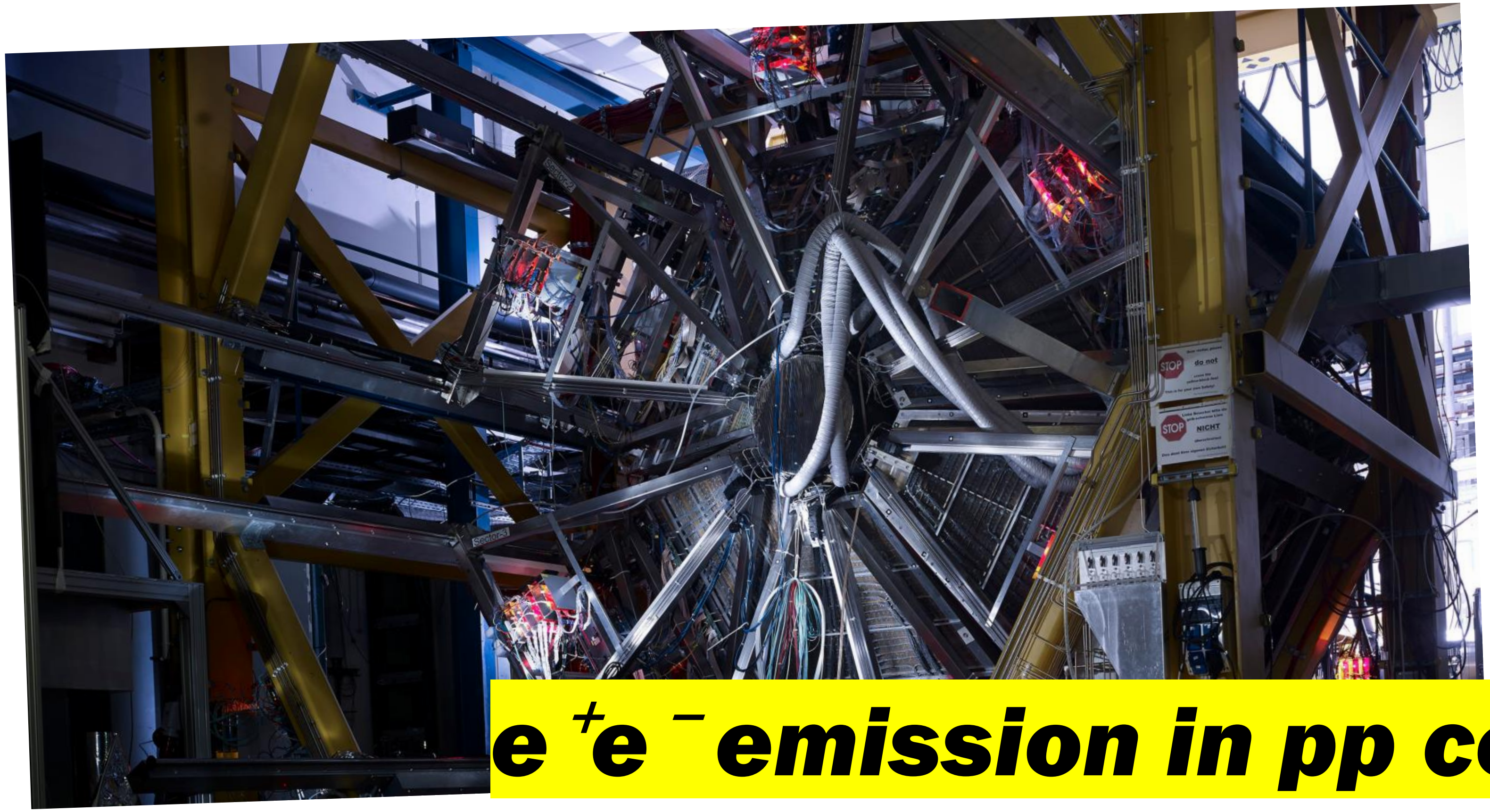


e^+e^- emission in pp collisions @ 4.5 GeV

HADES

Rayane ABOU YASSINE

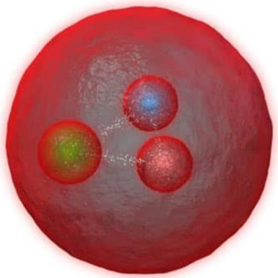
Journées de Rencontres Jeunes Chercheurs 2022

Outline

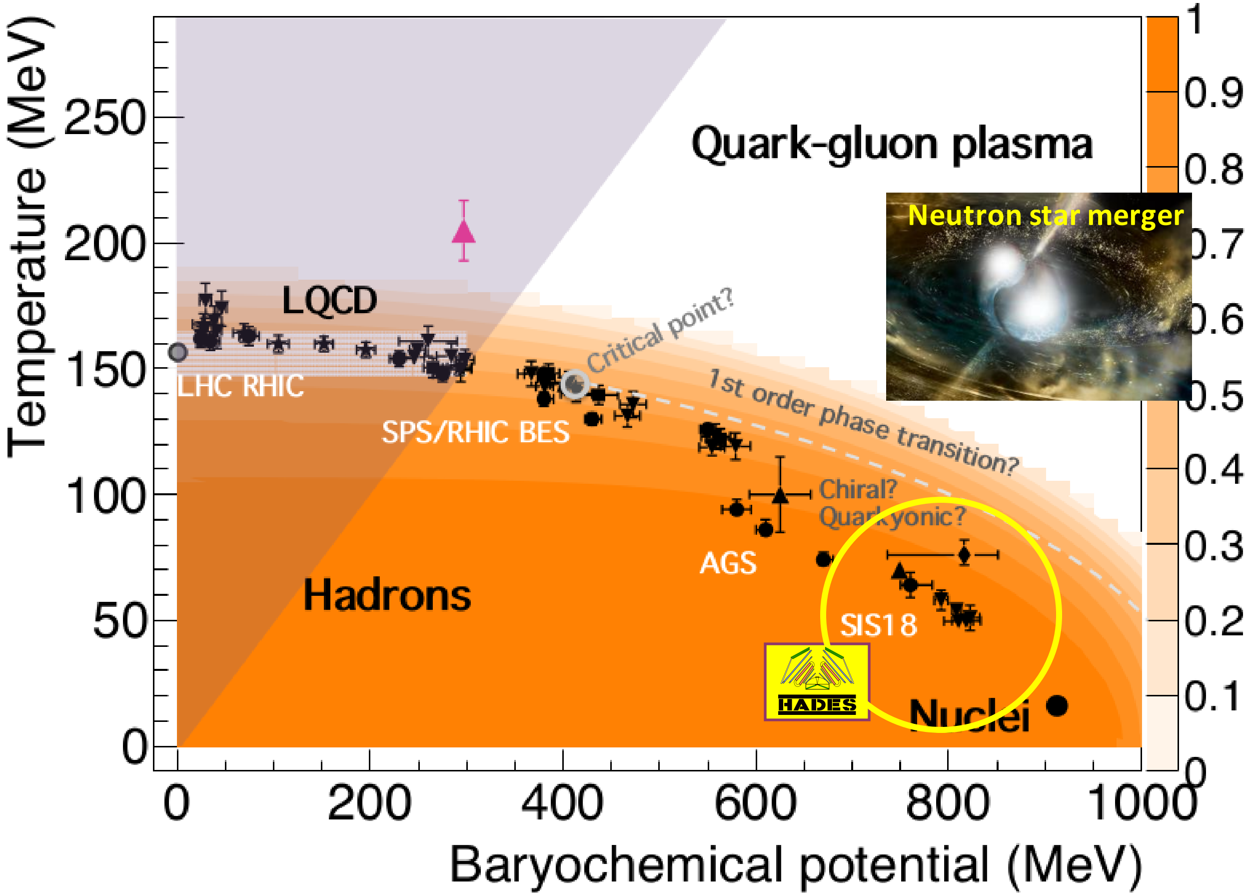
- Motivations.
- Data analysis.
- Simulations.
- Conclusion and outlook.

QCD phase diagram

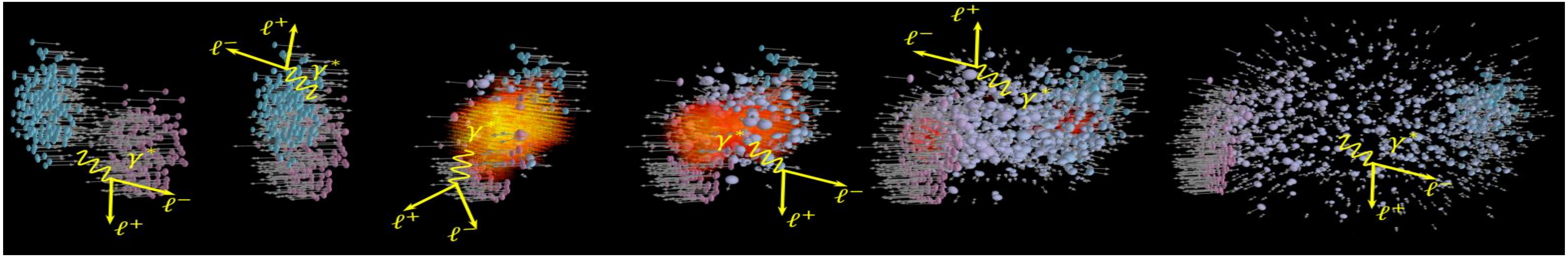
- HADES explores the high baryochemical potential region at low T, with heavy ion collisions SIS18 energies.
- Complementary to LHC, SPS, RHIC, etc …
  A+A: 1-3A GeV
  $\sqrt{s_{NN}}$ = 2-2.4 GeV } SIS18 range
- Equation of state of hadronic matter.
- Microscopic structure of baryon rich matter: baryonic resonances role.



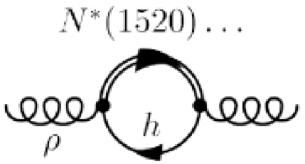
N(1440)
N(1520)
N(1535)
Δ(1232)
Δ(1620)



Why dileptons?

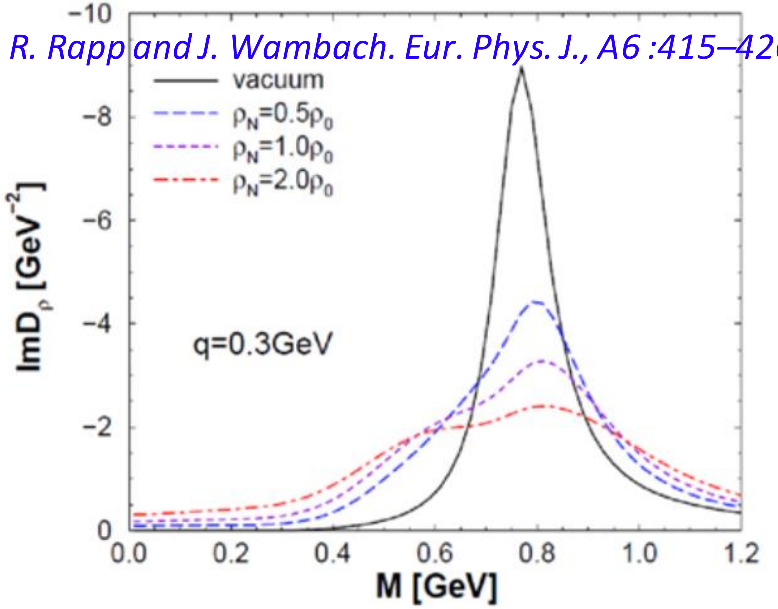


- Ideal probe of dense and hot phase of a heavy-ion collision.
- No strong final state interaction: mean free path larger than the system size ⇒reflect the whole history of the collision.
- Informations on matter properties (chiral symmetry restoration, fireball lifetime, temperature, etc ..).
- Study in-medium properties of vector mesons ($J^P = 1^-$) (ρ,ω,ϕ), by their decay to e^+e^- pairs → vector meson spectral function expected to be modified due to their coupling to baryons.



meson	mass (MeV/c²)	Γ (MeV/c²)	cτ (fm)	main decay	e^+e^- branching ratio
ρ	768	152	1.3	$\pi^+\pi^-$	4.4 10^{-5}
ω	782	8.43	23.4	$\pi^+\pi^-\pi^0$	7.2 10^{-5}
ϕ	1019	4.43	44.4	K^+K^-	3.1 10^{-4}

R. Rapp and J. Wambach. Eur. Phys. J., A6 :415–420, 1999.



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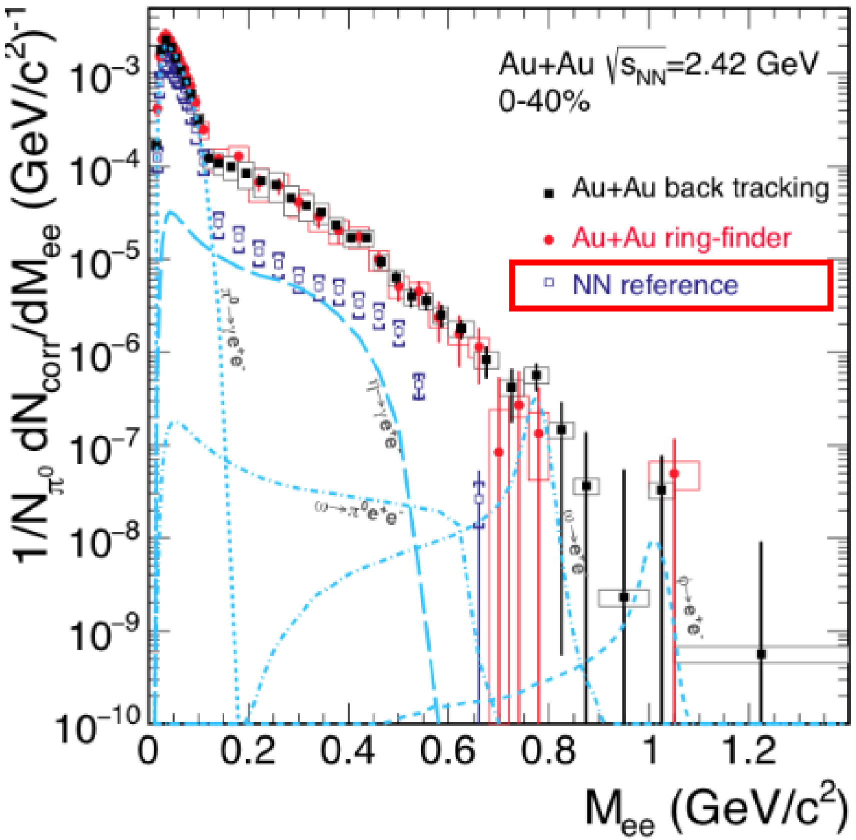
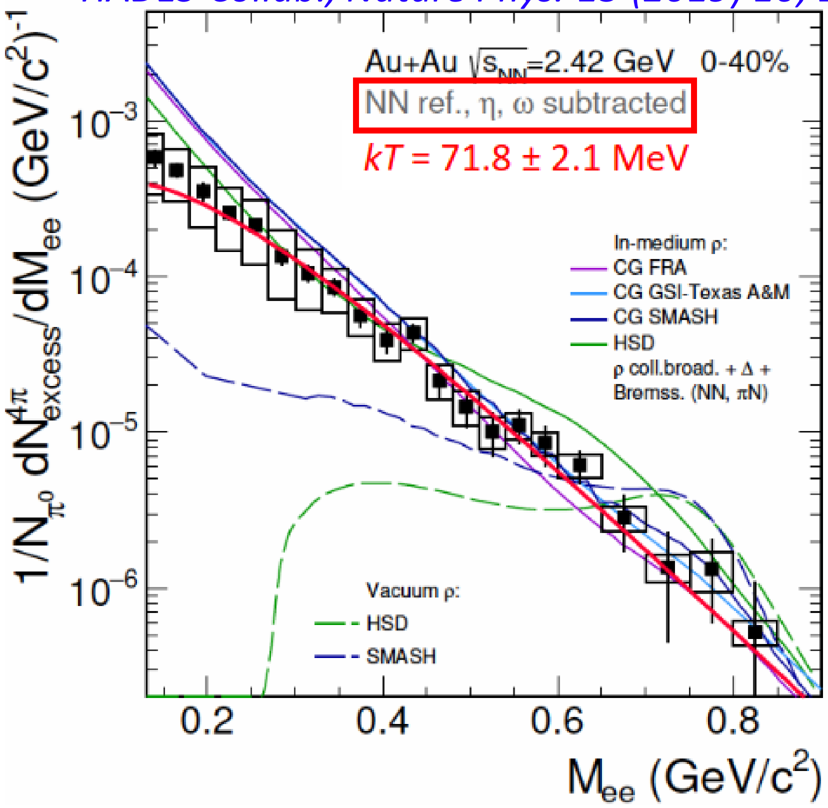
From heavy-ion to elementary reactions

- Elementary reactions don't produce a medium that can influence the structure of the hadrons via density and/or temperature effects.
- Dilepton inclusive channels provide reference spectra to the heavy ion collisions studies.
- Exclusive e^+e^- channels allow for selective study of production mechanisms.

