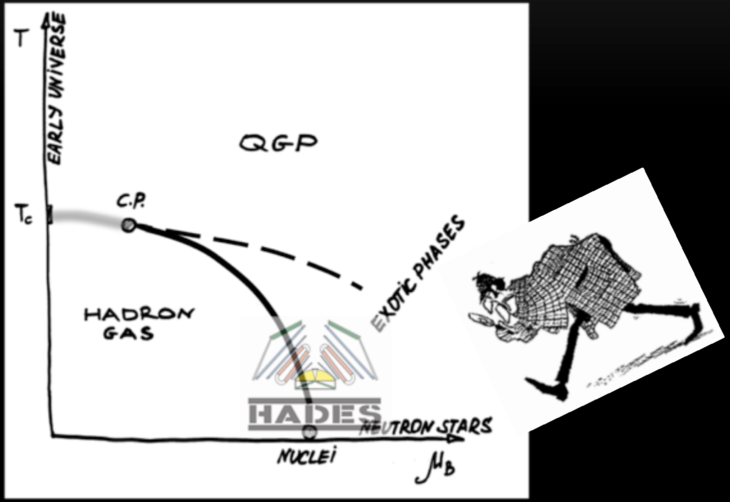
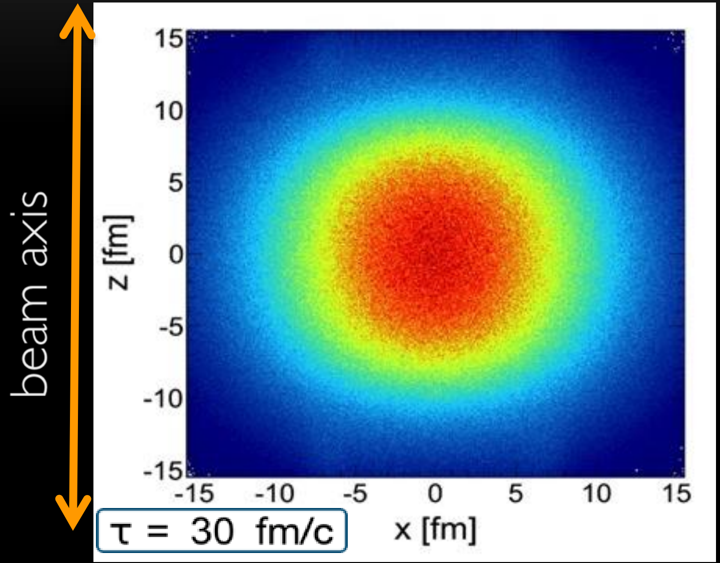


The electromagnetic response of resonance matter and other strange observations

Tetyana Galatyuk for the HADES Collaboration

Technische Universität Darmstadt / GSI Helmholtzzentrum für Schwerionenforschung

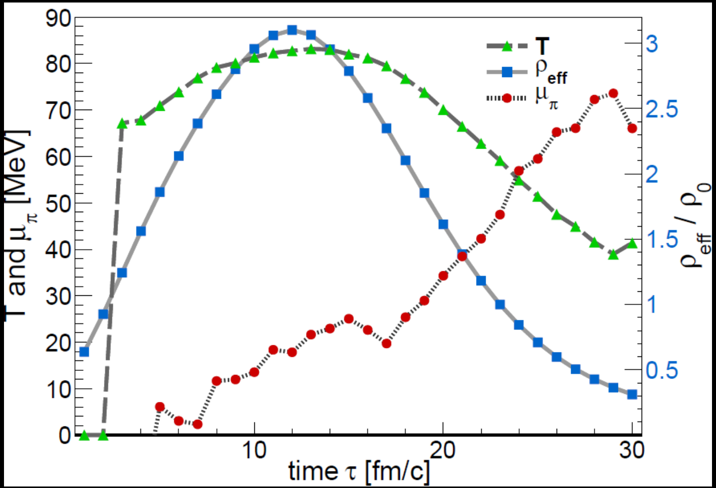
Baryonic matter at few GeV beam energy



- Au+Au $\sqrt{s_{NN}}$ = 2.42 GeV
- Long interpenetration times

- Baryon-dominated system throughout the evolution (N_π/A_{part} ≈ 10%)
- Comparatively long lifetime of the dense "fireball"

Central cell (3x3x3 fm3) thermodynamic properties from coarse graining UrQMD



TG, F. Seck et al., Eur. Phys. J.A 52 (2016) 131

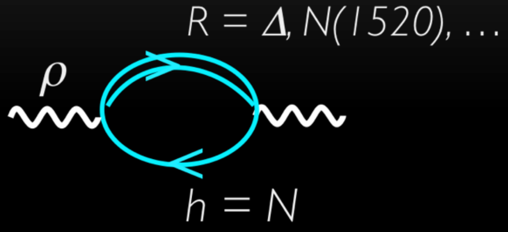
HADES explores baryon-rich matter with rare and penetrating probes

- **Emissivity of matter** (dileptons)

  Vector meson spectral functions modified by coupling to baryons

  Play substantial role in ρ melting observed in UrHIC

  cf. *R. Rapp, H. van Hees, PLB 753 (2016) 586*



- **Flavor production** (strangeness)

