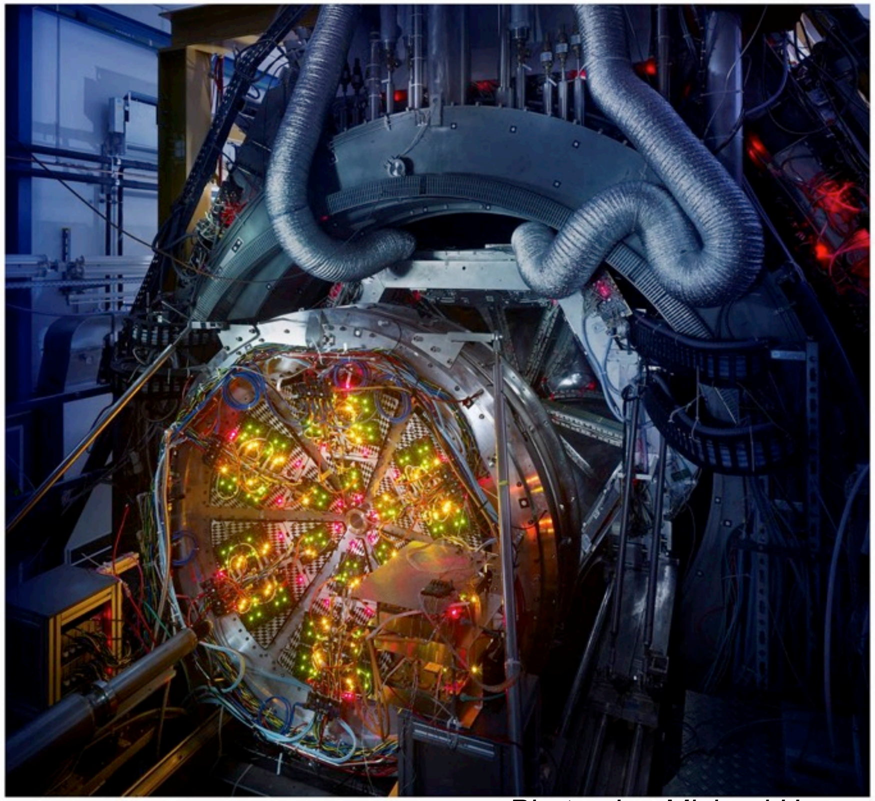


Photo: Jan Michael Hosan

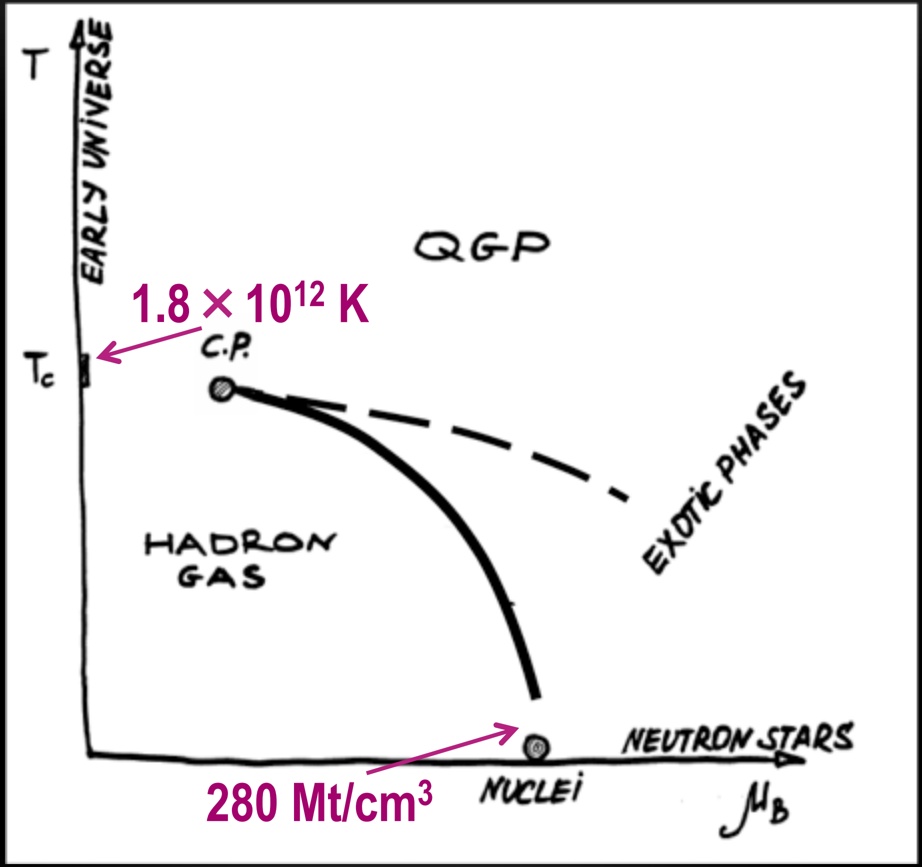
GSI FACILITY ASPECTS AND REQUIREMENTS: HADES

THE CASE OF RARE PROBES

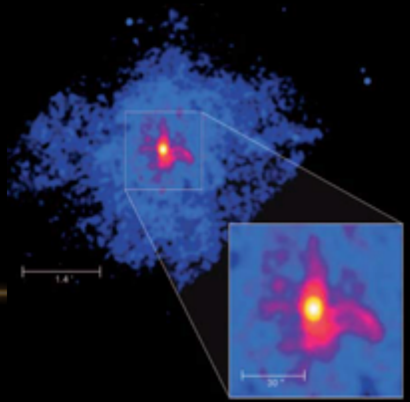
Tetyana Galatyuk for the HADES Collaboration
Technische Universität Darmstadt / GSI

