Photon HBT and the Prophecy of 2 dimensions

Ag + Ag 1.58 A GeV

Mateusz Grunwald

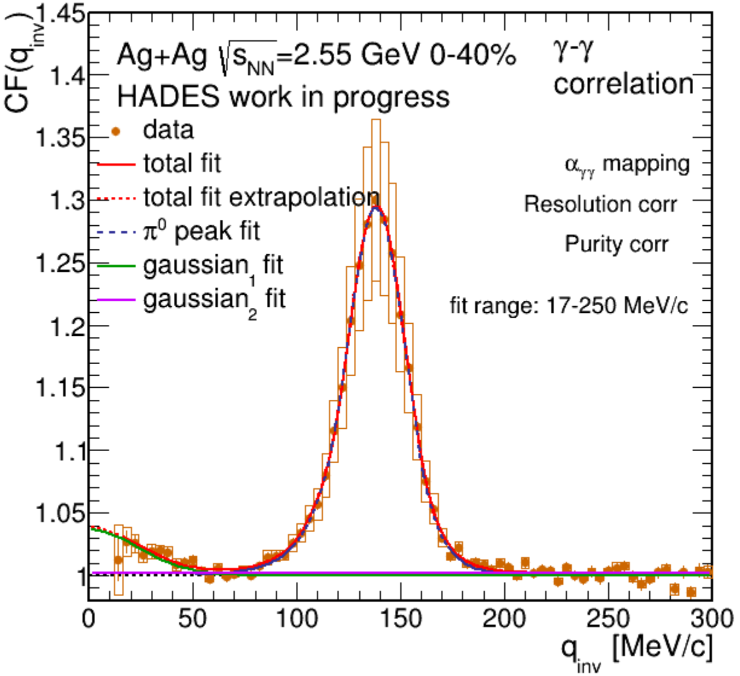
HADES

Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

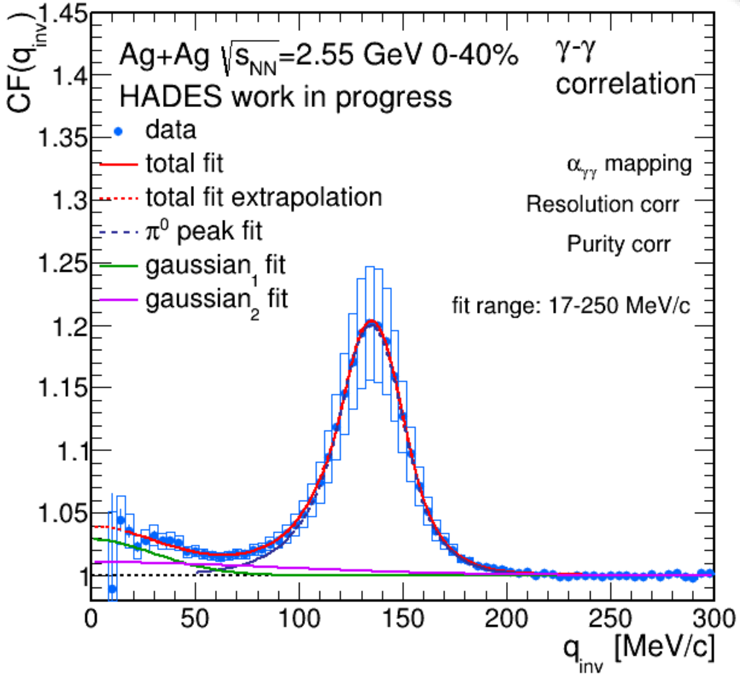
Warsaw University of Technology

Recap from (second to) last CM – γ-γ CFs fits

Simulations (SMASH+ Hgeant) = **no QS**



Data (days 74-80)



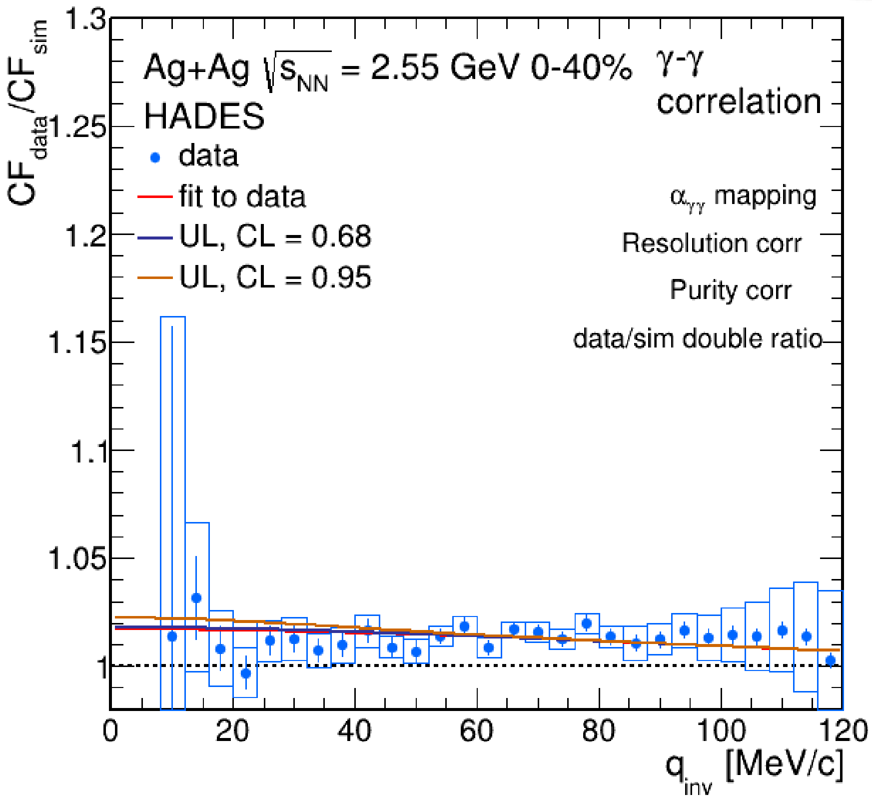
$$CF(q_{inv}) = 1 + \lambda_1 \exp(-q_{inv}^2 R_1^2) + \lambda_2 \exp(-q_{inv}^2 R_2^2) + f_{\pi^0}(q_{inv}, \mu_{\pi^0}, \sigma_{\pi^0}, k_L, k_H)$$

Systematics calculated with Barlow Test

Recap from last CM – upper limits

fit range: (17;100) [MeV/c]
k pseudo-experiments: 100000
R_1 = 4.59 [fm]
R_2 = 1.55 [fm] ; $\lambda_2 \cdot 10^{-2}$ = 1.71

	Fit to data	1σ (CL=0.68) upper limit	2σ (CL=0.95) upper limit
χ^2 (fit)	33.13	34.47	43.60
NDF	19	21 (all par fixed)	21 (all par fixed)
χ^2/NDF	1.74	1.64	2.08
$\lambda_1 \cdot 10^{-2}$	0 +/- 0.06	0.08	0.53
$\Delta\chi^2$	-	1.34269	10.4759
$\Delta\chi^2_{crit}$	-	1.34494	10.4935



Recap from last CM – analysis summary

- The analysis is complete – we do not see any significant direct photon related signal

- The F-C method was utilized to get an upper limit on direct photon correlation strenght (λ_1), being ≈ $8 \cdot 10^{-4}$ for CL=0.68 and ≈ $5 \cdot 10^{-3}$ for CL=0.95.

- The paper is almost done

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Study of two-photon femtoscopic correlations in Ag+Ag collisions at $\sqrt{s_{NN}}$ = 2.55 GeV with HADES

HADES collaboration

R. Abou Yassine[7,14], J. Adamczewski-Musch[6], C. Asal[9], M. Becker[12], A. Belounnas[14], A. Blanco[2], C. Blume[9,6,e], L. Chlad[15,g], P. Chudoba[g], I. Ciepał[4], J. Dreyer[8], W.A. Esmail[6], L. Fabbietti[11], H. Floersheimer[7], J. Förtsch[18], P. Fonte[2,a], J. Friese[11], I. Fröhlich[9], T. Galatyuk[7,6,c], R. Greifenhagen[8,d], M. Grunwald[17], M. Gumberidze[6], S. Harabasz[7,14], T. Heinz[6], C. Höhne[12,6], F. Hojeij[14], R. Holzmann[6], H. Huck[9], M. Idzik[3], B. Kämpfer[8,d], K-H. Kampert[18], B. Kardan[9,e], V. Kedych[7], S. Kim[18], I. Koenig[6], W. Koenig[6], M. Kohls[9,e], J. Kolas[17], G. Kornakov[17], R. Kotte[8], I. Kres[18], W. Krueger[7], A. Kugler[15], R. Lalik[5], S. Lebedev[6], S. Linev[6], F. Linz[6], L. Lopes[2], M. Lorenz[9,6], A. Malige[5], J. Markert[6], T. Matulewicz[16], S. Maurus[11], V. Metag[12], J. Michel[9], A. Molenda[3], C. Müntz[9], M. Nabroth[9], L. Naumann[8], K. Nowakowski[5], A. Opíchal[15,13], J. Orliński[16], J.-H. Otto[12], M. Parschau[9], C. Pauly[18], D. Pawlowska-Szymanska[17], V. Pechenov[6], O. Pechenova[6], D. Pfeifer[18], K. Piasecki[16], J. Pietraszko[6], T. Povar[18], K. Prościński[5,b], A. Prozorov[15,f], W. Przygoda[5], K. Pysz[4], B. Ramstein[14], N. Rathod[17], J. Ritman[6,1], A. Rost[7,6], A. Rustamov[6], P. Salabura[5], J. Saraiva[2], K. Scharmann[12], N. Schild[7], E. Schwab[6], F. Scozzi[7,14], F. Seck[7], I. Selyuzhenkov[6], U. Singh[5], L. Skorpil[9], J. Smyrski[5], S. Spies[9], A. Sreejith[18], H. Ströbele[9], J. Stroth[9,6,e], K. Sumara[5], O. Svoboda[15], M. Szala[9], P. Tlusty[15], M. Traxler[6], S. Treliński[4], I. C. Udrea[7,6], F. Ulrich-Pur [6], C. Ungethum[7], V. Wagner[15], A.A. Weber[12], C. Wendisch[6], J. Wirth[11,10], A. Władyszewska[5,b], H.P. Zbroszczyk[17], E. Zherebtsova[h], M. Zieliński[5], P. Zumbruch[6]

