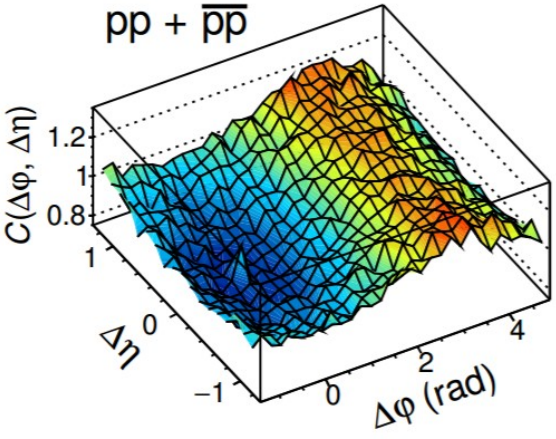
Investigatinon of hadron collisions with angular correlations

Małgorzata Janik
(for the ALICE Collaboration)



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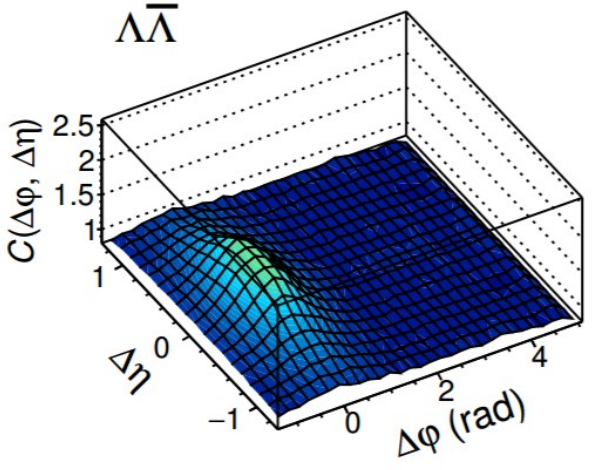
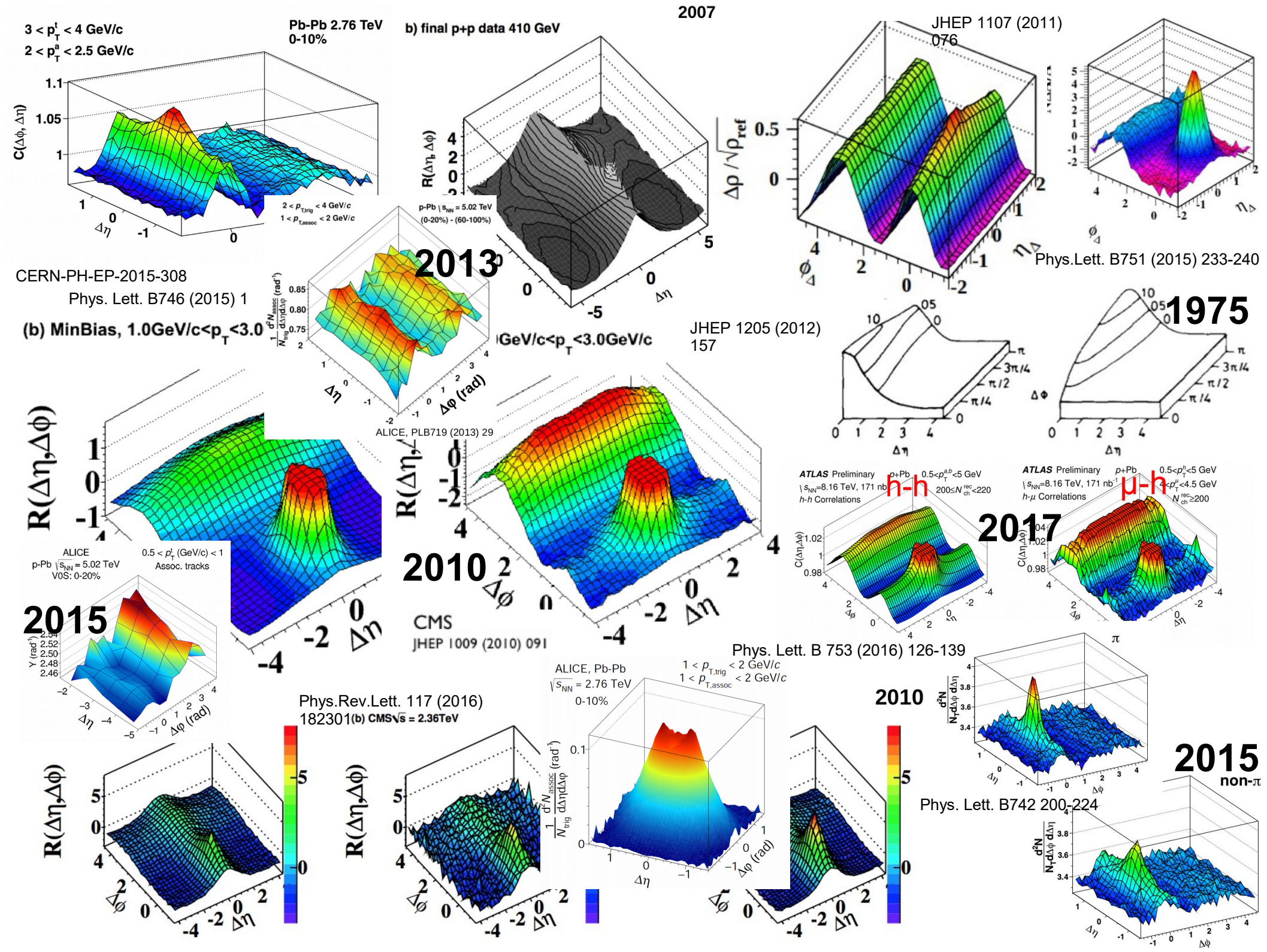
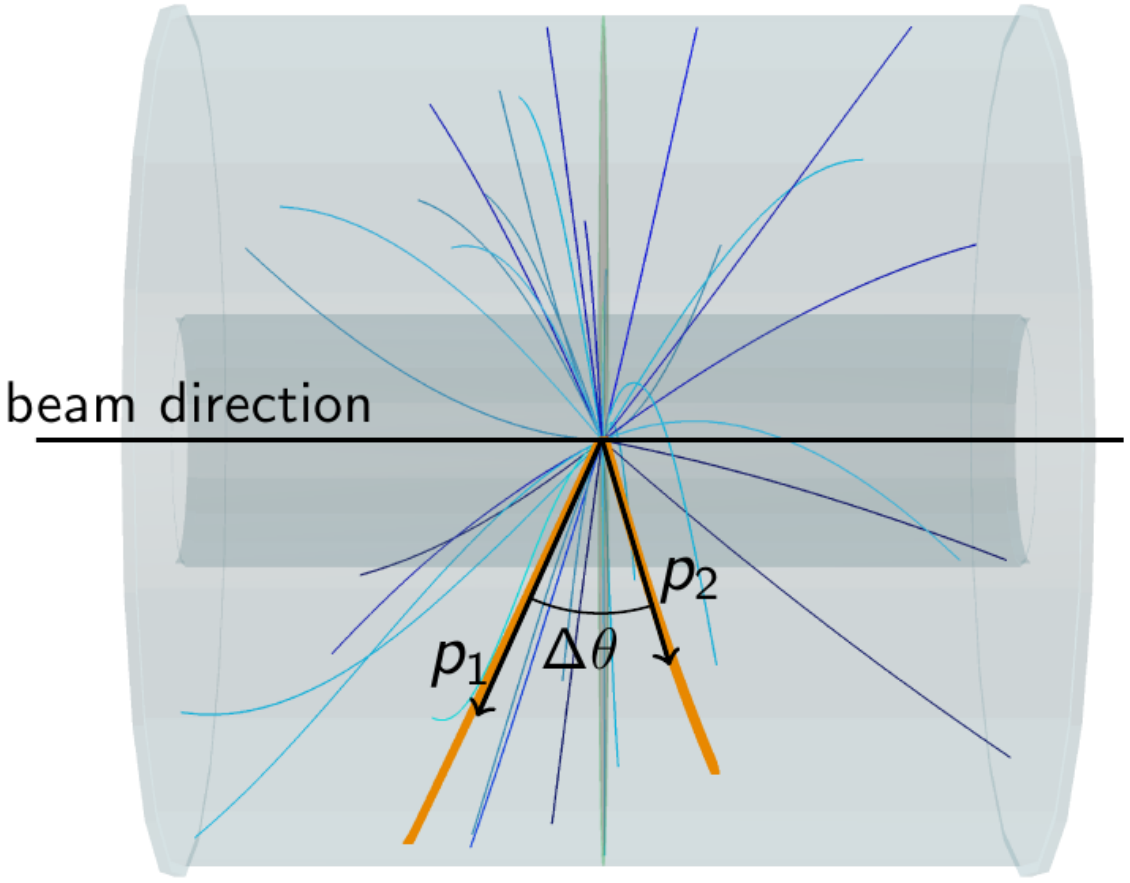


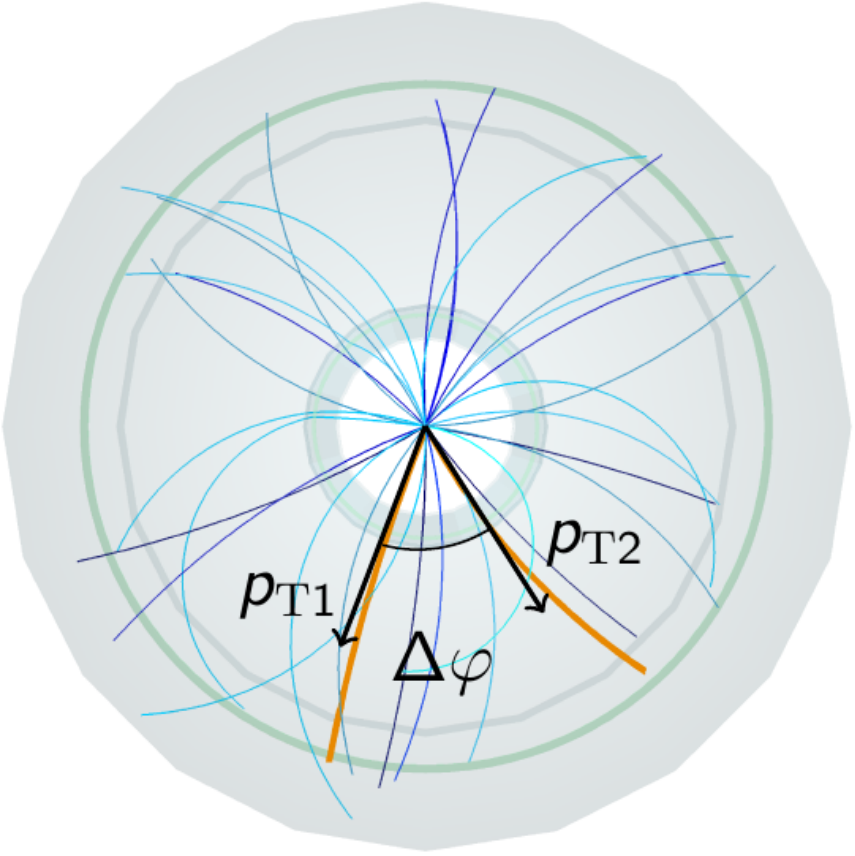
Spåtind 2018
2-7.01.2018

Eur. Phys. J. C77 (2017) 569


2007
3 < p_T^t < 4 GeV/c
2 < p_T^a < 2.5 GeV/c
Pb-Pb 2.76 TeV
0-10%
C(Δφ, Δη)
b) final p+p data 410 GeV
R(Δη, Δφ)
JHEP 1107 (2011) 076
Δρ / √ρ_ref
2013
p-Pb √s_NN = 5.02 TeV
(0-20%) - (60-100%)
2 < p_T,trig < 4 GeV/c
1 < p_T,assoc < 2 GeV/c
CERN-PH-EP-2015-308
Phys. Lett. B746 (2015) 1
(b) MinBias, 1.0GeV/c<p_T<3.0
GeV/c<p_T<3.0GeV/c
Phys.Lett. B751 (2015) 233-240
JHEP 1205 (2012) 157
1975
ALICE, PLB719 (2013) 29
R(Δη,Δφ)
2010
CMS
JHEP 1009 (2010) 091
ATLAS Preliminary
p+Pb
√s_NN=8.16 TeV, 171 nb^-1
h-h Correlations
0.5<p_T^a,b<5 GeV
200≤N_ch^rec<220
h-h
2017
μ-h
h-μ Correlations
0.5<p_T^h<5 GeV
2<p_T^μ<4.5 GeV
N_ch^rec≥200
Phys. Lett. B 753 (2016) 126-139
ALICE
p-Pb √s_NN = 5.02 TeV
V0S: 0-20%
0.5 < p_T^t (GeV/c) < 1
Assoc. tracks
2015
Phys.Rev.Lett. 117 (2016) 182301
(b) CMS √s = 2.36TeV
ALICE, Pb-Pb
√s_NN = 2.76 TeV
0-10%
1 < p_T,trig < 2 GeV/c
1 < p_T,assoc < 2 GeV/c
2010
2015
non-π
Phys. Lett. B742 200-224

Two-particle (Δη,Δφ) angular correlations





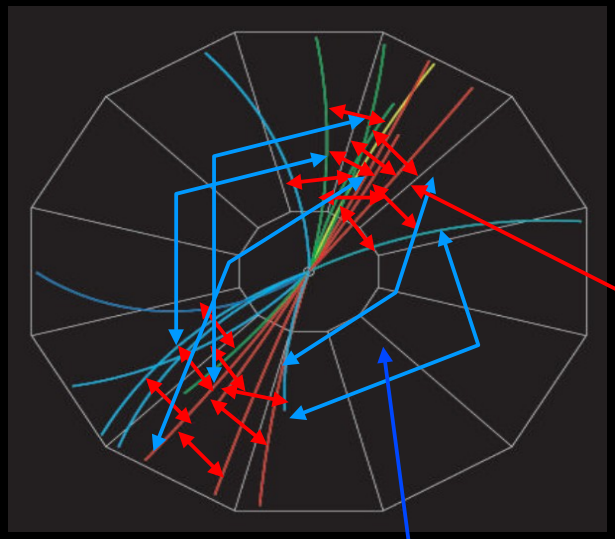
p - particle momentum;
θ - polar angle;
η - pseudorapidity:

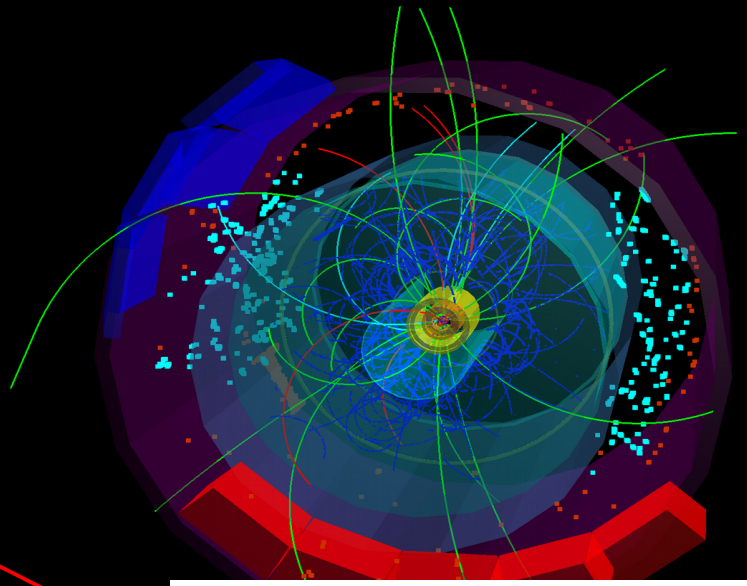
$$\eta = -\ln\left(tan\frac{\theta}{2}\right)$$

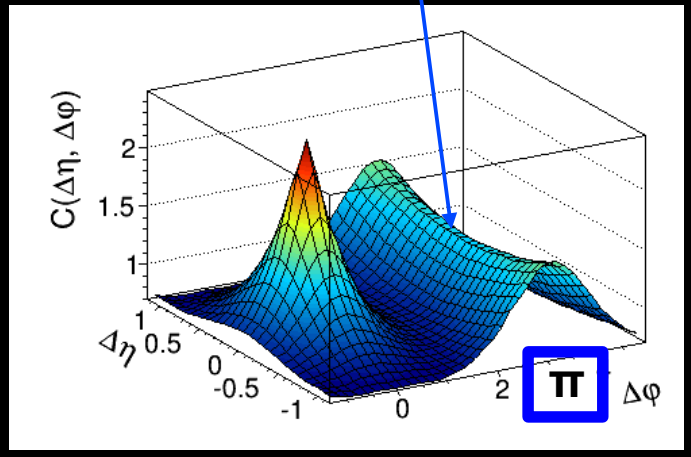
p_T - transverse momentum;
φ - azimuthal angle;