  Strong kinematic suppression of direct K^- production

  K^- couples strongly to baryons

$NN \rightarrow N\Lambda K^+$ $\quad E_{thr} = 1.58$ GeV

$NN \rightarrow NNK^+K^-$ $\quad E_{thr} = 2.49$ GeV

$NN \rightarrow NN\phi$ $\quad E_{thr} = 2.59$ GeV

- **Flow anisotropies**

  Preferred out-of-plane emission due to shadowing

- **Net baryon number fluctuations**

  No antiprotons, additional terms when correcting for volume fluctuations

High Acceptance DiElectron Spectrometer at GSI, Darmstadt

Hades gate

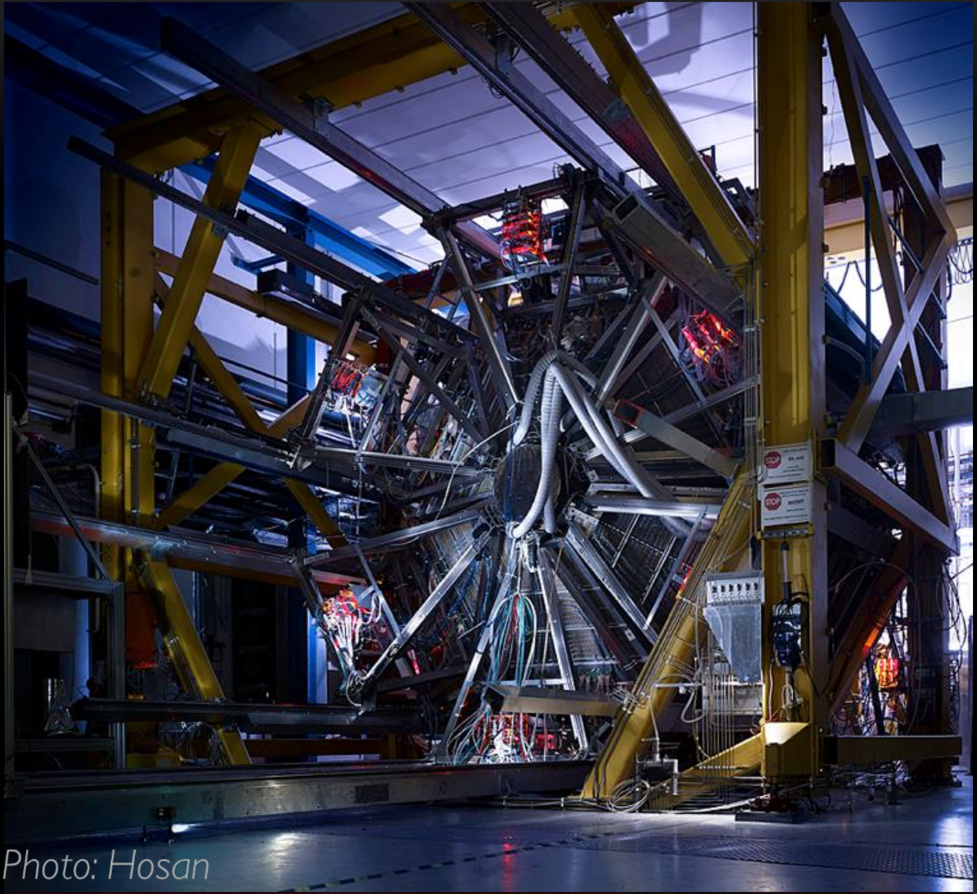


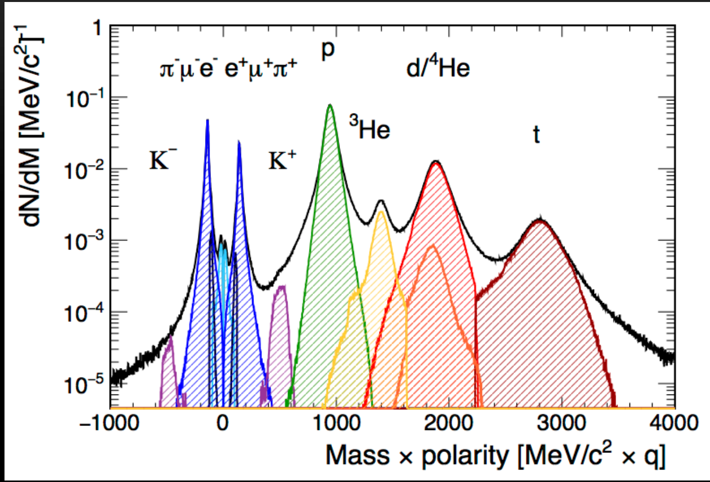
Photo: Hosan

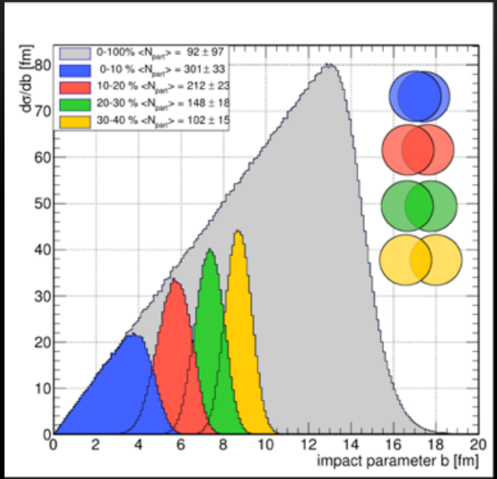
HADES program:

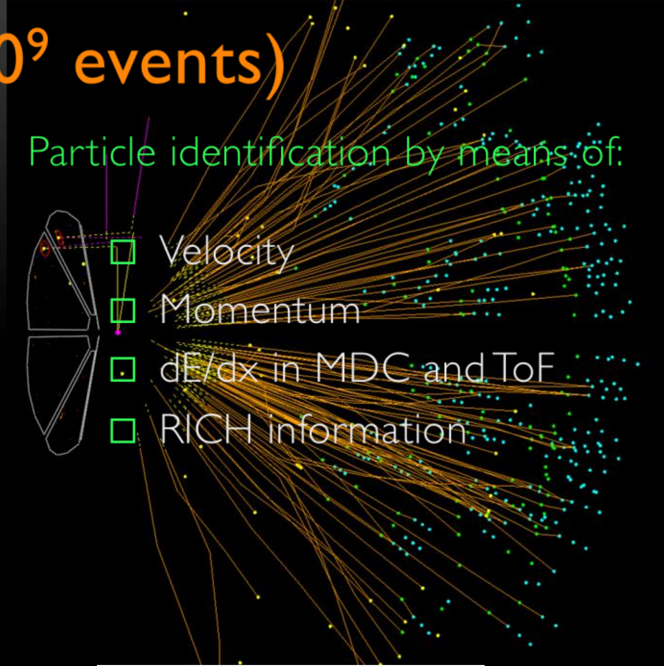
- Excitation function for low-mass lepton pairs and (multi-)strange baryons and mesons
- Various aspects of baryon-resonance physics

- Large acceptance: full azimuthal coverage, 18°-85° polar angle
- Interaction rate capability: up to 50kHz trigger rate
- Mass resolution 2 % (ρ/ω region)

HADES event reconstruction (2.5×10^9 events)

