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Insight into particle production mechanisms via angular correlations of pions, kaons, protons and lamdbas in pp collisions

Małgorzata Janik

Remark: this is a presentation for internal discussions during the GDRE workshop. For an article see arXiv:1612.08975.

For official ALICE presentation on this topic see presentation from CERN-LHC seminar: https://indico.cern.ch/event/632396/

In case of ideas and comments please contact: majanik@cern.ch

GDRE 2017
3-7.06.2017

Insight into particle production mechanisms via angular correlations of pions, kaons, protons and lamdbas in pp collisions

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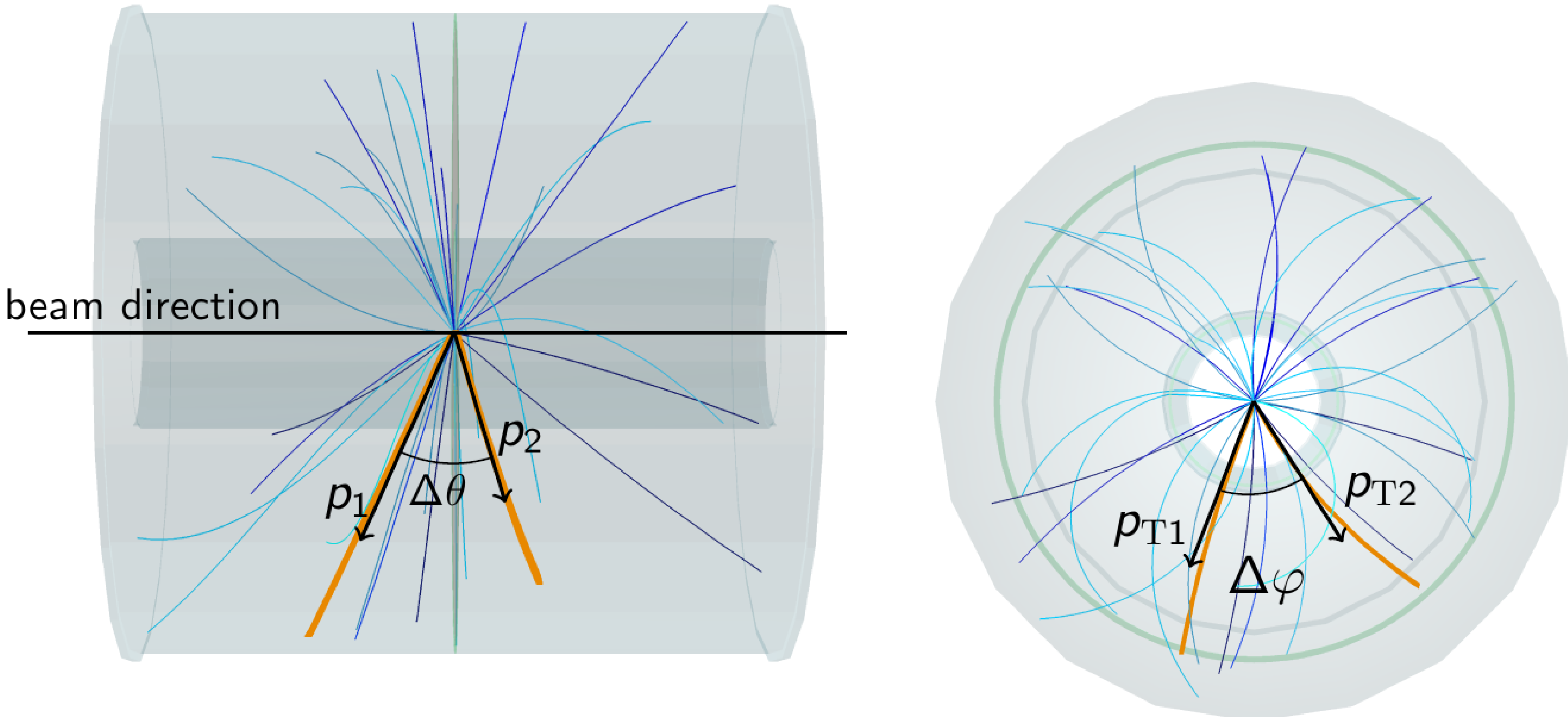
Two-particle (Δη,Δφ) angular correlations



p - particle momentum;

θ - polar angle;

η - pseudorapidity:

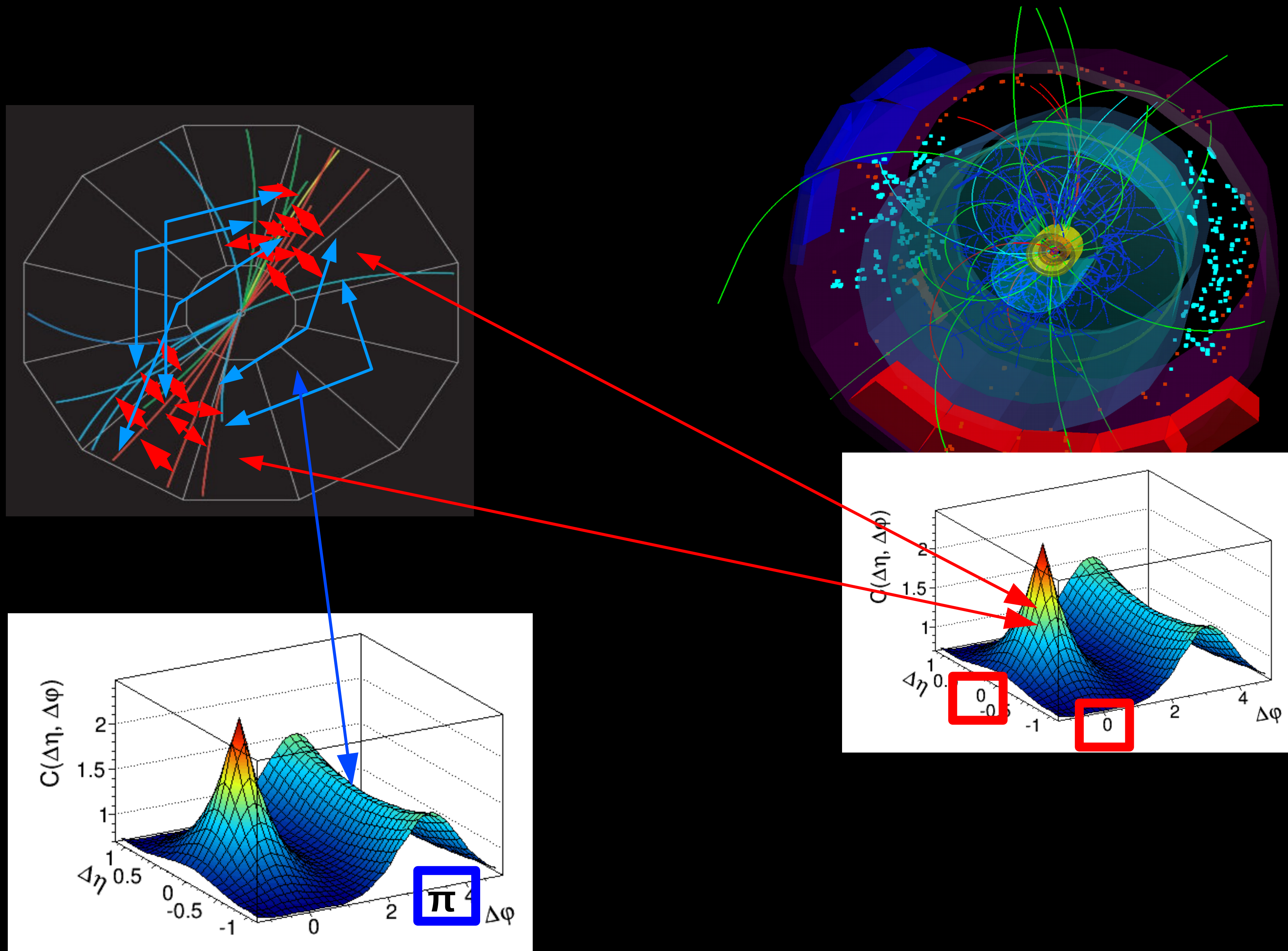
$$\eta = -\ln\left(tg\frac{\theta}{2}\right)$$

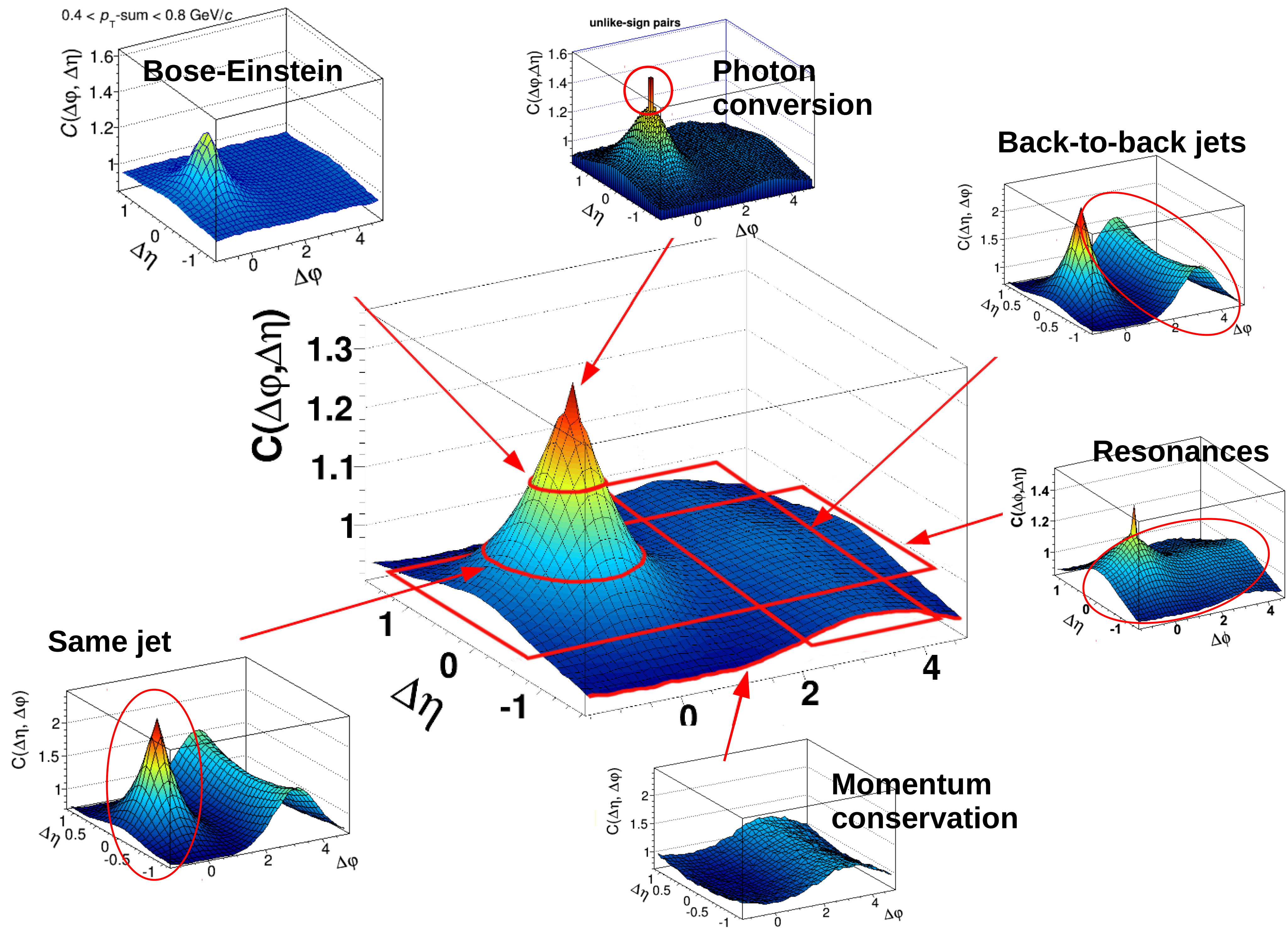
p_T - transverse momentum;

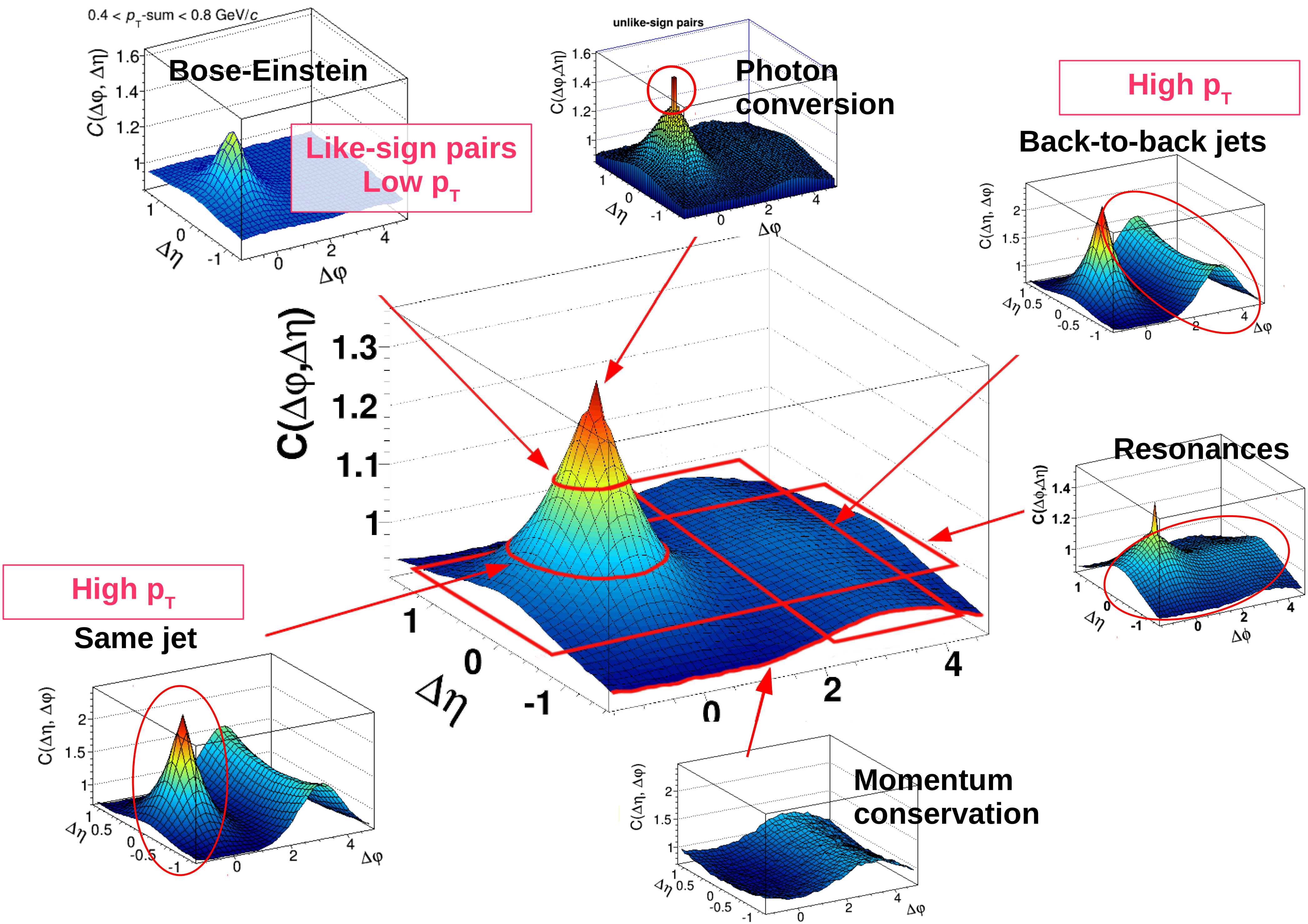
φ - azimuthal angle;

Fig. A. Zaborowska

(Δη,Δφ) angular correlations




Bose-Einstein
0.4 < p_T-sum < 0.8 GeV/c
Photon conversion
unlike-sign pairs
Back-to-back jets
Resonances
Same jet
Momentum conservation
C(Δφ,Δη)
Δη
Δφ

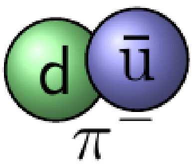


0.4 < p_T-sum < 0.8 GeV/c
Bose-Einstein
Like-sign pairs
Low p_T
unlike-sign pairs
Photon conversion
High p_T
Back-to-back jets
Resonances
High p_T
Same jet
Momentum conservation
$C(\Delta\varphi,\Delta\eta)$
$\Delta\eta$
$\Delta\varphi$

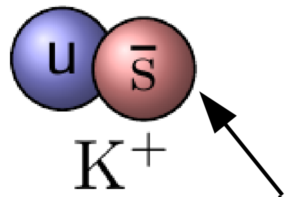
Can we learn something more?

One step further: identified particles!

