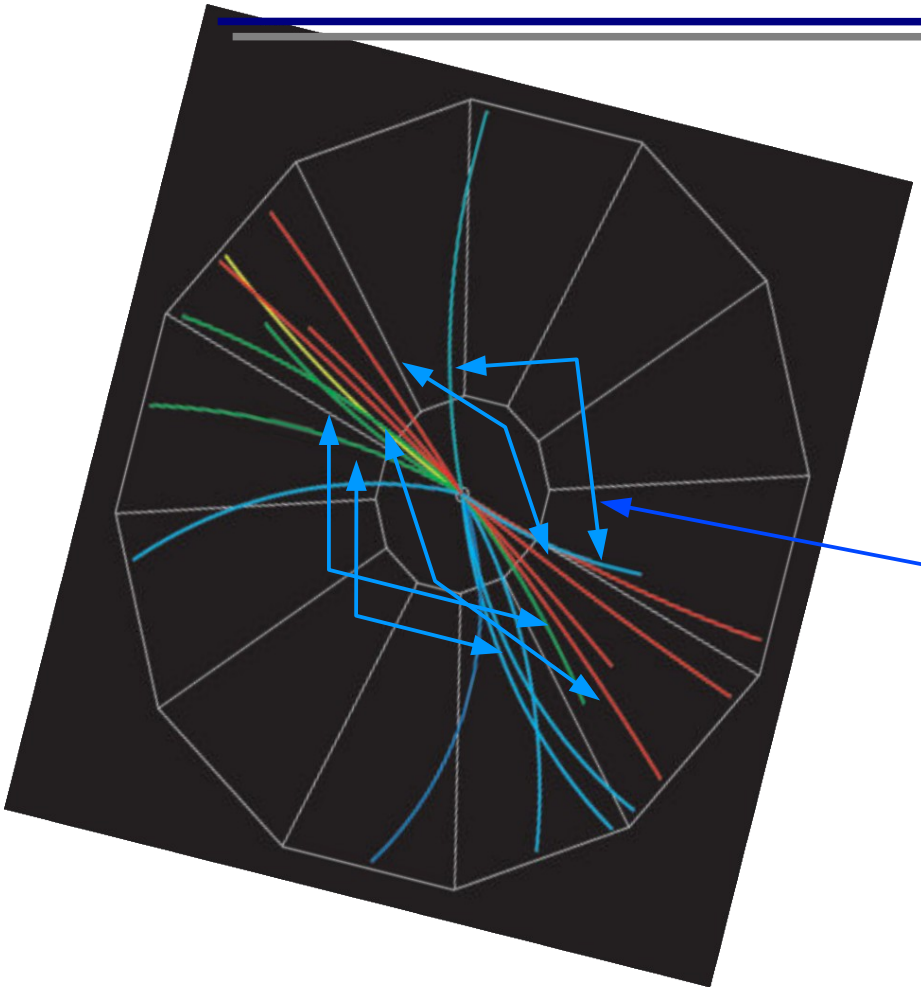


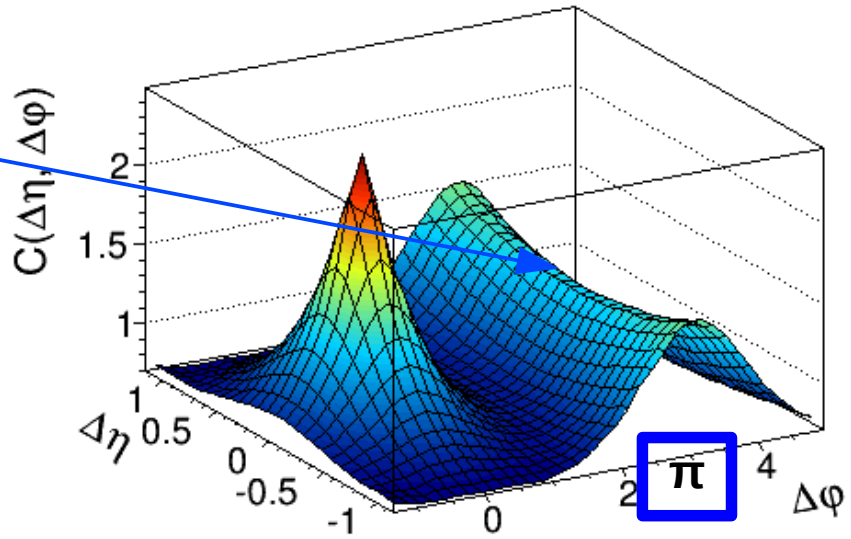


For particles from from back-to-back jets (blue):

- **Δφ ~ π**
- **Δη ~ const, if avaraged over many events**

ΔηΔφ angular correlations





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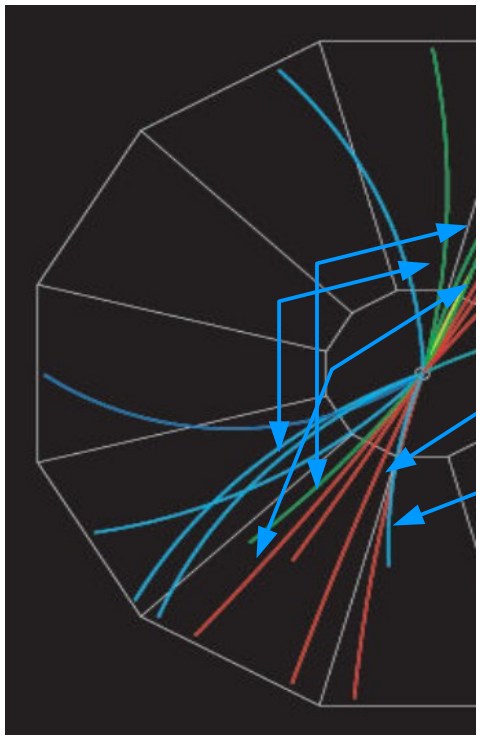

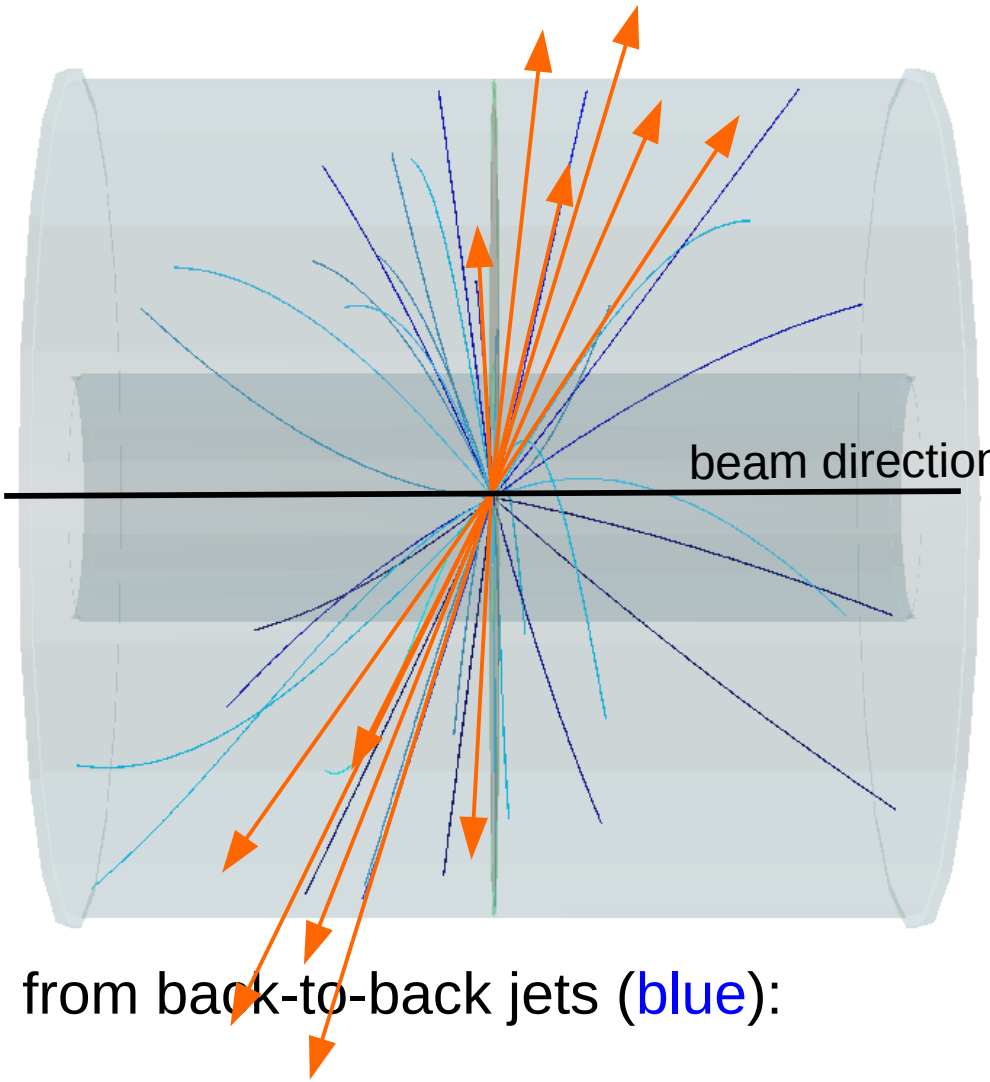

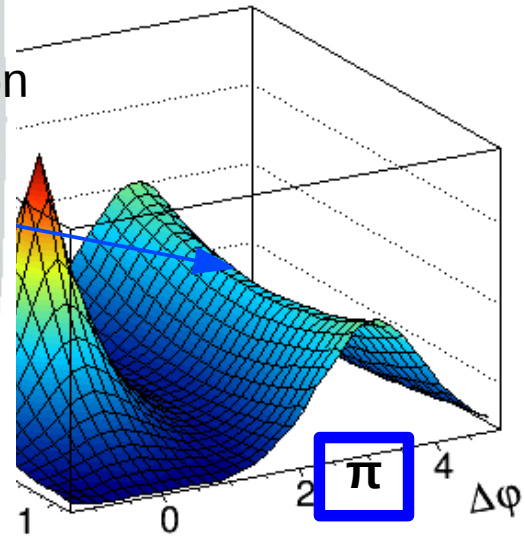

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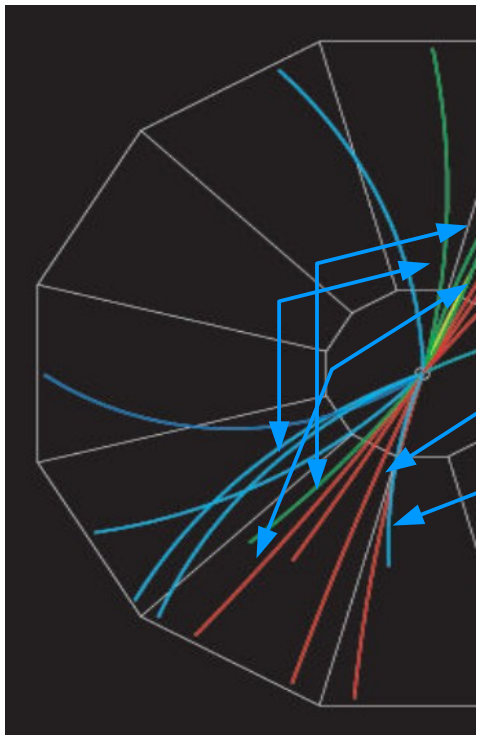

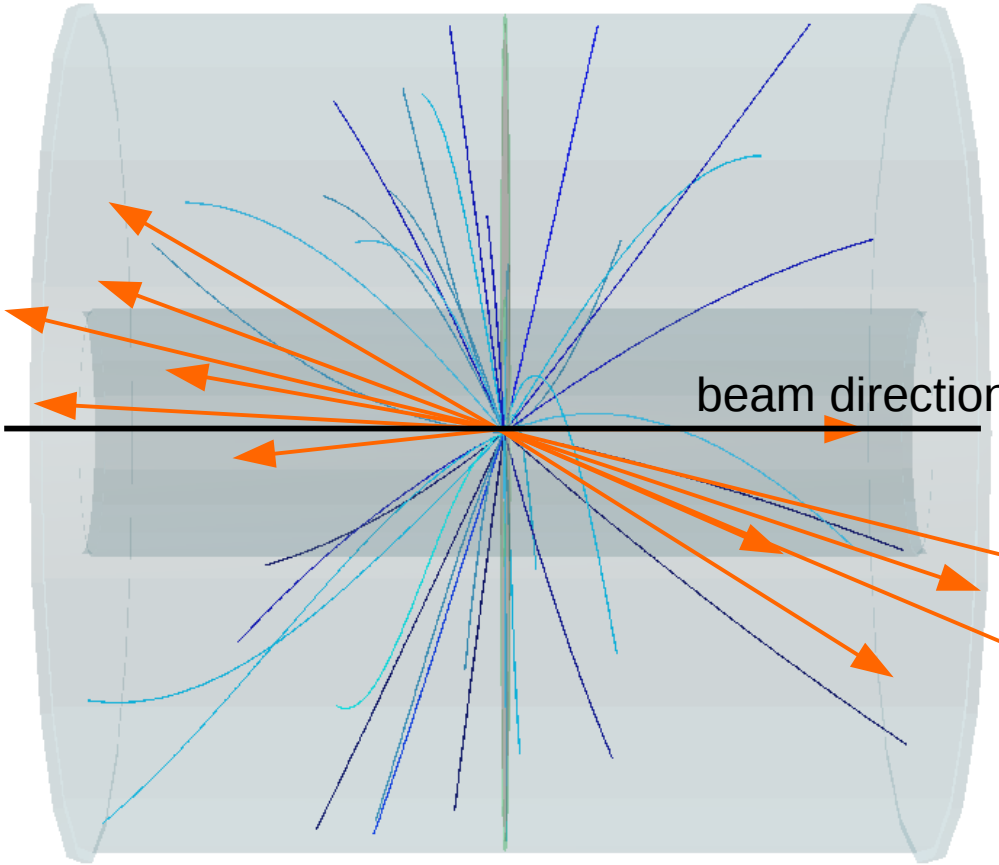

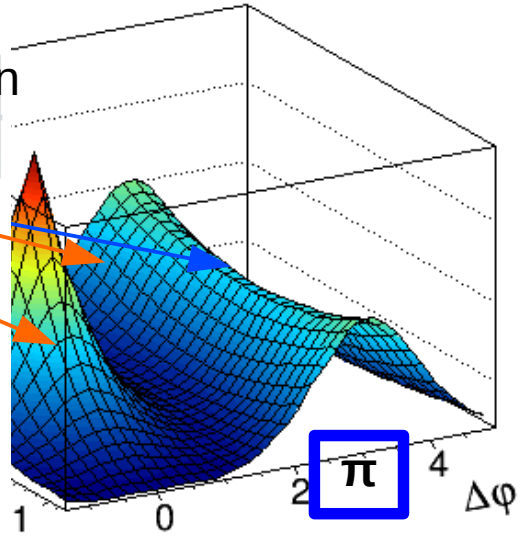

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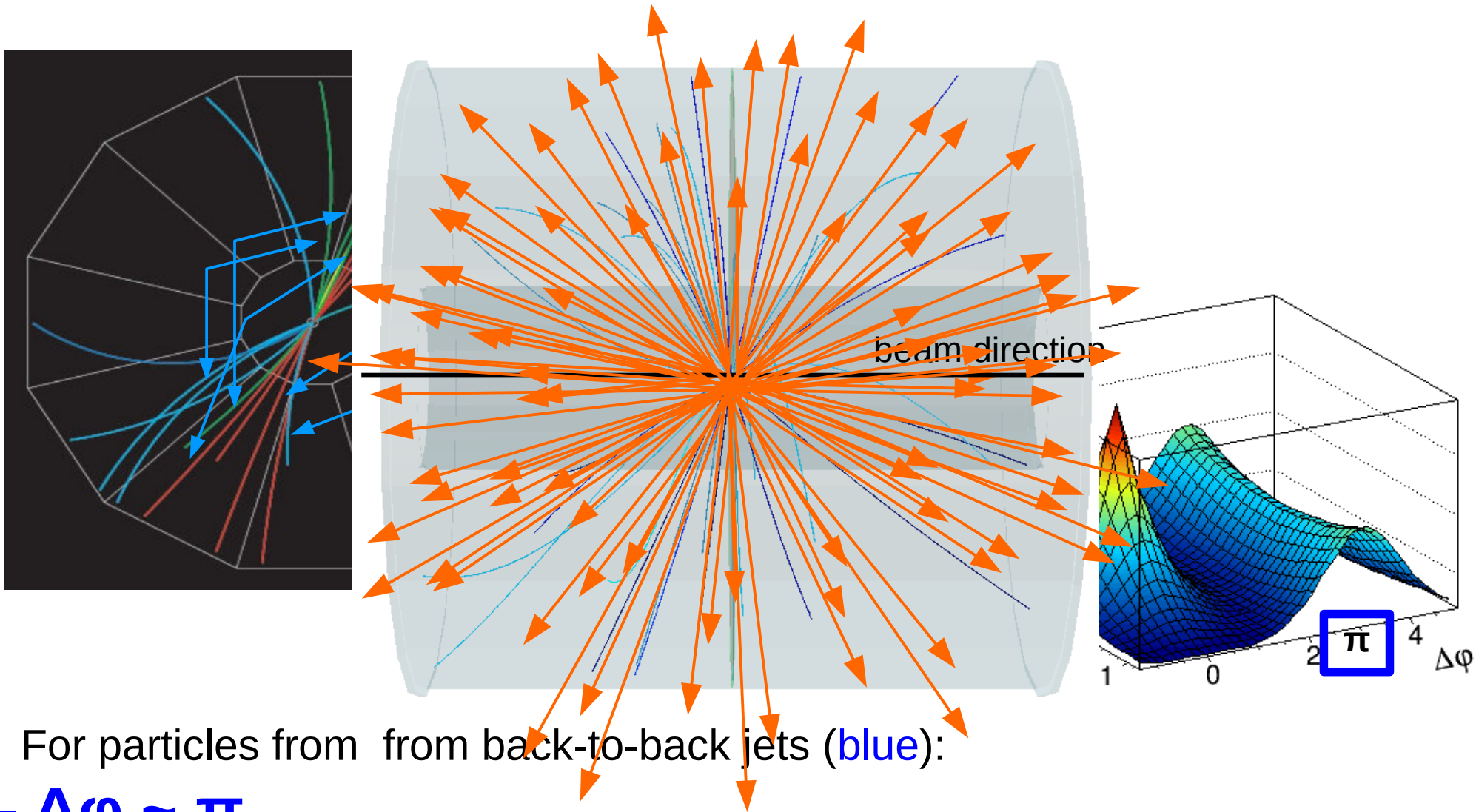
ΔηΔφ angular correlations



