Dilepton production in the proton-proton reaction at 4,5GeV with the HADES spectrometer

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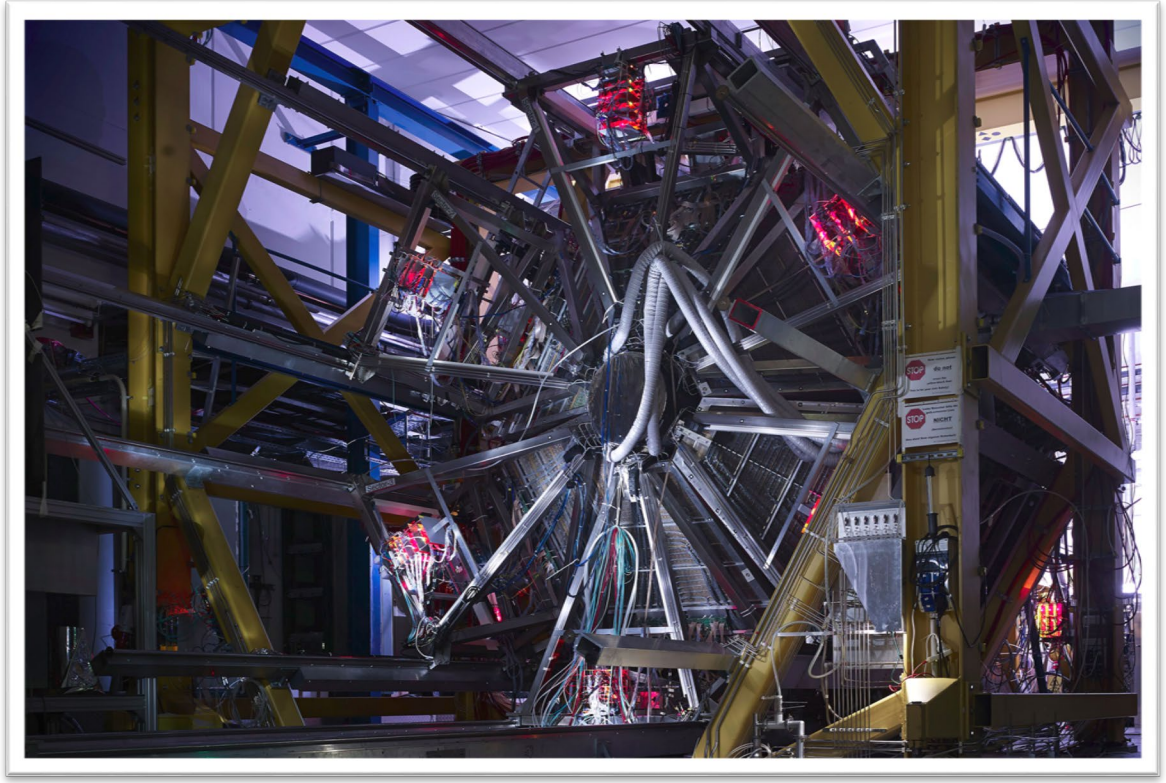
PHENIICS Fest 2023
11-12 May 2023

Outline

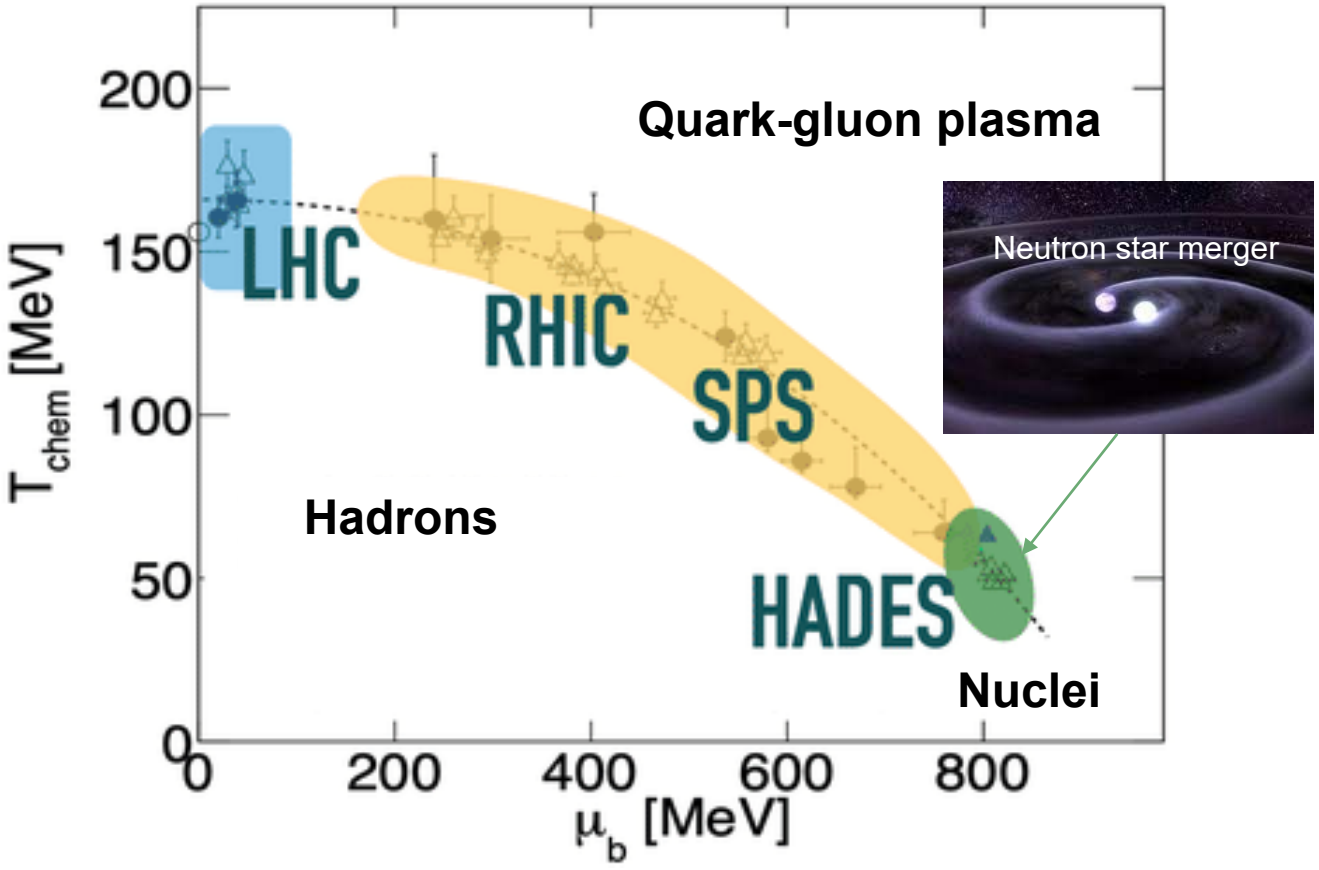
- Motivations.
  - HADES experiment.
  - Dileptons in HADES.
  - Elementary reactions.
- Data Analysis.
  - Single lepton selection.
  - e^+e^- invariant mass spectrum.
- Simulations.
- Conclusion and Outlook.



QCD phase diagram

- HADES explores the high baryochemical potential region at low T, with heavy ion collisions SIS18 energies.
- HADES is complementary to LHC, SPS, RHIC, etc …

  SIS18 energy range:
  - **A+A : 1-3A GeV.**
  - **$\sqrt{s_{NN}}$= 2-2,4 GeV.**
- Understand the equation of state of hadronic matter and baryonic resonances role.



