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

Horst Stöcker, GSI & FIAS

GSI

FAIR

Observers

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

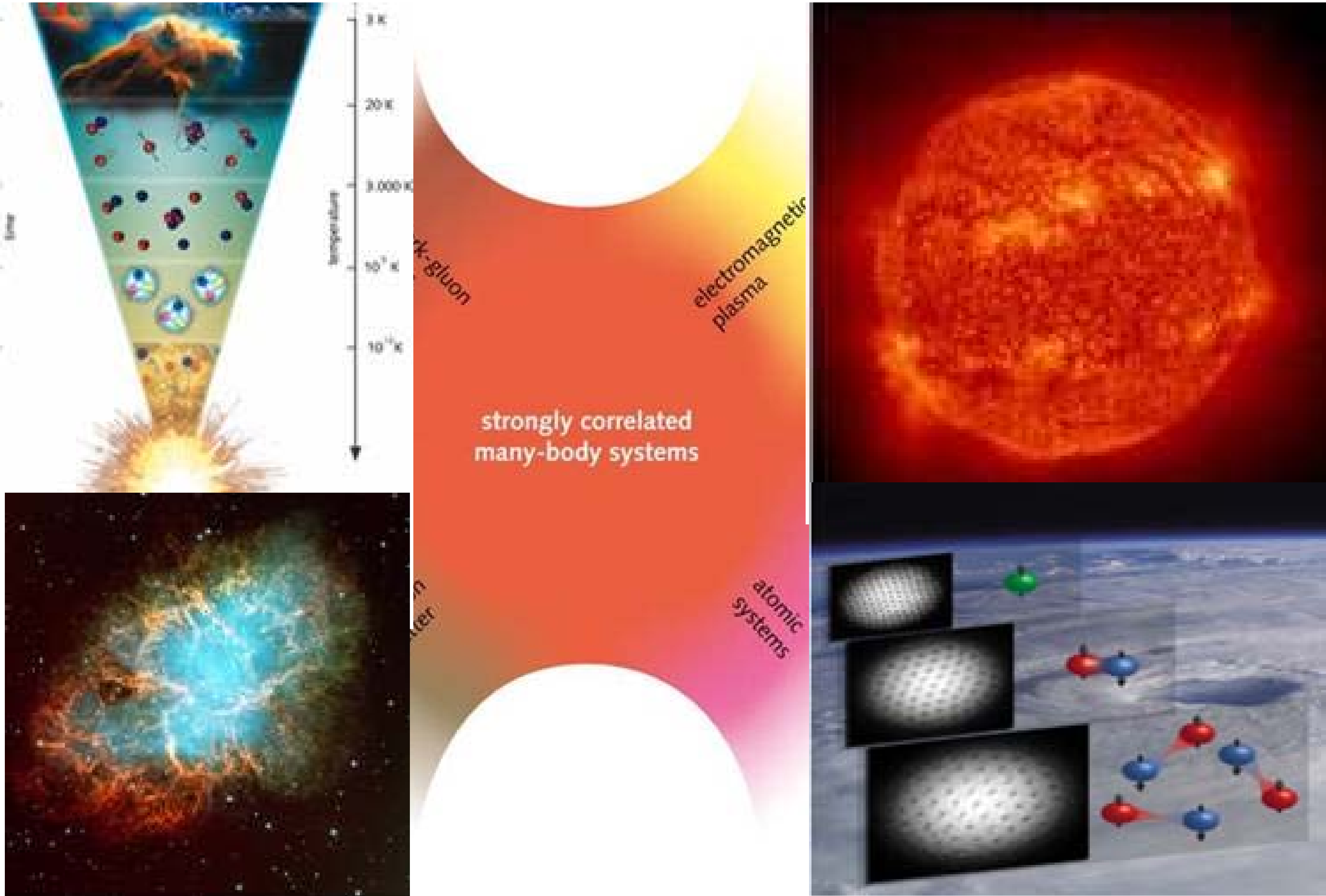
→ FAIR GmbH with International Shareholders

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

FAIR Start Event: November 7, 2007

A splendid perspective and eminent challenge !

FAIR Research Topics and Inter-links



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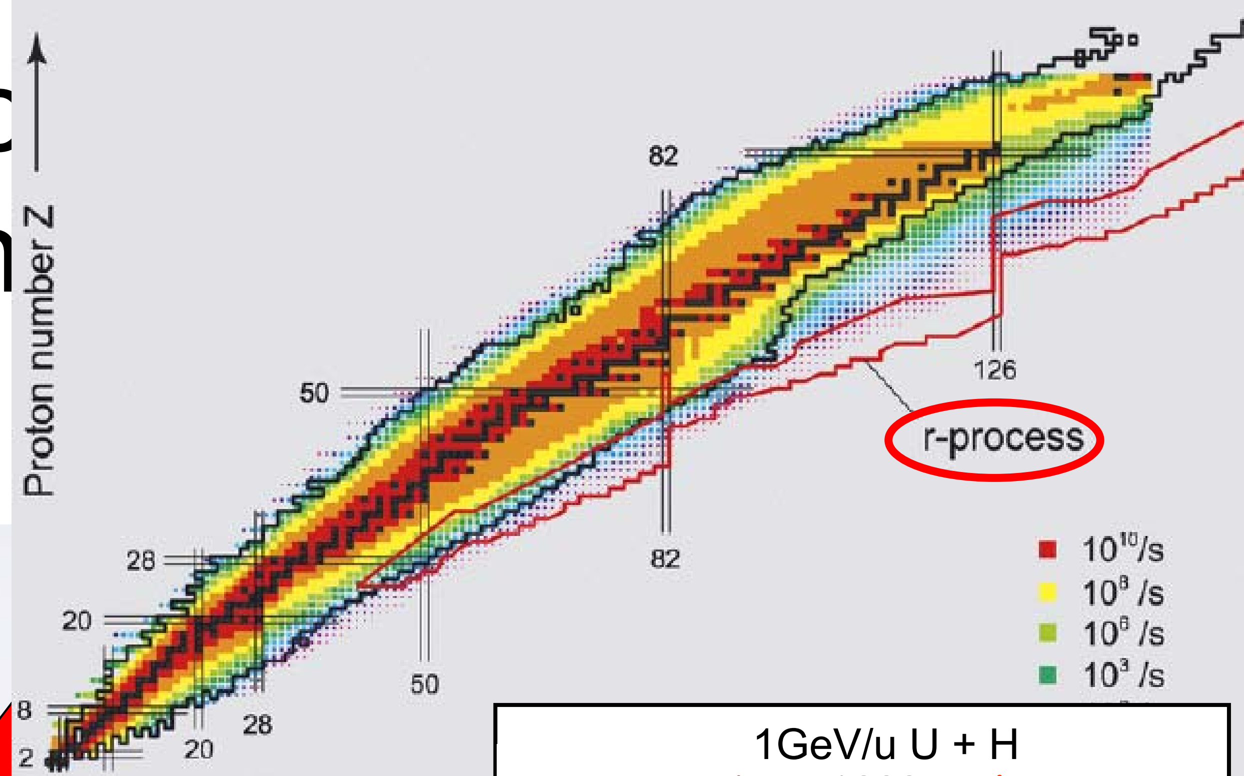
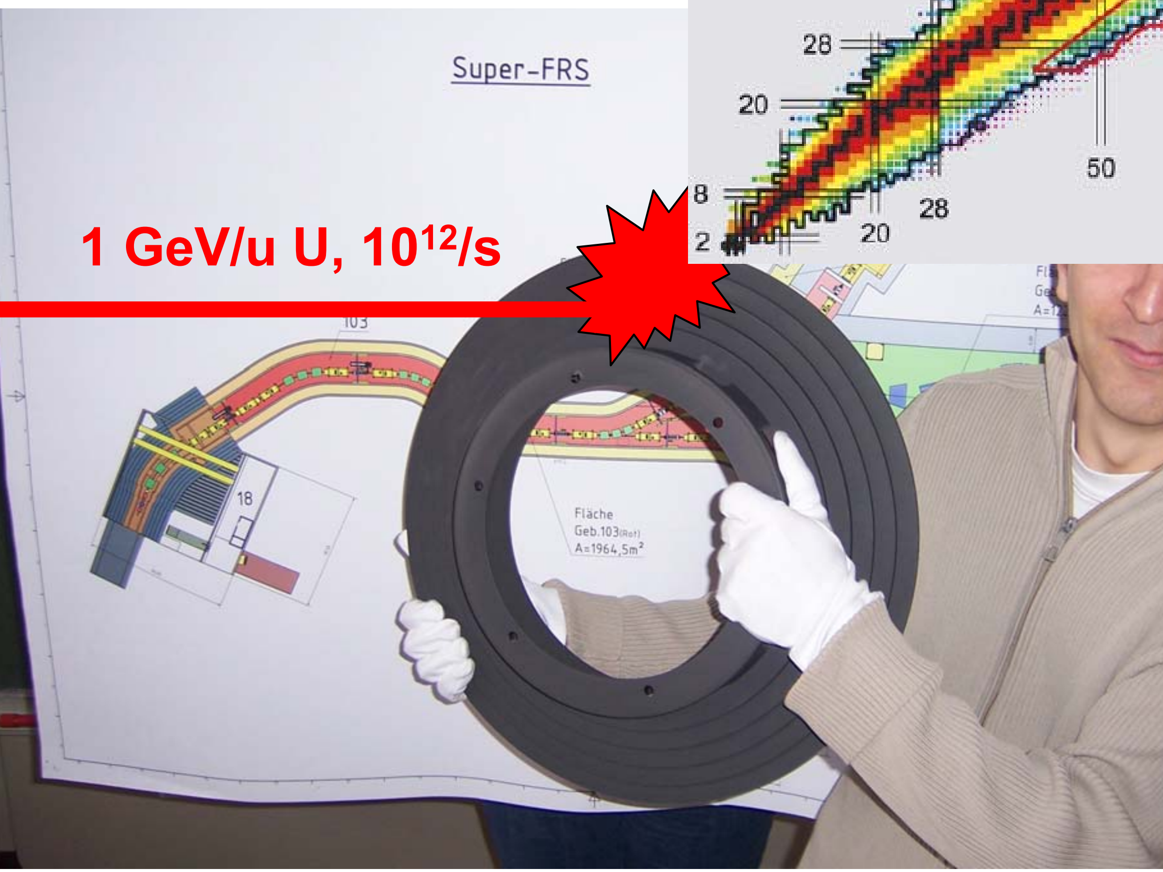
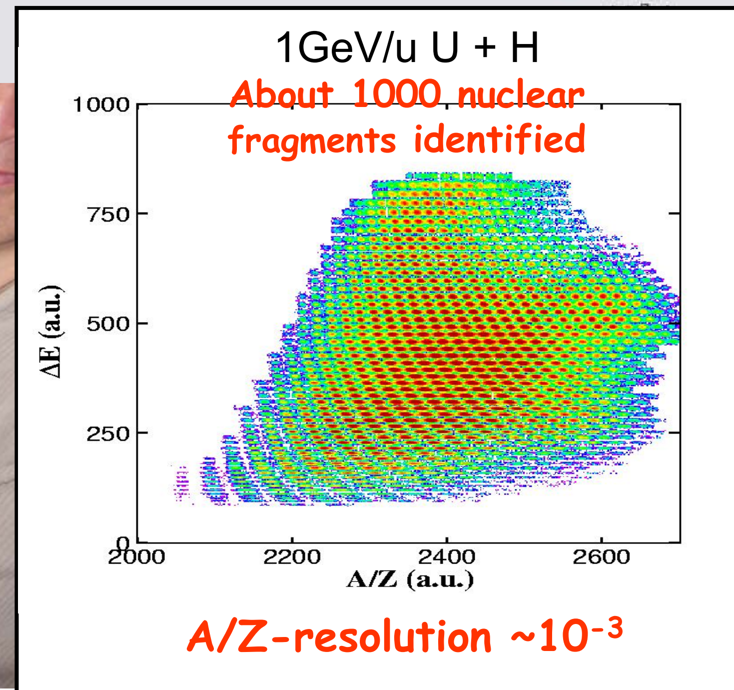
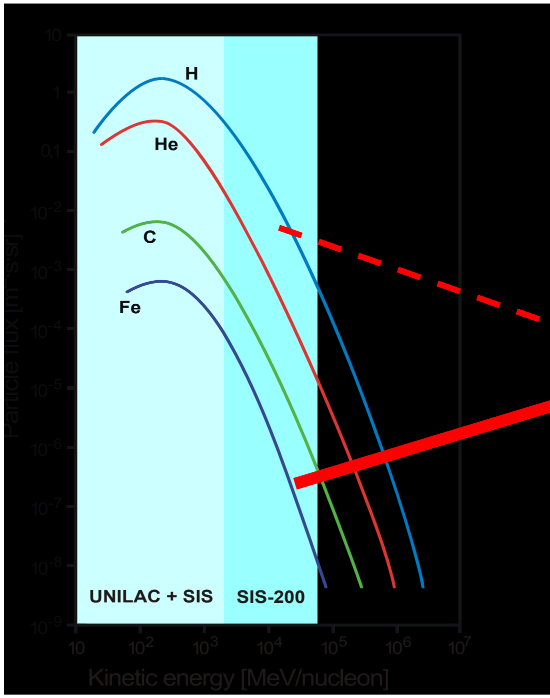




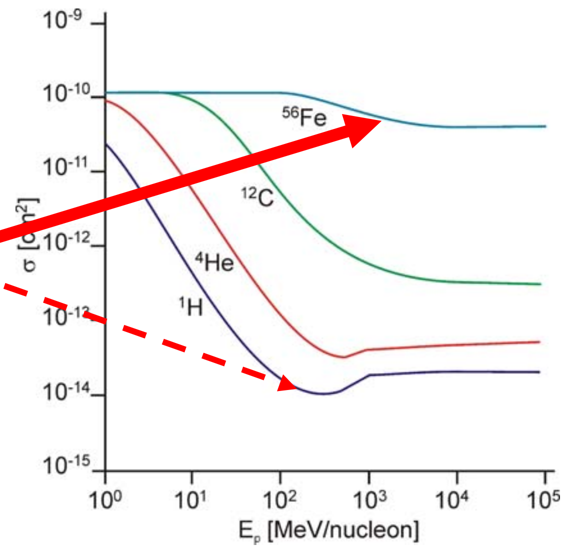


Applied Research

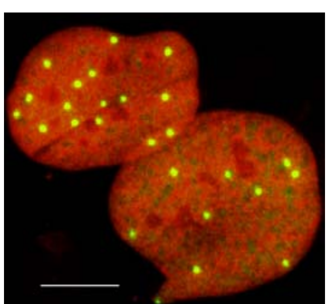
Radiobiology for space reserach



Cosmic particle spectrum



Risk cross sections



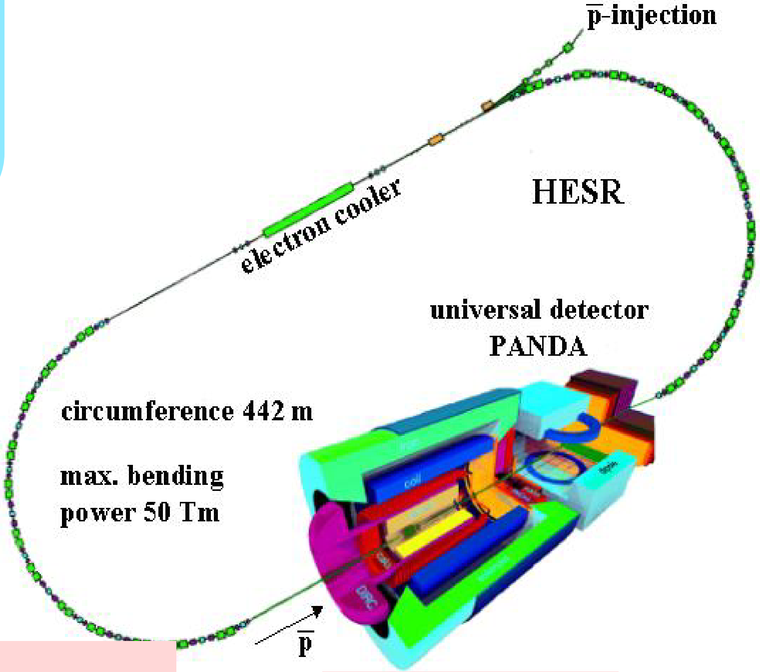
Approaches for risk estimates:
- Cytogenetics
- Cell transformation
- Tissue effects
- Modelling

FAIR QCD-Physics Program with Antiprotons

strange and charmed (anti-) baryons in nuclear field

hidden and open charm in nuclei

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



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

J/ψ spectroscopy confinement, in-medium effects

FLAIR

HESR Consortium
Jülich / Uppsala / Stockholm / GSI

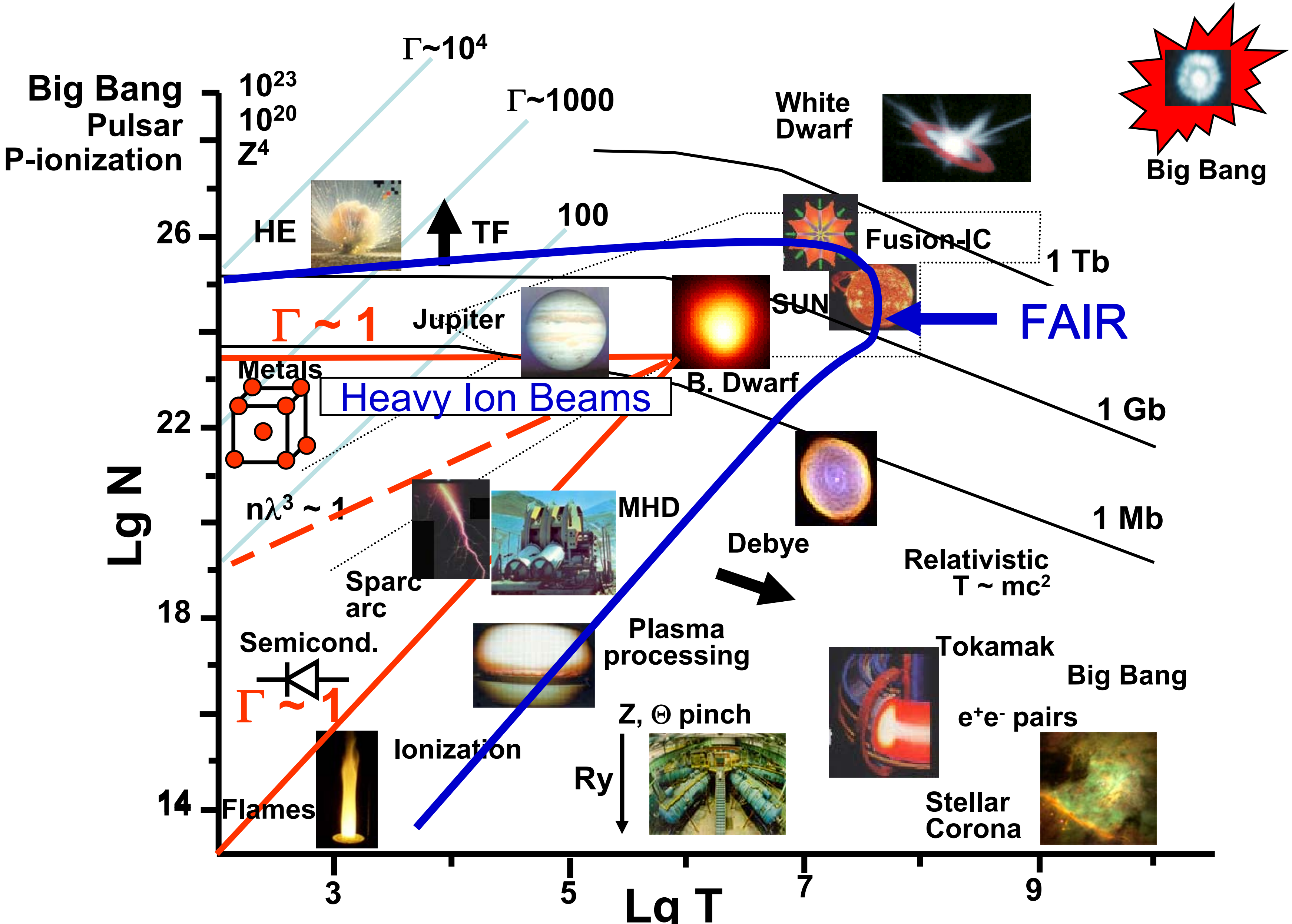
PANDA

CP-violation (D/Λ - sector)

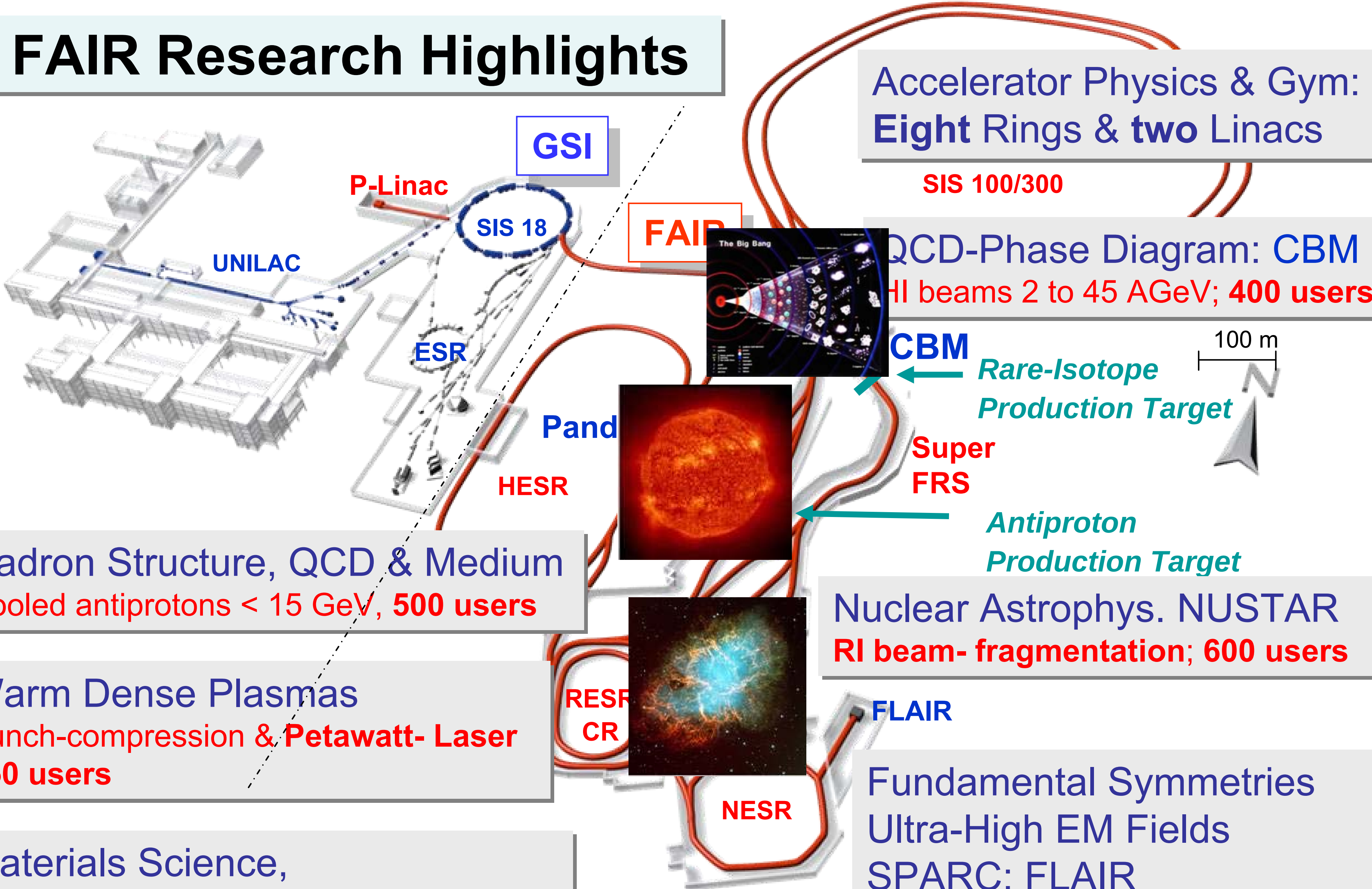
inverted deeply virtual Compton scattering

spin structure of the proton: polarized antiprotons in PAX

PHASE DIAGRAM OF MATTER



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**

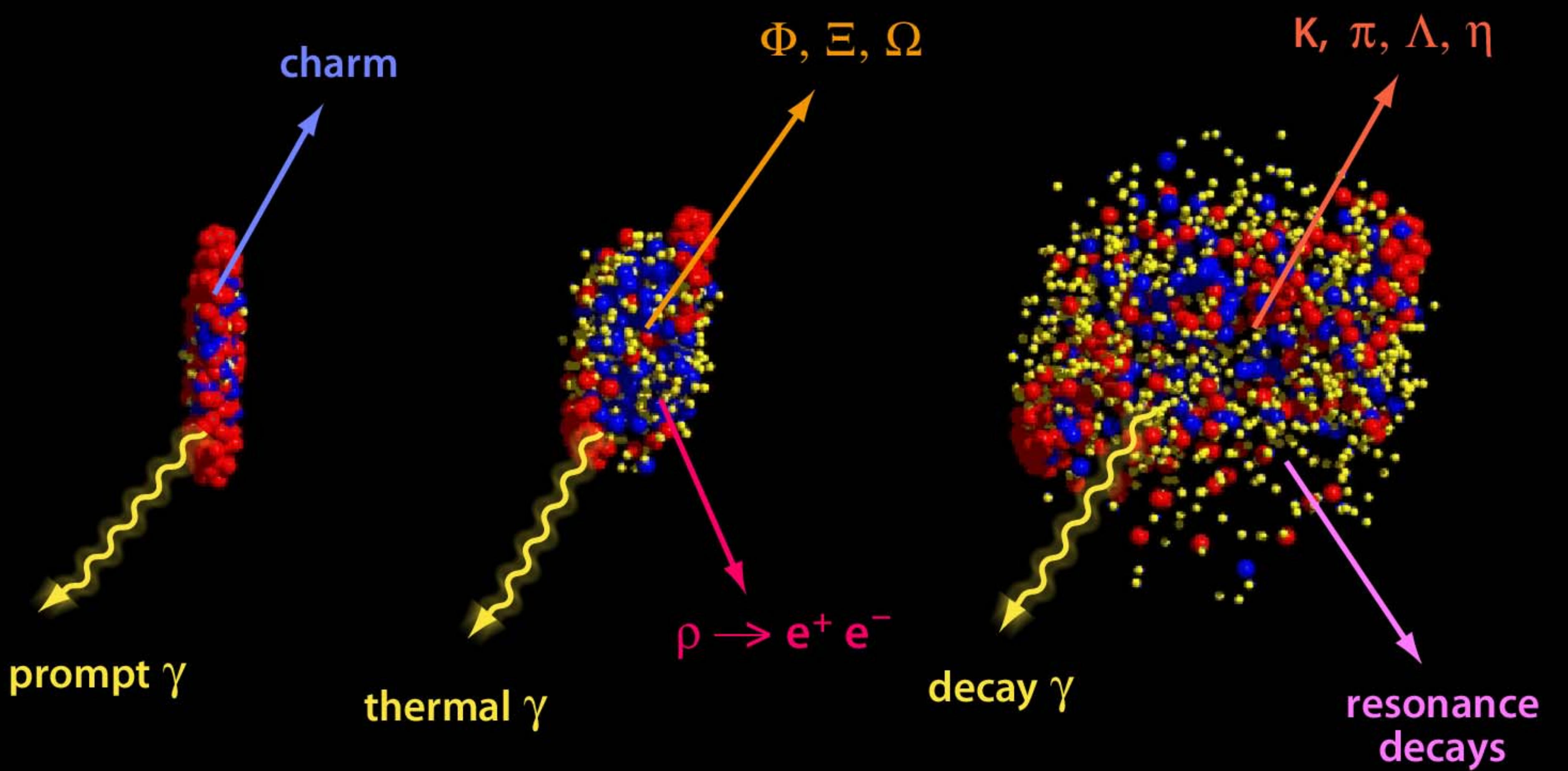
Warm Dense Plasmas
Bunch-compression & **Petawatt- Laser**
250 users

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**

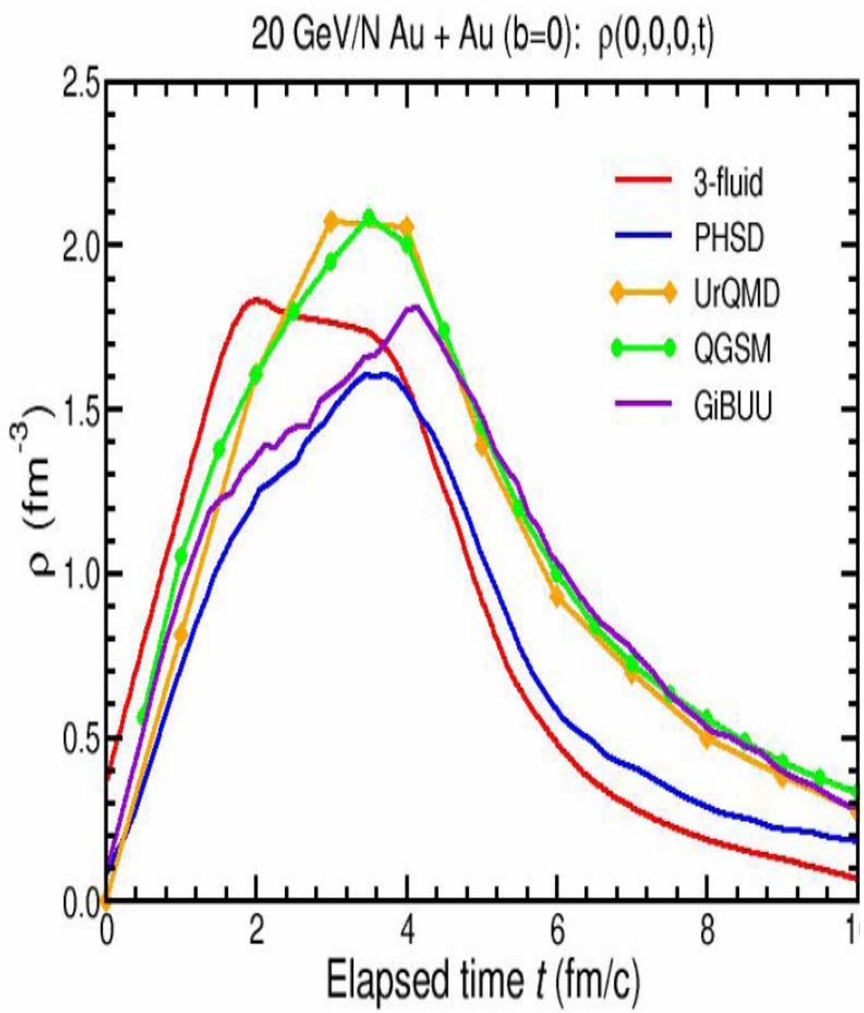
Compressed Baryonic Matter: **CBM Physics Topics**

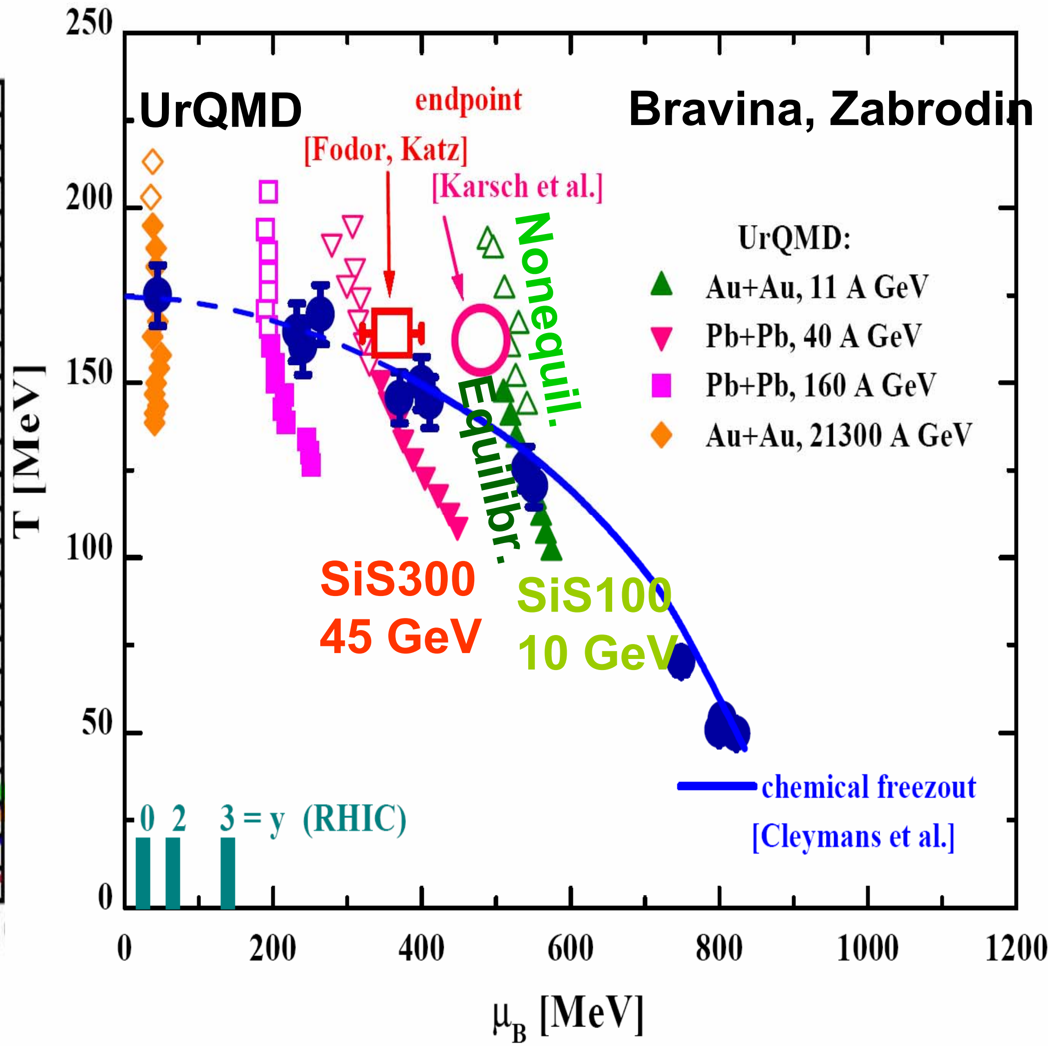
Probing the high density EoS: collapse of coll. flow of protons?
Q-H phase boundary@high ρ_B: multi-strange + charmed prod.
QCD critical point: E-by-E fluctuations; Energydep Hadron Yiel
Chiral symmetry rest. at high ρ_B : open charm, dilepton prod.