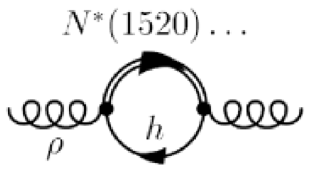
Nature Phys. 15 (2019) no.10, 1040-1045



HADES Collab., Nature Phys. 15 (2019) 10, 1040-10

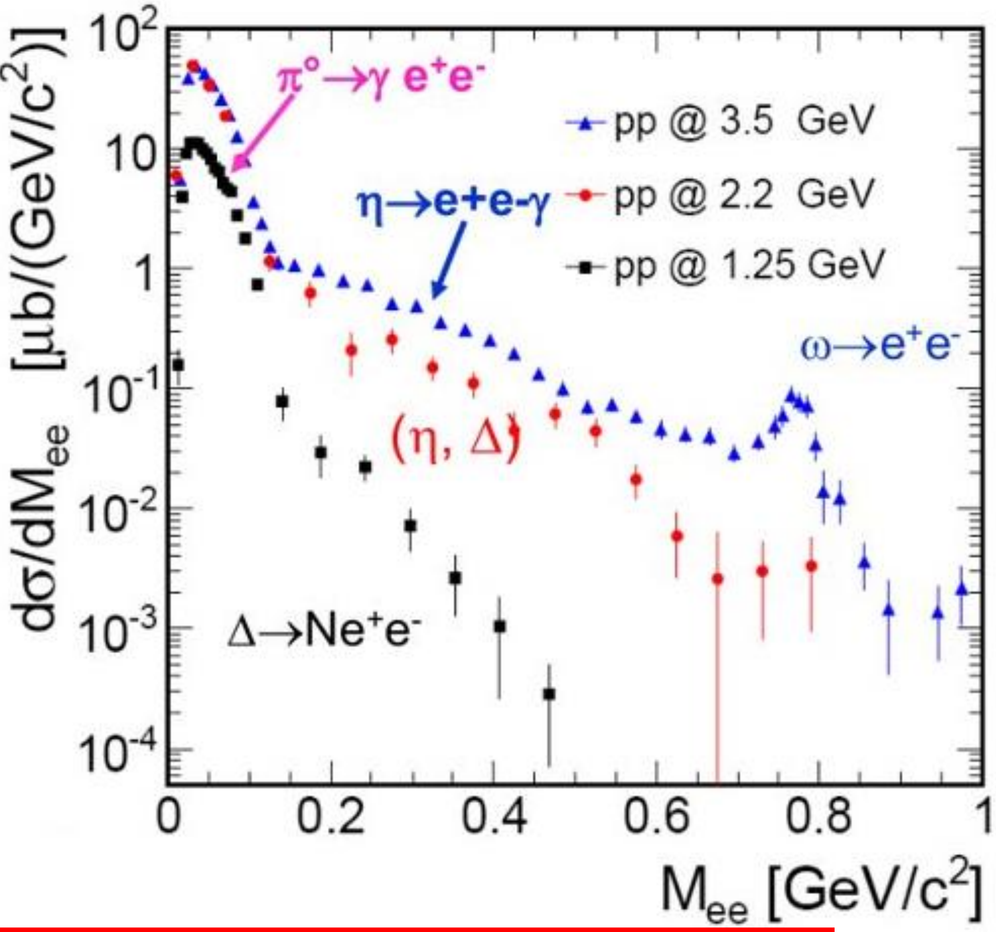


From heavy-ion experiments:
Strong broadening of in medium ρ spectral function due to its coupling with baryonic resonances.



Study of pp reactions with HADES

G. Agakishiev et al., PRC85 054005 (2012); Eur.Phys.J. A50 (2014) 8



Main dilepton sources for pp collisions

Long lived sources

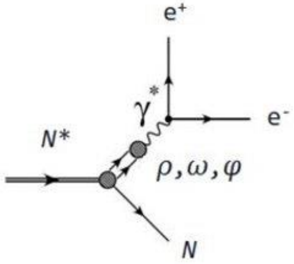
- π^0 Dalitz-decay (BR~1.2%): $\pi^0 \to \gamma e^+e^-$.

$\Delta(1232) \to N\pi^0$, $N(1520) \to N\pi^0\pi$,…

- η Dalitz decay (BR ~0.6%): $\eta \to \gamma e^+e^-$.

$N(1535) \to N\eta$,…

- η' Dalitz decay (BR~4.7x10^{-4}): $\eta' \to \gamma e^+e^-$.
- ω Dalitz-decay (BR~7.7x10^{-4}): $\omega \to \pi^0 e^+e^-$.
- ω direct decay (BR~7x10^{-5}): $\omega \to e^+e^-$.
- ϕ direct decay (BR~3x10^{-4}): $\phi \to e^+e^-$.

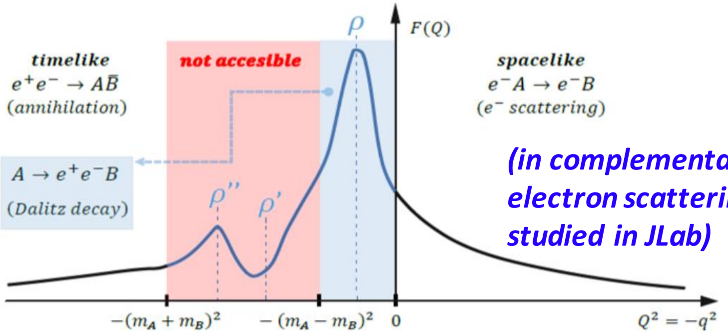


Short lived sources

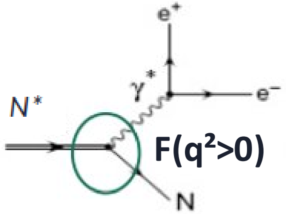
- ρ direct decay (BR~4x10^{-5}): $\rho \to e^+e^-$.
- Baryon Dalitz-decay $\Delta/N^* \to Ne^+e^-$.

} Vector dominance model.

→ Time-like electromagnetic baryon transition form factors.



(in complementary to electron scattering studied in JLab)



Recent experiment pp at 4.5 GeV/nucleon FEB22

- It will be reference for future heavy-ion collisions at higher energies (SIS100): role of baryonic resonances at this energy.
- Expected to see ϕ in the e^+e^- invariant mass spectrum.

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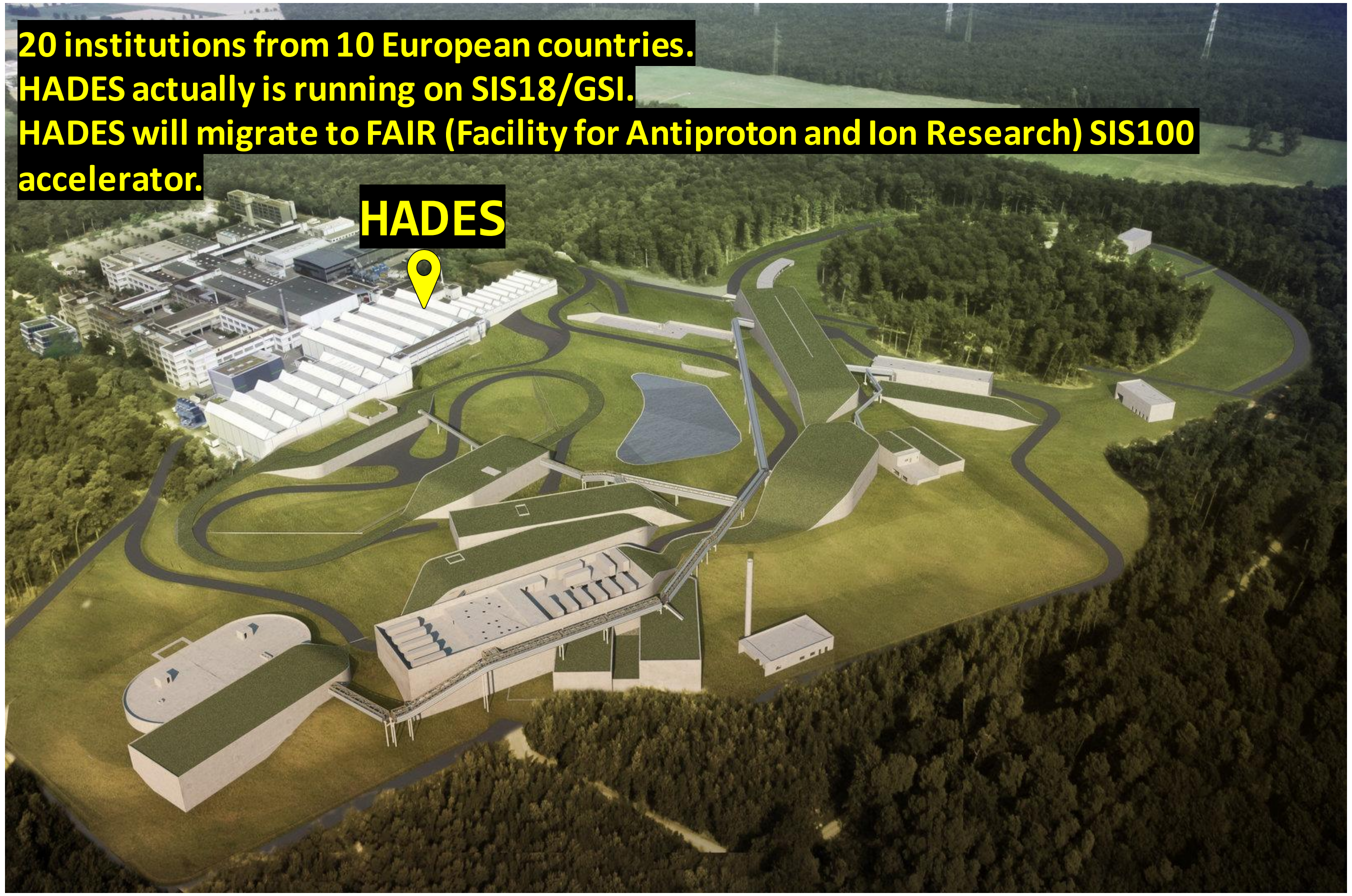
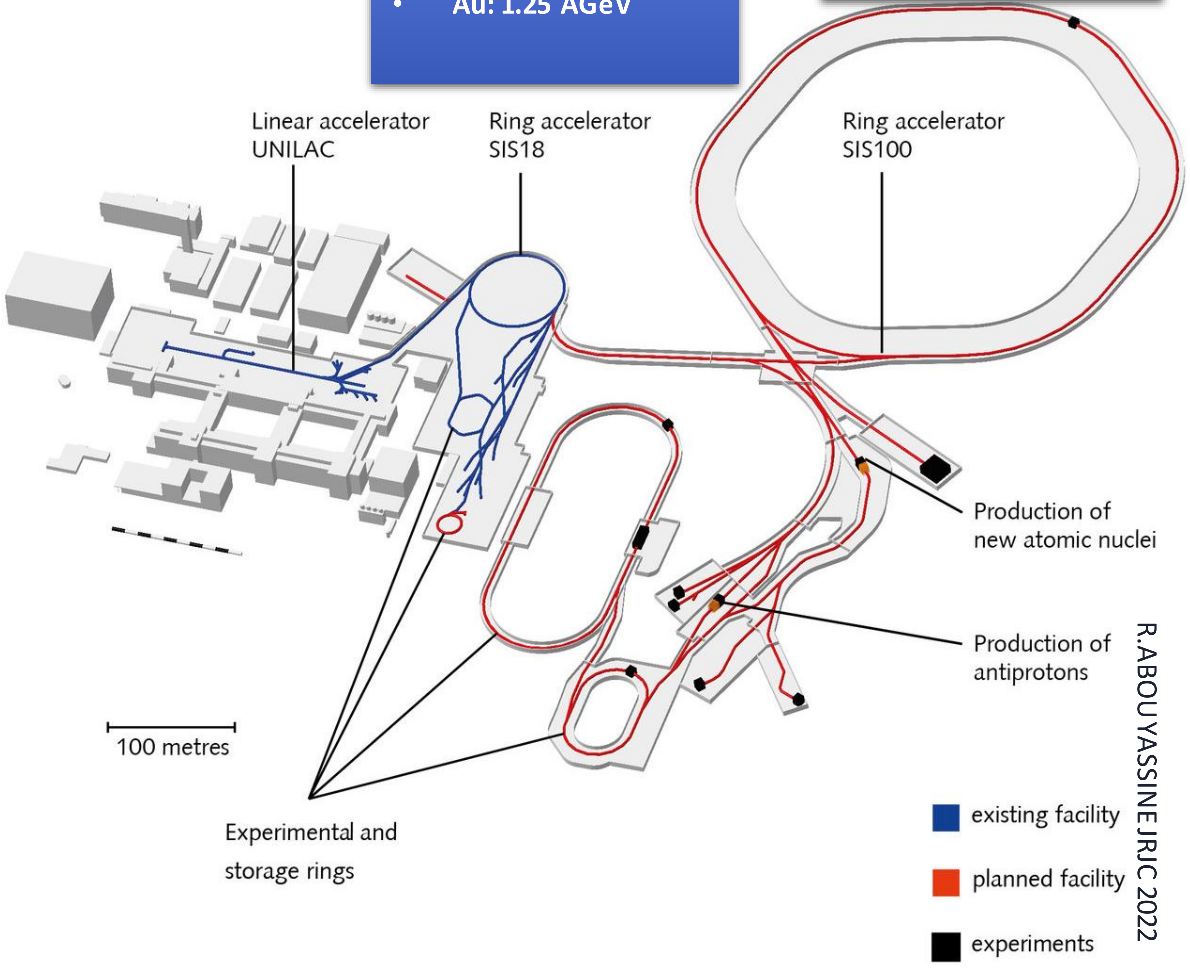
HADES collaboration and FAIR @ GSI



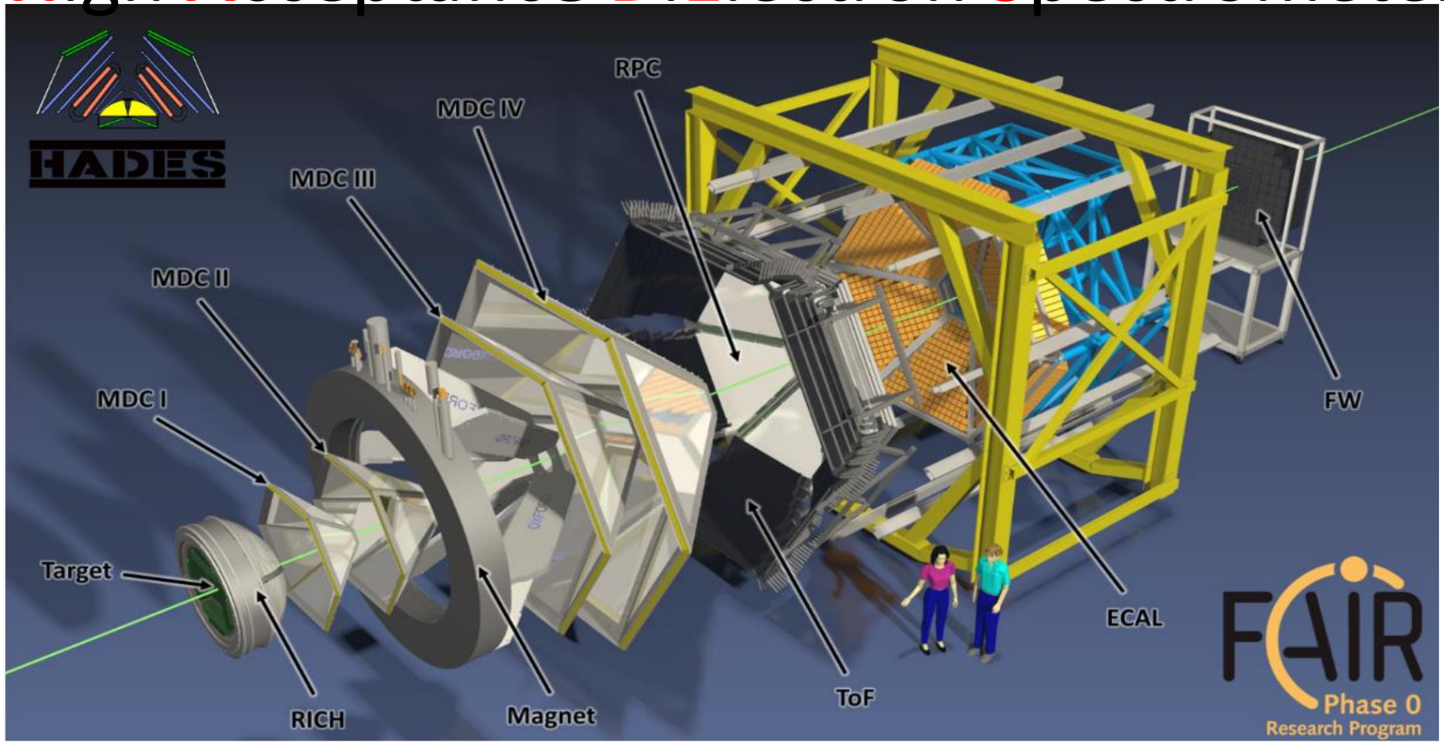
Emax:
- p: 4.5 GeV/nucleon
- Au: 1.25 AGeV

