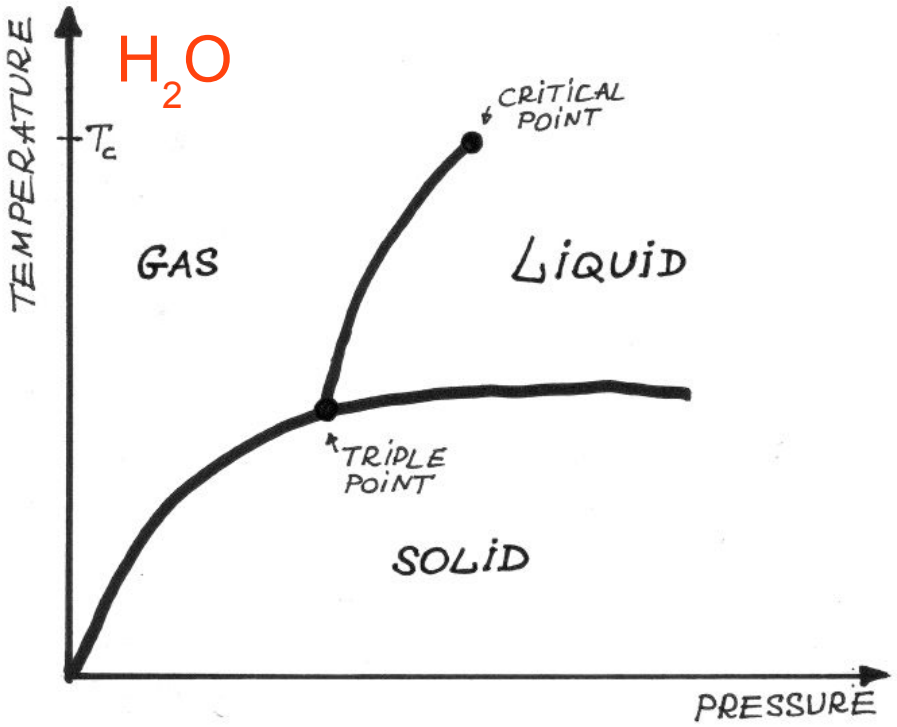
EXPLORING NUCLEAR MATTER AT SIS 18 ENERGIES

with the HADES

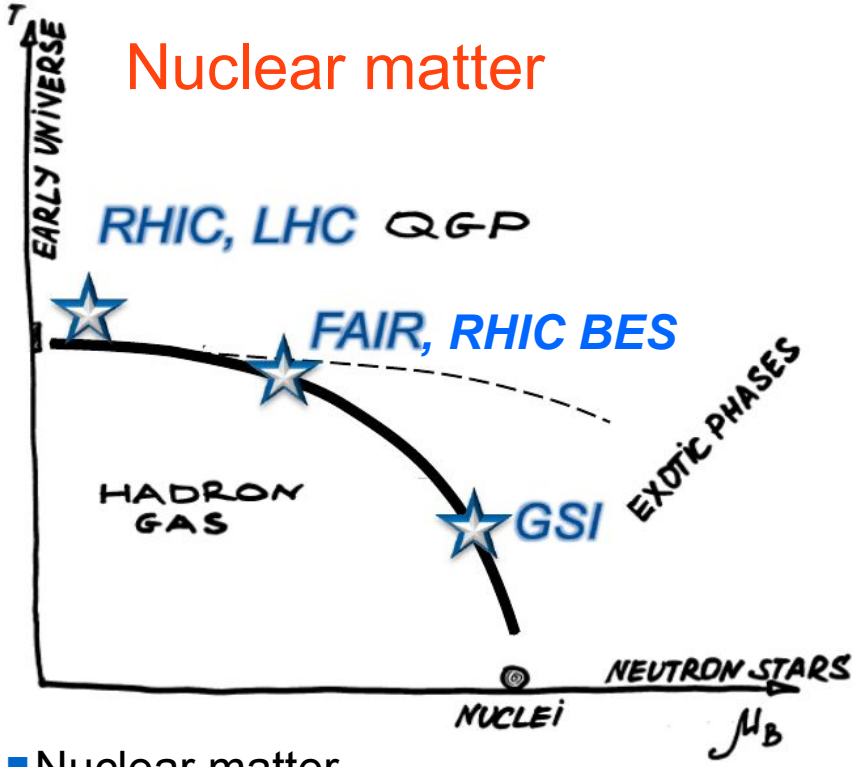
Claudia Behnke
for the HADES Collaboration

STRUCTURE OF (NUCLEAR) MATTER

Access different phases with heating and/or compression



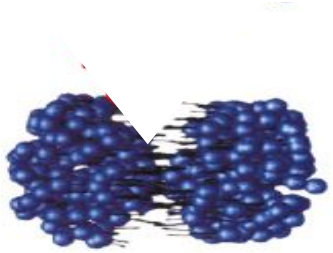
- Water:
  - Compression/heat:
    Can be set externaly
  - Observables:
    Phases & phase transitions
    observable bare by eye



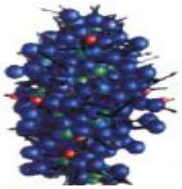
- Nuclear matter
  - Compression/heat:
    Heavy-ion collisions (partially controlled)
  - Observables:
    Bulk observables (hadron chemistry,...)
    Penetrating probes (γ, lepton pairs)

HEAVY-ION COLLISION

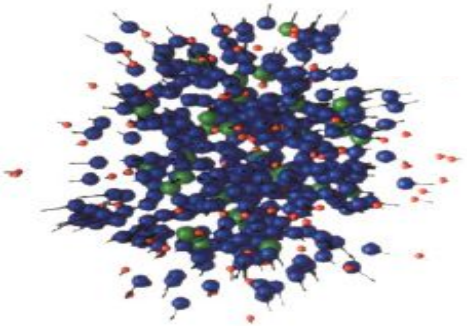
HIC at 1 GeV/u



First-chance NN collisions



Dense stage (~ 10 fm/c)



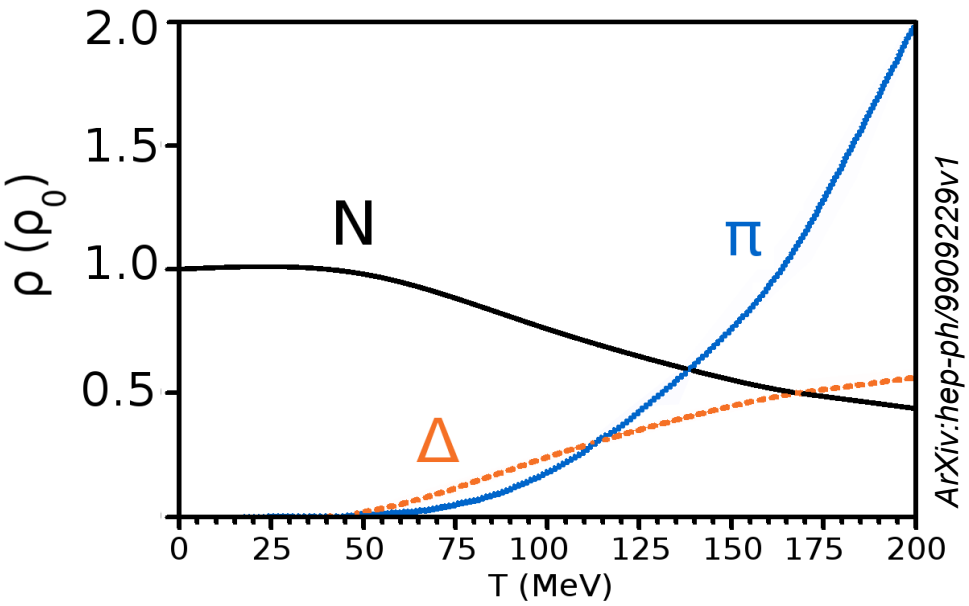
Freeze-out stage

STRUCTURE OF (NUCLEAR) MATTER

"Resonance matter":

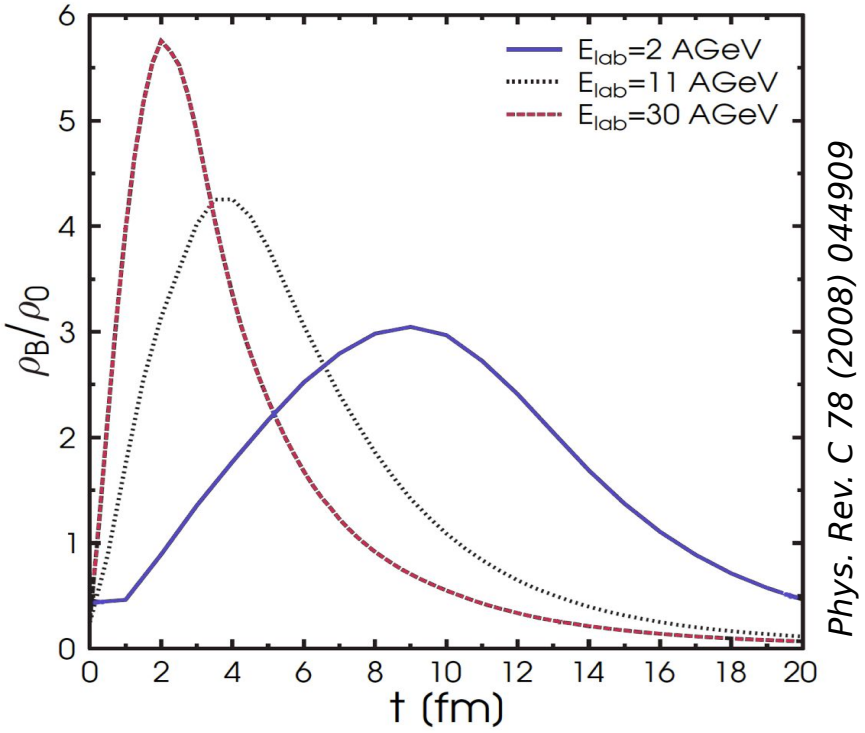
- Dominant contribution: Excitation and decay of baryonic resonances
- Life time resonance: τ ~1fm/c

Composition of a hot $\pi\Delta N$ gas (T)



Probing nuclear matter at SIS 18 (UrQMD simulation):

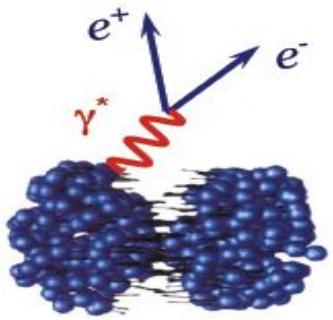
- Densities: $\rho_B/\rho_0 > 2$-3
- Freeze-out temperature: T < 100 MeV



"System stays above ground state density for τ~10 fm/c"

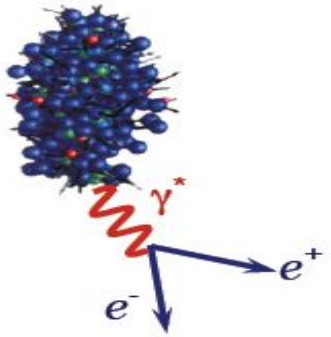
PROBES OF HEAVY-ION COLLISION

HIC at 1 GeV/u



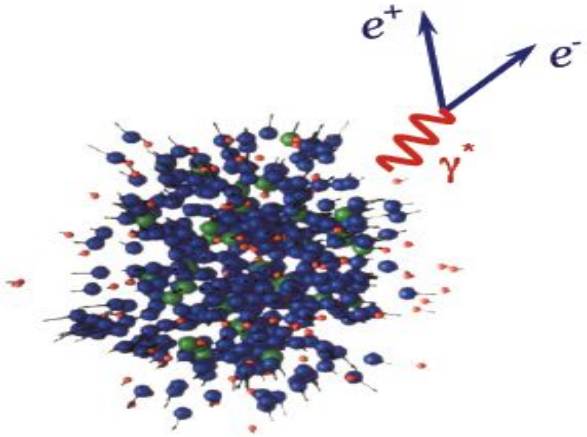
First-chance NN collisions

Baryonic sources:
- NN Bremsstrahlung
- Δ,N* $\rightarrow$ Ne$^+$e$^-$



Dense stage (~ 10 fm/c)