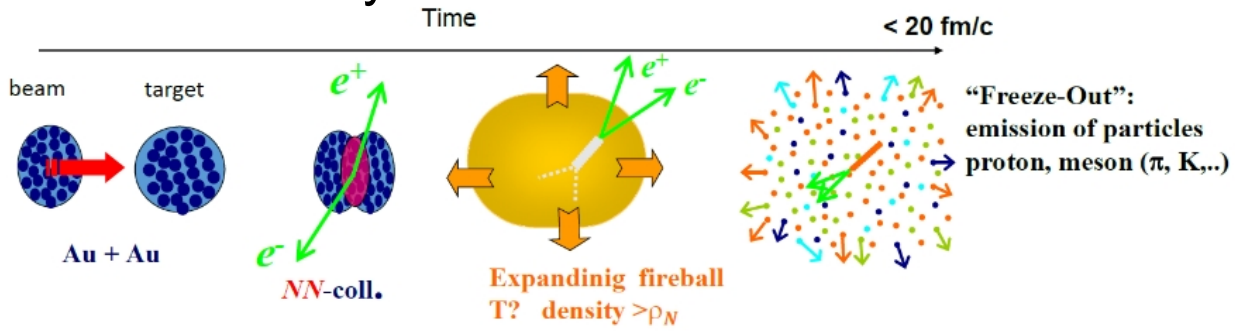
Dileptons

- **No strong interaction** at the final state during the collision

= informations on matter properties are **conserved**

= reflect whole history of the collision.

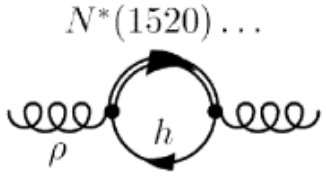
Ideal probe of dense and hot phase of a heavy-ion collision



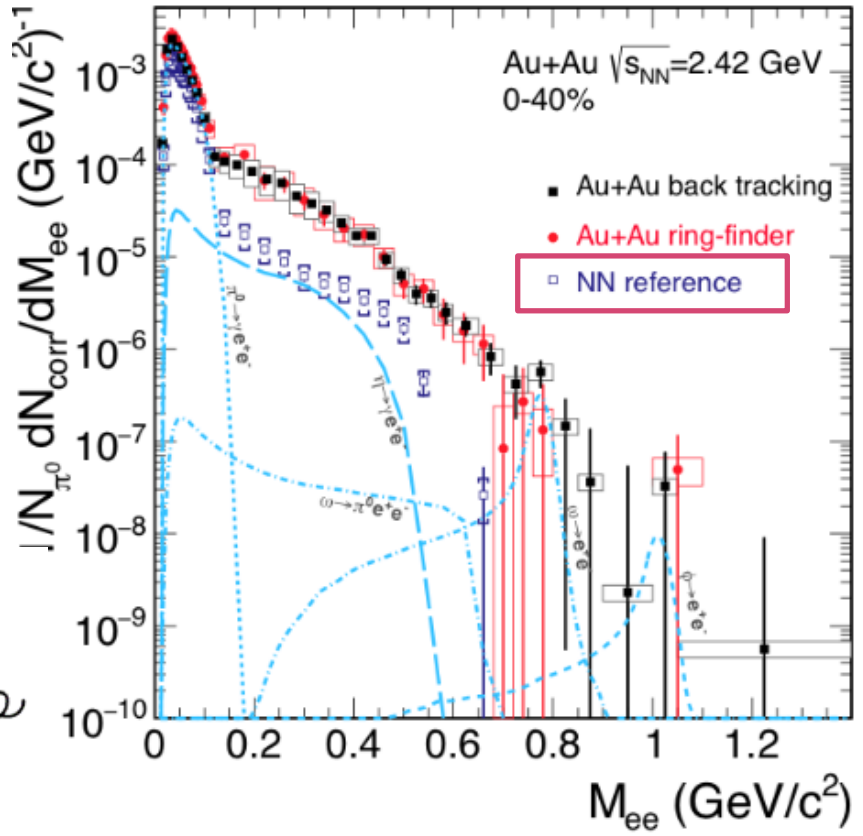
- Study in-medium vector mesons properties ($J^P = 1^-$)

→ vector meson spectral function expected to be modified due to their coupling to baryons.

meson	mass (MeV/c^2)	Γ (MeV/c^2)	$c\tau$ (fm)	main decay	e^+e^- branching ratio
ρ	768	152	1.3	$\pi^+\pi^-$	$4.4 \quad 10^{-5}$
ω	782	8.43	23.4	$\pi^+\pi^-\pi^0$	$7.2 \quad 10^{-5}$
ϕ	1019	4.43	44.4	K^+K^-	$3.1 \quad 10^{-4}$

