Dilepton reconstruction in Au+Au collisions at 1.23A GeV with HADES

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FOR THE HADES COLLABORATION

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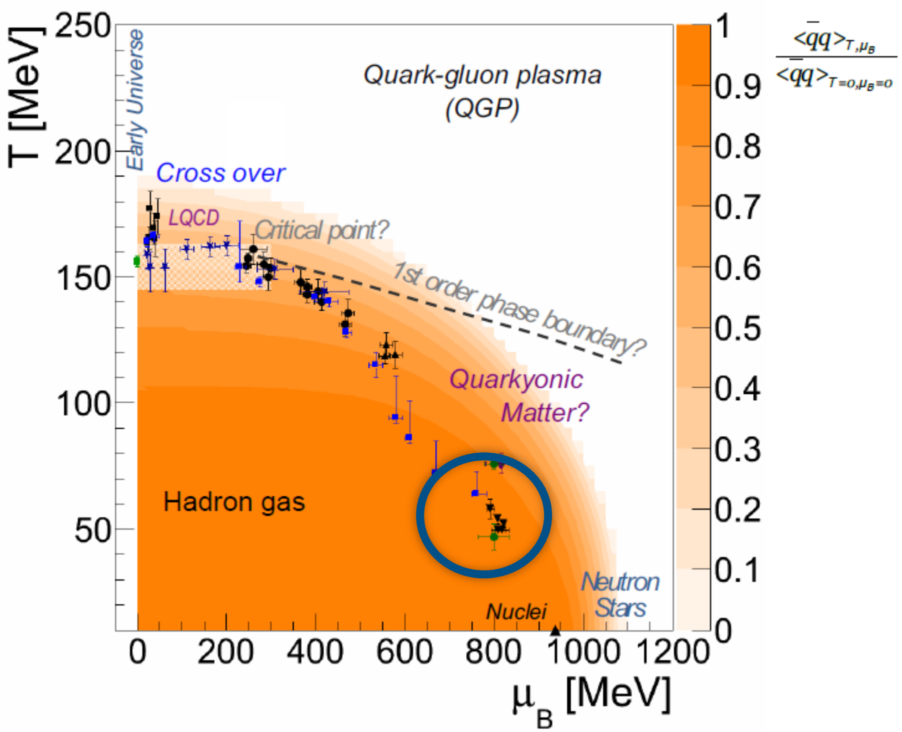
HADES

H-QM Helmholtz Research School Quark Matter Studies

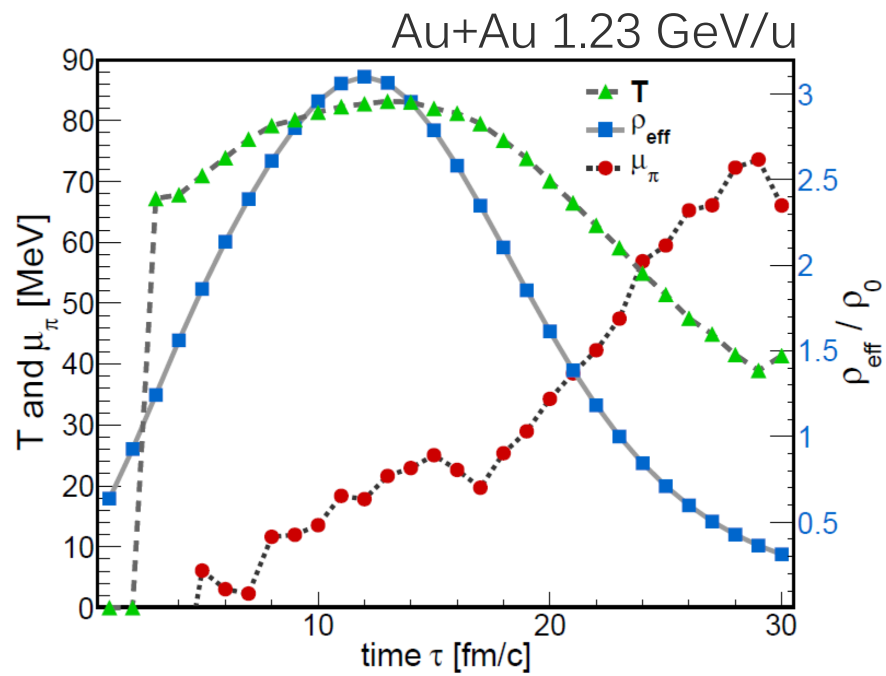
HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research

Introduction
HADES
Backtracking
e^+/e^- identification
Dilepton reconstruction

Motivation



Deconfined phases are accessible via heavy-ion collisions at relativistic energies.

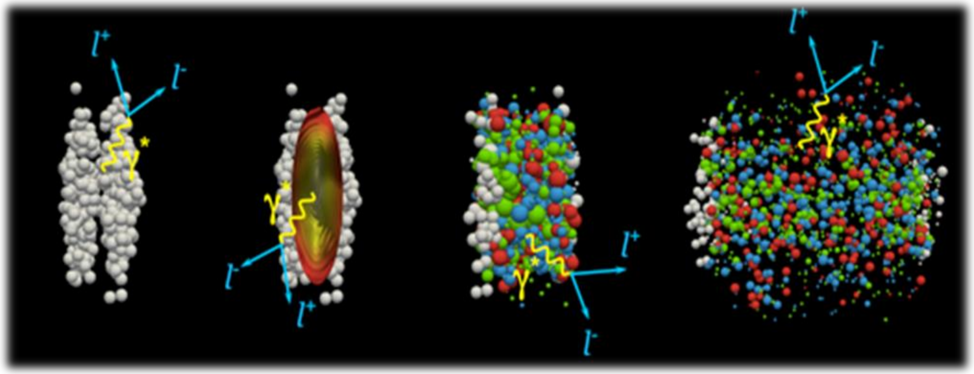


Investigation of **baryon dominated** and **long living strongly interacting** matter at T < 100 MeV and high densities.

LQCD: Z. Fodor et al., hep-lat/0402006
Condensate: B.J. Schaefer and J. Wambach, private communication
HADES data: M. Lorenz et al., Nucl. Phys. A (2014) QM14
A. Andronic et al., Nucl. Phys. A 837 (2010) 65
J. Cleymans et al. , Phys. Rev. C 60 (1999) 054908
J. Stachel, arXiv:1311.4662

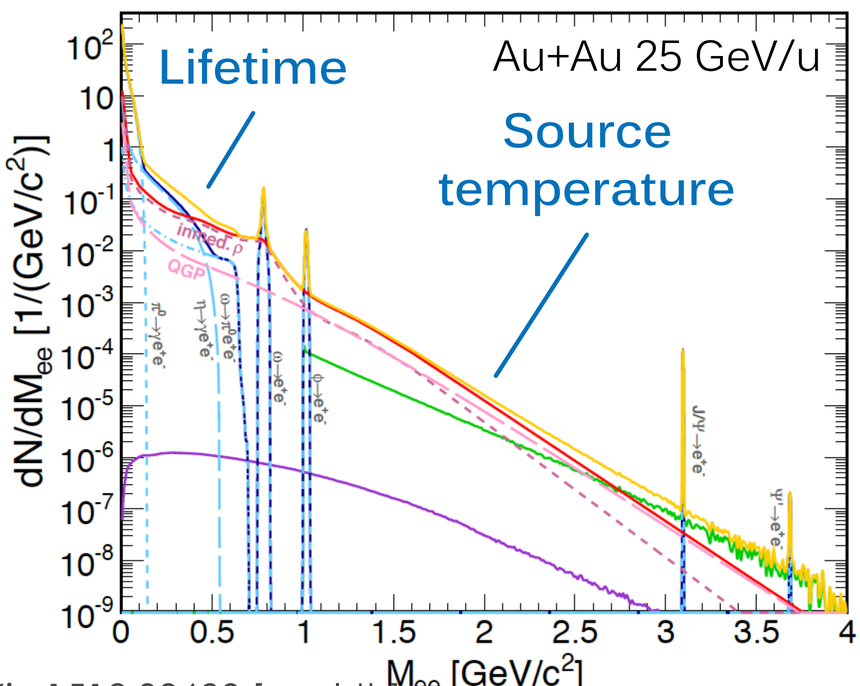
arXiv:1512.08688 [nucl-th]

Dilepton invariant mass spectrum



$\tau = 10^{-23}$ s

- Dilepton spectra represent the space-time integral of EM radiation
- Mass dependence allows separation of collision stages



arXiv:1512.08688 [nucl-th]

Drell-Yan: NN → l^+l^-X

Heavy-flavor: $c\bar{c}$ → l^+l^-

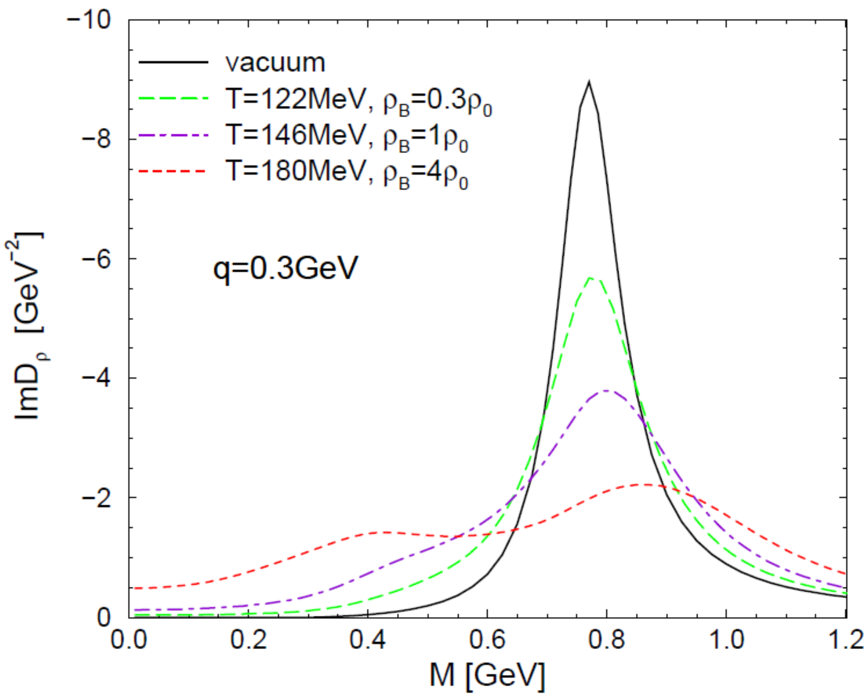
Medium radiation:

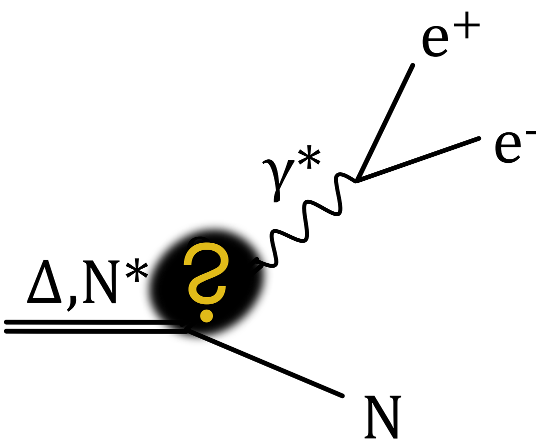
- QGP: $q\bar{q}$ → l^+l^-
- In-medium radiation ρ, ω → l^+l^-
- "4p annihilation": πa_1 → l^+l^-

Final state decays (hadron cocktail): π^0, η, ω, ϕ

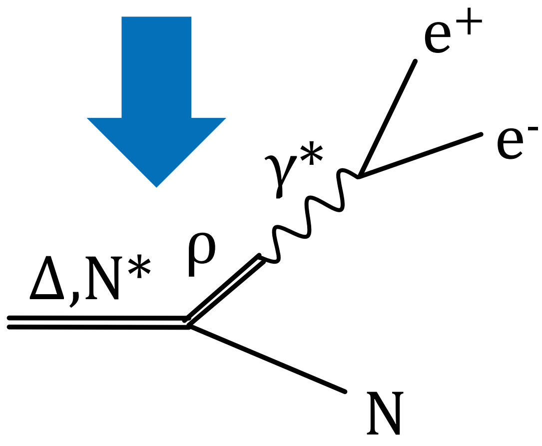
Medium modifications of hadrons

Modification of the ρ meson spectral function in hot and dense matter.





