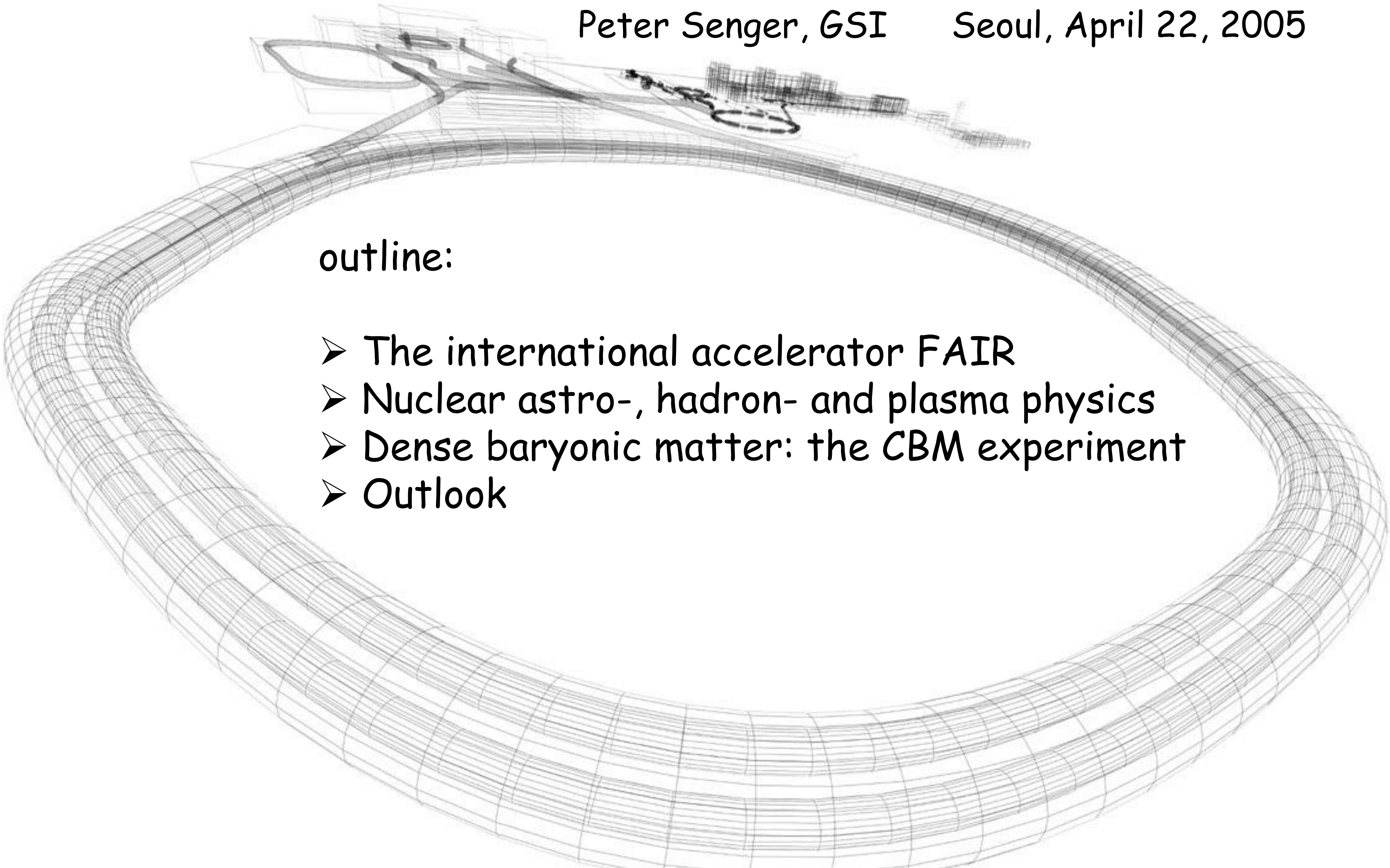
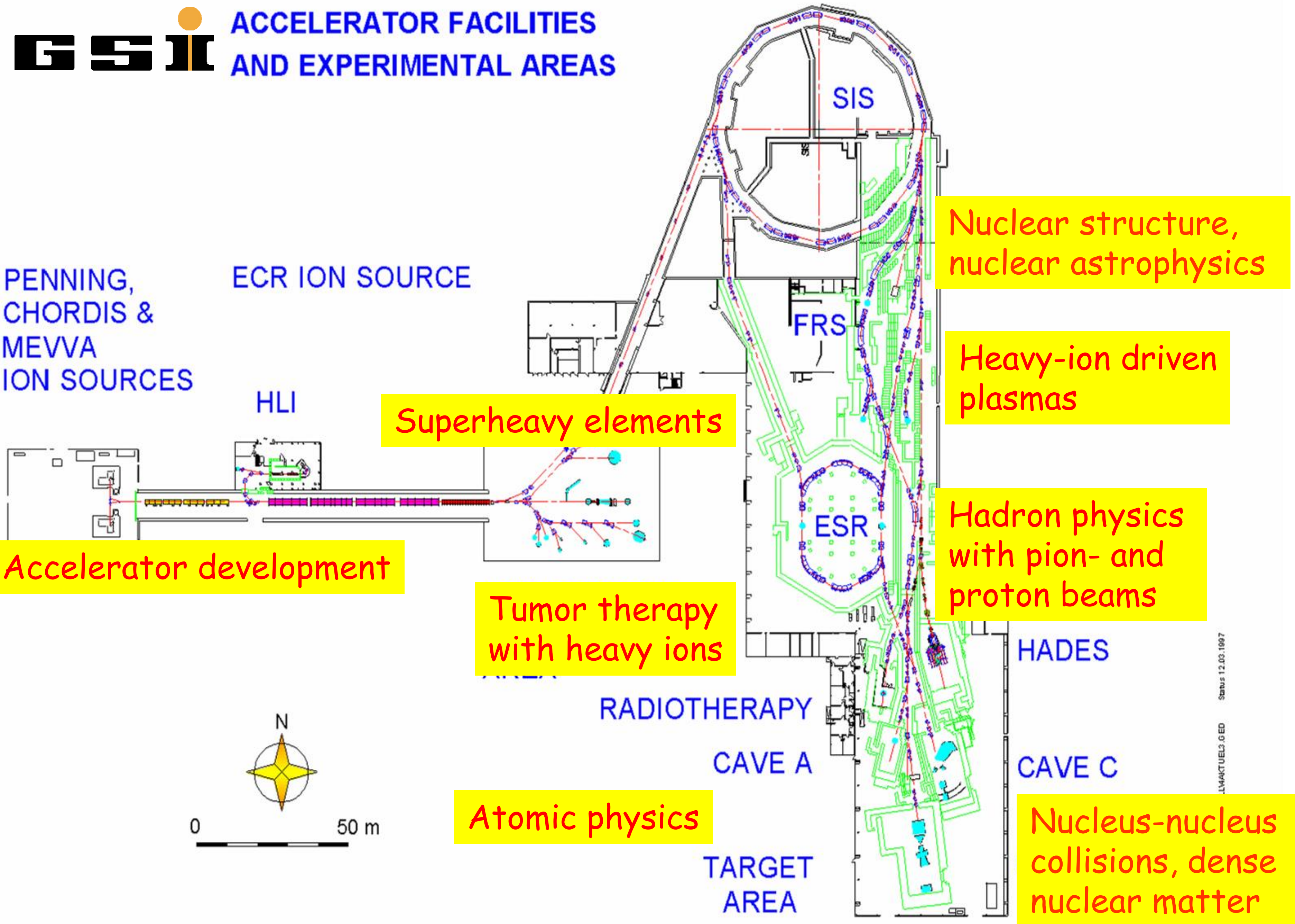
# The Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt/Germany

Peter Senger, GSI Seoul, April 22, 2005



outline:

- The international accelerator FAIR
- Nuclear astro-, hadron- and plasma physics
- Dense baryonic matter: the CBM experiment
- Outlook


GSI
ACCELERATOR FACILITIES
AND EXPERIMENTAL AREAS
SIS
PENNING,
CHORDIS &
MEVVA
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ECR ION SOURCE
HLI
FRS
ESR
HADES
RADIOTHERAPY
CAVE A
CAVE C
TARGET
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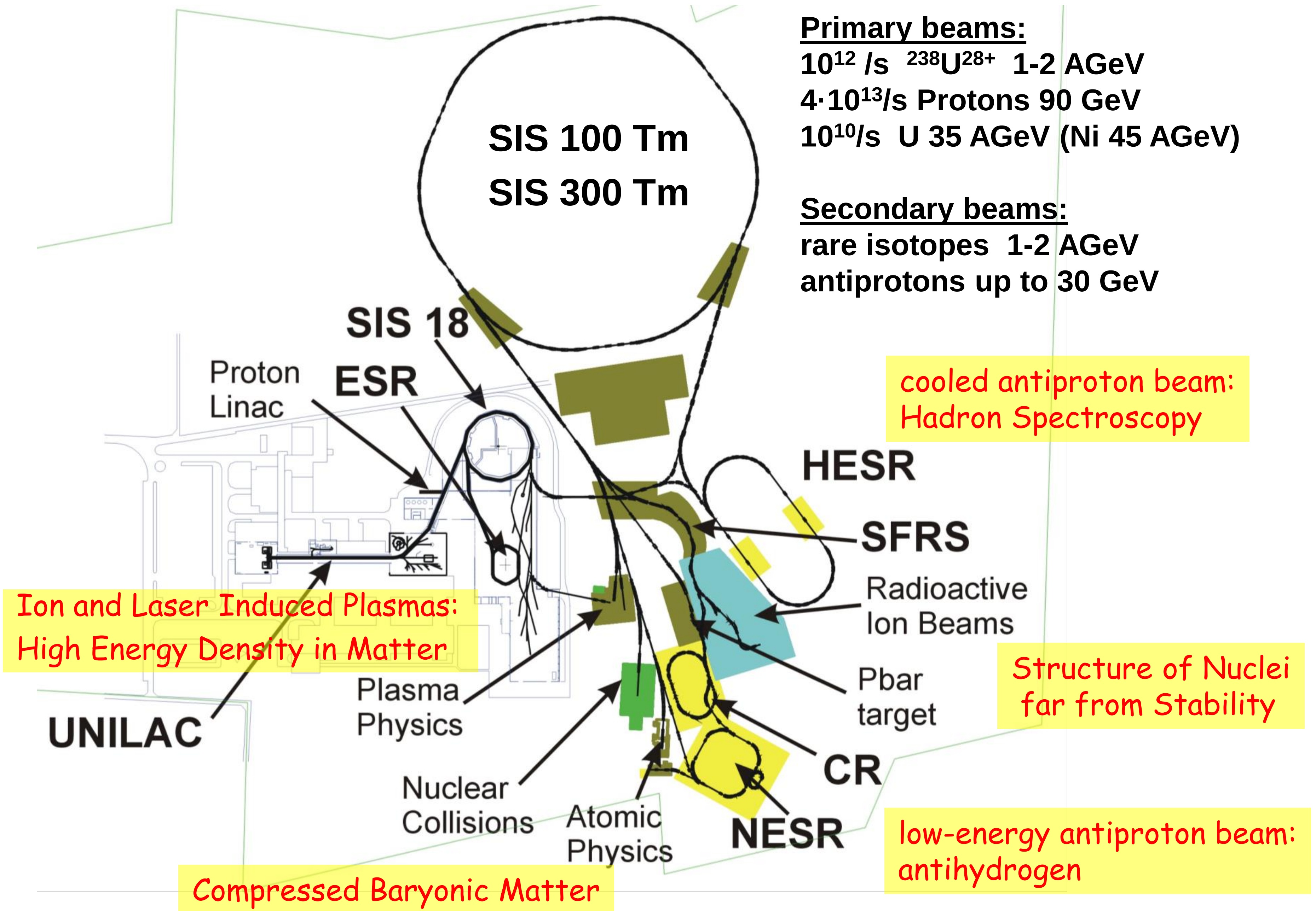
50 m
Nuclear structure, nuclear astrophysics
Heavy-ion driven plasmas
Superheavy elements
Accelerator development
Hadron physics with pion- and proton beams
Tumor therapy with heavy ions
Atomic physics
Nucleus-nucleus collisions, dense nuclear matter

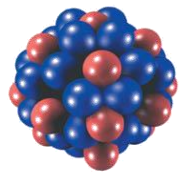
# The future Facility for Antiproton an Ion Research (FAIR)



# Research programmes at FAIR

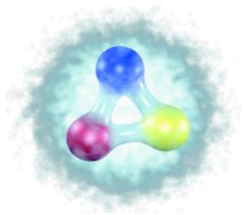
## Rare isotope beams; nuclear structure and nuclear astrophysics

nuclear structure far off stability
nucleosynthesis in stars and supernovae



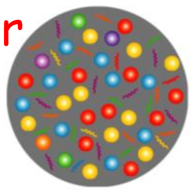
## Beams of antiprotons: hadron physics

quark-confinement potential
search for gluonic matter and hybrids
hypernuclei



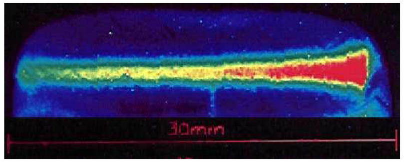
## high-energy nucleus-nucleus collisions: compressed baryonic matter

baryonic matter at highest densities (neutron stars)
phase transitions and critical endpoint
in-medium properties of hadrons



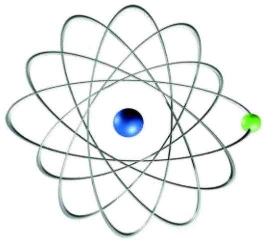
## pulsed heavy ion beams: plasma physics

matter at high pressure, densities, and temperature
fundamentals of nuclear fusion



