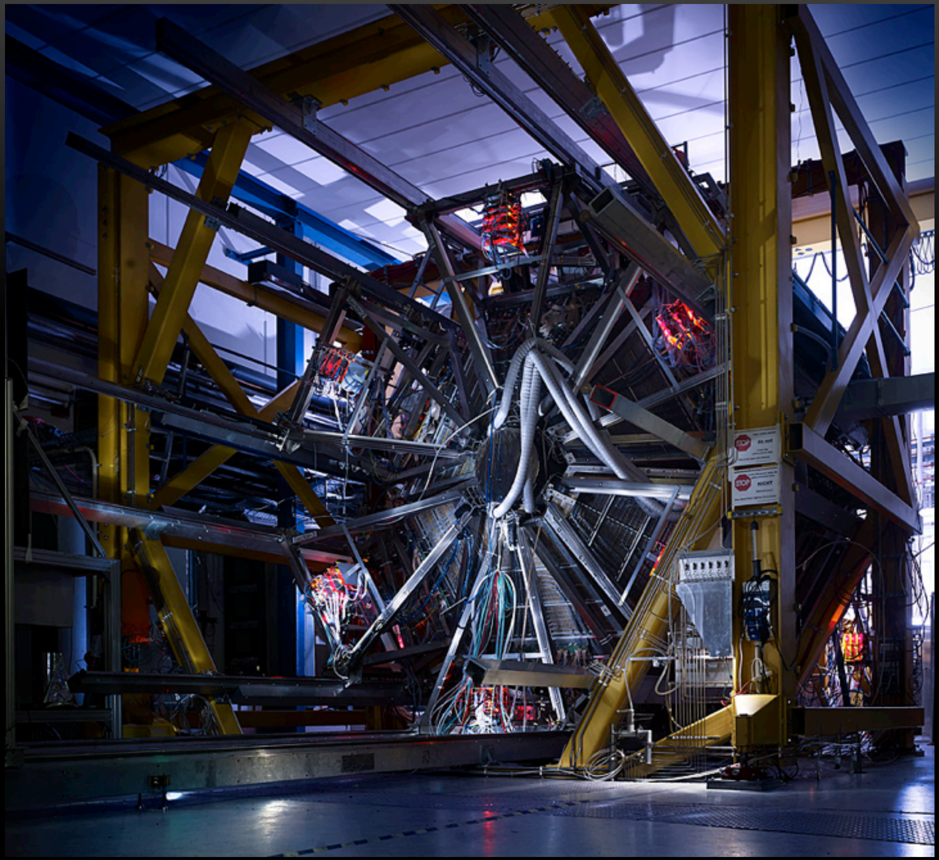
Jahrestagung des
Komitees Hadronen und Kerne
Bad Honnef, 1-2 Dezember 2016



Bericht zu HADES

Tetyana Galatyuk for the HADES Collaboration

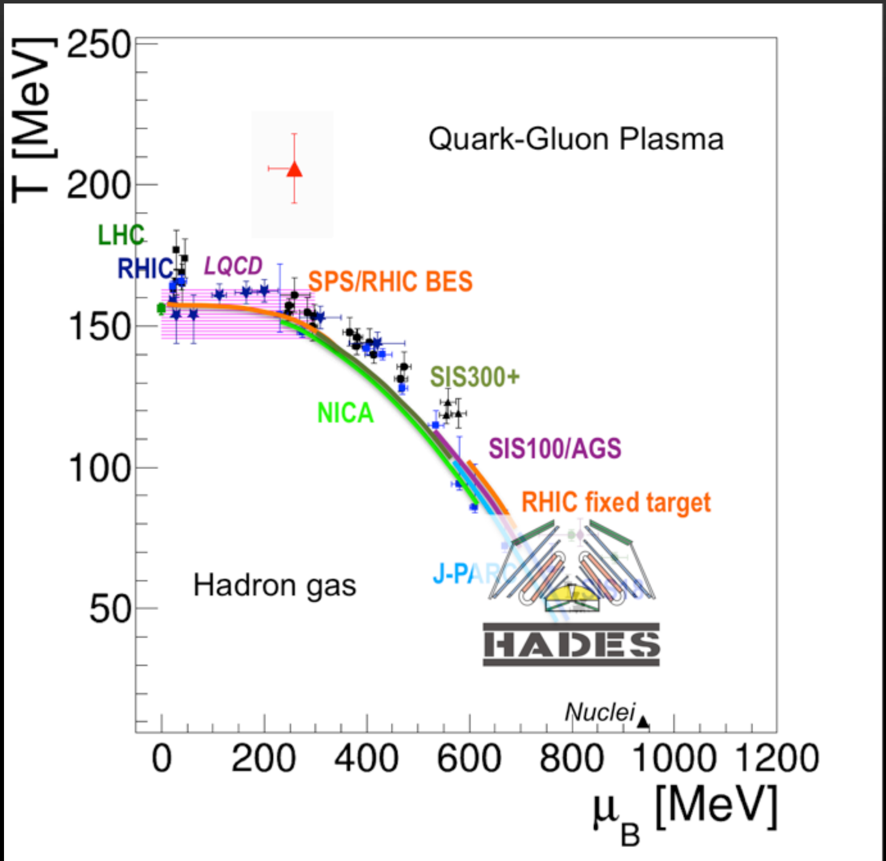
Technische Universität Darmstadt / GSI Helmholtzzentrum für Schwerionenforschung

The HADES Collaboration

~100 collaborators

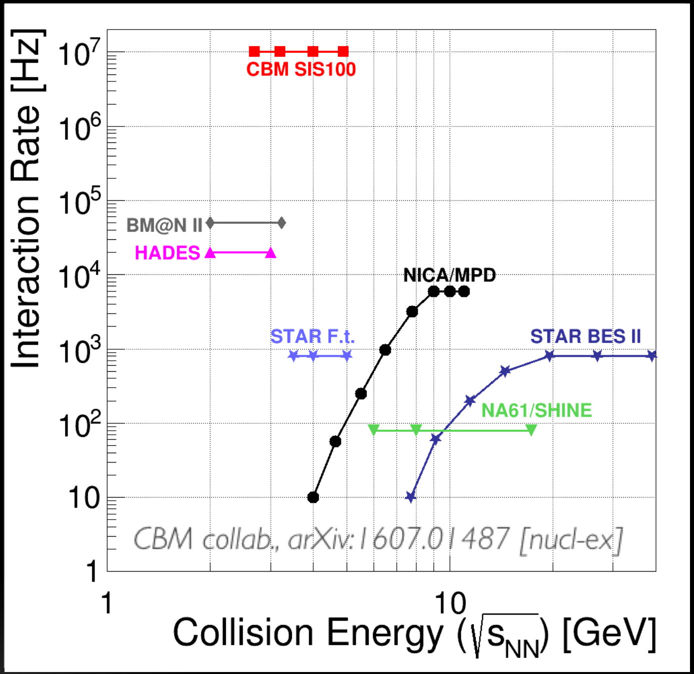
- IOP SAS, Bratislava, Slovakia
- INR & ITEP & MEPHI, Moscow, Russia
- LIP & ISEC, Coimbra, Portugal
- SIP JUC Cracow, Poland
- GSI, Damstadt, Germany
- TU Darmstadt, Germany
- HZDR, Dresden, Germany
- JINR Dubna, Russia
- GU Frankfurt, Germany
- JLU Giessen, Germany
- TU München, Germany
- Lisboa, Portugal
- Nicosia, Cyprus
- IPN Orsay, France
- NPI CAS, Rez, Czech Rep.
- USC – S. de Compostela, Spain
- FZ Jülich, Germany (James Ritman)
- U Wuppertal, Germany (Karl-Heinz Kampert)

Searching for landmarks of the QCD matter phase diagram



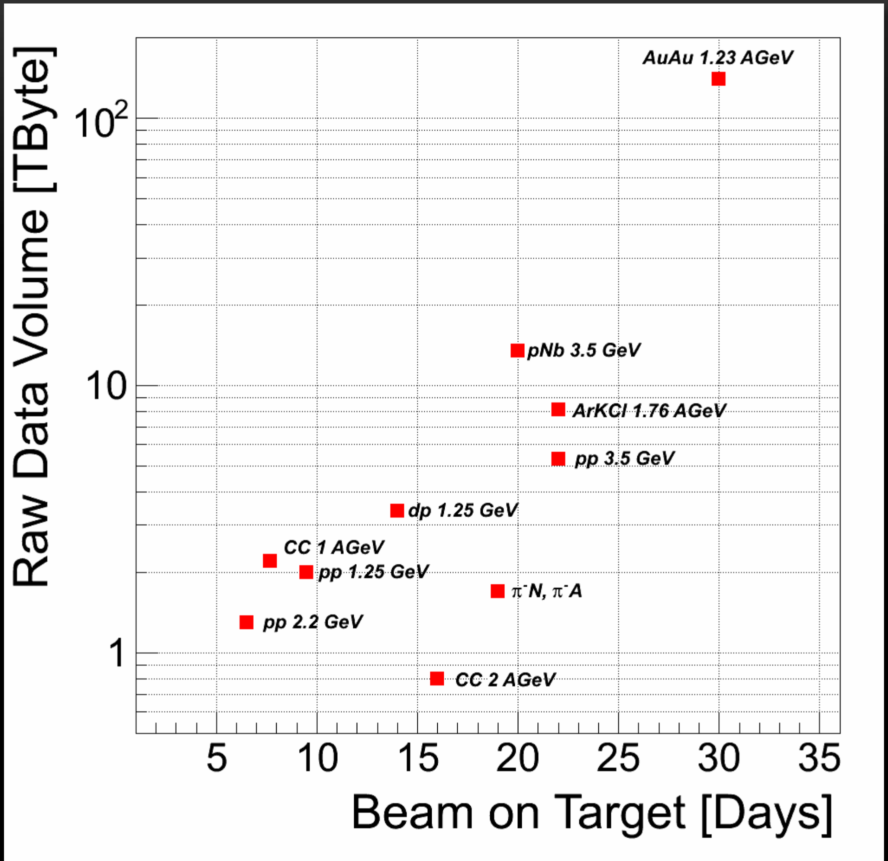
Observables:

- Flavor production (multi-strange, *charm*)
- Emissivity of matter (dileptons)
- Higher moments of e-b-e multiplicities (B, S, Q)



- HADES explores the highest-μ_B region
- Very competitive w.r.t. interaction rate
- HADES is part of the beam energy scan
  → marks lowest point of the excitation function

HADES strategy



- Heavy-ion, π and p beams
- Excitation function for low-mass lepton pairs and (multi-)strange baryons and mesons
- Various aspects of baryon-resonance physics
  - Time-like electromagnetic transition form factors (ρ baryon coupling)
  - Hyperon physics

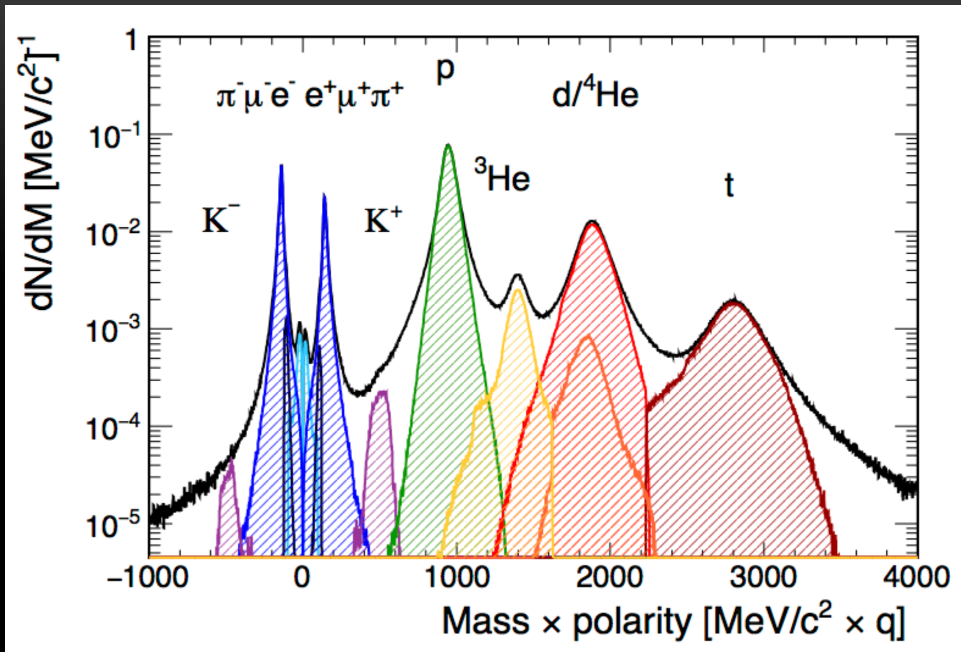
Special emphasis on sub-threshold particle production

