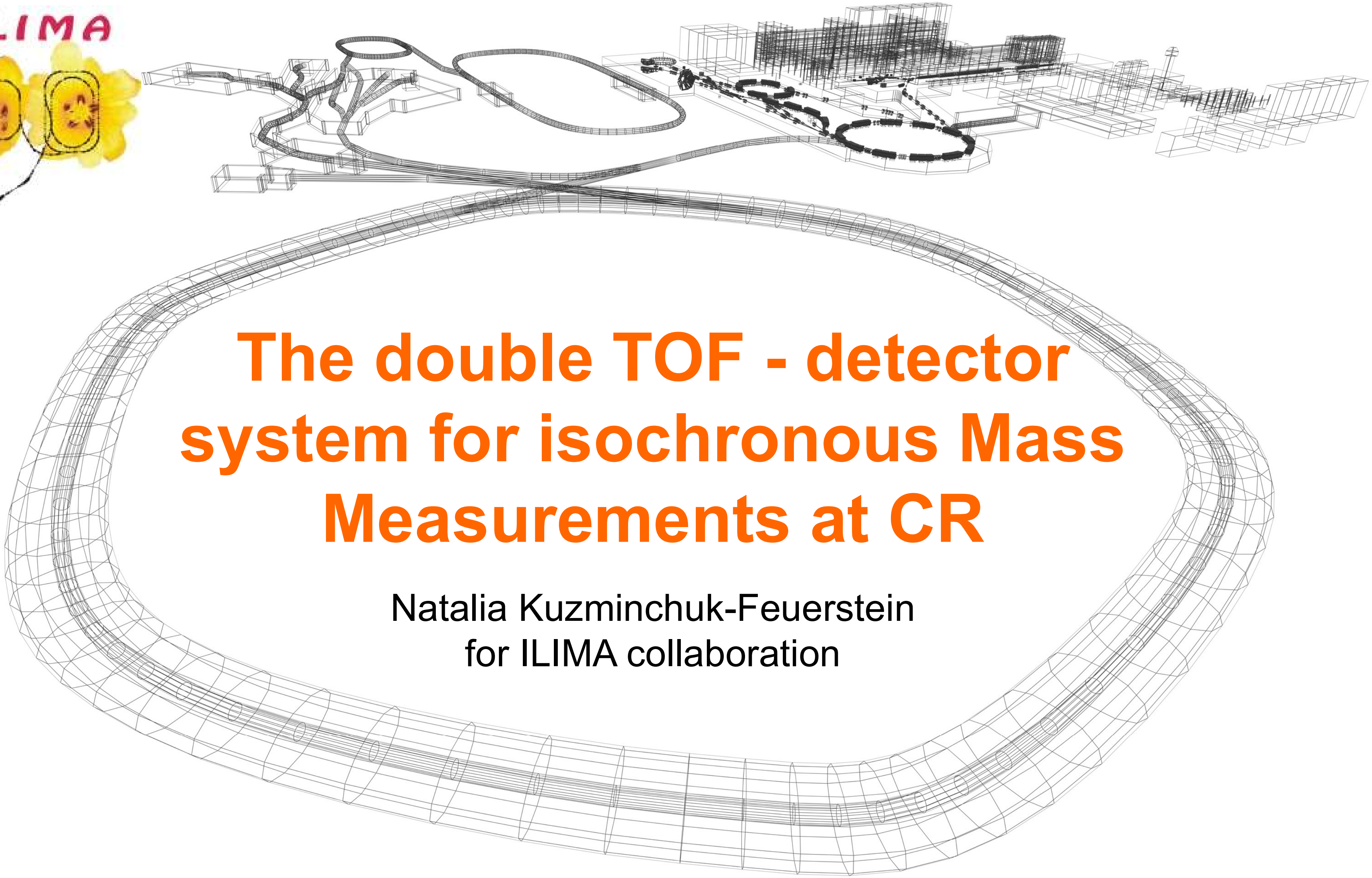


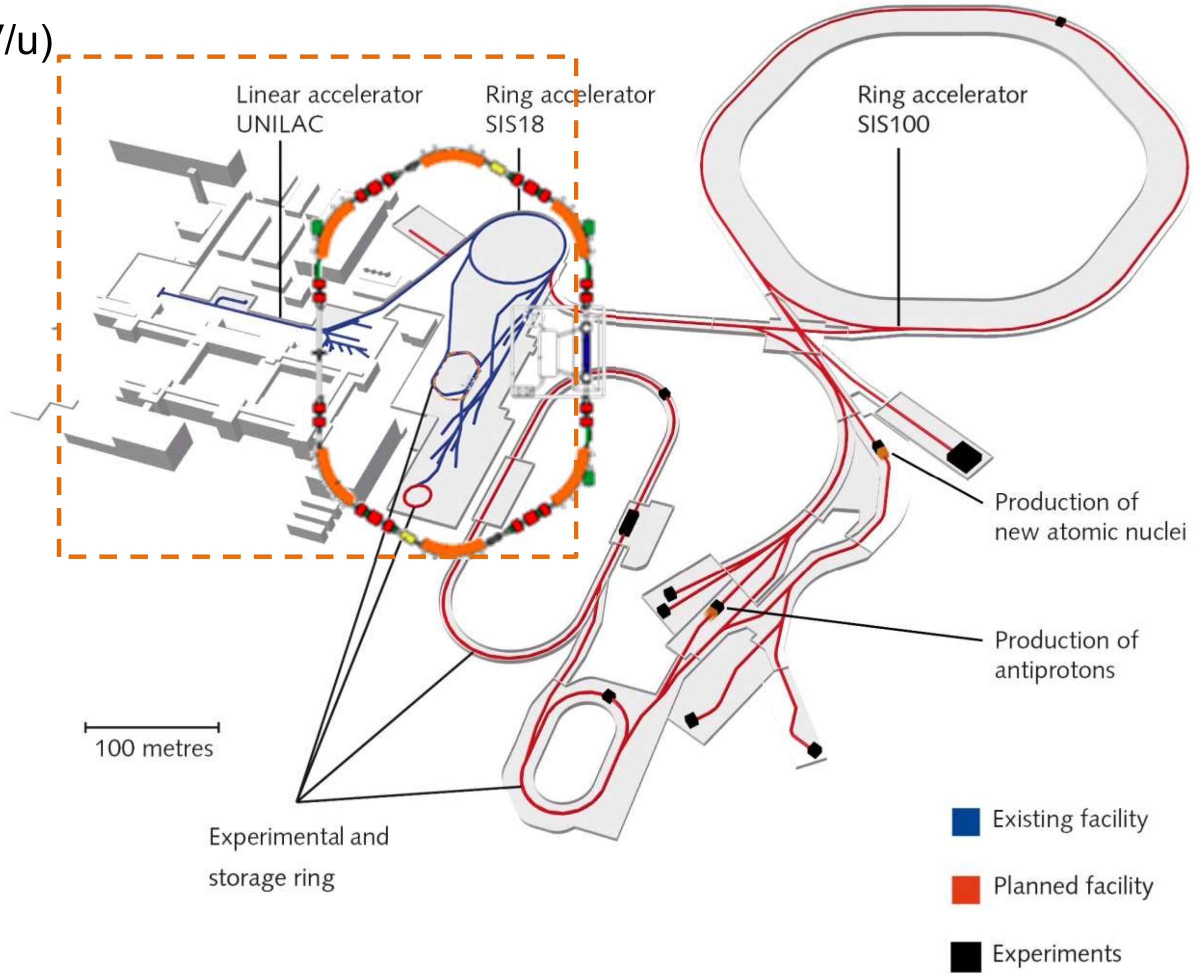
The double TOF - detector system for isochronous Mass Measurements at CR

Natalia Kuzminchuk-Feuerstein
for ILIMA collaboration

Experimental Storage Ring at GSI

- Experimental Storage Ring (ESR)
- Circumference: 108 m
- Magnetic lattice: 6 x 30° - dipole magnets,
  20 quadrupole magnets
- Bρ(max) = 10 Tm ($^{238}U^{92+}$: up to 55 MeV/u)
- ~500 ns/turn
- Ultra-high vacuum system: 10^{-11} mbar
- Cooling: Electron and stochastic
- Total cooling time: few seconds

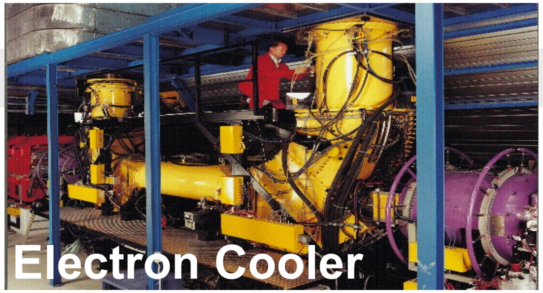
ESR



Mass Measurements at ESR

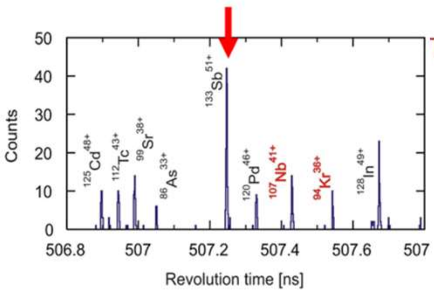
Mass determination from revolution-time measurements