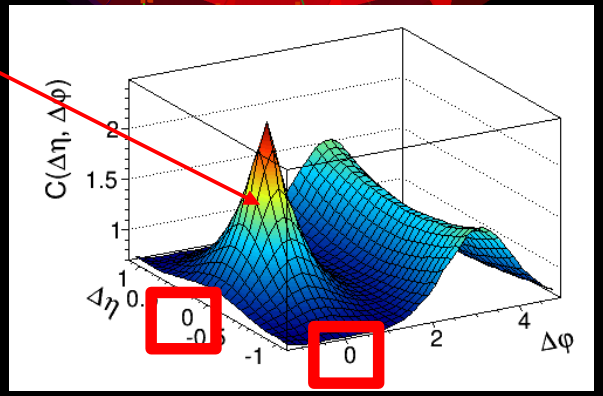
Fig. A. Zaborowska

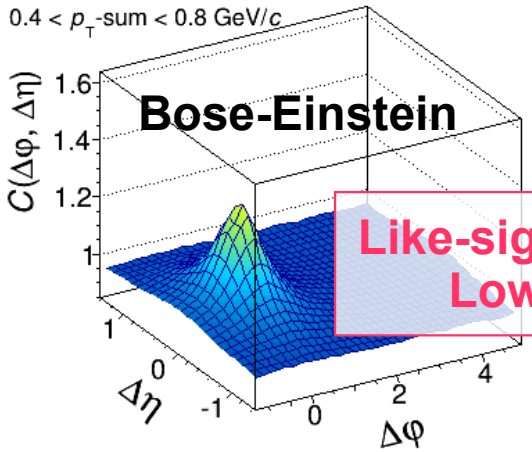
(Δη,Δφ) angular correlations





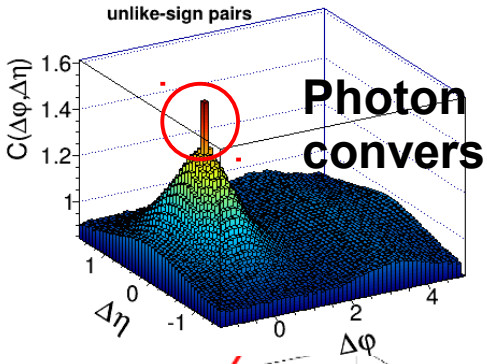






Bose-Einstein

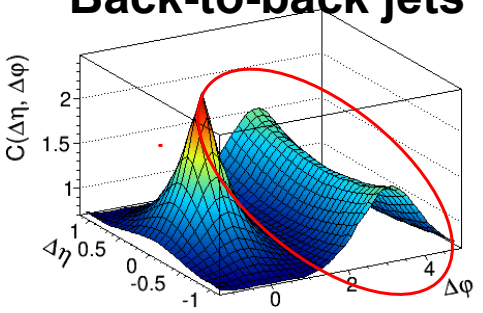
Like-sign pairs
Low p_T

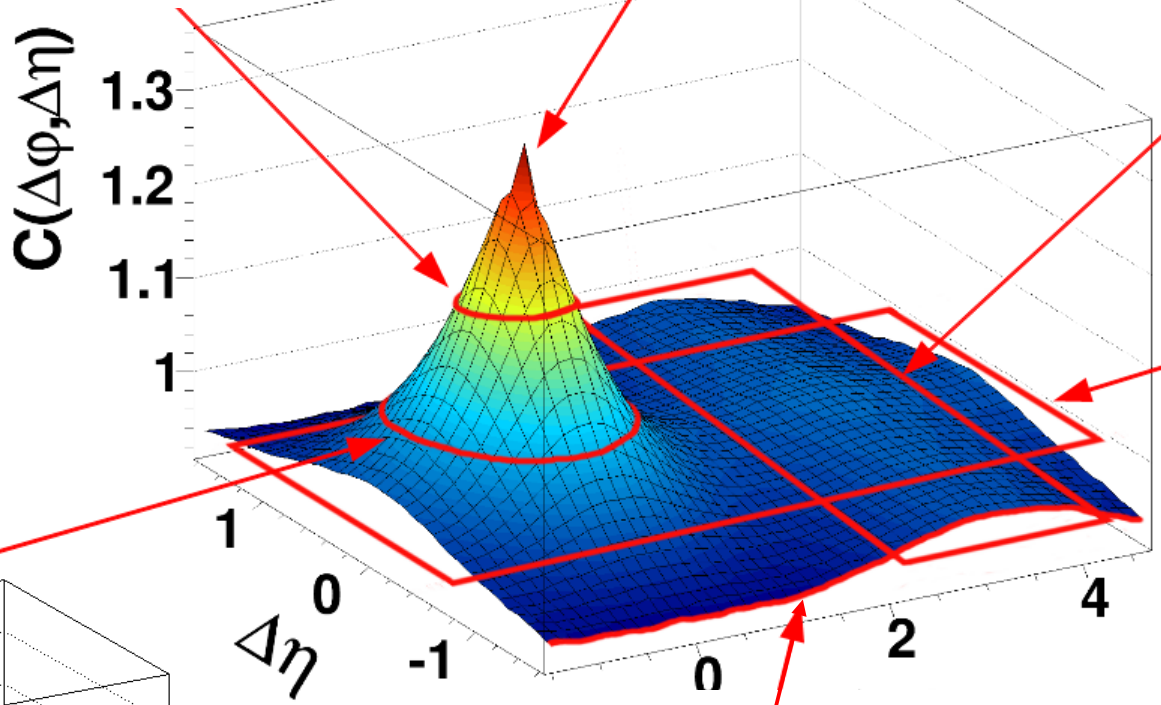


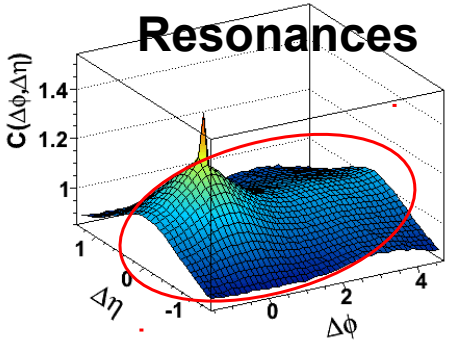
Photon conversion

High p_T

Back-to-back jets



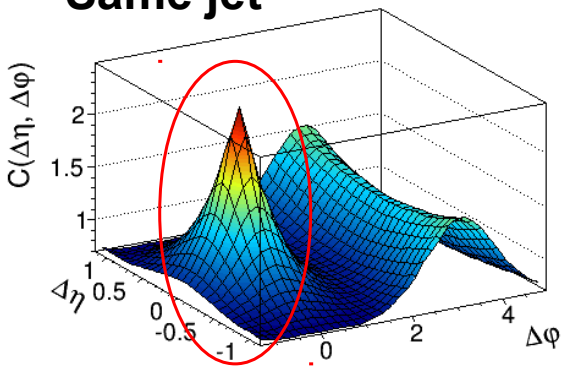


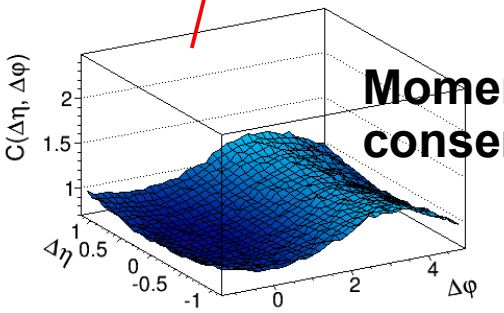


Resonances

High p_T

Same jet

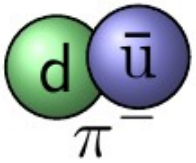




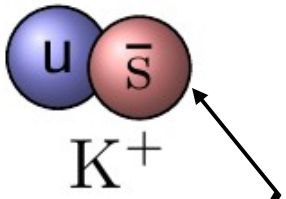
Momentum conservation

One step further: identified particles!

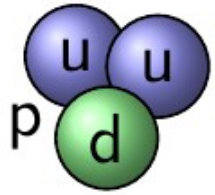
Unexplored phenomena: **conservation laws** and their influence on **particle production mechanisms –** study via correlation functions for particles with **different quark content**



Pion:
- Charge



Kaon:
- Charge
- Strange quark



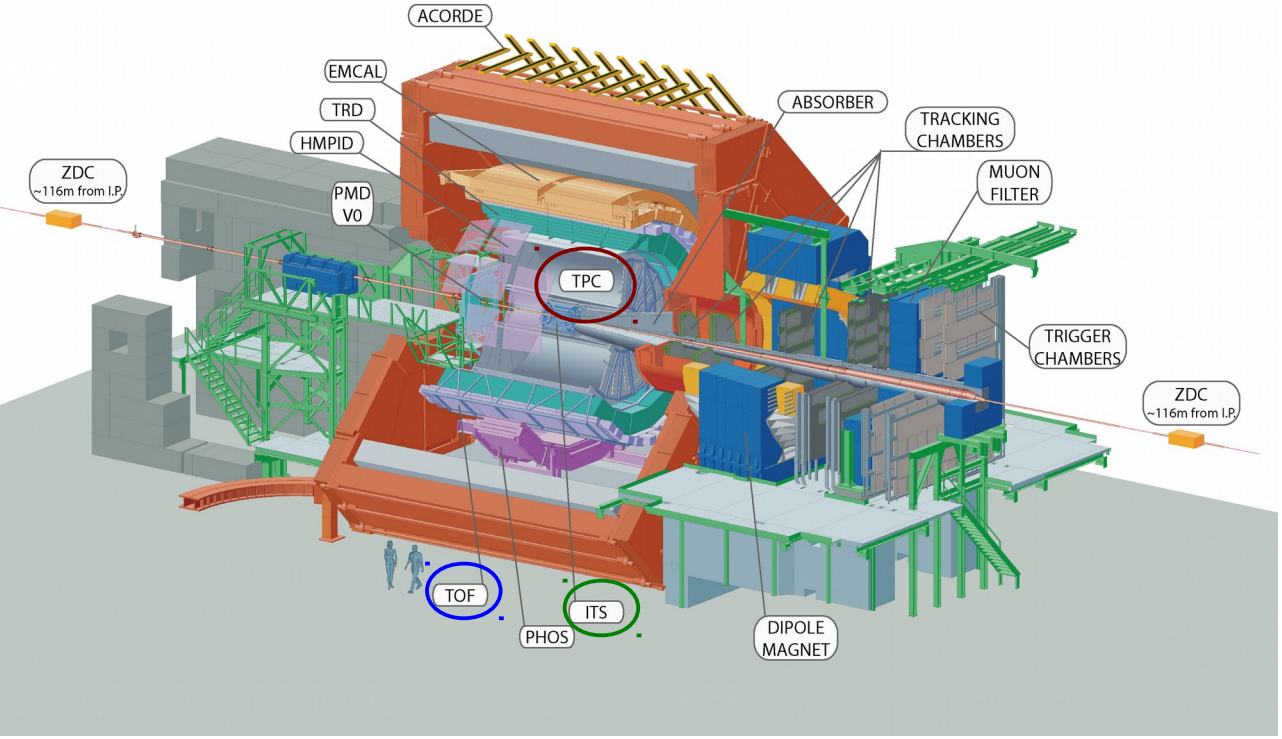
Proton:
- Charge
- Baryon

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

Useful to perform analysis in a more differential way:

- **charge dependence**
  - for unlike-sign pairs quantum numbers conserved: stronger correlation
  - for like-sign pairs new particles need to be produced: weaker correlations
- **identified particles**

Data sample & analysis



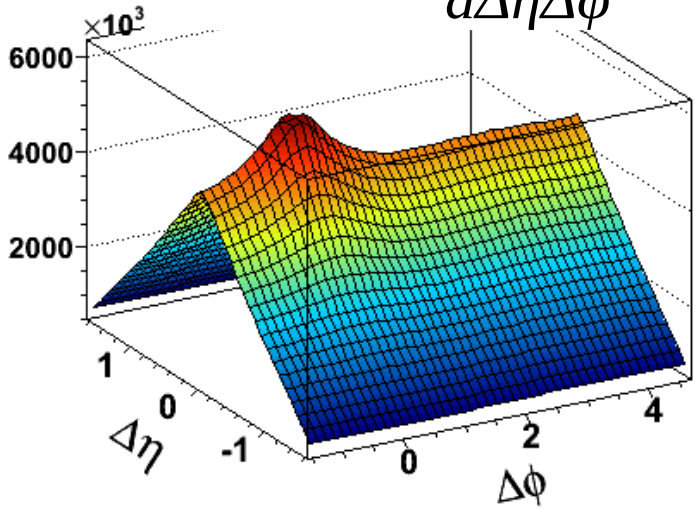
- Kinematic cuts:
  - $0.2 < p_T < 2.5$ GeV/*c for pions*
  - *$0.3 < p_T < 2.5$ GeV/c for kaons*
  - *$0.5 < p_T < 2.5$ GeV/c for protons*
  - *$0.7 < p_T < 2.5$ GeV/c for lambdas*
  - $|\eta| < 0.8$

- ~200 million minimum bias pp collisions at 7 TeV collected by ALICE in 2010
- Tracking:
  - Inner Tracking System (ITS)
  - Time Projection Chamber (TPC)
- Particle identification:
  - TPC
  - Time-of-Flight (TOF)
  - Λ topology reconstruction

(Δη,Δφ) Experimental Correlation Function

Signal distribution

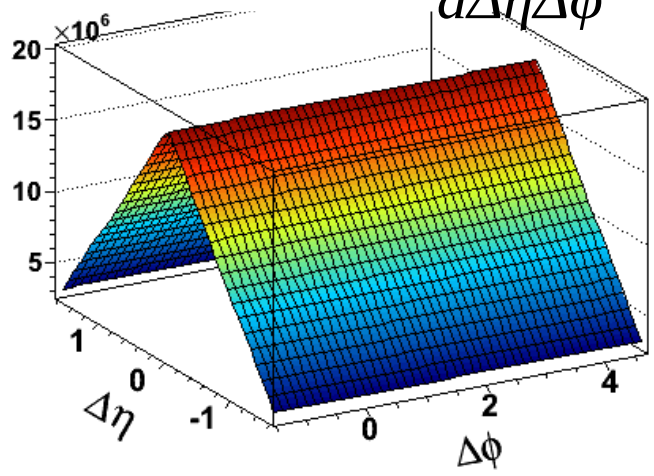
$$S(\Delta\eta,\Delta\varphi)=\frac{d^2N^{signal}}{d\Delta\eta\Delta\varphi}$$



Same event pairs

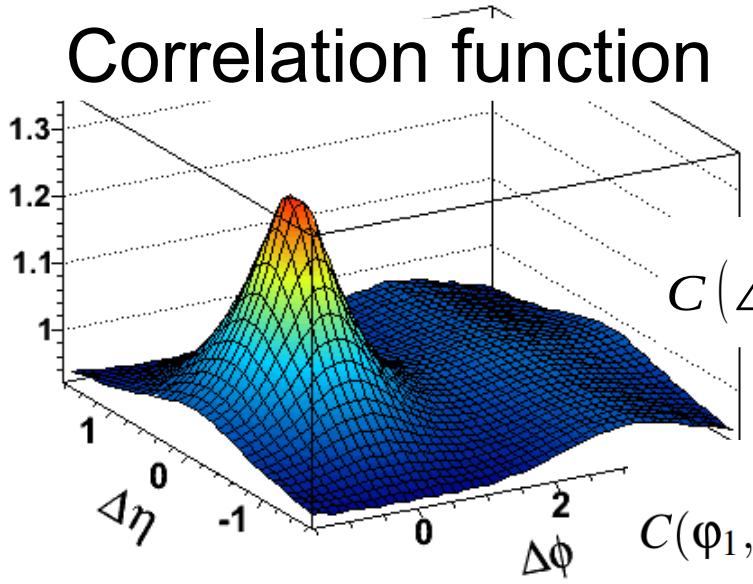
Uncorrelated reference

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



Mixed event pairs

Correlation function



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

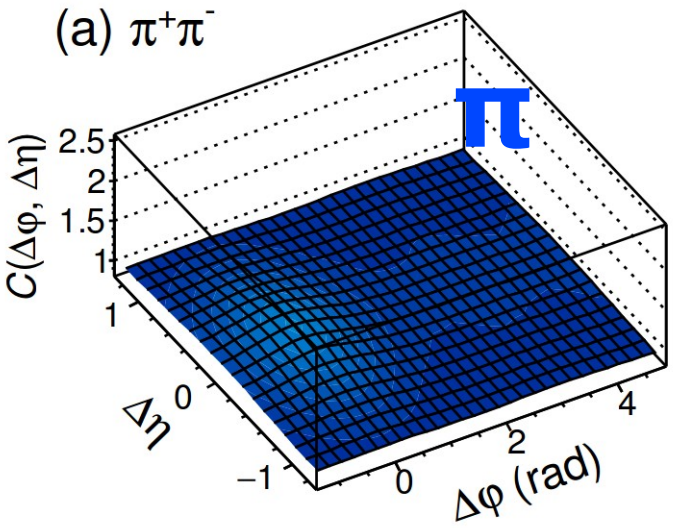
$$C(\Delta\eta,\Delta\varphi)=\frac{N^{mixed}_{pairs}}{N^{signal}_{pairs}}\frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

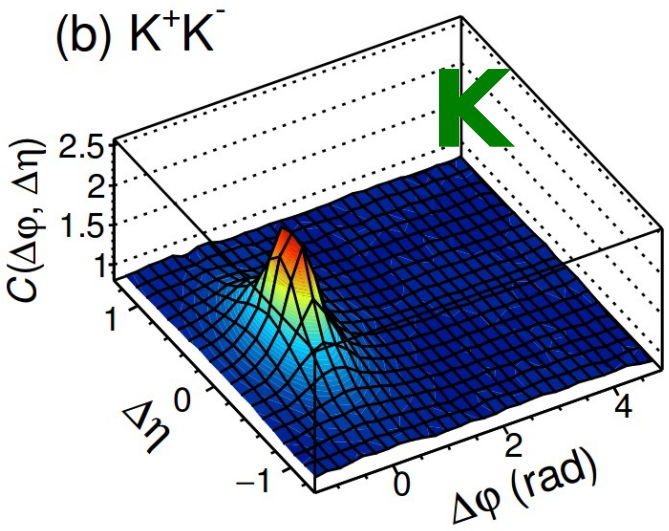
$$C(\varphi_1,\eta_1,\varphi_2,\eta_2)=\frac{P_{12}(\varphi_1,\eta_1,\varphi_2,\eta_2)}{P_1(\varphi_1,\eta_1)P_2(\varphi_2,\eta_2)}$$

