Dilepton production in the proton-proton reaction at 4.5 GeV with the HADES spectrometer

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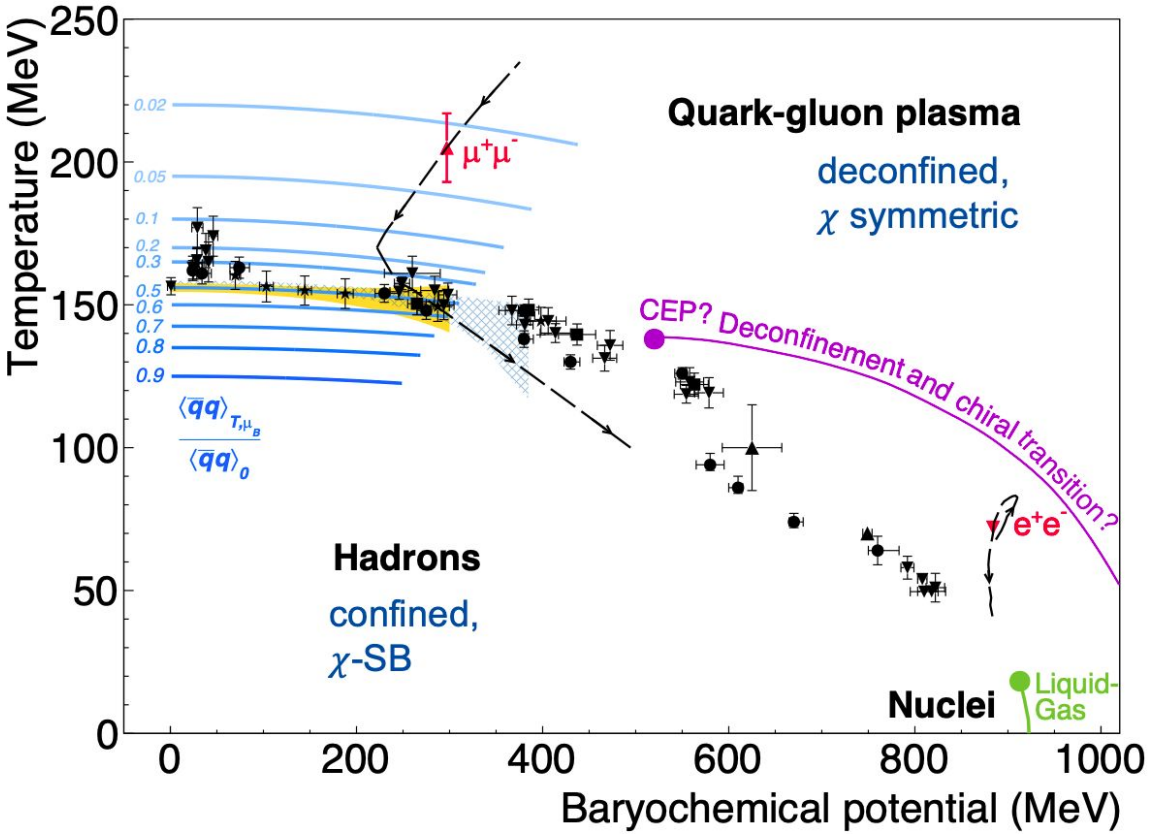
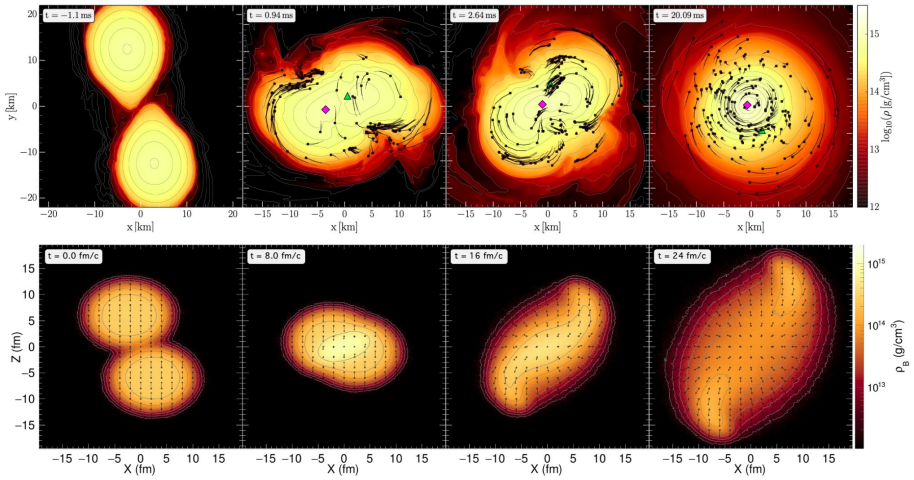
HADES motivations

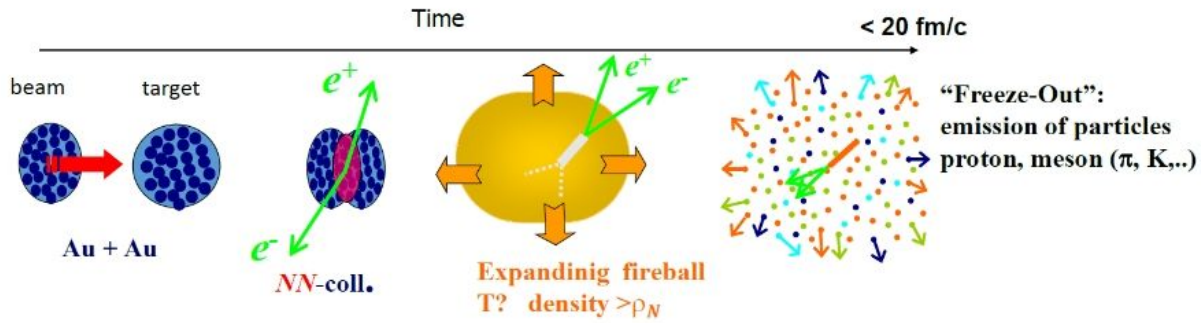
- Explores the high-μ_B region of the QCD phase diagram.
- Complementary to LHC, RHIC, SPS and uses heavy-ion, p, d and π beams in few GeV range.
- Understand the equation of state of baryon dominated matter.



[HADES] Nature Phys. 15(2019) 1040



Dileptons from heavy-ion to elementary reactions



- No strong interaction in the final state → can carry information from production site to detectors.

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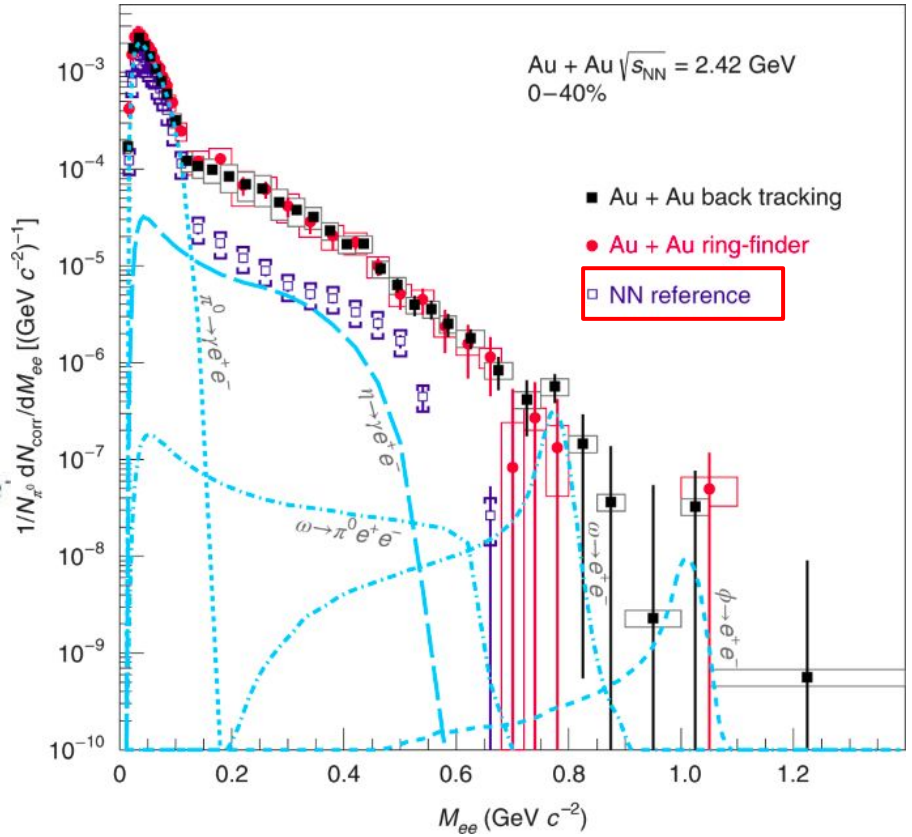
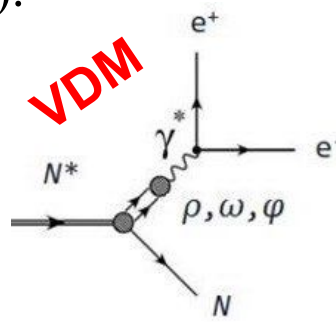


- Study of thermal dileptons from baryon rich matter requires knowledge of physics background →pp/pn measurements are needed.
- Meson Dalitz decays ($\pi^0/\eta \rightarrow \gamma e^+e^-$ and $\omega \rightarrow \pi^0 e^+e^-$).
- Vector meson direct decays ($\rho/\omega/\varphi \rightarrow e^+e^-$).
- Baryon Dalitz decay ($\Delta/N^* \rightarrow Ne^+e^-$).

