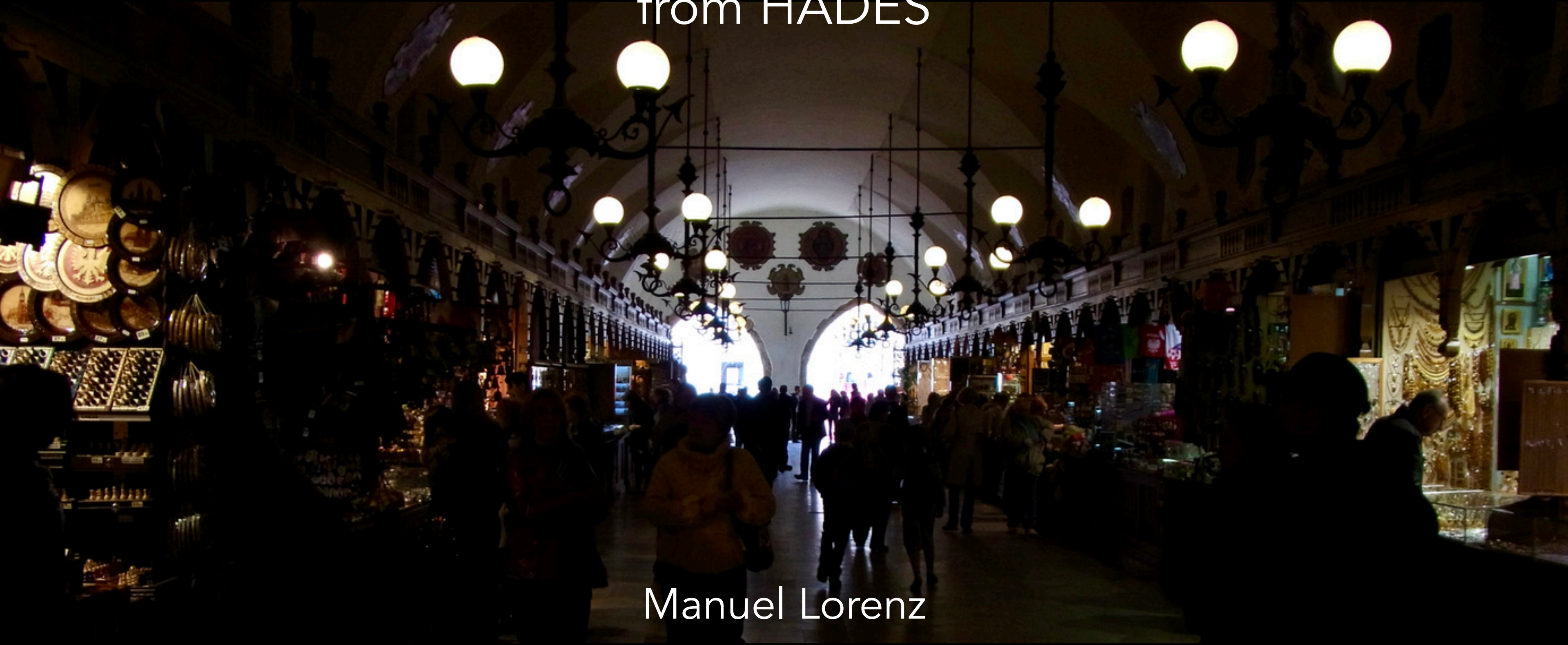
Results on Hadron Properties in π, p, A+A Collisions from HADES

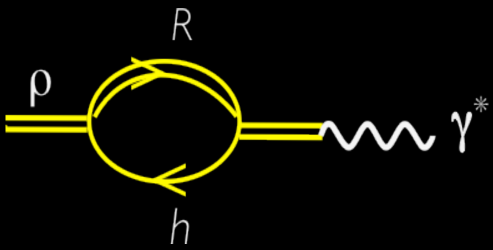


Manuel Lorenz
for the HADES collaboration
Goethe-University Frankfurt

Outline

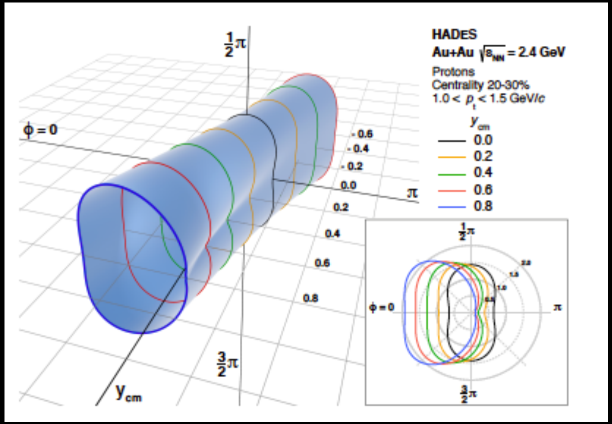
Introduction:

QCD and hadron properties
Observables and experimental access



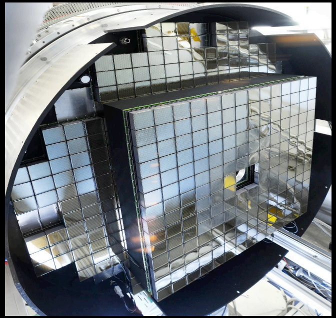
Results:

Dilepton radiation
Strangeness
Bulk properties in A+A

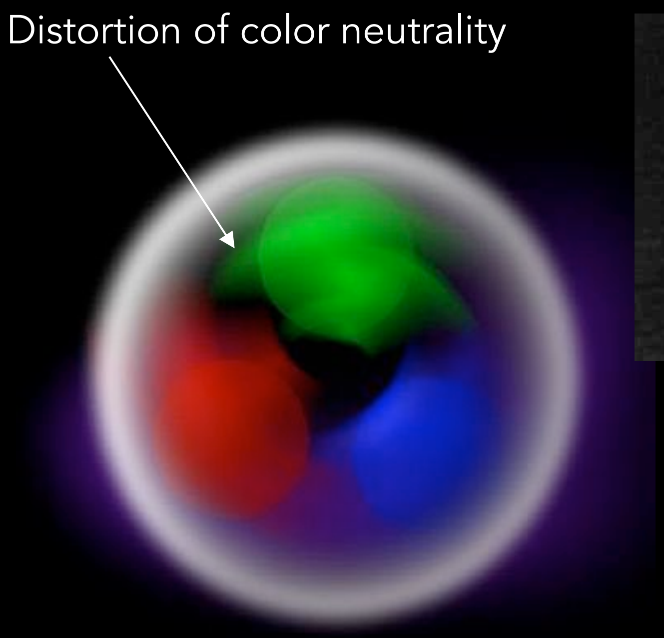


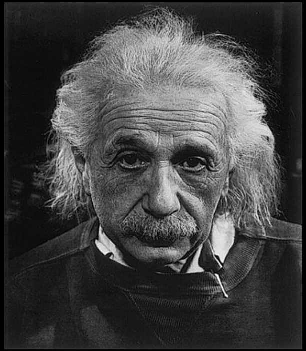
FAIR-Phase 0:

New detectors and new Ag+Ag data



QCD and the Generation of Mass





Localization "costs" energy!

$\Delta x \Delta p \geq \hbar$ $E^2=(pc)^2+(mc^2)^2$

"Observed hadron masses are nature's compromise between distortion of the vacuum and localization!" F. Wilczek

$M >> \sum m_i$

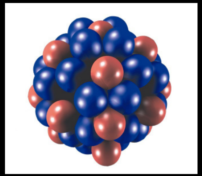
Only a few percent result from the Higgs-field.

The QCD vacuum is not empty but filled with condensates which must be displaced and are related to hadron properties:

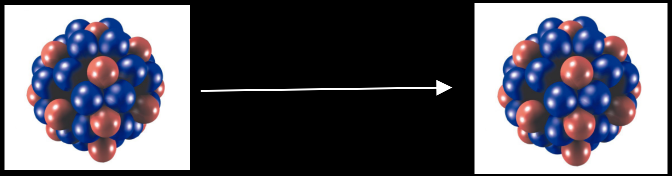
→ *Change vacuum, change hadron properties!*

Experimental Access and Observable

p,π,γ

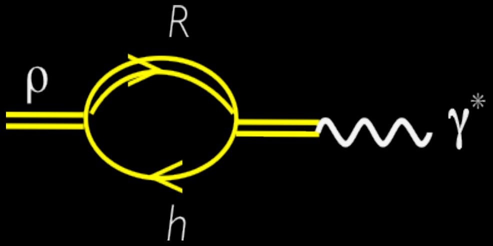


Experimental Access and Observable



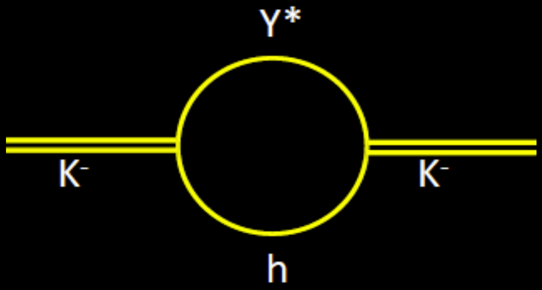
More controlled conditions in cold nuclear matter, no time evolution
Stronger effects in HIC, time evolution of density and temperature

Example: **ρ meson**



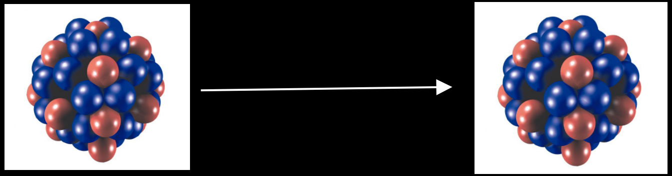
Probe: dilepton decay
Observable: line shape modifications

Example: **K^- meson**



Probe: reconstruction of hadron
Observable: Production yields and phase space distributions