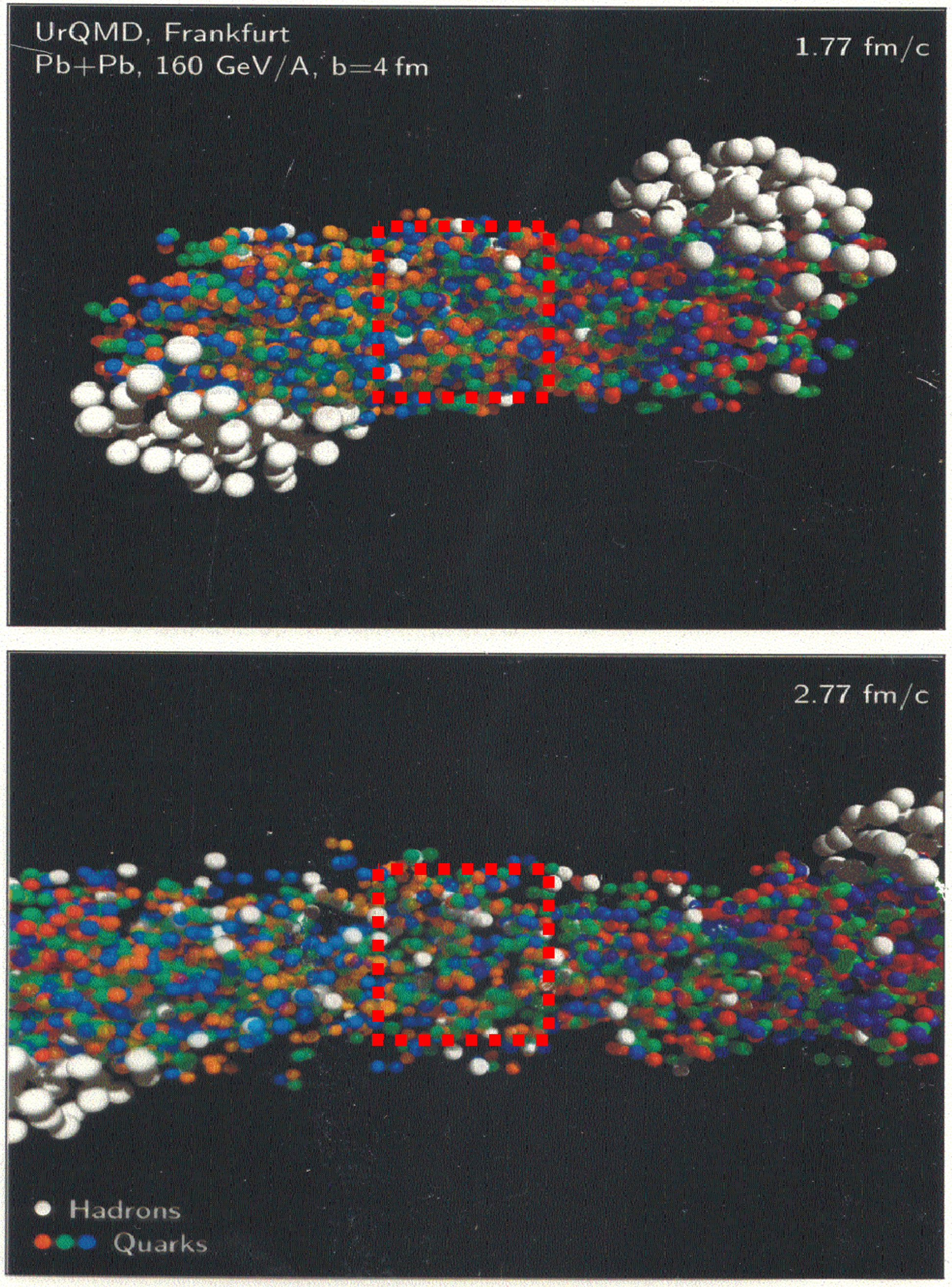
Big Bang- & Neutron Star-matter: CBM @ FAIR
QCD phases at High Density ρ_B

Tenfold Compression!   Crossing that 1. Order Transition!





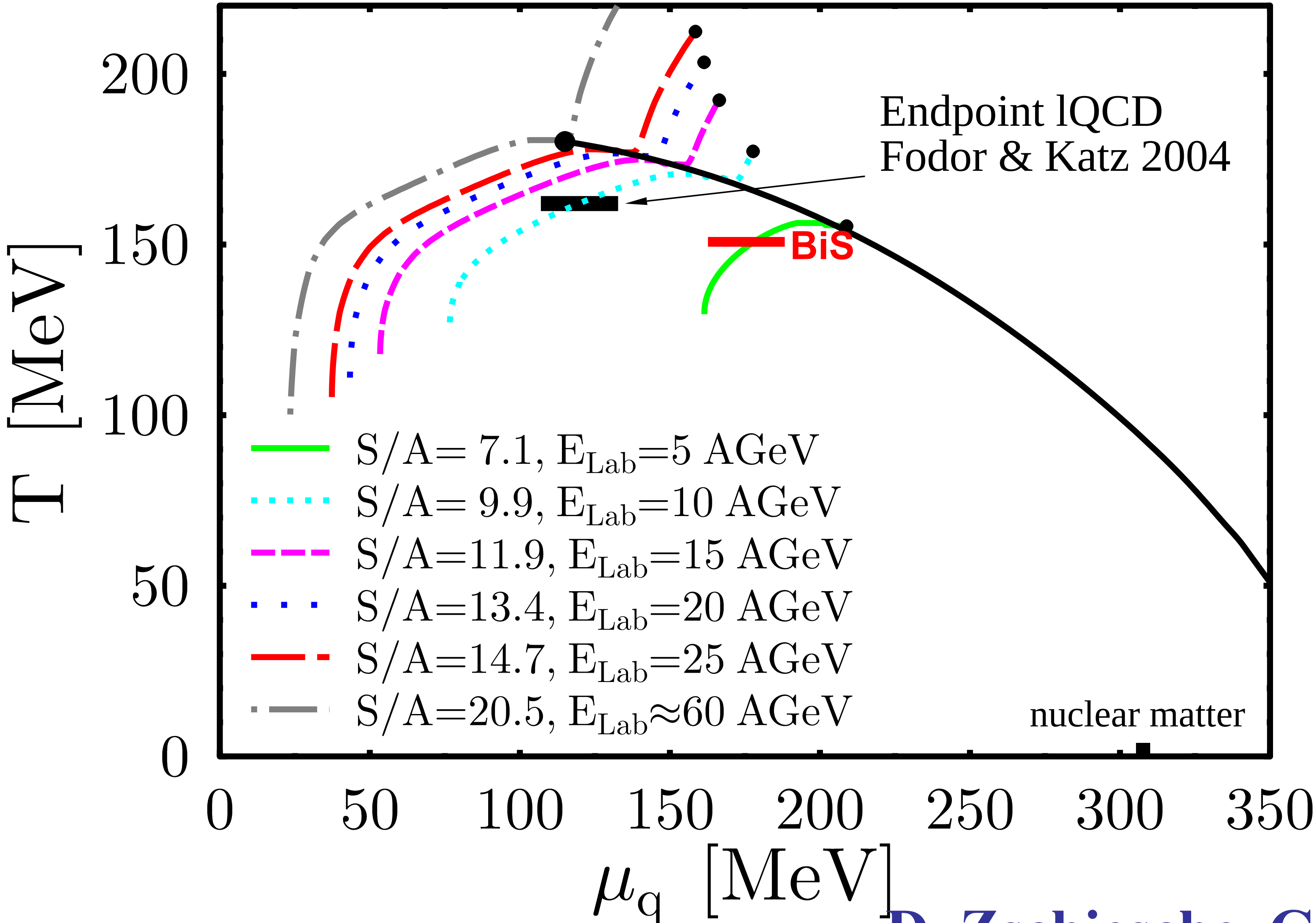
Simulating thermo-dynamics in central cell



Weber, Bravina

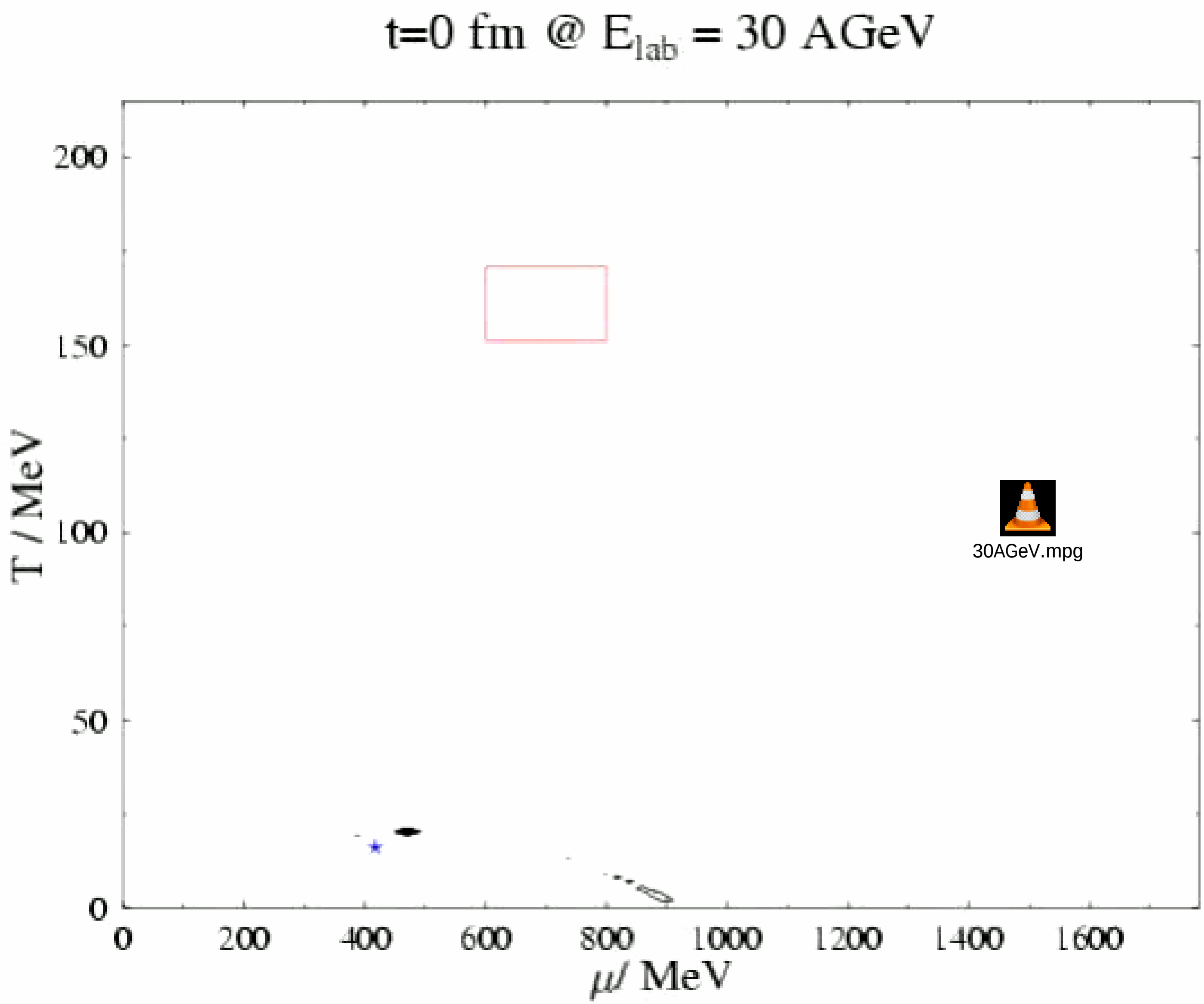
Ideal Hadron Gas differs strongly from

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



D. Zschiesche, G. Zeeb

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

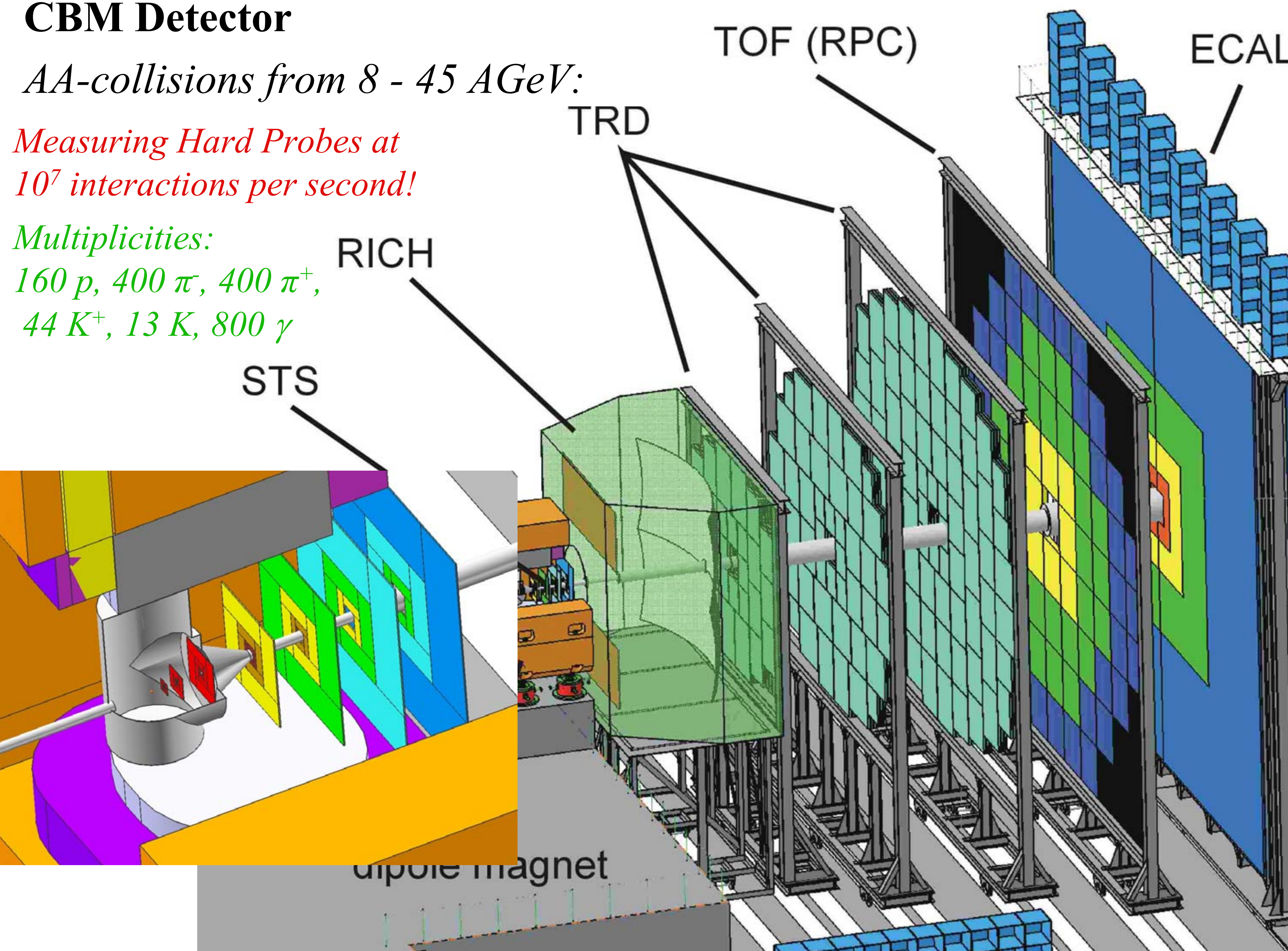


CBM Detector

AA-collisions from 8 - 45 AGeV:

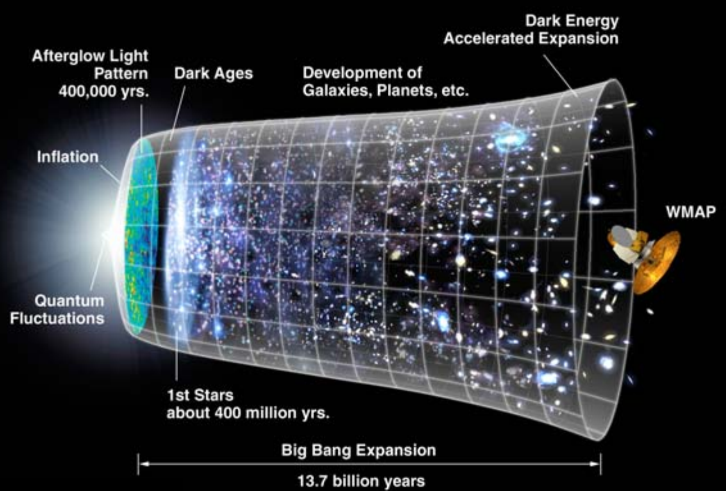
Measuring Hard Probes at
10^7 interactions per second!

Multiplicities:
160 p, 400 π^-, 400 π^+,
44 K^+, 13 K, 800 γ



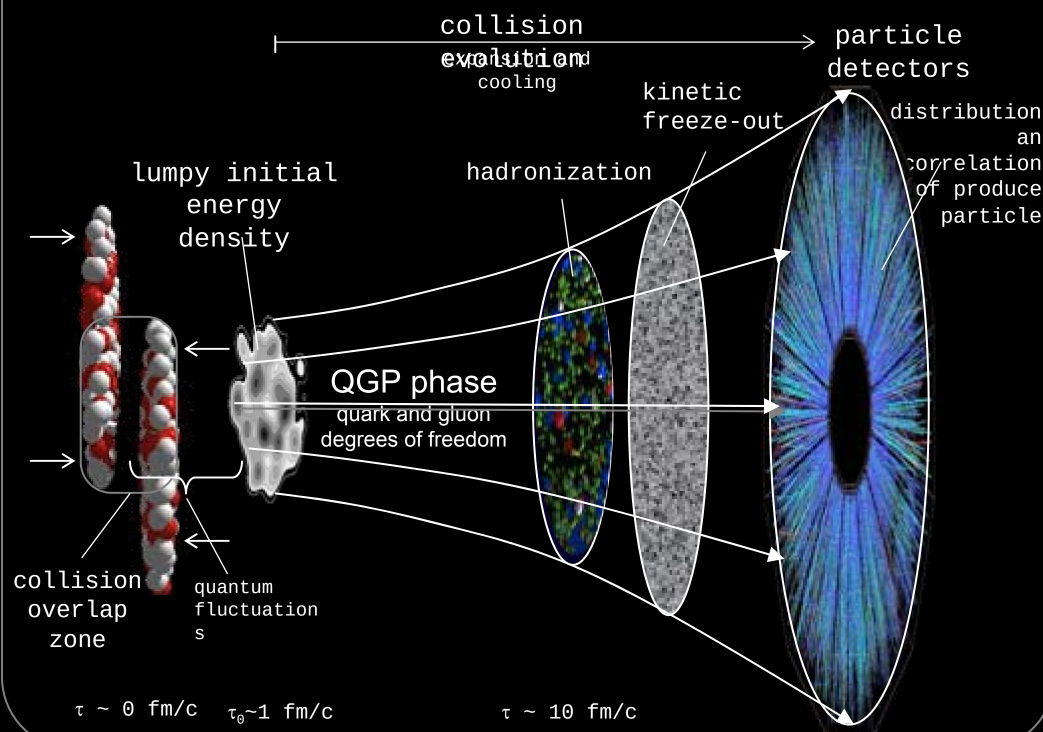
Analogy to the early universe: evolution of critical fluctuations

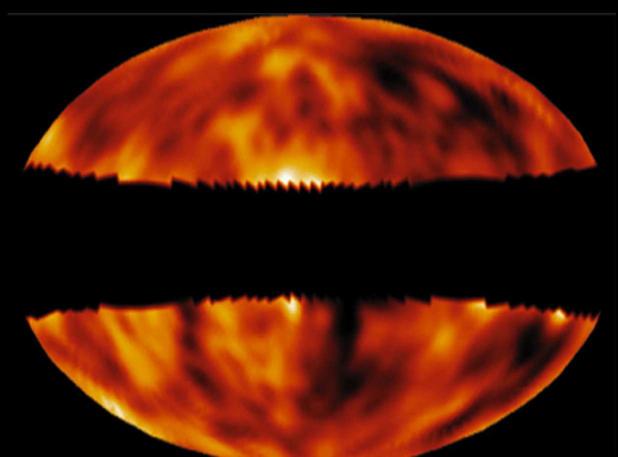
The Universe: Slow Expansion

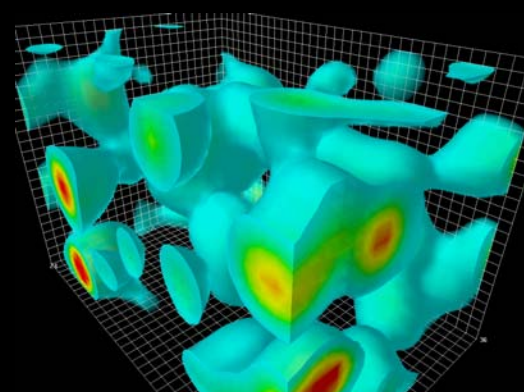


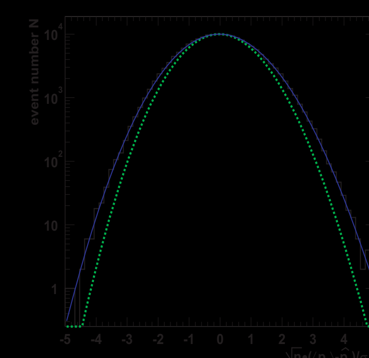
credit: NASA

Heavy-ion Collisions: Rapid Expansion









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_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

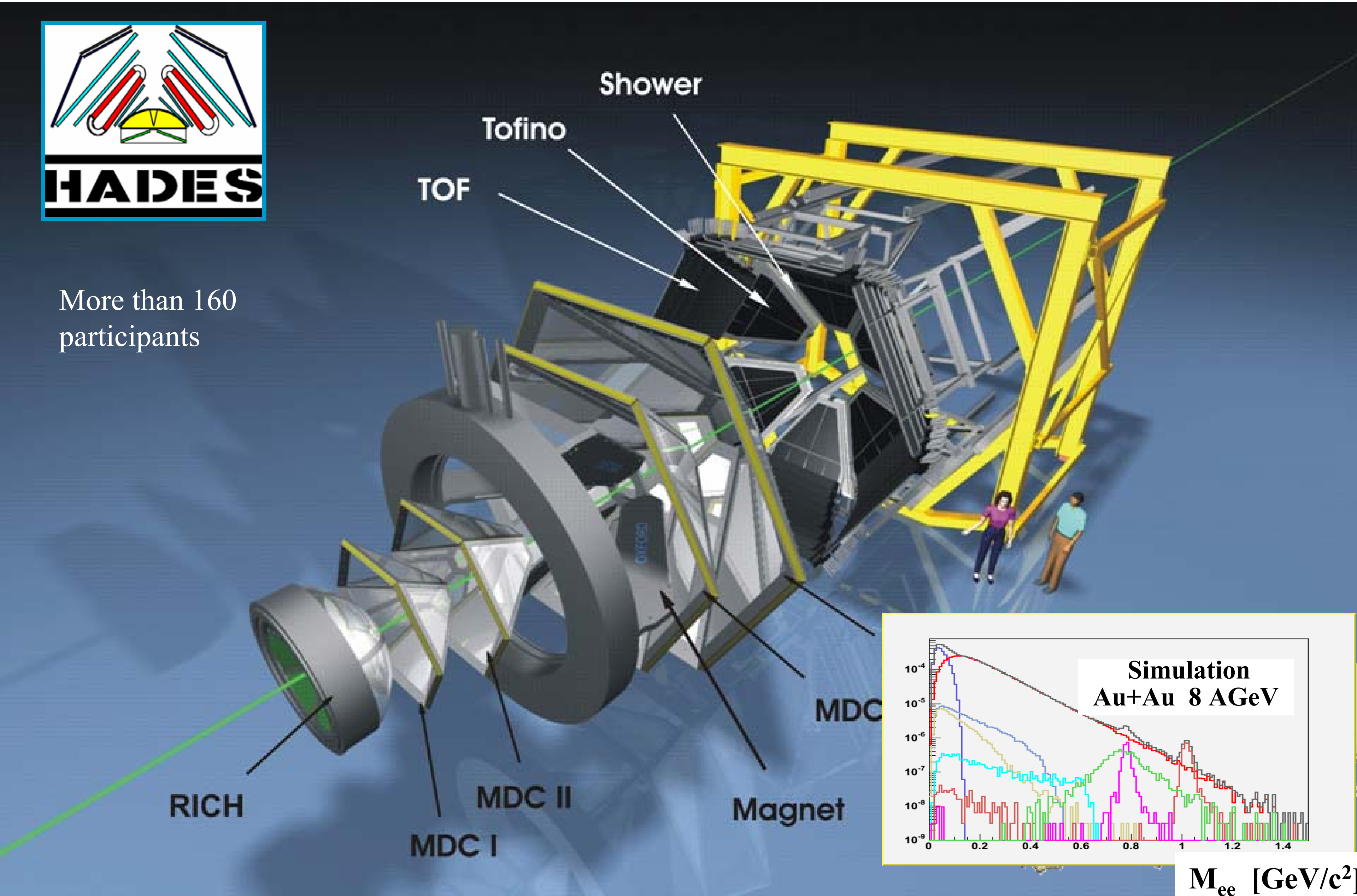
- **rare particle production at threshold**
  → ***EOS***
- **flow of charm, melting of quarkonia**
  (J/ψ, ψ', D^0, $D^{\pm}$, Λ_c)
  → ***deconfinement***
- **in medium modific. of vector mesons**
  ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$, D)
  → ***chiral symmetry restoration***
- **Strange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

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)

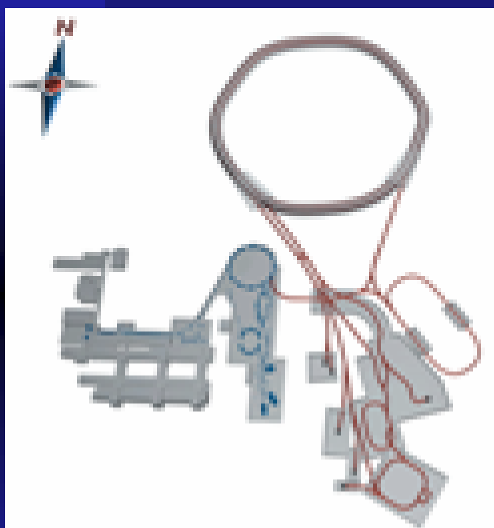
HADES at FAIR: di-electrons from 2-8 AGeV A+A

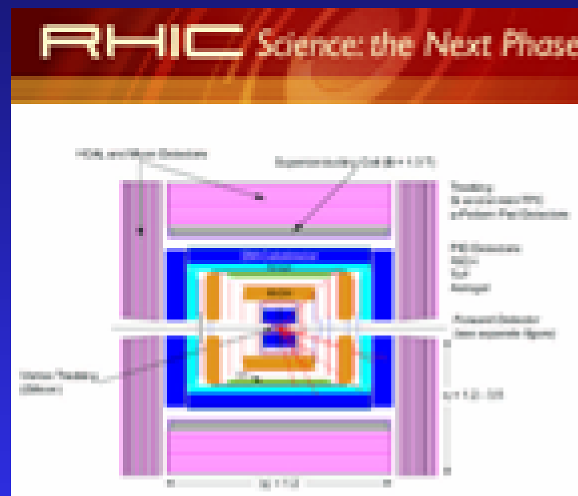


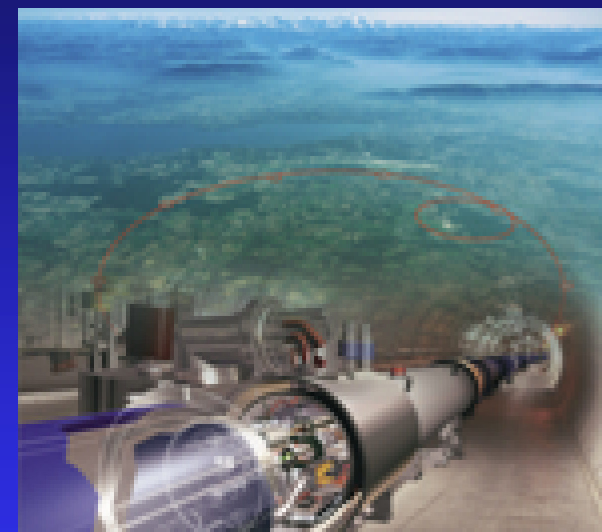
The future is bright

A three prong approach:

Highest Intensity **upgrade** **facility** **higher energy**







FAIR:
Facility for Antiproton & Ion Reseach

RHIC-II:
RHIC upgrade with new detector R2D

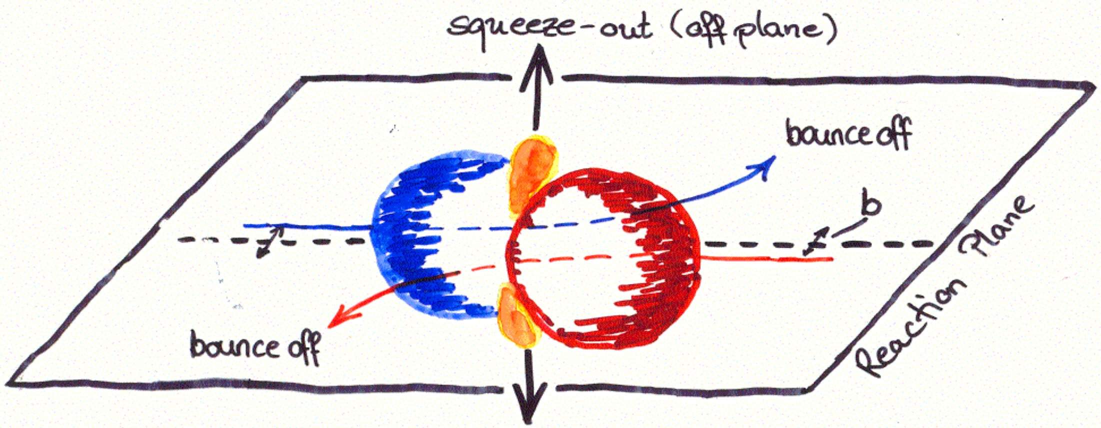
LHC:
Large Hadron Collider with ALICE, CMS, ATLAS

Directed Flow

Elliptic Flow

Squeeze-Out
= Elliptic Flow v2

Squeeze-Out => v2 = (px**2 - py**2) / pt**2



Bounce-Off
= Directed Flow v1

Bounce-Off
=v1= px/pt

Pressure ?
=> Baryon‘s v1, v2 !

=> Baryon Flow is
our Barometer !

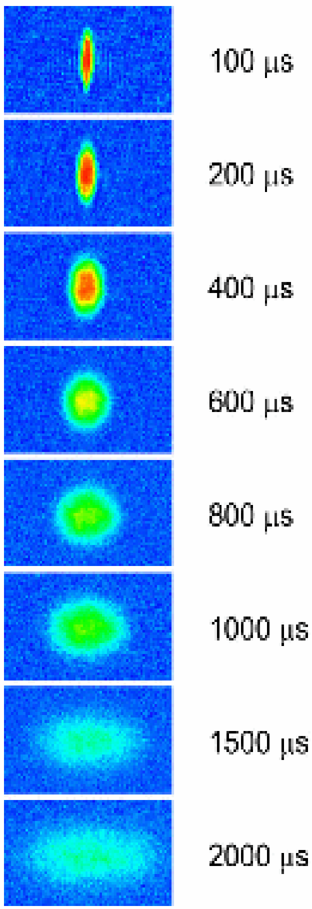
Pressure P can be measured by the momentum p_x:

$$p_x \sim \int P(e,\rho)\, dA\, dt$$

Elliptic flow with trapped Li^6

K.M.O'Hara et al, Science 298,2

T.Bourdel et al, PRL 91 020402



Proton Elliptic Flow: v2 is a barometer!