VDM

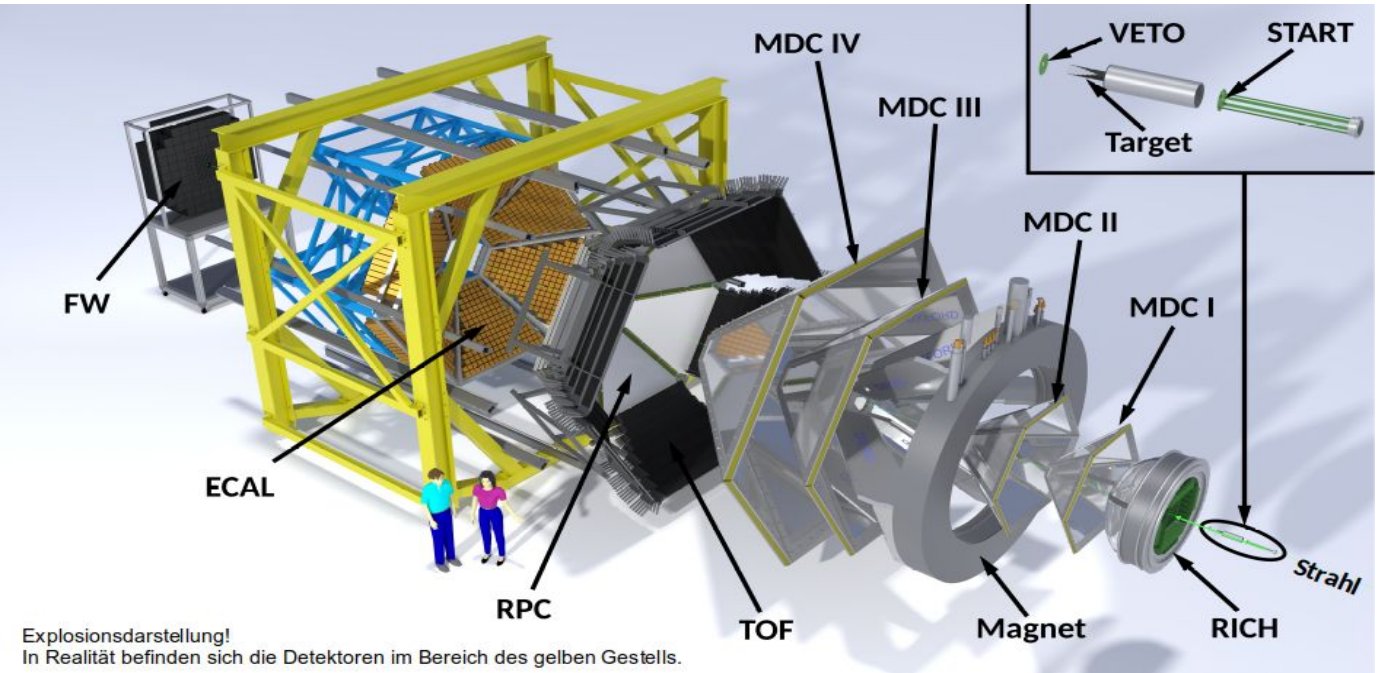


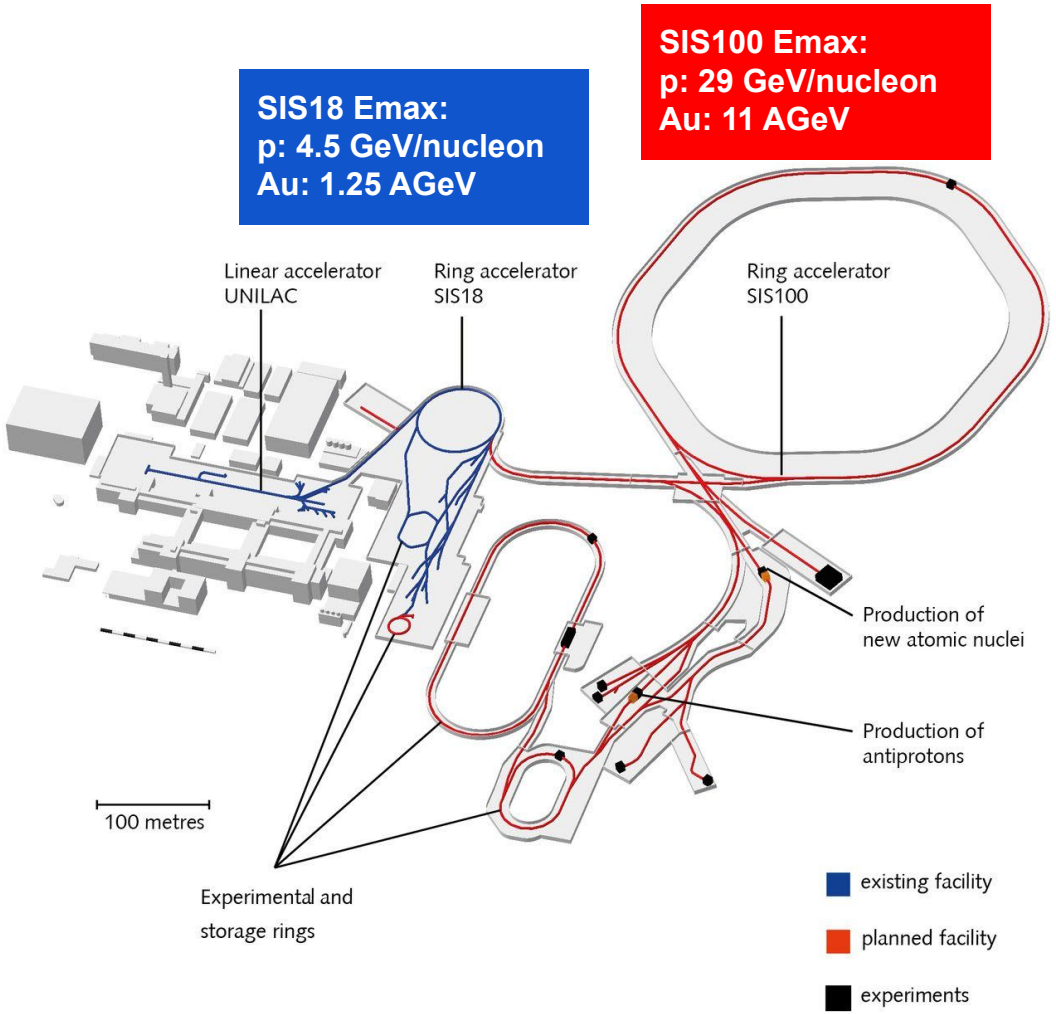
Elementary reactions studies by HADES

- **p+p** at 1.25, 2.2 and 3.5 GeV.
- **p+p** at **4.5** GeV (**Feb22**)
  - Reference for future HIC at SIS100 energies .
  - Inclusive e^+e^- cross sections.
  - Baryonic resonance contribution.

