Perspectives for NUSTAR Storage Ring Experiments

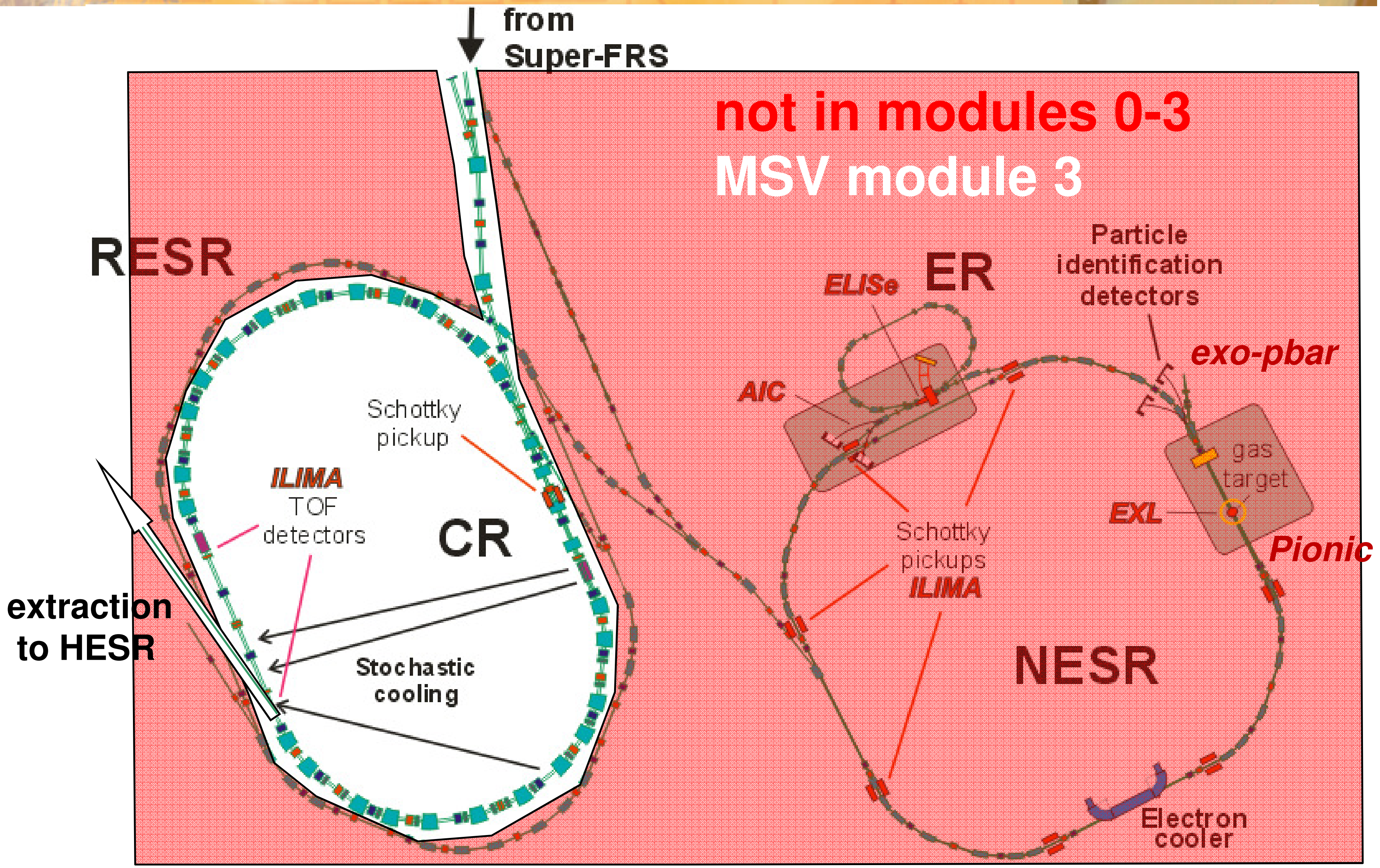
Helmut Weick, GSI
NUSTAR Week Warsaw, 29th Sept. 2015

- **Mass Measurements in CR**
- **Detector Development**
- **Reaction Experiments in Rings**
- **Perspectives with HESR, ESR, and CRYRING**

