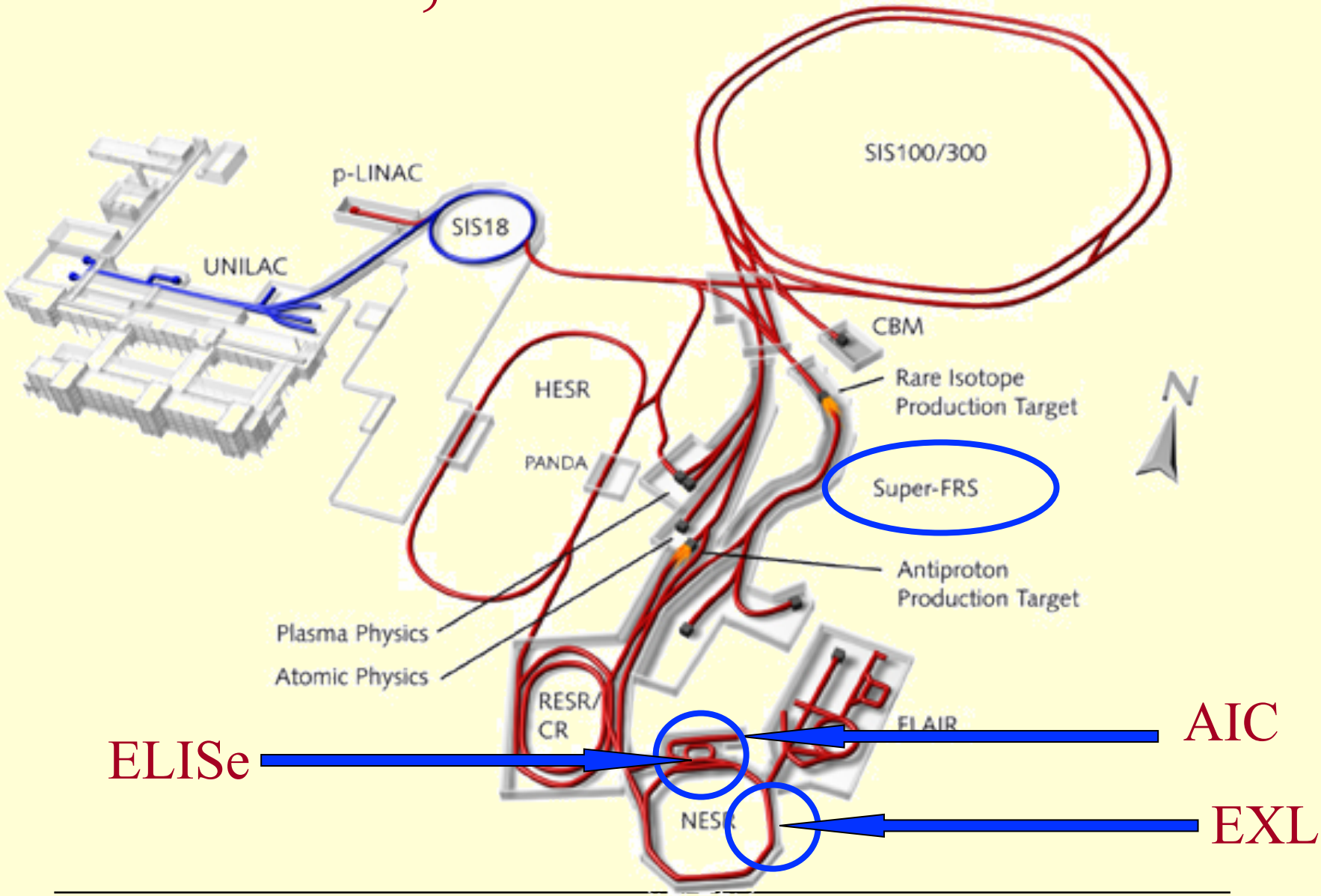
Plans for Nuclear Reactions Experiments with Rings @ ESR and @ FAIR

Nasser Kalantar-Nayestanaki,
KVI, University of Groningen

NUSTAR meeting, GSI

March 2, 2012

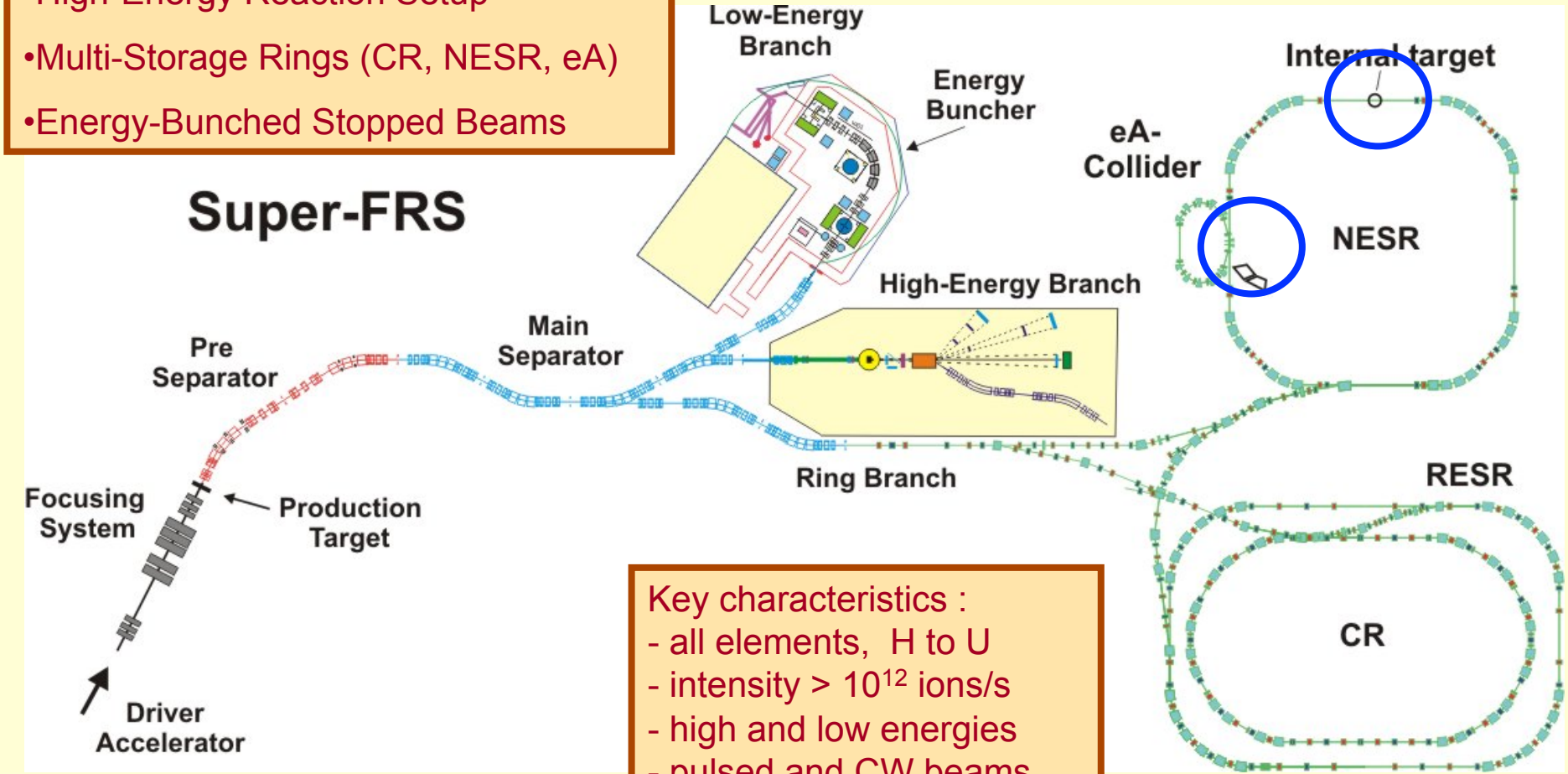
EXL, ELISe and AIC



Nuclear Physics with Radioactive Beams at FAIR

- Superconducting FRagment Separator
- High-Energy Reaction Setup
- Multi-Storage Rings (CR, NESR, eA)
- Energy-Bunched Stopped Beams

Three Experimental Areas



Key characteristics :
- all elements, H to U
- intensity > 10^{12} ions/s
- high and low energies
- pulsed and CW beams

Improvements over the present

Primary beams:

- **Factor 100-1000 over present intensities**

Secondary beams:

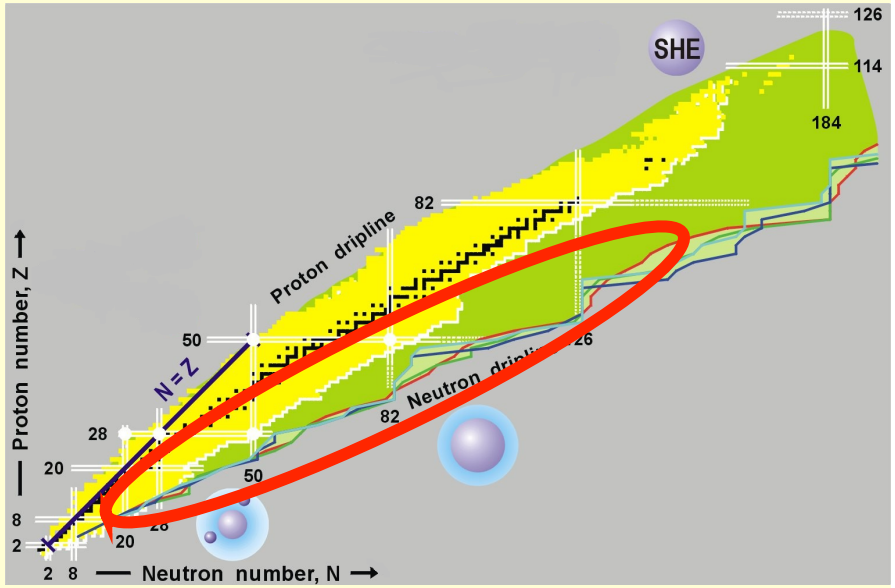
- **Broad range of radioactive beams up to**

  1.5-2 GeV/u; factor of 10000 improvement in intensity with respect to the present facility.

Main Physics Goals

regions of interest:

⇒ towards the driplines for light, medium, medium heavy and heavy nuclei



physics interest:

- matter distributions (halo, skin…)
- Charge distributions
- single-particle structure evolution (new magic numbers, new shell gaps, spetroscopic factors)
- NN correlations, pairing and clusterization phenomena
- new collective modes (different deformations for p and n, giant resonance strength)
- parameters of the nuclear equation of state
- in-medium interactions in asymmetric and low-density matter
- astrophysical r and rp processes, understanding of supernovae

Why low momentum transfers hadronic scattering?