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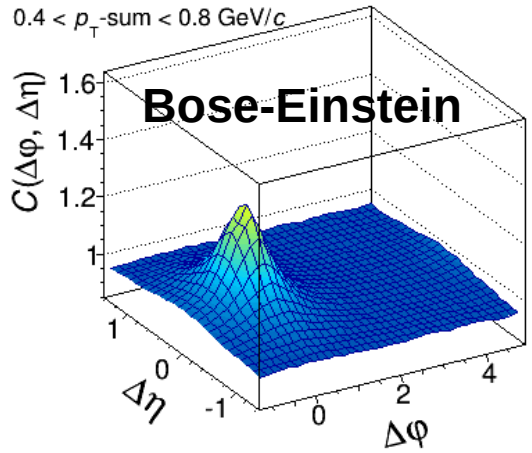
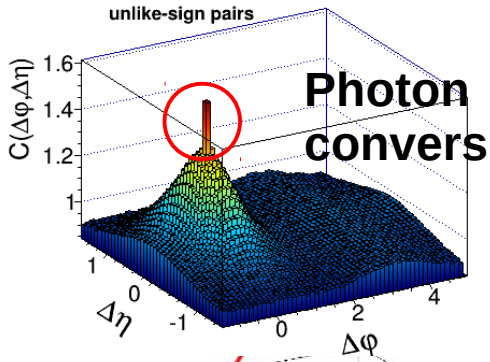
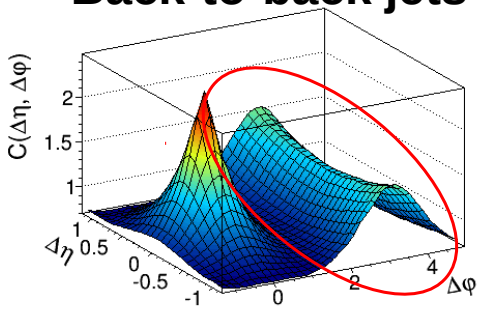
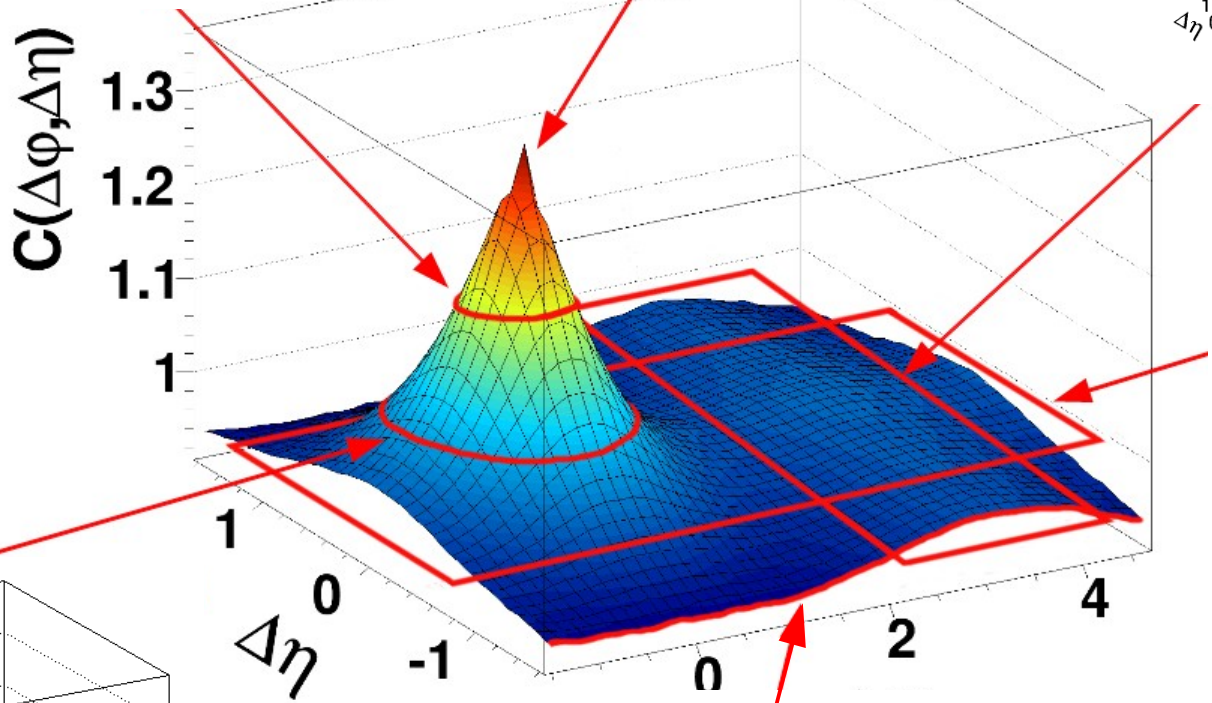
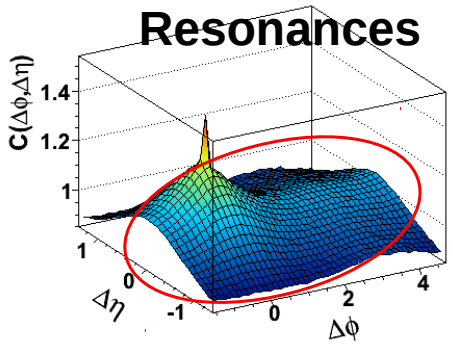
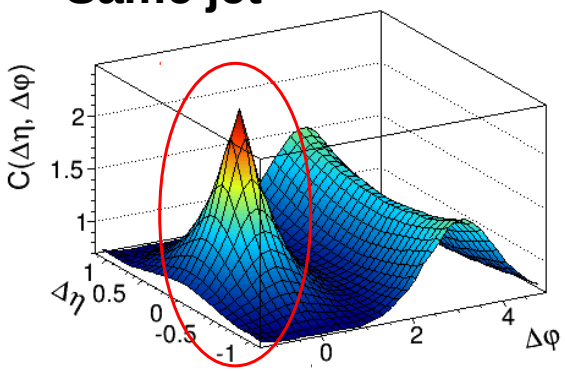

0.4 < p_T-sum < 0.8 GeV/c
$C(\Delta\varphi, \Delta\eta)$
Bose-Einstein
$\Delta\eta$
$\Delta\varphi$

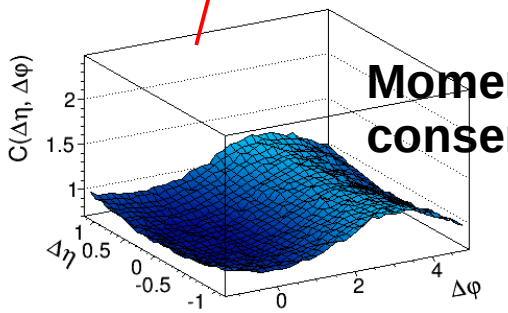

unlike-sign pairs
$C(\Delta\varphi,\Delta\eta)$
Photon conversion
$\Delta\eta$
$\Delta\varphi$

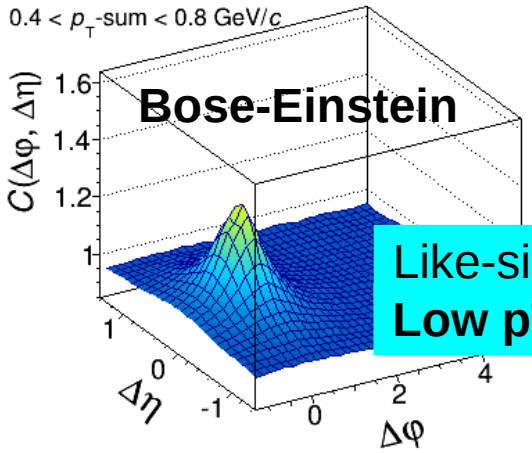

Back-to-back jets
$C(\Delta\eta, \Delta\varphi)$
$\Delta\eta$
$\Delta\varphi$


$C(\Delta\varphi,\Delta\eta)$
$\Delta\eta$


Resonances
$C(\Delta\phi,\Delta\eta)$
$\Delta\eta$
$\Delta\phi$

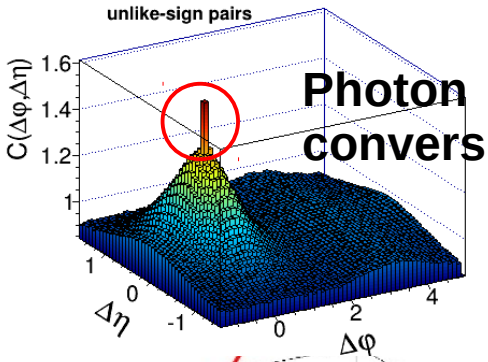

Same jet
$C(\Delta\eta, \Delta\varphi)$
$\Delta\eta$
$\Delta\varphi$


Momentum conservation
$C(\Delta\eta, \Delta\varphi)$
$\Delta\eta$
$\Delta\varphi$



