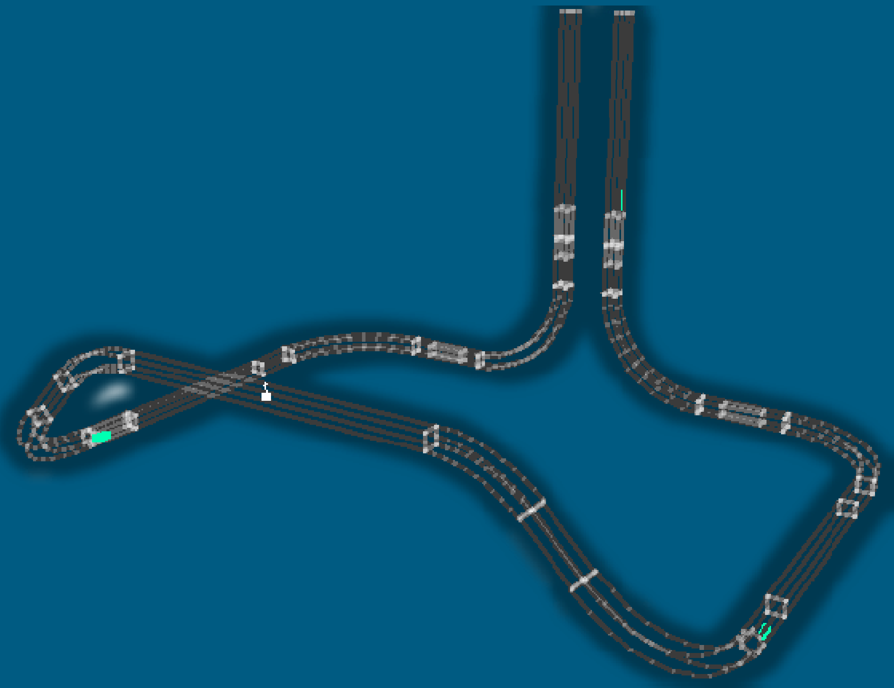
Model Development for the Automated Setup of the 2 MeV Electron Cooler Transport Channel

COOL 17
@ Gustav Stresemann Institute
Bonn – Bad Godesberg
19.09.2017



IKP-4, Forschungszentrum Jülich
A.Halama

Outline

Brief introduction:

COSY - e cooling - 2 MeV Cooler

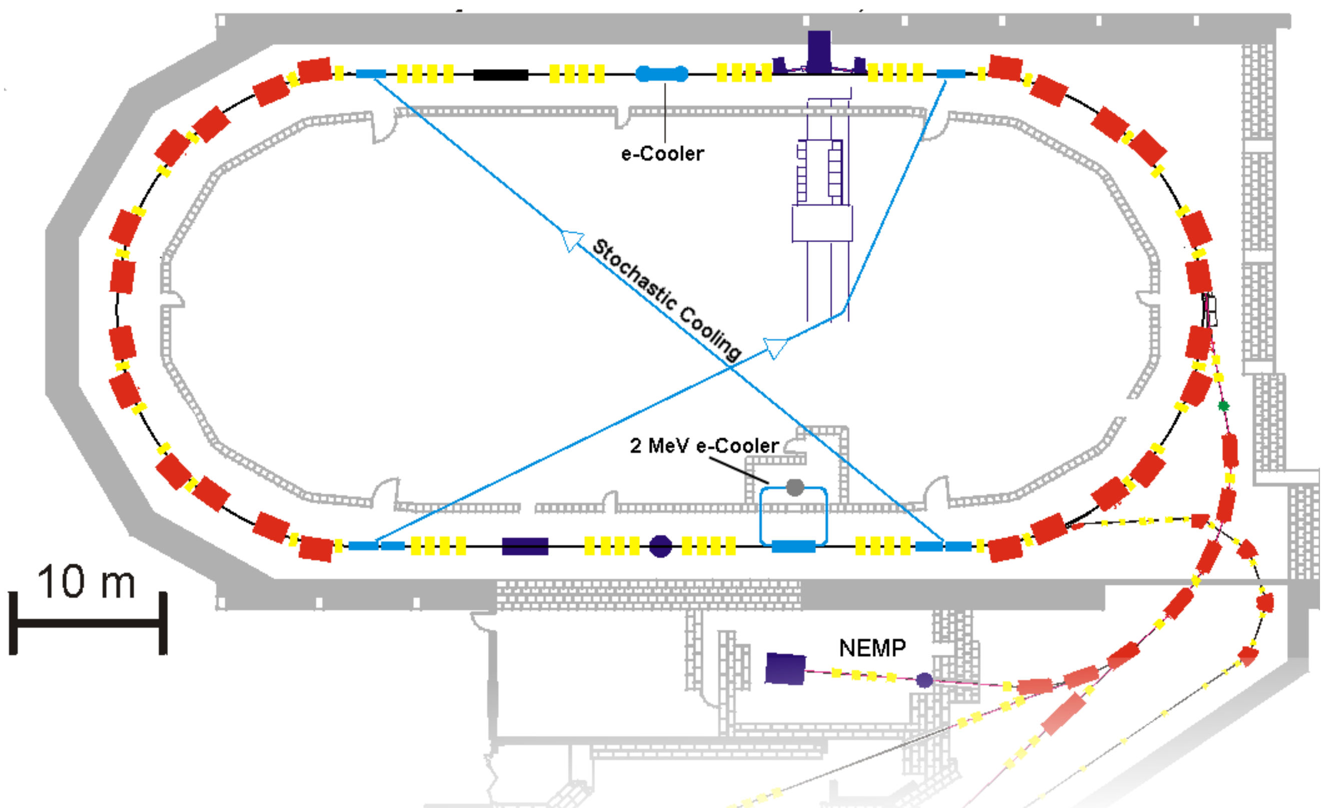
Beam properties in magnetized high energy e cooling

Model implementation, status and GUI

Near and far future plans and further possibilities

COSY (COoler SYnchrotron)

- 184 m circumference
- Protons/ Deuterons
- Polarized and unpolarized
- Stochasic + electron cooling
- internal and external fixed target sites
- Slow extraction capability

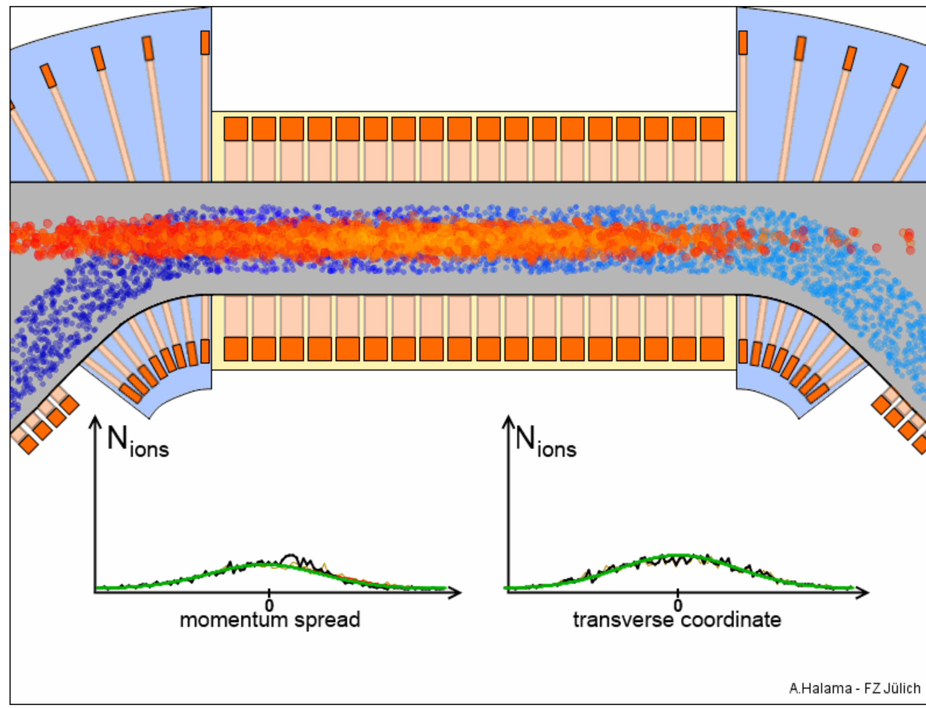


Prerequisites for electron cooling

- Matched orbit of both beams
- Overlapping a <u>cool</u> electron beam with ion-beam

• Quasi static with respect to moving reference frame (along average velocity ion)

So we need:
- Matched Velocity
- No higher order motion



2 MeV Cooler | Characteristics

Some design parameters: 2 MeV, 3 A

Highest achieved power: 1.25 MeV, 0.8 A

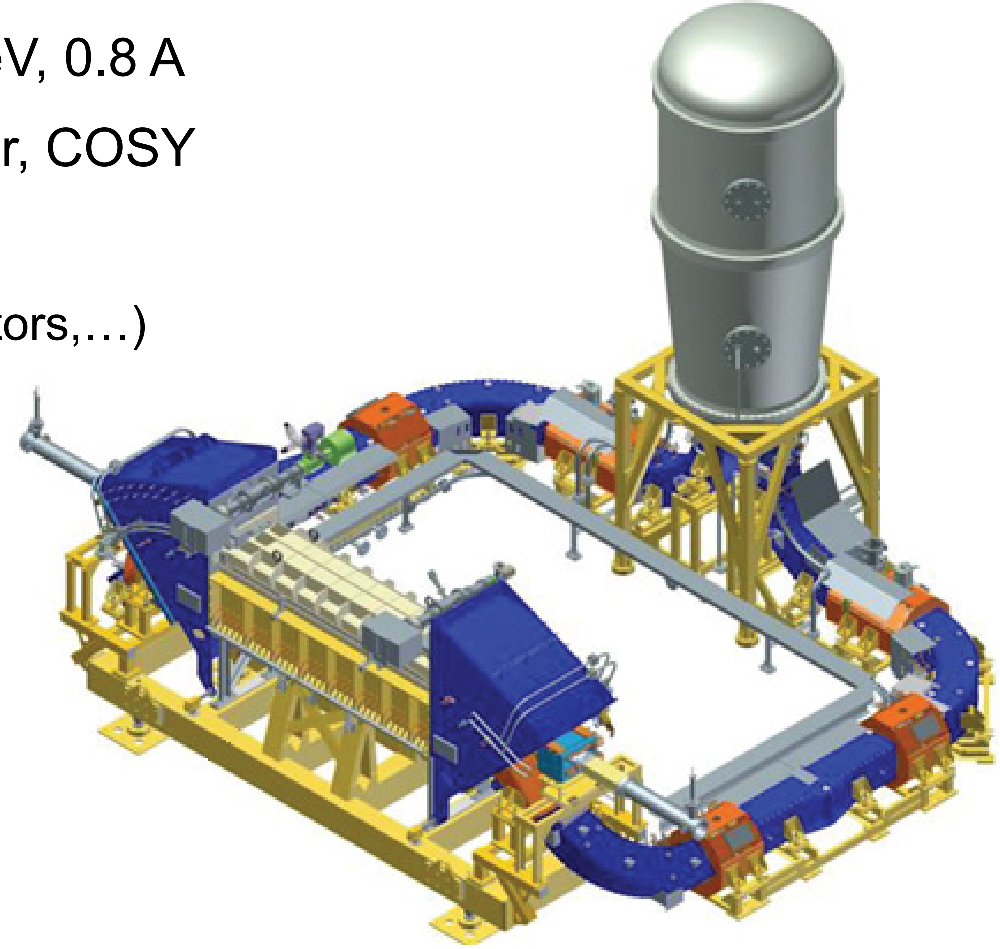
Design around existing accelerator, COSY

12 BPMs

(Beam current monitor, Vacuum monitors,…)

5 main common power supplies

~ 50 corrector power supplies



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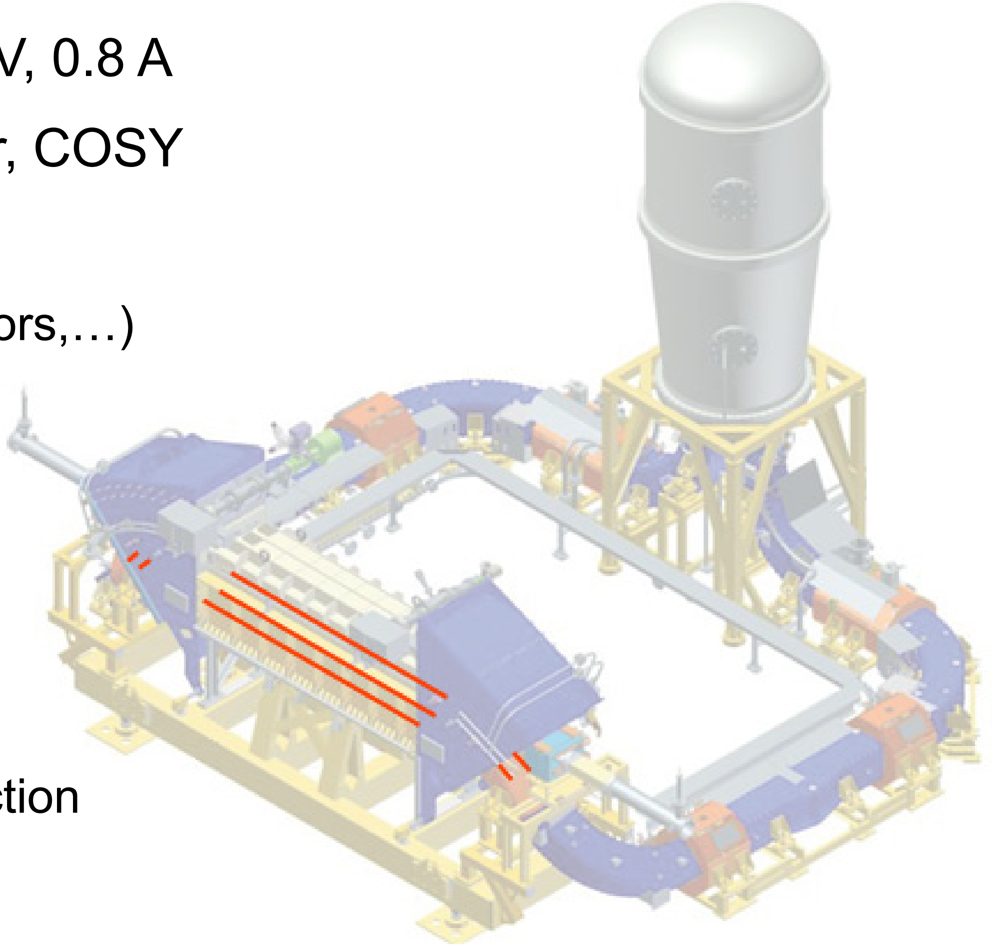

Main B-Fields: 1) Cooling section

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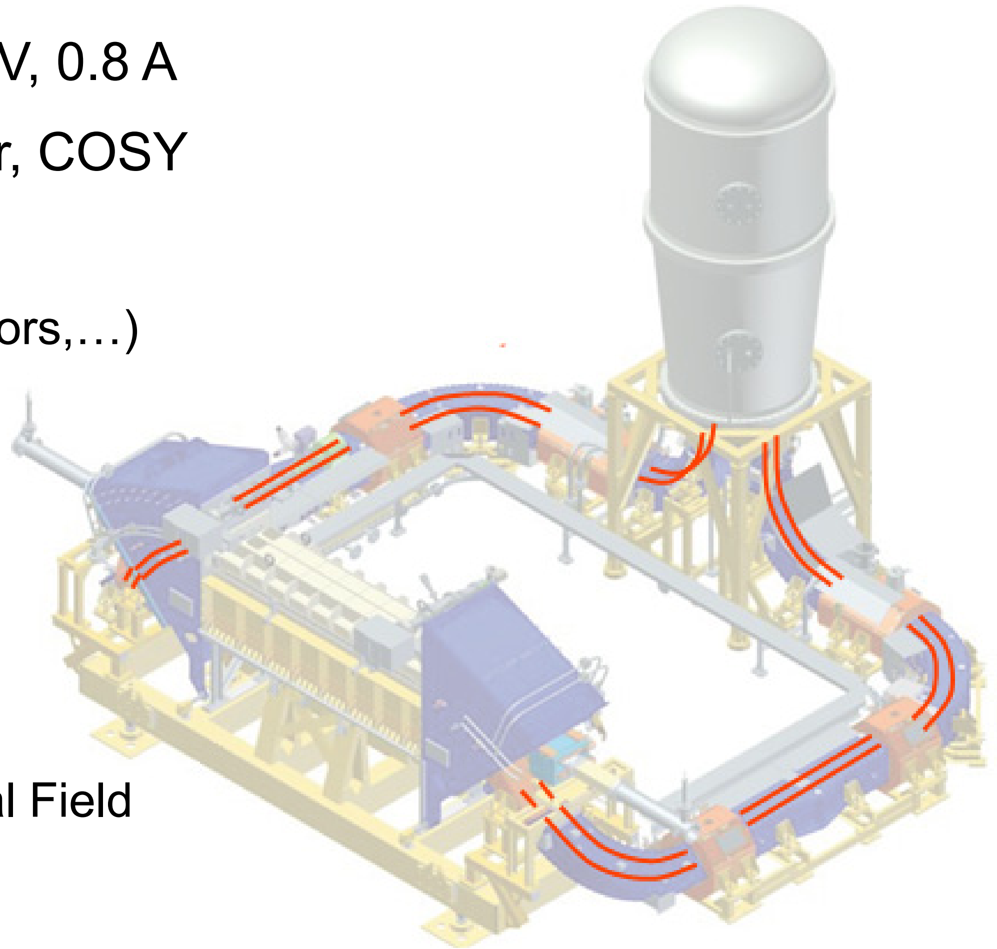

Main B-Fields: 2) Longitudinal Field

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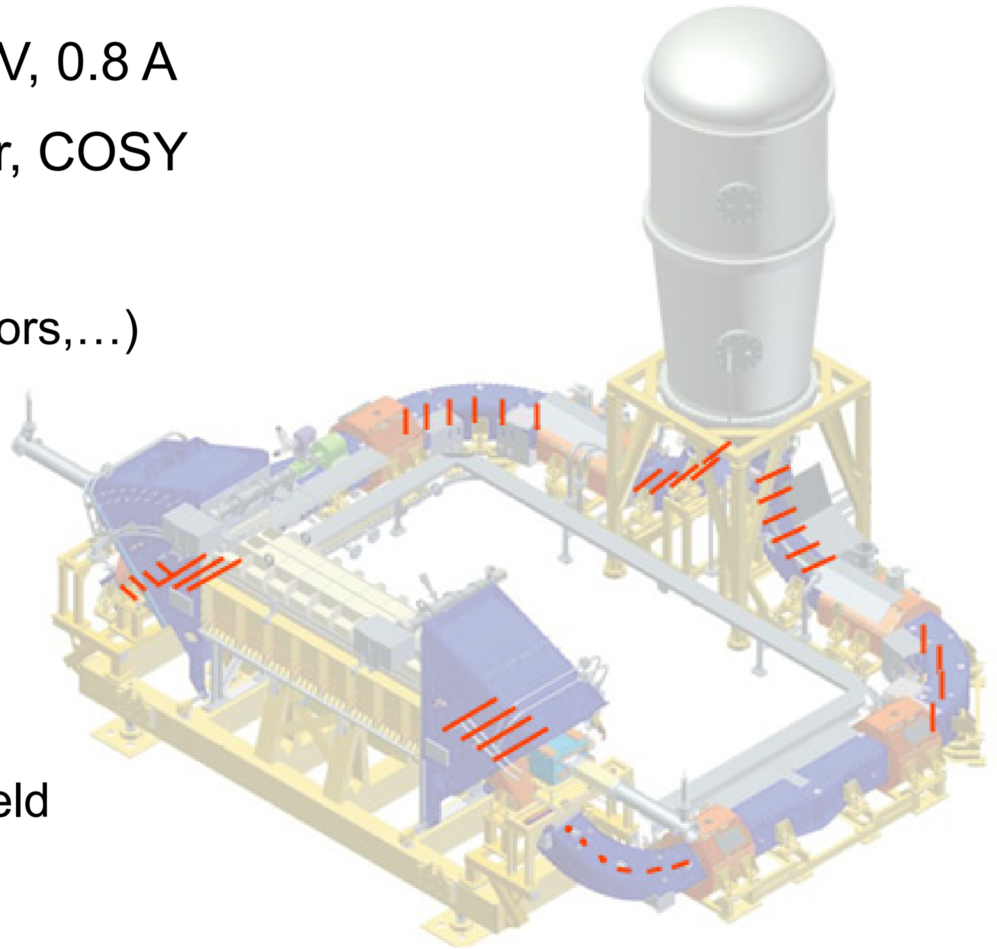
Main B-Fields: 3) Bending Field



