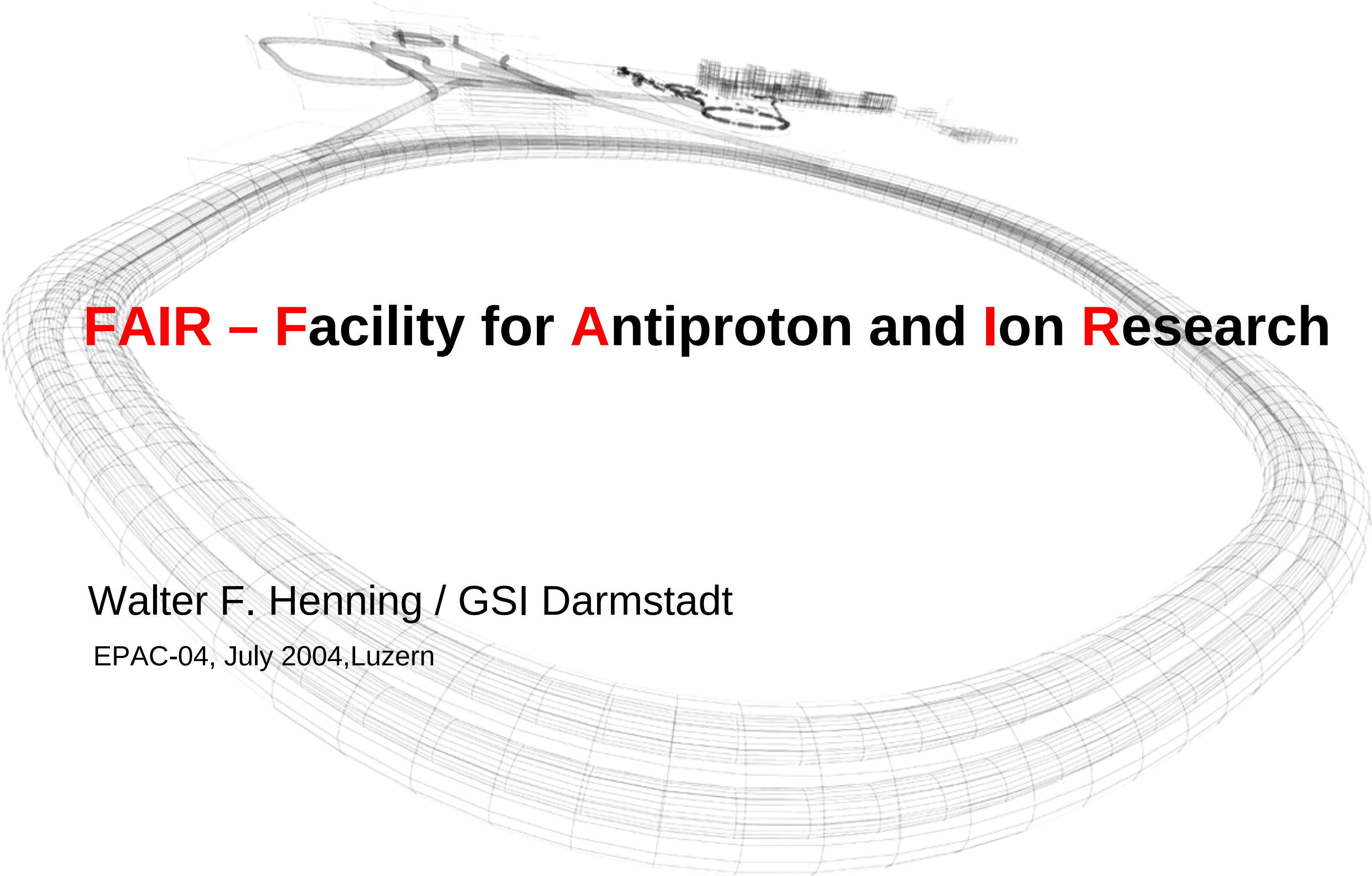


# FAIR – Facility for Antiproton and Ion Research

Walter F. Henning / GSI Darmstadt

EPAC-04, July 2004,Luzern

# GSI Darmstadt

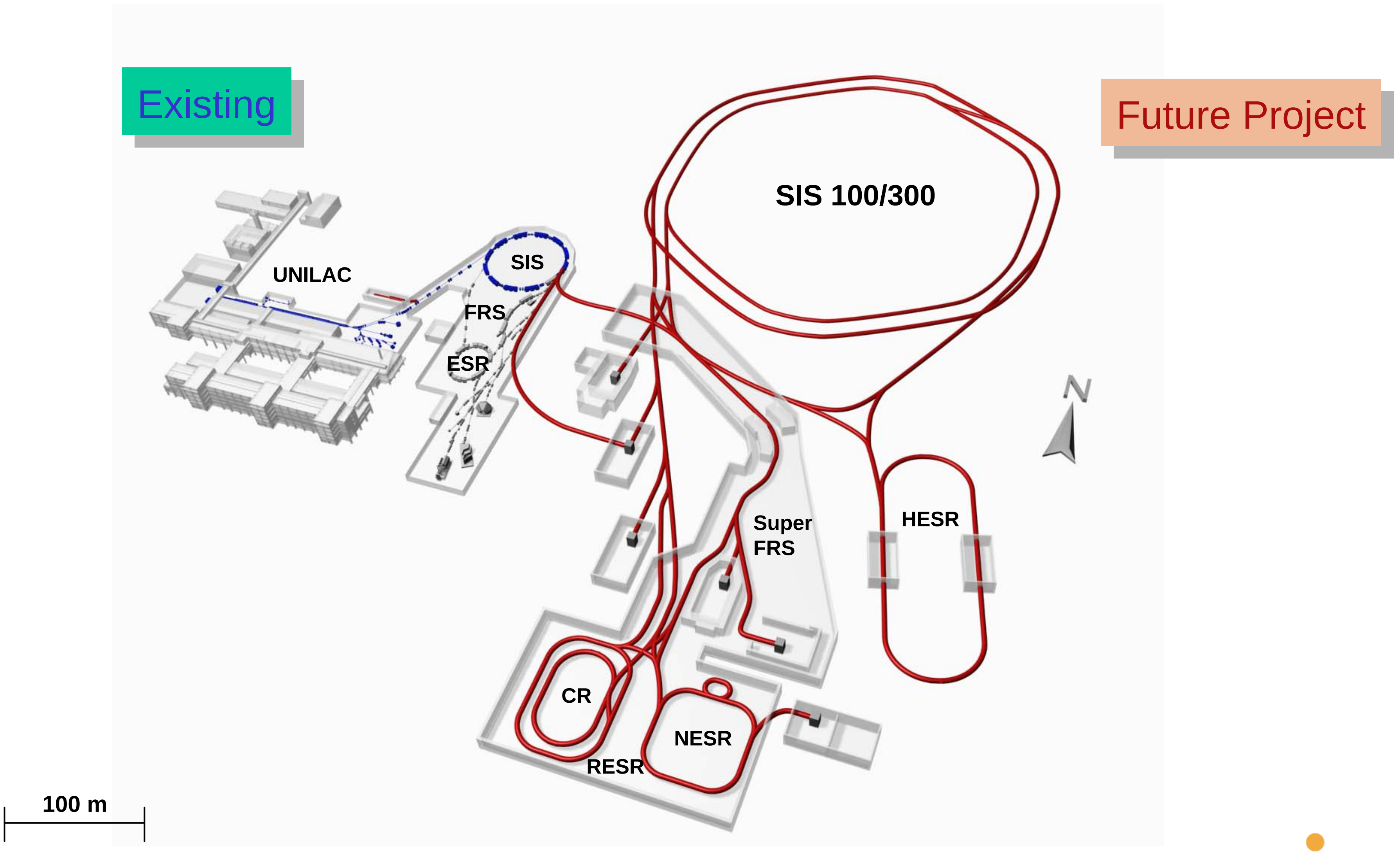
Member of the Helmholtz Association

# GSI Darmstadt

Introduction
Description of the Facility
Research Goals
Summary and Outlook

Member of the Helmholtz Association

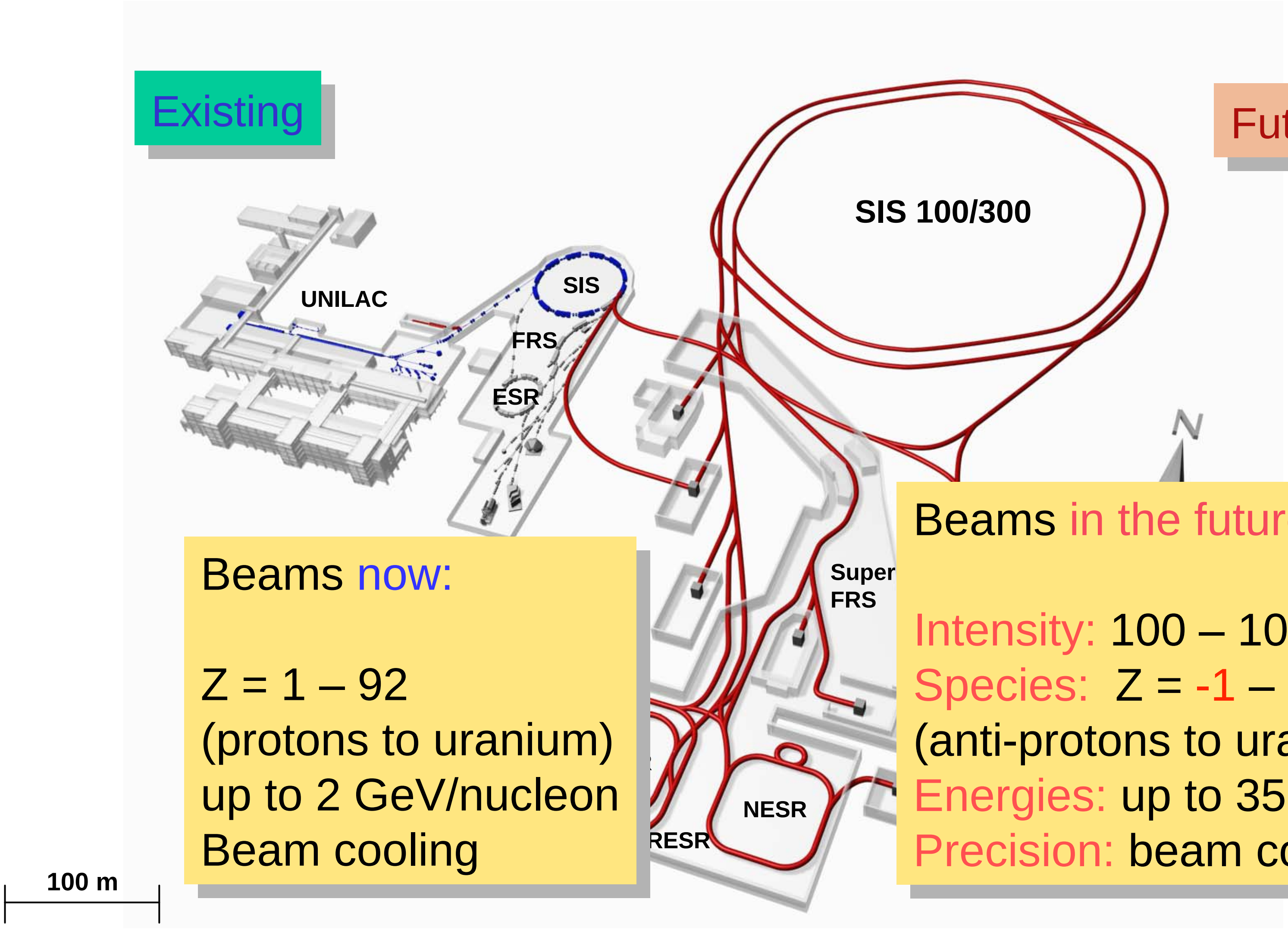
# The Future International Facility at GSI:
# FAIR - Facility for Antiproton and Ion Research



# The Future International Facility at GSI:
# FAIR - Facility for Antiproton and Ion Research

Existing

Future Project



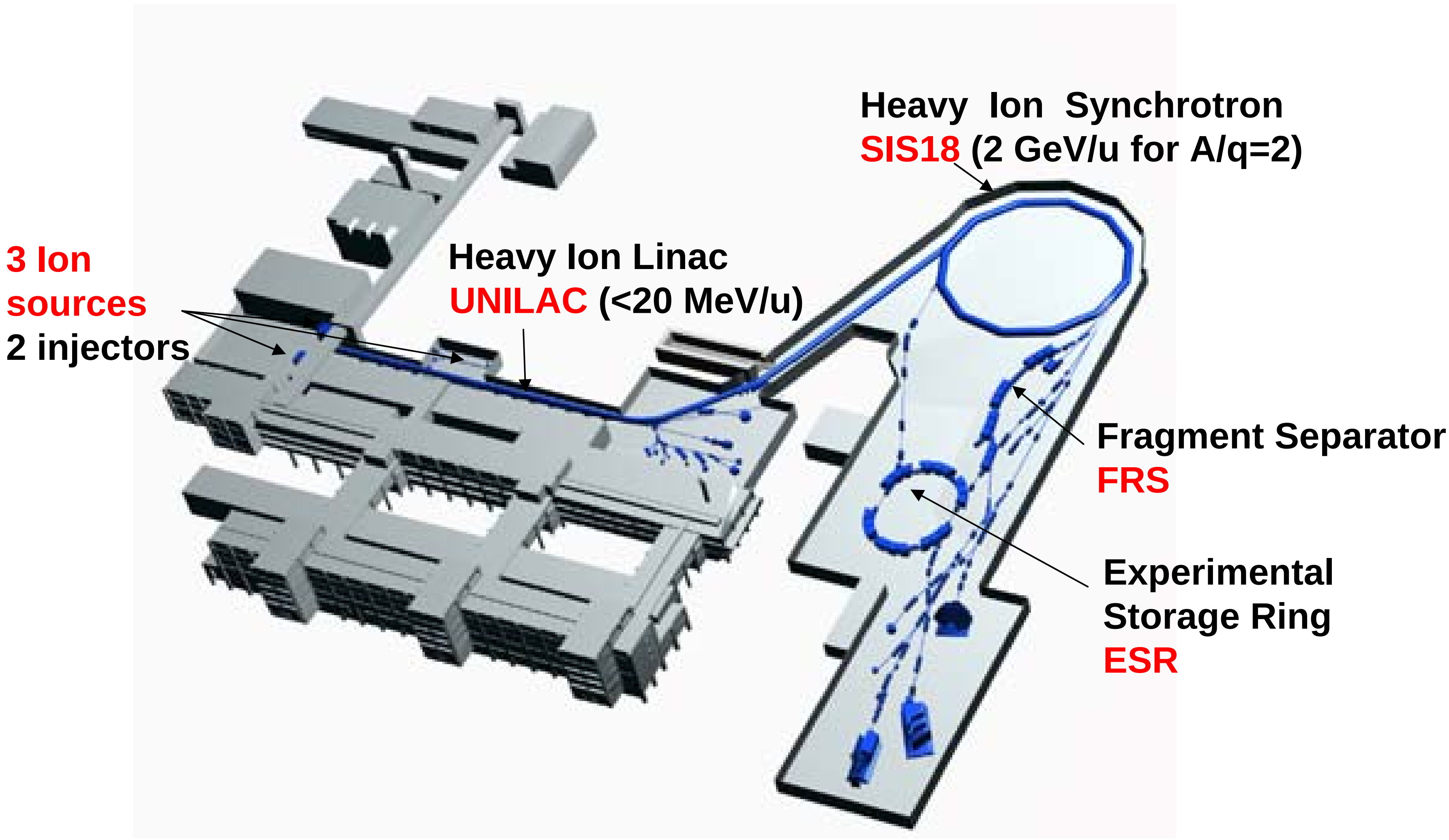

Beams now:

Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon
Beam cooling

Beams in the future:

Intensity: 100 – 1000 fold
Species: Z = -1 – 92
(anti-protons to uranium)
Energies: up to 35 - 45 GeV/u
Precision: beam cooling

