

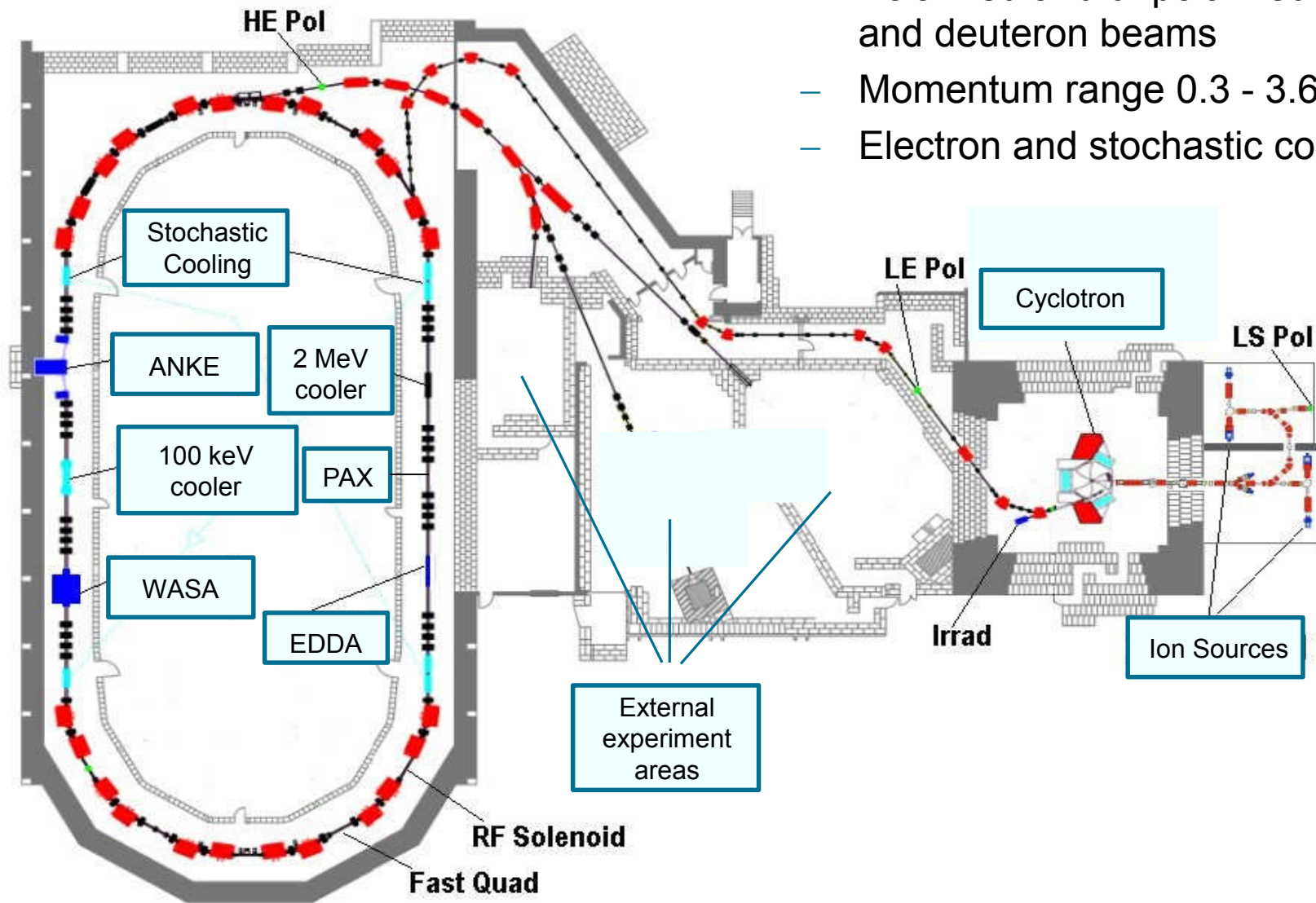
COSY

injection and tuning

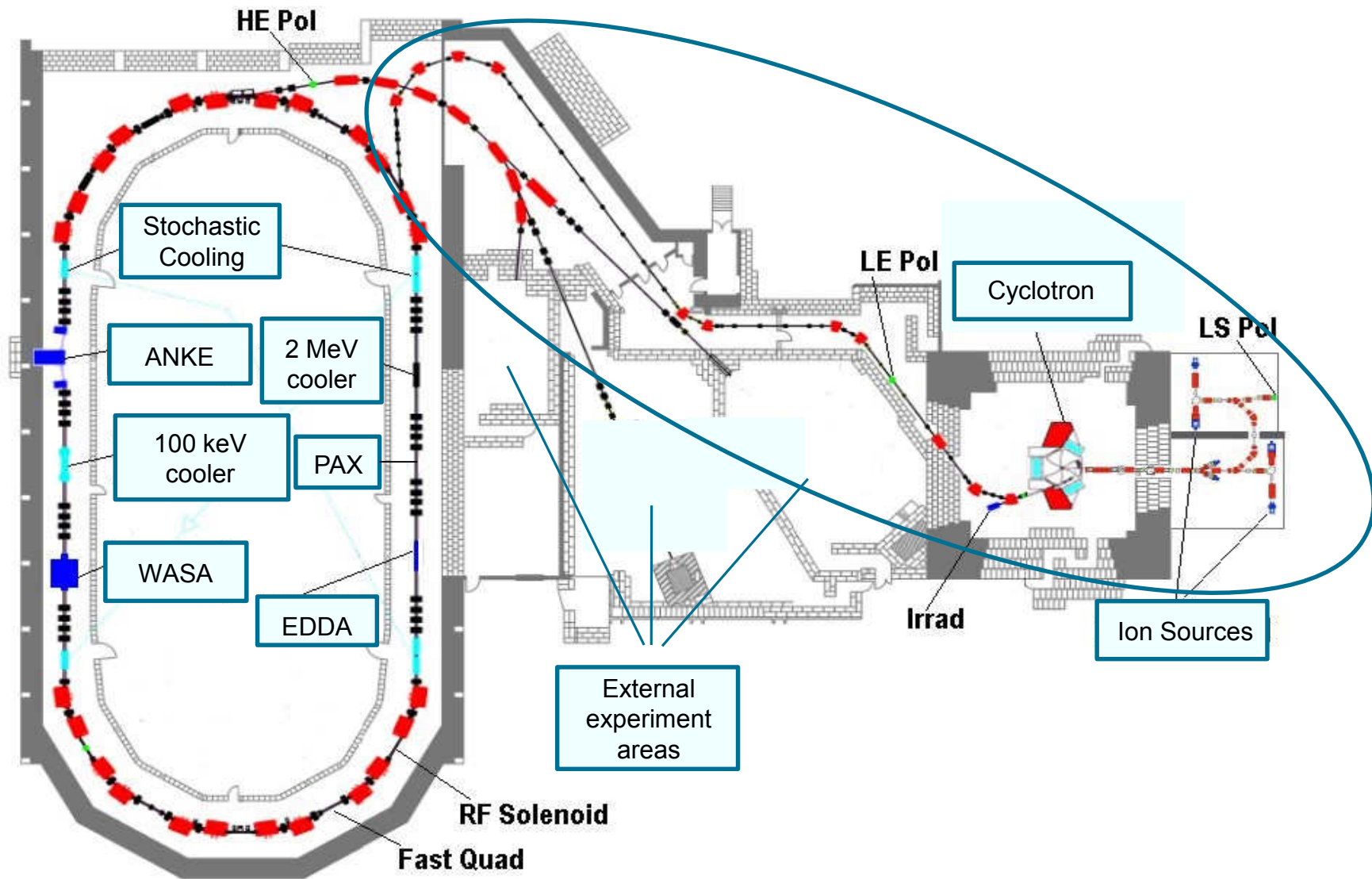
Workshop on Beam Dynamics and Control studies at COSY
November 18, 2016 | C. Weidemann

