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FORSCHUNGSZENTRUM

COSY and Beyond

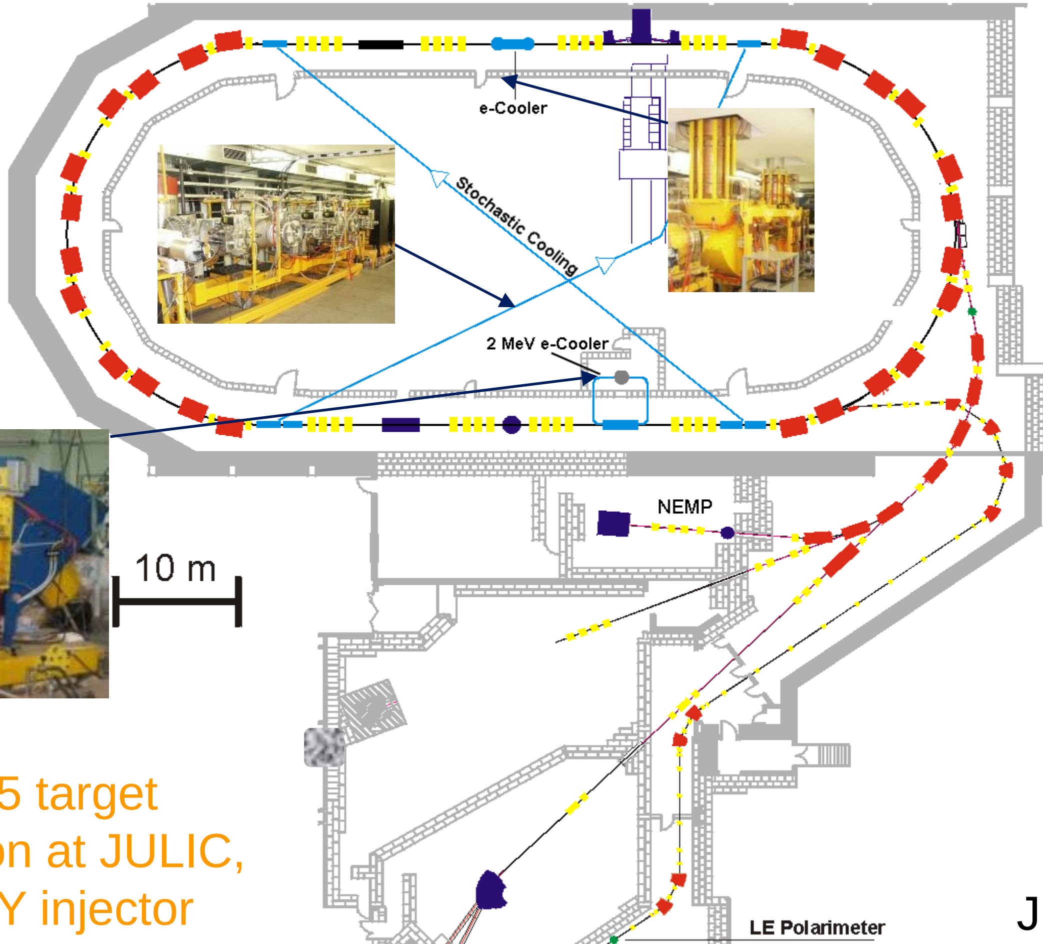
M. Bai on behalf of Institut für Kernphysik-4,
Forschungszentrum, Juelich

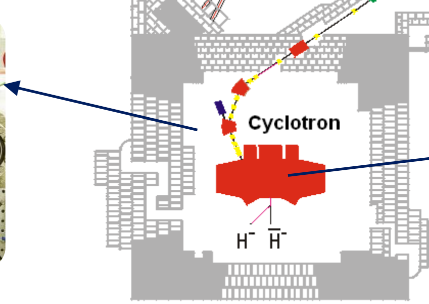
Georgia German School and Workshop for Basic Science, August 28 - Sept. 2, 2016

Outline

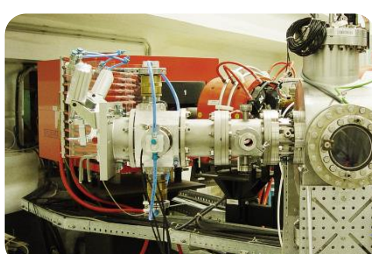
- Brief introduction and highlights
- COSY status and plan
  - FAIR contribution: HESR
  - Towards storage ring based EDM search for charged ions
  - Expanding its capability for multidisciplinary science research
- Summary

Cooler SYnchrotron





INM-5 target station at JULIC, COSY injector

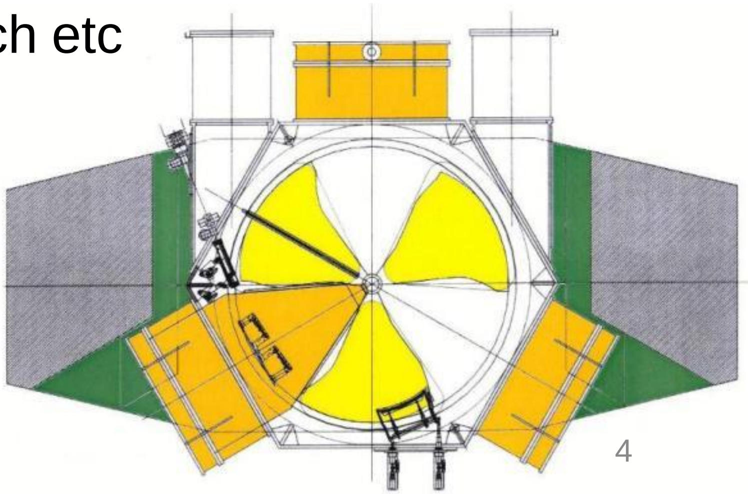


JULIC

JULIC: COSY injector

- Designed by AEG, 1st beam in 1968
  - Pole diameter: 3.3m/700 Tons iron
  - $\langle B \rangle_{max}$=1.35 Tesla, B_{hill}=1.97 Tesla
  - 3 ion sources, including polarized ion source
- Together with Big-Karl spectrometer, was the working horse for nuclear physics until COSY
- Upgraded for COSY in 1990
- Still provides excellent service for COSY, as well as nuclear medicine research etc

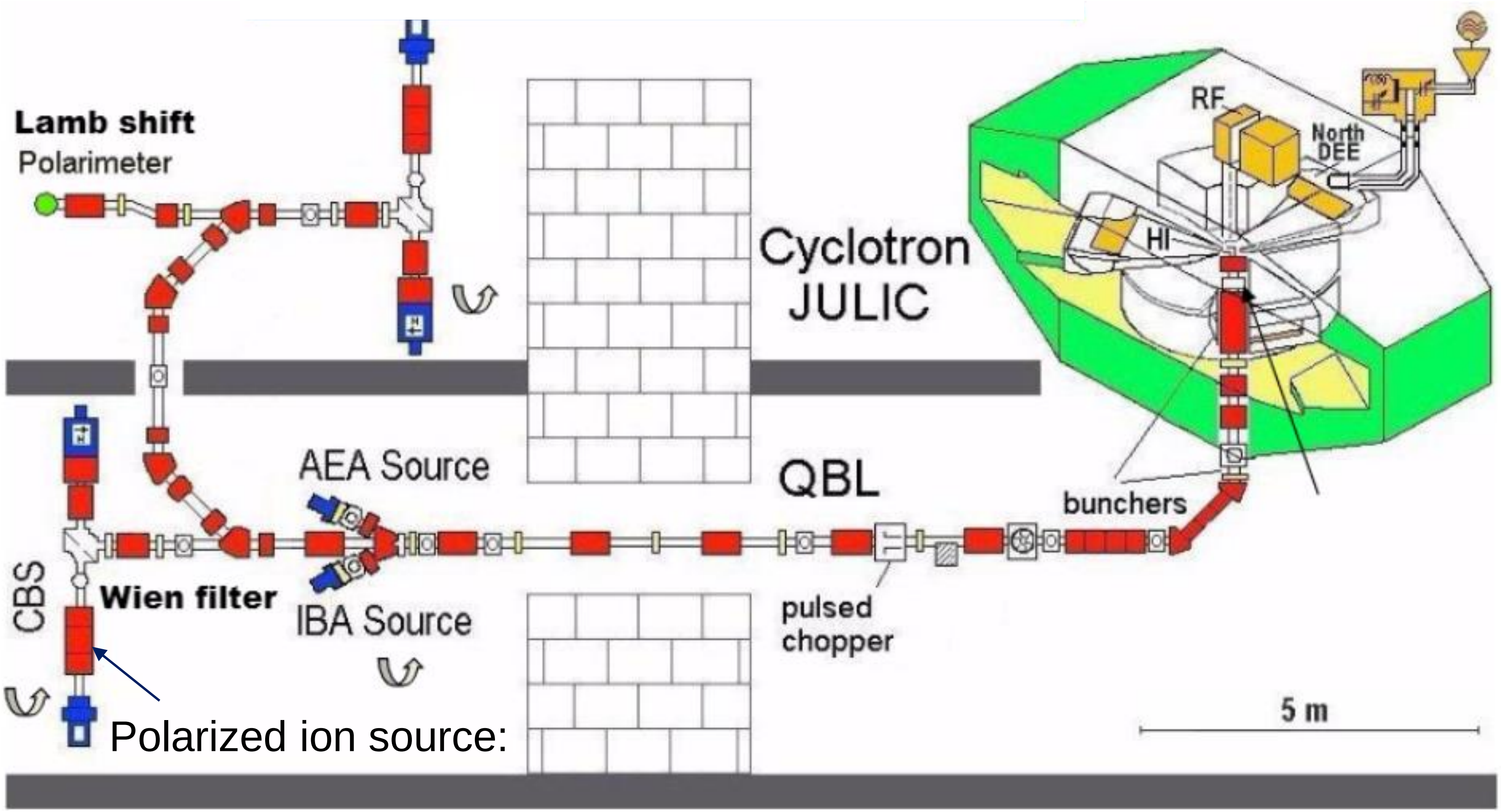
routinely 45 MeV H^- and 75 MeV D^- for COSY with 20 ms stripping injection/cycle



