Direct photon-photon HBT correlations in Ag+Ag collisions at $\sqrt{S_{\mathrm{NN}}} = 2.55$ GeV

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Abstract

The study of femtoscopic correlations of photon pairs, emitted from heavy-ion collisions, can serve as a unique probe of the evolution of the source in space and time. Unlike commonly used charged particles photons are not subject to strong, nor electromagnetic interactions. These properties imply no distortion of the information carried by γ from the point of their creation up to the detection in experiment. Therefore, it might be possible plausible to investigate source features, which are not only based on the information available after thermal freeze-out, but also include previous stages of the expansion. Moreover, results obtained this way are not burdened by distortions caused by surrounding particles. Unfortunately, direct photon detection is not trivial and the total photon yield is mainly dominated by π^0 meson decays, making a direct photon analysis suffering from the need to separate them from a background of photons emitted at different (later) stages of the collision.

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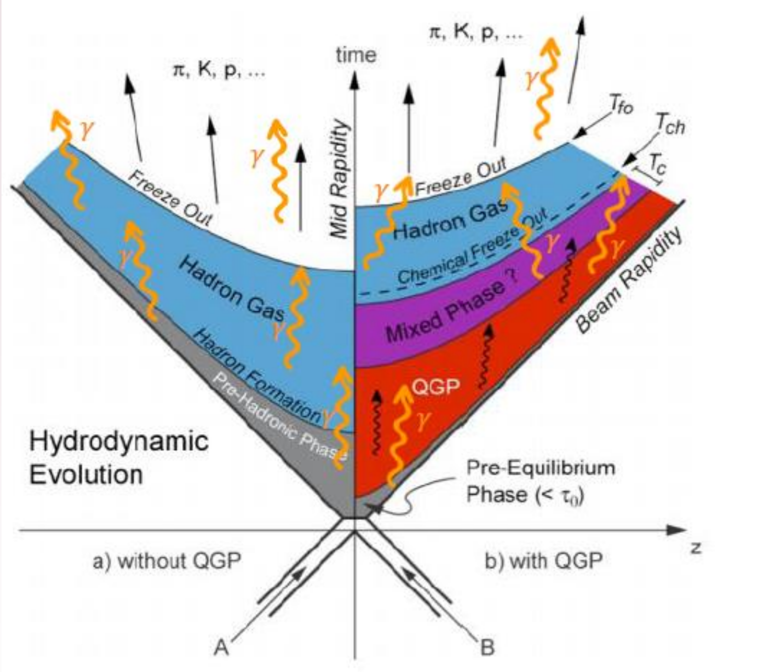
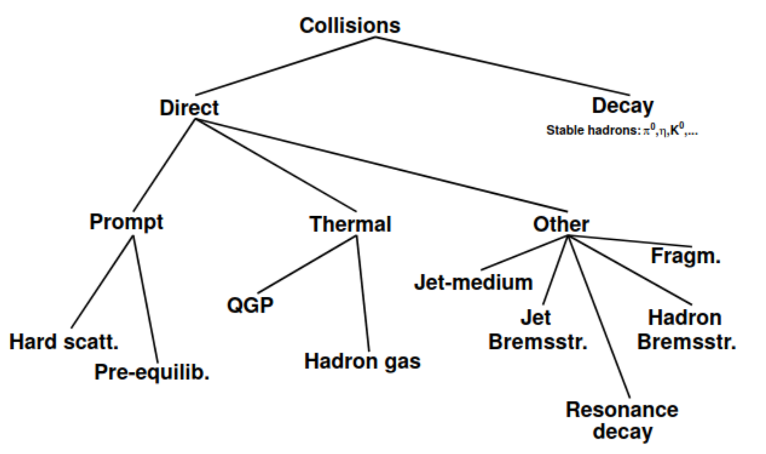
Motivation and challenges

- ✚ Clear and undistorted information (due to lack of interaction).
- ✚ Access to various stages of the collision by photons from different sources.
- ✚ Very simple correlation function parametrization (only Bose-Einstein statistics involved).
- ✚ Invulnerability to close track effects (no tracks reconstructed).

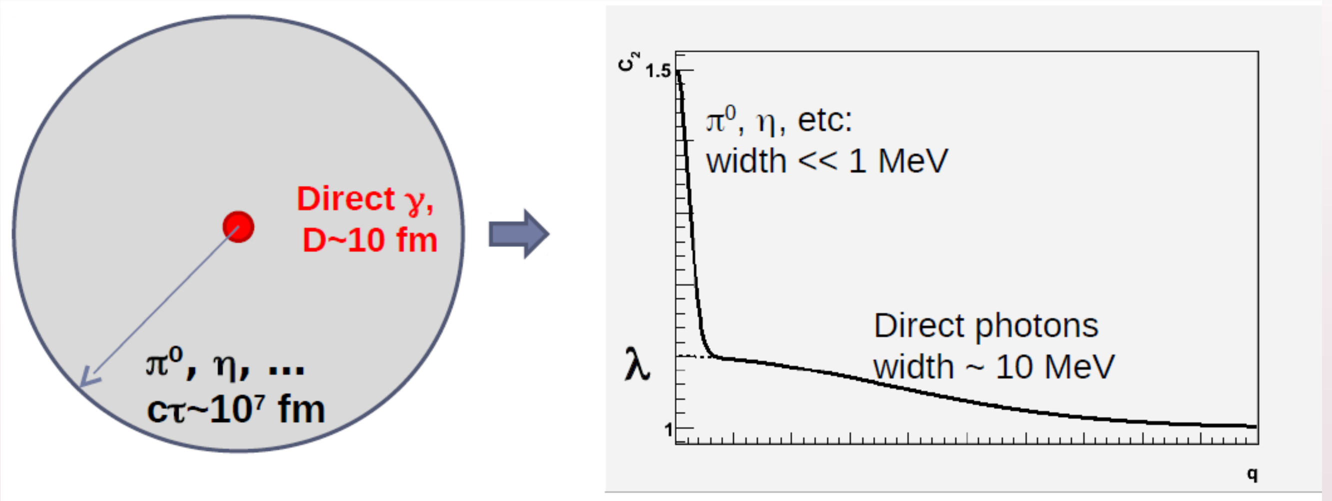


Photon emission during collisions
Source: J. Stachel. K. Reygers, QGP physics SS2015 6., „Space-time evolution of the QGP"

- Complex reconstruction.
- Small yield and highly dominated by π^0 and η decays.
- Very difficult to distinguish between photons from different sources.