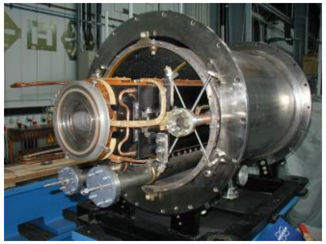

## atomic physics and applied research

highly charged atoms
stopped antiprotons (→ antihydrogen)
radiobiology

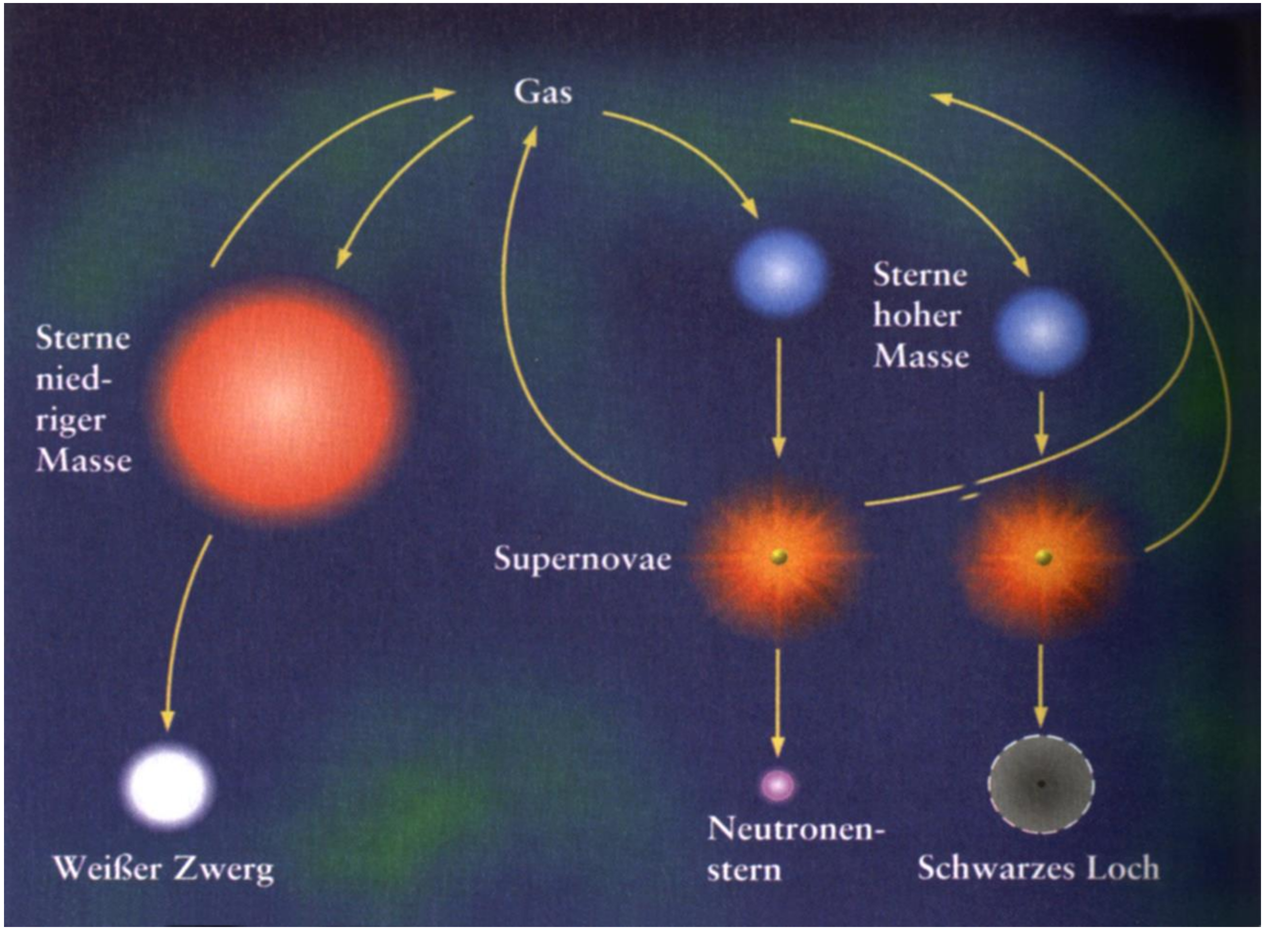


## accelerator physics

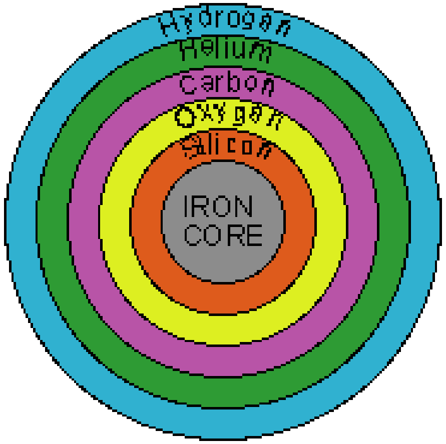
high intensive heavy ion beams
dynamical vacuum
rapidly cycling superconducting magnets
high energy electron cooling



# Birth and dead of stars




**Onion shell structure before explosion**



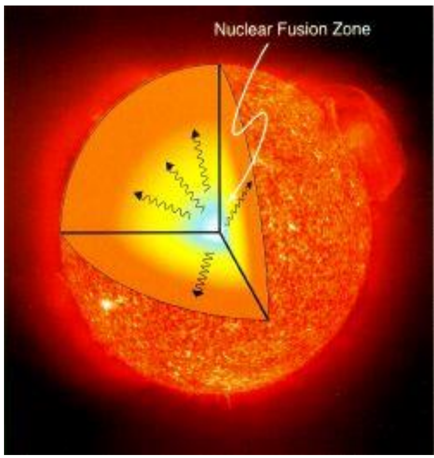

$M < \approx 8M_\odot$
red giant
white dwarf

$8M_\odot < M < 15M_\odot$
Supernova II
$1.4M_\odot < M_{core} < 2M_\odot$
neutron star

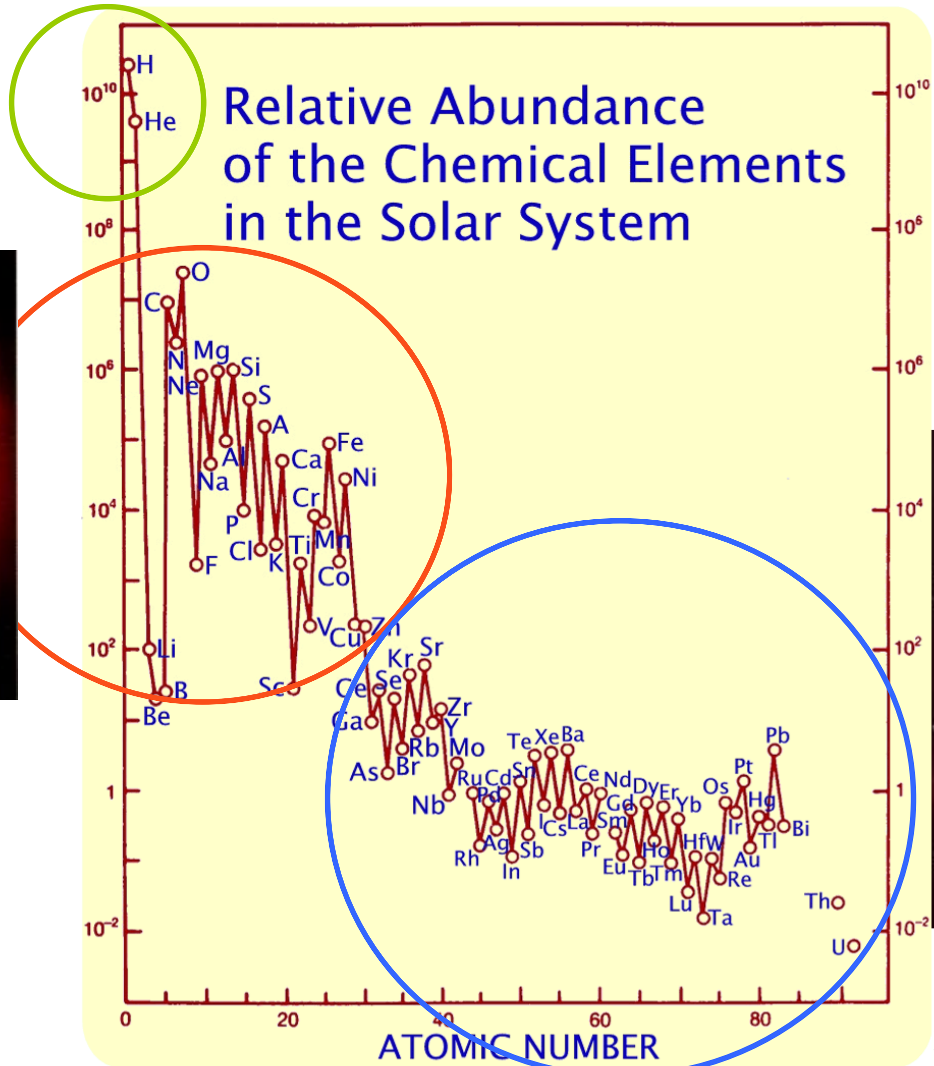
$M > \approx 15M_\odot$
Supernova IIa
$M > \approx 2M_\odot$
black hole