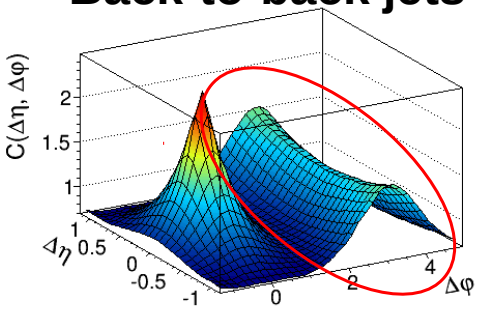
Bose-Einstein

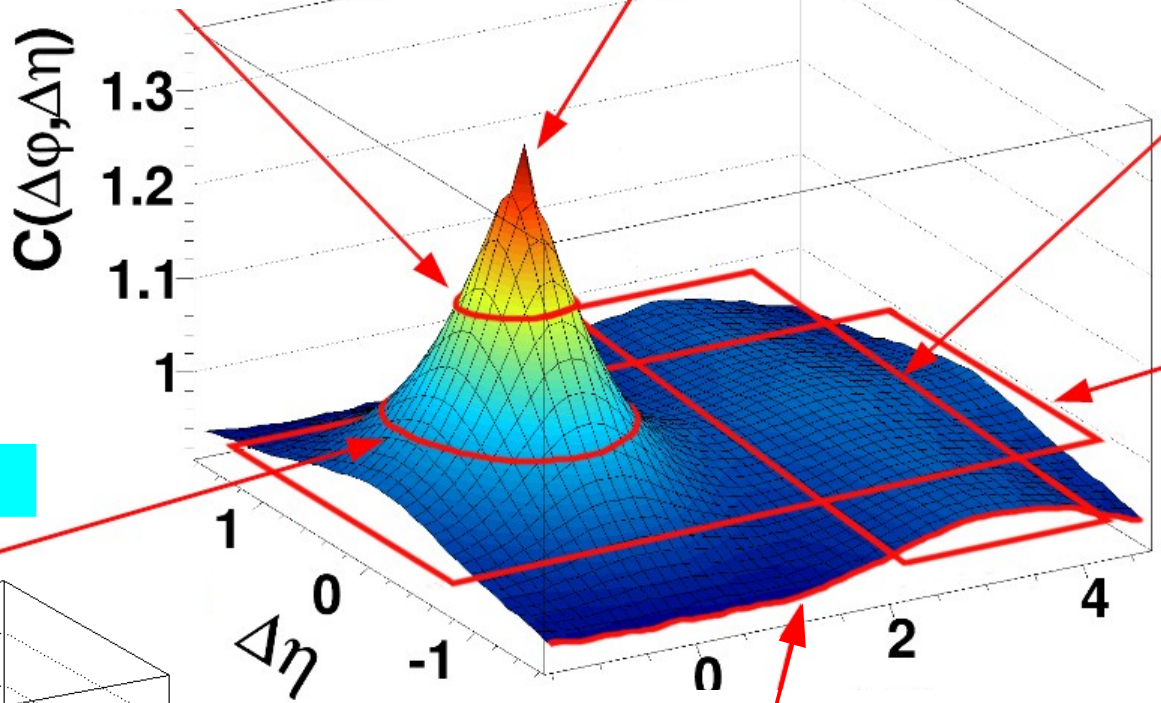
Like-sign pairs
Low pT



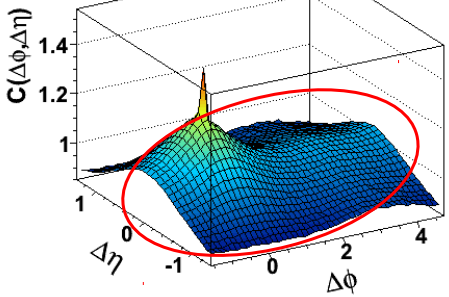
Photon conversion

Back-to-back jets



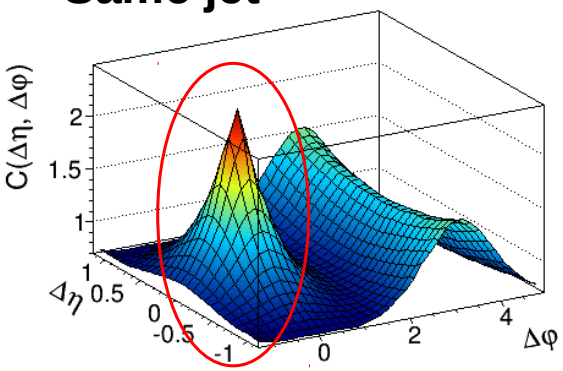


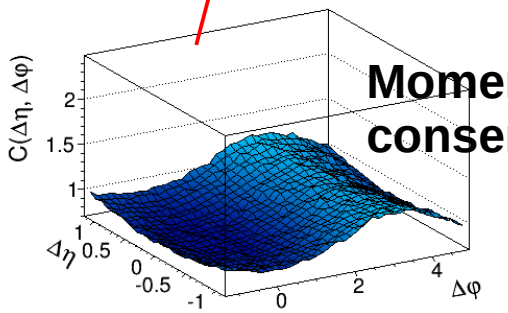
Resonances



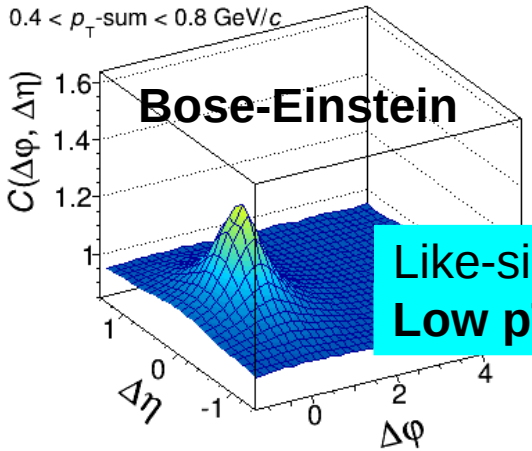
High pT

Same jet

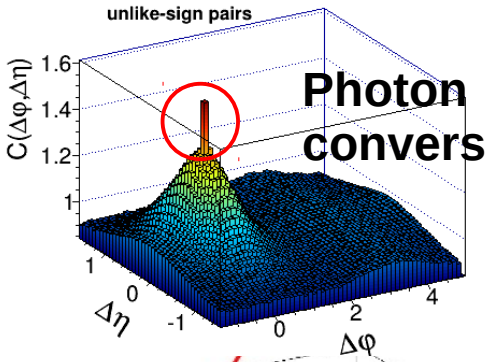


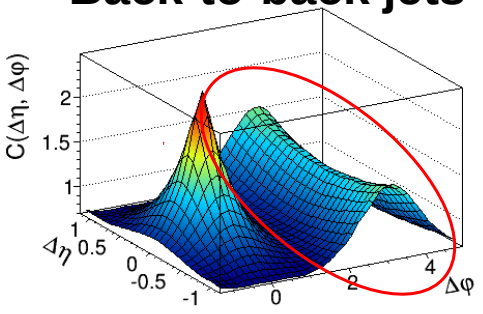


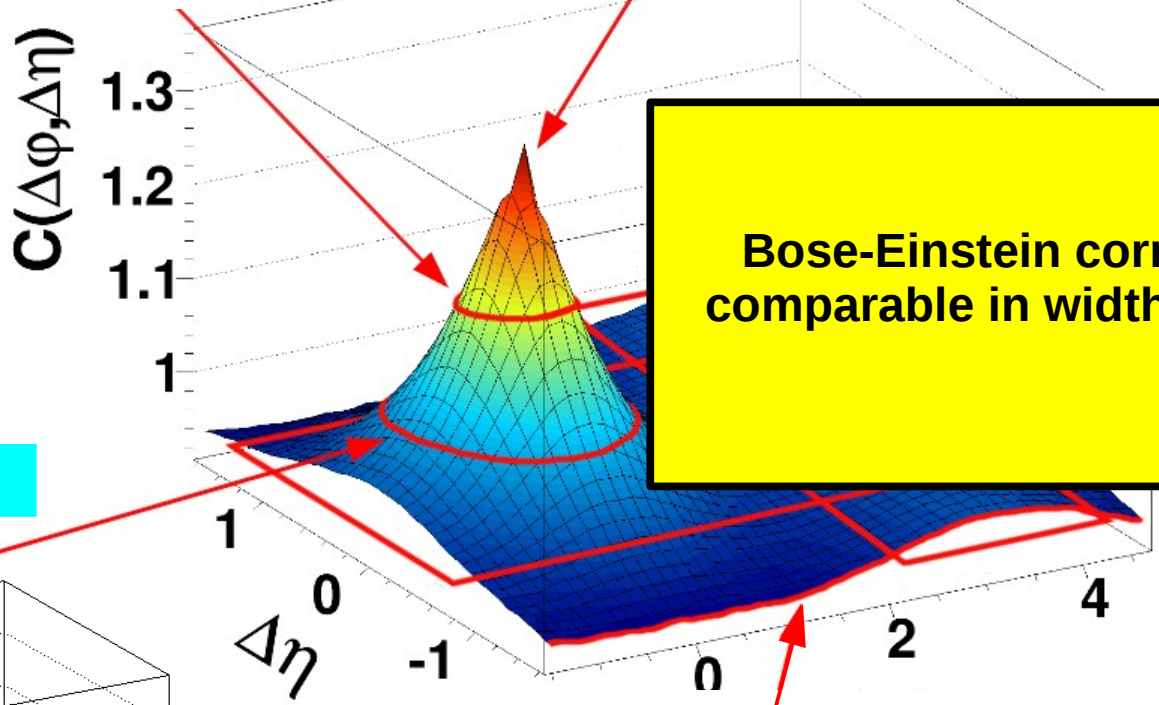
Momentum conservation



Like-sign pairs
Low pT



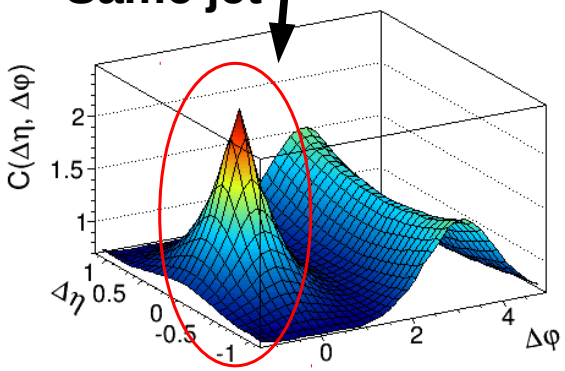


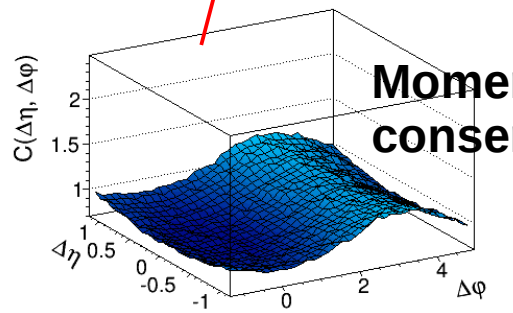


Bose-Einstein correlation peak is comparable in width to minijet peak!

High pT

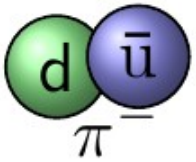
Same jet



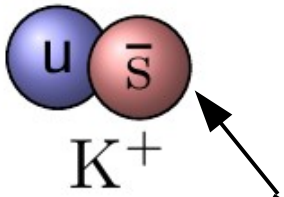


One step further: ΔηΔφ of identified particles!

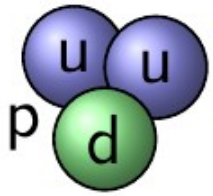
Unexplored phenomena **conservation laws** and their influence on **particle production mechanisms –** study via correlation functions for particles with **with different quark content**



Pion:
- Charge



Kaon:
- Charge
- Strange quark



Proton:
- Charge
- Baryon

particles	conservation laws: momentum	charge	strangeness	baryon number
pions	✓	✓		
kaons	✓	✓	✓	
protons	✓	✓		✓

Useful to perform analysis in a more refined way:

- charge dependence

- identified particles

Physics message

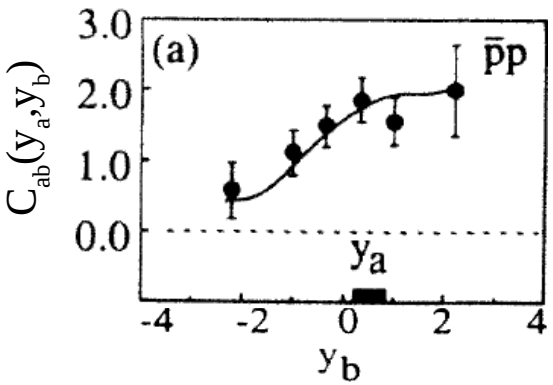
A Parametrization of the Properties of Quark Jets
R.D. Field, R.P. Feynman (Caltech). Nov 1977. 131 pp.
Published in Nucl.Phys. B136 (1978) 1

From mechanism of jet production:
Two primary hadrons with the same **baryon number** (or **charge** or **strangeness**) **are separated** by at least two steps in rank ("rapidity").

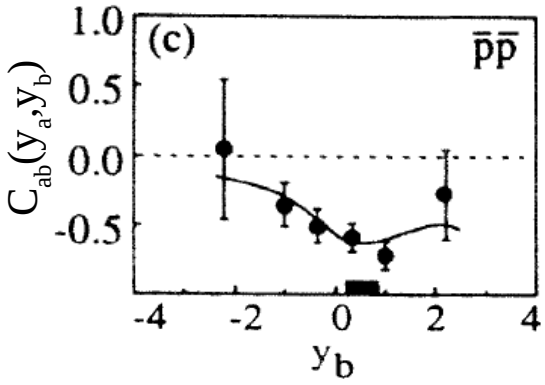
- **Models for e^+e^- agree** with observations seen in data.
- **Does the agreement still hold** for hadron-hadron collisions?

We are not likely to find two baryons or two antibaryons at the same phase space.

correlation

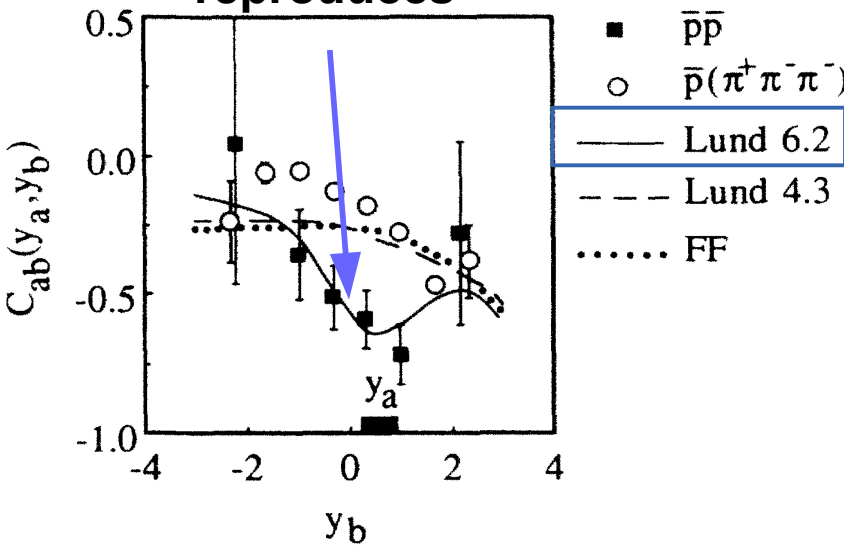


anti-correlation



Study of baryon correlations in e+e− annihilation at 29-GeV
TPC/Two Gamma Collaboration (H. Aihara et al.), Phys.Rev.Lett. 57 (**1986**) 3140

