



SMR.1751 - 55

Fifth International Conference on  
**PERSPECTIVES IN HADRONIC PHYSICS**  
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

**22 - 26 May 2006**

---

**Facility for Antiproton and Ion Research**

**Walter F. HENNING**  
Gesellschaft fuer Schwerionenforschung  
Theory Department  
Planckstrasse 1  
D-64291 Darmstadt  
GERMANY

---

These are preliminary lecture notes, intended only for distribution to participants

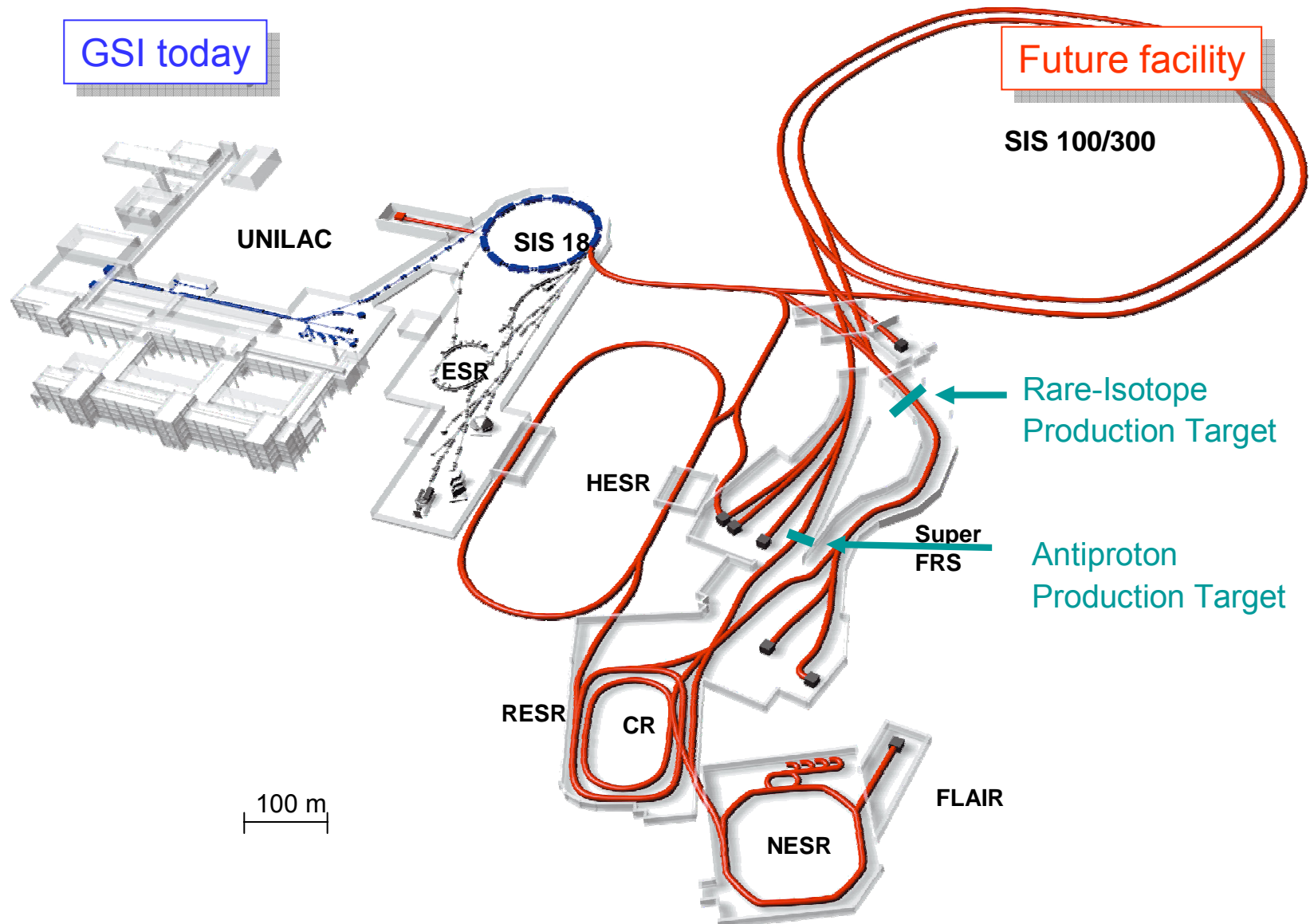


# Facility for Antiproton and Ion Research – Research Program and a Status Report

Walter F. Henning – GSI Darmstadt & University of Frankfurt  
Hadronic Physics, ICTP Trieste, May 26, 2006

- Brief overview of FAIR
- Hadron physics with antiprotons
- QCD Phase diagram with heavy ions
- Outlook

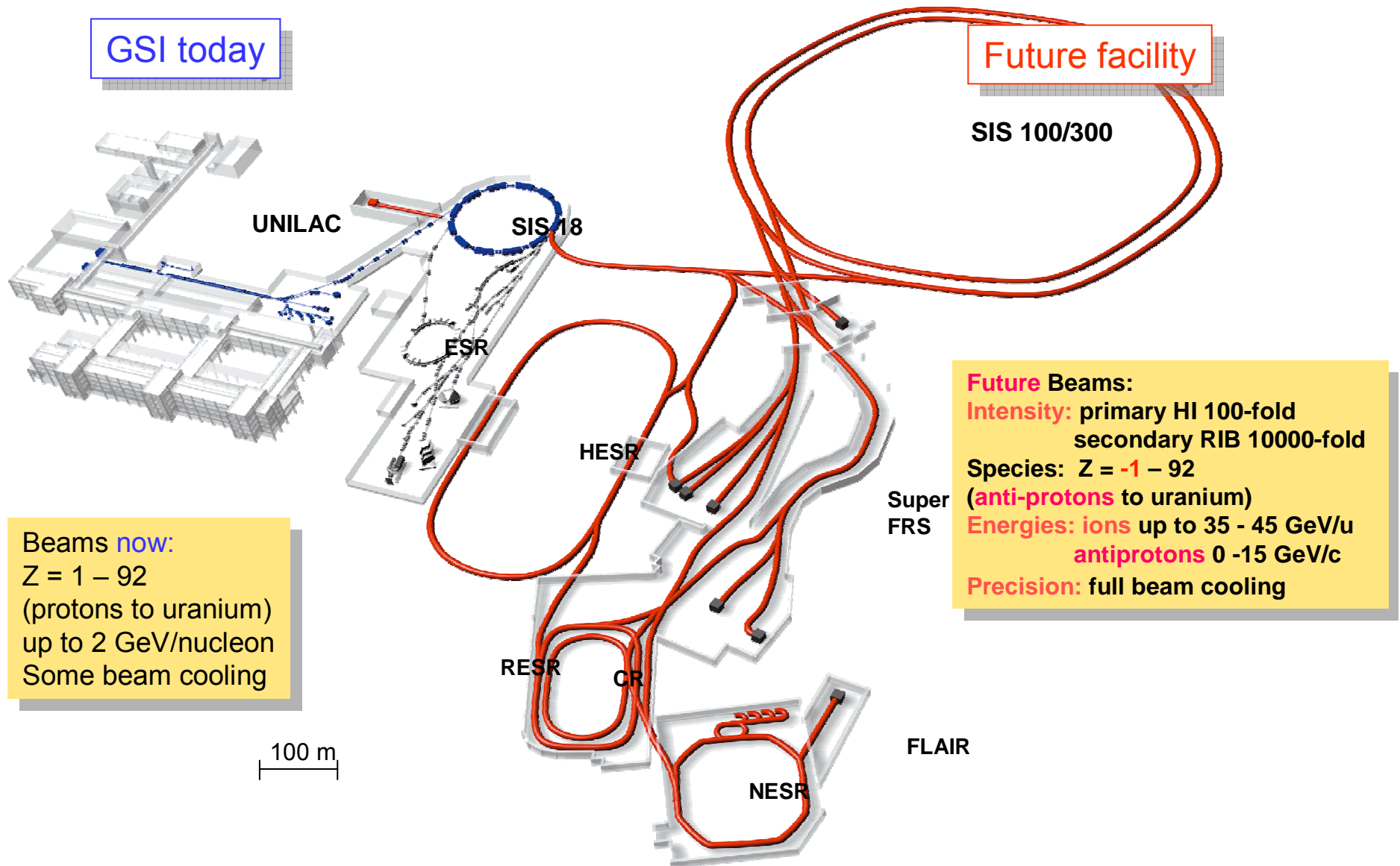
# FAIR - Facility for Antiproton and Ion Research



# FAIR - Facility for Antiproton and Ion Research

GSI today

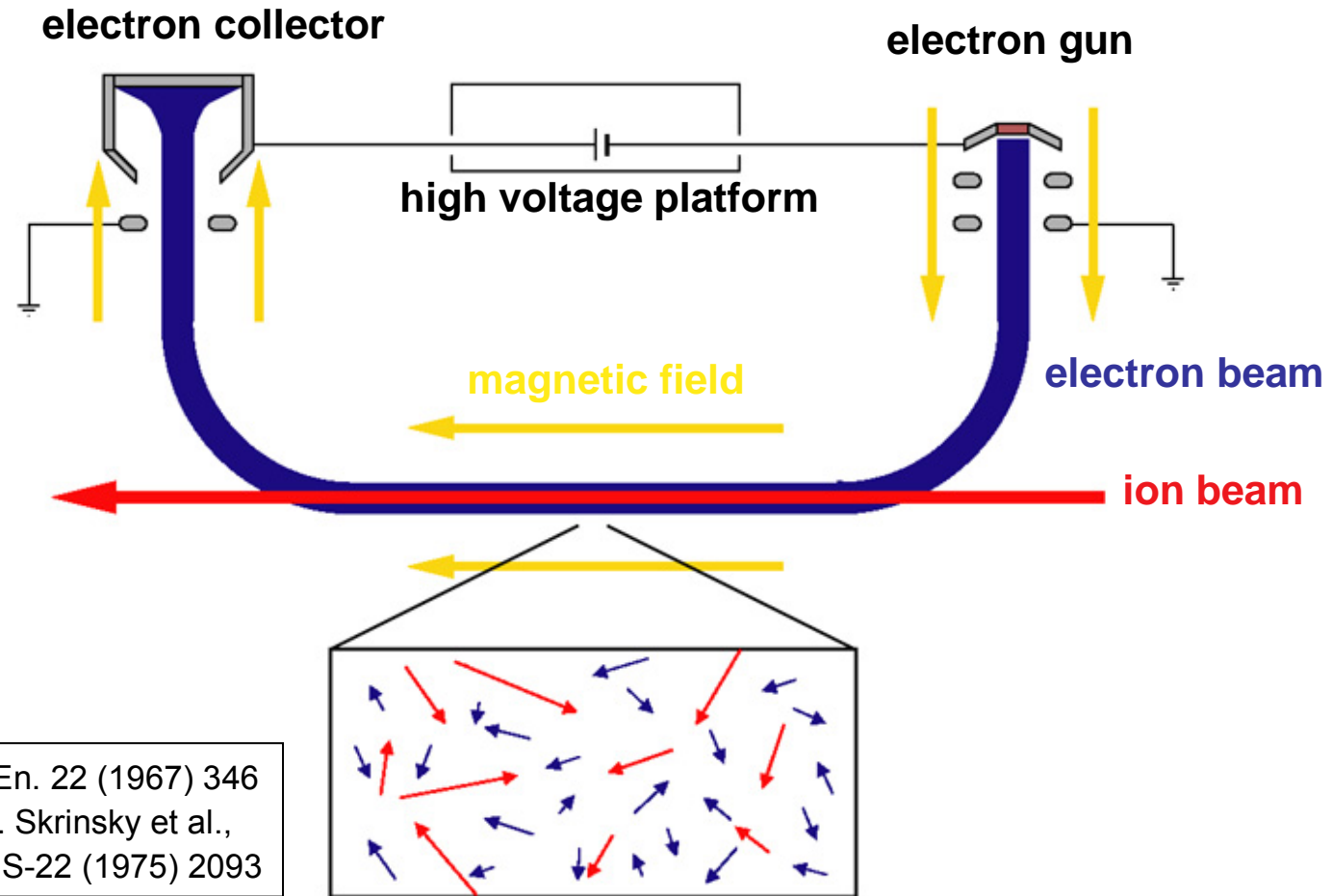
Future facility



Beams **now**:  
Z = 1 – 92  
(protons to uranium)  
up to 2 GeV/nucleon  
Some beam cooling

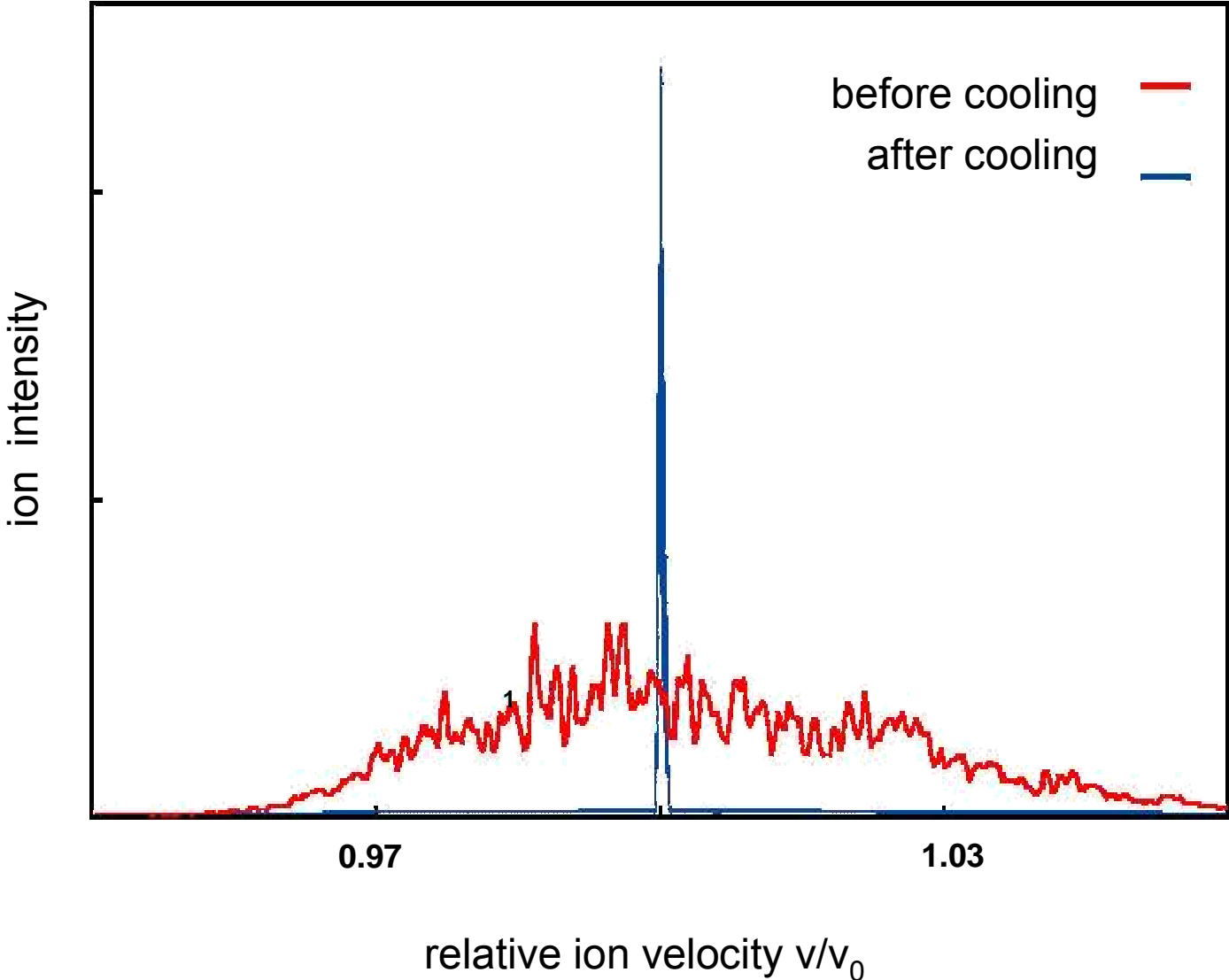
**Future Beams:**  
**Intensity:** primary HI 100-fold  
secondary RIB 10000-fold  
**Species:** Z = -1 – 92  
(**anti-protons** to uranium)  
**Energies:** ions up to 35 - 45 GeV/u  
**antiprotons** 0 -15 GeV/c  
**Precision:** full beam cooling