FOPI data+IQMD: probes EOS !

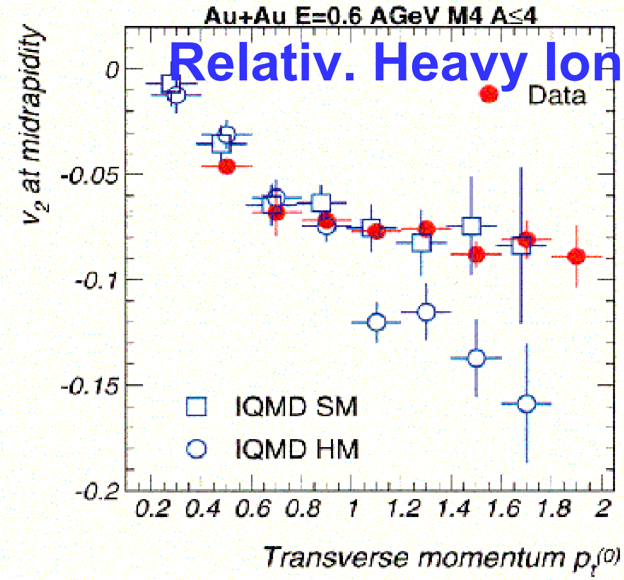
Negative v2 at SIS & AGS:

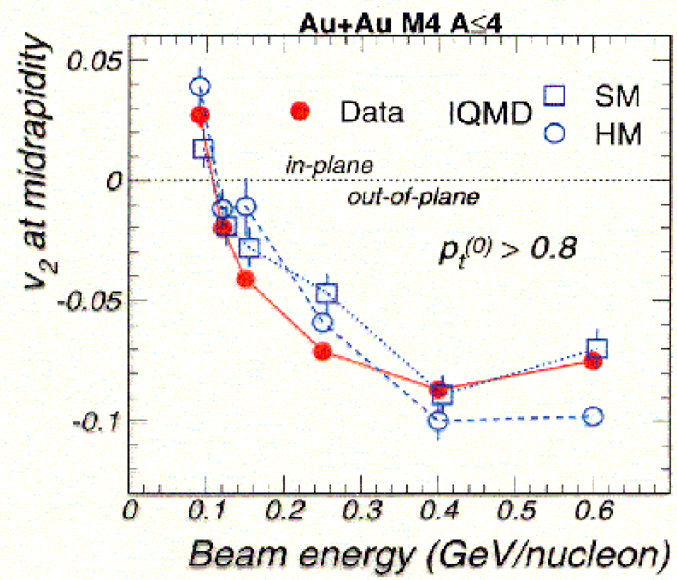
Squeeze Out!

Relativ. Heavy Ion Collision

FOPI-Dat

GSI

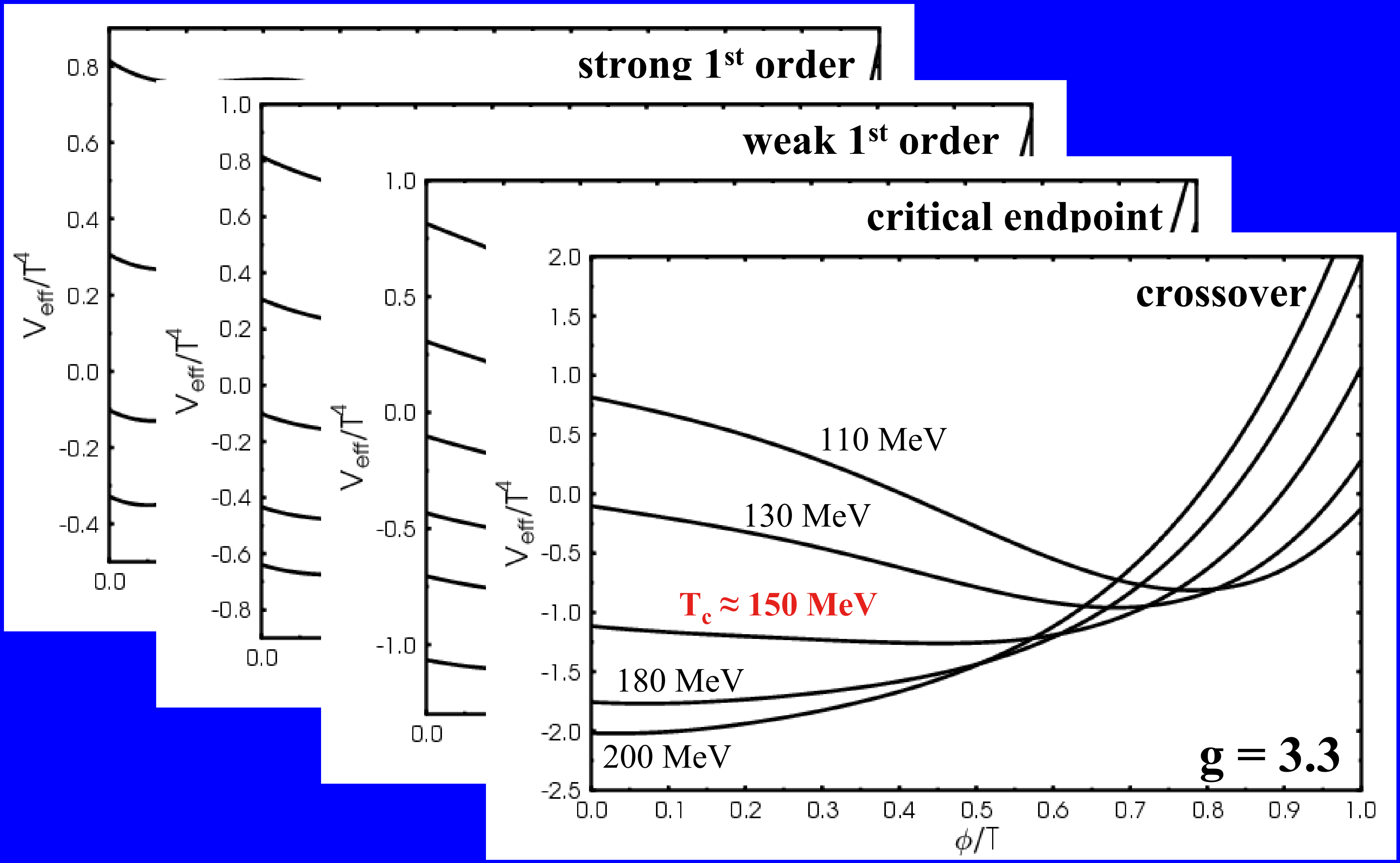




FOPI-Da

GSI

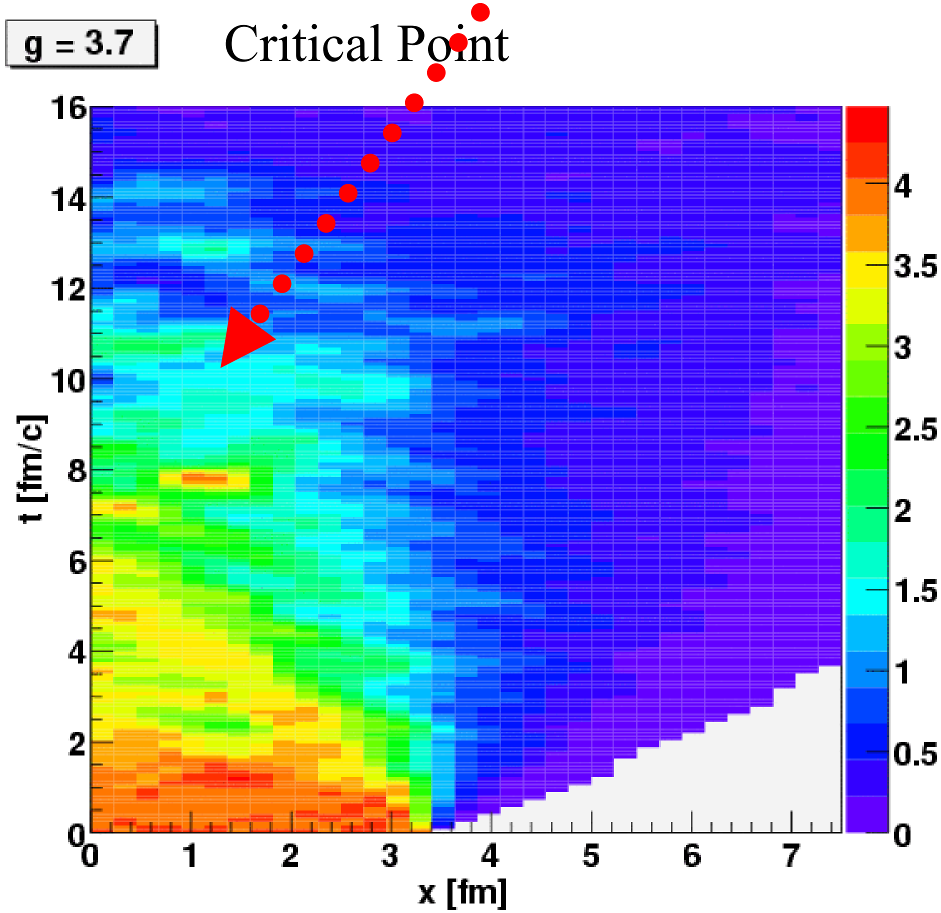
Effective Chiral Potential Dumitru, Paech

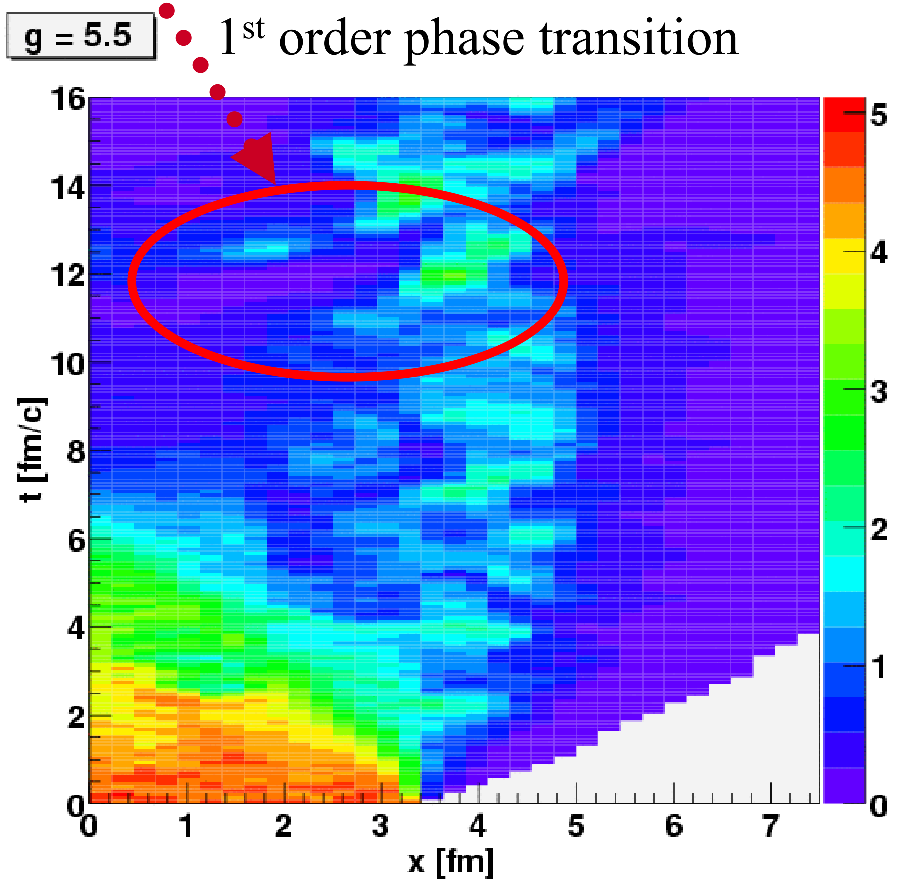


„lumpy-clumpy“ Phase Transition at FAIR-energies: Huge Fluctuations in Energy- (Baryon-) Density

$\frac{\Delta e}{e} << 1$

$\frac{\Delta e}{e} \sim 1$ **Paech, Dumitru, H.St.**





Observables:

- Space-Time Structure of Fluctuations!
  => reduces Flow v_1, v_2

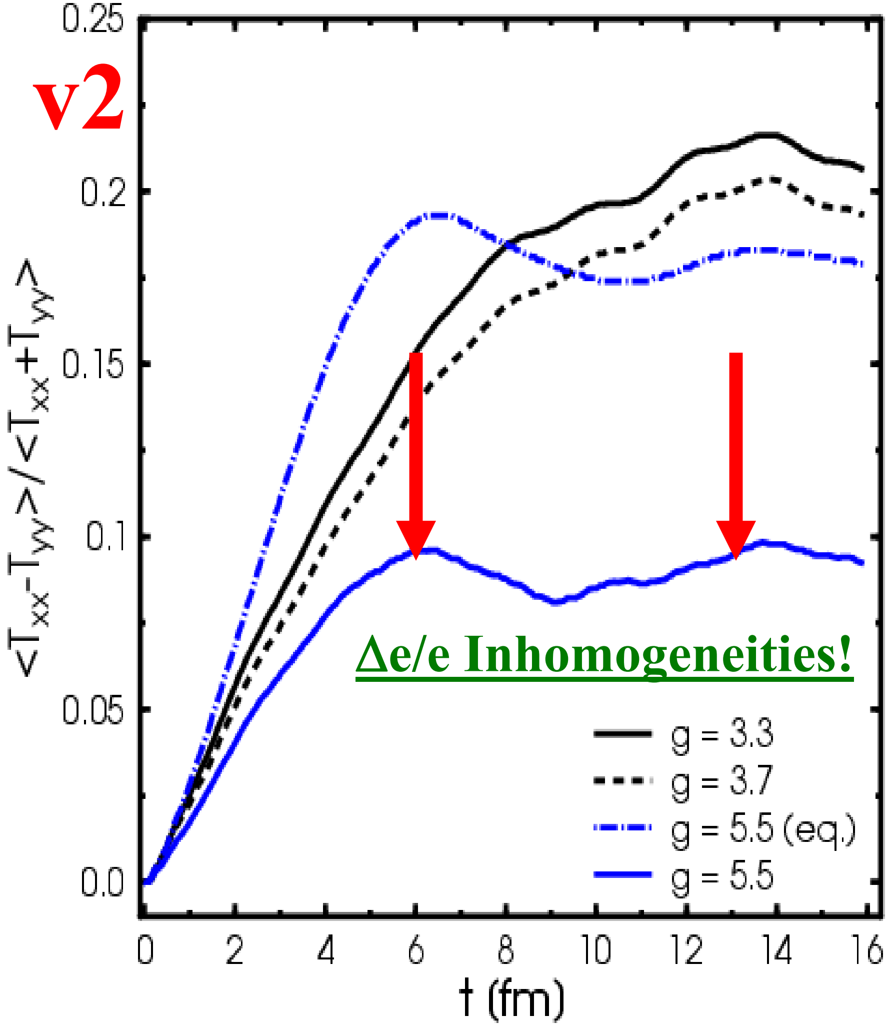
- Size ~ 1-2 fm --> $\Delta y << 1$

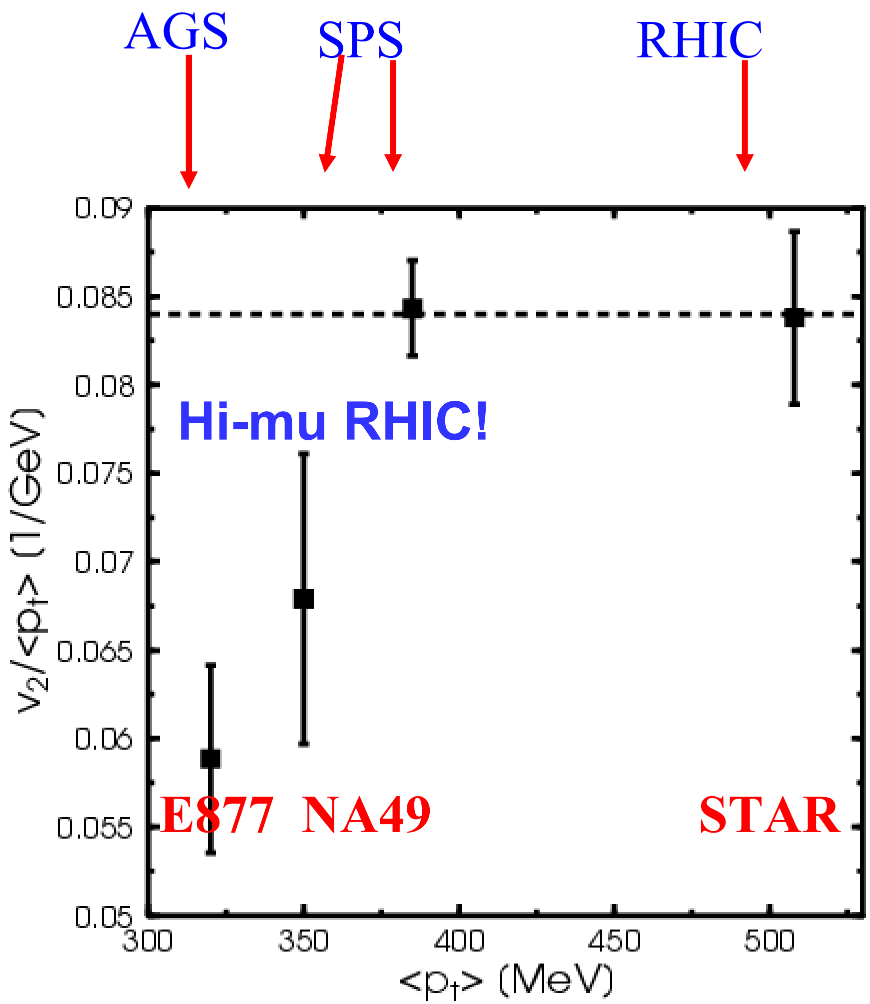
- Fluctuations of B-number in small rapidity bins ~ 1 are small

- Look for indirect probes (e.g. v_2, K/π ?),
- which depend non-linearly on Δe, $\Delta\rho_B$!

1.Order Phase Transition: Fluctuations of V_2

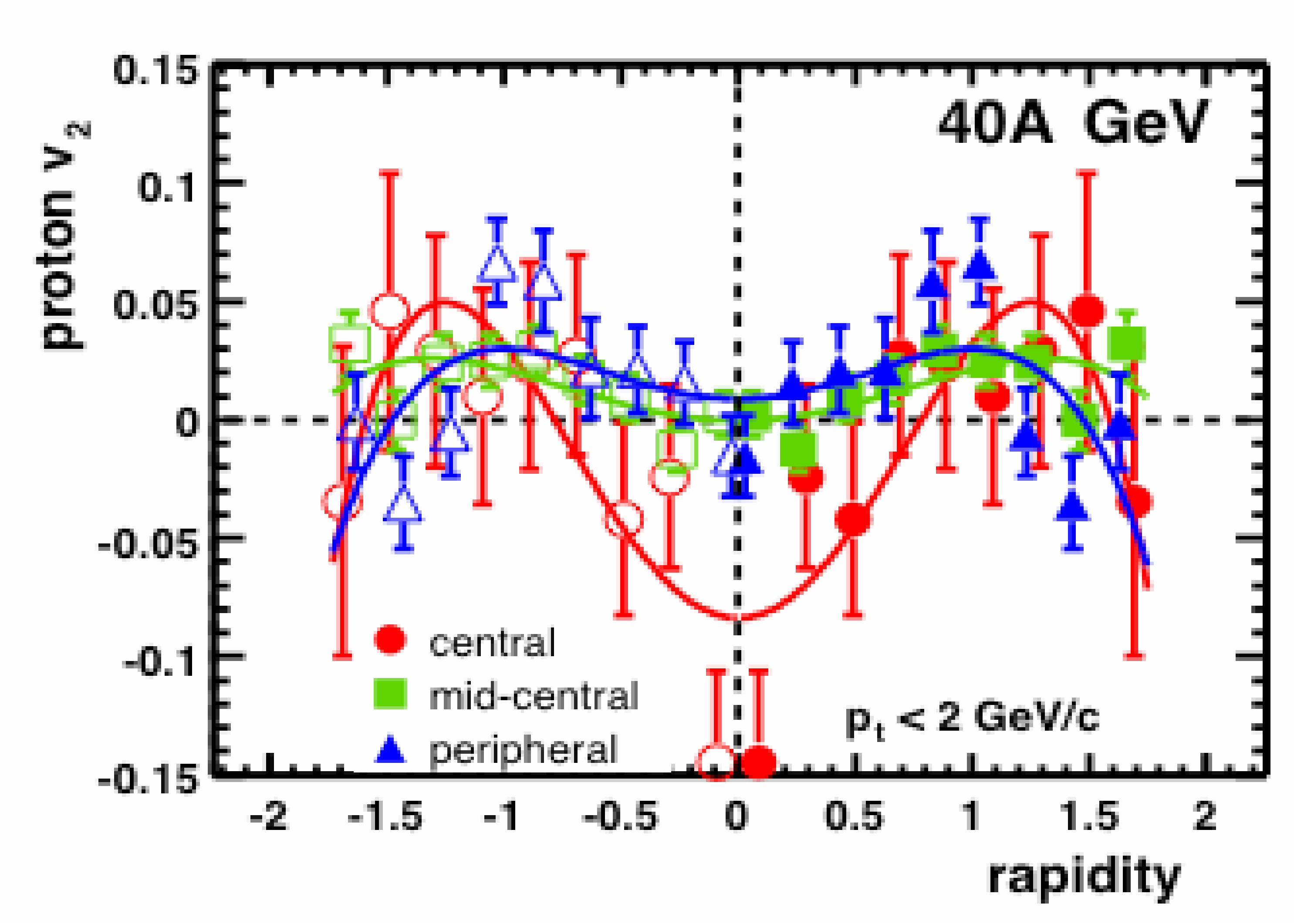
Paech, Dumitru, H.St.





Excitation Function: Elliptic flow

NA49 PRC C68 034903 (2003)



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

Excitation Function of Elliptic Flow

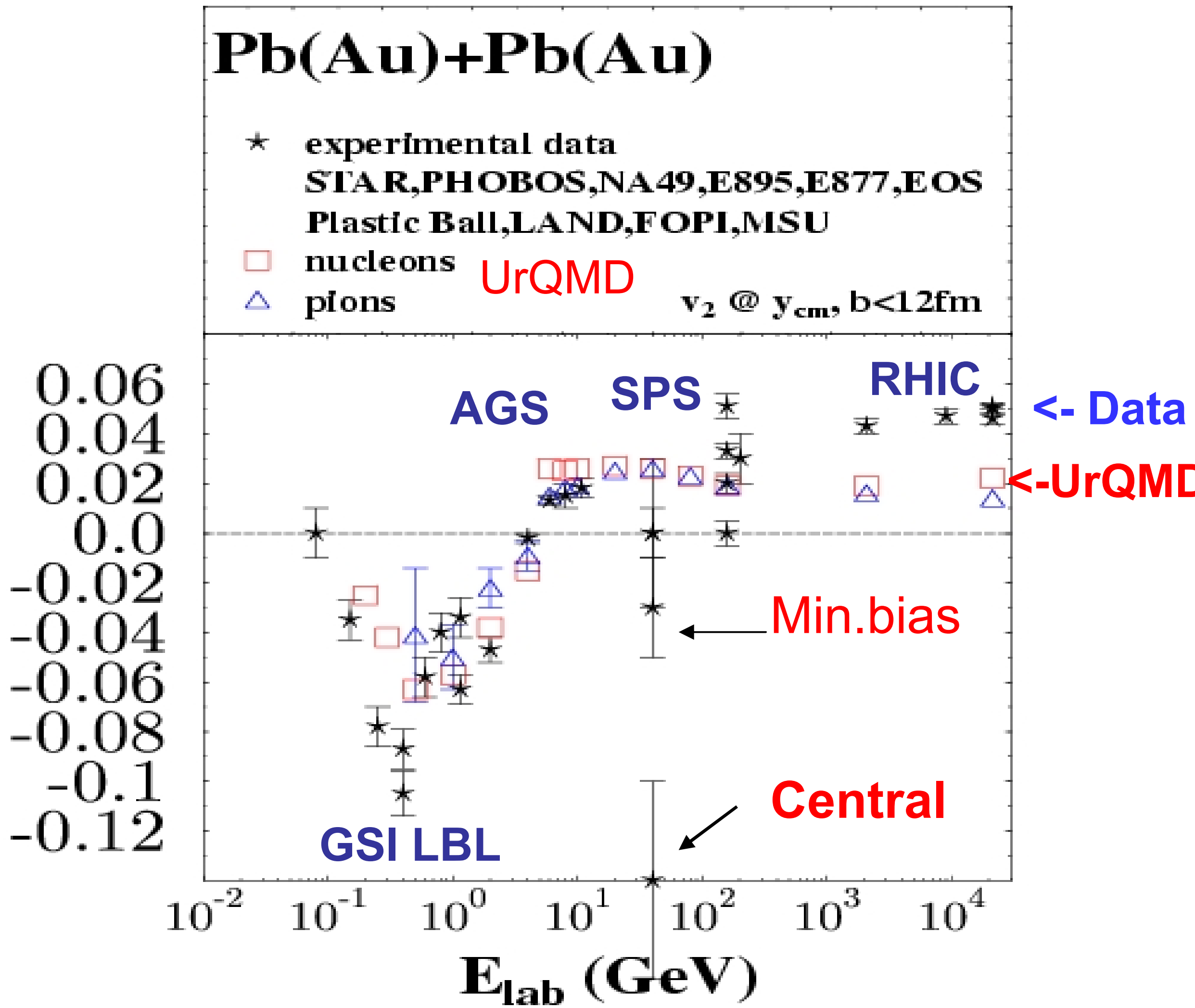
Flow - Excitation function over 6 orders of magnitude in Elab

- Sign of v_2 changes

- Collapse of Flow at 40 AGeV ?

- onset of deconfinement ?

- First order phase transition ?

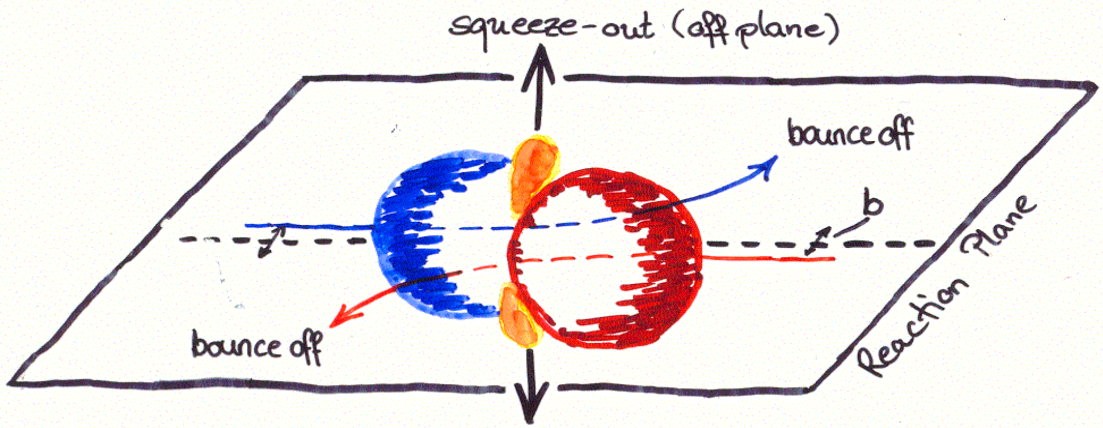


Baryon Flow
as Barometer:

BounceOff
=v1= px/pt

Pressure ->
baryon‘s v1,v2

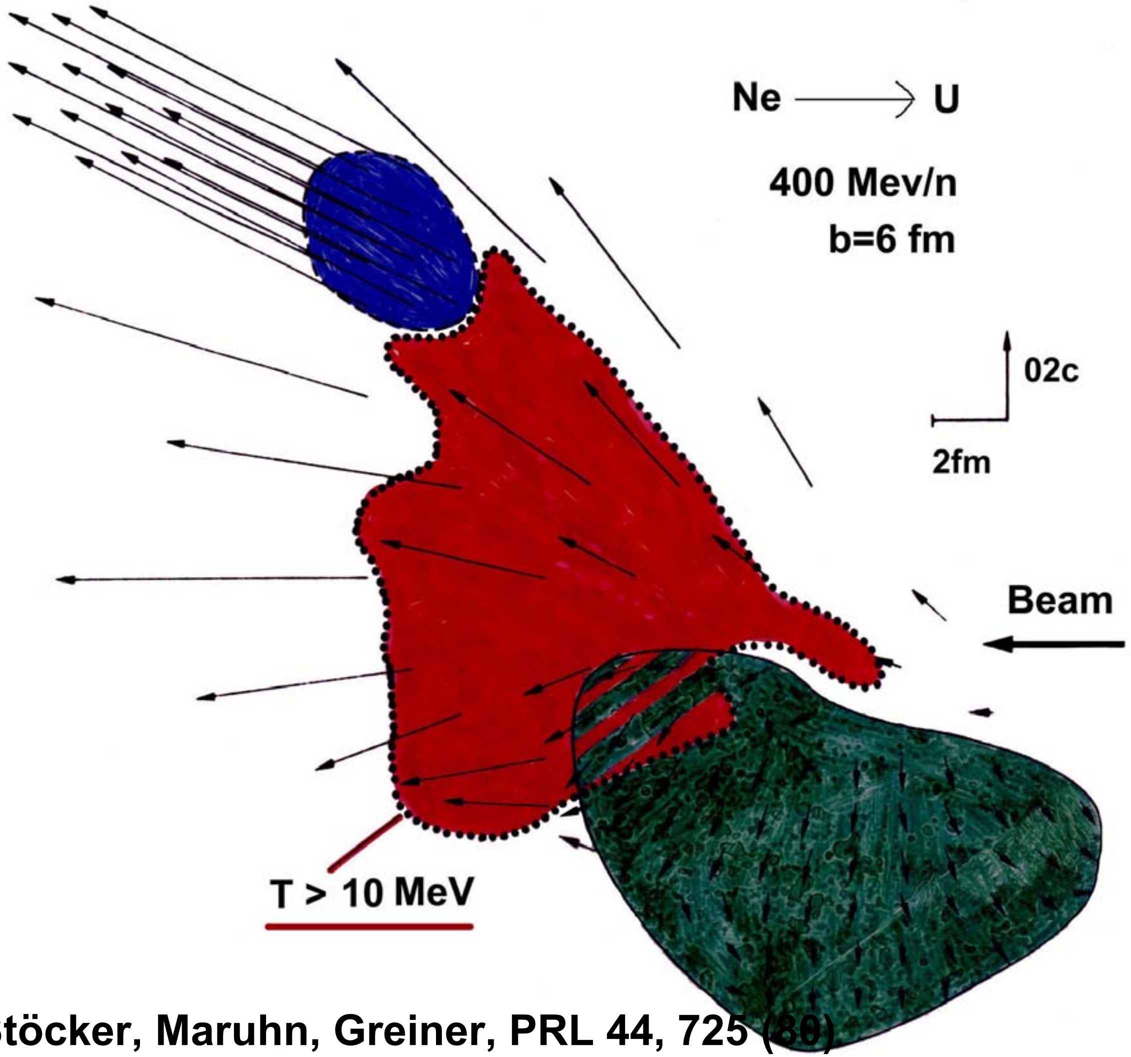
Directed Flow

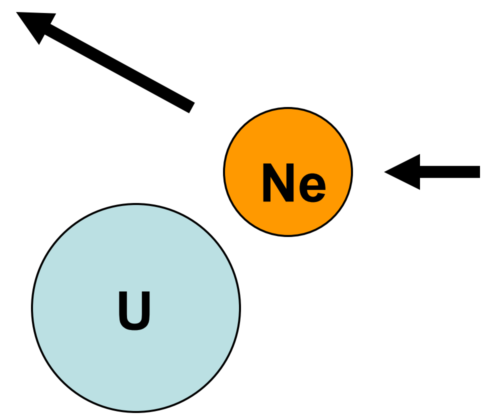


Pressure P can be measured by the momentum p_x:

$$p_x \sim \int P(e,\rho)\, dA\, dt$$

Bounce-Off: 3D-Hydrodynamics

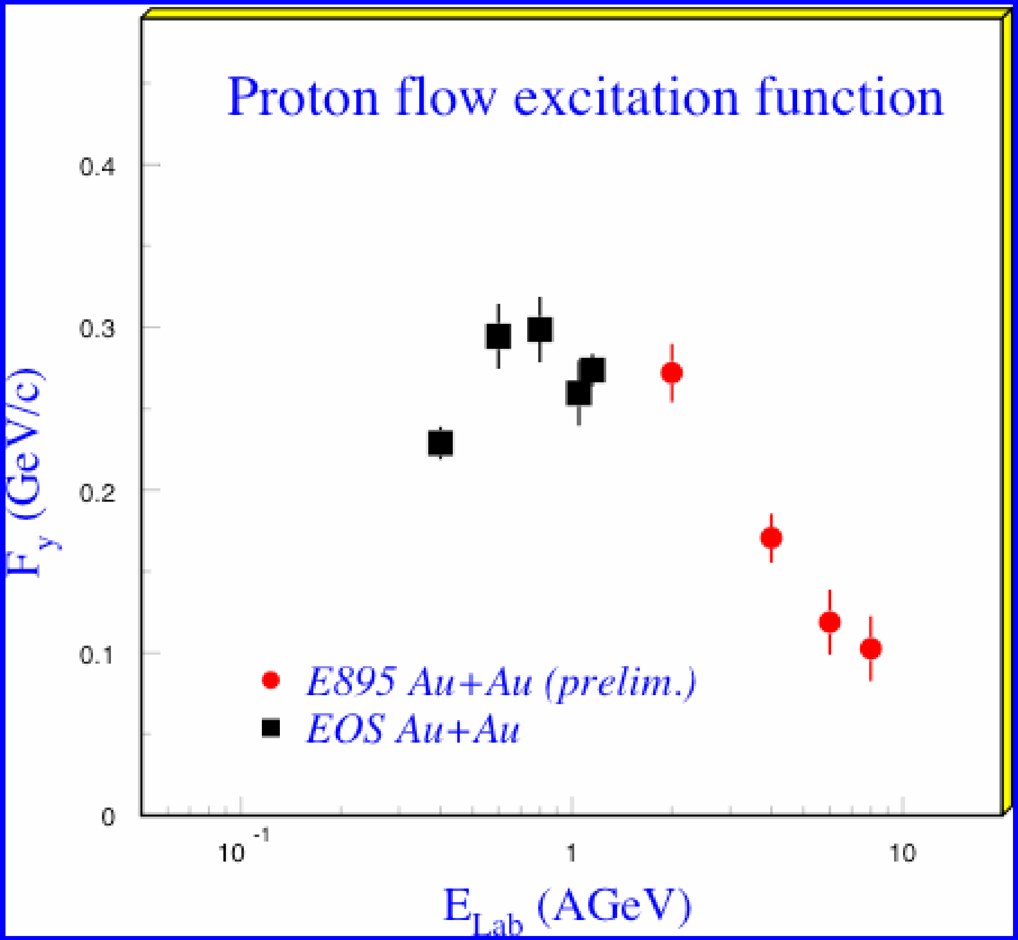




H.Stöcker, Maruhn, Greiner, PRL 44, 725 (80)