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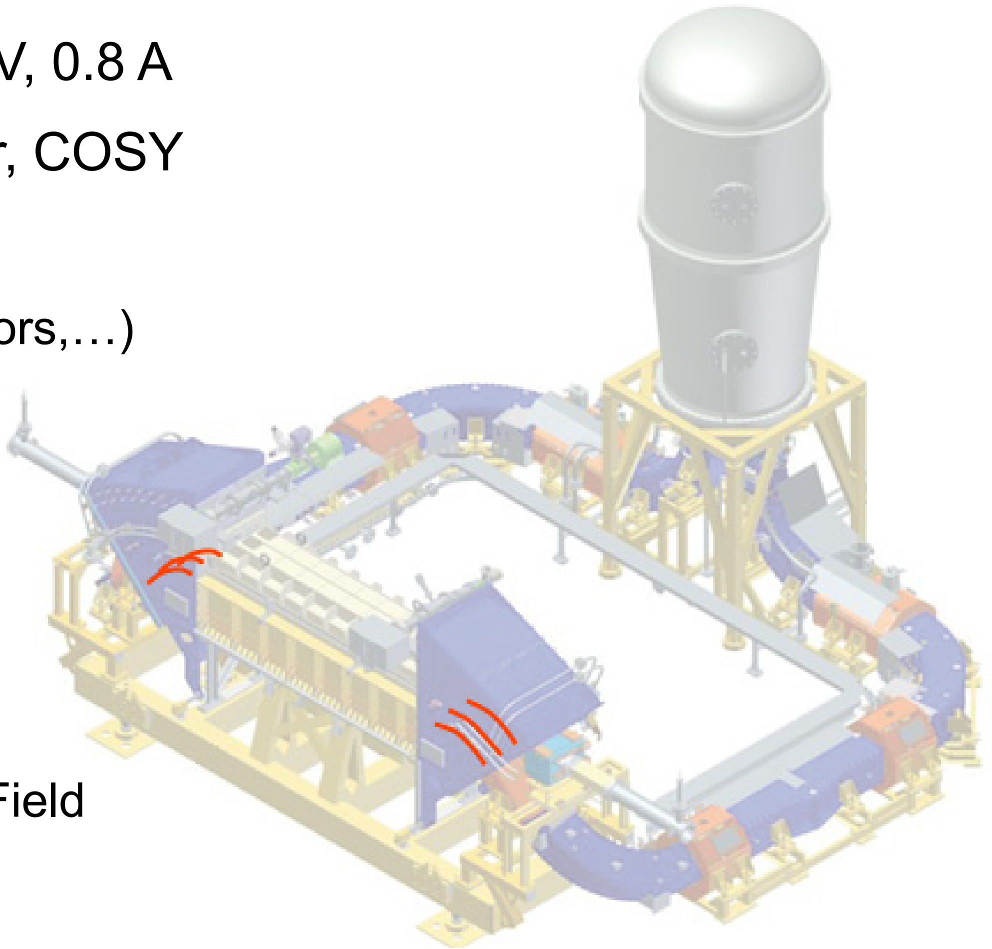

Main B-Fields: 4) Toroid 45° Field

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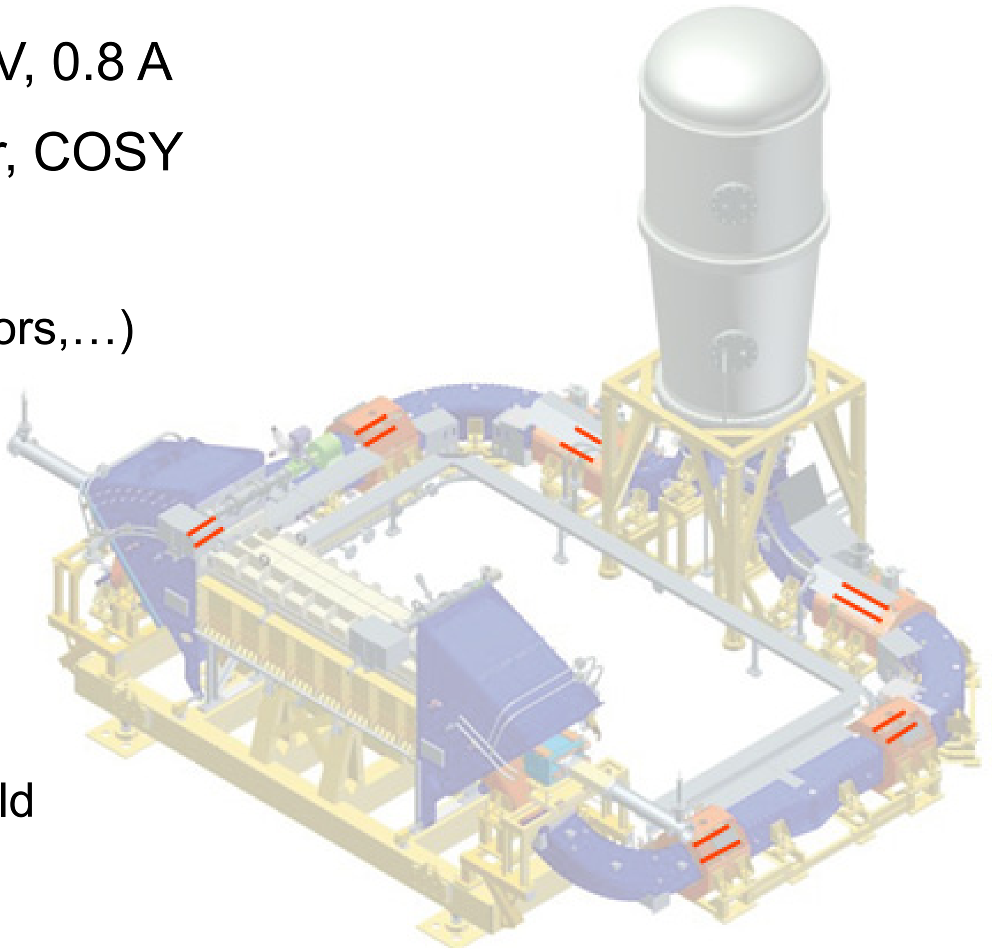
Main B-Fields: 5) Straight Field



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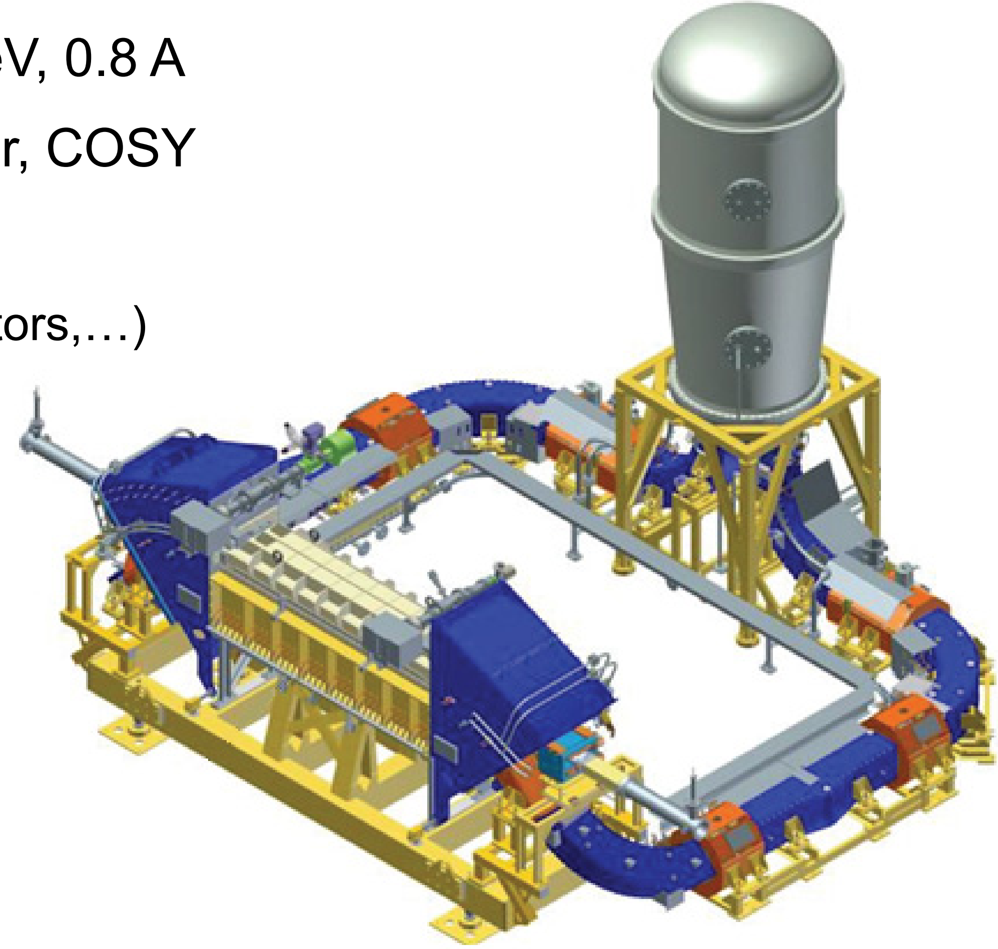


Motivation for a model based setup

- Achieving a better e beam quality. Thus higher
  - Cooling efficiency
  - Recuperation efficiency
  - Better vacuum conditions
  - Less radiation due to losses
- Compensate coupled effects during manual adjustment
  - Orbit shift at unregarded location | larmor rotation caused by orbit shift
- Enable unexplored beam regimes
- Ensure safe operation
  - with reproducible setups
  - using software safe guards (plausibility check)
- Save time and effort during e beam setup

e beam orbit

Gun modulates DC beam quadrantwise to make it visible to BPM system

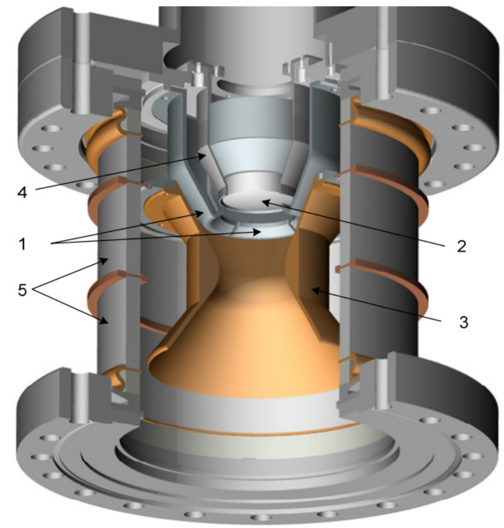
Orbit is set up completely manually

BPMs yield relative positioning but actual location might be off by ~ mm

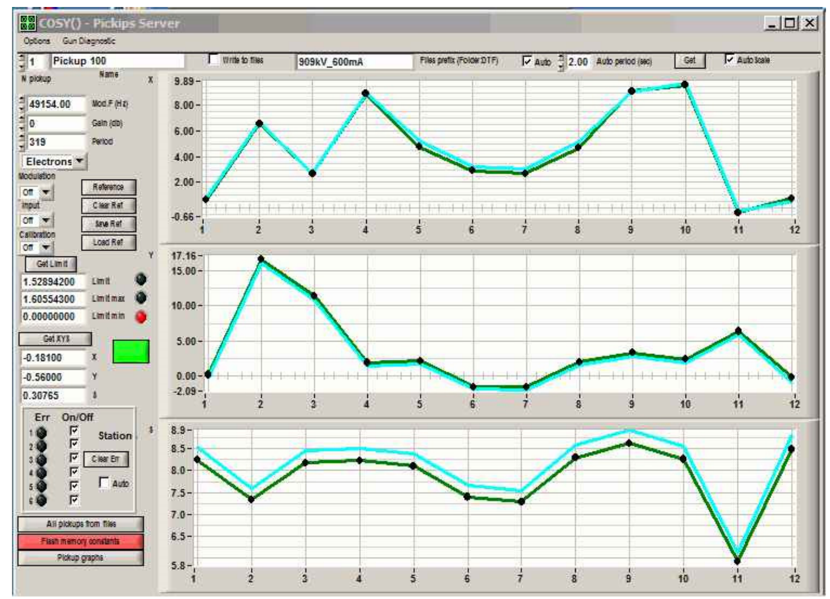
ORM can be measured or calculated.

Generally quadratic matrices can lead to overall nice orbit – but not here

Stepwise adjustment + feedback loops feasible



1)



1) Cool'11, Alushta, Urakine - Electron Gun with Variable Beam Profile for COSY COOLER M.Bryzgunov et al.

Reliability of calculated ORMs (@ 909 keV)

JÜLICH FORSCHUNGSZENTRUM

Calculated X

	b1	b2	l1v	lih	b3	t1	cv	ch	t2	b4	l2v	l2h	b5	b6
2	-2													
3	-2	0												
4	-2	0,2	-0	1,7										
5	-2	1,6	-2	1,2	-0									
6	-2	1,3	-2	1,1	-0	0,8								
7	-2	1,3	-2	0,6	-0	0,8	0	1						
8	-2	1,4	-2	1,3	-0	0,9	0	1,2	1					
9	-2	0,3	0,7	1,8	-2	0,8	1	1	0,9	-1				
10	-2	-0	0,3	1,5	-1	0,6	0,6	0,8	0,7	-1	-0	2		
11	-2	0,2	0,4	1,6	-1	0,9	0,9	1	0,9	-1	0,2	2,1	-0	
12	-3	-1	0,5	1,2	-3	0,4	0,7	0,5	0,4	-2	1,2	2	-1	-2

Measured X

	b1	b2	l1v	lih	b3	t1	cv	ch	t2	b4	l2v	l2h	b5	b6
2	-2													
3	-2	0,1												
4	-2	0,4	-1	2										
5	-2	1,4	-2	1,6	-0									
6	-1	1,3	-2	1,3	-0	1								
7	-2	1,4	-2	1,4	0	1	-0	1,1						
8	-2	1,2	-2	1,7	-0	1,1	0,1	1,4	1,2					
9	-2	-0	0,3	1,5	-1	0,6	0,7	0,9	0,7	-2				
10	-2	-0	0,4	2,3	-2	0,9	0,9	1,1	0,9	-1	-0	2,4		
11	-2	0,2	-0	2,2	-1	1	0,8	1,2	1	-1	-1	2,3	0,1	
12	-2	-0	0,6	1,7	-2	0,6	0,9	0,9	0,7	-2	0,8	2,6	-0	-2

sim y

Calculated Y

	b1	b2	l1v	lih	b3	t1	cv	ch	t2	b4	l2v	l2h	b5	b6
2	0,1													
3	0,2	-2												
4	-0	-2	3,1	0,1										
5	-1	-1	2,4	1,2	-2									
6	-1	-1	2,2	0,9	-2	-0								
7	-2	-1	2,1	0,7	-2	-0	0,8	-0						
8	-1	-2	2,6	1,1	-2	-0	0,9	-0	-0					
9	0,8	-1	3,1	0	-1	-0	0,9	-1	-0	-1				
10	0,5	-2	3	0,2	-1	-1	0,6	-1	-1	-2	6,9	0,3		
11	0,3	-2	3,2	-0	-1	-1	0,5	-1	-1	-1	7,1	0	-2	
12	0,6	-3	4	-0	-2	-1	0,8	-1	-1	-2	9,5	-0	-2	0,2

meas y

Measured Y

	b1	b2	l1v	lih	b3	t1	cv	ch	t2	b4	l2v	l2h	b5	b6
2	-0													
3	0,1	-2												
4	0,1	-2	3,1	0,2										
5	-1	-2	2,4	1,1	-2									
6	-1	-1	2,2	1	-2	0								
7	-1	-2	2,2	1	-2	0,1	0,9	-0						
8	-1	-2	2,6	0,9	-2	-0	1,1	-0	-0					
9	0,6	-2	3	-0	-1	-1	0,7	-1	-1	-2				
10	1,1	-3	4,2	-1	-2	-1	0,8	-1	-1	-2	7,6	-0		
11	1	-3	4,3	-1	-2	-1	0,8	-1	-1	-1	7,5	-0	-2	
12	1,2	-2	3,3	-1	-1	-1	0,6	-2	-1	-1	8,4	-1	-3	0,1

Values in mm/A

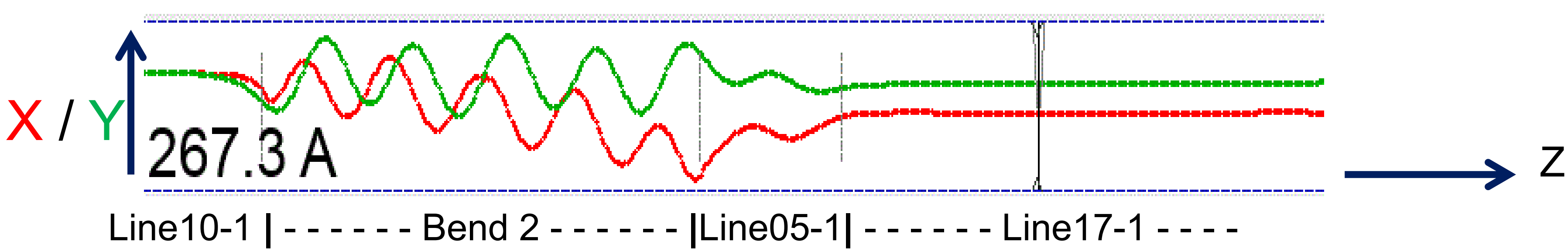
Larmor rotation

Transversal cyclotron motion with longitudinal velocity

Larmor rotation is inevitable but can be kept small

Occurs due to:

- off axis transiton of high gradient regions
- improper setting of longitudinal fields especially in bending section
  - also orbit dependend



Larmor radius measurement

Increased longitudinal B-field compresses spiral trajectory

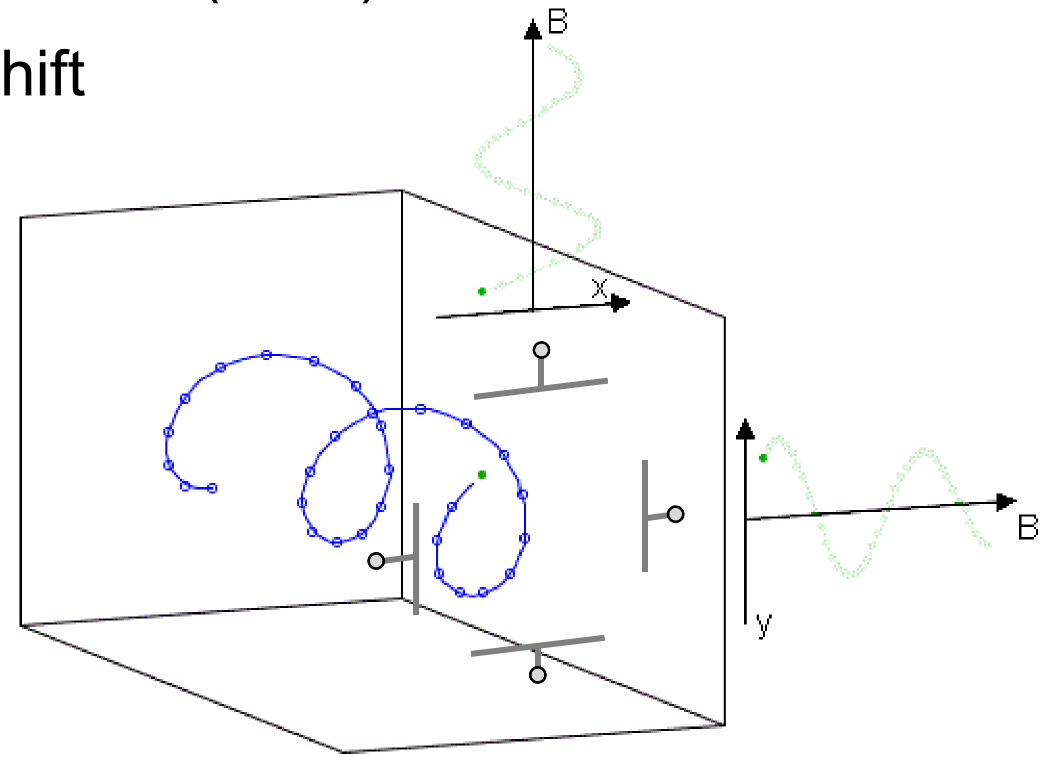
Phase change at fixed location (BPM)

seen as beam position shift

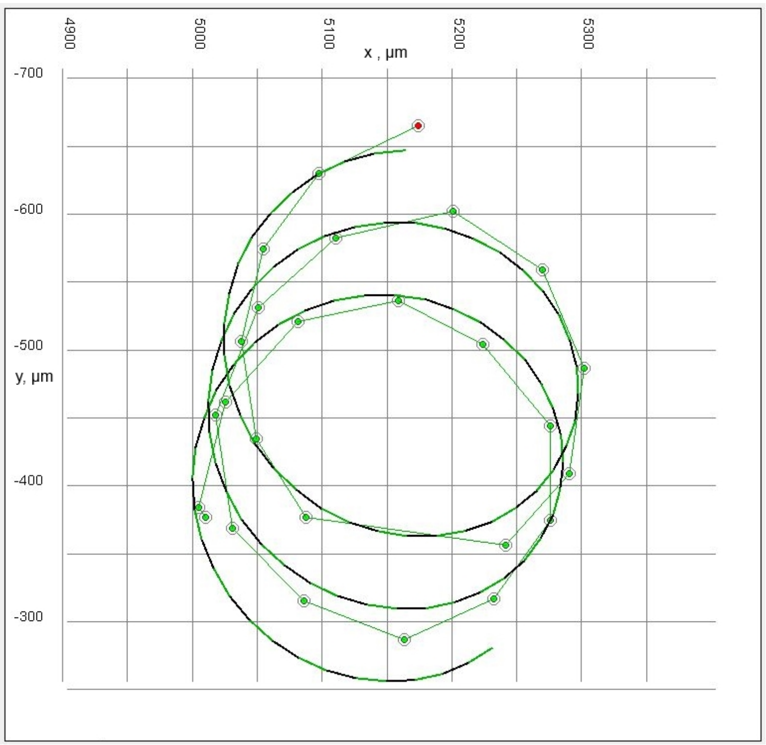
$$r_{Larmor} = \frac{m \cdot v_{\perp}}{e \cdot B}$$

$$l_{Larmor} = v_{\parallel} \cdot \frac{2\pi \cdot m}{e \cdot B}$$

$$\omega_s = \frac{L_{total} \cdot c}{E_{e0} \cdot \gamma \cdot \beta}$$

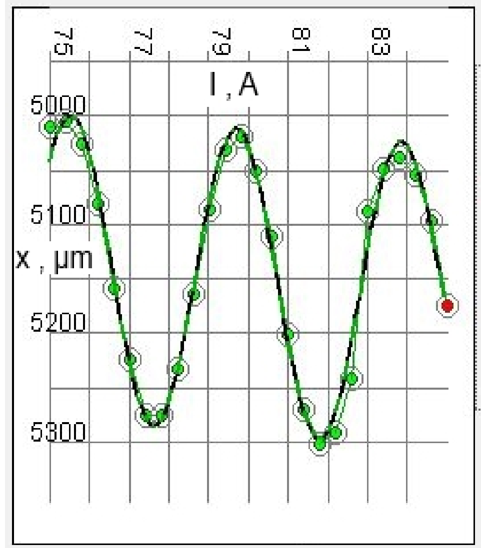


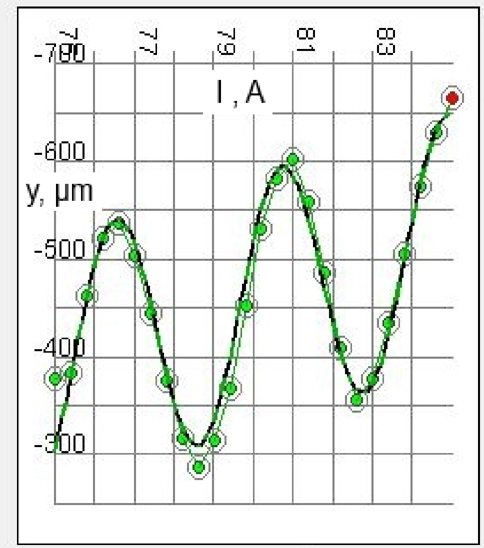
Actual results of a larmor radius measurement