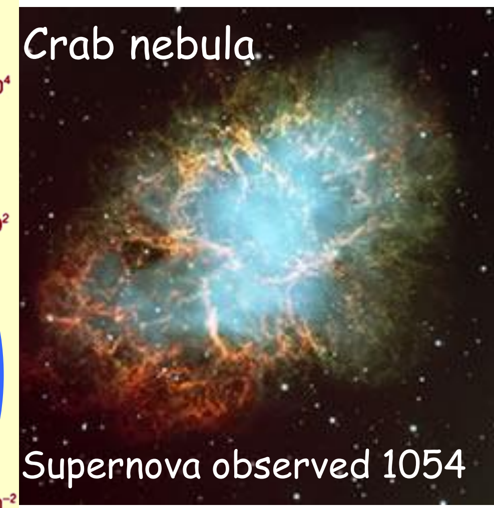
# The origin of elements

nucleosynthesis after big bang



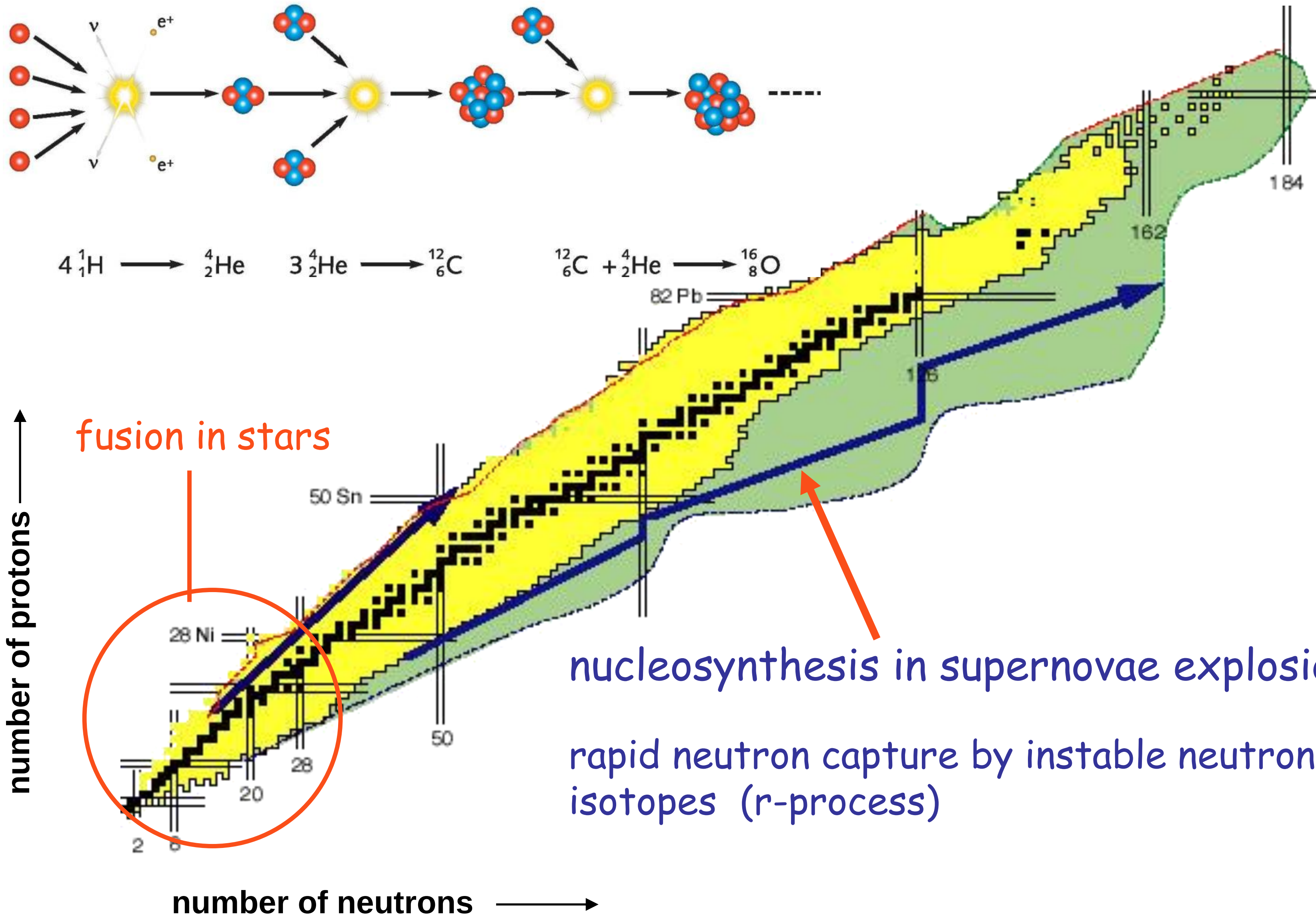

fusion in stars




neutron capture in red giants or supernova explosions

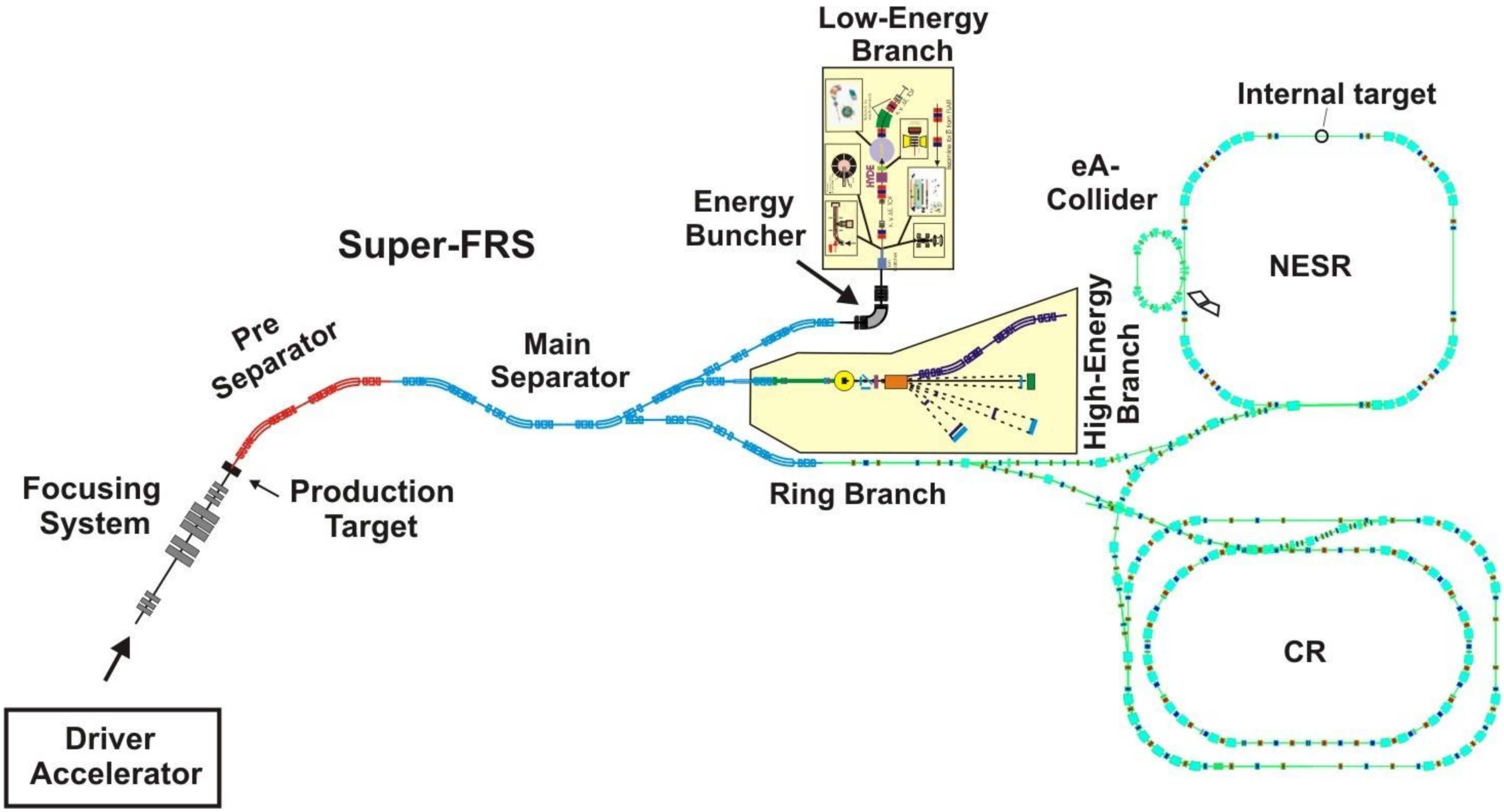
# The origin of elements



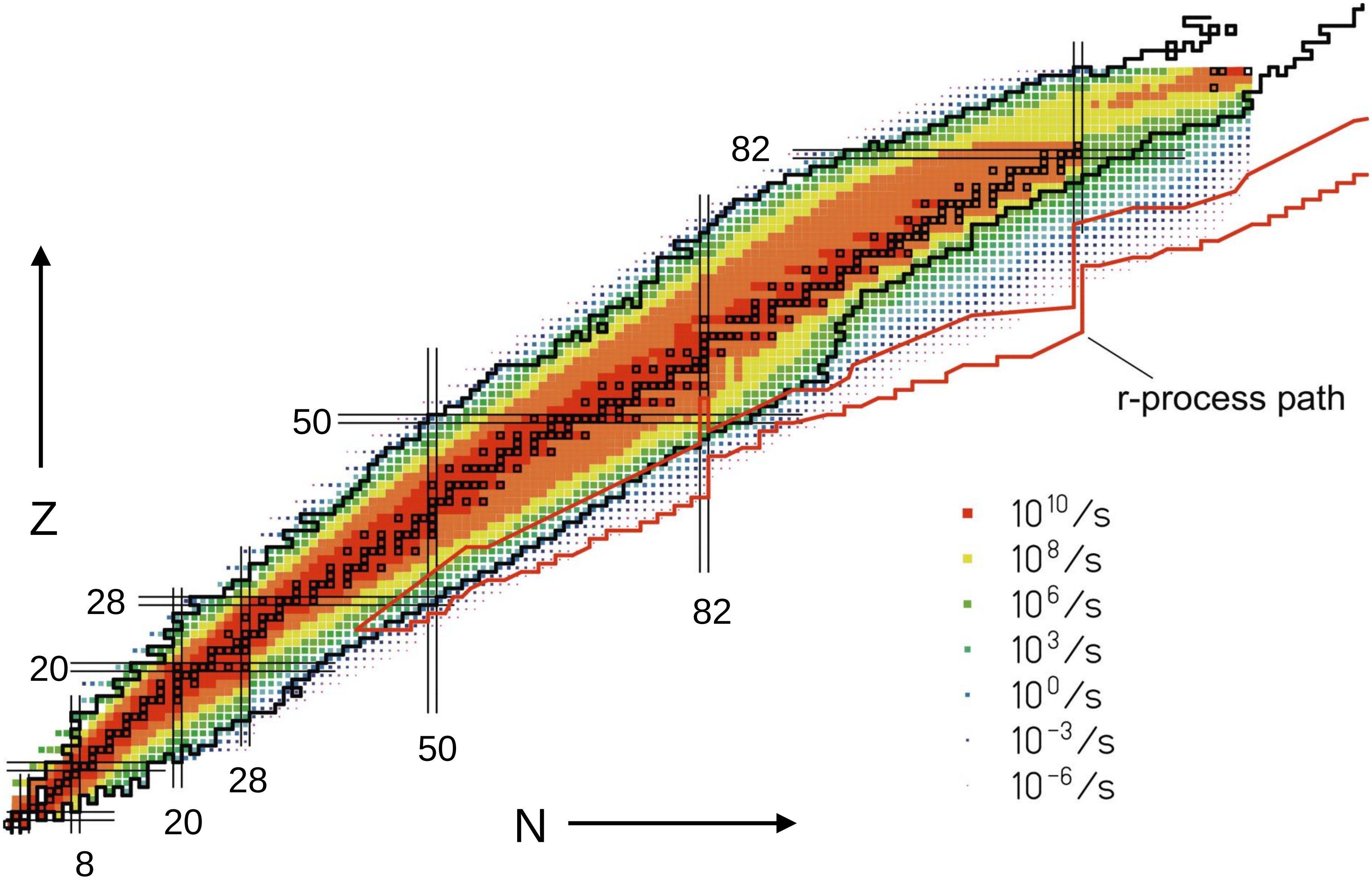

nucleosynthesis in supernovae explosions:

rapid neutron capture by instable neutron rich isotopes (r-process)

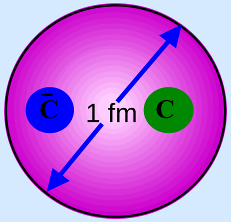
# FAIR: intensive rare isotope beams



# Exploring the path of nucleosynthesis with FAIR

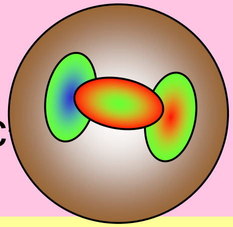


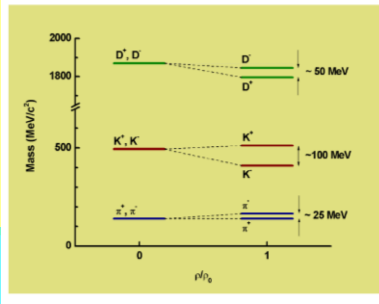
# Physics with high energy antiprotons




**Charmonium ( $\bar{c}c$ ) spectroskopy:**
precision measurements of mass, width, and decay channels of charmonium states ($\rightarrow$ quark confinement)

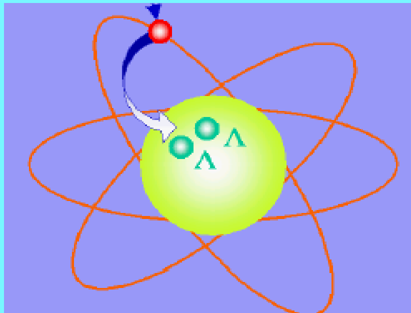
**Search for gluonic excitations:**
Charmed hybrids, glueballs in the mass region of charmonium (3 – 5 GeV/c



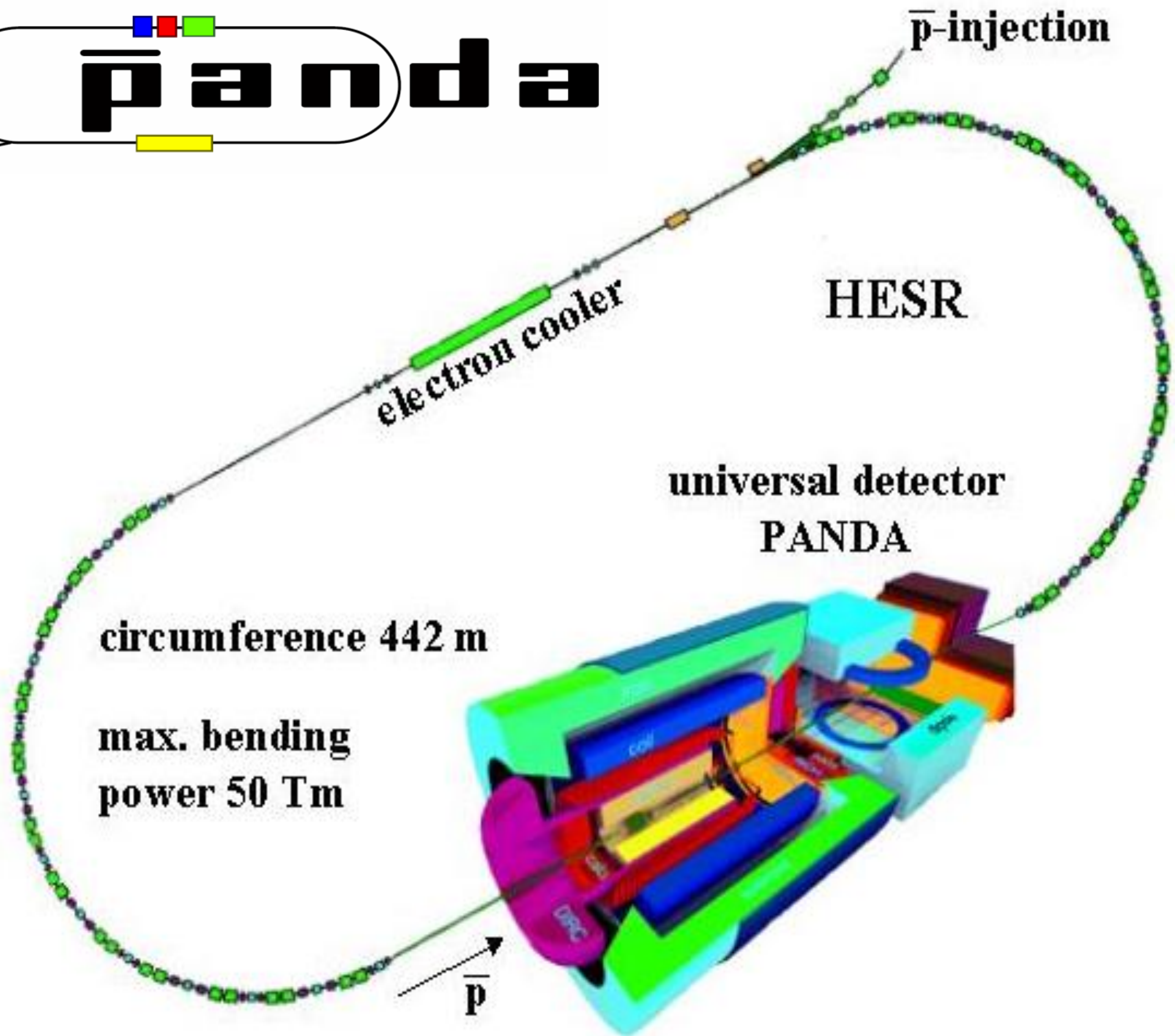



**Search for in-medium modifications of hadron properties**
Signal for onset of chiral symmetry restoration ?

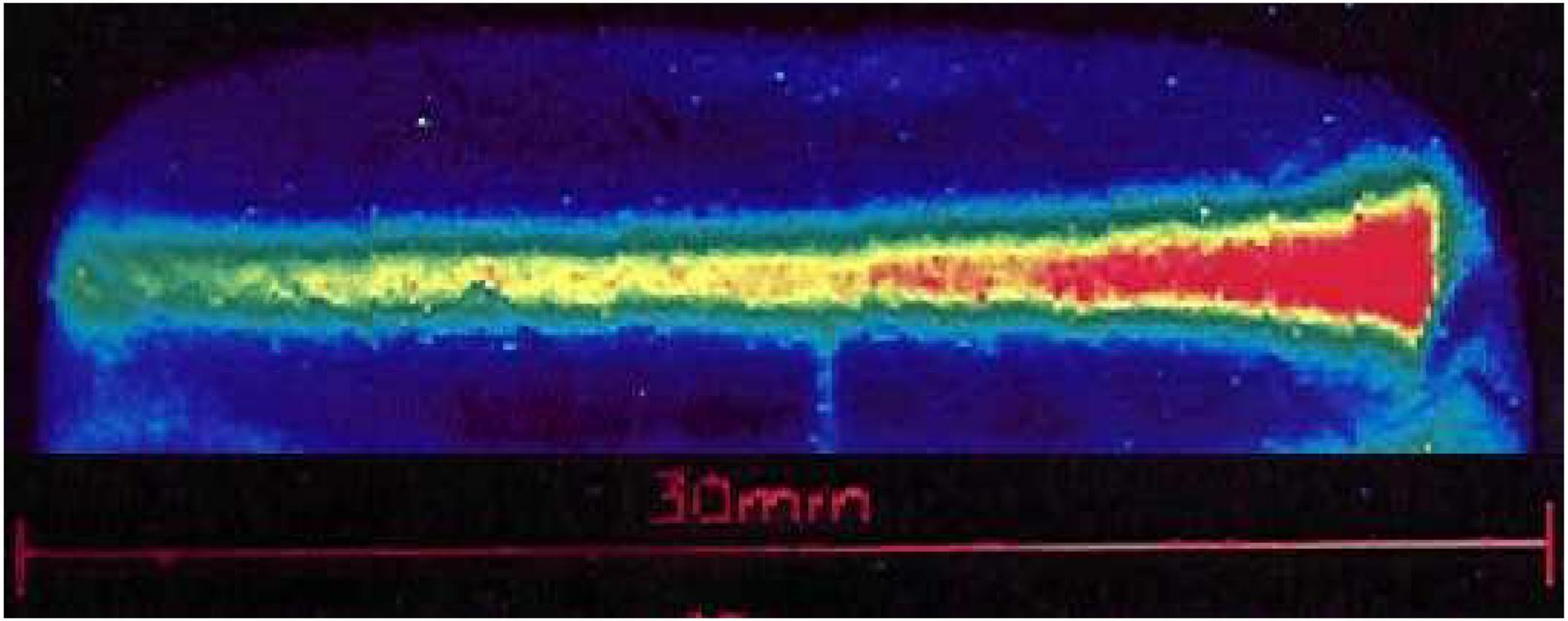
**Precision γ-spectroskopy of single and double hyper nuclei**
Information on nuclear structure and on hyperon-nucleon and hyperon-hyperon interaction.