# Electron-Beam Cooled Ion Beams

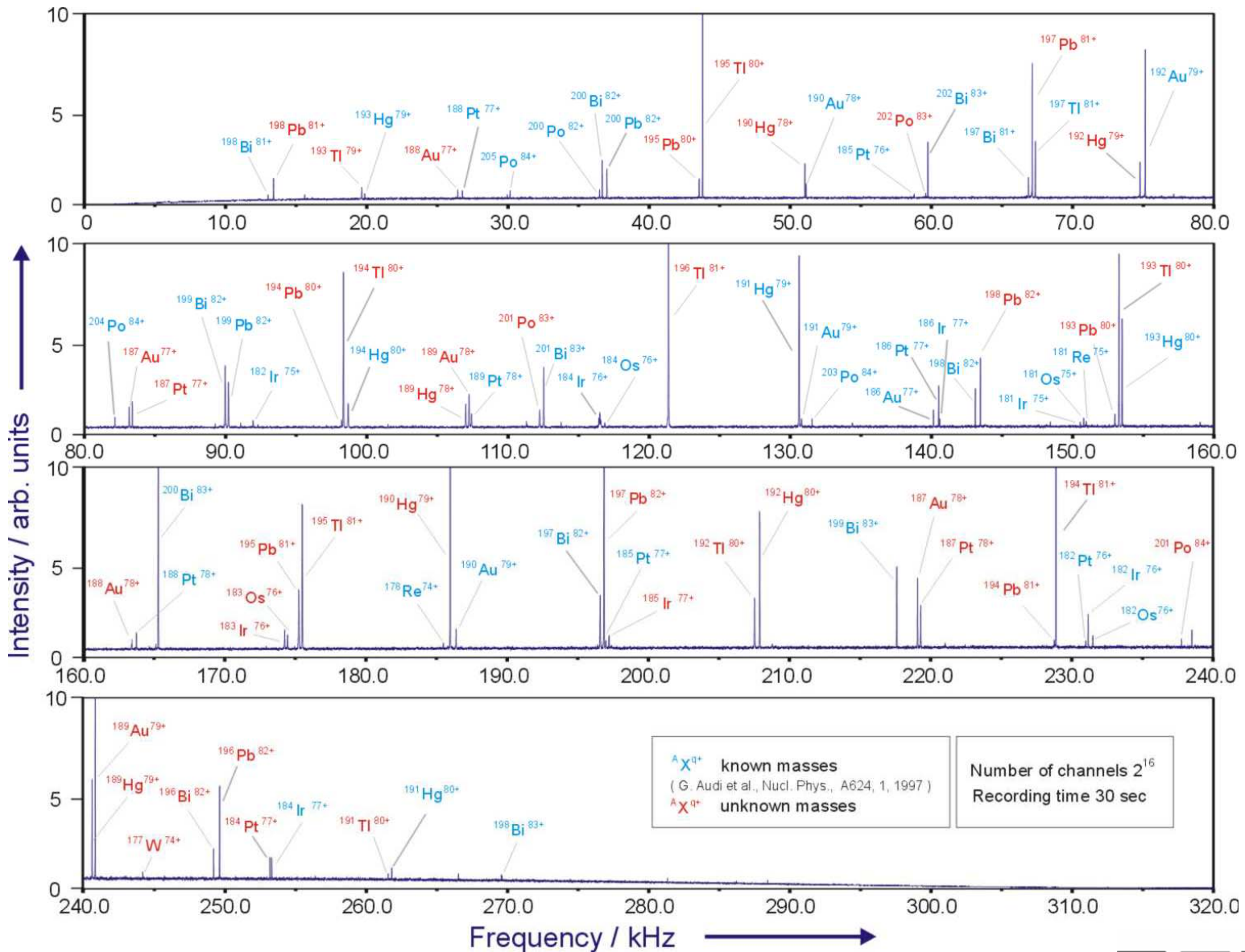


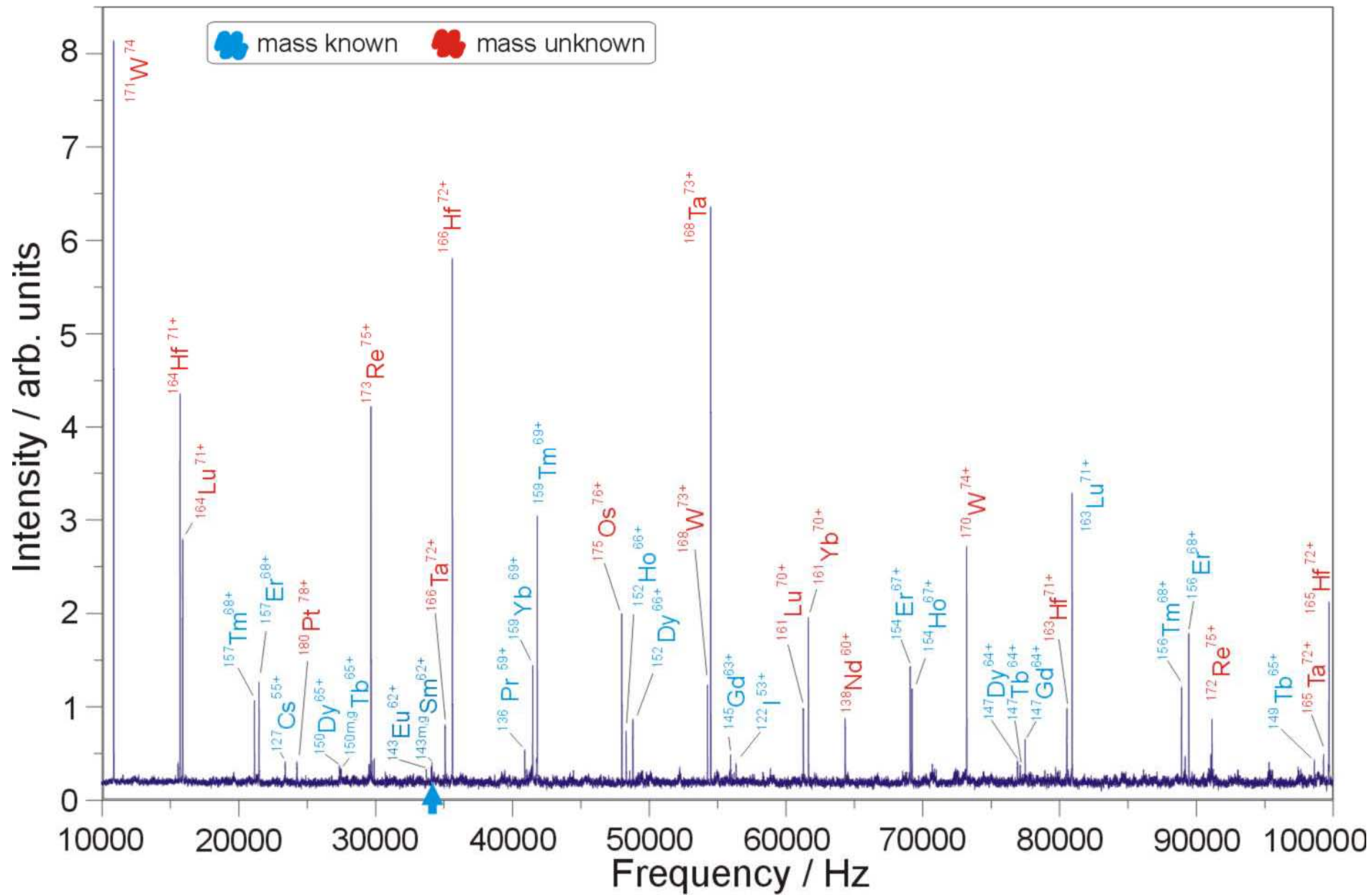
G.I. Budker, At. En. 22 (1967) 346  
G.I. Budker, A.N. Skrinsky et al.,  
IEEE NS-22 (1975) 2093

# Ion Beam Cooling ...

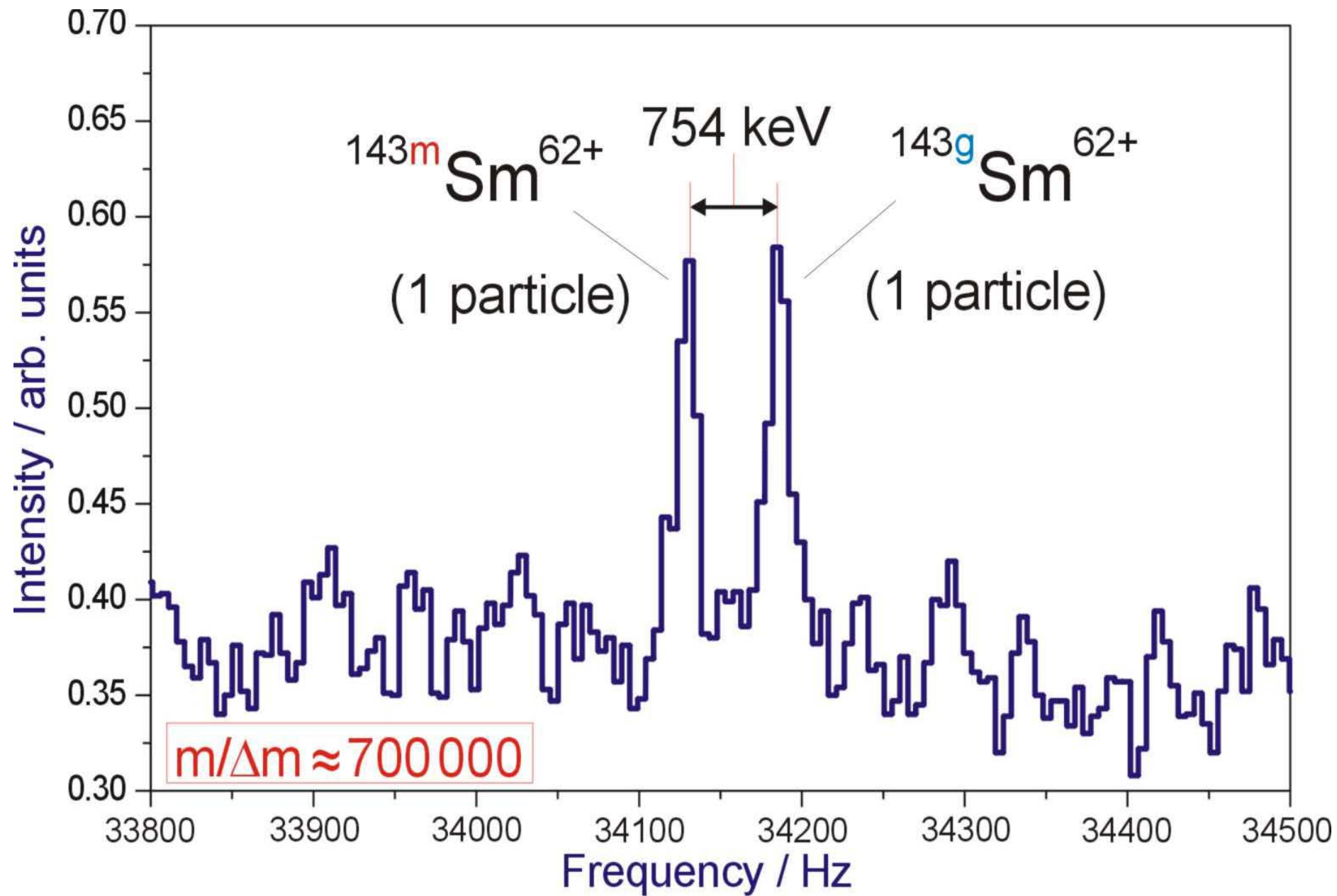


# Schottky Frequency Spectrum







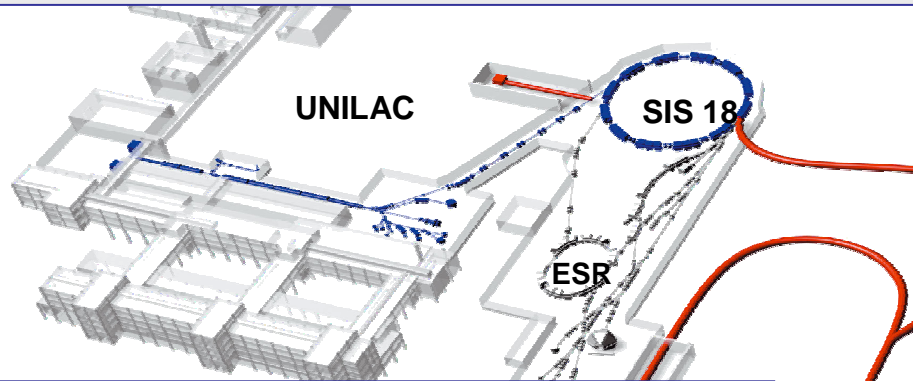


# Fields of Research at FAIR

Nuclear Structure & Astrophysics  
with  
beams of short-lived nuclei (0-1.5 GeV/u)

Nuclear Matter QCD-Physics  
with  
HI beams (2 to 45 GeV/u)

SIS 100/300



Physics of Dense Plasmas  
with  
compressed ion beams & high-intensity petawatt-laser

Hadron Physics & QCD  
with  
stored and cooled antiproton beams  
(0 to 15 GeV/c)





Fundamental Symmetries  
Ultra-high electro-magnetic fields  
& Quantenelectrodynamics  
with  
highly stripped ions and antimatter

Solid-state and biological applications  
with  
ion (& antiproton?) beams

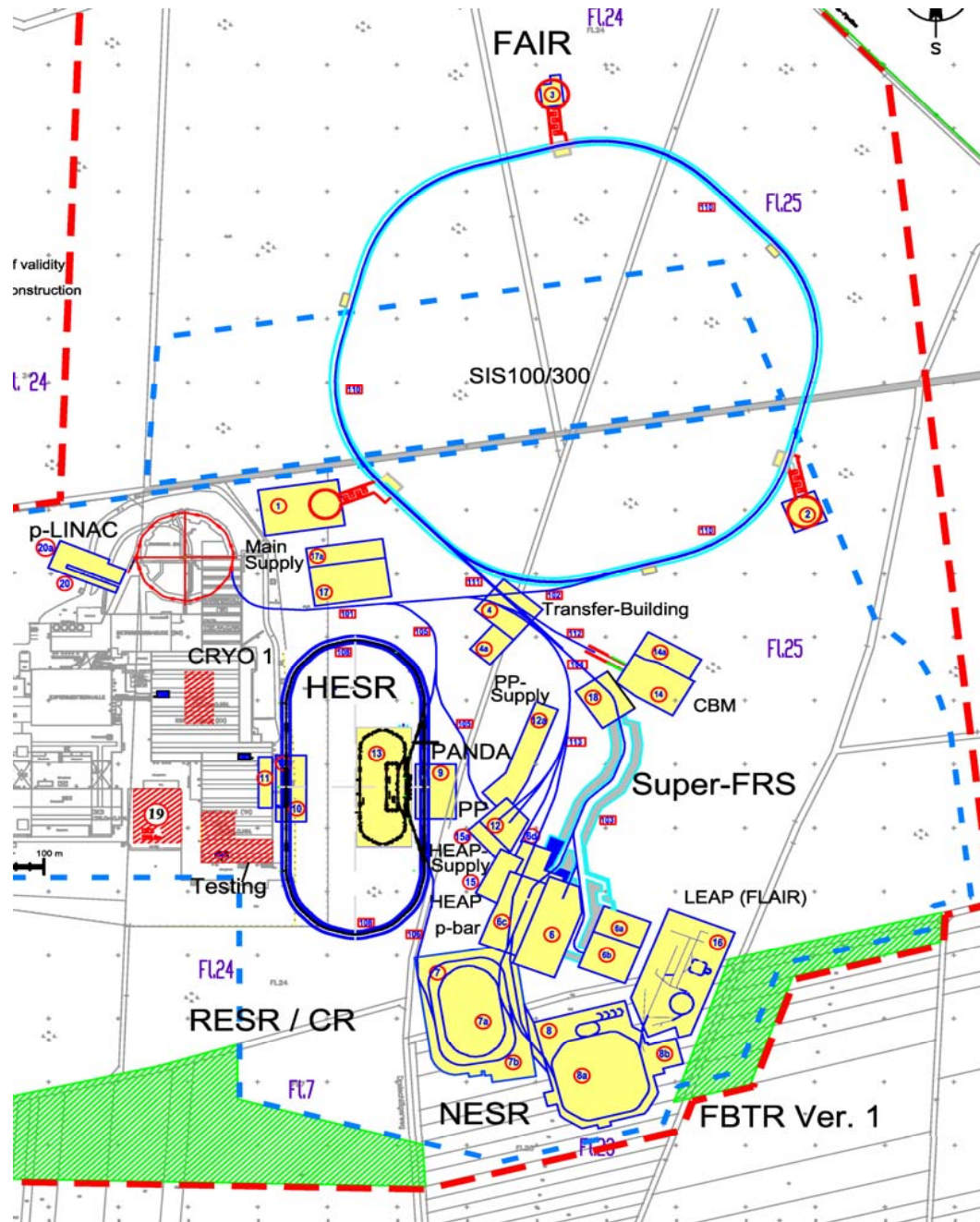
FLAIR

Accelerator Physics

LEGENDE

-  Ersatzaufforstung
-  B-Plan: Geltungsbereich
-  Baugrenze
-  Neue Gebäude

Construction Plan passed by the  
Magistrate of the City of Darmstadt  
in February 2006  
& by the Regional Administration  
in April 2006





