Cosmic matter in the Lab: FAiR = The International Facility for Antiproton and Ion Research

Horst Stöcker, GSI & FIAS

Austria China Finnland France Germany Greece India Italy Poland Slovenia Spain Sweden Romania Russia UK

The Big Challenge ...

Gain Factors

- Beam intensities by factors of 100 - 10000
- Beam energies by a factor 20
- Production of antimatter beams
- Factor 10000 in beam brilliance via cooling
- Efficient parallel operation of programs

Construction Period, Cost, Users

- Construction in three phases until 2016
- Total cost 1.2 B€
- Scientific users: 2500 - 3000 per year

Financing

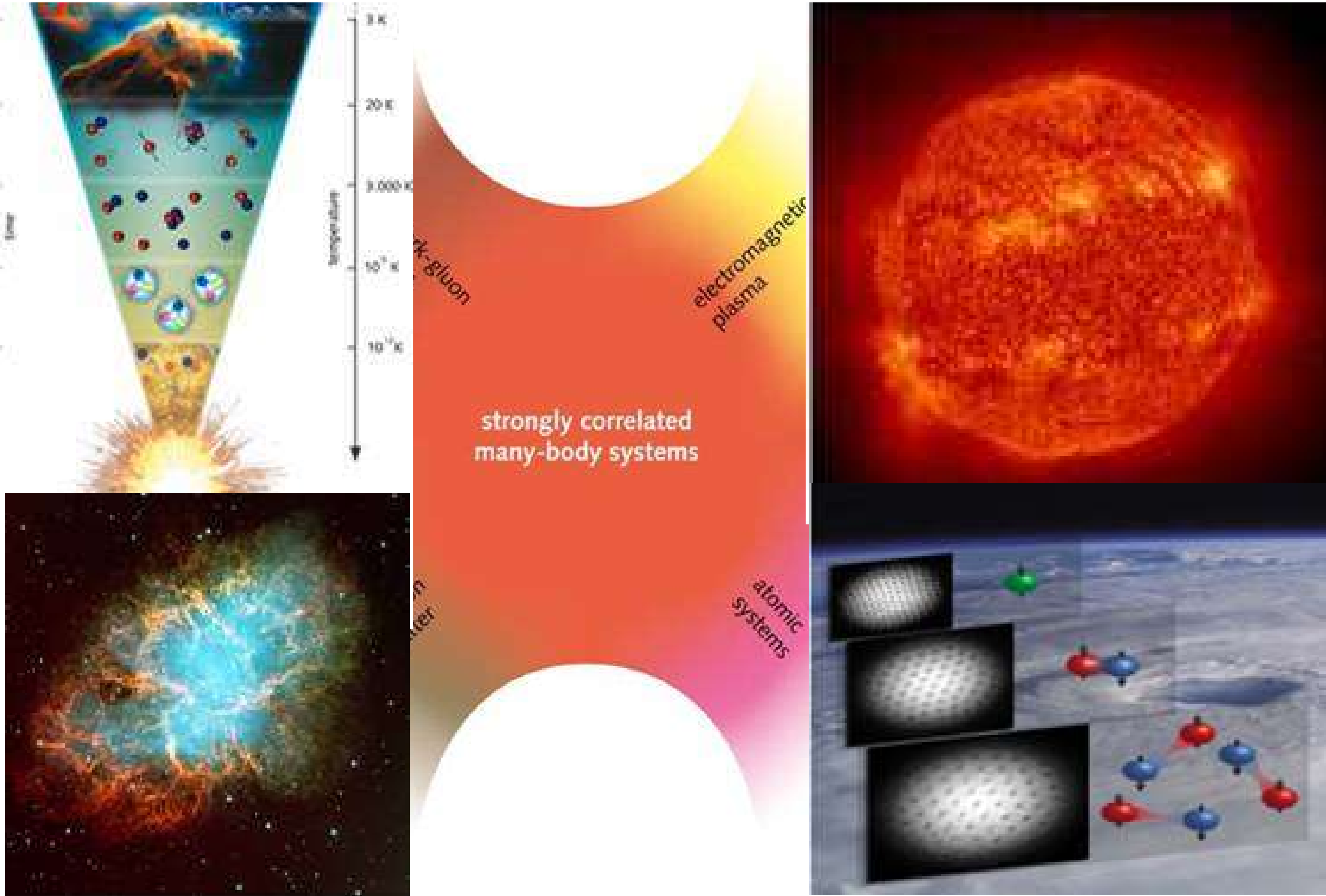
- 65 % Federal Government of Germany
- 10 % State of Hessen
- 25 % Partner Countries

→ FAIR GmbH with International Shareholders

Future facility

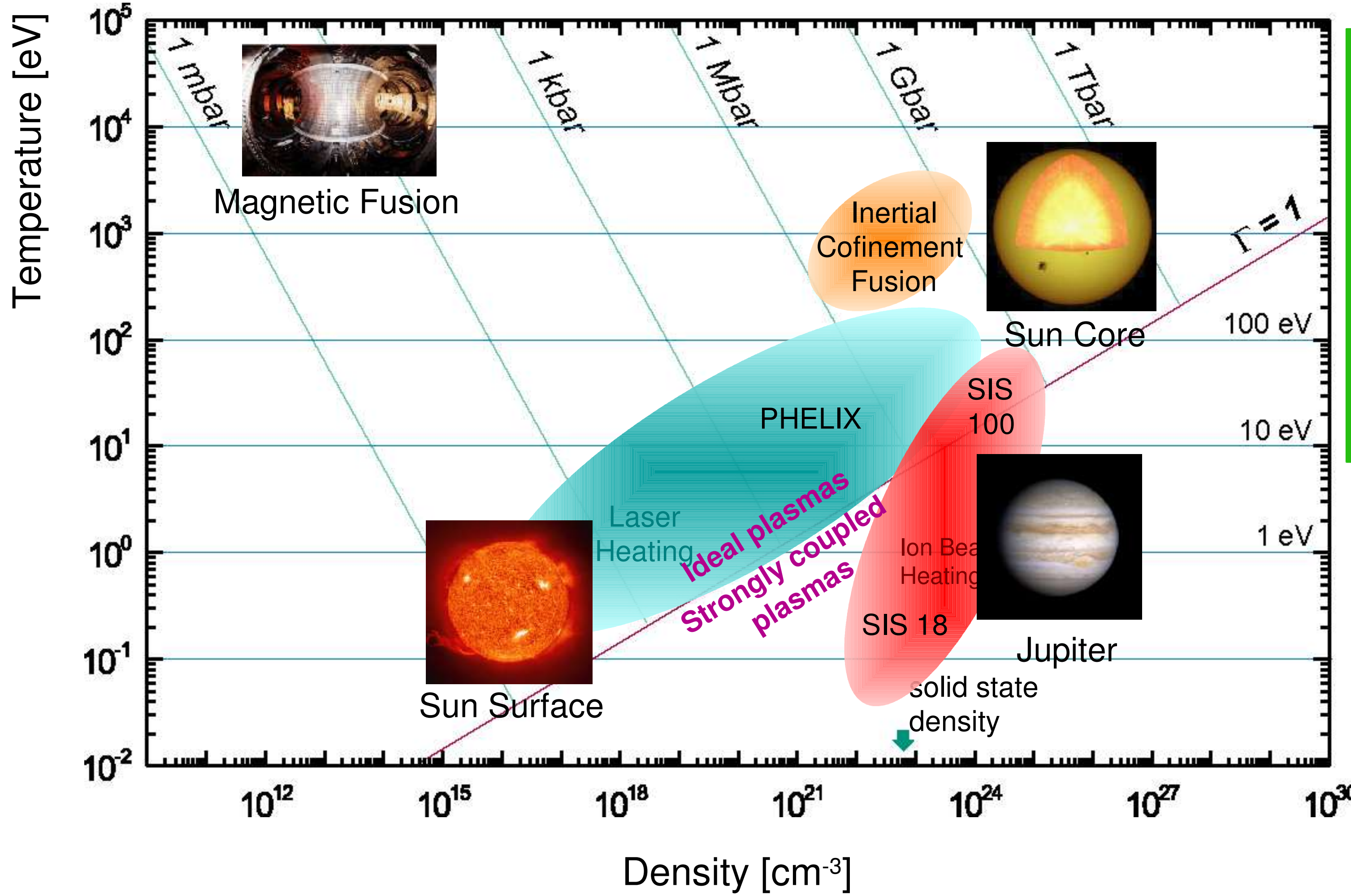
Largest fundamental science research project in Europe for the next decade!

FAIR Research Topics and Inter-links



Plasma physics with intense ion bunches and petawatt Laser pulses

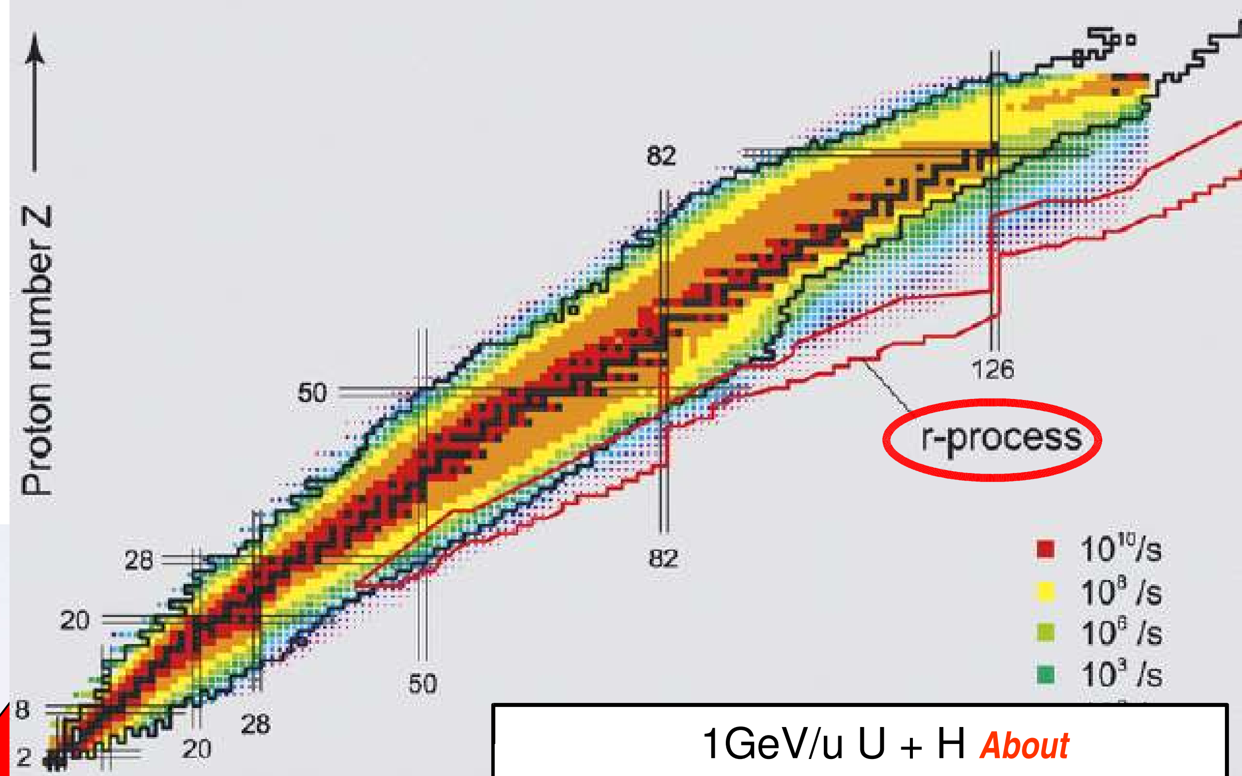
Matter at high energy densities



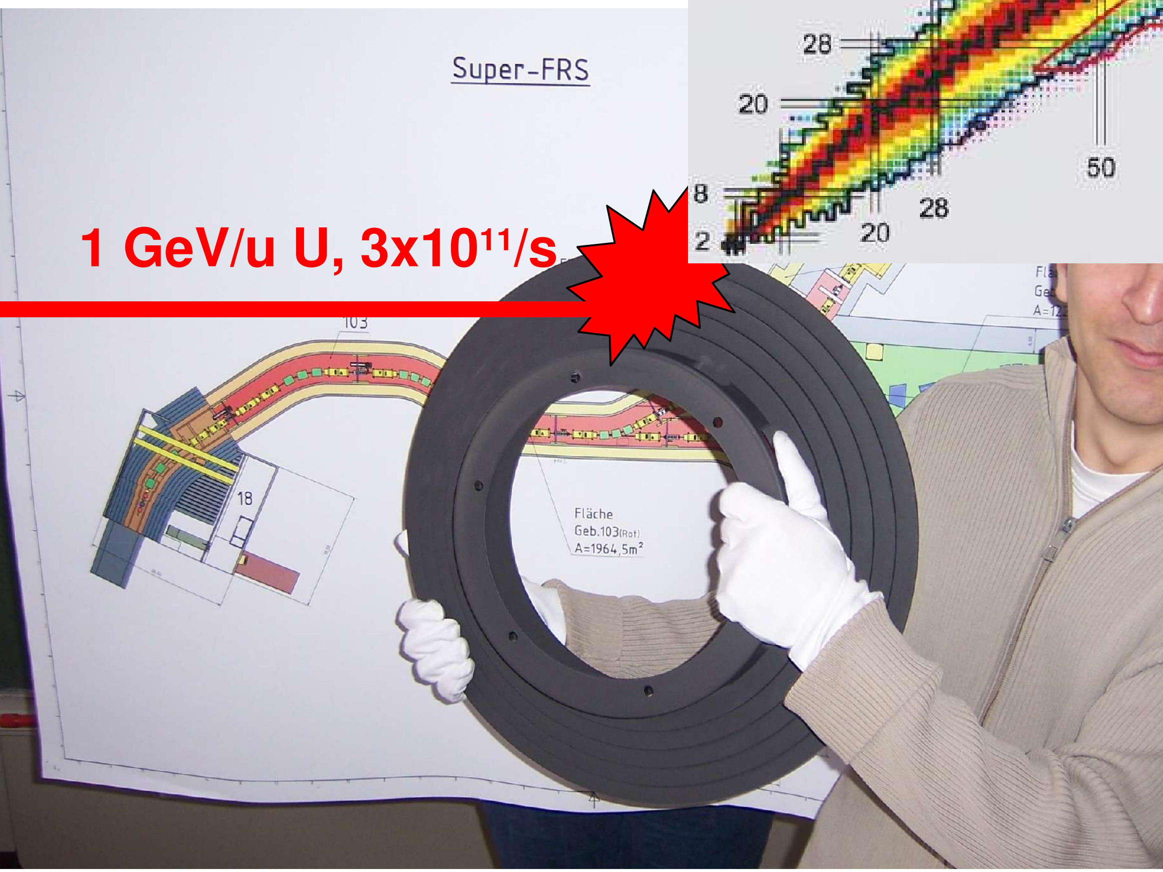
Physics of Fast Ignition (another way to clean energy production)

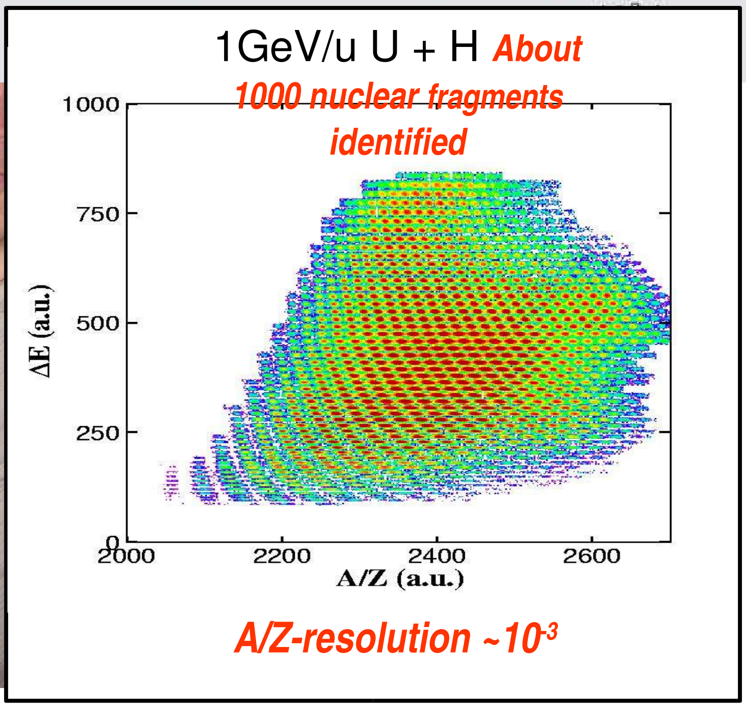
Equation of state of planetary and stellar matter