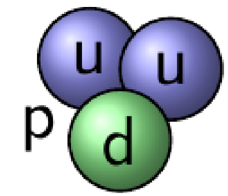
Unexplored phenomena: **conservation laws** and their influence on **particle production mechanisms –** study via correlation functions for particles with **different quark content**



Pion:
- Charge



Kaon:
- Charge
- Strange quark

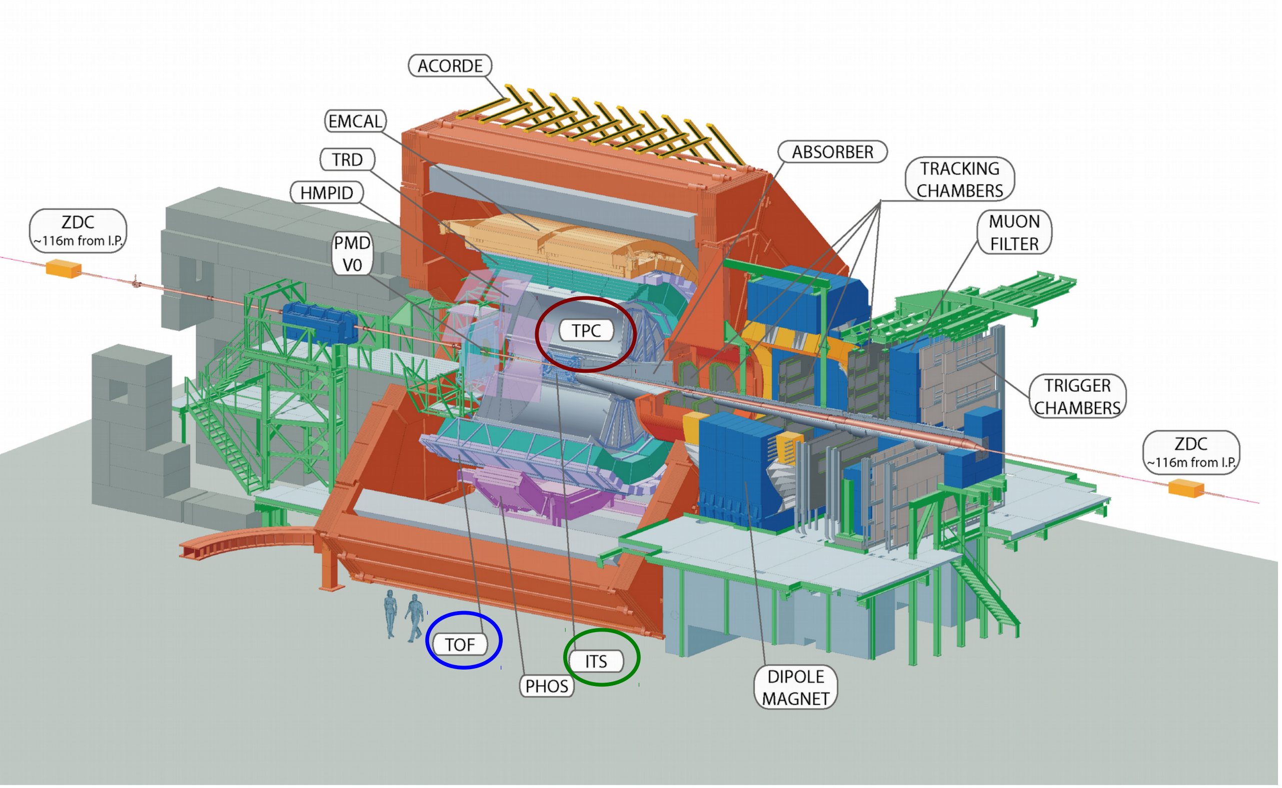


Proton:
- Charge
- Baryon

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

Useful to perform analysis in a more refined way:
- **charge dependence**
- **identified particles**

Data sample & analysis



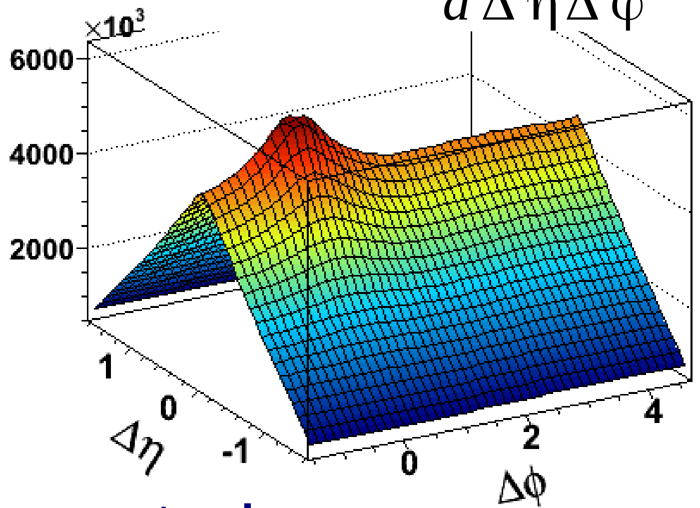
- ~200 million minimum bias pp collisions at 7 TeV collected by ALICE in 2010
- Tracking:
  - Inner Tracking System (ITS)
  - Time Projection Chamber (TPC)
- Particle identification:
  - TPC
  - Time-of-Flight (TOF)
- Recent paper **arXiv:1612.08975**

- 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*
  - $|\eta| < 0.8$

$(\Delta\eta,\Delta\varphi)$ Experimental Correlation Function

Signal distribution

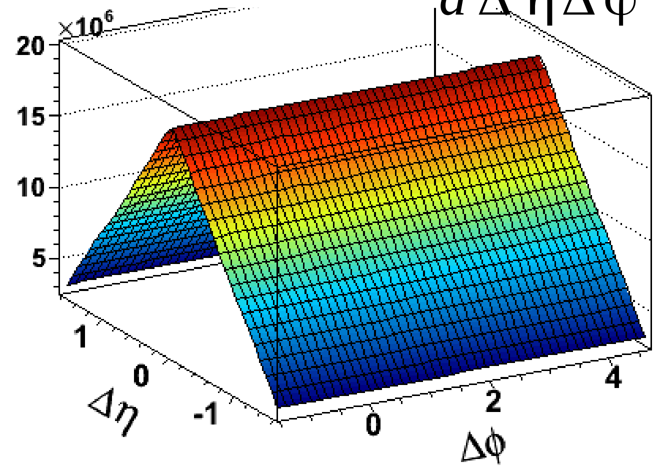
$$S(\Delta\eta,\Delta\varphi)=\frac{d^2 N^{signal}}{d\Delta\eta\Delta\varphi}$$



Same event pairs

Uncorrelated reference

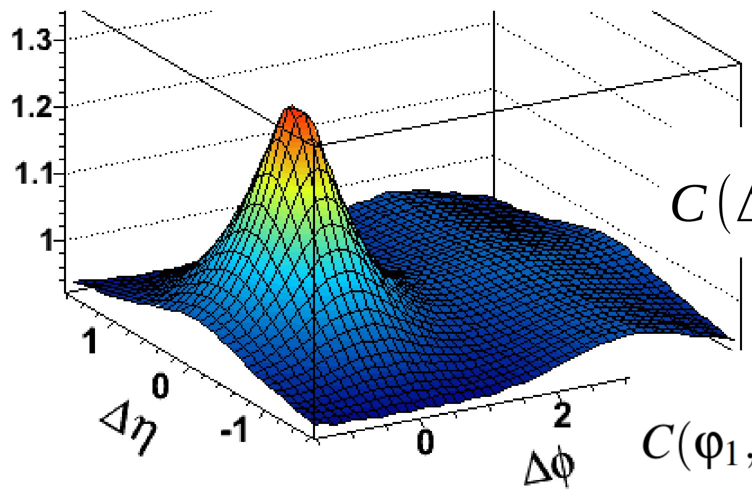
$$B(\Delta\eta,\Delta\varphi)=\frac{d^2 N^{mixed}}{d\Delta\eta\Delta\varphi}$$



Mixed event pairs

Correlation function

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

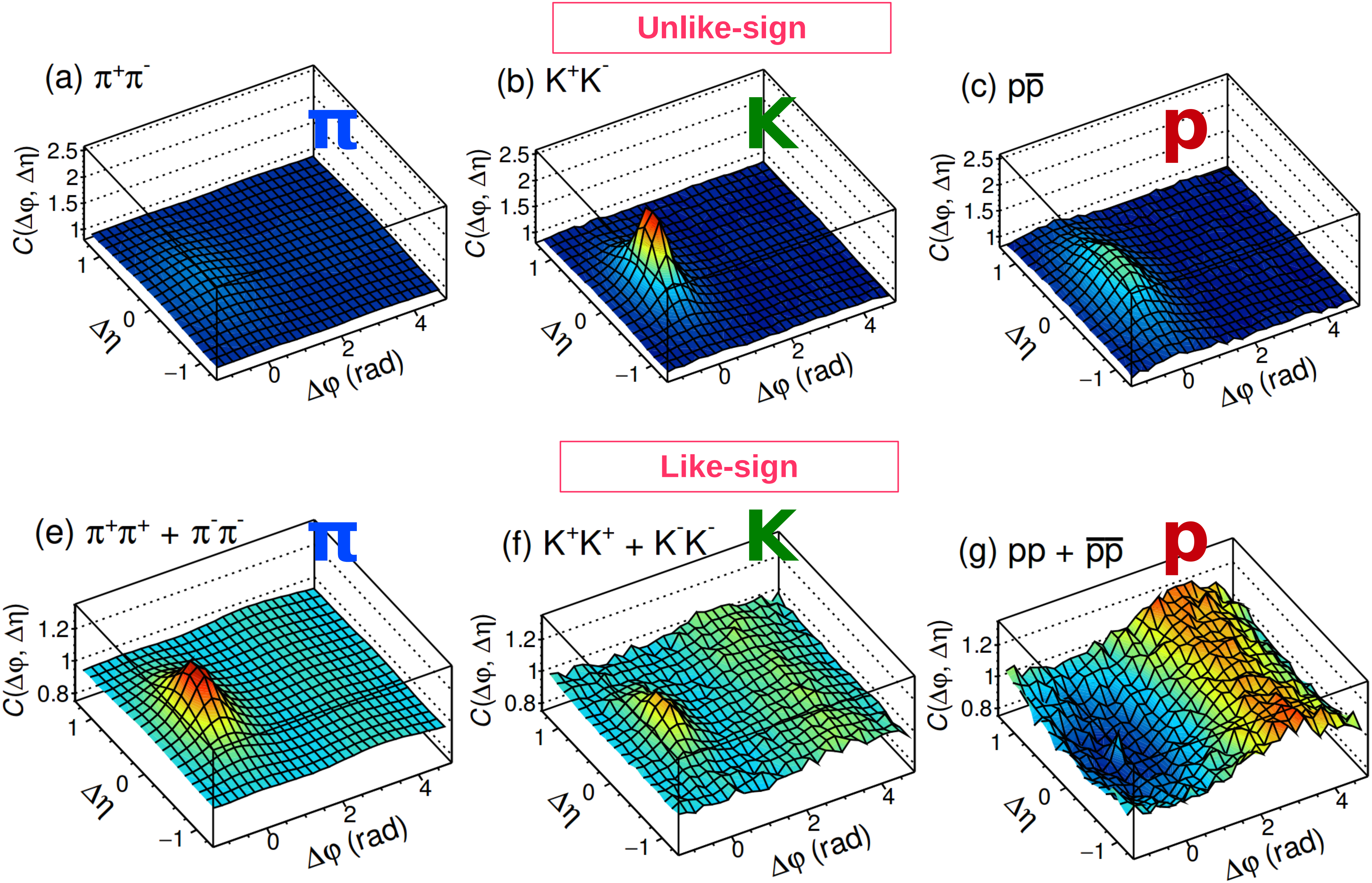


$$C(\Delta\eta,\Delta\varphi)=\frac{N^{mixed}_{pairs}}{N^{signal}_{pairs}}\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\varphi)}$$

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

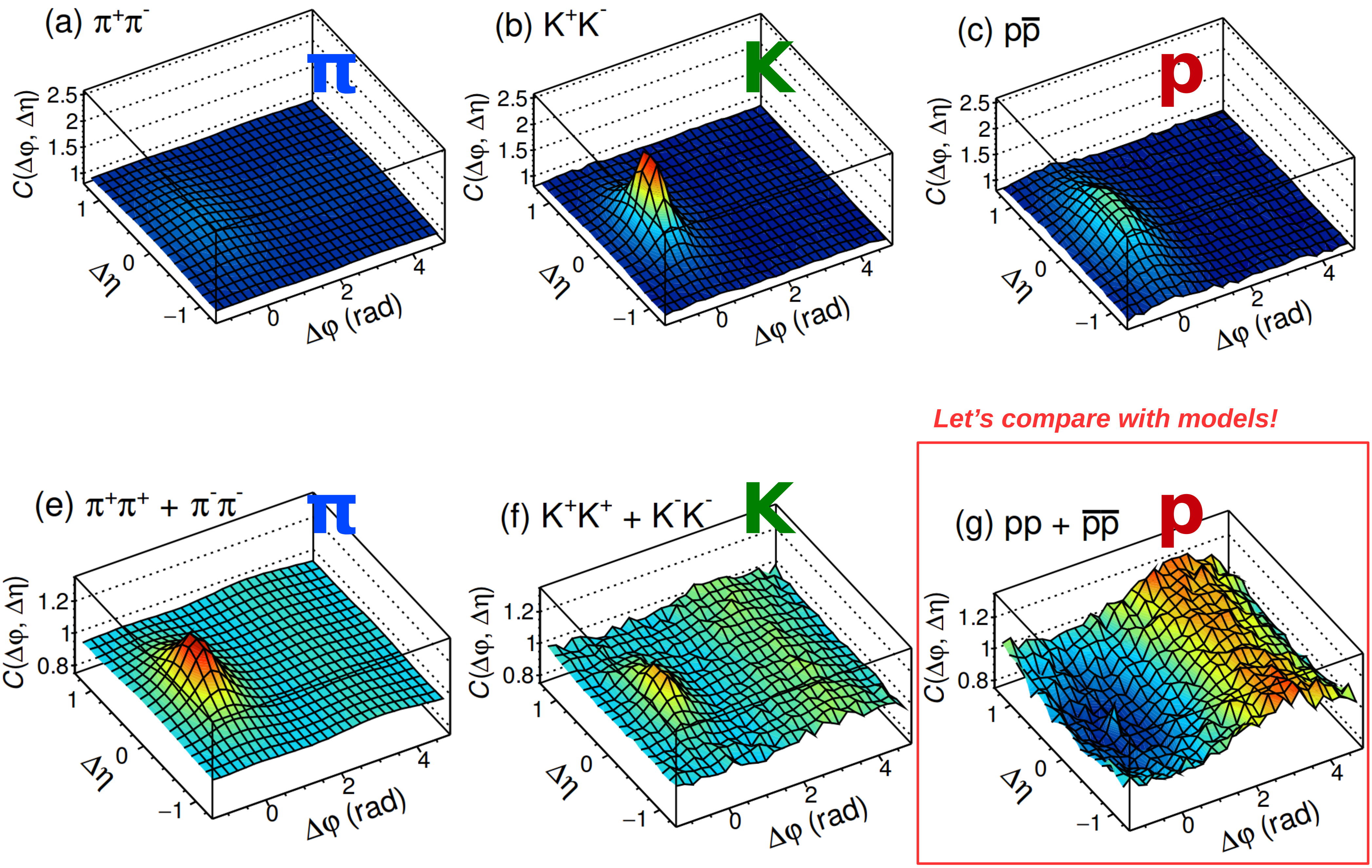
(Δη,Δφ) of identified particles

arXiv:1612.08975

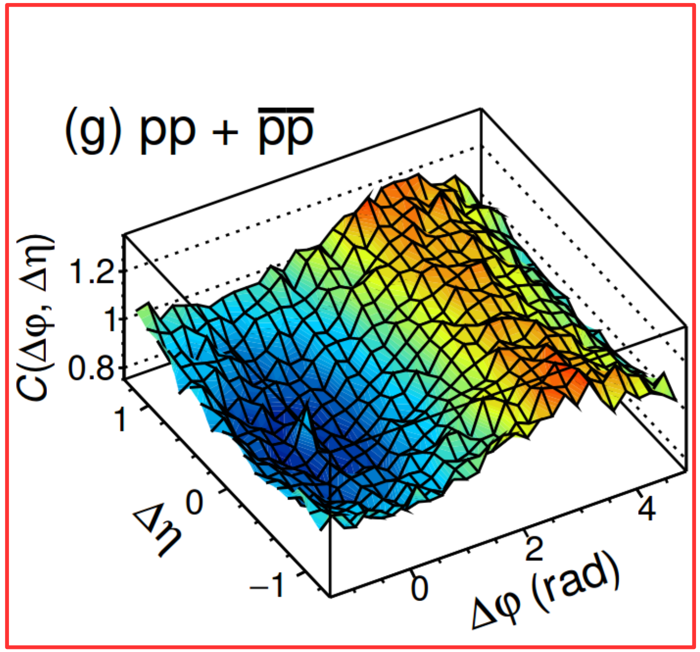


ΔηΔφ of identified particles

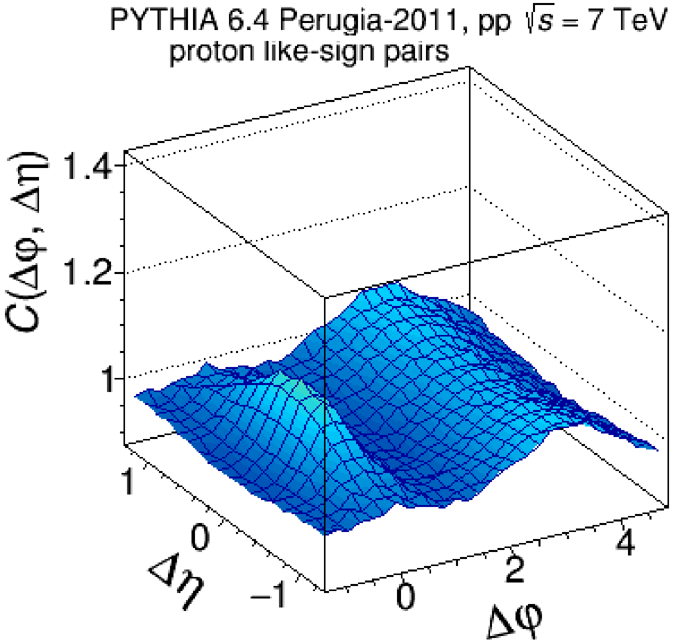
arXiv:1612.08975

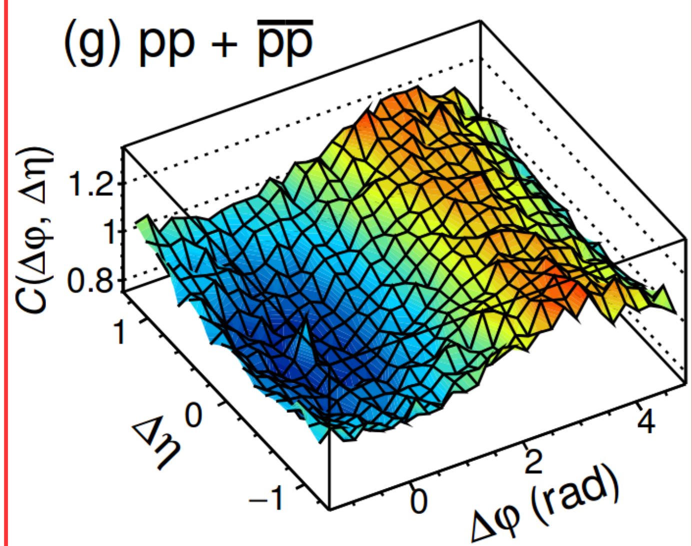


ΔηΔφ of identified particles in pp collisions

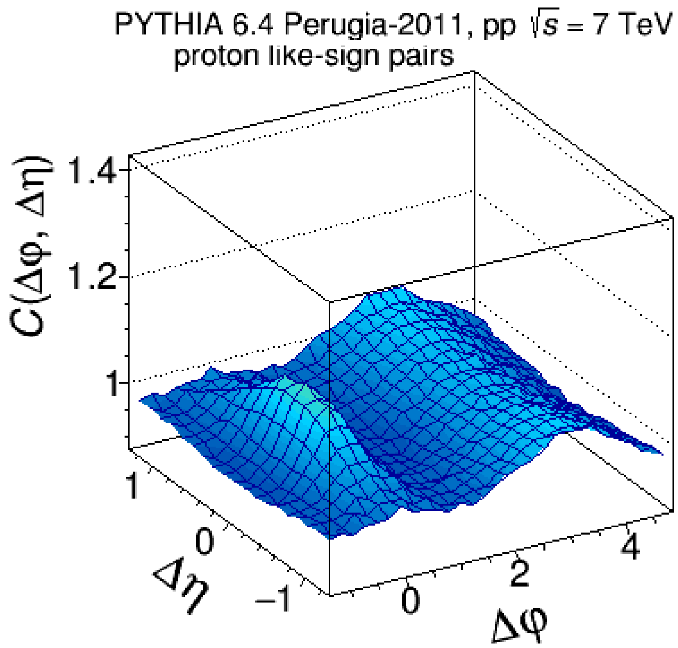


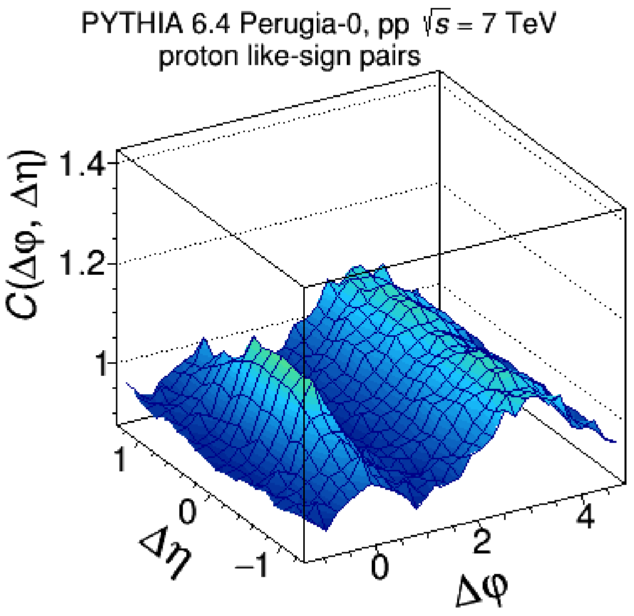
ΔηΔφ of identified particles in pp collisions