# FAIR Baseline Technical Report 2006

**Volume 1: Executive Summary**

**Volume 2: Technical Report Accelerators and Scientific Infrastructure**  
ca. 700 pages

**Volume 3: Techn. Experiment Proposals on QCD physics** (Volume 3A und 3 B;  
ca. 450 pages

**Volume 4: Techn. Experiment Proposals on Nuclear Structure and Astrophysics**  
ca. 700 pages

**Volume 5: Techn. Experiment Proposals on Atomic Physics, Plasma Physics and Applied Physics** ca. 500 pages

**Volume 6: Techn. Report Civil Constructions**

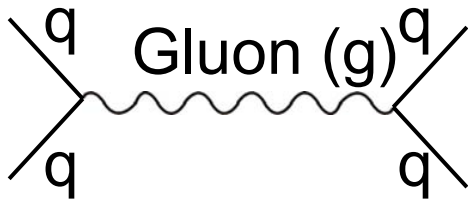
- a. Supplies
- b. Electrical systems
- c. Civil Engineering (Bung)
- d. Radiation Safety

**Supplement 1: Cost, Schedule, Manpower**

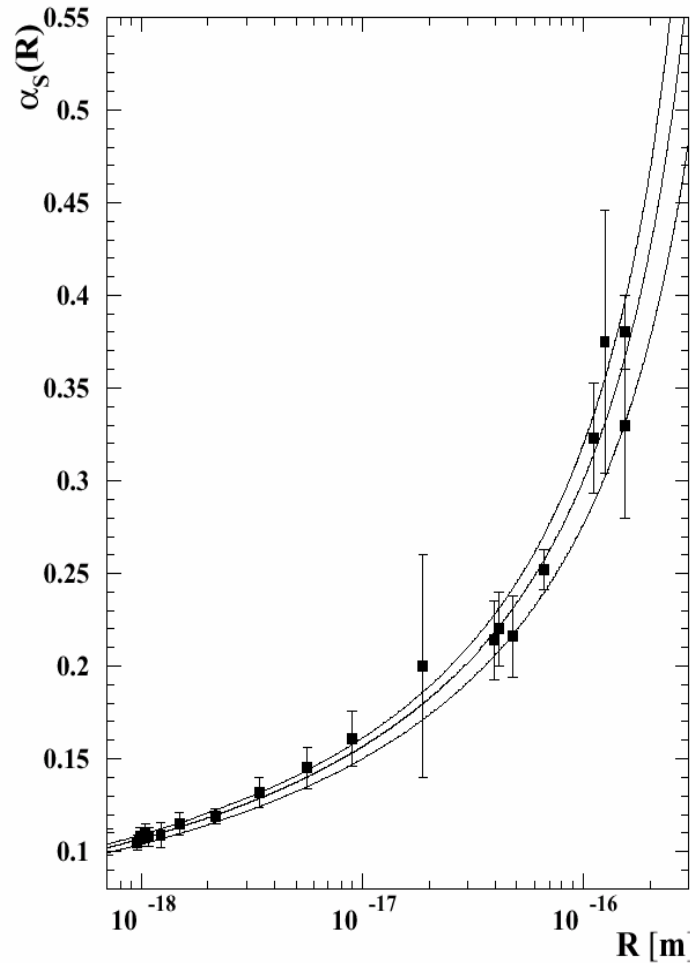
**Supplement 2: Costbook (5000 entries; 3500 WPs))**

# Transition from the perturbative to the non-perturbative regime of Quantum-Chromodynamics (QCD)

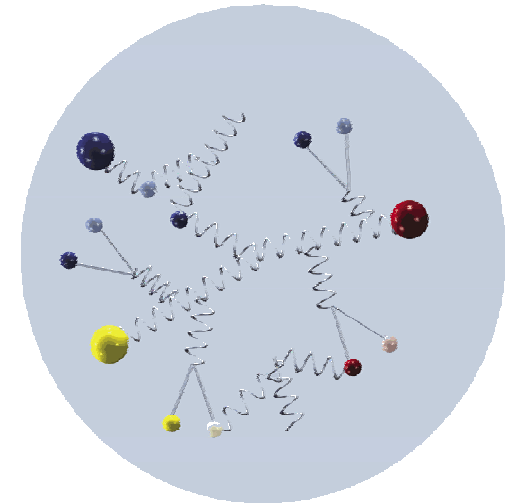
perturbative:  
QCD:  $a_s \ll 1$



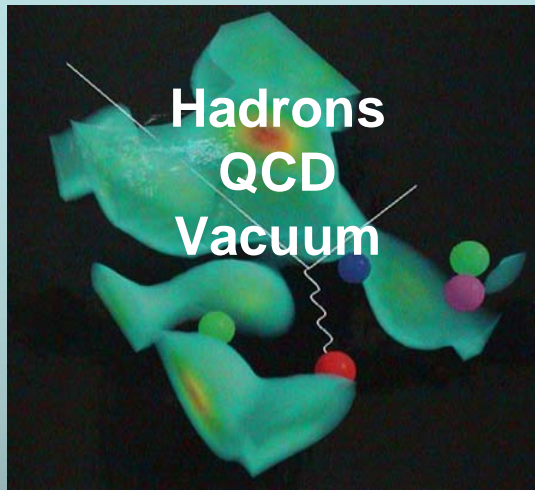
Quarks, Gluons  
One-Gluon Exchange



non-perturbative:  
QCD:  $a_s \leq 1$



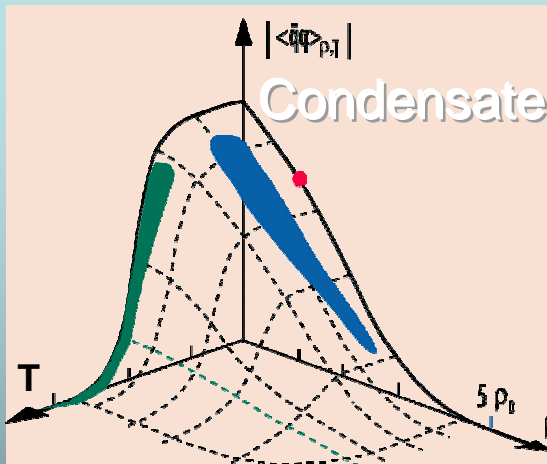
Hadrons:  
Baryons, Mesons  
Models, Lattice QCD



### QCD Bound Systems

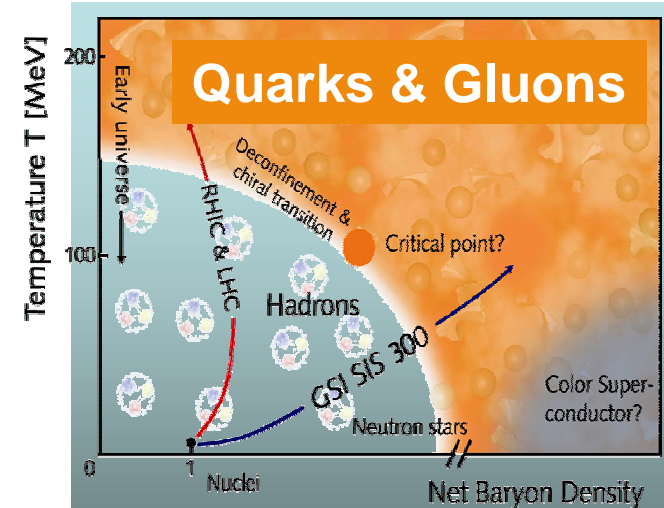
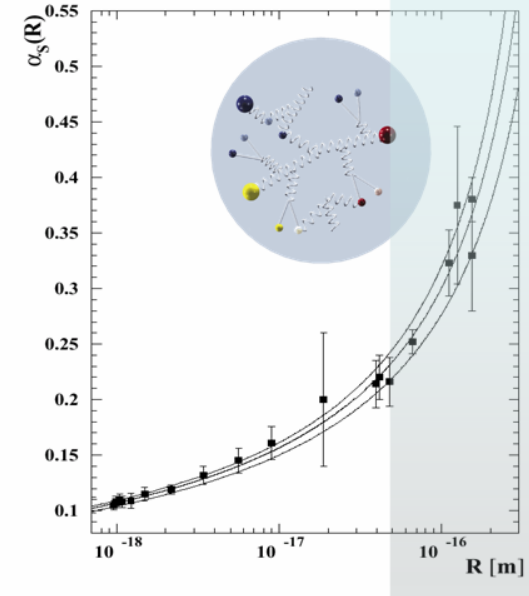
- hadron spectroscopy
- exotic systems: glueballs, glue-lumps, hybrids, molecules...
- spin observables
- van der Waals systems

## Non-perturbative QCD



### In-medium QCD

- shifts in hadron properties
- effective parameters
- symmetries: violations & restorations



### QCD Phase Diagram

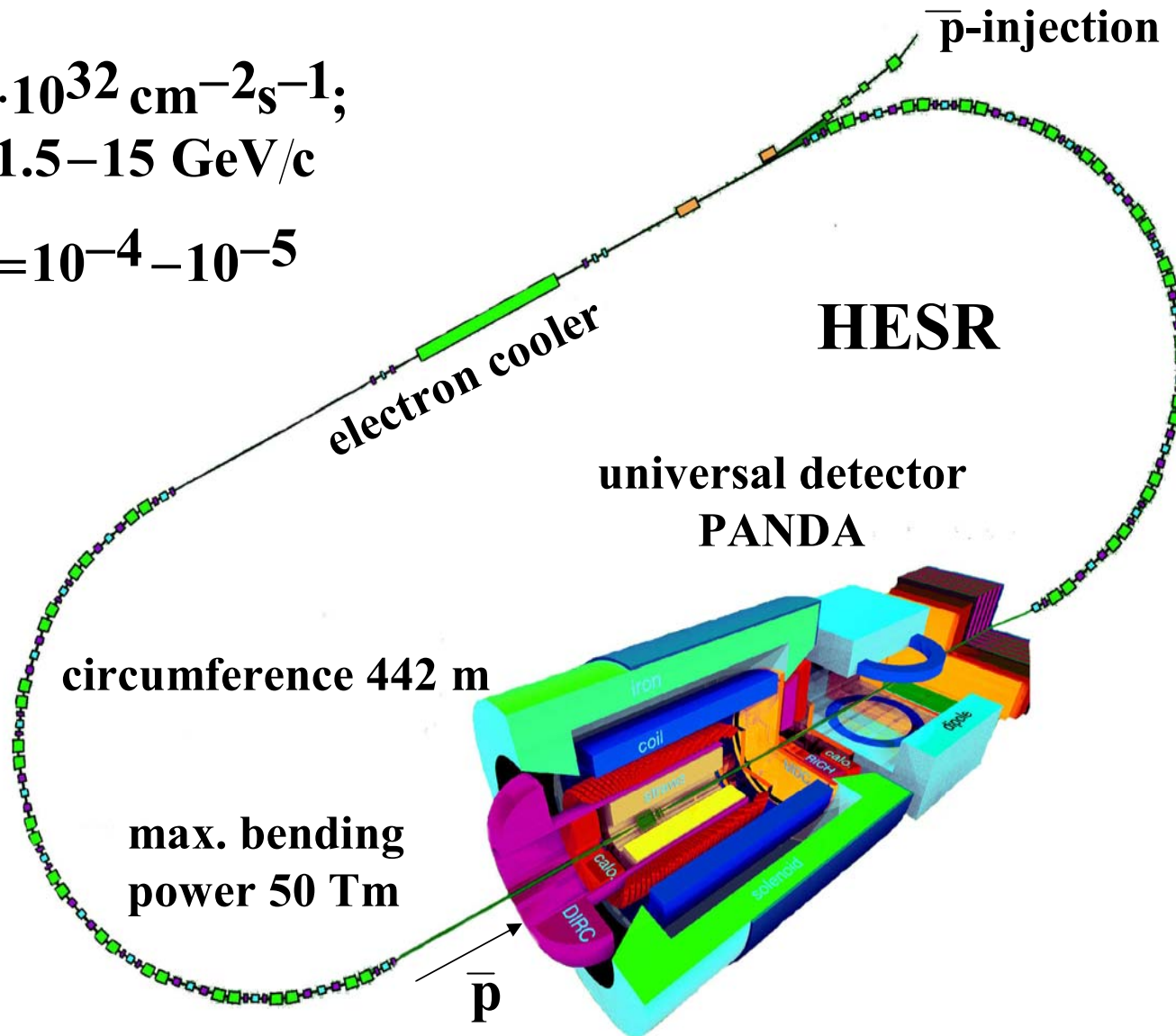
- phase transition & critical point
- QGP properties

# High-Energy Storage & Cooler Ring (HESR) und Detector

$$L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1};$$

$$p_{\bar{p}} = 1.5 - 15 \text{ GeV}/c$$

$$\delta p/p = 10^{-4} - 10^{-5}$$

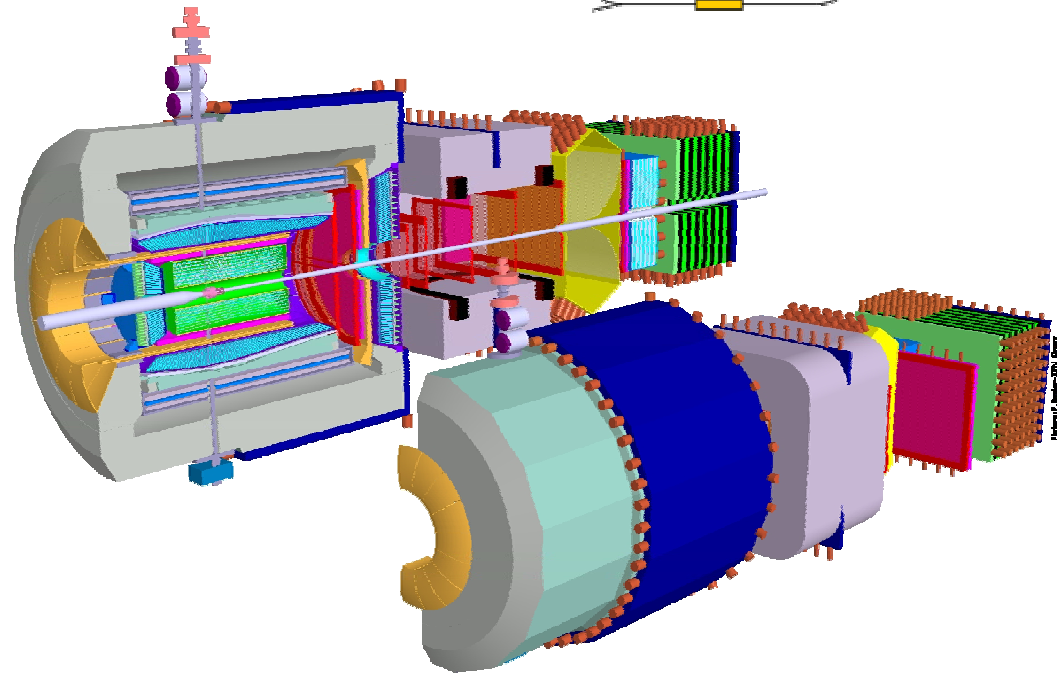




# Proposed Detector (Overview)

- High Rates
  - Total  $\sigma \sim 55$  mb
  - peak  $> 10^7$  int/s
- Vertexing
  - ( $\sigma_p, K_S, \Lambda, \dots$ )
- Charged particle ID
  - ( $e^\pm, \mu^\pm, \pi^\pm, p, \dots$ )
- Magnetic tracking
- Elm. Calorimetry
  - ( $\gamma, \pi^0, \eta$ )
- Forward capabilities
  - (leading particles)
- Sophisticated Trigger(s)

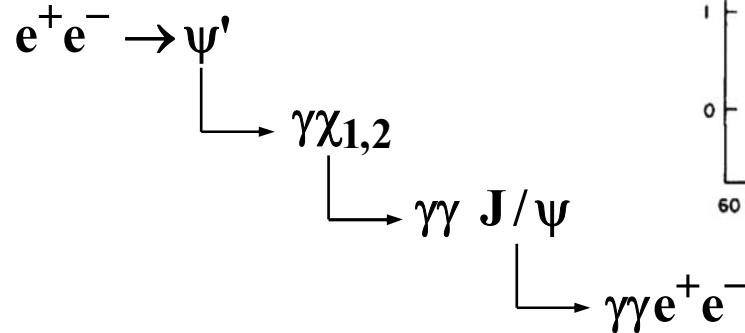
The logo for the PANDA experiment, featuring the word "panda" in a stylized, lowercase, bold font. The letter "a" is unique, with a small red square above it and a small yellow square below it. The entire logo is enclosed in a white, rounded rectangular border.