Production

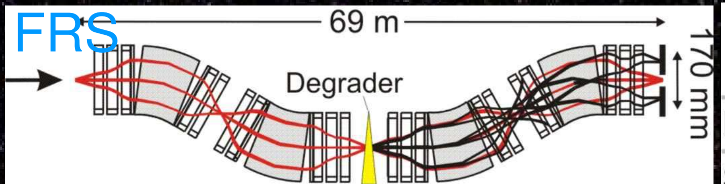


1 GeV/u U, $3x10^{11}$/s

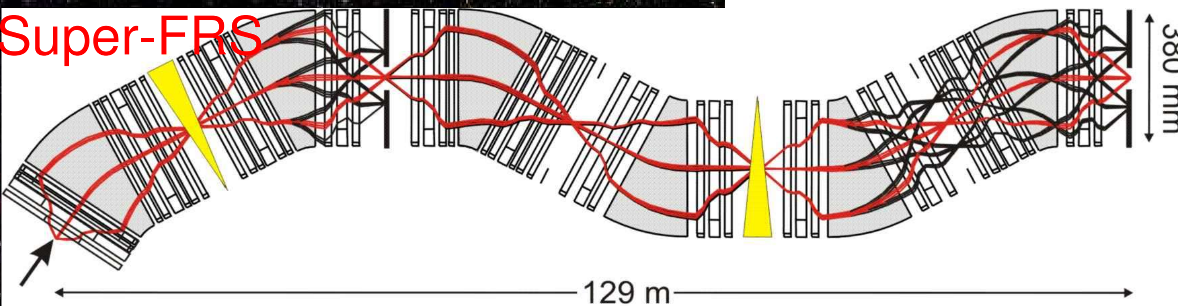


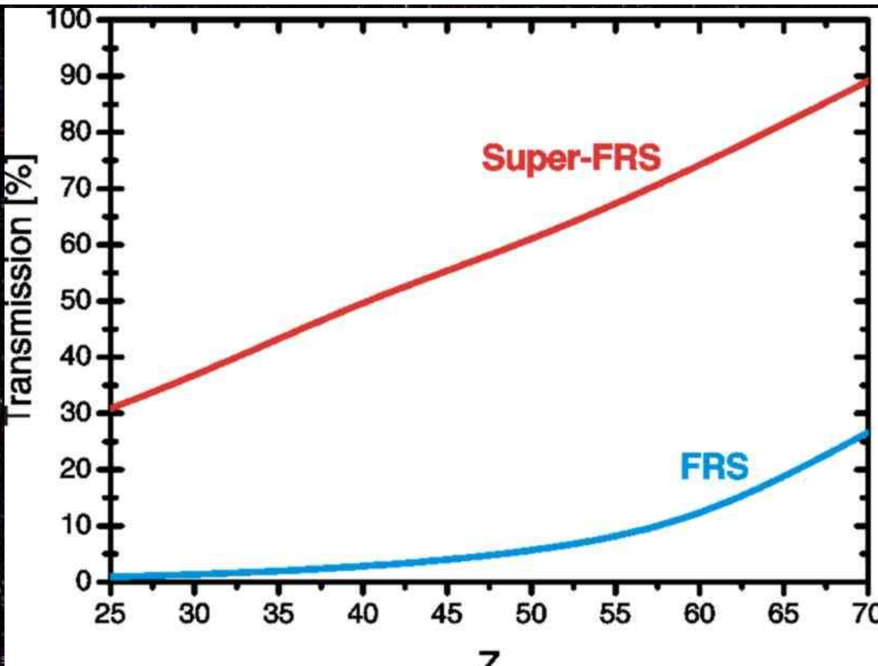


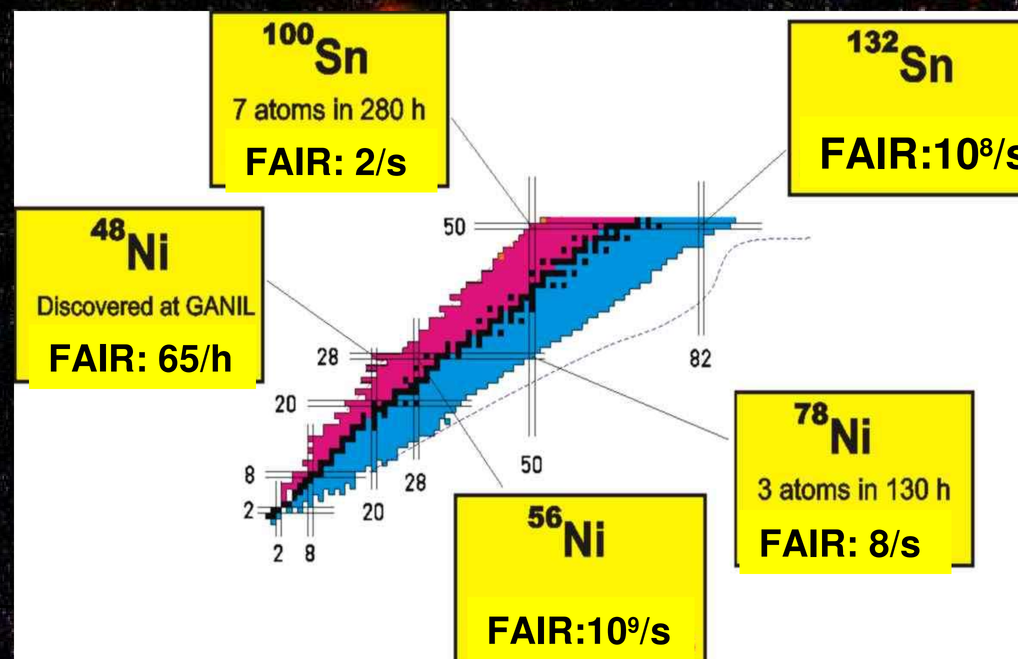
Comparison of FRS with Super-FRS, intensity gain



	$B\rho_{max}$	$\Delta p/p$	$\Delta\Phi_x$, $\Delta\Phi_y$	resolving power	gain factor ^{19}C	^{132}Sn
FRS	18 Tm	1.0 %	± 13, ±13 mrad	1500	1	1
Super-FRS	20 Tm	2.5 %	±40, ±20 mrad	1500	5	10
				including primary rate	250	20 000





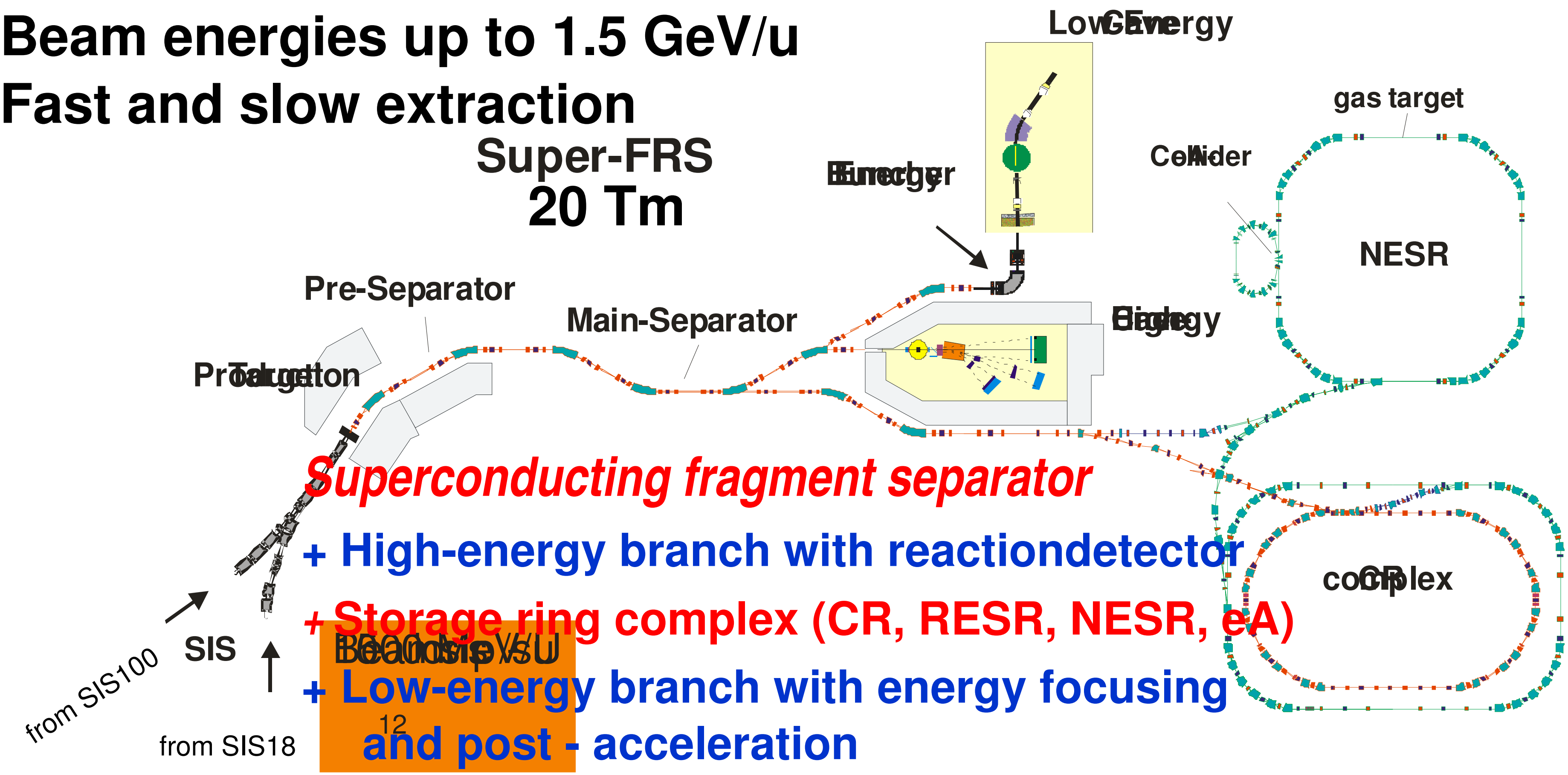


NUSTAR@FAIR

Important beam parameters:

- All elements from H to U
- Intensity ~ $3x10^{11}$ ions/sec.

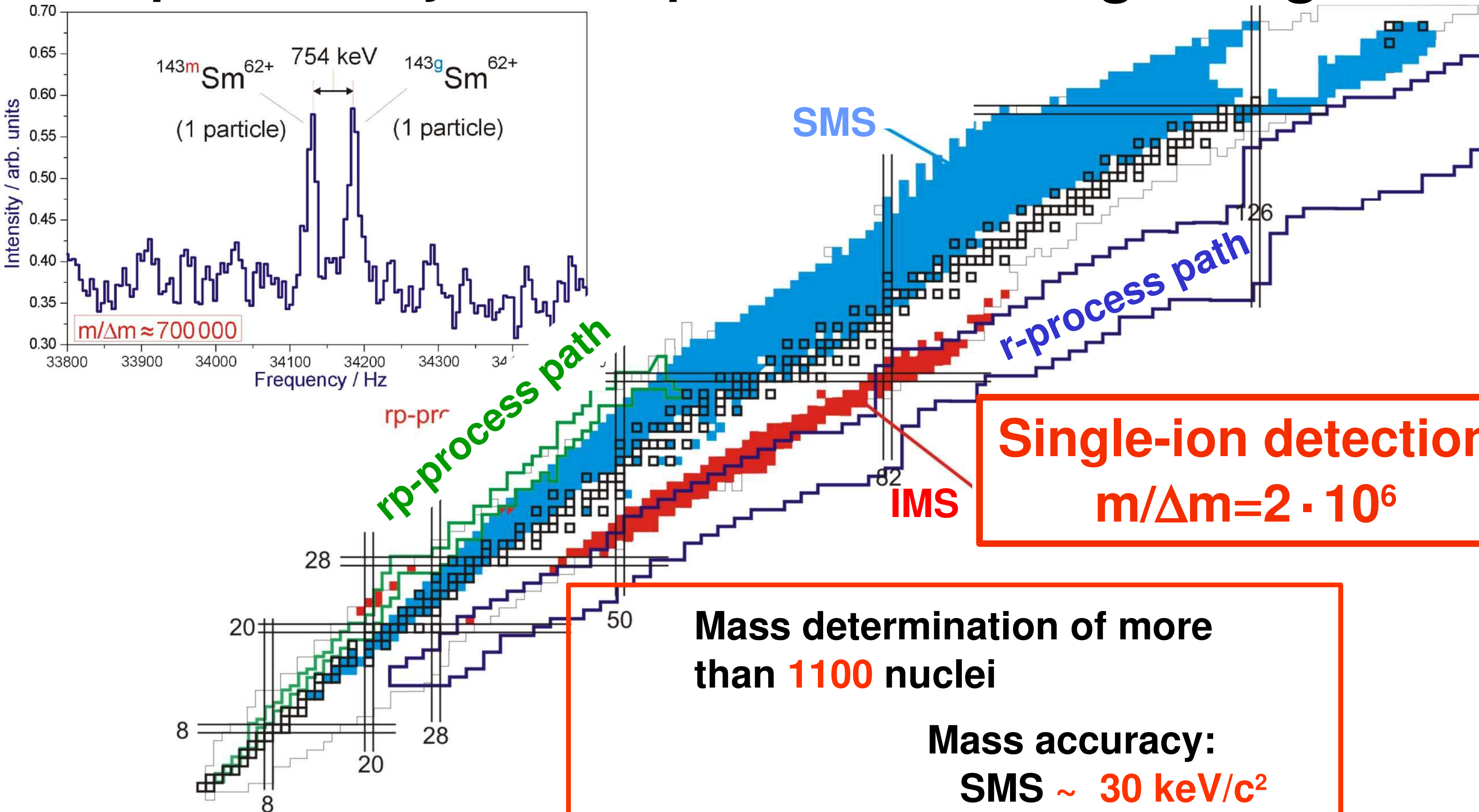
- Beam energies up to 1.5 GeV/u
- Fast and slow extraction



Superconducting fragment separator

+ High-energy branch with reactiondetector
+ Storage ring complex (CR, RESR, NESR, eA)
+ Low-energy branch with energy focusing and post - acceleration