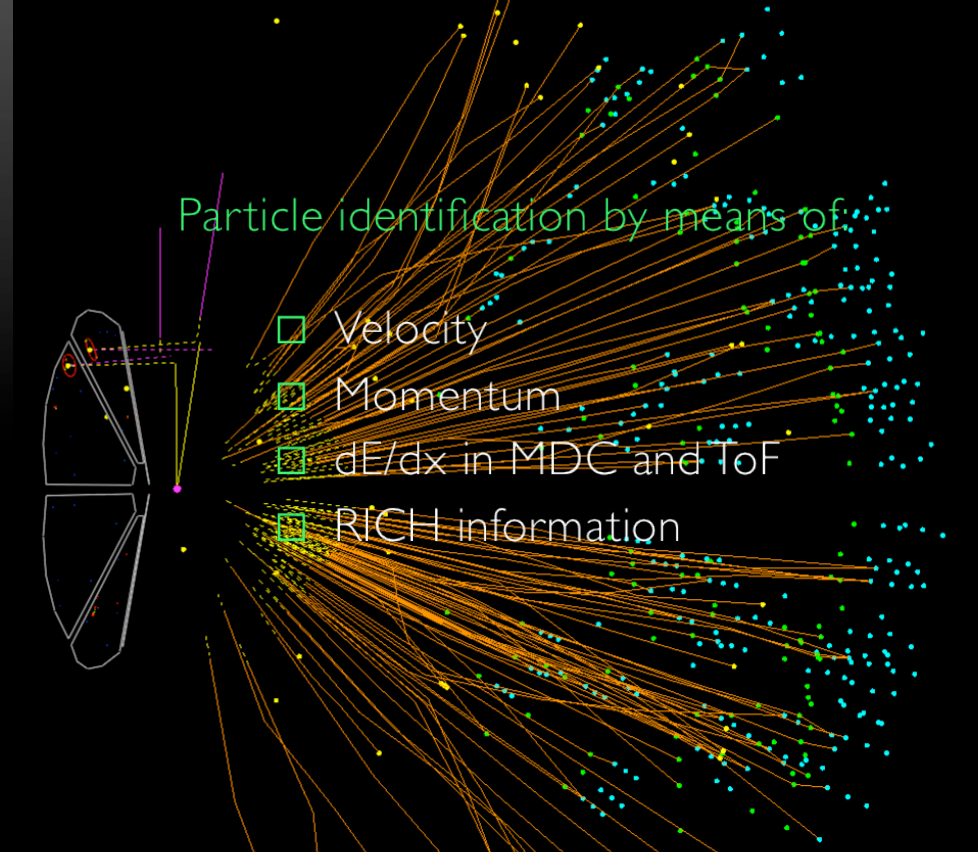
2002–2009: light A+A, p+p, n+p, p+A

2011–2014: Au+Au, π-induced reactions

2018–2020: FAIR phase 0 → high-statistics π+p/πA, p+A and A+A

HADES performance

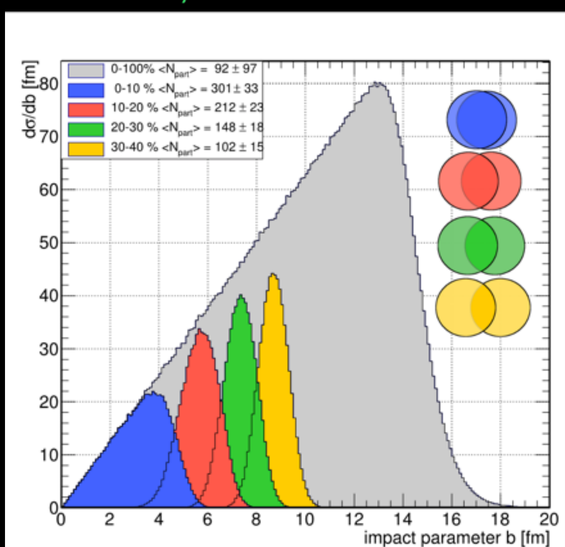




Particle identification by means of:

- Velocity
- Momentum
- dE/dx in MDC and ToF
- RICH information

Centrality: Glauber calculation



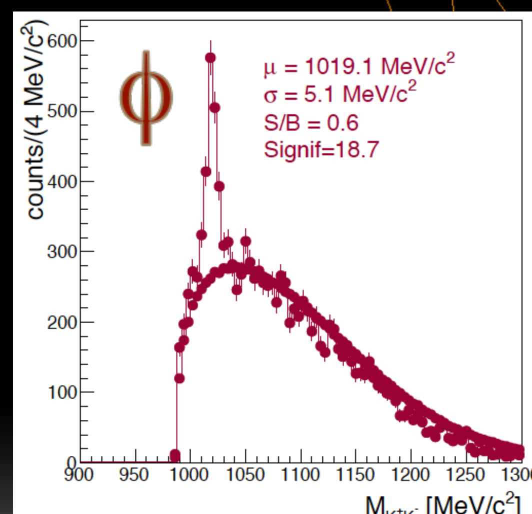
$\langle A_{part} \rangle$

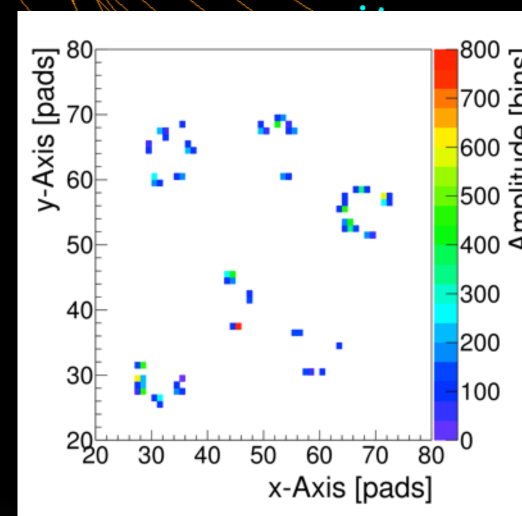
0-10% - 301

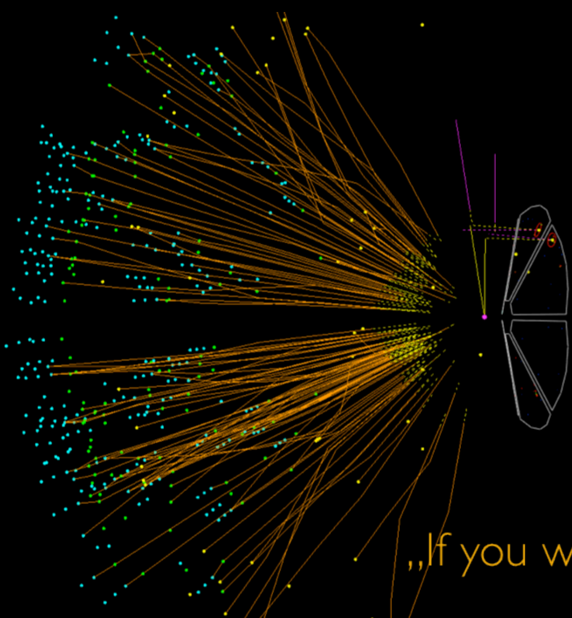
10-20% - 212

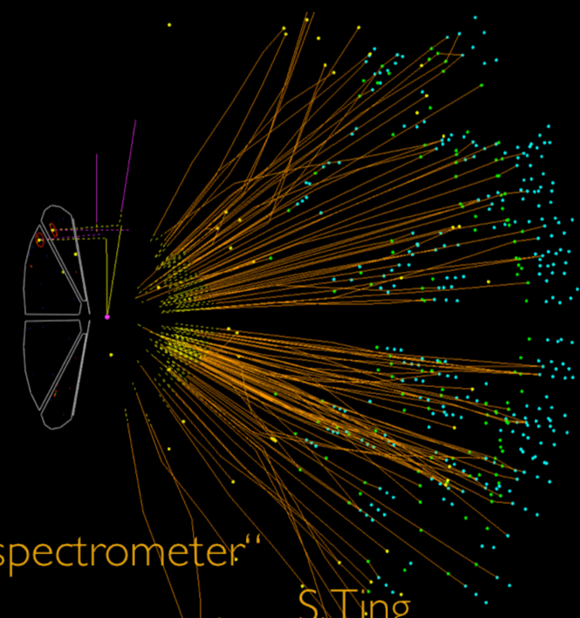
20-30% - 148

30-40% - 102







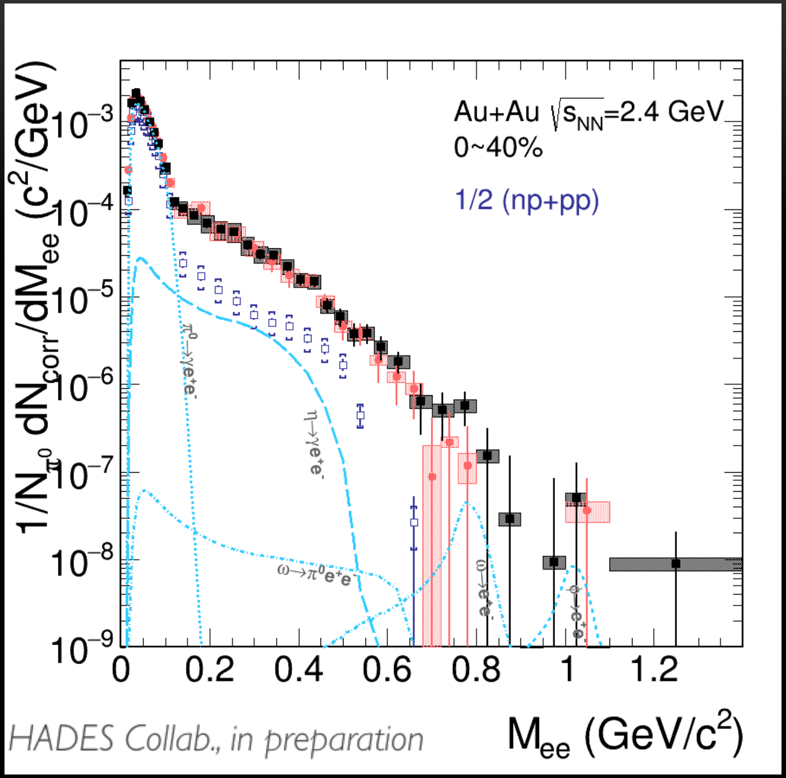


Emissivity of matter

„If you want to detect something new, build a dilepton spectrometer"

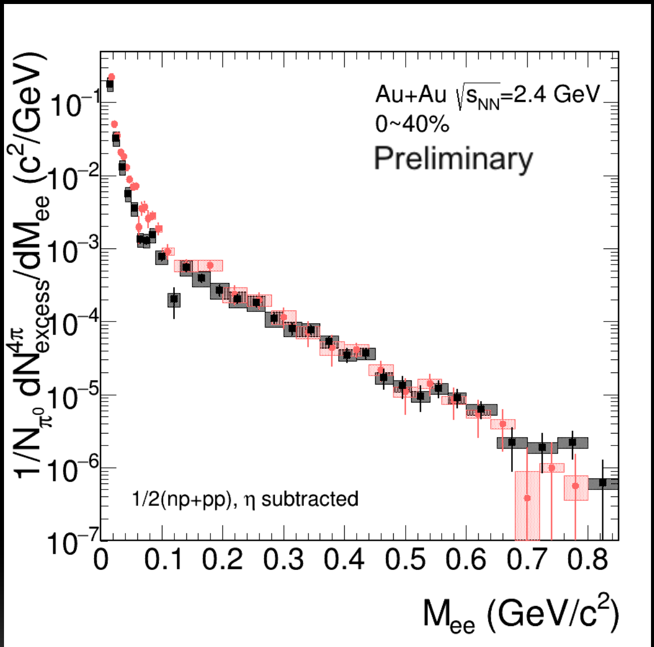
S. Ting

Excess radiation in Au+Au collisions



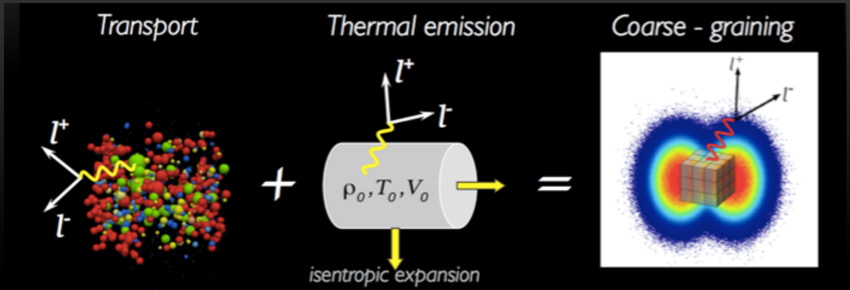
- Medium radiation goes beyond what is expected from a superposition of incoherent NN collisions and F.o. sources
- Strong excess (~$A_{part}^{1.3}$)
  - Regeneration of baryonic resonances
  - Subsummed into spectral functions
- Dilepton chronometer of the collision time