✓ Investigation of Nuclear Matter Distributions along Isotopic Chains:

⇒ halo, skin structure

⇒ probe in-medium interactions at extreme isospin (almost pure neutron matter)

⇒ in combination with electron scattering (ELISe project @ FAIR):
separate neutron/proton content of nuclear matter (deduce neutron skins)

method: elastic proton scattering at low q: high sensitivity to nuclear periphery

✓ Investigation of Giant Monopole Resonance in Doubly Magic Nuclei:

⇒ gives access to nuclear compressibility ⇒ key parameters of the EOS

⇒ new collective modes (breathing mode of neutron skin)

method: inelastic α scattering at low q

✓ Investigation of Gamow-Teller Transitions:

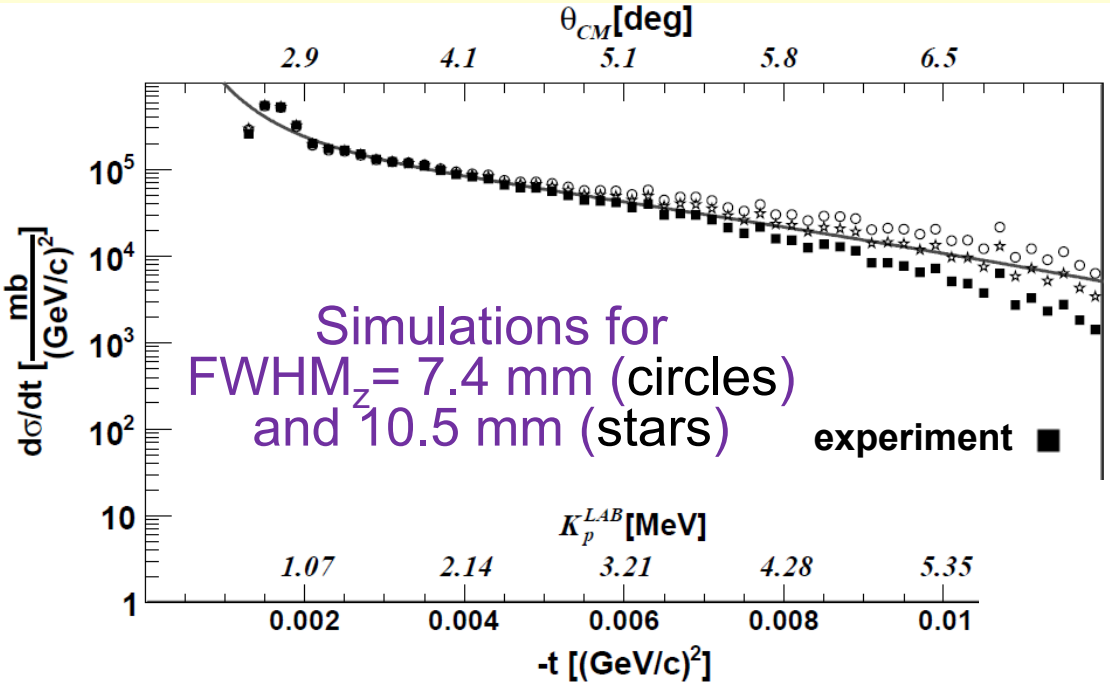
⇒ weak interaction rates for N = Z waiting point nuclei in the rp-process

⇒ electron capture rates in the pre-supernova evolution (core collapse)

method: (^{3}He,t), (d,^{2}He) charge exchange reactions at low q

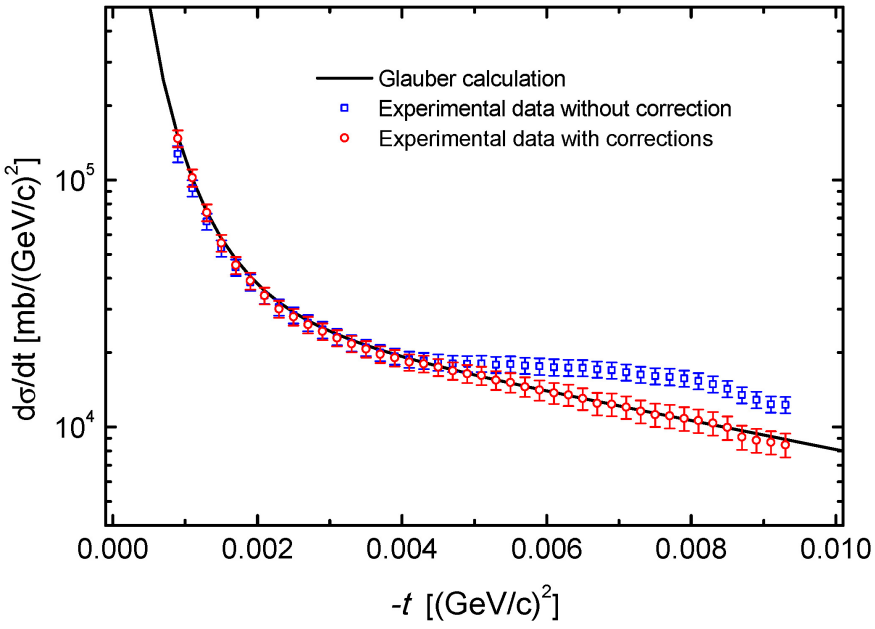
Elastic Scattering Cross Section

First feasibility measurements @ ESR in 2005 and 2011, ^{136}Xe(p,p) and ^{40}Ar(p,p) @ 350 MeV/u and 400 MeV/u, respectively

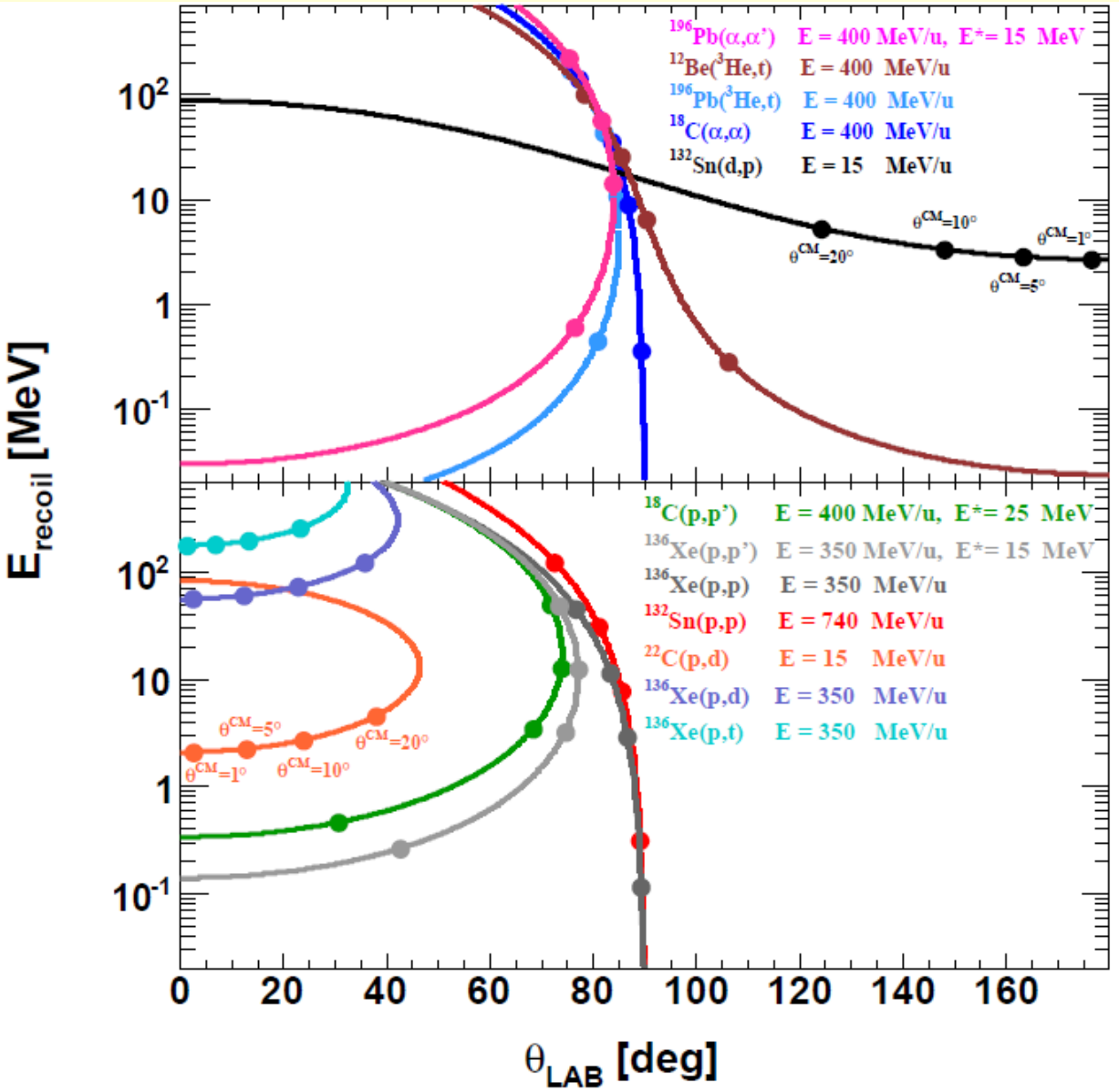


H. Moeini, St. Ilieva et al., NIM A 634, 77 (2011)

Y Ke et al., To be published



Kinematics for inverse reaction



Advantages and disadvantages of storage-ring experiments

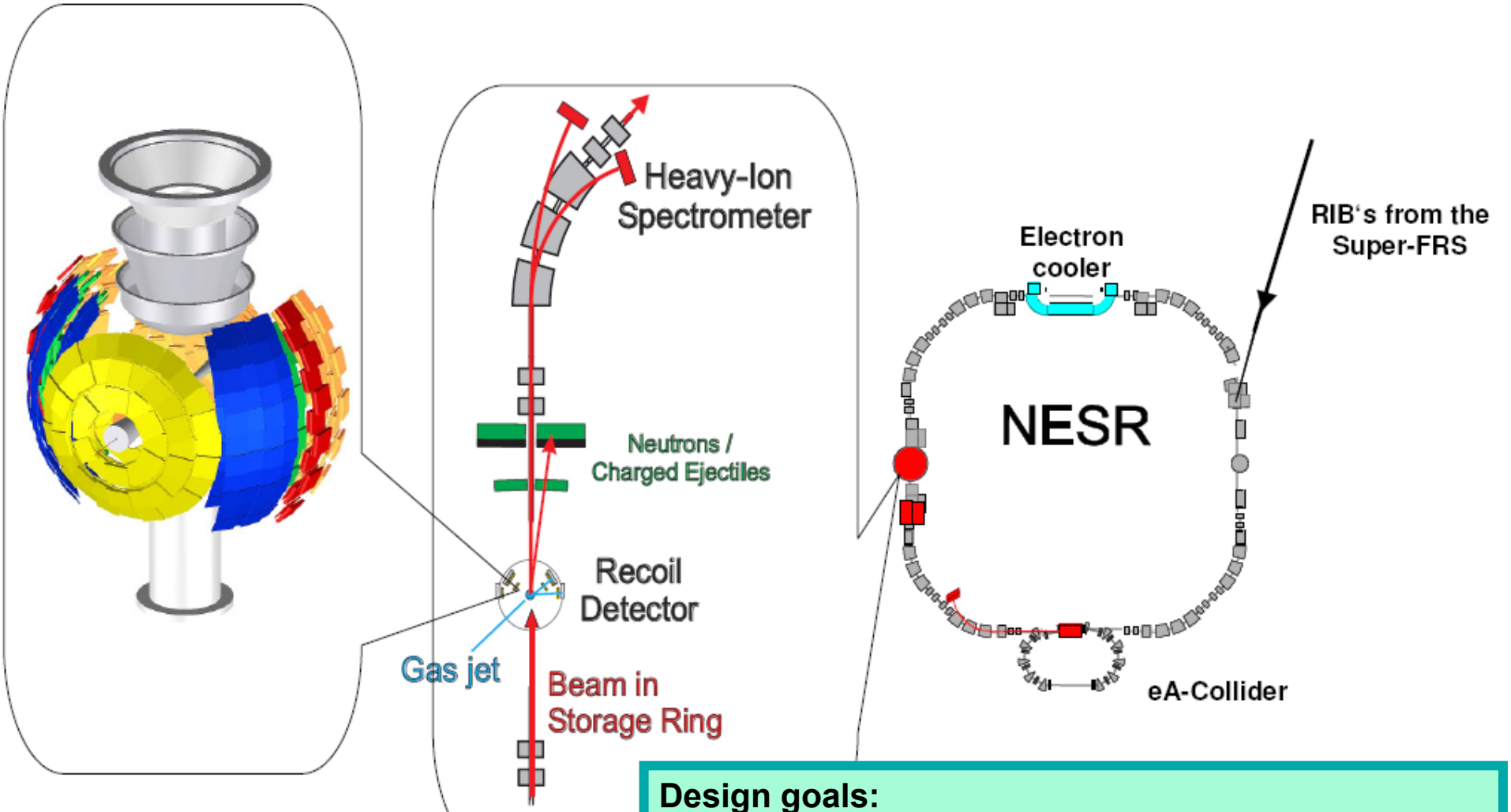
Advantages:

- Large intensities in the ring
- Little energy loss in the target
- No target window (no background)
- High resolution of the beam (cooling)
- Forward focusing for high-energy particles

Disadvantages (challenges):

- Ultra high vacuum
- Very small recoil energies for low q
- Thin targets

Details of the EXL setup

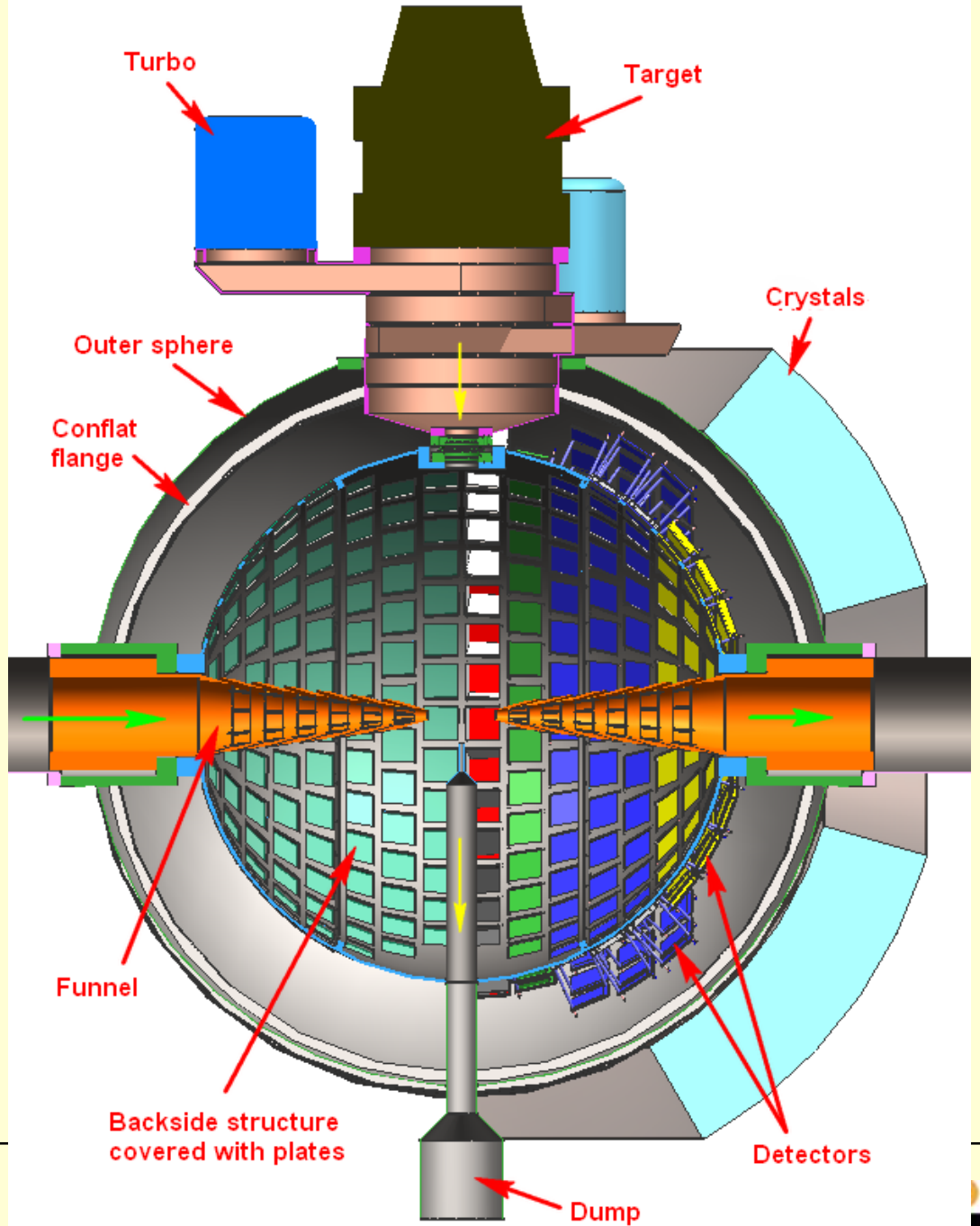


Detection systems for:

- Target recoils and gammas (p,α,n,γ)
- Forward ejectiles (p,n)
- Beam-like heavy ions

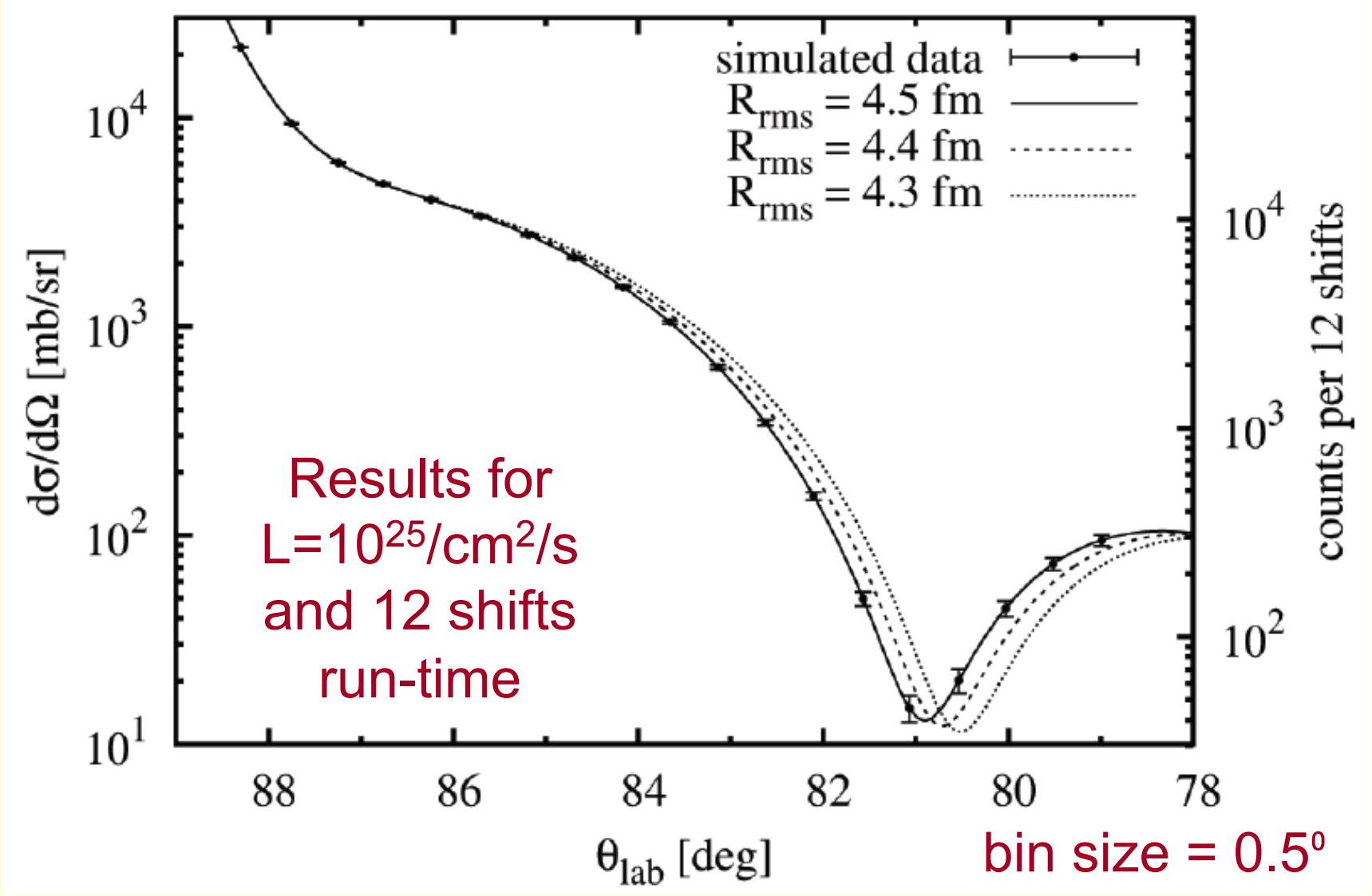
Design goals:

- Universality: applicable to a wide class of reactions
- Good energy and angular resolution
- Large solid angle acceptance
- Specially dedicated for low q measurements with high luminosity (> 10^{28} cm^{-2} s^{-1})

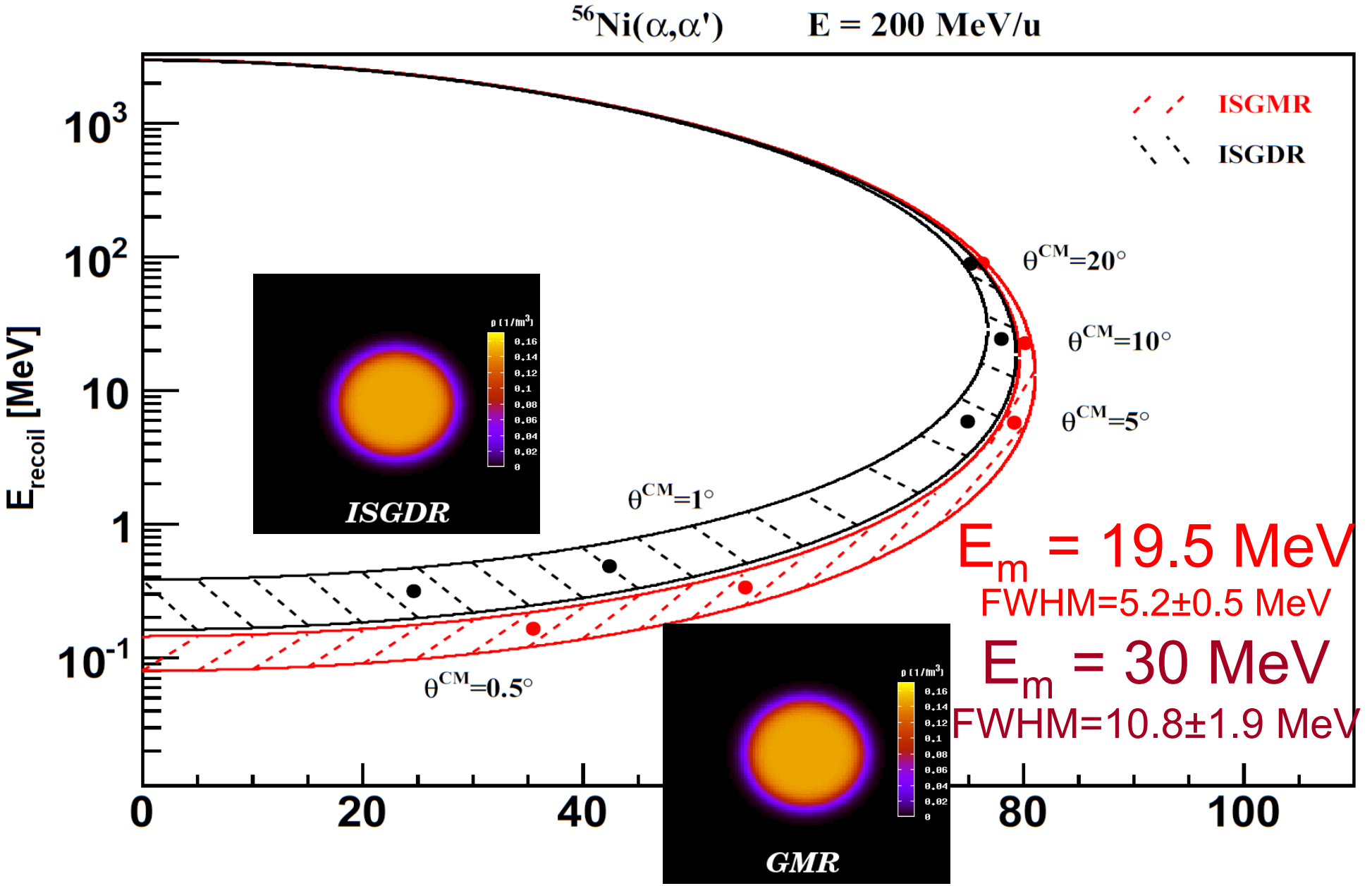

Turbo
Target
Crystals
Outer sphere
Conflat
flange
Funnel
Backside structure
covered with plates
Detectors
Dump