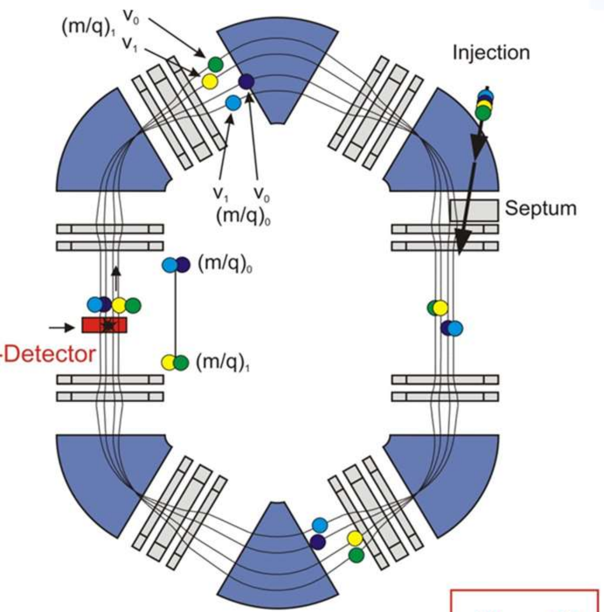
Access to exotic nuclei:
IMS: $T_{1/2}$> 50 μs (100 turns)
SMS: $T_{1/2}$> T_{cool}



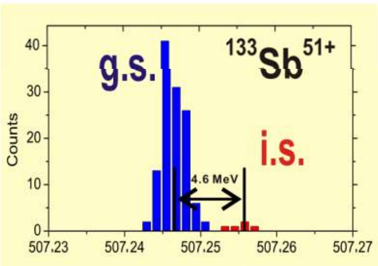
Isochronous Mass Spectrometry (IMS)

Resolving power:
FWHM = 2 x 10^5
Accuracy: 100 keV
Half-life: ~10 μs





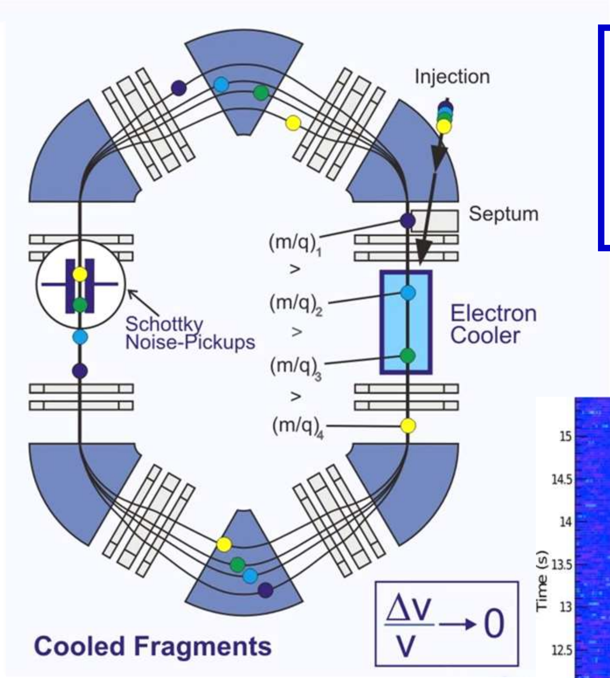
Hot Fragments



B. Sun et. al., Phys. Lett. B 688 (2010) 294

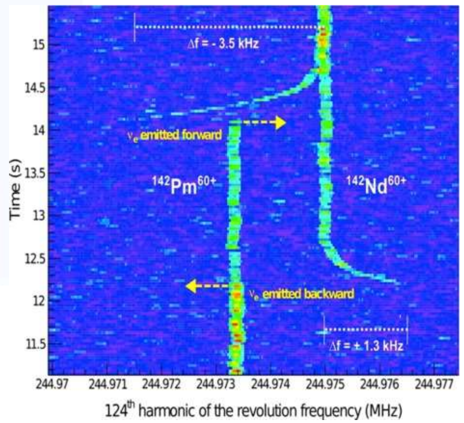
Schottky Mass Spectrometry (SMS)

Resolving power:
FWHM = 1 x 10^6
Accuracy: 30 keV
Half-life: ~ 1 s



$\gamma_t \rightarrow \gamma$

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

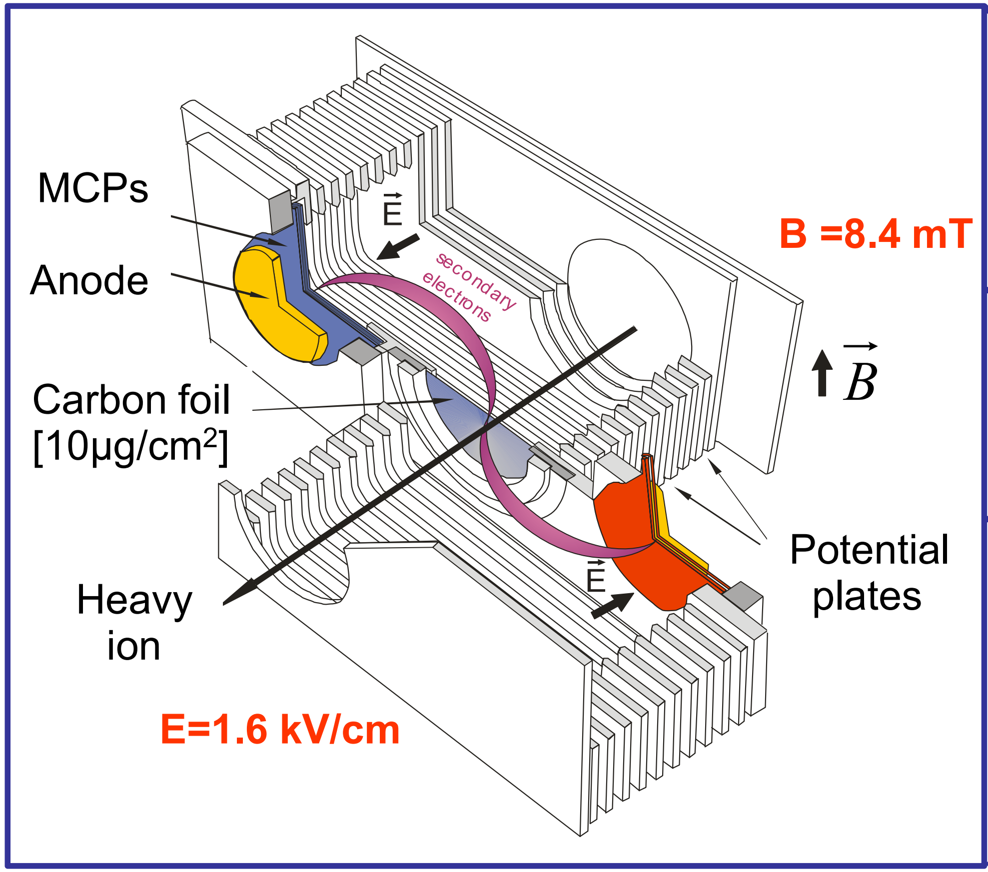


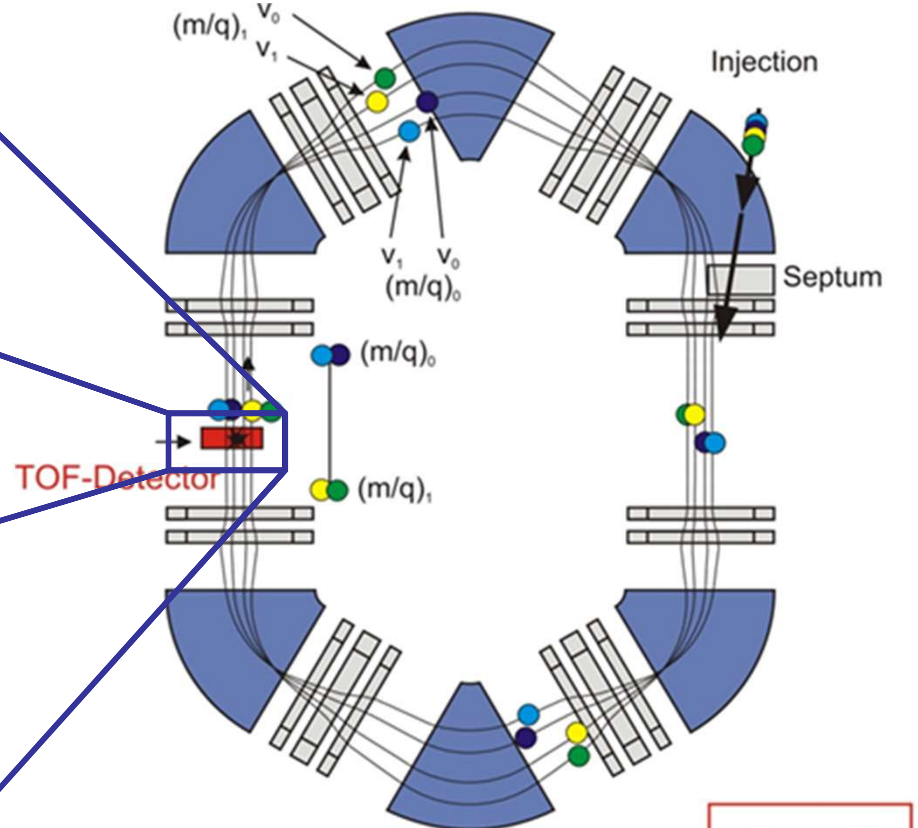
EC decay detected by Schottky-detector at ESR

