Dispersion-Matched Spectrometers for High-Resolution Experiments

Hans Geissel

GSI and Justus Liebig University Giessen

- Introduction “International Expert-Meeting, Quo Vadis?”
- Projectile Fragment Separators coupled to / used as Spectrometers
- Dispersive Spectrometers
- Energy-Loss (dispersion-matched) Spectrometers ($R_{16}=R_{26}=0$)
- New Features of the Ion-Optical Code MIRKO

International Expert Meeting, Quo Vadis?

Participation: By invitation only
World Experts in the field **and** Newcomers

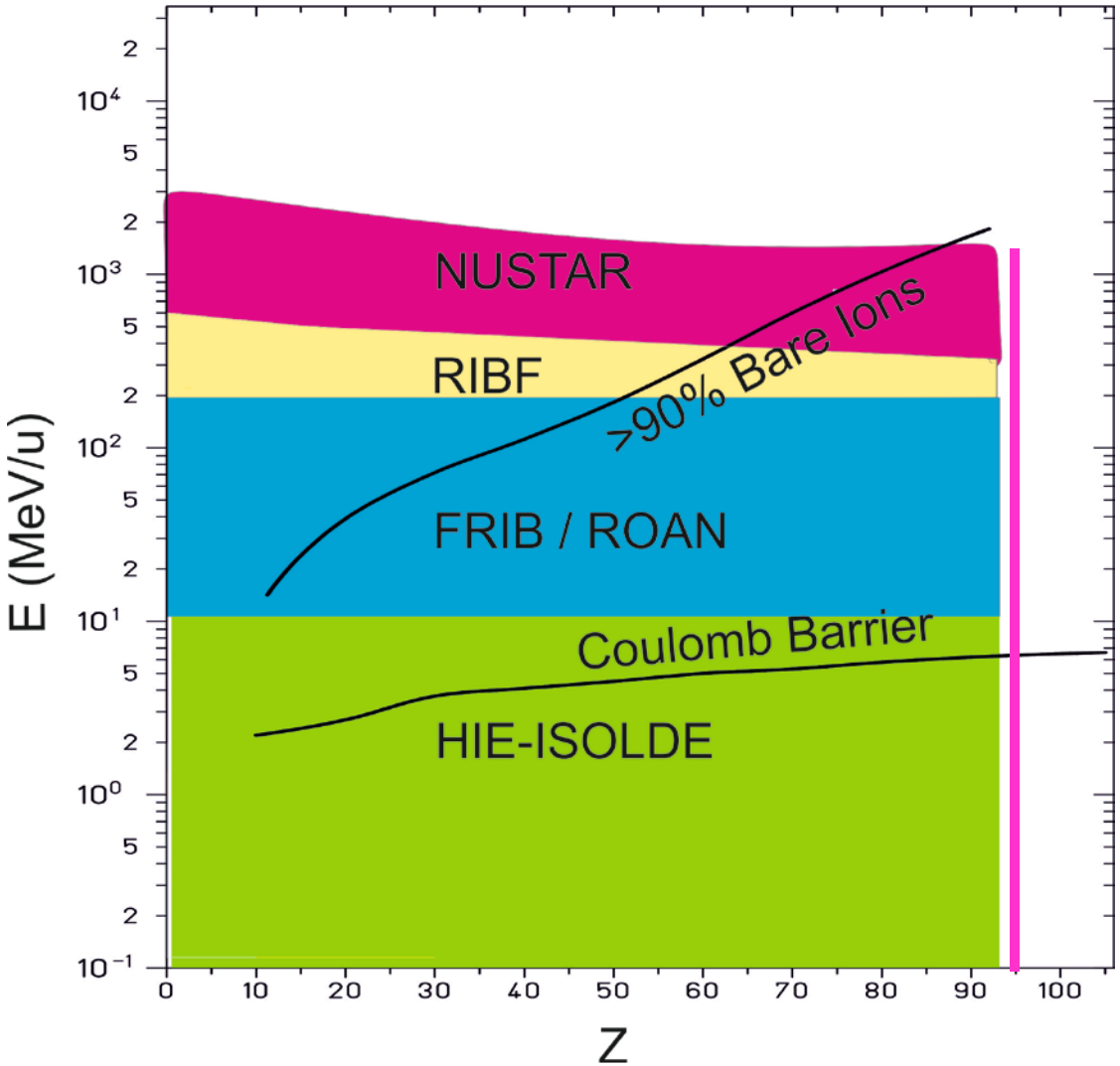
Present Goals of the Fragment Separator International Experts Meetings**:**

- stimulate collaboration in design, construction and operation of in-flight fragment separators
- solve technical and scientific challenges
- have open and frank discussion, exchange new ideas

Possible Future Orientation under the conditions that the different new facilities have quite different construction times:

- a **young generation** of experts have to be recruited and trained
- together we should **avoid duplication** of existing or already planned facilities
  our experts are capable of finding unique properties and experiments for each facility
- form a **network for separator / spectrometer operation and experiments**
- **... please find more ideas!**

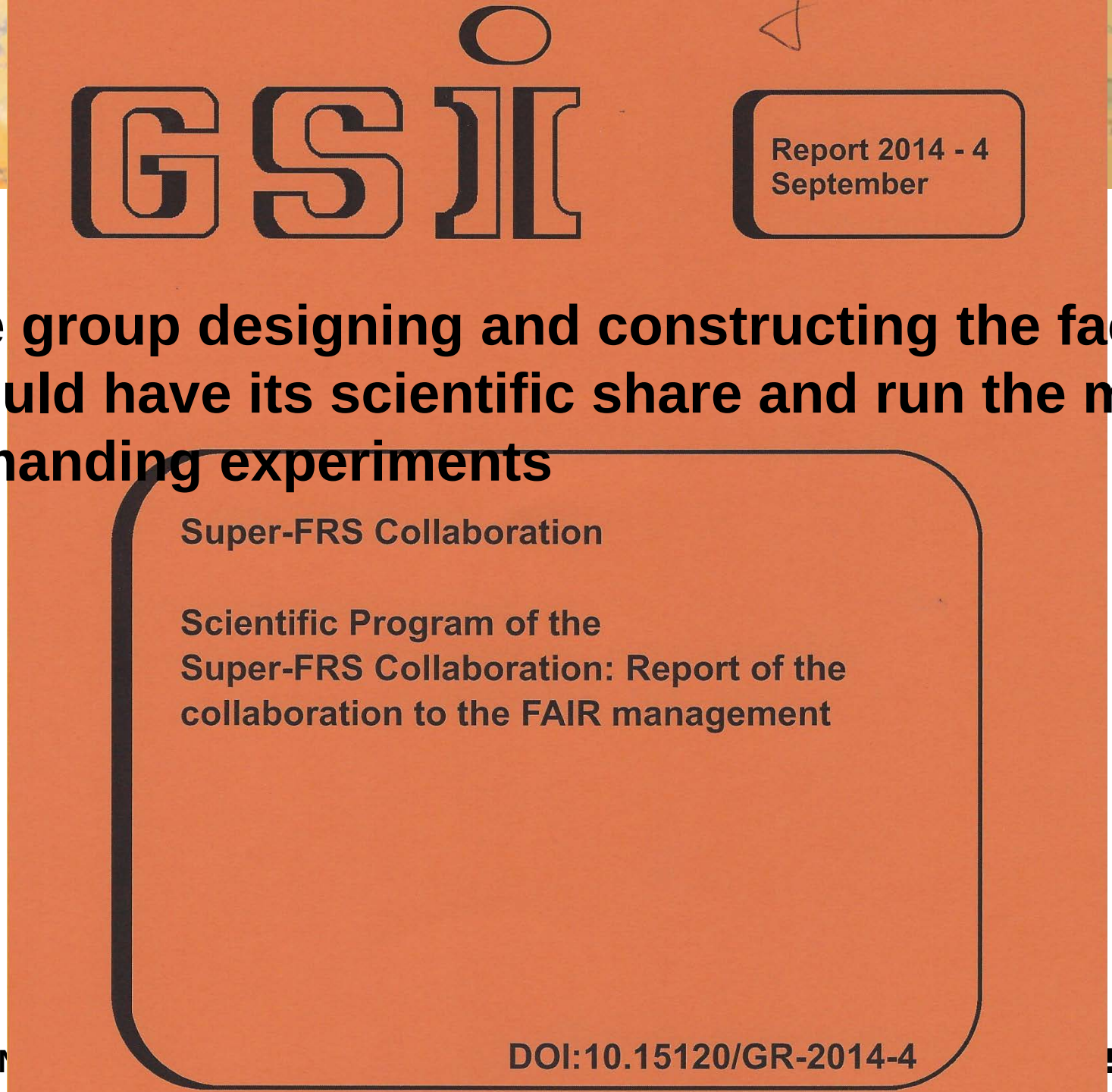
The Super-FRS Facility



- **High energies open unique research potentials:**

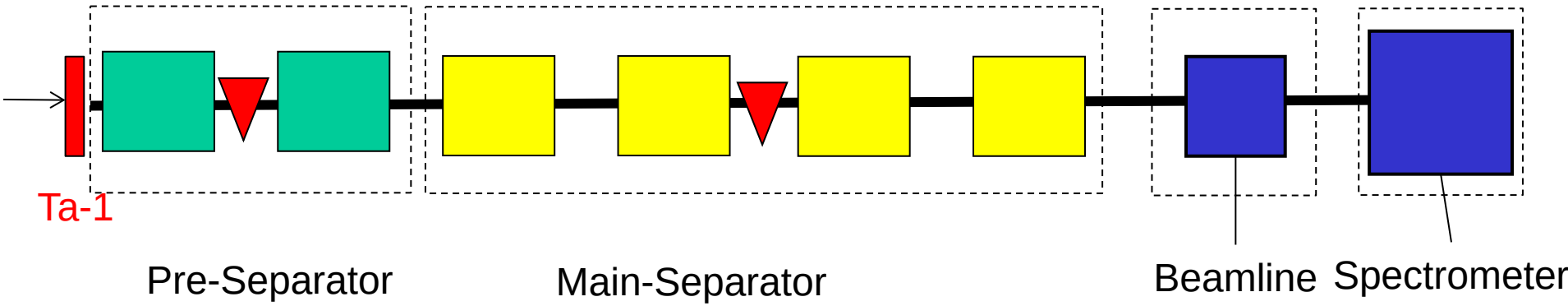
1. **Hypernuclei**
2. **Mesic nuclei** (π^-, η')
3. **Delta excitation**
4. **New decay modes**

- The group designing and constructing the facility should have its scientific share and run the most demanding experiments



In-Flight Separator coupled to a Spectrometer

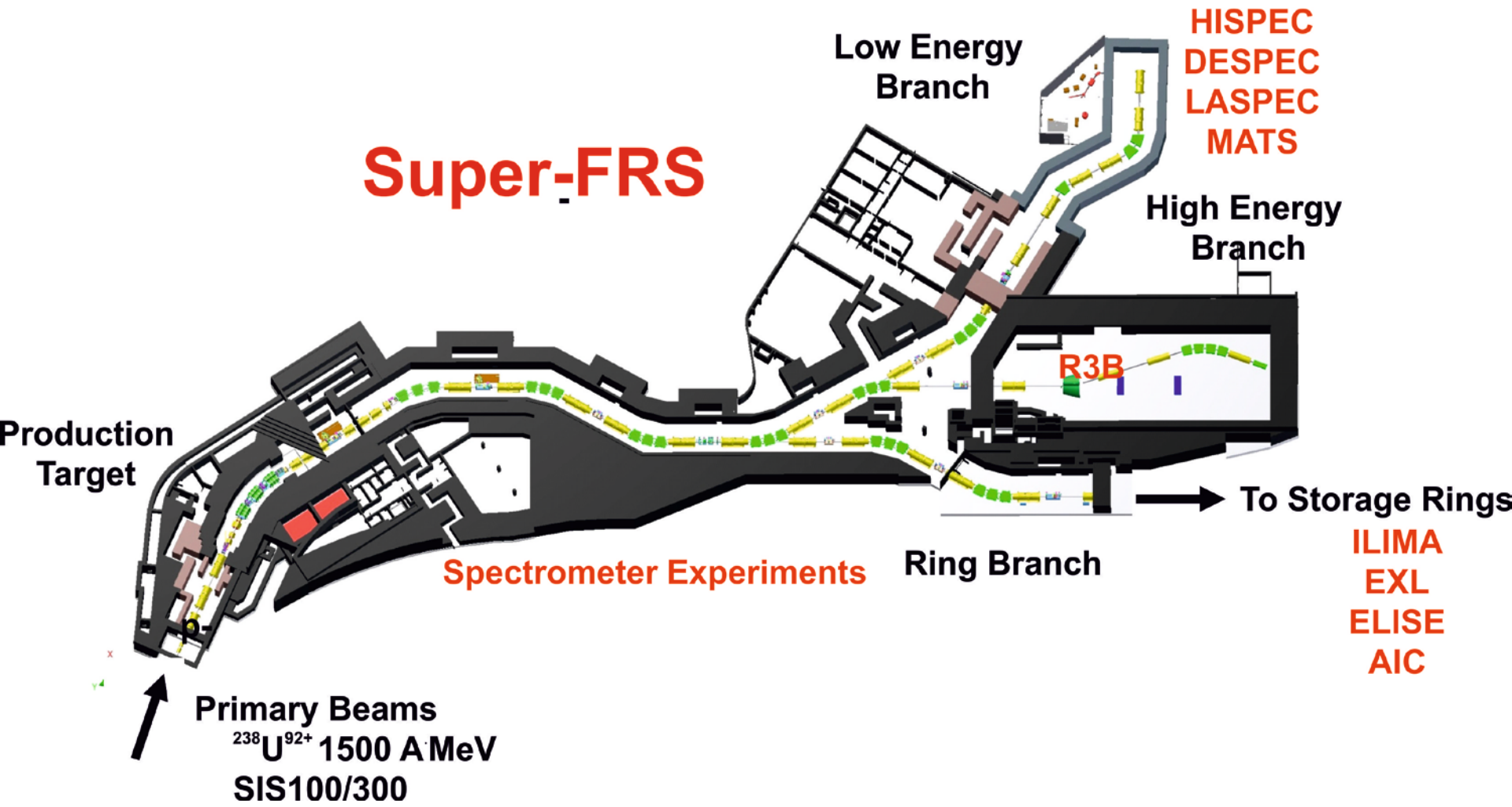
Standard Operation Mode



Examples: Big-RIPS -- Zero-Degree Spectrometer--- SHARAQ--- SAMURAI
A1900 – S800
FRS – ESR --- Ion-Catcher --- ALADIN
ARIS + Beamline + HRS
Super-FRS – E-Buncher – GLAD -- HRS