Courtesy of R. Gebel

Highlights of COSY

- Negative polarized H-/D- source
  - 45/35 µA H- / D- output
  - ~92% beam polarization in COSY



Courtesy of R. Gebel

Uniqueness of COSY

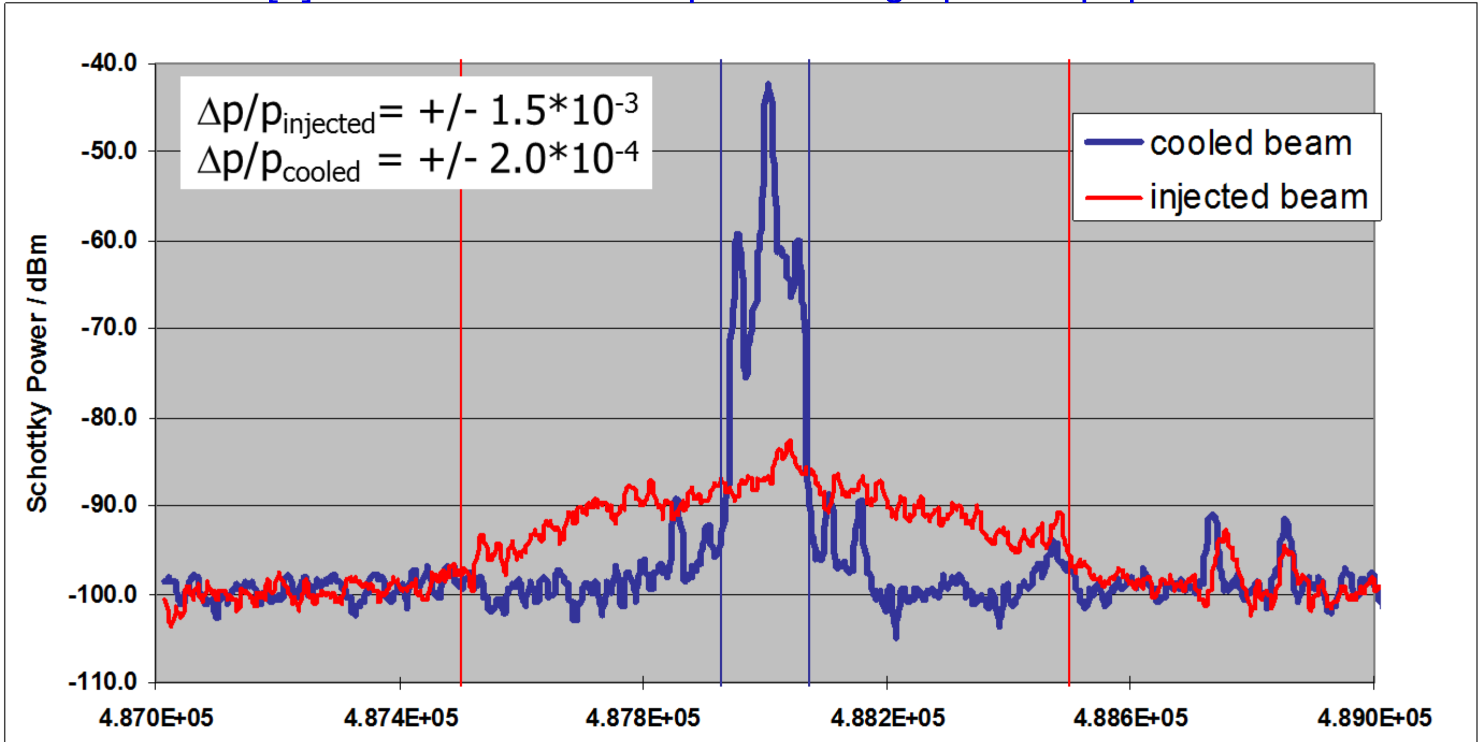
- Light ion beams with wide range of energy
  - Currently, COSY can provide proton and deuteron
    - between energy of 45MeV/75MeV to ~2GeV
    - Intensity at injection: <= 10^{11} protons
    - Intensity at higher energy: $<0.7^{11}$ protons
- Sophisticate beam cooling
  - Allows internal target operation
  - High brightness beam
- Extraction beam available in three of its beamlines
  - JESSICA, TOF and Big-Karl

Highlights of COSY

- Electron cooling

- constructed between 1988 -1993
- 2m long with electron energy from 24.5 -100 keV
- electron beam current: ≤ 4 A
- electron cathode size: 2.54 cm
- was the working horse for internal target experiments: WASA, ANKE, etc

[1] H. J. Stein *et al*, http://arxiv.org/ftp/arxiv/papers/1101/1101.5963.pdf



Courtesy of B. Lorentz

Highlights of COSY

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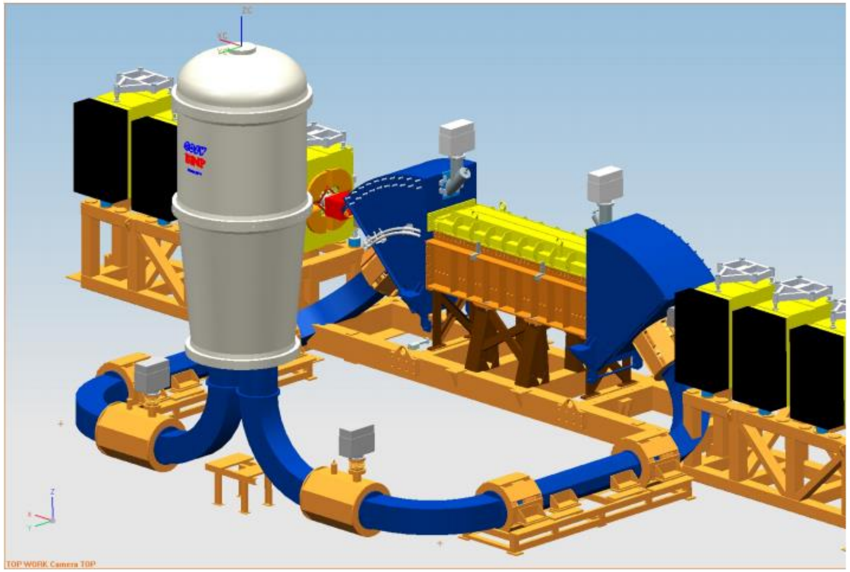
2 MeV electron cooler development



Design parameters

- Energy range: 0.025 - 2 MeV
- High voltage stability: < 10^{-4}
- Electron current: up to 3 A
- Electron beam diameter: 10 - 30 mm
- Cooling section length: 2.7 m
- Toroid radius: 1 m
- Cooling section solenoid: 0.5 - 2 kG

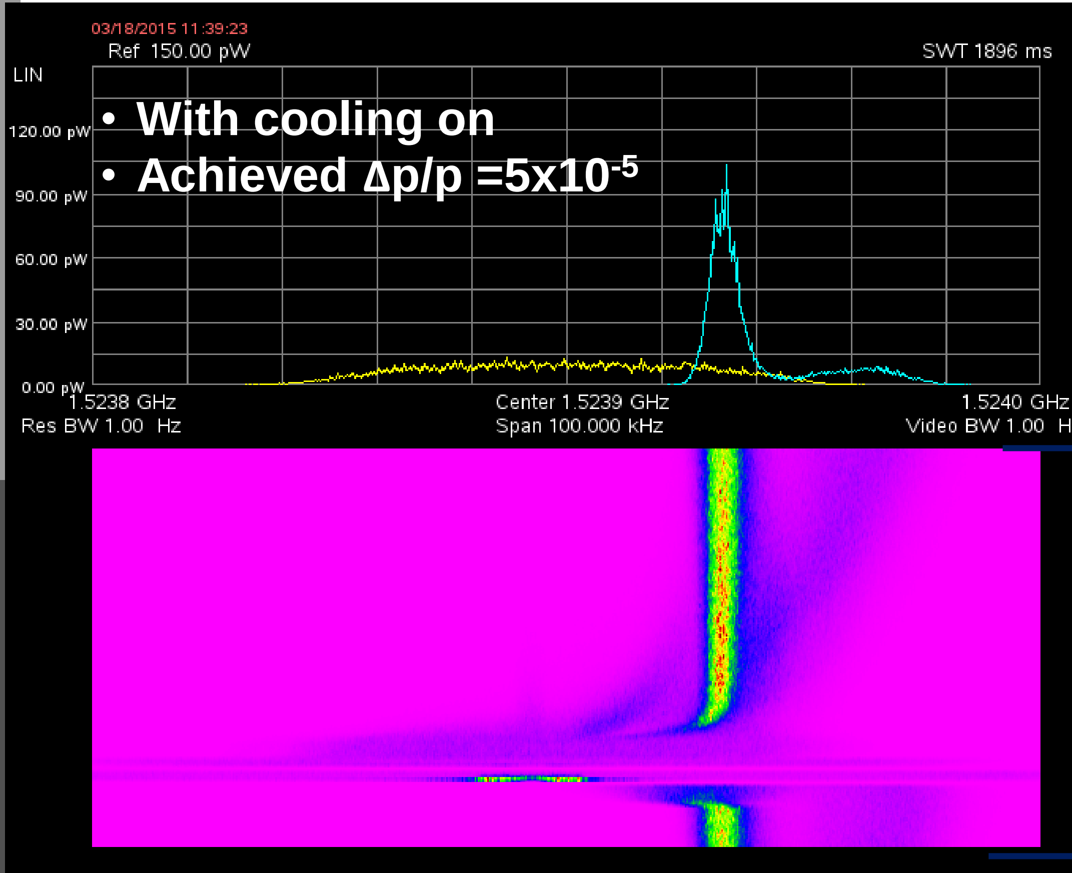
Courtesy of V. Kamerdzhiev

Currently achieved

Proton energy, MeV	Electron energy, MeV	Max. electron current, A
200	0.109	0.5
353	0.192	0.5
580	0.316	0.3
1670	**0.908**	**0.9**