Experimental Access and Observable



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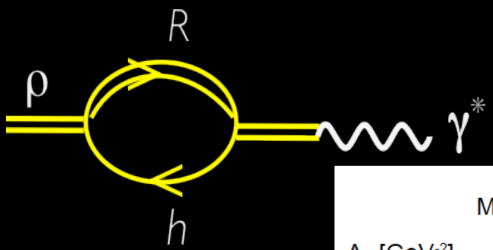
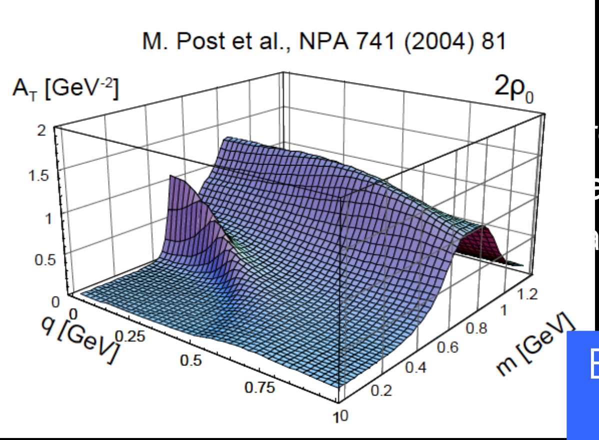
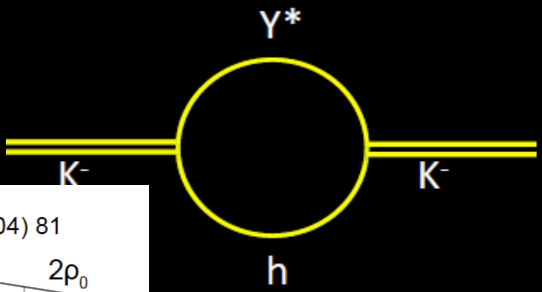


Probe: dilepton decay
Observable: line shape



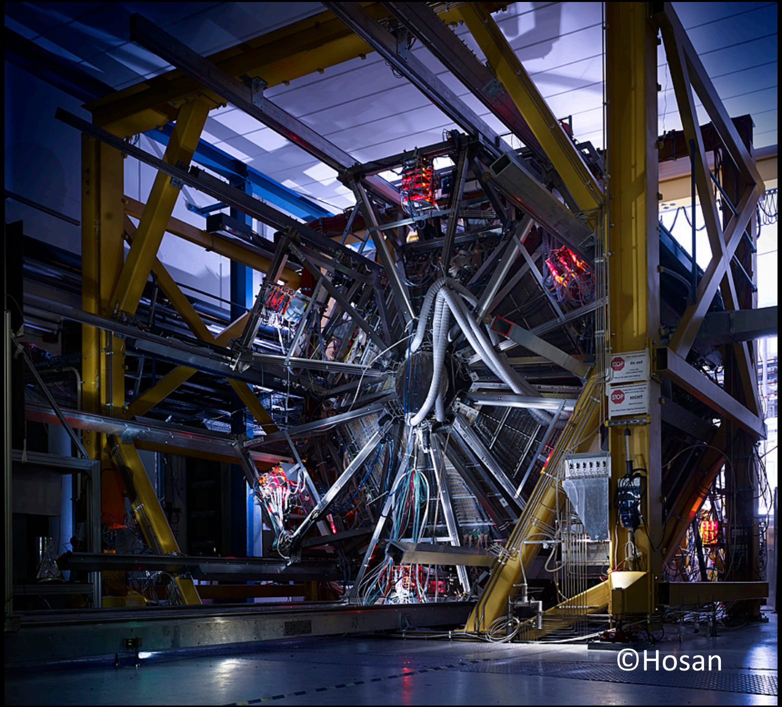
Example: **K⁻ meson**

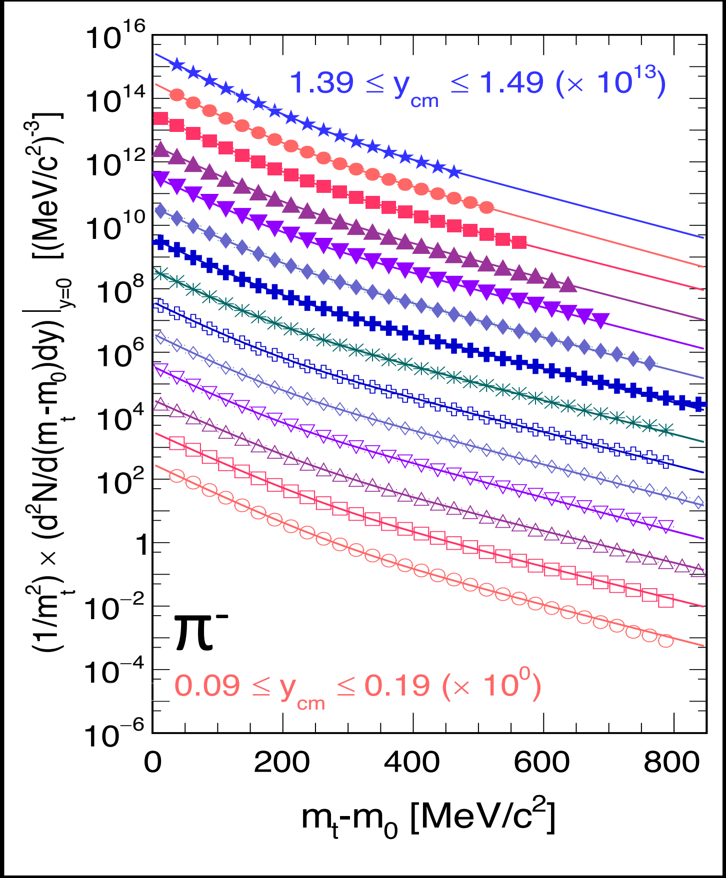


econstruction of hadron
able: Production yields
se space distributions

Effects mainly at small momenta
→ Ensure acceptance!

HADES





Fast detector: 16 kHz Ag+Ag

Large acceptance: full azimuthal and polar angle coverage of ϴ = 18° – 85°

Dilepton Radiation: p+Nb

for Strangeness in p+Nb
see K. Nowakowski 20/05/ 17:15

for Transition Form Factors in p+p:
see W. Przygoda17/05/ 16:45

Experimental Acceptance

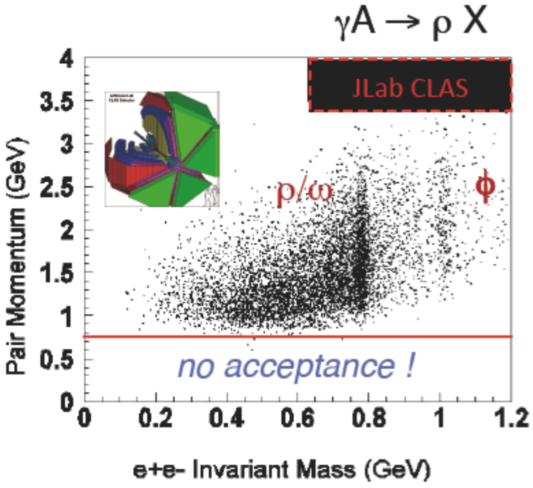
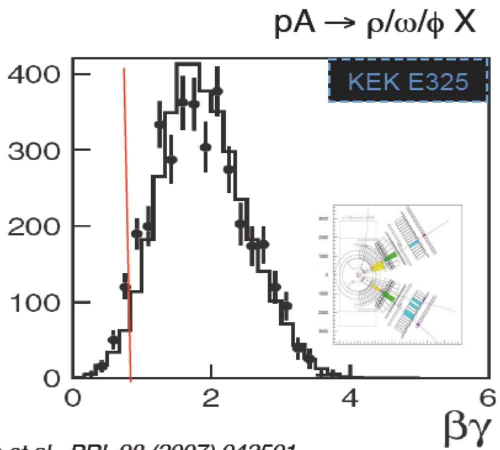
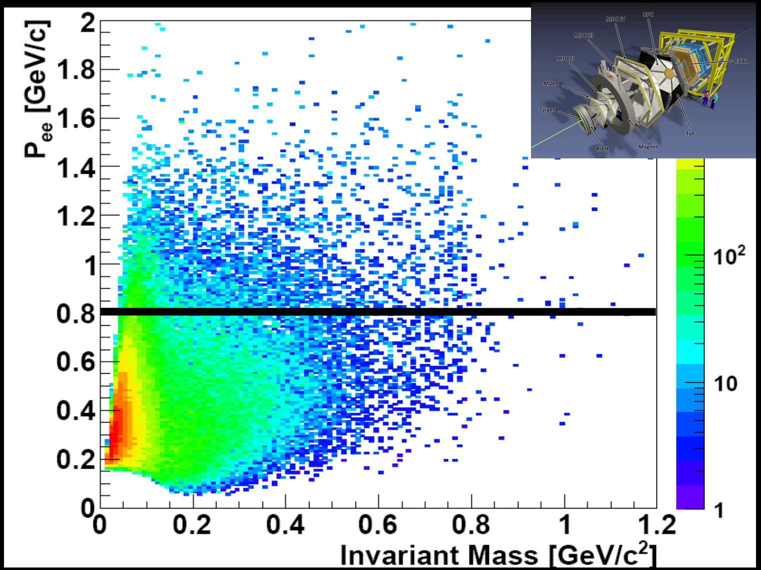