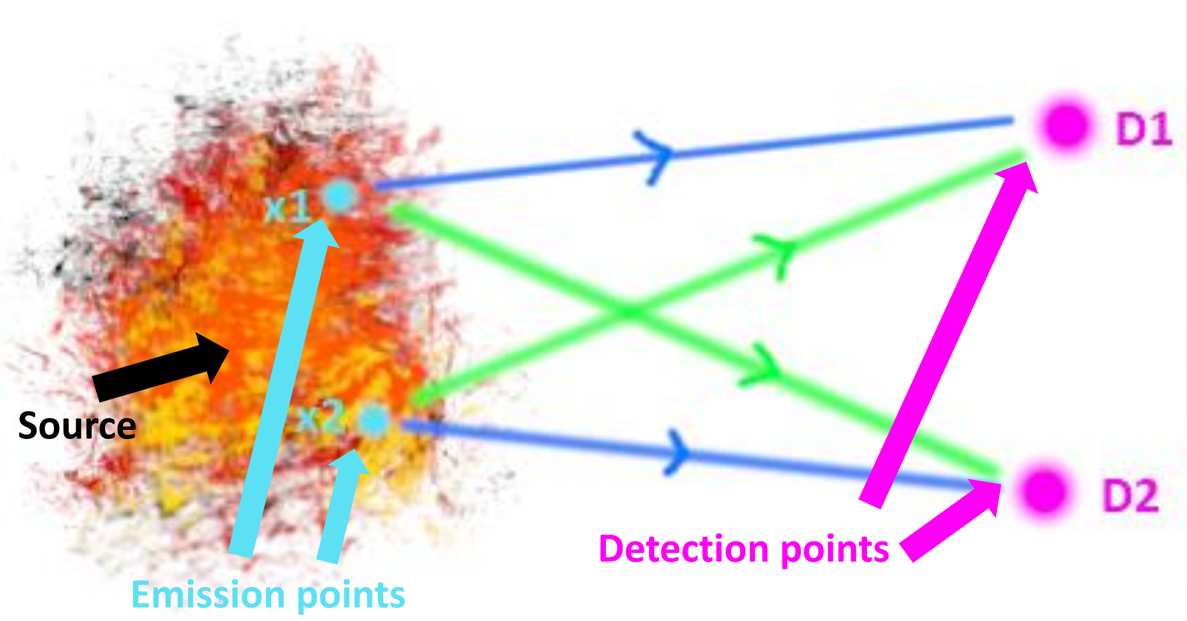
Plausible photon sources
Source: http://dx.doi.org/10.1088/1361-6633/ab6f57



Ideal photon correlation function with expected decay and direct photons inputs shown
Source: „Approaches to measure direct photon yield in AA collisions", D.Peresunko, NRC "Kurchatov institute", 29 November 2021 3rd workshop on "Physics performance studies at FAIR and NICA"

Femtoscopy

Typical source's size and lifetime: R ~ 10^{-15} m, τ ~ 10^{-23} s



Implausible to measure directly

Femtoscopic (HBT) correlations [1,2]:

$P_1(\vec{p})$ - probability of observing single particle with momentum p.
$P_{1,2}(\vec{p_1},\vec{p_2})$ - probability of observing the pair.

- Theoretical:

$$P_1(\vec{p}) = \int S(\vec{x},\vec{p})dx$$

$$P_{1,2}(\vec{p_1},\vec{p_2}) = \int S(\vec{x_1},\vec{p_1})\, S(\vec{x_2},\vec{p_2})\, |\psi(\vec{x_1},\vec{x_2})|^2 dx_1\, dx_2$$

$S(\vec{x},\vec{p})$ - emission function.
$\psi(\vec{x_1},\vec{x_2})$ - pair wavefunction.

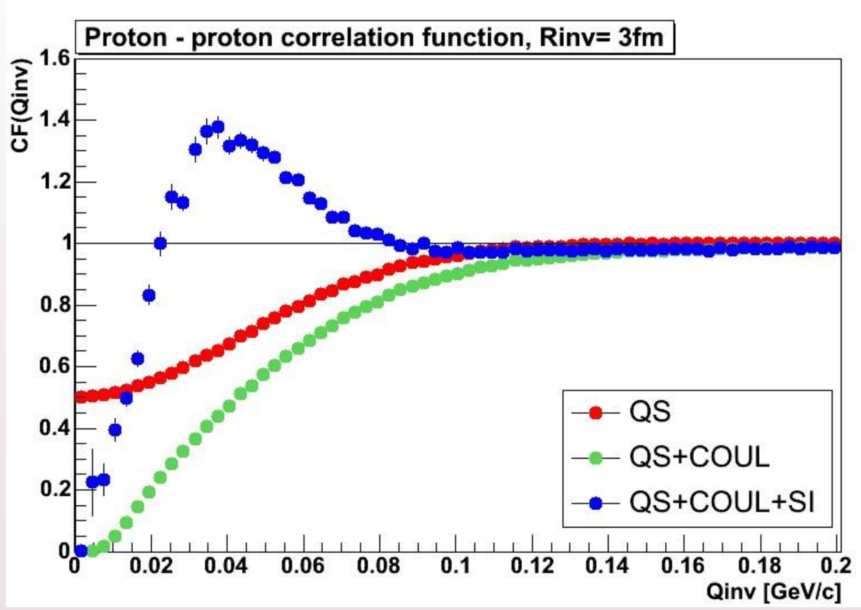
$$CF(\vec{p_1},\vec{p_2}) = \frac{P_{1,2}(\vec{p_1},\vec{p_2})}{P_1(\vec{p_1})P_1(\vec{p_2})}$$