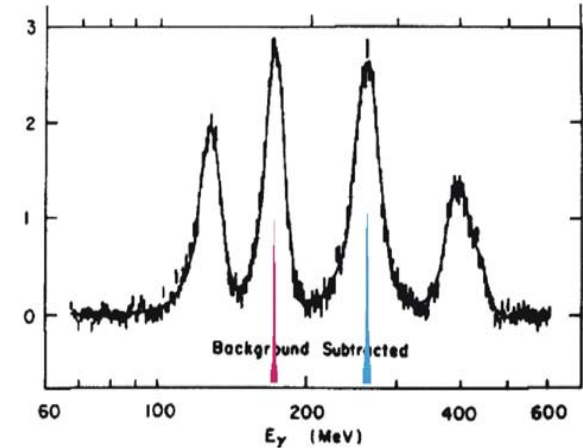
# Comparison $e^+e^-$ versus $p\bar{p}$

$e^+e^-$  interactions:  
 only  $1^-$  states formed  
 other states populated in  
 secondary decays  
 (moderate mass  
 resolution)

production of  $\chi_{1,2}$

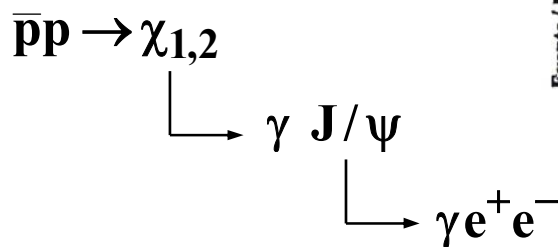


Crystal Ball

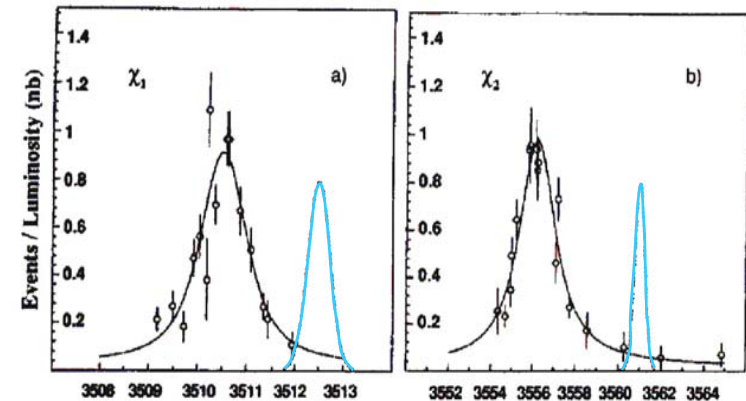


$p\bar{p}$  reactions:  
 all states directly formed  
 (very good mass  
 resolution)

formation of  $\chi_{1,2}$



E 760 (Fermilab)



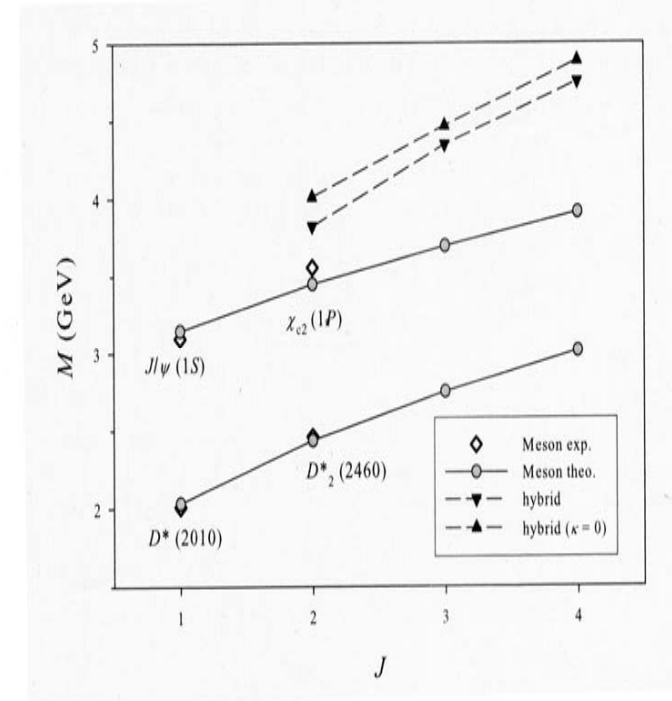
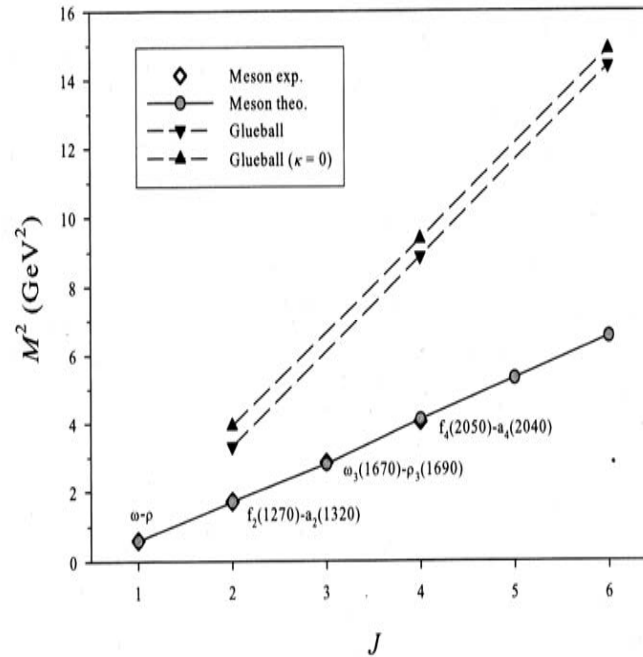
$\sigma_m$  (beam) = 0.5 MeV

## Glueballs, hybrids etc:

V. Mathieu, C. Semay, F. Brau;  
EPJA **27**, 225 (2006);

("Casmir scaling, glueballs,  
and hybrid gluelumps")

Rotating String Model (RSM)



## Multi-quark states:

"Tetraquarks" (*t Hooft: instanton induced effective quark interactions*)

Dmitrasinovic, V.  
Phys. Rev. Lett. **94**, 162002 (2005)  
Annals Phys. **321**, 355 (2006)

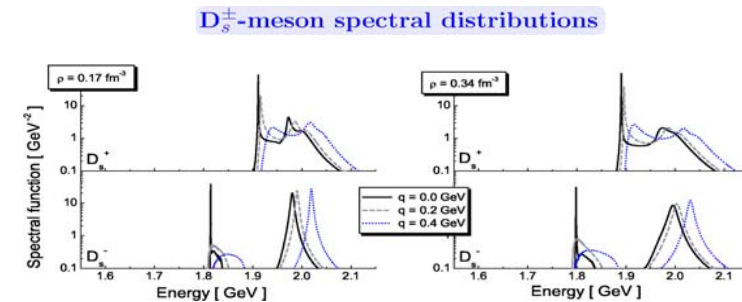
New resonances (Belle, BABAR, CDF, SELEX...)

$D_{sJ}^+(2317)$  vs.  $D_{J=0}^+(2308)$

Hadrogenesis: Coupled channels dynamics of meson & baryon resonances;  
Molecules...

Lutz, Hofmann, Kolomeitsev, Korpa;  
Nucl. Phys. A730, 110 & 392  
Nucl. Phys. A733, 142  
Phys. Lett. B582, 39  
hep-ph/0507071

New resonances  
& in-medium  
spectral distributions



- ✓ Self consistent computation:
- repulsive main mode
  - significant resonance-hole component

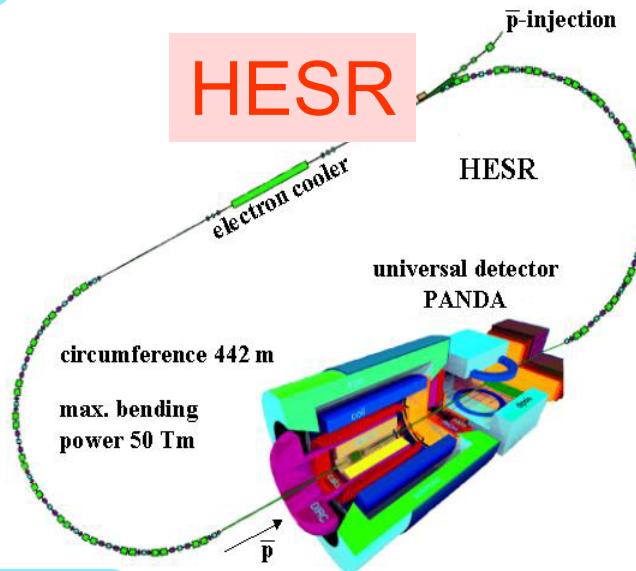
# Physics Program with Antiprotons

**J/ $\psi$  spectroscopy  
confinement**

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

**hidden and open  
charm in nuclei**

**strange and  
charmed baryons  
in nuclear field**



**fundamental  
symmetries:  
p in traps )**

**FLAIR**

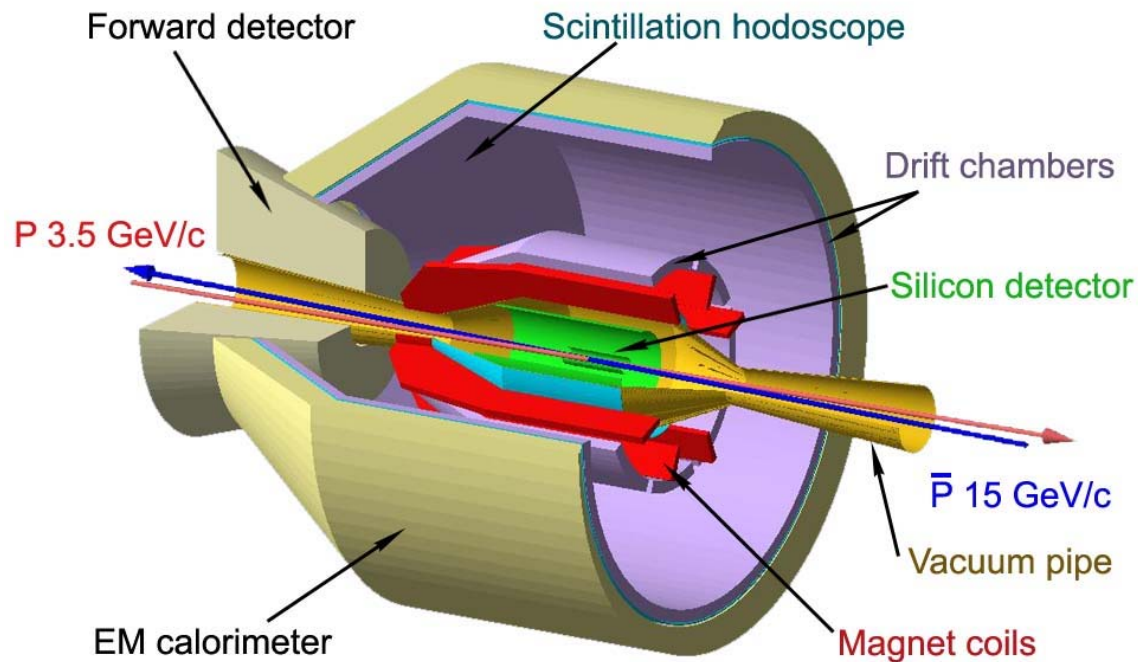
**CP-violation  
(D/ $\Lambda$  - sector)**