Vector meson dominance model

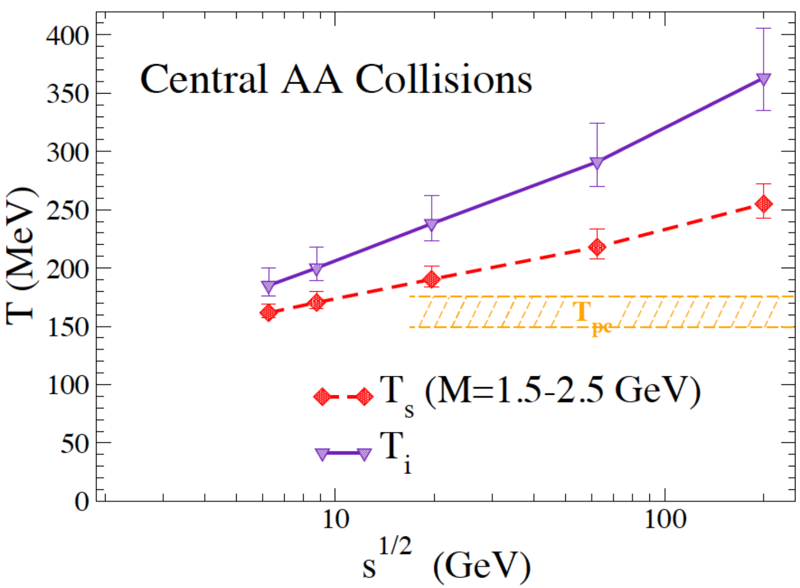


R.Rapp,J.Wambach,Adv.Nucl.Phys.25(2000)1

Measurements of excitation functions

Intermediate mass range

$1.1 < M_{e+e-} < 3.0$ GeV/c^2

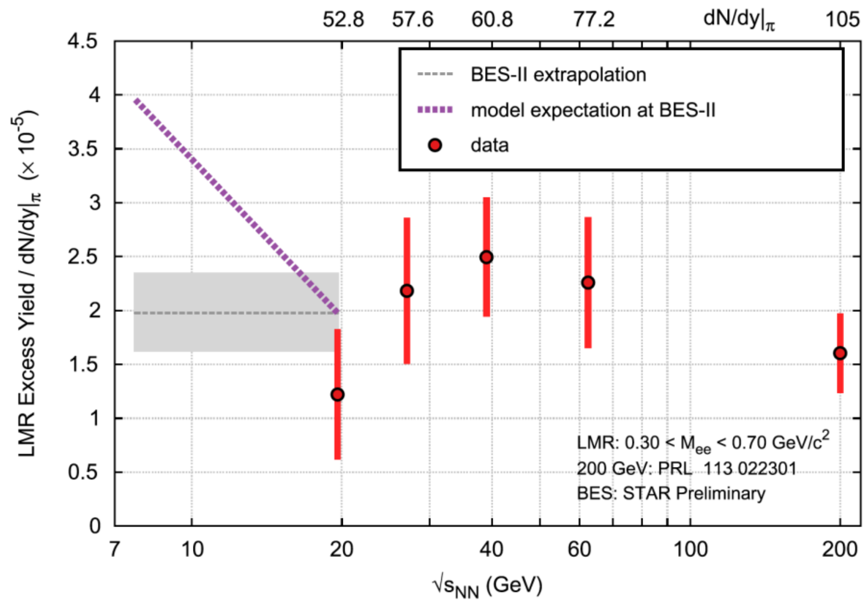


The average collision temperature T_S can be extracted by experiments

R. Rapp and H. Van Hees
Phys.Lett. B753 (2016) 586-590

Low mass range

$0 < M_{e+e-} < 1.1$ GeV/c^2



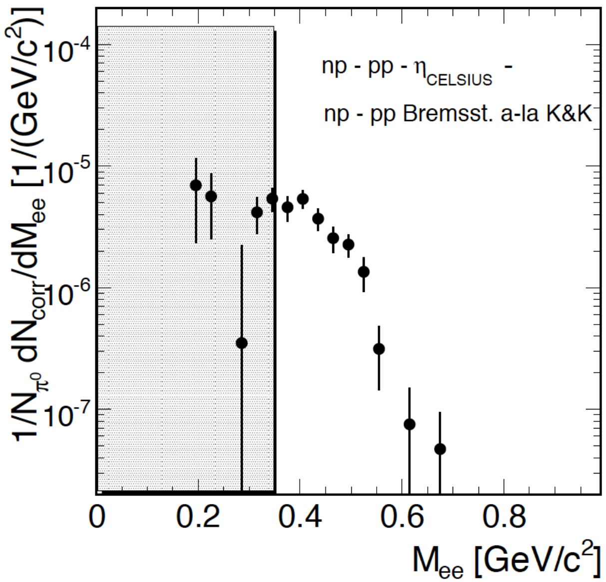
HADES measurement extends scan to lower energies:

$$\sqrt{s_{NN}} = 2.42\ GeV$$

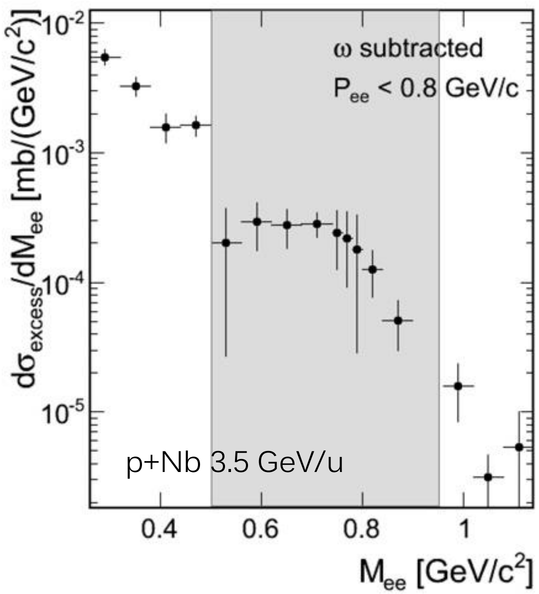
P. Huck et al. (STAR collaboration), NPA 931 (2014)

HADES measurements

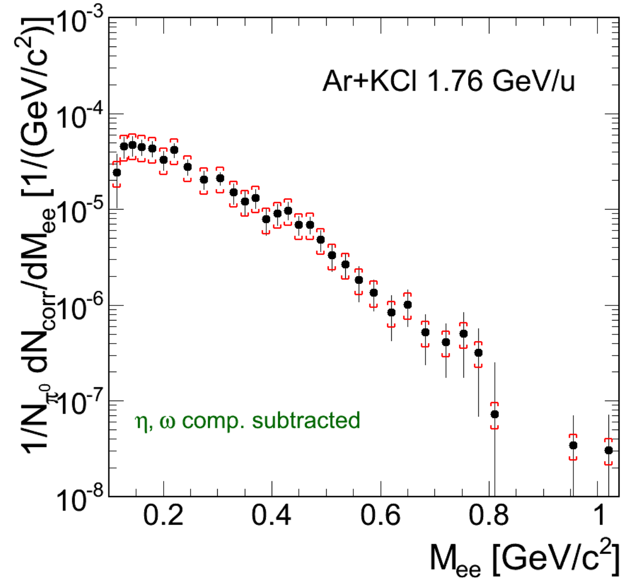
np – pp 1.25 GeV



pNb– pp 3.5 GeV



ArKCl – ½(np+pp) 1.76 GeV/u



- A strong broadening of in medium states is observed in elementary, p+A and medium sized A+A collisions.
- Excess yield scales with system size like $A_{part}^{1.4}$
- How does the excess evolve with system size? → **Au+Au collisions!**

HADES, PLB 715 (2012) 304–309

Introduction

HADES

Backtracking

e^+/e^- identification

Dilepton reconstruction

HADES experiment

Measurements at SIS18

Fixed target experiment

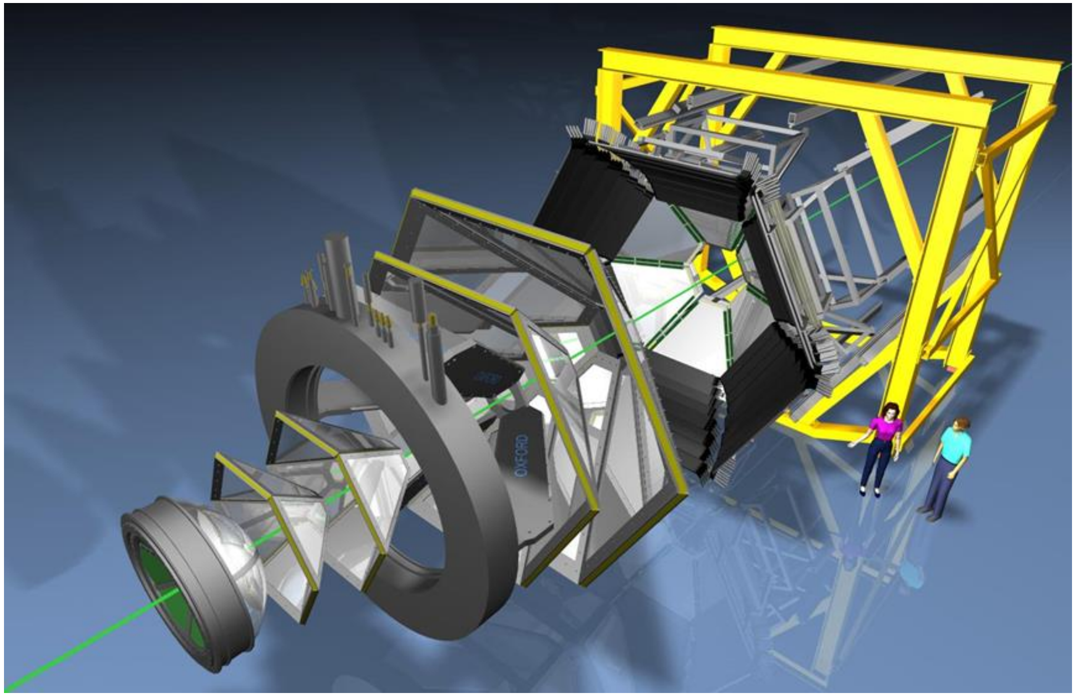
Fast detector

10-50 kHz trigger rate

Large acceptance

18° < θ < 85° (polar angle)