# Present GSI Accelerators



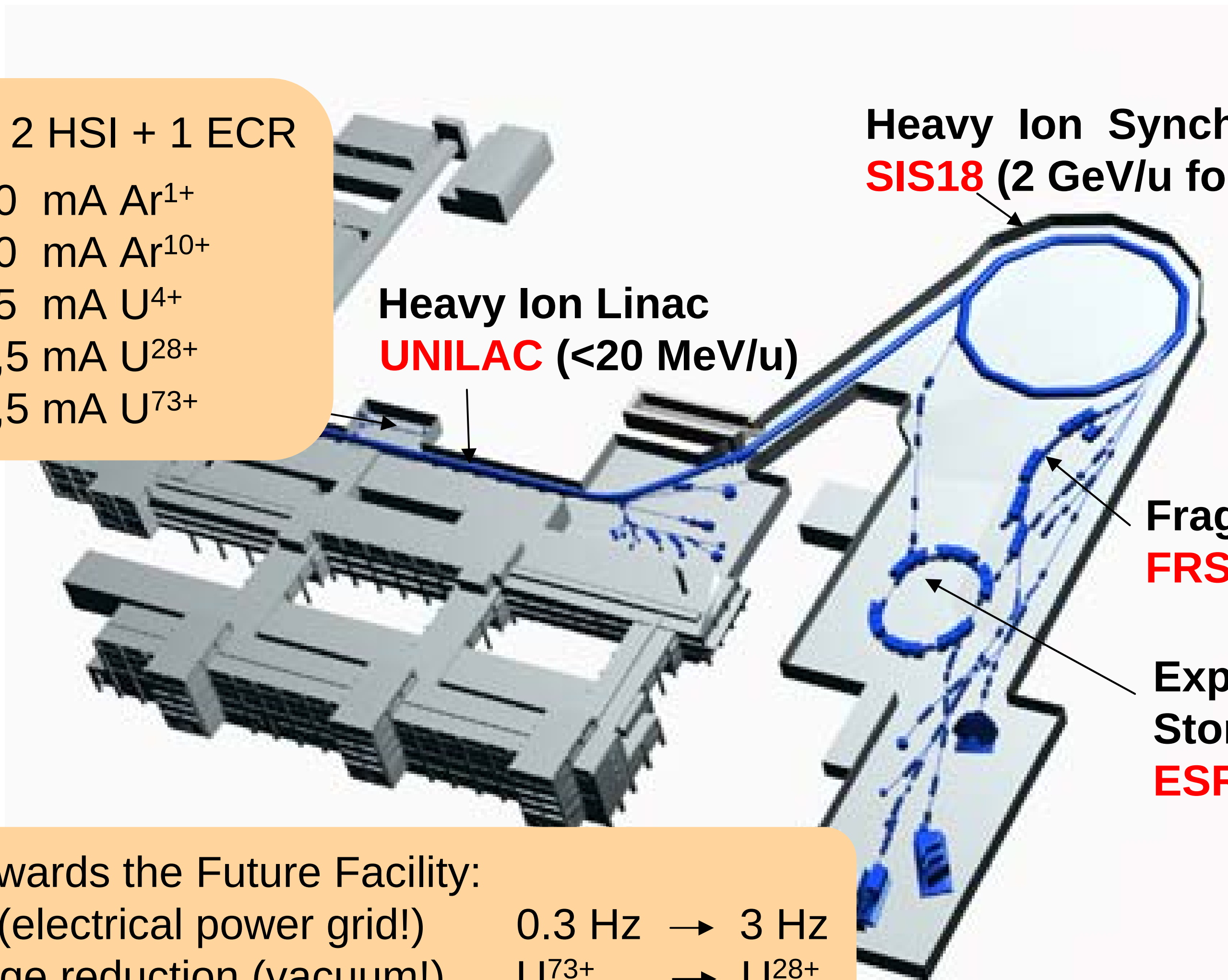
# Schedule and Parallel Operation of Present GSI Accelerators

<table>
<tr><th colspan="33">Beam-Time-Schedule 09.02.2004 - 11.03.2004</th></tr>
<tr><td></td><td colspan="32">Date</td></tr>
<tr><td></td><td>9.2</td><td>10.2</td><td>11.2</td><td>12.2</td><td>13.2</td><td>14.2</td><td>15.2</td><td>16.2</td><td>17.2</td><td>18.2</td><td>19.2</td><td>20.2</td><td>21.2</td><td>22.2</td><td>23.2</td><td>24.2</td><td>25.2</td><td>26.2</td><td>27.2</td><td>28.2</td><td>29.2</td><td>1.3</td><td>2.3</td><td>3.3</td><td>4.3</td><td>5.3</td><td>6.3</td><td>7.3</td><td>8.3</td><td>9.3</td><td>10.3</td><td>11.3</td></tr>
<tr><td></td><td colspan="32">ION-SOURCES</td></tr>
<tr><td>ECR</td><td colspan="7">3He</td><td colspan="8">124 Xe</td><td colspan="14">22 Ne</td><td colspan="3"></td></tr>
<tr><td>PIG</td><td colspan="7">94 Mo</td><td colspan="7">40 Ar</td><td colspan="8">56 Fe</td><td colspan="7">209 Bi</td><td colspan="3"></td></tr>
<tr><td>MUCIS</td><td colspan="27"></td><td colspan="5">40 Ar</td></tr>
<tr><td></td><td colspan="32">UNILAC</td></tr>
<tr><td>1. experiment</td><td>UU Mo</td><td colspan="6">94 Mo Y7 5.0 MeV/u</td><td></td><td colspan="6">40 Ar Y7 4.7 - 5.2 MeV/u</td><td></td><td colspan="3">UU ECR Ne</td><td colspan="11">22 Ne X1 7.0 MeV/u</td><td colspan="3">machine experiments</td></tr>
<tr><td>2. experiment</td><td colspan="2"></td><td colspan="3">94 Mo X0 11.4 MeV/u</td><td colspan="2">3He X6 11.4 MeV/u</td><td colspan="4">40 Ar X0 3.6 MeV/u</td><td colspan="3">40 Ar X1 7.1 MeV/u</td><td>UU Fe</td><td colspan="6">56 Fe Z6 5.9 MeV/u</td><td></td><td>UU Bi</td><td colspan="2">Bi X0 4.0 MeV/u</td><td colspan="4">209 BI Z4 11.4 MeV/u</td><td colspan="3"></td></tr>
<tr><td>3. experiment</td><td colspan="8"></td><td colspan="6">40 Ar Z6 5.9 MeV/u</td><td colspan="11"></td><td colspan="4">22 Ne Z6 11.4 MeV/u</td><td colspan="3"></td></tr>
<tr><td>transfer-line 1. beam</td><td>UU He</td><td colspan="6">3He 11.4 MeV/u</td><td>UU Xe</td><td colspan="7">124 Xe 11.4 MeV/u</td><td colspan="7">56 Fe 11.4 MeV/u</td><td>UU Bi</td><td colspan="6">209 Bi 11.4 MeV/u</td><td colspan="3"></td></tr>
<tr><td>transfer-line 2. beam</td><td colspan="23"></td><td colspan="6">22 Ne 11.4 MeV/u</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="32">SIS / ESR</td></tr>
<tr><td>1. experiment</td><td colspan="2">US He</td><td colspan="5">He HTM therapy-like</td><td colspan="2">US Xe</td><td colspan="6">124 Xe FRS 1 GeV/u cooler</td><td colspan="7">56 Fe HTB 1 GeV/u</td><td>US Bi</td><td colspan="6">209 Bi ESR 400 MeV/U cooler</td><td colspan="3">machine experiments</td></tr>
<tr><td>2. experiment</td><td colspan="9"></td><td colspan="3">124 Xe ESR 400 MeV/u cooler</td><td colspan="3">124 Xe HTA 200 MeV/u</td><td colspan="7">56 Fe HTA 200 MeV/u</td><td></td><td colspan="6">209 Bi HTA 70 -100 MeV/u</td><td colspan="3"></td></tr>
<tr><td>3. experiment</td><td colspan="23"></td><td colspan="6">22 Ne FRS 250 MeV/u</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="32">UU = tune UNILAC and transfer-line</td></tr>
<tr><td></td><td colspan="32">US = tune SIS and high energy beam-lines</td></tr>
</table>

# Present GSI Accelerators

3 Injectors: 2 HSI + 1 ECR

| HSI: | |
|---|---|
| | 10 mA $Ar^{1+}$ |
| | 20 mA $Ar^{10+}$ |
| | 15 mA $U^{4+}$ |
| | 2,5 mA $U^{28+}$ |
| | 0,5 mA $U^{73+}$ |




Upgrade towards the Future Facility:

| | | | |
|---|---|---|---|
| Frequency (electrical power grid!) | 0.3 Hz | → | 3 Hz |
| Space charge reduction (vacuum!) | $U^{73+}$ | → | $U^{28+}$ |

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HSI: 10 mA $Ar^{1+}$
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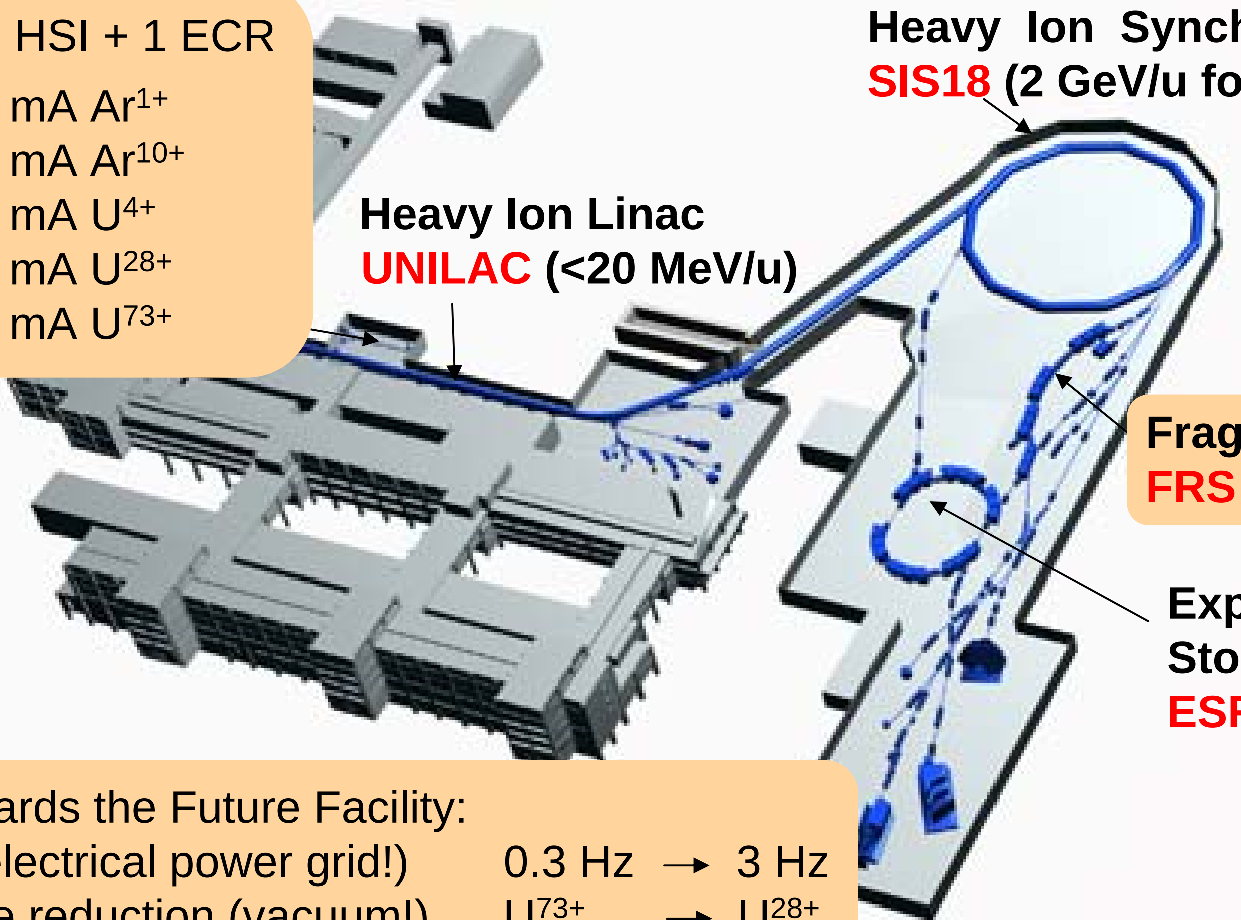
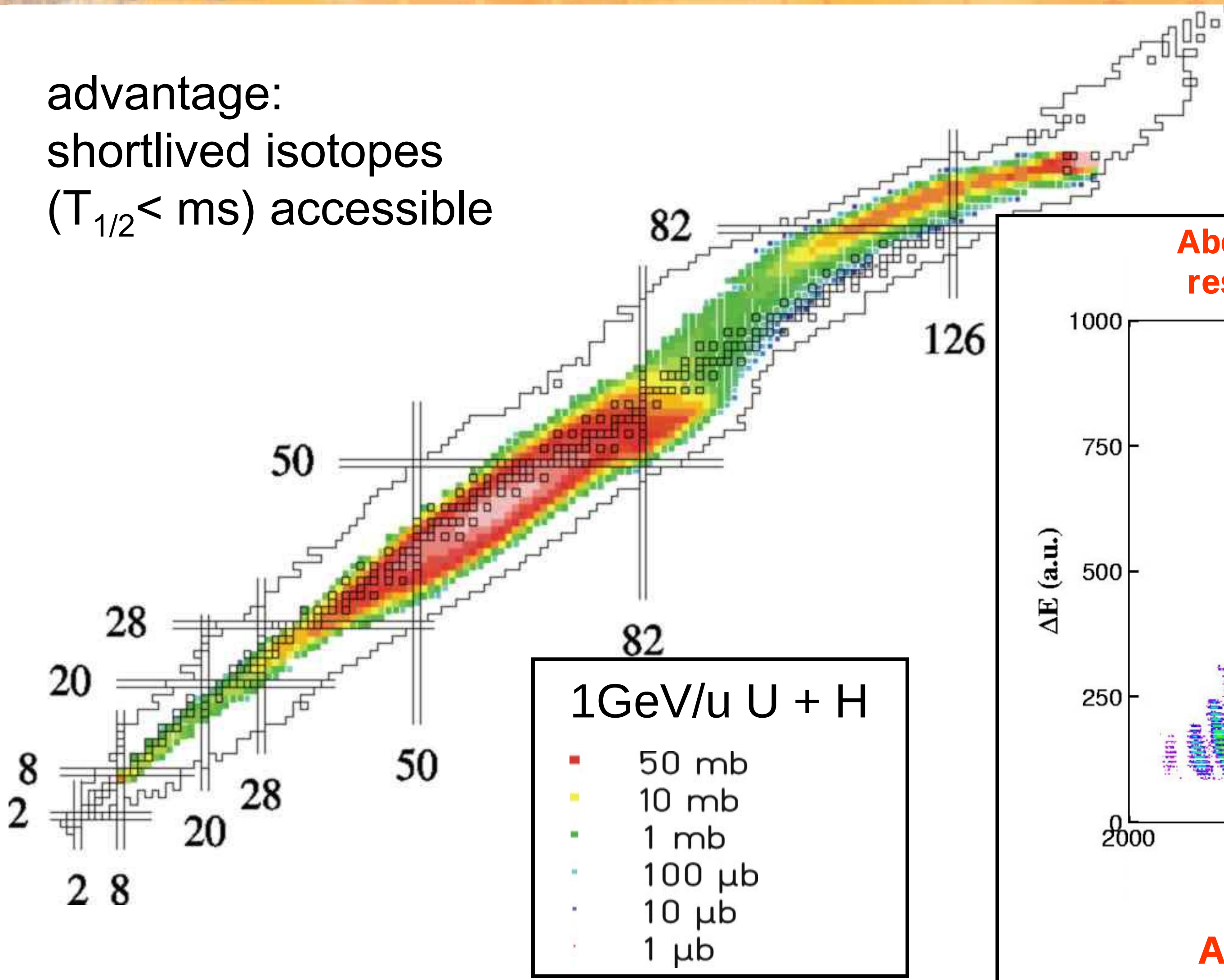
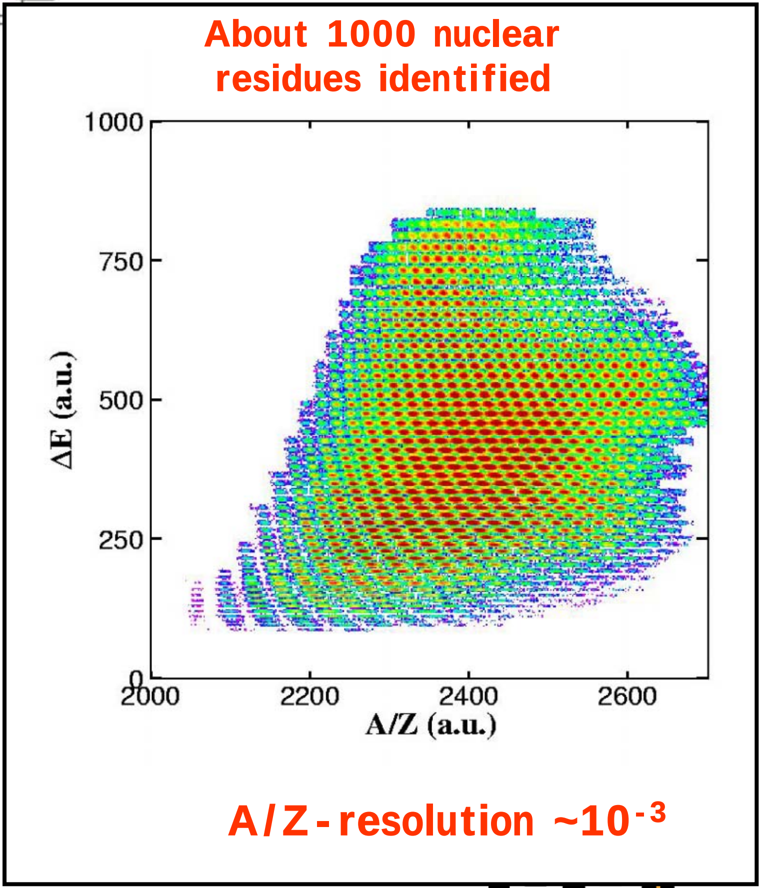



