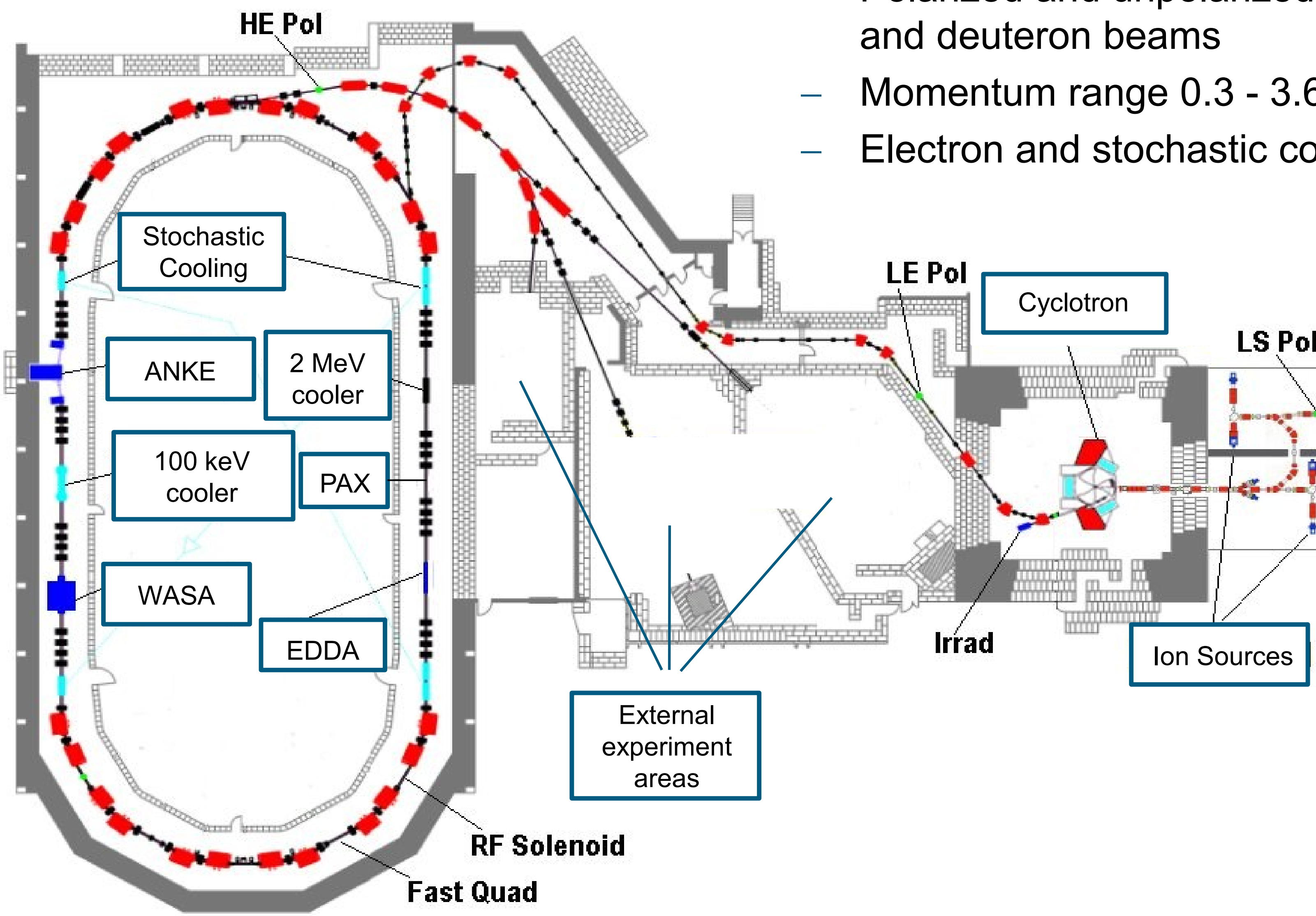
COSY
injection and tuning

Workshop on Beam Dynamics and Control studies at COSY

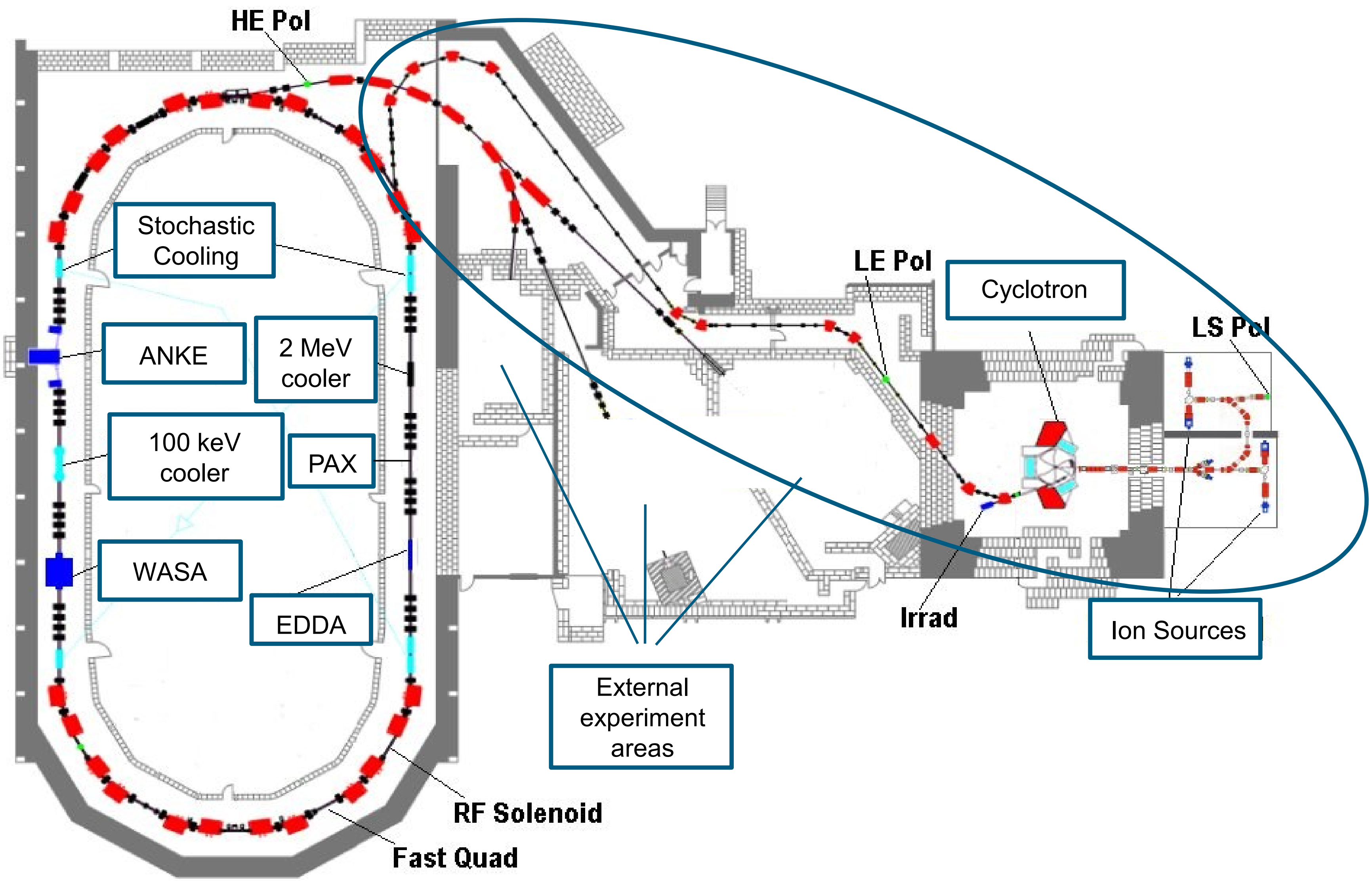
November 18, 2016 | C. Weidemann

COSY facility



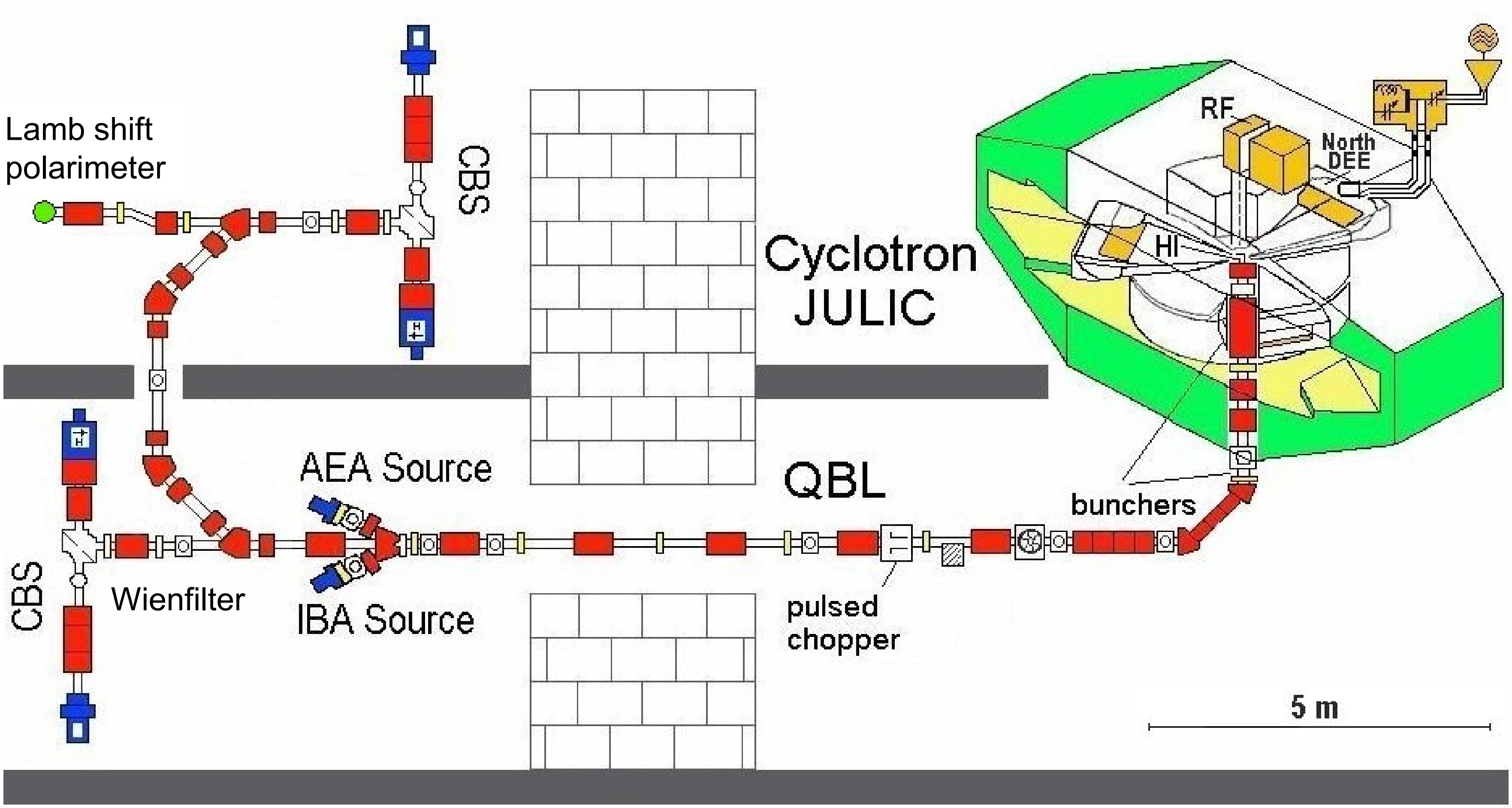
- Polarized and unpolarized proton and deuteron beams
- Momentum range 0.3 - 3.65 GeV/c
- Electron and stochastic cooling

COSY facility



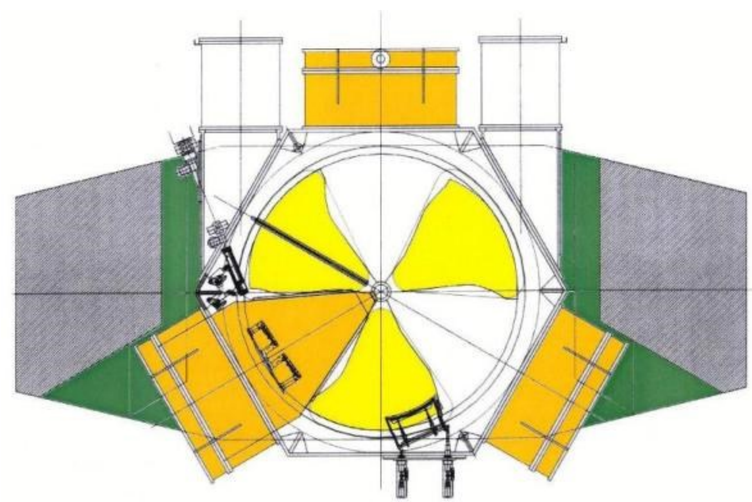
COSY - source and cyclotron

- 4.5 keV/u from source