Full azimuthal angle



Tracking system

4 drift chamber planes + superconducting magnet

Time-of-flight detectors

RPC + TOF for precise hadron identification

HADES experiment

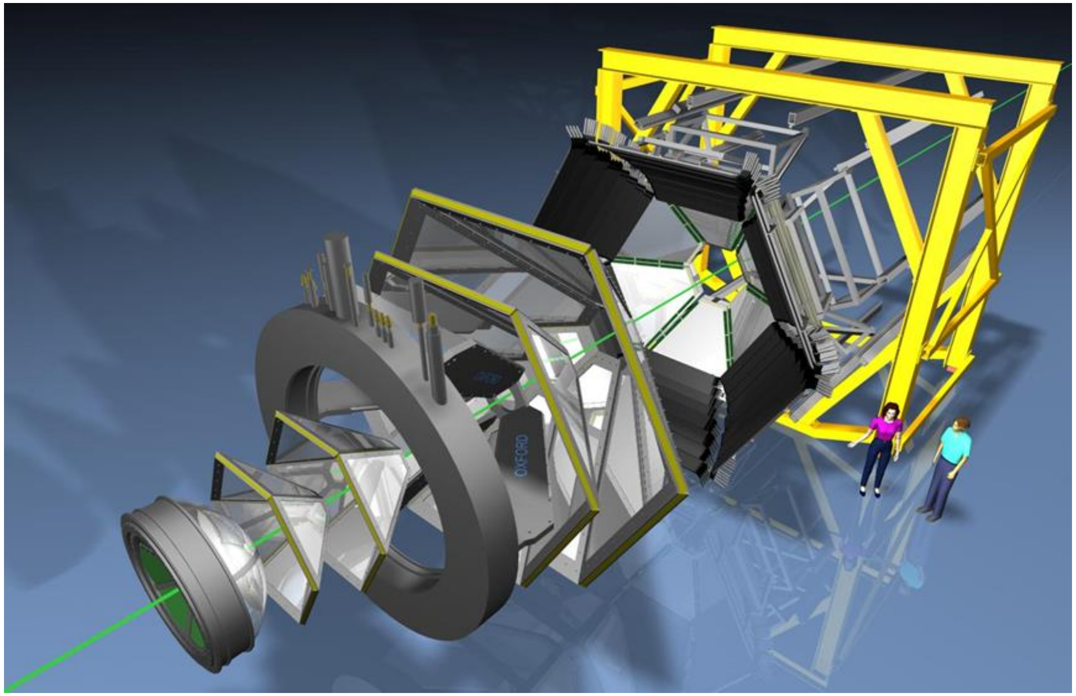
Excellent mass resolution

15 MeV/c^2 in the vector meson region

γ, γ^* are rare probes

Dilepton production is suppressed by factor α^2: Corresponds to **branching ratio $\cong 10^{-5}$**

At SIS18 energy range vector mesons are produced sub-threshold

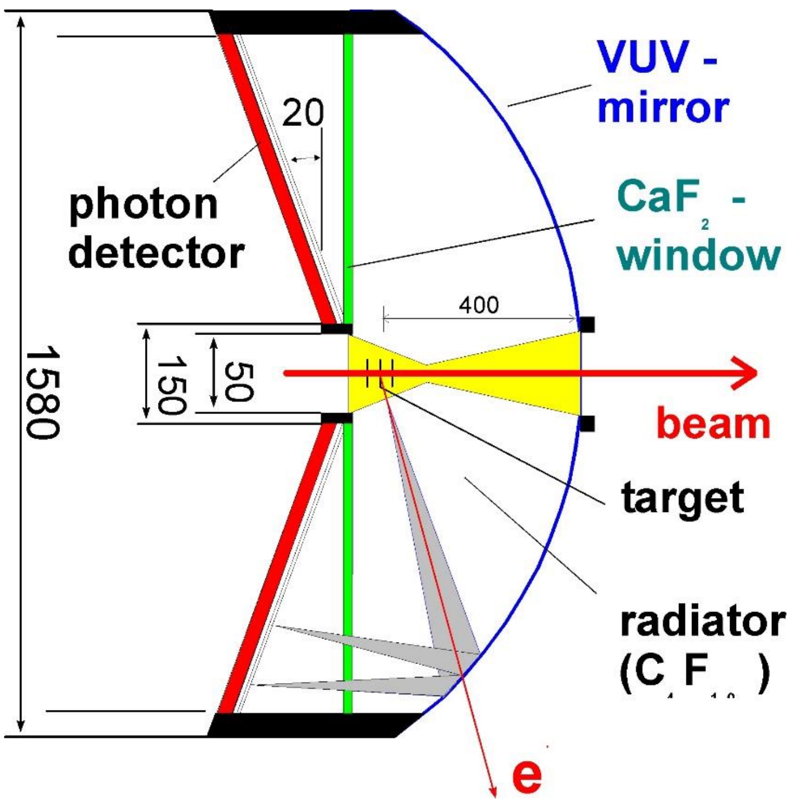


Ring Imaging Cherenkov detector (RICH) and PreShower:

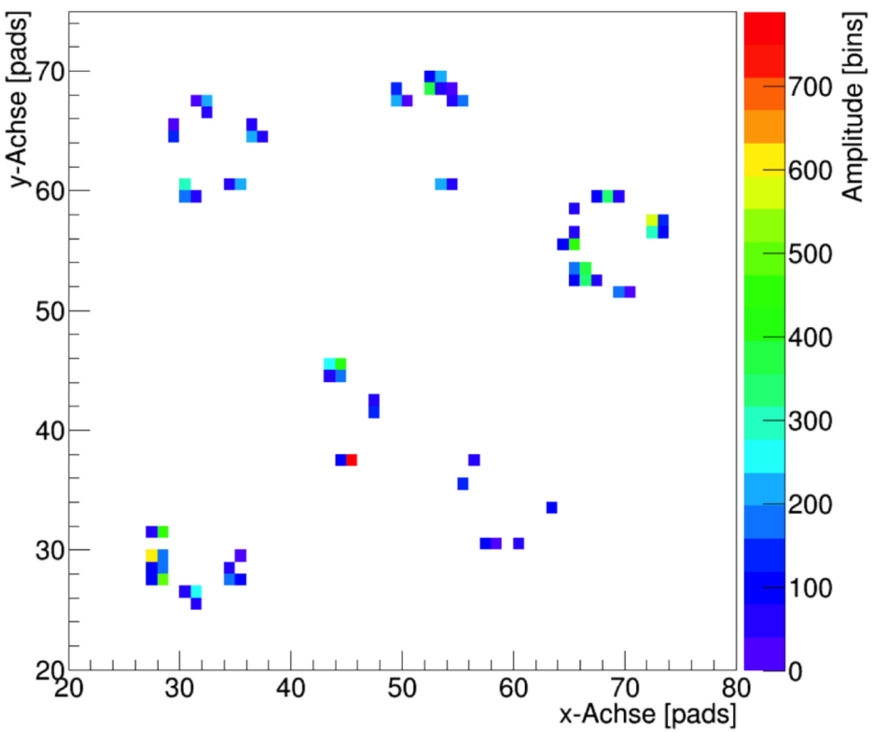
Lepton identification

RICH ring finder

Side view



Photon detector response



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Dilepton reconstruction

Concept

Track preselection

Selection of **good lepton candidates** based on particle velocity and specific energy loss