Y-Coordinate

X-Coordinate



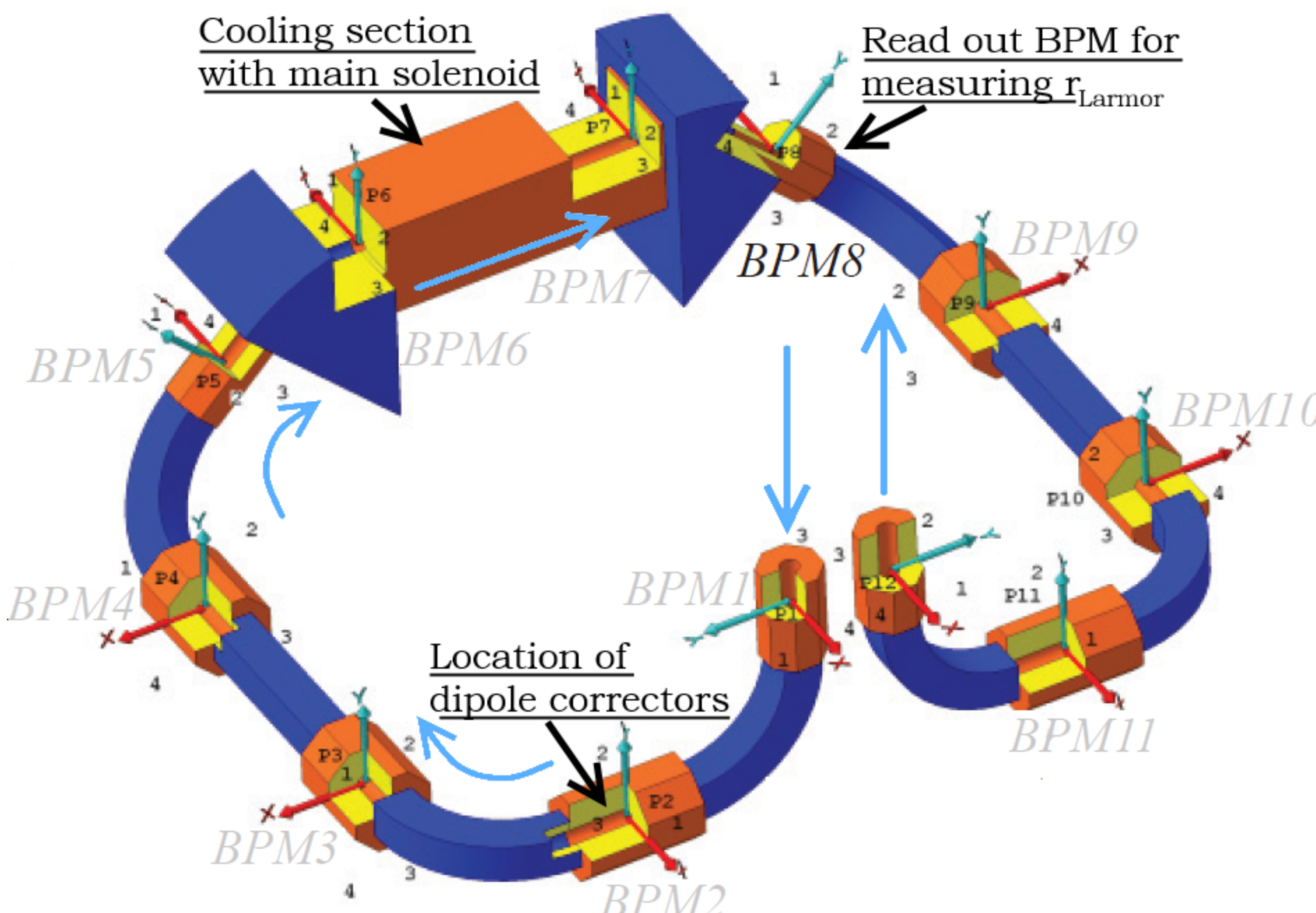


Respective coordinates vs. solenoid current

Larmor rotation compensation

Short dipoles kick the beam

decreasing larmor radius in cooling section



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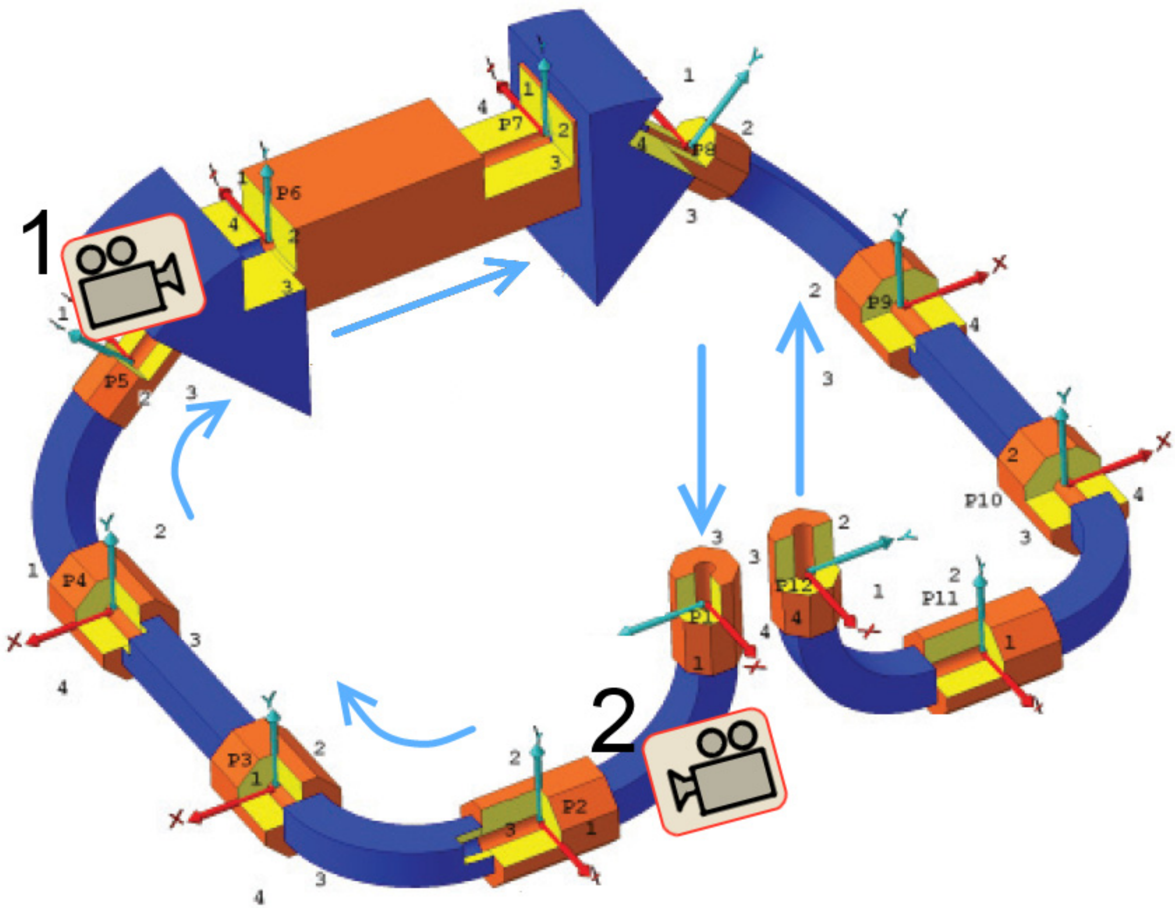
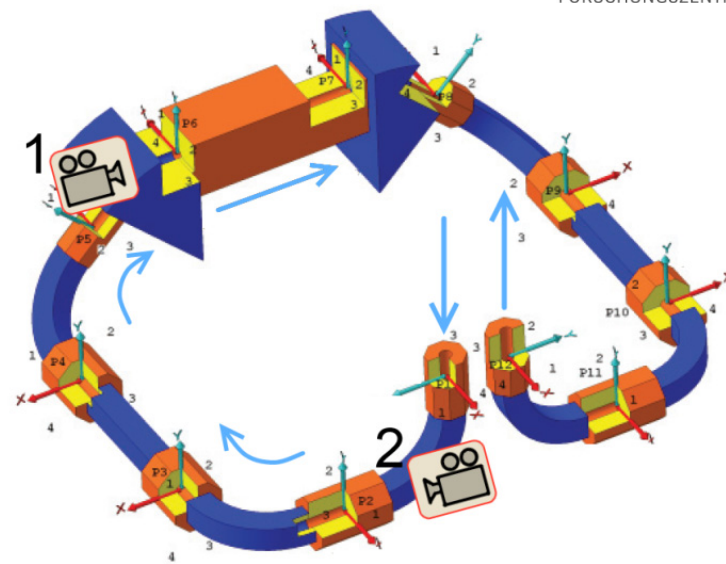
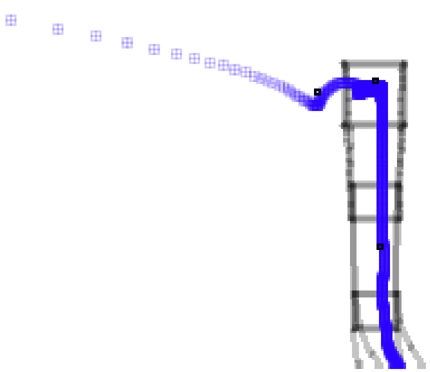


Larmor rotation compensation

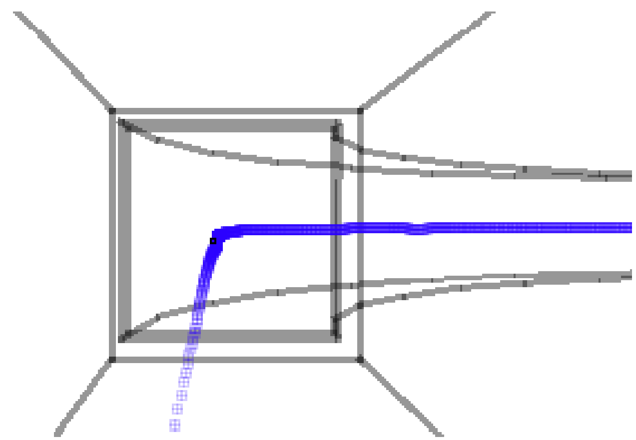
Looking along the beam as it was kicked:

1) In the cooling section
2) At the kick location



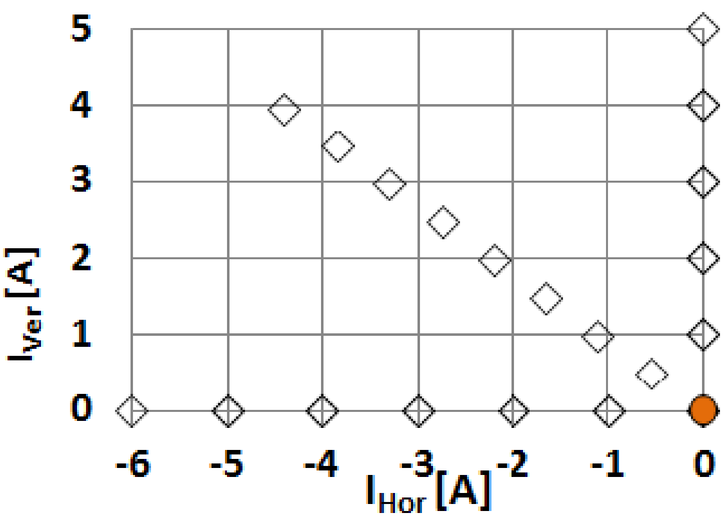


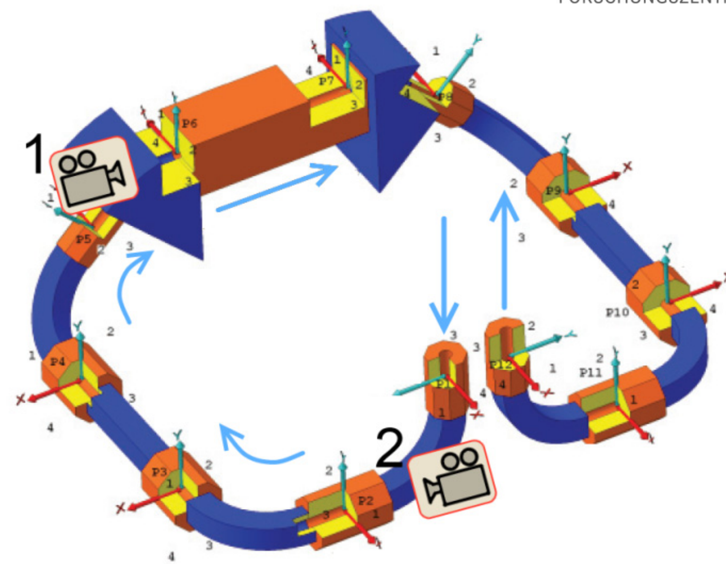
Cooling section



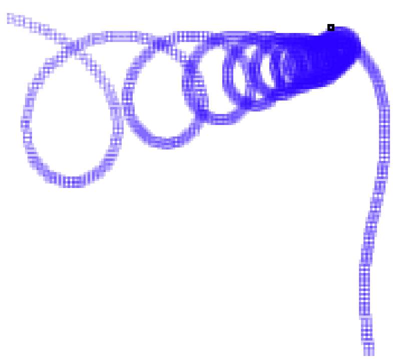
Kick location

Larmor rotation compensation

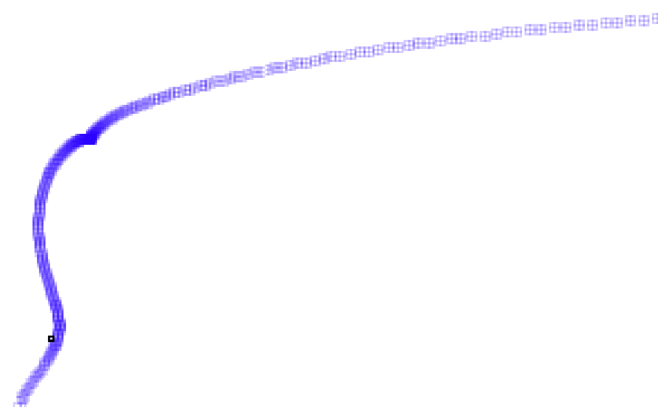




Sweeping the kicker currents to determine kick angle and strength

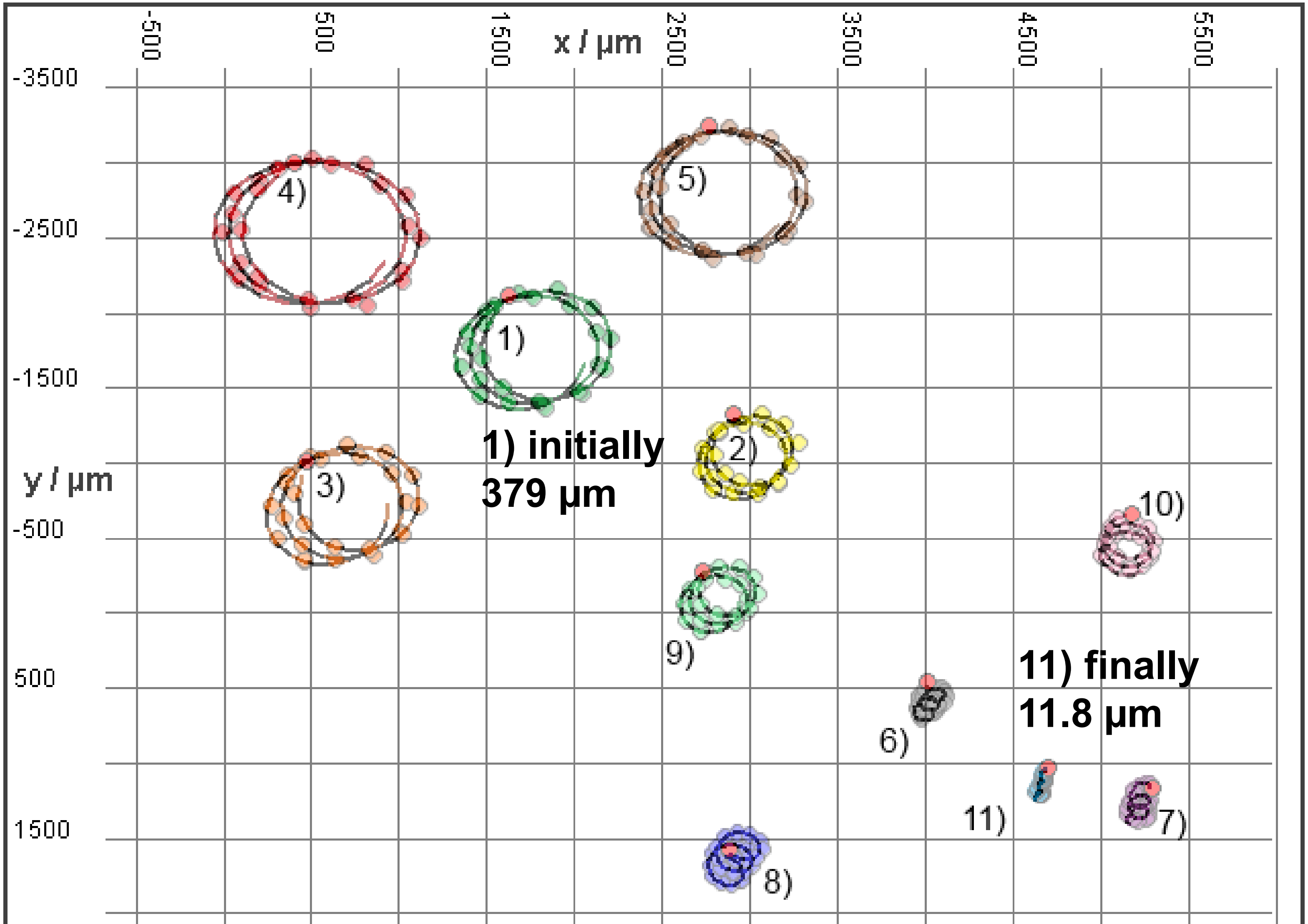


Cooling section



Kick location

Actual results of a larmor rotation compensation



Mitglied der Helmholtz-Gemeinschaft

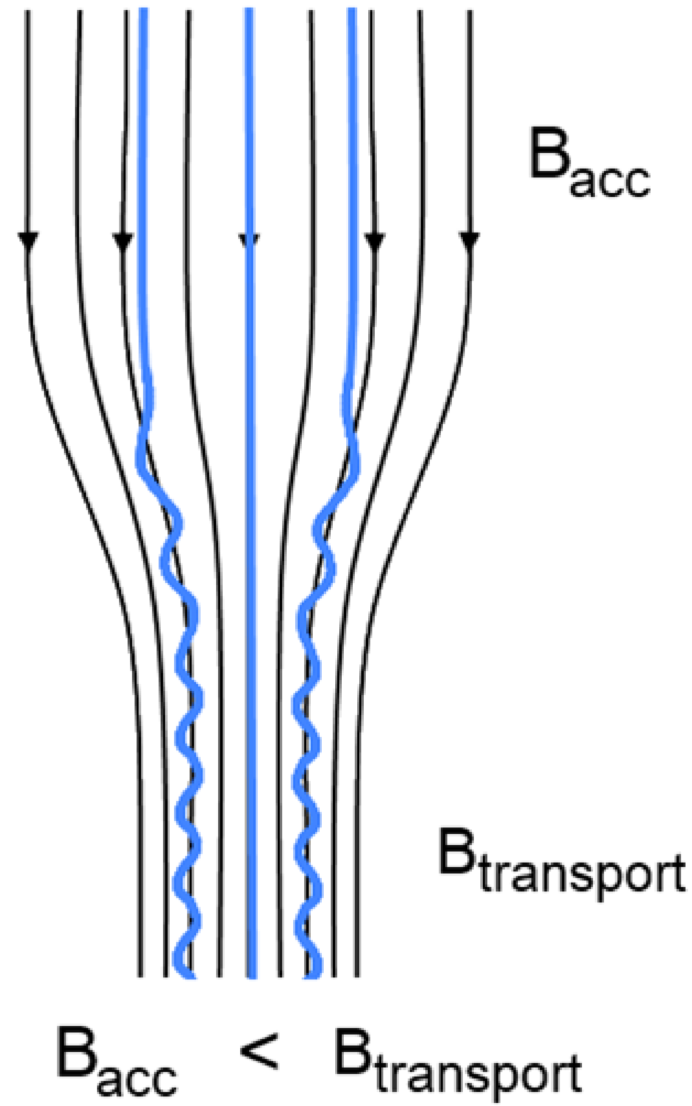
Galloping motion

Caused by passage through high gradient field

Similar to larmor rotation, thereby deterministic but not coherent

Individual larmor radius grows with distance to center

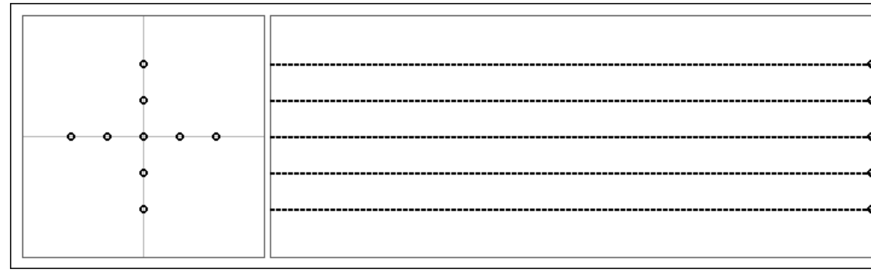
Larmor phase depends on tangential location of the individiual electron