Mass spectrometry: New Experimental Storage Ring ILIMA



Single-ion detection

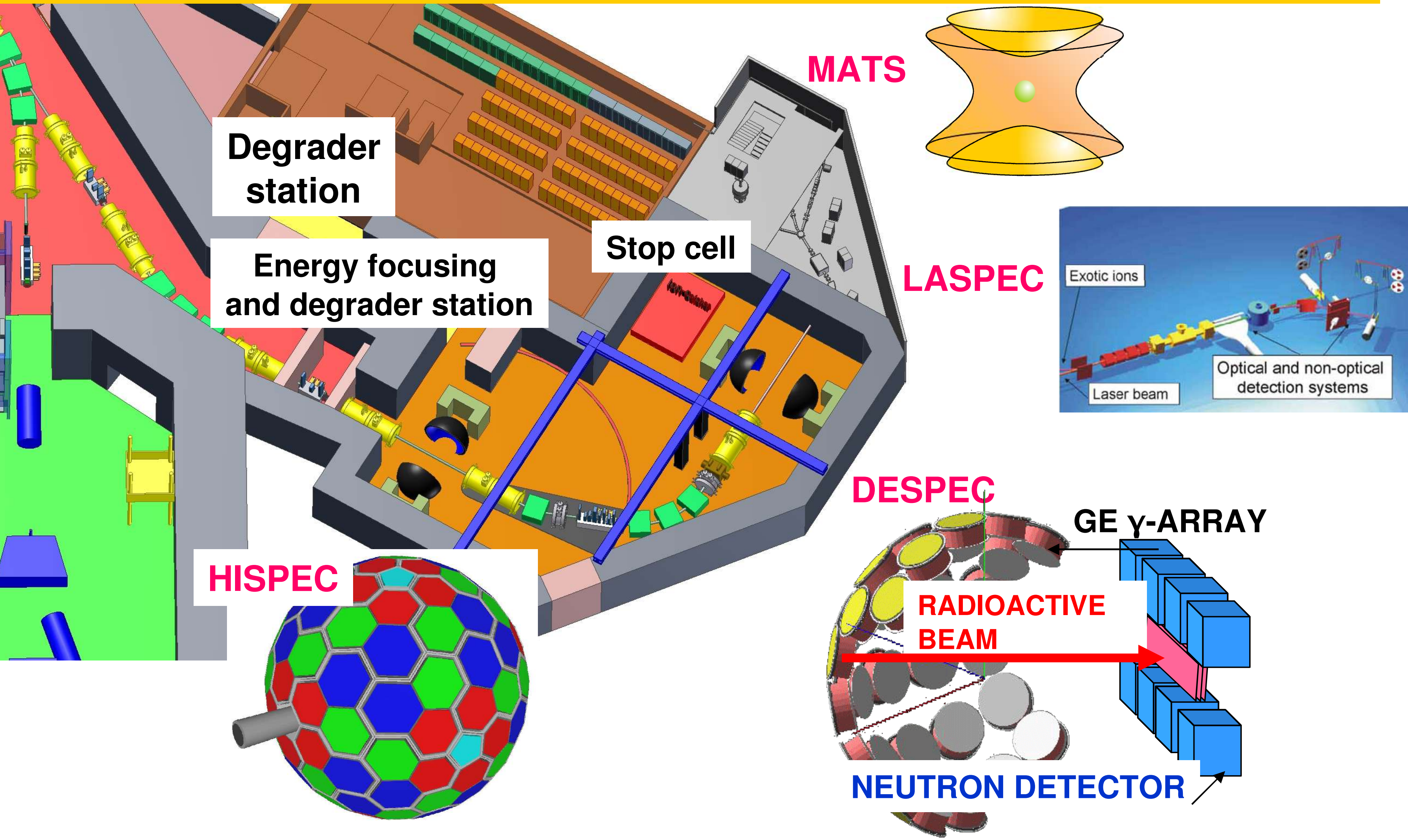
$m/\Delta m = 2 \cdot 10^6$

Mass determination of more than 1100 nuclei

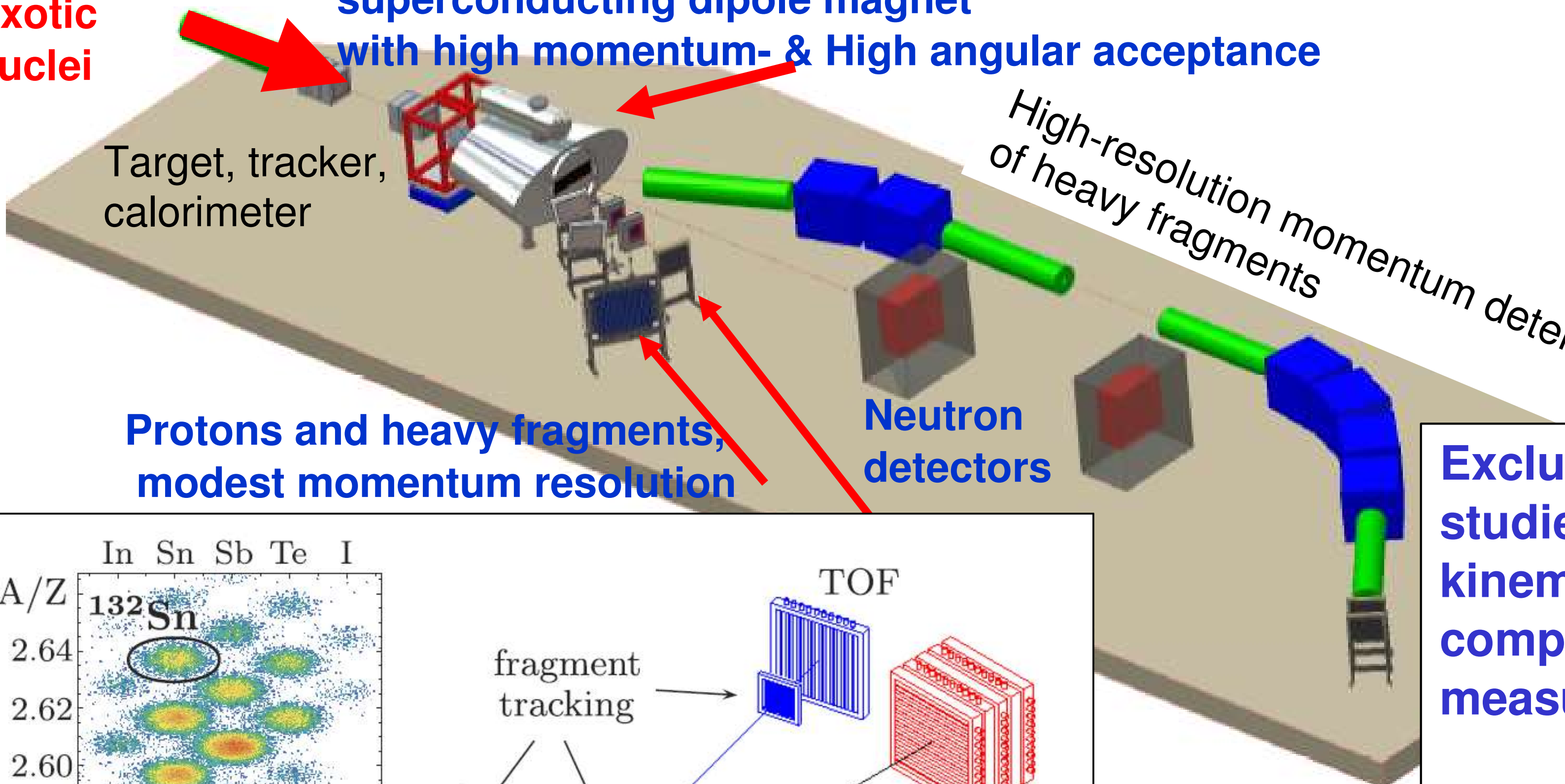
Mass accuracy:
SMS ~ 30 keV/c²
IMS ~ 100 keV/c²

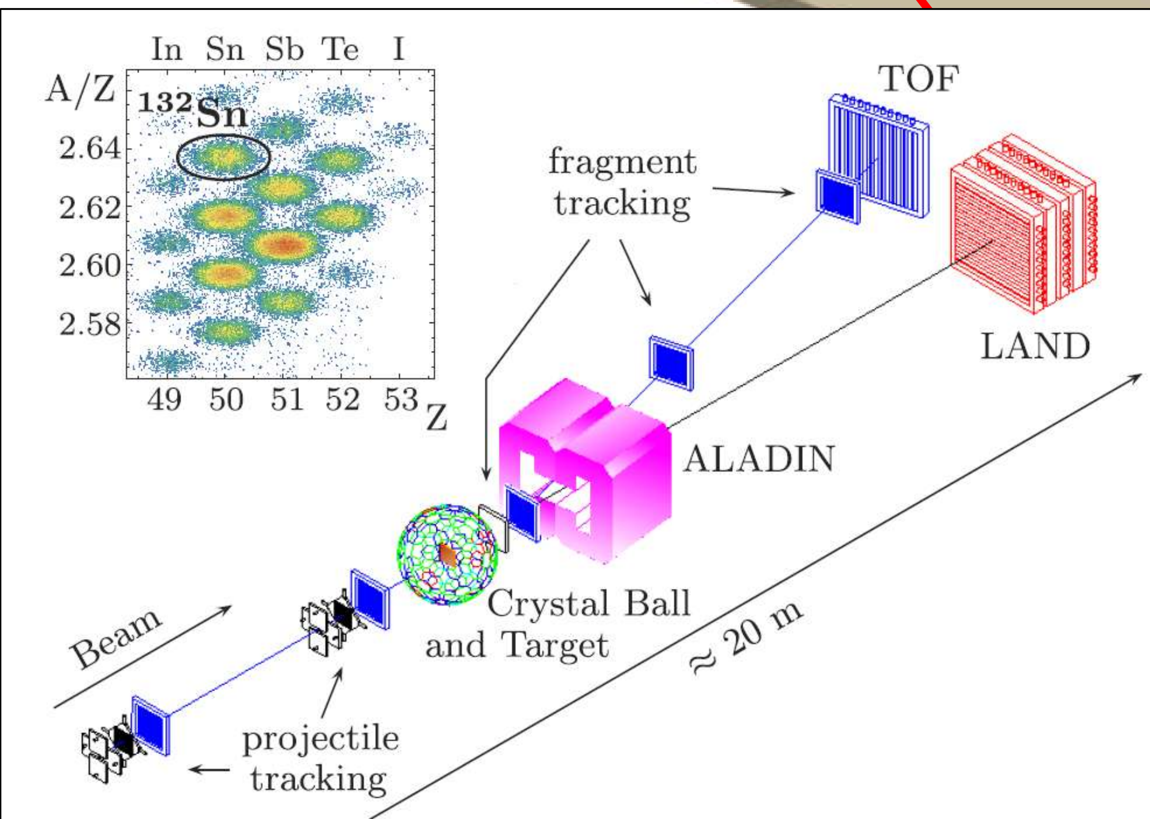
Results:
~ 350 new mass values
~ 300 improved mass values

Experiments with slowed-down, stopped and post-accelerated (single) ions at the **low-energy branch**



Reaction experiments with relativistic radioactive beams at Super-FRS **(R³B)**



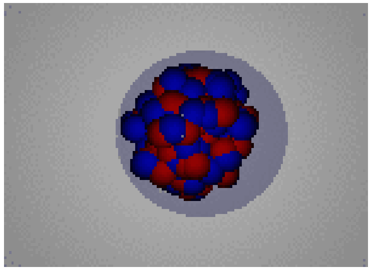


Exclusive reaction studies via kinematically complete measurements:

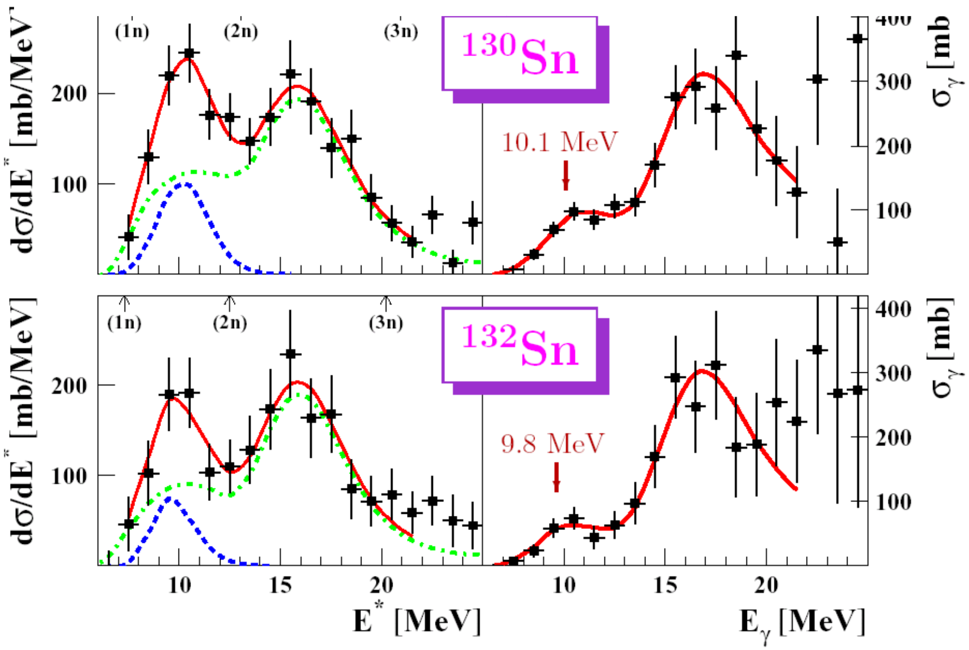
Determination of energy and momentum of all reaction products: reaction microscope

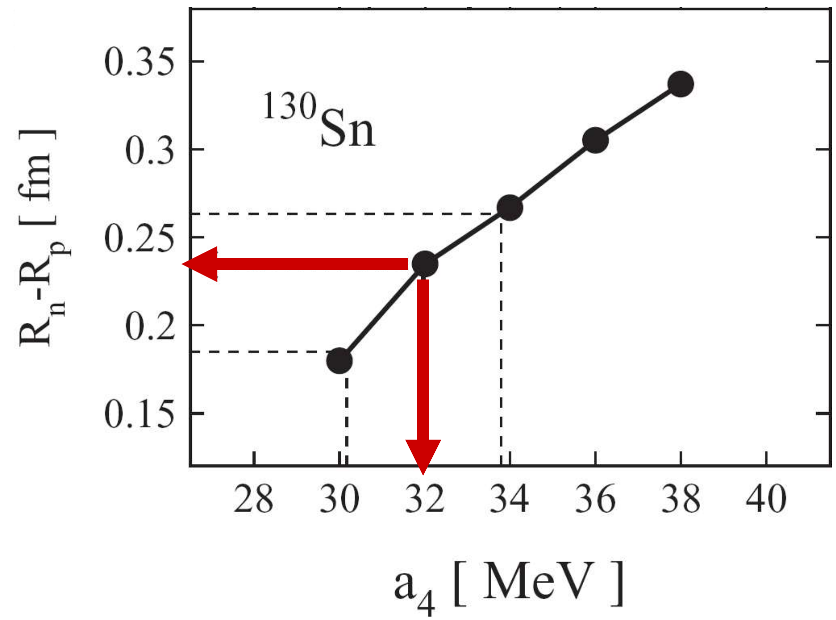
Pygmy-dipole resonance, neutron skins and equation of state of matter

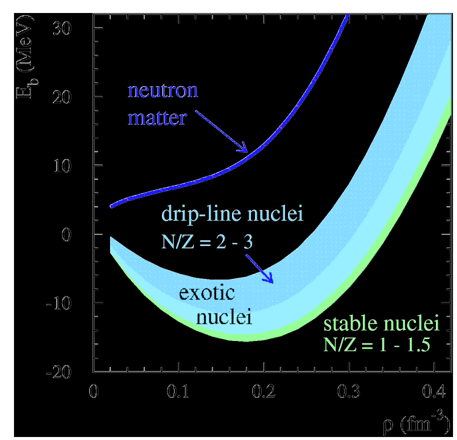
$$E\left(\rho, \frac{N-Z}{A}\right) = E(\rho, 0) + \left(a_4 + \frac{p_0}{\rho_0^2}(\rho - \rho_0)\right) \cdot \left(\frac{N-Z}{A}\right)^2$$



Oscillation of neutron skin versus nuclear core







	GSI	FAIR
Measuring time	10 d	100 s
Energy resolution	1 MeV	0,1 MeV

HypHI Project at GSI/FAIR

HypHI project started, design study

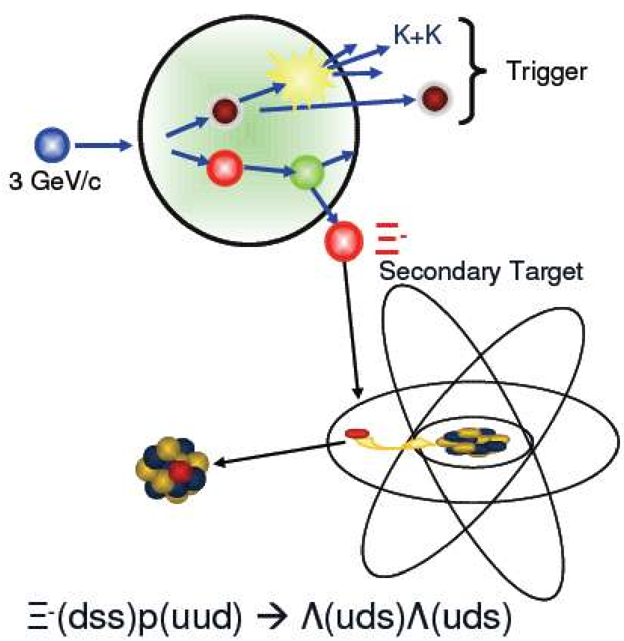
Planned Experiments:

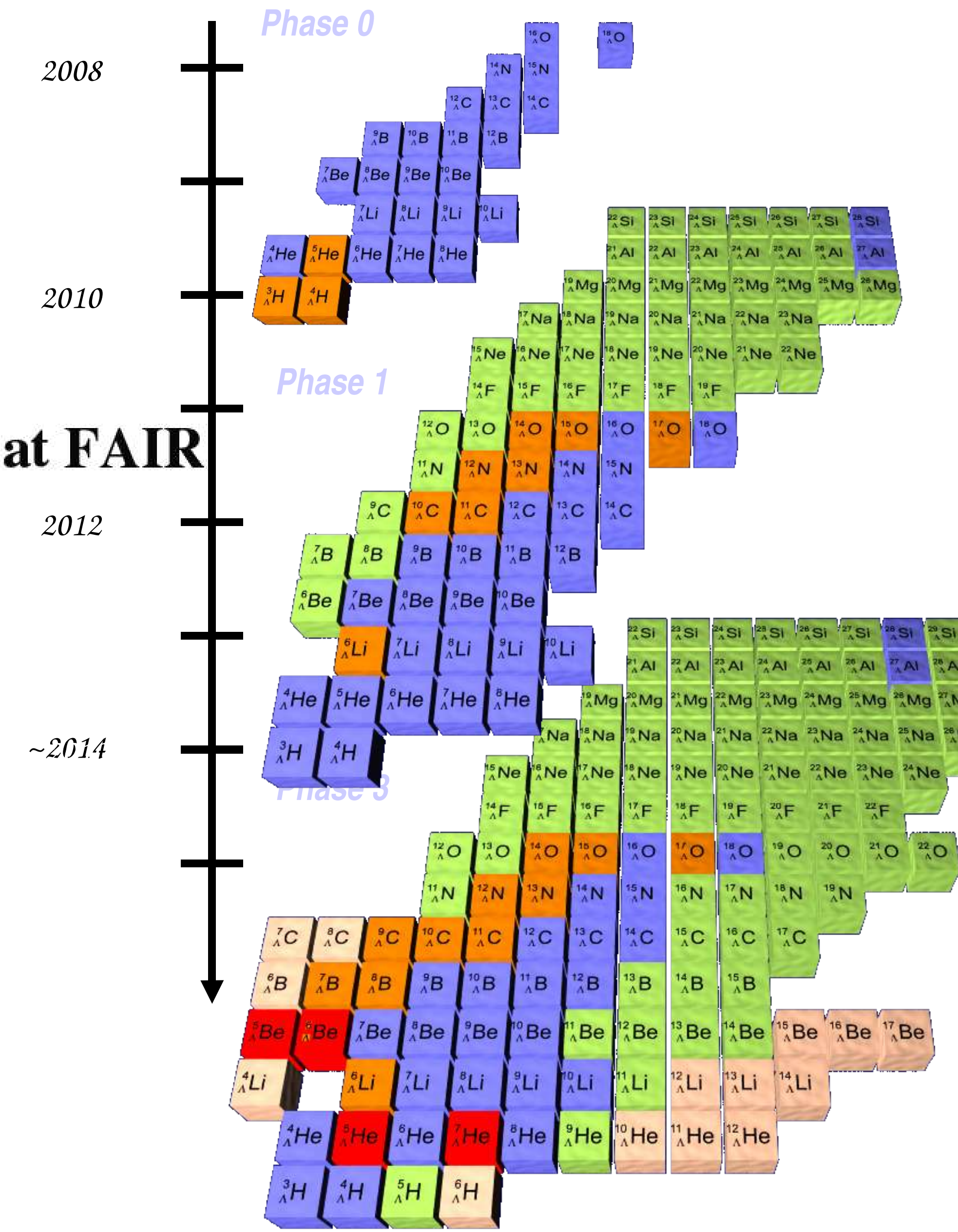
- **$^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ and $^{5}_{\Lambda}He$**
- **proton-rich hypernuclei**
- **neutron- rich hypernuclei at R3B/NuSTAR/FAIR**

Hypernuclear separator:

- **Hypernuclear magnetic moments**
- **Hypernuclear drip-lines**

Production of double hyper-nuclei at FAIR





Yields of Light Nuclei at AGS and Thermal Model

Addition of every nucleon → penalty factor R_p=48

but data are at very low p_t

p_t int. with A-dependent slope → R_p =26

Grand Canonical Ensemble:

$R_p \approx \exp[(m_n \pm \mu_b)/T]$

for T=125 MeV and μ_b = 540 MeV

→ R_p= 23 good agreement!

also good for antideuterons

data: R_p=2±1 10^5 GC: R_p=1.3 10^5

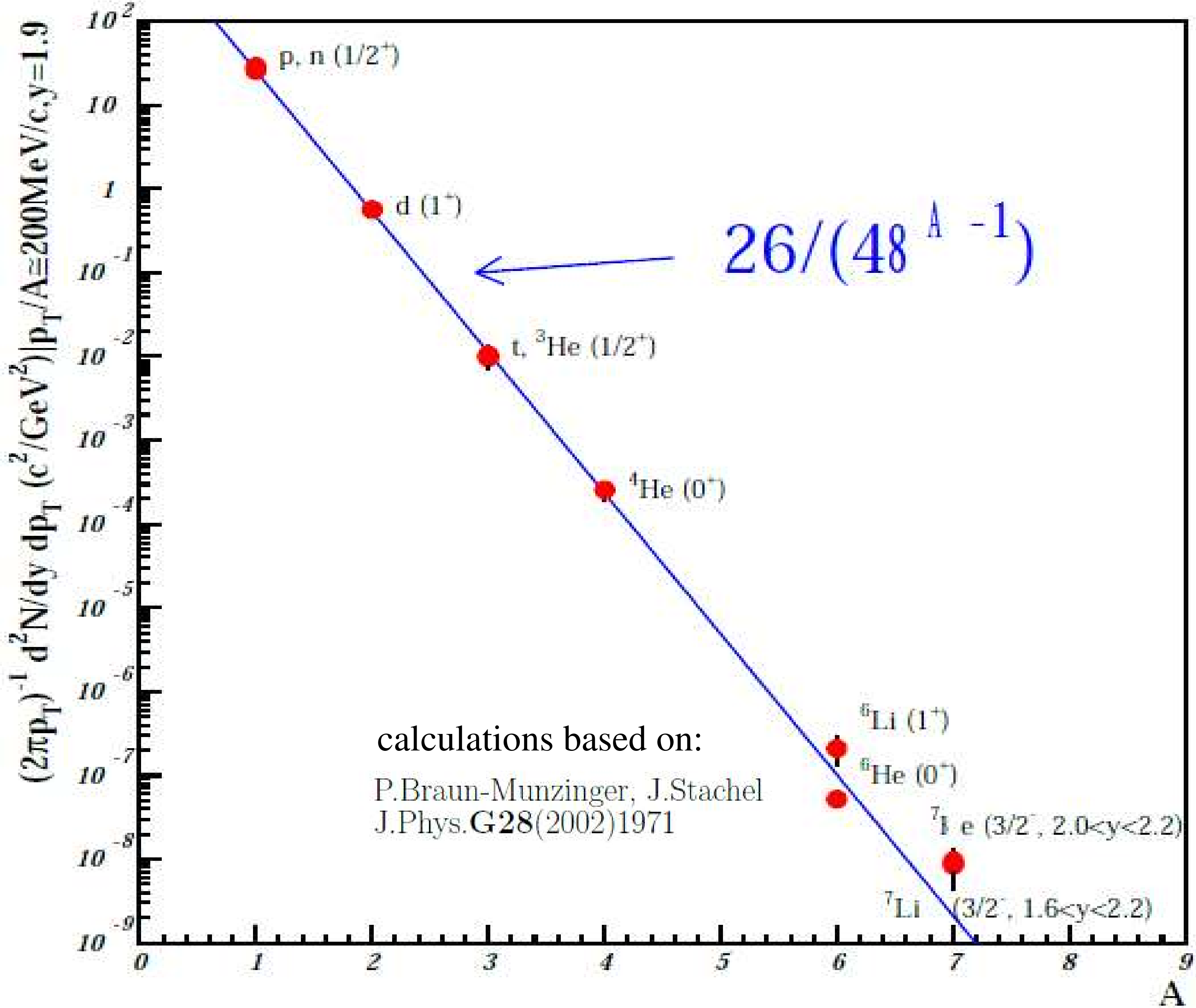
P.Braun-Munzinger, J.Stachel

J.Phys.**G28**(2002)1971

A.Antronic et al.

E864 Collaboration, Phys. Rev. **C61** (2000) 064908

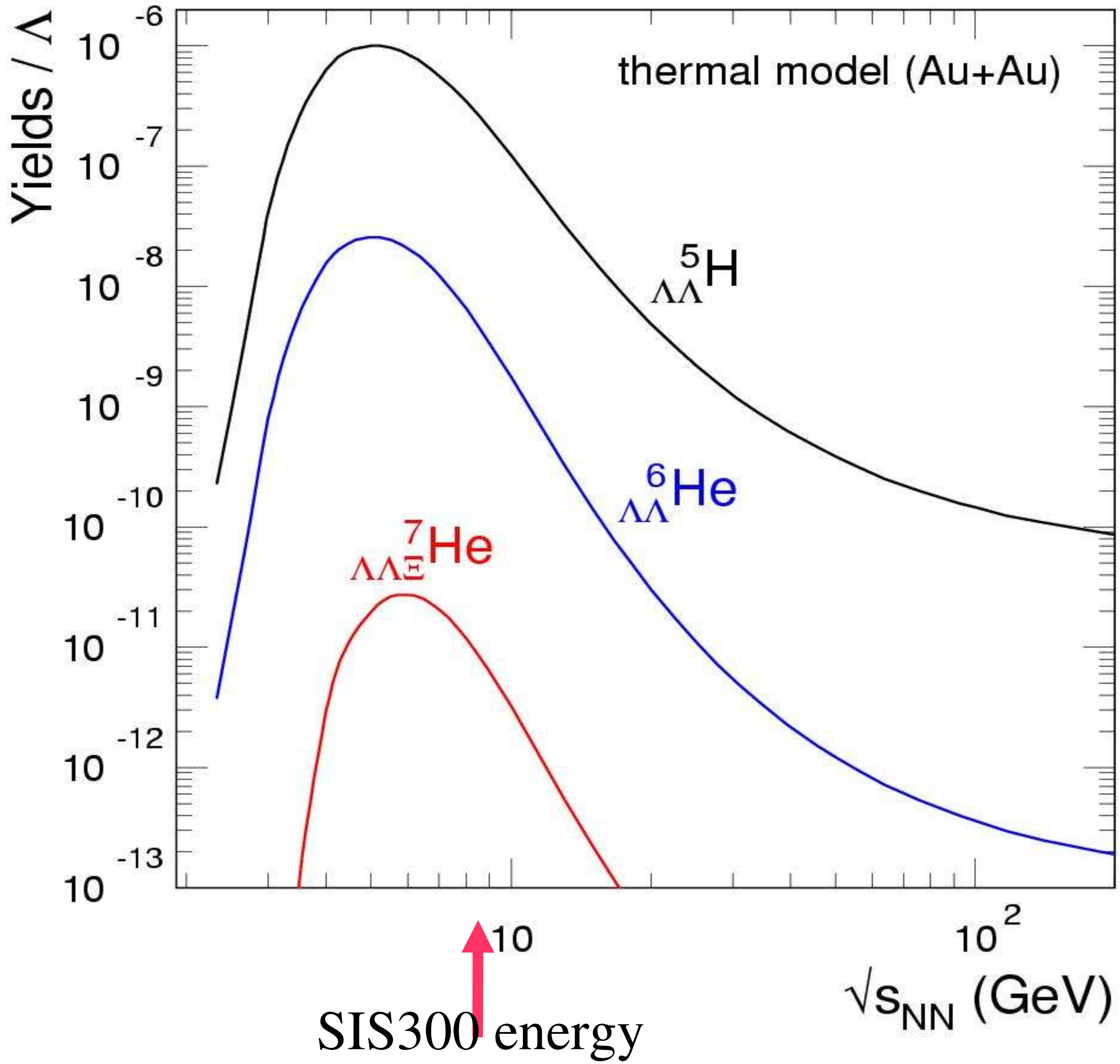
Yields of light nuclei at AGS enery and thermal model calculations



calculations based on:

P.Braun-Munzinger, J.Stachel
J.Phys.**G28**(2002)1971

Production yields of exotic hypernuclei

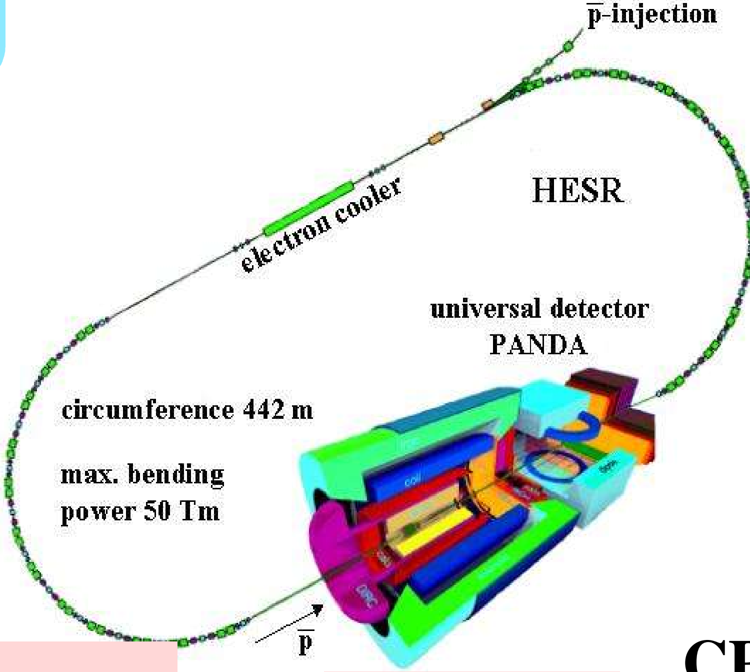


FAIR QCD-Physics Program with Antiprotons

strange and charmed (anti-) baryons in nuclear field

hidden and open charm in nuclei

glueballs (ggg) hybrids ($c\bar{c}g$)



J/ψ spectroscopy confinement, in-medium effects

fundamental symmetries: $\bar{p}$ in traps

FLAIR

HESR Consortium
Jülich / Uppsala / Stockholm / GSI

PANDA

CP-violation (D/Λ - sector)

inverted deeply virtual Compton scattering

spin structure of the proton: polarized antiprotons in PAX

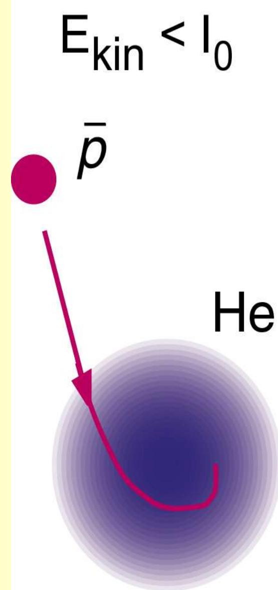
Flair @ FAIR:
Research Topics with Low-Energy Antiprotons

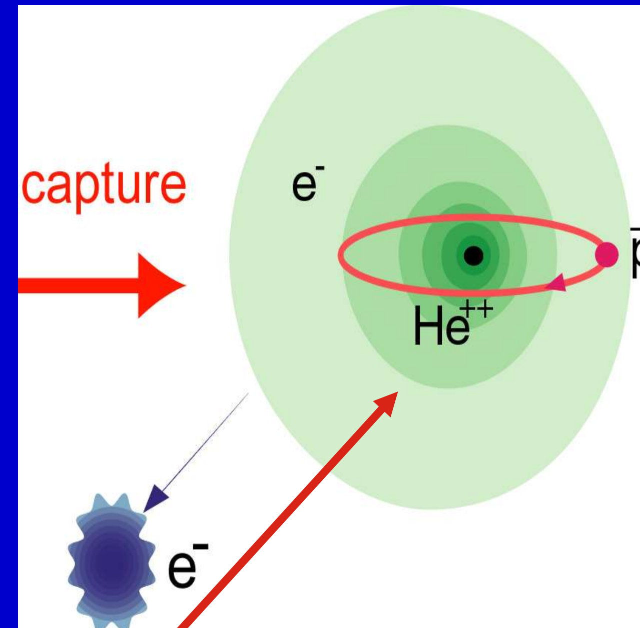
fundamental interactions

- **CPT (antihydrogen, HFS, magnetic moment)**
- **gravitation of antimatter**

- **atomic collision studies**
  - **ionization**
  - **energy loss**
  - **matter-antimatter collisions**
- **anti- protonic atoms**
  - **formation**
  - **strong nuclear interaction and surface effects**
  - **trapping anti- protons in nuclei: short lived bound states?**

***Later perhaps: Low Energy* Anti- He**





$\rho = 5\text{–}10 \times \rho_0$

I.Mishustin; L. Satarov, HSt; W Greiner;