Fig. from S.Leupold et al., nucl-th 0907.2388

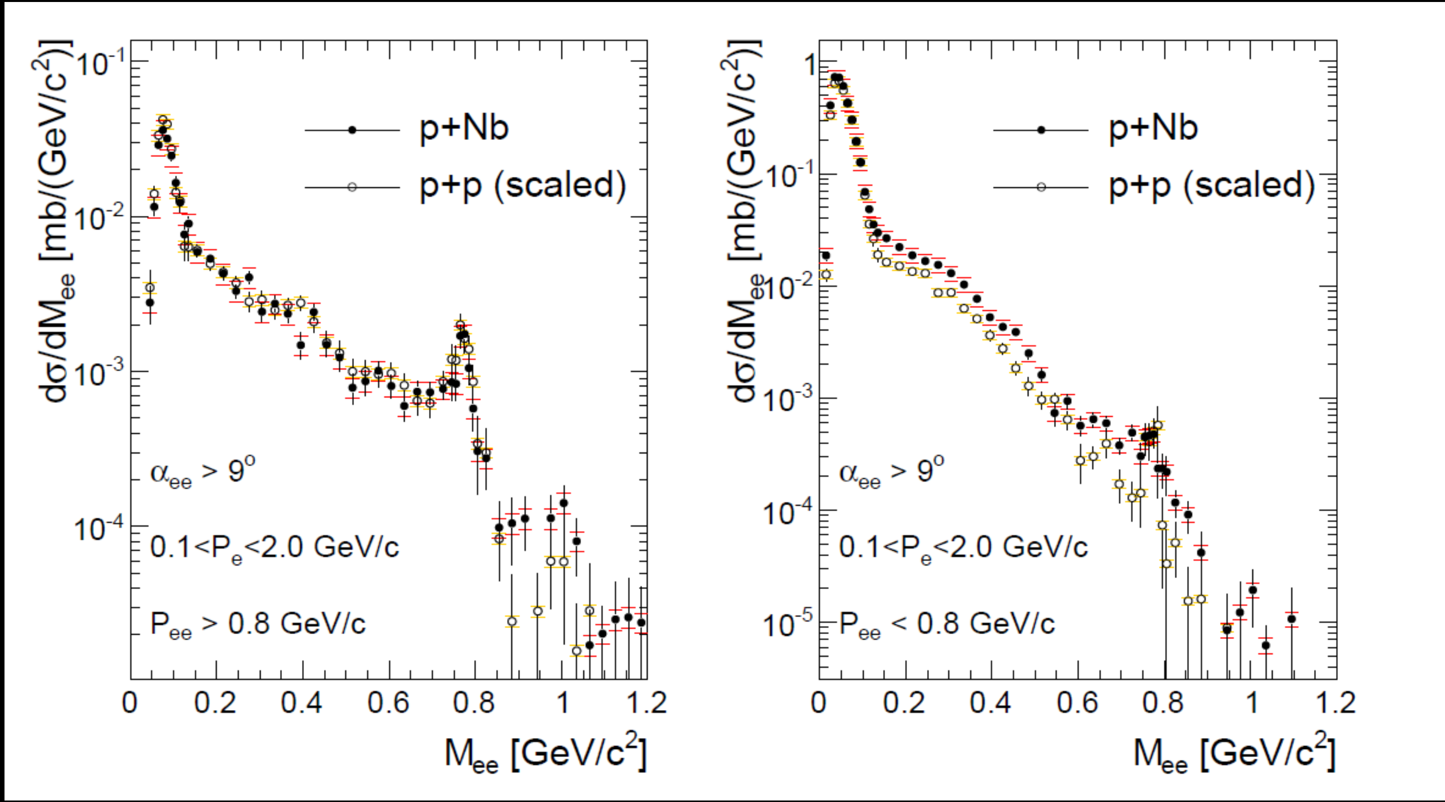


R.Muto et al., PRL 98 (2007) 042501



Compared to CLAS and KEK-E325 better coverage of slow vector mesons
→ compare "slow" and "fast" vector meson with p+p reference

"Fast" and "Slow"

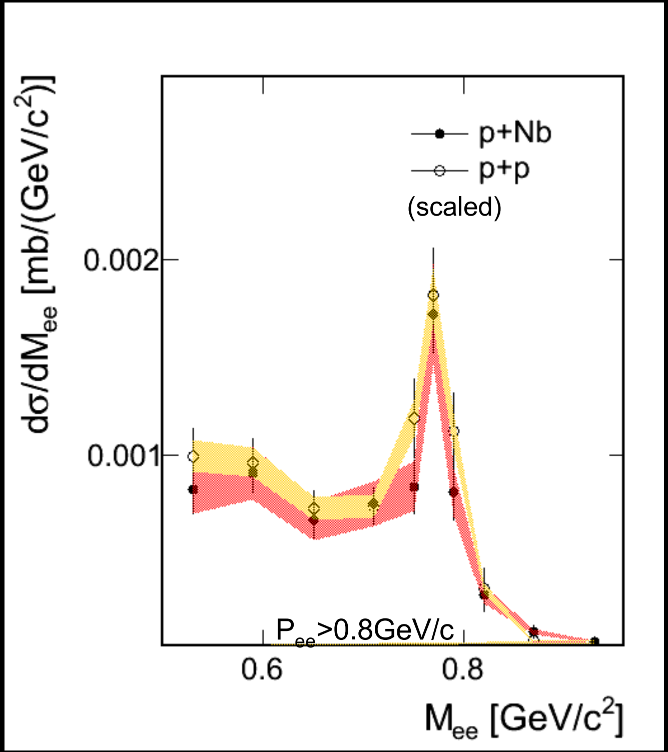


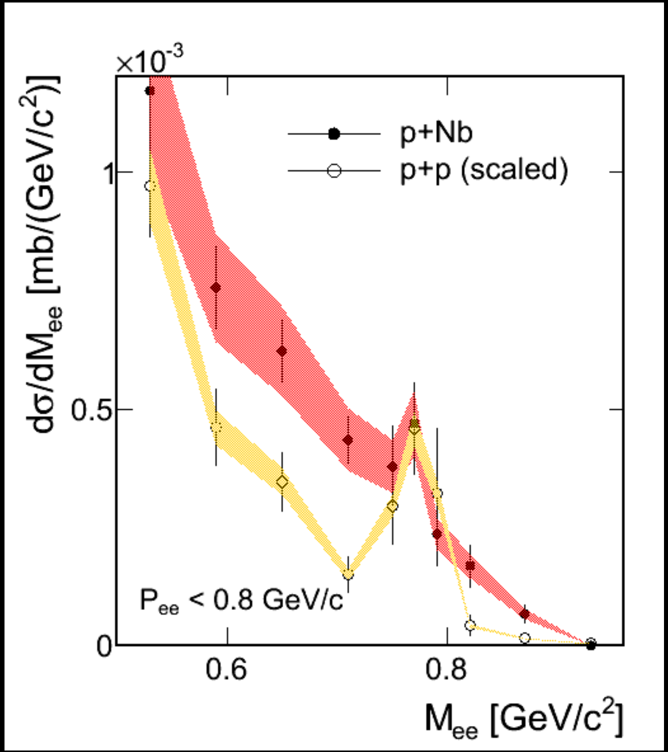
Phys.Lett. B715 (2012) 304-309

Scaled with "nuclear modification factor":

$$R_{pA} = \frac{d\sigma^{pNb}/dp}{d\sigma^{pp}/dp} \times \frac{\langle A^{pp}_{part}\rangle}{\langle A^{pNb}_{part}\rangle} \times \frac{\sigma^{pp}_{reaction}}{\sigma^{pNb}_{reaction}}.$$

"Fast" and "Slow" Vector Mesons



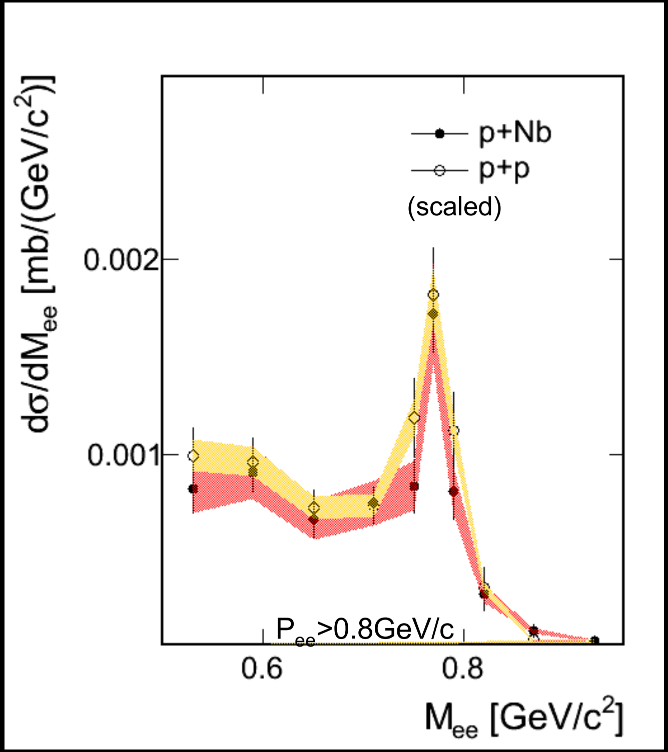


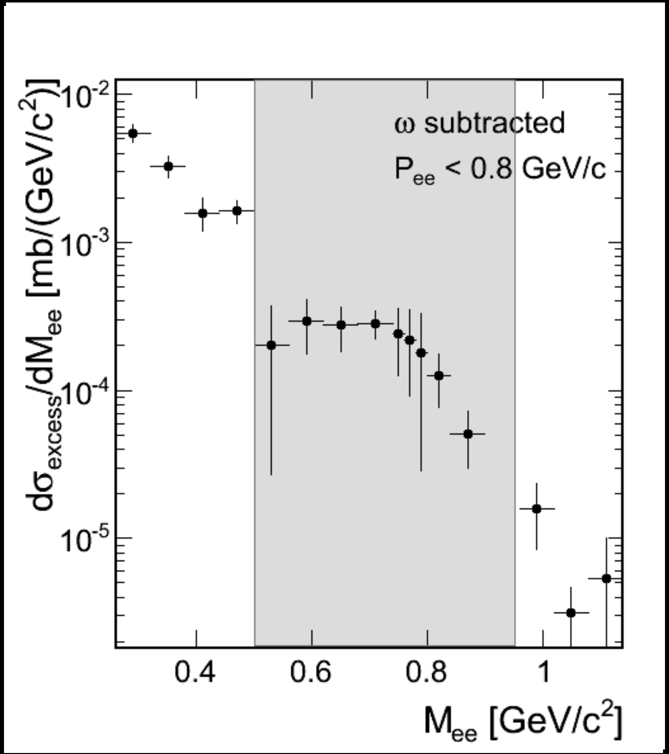
Phys.Lett. B715 (2012) 304-309

High momentum: no significant difference in line shape of continuum and **ω** mesons.

Low momentum: strong difference due to additional **ρ**-like contribution and suppression of **ω**'s

Fast and Slow Vector Mesons





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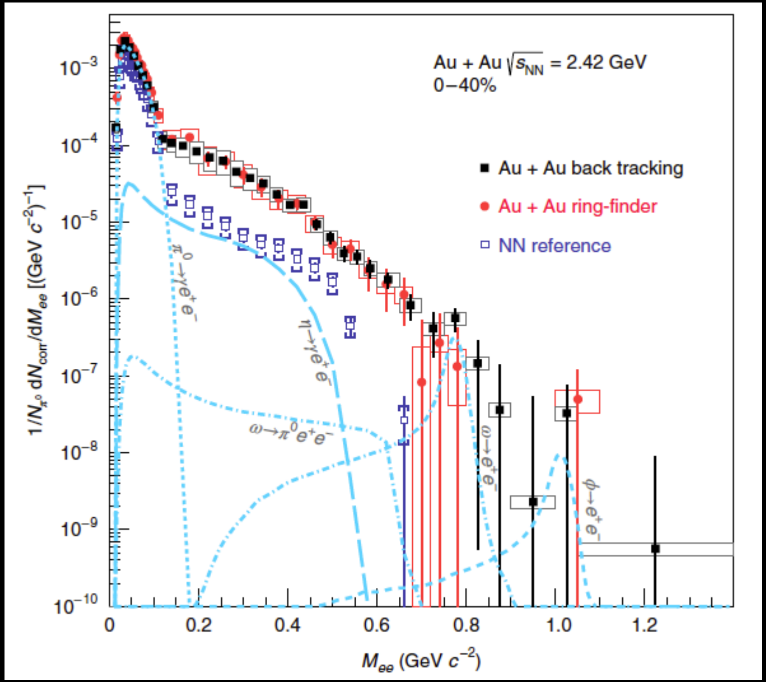
Dilepton Radiation: Heavy-Ions

Nature Phys. 15 (2019) 10, 1040-1045



- First measurement for a heavy collision system at low $\sqrt{s_{NN}}$.
- Strong excess (0.15<M<0.7 GeV/c^2) above components of meson decays at freeze-out and NN-reference.
- Isolation of excess by subtracting the NN-reference.