HADES experimental setup

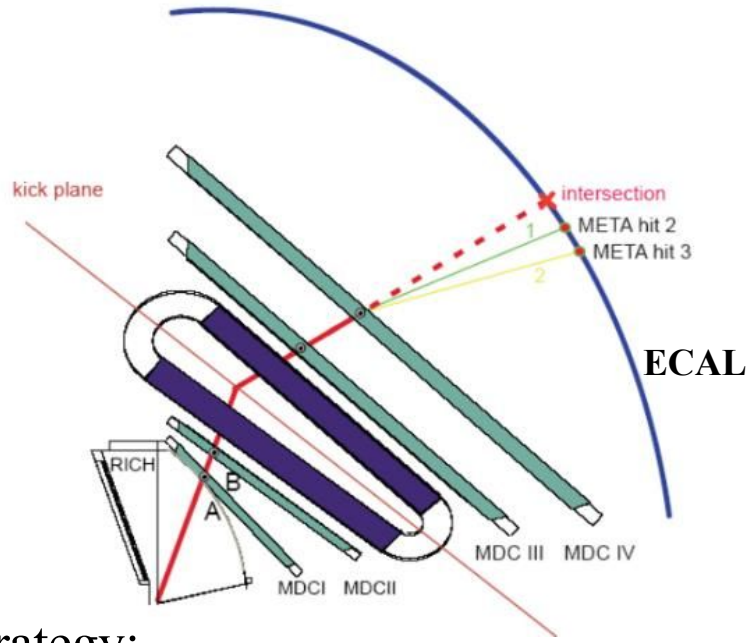
- Fixed target experiment.
- Focuses on the e^+e^- measurements.
- Large geometrical acceptance:
  $0° < \varphi < 360°$ and $18° < \theta < 85°$.
- Tracking system = 4 MDC planes + magnet.
- Lepton identification:
  - RICH → rings.
  - ECal → deposit energy.
  - Time of flight detectors TOF and RPC → β.
- FWD: $0.5° < \theta < 7°$.





Single lepton selection

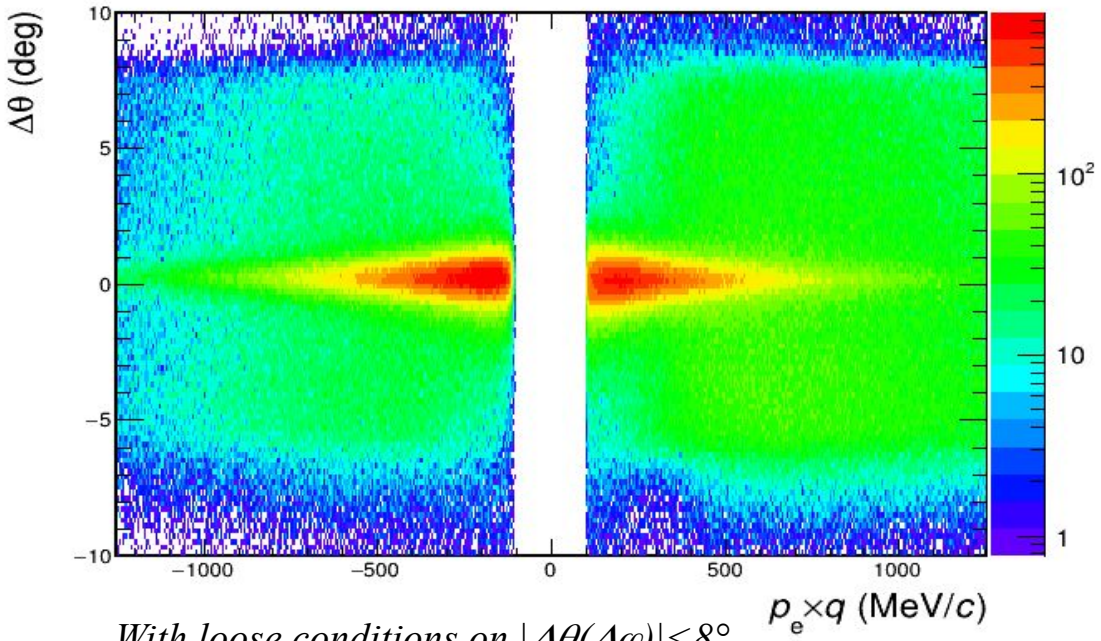
A. RICH: Ring-Track correlation:
$\Delta\theta(\Delta\varphi) = \theta_{Track} - \theta_{Ring}$.
B. ECal: Energy deposit.



Strategy:

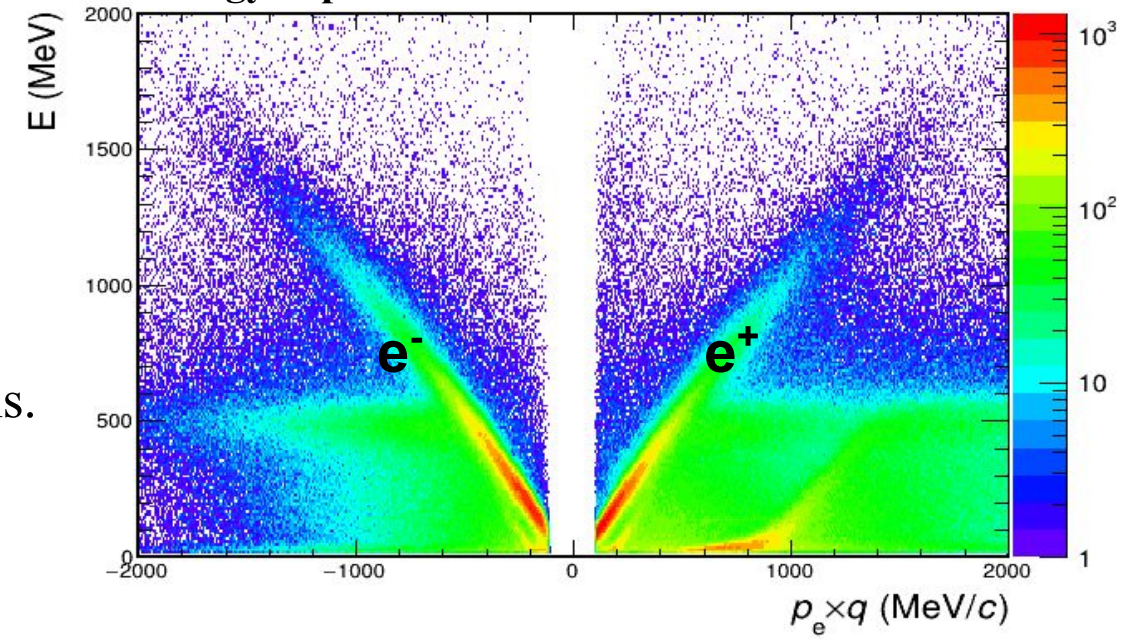
1. Make projections for different momentum bins.
2. Gaussian fit of the peak around 0.
3. Take σ values to define the cuts.

$\Delta\theta$ distributions in function of momentum



With loose conditions on $|\Delta\theta(\Delta\varphi)|<8°$

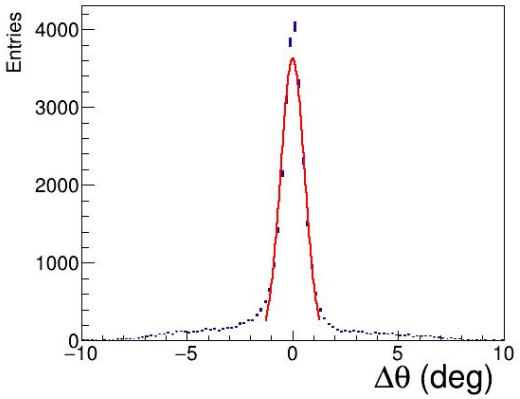
Energy deposit in ECAL in function of momentum