Superposition of dipole and quadrupole motion

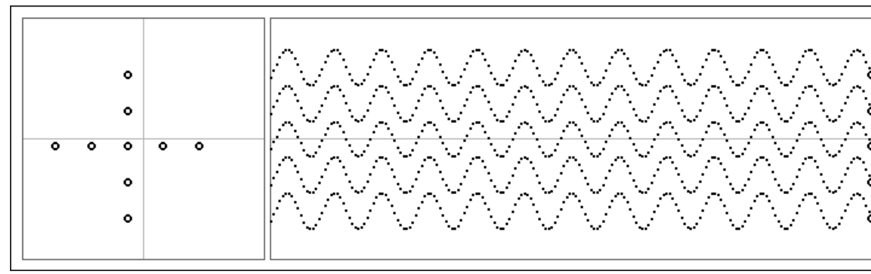
Theoretical cold beam

$$x = const, y = const$$



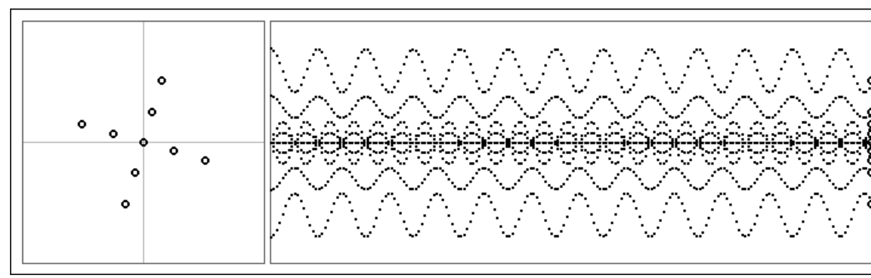
Pure larmor rotation

$$y(z) = y_0 + r_L \sin(zk + \varphi_L)$$

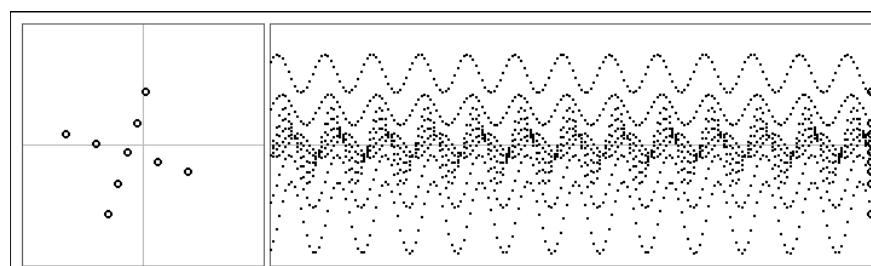


Pure galloping motion

$$y(z) = y_0 + r_G(x_0, y_0)\sin(zk + \varphi_G(x_0, y_0))$$



Superposition of coherent Larmor rotation and galloping



Measuring Galloping motion

Measure larmor rotation of each quadrant

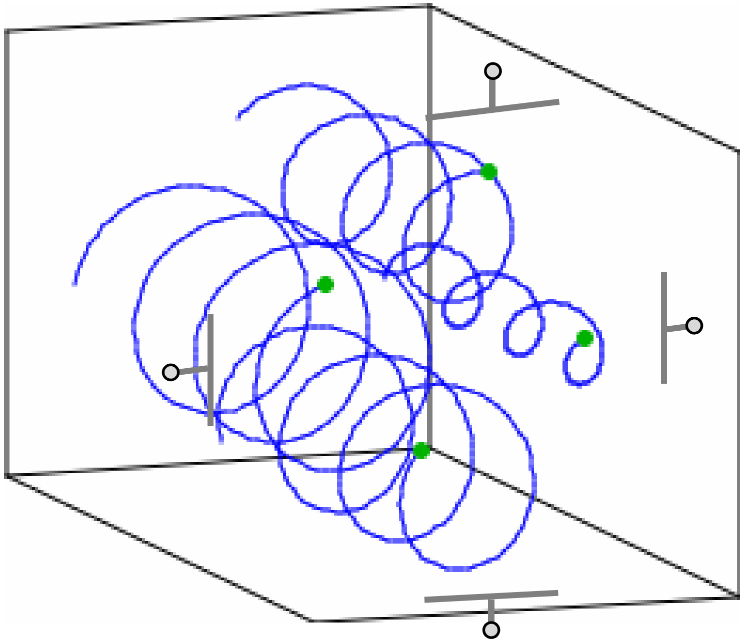
- enabled by quadrantwise modulation of the gun

Measure larmor of entire beam (center of charge)

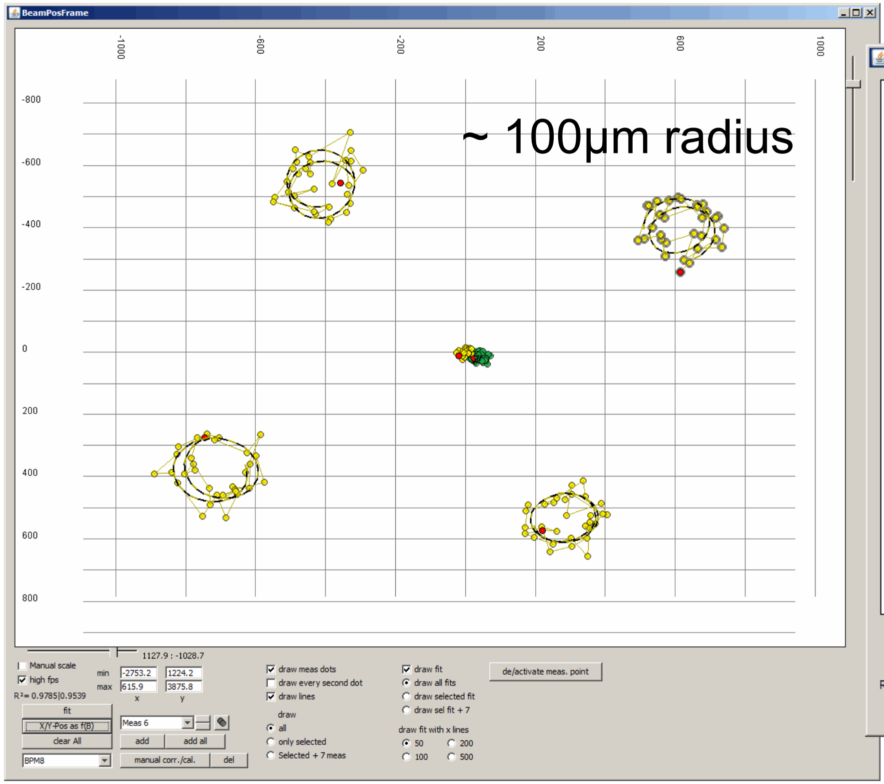
Expressed in sine & cosine coefficients,
larmor contribution can be subtracted

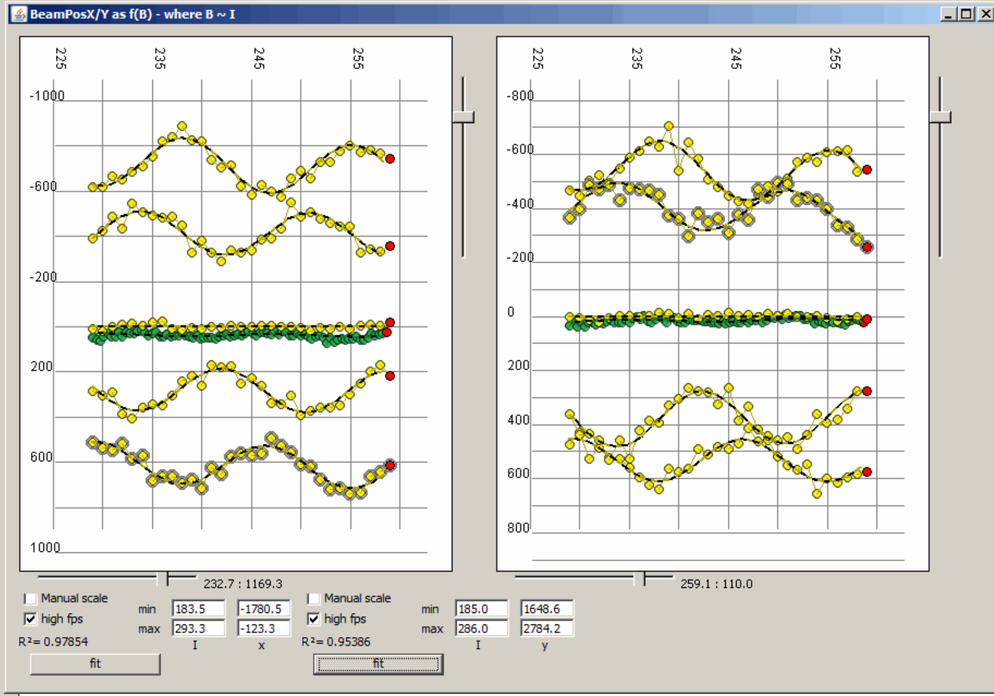
Characterisic quantity:

Galloping growth rate

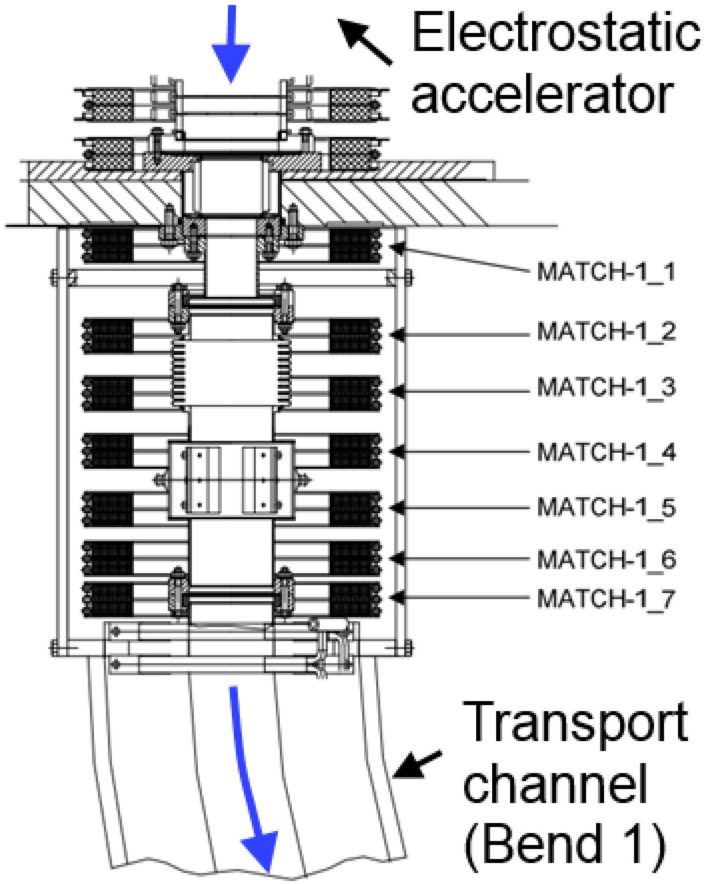


Actual measurement of the galloping motion

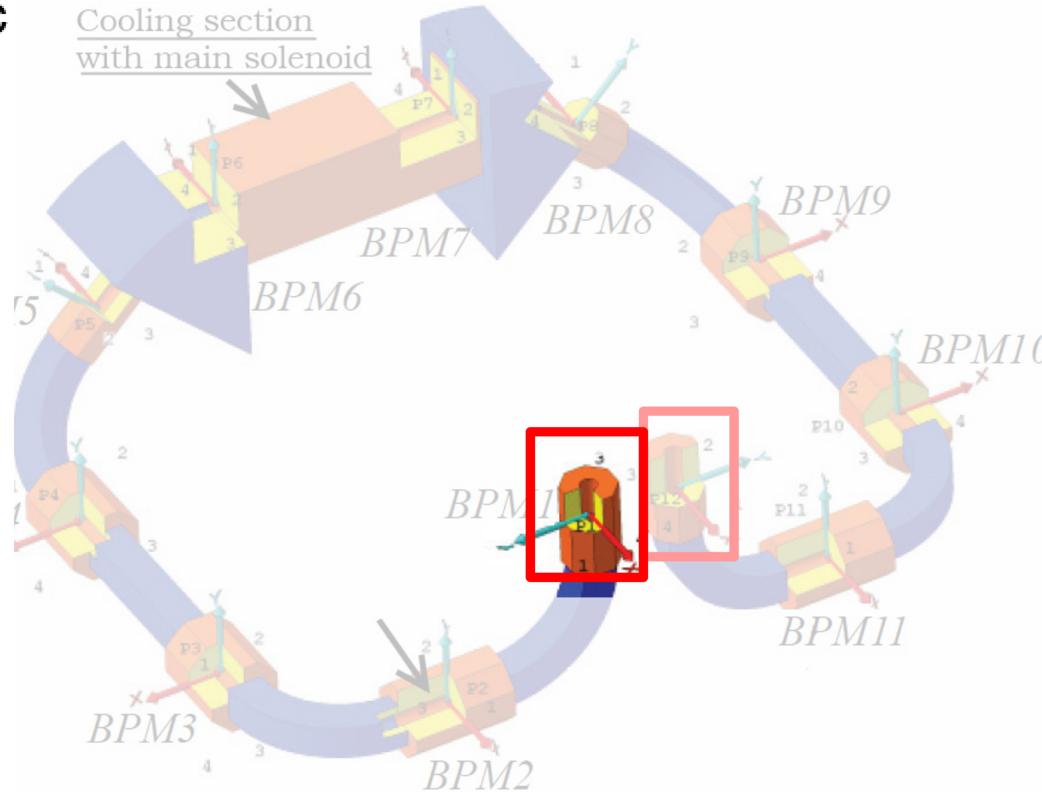




Magnetic matching section to compensate galloping

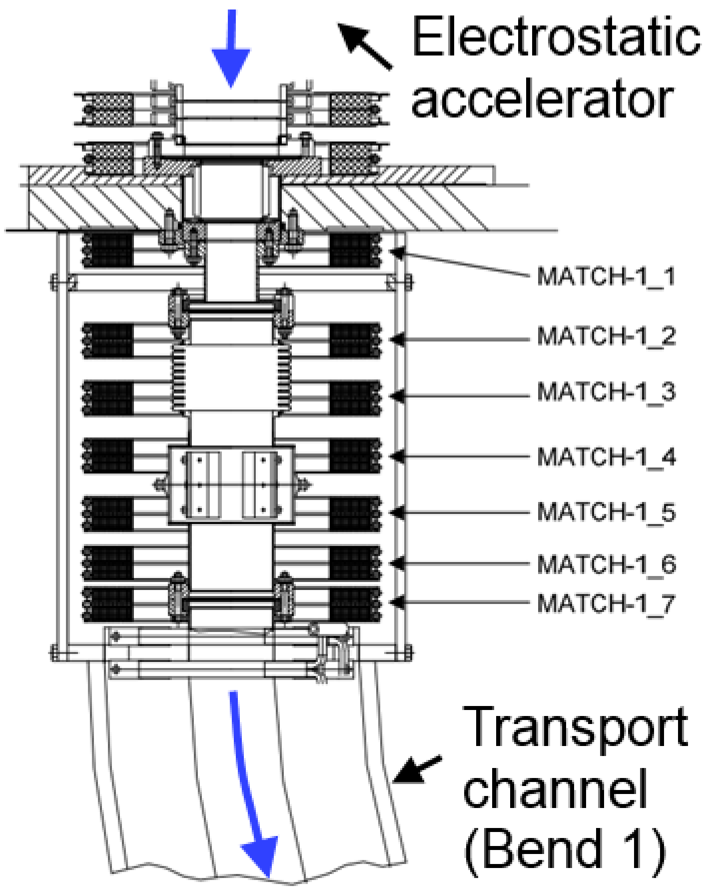


Matching section of the gun part.



Source: Internal Documentation / Technical Drawings

Magnetic matching section to compensate galloping



Matching section of the gun part.

A simple algorithm can lead to an optimized setting for the matching section

- Vary each magnet slightly
- Follow negative gradient of galloping growth rate
- repeat

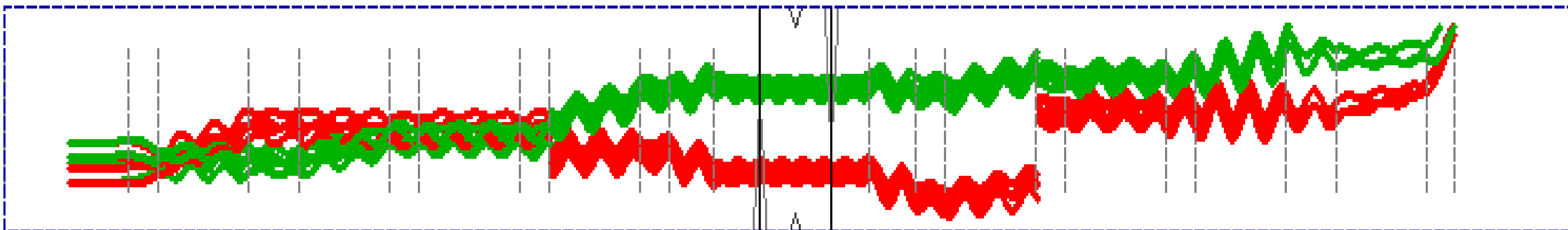
Source: Internal Documentation / Technical Drawings

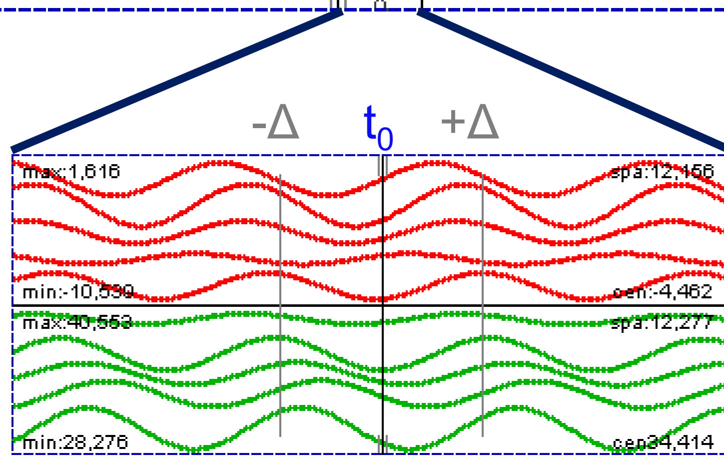
Treating larmor and galloping

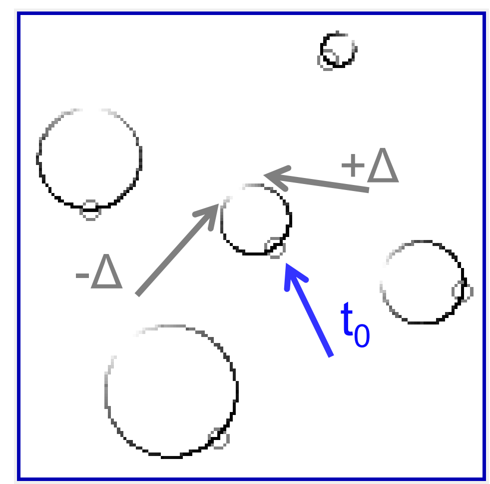
Initial trajectory

Superposition of larmor and galloping motion can be seen

Accel - Transport - Cooling Section - Transport - Decel







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Initial trajectory
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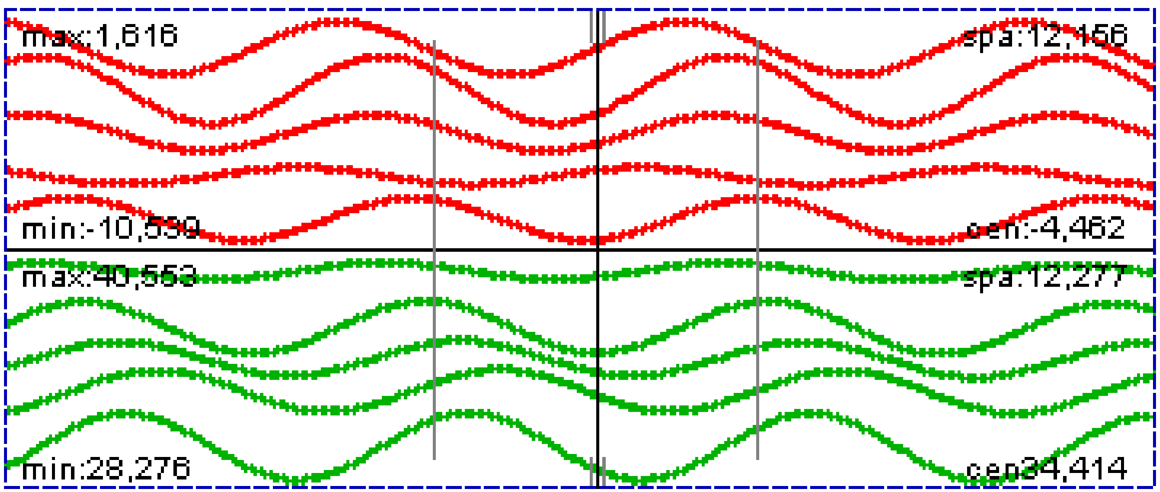
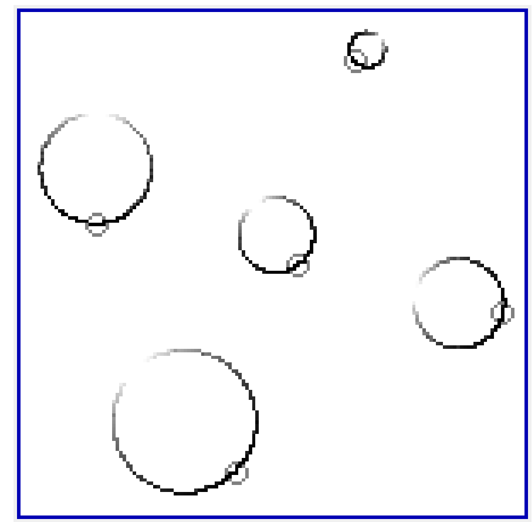
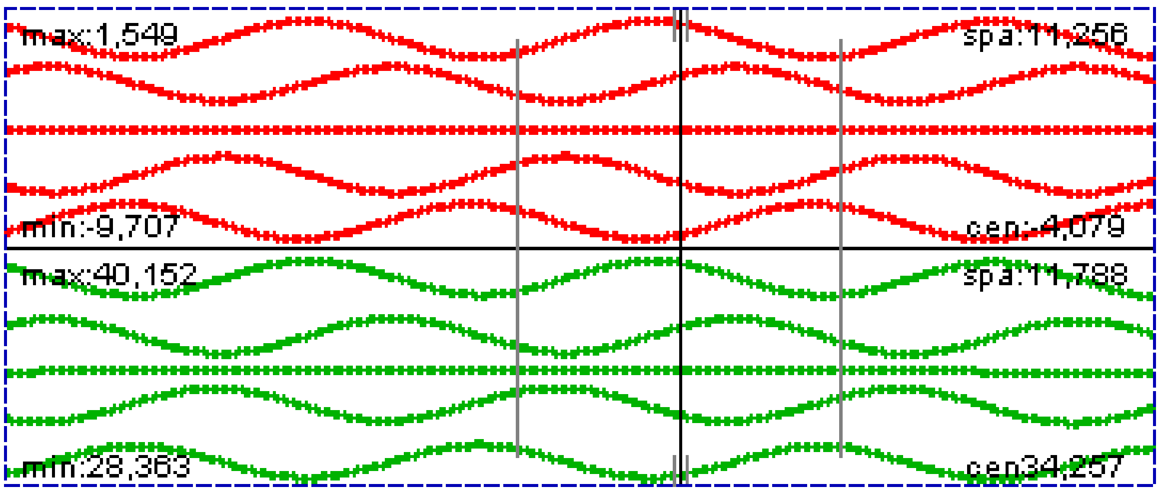