# Antiproton-Proton-Annihilation in Darmstadt

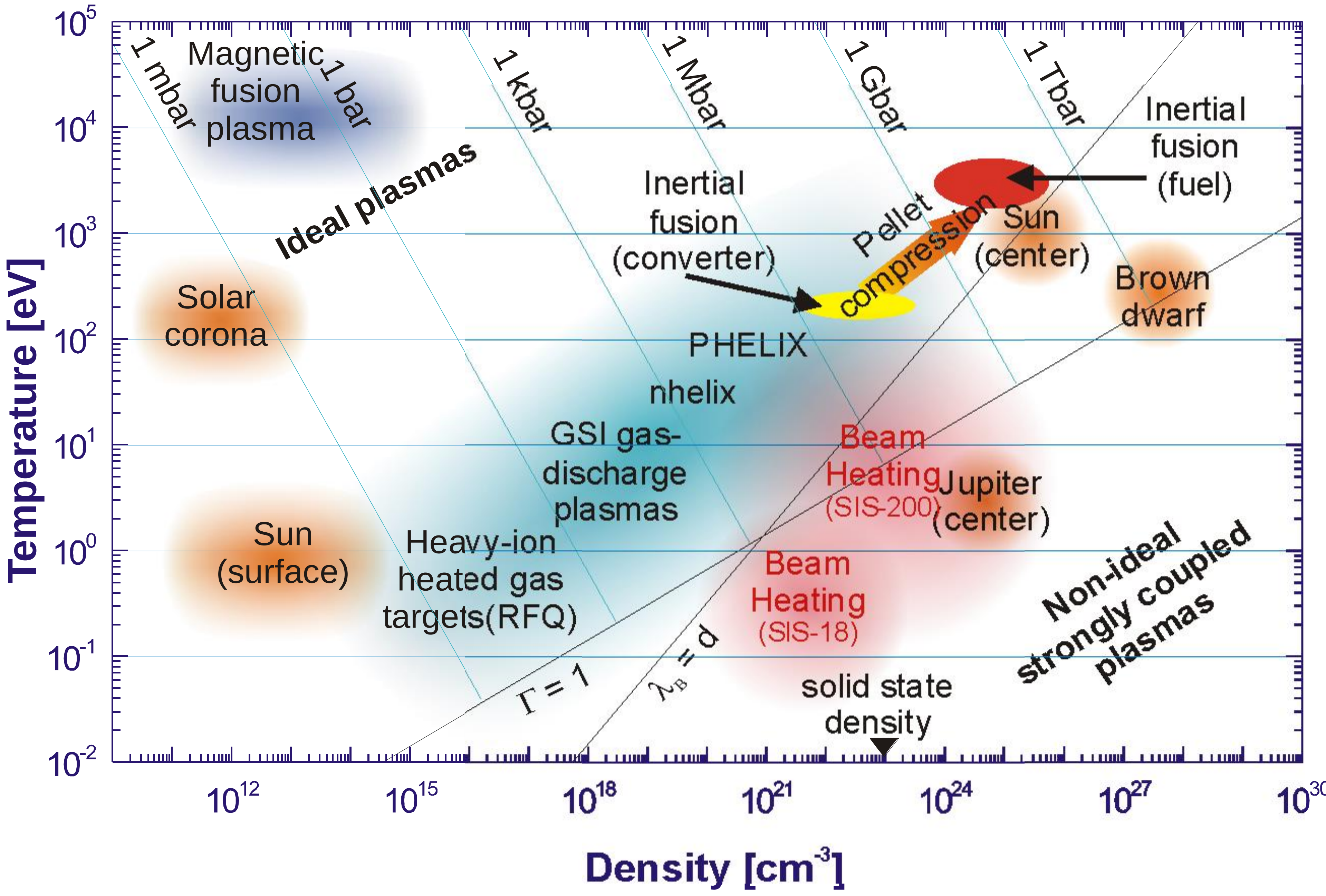


# Plasma physics with heavy ion beams



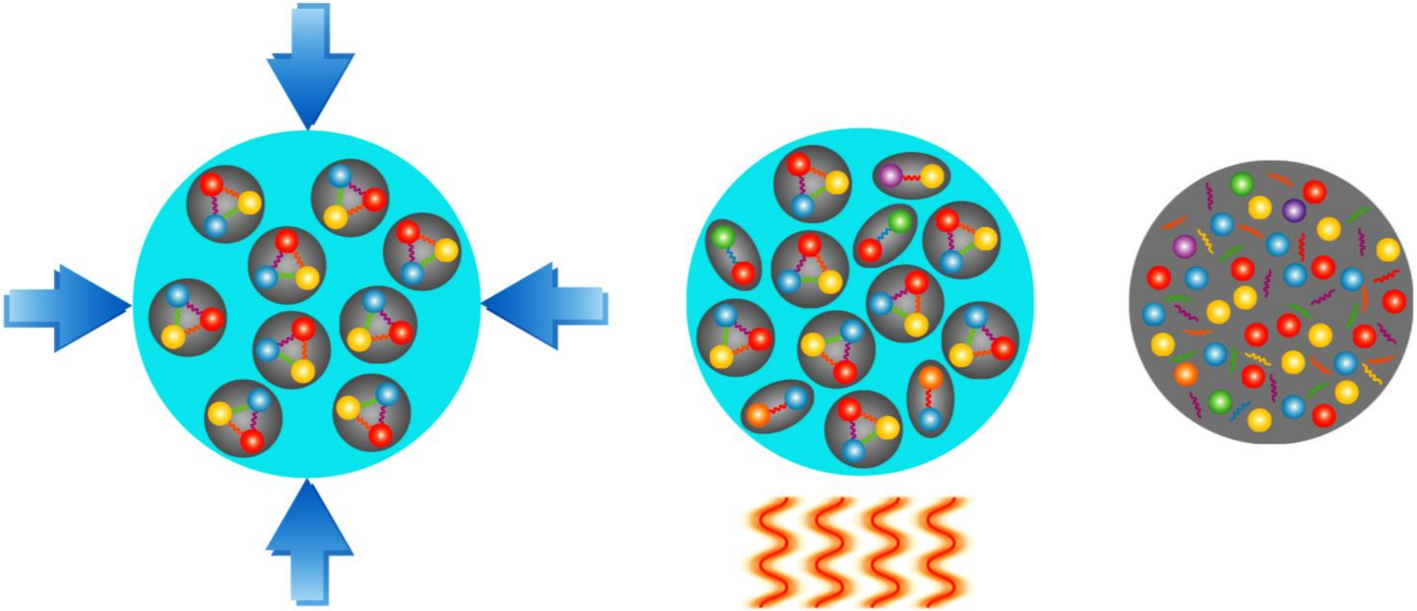

Neon beam at 300 A MeV penetrating an Ar Kristall

# The phase diagram of atomic matter



# States of strongly interacting matter

baryons hadrons partons

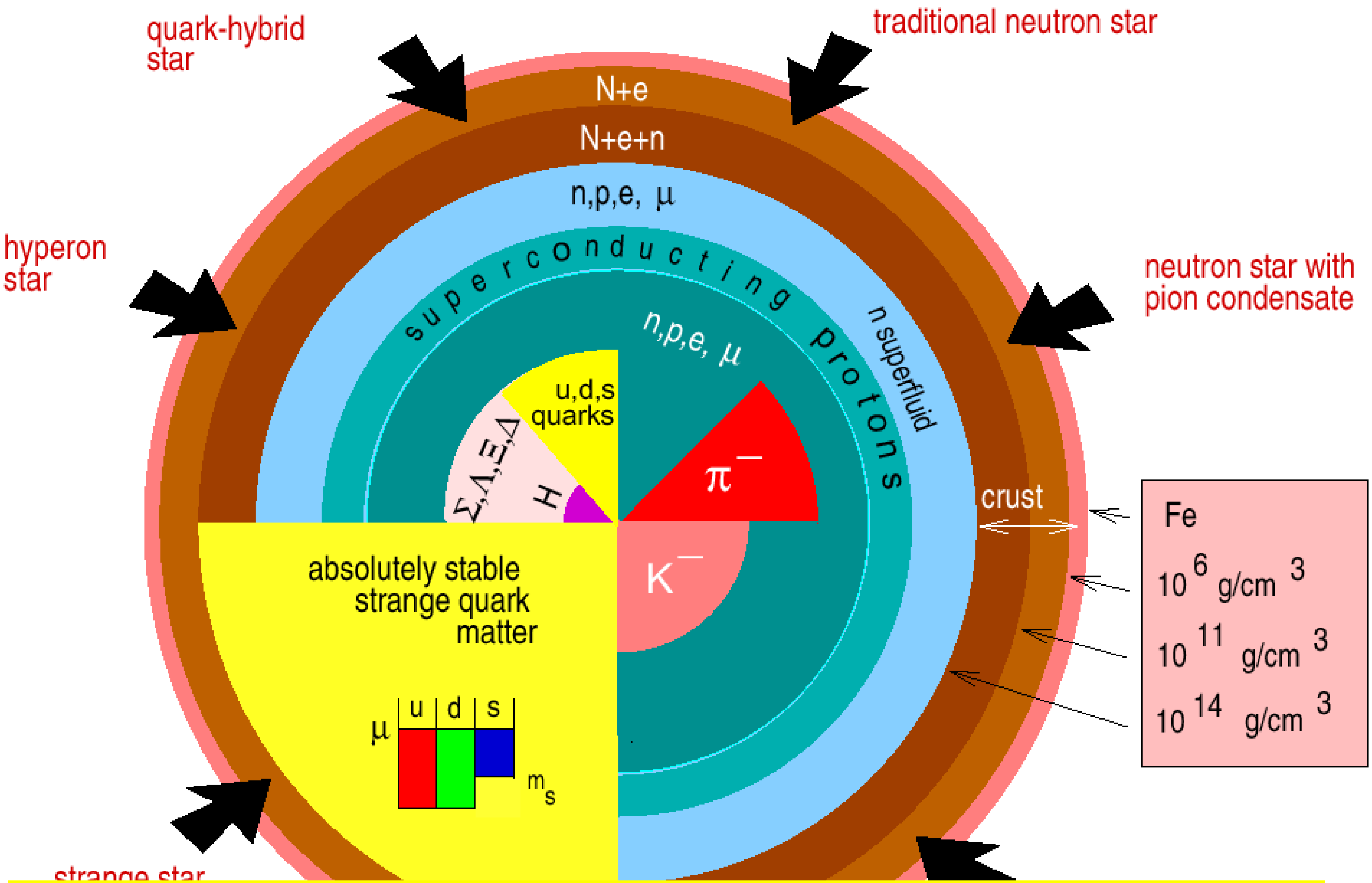


Compression + heating = quark-gluon matter

(pion production)

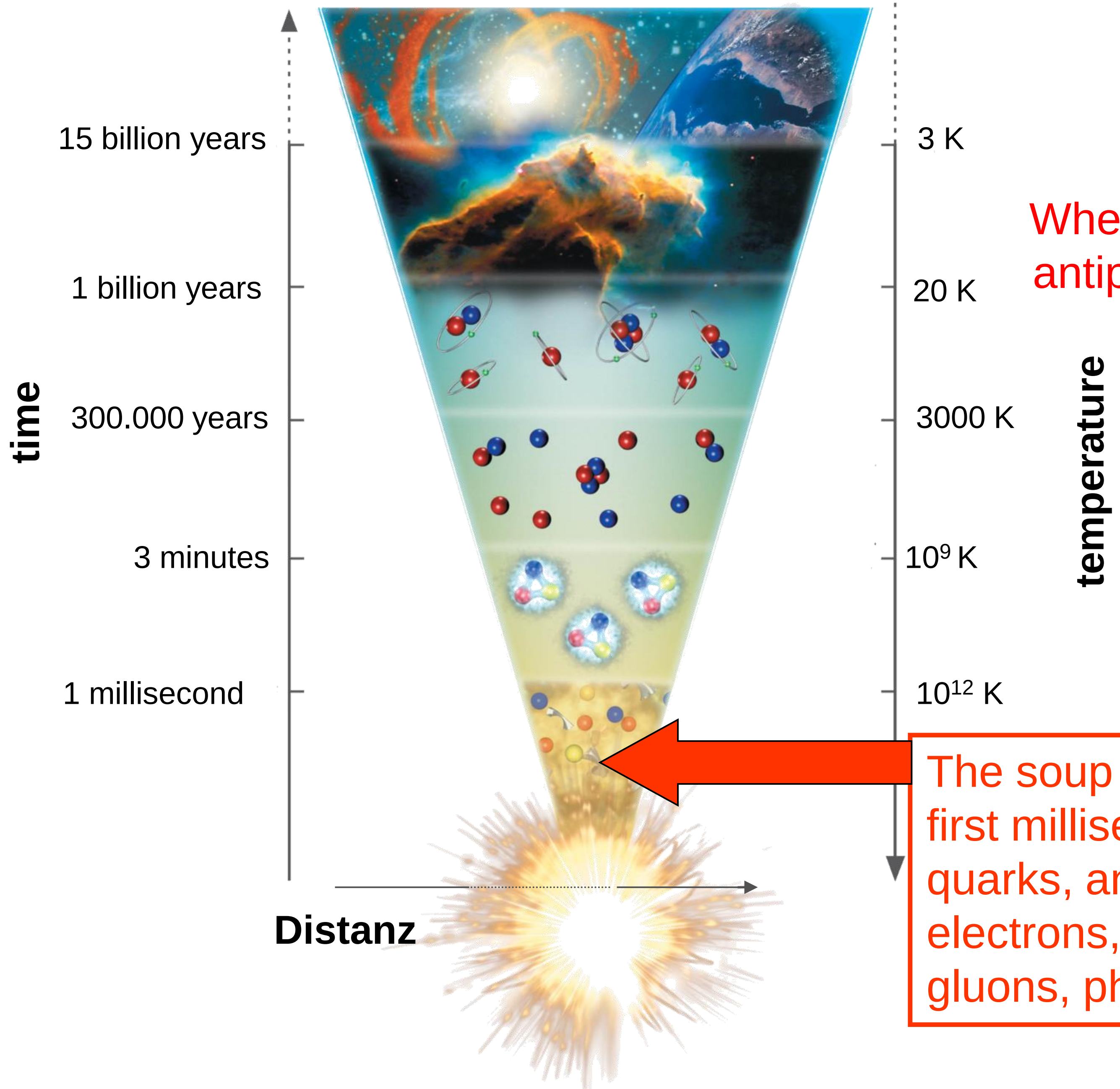
Neutron stars Early universe

# Strongly interacting matter in neutron stars




"Strangeness" of dense matter ?
In-medium properties of hadrons ?
Compressibility of nuclear matter?
Deconfinement at high baryon densities ?

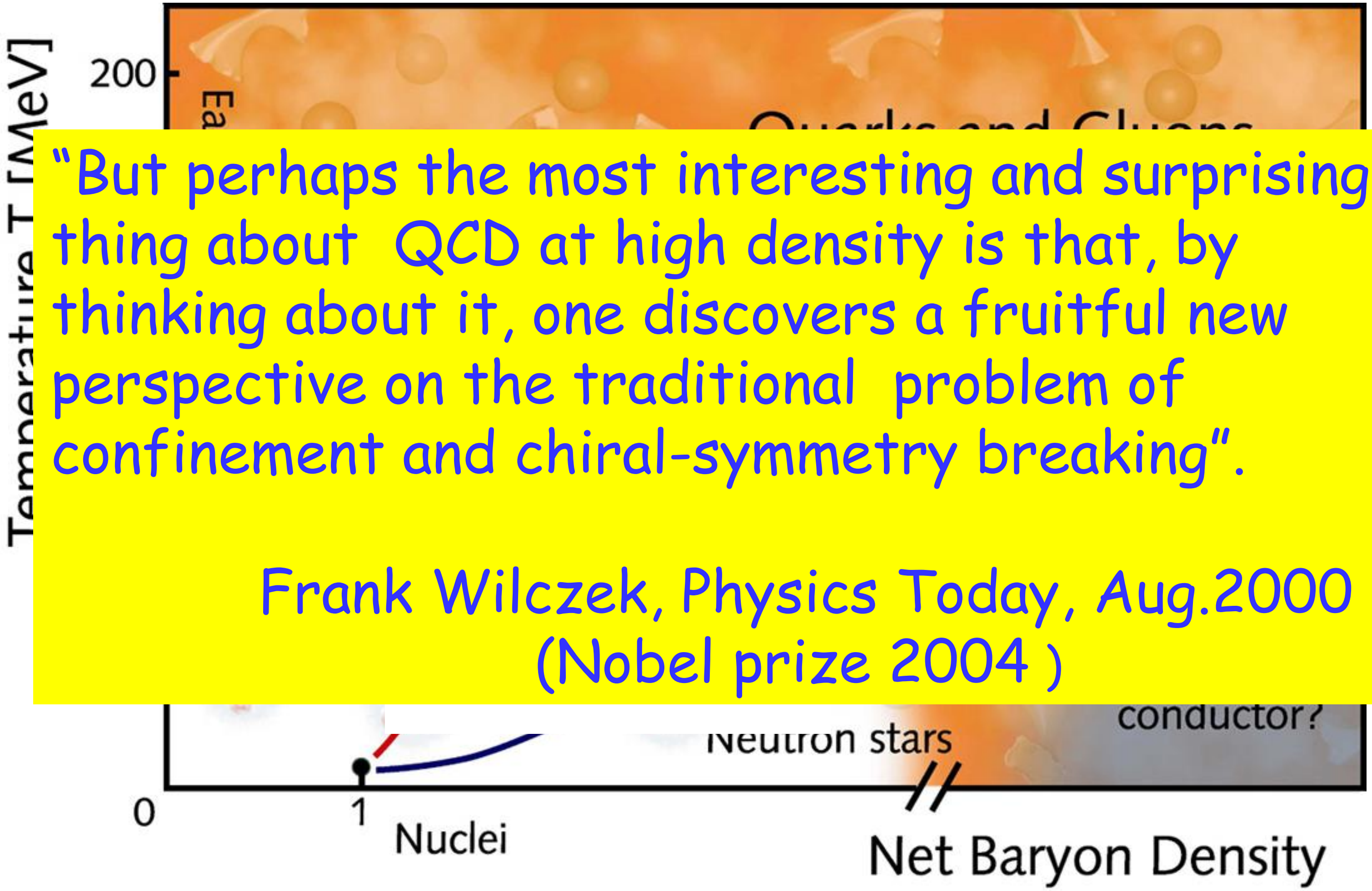
# The evolution of matter in the universe




Where are the antiparticles ?