Cold Nuclear Compression by

Vector Attraction of

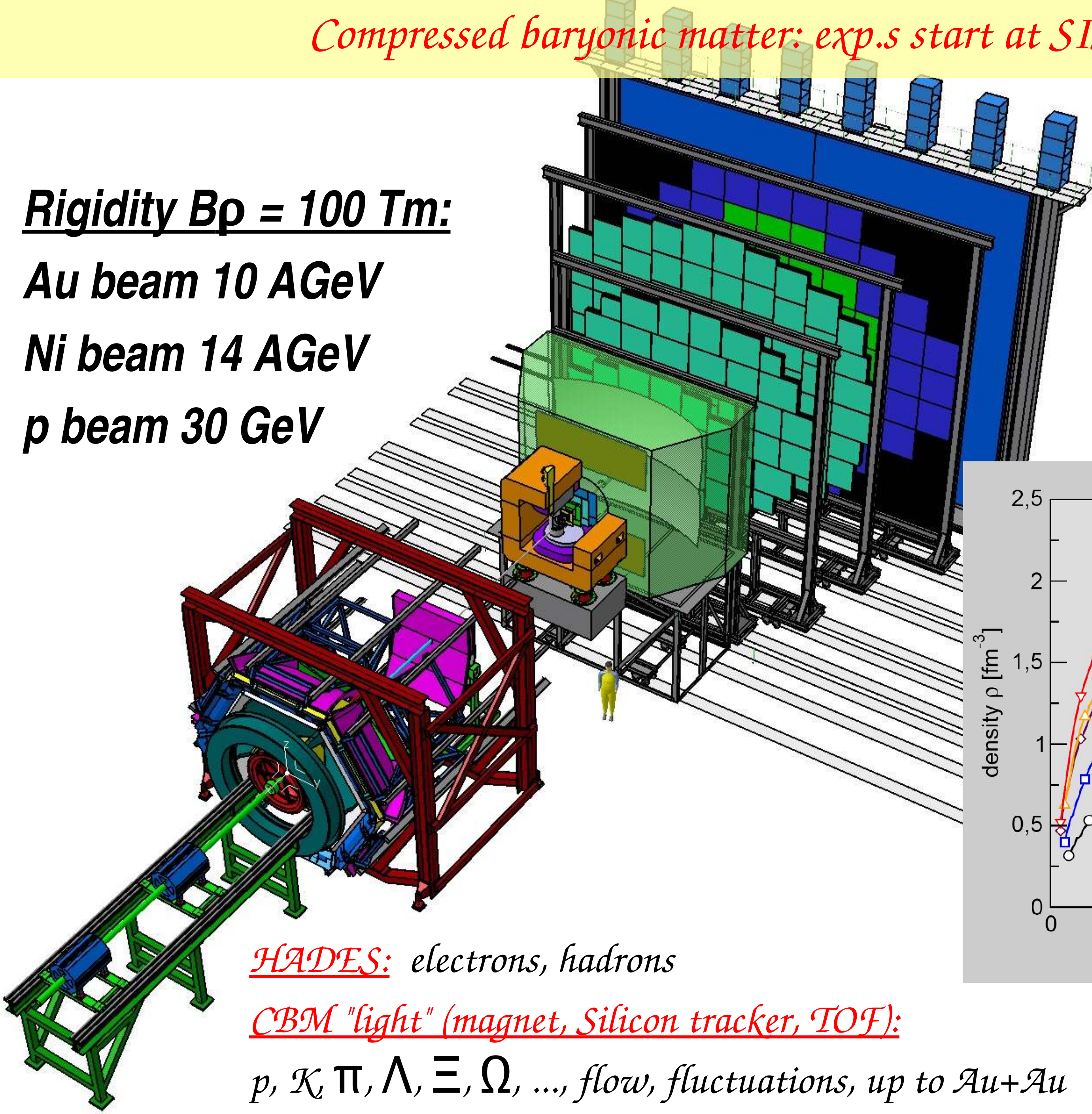
Compressed baryonic matter: exp.s start at SIS100

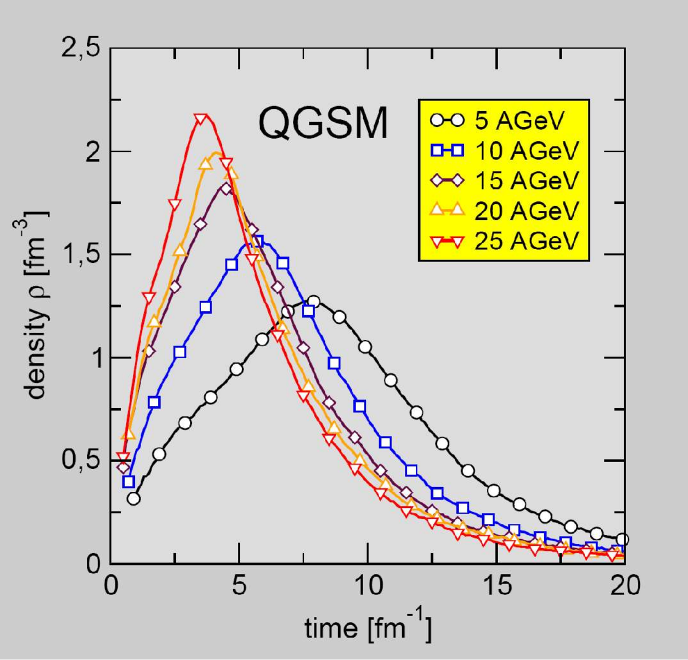
Rigidity Bρ = 100 Tm:

Au beam 10 AGeV

Ni beam 14 AGeV

p beam 30 GeV



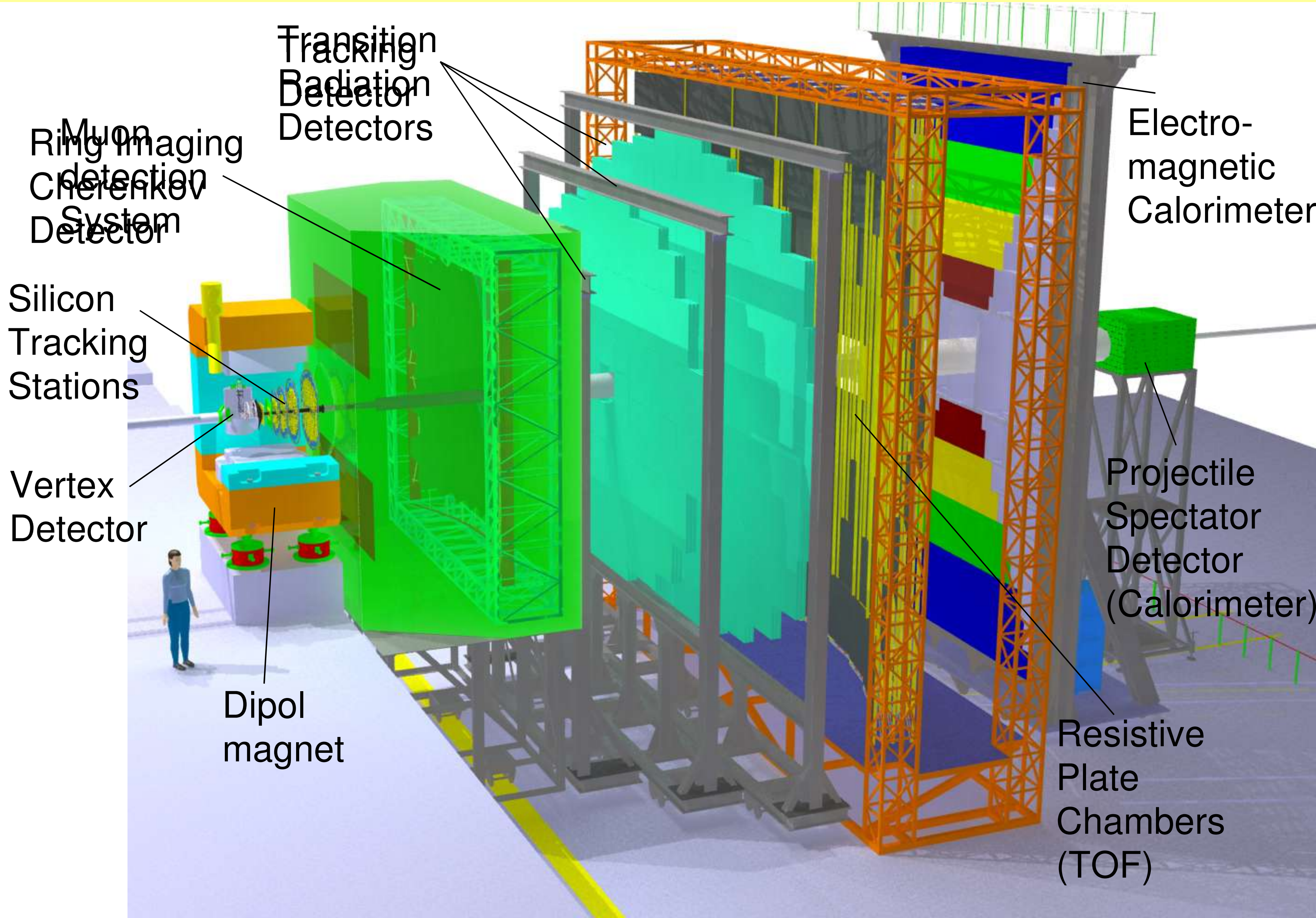


HADES: electrons, hadrons

CBM "light" (magnet, Silicon tracker, TOF):

p, K, π, Λ, Ξ, Ω, ..., flow, fluctuations, up to Au+Au

The Compressed Baryonic Matter Experiment



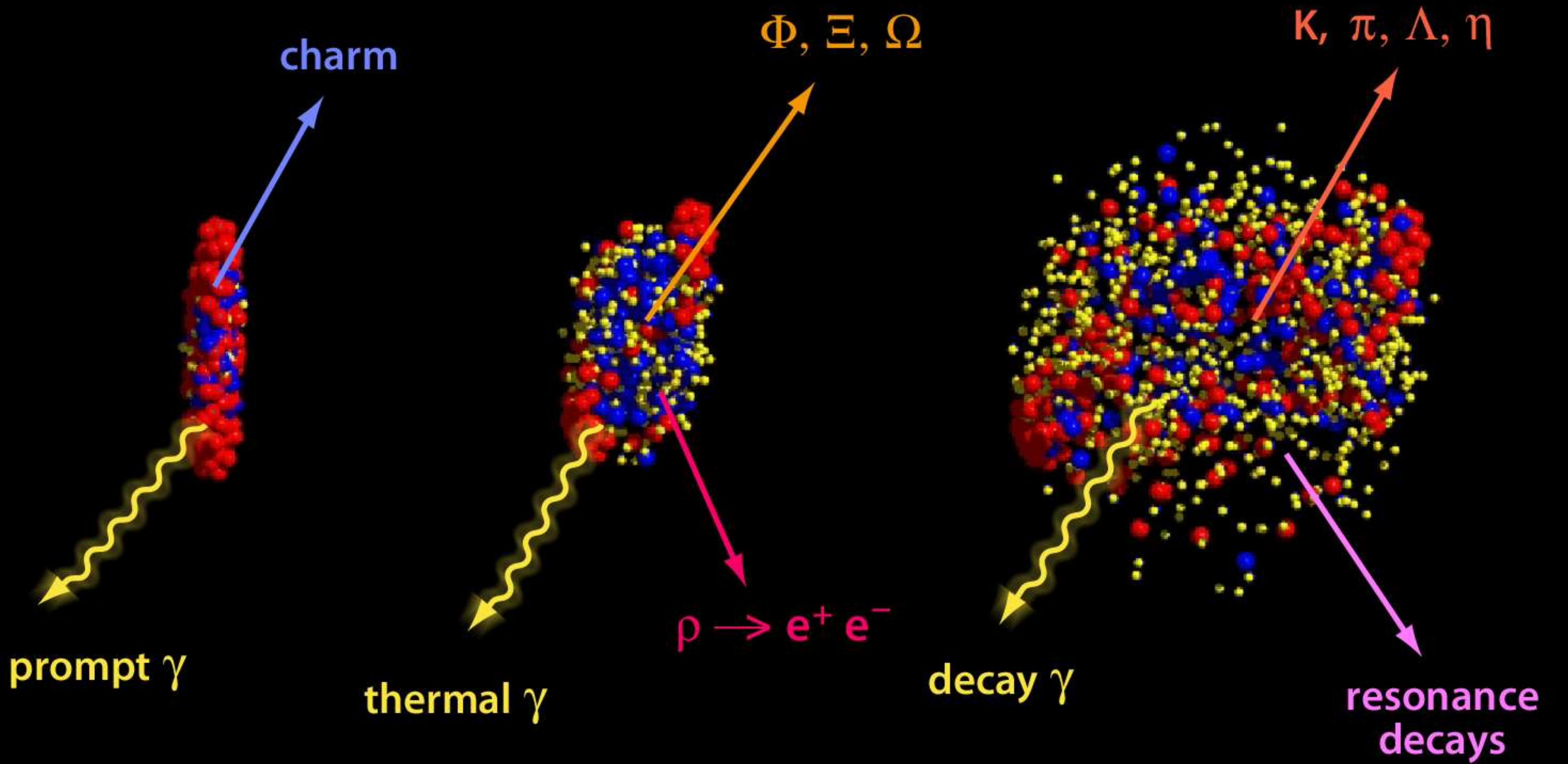
Compressed Baryonic Matter: **CBM Physics Topics**

Probing t*he high density EoS: collapse of coll. flow of protons?*

Q-H phase boundary@high ρ_B*: multi-strange + charmed prod.*

QCD critical point: E-by-E fluctuations; Energydep Hadron Yield

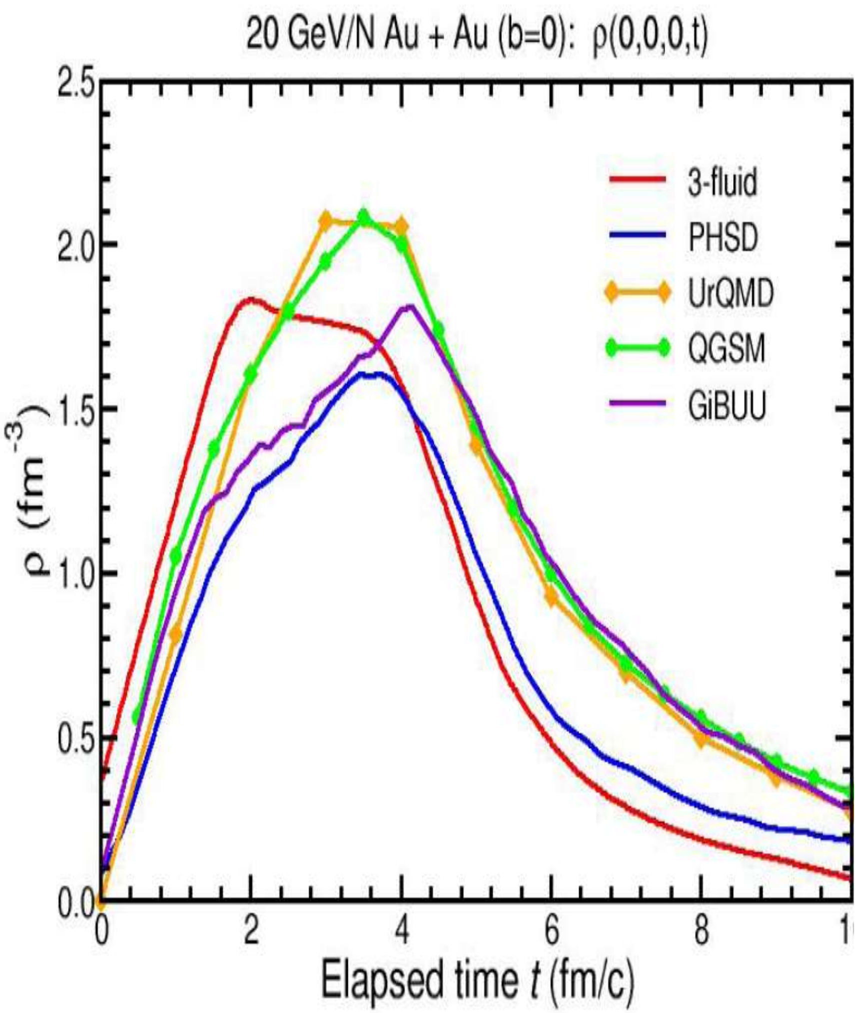
Chiral symmetry rest. at high ρ_B*: open charm, dilepton prod.*