GSI

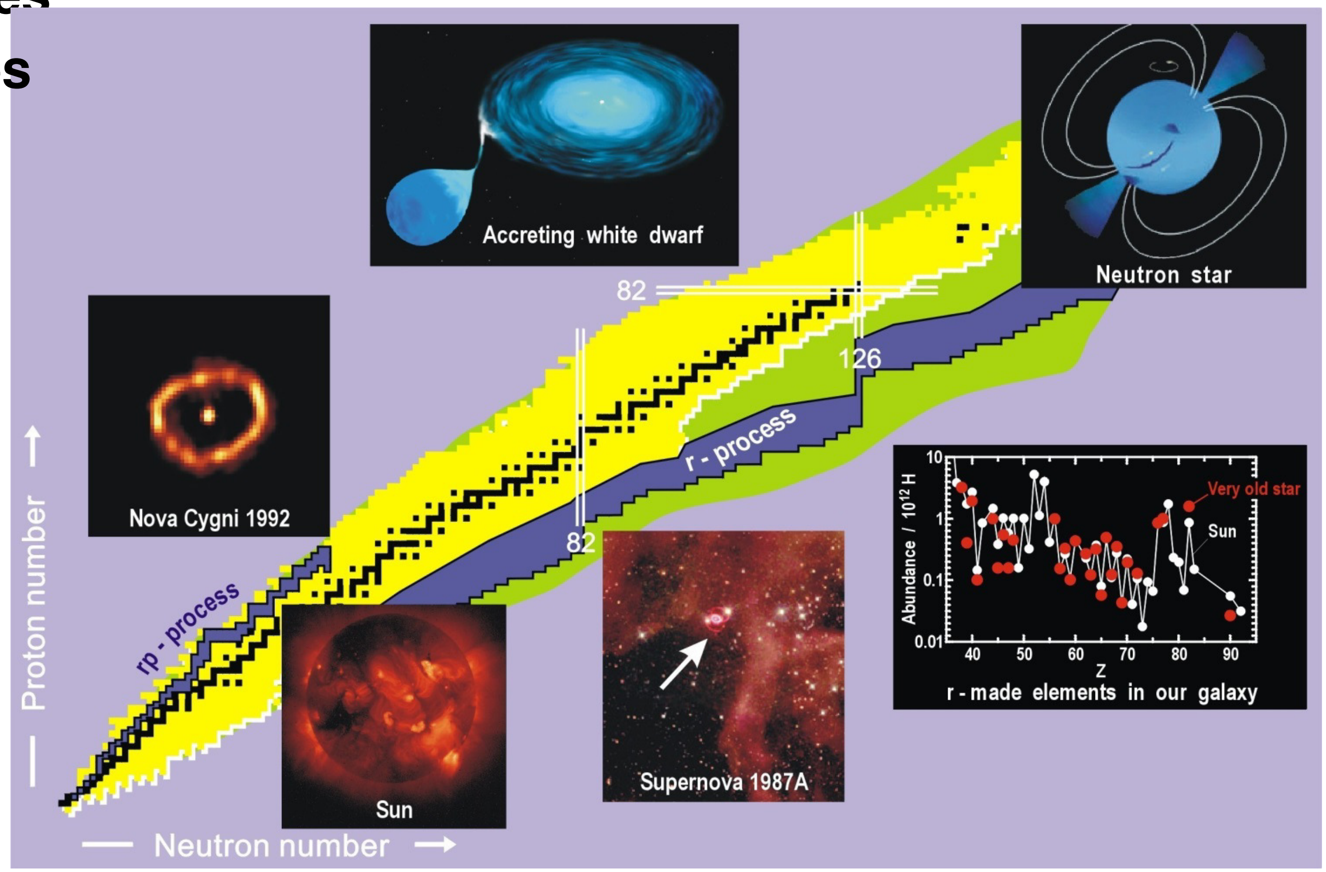
FAIR

Rings Overview 2009



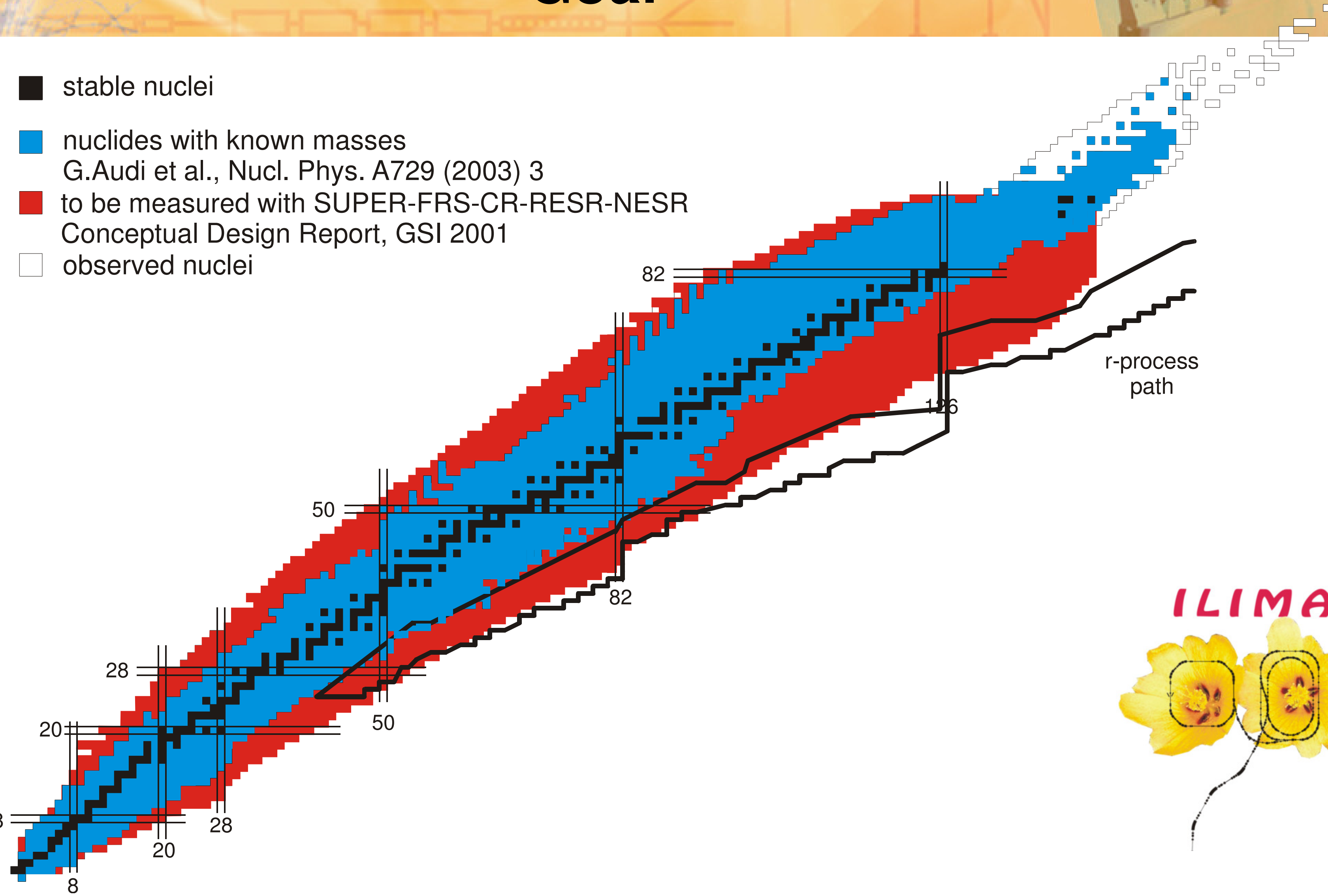
ILIMA = Isomeres, LIfetimes and MAsses

- Total binding energies
- Nuclear decay modes
- Separation energies
- Driplines
- Pairing correlations
- Deformations
- Shell closures
- Reaction Q-values
- Testing and improving nuclear theories
- Pathways of nucleosynthesis



ILIMA
- Goal -

- stable nuclei
- nuclides with known masses
  G.Audi et al., Nucl. Phys. A729 (2003) 3
- to be measured with SUPER-FRS-CR-RESR-NESR
  Conceptual Design Report, GSI 2001
- observed nuclei



ILIMA

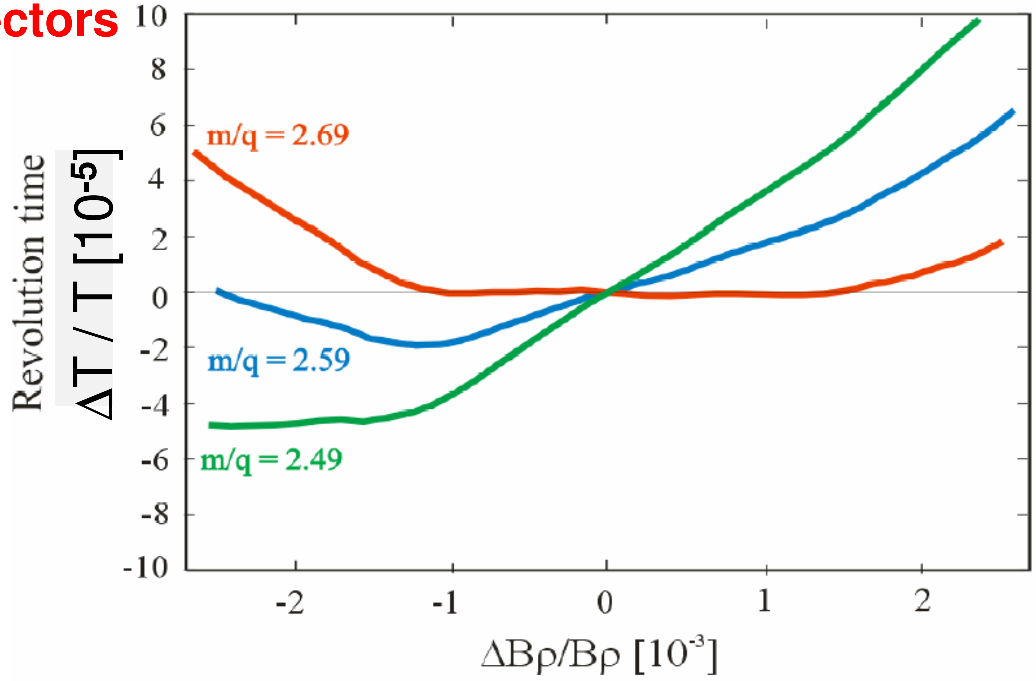
Isochronous Mass Measurements in CR

Tune isochronicity
also in higher orders

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

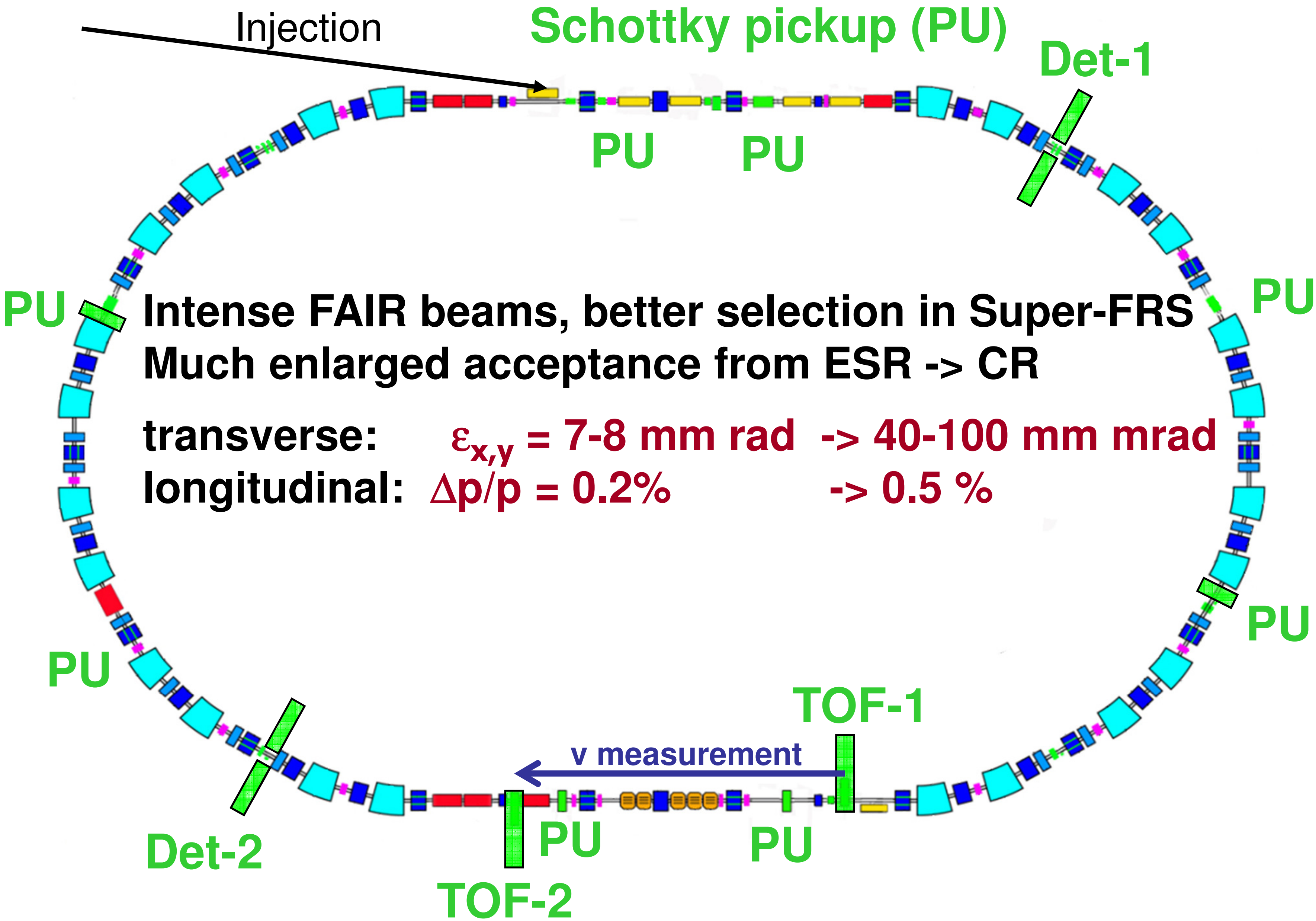
Exact isochronicity at fixed Bρ only for one m/q,
for efficiency and calibration wider band needed
-> Measure velocity with two ToF detectors
and apply correction in analysis.
ToF detectors are limited in rate.