[1]Ruhr-Universität Bochum, 44801 Bochum, Germany
[2]LIP-Laboratório de Instrumentação e Física Experimental de Partículas, 3004-516 Coimbra, Portugal
[3]AGH University of Krakow, Faculty of Physics and Applied Computer Science, 30-059 Krakow, Poland
[4]Institute of Nuclear Physics, Polish Academy of Sciences, 31342 Kraków, Poland
[5]Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
[6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[7]Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany
[8]Institut für Strahlenphysik, Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany
[9]Institut für Kernphysik, Goethe-Universität, 60438 Frankfurt, Germany
[10]Excellence Cluster 'Origin and Structure of the Universe' , 85748 Garching, Germany
[11]Physik Department E62, Technische Universität München, 85748 Garching, Germany
[12]II.Physikalisches Institut, Justus Liebig Universität Giessen, 35392 Giessen, Germany
[13]Faculty of Science, Palacký University Olomouc, 779 00 Olomouc, Czech Republic
[14]Laboratoire de Physique des 2 infinis Irene Joliot-Curie, Universite Paris-Saclay, CNRS-IN2P3, F-91405 Orsay, France
[15]Nuclear Physics Institute, The Czech Academy of Sciences, 25068 Rez, Czech Republic
[16]Uniwersytet Warszawski, Instytut Fizyki Doświadczalnej, 02-093 Warszawa, Poland
[17]Warsaw University of Technology, Faculty of Physics, 00-662 Warsaw, Poland
[18]Bergische Universität Wuppertal, 42119 Wuppertal, Germany

[a] also at Instituto Politecnico de Coimbra, Instituto Superior de Engenharia de Coimbra, 3030-199 Coimbra, Portugal
[b] also at Doctoral School of Exact and Natural Sciences, Jagiellonian University, Cracow, Poland
[c] also at Helmholtz Research Academy Hesse for FAIR (HFHF), Campus Darmstadt, 64390 Darmstadt, Germany
[d] also at Technische Universität Dresden, 01062 Dresden, Germany
[e] also at Helmholtz Research Academy Hesse for FAIR (HFHF), Campus Frankfurt, 60438 Frankfurt am Main, Germany
[f] also at Charles University, Faculty of Mathematics and Physics, 12116 Prague, Czech Republic
[g] also at Czech Technical University in Prague, 16000 Prague, Czech Republic
[h] also at University of Wrocław, 50-204 Wrocław, Poland
e-mail: hades-info@gsi.de (J. Stroth)

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Recap f ummary

- The analysis is comple
  significant direct photo
- The F-C method was u
  on direct photon corre
  8 · 10^{-4} for CL=0.68 ar
- The paper is almost do

* joking aside, I'm happy he wrote to me about that paper

correlations in Ag+Ag collisions at

Why 2D correlation?

gle α. The invariant momentum difference $Q_{\rm inv}$ coincides with the invariant mass and is equal to

$$Q_{\rm inv} = \sqrt{2\,p_1\,p_2\,(1-\cos\alpha)} \quad (3)$$
$$= 2\,\sqrt{p_1\,p_2}\,\sin\frac{\alpha}{2}\,. \quad (4)$$

In the limits of collinear and back-to-back pairs it becomes

$$Q_{\rm inv} = \begin{cases} \sqrt{p_1 p_2}\,\alpha\,, & \text{for } \alpha \to 0\,, \\ 2\,\sqrt{p_1 p_2} = 2p\,, & \text{for } \alpha \to \pi\,. \end{cases} \quad (5)$$

As one can see, $Q_{\rm inv}$ is not directly sensitive to the energy difference between the two photons. For pairs of massive identical particles a vanishing $Q_{\rm inv}$ implies $\mathbf{p}_1 = \mathbf{p}_2$. For photons it does not. $Q_{\rm inv}$ mostly reflects $q_{\rm side}$ and $q_{\rm long}$ and is only weakly related to $q_{\rm out}$. This means that the Bose-Einstein peak, which sits at $q_{\rm out} = q_{\rm side} = q_{\rm long} = 0$, in $C(Q_{\rm inv})$ is diluted by uncorrelated pairs with large $q_{\rm out}$. This deficiency of $C(Q_{\rm inv})$ has been noticed (Refs. [15–17, 19, 20]; see also Eq. (38) in Ref. [1]) and the resulting reduction of the peak amplitude λ was estimated and corrected for by performing a simulation accounting for the detector acceptance, the shape of the photon spectrum, and the assumed $R_{\rm out}$ [20].

Preserving the full height of the BE peak and at the same time keeping the π^0 peak narrow is possible in a two-dimensional analysis

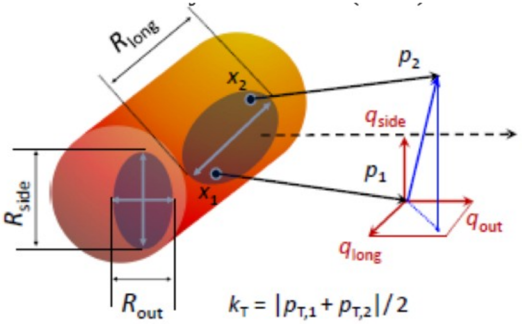
$$C(\Delta E, Q_{\rm inv})\,. \quad (6)$$

Why 2D correlation?

long - determined by the beam direction

out - determined by the pair trans. momentum

side - perpendicular to *long* and *side*



Our representation (6) is closely related to

$$C(q_{out}, \sqrt{q_{side}^2 + q_{long}^2}) \,. \quad (8)$$

The resulting relation between the $(\Delta E, Q_{inv})$ coordinates and $(q_{out}, \sqrt{q_{side}^2 + q_{long}^2})$ in LCMS is shown in Fig. 1. In the region below 0.1 GeV/c, where the Bose-Einstein peak is expected to be located for direct photons from heavy-ion collisions, the two sets of variables are very close to each other.

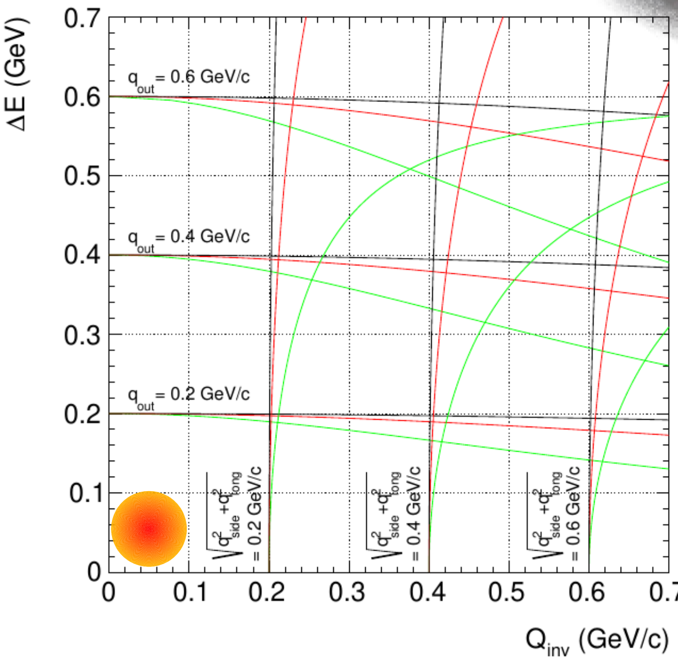


FIG. 1. Mapping of $(q_{out}, \sqrt{q_{side}^2 + q_{long}^2})$ on the $(\Delta E, Q_{inv})$ plane in LCMS. Lines of constant q_{out} and those of constant $\sqrt{q_{side}^2 + q_{long}^2}$ are shown in green, red, and black for the pair momentum K of 0.3, 0.6, and 1.2 GeV/c, respectively. In the region below 0.1 GeV/c, where the Bose-Einstein peak is expected to be located for direct photons from heavy-ion collisions, the two representations are very close to each other.