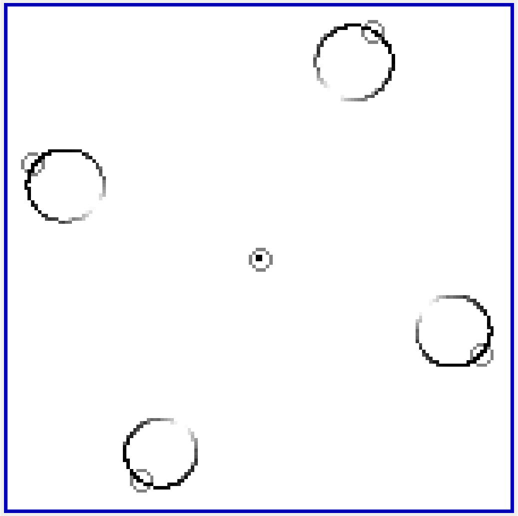


Initial larmor radius: 1.8 mm
Initial galloping growth: 0.17 μm/mm
Beam cooling is not possible

Treating larmor and galloping

Treat Larmor motion first
One can see now pure galloping motion

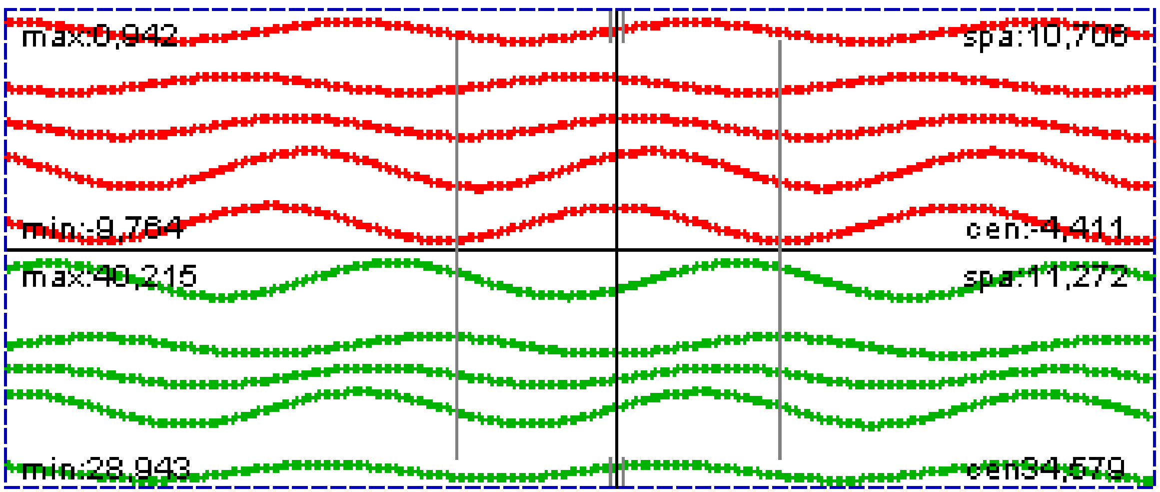


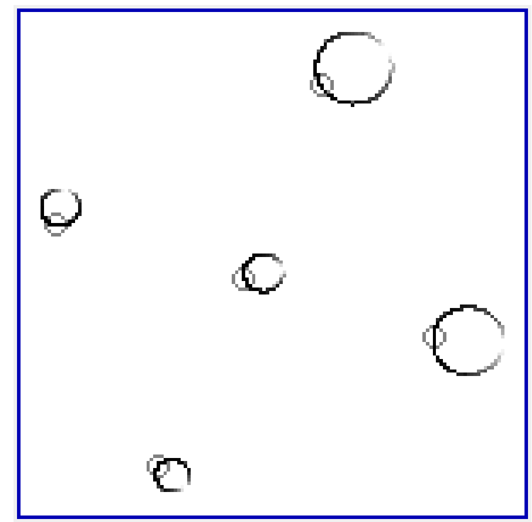


Initial larmor radius: 1.8 mm
Initial galloping growth: 0.17 μm/mm
Beam cooling is not possible

Treating larmor and galloping

Galloping treatment leads to changed transit
of beam center of charge through matching section

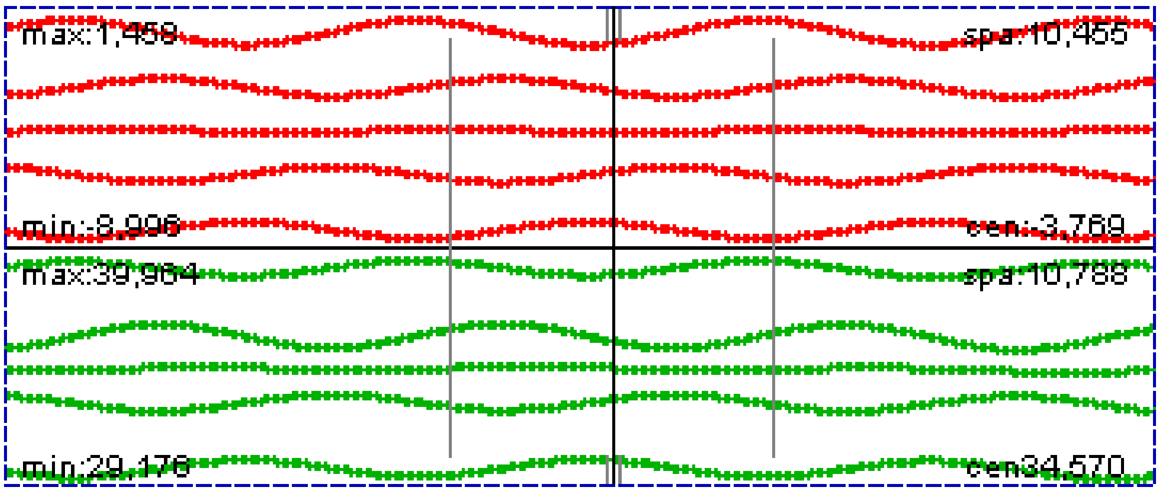


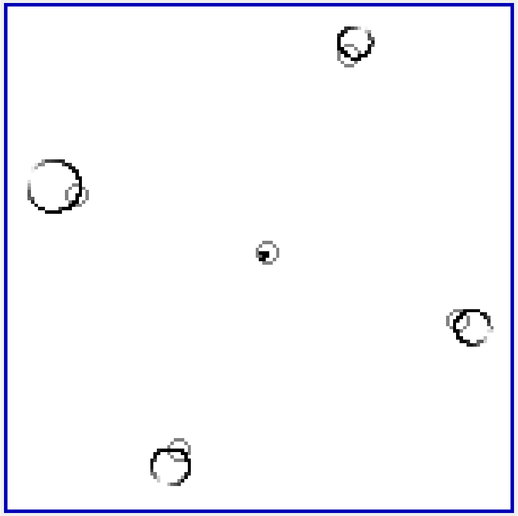


Initial larmor radius: 1.8 mm
Initial galloping growth: 0.17 µm/mm
Beam cooling is not possible

Treating larmor and galloping

After final larmor treatment, the results can be compared



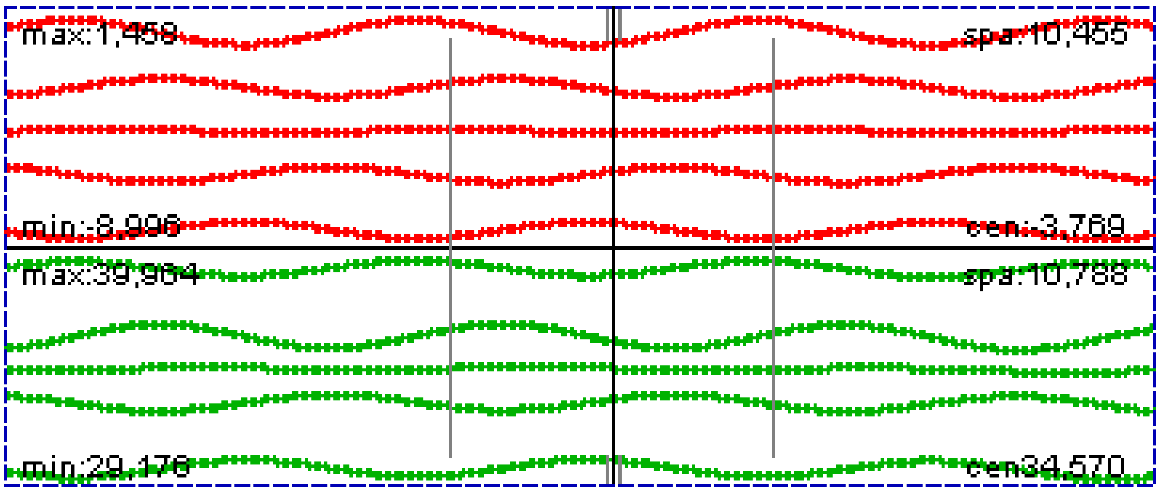


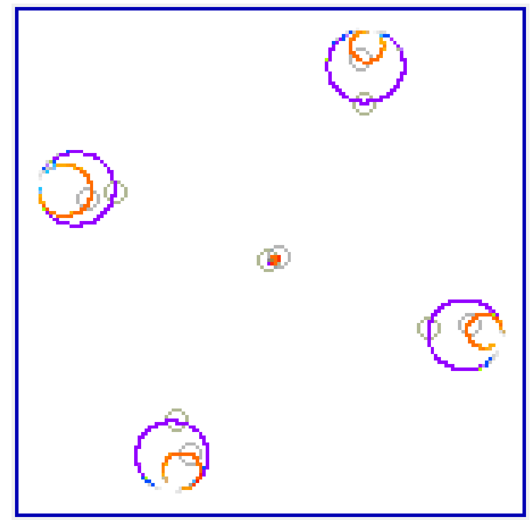
Initial larmor radius: 1.8 mm
Initial galloping growth: 0.17 µm/mm
Beam cooling is not possible

Final larmor radius < 100 µm
Final galloping growth: 0.11 µm/mm

Treating larmor and galloping

After final larmor treatment, the results can be compared





Initial larmor radius: 1.8 mm
Initial galloping growth: 0.17 µm/mm
Beam cooling is not possible

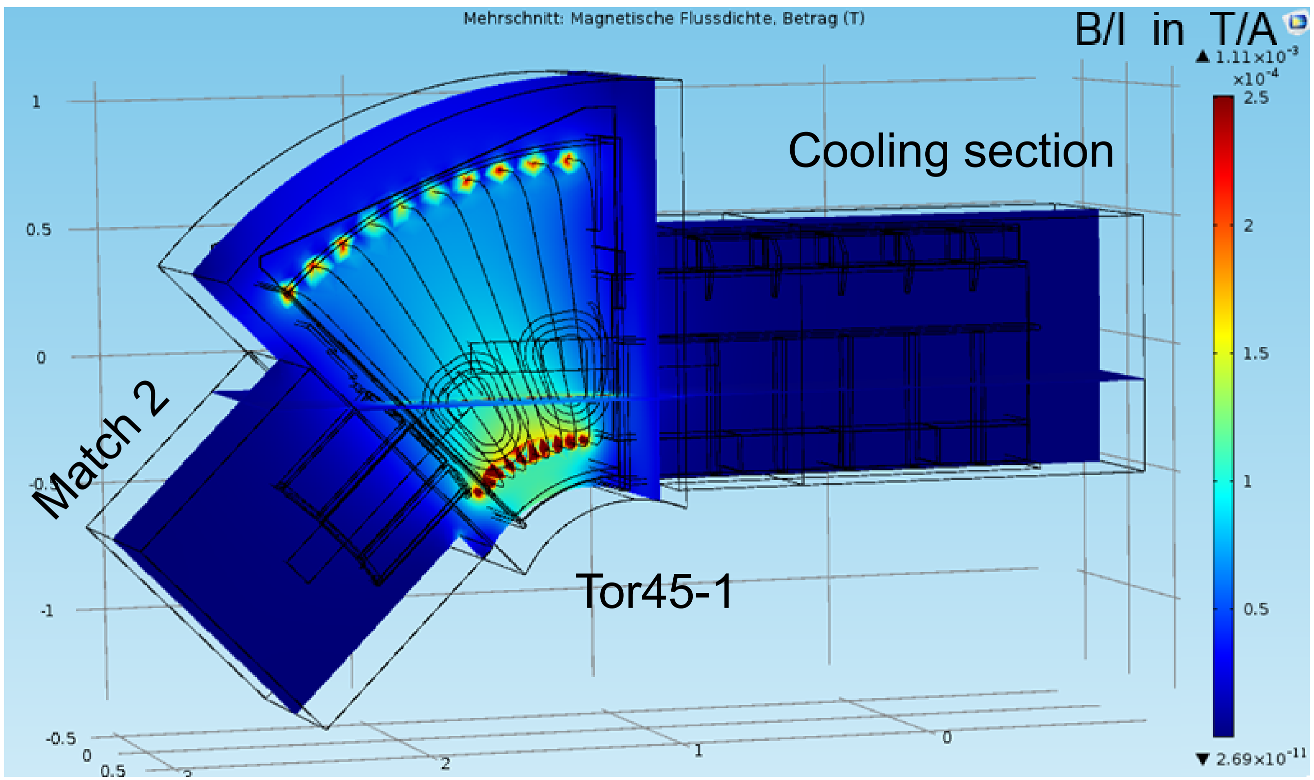
Final larmor radius < 100 µm
Final galloping growth: 0.11 µm/mm

Model: Magnetic Environment

Comsol simulations of each magnetic element @ 1 A

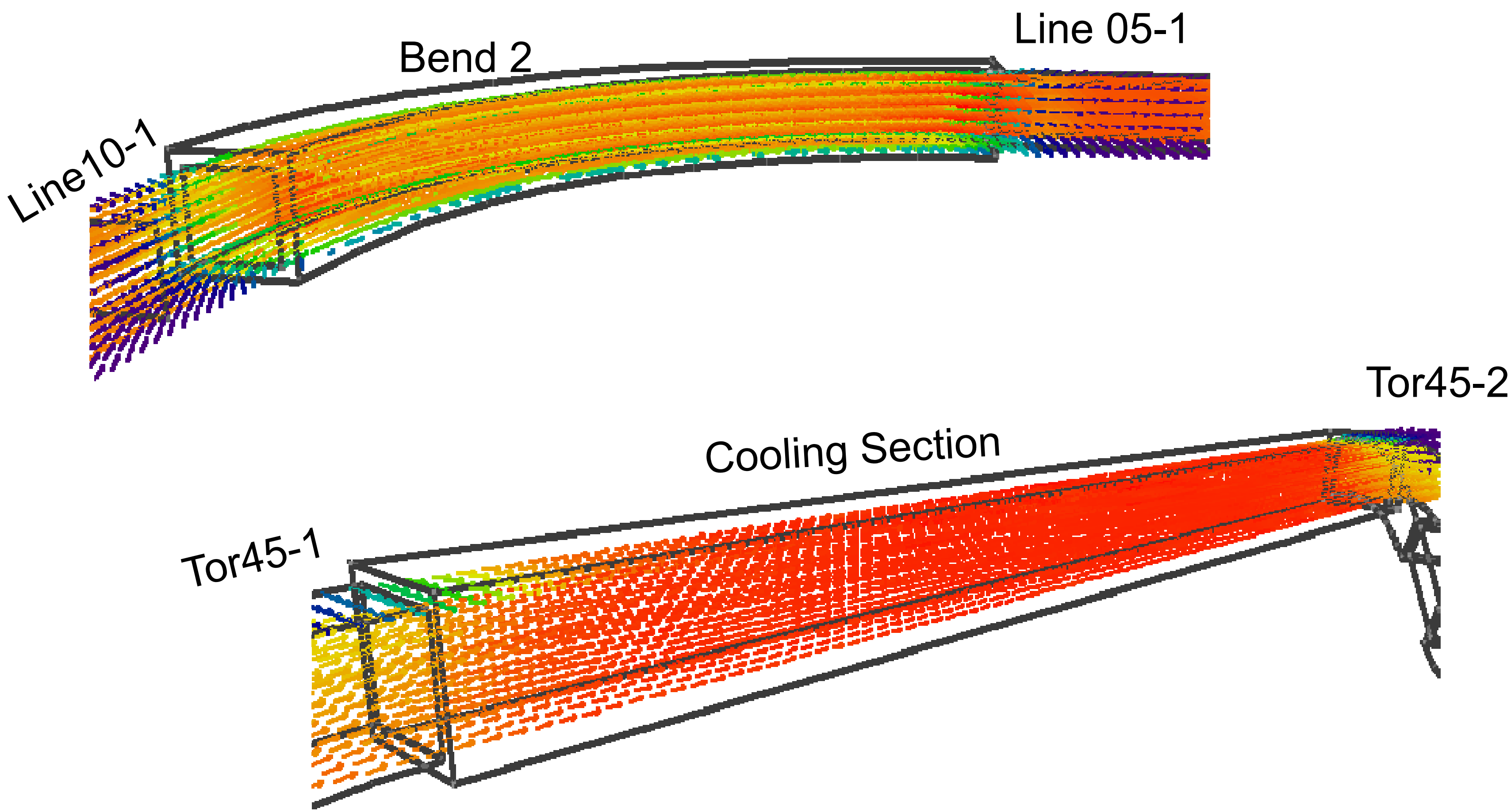
With and without magnetic shielding

Yield: 3D cloud data of magnetic fields



Model: Field maps

For indexed access fields have been translated onto equidistant grid



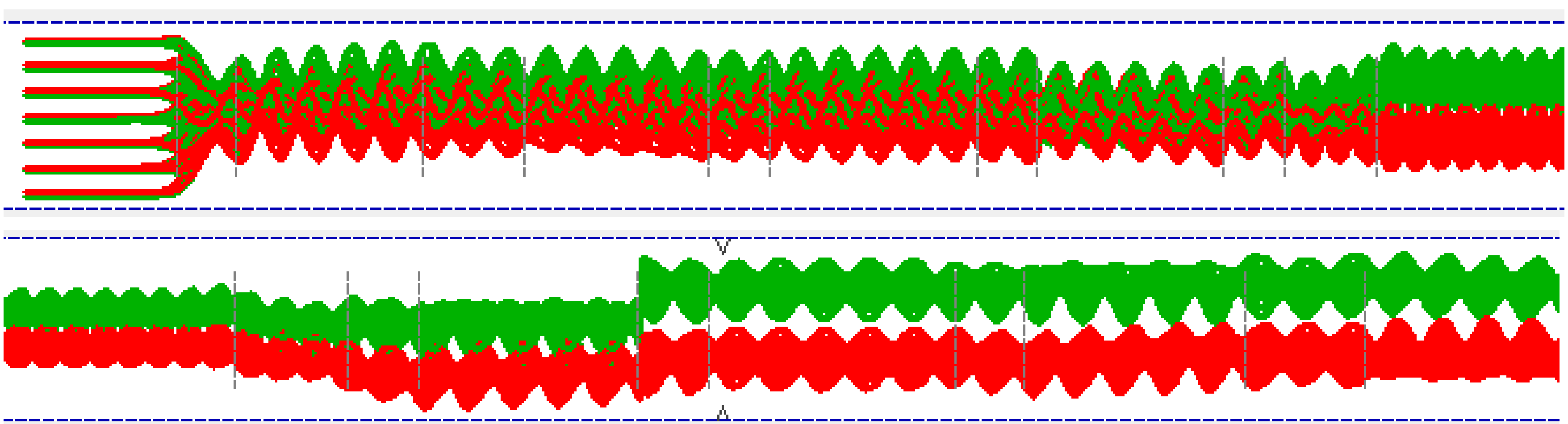
Electron trajectory in BPM coordinate system