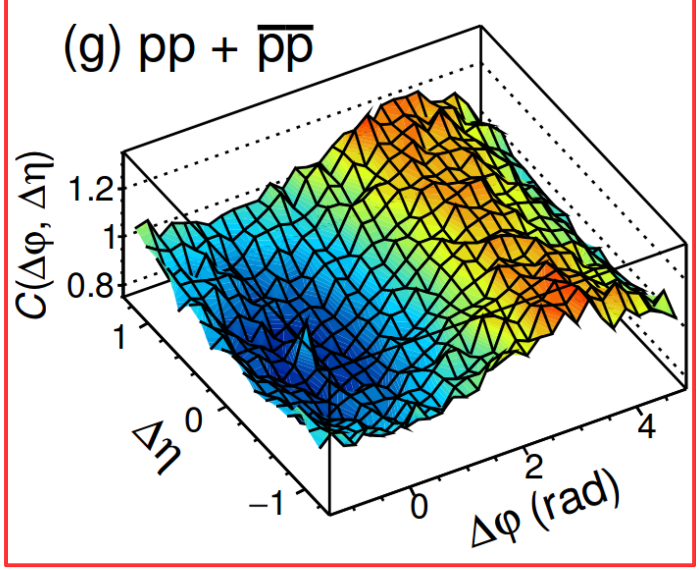




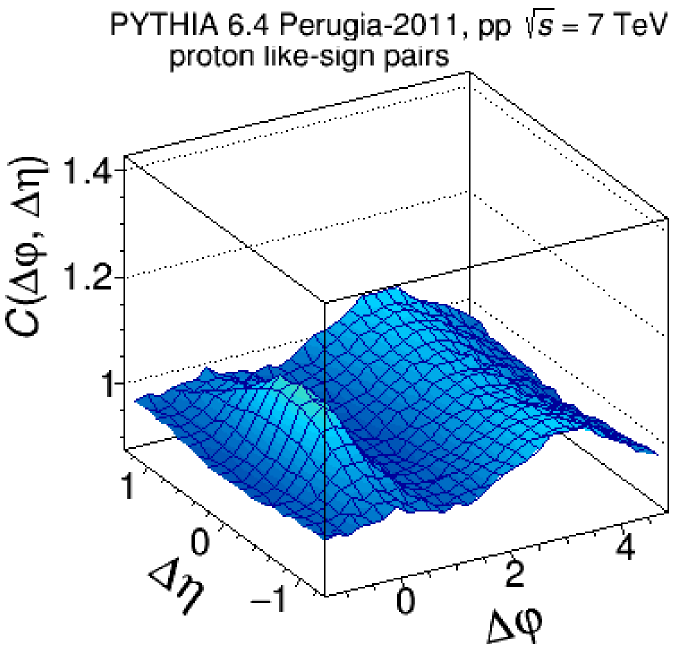
ΔηΔφ of identified particles in pp collisions

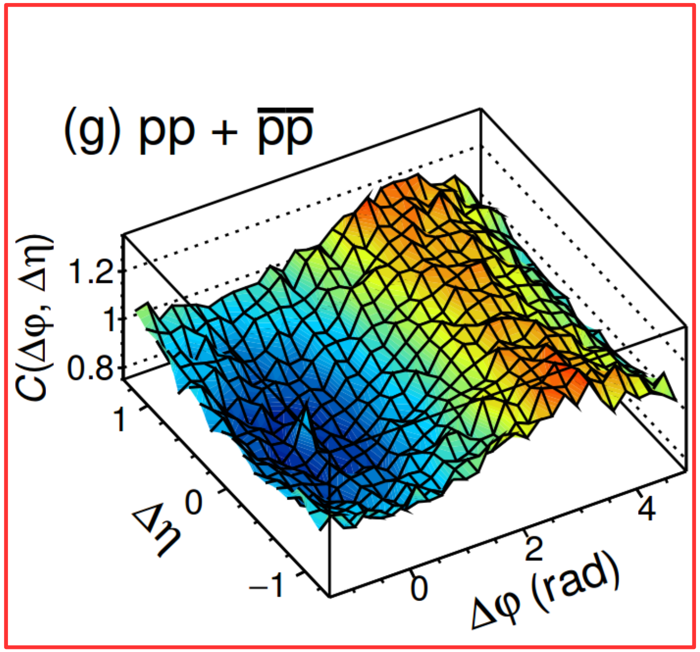




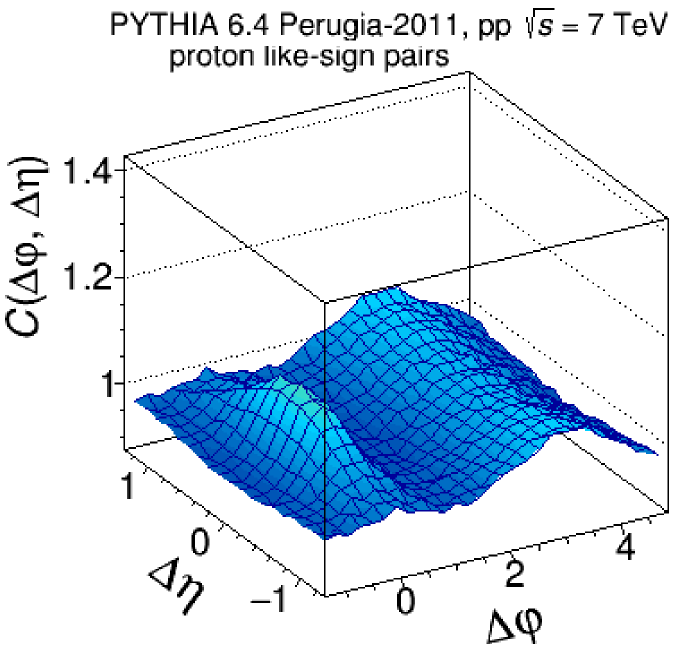


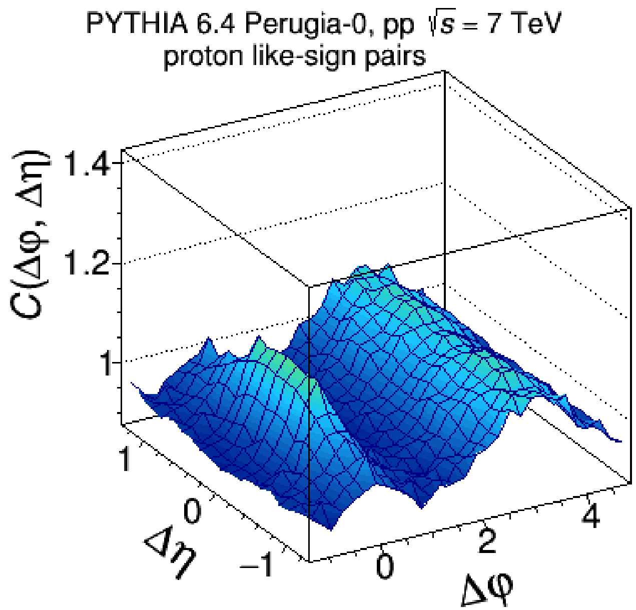
ΔηΔφ of identified particles in pp collisions

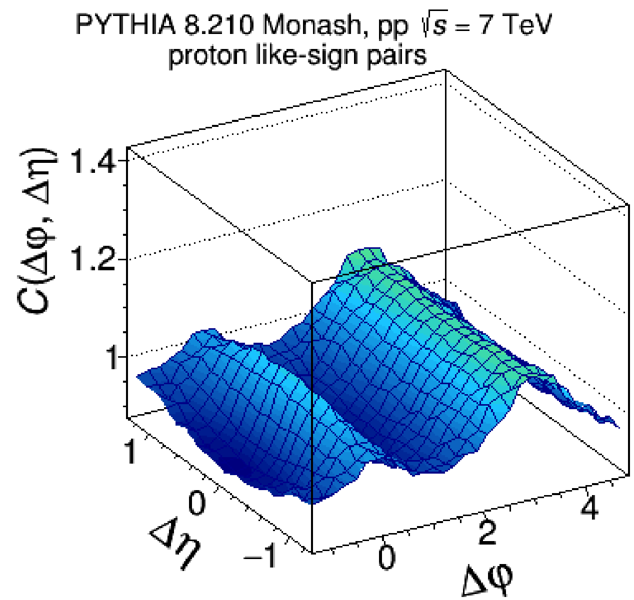




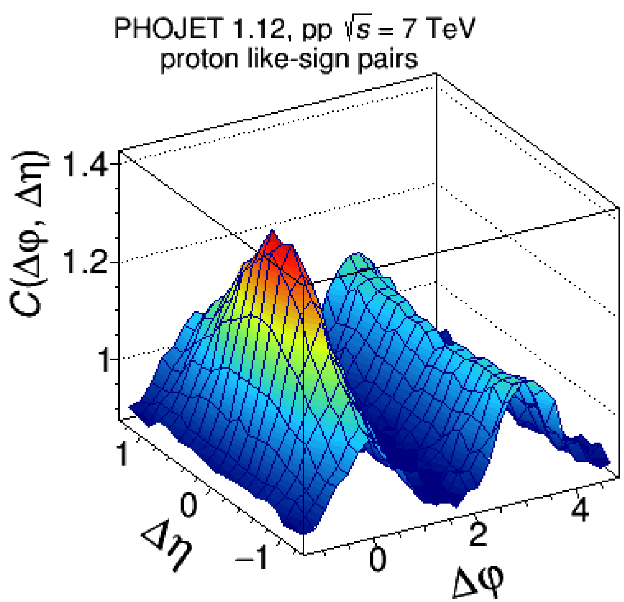
ΔηΔφ of identified particles in pp collisions

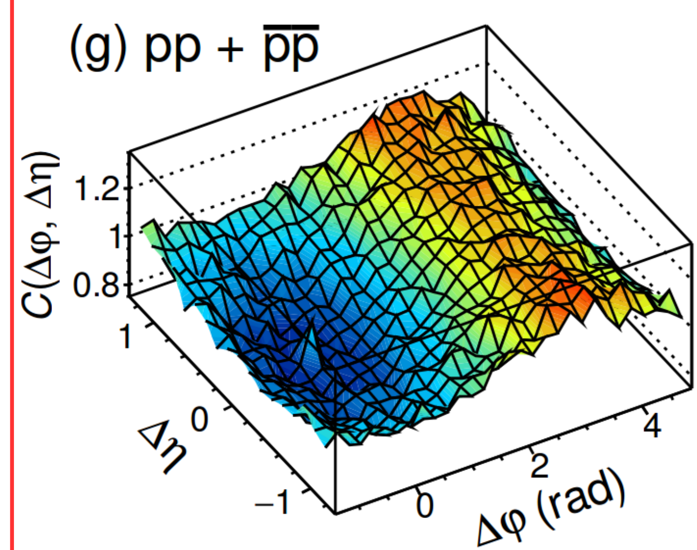






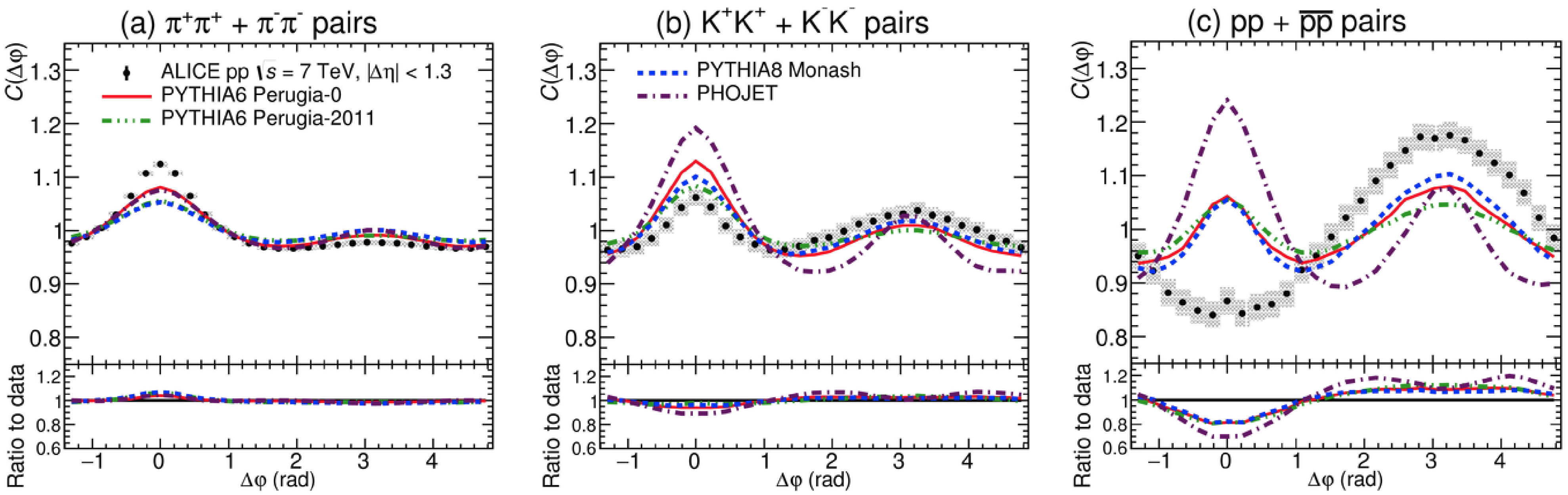
None of common MC models reproduces ALICE data!





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 – 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**

Comparison to MC models: unlike-sign

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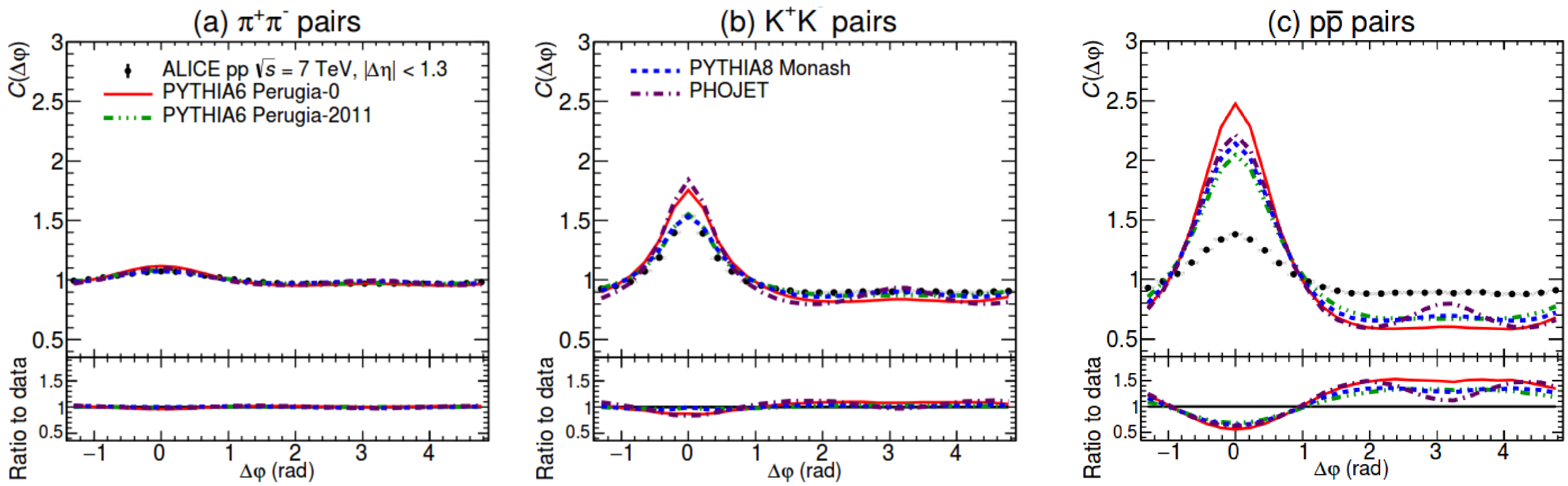


• The models reproduce reasonably well the angular correlations for mesons

• The models fail to reproduce the results for baryons – able to produce 2 baryons close in the phase space, also baryon-antibaryon pairs have 2 x the magnitude for MC