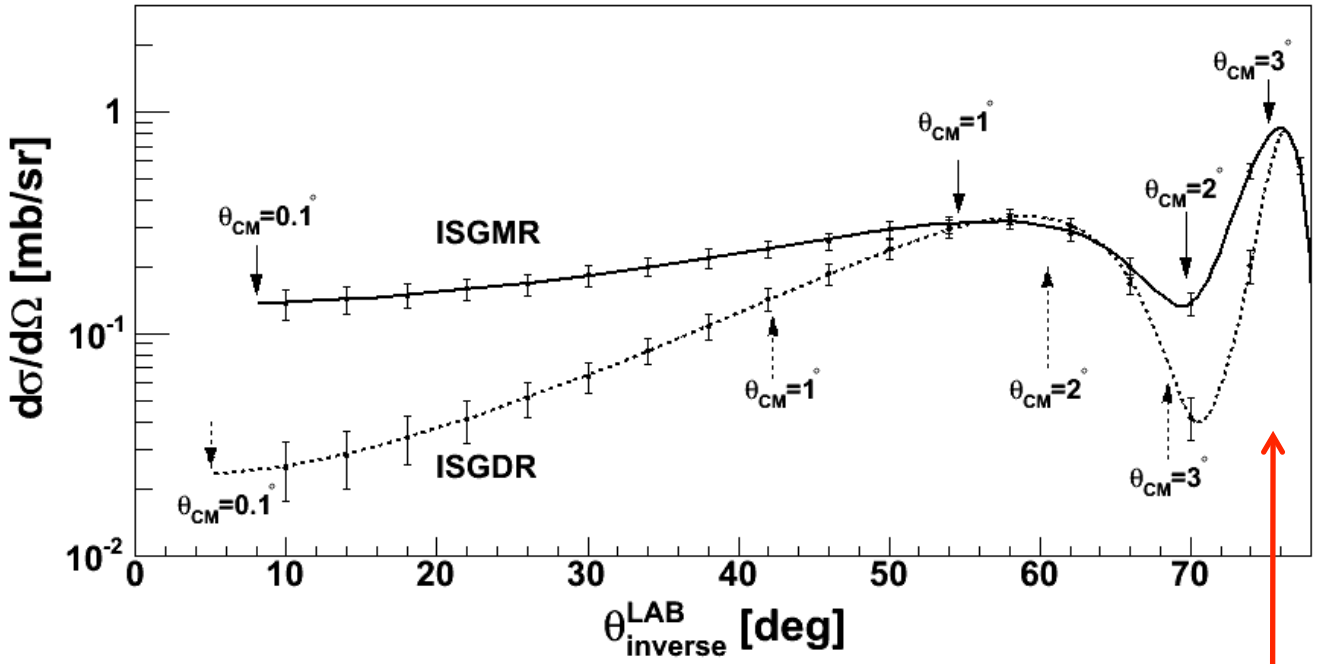
Short Term Plans

Proton elastic-scattering cross sections at 400 MeV/u



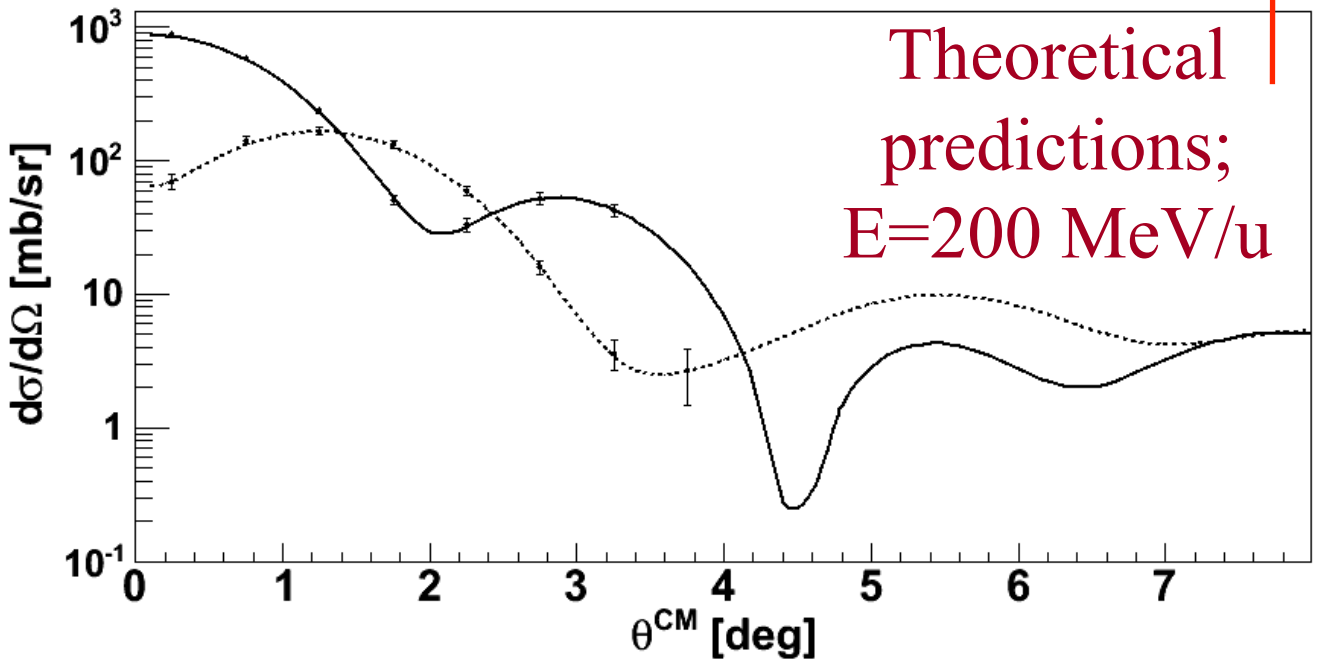
ISGMR/ISGDR channels in ^{56}Ni with (α,α')