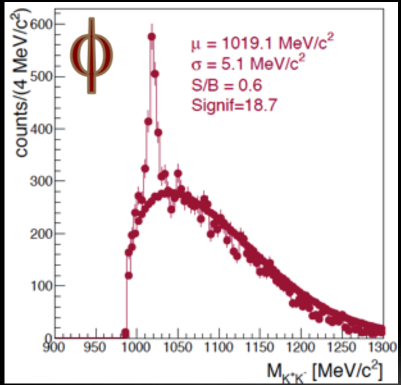


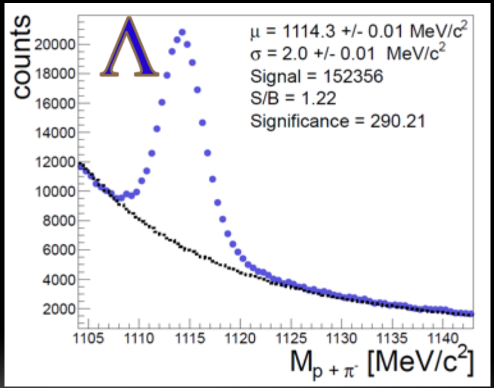


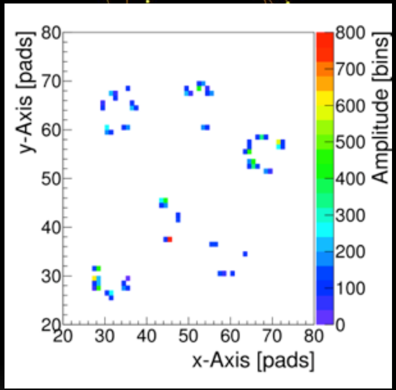


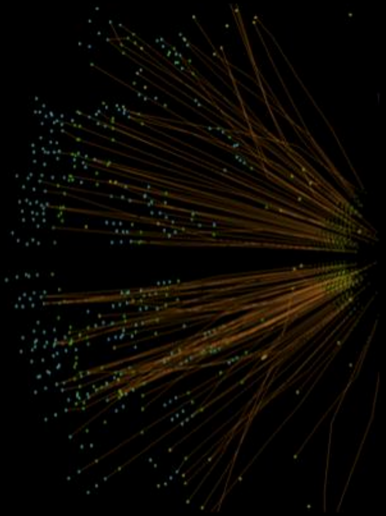
Particle identification by means of:

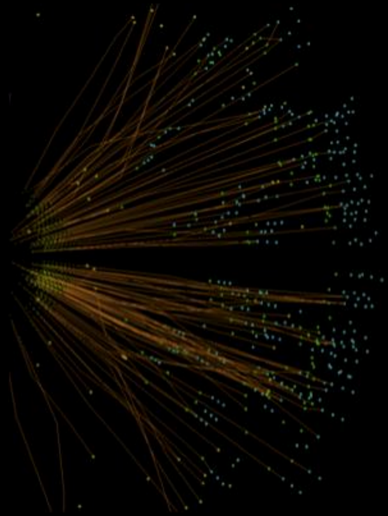
- Velocity
- Momentum
- dE/dx in MDC and ToF
- RICH information



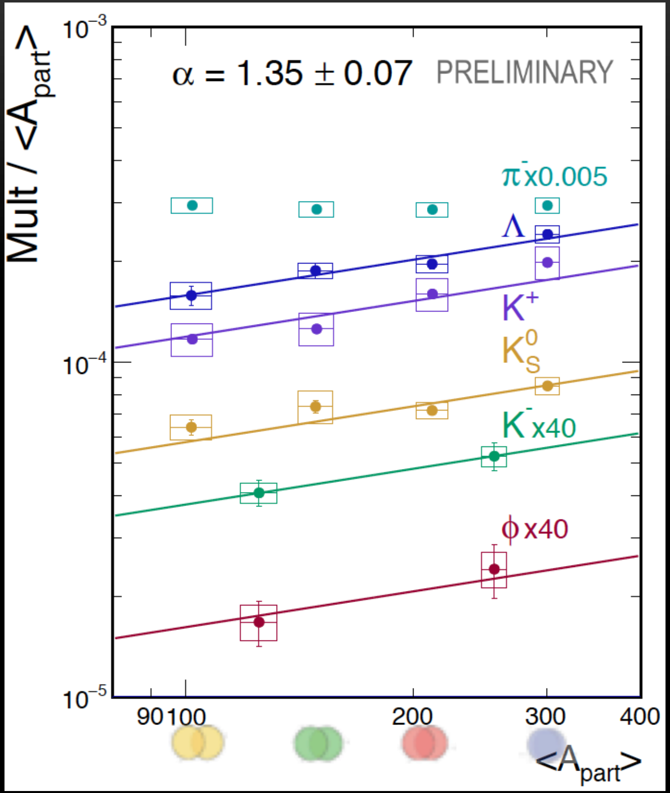








Final state
“Hadron-chemistry”

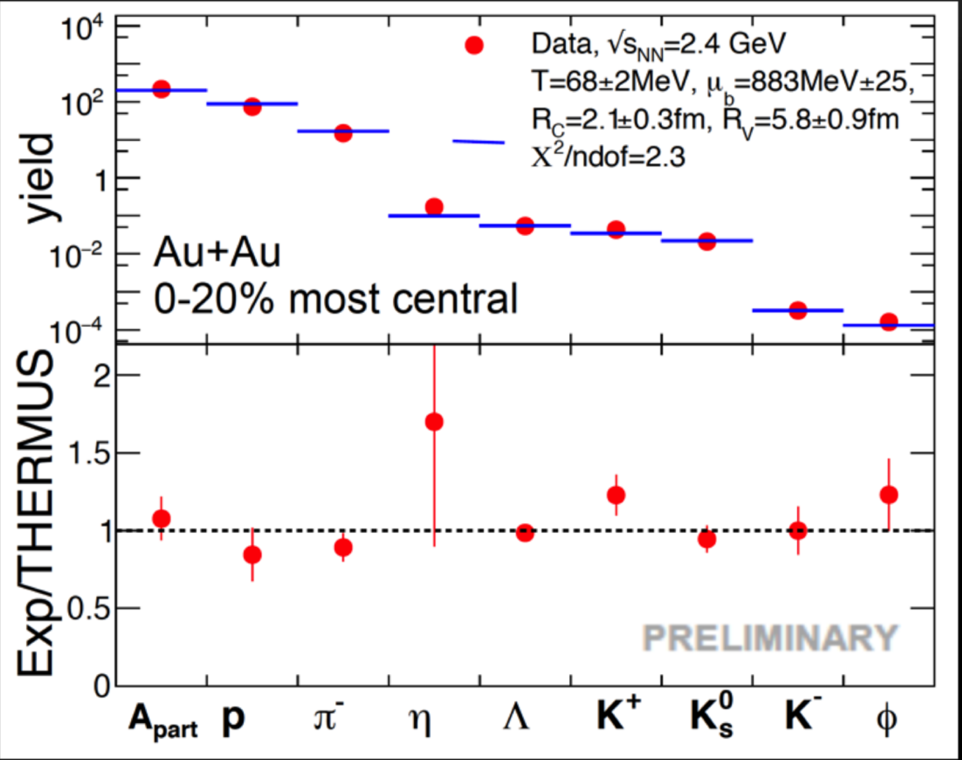


Strange particle production

- First comprehensive data set on strange particle productions from the Au+Au at $\sqrt{s_{NN}}$ = 2.42 GeV
- Far below (free NN) threshold
  → strong constraints on production mechanism
- Universal scaling with participant number A^{α}_{part}
  (Mult ~ A^{α}_{part}, with $\alpha > 1$)
- Production yields reflect matter properties