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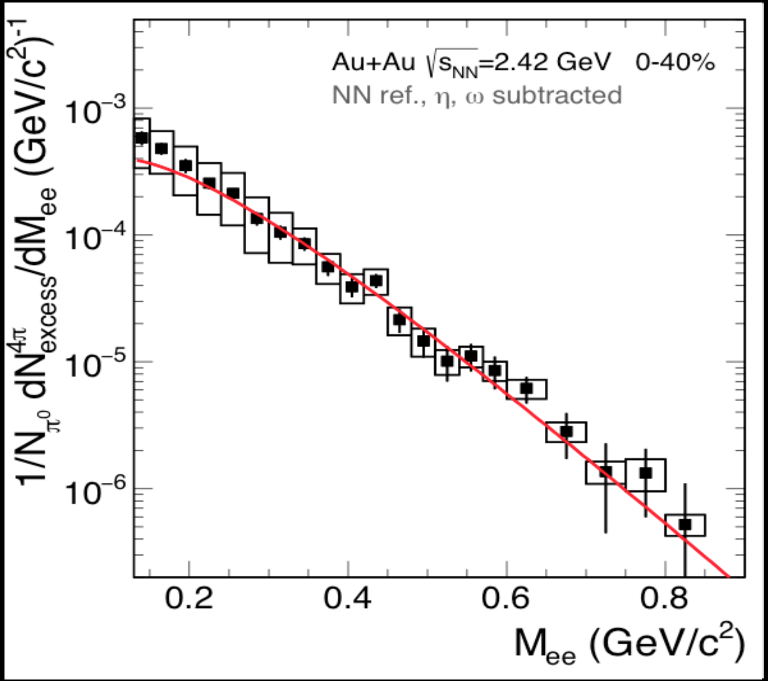

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- Exponentially falling spectrum,
  → extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV

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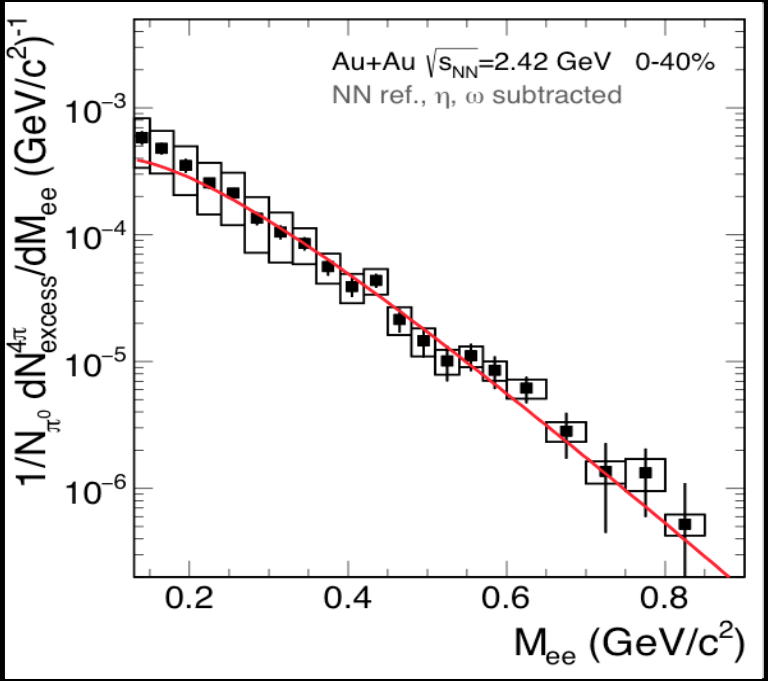

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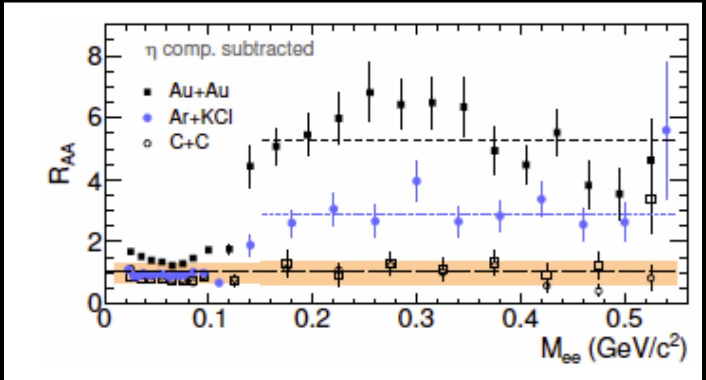
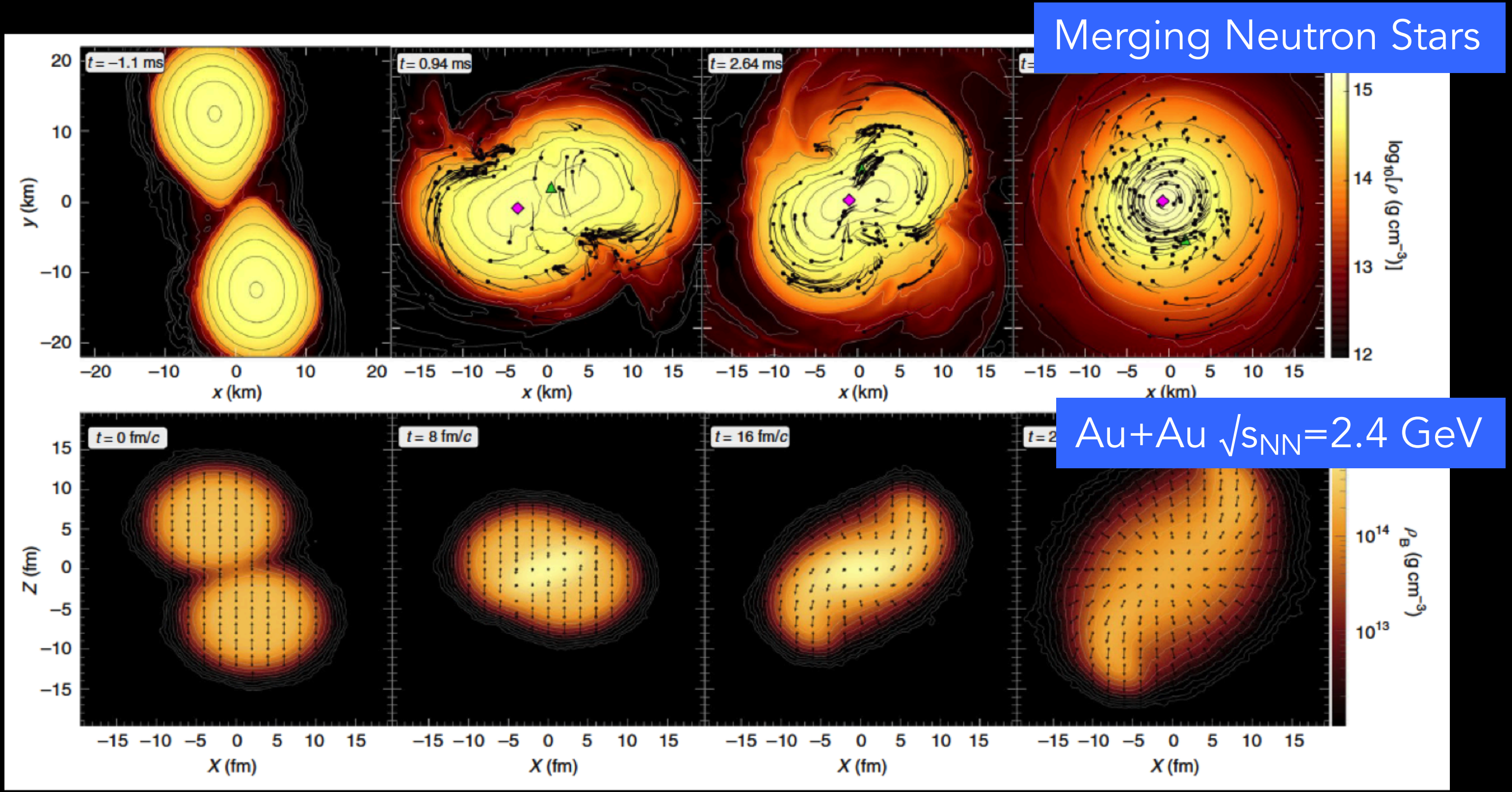


Onset of medium radiation ("fireball") in Ar+KCl collisions

Neutron star merger and HIC at HADES



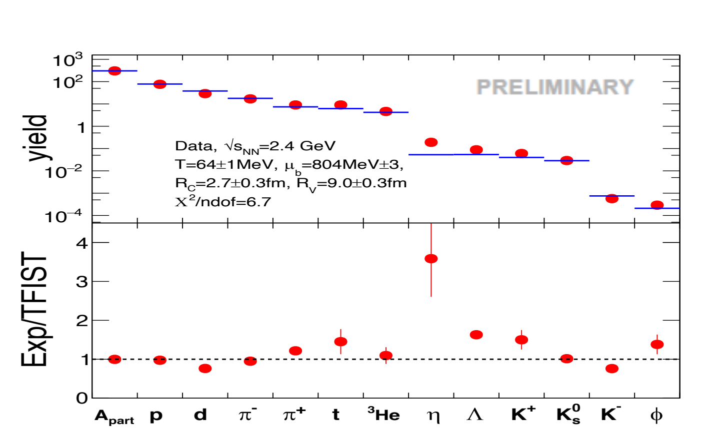
Nature Phys. 15 (2019) 10, 1040-1045

T ≈ 70 MeV, $\rho \approx 3\rho_0$ in both cases

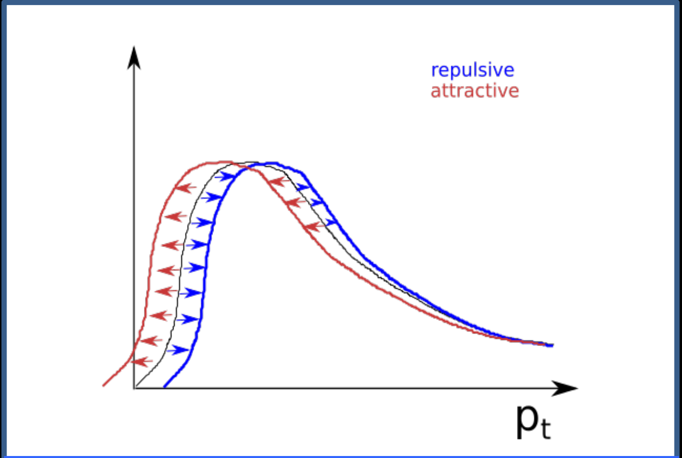
M. Hanauske, J.Phys.: Conf. Series878 012031 (2017)
L. Rezzolla et. al. PRL 122, n0.6, 061101 (2019)
Au+Au simulation UrQMD: S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 255 (1998).