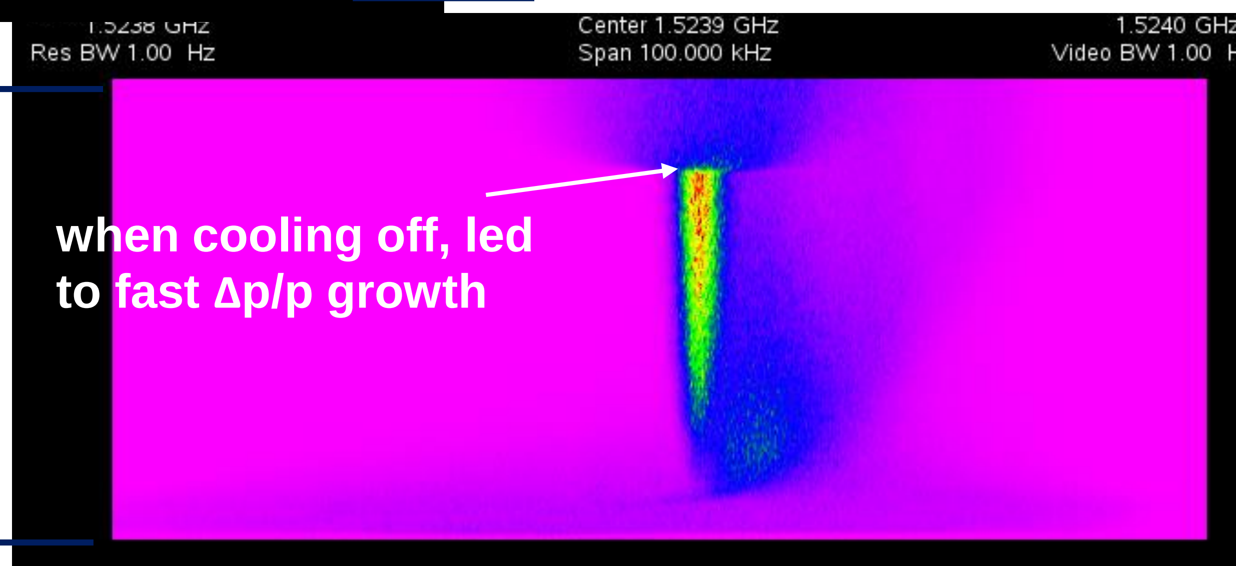
2 MeV electron cooler

- 5×10^8 protons at 1.66 GeV, DC
- Electron current 0.8 A, with 1.3 kG solenoid



500s

Courtesy of V. Kamerdzhiev



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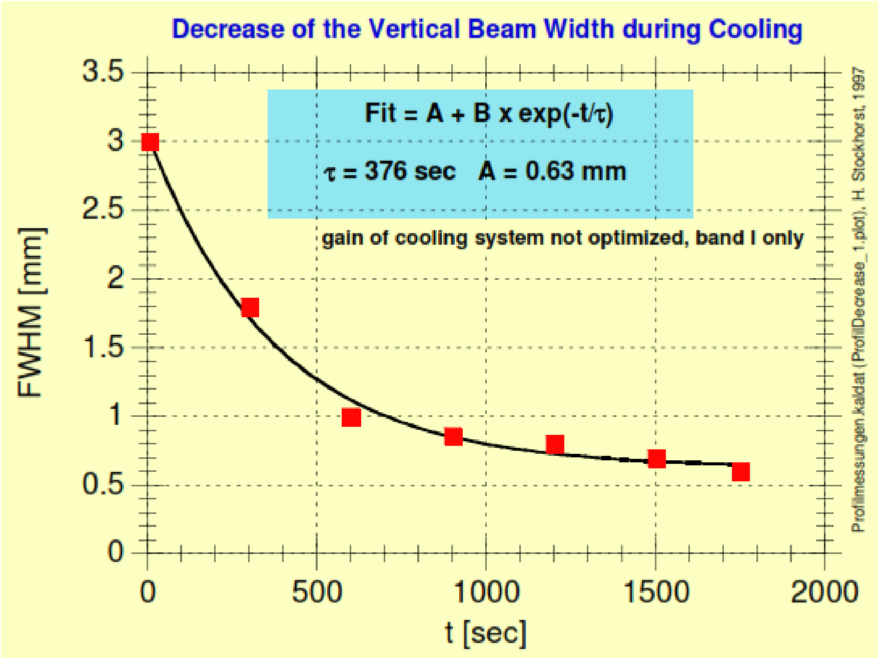
M. Bai

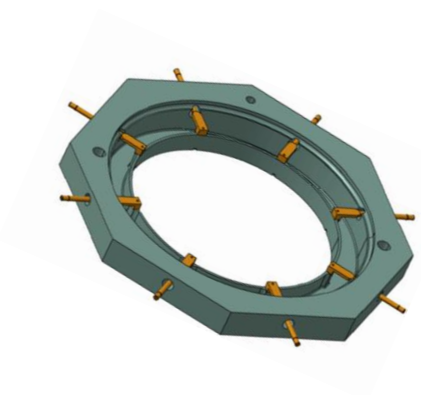
Highlights of COSY

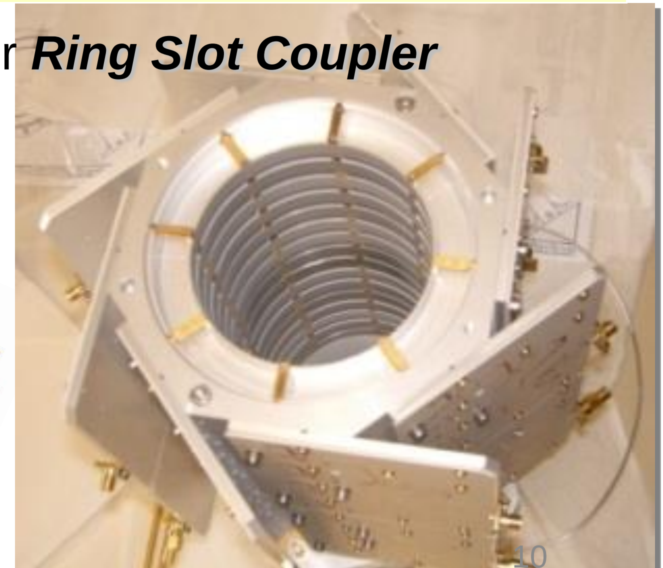
- Stochastic cooling at COSY
  - Transverse betatron cooling
  - Longitudinal cooling using notch filter technique
  - Effective from beam energy 1.5 GeV/c to 3.7 GeV/c
  - Bandwidth: 1-3 GHz



- Stochastic cooling for HESR
  - Novel compact design of pickup/kicker
    - ring-slot coupler
    - bandwidth of 2-4 GHz
    - high sensitivity
    - fixed aperture