- Inclusive excess mass spectrum
  - Fully corrected for acceptance
  - All known e^+e^- sources subtracted
- Almost exponential spectrum up to vector meson region!
- Fit to $dN / dM \propto M^{3/2} \times e^{-M/T} \to T_{\text{Emitting Source}} = 67 \pm 5$ MeV



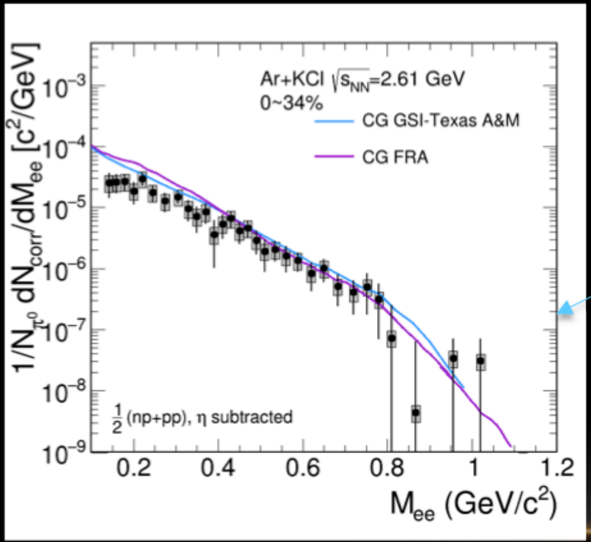
Thermal dilepton emission at SIS18?

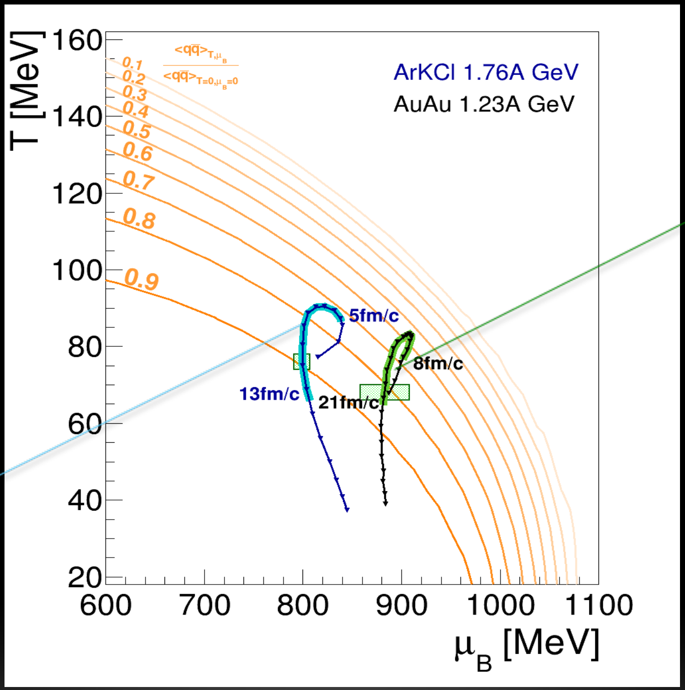
CG FRA: Phys. Rev. C 92, 014911 (2015)
CG GSI-Texas: Eur.Phys.J. A52 (2016) no.5, 131
HADES ArKCl F.o.: Phys.Rev.C 84 (2011) 014902
Condensate: B.J. Schaefer and J. Wambach
Trajectories: F. Seck extracted from UrQMD

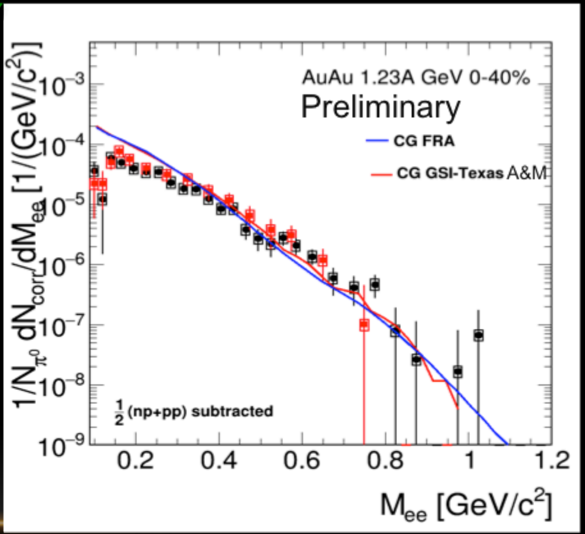


- Bulk evolution from microscopic transport
- Apply in-medium ρ&ω spectral functions to compute EM emission rates

- Coarse-graining method works at low energies
- Excess yield driven by temperature and size/ lifetime (four-volume integral)
- Thermal emission governed by the in-medium ρ spectral function (VDM)
- Broadening of the in-medium ρ driven by ρ-baryon coupling → supports medium effects at UrHIC!

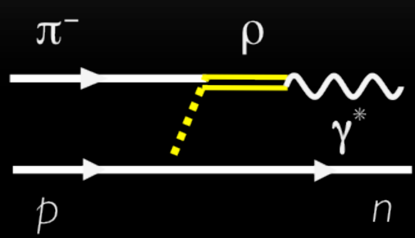


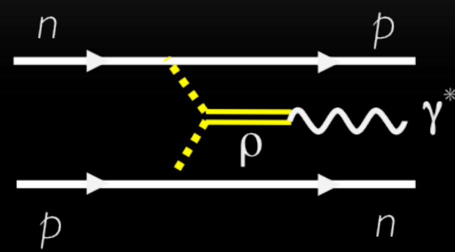


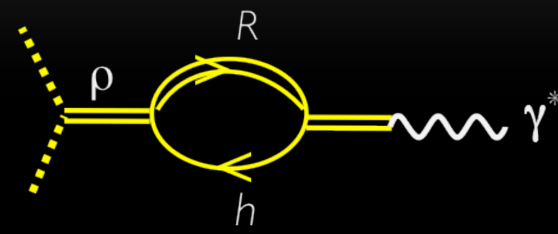


The role of virtual pions in dilepton production

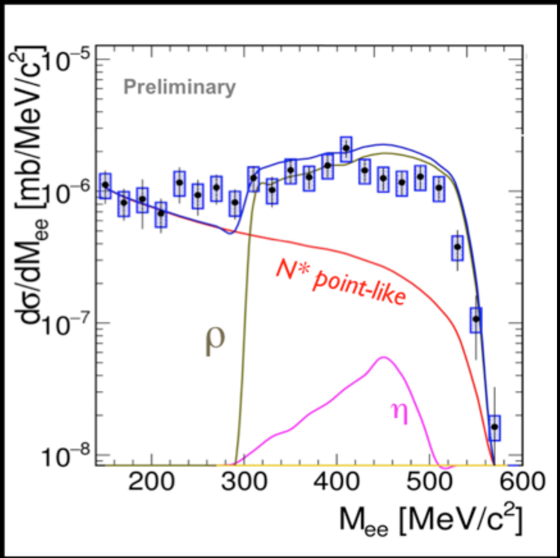
Three different collision systems, three surprises but likely the same underlying mechanism

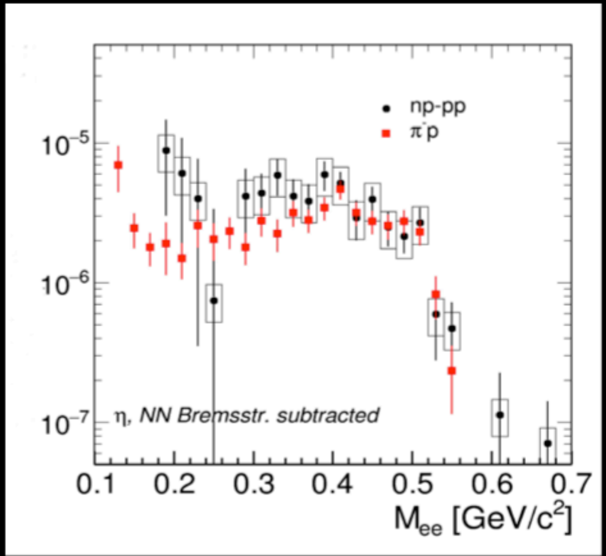


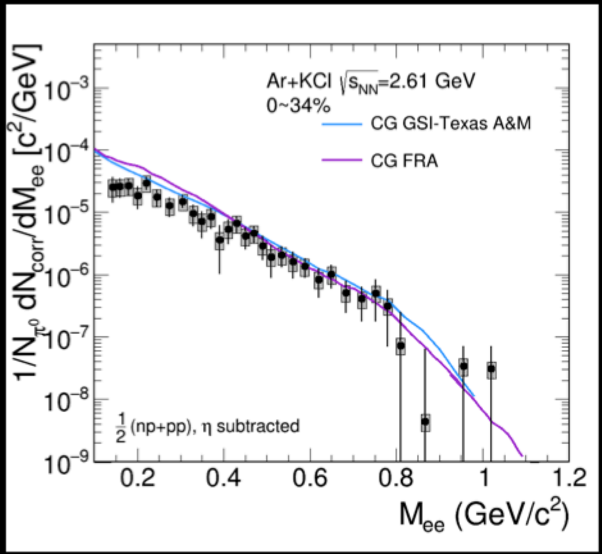




Exclusive $\pi^- p \rightarrow n e^+ e^-$ at $\sqrt{s}$ = 1.49 GeV





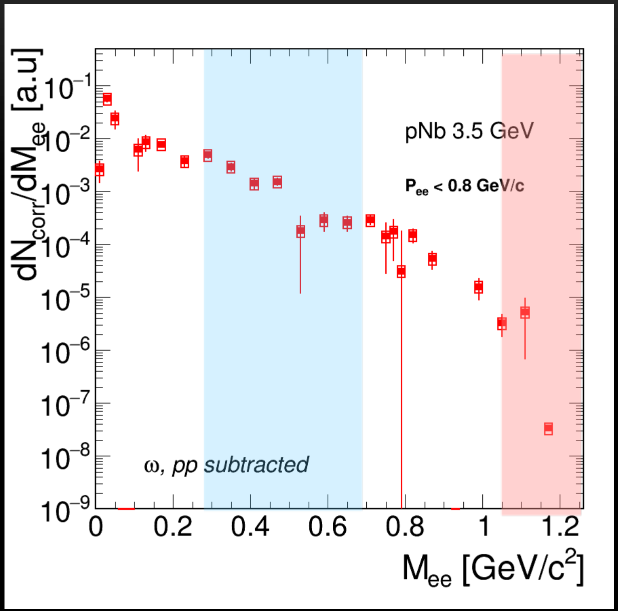


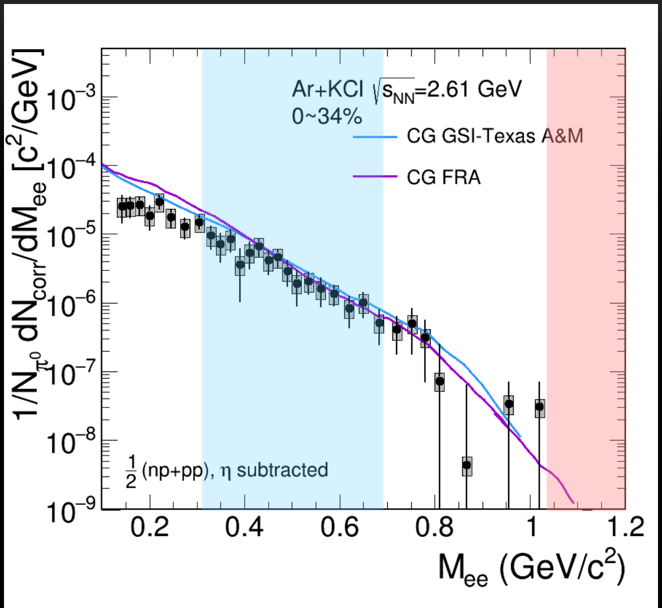
ρ meson contribution from the measured $\pi^+\pi^-$ channel and using the strict VMD