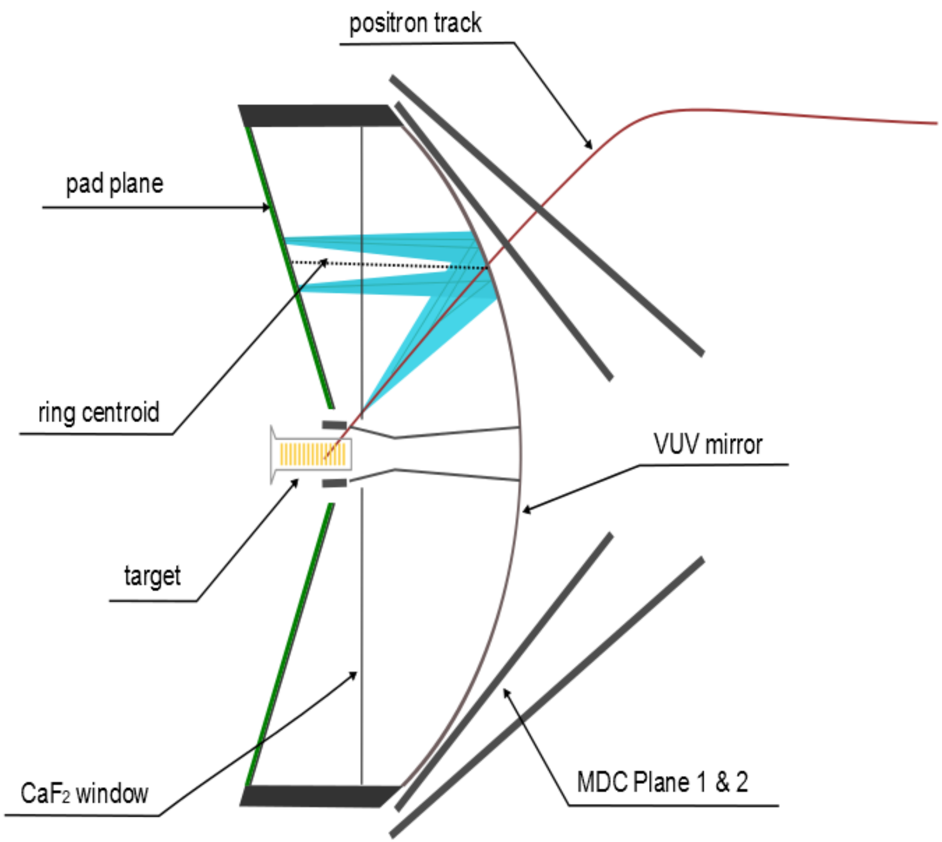
Determination of expected ring centers

Based on angular information provided by reconstructed particle tracks

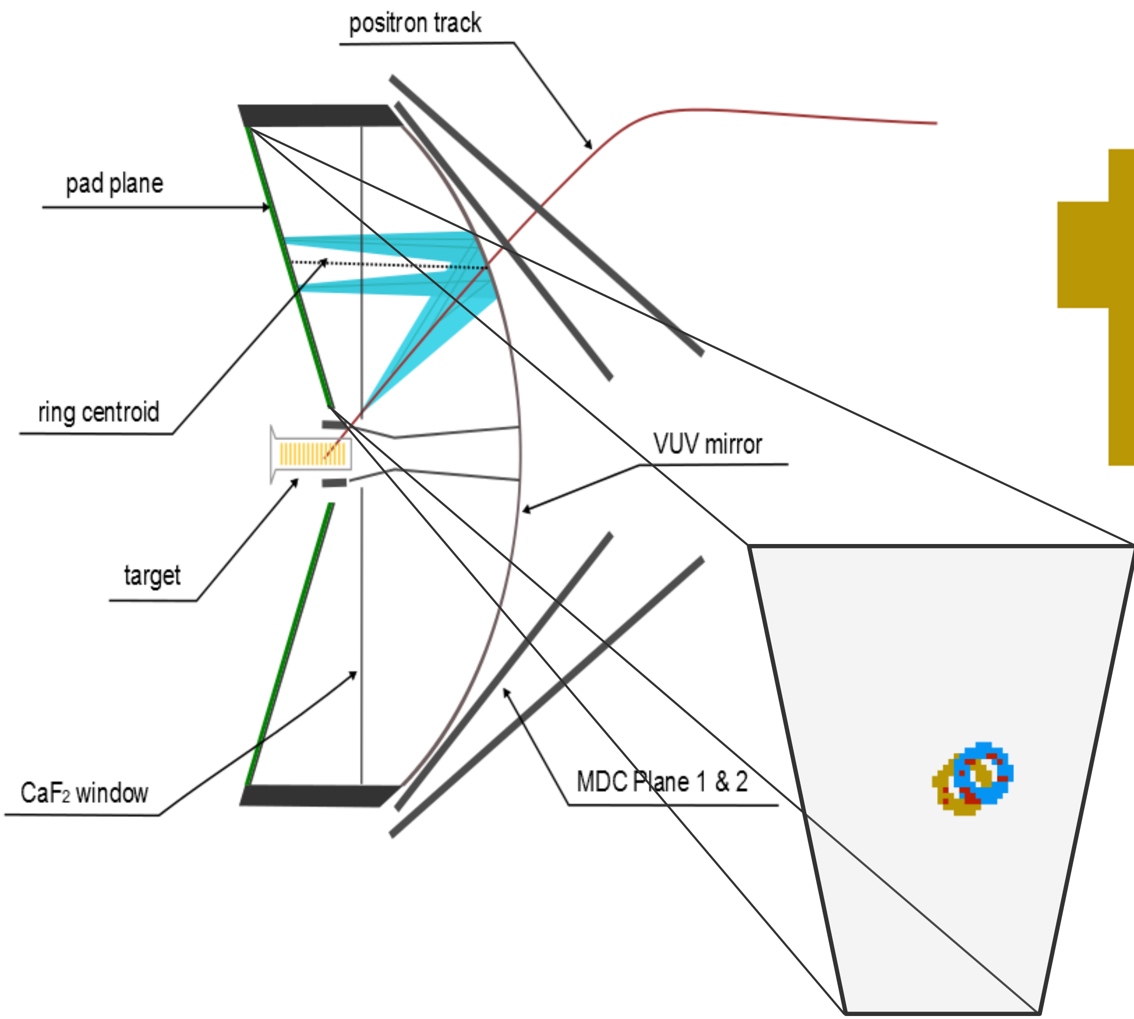
Motivation

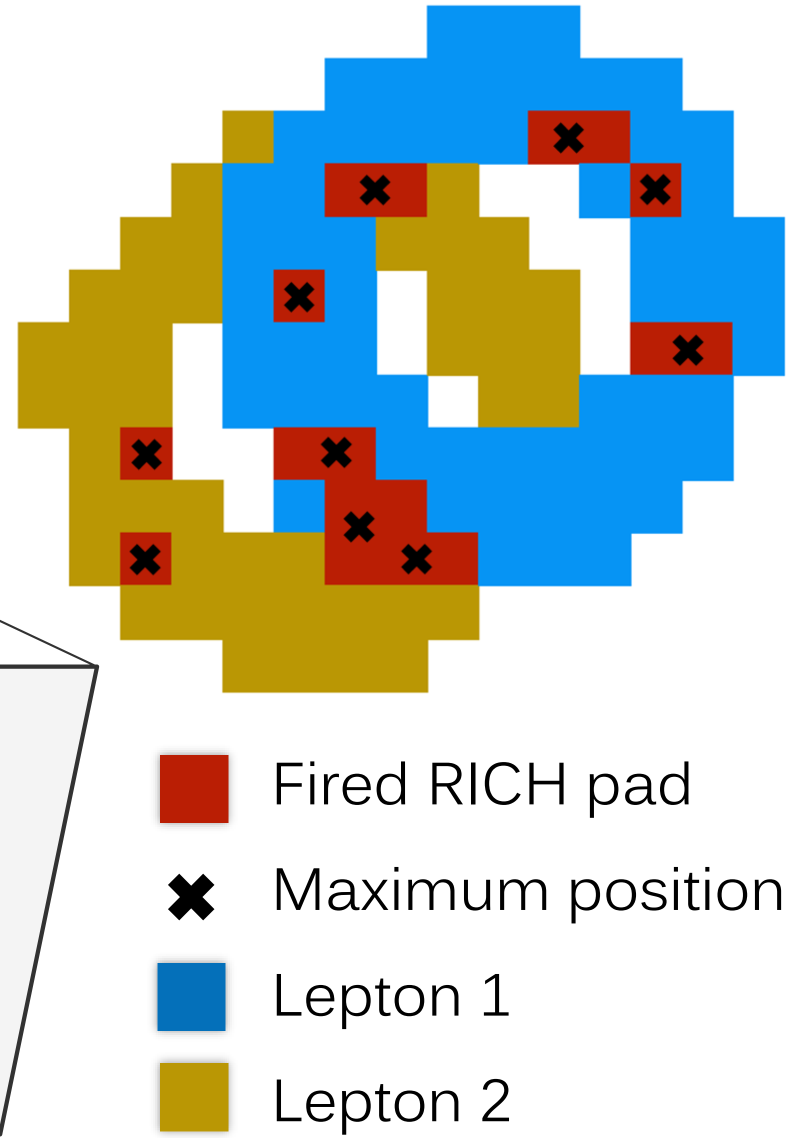
- Exclude multiple scattering in mirror from matching quality
- Allow overlapping rings
- Identify true close pairs

Implementation



Ring identification





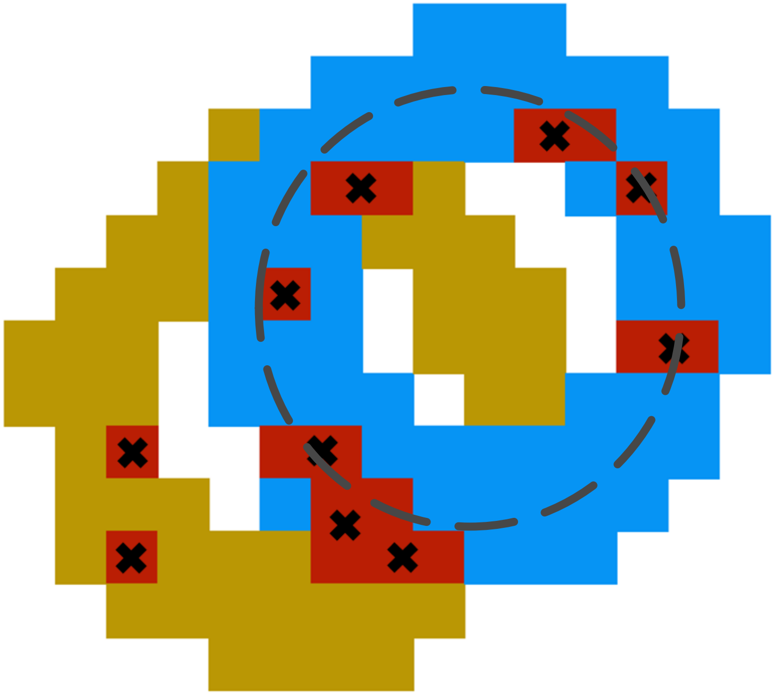
Backtracking observables

Single Leptons

- Maxima number = Photons
- Cluster charge and pads
- Maximum position based ring quality

Close Pairs

- Maxima shared with overlapping ring



Fired RICH pad
Maximum position
Lepton 1
Lepton 2

Introduction

HADES

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e^+/e^- identification

Dilepton reconstruction

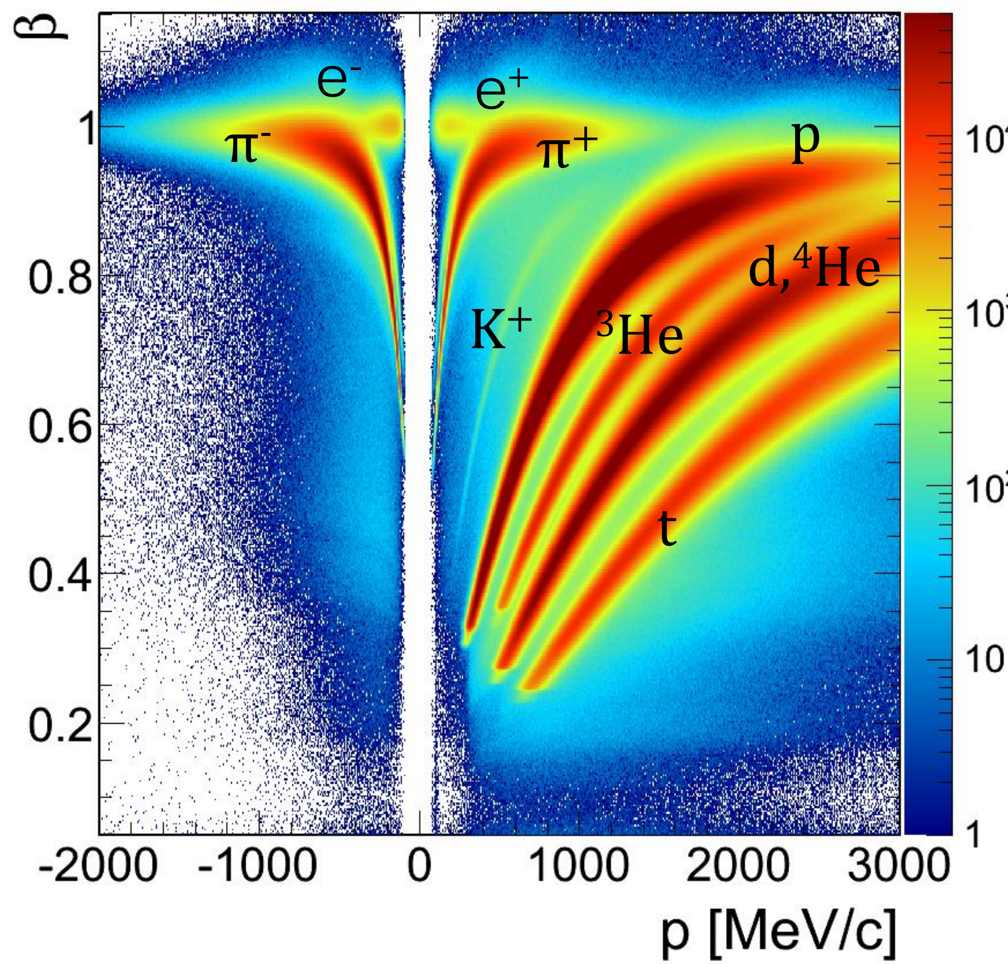
e^+/e^- identification

Data sample

- 47% most central Au+Au collisions recorded
- 5.85 x 10^9 events

Lepton identification

- **RICH ring / Backtracking**
- Particle velocity
- Specific energy loss
- Electromagnetic shower
- Track quality