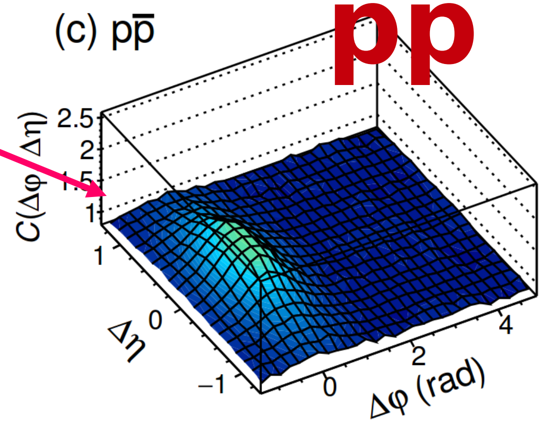
• **Energy and local baryon-number conservation laws are implemented in all studied models - not enough to explain the anti-correlation**

7 TeV pp vs. 29 GeV e^+e^- collisions

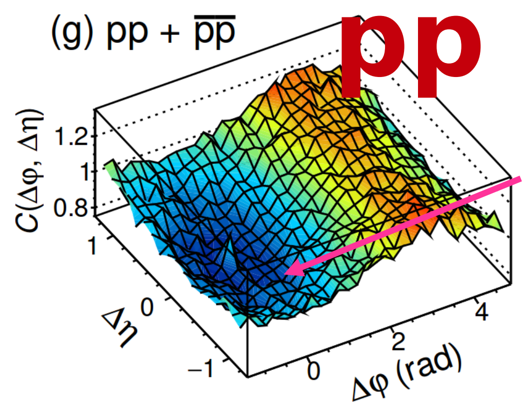
ALICE

correlation

$p\bar{p}$



pp

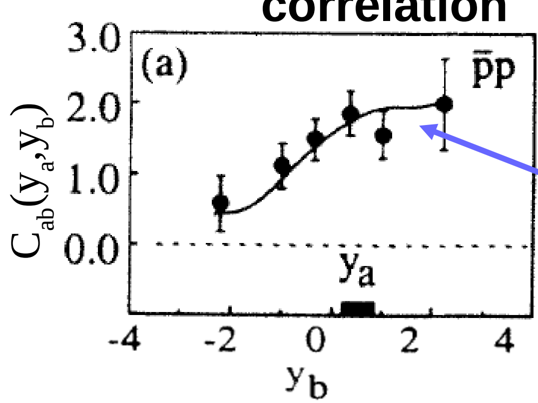


anti-correlation

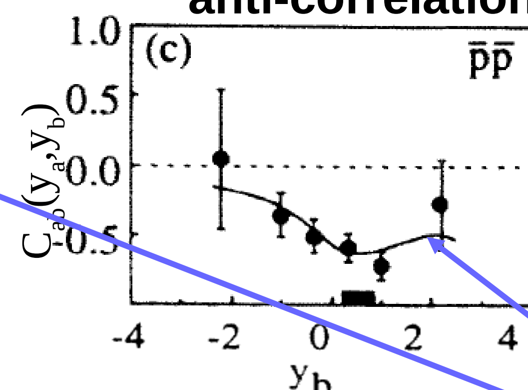
Much more unlike-sign baryons close together in the phase-space than like-sign baryons.

e^+e^-

correlation



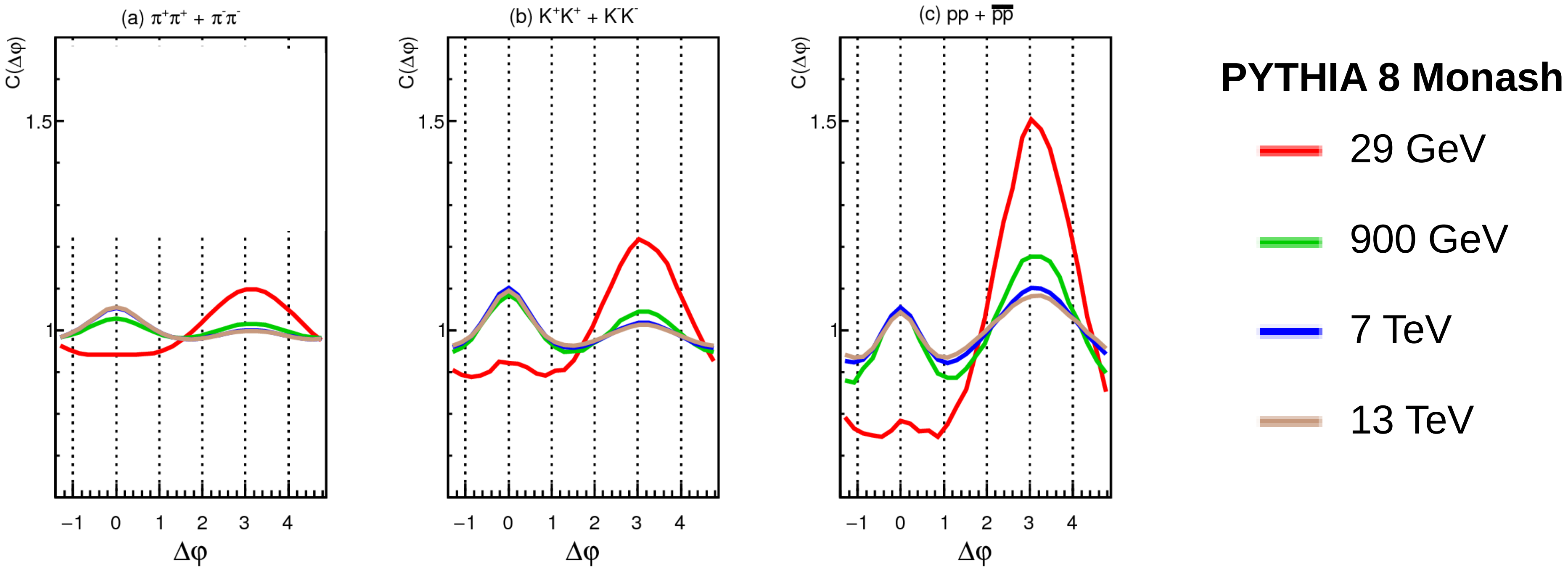
anti-correlation



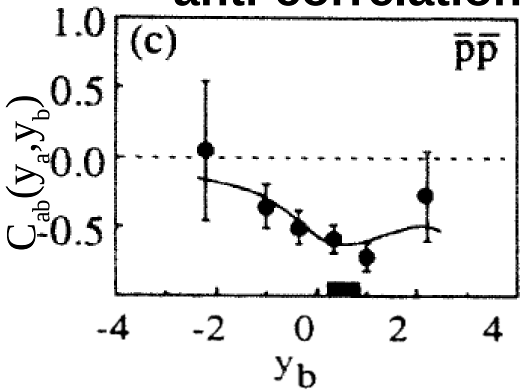
TPC/Two Gamma Collaboration (H. Aihara et al.), Phys.Rev.Lett. 57 (**1986**) 3140

Models (Lund 6.2) **for e^+e^- agree** with observations seen in data.

Comparison to MC models



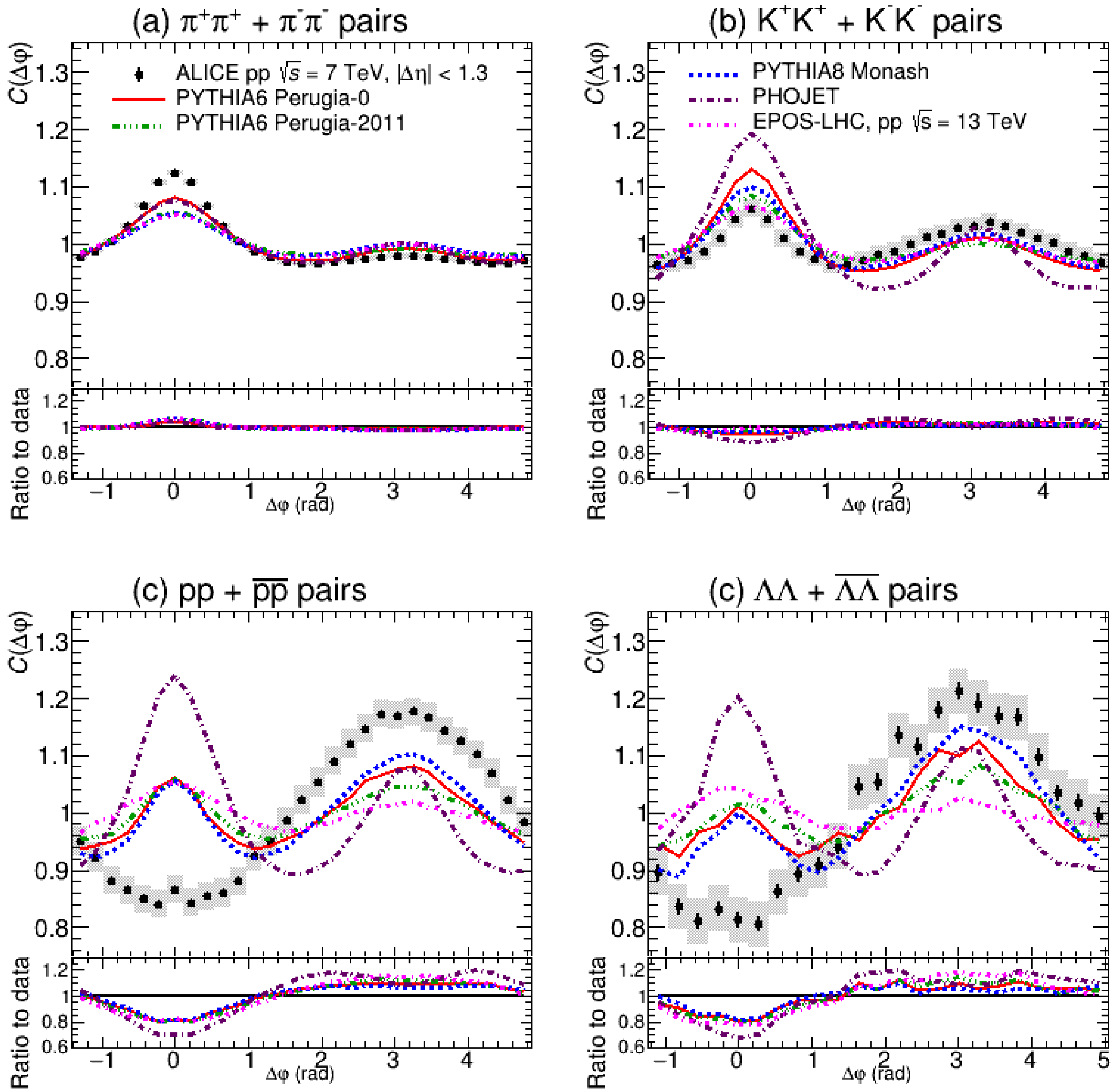
anti-correlation



Pythia 8 Monash:

- **Also shows strong anti-correlation at 29 GeV for pairs of baryons in ΔηΔφ**

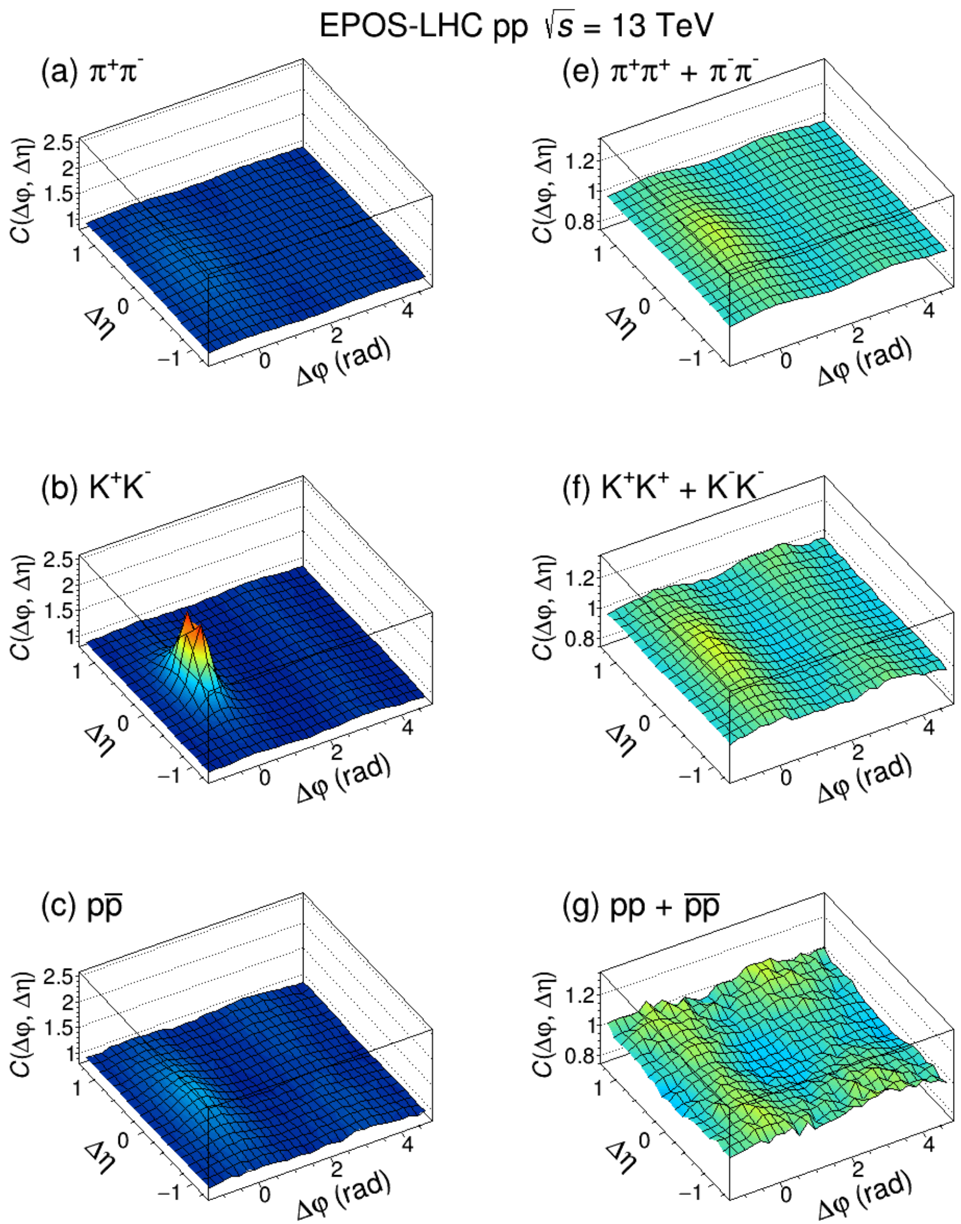
Comparison to EPOS



EPOS-LHC 13 TeV

- **Do not reproduce anticorrelation**

Comparison to EPOS



EPOS-LHC 13 TeV

- **Do not fully reproduce anti-correlation**

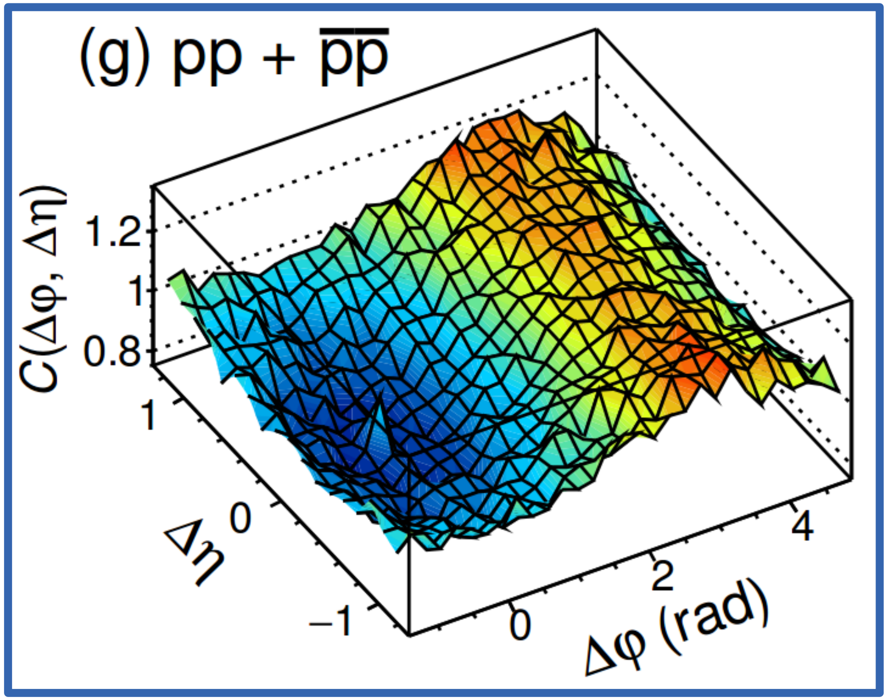
Possible explanations

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, but why at 7 TeV?!**

Other possible explanations:

- Too small pT range?
- Coulomb repulsion?
- Other baryons?
- Fermi-Dirac Quantum Statistics?