PHASE DIAGRAM OF MATTER

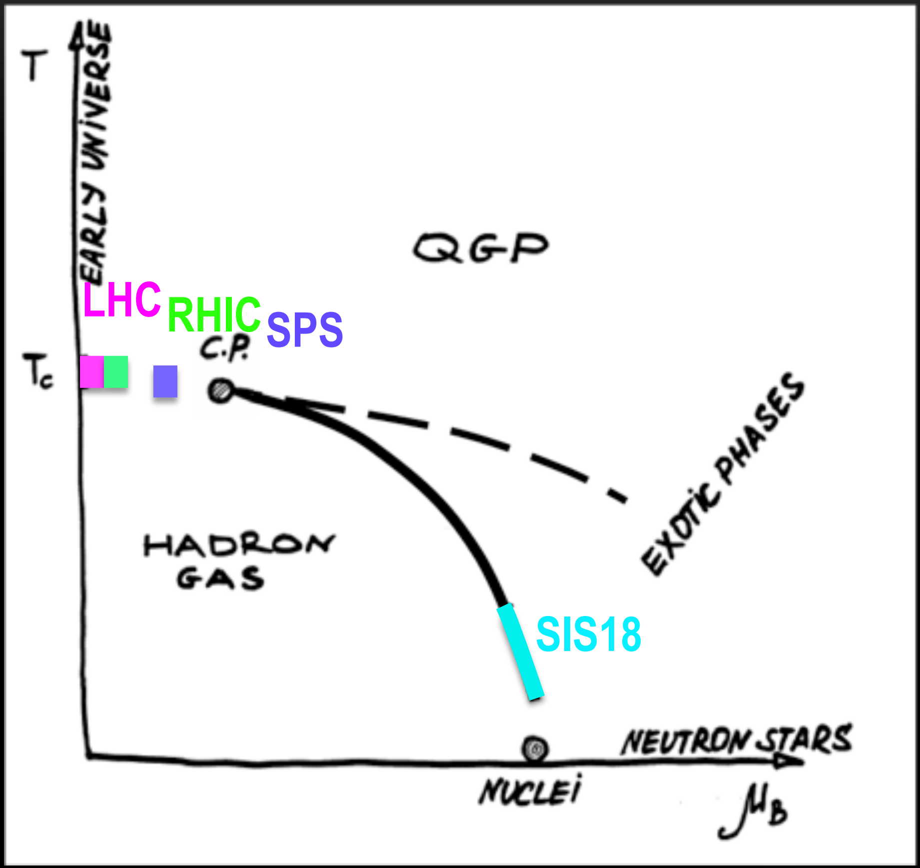
From the "Big Bang" to Neutron stars



Accessible through heavy-ion collisions

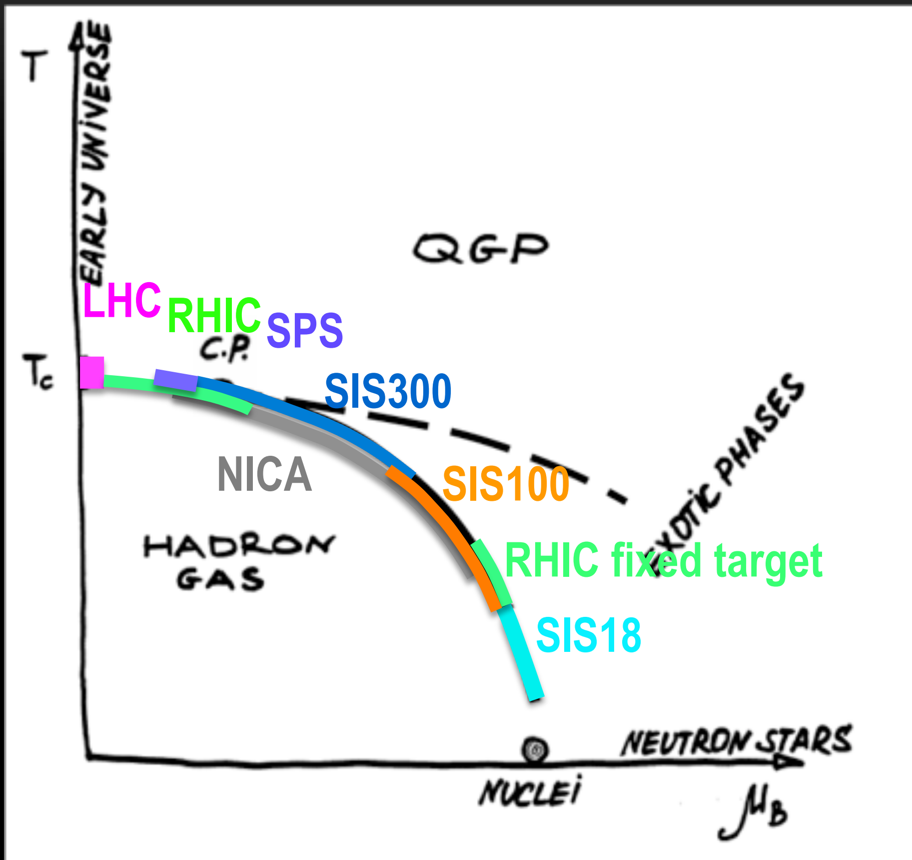


PHASE DIAGRAM OF MATTER



- Until recently:
  - LHC, RHIC, SPS, SIS18

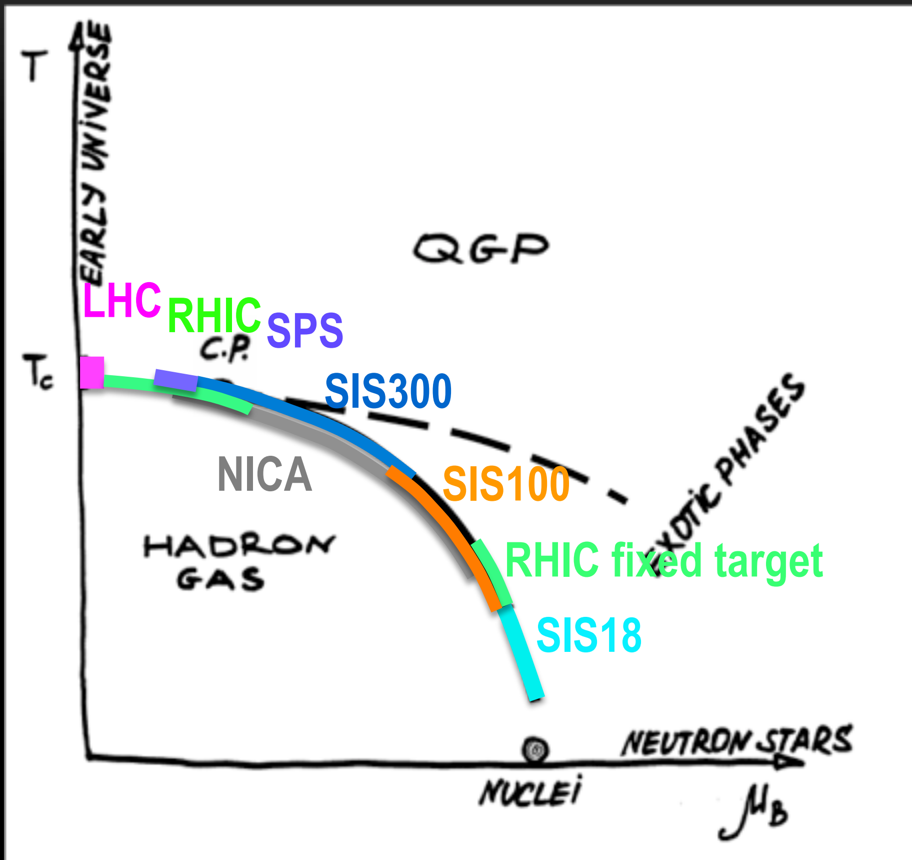
PHASE DIAGRAM OF MATTER



- Until recently:
  - LHC, RHIC, SPS, SIS18
- Now and future:
  - RHIC BES, RHIC Fixed target, SPS, NICA, SIS300/100, SIS18

Why moving towards lower beam energies?

PHASE DIAGRAM OF MATTER



- Until recently:
  - LHC, RHIC, SPS, SIS18
- Now and future:
  - RHIC BES, RHIC Fixed target, SPS, NICA, SIS300/100, SIS18

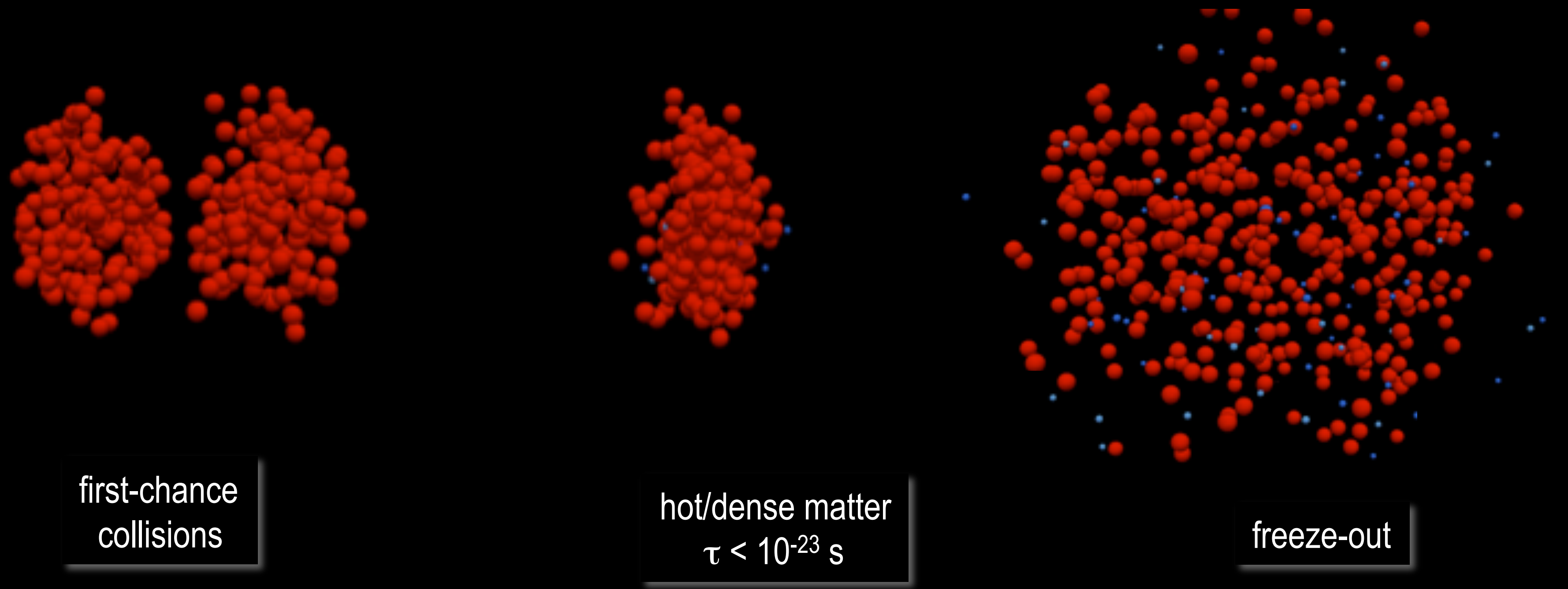
Why moving towards lower beam energies?

→ Under which "pressure" does matter deconfine and/or restore symmetry?