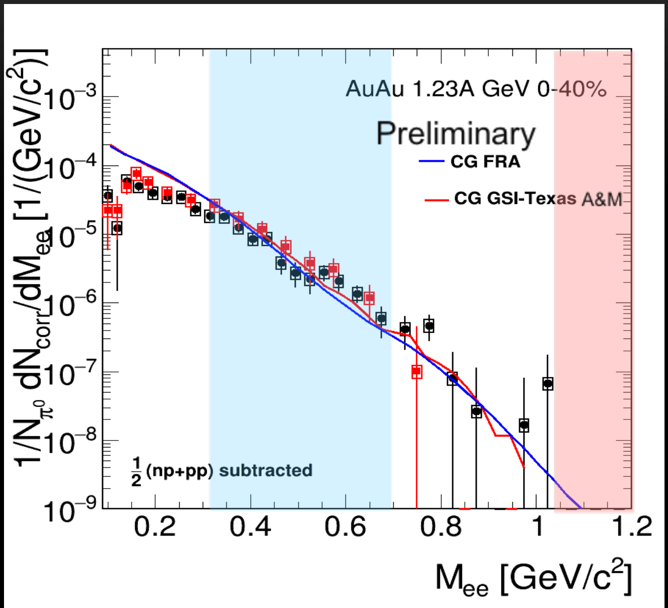
Data: HADES collab., PLB 690 (2010) 118
R. Shyam and U. Mosel, PRC 82:062201, 2010
M. Bashkanov, H. Clement, Eur. Phys. J. A50, 107, (2014)

CG FRA: Phys. Rev. C 92, 014911 (2015)
CG GSI-Texas A&M: Eur.Phys.J. A52 (2016) no.5, 13

What Next?

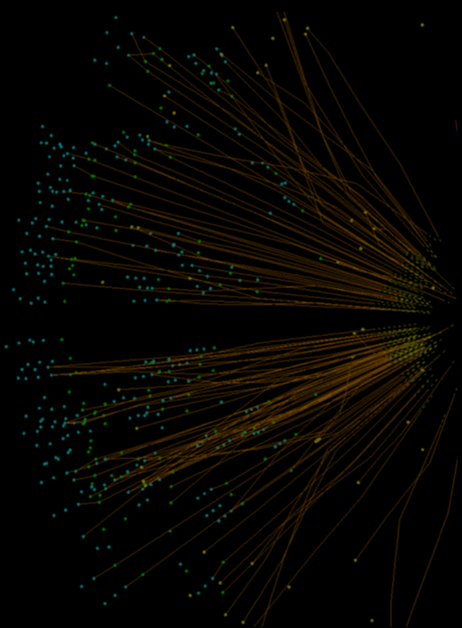




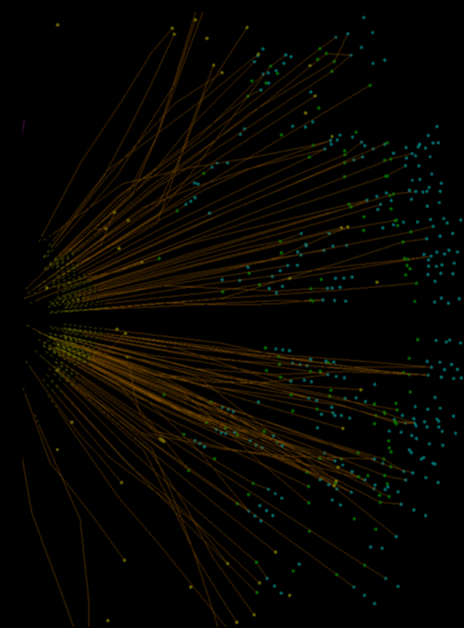


- 0.3<M<0.7 GeV/c^2: Rapid increase of relative yield reflects the number of Resonances regenerated in fireball → HADES "R-clock"

- HADES can explore M > 1.1 GeV/c^2
  - Measure changes in yield, shape, slope in high statistic πp & πA; pp & pA; AA
  - ρ-a1 spectral functions



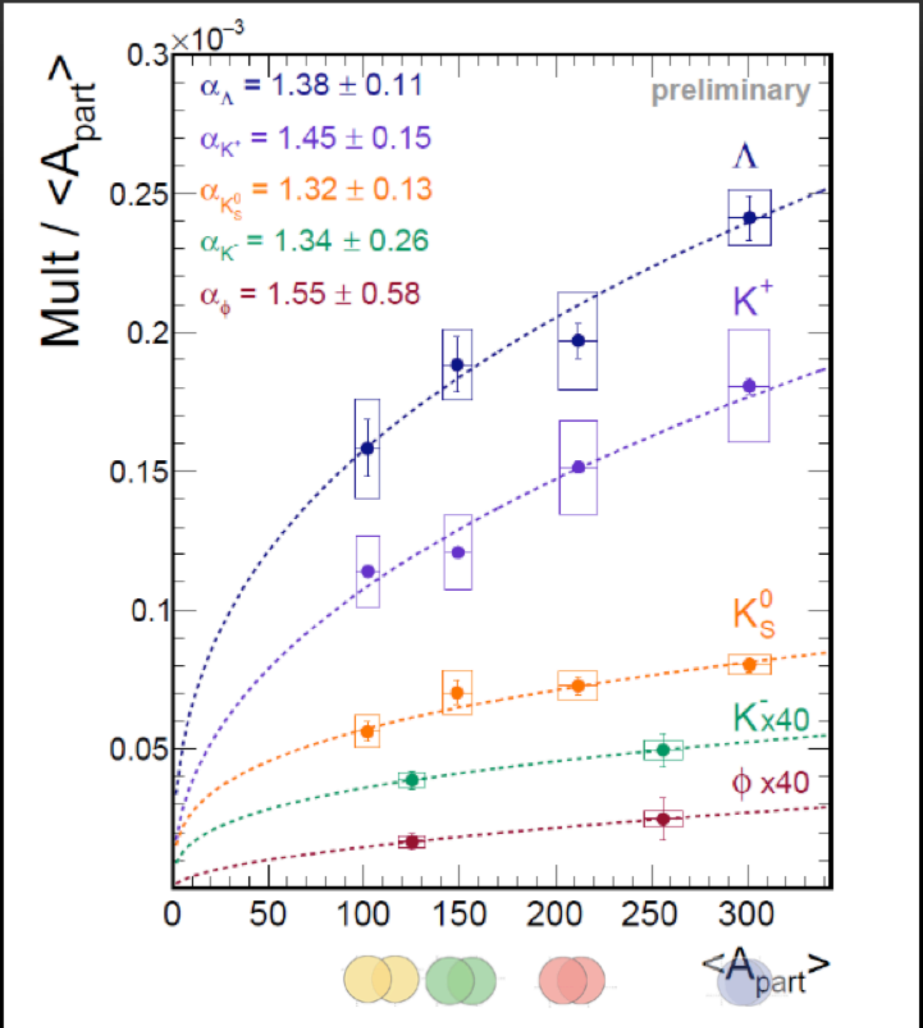
Final state
“Hadron-chemistry”



Strange particle production

Au+Au collisions at 1.23*A* GeV

HADES Collab., in preparation

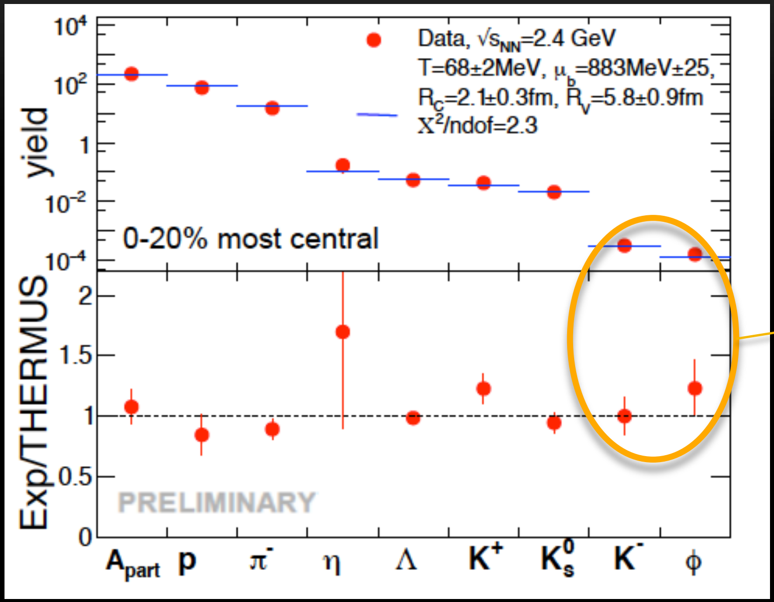


$NN \rightarrow N\Lambda K^+$ E_{thr} = 1.58 GeV
$NN \rightarrow NNK^+K^-$ E_{thr} = 2.49 GeV
$NN \rightarrow NN\phi$ E_{thr} = 2.59 GeV

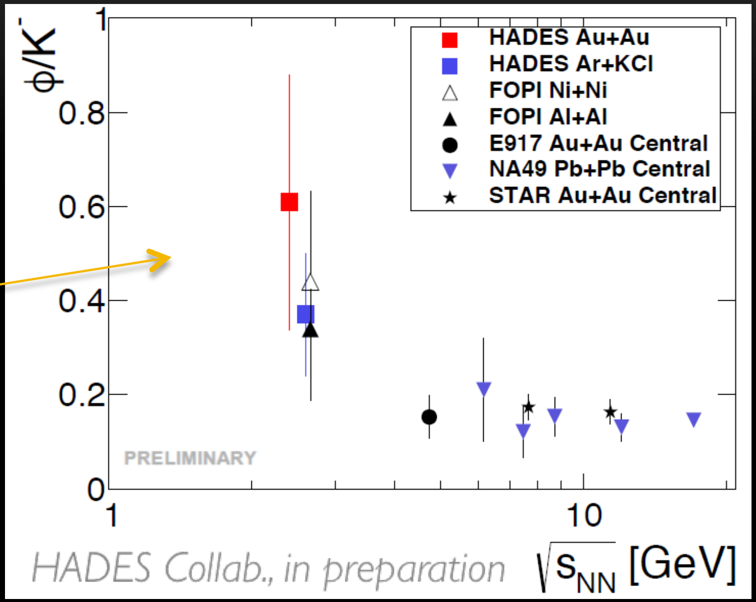
- First comprehensive set of results on strange particle productions at this low beam energy
- Far below (free NN) threshold → strong constraints on production mechanism
- Particle yields rise with A_{part} faster than linear
- Same **α** for all strange particles! → no hierarchy in production threshold?

The role of ϕ meson: do K^+, K^- freeze-out sequentially?

