Strange Results from HADES and Prospects for Future

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Outline:

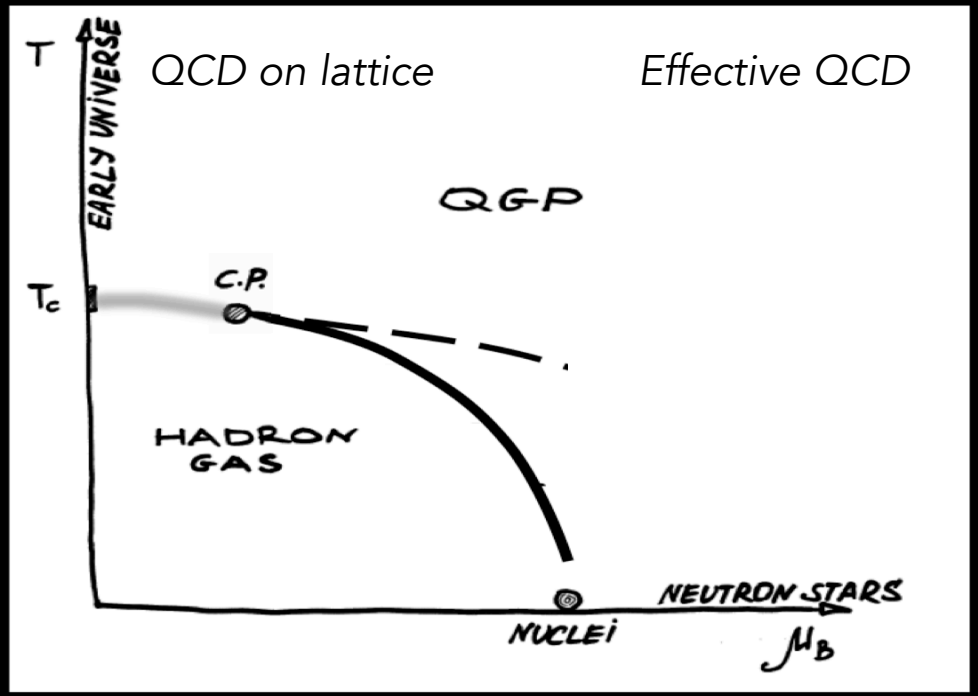
- HADES and the baryon-rich side of the phase diagram
- Virtual photon radiation

  π+p over p+Nb to Au+Au
- Strangeness production

  Au+Au
- FAIR Phase 0 and Phase 1

  Ag+Ag, p+p, π+A

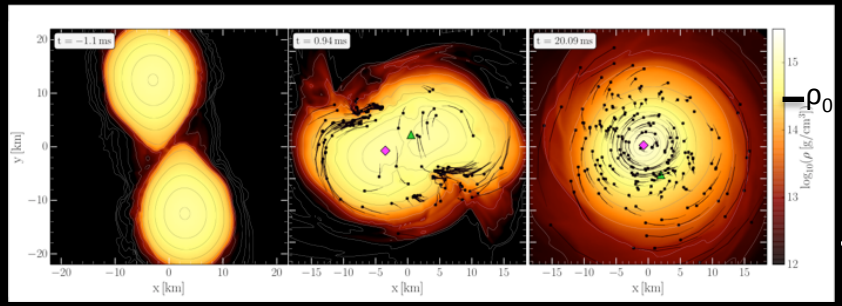
The Baryon-dominated Side of the Phase Diagram



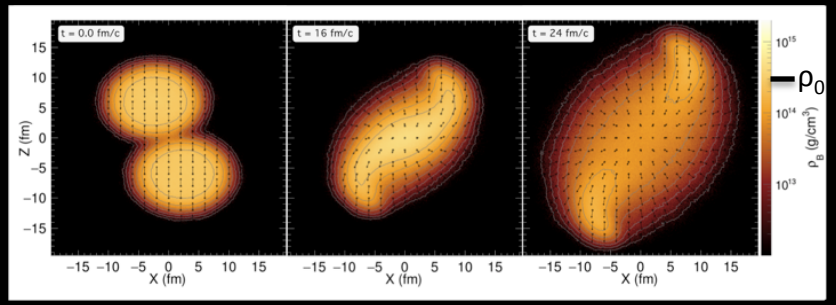
HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
Large stopping → baryon-dominated

Similar conditions as in merging Neutron Stars

Merging Neutron Stars



Central Au+Au $\sqrt{s_{NN}}$=2.4 GeV



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).

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

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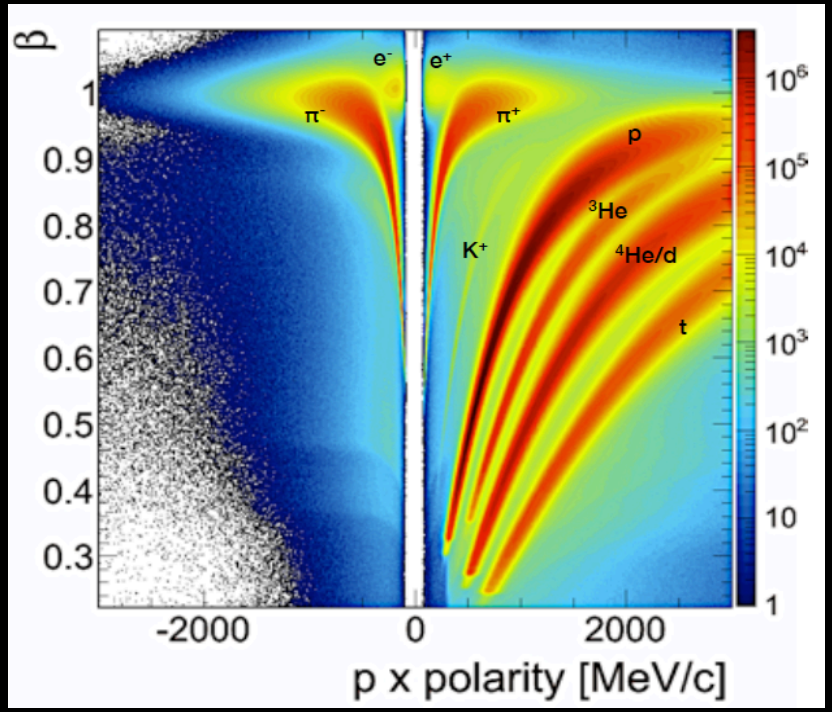
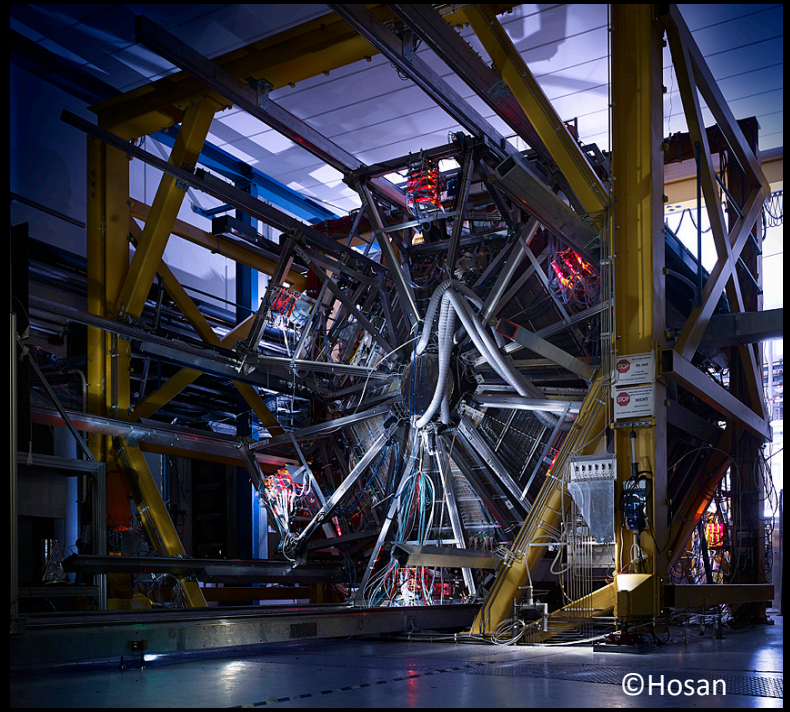


HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
Large stopping → baryon-dominated

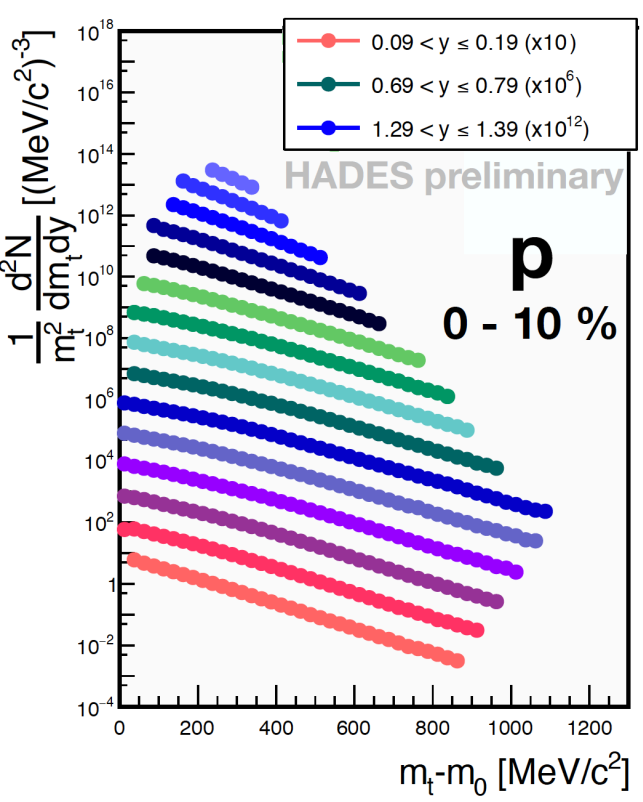
Clear hierarchy in hadron yields:
p ≈ 100, lt. nuclei ≈ 50 π ≈ 10, $K^+ \approx 10^{-2}$, $K^- \approx 10^{-4}$

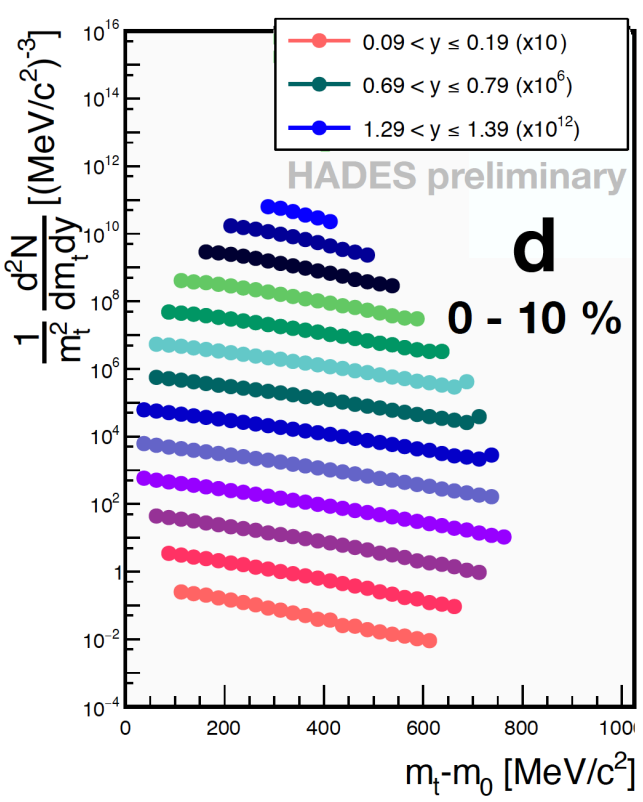


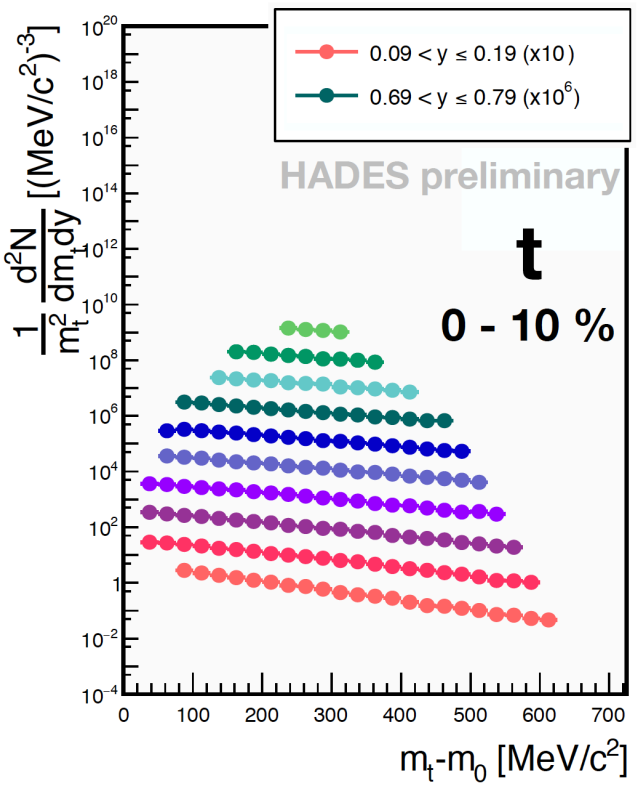
Fast detector: 8 kHz trigger rate (16 kHz Ag+Ag)
Acceptance: Full azimuthal and
polar angle coverage of Θ = 18° – 85°