Neutron Star Matter under the Microscope: How "strange" is it?

Chemistry:
How much strangeness is there?
How is it distributed amoung different hadrons?



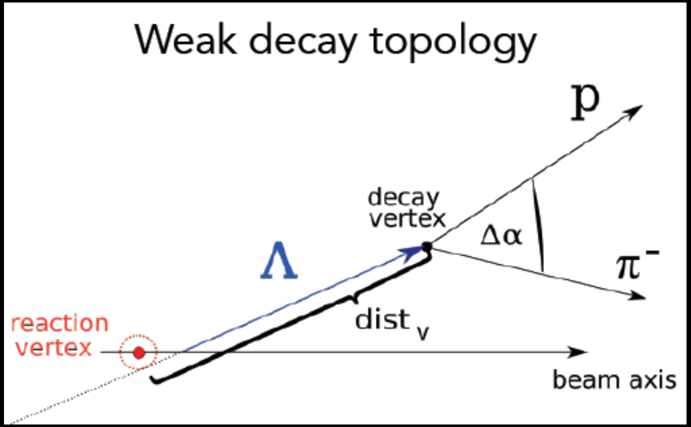
Kinematics:
K, Y – nucleon potential?



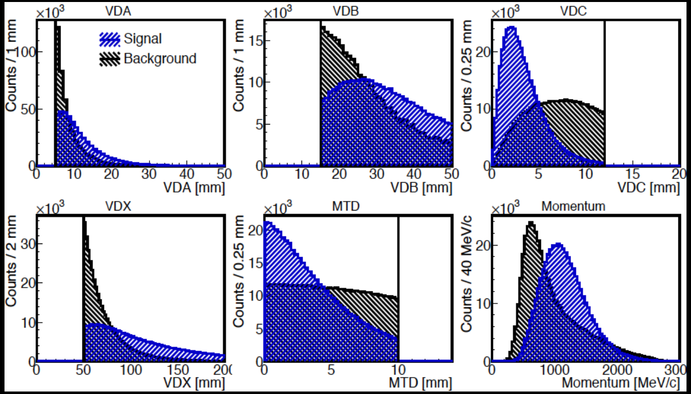
See K. Piasecki 19/05/ 18:25

Relevant for stability of neutron stars

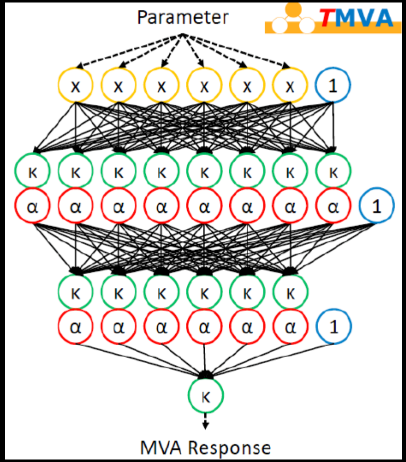
Weak decay topology recognition with neural networks



↓ Results in several parameters

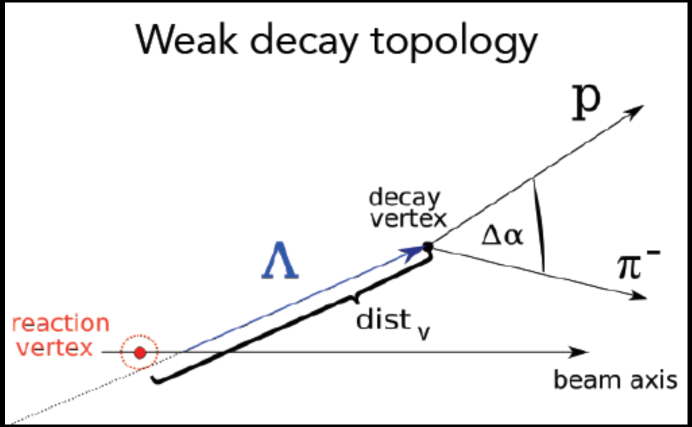


Which can be fed into an ANN



MA S. Spies, PhD F. Kornas, Phys.Lett. B793 (2019) 457-463

Weak decay topology recognition with neural networks



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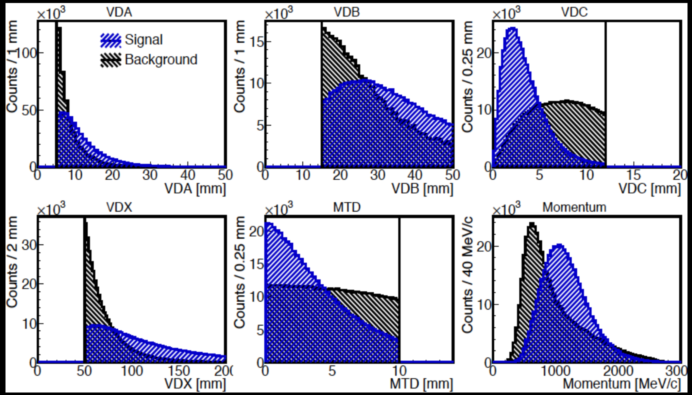
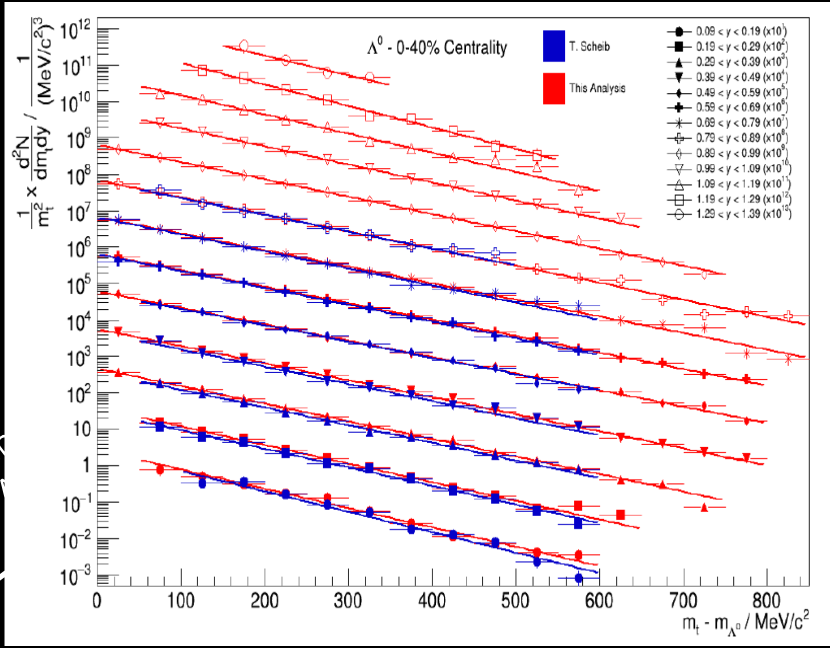


Which ca
into an



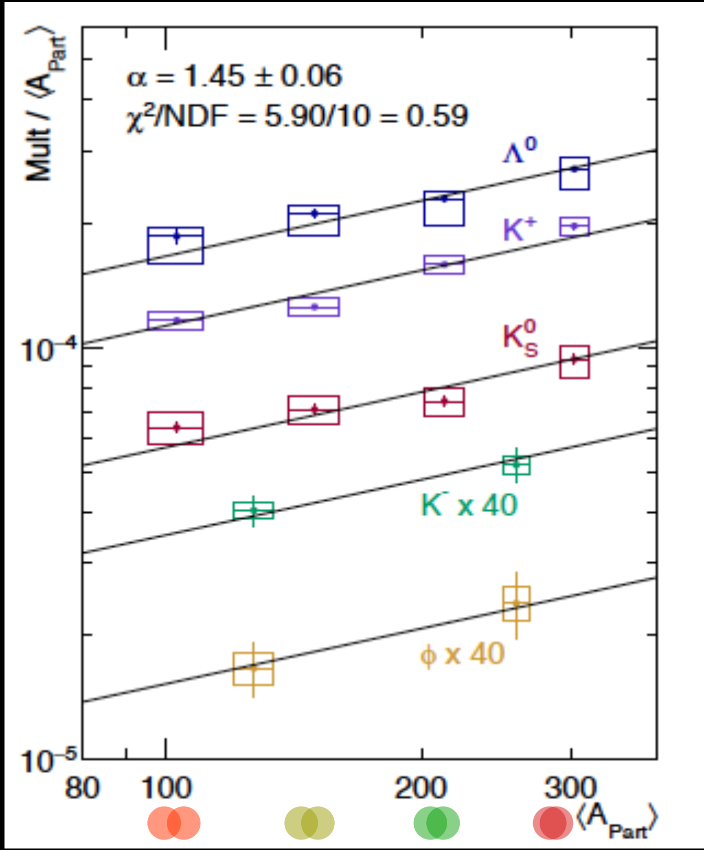
MA S. Spies, PhD F. Kornas, Phys.Lett. B793 (2019) 457-463

ANN in combination with pre-selection on topology parameters improves performance → reduction of uncertainty for 4π yield extraction.