COSY facility

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

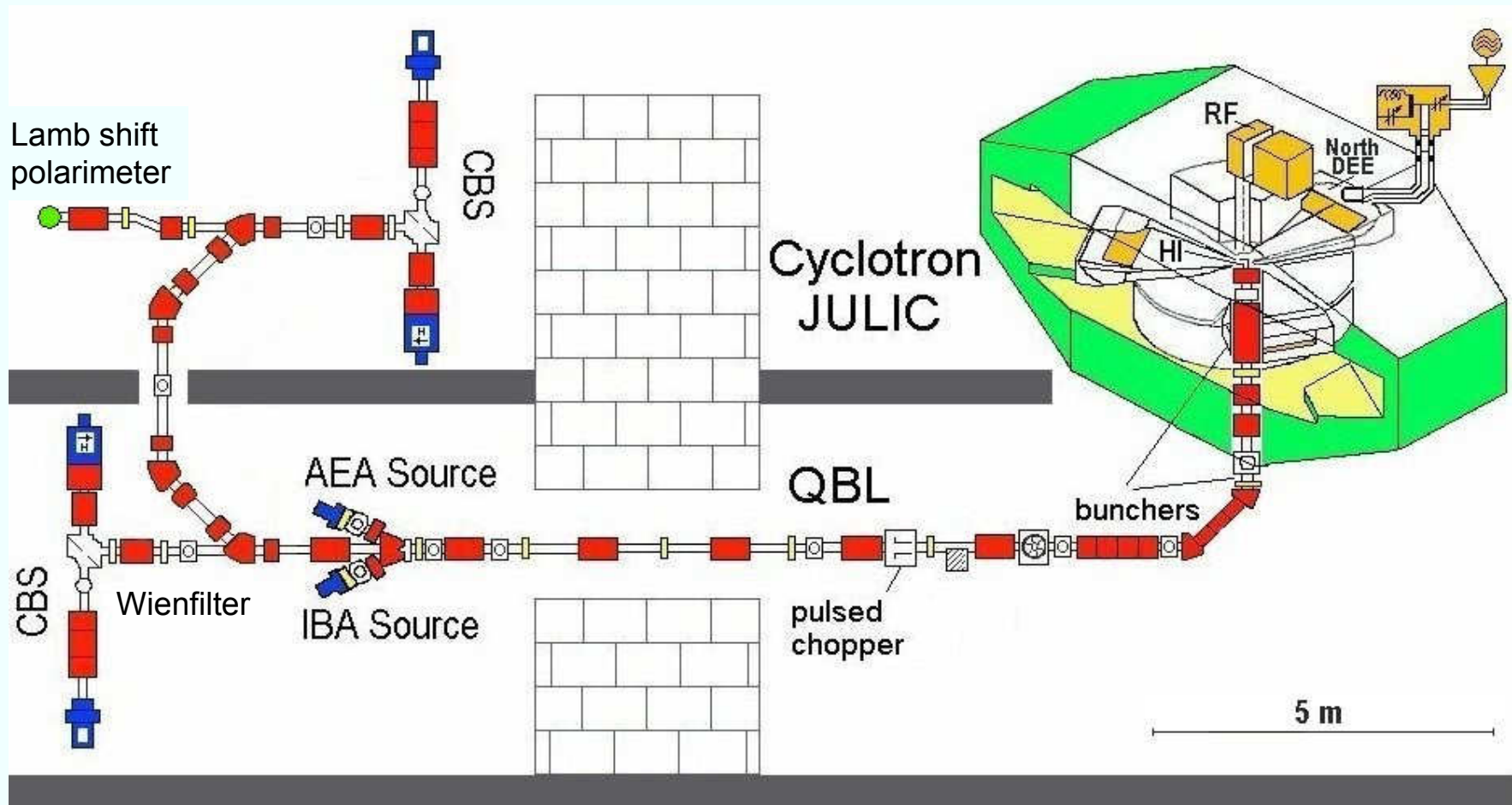


COSY facility



COSY - source and cyclotron

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



COSY - cyclotron JULIC



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

AEG design

Request for quote: 1961

First internal beam: 1968

Upgrade for COSY: 1990

Pole diameter 3.3 m / 700 t iron

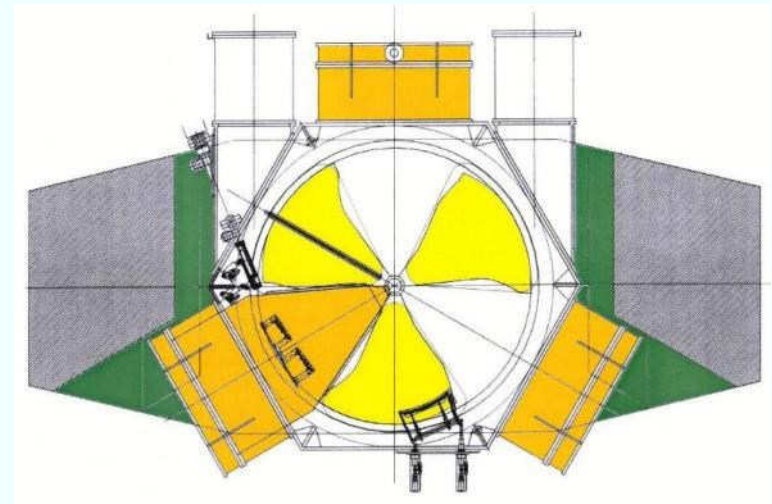
$\langle B \rangle_{\max} = 1.35 \text{ T}$ $B_{\text{hill}} = 1.97 \text{ T}$

20 – 30 MHz ($h=3$)

22.5-45 MeV/A

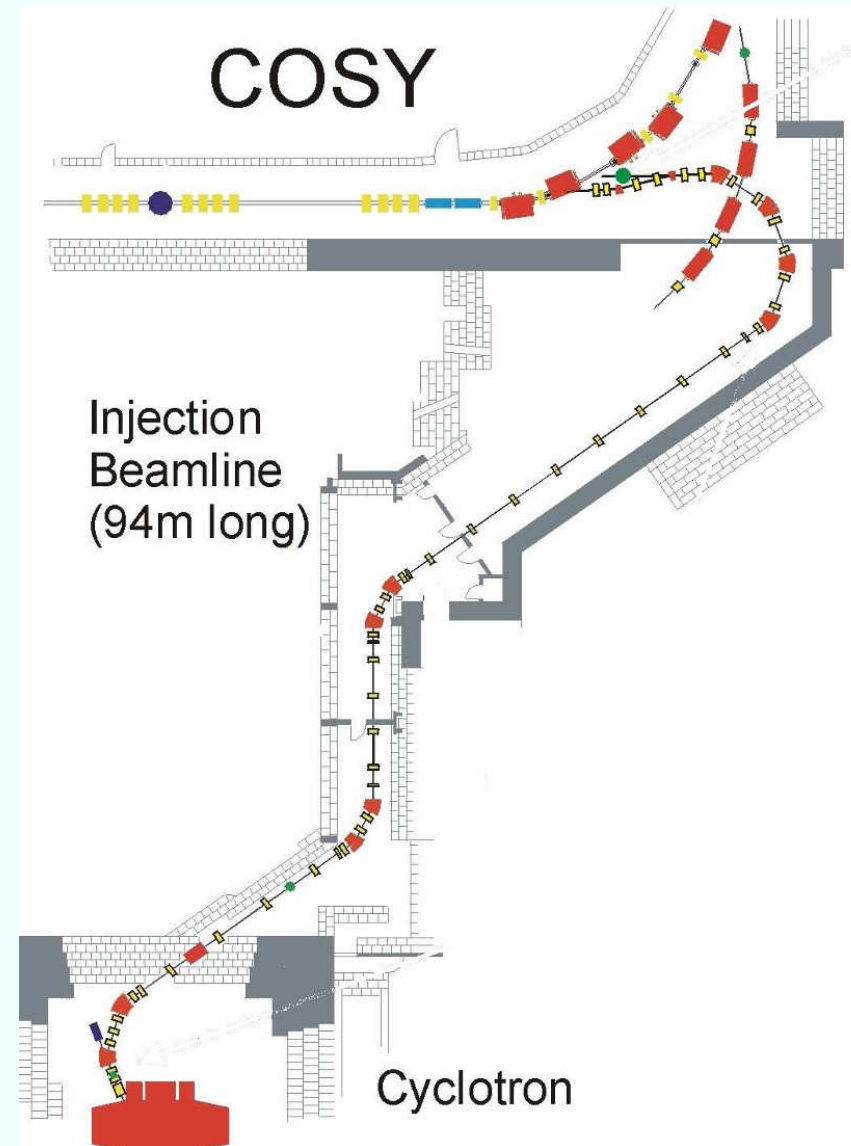
2-4.5 keV/A injection

3 ion sources (2 multicusp + pol. CBS)