Isochronous Mass Spectrometry

GSI

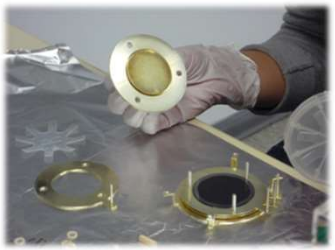
Time-of-Flight Detector



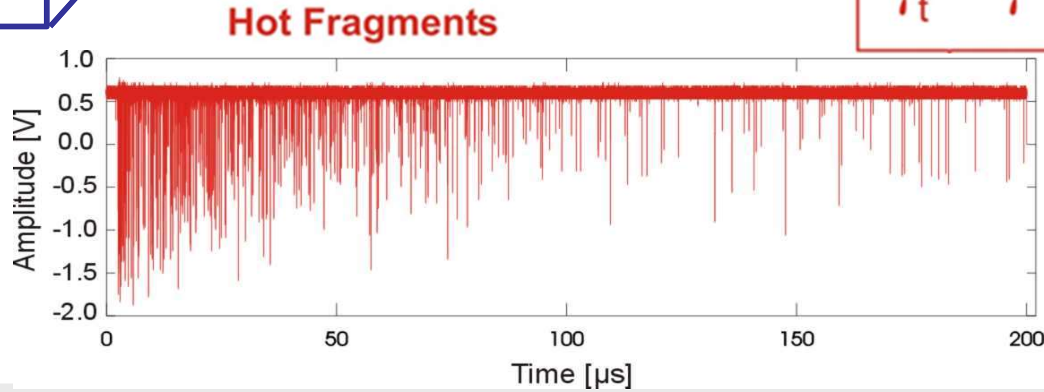


$\gamma_t \rightarrow \gamma$

MCP detector



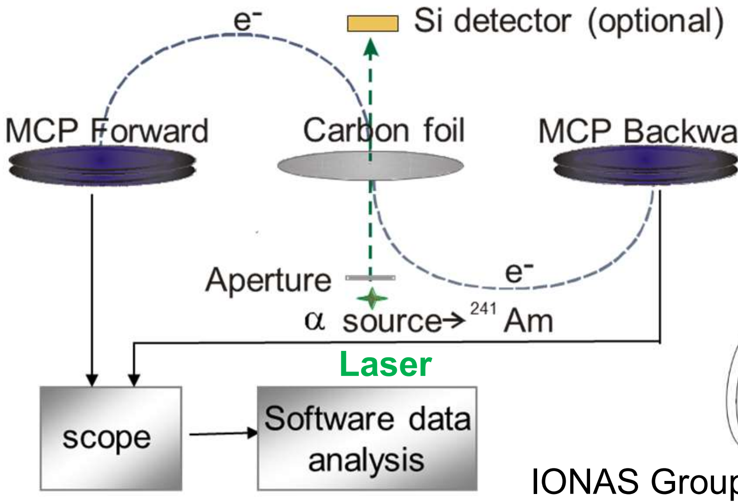
Carbon foil Ø 40 mm

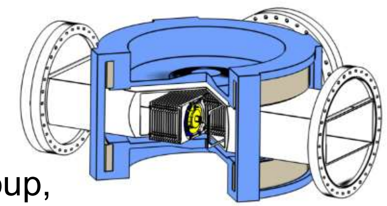


Optimization of TOF-ESR detector

N. Kuzminchuk–Feuerstein et. al., NIM A 821 (2016) 160

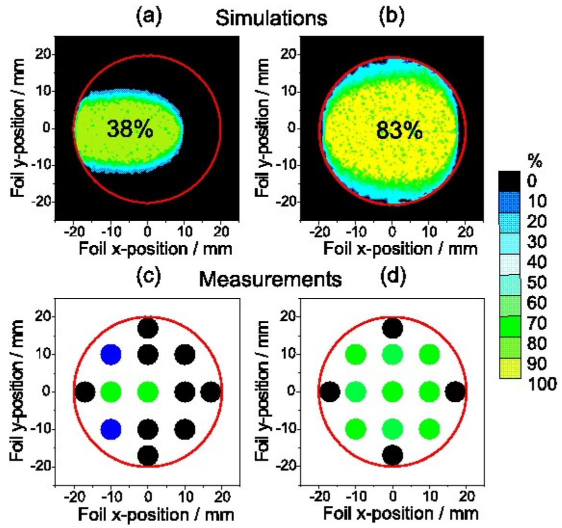
Set up for offline measurements



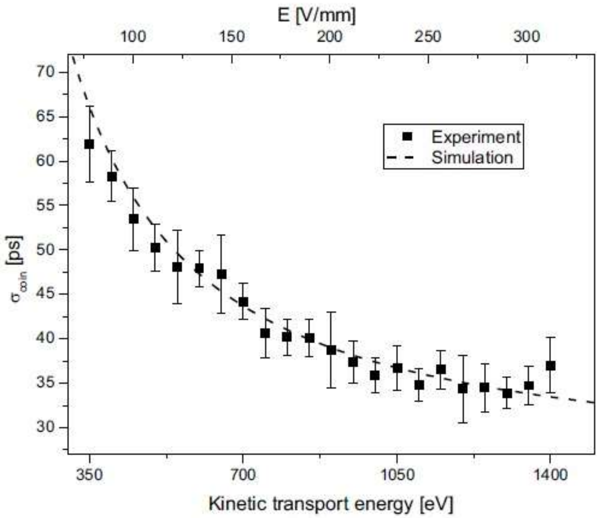


IONAS Group,
JLU Universität Gießen

Electron transport efficiency

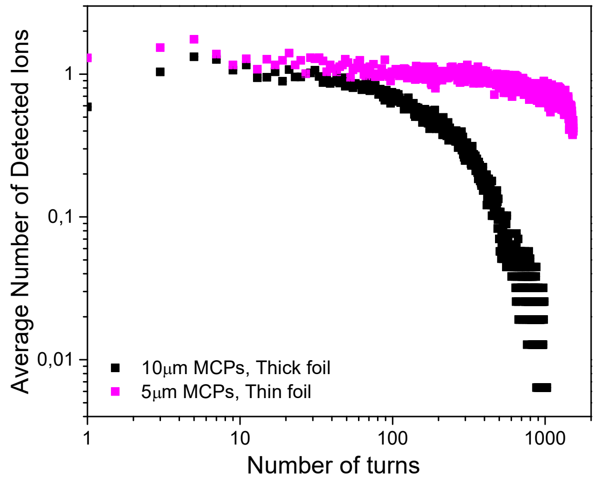


Timing accuracy



Rate capability (ESR)