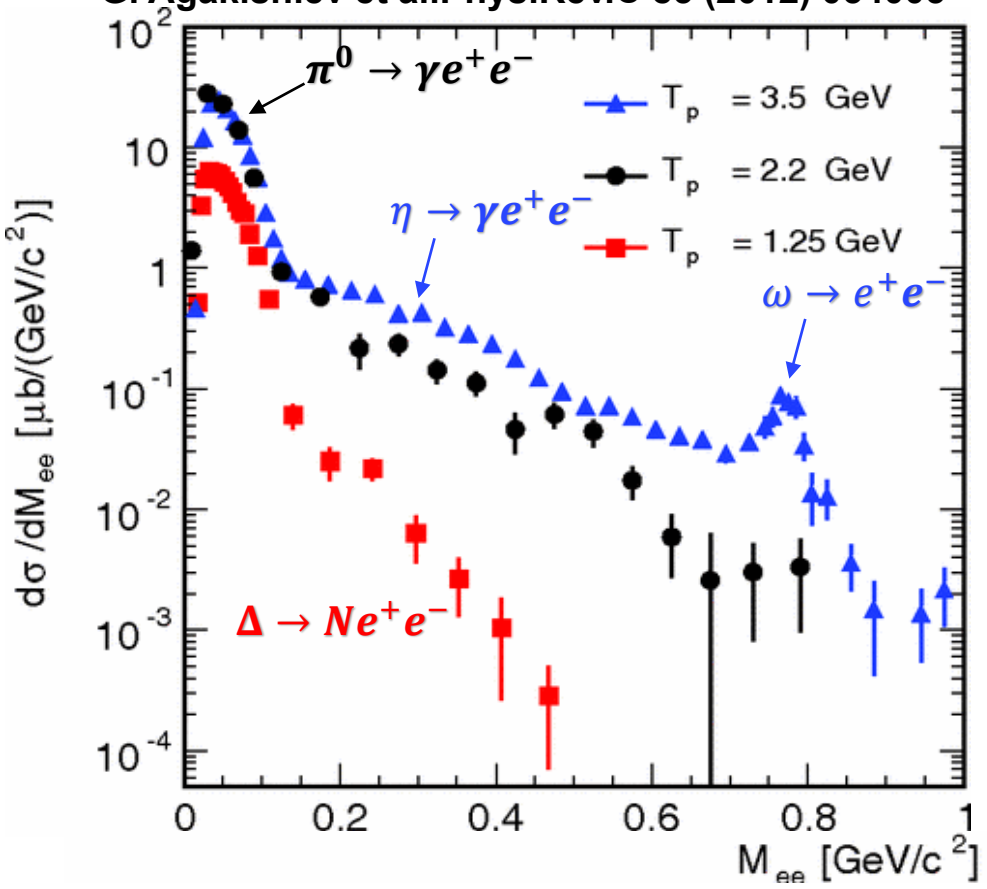


Nature Phys. 15 (2019) no.10, 1040-1045



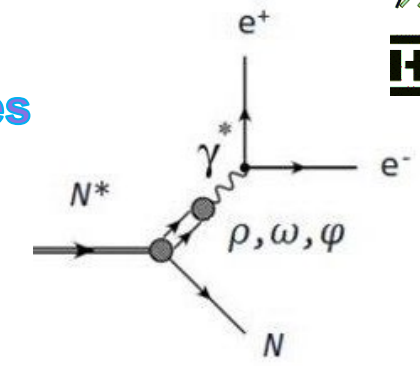
pp collisions studies with HADES

G. Agakishiev et al.Phys.Rev.C 85 (2012) 054005



pp @ 4,5 GeV

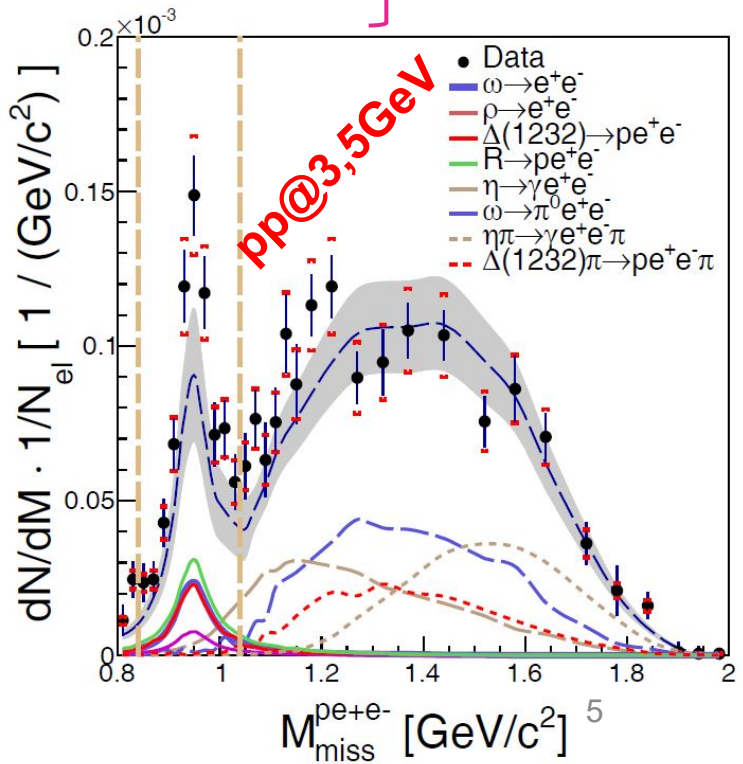
Dilepton sources at SIS18 energies



- π^0 Dalitz decay ($\pi^0 \to \gamma e^+e^-$).
- η Dalitz decay ($\eta \to \gamma e^+e^-$).
- ω Dalitz decay ($\omega \to \pi^0 e^+e^-$).
- Vector meson direct decays ($\omega/\rho/\phi \to e^+e^-$).
- Baryon Dalitz decays ($\Delta/\mathrm{N}^* \to Ne^+e^-$).

$\mathbf{pp \to ppe^+e^-}$

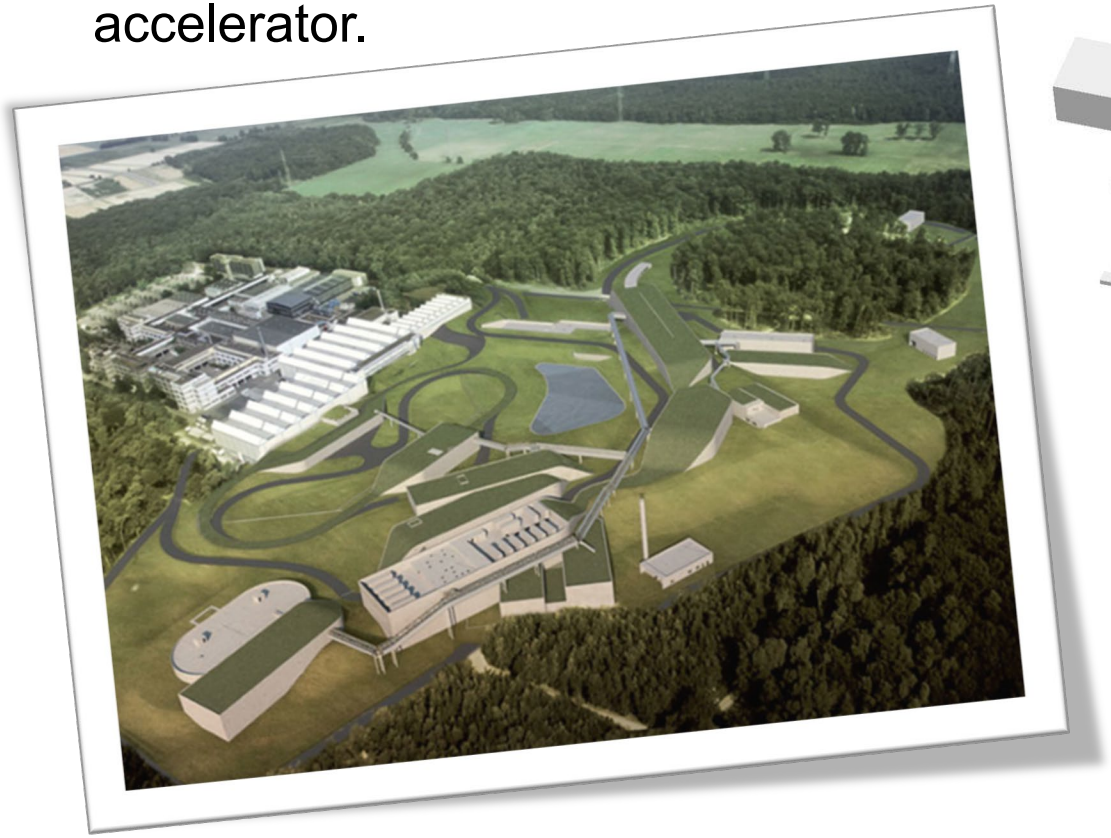
Selective study of
pp→Δ$^+$/N* (pe$^+$e$^-$)p
and
pp→ppρ/ω(e$^+$e$^-$)
and investigation of **VDM**



- Reference for future HIC at SIS100 energies → baryonic resonances role.
- ϕ meson peak should be observed in the e$^+$e$^-$ invariant mass spectrum.