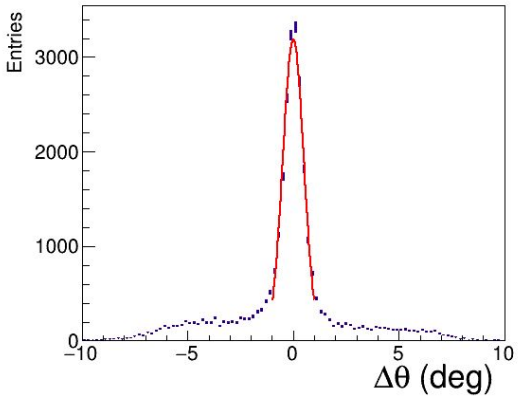
Define cuts on RICH parameters

Some $\Delta\theta$ distributions for e^- for momentum bins of 50 MeV/c

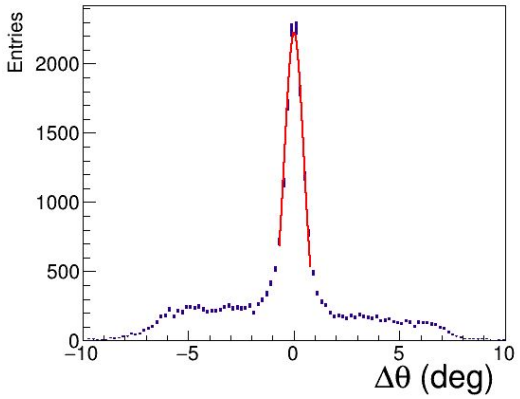
150<p_e(MeV/c)<200



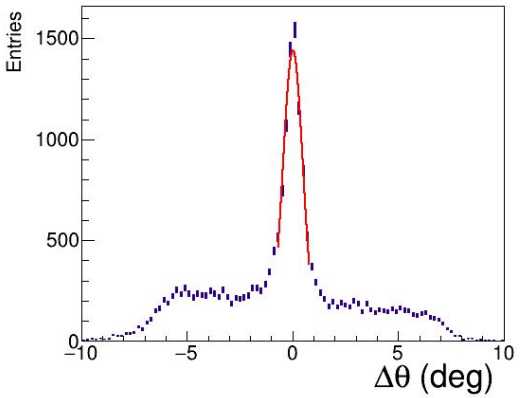
250<p_e(MeV/c)<300



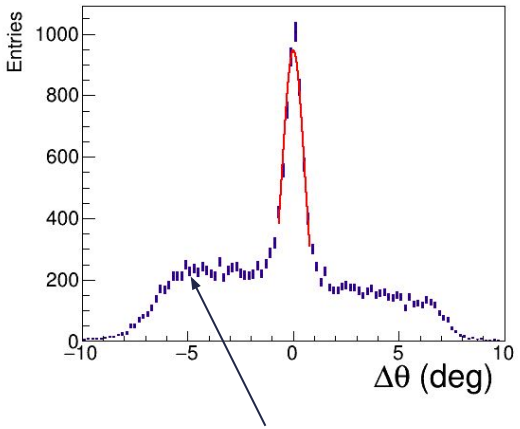
350<p_e(MeV/c)<400



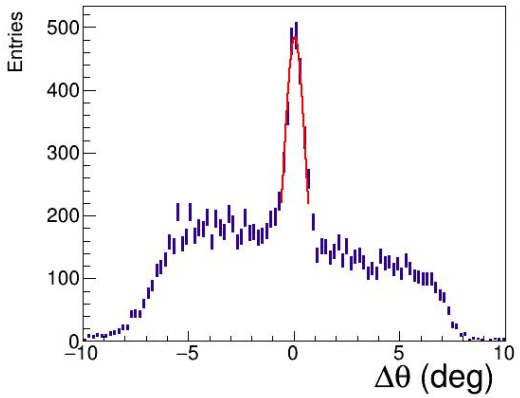
450<p_e(MeV/c)<500



550<p_e(MeV/c)<600

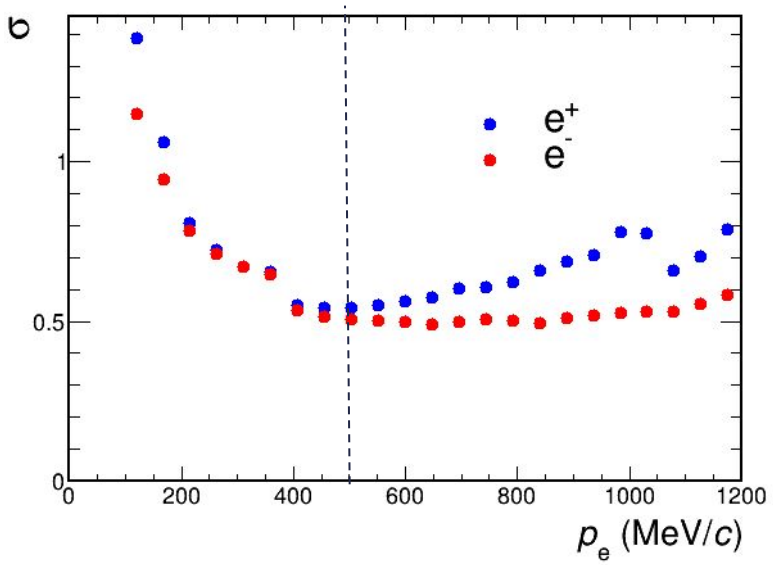


750<p_e(MeV/c)<800

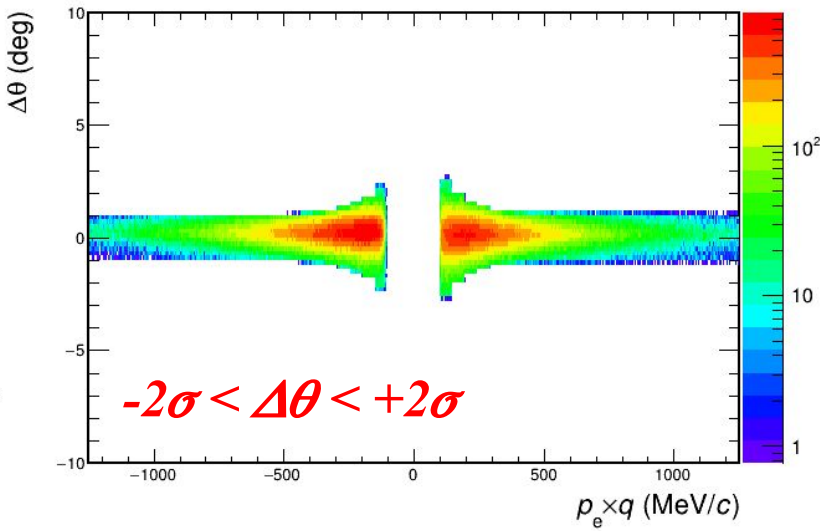


Random matches between a ring and a track

σ of $\Delta\theta$ distributions

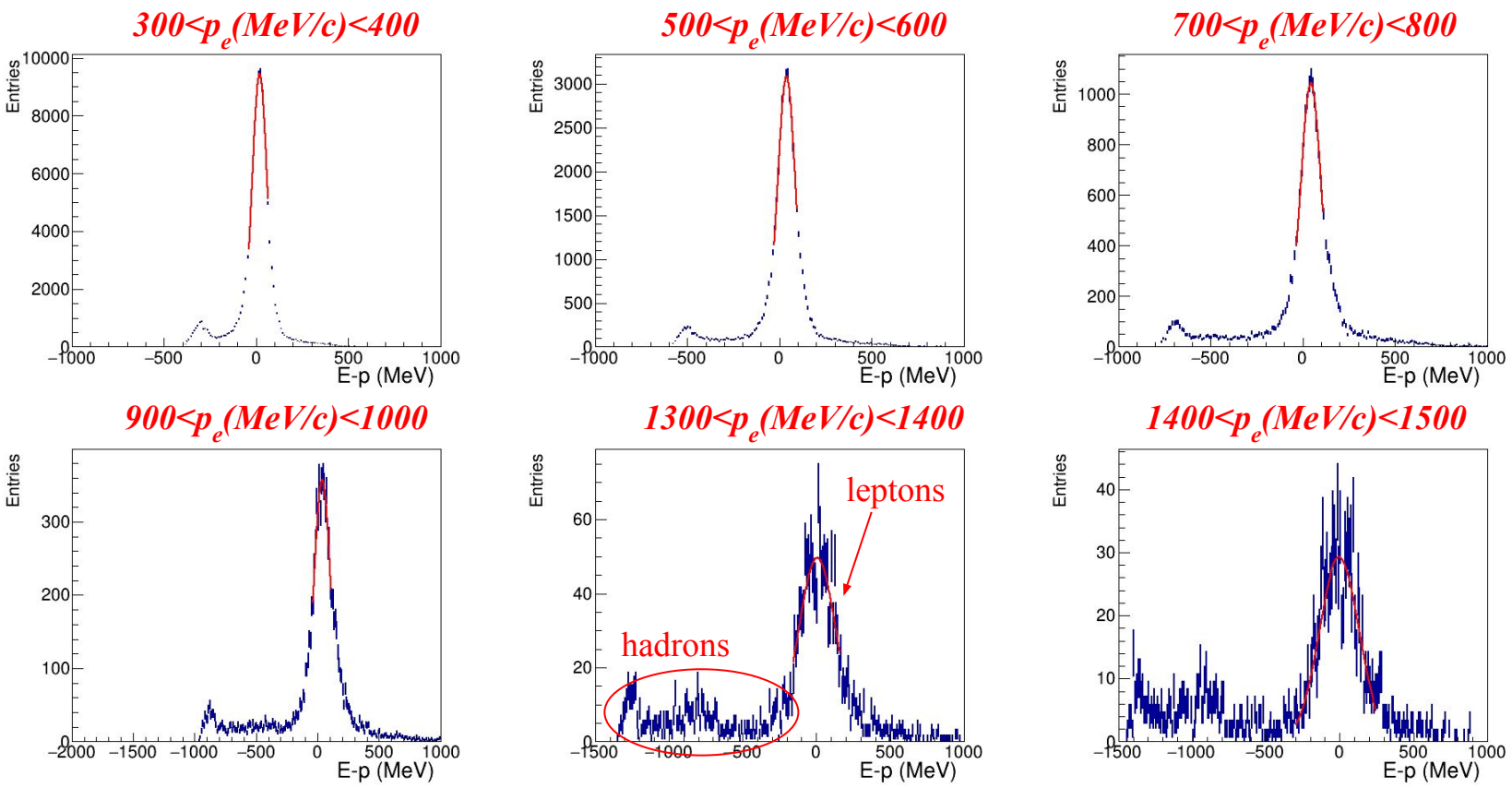


$\Delta\theta$ distributions after RICH cuts

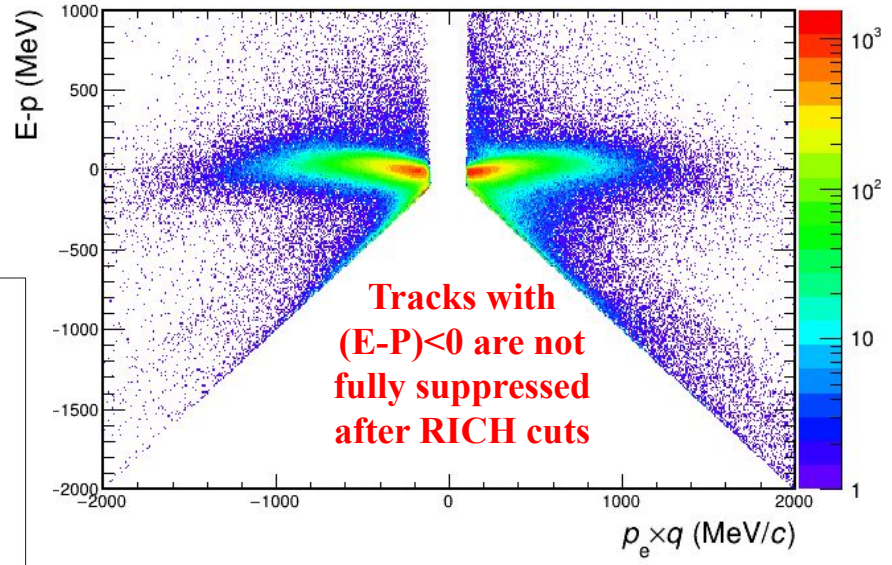