Up to 10 times larger number of turns
→ Higher mass measurement accuracy

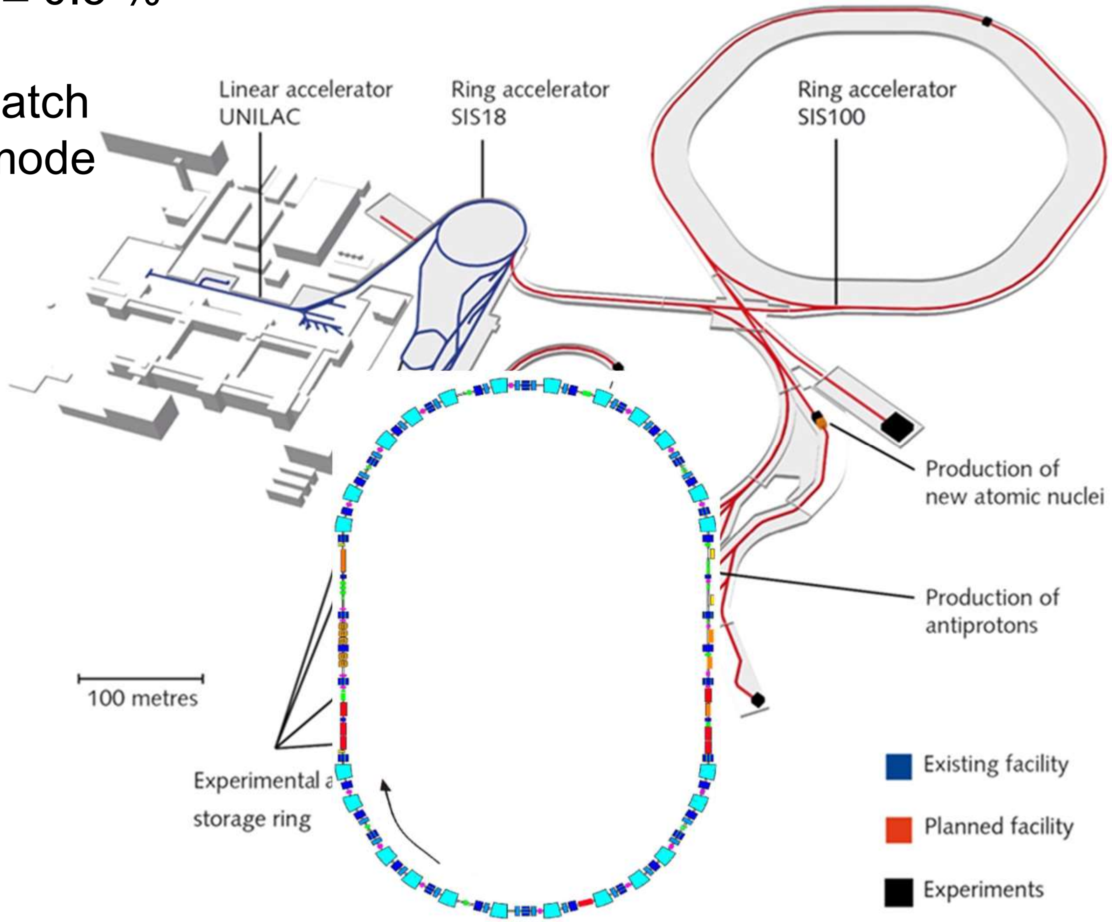


Collector Ring at FAIR

Super-FRS primary beams ~ 10^{12} /s, 1.5-2 GeV/u from p to ^{238}U
Factor 1000 over present intensity

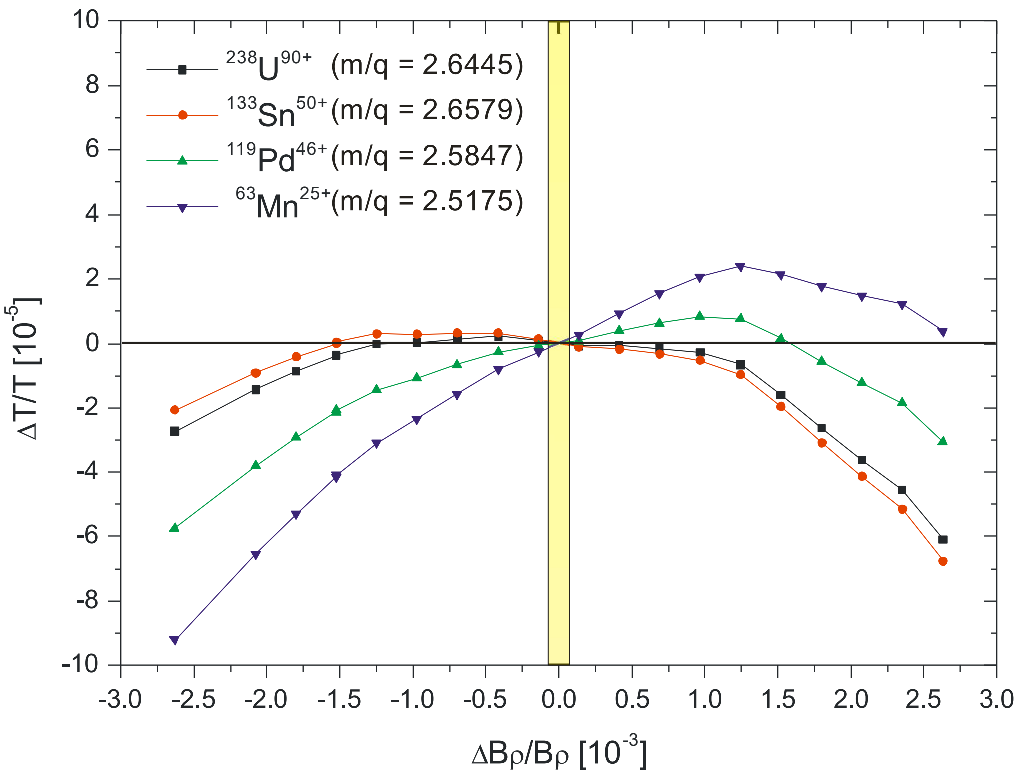
- Improved injection line from Super-FRS, Bρ/Bρ=0.5%
- Increased transverse and longitudinal momentum acceptance in isochronous mode Δp/p = ± 0.5 %
- Zero dispersion on straight sections to match the beam parameters with isochronous mode from the first turn on.

CR

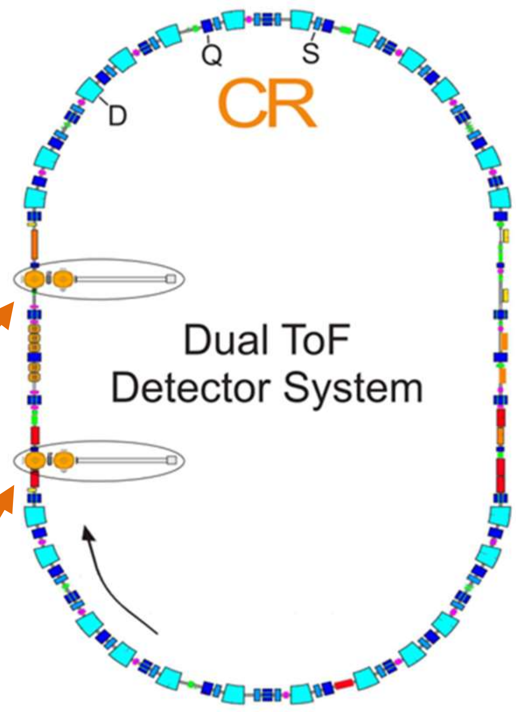


Isochronous Mass Spectrometry

The isochronous condition $\gamma = \gamma_t$ can be fullfiled only for a smaller range of mass-to-charge ratio



$$R = \frac{m}{\Delta m} = \frac{1}{\gamma_t^2}\frac{T}{\Delta T}$$



Possible solution, to use two TOF-detectors

- to correct for a wide mass-to-charge range
- in-ring velocity measurements of each particles in addition to its revolution time

Physics requirements and design goals

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

Second term of equation not vanishing for non-isochronous ions

Correction by measuring velocity with two TOF detectors in 16.9 m distance:

$$s = 16.9\, m$$
$$\gamma_t = 1.67$$

Timing accuracy

$$t = \frac{s}{v} = \frac{16.9\, m}{2.39938 \cdot 10^8\, \frac{m}{s}} = 70 \text{ ns}$$