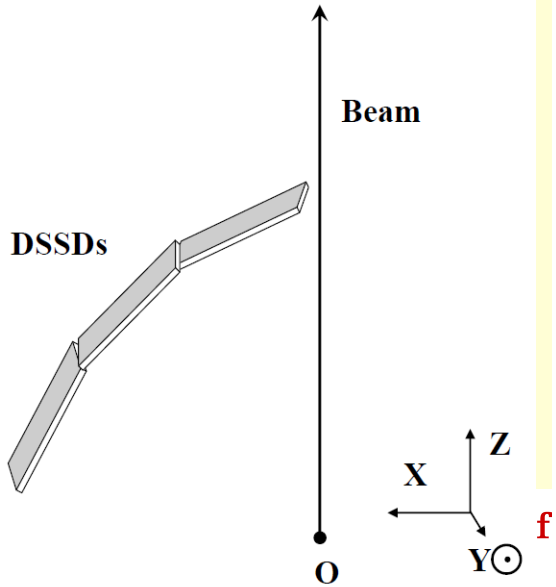


Simulation results for $L=10^{25}/cm^2/s$ and 15 days run-time

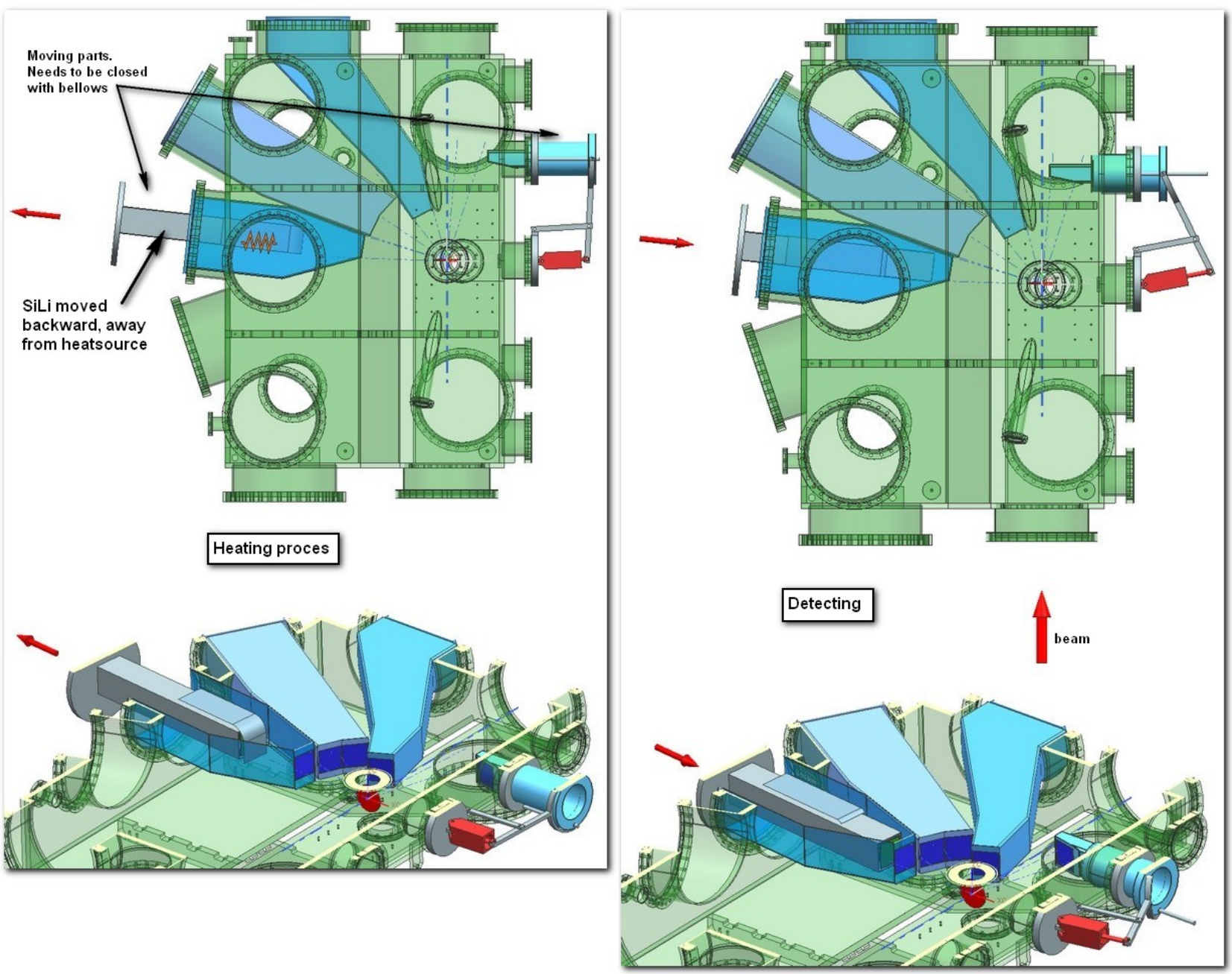
$/J_{1,inv.}$

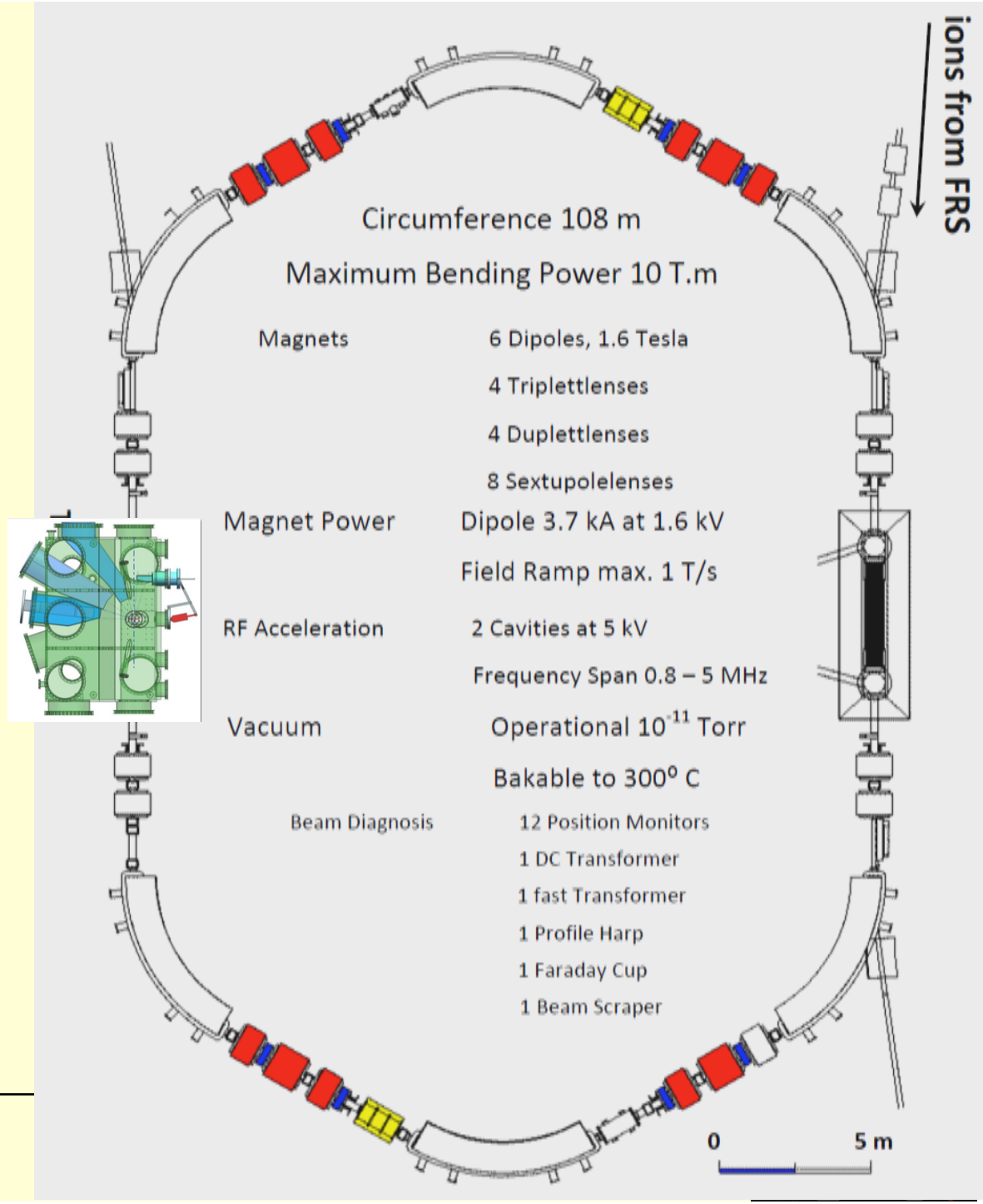


Theoretical predictions; E=200 MeV/u



The new ESR Scattering chamber



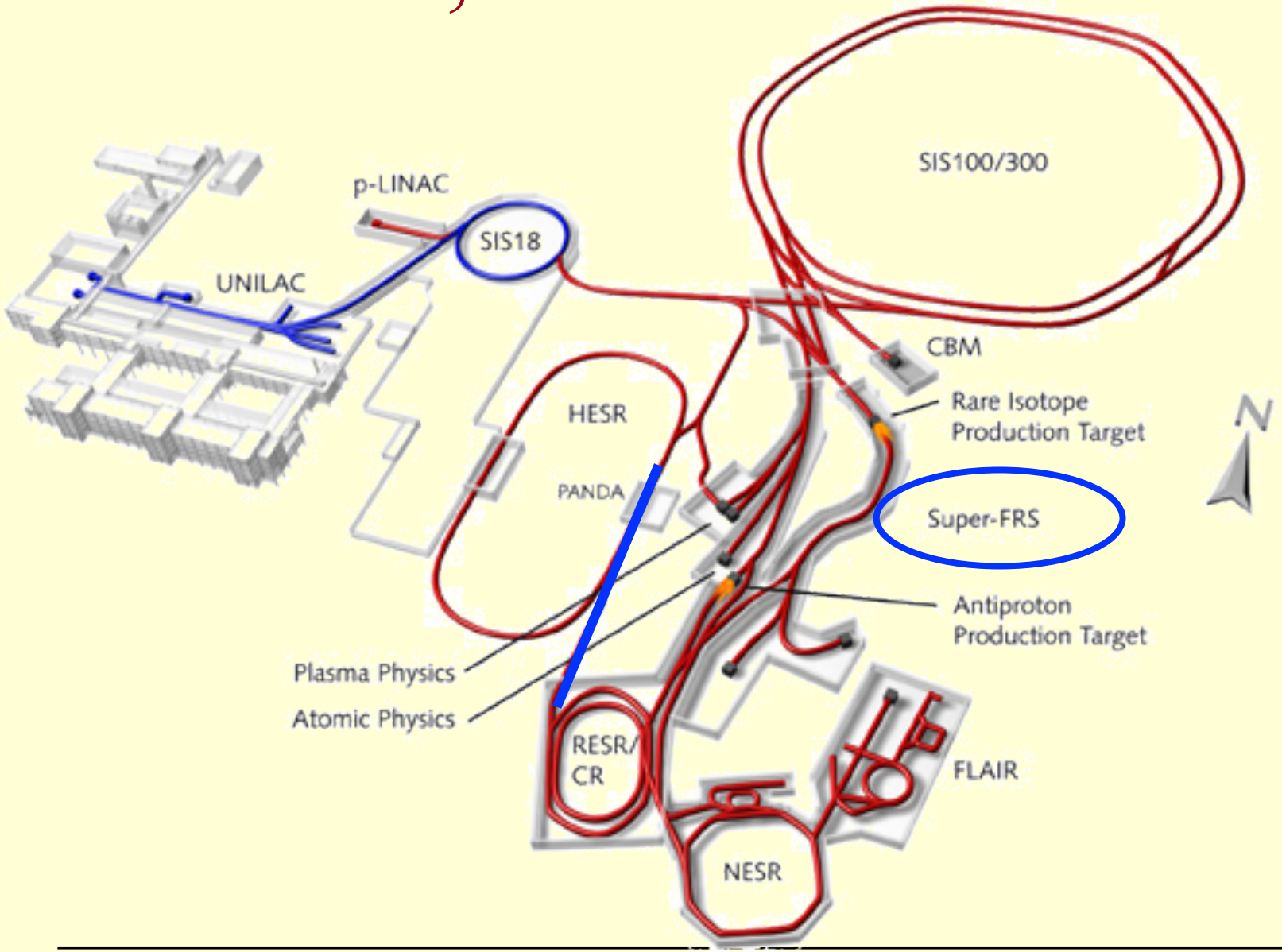


KVI

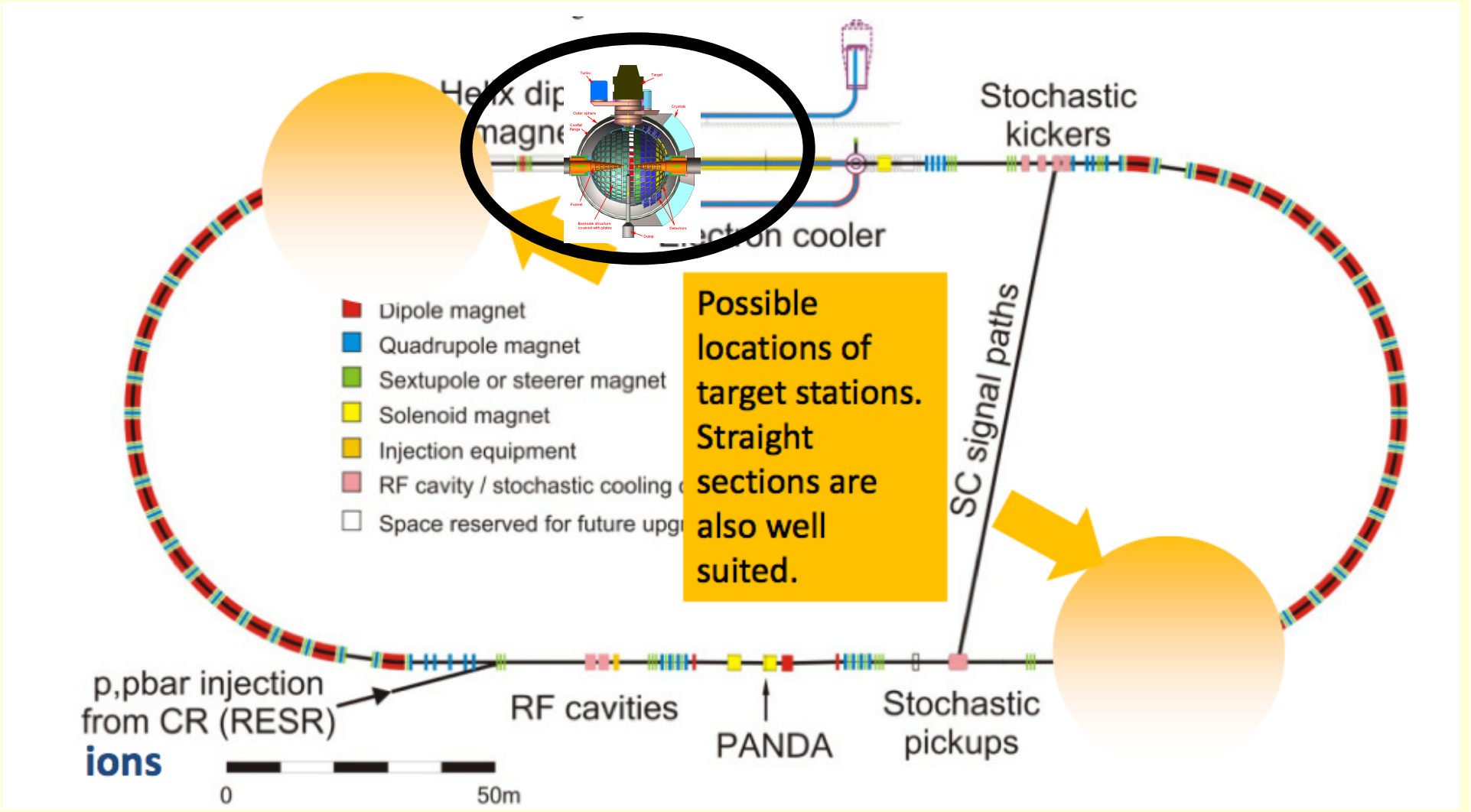
university of groningen

Intermediate Term Plans

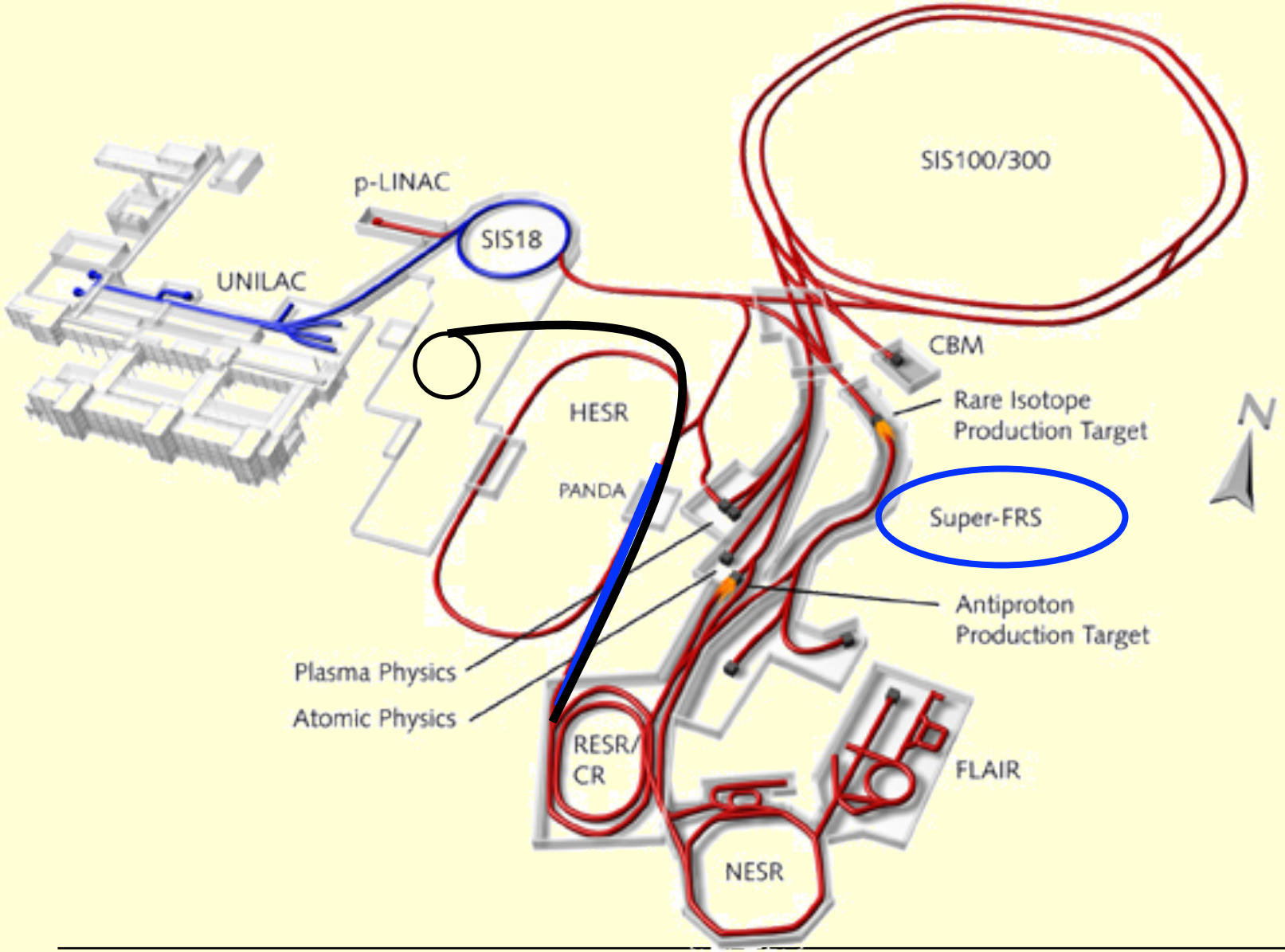
EXL, ELISe and AIC

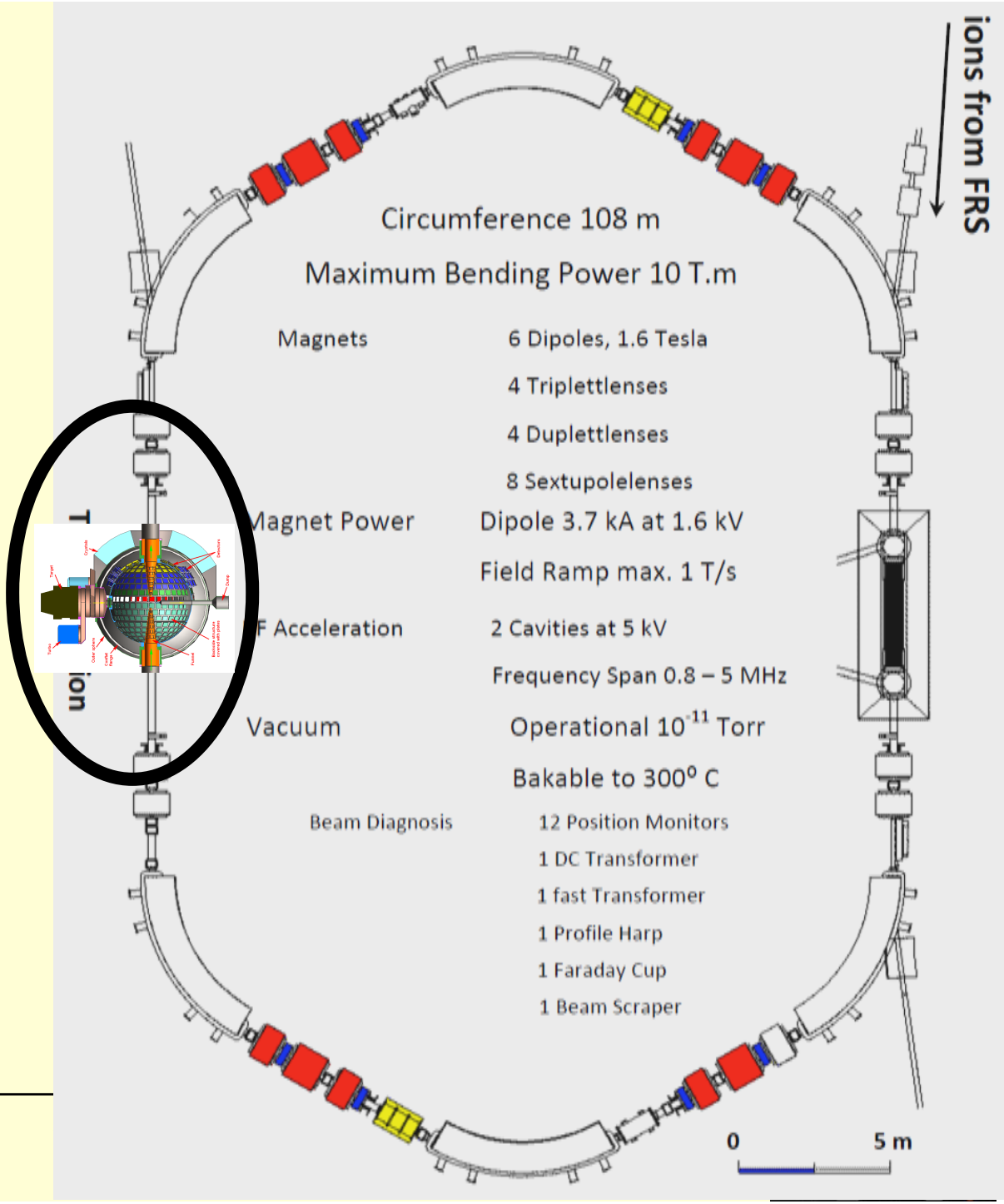