Upgrade towards the Future Facility:
Frequency (electrical power grid!) 0.3 Hz → 3 Hz
Space charge reduction (vacuum!) $U^{73+}$ → $U^{28+}$

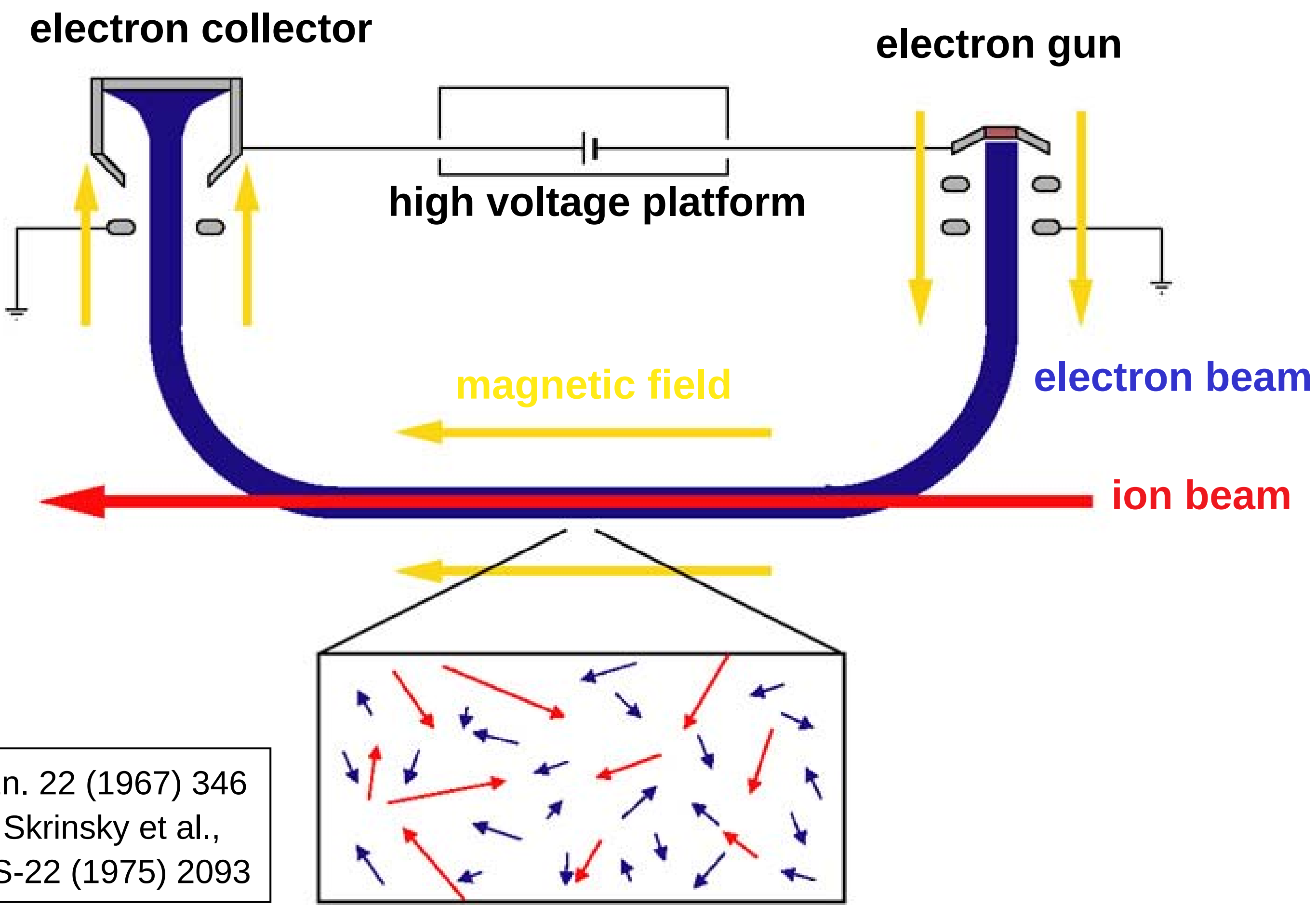
# Production of exotic nuclear beams by fragmentation

advantage:
shortlived isotopes
($T_{1/2}$< ms) accessible



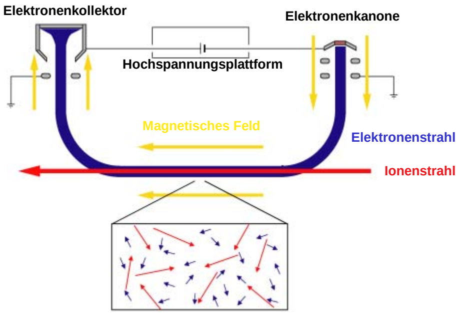



# Elektronenstrahlgekühlte Ionenstrahlen

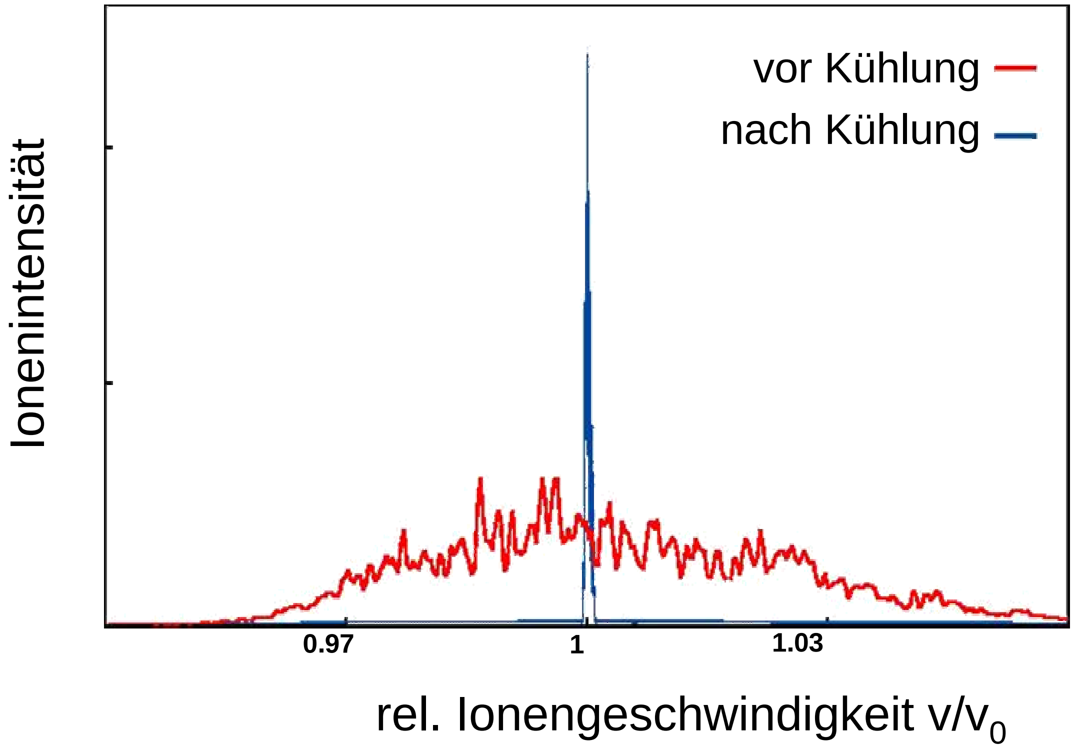


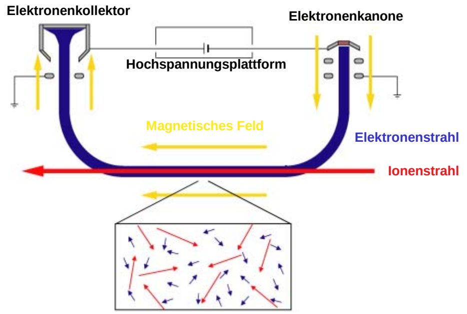

G.I. Budker, At. En. 22 (1967) 346
G.I. Budker, A.N. Skrinsky et al.,
IEEE NS-22 (1975) 2093