Macroscopic description of hadron production

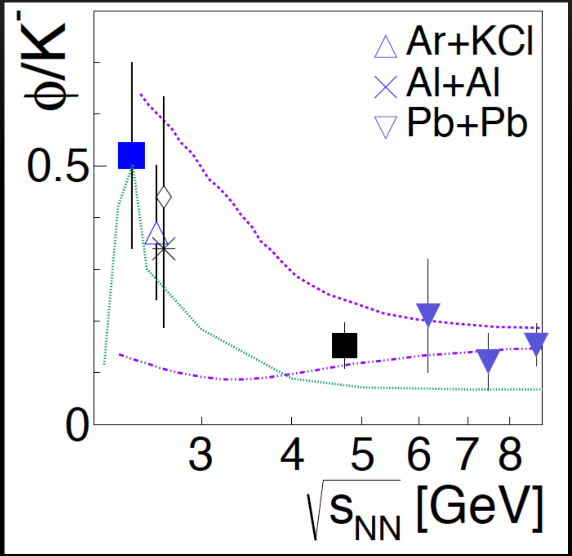
- Grand canonical ensemble (T, μ_B, V)
- Strangeness canonically suppressed at low temperatures → needs additional parameter: $R_c < R_V$
- Hadron abundances described by four parameters T, $\mu_{B,}$ R_V, R_c
- What is the mechanism responsible for system thermalization?
- "Matter" formed also at low energies (high μ_B)

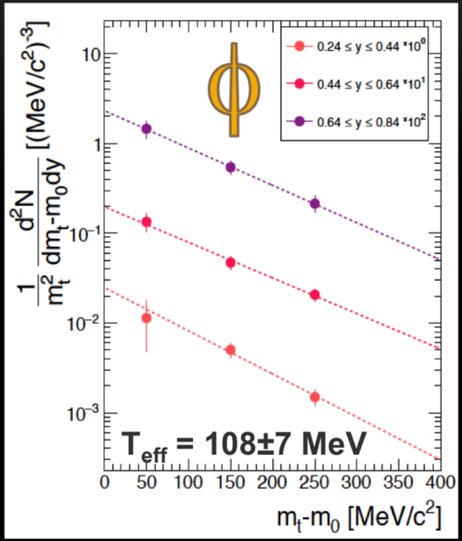


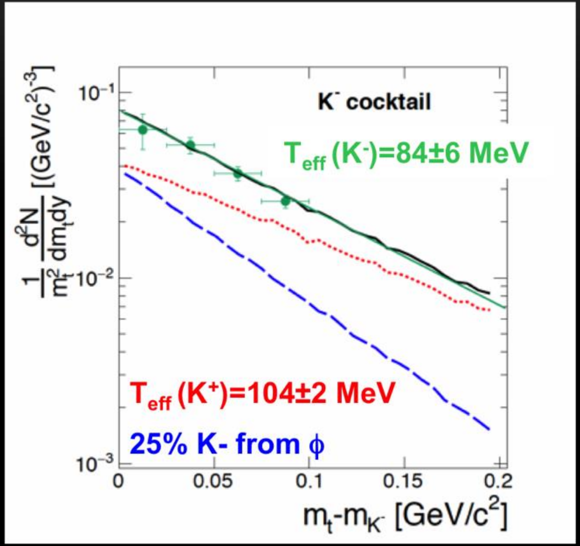
THERMUS v2.3
S. Wheaton, J. Cleymans Comput.Phys.Commun. (2009) 180

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

HADES: arXiv:1703.08418v1 [nucl-ex]







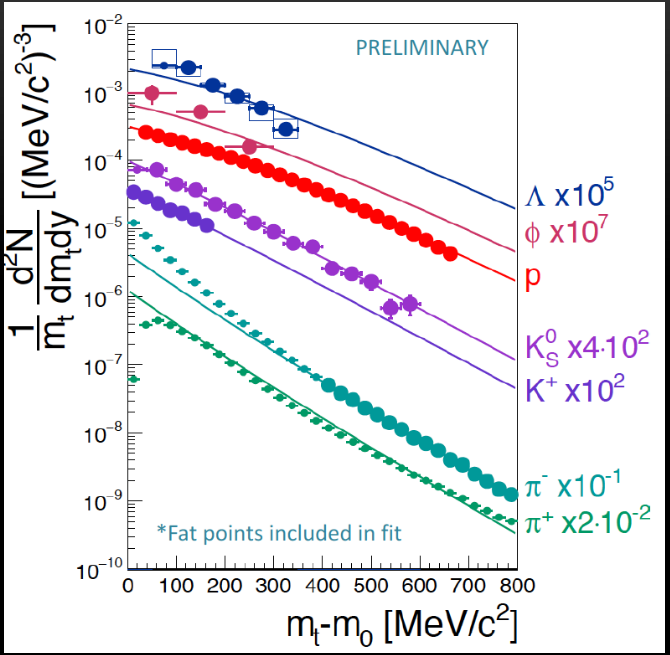
- Sizeable increase of ϕ meson to K^- ratio around production threshold
  25% of K^- are from ϕ decays

- Sufficient statistics to perform multi-differential analysis for K^+, K^- and ϕ

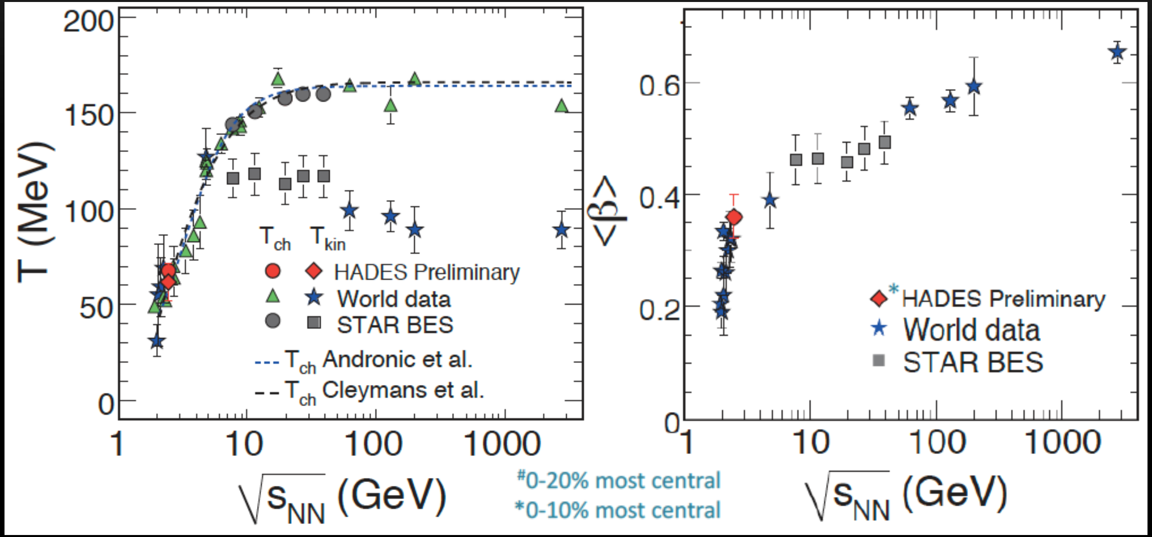
- Unique freeze-out criteria when ϕ decay kinematics is taken into account → no evidence for sequential freeze-out of K^+, K → support for statistical model