**inverted deeply virtual  
Compton scattering**

**spin structure of the proton  
with polarized antiprotons**

**PAX**

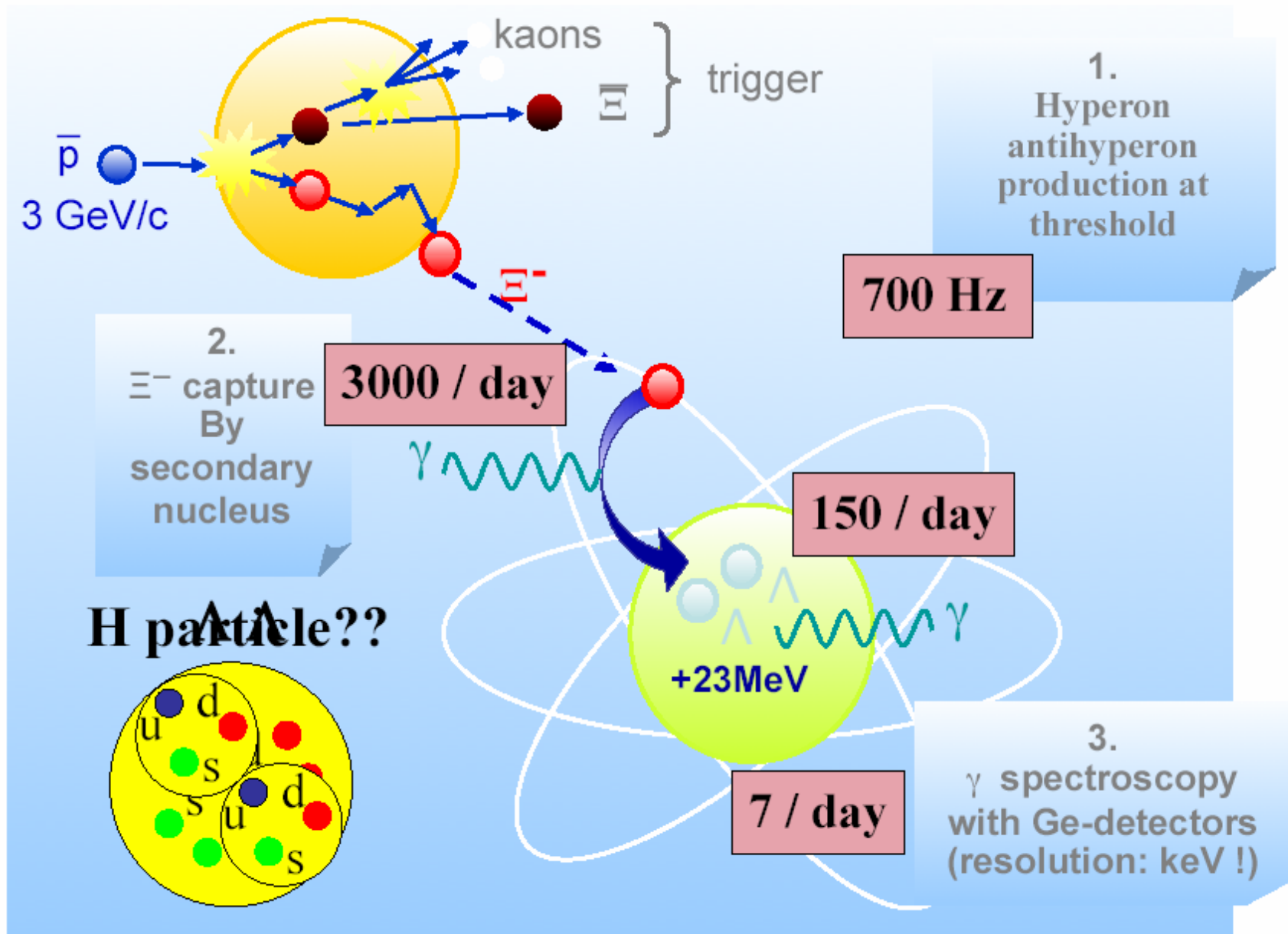
# PAX – Polarized Antiproton Experiment



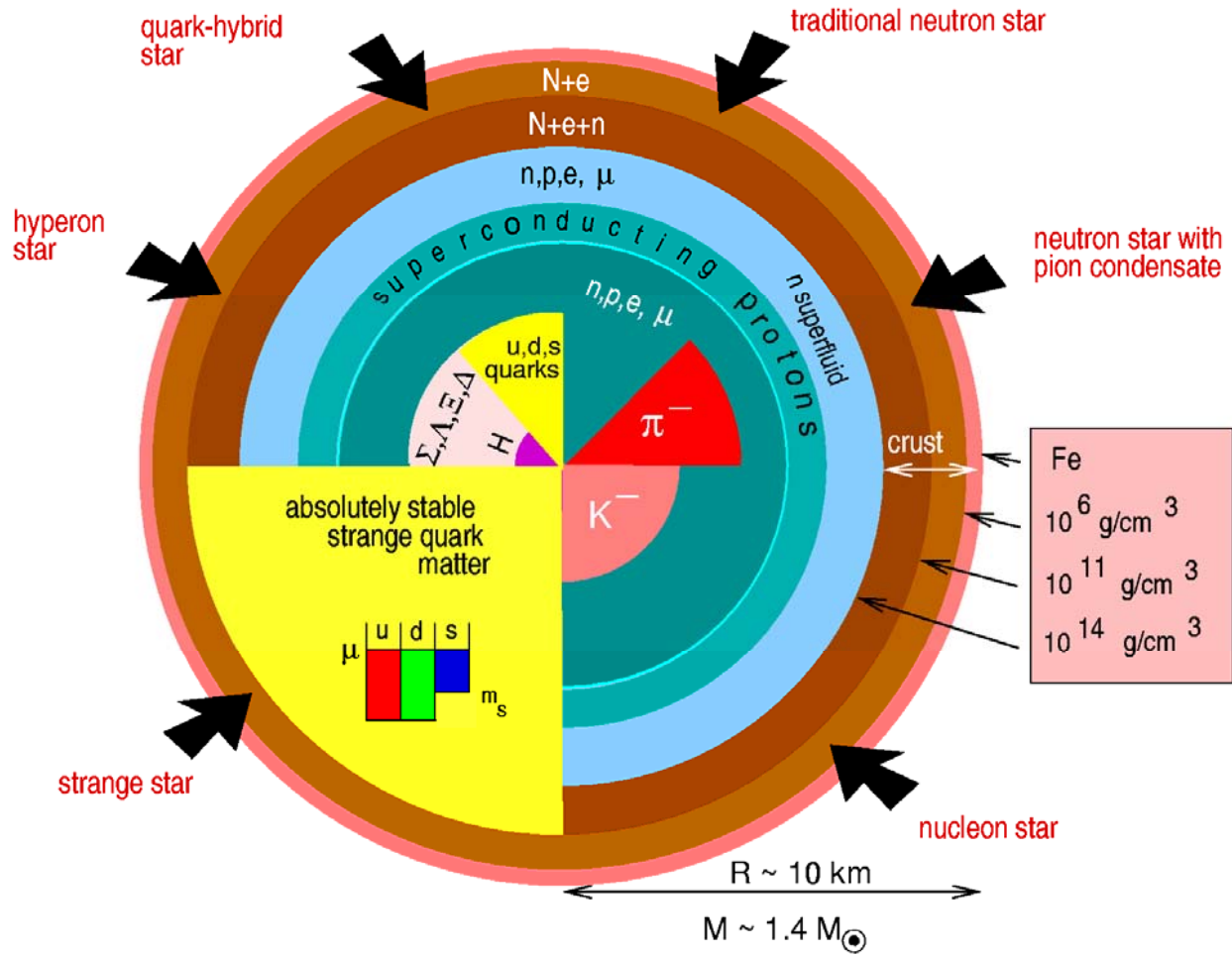
PAX Detector

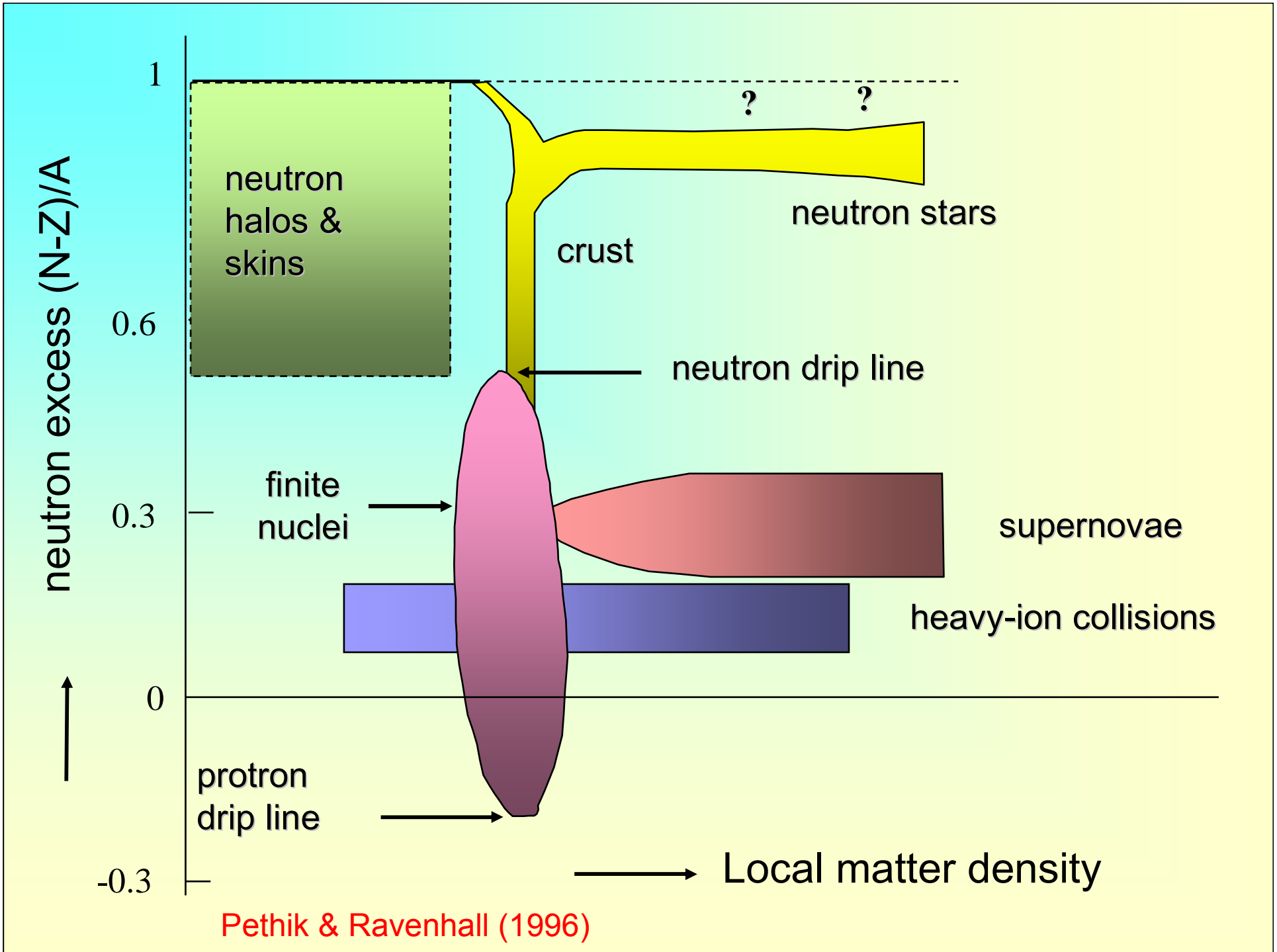
- Transversity Measurements
- Drell-Yan Production
- Proton Formfactors timelike  $G_{E,M}$
- Asymmetric Beams with p and  $\bar{p}$
- Requires COSY-like antiproton polarizer ring (APR)
- Staged concept due to exclusivity of experimental set-ups