In-medium spectral functions

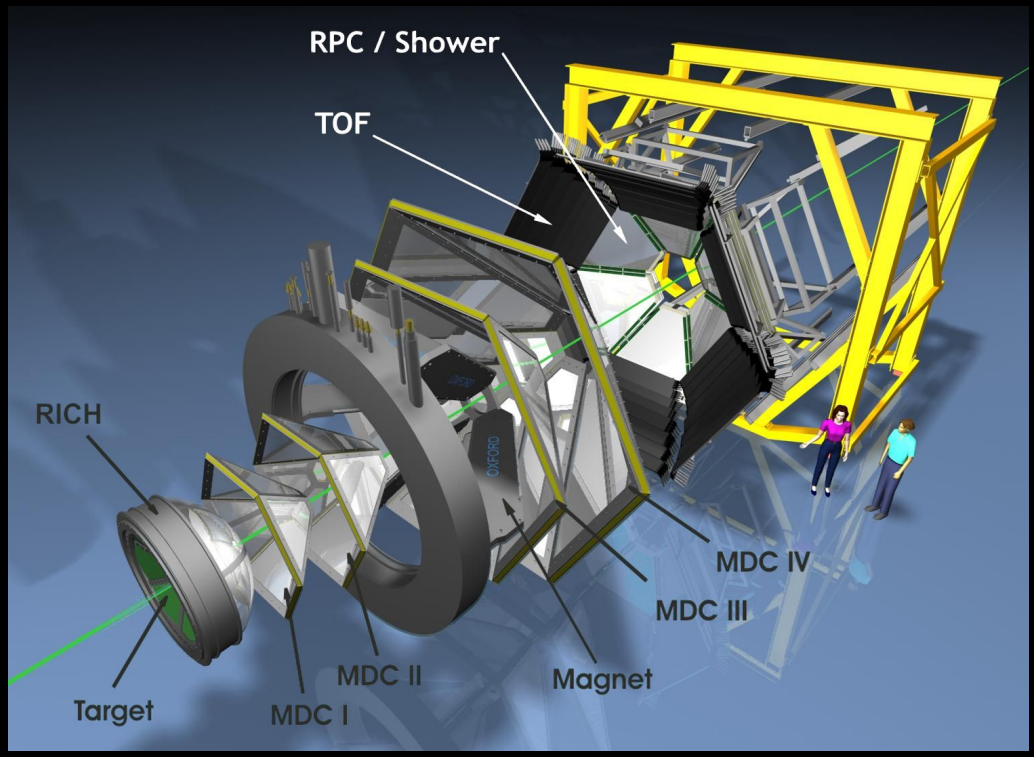


Freeze-out stage

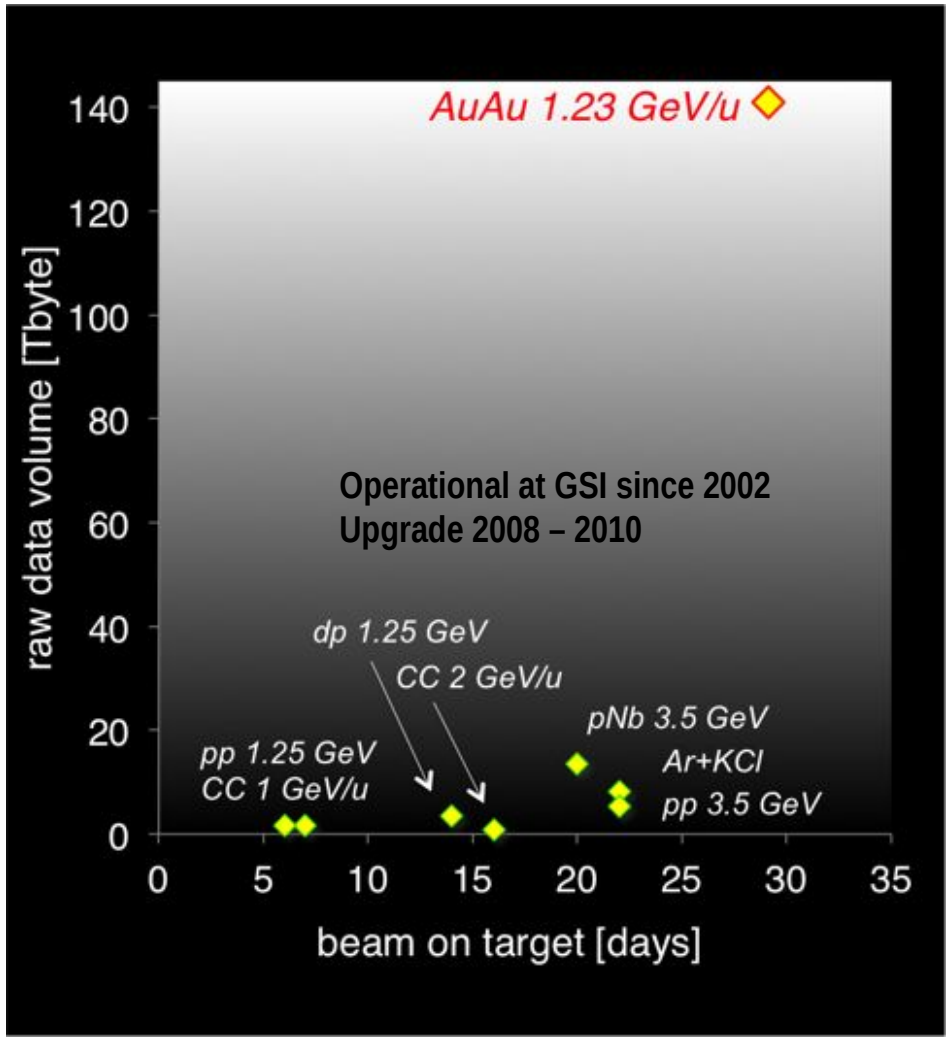
Hadronic final state:
p, $\pi^{+/-}$, k, Λ, ϕ, π^0,η, ω

THE HADES AT GSI, DARMSTADT, GERMANY

- Full azimuthal coverage, 18° to 85° in polar angle
- Hadron and lepton identification:
  - Tracking with 4x6 Multiwire Drift Chambers and superconducting magnet
  - Time of flight measurement with ToF and RPC Walls
  - Specific energy loss in MDC and ToF
  - RICH and shower detectors to identify leptons
- 50 kHz event rate (400 Mbyte/s peak data rate)

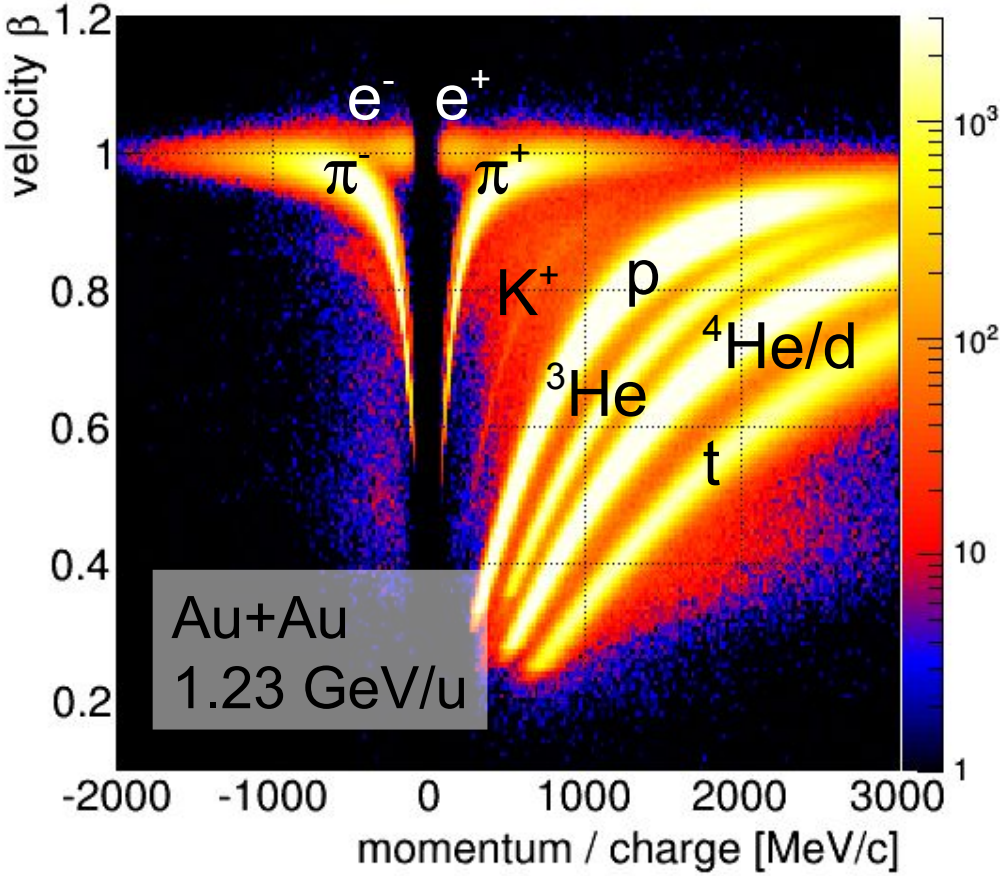


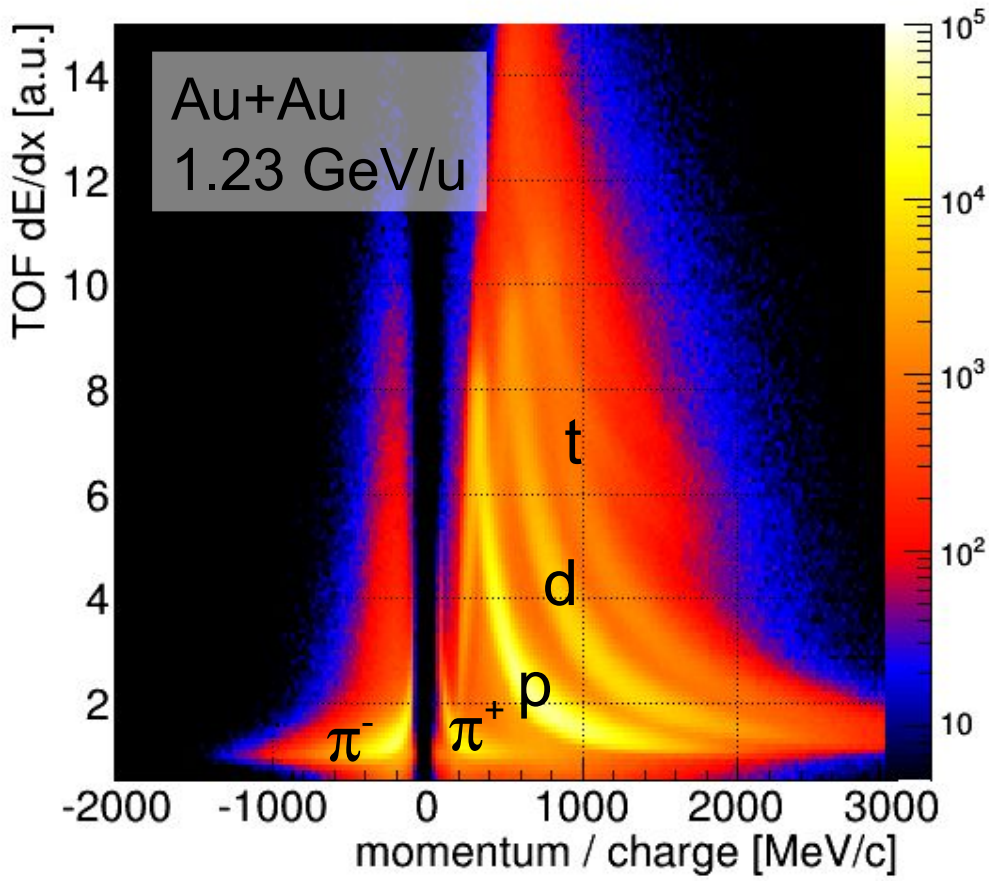
HADES BEAM TIMES



2002	C+C	2.0 GeV/u
2004	C+C	1.0 GeV/u
2005	Ar+KCl	1.76 GeV/u
2006	p+p	1.25 GeV, 2.2 GeV, 3.5 GeV
2007	d+p	1.25 GeV
2008	p+Nb	3.5 GeV
2012	Au+Au	1.23 GeV/u
2014	π^- + W, π^- + C, π^- + PE	0.656 GeV/c, 0.69 GeV/c, 0.748 GeV/c, 0.8 GeV/c 1.7 GeV/c

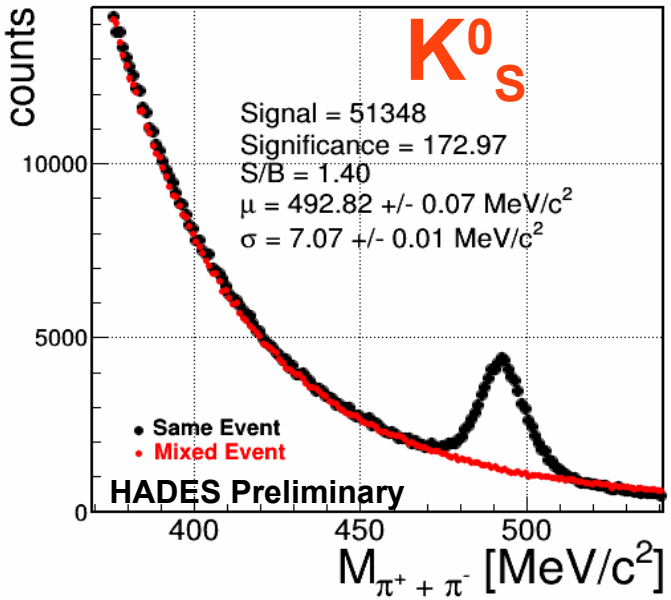
PARTICLE RECONSTRUCTION



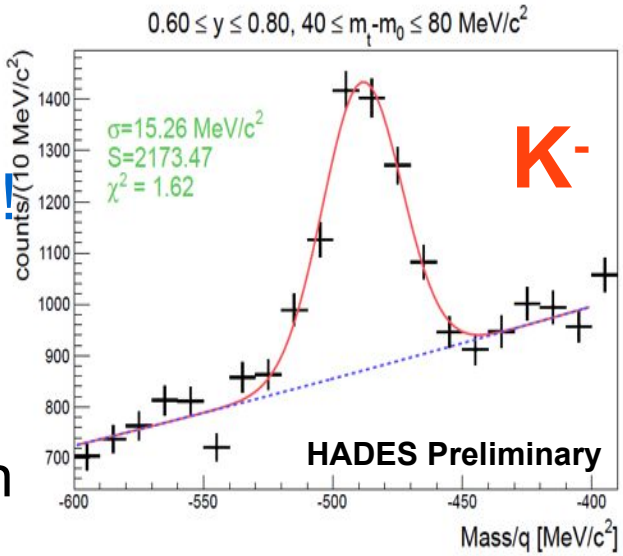


- Particle identification:
  - β vs momentum/charge
  - dE/dx vs momentum/charge
- For leptons a correlation to RICH ring is required

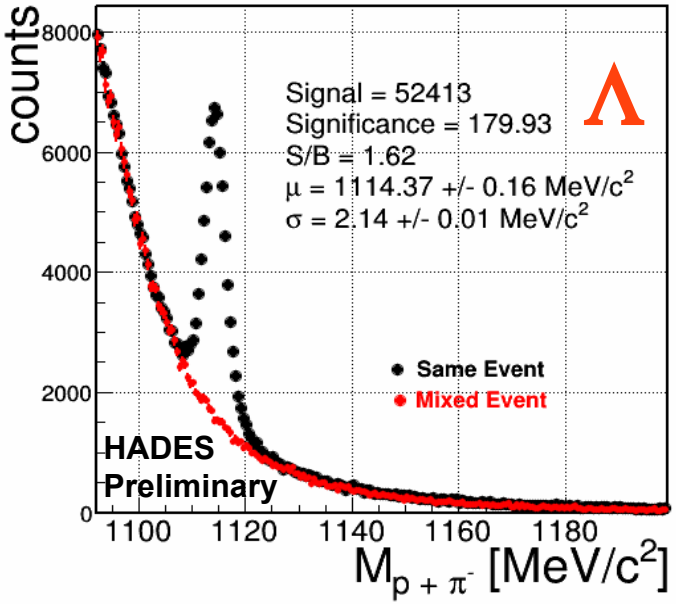
PARTICLE RECONSTRUCTION



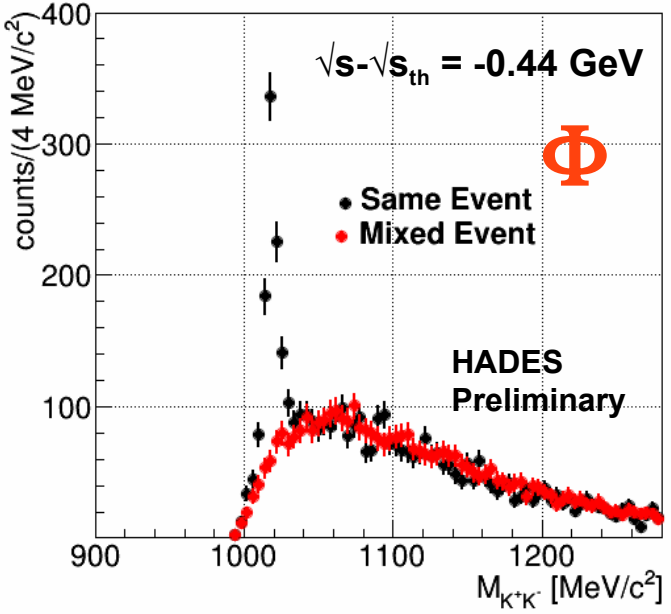
First measurements at such low beam energy!



Far below NN production threshold!