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

Flow and its anisotropies



STAR arXiv:1701.07065, 2016



- Kinetic freeze-out parameters from blast wave fit to hadron spectra
- T_{kin}=62±10 MeV, $\langle\beta_r\rangle$=0.36±0.04
- Λ and ϕ fall out of the trend

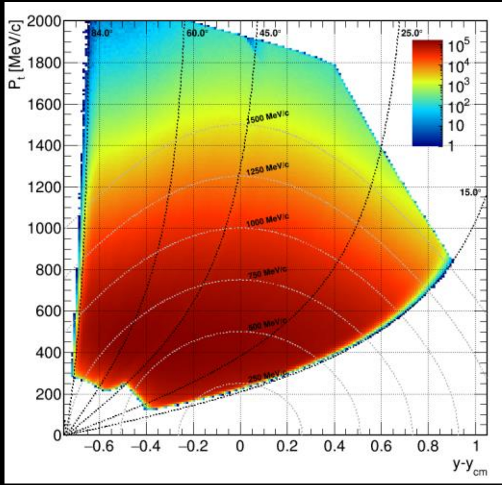
- Global freeze-out parameters fit well into trend of world data
- $T_{kin} < T_{chem}$ also at low energies (high μ_B)

(Net)-Proton Number Fluctuations

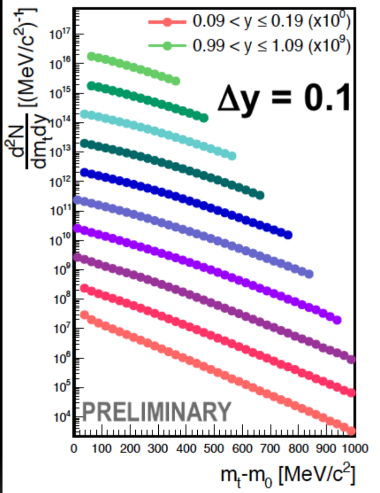
The experimental challenge …

- Phase space region, not to large not to small
- Data need efficiency corrections! Note that efficiency = acc × det.eff. × rec.eff.
  → Two methods tested and validated with full MC simulations and realistic detector response
- Volume fluctuations due to centrality selection, no antiprotons, no terms cancel!

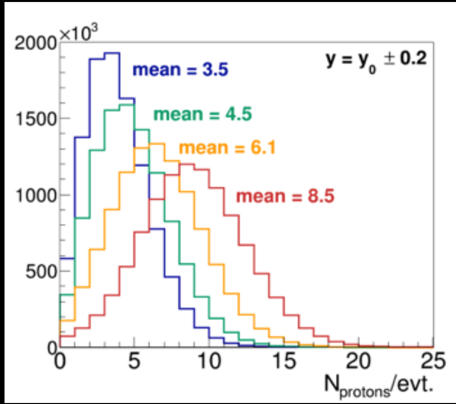
HADES y – p_t coverage for protons



Proton m_t spectra

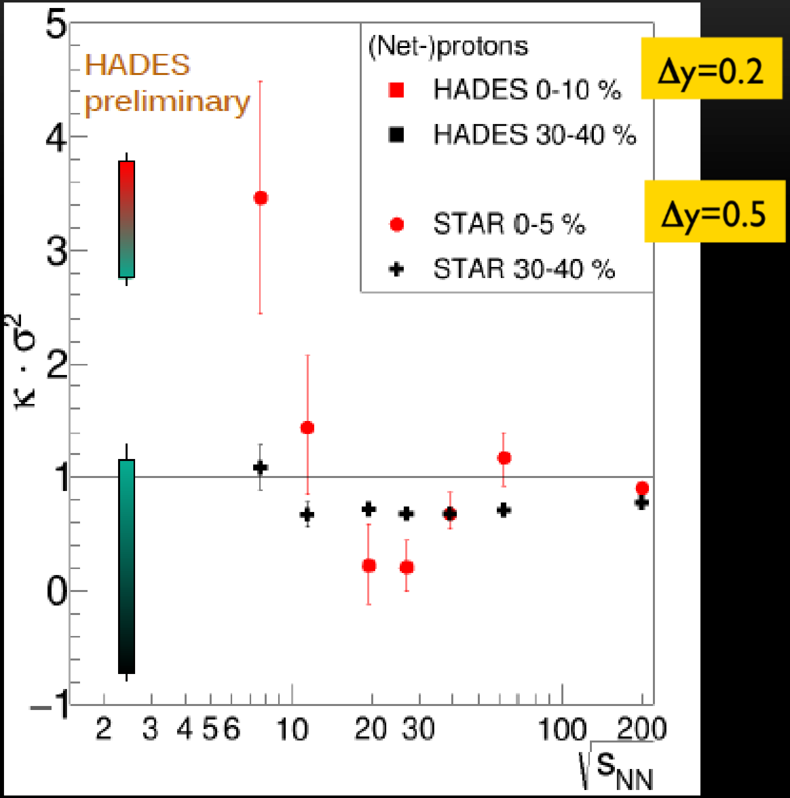


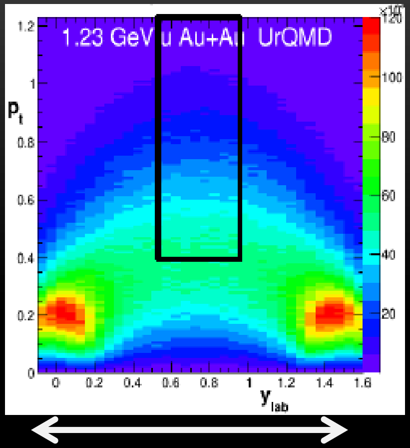
Proton multiplicity distributions



Analysis based on 40×10^6 Au+Au evts divided into 4 centrality classes

(Net)-Proton Number Fluctuations





Rapidity gap = 1.5 units!