# Production of double hypernuclei



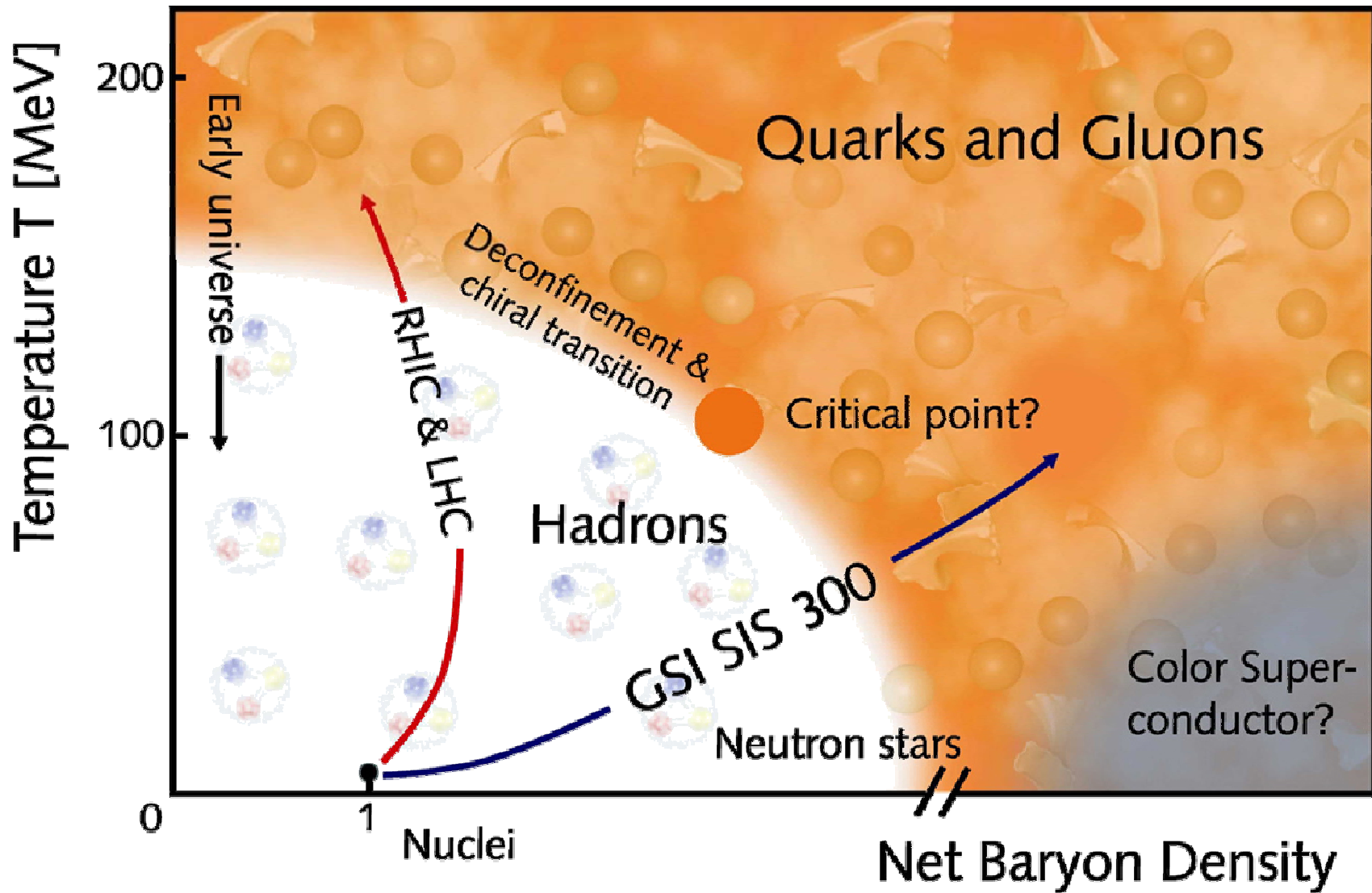
# Properties of neutron stars



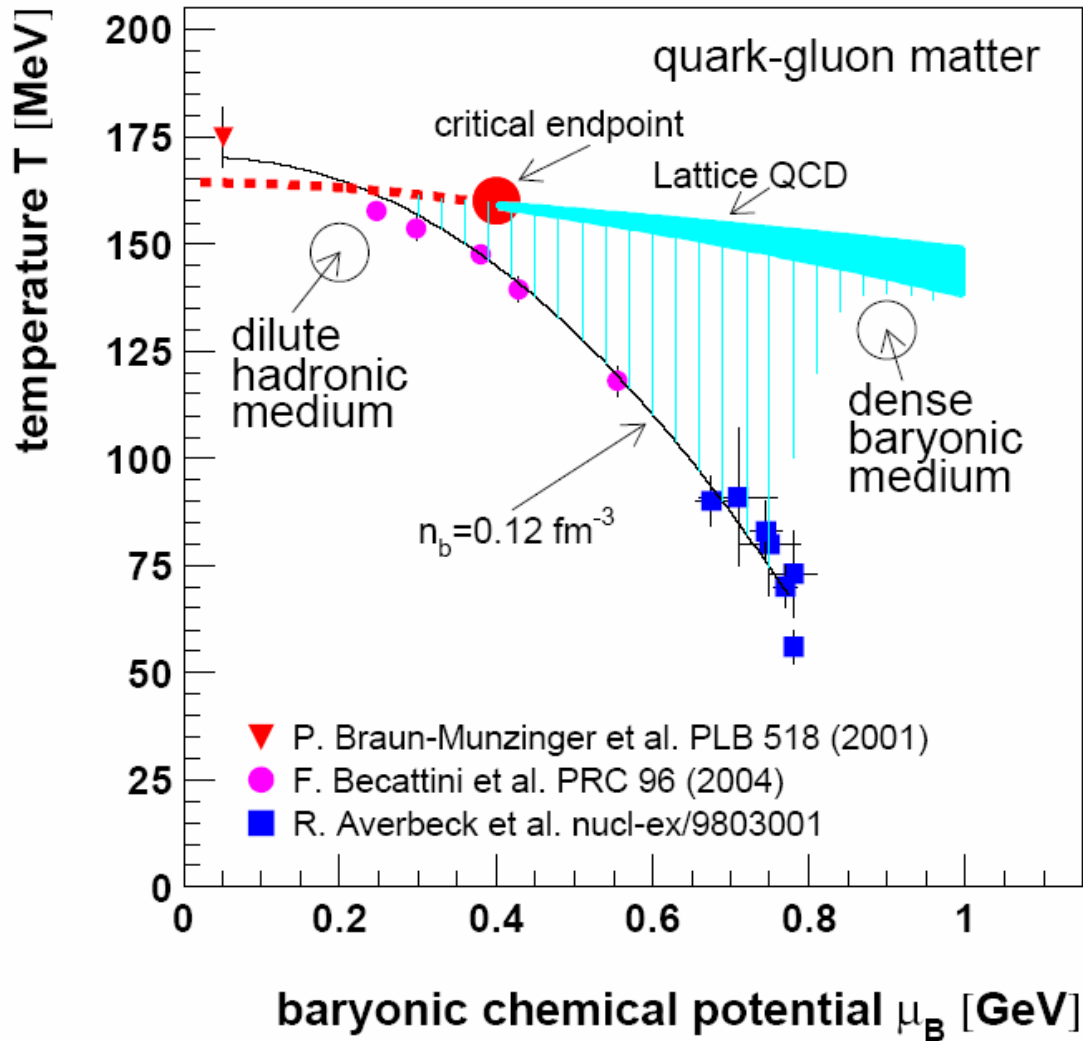




# The phase diagram of strongly interacting matter

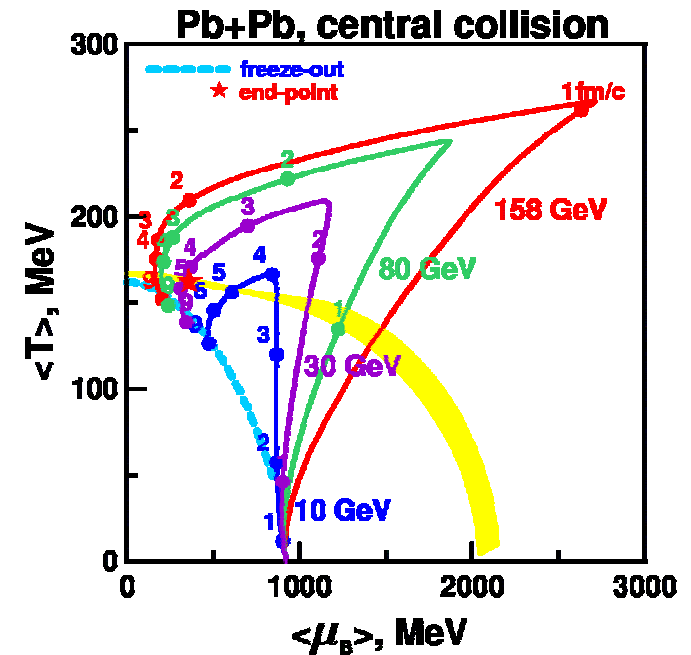


# Mapping the QCD phase diagram

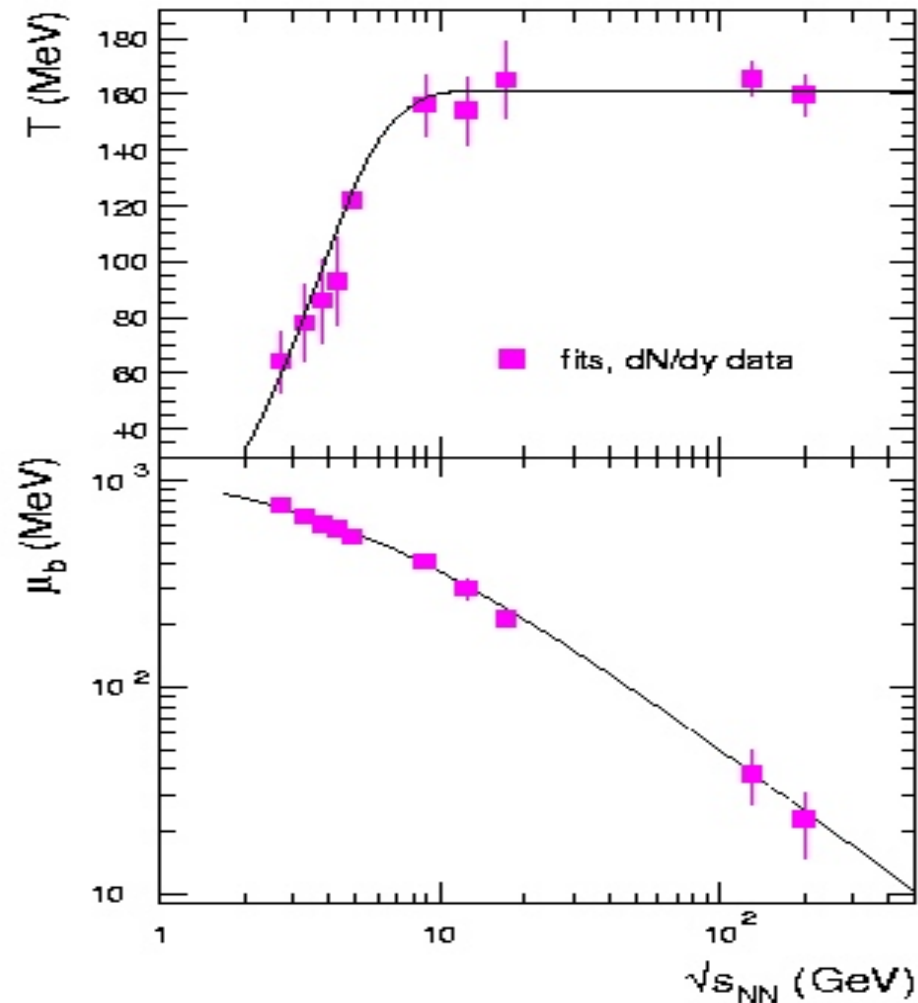


Critical endpoint:  
 Z. Fodor, S. Katz, hep-lat/0402006  
 S. Ejiri et al., hep-lat/0312006

Hadron gas EOS:  
 V. Toneev, Y. Ivanov et al.  
 nucl-th/0309008



# Chemical freeze-out and limiting (critical) temperature



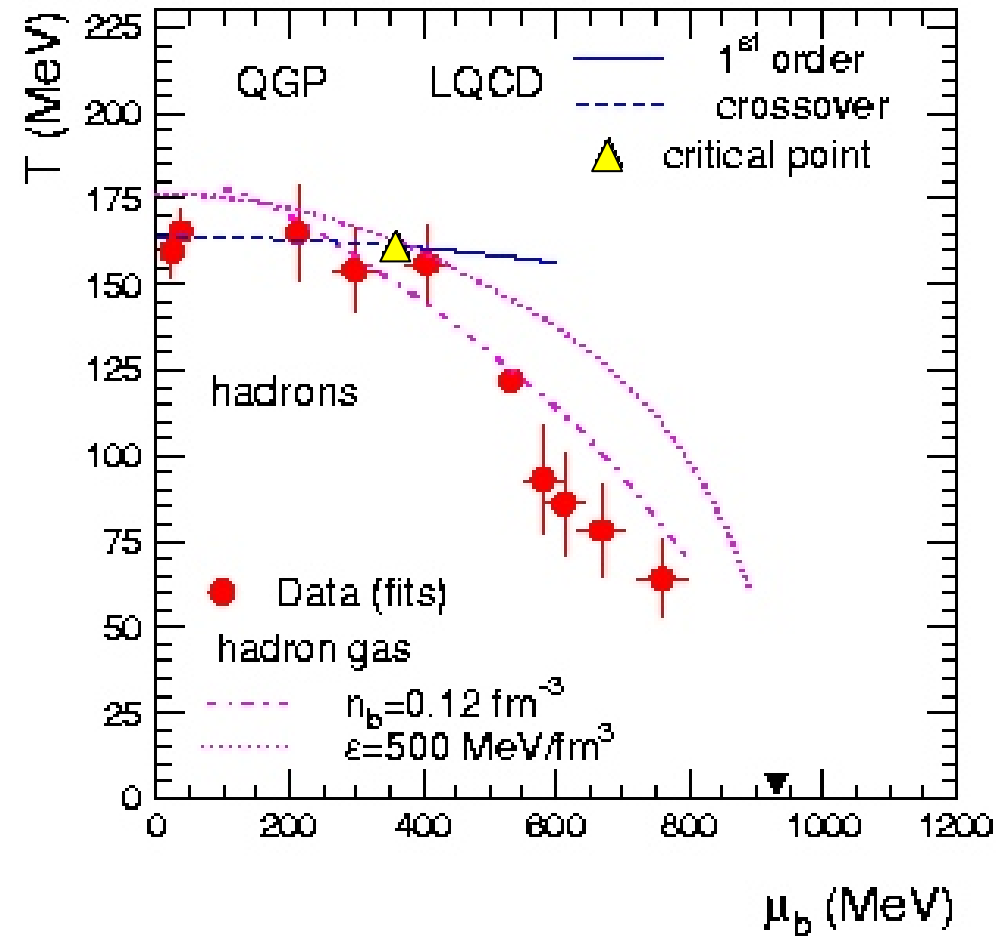
$$T_{\text{lim}} = 161 \pm 4 \text{ MeV}$$

A. Andronic,  
P. Braun-Munzinger,  
J. Stachel,  
Nucl. Phys. A (in print)  
nucl-th/0511071

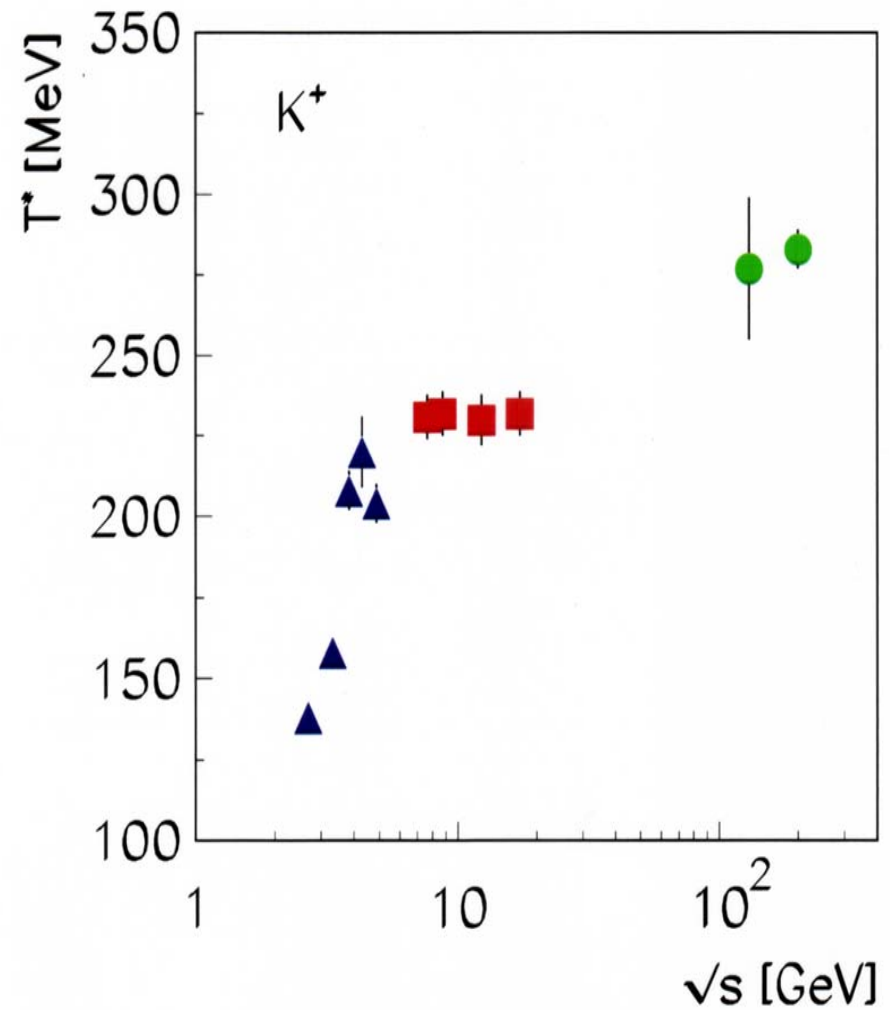
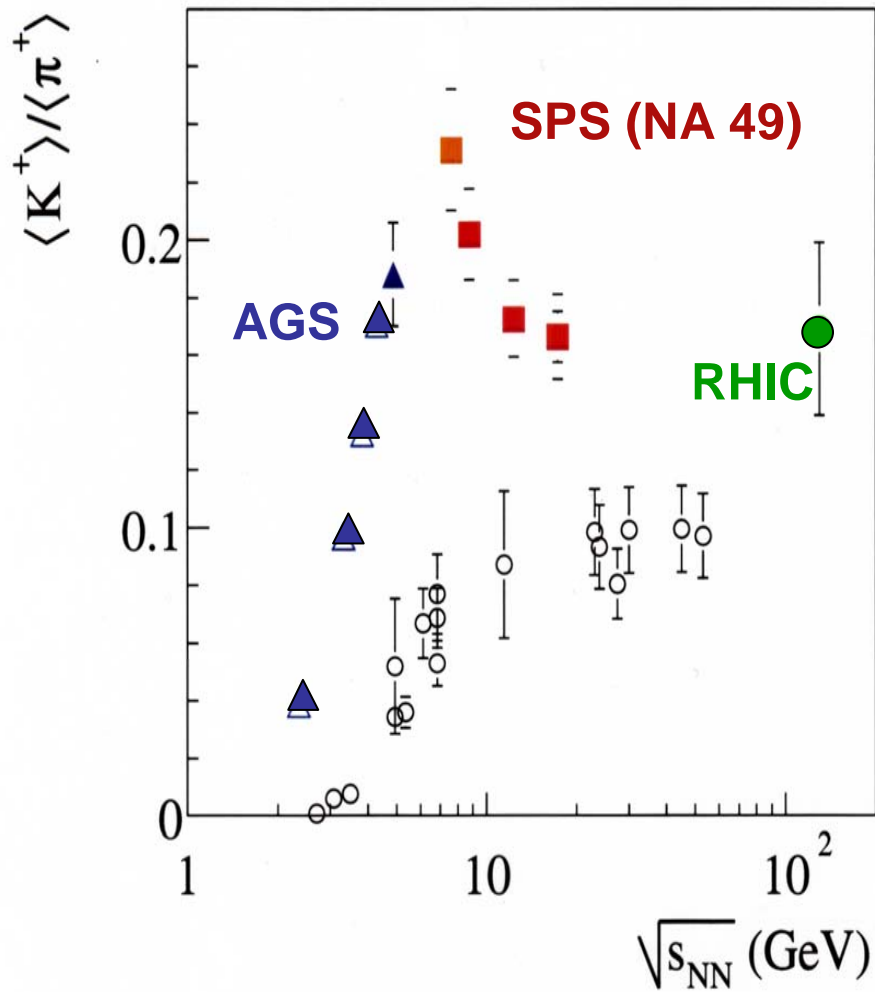
# Chemical freeze-out and the QCD phase diagram

New analysis:

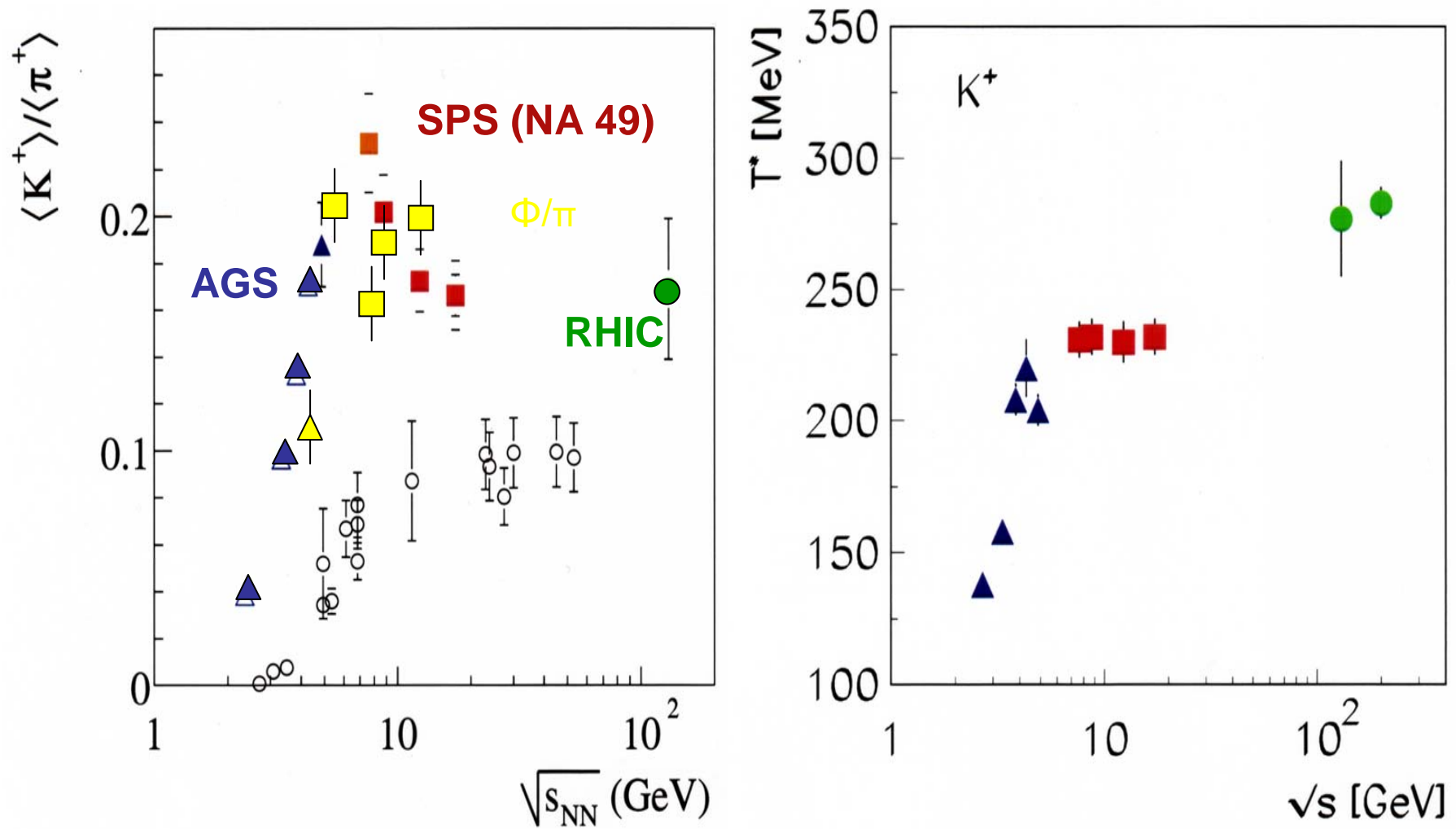
- chemical freeze-out points delineate the QCD phase boundary at small  $\mu_b$
- new points at large  $\mu_b$