2.2×10^9 events analyzed

Protons and Light Nuclei (the Bulk)





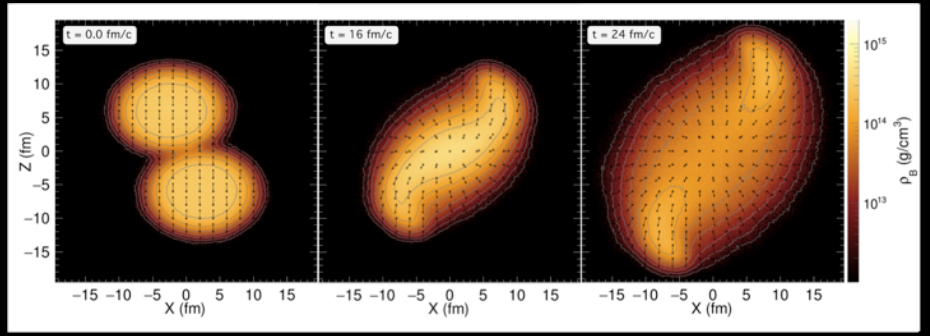


High statistic multi-differential data

Dielectron Radiation

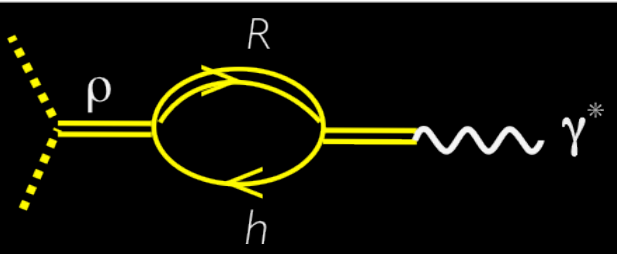
Dielectron Radiation

- Undistorted information

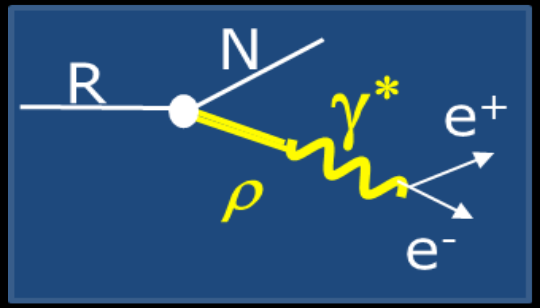


- Radiation from all phases of the collision

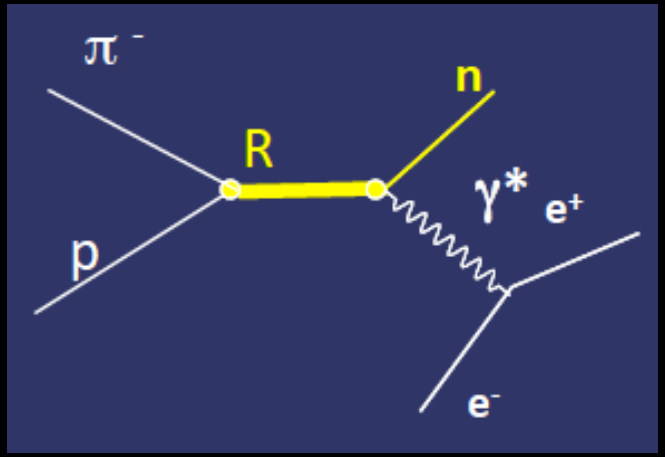
- Vector meson spectral functions modified by coupling to baryons



- Note the similarity to Dalitz decays of baryonic resonances within the Vector Dominance Model (VDM)



π beam experiments with HADES



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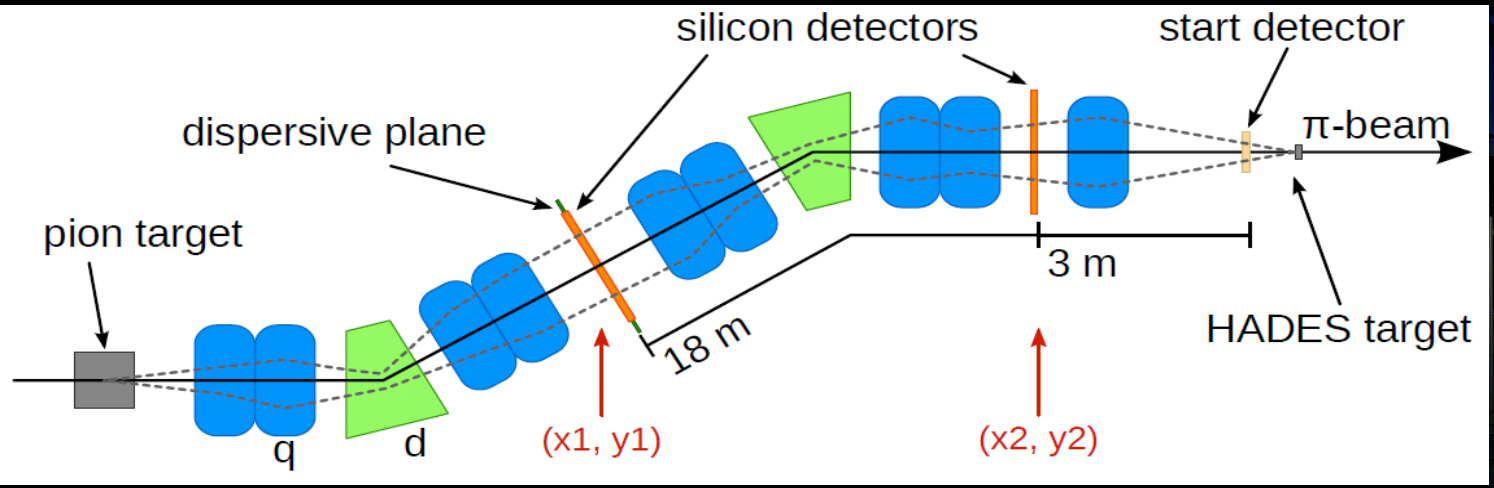
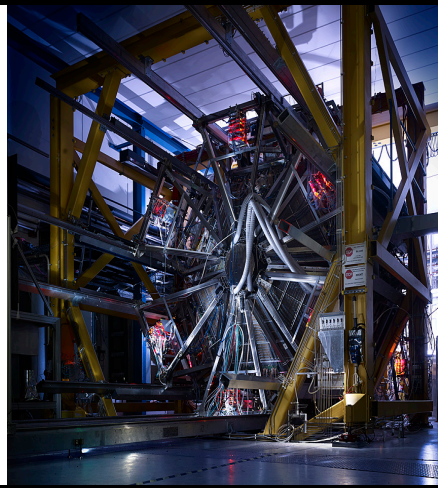




HADES combines a pion beam with dielectron spectrometry, particle identification and secondary vertex reconstruction.

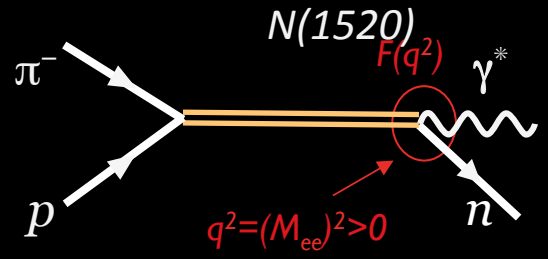
Successful pioneering experiment in 2014 in the N(1520) region.

Unique tool for baryon resonance studies.

ρ-Baryon Coupling Mechanism

π^- beam $\sqrt{s_{\pi N}}$= 1.49 GeV

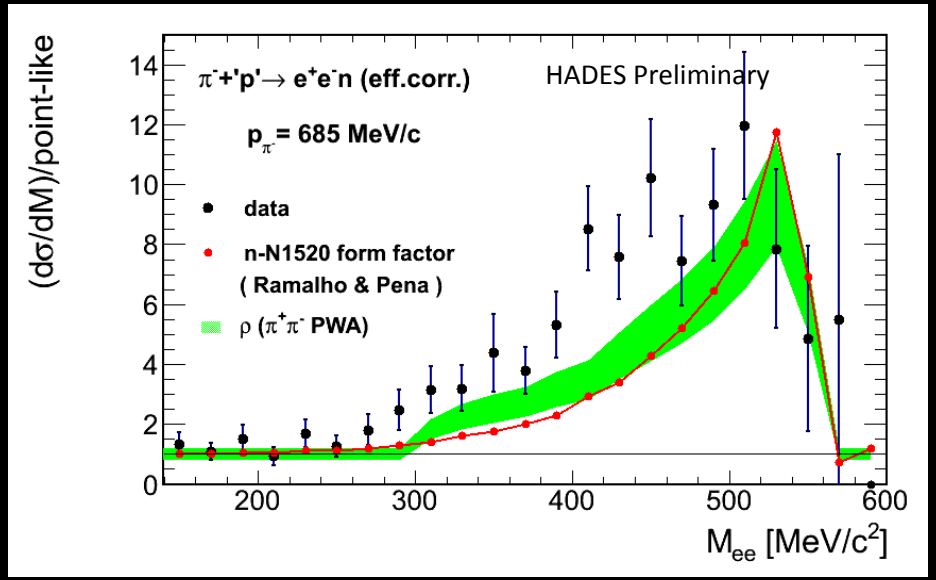
$\pi^-+p \rightarrow \pi^-+\pi^-+n$ (PWA)
$\pi^-+p \rightarrow e^+e^-+n$



Two consistent approaches:

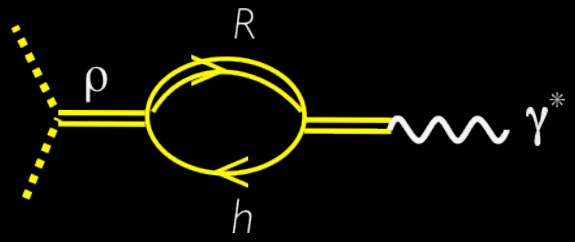
- Vector-Meson dominance
  E. Speranza *et al.*, Phys.Lett. B764 (2017) 282
- Time-like form factor models with dominant meson cloud contribution
  G. Ramalho, T. Pena Phys. Rev. D95 (2017), 014003

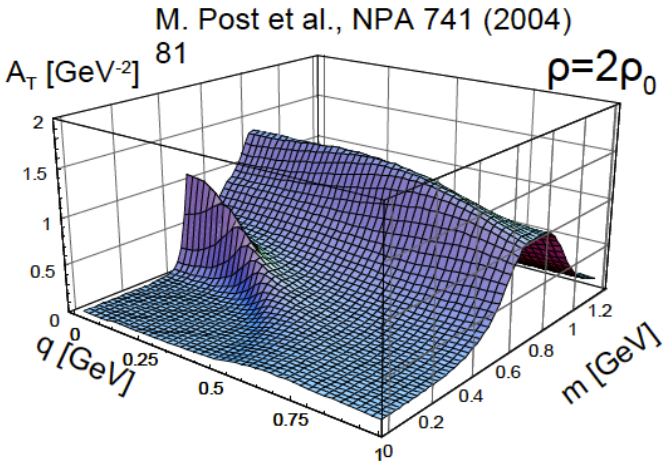
e^+e^- invariant mass distribution ratio to point-like contributions