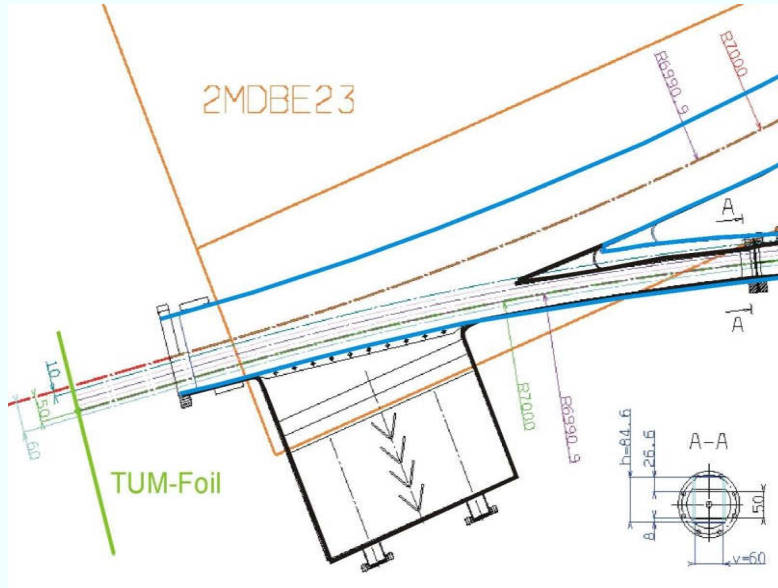


COSY - injection beam line

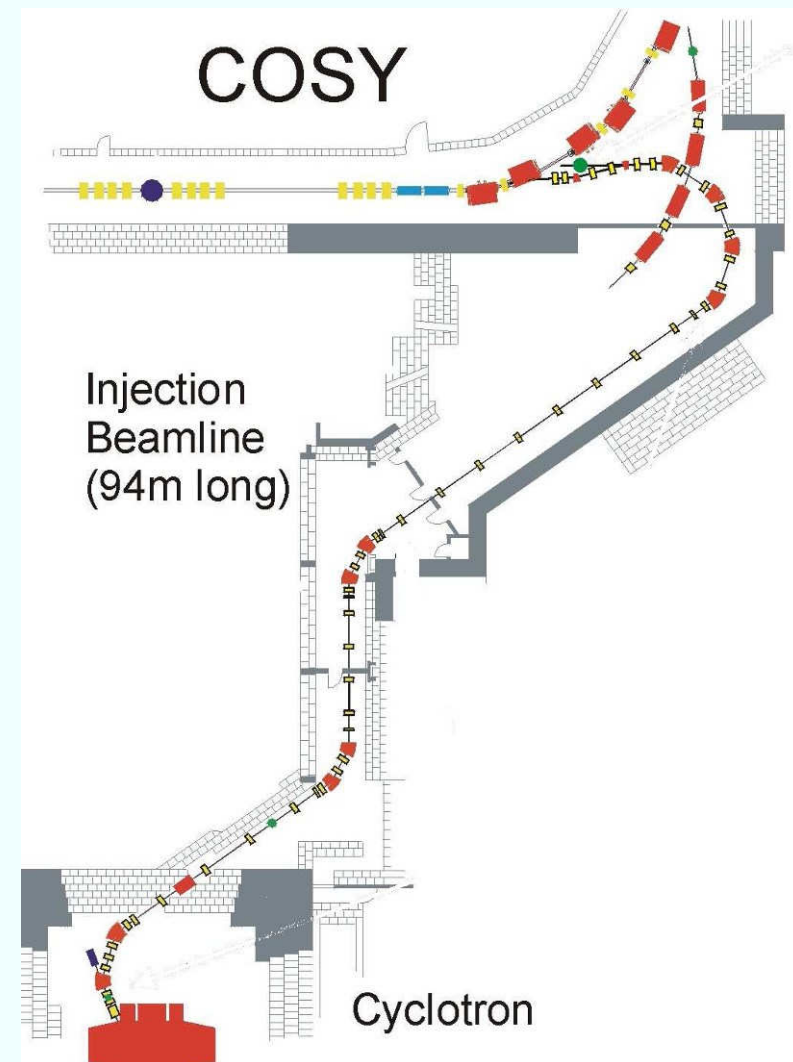
- Transfer line from cyclotron to COSY
- 45 MeV protons or 76 MeV deuterons
- 5 bent and 6 straight sections ($l = 94$ m)
- 30 mm vertical offset
- Typical beam current: 10 μA
($\sim 10^{11}$ particles in COSY)
- $\sim 95\%$ transmission from cyclotron exit to COSY entrance



COSY - injection



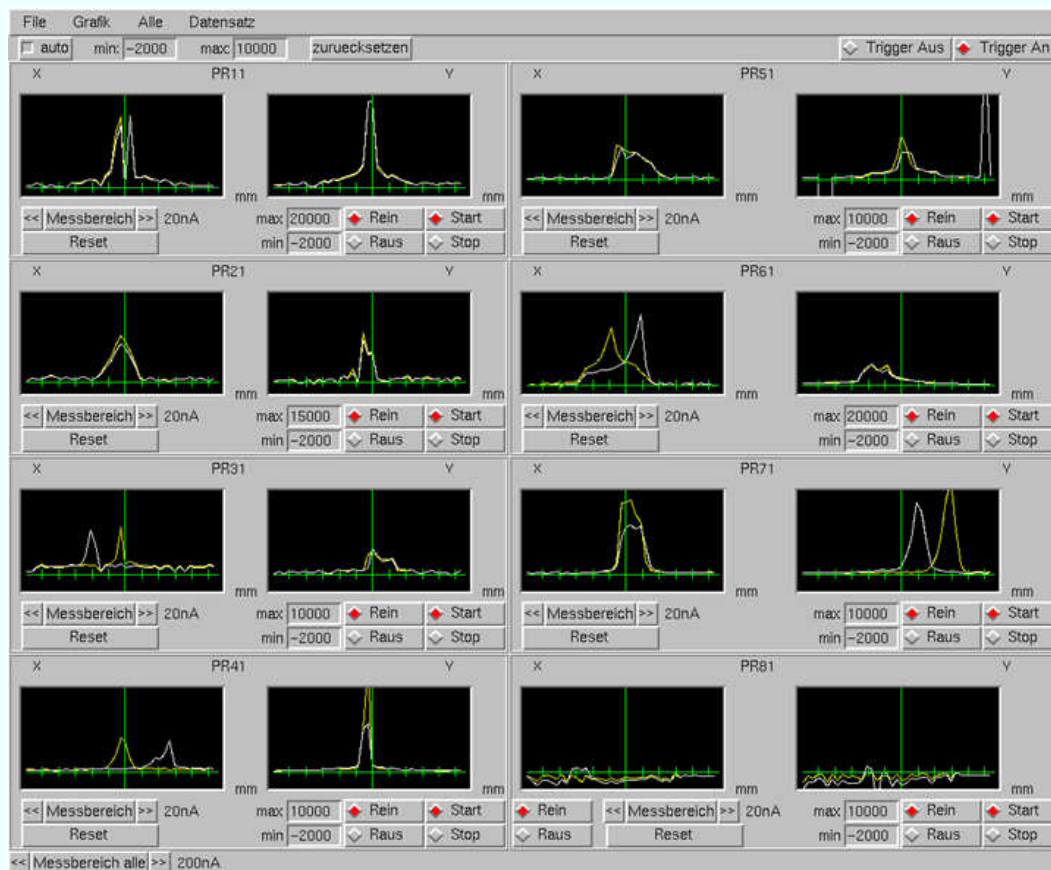
- Stripping injection of H^-
- 3 fast ramping bumper magnets in COSY move orbit on the stripping foil
- Injection onto „distorted orbit“
- Reduction of injection bump within 20 ms