Define cuts on ECal parameters

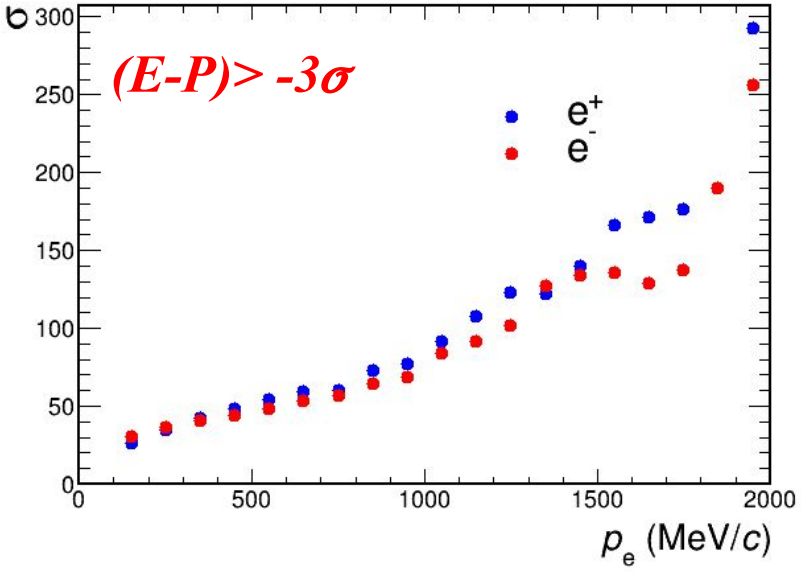
Some (E-P) distributions for e^+ for momentum bins of 100 MeV/c after RICH cuts.



Energy deposit in ECAL - momentum in function of momentum



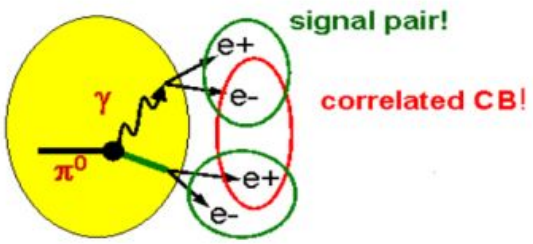
σ of (E-P) distributions



Reconstruction of signal e^+e^-

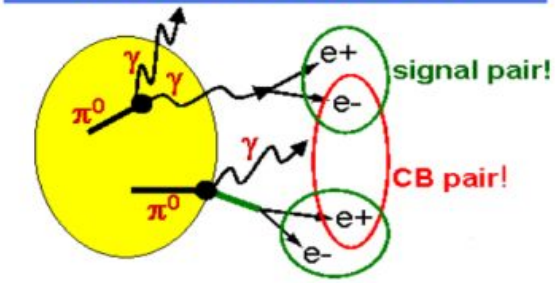
- Combine single e^+/e^- candidates into pairs.
- Combinatorial Background mostly due to the conversion in the detector material.
- Rejecting e^+e^- pairs from random γ or γ^*.
- Same-event like-sign CB geometric/arithmetic mean. $CB = 2\sqrt{N_{++}N_{--}}$ $\quad$ $Signal = N_{+-} - CB$

Correlated CB



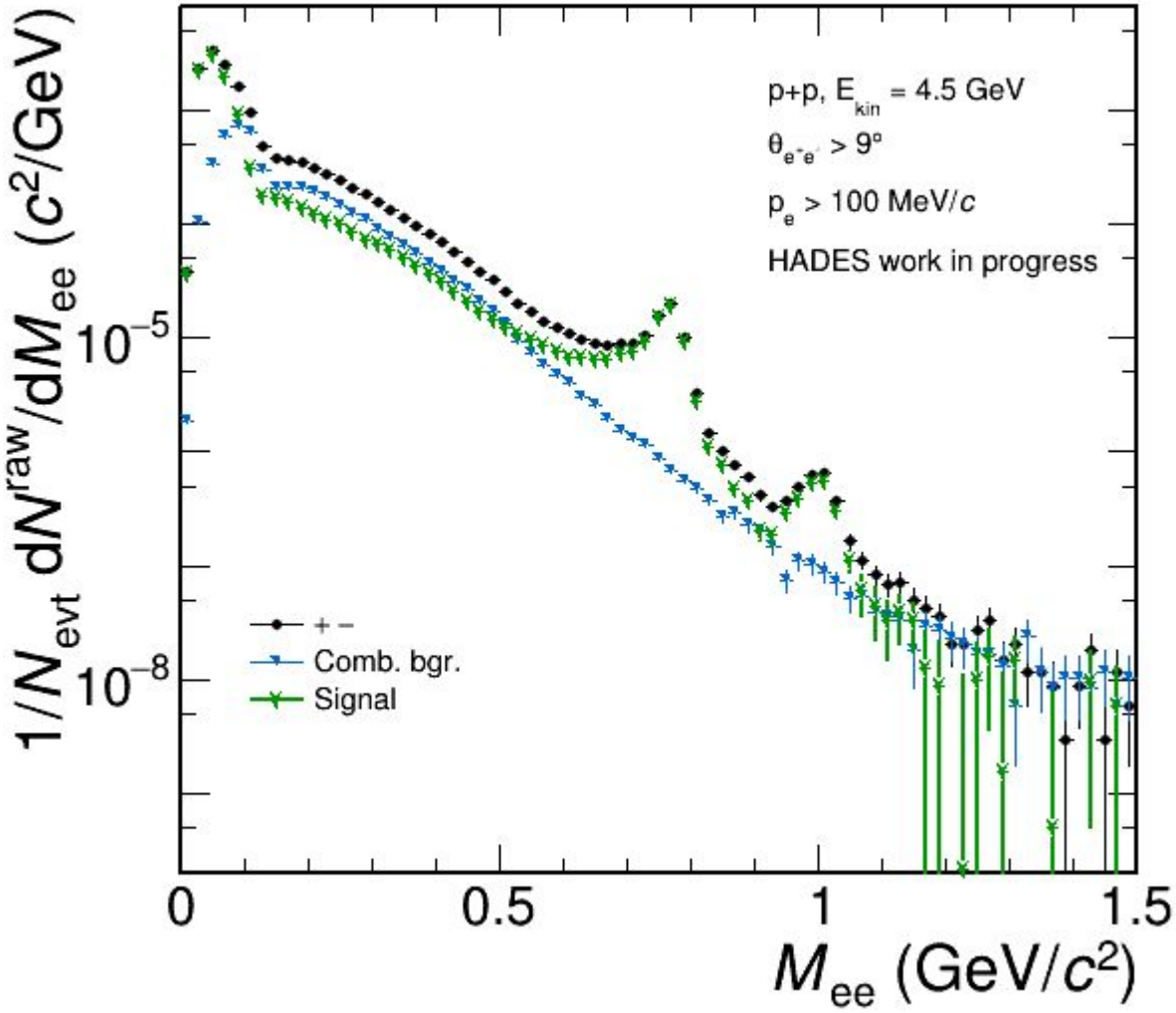
Same mother particle, different intermediate photons.