model reproduces

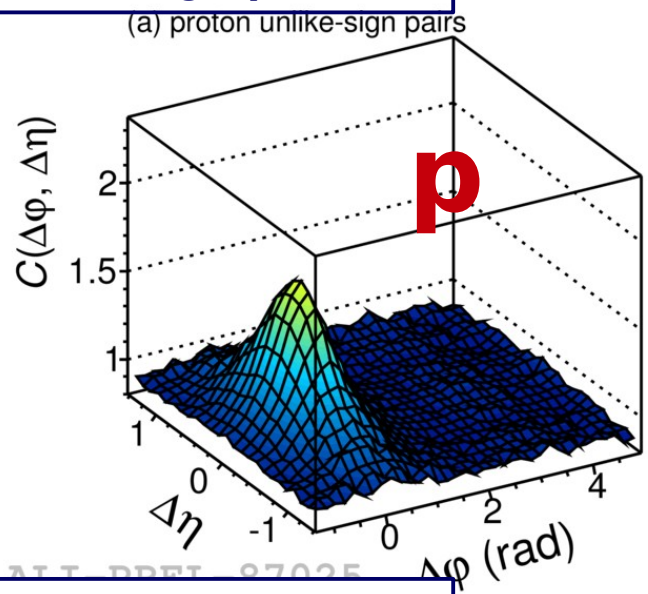


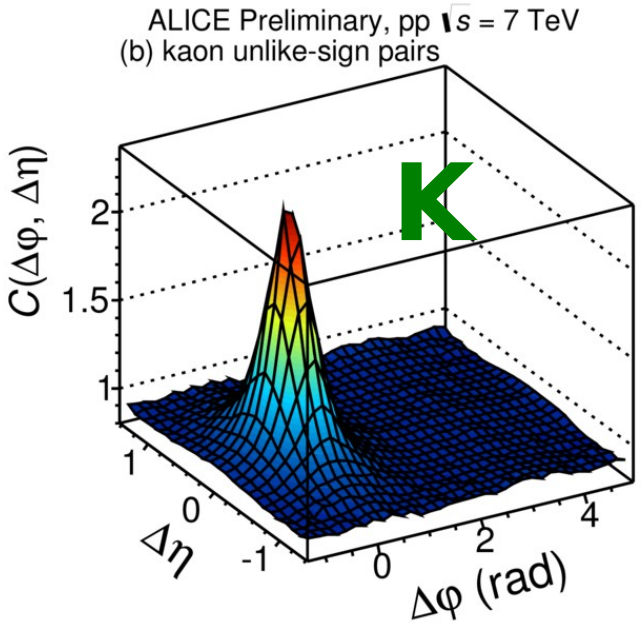
ΔηΔφ of identified particles

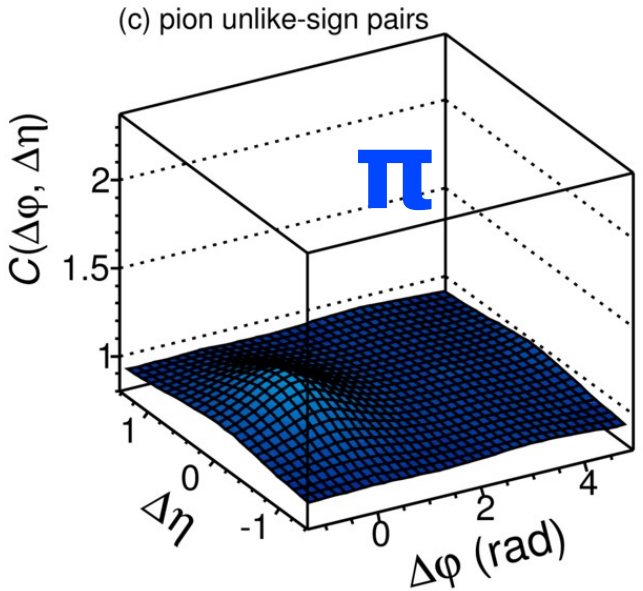
7 TeV pp ALICE

Unlike-sign pairs

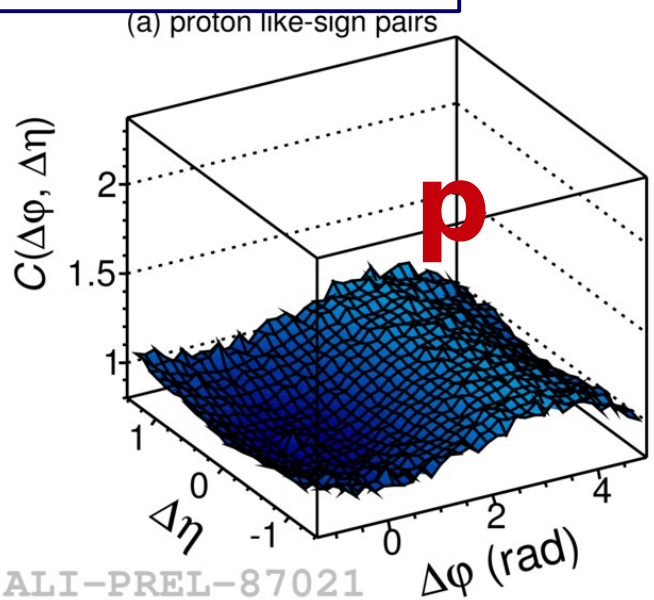
p_T<4.0 GeV/*c*

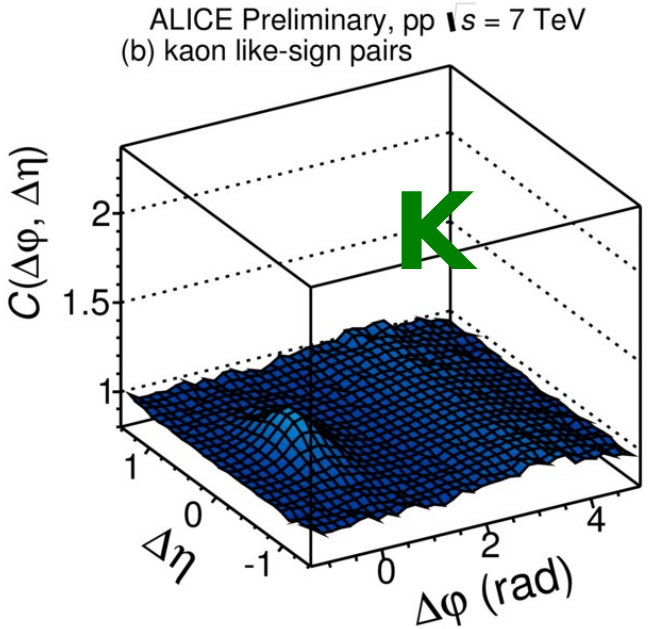


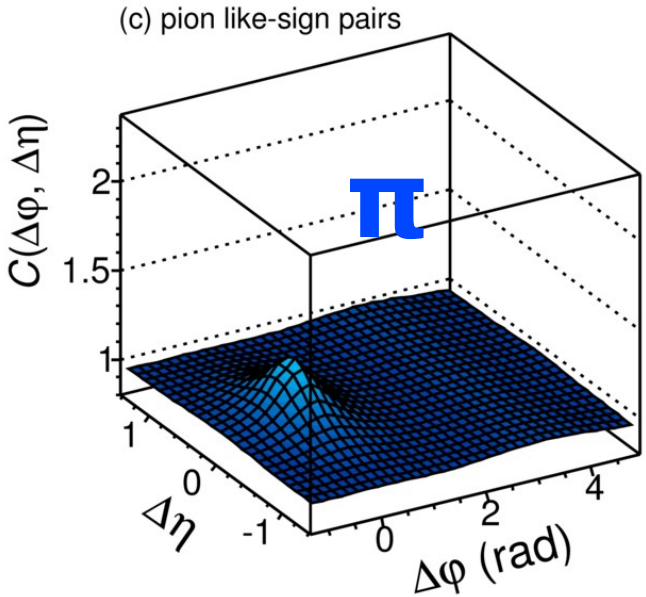




Like-sign pairs





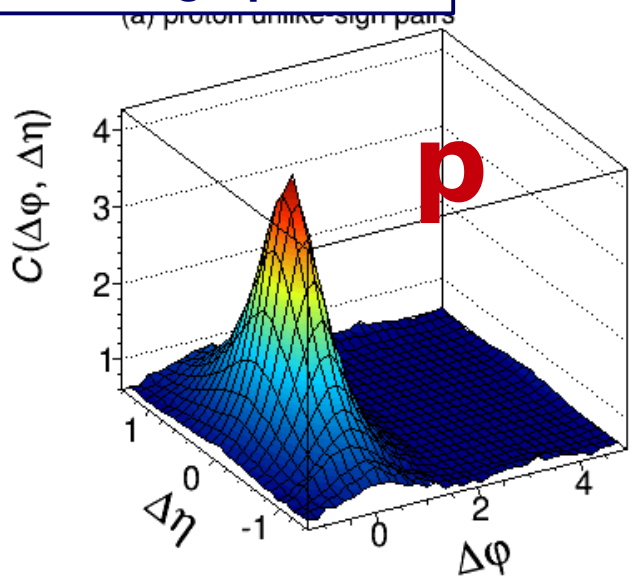


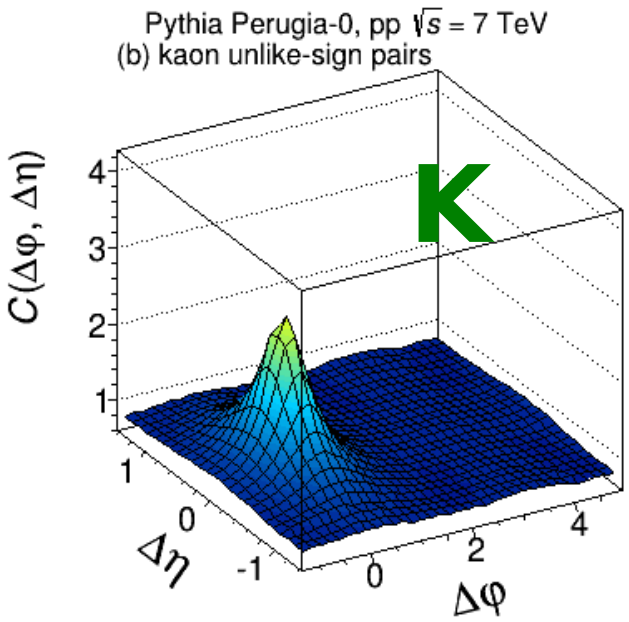
Pythia

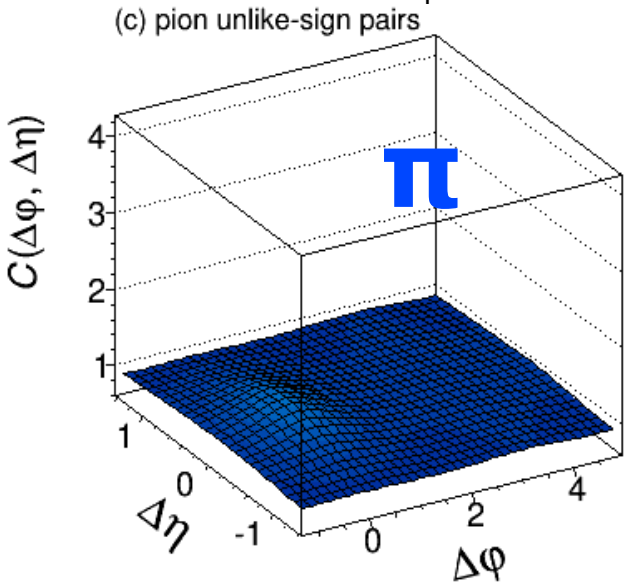
Monte Carlo Simulations

Unlike-sign pairs

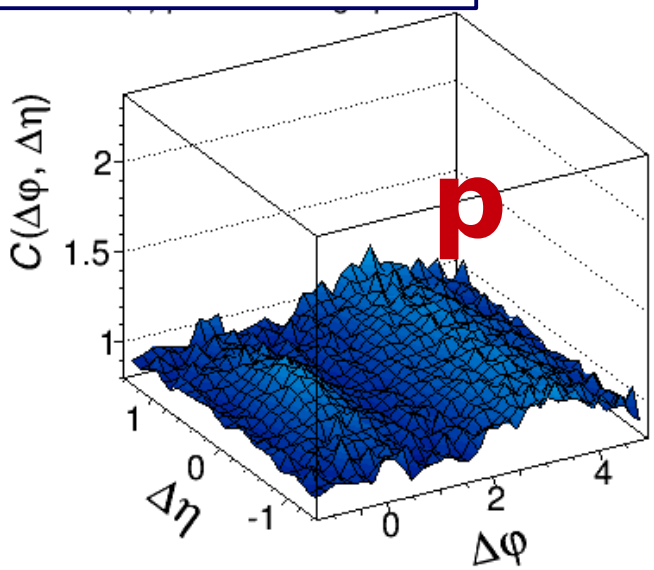
p_T<4.0 GeV/*c*

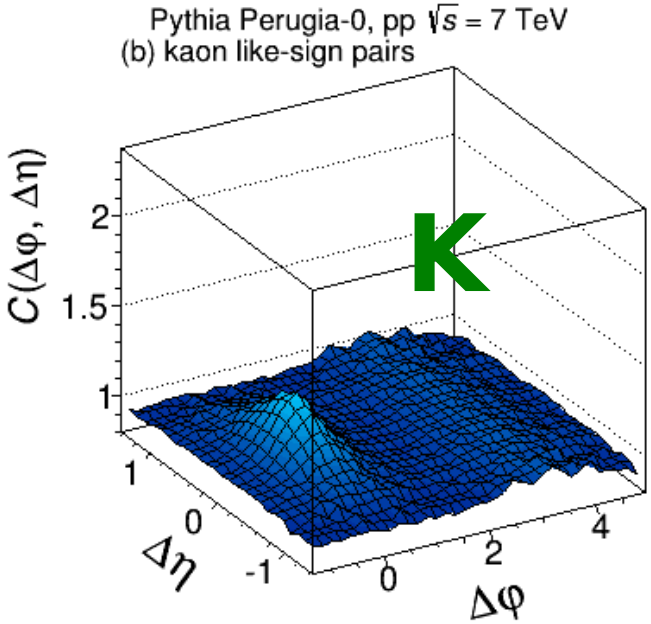


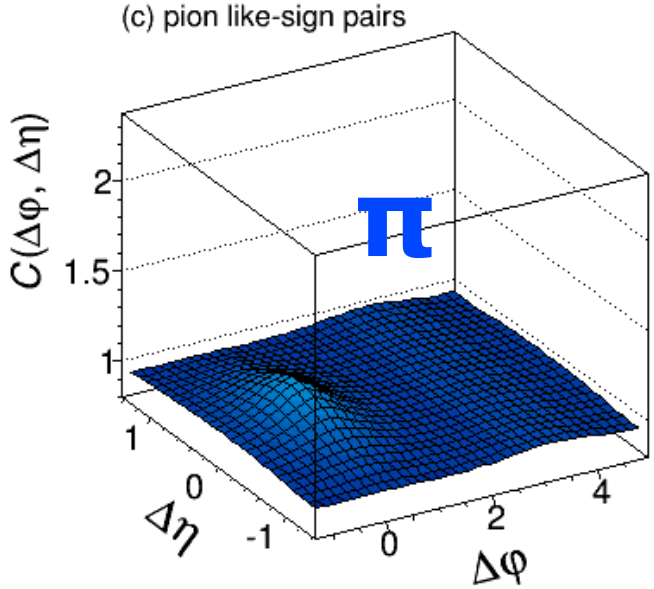




Like-sign pairs







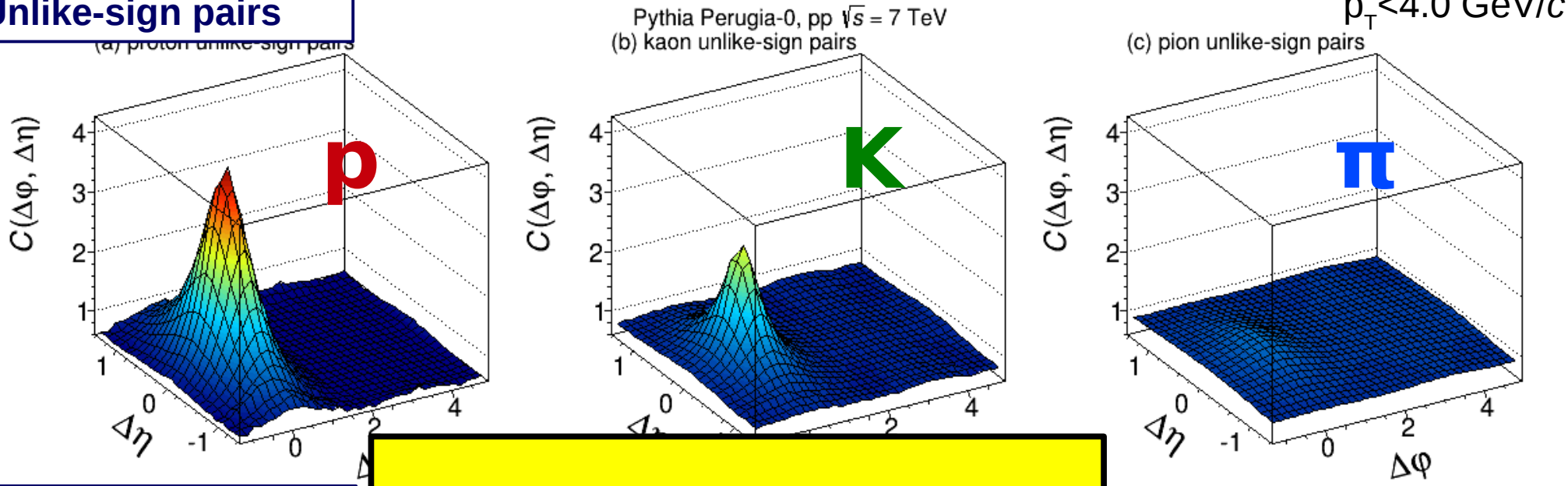
Pythia Perugia-0 **does not reproduce the shape** of the correlation function for identified particles.

Pythia

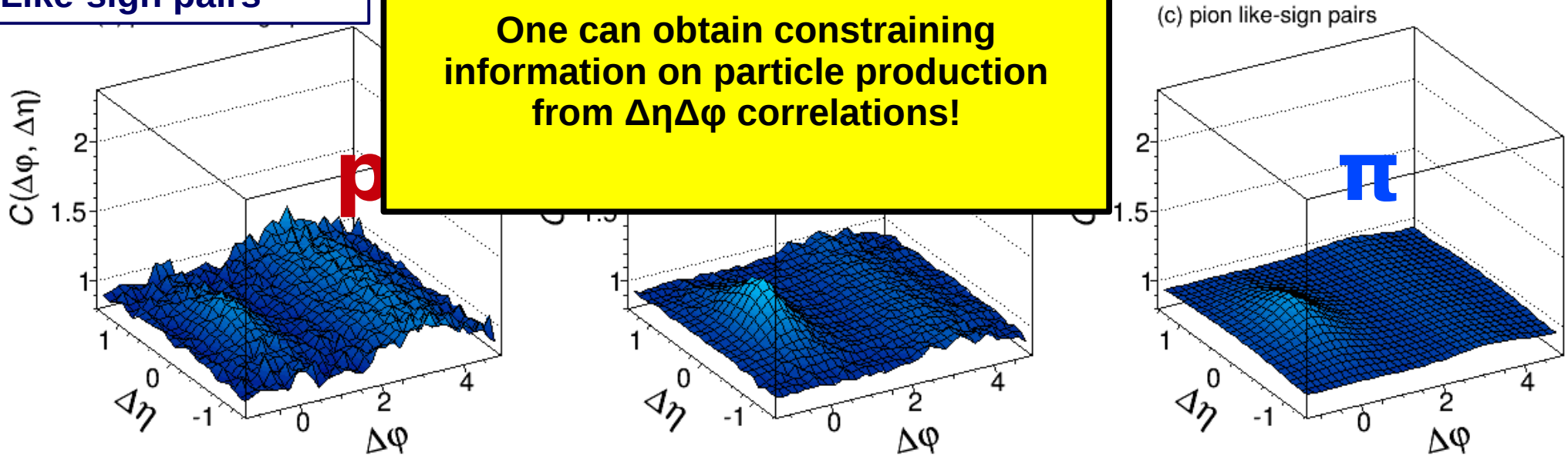
Monte Carlo Simulations

Unlike-sign pairs

p_T<4.0 GeV/*c*



Like-sign pairs

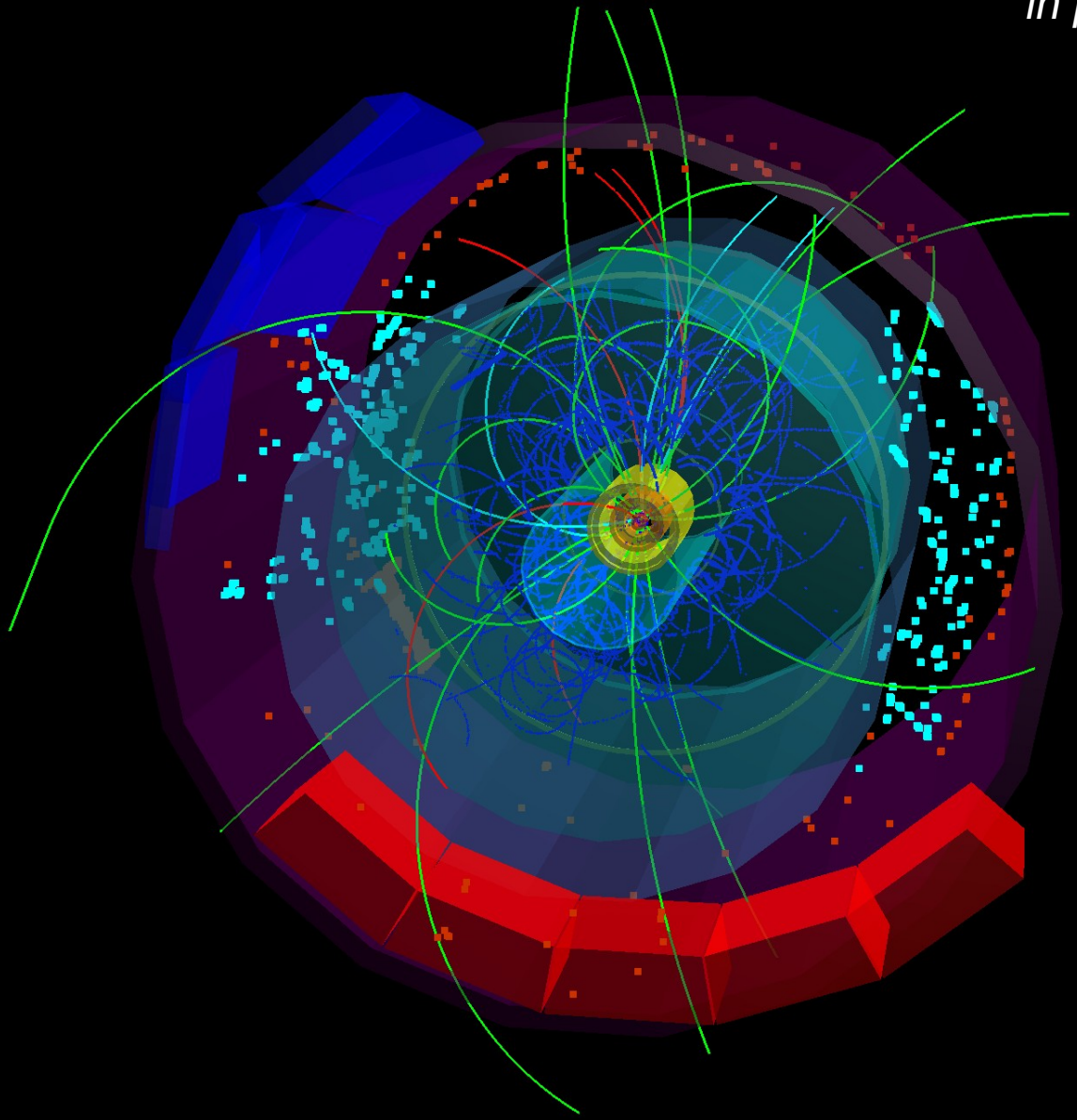


One can obtain constraining information on particle production from ΔηΔφ correlations!