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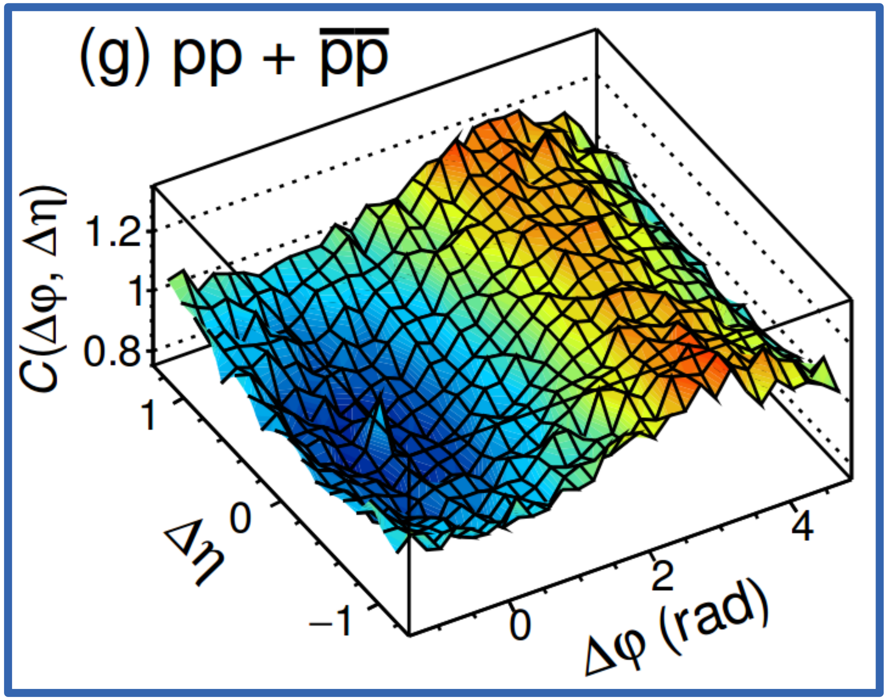
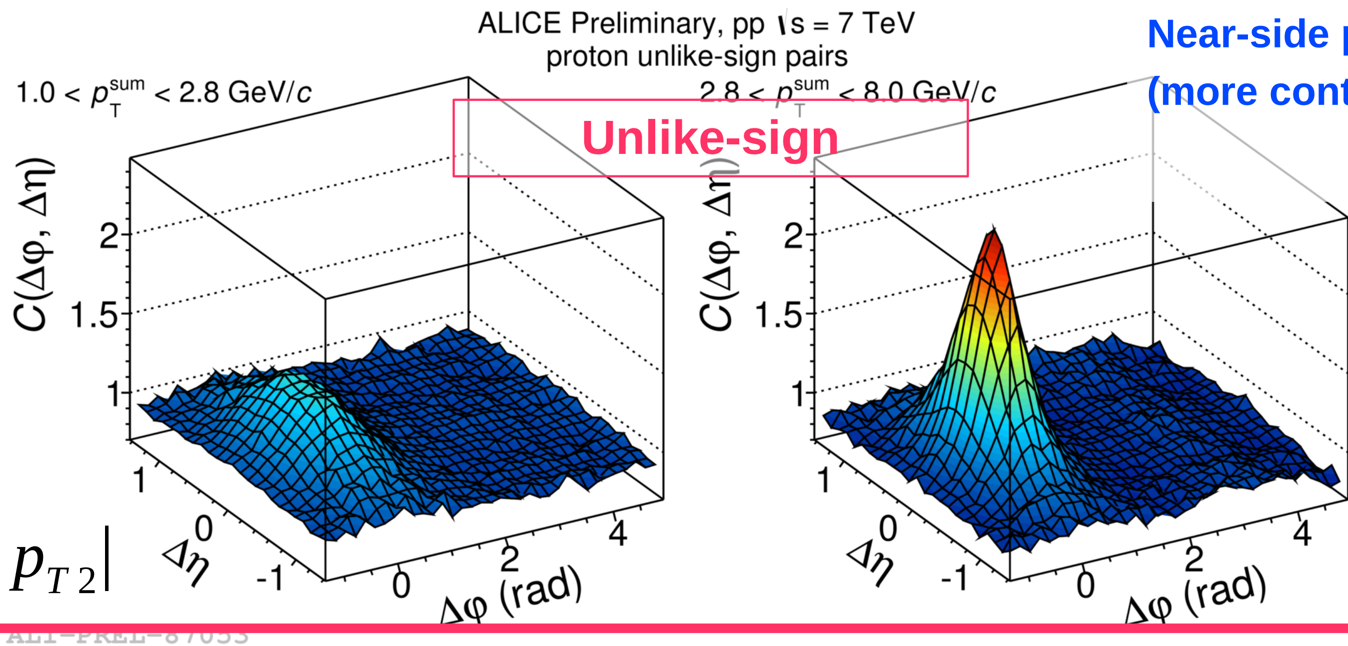


Protons

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

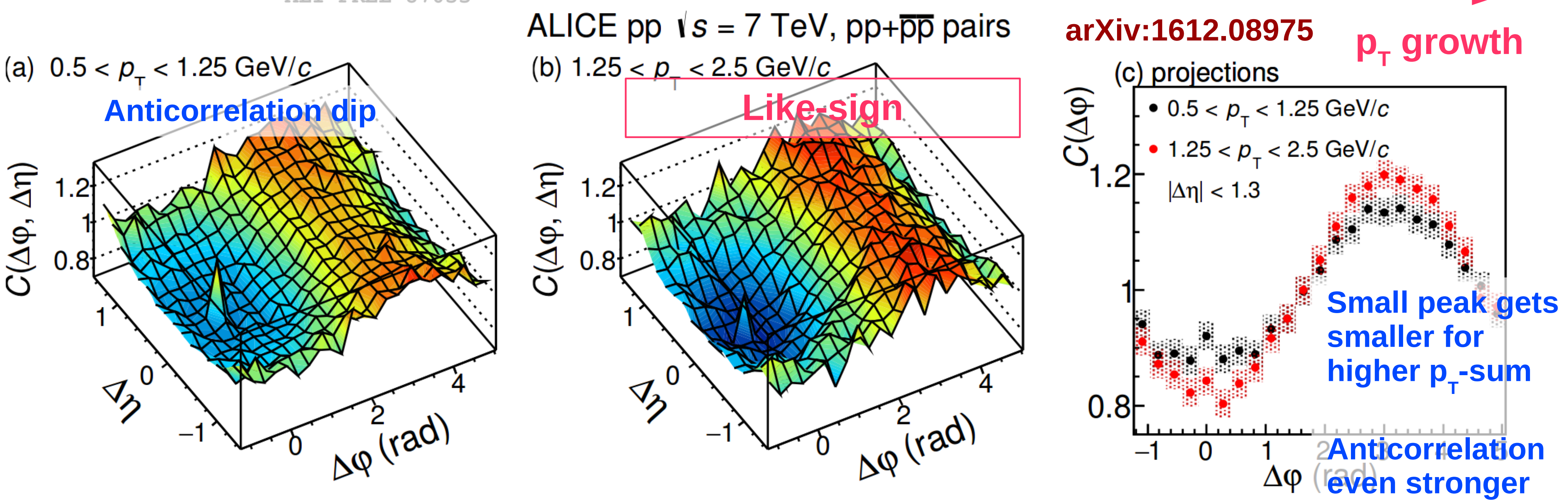
Near-side peak grows with p_T (more contribution from jets)



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

p_T growth

arXiv:1612.08975



Anticorrelation dip

Small peak gets smaller for higher p_T-sum

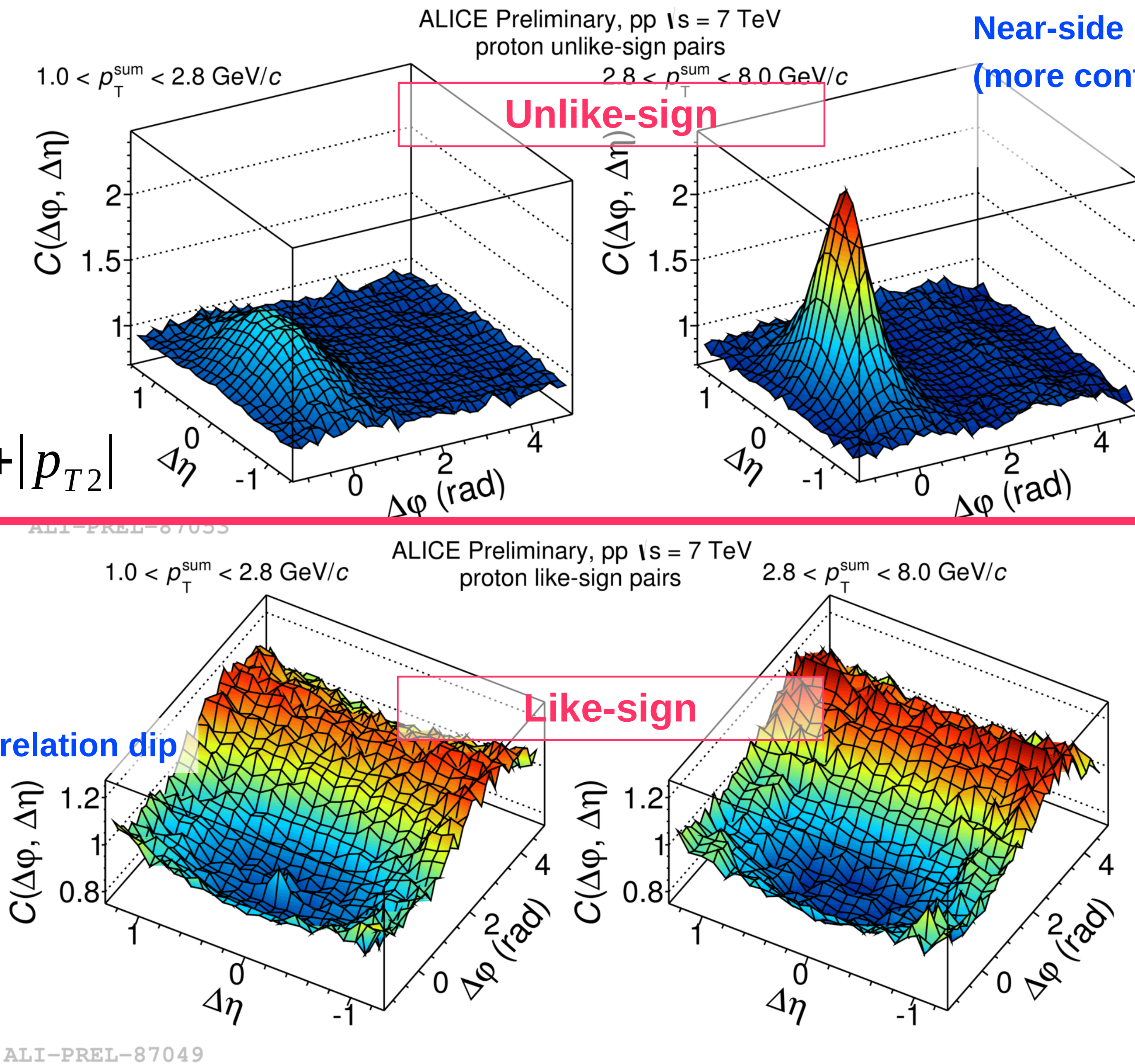
Anticorrelation even stronger

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

Possible explanations

Not likely (checked with MC):

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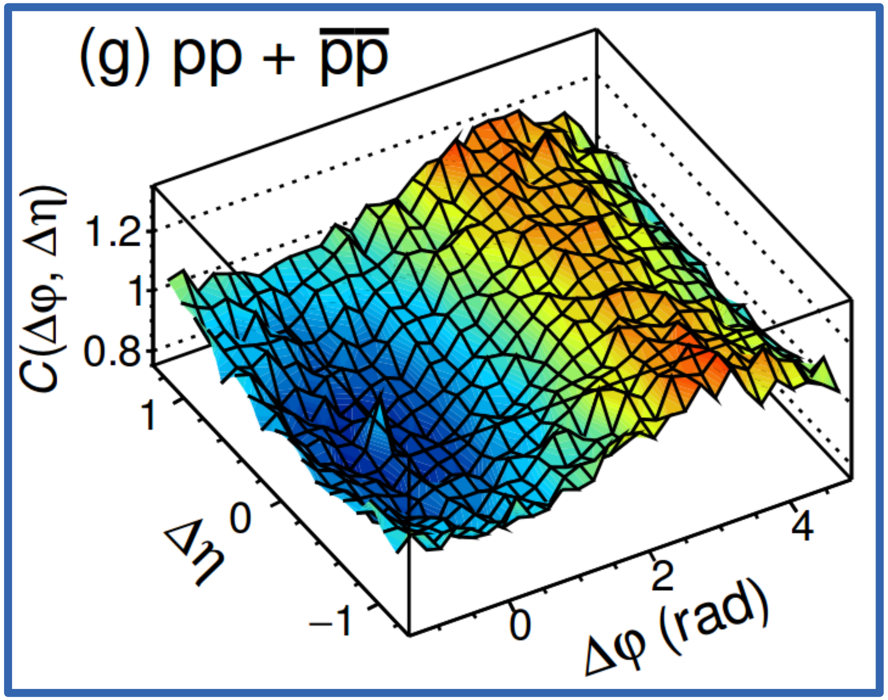
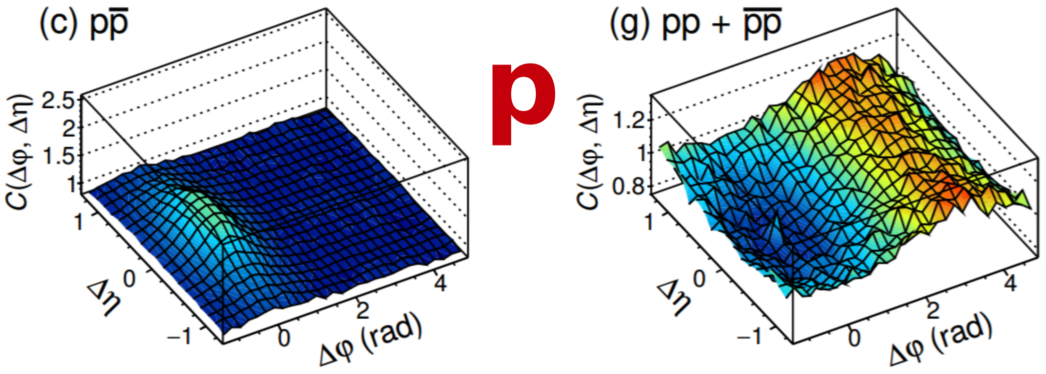


Other baryons?

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



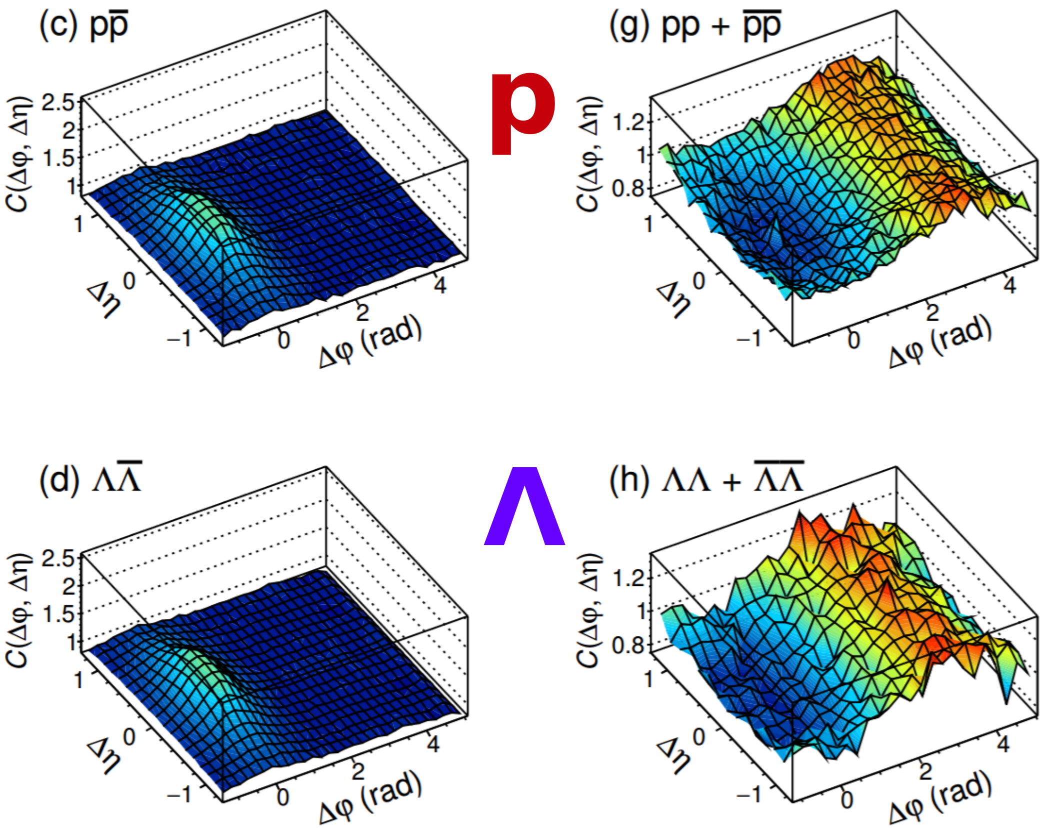
Other baryons?