See also
Ar+KCl in HADES: PRC 86 (2010)
Al+Al in FOPI: EPJA 52 (2016)



HADES Collab. Eur.Phys.J. A52 (2016) no.6, 178

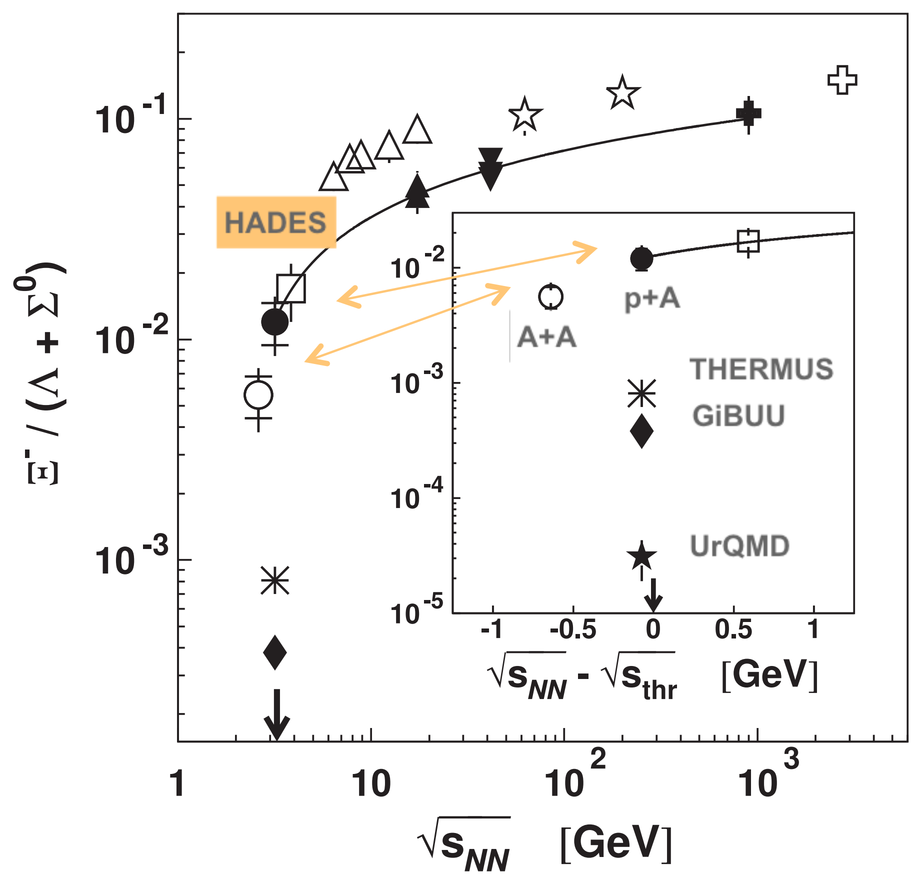


HADES Collab., in preparation

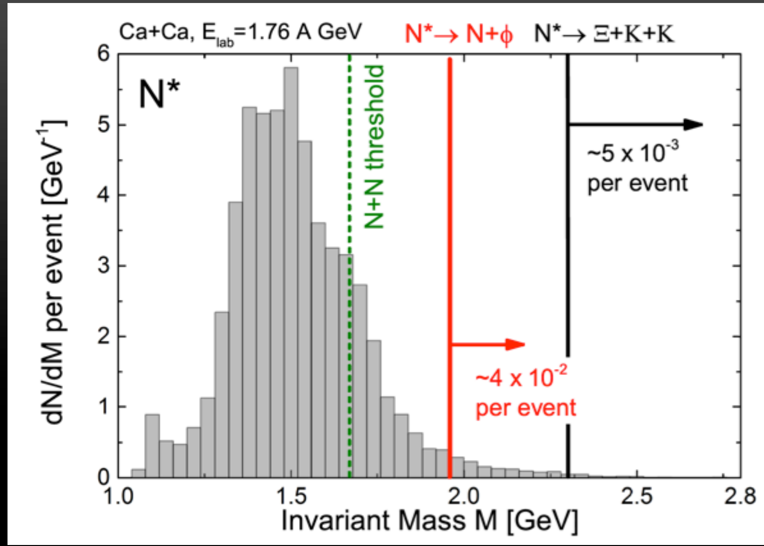
- Grand canonical ensemble (T, μ_B, V and sometimes γ_s)
- Strangeness canonically suppressed
- Thermal equilibrium also at low energies (high μ_B)?
- What is the mechanism responsible for system thermalization?

- Sizeable increase of ϕ meson to K^- ratio around production threshold 30% of K^- are from ϕ decays
- Unique freeze-out criteria when ϕ decay kinematics is taken into account → no evidence for sequential freeze-out of K^+, K^- → support for statistical model

What is so strange about Ξ^-?



HADES collab. PRL 103 (2009) 132310
HADES collab. PRL 114 (2015) 212301

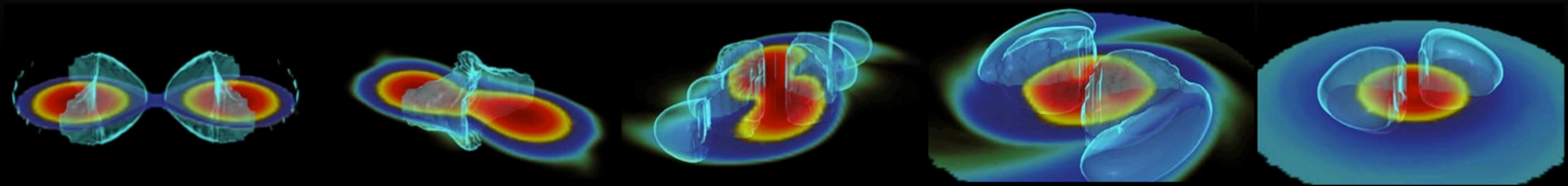


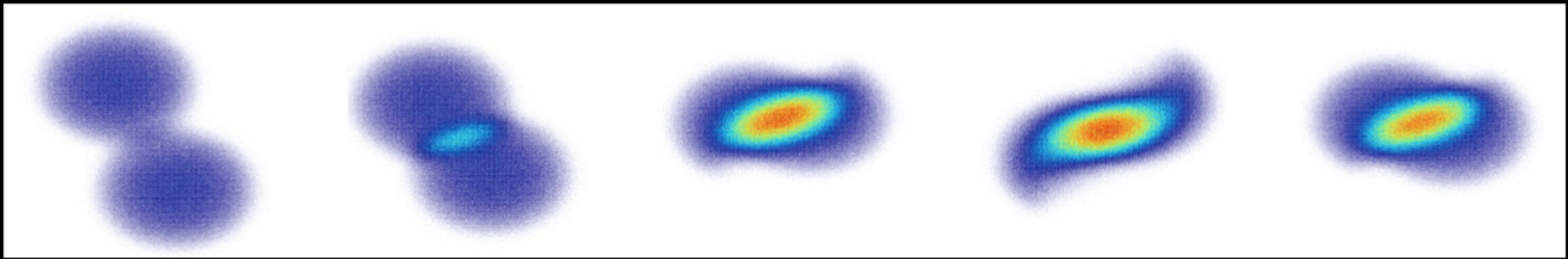
J. Steinheimer et al., J.Phys. G43 (2016) no.1, 015104

- Multi-strange baryons (Ξ, Ω) are expected to be a sensitive probe for "Compressed Baryonic Matter".
- HADES observes unexpectedly large production cross sections in Ar+KCl and in pNb
- Attempts to theoretically describe the production based on the decay of heavy resonances looks promising but has to be further scrutinized.
- Reference measurements needed → p+p run
  - Highest proton beam momentum which can be used for stable runs: Bρ = 5.4 GeV/c → E_{kin} = 4.5 GeV ($\sqrt{s}$ = 3.47 GeV) → strangeness production, i.e. cascade

Cosmic matter in the laboratory

http://flash.uchicago.edu/~calder/neutron.html





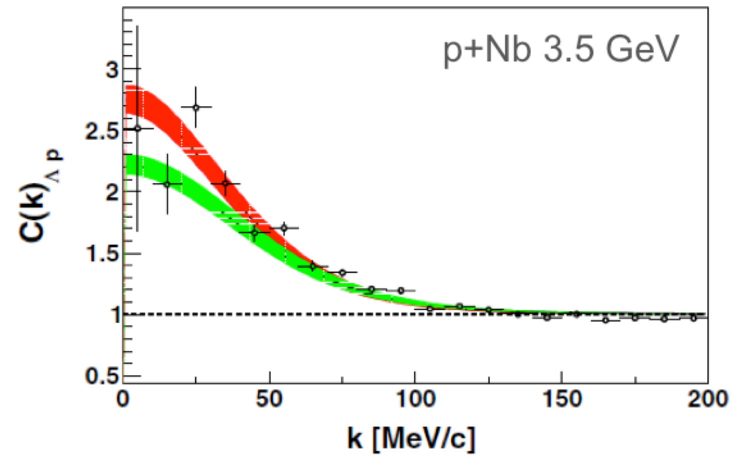
Images: Florian Seck
Bass et al., Prog. Part. Nucl. Phys. 41 (1998)

- High densities: ρ_{max} up to 3 ρ_0
- Moderate temperatures: T = 50 – 100 MeV

Matter in Compact Stars

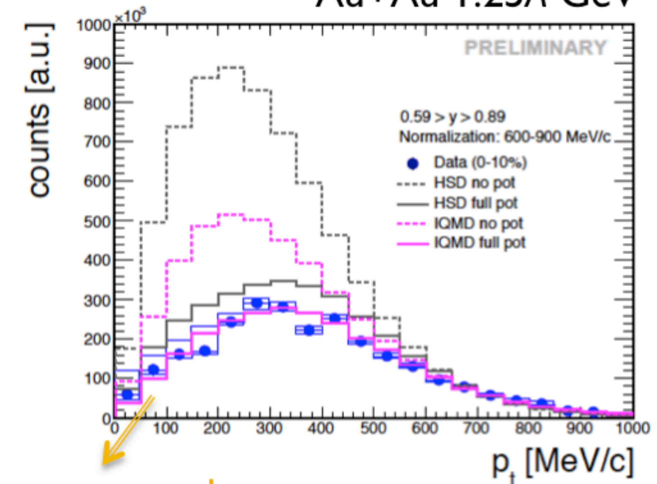
- Hyperons in neutron stars: new vistas?
  - Many models with hyperons fail to describe a $2M_\odot$ pulsar mass
  - Breakdown of baryonic models at high densities?
  - Onset of a new phase not based on baryon d.o.f.?
- QCD matter in compact stars
  - Composition of high-density neutron star cores: unknown (green band)
  - Input needed from relativistic heavy-ion experiments
- HADES
  - ΛN, ΞN further studies in high statistic p+Ag in 2018
  - Data support in-medium repulsive vector K^0 potential ~40 MeV *[PRC 82 (2009) 044907; PRC 90 (2014) 054906]*