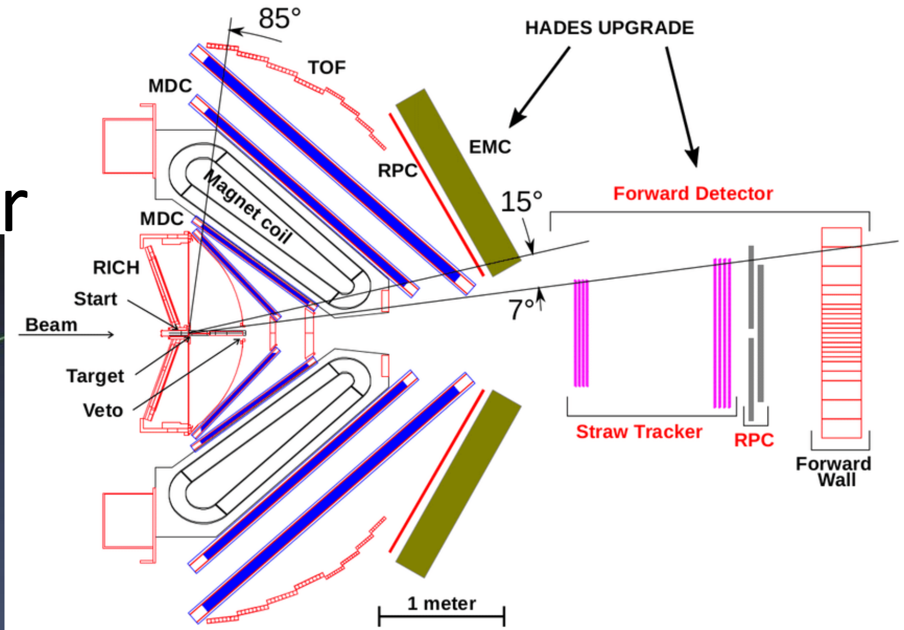
Emax:
- p: 29 GeV/nucleon
- Au: 11 AGeV



HADES experimental setup

High Acceptance DiElectron Spectrometer





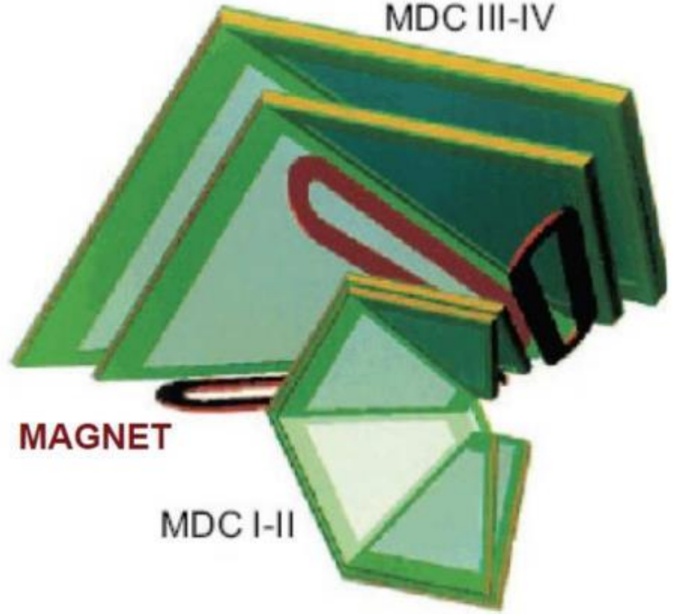
- Fixed target experiment.
- Large geometrical acceptance: full azimuthal range and polar angles 18° and 85°.
- Efficient track reconstruction and momentum determination (MDC+Magnet) and particle identification (RICH, TOF, RPC and ECal).
- FWD: polar angles [0.5°-7°].

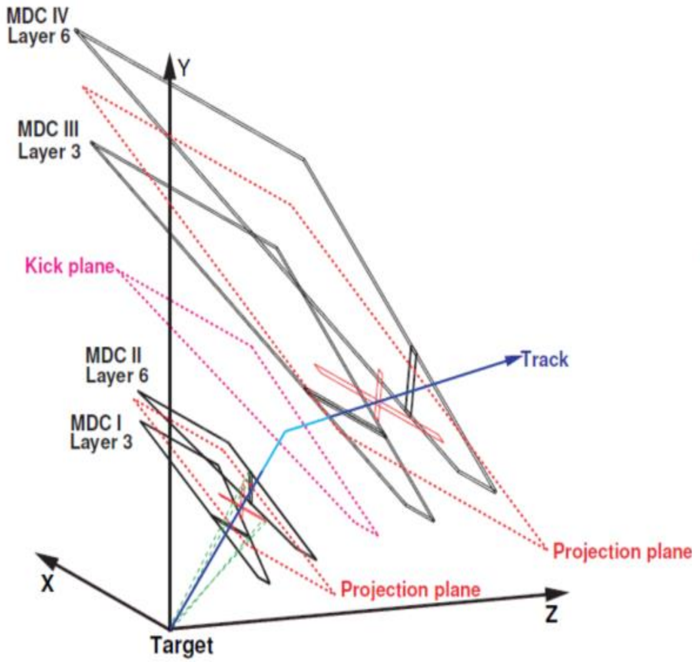
Experiments (2004-2022)

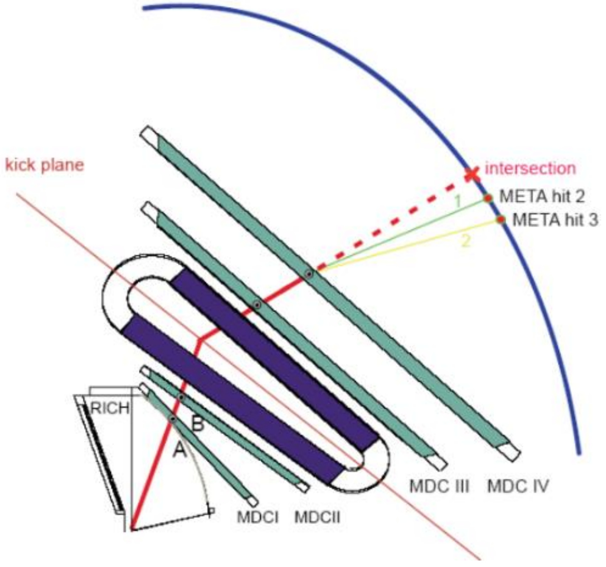
- Dense and hot hadronic matter studies: **C+C** (1 and 2 AGeV), **Ar+KCl** (1.75 AGeV), **Au+Au** (1.25 AGeV), **Ag+Ag** (1.65 AGeV).
- Cold matter studies : **p+Nb** (3.5 GeV), **π^-+C/W** (1.7 GeV/c), **π^- + CH2/C** (0.7 GeV/c).
- Elementary reactions: **p+p** (1.25, 2.2, 3.5 and recently 4.5 GeV), **d+p** (1.25 GeV/nucleon).

Track reconstruction and momentum determination

- Principle: reconstruction of particle momentum by the measurement of their deflection in the magnetic field.
- Two segments are fitted to the hits measured in inner and outer MDC chambers.
- Full track reconstruction and momentum determination using fourth order Runge-Kutta algorithm.
- Outer segments need to be combined with META hits (time of flight measurements in TOF and RPC).







Lepton identification using time of flight

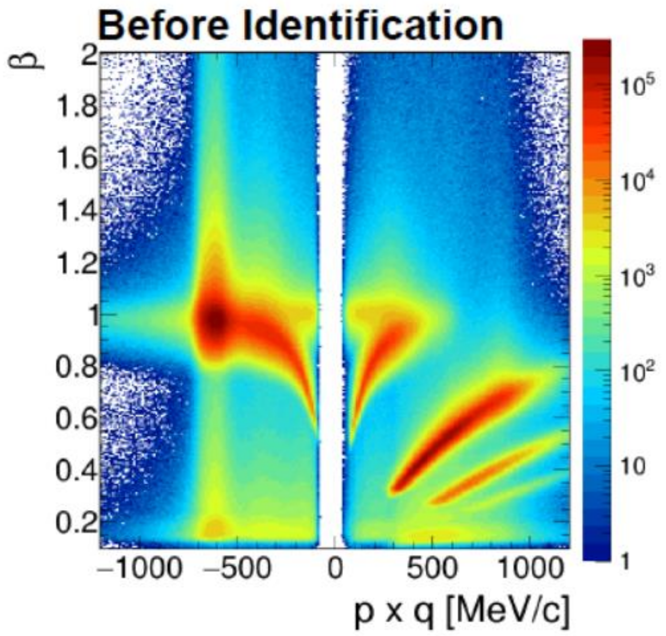
Time of flight measurement

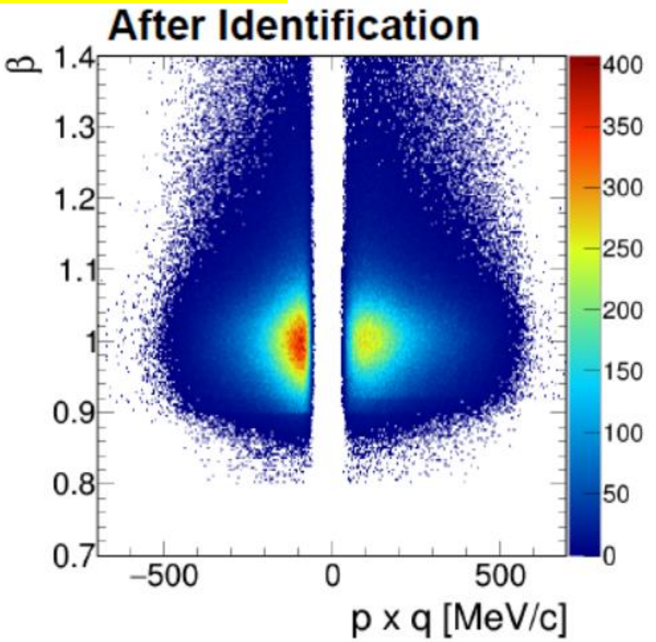
- Measured using difference of arrival time between the START and the TOF detectors signals.

Time and momentum correlation

- Track length + time of flight ⇒ velocity (β).
- For given mass ⇒ correlation between β and P.

$$p = \beta \times m / \sqrt{1 - \beta^2}$$





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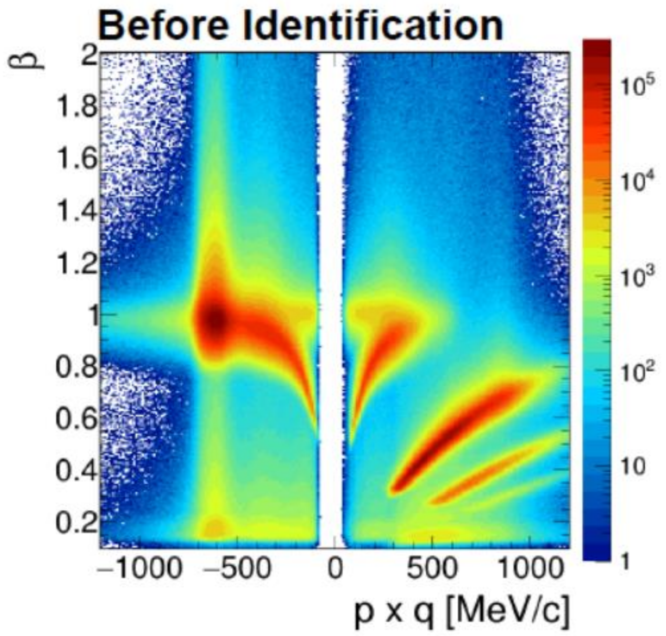