Pickup/Kicker ***Ring Slot Coupler***



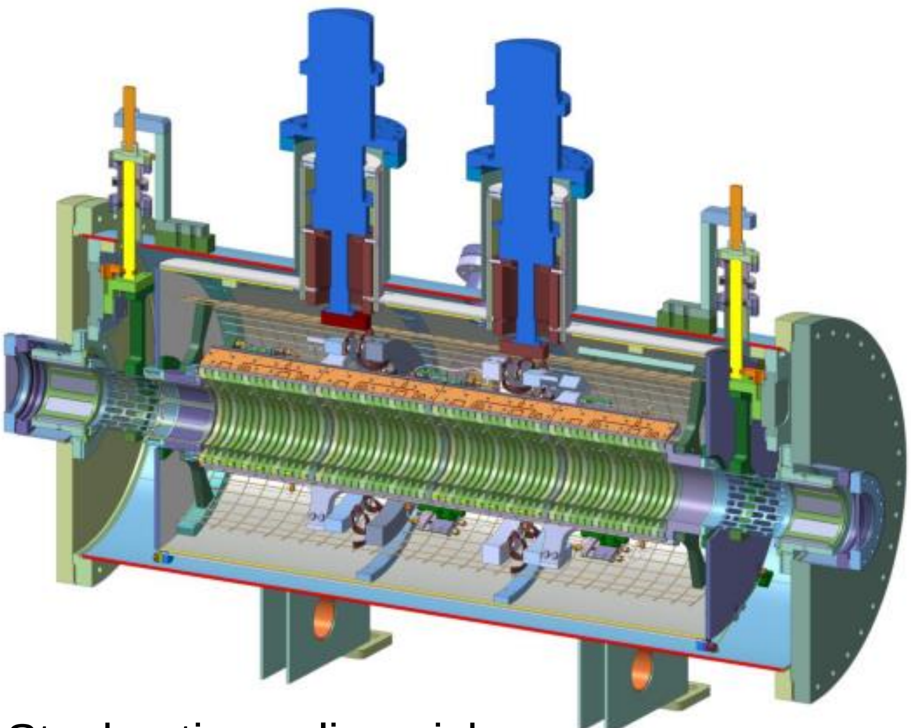


R. Stassen, L. Thorndahl *):

Courtesy of H. Stockhorst

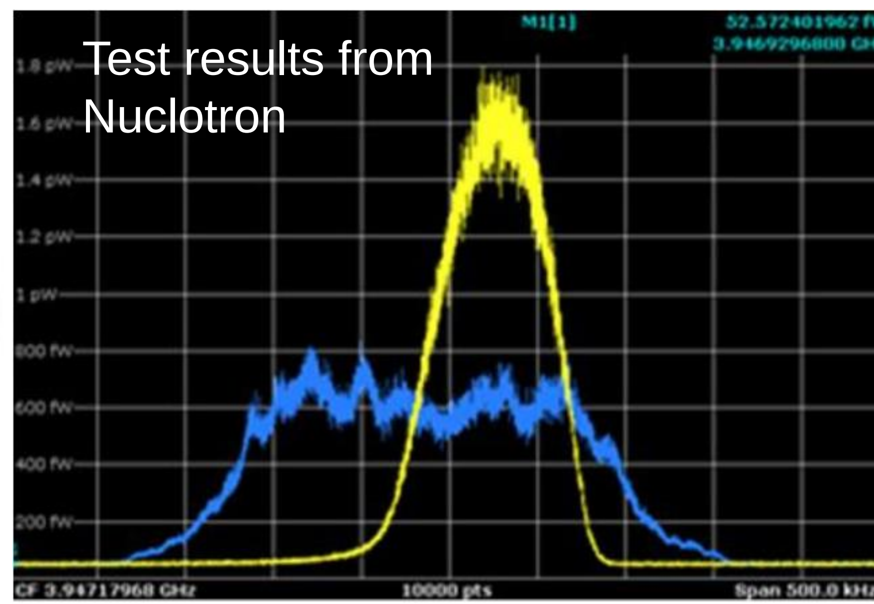
Highlights of COSY

- Was prototyped and tested at COSY and Nuclotron (JINR)
  - $2x10^9$ Deuteron beam
  - Beam energy at 3 GeV
  - Cooling time 480 sec



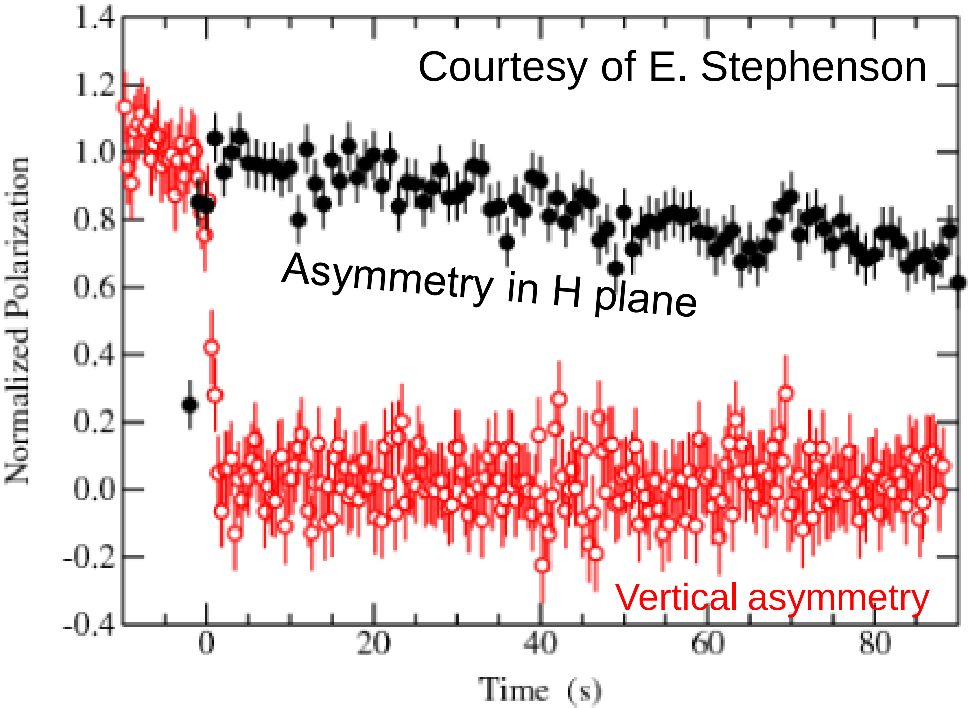
Stochastic cooling pickup

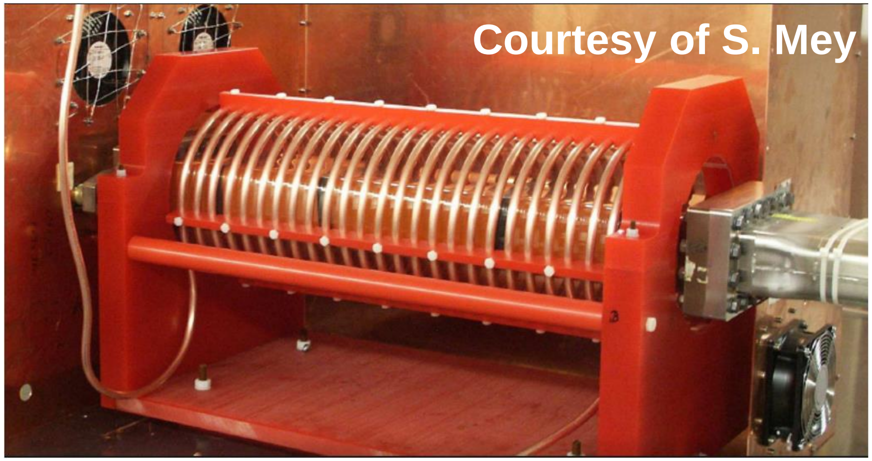
R. Stassen, H. Stockhorst, et al



Highlights of COSY

- Polarized beam manipulation
  - RF solenoid to achieve full spin flip, as well as the tool to place spin into horizontal plane





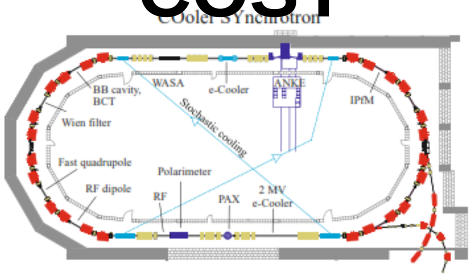
- Effective length: 0.564 m
- # of turns: 25
- Inductance: 40 uH
- Resonant frequency: 425 ~ 1940 kHz
- Maximum field strength: 4.3 T-mm

Accelerator group current tasks

- COSY operation
  - Test facility for FAIR
  - Precision experiments
    - TRIC, EDM precursor experiment, PAX
  - Multidisciplinary science research
    - Irradiation effect, Medical radionuclide study, HBS R&D, etc
- HESR@FAIR development
- Key technology development for the investigation of storage ring based EDM search
  - Electrostatic-magnetic deflector
- Expanding COSY capabilities
  - High precision beam control
  - nA extraction beam current