Integration of instantaneous velocities leads to electron traces

These can be fitted piecewise for each section of homogeneous* magnetic fields

$$x(z) = x_0 + zm_x + A\sin(zk) + \mathrm{B}\cos(zk)$$

$$y(z) = y_0 + \mathrm{zm_y} + \mathrm{B}\sin(zk) - A\cos(\mathrm{zk})$$



Status of the Model

Expected physical effects are accounted for in the model
Thus:

Orbit: ORM can be calculated and measured for calibration of dipole correcors (slide 8)

Shape: Beam shape influence has been shown (characterization during upcoming test period in two weeks)

Larmor: Beam kick principle works (slide 11)

Galloping: Numeric methods offer proper setup of matching magnets (slide 16)

Status of the Model

A "relative" agreement of both the model and the cooler enables finding optimized setups for the cooler

while an actual working point has to be given by the cooler

Response schemes are used to calibrate the model

Next steps for the model

Towards an absolute calibration

Advantages:

Any beam behavior is known for any machine setup

Compensation possible without measuring feedback

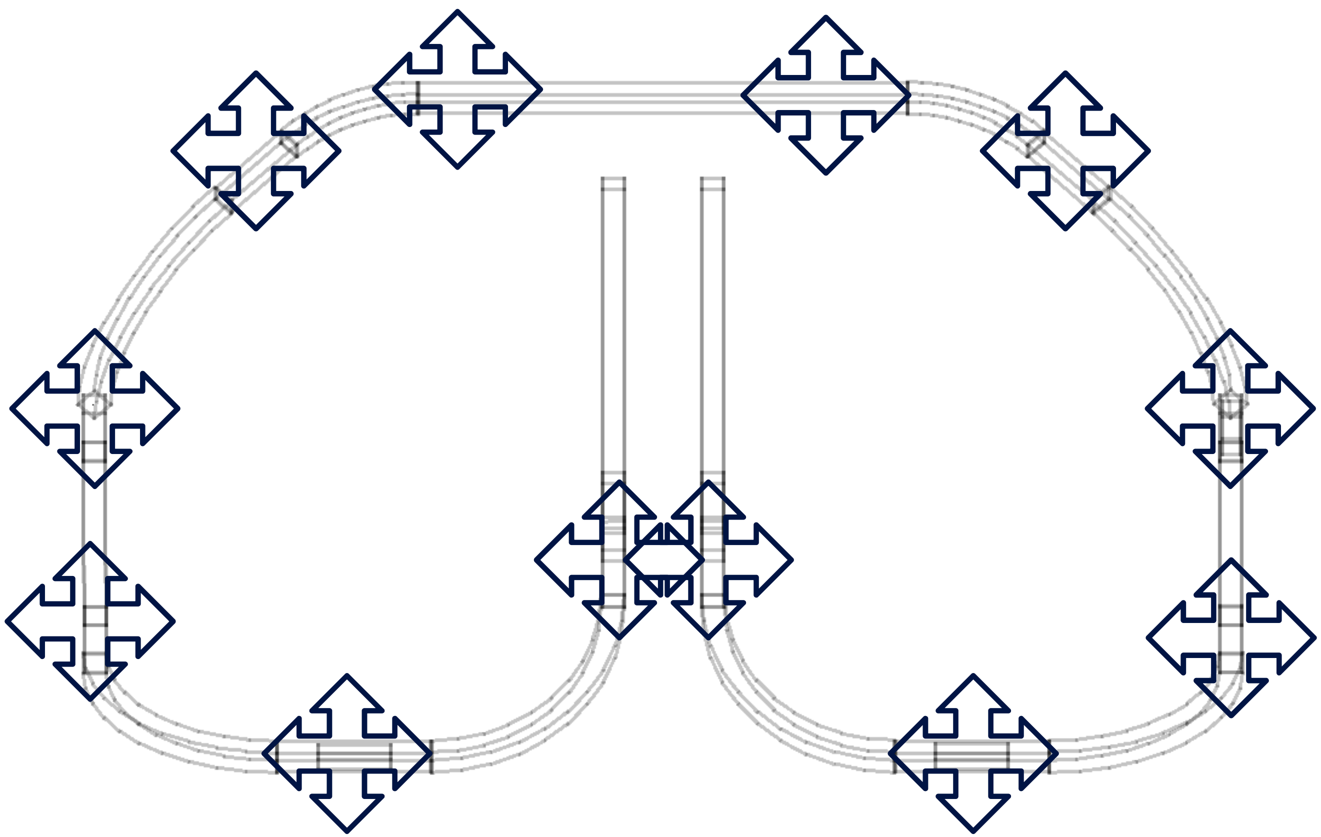
Effects of manual adjustments can be tested with help of the model

Optimized beam properties can be aimed for in more magnetic elements

Method 1 towards absolute calibration

Forth/ back tracing at each measures BPM location with angular and positional variations

Fit the most suitable match to determine for least RMS deviation



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Method 2 towards absolute calibration

Stepwise larmor assisted calibration

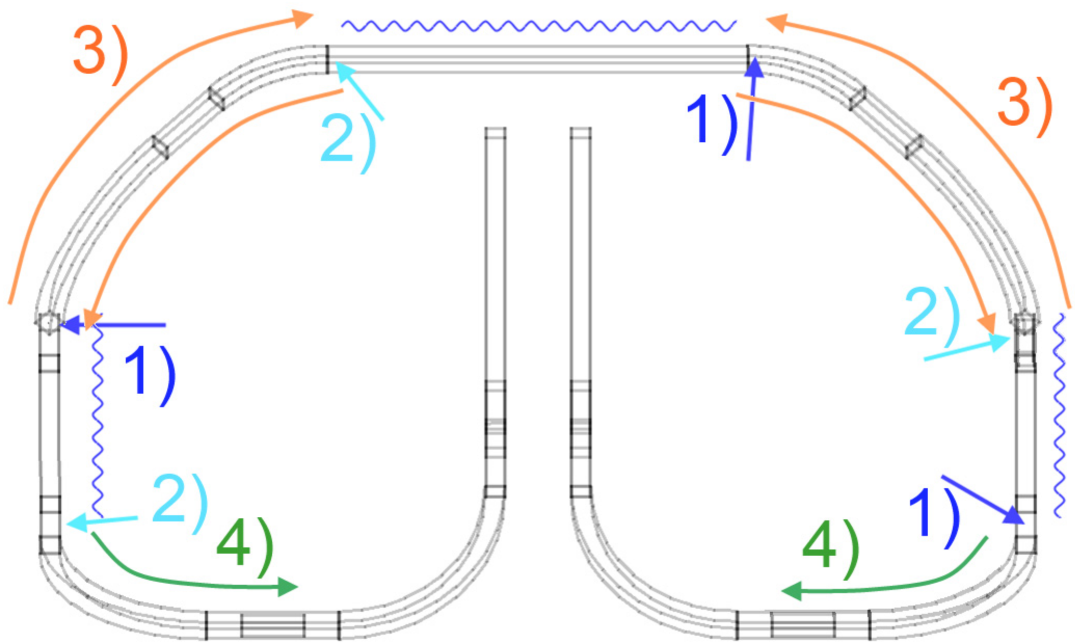
1) Larmor condition is best known in the 3 straight elements

2) Relative position of the two surrounding BPMs can be found

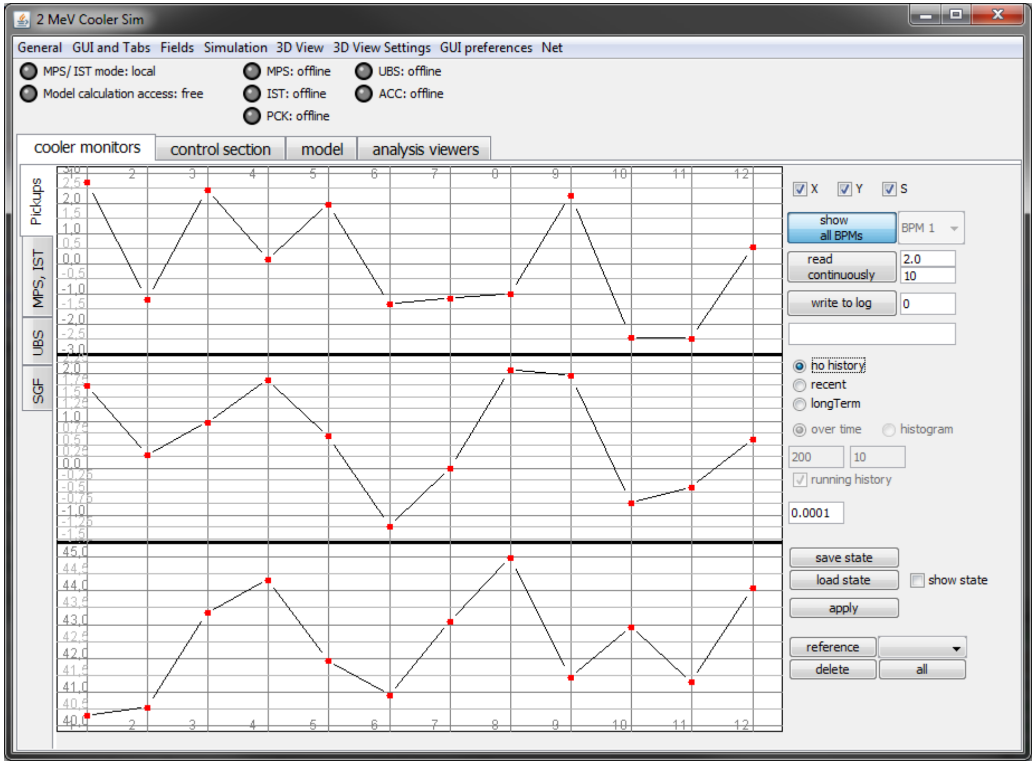
3) Tracing beween these elements can calibrate local longitudinal fields

Relative position of grouped BPM can be narrowed down

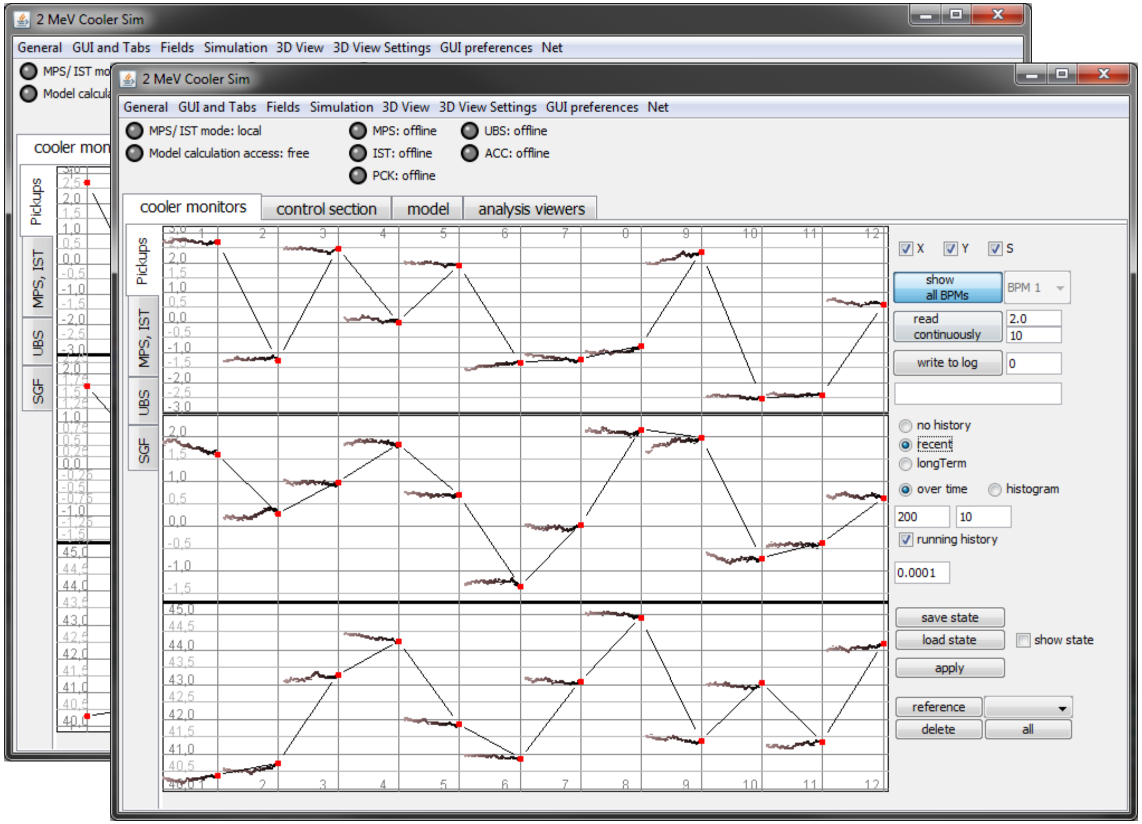
4) Tracing further back/ forth yields most authentic trajectory