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

- Correlation functions were calculated for lambda hiperons

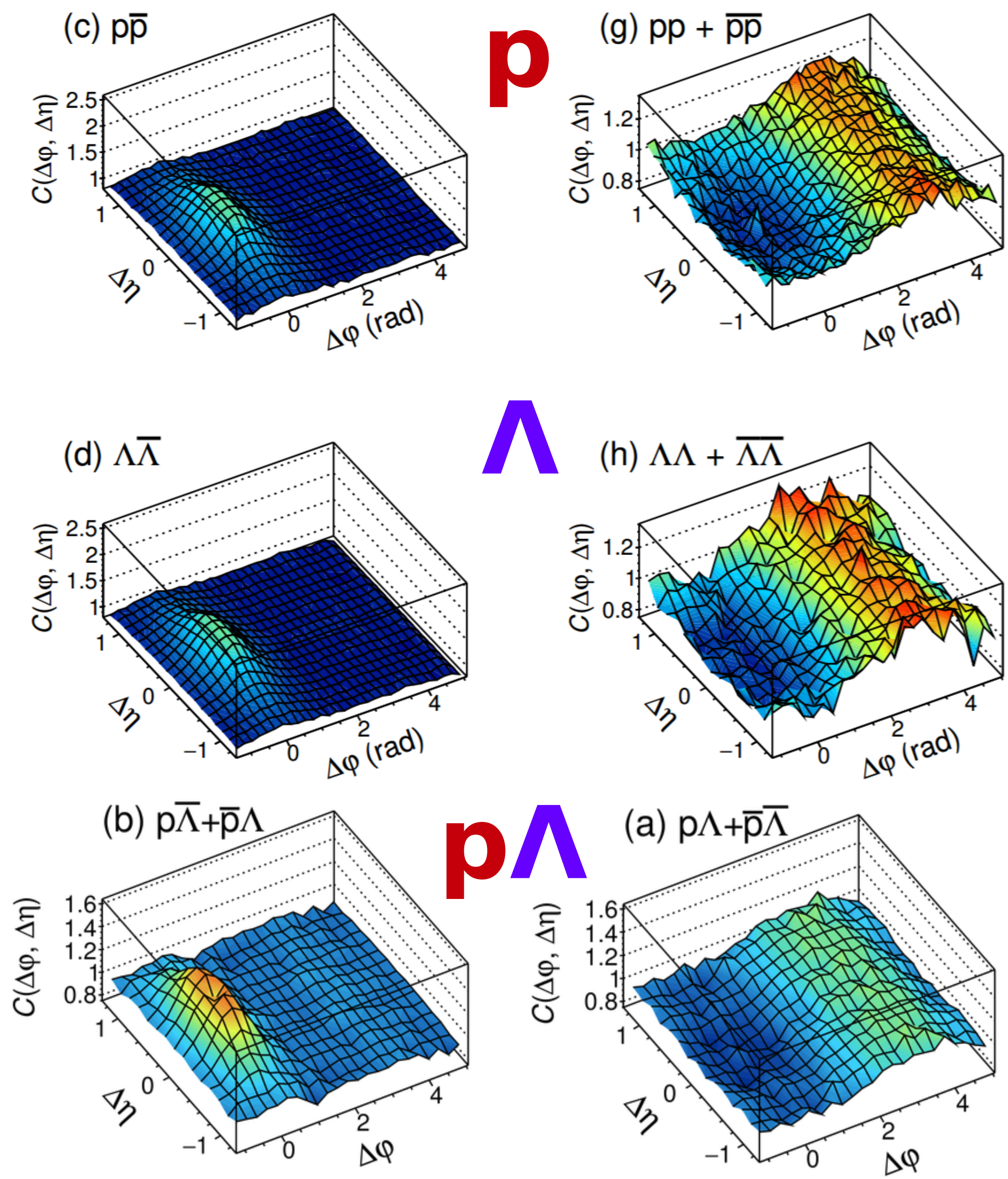
- **All observations from pp can be extended to ΛΛ**

- Since Λ baryons are neutral, we are sure that effects of Coulomb repulsion plays marginal role



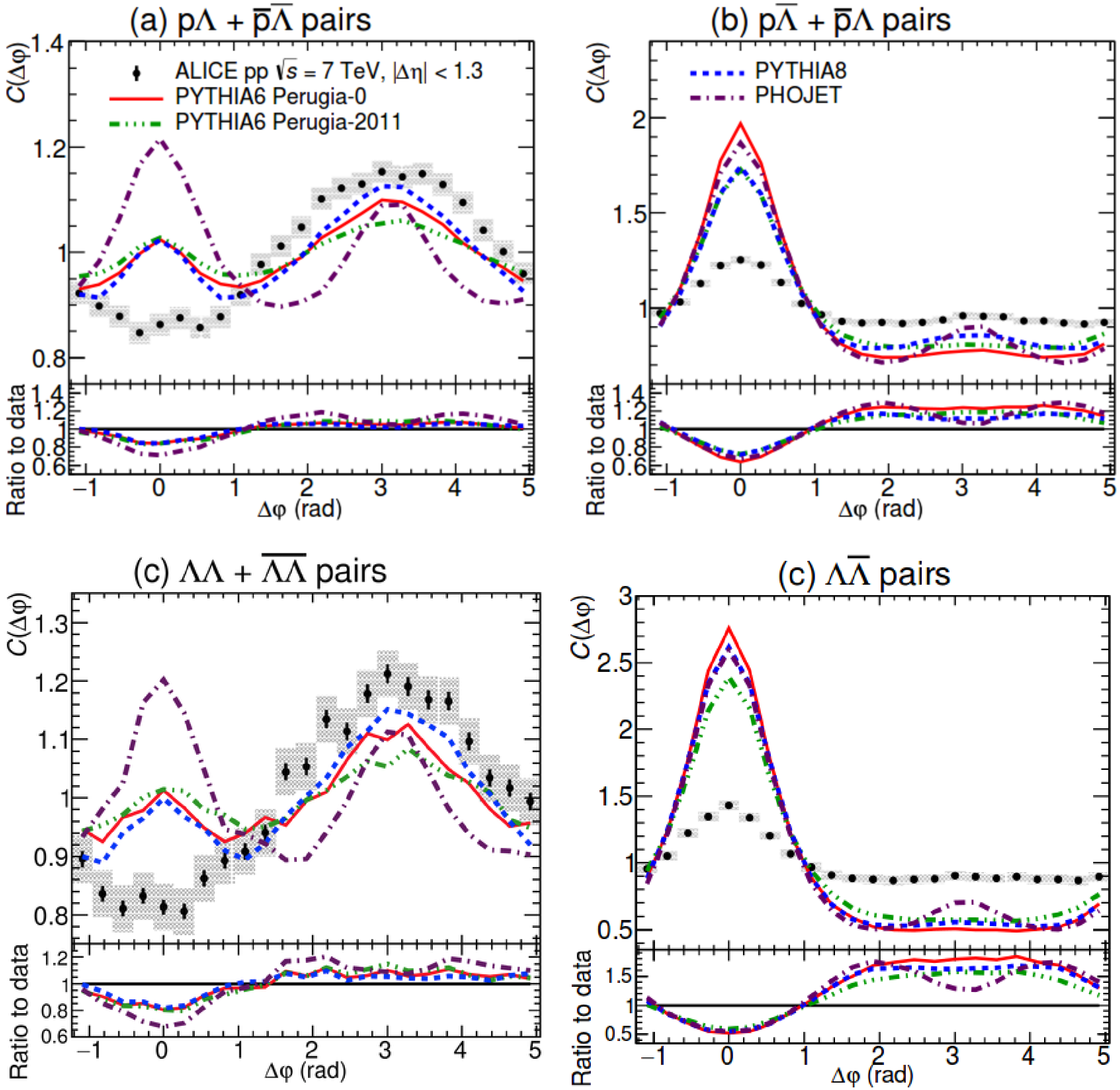
pΛ correlation functions

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



Comparison to MC models

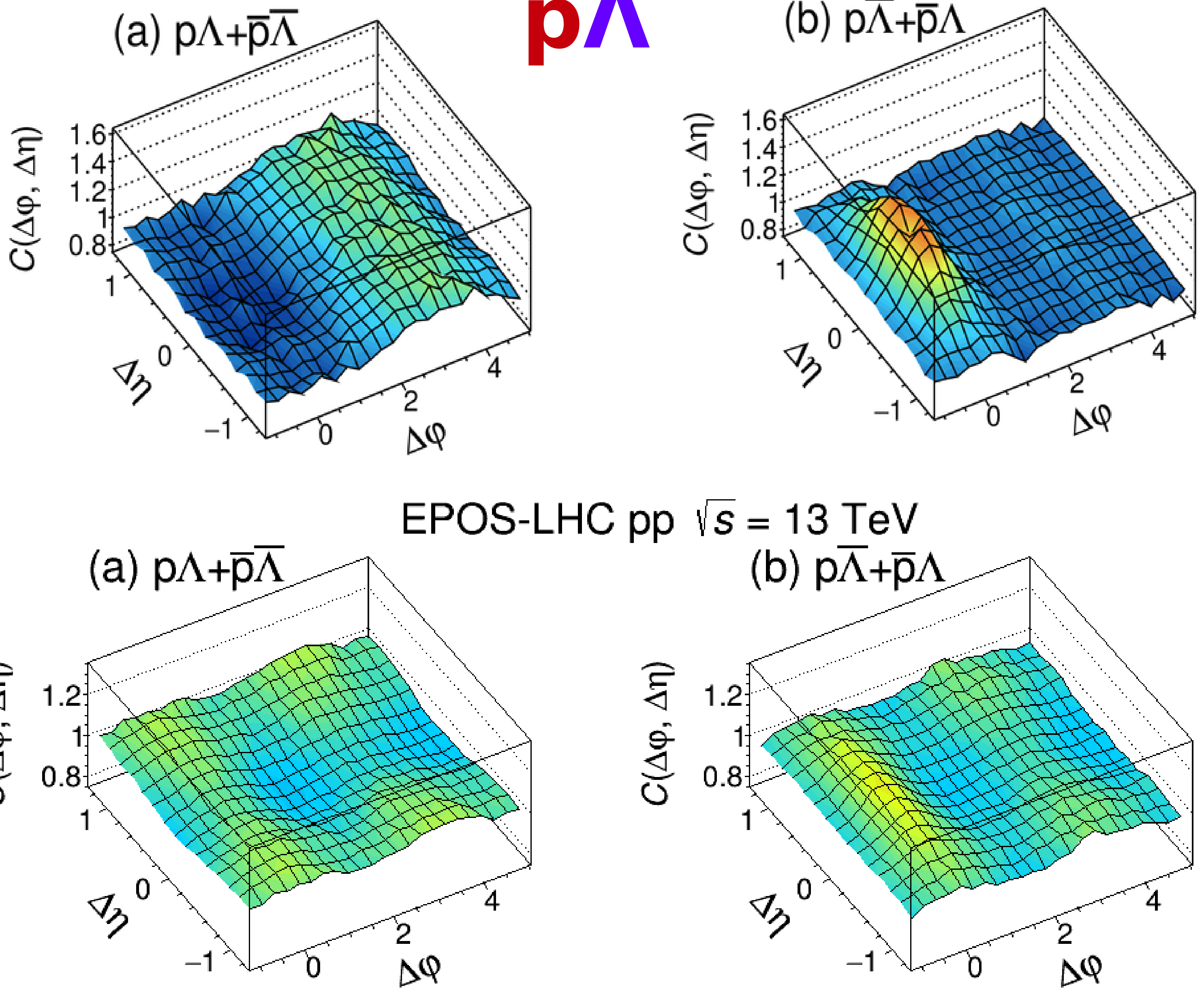
arXiv:1612.08975



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

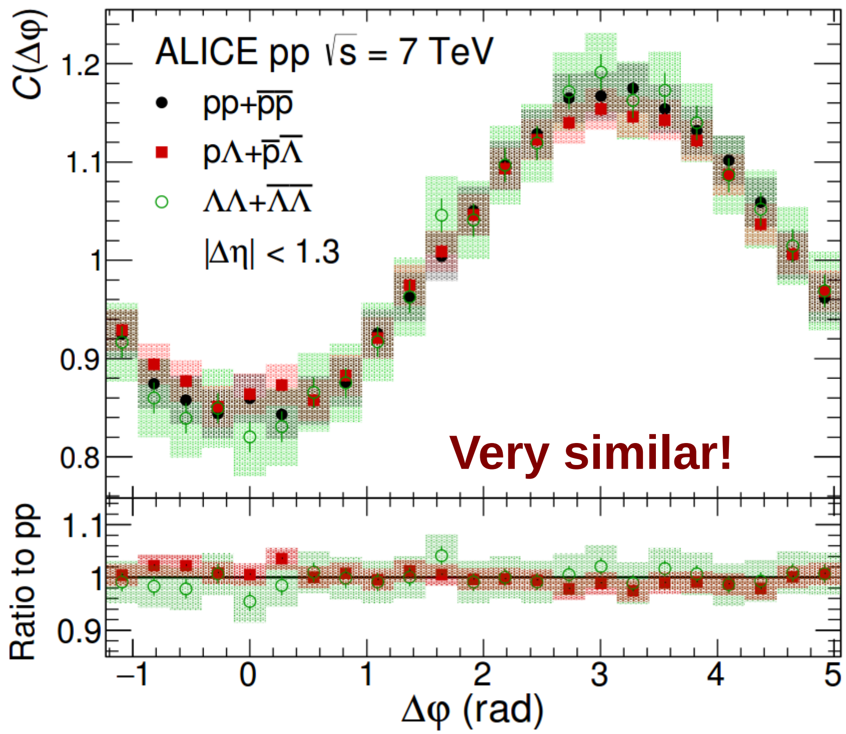
Comparison to EPOS

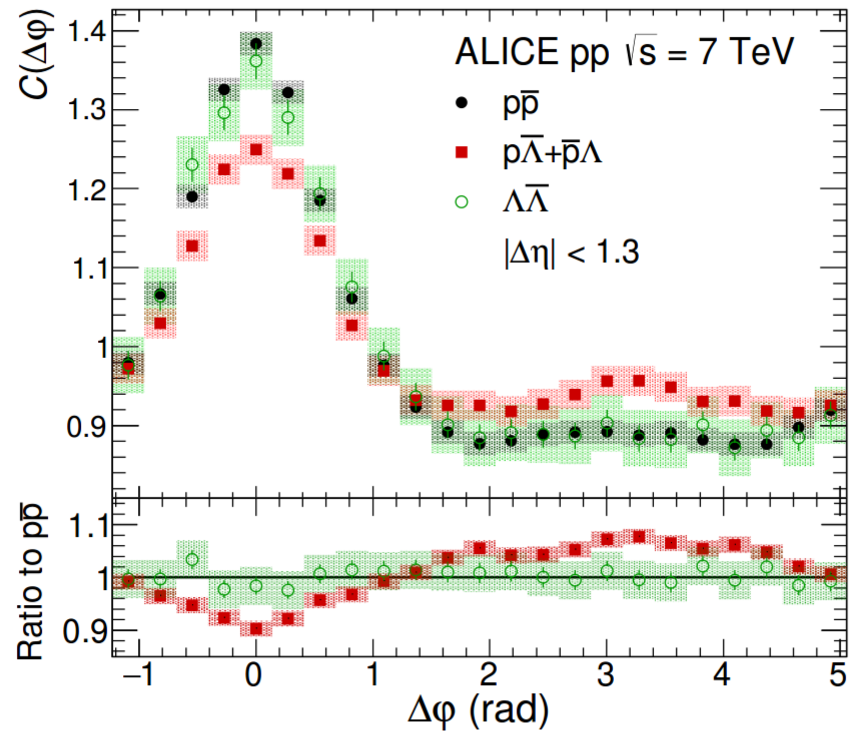
pΛ



Comparison between pp, pΛ, ΛΛ

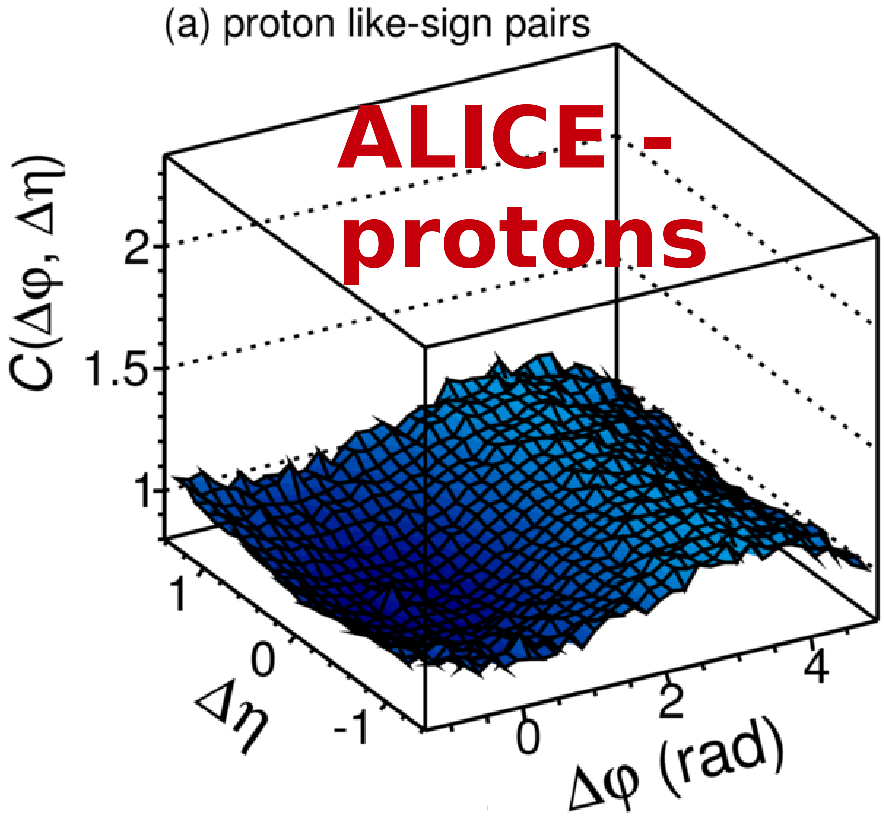
arXiv:1612.08975





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

(Δη,Δφ) of identified particles of pp collisions



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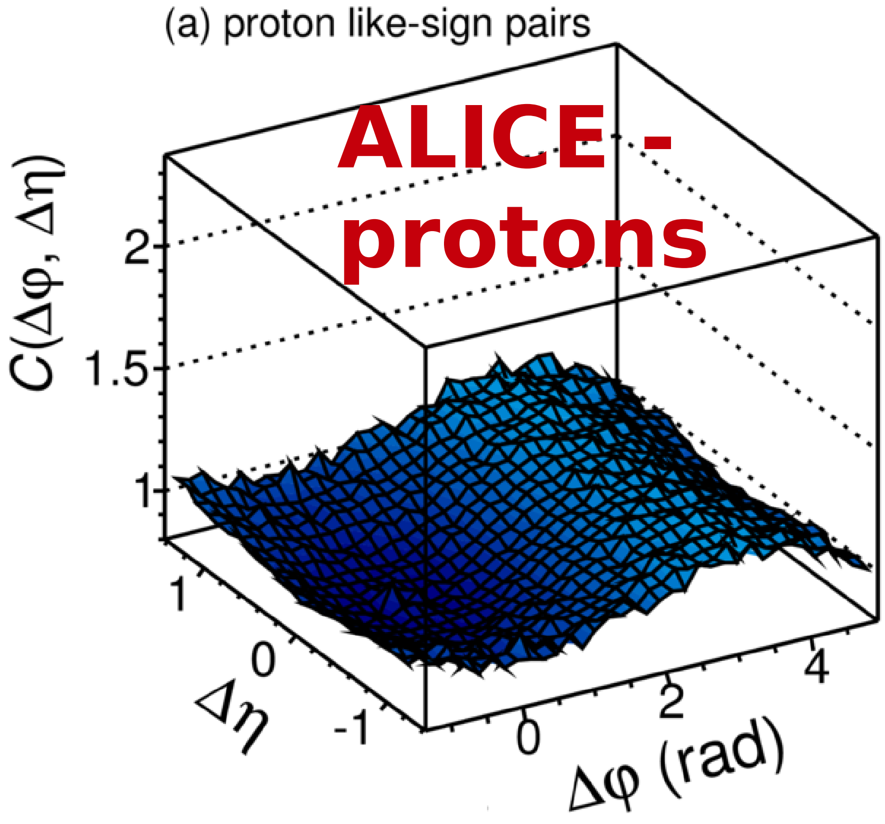
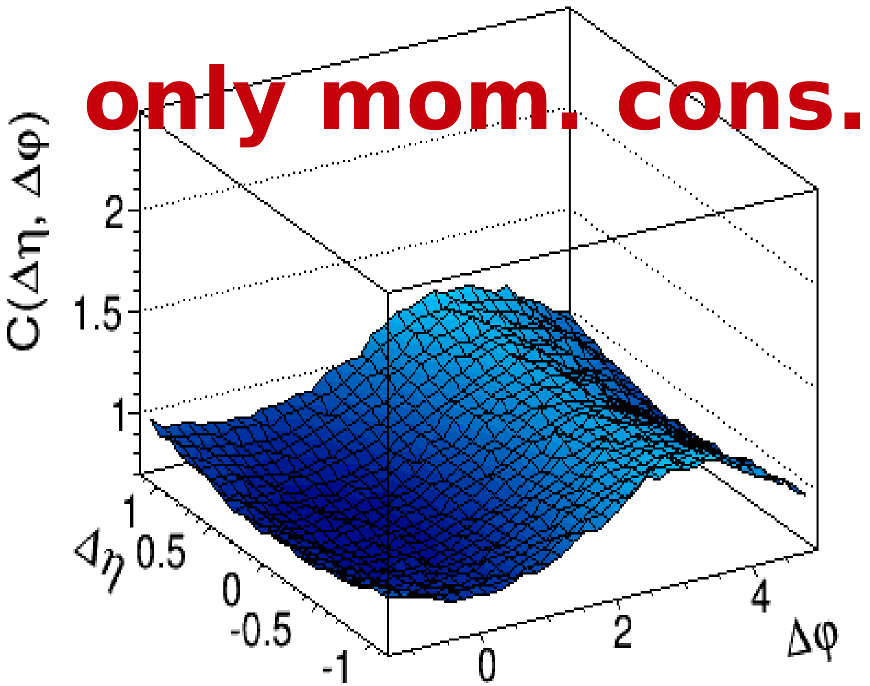
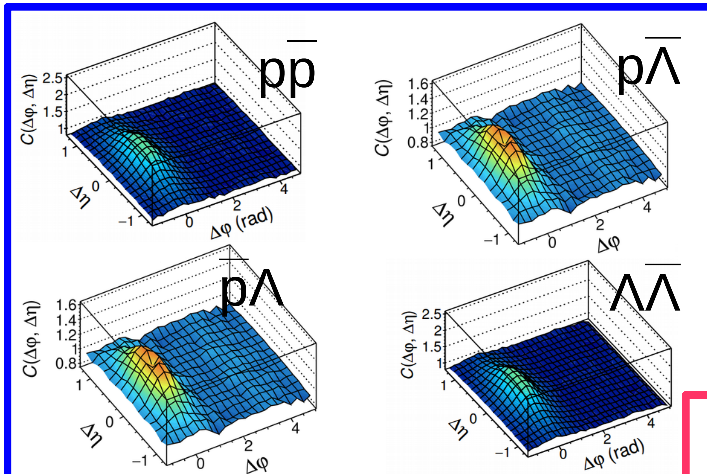