- 45 MeV (proton), 76 MeV (deuteron) from cyclotron



COSY - cyclotron JULIC

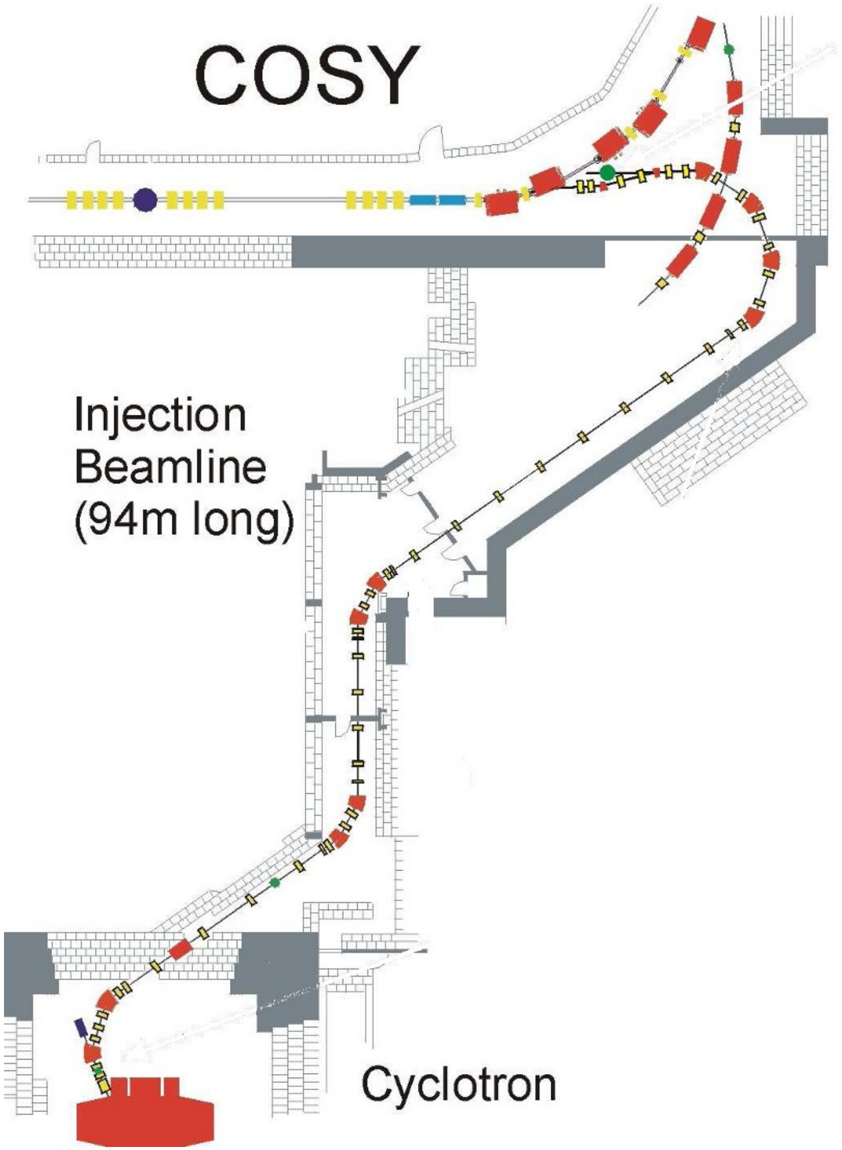
AEG design
Request for quote: 1961
First internal beam: 1968
Upgrade for COSY: 1990
Pole diameter 3.3 m / 700 t iron
$\langle B \rangle_{max}$ =1.35 T B_{hill} = 1.97 T
20 – 30 MHz (h=3)
22.5-45 MeV/A
2-4.5 keV/A injection
3 ion sources (2 multicusp +pol. CBS)



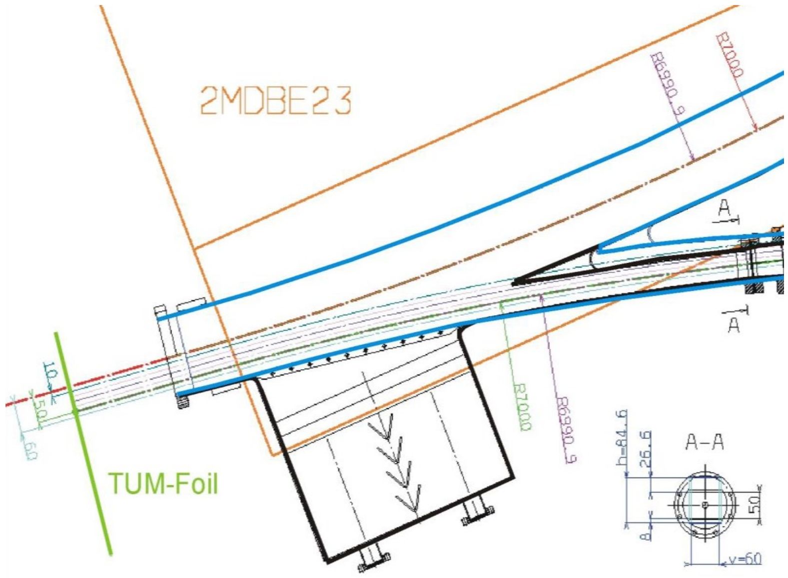
45 MeV H^- and 76 MeV D^- for COSY with 20 ms stripping injection/cycle