Strangeness in Au+Au @ $\sqrt{s_{NN}}$= 2.4 GeV

Complete set of strange hadrons produced below NN-threshold: NN→NYK$^+$: $\sqrt{s_{NN}}$= 2.55 GeV
NN→NNK$^+$K$^-$: $\sqrt{s_{NN}}$= 2.86 GeV

Phys.Lett. B793 (2019) 457-463



→ unique observable:

Energy must be provided by the system.

Strange particle yields rise stronger than linear with

$<A_{part}>$ (M ~ $<A_{part}>^{\alpha}$)

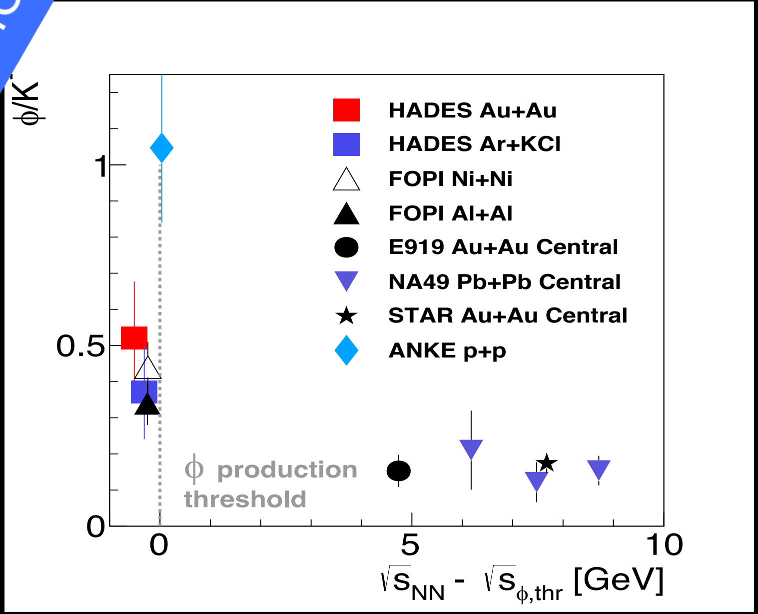
Universal $<A_{part}>$ dependence of strangeness production

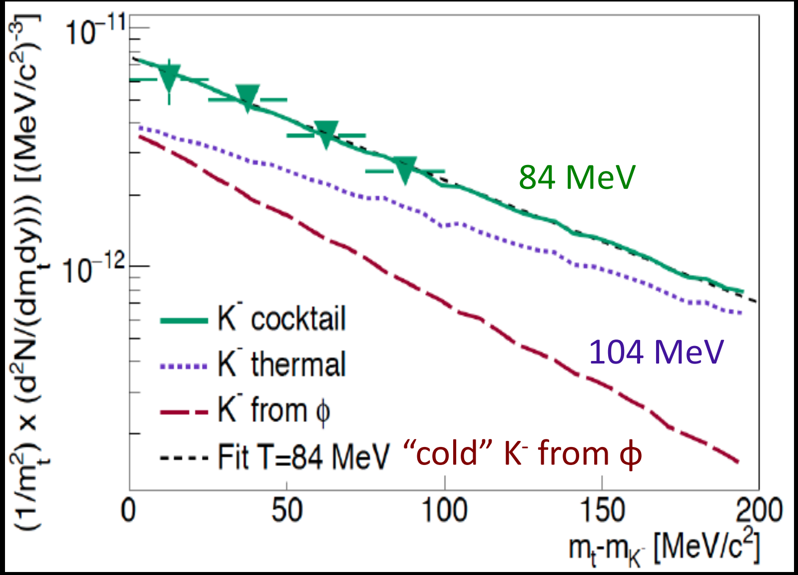
→ Hierarchy in production threshold not reflected in scaling

Scaling with absolute amount of ssbar, not with individual hadron states.

Reminder

Φ-AntiKaon Interplay in HIC





Phys.Lett. B778 (2018) 403-407

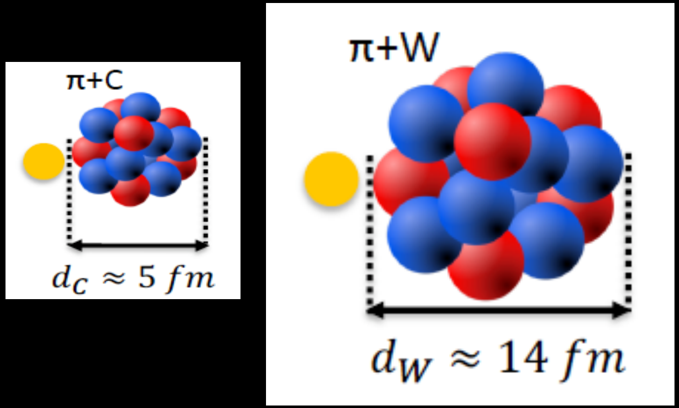
Increased in HIC at low $\sqrt{s_{NN}}$:
→ 25% of K^- result from **Φ** decays!

Φ feed-down can explain lower inverse slope parameter of K^- spectrum (T_{eff} = 84 ± 6 MeV) in comparison to the one of K^+(T_{eff} = 104 ± 1 MeV)

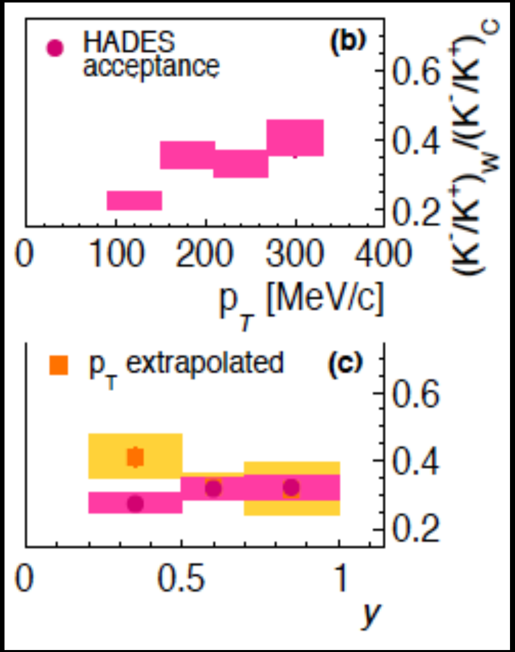
→ No indication for sequential K^+K^- freeze-out from K^- spectrum if corrected for feed-down.

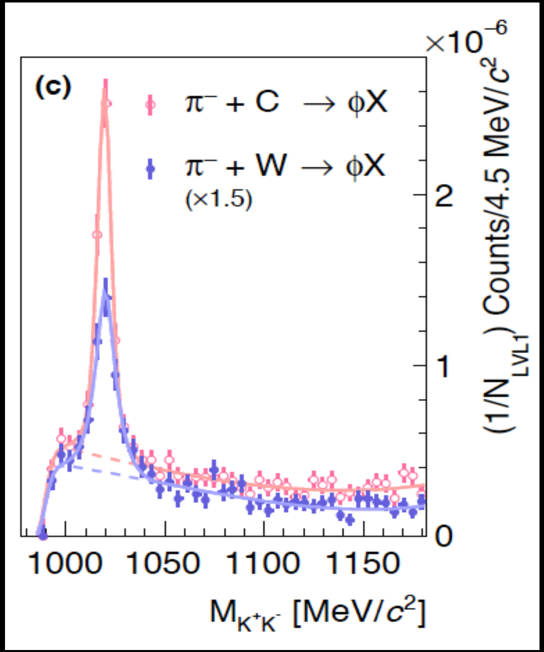
M. Lorenz et al. PoS BORMIO2010 (2010) 038

Φ-AntiKaon Interplay in Cold Matter



→ Mean free path $\lambda_\pi = 1.5\ fm$
$(p_\pi = 1.7\ GeV/c, \rho_B \approx \rho_0)$





→ Suppression of K^- relative to K^+

→ Similar suppression for ϕ like for K^-

In HADES acceptance:

$(\phi/K^-)_C = 0.55 \pm 0.04(stat)^{+0.06}_{-0.07}(sys)$

$(\phi/K^-)_W = 0.63 \pm 0.06(stat) \pm 0.11(sys)$

Phys.Rev.Lett. 123 (2019) 2, 022002

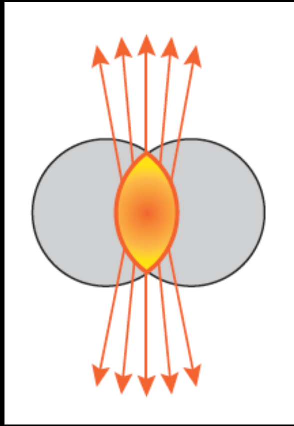
Global Collision Dynamics

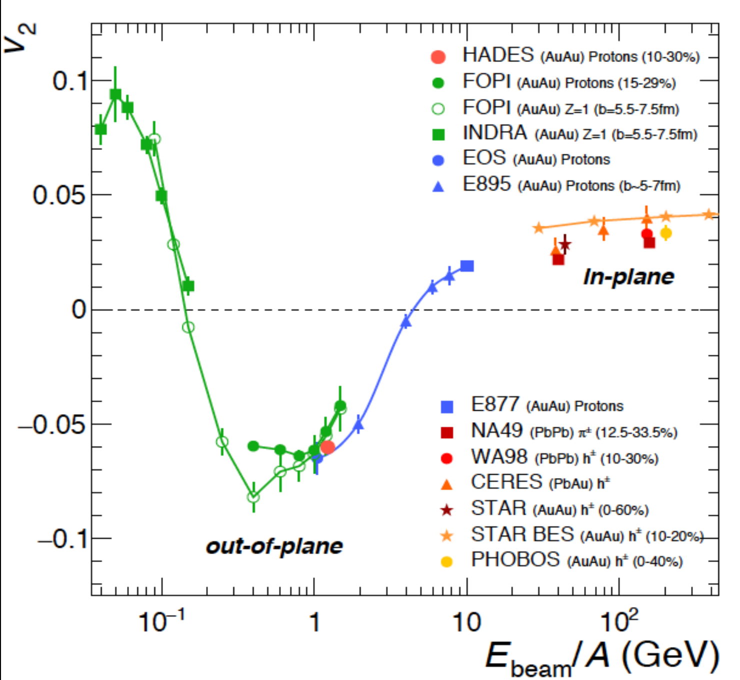
Flow Anisotropies

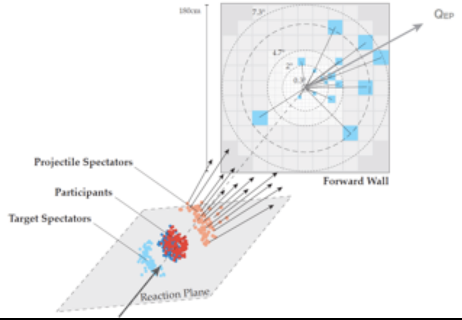
Out-of-plane v_2

- Long spectator passing time

  $\tau_{passing} \approx \tau_{expansion}$
- Squeeze-out





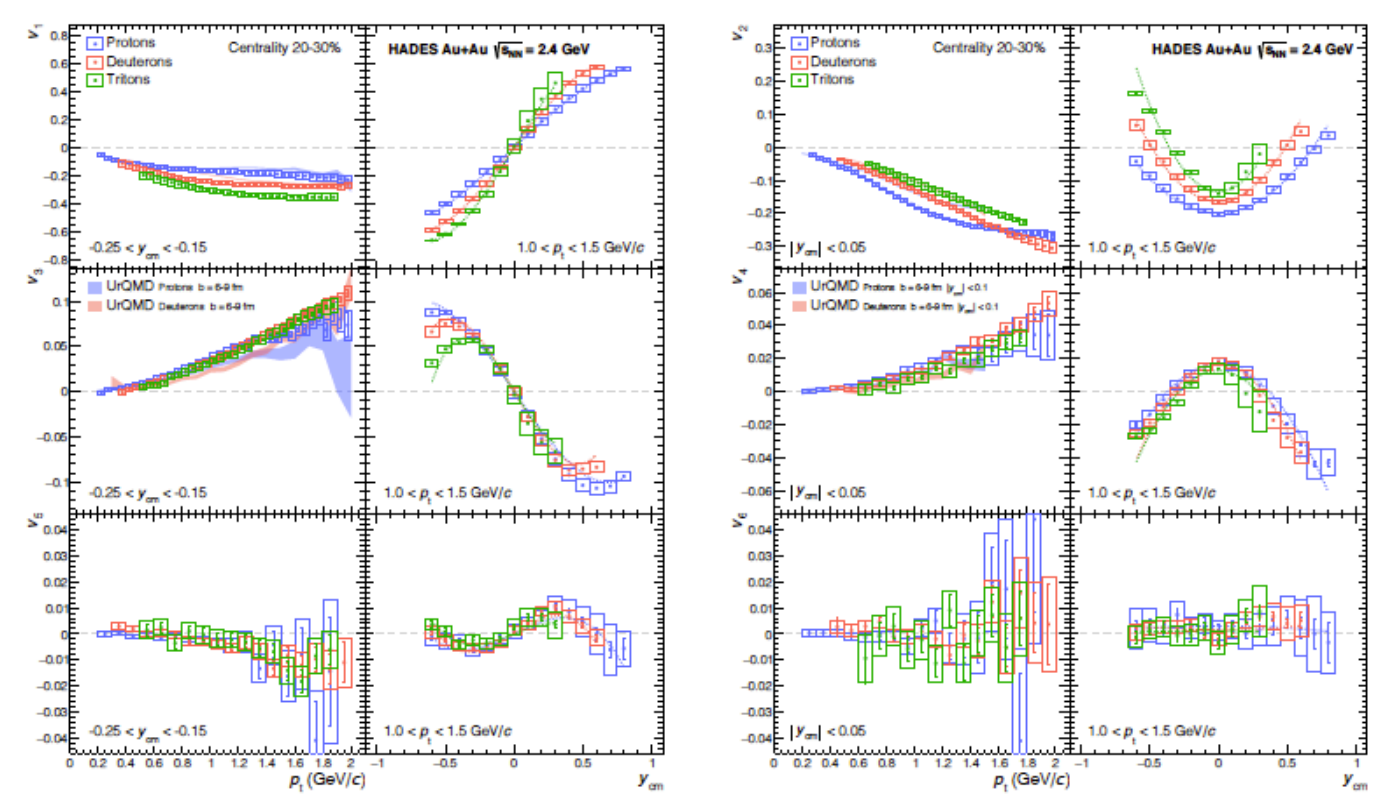


Event plane reconstruction based on hits of charged projectile spectators in the FW

p, d, t : v_1 - v_6

First analysis up to v_6 in this energy regime

sensitve to EOS

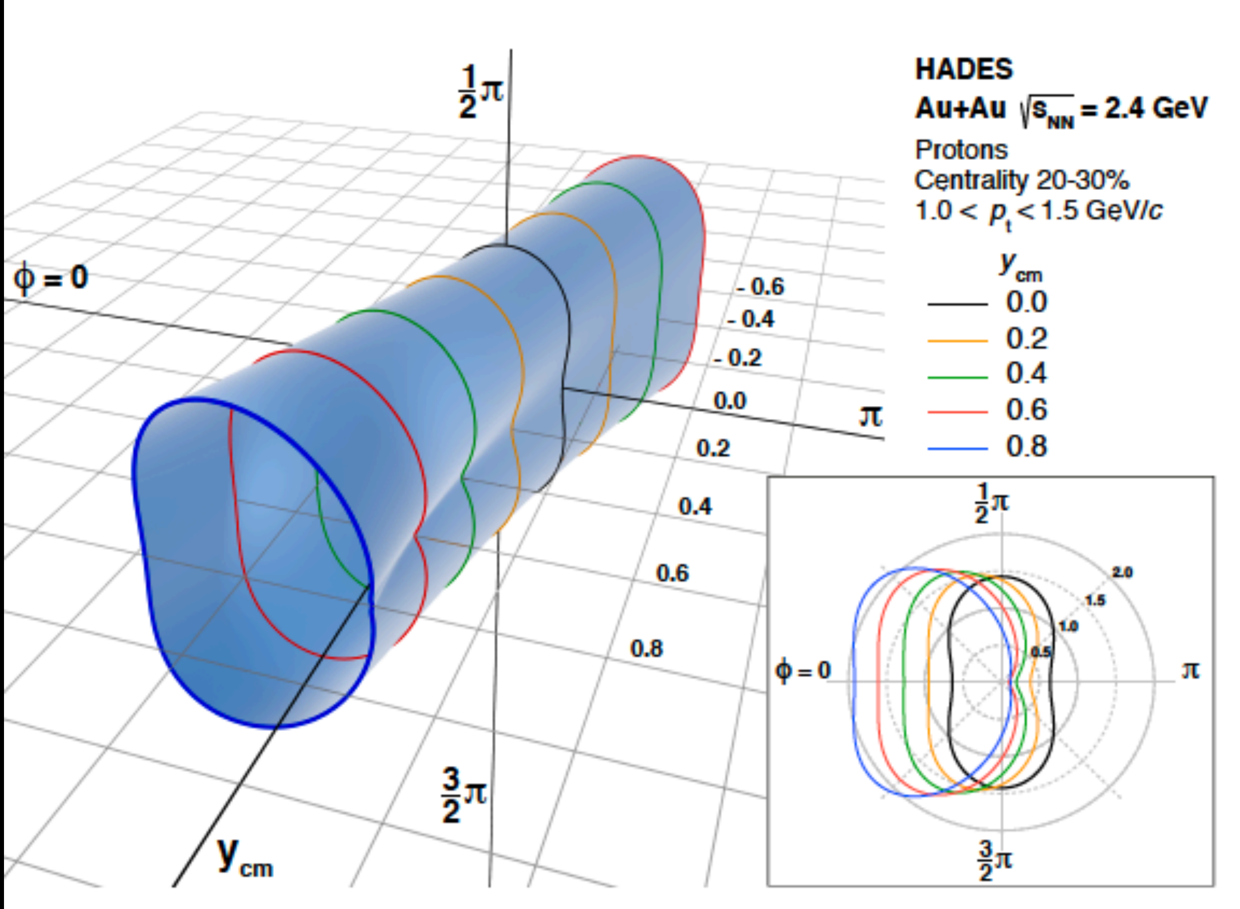


Phys.Rev.Lett. 125 (2020) 262301

Parameterization of y dependence:

$$v_{1,3,5}(y_{cm}) = a y_{cm} + b y_{cm}^3$$
$$v_{2,4,6}(y_{cm}) = c + d y_{cm}^2$$

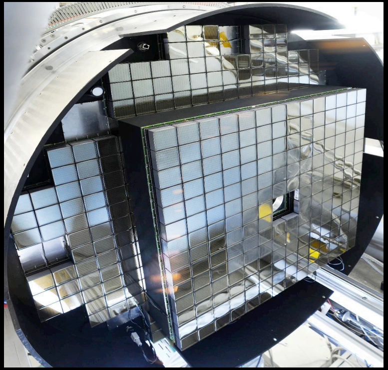
3D Visualization of Particle Flow

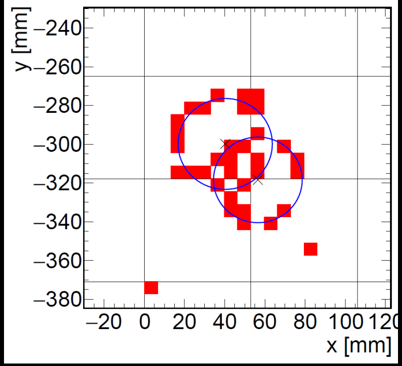


Phys.Rev.Lett. 125 (2020) 262301

FAIR - Phase 0

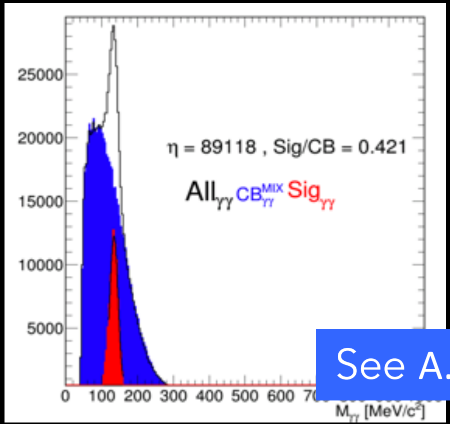
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Virtual Photons