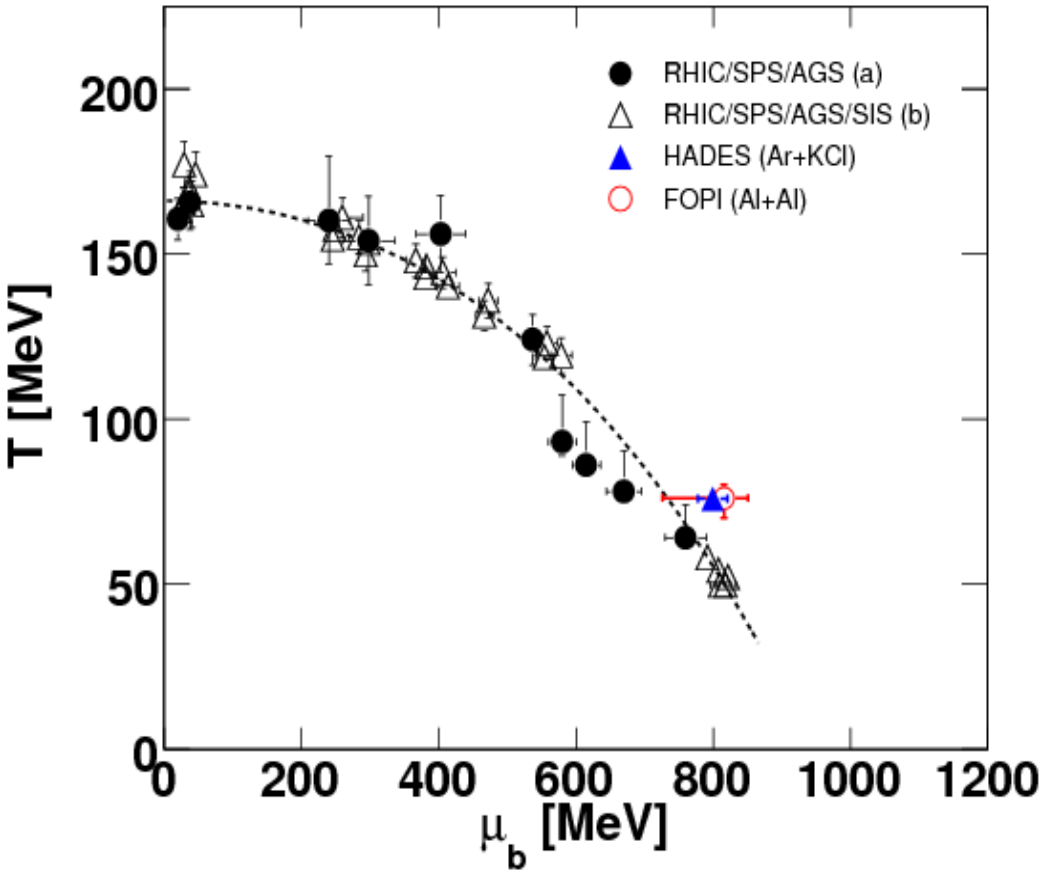


Strong constraints on production mechanism!



PhD T. Scheib & H. Schuldes

STRUCTURE OF (NUCLEAR) MATTER

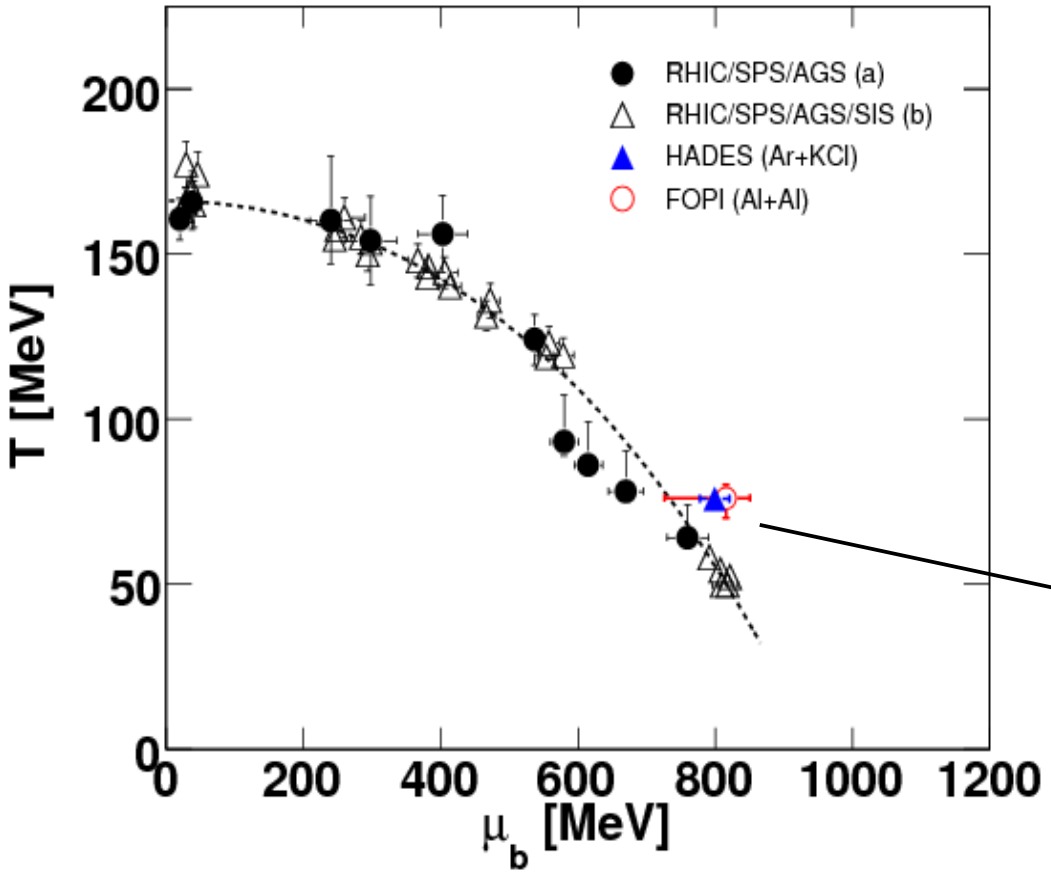


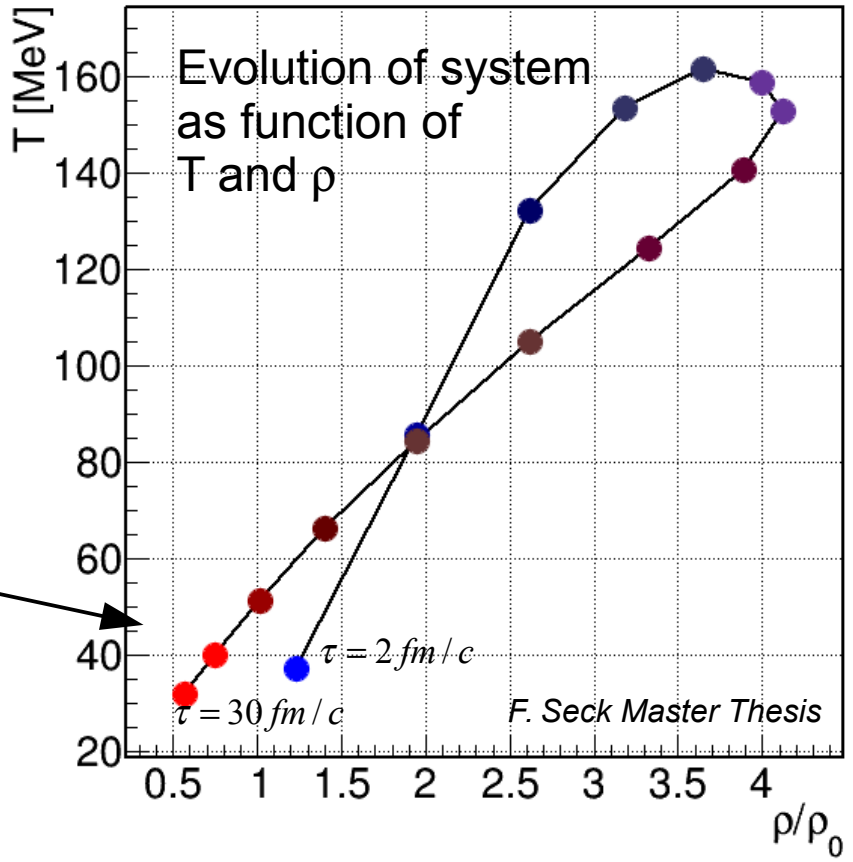
Hadronic yields fitted with statistical model (THERMUS) to obtain temperature T and baryochemical potential μ_B

Describes system at freeze-out!

Filled circles: Nucl.Phys. A772, 167 (2006); open triangles; Phys. Rev. C 73, 034905 (2006); Red circle: Phys. Rev. C 76,052203 (2007); dashed line corresponds to a fixed energy per nucleon of 1 GeV, calculated according to: Phys. Rev. C76,052203 (2007) HADES Point Blue Triangle: Eur.Phys.J. A47 (2011) 21

STRUCTURE OF (NUCLEAR) MATTER





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PROBES OF HEAVY-ION COLLISION

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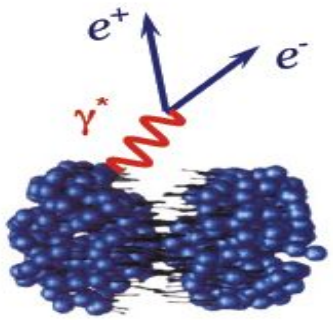
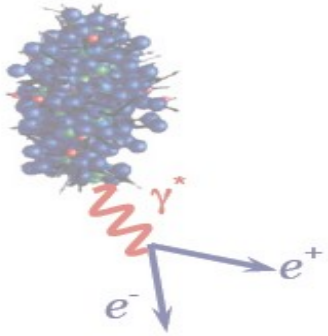
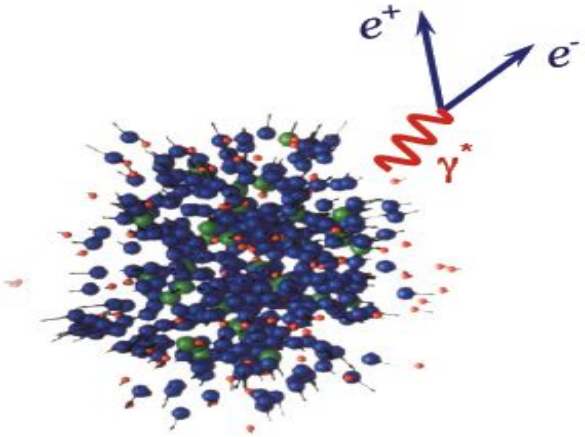






First-chance NN collisions

Baryonic sources:
- NN Bremsstrahlung
- Δ,N* $\rightarrow$ Ne$^+$e$^-$

Dense stage (~ 10 fm/c)

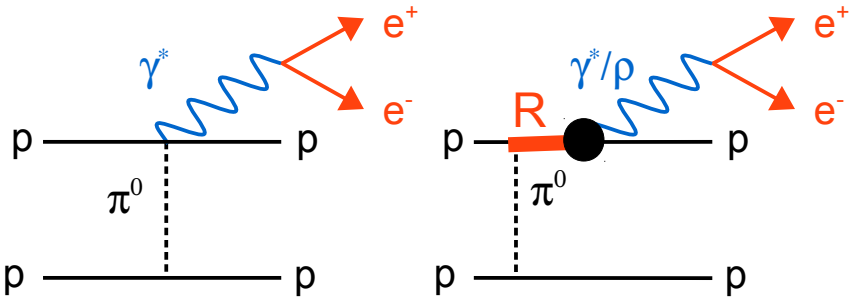
In-medium spectral functions

Freeze-out stage

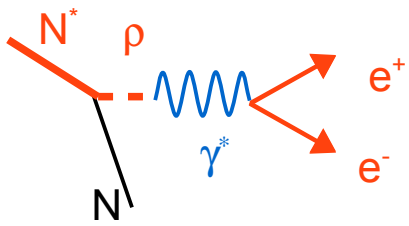
Hadronic final state:
p, $\pi^{+/-}$, k, Λ, ϕ, π^0,η, ω

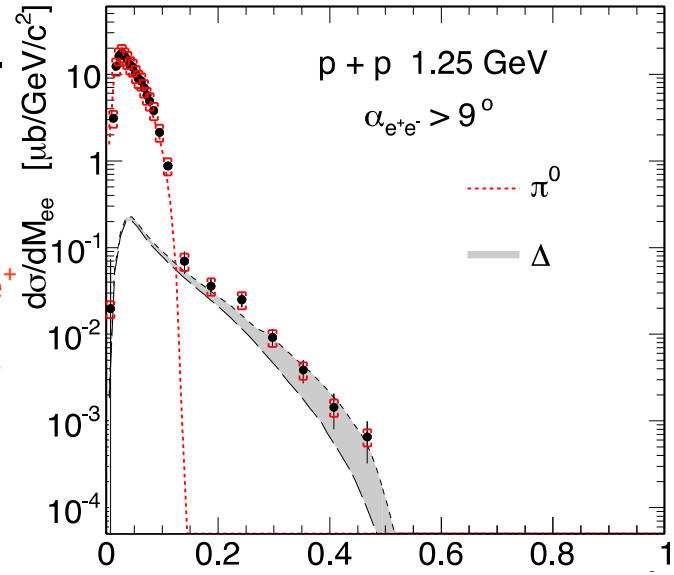
FIRST-CHANCE COLLISIONS

Can be probed with elementary reactions: n+p, p+p, ...



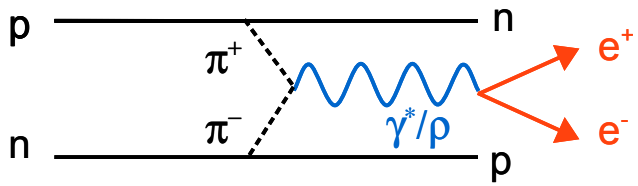
VMD

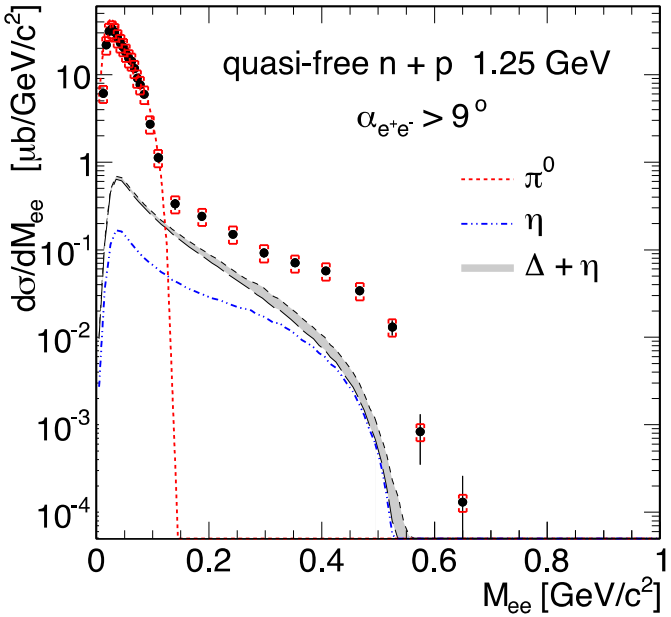




Results:

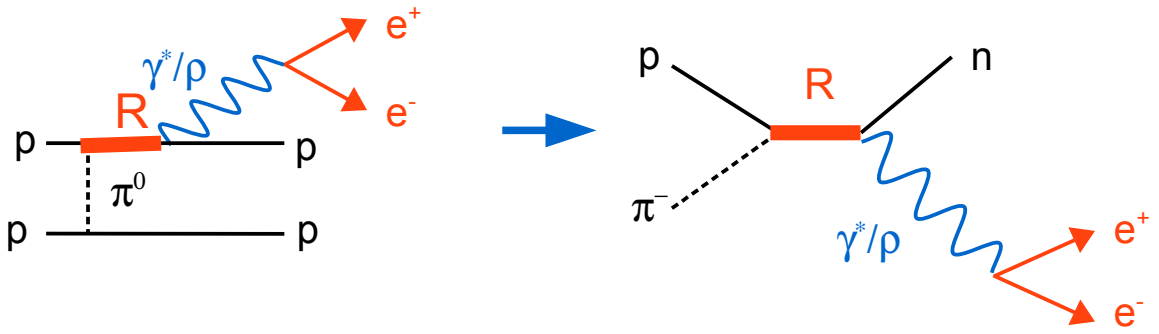
- Role of the VDM in elementary collisions
- Remarkable isospin effect!