"v_1" Excitation Function

F_y is a measure for v_1



E895 Collaboration, PRL 84, 5488 (2000)

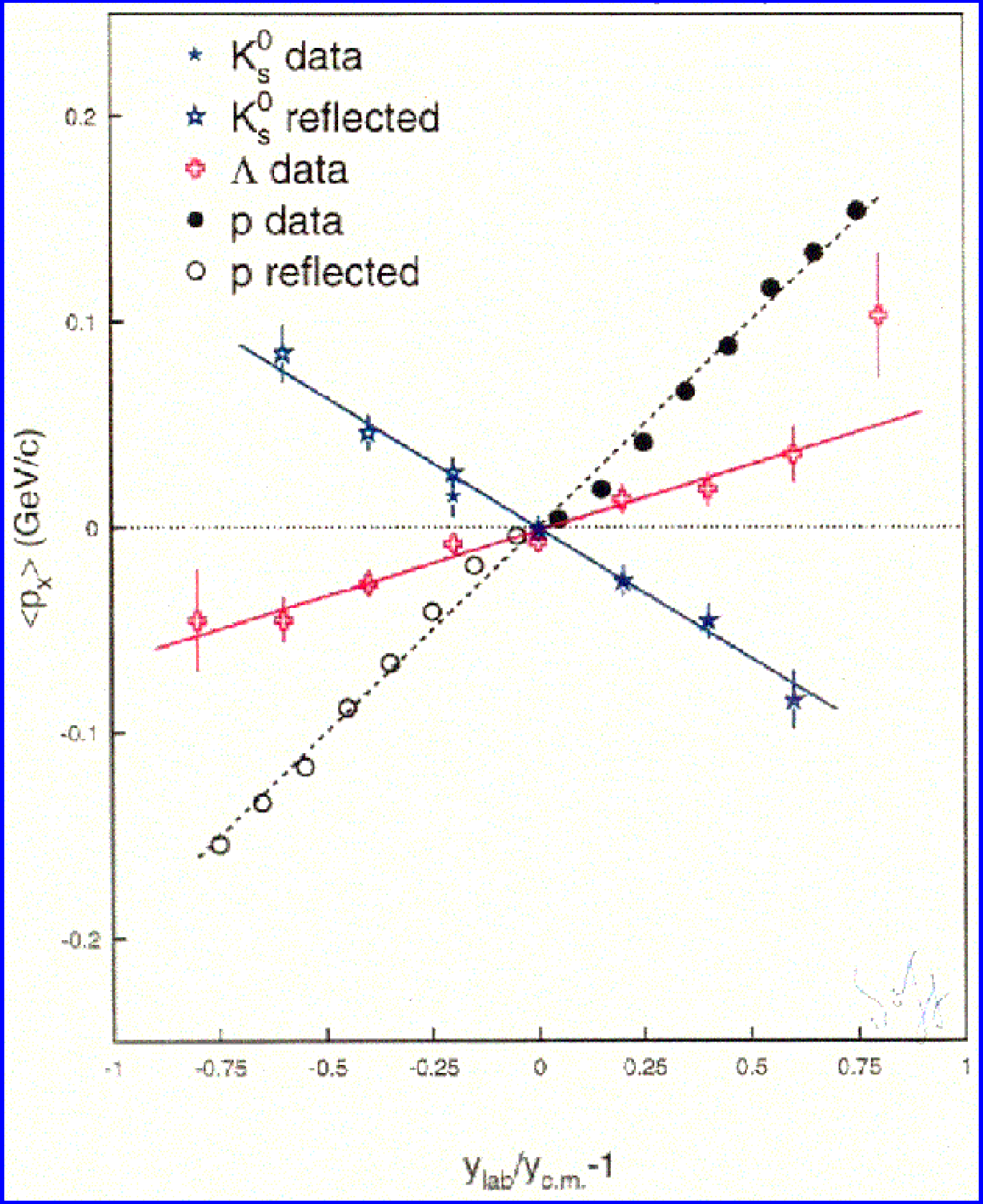
Directed flow:
Max at Elab ~ 1 AGeV

Flow is sensitive to changes in EoS, softening

Resonance Matter

Method works!

6 AGeV: Flow of Baryons linear: No Phase Transition -but also no single thermalized source!

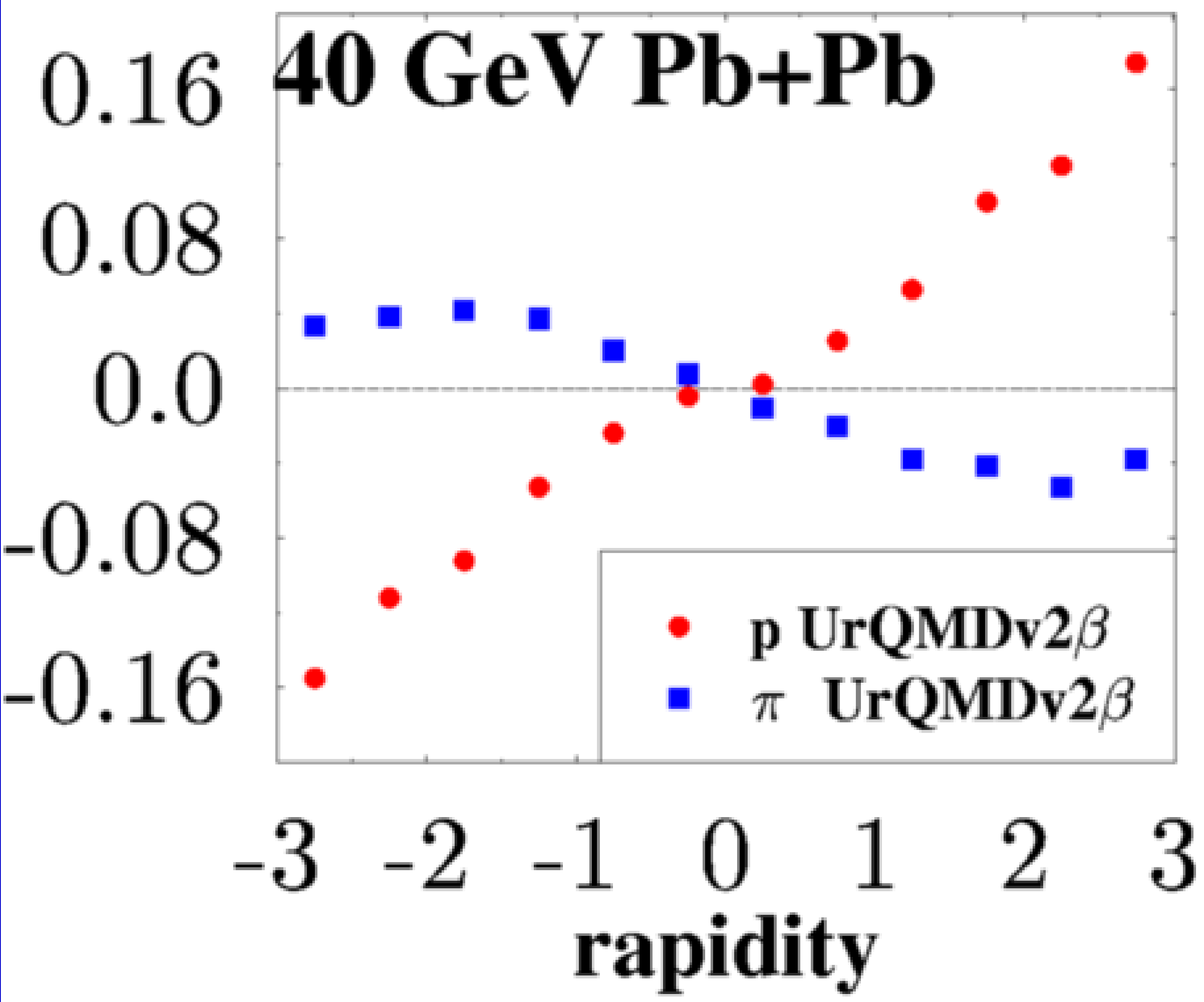


Strange Baryons flow !

But Pions & Strange Mesons K show Anti-flow! E895

- Soff: UrQMD Predicts Proton v1 Rises Linearly with y & E -

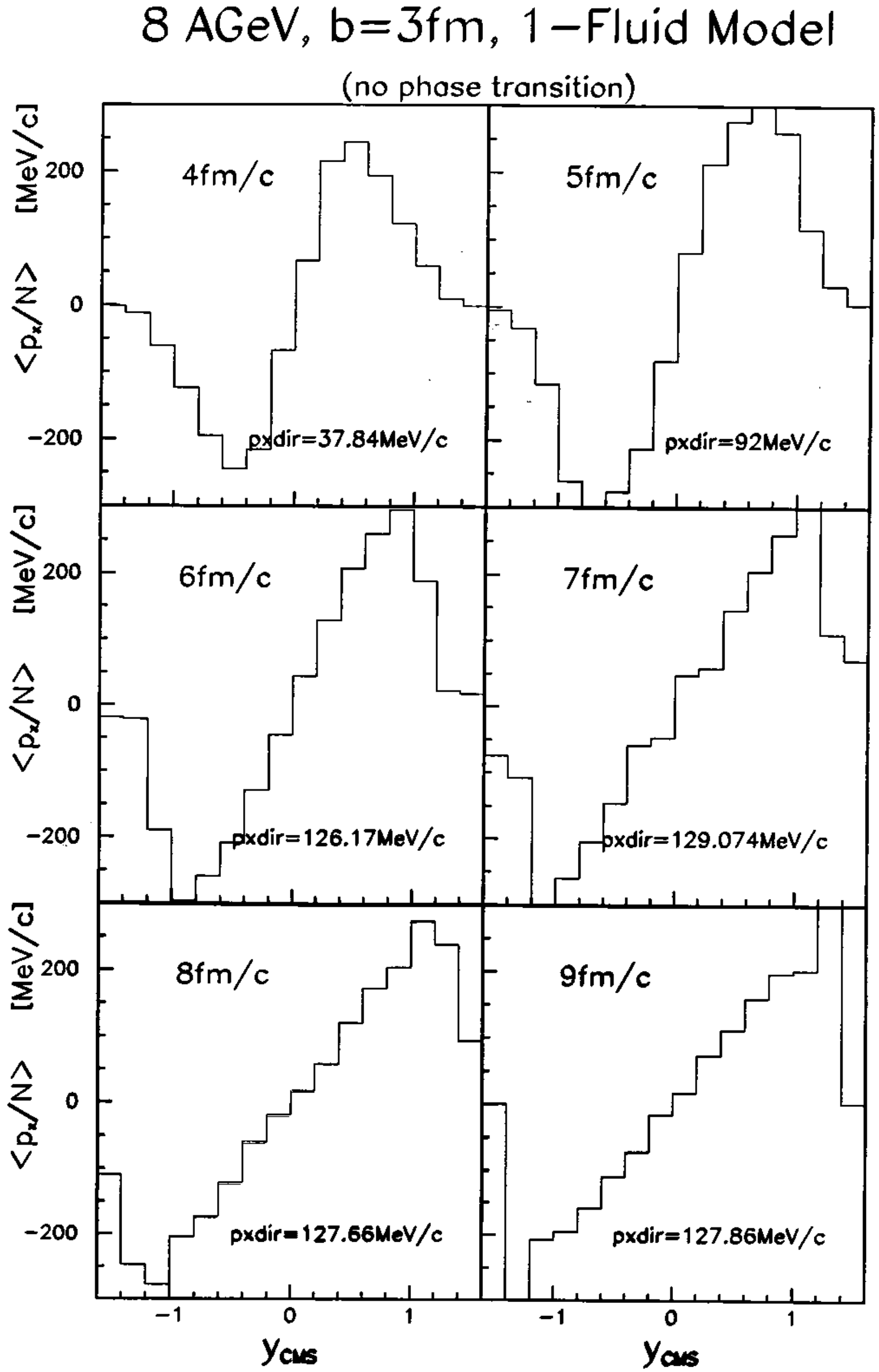
What do Data Say?



Full 3Dim Hydro, NO P.T.:

proton v1=px/pt rise linearly

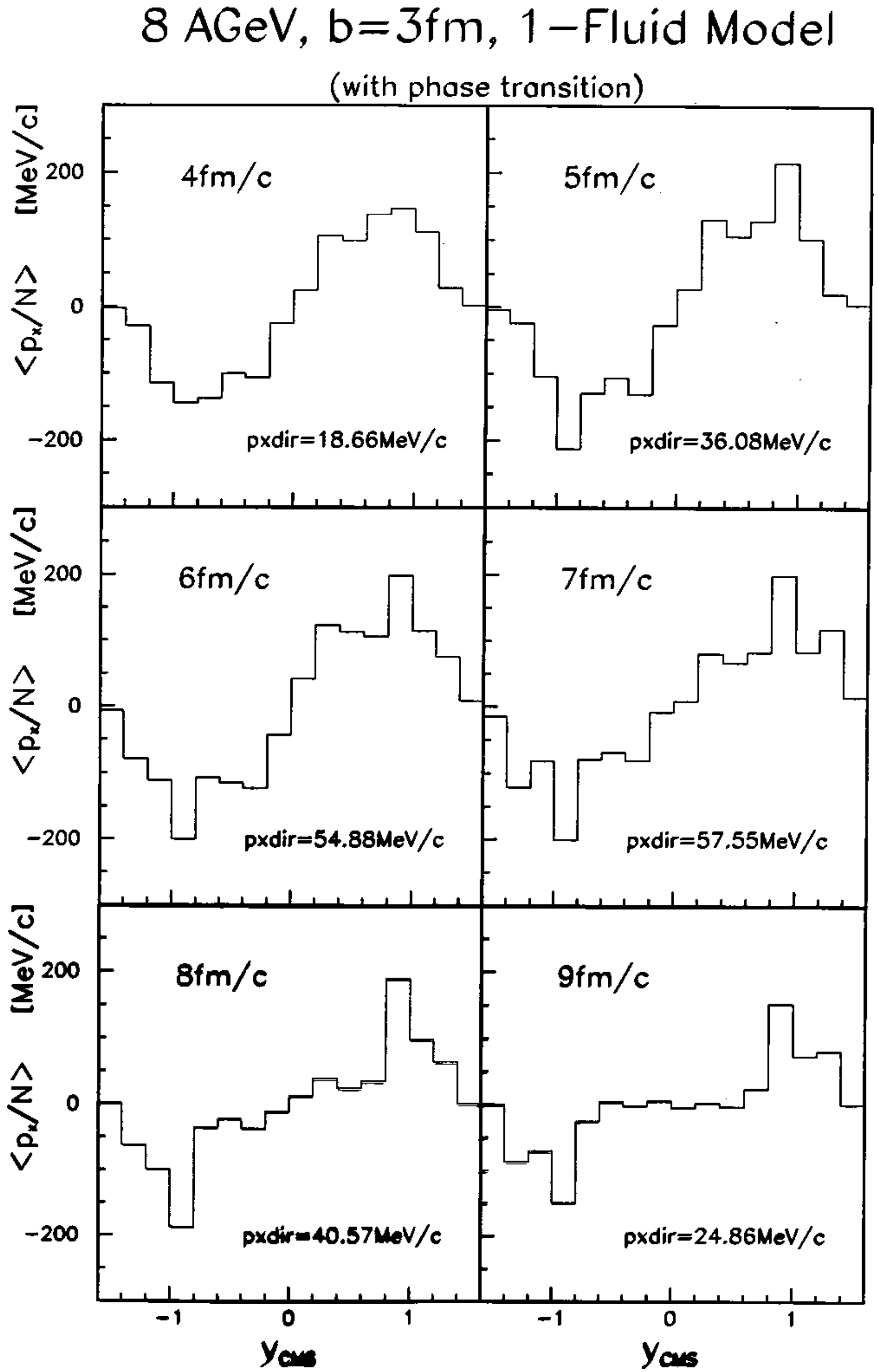
Brachmann, Dumitru, Rischke



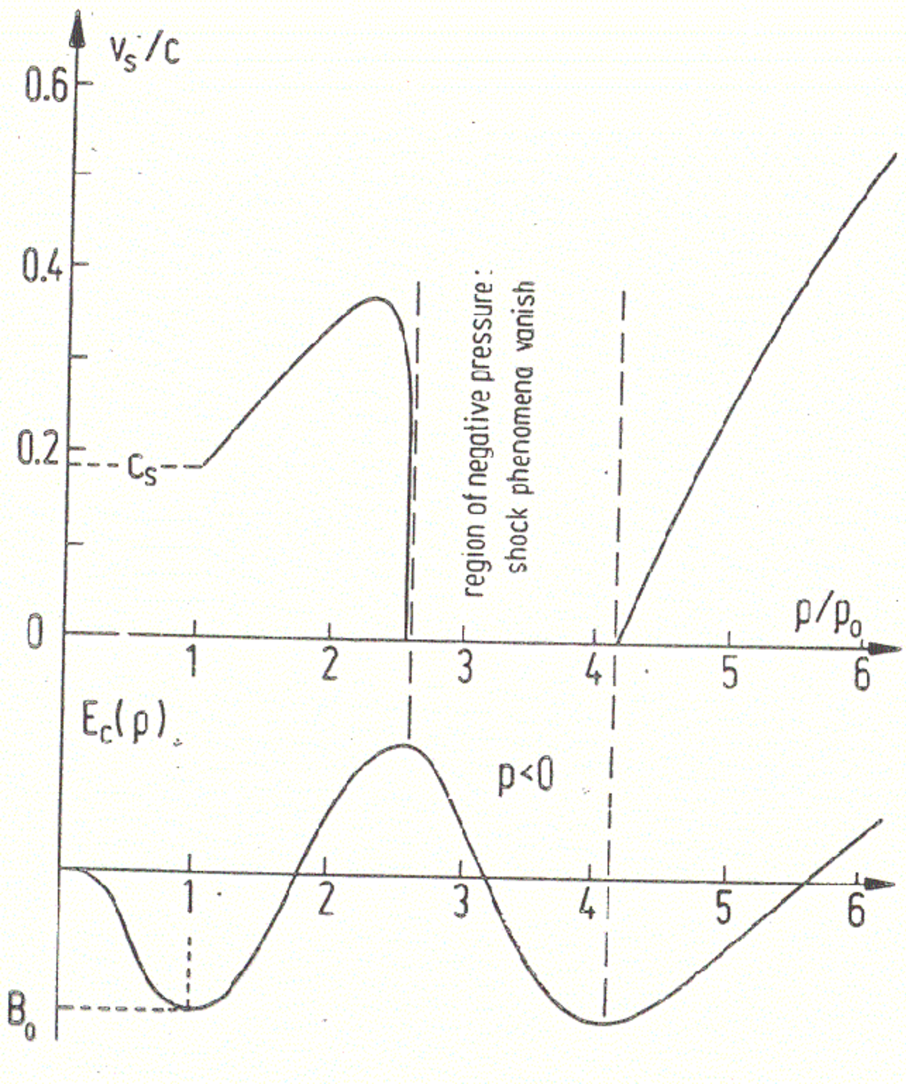
BUT: Hydro w. 1.Order Phase Transition:

Collapse of proton flow!!!

Brachmann Dumitru



Influence of secondary minimum in $E_c(\rho)$ on the propagation of shock waves
Stöcker, Hofmann, Scheid, Greiner 1974/75

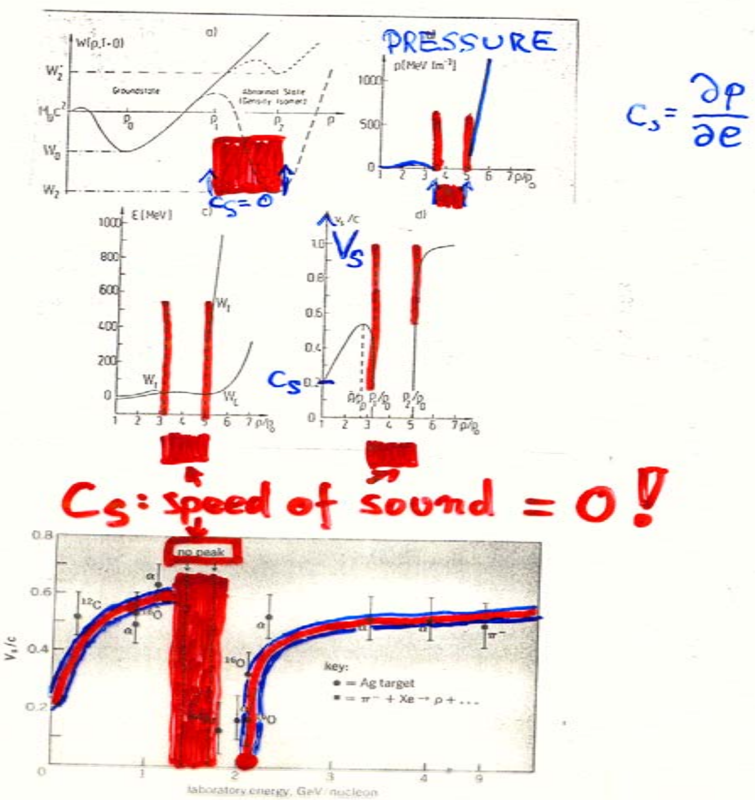


VOLUME 36, NUMBER 2 PHYSICAL REVIEW LETTERS 12 JANUARY 1976

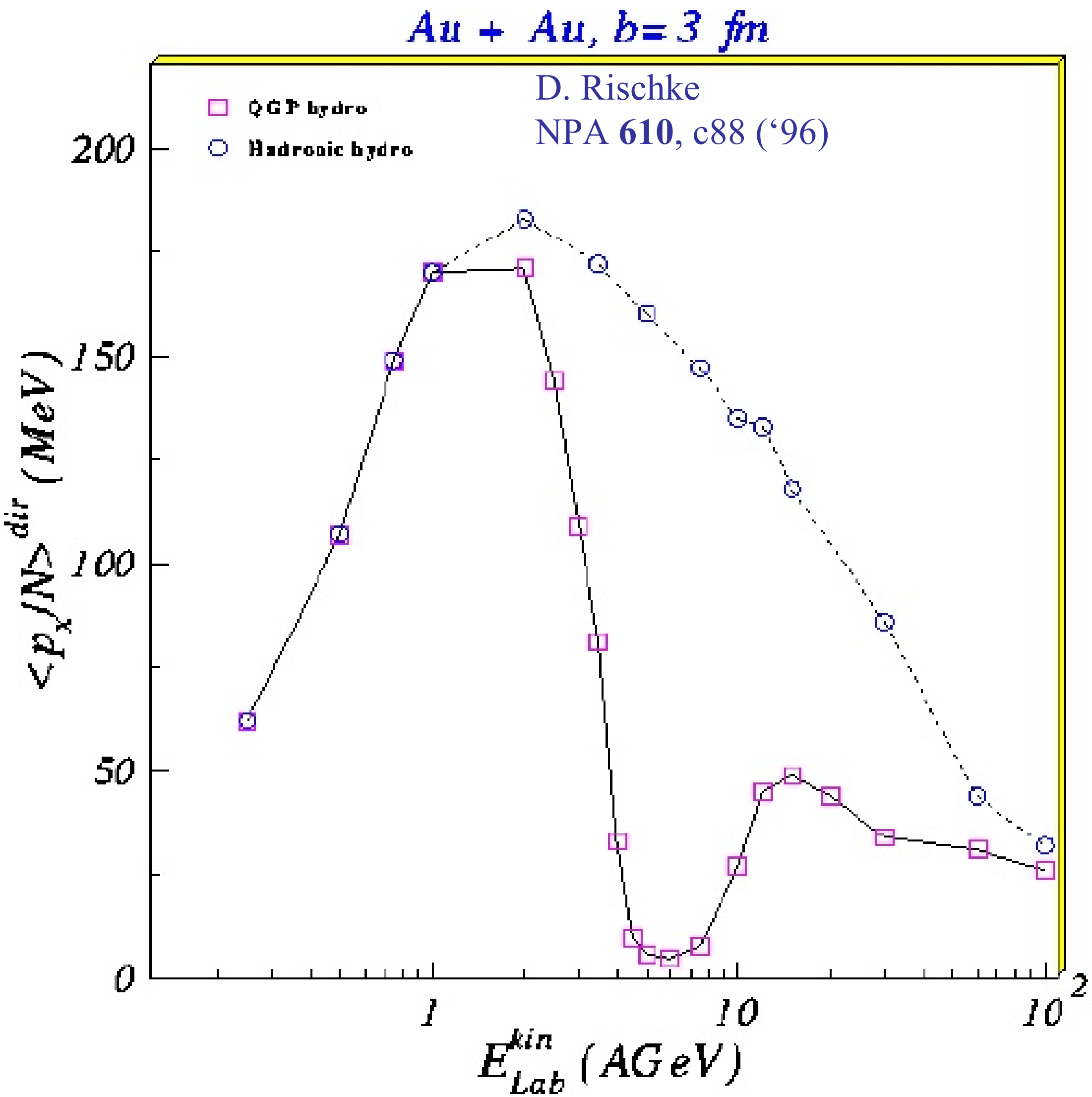
Possibility of Detecting Density Isomers in High-Density Nuclear Mach Shock Waves*

Jürgen Hofmann, Horst Stöcker, Ulrich Heinz, Werner Scheid, and Walter Greiner
Institut für Theoretische Physik der Universität Frankfurt am Main, Frankfurt am Main, Germany
(Received 29 September 1975)

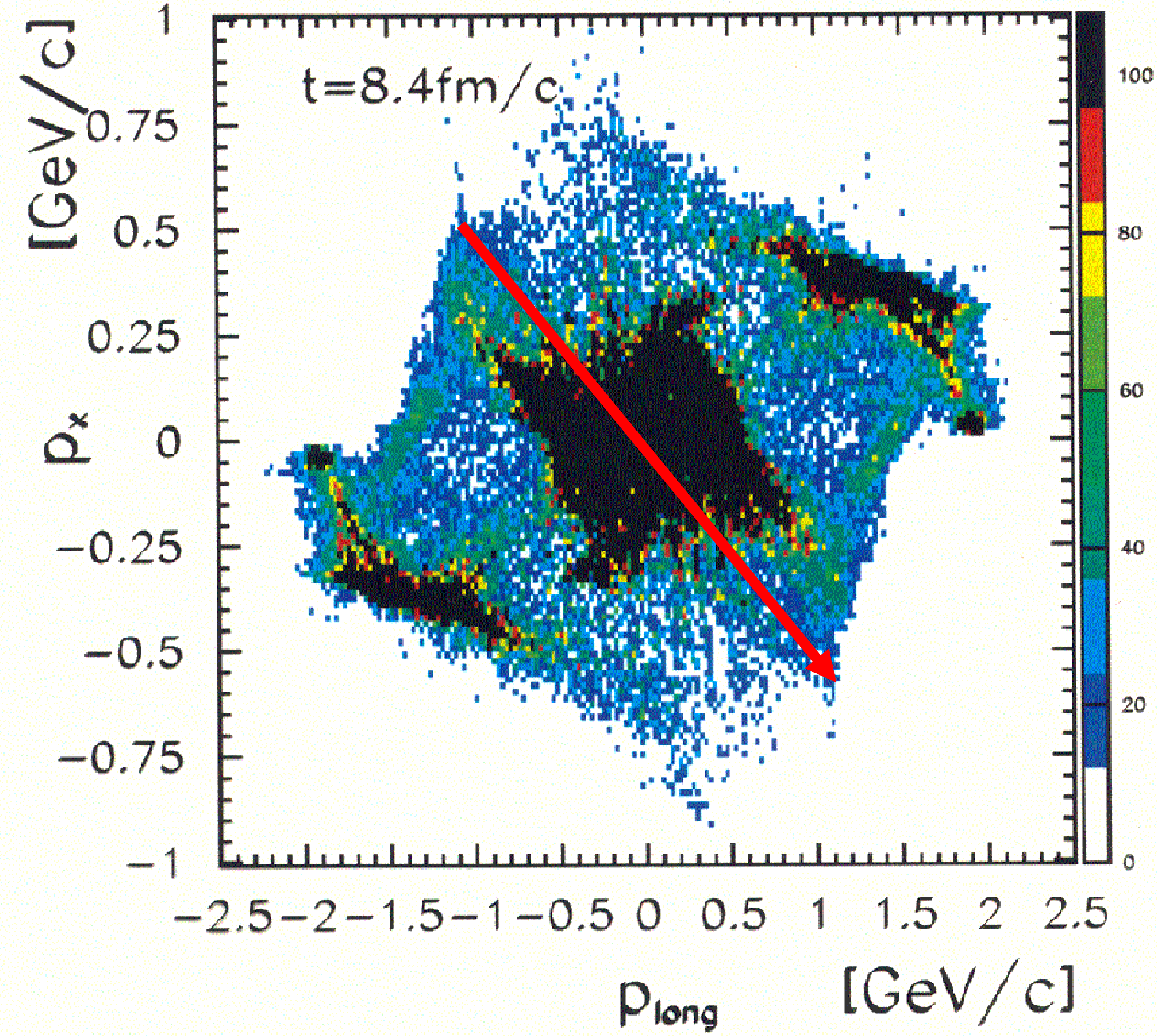
Up to now no experimentally feasible method for detecting abnormal nuclear states has been known. We propose to observe them in high-energy heavy-ion collisions through the disappearance of, or irregularities in, high-density nuclear Mach shock phenomena.