Invariant mass and angular distributions are consistent with ρ decay and VDM form factor models

Vector-mesons in cold nuclear matter: p+Nb @ 3.5 GeV





Effects restricted to momenta smaller 0.8 GeV
→ ensure acceptance

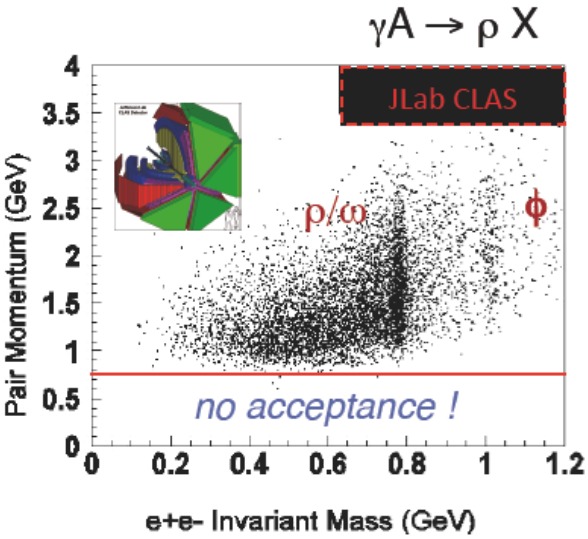
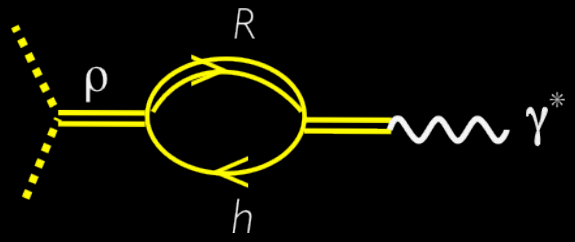
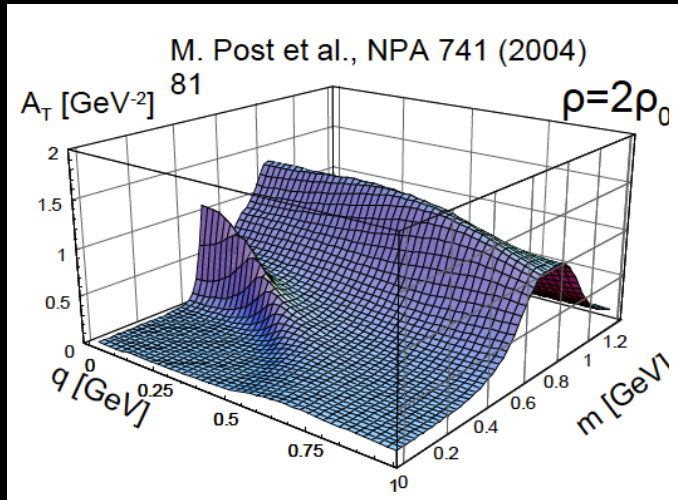


Fig. from S.Leupold et al., nucl-th 0907.2388

Vector-mesons in cold nuclear matter: p+Nb @ 3.5 GeV





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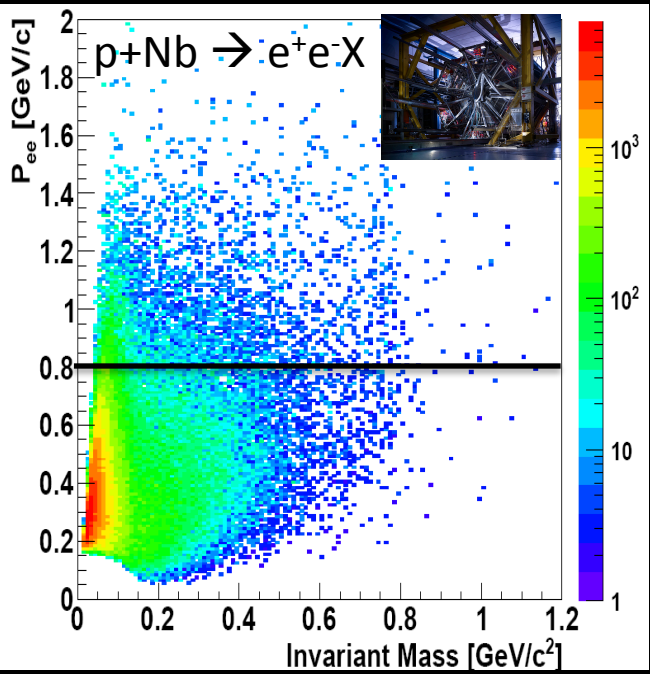

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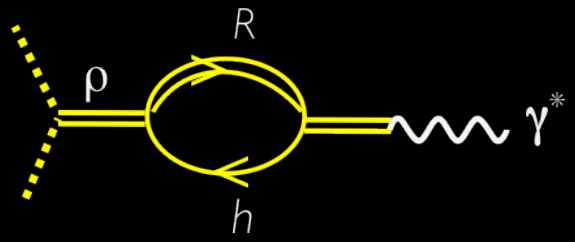
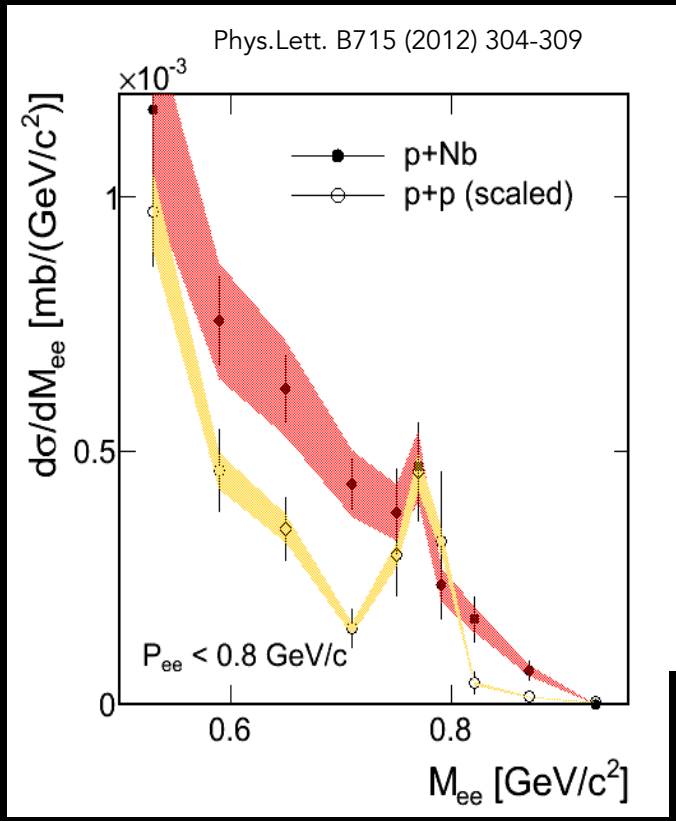
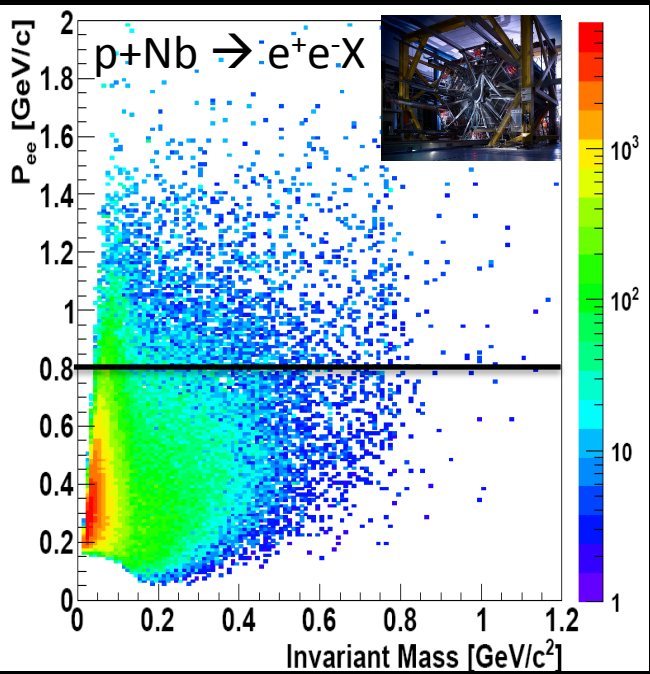
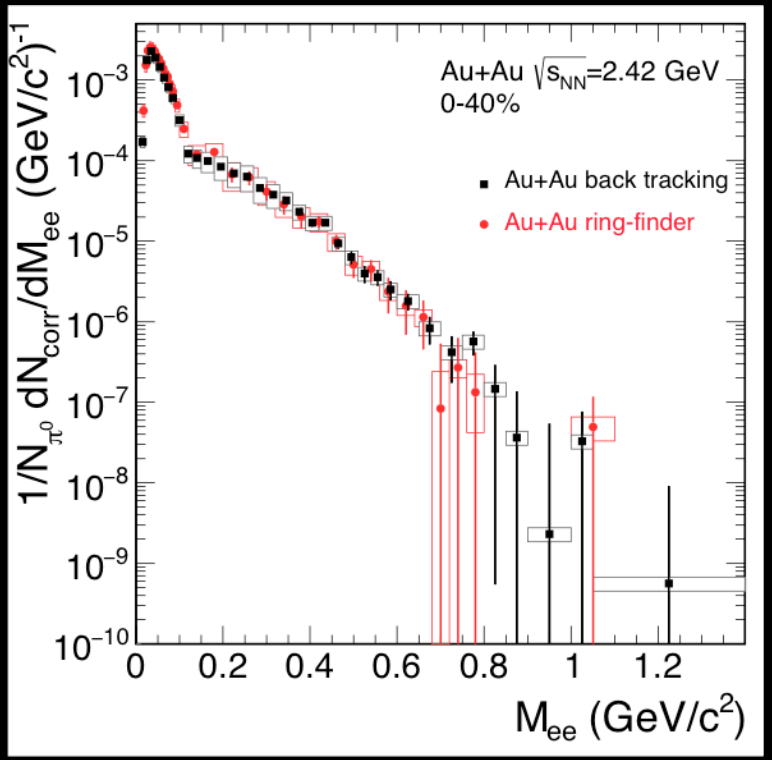






Strong modification of line shape compared to p+p for P_{ee}<0.8 GeV/c.

Dielectron Radiation from Au+Au $\sqrt{s_{NN}}$=2.4 GeV



- First measurement for a heavy system at low $\sqrt{s_{NN}}$.