- First measurement of the Δ transition form factor in the time-like region
  - But resonance form factors are barely known...

RESONANCE CONTRIBUTION

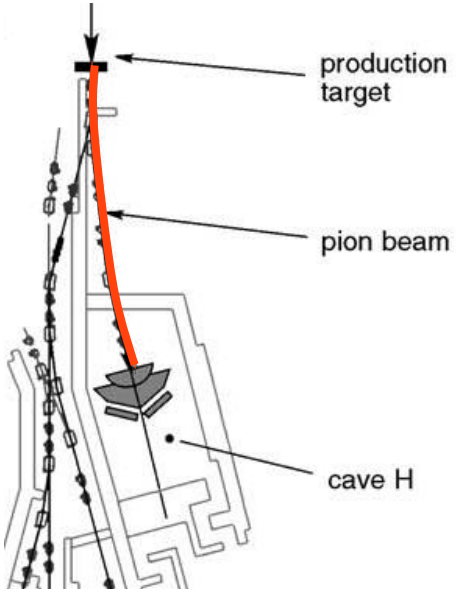


System	π-Momentum [GeV/c]	Goal
π^- + A	1.7	Kaon in medium potential
π^- + p	0.69	**Dilepton emission from baryon resonace**
π^- + p	0.656 0.748 0.8	Excertation function from baryon resonace measured with hadrons

Primary beam:
10^{11} N (2A GeV) /spill

Beam time for 25 days

Secondary π-beam:
- Intensity: ~ $3 \cdot 10^5$ π^-/spill
- Momentum:
  0.6 < p < 1.7 GeV/c



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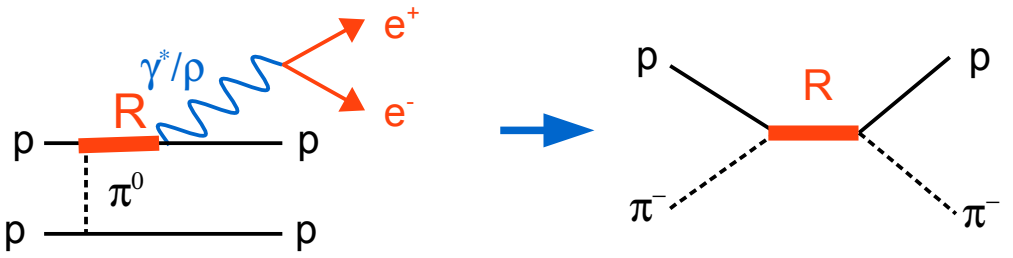
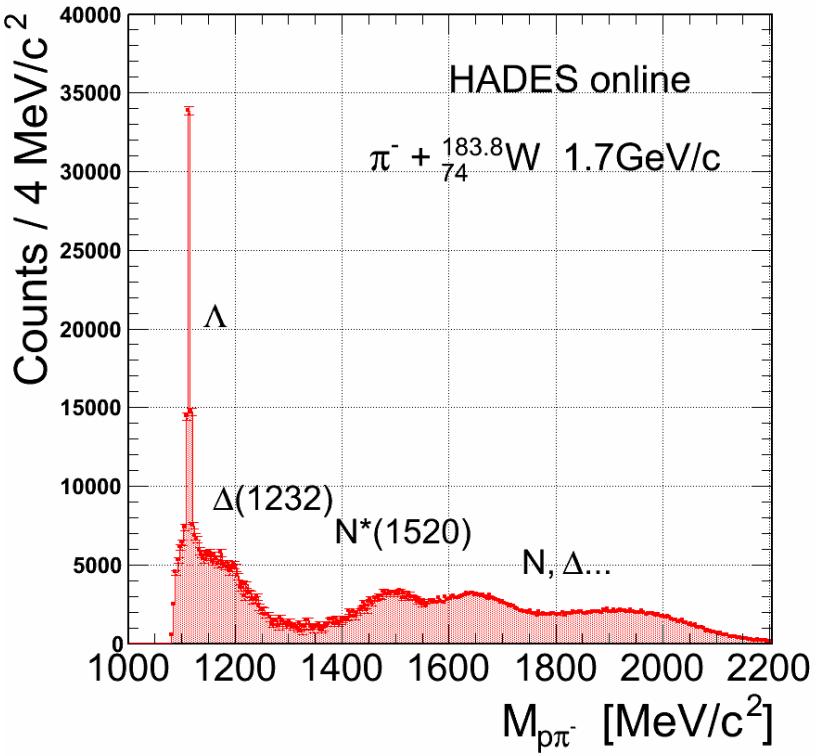


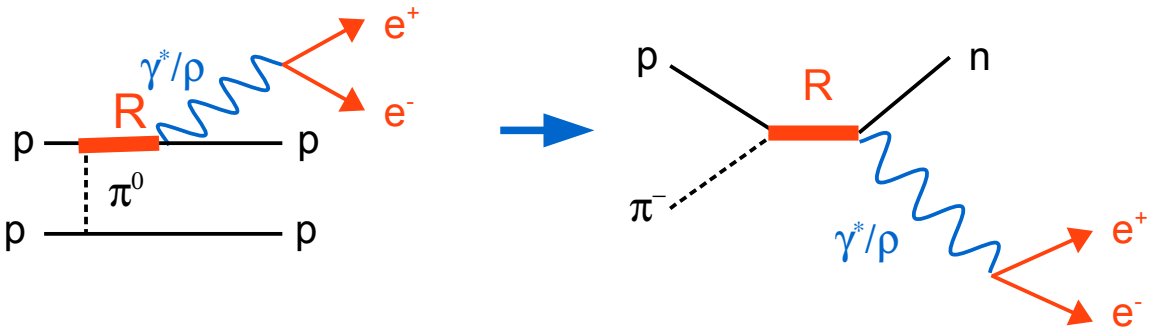


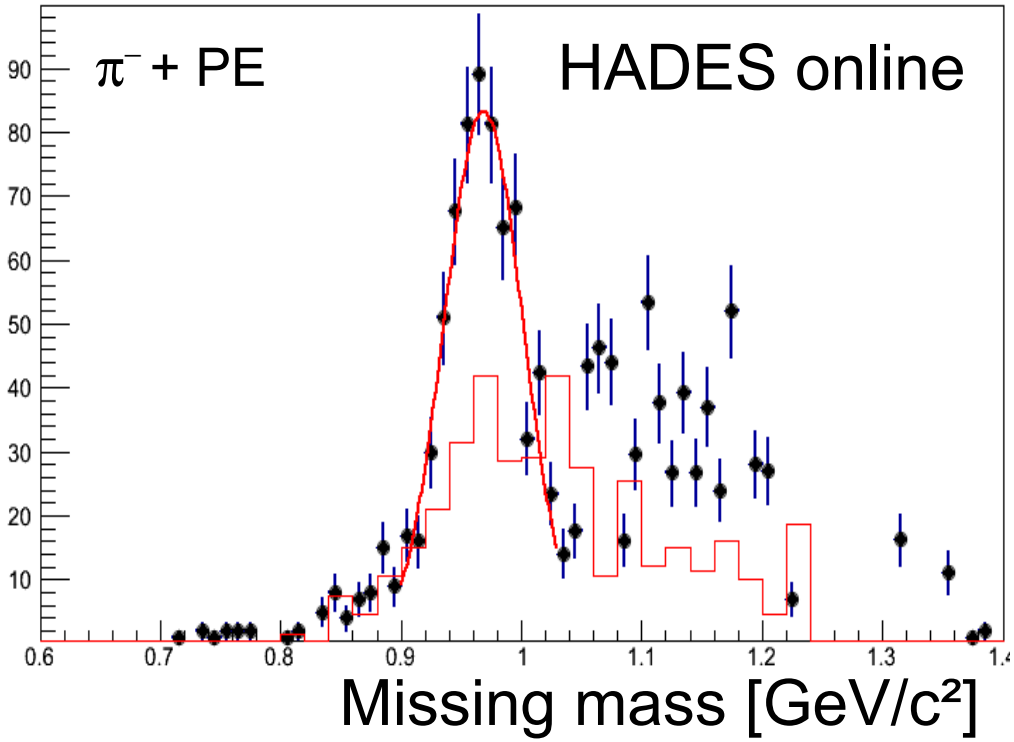
π^-p experiments:

- Crucial to control the interpretation of medium effects from SIS to LHC
- Unique chance to study time-like electromagnetic structure of higher lying resonances

RESONANCE CONTRIBUTION

Exclusive analysis





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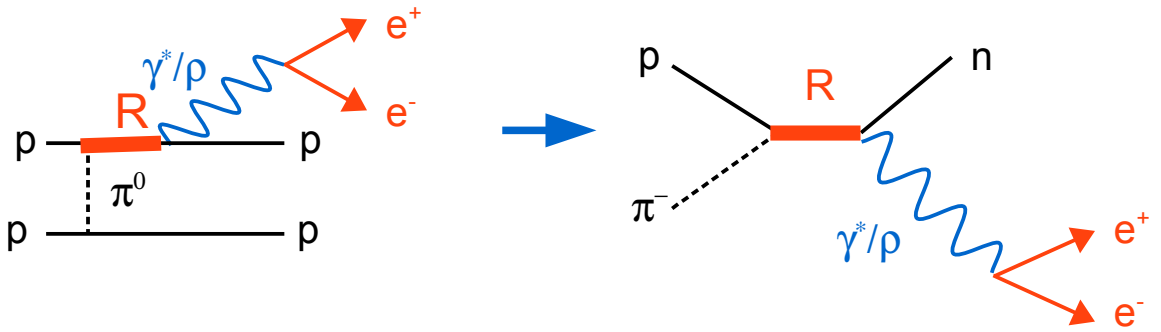

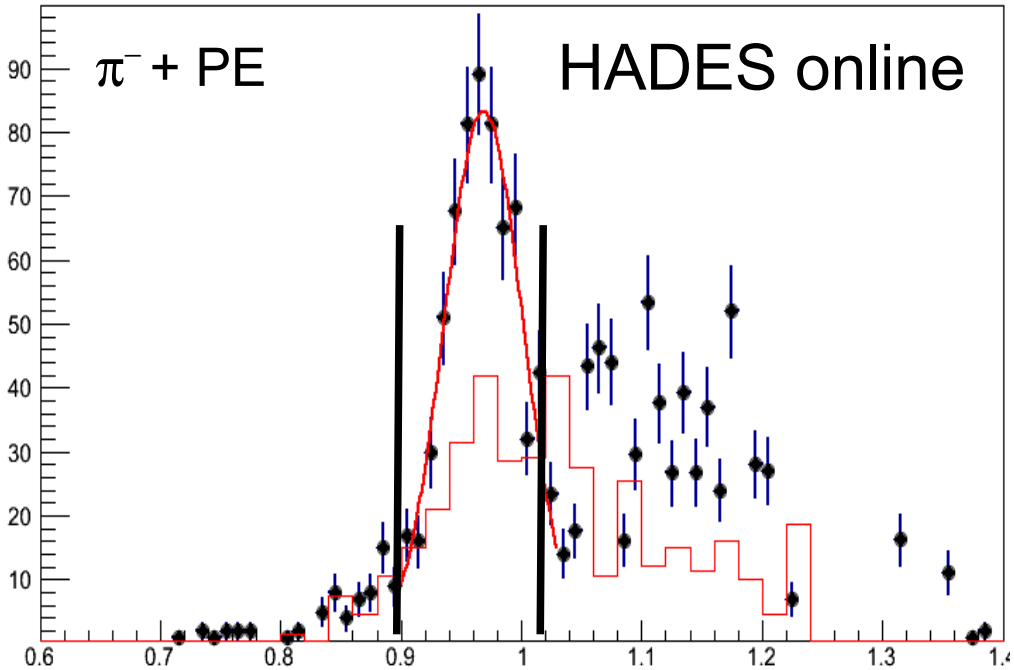

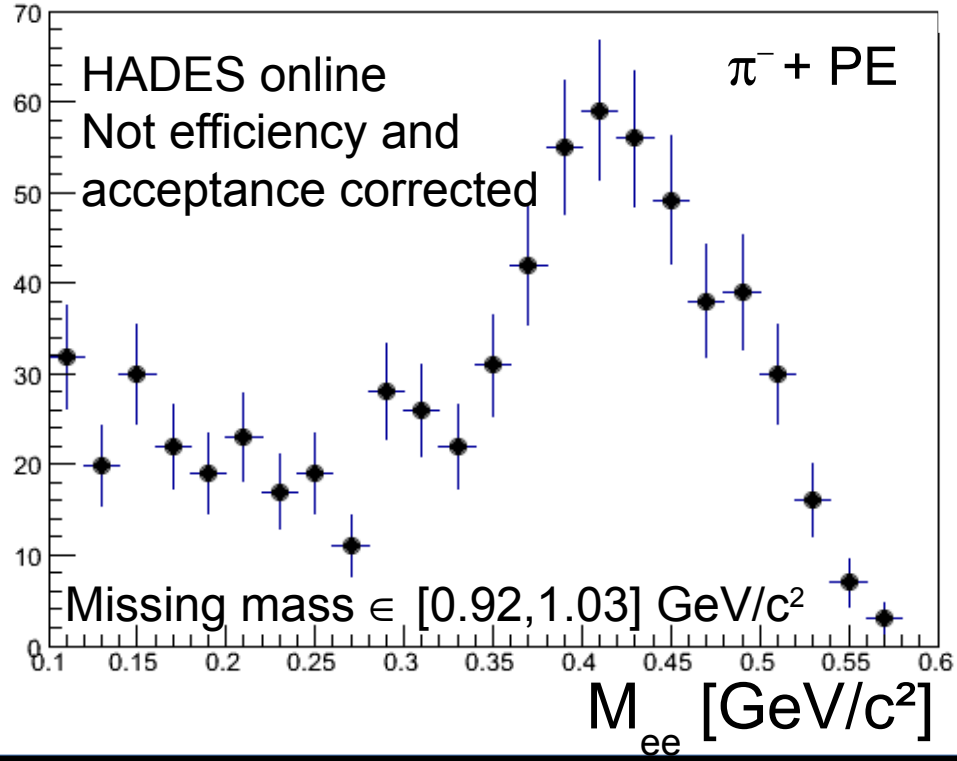

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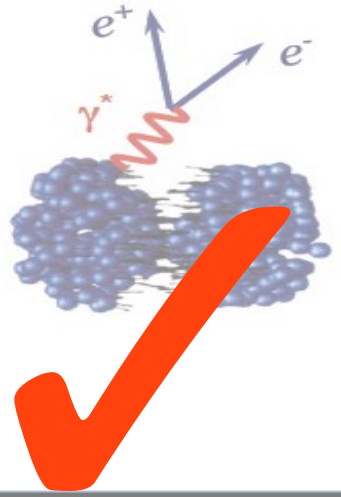