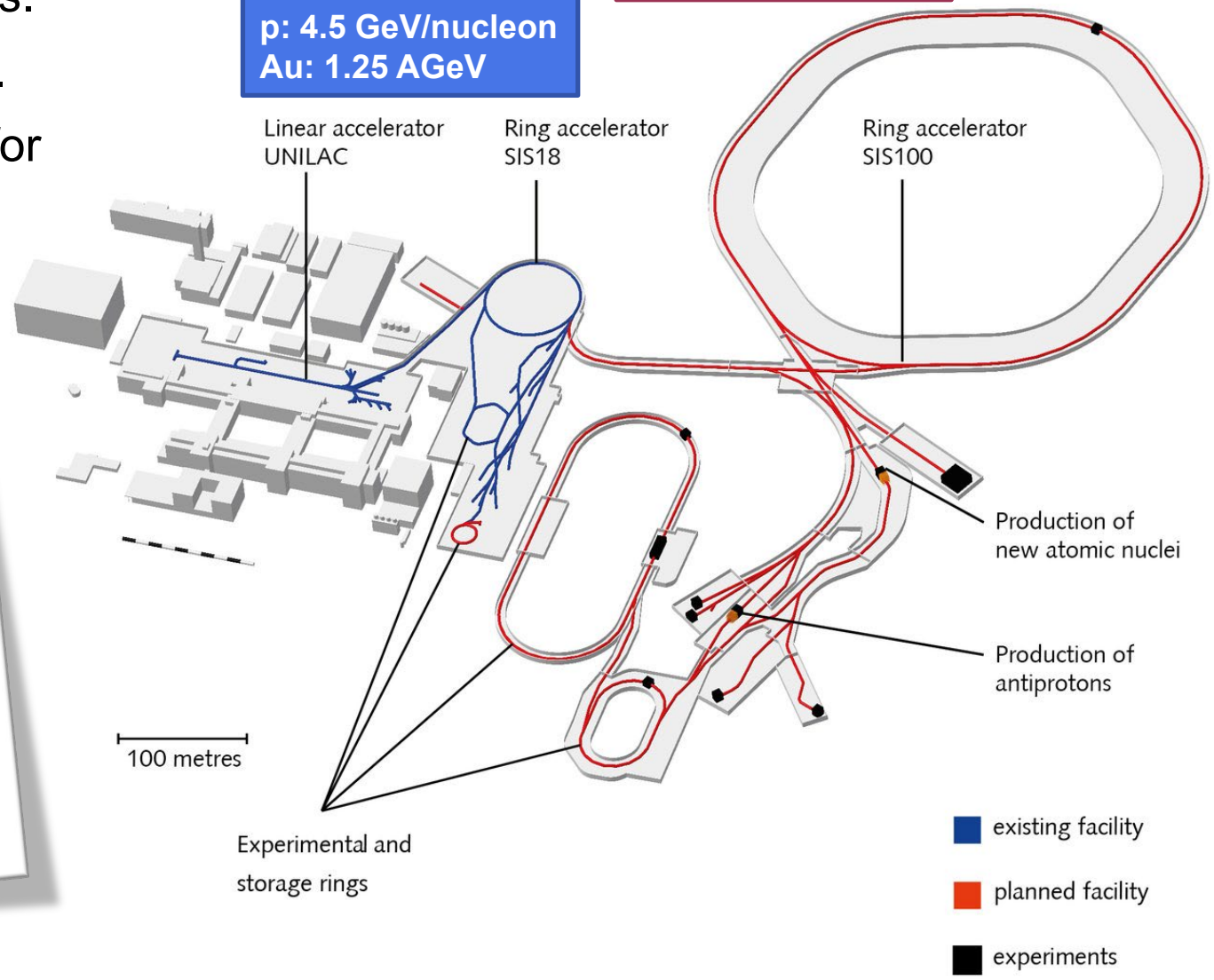
HADES collaboration

- 18 institutions from 9 European countries.
- HADES currently running on SIS18/GSI.
- HADES will be moved to FAIR (Facility for Antiproton and Ion Research) SIS100 accelerator.



SIS18 Emax:
p: 4.5 GeV/nucleon
Au: 1.25 AGeV

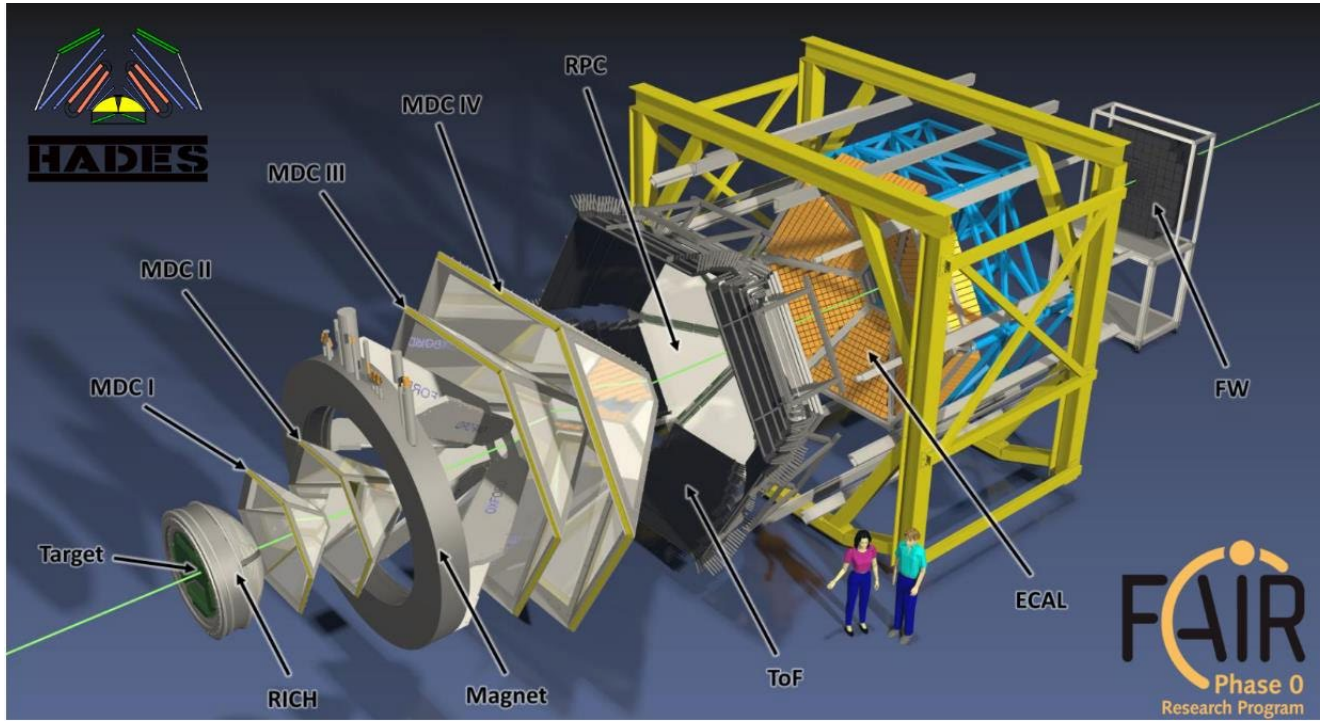
SIS100 Emax:
p: 29 GeV/nucleon
Au: 11 AGeV



HADES experimental setup

High Acceptance DiElectron Spectrometer

- Fixed target experiment.
- Large geometrical acceptance: full azimuthal range and polar angles 18° and 85°.
- Efficient track reconstruction and momentum determination (MDC+Magnet) and particle identification (RICH, TOF, RPC and ECal).
- FWD: polar angles [0.5°-7°].



Experiments (2004-2022)

- Dense and hot hadronic matter studies: **C+C**(1 and 2 AGeV), **Ar+KCl**(1.75 AGeV), **Au+Au**(1.25 AGeV), **Ag+Ag**(1.65 AGeV).
- Cold matter studies: **p+Nb**(3.5GeV), **π^-+CH2/C** (0.7 GeV/c).
- Elementary reactions: **p+p** (1.25, 2.2, 3.5 and recently 4.5 GeV), **d+p** (1.25 GeV/nucleon).

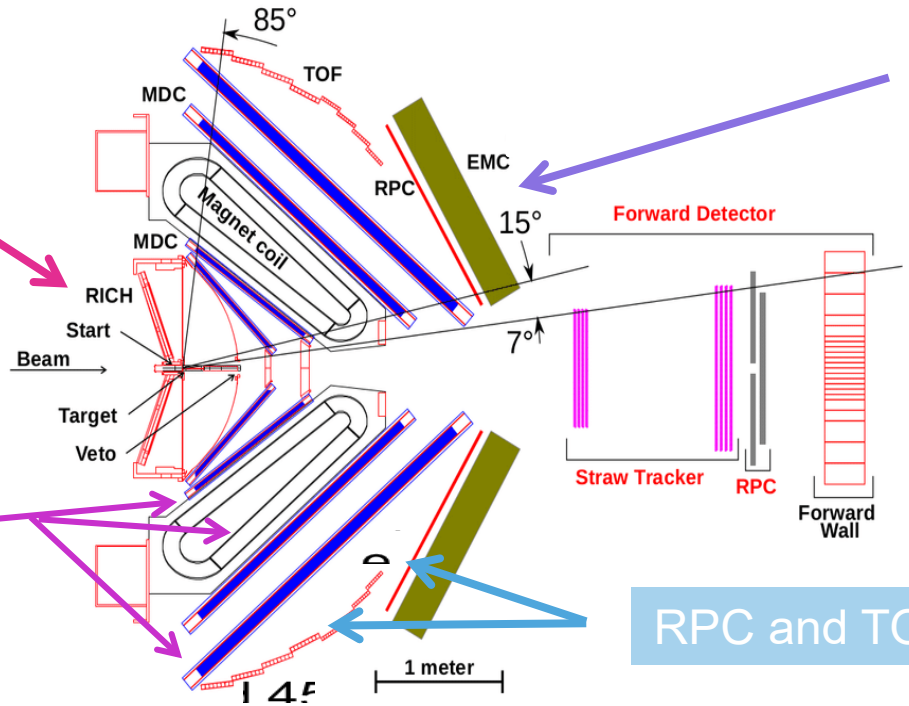
Particle reconstruction and identification

RICH

- Radiator gas C_4F_{10}

→ Cherenkov light only for electrons.

- RICH-MDC correlation.
- $\Delta\theta(\Delta\phi) = \theta_{Track} - \theta_{Ring}$.



ECAL

- Polar angle coverage between 12° and 45°.
- For pp at 4,5 GeV only 5 sectors were used.
- e^+/e^- leave all their energy in the ECal → $(E - P) = 0$.
- Hadrons leave much less energy → $(E - P) < 0$.

