Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

ALICE

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What can we learn from femtoscopy and angular correlations in ALICE?

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for the ALICE Collaboration

XIII Polish Heavy-Ion Workshop
Wrocław, Poland
7/01/2018

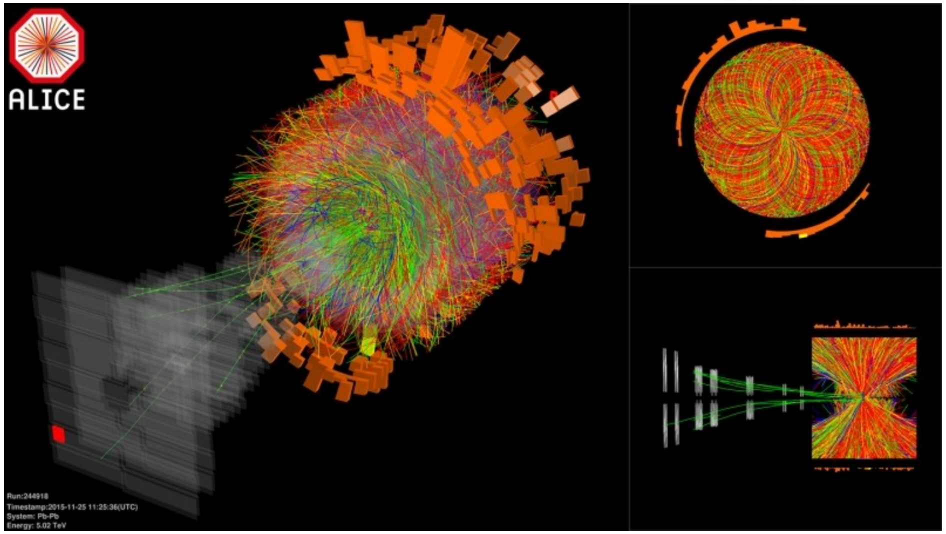
Femtoscopy – going beyond the system size

Correlations of baryons

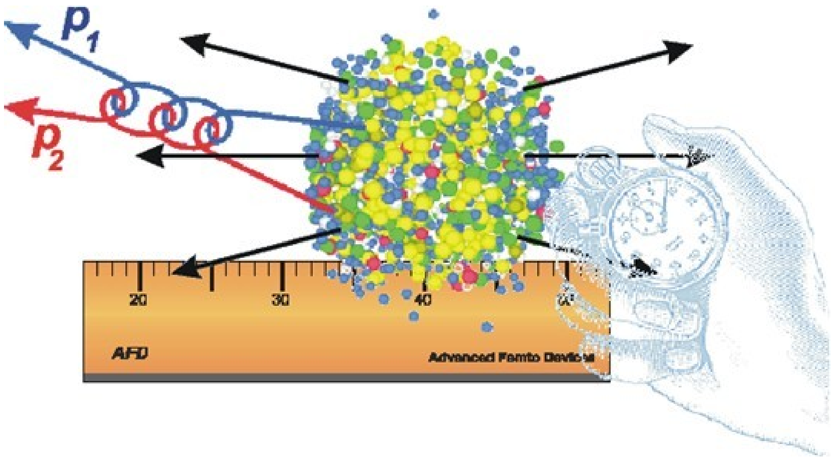
$K^0_s K^{\pm}$ and other correlations

Disclaimer: some plots are labeled “Work in progress”
They will not be kept on Indico conference page

Femtoscopy technique



from M. Lisa and S. Pratt



- Femtoscopy – measures space-time characteristics of the source using particle correlations in <u>momentum space</u>
- Main sources of correlations:
  - Quantum statistics (QS)
    - bosons (i.e. pions) – Bose-Einstein QS
    - fermions (i.e. protons) – Fermi-Dirac QS
  - Final-state interactions (FSI)
    - strong interaction
    - Coulomb repulsion or attraction

$$C(q)=\int S(r)|\Psi(q,r)|^2 d^4 r$$

In the experiment:

$$C(q)=A(q)/B(q)$$

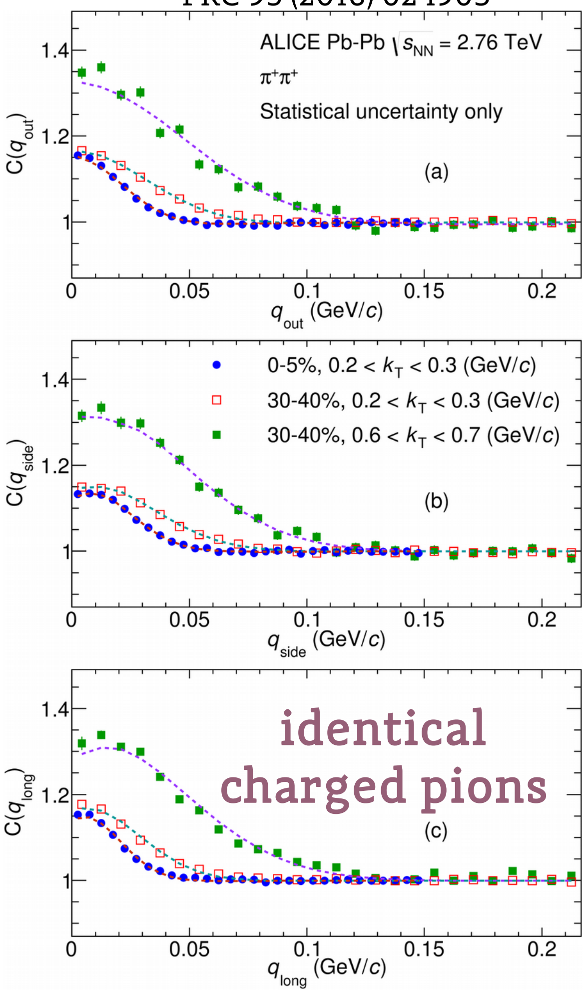
$A(q)$ - signal distribution ("same" events)

$B(q)$ - background distribution ("mixed" events)

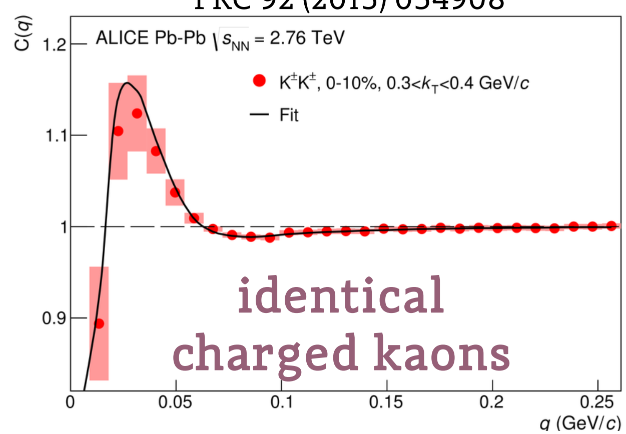
How does it look like?

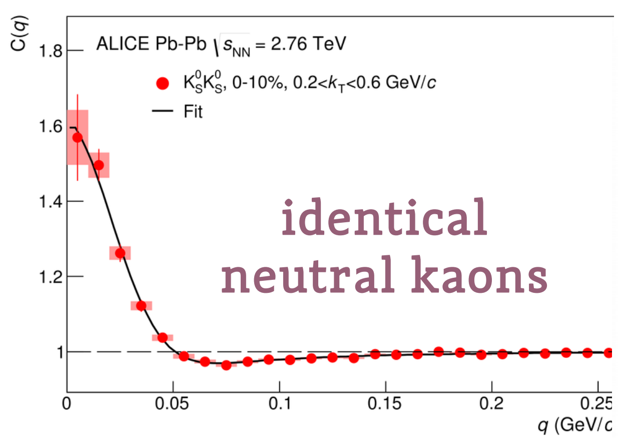
Correlation functions have different shapes, depending on the pair type (interaction involved), collision system and energy, pair transverse momentum, etc.

PRC 93 (2016) 024905



PRC 92 (2015) 054908





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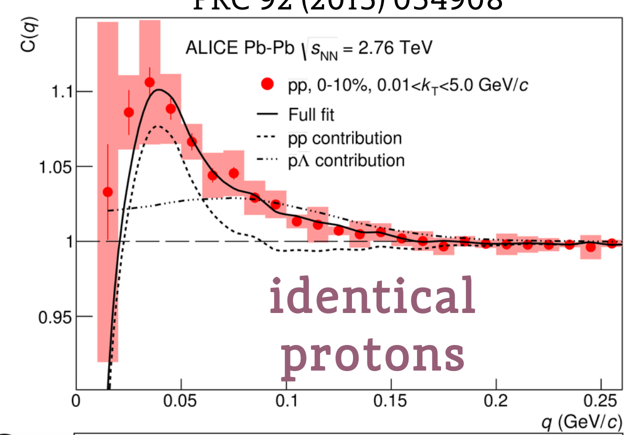
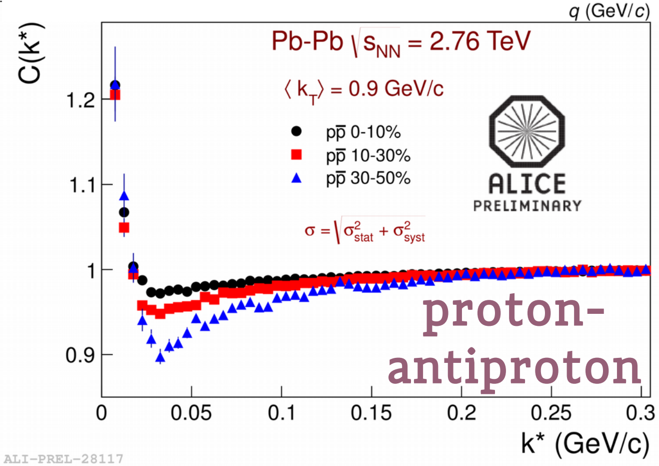


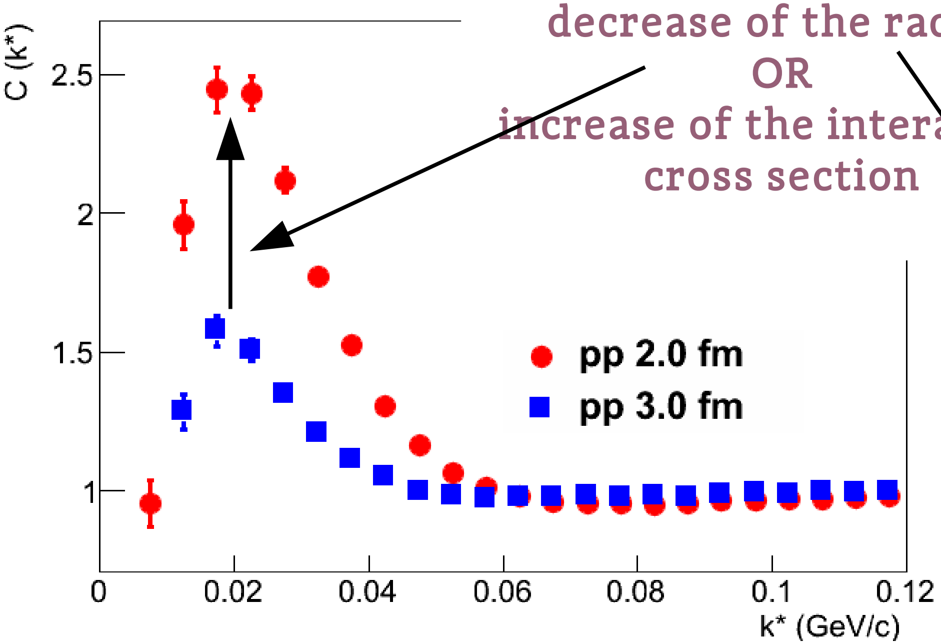


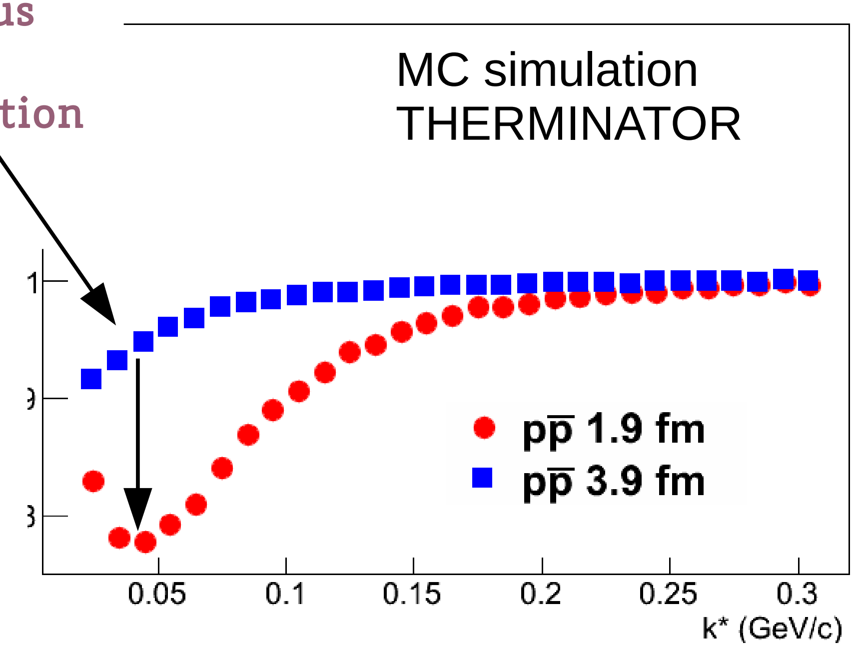
Beyond the system size

$$C(q)=\int S(r)|\Psi(q,r)|^2 d^4 r \qquad q=2\cdot k^*=p_1-p_2$$

- $C(q)$: measured correlation
- $S(r)$: emission function (source size/shape)
- $|\Psi(q,r)|^2$: pair wave function (includes cross section)

increase of (anti)correlation
=
decrease of the radius
OR
increase of the interaction cross section





Beyond the system size

$$C(q)=\int S(r)|\Psi(q,r)|^2 d^4 r \qquad q=2\cdot k^*=p_1-p_2$$

measured correlation — emission function (source size/shape) — pair wave function (includes cross section)

$$\Psi=\exp(-ik^* r)+f\frac{\exp(ik^* r)}{r}$$ s-wave scattering approximation

$$f^{-1}(k^*)=\frac{1}{f_0}+\frac{1}{2}d_0 k^{*2}-ik^*$$ effective range approximation

- If only Strong Final State Interaction (FSI) the result of integration:

$$C(k^*)=1+\sum_S \rho_S\left[\frac{1}{2}\left|\frac{f^S(k^*)}{R}\right|^2\left(1-\frac{d_0^S}{2\sqrt{\pi}R}\right)+\frac{2\Re f^S(k^*)}{\sqrt{\pi}R}F_1(2k^*R)-\frac{\Im f^S(k^*)}{R}F_2(2k^*R)\right]$$

Lednicky, Lyuboshitz, Sov. J. Nucl. Phys., 35, 770 (1982)

where ρ_S are the spin fractions

- The correlation function is characterized by **three parameters**:
  - **radius** R, **scattering length** f_0, and **effective radius** d_0
  - **cross section** σ **(at low** k^*) is simply: $\sigma=4\pi|f|^2$

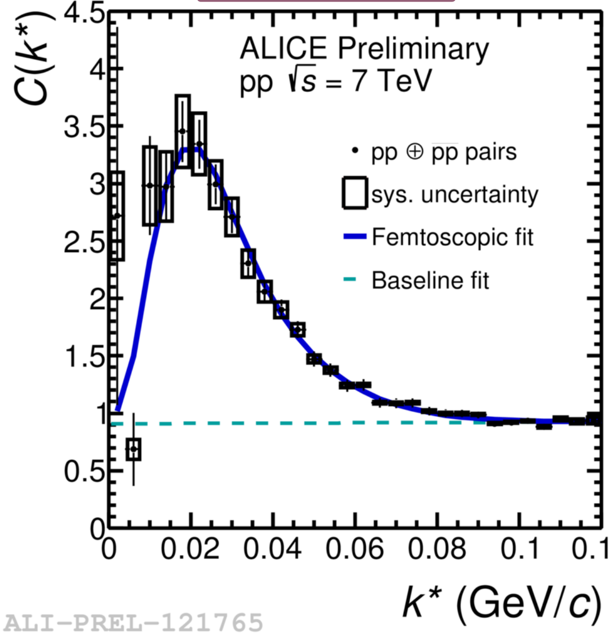
Potential applications

- Input to models with re-scattering phase (eg. UrQMD):
  - annihilation cross sections only measured for $p\bar{p}$, $\bar{p}n$, and $\bar{p}d$ pairs – UrQMD currently **guesses it for other systems** from $p\bar{p}$ pairs
- Structure of baryons/search for CPT violation
  STAR, Nature 527, 345-348 (2015)
- Search for H-dibaryon
  ALICE, PLB 752 (2016) 267-277
- Hypernuclear structure theory
  Nucl.Phys. A914 (2013) 377-386
- Neutron star equation of state
  Nucl.Phys. A804 (2008) 309-321

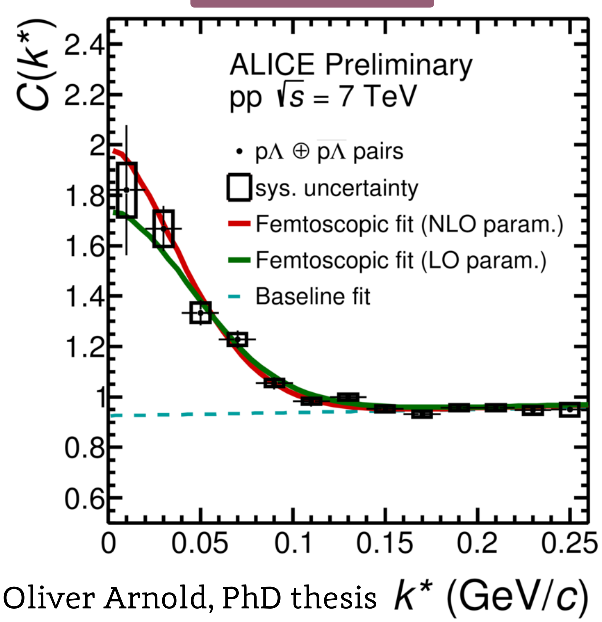
- Relativistic heavy-ion collisions at LHC or RHIC produce very similar number of baryons and antibaryons, “matter-antimatter pair factories”

Baryon-baryon correlations

pp+$\overline{\text{pp}}$



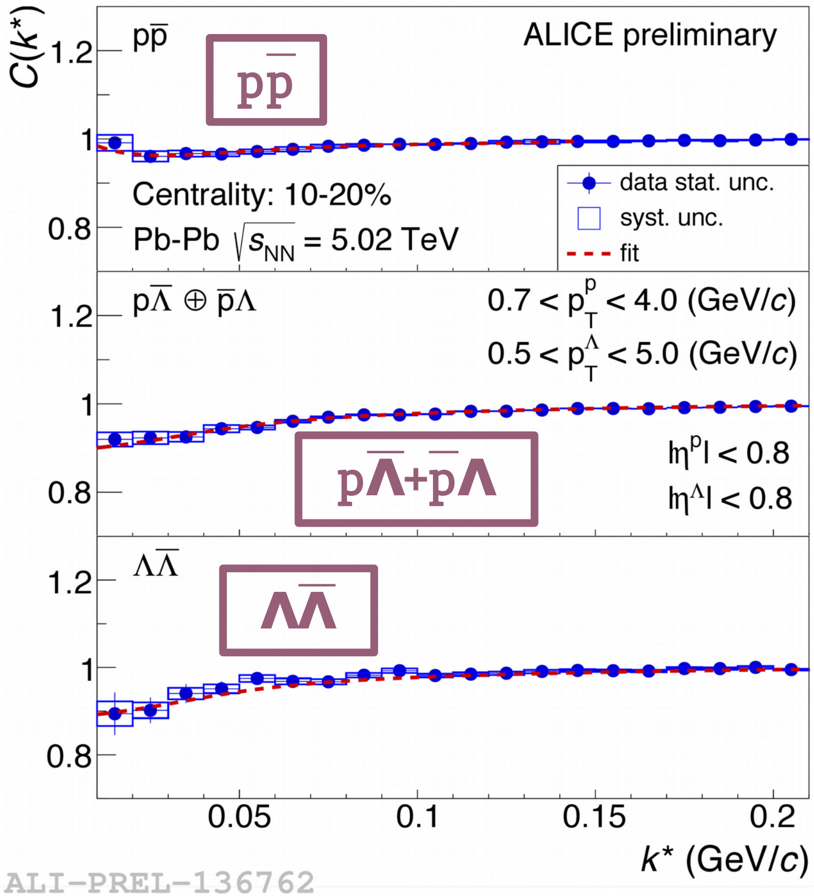
pΛ+$\overline{\text{p}\Lambda}$

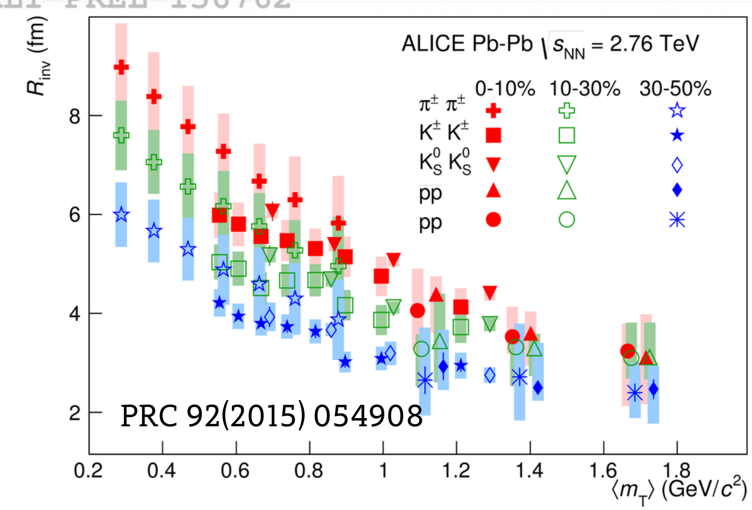


Oliver Arnold, PhD thesis
QM 2017

- ALICE particle identification capabilities allow us to measure correlations of different baryons
- Except for pairs like proton-proton or proton-neutron, cross sections for other baryons practically not known
  - eg. only ~30 points for proton-lambda interaction measurements exist
- ALICE can constrain cross sections for these systems at low relative momentum k*
- Assuming LO and NLO scattering parameter predictions in the fit (from Nucl. Phys. A915, 24-58)
- Preliminary results of simultaneous fit to proton-proton and proton-lambda correlation functions:
  - extracted source size: $R = 1.31 \pm 0.02 \quad fm$
  - NLO predictions seems to be slightly more accurate, however we still lack statistics
  - we hope to have more accurate results after analysing 13 TeV LHC Run2 data