- Establish the nature of phase transitions
- Understand generation of mass in strong interactions (fate of the QCD condensates in the medium)

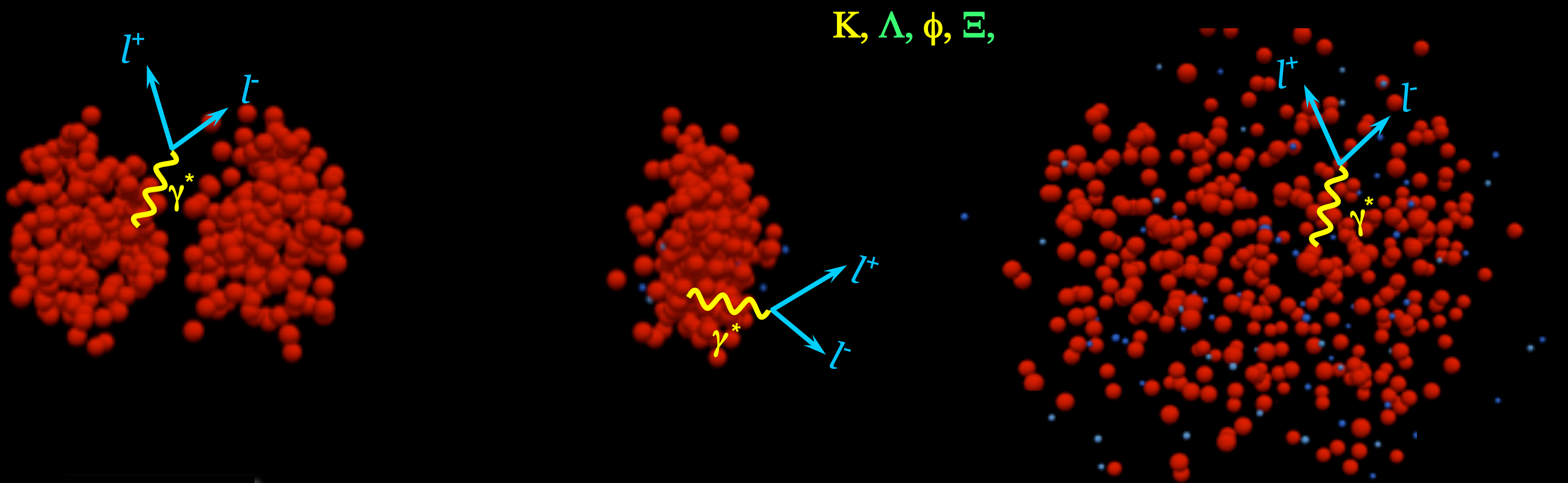
→ Experimental test!

COURSES OF THE HEAVY-ION COLLISION



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

COURSES OF THE HEAVY-ION COLLISION



first-chance collisions

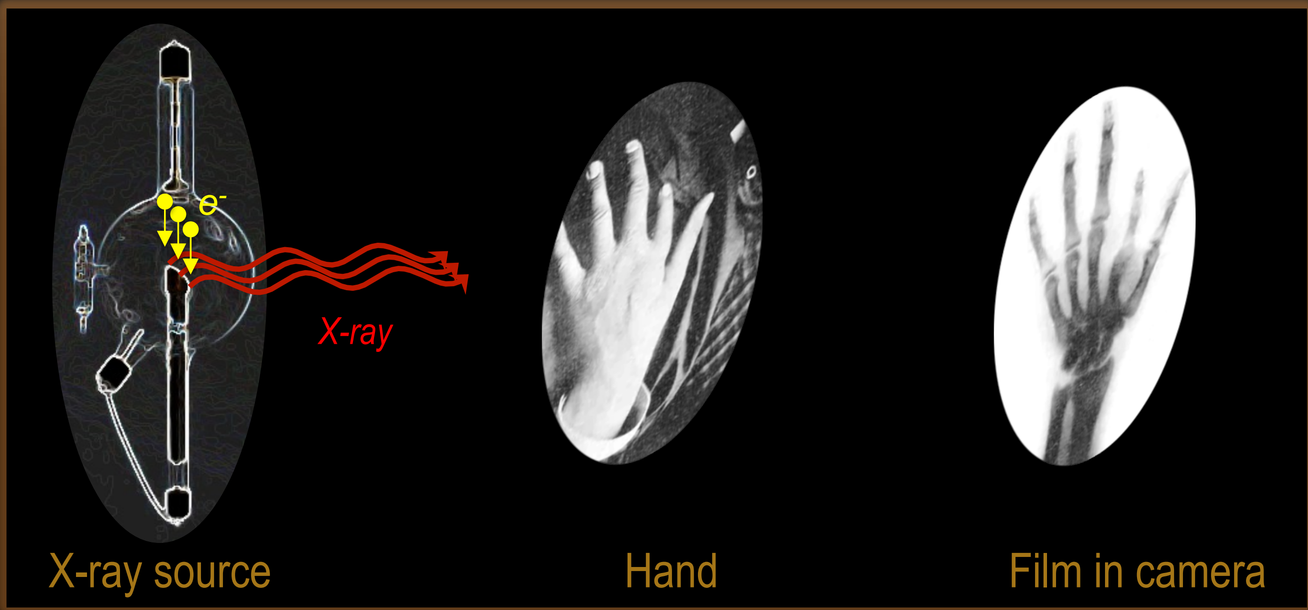
hot/dense matter
$\tau < 10^{-23}$ s

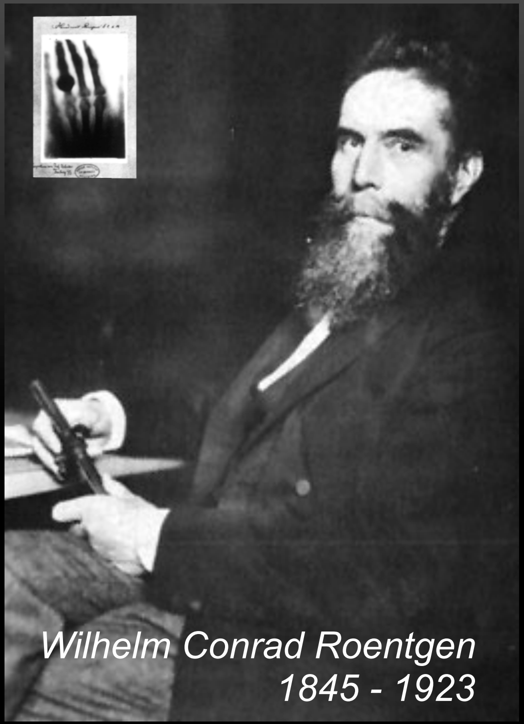
freeze-out

HADES → Rare and penetrating probes

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

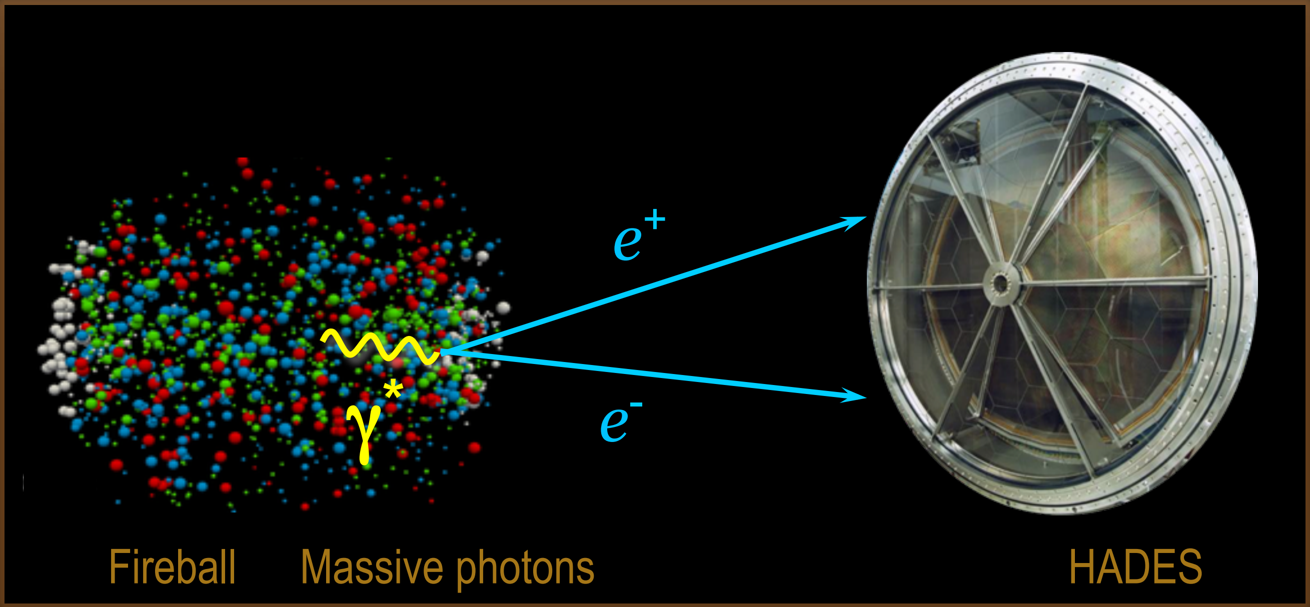
ELECTROMAGNETIC RADIATION AS A TOOL TO STUDY PROPERTIES OF "MATTER"





- X-ray technology has allowed us to look inside the human body since 1895
- X-rays widely used beyond medical applications