MDCs + Magnet

- Particle deflection in the magnetic field → Momentum.
- Fit 2 segments infront and behind magnetic field.
- 4^{th} order Runge-Kutta algorithm.

RPC and TOF

- RPC : $18° < \theta < 45°$.
- TOF : $44° < \theta < 88°$.
- Time of flight measurements.
- Correlation between β and P.

Particle reconstruction and identification

RICH

- R… gas C… F…
- → …
- el…
- …
- $\Delta\theta(\Delta\phi) = \theta_{\mathrm{Track}} - \theta_{\mathrm{Ring}}$.

A

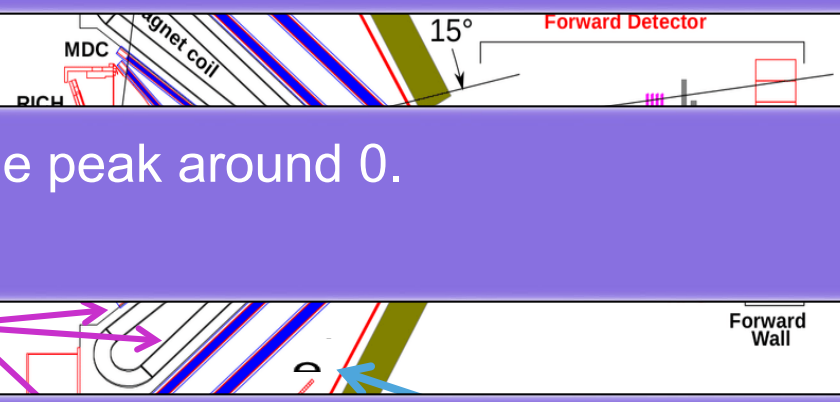
Make projections for different momentum bins for the parameters.

B

Gaussian fit of the peak around 0.

C

Take σ values, and put the cut $\pm R\sigma,\ R = 2\ or\ 3$



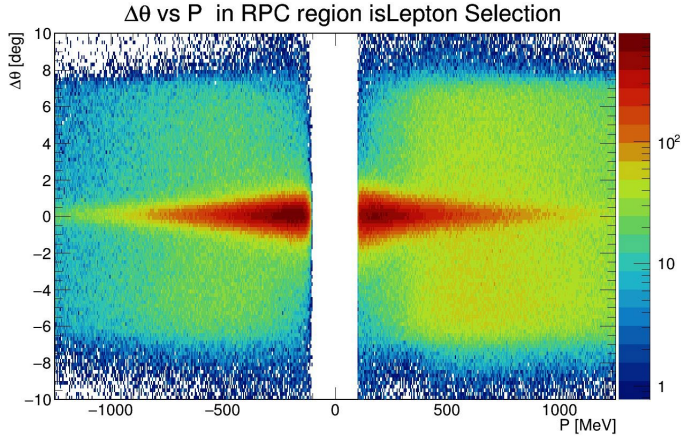
MDCs + Magnet

- Pa… ma…
- Fit 2… …ents infront and behind magnetic field.
- 4^{th} order Runge-Kutta algorithm.

ECAL

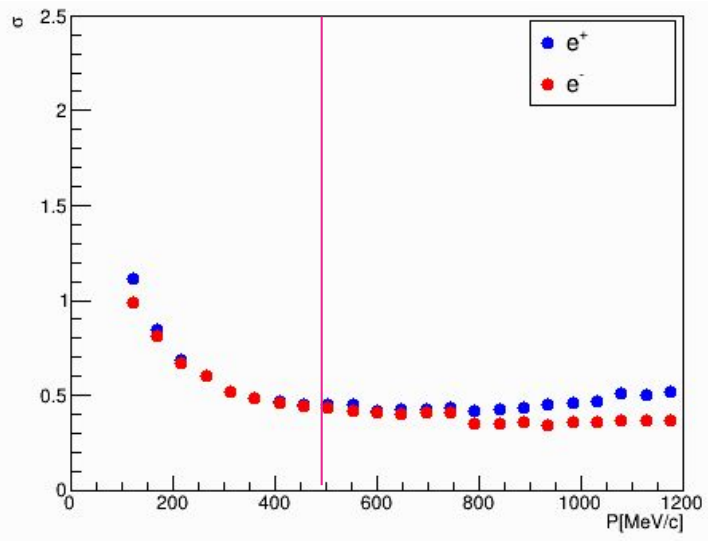
… sectors were used.
- e^+/e^- leave all their energy in …
- TOF : $44° < \theta < 88°$.
- Time of flight measurements.
- Correlation between β and P.