A versatile system is advantageous to explore new operation modes and unique experiments

Super-FRS is a Powerful Separator and a High Resolution Spectrometer



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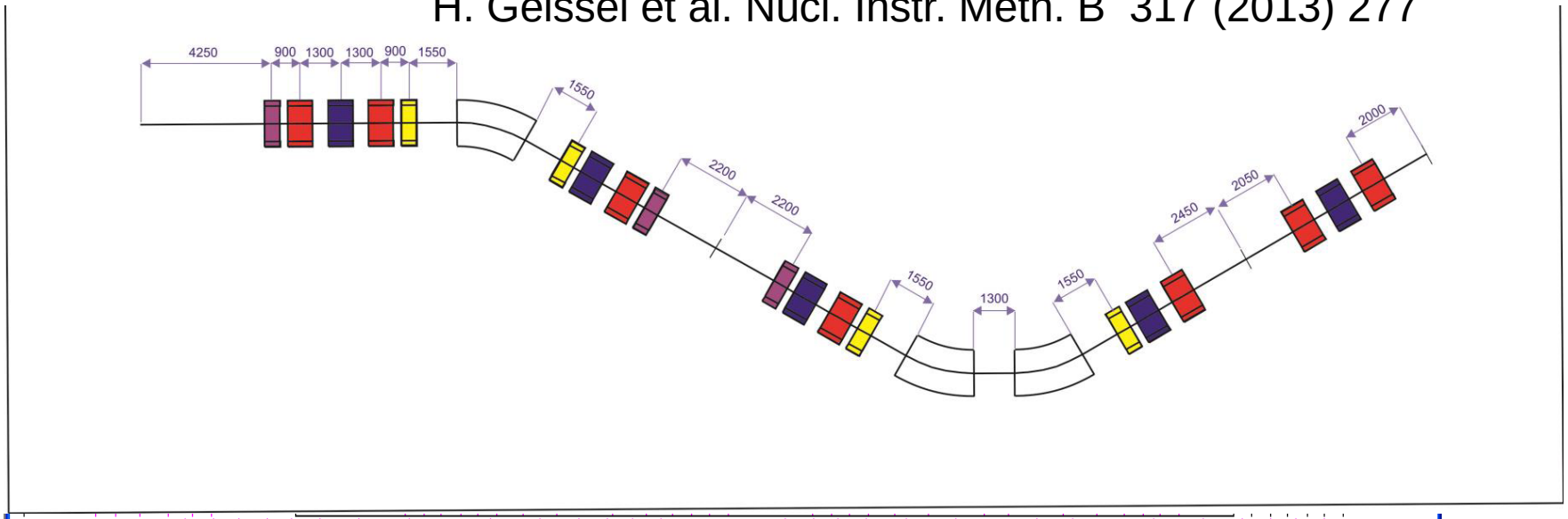
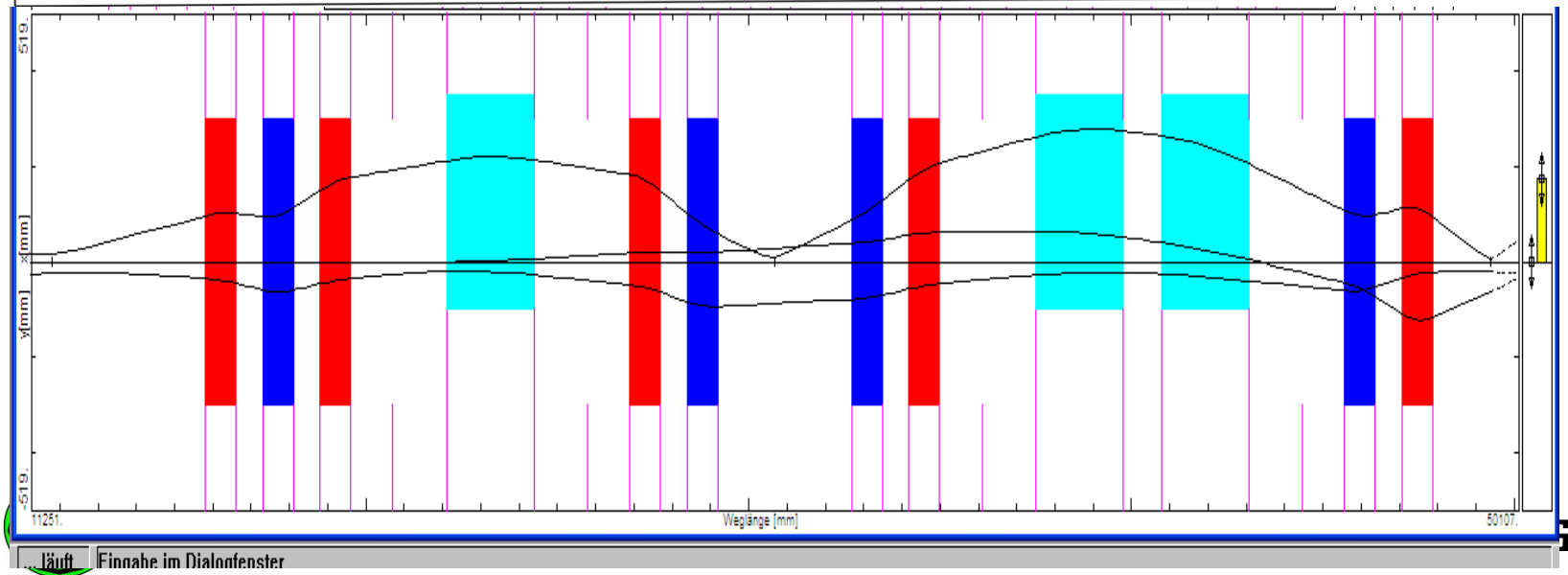
Energy-Buncher of Super-FRS is a Powerful High Resolution Spectrometer

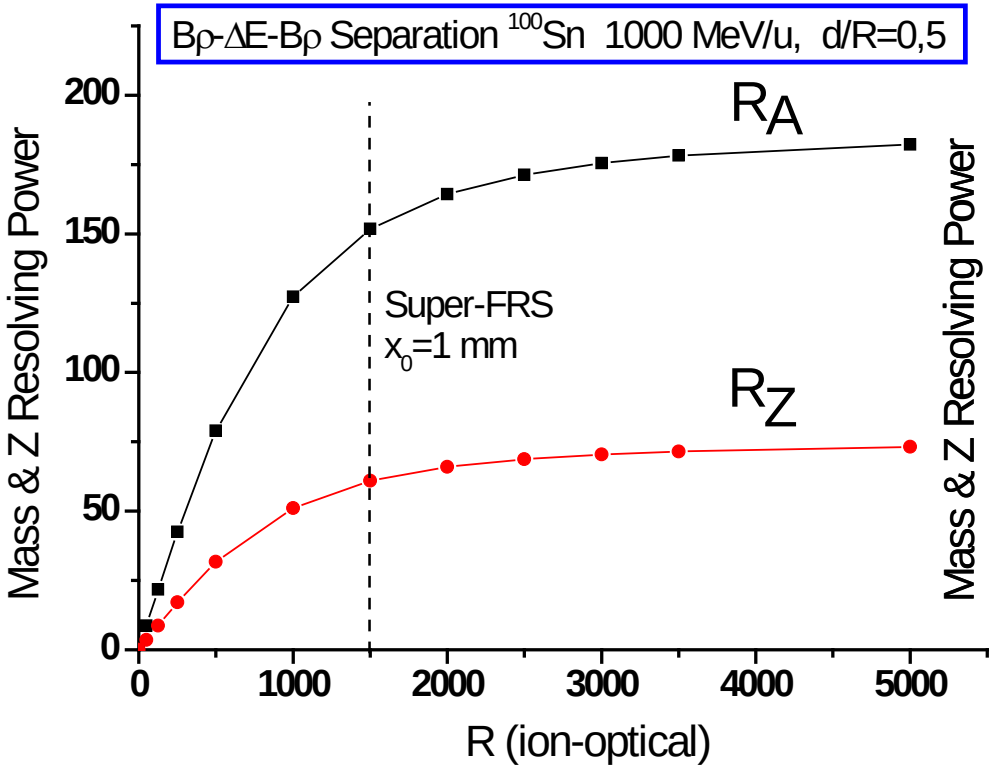
H. Geissel et al. Nucl. Instr. Meth. B 317 (2013) 277

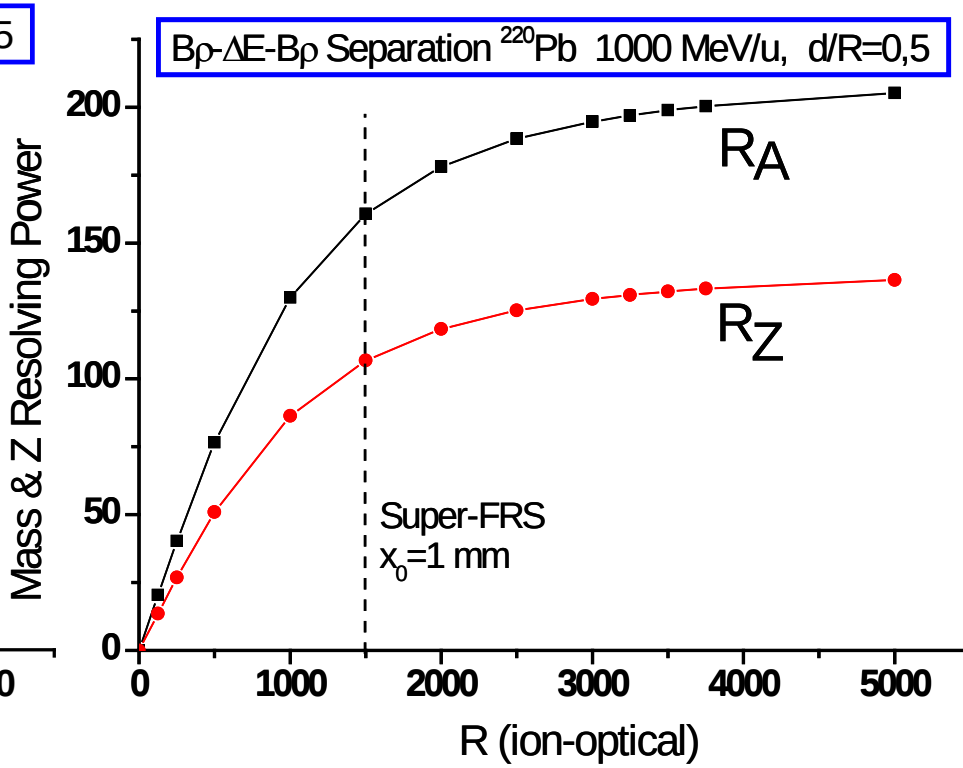




Which Ion-optical Resolution yields the required A- and Z-Resolution?

H.G. et al. Nucl. Instr. Meth. A 282 (1989) 247





FRS : ε= 20 π mm mr and 2 % dp/p transmission

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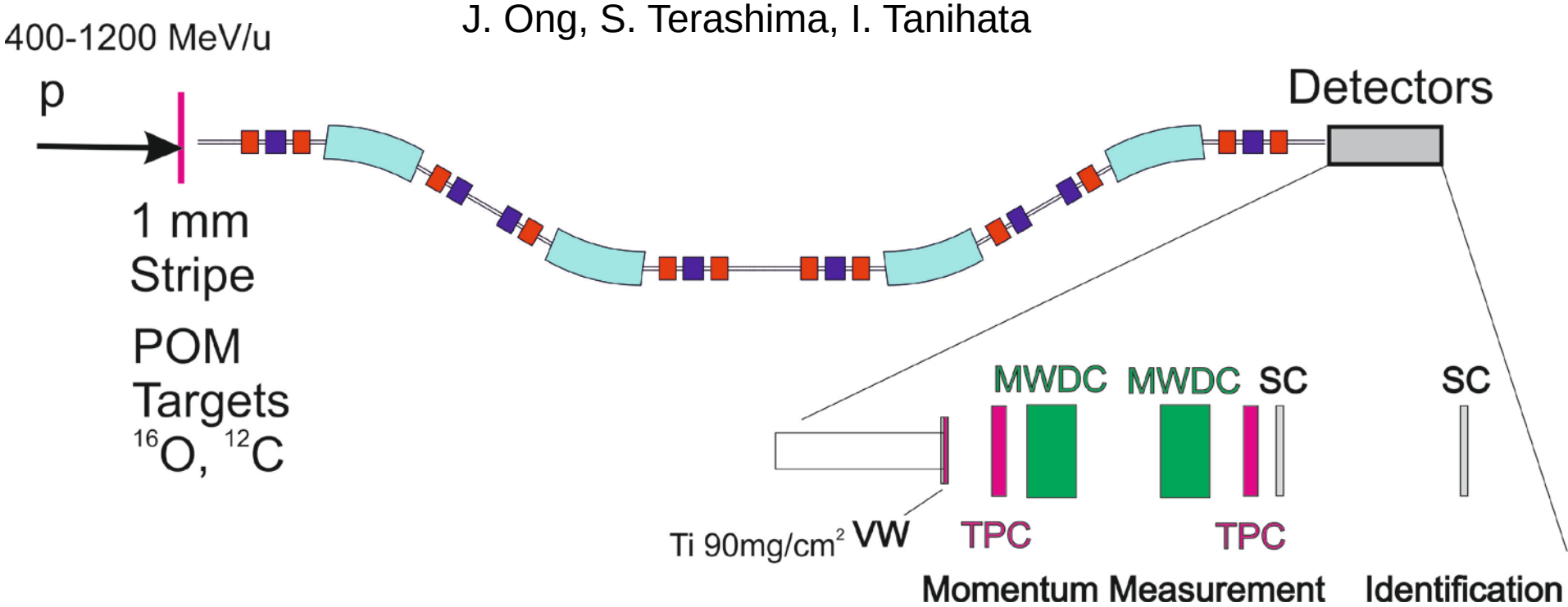
FRS and Detector Setup
August 2014