Pythia Perugia-0 **does not reproduce the shape** of the correlation function for identified particles.

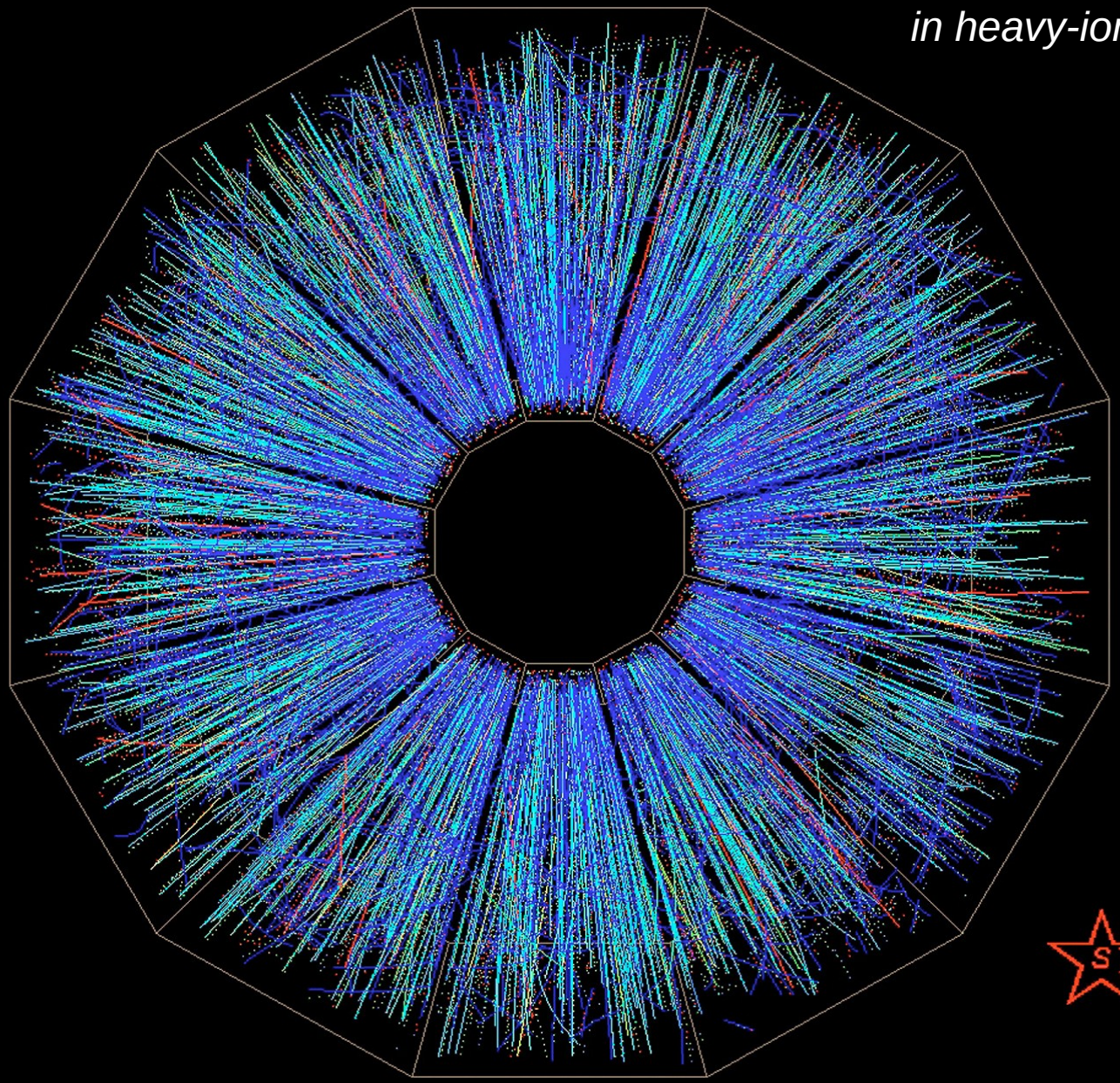
ΔηΔφ angular correlations

in pp collisions

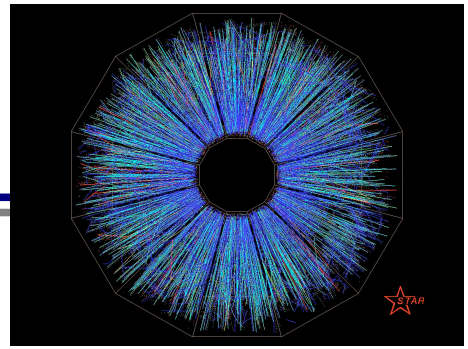


ΔηΔφ angular correlations

in heavy-ion collisions

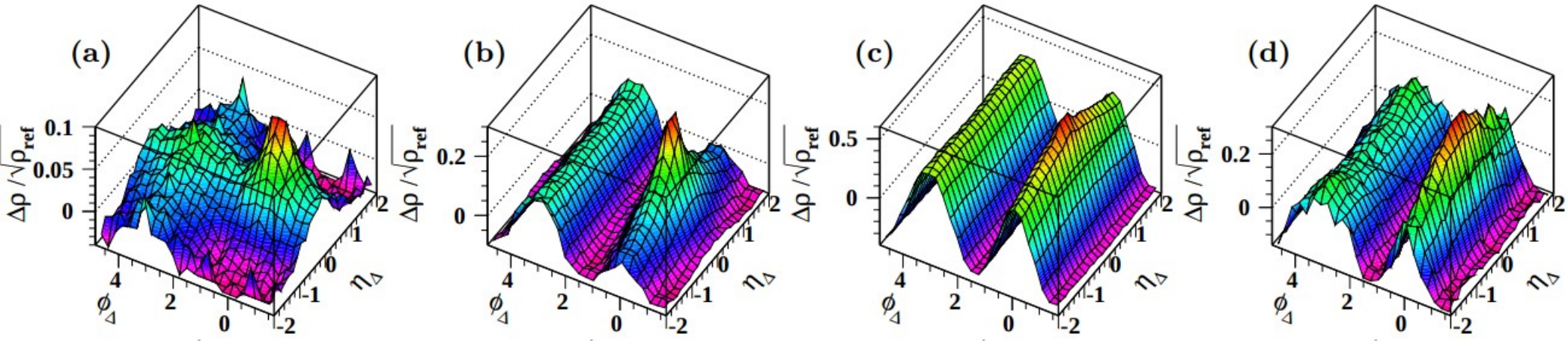


Angular correlations in Au-Au

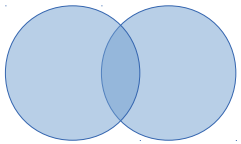


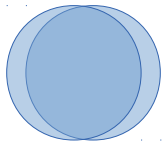
Heavy-ions

centrality



STAR: 10.1103/PhysRevC.86.064902



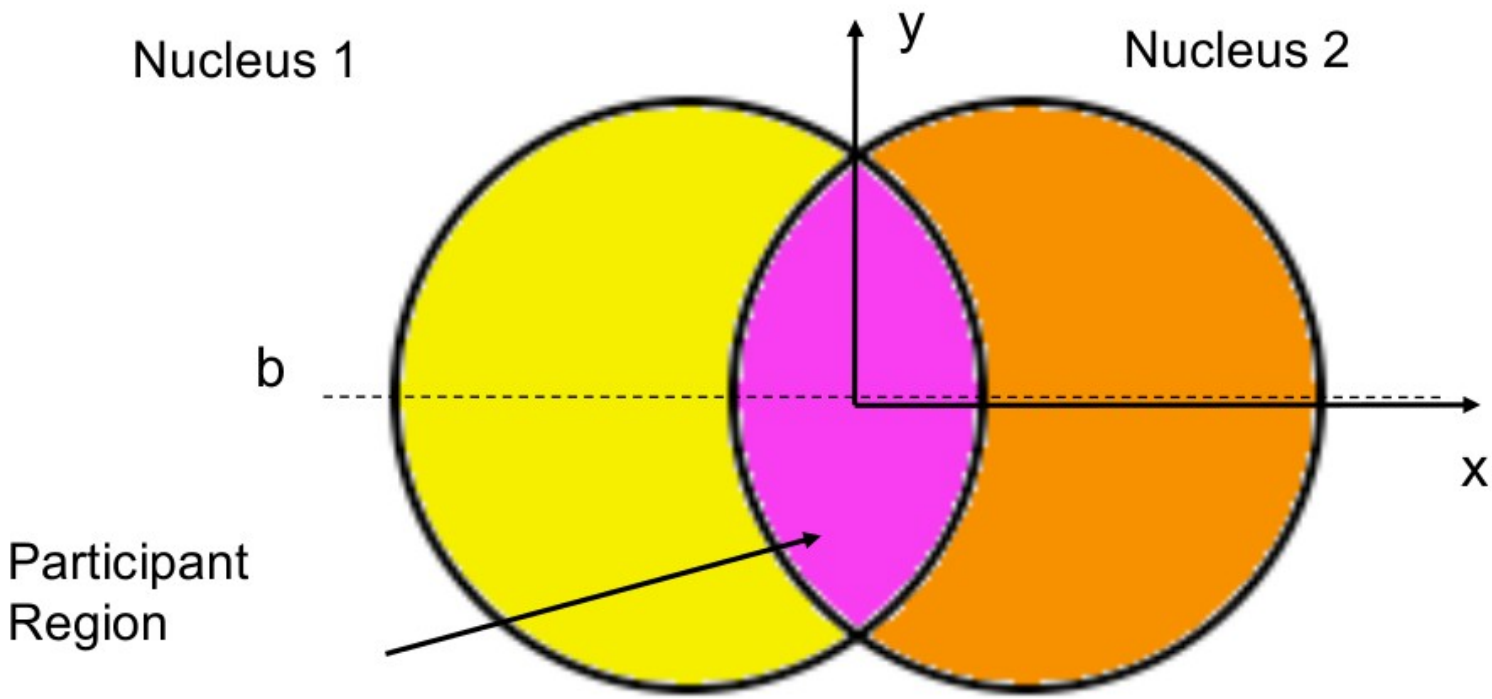


Similar to pp

Strong contribution of flow

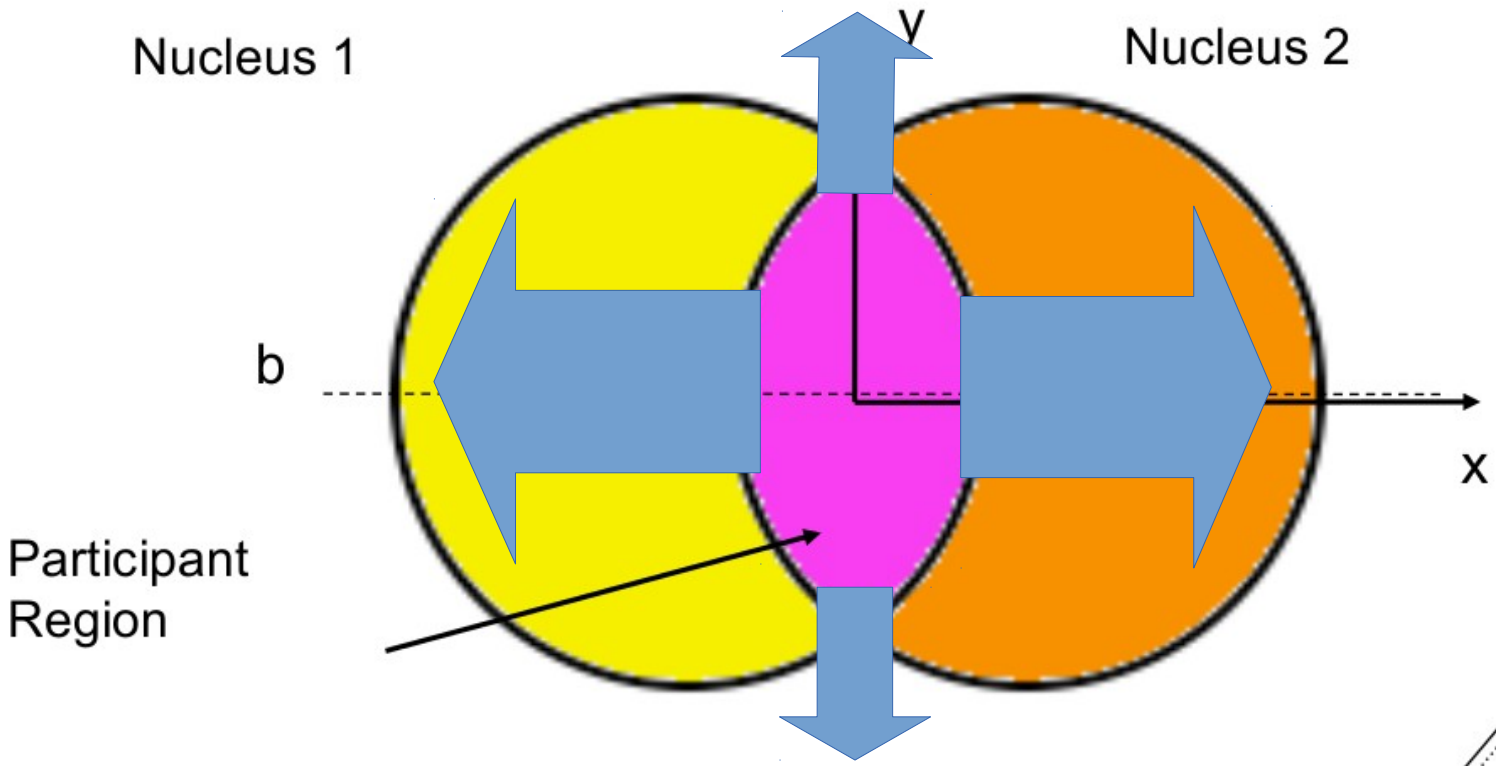
Collective effects: flow

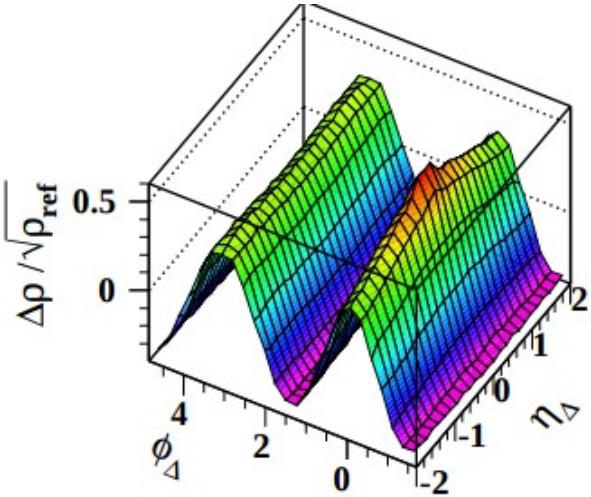
Flow:
Textbook signature of QGP

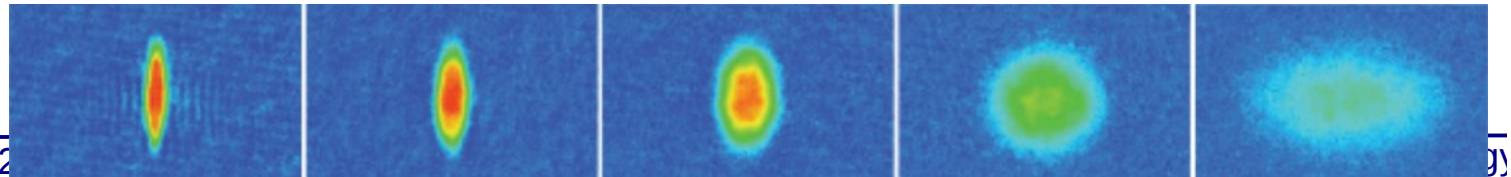


Collective effects: flow

Flow:
Textbook signature of QGP



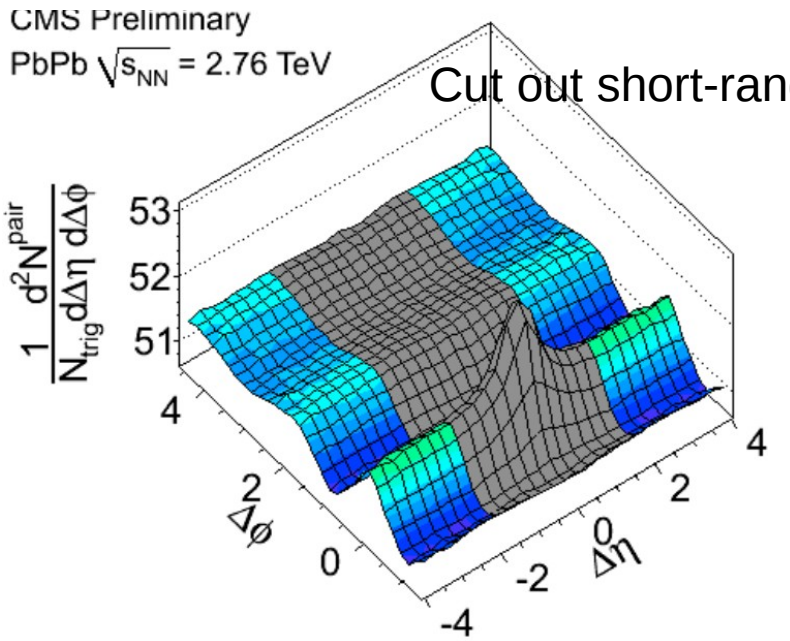




Collective effects: flow

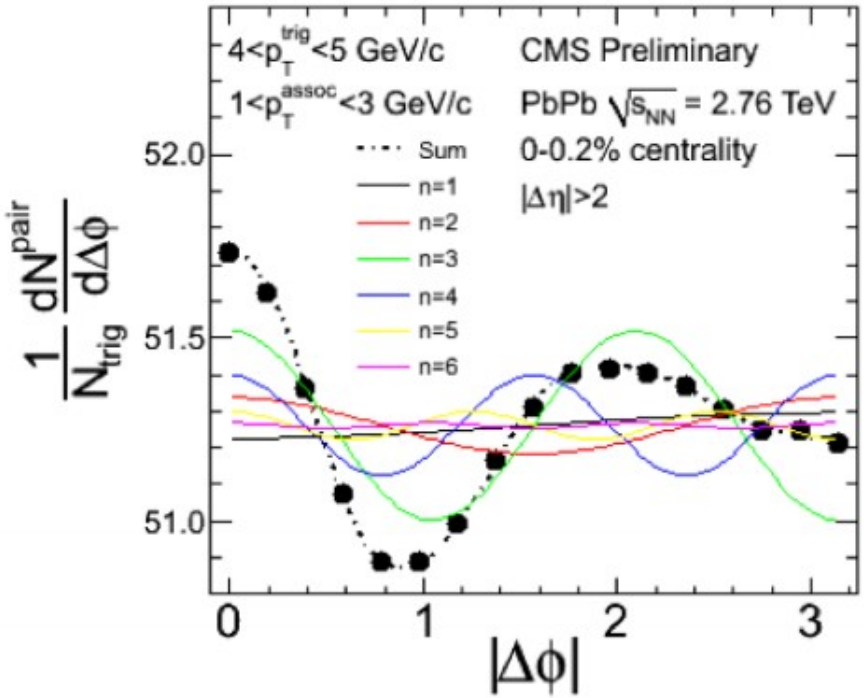
Fourier coefficients:

$$\frac{1}{N_{\text{trig}}}\frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi}\left\{1 + \sum_{n=1}^{\infty} 2V_n^{\text{f}}\cos(n\Delta\phi)\right\},$$