# Strangeness Production in Au+Au / Pb+Pb

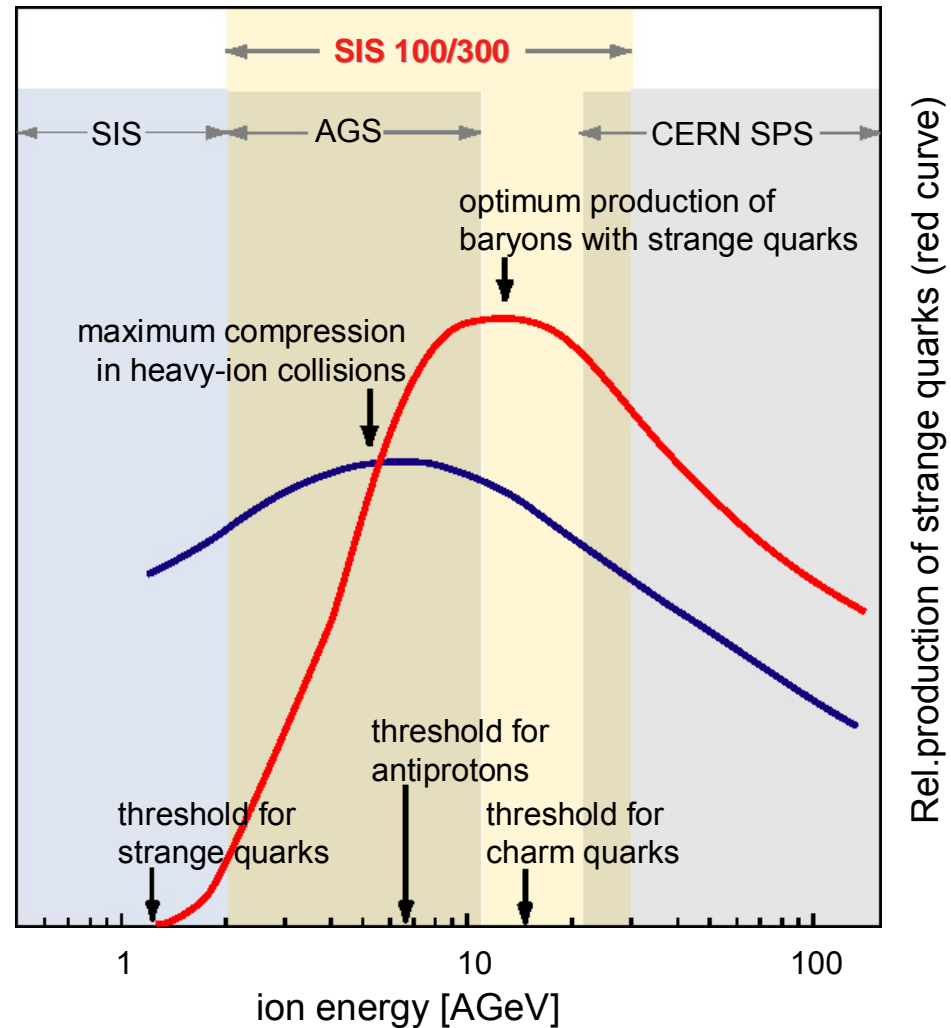
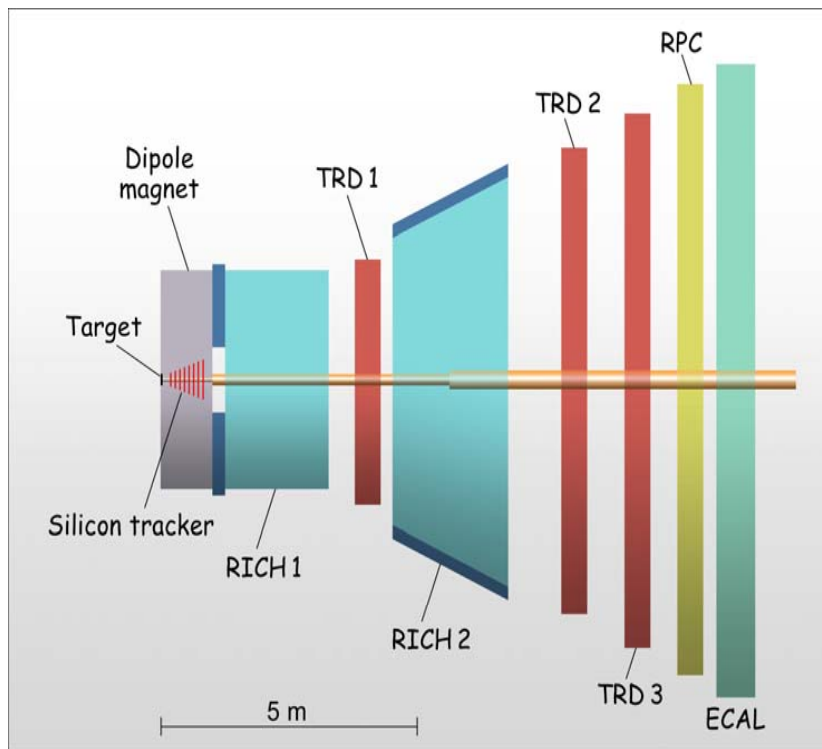


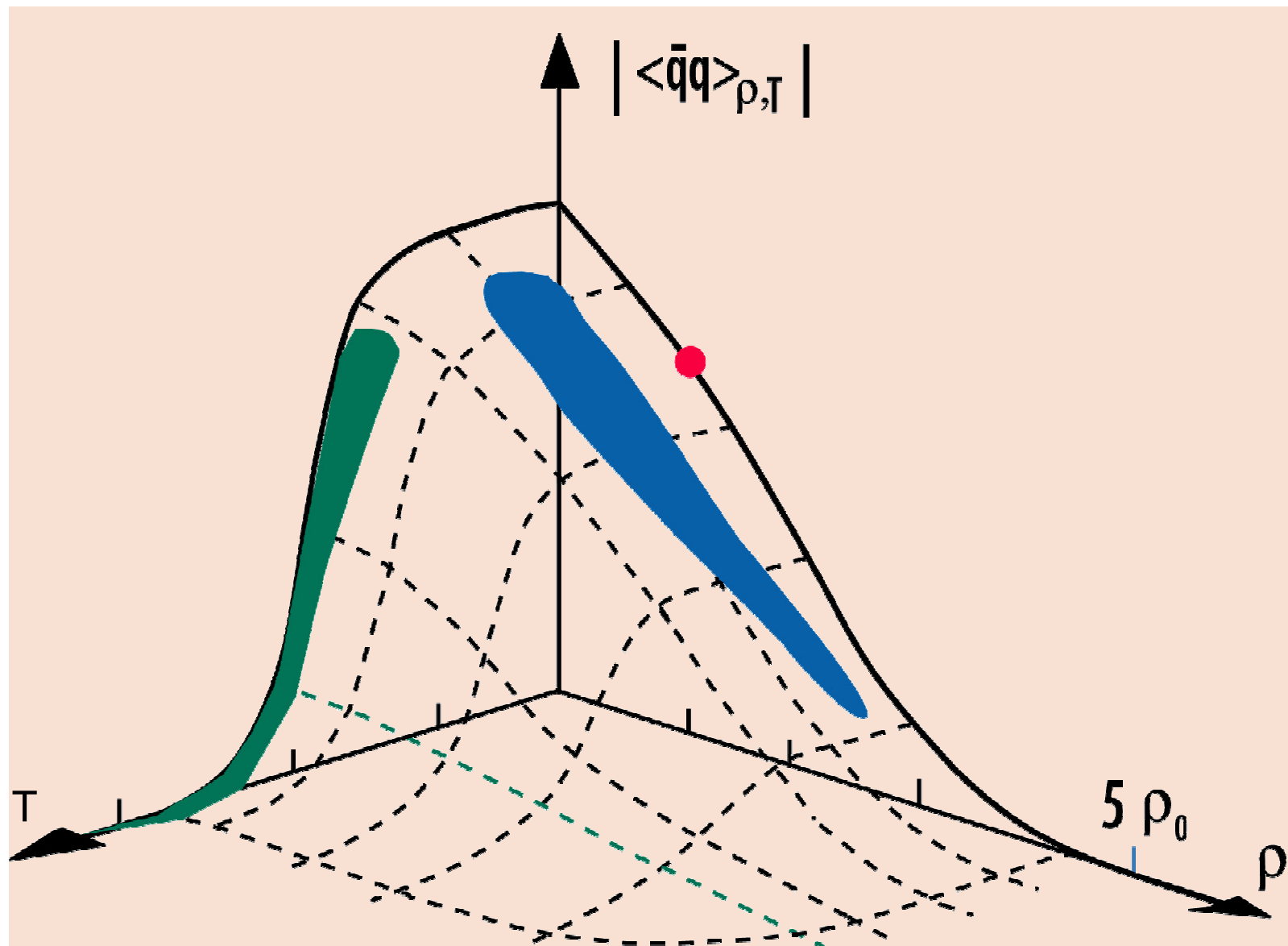
# Strangeness Production in Au+Au / Pb+Pb



# NN Collisions at 2-40 AGeV

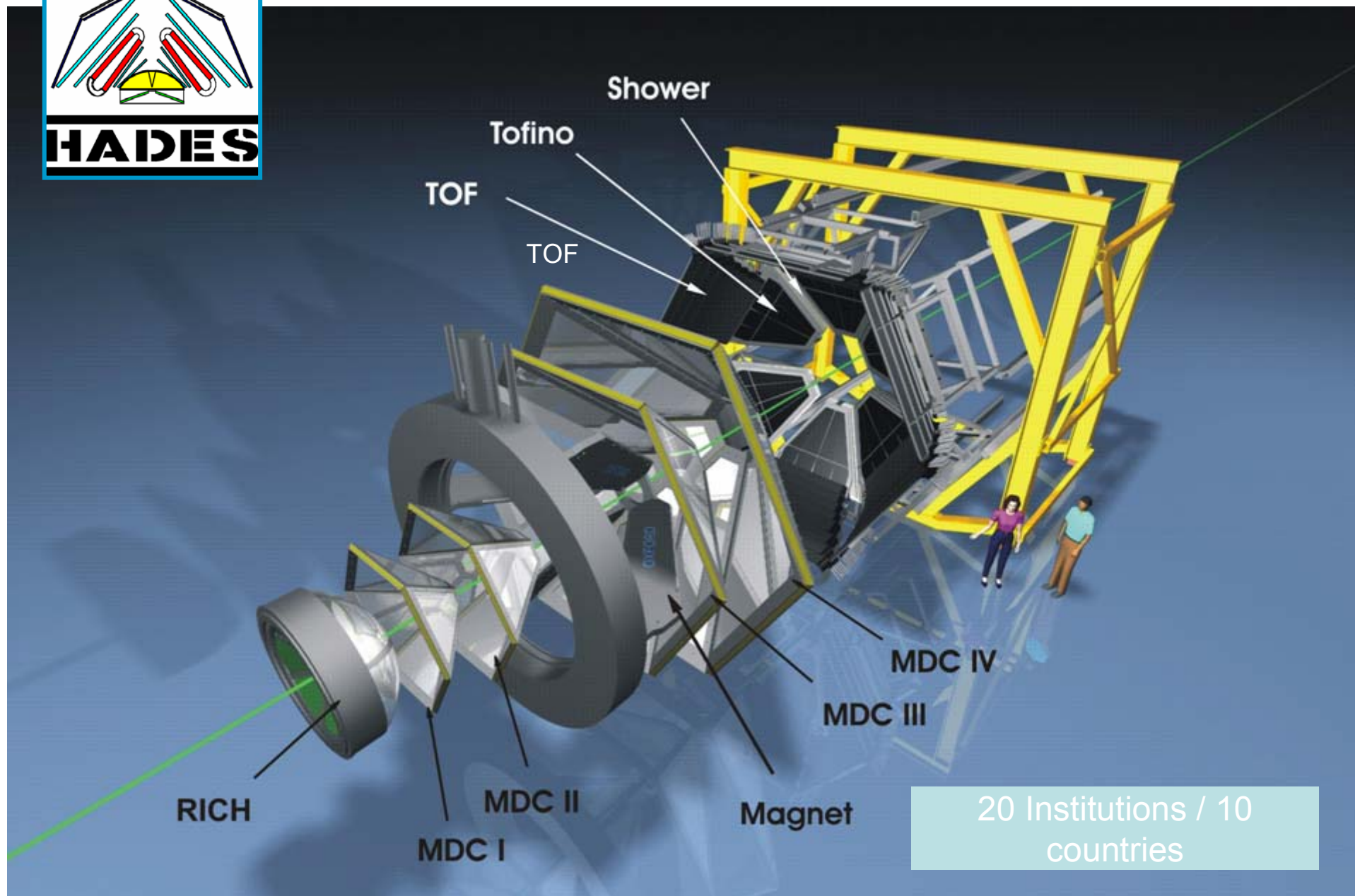
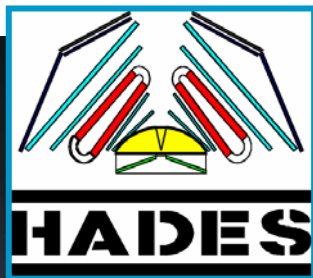
## The CBM Experiment at FAIR





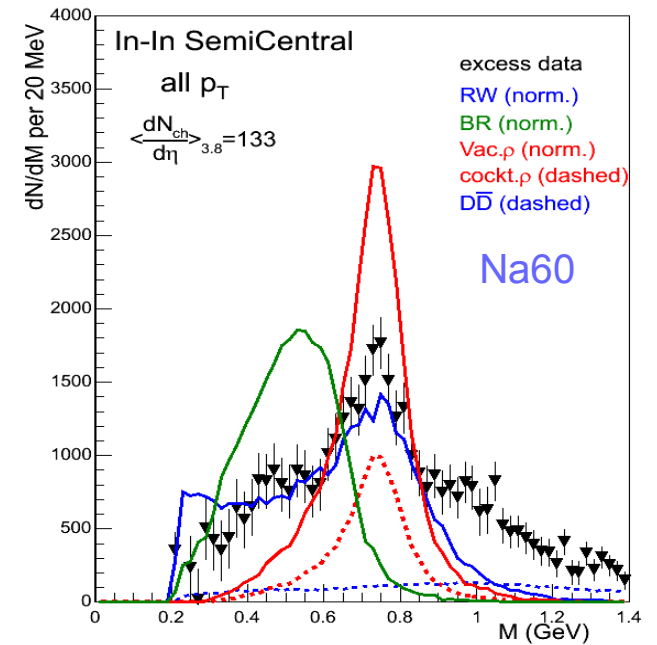
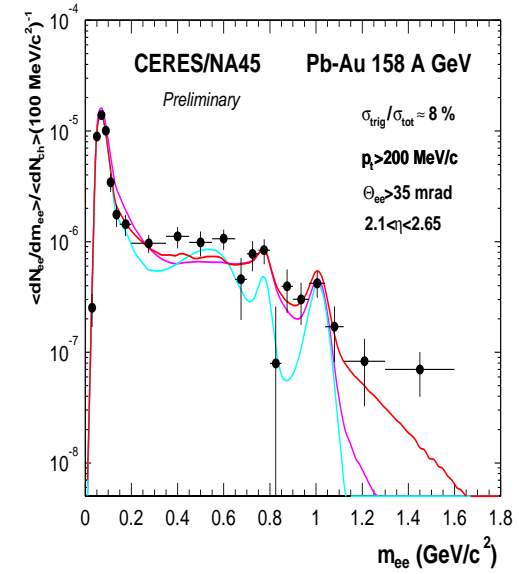
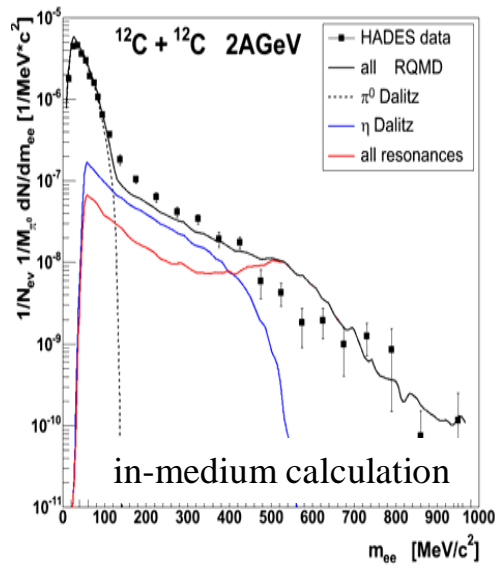
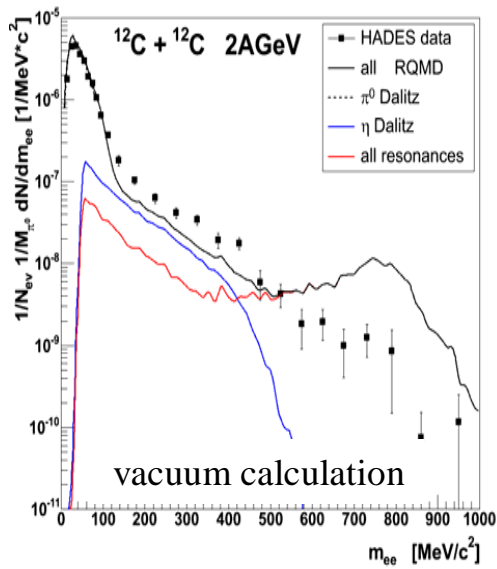