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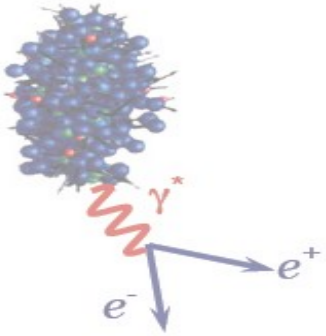

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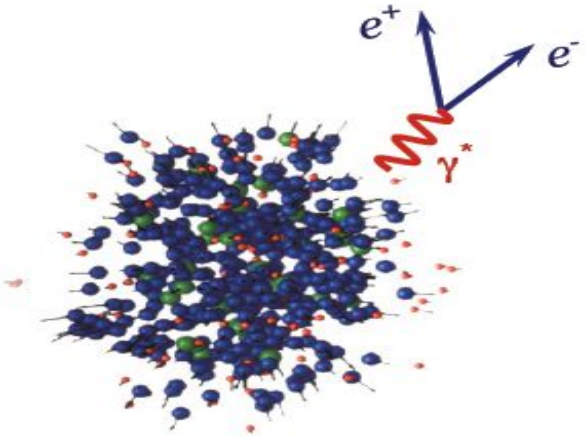

Freeze-out stage

Hadronic final state:
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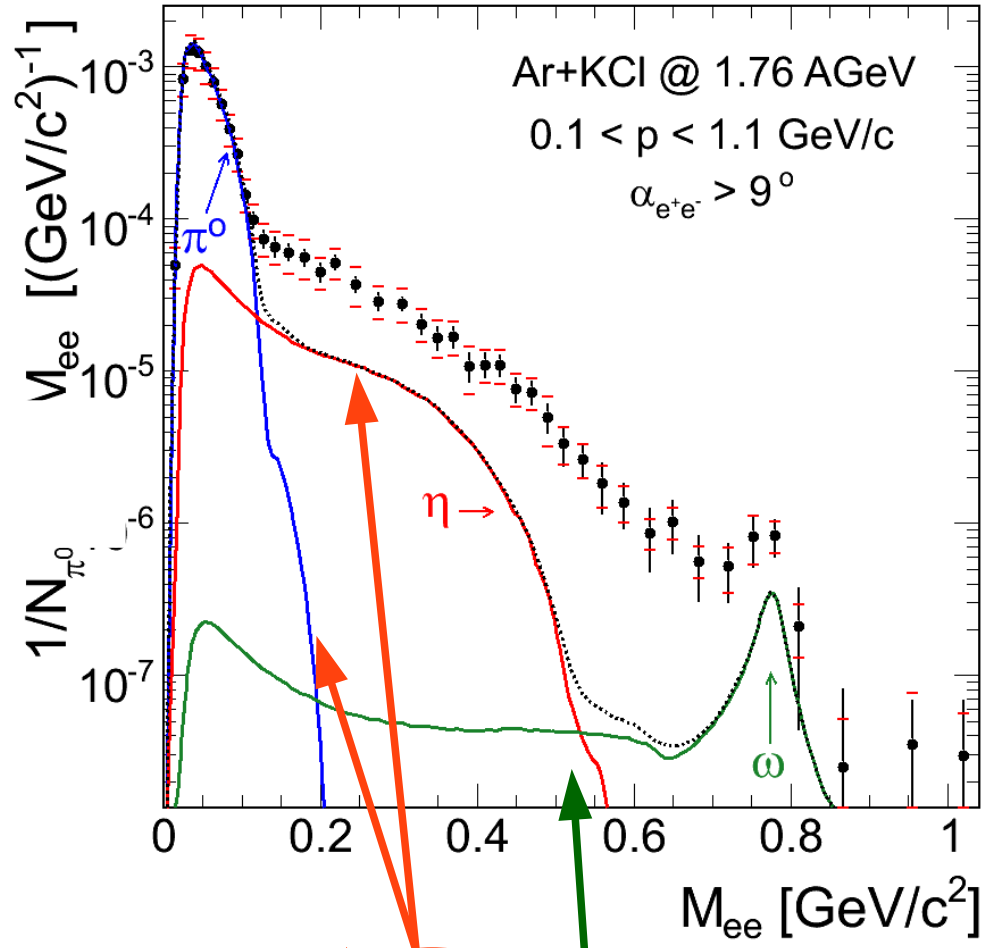
THE FREEZE-OUT "COCKTAIL"

Phys.Rev. C84 (2011)



$\pi^0, \eta \rightarrow \gamma e^+e^-$

$\omega \rightarrow \pi^0 e^+e^-$; $\omega \rightarrow e^+e^-$

- ✔ $Mult_{\pi^0}$ is essential for spectrum normalisation
- ✔ "no $Mult_{\eta}$, no $Mult_{Excess}$!"

$\pi^0, \eta \rightarrow \gamma\gamma \overset{conv}{\Rightarrow} e^+e^-e^+e^-$

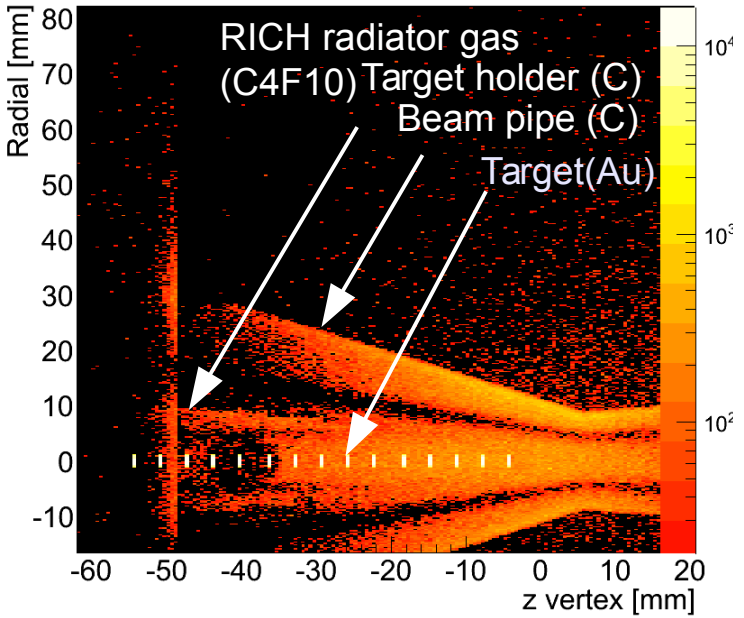
$\pi^0, \eta \rightarrow \gamma e^+e^- \overset{conv}{\Rightarrow} e^+e^-e^+e^-$

STAR: PhysRevC.70.044902
CDF: PhysRevD.70.074008
ALICE: Phys. Lett. B 717,162

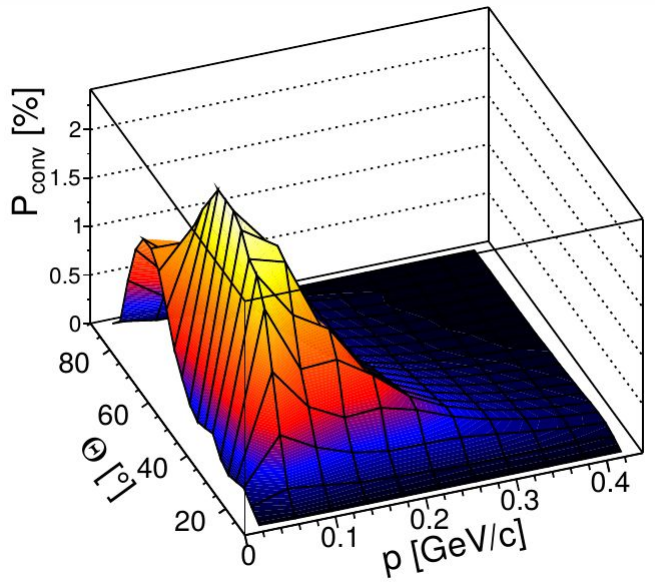
HADES: - p+Nb 3.5 GeV: PhysRevC.88.024904

MEASURE NEUTRAL MESONS

Definition conversion probability:
The probability that a e^+e^- pair from γ will be detected by HADES

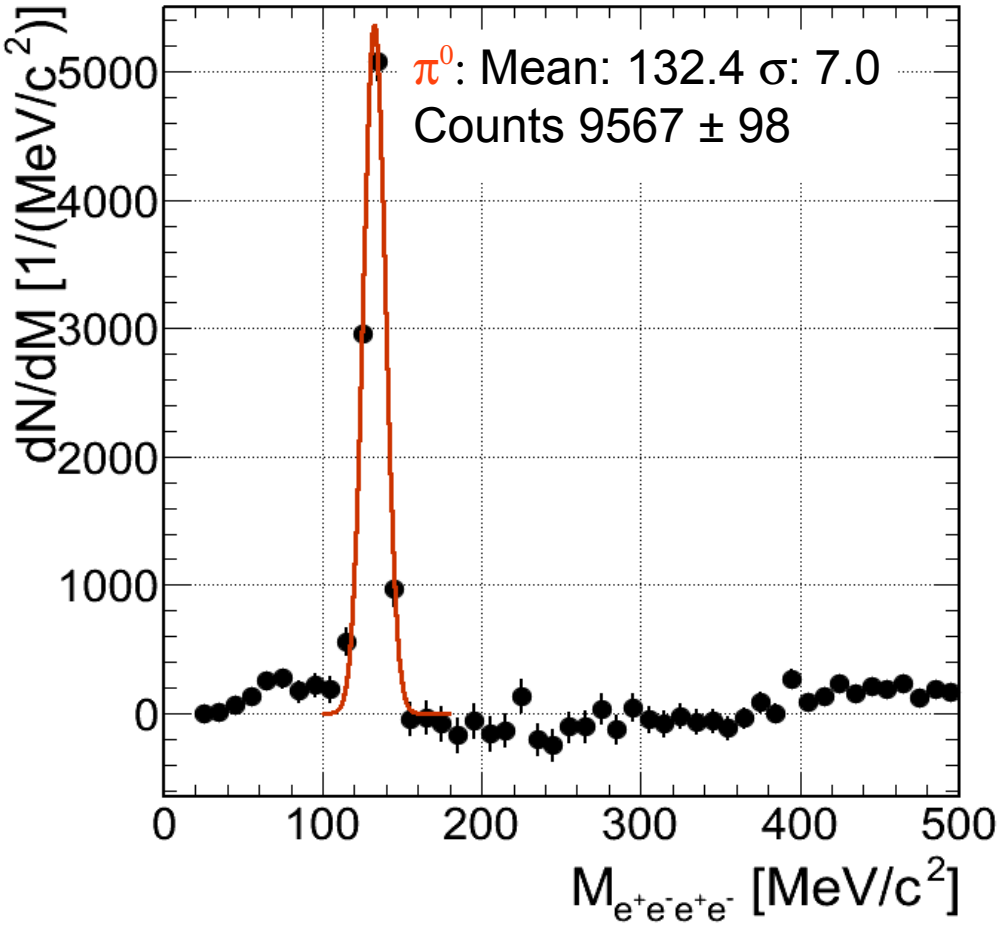


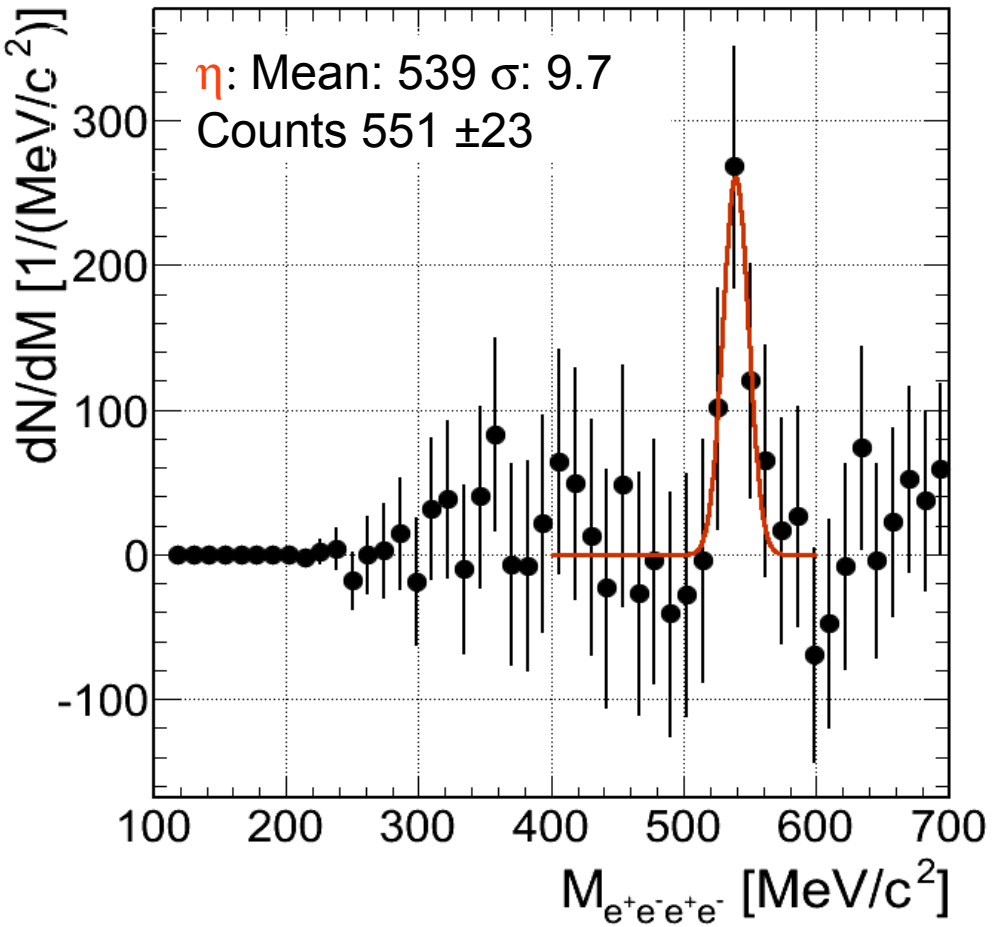
Material	Conv [%]
Target	0.05
δ-shield	0.05
Beam pipe	0.04
Radiator gas	0.11
Mirror	0.08
Sum*	**0.36**



*all values are obtained from Geant3 simulations!

