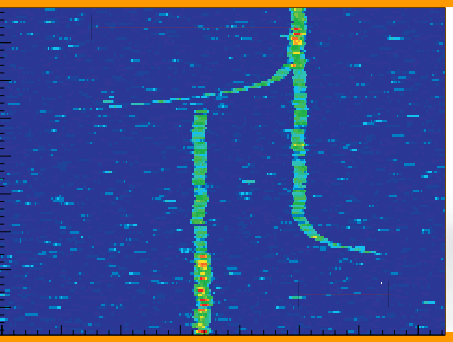
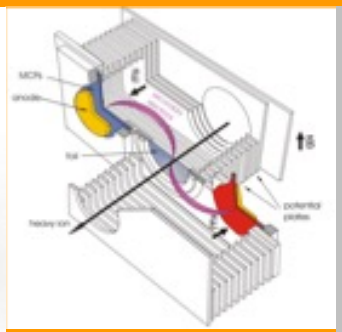
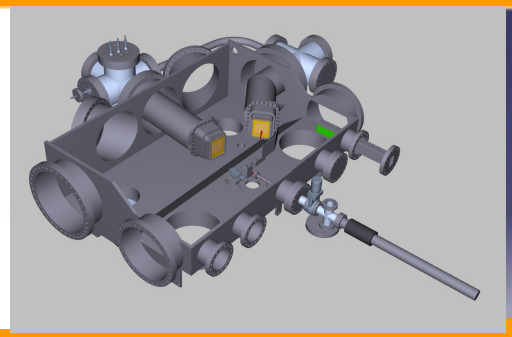
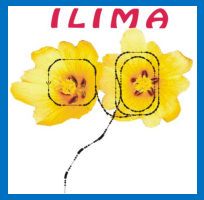



Yuri A Litvinov

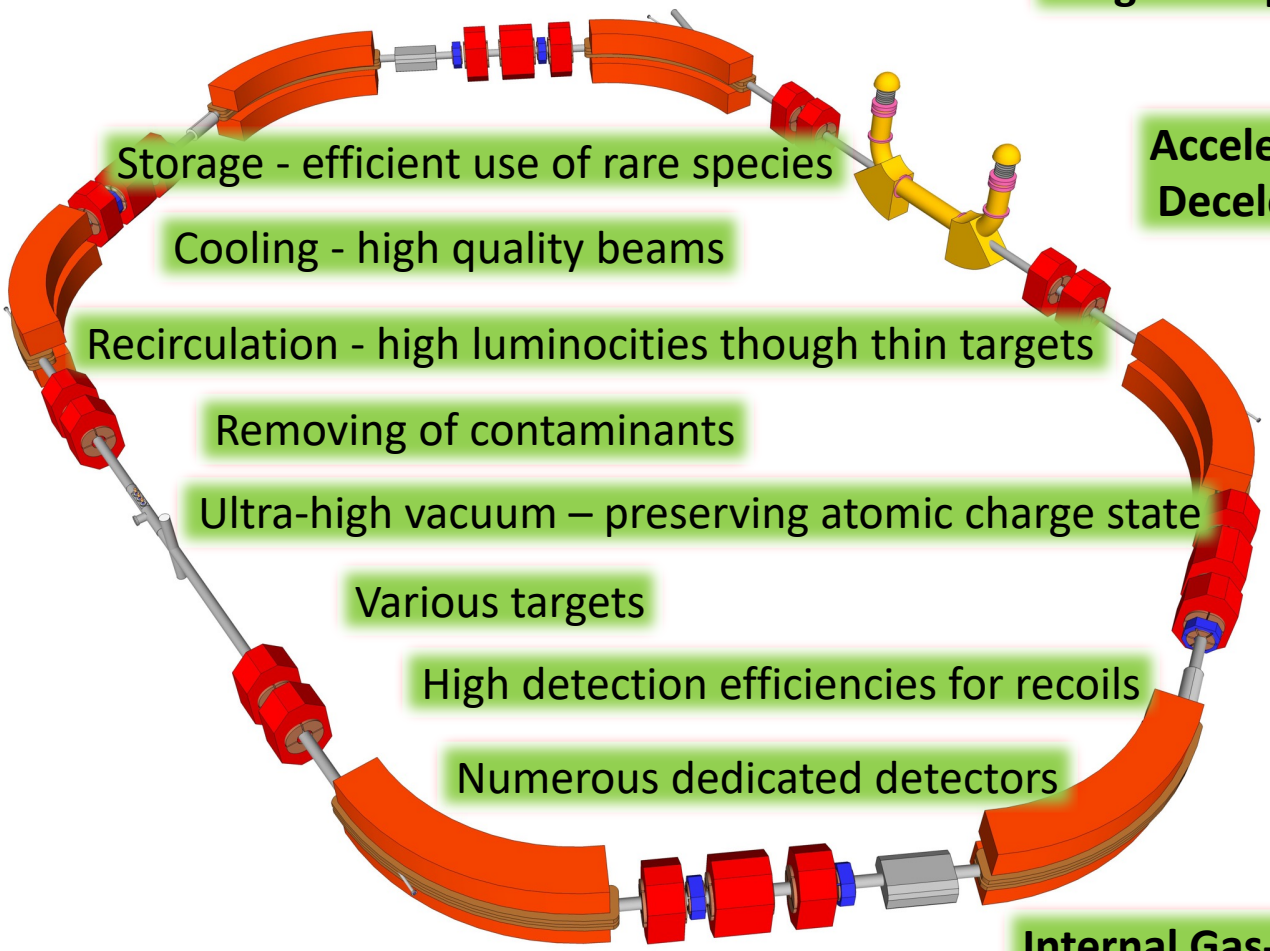
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

On behalf of the storage ring collaborations



FAIR/GSI Research Retreat 2023
13-14 February 2023
Hotel Tobbaccon, Bensheim, Germany

Why storage rings? - Versatile Capabilities



Storage - efficient use of rare species

Cooling - high quality beams

Recirculation - high luminocities though thin targets

Removing of contaminants

Ultra-high vacuum – preserving atomic charge state

Various targets

High detection efficiencies for recoils

Numerous dedicated detectors

Large Acceptance

Beam Accumulation

Acceleration/ Deceleration

Beam Cooling:
- **Stochastic**
- **Electron**
- **(Laser)**

UHV

Beam Bunching

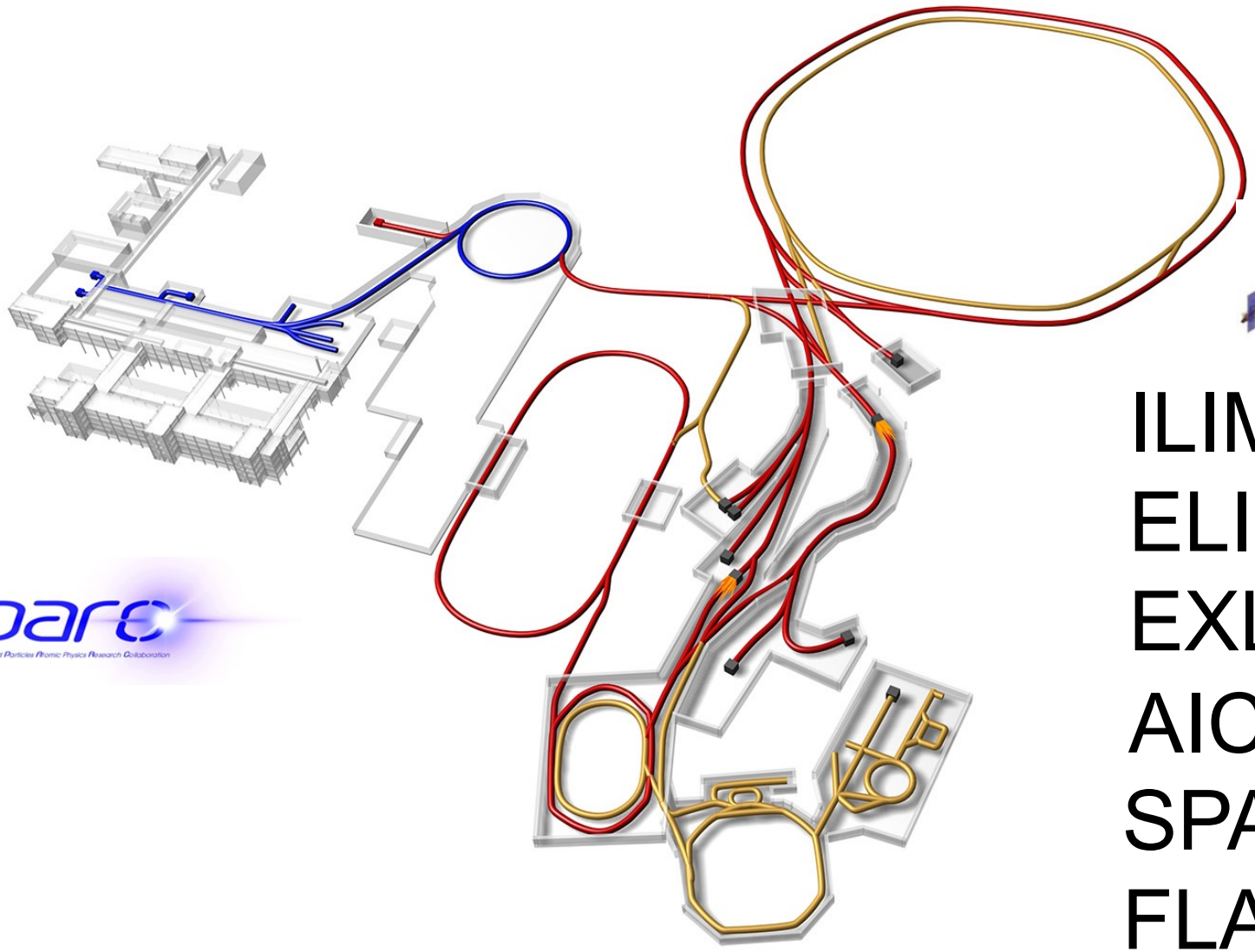
Various targets:
- **Electrons**
- **Photons**
- **Atoms**
- **(Ions)**
- **(Neutrons)**

