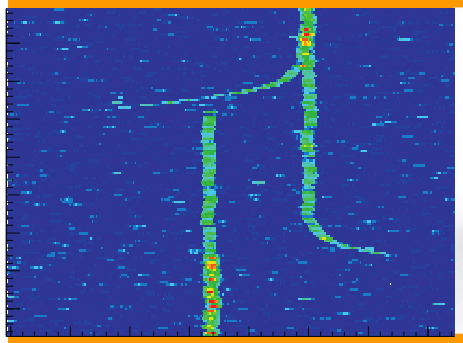
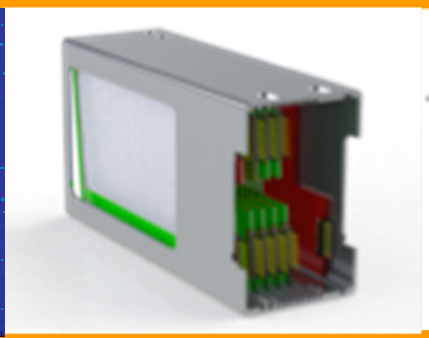
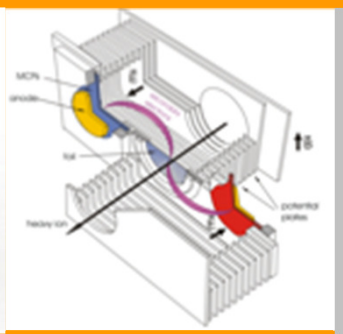
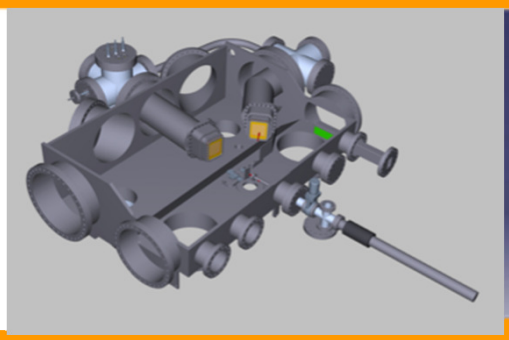
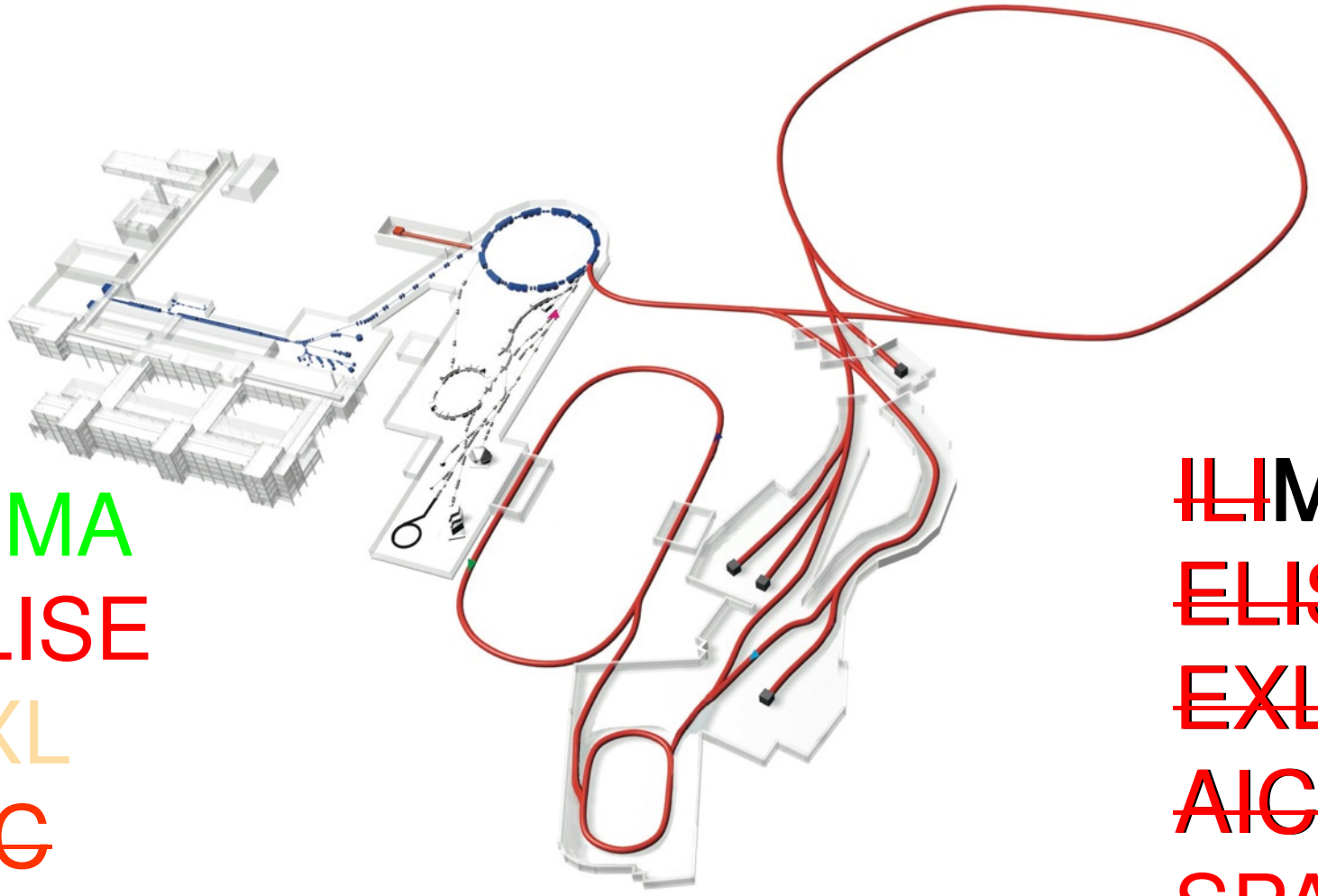