COSY - injection beam line

Diagnostics

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



Dipole magnet

Quadrupole magnet

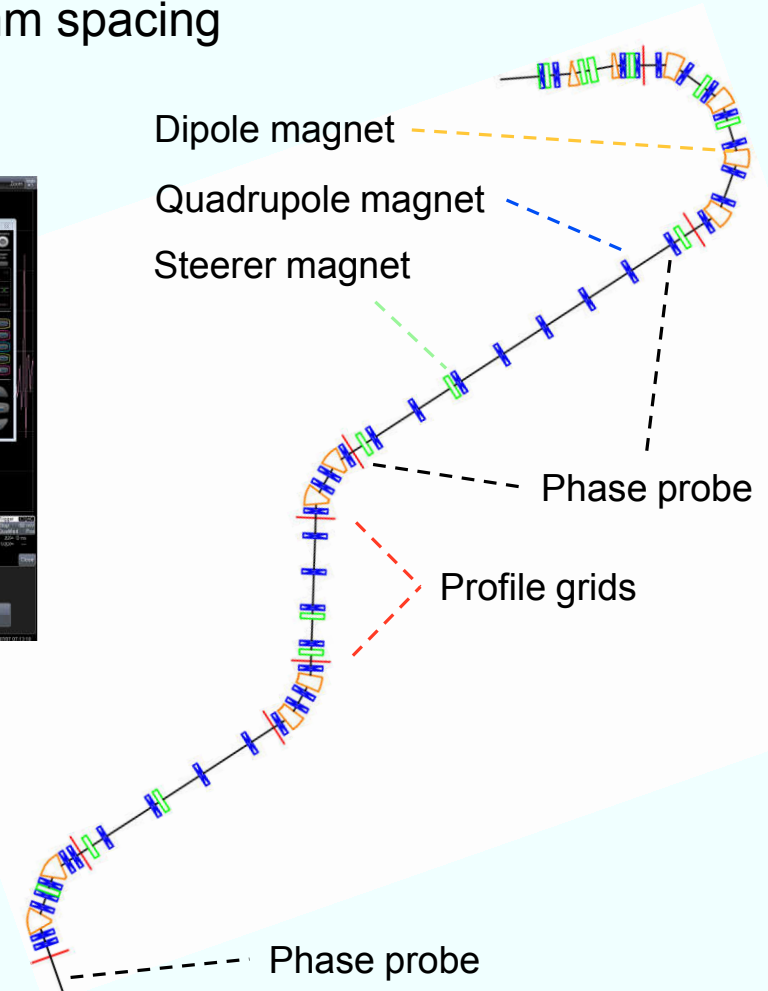
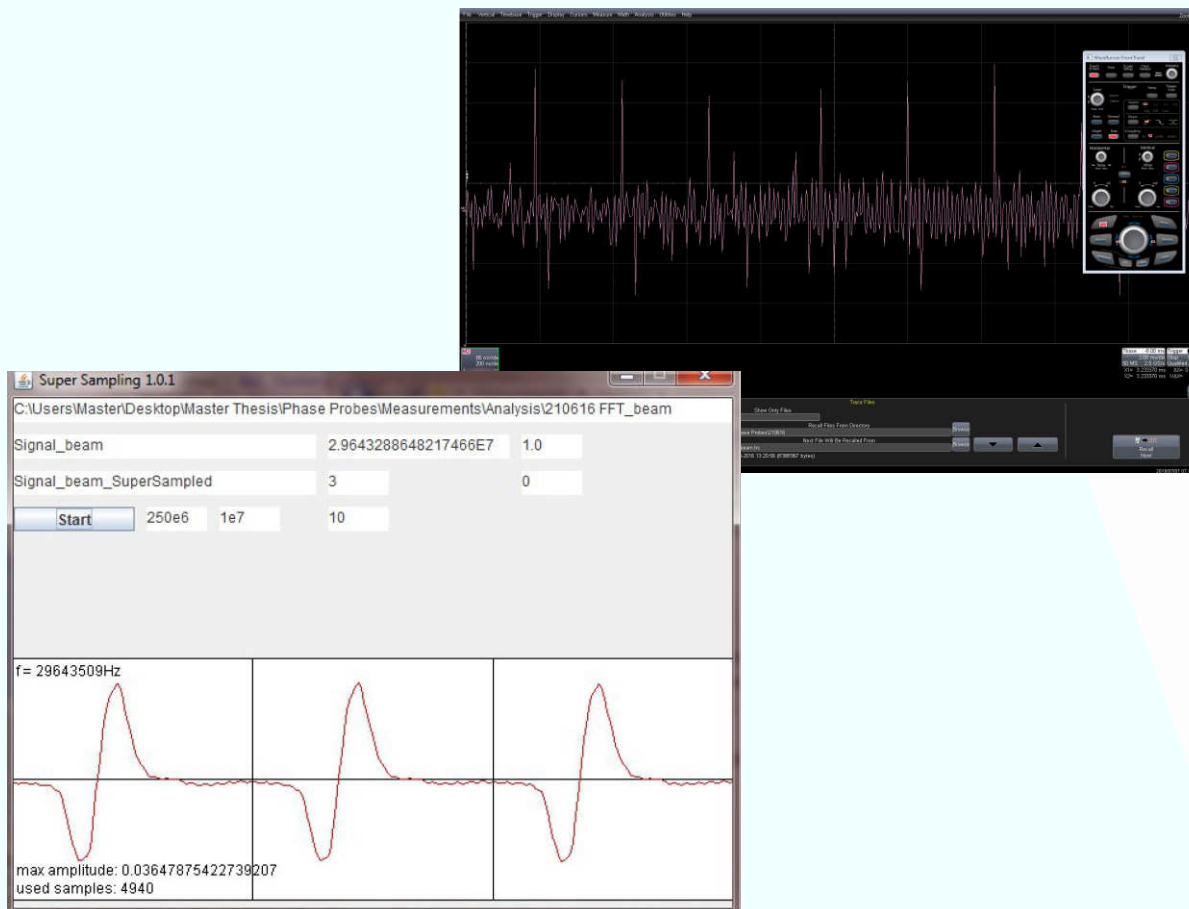
Steerer magnet

Profile grids

COSY - injection beam line

Diagnostics

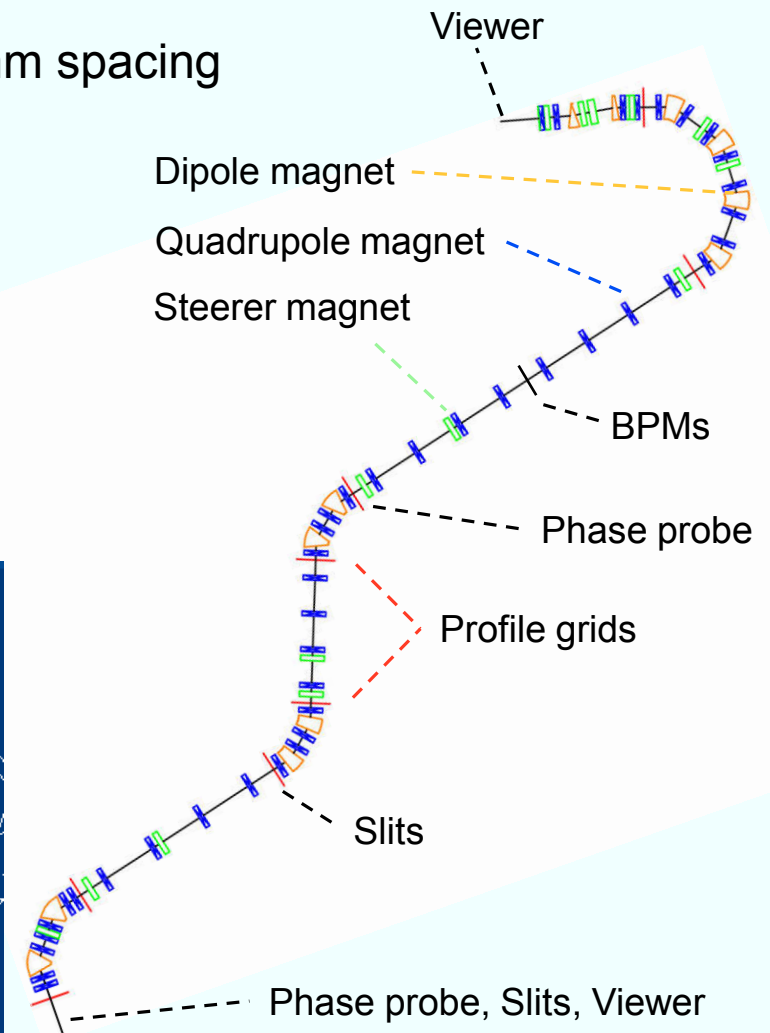
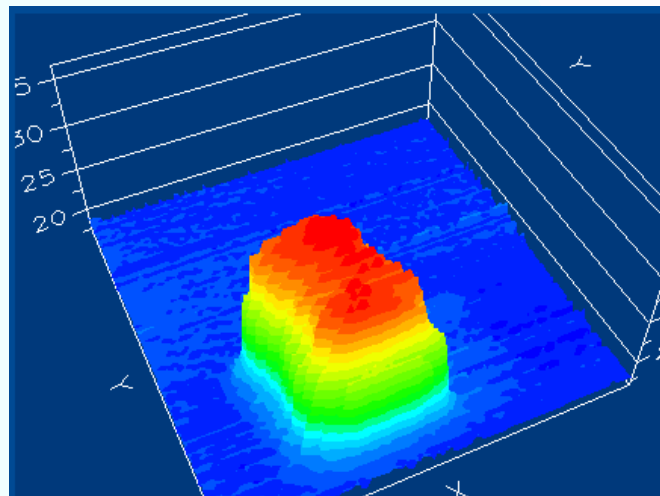
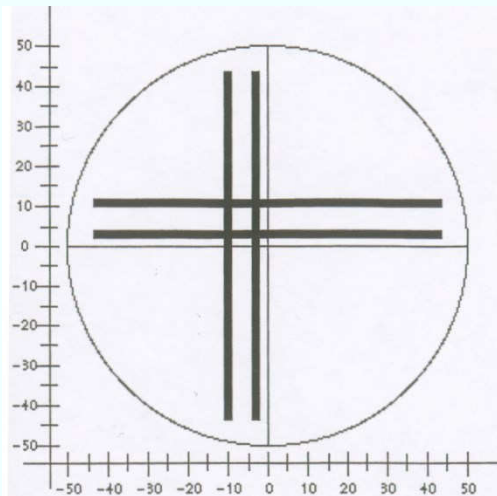
- 8 Profile grids (harps): 39 wires (x, y) , 1 mm spacing
- 3 Phase probes for energy determination



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.