Collapse of Shock at Phase Transition in EoS



Later dubbed "softest point" of EoS



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

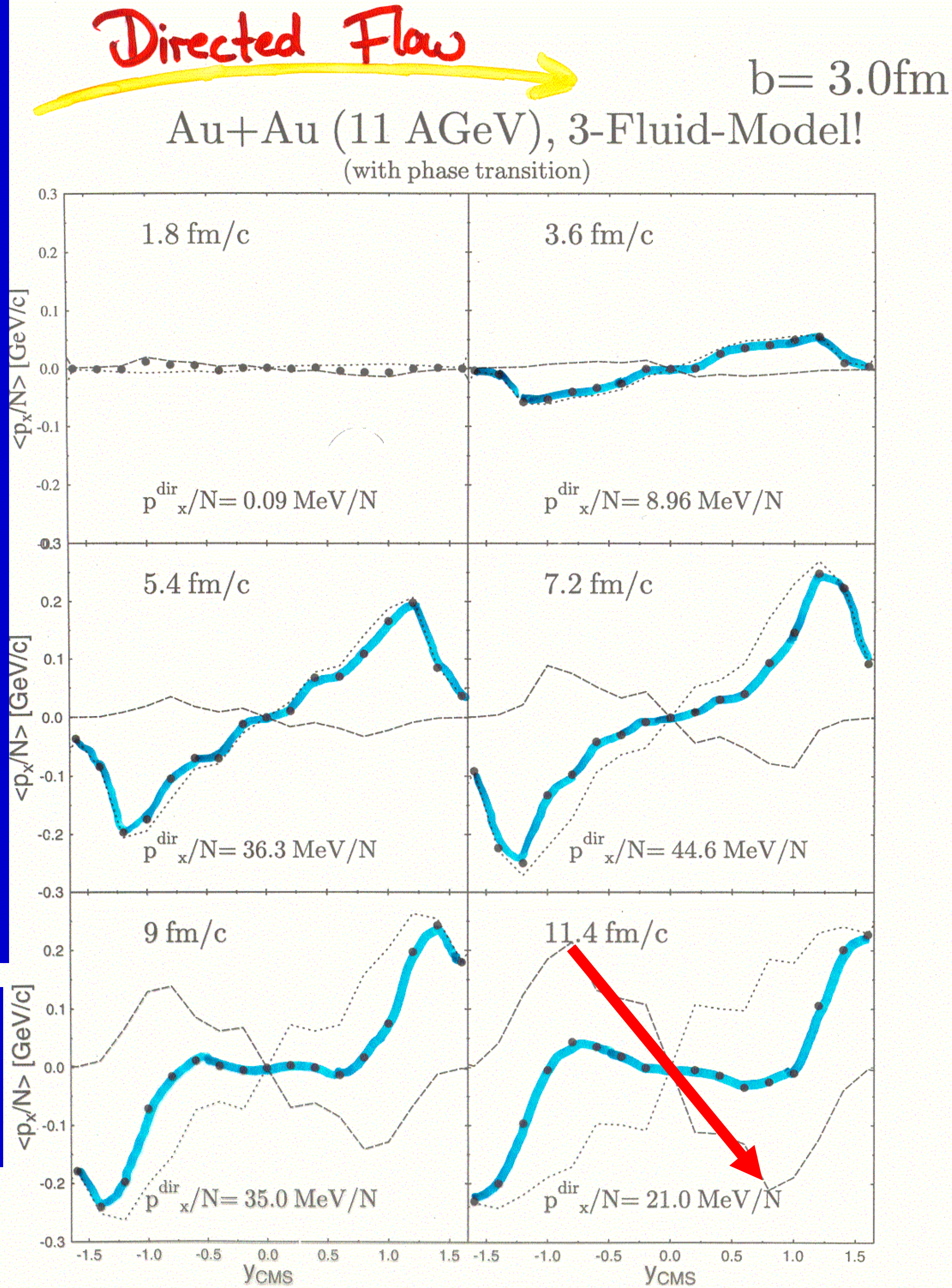
3 Dim. hydro
mu > mu-crit:
1.order transition

Negative v1-flow = Anti-Flow of protons

at E > 11 AGeV

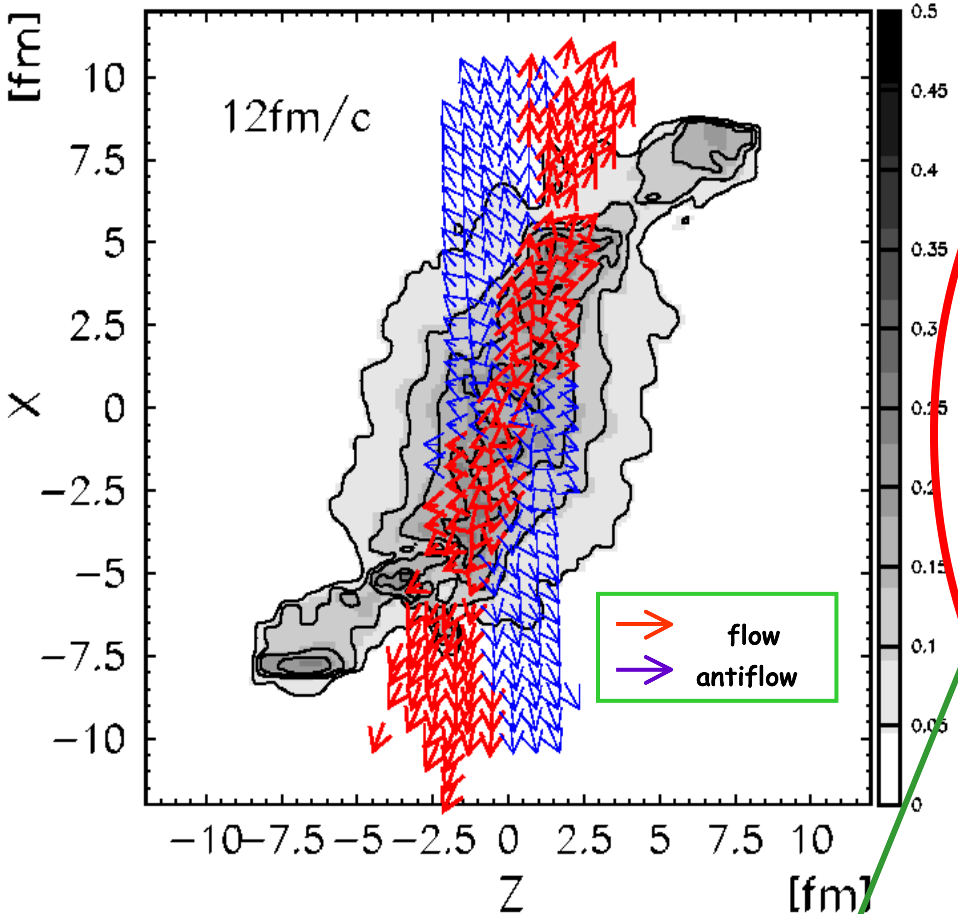
Brachmann, Dumitru:

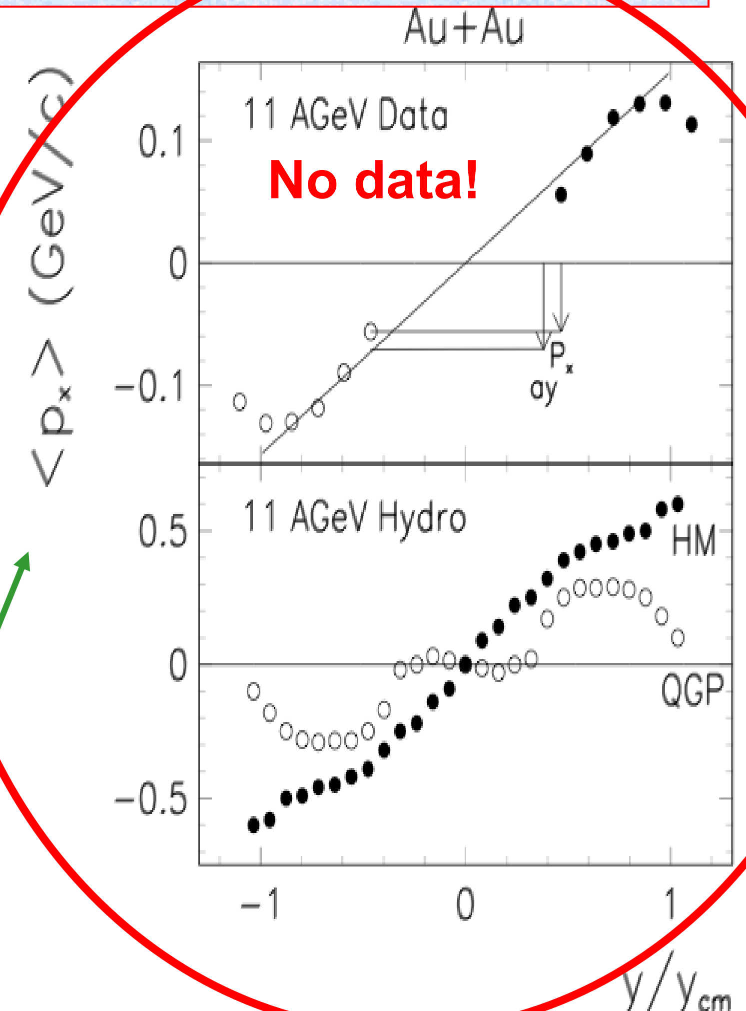
„It“ is in the protons.



Proton Directed flow (v_1) and phase transition

Anti-flow/3rd flow component, with QGP $\Rightarrow$ v_1 flat at middle rapidity.

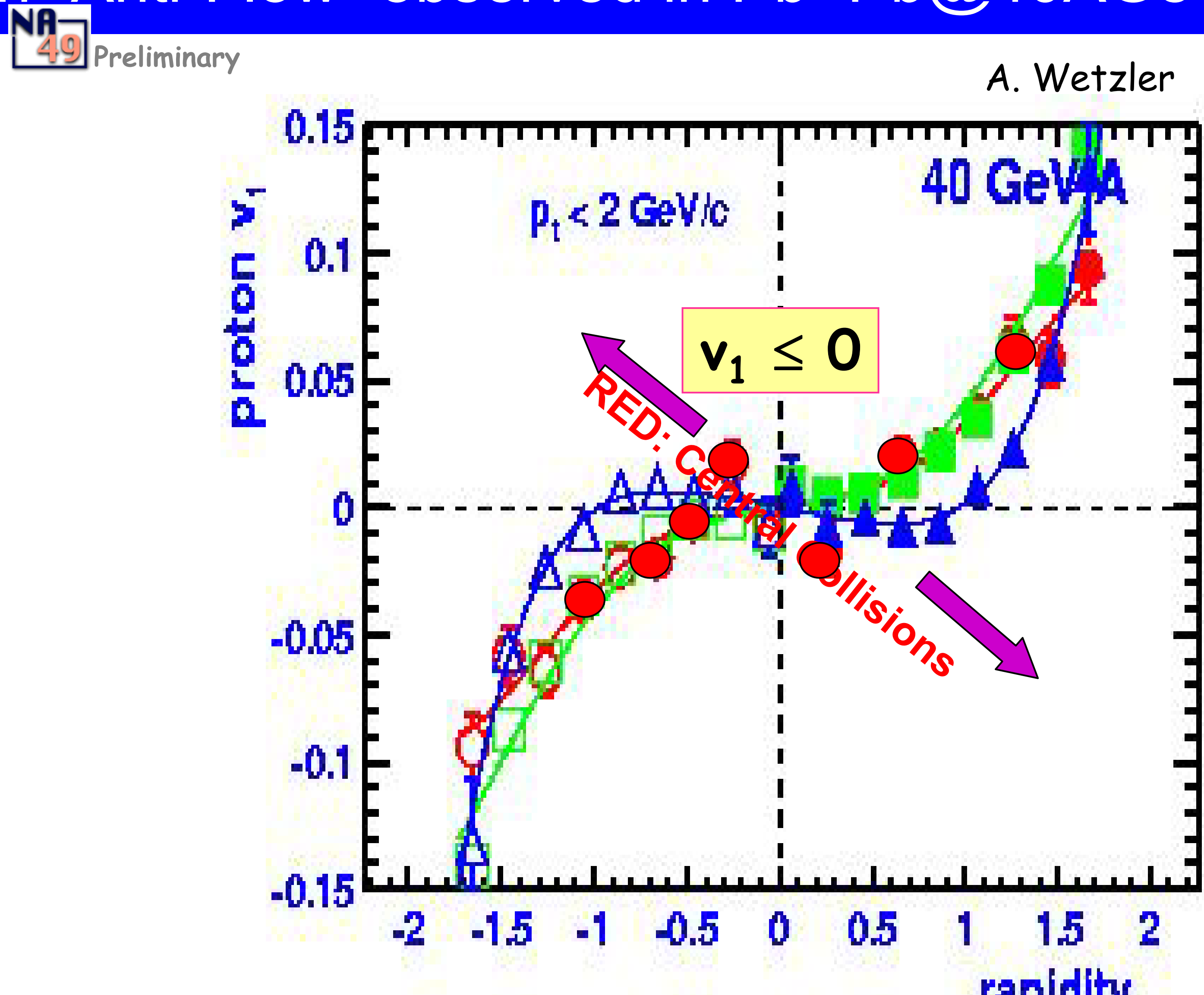




Brachmann, Soff, Dumitru, Stocker, Maruhn, Greiner Bravina, Rischke , PRC 61 (2000) 024909.
L.P. Csernai, D. Roehrich PLB 458, 454 (1999) M.Bleicher and H.Stocker, PLB 526,309(2002)

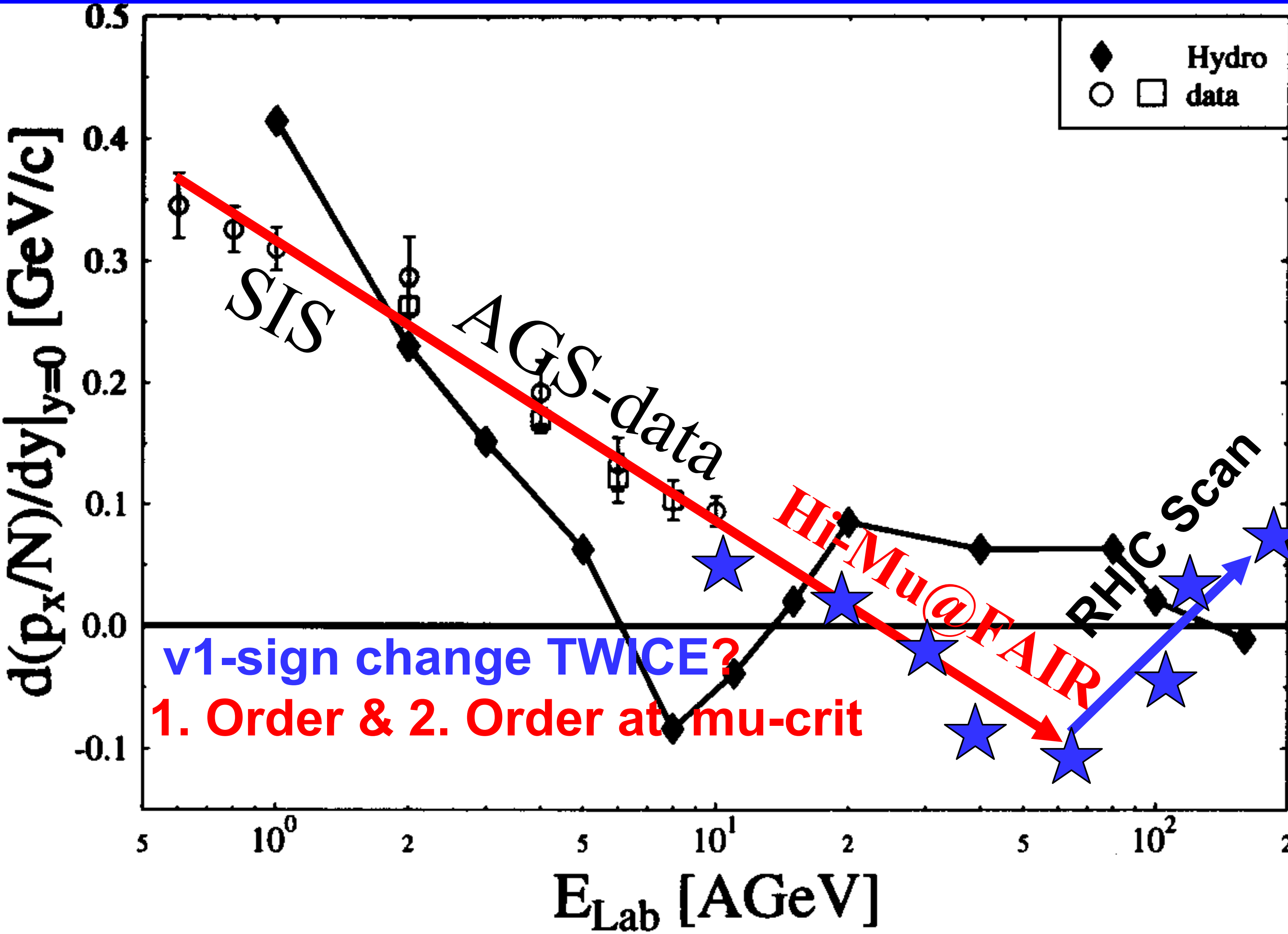
Hydro [Csernai, HIPAGS'93]

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



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

v1-proton 3DHydro: PROTON-AntiFlow AGS, FAIR, RHIC
Extrapolated Data: Anti-Flow @ 30 AGeV: Hi-Mu-RHIC!



Brachmann, Dumitru, Rischke

VOLUME 36, NUMBER 2 PHYSICAL REVIEW LETTERS 12 JANUARY 1976

Possibility of Detecting Density Isomers in High-Density Nuclear Mach Shock Waves*

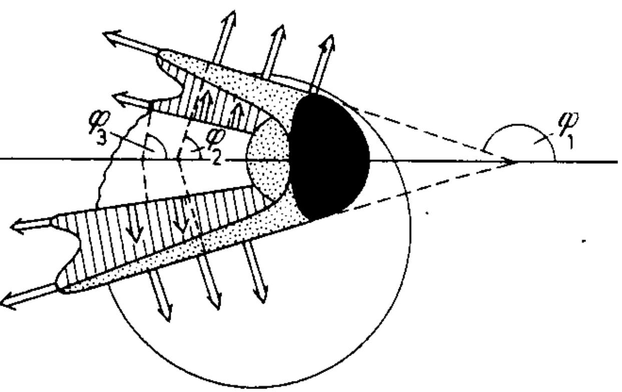
Jürgen Hofmann, Horst Stöcker, Ulrich Heinz, Werner Scheid, and Walter Greiner
Institut für Theoretische Physik der Universität Frankfurt am Main, Frankfurt am Main, Germany

(Received 29 September 1975)

Up to now no experimentally feasible method for detecting abnormal nuclear states has been known. We propose to observe them in high-energy heavy-ion collisions through the disappearance of, or irregularities in, high-density nuclear Mach shock phenomena.

1975: First Paper on energy scan to measure 1. Order phase transition by collapse of flow: dissappearance of speed of sound: 90° Mach angle!

massless chiral state **(Lee – Wick matter) and** ***Quark Matter*** **by J. Collins and M. Perry,** ***Phys. Rev. Lett.*** **, 34, 1353 (1975)**



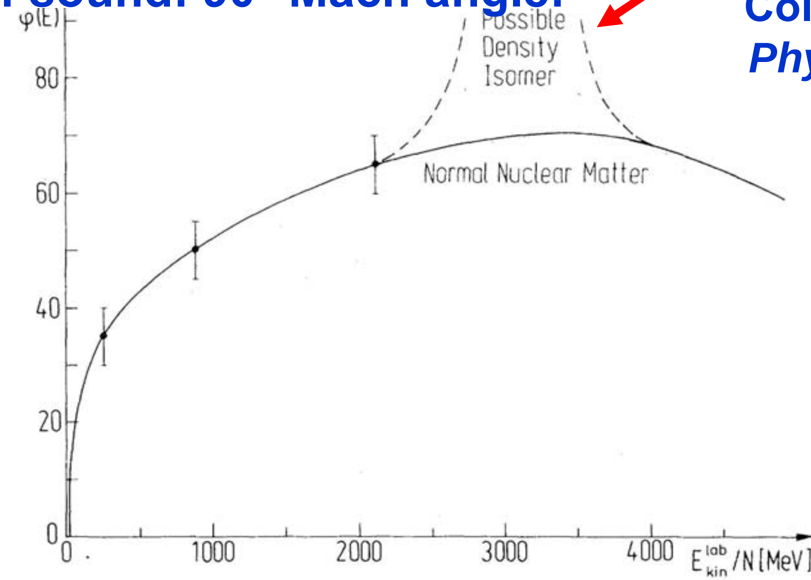


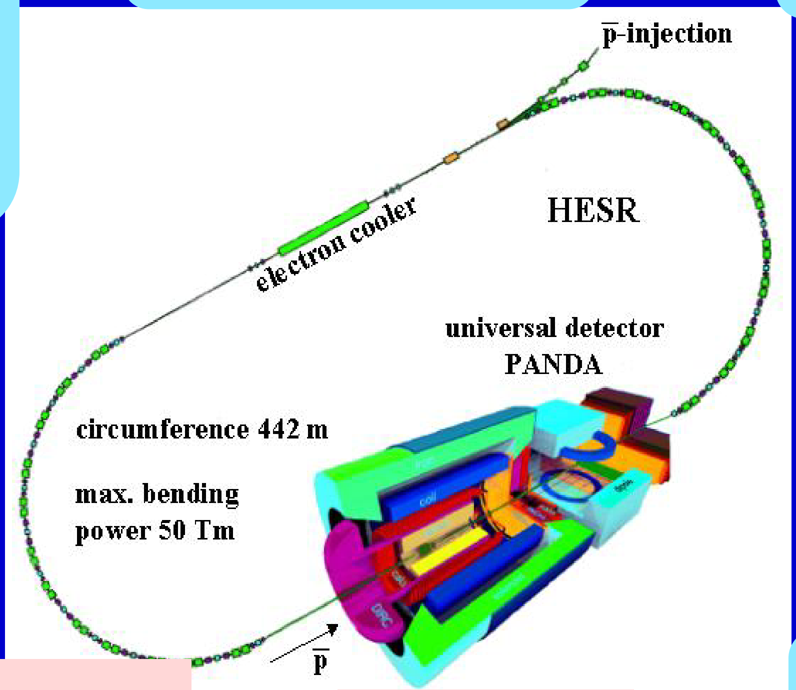
FIG. 3. The Mach angle $\varphi(E)$ as a function of the projectile energy (per nucleon, N). The presently available experimental results (Ref. 8) are indicated. The consequence of a possible density isomer will affect the Mach angles as schematically indicated by the dashed curve.

FAIR QCD-Physics Program with Antiprotons

strange and charmed (anti-) baryons in nuclear field

hidden and open charm in nuclei

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



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

J/ψ spectroscopy confinement, in-medium effects

FLAIR

HESR Consortium
Jülich / Uppsala / Stockholm / GSI

PANDA

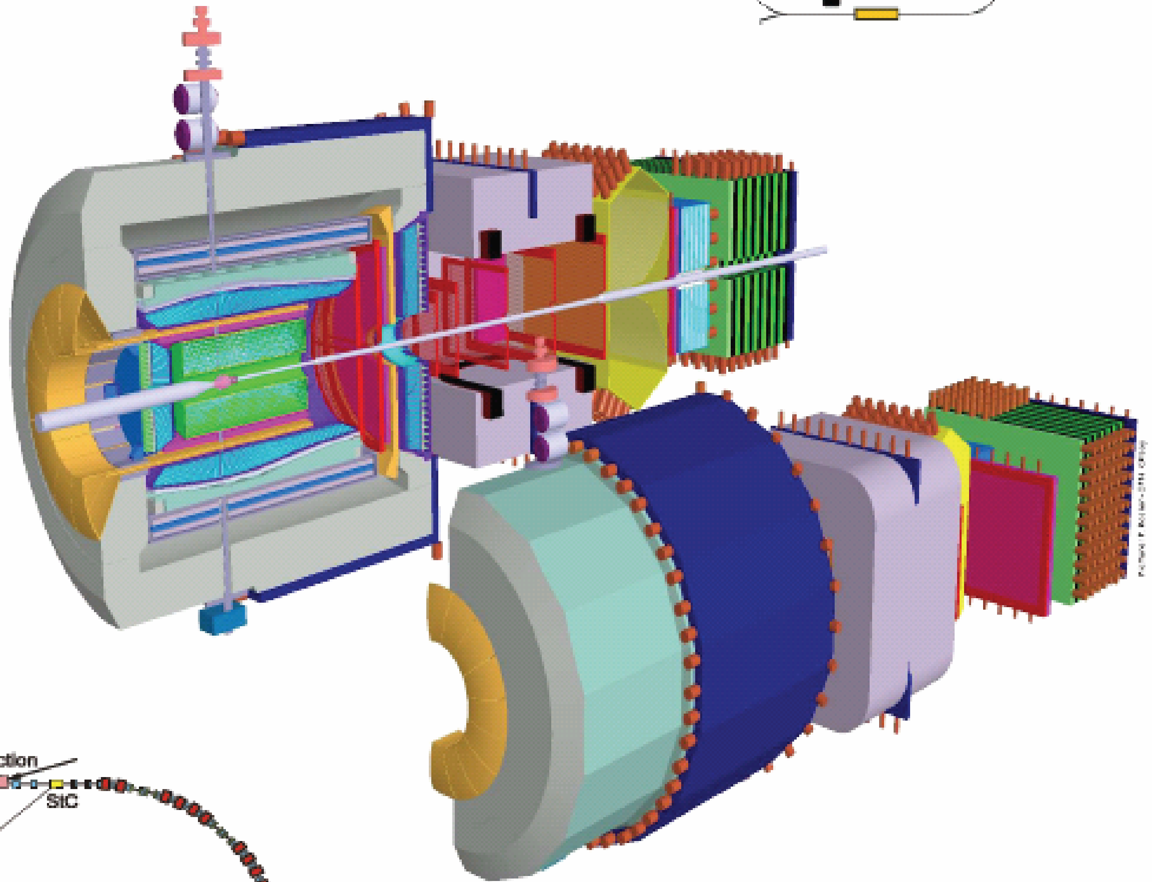
CP-violation (D/Λ - sector)

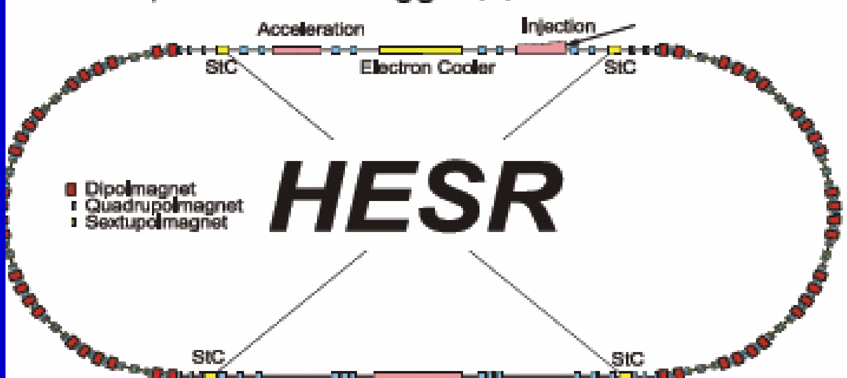
inverted deeply virtual Compton scattering

spin structure of the proton: polarized antiprotons in PAX

Layout of the Antiproton Detector

- High Rates
  - Total σ ~ 55 mb
  - peak > 10^7 int/s
- Vertexing
  - (σ_p,K_S,Λ,…)
- Charged particle ID
  - ($e^\pm$,$\mu^\pm$,$\pi^\pm$,p,…)
- Magnetic tracking
- Elm. Calorimetry
  - (γ,π^0,η)
- Forward capabilities
  - (leading particles)
- Sophisticated Trigger(s)



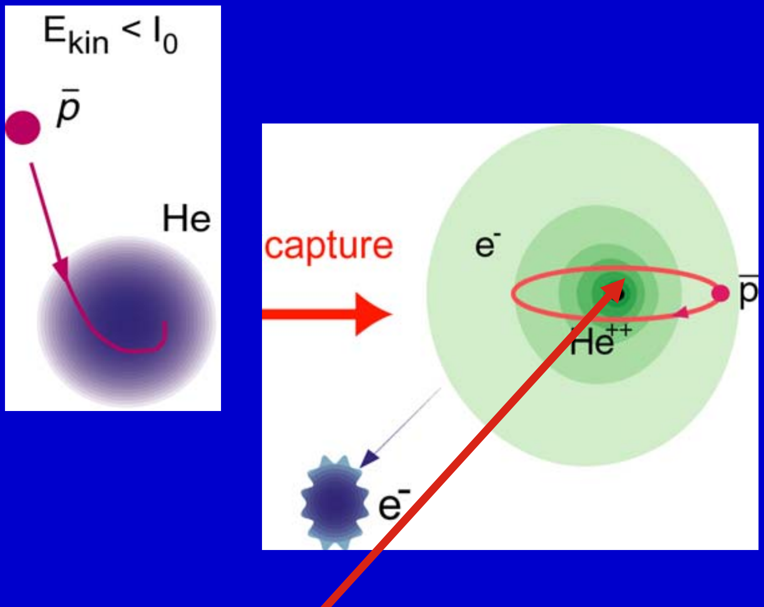


in ring experiment

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-Helium**



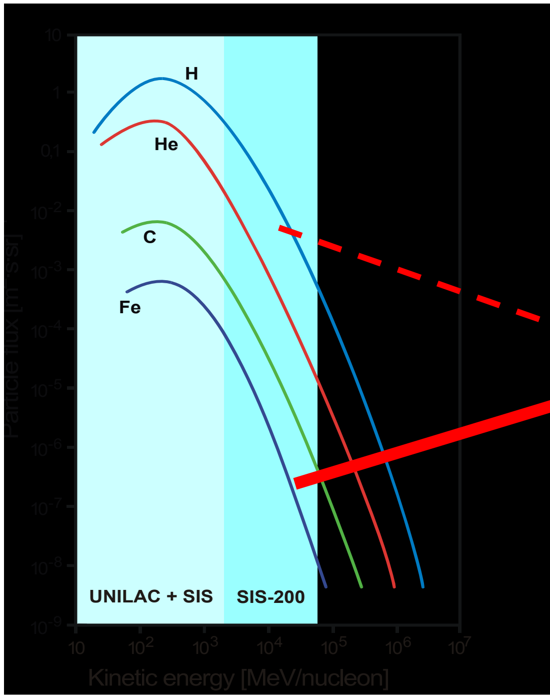
$\rho = 5\text{–}10 \times \rho_0$

I.Mishustin; L. Satarov, H. Stoecker; W. Greiner;

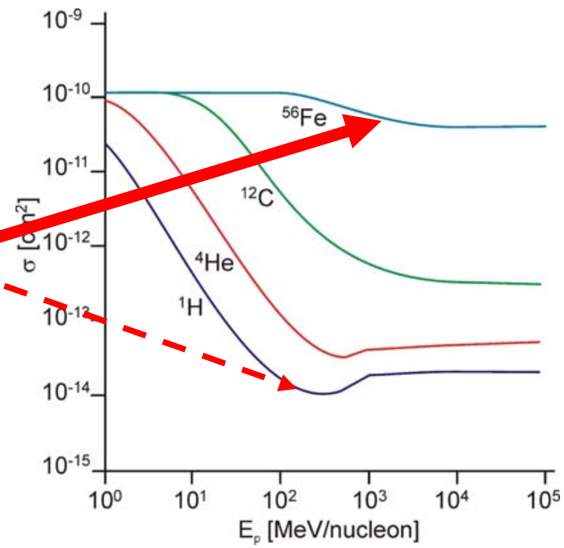
Cold Nuclear Compression by Vector Attraction of p-bars in medium

Applied Research

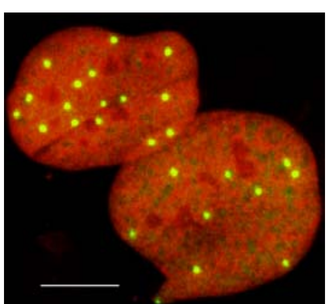
Radiobiology for space reserach



Cosmic particle spectrum



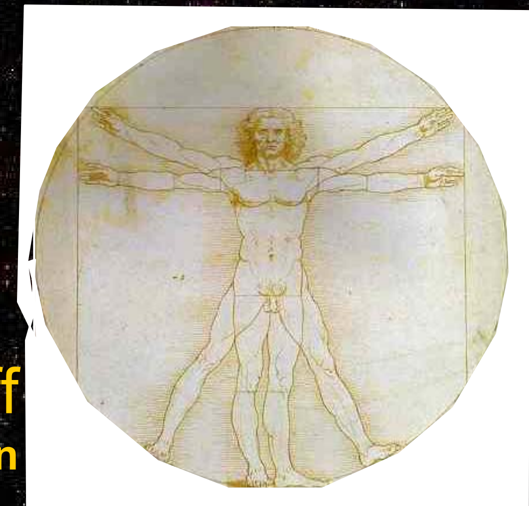
Risk cross sections



Approaches for risk estimates:

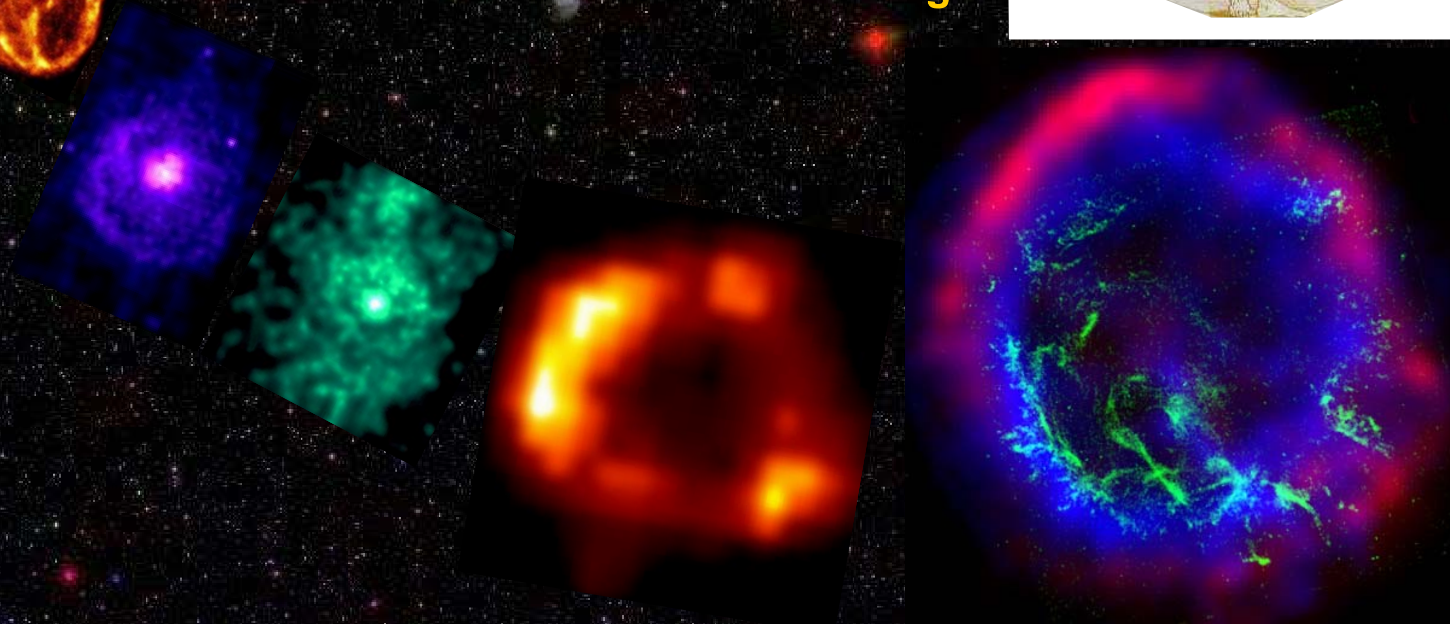
- Cytogenetics
- Cell transformation
- Tissue effects
- Modelling

Each heavy atom in our body was build and processed through ~100-1000 star generations since the initial Big Bang event!