# Speicherringe: Gekühlte Ionenstrahlen

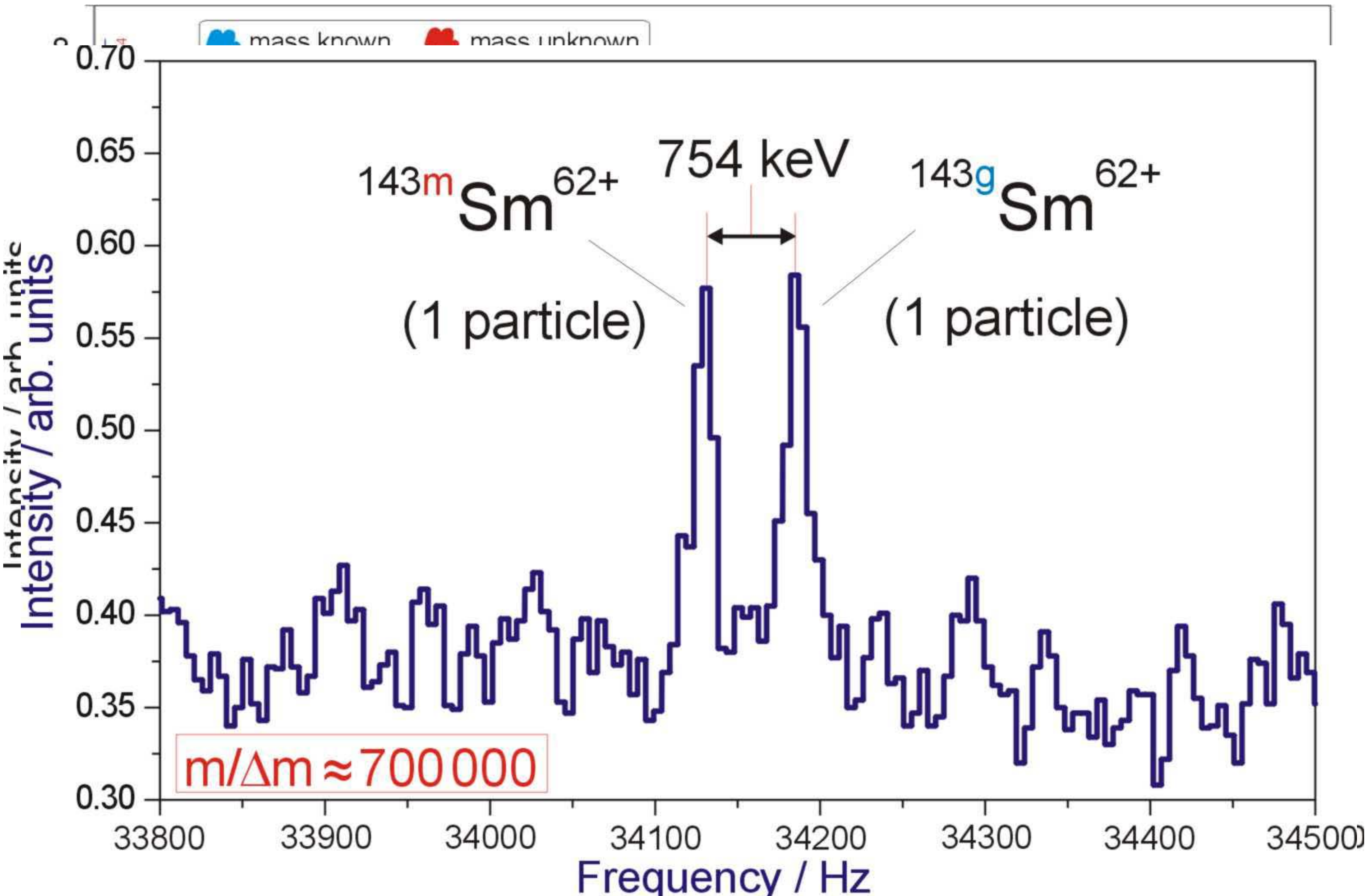


# Speicherringe: Gekühlte Ionenstrahlen

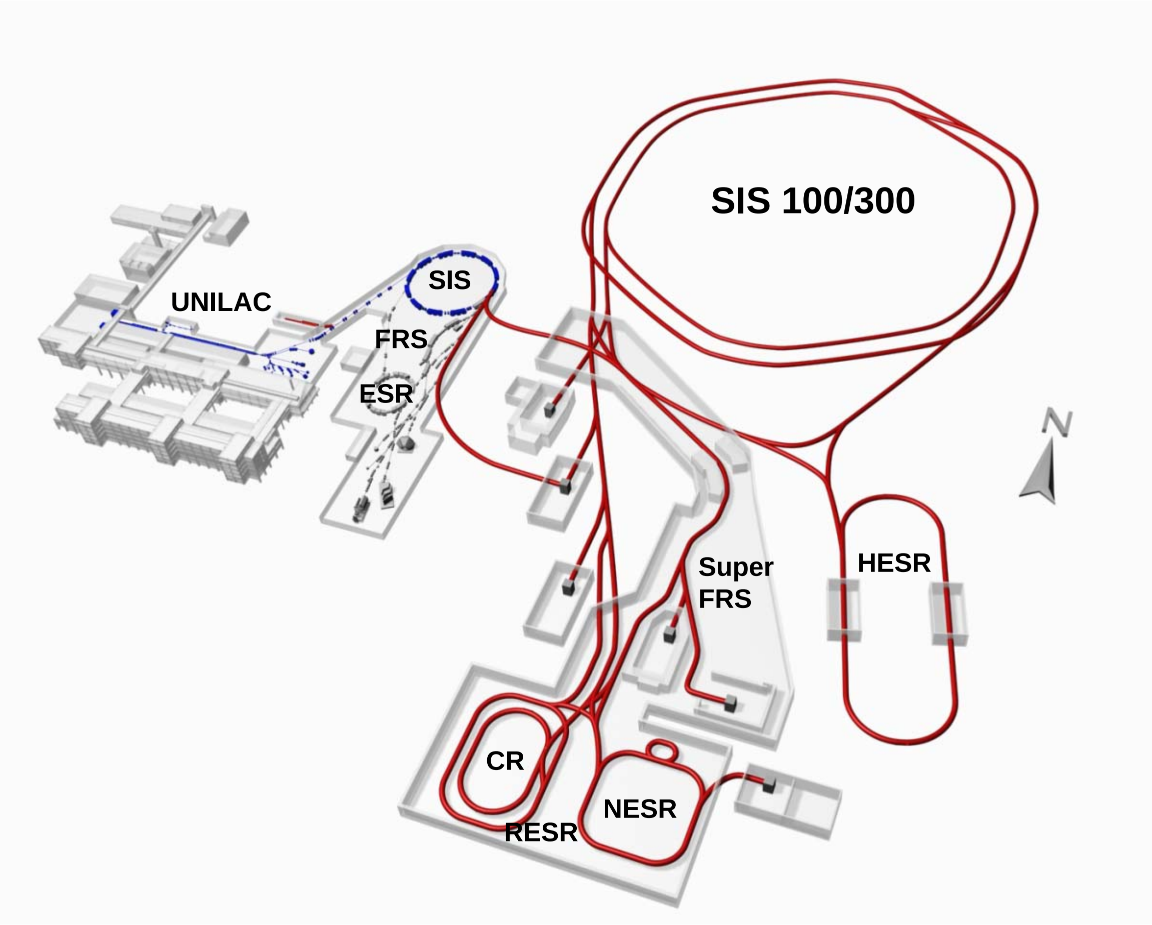


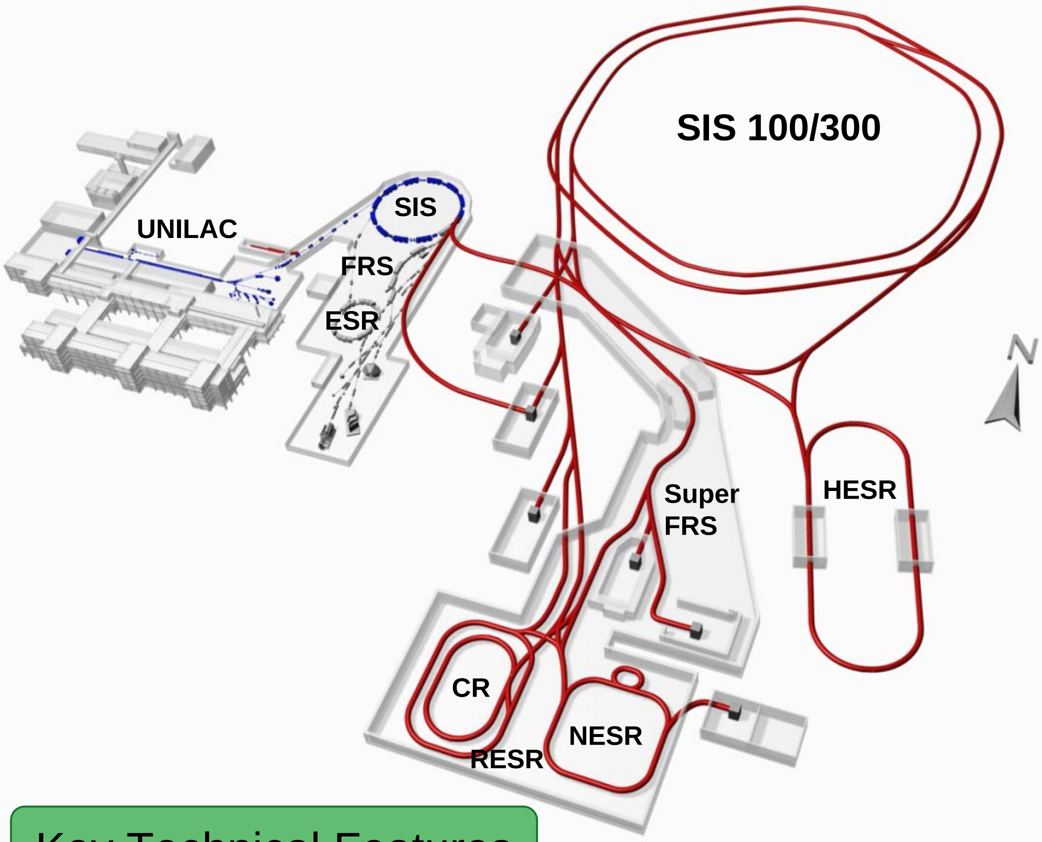

# Schottky Frequenz Spectrum



# FAIR: Facility Characteristics



# FAIR: Facility Characteristics




## Primary Beams

- $10^{12}$/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- $2(4)\times10^{13}$/s 30 GeV protons
- $10^{10}$/s $^{238}U^{73+}$ up to 35 GeV/u
  (up to 90 GeV protons)

## Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

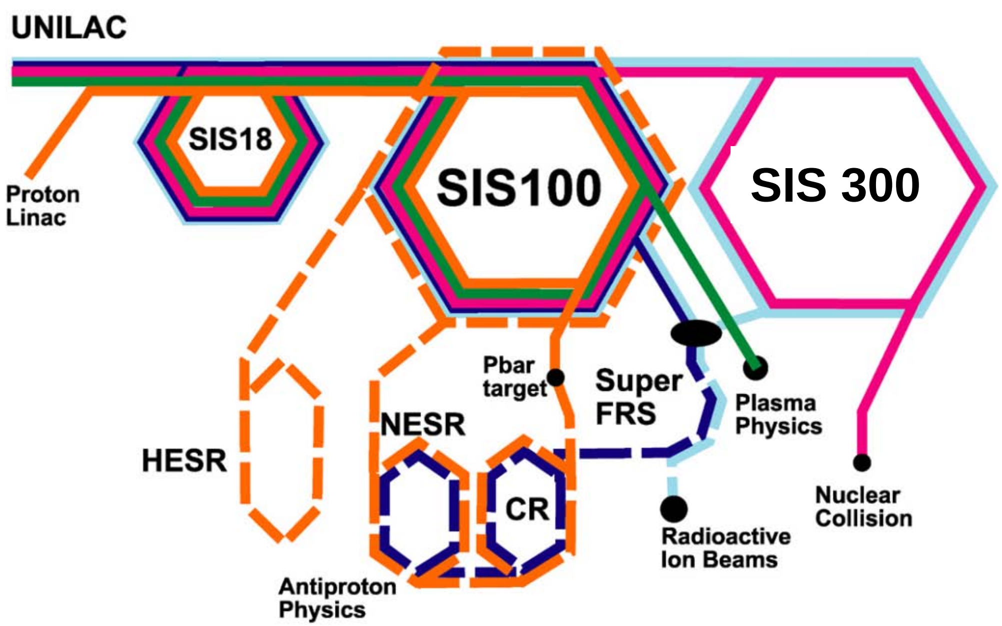
## Storage and Cooler Rings

- Radioactive beams
- e – A collider
- $10^{11}$ stored and cooled 0.8 - 14.5 GeV antiprotons

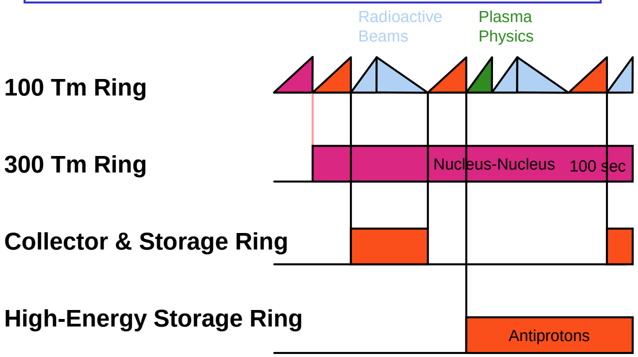
## Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

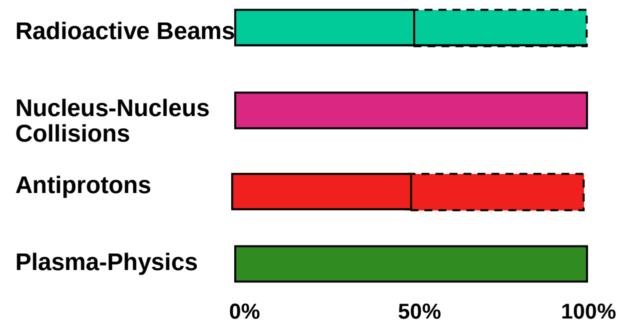
# Parallel Operation




## Duty-Cycles of the Accelerator Rings

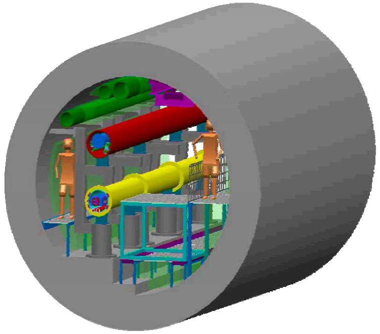



## Duty-Cycles of the Physics Programs



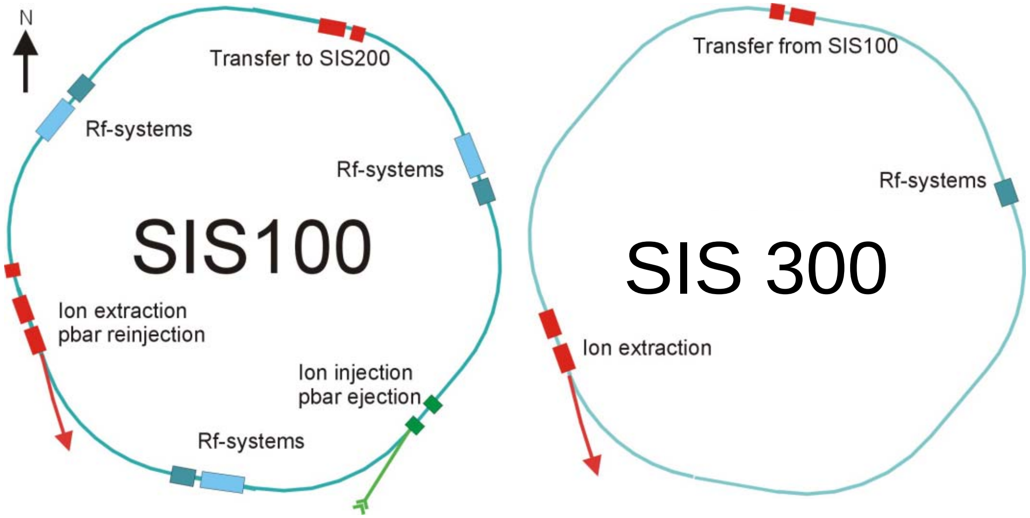
# New SIS 100/300 Synchrotron

Two synchrotrons in one tunnel (1080 m circumference)

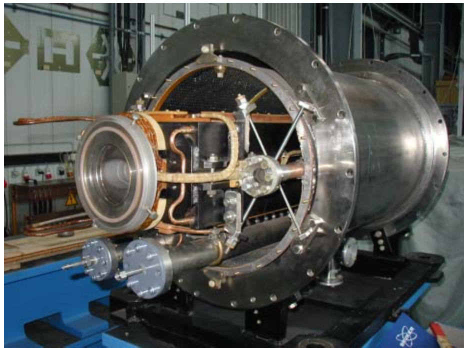


Booster and compressor

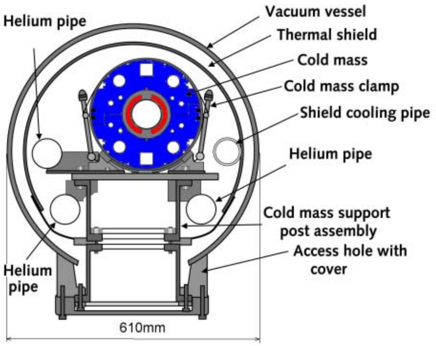
Stretcher and high energy ring




R&D programm in rapidly cycling superconducting magnets



Nuclotron dipole magnet:
B=2T, dB/dt=4T/s




RHIC type dipole magnet:
B=4T → 6T, dB/dt=1T/s

# R&D in Superconducting Magnet Technology

## Collaboration Network

**SIS200/300 cos θ magnet**

BNL (US) 1/2001
Twente University (NL)
Jena University (D)
IHEP (RU) 6/2002

**SIS 100: window-frame magnet**

JINR (RU) 2/2000
LBNL (US)
Bochvar Institute (RU)
BINP (RU) 6/2002

**Large Aperture Magnets (Storage Rings, SFRS, R3B)**

NSCL/MSU (US) 1/2002
CEA (F)

**Scientific Coordination**
**Magnet and Cryogenic Design**
**Magnet Test Facility**
**GSI**

**Magnet Design Software**

CERN (CH)
TU Darmstadt (D)

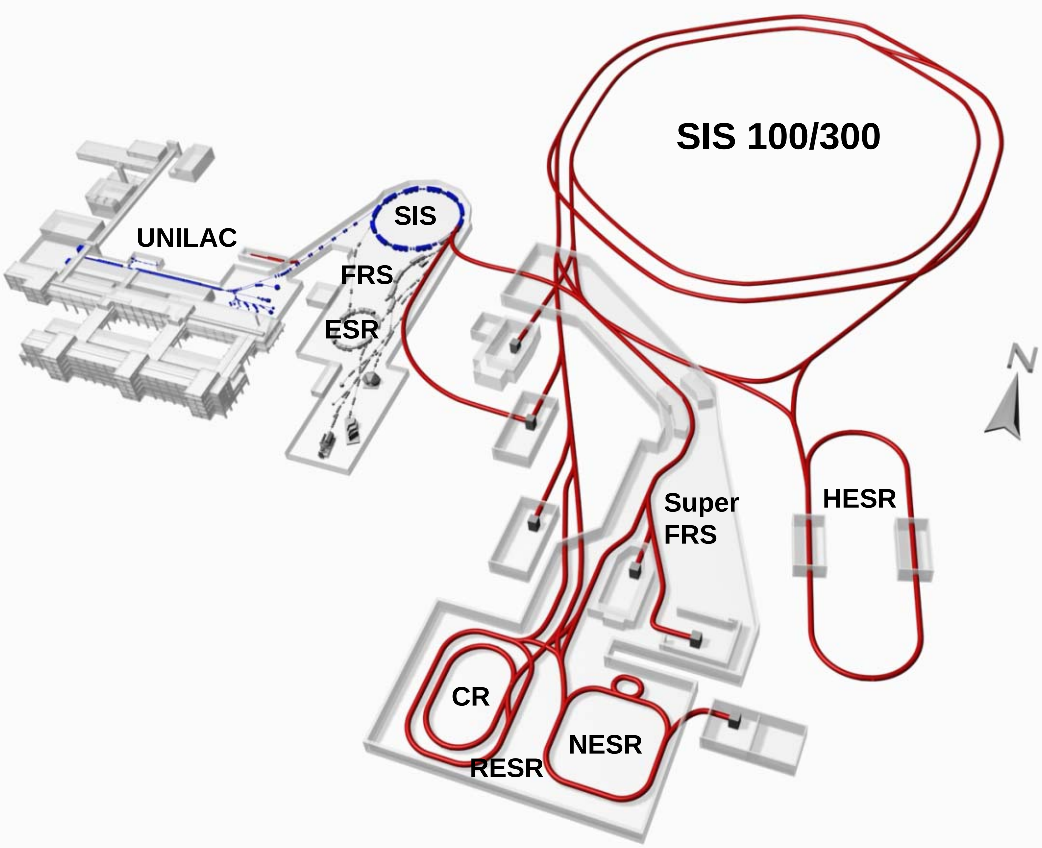
**Consulting**

CERN (CH) 8/2002
FZ Karlsruhe (D)
DESY (D)
M.N. Wilson (GB)
B. Hassenzahl (US)