ELECTROMAGNETIC RADIATION AS A TOOL TO STUDY PROPERTIES OF "MATTER"

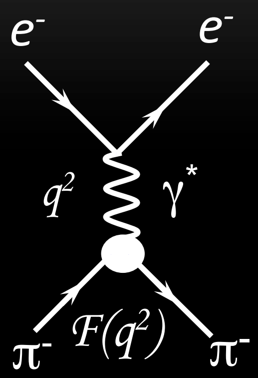


Explore microscopic structure of extreme states of matter with electromagnetic radiation

PHOTONS AS HADRONS

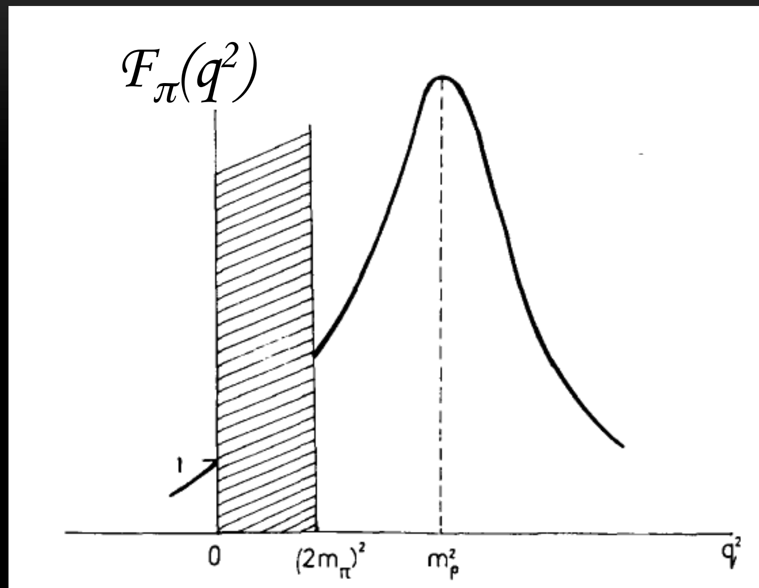
HOW DO PHOTONS COUPLE TO HADRONS?

space-like photons

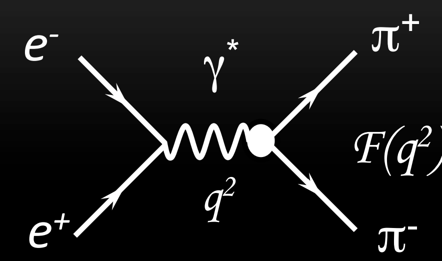


$q^2 < 0$

$\Delta p \Delta x \geq \hbar/2$



time-like photons



$q^2 > 0$

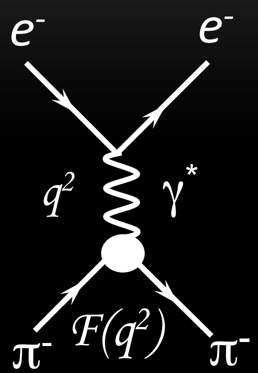
$\Delta E \Delta t \geq \hbar/2$

$$F(q^2) = \frac{d\sigma/dq^2}{\left(d\sigma/dq^2\right)_{\text{point like}}}$$ → *Form Factor*

$$q^2 = (\Delta E)^2 - (\Delta p)^2$$ → *Squared 4-momentum*

HOW DO PHOTONS COUPLE TO HADRONS?

space-like photons



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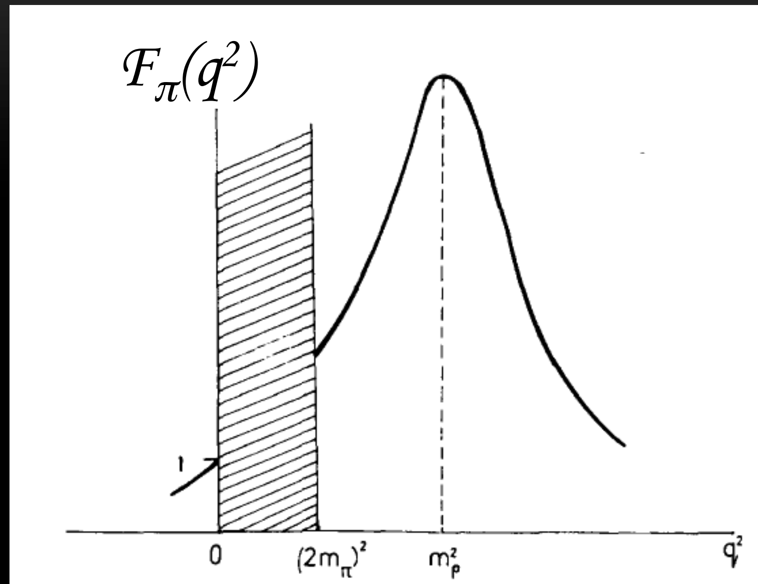
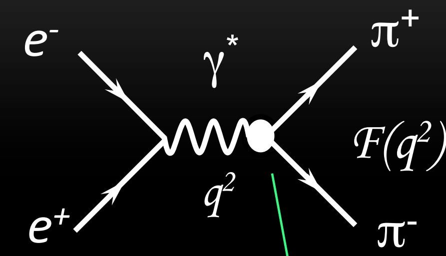


time-like photons



$q^2>0$

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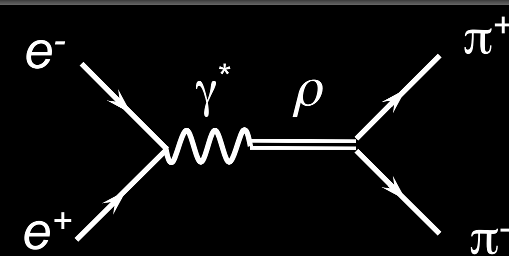


- $J^P = 1^-$ for both γ^* and Vector Meson
- Strong coupling of γ^* to Vector Meson
  → Vector Meson Dominance model
- Observable: vector mesons (ρ, ω, ϕ)

$$F(q^2) = \frac{d\sigma/dq^2}{\left(d\sigma/dq^2\right)_{\text{point like}}}$$

→ *Form Factor*

$$q^2 = (\Delta E)^2 - (\Delta p)^2$$

→ *Squared 4-momentum*

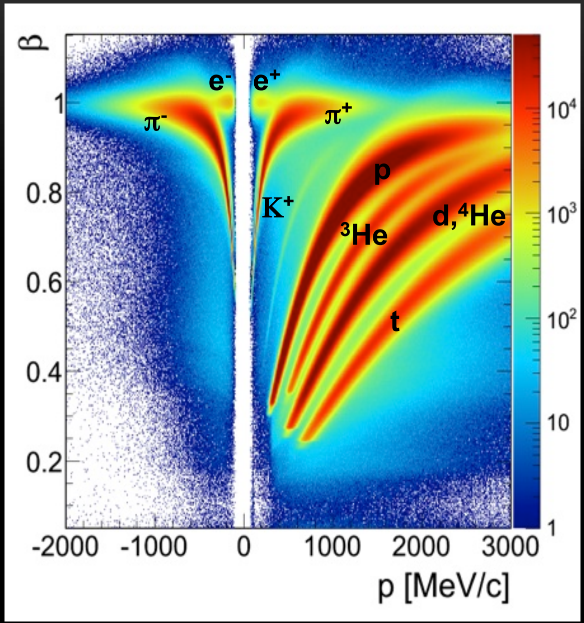
THE EXPERIMENTAL CHALLENGE …

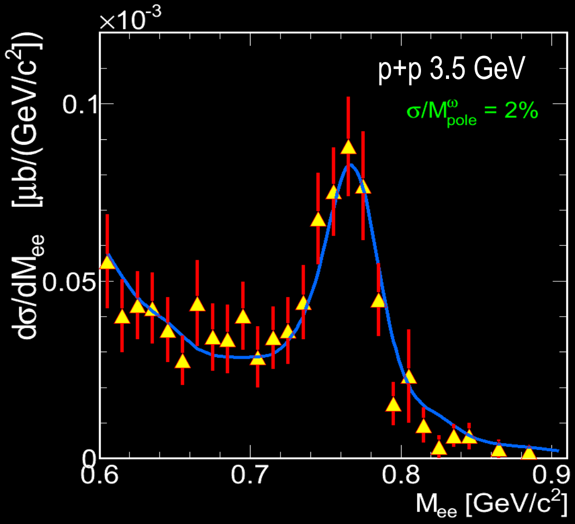
- Lepton pairs are rare probes (BR < 10^{-4})
- at SIS energies sub-threshold vector meson production
  → 1 ρ decay per 10 mio events
- Large combinatorial background in e^+e^- from
  Dalitz decays ($\pi^0 \rightarrow e^+e^-\gamma$) and conversion pairs ($e^+e^-$)
- Isolate the contribution to the spectrum from the dense stage