Uncorrelated CB



Different mother particles.

Inclusive e^+e^- invariant mass spectrum

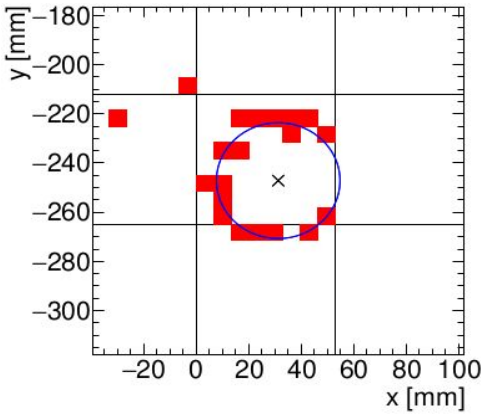


CB reduction

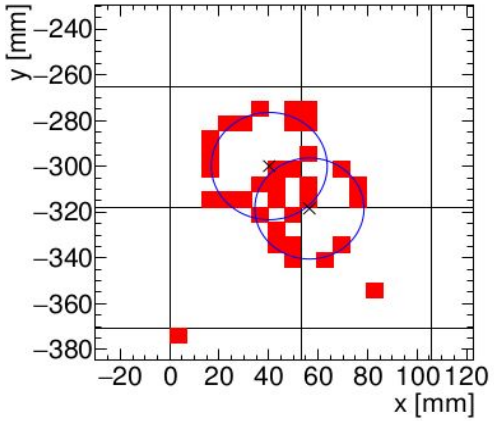
- CB mainly due to conversion (close tracks/rings).
- Cut on rings:
  - Cut on the ring opening angle $\theta_{Ring} > 9°$.
  - Cal dependent double ring identification (cut on N_{Cals}).