NUSTAR storage ring experiments

Yuri A Litvinov
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

HIC4FAIR Workshop Detectors & Accelerators
28-31 July 2015
Hamburg, Germany

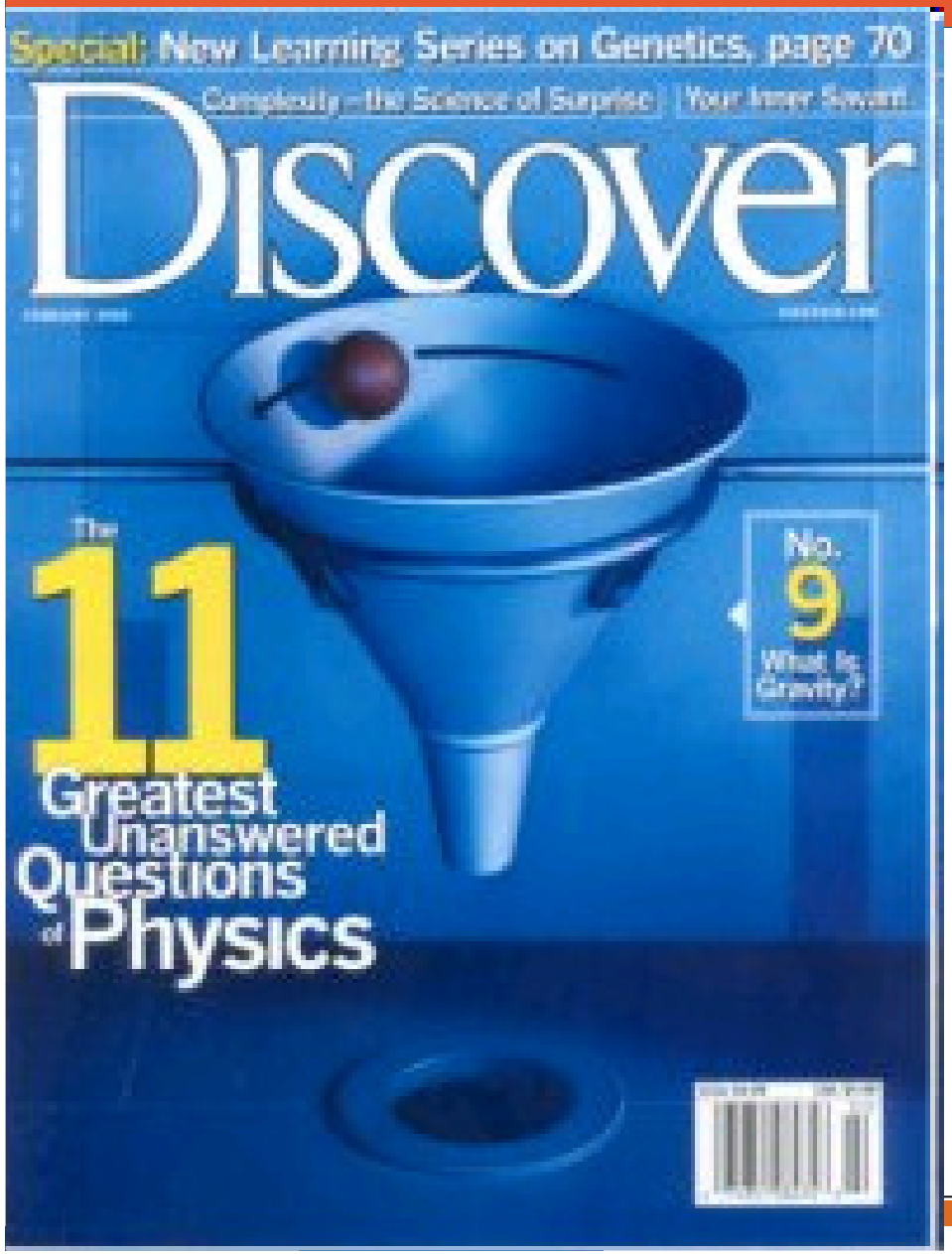
FAIR FV vs. MSV



ILIMA
ELISE
EXL
~~AIC~~
SPARC

~~ILI~~MA
~~ELISE~~
~~EXL~~
~~AIC~~
~~SPARC~~

National Research Council's board on physics and astronomy

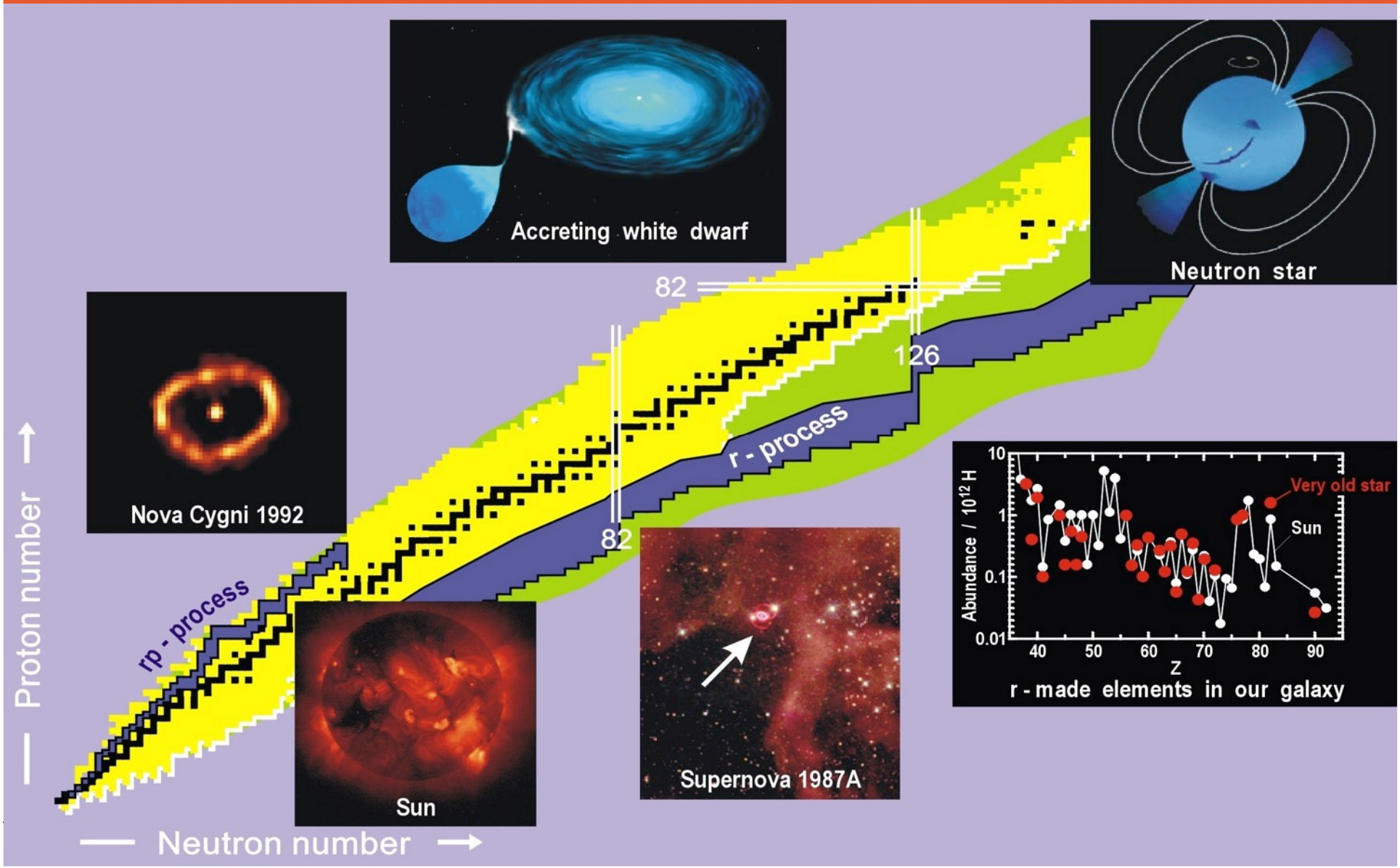


02.01.2002
The 11 Greatest Unanswered Questions of Physics