The soup of the first millisecond: quarks, antiquarks, electrons, positrons, gluons, photons

# The phase diagram of strongly interacting matter

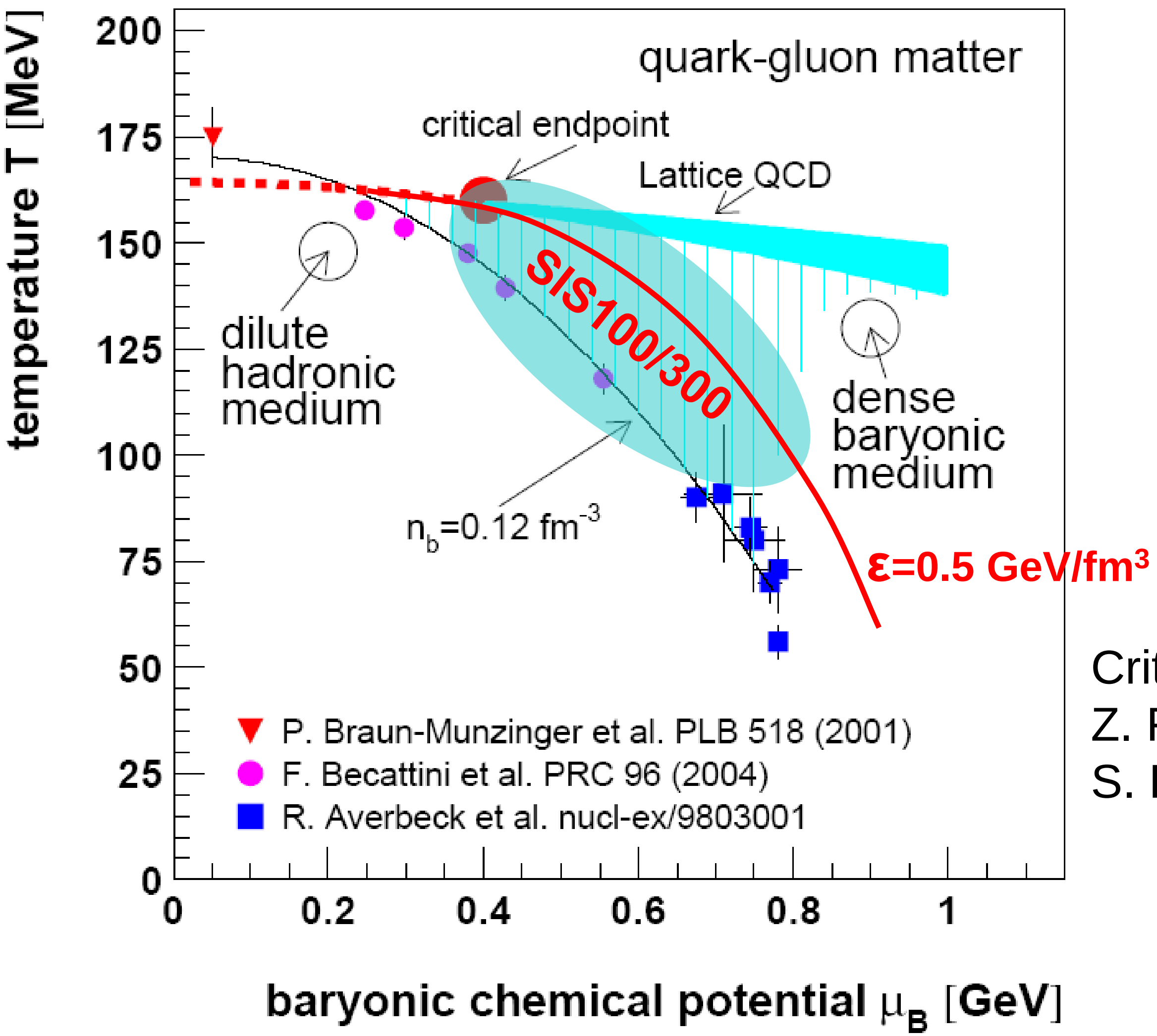



"But perhaps the most interesting and surprising thing about QCD at high density is that, by thinking about it, one discovers a fruitful new perspective on the traditional problem of confinement and chiral-symmetry breaking".

Frank Wilczek, Physics Today, Aug.2000
(Nobel prize 2004 )

SPS, RHIC, LHC: high temperature, low baryon density
FAIR: moderate temperature, high baryon density

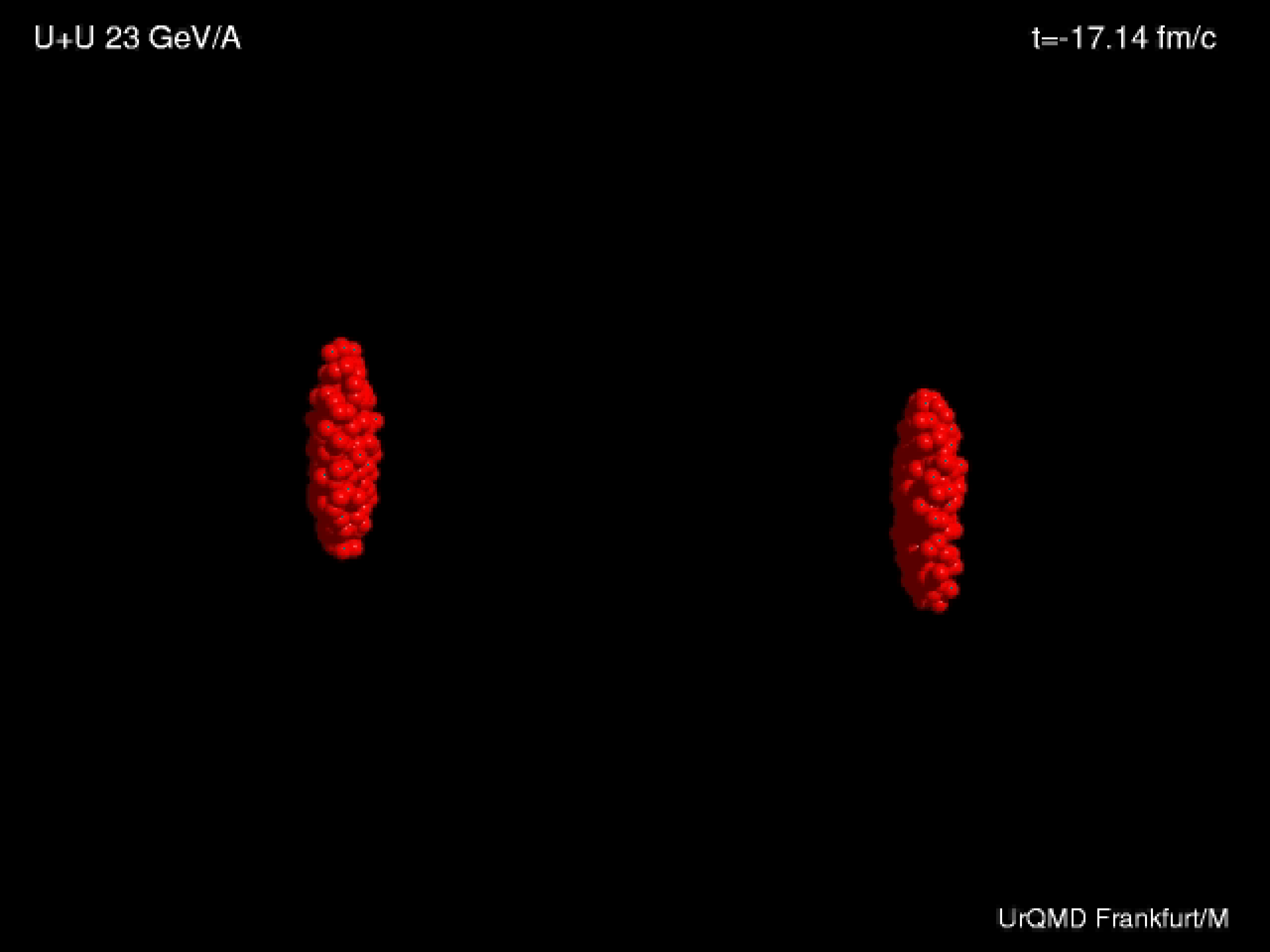
# Mapping the QCD phase diagram with heavy-ion collisions



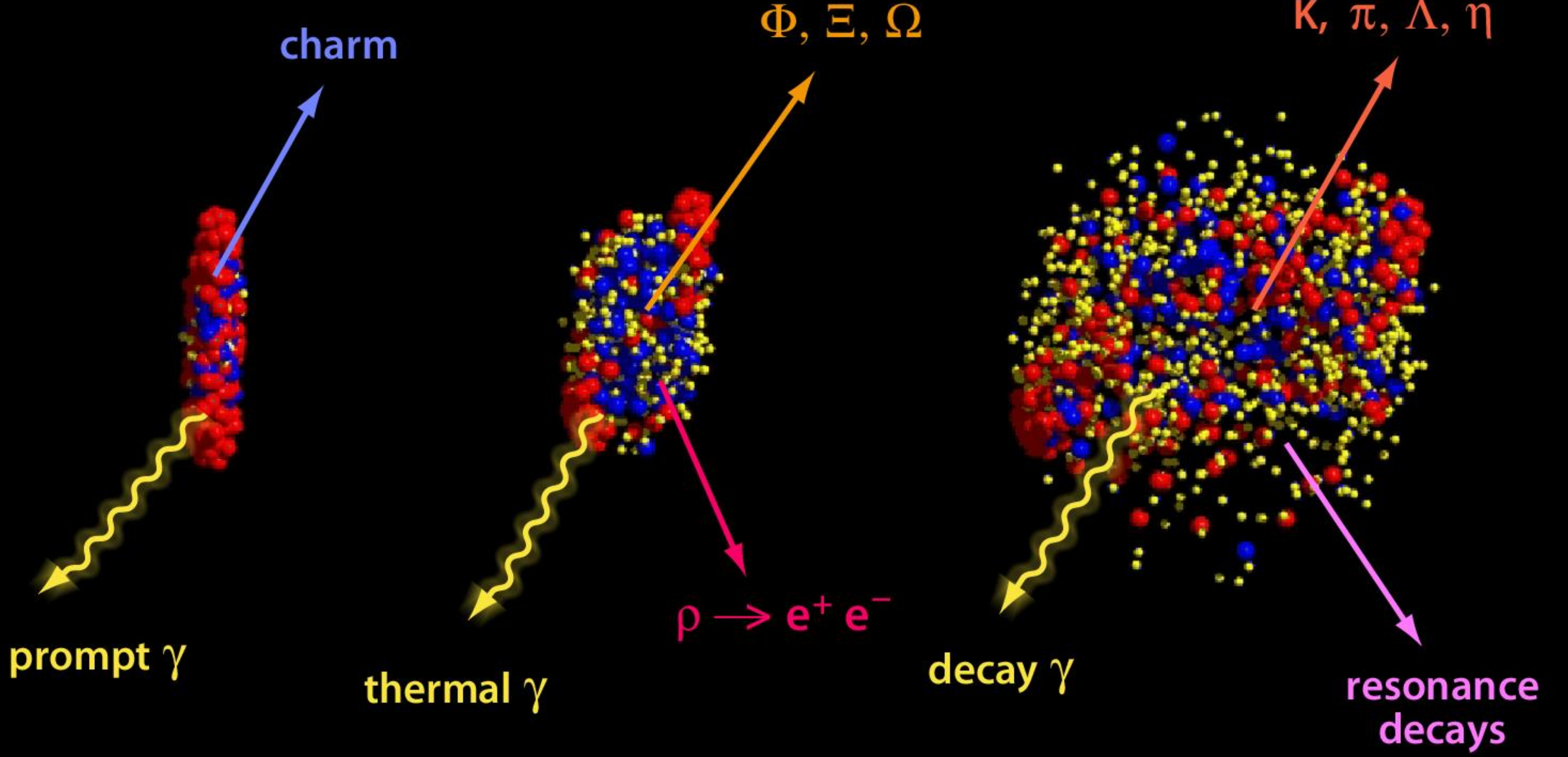

Critical endpoint:

Z. Fodor, S. Katz, hep-lat/0402006

S. Ejiri et al., hep-lat/0312006


U+U 23 GeV/A
t=-17.14 fm/c
UrQMD Frankfurt/M

# Diagnostische Sonden



# CBM physics topics and observables

- In-medium modifications of hadrons
  - ↳ onset of chiral symmetry restoration at high $\rho_B$