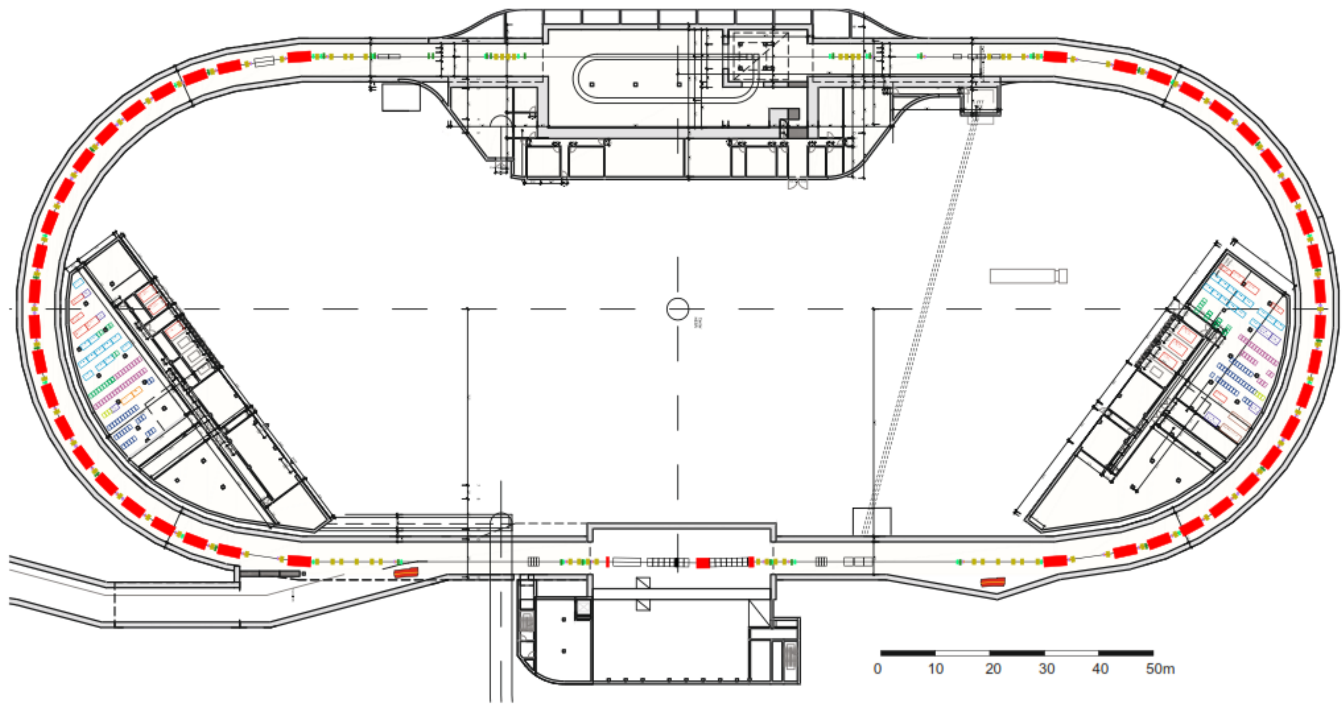
From COSY to HESR

COSY



Trajectory
Dipoles
Quadrupoles
Sextupoles
SteererH
SteererV
BPM

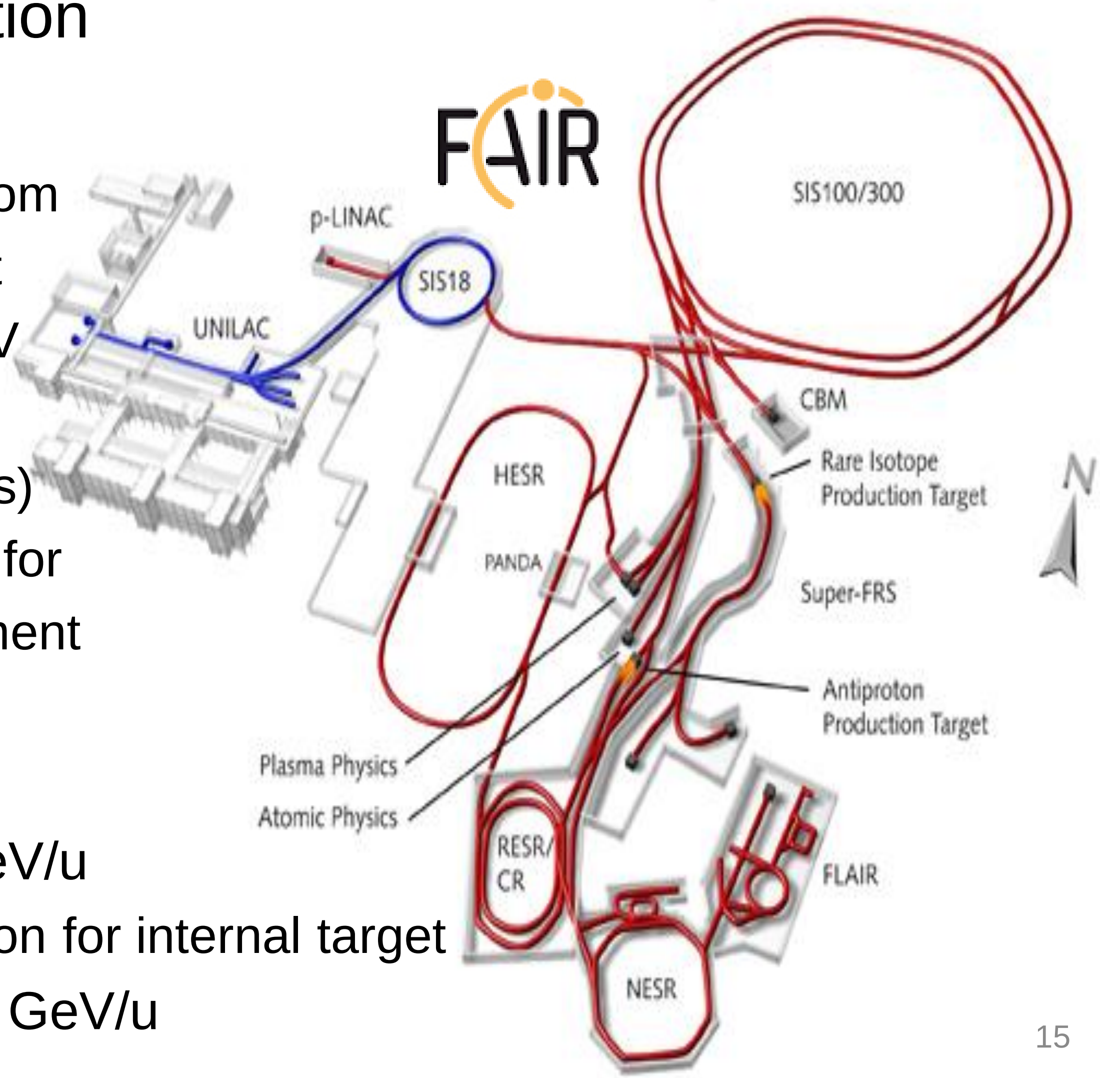
High Energy Storage Ring



	Circumference	Energy range	Species
COSY	184m	0.3 ~ 3.7 GeV/c	Proton/deuteron
HESR	575m	1.5 ~ 15 GeV/c	Antiproton, heavy ion

HESR Challenges

- Design to achieve high resolution and high luminosity for internal target operation
  - Anti-proton
    - Accumulating beam from Collector Ring (CR) at injection energy 3 GeV
    - Deceleration to 1 GeV (cooling at 2 GeV, 25 s)
    - Energy compensation for internal target experiment



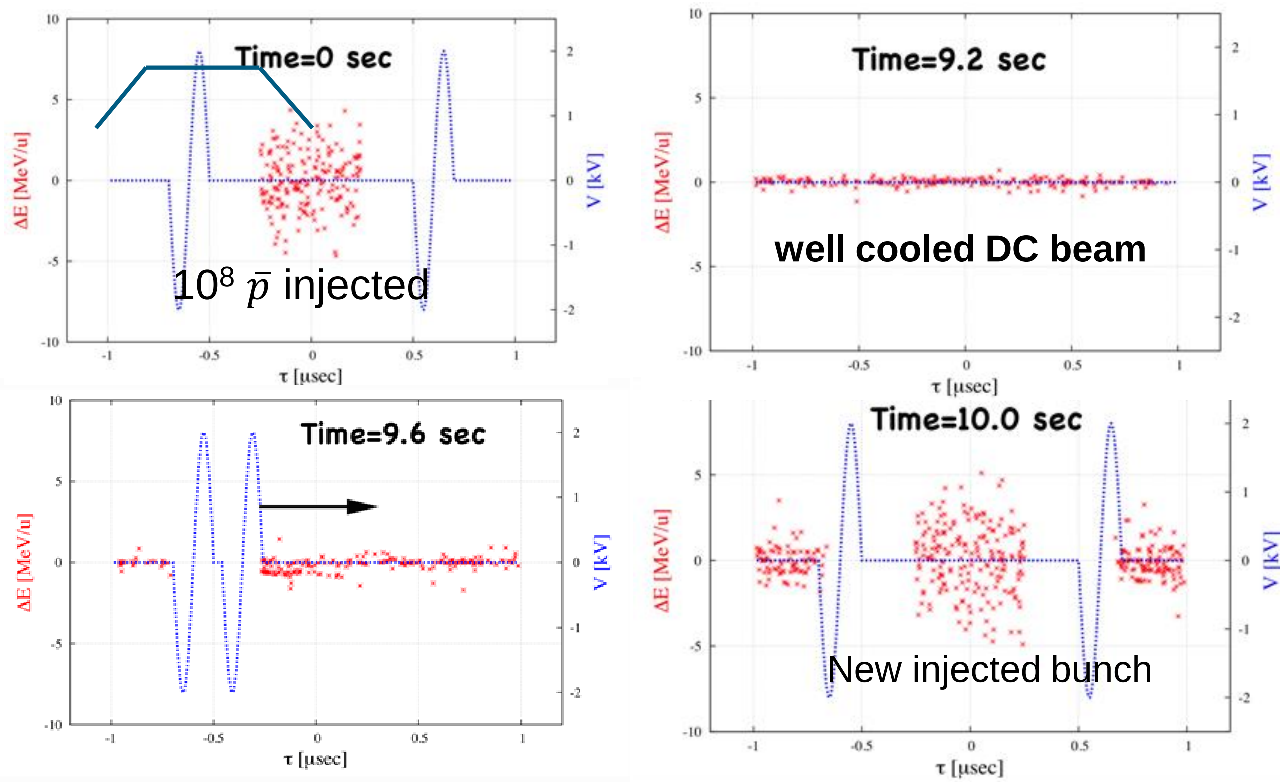
  - Heavy ion
    - Injection at 740 MeV/u
    - Energy compensation for internal target experiment up to 5 GeV/u

HESR Challenges:

high resolution and high luminosity for internal target operation

- Antiproton accumulation: direct injection from Collector Ring (CR)
  - Longitudinal stack with moving barrier bucket is favored over the conventional radial stacking technique (AD@CERN, FNAL)
    - Save space, and also eliminate the needs of dedicated cooling for injection as well as for stacking
    - PoP was demonstrated in SIS18@GSI [M. Steck et al, Cool'11]

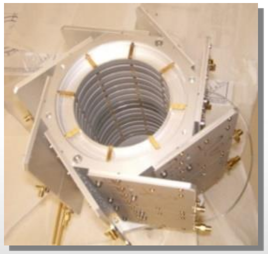
Schmatics of longitudinal stacking:
Simulation by T. Katayama



Courtesy of H. Stockhorst

HESR Challenges

HESR SC kicker tank

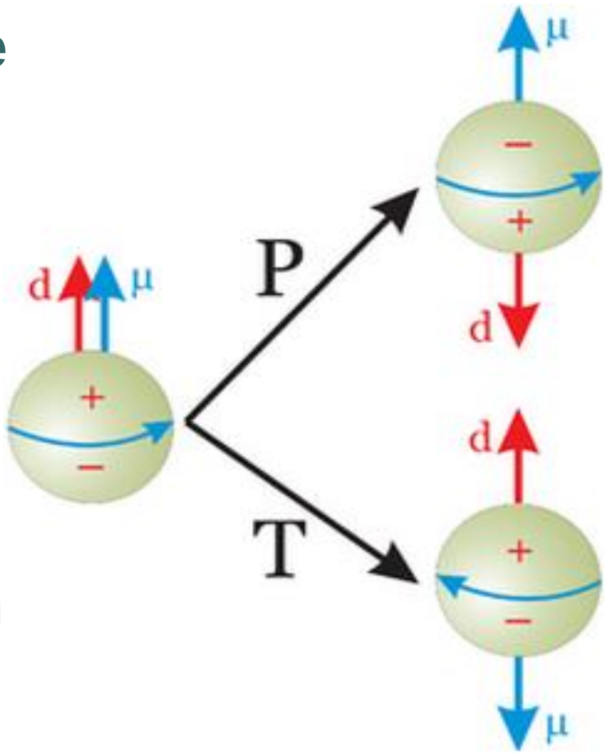


- Beam cooling
  - Stochastic cooling
    - Needs to cover entire energy range
    - compact design and large bandwidth
      - 2-4 GHz first
      - 4-6 GHz 2nd if necessary
    - High sensitivity with fixed aperture
  - High energy electron cooling
    - With conventional un-bunched electron beam cooling, 8 MeV electron beam is required to cover the energy range of HESR