DATA QUALITY

- The decisive parameters: Number of Interactions and Signal/Background
  - Range of $\mathcal{B}/\mathcal{S}$: 20 - 100 → $\mathcal{B}/\mathcal{S} \gg 1$;
    - Effective sample size: $\mathcal{S}_{eff} \sim \mathrm{I} \times \mathcal{S}/\mathcal{B}$ reduction by factors of 20-100
    - Systematics: $\delta\mathcal{S}_{eff}/\mathcal{S}_{eff} = \delta\mathcal{B}/\mathcal{B} \times \mathcal{B}/\mathcal{S}$ $\delta\mathcal{B}/\mathcal{B} = 2…5\times10^{-2}$

EXPLORING QCD PHASE STRUCTURE WITH HADES USING RARE PROBES





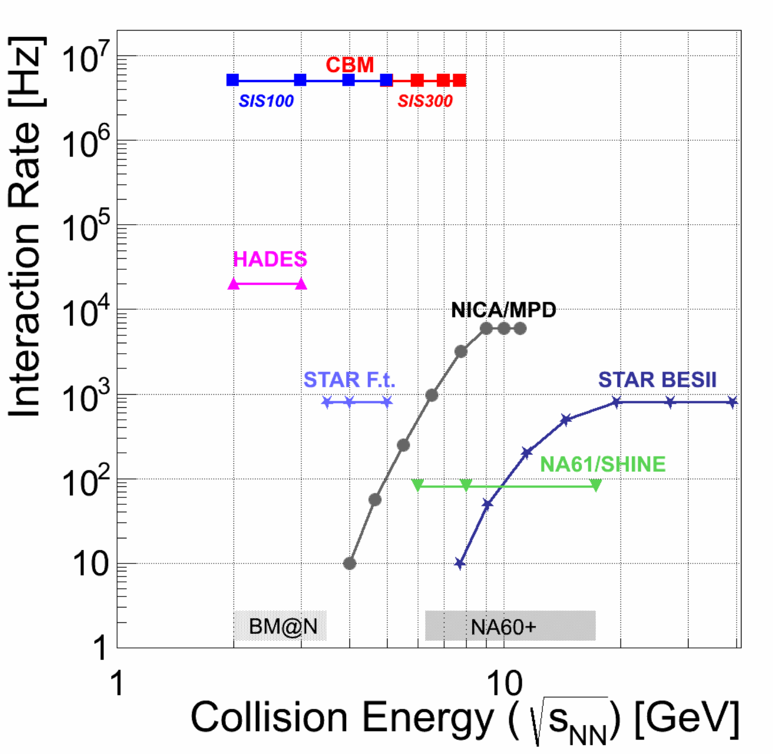
- Low-mass fixed-target experiment
- Hadron and lepton identification
- Event-plane reconstruction

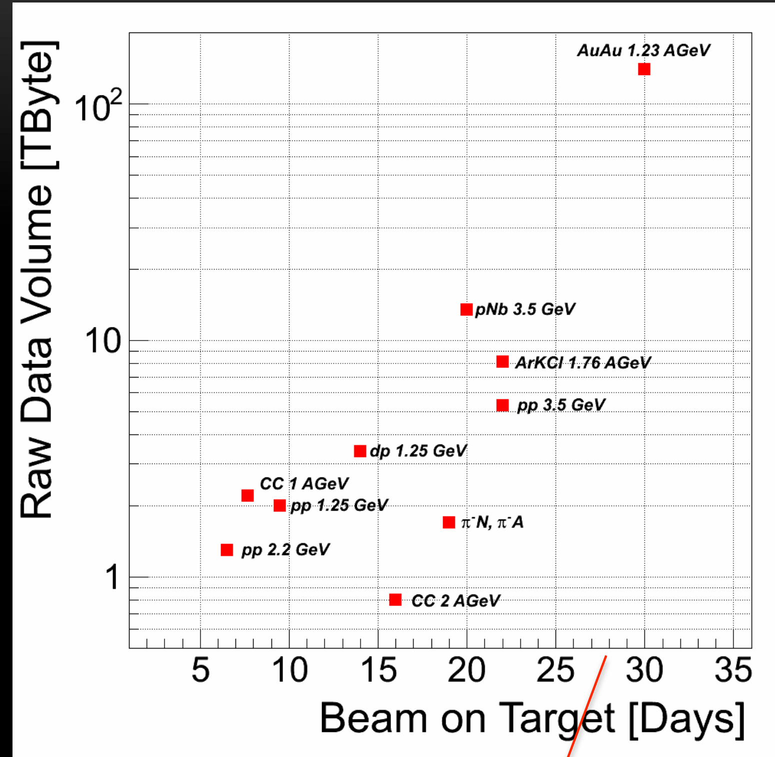
- e^+e^- pair acceptance 35%
- Mass resolution 2 % (ρ/ω region)

- ~ 80.000 channels
- 50 kHz event rate (400 Mbyte/s peak data rate)

- HADES strategy:
  - Dileptons
  - Flavor production (multi-)strange
  - Fluctuations of conserved quantum numbers
  - Various aspects of baryon-resonance physics

THE HADES



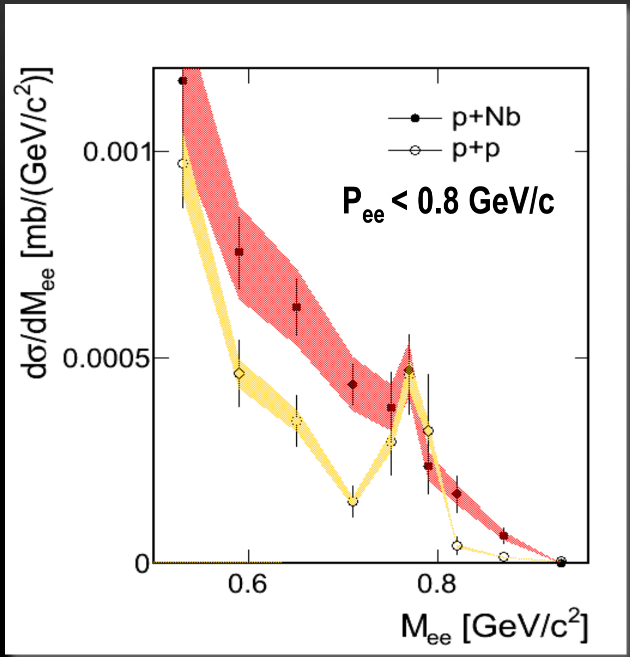


Colliders not competitive to fixed-target experiments in terms of interaction rate
→ Rare probes difficult to access, if at all…

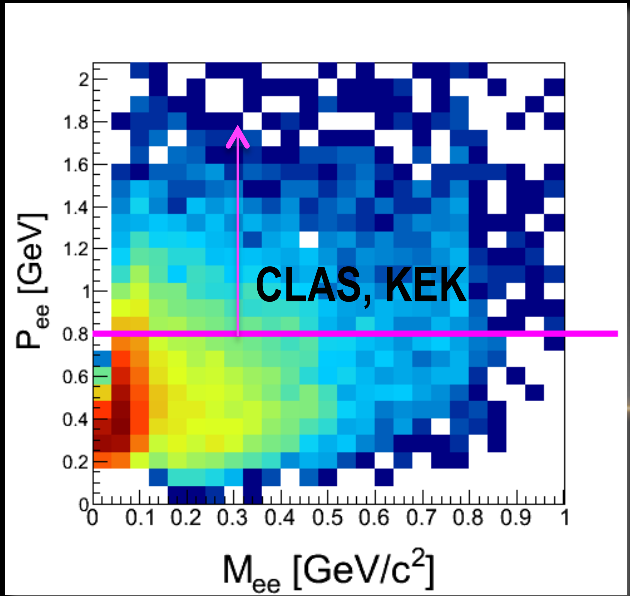
Request
one run per year with
minimum of four weeks
beam on target
for production!