Tao / F90 / C++

- Initialization
- Calculations / Optimization
- Visualization
- Data handling

- settings
- commands



- optics data



BMAD

Beam parameters

Machine settings

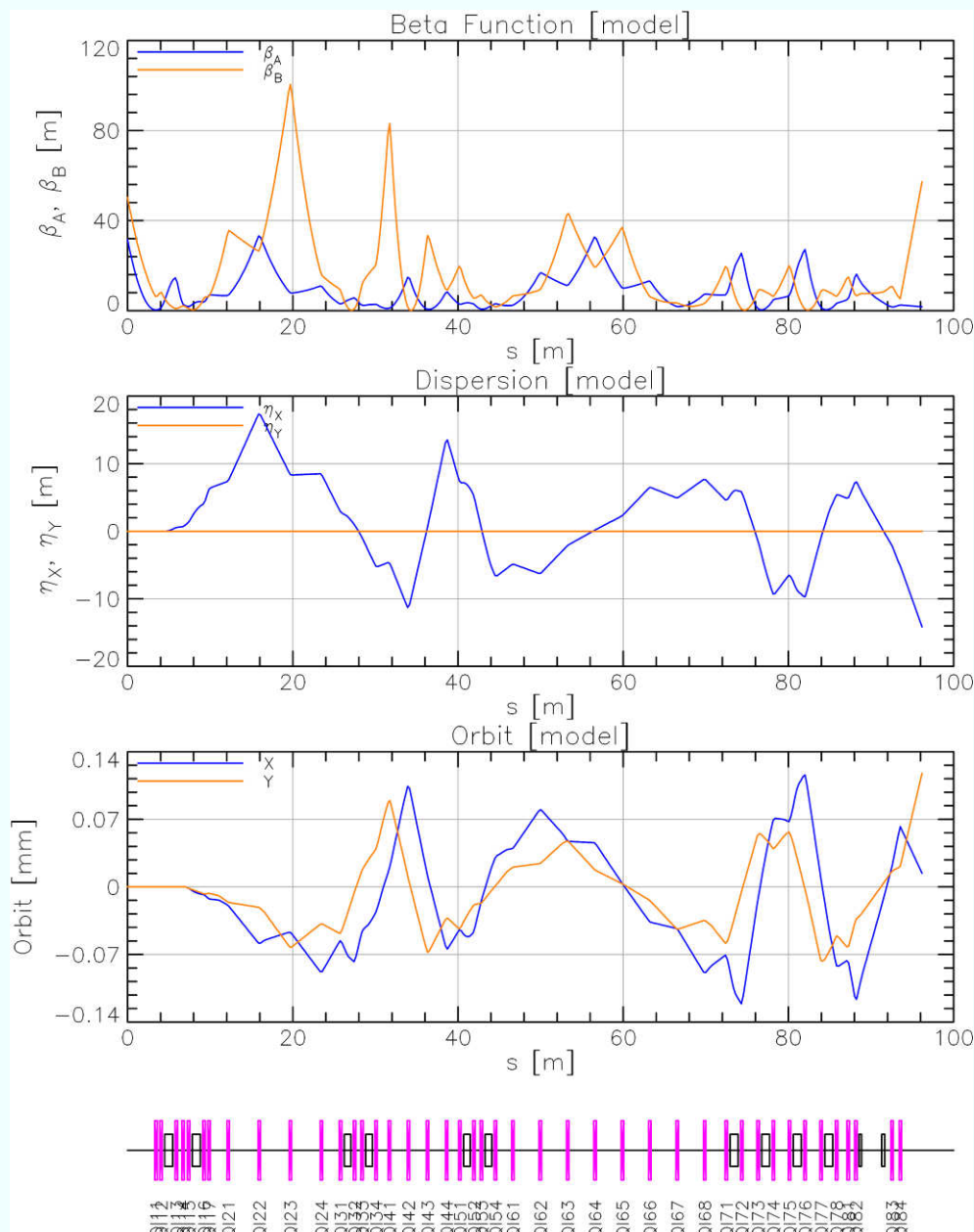
Lattice

IBL modeling

Data

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

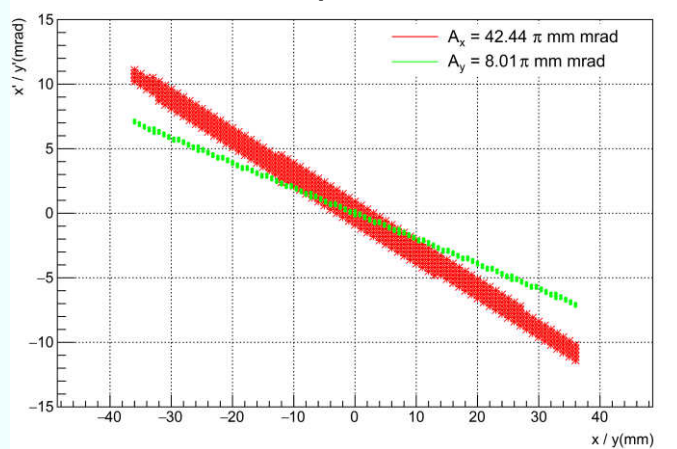
Data_Type	Description	Source
alpha.a, alpha.b	Normal-Mode alpha function	lat
apparent_emit.x, apparent_emit.y	Apparent emittance	beam, lat
beta.a, beta.b, beta.c	Normal-mode beta function	beam, lat
beta.x, beta.y, beta.z	Projected beta function	beam, lat
bpm_orbit.x, bpm_orbit.y	Measured orbit	lat
bpm_phase.a, 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.deta.p.x, chrom.deta.p.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 $\langle x \rangle$ / $\langle x^2 \rangle$ & 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,	Global ("floor") position	lat
floor.theta, floor.phi, floor.psi		
gamma.a, gamma.b	Normal-mode gamma function	lat



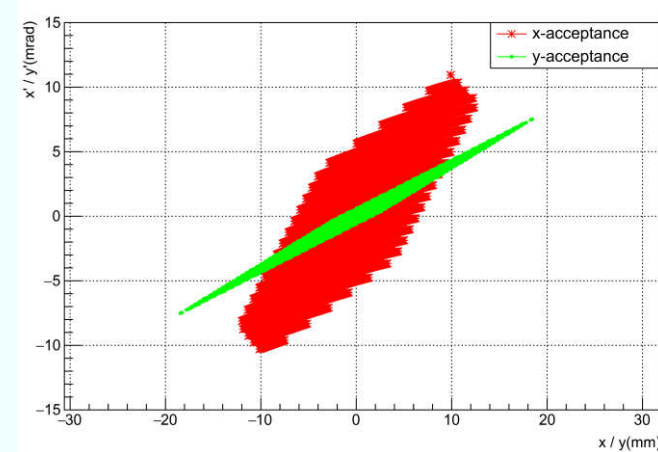
Tracking

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

Acceptance

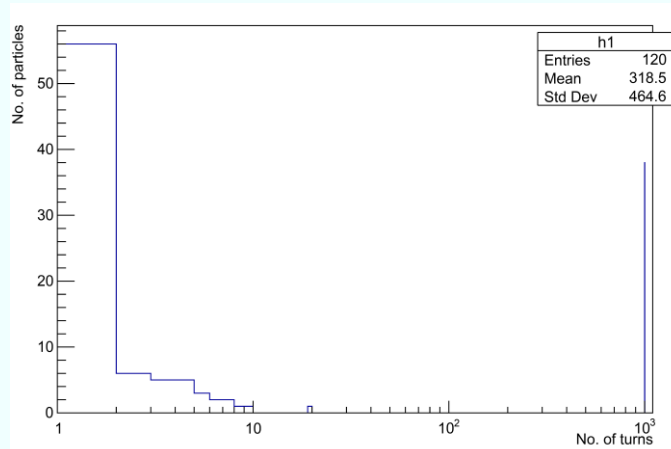


Phase space at IBL exit

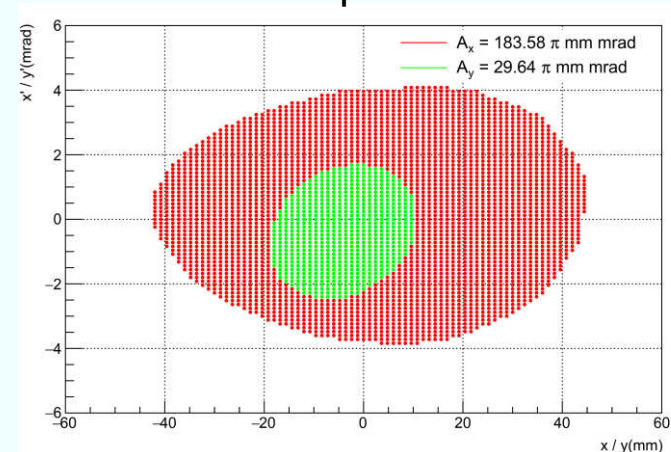


COSY Multi-turn tracking (for 1000 turn $\rightarrow$ 50 turns)