Λ-N correlation function

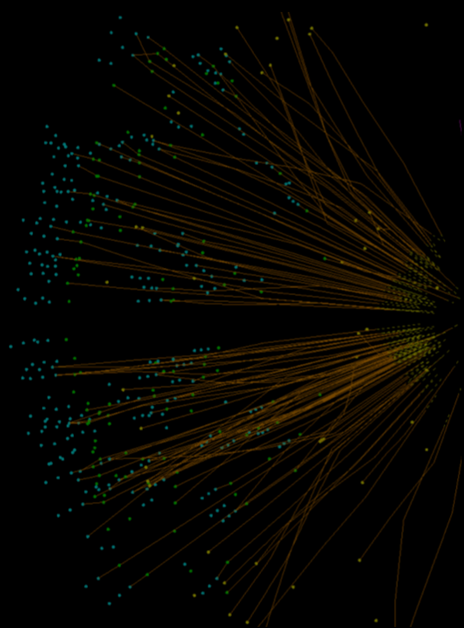


HADES collab., PRC 94 (2016) no.2, 025201

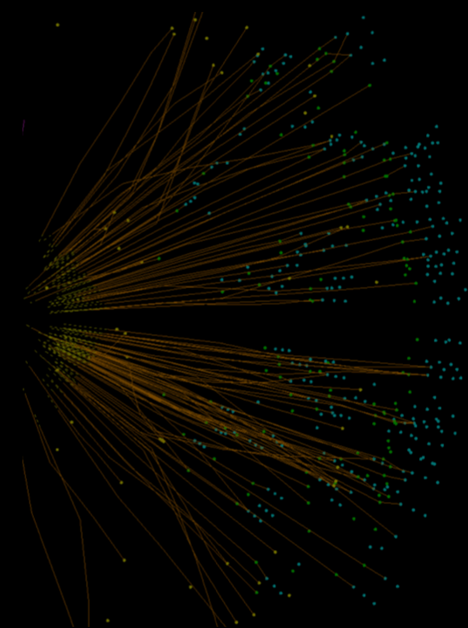
Au+Au 1.25*A* GeV



p_t coverage down to zero p_t



Upgrade projects



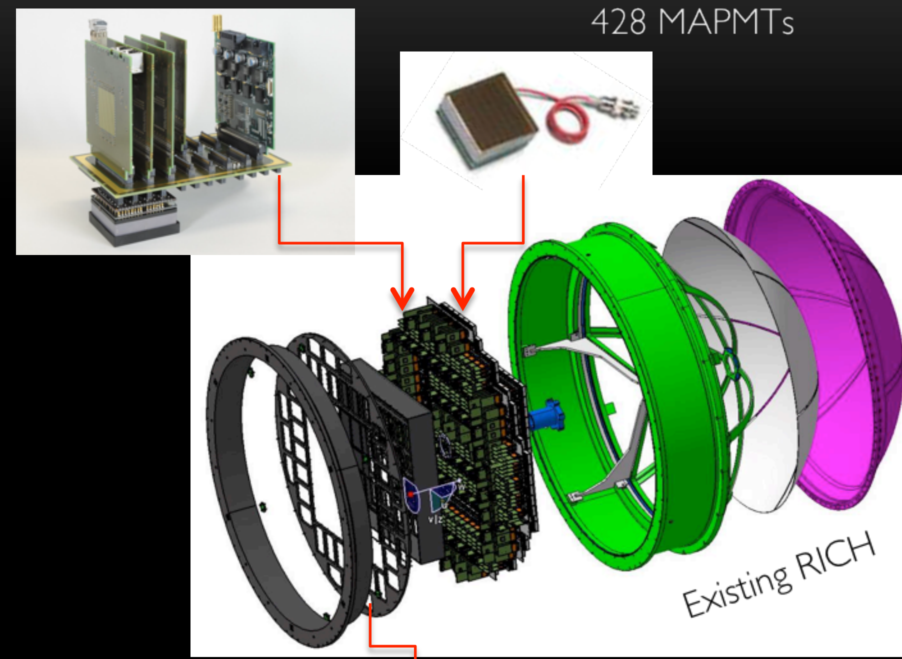
RICH 700: joint development CBM & HADES

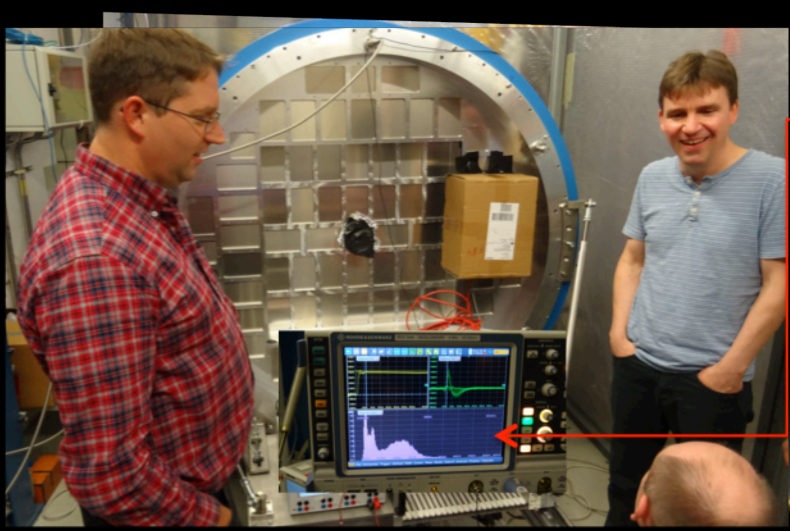
Participating institutes: TU München, U. Gießen, GSI, U. Wuppertal

- Multi anode photo tubes replace CsI based gaseous UV Photon detector
  → close pair rejection ~4 times better

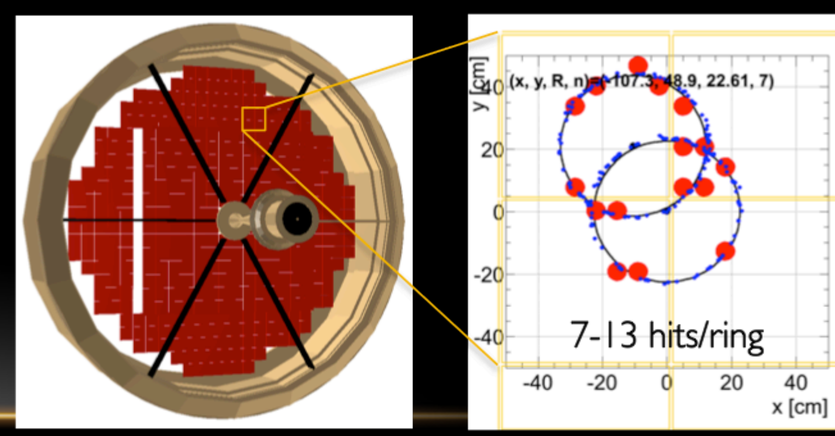
- Design completed
- Test chamber installed at GSI
- ~450 MAPMTs tested
- Read out chain running
- Fully implemented in software

RICH installation: early summer 2017



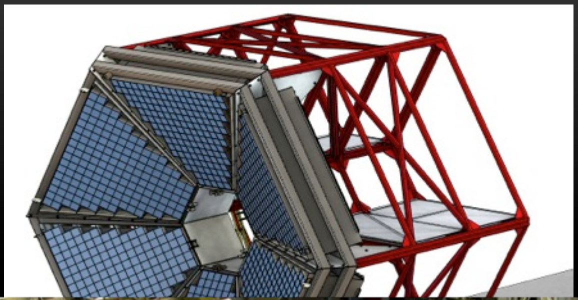


First measurements of single photons

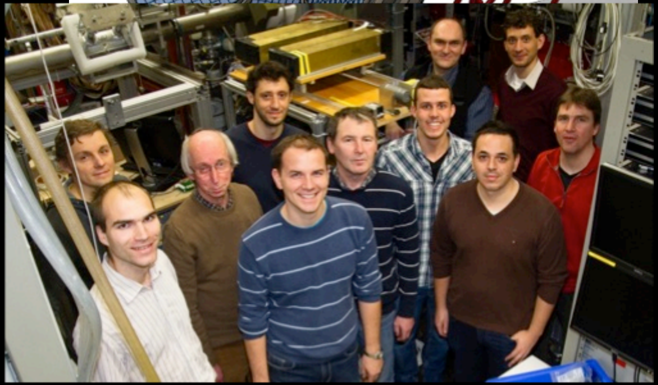


Electromagnetic Calorimeter for HADES

Participating institutes: TU Darmstadt, U Krakow, INR/RAS Moscow, INP/CAS Rez, TU Munich, IP Bratislava, MEPhi Moscow and GSI



- Replaces Pre-Shower detector
- Enables photon measurements $\frac{\sqrt{E}}{E} \approx 5.5-6\%$
- Electron-to-pion separation for p>0.4 GeV/c

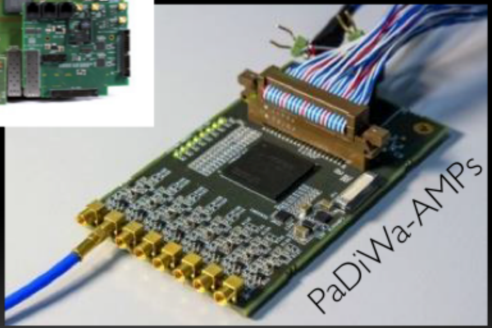


- Main frame: design completed, installation 2017
- Lead-glass modules (OPAL)
- Hamamatsu 3" PMT delivery ongoing (2 sectors)
- Read-out: PaDiWa-AMPS + TRBv3 (mass production ~6 month)

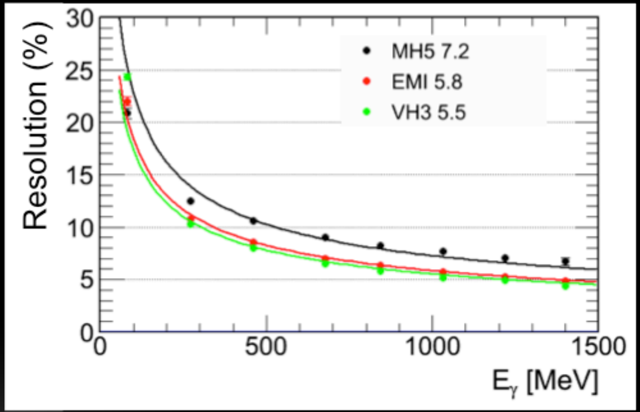
5 sectors ready for 2018 beam times

Modules assembly (GSI det. lab.)

TRBv3



Tests at MAMI facility
(8 energies in one measurement)

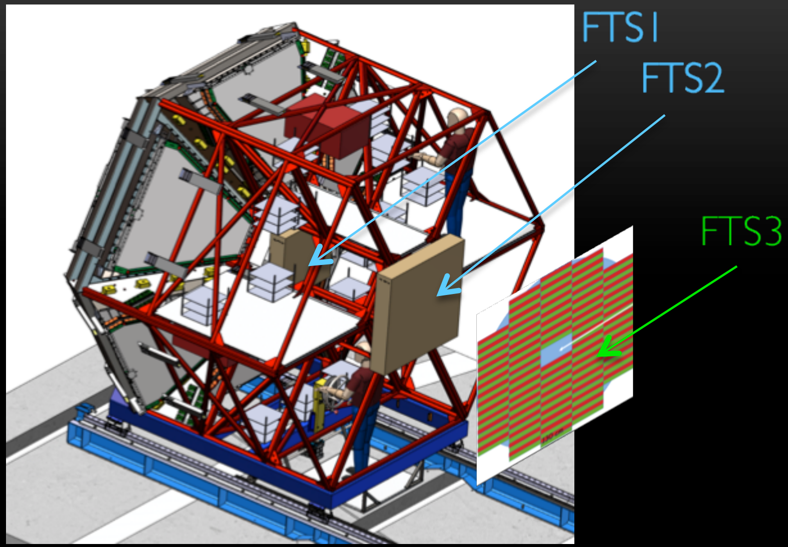


Forward Tracker: synergy project with PANDA

Participating institutes: JU Krakow, FZ Jülich, IPNO Orsay, LIP Coimbra

- Enhance HADES capabilities for exclusive channels
- Hyperon production and EM decays

- Angular acceptance: $\theta \leq 6.5°$
- Reconstruction of straight tracks (~150 μm, angular resolution ~1 mrad for 1 GeV/c protons)



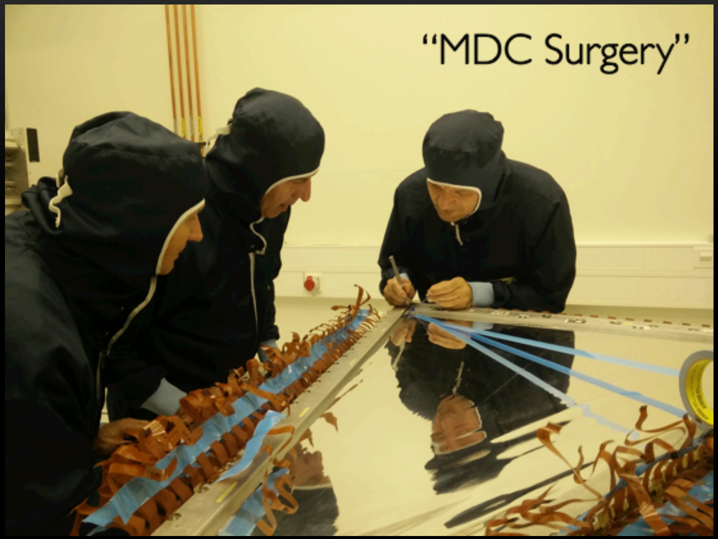
- Straw tubes & RPC: PID via dE/dx & ToF

- Double layer of straw (compatible with stations for the PANDA Forward Tracker)
- Straws production by FZ Juelich and mechanics components by Kraków

- FTS3: similar to the small cells of the current RPC

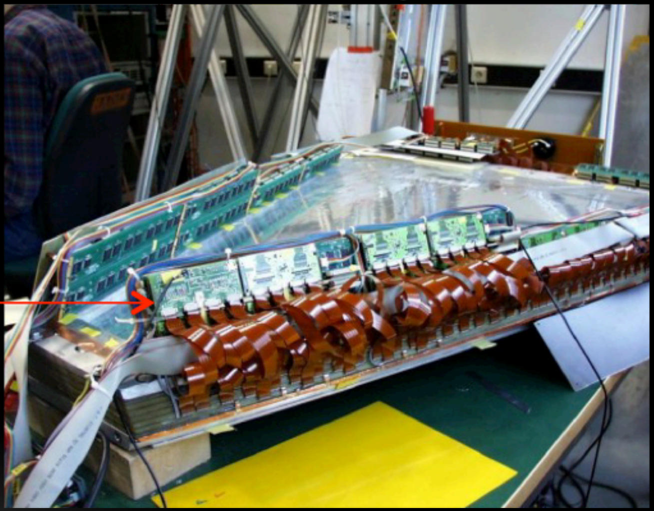
Towards new MDC front-end electronics

Participating institutes: U. Frankfurt, GSI, LIP Coimbra



- Aging prevention: Inert gas mixture Ar/CO_2
- FEE upgrade: Alternatives to ASD8 chip & multi-hit TDC
- SIS100 : Redundancy & Precision → new MDC II chambers for HADES

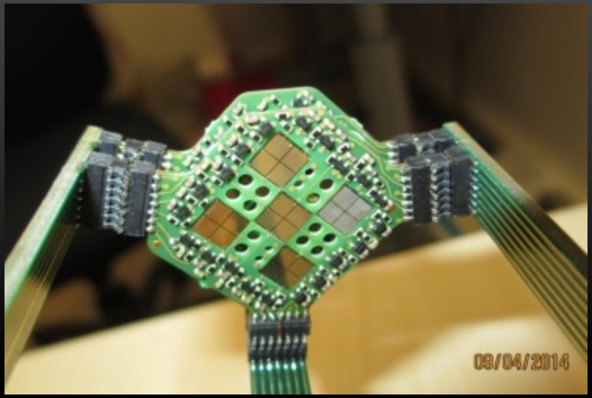
@ GSI det. lab.