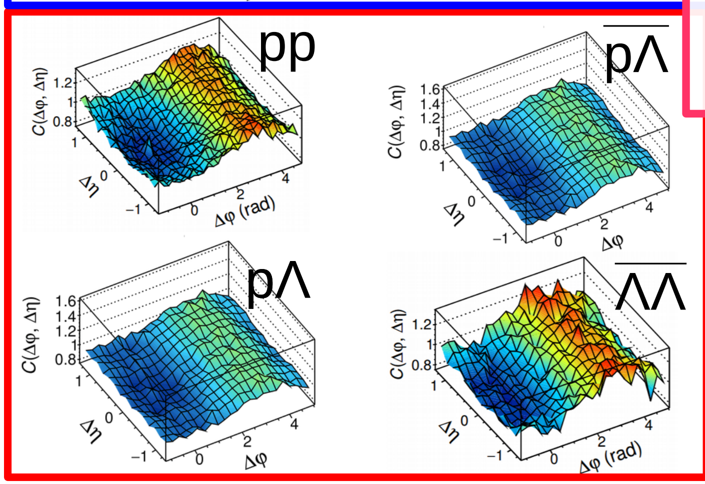


Events with angular momentum conserved only

ΔηΔφ of identified particles of pp collisions

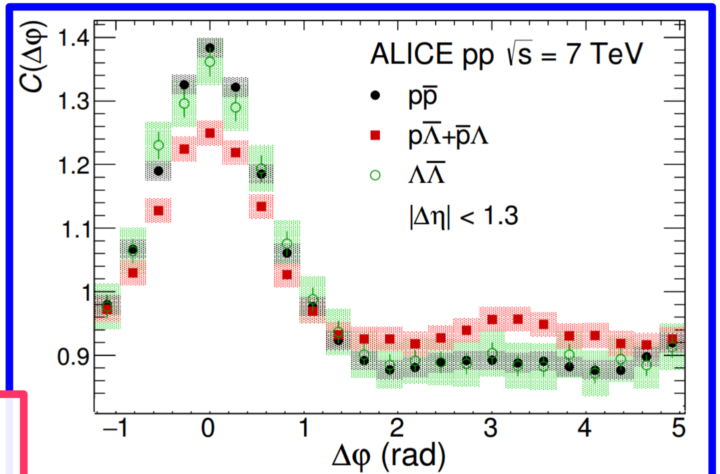
baryon-antibaryon
correlation

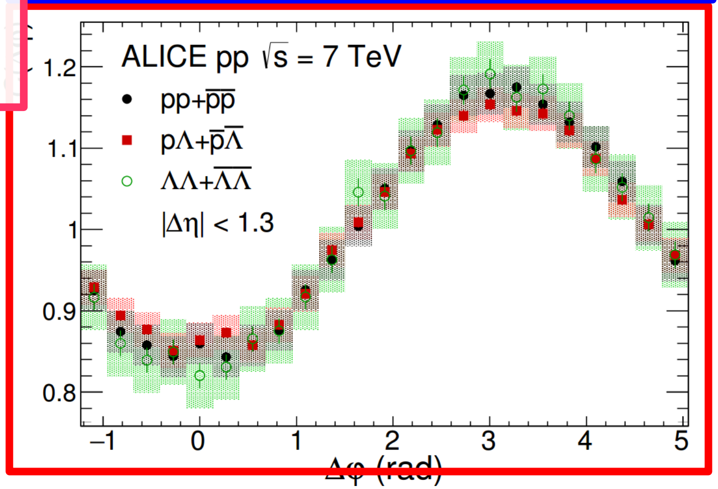




common behaviour for all baryons

baryon-antibaryon
correlation





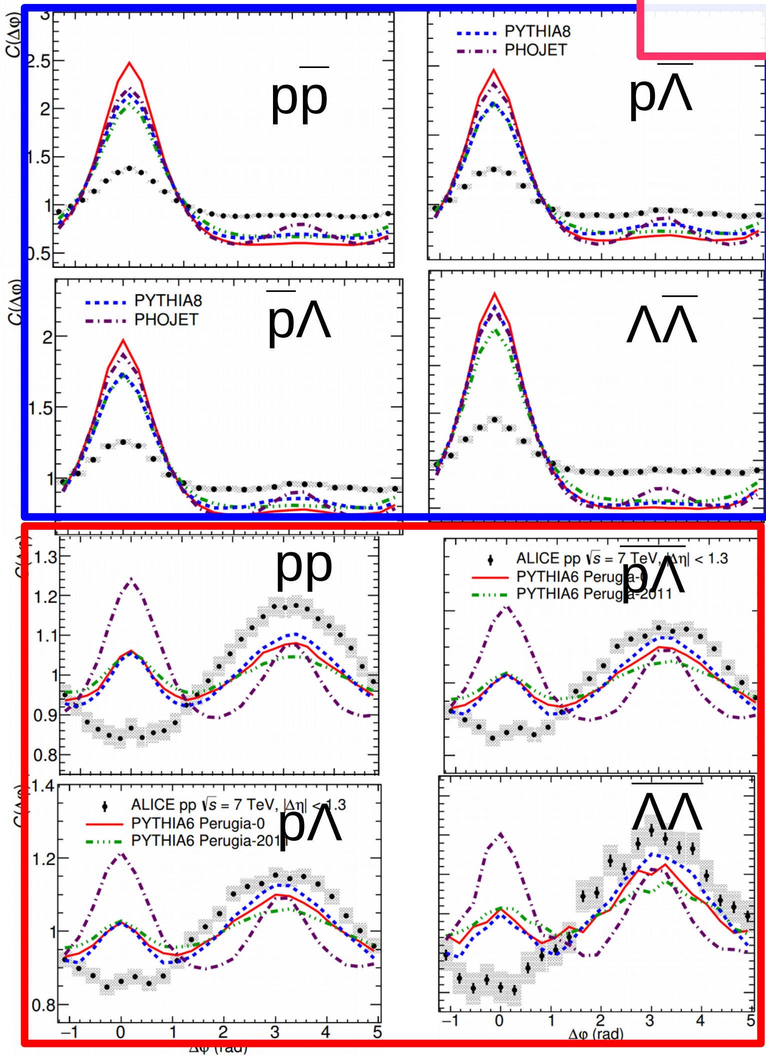
(anti)baryon-(anti)baryon
anticorrelation!

(anti)baryon-(anti)baryon
anticorrelation!

ΔηΔφ of identified particles of pp collisions

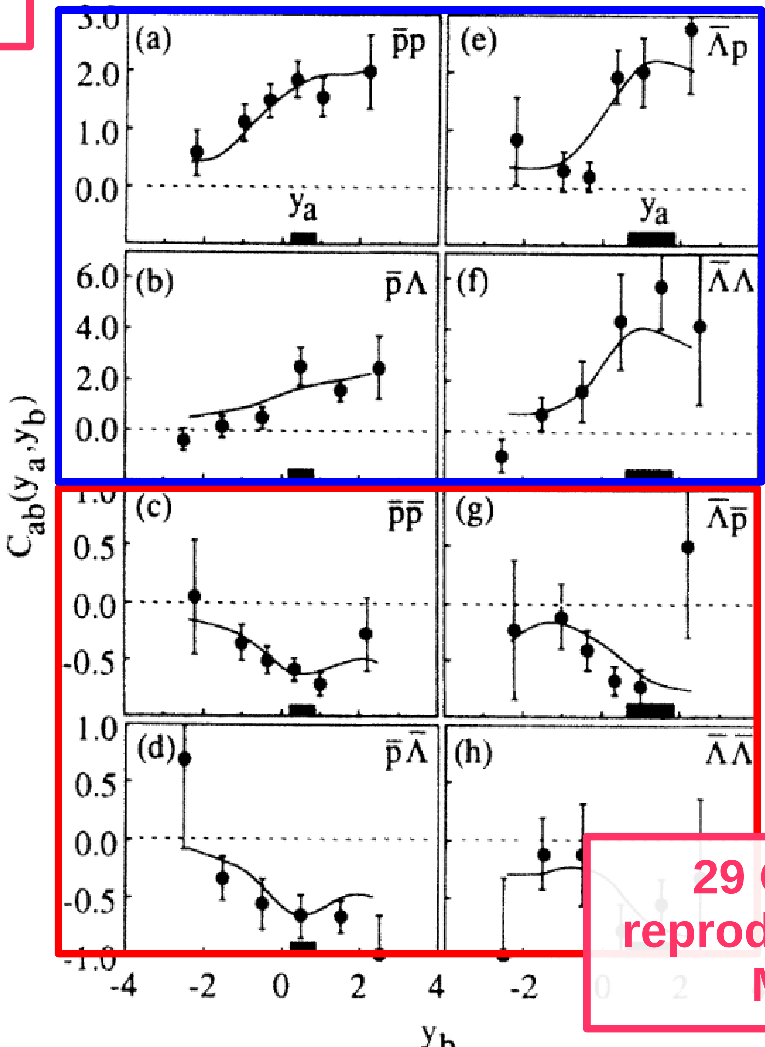
baryon-antibaryon
correlation

7 TeV : not reproduced by MC



(anti)baryon-(anti)baryon
anticorrelation!

baryon-antibaryon
correlation

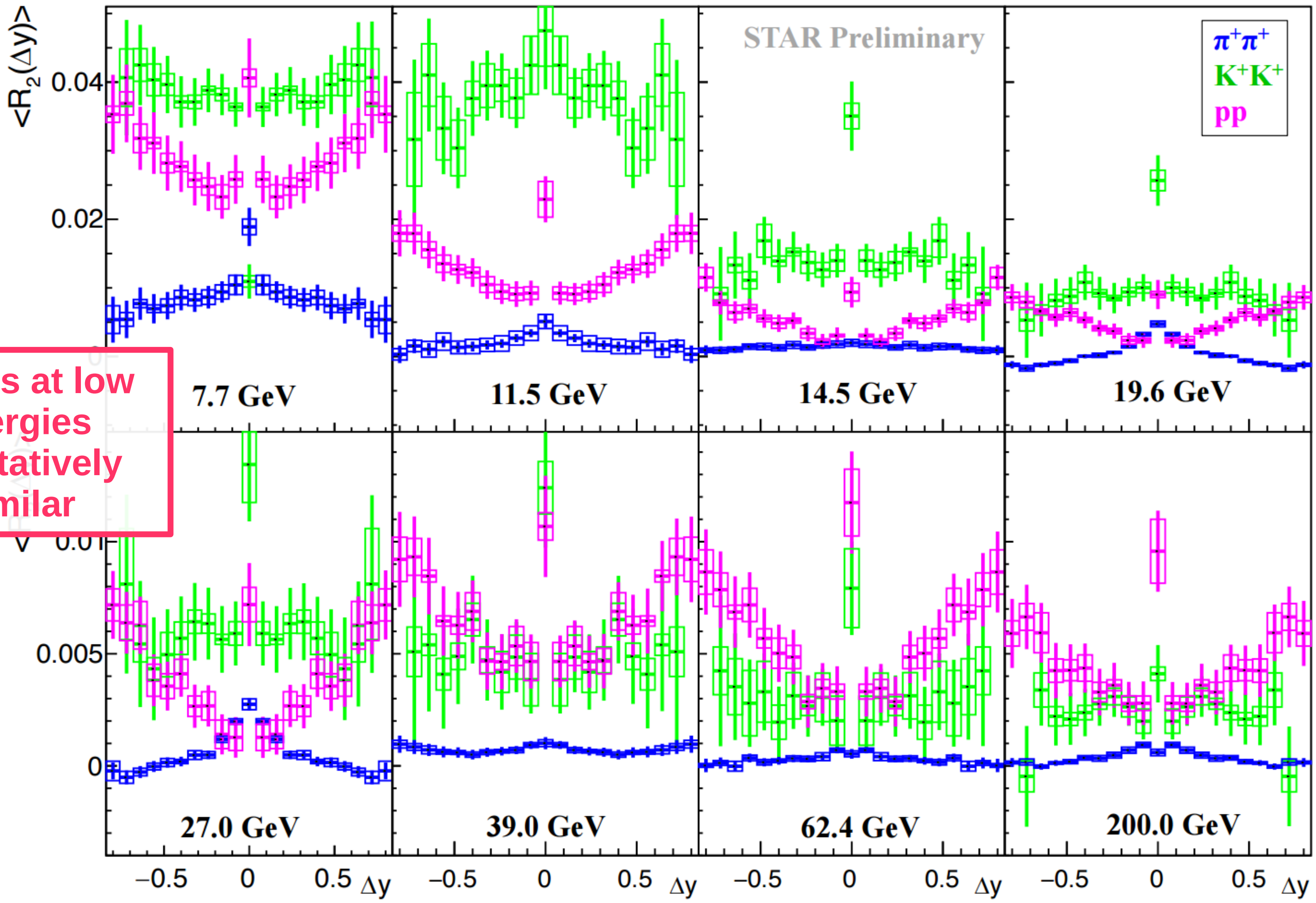


29 GeV : reproduced by MC

antibaryon-antibaryon
anticorrelation!

$\pi^+\pi^+$, 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

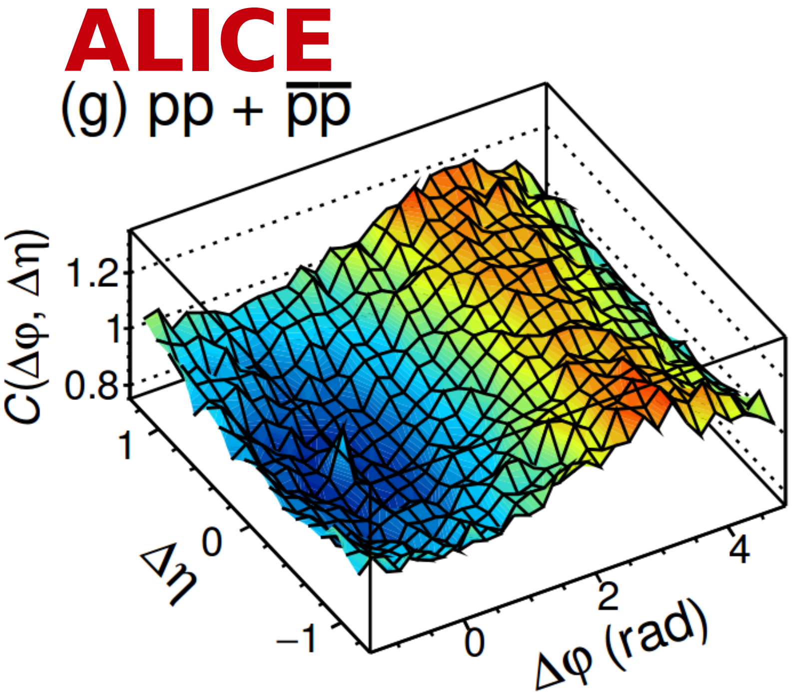
Point at Δy=0 reflects combination of SRC and the removal of track merging effects

S. Jowzaee, Quark Matter 2017

9

Summary

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



Baryon-baryon correlations not reproduced by MC models:

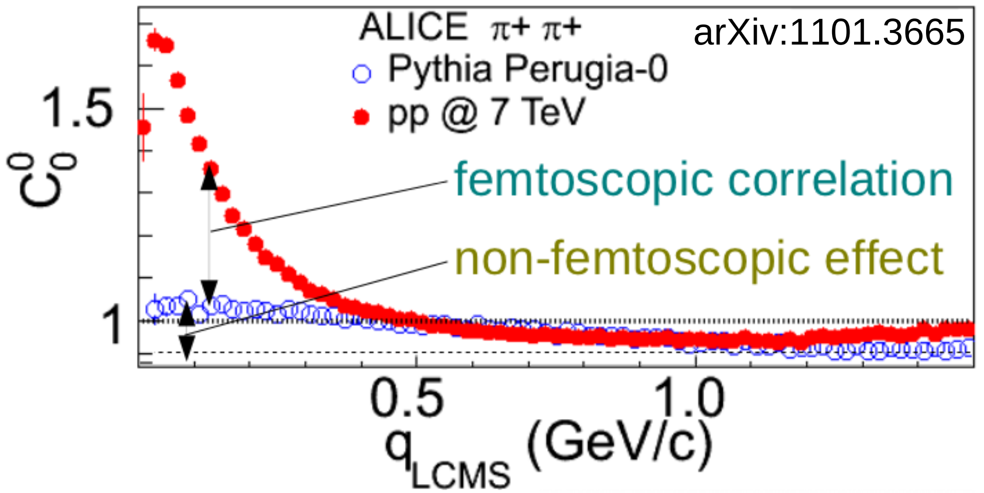
- **Pythia6**
- **Pythia8**
- **Phojet**
- **EPOS**
- **HERWIG**