EDM search at COSY

http://collaborations.fz-juelich.de/ikp/jedi/about/introduction.shtml

- What is EDM, and Why?
  - **Describes the separation of positive and negative charge inside a particle**
  - **It aligns along the spin axis of the particle, and violates both parity (P) and time reversal (T)**
  - **Hence, significant EDM measurement of fundamental particles is an effective probe of CP-violation, could be the key to explain the asymmetry between matter and antimatter**



More details in H. Stroeher, “precision Physics”, Plenary session I, and in Plenary session 5, as well as JEDI collaboration meeting

Member of the Helmholtz Association

Storage Ring based EDM challenges

- Long spin coherence time
- Fast polarimeter with high efficiency
  - Measure the spin buildup due to EDM signal
  - Spin manipulation
- Monitor/mitigate systematic fake EDM signals due to various sources of un-wanted fields
  - a radial magnetic field of $B_r = \frac{d}{\mu} E_r$ produces the same signal as radial E field of E_r
    - **Can be mitigated by CW-CCW rotating beams**
  - Requires not only state of the art of quality control of the magnetic/electric fields, but also high precision beam monitoring/control

COSY: ideal for EDM development

Long history of polarized beams

- Polarized protons and deuterons

Excellent beam cooling setups for spin manipulations

In-house expertise with international collaborations

- **J**uelich **E**lectric **D**ipole moment **I**nvestigation
- A number of impressive developments
  - >1000 sec spin coherence time has been achieved with polarized deuteron beam at momentum of 970MeV/c, pre-cooled (FZJ Annual Report 2015, Juel-4393)
  - High efficient polarimeter that allowed spin tune measurement with 10^{-10} precision (PRL 115, 094801, 2015)
  - Latest demonstration of real-time feedback on controlling spin direction

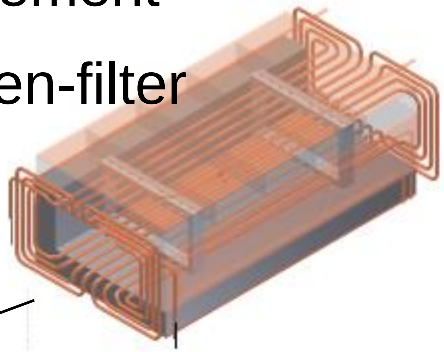
More details in the JEDI collaboration meeting

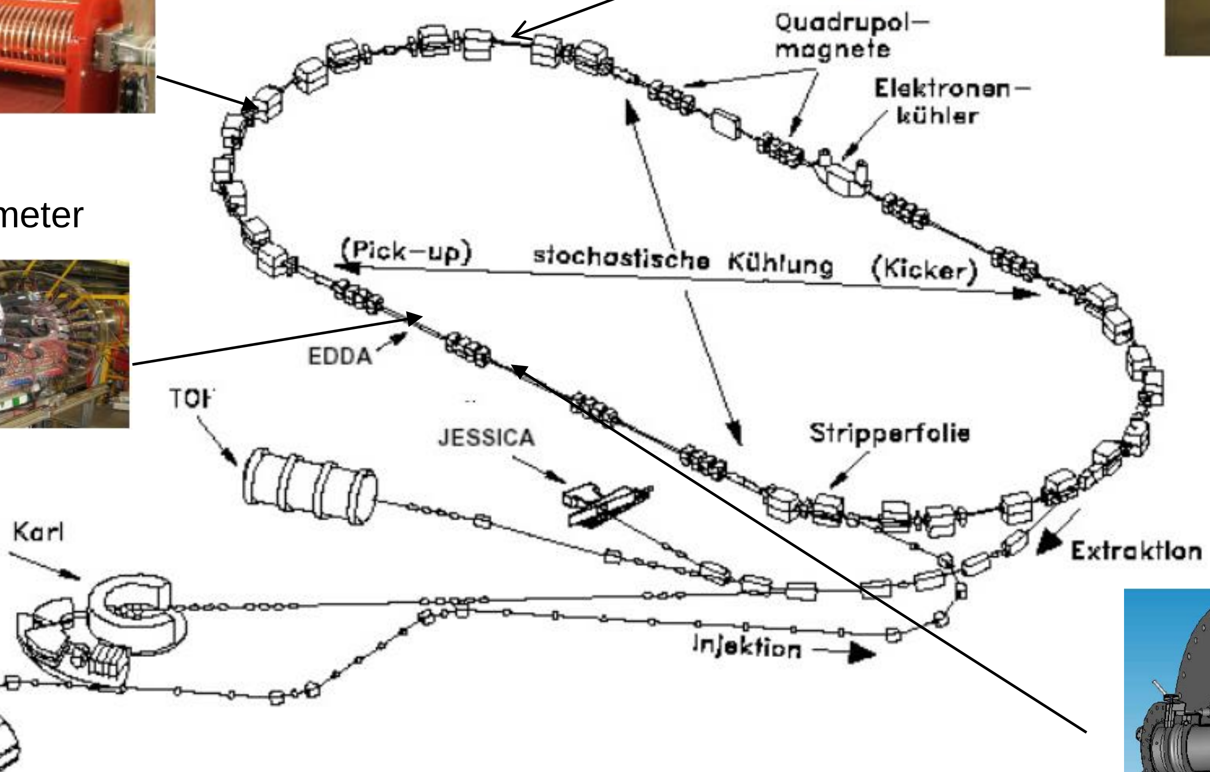
EDM precursor experiment @ COSY

- Direct deuteron EDM measurement
- Partial spin frozen with RF Wien-filter

RF solenoid

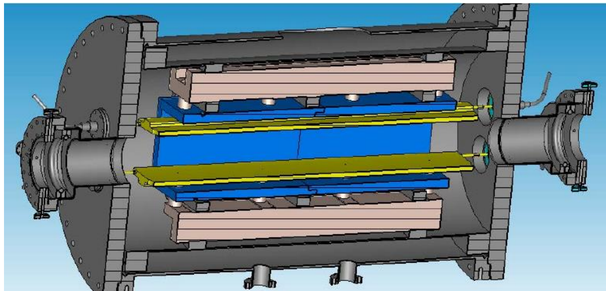
polarimeter





RF wien filter by
S. Mey and R. Gebel

RF wien filter by J. Slim,
A. Nass, F. Rathmann etc



Challenges with precursor

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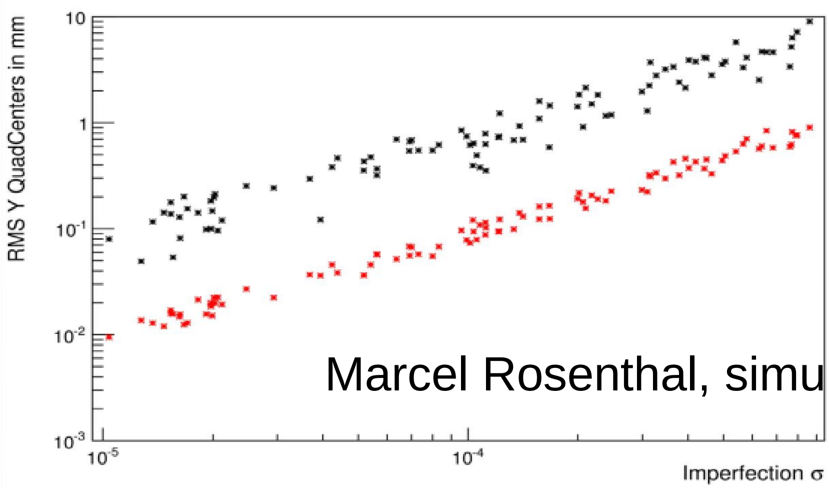
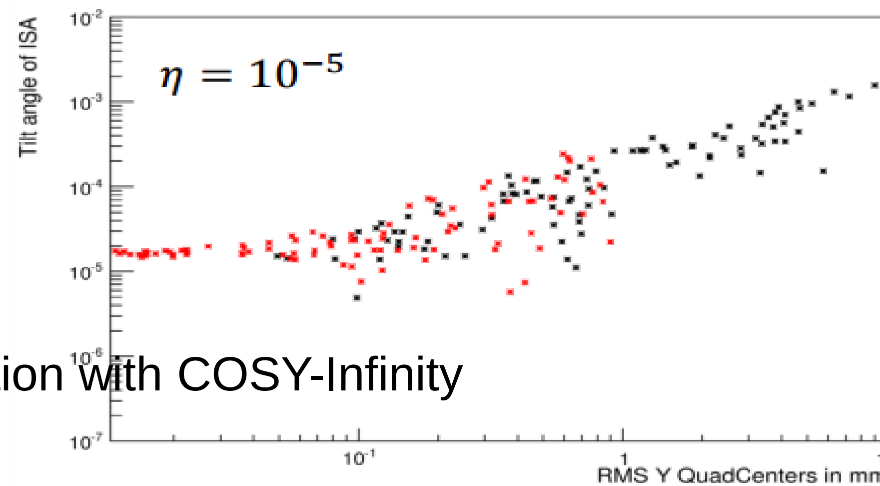
Imperfection of the machine tilts stable spin direction away from vertical. Excluding other systematics, rms c.o ~ 100 μm puts the precision limit ~ 5×10^{-18} e-cm