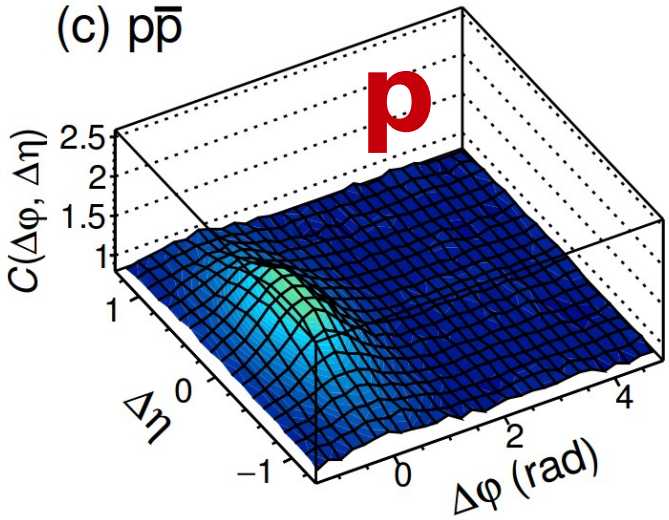
(Δη,Δφ) of identified particles

arXiv:1612.08975

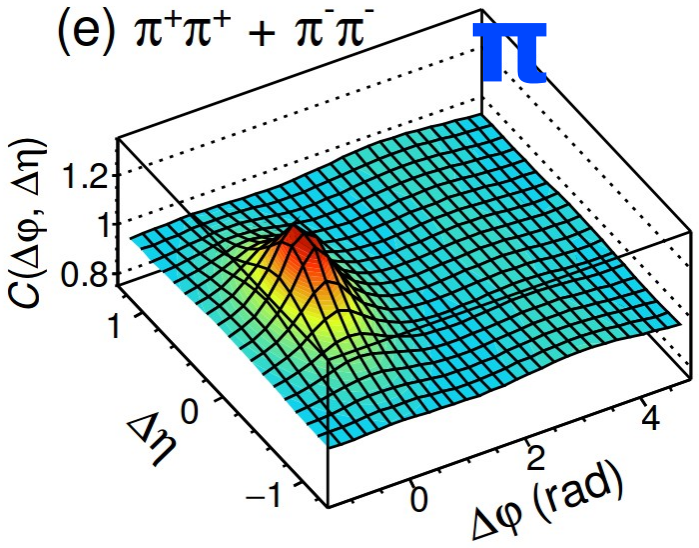
Unlike-sign

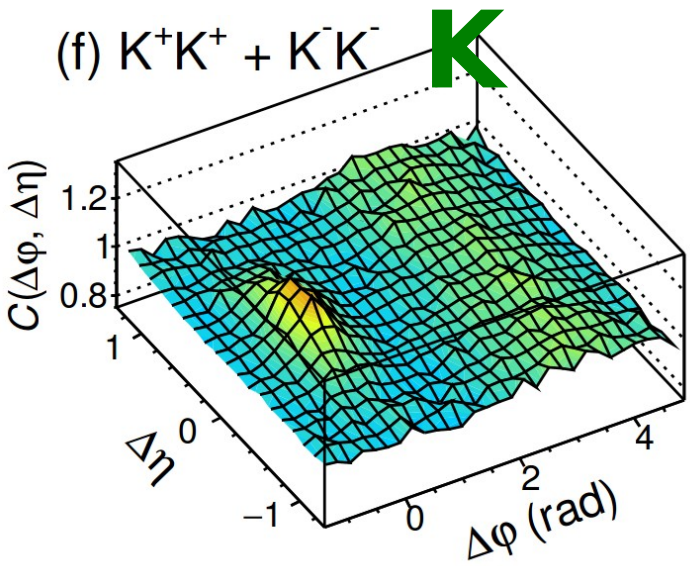


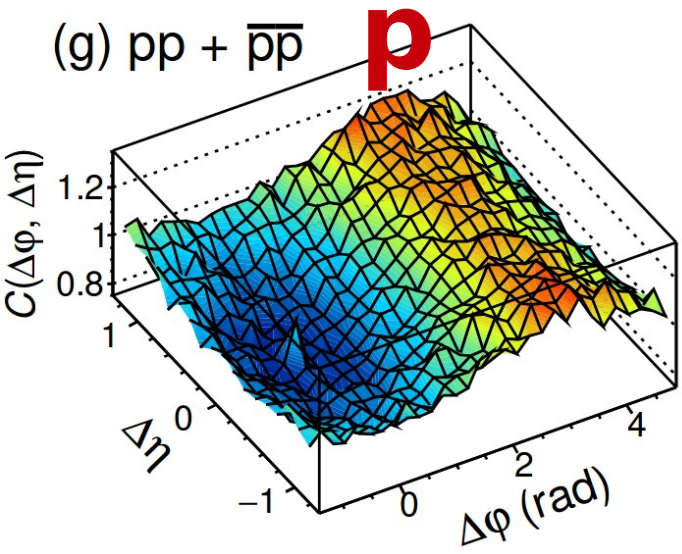




Like-sign







(Δη,Δφ) of identified particles

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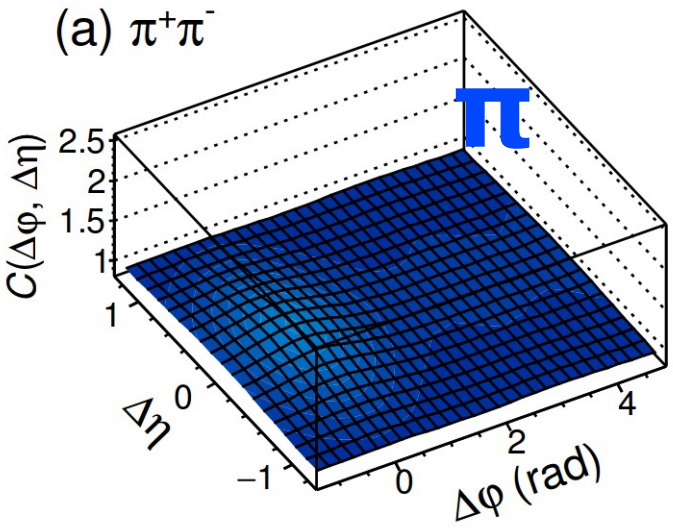
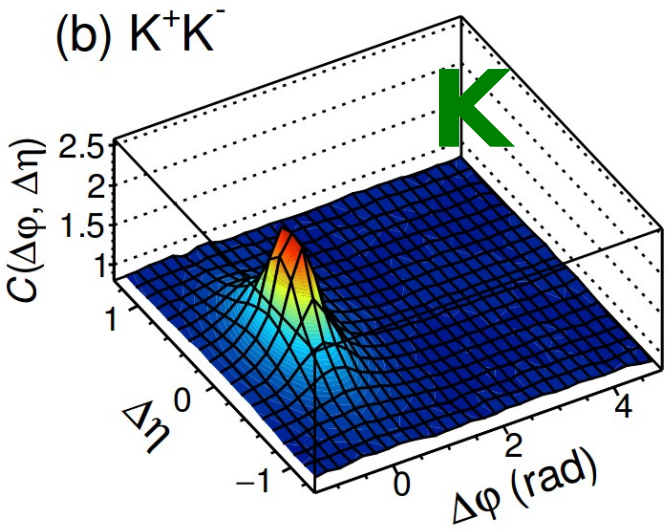
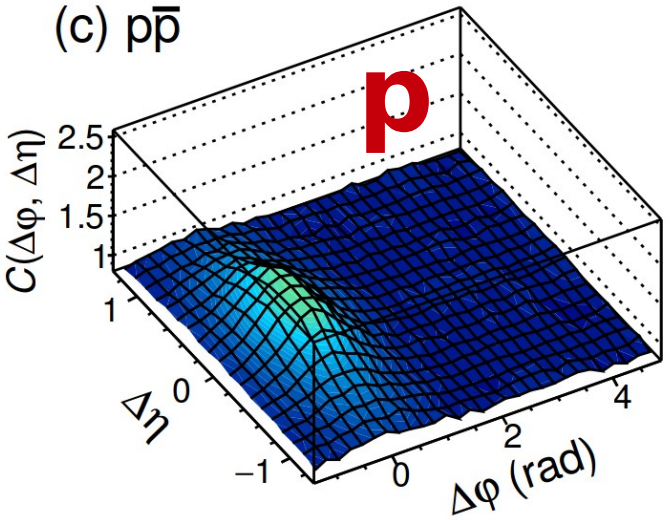
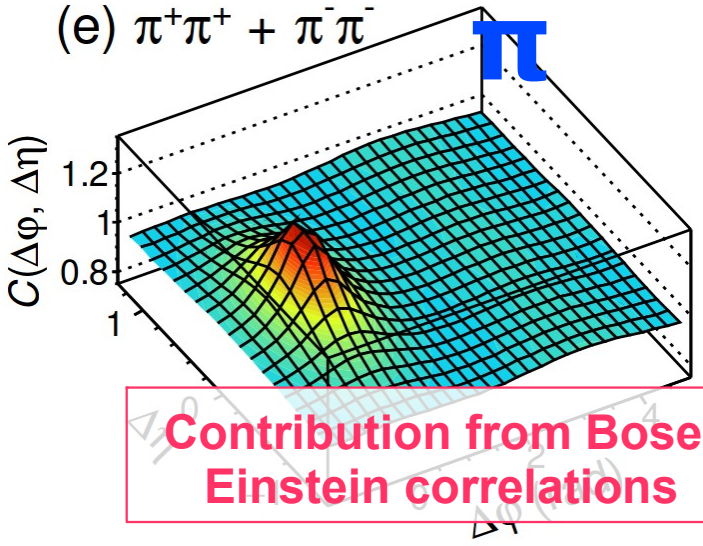
Unlike-sign



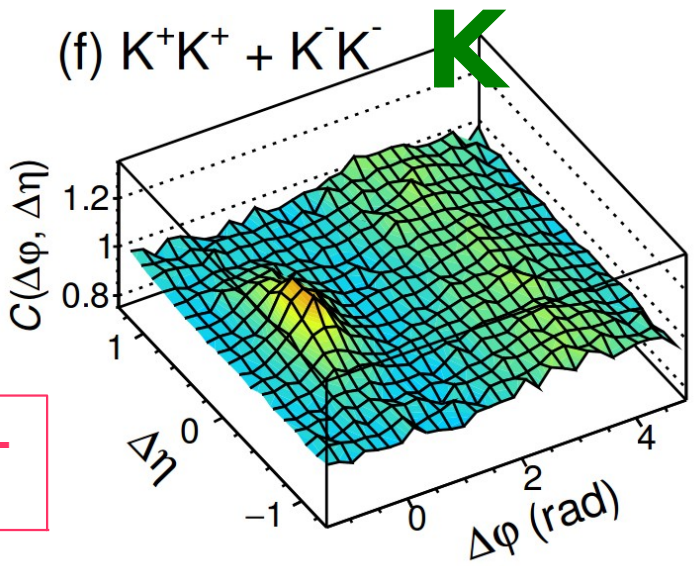


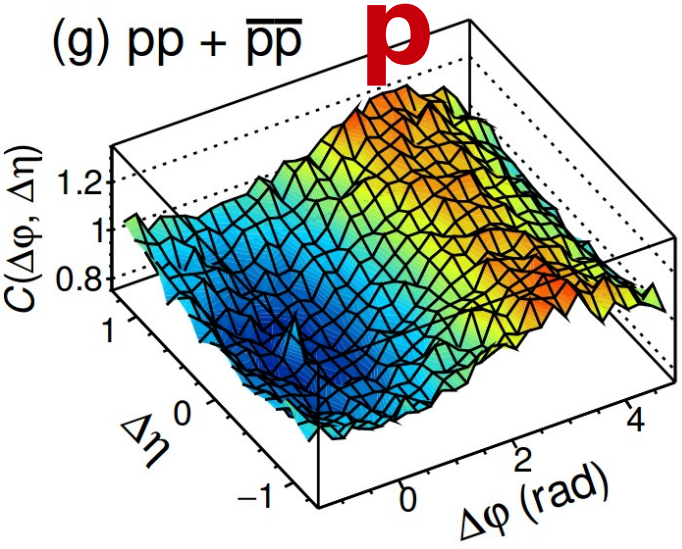


Like-sign



Contribution from Bose-Einstein correlations

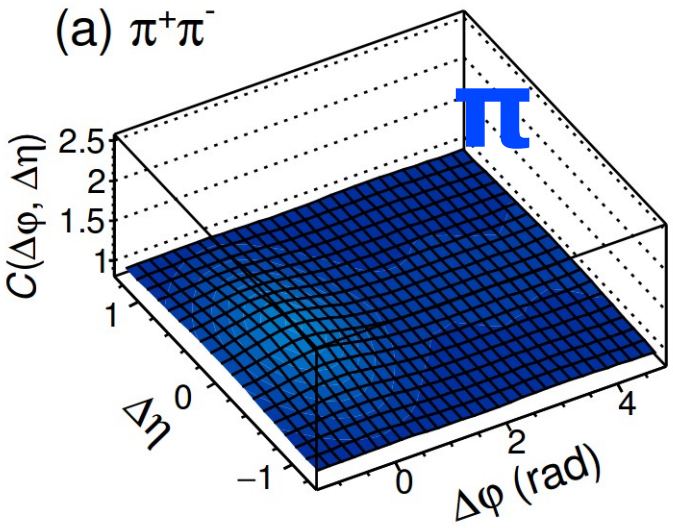


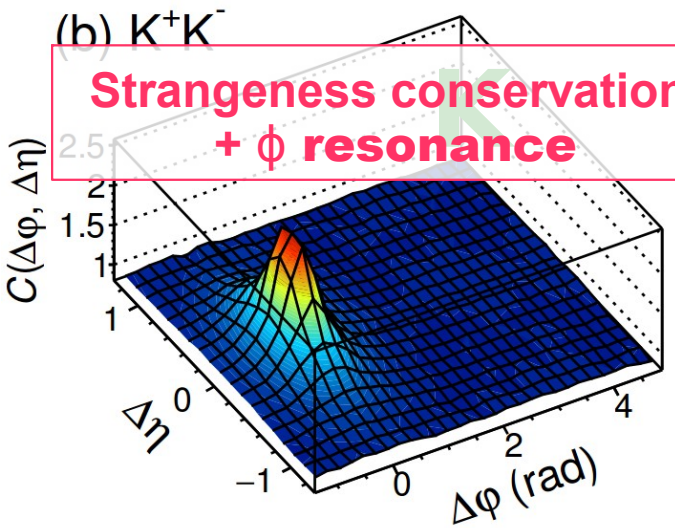


(Δη,Δφ) of identified particles

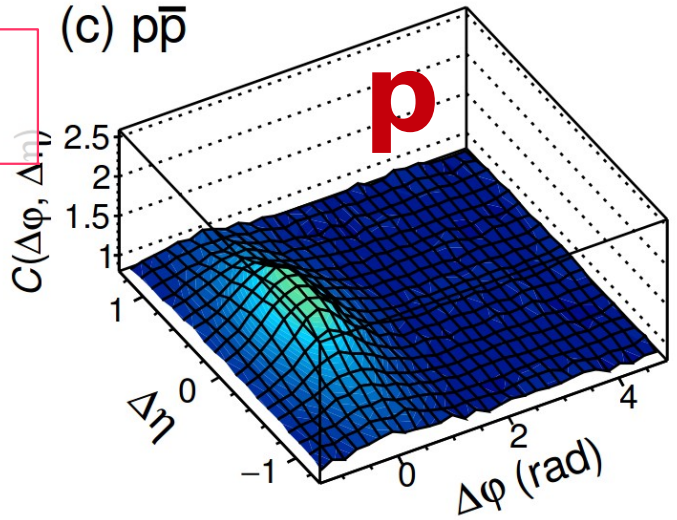
arXiv:1612.08975

Unlike-sign





Strangeness conservation + ϕ resonance



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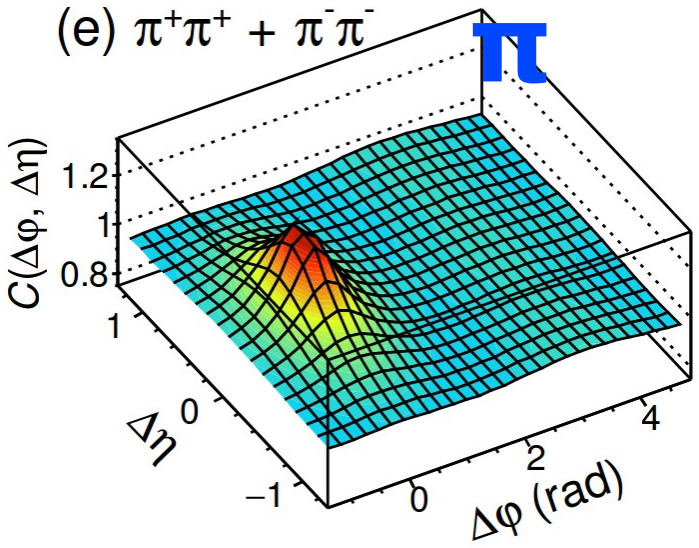