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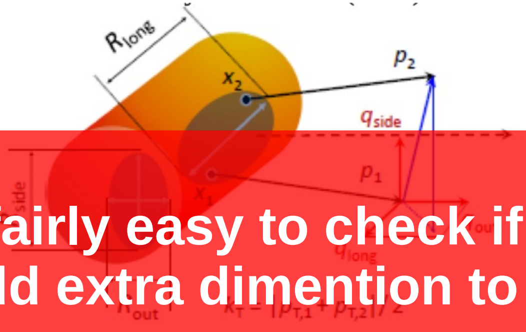
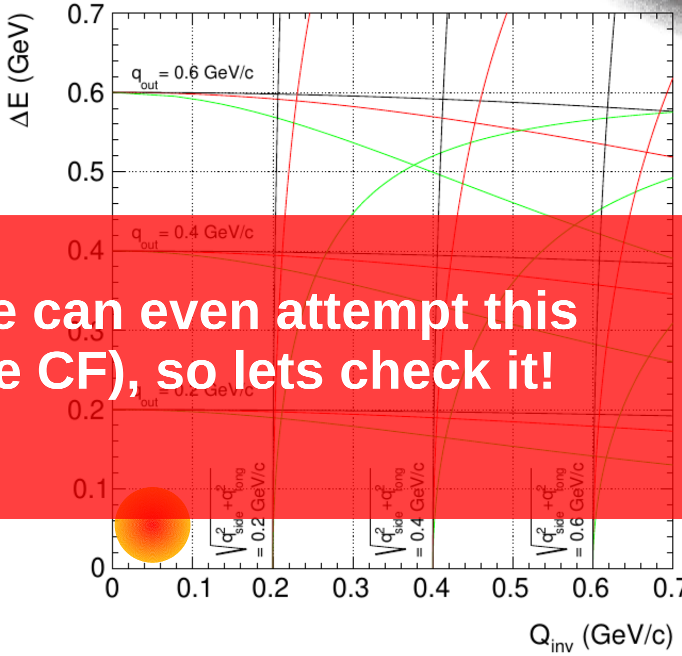


Seems fairly easy to check if we can even attempt this (just add extra dimention to the CF), so lets check it!

Our representation (6) is closely related to

$$C(q_{\rm out}, \sqrt{q^2_{\rm side} + q^2_{\rm long}})\ . \qquad (8)$$

The resulting relation between the $(\Delta E, Q_{\rm inv})$ coordinates and $(q_{\rm out}, \sqrt{q^2_{\rm side} + q^2_{\rm long}})$ in LCMS is shown in Fig. 1. In the region below 0.1 GeV/c, where the Bose-Einstein peak is expected to be located for direct photons from heavy-ion collisions, the two sets of variables are very close to each other.



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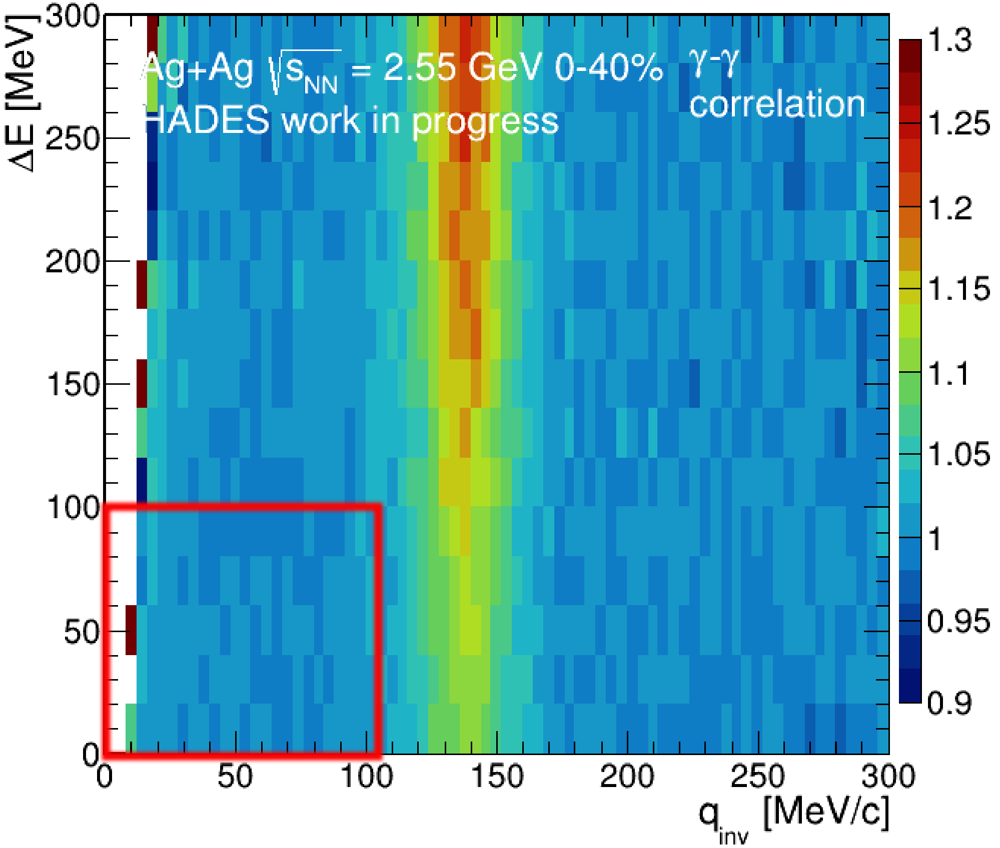
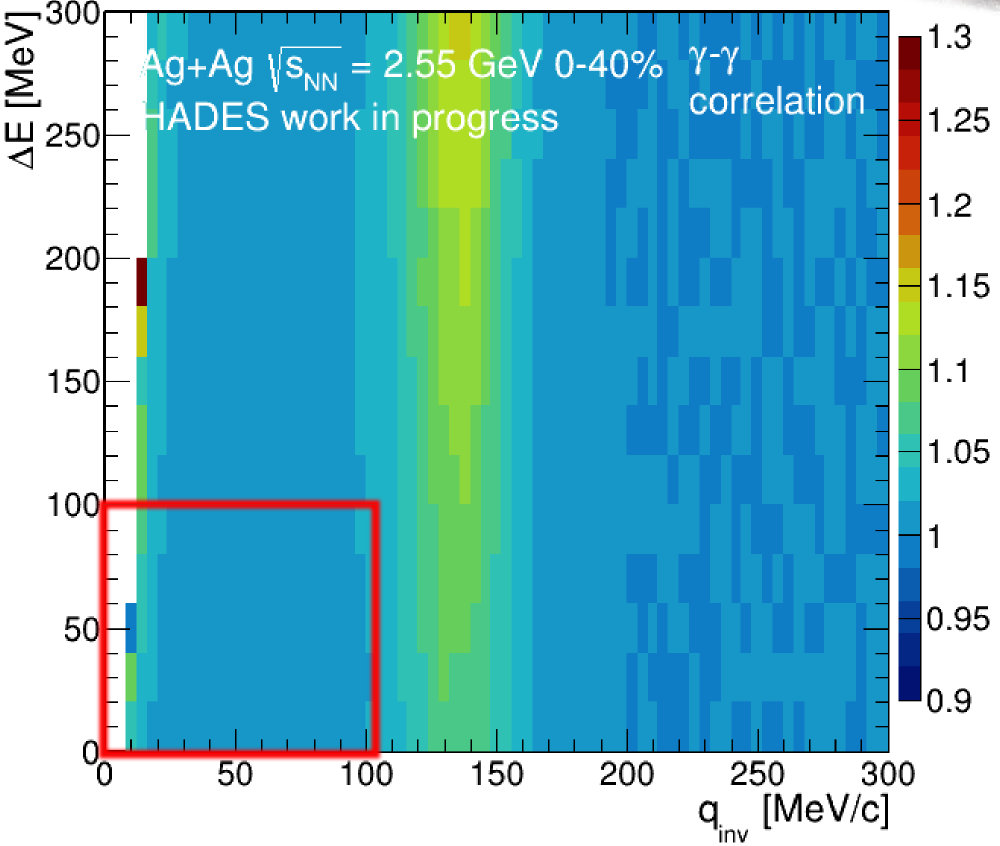
2D correlation attempt