- New gas mixture Ar/CO_2 validated with high load (emulated by a X-ray tube), successful qualification of additive (water) to minimize charging-up.
- State-of-the-art FEE concepts are being evaluated based on the PASTTREC ASIC and a FPGA based multi-hit TDC
- Test chamber: design concluded, construction started.

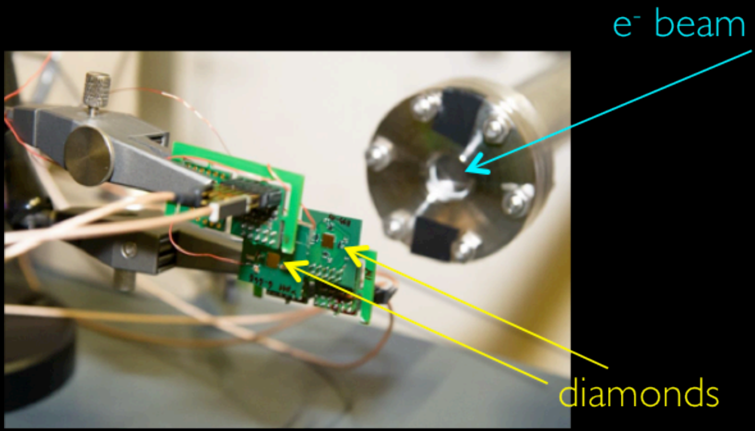
No Shower, new RICH and MDC "conventional DAQ": 90 kHz

T0 diamond detectors

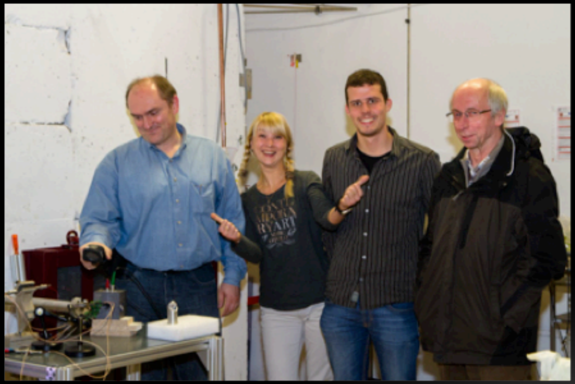


Mosaic scCVD diamond detector
4×10^5 π/s , $\Delta\tau$ = 200 ps!

- T0 determination < 50 ps
- Precise beam profile measurement in X and Y positions
- Beam halo monitoring



- E_{e-} = 70 - 130 MeV
- Beam currents: up to 20μA
- Beam spot: 2 x 2 mm^2

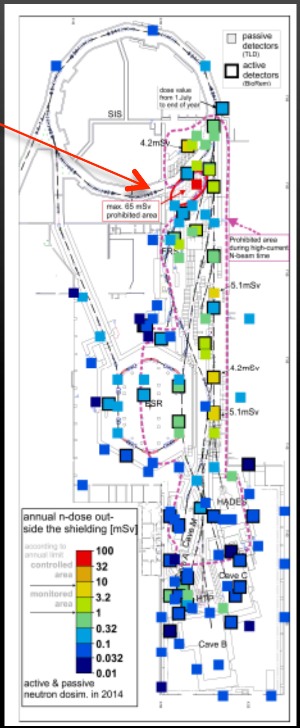


- New design: 2 stage amplification
  - Booster amplifiers inside vacuum, close to the 1st stage
  - PCB design in preparation

- Test beam time March 2017 (Jülich)
- Test place set-up at S-DALINAC (part of GRK2128 "AccelencE")

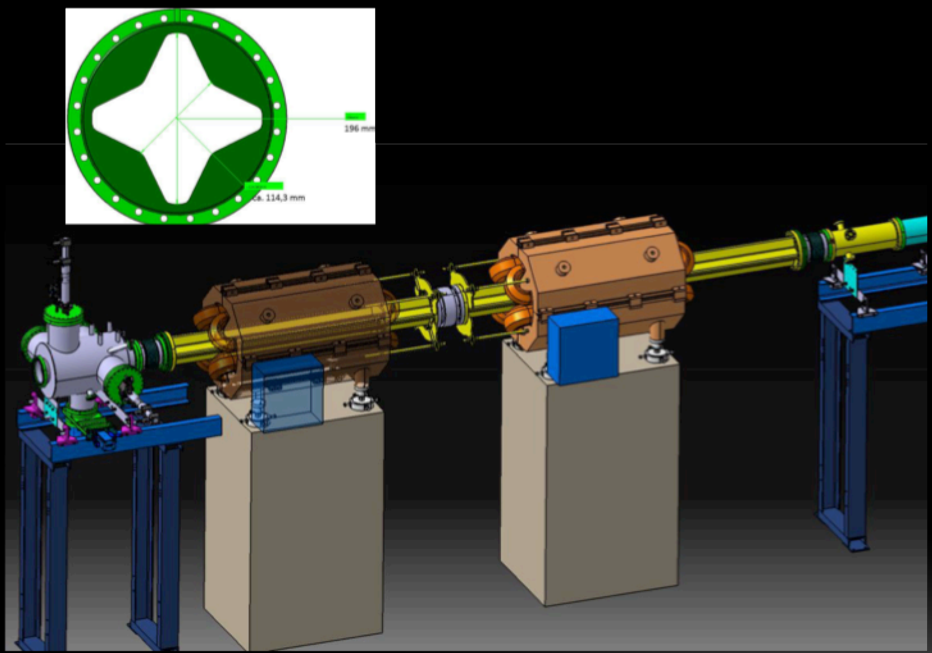
ACCELENCE

π beam improvements



- High current experiment in July/August 2014
  - 4×10^5 π /spill at 0.69 GeV/c on HADES target were reached with $\sim10^{11}$ N_2 ions/spill

  BUT
  - Too high radiation level in NE5 and SIS tunnel (Intensity had to be reduced to 1.5×10^5 π /spill)



- Shielding
- Increased beam aperture: 110 → 125 mm
- Improved extraction
- Improved beam transport
- Beam diagnostic of primary beam (to be installed)

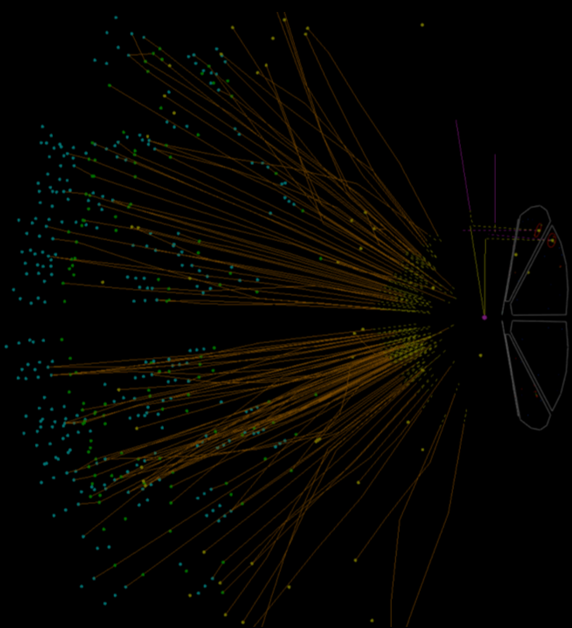
"… In order to increase the extraction efficiency of the SIS18 (only 50-60%, activation issue in 2014), a new position for the electrostatic extraction septum is foreseen"

Encouraging prospects for studying QCD matter in the region of finite μ_B with HADES

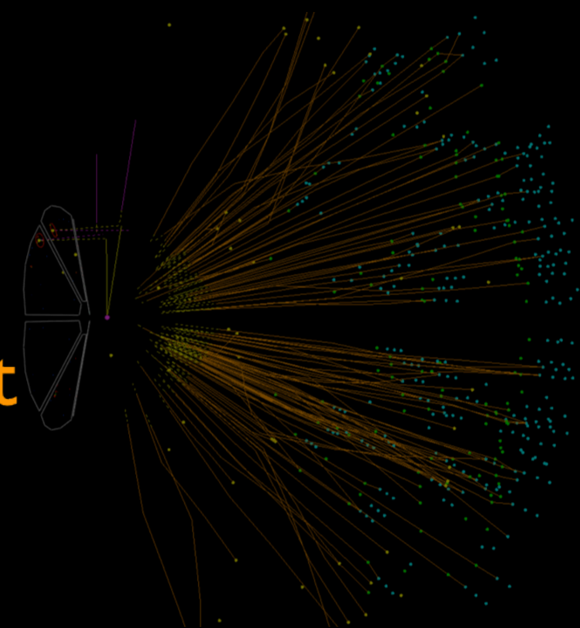
- Unique possibility of characterizing properties of baryon dominated matter with rare and penetrating probes:
  - Long-lived states of compressed resonance matter are produced in heavy-ion collisions in the few-GeV energy regime
  - This state of matter might be much more exotic than a hadron gas

- HADES is at the moment the only facility world-wide which combines a pion beam with dilepton spectrometry, an excellent particle identification and good secondary vertex reconstruction capabilities.

- Roadmap:
  - 2016-18: upgrade HADES
  - 2018-2021: we anticipate three long runs, e.g.:
    - $\pi+(CH_2)_n/LH_2$: baryon em transition form factors, baryonic resonances with strangeness
    - p+A/p+p: strangeness/vector mesons in medium
    - A+A: medium system at maximal energy
  - 2021^+: move HADES to SIS100 → continuation at higher beam energies

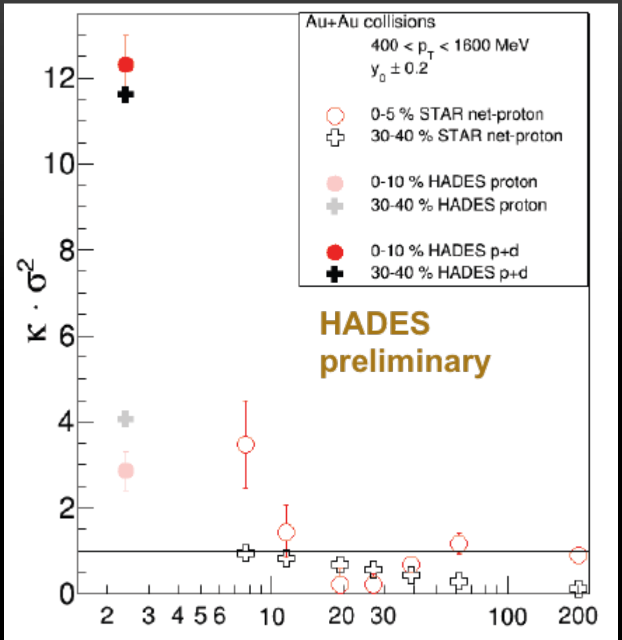


Vielen Dank
für Ihre Aufmerksamkeit

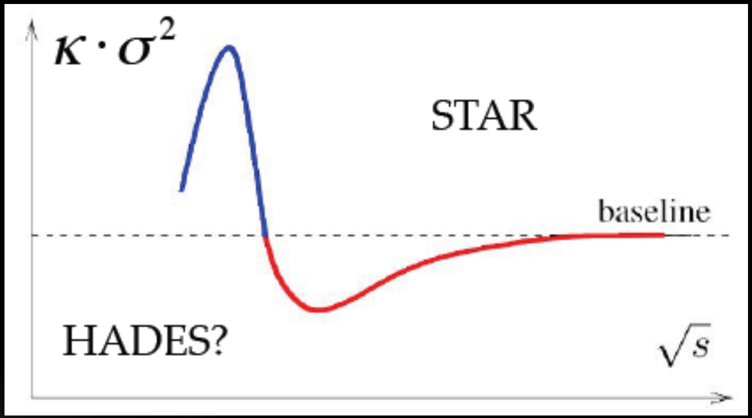


Proton number fluctuations

- Related to phase structure of hot and dense matter (e.g. spinodal decomposition of the mixed phase)
- Search for the critical point
- Higher moments probe the tails. Statistics!
  → Striking signal
  → FAIR-energy data are missing
- Need to control:
  - Fluctuations to due baryon stopping
  - Role of heavier fragments
  - Centrality resolution, ect.