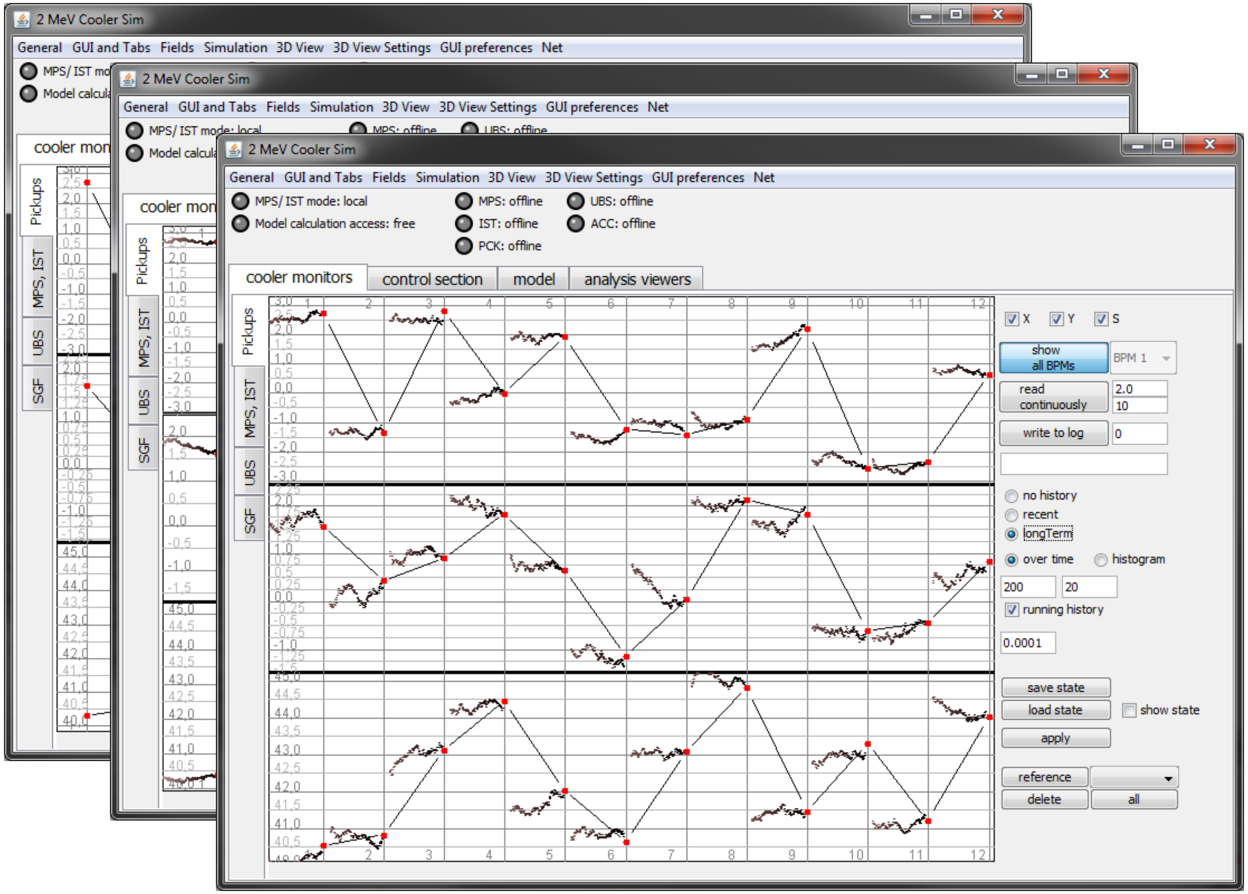
GUI Slide show



GUI Slide show

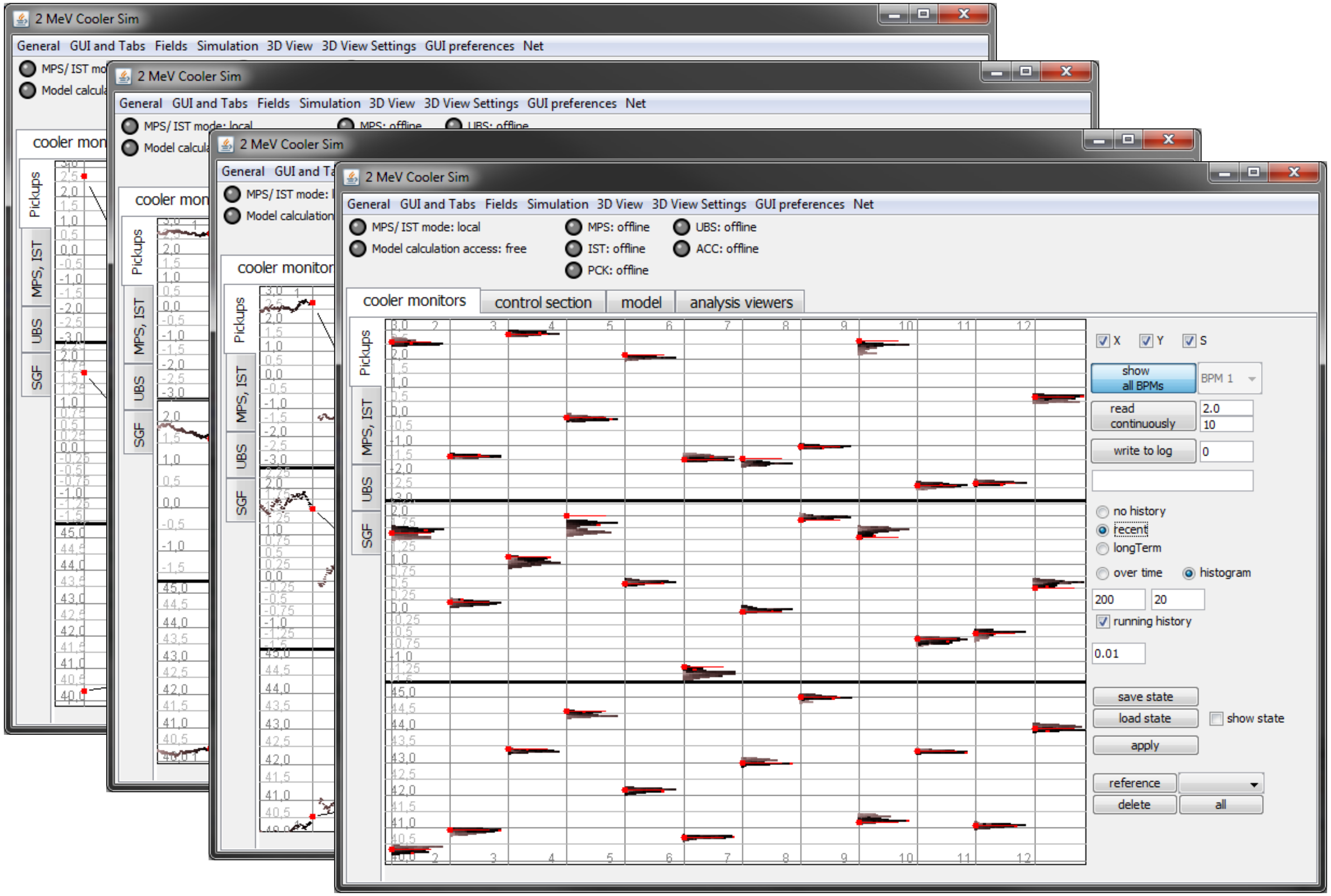


GUI Slide show

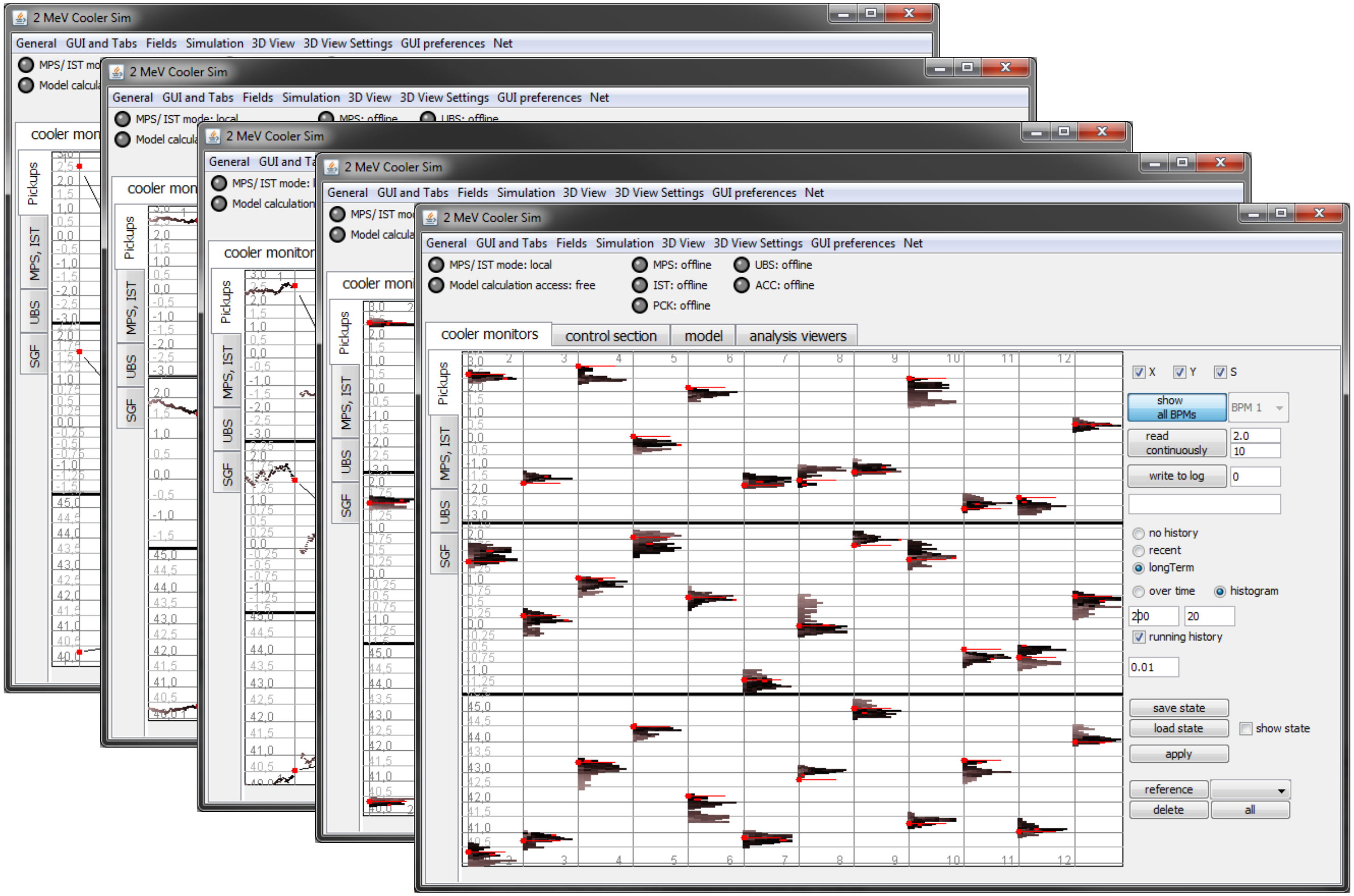


Mitglied der Helmholtz-Gemeinschaft

GUI Slide show



GUI Slide show



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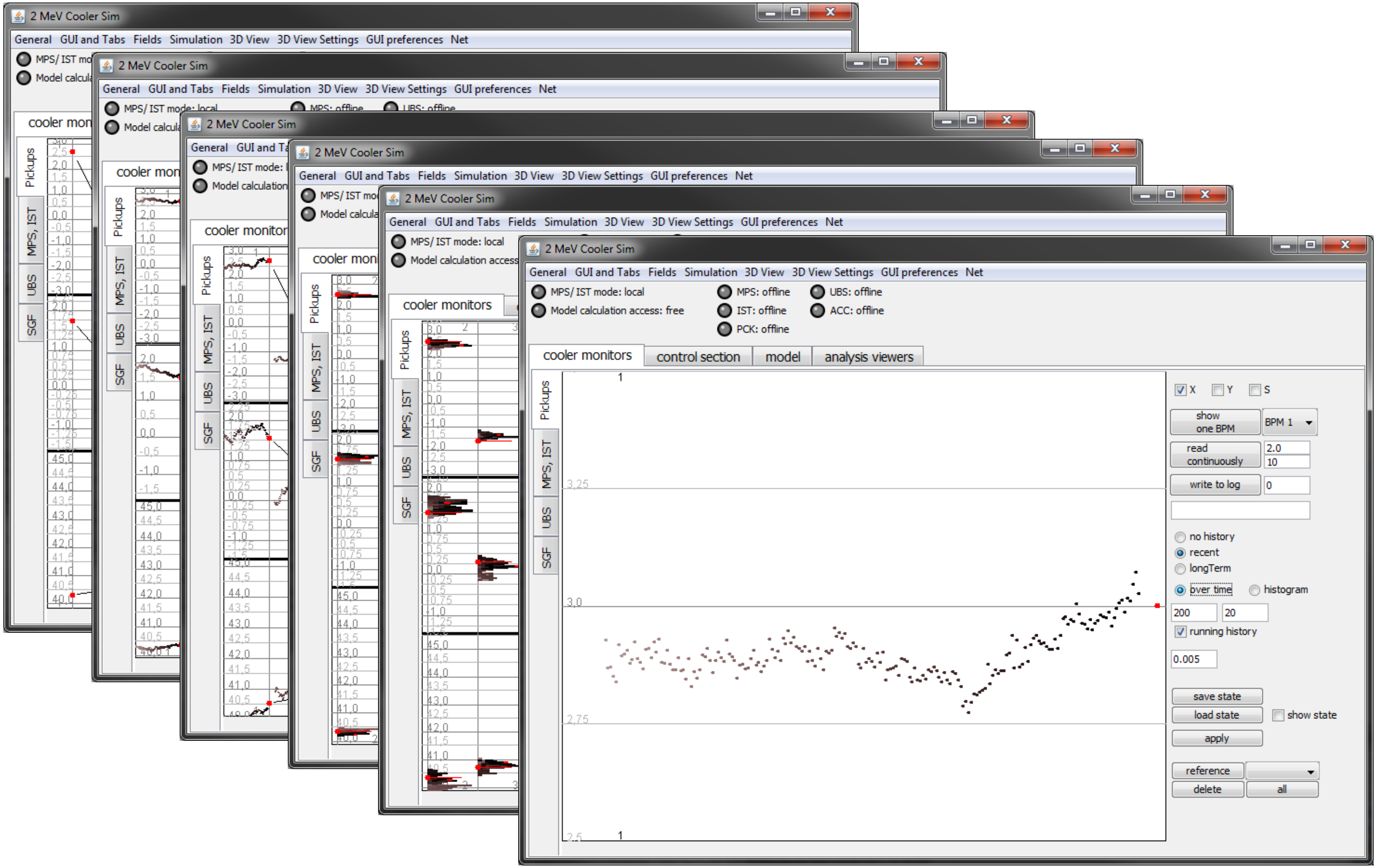

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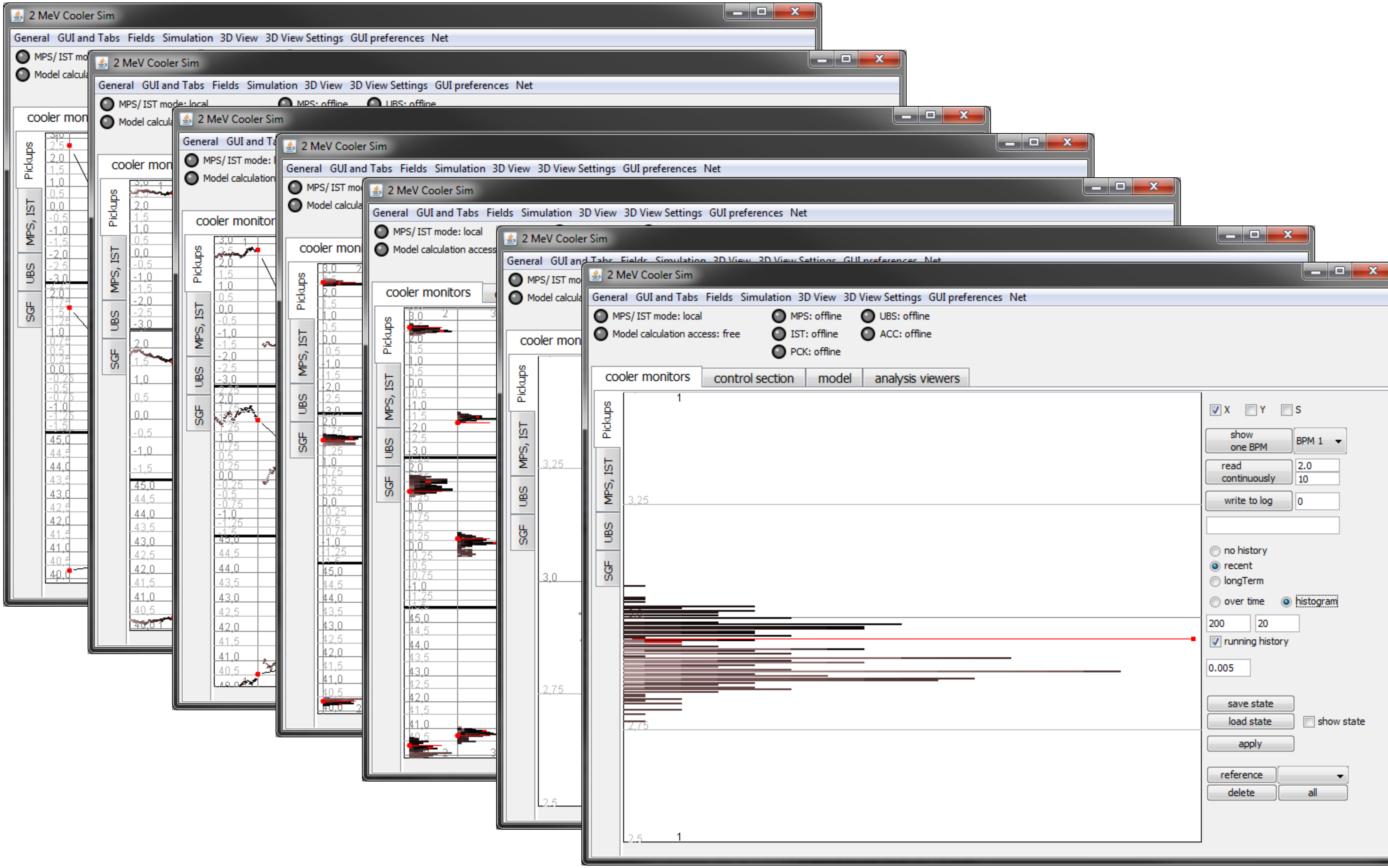

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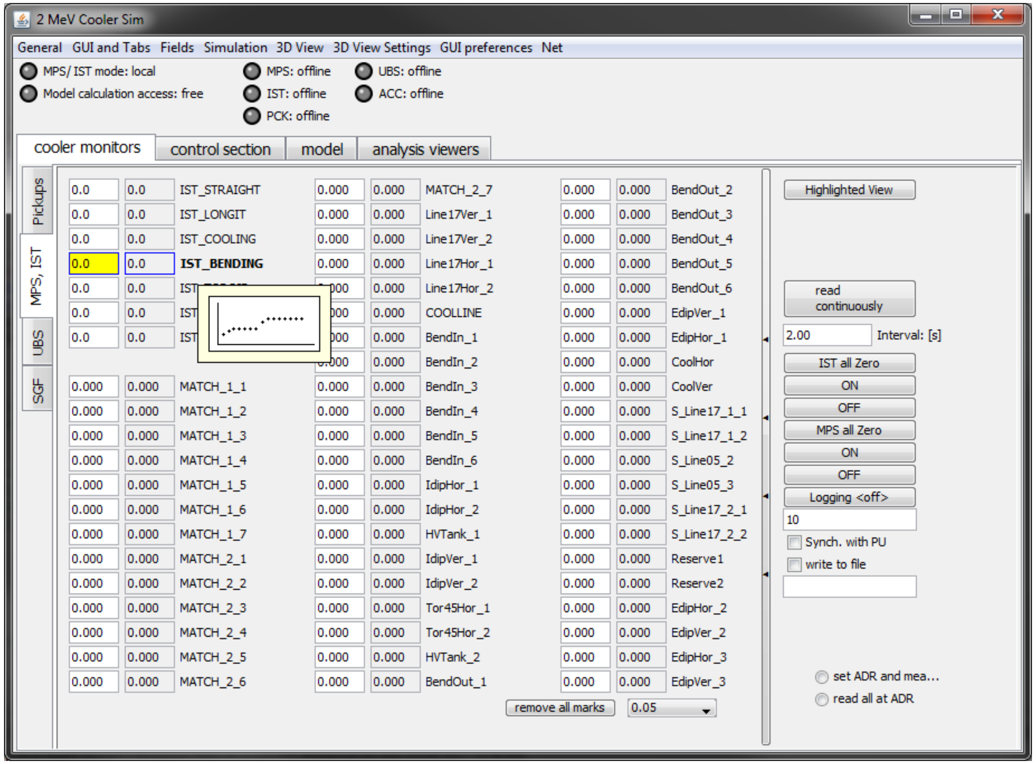

GUI Slide show

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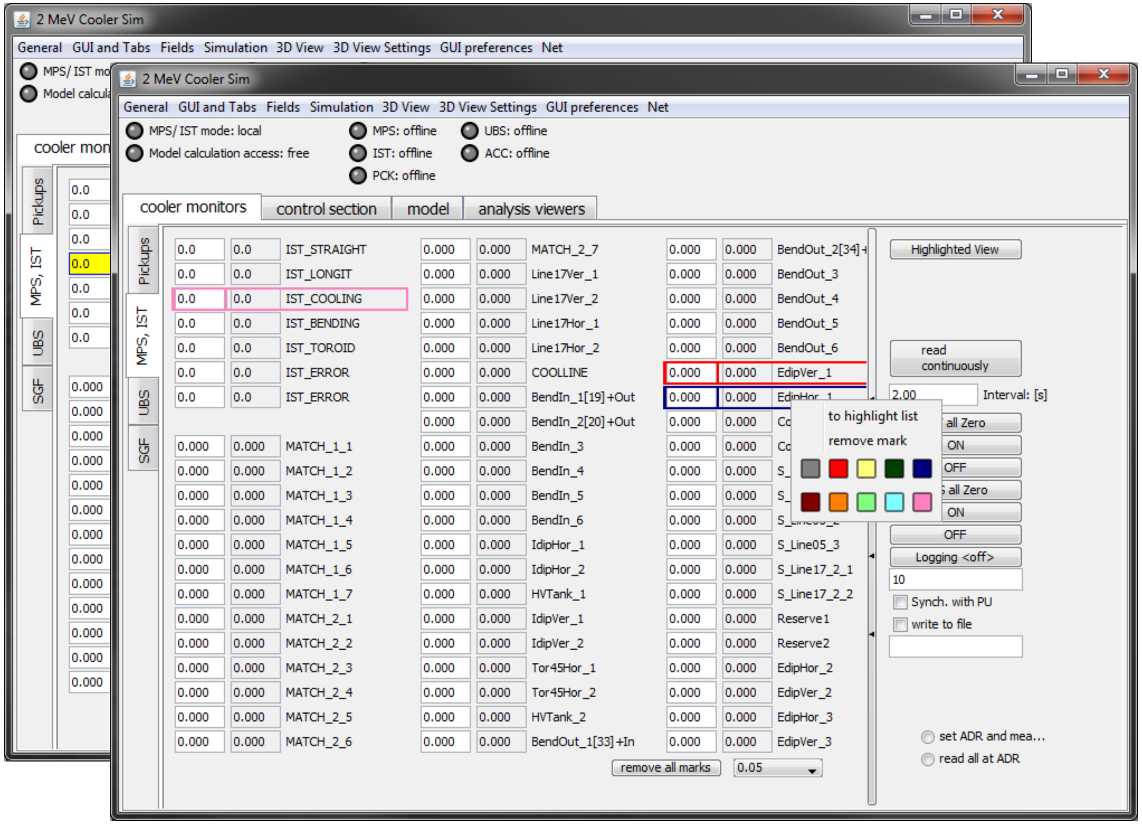

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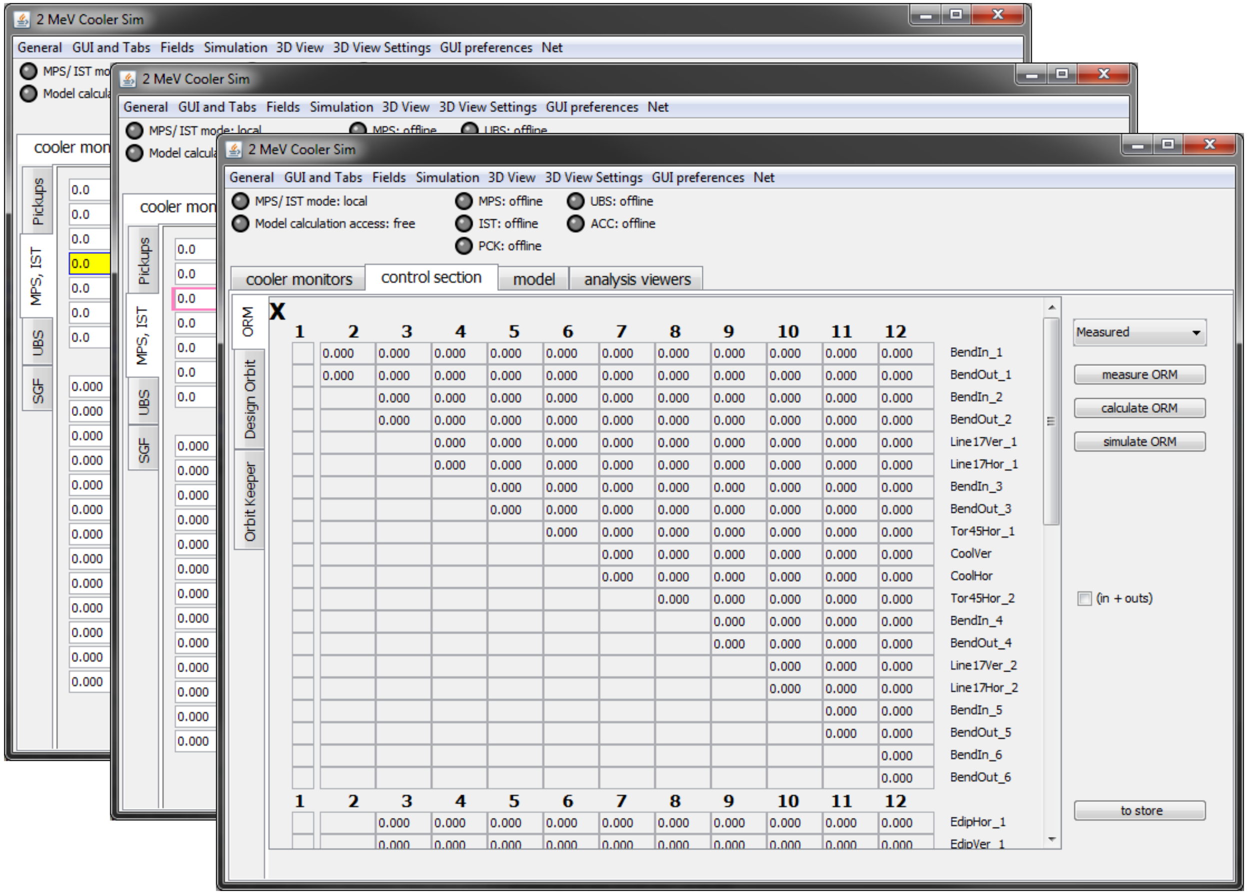

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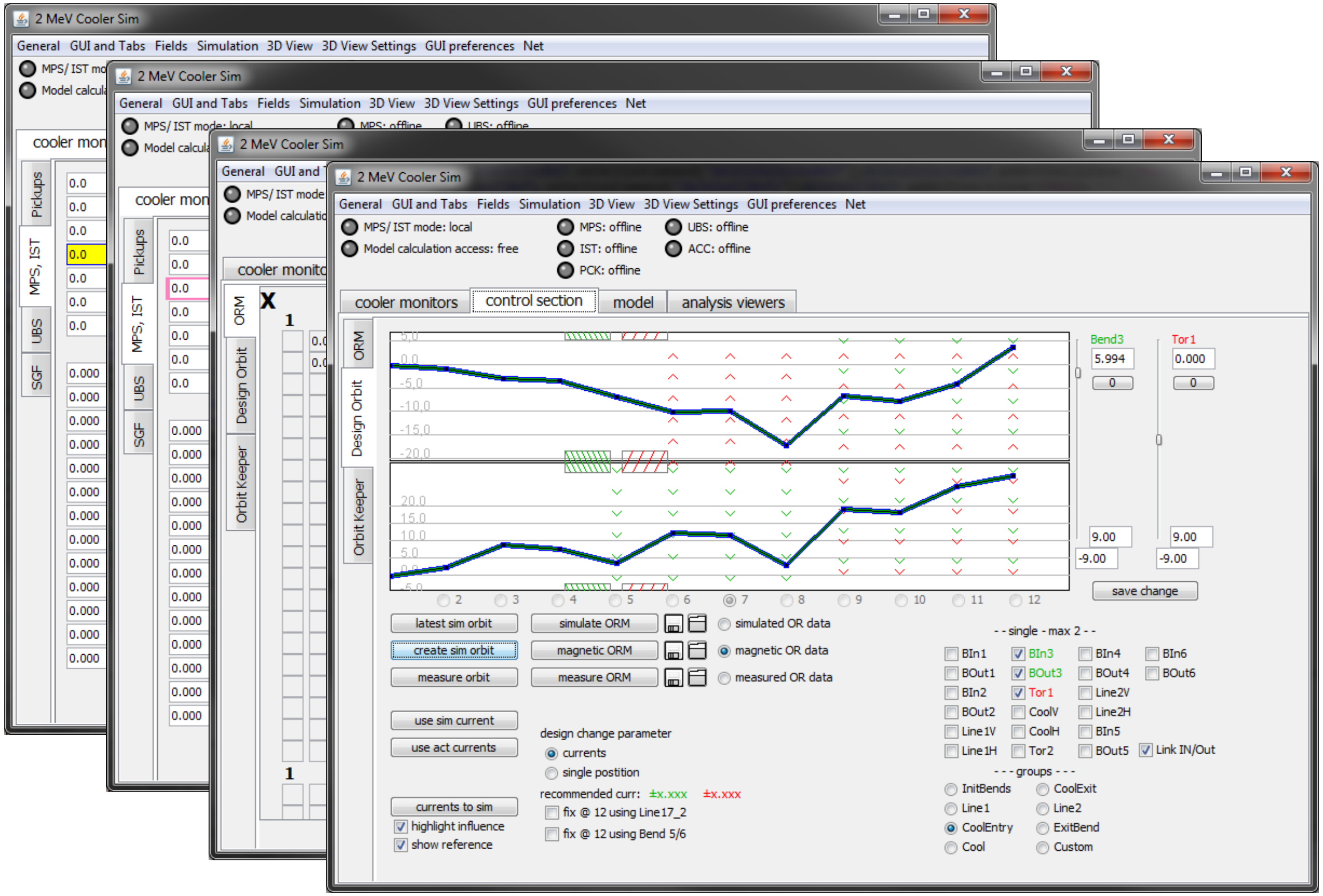