$S(Q_{INV})$ – same event particles Q_{INV} distribution.
$B(Q_{INV})$ – different event particles Q_{INV} distribution.

- Experimental:

$$CF(Q_{INV}) = \frac{S(Q_{INV})}{B(Q_{INV})}$$

$$Q_{INV} = \sqrt{(\vec{p_1}-\vec{p_2})^2 - (E_1 - E_2)^2}$$



Example of correlation function
Source: Hanna Paulina Zbroszczyk, „Eksperymentalne aspekty badania korelacji femtoskopowych w zderzeniach relatywistycznych ciężkich jonów".

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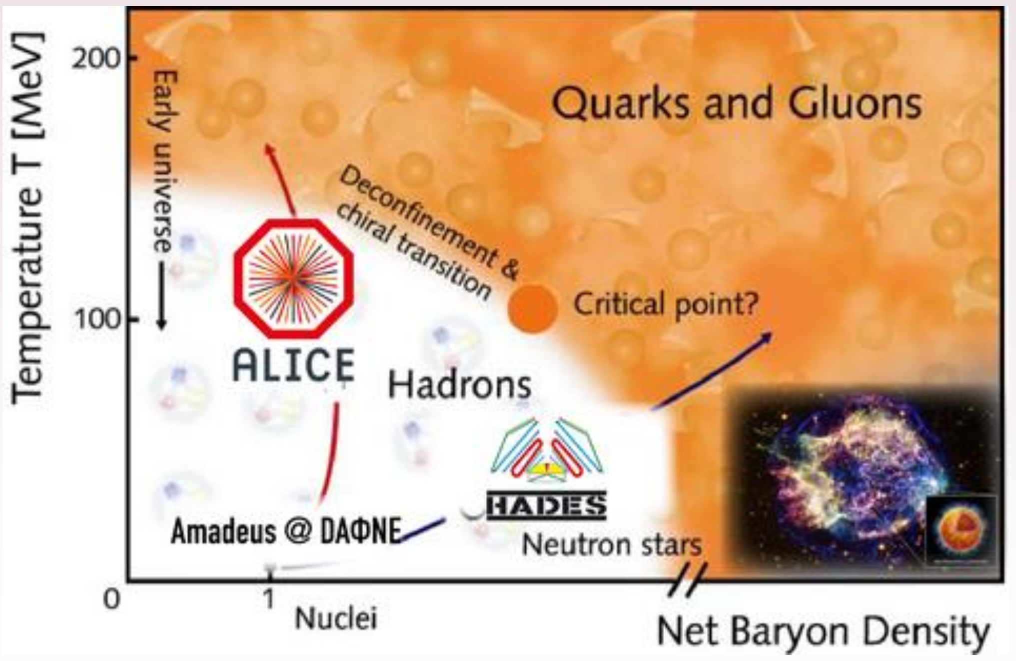
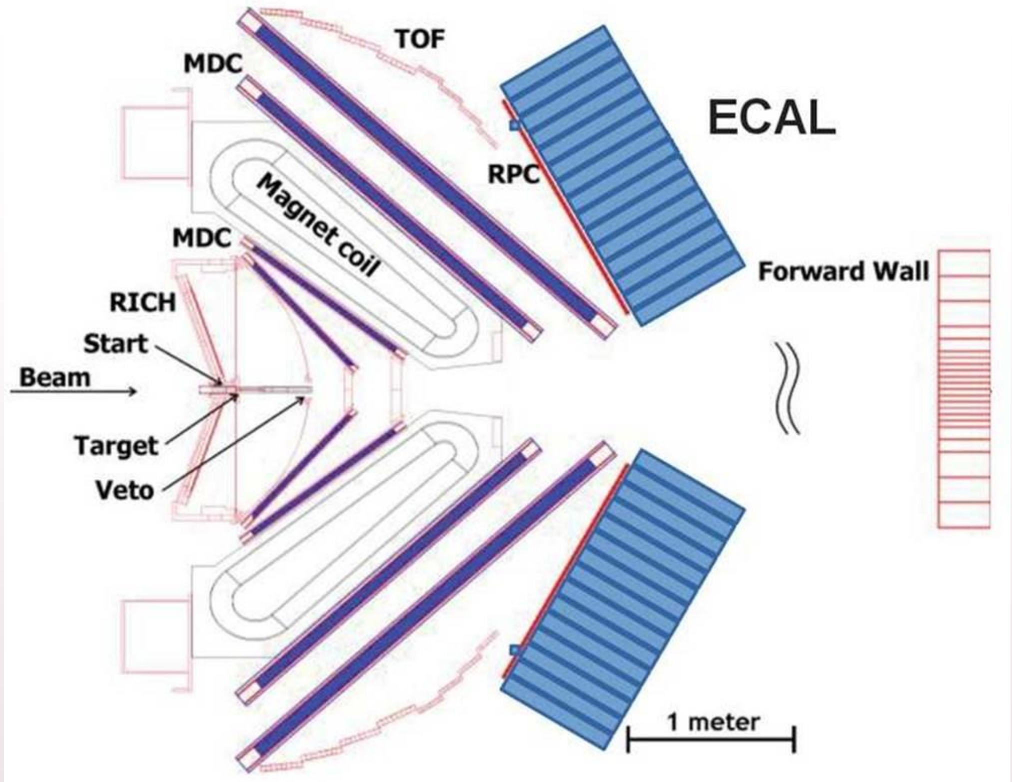
The HADES spectrometer