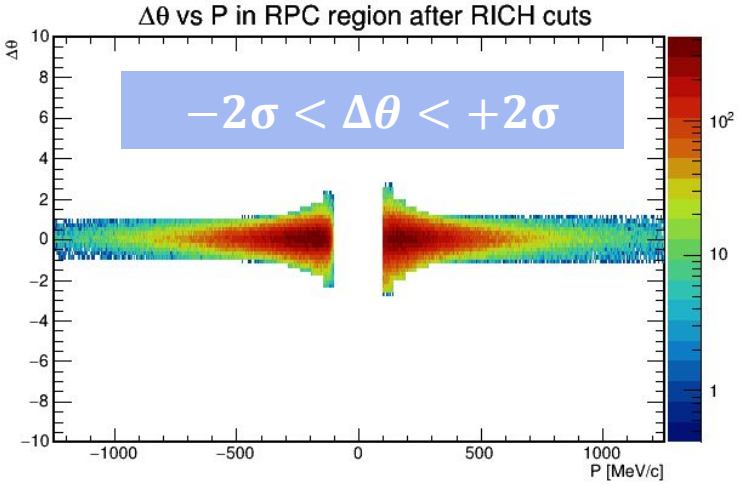
Define cuts on RICH parameters



Random matches between a ring and a track

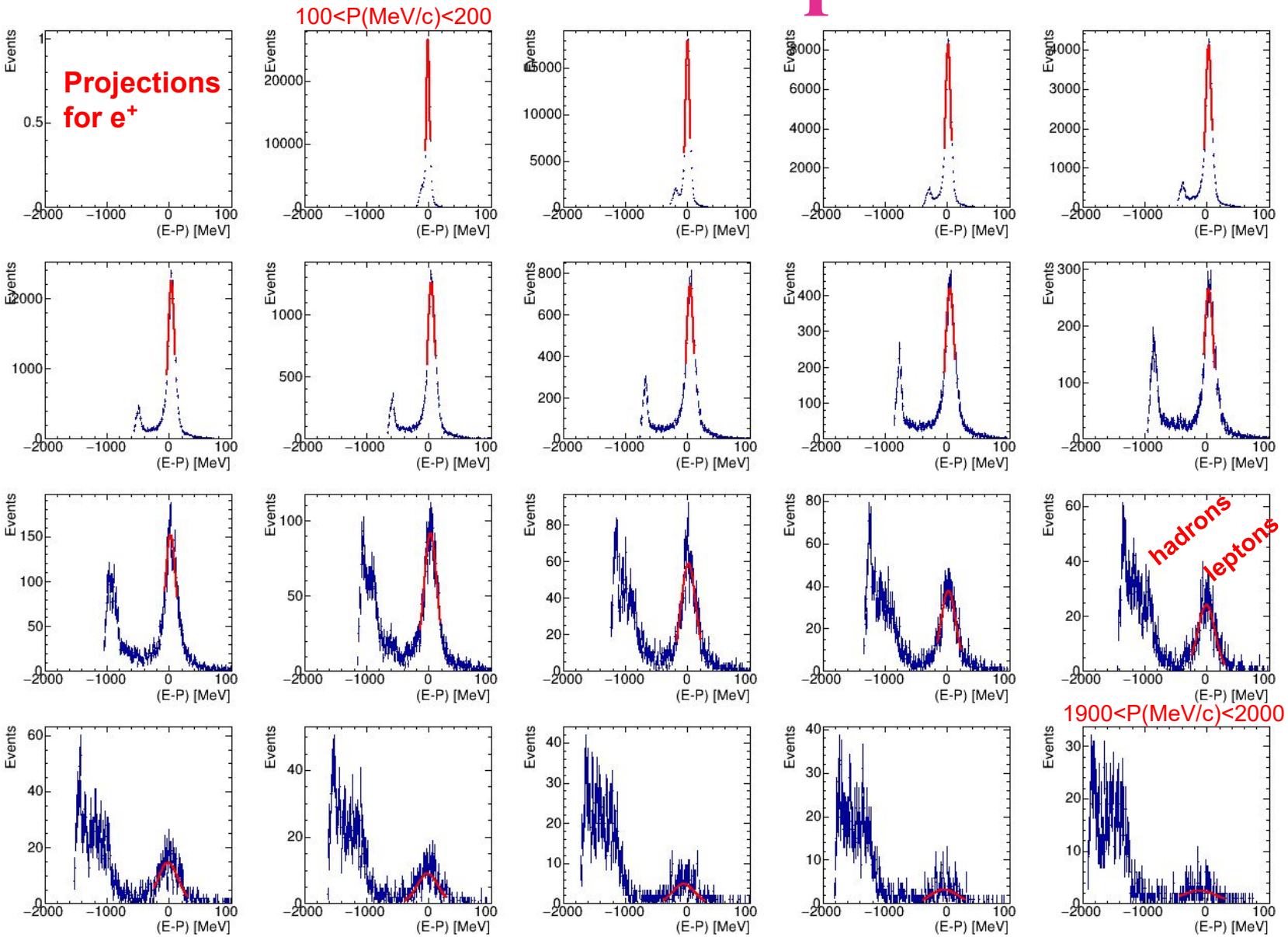
σ of $\Delta\theta$ distributions

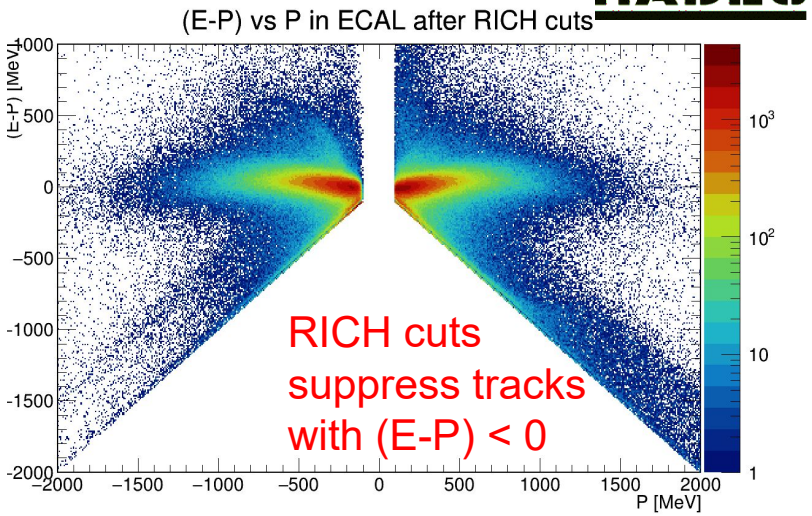




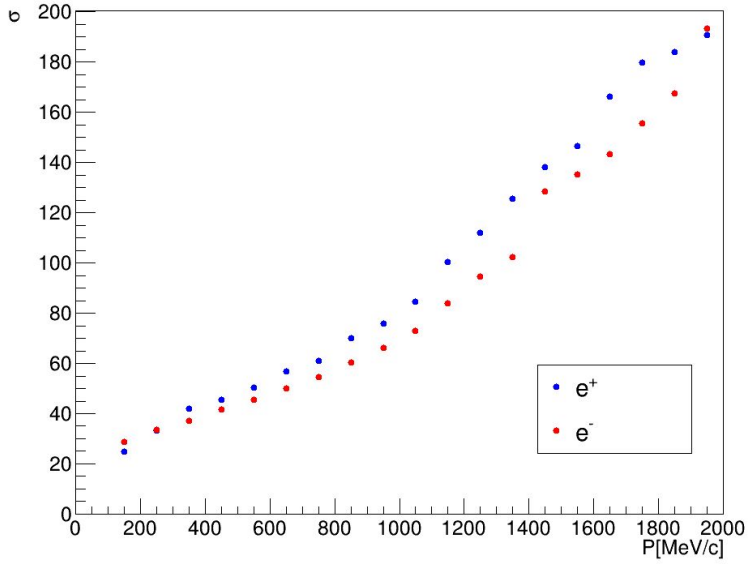
Define cuts on ECal parameters

$-3\sigma < E - P < +3\sigma$





σ of (E-P) distributions



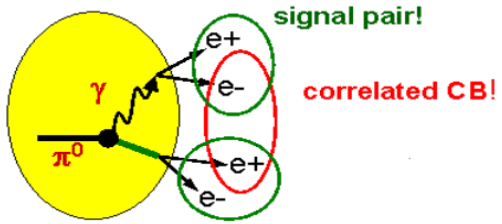
e^+e^- pairs

- Single e^+/e^- are combined into pairs.
- Combinatorial Background mostly due to conversion in the detector material.
- Rejection of e^+e^- pair combinations from different real or virtual photons.
- Same-event like-sign CB geometric mean.

$$\mathbf{CB = 2\sqrt{N_{++}N_{--}}}$$

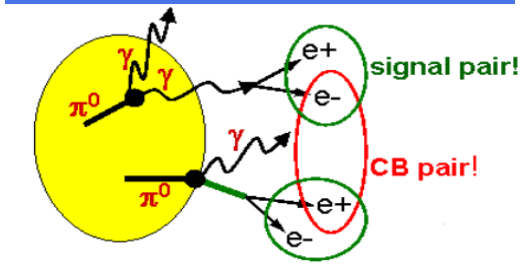
$$\mathbf{Signal = N_{+-} - CB}$$

Correlated CB



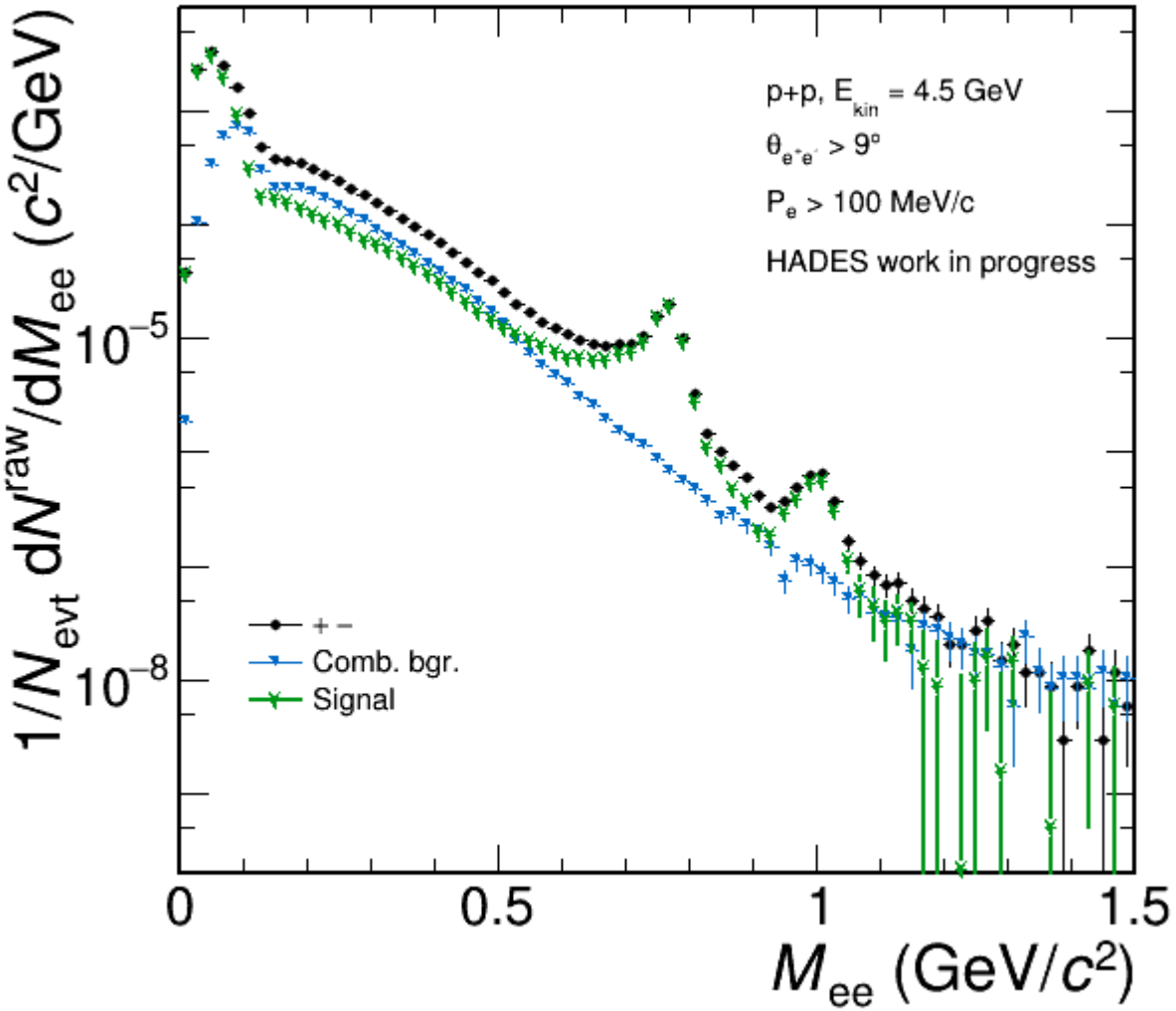
Same mother particle, different intermediate photons