Jeremi Niedziela, PhD thesis
ŁG, ISMD 2017

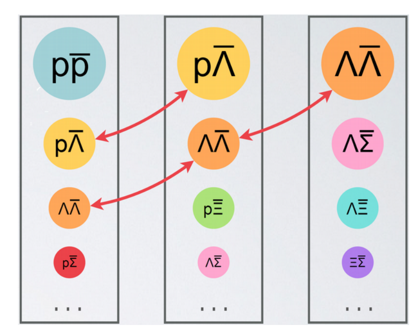




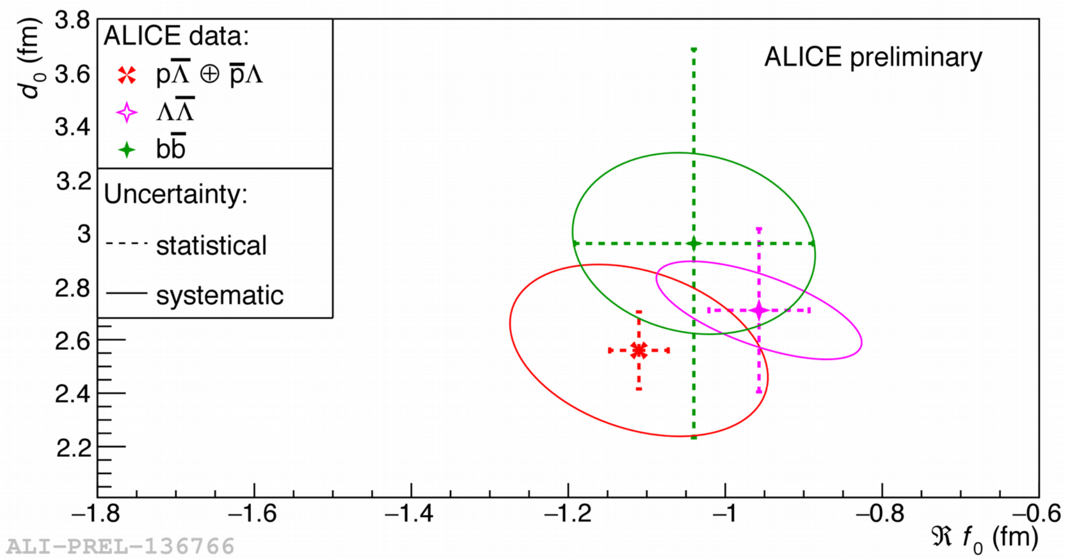
Baryon-antibaryon correlations

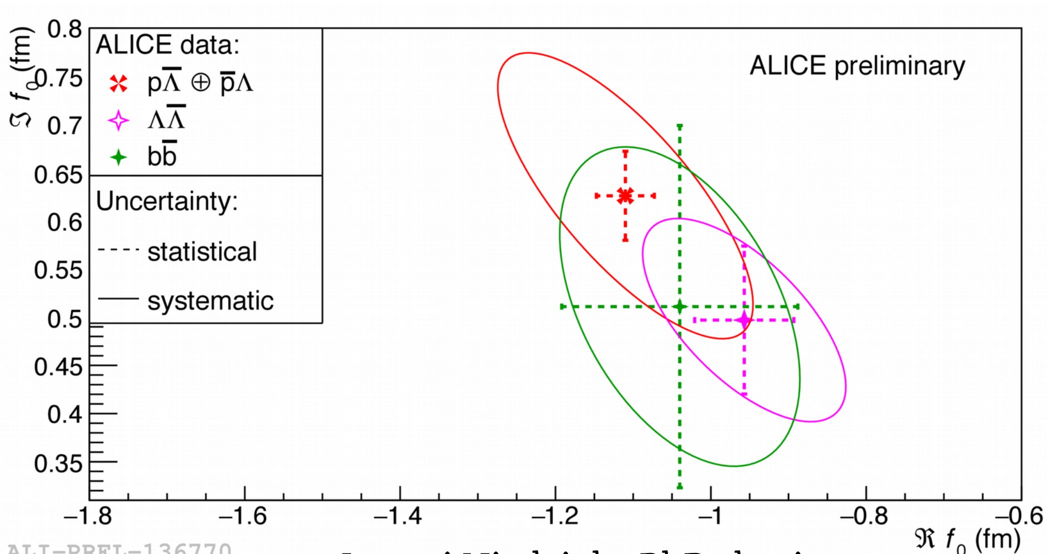
Explanation of the fitting procedure:

- **χ^2** is calculated from a "global" fit to all functions:
  2 data sets, 3 pair combinations, 6 centrality bins (**total 36 functions**)
- simultaneous fit accounts for parameters **shared** between different systems (such as ΛΛ̄ scattering length)
- **radii scale with multiplicity** for a given system $R_{inv} = a \cdot \sqrt[3]{N_{ch}} + b$
- for different systems we assume **radii scaling with** m_T
- Fractions of **residual pairs** taken from AMPT



Baryon-antibaryon correlations





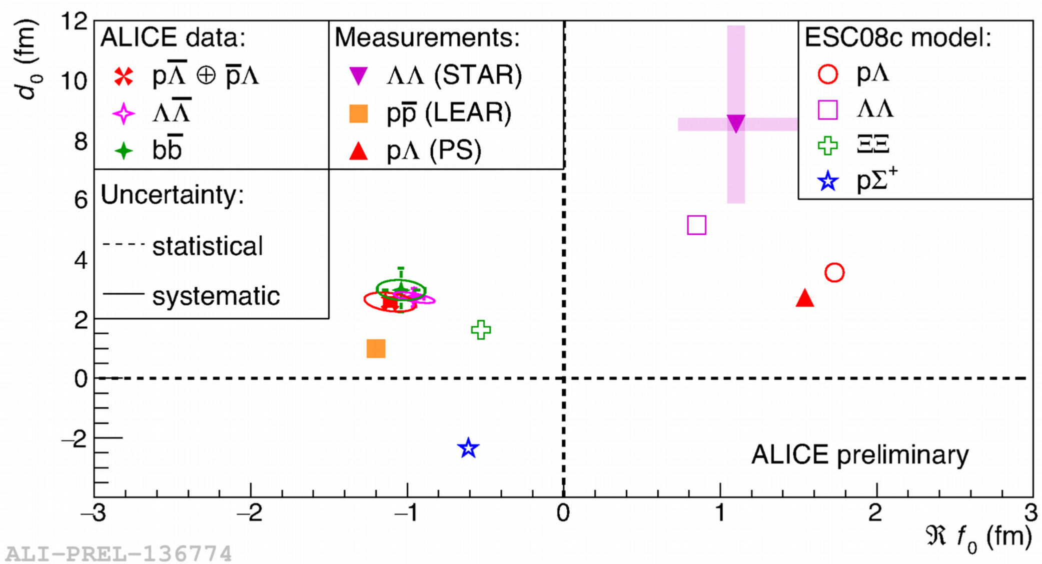
Jeremi Niedziela, PhD thesis
ŁG, ISMD 2017

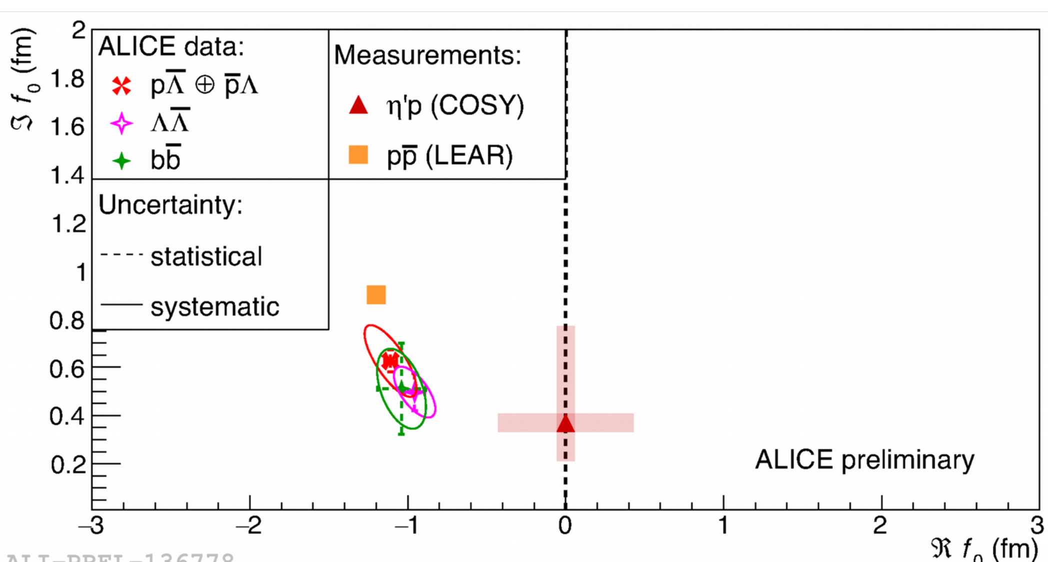
Conclusions from fitting:

- Interaction parameters are measurable
- Scattering parameters for **all baryon-antibaryon pairs are similar to each other** (UrQMD assumption is valid)
- We observe a **negative real part of scattering length** → repulsive strong interaction or creation of a bound state (existence of baryon-antibaryon bound states?)
- Significant **positive imaginary part of scattering length** – presence of a non-elastic channel – annihilation

Next steps: try to look for baryon-antibaryon bound states

Baryon-antibaryon correlations





Jeremi Niedziela, PhD thesis
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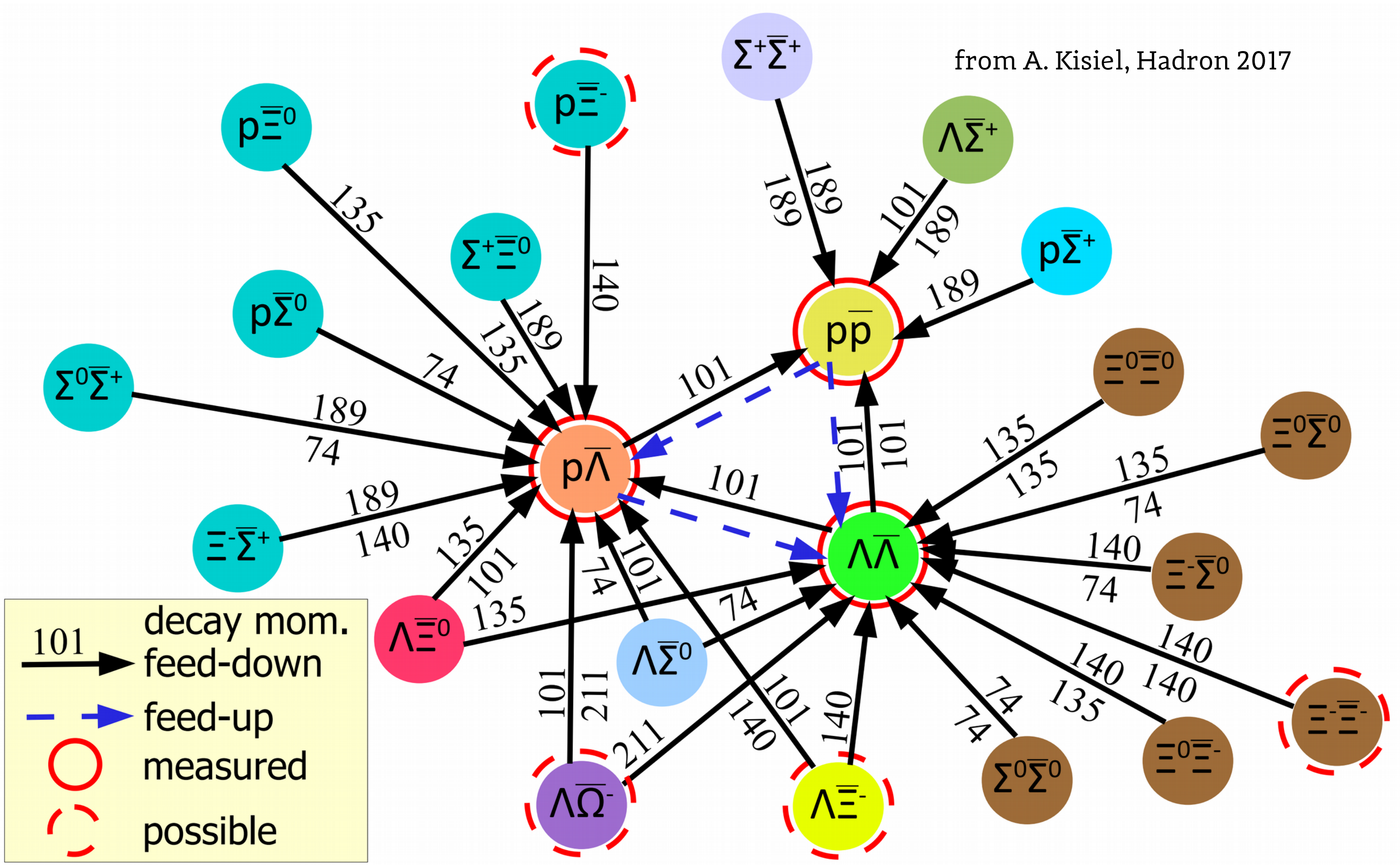
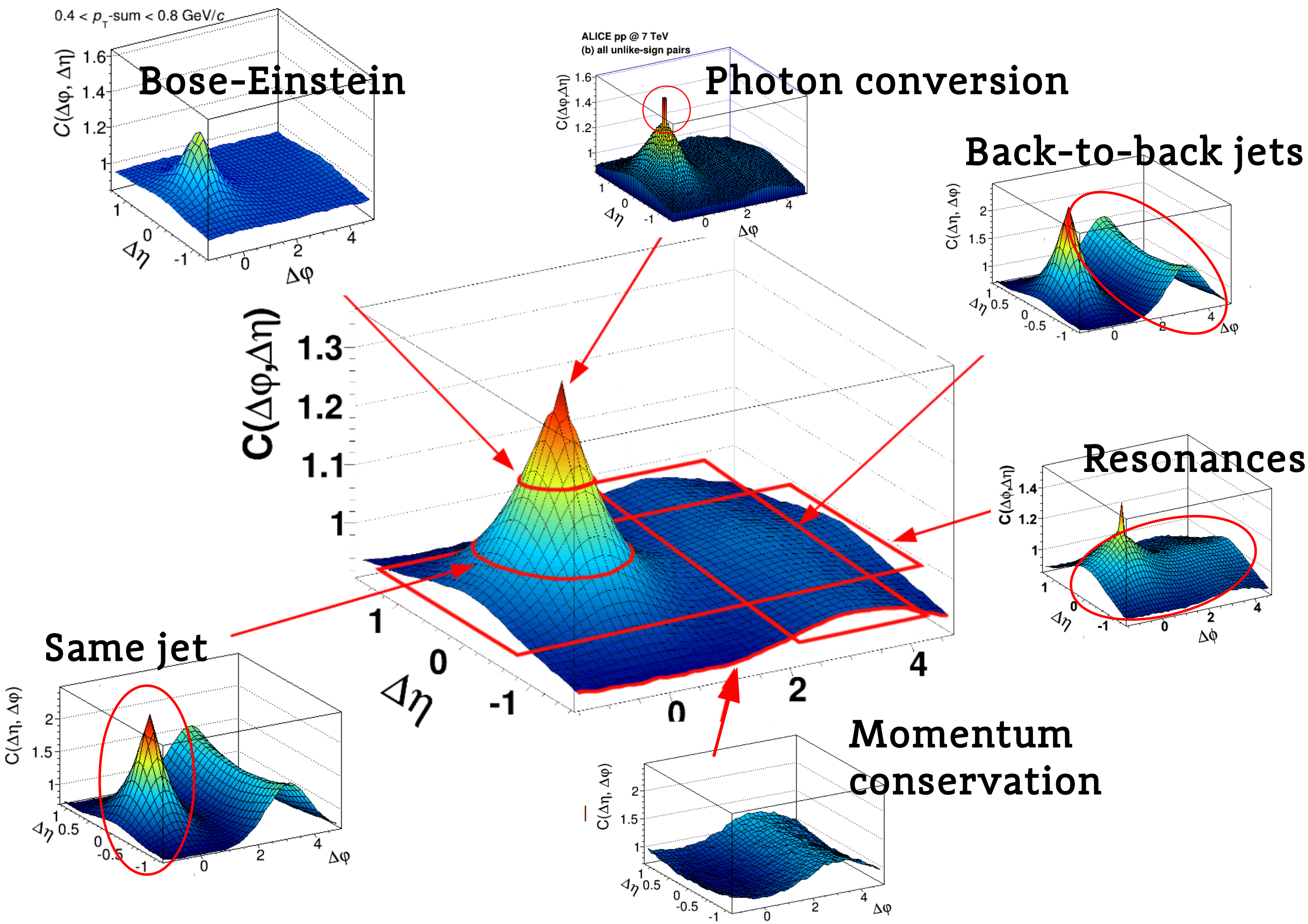
Other possibilites



What about other types of correlations?

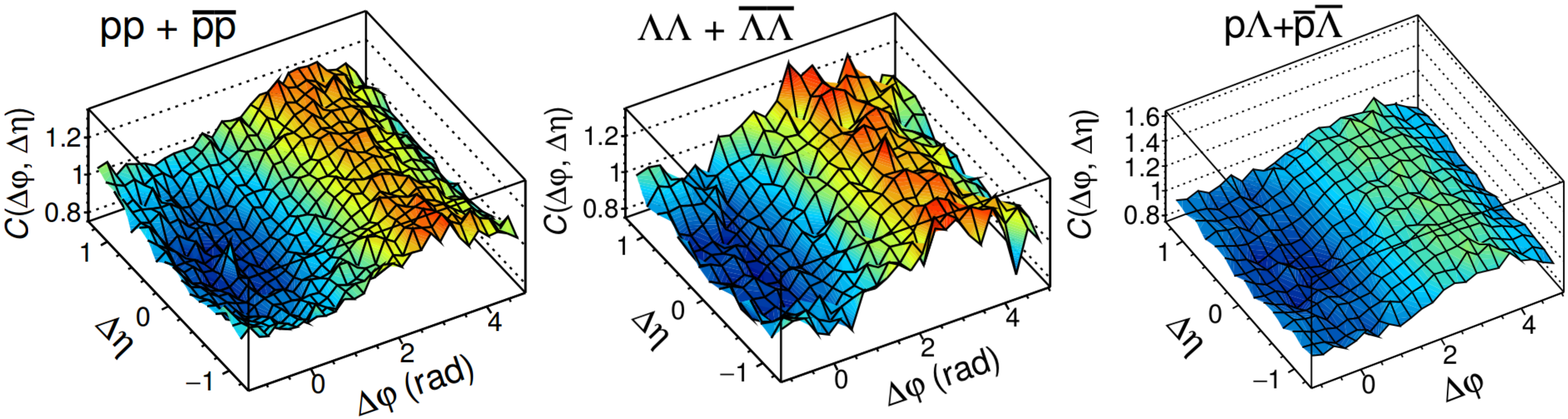
Let's look at angular space



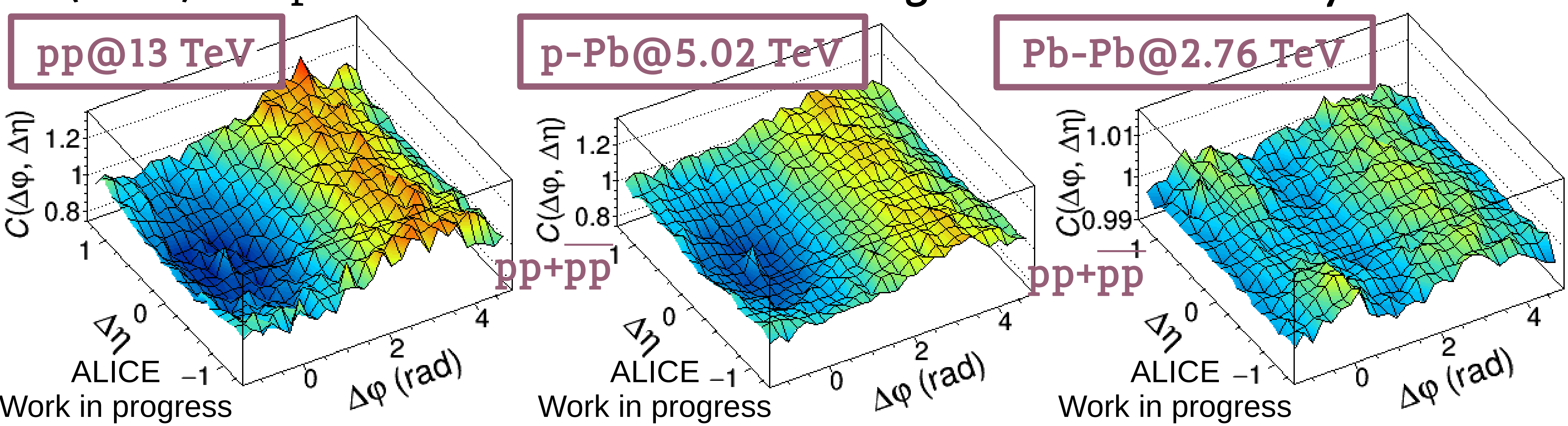
ΔηΔφ of baryons

Eur.Phys.J. C77 (2017) 8, 569

Małgorzata Janik, ŁG



- We found that all baryon-baryon pairs show a **depression** instead of a typical near-side peak
- **(New)** It is present for **all collision energies and collision systems**