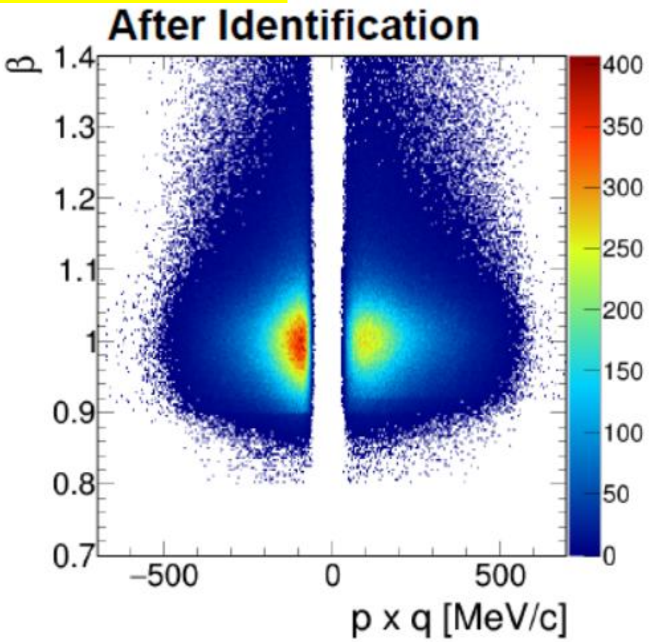

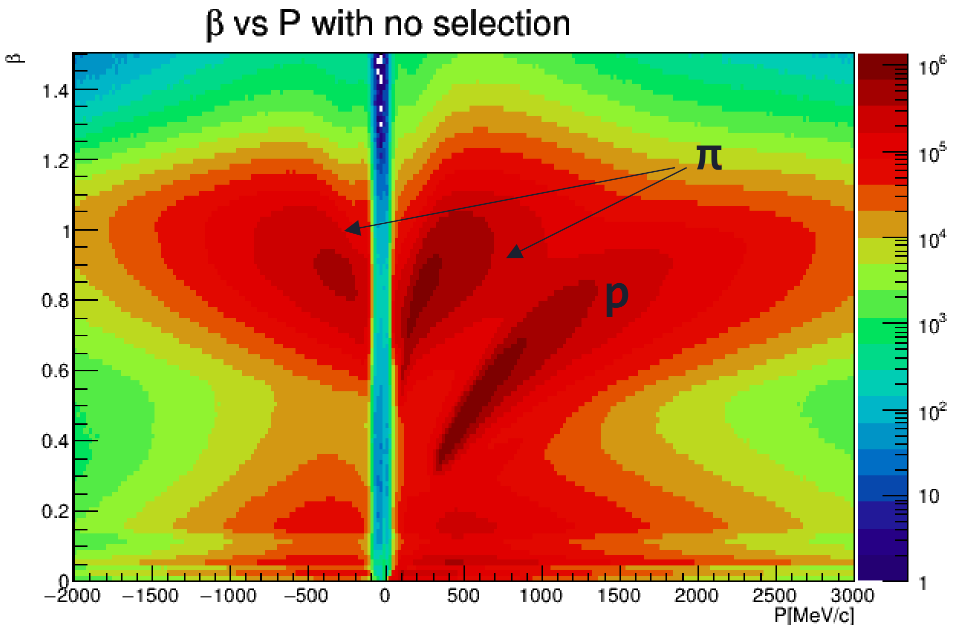

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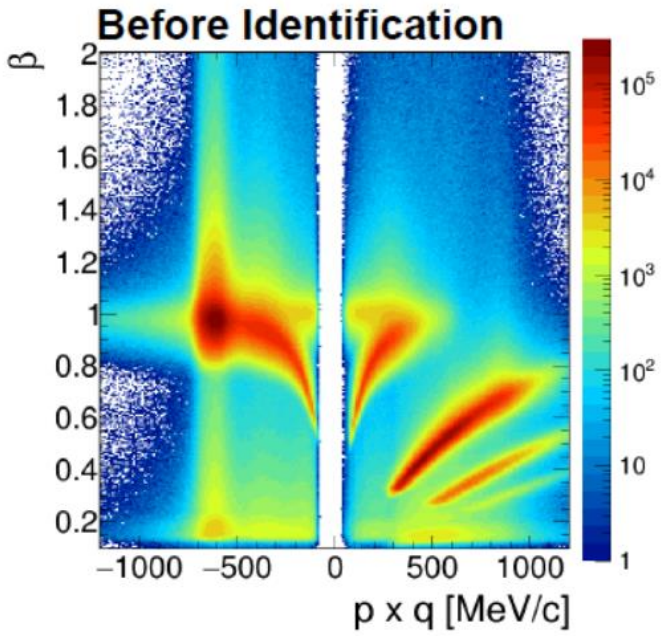
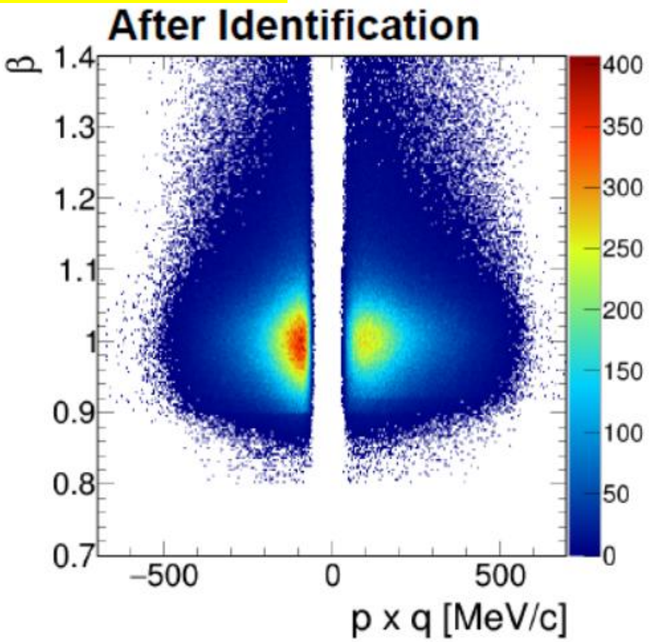
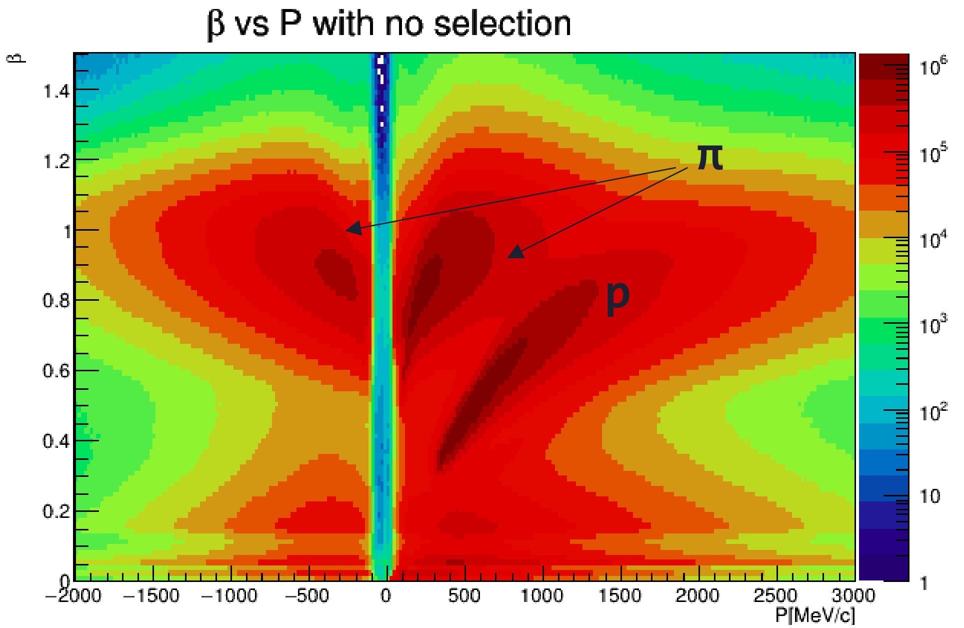
Waiting for the START detector calibration!







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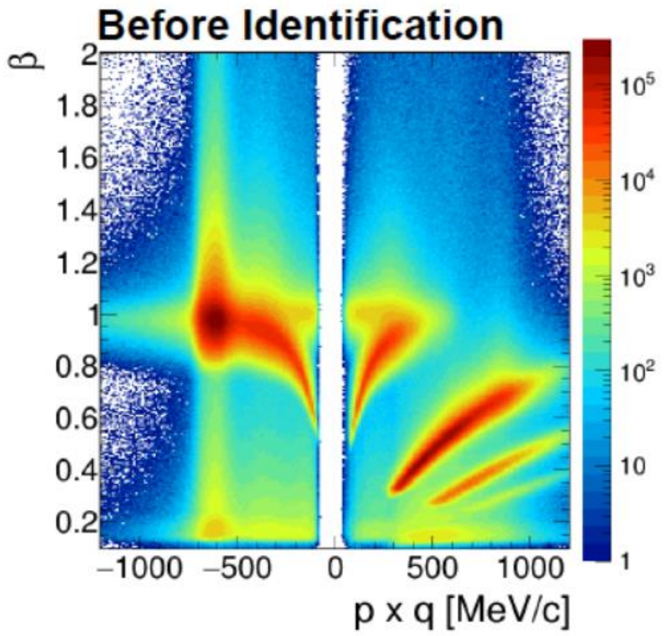
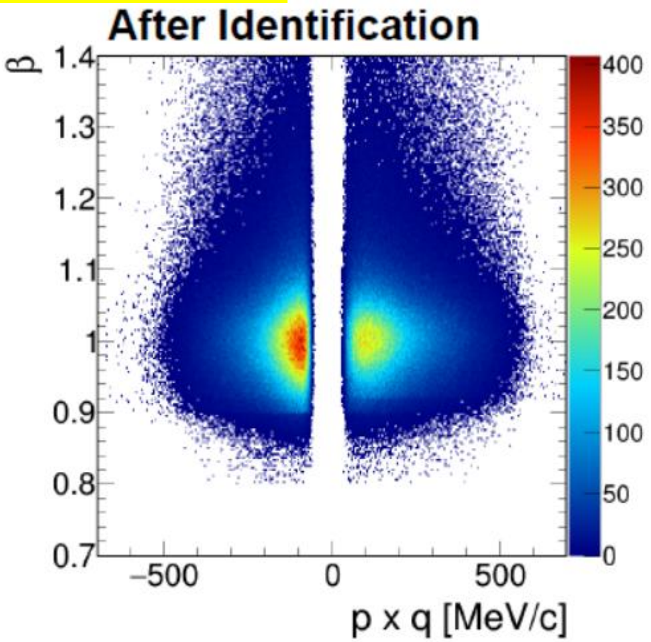
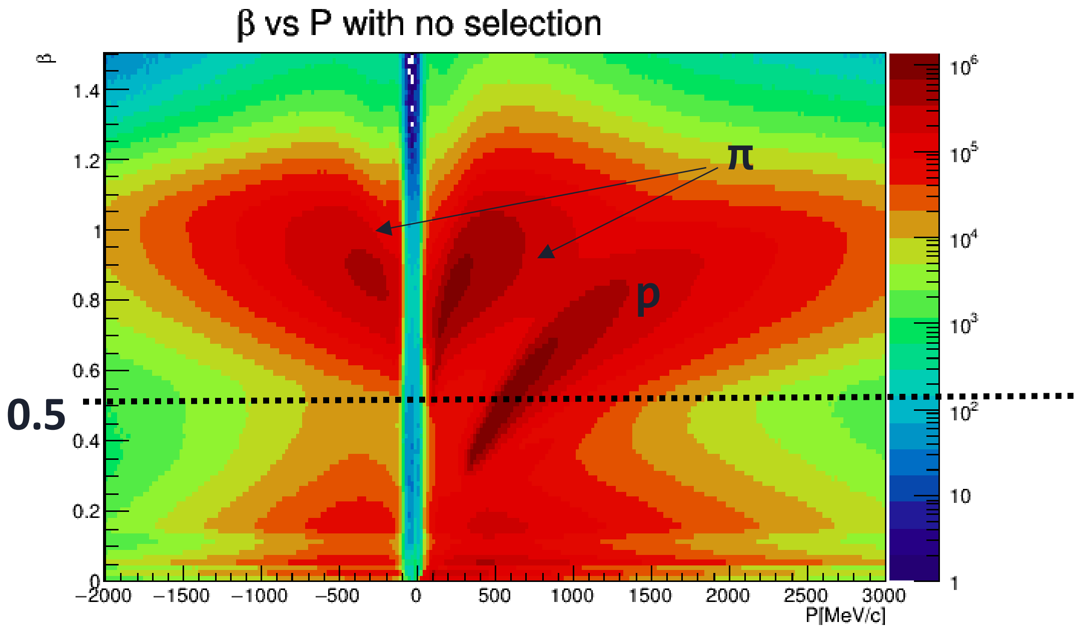




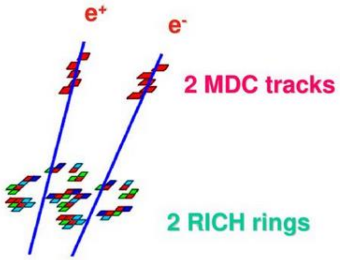
Waiting for the START detector calibration!

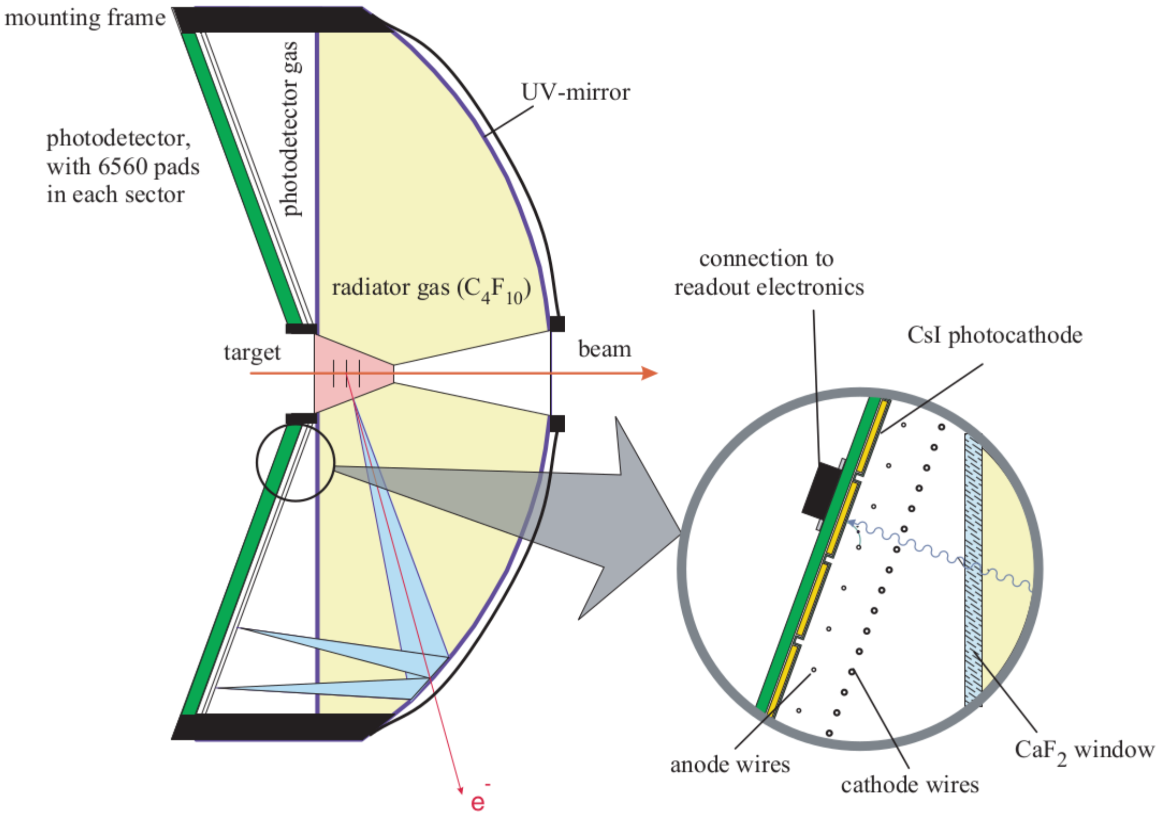
Loose cut on β>0.5



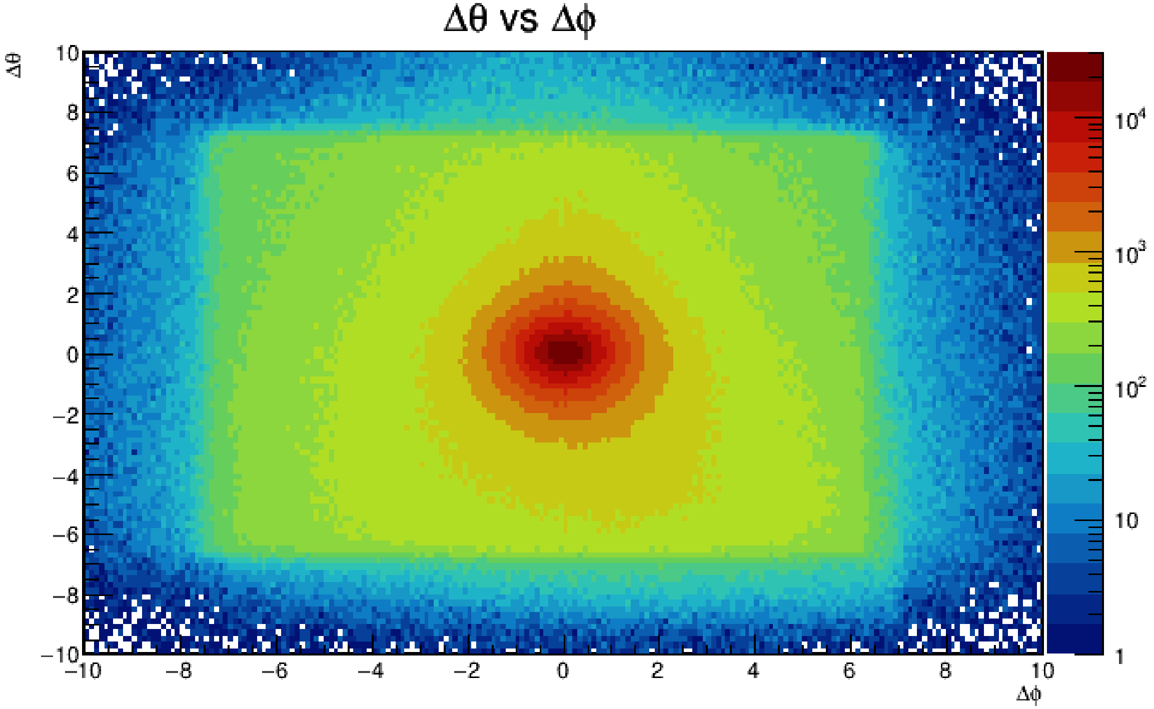
Lepton identification using RICH

- RICH: only e^+e^- give a signal (ring).
- **RICH-MDC correlation:** consider spatial correlation between the track directions found in the RICH and the inner MDCs track segments.
- Need to put cuts on the differences between the angles of the track candidate and the rich ring center: Δθ and Δϕ.





First e^+e^- candidates selection criteria:
Δθ and Δϕ between -8° and 8°.