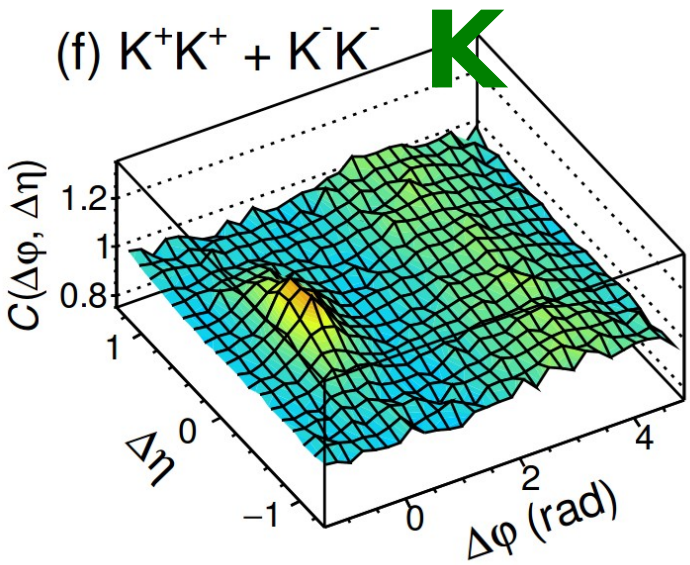

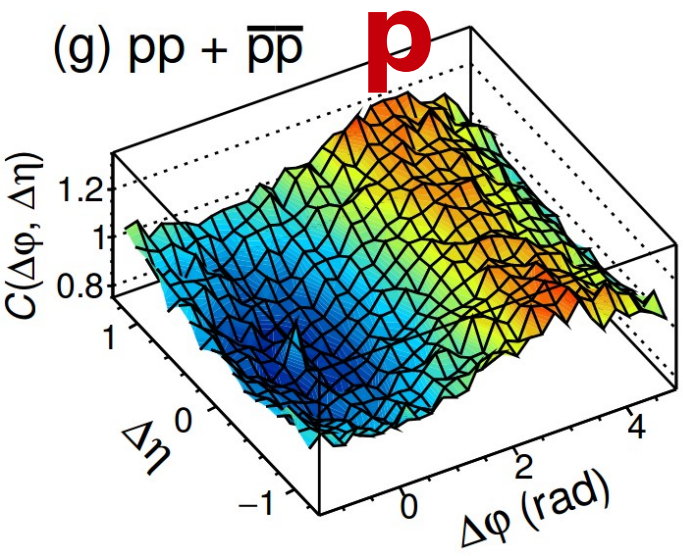

(Δη,Δφ) of identified particles

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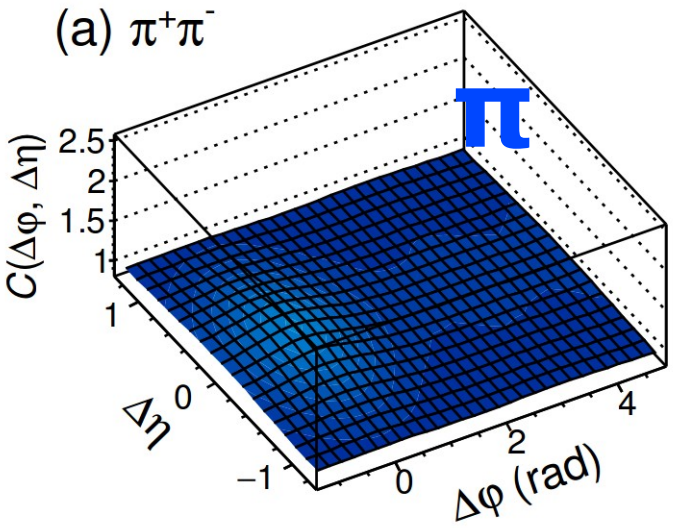
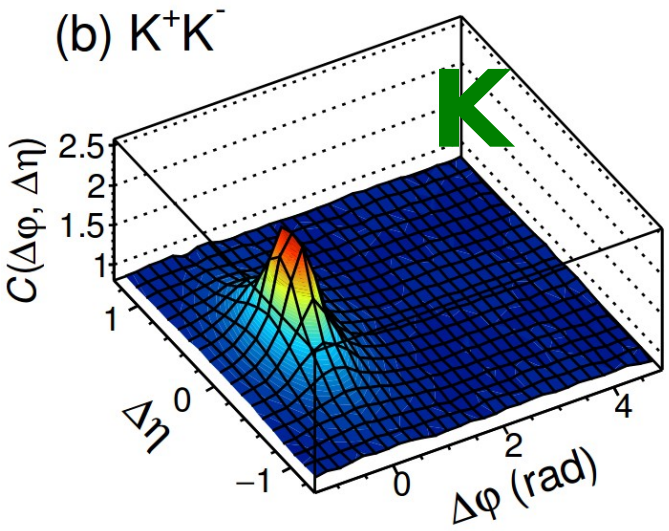
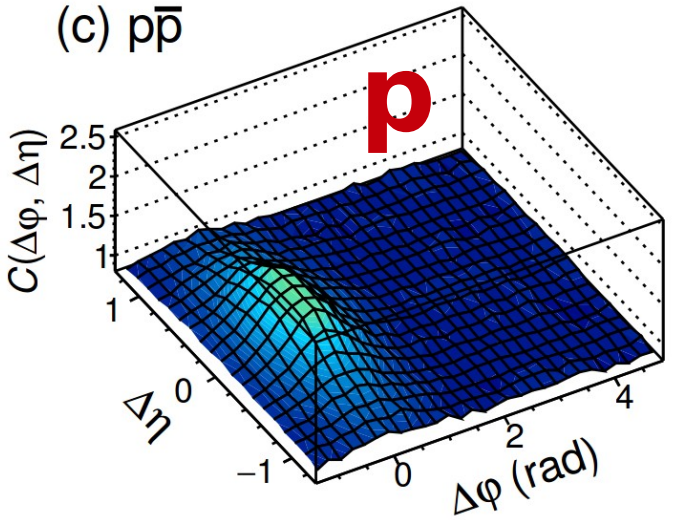
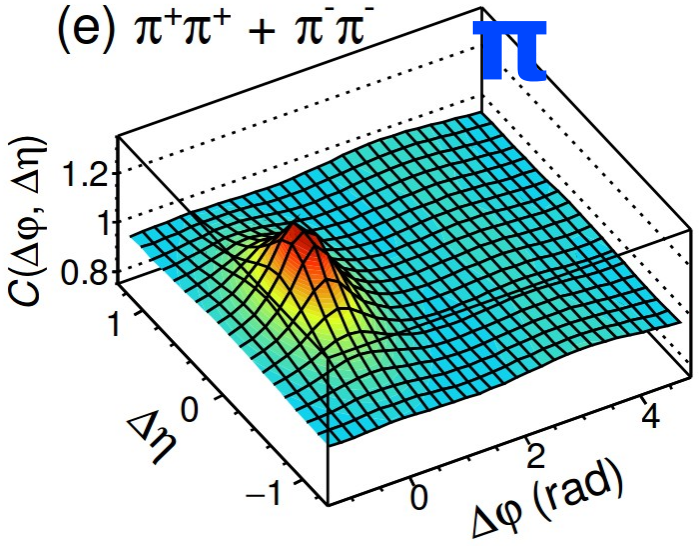
Unlike-sign

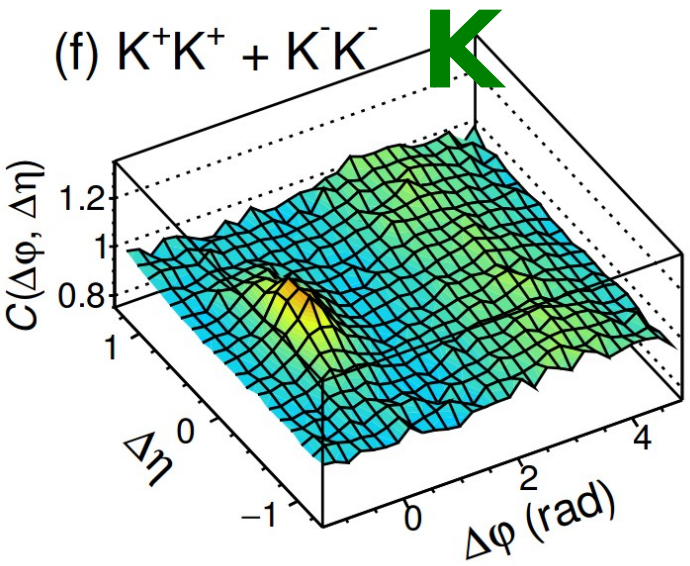


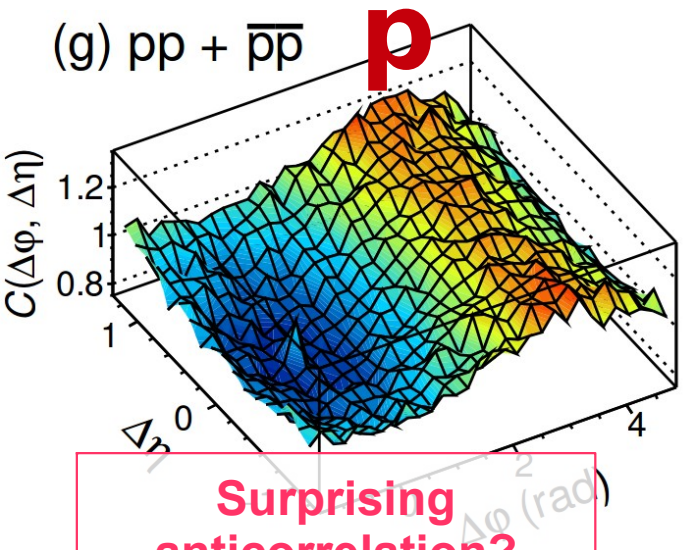




Like-sign



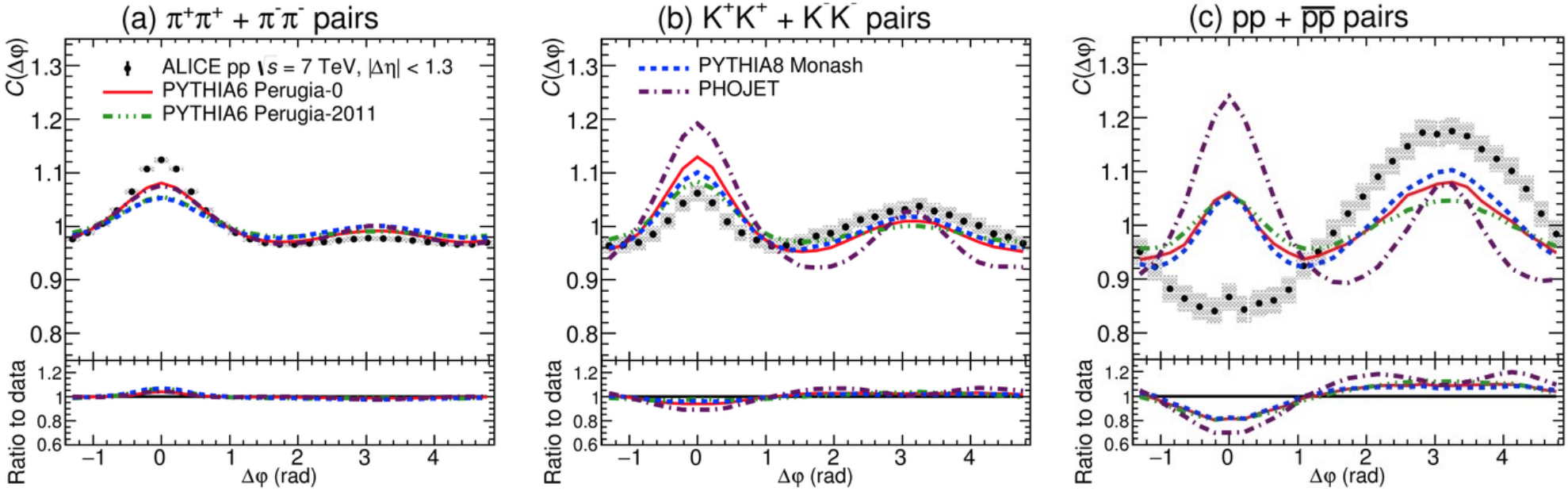




Surprising anticorrelation?

Comparison to MC models: like-sign

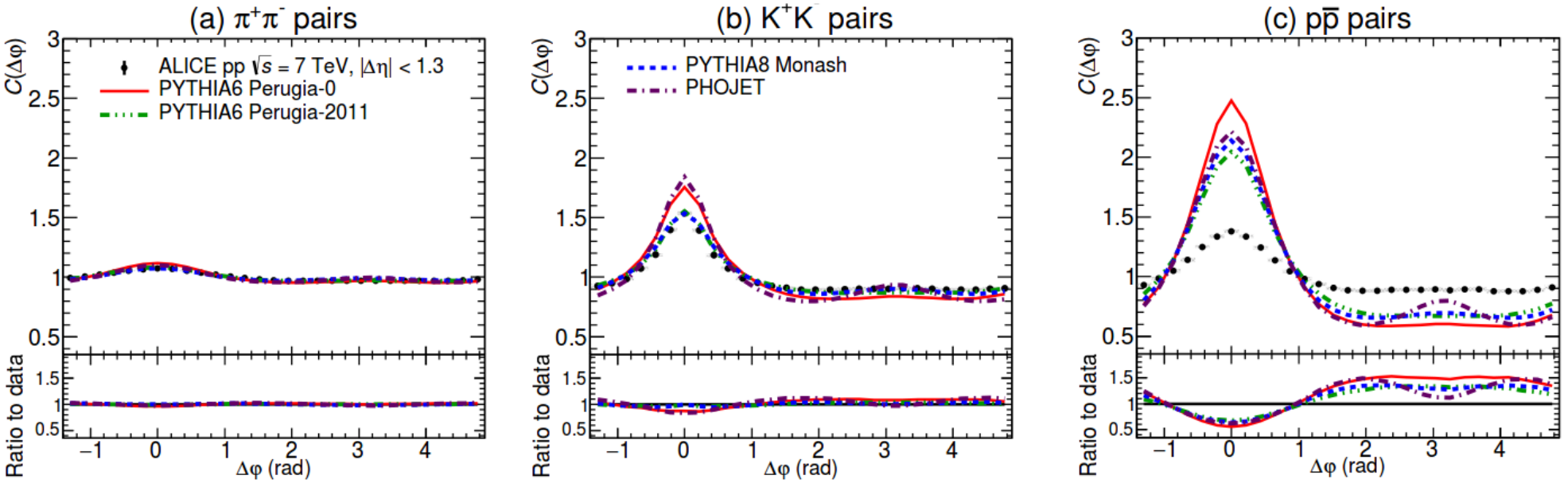
arXiv:1612.08975



- The models reproduce reasonably well the angular correlations for mesons
- The models fail to reproduce the results for baryons – they are able to produce 2 baryons close in the phase space
- **Energy and local baryon-number conservation laws are implemented in all studied models - not enough to explain the anti-correlation observed in experimental data**

Comparison to MC models: unlike-sign

arXiv:1612.08975



- The models reproduce reasonably well the angular correlations for mesons
- The models fail to reproduce the results for baryons – they are able to produce 2 baryons close in the phase space, also baryon-antibaryon pairs have 2 x the magnitude for MC
- **Energy and local baryon-number conservation laws are implemented in all studied models - not enough to explain the anti-correlation observed in experimental data**

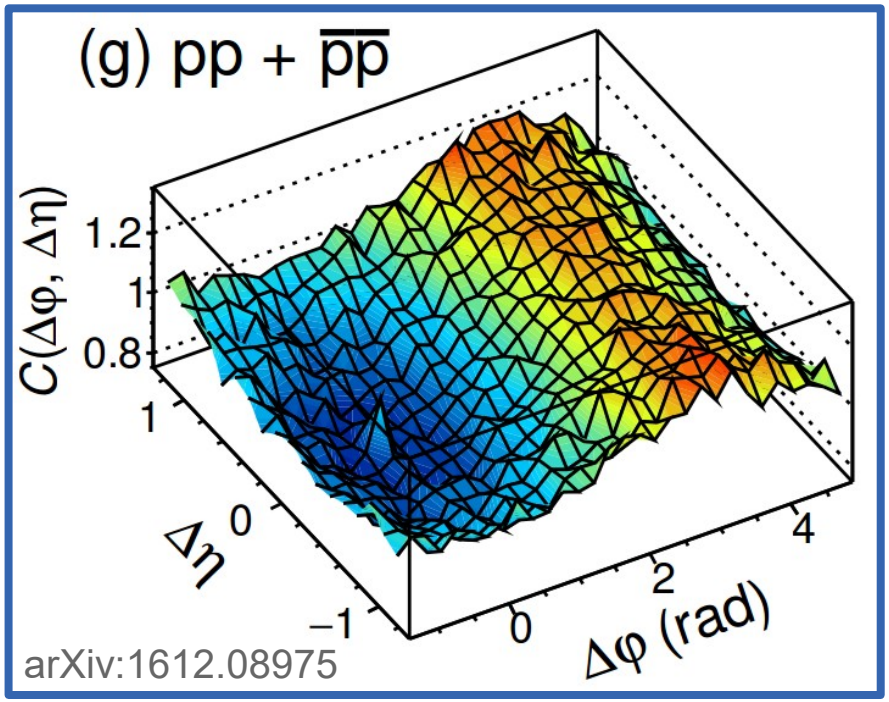
Possible explanations

Not likely (checked with MC):

- Depletion is a simple manifestation of "local" baryon number conservation and energy conservation
  - Production of 2 baryons in a single mini-jet would be suppressed if the initial parton energy is small when compared to the energy required to produce 4 baryons in total (2 in the same mini-jet + 2 anti-particles)
    – fine at 29 GeV, PRL 57 (1986) 3140, but why at 7 TeV?!