**Cryogenics**

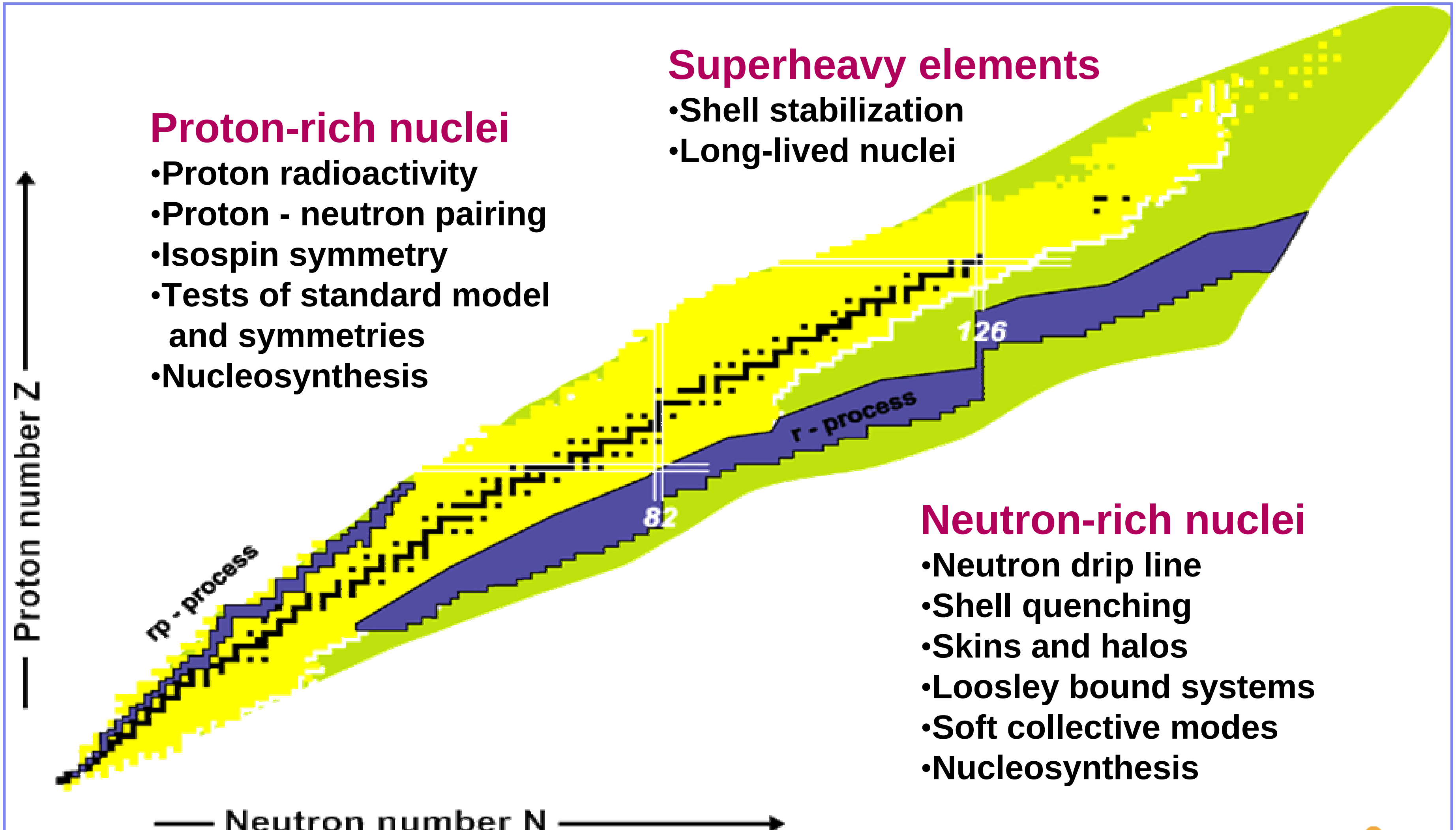
TU Dresden (D)
ACT Inc. (US)

# FAIR: Research Areas




- Nuclear Structure Physics and Nuclear Astrophysics with Radioactive Ion-Beams
- Hadron Physics with Antiprotons
- Physics of Nuclear Matter with Relativistic Nuclear Collisions
- Plasma Physics with Highly Bunched Laser- and Ion-Beams
- Atomic Physics and Applied Science
- Accelerator Physics

# Structure and Dynamics of Nuclei – Radioactive Beams at FAIR

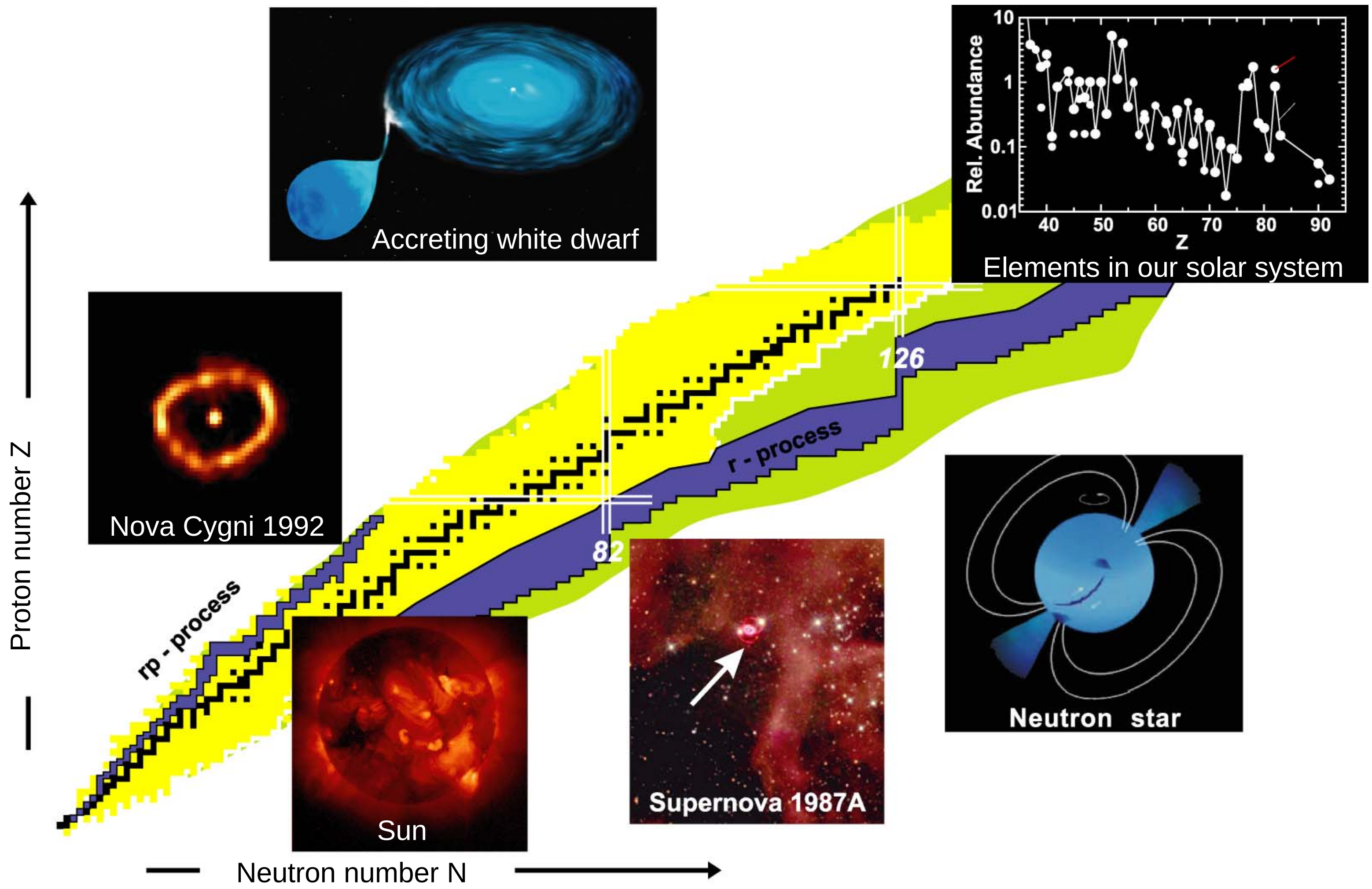



## Proton-rich nuclei
- Proton radioactivity
- Proton - neutron pairing
- Isospin symmetry
- Tests of standard model and symmetries
- Nucleosynthesis

## Superheavy elements
- Shell stabilization
- Long-lived nuclei

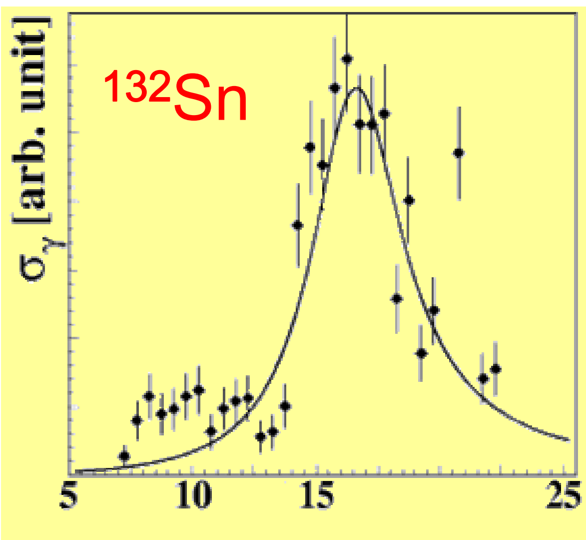
## Neutron-rich nuclei
- Neutron drip line
- Shell quenching
- Skins and halos
- Loosley bound systems
- Soft collective modes
- Nucleosynthesis

# Nuclear Physics in the Universe

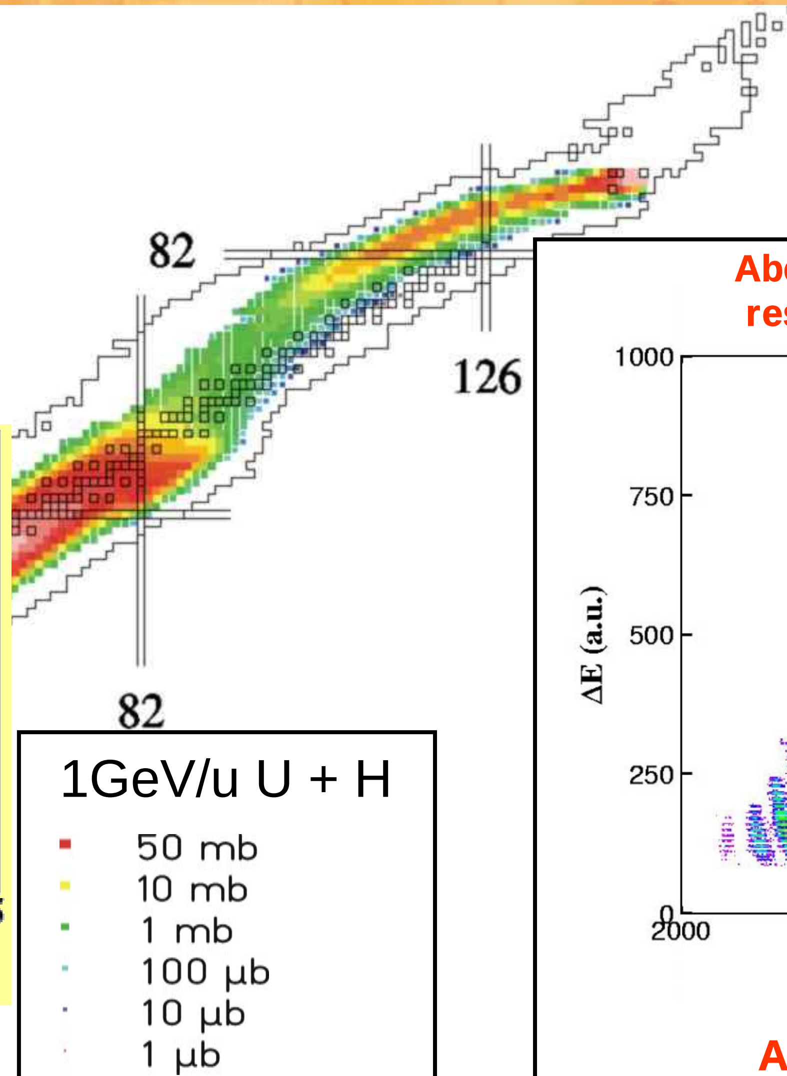


# Production of exotic nuclear beams by fragmentation

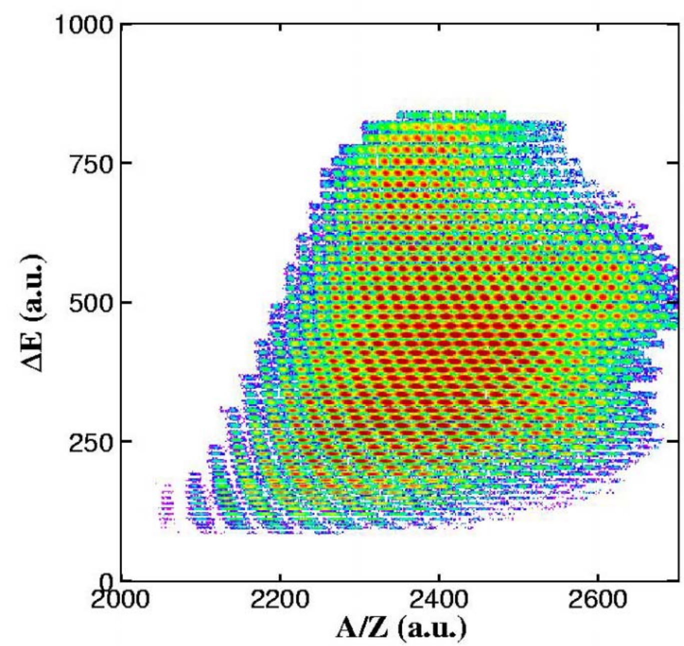
advantage:
shortlived isotopes
($T_{1/2}$< ms) accessible




Land Collaboration
P. Adrich et al., 2004




About 1000 nuclear residues identified



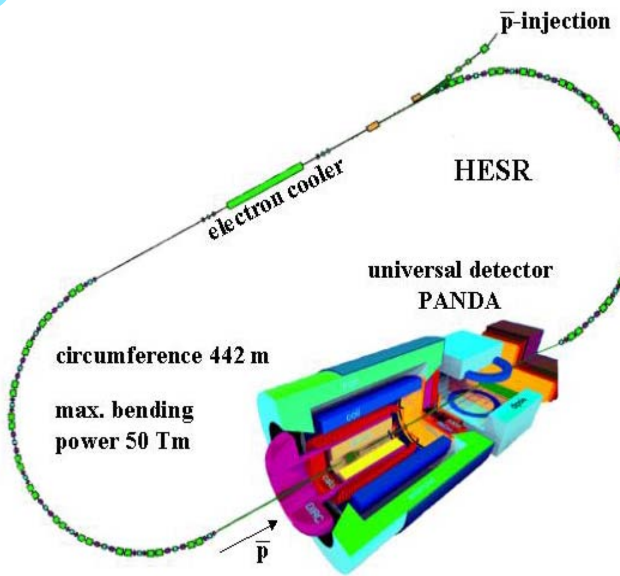

A/Z-resolution ~$10^{-3}$

# Physics program at the High Energy Storage Ring (HESR)

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

J/ψ spectroscopy
confinement

hidden and open
charm in nuclei




strange and charmed
baryons in nuclear
fields

fundamental
symmetries:

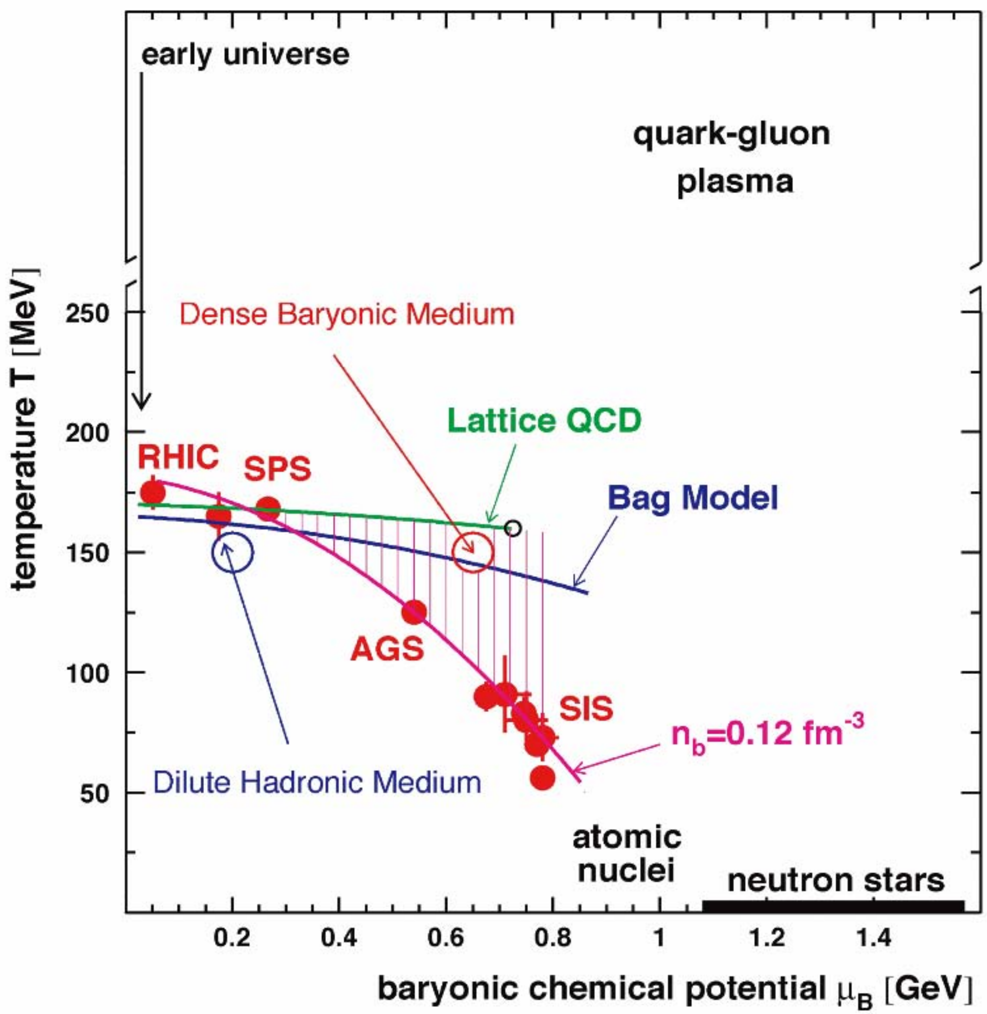
antiprotons in
traps (FLAIR)

inverted deeply virtual
Compton scattering

CP-violation
(D/Λ - sector)

New proposals: ASSIA, PAX (pol. target; pol. $\bar{p}$ – beams)

# Nuclear Matter and the Quark-Gluon Plasma – Relativistic Nuclear Beams at FAIR

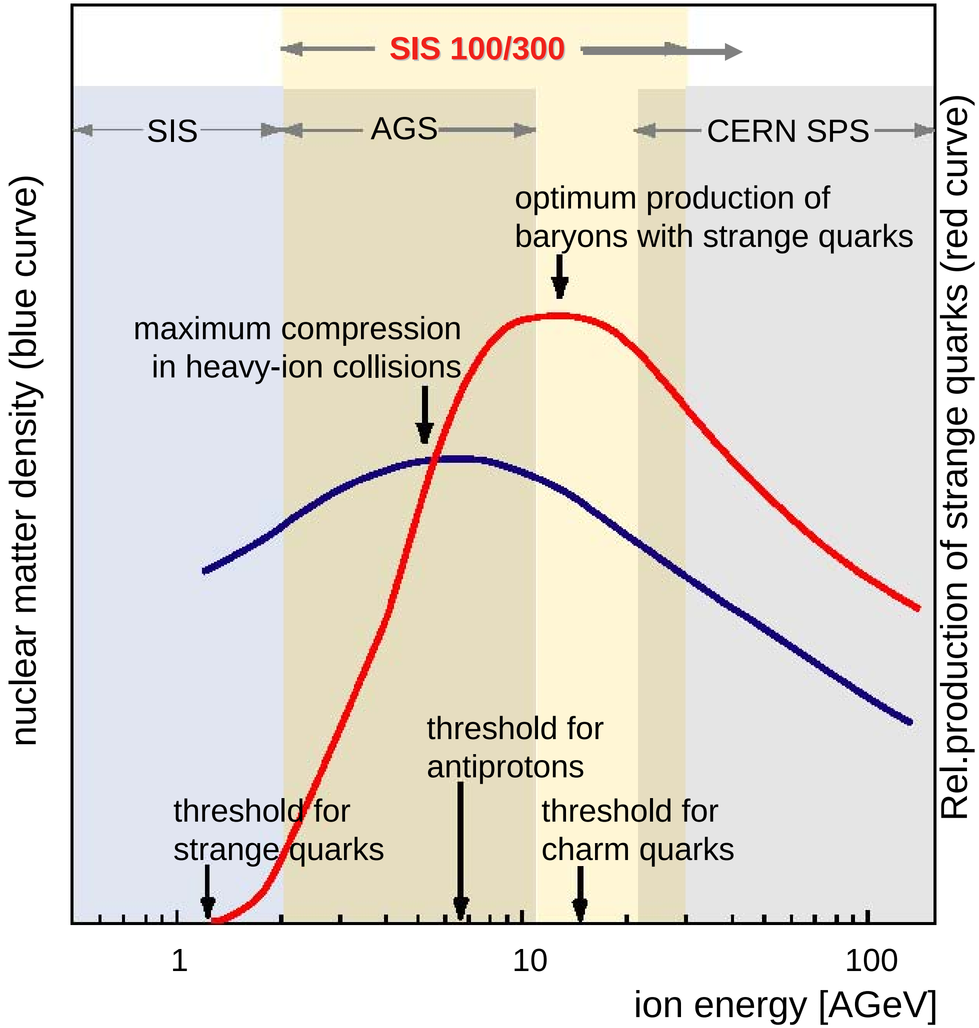



## QCD- Phase Diagram

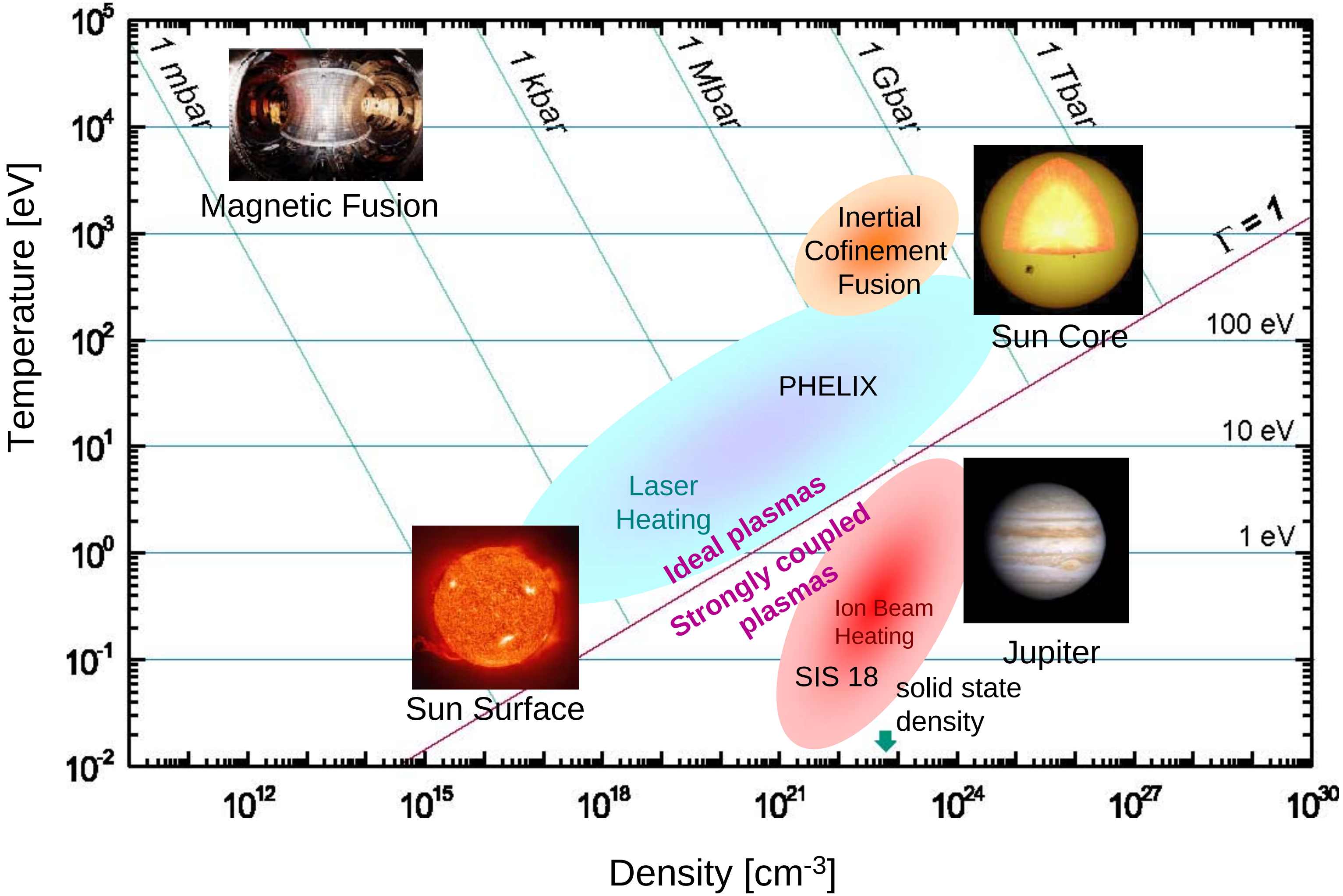
study of compressed baryonic / strange matter in nucleus-nucleus collisions up to laboratory energies of 35 AGeV

important probe: dilepton pairs

# NN Collisions at 2-40 AGeV

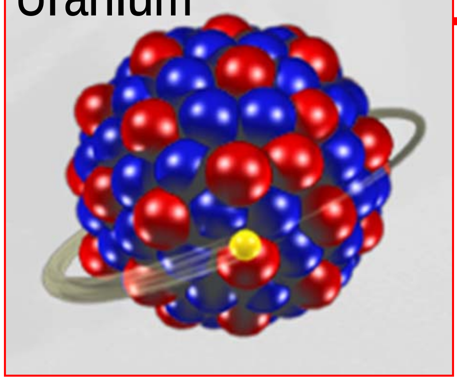


# High Power Density in Matter
# – Physics of Dense Plasma

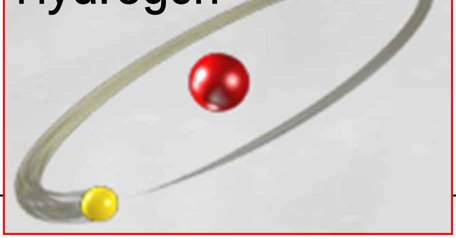


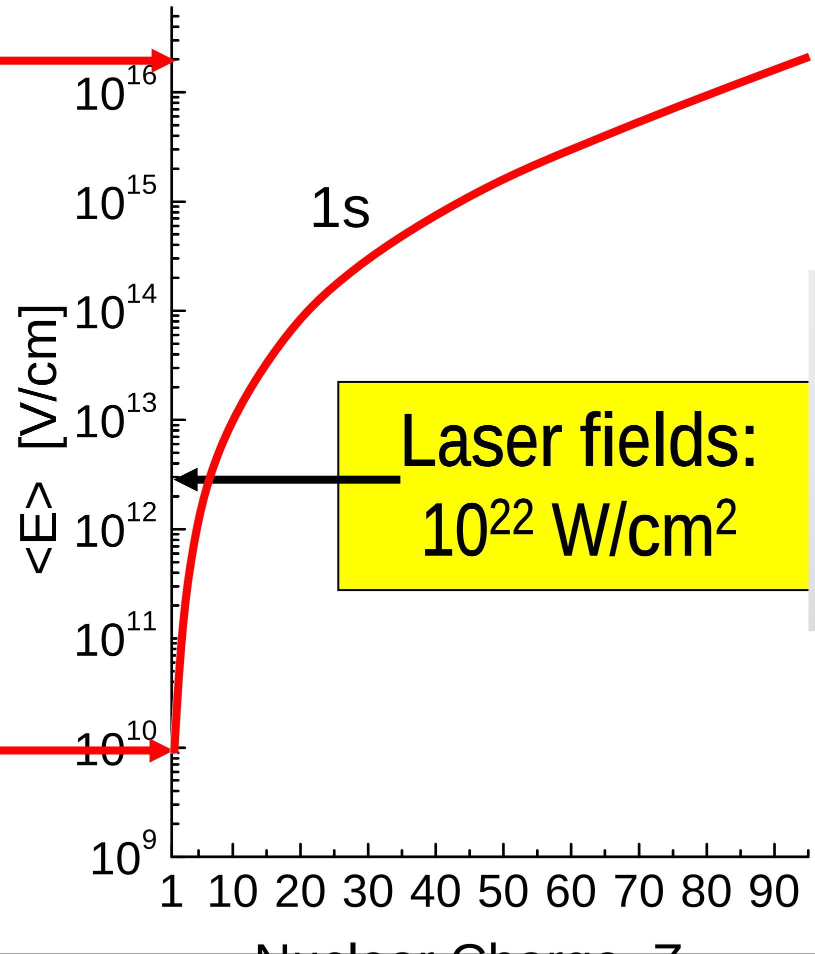
# 1. Extreme Static Electromagnetic Fields