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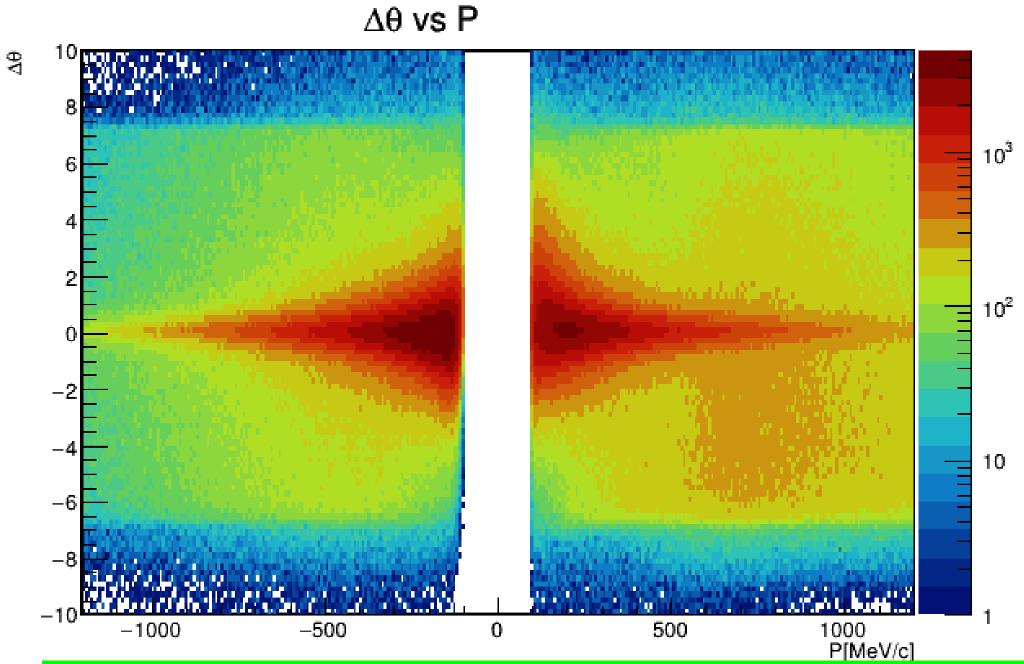
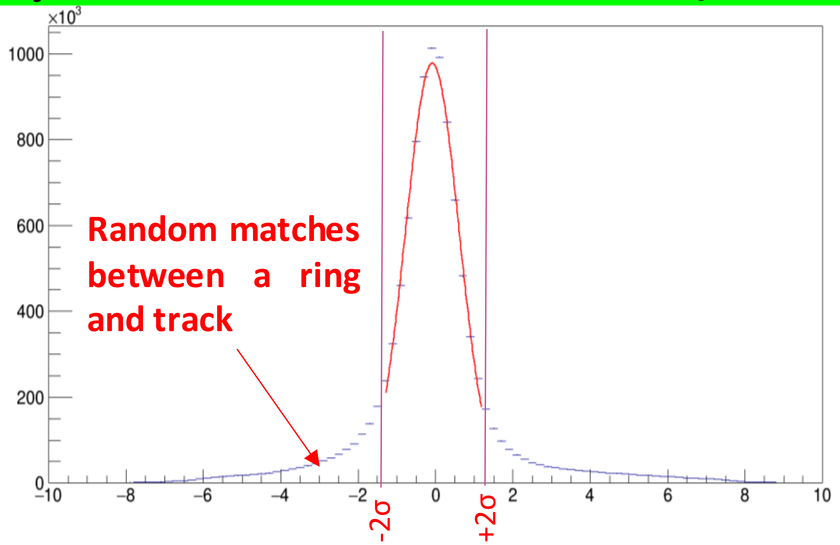
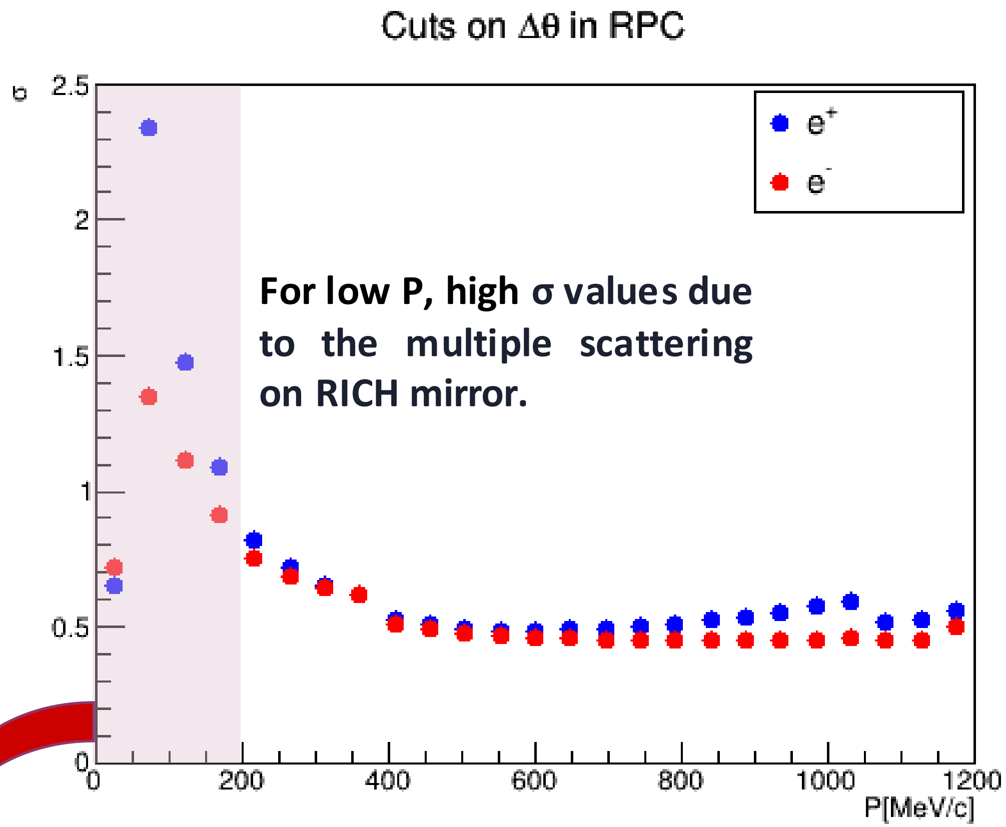
Adjusting cuts on RICH parameters



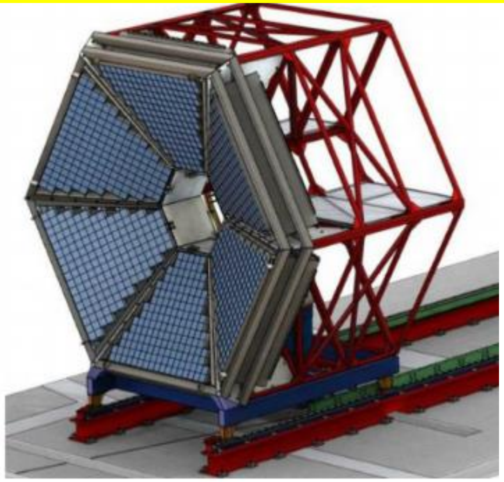
Δθ projections on slices of momenta 50MeV/c + Gaus Fit.



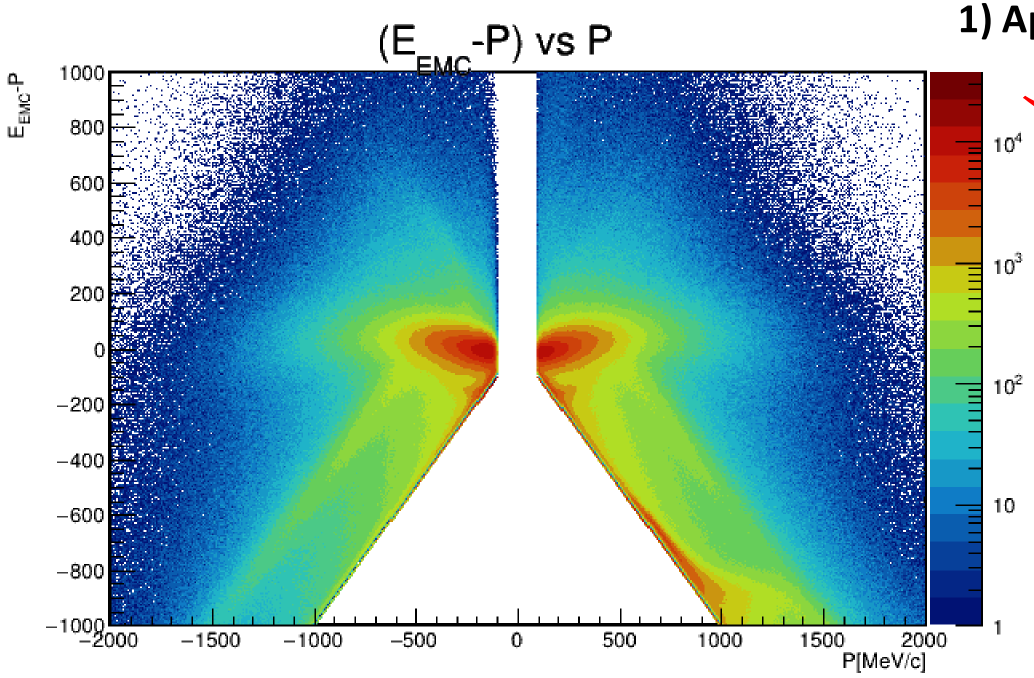


- Do same work for Δϕ.
- Put cuts on Δθ & Δϕ between **-2σ** and **2σ**.

Lepton identification using ECAL



- Improve the lepton-pion separation at high momenta.
- e^+/e^- leave all their energy in the ECal (E-P close to 0).
- Hadrons leave much less energy (E-P <0).
- 6 sectors covering $12^\circ < \theta < 45^\circ$.
- First sector not present.



1) Apply RICH cuts

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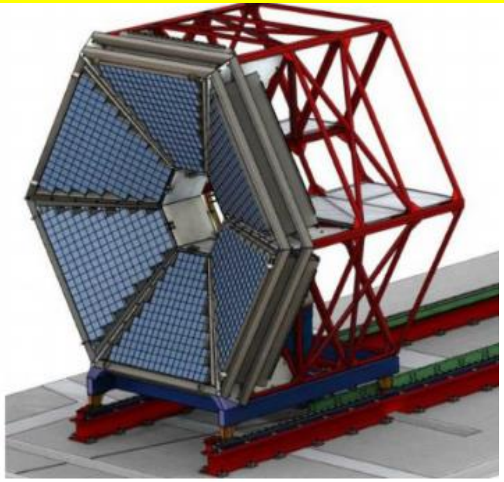
Lepton identification using ECAL



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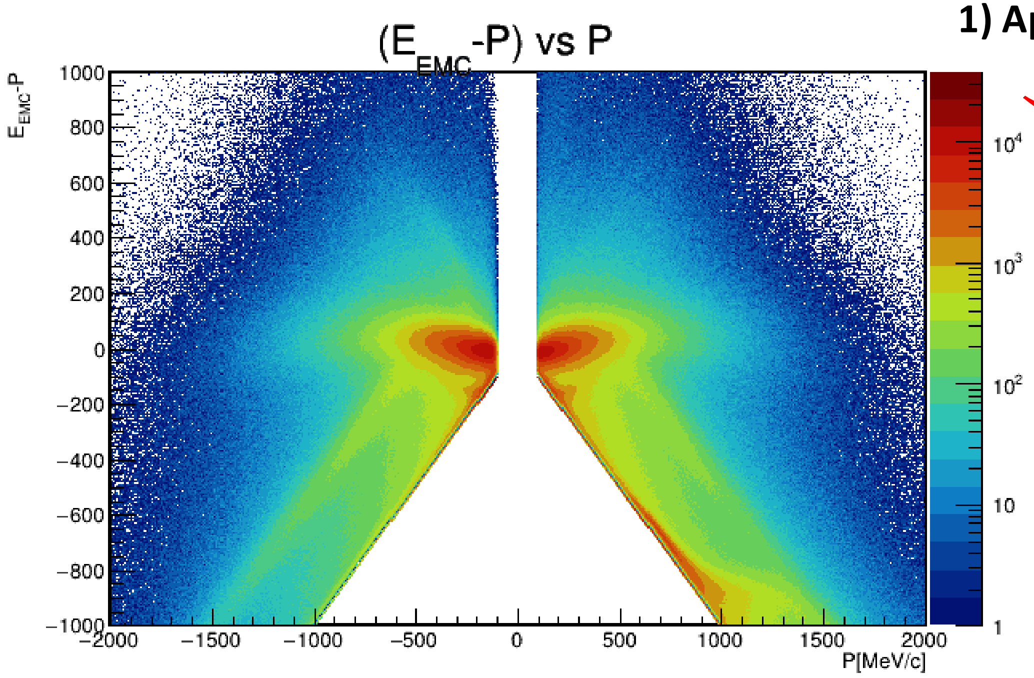

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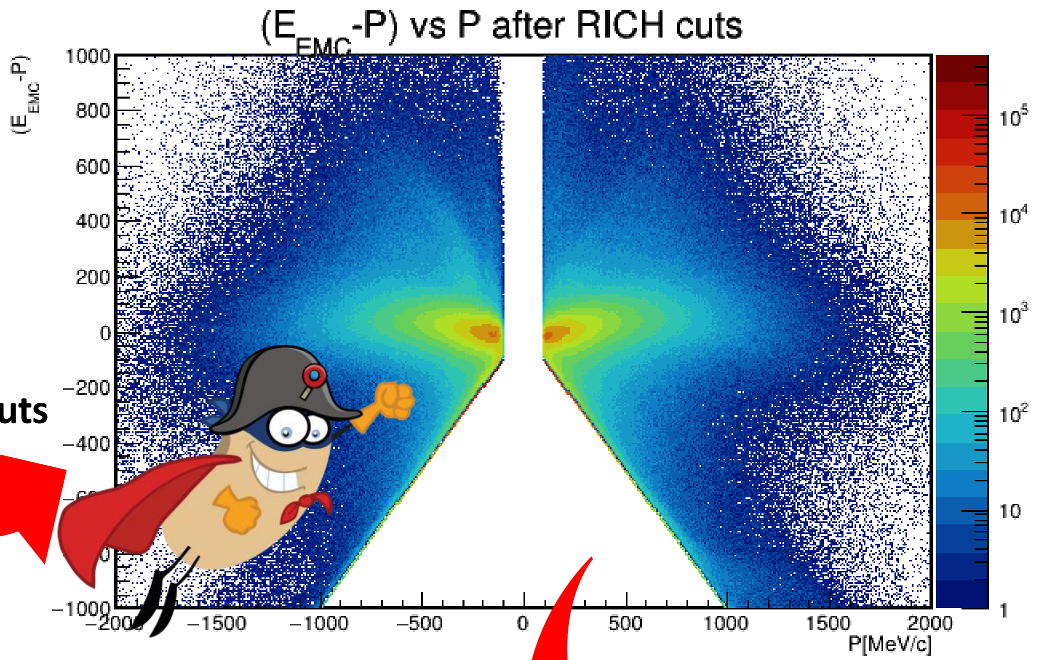