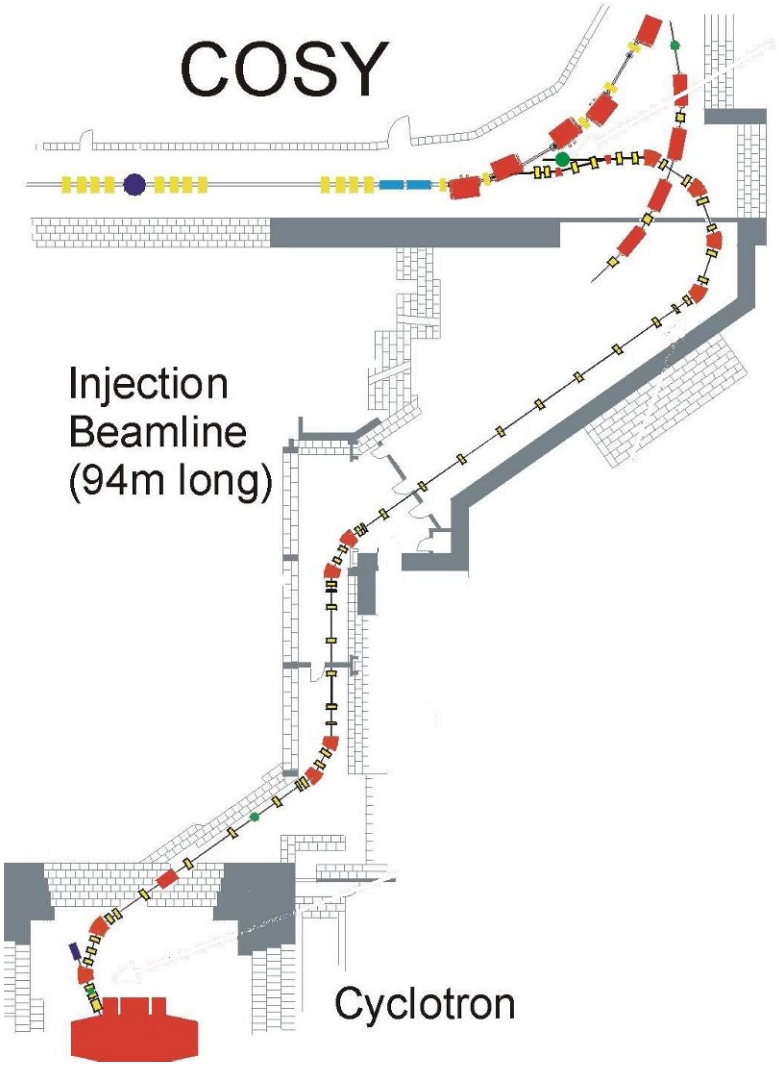
COSY - injection beam line

- Transfer line from cyclotron to COSY
- 45 MeV protons or 76 MeV deuterons
- 5 bent and 6 straight sections (l = 94 m)
- 30 mm vertical offset
- Typical beam current: 10 µA
  ($\sim 10^{11}$particles in COSY)
- $\sim 95\%$ transmission from cyclotron exit to COSY entrance



COSY - injection



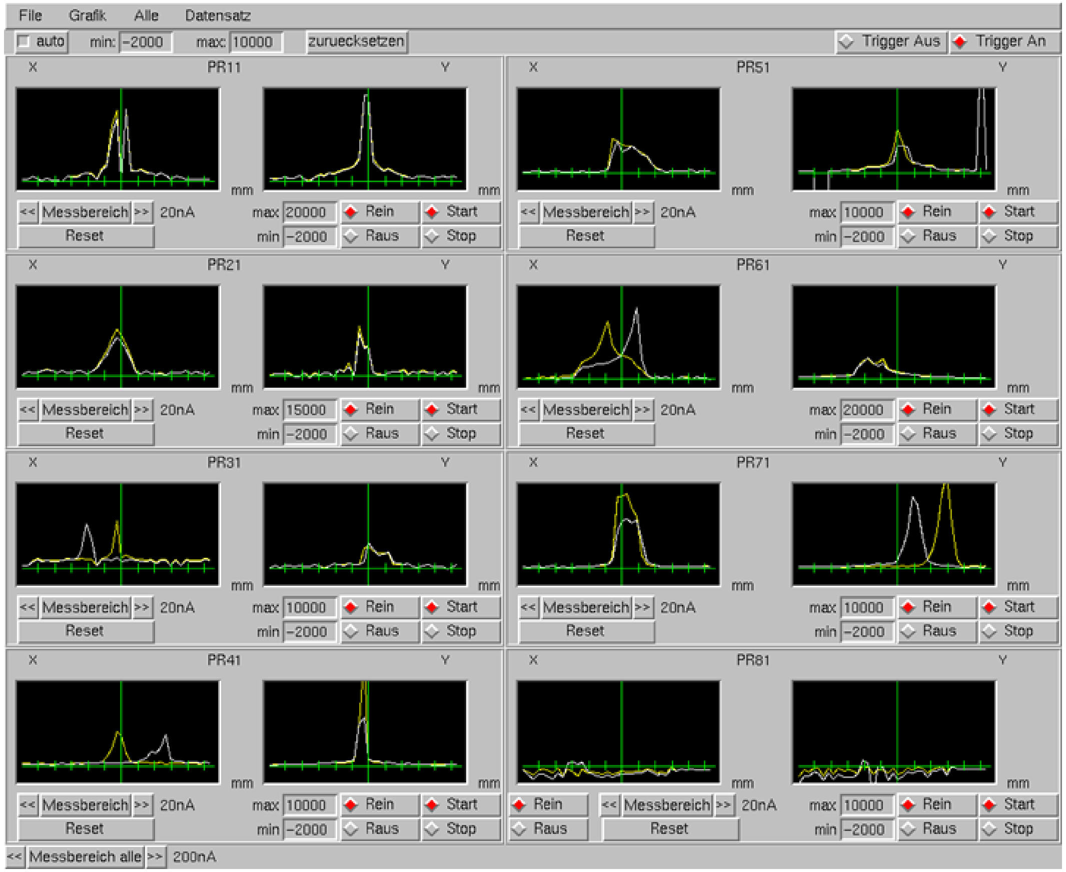


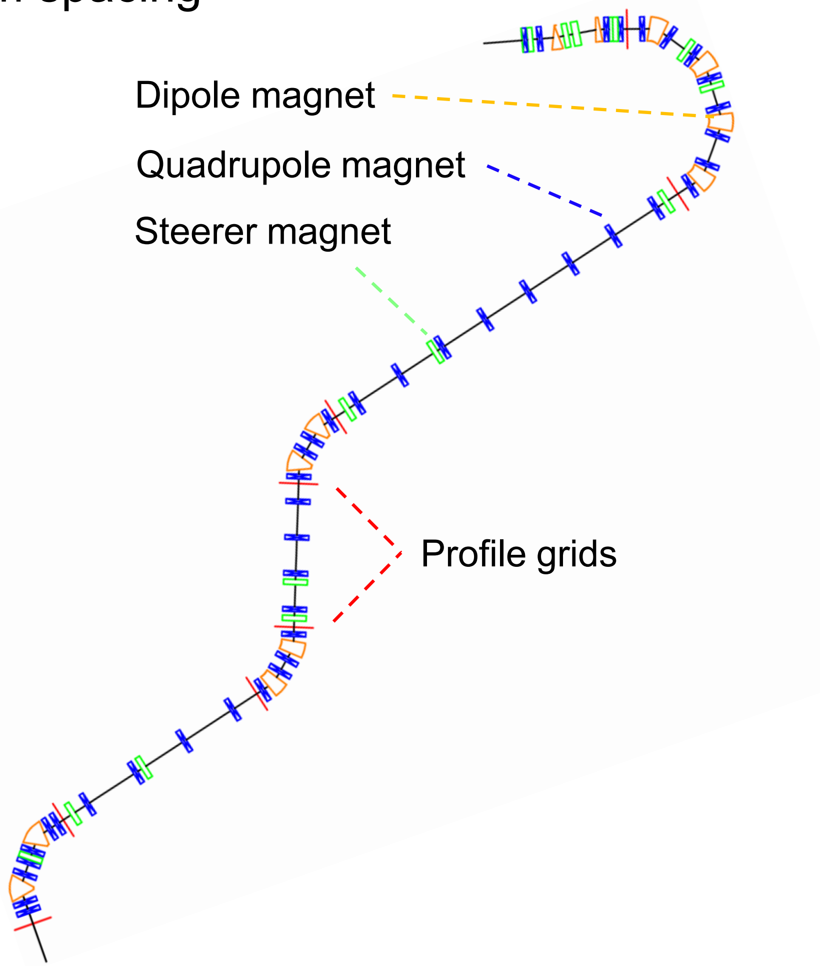
- Stripping injection of H^-
- 3 fast ramping bumper magnets in COSY move orbit on the stripping foil
- Injection onto „distorted orbit“
- Reduction of injection bump within 20 ms

COSY - injection beam line

Diagnostics

– 8 Profile grids (harps): 39 wires (x, y) , 1 mm spacing

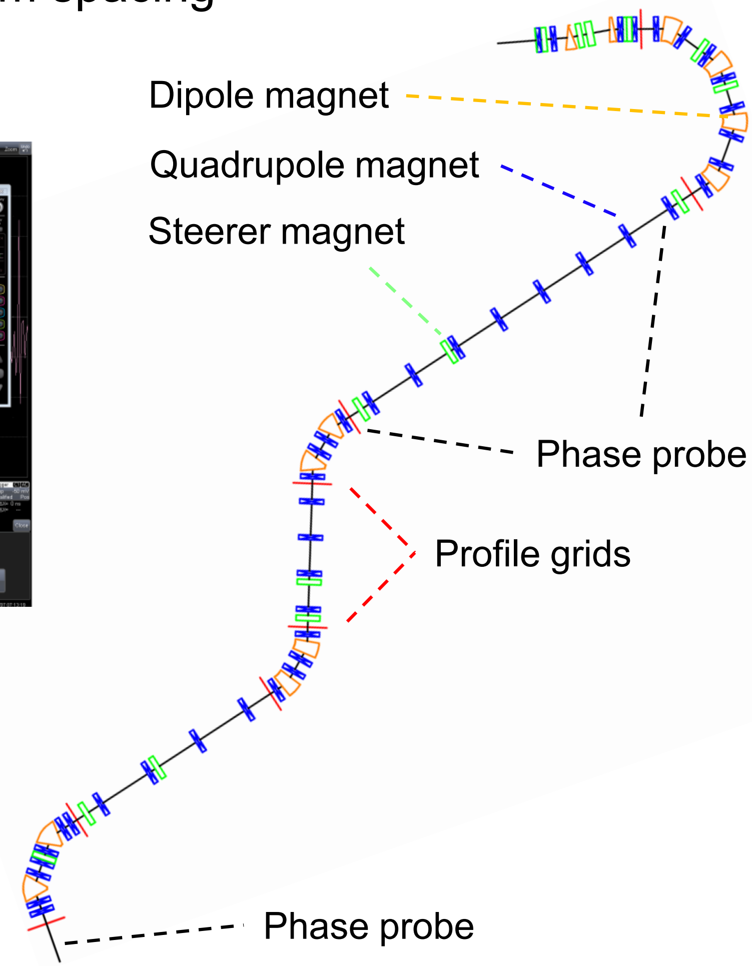




COSY - injection beam line

Diagnostics

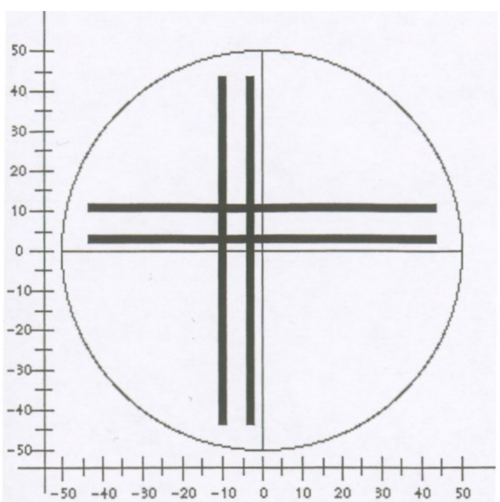
- 8 Profile grids (harps): 39 wires (x, y) , 1 mm spacing
- 3 Phase probes for energy determination