Using HESR


Stochastic kickers
cooler
Dipole magnet
Quadrupole magnet
Sextupole or steerer magnet
Solenoid magnet
Injection equipment
RF cavity / stochastic cooling
Space reserved for future upg
Possible locations of target stations. Straight sections are also well suited.
SC signal paths
p,pbar injection from CR (RESR)
ions
RF cavities
PANDA
Stochastic pickups
0
50m

Transfer line to ESR



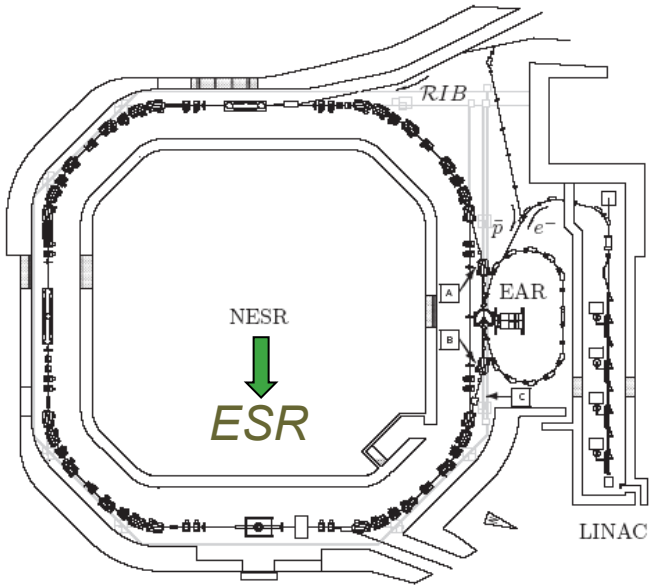


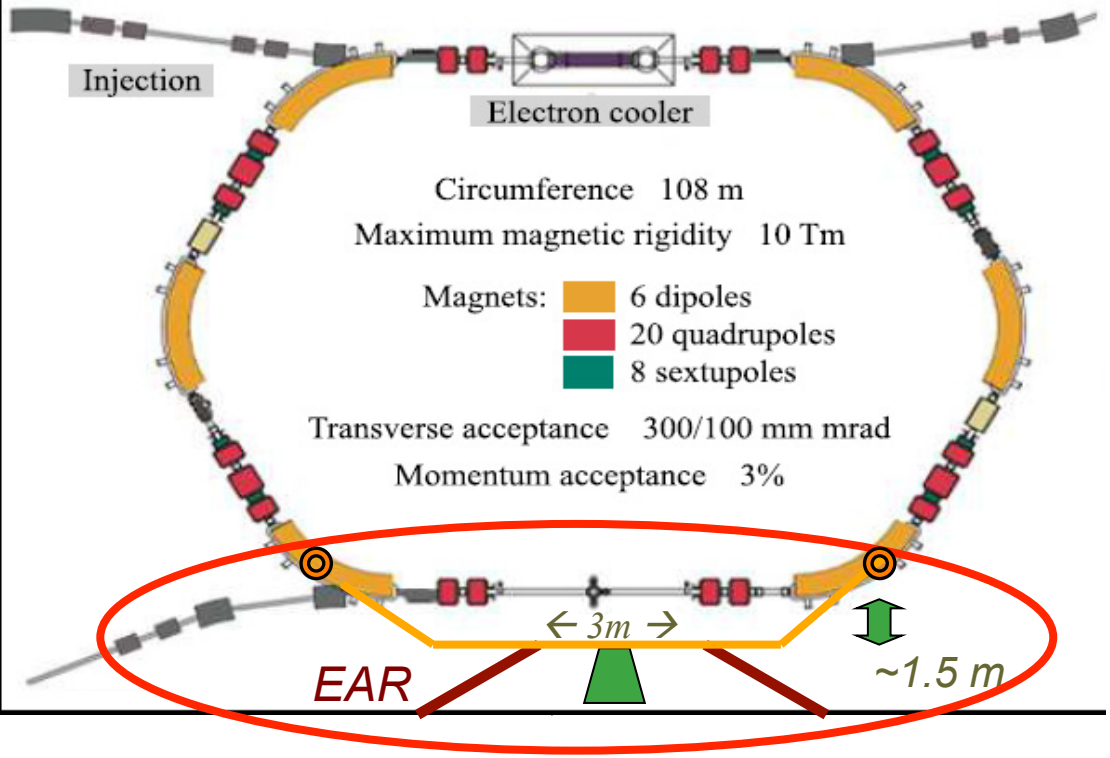
KVI

university of groningen

ELISe /AIC @ ESR ?