Simulations, $\alpha_{\gamma\gamma}$ mapping

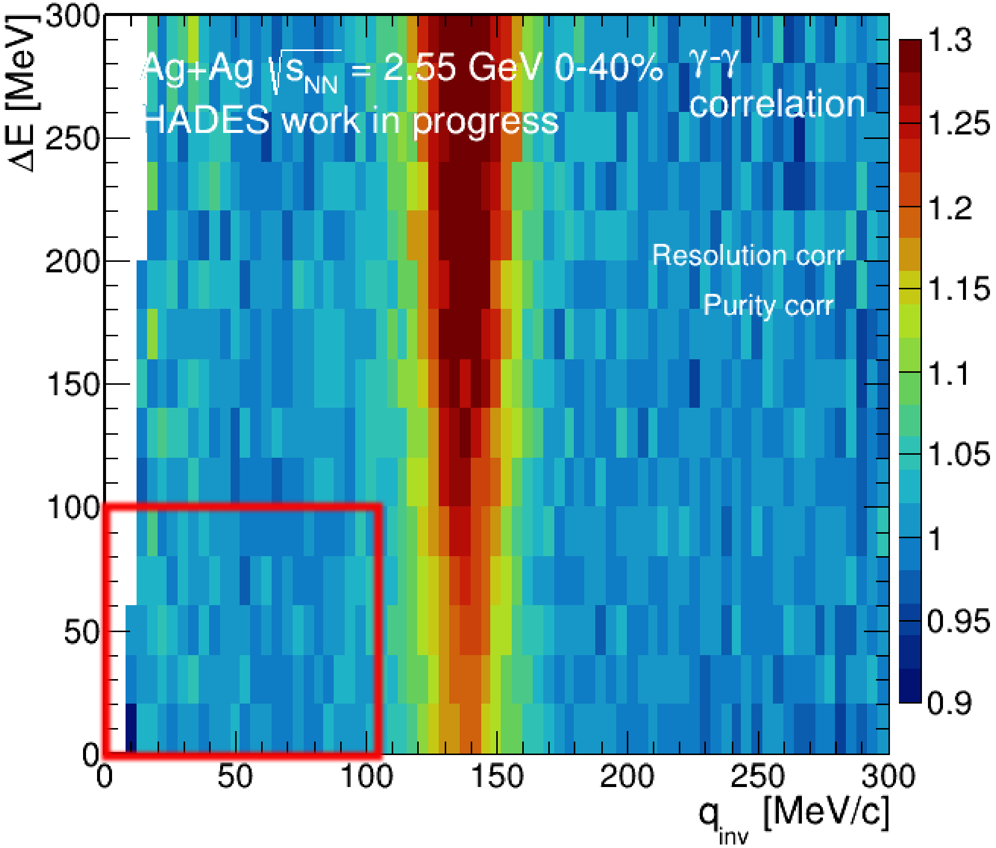


Data, $\alpha_{\gamma\gamma}$ mapping

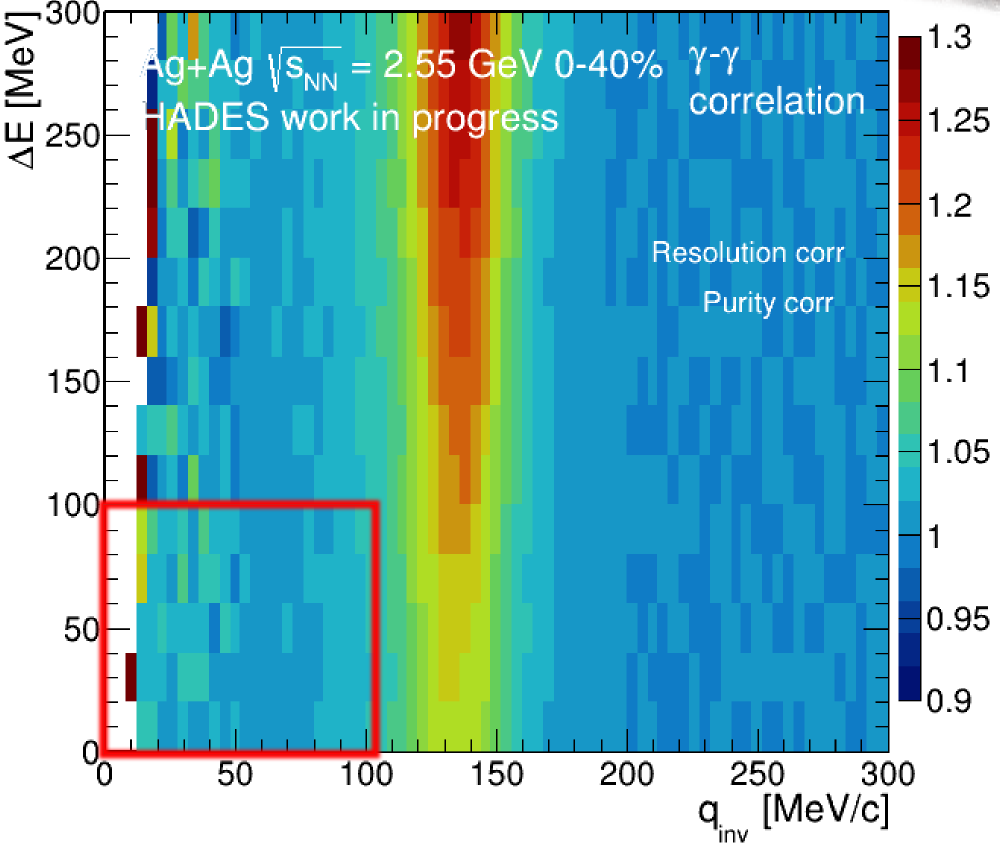


2D correlation attempt

Simulations, full correction

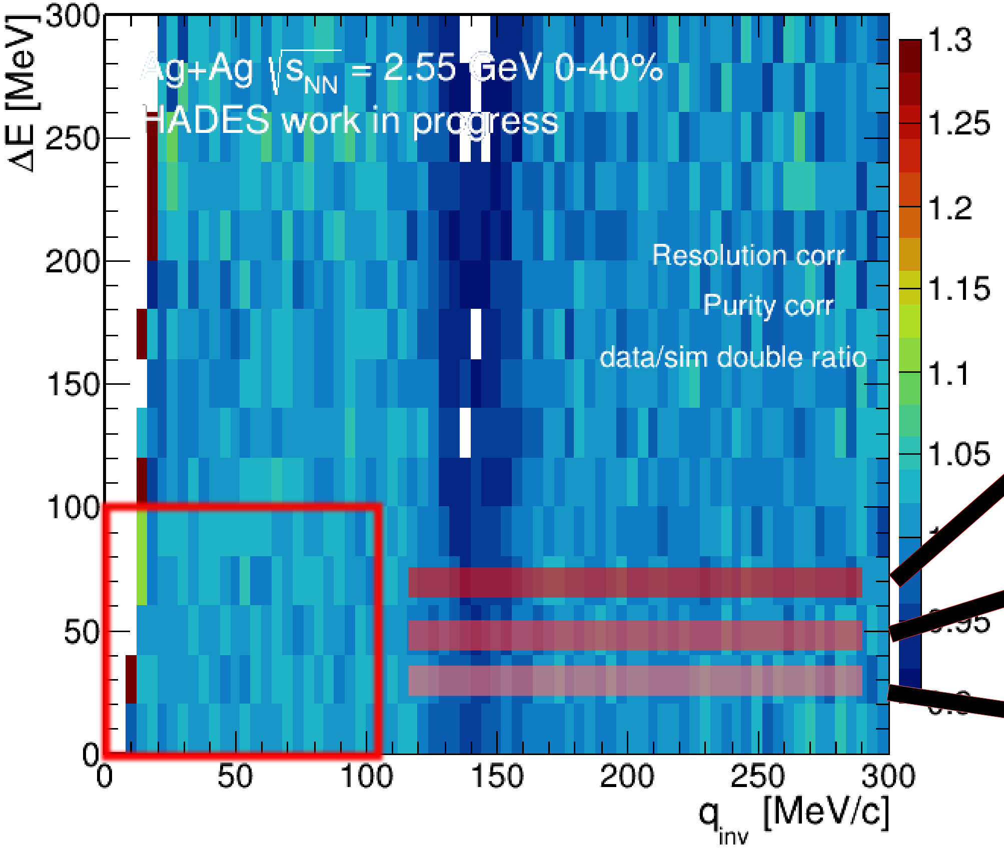


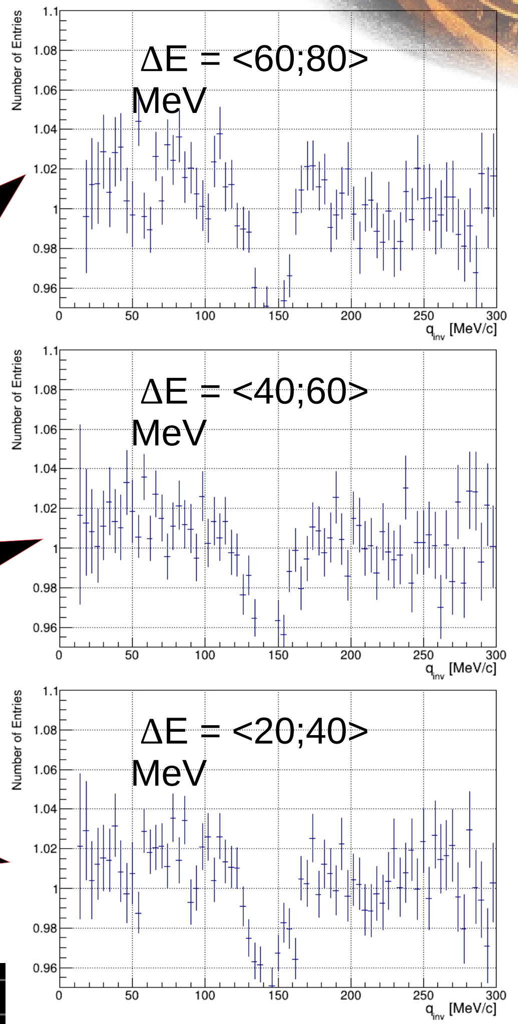
Data, full correction



2D correlation attempt

Data/Simulations ratio, full correction





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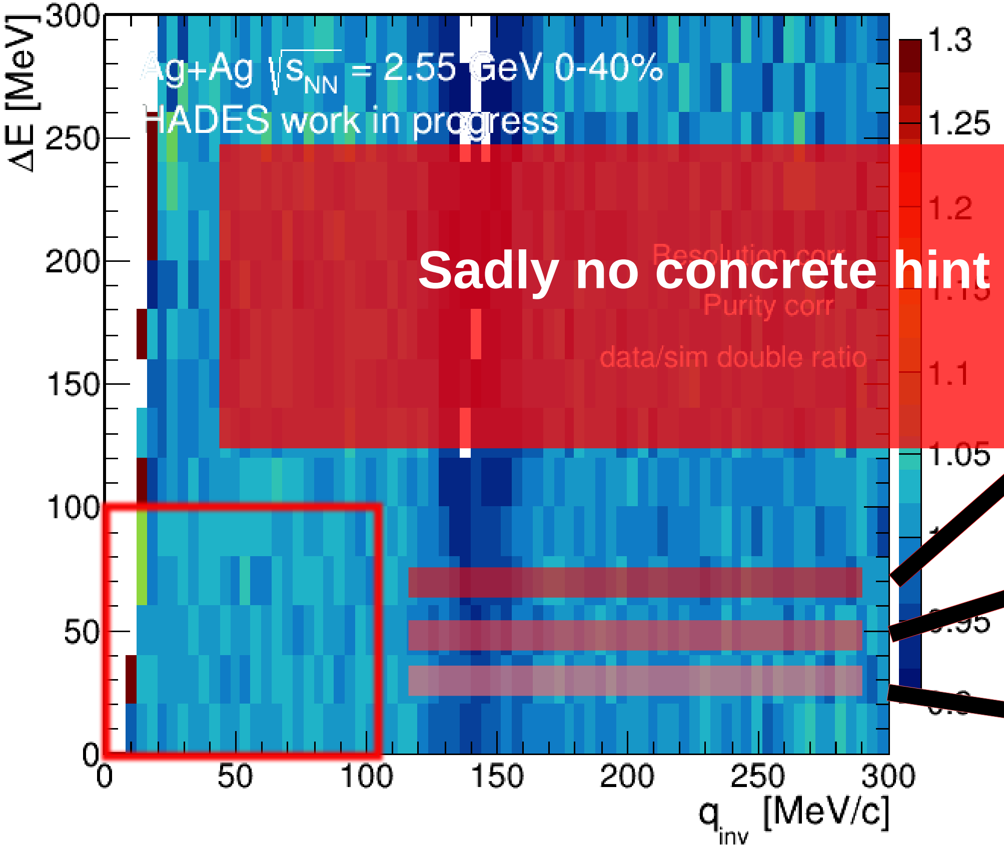
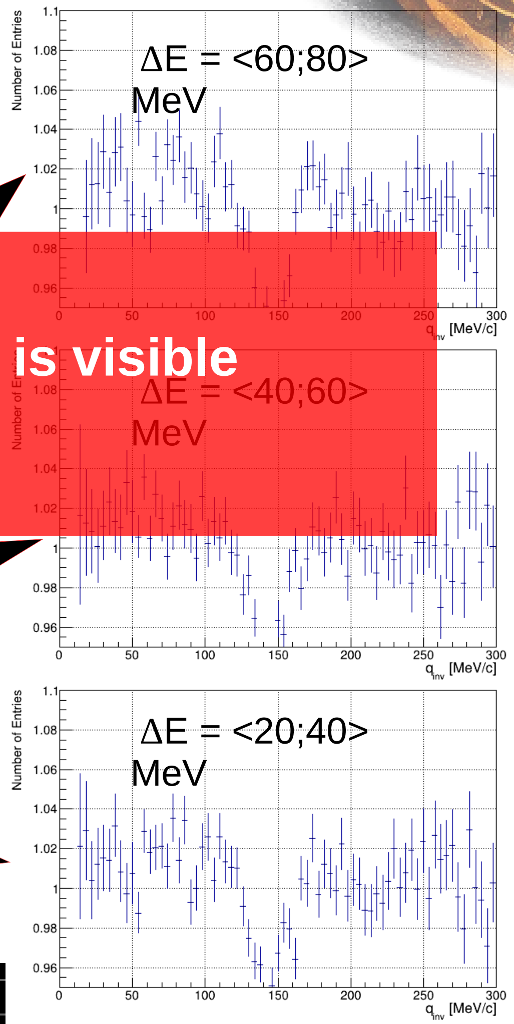
Data/Simulations ratio, full correction



Sadly no concrete hint of direct γ signal is visible



Summary

- The 2D correlations were attempted, to check if we have a “diluted peak” case
- We don’t (or at the very least we cannot see anything more using 2D correlations)
- The paper is almost done (finalizing the discussion with internal referees)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[14]Laboratoire de Physique des 2 infinis Irene Joliot-Curie, Universite Paris-Saclay, CNRS-IN2P3, F-91405 Orsay, France