Schottky is more efficient.
Resonant Schottky can see single ions without cooling. But also additional Bρ information needed.



measured isochronicity curve in ESR
transformed to other m/q

CR for ILIMA

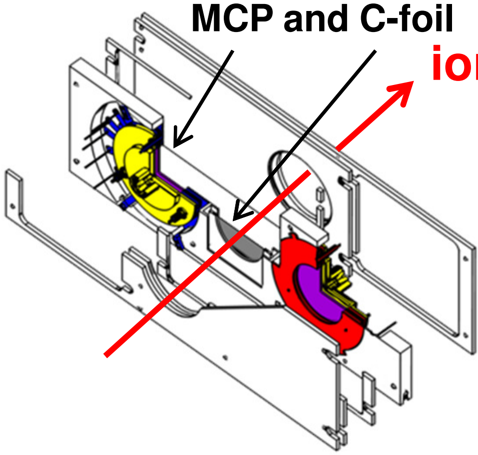


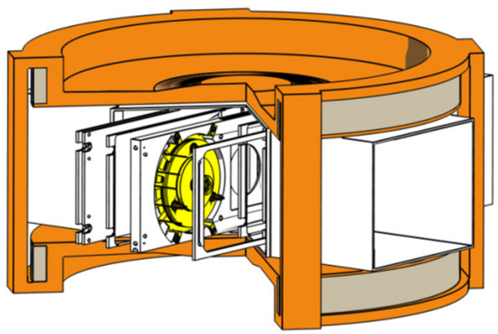
Intense FAIR beams, better selection in Super-FRS
Much enlarged acceptance from ESR -> CR

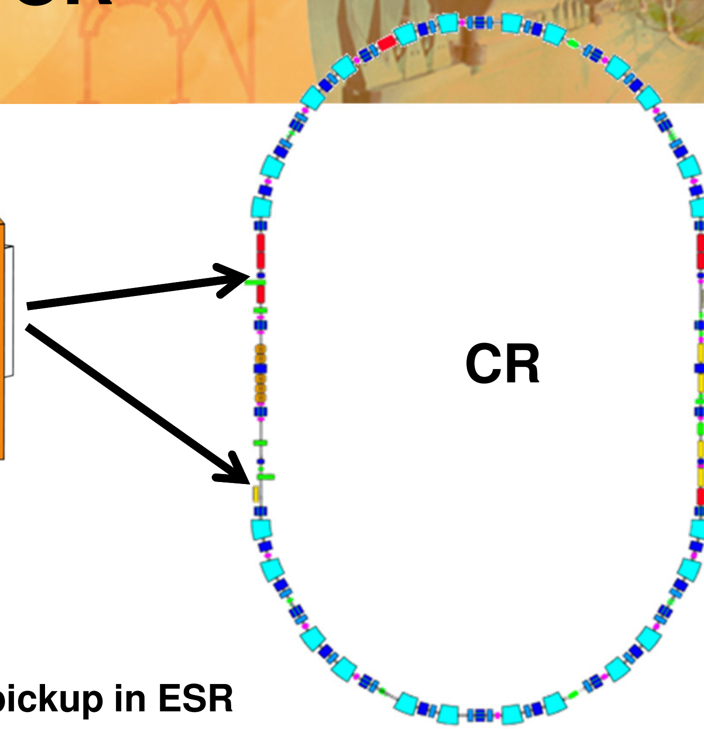
transverse: $\varepsilon_{x,y}$ = 7-8 mm rad -> 40-100 mm mrad
longitudinal: $\Delta p/p$ = 0.2% -> 0.5 %

L = 221.45 m, $B\rho_{max}$ = 13 Tm

Detector Systems for CR





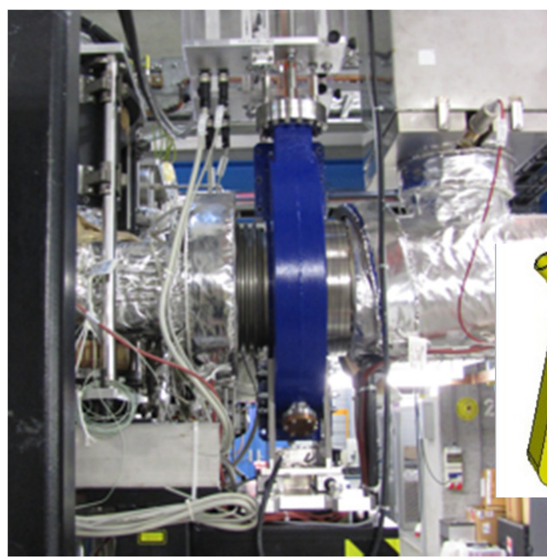


Electron transport efficiency ≈ 98%
Timing accuracy ≈ 35 ps

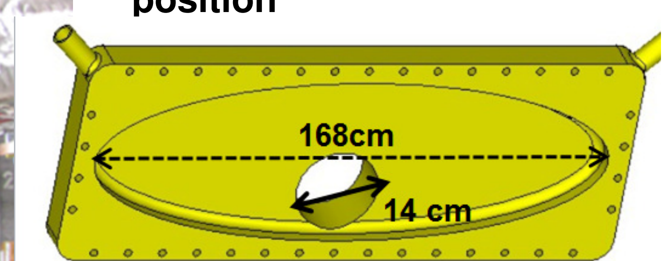
- **Active area x 4 required**
- **Limited space in the ring**
- **Simulations for CR and ToF detector show even better timing than in ESR**

M. Diwisch, thesis University Giessen 2014
N. Kuzminchuk et al., subm. to NIM B

resonant Schottky pickup in ESR

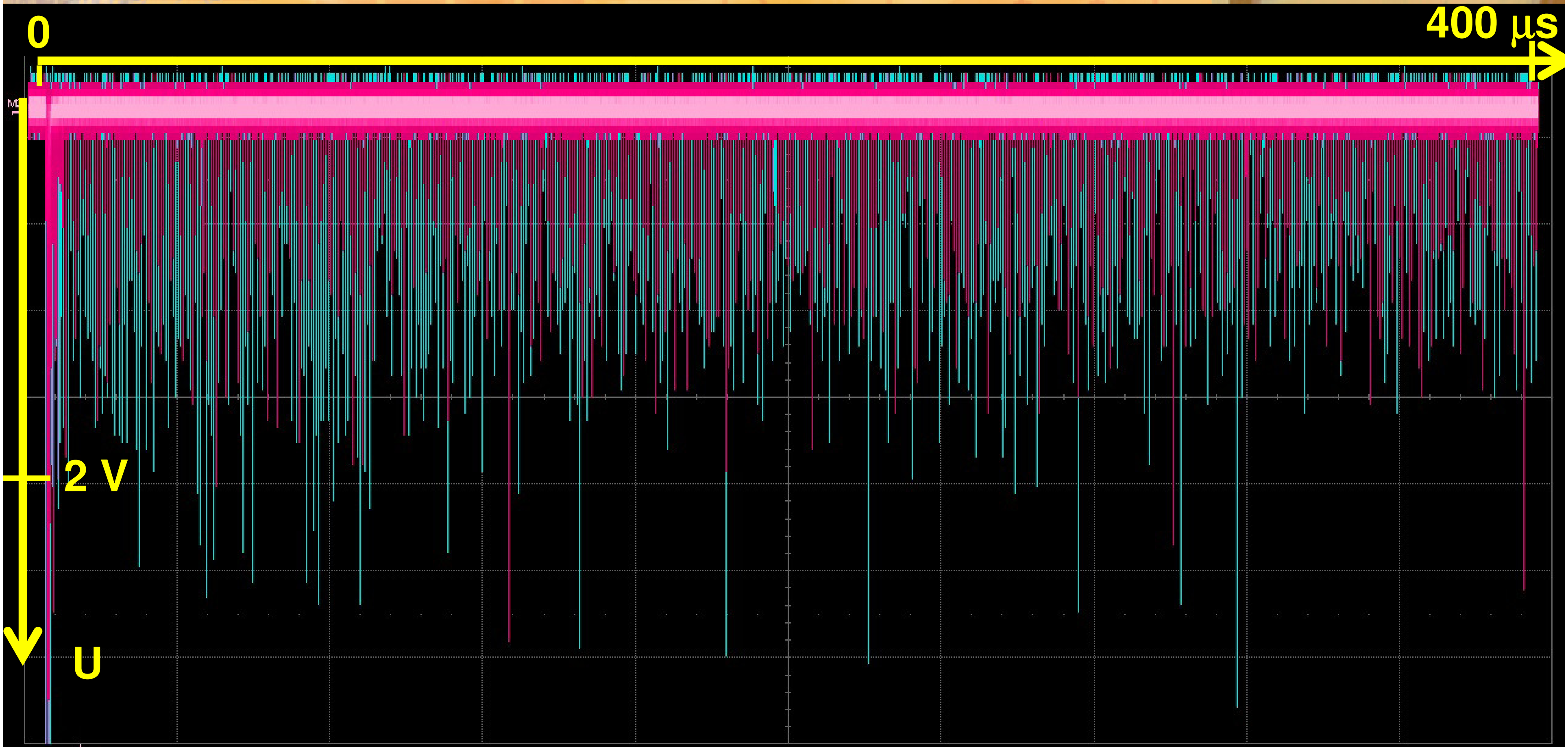


development of position sensitive Schottky pickup, asymmetric cavity, signal strength gives position