Internal Gas-Jet Target

Non-destructive particle detection

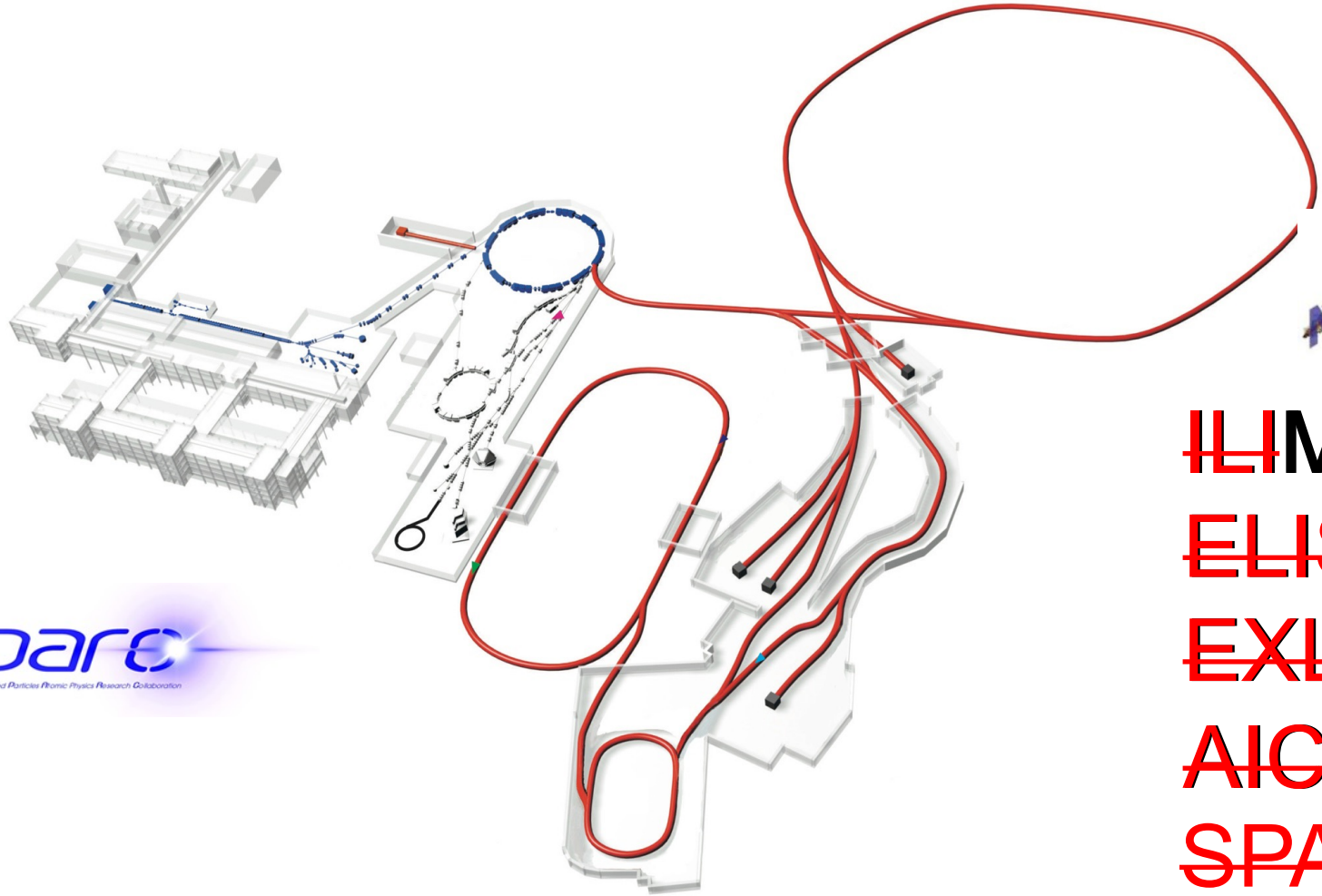
Detection:
- **Electrons**
- **Photons**
- **Recoils**