[15]Nuclear Physics Institute, The Czech Academy of Sciences, 25068 Rez, Czech Republic
[16]Uniwersytet Warszawski, Instytut Fizyki Doświadczalnej, 02-093 Warszawa, Poland
[17]Warsaw University of Technology, Faculty of Physics, 00-662 Warsaw, Poland
[18]Bergische Universität Wuppertal, 42119 Wuppertal, Germany

[a] also at Instituto Politecnico de Coimbra, Instituto Superior de Engenharia de Coimbra, 3030-199 Coimbra, Portugal
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[g] also at Czech Technical University in Prague, 16000 Prague, Czech Republic
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e-mail: hades-info@gsi.de (J. Stroth)

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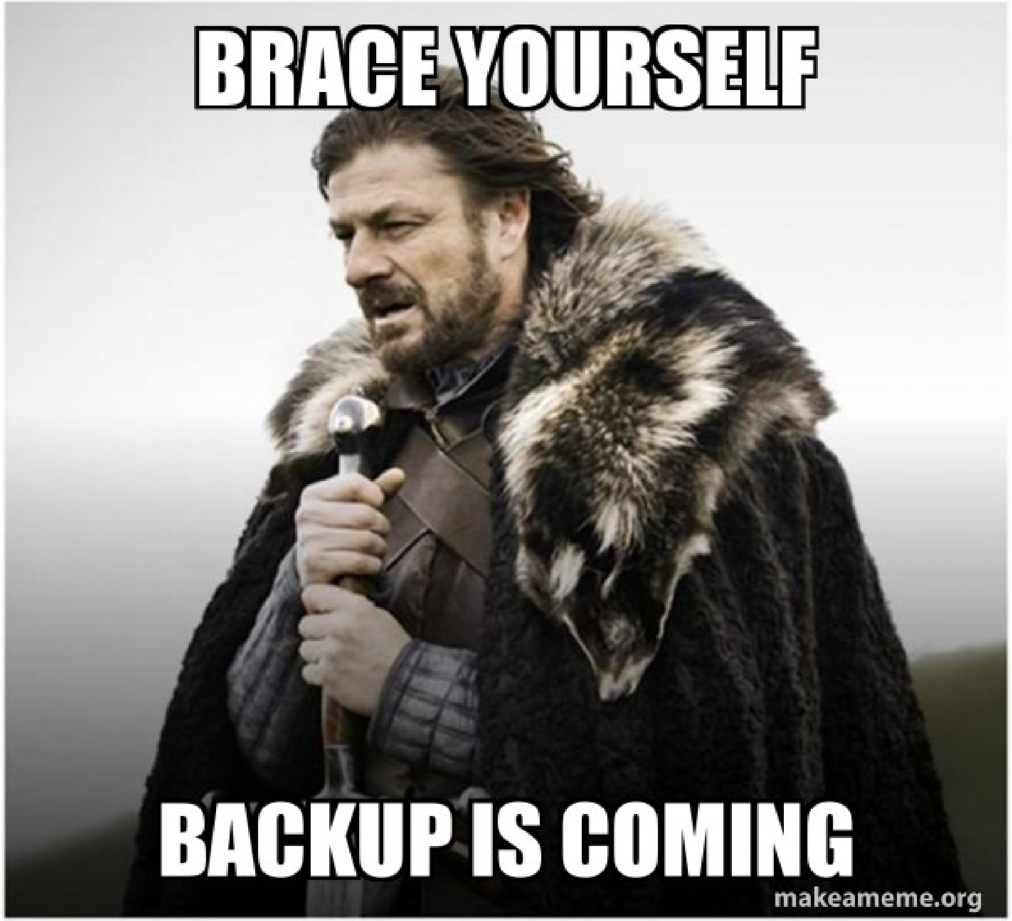
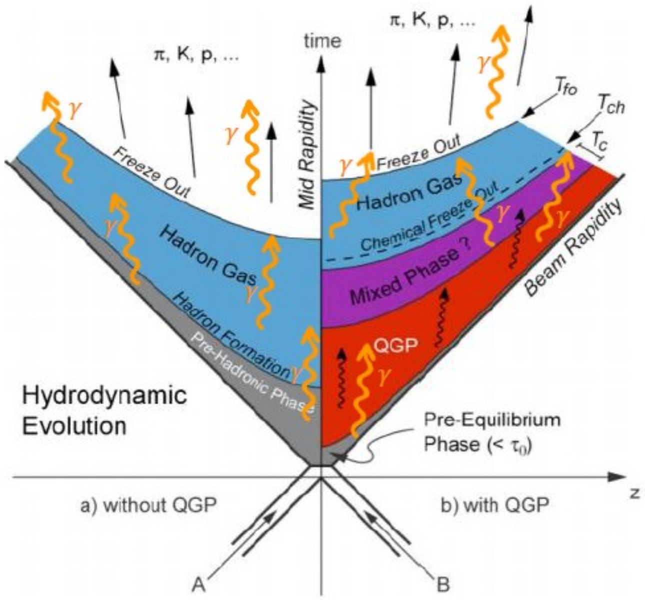
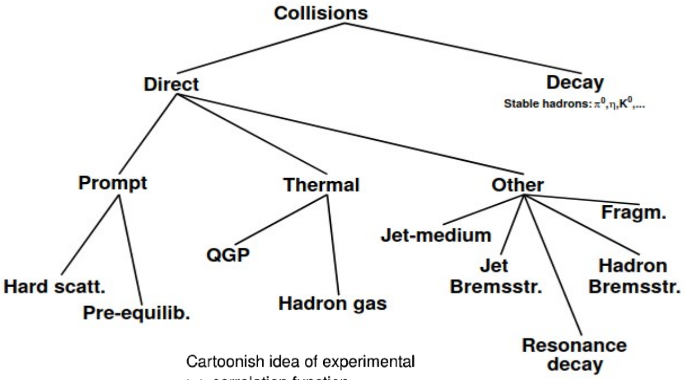
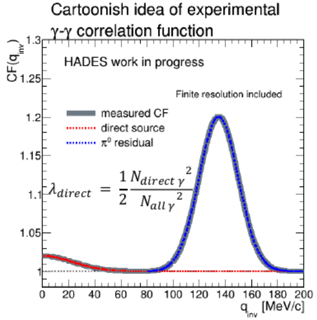