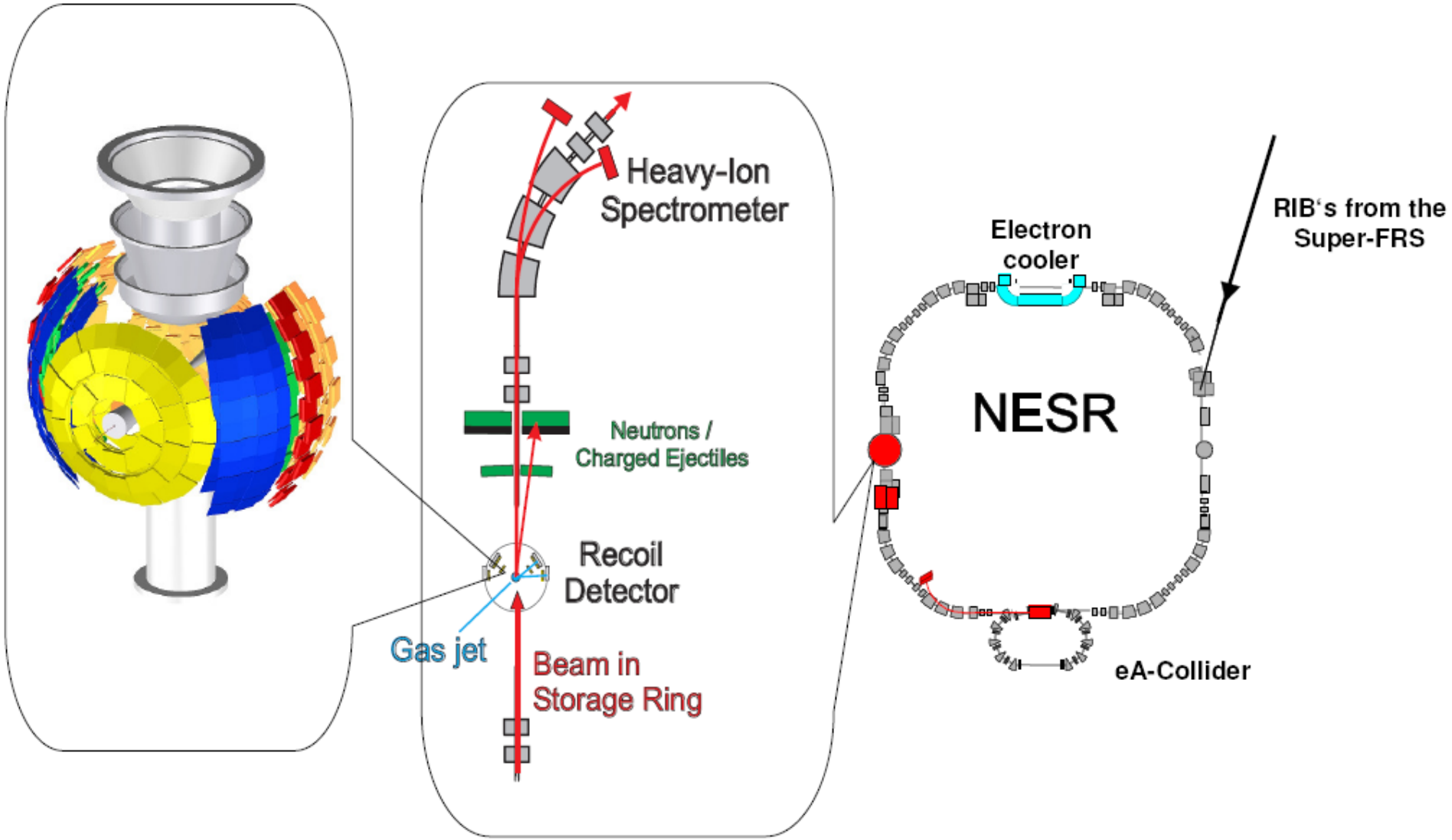
- C type magnets
- Idea: build bypass by selectively compensating the dipole field in one of the quarters of the dipoles





Long Term Plan

Details of the EXL setup

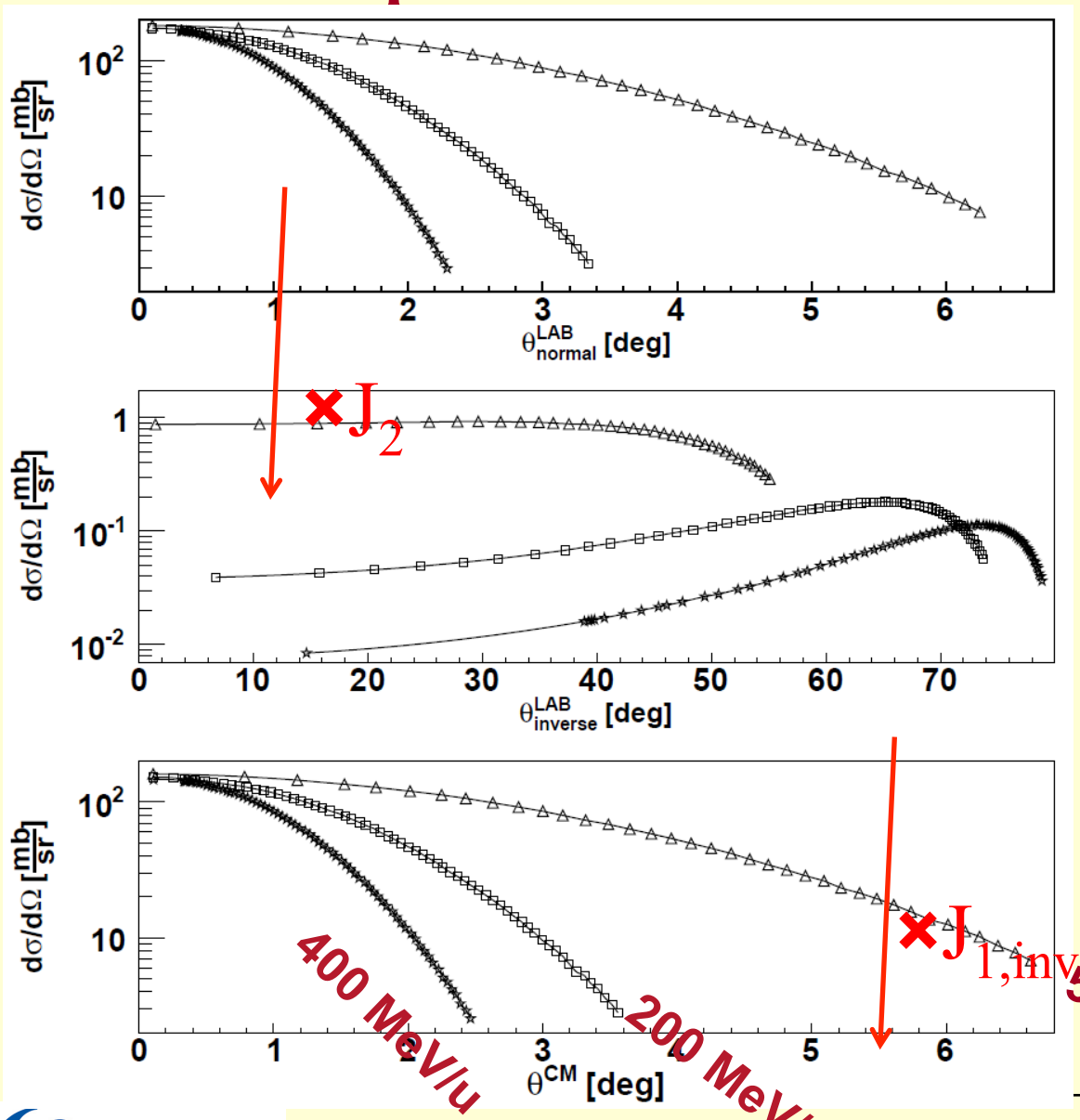


Concluding remarks

- The first experiments with EXL @ ESR with beams close to stability are well underway and will start already in 2012 (Short term). To go beyond, FAIR/superFRS intensities are mandatory.
- Options are: HESR and transfer line to ESR (Intermediate term) and NESR (Long term). The optics studies and cost estimates are also starting for the HESR and the transfer line to ESR.
- The plans for the transfer line(s) is a viable option and should be in line with RESR discussion and any other discussion which is beyond MSV.
- The ESR option opens possibilities for ELISe (and AIC).
- This roadmap makes the ring activities worldwide unique.

Thank you!