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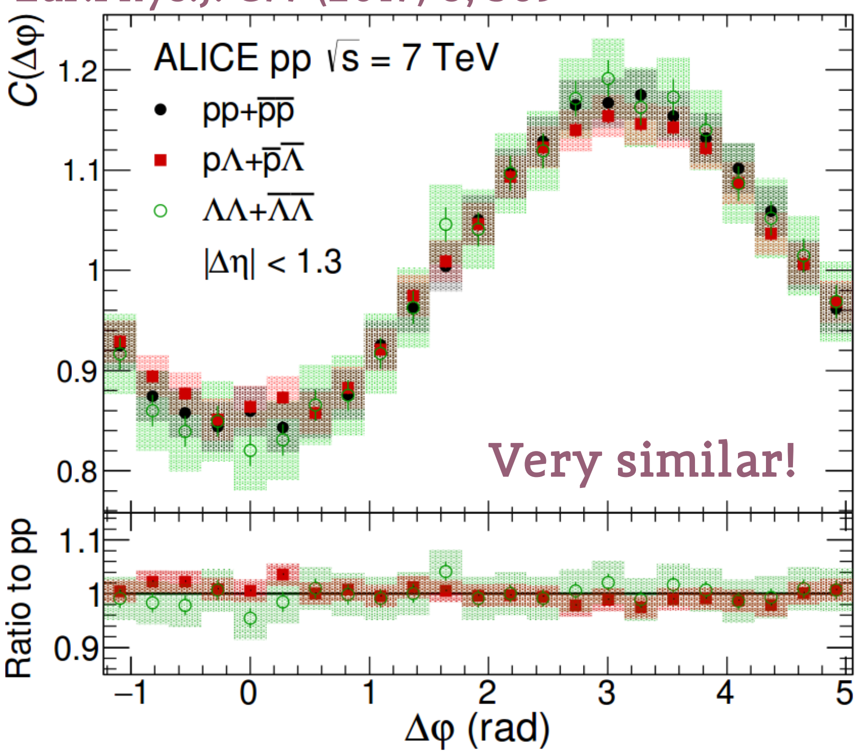

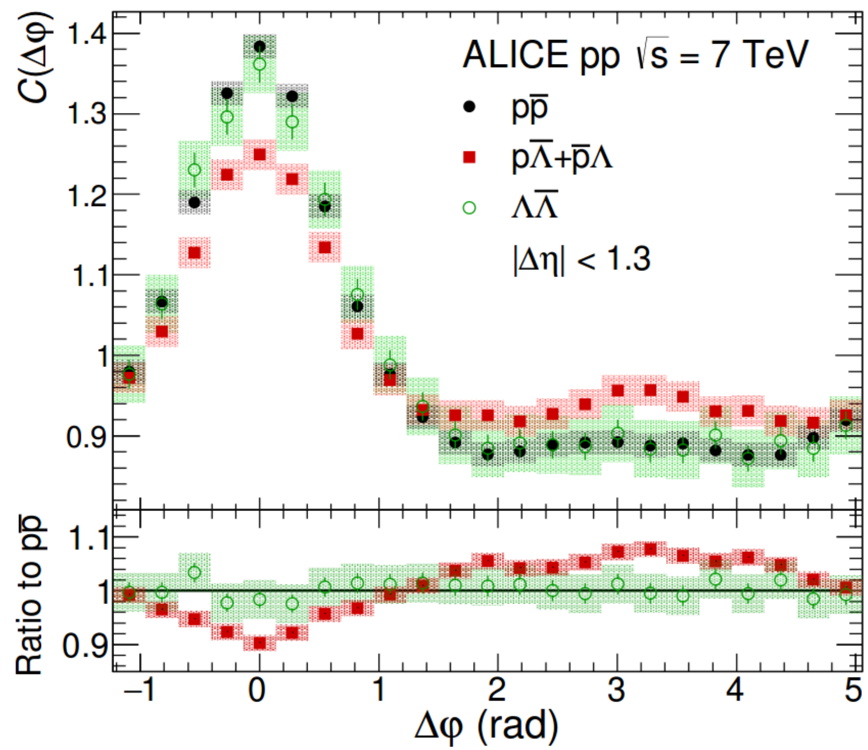

- Projections show how similar are baryon-baryons pairs to each other
- Similarity between pairs, to a lesser extent, is also observed in the baryon-antibaryon case

Possible explanations:

- Fermi-Dirac Quantum Statistics? **NO (non-identical particles)**
- Coulomb repulsion? **NO (uncharged particles)**
- **Strong Final-State Interactions?** (see next slides)

ΔηΔφ of baryons

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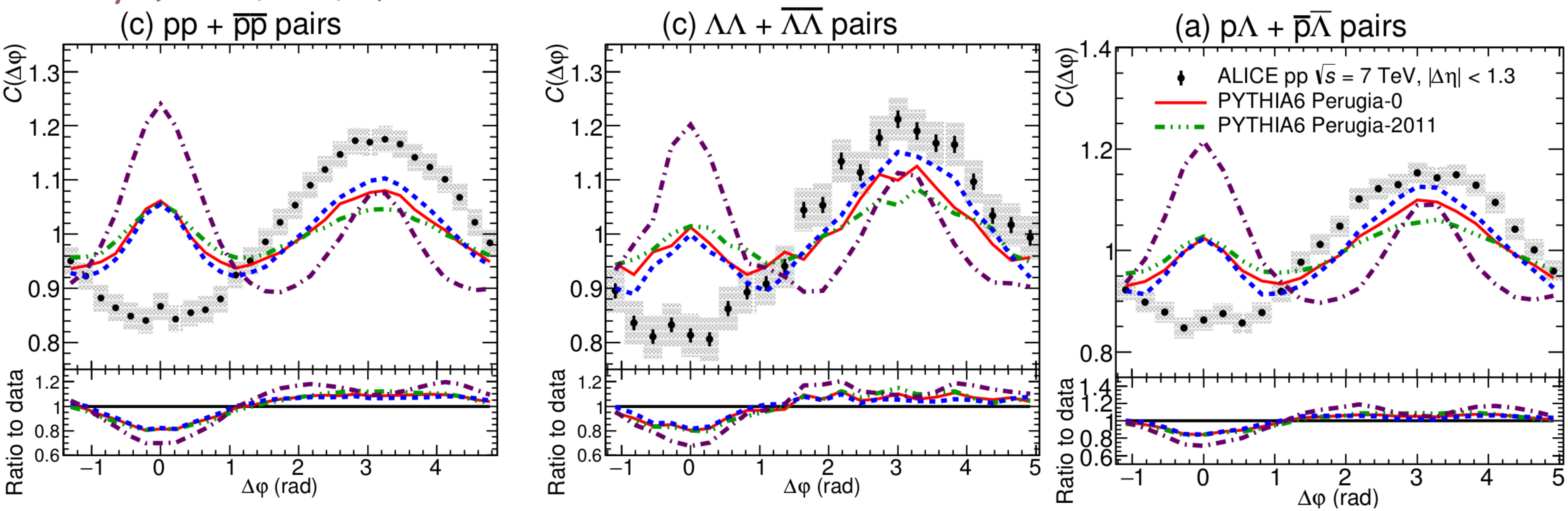


- None of studied MC models (PYTHIA, PHOJET, EPOS, HERWIG) agrees with the data even qualitatively

- What can be the explanation of this effect?

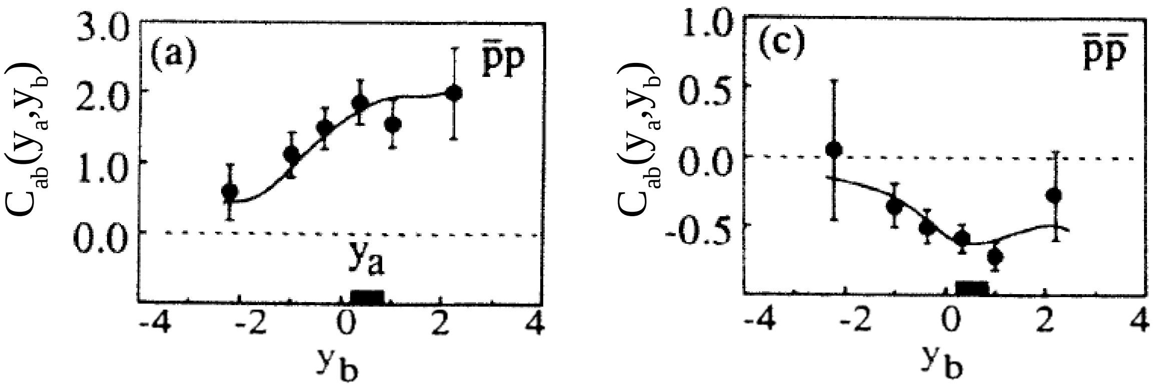
Let's look at similar studies in e^+e^- collisions at √s = 29 GeV (SLAC-PEP) from late 80's

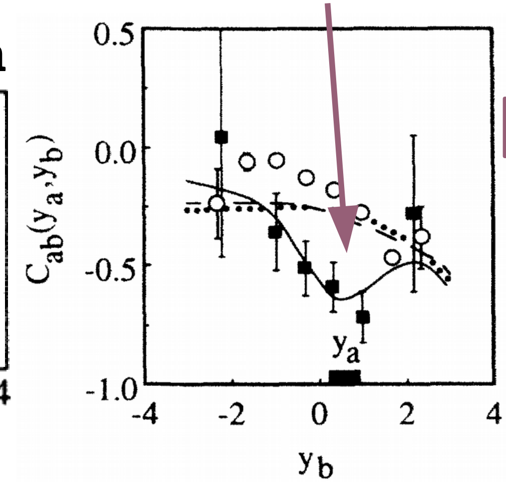
Rapidity correlations in e^+e^-

Models for e^+e^- agree with observations seen in data

TPC/Two Gamma Collaboration

correlation **anti-correlation**





Lund model describes data

Phys.Rev.Lett. 57 (1986) 3140

Hypothesis from e^+e^- studies at $\sqrt{s}$ = 29 GeV at SLAC-PEP:

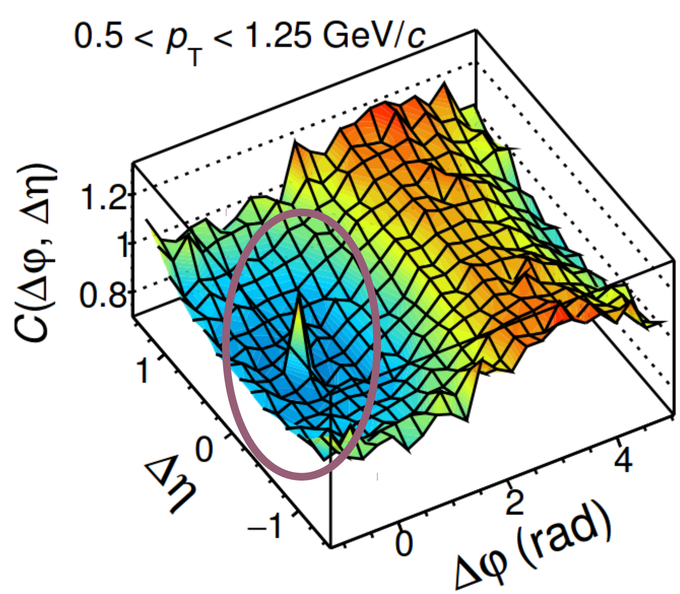
- Depletion is a manifestation of **"local" baryon number conservation**

- Production of 2 baryons in a single 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 explanation at 29 GeV collision energy, but why at 7 TeV?!**

We have seen from both measurements that baryons are interesting indeed

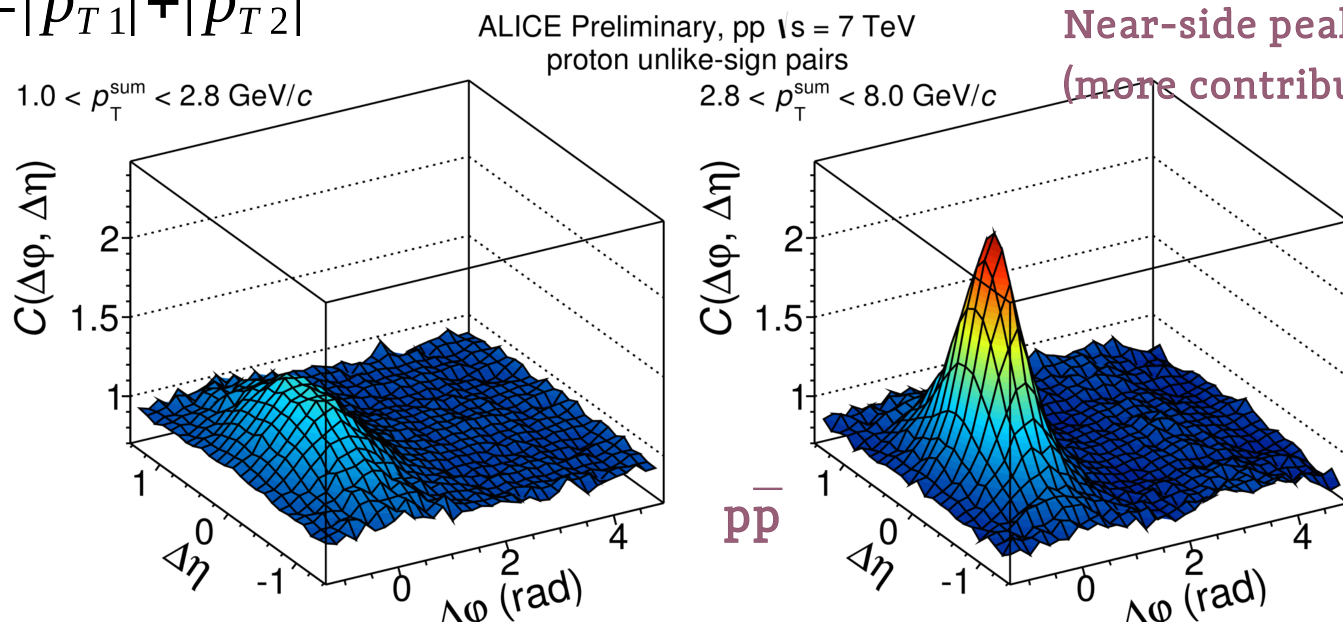
So, are there any direct connections between femtoscopic and angular correlations?

1) Possible origin of the “small peak”



ΔηΔφ of protons vs p_T

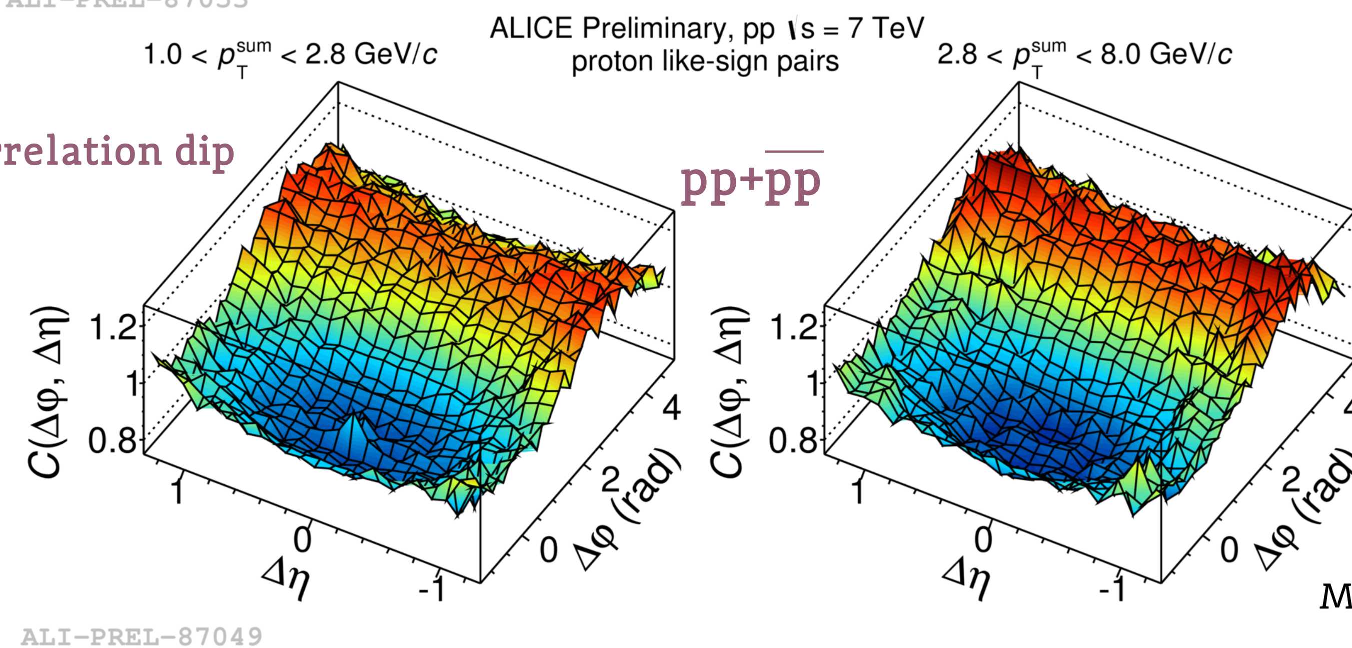
$$p_T^{\mathrm{sum}} = |p_{T\,1}| + |p_{T\,2}|$$



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

$p\bar{p}$

p_T growth



Anticorrelation dip

$pp + \bar{p}\bar{p}$

Small peak disappears for high p_T-sum

Shape of the dip does not change

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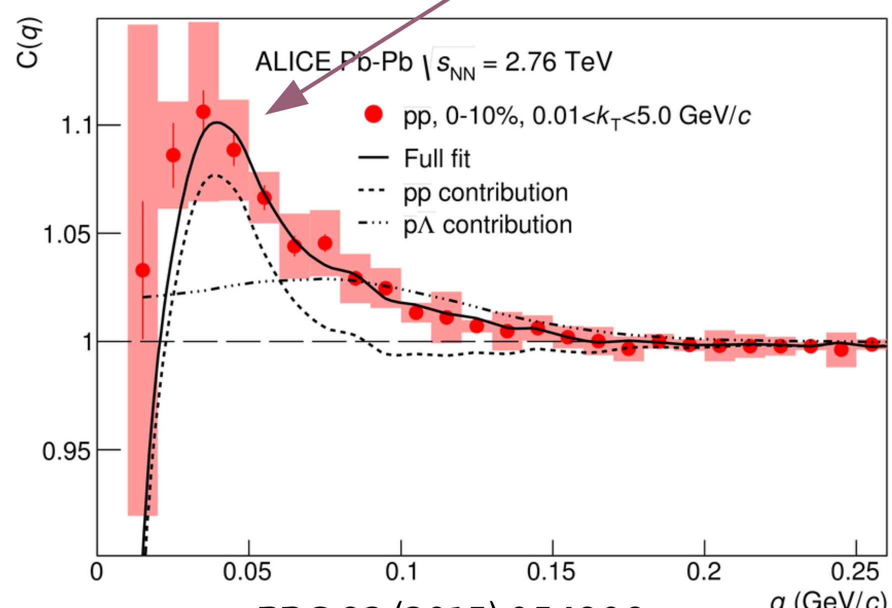
Femto correlations of protons

Possible origin of the small peak: QS(Fermi-Dirac) +Coulomb+Strong

- Visible in femtoscopic correlation function
- Dominant effect around q_{inv} = 0.04 GeV/c
- **Strong interaction** the only source of positive correlation for baryons



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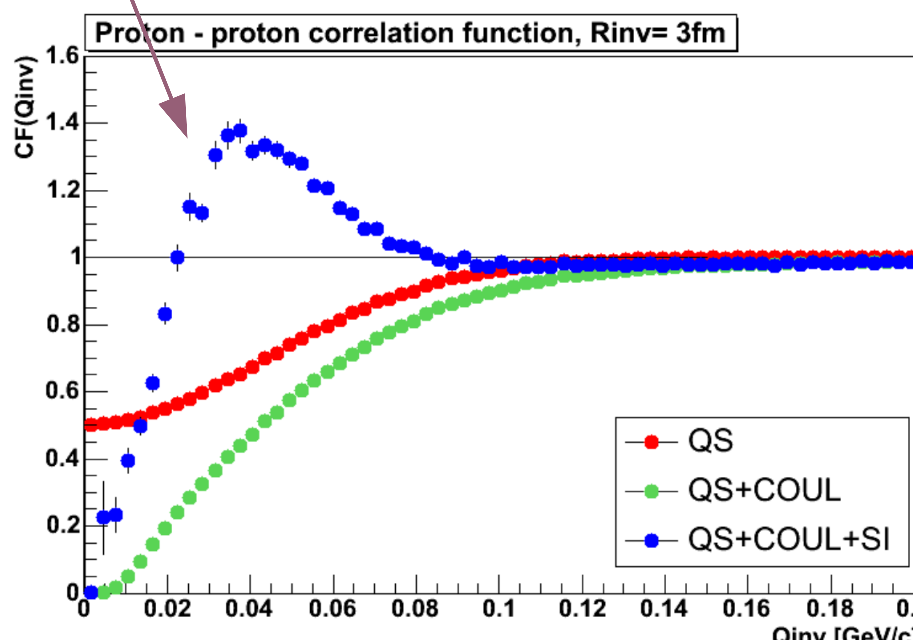

H. Zbroszczyk, PhD thesis

Femto correlations of protons

- **Direct transformation from $C(q_{inv})$ to $C(\Delta\eta\Delta\varphi)$ not possible**