FAIR FV vs. MSV



ILIMA
ELISE
EXL
AIC
SPARC
FLAIR

FAIR FV vs. MSV



~~ILI~~MA

~~ELISE~~

~~EXL~~

~~AIC~~

SPARC

~~FLAIR~~

ILIMA Set-Up at FAIR

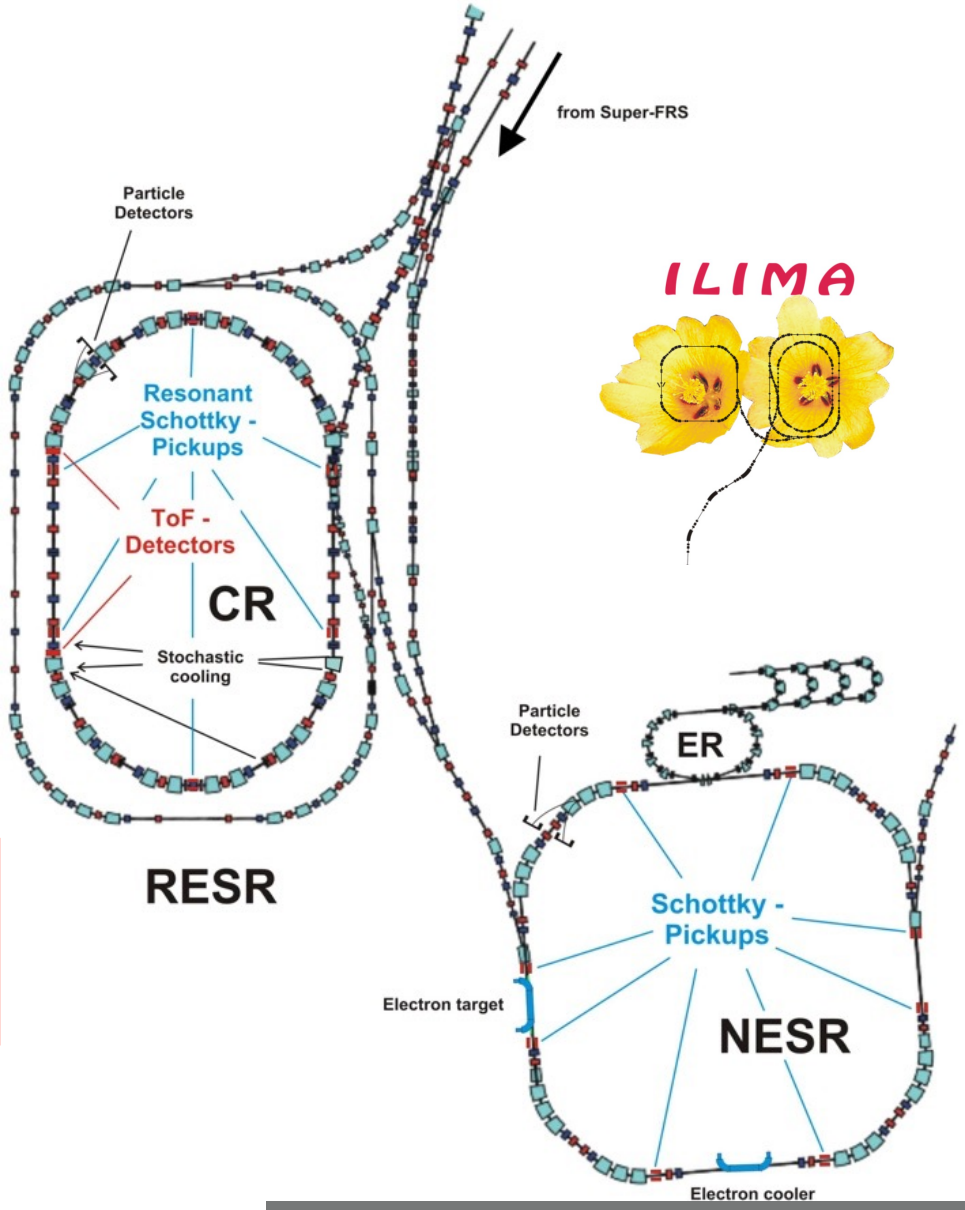
Isochronous Mass Spectrometry in the CR

$$\gamma \rightarrow \gamma_t$$

Schottky Mass Spectrometry in the CR & NESR

$$\frac{\Delta v}{v} \rightarrow 0$$

$$\frac{\Delta t}{t} = -\frac{\Delta f}{f} = \frac{1}{\gamma_t^2} \cdot \frac{\Delta(m/q)}{m/q} + \left(\frac{\gamma^2}{\gamma_t^2} - 1\right) \cdot \frac{\Delta v}{v}$$



Masses: Fundamental Properties of Atomic Nuclei

- ➢ **Binding energies**
- • **Mass models**
- • **Shell structure**

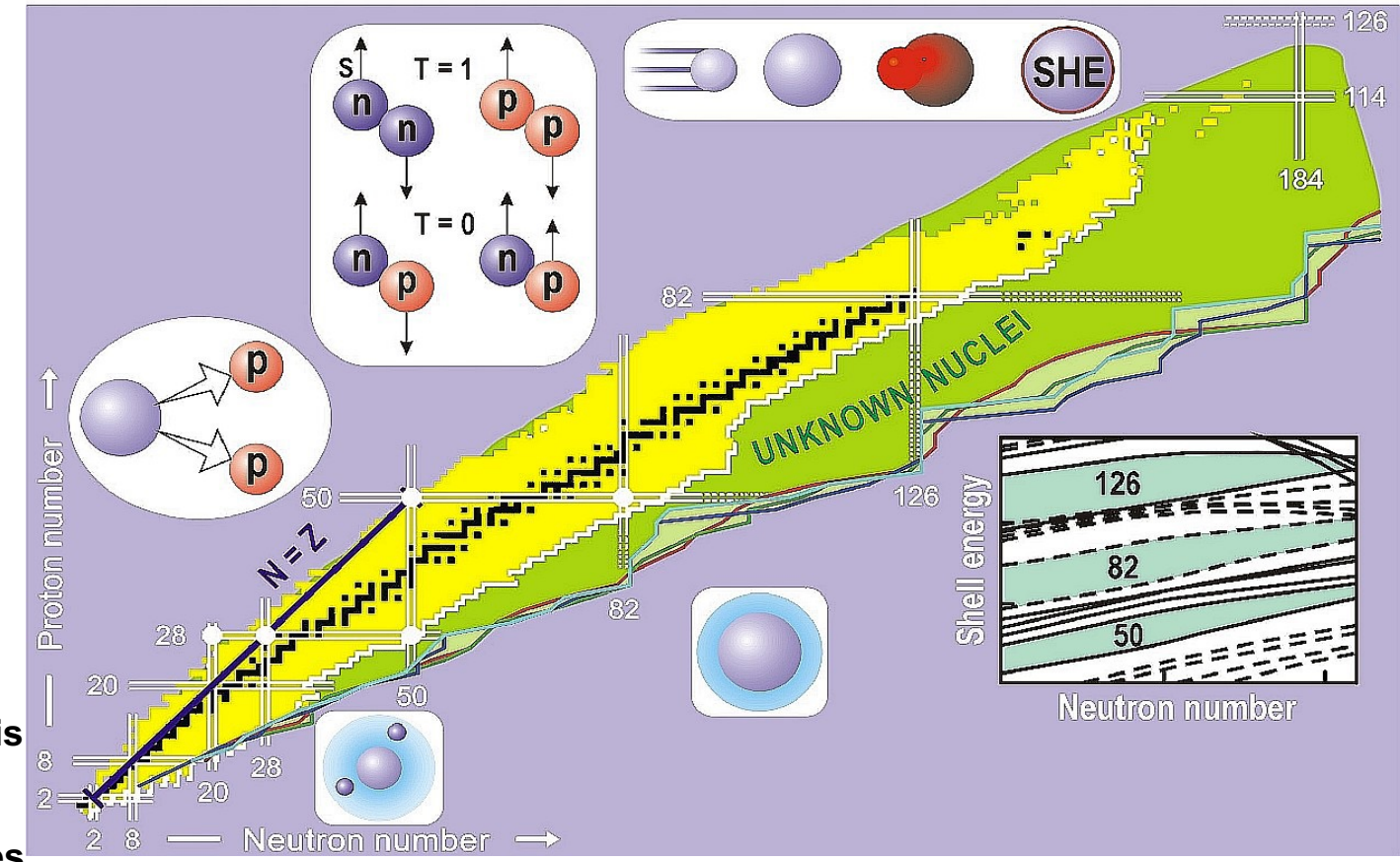
- ➢ **Correlations**
- • **pairing**

- ➢ **Reaction phase space**
- • **Q-values**
- • **Reaction probabilities**

- ➢ **The reach of nuclei**
- • **Drip lines**
- • **Specific configurations and topologies**

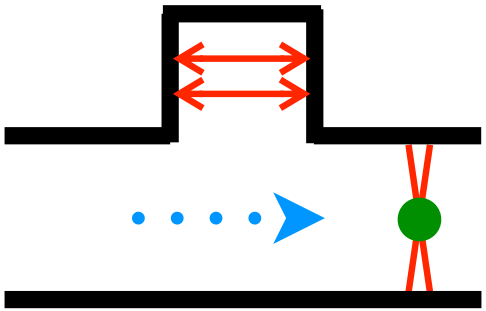
- ➢ **Nuclear astrophysics**
- • **Paths of nucleosynthesis**

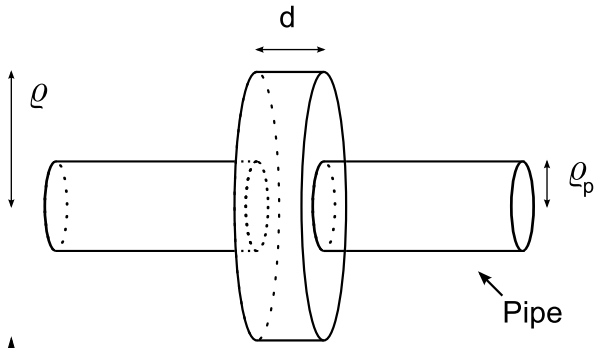
- ➢ **Fundamental symmetries**
- ➢ **Metrology**
- ➢ **…..**

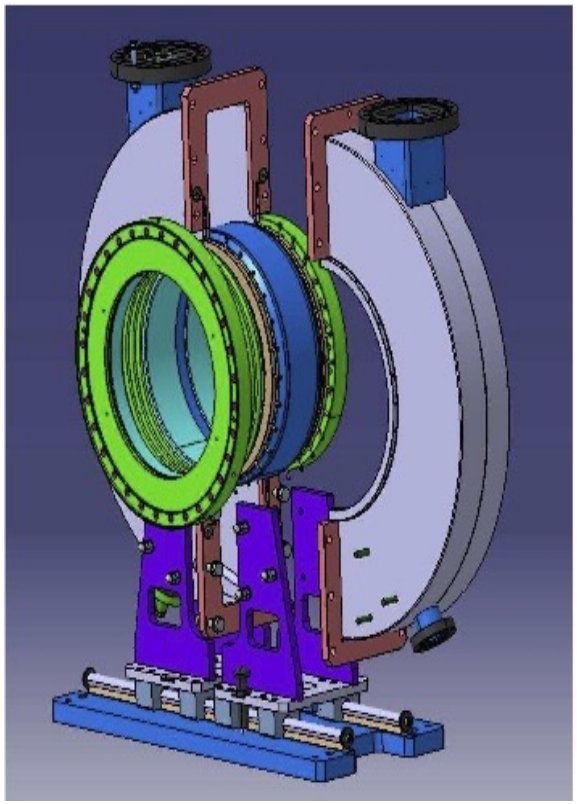


The goal:
Measure the revolution frequency of a single ion within a few miliseconds