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

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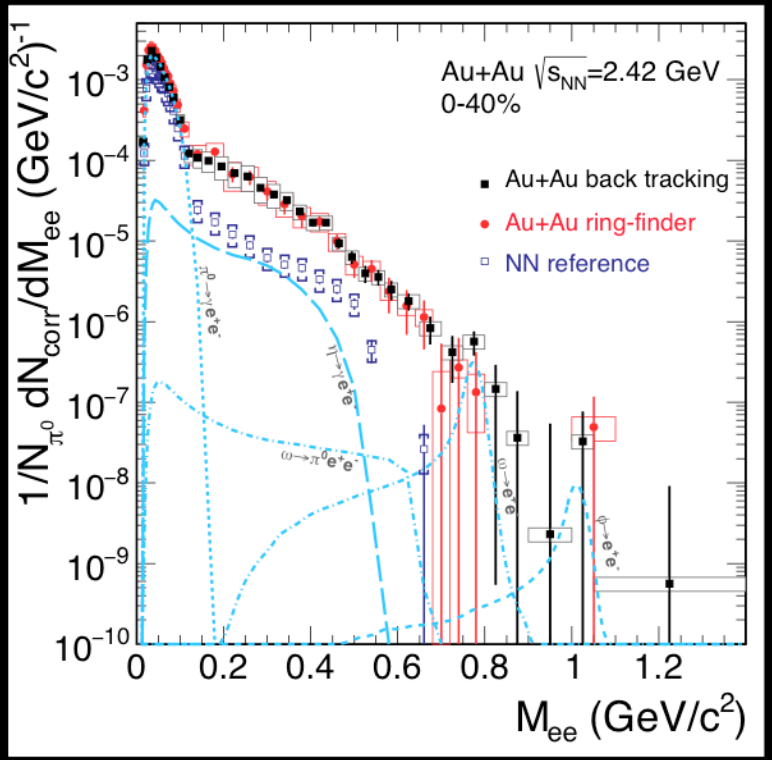

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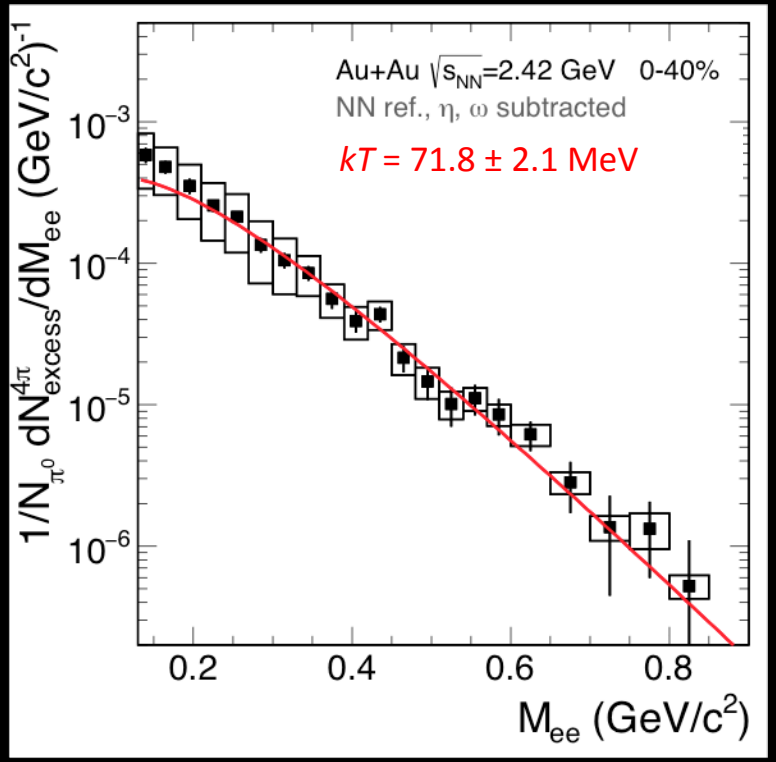
- Strong excess (0.15<M<0.7 GeV/c^2) above components of meson decays at freeze-out and elementary reference.
- Isolation of excess by subtracting the elementary reference.

Dielectron Radiation from Au+Au $\sqrt{s_{NN}}$=2.4 GeV

Acceptance corrected excess yield.



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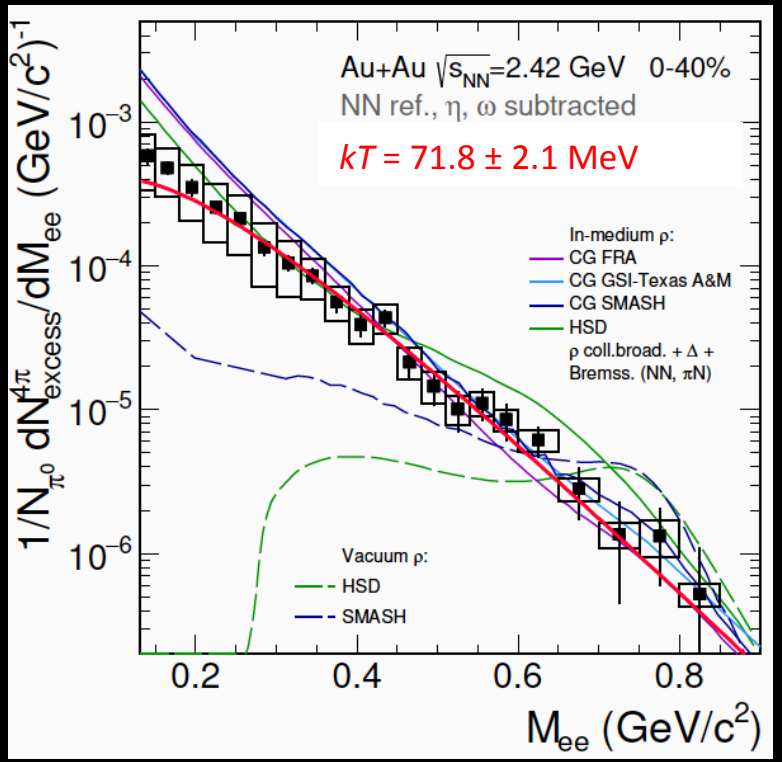

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- Exponentially falling spectrum,
  → extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV
- Thermal rates folded over coarse-grained transport medium evolution works at low energies
- Supports baryon-driven medium effects at SPS, RHIC (LHC)!

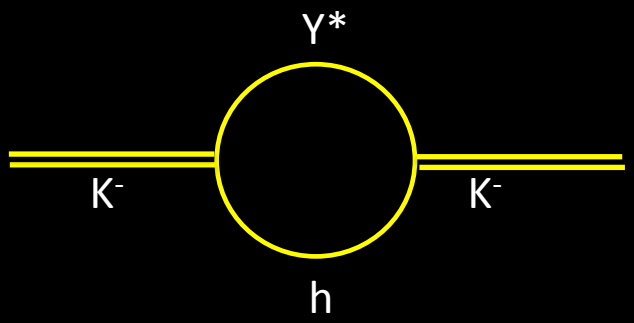
Strangeness

(Sub-Threshold) Strangeness Production

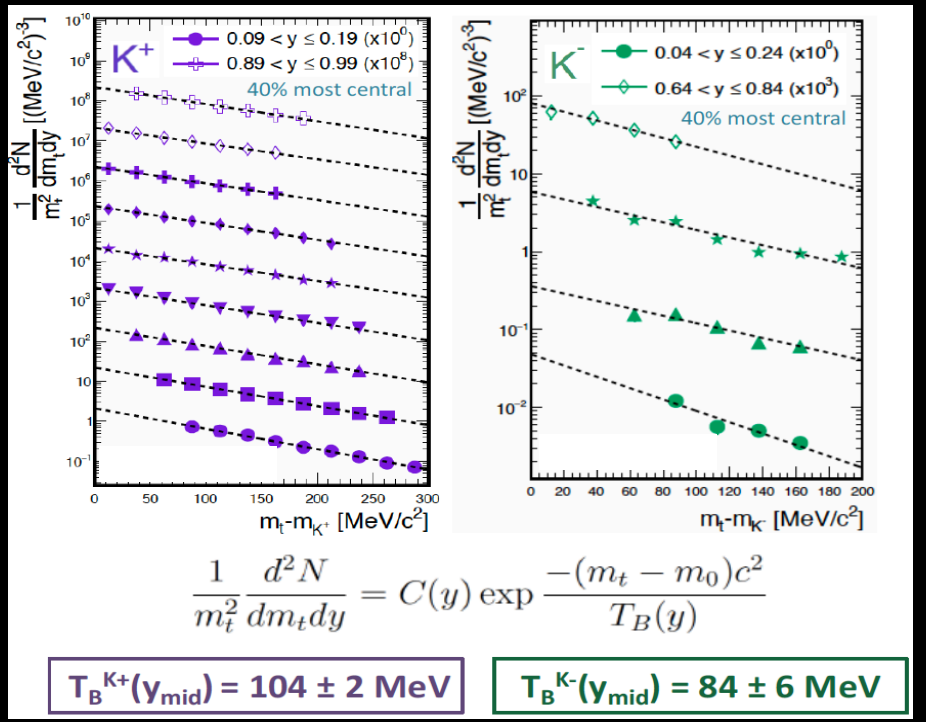
Unique observable:
Not produced in binary NN collisions at $\sqrt{s_{NN}}$= 2.4 GeV (no obvious elementary reference)

NN→NYK$^+$: $\sqrt{s_{NN}}$= 2.55 GeV,
NN→NNK$^+$K$^-$: $\sqrt{s_{NN}}$= 2.86 GeV
(strong K$^-$ suppression).

Energy must be provided from the system.



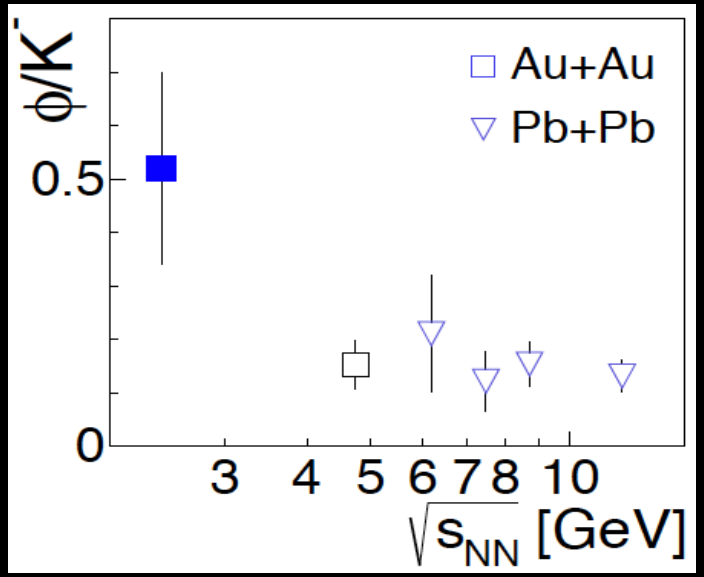
Coupling of K$^-$ to baryons
and strangeness exchange reactions
e.g. πY→NK$^-$.



Kaons and antikaons show different slopes.

Phys.Lett. B778 (2018) 403-407

Φ-AntiKaon Interplay in HIC



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

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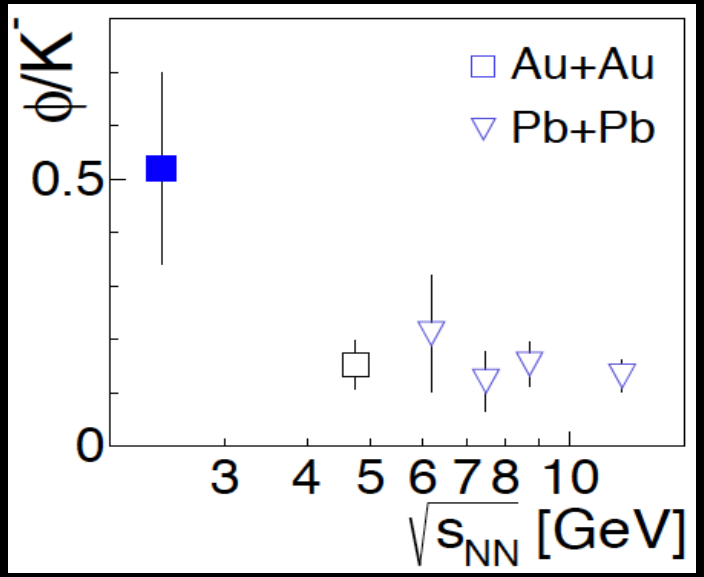

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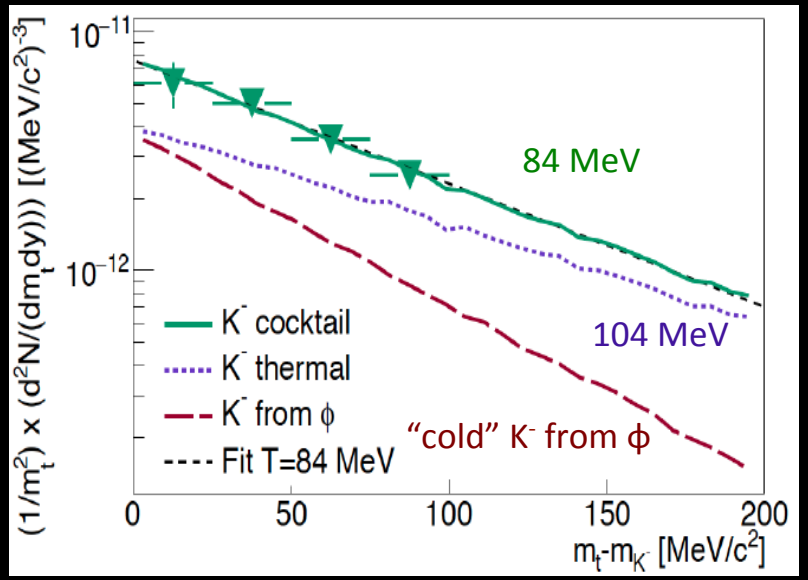