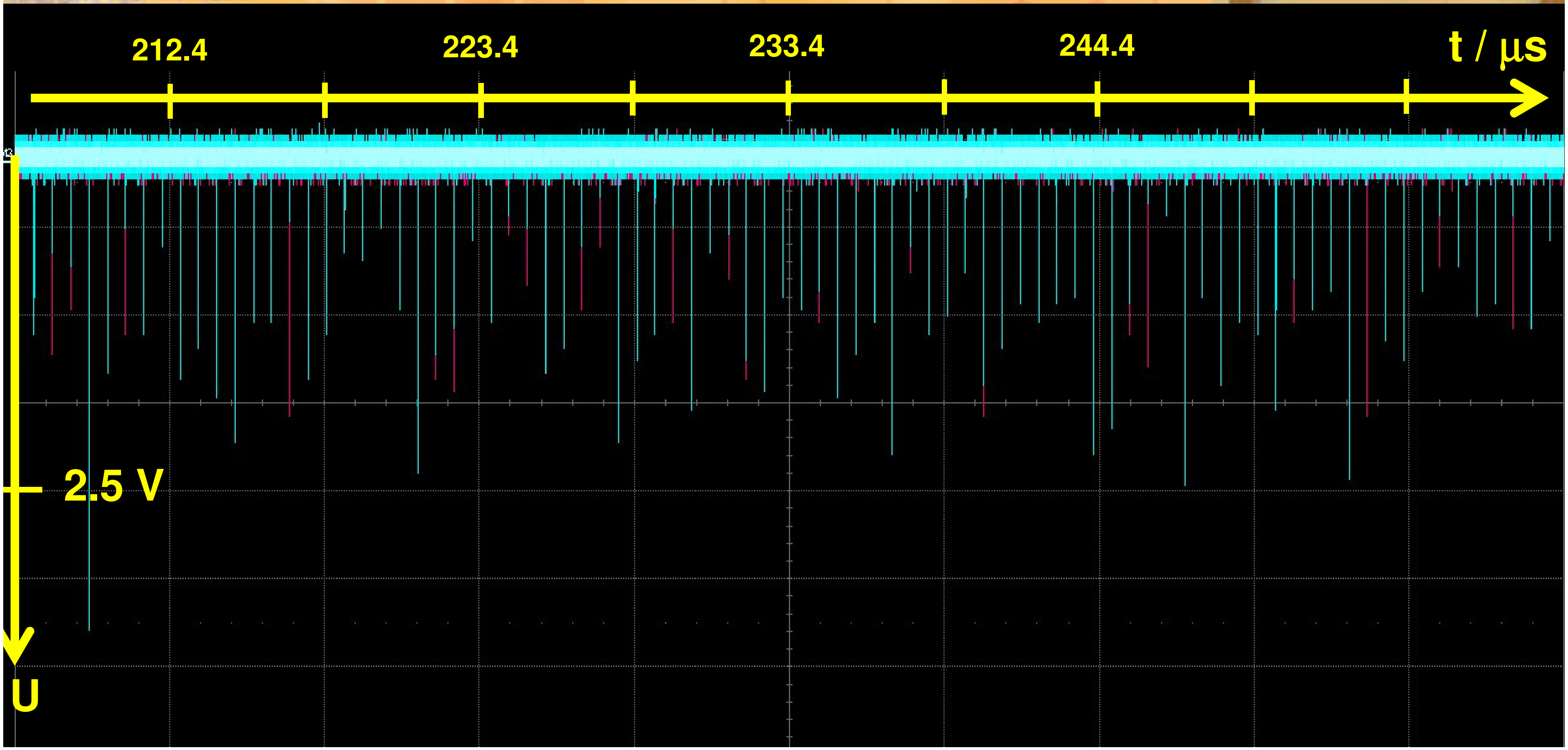
S. Sanjari, X. Chen

ToF Detector Signals



^{238}U beam on improved ToF detector in ESR, Oct 2014
old detector but new channel plates, new field settings,
Almost no decrease of pulse height even after 800 turns.

ToF Detector Signals 2

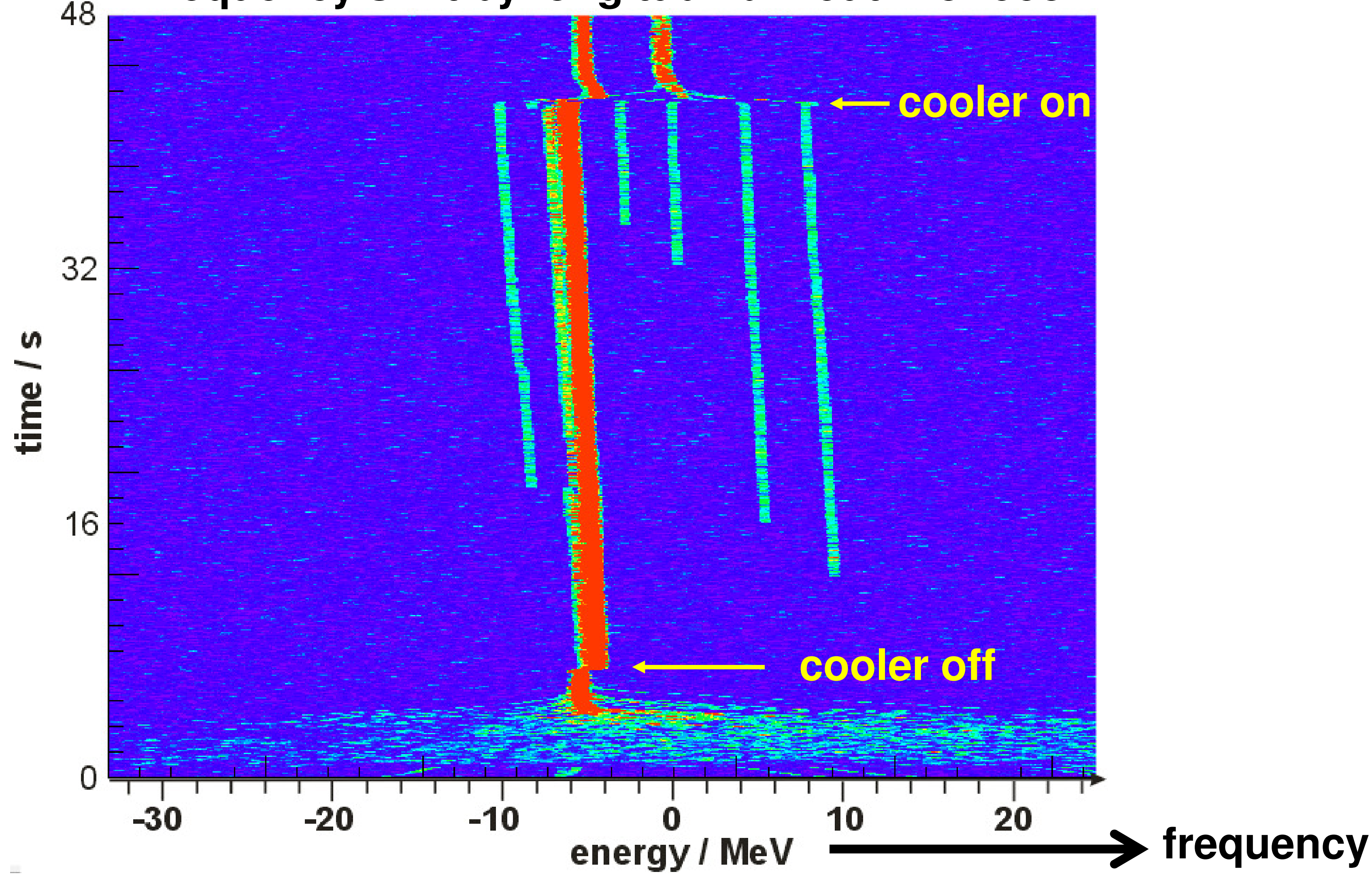


A good signal from every turn on both sides (blue and red), in the past only shorter sequences with gaps.

R. Knöbel, M. Diwisch

Schottky Spectrum

EC decay of ^{142}Pm, cooling switched off
Frequency shift by longitudinal neutrino recoil

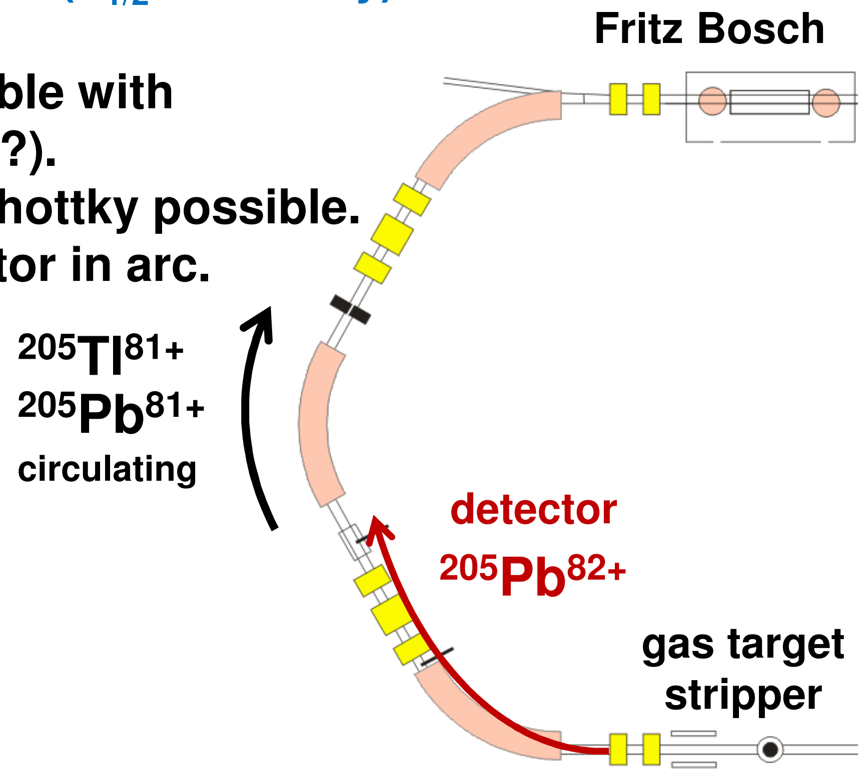


Applications for Particle Counters

Lifetime of ^{205}Tl for bound-state β-decay

Calibrate neutrino capture cross section in Tl for solar neutrino flux, influence on cosmic clock for S-process ^{205}Pb ($T_{1/2}$=1.7x10^7 y).

^{205}Pb EC Q-value so small that inverse possible with bound-state β-decay (Q=+31 keV, $T_{1/2}$ ~ 120d ?). Intense beam needed, no separation with Schottky possible. But after gas stripper nicely visible on detector in arc.