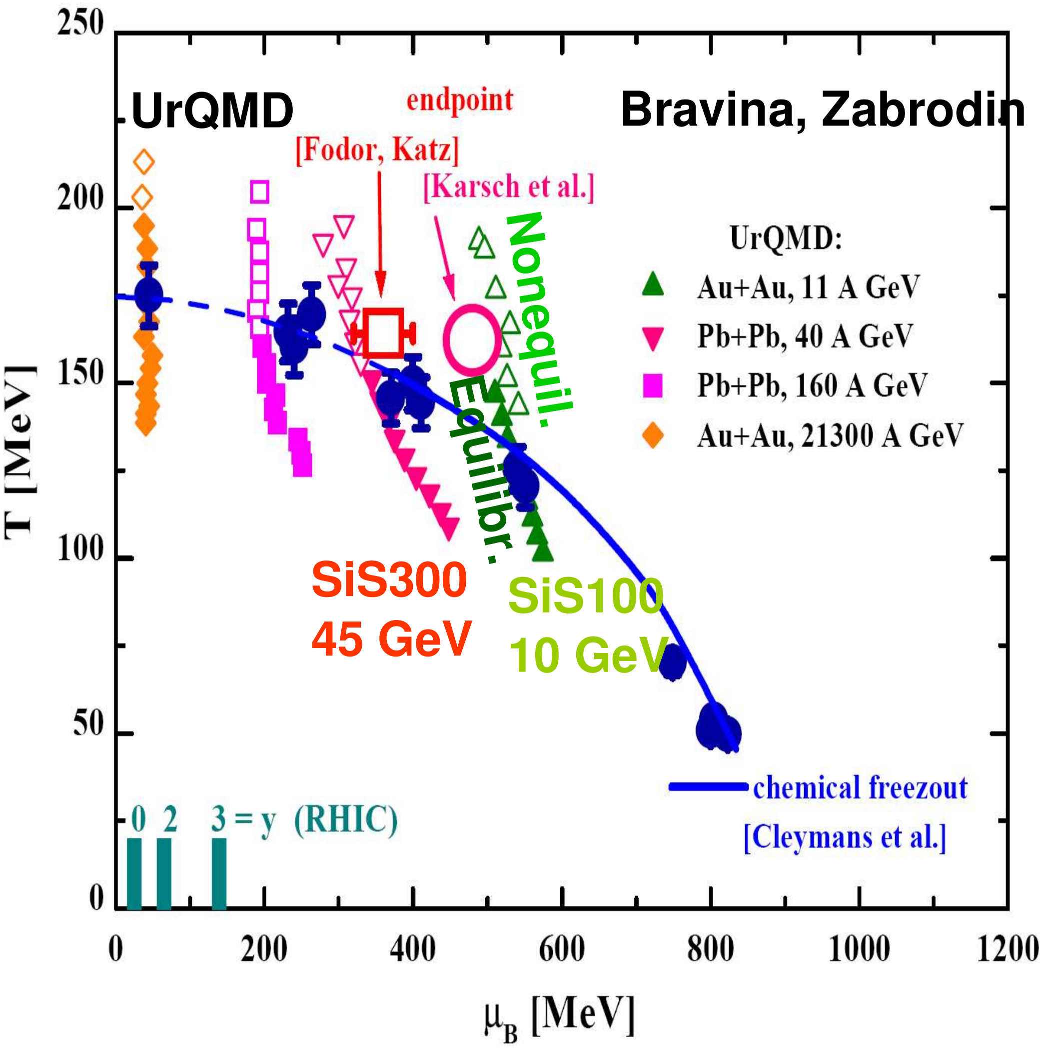


Big Bang- & Neutron Star-matter: CBM @ FAIR

QCD *phases at High Density* ρ_B

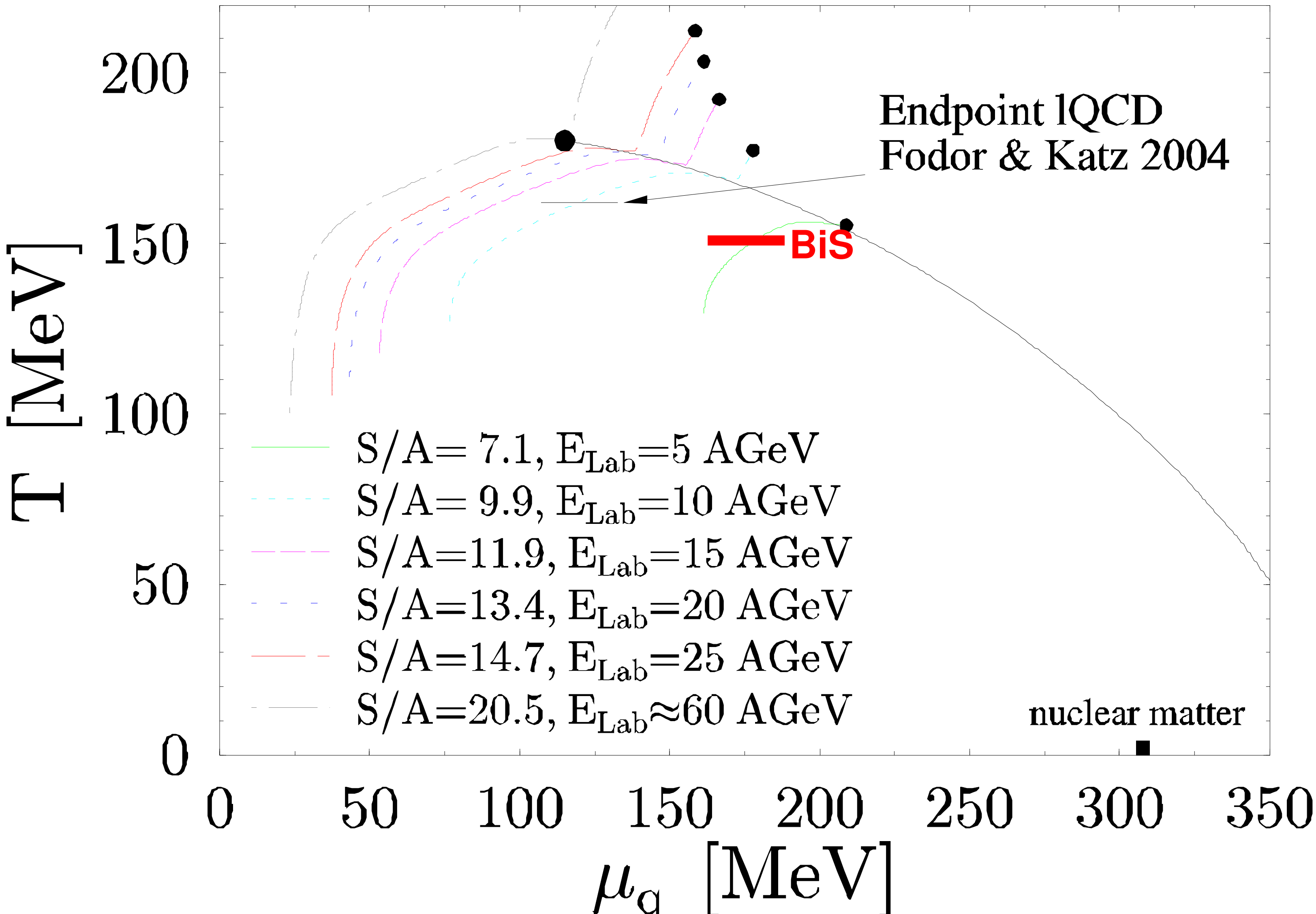
Tenfold Compression! Crossing that 1. Order Transition!





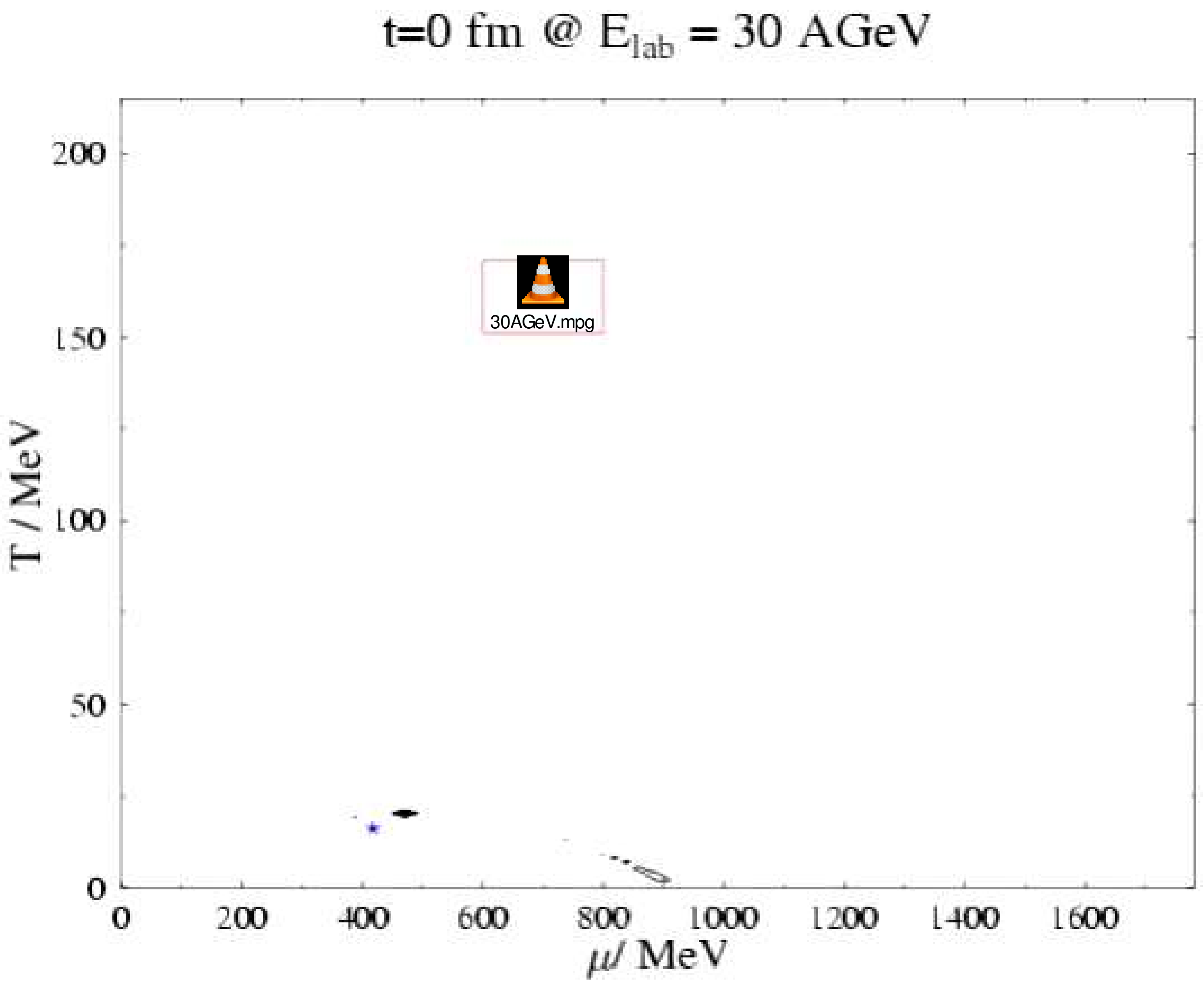
Ideal Hadron Gas differs strongly from

Chiral SU(3) hadron model with mu-crit@S/A=7-10!



Stefan Schramm, D. Zschiesche, G. Zeeb

30AGeV 3Dim 3-Fluid First Order: Baeuchle, Bleicher, H.St.



CBM: rich physics program near the critical point

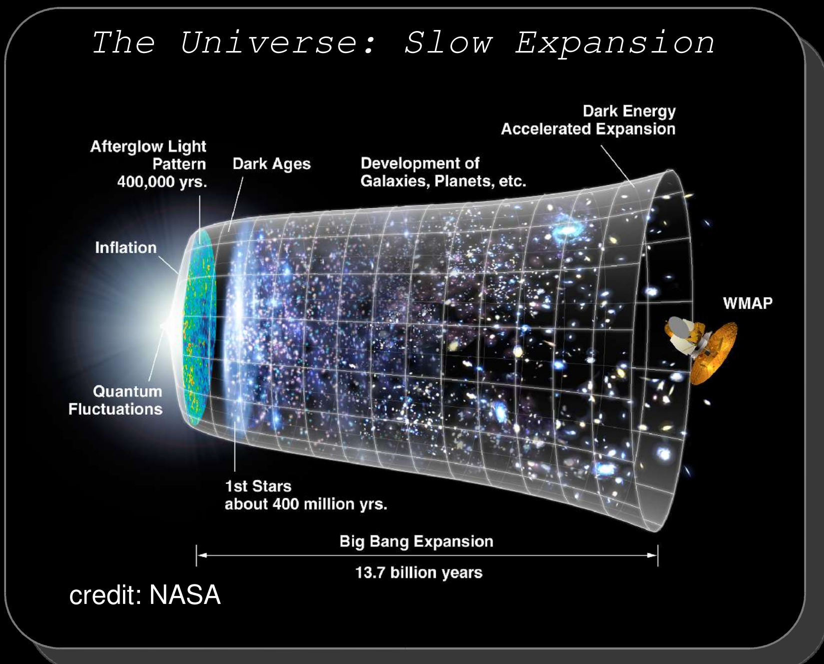
low luminosity
=> abundant probes

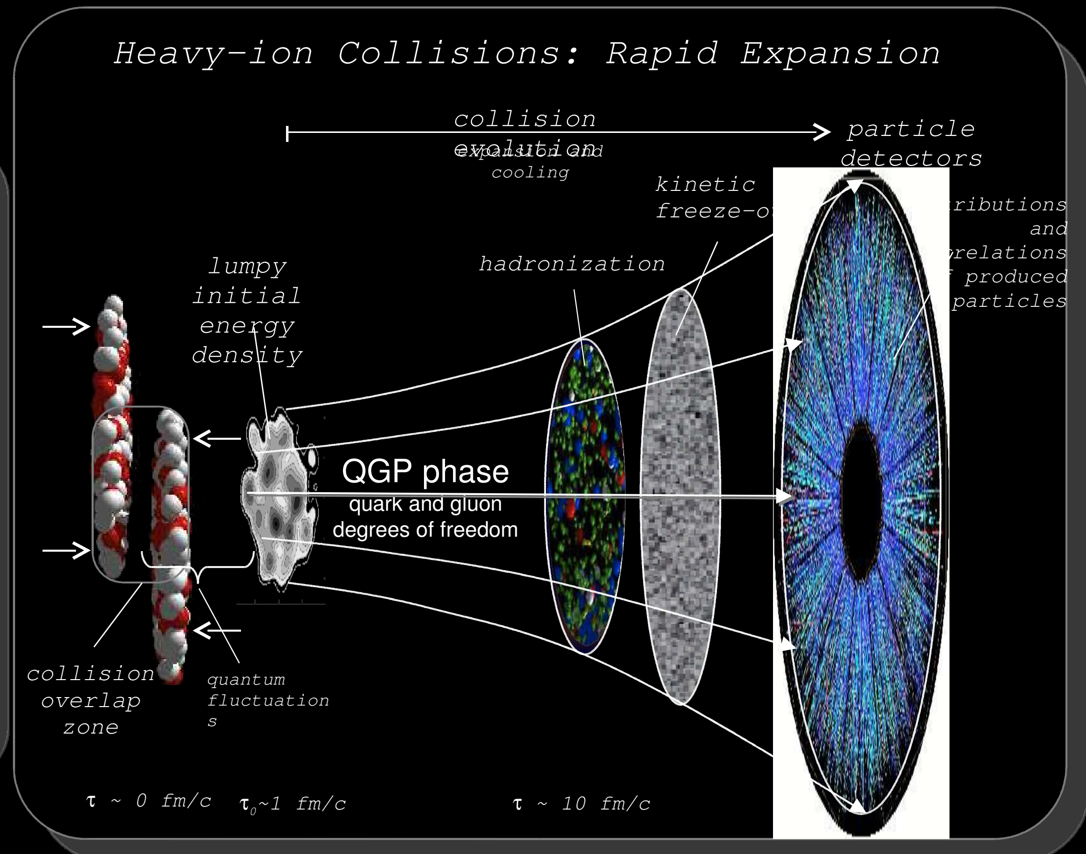
- **yields and particle ratios**
  → *T and μ_B*
- **identified particle elliptic flow $v_{1,2}$**
  → *collapse of proton flow?*
- **K/π, p/π, ⟨p_T⟩ fluctuations**
  → *critical point signal*
- **scale dependence of fluctuations**
  → *source of the signal*
- **v_2 fluctuations**
  → *promising new frontier?*