Turn survival

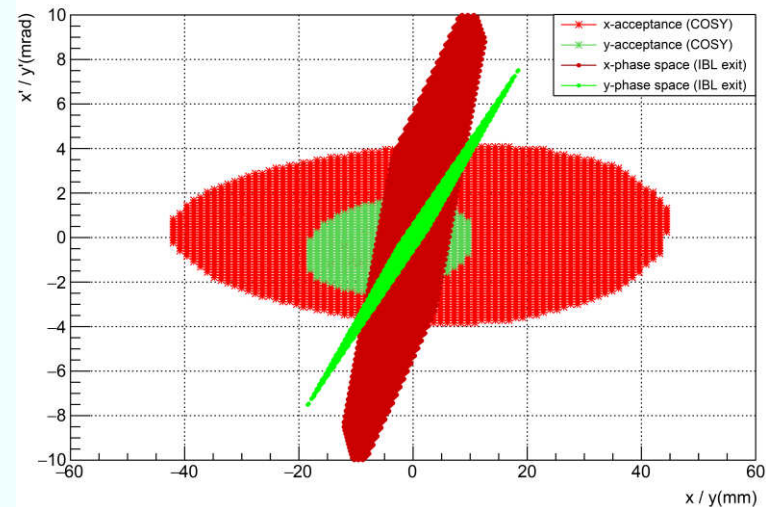


Acceptance



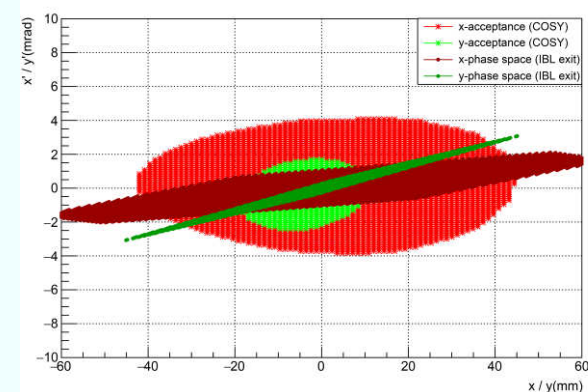
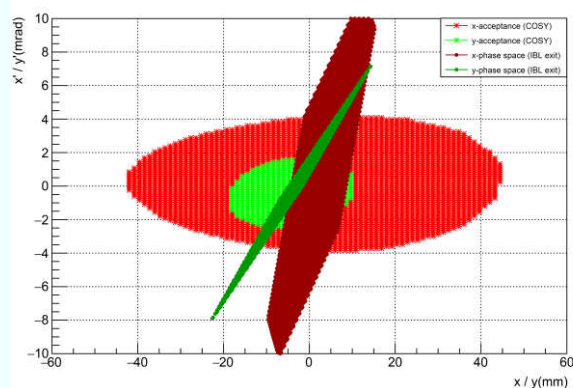
Tracking

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

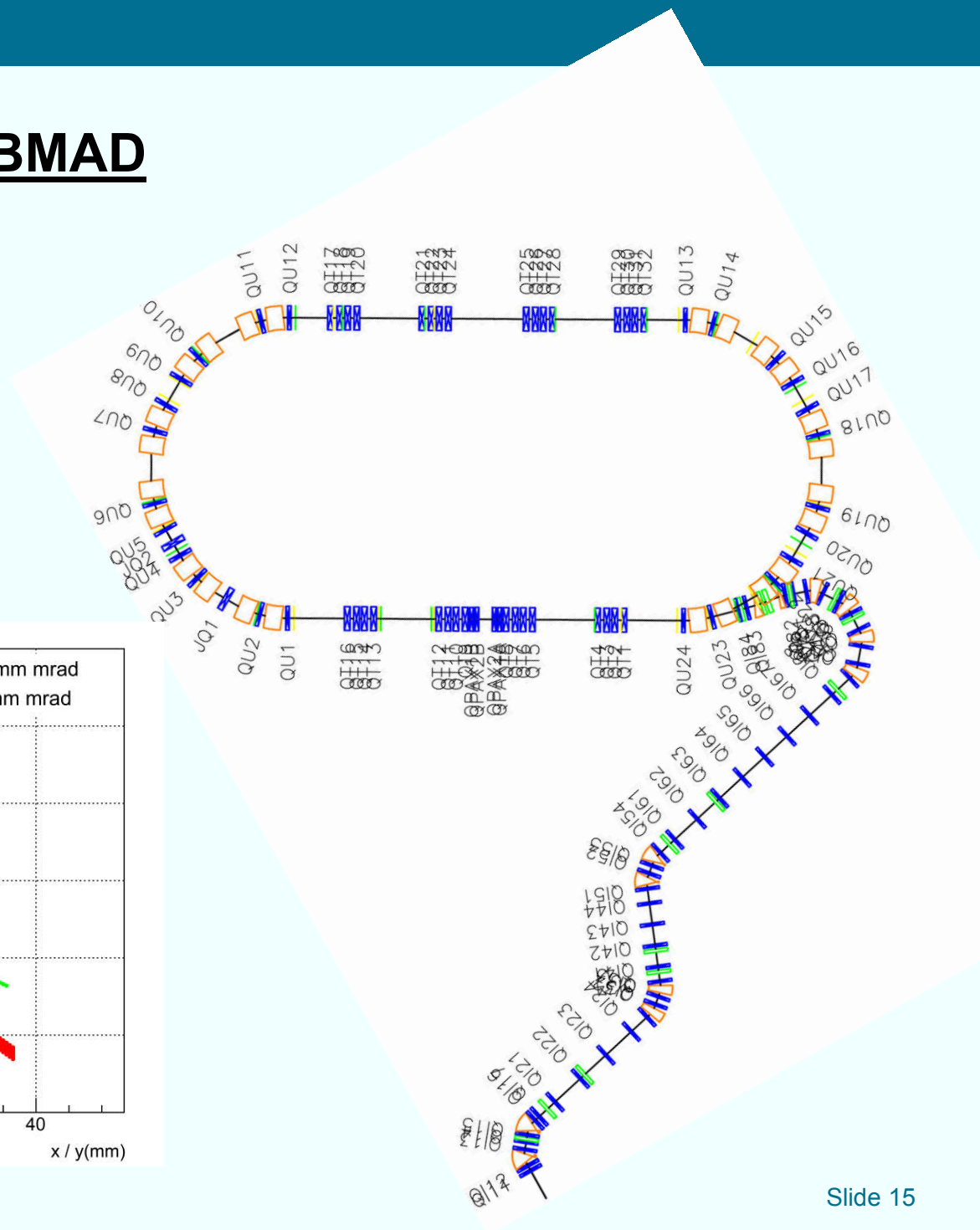
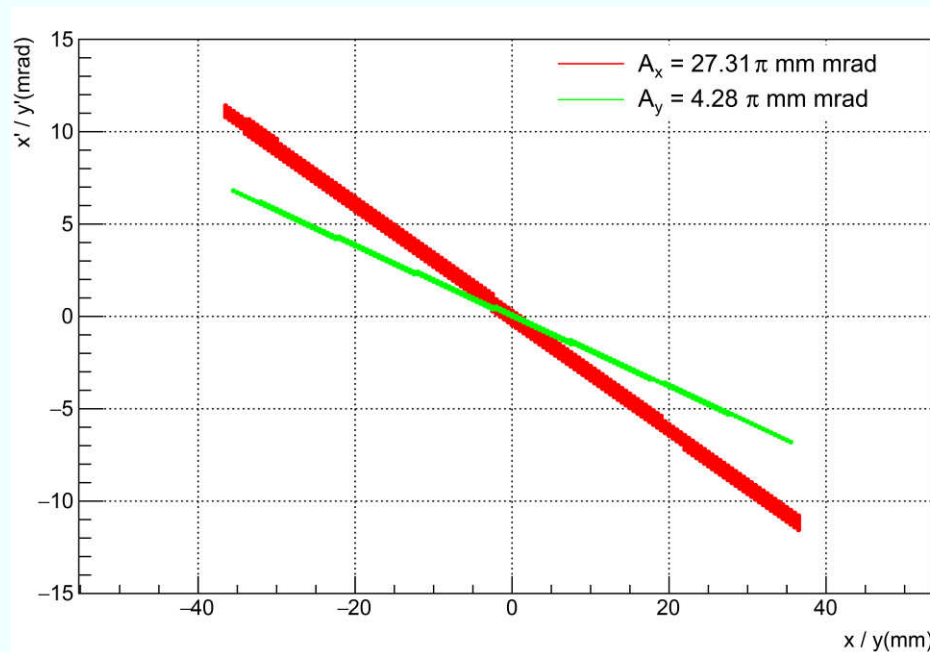