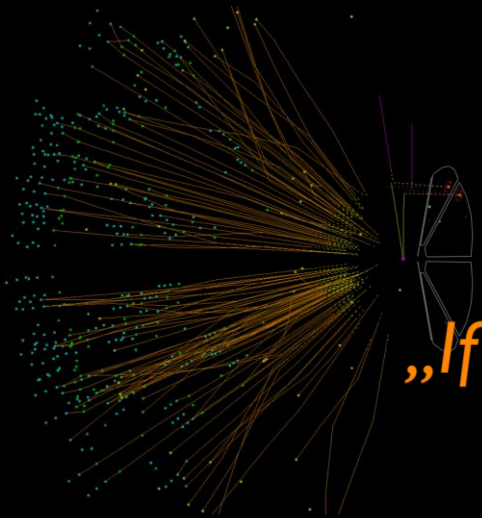
Need to select a phase-space bite small enough to avoid spectators, but large enough to stay away from Poisson limit! → $\Delta y=0.2$

How about bound protons? d/p = 0.3 – 0.4
→ deuteron fluctuation analysis is ongoing

red/black = unfolding (preferred method) + vol. flucs. corr.

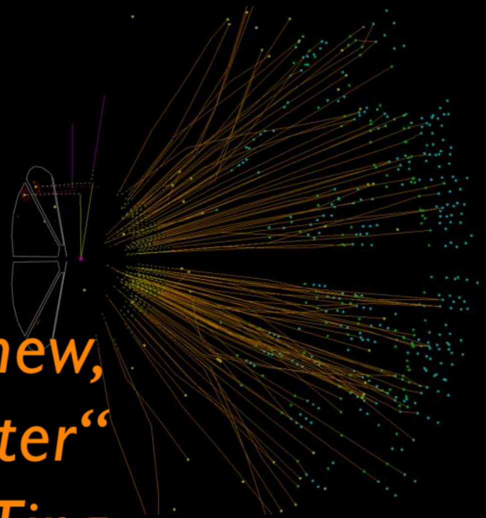
green = evt-by-evt eff correction of factorial moments + vol. flucs. corr.

QM2017, R. Holzmann

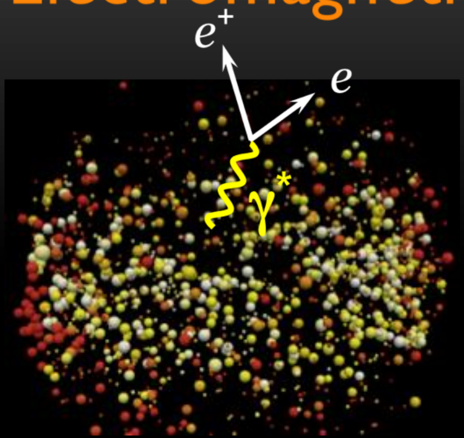


„If you want to detect something new,
build a dilepton spectrometer“

S. Ting



Electromagnetic radiation



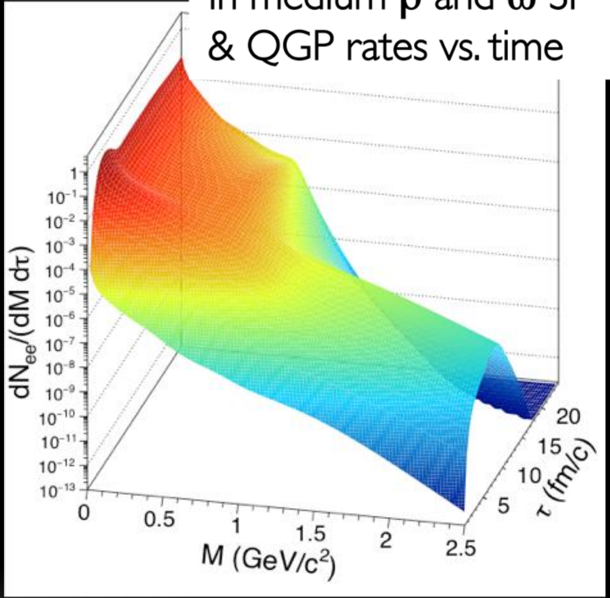
- No strong final state interactions
  → leave reaction volume undisturbed
- Encodes information on collisions (T, μ_B, τ_{coll})

The vector correlator is directly accessible in HIC:

$$\frac{dN_{ll}}{d^4x d^4q} = \frac{-\alpha_{EM}^2}{\pi^3 M^2} f^B(q_0;T)\,\mathrm{Im}\Pi_{EM}^{\mu\nu}(M,q;\mu_B,T)$$

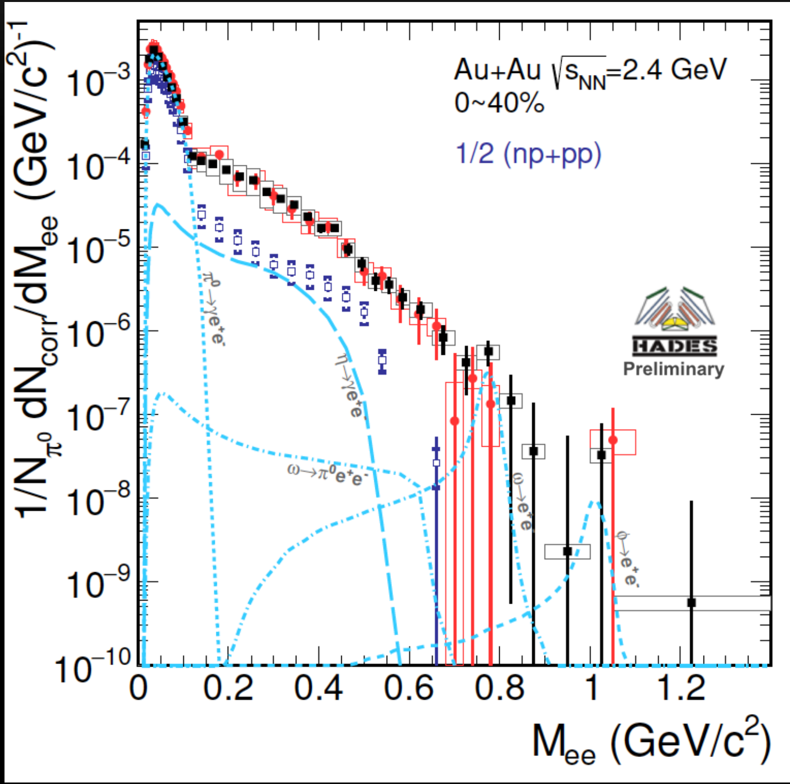
→ Unique direct access to in-medium spectral function

In medium ρ and ω SF
& QGP rates vs. time



Virtual photon emission

Two independent analyses (red, black)