Cut out short-range

Pre-LHC:
Only v1, v2 seemed important



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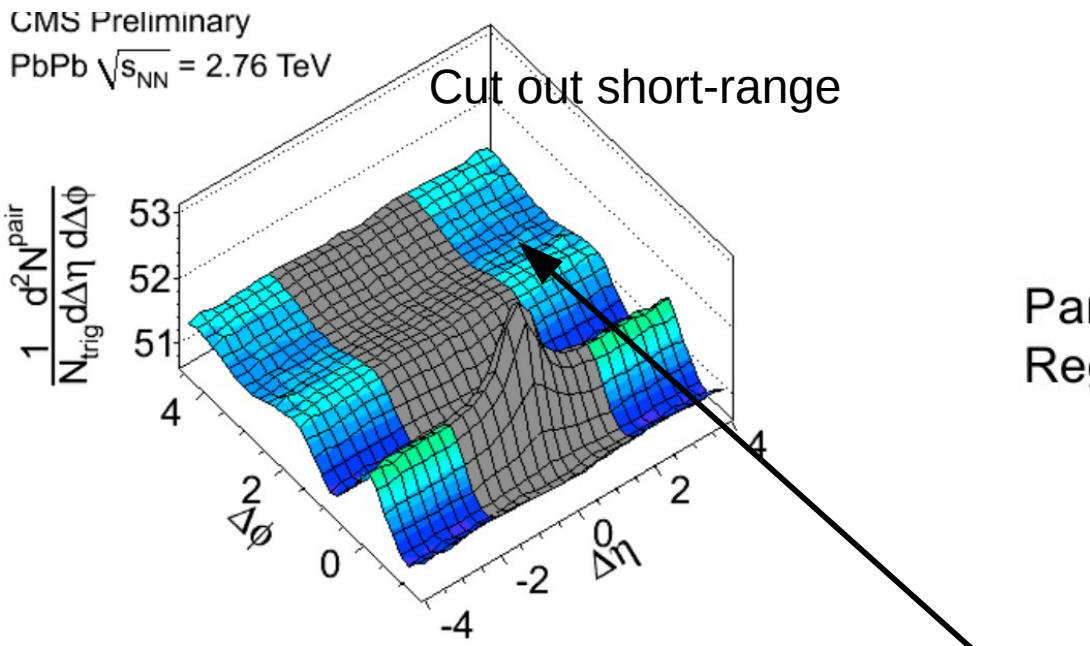

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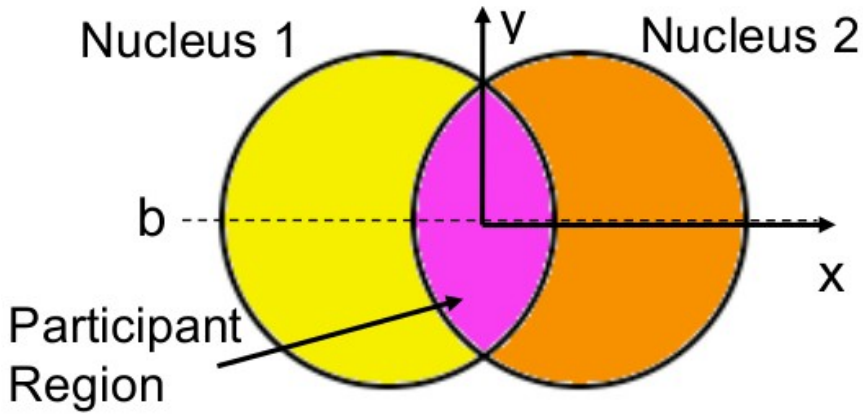
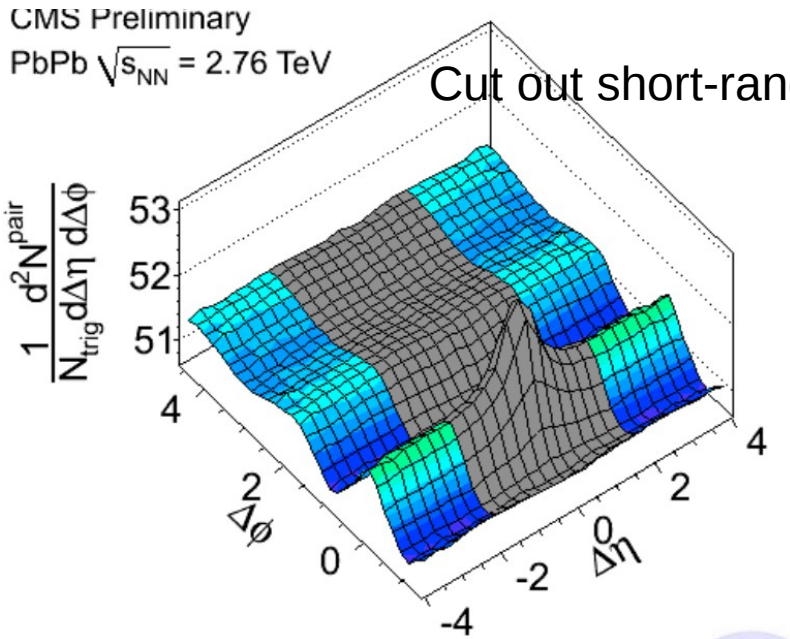


Pre-LHC: **fancy explanations**
- Double ridge?
- Mach cones?

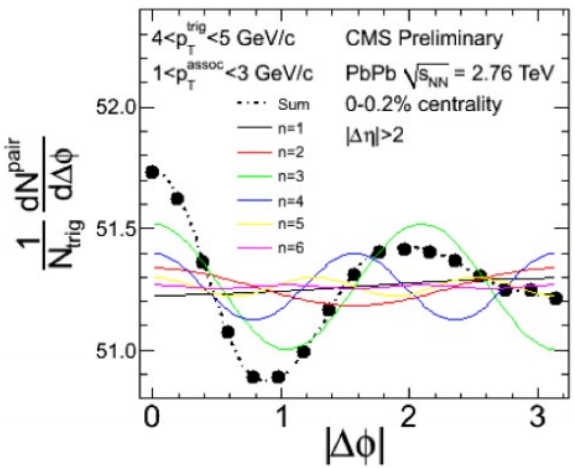
Collective effects: flow

Fourier decomposition:

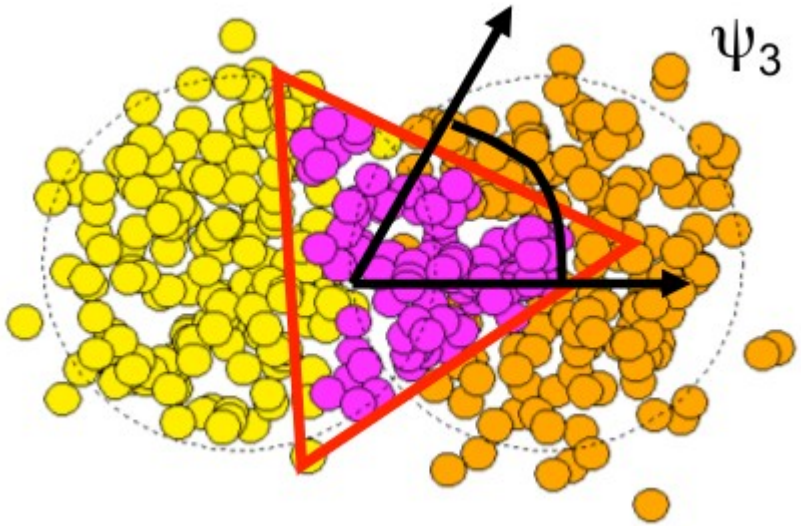
$$\frac{1}{N_{\text{trig}}}\frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi}\left\{1 + \sum_{n=1}^{\infty} 2V_n^{\text{f}}\cos(n\Delta\phi)\right\},$$

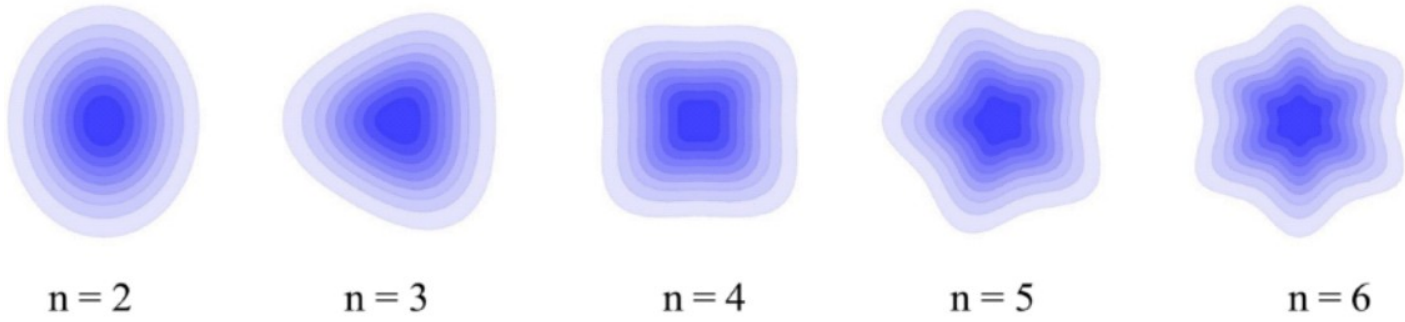


Cut out short-range



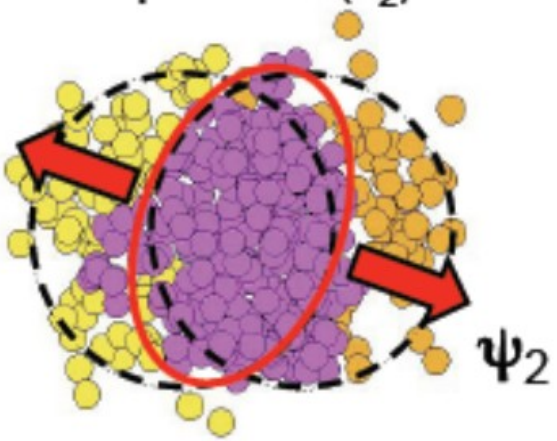
Precise measurements of LHC:
higher harmonics due to fluctuations of initial conditions

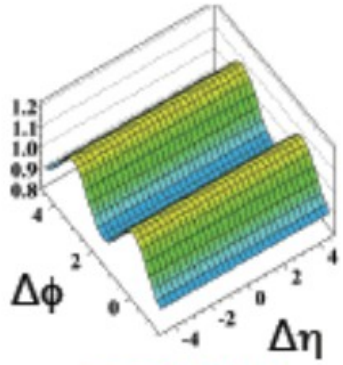




Collective effects: flow

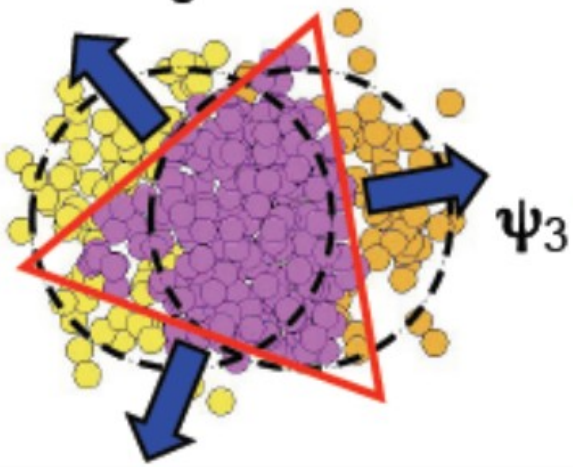
Elliptic flow (v_2)

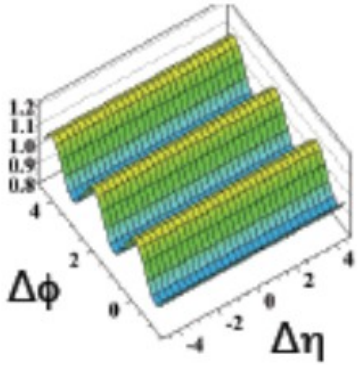




~ cos(2Δφ)

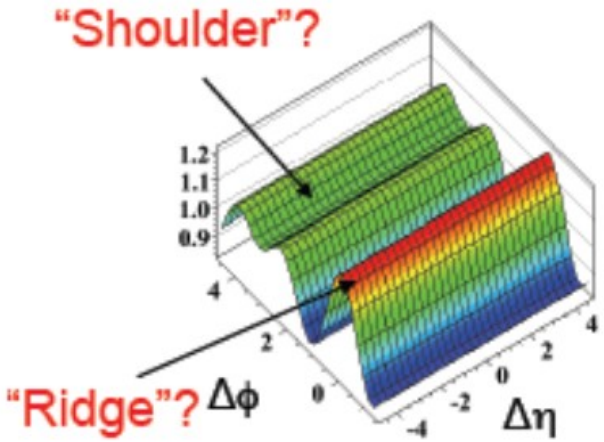
Triangular flow (v_3) from fluctuating initial condition





~ cos(3Δφ)