THE FREEZE-OUT "COCKTAIL"





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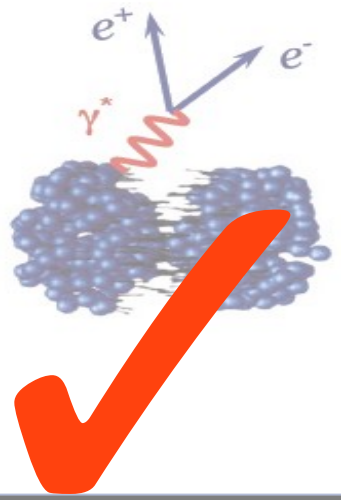

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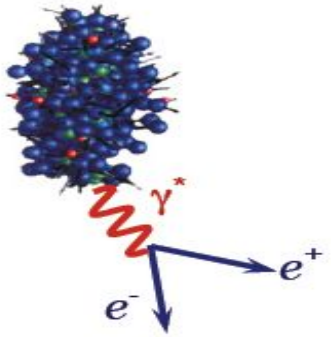
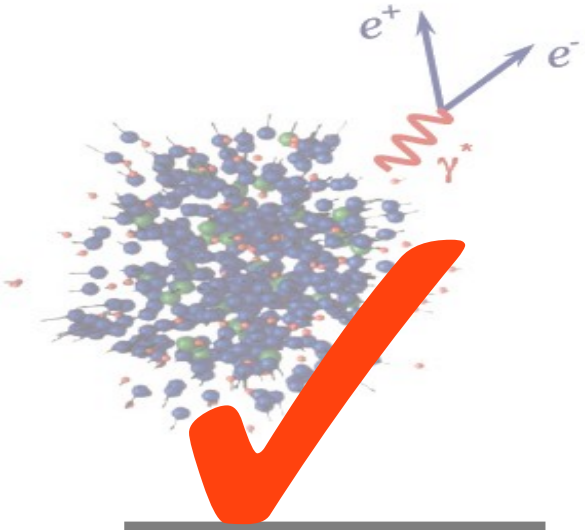
- NN Bremsstrahlung
- Δ,N* $\rightarrow$ Ne$^+$e$^-$



Dense stage (~ 10 fm/c)

In-medium spectral functions

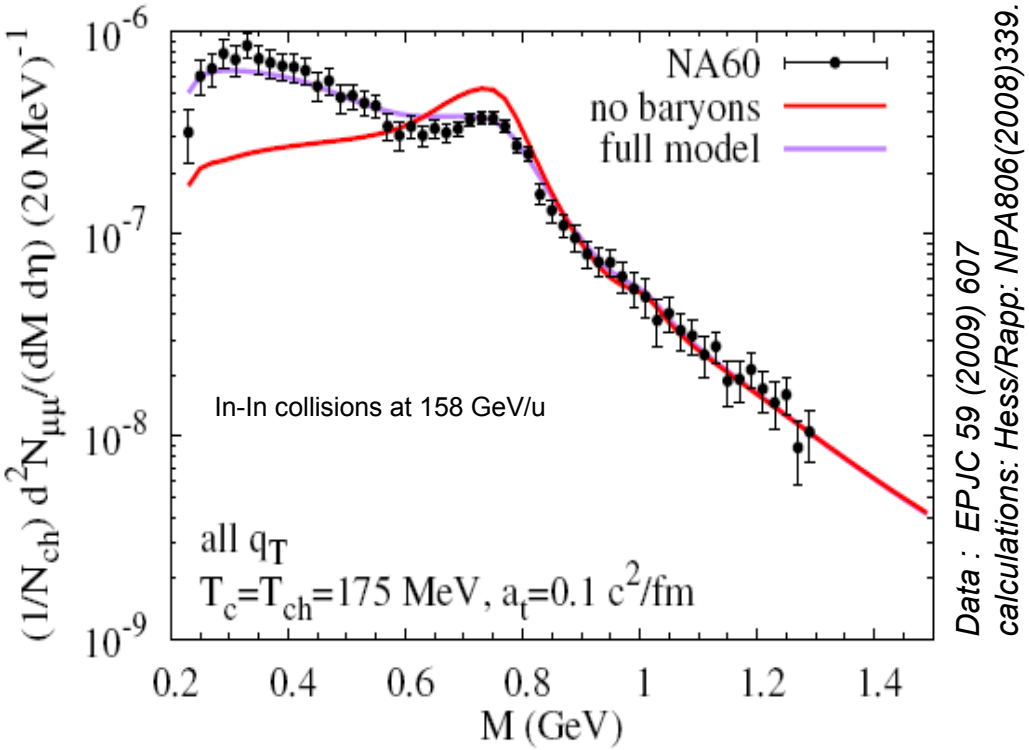


Freeze-out stage

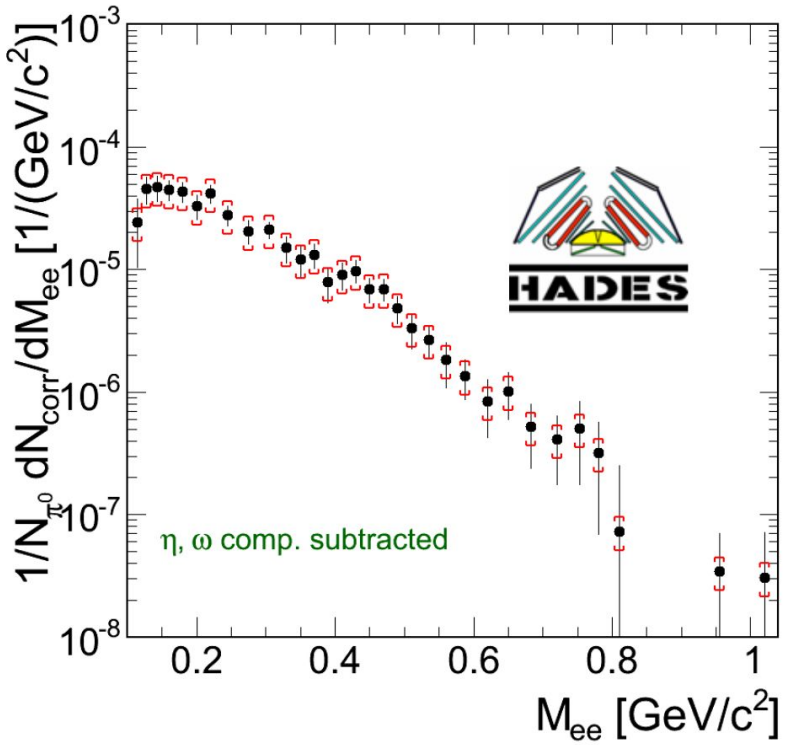
Hadronic final state:
p, $\pi^{+/-}$, k, Λ, ϕ, π^0,η, ω

DENSE STAGE

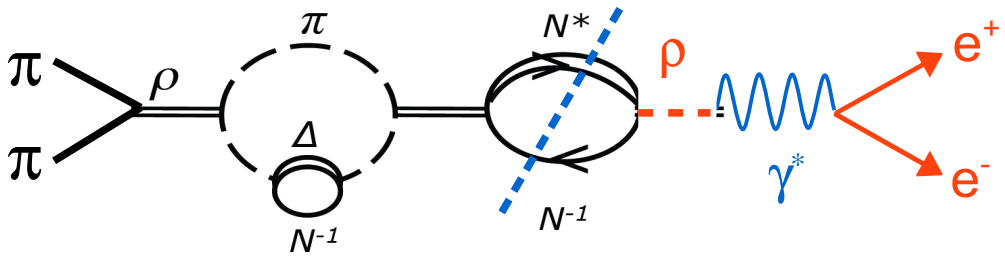
NA60 acceptance corrected $\mu^+\mu^-$ excess spectrum



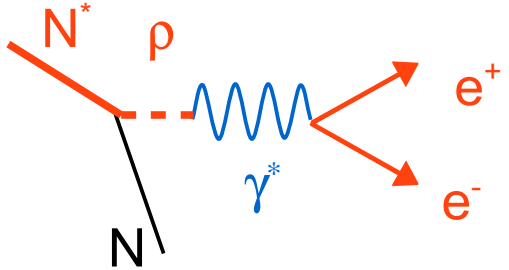
Excess yield, ^{39}Ar+^{41}KCl at 1.76 GeV/u



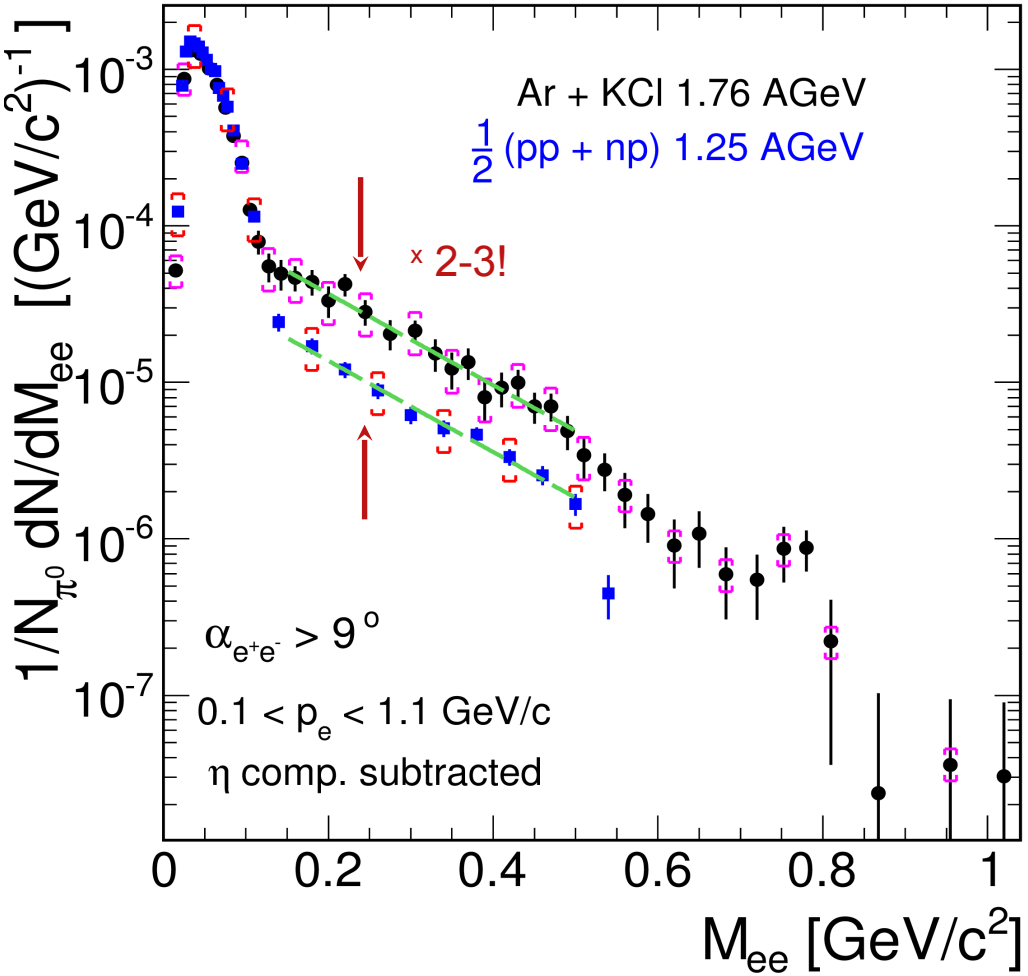
Strength of dilepton field at low masses is due to coupling to baryons



Dalitz-decay of baryonic resonances is dominant source at low beam energies



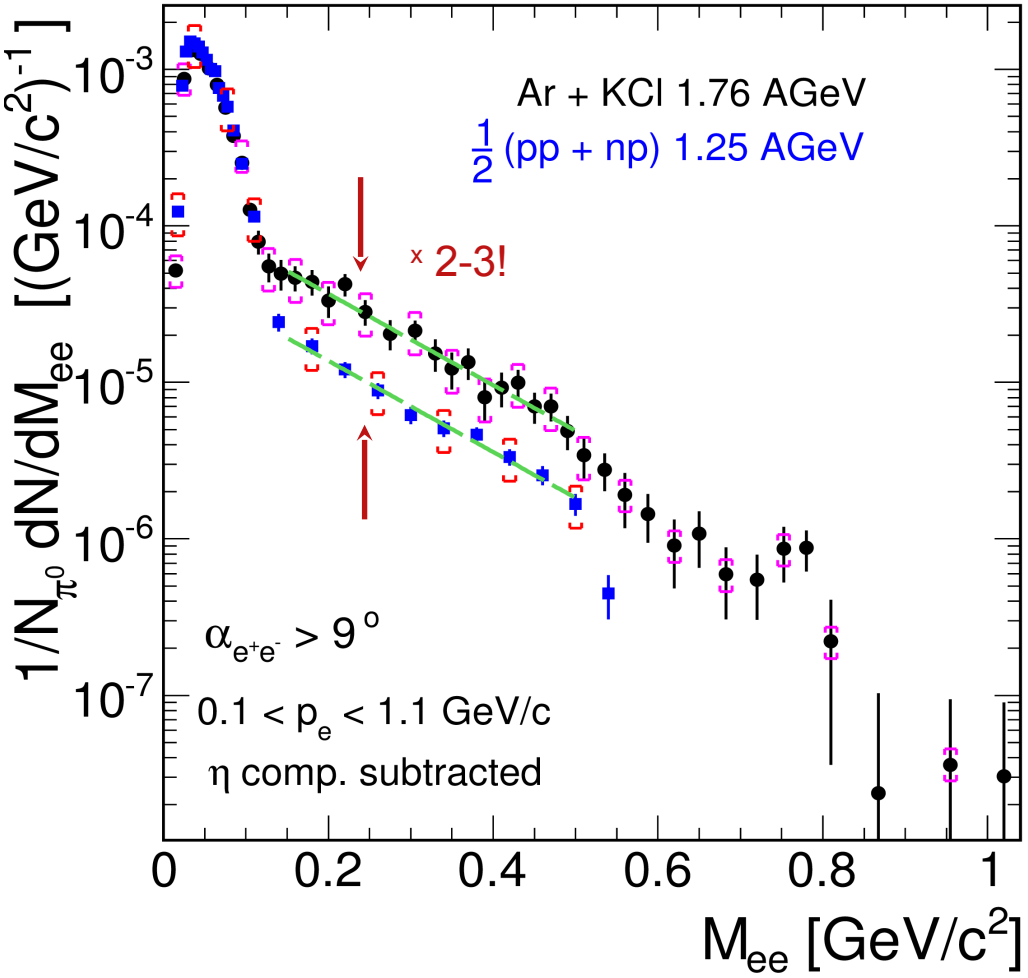
DENSE STAGE

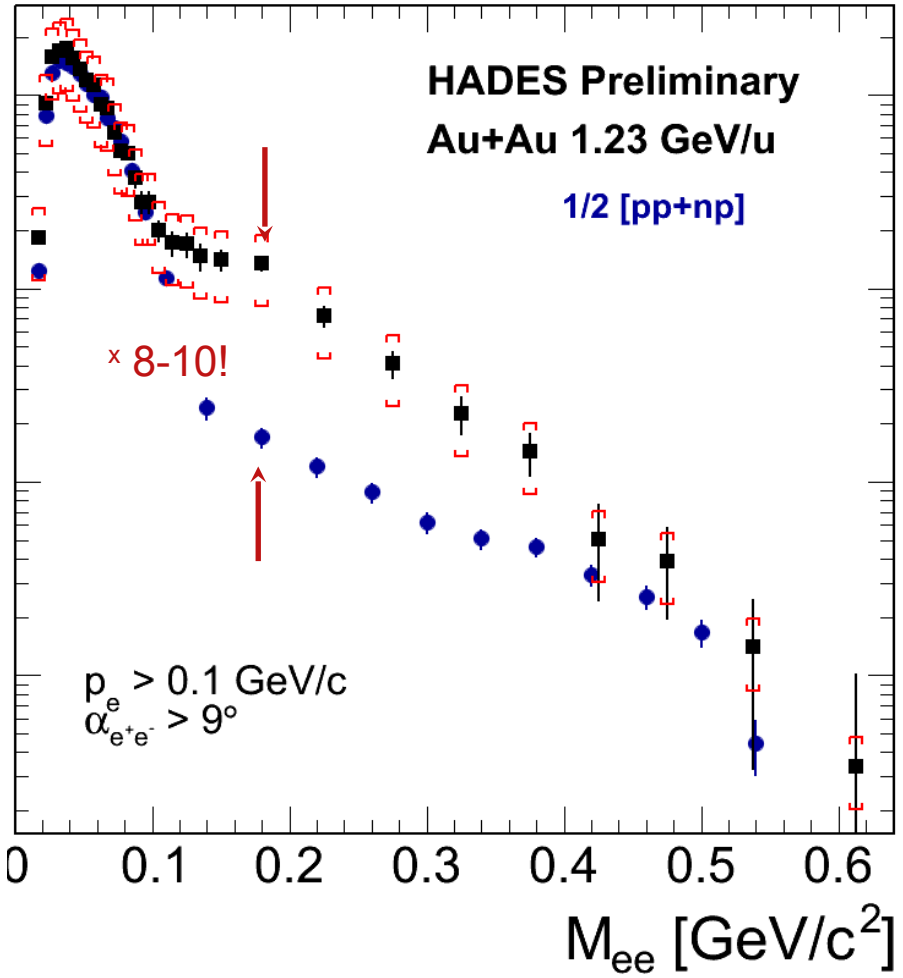


- Normalization to N_{π^0} takes care about A_{part}
- scaling Excess of radiation in 0.12 < M < 0.55 GeV/c²