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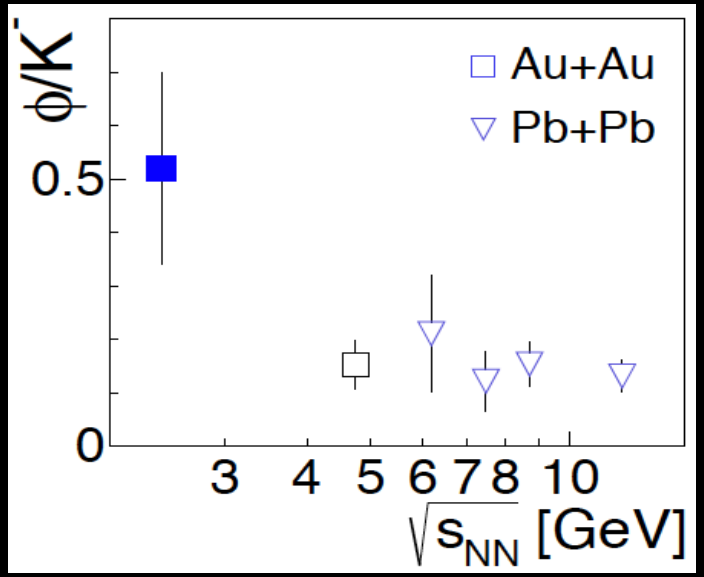

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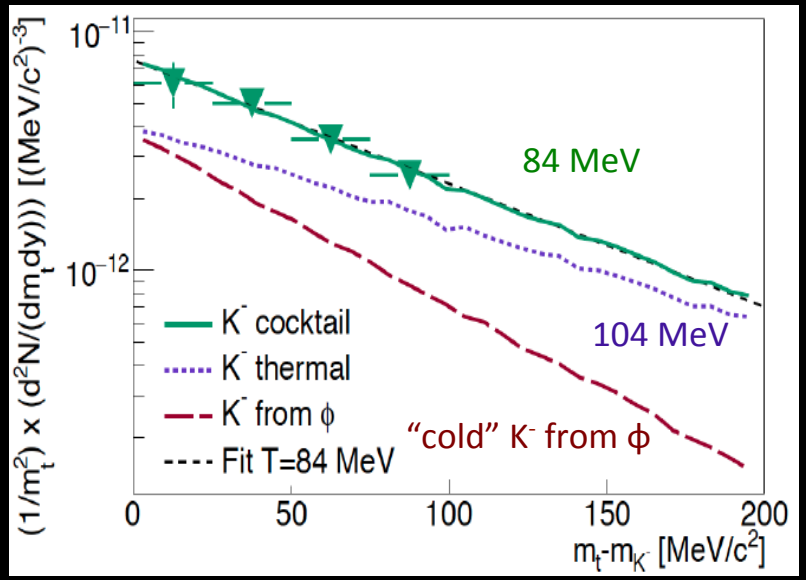

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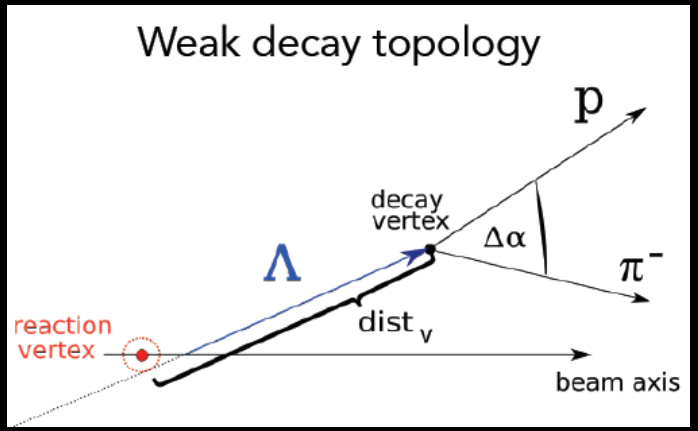
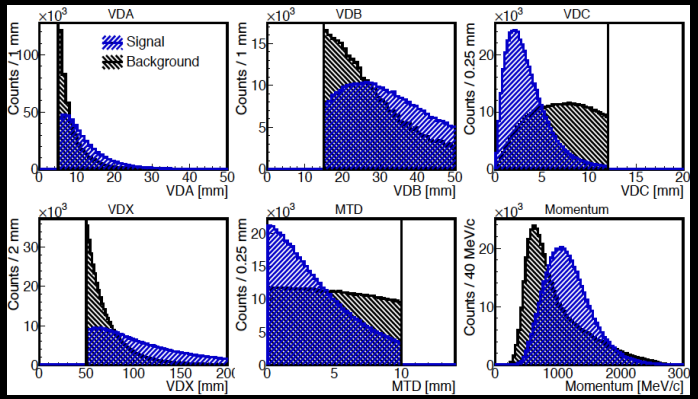
→ No indication from K^- spectrum for sequential K^+K^- freeze-out if corrected for feed-down.

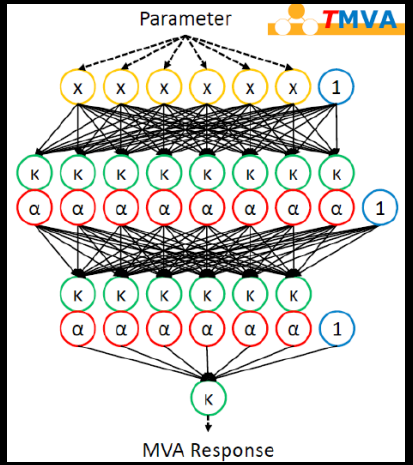
Weak decay topology recognition with neural networks



Results in several parameters



Which can be fed into an ANN



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

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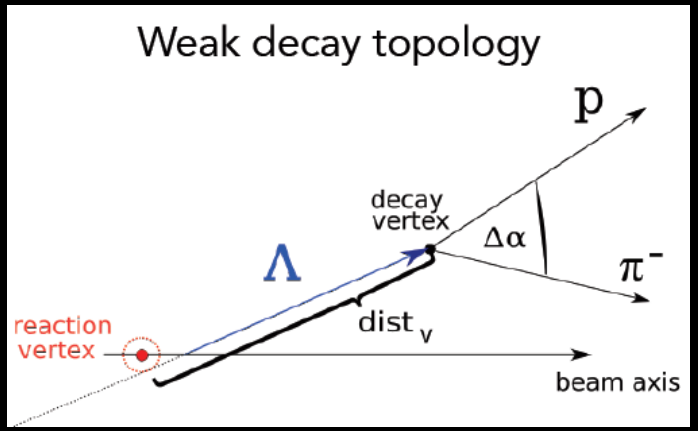

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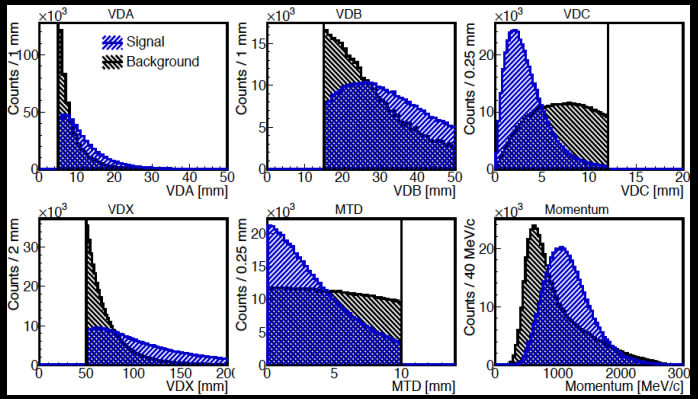

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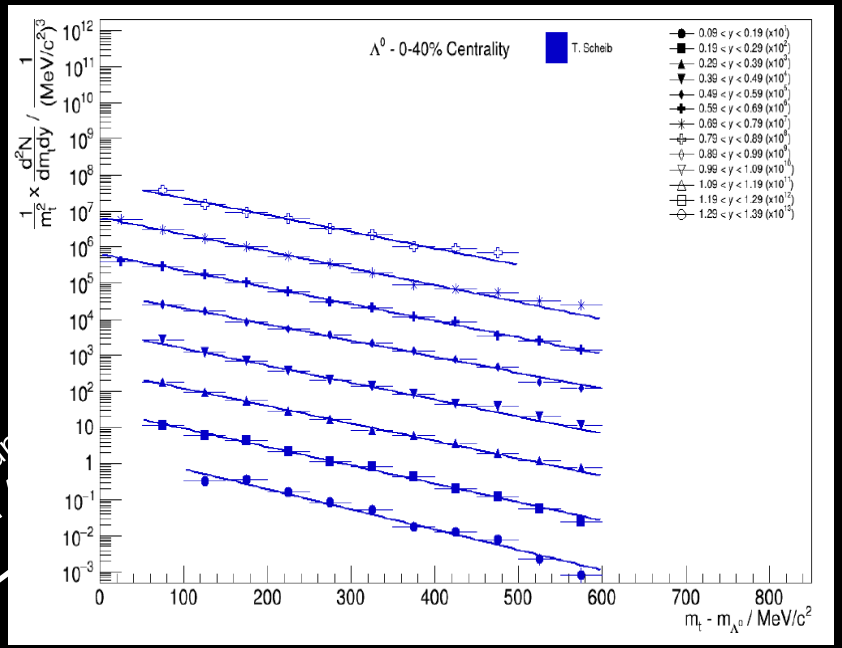

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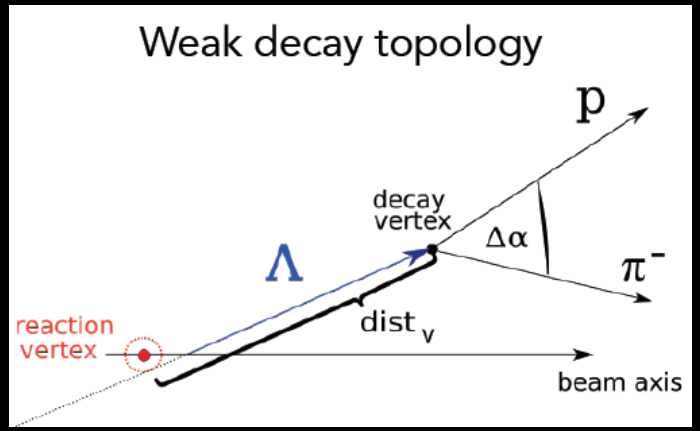

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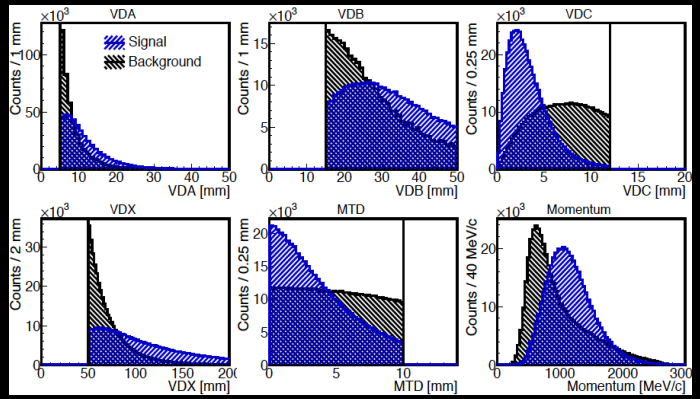

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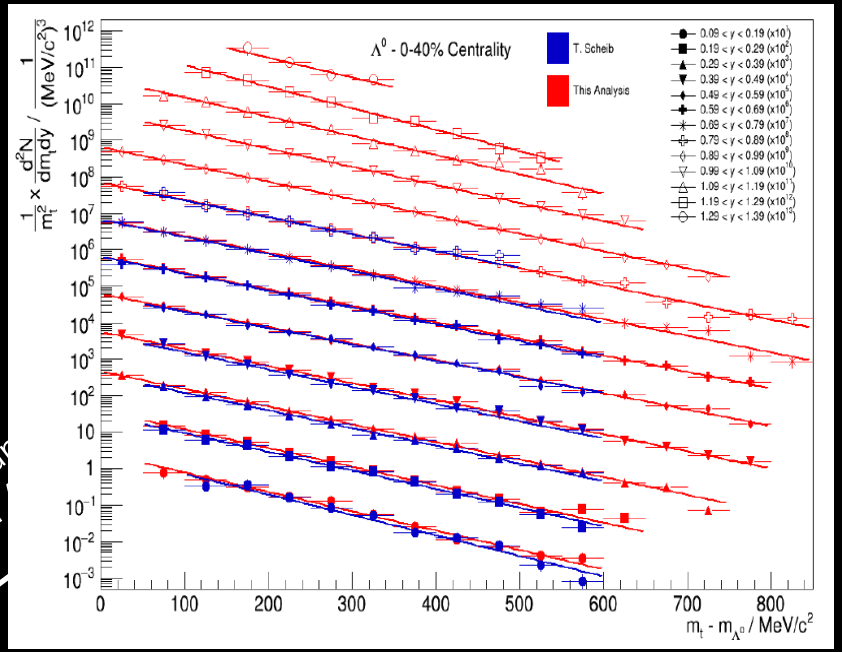

ANN in combination with pre-selection on topology parameters improves performance → reduction of uncertainty for 4π yield extraction.