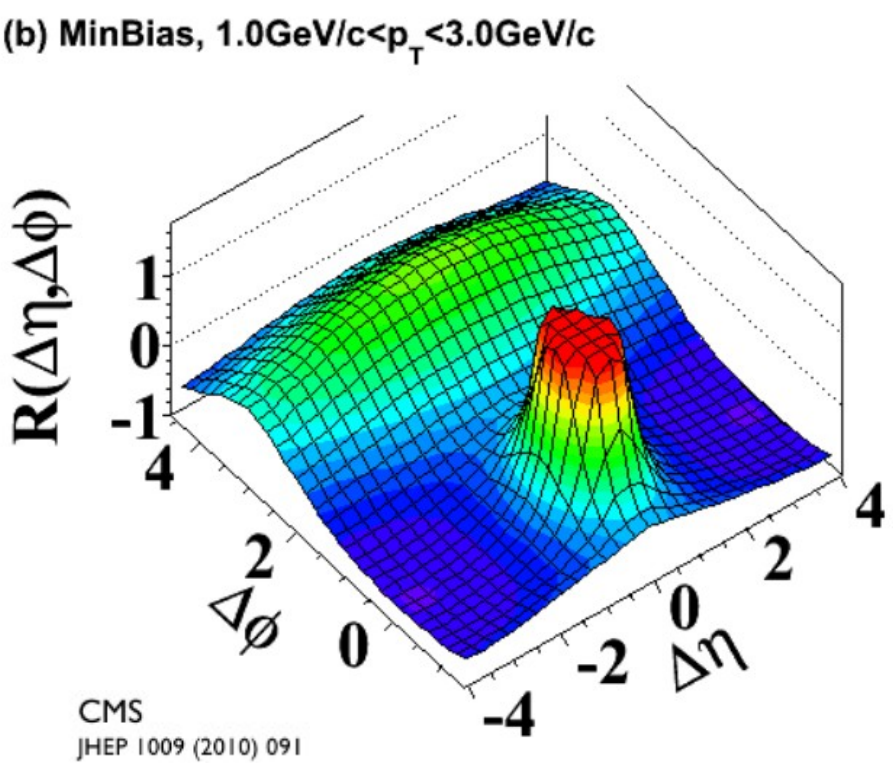
Add $V_{2\Delta}$ and $V_{3\Delta}$

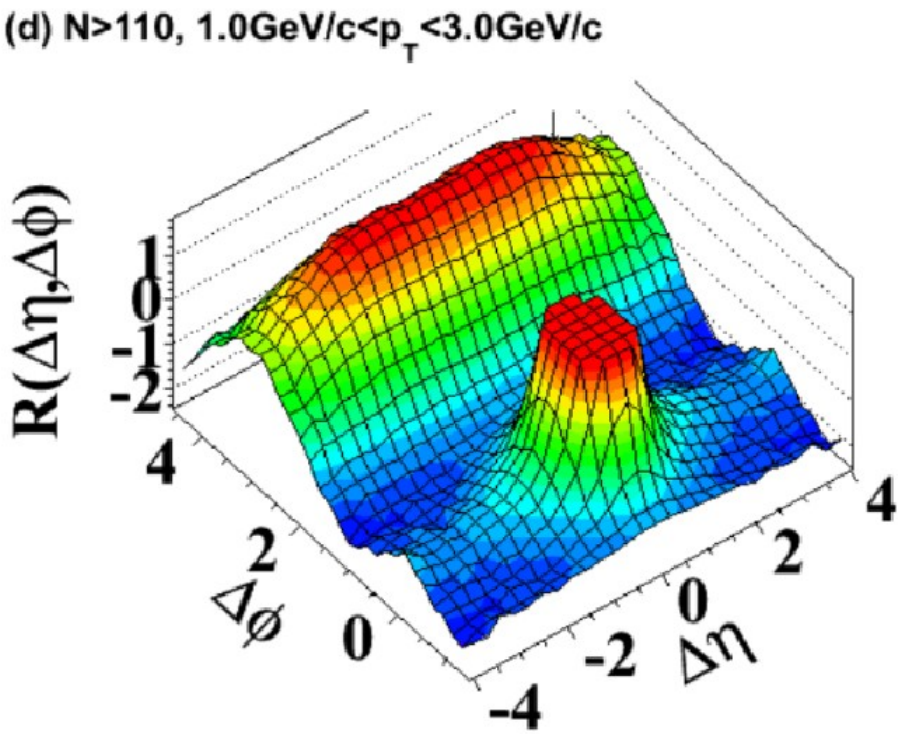


The Ridge: CMS 2010

The Ridge: CMS 2010

First LHC discovery

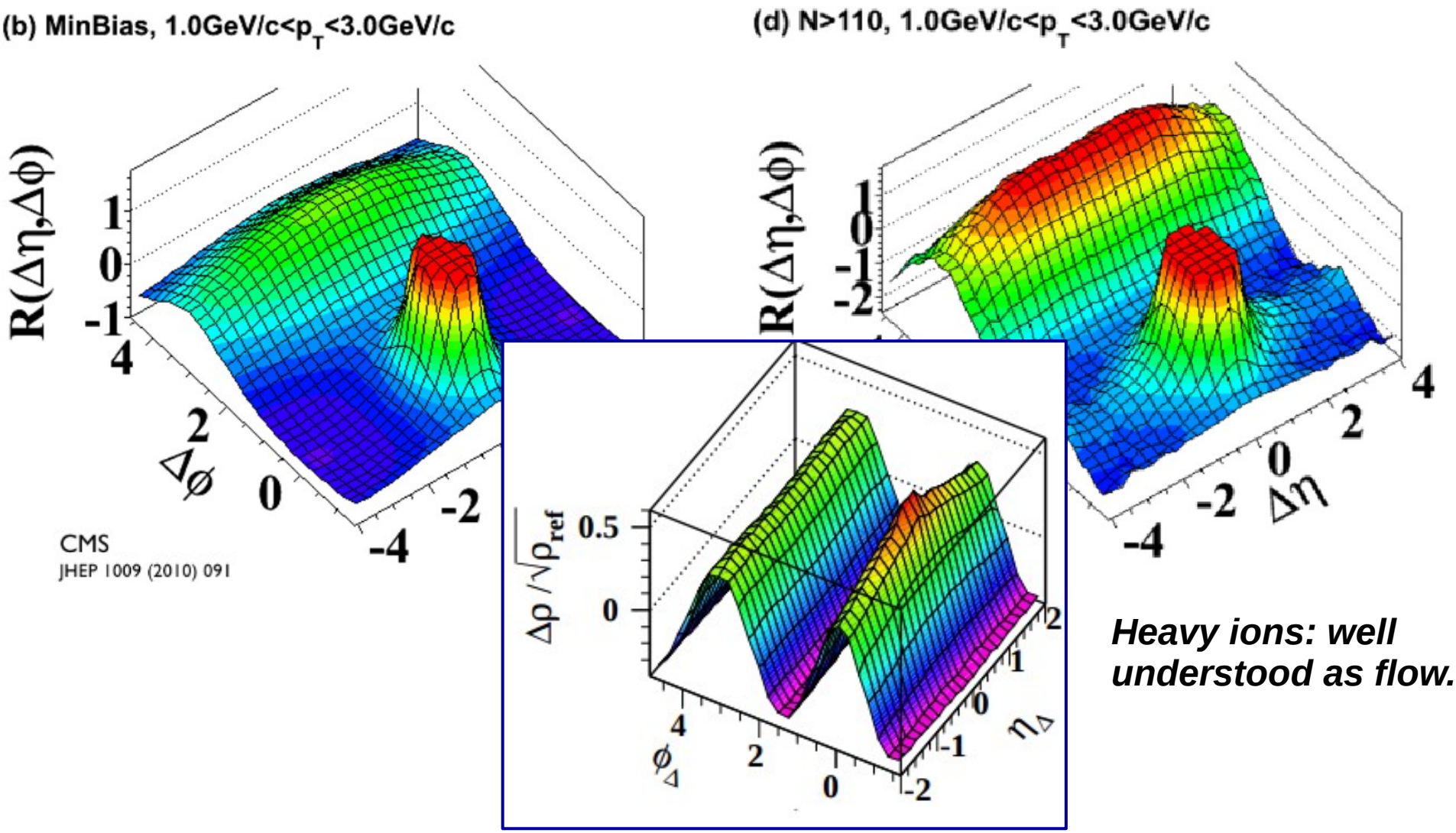




Ridge-like structure in pp!

The Ridge: CMS 2010

First LHC discovery

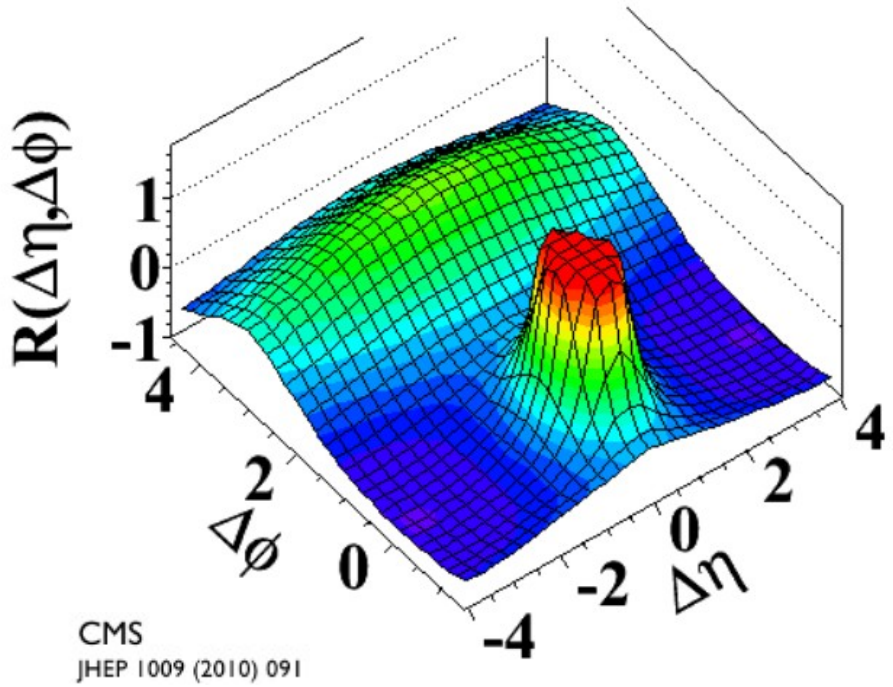


Heavy ions: well understood as flow.

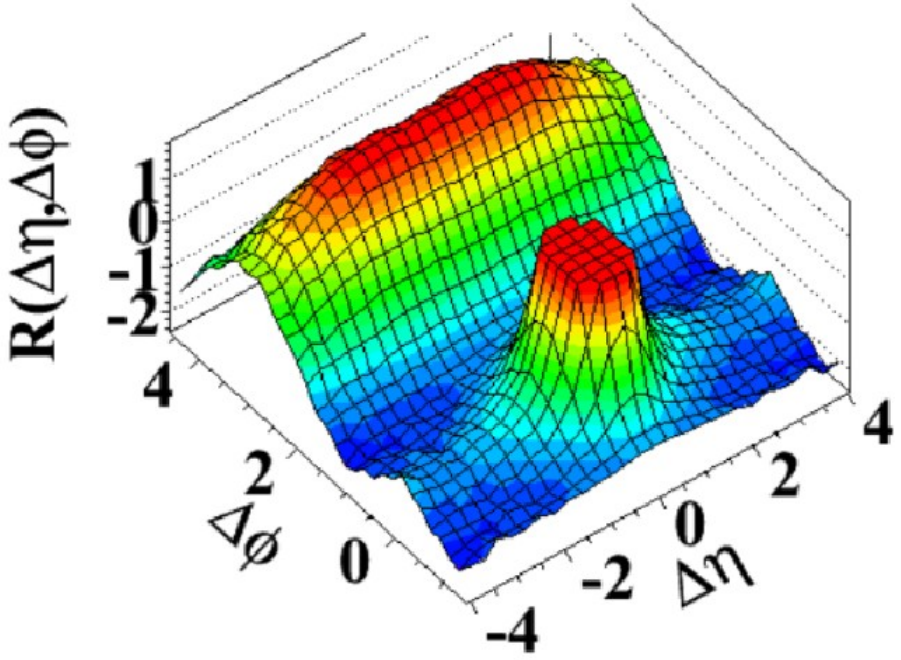
The Ridge: CMS 2010

First LHC discovery

(b) MinBias, 1.0GeV/c<p_T<3.0GeV/c



(d) N>110, 1.0GeV/c<p_T<3.0GeV/c



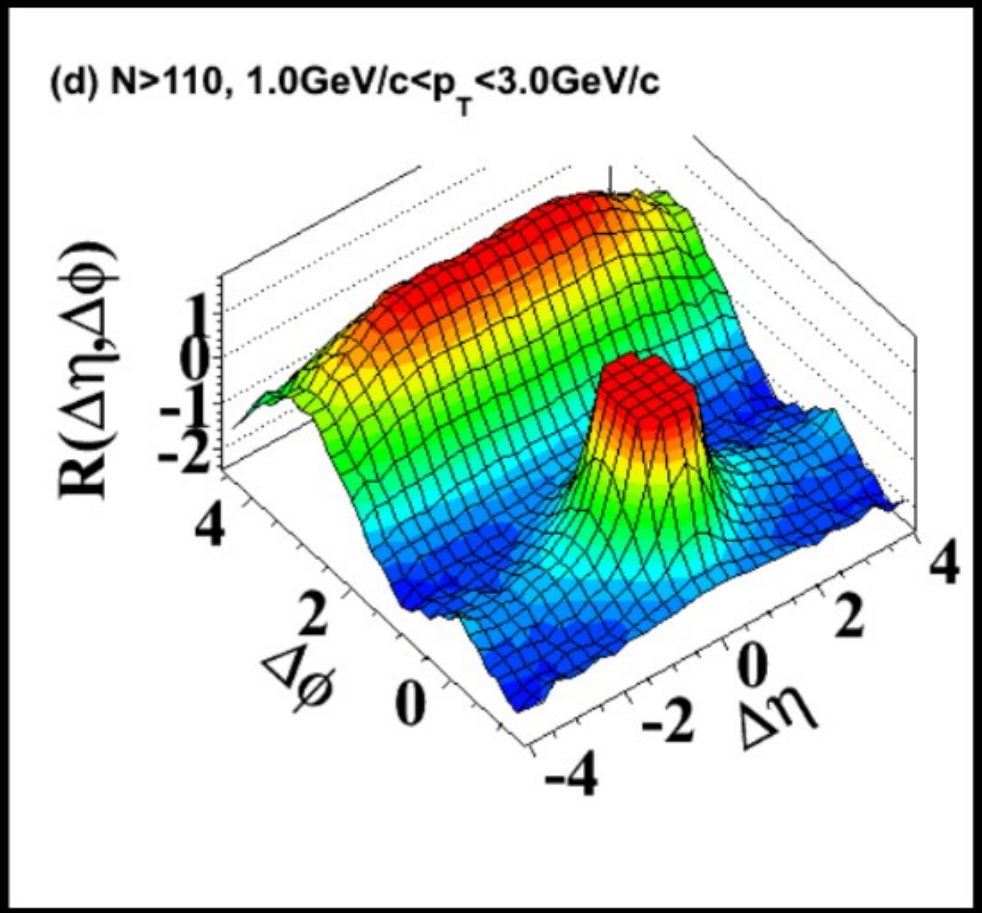
Ridge-like structure in pp!

In pp? Flow?!

The Ridge: CMS 2010

High multiplicity (N>110)

~100 citations within a year



Interpretation:

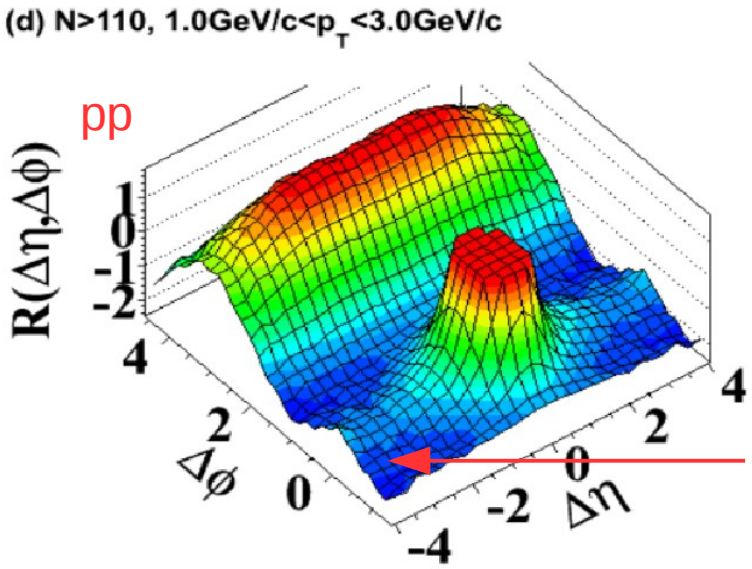
Multi-jet correlations
Jet-Jet color connections
Jet-proton remnant color connections
Jet-remnant connections + medium
Glasma correlations
Quantum entanglement
Angular momentum conservation
Angular momentum conservation + medium
Hydrodynamic flow

?

Multiplicity in these events is dominated by jet contribution.