Jan-Hendrik Otto, http://dx.doi.org/10.22029/jlupub-7207

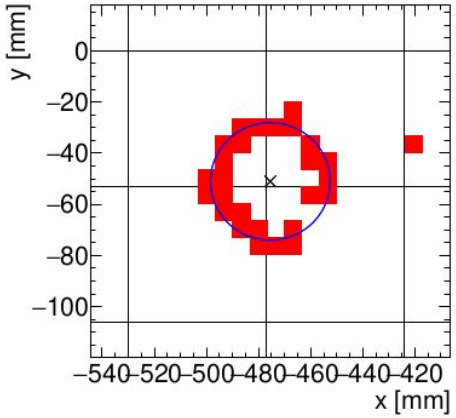
One ring = one electron



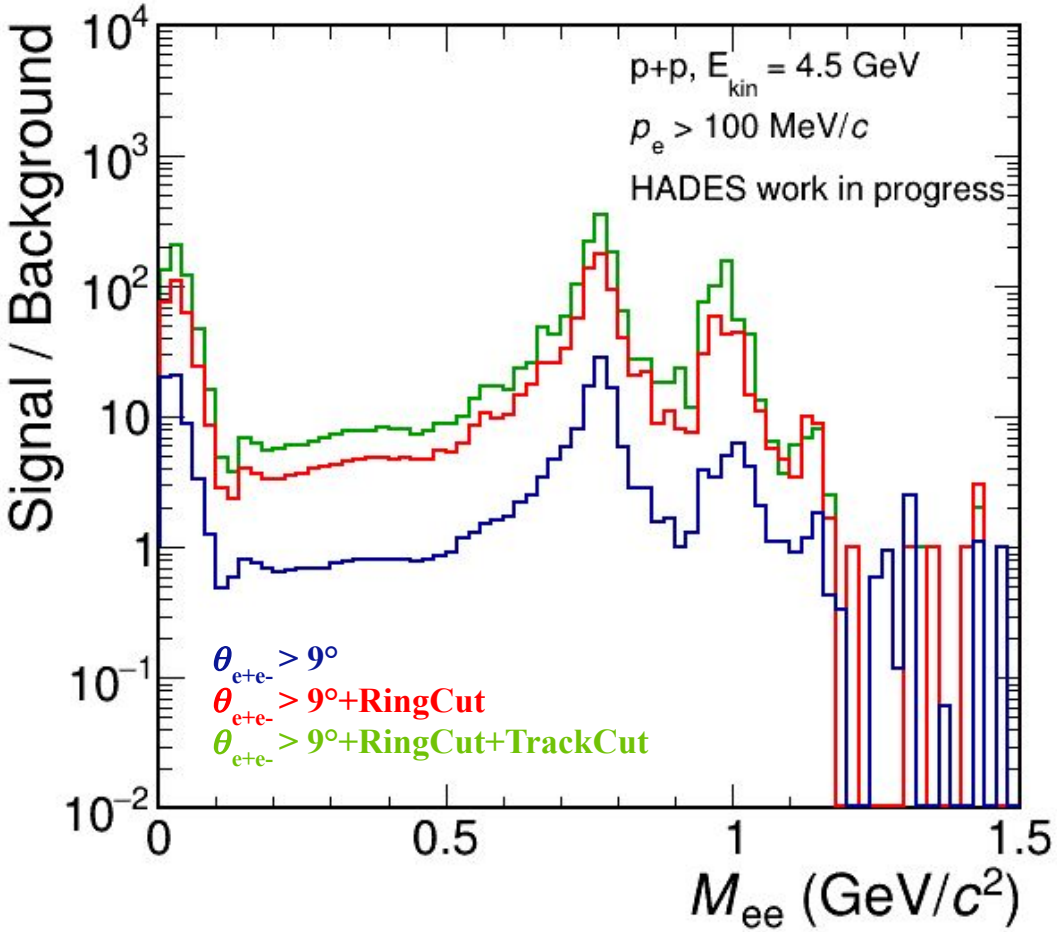
Close-by ring = small oangle



Double ring

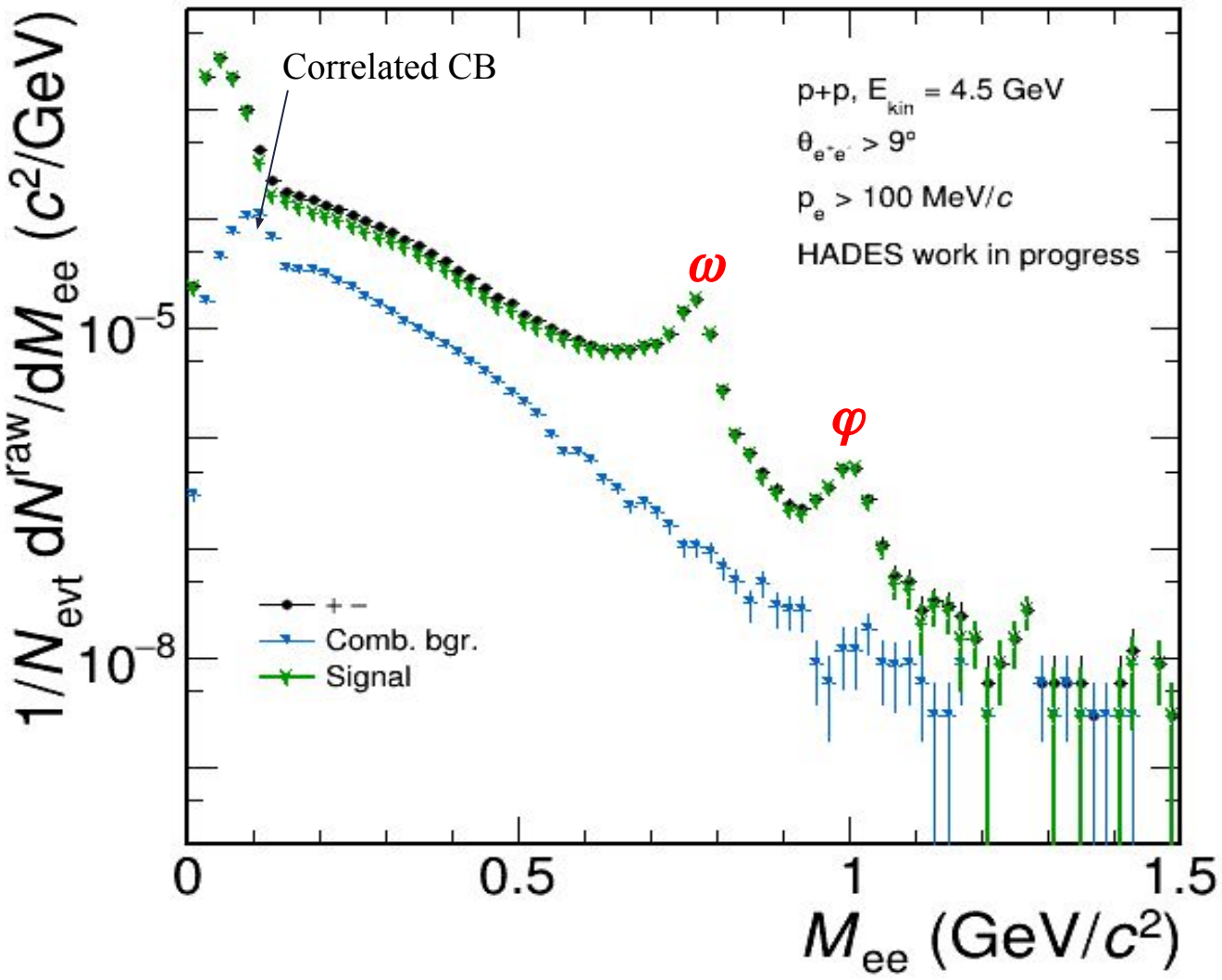


Signal to background ratio



- Cut on tracks:
  Tracks with a not fitted track in the vicinity of 4° are excluded from the analysis.

e^+e^- invariant mass spectrum



- Very low CB thanks to appropriate rejection of leptons from real photon conversion.
- Vector mesons, ω and φ, are clearly seen.
- At high invariant mass ($M_{e+e-} > 1.02$ GeV/c^2) e^+e^- are also reconstructed.

Number of e^+e^- pairs

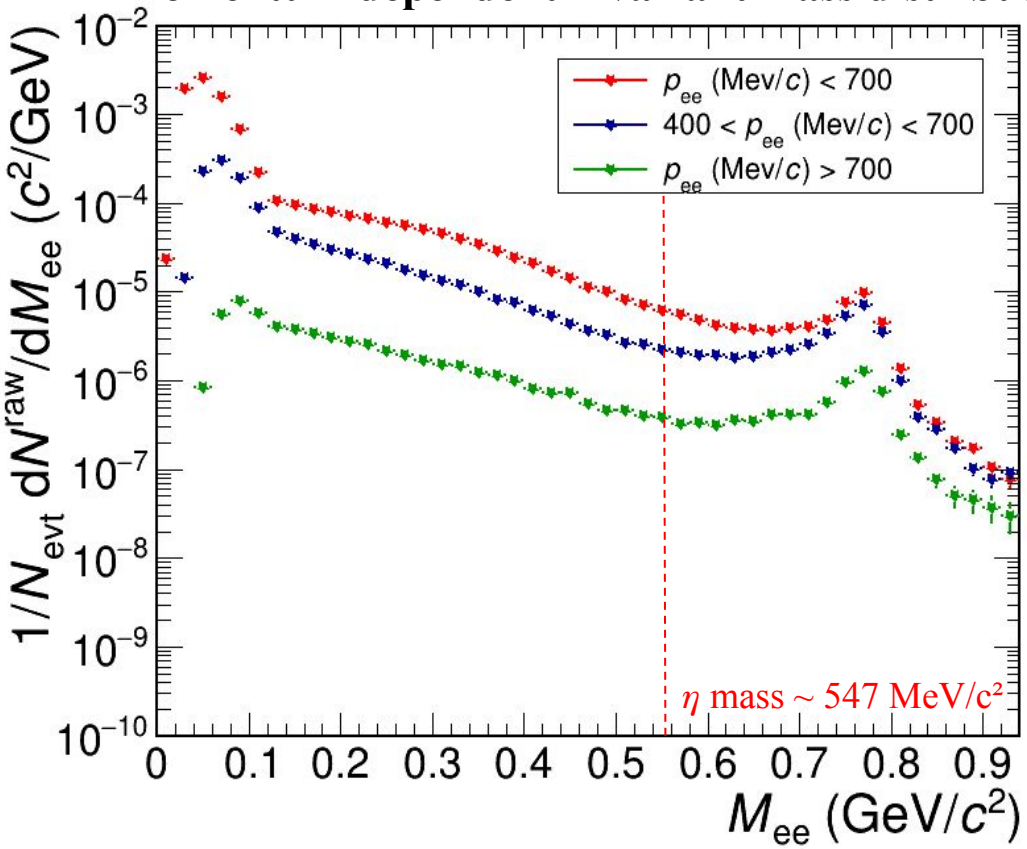
M_{ee} < 150 (MeV/c²)	150<M_{ee}<700 (MeV/c²)	M_{ee}>1020 (MeV/c²)
2×10^6	33×10^4	100