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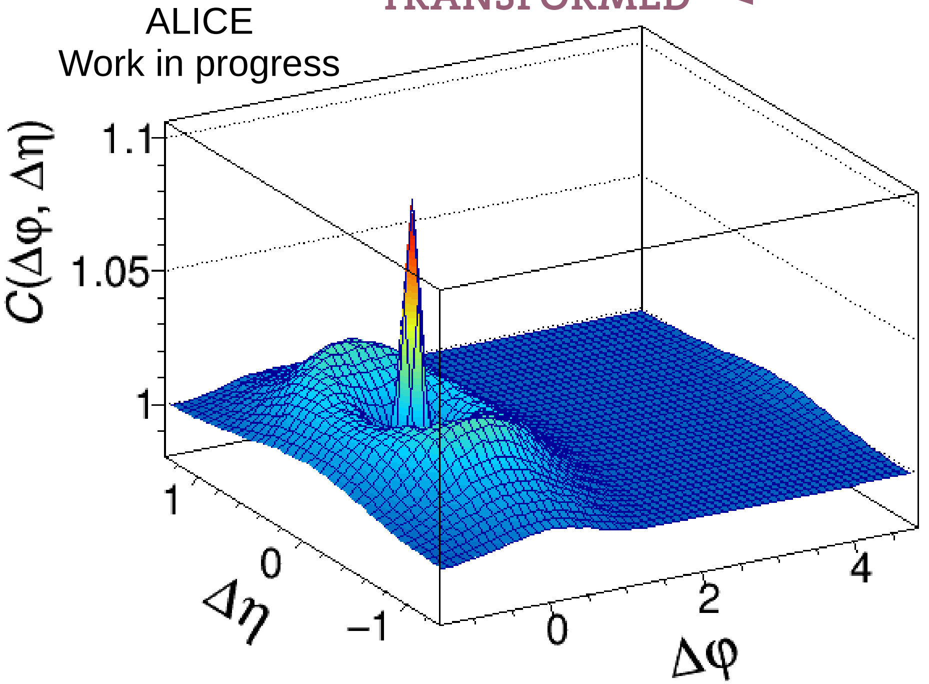
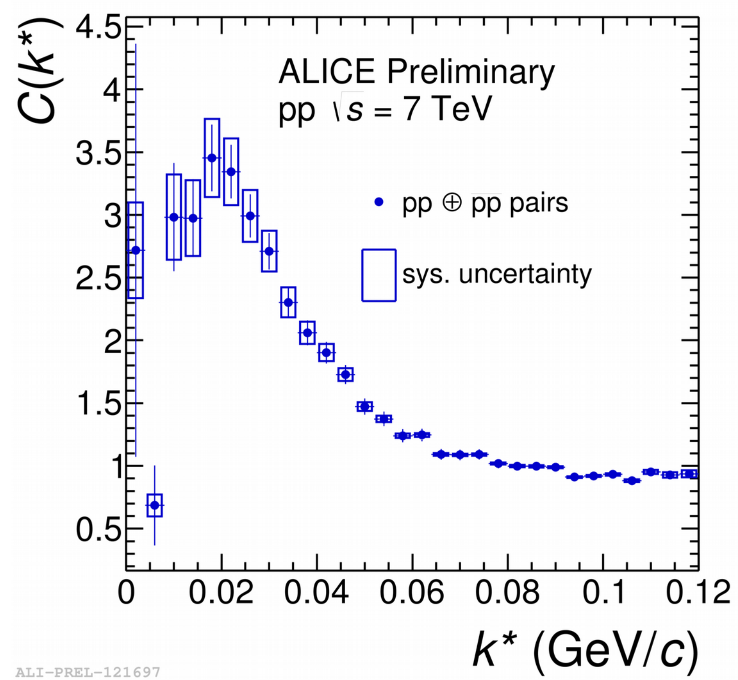
- **One can use a simple Monte Carlo procedure:**
  - generate random η and φ values from uniform distributions (for 2 particles: η_1, η_2, φ_1, φ_2)
  - generate random p_T value from measured p_T distribution (for 2 particles: p_{T1}, p_{T2})
  - calculate q_{inv} from generated η_1, η_2, φ_1, φ_2, p_{T1} and p_{T2} (the longest step)
  - randomly select q_{inv} and take a corresponding value from measured femtoscopic correlation and apply it as a weight while filling the numerator of ΔηΔφ correlation

TRANSFORMED ← **MEASURED**





Femto correlations of protons

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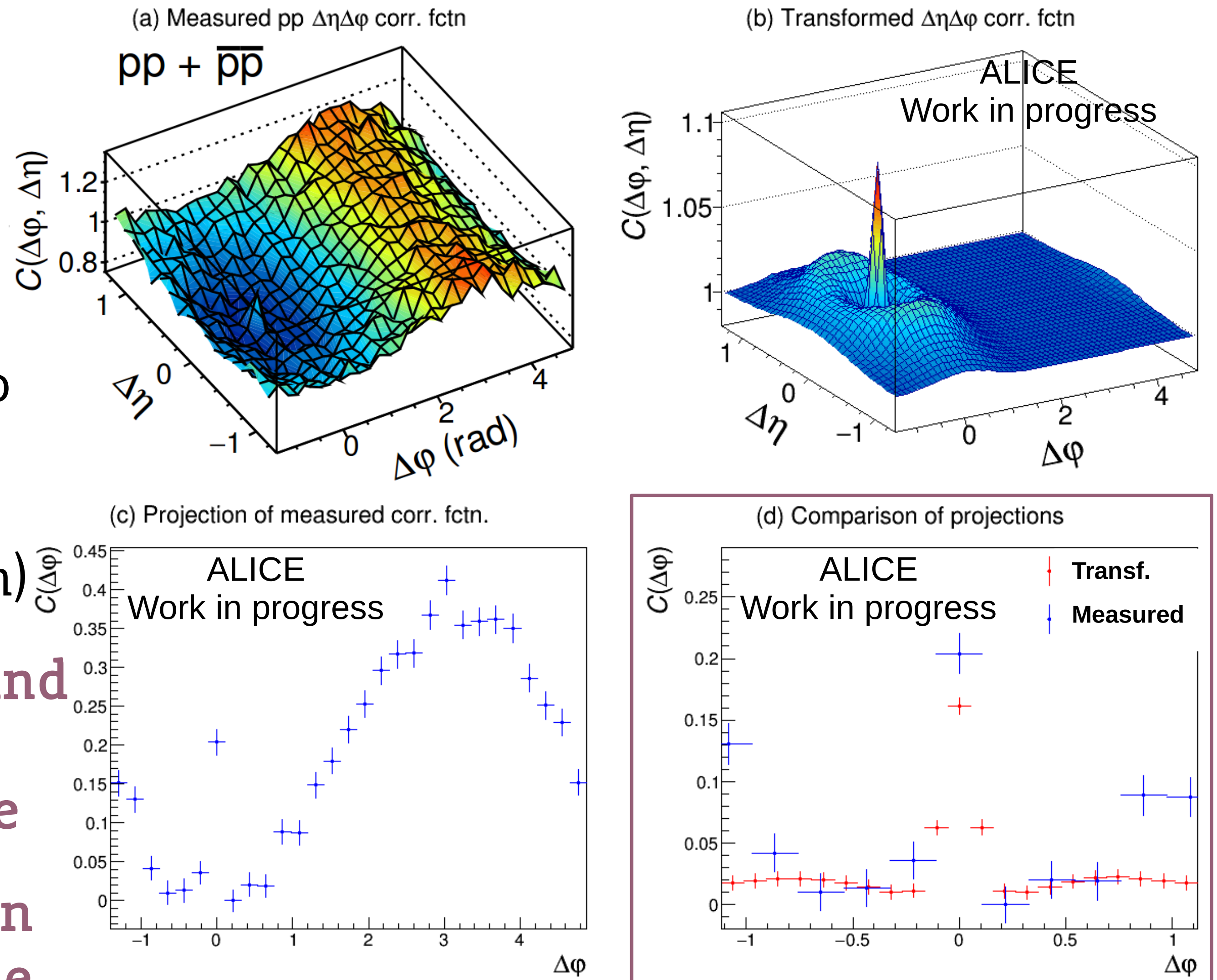
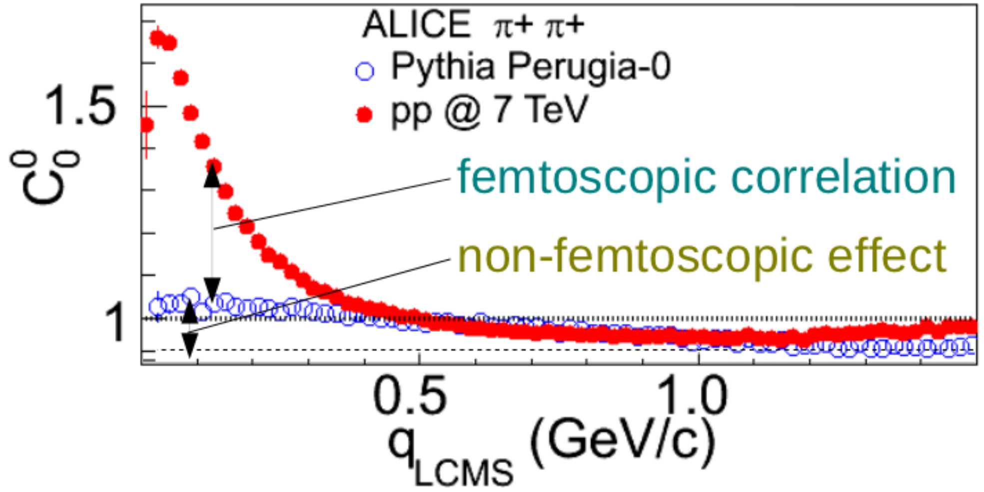
Results:

- Femto correlation produces spike at $(\Delta\eta,\Delta\varphi)=(0,0)$
- Comparison of two peaks: 1-bin wide projection on $\Delta\varphi$ (subtract minimum)
- **Both the height and the width of two peaks comparable**
- **Strong interaction does not cause the wide depletion**



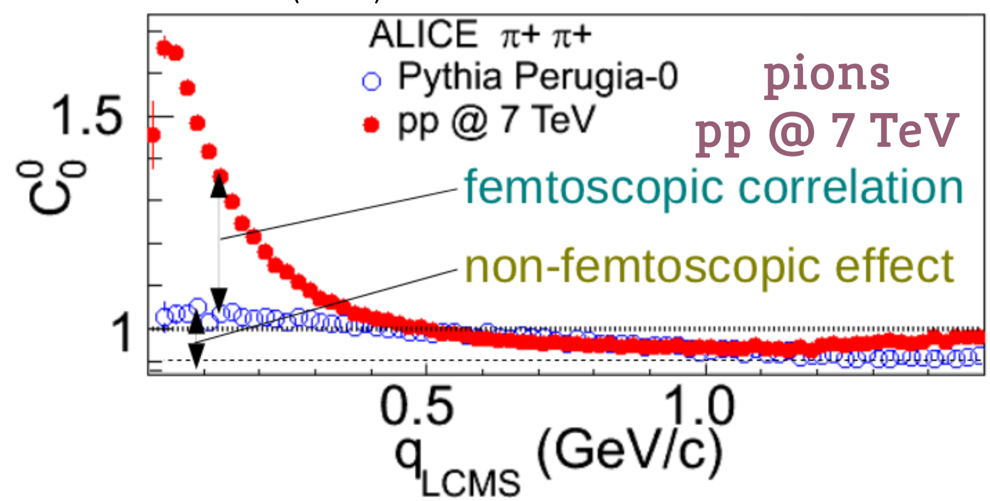
2) Non-femtoscopic correlations



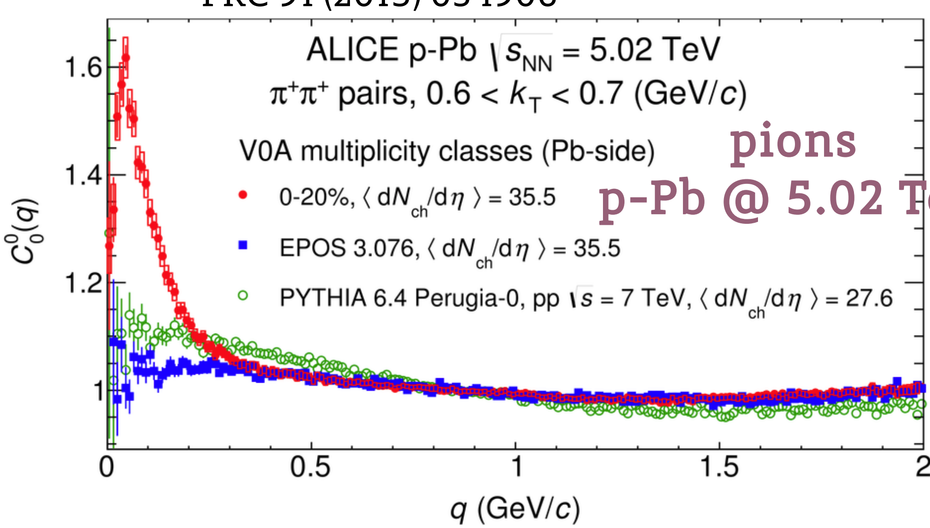
Non-femtoscopic correlations

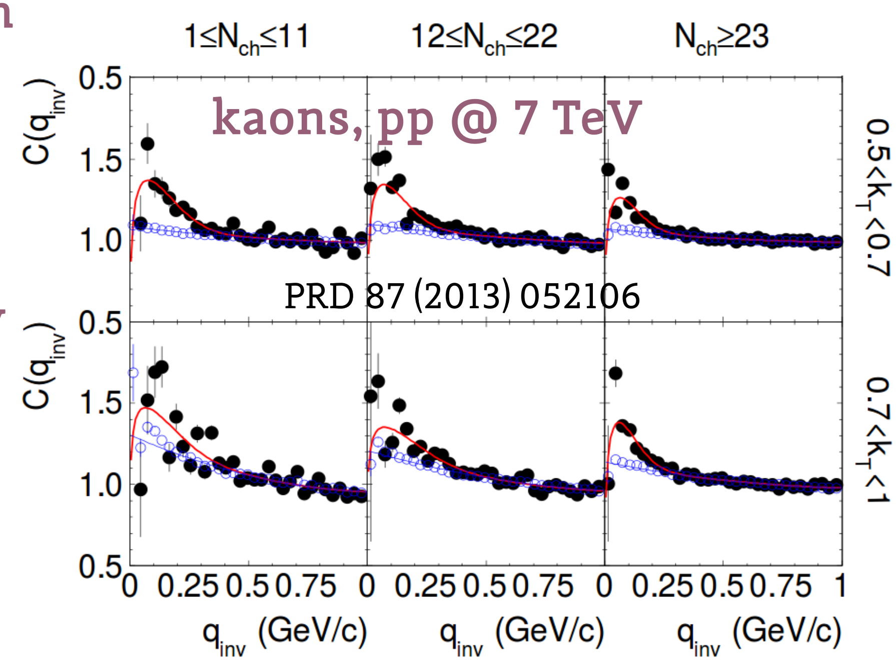
- Non-femtoscopic correlations visible in small systems for pions and kaons:
  - Grow with increasing k_T
  - Grow with decreasing multiplicity
  - **Significant source of systematics in the fitting procedure**
- So far only <u>hypothesis</u> of (mini-)jet origin
- How do baryon correlations look like in pp?

PRD 84 (2011) 112004



PRC 91 (2015) 034906





Angular vs femto corr. fctn.

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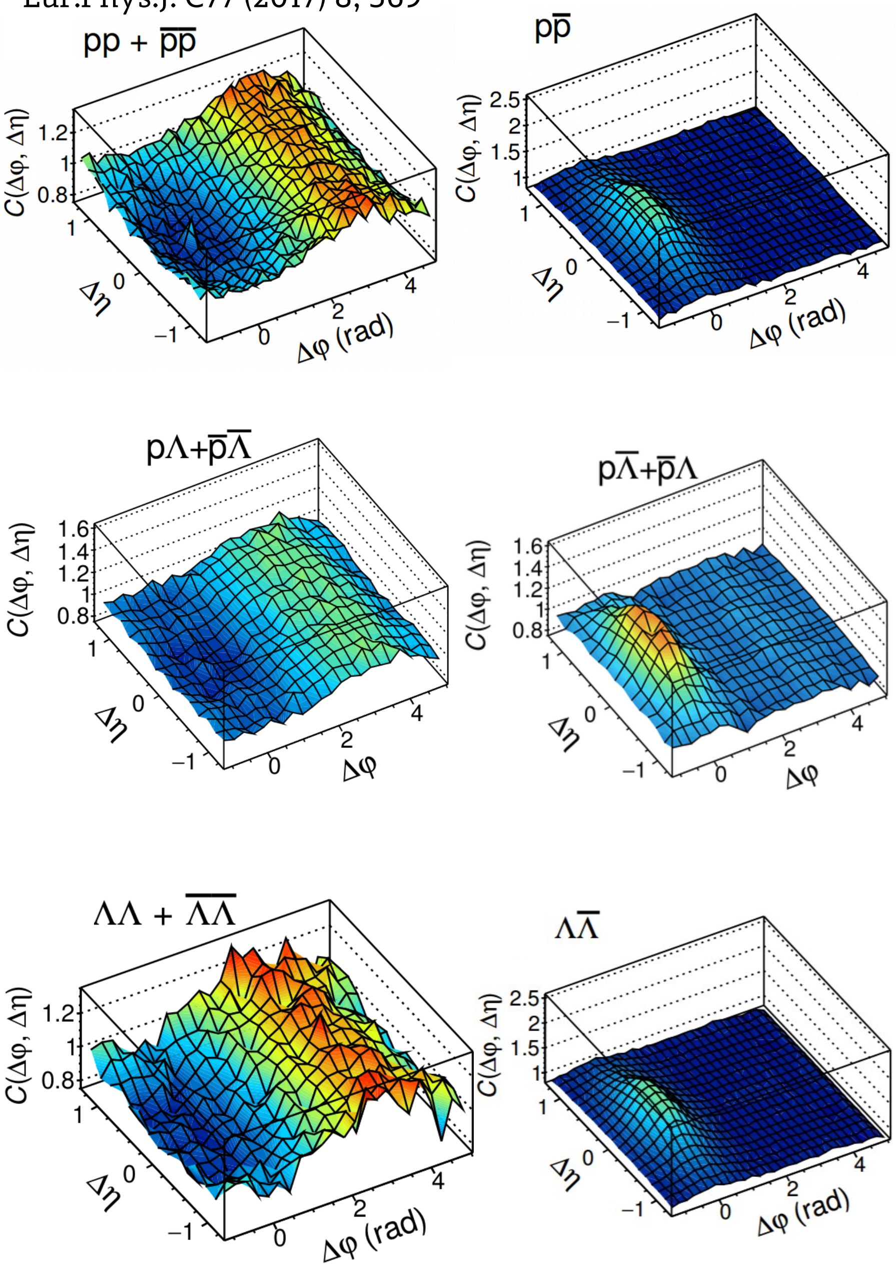
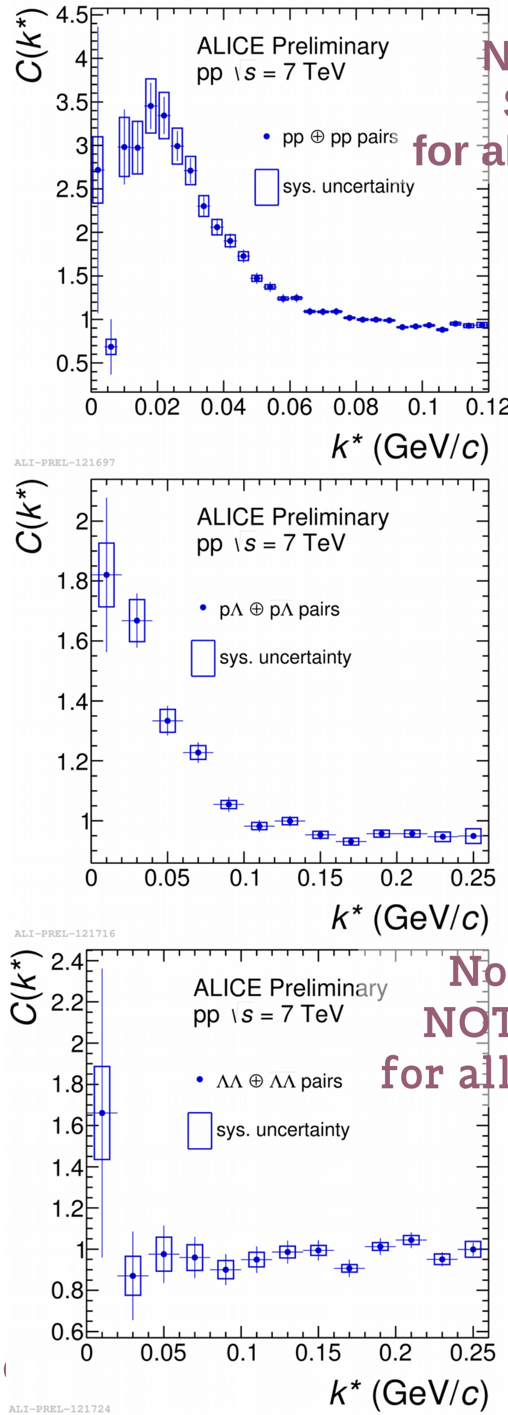
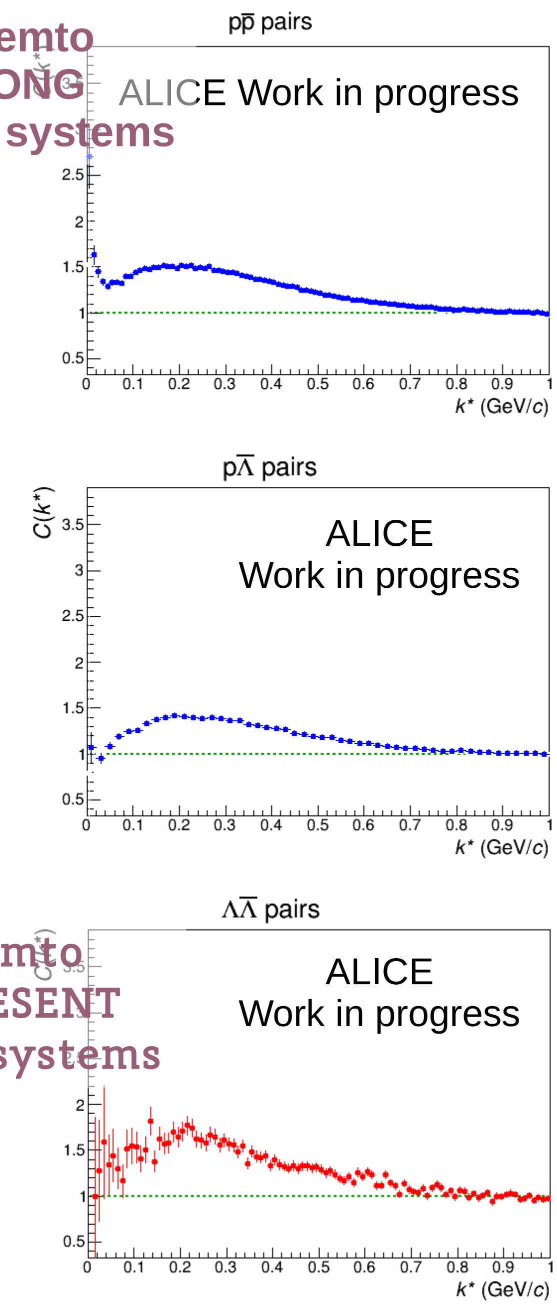






Non-femto
STRONG
for all bb systems

Non-femto
NOT PRESENT
for all bb systems

Femtoscopy – going beyond the system size

Correlations of baryons

$K^0_sK^{\pm}$ correlations

Motivation for $K^0_s K^{\pm}$ analysis

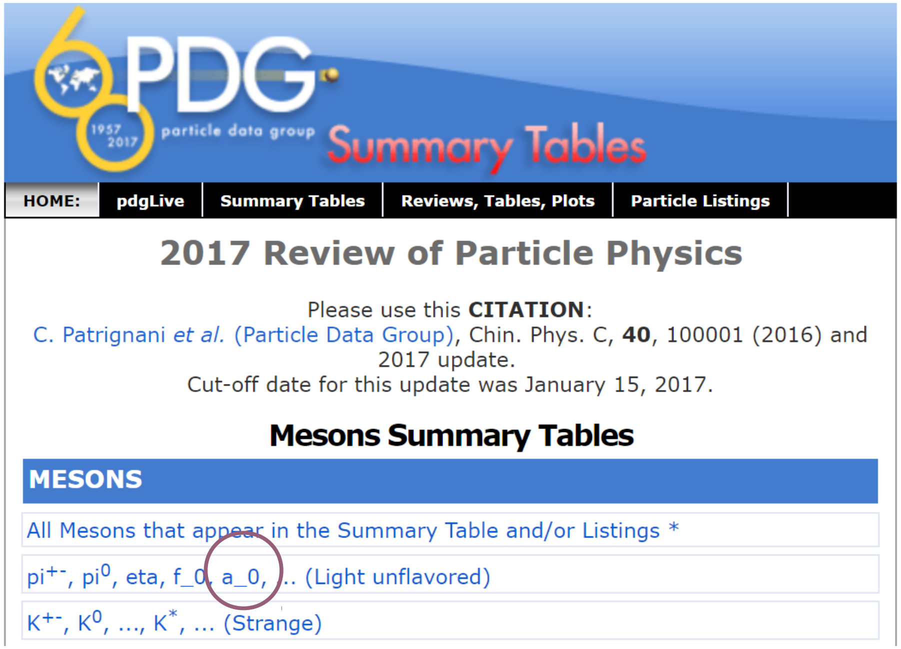
Tom Humanic

- Which sources of correlations are present in kaon systems?
  - Quantum Statistics (QS) – both $K^0_s K^0_s$ and $K^{\pm}K^{\pm}$
  - Coulomb FSI – $K^{\pm}K^{\pm}$
  - **Strong FSI –** $K^0_s K^0_s$ **(via** $f_0(980)/a_0(980)$ **resonances)**
- Why are $K^0_s K^{\pm}$ pairs interesting?
  - only Strong FSI:
    - $f_0(980)$ resonance is isospin = 0 → no $f_0(980)$ strong interaction
    - $a_0(980)$ **resonance is isospin = 1 as is the kaon pair → only** $a_0(980)$ **strong interaction present**
- We can study the properties of the $a_0(980)$ resonance, which is a proposed tetraquark state (PRC 75 (2007) 045206)
- $a_0(980)$ mass and coupling par. (in GeV) from fits to ϕ decay exp.:

$$f(k^*) = \frac{\gamma_{a_0 \to K\bar{K}}}{m_{a_0}^2 - s - i\gamma_{a_0 \to K\bar{K}} k^* - i\gamma_{a_0 - \pi\eta} k_{\pi\eta}}$$

	m_{a0}	$\gamma_{a0 \to K\bar{K}}$	$\gamma_{a0 \to \pi\eta}$	Reference
"Martin"	0.974	0.3330	0.2220	Nucl. Phys. B 121, 514 (1977)
"Antonelli"	0.985	0.4038	0.3711	arXiv: hep/ex-0209069 (2002)
"Achasov1"	0.992	0.5555	0.4401	Phys. Rev. D 68, 014006 (2003)
"Achasov2"	1.003	0.8365	0.4580	Phys. Rev. D 68, 014006 (2003)

Motivation for $K^0_s K^\pm$ analysis


PDG Summary Tables
particle data group
1957 2017
HOME: pdgLive Summary Tables Reviews, Tables, Plots Particle Listings

2017 Review of Particle Physics

Please use this **CITATION**:
C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update.
Cut-off date for this update was January 15, 2017.