DILEPTONS

VECTOR MESON MODIFICATIONS IN p+A REACTIONS



HADES: *Phys.Lett. B715 (2012)*

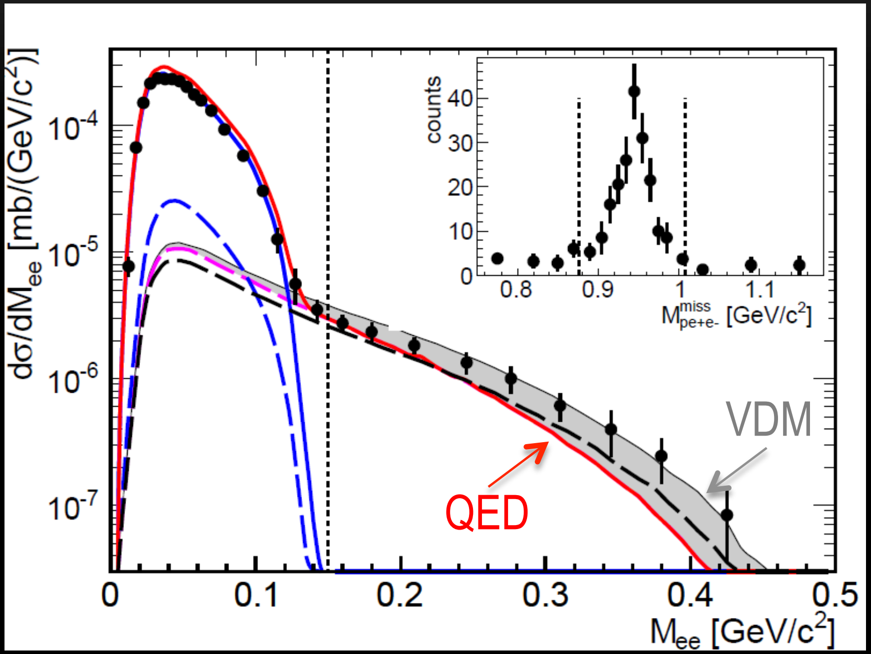


- Are there **narrow in-medium vector meson states** with substantially shifted pole mass?
- First measurement of in-medium vector meson decays in the relevant momentum region (P_{ee} down to 200 MeV/c)
- HADES has so far not observed such states **but statistical significance is limited.**
- KEK-E325 has published data for ρ− and ω−meson production:
  - Contradicting to CLAS and HADES
  - HADES sees rather a melting than a shift
  - CLAS, KEK : high relative momentum to the medium

PDG Entry 2012, 2014
BR(η→e^+e^-) < 2.5x10^{-6} (90% CL)

LEPTON PAIRS FROM pp AT 1.25 GeV

Δ^+ Dalitz decay via $pn\Delta^+ \{\rightarrow pe^+e^-\}$



Goal

- Reference measurement for Au+Au at 1.23*A* GeV
- Exploring hadron electromagnetic structure

Results

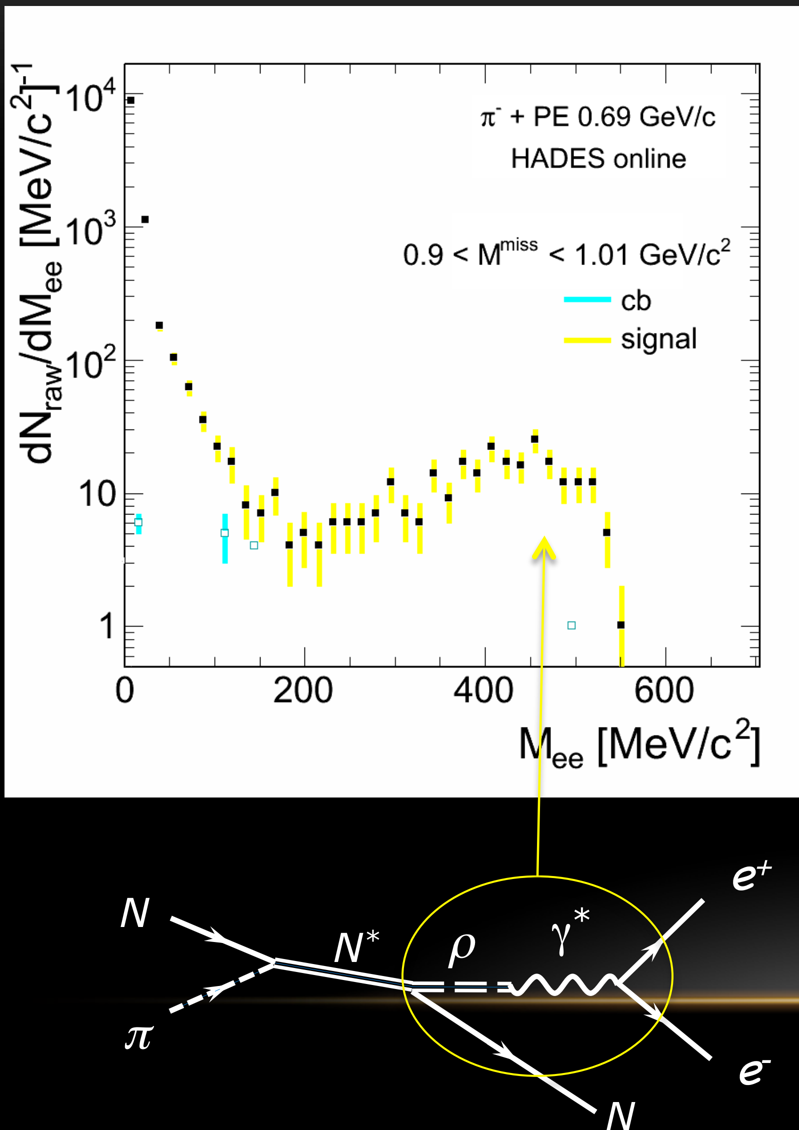
- First direct access to the Δ transition form factor in the time-like region
  - Branching ratio ($\Delta^+ \rightarrow pe^+e^-$) = 4.42×10^{-5}

Aim for PDG Entry 2016
BR($\eta \rightarrow e^+e^-$) < 2.5×10^{-6} (90% CL)

- Signal = 200 (M_{ee} > 0.15 GeV/c^2)

But statistical significance is limited to differentiate between QED vs VMD scenarios

BARYON-RESONANCE ELECTROMAGNETIC TRANSITION FORM FACTOR



- **Vector Meson Dominance:** the basis of emissivity calculations for QCD matter.
- Virtual excitation of ρ-meson states in the baryons' meson cloud?
- Needs measurement of electromagnetic transition form factors in the time-like region!

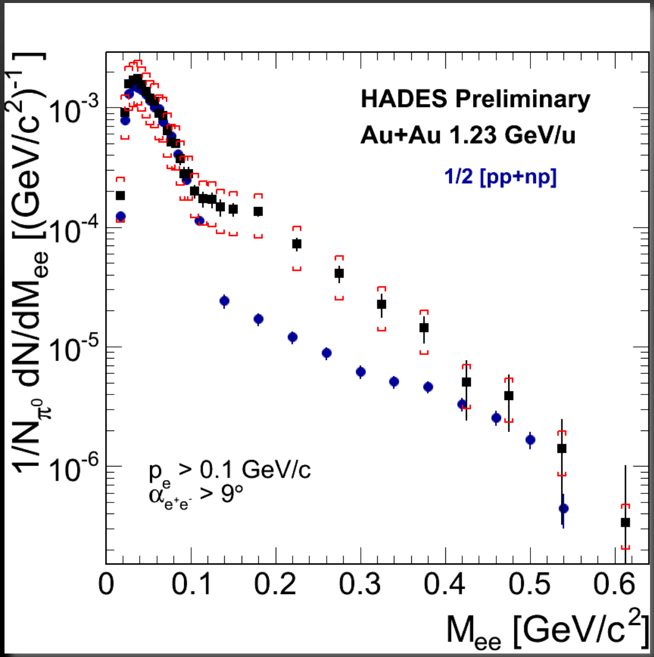
→ s-channel π-N scattering

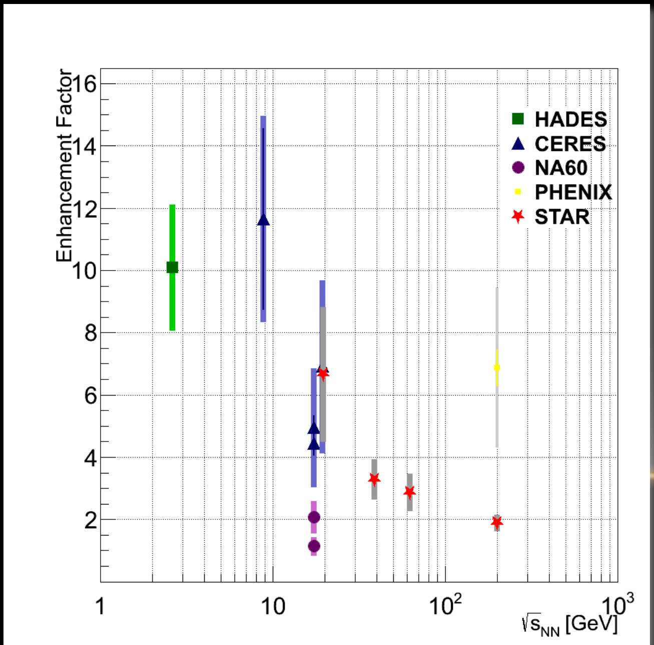
- $\pi N \rightarrow R \rightarrow N e^+e^-$
- $\pi N \rightarrow R \rightarrow N \pi^+\pi^-$

→ Crucial to control the interpretation of medium effects from SIS to LHC

→ Unique chance to study time-like electromagnetic structure of higher lying resonances!