- Fixed target experiment, 1-2 A GeV kinetic beam energy.
- Probing low-temperature and high-density matter (neutron star mergers region).
- Designed for measurement of light vector mesons, decaying into dilepton pairs (ρ,ω,ϕ).
- High angular acceptance ($0<\varphi<2\pi$, $18°<\theta<85°$), split into 6 sectors.
- High $e^{\pm}$ reconstruction efficiency and $\pi^{\pm}/p^{+}$ separation (RICH, TOF/RPC + MDC, ECAL).



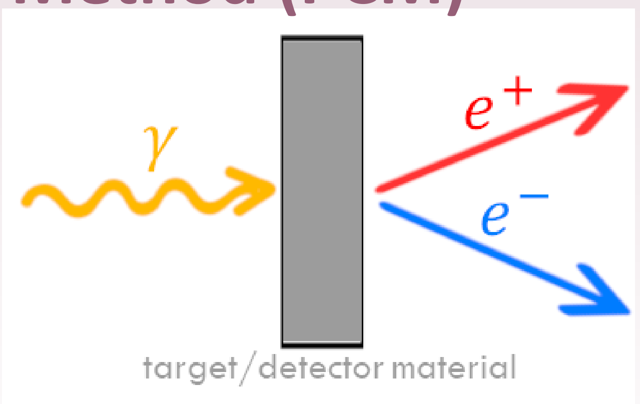
QCD phase diagram
Source: https://www.denseandstrange.ph.tum.de/en/research/



HADES cross-section
Source: https://www-hades.gsi.de

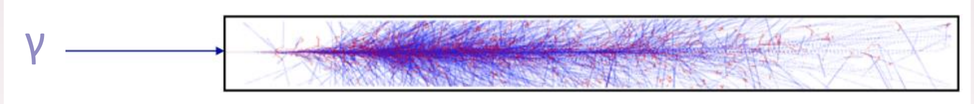
Photon detection with HADES

Photon Conversion Method (PCM)



- ✚ High acceptance of $e^{\pm}$ in HADES.
- ✚ High momentum resolution of reconstructed photons.
- \- Conversion probability decreases drastically with an increase of γ energy and momentum – low statistics.
- \- Close track effects on $e^{\pm}$ level.
- \- 2 stage reconstruction ($e^{\pm} \rightarrow \gamma$).

ECAL detection



Electromagnetic callorimeter visualisation
Source: Electromagnetic and hadronic calorimeters, Silvia Masciocchi, GSI Darmstadt and University of Heidelberg

- ✚ Direct reconstruction.
- ✚ Based on γ energy deposition – high statistics.
- \- Low granularity – poor angular resolution (merging close by showers).
- \- Covers only small θ angle.
- \- ~50% of modules available during beamtime in 2019.

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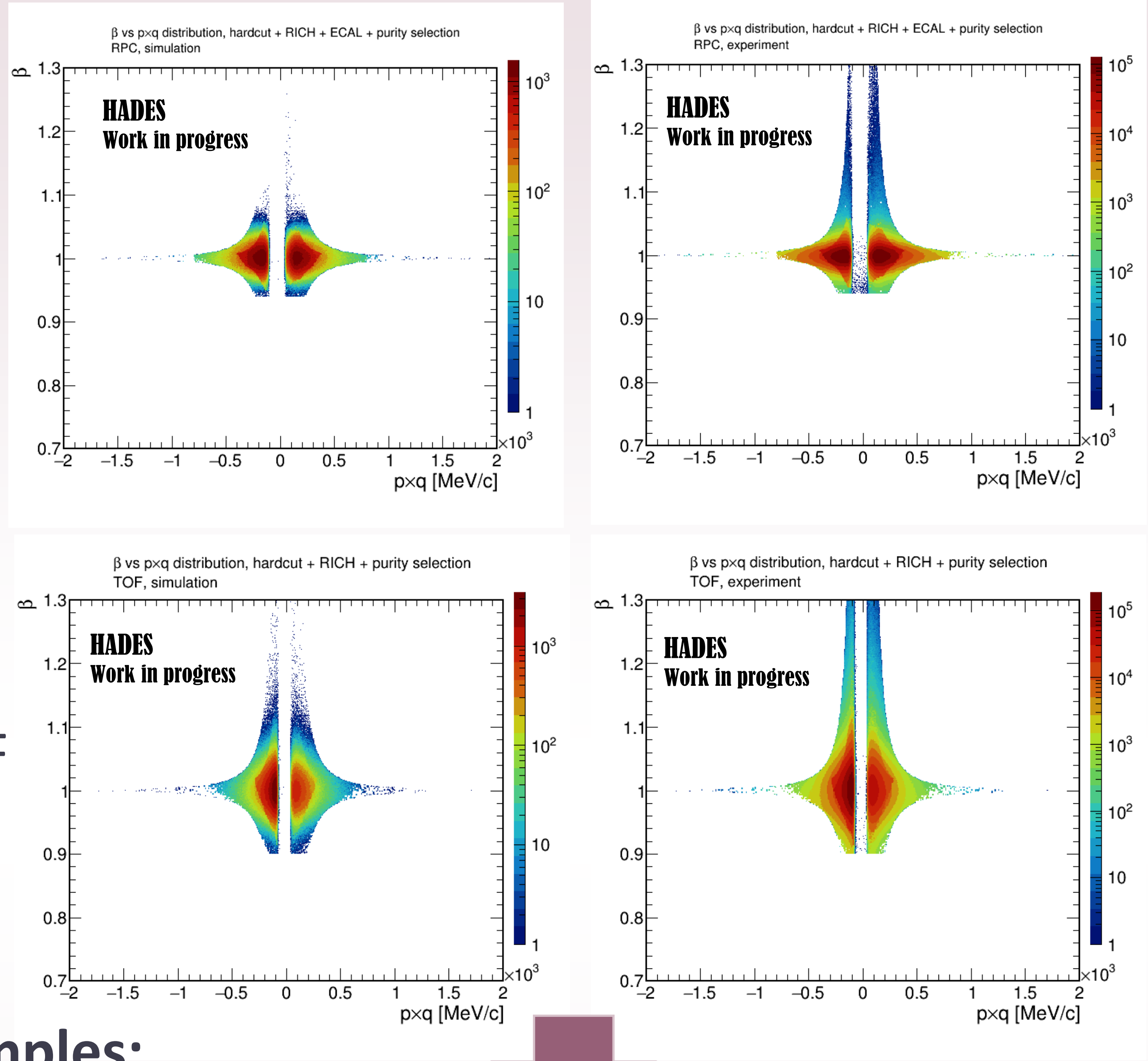
Photons reconstructed with PCM