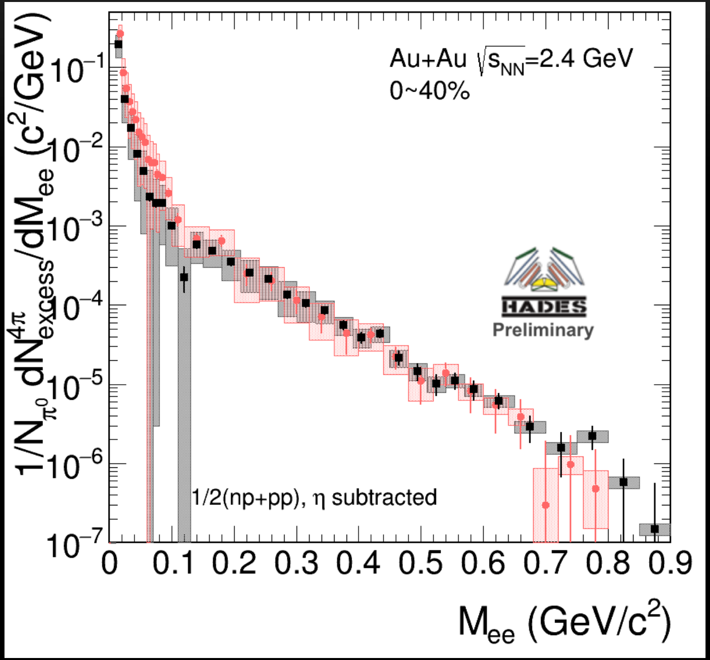


- First measurement of e^+e^- for a heavy system in this energy regime
- Normalization to number of neutral pions
- Strong excess yield ($0.15<M<0.7$ GeV/c^2) above e^+e^- cocktail components of meson decays at freeze-out and elementary baryonic reference observed

→ Medium radiation

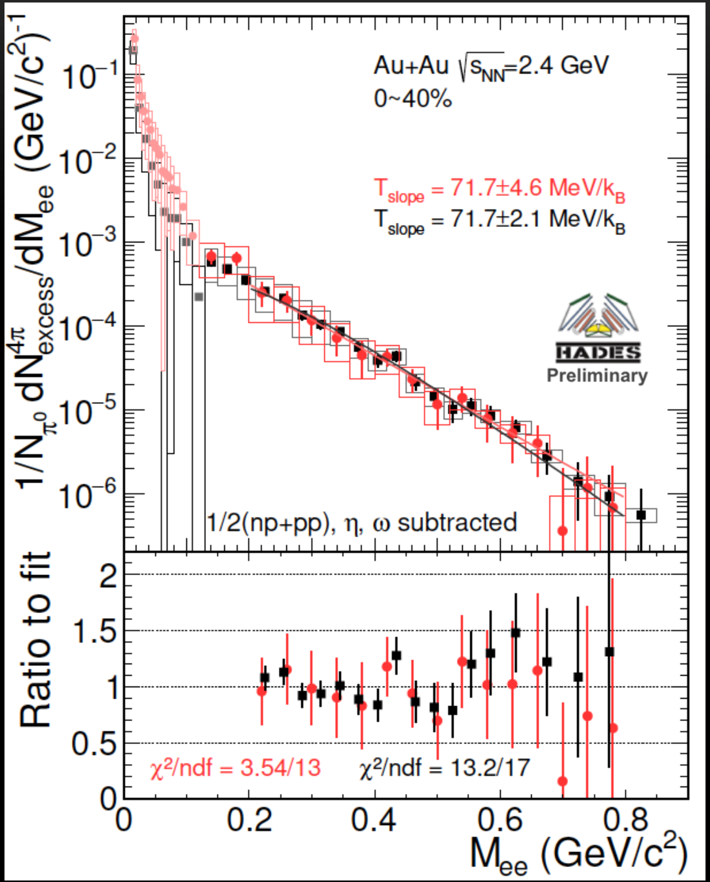
HADES., collaboration review

Virtual photon emission – isolation of excess



- Isolation of excess radiation by subtracting experimentally measured contributions from first chance (NN reference) and late emission (η)
- Acceptance corrected excess yield
- M_{ee}<1 GeVc^2 ~ exponential fall-off - 'Planck-like'
→ measurement of radiating source temperature

Virtual photon emission – fireball thermometer



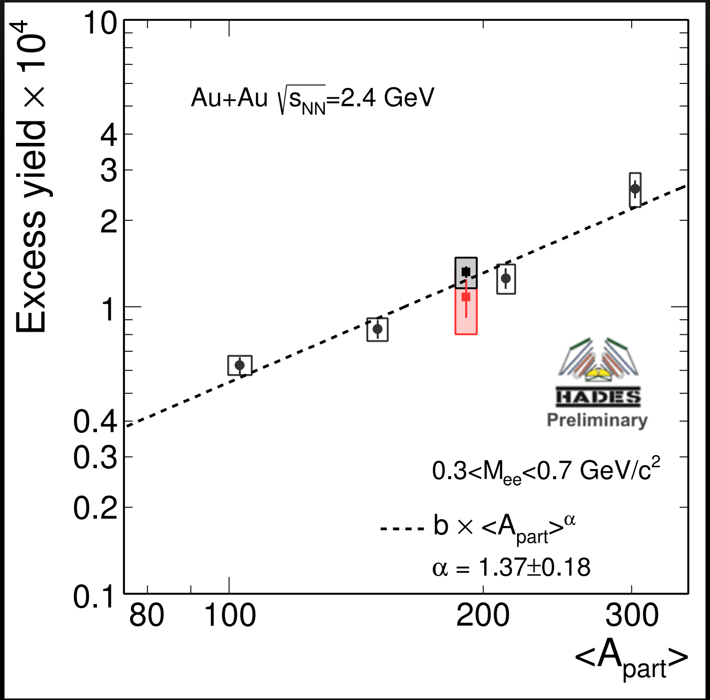
- Isolation of excess radiation by subtracting experimentally measured contributions from first chance (NN reference) and late emission (η)
- Acceptance corrected excess yield
- M_{ee}<1 GeVc² ~ exponential fall-off - 'Planck-like'

→ measurement of radiating source temperature

→ fit $\frac{dN}{dM} \sim M^{\frac{3}{2}} \times \exp\left(-\frac{M}{T}\right)$ to range **M=0.1–0.8** GeV