Other possible explanations:

- Other baryons?
- Coulomb repulsion?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

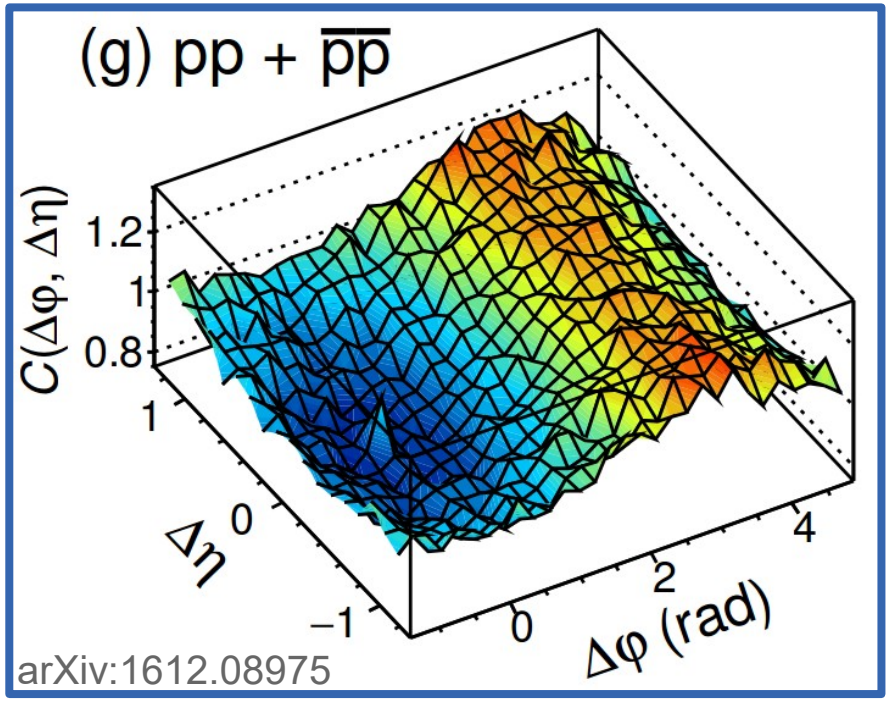


Possible explanations

Other possible explanations:

- Other baryons?
- Coulomb repulsion?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

Study Λ correlations



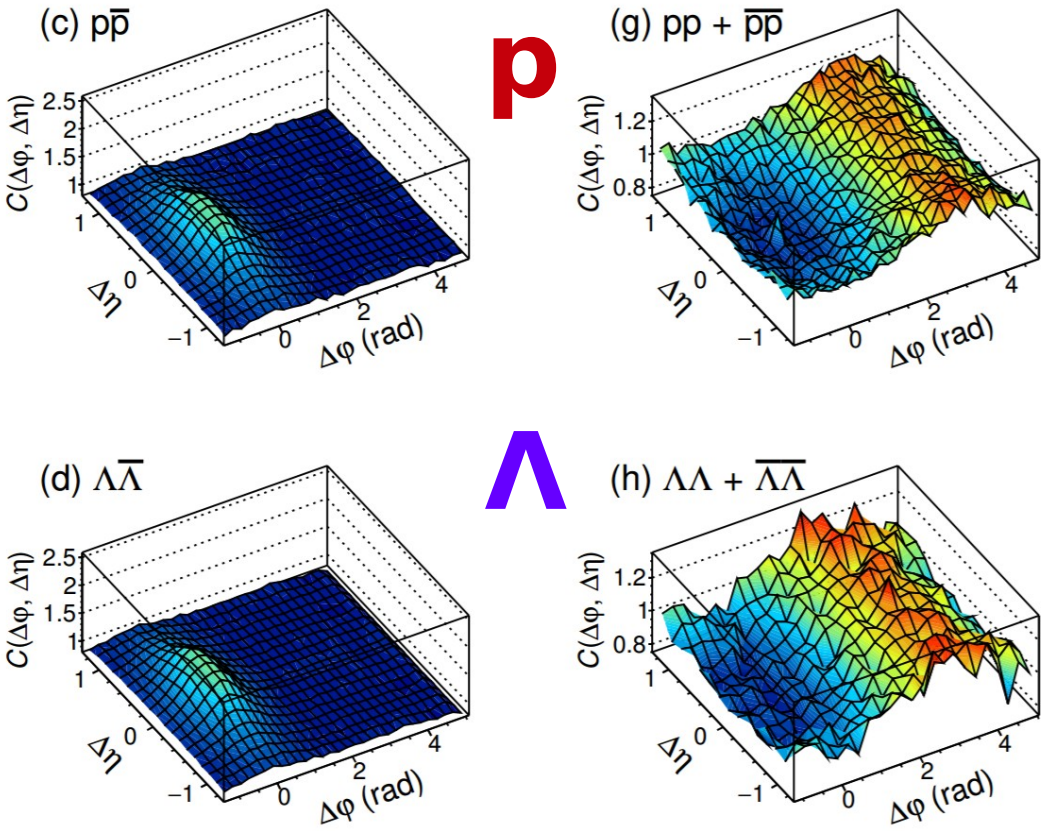
ΛΛ correlation functions

- Useful to check if effect persists for other baryons than protons – is this a common effect for all baryons?

- Correlation functions were calculated for **ΛΛ** pairs

- **Λ** baryons are neutral → no Coulomb repulsion

- **All observations from pp can be extended to ΛΛ**

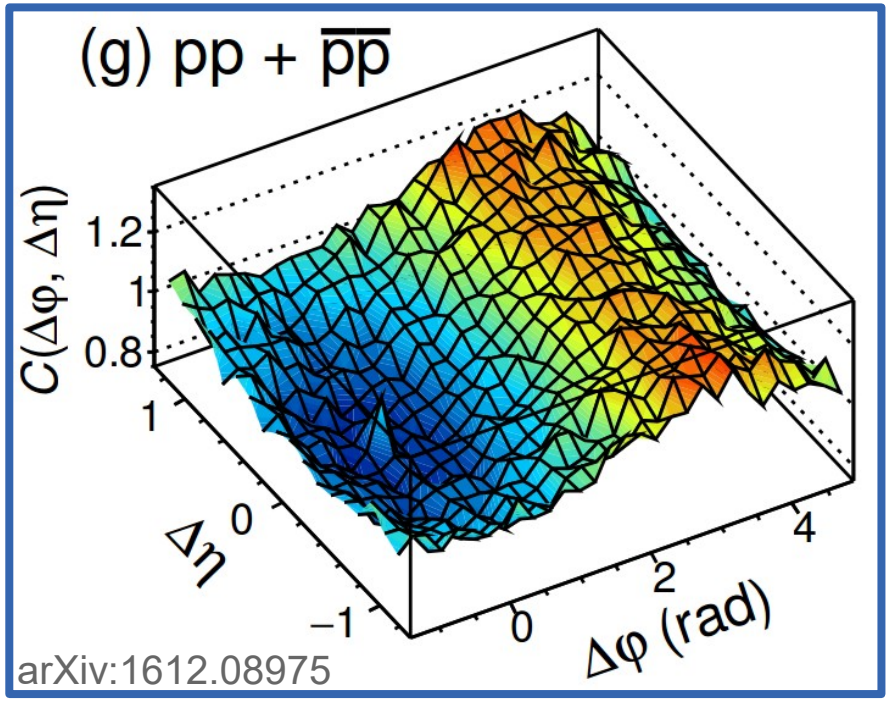


Possible explanations

Other possible explanations:

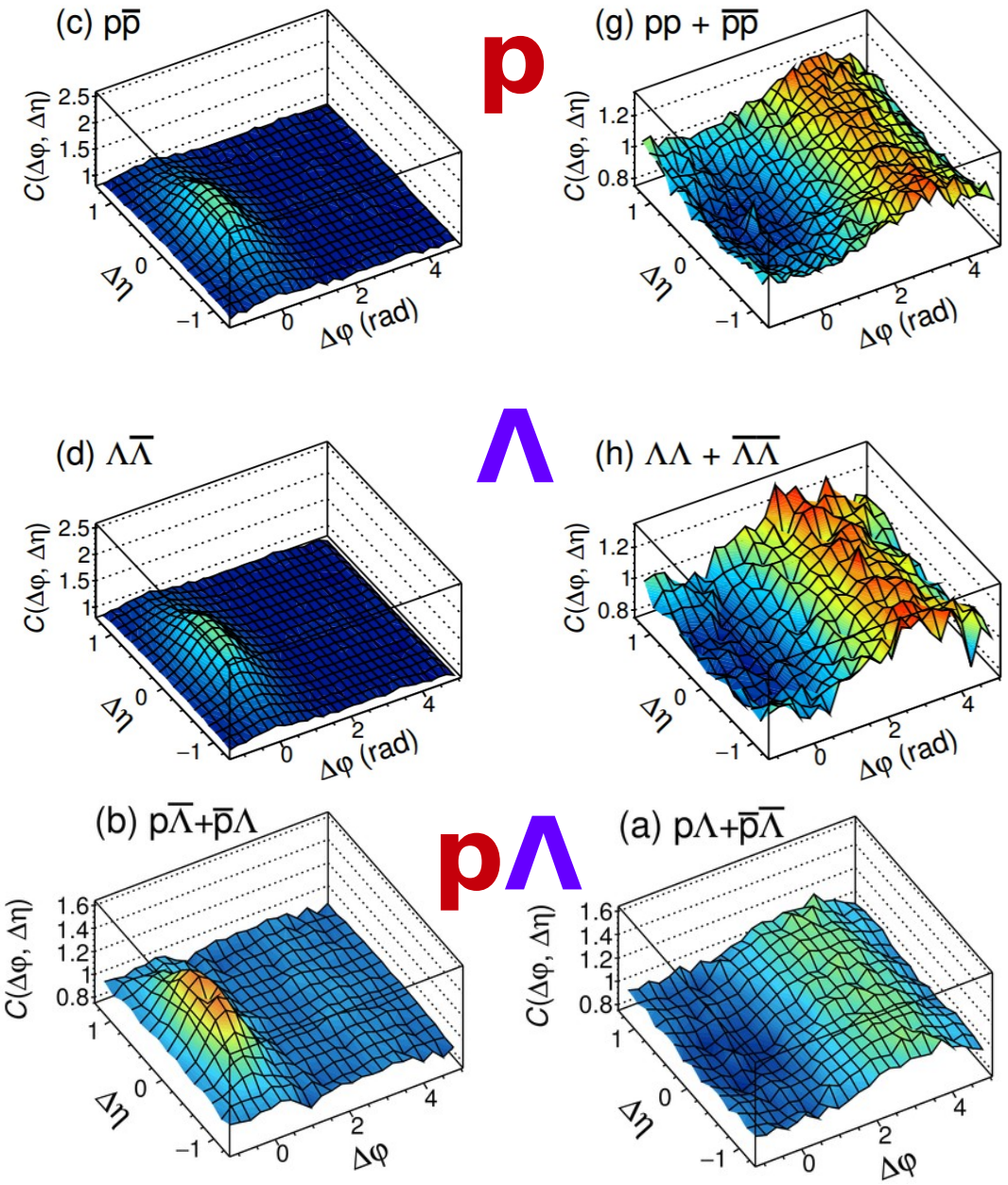
- Other baryons?
- Coulomb repulsion?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

Study pΛ correlations



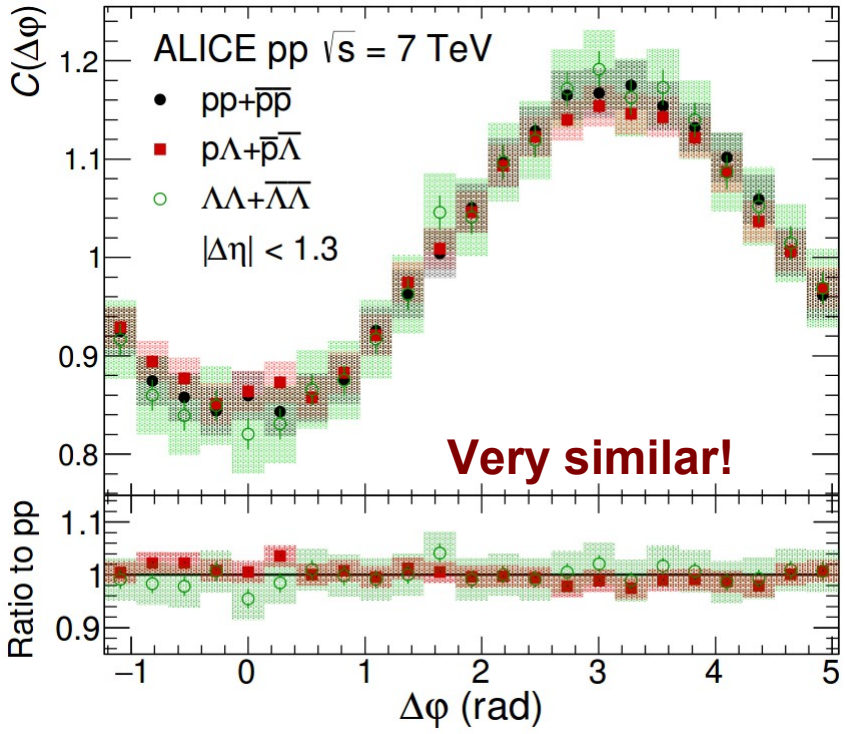
ΛΛ and pΛ correlation functions

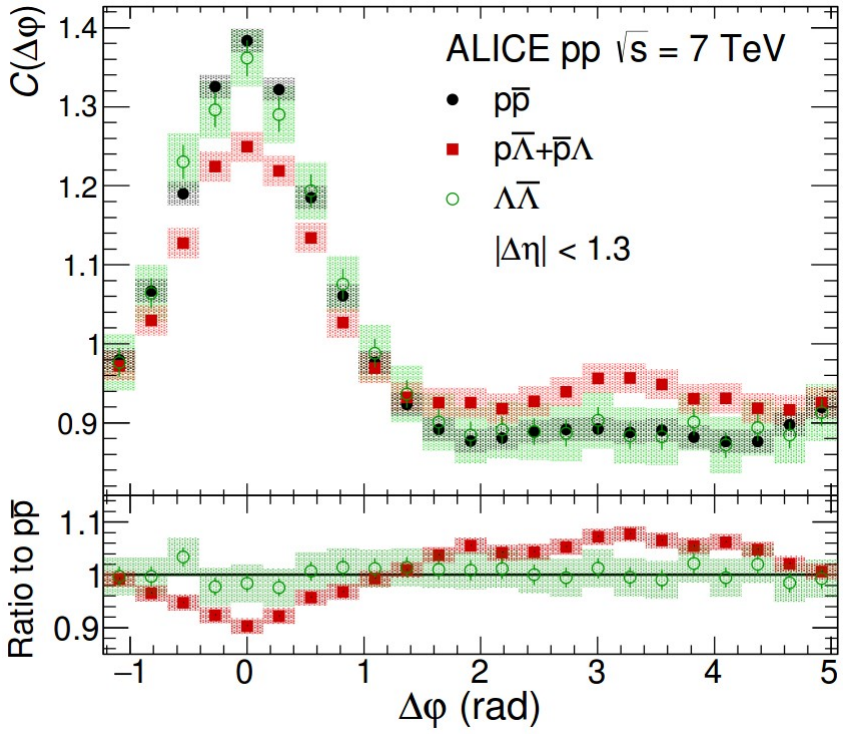
- Useful to check if effect persists for other baryons than protons – is this a common effect for all baryons?
- Correlation functions were calculated for **ΛΛ and pΛ** pairs
- **Λ** baryons are neutral → no Coulomb repulsion
- **p** and **Λ** are not identical → no effect from Fermi-Dirac statistics
- **All observations from pp can be extended to ΛΛ and pΛ**



Comparison between pp, pΛ, ΛΛ

like-sign arXiv:1612.08975 **unlike-sign**





The shape of the correlation function for all studied baryon–baryon pairs is similar, regardless of particles' electric charge or quantum effects.

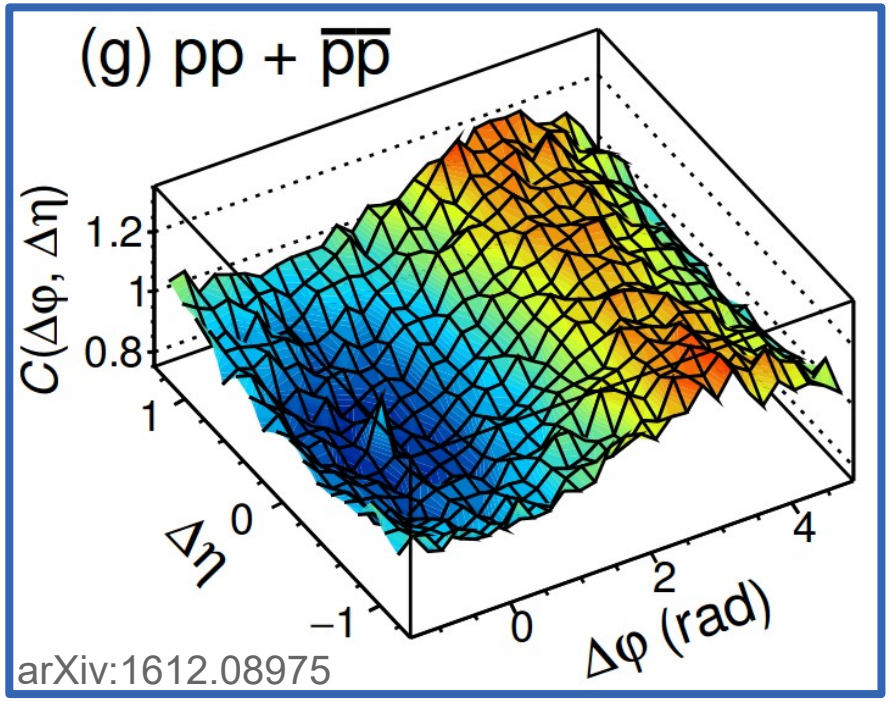
The observed depression is a characteristic attribute connected to the baryon number of the studied particles?