Accuracy of velocity measurement of one turn

$$\frac{dt}{t} = \frac{0.035\, ns \cdot \sqrt{2}}{70\, ns} = 7 \cdot 10^{-4}$$

After 10 turns this can be improved to $\frac{dt}{t} < 1 \cdot 10^{-4}$

Physics requirements and design goals

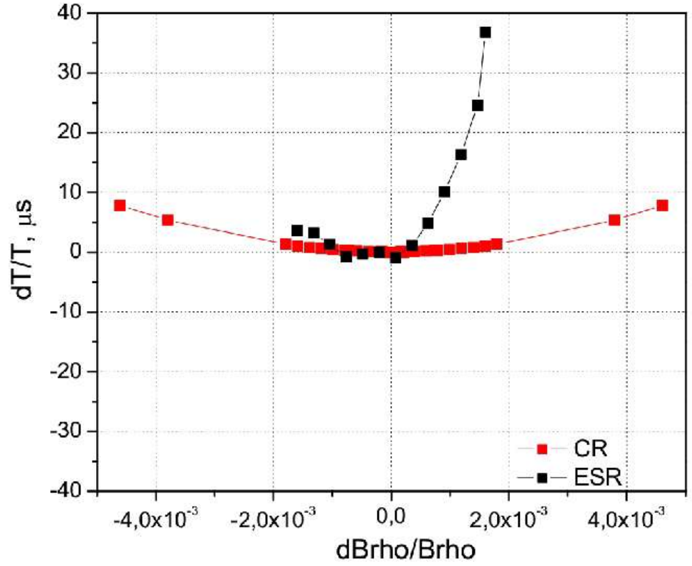
ESR

C = 108 m
Bρ = 8.4 Tm
γ_t = 1.4
Δp/p = ±0.12 % isoc. mode
ε_x = 7 mm mrad

CR

C = 221.45 m
Bρ = 13 Tm
γ_t = 1.67
Δp/p = 0.5 %
ε_x = 100 mm mrad

Improved injection line from S-FRS

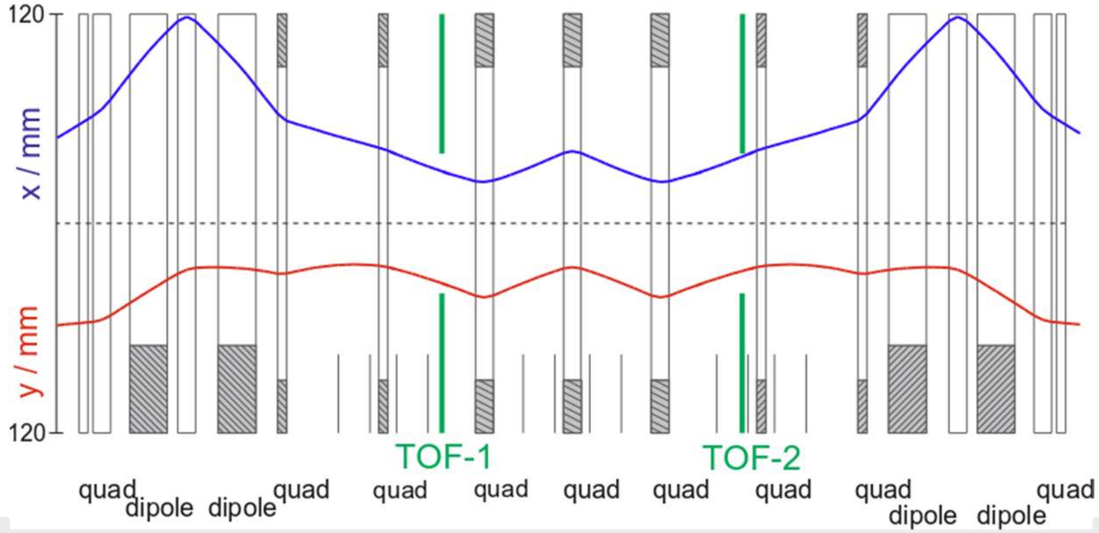


Phase space ellipse $\gamma x^2 + 2\alpha x a^2 + \beta a^2 = \varepsilon$

Maximum beam size $X_{max} = \sqrt{\beta\varepsilon}$

$$N_{ions} \approx \varepsilon_x \cdot \varepsilon_y \cdot \frac{\Delta p}{p}$$ → to inject and to store ~ 500 times more ions in CR

beam emittance (X and Y) = 100 mm mrad, ∅ TOF=80 mm



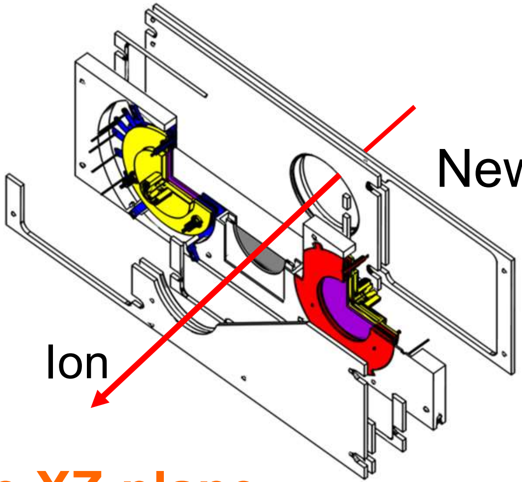
Larger TOF detector with larger beam acceptance is required!

Physics requirements and design goals

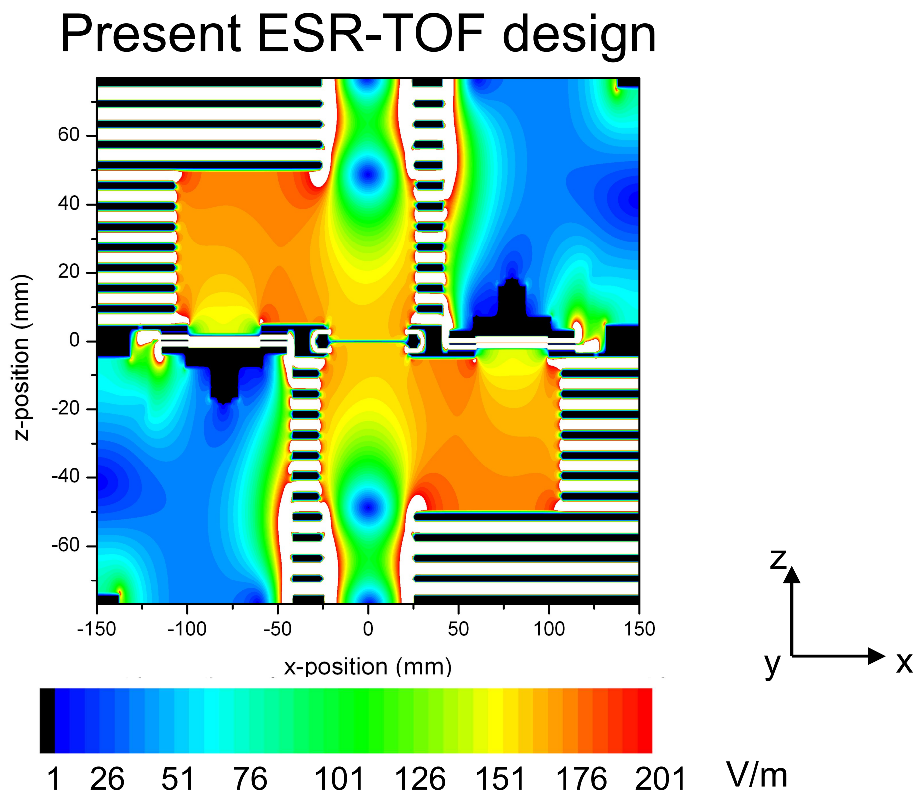
Main challenges	Possible solution
Larger CR acceptance ε=100 mm mrad	Implementation of Ø 80 mm carbon foil
Larger total detection geometry	Higher electrical field strength
Longer flight path from foil to MCPs	Better electric field homogeneity
Increase of time uncertainty	New arrangement, shape and number of electrodes
A compact geometry	

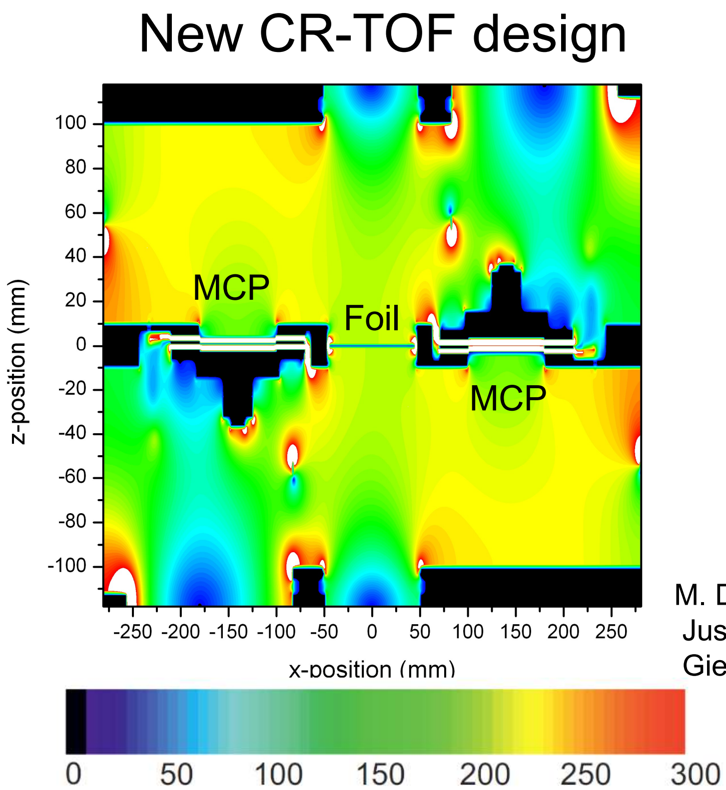
Summary of physics simulation (Electrodes)

	ESR-TOF detector	CR-TOF detector
Foil diameter	40 mm	80 mm
x (width)	300 mm	562 mm
y (height)	90 mm	180 mm
z (depth)	154 mm	236 mm
Time spread σ	45 ps	35 ps
Electron transport efficiency	78%	97%
Magnet pole-shoe diameter	500 mm	$\geq$ 900 mm
Electric field (E)	156 V/mm	207 V/mm
Magnetic flux density (B)	8.41 mT	7.44 mT