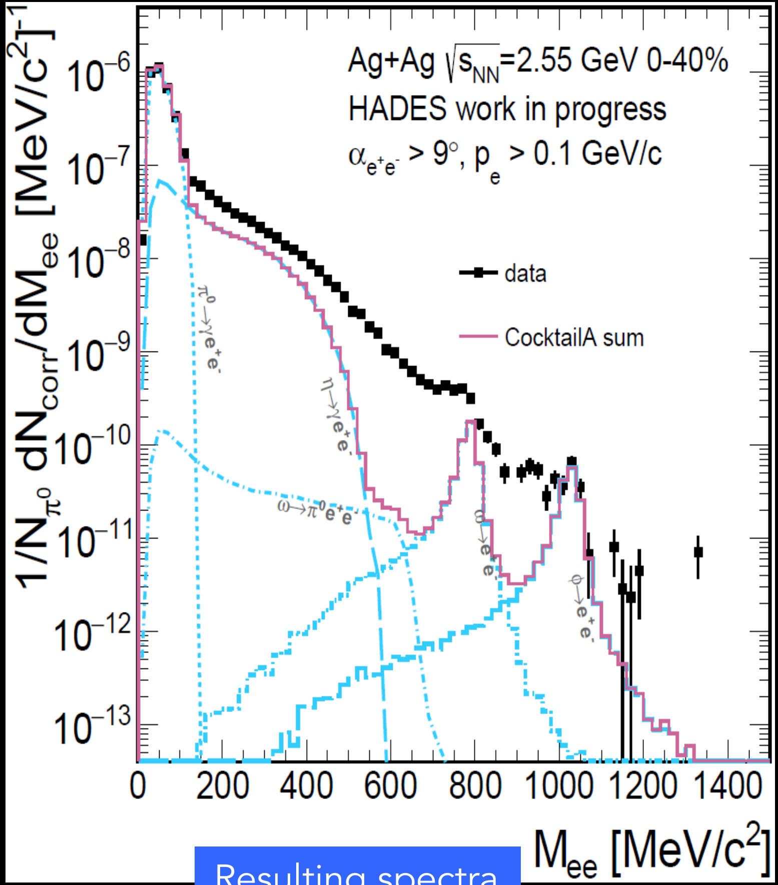
½ of the modules CBM RICH photon detector

Stable operation during 4 weeks of beamtime



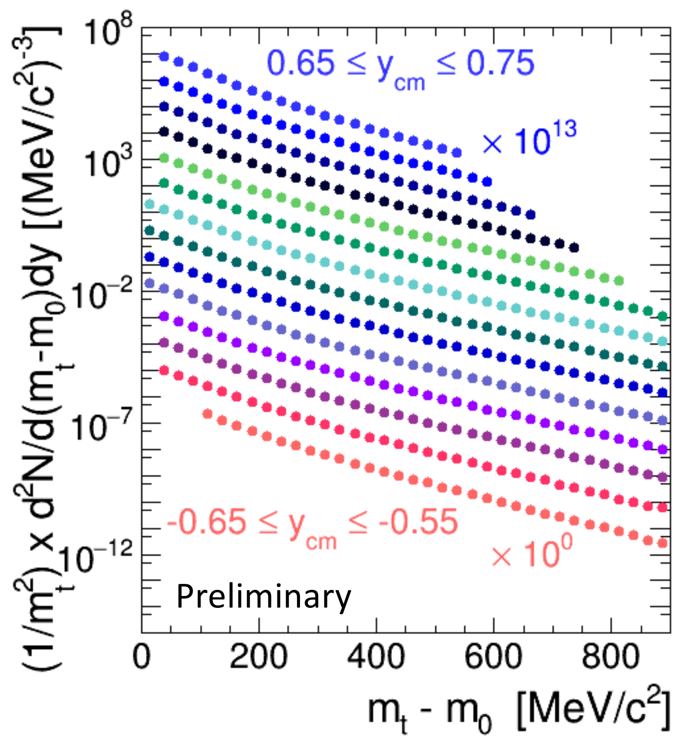
← Supplemented by new ECAL detector

See A. Prozorov 18/05/ 17:15

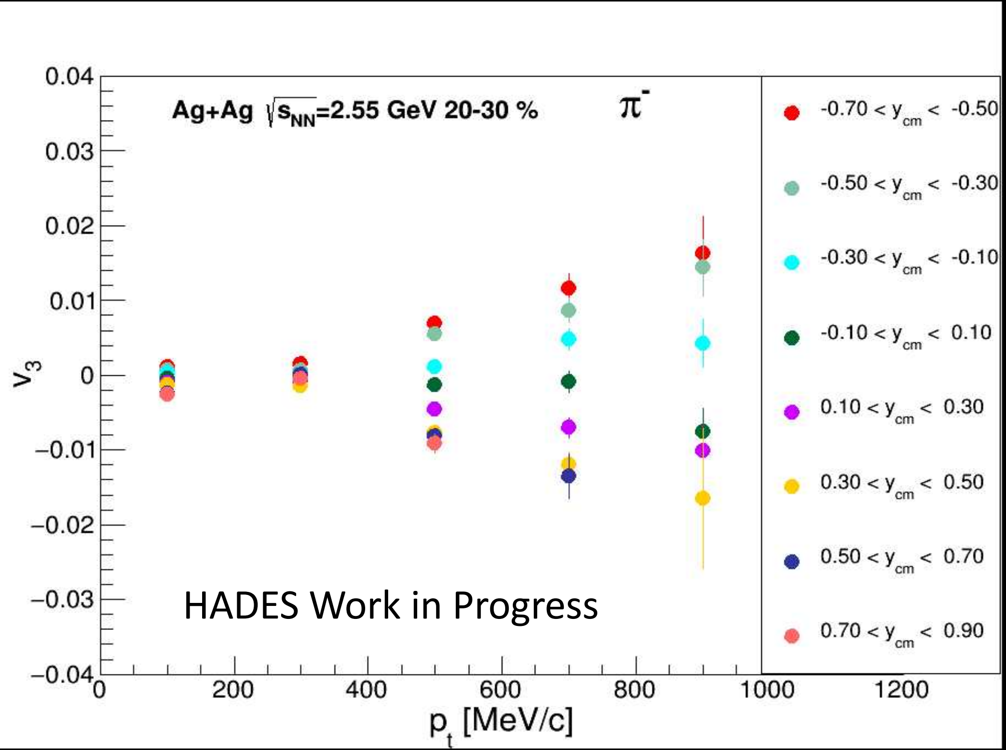


Resulting spectra

Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Charged Pions



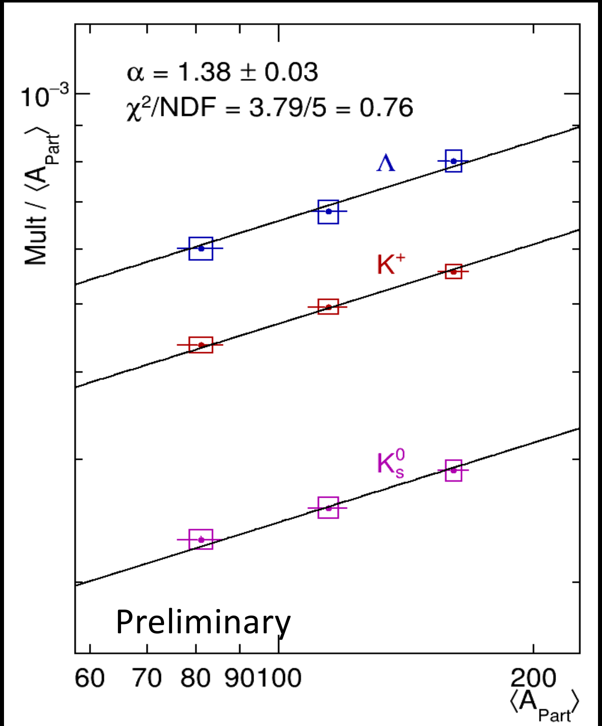
π^- - 0-10% Centrality

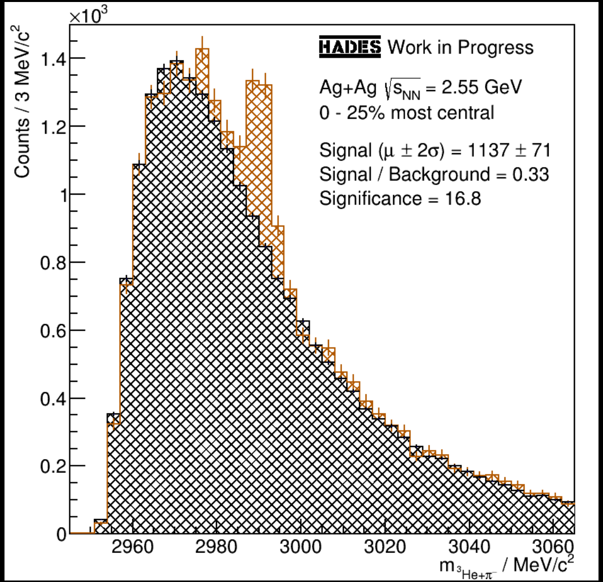


High statistics allow for higher flow coefficients

→ First observation of pion v_3 at this energy

Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Strangeness





First observation $^{3}_{\Lambda}H$ at midrapidity in this energy range

Slightly lower slope α_{Ag+Ag} = 1.38 ± 0.03

Test for universal scaling: K^{-} and **φ**

Summary

Virtual Photons:

p+Nb:
strong difference due to additional **ρ**-like contribution and suppression of **ω**'s for low pair momenta

HIC:
Strong broadening of the **ρ**, exponentially falling spectrum,
→ extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV
Onset of medium radiation in Ar+KCl collisions.

Strangeness:

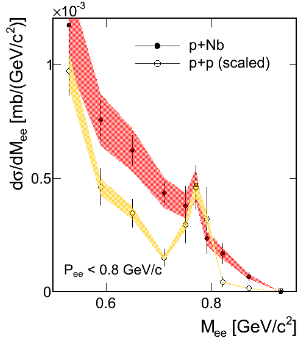
No indication for sequential K^+K^- freeze-out if p_t spectra corrected for feed-down.
Universal $\langle A_{part} \rangle$ dependence of strangeness production.

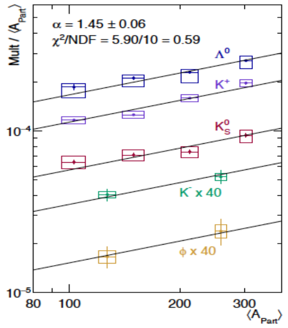
The Bulk:

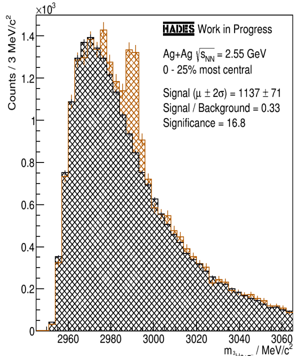
First data on: flow anisotropies up to v_6.

FAIR-Phase0:

High quality data ~~to come~~ are here
A lot to come in the next years.







The Team