simulation | experiment

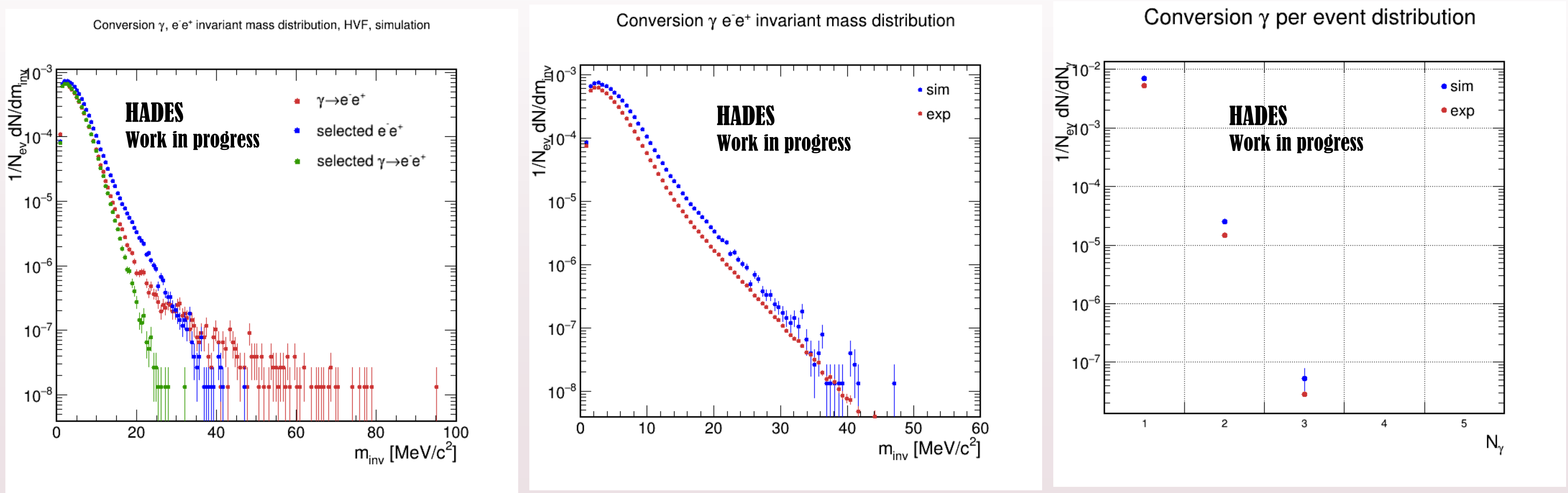
Reconstructed e± samples:

RPC

TOF



Reconstructed γ samples:

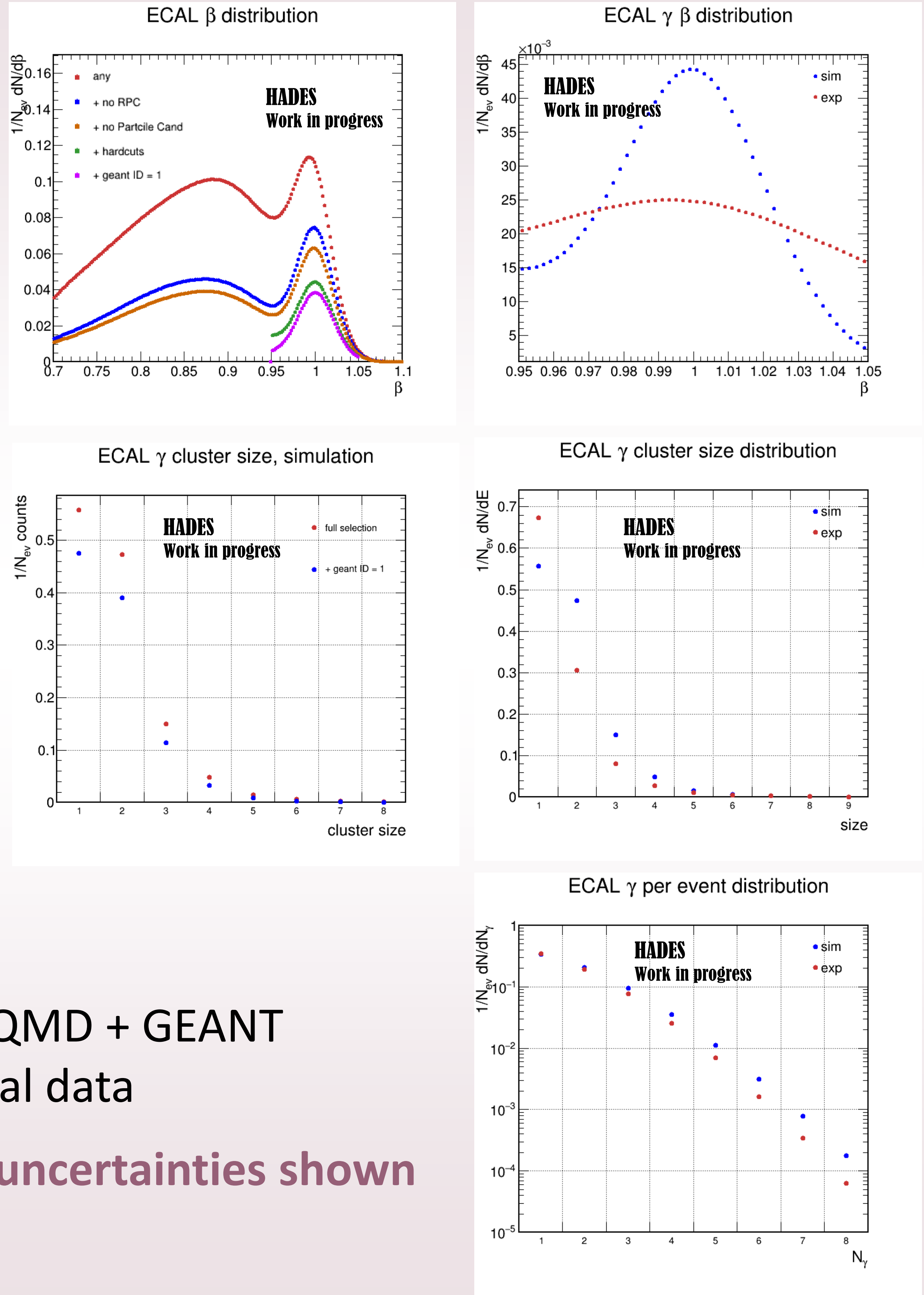


Centrality: 0-40%

Photon reconstructed with ECAL

simulation | simulation vs experiment

Reconstructed γ samples:



Photons from real data are more smeared due to calibration and noise issues

simulation = UrQMD + GEANT
experiment = real data

Only statistical uncertainties shown

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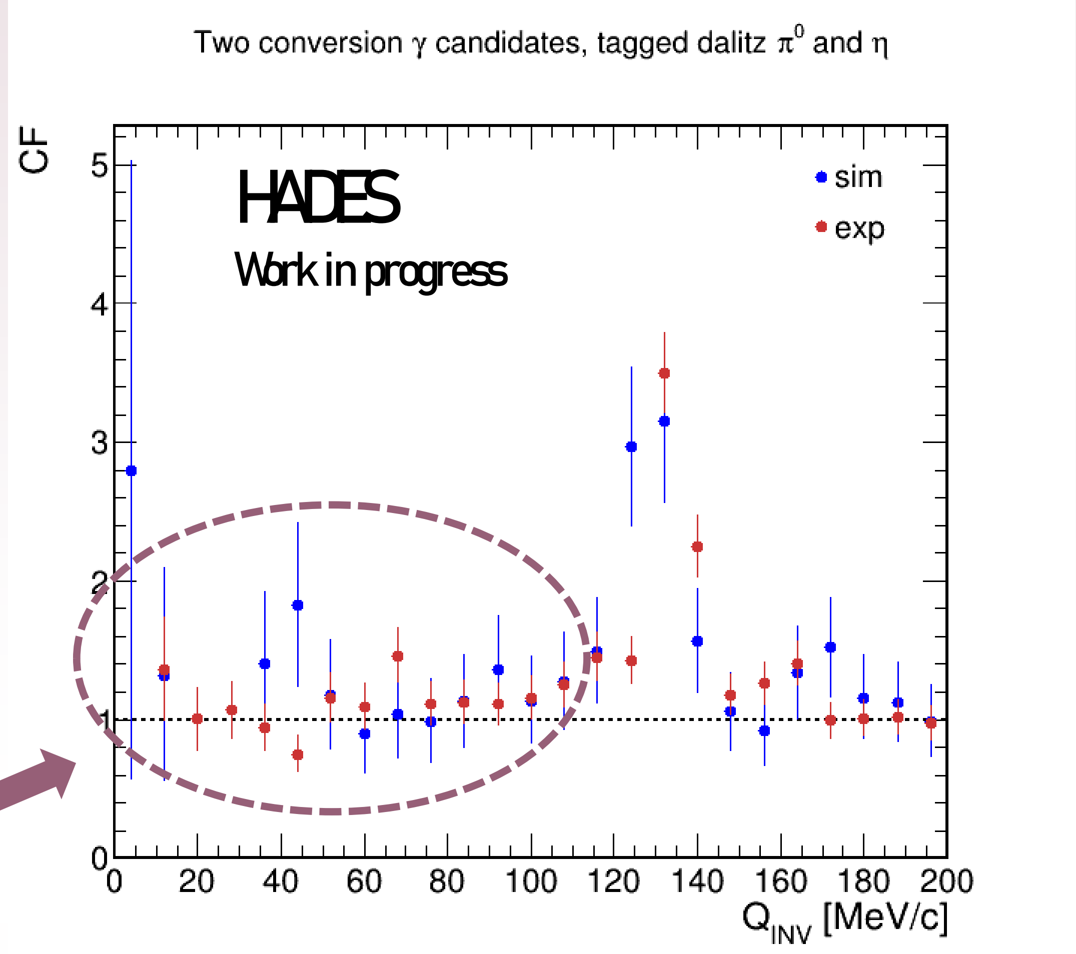
Obtained correlation functions