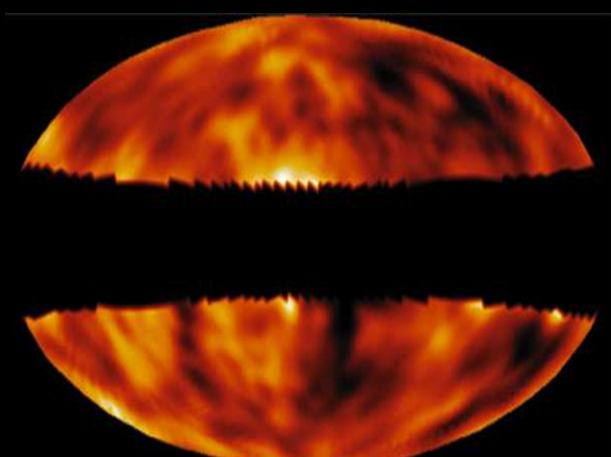
highest luminosity
=> rare probes

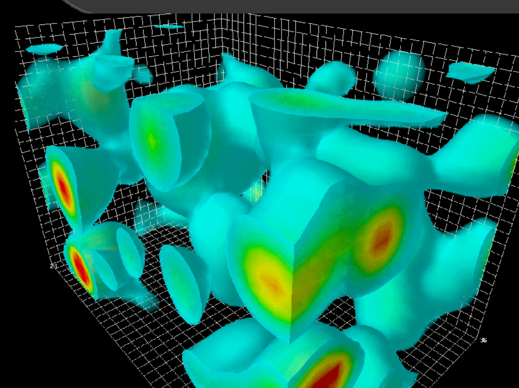
- **rare particle production at threshold**
  → *EOS*
- **flow of charm, melting of quarkonia**
  (J/ψ, ψ', D^0, $D^\pm$, Λ_c)
  → *deconfinement*
- **in medium modific. of vector mesons**
  (ρ,ω,φ → e^+e^-($\mu^+\mu^-$), D)
  → *chiral symmetry restoration*
- **Strange matter droplets**

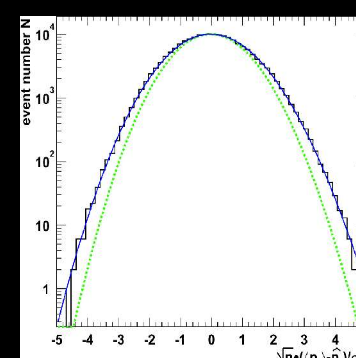
Analogy to the early universe: evolution of critical fluctuations