Estimated counts of ω and φ

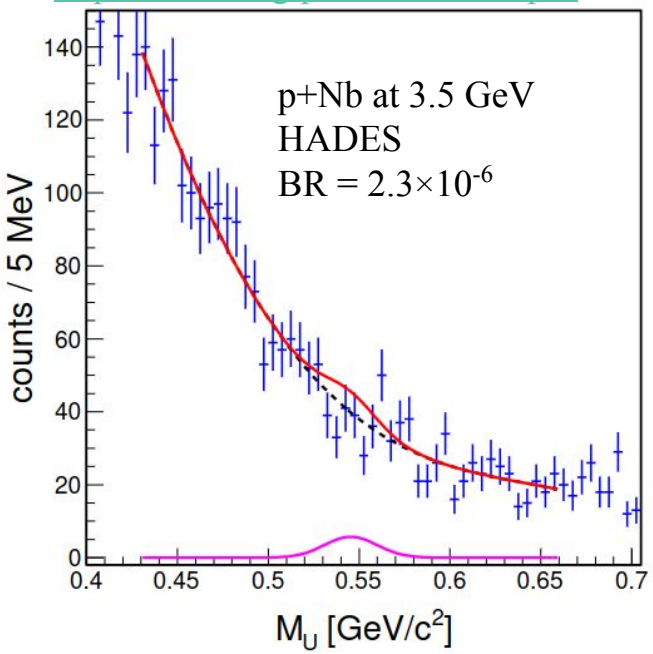
N_ω	N_φ
16000	350

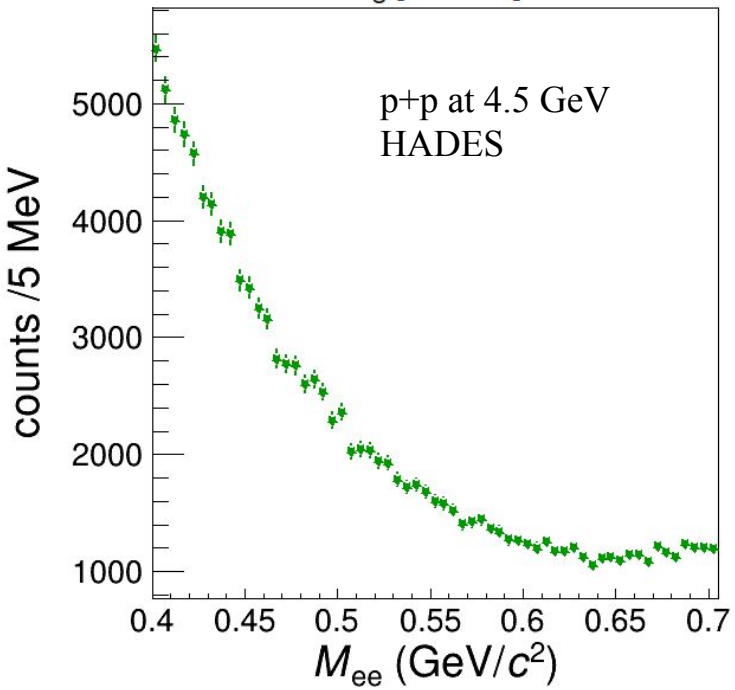
η meson decay into e^+e^-

Momentum dependent invariant mass distributions



https://arxiv.org/pdf/1311.0216.pdf

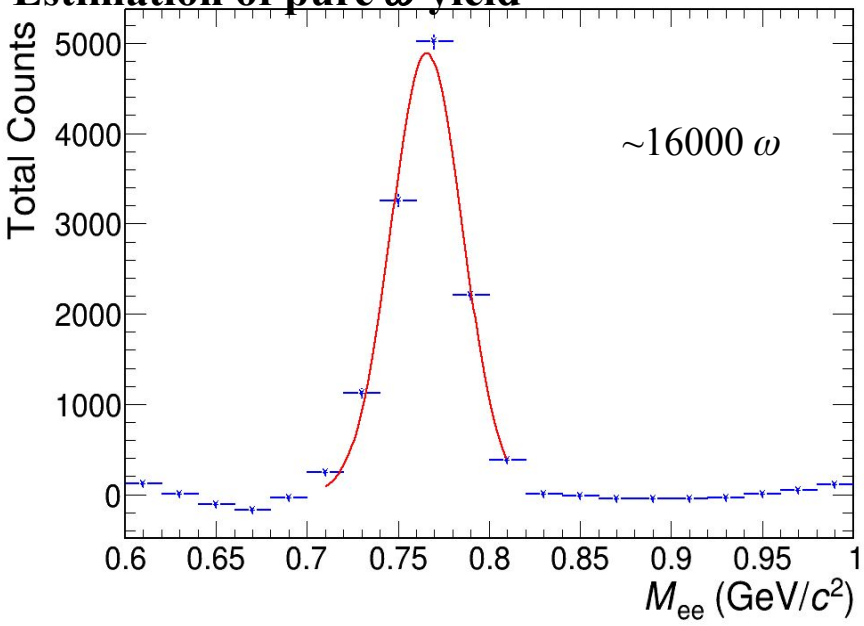




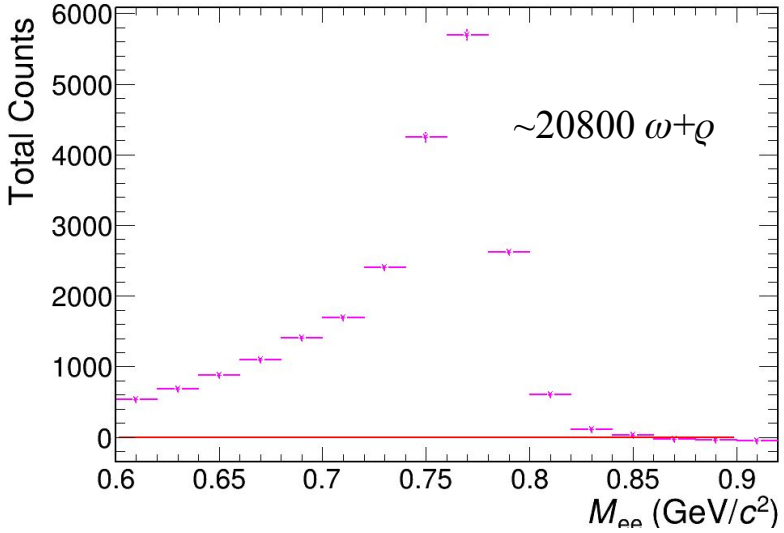
- BR ($\eta \rightarrow e^+e^-$) < 7×10^{-7}.
  https://inspirehep.net/literature/1678641
- Measured by VEPP-2M.
- Improving BR limit with pp measurements at 4.5 GeV with HADES ?

ω cross section

Estimation of pure ω yield



Estimation of ω yield with ϱ contamination



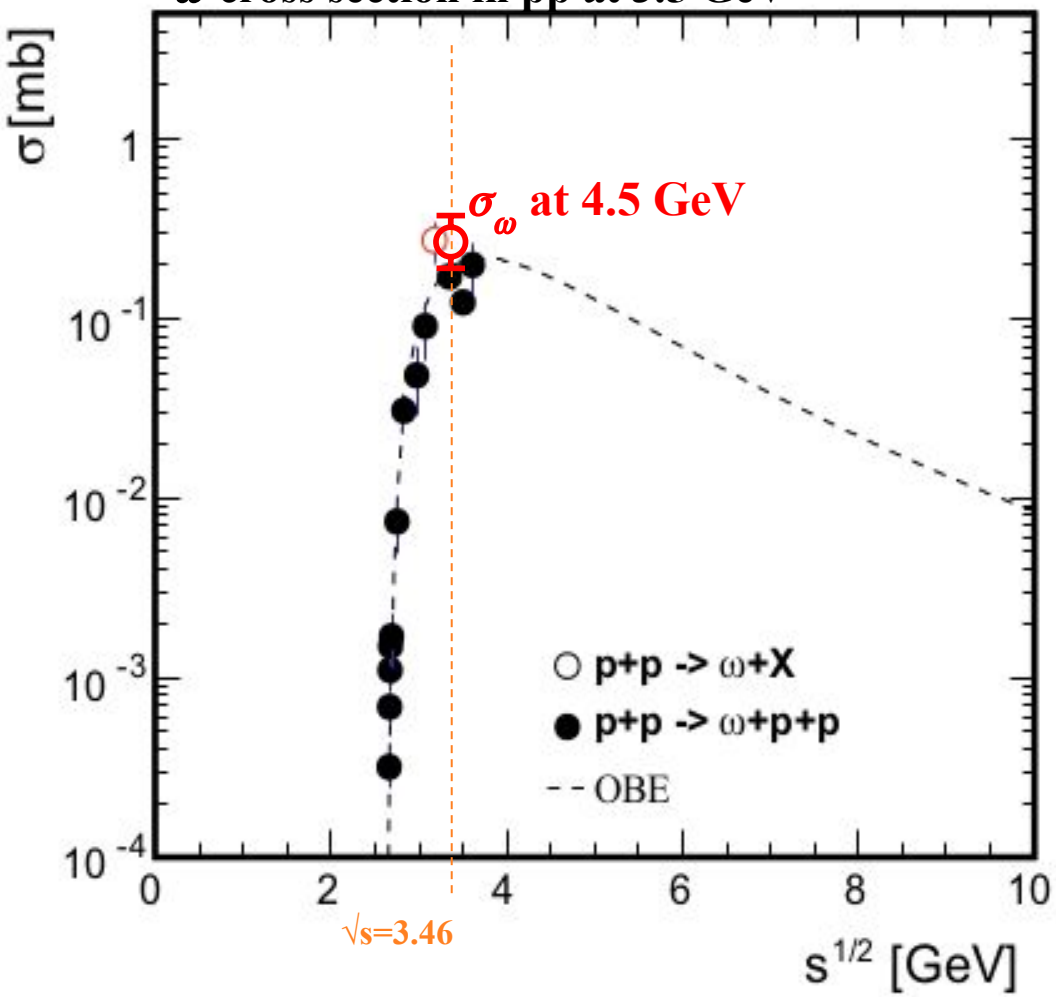
Signal fit = Exponential + two gaussians.

- Signal - Expo = $\omega+\varrho \rightarrow \sigma_{\omega+\varrho}$ = 0.32 mb
- Signal - Expo - Gaus= pure $\omega \rightarrow \sigma_{\omega}$ = 0.24 mb

$\Big\}$ **$0.24 < \sigma_{\omega}$(mb)< 0.32**

[HADES] Eur. Phys. J. A (2012) 48: 640

ω cross section in pp at 3.5 GeV



Luminosity = 5.1±0.2 pb^{-1}
BR($\omega \rightarrow e^+e^-$) = 7.3×10^{-5}
Acc×Eff = 0.25

Conclusion and outlook

- pp at 4.5 GeV is a reference for heavy-ion collisions at SIS100 energies.
- Large statistics are measured. Data are calibrated and the analysis is ongoing.
- Raw data are extracted → work on efficiency and acceptance correction.
- Inclusive π^0, ω and φ cross sections will be extracted.
- Ongoing simulations (PLUTO, SMASH).
- Exclusive channels studies : $pp \rightarrow ppe^+e^-$ for selective study of baryon Dalitz decay and ϱ/ω decays, using missing mass.

Thank you for your attention