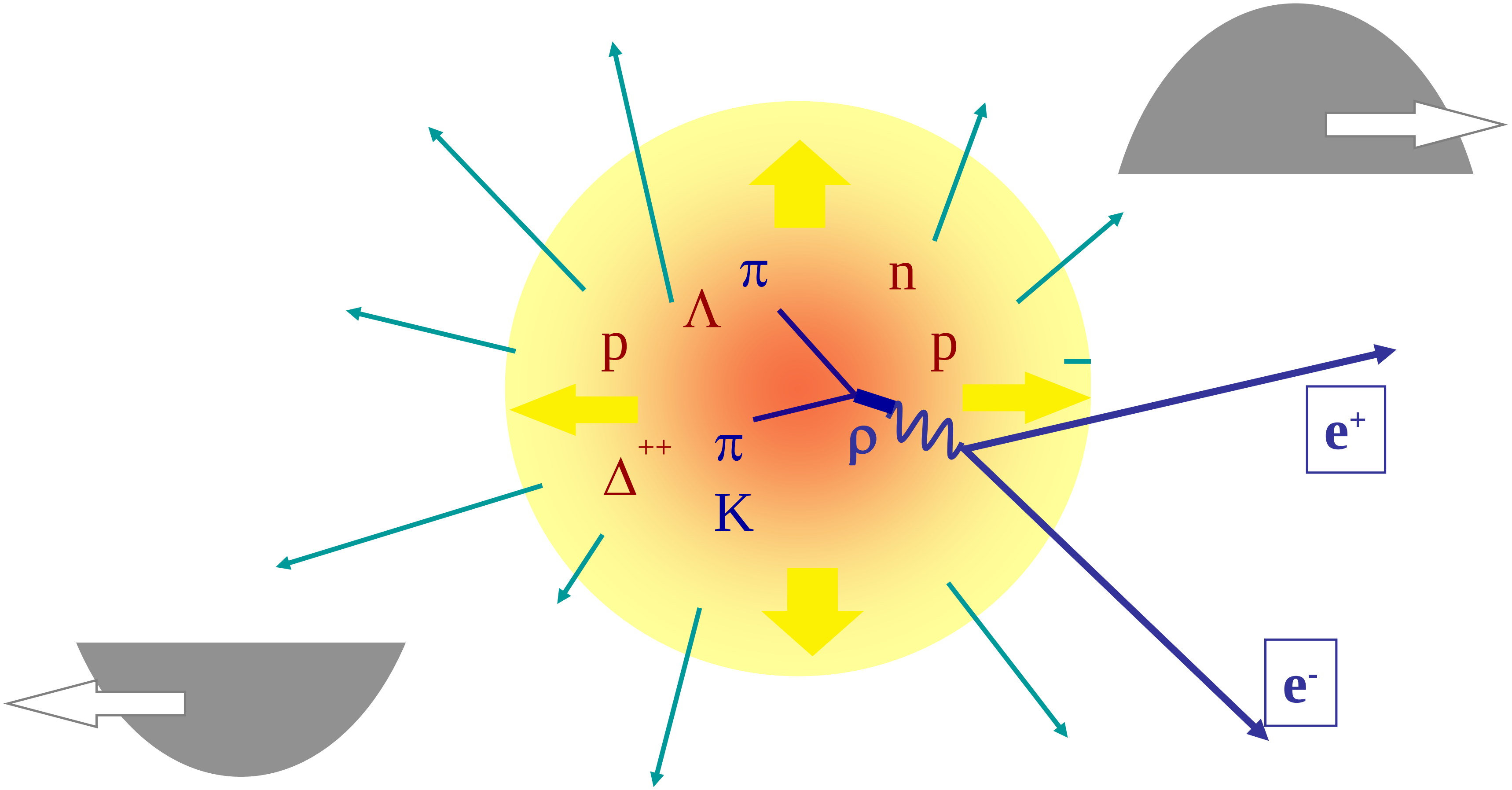
    measure: $\rho, \omega, \phi \rightarrow e^+e^-$

    open charm (D mesons)
- Strangeness in matter
  - ↳ production and propagation of strange particles

    measure: K, $\Lambda$, $\Sigma$, $\Xi$, $\Omega$
- Indications for deconfinement at high $\rho_B$
  - ↳ production and propagation of charm

    measure: $J/\psi$, D
- Critical point
  - ↳ event-by-event fluctuations

# Looking into the fireball …

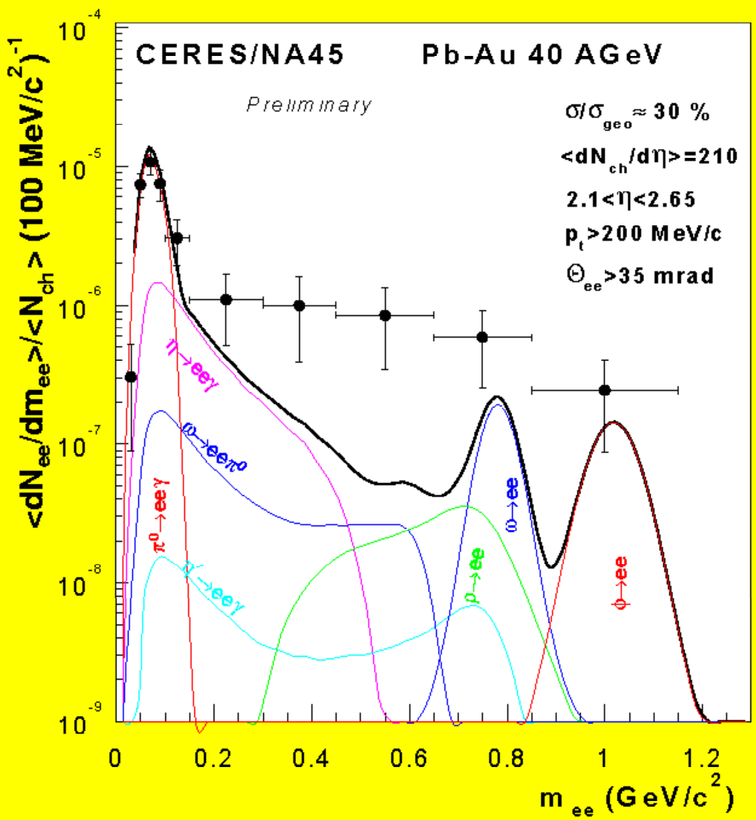



… using penetrating probes:

short-lived vector mesons decaying into electron-positron pairs

# Invariant mass of electron-positron pairs from Pb+Au at 40 AGeV

CERES Collaboration: D.Adamova et al., Phys. Rev. Lett. 91 (2003) 042301




Number of pairs for m>0.2 GeV/c2: 180+-48

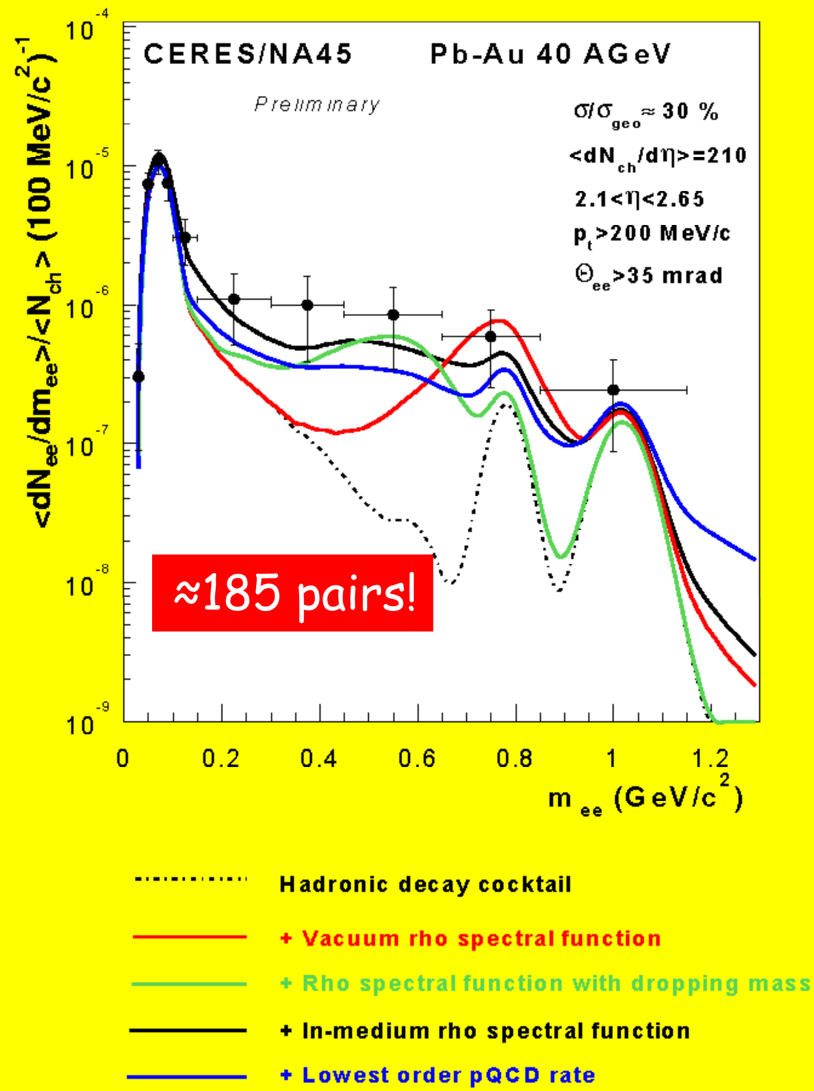
Ratio Signal/Background: 1/6

Hadronic decay cocktail:

- particle ratios taken from thermal model for Pb-Pb

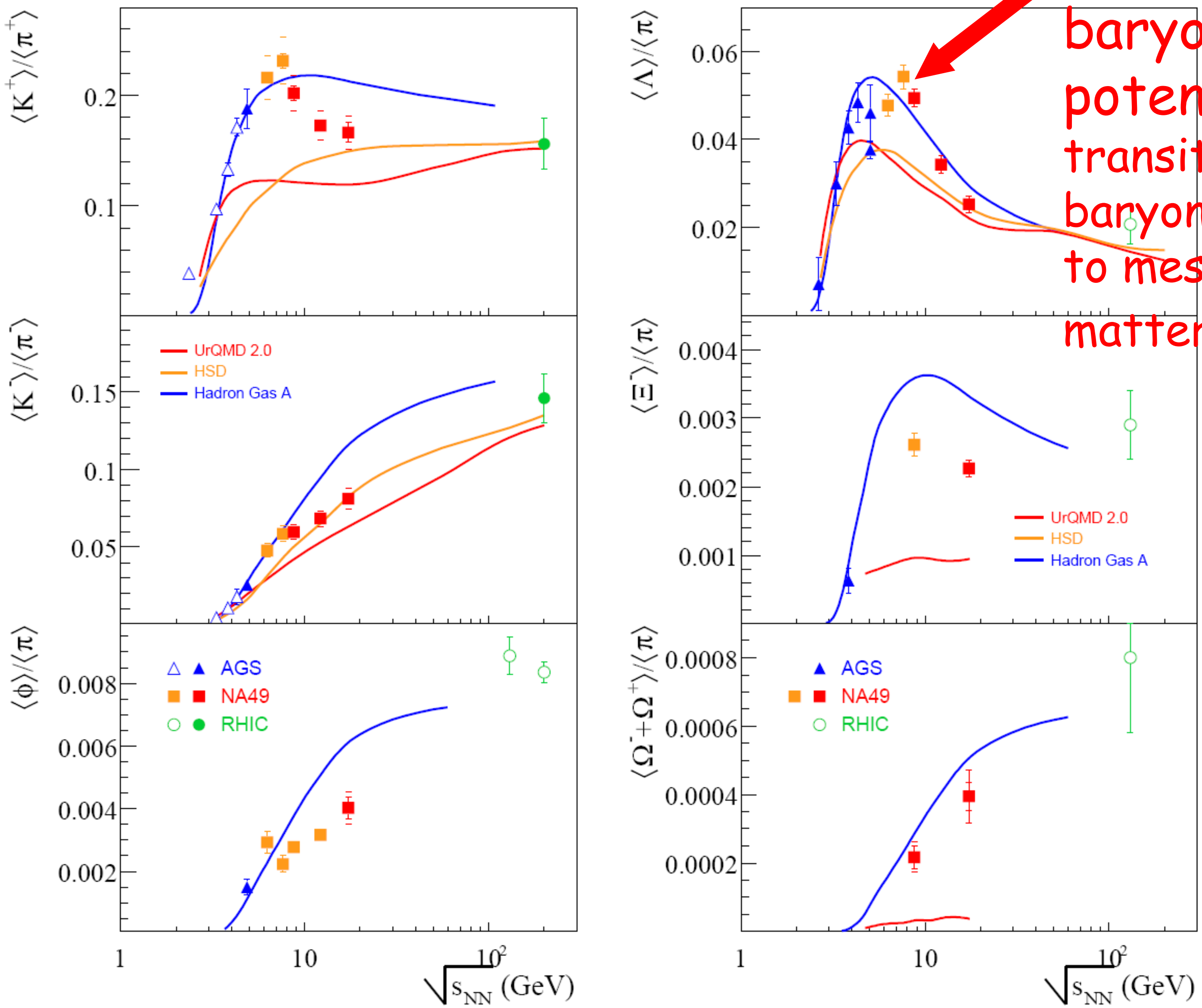
-rapidity and pt distributions from systematics in Pb-Pb

Enhancement: measured pairs/decay cocktail: 5.0 +- 1.3



# Strangeness/pion ratios versus beam energy

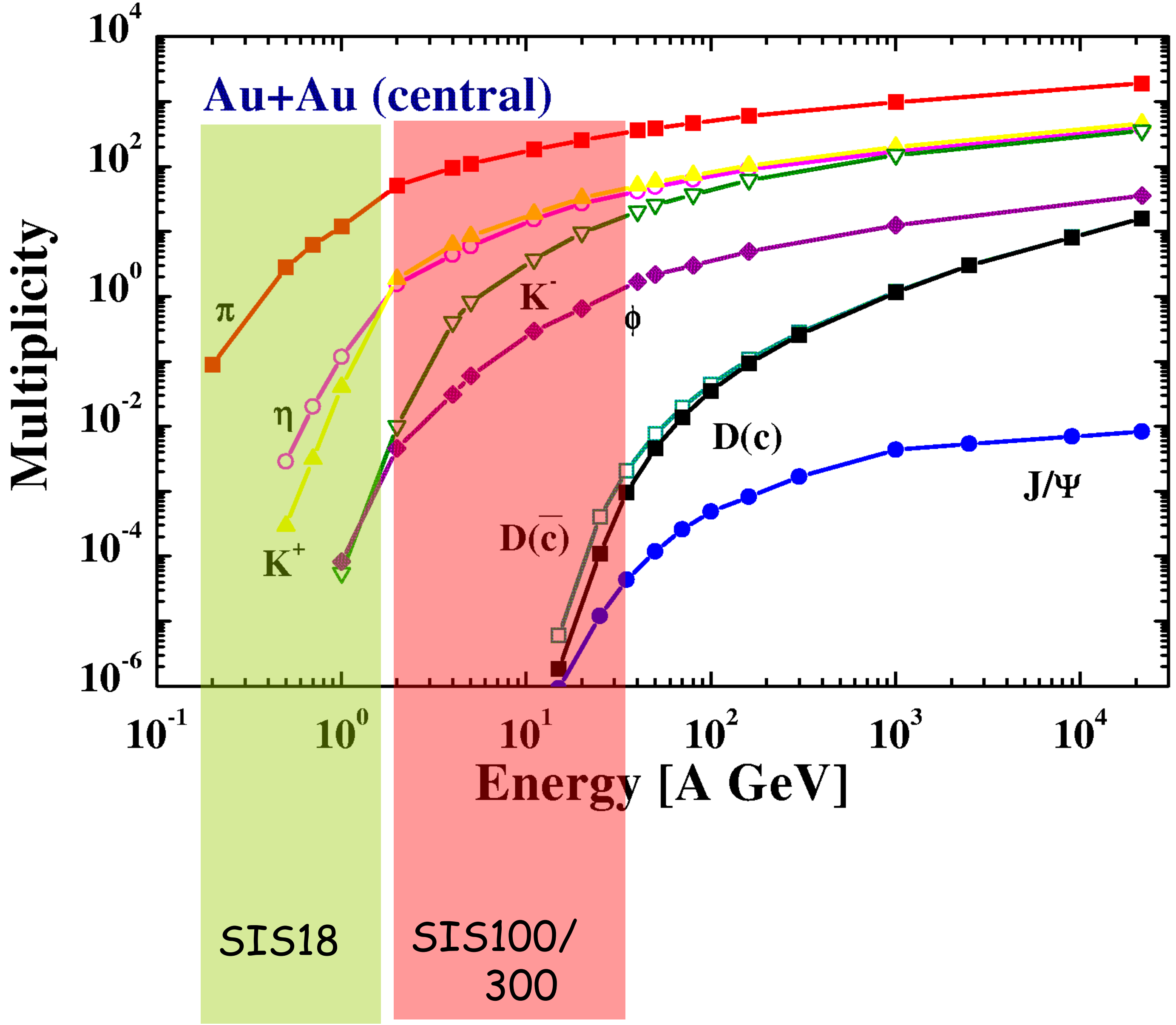
C. Blume et al., nucl-ex/0409008



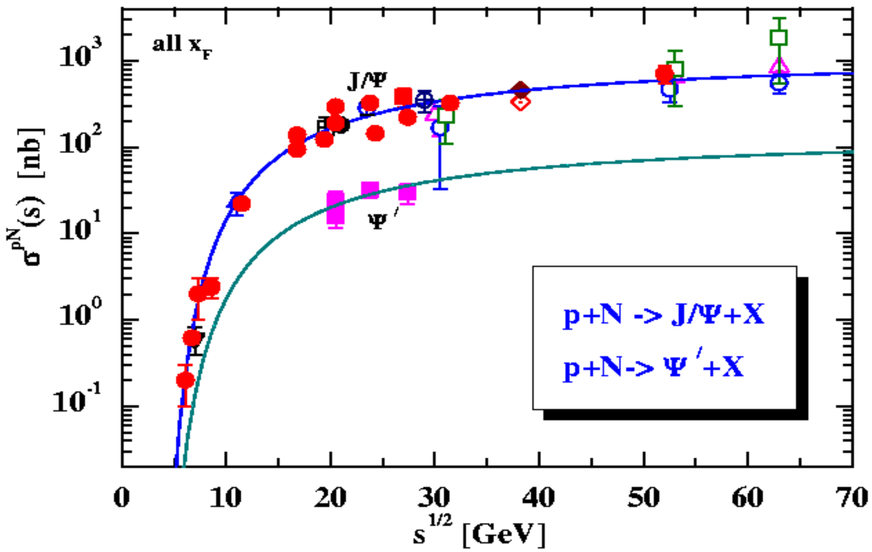

Decrease of baryon-chemical potential:
transition from baryon-dominated to meson-dominated matter