Uranium



Hydrogen



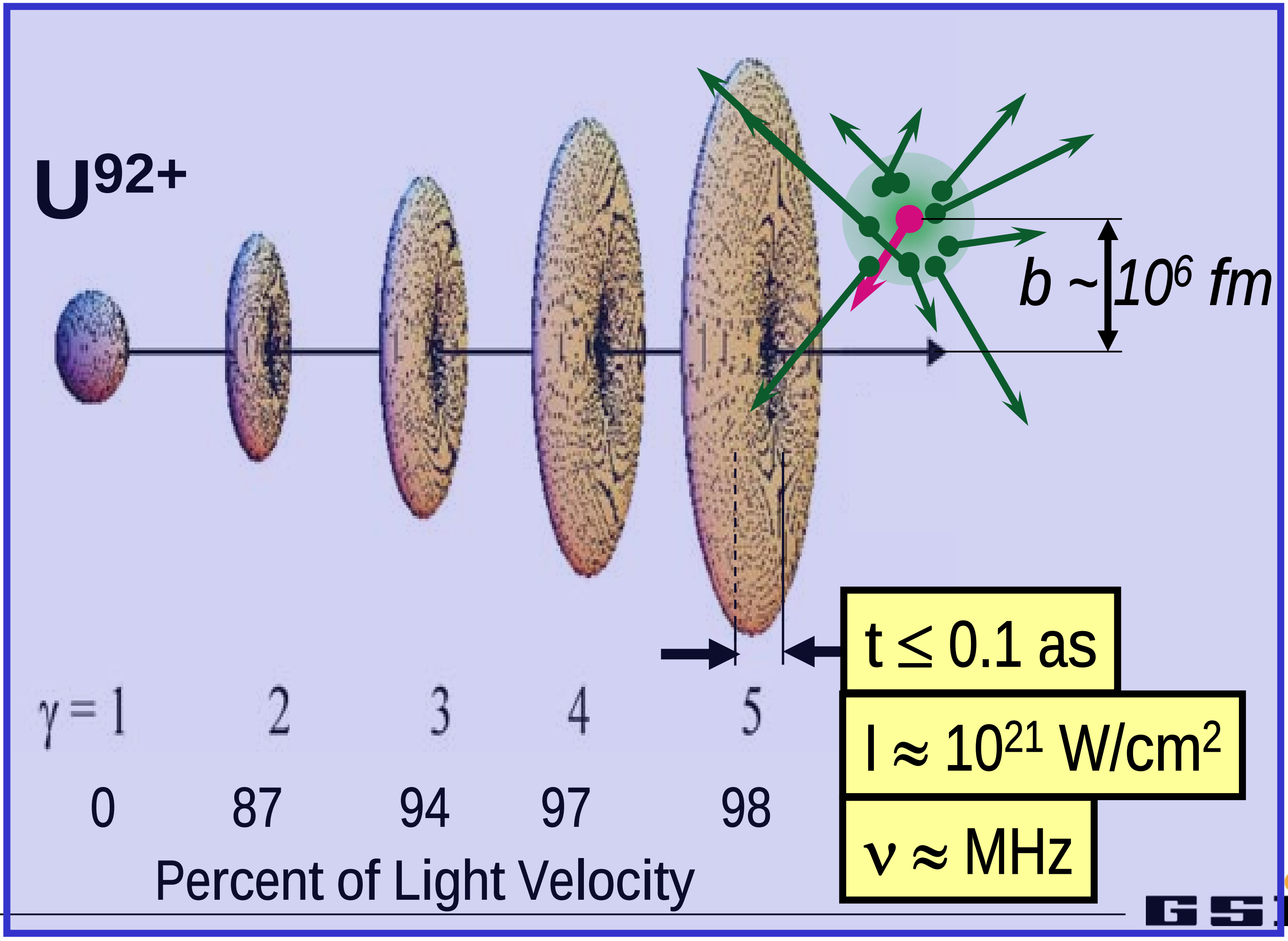



$\Delta E \approx 500$ eV
$Z \cdot \alpha \approx 1$

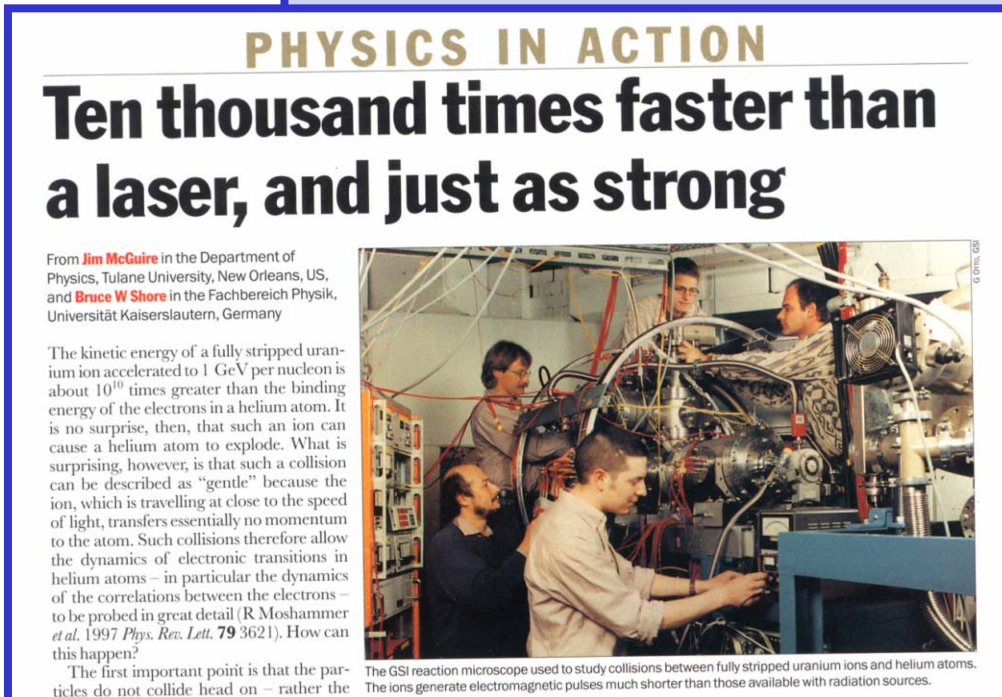
**Q**uantum
**E**lectro-
**D**ynamics

$\Delta E \approx 10^{-6}$ eV
$Z \cdot \alpha \approx 10^{-2}$

## 2. Extreme Dynamic Fields



## 2. Extreme Dynamic Fields



PHYSICS IN ACTION

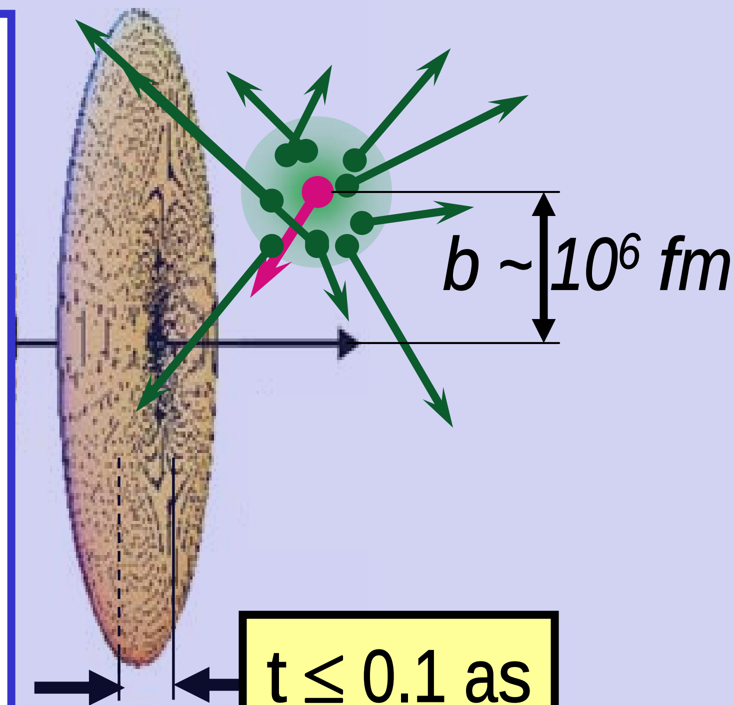
**Ten thousand times faster than a laser, and just as strong**

From **Jim McGuire** in the Department of Physics, Tulane University, New Orleans, US, and **Bruce W Shore** in the Fachbereich Physik, Universität Kaiserslautern, Germany

The kinetic energy of a fully stripped uranium ion accelerated to 1 GeV per nucleon is about $10^{10}$ times greater than the binding energy of the electrons in a helium atom. It is no surprise, then, that such an ion can cause a helium atom to explode. What is surprising, however, is that such a collision can be described as "gentle" because the ion, which is travelling at close to the speed of light, transfers essentially no momentum to the atom. Such collisions therefore allow the dynamics of electronic transitions in helium atoms – in particular the dynamics of the correlations between the electrons – to be probed in great detail (R Moshammer *et al.* 1997 *Phys. Rev. Lett.* **79** 3621). How can this happen?

The first important point is that the particles do not collide head on – rather the

The GSI reaction microscope used to study collisions between fully stripped uranium ions and helium atoms. The ions generate electromagnetic pulses much shorter than those available with radiation sources.




$\gamma = 1$ 2 3 4 5

0 87 94 97 98

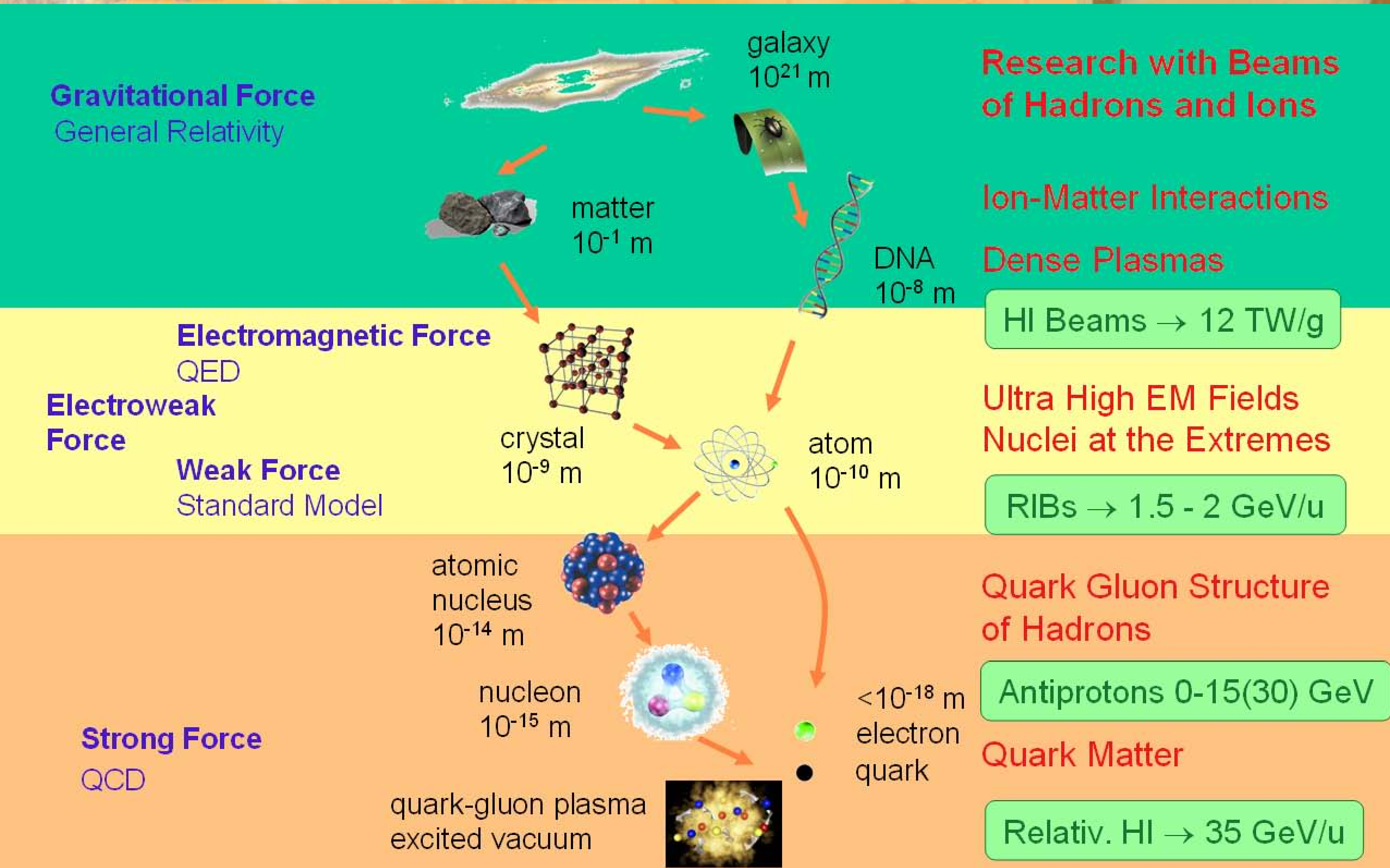
Percent of Light Velocity

$t \leq 0.1$ as

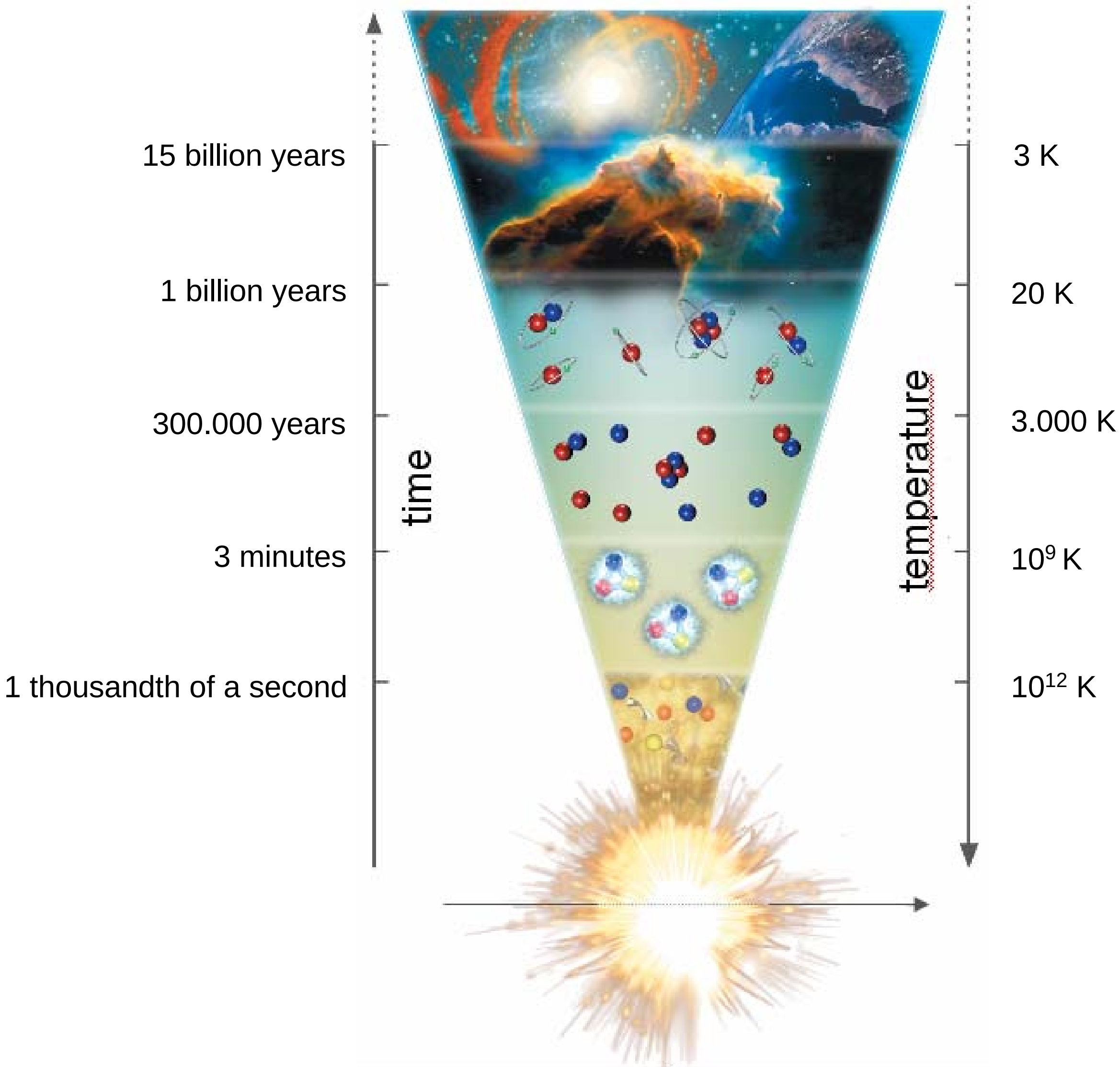
$I \approx 10^{21}$ W/cm$^2$

$\nu \approx$ MHz

# The Structure of Matter



# Physics of the Universe




**RESEARCH WITH ION BEAMS**

- Novae, supernovae compressed nuclear matter
- Synthesis of heavy elements
- r-process and rp-process