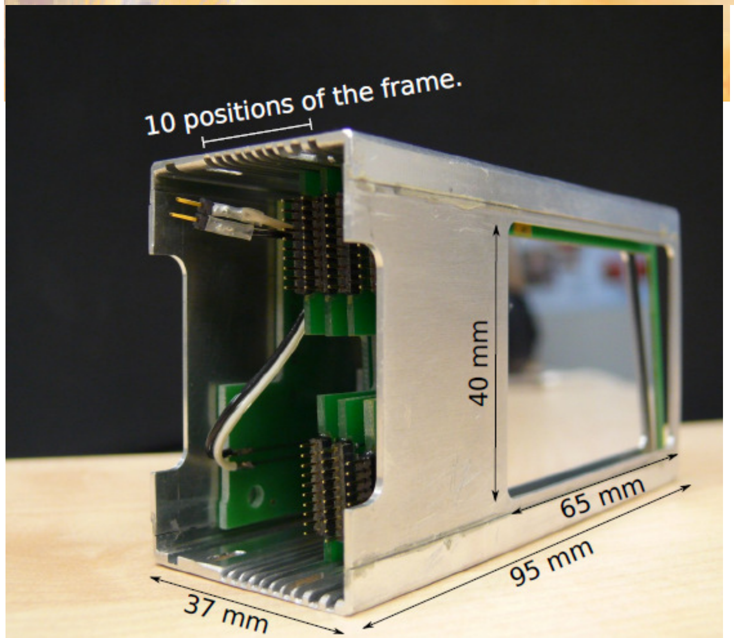
Check for oscillations in bound-state beta decay

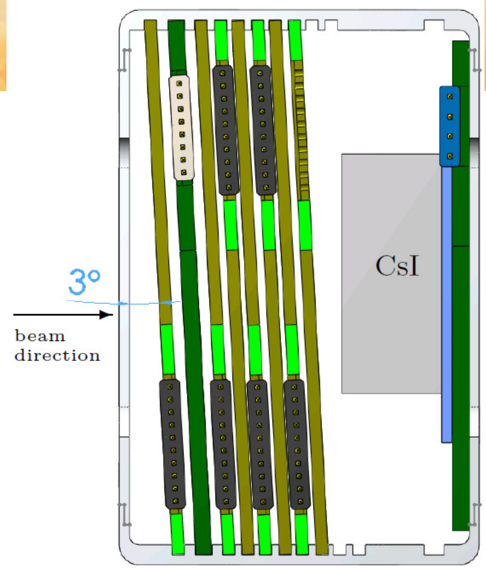
Neutrino recoil large enough to deflect ions onto detector

Beta delayed neutrons

spontaneous β-decay in ring -> changed orbit different position on detector with n emission + particle (mass) identification to find ratio.

Detector for In-Ring Decay

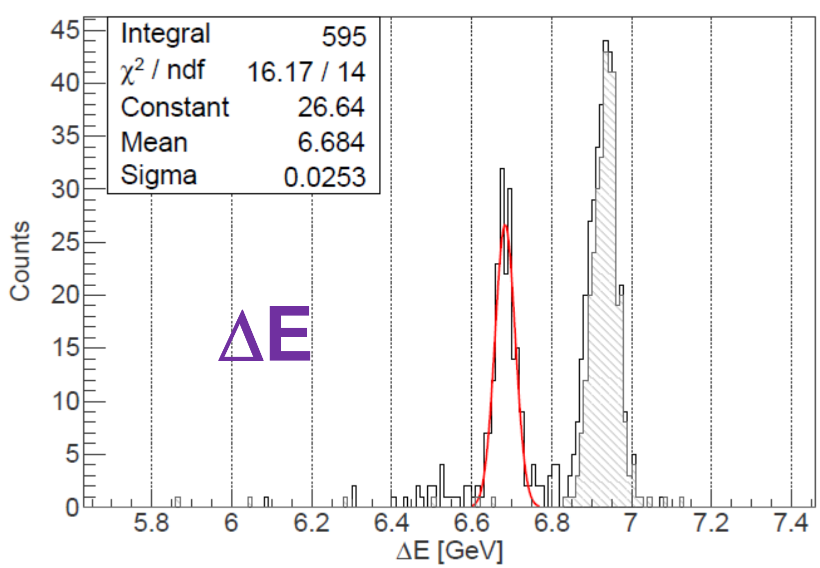


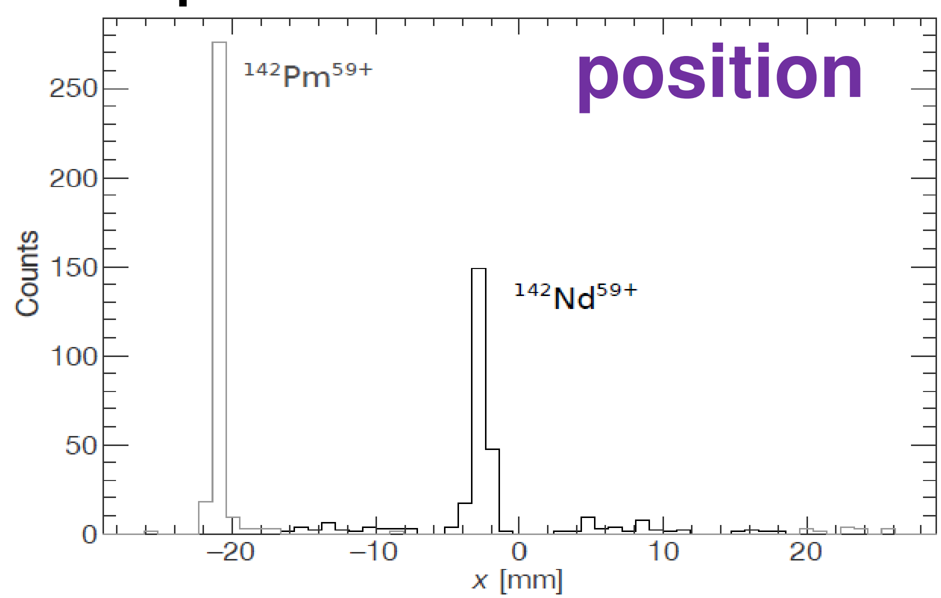


DSSD stack for ΔE-E
active area 40mm x 60mm
also with CsI calorimeter
+ Si photo diode,
to identity Z and A.

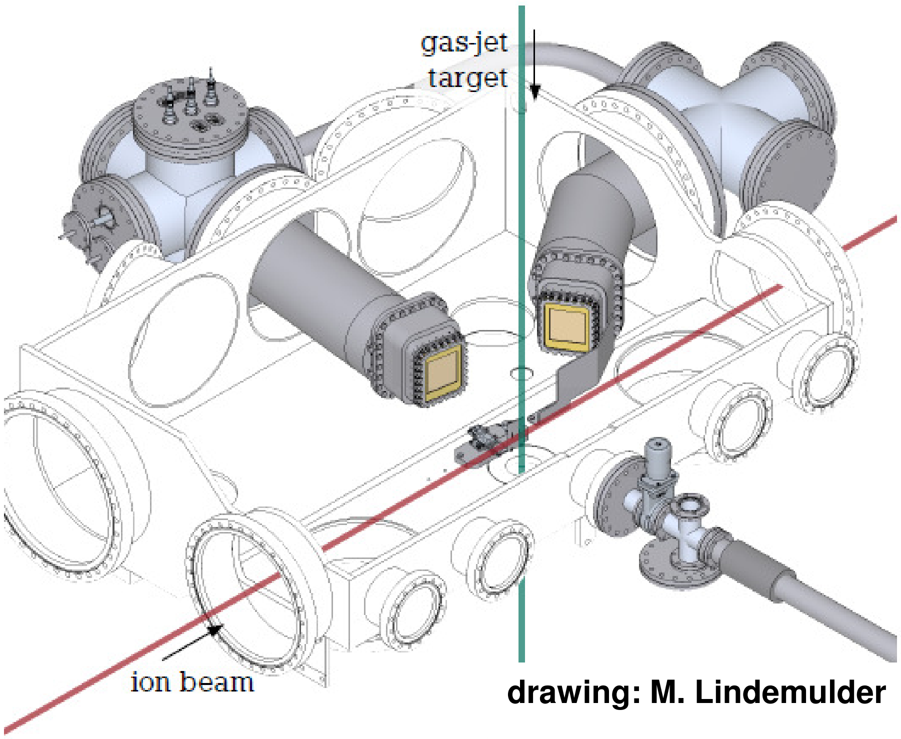
Ali Najafi

β^+ decay: $^{142}Pm^{60+}$ → $^{142}Nd^{59+}$, electron capture $^{142}Pm^{59+}$