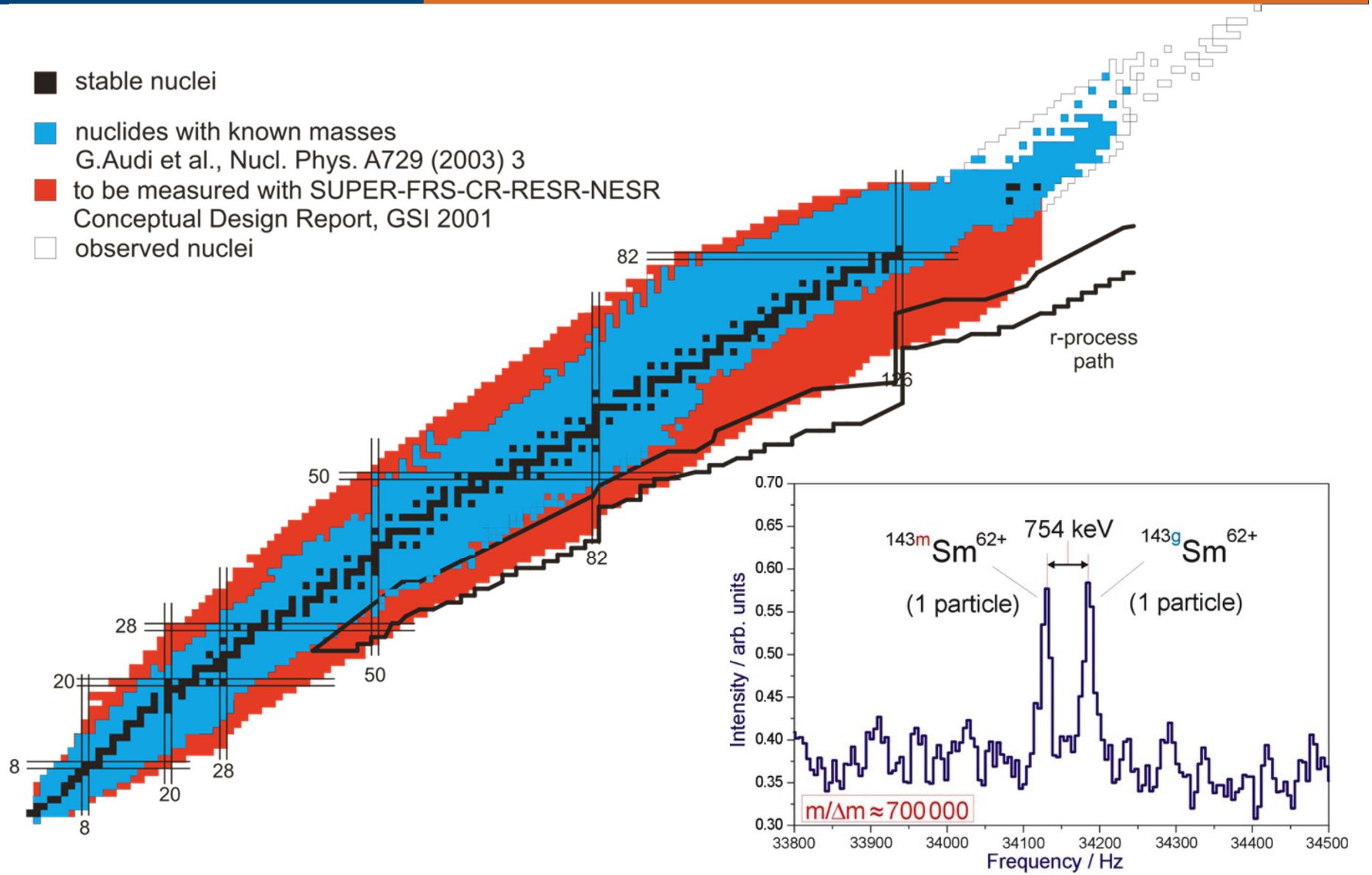
Resolution of these profound questions could unlock the secrets of existence and deliver a new age of science within several decades
by Eric Haseltine, Illustrations by Dan Winters & Gary Tanhauser

3. How were the heavy elements from iron to uranium made?

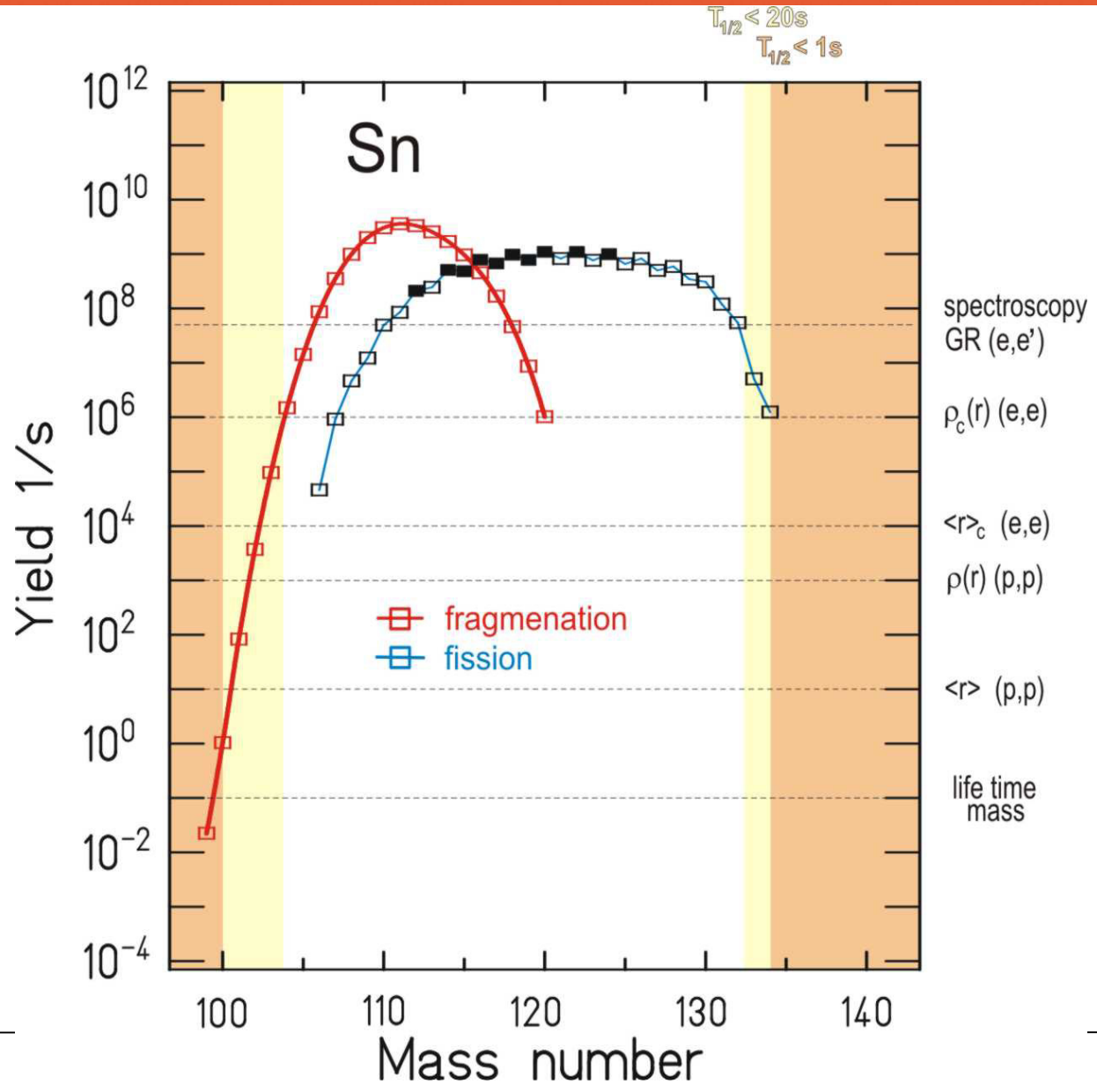
The r (rapid neutron capture) –process creates about 50% of nuclei; its site is still unknown