Experiment to study the contribution of tensor interaction via the $^{16}O(p,d)$ reaction at 400-1200 MeV/u

J. Ong, S. Terashima, I. Tanihata



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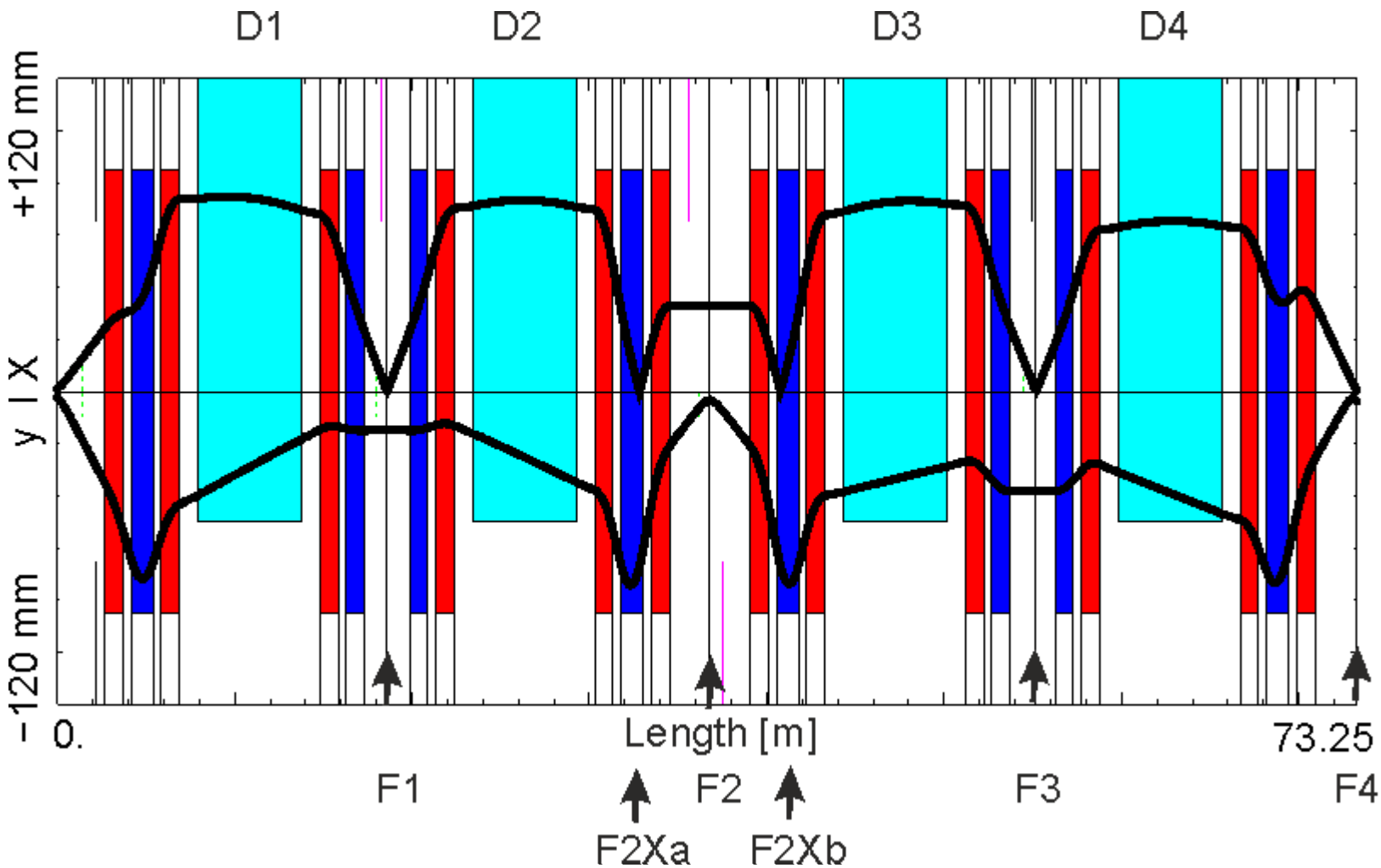
High-Resolution Momentum Measurements with a Dispersive FRS Mode at all Focal Planes



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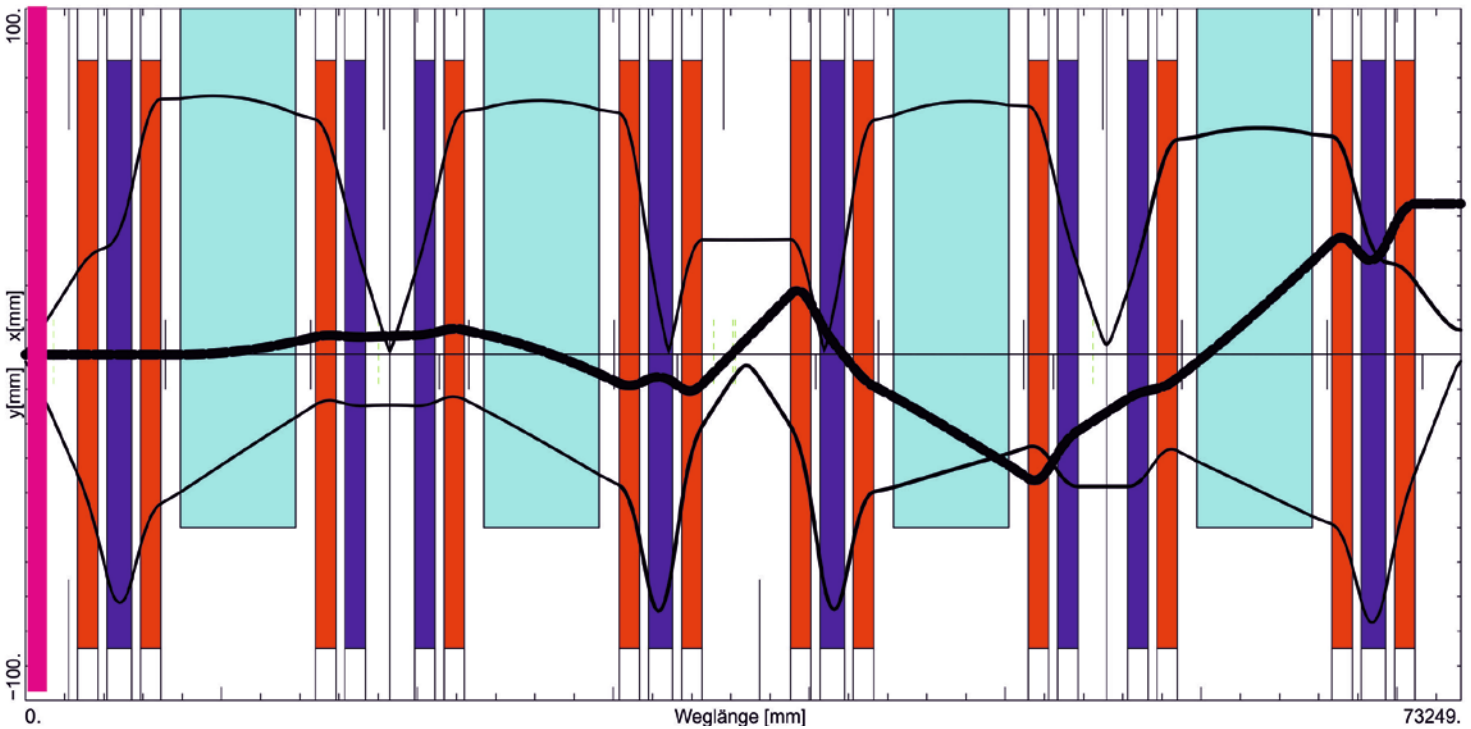
High-Resolution Momentum Measurements with a Dispersive FRS Mode at all Focal Planes

$2x_0$ =1 mm



R_{16}

$$R_{io} = \frac{p}{\Delta p} = \frac{R_{16}}{2R_{11}\,x_0} = 16500$$

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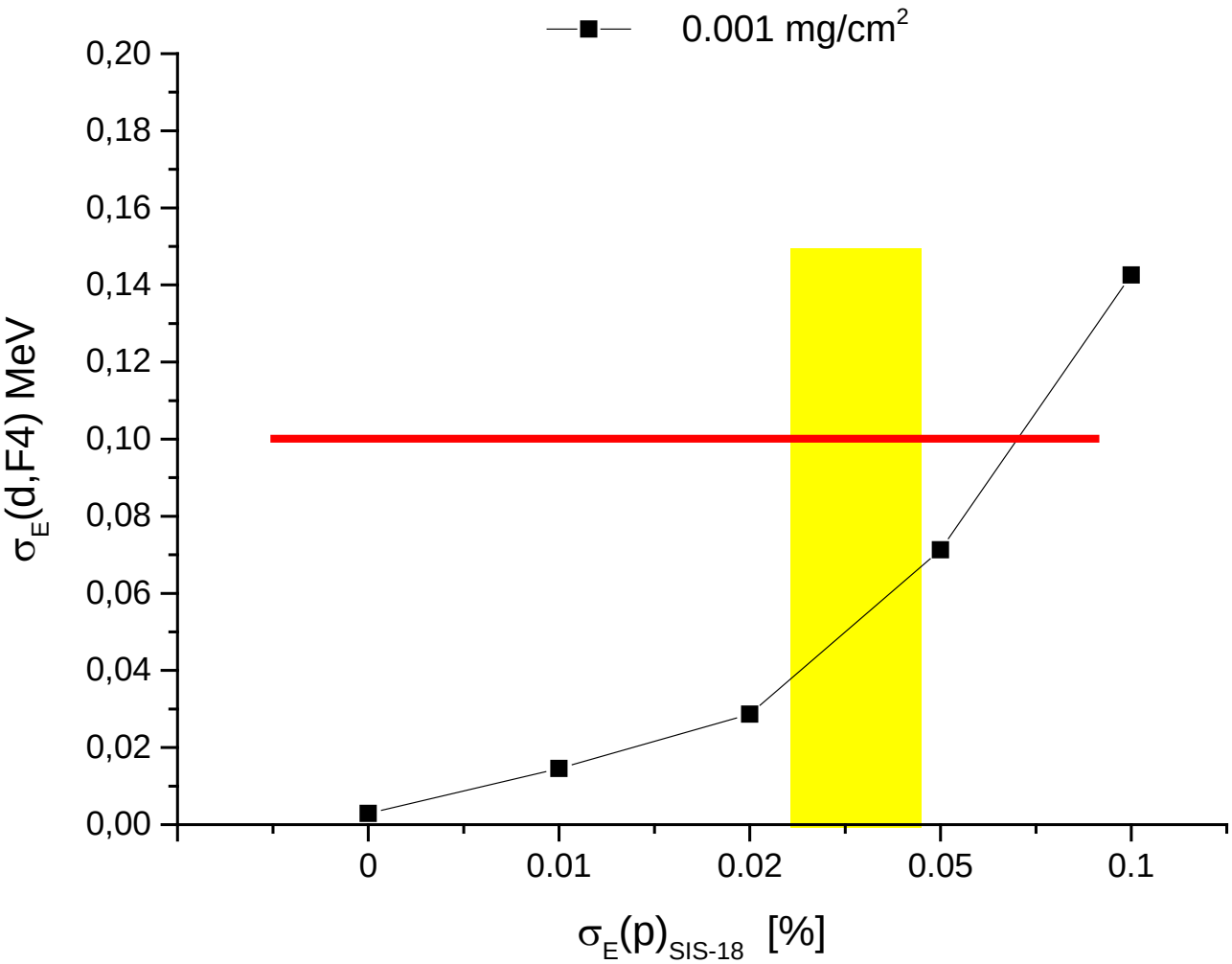
Limitation of Energy Spread of the Protons from the Accelerator