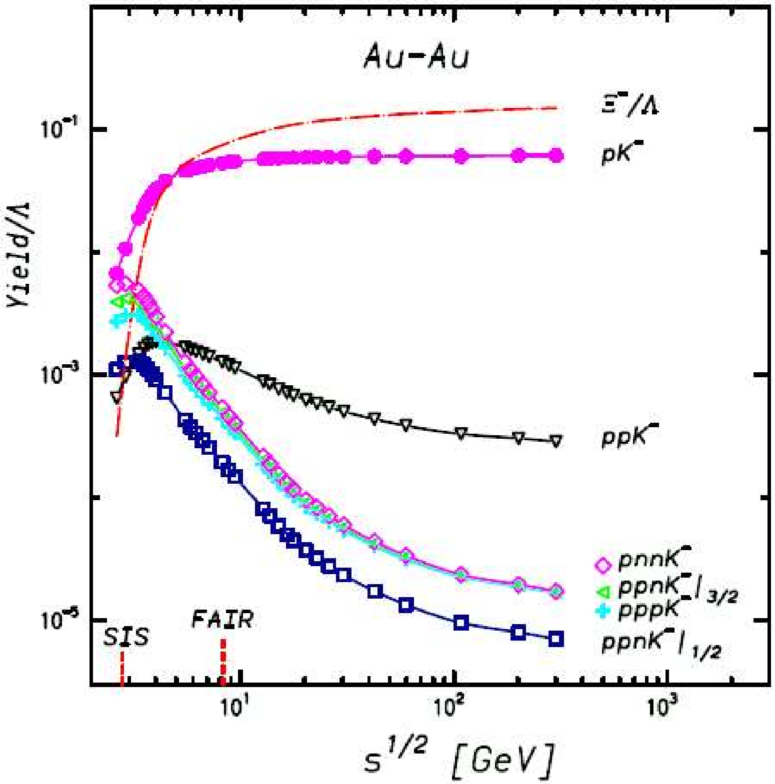


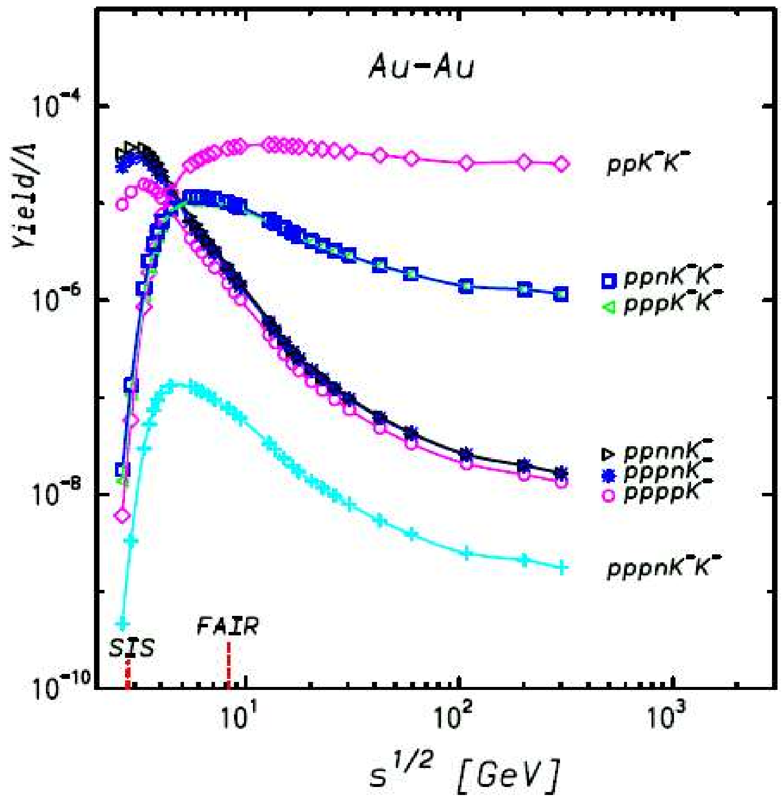




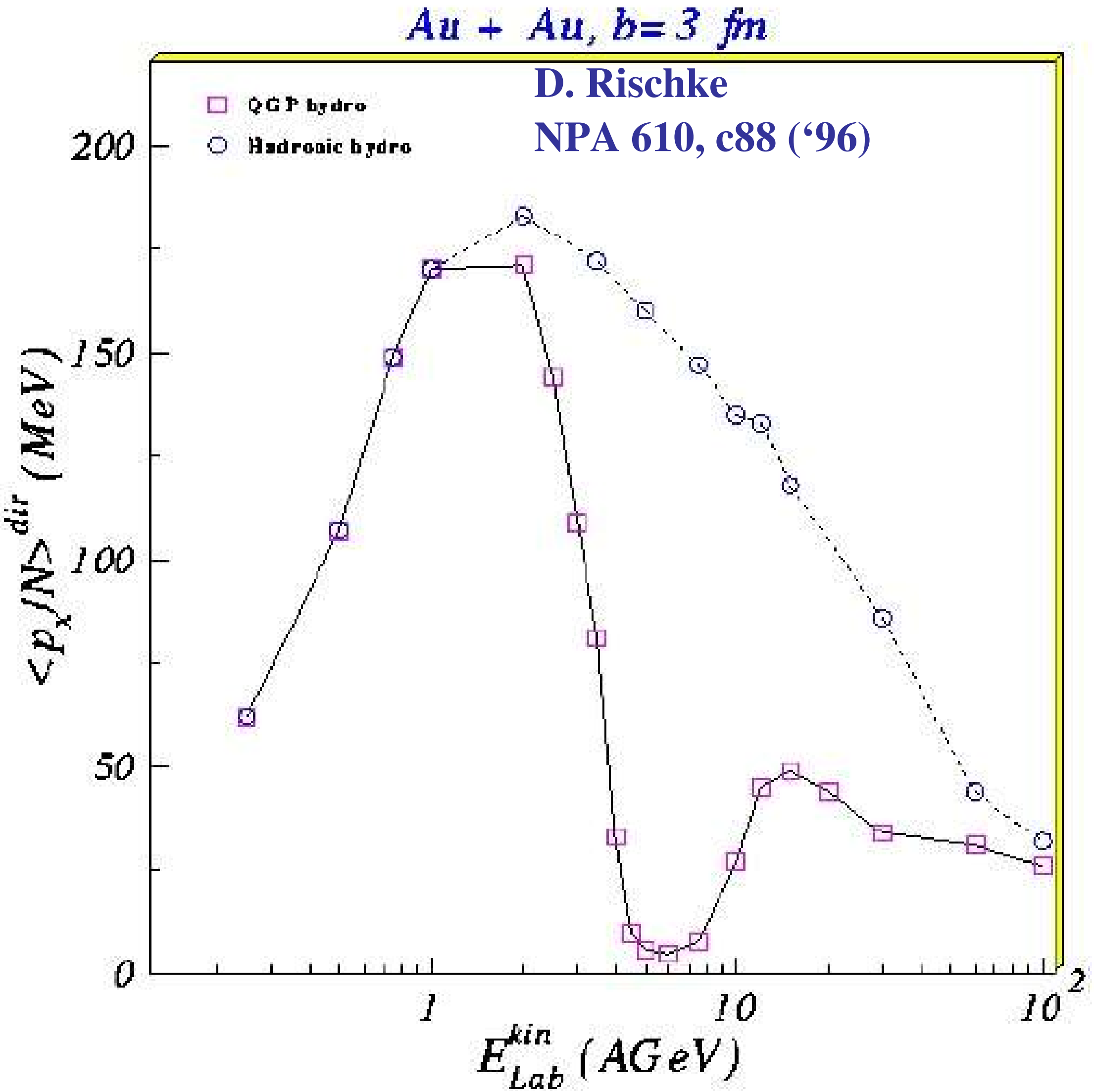


Production yields of possible exotic kaon clusters

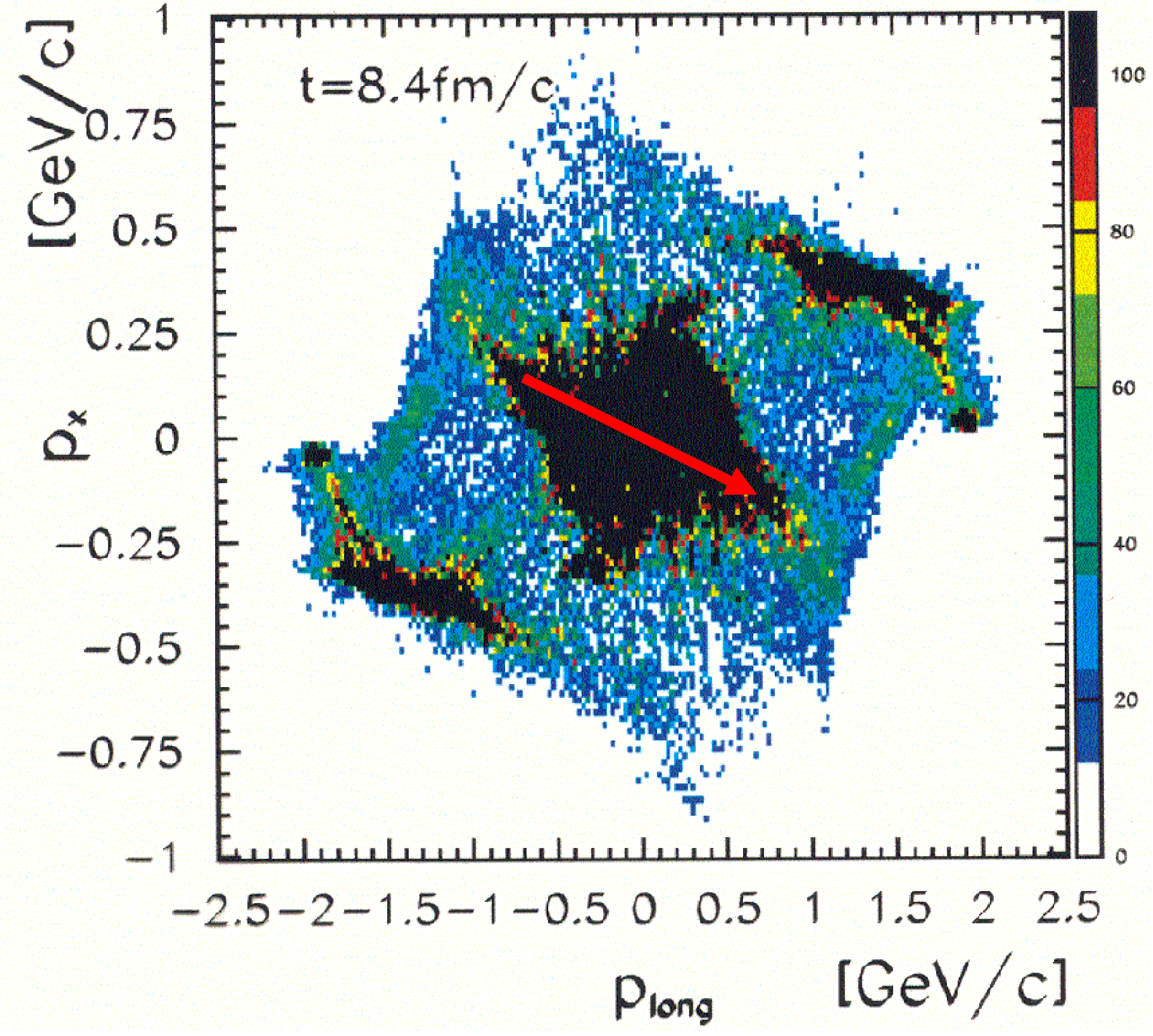




Collapse of Shock at Phase Transition in EoS

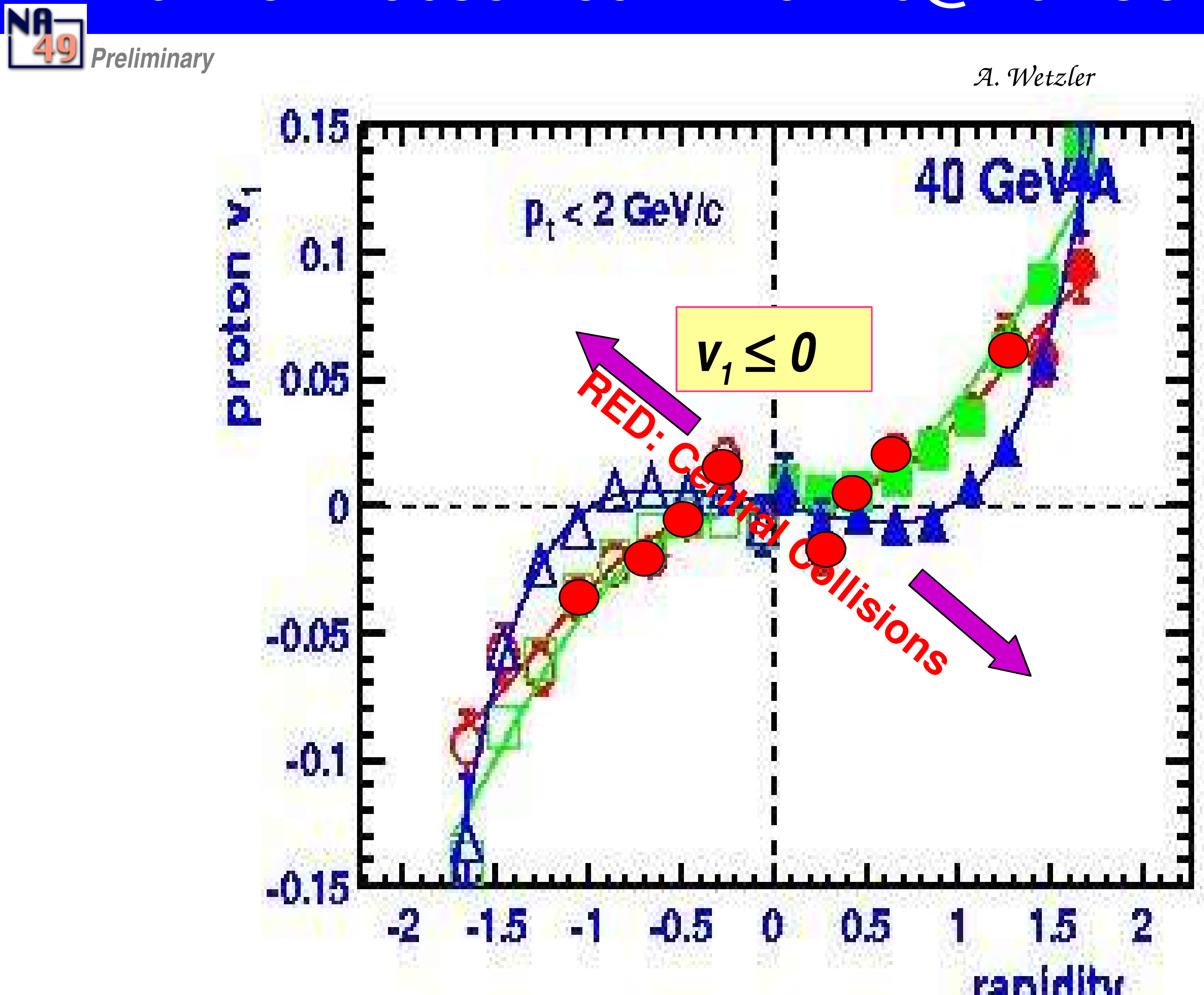


Later dubbed "softest point" of EoS



- Au+Au, 8GeV, b=3fm, Triple differential Cross section

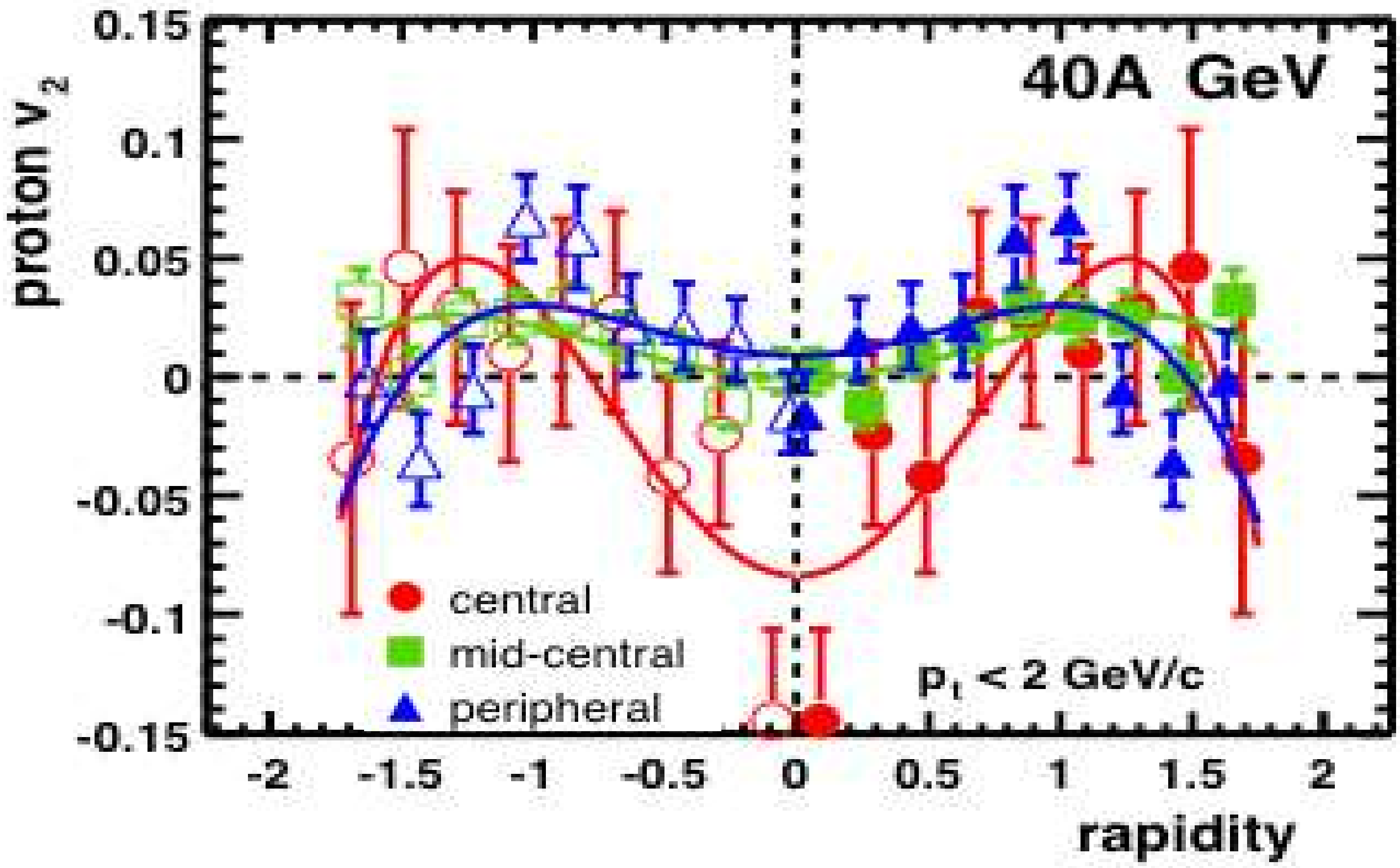
Proton “Anti-Flow” observed in Pb+Pb@40AGeV: NA49



Anti-Flow” discovered? => 1. Order Phase Transition!

Excitation Function: Elliptic flow

NA49 PRC C68 034903 (2003)



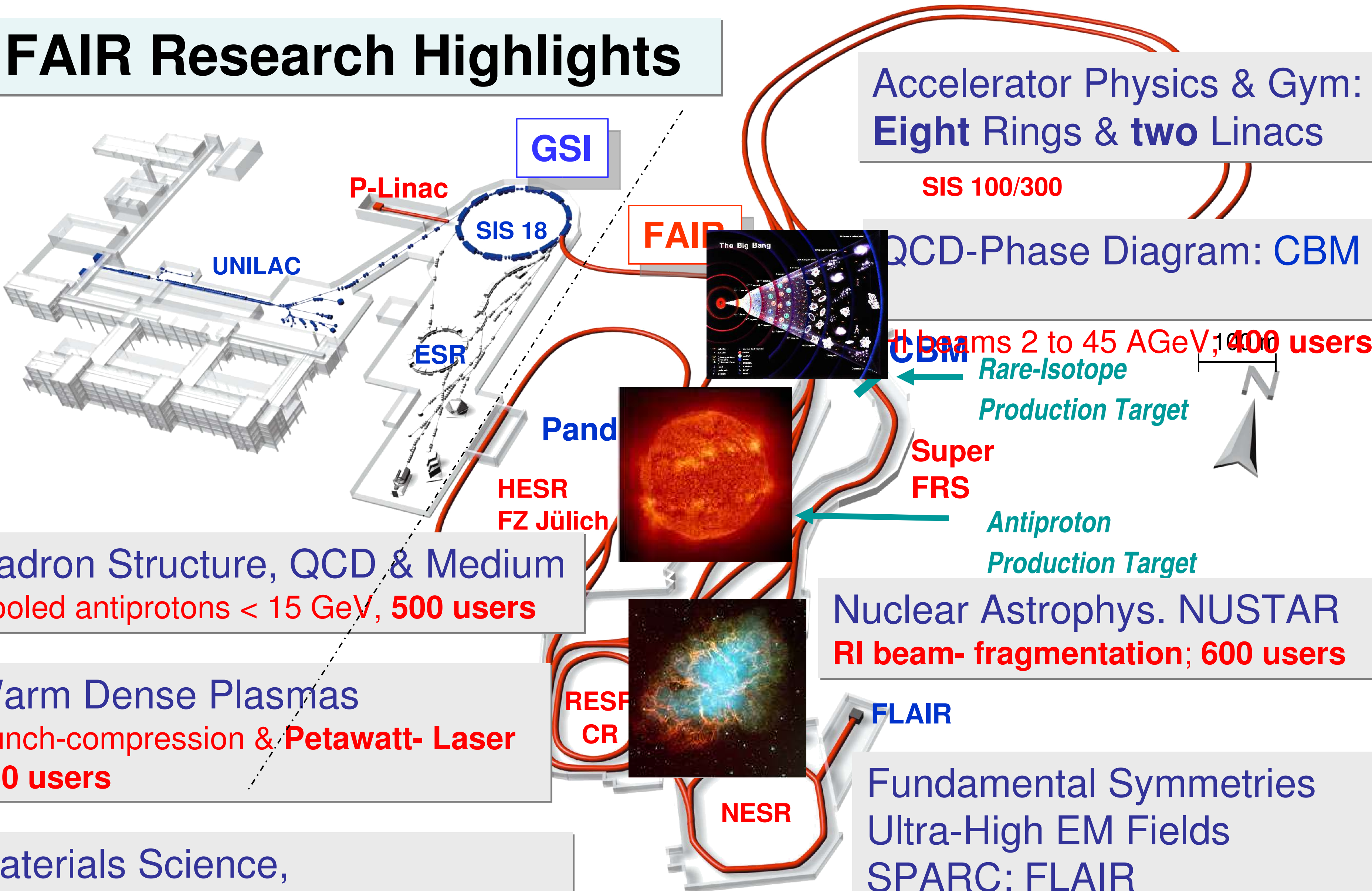
Wetzler, NA49 data: Collapse of proton flow at 40AGeV?

Other measures to look for

- Disappearance of partonic signatures from RHIC
  - Disappearance of quark scaling in particle identified high momentum elliptic flow ?
  - Disappearance of ideal hydro description in low momentum elliptic flow ?
  - Disappearance of nuclear suppression at high momentum ?

- To probe the system - resonances
  - Hadronic lifetime measurements through resonance rescattering and regeneration
  - Chiral symmetry restoration through chiral resonance partners (e.g. ρ and a_1)

FAIR Research Highlights



Accelerator Physics & Gym:
Eight Rings & **two** Linacs

QCD-Phase Diagram: CBM
HI beams 2 to 45 AGeV; **400 users**

Hadron Structure, QCD & Medium
Cooled antiprotons < 15 GeV, **500 users**

Nuclear Astrophys. NUSTAR
RI beam- fragmentation; **600 users**

Warm Dense Plasmas
Bunch-compression & **Petawatt- Laser**
250 users

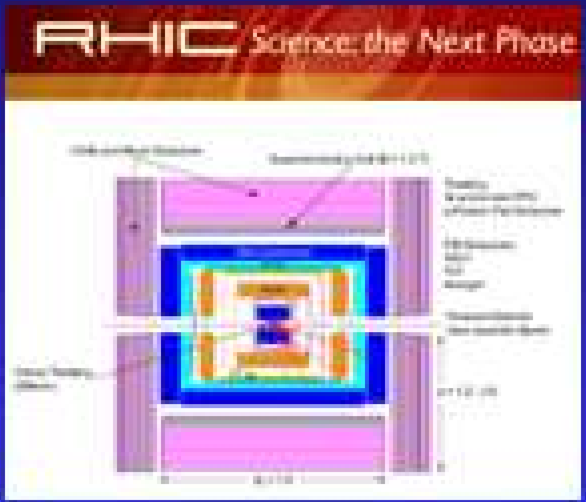
Fundamental Symmetries
Ultra-High EM Fields
SPARC; FLAIR
Antiprotons, Hi-Z ions; **250 users**

Materials Science,
Space- and Radiation Biology
(Ion- & antiproton- beams; **350 users**

The future is bright

A three prong approach:

Highest Intensity | upgrade facility | higher energy



FAIR

Facility for Antiproton & Ion Reseach

RHIC-II

RHIC upgrade with new detector R2D

LHC

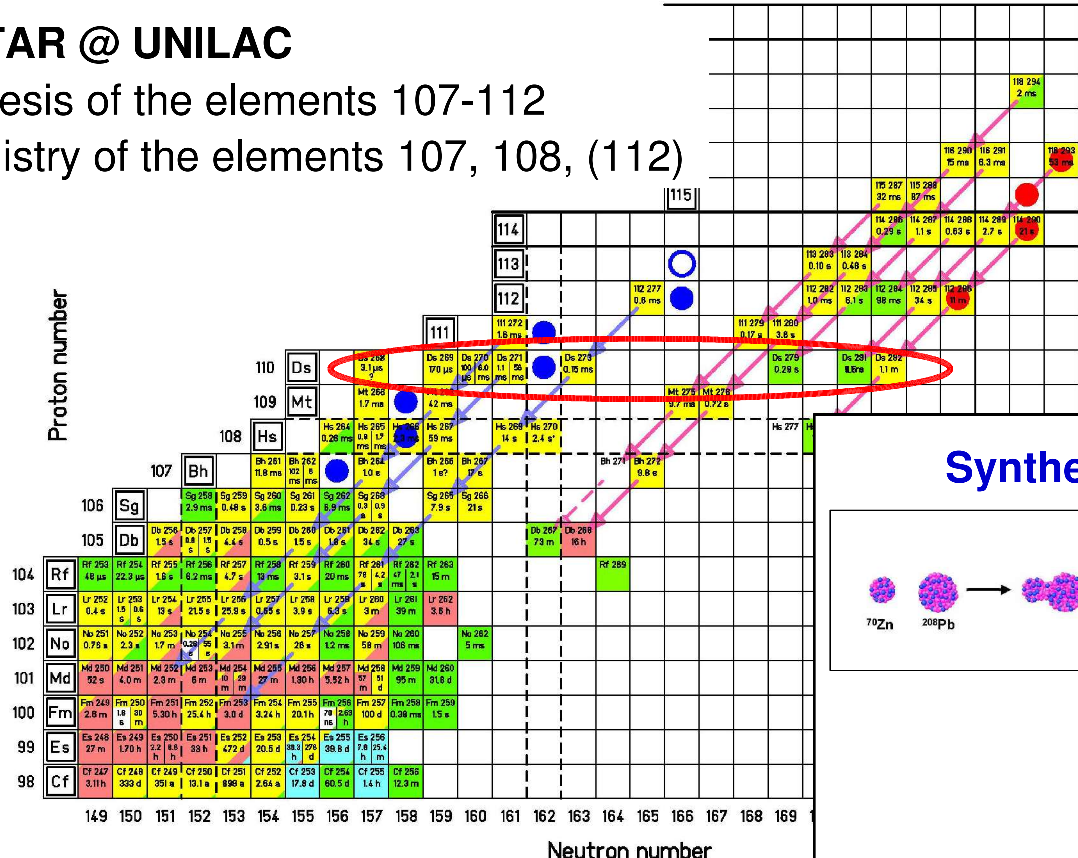
Large Hadron Collider with ALICE, CMS, ATLAS

Synthesis and study of the heaviest elements

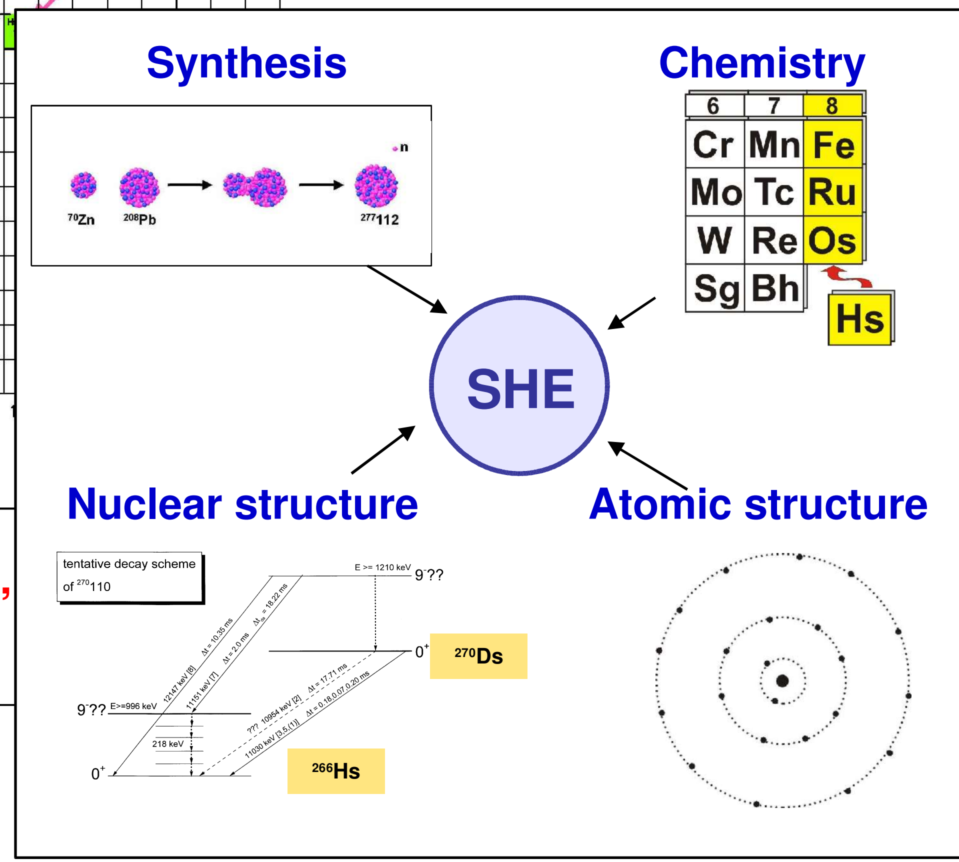
NUSTAR @ UNILAC

Synthesis of the elements 107-112

Chemistry of the elements 107, 108, (112)



SHIP and TASCA



IUPAC:

Element 110 is named "Darmstadtium"

Chemical symbol is "Ds"