HI Beams → 12 TW/g

- Neutron stars – strangeness matter

RIBs → 2 GeV/n

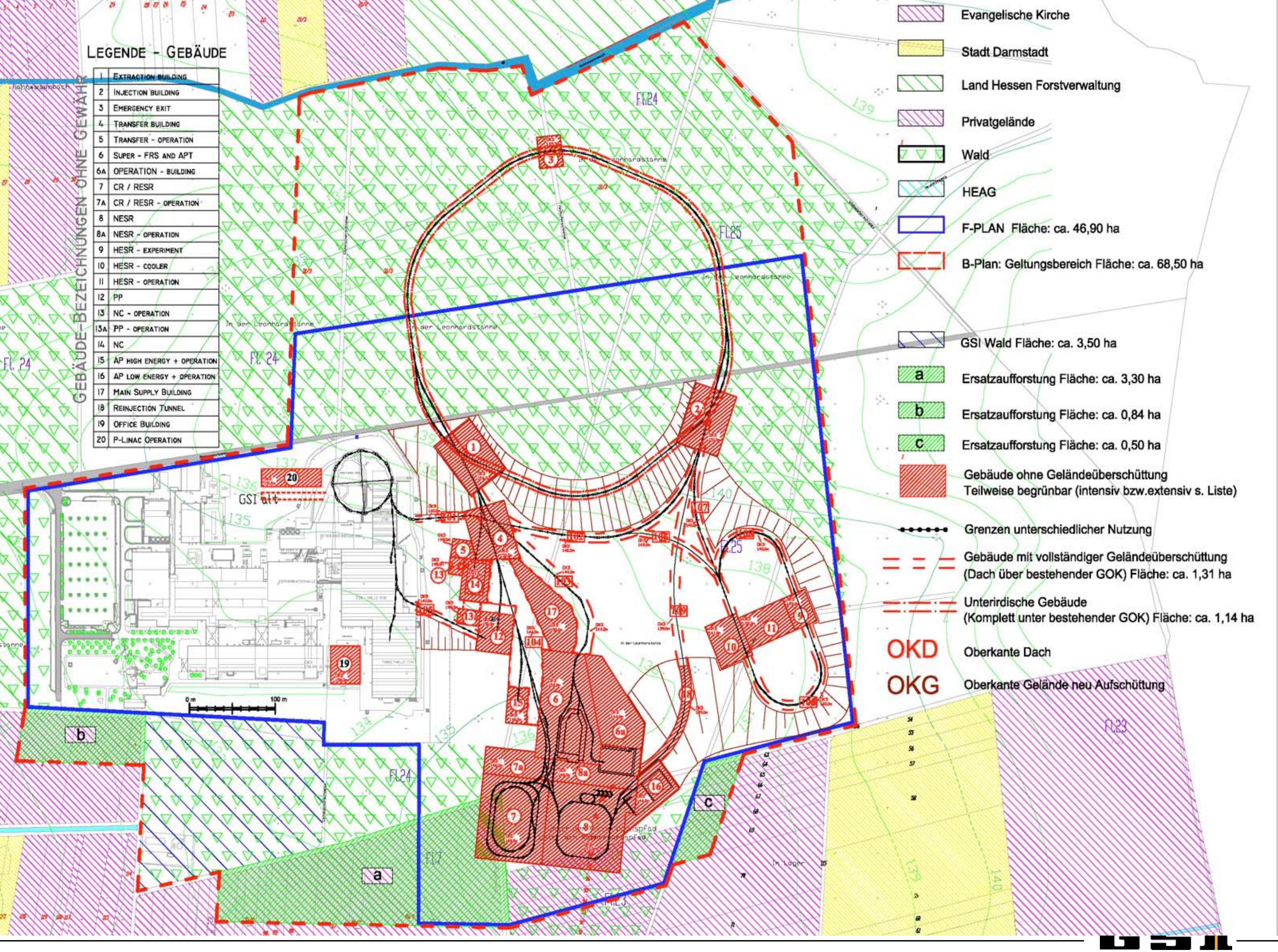
- Synthesis of light elements

Antiprotons 0-15(30) GeV

- Dark matter
- Chiral symmetry breaking

Relativ. HI → 35 GeV/n

- Quark-gluon plasma


Legende - Gebäude
1 Extraction building
2 Injection building
3 Emergency exit
4 Transfer building
5 Transfer - operation
6 Super - FRS and APT
6a Operation - building
7 CR / RESR
7a CR / RESR - operation
8 NESR
8a NESR - operation
9 HESR - experiment
10 HESR - cooler
11 HESR - operation
12 PP
13 NC - operation
13a PP - operation
14 NC
15 AP high energy + operation
16 AP low energy + operation
17 Main Supply Building
18 Reinjection Tunnel
19 Office Building
20 P-Linac Operation
Gebäude-Bezeichnungen ohne Gewähr
Evangelische Kirche
Stadt Darmstadt
Land Hessen Forstverwaltung
Privatgelände
Wald
HEAG
F-PLAN Fläche: ca. 46,90 ha
B-Plan: Geltungsbereich Fläche: ca. 68,50 ha
GSI Wald Fläche: ca. 3,50 ha
a Ersatzaufforstung Fläche: ca. 3,30 ha
b Ersatzaufforstung Fläche: ca. 0,84 ha
c Ersatzaufforstung Fläche: ca. 0,50 ha
Gebäude ohne Geländeüberschüttung
Teilweise begrünbar (intensiv bzw.extensiv s. Liste)
Grenzen unterschiedlicher Nutzung
Gebäude mit vollständiger Geländeüberschüttung
(Dach über bestehender GOK) Fläche: ca. 1,31 ha
Unterirdische Gebäude
(Komplett unter bestehender GOK) Fläche: ca. 1,14 ha
OKD Oberkante Dach
OKG Oberkante Gelände neu Aufschüttung
GSI alt
In der Leonhardstanne
0 m
100 m
M:\PKA\GA\Bau\Zeichnungen\2004\Masterplan_20040510_RING_GROSS_KURZ

# Key Developments and Milestones

1996-99 Discussion of Future Directions for the GSI Facilities
(Workshops and White Papers from 9 Working Groups, LoI Antiprotons)

2000 Development of Facility Concept

2001 Conceptual Design Report (700 pages, ca. 500 authors worldwide)

2002 Evaluation by the German Wissenschaftsrat & Recommendation for Realization

2002-03 Formation of Proto-Collaborations (PANDA / CBM / NUSTAR / FLAIR )

2003 Decision by the Federal Government to Construct Facility
(2 conditions: 25% of funding from international sources; technical staging)

2002-2003 Development of Staged Construction Concept and Science Programs

2003 2nd International Workshop

2004 Letters of Intent: 1800 participants,, (PANDA: ~ 320 participants, 44 institutions, 11 countries; CBM ~ 250 participants, 38 institutions, 15 countries; NUSTAR: ~450 participants, 98 institutions, 27 countries; FLAIR: ~ 250 participants, 48 institutions, 14 countries; ...)

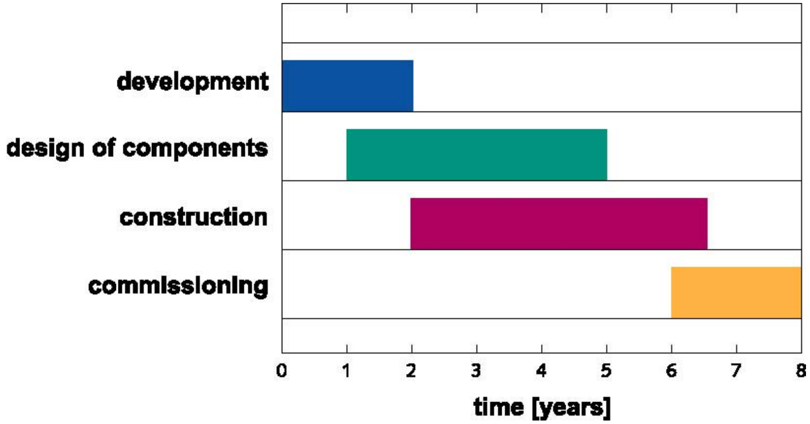
2004 Formation of the International Steering Committee (ISC-FAIR) and working groups (AFI-FAIR & STI-FAIR); first financial plan from the German government (federal and state)

# Users, Costs and Schedules Estimates from July 2001

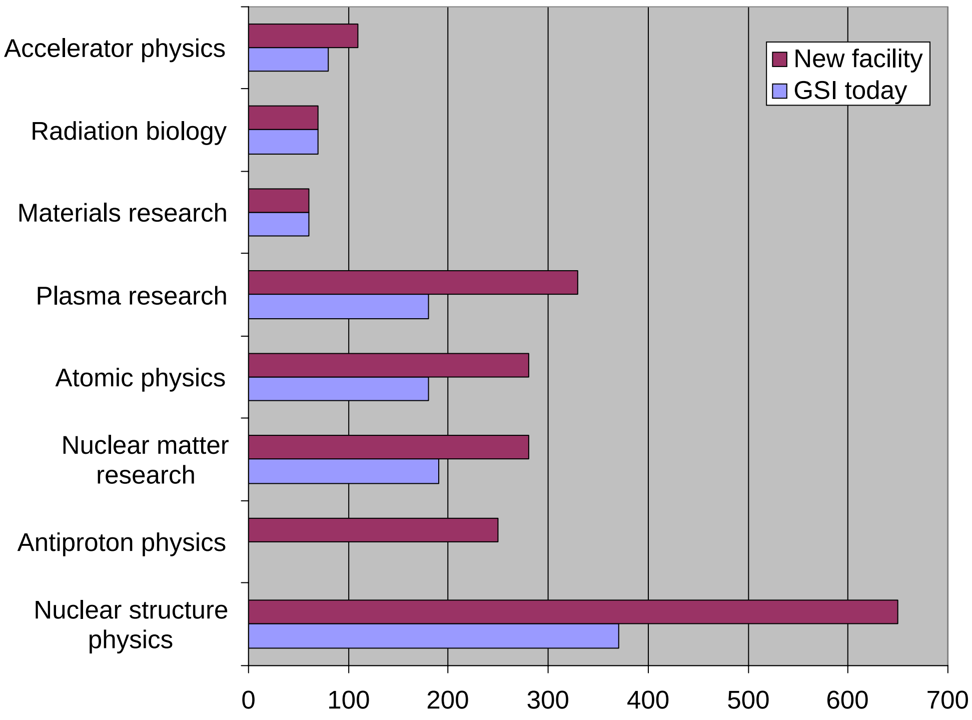
## COSTS

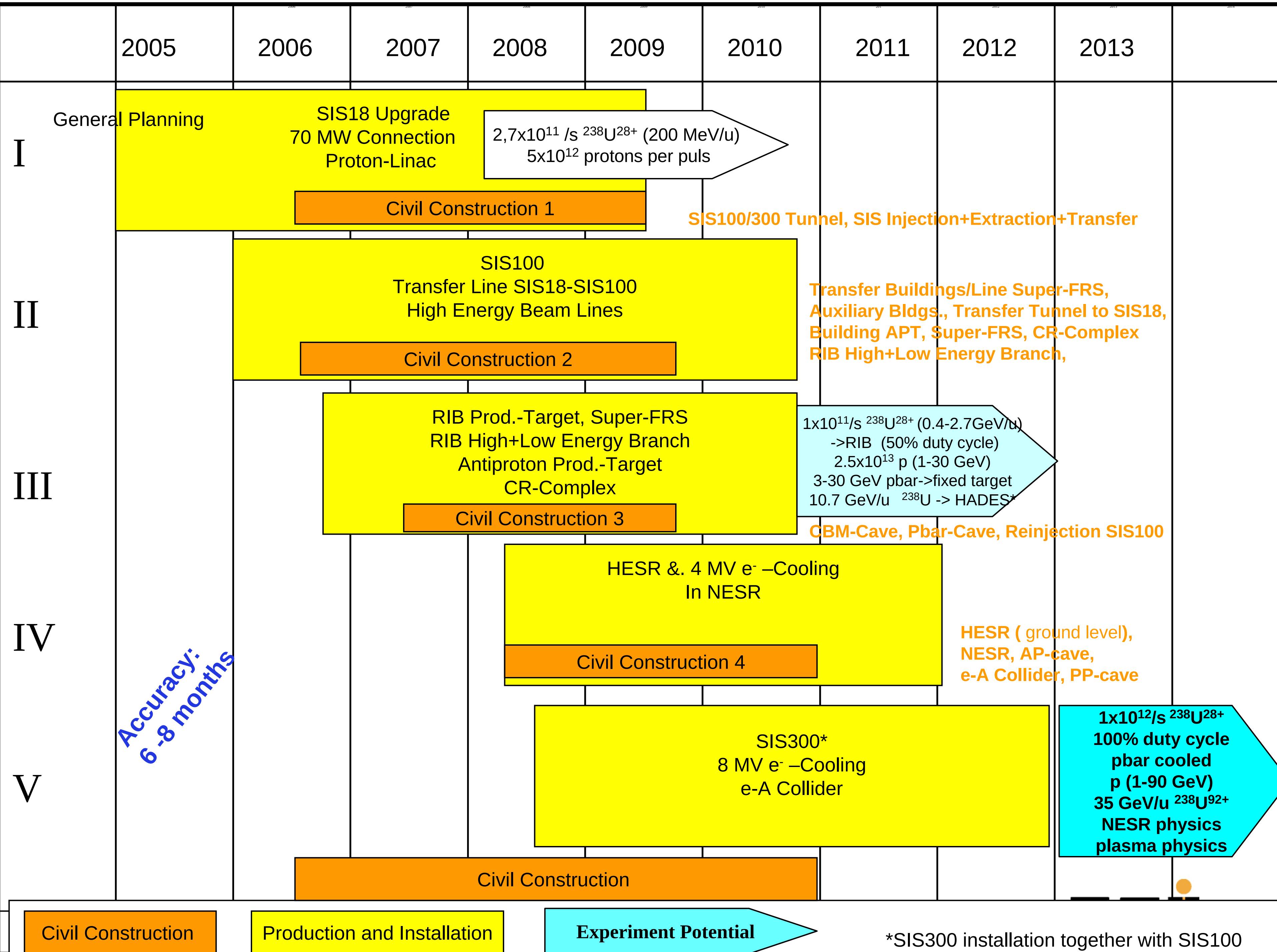
| | |
|---|---|
| Building and infrastructure: | 225 Mio. € |
| Accelerator: | 265 Mio. € |
| Experimental stations / detectors: | 185 Mio. € |
| Total: | 675 Mio. € |

## SCHEDULE




## Users interest




2005
2006
2007
2008
2009
2010
2011
2012
2013
General Planning
I
SIS18 Upgrade
70 MW Connection
Proton-Linac
2,7x10$^{11}$ /s $^{238}U^{28+}$ (200 MeV/u)
5x10$^{12}$ protons per puls
Civil Construction 1
SIS100/300 Tunnel, SIS Injection+Extraction+Transfer
II
SIS100
Transfer Line SIS18-SIS100
High Energy Beam Lines
Civil Construction 2
Transfer Buildings/Line Super-FRS,
Auxiliary Bldgs., Transfer Tunnel to SIS18,
Building APT, Super-FRS, CR-Complex
RIB High+Low Energy Branch,
III
RIB Prod.-Target, Super-FRS
RIB High+Low Energy Branch
Antiproton Prod.-Target
CR-Complex
Civil Construction 3
1x10$^{11}$/s $^{238}U^{28+}$ (0.4-2.7GeV/u)
->RIB (50% duty cycle)
2.5x10$^{13}$ p (1-30 GeV)
3-30 GeV pbar->fixed target
10.7 GeV/u $^{238}U$ -> HADES*
CBM-Cave, Pbar-Cave, Reinjection SIS100
IV
HESR &. 4 MV e$^-$ –Cooling
In NESR
Civil Construction 4
HESR ( ground level),
NESR, AP-cave,
e-A Collider, PP-cave
Accuracy:
6 -8 months
V
SIS300*
8 MV e$^-$ –Cooling
e-A Collider
1x10$^{12}$/s $^{238}U^{28+}$
100% duty cycle
pbar cooled
p (1-90 GeV)
35 GeV/u $^{238}U^{92+}$
NESR physics
plasma physics
Civil Construction
Civil Construction
Production and Installation
Experiment Potential
*SIS300 installation together with SIS100

# Radiation Safety Approval Procedure

In February 2002, one year before the “green light” was obtained from the German government, GSI applied for the Construction of an International Facility for the Research with Ion and Proton Beams at the **Hessian Ministry for Environment**

Hessisches Ministerium
für Umwelt, ländlichen Raum
und Verbraucherschutz

In December 2003, GSI received official letter with the first approval:

....the planned facility will fulfill the requirements in accordance with the German radiation protection laws for the construction of the whole installation and the operation as outlined in the Conceptual Design Report.

# International (Committee) Structure for the Facility for Antiproton and Ion Research (FAIR)

International Steering Committee
(ISC-FAIR) *H. Schunck*

Working Group on
Administrative and Financial Issues
(AFI-FAIR) *H-F. Wagner*

Working Group on
Scientific and Technical Issues
(STI-FAIR) *S. Gales*

**PAC / QCD**
*R. Chiavassa*

**PAC / NSTR**
*R. Casten*

**PAC / APPA**
*D. Schwalm*

**TAC / ACC**
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- International Steering Committee (ISC-FAIR) *H. Schunck*
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  - Working Group on Scientific and Technical Issues (STI-FAIR) *S. Gales*
    - **PAC / QCD** *R. Chiavassa*
    - **PAC / NSTR** *R. Casten*
    - **PAC / APPA** *D. Schwalm*
    - **TAC / ACC** *Y. Cho*

LoI Submission (1800 authors):
Jan. 15 & April 15, 2004
PAC Meeting:
June 14-16, 2004

# FAIR: Facility for Antiproton and Ion Research