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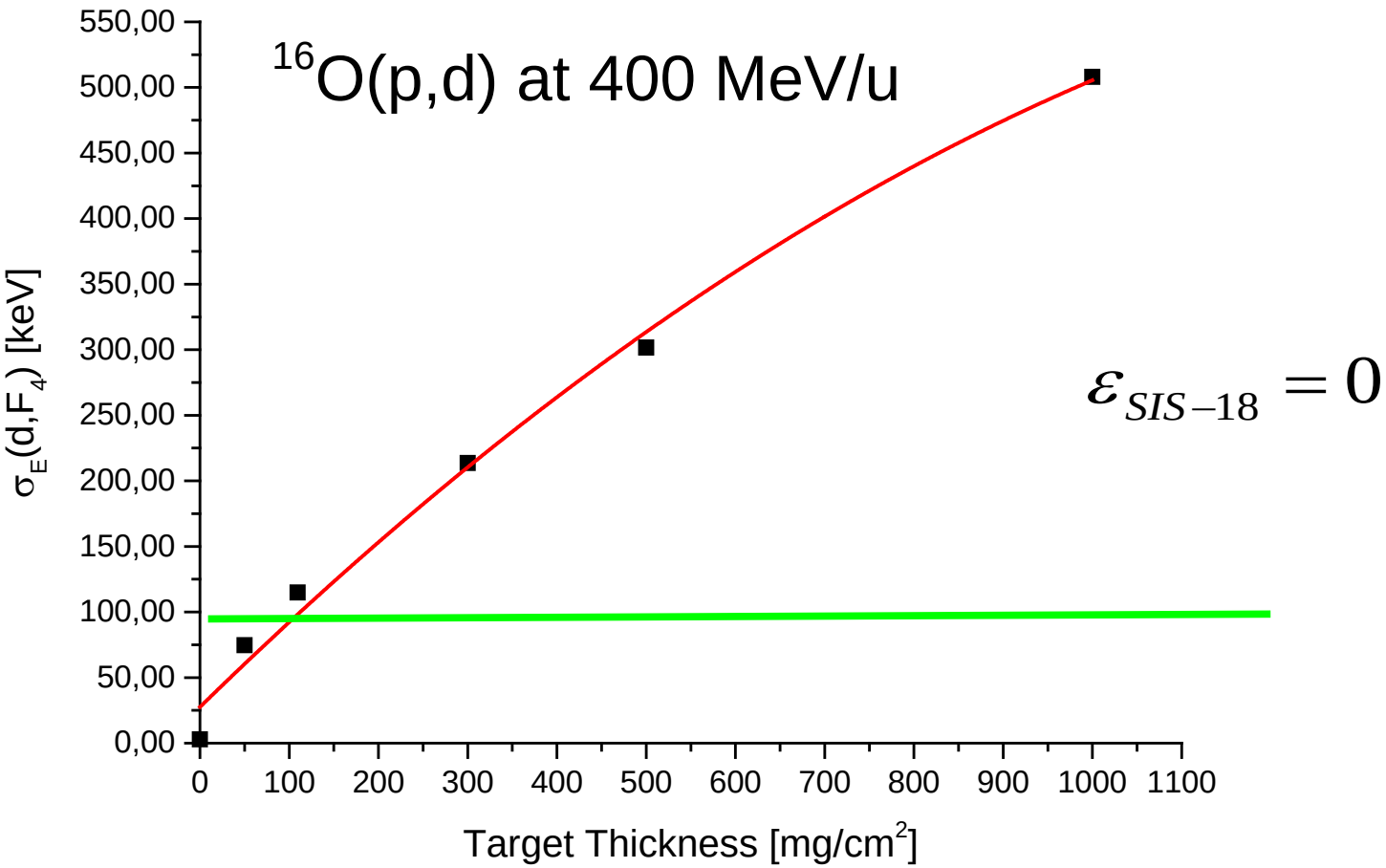
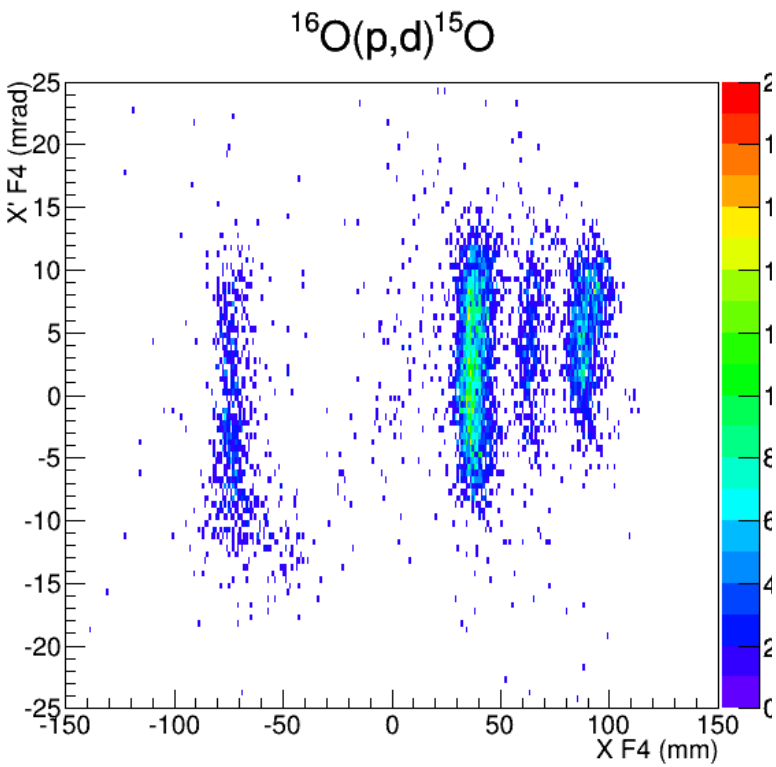
Limitation of Target Thickness

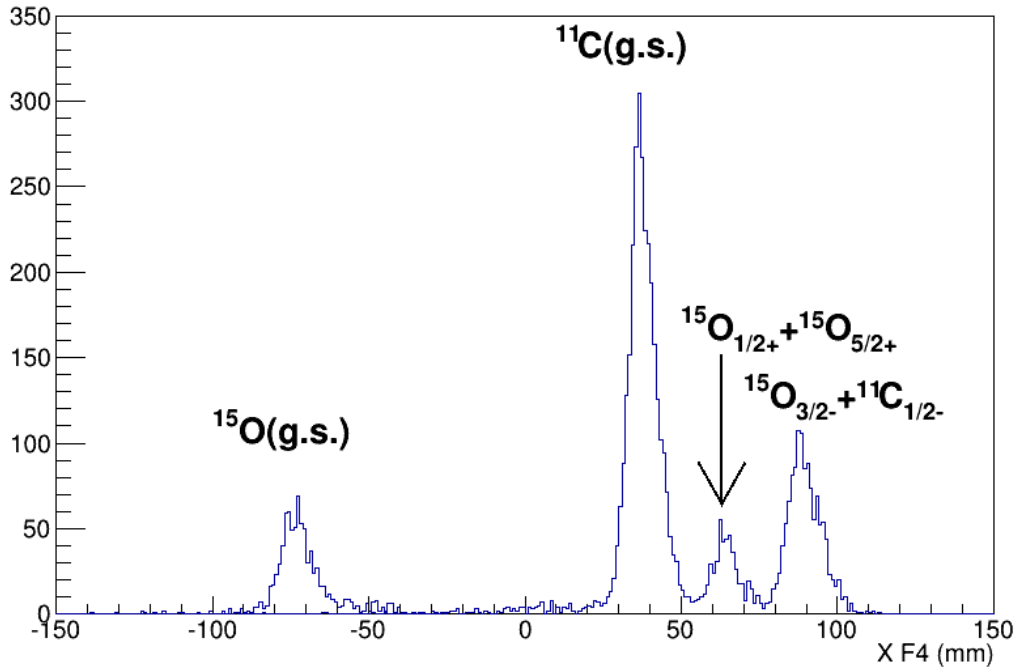


Deuteron spectra (high performance of FRS)

Proton beam @400 MeV/u **Pom (p,d)** $\theta_{lab} = 0^o$

POM Target $(CH_2O)_n$



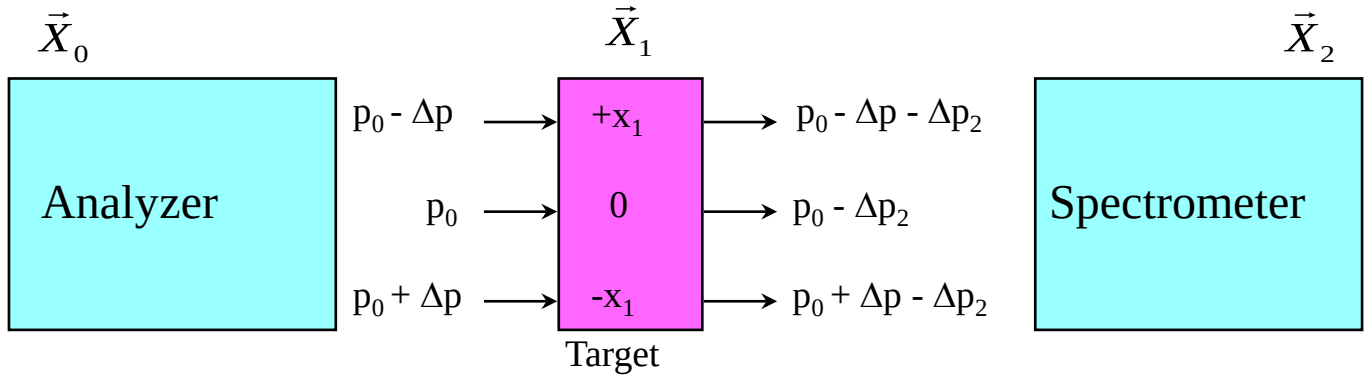


Limitations for High-Resolution Spectrometer Experiments with Exotic Heavy Ions

Challenges due to:

- **Phase-Space of Primary Beams (see (p,d) reaction @ FRS)**
- **Large Phase of Exotic Nuclei**
- **Atomic Interaction in Targets, Degraders and Detectors**
- **Required High Spectrometer Resolving Power**

Principle of an Energy-Loss Spectrometer



Point - to - point image condition: $(R_{12} = (x, x') = 0)$

$$x_1 = {}^1R_{11} x_0 + {}^1R_{16} \overbrace{\left(\frac{p - p_0}{p_0} \right)}^{\delta}$$

$$x_2 = {}^2R_{11} x_1 + {}^2R_{16} \left(\delta - \frac{\Delta p_2}{p_0} \right)$$

$$x_2 = {}^2R_{11}\, {}^1R_{11} x_0 + \underbrace{\left({}^2R_{11}\, {}^1R_{16} + {}^2R_{16} \right)}_{=0} \delta - {}^2R_{16} \frac{\Delta p_2}{p_0}$$

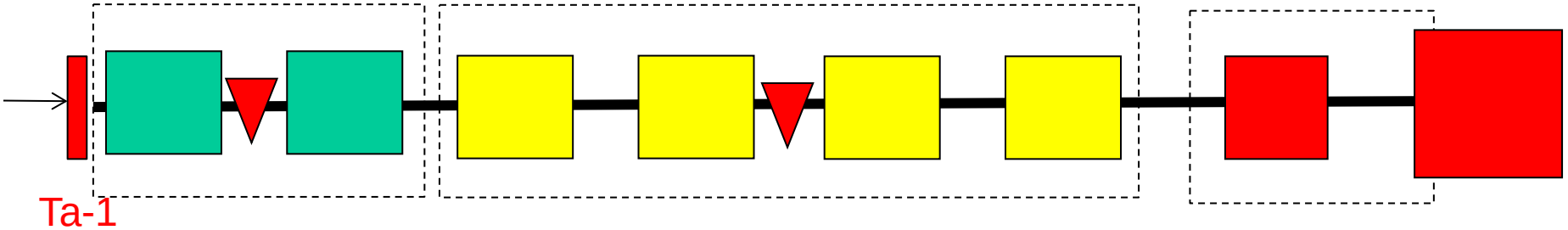
Image size of the final focus is independent of the incident momentum spread if

$${}^2R_{16} = -{}^2R_{11}\, {}^1R_{16}$$

Analogous one can find conditions for the angular distribution generated in the secondary target.

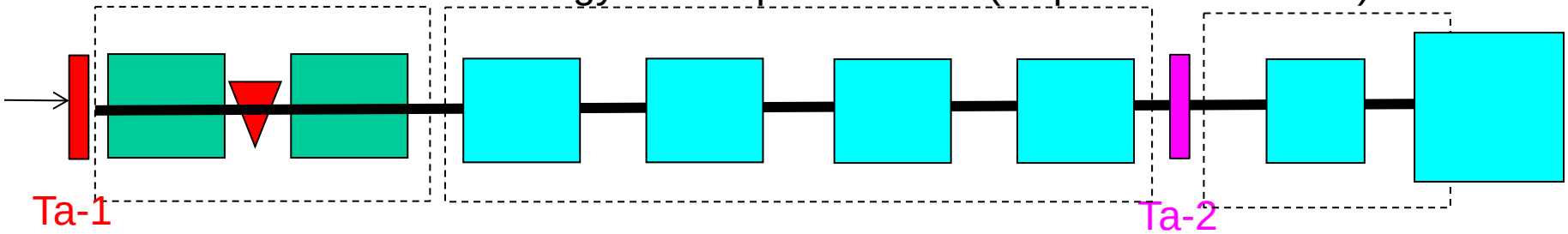
The Stages of an In-Flight Separator coupled to a Spectrometer

Standard Operation Mode



Pre-Separator Main-Separator Beamline Spectrometer

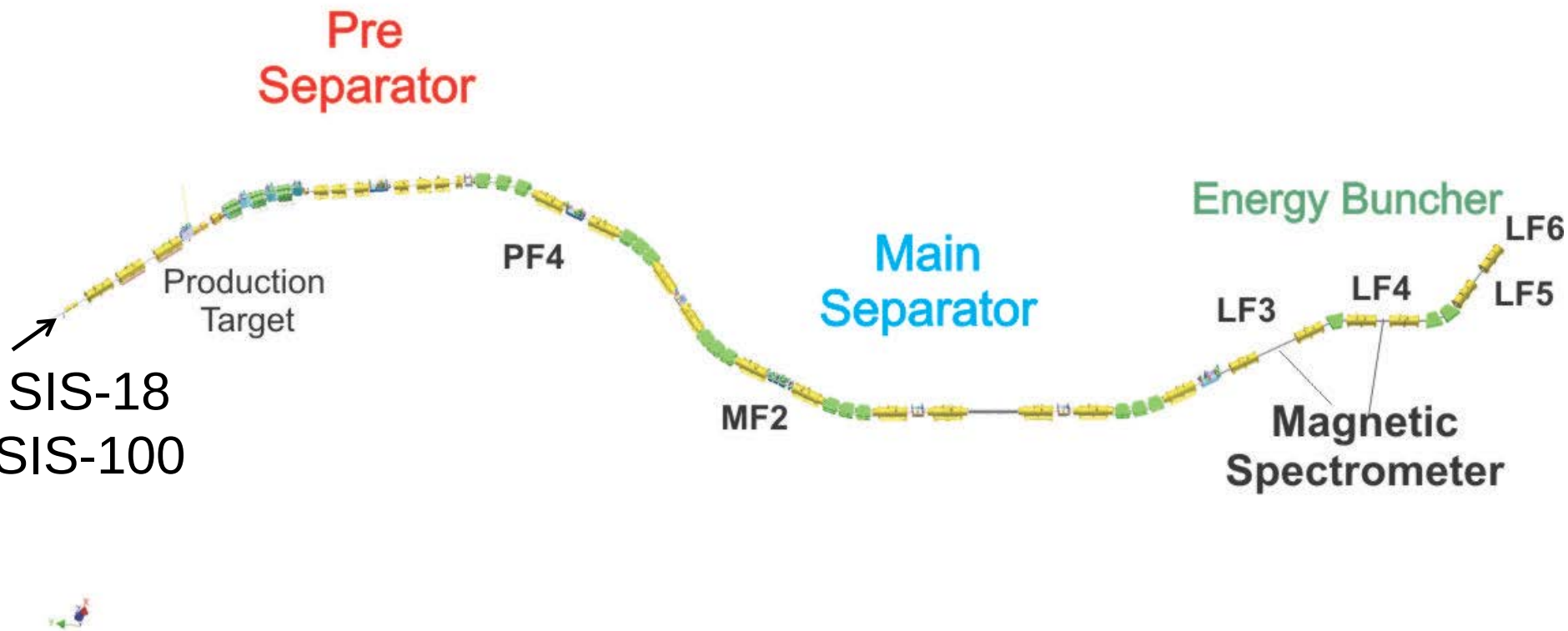
Energy-Loss Spectrometer (dispersion matched)