2) Define ECal cuts : projections+gaus fit.
Take -2σ < (E-P) < 2σ

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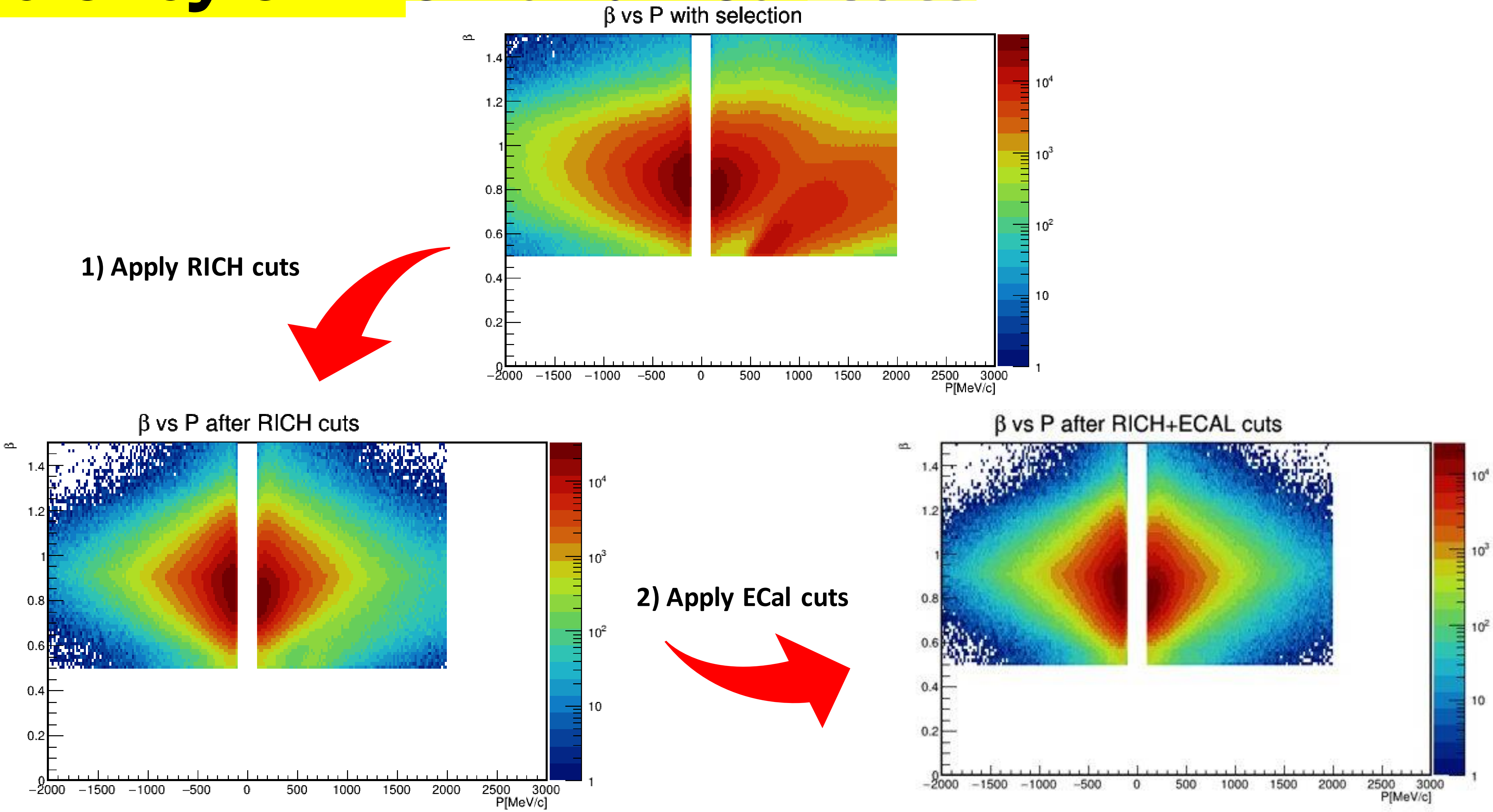
Efficiency of RICH and ECal cuts

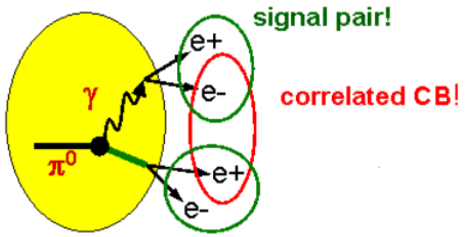


e^+e^- pairs selection

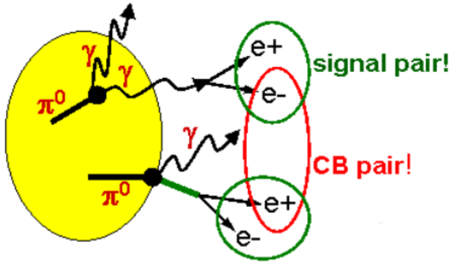
- After selection of single e^+/e^- , they should be combined into pairs .
- e^+e^- pair combinations from different virtual or real photons conversion : **to be rejected!**
- **Combinatorial background** estimation based on like-sign pairs.

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

- **Correlated CB**: e^+ and e^- coming from the same mother particle, but not from the same intermediate (virtual) photon.



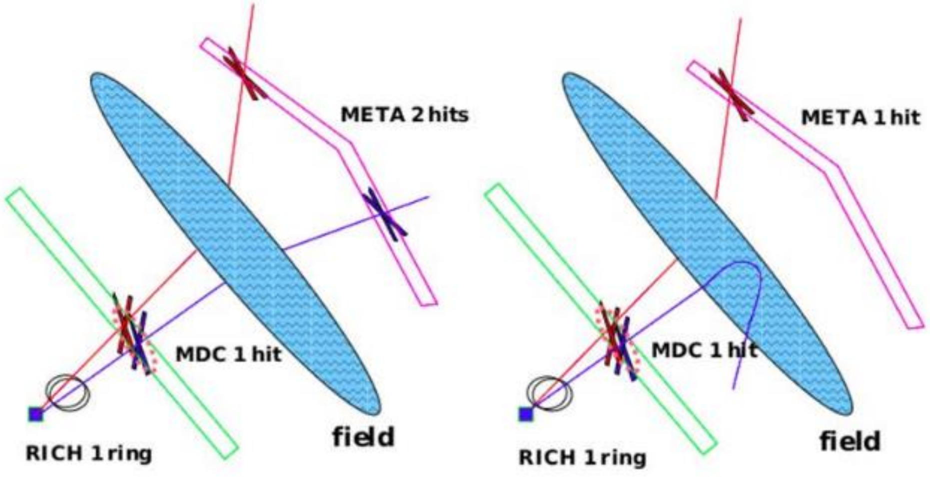
- **Uncorrelated CB**: e^+e^- coming from different mother particles.



CB can be reduced !

Single lepton Cuts:

- CB mostly due to conversion: "close pairs" (small opening angles).
- To reject rings matched to 2 inner segments with opening angle <9°.



Pair Cut:

- Cut on the opening angle between MDCs tracks to supress the reconstructed conversion pairs which survived the previous cuts.
- Take $\theta_{e^+e^-}$ >9°.

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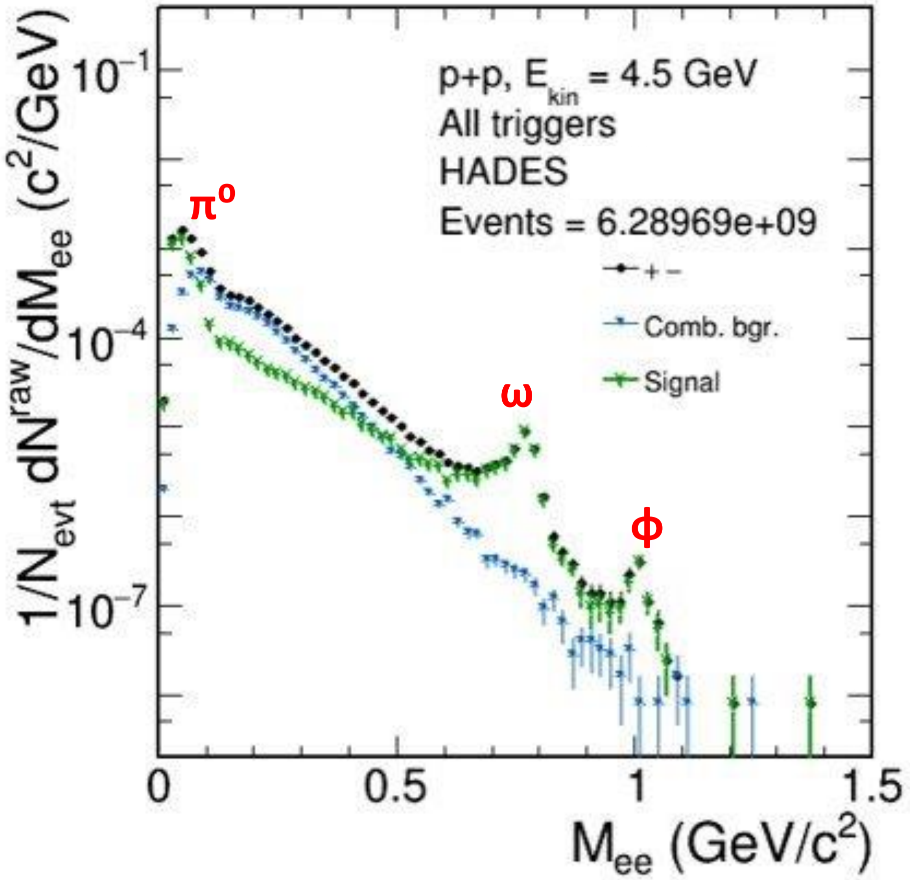
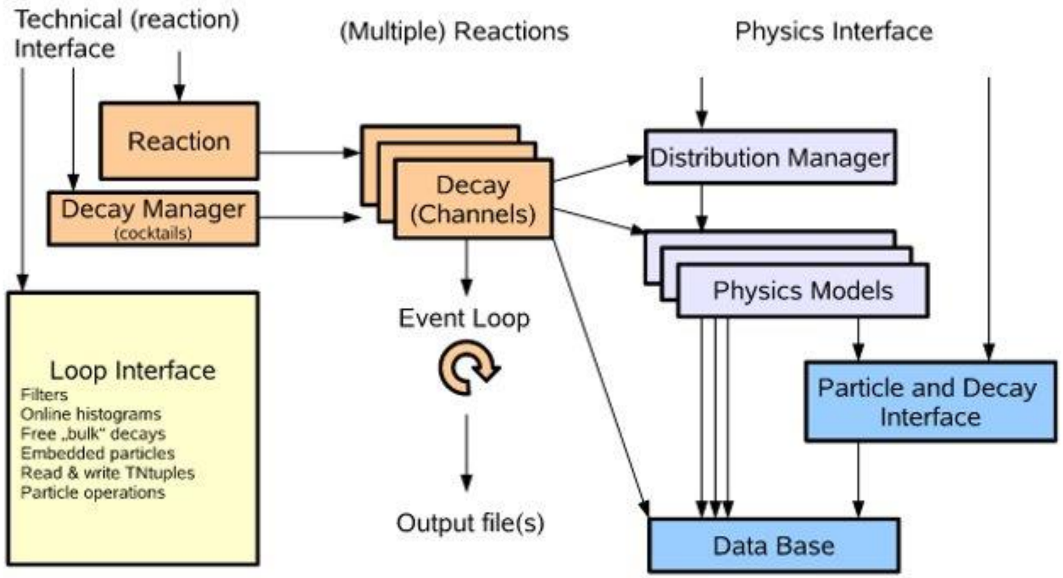
Invariant mass spectra



- Invariant mass spectra for data collected in 5 days.
- Clear peaks arround the mass of π^0, ω and ϕ.
- Still preliminary: e^+/e^- selection purity will be improved after START detector calibration.

PLUTO simulations for pp @ 4.5 GeV

- PLUTO is an event generator.
- Developed by HADES collaboration.
- Based on ROOT.
- Used to describe the particles production and their hadronic and leptonic decays in elementary and heavy-ion reactions.
- Try to build "inclusive" dilepton cocktail for pp at 4.5 GeV to compare it to data, where we ask to have e^+e^- in the exit channel.
- Inputs: cross sections for the different dilepton sources mentioned before.
- Pass events through Geant: detector geometry+instrumental effects.
- Reconstruction similar to data analysis.



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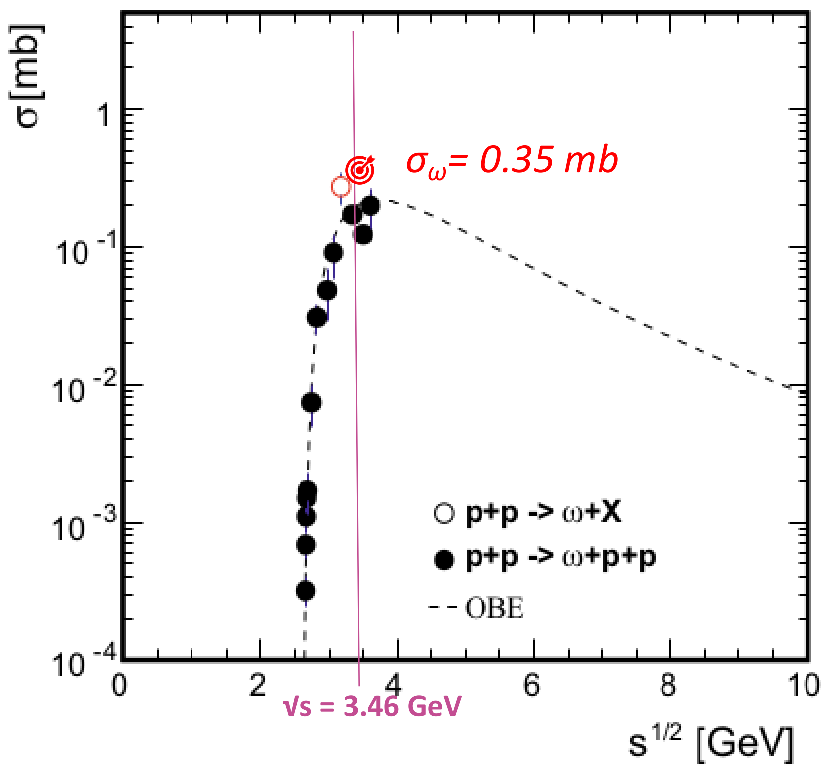
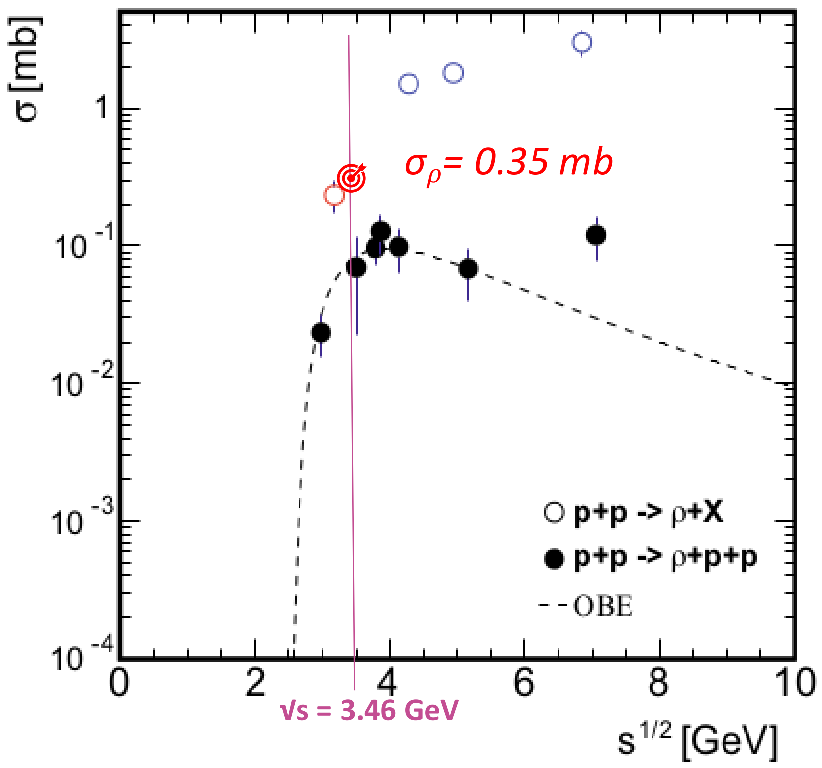
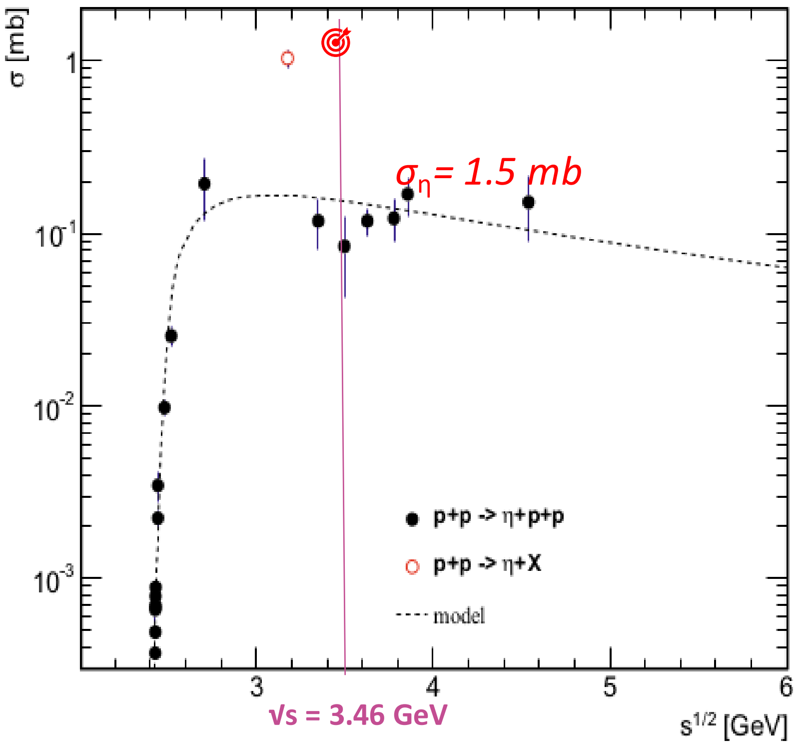
Mesons cross sections