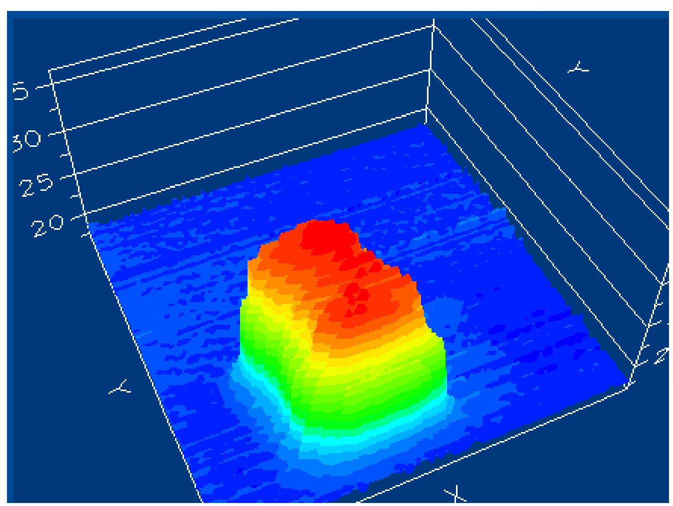


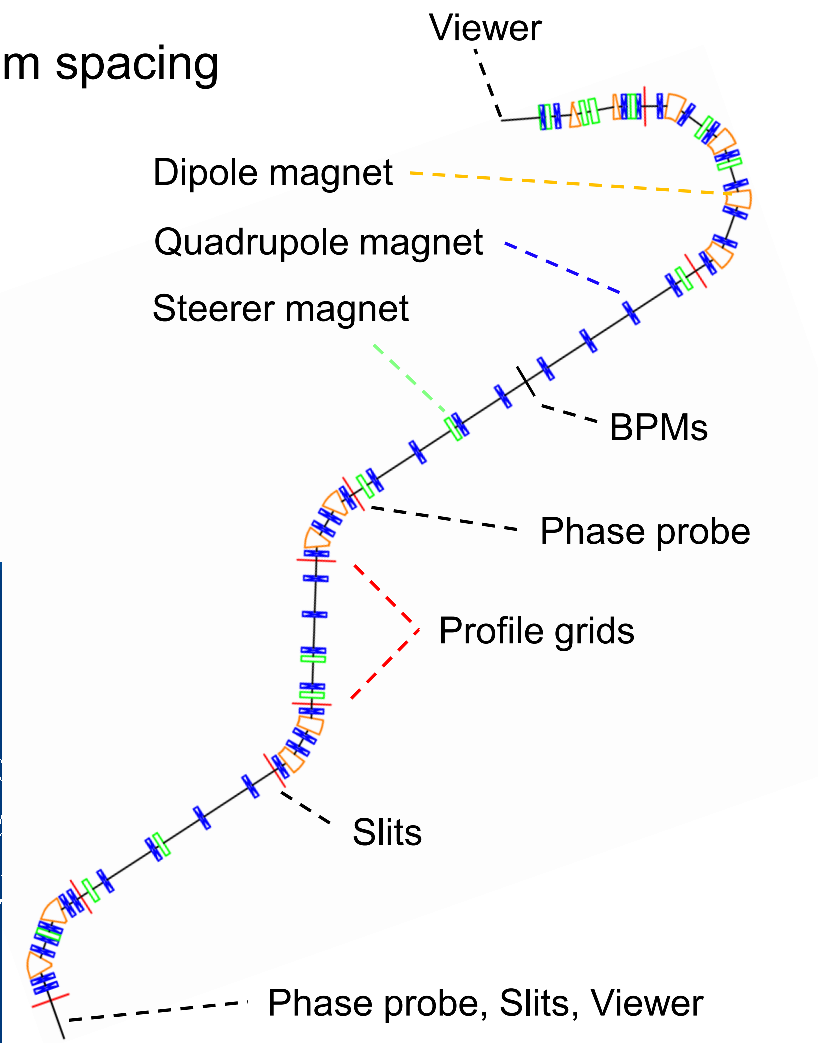
COSY - injection beam line

Diagnostics

- 8 Profile grids (harps): 39 wires (x, y) , 1 mm spacing
- 3 Phase probes for energy determination
- 2 BPMs, 5 Viewers
- Ionisation chambers, Bragg peak chamber
- Radiographic films
- 2 Systems of horizontal and vertical slits
- Polarimeter







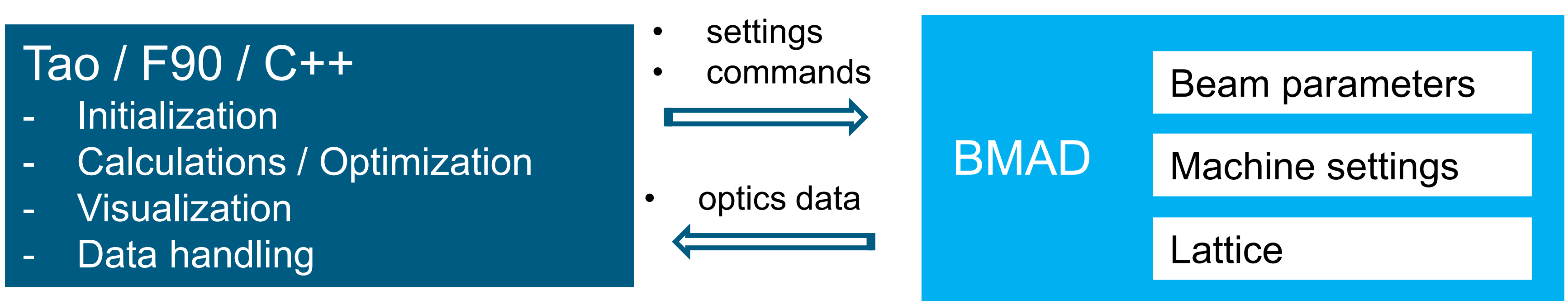
IBL modeling

BMAD http://www.lepp.cornell.edu/~dcs/bmad/

- Bmad is an object oriented, open source, subroutine library for relativistic charged-particle dynamics simulations in accelerators and storage rings
- Includes various tracking algorithms like Runge-Kutta and symplectic integration.
- Bmad has routines for calculating transfer matrices, emittances, Twiss parameters, dispersion, coupling, etc.

TAO

- Tao is a general purpose simulation program, based upon Bmad
- Can be used to view lattices, do Twiss and orbit calculations, nonlinear optimization on lattices, etc., etc.