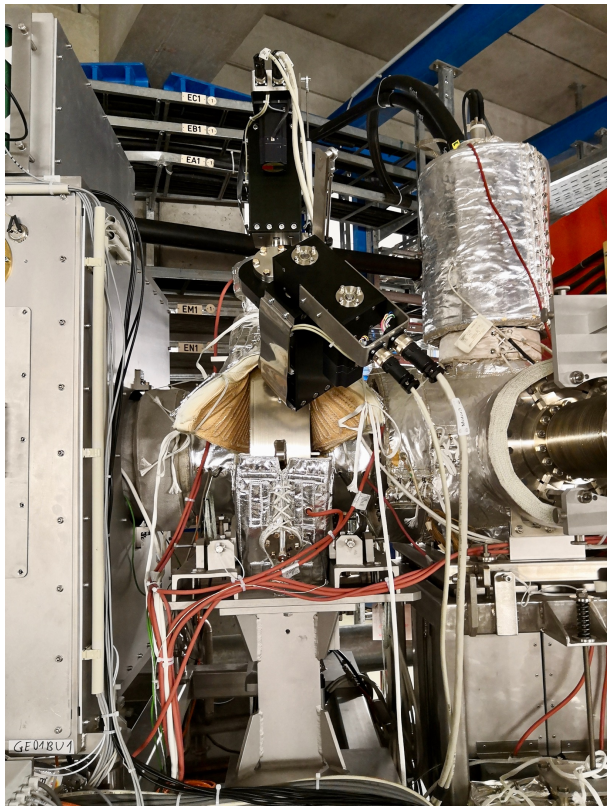
Non-Destructive Particle Detection







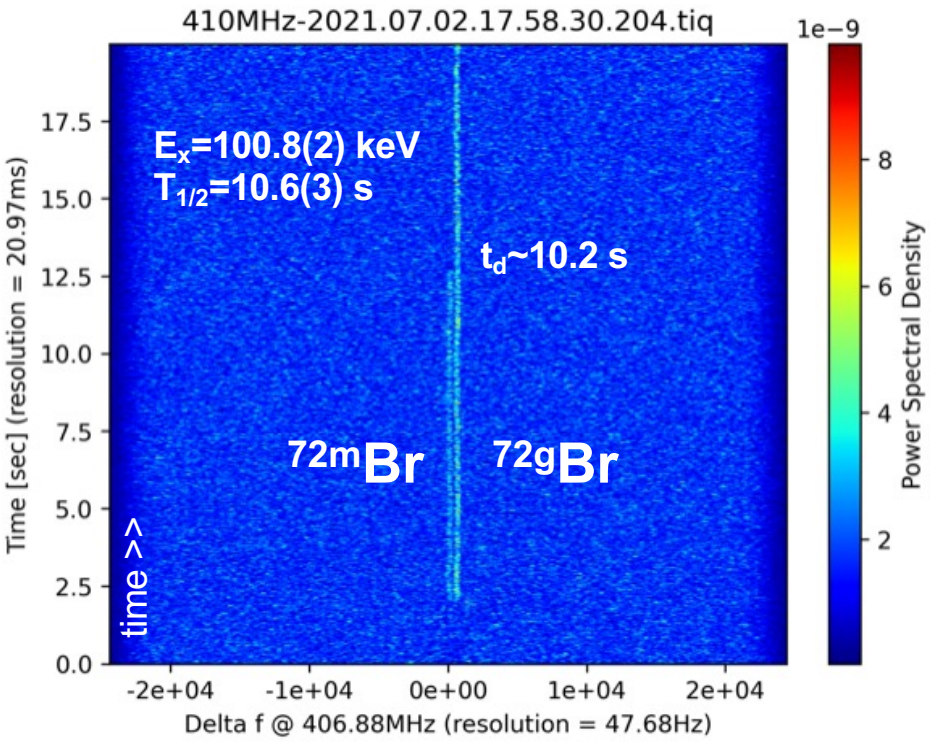
F. Nolden et sl., Nucl. Instr. Meth. A (2011)



S. Sanjari et al., Rev. Sci. Instr. (2020)

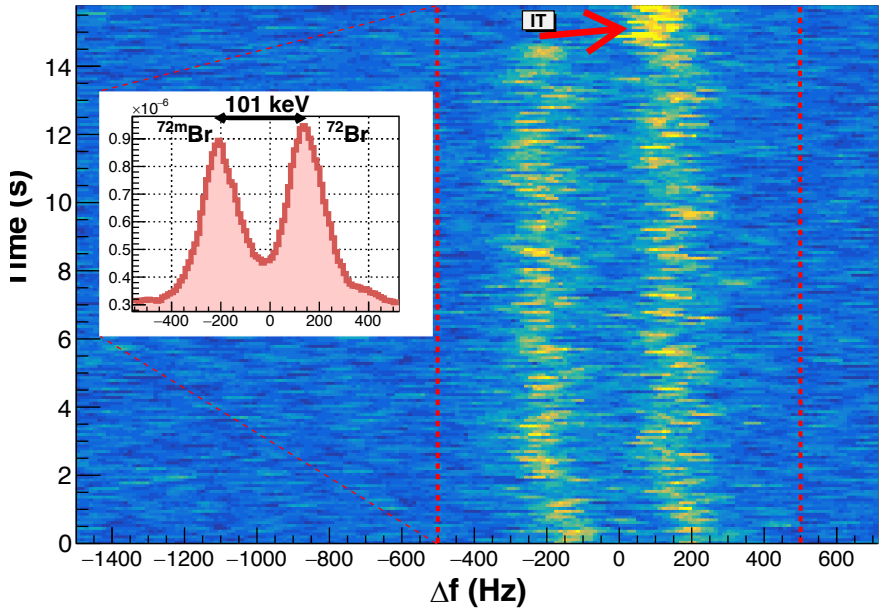
The goal: to measure the revolution frequency of a single ion within a few miliseconds