# In-medium properties of hadrons

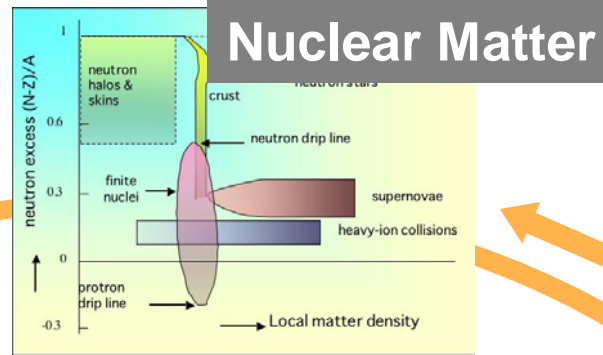
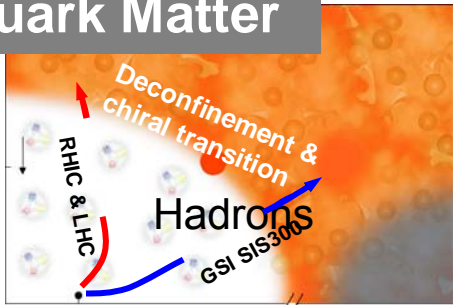


20 Institutions / 10 countries

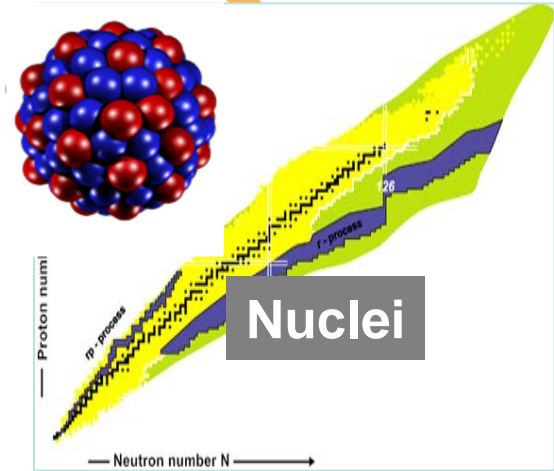
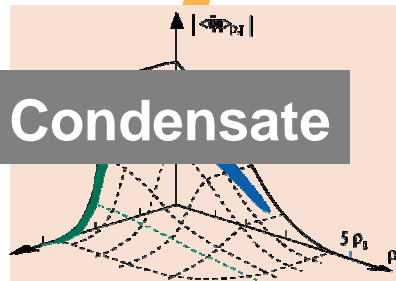
# In-medium properties of hadrons



# Quark Matter



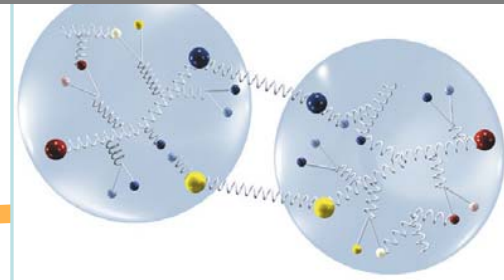
# Condensate



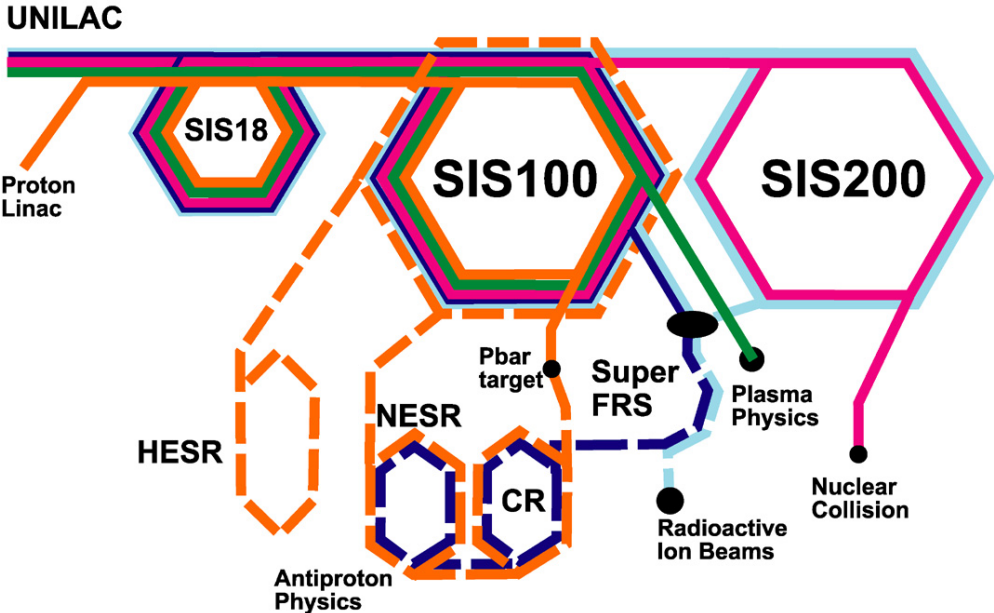
# Hadrons QCD Vacuum



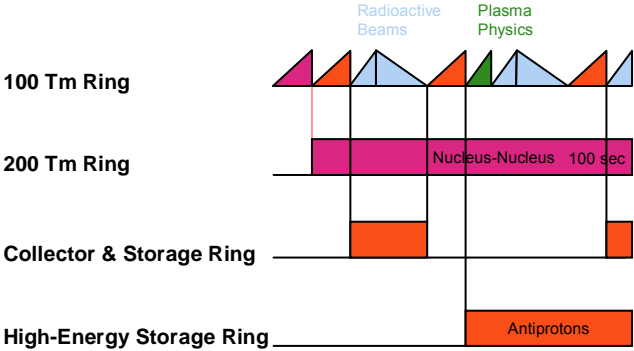
# Nucleon-Nucleon / Meson Systems



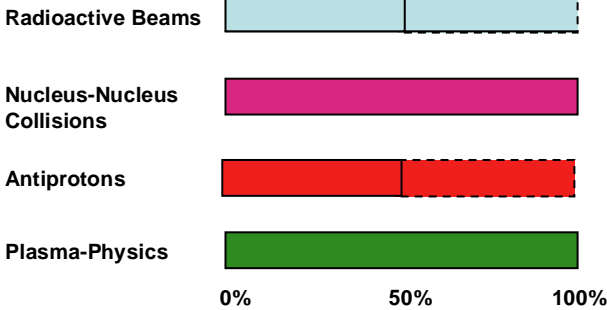
# Parallel Operation

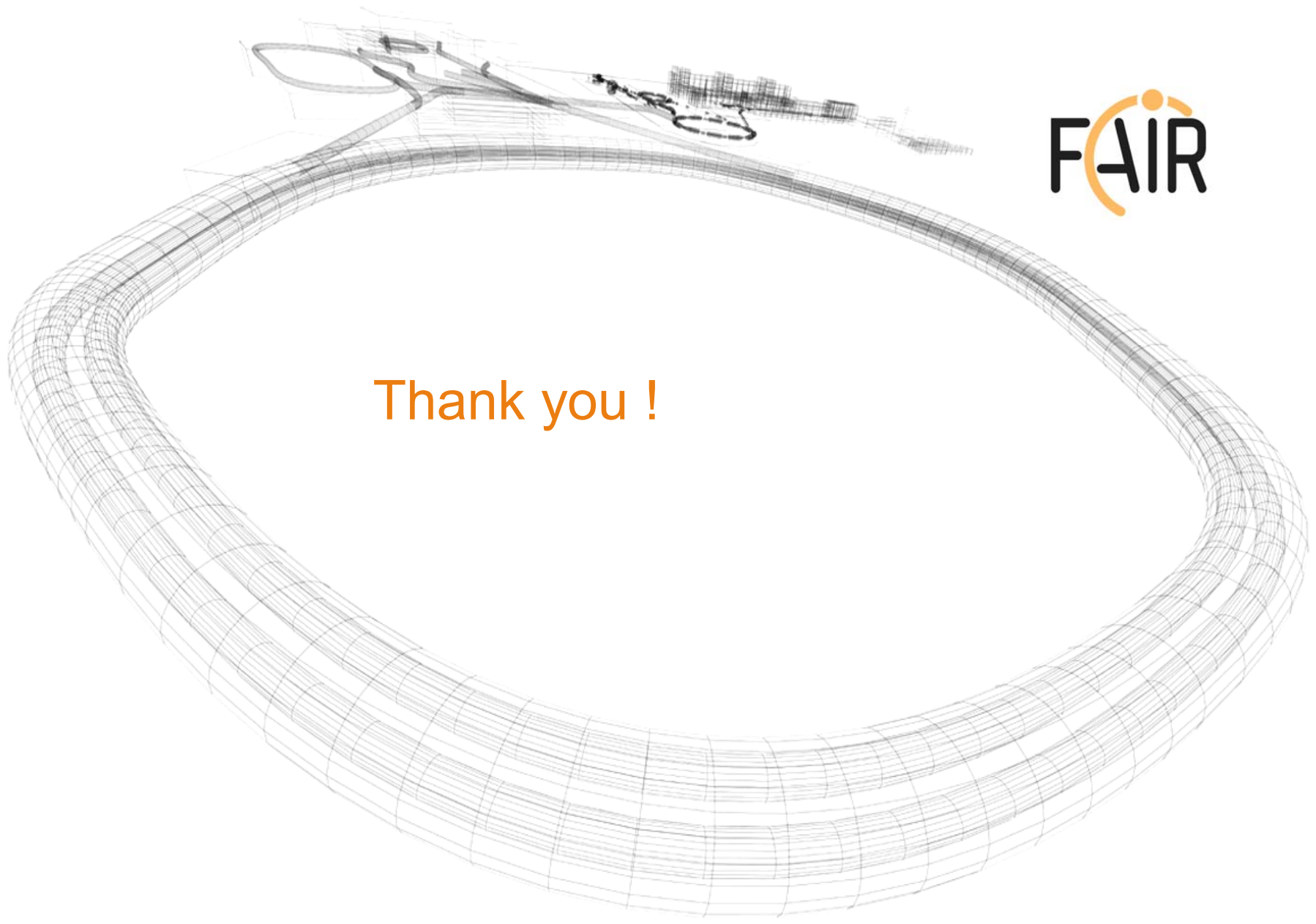


Duty-Cycles of the Accelerator Rings



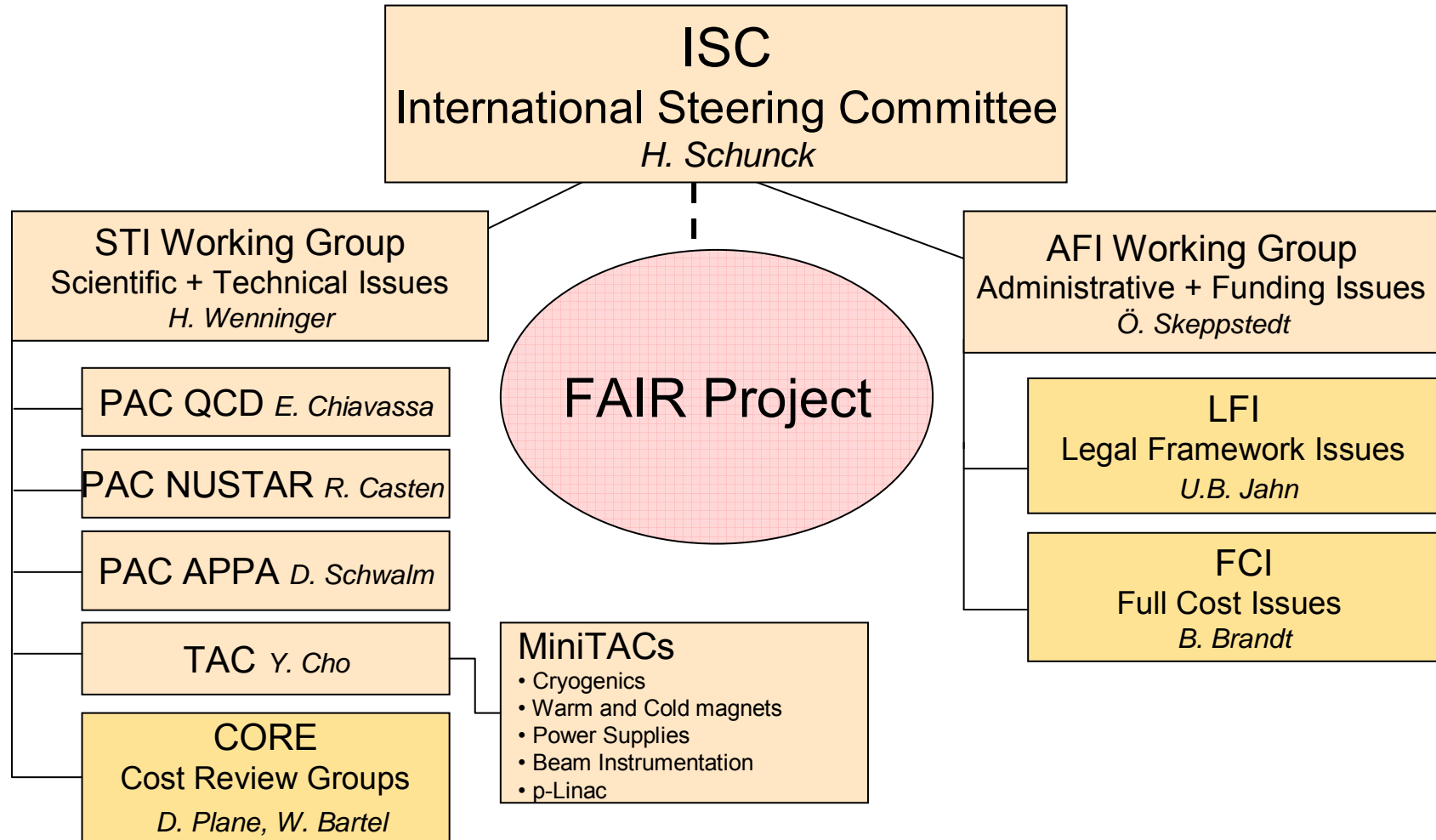
Duty-Cycles of the Physics Programs





Thank you !

# Scientific, Technical and Legal Framework for FAIR



Observers:



# Scientific, Technical and Legal Framework for FAIR



- **Baseline Technical Report**
  - accelerator TR's
  - experiment proposals
  - civil construction plans (~ 3500 pages)
- **PAC & TAC Review Reports**
- **Cost Book**
- **Cost Review Reports**
  - accelerator & civil construction (CORE-A)
  - experiments (CORE-E)

- **Convention**
- **Articles of Association**
- By-Laws
- Final Act Document
- Legal Framework Report (LFI)
- Full Cost Structure Report (FCI)