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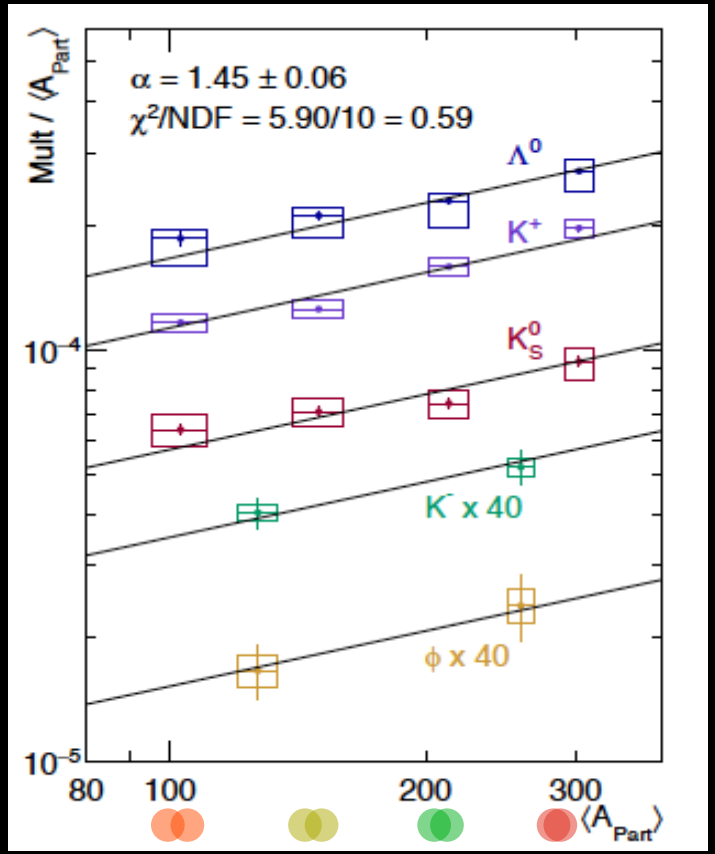
Strangeness in Au+Au @ $\sqrt{s_{NN}}$= 2.4 GeV

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



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→ unique observable:

Energy must be provided from the system.

Strange particle yields rise stronger than linear with

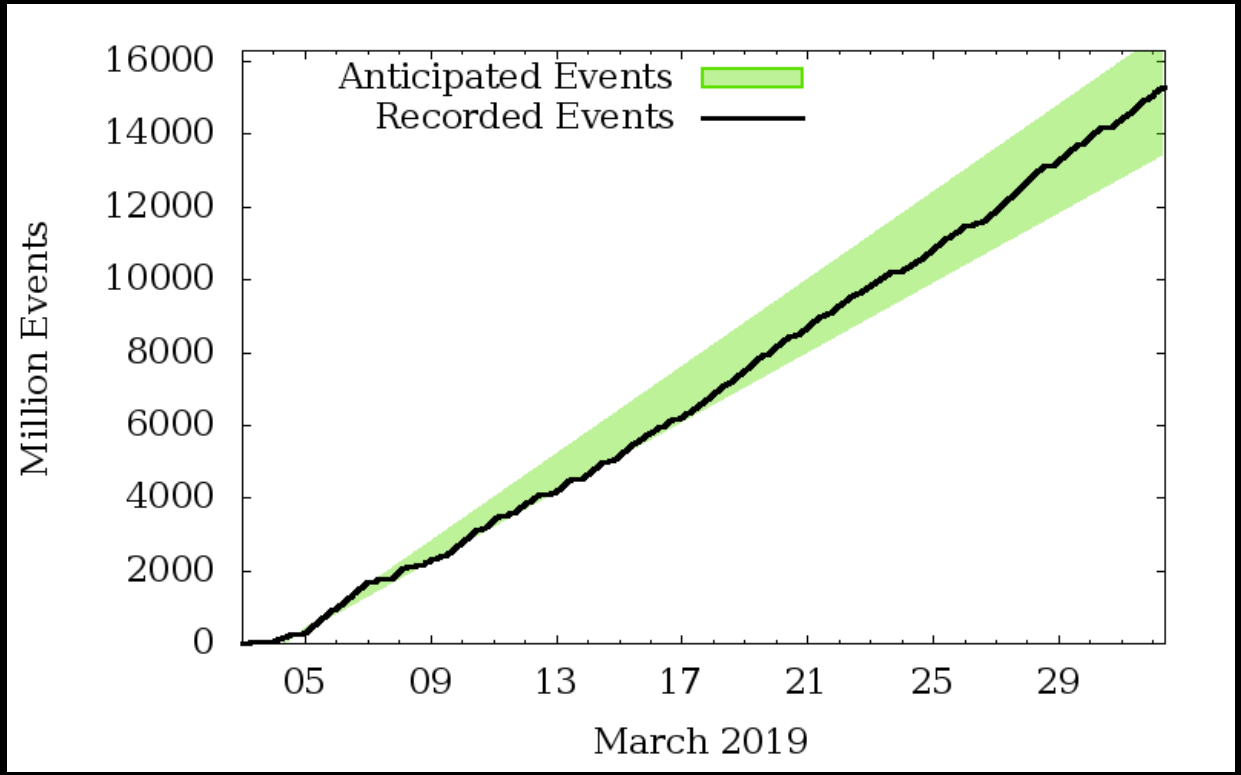
$\langle A_{part} \rangle$ ($M \sim \langle A_{part} \rangle^{\alpha}$)

Universal $\langle A_{part} \rangle$ dependence of strangeness production

→ Hierarchy in production threshold not reflected

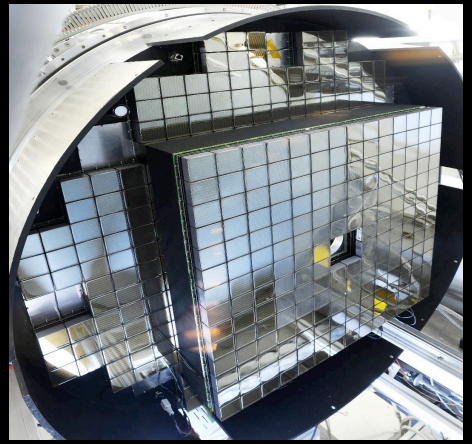
FAIR-Phase 0

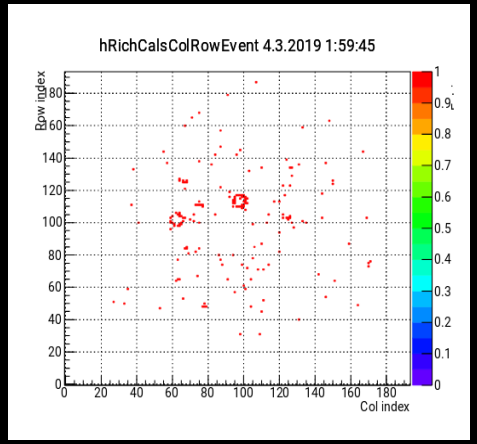
Ag+Ag $\sqrt{s_{NN}}$= 2.6 (2.4) GeV



~ 15 billion events collected during March 2019

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

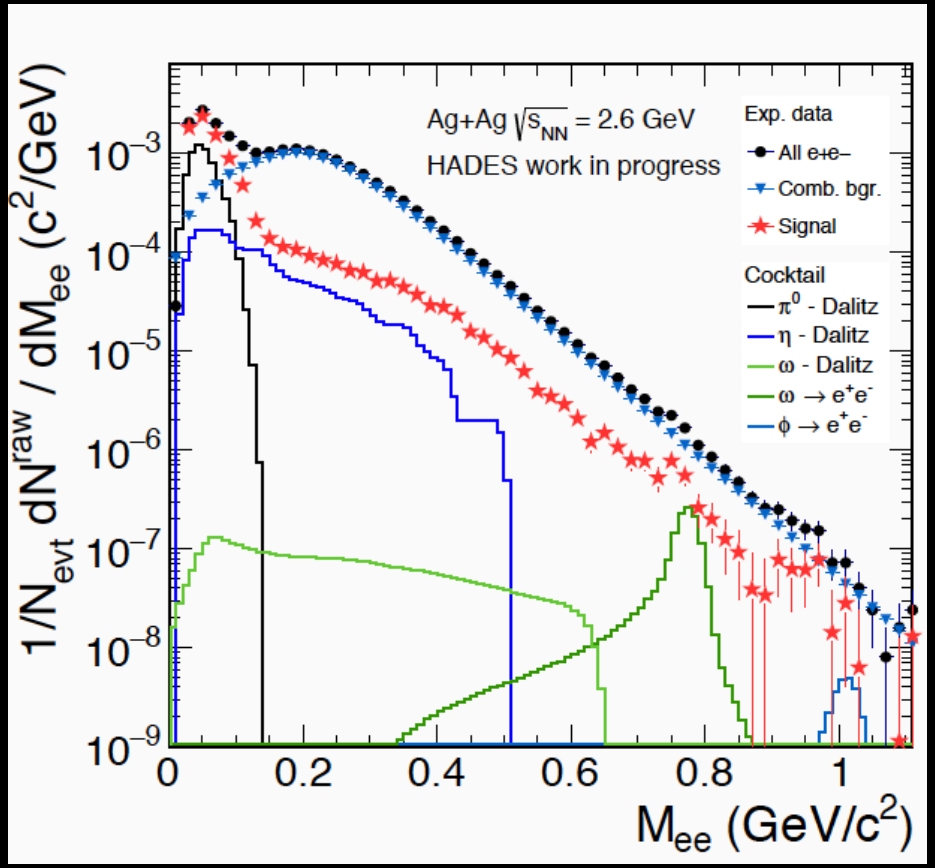




½ of the CBM RICH photon detector

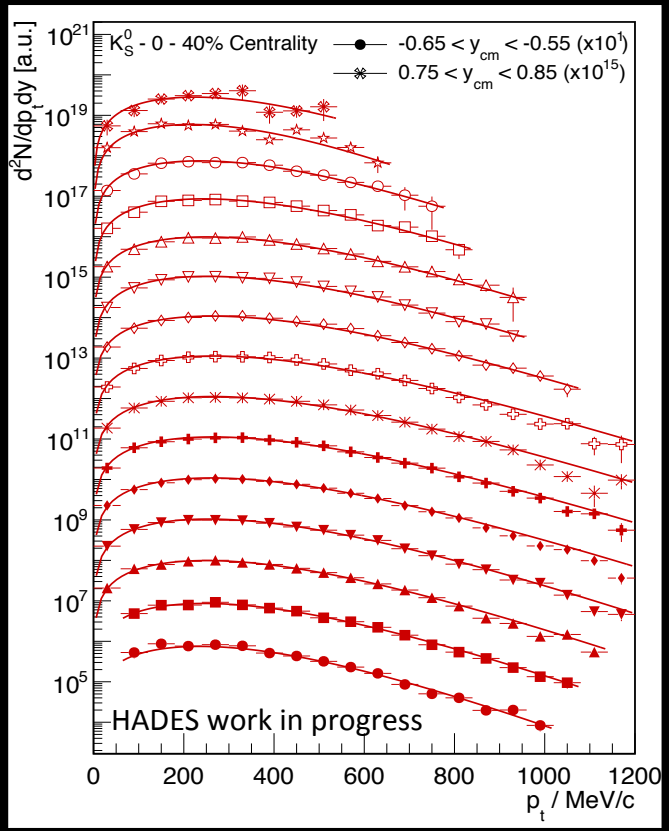
Stable operation during 4 weeks of beamtime