Combined Isochronous+Schottky Mass Spectrometry

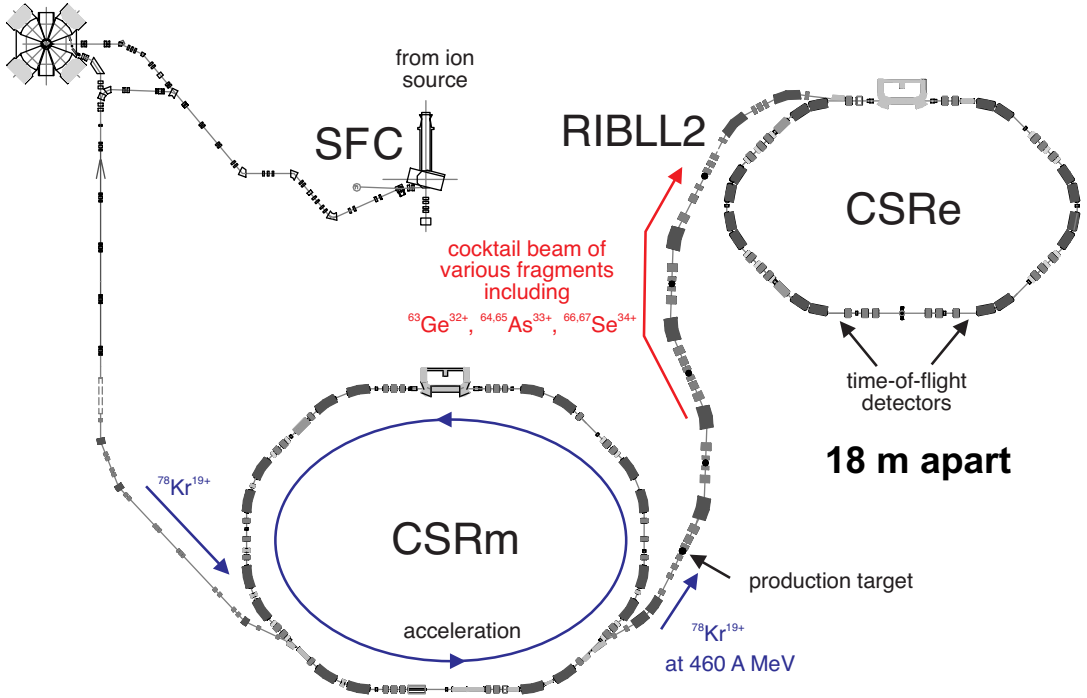


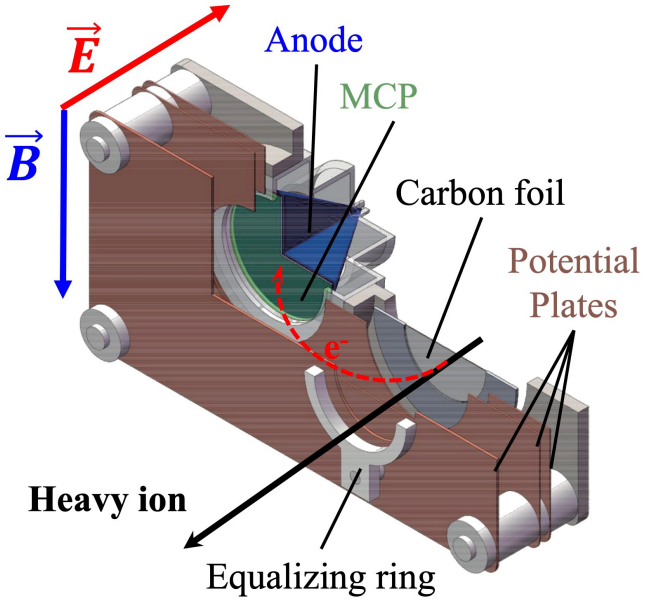
$\rightarrow \Delta m/m < 10^{-6}$

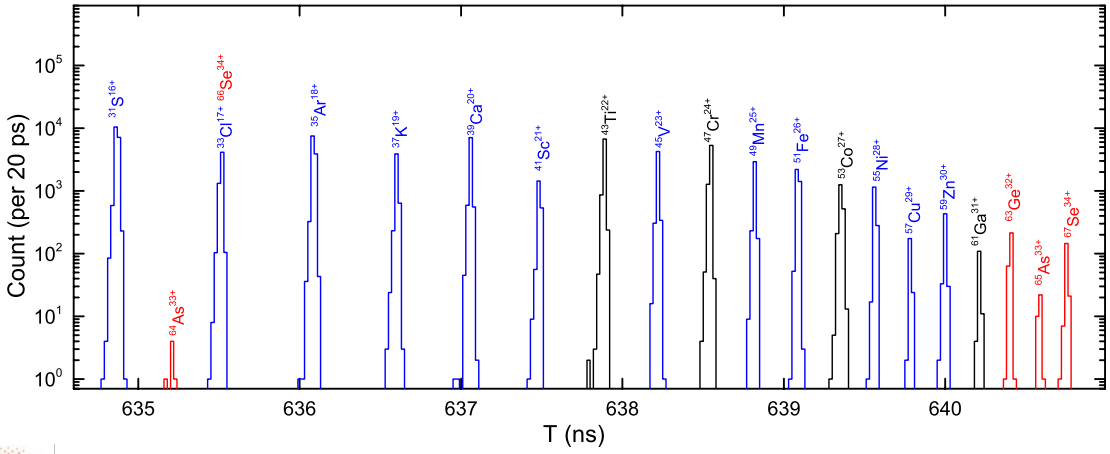
Schottky spectra of single events
Separation of the 101 keV isomer in ^{72}Br



Isochronous Mass Measurements





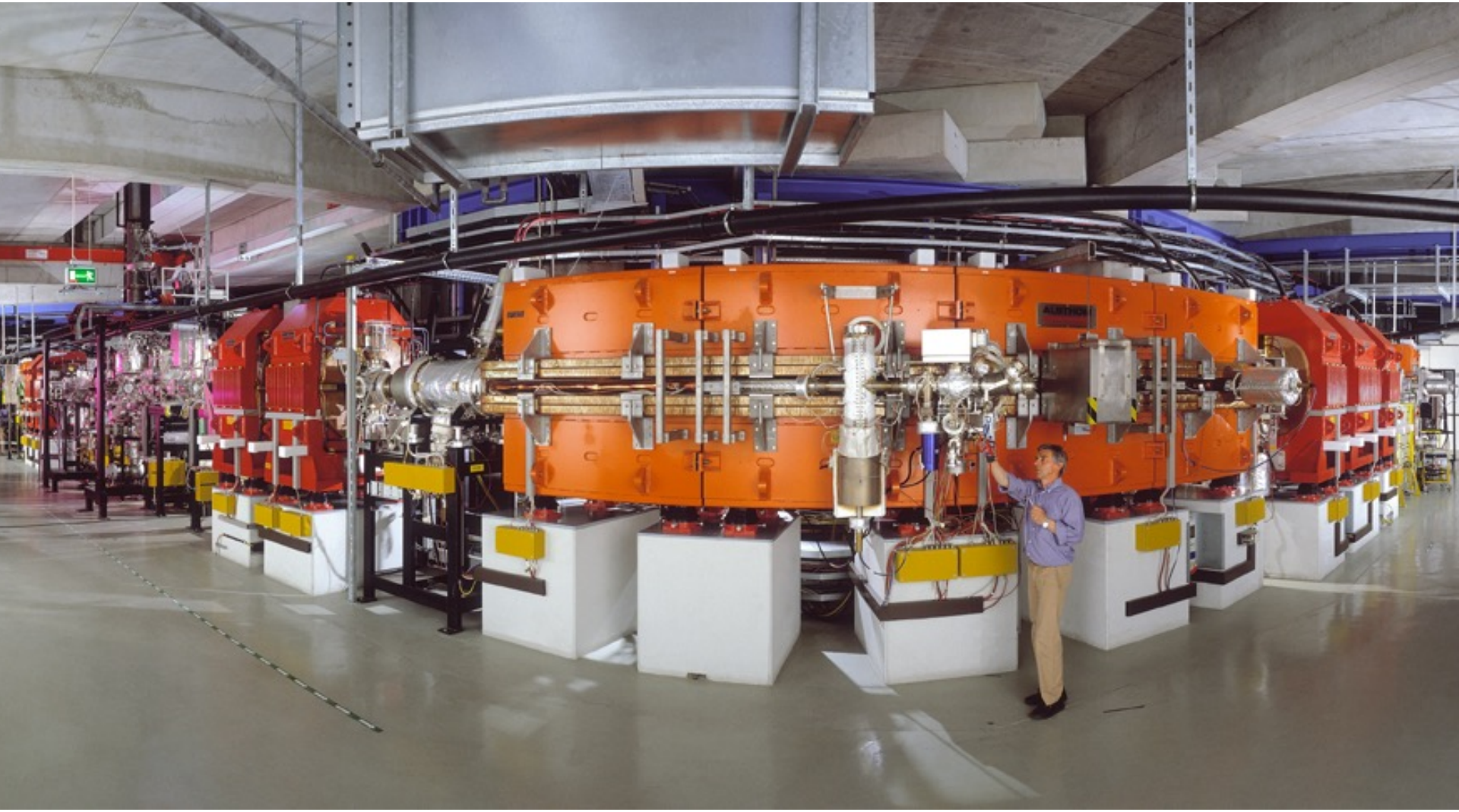


^{78}Kr projectile fragments

Rate of the most exotic species is 6 ions in 2 weeks, which is sufficient for the mass measurement with relative precision of 1.7 10^{-6}