DILEPTON EXCITATION FUNCTIONS





- ❑ Dileptons as spectrometer, thermometer, chronometer, barometer

→ No measurement for beam energies of 2-40*A* GeV

→ SIS energy range is ideal to look for onset of QGP radiation

→ Measure excitation function of ρ-spectral function and… expect the unexpected → critical point?

→ Decrease of T for lower beam energies → plateau around onset of deconfinement?

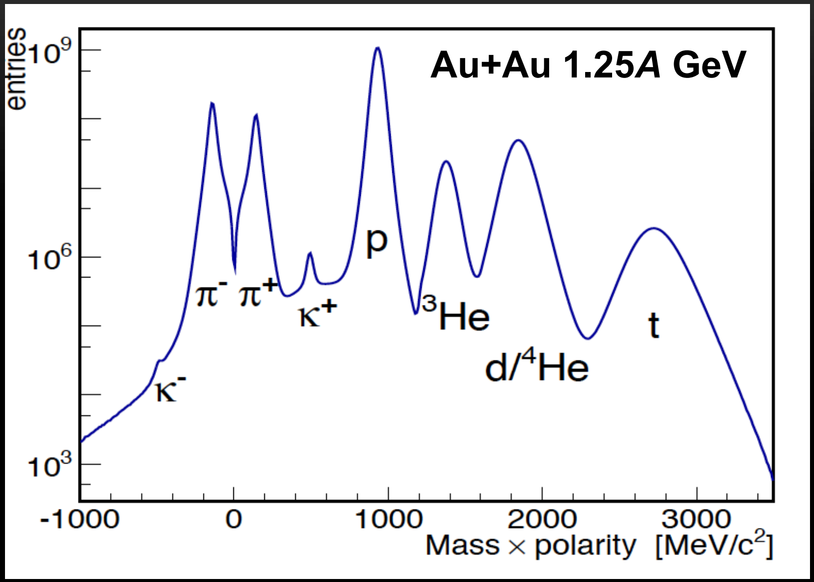
FLAVOR PRODUCTION (MULTI-)STRANGE OBJECTS

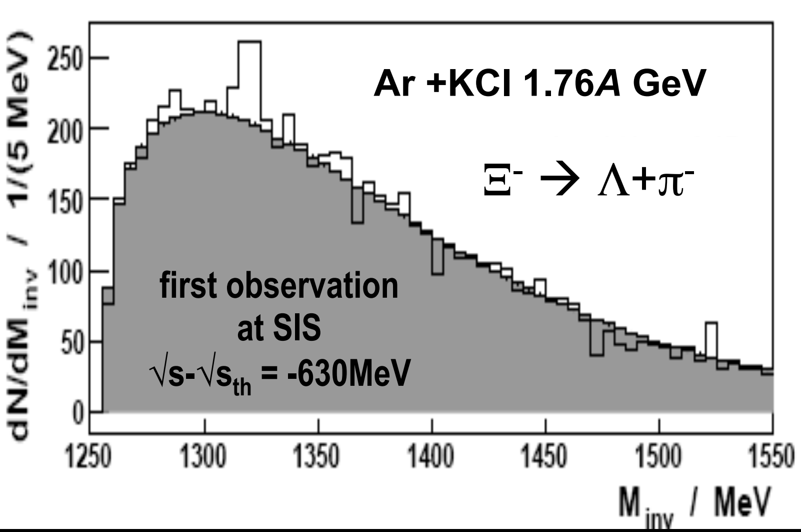
STRANGENESS PRODUCTION AT SIS ENERGIES

Experimental challenge: at SIS energies strangeness produced sub-threshold

- **Elementary collisions**
  - K^+ production
    NN → $NK^+\Lambda$ $\quad E^{kin}_{thr} = 1.58$ GeV
  - K^- production
    NN → NNK^+K^- $\quad E^{kin}_{thr} = 2.49$ GeV

- **Heavy-ion collisions**
  → production below free NN threshold:
  - Secondary collisions of exited baryons
  - Reduced in-medium K^- mass?





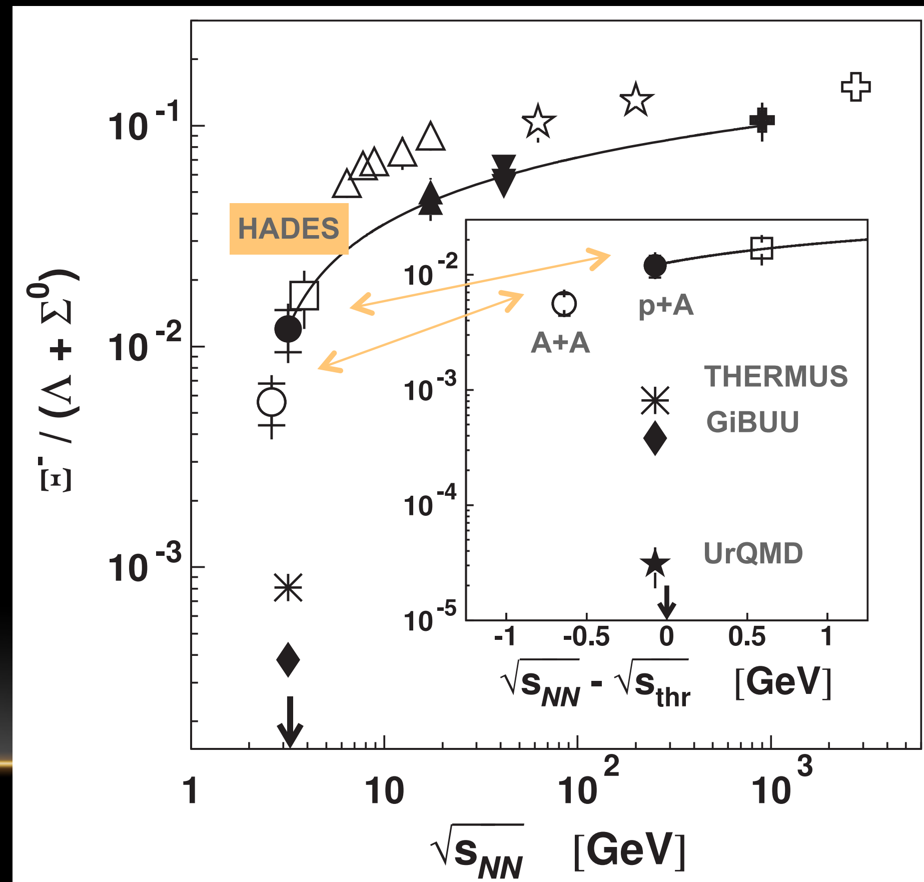
Phys. Rev. Lett. 103, 132301, (2009)

2015 HADES HIGHLIGHT

PRL **114**, 212301 (2015) PHYSICAL REVIEW LETTERS week ending 29 MAY 2015

Subthreshold Ξ^- Production in Collisions of p(3.5 GeV) + Nb

- **Multi-strange baryons** (Ξ, Ω) are expected to be a sensitive probe for "Compressed Baryonic Matter".
- HADES observes **unexpectedly large** production cross sections, first in ' Ar+KCl collisions, and now in proton induced reactions (cold matter).
- Attempts to theoretically describe the production based on the **decay of heavy resonances** (arXiv:1503.07305-Jan Steinheimer et al.) looks promising but has to be further scrutinized.



→ **Reference measurements are needed:**
- → **Production cross section of N***
- → **Branching ratios**

HADES PHYSICS PROGRAM AT SIS18… FROM 2018 ON

Unique opportunity by combining a
high-acceptance di-electron spectrometer with pion beams

- Role of the meson cloud in the emissivity of (dense) baryonic matter
  - Baryon-resonance electromagnetic form factors
  - ρ-meson nucleon coupling
  - In-medium vector meson propagation
- Strangeness production and propagation
  - Production of multi-strange baryons / ϕ-meson

π+p

π/p+A

A+A

- No beam time request for before second half of 2018 → upgrades not finished yet
- Request one run per year with least **4 weeks beam** on target **for production**