Why photons?

- Undistorted signal
- Information about
early stages (inaccessible for hadrons → **complementary analysis to "standard" HBT**)
- Probing before-freezout era
- **A way to hunt for direct photons at low p_T / low collision energy & high multiplicity environment**







$$\lambda_{direct} = \frac{1}{2}\left(\frac{N_{\gamma direct}}{N_{\gamma all}}\right)^2 \ll 10^{-1}$$

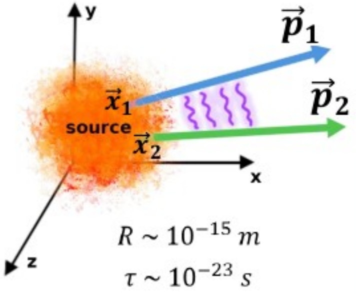
$$\downarrow$$

$$N_{\gamma direct} = \sqrt{2\lambda_{direct}}\, N_{\gamma all}$$

$$Q_{INV} = \sqrt{(\vec{p}_1 - \vec{p}_2)^2 - (E_1 - E_2)^2} = M_{\gamma\gamma} \qquad M_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos(\alpha_{\gamma\gamma}))}$$

Femtoscopy

Goal - measure source's space-time characteristics and/or interactions between particles through low relative momentum correlations.



Theory

Single particle emission function: $P(\vec{p}) = \int S(\vec{x})\, d^3x$

Correlation function:

$$CF(\vec{p}_1, \vec{p}_2) = \frac{P(\vec{p}_1, \vec{p}_2)}{P(\vec{p}_1)P(\vec{p}_2)}$$

Two particle emission function: $P(\vec{p}_1, \vec{p}_2) = \int S(\vec{x}_1; \vec{x}_2)\, |\Psi(\vec{x}_1, \vec{p}_1; \vec{x}_2, \vec{p}_2)|^2 d^3x_1 d^3x_2$

$\vec{x}$: particle's position

$\vec{p}$: particle's momentum

$\Psi(\vec{x}_1, \vec{p}_1; \vec{x}_2, \vec{p}_2)$: two particle's wave function

$S(\vec{x})$: source function

$q = |\vec{p}_1 - \vec{p}_2|$: momentum difference

$N_{same}(q)$: same event distribution

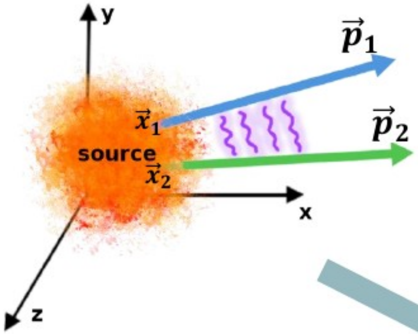
$N_{mixed}(q)$: mixed event distribution

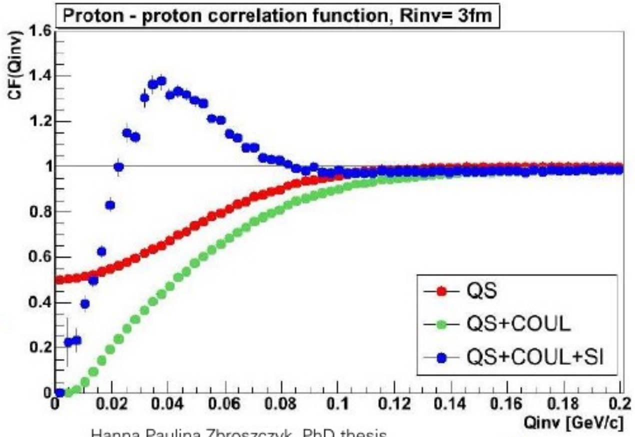
Experiment

Correlation function:

$$CF(q) = \frac{N_{same}(q)}{N_{mixed}(q)}$$

Femtoscopy





Hanna Paulina Zbroszczyk, PhD thesis

Effects and interactions:

- QS – quantum statistics (Bose-Einstein or Fermi-Dirac), identical particles
- Coul – Coulomb interactions, charged particles
- SI – strong interactions, hadrons

$q = |\vec{p}_1 - \vec{p}_2|$: momentum difference

$r = |\vec{x}_1 - \vec{x}_2|$: relative distance

$$CF(q) = \int S(r)|\Psi(r,q)|^2 d^3r$$

Determine the geometry and dynamic properties (traditional femtoscopy)

Determine the interactions (non-traditional femtoscopy)

Mapping 2.0 – improved merging correction

Previously:

- Only minimum bias case (one map to fix them all)
- Arbitrary (by eye) chosen thresholds for sizes combinations
- Quite complex fitting function, requiring border cases to work properly (every “bigger” sizes combination has to have treshold larger or equal to smaller one)

$$f(s_1,s_2)=As_1^2+Bs_2^2+Cs_1s_2+Ds_1+Es_2+F$$

+ border cases

Currently:

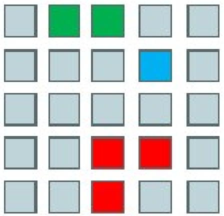
- Separate cases for every 10% centrality class
- Chosen by cutoff percentage (dependent on size, centrality and combination od sizes), limited at 99.9%
- Simplified fitting function, with no border cases

$$f(s_1,s_2)=As_1^2+Bs_2^2+Cs_1s_2+Ds_1+Es_2+F$$

~~+ border cases~~

```
double cutoff = 0.83; // how much of split garbage we want to reject (1=all)
double midcentralReduction = 0.02; // how much we reduce cutoff for 10-20 and 20-30%
double peripheralReduction = 0.06; // how much we reduce cutoff for 30-40%
double nonDiagonalIncrease = 0.07; // how much we increase cotoff for non-diagonal cases per size difference
double sizeIncrease = 0.06; // how much we increase cutoff per size of each cluster
double tresholdLimit = 4.8; // lowest acceptable treshold (hardware limit)
```

Mapping idea



Modules are ~ 2.2° (92 mm) wide, Can't separate 2γ within 300 *ps* interval

Opening angle „hardware threshold" ~ 4.4° (for 2 „size 1" clusters)

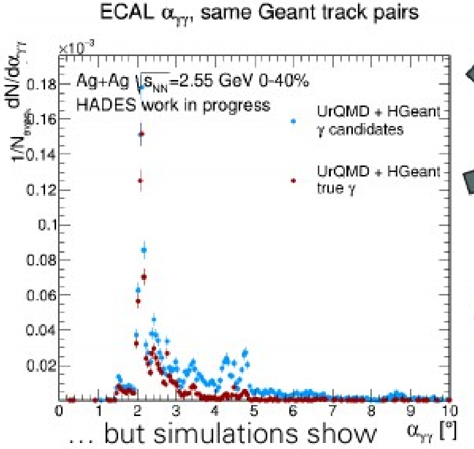
γ triggers:

1 module → cluster size 1

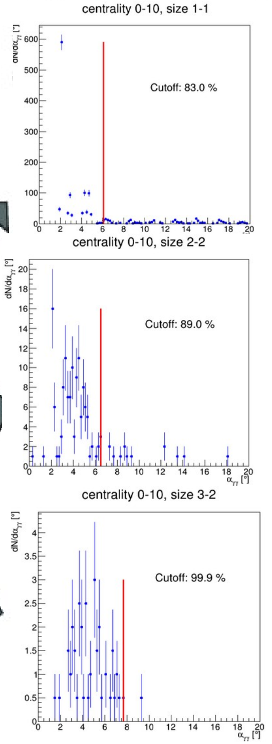
2 modules → cluster size 2

3 modules → cluster size 3

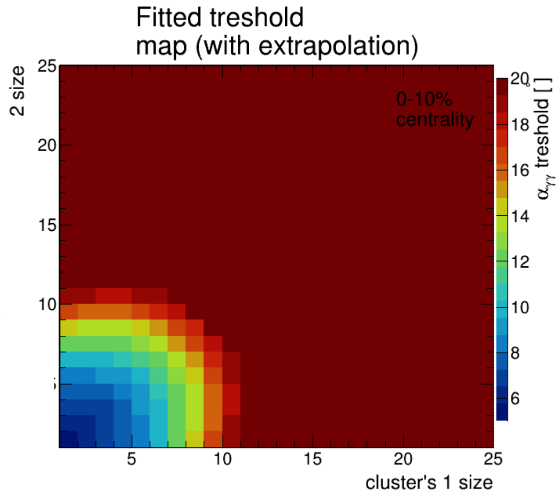
...