HADES pp at 3.5 GeV

HADES Collaboration (G. Agakichiev et al.), Eur. Phys. J. A (2012) 48: 64





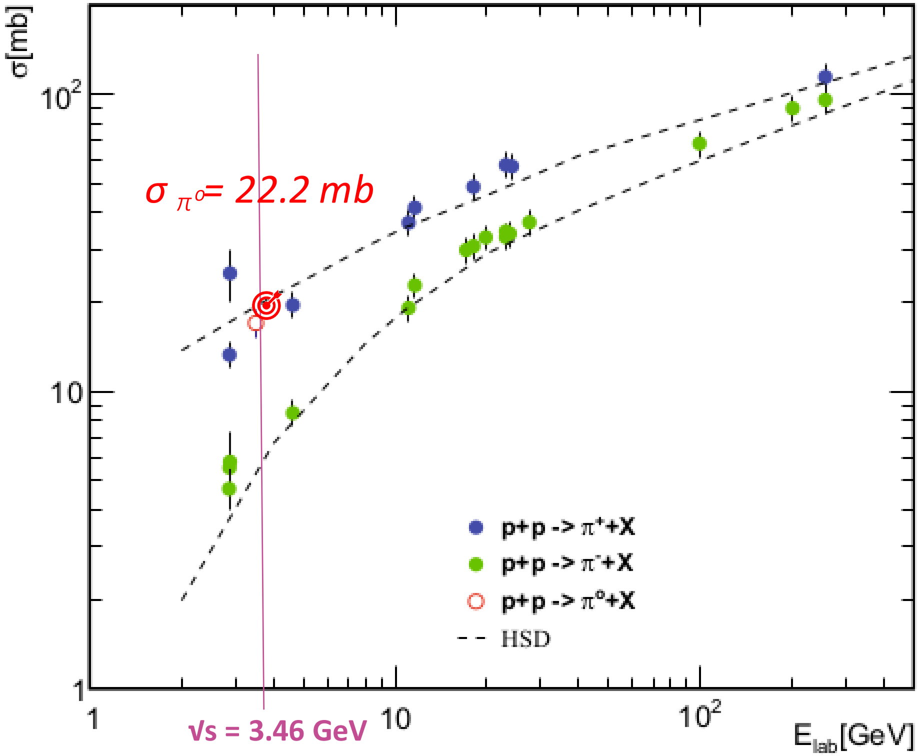


Cross sections:

- $\sigma_{\eta'}$=0.83×10^{-2} σ_η *(Measured by DISTO in pp collisions at 3,67GeV)*
- σ_φ=8×10^{-3}σ_ω *(Measured by ANKE in pp collisions at 2.8GeV)*

π^0 cross section

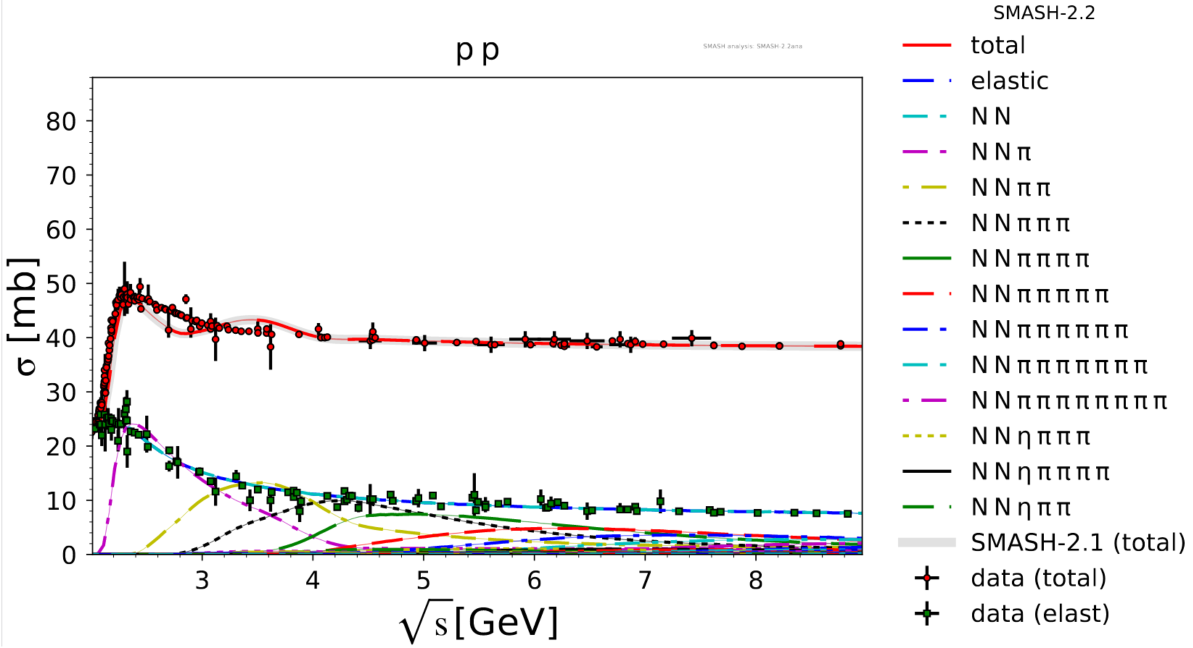
- Inelastic cross section of π^0 production, from pp at 3.5 GeV.



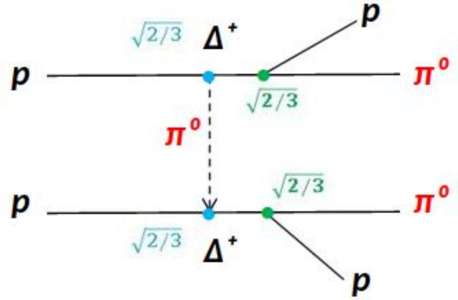
- At 4.5 GeV, one, two and three pion production coexist.
- As a first step, try to introduce one and two pion production in the cocktail.

Cross sections: $\sigma_{\pi^0\pi}$= 11 mb

1. Very scarce information on pp→NNππ ⇒ use SMASH (transport model) results.



2. Isospin factors deduced from ΔΔ model for pp→ppπ⁰π⁰ and pp→pnπ⁰π⁺.



Baryons cross sections

Baryon Dalitz-decay: e^+e^- source

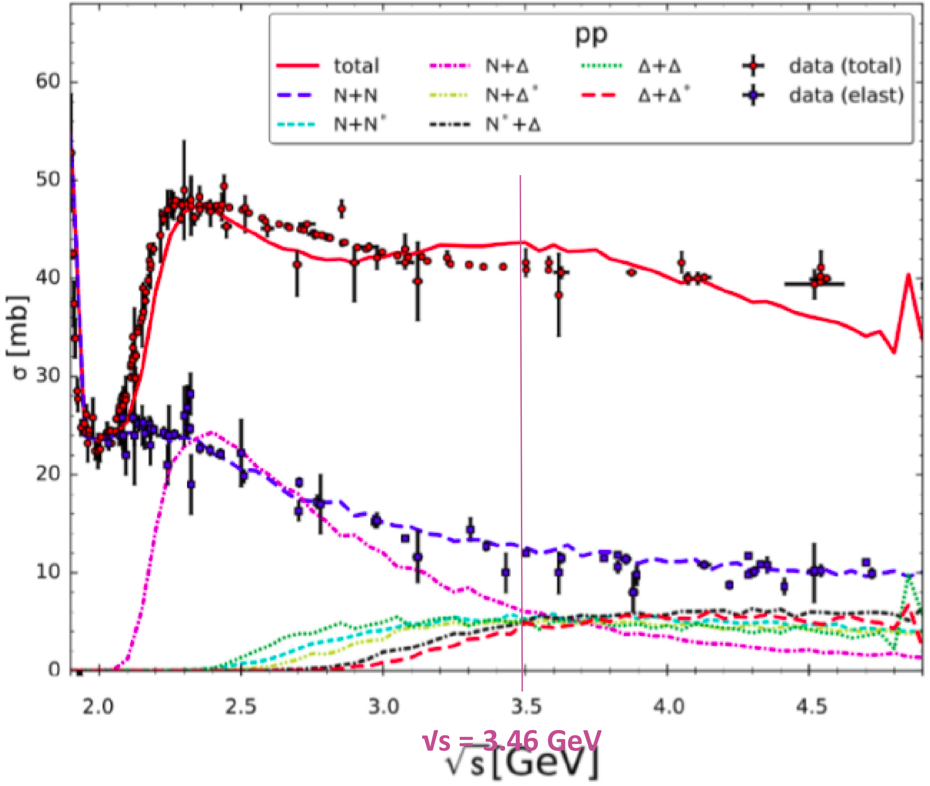
- $pp \rightarrow p\Delta^+(pe^+e^-)$.
- $pp \rightarrow pN^+(pe^+e^-)$.
- $pp \rightarrow \Delta^+(pe^+e^-)\Delta^+(p\pi^0 \,/\, n\pi^+)$.
- $pp \rightarrow \Delta^{++}(p\pi^+)\Delta^0(ne^+e^-)$.

Main contributions:
N(1520),
Δ(1232)
and Δ(1232) Δ(1232)

Effective cross sections

- N(1520) : *σ = 5 mb, BR~2.3x10⁻⁵.*
- Δ(1232) : *σ = 11.5 mb.*
- Δ(1232) Δ(1232) : *σ = 8.3 mb, BR~6.6x10⁻⁵.*

SMASH



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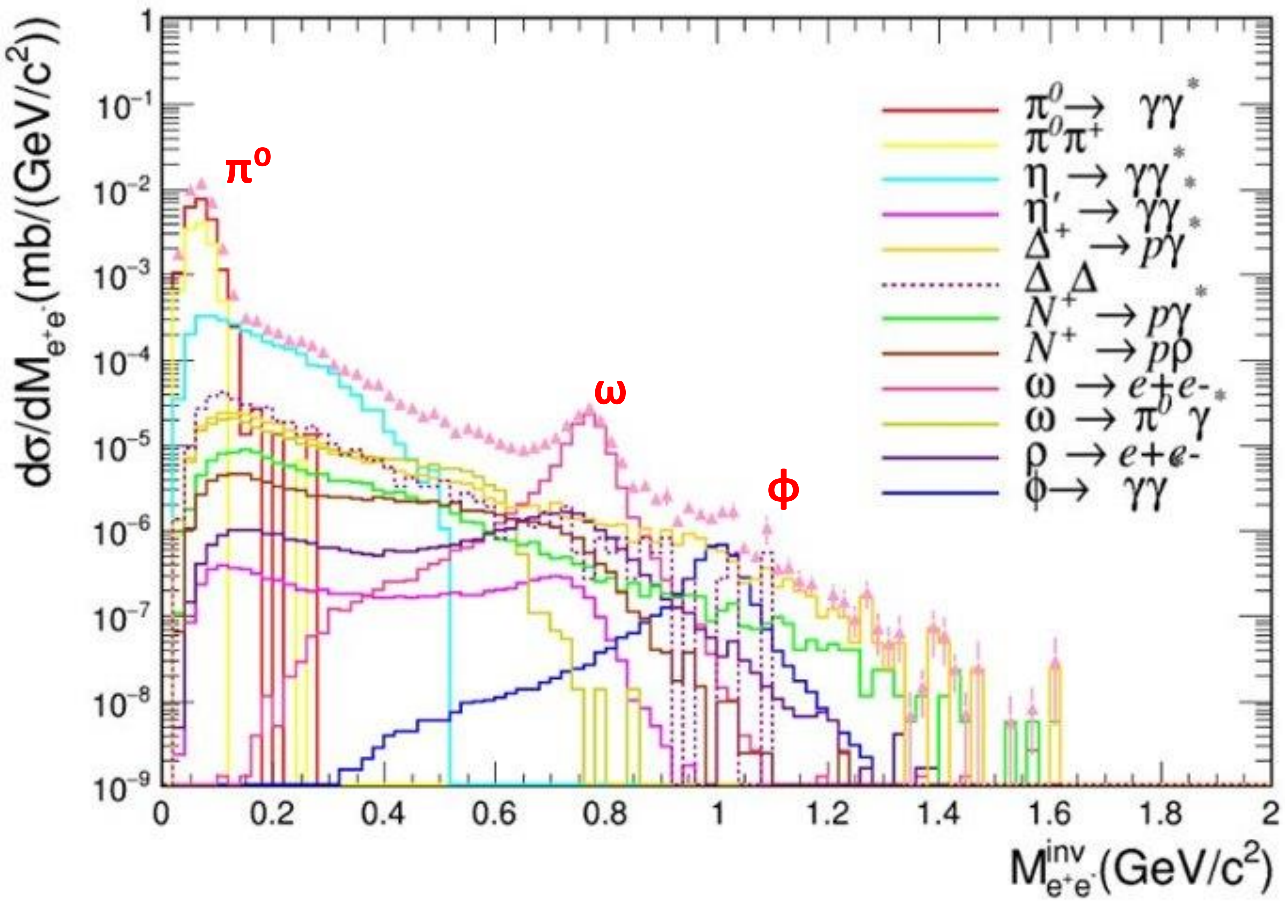
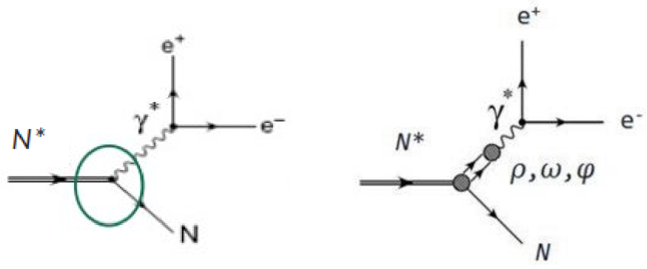
Cocktail at 4.5 GeV



FUTUR PLAN:

- Study the exclusive channel $pp \to pe^+e^-X$.
- Detect proton (in HADES or FWD) in addition to e^+e^- pair.
- Select $pp \to ppe^+e^-$ using missing mass : to be arround the proton mass (X=p).
- Selective study of $pp \to \Delta^+/N^*\ (pe^+e^-)p$ and $pp \to pp\rho/\omega(e^+e^-)$ investigation of VDM.