# Meson production in central Au+Au collisions

W. Cassing, E. Bratkovskaya, A. Sibirtsev, Nucl. Phys. A 691 (2001) 745



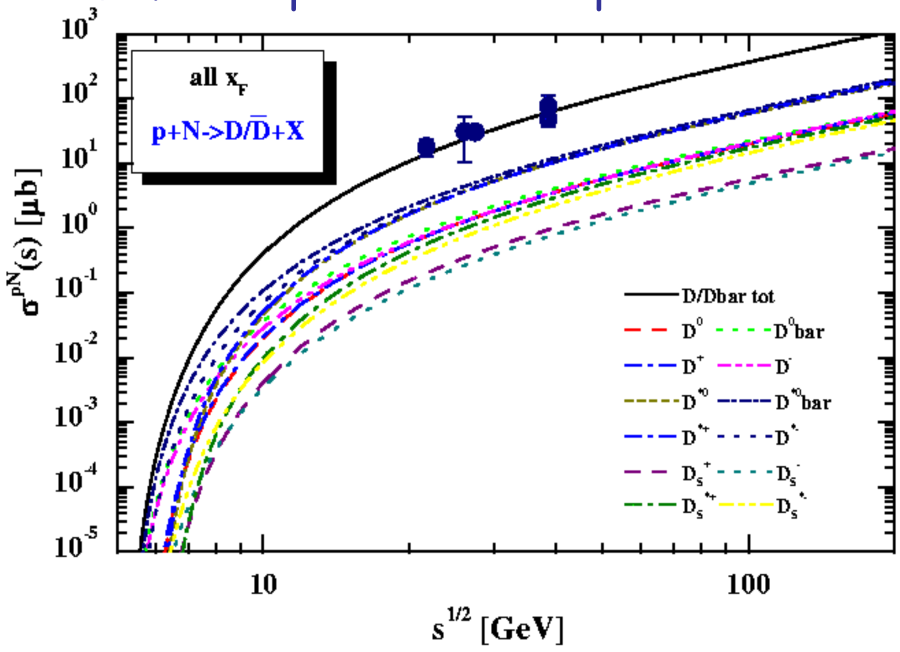
# J/ψ measurement requires high beam intensities and lepton identification




| central collisions | 25 AGeV Au+Au | 158 AGeV Pb+Pb |
|---|---|---|
| J/ψ multiplicity | $1.5\cdot10^{-5}$ | $1\cdot10^{-3}$ |
| beam intensity | $1\cdot10^{9}$/s | $2\cdot10^{7}$/s |
| interactions | $1\cdot10^{7}$/s (1%) | $2\cdot10^{6}$/s (10%) |
| central collisions | $1\cdot10^{6}$/s | $2\cdot10^{5}$/s |
| J/ψ rate | 15/s | 200/s |
| 6% J/ψ $\rightarrow e^+e^-$ ($\mu^+\mu^-$) | 0.9/s | 12/s |
| spill fraction | 0.8 | 0.25 |
| acceptance | 0.25 | ≈ 0.1 |
| J/ψ measured | 0.17/s | ≈ 0.3/s |
| | ≈ $1\cdot10^{5}$/week | ≈ $1.8\cdot10^{5}$/week |

# D-meson measurement requires vertex resolution

D meson production in pN collisions




Some hadronic decay modes

$D^{\pm}$ ($c\tau$ = 317 μm):

$D^+ \rightarrow K^0\pi^+$ (2.9±0.26%)

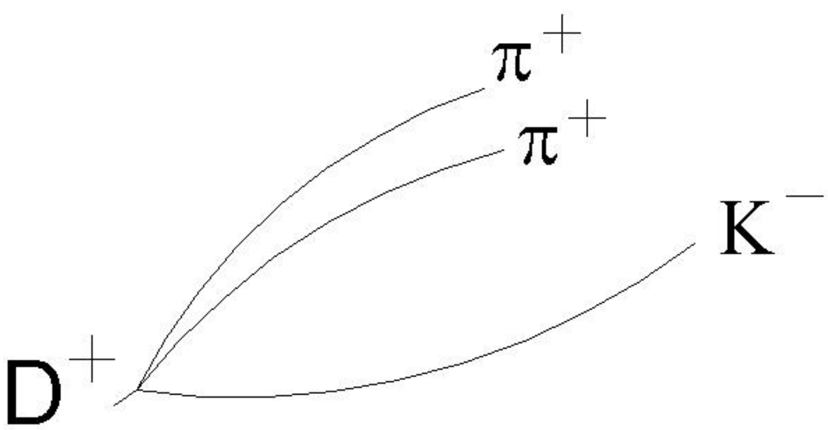
$D^+ \rightarrow K^-\pi^+\pi^+$ (9 ± 0.6%)

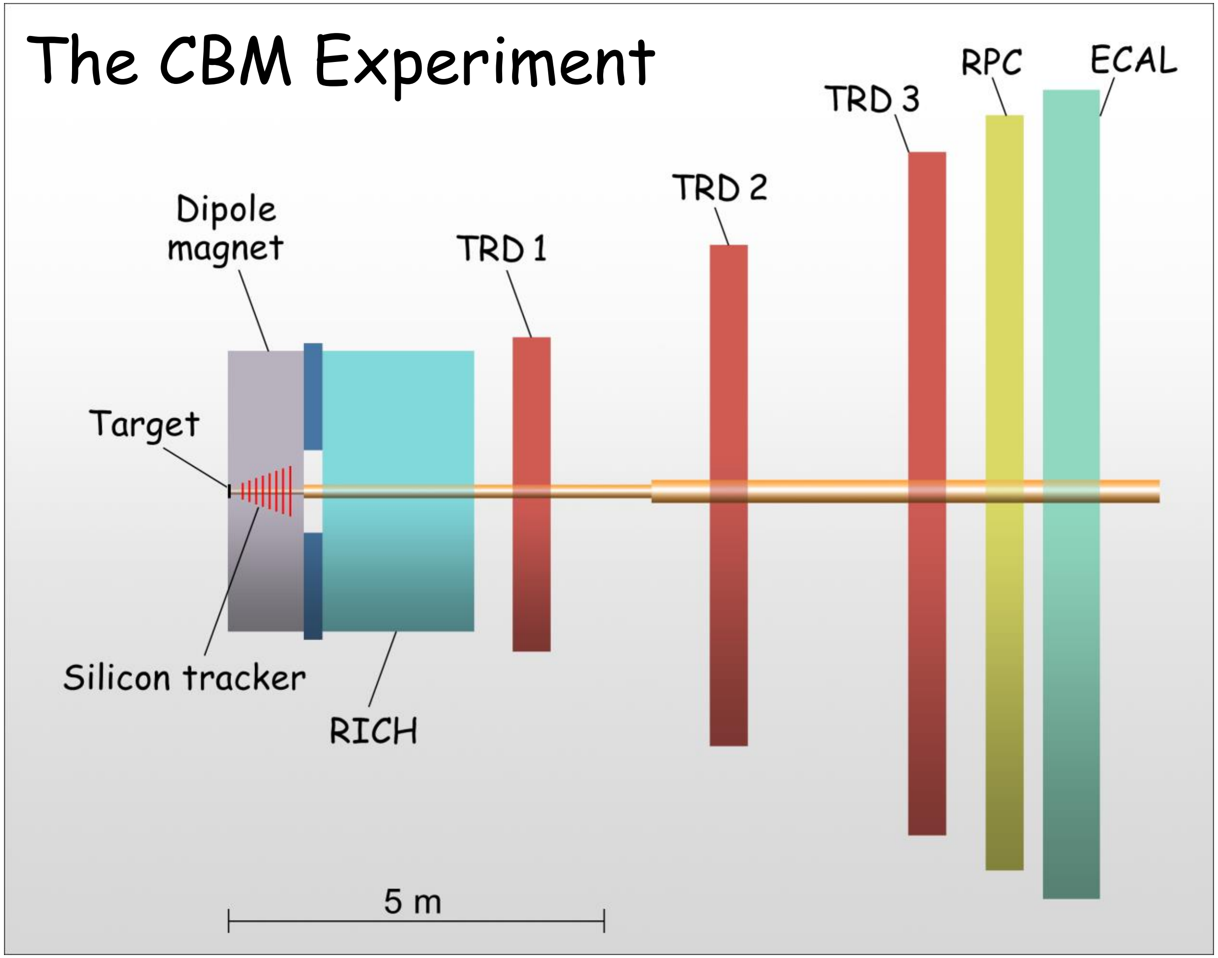
$D^0$ ($c\tau$ = 124.4 μm):

$D^0 \rightarrow K^-\pi^+$ (3.9 ± 0.09%)

$D^0 \rightarrow K^-\pi^+ \pi^+ \pi^-$ (7.6 ± 0.4%)

Measure displaced vertex
with resolution of ≈ 50 μm !



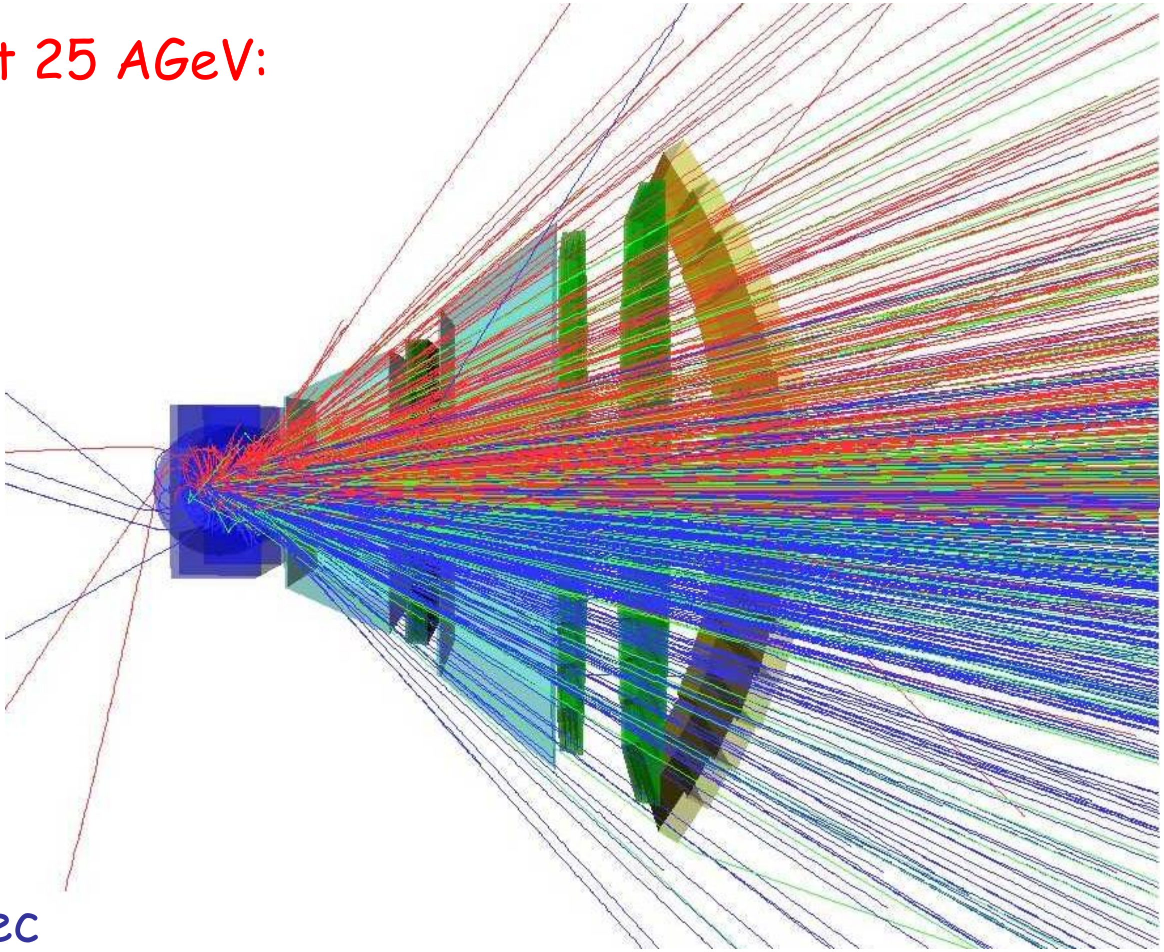



- Radiation hard Silicon (pixel/strip) Tracking System in a magnetic dipole field
- Electron detectors: RICH & TRD & ECAL: pion suppression better $10^4$
- Hadron identification: TOF-RPC
- Measurement of photons, $\pi^0$, $\eta$, and muons: electromagn. calorimeter (ECAL)
- High speed data acquisition and trigger system