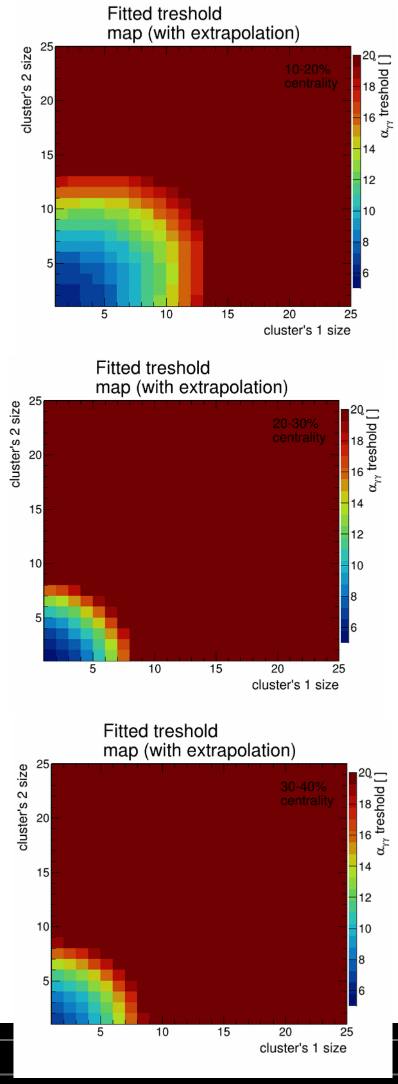


... but simulations show some „split" clusters



$\alpha_{\gamma\gamma}$ [°]





Recap from last CM – γ-γ CFs fits

Table 3 Obtained fit parameters for simulation (Fig. 6, left panel)

parameter	value	stat. uncert.	syst. uncert. (Barlow)
χ^2/NDF	1.09		
R_1 [fm]	5.82	± 0.59	$+0.16\ -0.67$
$\lambda_1 \cdot 10^{-2}$	3.64	± 0.70	$+1.04\ -1.12$
R_2 [fm]	0.00	± 0.83	$+0.00\ -0.00$
$\lambda_2 \cdot 10^{-2}$	0.20	± 0.09	$+0.08\ -0.05$
μ_{π^0} [MeV/c^2]	138.42	± 0.11	$+0.06\ -0.18$
σ_{π^0} [MeV/c^2]	14.22	± 0.15	$+0.15\ -0.09$
k_L	1.14	± 0.04	
k_H	1.53	± 0.10	

Table 4 Obtained fit parameters for real data (Fig. 6, right panel)

parameter	value	stat. uncert.	syst. uncert. (Barlow)
χ^2/NDF	2.11		
R_1 [fm]	4.59	± 0.42	$+0.45\ -0.39$
$\lambda_1 \cdot 10^{-2}$	2.85	± 0.28	$+0.96\ -1.23$
R_2 [fm]	1.55	± 0.13	$+0.03\ -0.00$
$\lambda_2 \cdot 10^{-2}$	1.04	± 0.22	$+0.20\ -0.21$
μ_{π^0} [MeV/c^2]	135.04	± 0.04	$+0.16\ -0.22$
σ_{π^0} [MeV/c^2]	15.55	± 0.06	$+0.14\ -0.19$
k_L	0.91	± 0.02	
k_H	1.28	± 0.02	

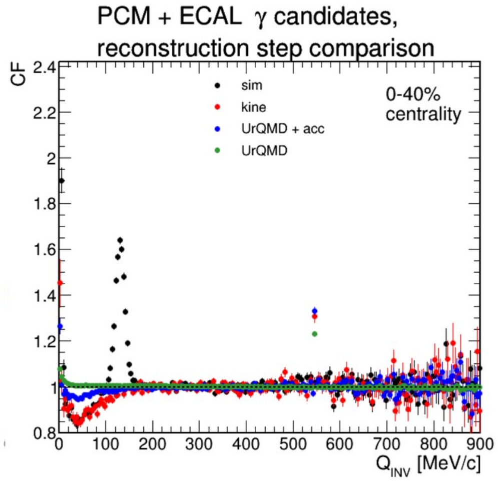
Similar values of R_1 and λ_1 → <u>that's (sadly) not a direct-ish photon signal</u>, but some aparatus effect.

$$CF(q_{inv}) = 1 + \lambda_1 \exp(-q_{inv}^2 R_1^2) + \lambda_2 \exp(-q_{inv}^2 R_2^2) + f_{\pi^0}(q_{inv}, \mu_{\pi^0}, \sigma_{\pi^0}, k_L, k_H)$$

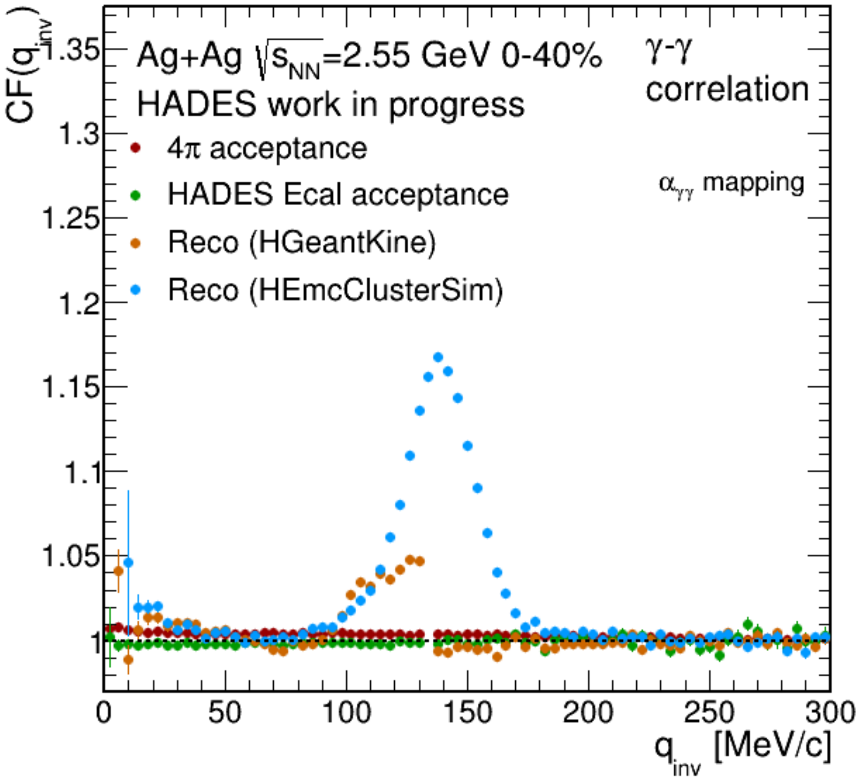
Systematics calculated with Barlow Test

Recap from last CM – reconstruction fault

Quite some time ago when I was working on hybrid approach (PCM+Ecal) I've found some strange effects are related to reconstruction of (Ecal) photons.



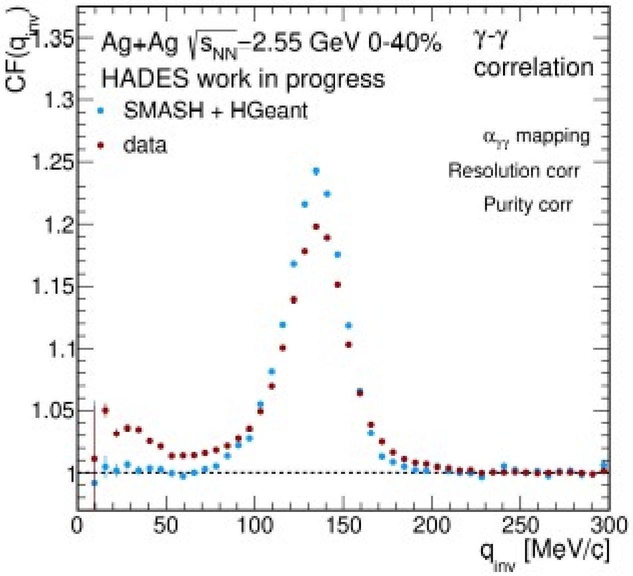
… and it seems to be the case here as well! No such effect is visible before reconstruction!