Mesons Summary Tables

MESONS

All Mesons that appear in the Summary Table and/or Listings *

pi+-, pi0, eta, f_0, a_0, ... (Light unflavored)

K+-, K0, ..., K*, ... (Strange)

PHYSICAL REVIEW D **79**, 074014 (2009)

Global aspects of the scalar meson puzzle

Amir H. Fariborz,[1,*] Renata Jora,[2,†] and Joseph Schechter[3,‡]

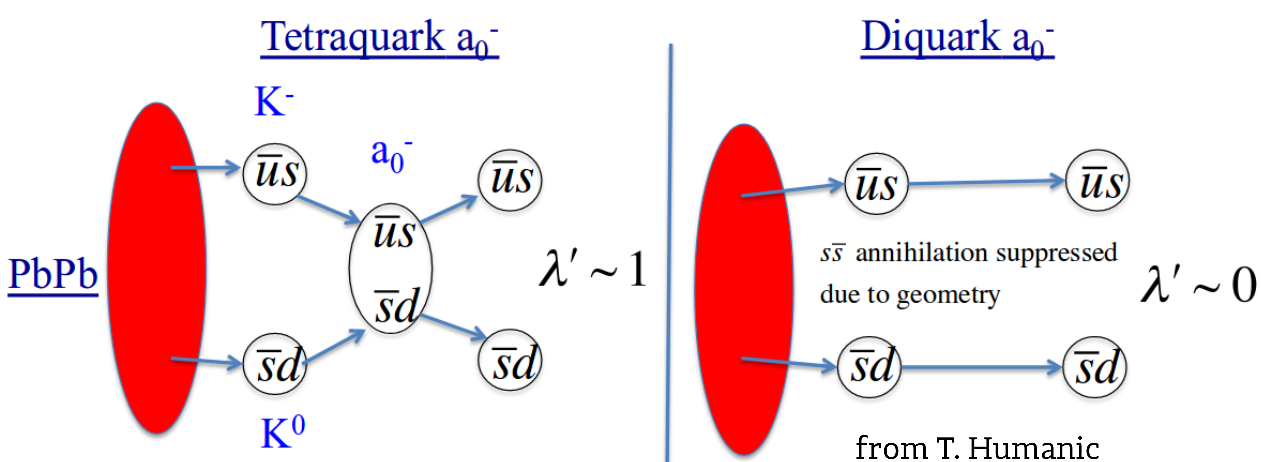
TABLE II. m_a and $m_{a'}$ are inputs. Typical predicted properties of scalar states: $\bar{q}q$ percentage (2nd column), $\bar{q}\,\bar{q}\,qq$ (3rd column) and masses (last column).

State	$\bar{q}q\%$	$\bar{q}\,\bar{q}\,qq\%$	m (GeV)
a	24	76	0.984
a'	76	24	1.474
κ	8	92	1.067

a_0 predicted to be 76% tetraquark
PDG still lists it as a light meson

- **How femtoscopy can help to determine which state it is?**

$\lambda' \equiv \lambda_{K^0K^-}/\lambda_{KK}$ for $\bar{u}s\bar{s}d$ vs. $\bar{u}d$ a_0^- expected from geometry

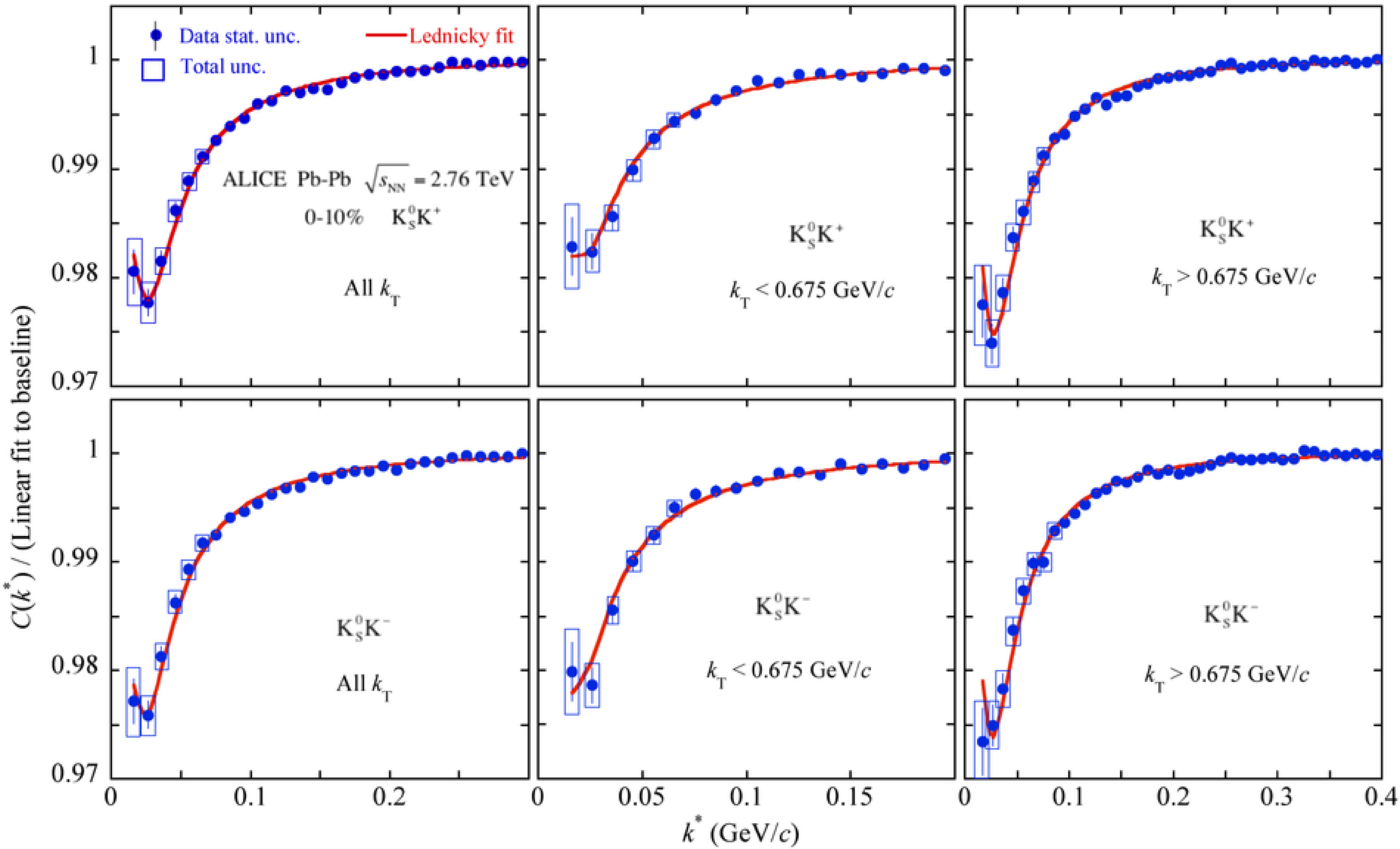


For details read the paper: PLB 774 (2017) 64-77

Measured correlation functions $C_{raw}(k^*)$/(linear fit)

PLB 774 (2017) 64-77

Tom Humanic

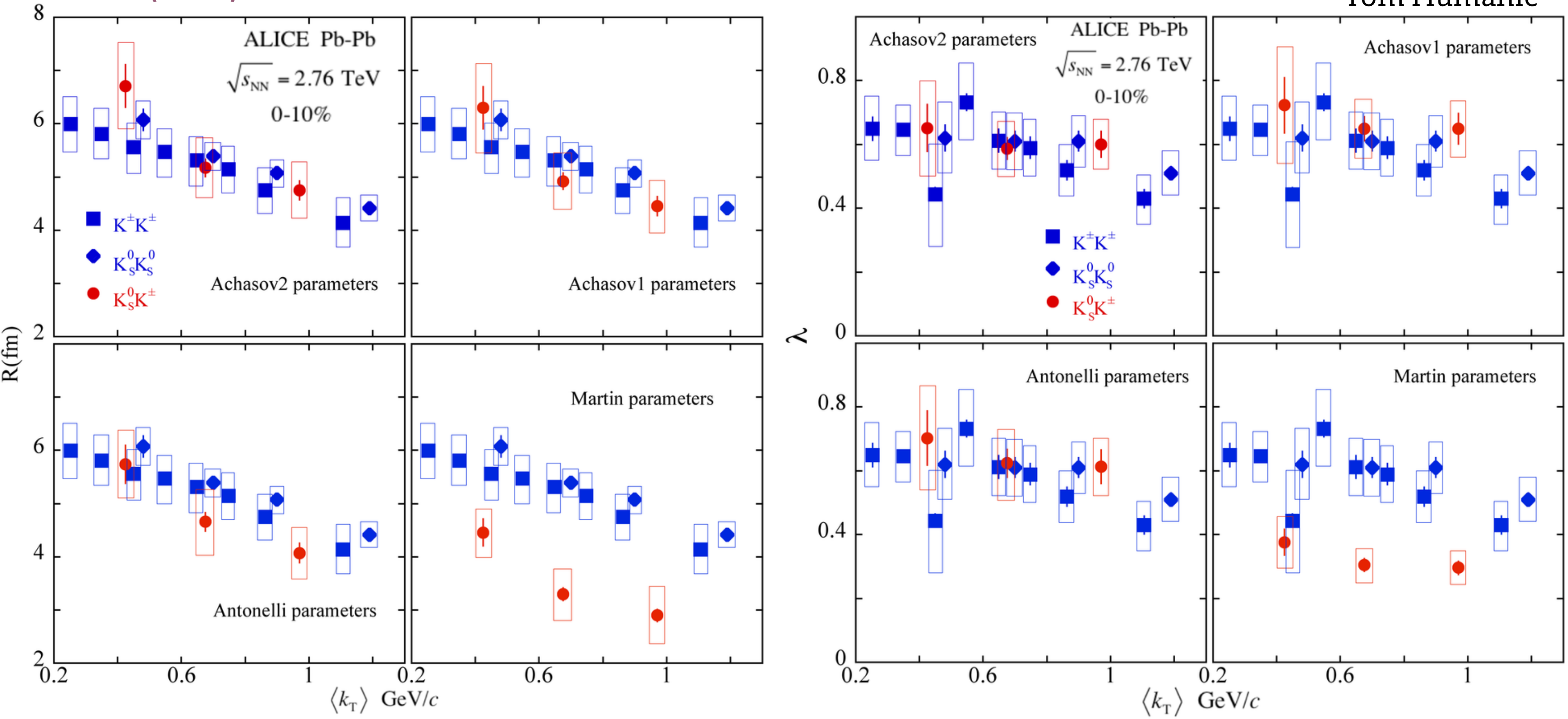


The $a_0(980)$ final interaction gives an excellent fit to the data!

Results of the fit

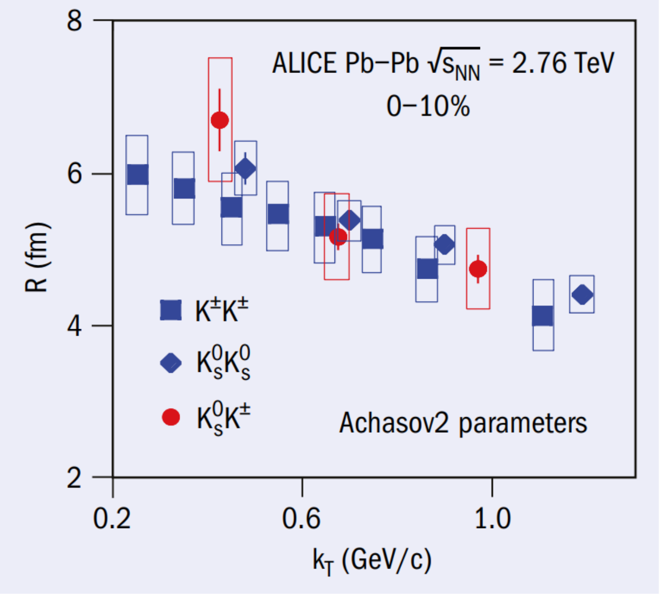
PLB 774 (2017) 64-77

Tom Humanic



- "Martin" parameter fits much lower
- **Present results favor higher** $a_0(980)$ **parameters** (eg. "Achasov" parameters)
- **Results support the** a_0 **tetraquark hypothesis** (similar conclusions drawn from recent analysis in pp collisions)

ALICE studies possible light tetraquark



Radius parameters versus average transverse kaon-pair momentum determined from K^0_S–$K^{\pm}$ correlations and identical-kaon correlations in central ALICE lead–lead collisions.

The $a_0(980)$ resonance is formally classified by the Particle Data Group as a light diquark (quark + antiquark) meson similar to the pion. However, it has long been considered as a candidate tetraquark state made up of two quarks and two antiquarks. Existing experimental evidence based on the radiative decay of the φ meson has not been convincing, so the ALICE collaboration took a different approach to study the a_0 by measuring K^0_S–$K^{\pm}$ correlations in lead–lead collisions at the LHC. Since the kaons are not identical there is no Hanbury–Brown–Twiss interferometry enhancement, and since the K^0_S is uncharged there is no Coulomb effect. Nevertheless, because the rest masses of the two kaons reach the threshold to produce the a_0 it is expected that there is a strong final-state interaction between the two kaons through the a_0 resonant channel.

Using the data from central lead–lead collisions with a nucleon–nucleon energy of 2.76 TeV, ALICE fitted the experimental two-kaon yield to extract the radius and emission strength of the kaon source assuming only a final-state interaction through the a_0 (see figure).

Both the radii and the emission strength from the K^0_S–$K^{\pm}$ analysis agree with the identical kaon results, suggesting that the final-state interaction between the K^0_S and $K^{\pm}$ goes solely through the a_0 resonance without any competing non-resonant channels. A tetraquark a_0 is expected to couple more strongly to the two kaons, since it has the same quark content, while the formation of a diquark state requires the annihilation of the strange quarks, which is suppressed due to geometric effects and a selection rule. Although there are no quantitative predictions for the magnitude of this suppression that would result for a diquark form of a_0, the qualitative expectation is that this would open up non-resonant channels that would compete with the a_0 final-state interaction, making it smaller than the identical-kaon values. The ALICE result of the final-state interaction going solely via the a_0 thus favours the interpretation of the a_0 as a tetraquark state.

● **Further reading**

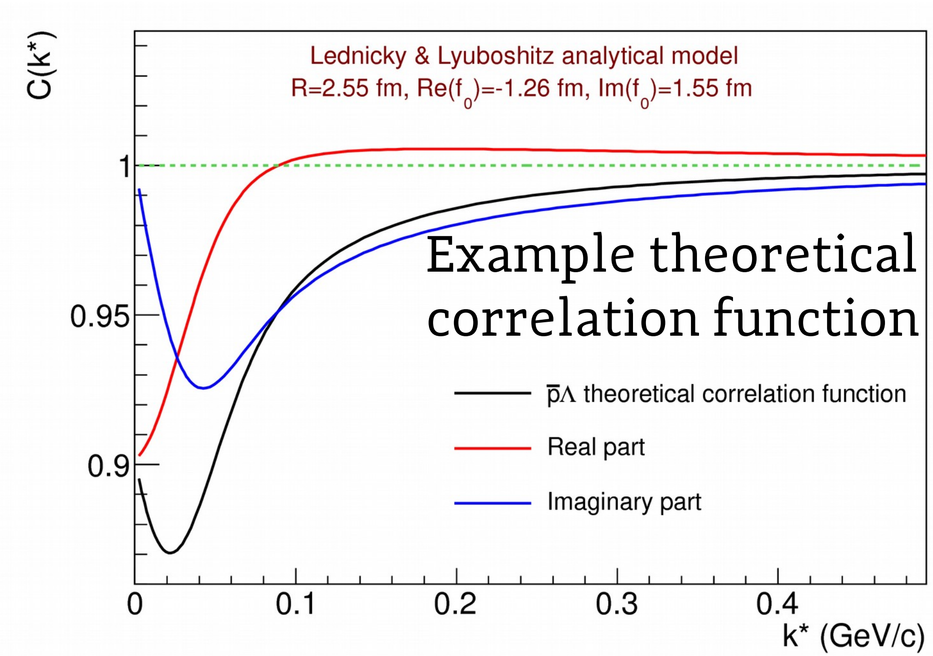
ALICE Collaboration 2017 *Phys. Lett. B* **774** 64.

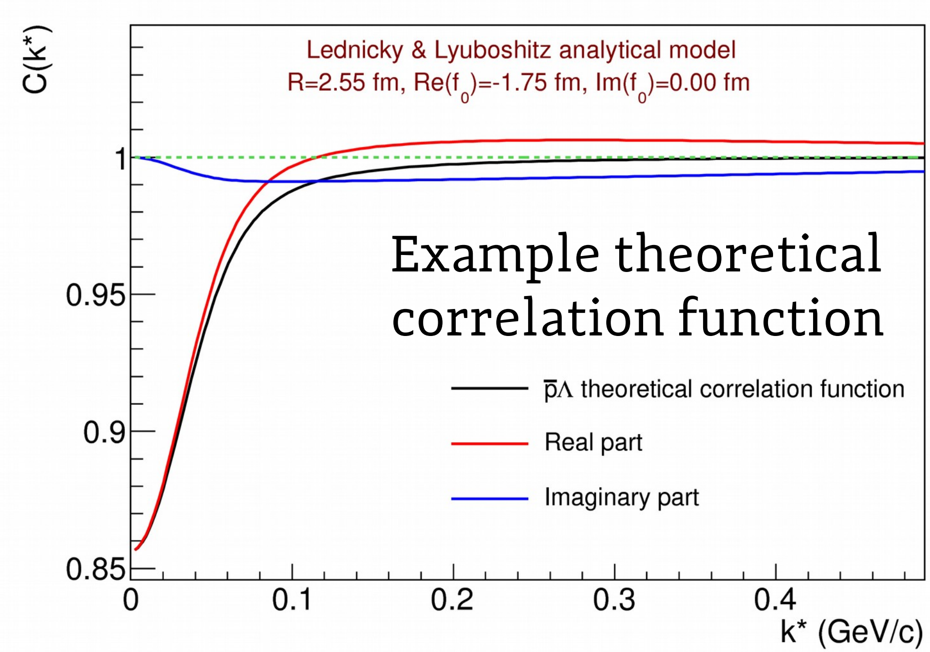
Summary

- **ALICE can probe strong interaction cross sections with femtoscopy**
- **Correlations of baryons reveal interesting features and baryons in general seem to be of great importance:**
  - Unique experimental environment at RHIC and LHC → "matter-antimatter pair factories"
  - Femtoscopic correlation functions sensitive to strong interaction potential, including annihilation, possible $b\bar{b}$ bound states?
  - Angular correlations reveal unexpected behavior – no two or more baryons in a single (mini-)jet?
- **$K^0_sK^\pm$ femtoscopic correlations measured for the first time:**
  - $a_0(980)$ FSI gives excellent description of the signal
  - No difference wrt identical kaons if larger mass and coupling $a_0(980)$ parameters used ("Achasov1" and "Achasov2") - e.g. "$a_0(1000)$" favored over "$a_0(980)$" → supports a tetraquark hypothesis
- **Clear connection between femtoscopic and angular correlations:**
  - "Small peak" in angular correlations consistent with strong interaction studied with femtoscopy and does not explain the depletion


THANK YOU!