Possible explanations

Other possible explanations:

- Other baryons?
- Coulomb repulsion?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

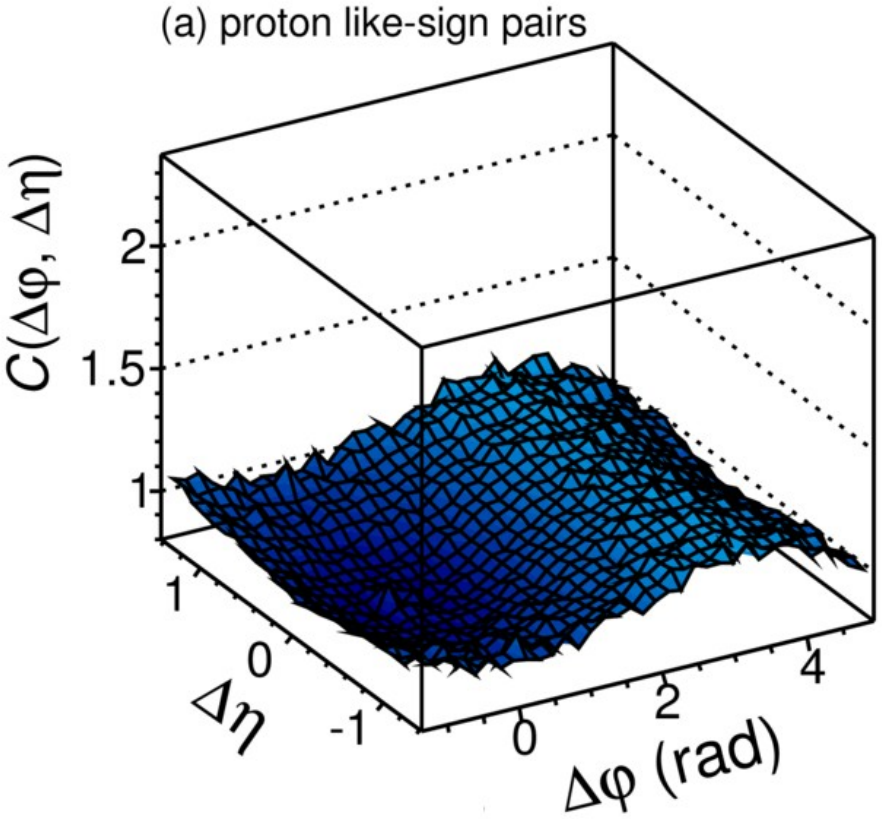
Several possible explanations checked and ruled out



(Δη,Δφ) of identified particles of pp collisions

protons

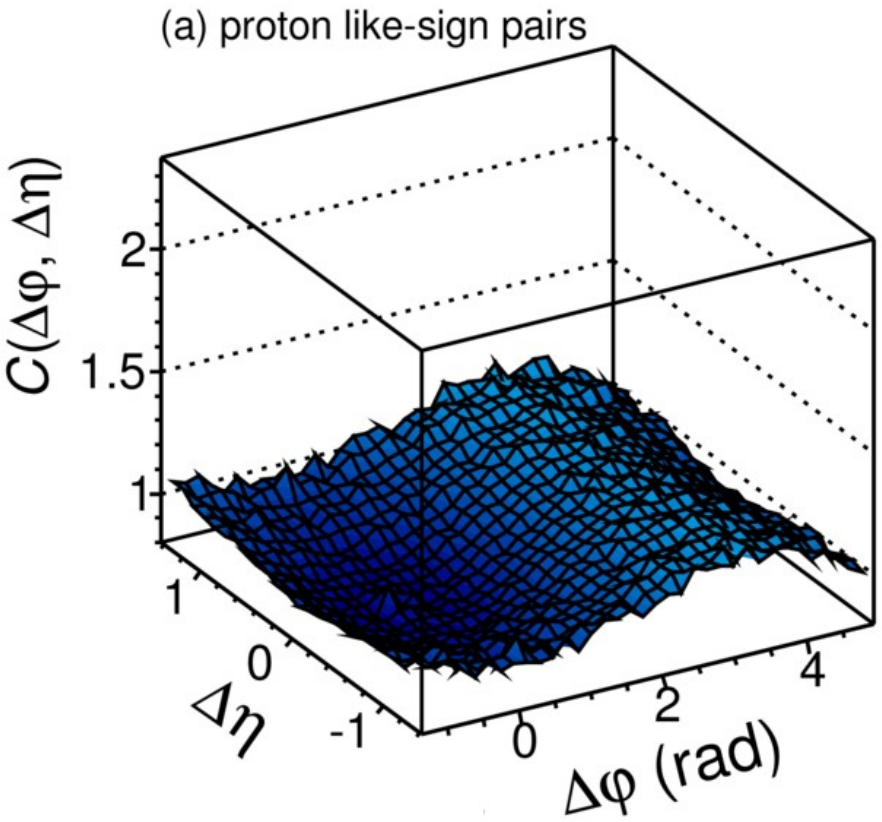
ALICE exp data



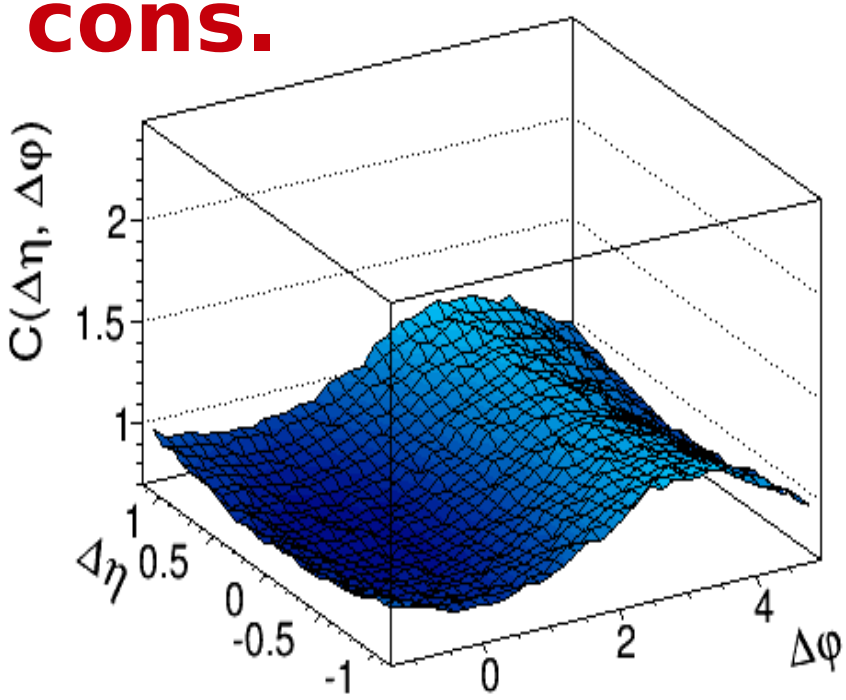
(Δη,Δφ) of identified particles of pp collisions

protons

ALICE exp data



MC only mom. cons.

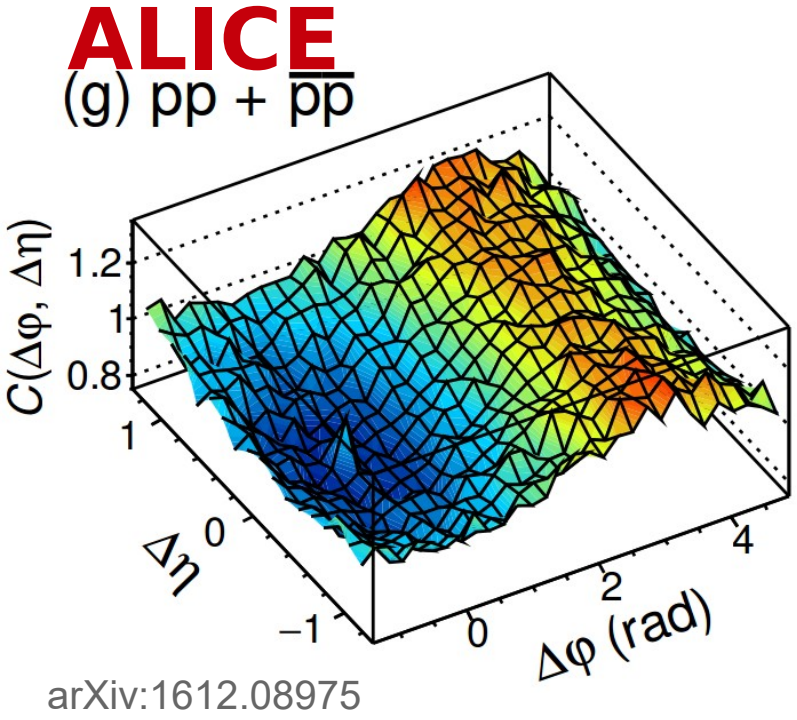


Toy Monte Carlo Events
with momentum conservation only

Strong suppression of any other effects ?
What is the underlying mechanism ?

Summary

- Correlation studies allow us to investigate a wide range of physics phenomena
- Still new mysteries to solve



arXiv:1612.08975

Baryon-baryon correlations not reproduced by MC models:

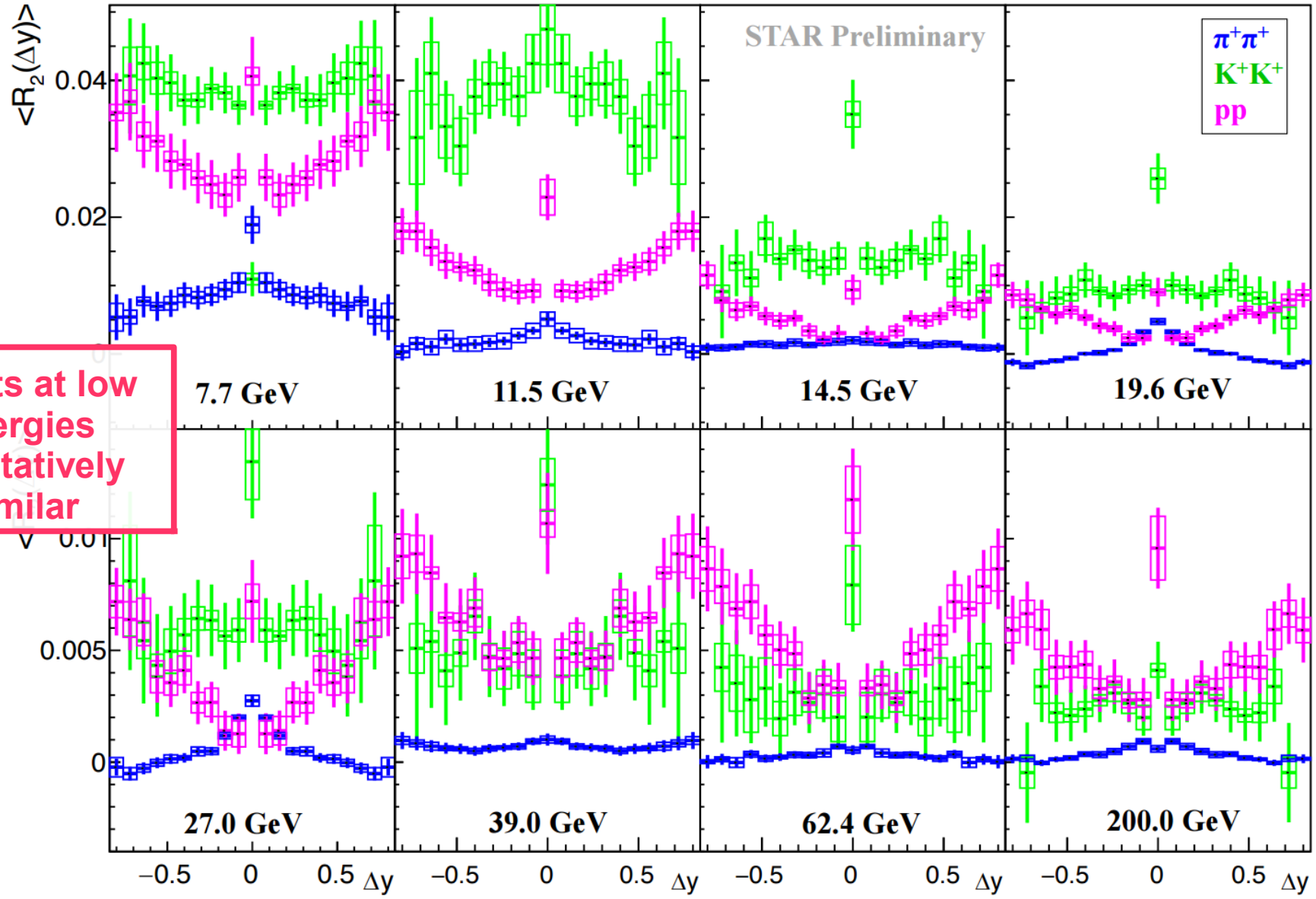
- Pythia6
- Pythia8
- Phojet
- EPOS
- HERWIG

No explanation found so far

Backup

$\pi^+\pi^+$, K^+K^+ and pp, 0-5% centrality

SRC was not subtracted



Effects at low energies qualitatively similar

Minima in $<R_2>$ of protons around Δy=0 at all beam energies

Point at Δy=0 reflects combination of SRC and the removal of track merging effects

STAR

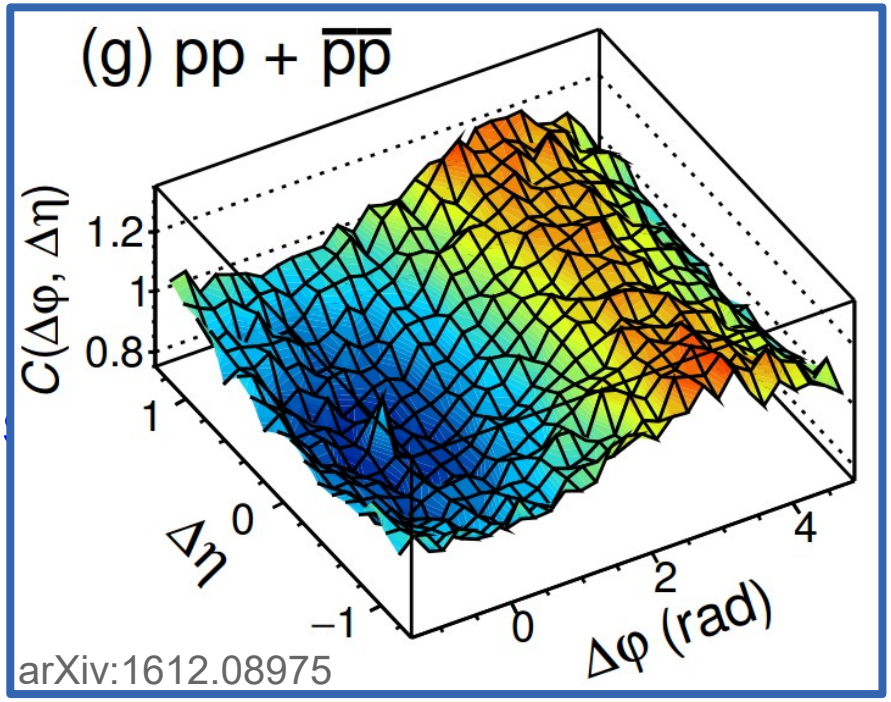
S. Jowzaee, Quark Matter 2017

Possible explanations

Other possible explanations:

- Other baryons?
- Coulomb repulsion?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

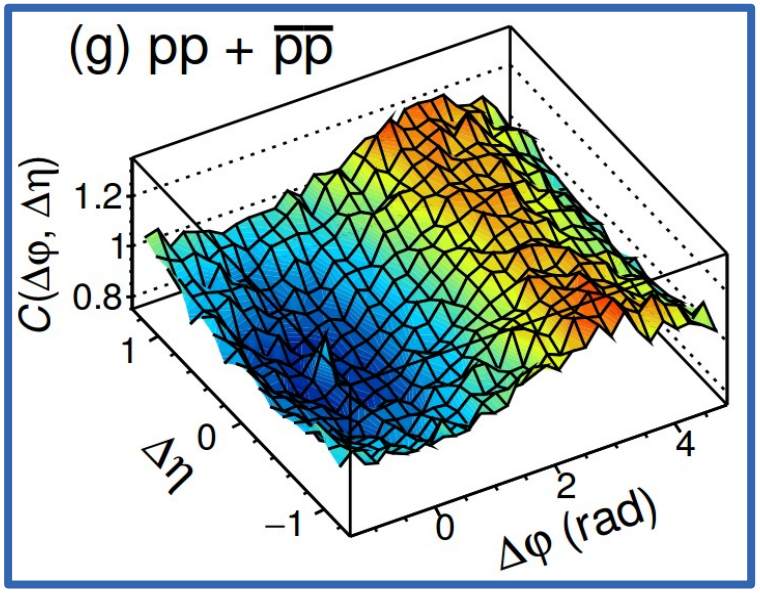
Study femtoscopic correlations



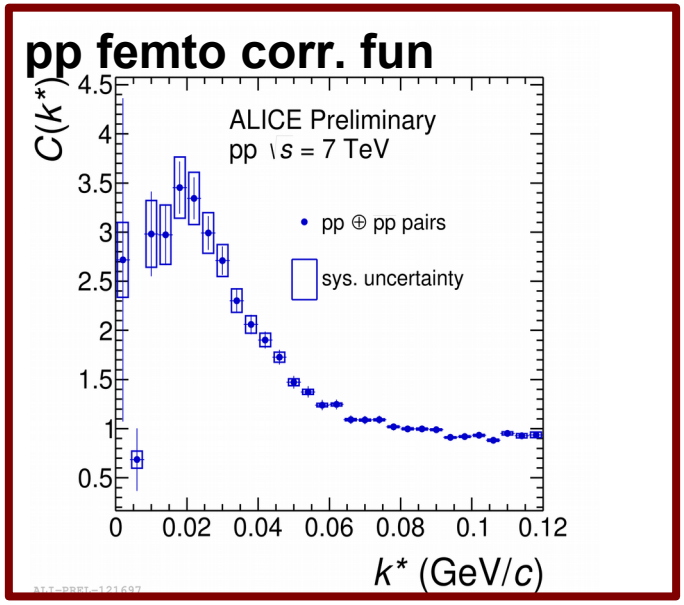
Possible explanations

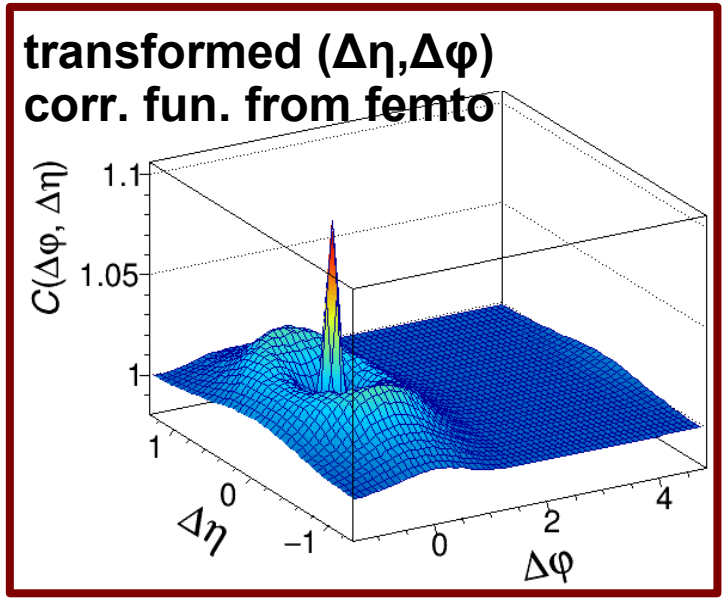
Other possible explanations:

- **Other baryons?**
- **Coulomb repulsion?**
- **Fermi-Dirac Quantum Statistics?**
- **Strong Final-State Interactions?**
  - Femto correlation produces spike at (Δη,Δφ)=(0,0)
  - FSI cannot produce observed anti-correlation



arXiv:1612.08975

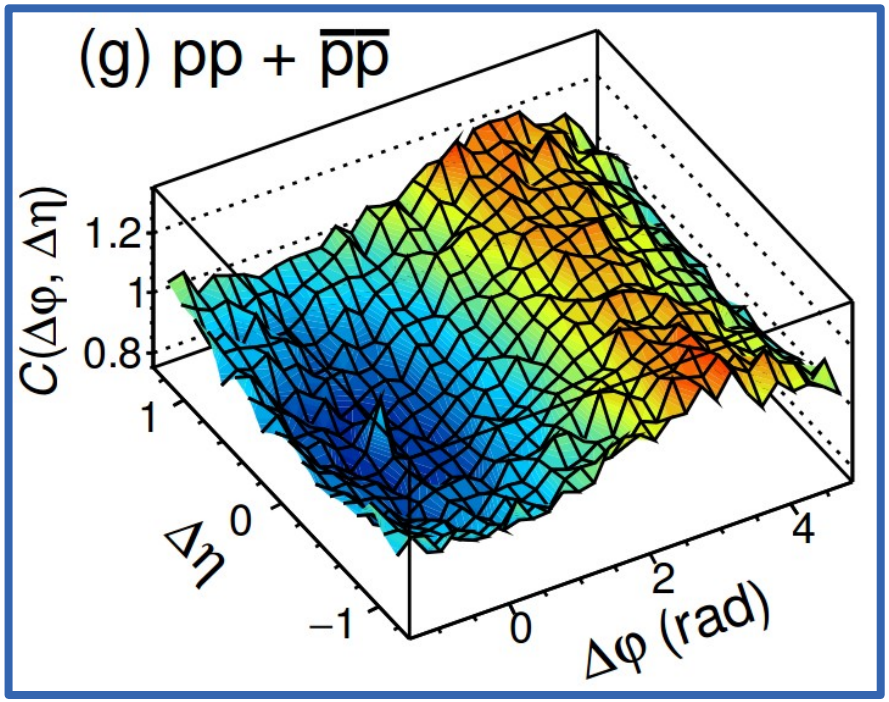




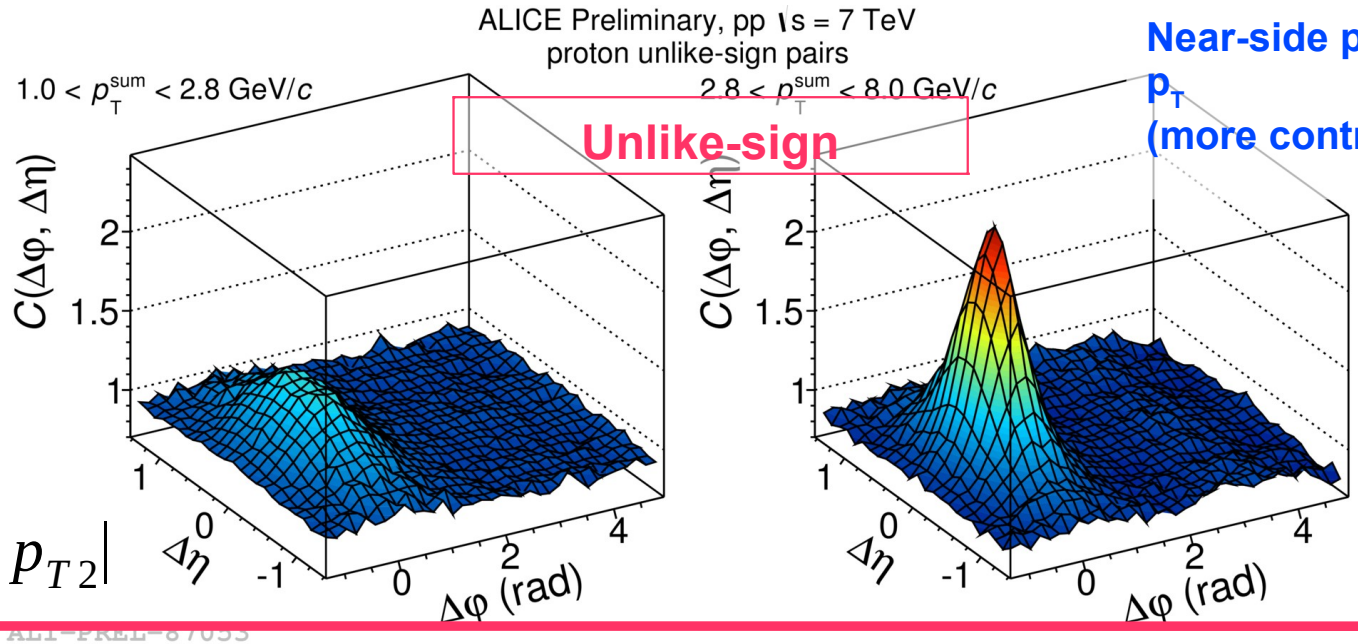
Possible explanations

Other possible explanations:

- Dependence on p_T range?
- Coulomb repulsion?
- Other baryons?
- Fermi-Dirac Quantum Statistics?
- Strong Final-State Interactions?

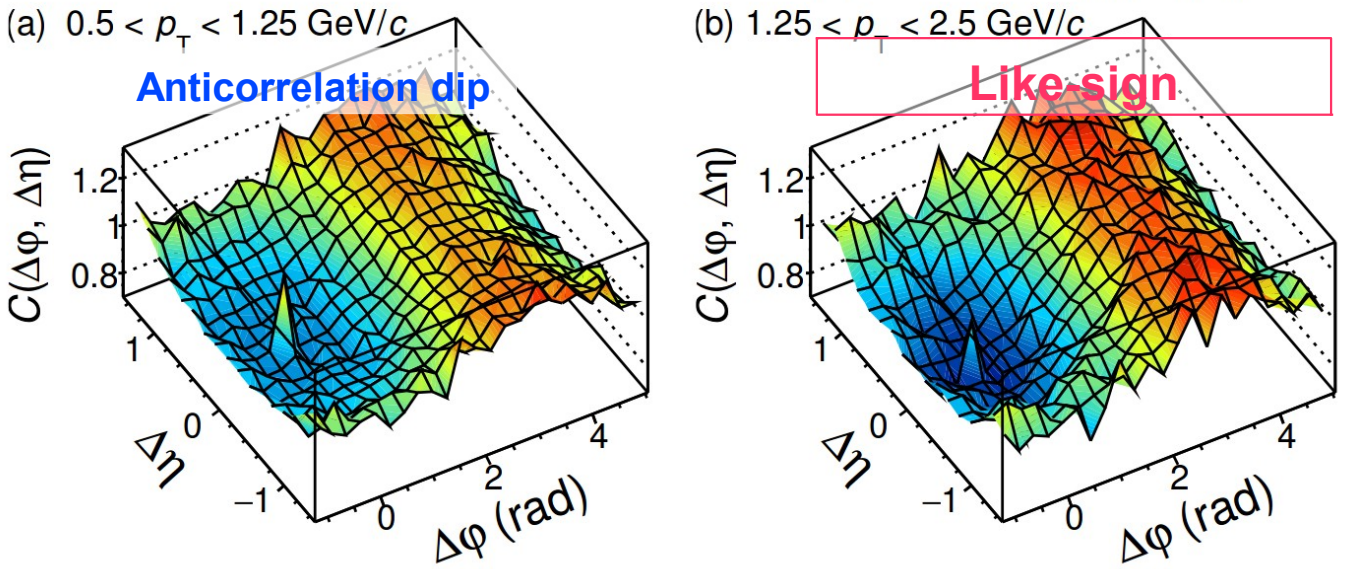


Protons



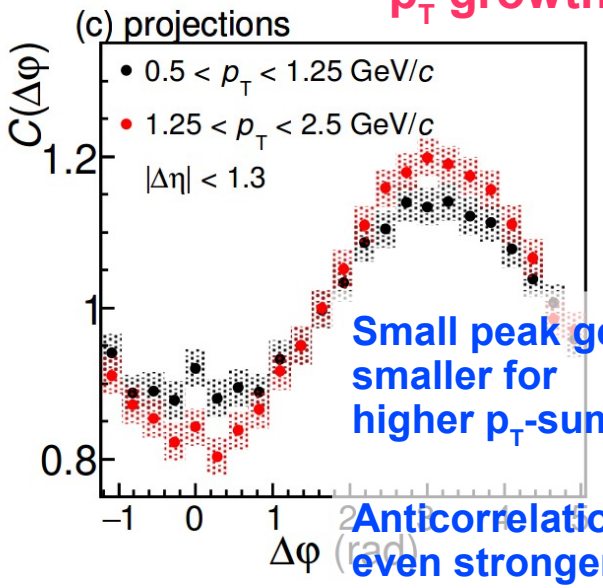
Near-side peak grows with p_T (more contribution from jets)

$$p_T^{sum} = |p_{T1}| + |p_{T2}|$$



arXiv:1612.08975

p_T growth

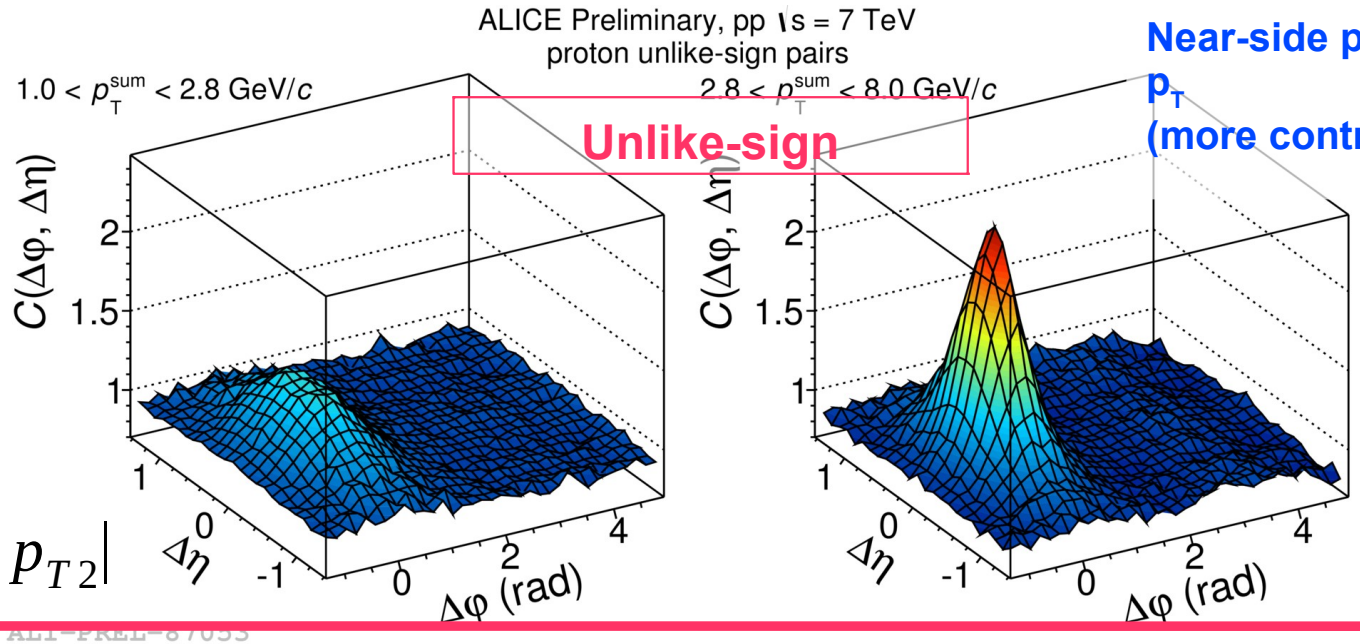


Small peak gets smaller for higher p_T-sum

Anticorrelation even stronger

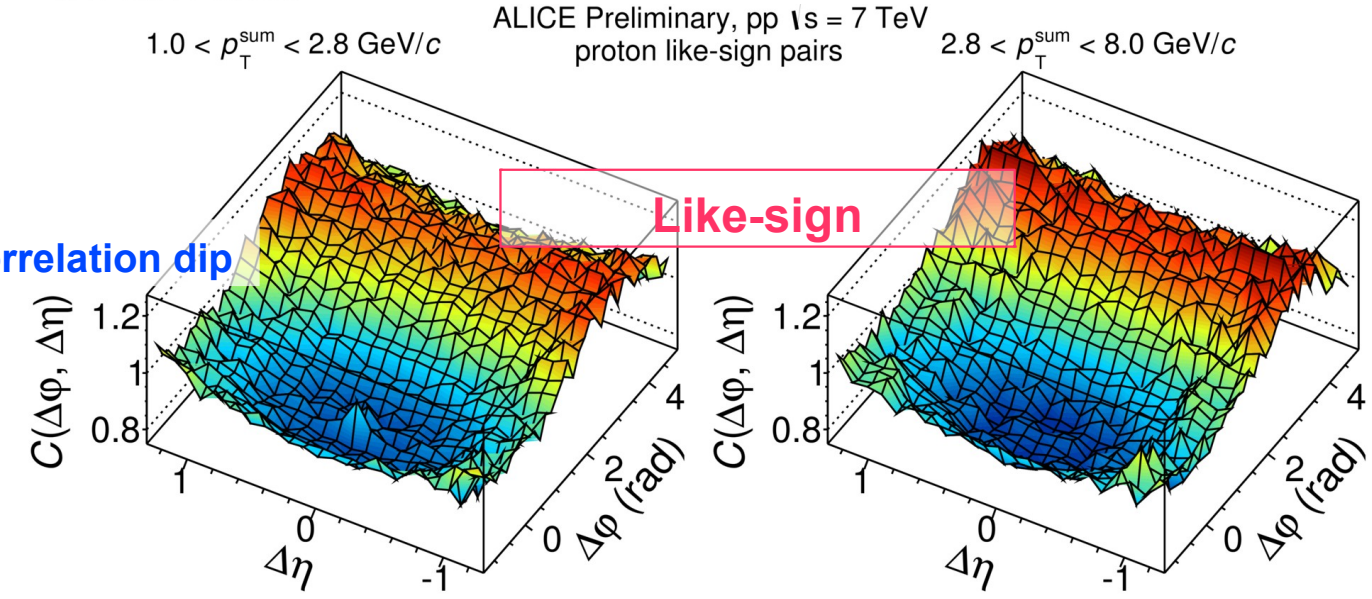
Protons

$$p_{Tsum} = |\vec{p}_{T1}| + |\vec{p}_{T2}|$$



Near-side peak grows with p_T (more contribution from jets)

$$p_T^{sum} = |p_{T1}| + |p_{T2}|$$



p_T growth

Anticorrelation dip

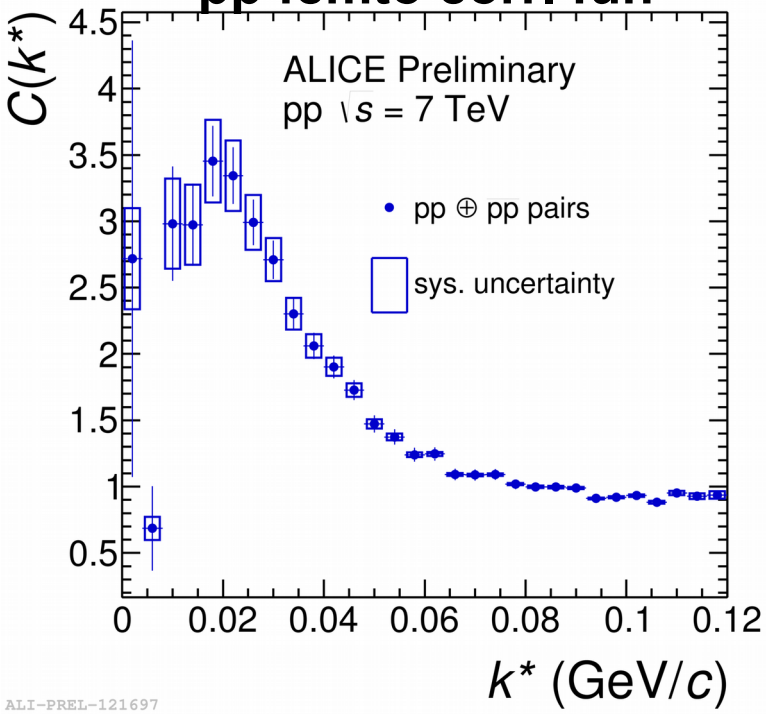
Small peak disappears for high p_T-sum

Shape of the dip does not change

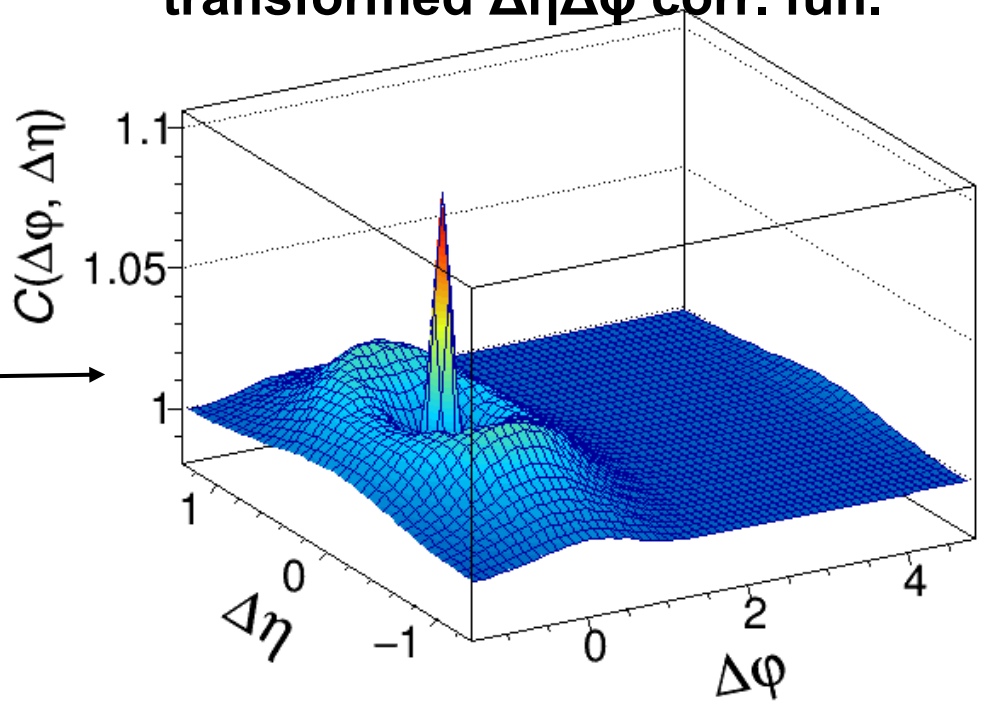
Proton correlations – transformation

- Direct transformation from $C(q_{inv})$ to $C(\Delta\eta\Delta\varphi)$ **not possible**
- One can employ a simple **Monte Carlo procedure:**
  - generate random η and φ from uniform distributions (for 2 particles: η_1, η_2, φ_1, φ_2)
  - generate random p_T from measured p_T distribution (for 2 particles: p_{T1}, p_{T2})
  - calculate k* from generated η_1, η_2, φ_1, φ_2, p_{T1} and p_{T2}
  - take the value of measured femtoscopic correlation function at given k* and apply it as weight while filling the numerator of ΔηΔφ