Tracking

Combined tracking using BMAD

- Connect IBL to COSY

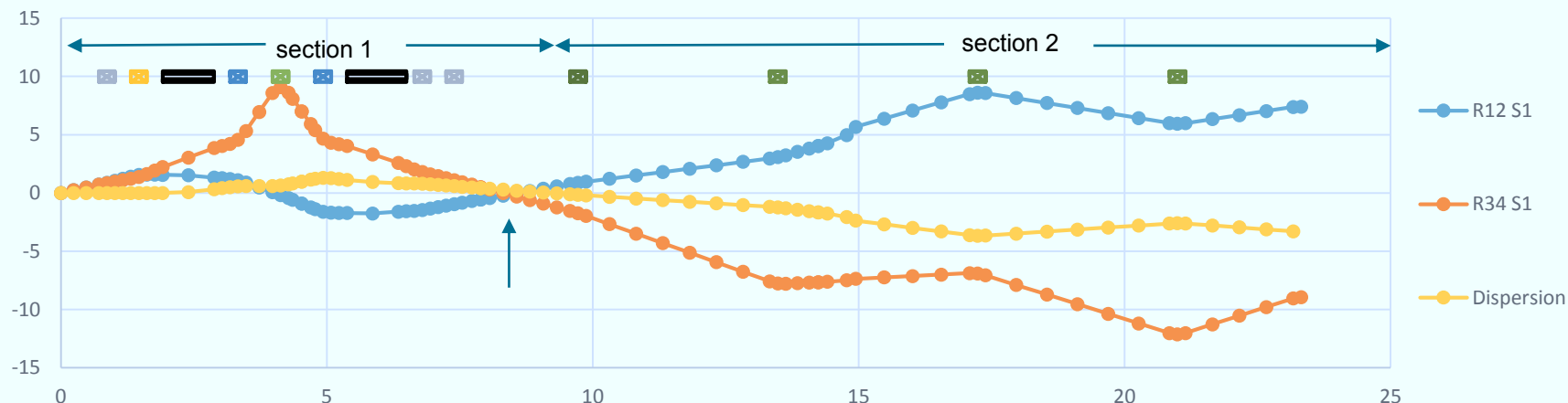
Combined acceptance



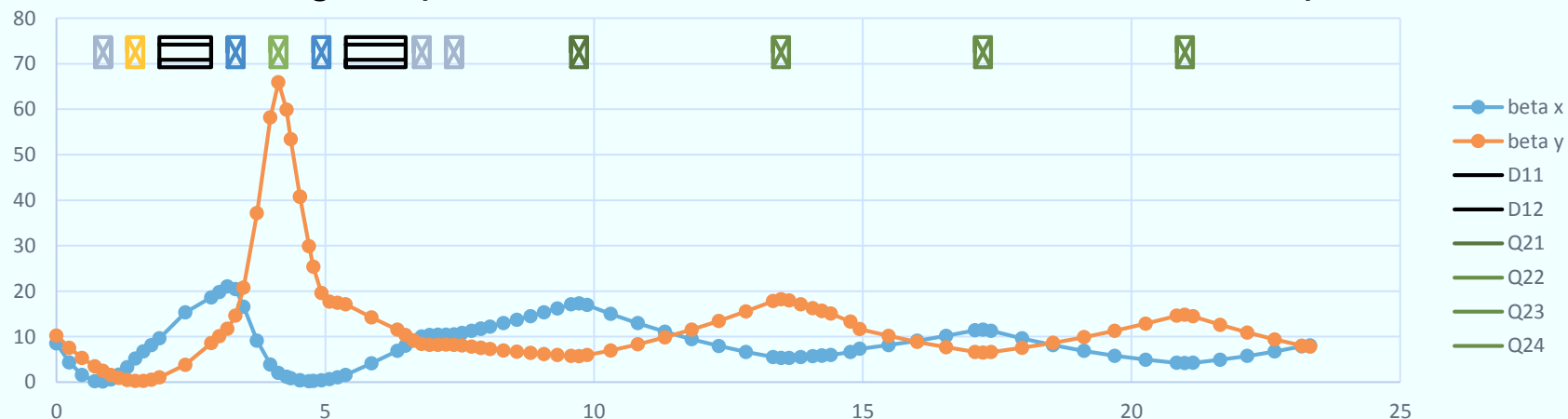
IBL modeling

Transport Excel (Sig Martin)

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



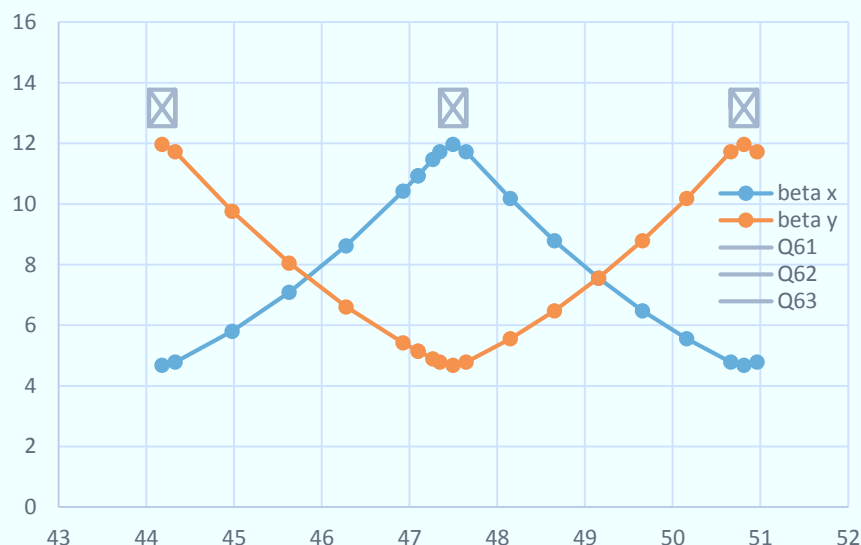
- Fit settings of section 2 for FODO structure (large β -function)
- Perfect matching not possible due to different distances between quads