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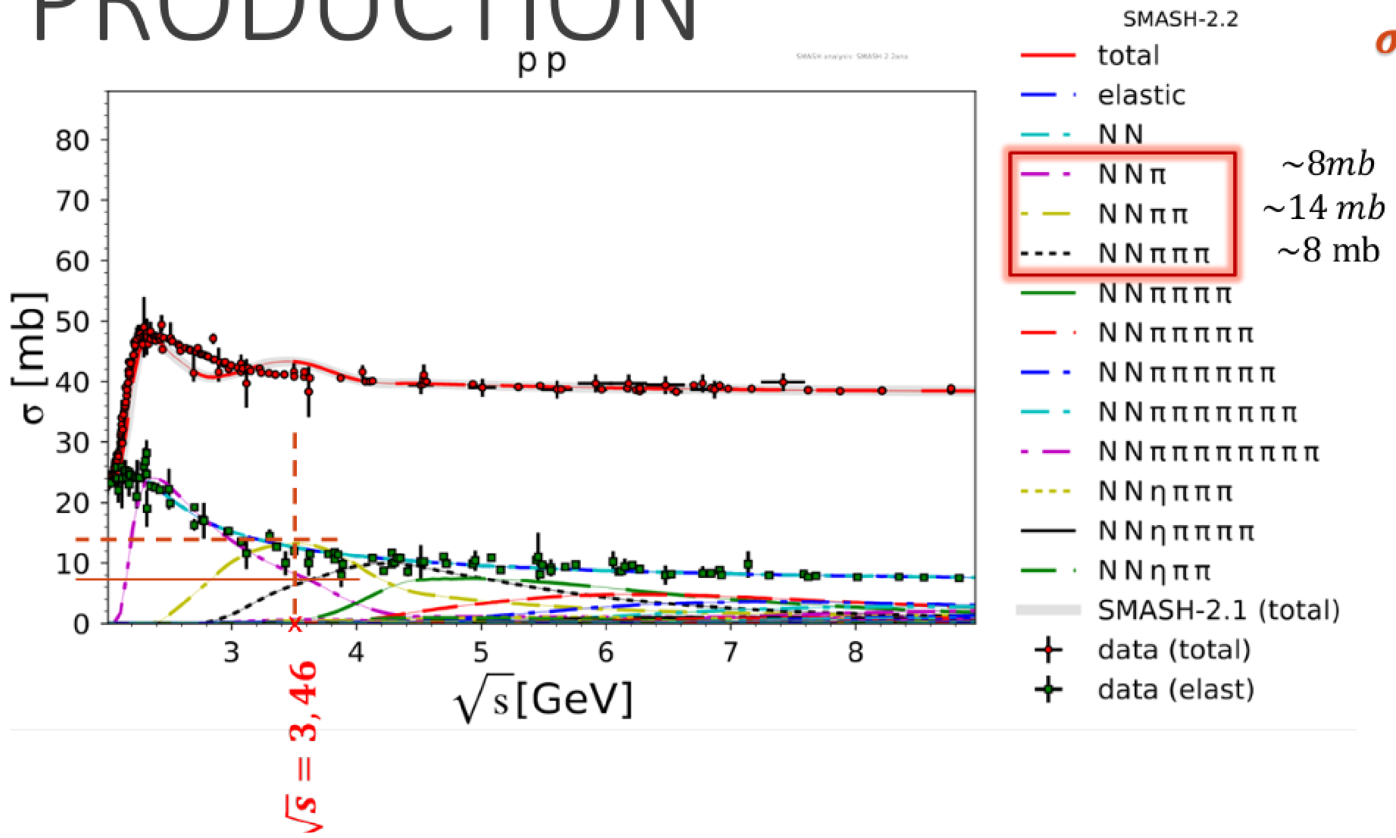
Conclusion and Outlook

- Dileptons are an ideal probe to describe properties of hot and dense QCD matter.
- This analysis will be a reference for heavy-ion collisions at SIS100 energies.
- Cuts on RICH and ECal help to select good leptons as much as possible.
- Waiting for more calibrations and MS correction that will improve the quality of our selection.
- Data will be compared to the transport models simulations.
- Extraction of ω and ϕ cross sections.
- Study of the exclusive channel $pp \rightarrow ppe^{+}e^{-}$ is a plan for selective study of baryon resonance Dalitz decay and ρ/ω decays.

Thank you for your attention!

Backup slides

IMPROVE π^0 KINEMATICS BY GENERATING 2 PION PRODUCTION



$$\sigma_{pp\to NN\pi\pi} = \sigma_{\pi^0\pi^0} + \sigma_{\pi^0\pi^+} + \sigma_{\pi^+\pi^-} + \sigma_{\pi^+\pi^+} \approx 14mb$$

1) $pp \to pp\pi^0\pi^0 \Leftrightarrow pp \to \Delta^+(p\pi^0)\Delta^+(p\pi^0).$

$$\sigma_{\pi^0\pi^0} = \frac{2}{3} \times \frac{2}{3} \times \sigma_{\Delta^+\Delta^+}$$

2) $pp \to pn\pi^0\pi^+ \Leftrightarrow pp \to \Delta^+(p\pi^0)\Delta^+(n\pi^+)$

$|| \; pp \to \Delta^{++}(p\pi^+)\Delta^0(n\pi^0).$

$$\sigma_{\pi^0\pi^+} = \frac{2}{3} \times \frac{1}{3} \times 2 \times \sigma_{\Delta^+\Delta^+} + 1 \times \frac{2}{3}\sigma_{\Delta^{++}\Delta^0}$$

3) $pp \to pp\pi^+\pi^- \Leftrightarrow pp \to \Delta^{++}(p\pi^+)\Delta^0(p\pi^-).$

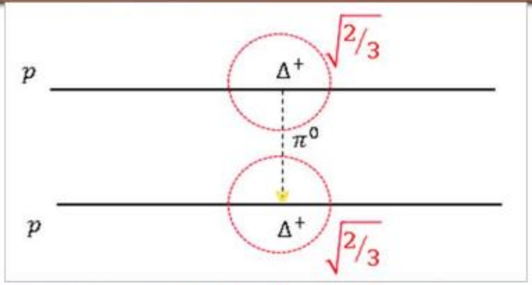
$$\sigma_{\pi^+\pi^-} = 1 \times \frac{1}{3} \times \sigma_{\Delta^{++}\Delta^0}$$

4) $pp \to nn\pi^+\pi^+ \Leftrightarrow pp \to \Delta^+(n\pi^+)\Delta^+(n\pi^+).$

$$\sigma_{\pi^+\pi^-} = \frac{1}{3} \times \frac{1}{3} \times \sigma_{\Delta^+\Delta^+}$$

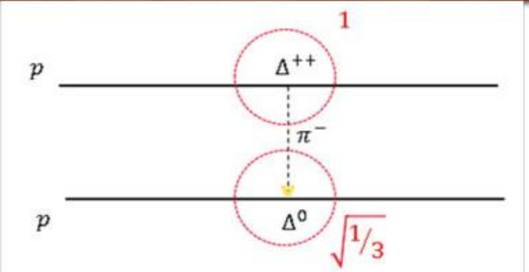
CROSS SECTIONS

$pp \rightarrow \Delta^+\Delta^+ \rightarrow pp\,\pi^0 e^+ e^-$ OR $pp \rightarrow \Delta^+\Delta^+ \rightarrow np\,\pi^+ e^+ e^-$



$$\sigma_{\Delta^+\Delta^+} = \left(\sqrt{\frac{2}{3}}\right)^2 \times \left(\sqrt{\frac{2}{3}}\right)^2 \times \frac{\sigma_{tot}}{\left(\sqrt{\frac{2}{3}}\right)^2 \times \left(\sqrt{\frac{2}{3}}\right)^2 + 1^2 \times \left(\sqrt{\frac{1}{3}}\right)^2} \sim \frac{4}{7}\sigma_{tot}$$

$pp \rightarrow \Delta^{++}\Delta^0 \rightarrow np\,\pi^+ e^+ e^-$



$$\sigma_{\Delta^{++}\Delta^0} = 1^2 \times \left(\sqrt{\frac{1}{3}}\right)^2 \times \frac{\sigma_{tot}}{\left(\sqrt{\frac{2}{3}}\right)^2 \times \left(\sqrt{\frac{2}{3}}\right)^2 + 1^2 \times \left(\sqrt{\frac{1}{3}}\right)^2} \sim \frac{3}{7}\sigma_{tot}$$

$$\boldsymbol{\sigma_{pp\rightarrow NN\pi\pi} = \sigma_{\pi^0\pi^0} + \sigma_{\pi^0\pi^+} + \sigma_{\pi^+\pi^-} + \sigma_{\pi^+\pi^+} \approx 14mb}$$

$$\sigma_{\Delta^+\Delta^+} = \frac{4}{7}\sigma_{\Delta\Delta} \;\&\; \sigma_{\Delta^{++}\Delta^0} = \frac{3}{7}\sigma_{\Delta\Delta}$$

Effective ΔΔ cross section.

$$\sigma_{pp\rightarrow NN\pi\pi} = \sigma_{\Delta\Delta}$$

$$\sigma_{\pi^0\pi} = \sigma_{\pi^0\pi^0} + \sigma_{\pi^0\pi^+} = \frac{50}{63}\sigma_{pp\rightarrow NN\pi\pi} \approx 11\,mb.$$

BARYON CROSS SECTIONS

$$\sigma_{inel} = \sigma_{\Delta} + \sigma_{\Delta^*} + \sigma_{N^*} + \sigma_{\Delta\Delta} + \sigma_{\Delta\Delta^*}$$

Effective N(1520) cross section

$$\sigma_{N^*} = 5\ mb.$$

$$\sigma_{\Delta} = 7,5\ mb.$$

$$\sigma_{N\Delta^*} = 4\ mb.$$

Effective Δ(1232)cross section

$$\sigma_{\Delta} = \sigma_{\Delta} + \sigma_{\Delta^*} = 11,5\ mb$$

$$\sigma_{\Delta\Delta} = 4,3\ mb.$$

$$\sigma_{\Delta\Delta^*} = 4\ mb.$$

Effective Δ(1232)Δ(1232)cross section

$$\sigma_{\Delta\Delta} = \sigma_{\Delta\Delta} + \sigma_{\Delta\Delta^*} = 8,3\ mb$$

- New inputs for PLUTO.
- Add the double delta production to the cocktail.
- Simulated as $\Delta^+(pe^+e^-)\Delta^+$ with :

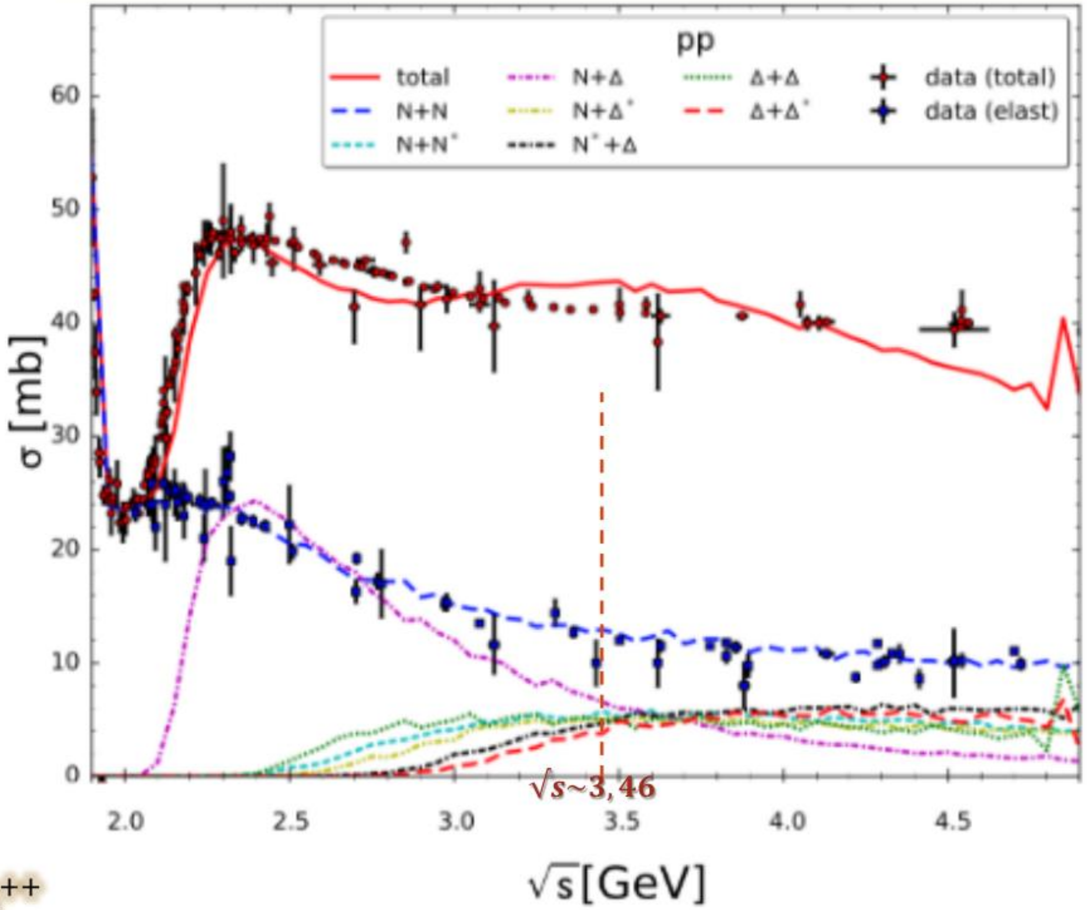
$$BR = BR_{\Delta \to Ne^+e^-} \times \left(\frac{4}{7} \times 2 + \frac{3}{7}\right)$$

$4,2 \times 10^{-5}$

$\Delta^+\Delta^+$

$\Delta^0\Delta^{++}$

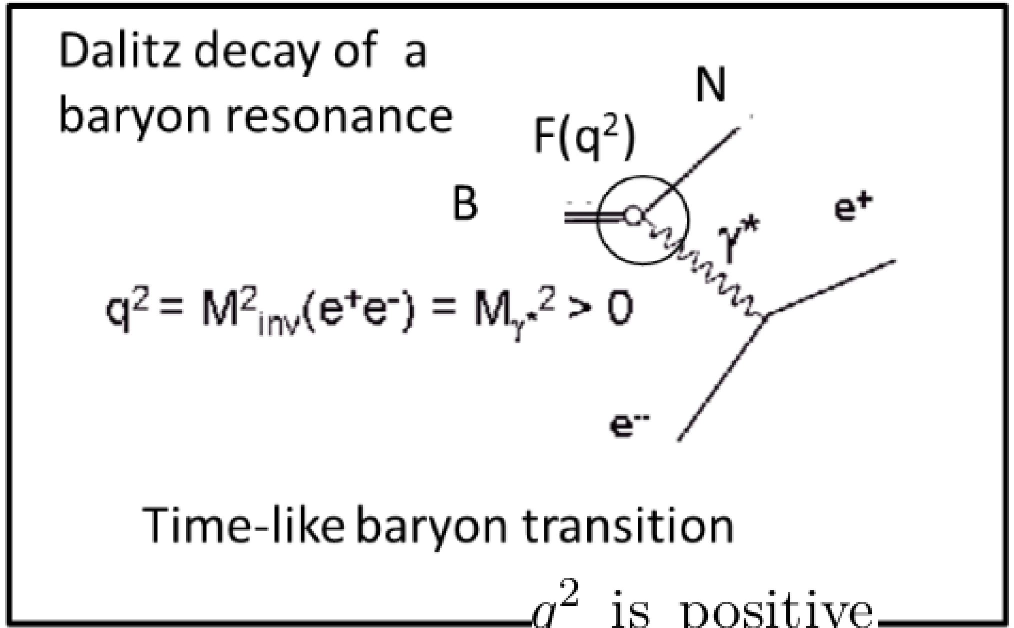
SMASH



$$q = p_N - p_B$$

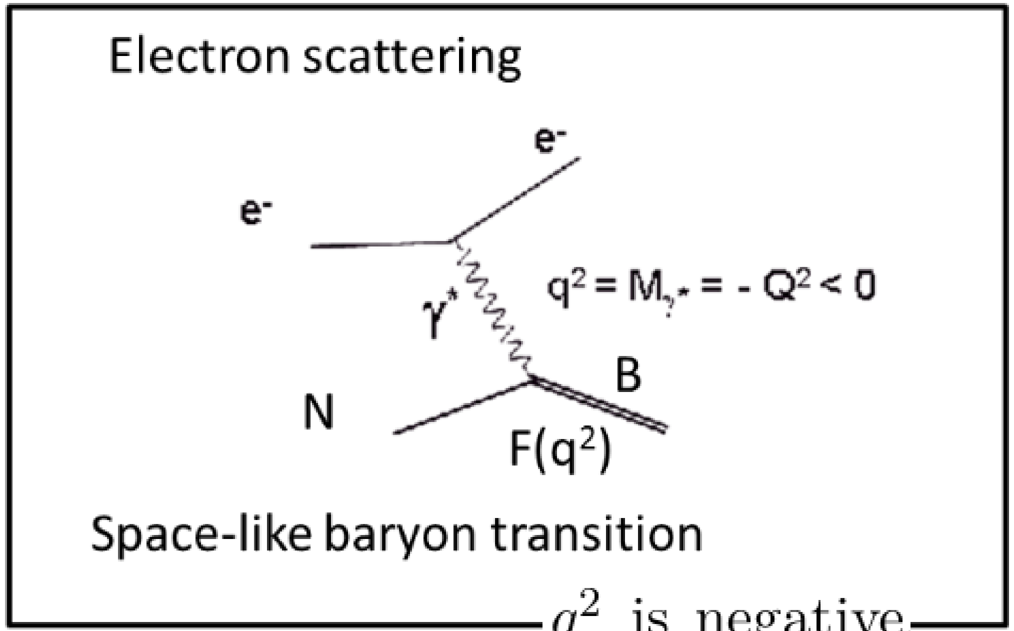
$$M_\gamma^2 = q^2 = (W_B - W_N)^2 - (\vec{p_B} - \vec{p_N})^2$$

q^2 is just limited by the energy of the incident electron



q^2 is positive

$$q^2_{max} = (M_B - M_N)^2$$



q^2 is negative