Analyzer Spectrometer

Low-Energy Branch of the Super-FRS

Dispersion-Matched: Main Separator—Energy Buncher



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H. Geissel (2012)

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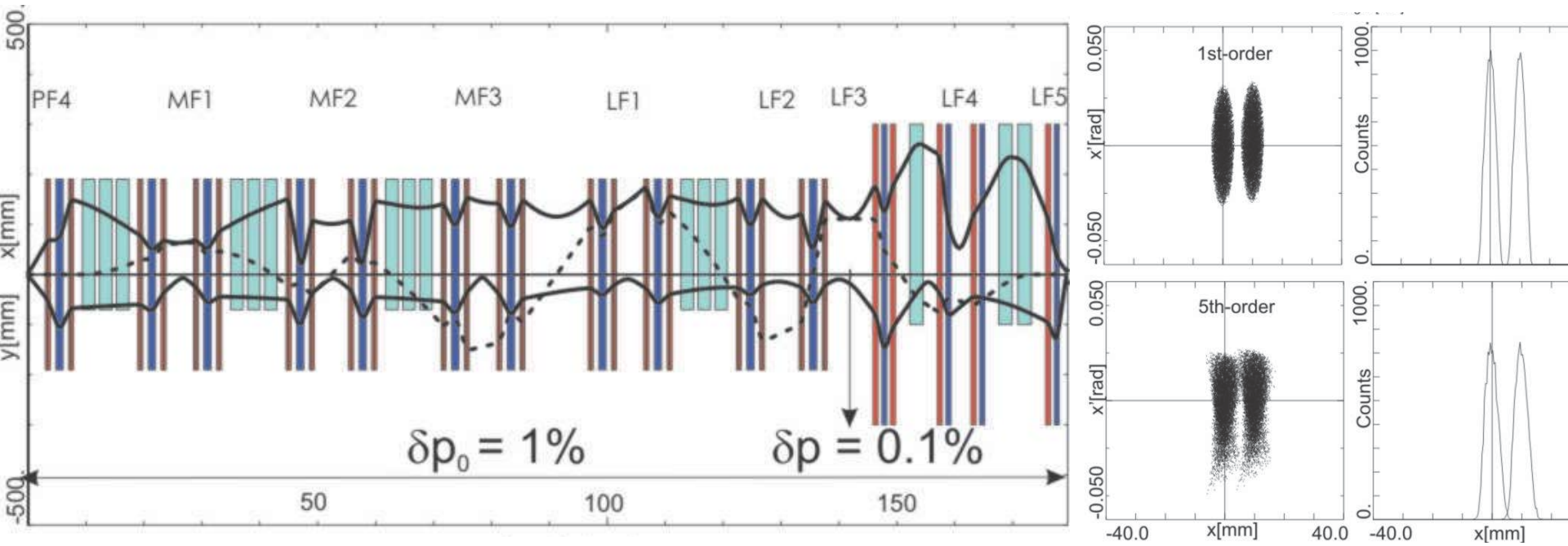
E-Loss Spectrometer

Super-FRS LEB-S-EB-Dispersion-Matched

Super-FRS Dispersion-Matched -with HRS (H.G. R3B Meeting 2014)



$$R_{16} = R_{26} = R_{21} = 0$$

H. Geissel et al. NIM B 2013

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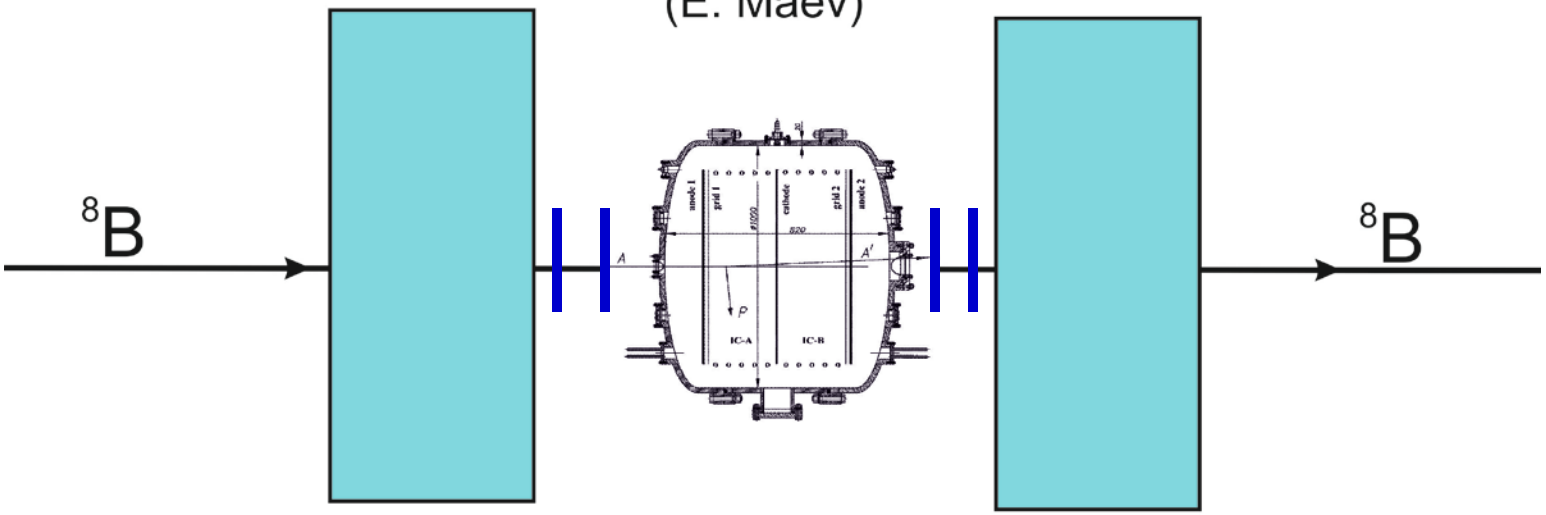
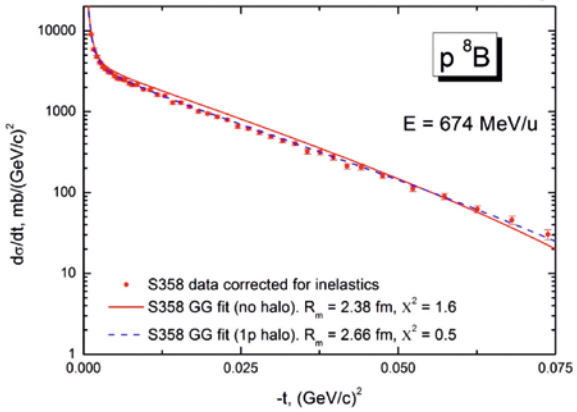
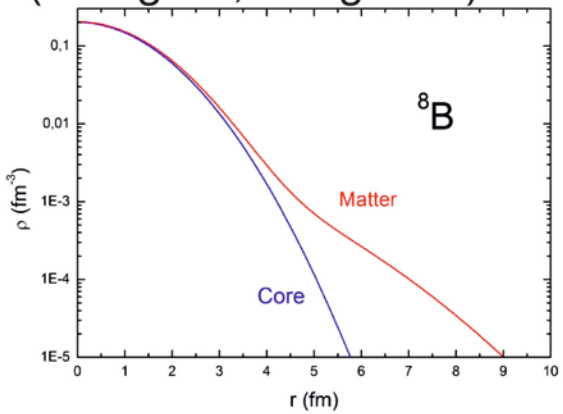
Active Target in the Dispersion-Matched Spectrometer

IKAR in a Dispersion-Matched Spectrometer
(E. Maev)



Previous Preliminary Results (A. Inglesi, P. Egelhof)