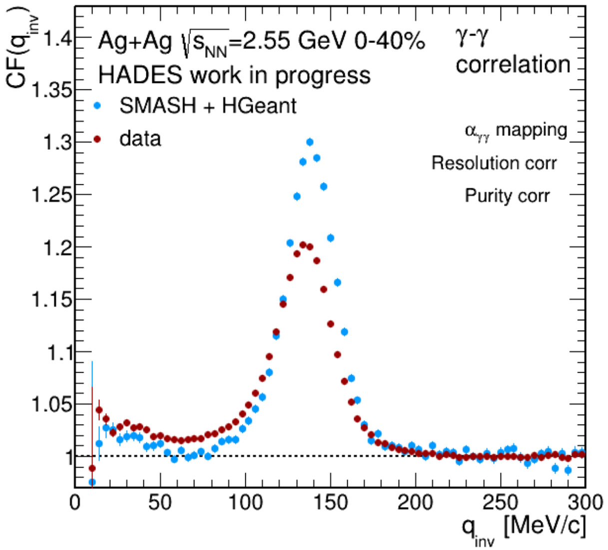
This <u>is probably</u> caused by reconstruction algorithm (cluster finder parameters)

CF before & after changed cluster finder

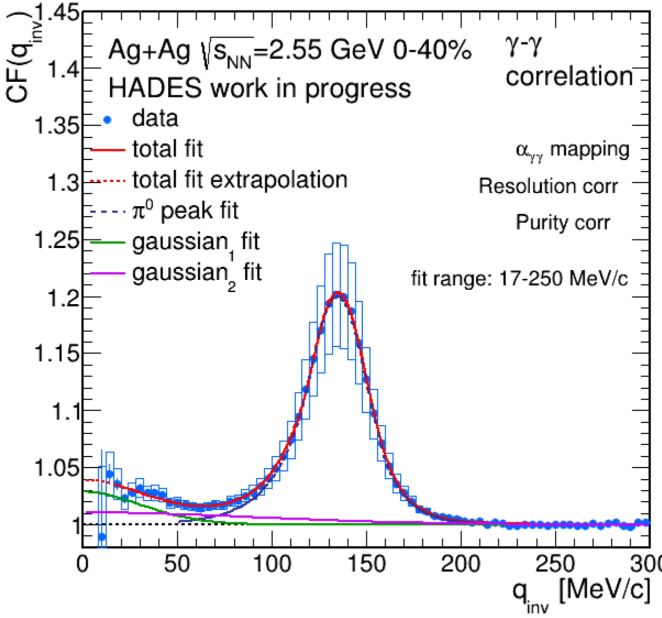
My digitizer, sim-like cluster finder (all cluster sizes)



My digitizer, data-like cluster finder (cluster sizes < 4)



π^0-π^0 residual correlation



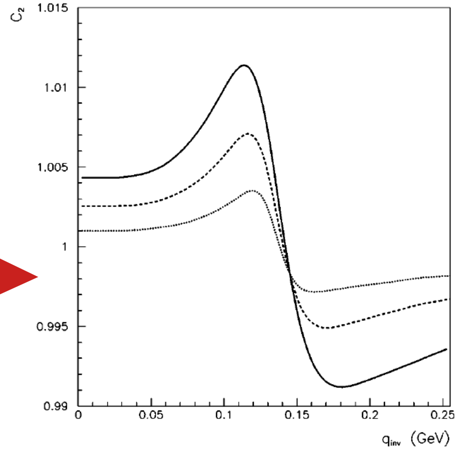
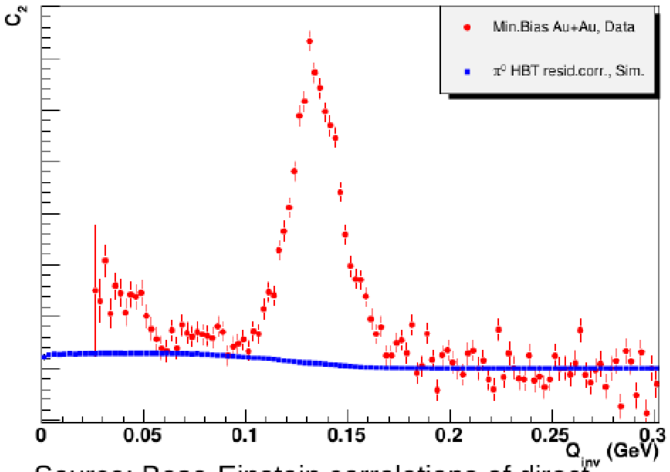


FIG. 1. Correlation functions for photons, produced by pions for three radii R_{inv} of the pion correlation function: 4 fm (solid line), 5 fm (dashed line), and 7 fm (dotted line).

Source: Hanbury Brown–Twiss interferometry of direct photons in heavy ion collisions
D. Peressounko, PHYSICAL REVIEW C 67, 014905 (2003)



Source: Bose-Einstein correlations of direct photons in Au+Au collisions at $s_{NN}\surd 200$ GeV, D.Peressounko (for the PHENIX Collaboration), Int.J.Mod.Phys.E16:2235-2240,2007

R_1 [fm]: $4.59 \pm 0.42 + 0.45 - 0.39$

λ_1 $(\cdot 10^{-2})$: $2.85 \pm 0.28 + 0.96 - 1.23$

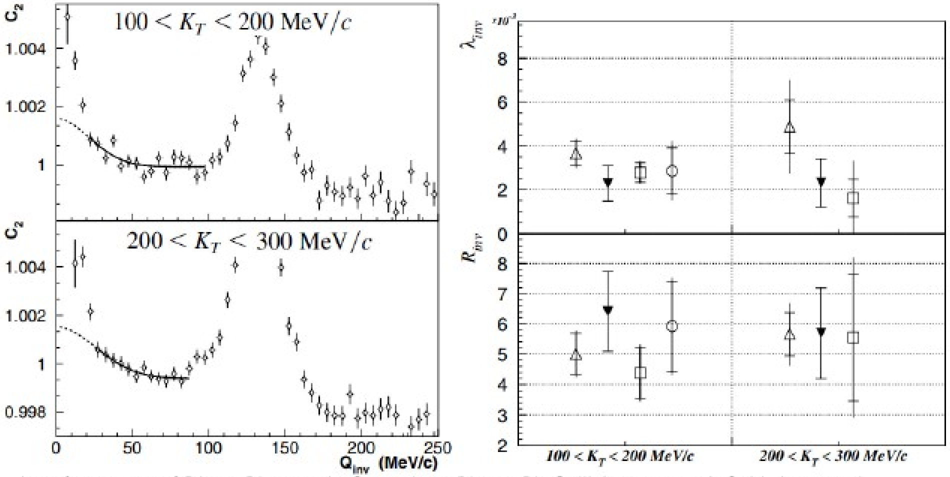
R_2 [fm]: $1.55 \pm 0.13 + 0.03 - 0.00$

λ_2 $(\cdot 10^{-2})$: $1.04 \pm 0.22 + 0.21 - 0.22$

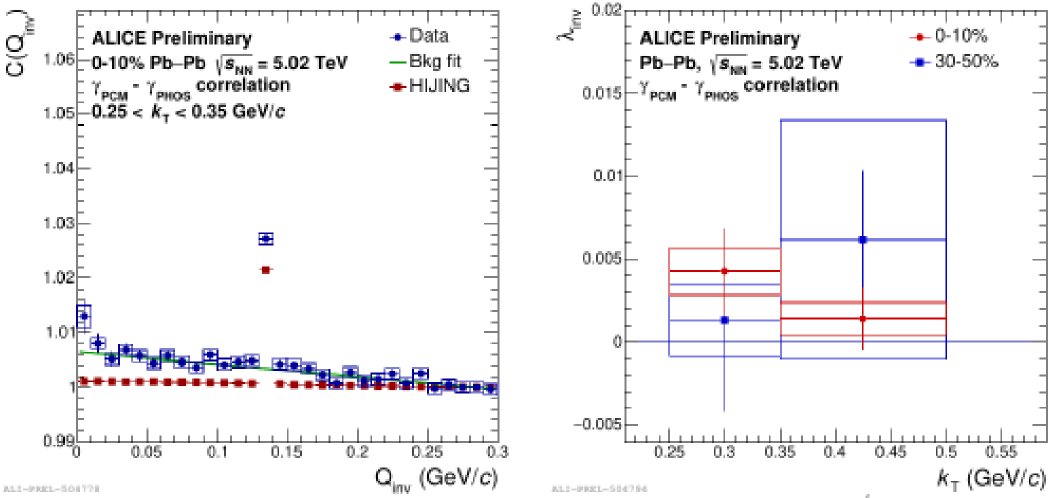
$\mu_{\pi 0}$[MeV]: $1.35 \cdot 10^2 \pm 0.04 + 0.16 - 0.22$

$\sigma_{\pi 0}$[MeV]: $1.55 \cdot 10^1 \pm 0.06 + 0.14 - 0.19$

Other experiment results



Interferometry of Direct Photons in Central 208Pb 208Pb Collisions at 158A GeV, Aggarwal, M. M., Physical Review Letters, 93(2). doi:10.1103/physrevlett.93.022301



Direct photon production and HBT correlations in Pb–Pb collisions at √ sNN = 5.02 TeV with ALICE experiment, Meike Charlotte Danisch on behalf of the ALICE Collaboration, Acta Physica Polonica B Proceedings Supplement