Rapid increase of relative yield reflects the number of Δ's/ N*'s regenerated in fireball

DENSE STAGE





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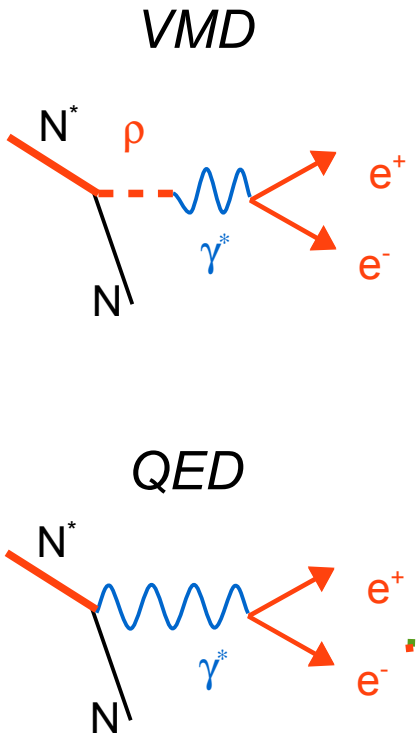
Rapid increase of relative yield reflects the number of Δ's/ N*'s regenerated in fireball

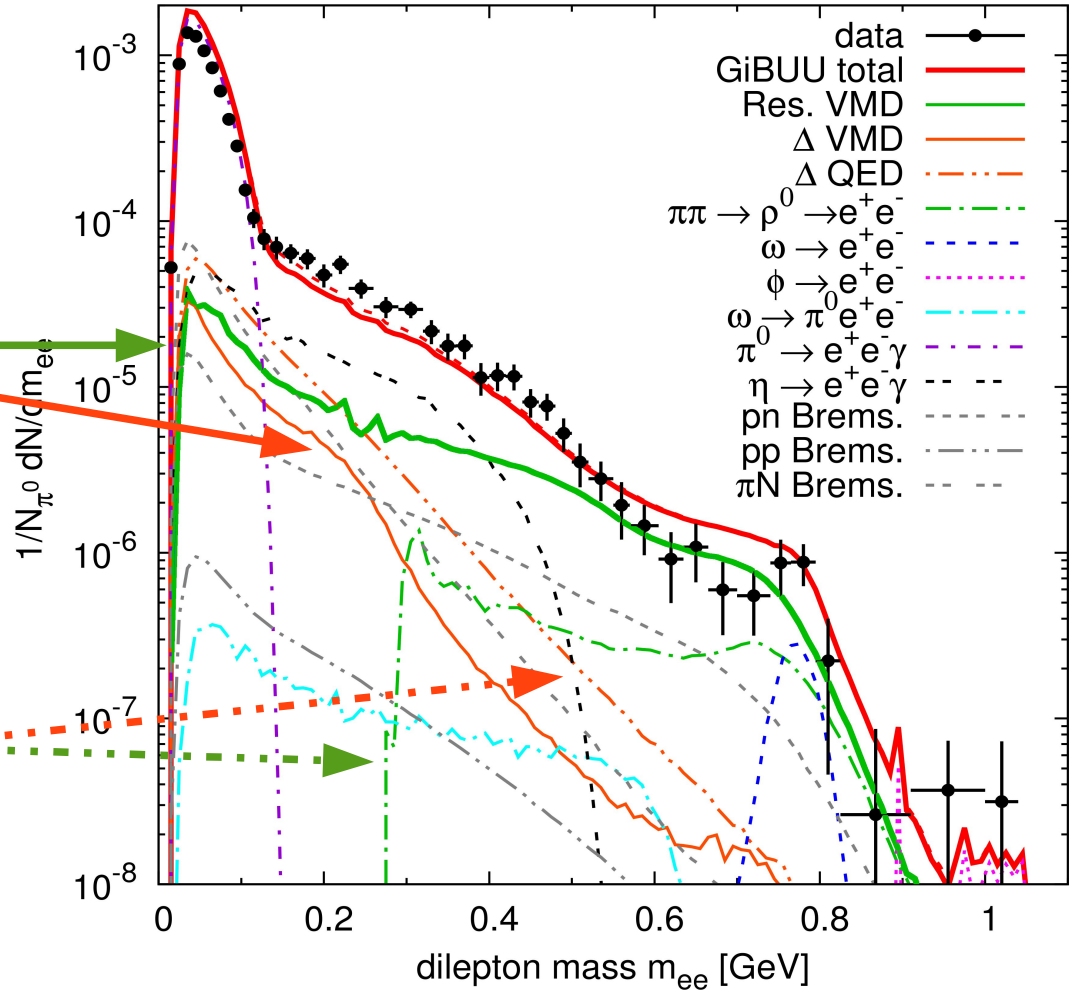
COMPARISON TO TRANSPORT

GiBUU: uses strict VMD for all resonances!

→ Decay of resonances via ρ

Ar+KCl 1.76 GeV/u

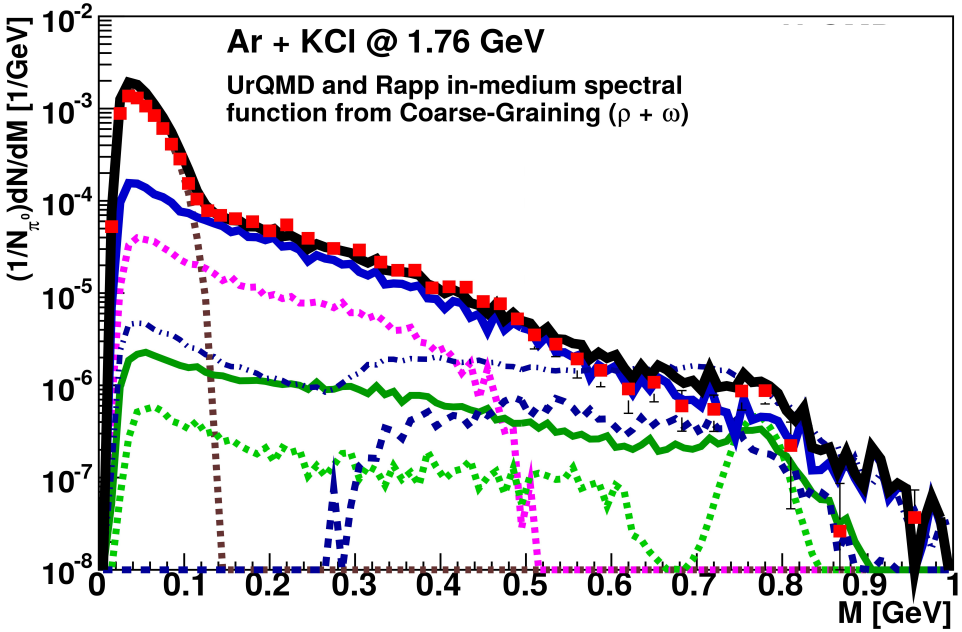


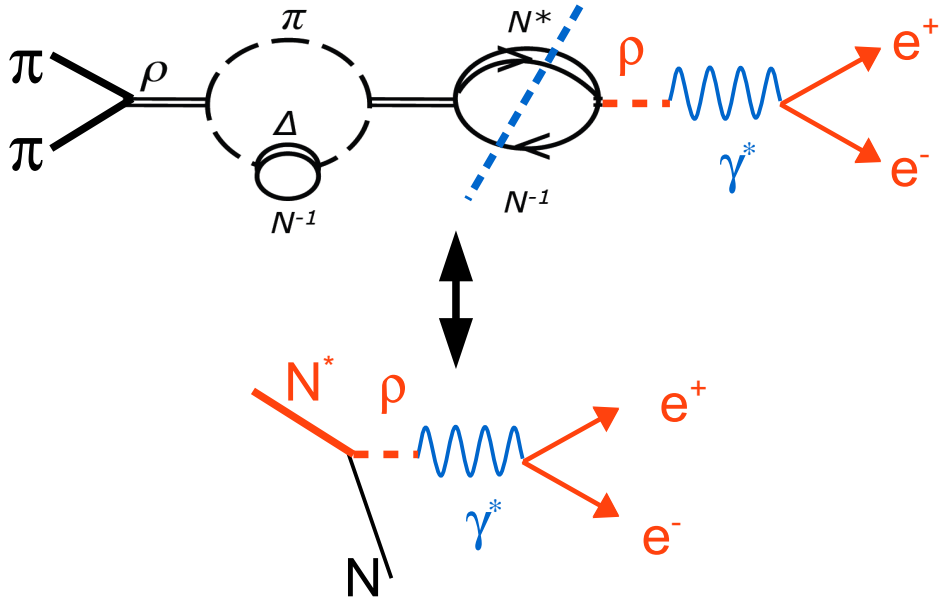


arXiv:1410.4206

COMPARISON TO TRANSPORT

S. Endres, FAIRNESS 2014





UrQMD

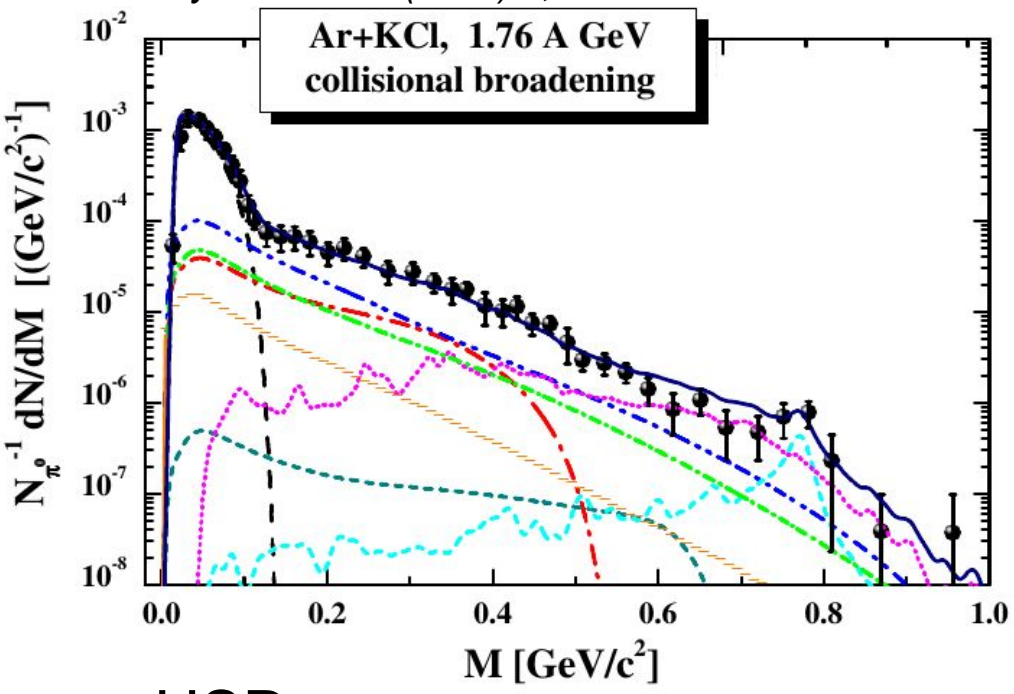
- π
- η
- ω
- ρ
- in-medium ρ
- in-medium ω

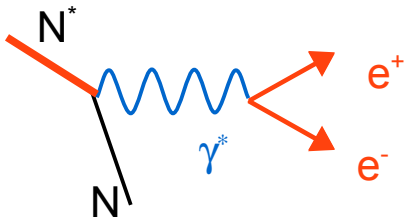
In-medium modifications are visible with baryonic resonances