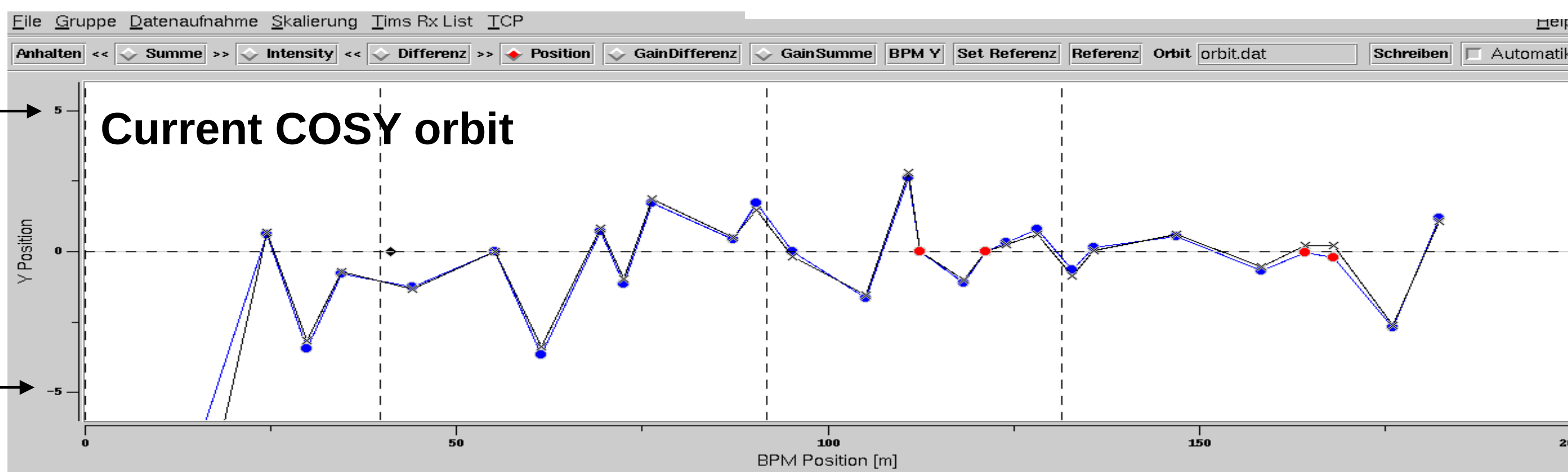




Marcel Rosenthal, simulation with COSY-Infinity

5mm

-5mm



Challenges with precursor

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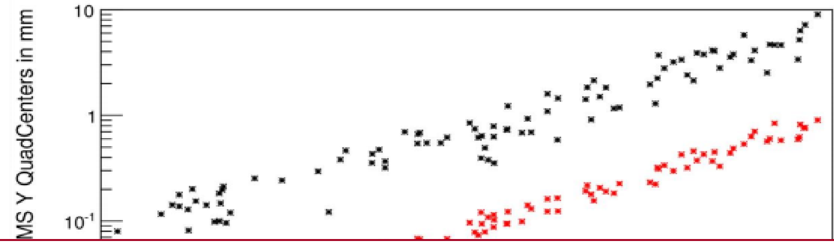
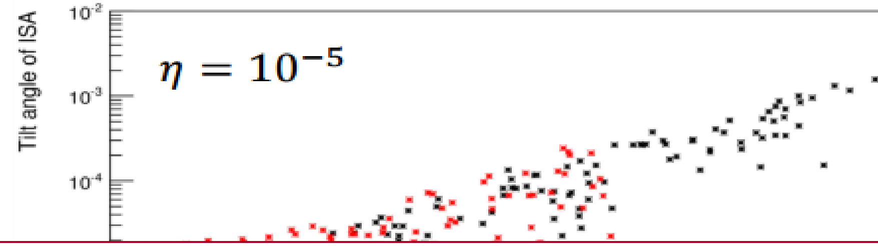
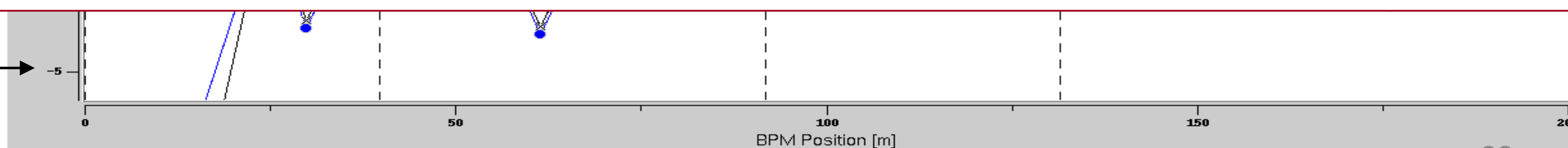


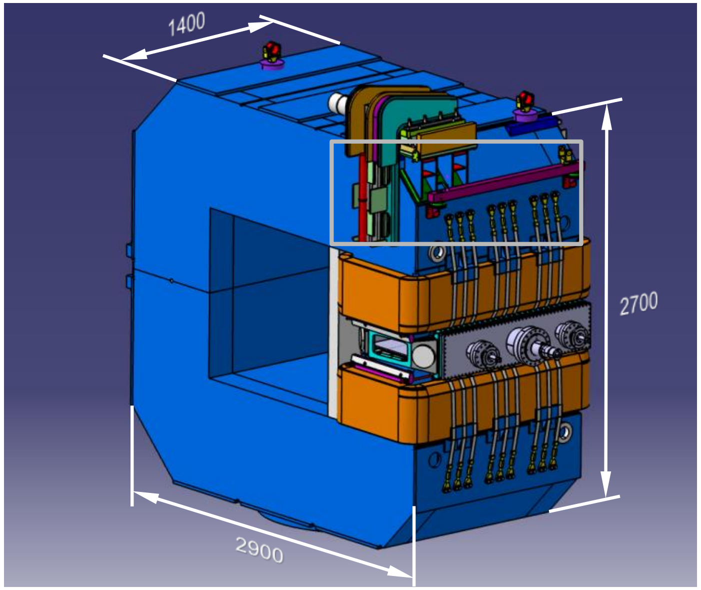


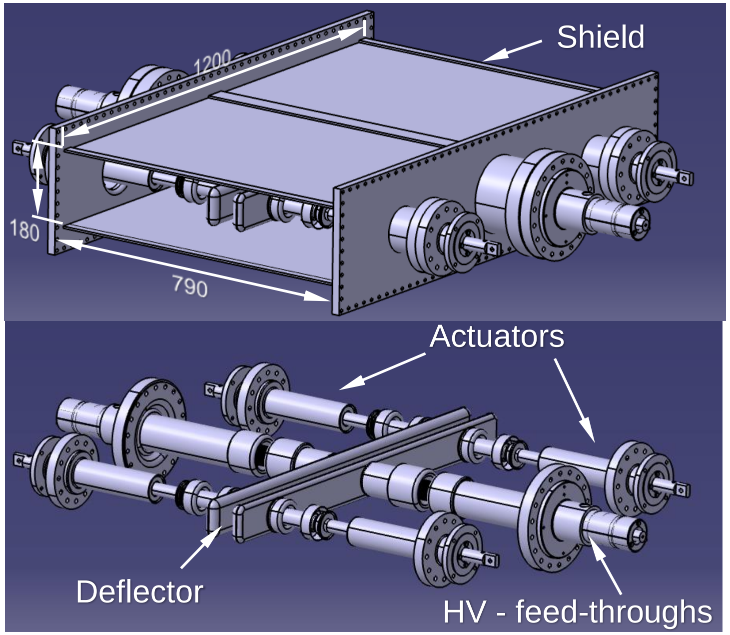
- Implemented automation of ORM data taking (F. Hinder, M. Simon)
- Implemented ORM based optics measurement (D. Ji [IHEP])
- COSY BPM upgrade are in working progress
  - In collaboration with cosylab. Stage 0 is to modernize orbit control and realize slow orbit feedback by the end of 2016
- ORM based COSY online model improvement (working progress)



ExB deflector

- Goal is to investigate/demonstrate the feasibility of ExB deflector for spin frozen storage ring with E~8MV/m and B~0.3 Tesla
- Test setup using existing ANKE-D2 magnet together with electrostatic plates to study the effect of magnetic field on the E field strength
- Prototype the ExB deflector