Nuclides in reach with ILIMA



Production Cross-Sections for Tin-Isotopes



REQUIREMENT SLIDE #1

COMMON FOR ALL EXPERIMENTS

BEAMS: ALL KINDS FROM p TO ^{238}U

INTENSITY: MAXIMUM ACHIEVABLE

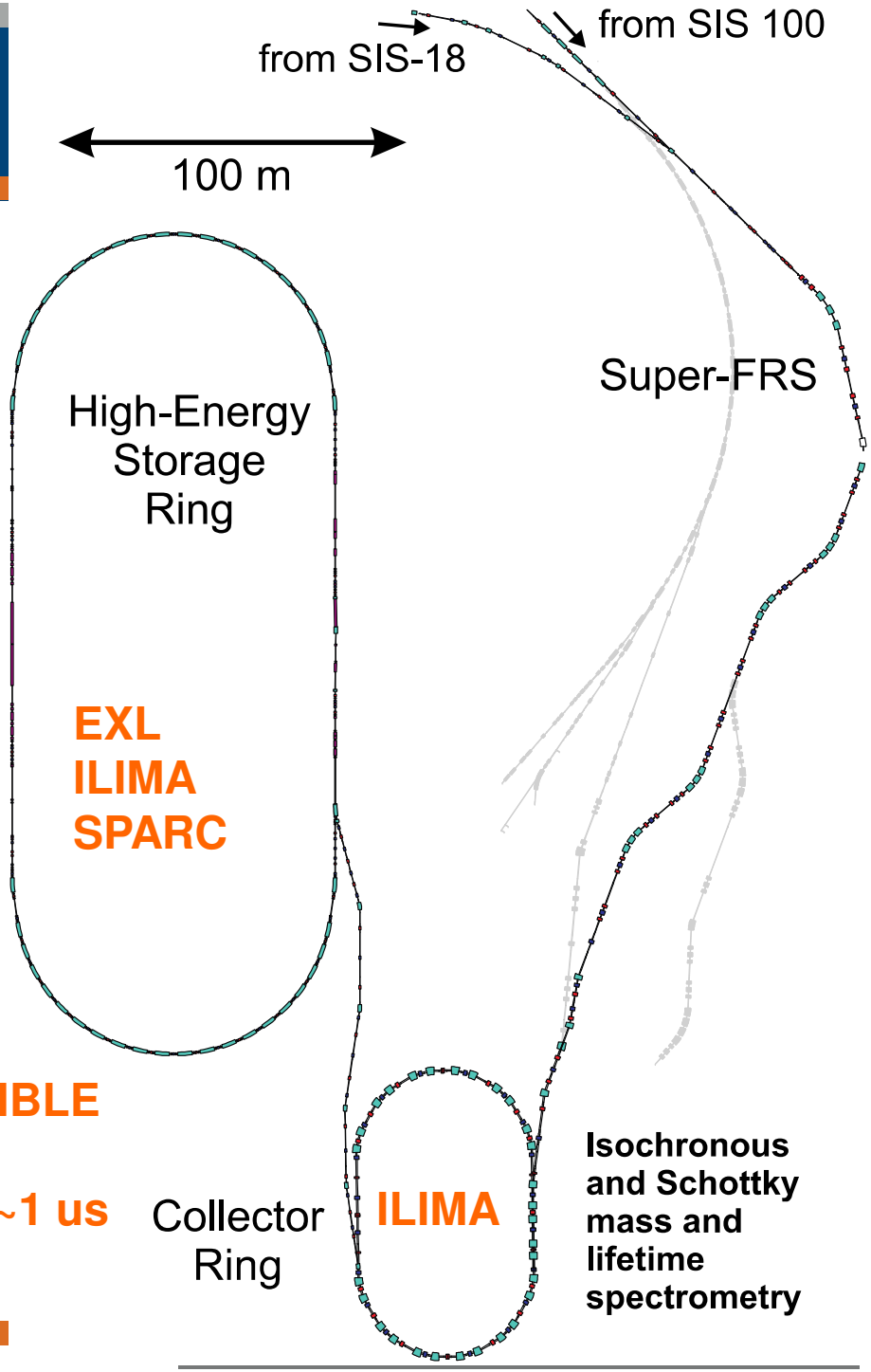
ENERGIES: 200-2000 MeV/u

ALL @ HESR

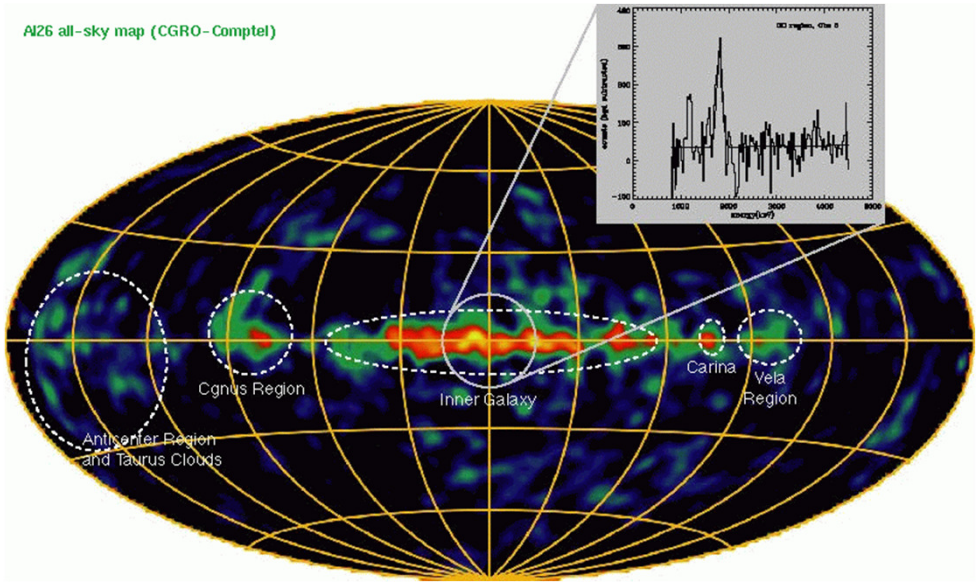
INJECTIONS AS OFTEN AS POSSIBLE
LIMITED BY HESR (0.1 Hz)
ACCUMULATION IF LIFETIMES ALLOW
STOCHASTIC COOLING
ELECTRON COOLING (CELSIUS)
BUNCH ROTATION IN CR =
PULSE LENGTH = ~50 ns

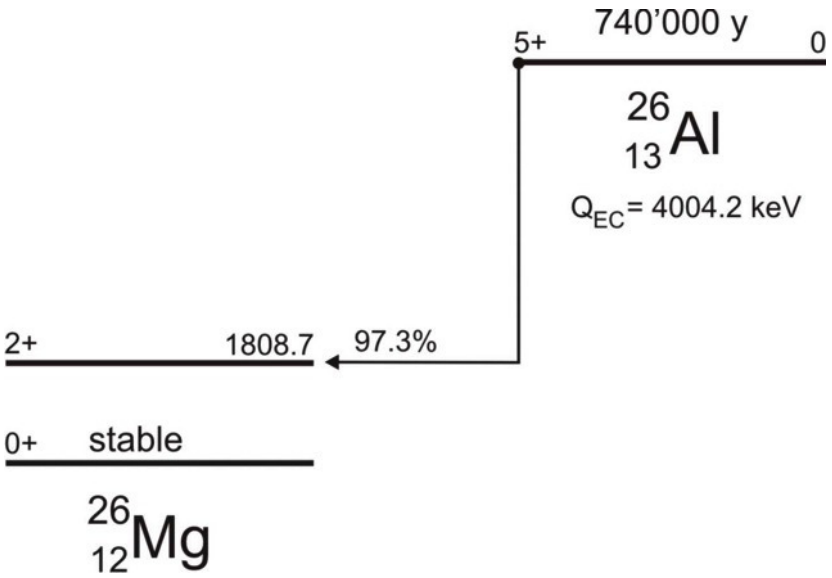
ILIMA @ CR

MEASUREMENT TIME IS 1 ms =
INJECTIONS AS OFTEN AS POSSIBLE
ISOCHRONOUS MODE = NO COOLING =
NO BUNCH ROTATION = PULSE LENGTH ~1 us