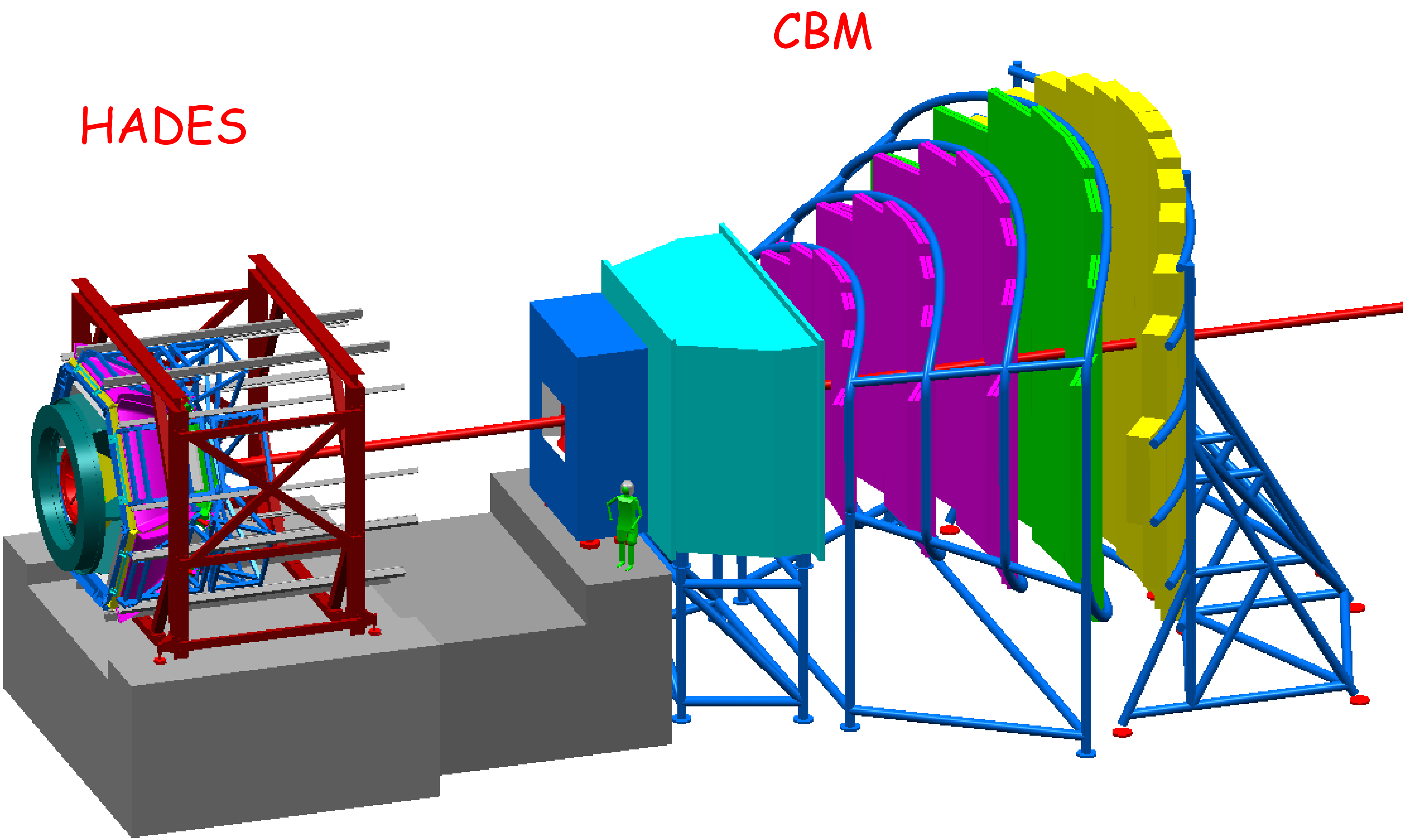
# Experimental challenges

Central Au+Au collision at 25 AGeV:
URQMD + GEANT4

160 p
400 $\pi^-$
400 $\pi^+$
44 $K^+$
13 $K^-$



- $10^7$ Au+Au reactions/sec
  (beam intensities up to $10^9$ ions/sec, 1 % interaction target)
- determination of (displaced) vertices with high resolution (< 50 $\mu$m)
- identification of electrons and hadrons


HADES
CBM

# CBM Collaboration : 41 institutions, > 300 Members

Croatia:
RBI, Zagreb

China:
Wuhan Univ.

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IReS Strasbourg

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

Germany:
Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Kaiserslautern
Univ. Mannheim
Univ. Marburg
Univ. Münster
FZ Rossendorf
GSI Darmstadt

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice

Portugal:
LIP Coimbra

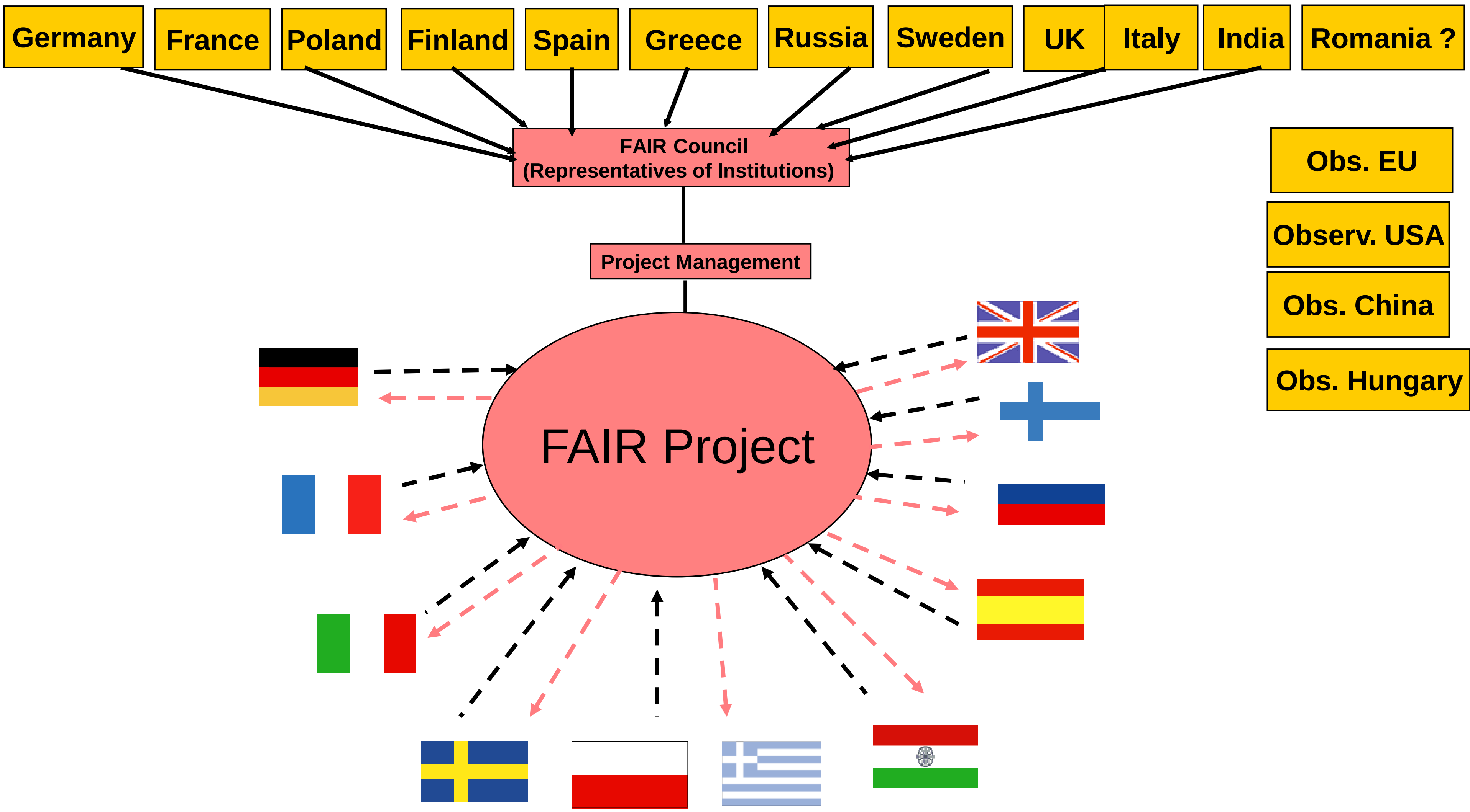
Romania:
NIPNE Bucharest

Russia:
CKBM, St. Petersburg
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.

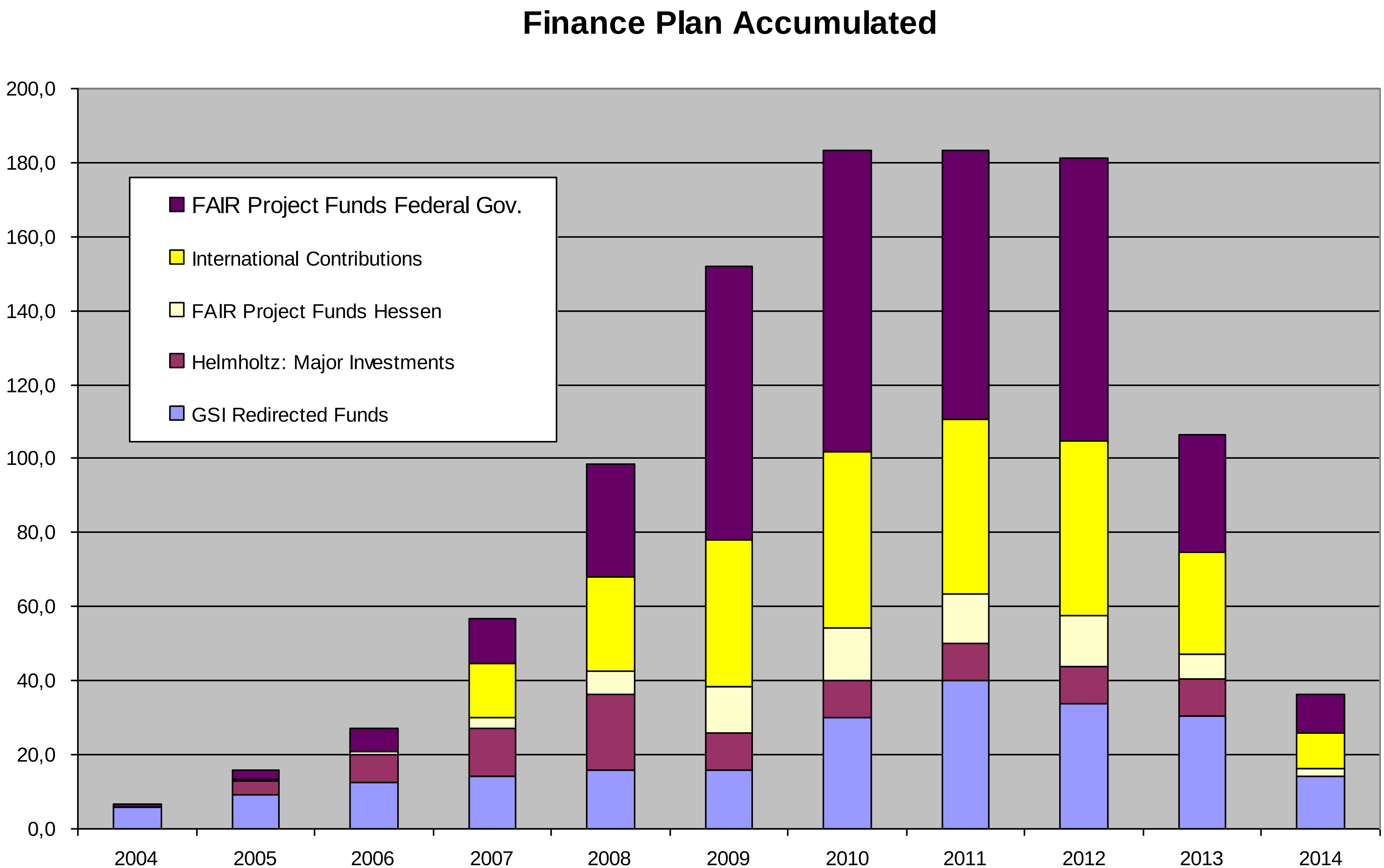
Spain:
Santiago de Compostela Univ.

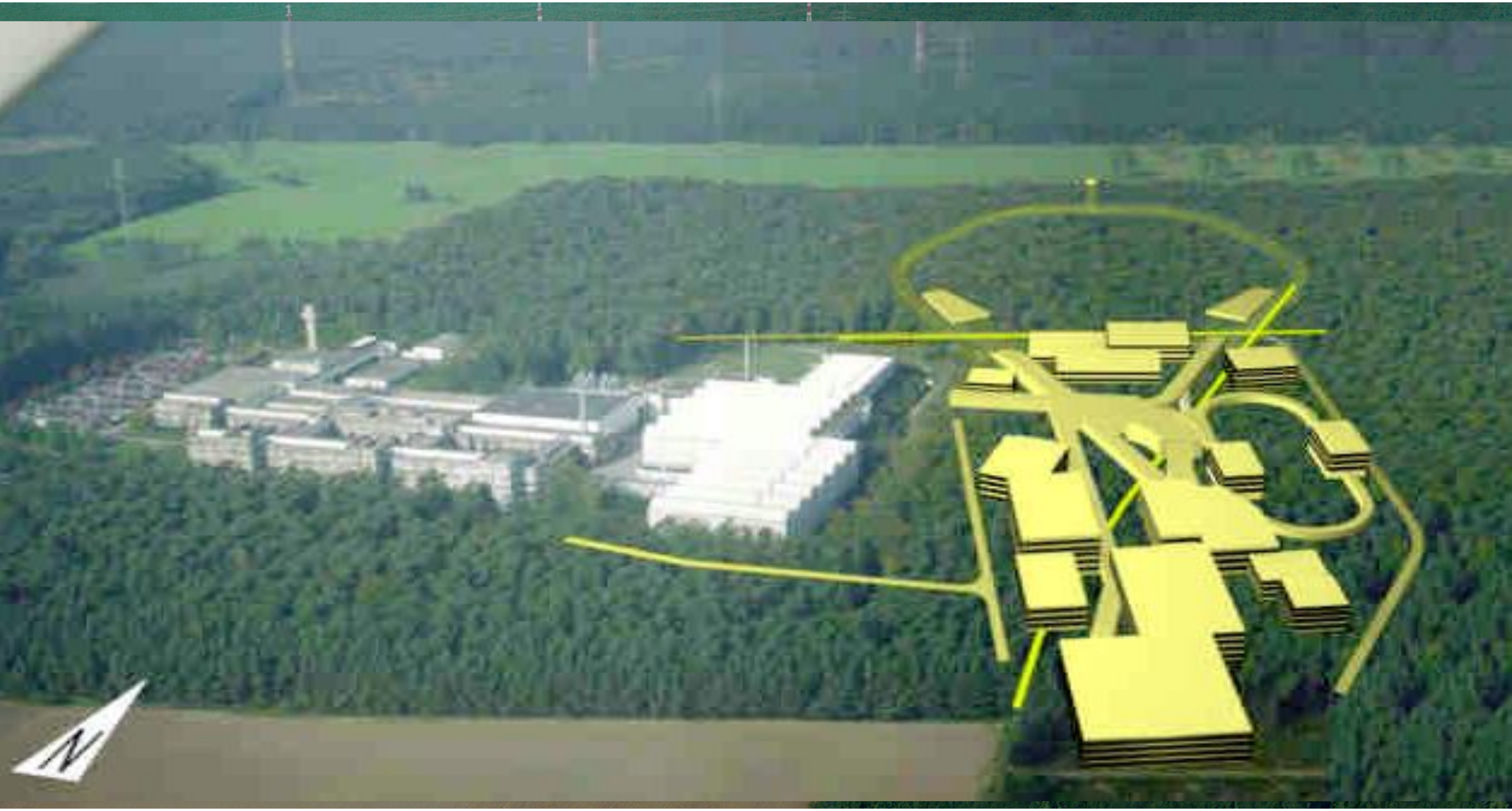
Ukraine:
Shevshenko Univ. , Kiev

# The FAIR member states (March 2005)



# Funding profile




N