Simulated electrical field strength in the XZ-plane

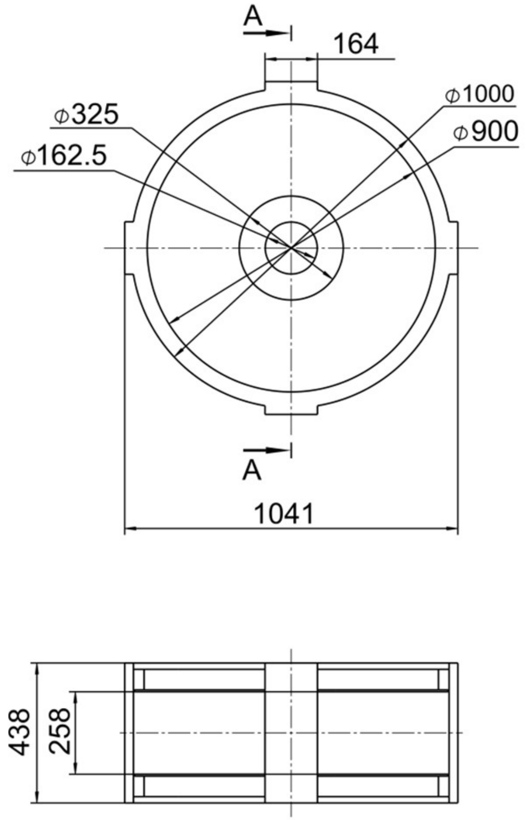


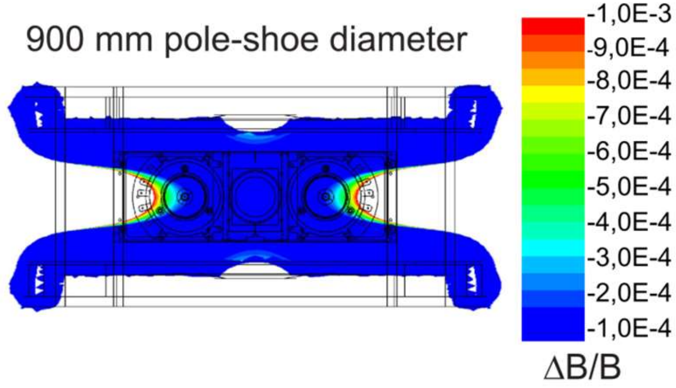


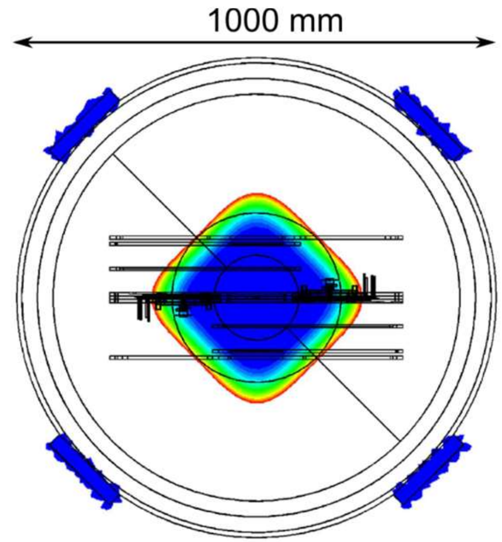
M. Diwisch, PhD Thesis, Justus-Liebig Universität Gießen (2015)

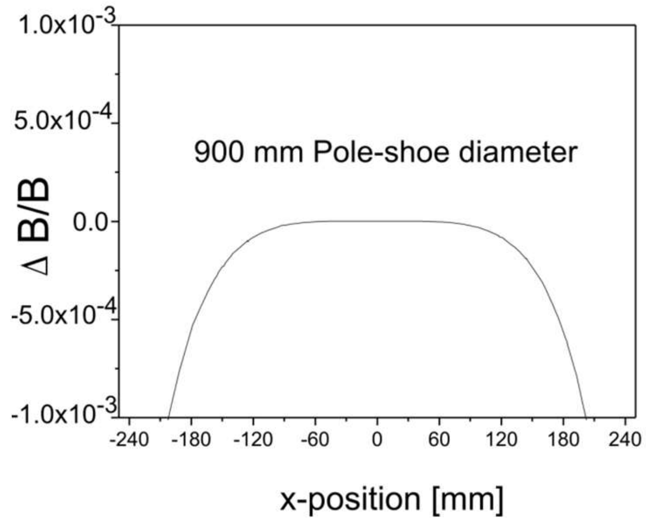
Summary of physics simulations (Magnets)

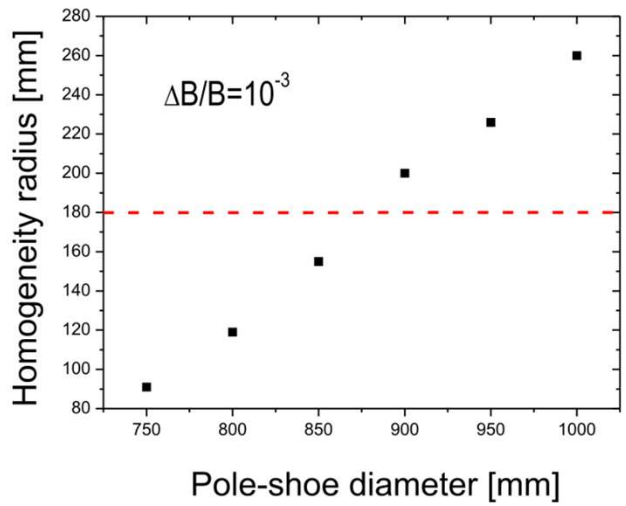
- Required relative homogeneity $\Delta B/B < 10^{-3}$ in a 180 mm radius (SE transport)
- Pole shoe diameter of at least Ø 900 mm
- A gap G_0 of at least 258 mm





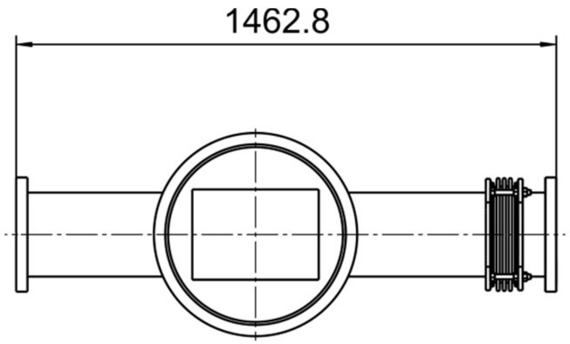


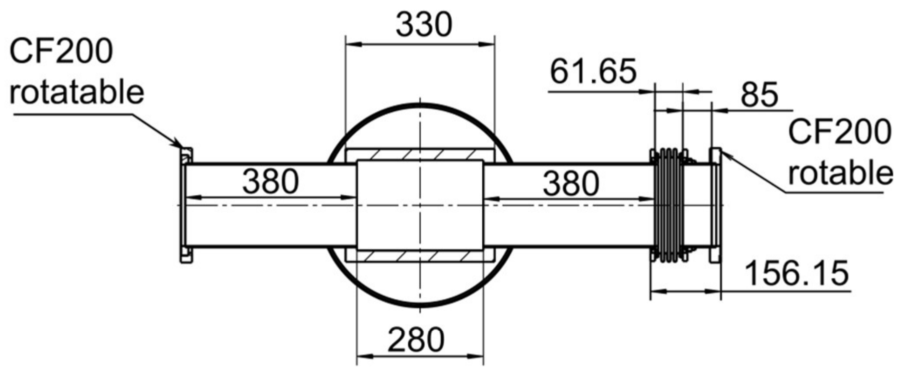




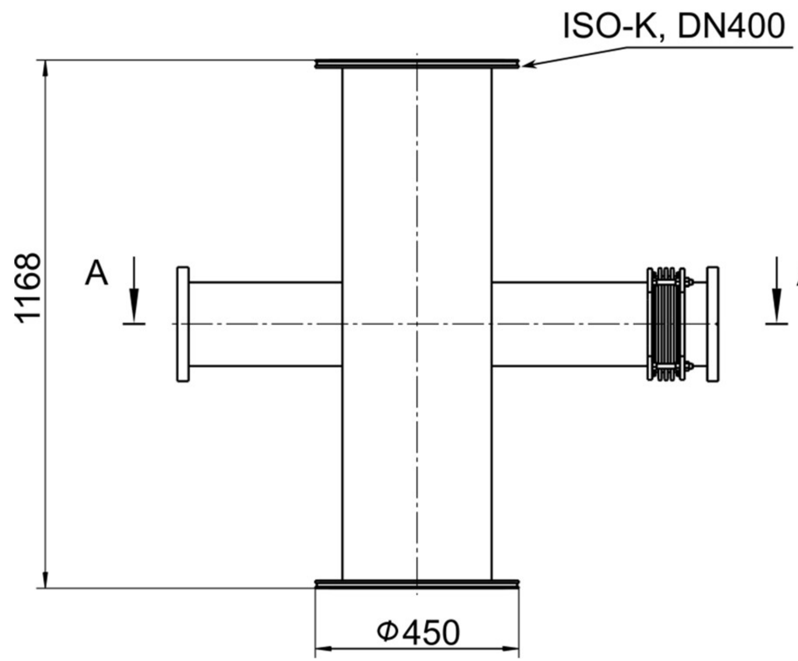
Summary of physics simulation (Chamber)