Stellar Gamma-Ray Emitters





Hydrogen-like ^{26}Al

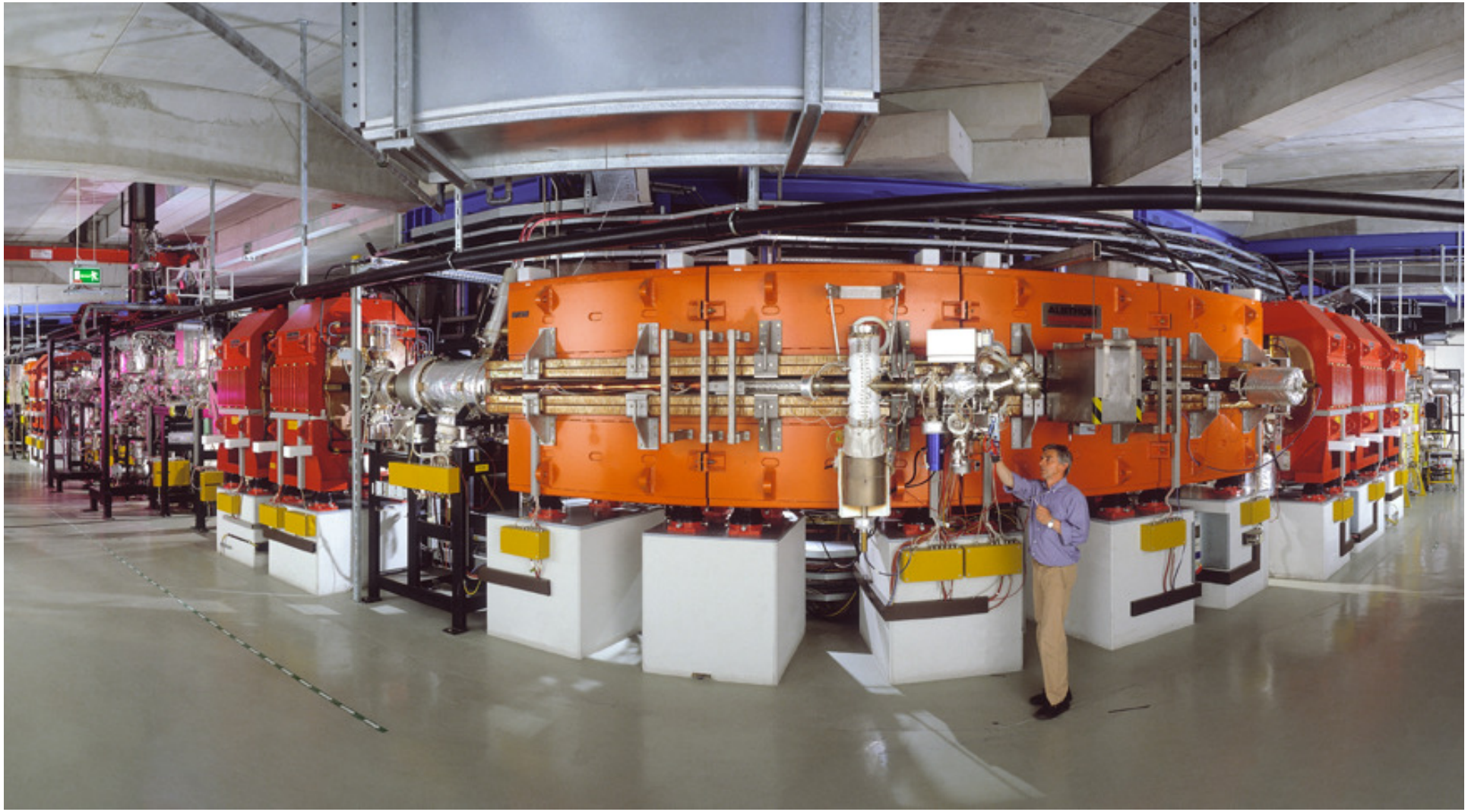
$\mu > 0$

$F = I + s$ { 13/2 (11/2) $\Delta I=3$ (?) / $\Delta I=4$ → 5/2, 3/2 } $F = I + s$

$\mu < 0$

$F = I + s$ { 11/2 (13/2) $\Delta I=4$ / $\Delta I=5$ → 5/2, 3/2 } $F = I + s$

Experimental Storage Ring ESR



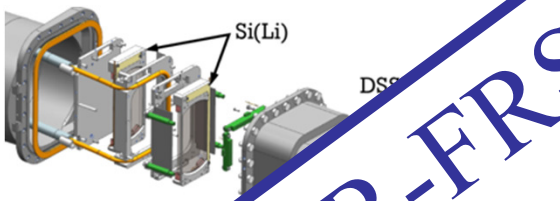
ESR: B. Franzke, NIM B 24/25 (1987) 18

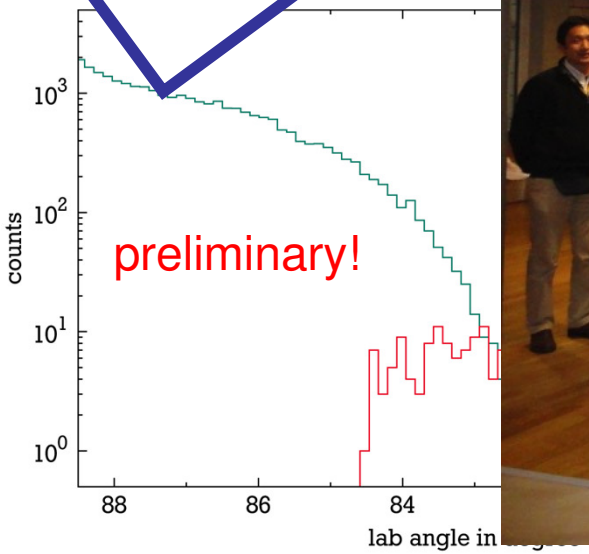
Stochastic cooling: F. Nolden et al., NIM B 532 (2004) 329
Electron cooling: M. Steck et al., NIM B 532 (2004) 357