<table>
<tr><th colspan="10">April 2007</th><th colspan="10">Schedule as of 11-Apr-2007</th></tr>
<tr><th colspan="5">Week 15</th><th colspan="7">Week 16</th><th colspan="7">Week 17</th><th>W</th></tr>
<tr><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td></tr>
<tr><td colspan="2">SIS start</td><td colspan="18">S301, Salabura/Stroth, 1H (MUCIS) 3500MeV, 10^8 / spill, 10 s extraction, perfect spill structure, small intensity variations, minimized halo, HAD</td></tr>
<tr><td></td><td></td><td>c)</td><td>d)</td><td></td><td></td><td></td><td></td><td></td><td colspan="5">S280, Berdermann, 1H (MUCIS), > 2 GeV, 1e5/spill, spill=4s, 1:10 block mode, HTA</td><td colspan="5">S297, Herrmann/Leifels, 1H (MUCIS), 3.5GeV, 1e8/spill, max. extr. block mode, HTB</td><td>e)</td></tr>
<tr><td></td><td></td><td colspan="9">E070, Moshammer/Hagmann, 64 Ni (EZR), 100 -400AMeV, 1e8/spill, SIS cooler, ESR jet target</td><td></td><td></td><td></td><td colspan="5">f)
E055, Ni, FRS-ESR</td><td></td></tr>
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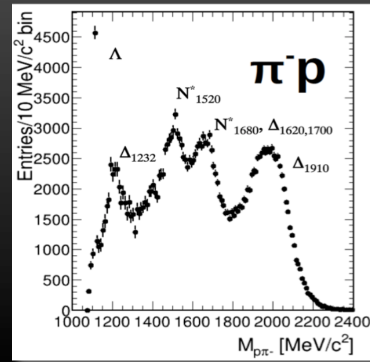
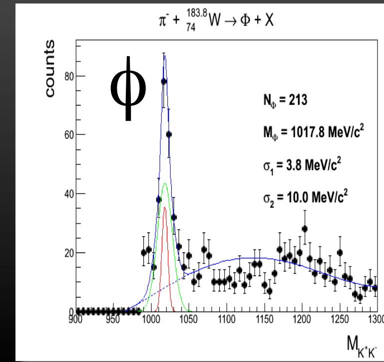
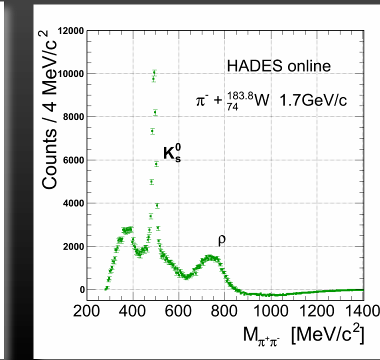
π BEAM RUN IN 2014:

MEASUREMENT COMBINED WITH MACHINE DEVELOPMENTS FOR SIS100







”IF YOU ARE OUT TO DESCRIBE THE TRUTH, LEAVE ELEGANCE TO THE TAILOR”

A. EINSTEIN

PERSPECTIVES OF THE π BEAM EXPERIMENTS

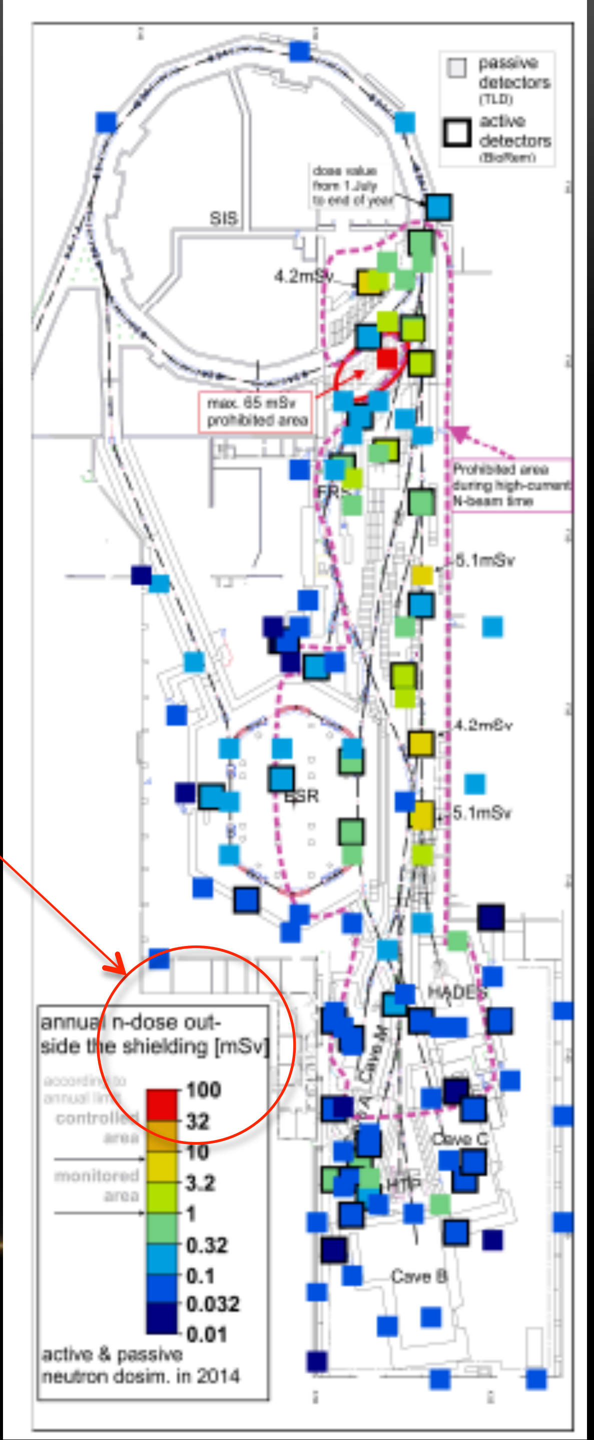
π^- BEAM IN 2014

- High current experiment in July/August 2014
  - 400.000 π /spill at 0.69 GeV/c on HADES target were reached with ~0.9 × 10^{11} N_2 ions/spill

BUT

  - Too high radiation level in NE5 and SIS tunnel
    (Intensity had to be reduced to 150.000 π /spill):
  - Hottest areas:
    - extraction area – mSv/h
    - first quadrupole after the septum – 1.5mSv/h (6 weeks after the high int. run)
      → 4 times higher than ever measured at this point
    - TH3MU1 – in Jan. 2015 - 60 µSv/h
    - air activation - for the first time at GSI – more than 1000 Bq/m3 of Ar-41 outside controlled areas!
  - 40 days of high current N-beam – 90% of total annual dose in halls TR and EX
    Dose Measurements at SIS18 and connected experimental halls TR, EX, TH.
    T. Radon et al. to be published in GSI annual report.

100 mSv



FOR A LATER FAIR OPERATION THIS BEAM TIME HAS BEEN A REALISTIC TEST CASE.

T. Radon, GSI annual report 2014

GOALS FOR π^- BEAM AT SIS18

π- beams

- Exciting observation from explorative experiment in 2014
- Needs more statistics: maximum intensity, > 4 weeks beam-on-target
  - Maximize π^- flux on HADES target
  - Achieve stable running conditions with respect to radiation safety

GOALS FOR π^- BEAM AT SIS18

π- beams

- Exciting observation from explorative experiment in 2014
- Needs more statistics: maximum intensity, > 4 weeks beam-on-target
  - Maximize π^- flux on HADES target
  - Achieve stable running conditions with respect to radiation safety
- Current limitations come from radiation issues, therefore:
  - optimize extraction efficiency - what can be done to substantially increase this efficiency?
  - optimize transfer line efficiency
  - enlarge aperture where necessary
  - improved shielding
  - better and more granular monitoring of the radiation level
  - better beam line monitoring
  - diagnostic of beam profile near the production target
  - improve predictions from Mirco to calculate the beam line settings
- Dual harmonics, more bunches in SIS at space charge limit
- HADES beam line controllable with new control software
  - More/better beam diagnostic elements in our beam line
    → reliable and fast beam line setting

GOALS FOR p , A BEAM AT SIS18

p beam

- Highest proton beam momentum which can be used for stable runs
  - $B\rho$ = 5.4 GeV/c → E_{kin} = 4.5 GeV ($\sqrt{s}$ = 3.47 GeV)
    → strangeness production, i.e. cascade
    → VM production

HI beam

- Maximize duty cycle
  - Fast ramping
  - Moderate primary beam intensities $<10^7$ (slow extraction, ~10 sec)
  - Minimal rate fluctuations during the spill (micro-spill structure)
- Stable beam spot (< 0.5 mm spread during spill)
- Fast micro spill structure monitoring in the beam line
- Maximize beam energy? → i.e. re-injection via ESR

  - Limit number of parasitic users → disproportional loss of statistics
  - Minimize set-up time of the experiment → mainly beam transport optimization
  - Avoid changes in UNILAC settings → seem to influence extraction efficiencies
  - Avoid ion source changes during a run

THE HADES COLLABORATION

- Catania, Italy
- Coimbra, Portugal
- Cracow, Poland
- GSI Damstadt, Germany
- TU Darmstadt, Germany
- Dresden, Germany
- Dubna, Russia
- Frankfurt, Germany
- Giessen, Germany
- Lisboa, Portugal
- München, Germany
- Milano, Italy
- Moscow, Russia
- Nicosia, Cyprus
- Orsay, France
- Rez, Czech Rep.
- Santiago de Compostela, Spain

18 institution partners
~100 collaborators

The heavy-ion programs from SIS to LHC energies need reference measurements for which HADES is an ideal detector system

THANK YOU!

BONUS SLIDES