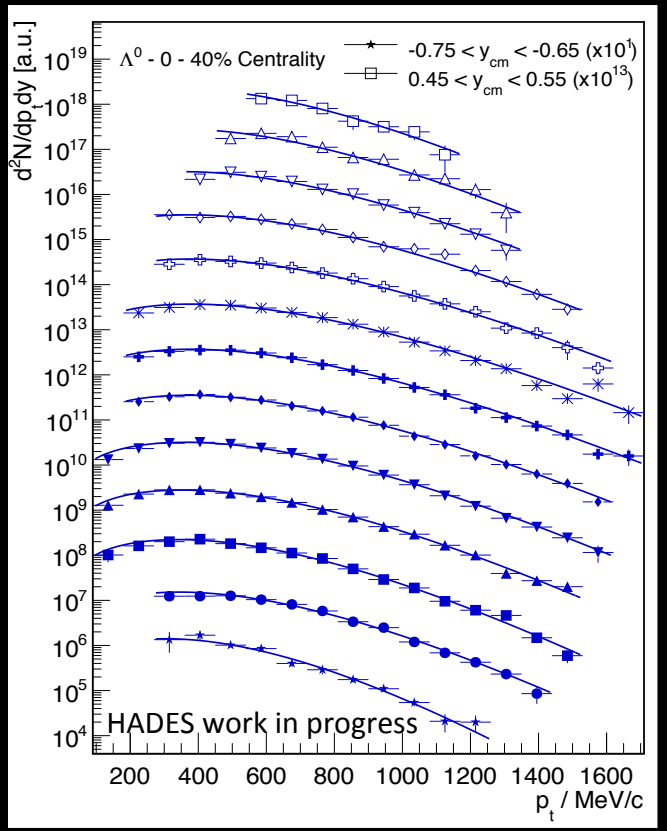
Resulting spectrum →

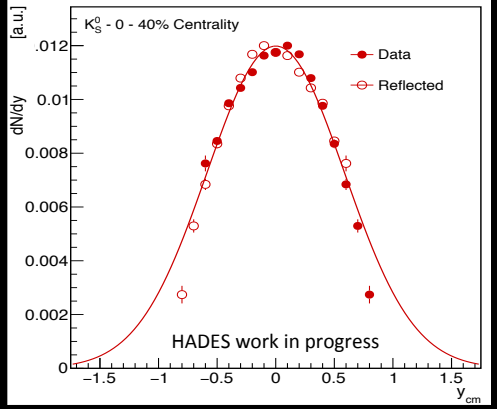


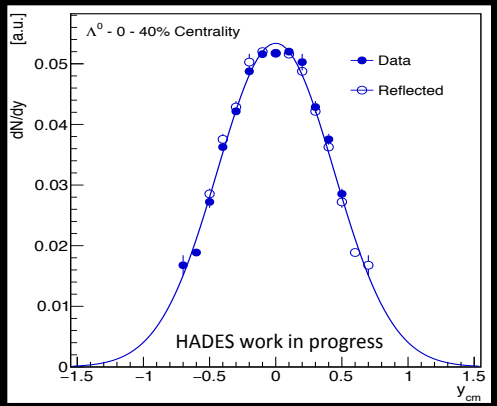
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Strangeness

K^0_s and Λ production at the NN-threshold









The Future I: p+p @ 4 GeV Hyperon EM coupling

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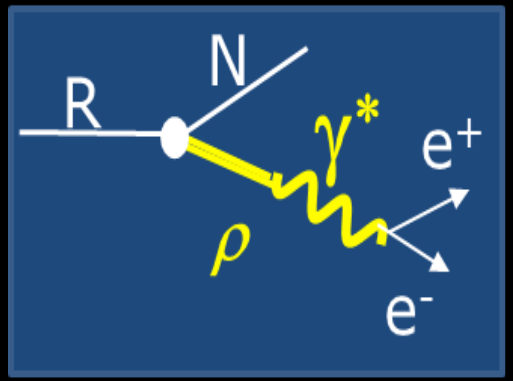
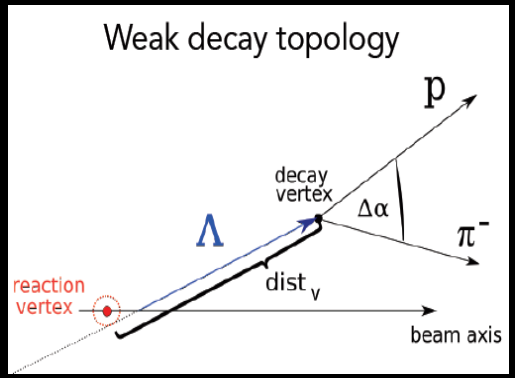
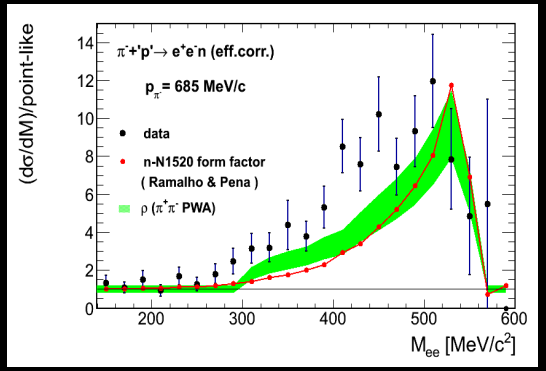
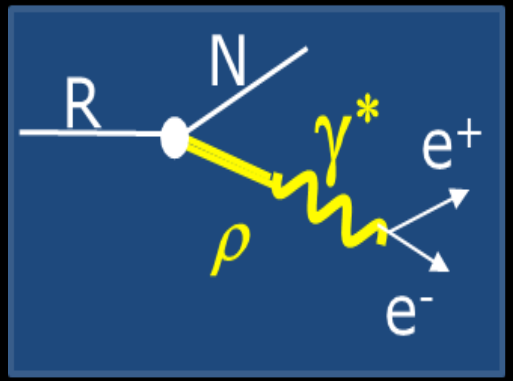


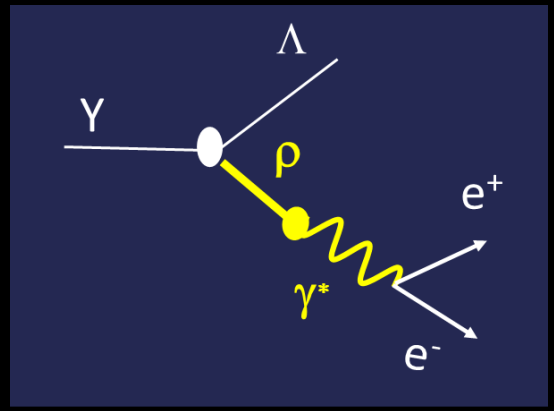


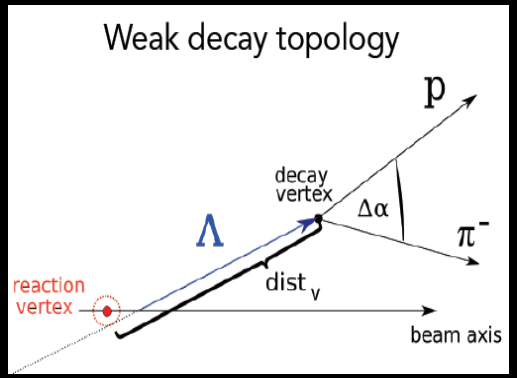


e^+e^- : time-like baryon transitions
+ secondary vertex for weak decays:

The Future I: p+p @ 4 GeV Hyperon EM coupling



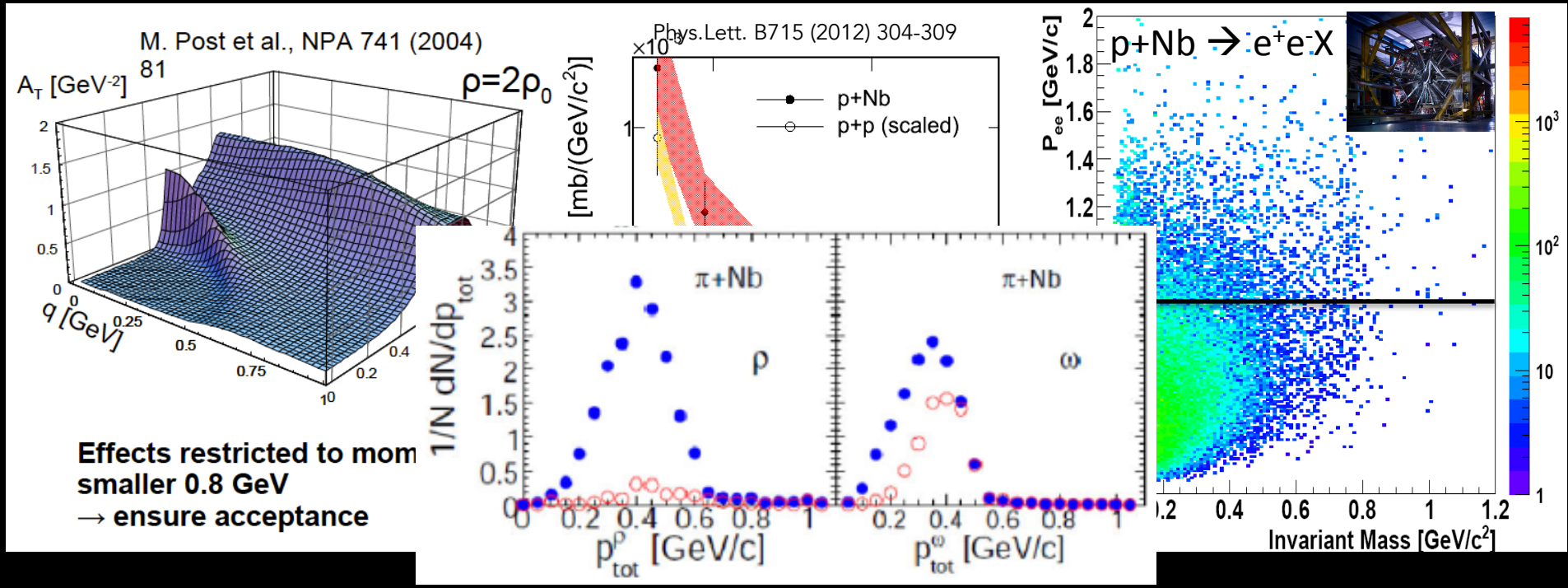




e^+e^- : time-like baryon transitions
+ secondary vertex for weak decays:

hyperon transitions (terra incognita)