pp femto corr. fun



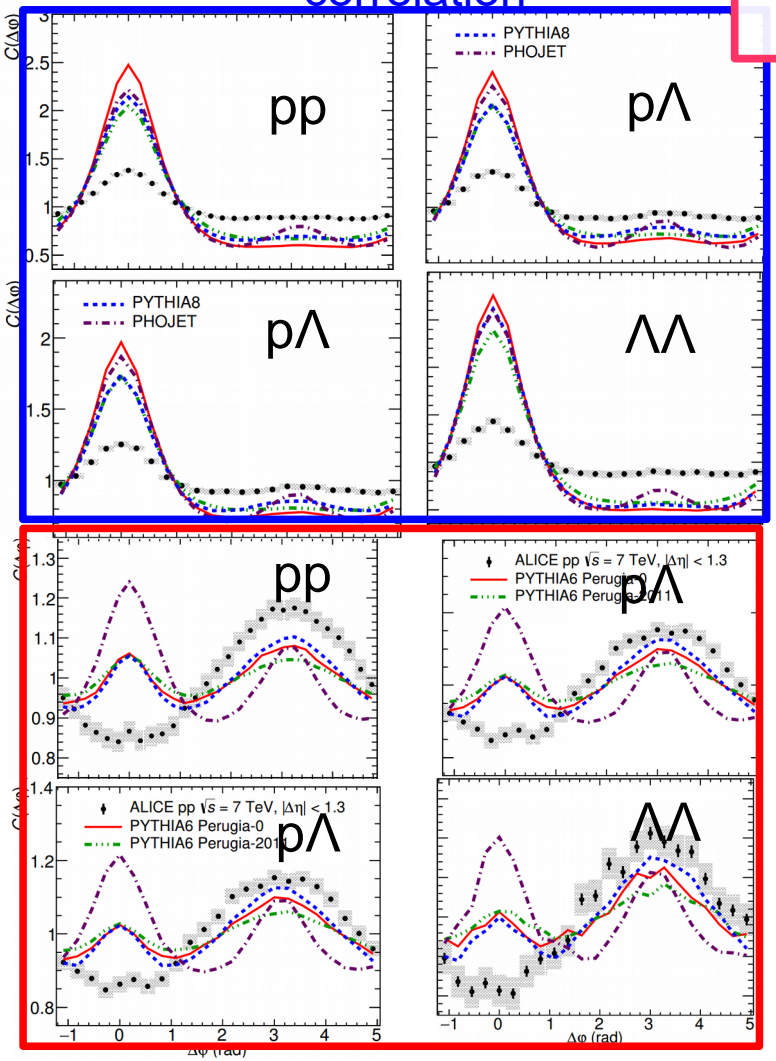
transformed ΔηΔφ corr. fun.



(Δη,Δφ) of identified particles of pp collisions

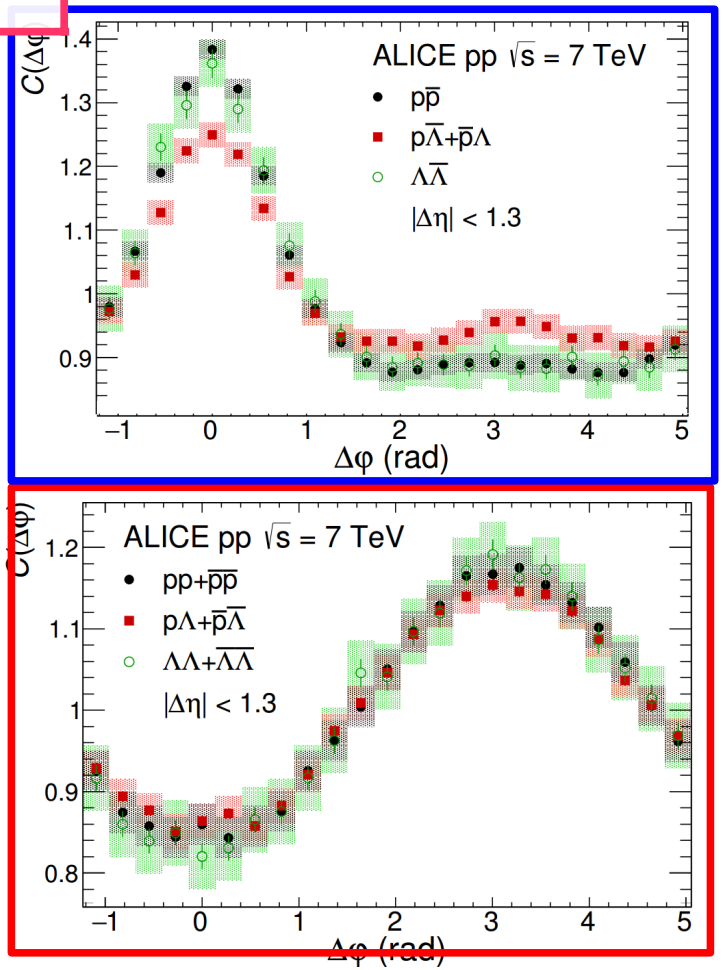
baryon-antibaryon correlation

7 TeV : not reproduced by MC



(anti)baryon-(anti)baryon anticorrelation!

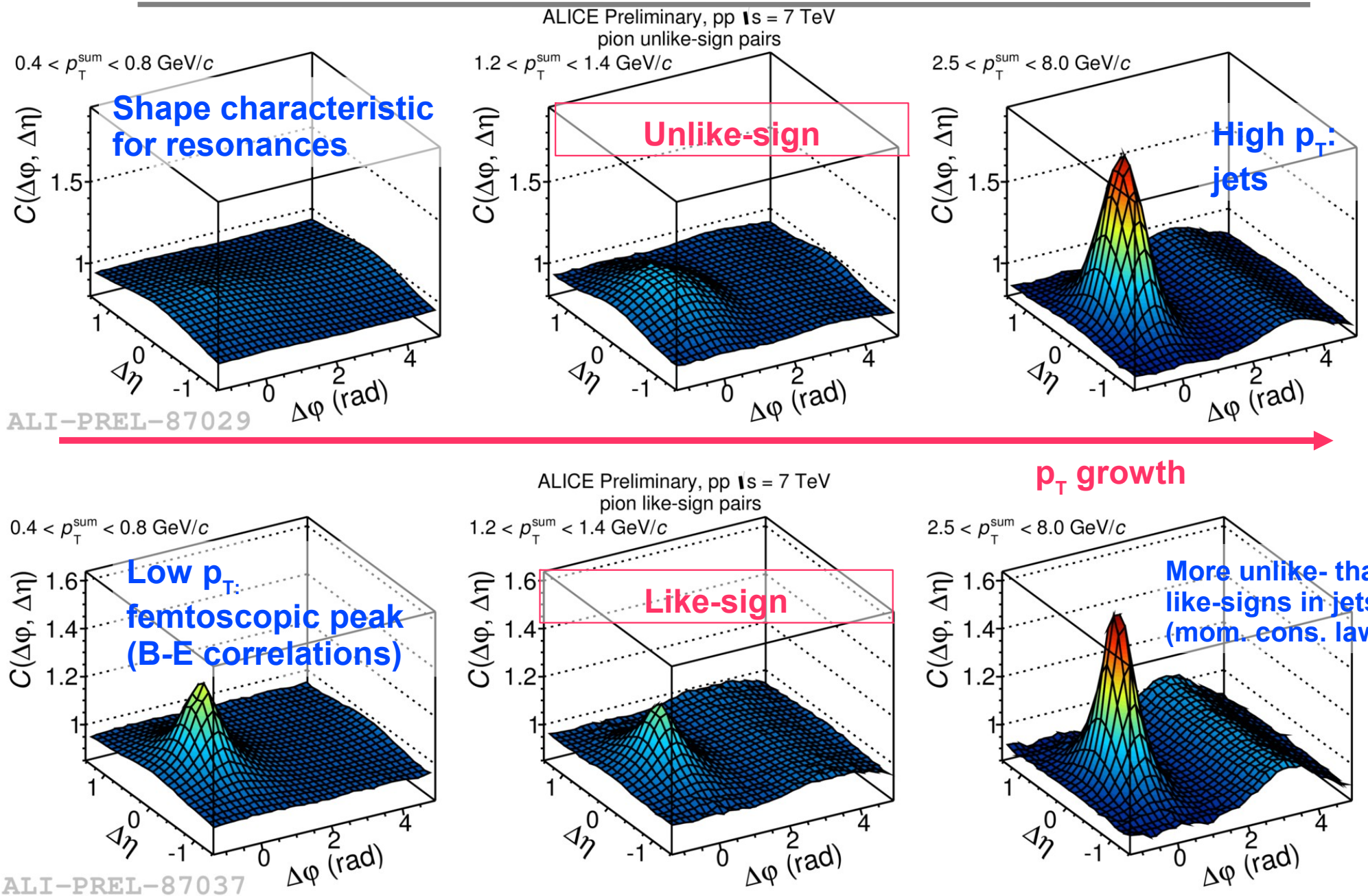
baryon-antibaryon correlation



(anti)baryon-(anti)baryon anticorrelation!

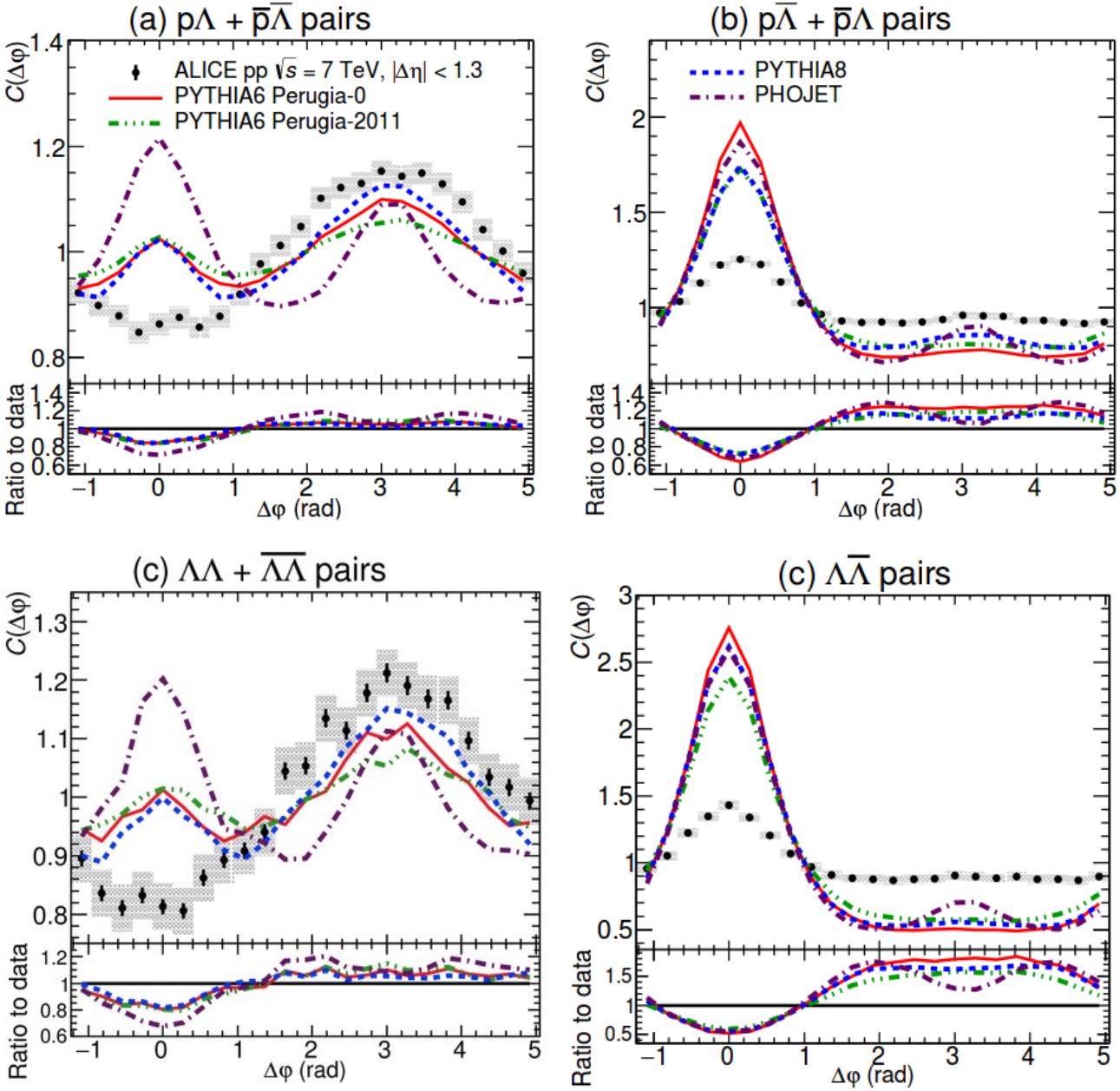
Pions

$$p_{Tsum} = |\vec{p}_{T1}| + |\vec{p}_{T2}|$$



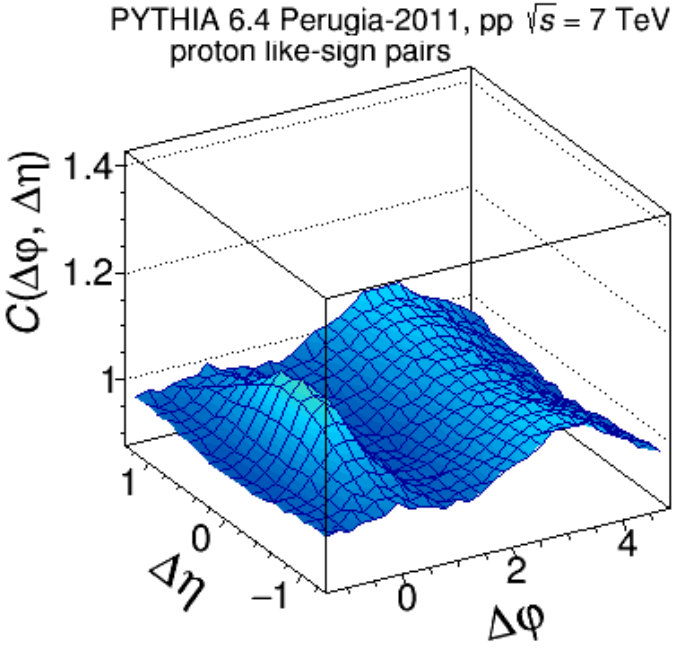
Comparison to MC models

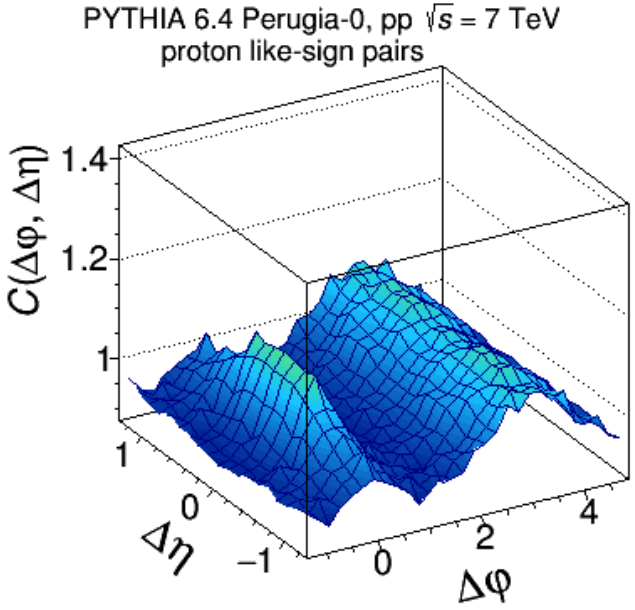
arXiv:1612.08975

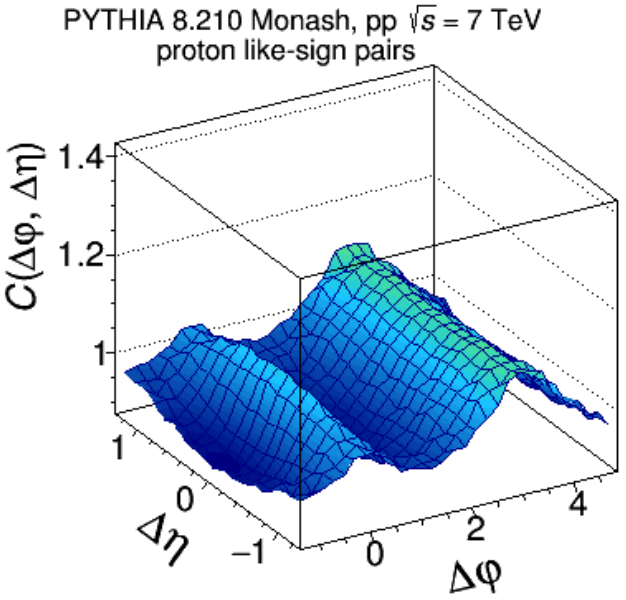


- **The models fail to reproduce the results for baryons for all pair combinations**

(Δη,Δφ) of identified particles in pp collisions







Let's compare with models!

None of common MC models reproduces ALICE data!