Courtesy: M. Wang and Y.H. Zhang

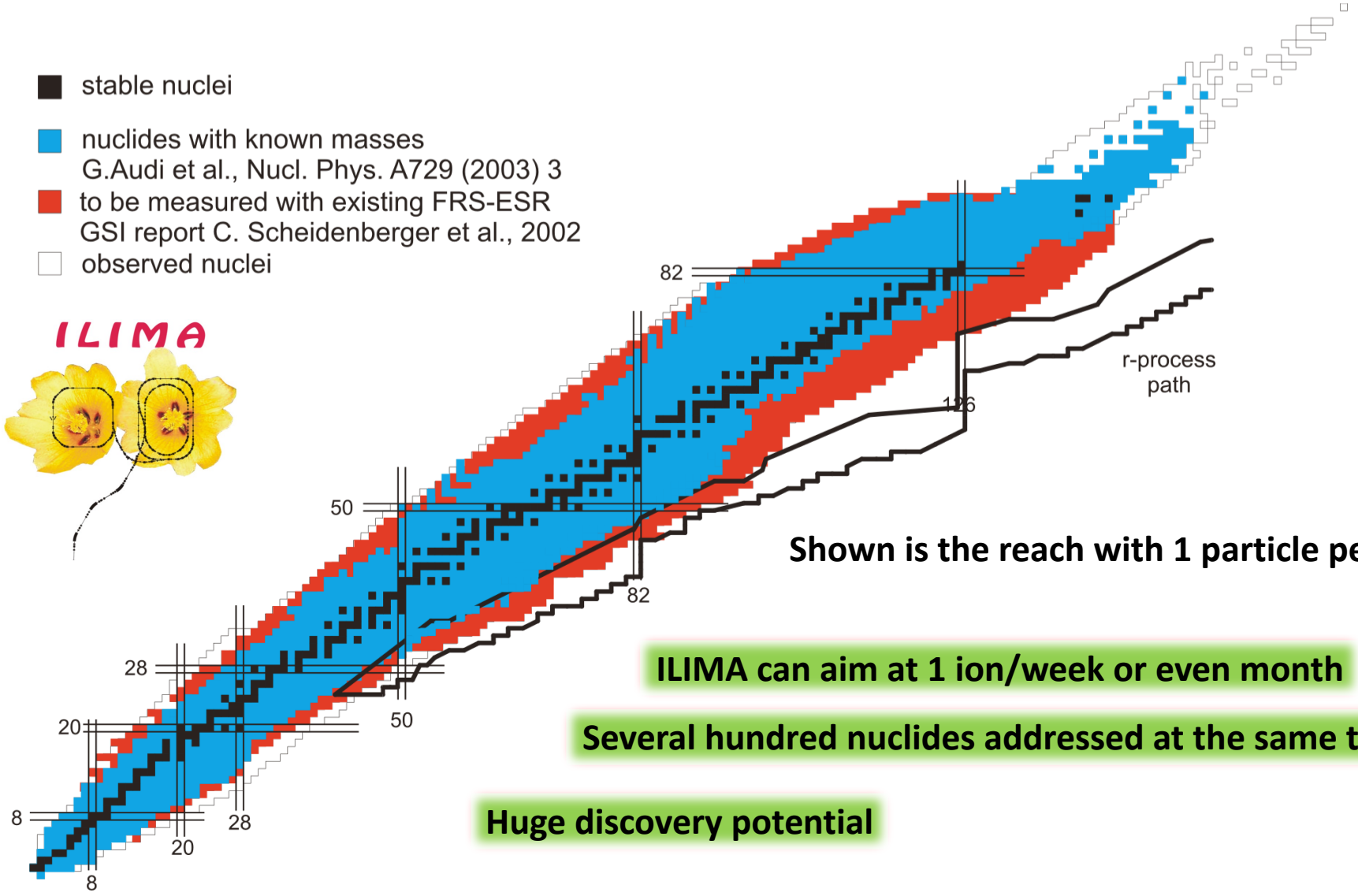
Experimental Storage Ring ESR



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

ILIMA @ FAIR Phase-0



Shown is the reach with 1 particle per hour

ILIMA can aim at 1 ion/week or even month

Several hundred nuclides addressed at the same time

Huge discovery potential

NUSTAR@RINGS in FAIR Phase-0

Competitive physics cases

Measurement of masses, lifetimes, beta-delayed neutron probabilities
Search for new isomeric states, exotic decay modes, **various reactions**

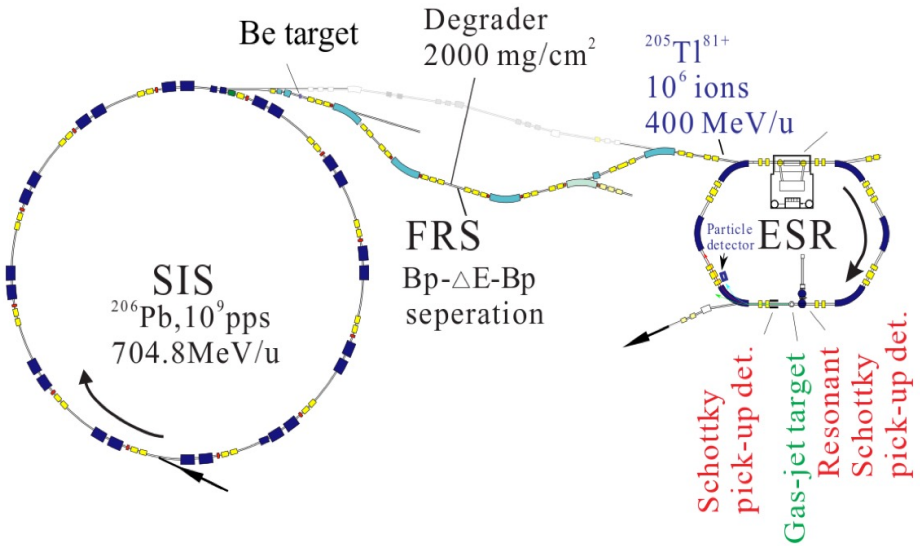
Facilities: FRS, ESR and CRYRING@ESR

Requirements and improvements:

- **Isochronous mode**
- **Transmission FRS-ESR and TE-ESR**
- Upgrade of tof-detector
- **Transverese Schottky detectors**
- **Deceleration**

!!! Significant increase of beam time !!!
(the argument of the CR soon coming is no longer valid)

Experiment during the COVID 23.03 – 01.04 – 06.04



Enriched ^{206}Pb beam

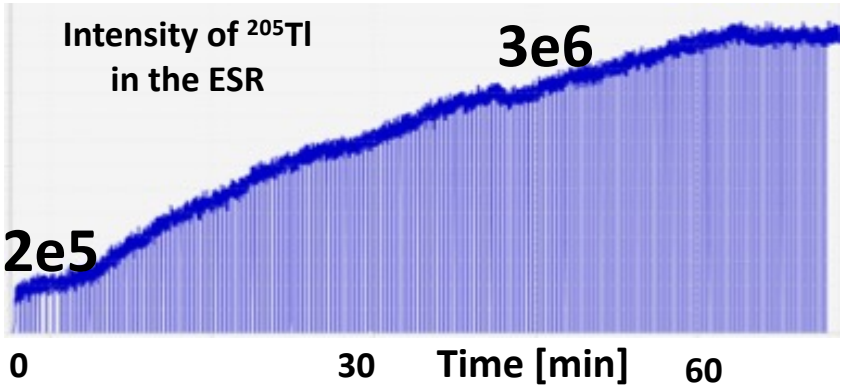
Separation from $^{205}Pb^{81+}$

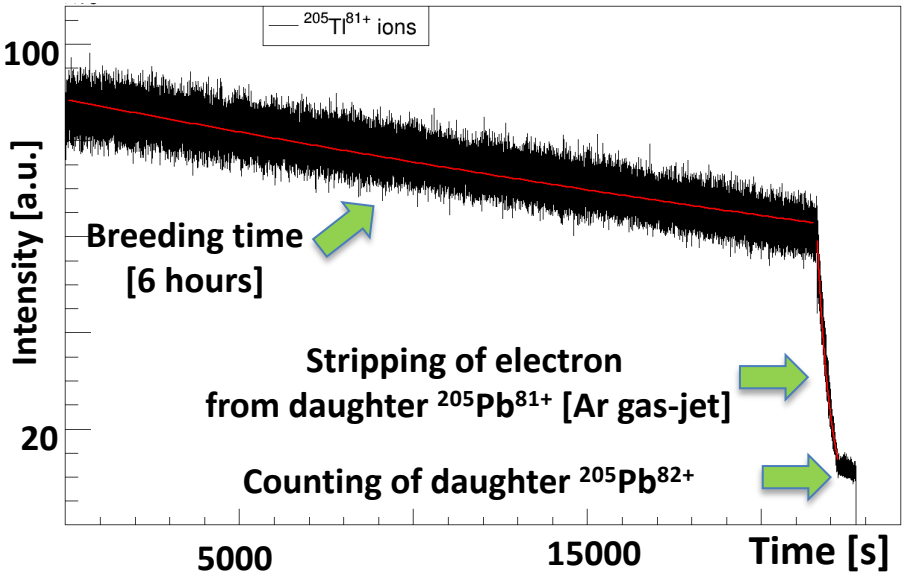
Target:

$I(^{205}Tl^{81+})/I(^{205}Pb^{81+}) = 1/15$

ESR:

$I(^{205}Tl^{81+})/I(^{205}Pb^{81+}) = 1000/1$





Stochastic and electron cooling

Accumulation

Long breeding times of up to 10 h

Ar gas jet to remove electron from $^{205}Pb^{81+}$

erc ASTRUm

Courtesy R. J. Chen and R. Singh Sidhu

Why storage rings? - Versatile Capabilities

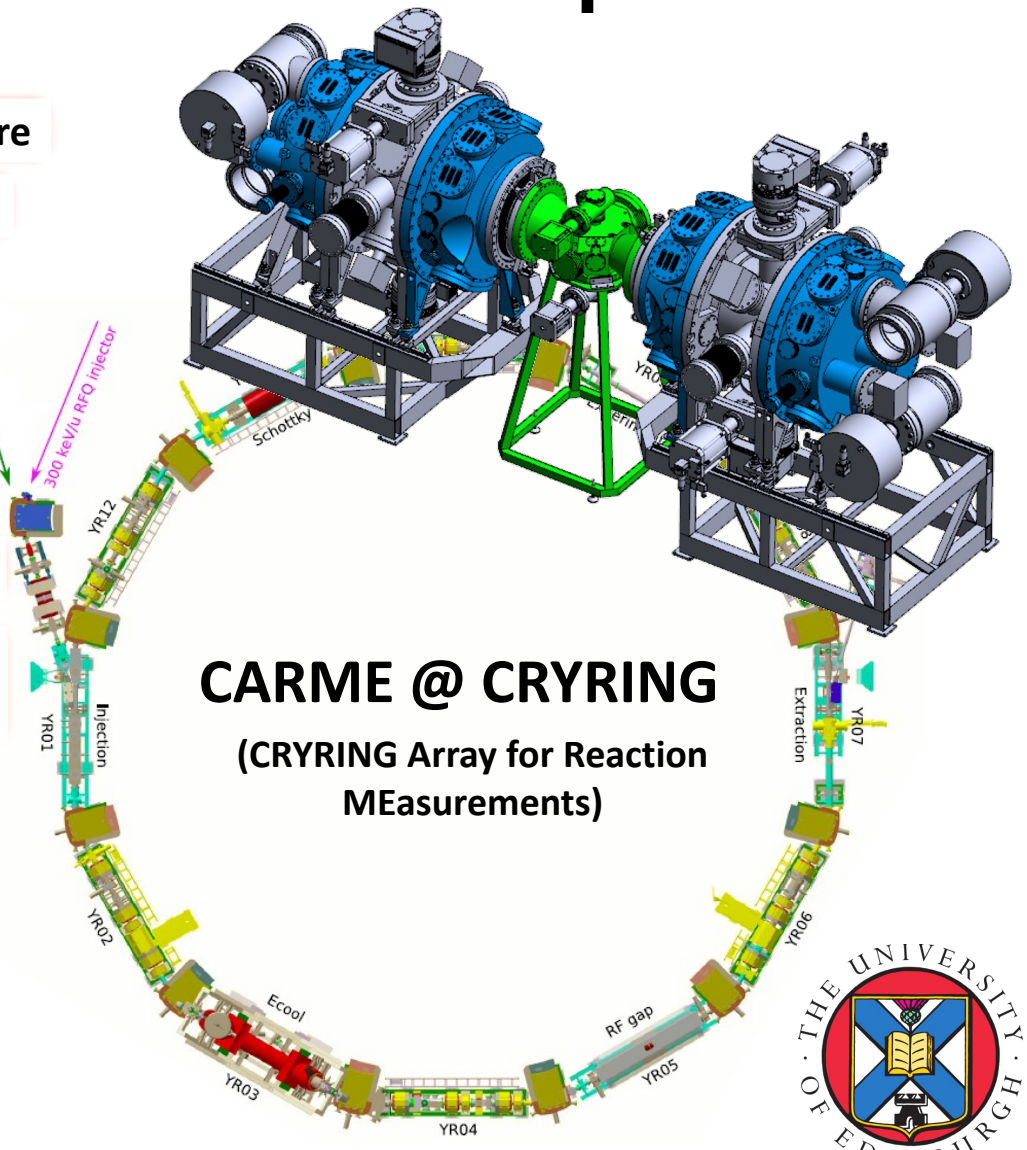
- Nuclear Excitation by (target) Electron Capture
- Nuclear Excitation by (free) Electron Capture
- Electron Capture in H- and Li-like Ions
- Alpha decay of highly-charged ions
- Transfer reactions
- Long-lived isomeric states
- Di-electronic recombination on exotic nuclei
- Astrophysical reactions for BBN and Novae, rp- and nup-processes

ERC SG Bruno

- Surrogate reaction studies

ERC AG Jurado

- Giant resonances
- Electron-Ion scattering (future)



CARME @ CRYRING

(CRYRING Array for Reaction MEasurements)

Courtesy: Carlo Bruno

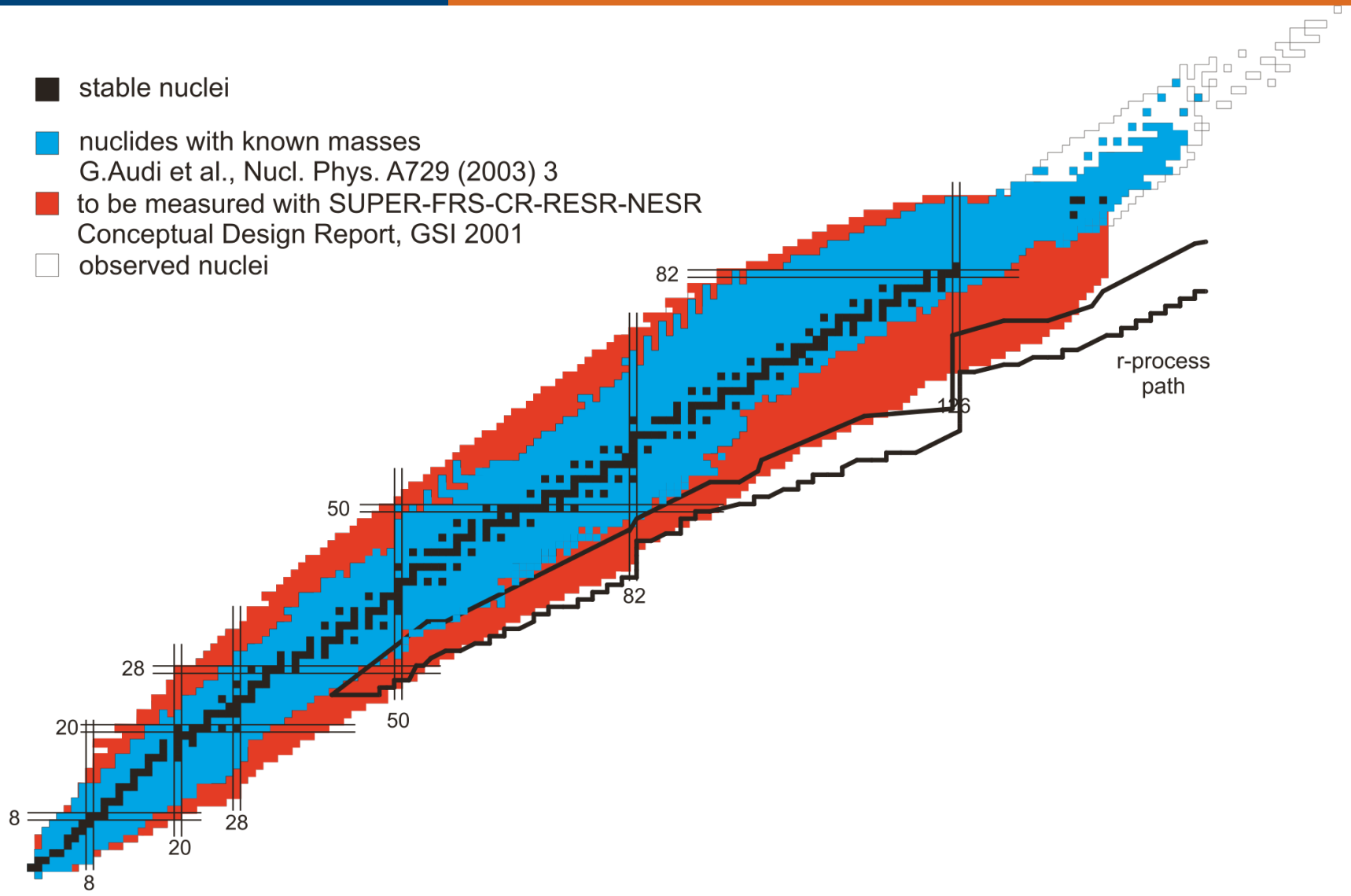
FAIR Green Paper

Beside the reaction microscope mentioned, novel instrumentations will be developed and used by the collaboration. These include micro-calorimeters and polarimeters for hard X-rays and spectrometers for electrons, positrons and ions. In addition, novel lasers and targets (gaseous, micro droplet, and superfluid targets) will be exploited. All these developments are also of particular relevance for future prospects of the SPARC physics programme which concentrates on storage rings and traps, and will become possible with Module 4. For the realization of this programme the ESR storage ring and the HITRAP facility need to be maintained in operation at GSI until they shall be surpassed by Module 4.