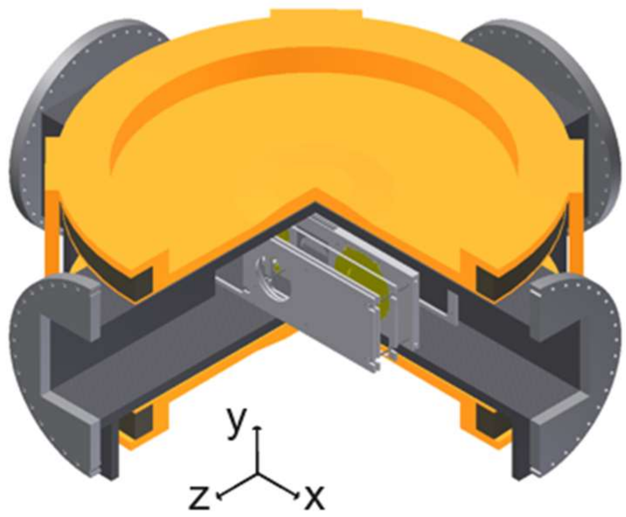
The CR is evacuated to a pressure of $3 \cdot 10^{-9}$ mbar



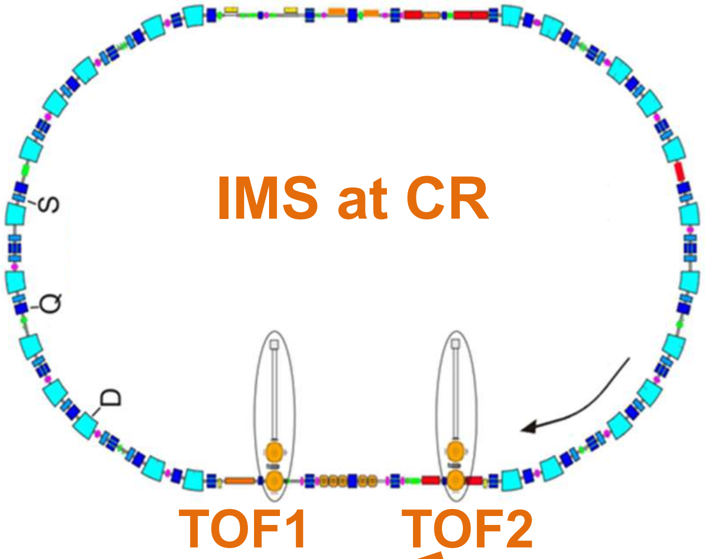


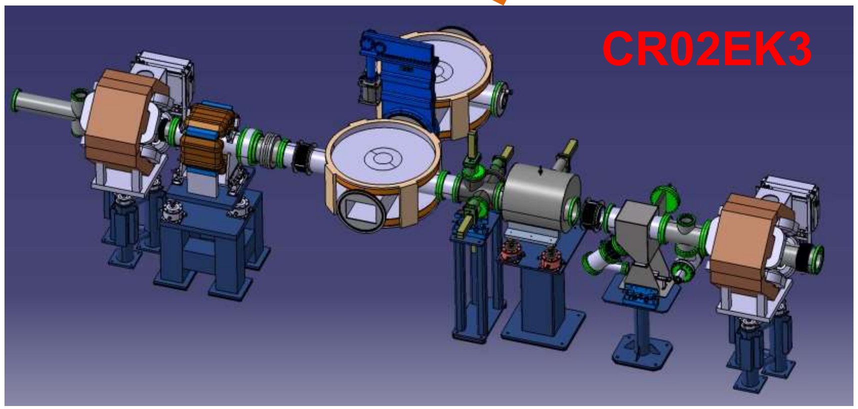
Section view A-A

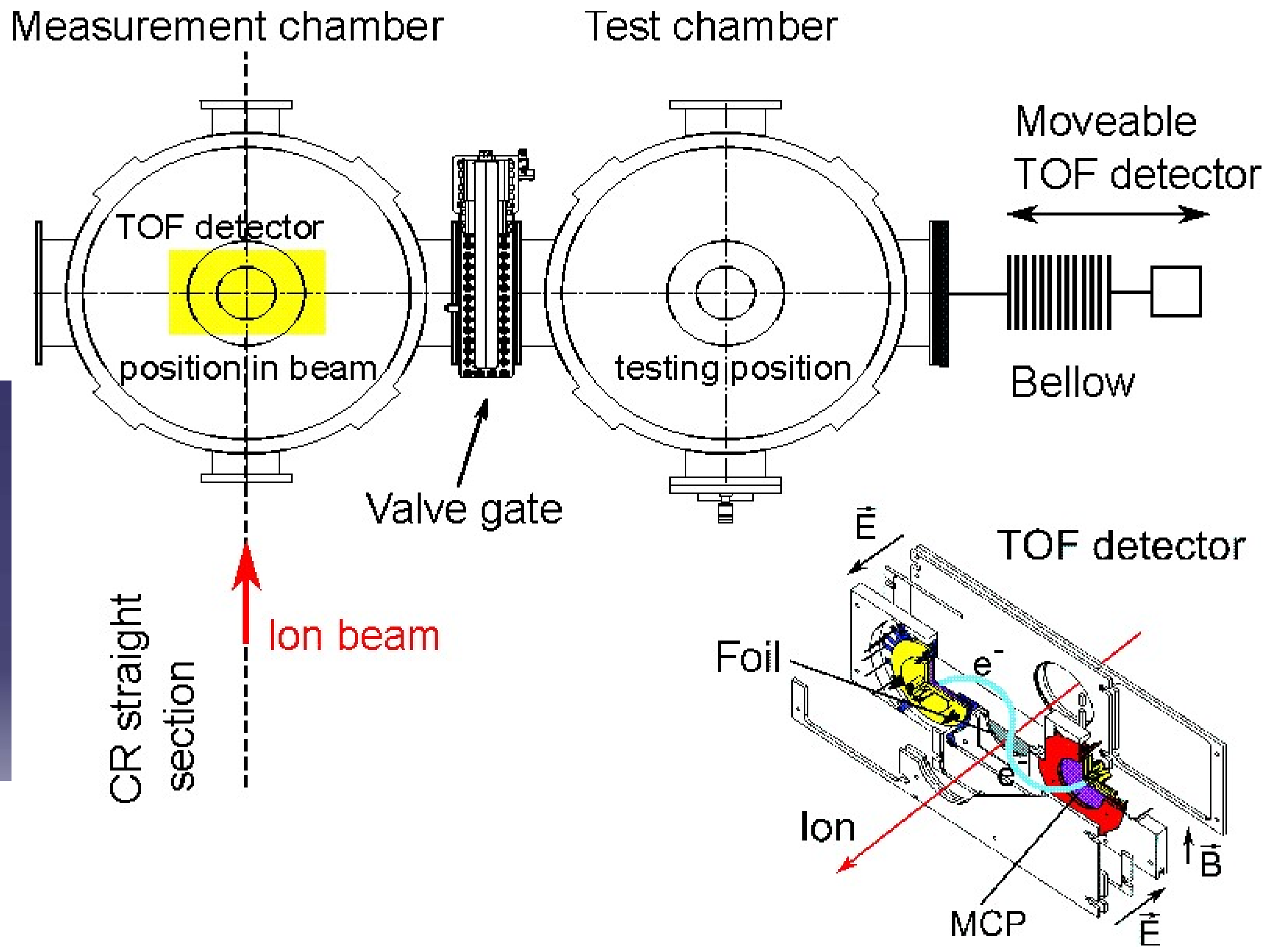




The overall setup of the TOF detector







Summary and Outlook

- With a new TOF-double detector System we aim in-ring velocity measurements to improve the mass resolving power

- Using the previous knowledge from existing ESR-ToF detector combined with the numerical simulations for the new CR-ToF detector a final technical design has been made
  - Electric field homogeneity
  - Magnetic field homogeneity
  - Electron transport efficiency
  - Timing accuracy

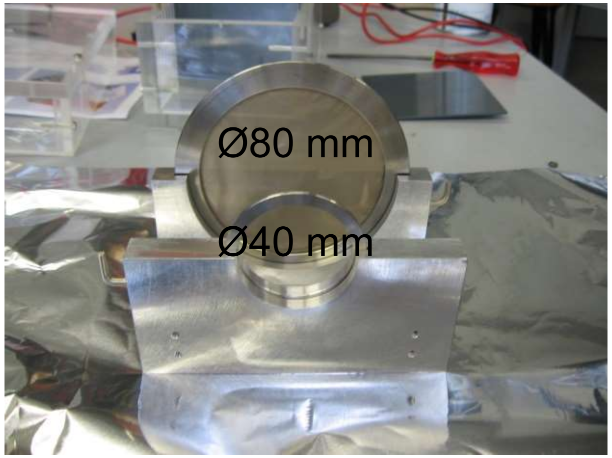
FAIR/NUSTAR/ILIMA/IMS/TDR dual TOF-Detector system