Particle identification via a neural network

I. Training

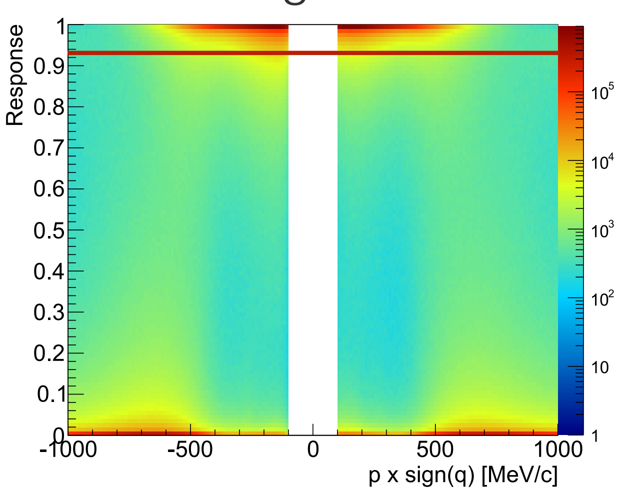
- Input of measured observables
- Fully based on simulation

II. Evaluation of response value during analysis.

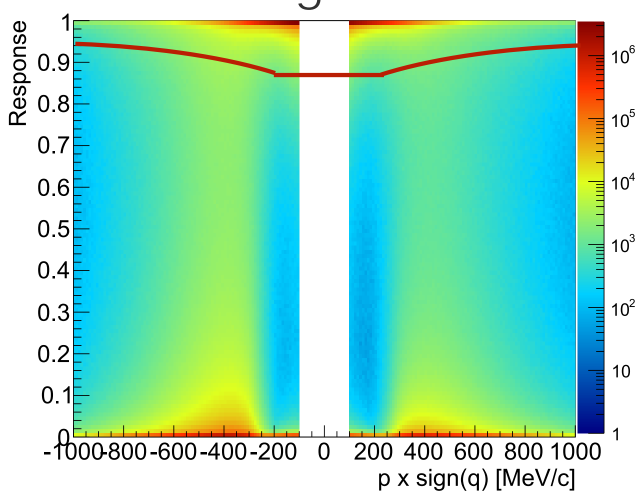
III. Response value threshold

- Tuned for high Sig/Bg and significance of

Polar angle: 18°-45°

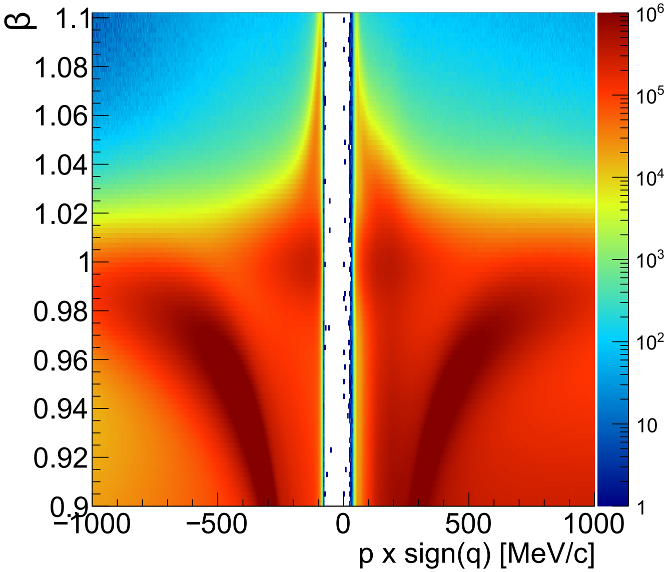


Polar angle:44°-85°

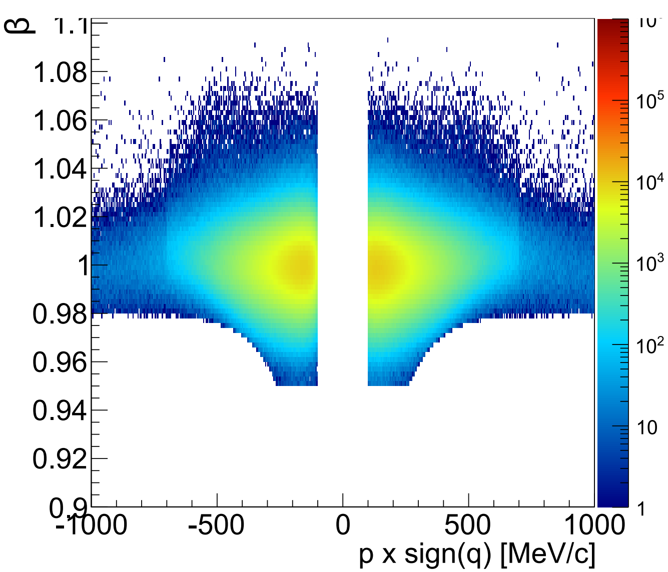


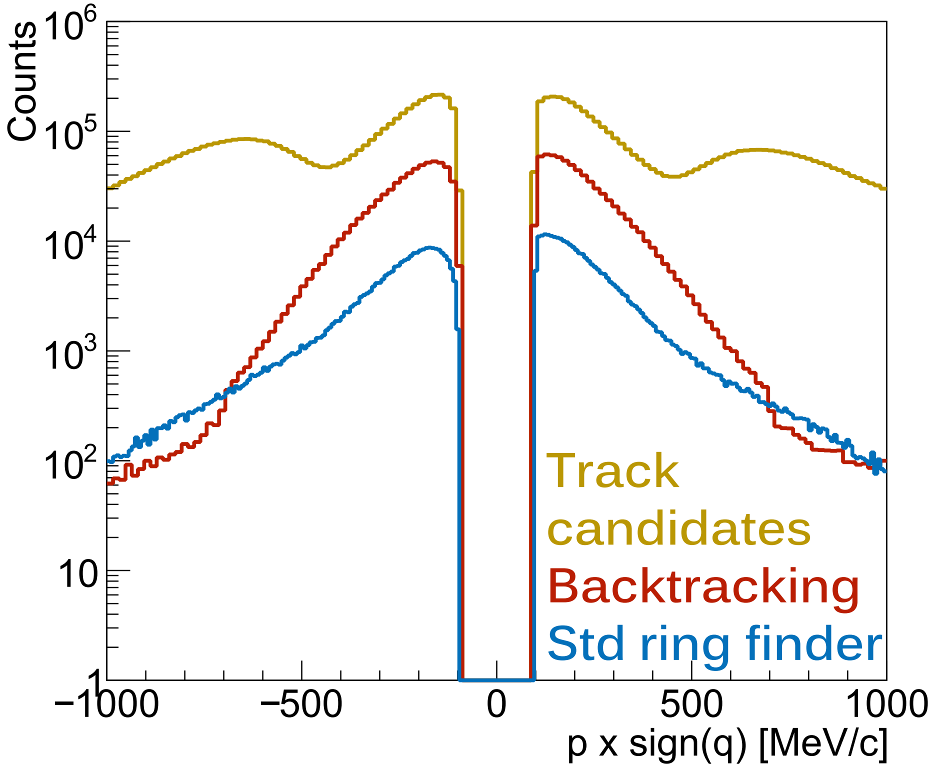
Lepton identification results

Track candidates



Selected leptons





Trade-off between purity and efficiency

Introduction

HADES

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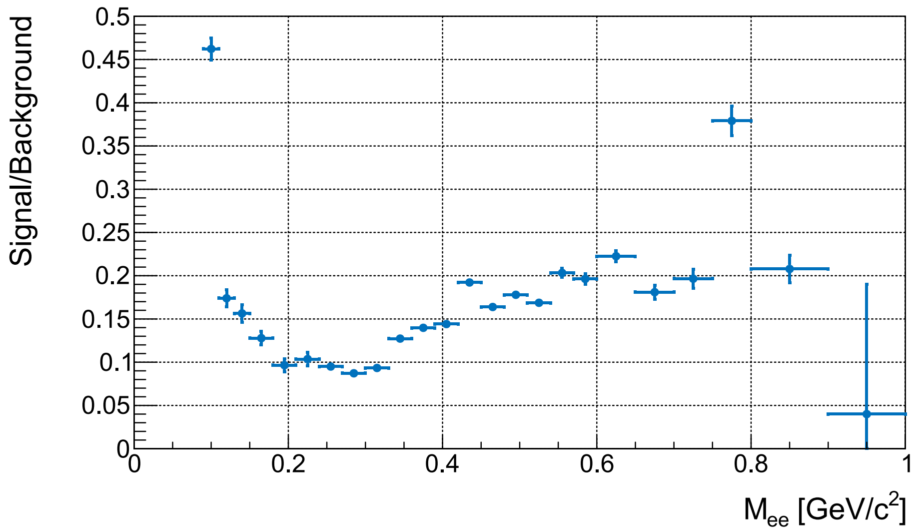
e^+/e^- identification

Dilepton reconstruction

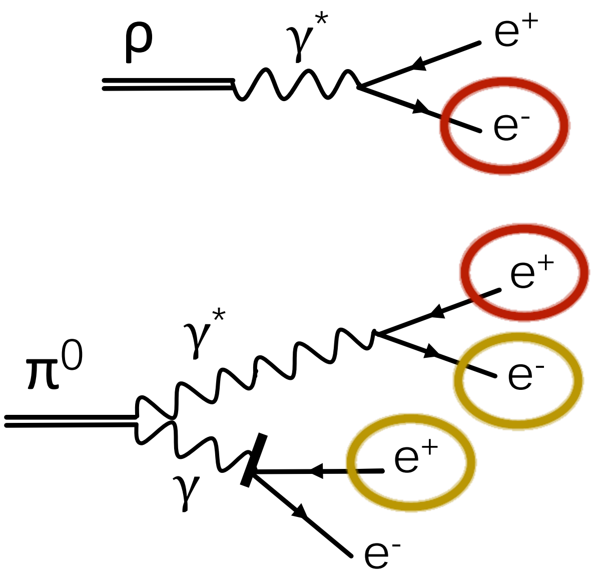
Lepton pairing

Signal estimation

1. Pair combination
   - Combination of all pairs
2. Background estimation
   - Two background types
3. Background subtraction
   - Precise background knowledge