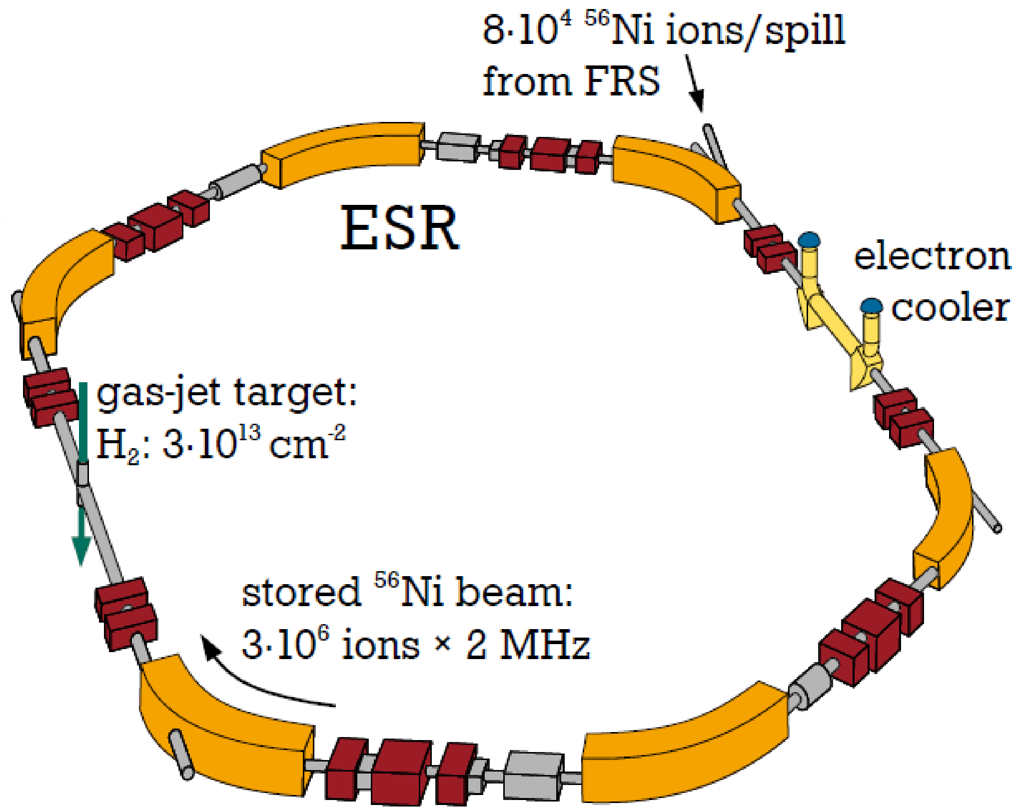




Reactions: EXL Detector in ESR



drawing: M. Lindemulder



Picture: Phys. Scr. T156 (2013) 014016

ΔE, E, x

DSSD: 128 × 64 strips, (6 × 6) cm^2, 285 μm thick

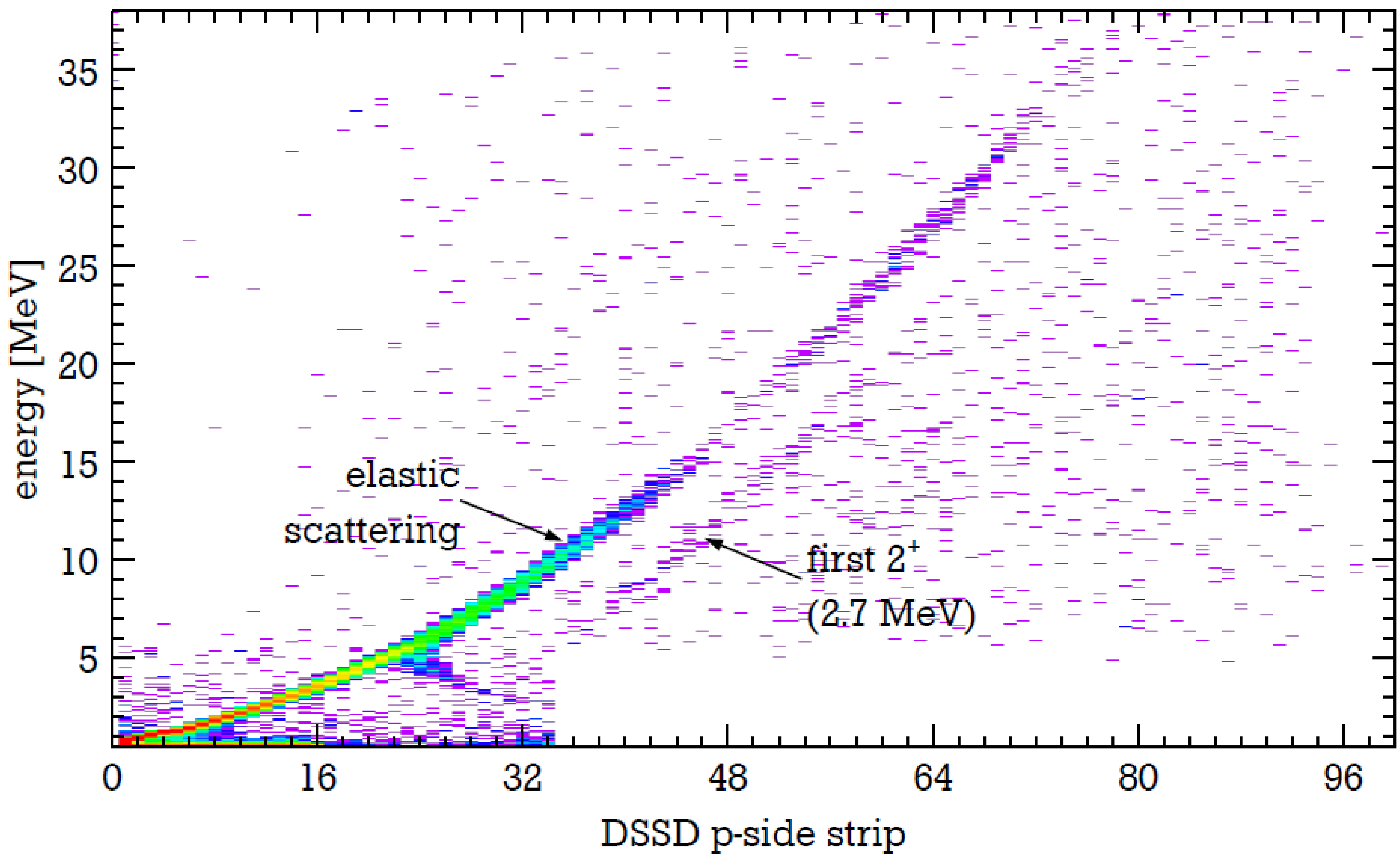
Si(Li): 8 pads, (8 × 4) cm^2, 6.5 mm thick