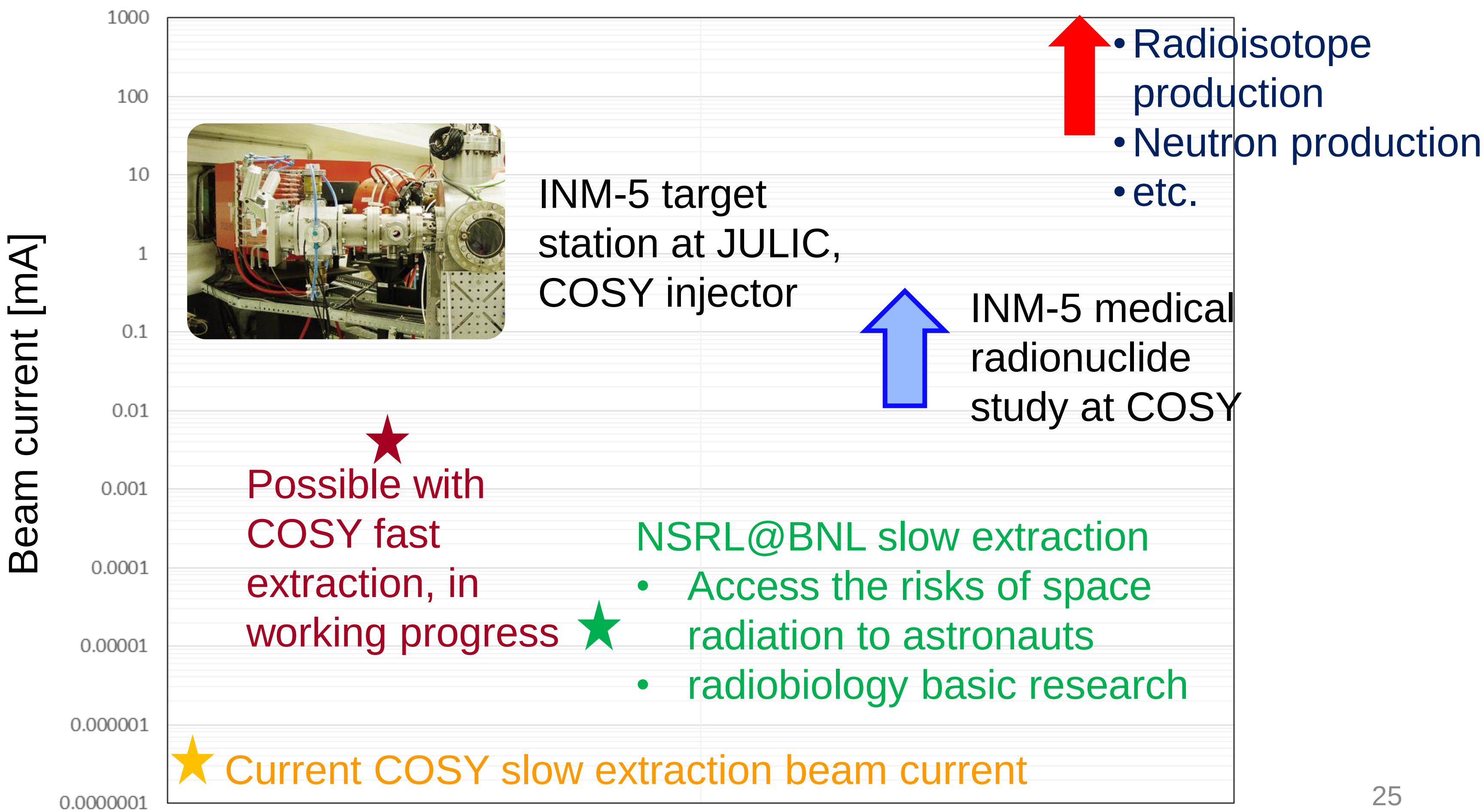




More details in J. Boeker's presentation in JEDI collaboration meeting

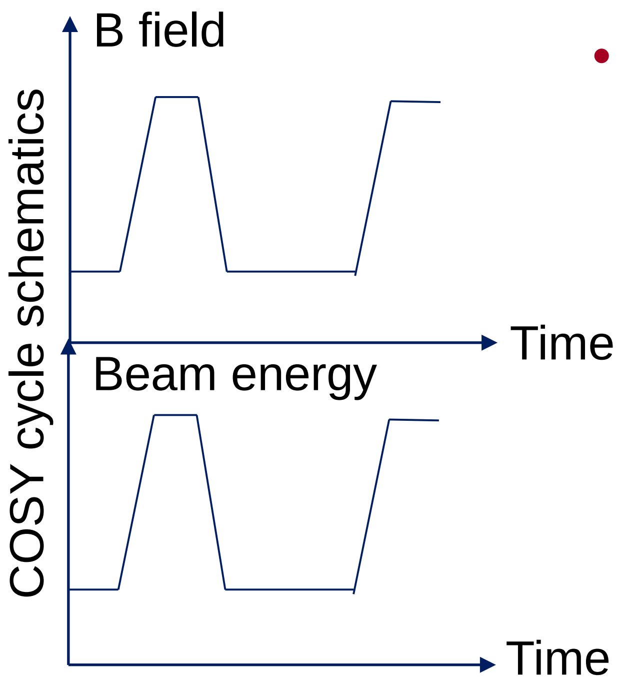
Extending COSY Capability

- ~100 MeV – 2 GeV light ion beams have been applied in a variety of fields ranging from nuclear medicine, radiobiology, hadron therapy and industrial applicaitons
- A dedicated kickoff meeting was held to explore the potential interests



nA extraction beam current development

- **Approach for higher extraction beam current**
  - Increase the beam intensity
    - Improve injection efficiency
    - Improve RF capture efficiency
  - Run COSY faster
    - Currently achieved 4 sec cycle with 1 sec extraction

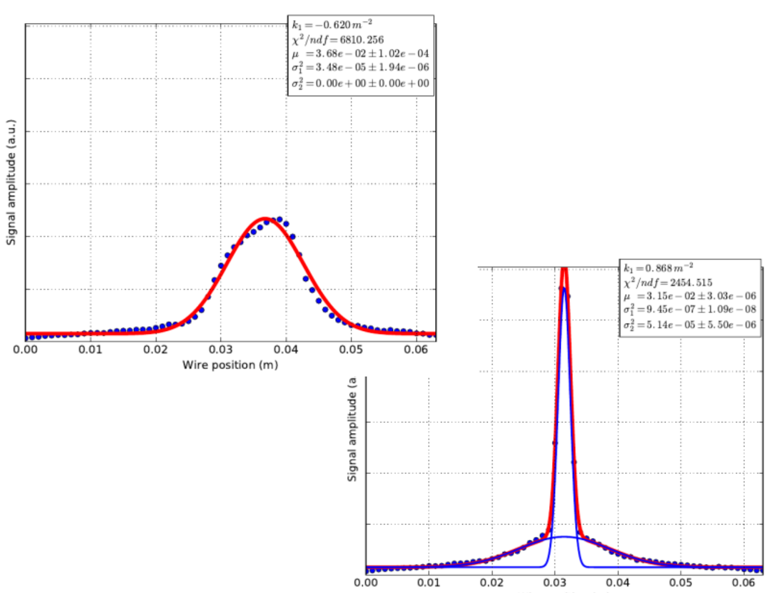


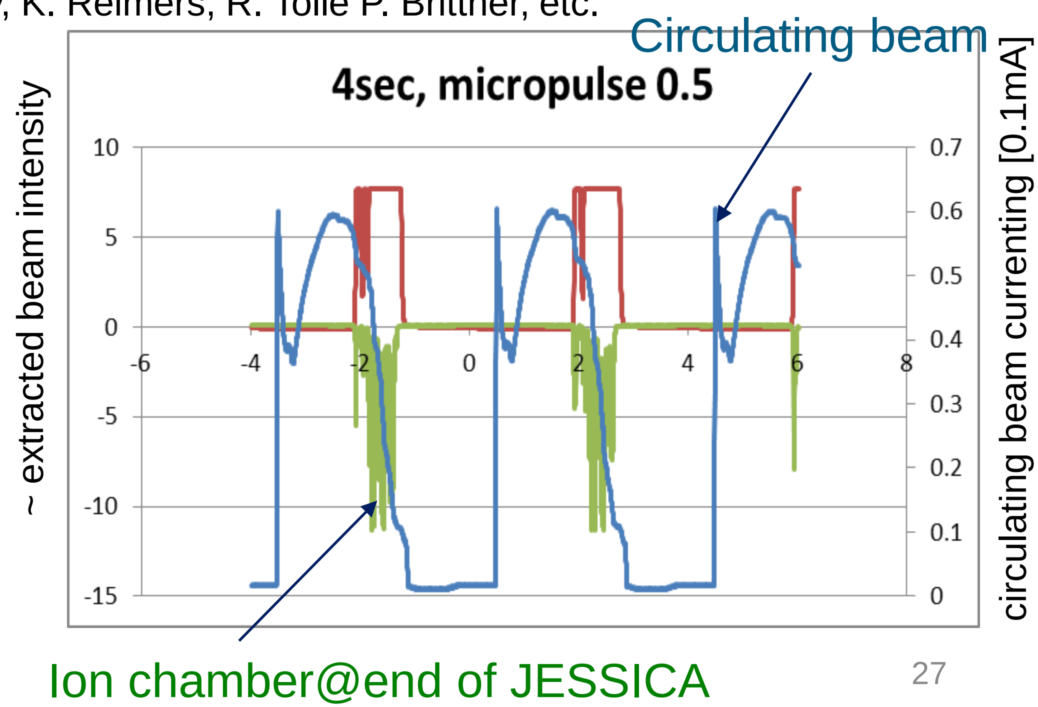
- **Approach for improving beam quality**
  - Beam line optics improvement
    - Beam based optics measurement
    - Optics model improvement based on beam measurements

Current status

- ~ 2nA extraction current with 4 sec cycle with 1 sec extraction
- JESSICA optics was also measured and analyzed
  - Beam emittance ~ 1 π and 5 π mm-mrad in horizontal and vertical, respectively
  - Its optics model is benchmarked and improved
  - Options for further improvement of beam quality control were explored, and plan to be studied/implemented

B. Lorentz, R. Gebel, Y. Dutheil, V. Kamerdzhiev, K. Reimers, R. Tolle P. Brittner, etc.





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Summary

- COSY served nuclear physics as the working horse for over two decades with outstanding physics[1], as well as many excellent PhD students

  [1] C. Wilkin et al, The legacy of the Experimental Hadron Physics program at COSY, EPJ Review, to be submitted

- It has been evolved to a test bed for detector as well as accelerator development, and has become a facility for the precision frontier physics experiments
  - EDM precursor experiment, **T**ime-**R**eversal **I**nvariance at **C**OSY, **P**olarized **A**ntiproton e**X**periment

- Together with the colleagues from other institutes, the accelerator group is also investing its efforts in
  - COSY upgrade for EDM precursor experiment
  - Developing key technologies for dedicated EDM storage ring, together with JEDI
  - Expanding COSY capability for multidisciplinary science research