Example correlation function

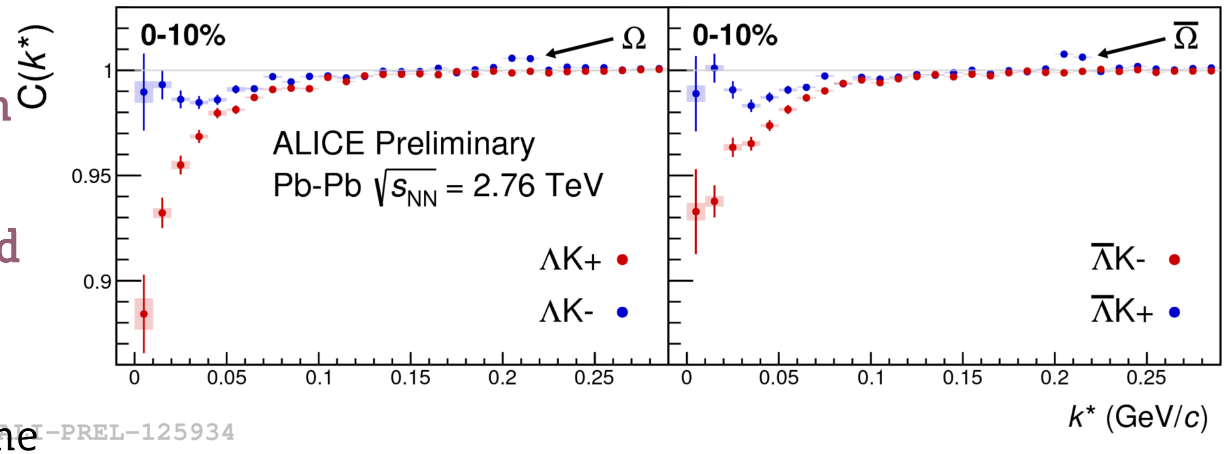


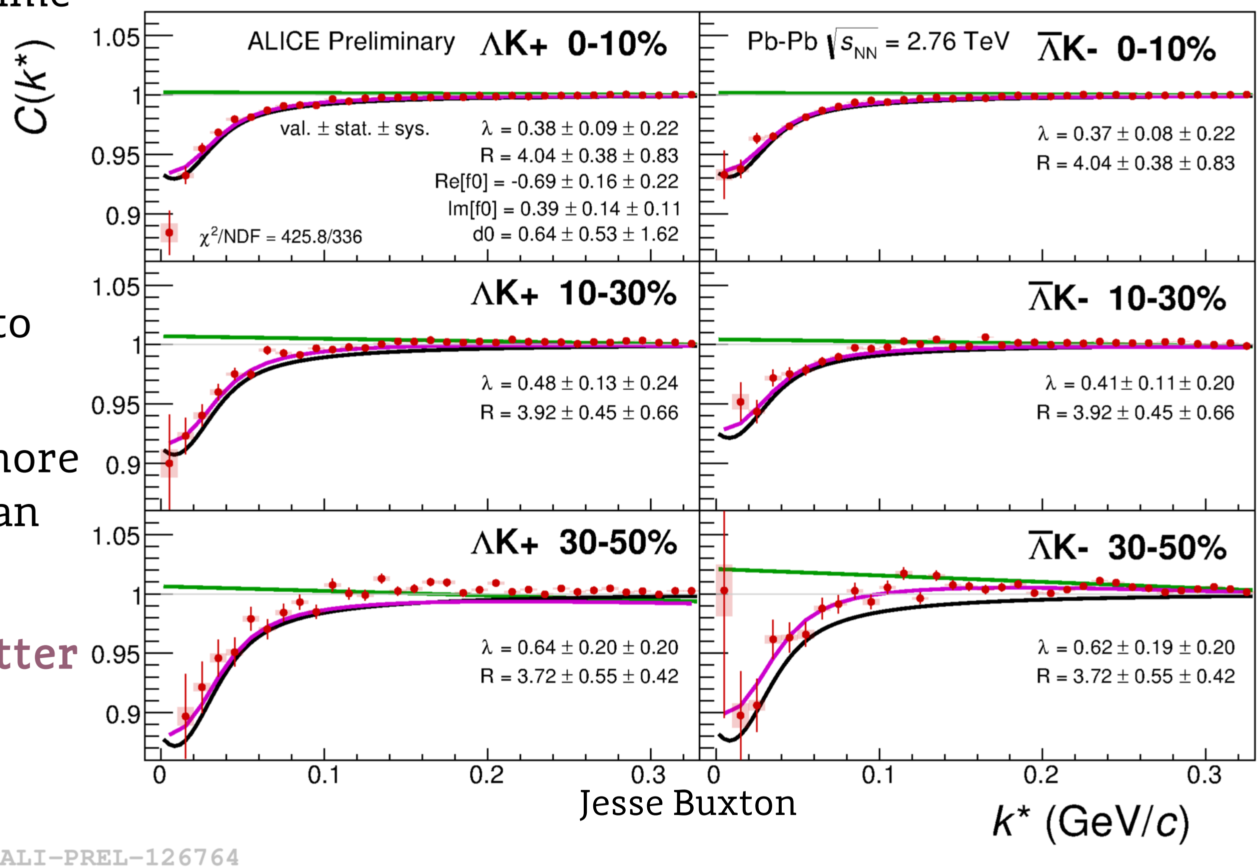


- Real and imaginary part of scattering length have **distinctively different contributions**
- Contribution from Re(f_0) is either positive or negative but **very narrow** (up to 100 MeV/c) in k^*
- The Im(f_0) accounts for baryon-antibaryon annihilation and produces a **wide** (hundreds of MeV) **negative correlation**

Other interesting pairs

- Many other interesting correlations not covered in this talk
- Lambda-kaon (both charged and neutral) pairs
  - scattering parameters measured for the first time
- ΛK^+ shows greater suppression at low k* compared to: ΛK^-:
  - effect arising from $s\bar{s}$ annihilation compared to $u\bar{u}$?
  - or S=0 ΛK^+ system has more interaction channels than S=-2 ΛK^-?
- For details see Quark Matter 2017 poster by J. Buxton http://cern.ch/go/qwF7





Jesse Buxton

Rapidity correlations in e^+e^-

A Parametrization of the Properties of Quark Jets
R.D. Field, R.P. Feynman (Caltech)
Nucl.Phys. B136 (1978) 131

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

R. Feynman
"Quark Jets"
8th ISMD 1977

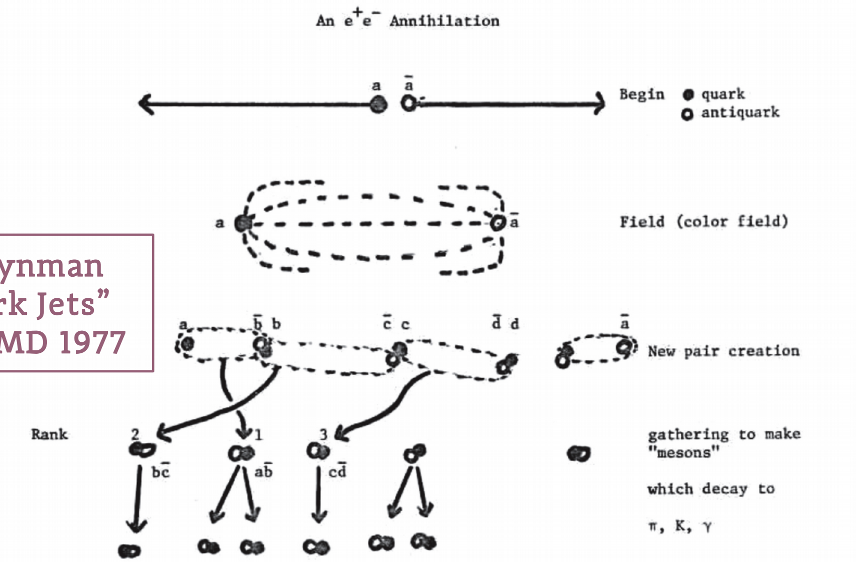
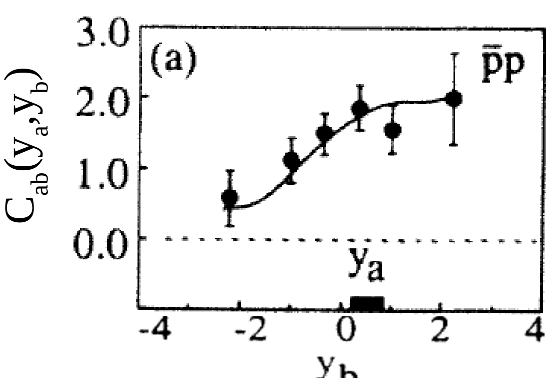


Fig. 10. Transparency from a talk Feynmen gave on our model for how quarks fragment into hadrons at the International Symposium on Multiparticle Dynamics (ISMD), Kaysersberg, France, June 12, 1977.

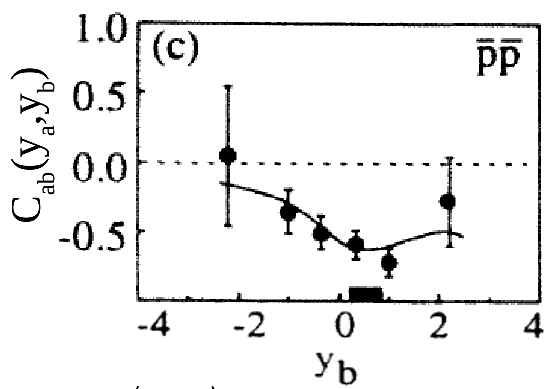
We are not likely to find two baryons or two antibaryons at the same rapidity

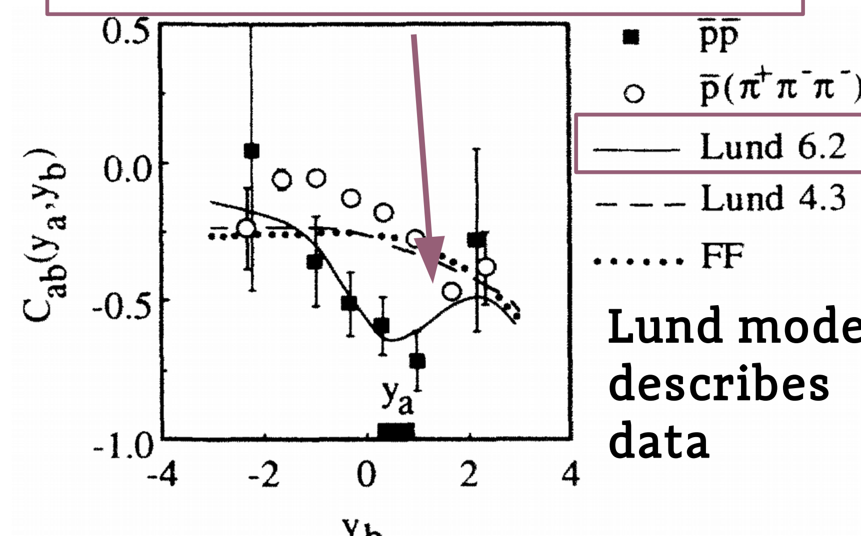
Models for e^+e^- agree with observations seen in data

correlation



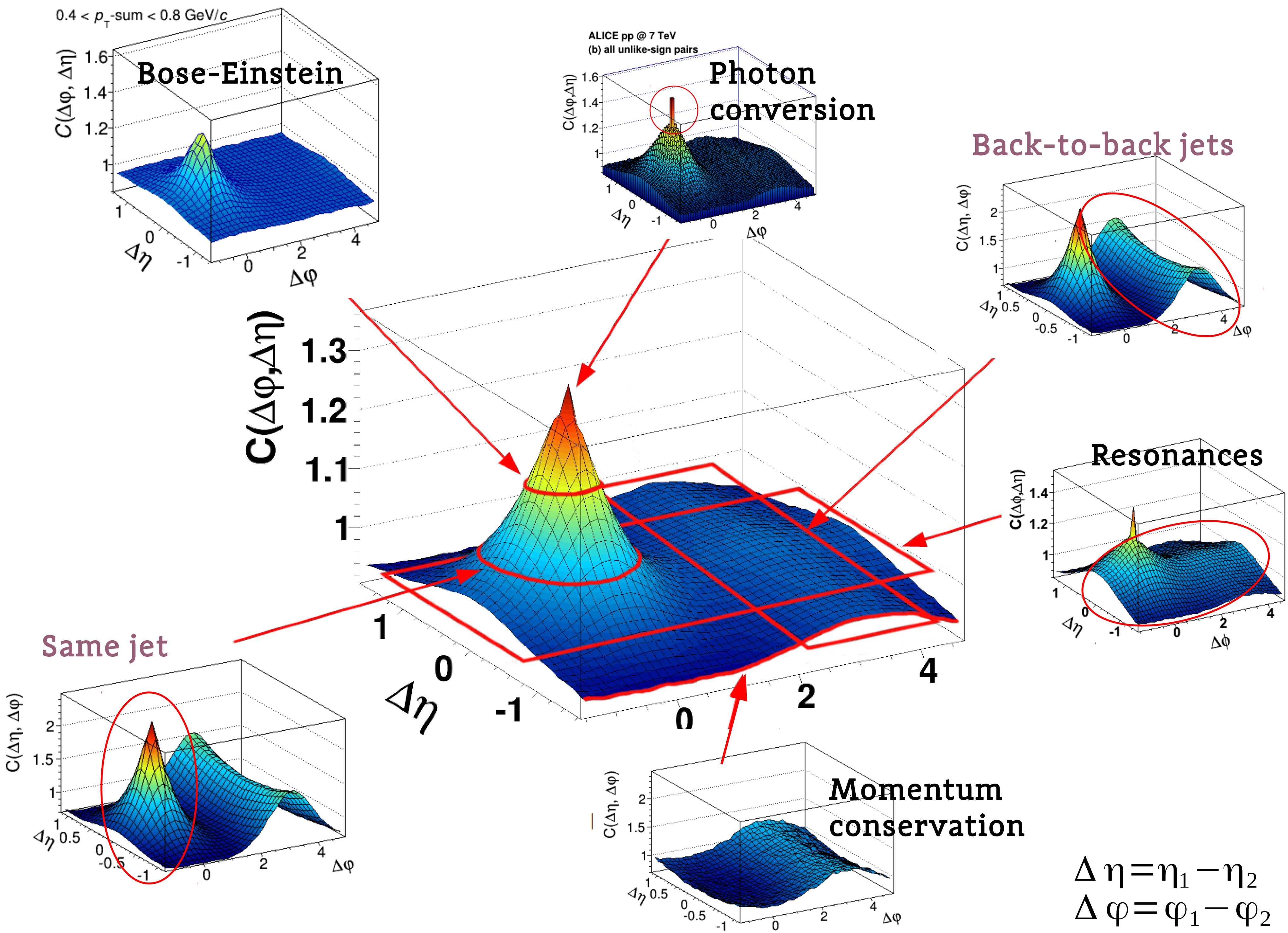
anti-correlation





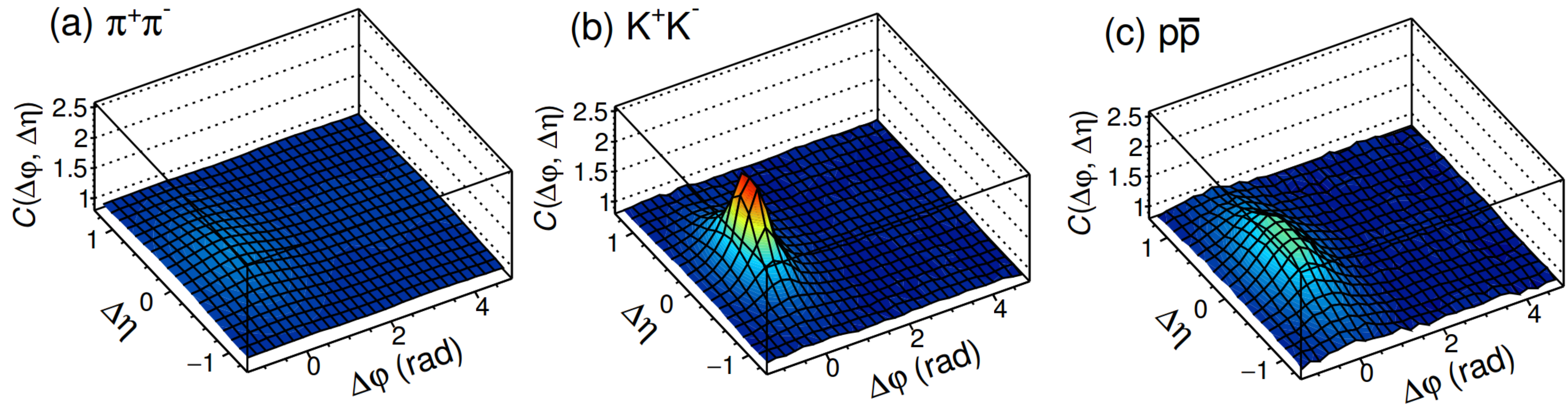
Lund model describes data

TPC/Two Gamma Collaboration, Phys.Rev.Lett. 57 (1986) 3140



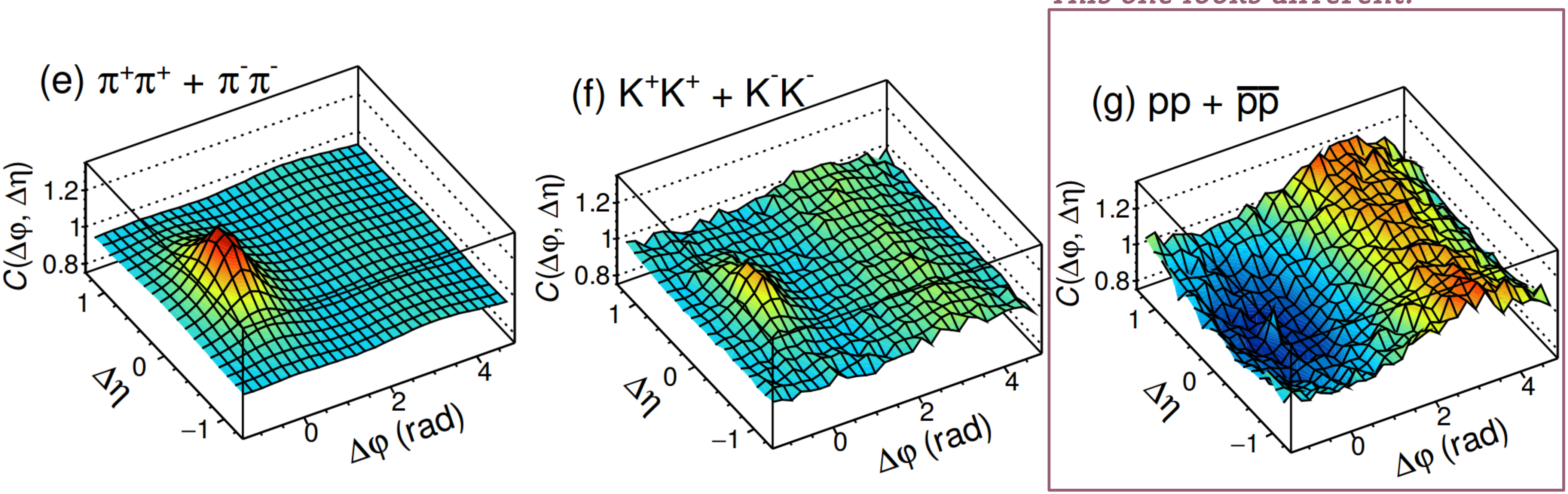
Bose-Einstein
0.4 < p_T-sum < 0.8 GeV/c
Photon conversion
ALICE pp @ 7 TeV
(b) all unlike-sign pairs
Back-to-back jets
Resonances
Same jet
Momentum conservation
C(Δφ,Δη)
Δη
Δφ
$\Delta\eta = \eta_1 - \eta_2$
$\Delta\varphi = \varphi_1 - \varphi_2$