Intermediate storage ri ties @ ESR

Elastic p-scatterin

SUPER-FRS Intensities are required





First realization of an RIB electron collider setup at the ESR

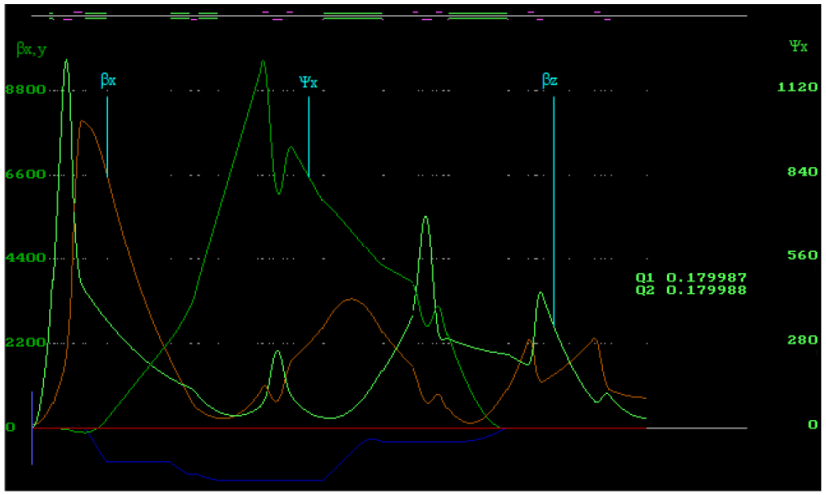
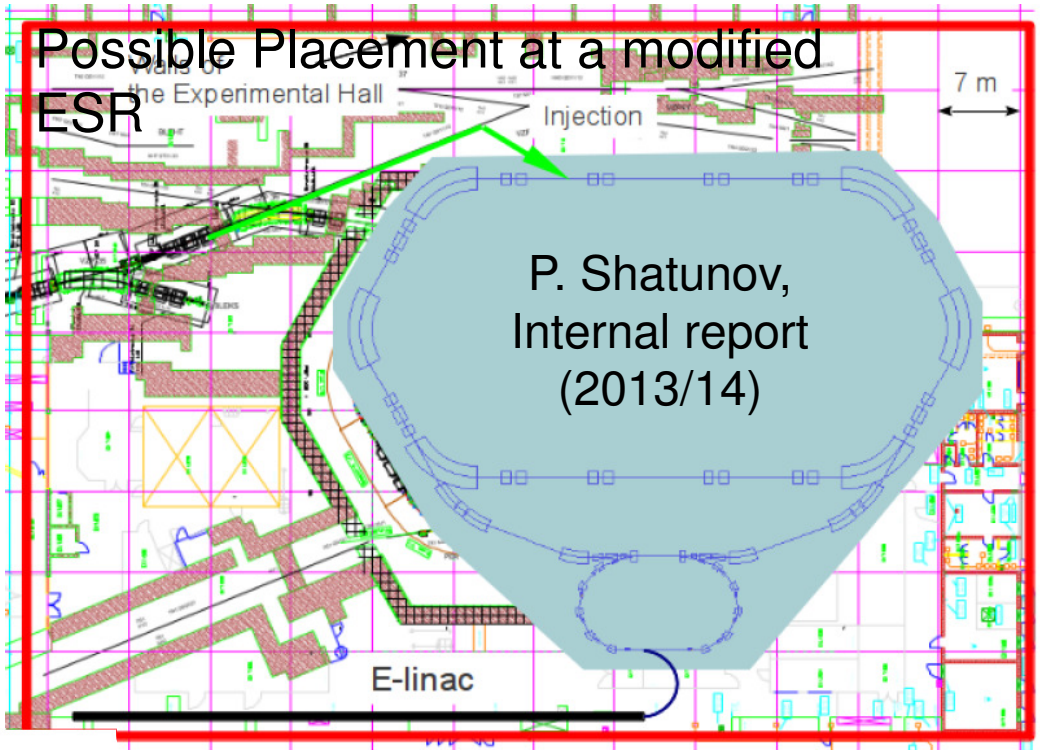
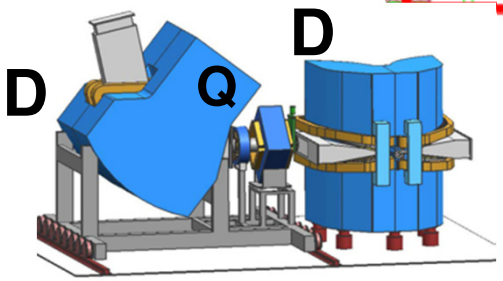


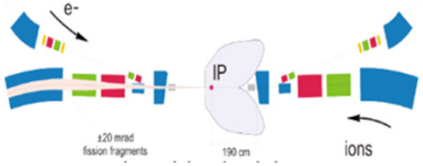
Figure 9. Beta (β, cm) and dispersion (Ψ, cm) functions of stretched ESR (1 half) in the collider mode.



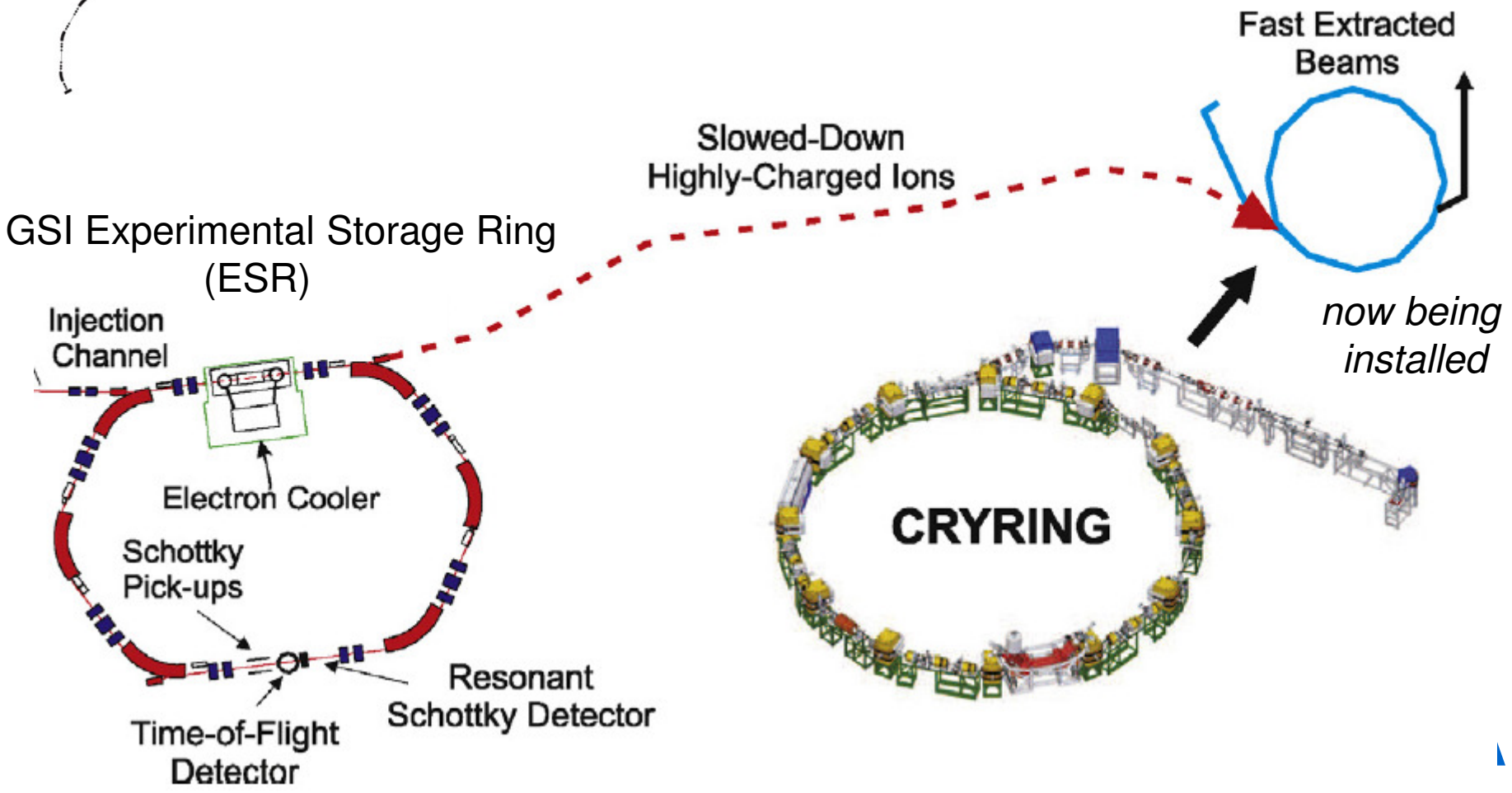
GPA Berg et al.,
NIM **A640** (2011) 123
NIM **A659** (2011) 198



ELISe Collaboration
NIM **A637** (2011) 60



Possibility to prepare <100 keV bare ions



Walker, Litvinov and Geissel, Int. J. Mass Spec. 349-350 (2013) 247

The case of CRYRING

ESR: beam energies > 4.0 MeV/u
reaction rates measurements in the Gamow window of the **p-process**