Background types



Correlated background

Uncorrelated background

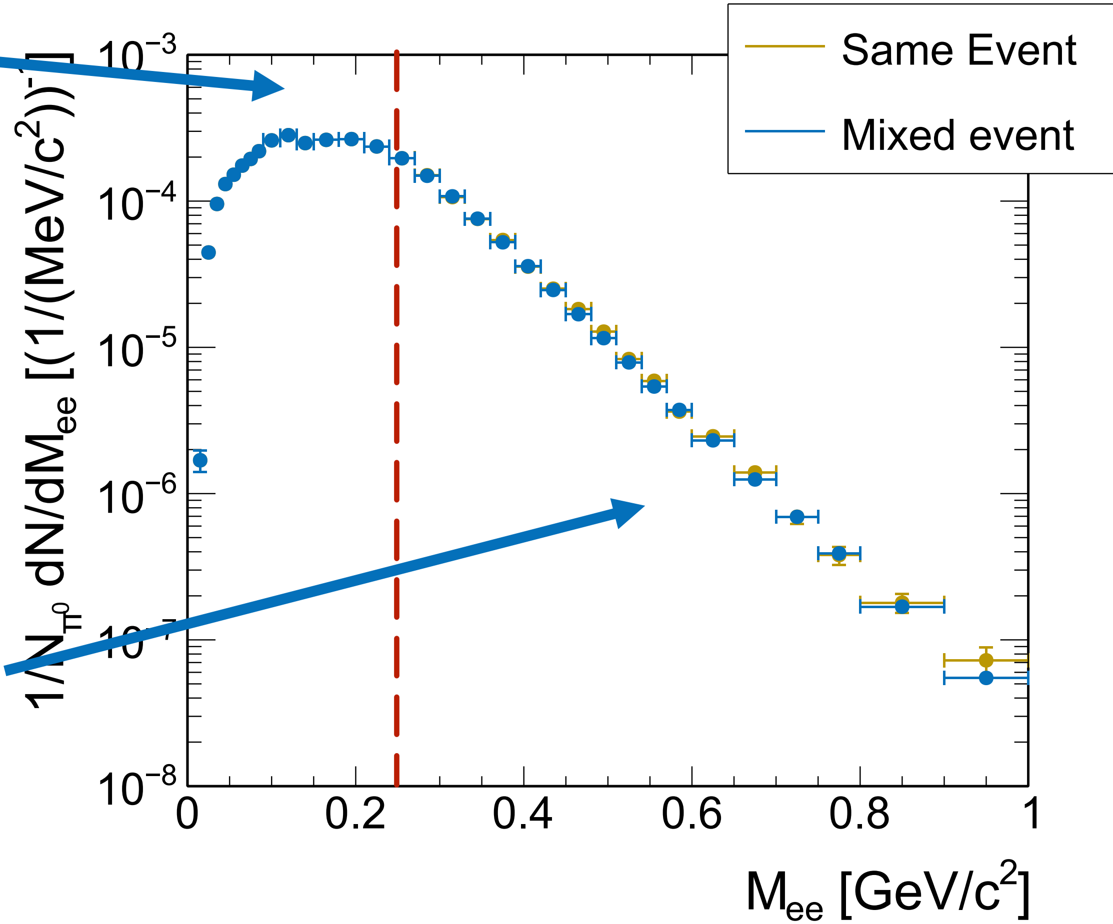
Background estimation

Same event like-sign

- Geometrical mean: $2\sqrt{N_{++}N_{--}}$
- Consideration of correlated background
- Normalization included

Mixed event unlike-sign

- Combinations of leptons from different events
- High statistics



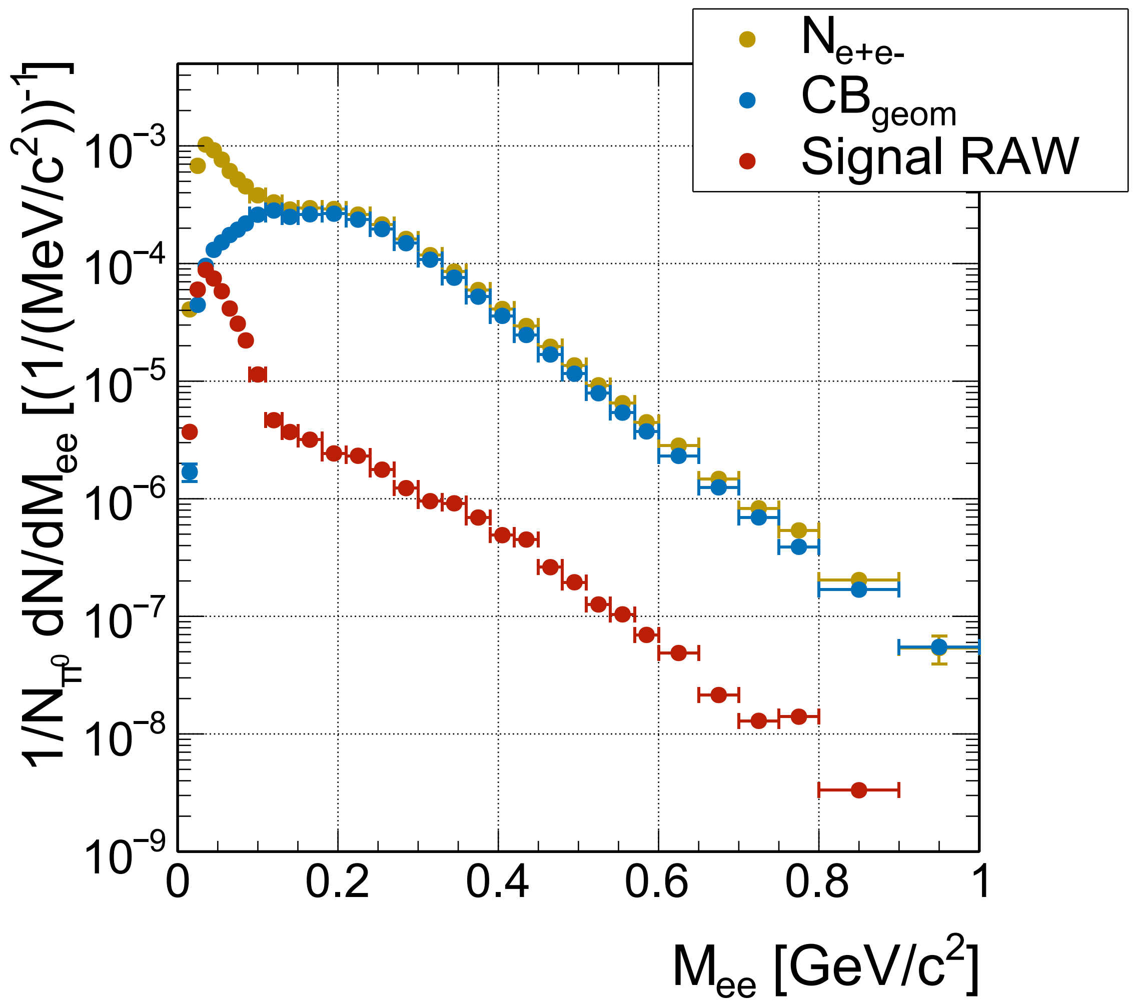
Invariant mass spectra RAW

Signal = N_{e+e-} - CB

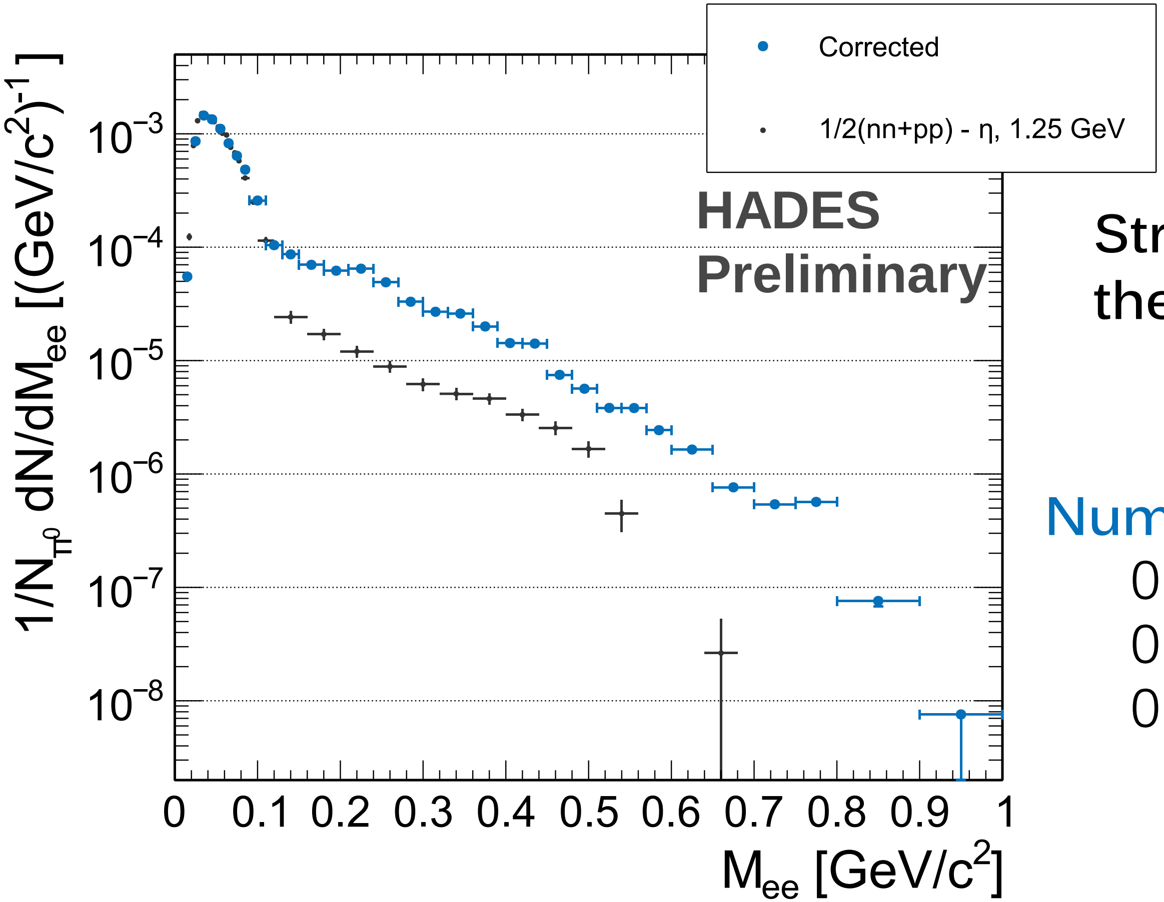
BG Rejection cuts:

- P > 0.1 GeV/c
- $\alpha_{e+e-} > 9°$

Normalized to the number of produced π^0



Corrected spectrum



Strong enhancement above the π^0 mass region

Number of reconstructed pairs

0.00 - 0.15 GeV/c^2: **$1.53 \cdot 10^7$**

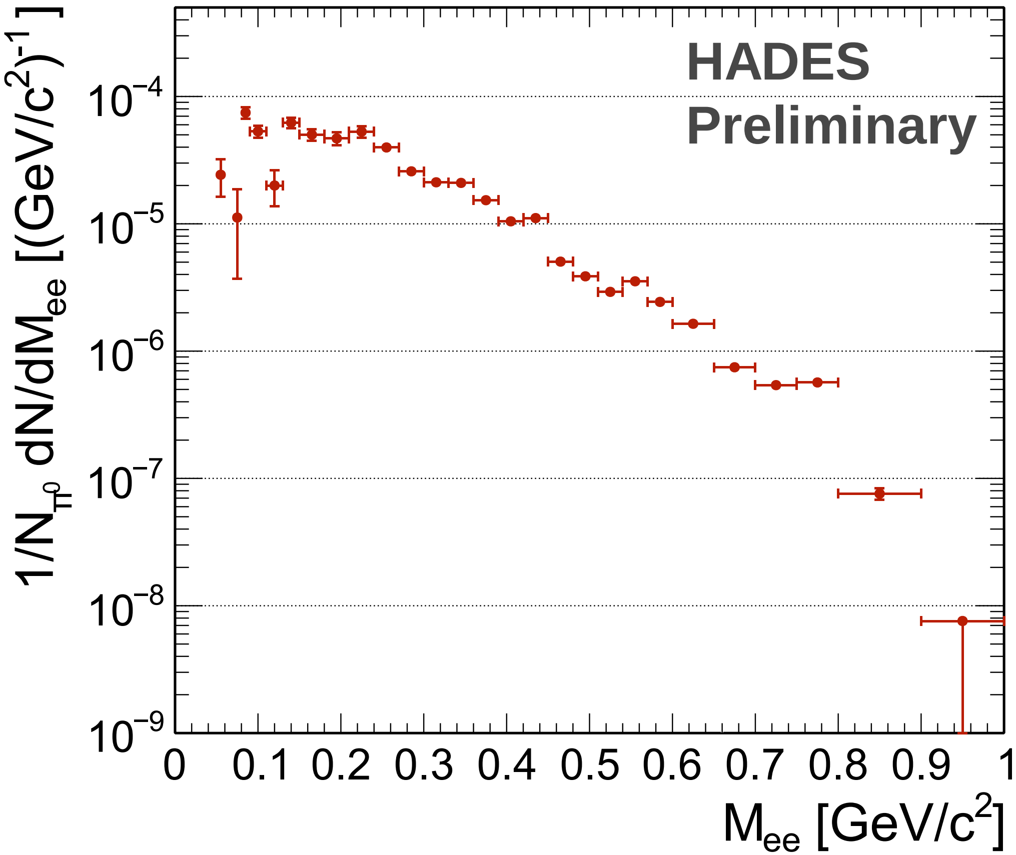
0.15 - 0.55 GeV/c^2: **$6.04 \cdot 10^5$**

0.55 - 1.00 GeV/c^2: **$1.23 \cdot 10^4$**

- Only statistical errors included

Excess yield

AuAu – ½(np+pp) 1.23 GeV/u



Excess yield

- Spectra corrected for efficiency NOT for acceptance
- Almost exponential spectrum up to 1 GeV/c^2

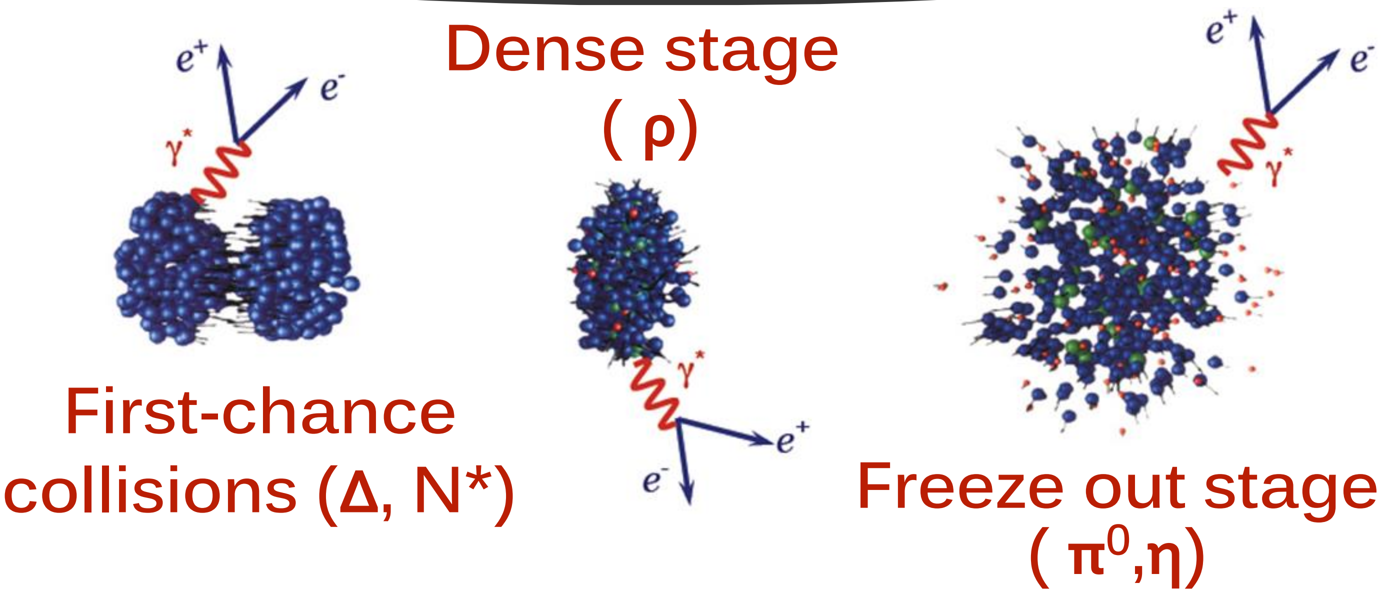
Conclusion & Outlook

- High efficient e^+/e^- reconstruction with backtracking
- Dielectron spectrum reconstructed up to 1 GeV/c^2
- Further measurements at SIS18 and at higher energies with SIS100

The HADES collaboration

Backup

EM probes in heavy ion collisions



γ, γ* do not interact strongly

Can be used to extract primary information of the hot and dense phase

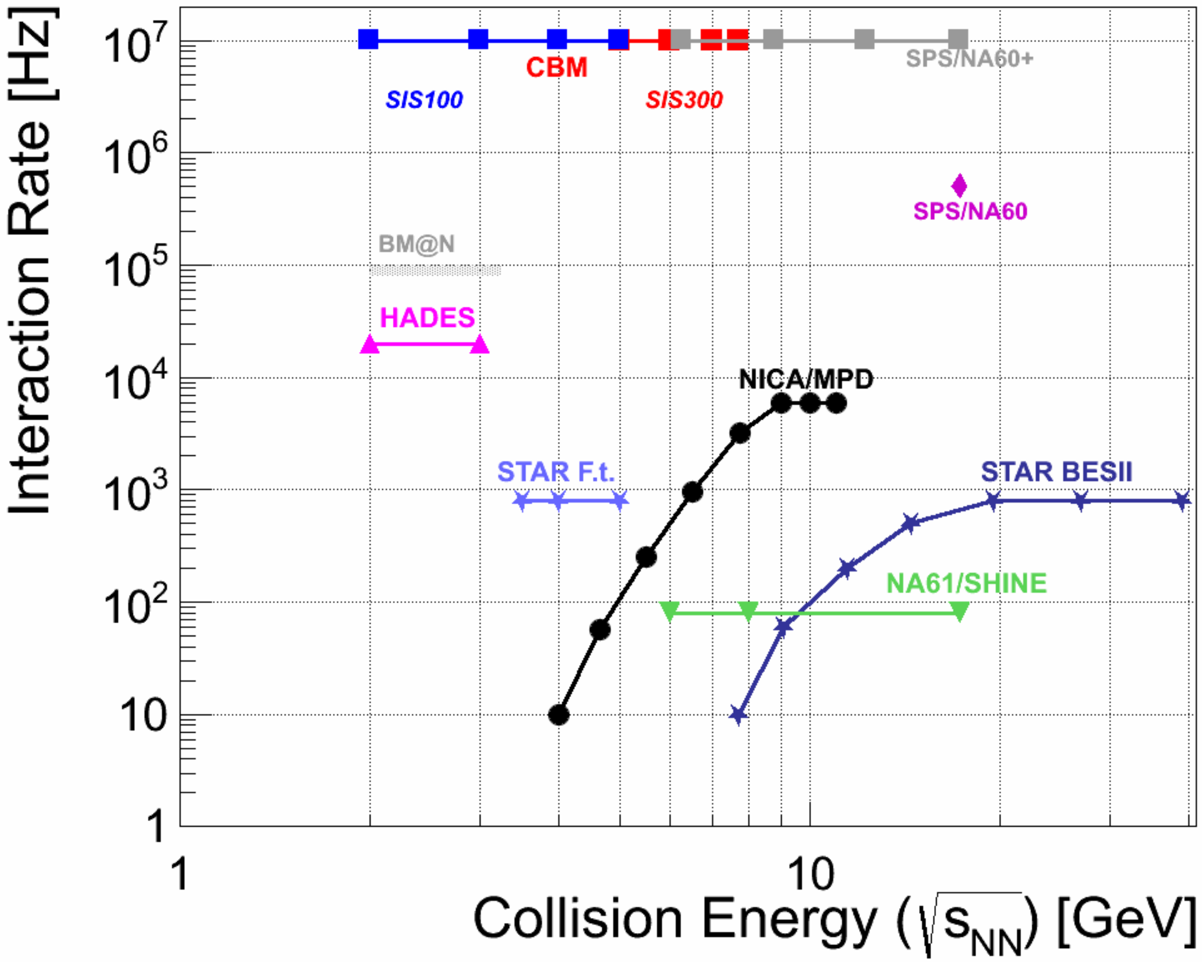
γ, γ* are produced in all collision stages

Contributions from all stages have to be identified precisely

γ, γ* probe EM structure of strongly interacting matter

Invariant mass monitors directly spectral function

Overvie experiments

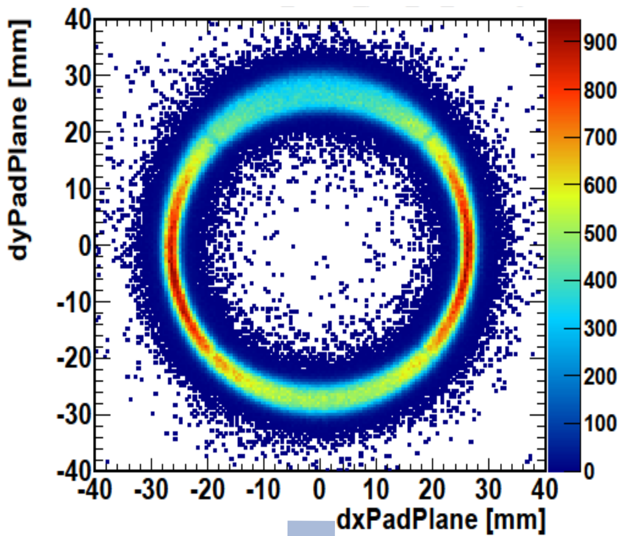


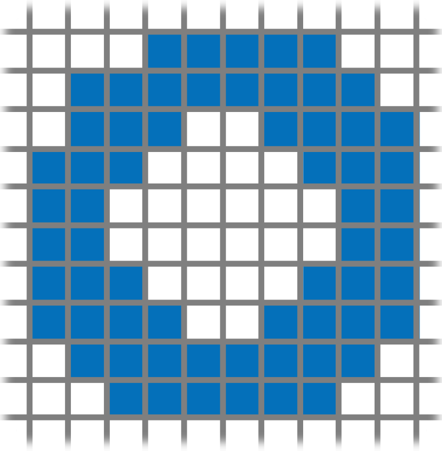
Implementation

Transformation from track angles to pad plane coordinates

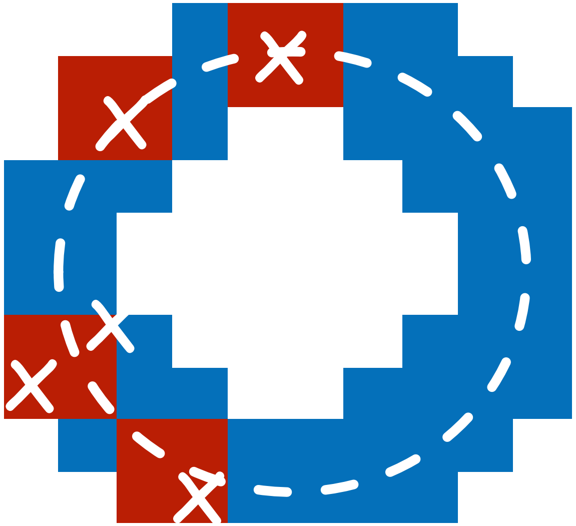
Position depended parameterization of rings