Centrality: 0-40%   Only statistical uncertainties shown

simulation = only photons from π^0 and η included, no quantum statistics modeled → no correlation expected

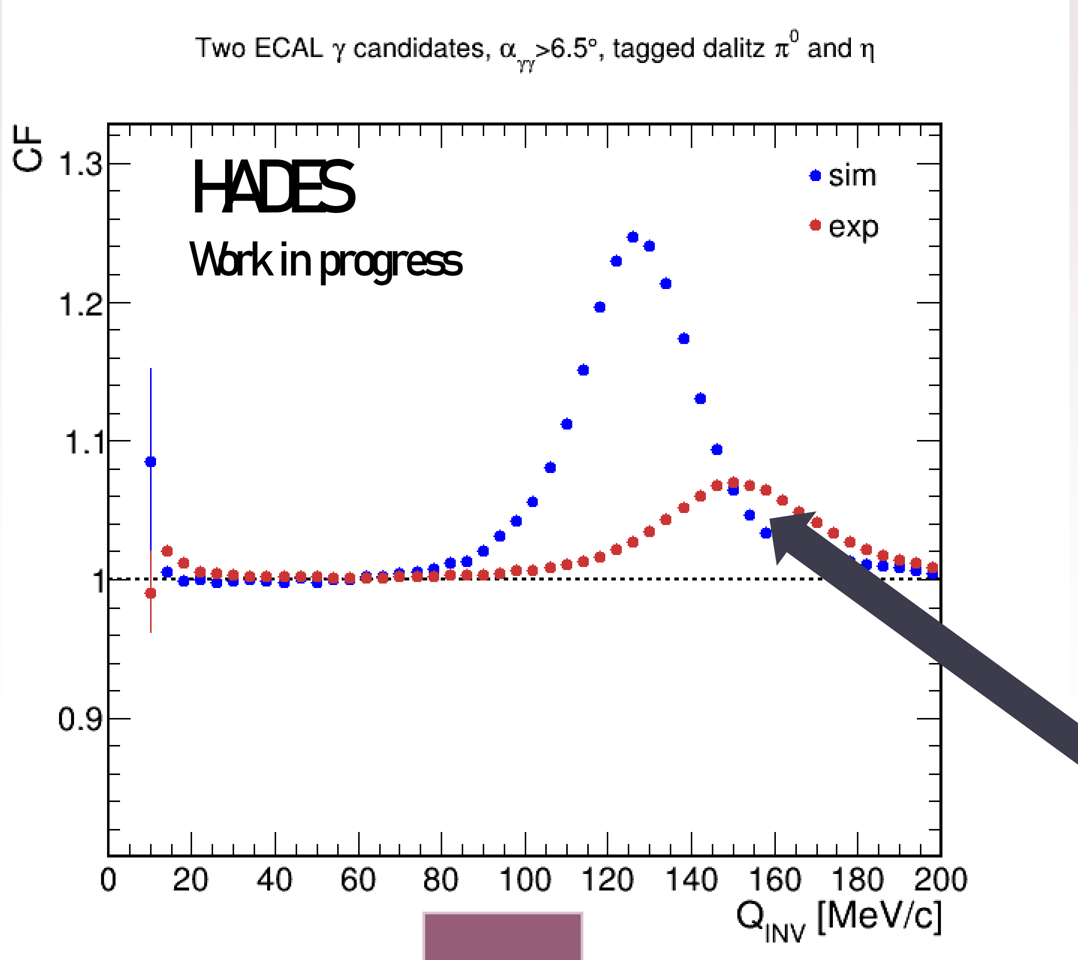
experiment = all kind of detected photons, quantum statistics involved → $\pi^0/\ \eta$ and direct γ correlation expected