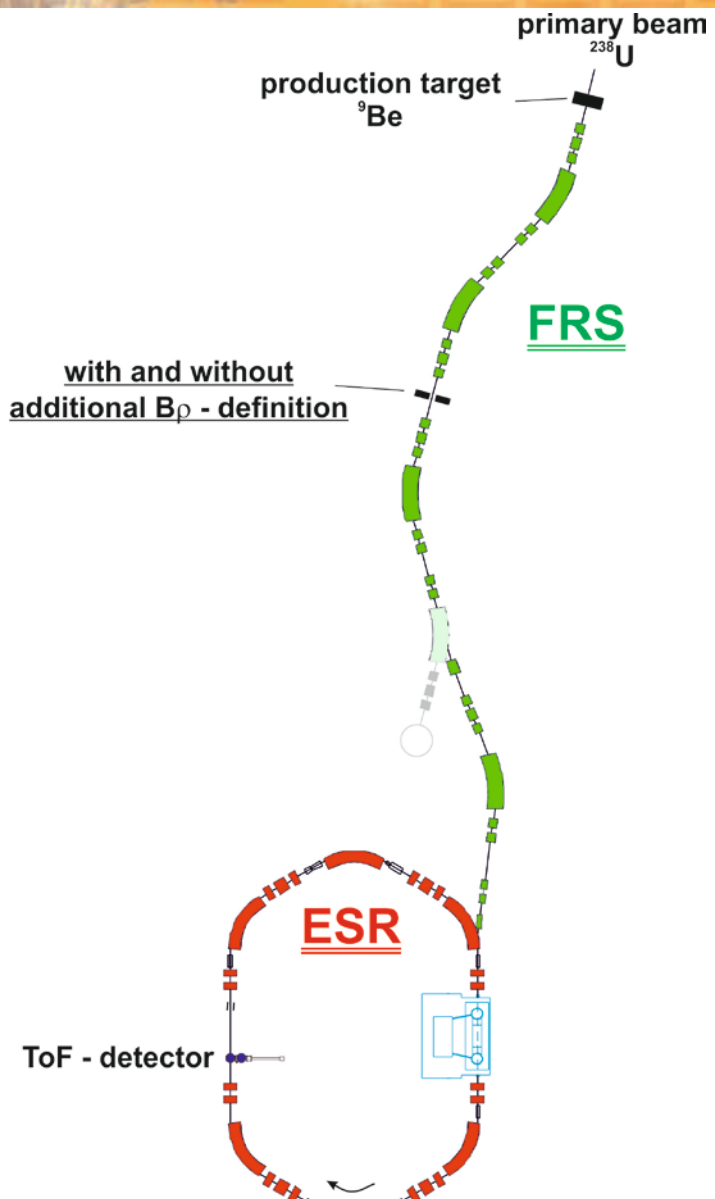


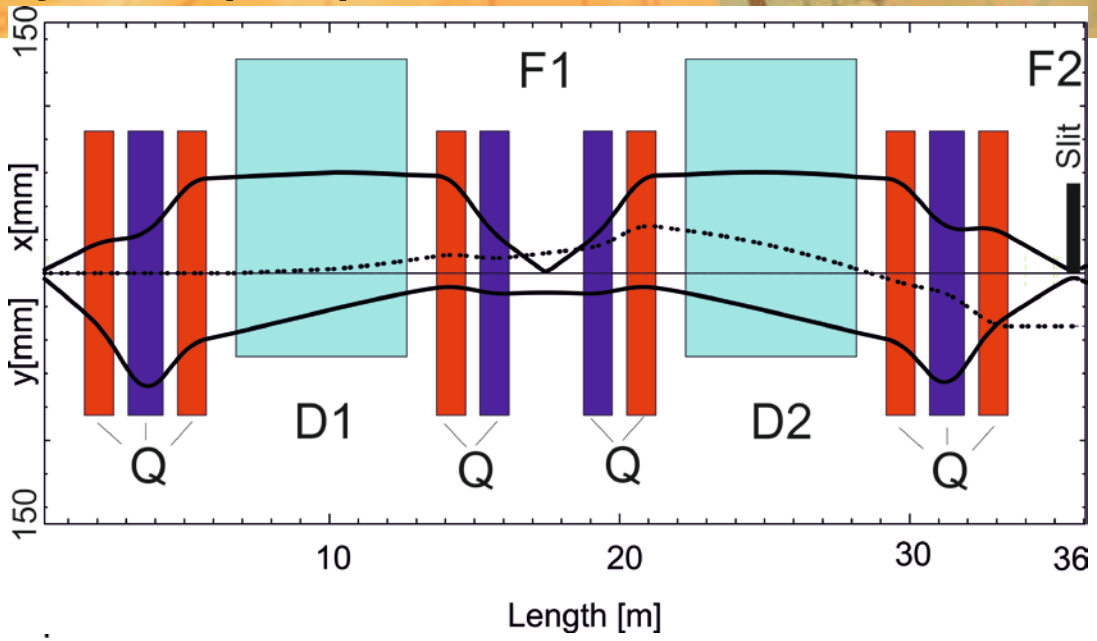


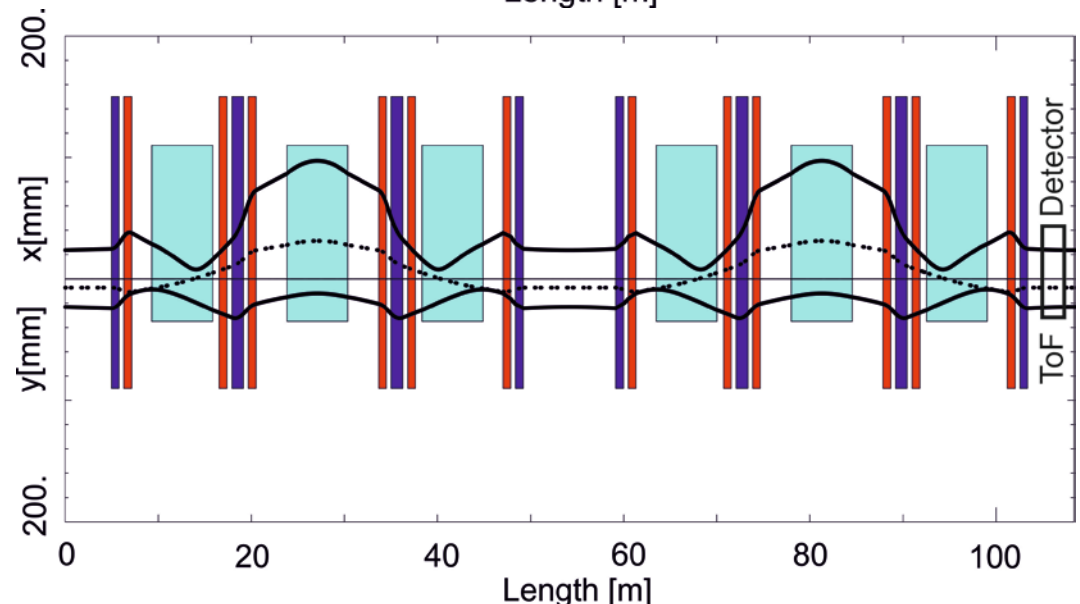
IMS Brho-Tagging

M. Diwisch, PHD 2015

Eur. Phys. J. A (2016) 52: 138

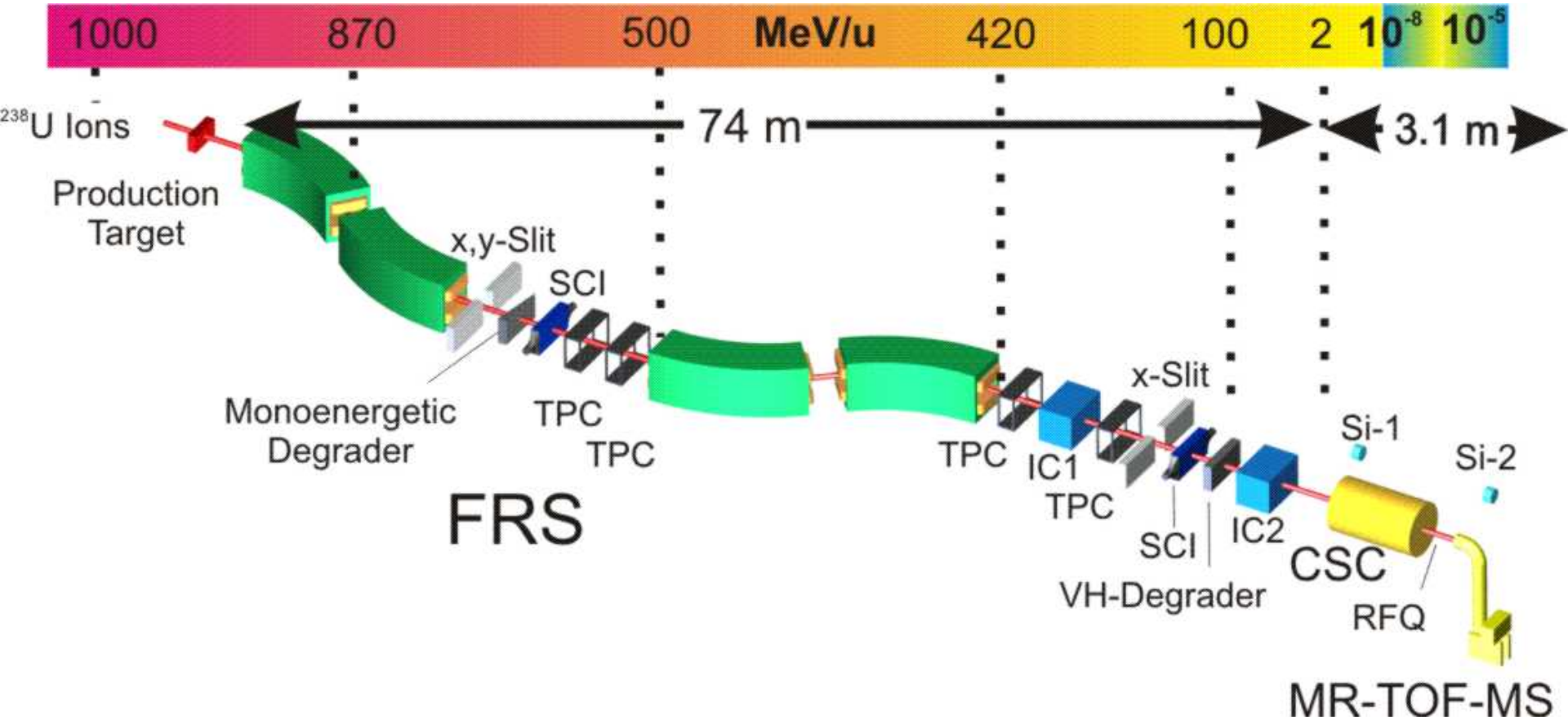






FRS--CSC-MR-ToF-MS

S. Purushothaman et al., EPL 2013

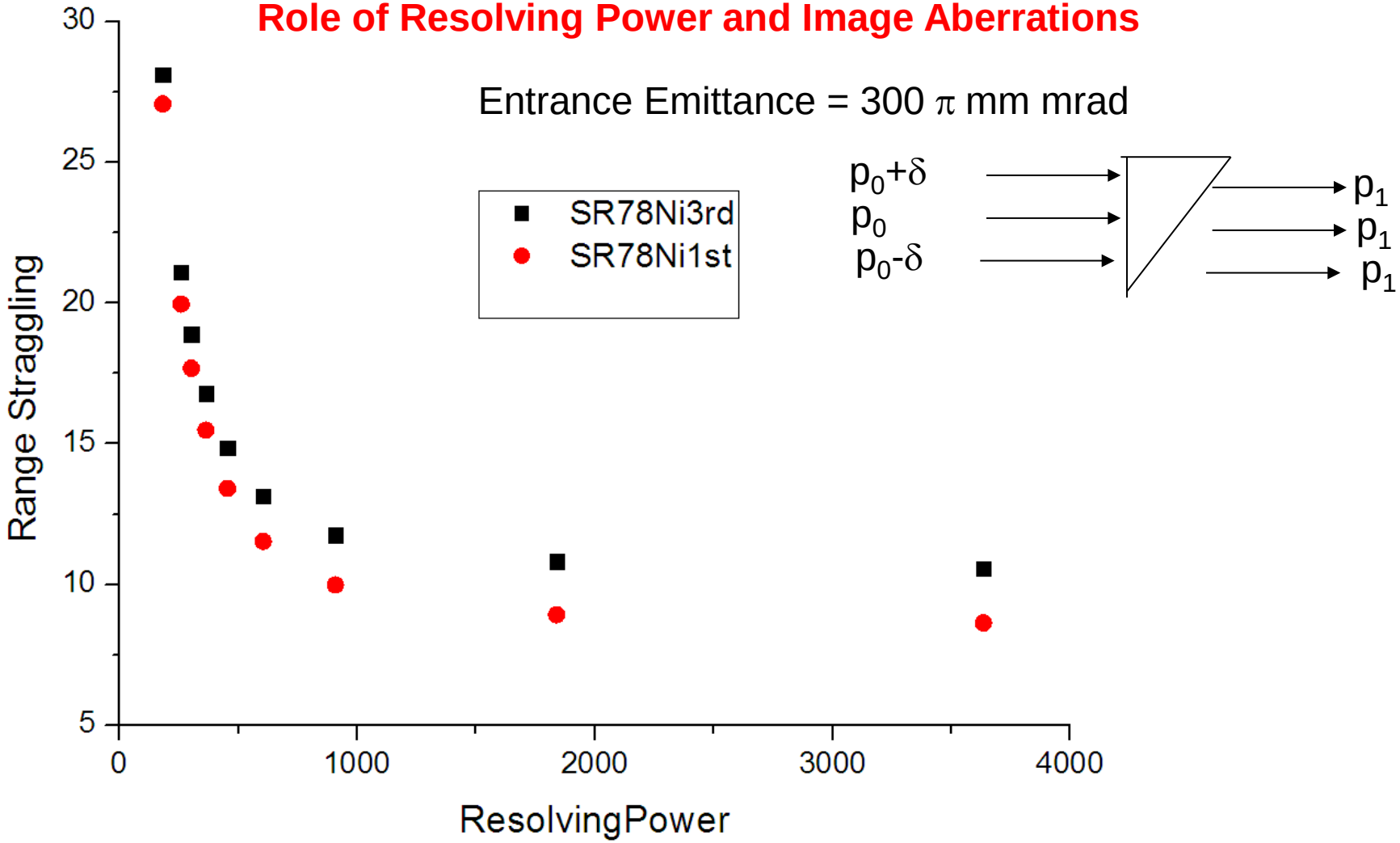


See Talk Timo Dickel

Investigation of the Layout of the E-Buncher

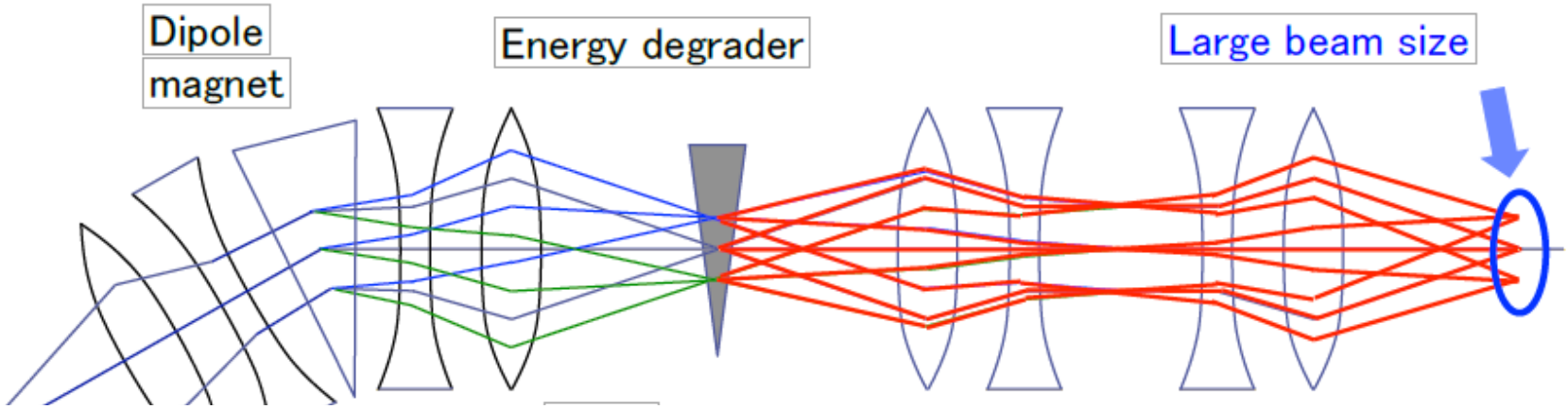
Role of Resolving Power and Image Aberrations