Information extraction out of measured signals





Ring quality



- 2D Gaussian function
- Single photon cluster fit to determine σ_x, σ_y
- x,y position has to be inside maximum pad

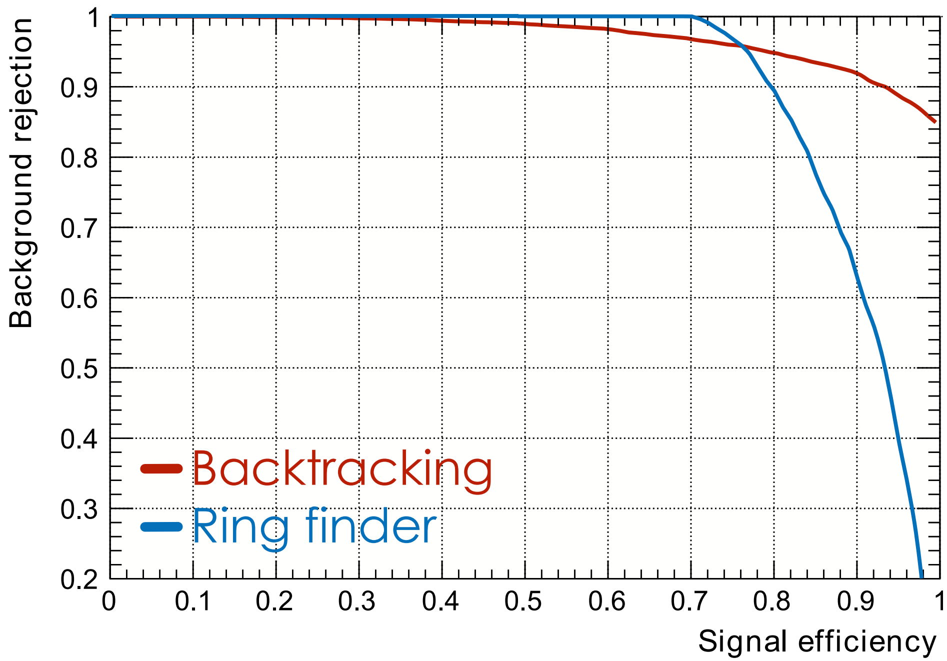
$$\chi^2_{Bt} = \frac{\sqrt{\sum^n \left(\frac{\sqrt{\Delta x^2 + \Delta y^2}}{\sqrt{\sigma^2_{Geom} + \sigma^2_{Err}}} \right)^2}}{n}$$

$$d = \sqrt{\Delta x^2 + \Delta y^2} \qquad n = Number\ of\ maxima$$

$$\sigma_{Err} = \frac{1}{2} Pad \qquad \sigma_{Geom} = Photon\ distribution\ width$$

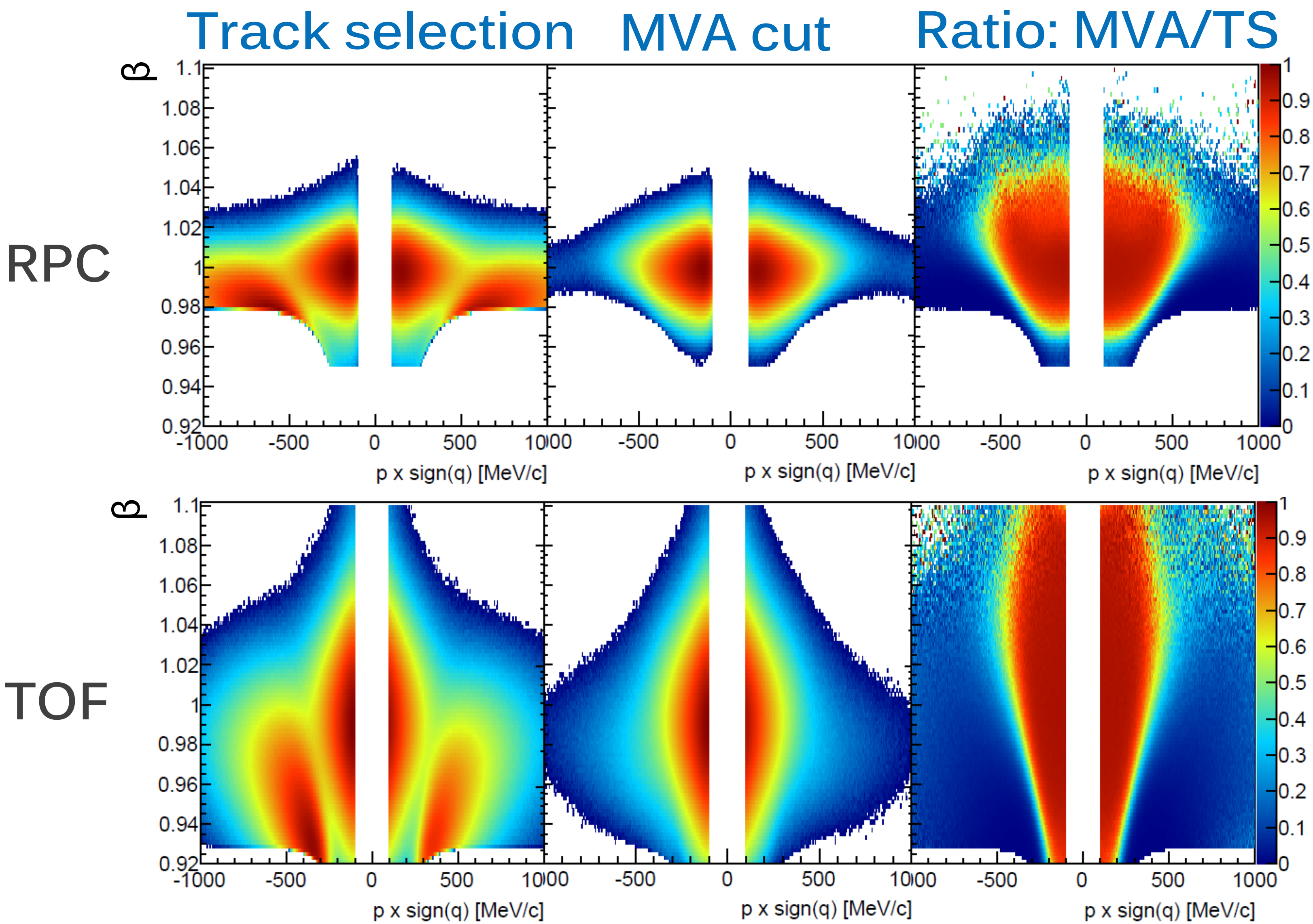
Single lepton identification

Ring finder vs backtracking



Trade-off between purity and efficiency

Results: Momentum vs β



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Mixed event unlike-sign

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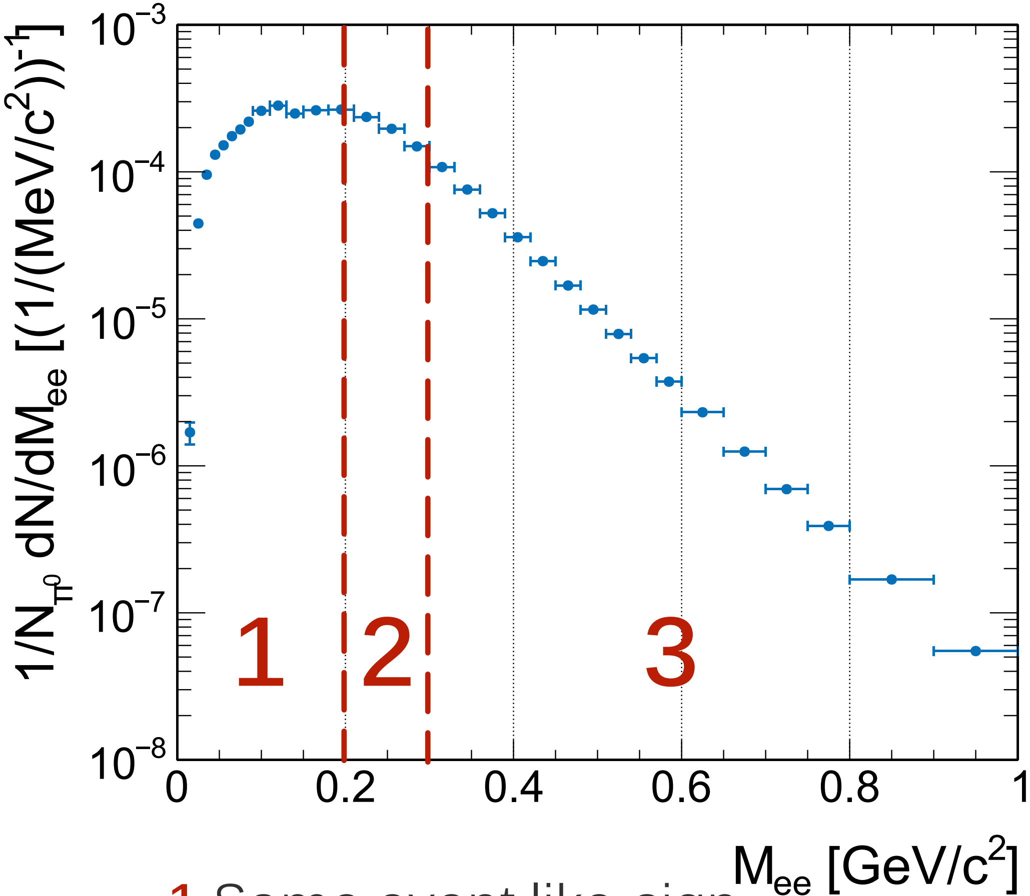
- High statistics



1 Same event like-sign
2 Normalization region
3 Mixed event unlike-sign

Efficiency correction

Single lepton efficiency

- Based on simulation
- Separate matrix for e^+ and e^-

440 MeV < p < 450 MeV