Uncorrelated CB



Different mother particles

Pair cut : $\theta_{e^+e^-} > 9°$.

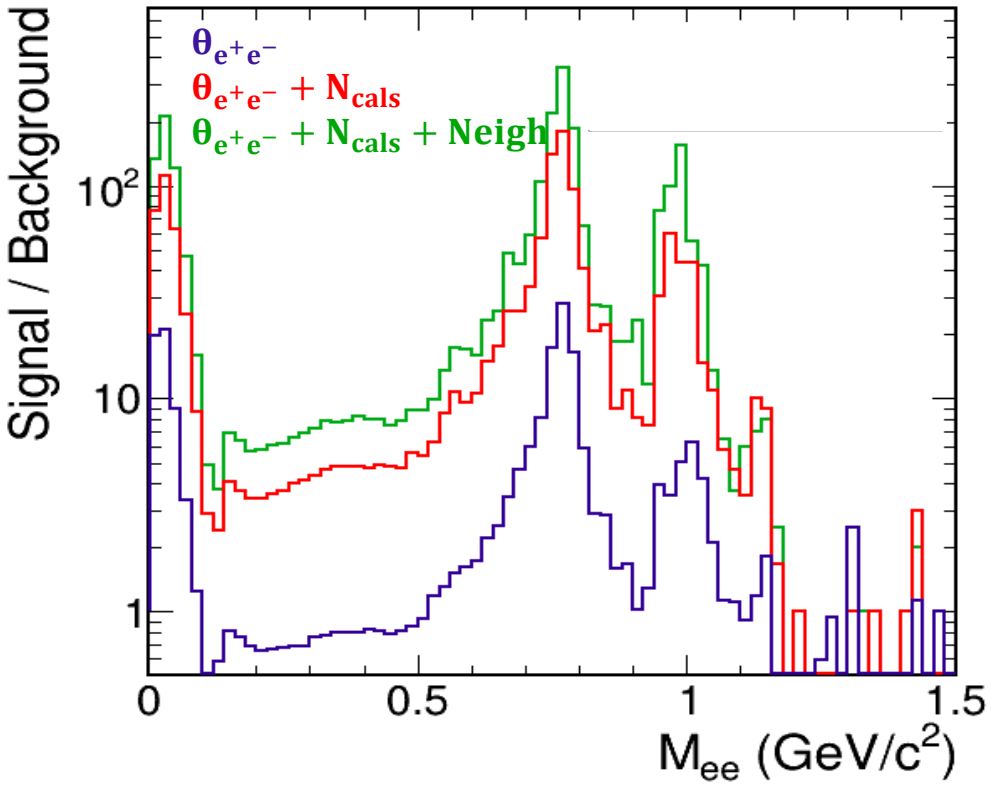


CB reduction

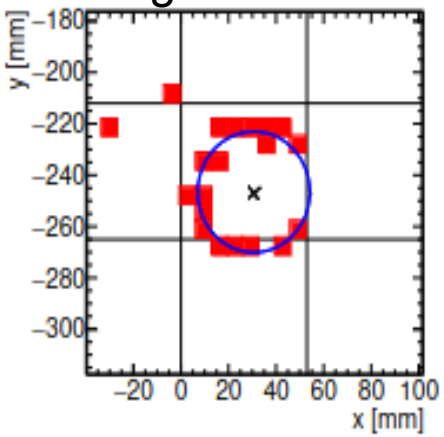
Jan-Hendrik Otto, http://dx.doi.org/10.22029/jlupub-7207

Cut on rings

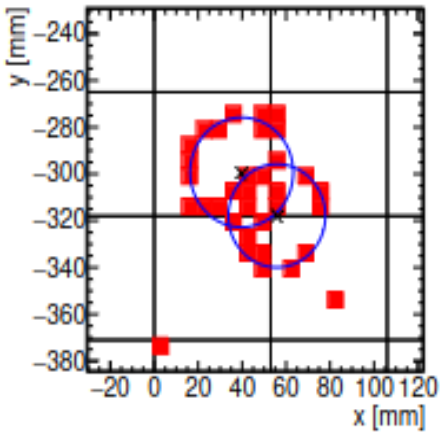
- Reject rings with opening angle <9°.
- Cal dependent double ring identification (cut on N_{cals}).



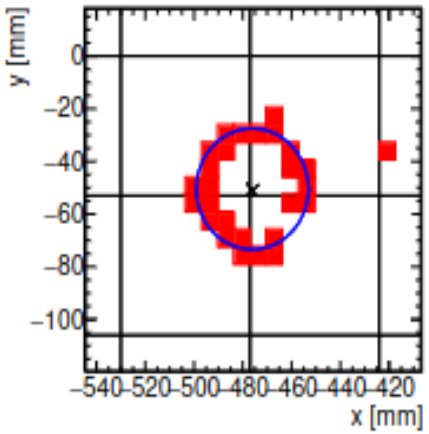
One electron signature



Close-by ring (small oangle)