Experiments with the ESR



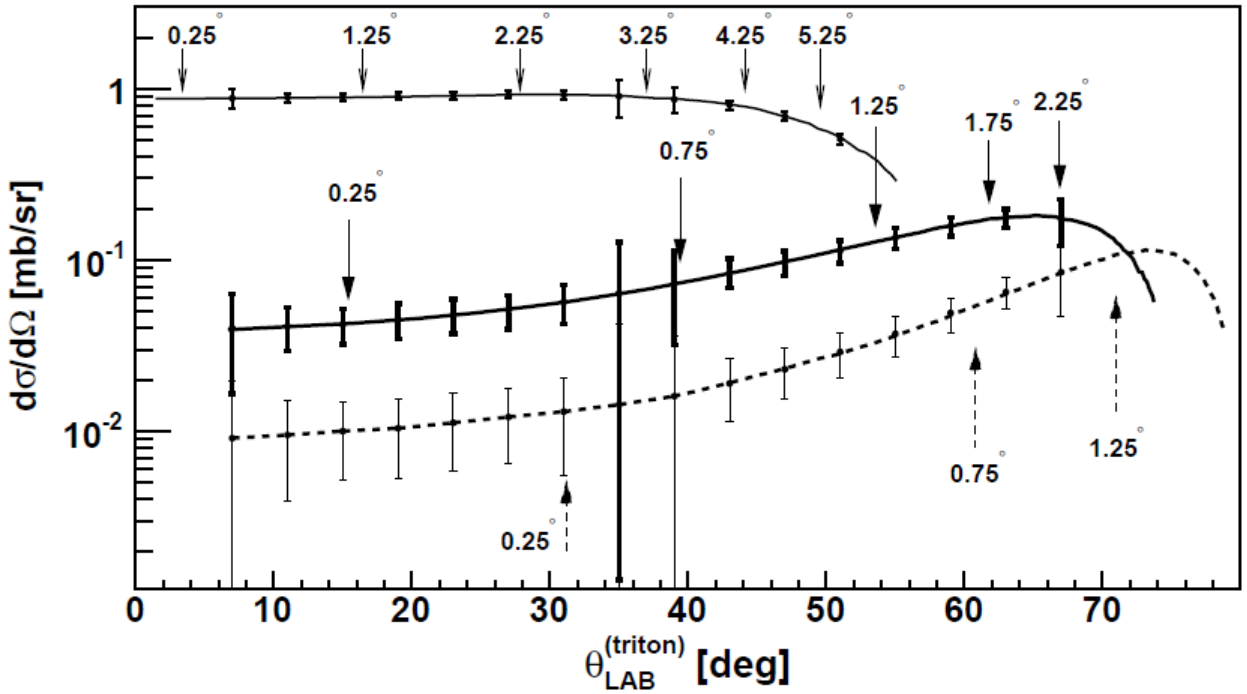
Cross sections

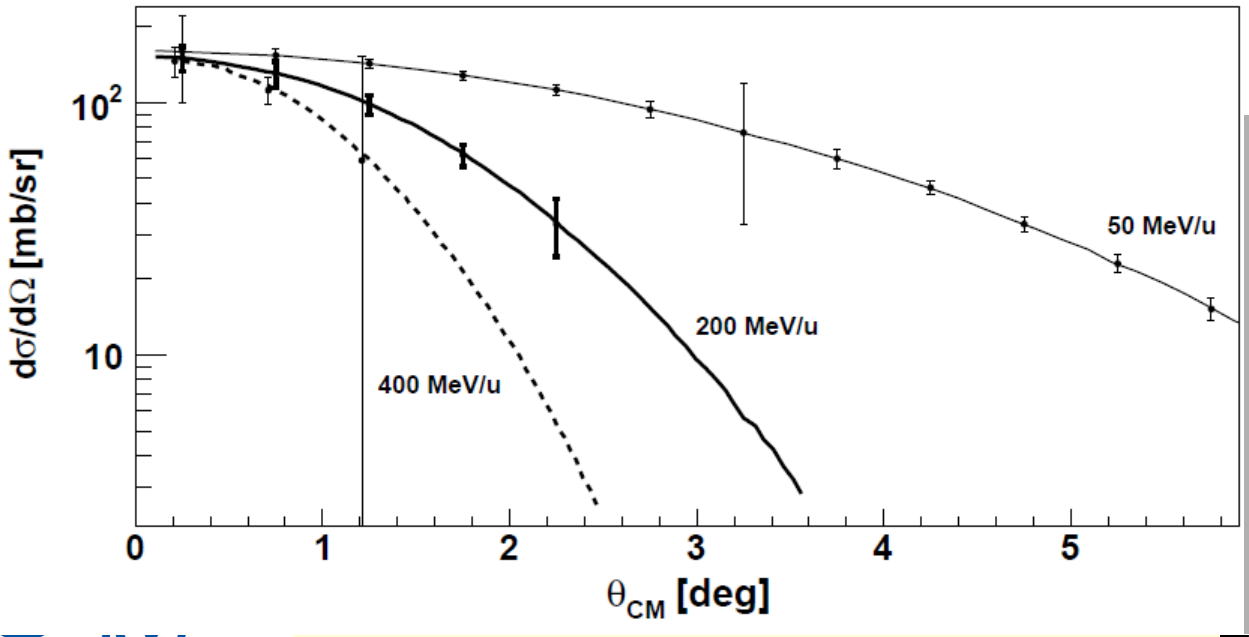
$^{56}Ni(^{3}He,t)\,^{56}Cu$

4 MeV excitation

LAB

CM



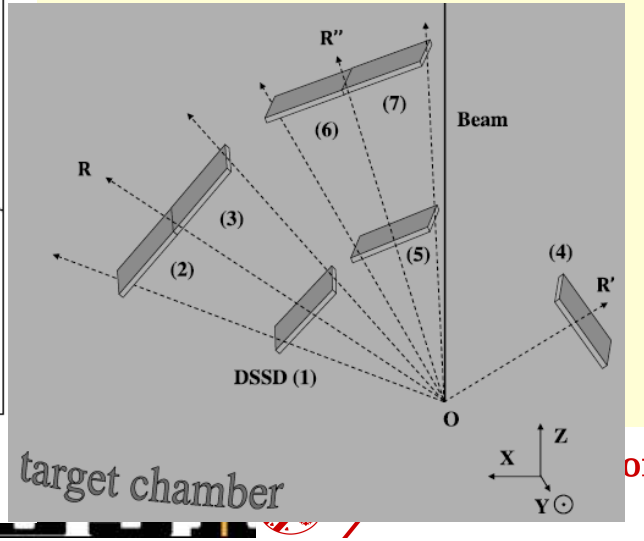


Error estimation

15 days run-time

^{56}Ni(^{3}He,t) ^{56}Cu

4 MeV excitation



The EXL Collaboration


Univ. São Paulo


TRIUMF Vancouver


IMP Lanzhou


VTT Helsinki


IPN Orsay, CEA Saclay


GSI Darmstadt, TU Darmstadt, Univ. Frankfurt, FZ Jülich, Univ. Giessen, Univ. Mainz, Univ. Munich


INR Debrecen


SINP Kolkata, BARC Mumbai


KVI Groningen


INFN/Univ. Milano


Univ. Teheran


Univ. Osaka


JINR Dubna, PNPI Gatchina, KRI St. Petersburg, Ioffe Inst. St. Petersburg, Kurchatov Inst. Moscow


CSIC Madrid, Univ. Madrid


Univ. Lund, Mid Sweden Univ., Univ. Uppsala, Chalmers Inst. Göteborg


Univ. Basel


Univ. Birmingham, CLRC Daresbury, Univ. Surrey, Univ. York, Univ. Liverpool, Univ. Edinburgh


Tbilisi State University, Ilia Chavchavadze State University, Tbilisi, Georgia

Spokesperson: N. Kalantar (KVI)
Deputy: P. Egelhof (GSI)
18 countries, 34 institutes, ~150 participants

Light-ion induced direct reactions

- Elastic scattering (p,p), (α,α), …

  Nuclear matter distribution $\rho_{matter}(r)$, skins, halo structures

- Inelastic scattering (p,p'), (α,α'), …

  Deformation parameters, B(E2) values, transition densities, giant resonances

- Charge exchange reactions (p,n), (^{3}He,t), (d,^{2}He), …

  Gamow-Teller strength

- Transfer reactions (p,d), (p,t), (p, ^{3}He), (d,p), …

  Single particle structure, spectroscopic factors

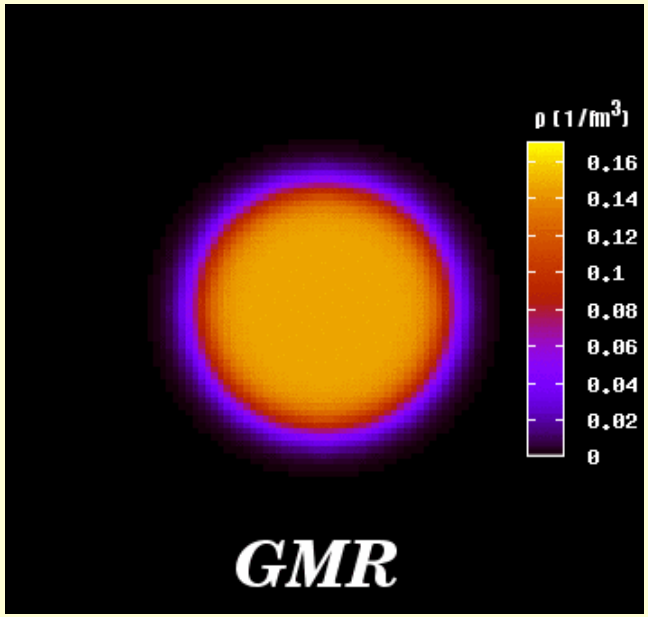
  Spectroscopy beyond the driplines

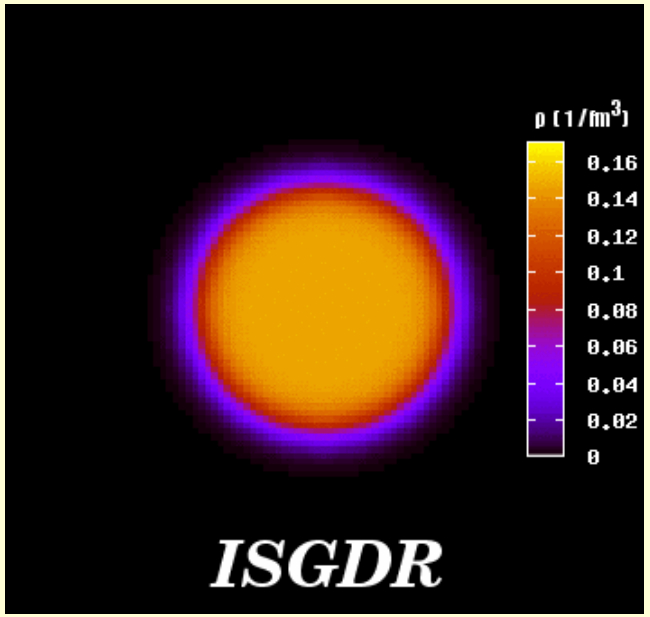
  Neutron pair correlations

  Neutron (proton) capture cross sections

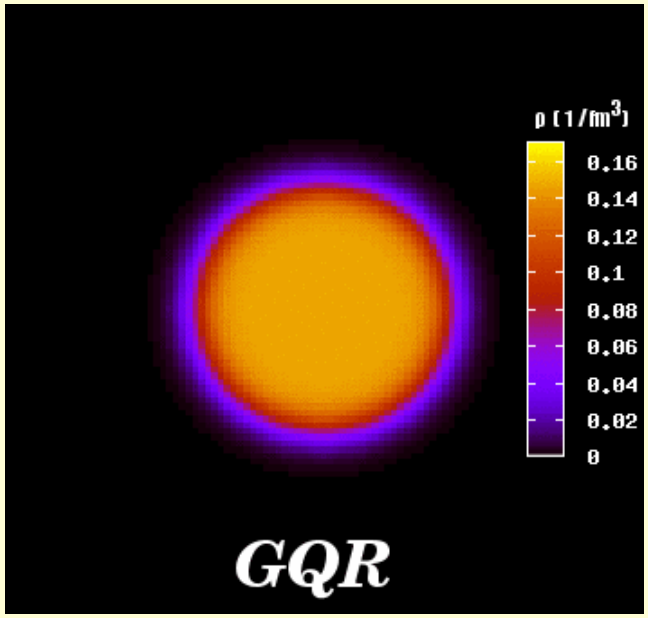
- Knock-out reactions (p,2p), (p,pn), (p,p^{4}He), …

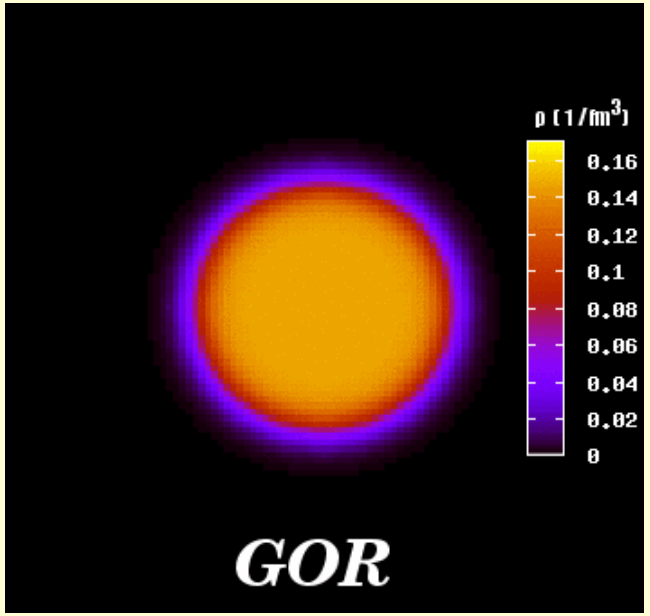
  Ground state configurations, nucleon momentum dist., cluster correlations


ρ [1/fm³]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
GMR


ρ [1/fm³]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ISGDR

M. Itoh


ρ [1/fm³]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
GQR


ρ [1/fm³]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
GOR

Kinematics for inverse reaction for ^{56}Ni