The Future II: π+A in medium VM

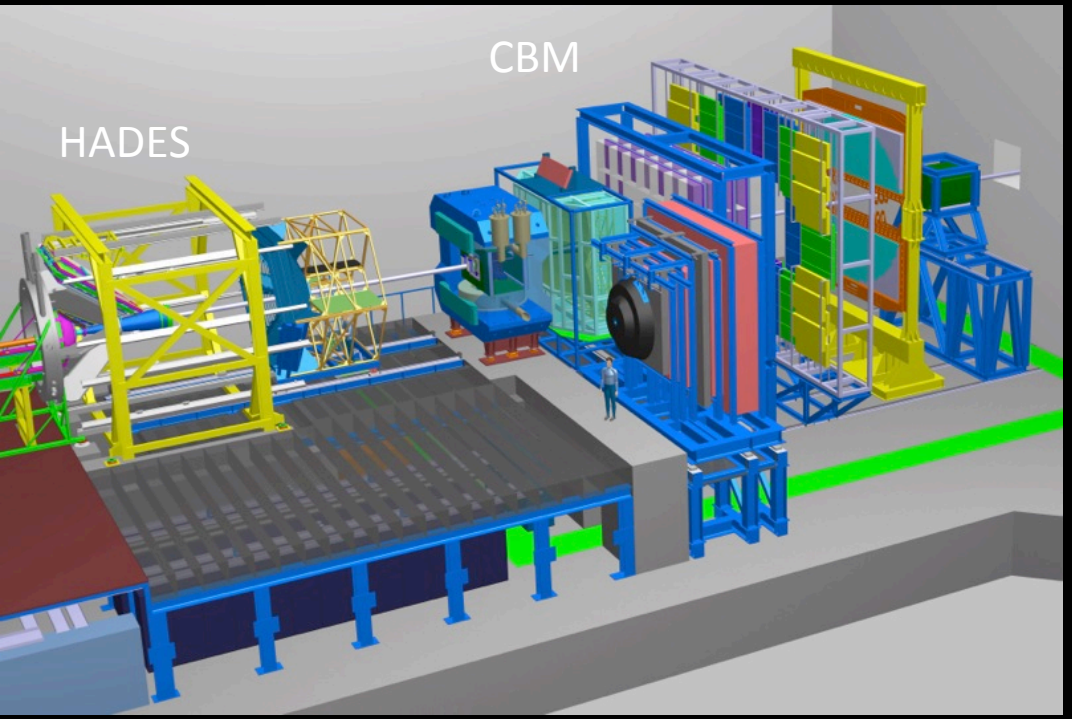


π-induced reactions:
Low momenta vector mesons

Towards FAIR Phase I

Towards FAIR Phase I

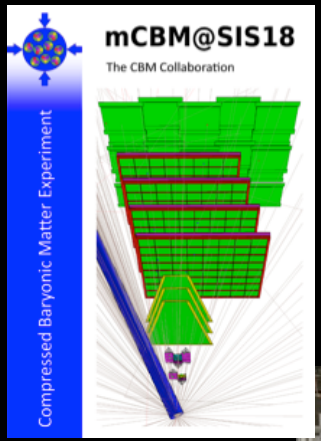
CBM Setup



- Fixed target experiments
  → obtain highest luminosities
- Free-streaming FEE
  → nearly dead-time free data taking
- Tracking based entirely on silicon
  → fast and precise track reconstruction
  → 4D Tracking
- On-line event selection
  → high-selective data reduction

Day-1setup: R_{int} = 0.5 MHz (0.1 MHz with MVD)
Phase-1 setup: Day-1+ECAL+Compute Performance → R_{int} = 10 MHz

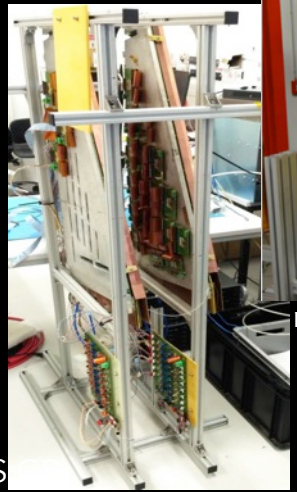
mCBM at SIS18 FAIR Phase 0



Demonstrator for full CBMdata taking and analysis chain under full load (Au-Au, 10^7 interactions/s)

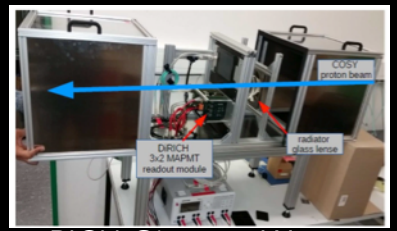
$mMVD_{2020}$ Frankfurt

mSTS



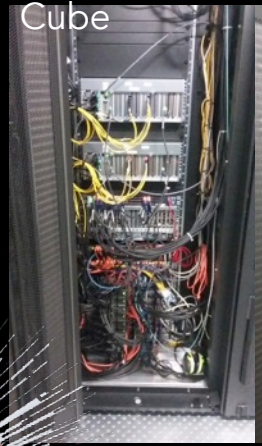
mMUCH VECC

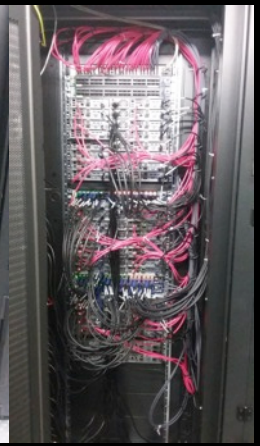
mTRD Münster, Frankfurt



mRICH Giessen, Wuppertal

mFLES racks @ Green IT Cube





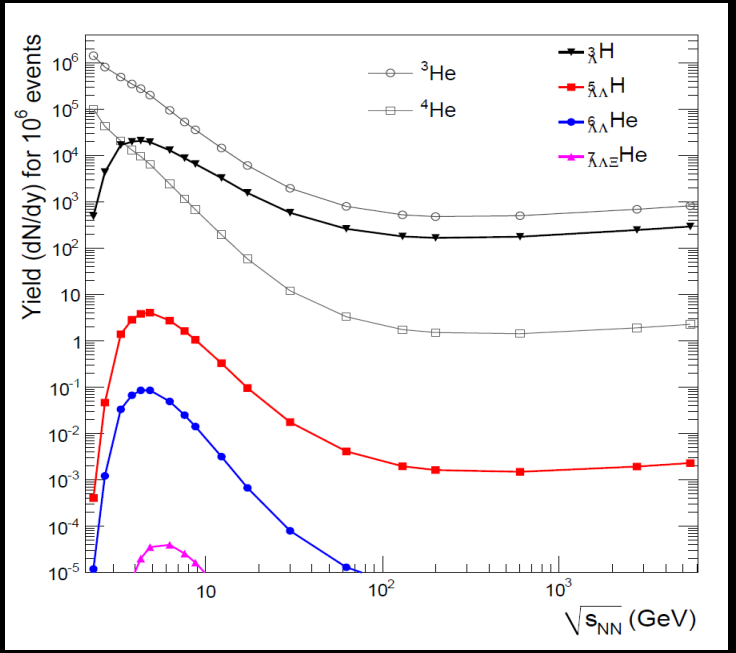
mCBM will focus on:

- Free streaming data transport to a computer farm
- Online reconstruction and event selection
- Offline data analysis

First beam time in 2019

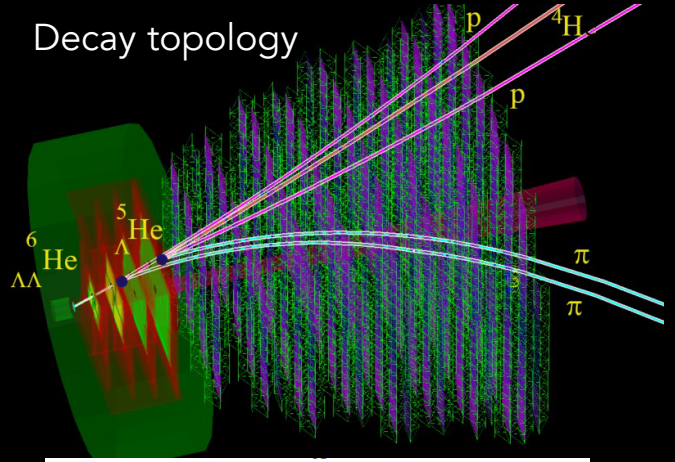
Hypernuclei at CBM: ΛΛ – hypernuclei

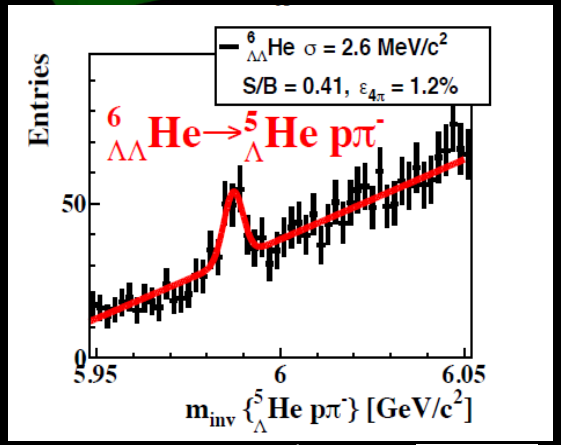
Thermal model prediction for Au+Au



A. Andronic, et al., Phys. Lett. B697 (2011) 203

Decay topology





^{4}He pπ$^-$

Runtime estimate at peak interaction rate of 10 MHz

Signal counts per week:

$S_w = R_{peak} * f_{av} * e_{duty} * P_{prod} * f_{mb/cen} * BR * e_{reco} * DT$

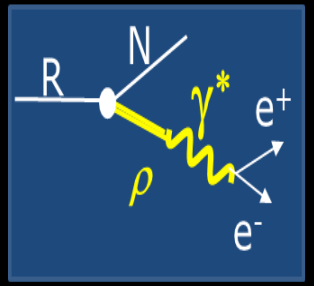
$= 10^7 * 0.5 * 0.7 * 10^{-7} * 0.25 * 0.1 * 0.012 * 6\ 10^5$

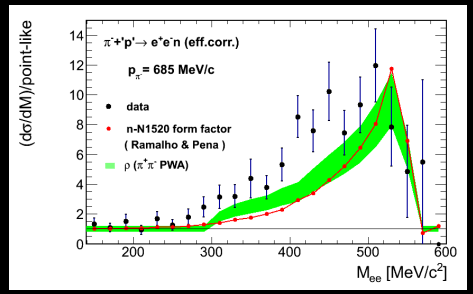
$= 60$

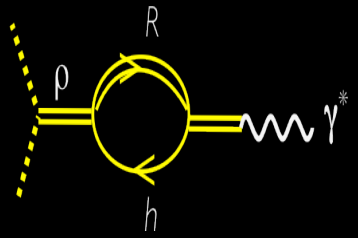
Summary

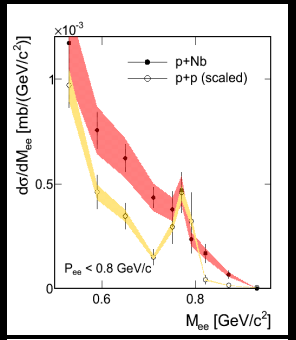
Dielectron Radiation:

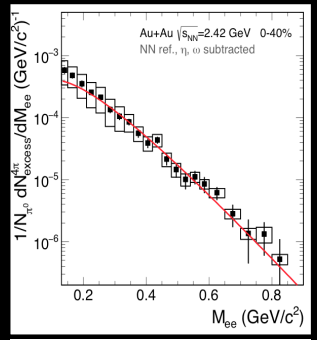
Consistent picture emerging from π+p over p+A to A+A

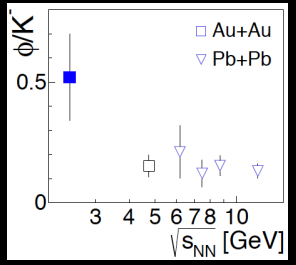


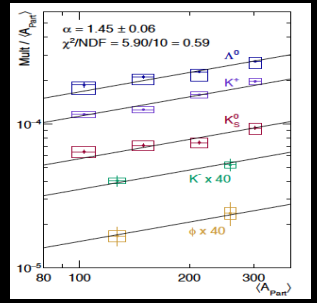












Strangeness:

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

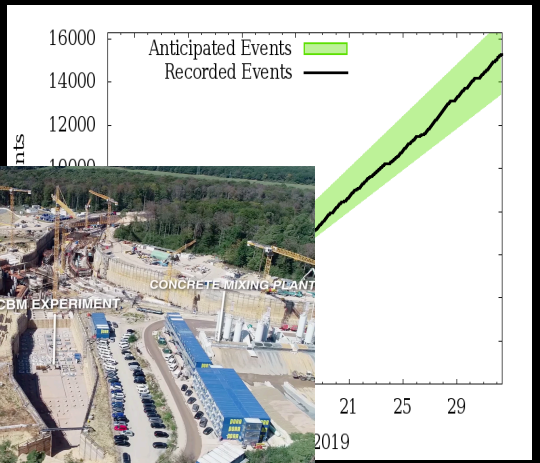
Universal $\langle A_{part} \rangle$ dependence of strangeness

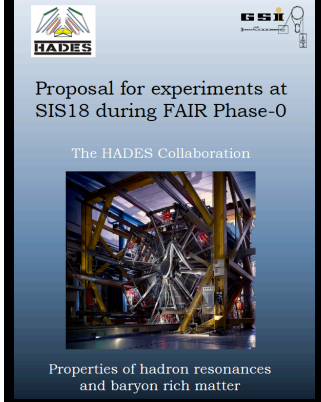
FAIR-Phase 0:

High quality data ~~to come~~ are here

Future: Hyperon EM coupling

FAIR-Phase 1:





The HADES collaboration

Thank you for your attention!