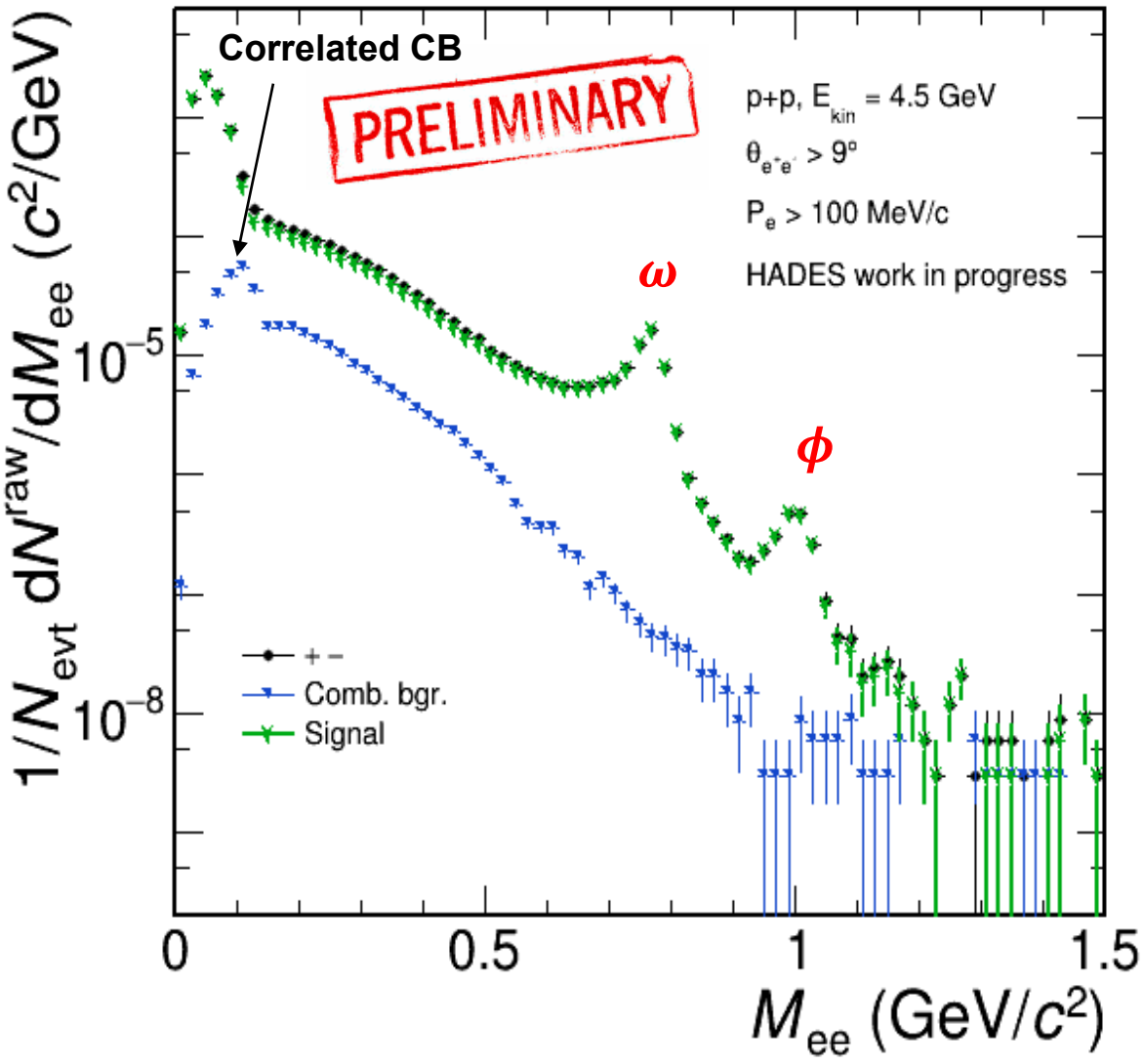
Double ring



Cut on tracks

- Tracks with a not fitted track in the vicinity of 4° are excluded from further analysis.

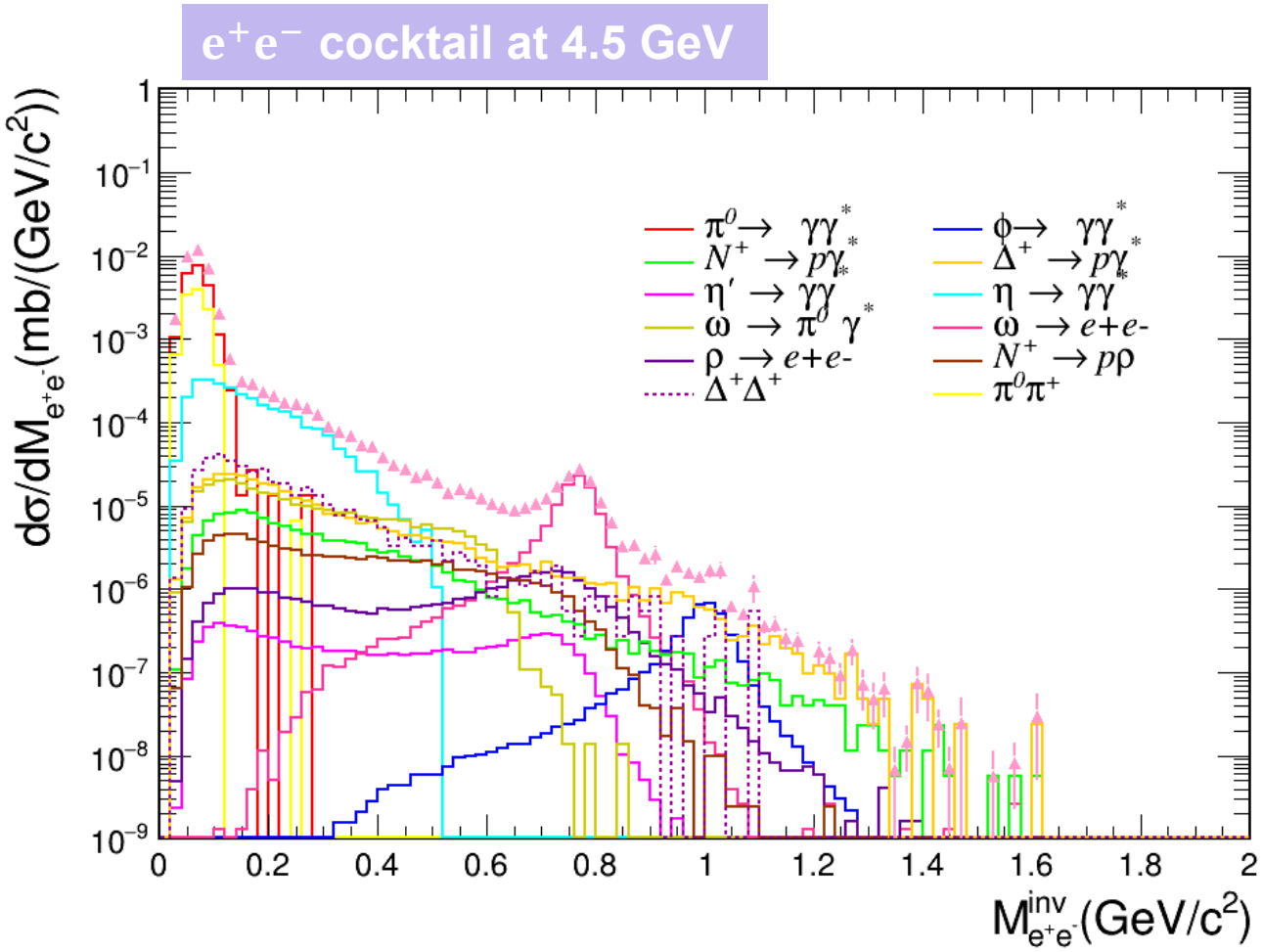
e^+e^- invariant mass spectrum



- Very low combinatorial background thanks to appropriate rejection of leptons from real photon conversion (S/B ~350 and ~ 150 in ω and ϕ region respectively).
- Vector mesons peaks are clearly seen, ω and φ.
- e^+e^- pairs are also reconstructed in the high invariant mass region ($M_{e^+e^-} > 1020\ MeV/c^2$).

$N_{+-}^{M_{ee}<150}$	$N_{+-}^{150<M_{ee}<M_\omega}$	N_ω	N_ϕ	$N_{+-}^{M_{ee}>1020}$
2×10^6	33×10^4	11000	350	100

PLUTO simulations



- PLUTO, event generator developed by HADES collaboration.
- Inputs: cross sections for the different dilepton sources.
- Pass events through Geant: detector geometry+instrumental effects.
- Reconstruction similar to data analysis.
- Build "inclusive" dilepton cocktail for pp at 4.5GeV.
- Flexible tool for comparison to data.

Importance of simulations

- Efficiency, acceptance corrections.
- Study detector effects.

Transport models developed by theoretician (SMASH, UrQMD) will be also used

Conclusion and Outlook

- Dileptons are an ideal probe to describe properties of hot and dense QCD matter.
- pp at 4,5 GeV is a reference for heavy-ion collisions at SIS100 energies.
- Finalized optimization of lepton selection.

- Data will be compared to simulations (PLUTO, SMASH).
- Extraction of ω and φ cross sections.
- Study of the exclusive channel $pp \rightarrow ppe^+e^-$ for selective study of baryon resonance Dalitz decay and ρ/ω decays, using missing mass.

Thank you for your attention!