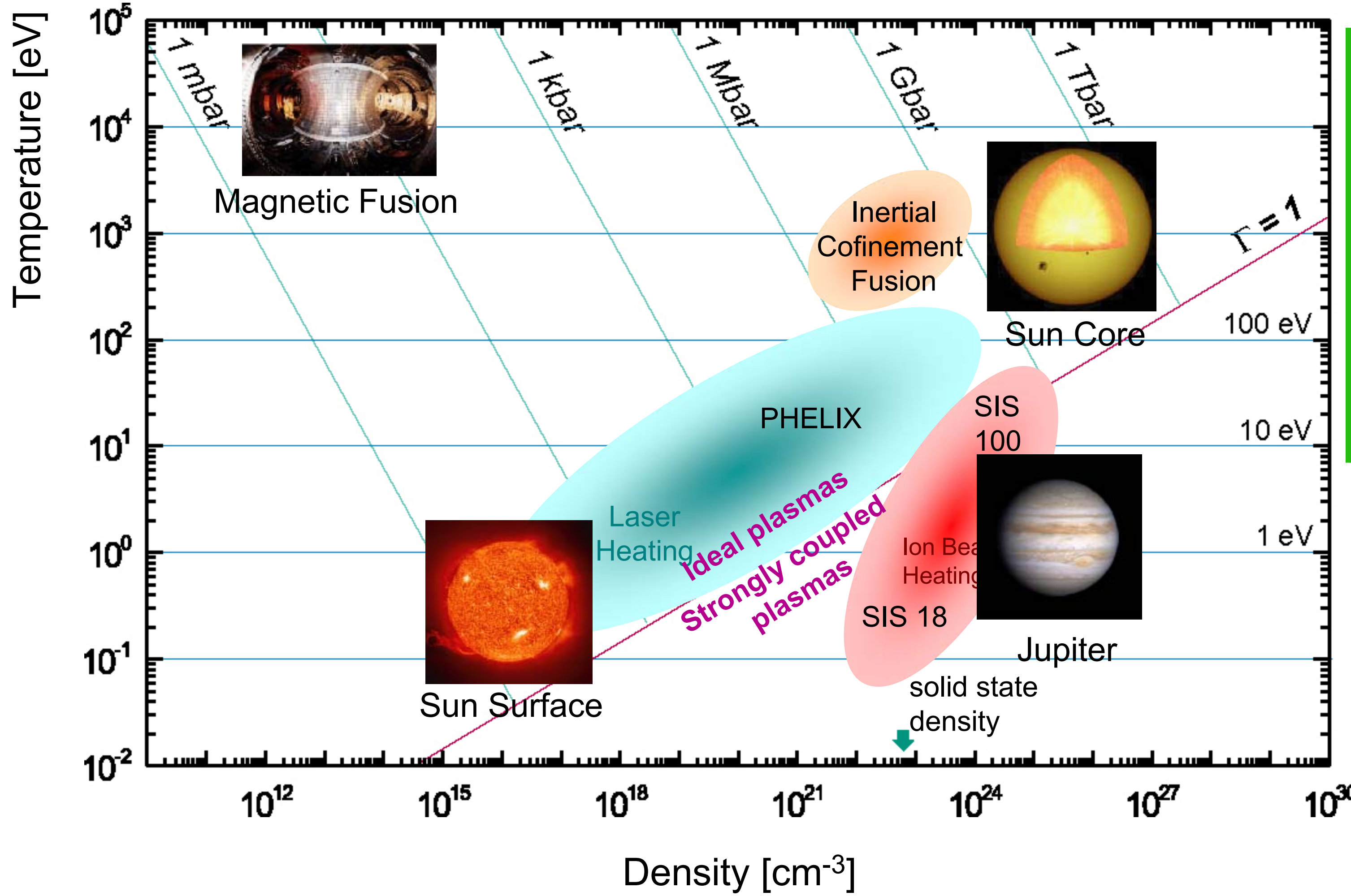
We are made of star stuff

Carl Sagan



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)

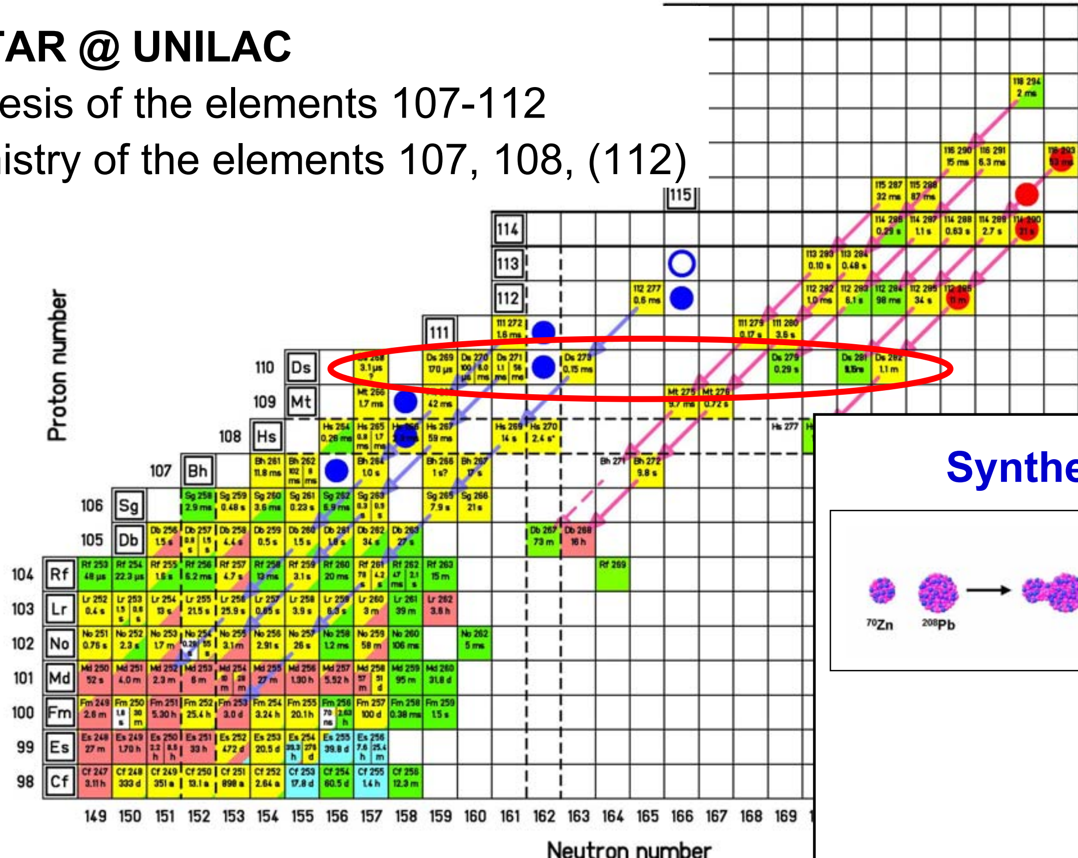
Equation of state of planetary and stellar matter

Synthesis and study of the heaviest elements

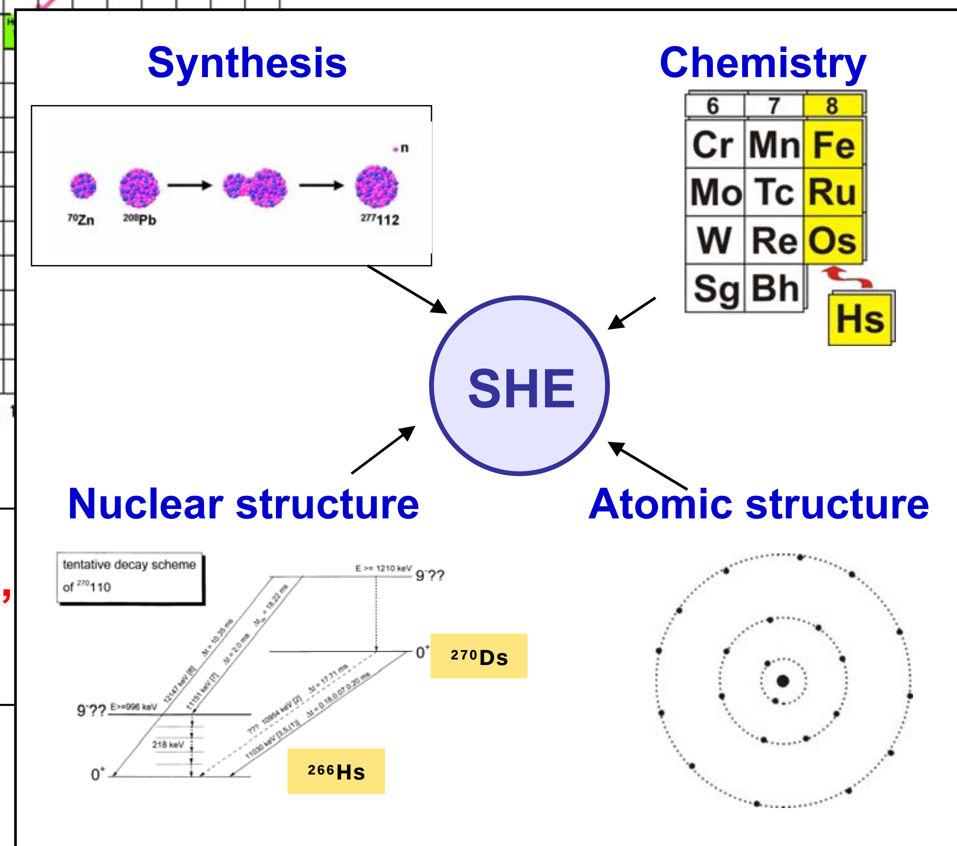
NUSTAR @ UNILAC

Synthesis of the elements 107-112

Chemistry of the elements 107, 108, (112)



SHIP and TASCA

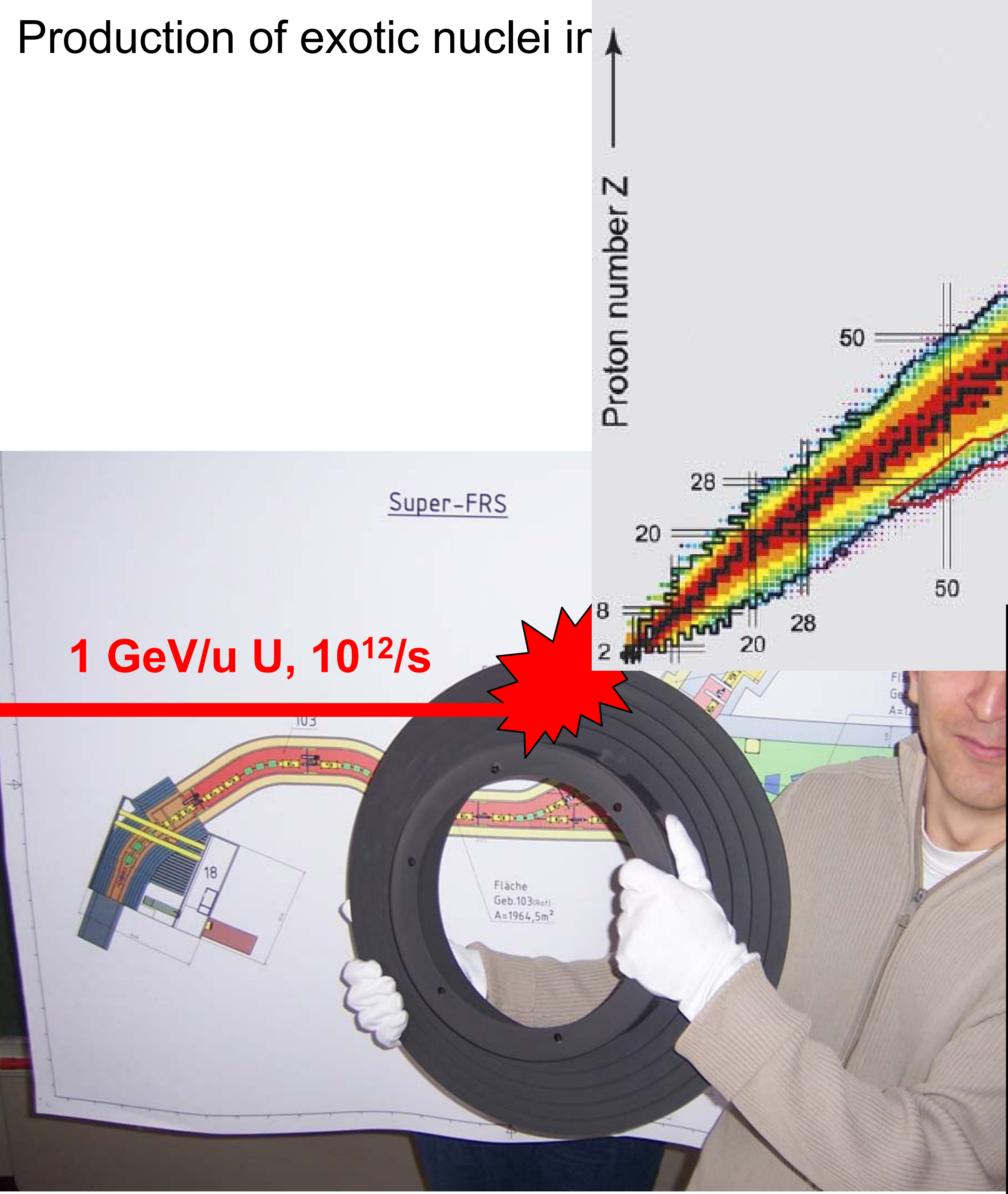


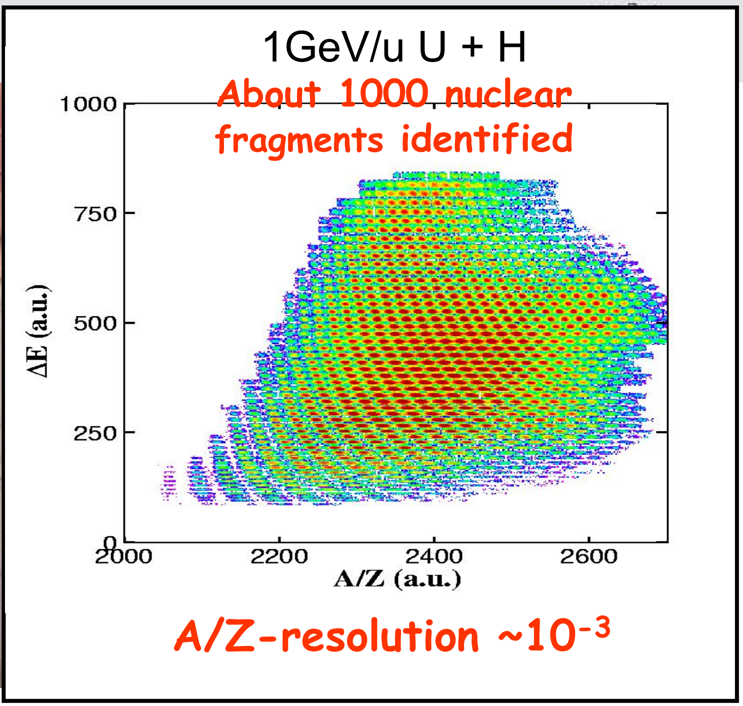
IUPAC:

Element 110 is named "Darmstadtium"

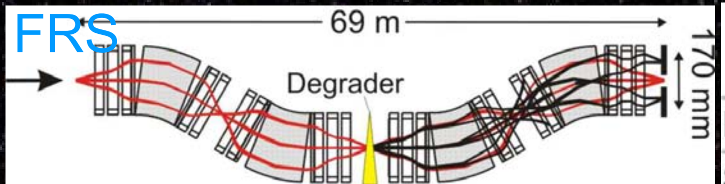
Chemical symbol is "Ds"

Production of exotic nuclei in

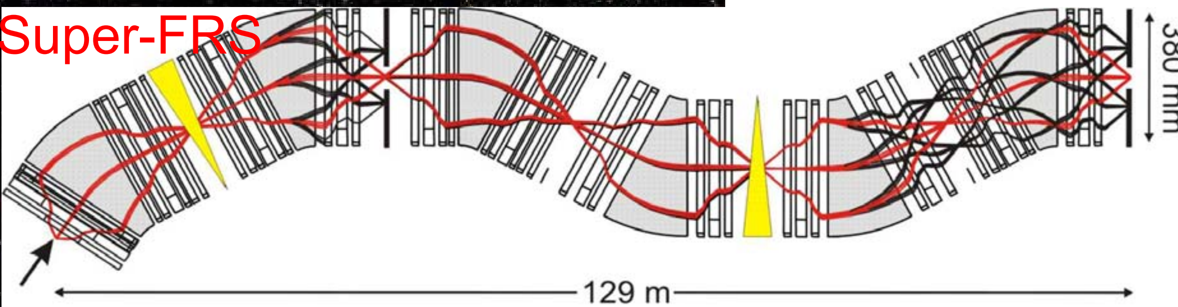


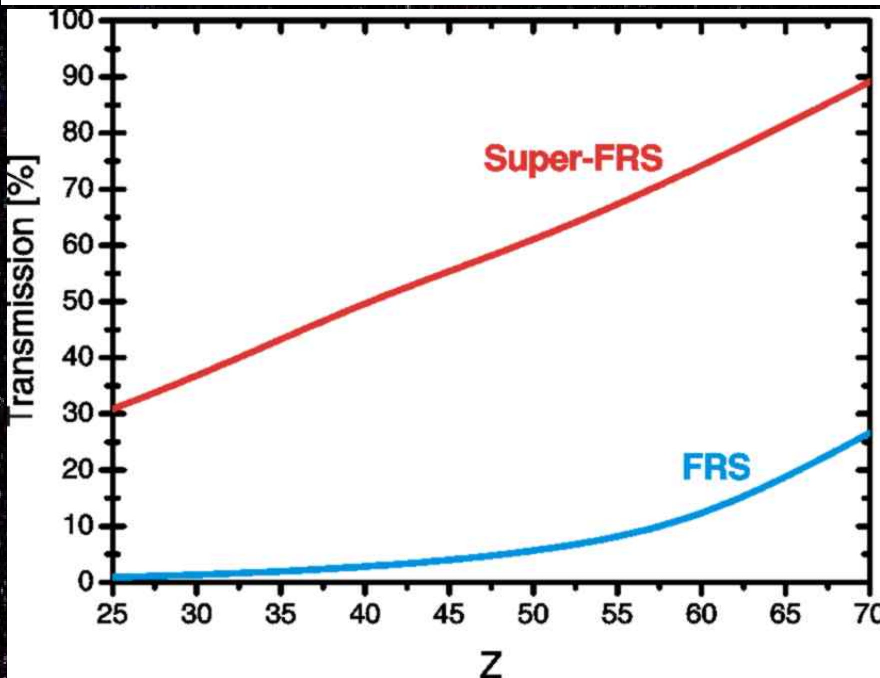


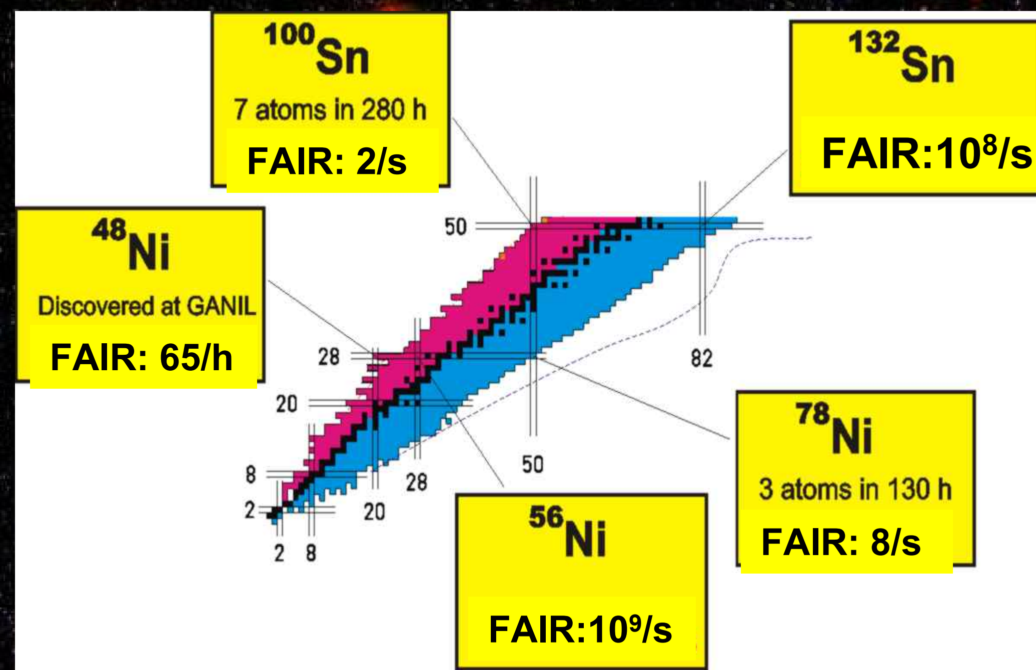
Comparison of FRS with Super-FRS, intensity gain



	$B\rho_{max}$	$\Delta p/p$	$\Delta\Phi_x$, $\Delta\Phi_y$	resolving power	gain factor ^{19}C	gain factor ^{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



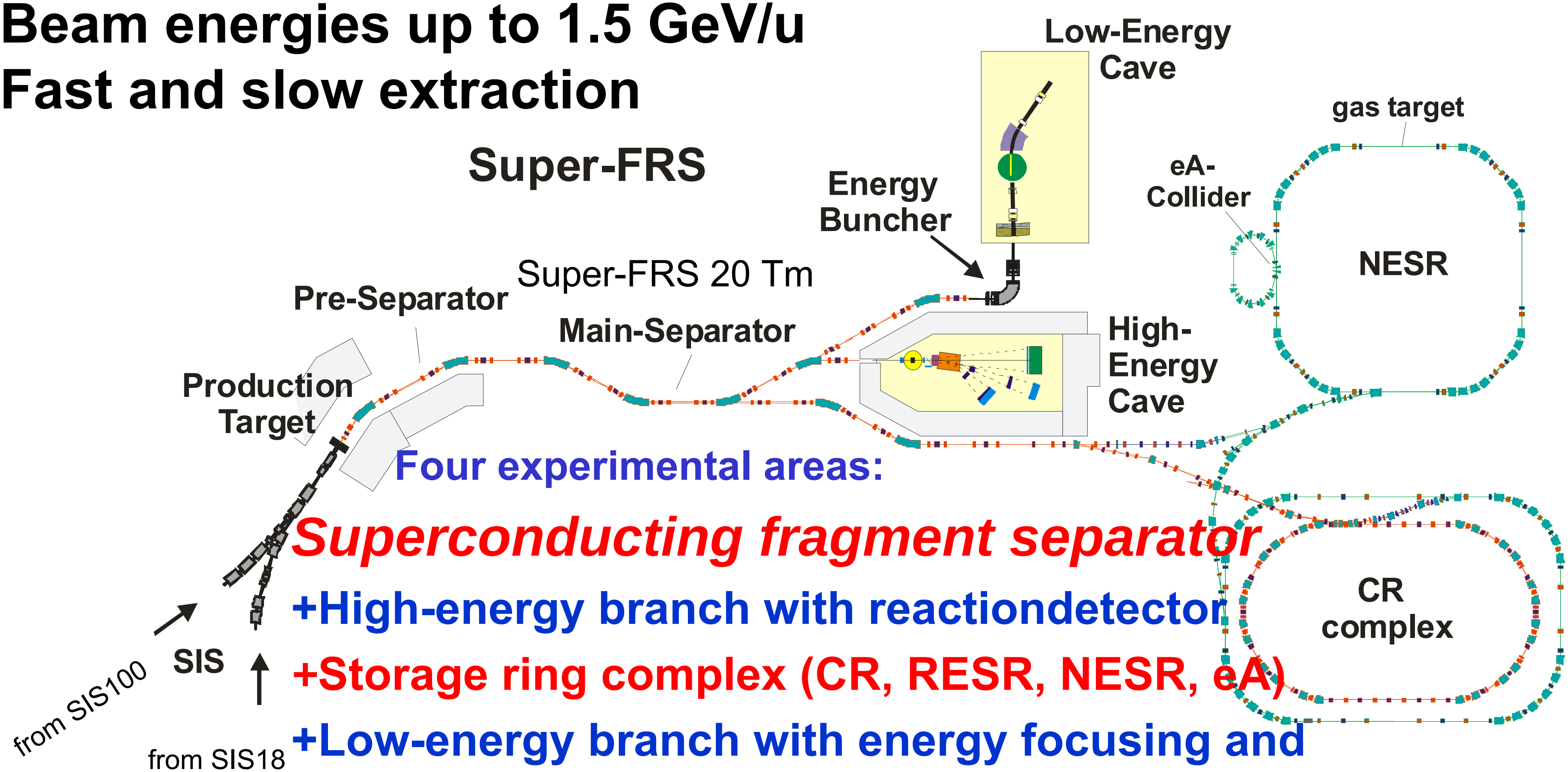




The NUSTAR - facility at FAIR

Important beam parameters:

- All elements from H to U
- Intensity ~ 10^{12} ions/sec.
- Beam energies up to 1.5 GeV/u
- Fast and slow extraction



Four experimental areas:

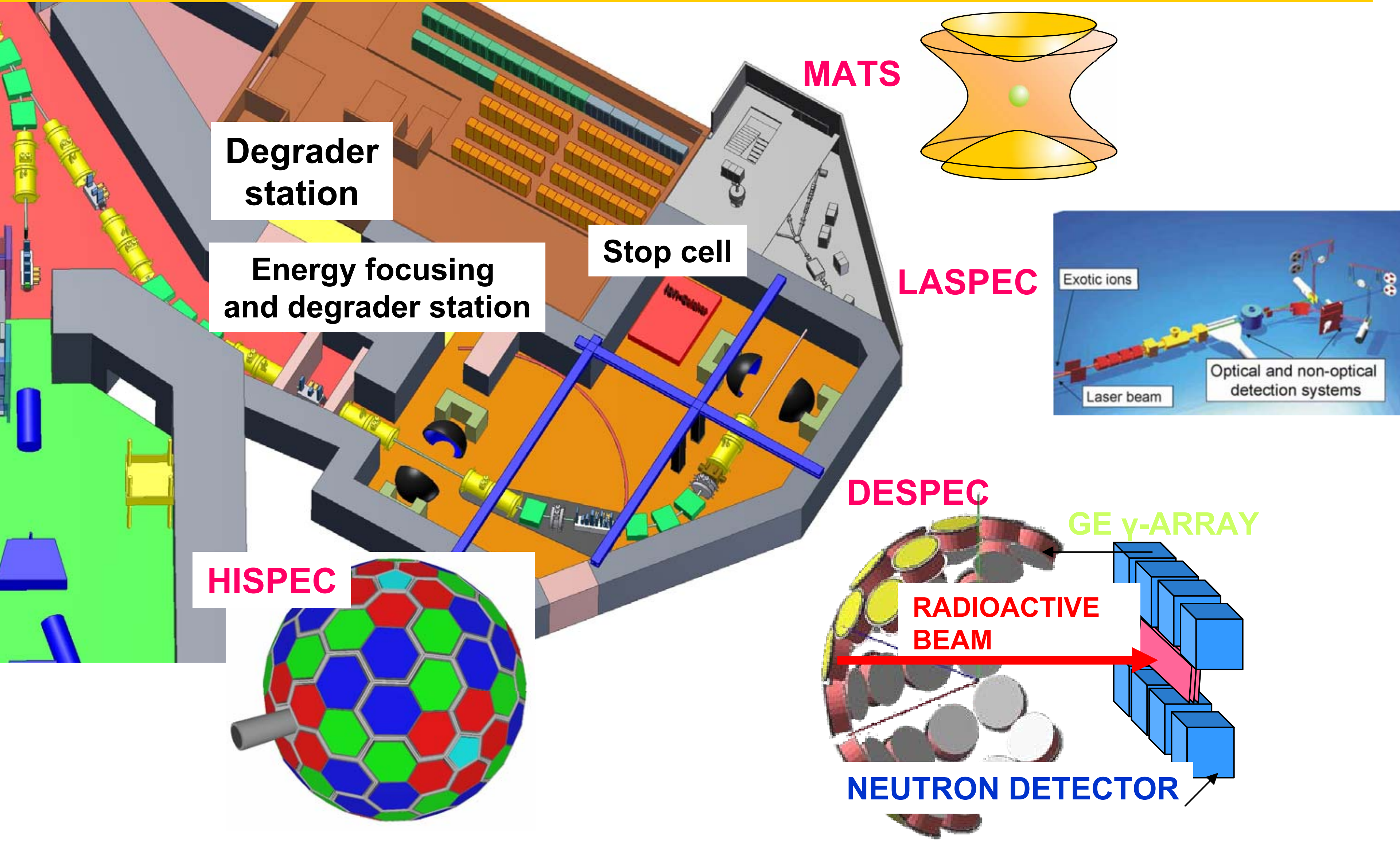
Superconducting fragment separator

+High-energy branch with reactiondetector

+Storage ring complex (CR, RESR, NESR, eA)

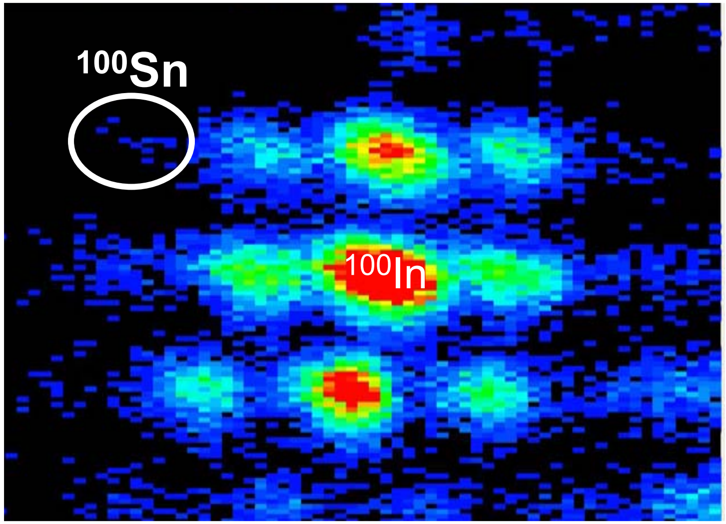
+Low-energy branch with energy focusing and post - acceleration

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

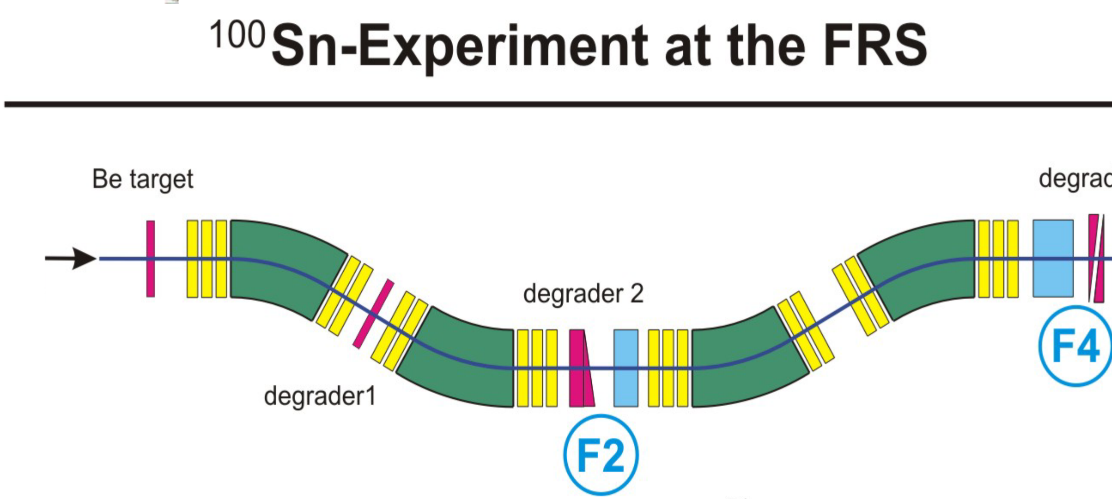


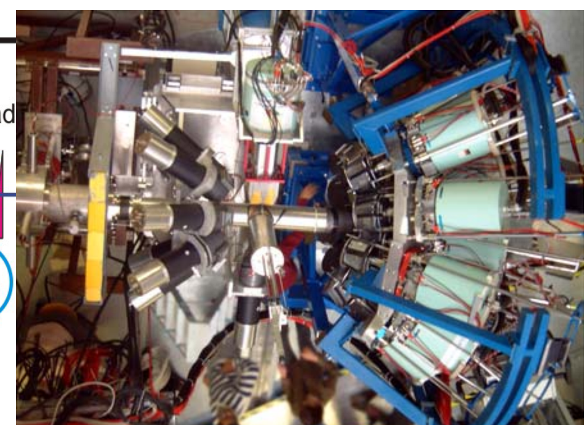
Decay spectroscopy with single atoms **(DESPEC)**