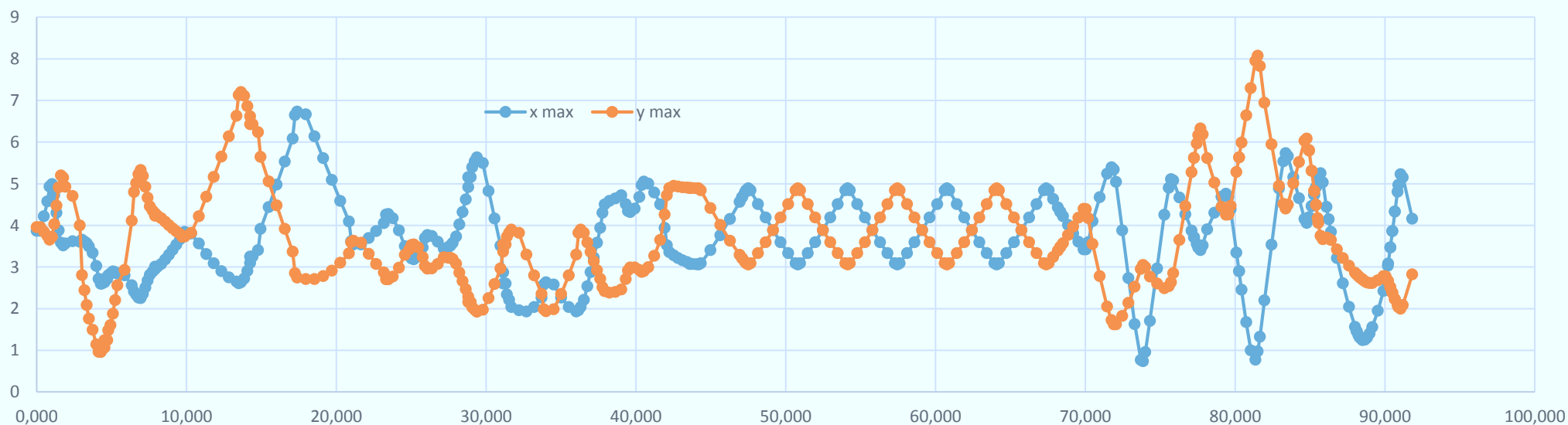
IBL modeling

Transport Excel (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

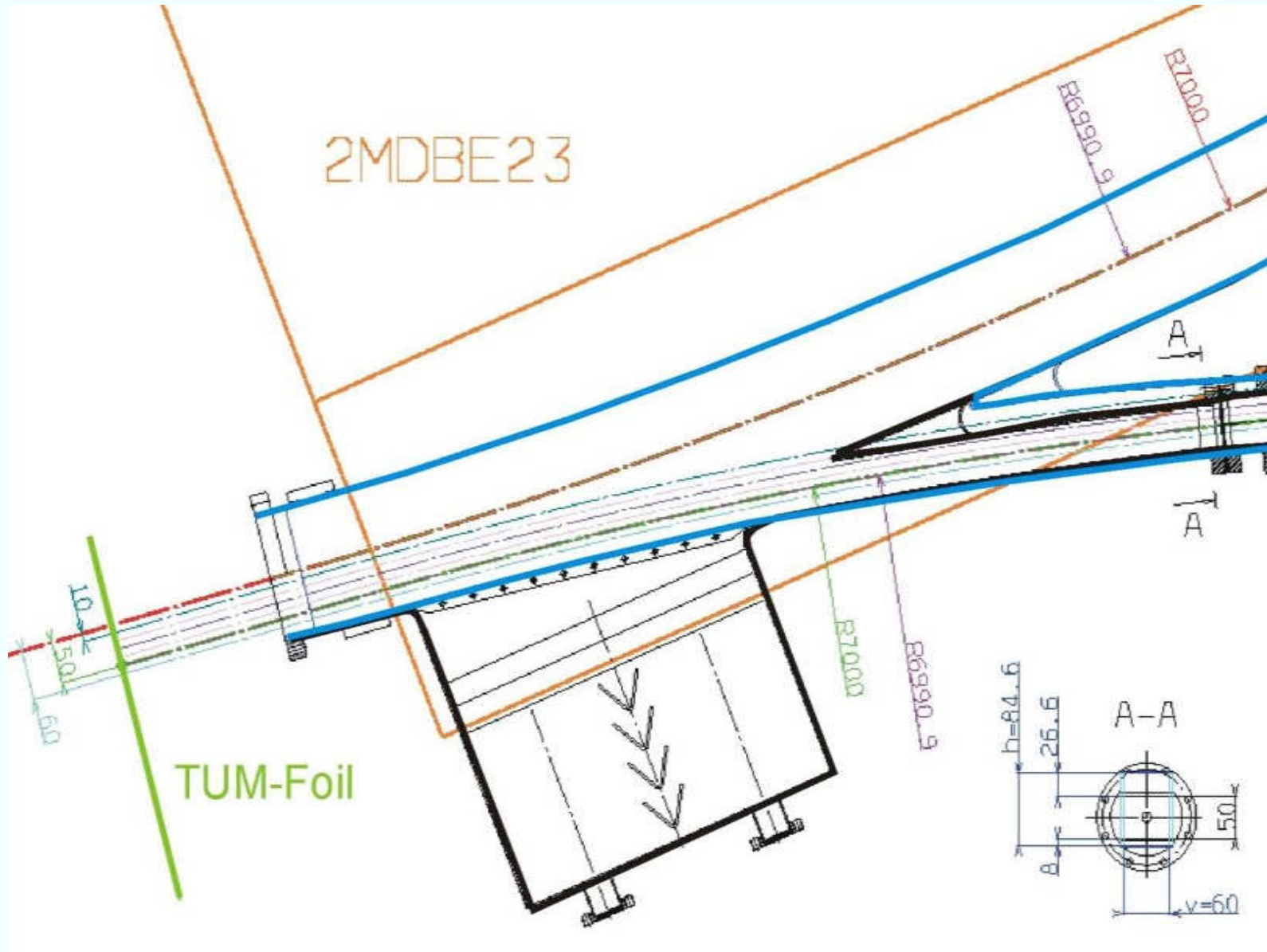
Plan:

- 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

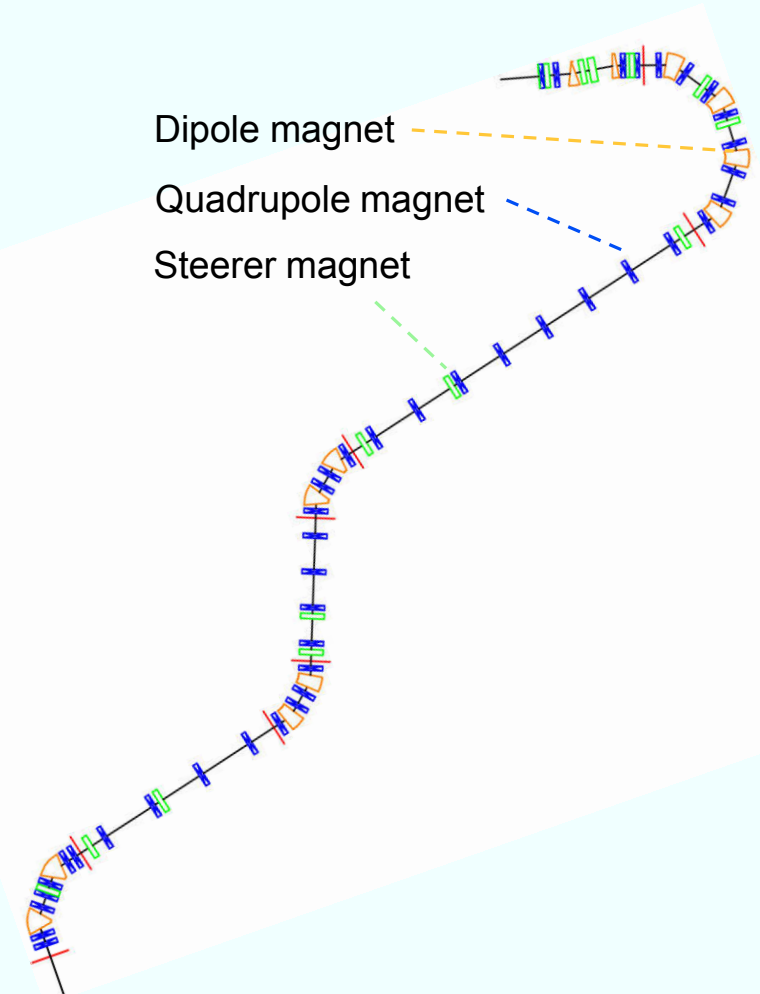


Transmission through IBL

Transmission									
File		Konfiguration		Eintraege uebernehmen		Mikropulsung Werte uebernehmen (Timing-Sender, Zielimpuls)			
Datum:					Tue Oct 21 17:42:05 MEST 2003				
Arbeitsdirectory:					/mnt/cc-l/operator				
Alte Transmissionsdaten: Die Okt 21 14:55:06 CEST 2003									
Quellen-Strahlfuehrung H- -Quelle 1 (IBA) H- -Quelle 2 (AEA) H- -Pol-Quelle 									
FB3	216	[uA]							
FB5	74	[uA]	FB5 / FB3 = 34.3 %						
Zyklotron									
Phasensonde300	23.2	[uA]	PS300 / FB5 = 31.4 %						
Phasensonde1310	14.7	[uA]	PS1310 / PS300 = 63.4 %						
BC11	9	[uA]	BC11 / PS1310 = 61.2 %						
BC11 / FB5 = 12.2 %									
Injektions-Strahlfuehrung Ladungsaustausch = 0.8									
P	293.7	[MeV/c]	Makro: Dauer	20	[ms]				
BC81	8.5	[uA]	Mikro: Dauer		[ms]				
			Wiederholzeit		[ms]	N = 1.1e+12 p		BC81 / BC11 = 94.4 %	
Synchrotron Experiment 3 Mode (intern) 									
Zielimpuls	2678	MeV/c							
BCT (Injektion)	2380	mV	Umlaufsfreq.	0.4882	MHz	N = 3.0e+11 p	Inj.:	BCT-I / BC81 = 34.1 %	
BCT (Einfang)	1340	mV				N = 1.7e+11 p	BCT-E / BCT-I = 56.7 %		
BCT (Flat Top)	3620	mV	Umlaufsfreq.	1.542	MHz	N = 1.5e+11 p	Beschl.:	BCT-TOP / BCT-E = 88.2 %	

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)
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- Typical beam current: 10 μA
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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,...)



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BMAD

Beam parameters

Machine settings

Lattice