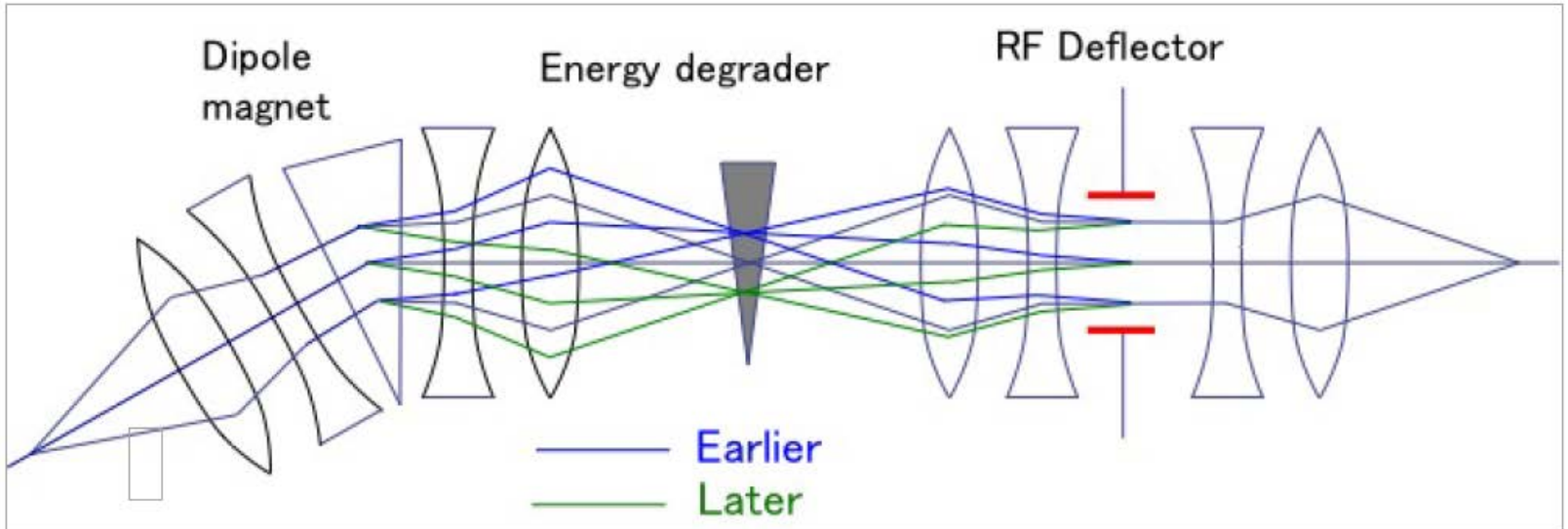
Entrance Emittance = 300 π mm mrad



Novel Method of Energy Bunching and Position Compression

- **OEDA Project : S. Shimoura et al. RIKEN**

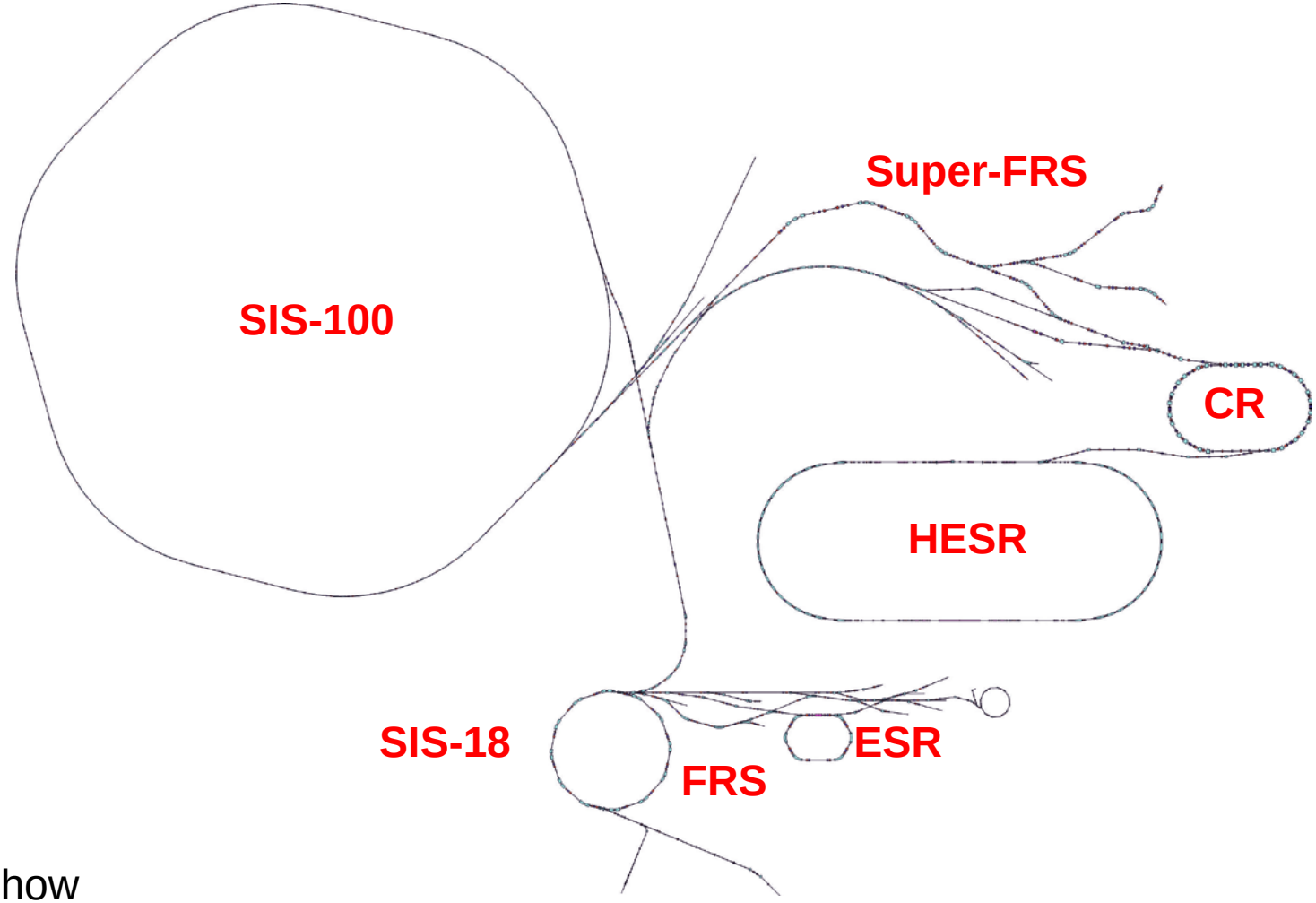




New Features of MIRKO

B. Franczak, H. Geissel to be published in NIM

- **The calculated optical design can be directly converted in a geometrical layout of a new facility**



New Features of MIRKO

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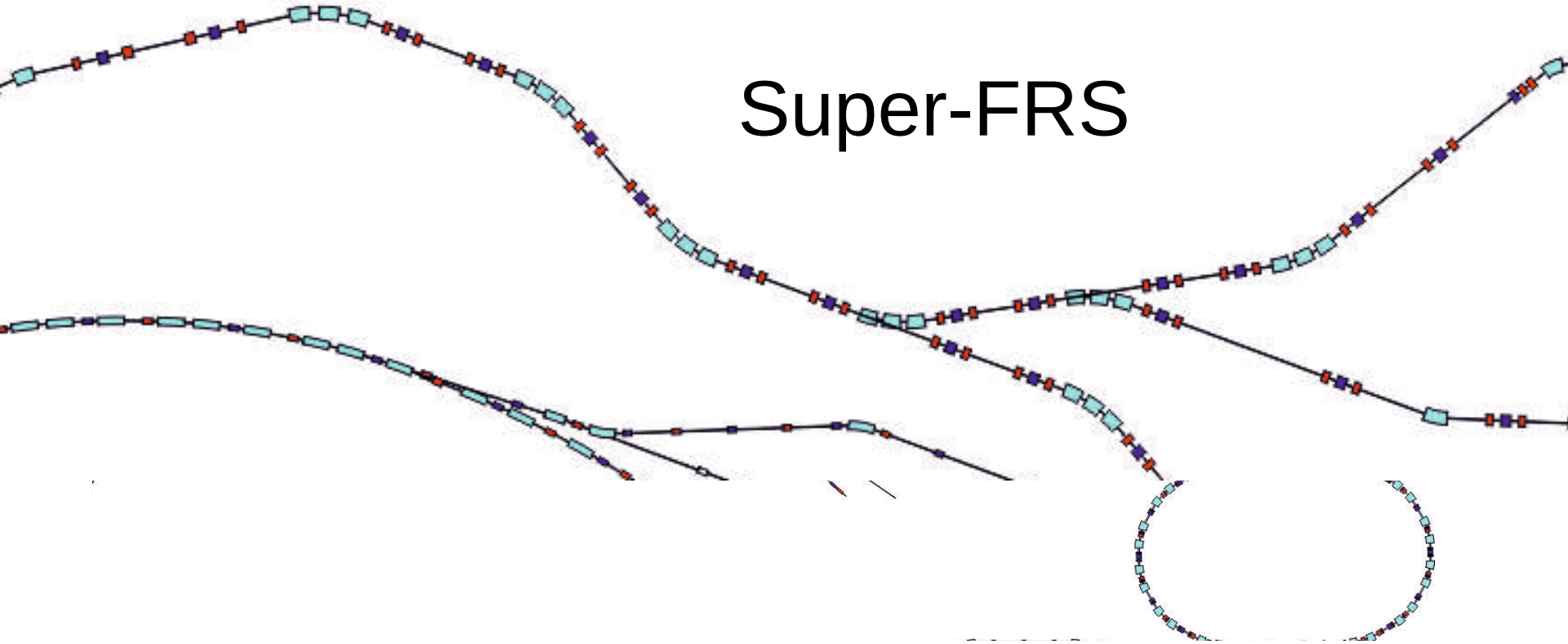

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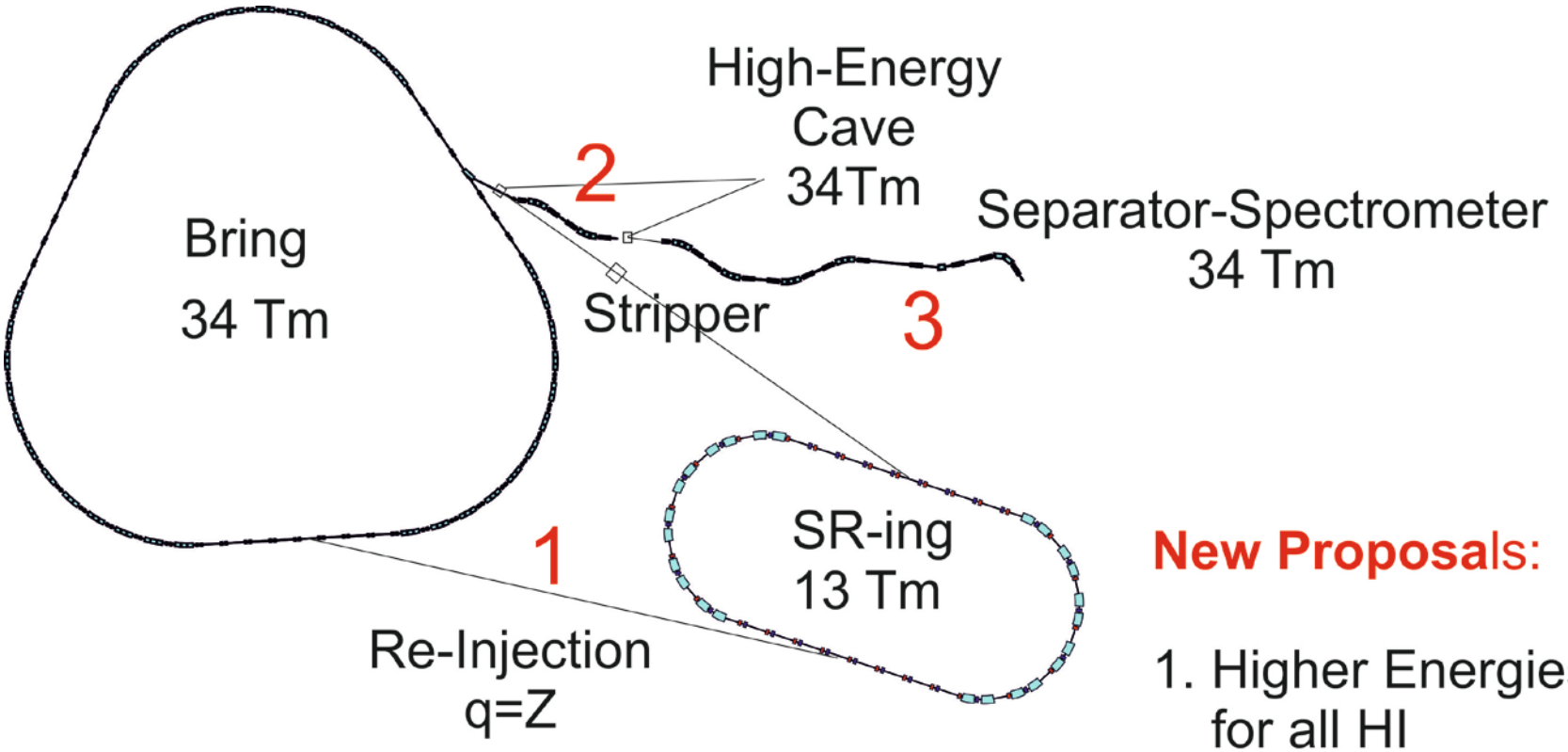
HIAF Factory for Exotic- and Hyper-Nuclei



New Proposals:

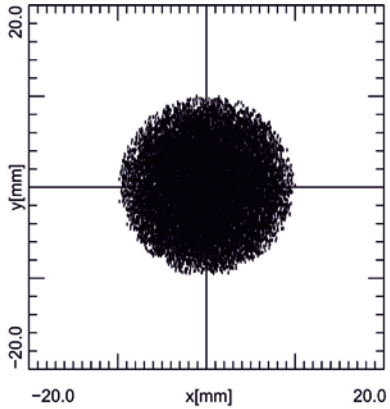
1. Higher Energies for all HI
2. Factory for Exotic- and Hypernuclei
3. 4-Stage Spectrometer

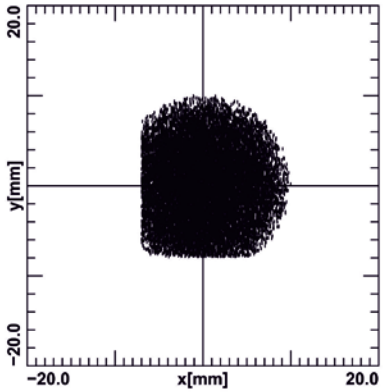
New Features of MIRKO

B. Franczak, H. Geissel to be published in NIM

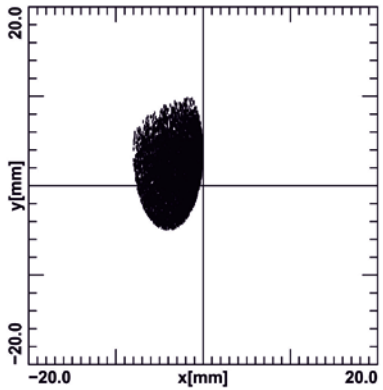
- **Realistic Apertures, changes of l_{eff} preserving the length**