March 10, 2008, result of 1 shift



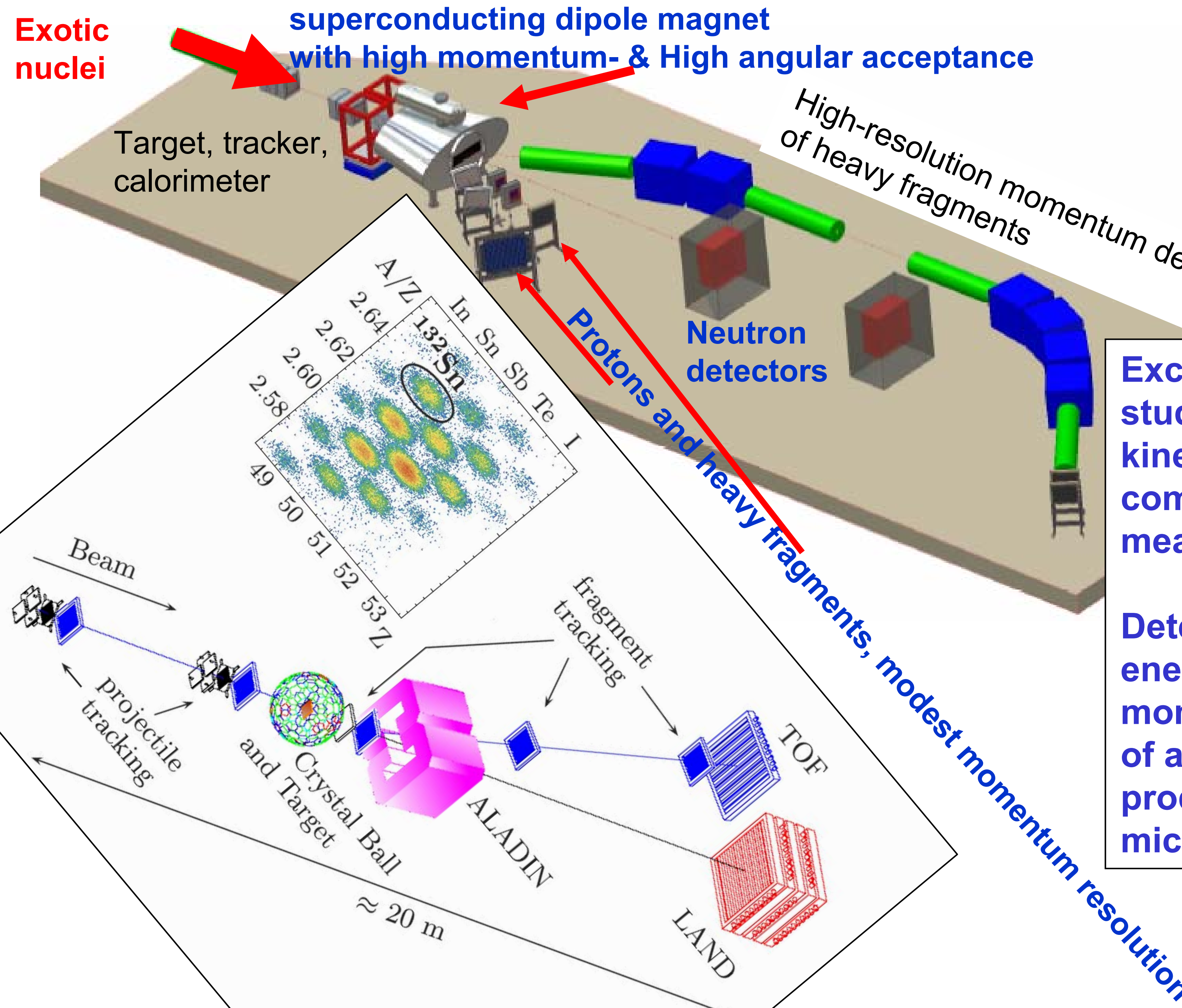
in total > 250 ^{100}Sn ions implanted, analysis in progress





T.Faestermann, M.Gorska and RISING-collaboration

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

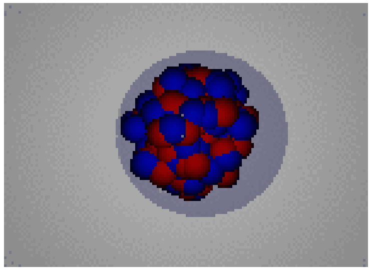


Exclusive reaction studies via kinematically complete measurements:

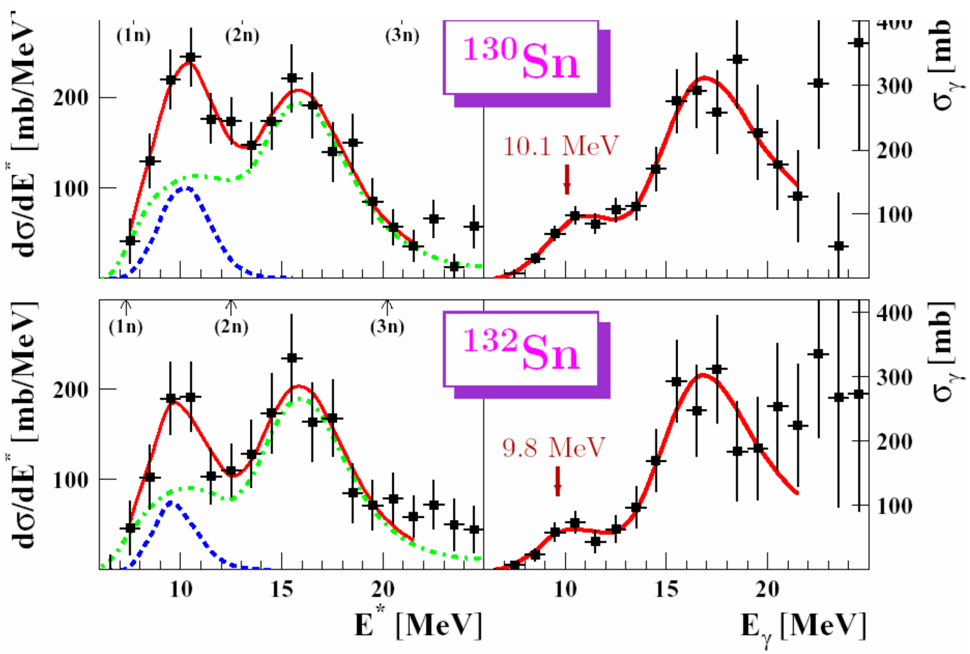
Determination of energy and momentum of all reaction products: reaction microscope

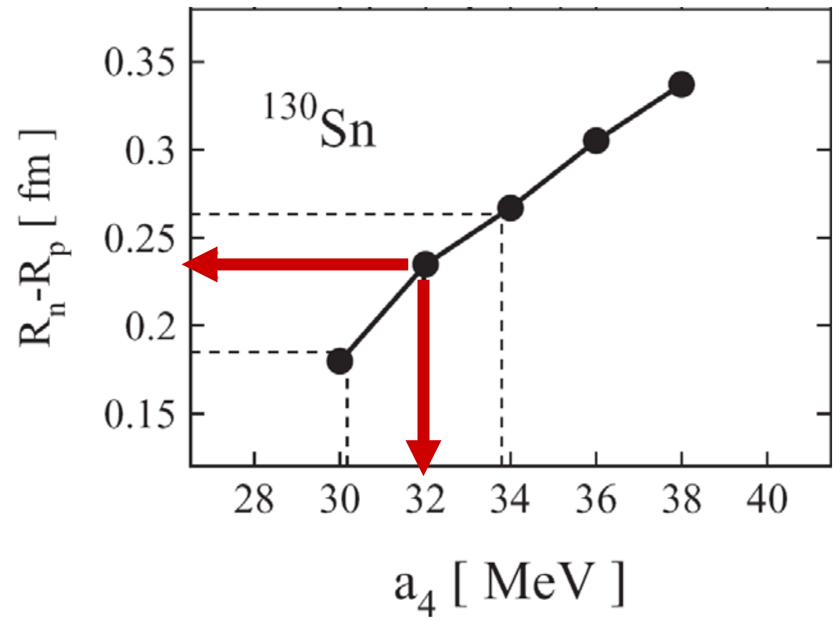
Pygmy-dipole resonance, neutron skins and equation of state of matter

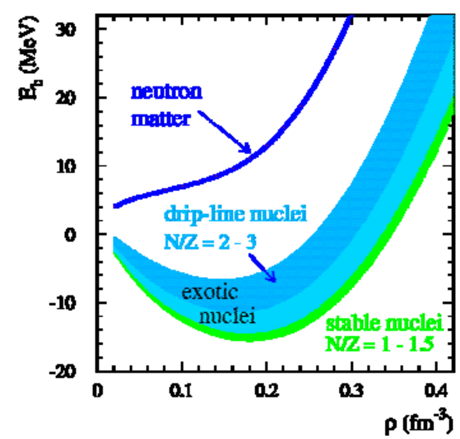
$$E\left(\rho,\frac{N-Z}{A}\right)=E(\rho,0)+\left(a_4+\frac{p_0}{\rho_0{}^2}\;(\rho-\rho_0\;)\right)\cdot\left(\frac{N-Z}{A}\right)^2$$



Oscillation of neutron skin versus nuclear core







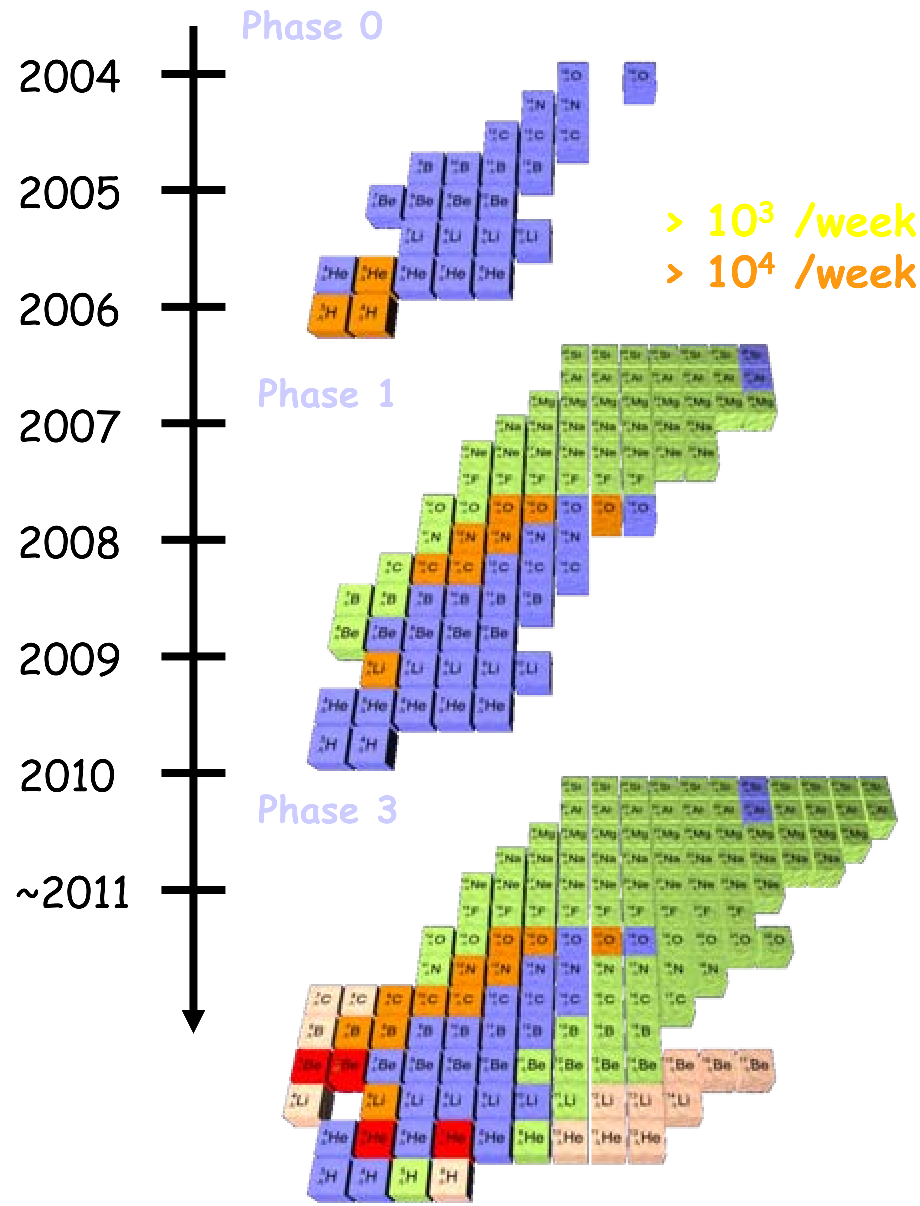
	GSI	FAIR
Measuring time	10 d	100 s
Energy resolution	1 MeV	0,1 MeV

HypHI Project at GSI/FAIR

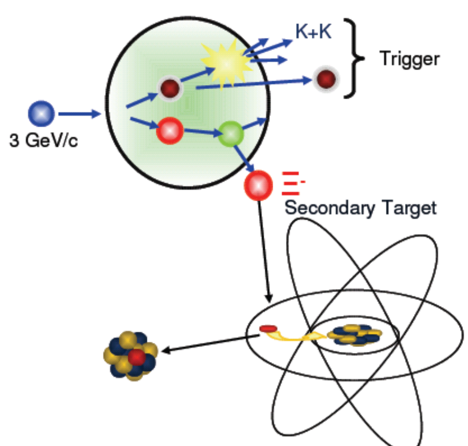
HypHI project started, design study

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

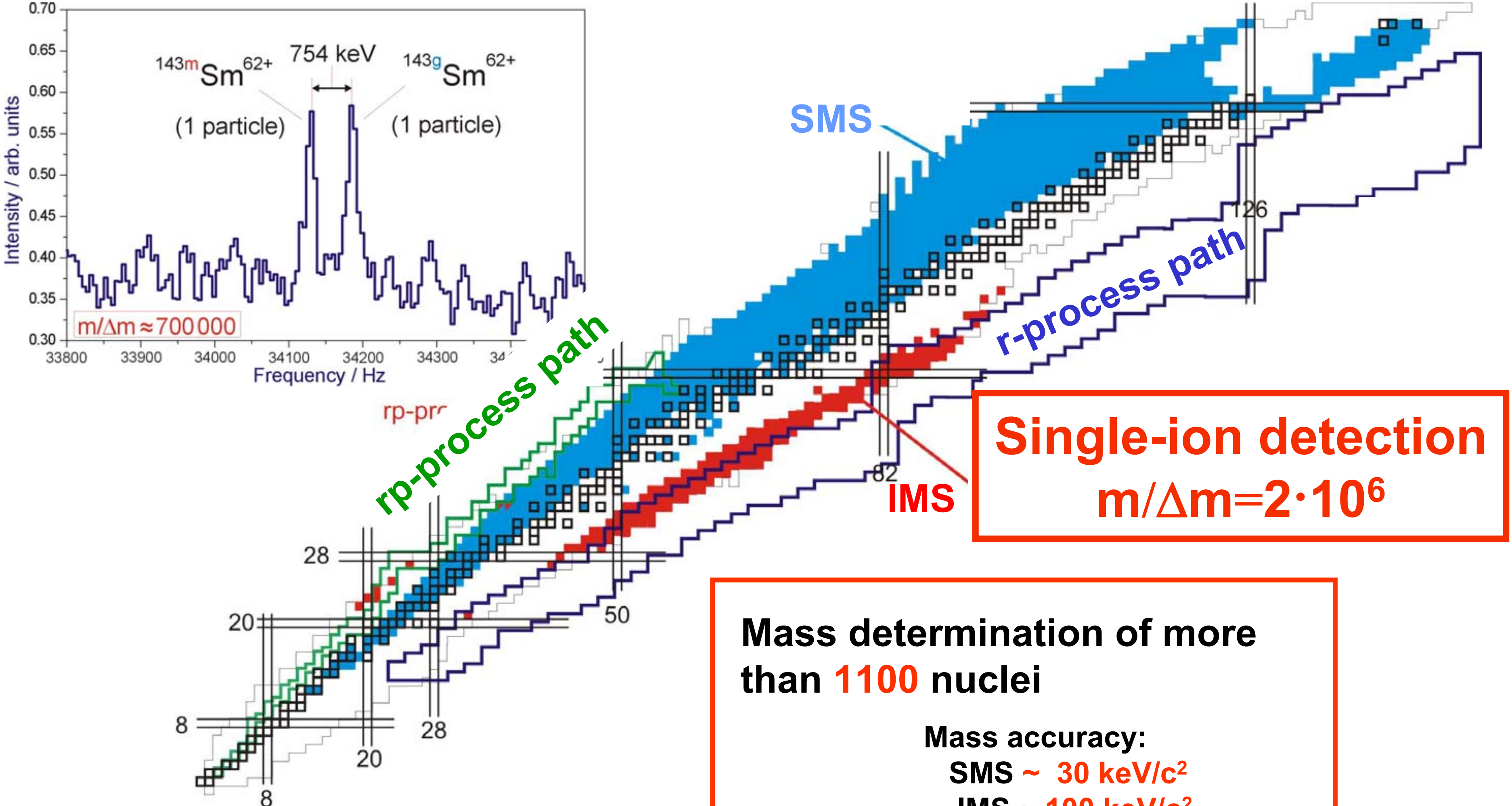


Production of double hyper-nuclei at FAIR



$\Xi^{-}(dss)p(uud) \rightarrow \Lambda(uds)\Lambda(uds)$

Mass spectrometry at the storage ring (ILIMA)



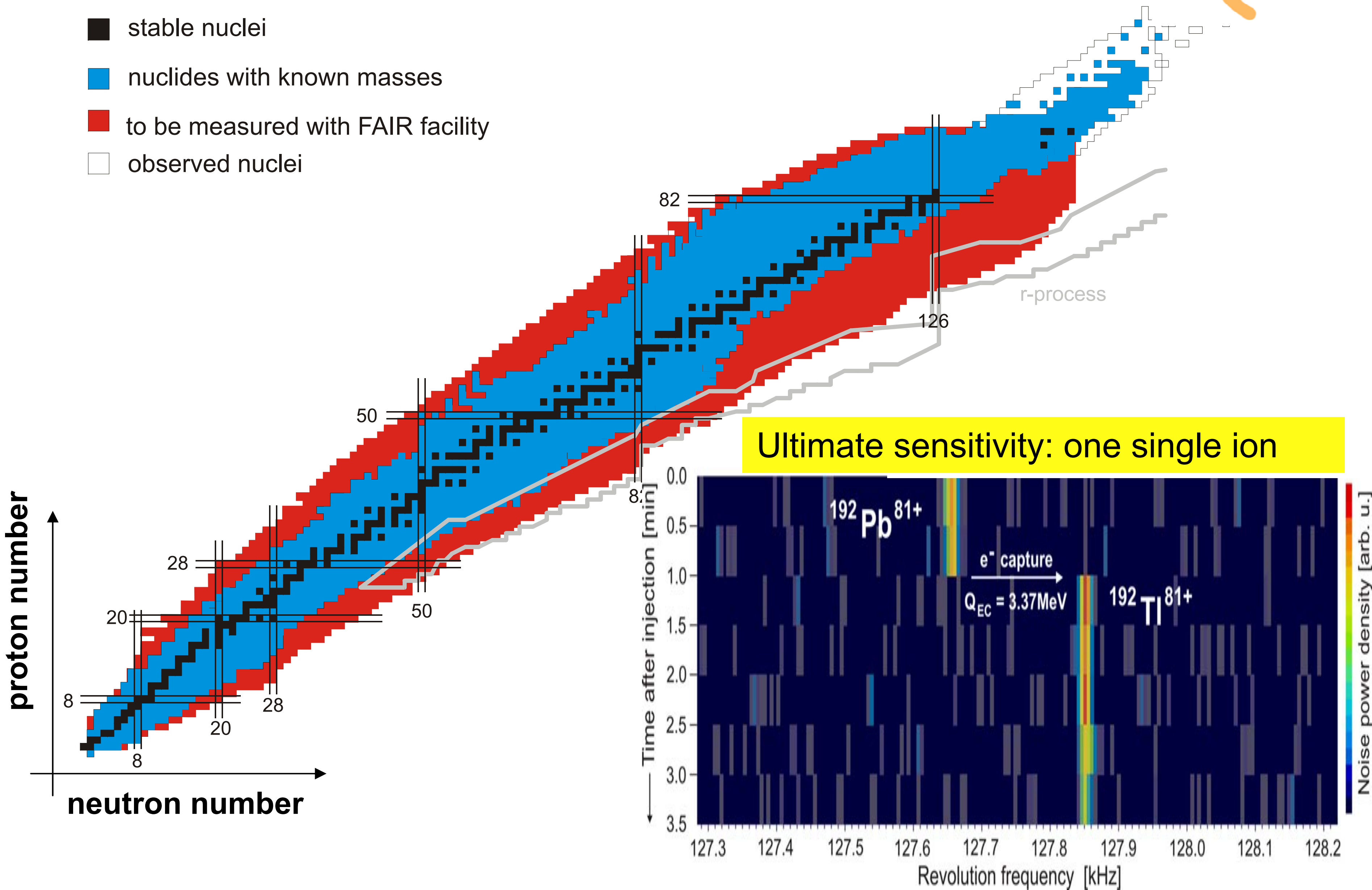
Single-ion detection
$m/\Delta m = 2\cdot10^6$

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

R-Process Nuclei - to be measured at FAIR



Single-Particle Decay Spectroscopy

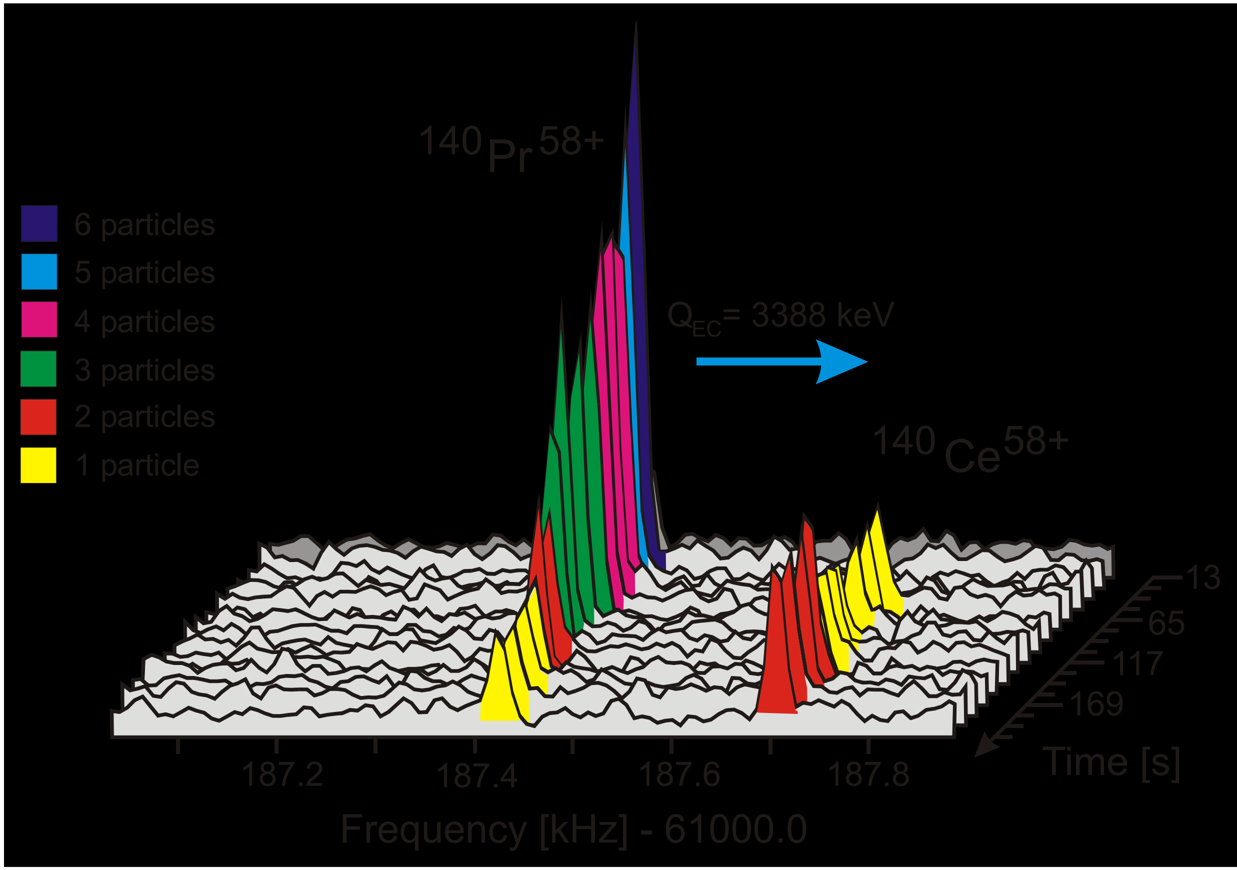
Sensitivity to single stored ions

Well-defined creation time t_0

Well-defined quantum states

Two-body β-decay (g.s. → g.s.) emission of flavour eigenstate ν_e Entanglement of ν_e and daughter atom by momentum and energy

Recording the correlated changes of peak intensities of mother- and daughter ions defines the decay

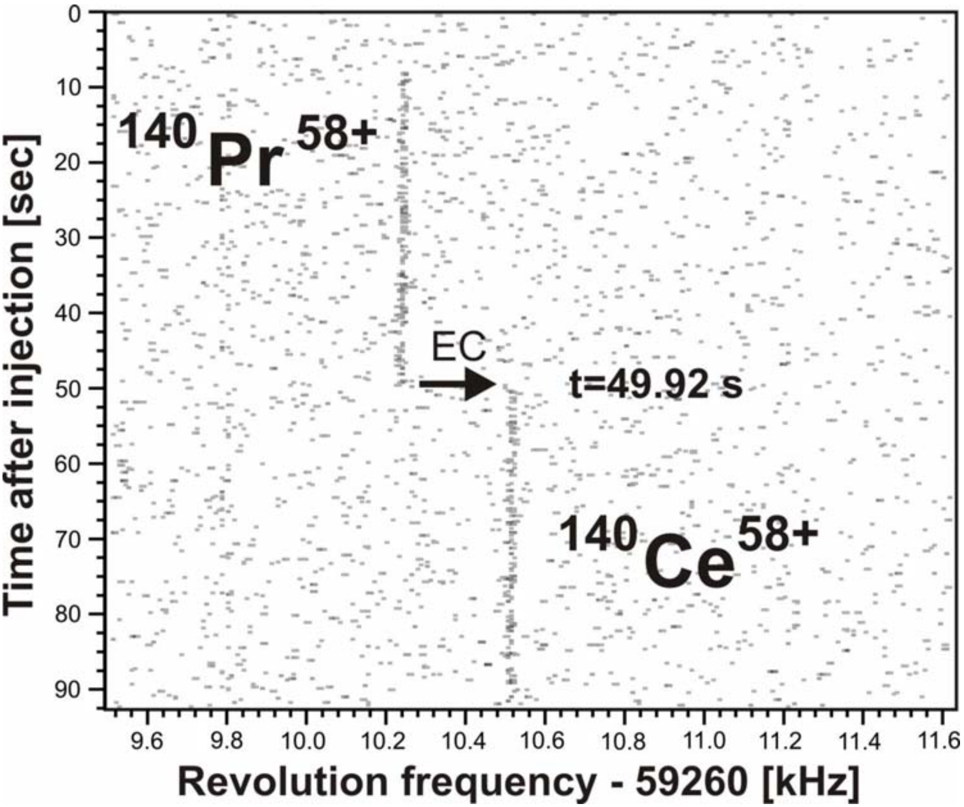


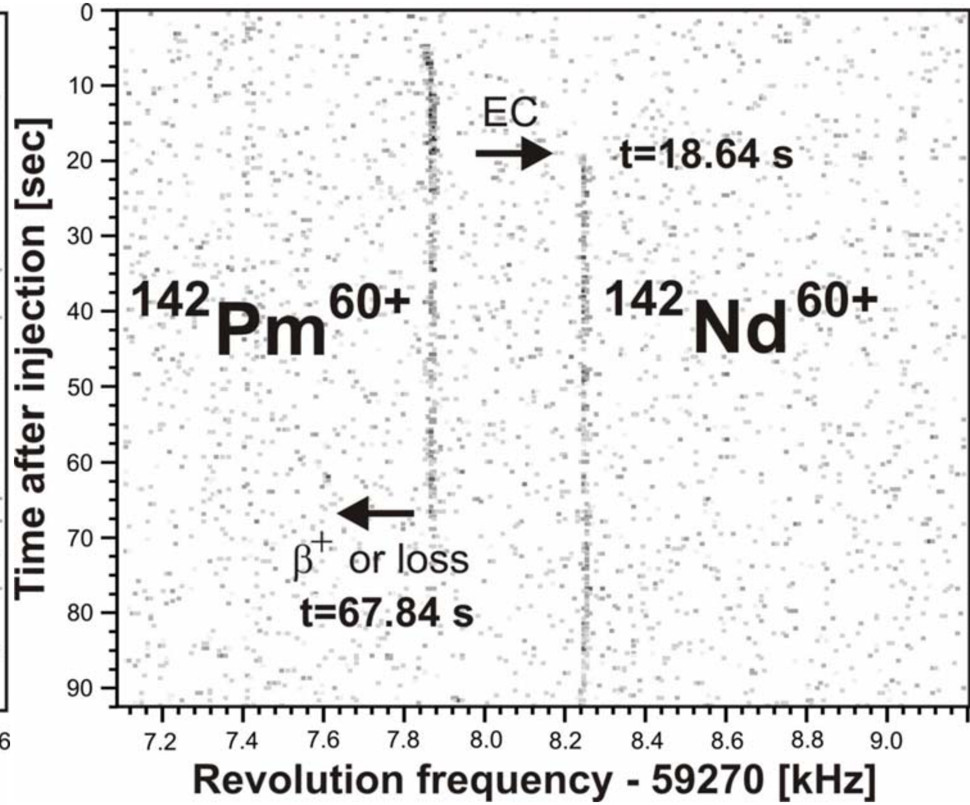
Time-dependence of detection efficiency and other systematical errors are nearly excluded