ΔηΔφ of identified particles

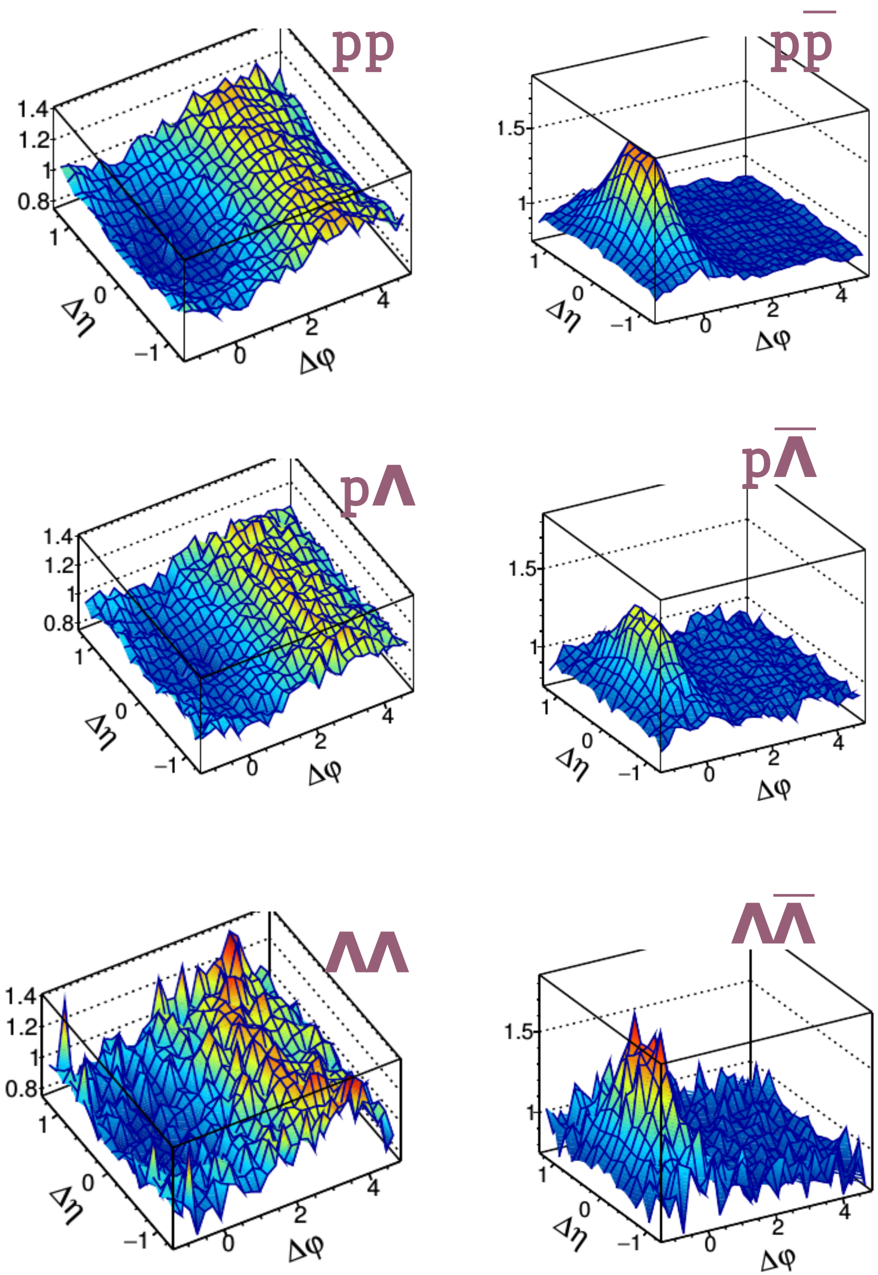


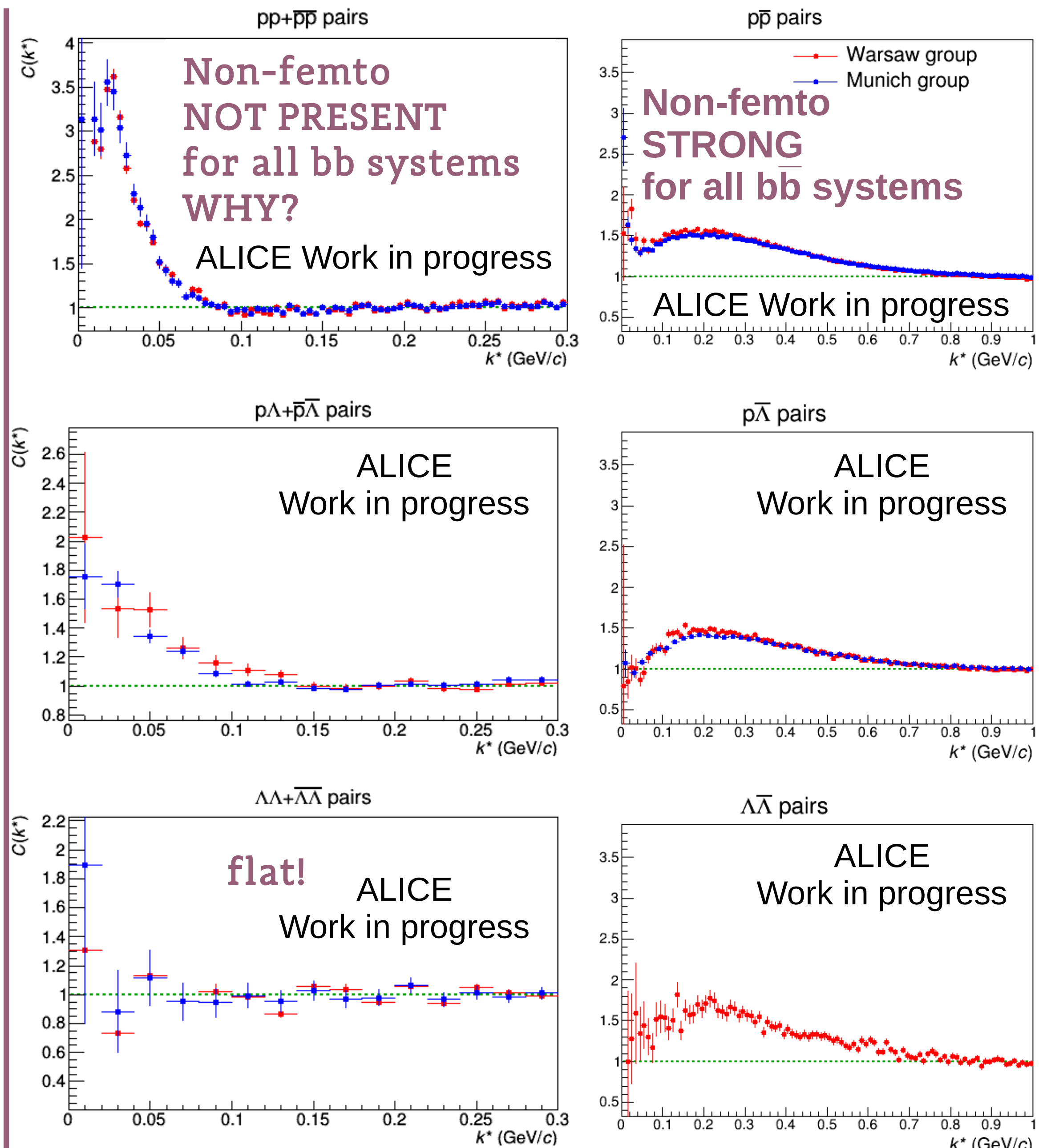
Eur.Phys.J. C77 (2017) 8, 569

This one looks different!



Angular vs femto corr. fctn.

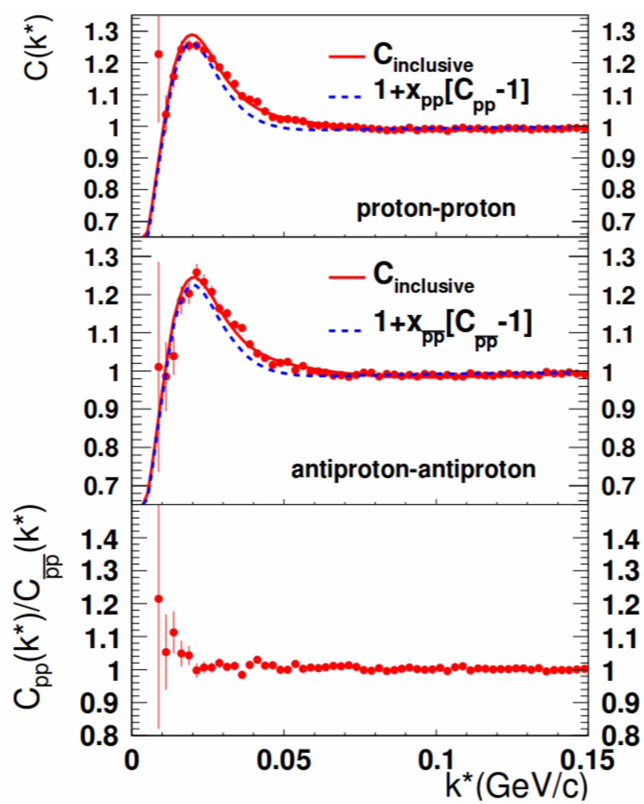




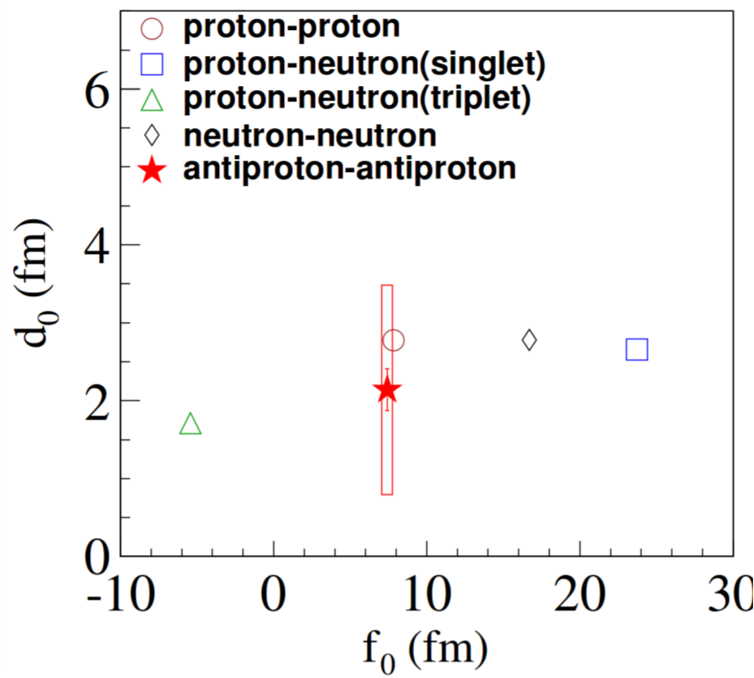
Au-Au: pp and $\overline{pp}$ correlations @ STAR

Figure 4 presents the first measurement of the antiproton-antiproton interaction, together with prior measurements for nucleon-nucleon interactions. Within errors, the f_0 and d_0 for the antiproton-antiproton interaction are consistent with their antiparticle counterparts – the ones for the proton-proton interaction. Our measurements provide parameterization input for describing the

- Exactly the same methodology was used by STAR to measure $\overline{pp}$ interaction (Nature paper)
- **Conclusions:**
  - LHC and RHIC are "baryon-antibaryon pair factories" - unique opportunities
  - Both ALICE and STAR, with their perfect PID, are the only experiments where such measurements are possible



STAR Collaboration
Nature 527,345-348 (2015)



Residual correlations in pp

- The excess about 50 MeV/c in k* is explained by residual correlations, from main decay channel leading to protons:

$$\Lambda \rightarrow p + \pi^{-}$$

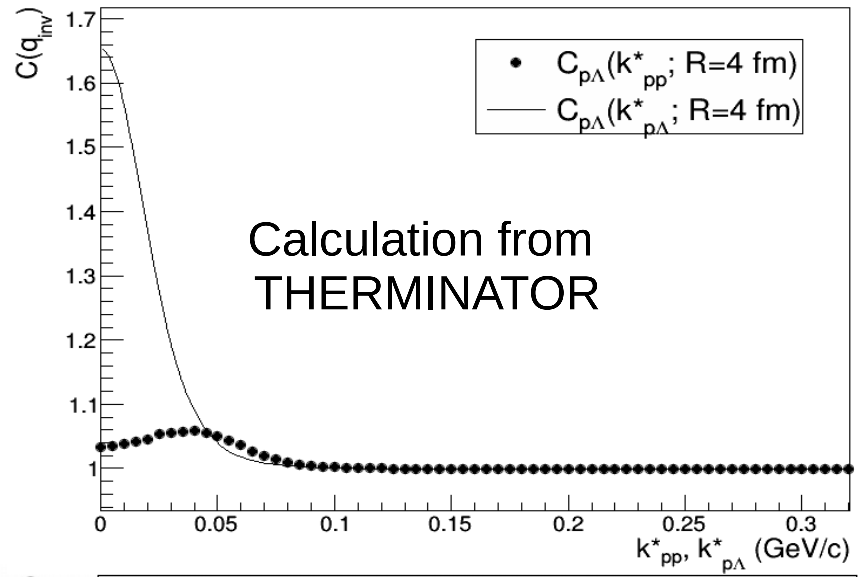
- Fitting function is a combination of theoretical pp and pΛ functions:

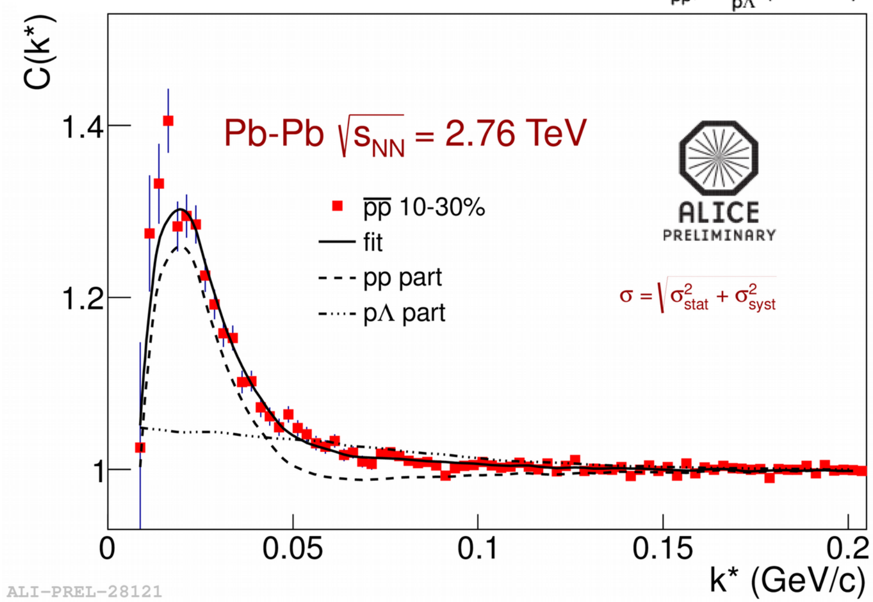
$$C_{meas}(k^{*}) = 1 + \lambda_{pp}(C_{pp}(k_{pp}; R) - 1) + \lambda_{p\Lambda}\left(\int C_{p\Lambda}(k_{p\lambda}; R)\, T(k_{p\lambda}, k_{pp}) - 1\right)$$

- Assume Gaussian source, $R_{pp}/R_{p\Lambda}$ ratio, decay kinematics taken into account.

- Results with RC effect taken into account published in:

Phys. Rev. C 92, 054908 (2015)

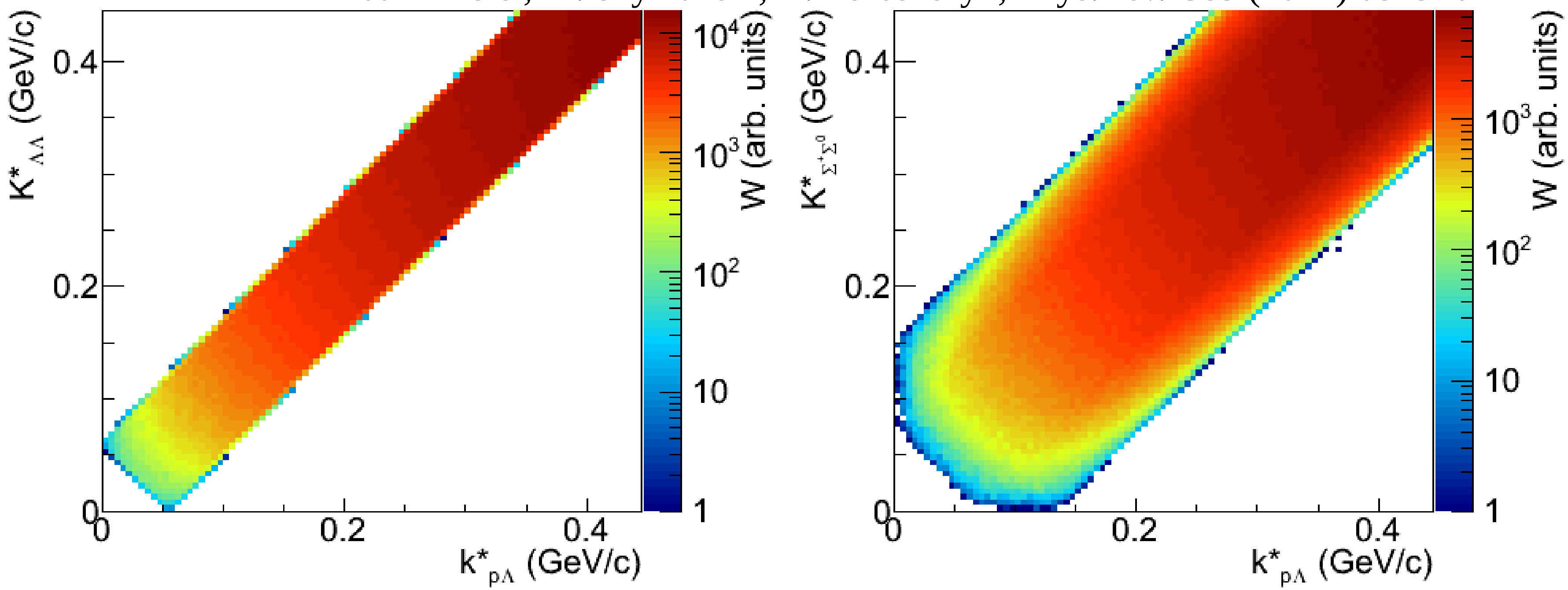




Residual correlations in pp – transformation matrix

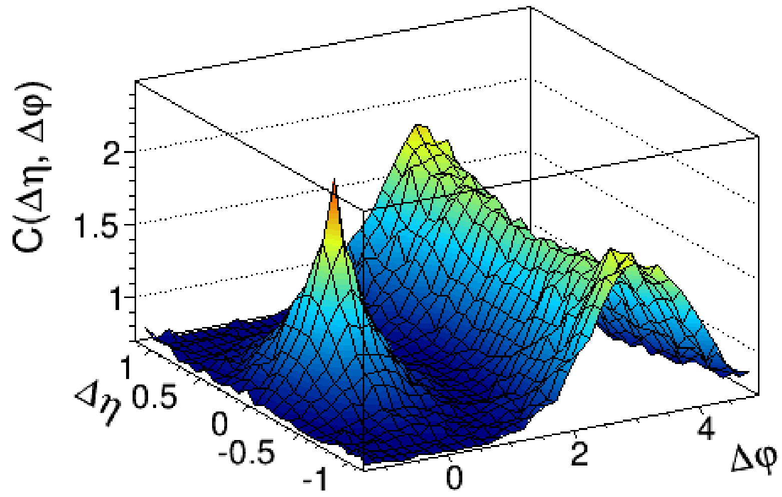
- The transformation matrix T from parent pair k^* to the daughter pair k^* determined by random decay, bound by decay momenta
- When only one particle decays, it has a rectangular shape, for pairs when both particles decay it is smeared more

F. Wang, S. Pratt; Phys. Rev. Lett. 83, 3138 (1999)
Adam Kisiel, M. Szymański, H. Zbroszczyk, Phys.Rev. C89 (2014) 054916

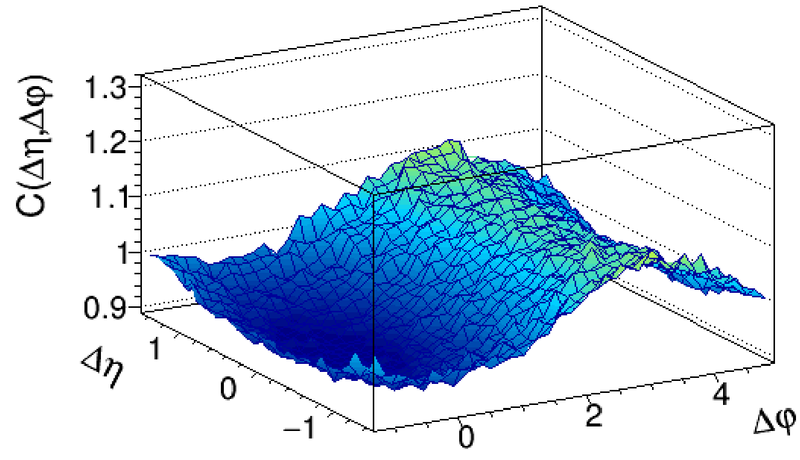


Conservation Laws Model (CALM): Simple MC

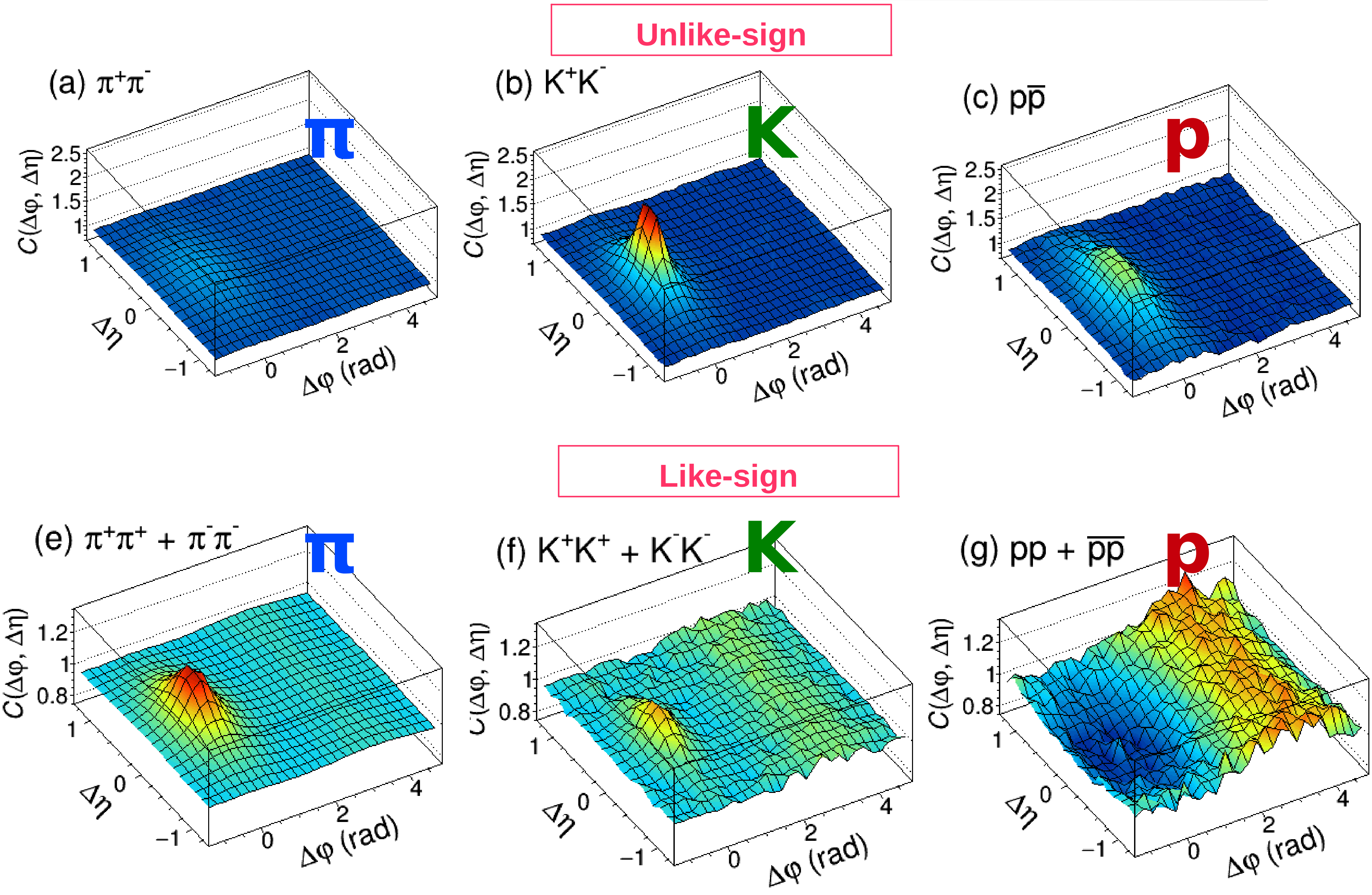
Jet correlations dominate the correlation function shape