Entrance Cloud

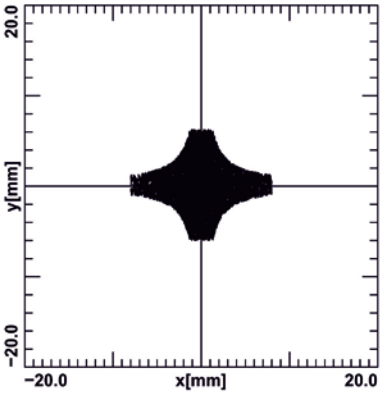




Rectangular



Elliptical

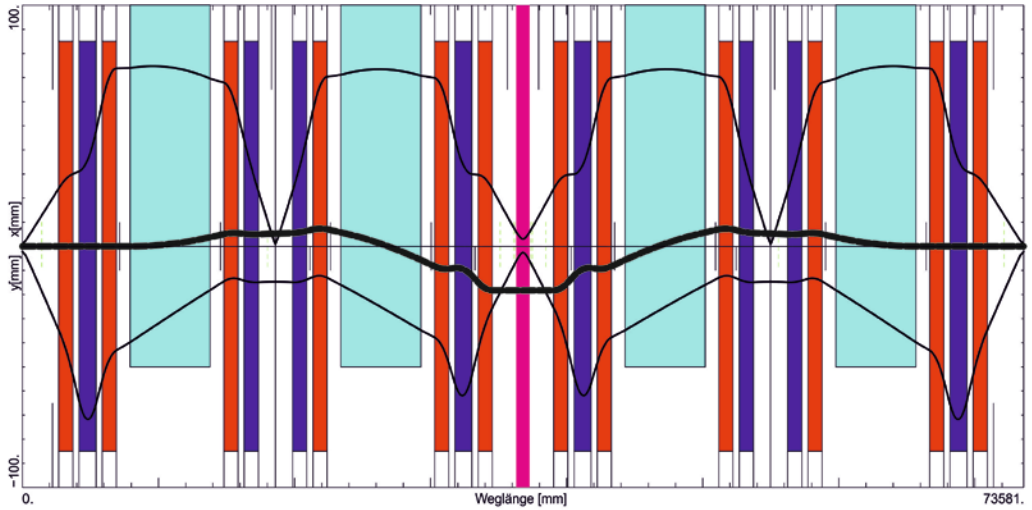


Hyperbolic Apertures

MIRKO & Degraders
Overall Dispersive vs. Dispersion-Matched

B. Franczak, H. Geissel

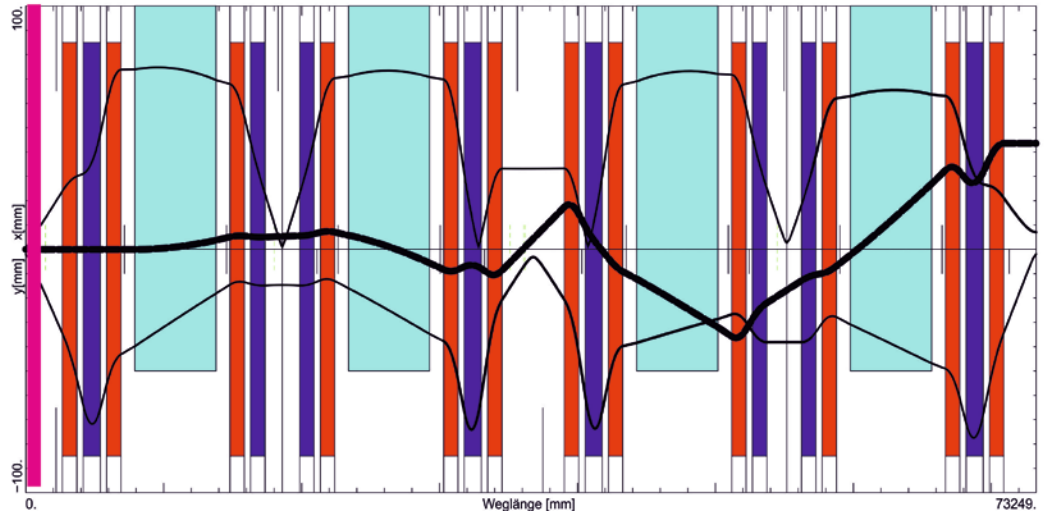
Energy Degrader



FRS:

Dispersion-matched

Energy Degrader



Overall dispersive

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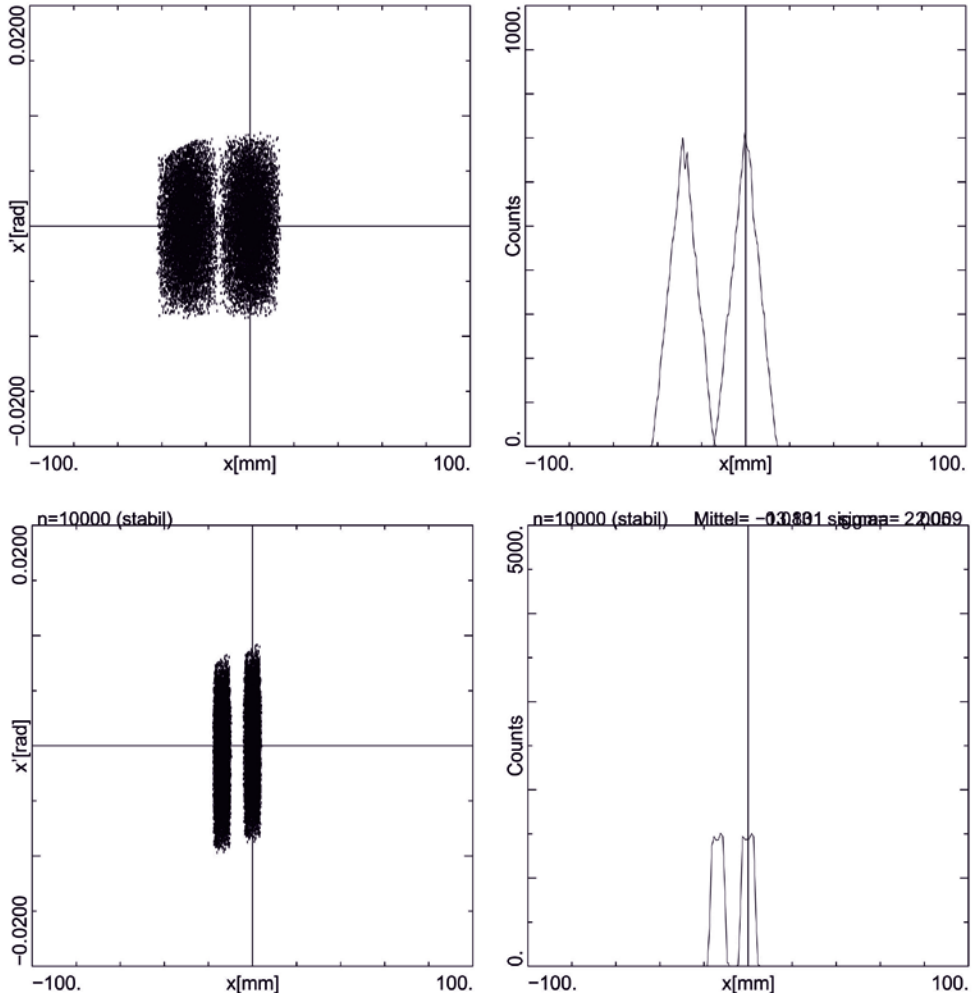
MIRKO & Degraders
Overall Dispersive vs. Dispersion-Matched

B. Franczak, H. Geissel

Initial spread $\sigma 66$=4e-4, „Degrader“: E-loss dE/E=2/800, straggling $\delta p/p$=4e-4



4 x dispersive

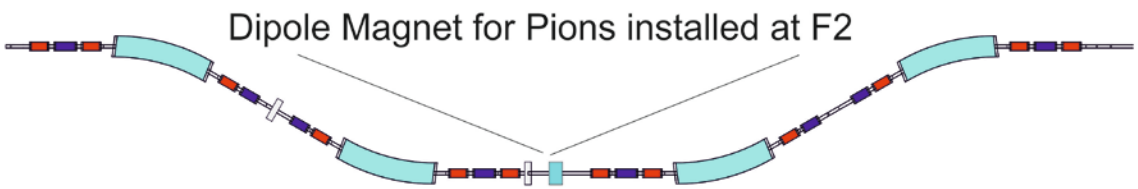
2 x dispersive

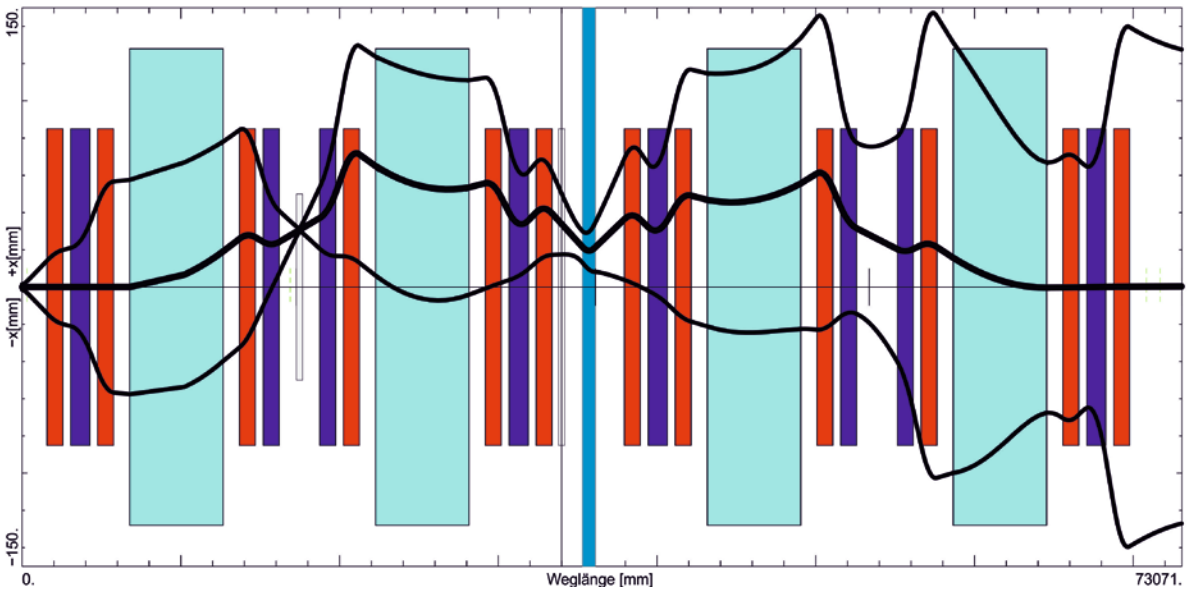
overall achromatic

New Features of MIRKO

- **Transmission Optimization (Pion Dipole Magnet at FRS F2)**

Fit conditions at different positions





Factor of 5 Improvement

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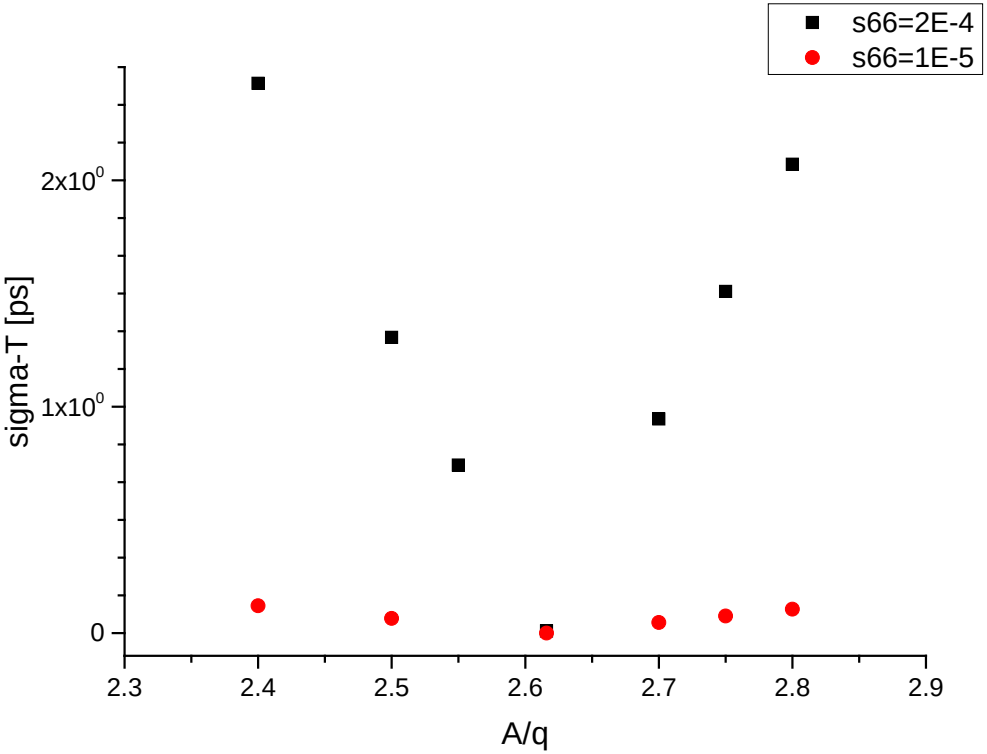
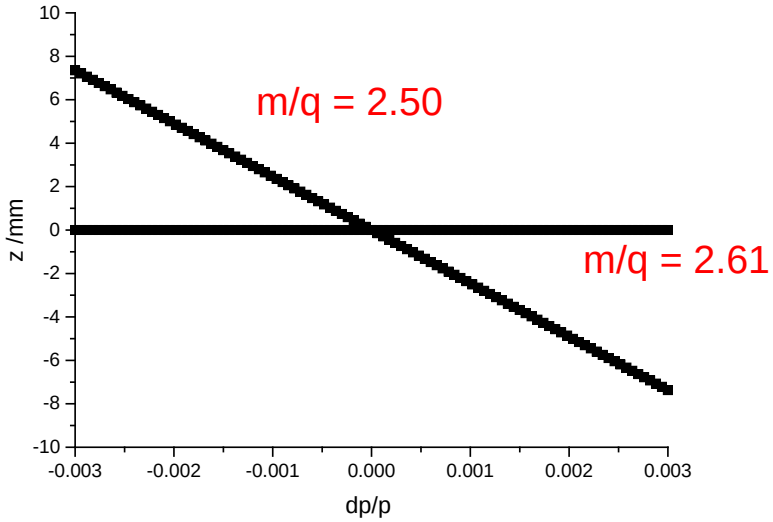
New Features of MIRKO

Isochronous Mode of the ESR, Limitations





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Summary

- Our Int. Expert Meeting has a good future, new challenges are on the horizon

- Recent in-flight separator / spectrometer experiments provide excellent scientific results, e.g. :
  totally dispersive (FRS, the role of tensor force)
  mesic atoms / nuclei (BigRIPS, FRS)
  delta-excitation with exotic nuclei (FRS)

- The coupling of in-flight separators with high-resolution systems has unique scientific potential:
  e.g. dispersion-matched spectrometers (A1900-S800, BigRIPS-Sharaque)
  storage rings (FRS-ESR)
  ion-catcher traps (MR-ToF, Penning)
  (A1900-LEBIT, FRS-Ion-Catcher, BigRIPS-SLOWRI)