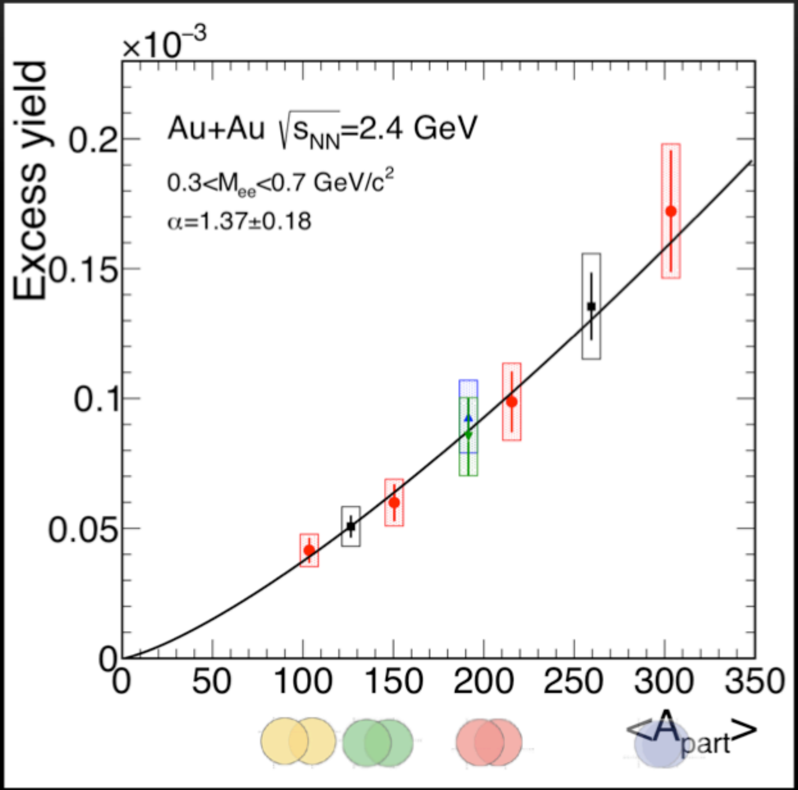
HADES: R. Holtzman, SQM16
STAR: X. Luo et al., PoS (CPOD14) 2016

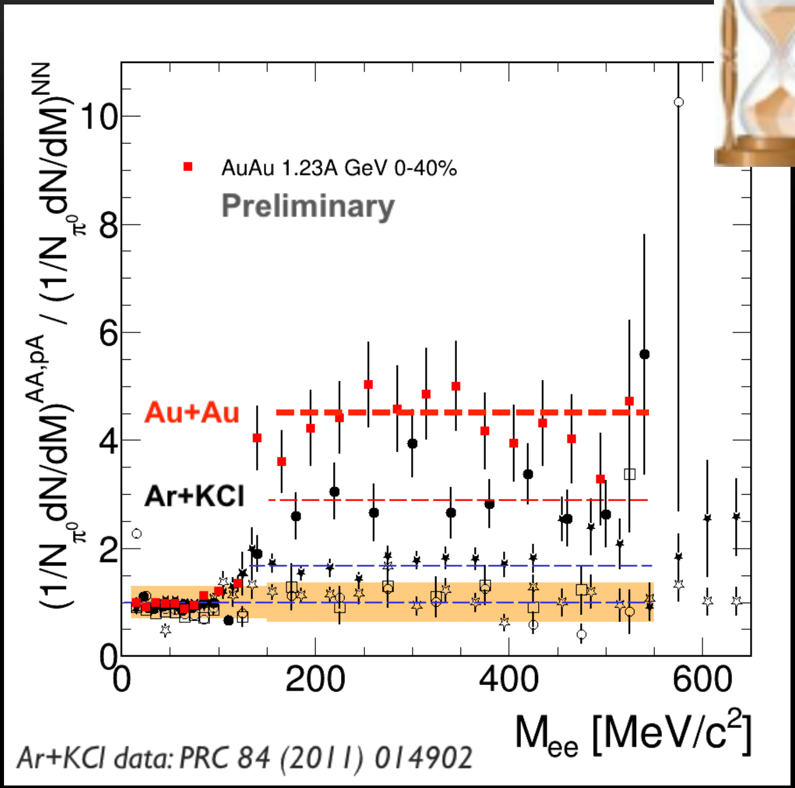


M. Stephanov, Phys. Rev. Lett. 107 (2011) 052301

Centrality and system size dependence of the excess

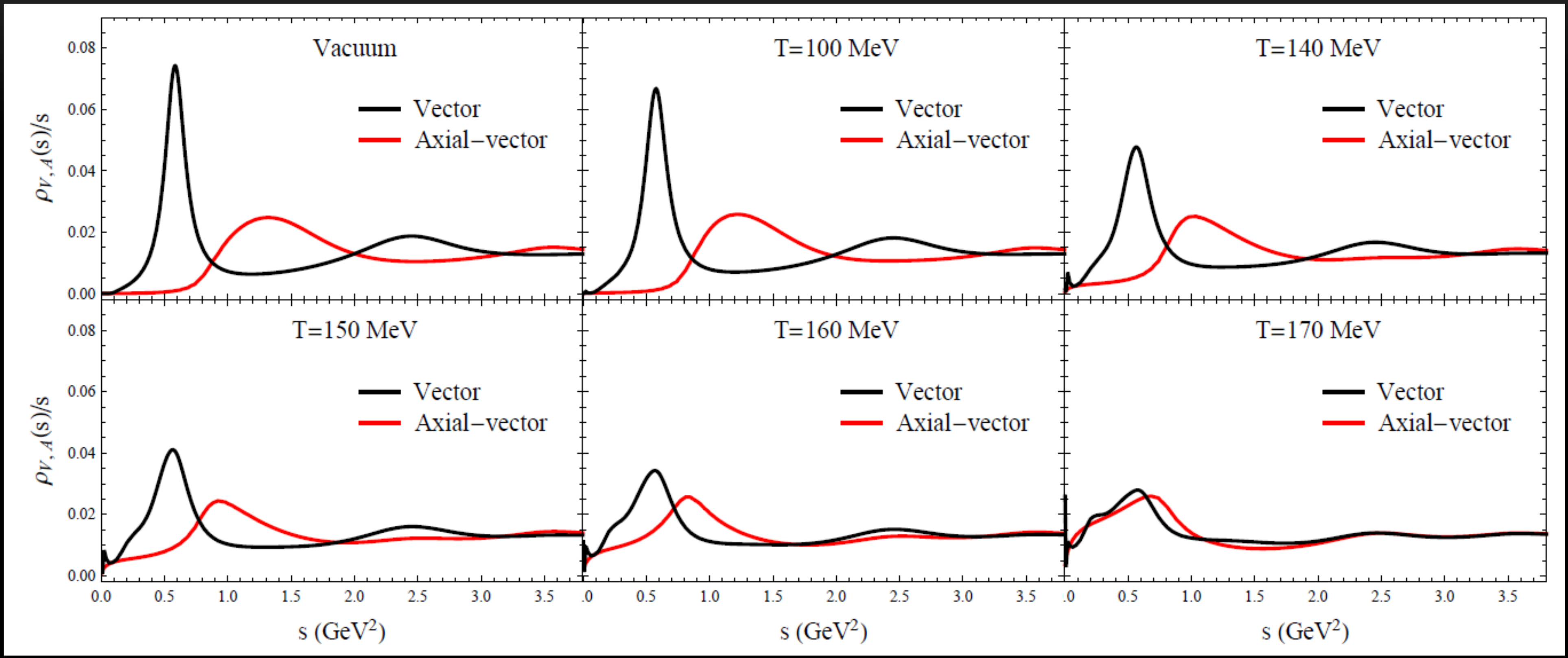
Excess radiation $0.3 < M < 0.7\ GeV/c^2$





- Strong excess ($\sim A_{part}^{1.3}$, interplay $V \otimes \tau_{coll}$)
- Dilepton chronometer of the collision time

- Medium radiation goes beyond what is expected from a superposition of incoherent NN collisions
  - → Regeneration of baryonic resonances
  - → Subsummed into spectral functions

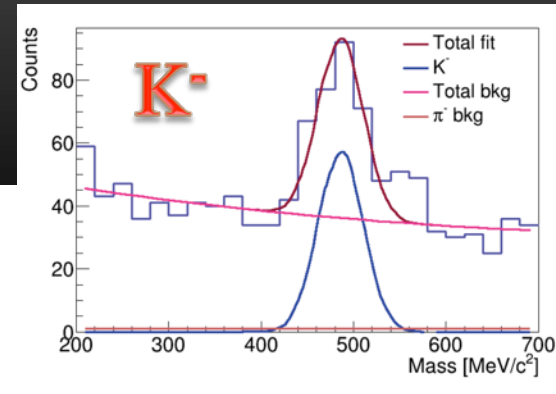


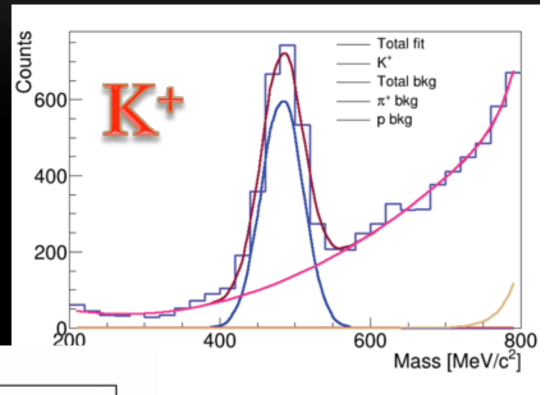
Vacuum
T=100 MeV
T=140 MeV
T=150 MeV
T=160 MeV
T=170 MeV
Vector
Axial−vector
$\rho_{V,A}(s)/s$
s (GeV^2)
0.00
0.02
0.04
0.06
0.08
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

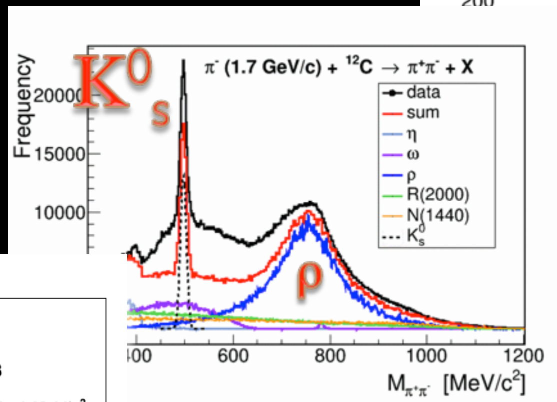
(Anti)Kaon in Medium

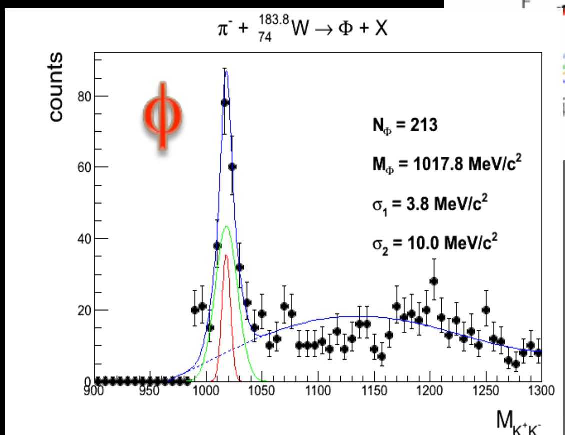
πA experiments Jul-Aug 2014

- Measurement of kaon (K^+, K^-) absorption in cold nuclear matter → kaon-nucleon potential
- Meson absorption in cold nuclear matter (ϕ)









- π^- momentum 1.7 GeV/c
- C and W targets
- Evidence of K^- disappearance in four (θ, p, p_T, y) observables