Q. Zhong et al., J. Phys. CS 202 (2010) 012011

→

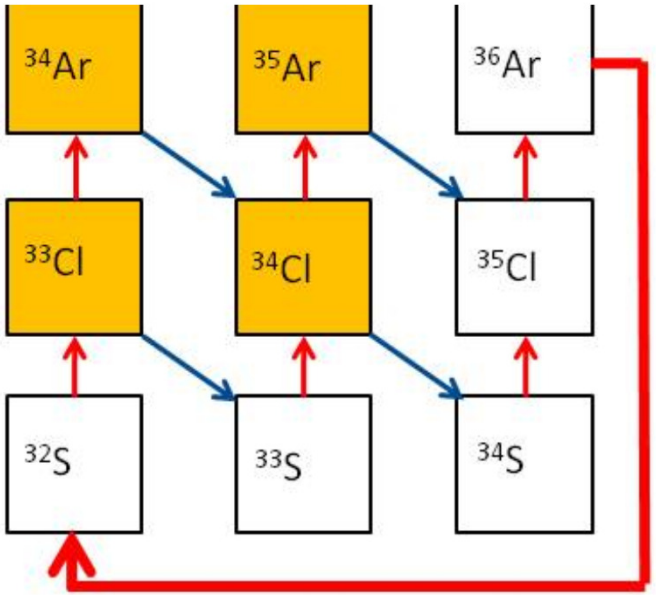
Cryring+ESR: beam energies 0.1-1.0 MeV/u
reaction rates measurements in the Gamow window of the **rp-process**

R. Reifarth et al., Cryring Physics Book

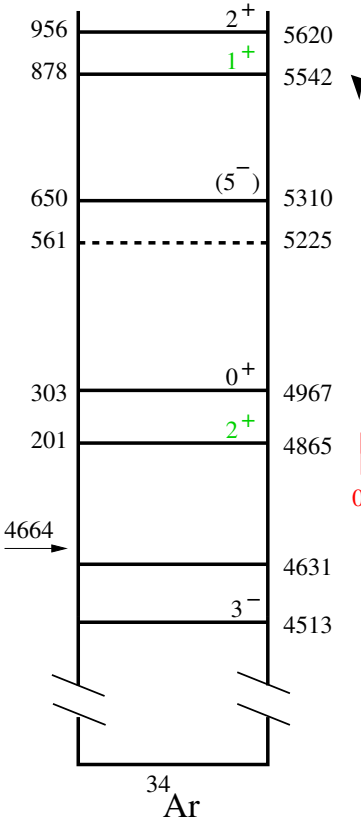
One example: ^{33}Cl(p,γ)^{34}Ar by-pass of ^{34m}Cl γ-ray emitting isomer

Novae physics

Production of ^{34m,g}Cl



S. Bishop and Yu. Litvinov, Cryring Physics Book



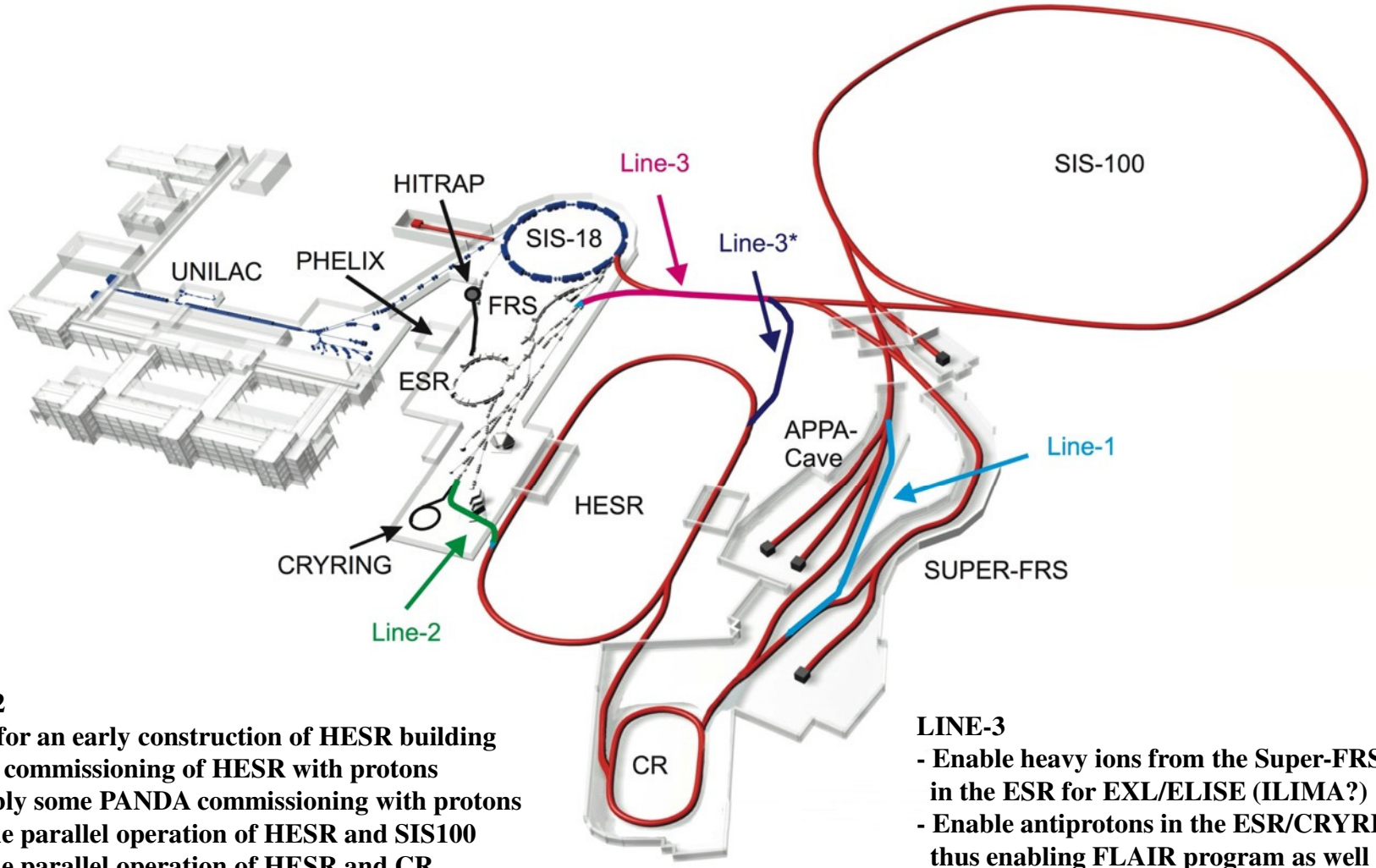
resonance strengths

assuming 10^6 stored ^{33}Cl we can expect:

1200 count/hr
1 count/s
2 counts/s
10 counts/day
1 count/s

1.0
0.3
0.1

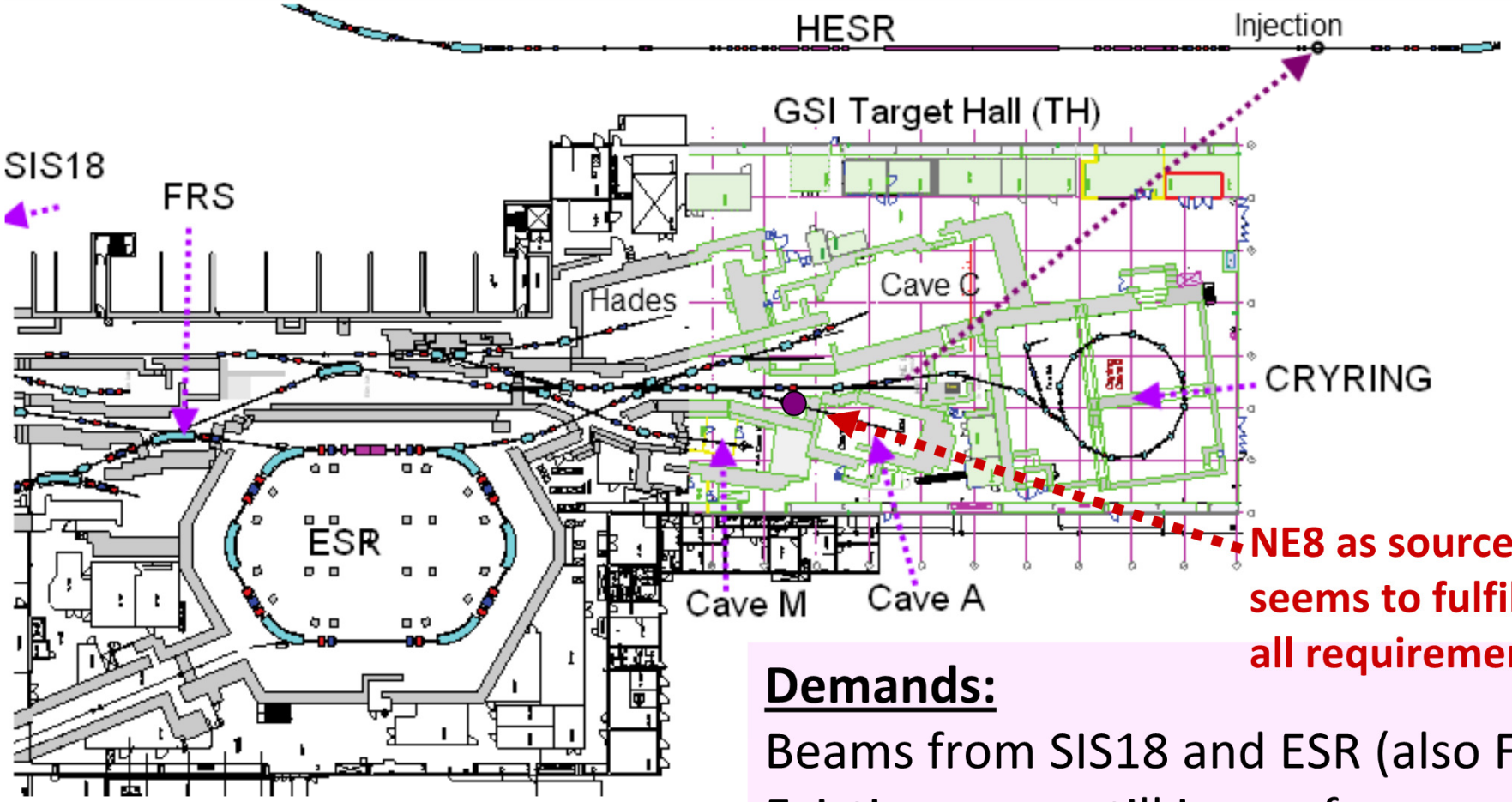
Extensions of the MSV of FAIR



LINE-2
- **Push for an early construction of HESR building**
- **Early commissioning of HESR with protons**
- **Possibly some PANDA commissioning with protons**
- **Enable parallel operation of HESR and SIS100**
- **Enable parallel operation of HESR and CR**
- **Realization of SPARC program at the HESR**
- **Realization of a part of ILIMA with ESR-HESR**

LINE-3
- **Enable heavy ions from the Super-FRS in the ESR for EXL/ELISE (ILIMA?)**
- **Enable antiprotons in the ESR/CRYRING, thus enabling FLAIR program as well as hadron physics with slow antiprotons**

Spatial conditions in the HEBT behind SIS18/ESR



NE8 as source point seems to fulfill all requirements

Demands:

Beams from SIS18 and ESR (also FRS)

Existing caves still in use for expmts.

Minimized costs

Early realization (2017/2018)

SUMMARY

- **BEAMS - ALL! From p to ^{238}U**
- **BEAM DEVELOPMENTS – Be, Tl and Th**
- **BEAM ENERGIES – 200 – 2000 MeV/u**
- **FAST EXTRACTION – 50 ns / ~1 us**
- **BEAM EMITTANCE – to assure the best transmission through the Super-FRS**
- **ISOCHRONOUS MODE OF CR**
- **FAST STOCHASTIC COOLING IN CR**
- **STOCHASTIC/ELECTRON COOLING IN HESR**
- **REPETITION CYCLE – 0.1 Hz – 1 Hz**
- **!!! NuSTAR PHYSICS REQUIRES HIGHEST INTENSITIES FOR ALL BEAMS!!!**

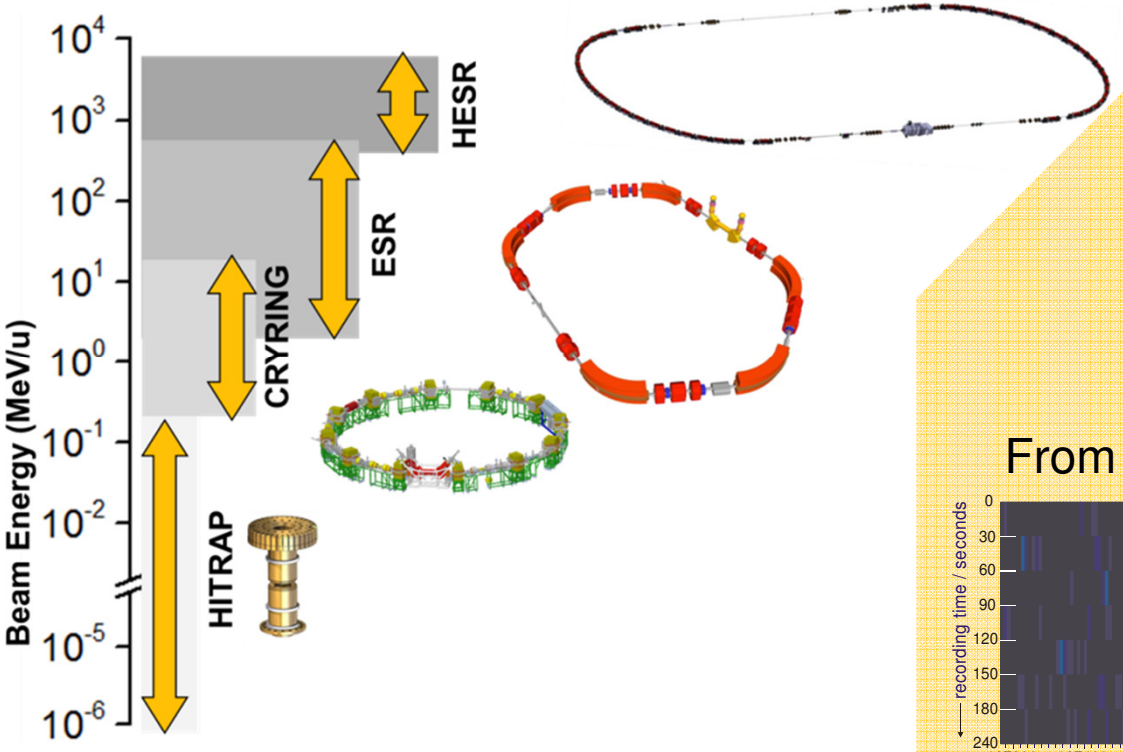
Ion Beam Facilities / Trapping & Storage

Worldwide Unique !

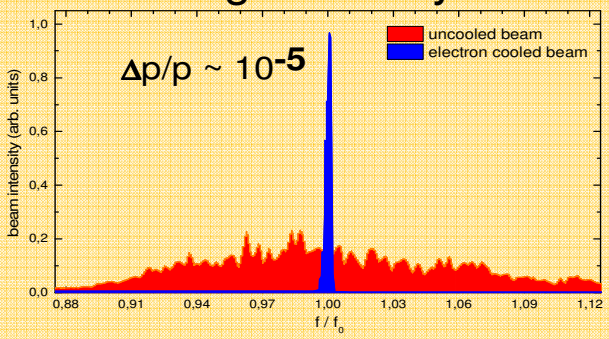
Stored and Cooled

Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei

From Rest to Relativistic Energies (up to 4.9 GeV/u)



Cooling: The Key for Precision



From Single Ions to Highest Intensities