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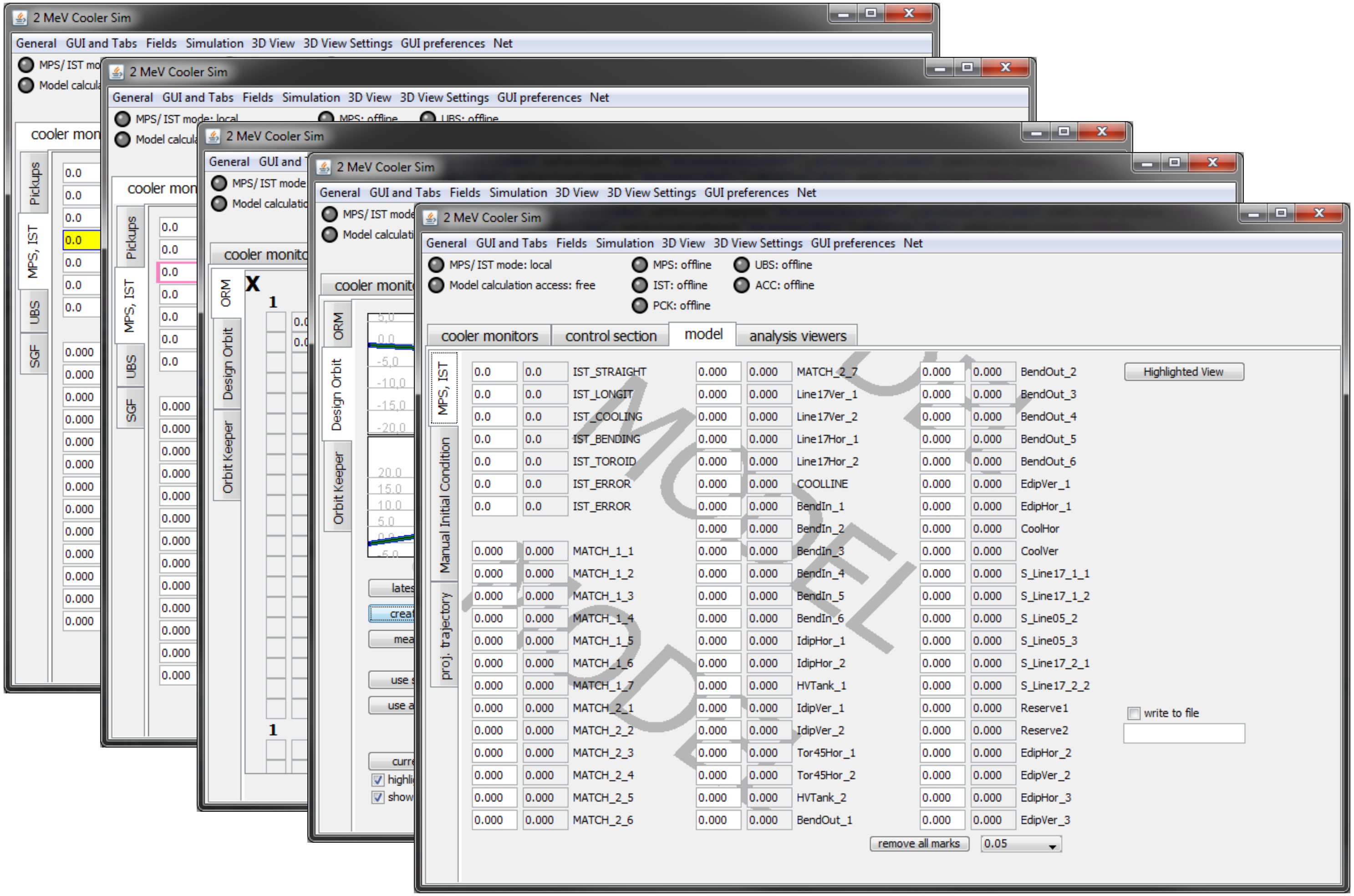

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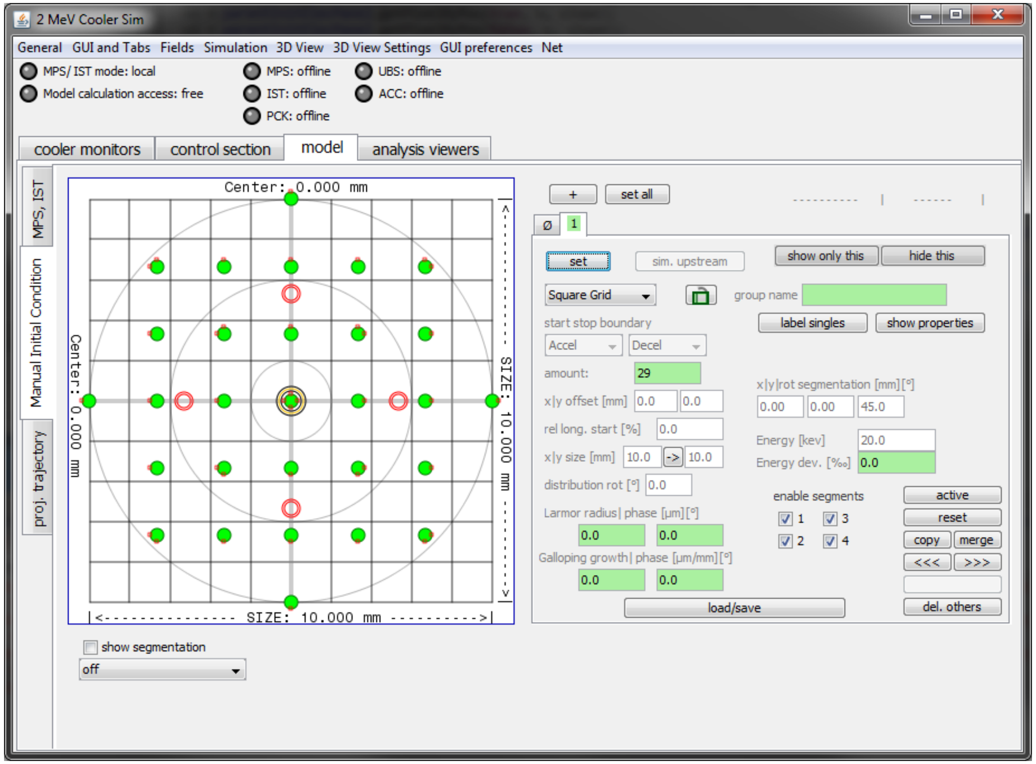
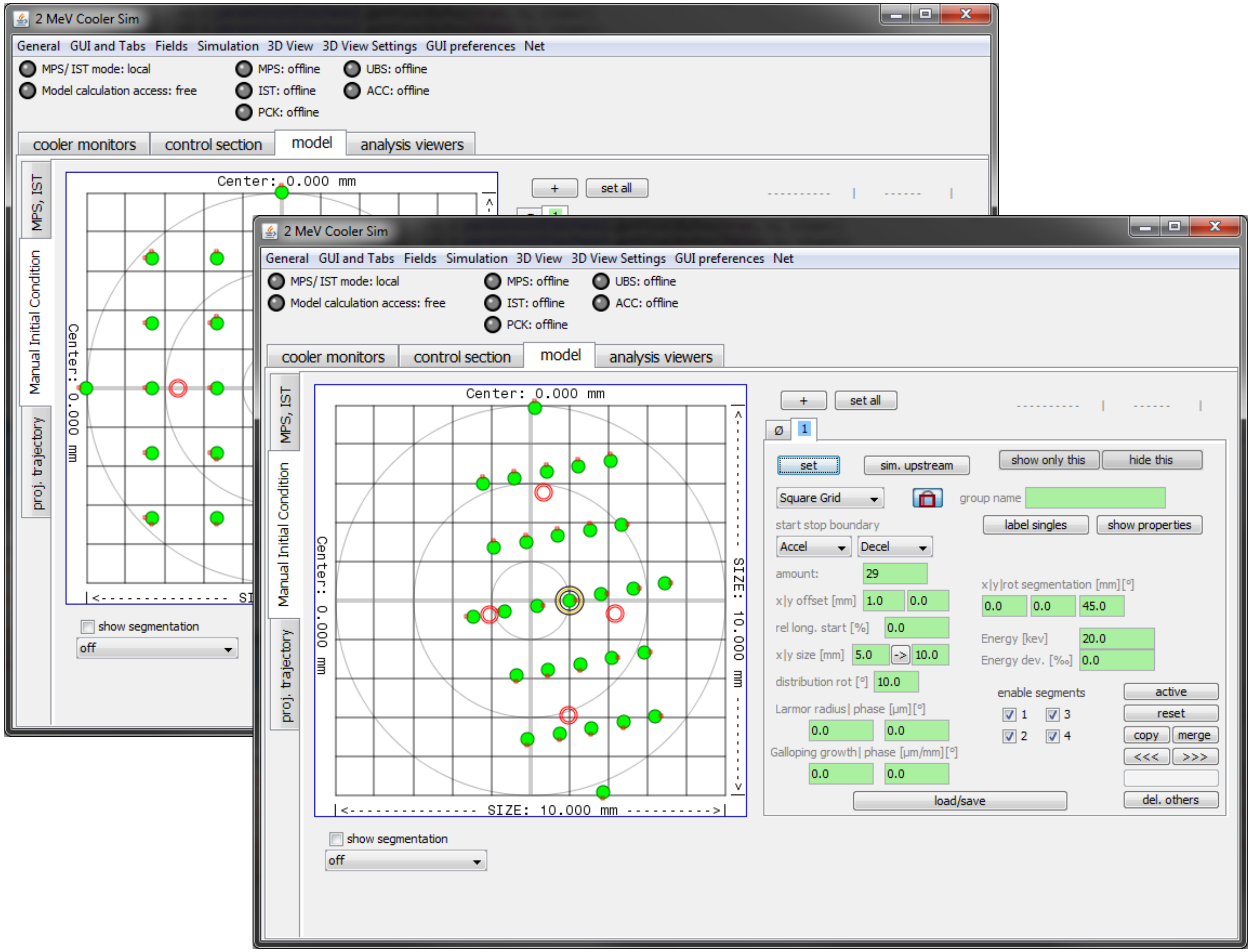
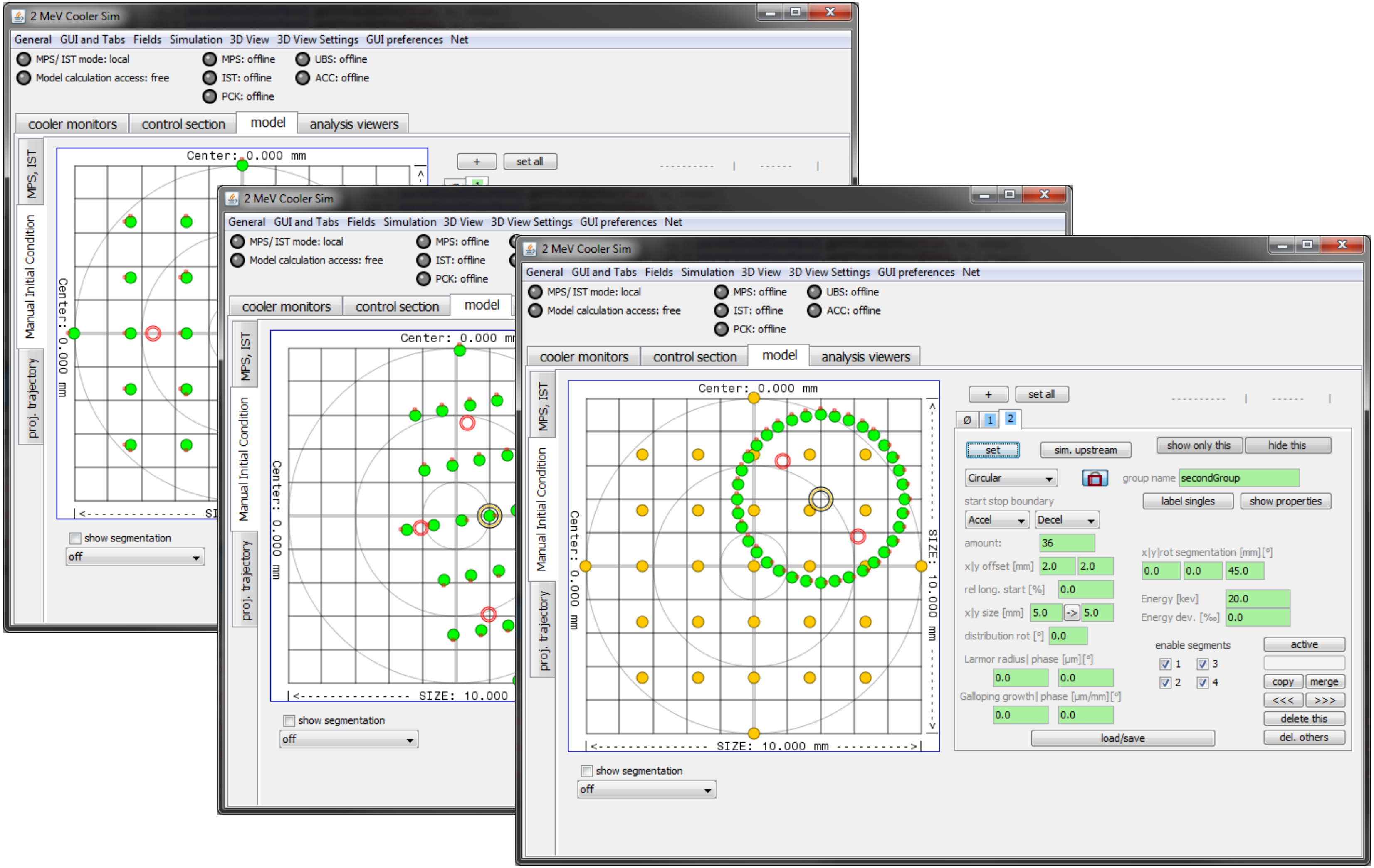


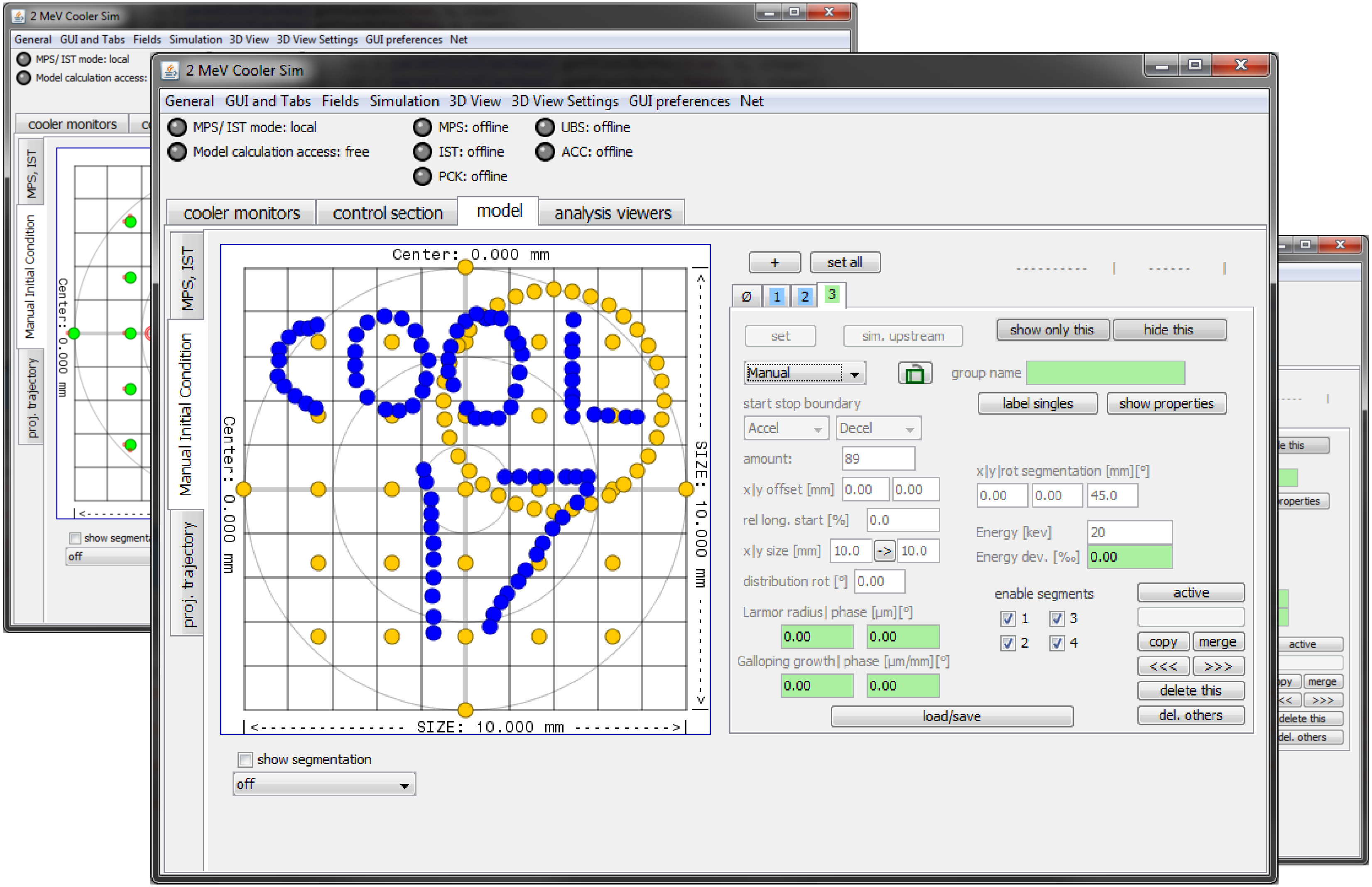
GUI Slide show



GUI Slide show



GUI Slide show



Outlook and wish list

Include gun and collector into the model

Work with optics; Find proper transferfunctions and charactersation paramters for given and generic magnetic elements

Build a general sand box software

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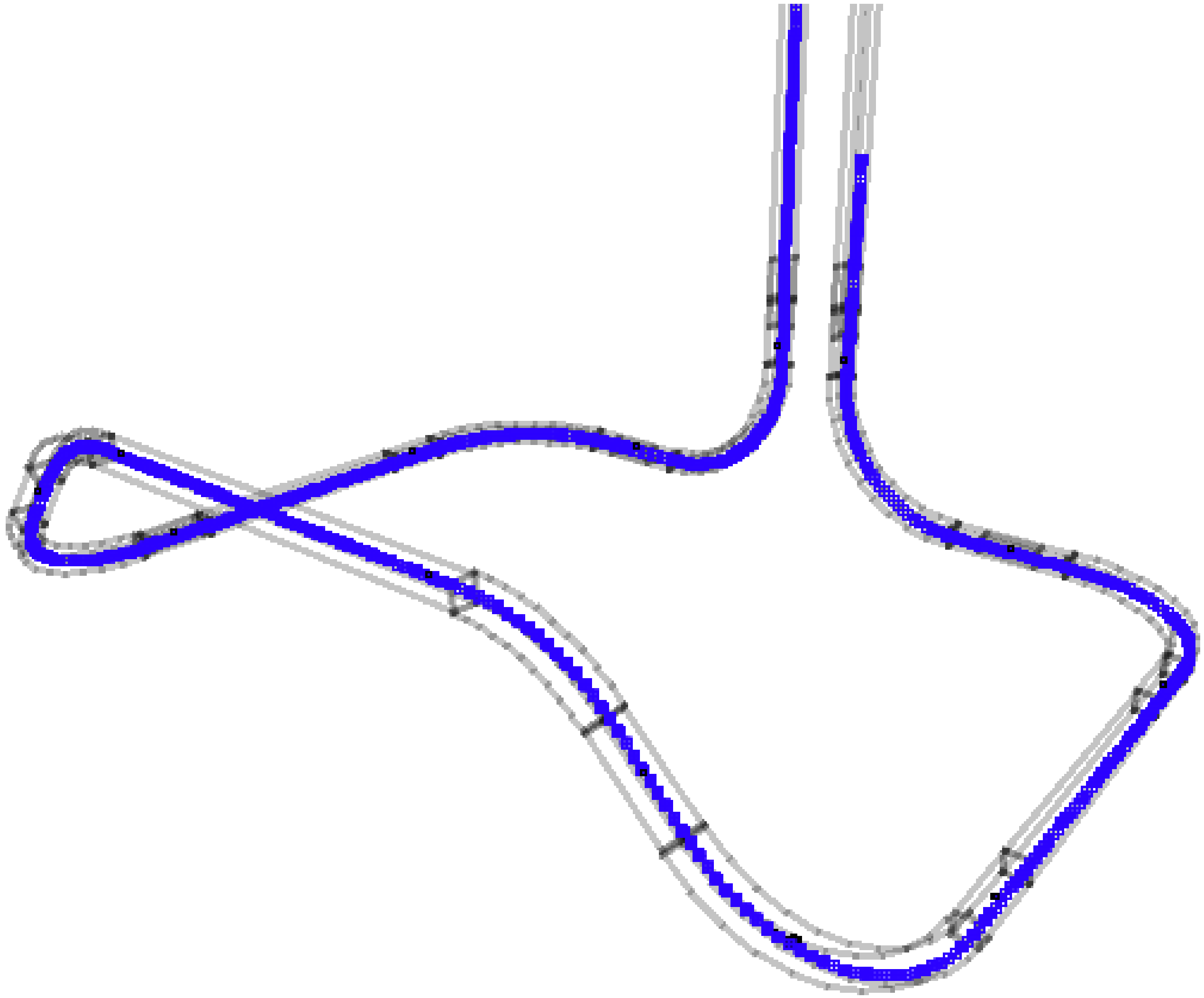

Just one more slide

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Thank you very much for your attention

Let‘s hope, there is time for questions