- $\langle T \rangle_{\text{emitting source}}$ = 72 ± 2 MeV/k_B

Virtual photon emission – fireball chronometer



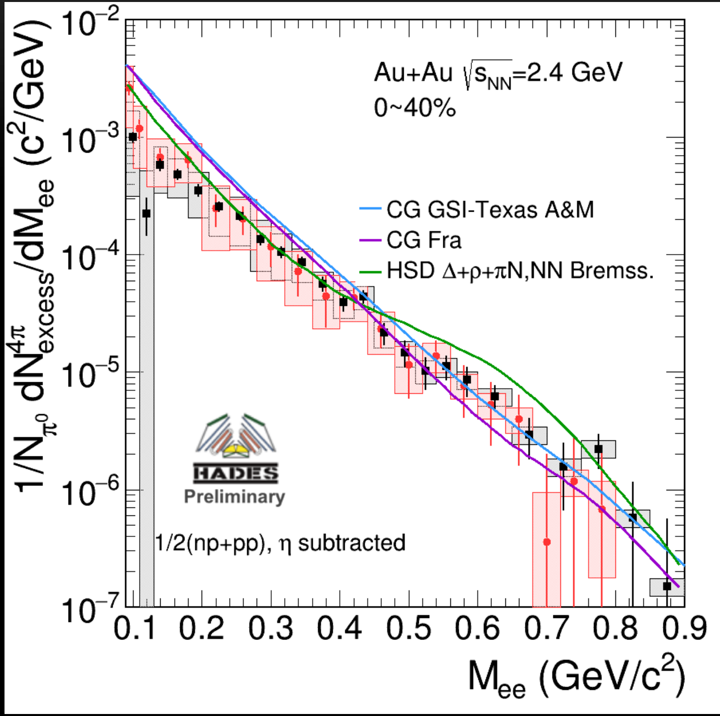
- Strong excess ($\sim A_{part}^{1.3}$, interplay $V \otimes \tau_{coll}$)
- Rapid increase of relative yield reflects the number of Δ's/ N*'s regenerated in fireball
- Dilepton chronometer of the collision time

What is the nature of the excess?

→ Regeneration of baryonic resonances

→ Subsumed into spectral functions

Thermal dileptons at SIS18?

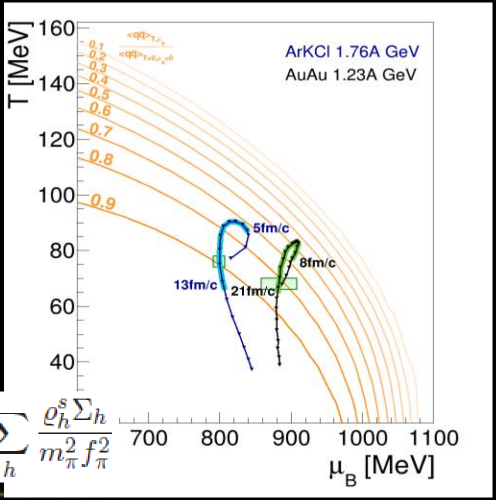


- Strong broadening of the in-medium ρ
- Thermal rates folded over coarse-grained UrQMD medium evolution works at low energies
- Supports baryon-driven medium effects at UrHIC (SPS and RHIC)!

T_{max} = 85 MeV, $\rho = 3\,\rho_0$

→ Excitation of the vacuum (melting of condensate) matches spectral medium effects!

$$\frac{\langle\langle \bar{q}q \rangle\rangle (T,\mu_B)}{\langle \bar{q}q \rangle} = 1 - \sum_h \frac{\varrho_h^s \Sigma_h}{m_\pi^2 f_\pi^2}$$



HADES., collaboration review

CG FRA: Phys. Rev. C 92, 014911 (2015)
CG GSI-Texas A&M: Eur.Phys.J.A52 (2016) no.5, 131

Résumé …

- First measurement of acceptance corrected excess spectrum at low energies
  → robust understanding of low-mass dilepton excess radiation by ρ-baryon coupling.
- Analyzed proton nb fluctuations → HADES data allow to extend RHIC results towards low $\sqrt{S_{NN}}$,
  but interpretation needs input from theory.
- Unexpectedly high φ multiplicities. Feed down correction important when interpreting kaon spectra.
- Strange hadrons → Universal scaling with participant number A_{part}
- Completion of the excitation functions of flow, T_{chem}, T_{kin} and $\langle\beta_T\rangle$

- Exciting results from Au+Au collisions at $\sqrt{S_{NN}}=2.42$ GeV
  → suggest "thermalize" strongly interacting medium created

… and prospects

- Strong scientific program for FAIR Phase-0
- Important measurements to complement the exploration of the phase diagram and to provide a valuable reference measurements
  - π+p/A $\sqrt{s}$=1.7 – 1.9 GeV: EM structure of baryonic resonances
  - Ag+Ag at 1.65A GeV: multi-strange hadrons & intermediate-mass dileptons
- Continue physics program at higher energies SIS100

Submitted to PAC on June 19, 2017

The HADES Collaboration

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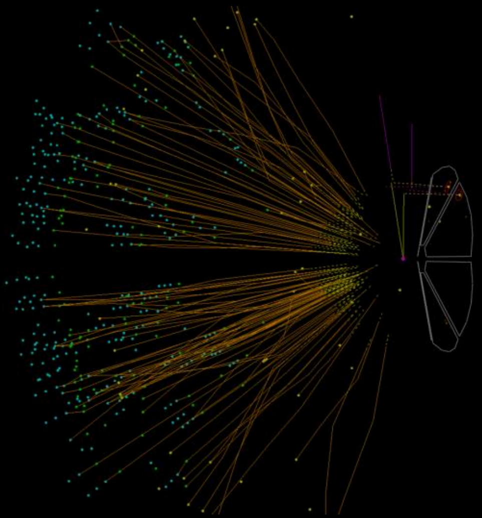
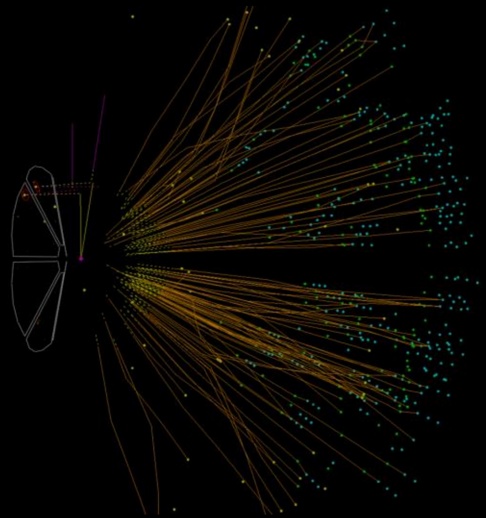
- LIP & ISEC, Coimbra, Portugal
- SIP JUC Cracow, Poland
- GSI, Damstadt, Germany
- TU Darmstadt, Germany
- HZDR, Dresden, Germany
- JINR Dubna, Russia
- GU Frankfurt, Germany
- JLU Giessen, Germany
- TU München, Germany
- Lisboa, Portugal
- Nicosia, Cyprus
- IPN Orsay, France
- NPI CAS, Rez, Czech Rep.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

~100 collaborators





Thank you
for your attention!