No explanation found so far

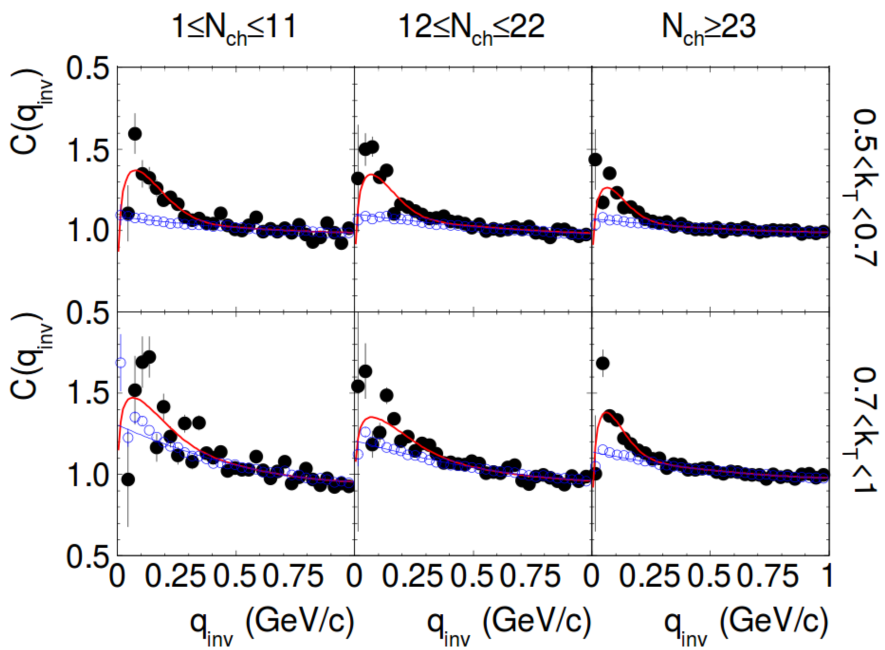
The End

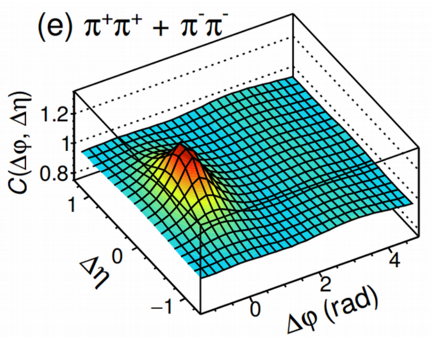
Non-femtoscopic correlations

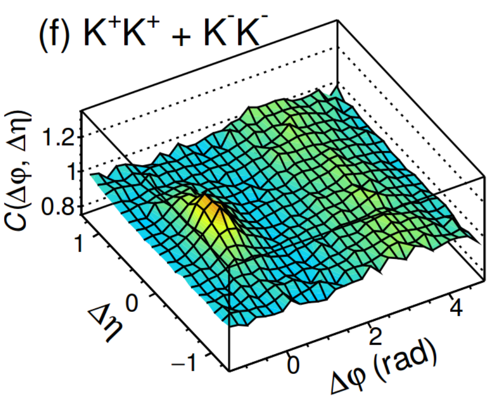
- Non-femtoscopic correlations visible in small systems for **pions** and **kaons**:
  - Grow with increasing k_T
  - Grow with decreasing multiplicity
  - **Significant problem in the fitting procedure**
- So far **hypothesis of minijet/jet origin**
- **How do baryon correlations look in pp?**

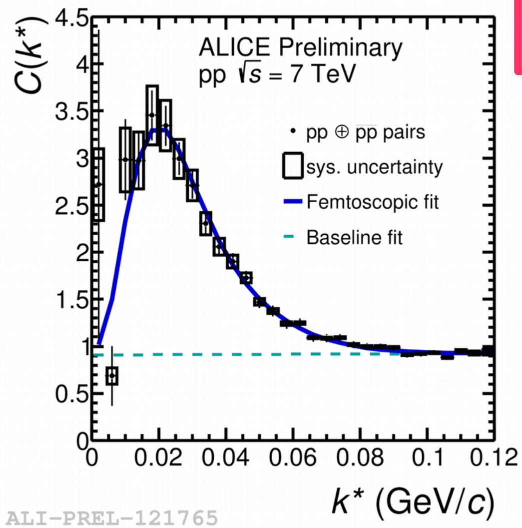


arXiv:1212.5958

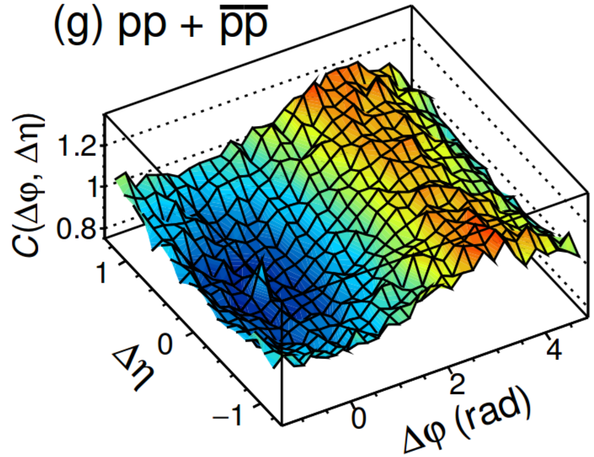


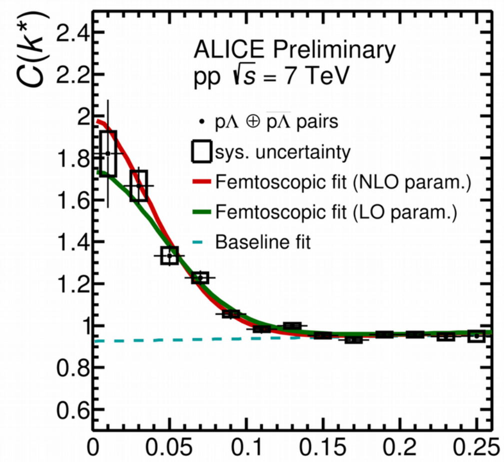






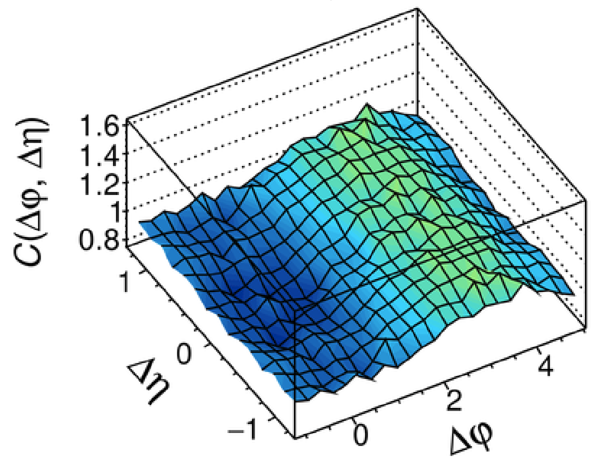
pp+p̄p̄

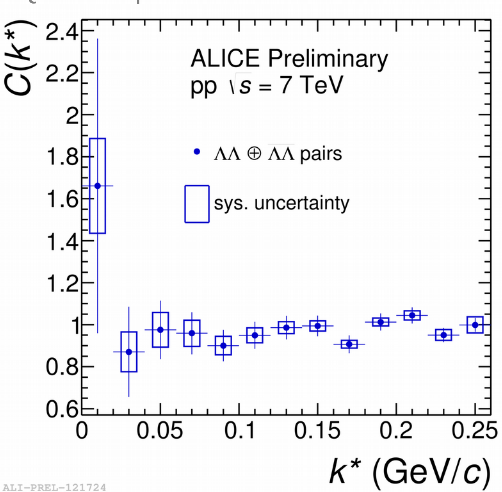




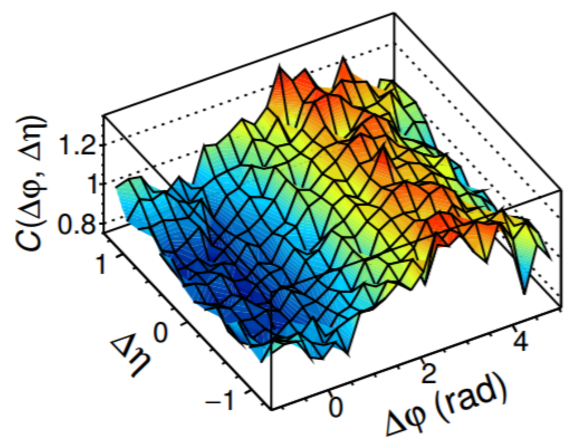
Oliver Arnold
QM 2017 poster

pΛ+p̄Λ̄





ΛΛ+Λ̄Λ̄



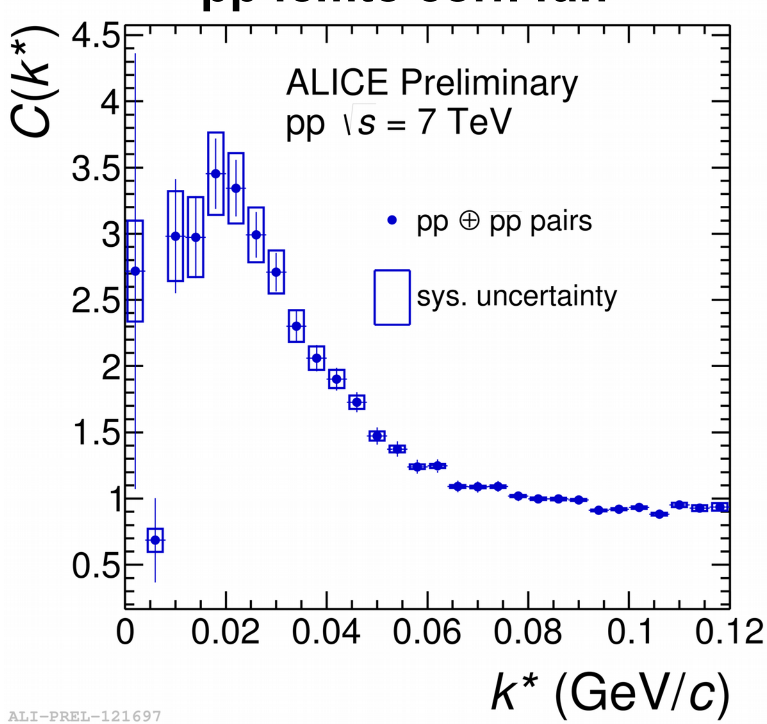
Flat baseline for all baryon-baryon pair measurements.

Consistent picture from femtoscopic measurements and ΔηΔφ!

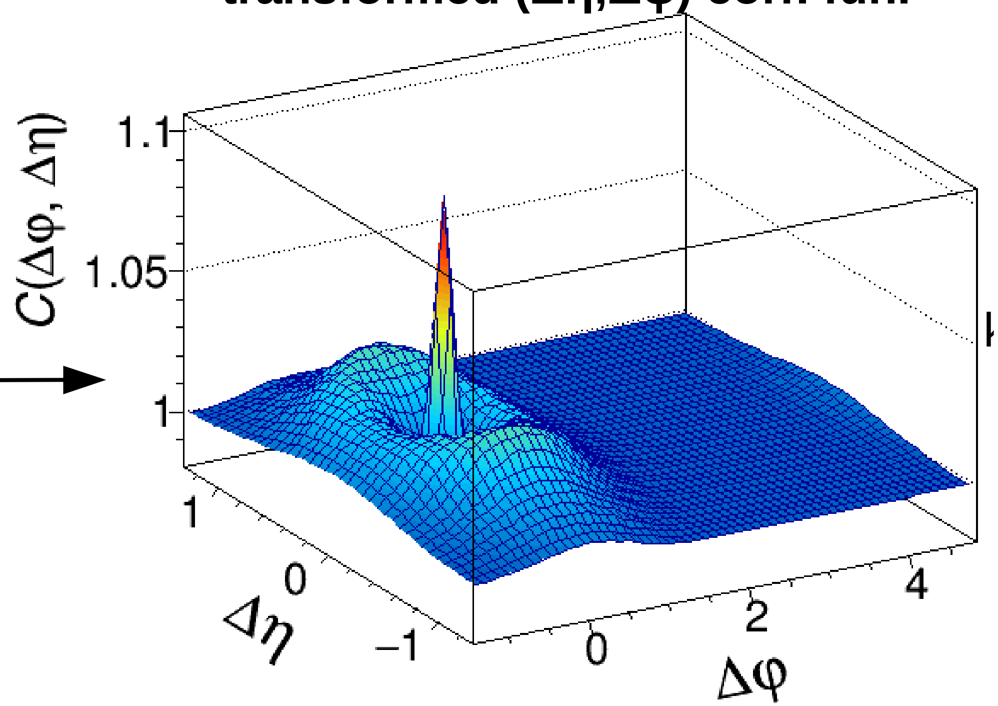
Proton correlations – transformation

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

pp femto corr. fun



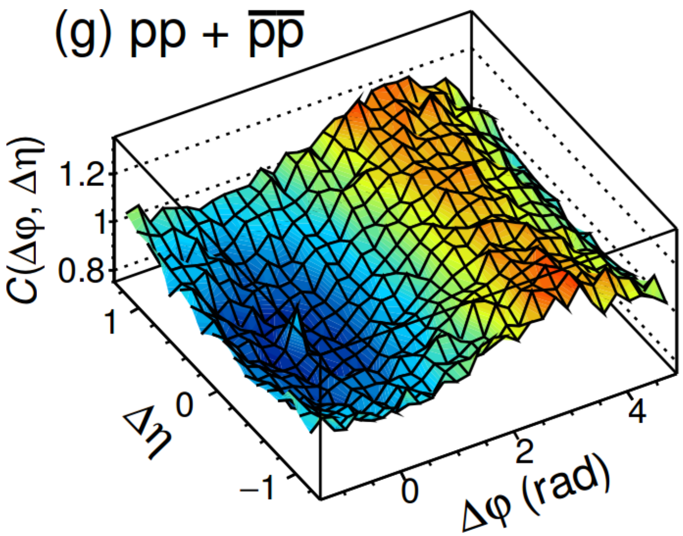
transformed (Δη,Δφ) corr. fun.

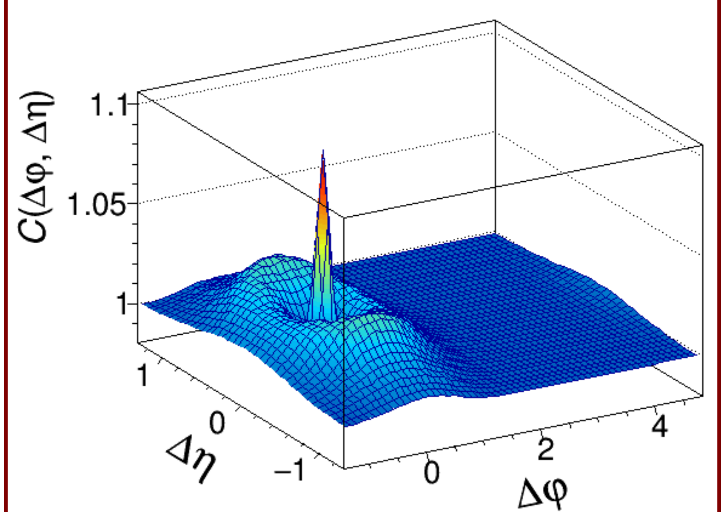


Protons – femtoscopic correlations

Results:

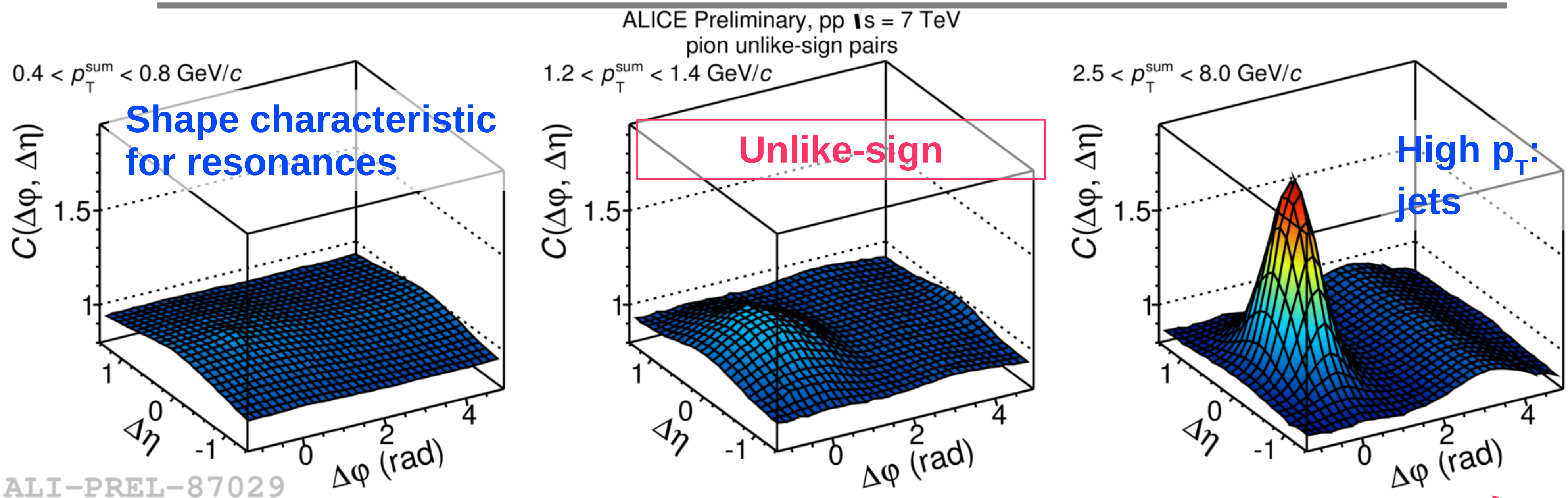
- Femto correlation produces spike at $(\Delta\eta,\Delta\varphi)=(0,0)$
- Both the height and the width of two peaks comparable
- FSI cannot produce observed anti-correlation
- **Unsolved question: why are baryons so different?**





Pions

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



p_T growth