Active vacuum barrier

B. Streicher et al., Nucl. Instr. and Meth. A 654, 604 (2011).

luminosity: $2 \cdot 10^{26} \frac{\text{particles}}{\text{s cm}^2}$

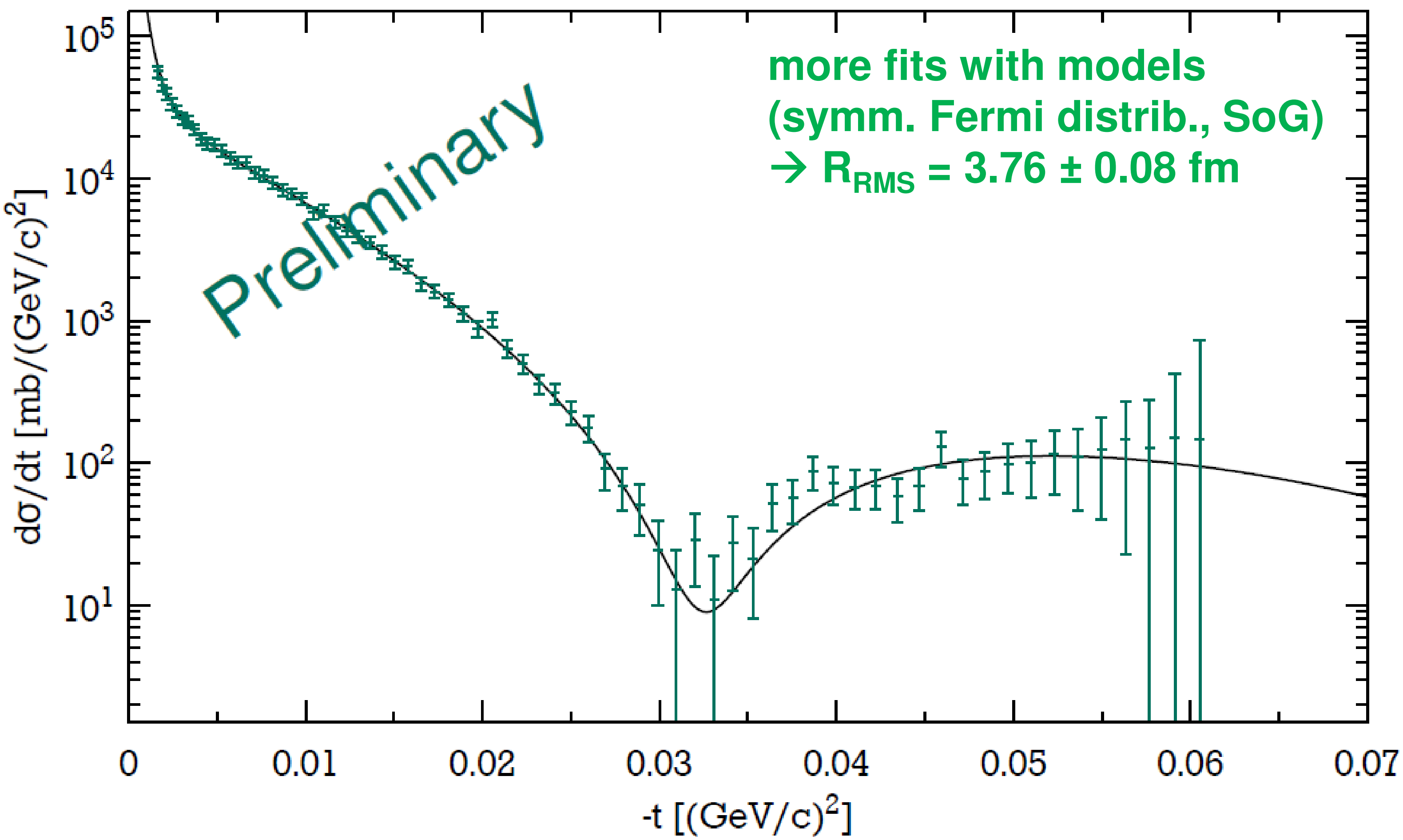
$^{56}Ni(p,p)$ scattering distribution



EXL collaboration, thesis Mirko von Schmid

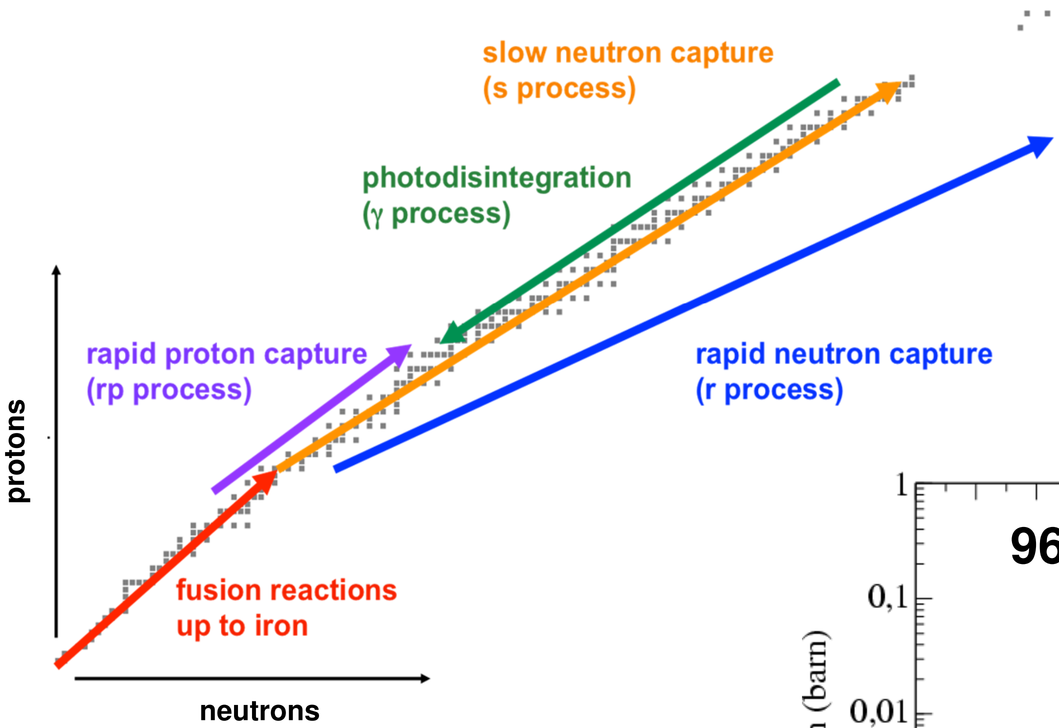
^{56}Ni(p,p) scattering distribution

Measured at 390 MeV/u and a fit based on Glauber multiple scattering theory

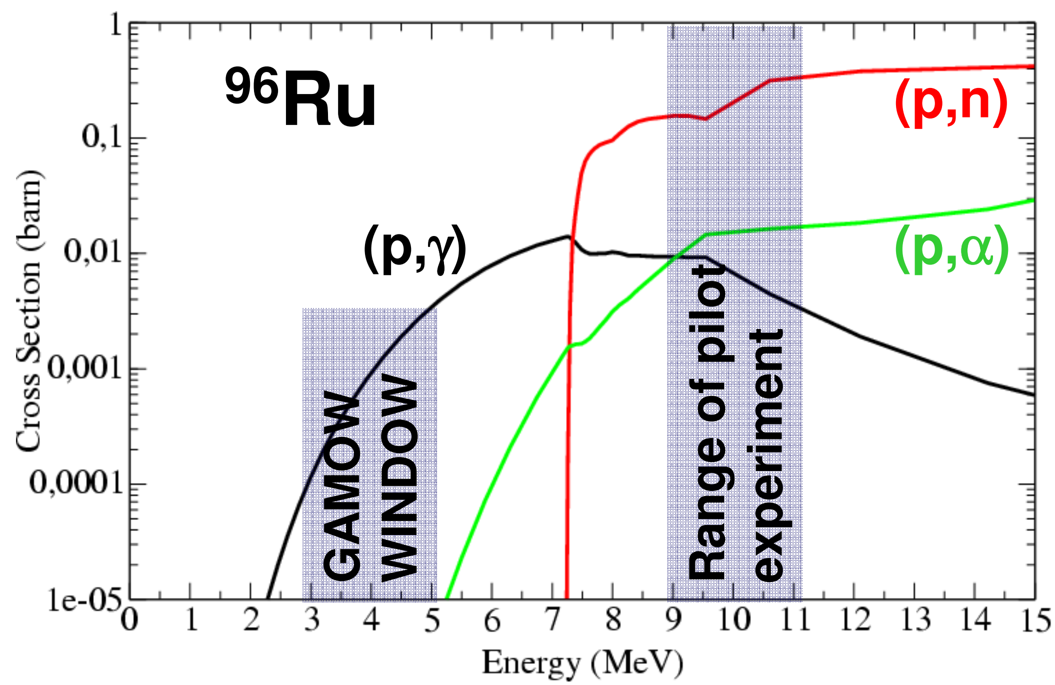


EXL collaboration, thesis Mirko von Schmid

Low Energy Reactions

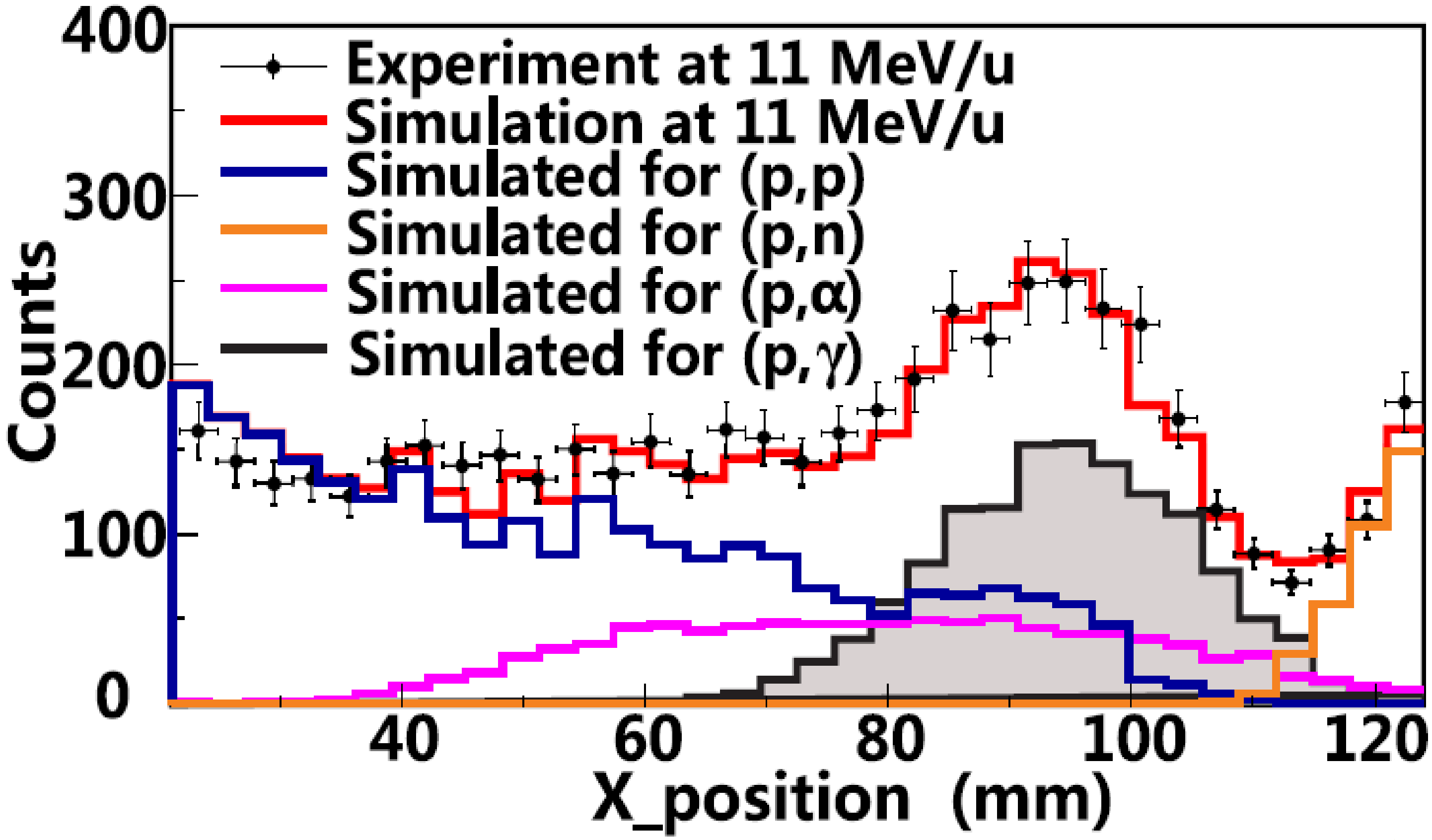


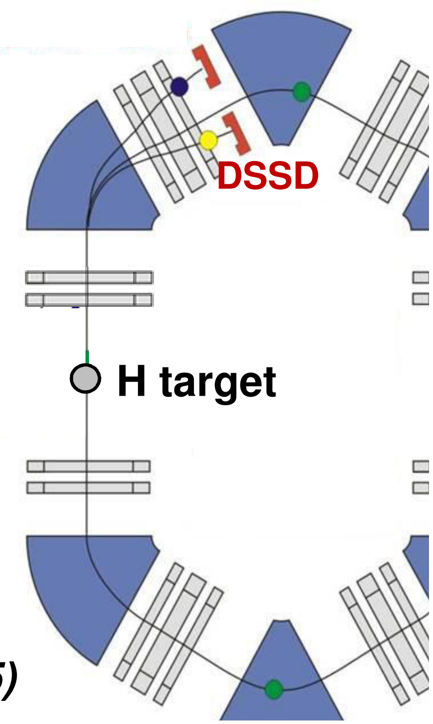
Transfer reactions near Gamow window with astrophysical importance



René Reifarth

Results for ^{96}Ru(p,γ)