Restricted counting statistics

F. Bosch et al., Int. J. Mass Spectr. **251** (2006) 212

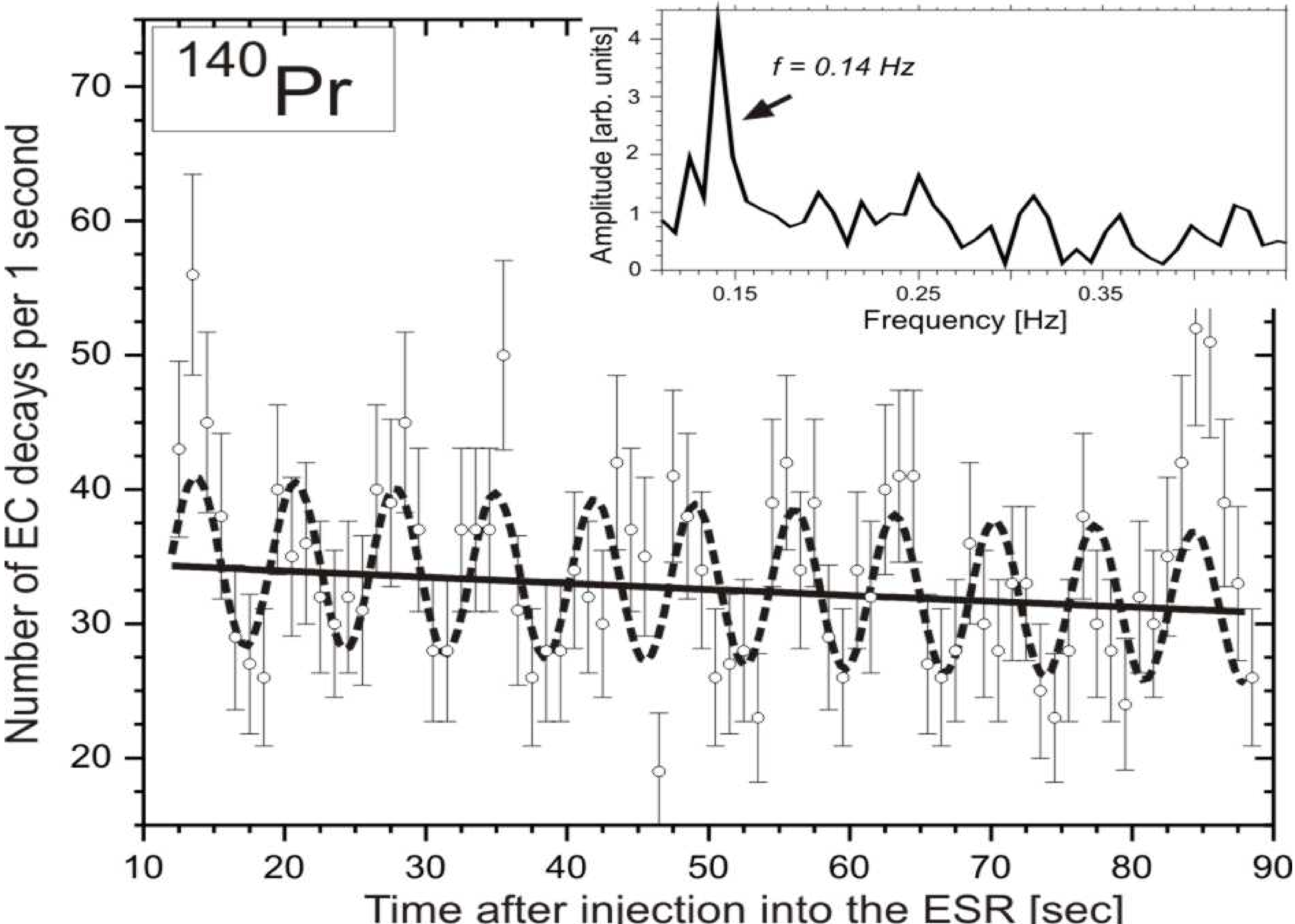
Examples of measured time-frequency traces



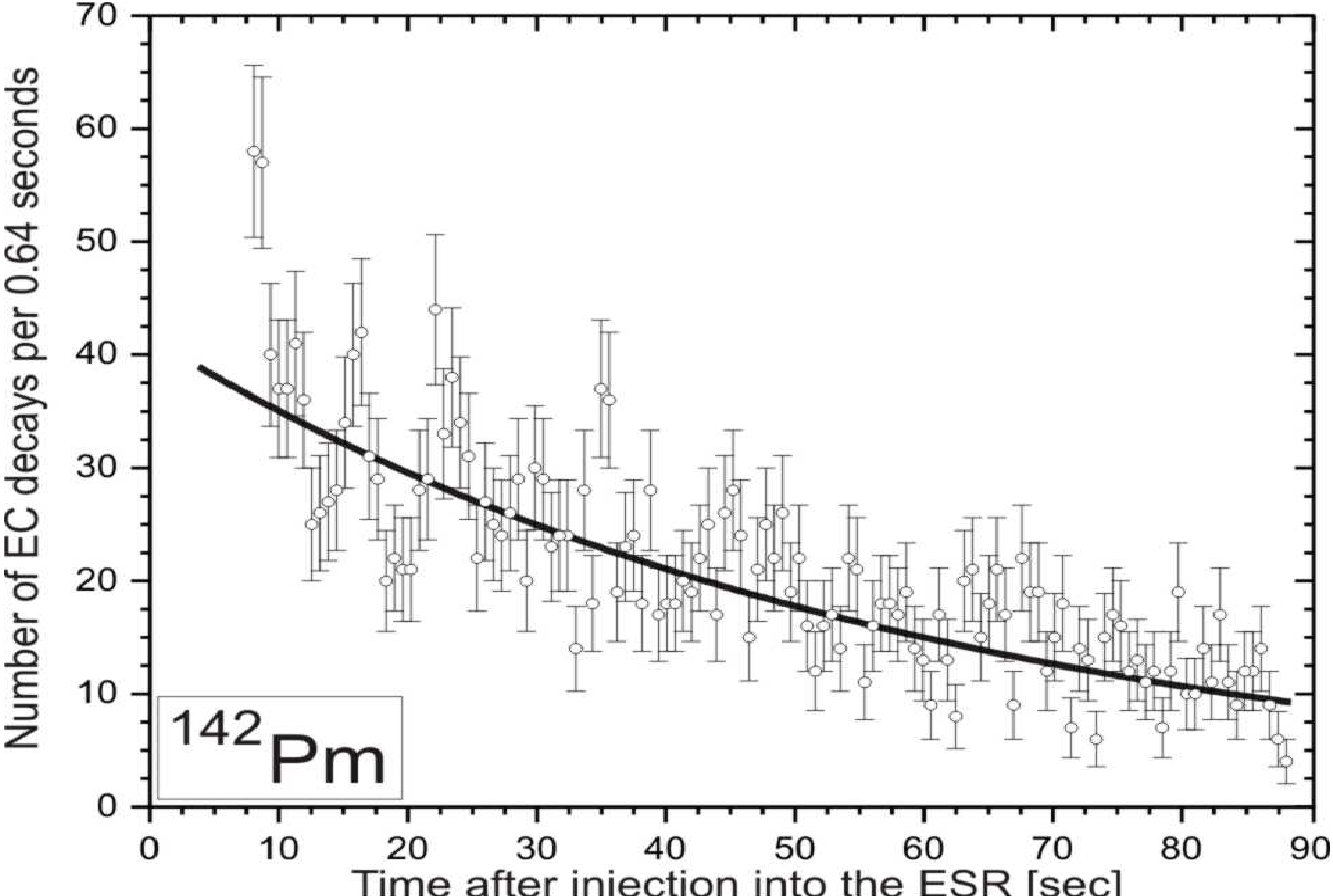


1. Continuous observation
2. Parent/daughter correlation
3. Detection of all EC decays
4. Delay between decay and "appearance" due to cooling

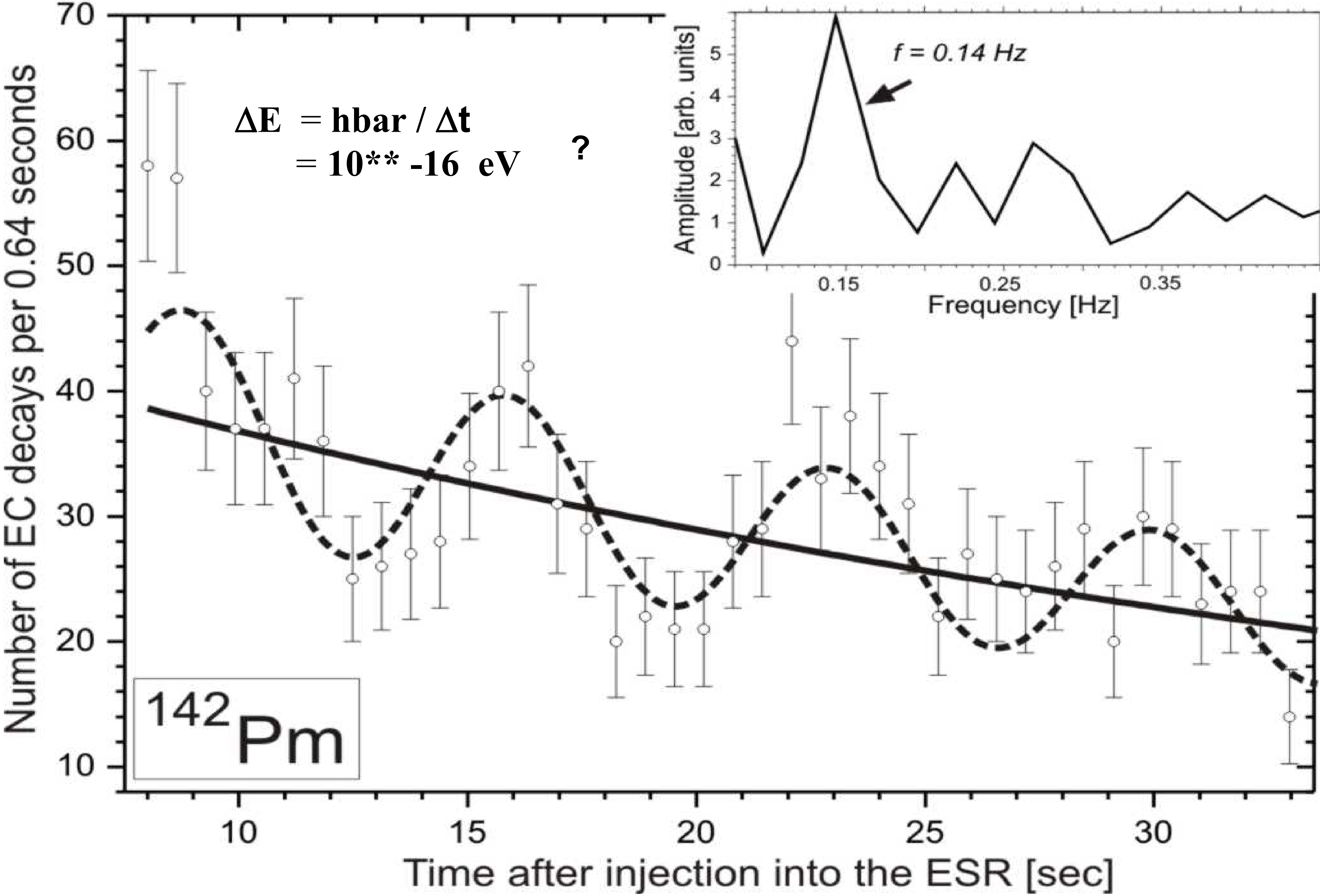
Praesodymium: all 2650 EC decays from 7102 injections



^{142}Pm: 2740 EC decays from 7011 injections



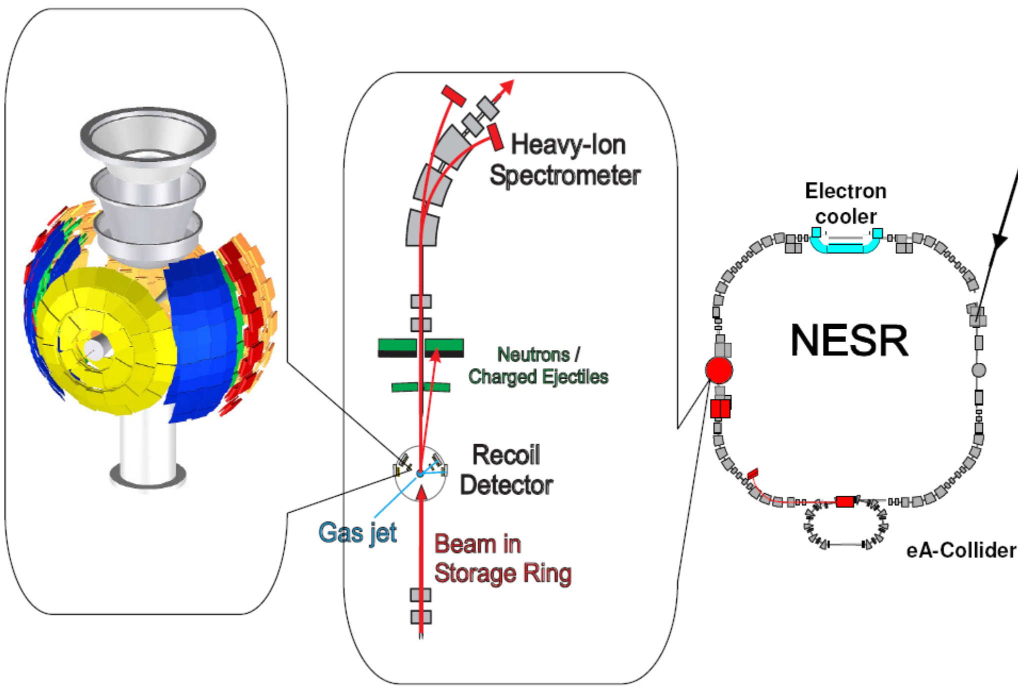
^{142}Promethium: zoom on the first 33 s after injection



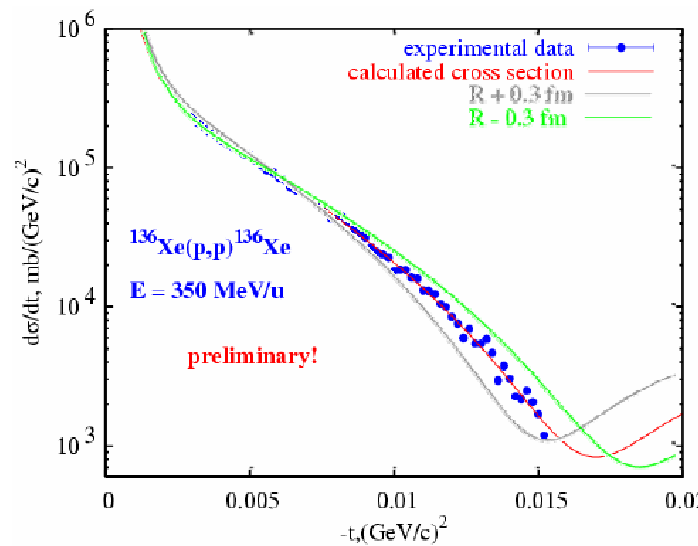
Scattering of stored nuclear beams on light hadronic probes (EXL)

- Inverse kinematics
- Thin gas target (~$10^{15}/cm^2$)
- Kinematically complete measurement
  - Elastic scattering (p,p) …
  - Inelastic scattering (p,p’), (α,α’) ...
  - Charge-exchange reactions (p,n), (^{3}He,t), (d,^{2}He) …
  - Quasi-free scattering (p,pn), (p,2p), (p, pα) …

→ Excitation energy and form factors via recoil ions at small energy / small momentum transfer



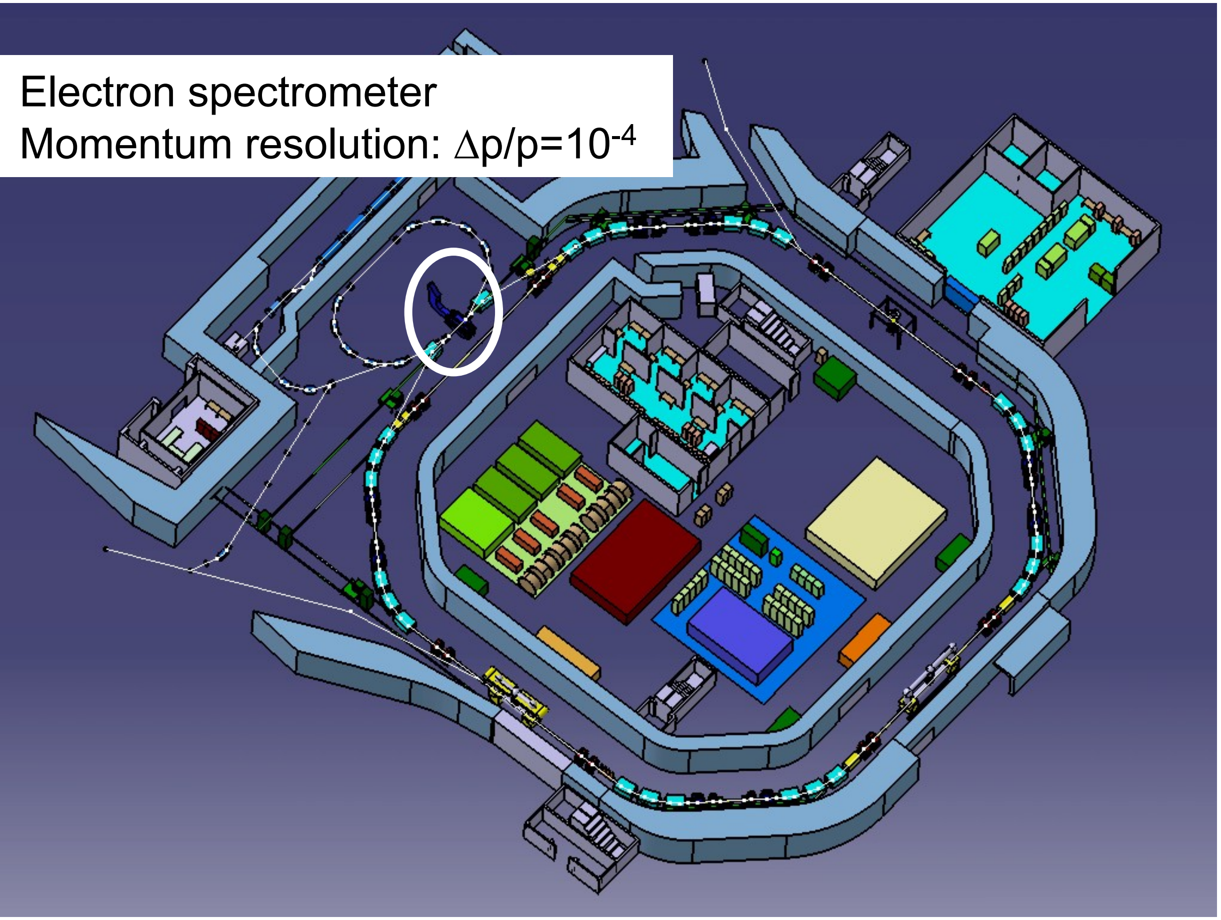
Feasibility study (p,p) with 350 MeV/u ^{136}Xe-ions at ESR

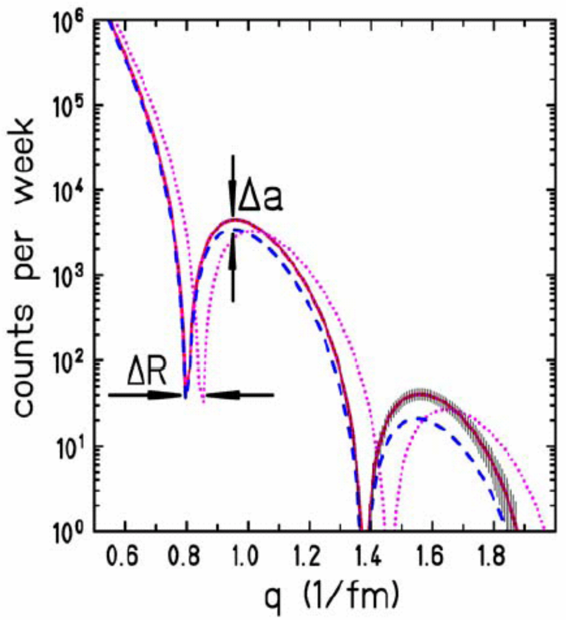


Nuclear matter radius: R_m = 4.89 (10) fm

S. Ilieva et al.,
Eur. Phys. J. Special Topics **150**, 357–358 (2007)

Electron scattering on stored exotic nuclei (ELISE)



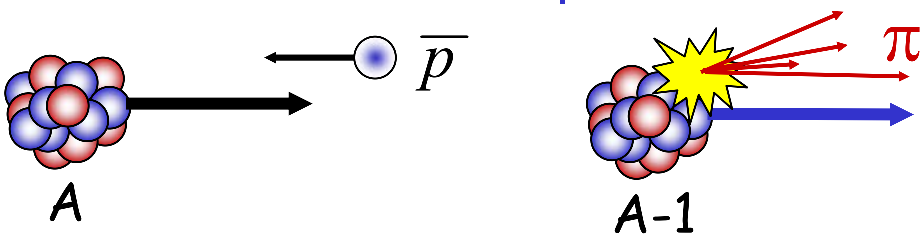


Measurement of elastic [F(q)] and inelastic [$F_\ell(q)$] form factors:

- (e,e), 10^{24} cm^{-2} s^{-1}: Charge density distribution
- (e,e'), 10^{28} cm^{-2} s^{-1}: Selective el.-magnetic excitation → electric and magnetic multipolarities
- (e,e'N), 10^{29} cm^{-2} s^{-1}: Single particle structures from quasi-free scattering

Antiprotonic probes: reactions (AIC) and exotic atoms (exo+pbar)

Reactions with antiprotons



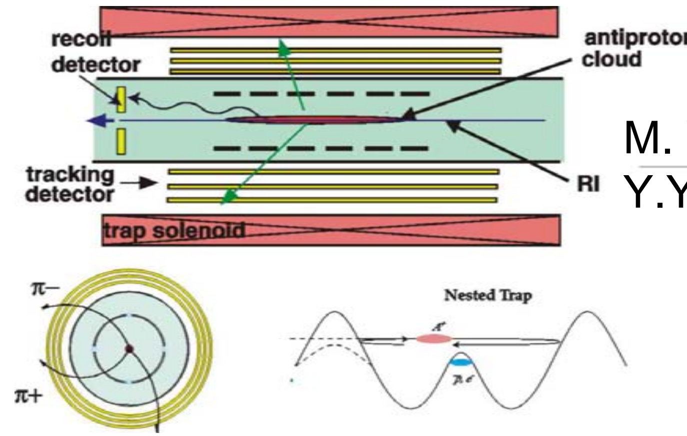
AIC:
at high energy the annihilation cross-section becomes proportional to the mean square radius

exo+pbar:
antiprotonic X rays and pions provide information on the nuclear periphery

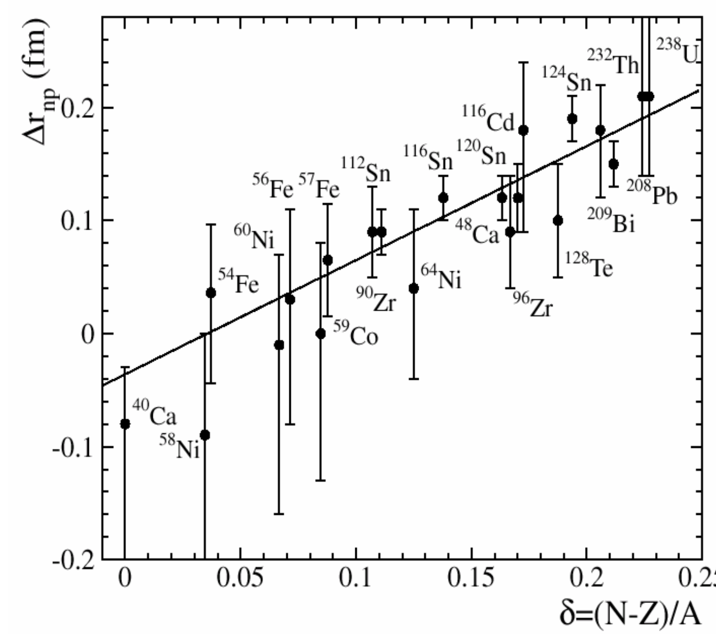
➔ Matter and neutron-proton distribution at the nuclear surface

H. Lenske, P. Kienle, PL **B 647** (2007) 82
P. Kienle, NIM **B 214** (2004) 193

Exotic atoms

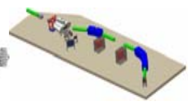
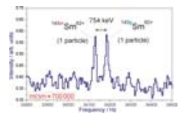
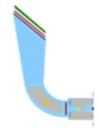
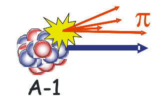
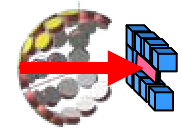
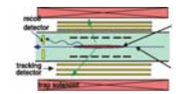
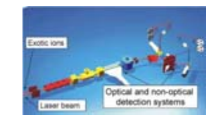


M. Wada, Y.Yamazaki



A. Trzcinska et al., PRL **87** (2001)

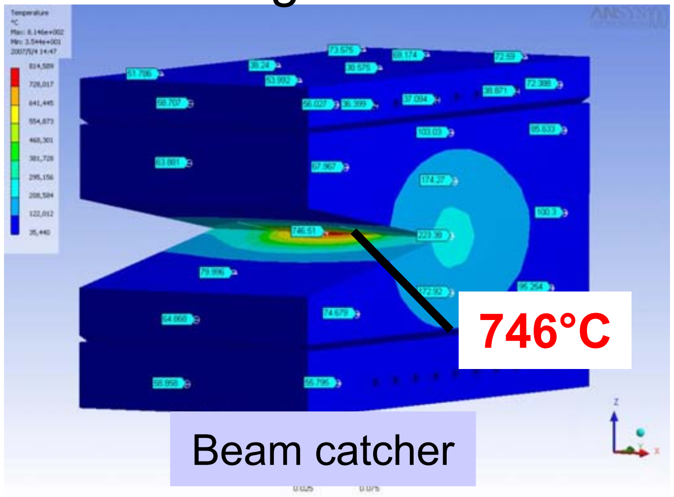
Complementary ot the NUSTAR experiments

Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC/ DESPEC	exo+ pbar	MATS	LASPEC
									

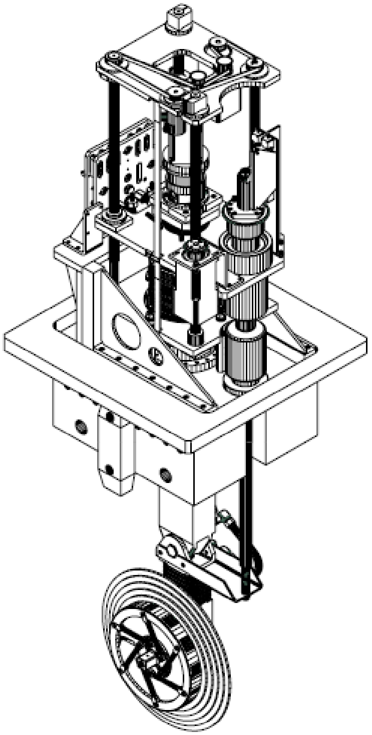
	Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC DESPEC	exo+pbar	MATS	LASPEC
Masses			bare ions, mapping study				Q-values, isomers		dressed ions, highest precision	
Half-lives	ps…ns-range		bare ions, s…h				dressed ions, μs…s			
Matter radii	interaction x-sect	matter radii		matter densitiy distributions		matter radii from absorption		nuclear periphery		
Charge radii					charge density distribution					mean square radii
Single-particle structure	high resolution, angular momentum	complete kinematics, neutron detection		low momentum transfers			high-resolution spectroscopy			

Technological challenge: components for highest intensities

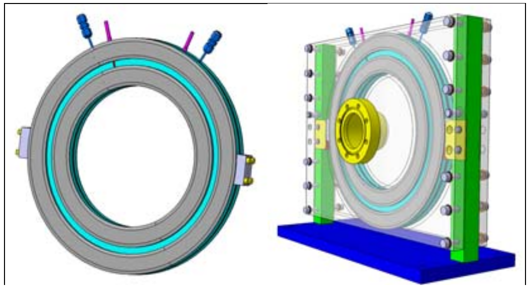
Remote controlled operation and maintenance of all installations



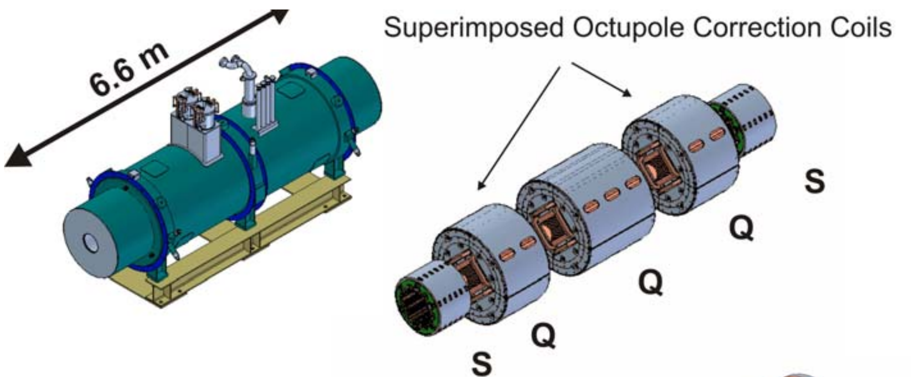
Target for 10^{12} U /100ns



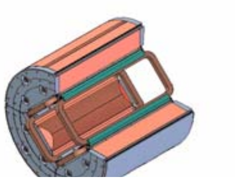
Concept for vacuum sealing



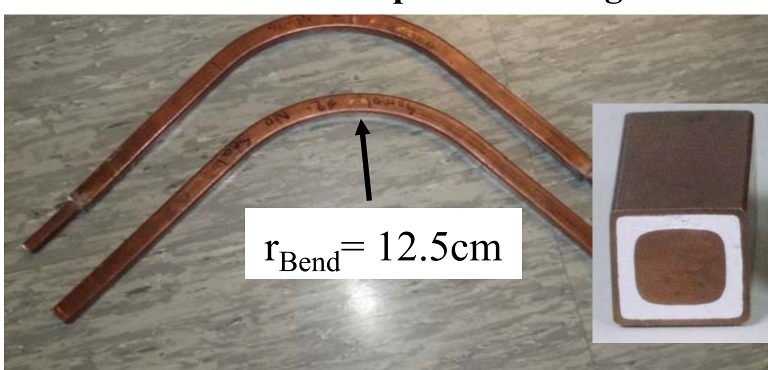
Superferric Quadrupole-Multipletts



Effective length (quads)	0.8 / 1.2 m
Aperture (warm)	± 190 mm
Pole radius	240 mm
Field gradient	1.0 - 10.0 T/m



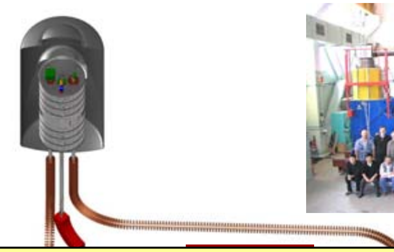
Radiation resistent superconducting cables



• Accelerator Developments

Beam quality:
Electron & Stochastic Cooling

Compact & efficient acceleator design:
Rapidly cycling sc magnets: dB/dt ~ 4T/s



Prototyp *SIS100* bending magnet (BNG) 13 Dez. 07, BINP April 08, JINR – late 08

Prototyp *SIS300* bending magnet (INFN) – Jan./Feb. 2009, IHEP Protvino – late 09

Prototyp bending magnet *Super-FRS* (FAIR China) – April 2008

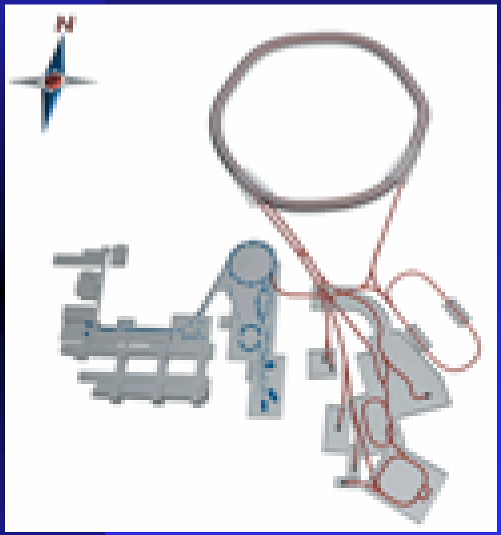
Fa
Frequency variable ferrite or MA loaded resonators

XHV ~10^{-12} mbar

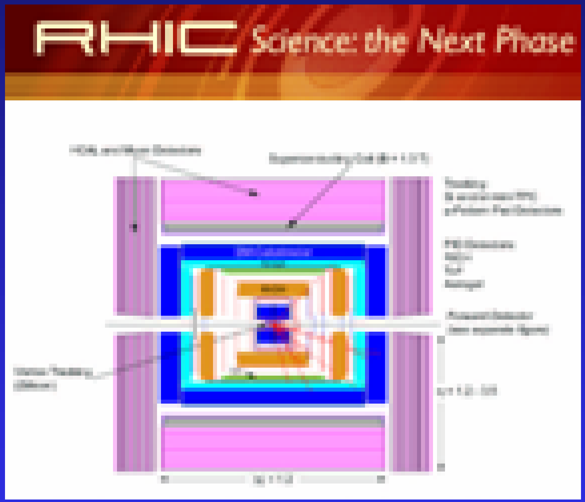
The future is bright

A three prong approach:

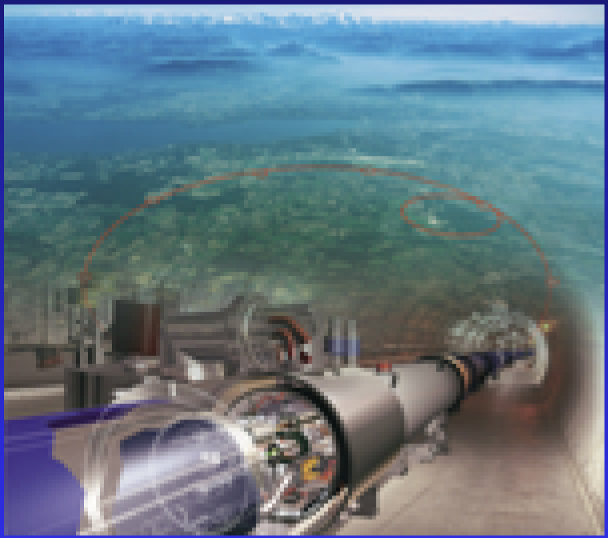
lower energy | **better facility** | **higher energy**



FAIR:
Facility for Antiproton & Ion Reseach



RHIC-II:
RHIC upgrade with new detector R2D



LHC:
Large Hadron Collider with ALICE, CMS, ATLAS