Similar Idea: F. Seck Master Thesis

COMPARISON TO TRANSPORT

Phys.Rev. C87 (2013) 6, 064907



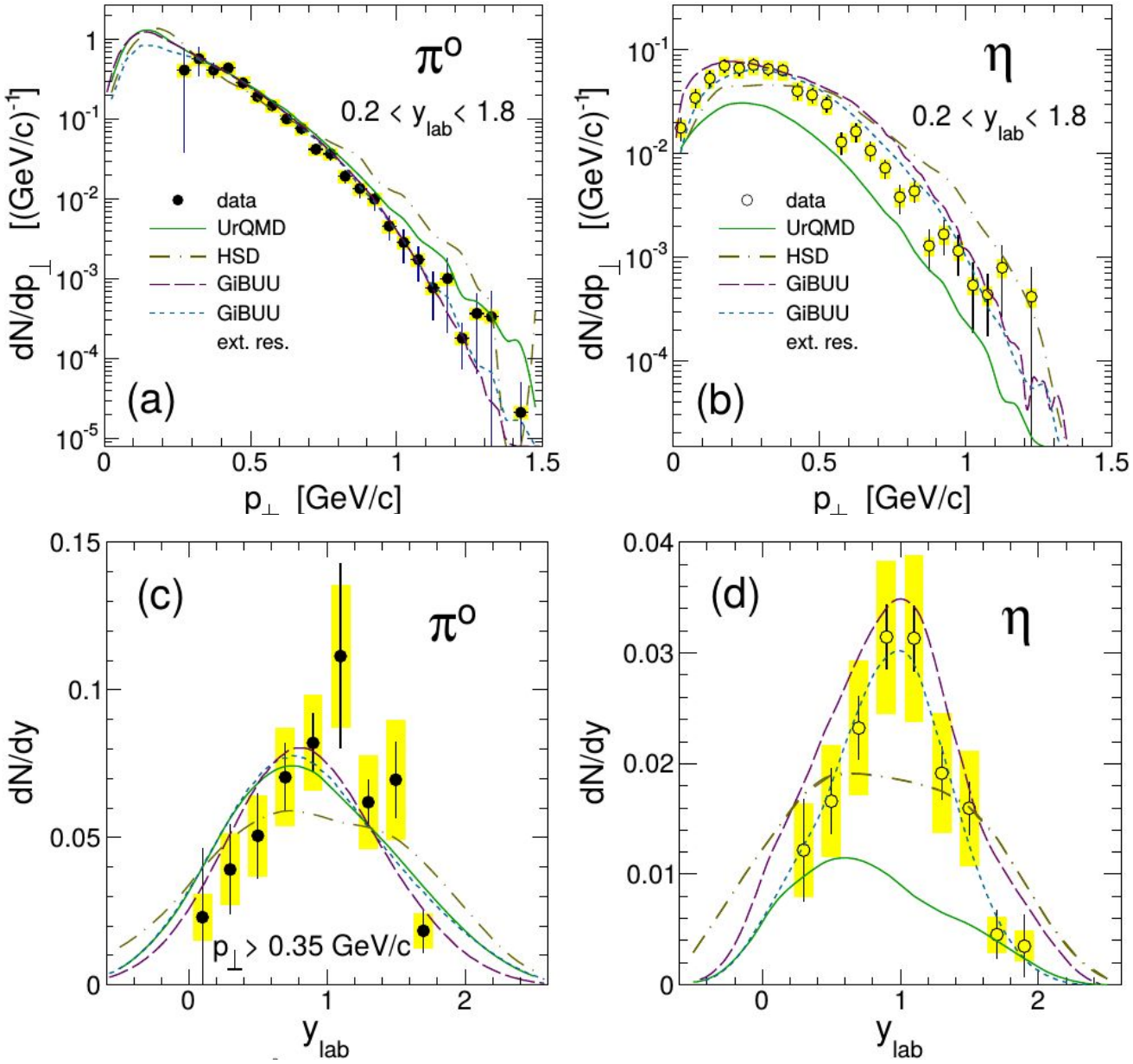


- No VMD inside
- Resonance decay via virtual photon
- Dileptons from rho coming from time integration method
- Collisional broadening to explain medium modifications

KNOW YOUR REFERENCE

Reconstruction of π^0 and η (from p+Nb) with full conversion method!

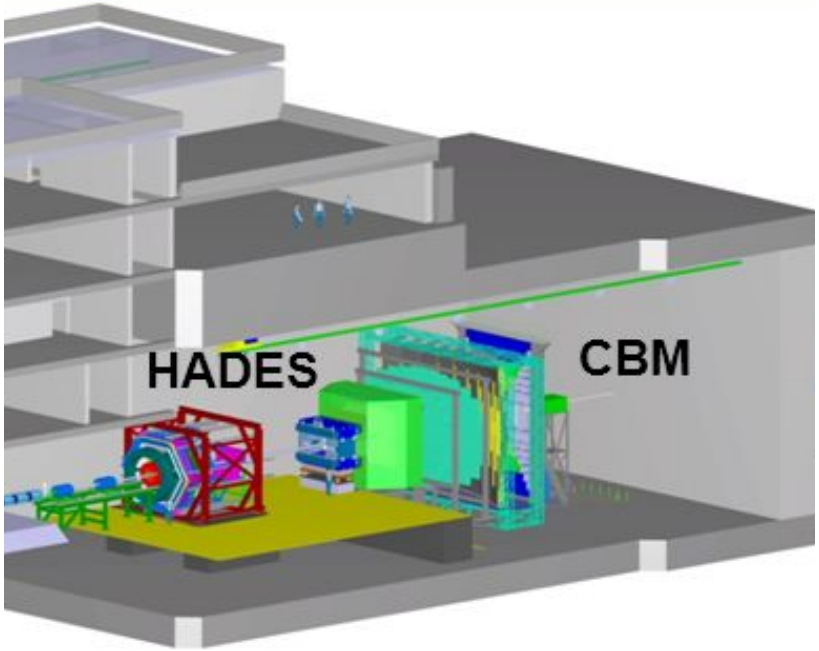
π^0 and η need to be understood!



Phys.Rev. C88 (2013) 024904

FUTURE AT SIS 18/SIS 100

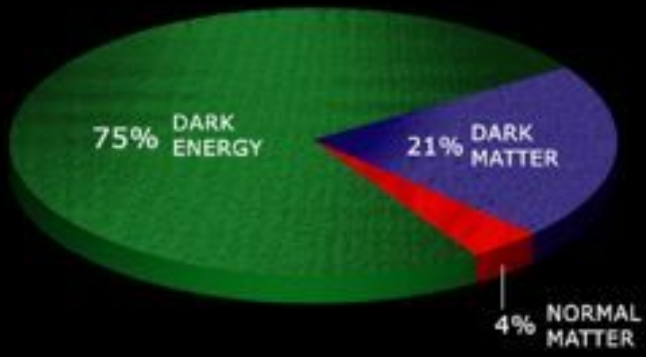
- π beams with HADES in 2017,2018,2019...
- Ag+Ag at SIS 18
- HADES will move to SIS100
- Operational from the very beginning
- Important reference measurements:
  - p+n
  - p+A
  - Proton beam energy up to 29 GeV
- Heavy ions
  - HADES A+A < 3.5 GeV
  - CBM: A+A 3.5 - 35 GeV



HADES COLLABORATION

WHAT ELSE DID WE LEARN?

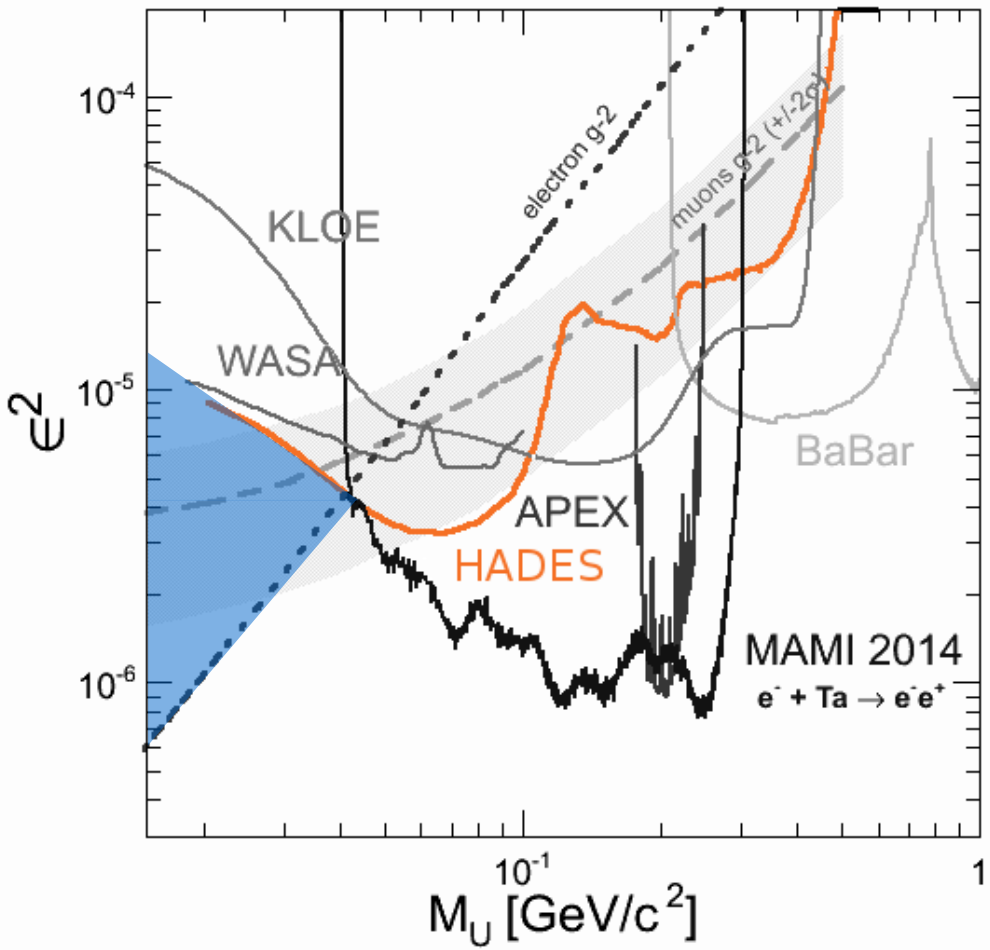
- Analysis of cosmic microwave background anisotropies
- Large-scale structures in the universe (galaxies, clusters of galaxies). In particular orbital velocity profiles of galaxies
- Also, hints from cosmic ray spectrum (e^+/e^- excess > 10 GeV, 511 keV line)



$$\eta \rightarrow \gamma\gamma^* \rightarrow \gamma e^+e^-$$
$$\hookrightarrow \gamma U \rightarrow \gamma e^+e^-$$

Searching the U boson ! in electromagnetic processes

MIXING PARAMETER: COMPARISON WITH WORLD DATA SET

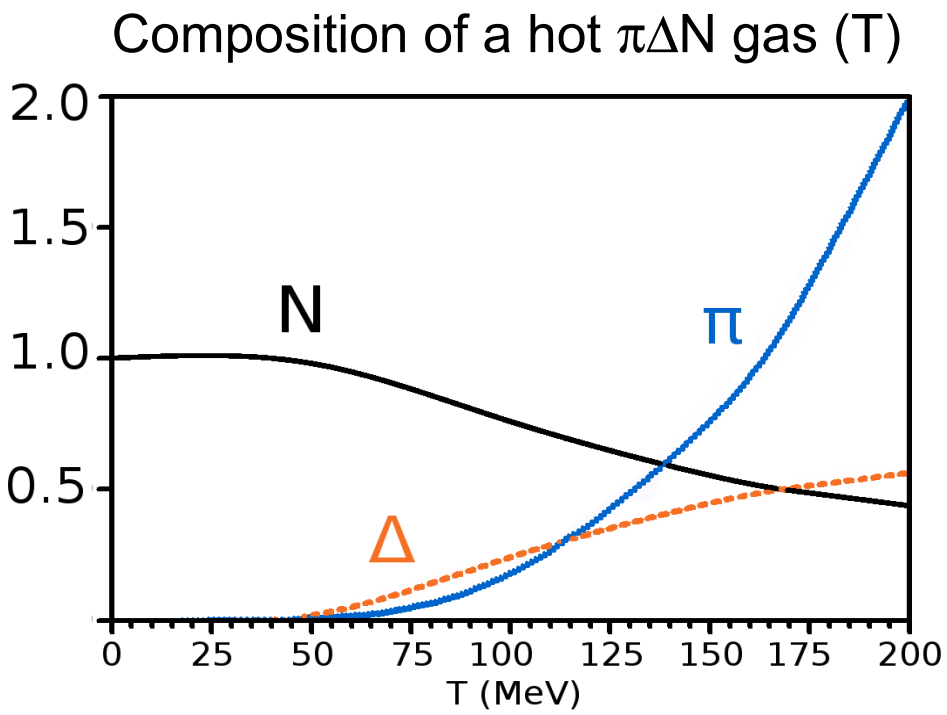


- $\varepsilon^2=\alpha'/\alpha$ ($\varepsilon^2 \approx 10^{-2}$-$10^{-8}$)
- For the first time a rather broad mass range is covered: $0.02 < M_U < 0.6$ GeV/c^2
  - Clear improvement at low masses ($M_U < 0.1$ GeV/c^2)
  - Complementary information to the KLOE-2 results at higher masses ($M_U > 0.13$ GeV/c^2)
- Au+Au e^+e^- data might allow to constrain the low-mass region even further

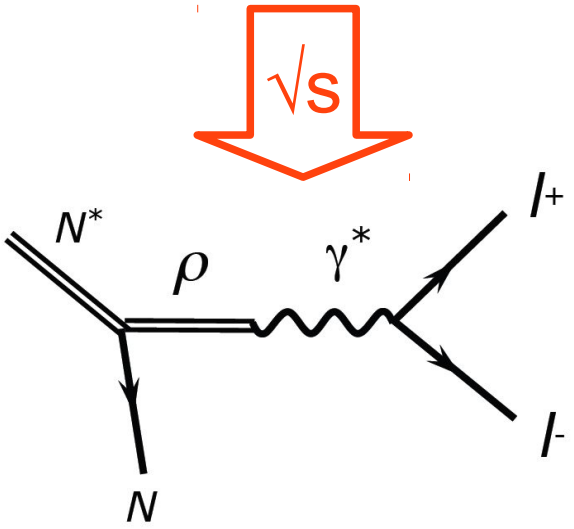
Phys. Rev. Lett. 112 (2014), 221802

Master thesis C. Ungethüm

EMISSIVITY OF DENSE MATTER

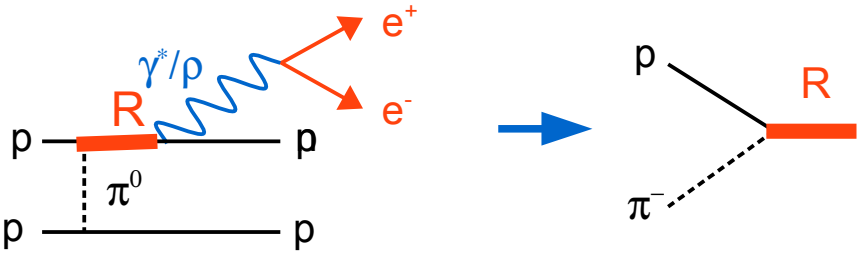


SIS

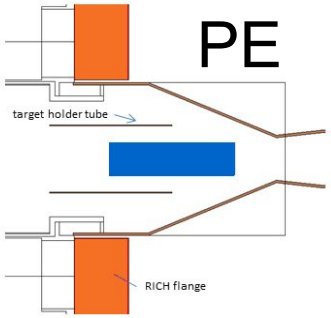


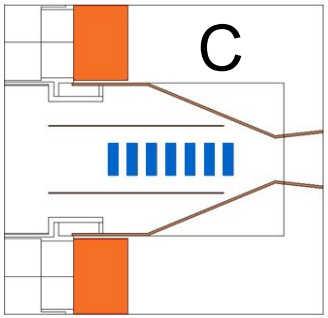
R. Rapp and J. Wambach, ArXiv:hep-ph/9909229v1

RESONANCE CONTRIBUTION



Liquid hydrogen target: Large emittance of π-beam ☹





Use C_2H_2 target (5cm length)

- Protons: factor 2 more than in LH_2
- But also carbon inside
  - ➔ Measure carbon as reference

π^- + PE

π^- + C

p = 0.69 GeV/c

775M evts

115M evts

Primary beam:
10^{11} N (2A GeV) /spill

Beam time for 25d

Secondary π–beam:

- Intensity I ~ 3* 10^5 π^-/spill
- Momentum:
  0.6 < p < 1.7 GeV/c