2γ from PCM

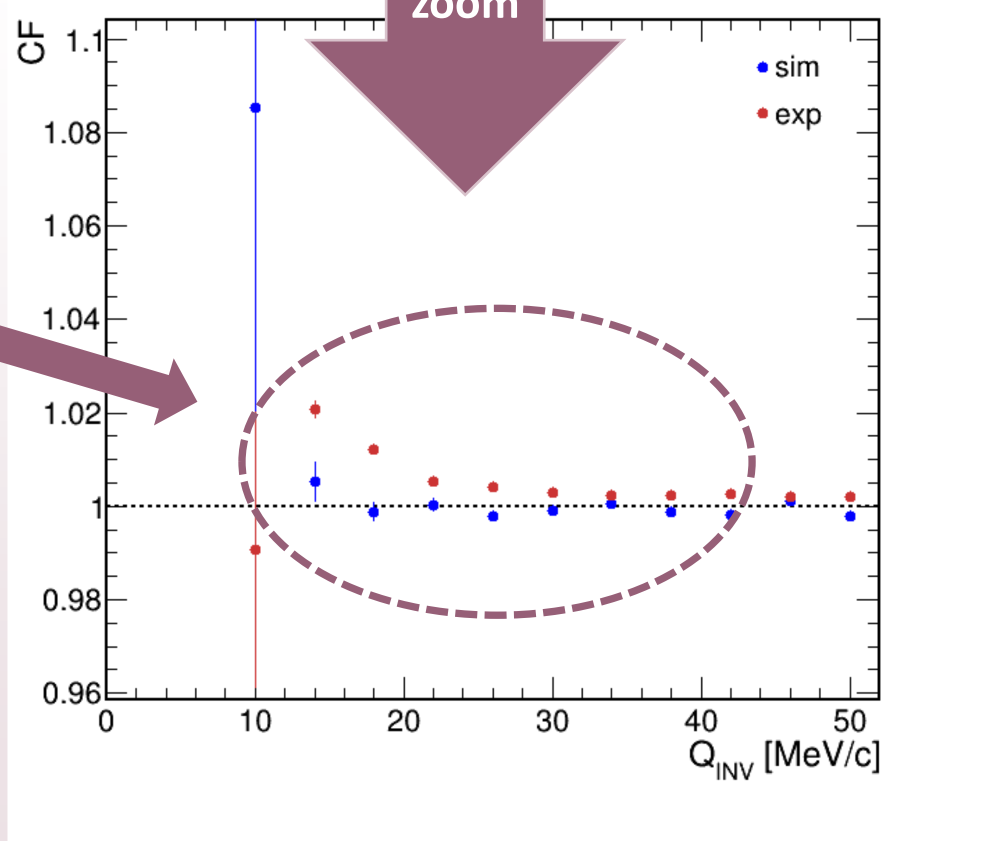


No visible correlation (not enough statistics)

2γ from ECAL

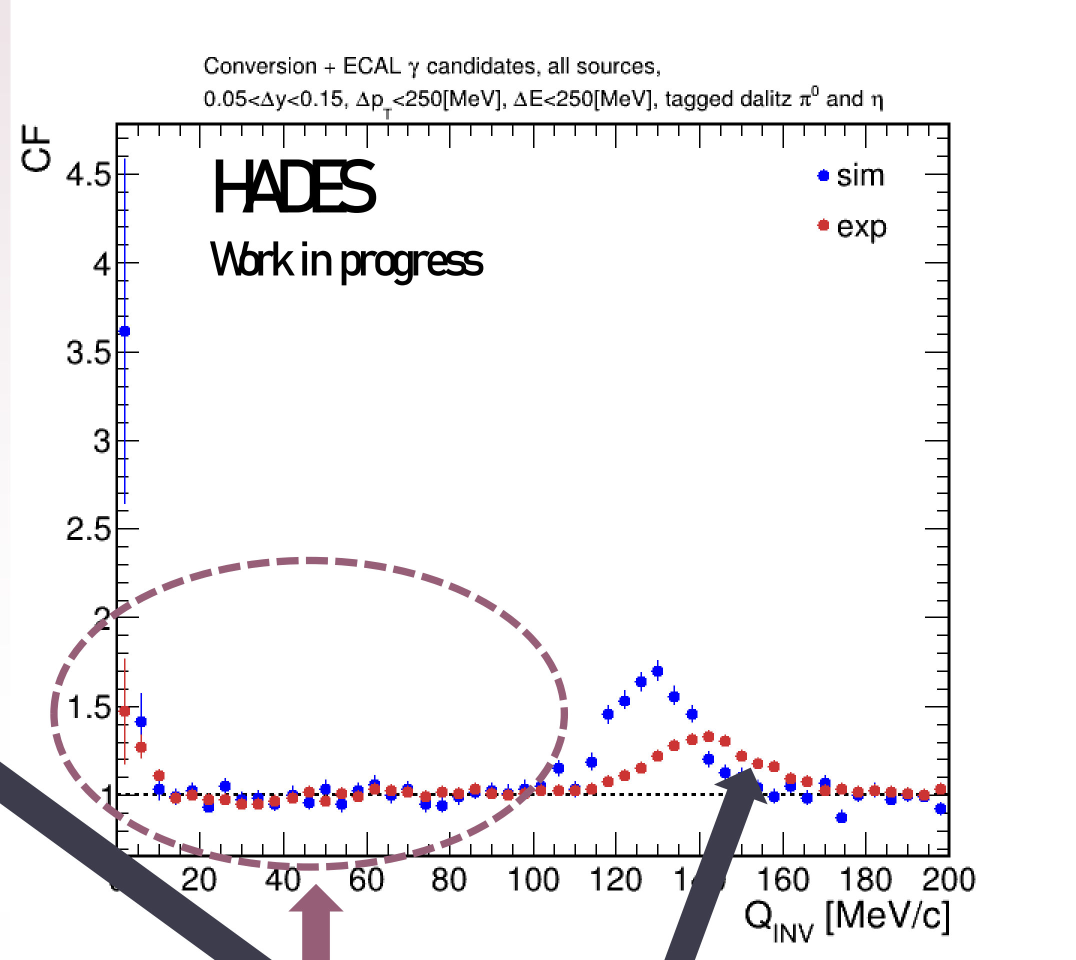


zoom



Visible slight and wide structure for Q_{inv}<50 MeV → **needs further investigation**

PCM γ + ECAL γ



π^0 peak shifted in real data, ECAL calibration is in progress.

Only $\pi^0/\ \eta$-like correlation visible (below 15 MeV/c), no enhancement in „direct region" (15-50 MeV/c) observed.

Further plans:

- Use full statistics available for real data.
- Investigate in more detail 2 ECAL photon correlation.
- Fit theoretical function (Gaussian parametrization).
- Try increasing signal/noise ratio to enhance correlation effect.
- Estimate statistical uncertainties.

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References:

[1] R. Hanbury Brown & R.Q. Twiss (1954) LXXIV. A new type of interferometer for use in radio astronomy, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 45:366, 663-682

[2] Interference of identical particles in processes with excited nuclei and resonance states, V.G. Grishin, G.I. Kopylov, M.I. Podgoretsky, published in: Yad.Fiz. 13 (1971), 1116-1125