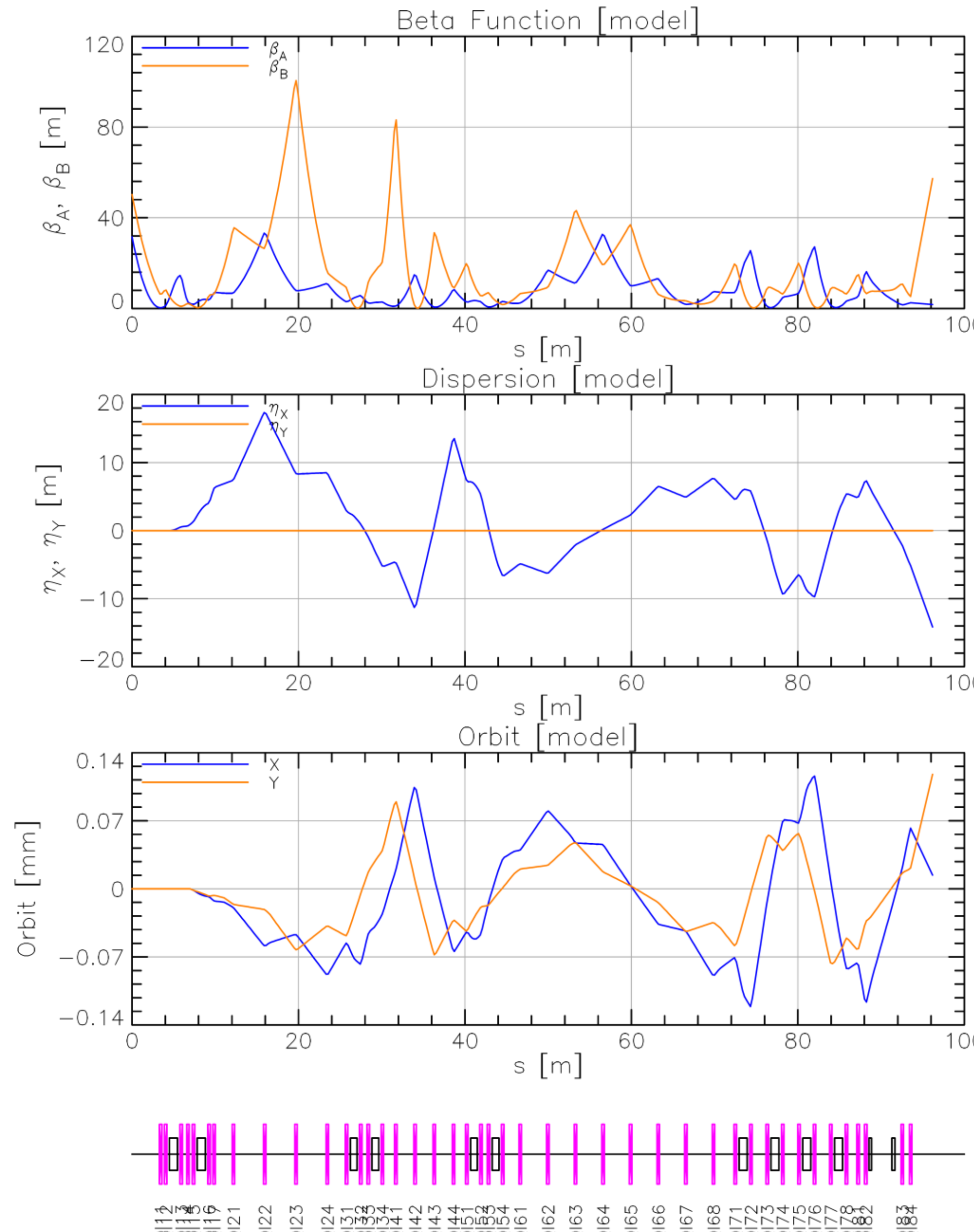


IBL modeling

Data

- Betatron amplitude
- Phase advance
- Dispersion
- Orbit
- Coupling
- …

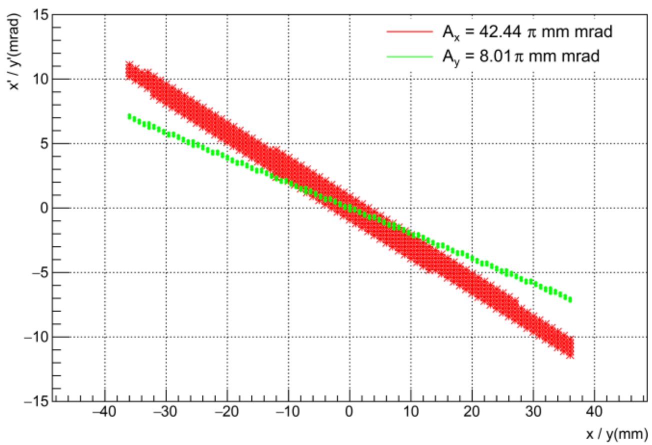
Data_ Type	*Description*	Source
alpha.a, alpha.b	Normal-Mode alpha function	lat
apparent_emit.x, apparent_emit.y	Apparent emittance	beam, lat
beta.a, beta.b, beta.c	Normal-mode beta function	beam, lat
beta.x, beta.y beta.z	Projected beta function	beam, lat
bpm_orbit.x, bpm_orbit.y	Measured orbit	lat
bpm_phase.a, bpm_phase.b	Measured betatron phase	lat
bpm_eta.x, bpm_eta.y	Measured dispersion	lat
bpm_k.22a, bpm_k.12a, bpm_k.11b, bpm_k.12b	Measured coupling	lat
bpm_cbar.22a, bpm_cbar.12a, bpm_cbar.11b, bpm_cbar.12b	Measured coupling	lat
c_mat.11, c_mat.12, c_mat.21, c_mat.22	Coupling	lat
cbar.11, cbar.12, cbar.21, cbar.22	Coupling	lat
chrom.dtune.a, chrom.dtune.b	Chromaticities for a ring	lat
chrom.dbeta.a, chrom.dbeta.b	Normalized Chromatic beta beats $(1/\beta_{a,b})\partial\beta_{a,b}/\partial\delta$	lat
chrom.dphi.a, chrom.dphi.b	Chromatic phase deviations $\partial\phi_{a,b}/\partial\delta$	lat
chrom.deta.x, chrom.deta.y	Second order dispersions $\partial\eta_{x,y}/\partial\delta$	lat
chrom.detap.x, chrom.detap.y	Second order dispersion slopes $\partial\eta'_{x,y}/\partial\delta$	lat
damp.j_a, damp.j_b, damp.j_z	Damping partition number	lat
dpx_dx, dpx_dy, etc.	Bunch <x px> / <x^2> & Etc...	beam
e_tot	Beam total energy (eV)	lat
element_attrib.<attrib_name>	lattice element attribute	lat
emit.a, emit.b, emit.c	Emittance	beam, lat
eta.x, eta.y, eta.z	Lab Frame dispersion	beam, lat
eta.a, eta.b	Normal-mode dispersion	beam, lat
etap.x, etap.y	Lab Frame dispersion derivative	beam, lat
etap.a, etap.b	Normal-mode dispersion derivative	beam, lat
expression: <arithmetic expression>	See the text	lat
floor.x, floor.y, floor.z, floor.theta, floor.phi, floor.psi	Global (“floor”) position	lat
gamma.a, gamma.b	Normal-mode gamma function	lat



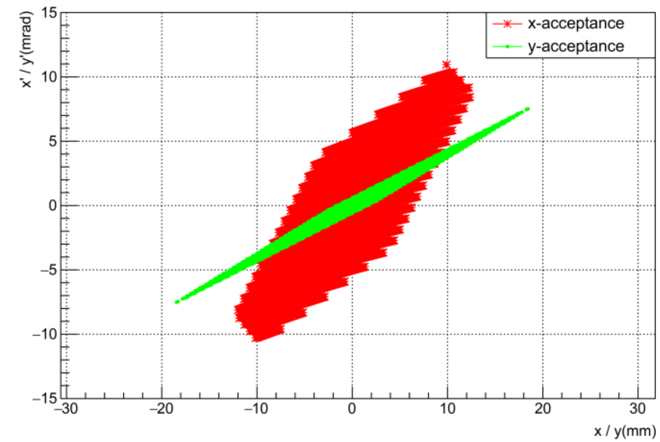
Tracking

IBL Tracking of particles for a wide range of starting parameters (x, y, px, py)

Acceptance

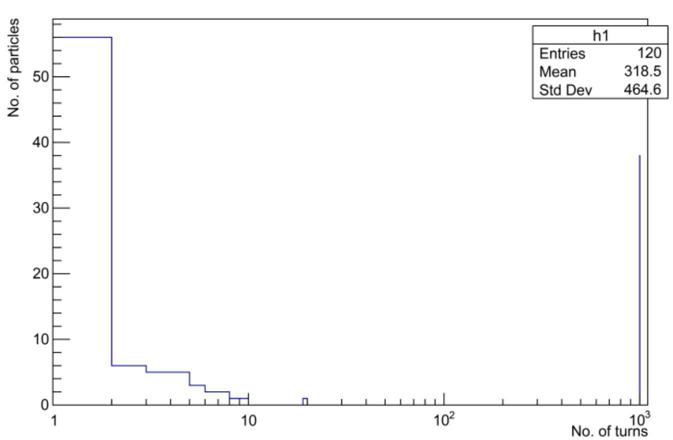


Phase space at IBL exit

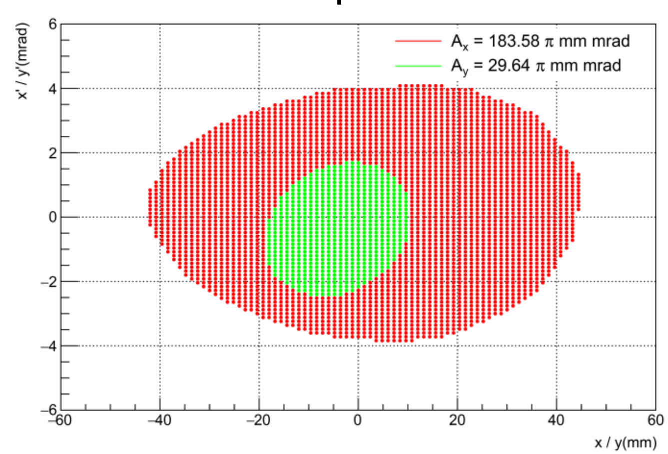


COSY Multi-turn tracking (for 1000 turn → 50 turns)