Anti-correlation shape can be easily reproduced with a toy Monte Carlo with conservation laws included (no other physics)

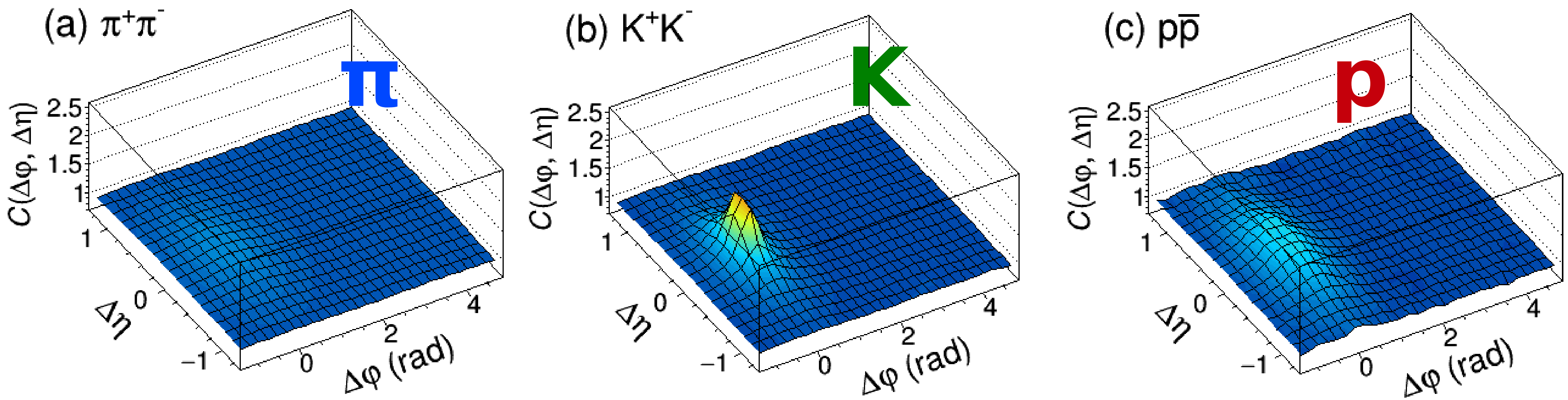


ΔηΔφ of identified particles – pp 13 TeV

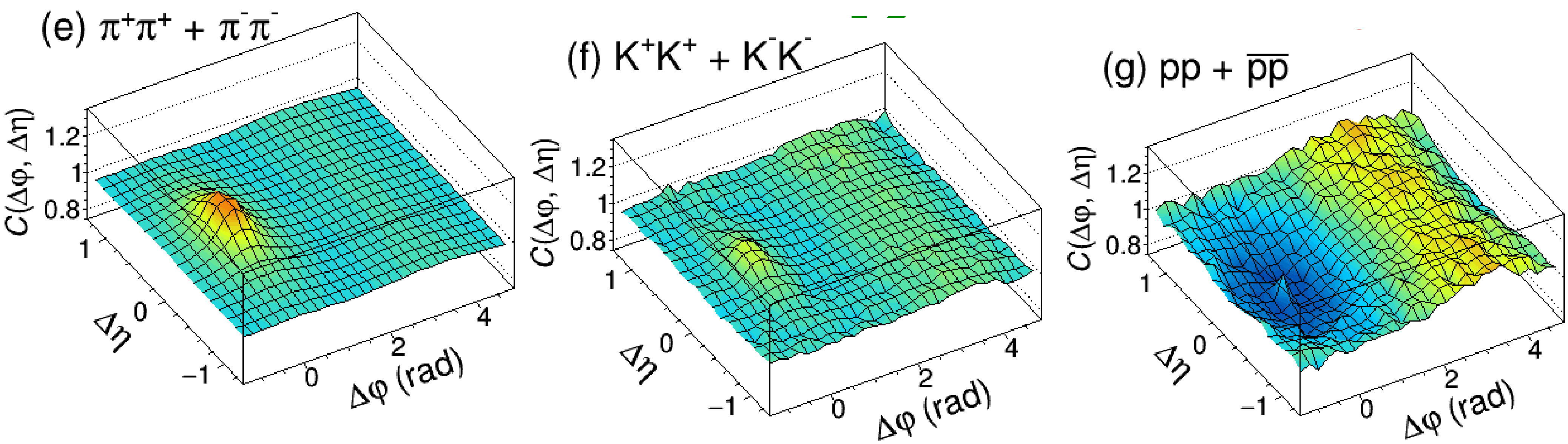


ΔηΔφ of identified particles – p-Pb 5.02 TeV

Unlike-sign

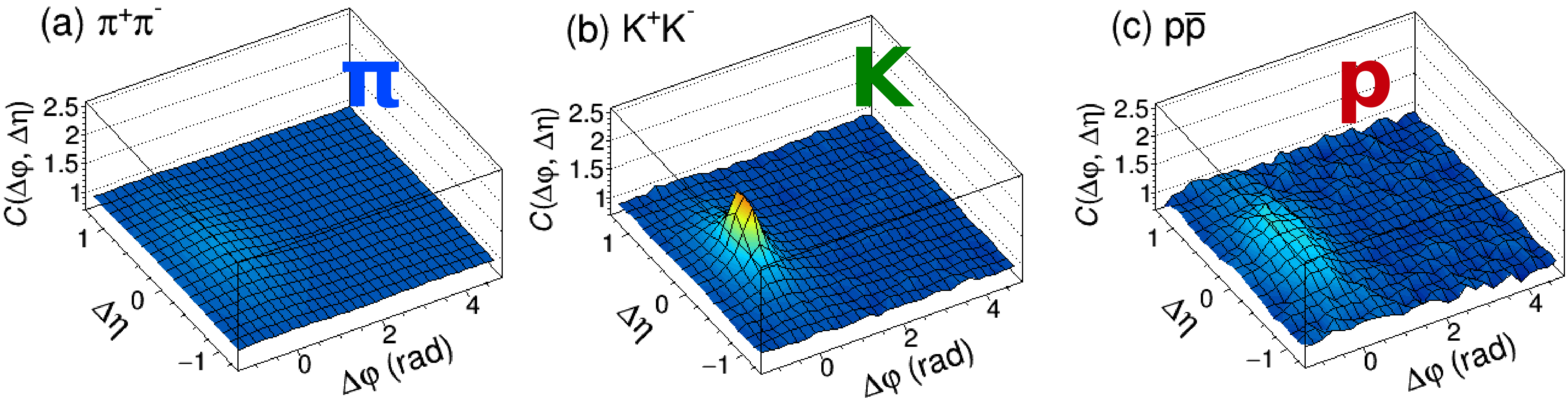


Like-sign

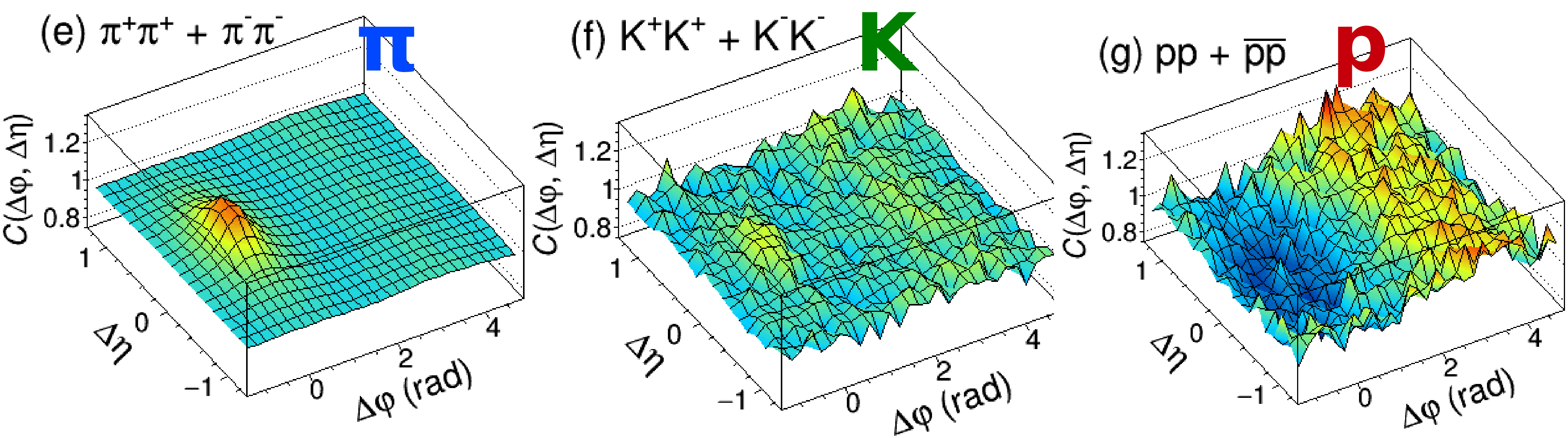


ΔηΔφ of identified particles – p-Pb 8.16 TeV

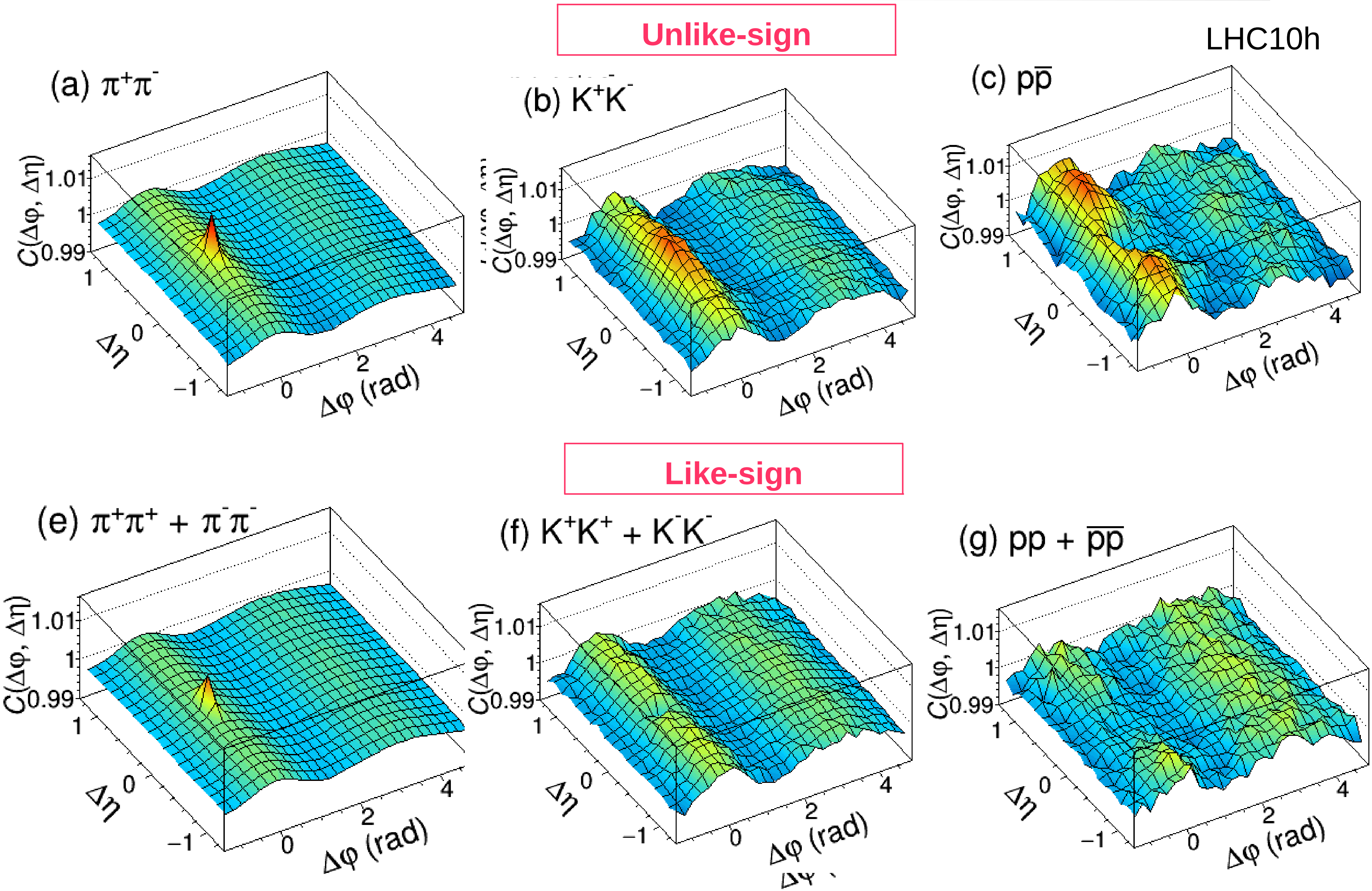
Unlike-sign



Like-sign

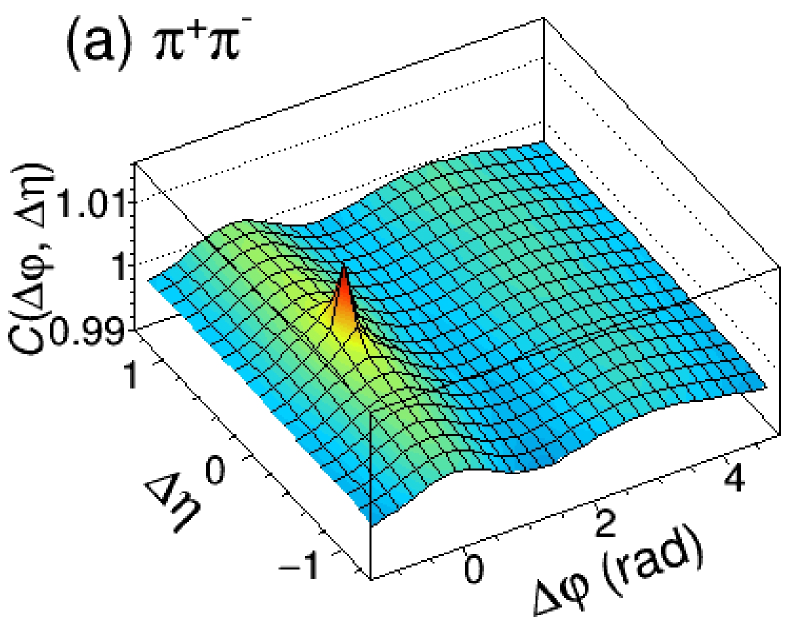


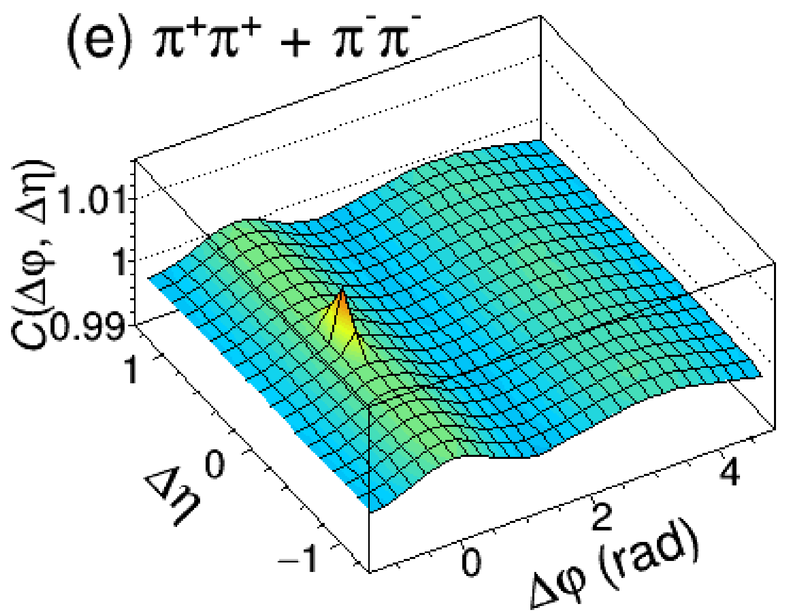
ΔηΔφ of identified particles – Pb-Pb 2.76 Run1



pions – Pb-Pb 2.76 Run1

LHC10h





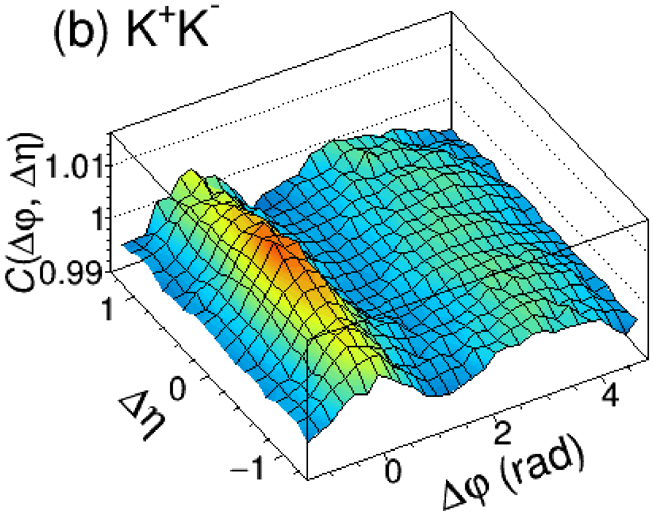
Cosine shape characteristic for flow + narrow spike in (0,0)

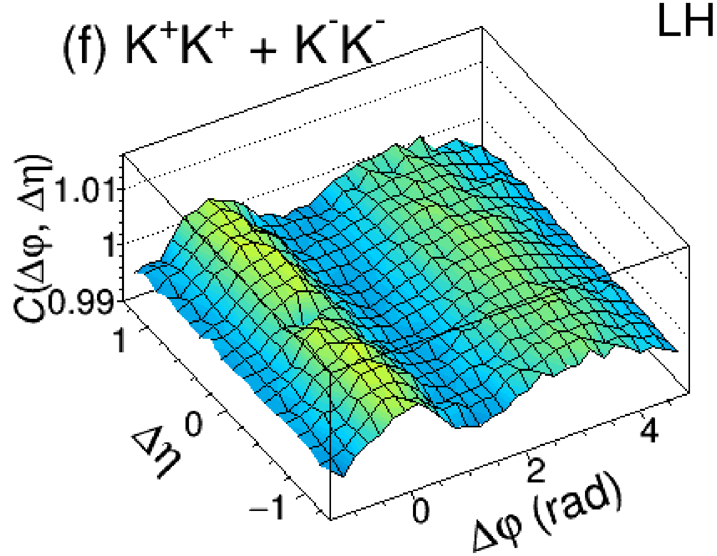
- Narrow spike in both like- and unlike-sign pairs
- ***- splitting?***
- ***- gamma conversion?***
- ***- any ideas?***

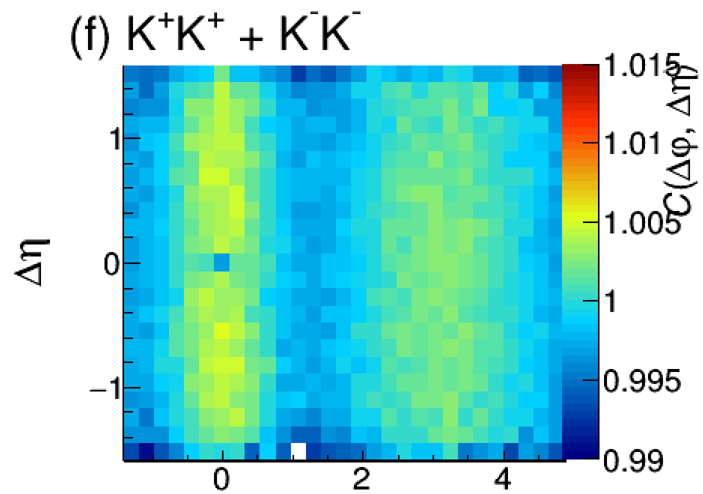
To be done:
- ***- Study how does the spike depend on two-track cuts***

kaons – Pb-Pb 2.76 Run1

LHC10h





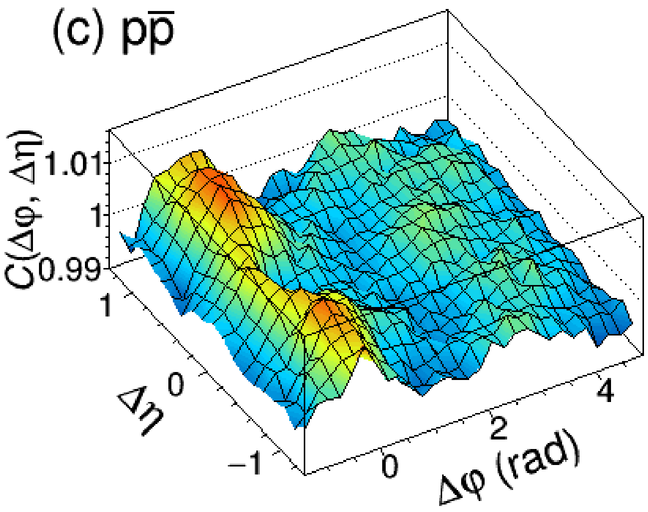


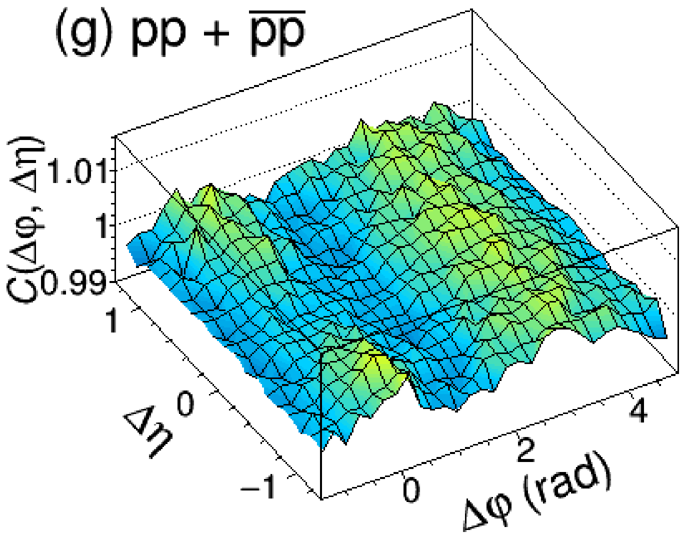
Cosine shape characteristic for flow
+ narrow dip in (0,0) for like-sign kaons

Detector effect?

protons – Pb-Pb 2.76 Run1

LHC10h





Dip for protons ~ (0,0)

*- for unlike-sign protons: **annihilation**?*
(narrow dip centralized in (0,0))

- for like-sign protons: the same effect as for pp and p-Pb?
(wide anti-correlation similar to one observed in smaller systems)