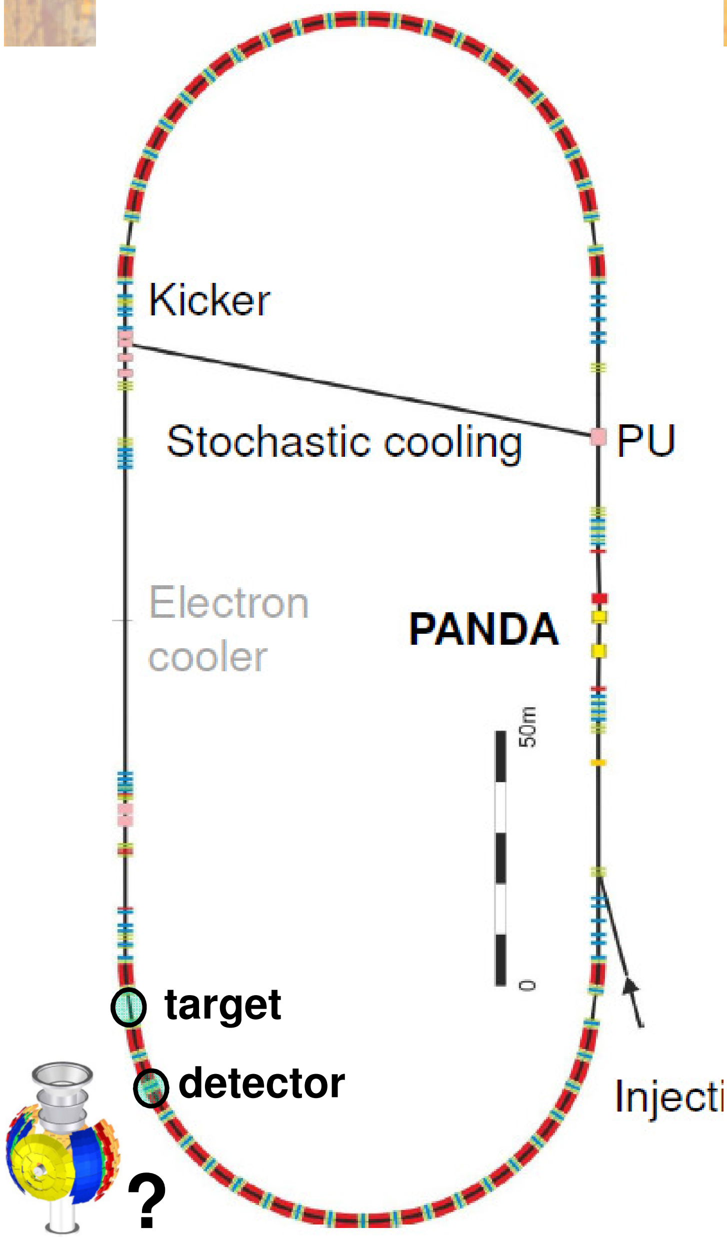




E_{CM} (MeV)	Cross section (mb)
8.976	$8.28^{+2.58}_{-2.76}$
9.973	$7.83^{+2.13}_{-2.13}$
10.971	$9.13^{+2.59}_{-2.94}$

Bo Mei *et al.*,
Phys. Rev. C 92, 035803 (2015)

HESR Perspectives



Circumference = 574 m
Bρ = 5 – 50 Tm (5 Tm, m/q=2.5 → 176 MeV/u)
small aperture (50 mm radius).

Injection at 740 MeV/u, deceleration,
fast stochastic cooling,
extra electron cooler for lower energies ?

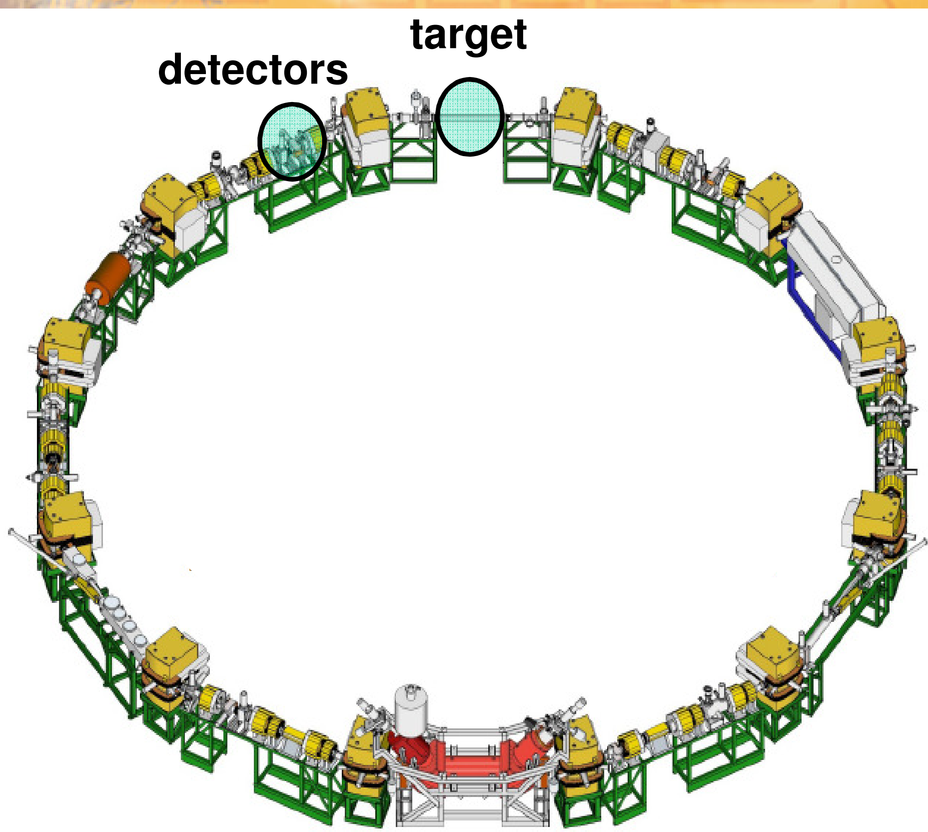
Heavy ions now foreseen in HESR.
Most HESR magnets were ordered,
partially already delivered.

Target (micro droplet and gas cluster jet),
low beam diameter at target (Δx_{FWHM}~2.4 mm)

Also strong interest from SPARC. We
must share setup, narrow space in tunnel.

CRYRING

- under construction behind ESR -



Circumference = 54.17 m
inject ESR beam at 1.44 Tm,
heavy ions E_{max} = 12-25 MeV/u
E_{min} limited by charge exchange,
vacuum $10^{-11} – 10^{-12}$ mbar,

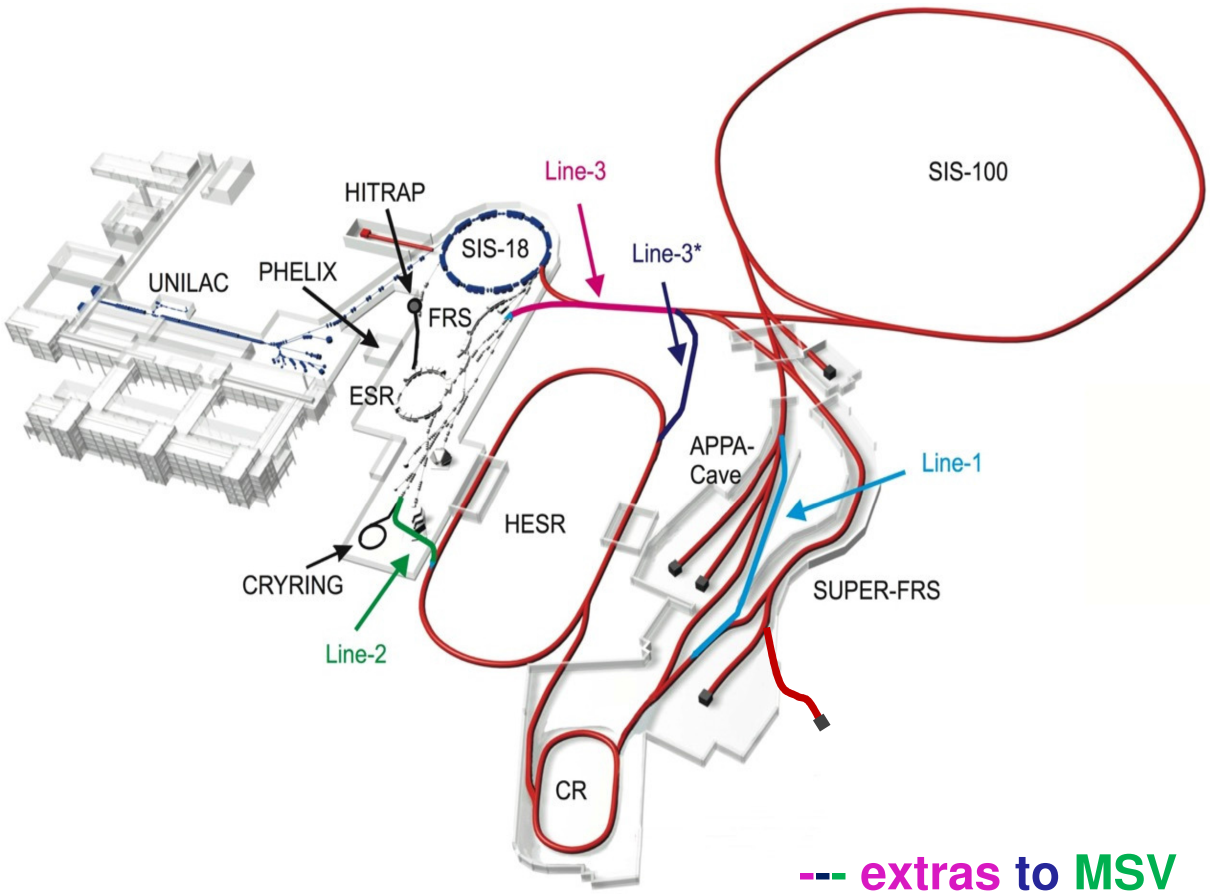
Add gas jet target and detectors.

All Storage Ring Perspectives

- CR, HESR, ESR, CRYRING together cover large energy range,
- via CR also effective cooling and large increase of intensity.
- Coupling to ESR is possible but not in MSV.

ILIMA: CR isochronous
mass measurements
HESR lifetimes
EXL: HESR + ESR
low E reactions CRYRING

ELISe, AIC
future possibility
with extended ESR



--- extras to MSV

Summary

- ILIMA direct mass measurements in CR
  with much improved detectors.

- Lifetime measurements with electron cooler in HESR possible.

- Existing EXL detector can be extended in ESR or HESR.
  Detailed planning for HESR should be done.

- For low energy reactions CRYRING is suited.

- Large acceptance of CR gives big gain factor, fast cooling.
  Such a gain is not possible with FRS + ESR only,
  → connection needed for high luminosity in ESR or CRYRING.

- Some uncertainty about MSV, maybe more after today.