Turn survival

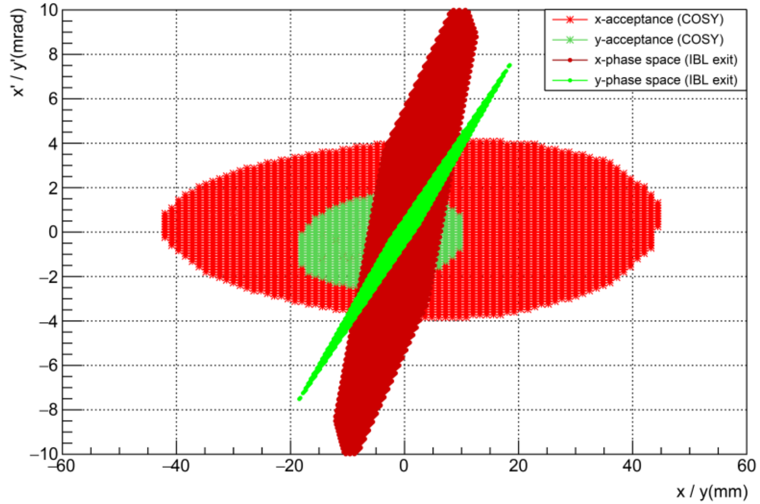


Acceptance



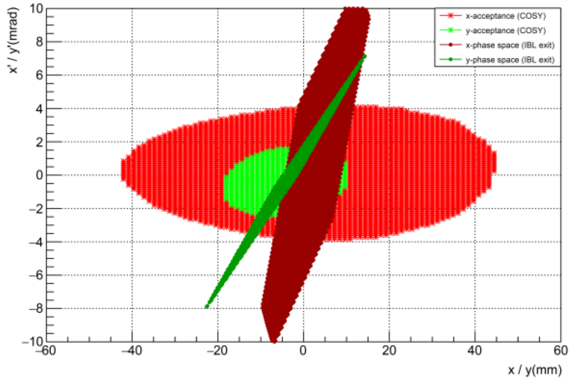
Tracking

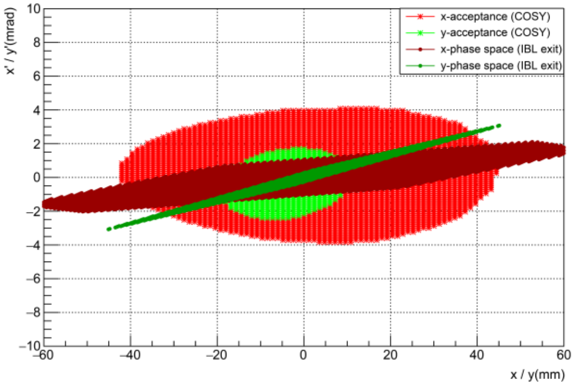
Phase space at IBL exit and COSY acceptance



Improve injection efficiency

- Optimize overlap of IBL phase space and COSY acceptance
- Identify „knobs“ for e.g. transverse shifts of the beam at inj. foil
- COSY settings (injection bump, e-cooler beam) to match IBL