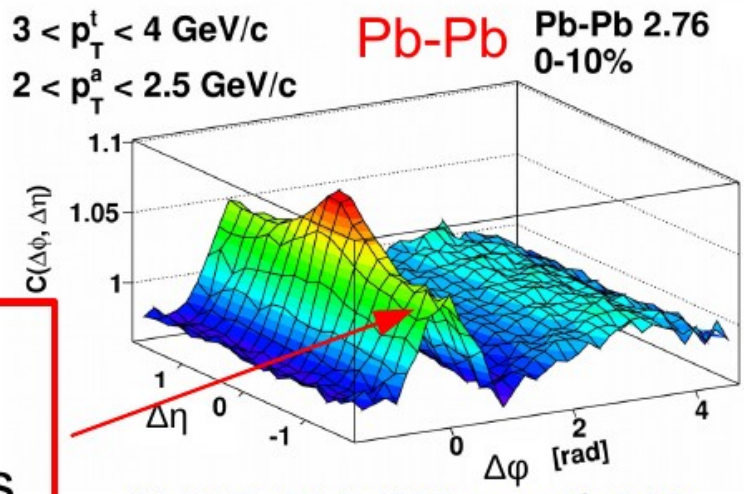
Gunther Roland International Conference on the Initial Stages of High-Energy Nuclear Collisions Illa da Toxa September 2013

The Ridge

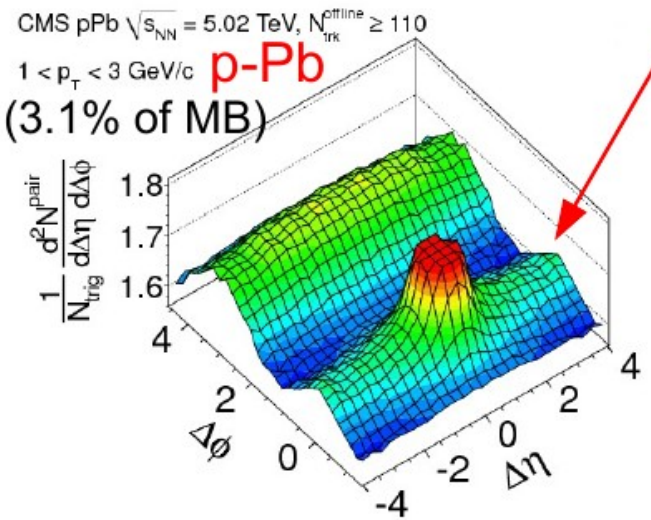


CMS, JHEP 1009 (2010) 91

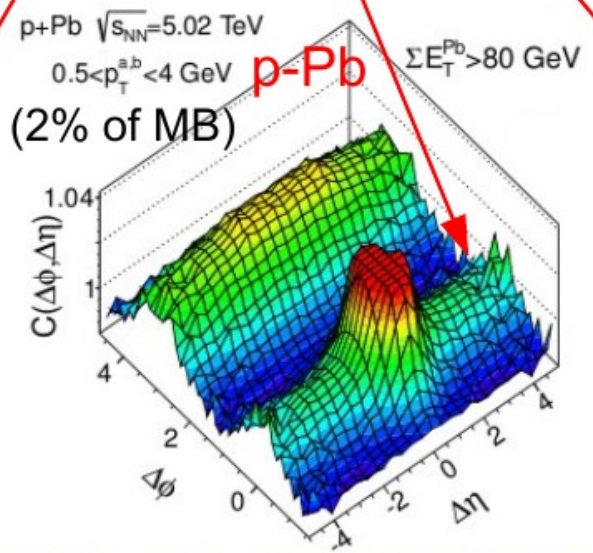
Near-side (NS) ridges in high multiplicity events at LHC energies



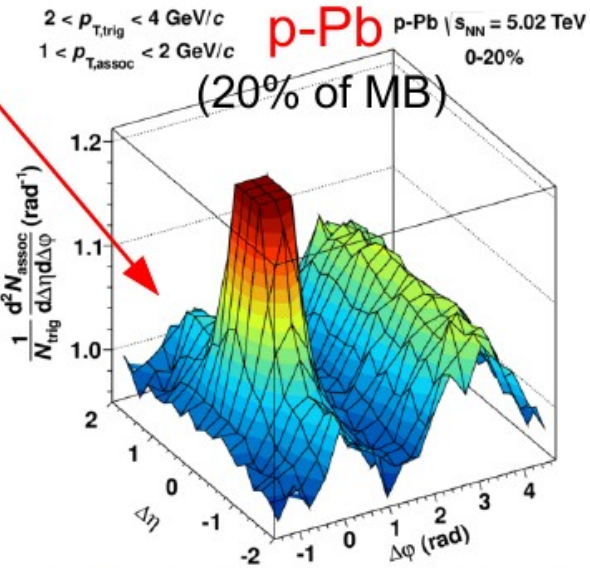
ALICE, PLB 708 (2012) 249



CMS, PLB 718 (2012) 795



ATLAS, PRL 110 (2013) 182302



ALICE, PLB 719 (2013) 29

Conclusions

- ΔηΔφ correlations are easy-to-obtain observable that is sensitive to number of physics mechanisms:
  - jets/mini-jets,
  - flow,
  - “the Ridge”,

  but also
  - Bose-Einstein and other femtoscopic correlations,
  - resonances, gamma conversions,
  - particle production and conservation laws.

Less known

Conclusions

- ΔηΔφ correlations are easy-to-obtain observable that is sensitive to number of physics mechanisms:
  - jets/mini-jets,
  - flow,
  - “the Ridge”,

  but also
  - **Bose-Einstein** and other femtoscopic correlations,
  - resonances, **gamma conversions,**
  - particle production and conservation laws.

Common misconceptions

Bose-Einstein correlations similar in width to minijets; gamma conversions very narrow!

Conclusions

- ΔηΔφ correlations are easy-to-obtain observable that is sensitive to number of physics mechanisms:
  - jets/mini-jets,
  - flow,
  - **“the Ridge”,** *various explanations*

    but also
  - Bose-Einstein and other femtoscopic correlations,
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  - **particle production and conservation laws.**

    current popular MC models do not reproduce the correlation shape for baryons at all

Still some unresolved puzzles

Conclusions

- ΔηΔφ correlations are easy-to-obtain observable that is sensitive to number of physics mechanisms:
  - jets/mini-jets,
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  - **“the Ridge”,** *various explanations*

  but also
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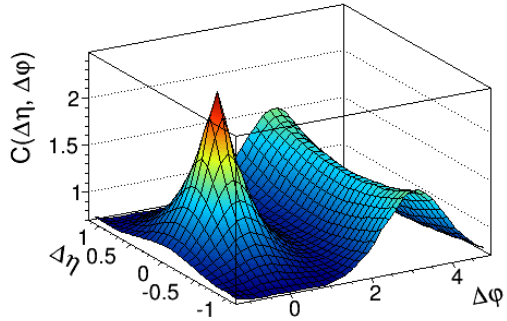
Less known

Still some unresolved puzzles

Common misconceptions



Still a lot to study and discover: with very well-known and easily-obtainable observable!

Backup

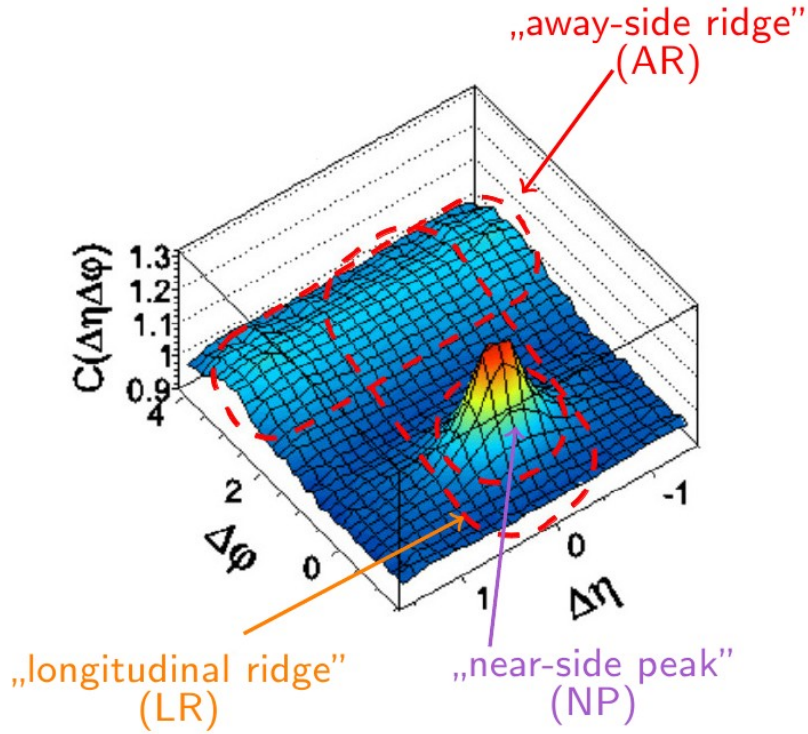
Physics goals

We observe clear structures in the correlation:

- near-side peak (NP)
- away-side ridge (AR)
- longitudinal ridge, (LR) etc...

We would like to associate them with physics phenomena, such as:

- **minijets**
- **femtoscopic correlations**
- resonances
- photon conversion
- momentum conservation
- …



Since each correlation source has a **unique distribution** on (Δη,Δφ) we would like to quantify their contributions to the overall shape using a **fitting procedure**.

My goal: verification of the association and quantitative estimate of the physics phenomena.

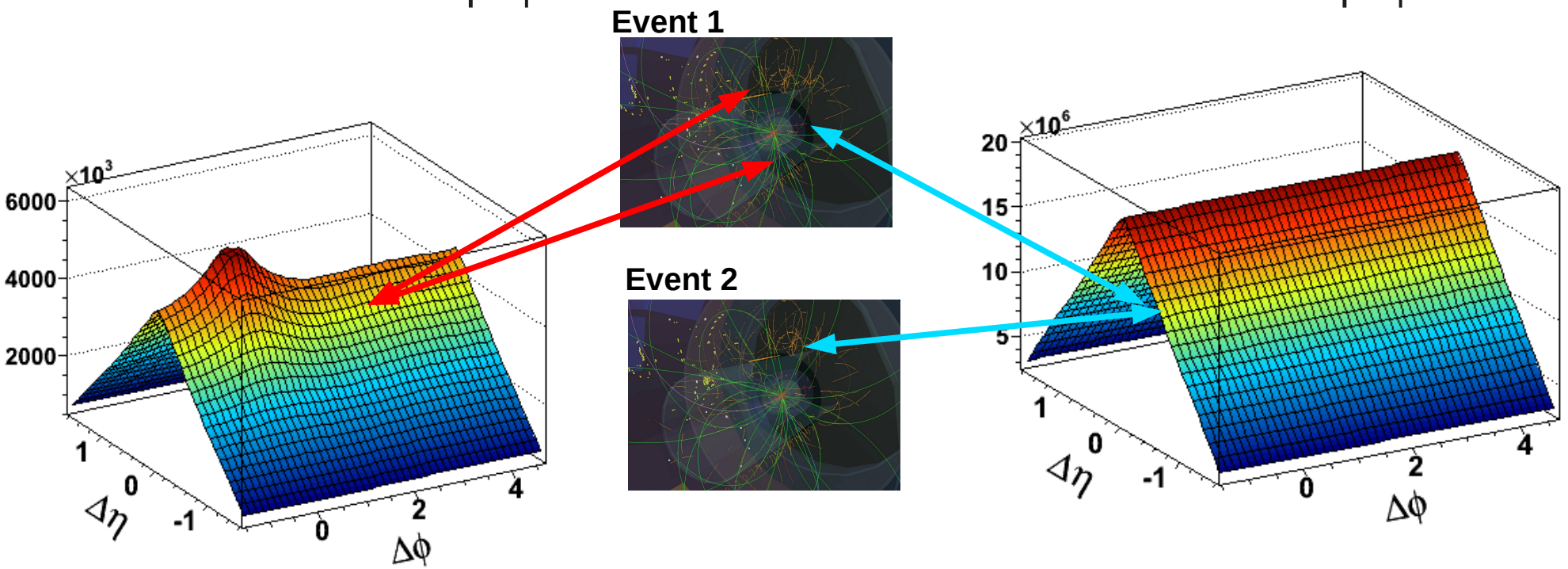
ΔηΔφ Experimental Correlation Function

Signal distribution

$$S(\Delta\eta,\Delta\varphi)=\frac{d^2N^{signal}}{d\Delta\eta\Delta\varphi}$$

Background distribution

$$B(\Delta\eta,\Delta\varphi)=\frac{d^2N^{mixed}}{d\Delta\eta\Delta\varphi}$$



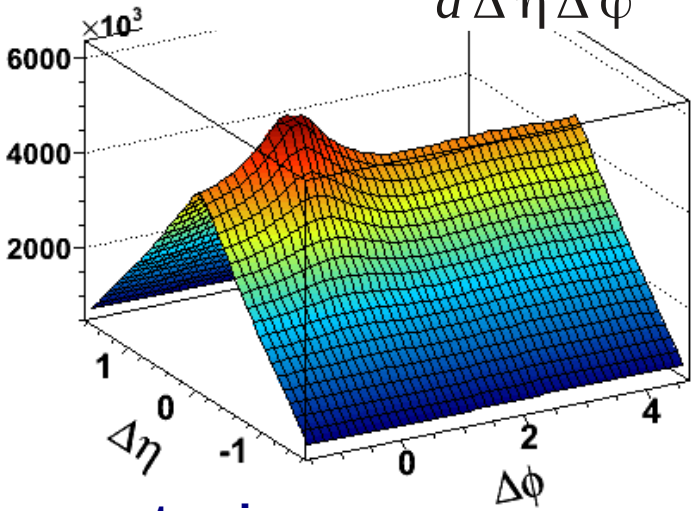
Same event pairs

Mixed event pairs

ΔηΔφ Experimental Correlation Function

Signal distribution

$$S(\Delta\eta,\Delta\varphi)=\frac{d^2N^{signal}}{d\Delta\eta\,\Delta\varphi}$$



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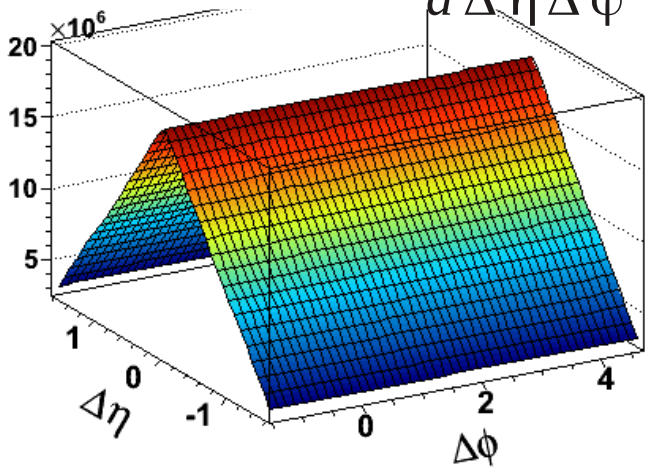
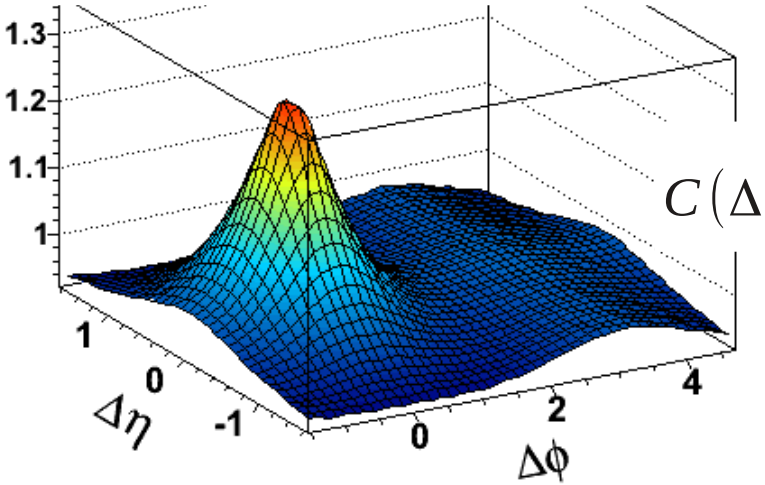
$$B(\Delta\eta,\Delta\varphi)=\frac{d^2N^{mixed}}{d\Delta\eta\,\Delta\varphi}$$



Mixed event pairs

Ratio signal/background



$$\Delta\eta=\eta_1-\eta_2$$
$$\Delta\varphi=\varphi_1-\varphi_2$$

$$C(\Delta\eta,\Delta\varphi)=\frac{N^{mixed}_{pairs}}{N^{signal}_{pairs}}\frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$