Green Paper
The Modularized Start Version

October 2009

ILIMA in FAIR MSV

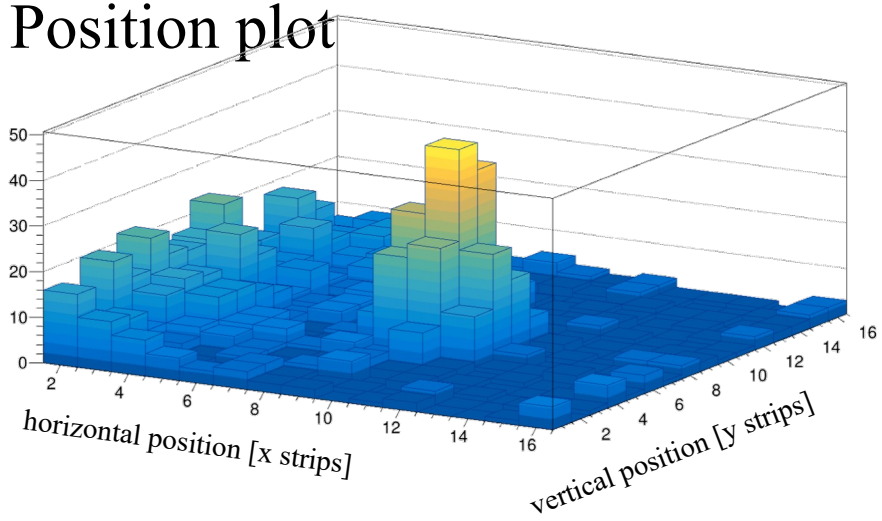


ILIMA Endeavor at FAIR

FAIR - CORE Facility	→	ILIMA (Isomeric Beams, Lifetimes, Masses)
FAIR - MSV	→	MA (Masses)
Development os Multiple Resonant Schottkies	→	LIMA (Lifetimes, Masses)
ILIMA @ HESR	→	ILIMA (Isomeric Beams, Lifetimes, Masses)
ILIMA @ CR, HESR, ESR and CRYRING	→	Extended ILIMA even beyond original LOI
FAIR – 11 in 22	→	ILIMA (Lifetimes, Masses)
FAIR - IO	→	ILIMA ( )
FAIR - FS	→	ILIMA ( )
FAIR - FS+	→	ILIMA ( )
FAIR Phase-0	→	Good question

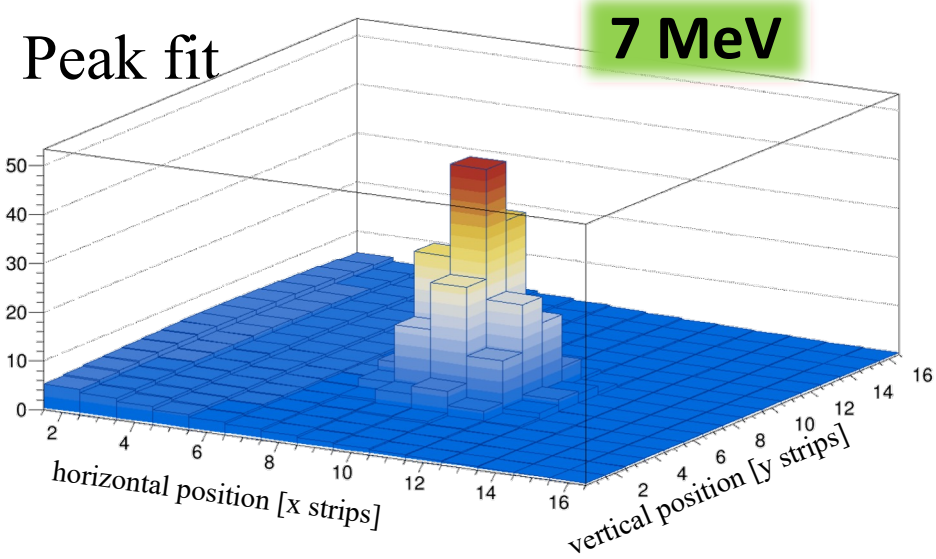
Proton capture on radioactive ^{118}Te

Position plot

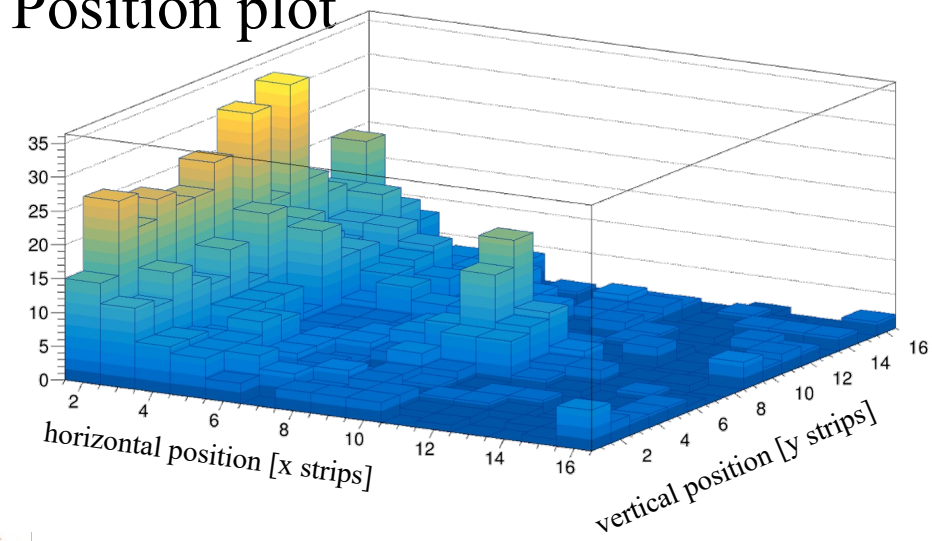


Peak fit

7 MeV

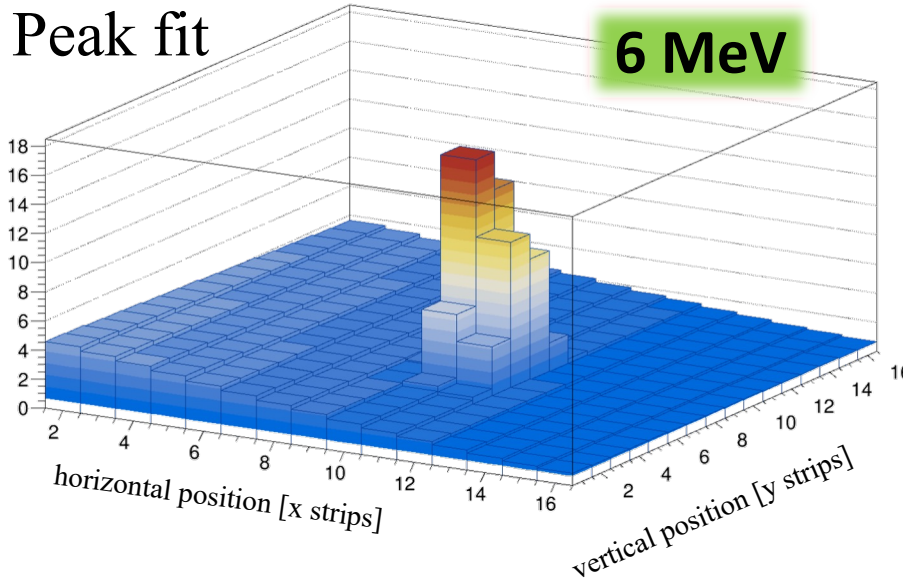


Position plot



Peak fit

6 MeV



Courtesy J. Glorius and S. Dellmann