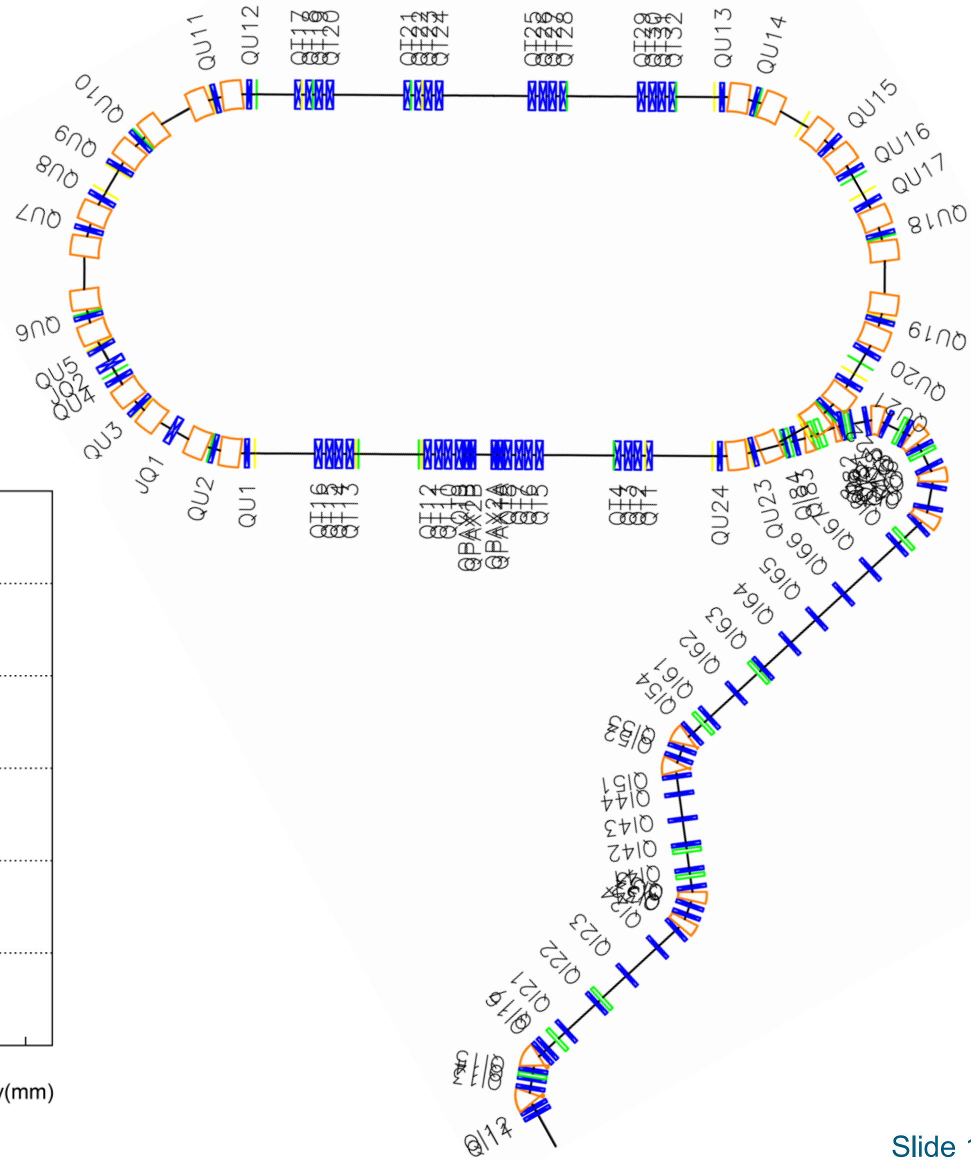




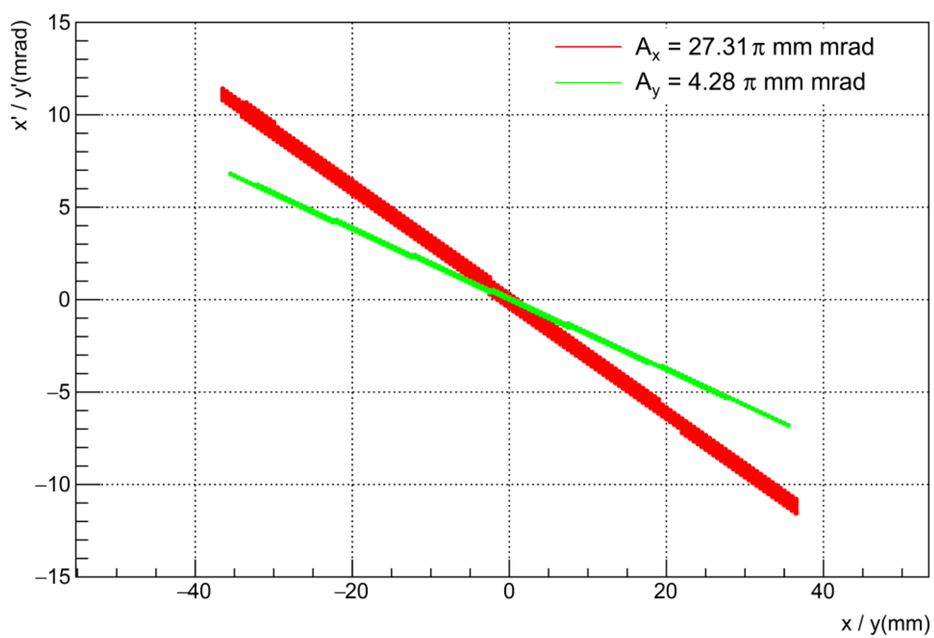
Tracking

Combined tracking using BMAD

- Connect IBL to COSY



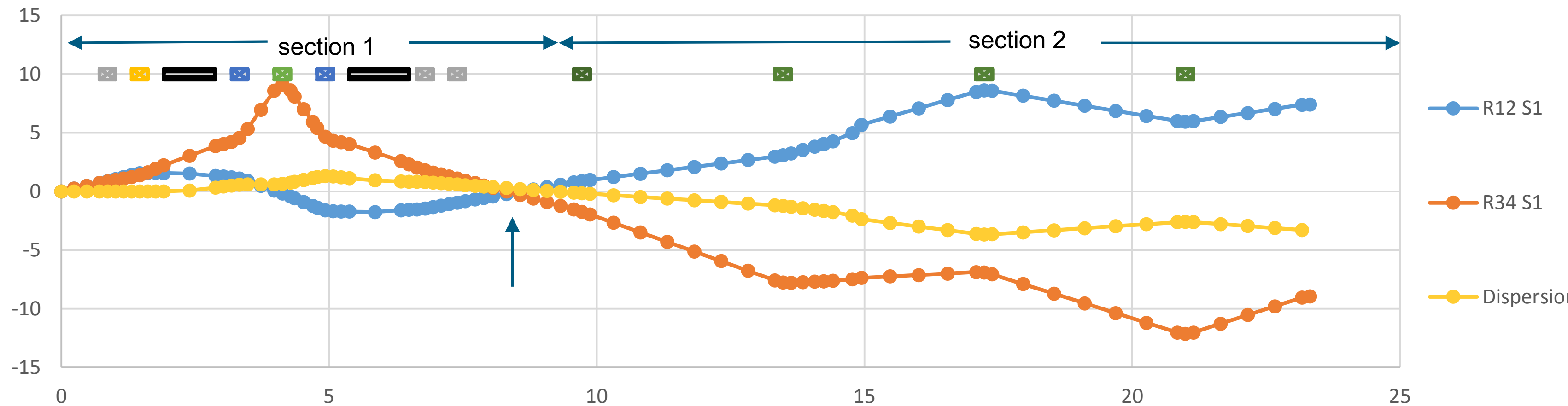
Combined acceptance



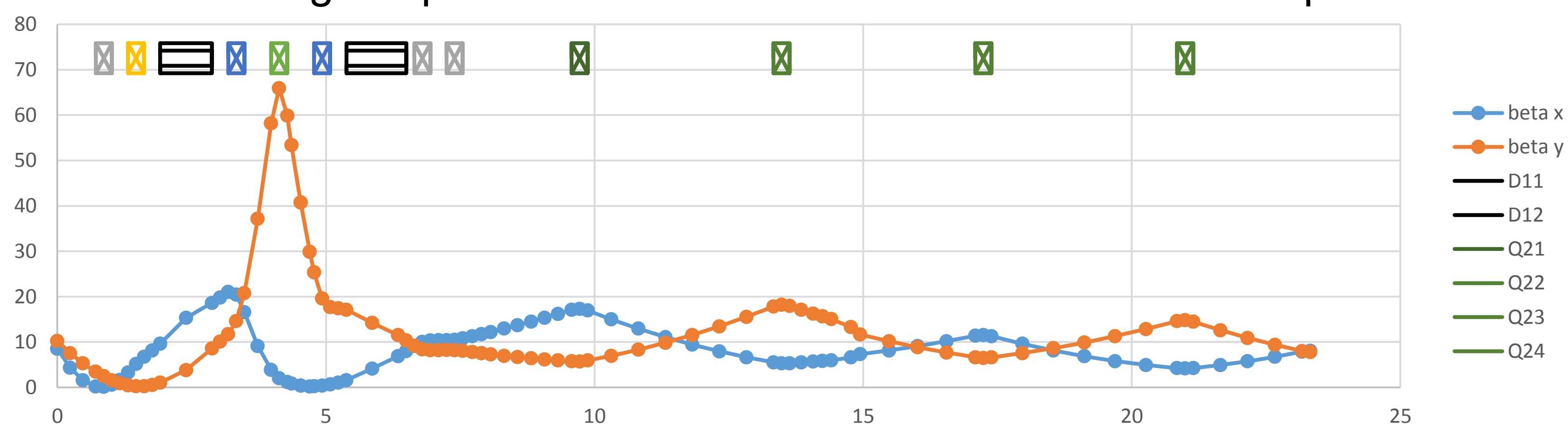
IBL modeling

Transport Excel (Sig Martin)

- Match section 1 to be achromatic (D = 0) at exit



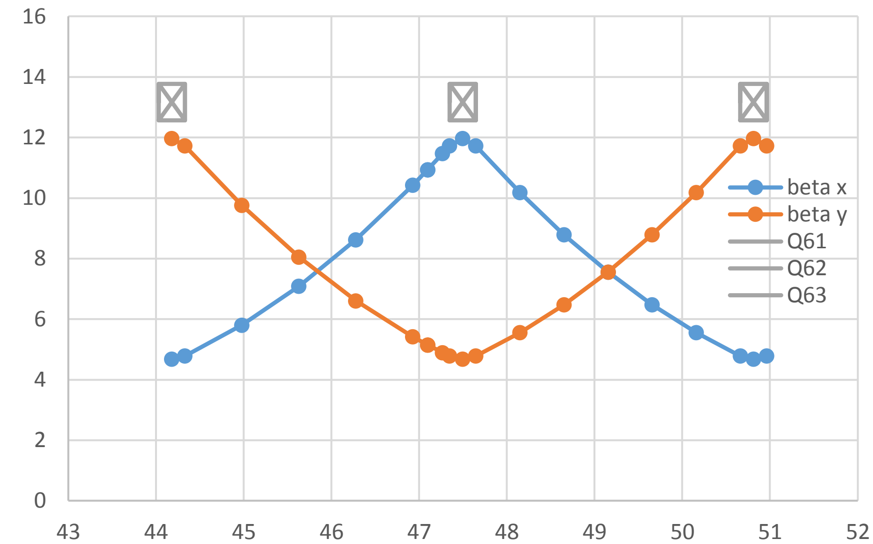
- Fit settings of section 2 for FODO structure (large β-function)
- Perfect matching not possible due to different distances between quads



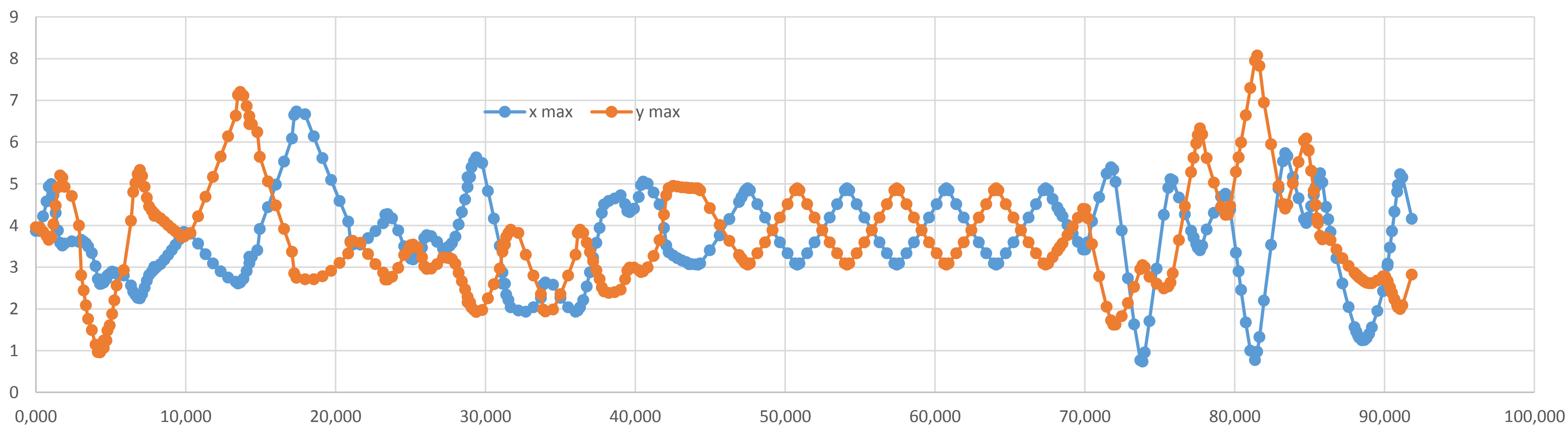
IBL modeling

<u>Transport Excel</u> (Sig Martin)

- Fit settings of section 6 for FODO:
  - β-functions in Q61 and Q63
  - $\alpha_x = \alpha_y = 0$ in all quads
- New quadrupole settings can be used for particle tracking



Beam sizes along IBL



Summary and Outlook

Status:

- Injection beam line model + COSY model are set up in BMAD
- Combined tracking is working
- Many diagnostic tools available and working
- Profile measurements taken

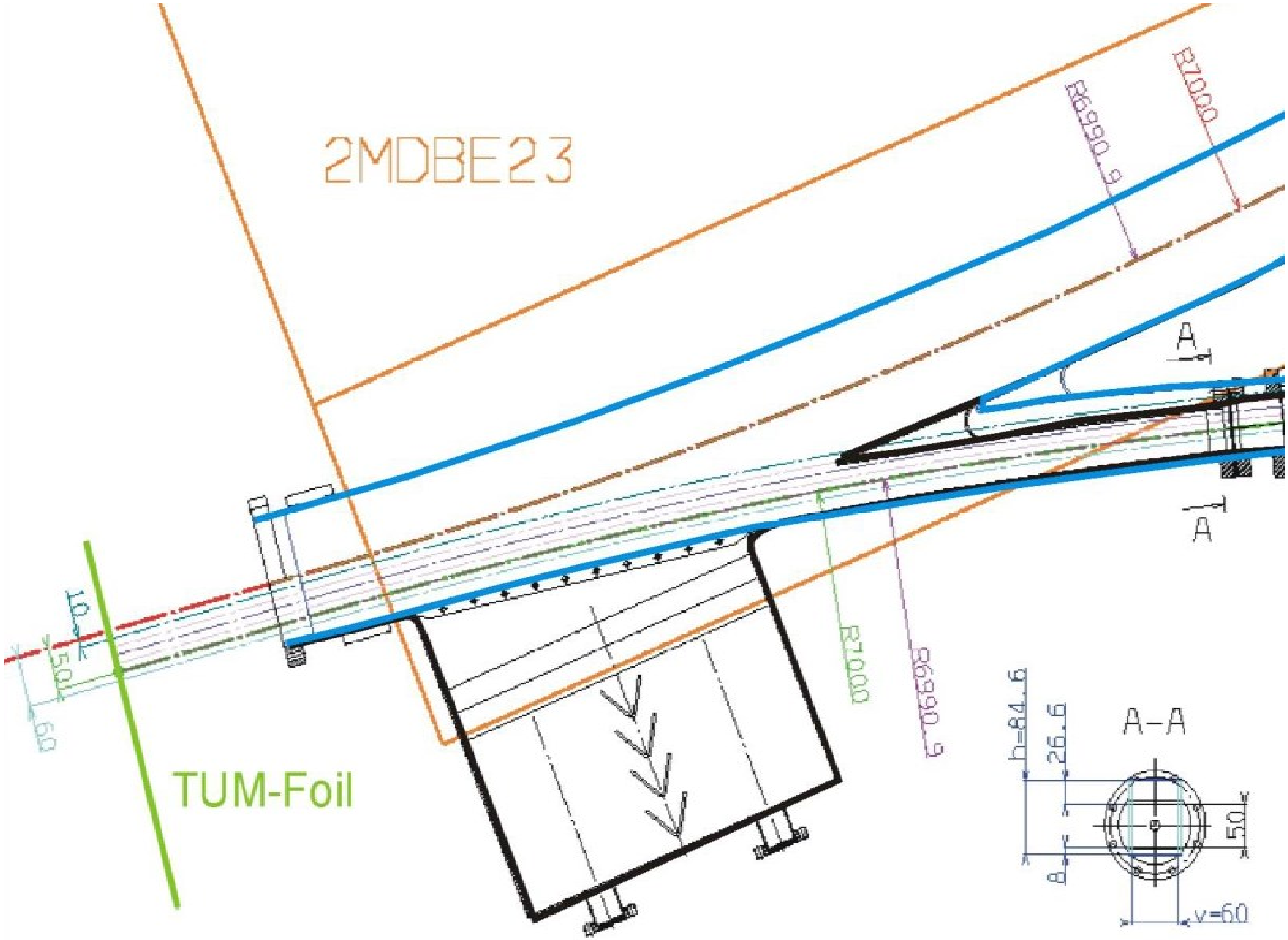
Plan:

- Analysis of profile grid data (k-modulation, spot scanning)
- Improve model for better agreement with measurements
- Insert documentation data (positions, calibration factors)
- Implement final dipole magnet correctly (Analyze existing floating wire measurements)
- Determine tools for better matching of injection into COSY
- Adjust COSY settings (injection bump, orbit, e-cooler beam) to match IBL

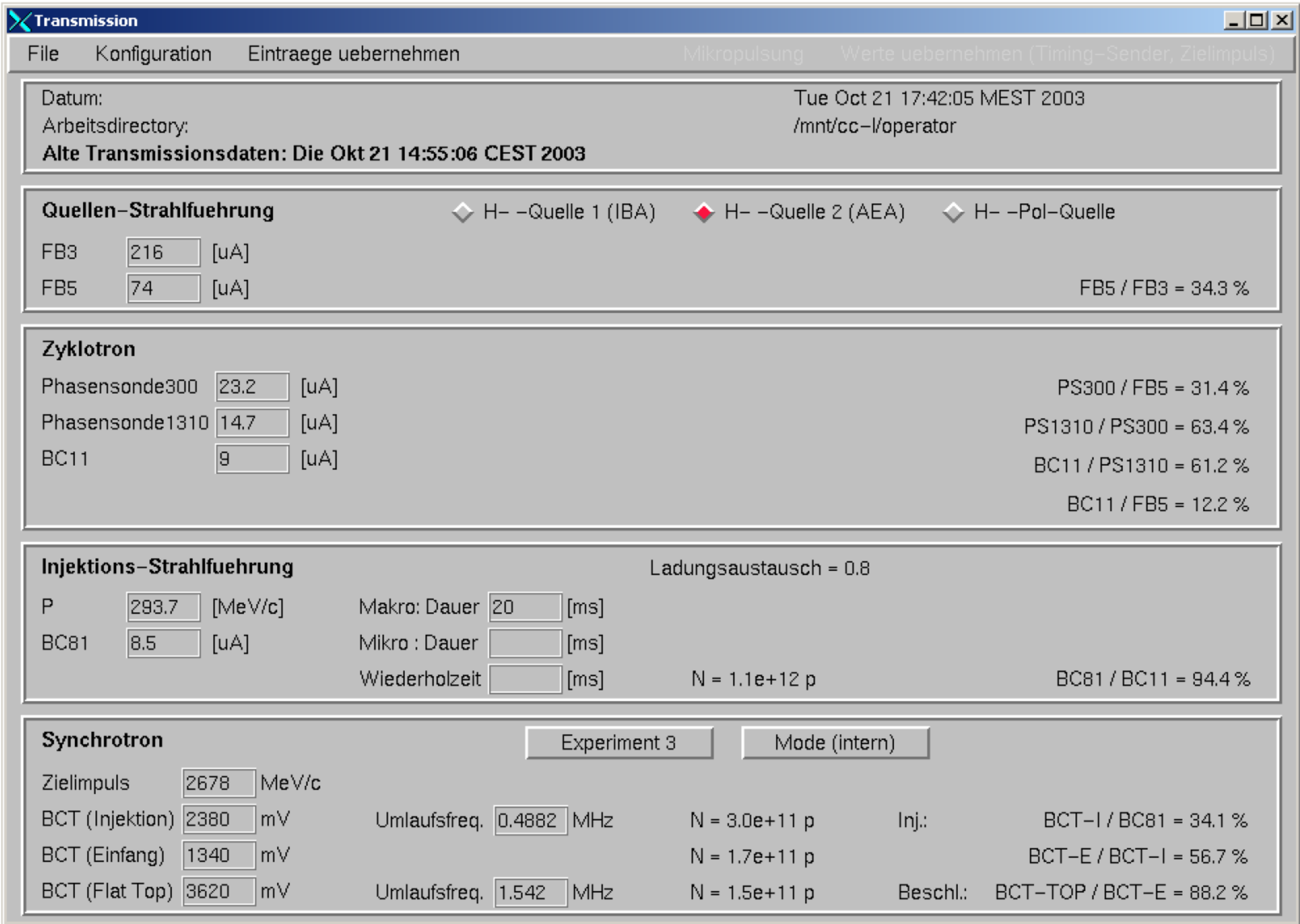
Thanks to R. Gebel, S. Martin, J. Stein for information and support

Spare slides

Spare slides

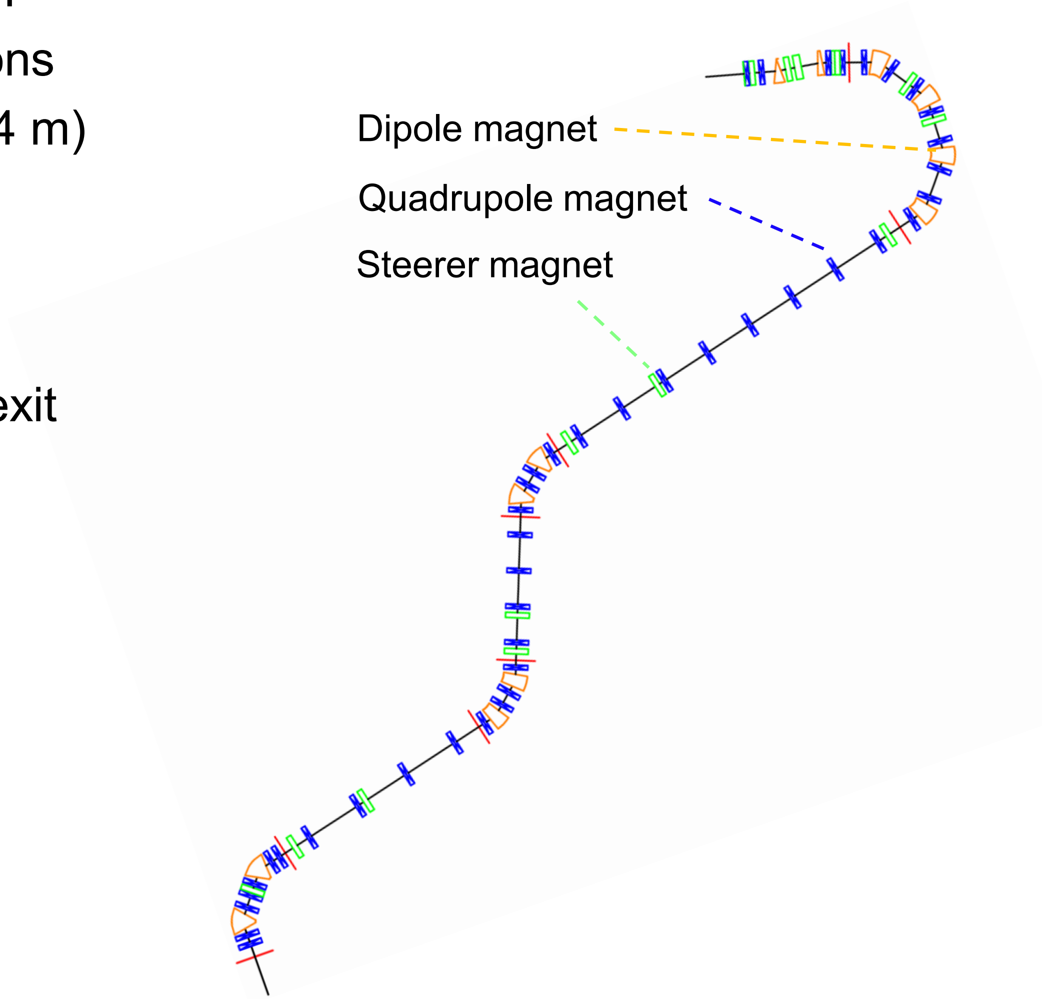


Transmission through IBL



COSY - injection beam line

- Transfer line from cyclotron to COSY
- 45 MeV protons or 76 MeV deuterons
- 5 bent and 6 straight sections (l = 94 m)
- 30 mm vertical offset
- Typical beam current: 10 μA ($\sim 10^{11}$ particles in COSY)
- $\sim 95\%$ transmission from cyclotron exit to COSY entrance



COSY – injection beam line

MAD-8 (Methodical Accelerator Design)

- Currently used tool for “online” modeling
- Loading of present machine parameters for direct optics improvement
- MAD is a general-purpose tool for charged-particle optics design and studies in alternating-gradient accelerators and beam lines.
- The MAD scripting language is de facto the standard to describe particle accelerators, simulate beam dynamics and optimize beam optics

MAD-X (http://madx.web.cern.ch/madx/)

- Actual version of MAD: presently used for “offline” modeling
- Version controlled model
- Model can be generated using COSY Database

Other

- Transport, Turtle
- 3D-field solver with particle trace (CST, COMSOL, GPT,..)

Software

BMAD http://www.lepp.cornell.edu/~dcs/bmad/

- Bmad is an object oriented, open source, subroutine library for relativistic charged-particle dynamics simulations in accelerators and storage rings
- Includes various tracking algorithms like Runge-Kutta and symplectic integration.
- Bmad has routines for calculating transfer matrices, emittances, Twiss parameters, dispersion, coupling, etc.

TAO

- Tao is a general purpose simulation program, based upon Bmad
- Can be used to view lattices, do Twiss and orbit calculations, nonlinear optimization on lattices, etc., etc.