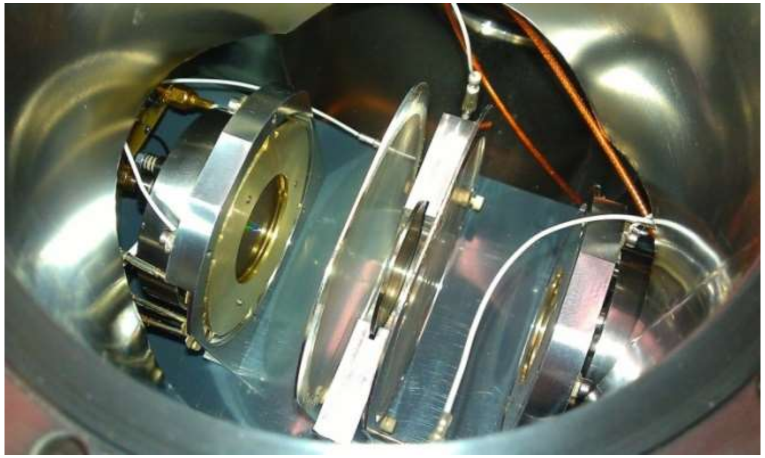
Technical Report for the Design, Construction and Commissioning of the Dual TOF-Detector System for ILIMA

December 19, 2017

ILIMA	Name	E-mail
Spokesperson	Takayuki Yamaguchi	yamaguti@phy.saitama-u.ac.jp
Deputy Spokesperson	Yuri Litvinov	y.litvinov@gsi.de
Project Manager	Helmut Weick	h.weick@gsi.de
Technical director	Yuri Litvinov	y.litvinov@gsi.de
Work Package Leader	Wolfgang R. Plass	wolfgang.r.plass@exp2.physik.uni-giessen.de

- Practical feasibility and mechanical manageability of Ø 80 mm foil inside the vacuum chamber. First dedicated timing measurement was performed





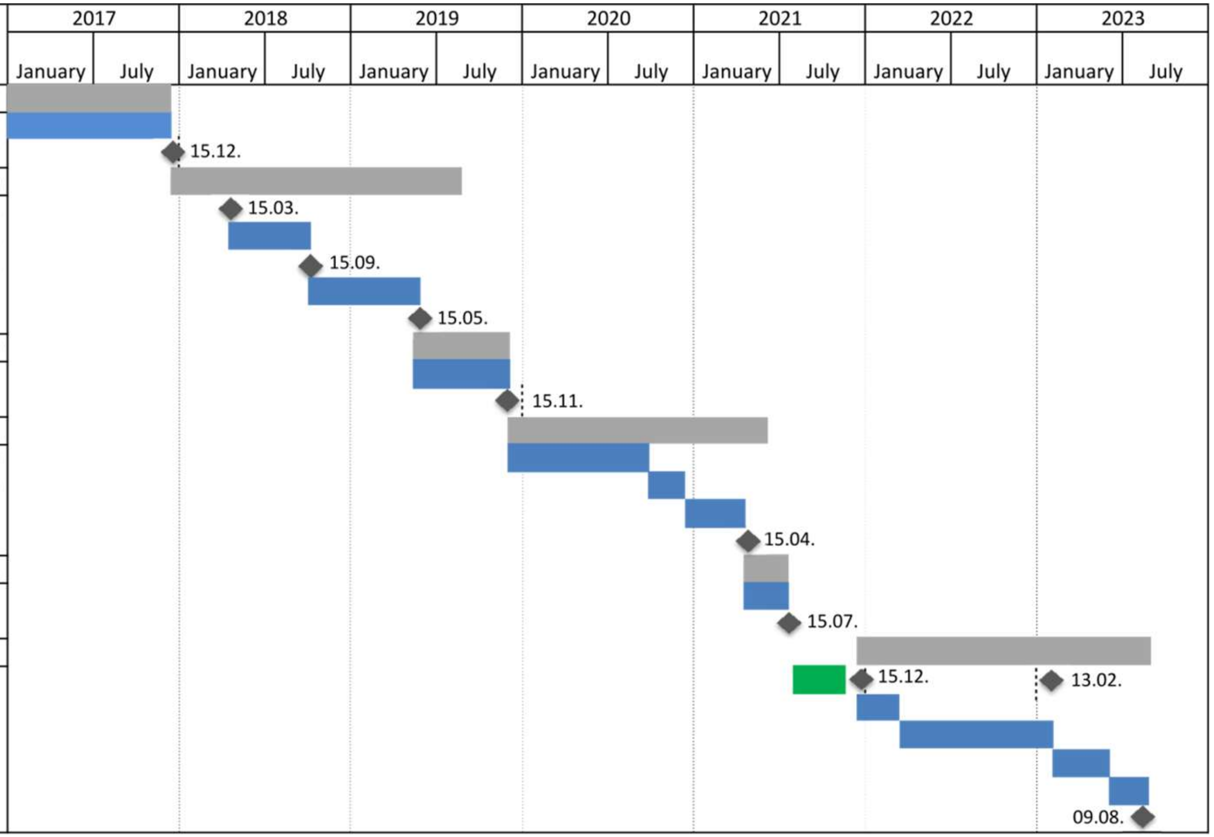
TU Munich (Dr. T. Faestermann, Dr. R. Gernhäuser)

Project organization and Time schedule

In the ILIMA collaboration the working group ”TOF detector” does the development and detailed planning. In the FAIR project structure it is integrated as a part of the NUSTAR subproject with the project leader for ILIMA being the ILIMA project manager (H. Weick) and a work-package leader (W.R. Plass). The detectors are directly integrated into the storage ring. For the technical design, construction, installation, and commissioning of the whole CR and its components are BINP Novosibirsk and the group at GSI are responsible.

status December, 2017

Activity code	Task	Duration	Start	Finish
	Conceptual Design Phase		01.01.14	15.12.17
S002	conceptual design work	1060 d	25.11.16	09.11.17
	submit TDR		15.12.17	15.12.17
	Contracting and detailed design	**540 d**	**15.12.17**	**24.09.20**
S002.M3	TDR approval		15.03.18	15.03.18
S002.A4	Prepare Contract	180 d	16.03.18	15.09.18
S002.M4	Contract is signed		15.09.18	15.09.18
S002.A7	Finalize planning, detailed design	240 d	16.09.18	15.05.19
S002.M7	FDR Accepted/planning completed		15.05.19	15.05.19
S003	**Procurement**	**180 d**	**16.05.19**	**15.11.19**
S003.AX1	Acquire material	180 d	16.05.19	15.11.19
S003.MX1	All material is acquired		15.11.19	15.11.19
S005	**Manufacturing of components**	**510 d**	**16.11.19**	**11.02.21**
S005.A92	detector component construction	300 d	16.11.19	15.09.20
S005A93	Component testing	90 d	16.09.20	15.12.20
S005.A92	vacuum chambers construction	120 d	16.12.20	15.04.21
S005.M9	acceptance test completed (FAT)		15.04.21	15.04.21
	Shipment	**90 d**	**16.04.21**	**15.07.21**
S006.ATS	Shipment to FAIR	90 d	16.04.21	15.07.21
S006.M92	End of shipment		15.07.21	15.07.21
S005	**Assembly of components**	**603 d**	**15.12.21**	09.08.23
	buffer, tunnel ready for ToF installation 1+2		15.12.21	13.02.23
S007.A112	Component construction, phase 1	70 d	15.12.21	22.02.22
	alignment and assembly outside tunnel	355 d	23.02.22	12.02.23
S007.A112	Component construction, phase 2	90 d	13.02.23	13.05.23
S007.A119	Component testing	88 d	14.05.23	09.08.23
S007.M11	Components accepted without beam		09.08.23	09.08.23



Site Acceptance Test

SAT A

- Equipment of *all* vacuum chambers with the magnets, CF400 ISO gate valves and installation on the support
- Equipment of the *test* chambers with the diagnostic for offline tests and pumping station
- Assembling of the TOF detector electrodes
- All assembling units have to be tested on vacuum
- Measurement of the TOF detector performance offline

SAT Ba

- In the first installation phase four big vacuum chambers equipped with magnet each and CF400 ISO gate valve shall be integrated in the beam-line of the CR
- Alignment

SAT Bb

✓ Commissioning with beam

Merci de votre attention !

Samuel Ayet San Andr´eas[1,2], Julian Bergmann[2], Timo Dickel[1,2], Marcel Diwisch[2], Oleksiy Dolinskyy[1], Benjamin Fabian[2], Hans Geissel[1,2], Christine Hornung[2], Ronja Knöbel[1,2], Christophor Kozhuharov[1], Natalia Kuzminchuk-Feuerstein[1,2], Wayne Lippert[2], Sergey Litvinov[1], Yuri Litvinov[1], Svetlana Nazarenko[2], Wolfgang R. Plaß[1,2], Christoph Scheidenberger[1,2], Markus Steck[1], Baohua Sun[1,2], Helmut Weick[1], Matti Werner[2] and ILIMA collaboration

[1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt
[2]Justus-Liebig-Universität, Gießen

Funding: **BMBF** (05P09RGFN9), (05P16RGFN1), **GSI** (strategic university cooperation GSI-JLU-FAIR)