Bunch Compressor for Intense Proton Beams

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Outlines:

- Frankfurt Neutron Source FRANZ
- Bunch Compressor Concepts
- Single Bunch Beam Dynamics
- Magnet Design
- Final Focus – Effects of Space Charge Forces

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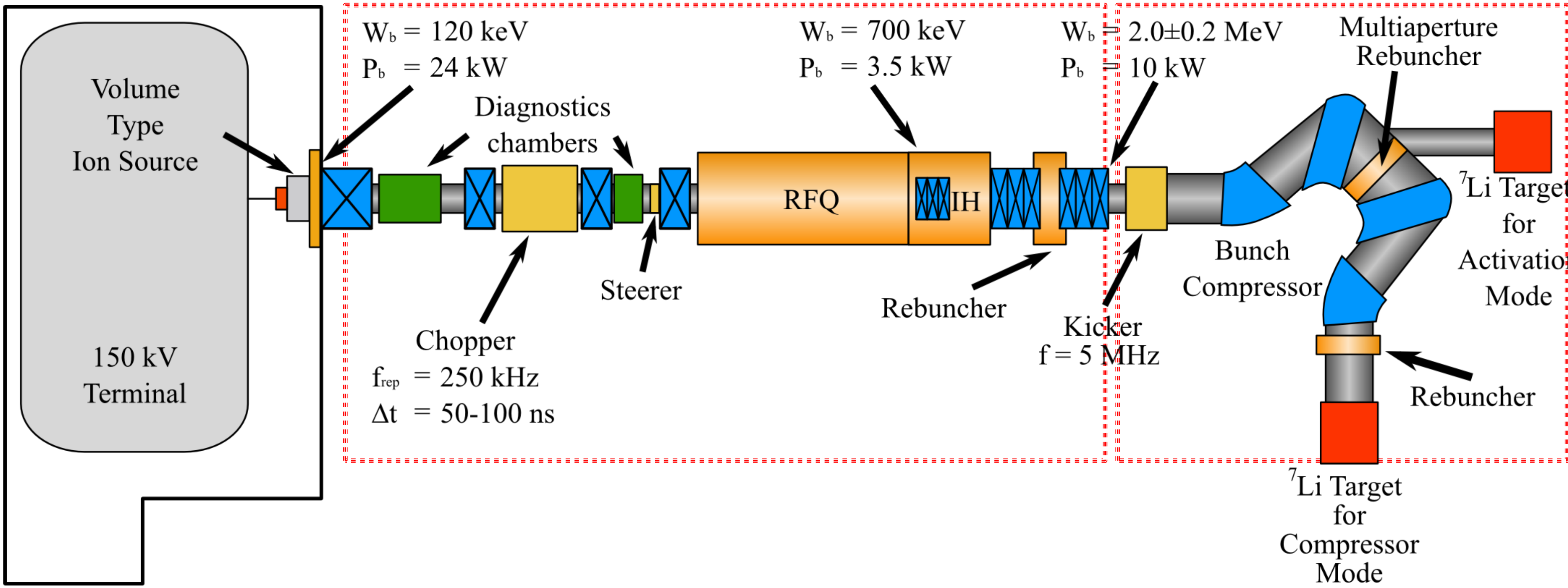
Frankfurt Neutron Source FRANZ

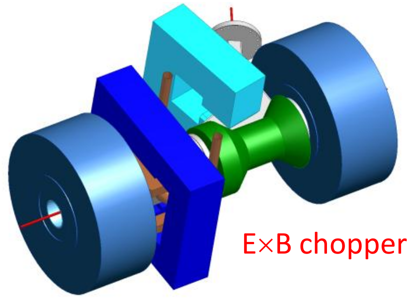


- ***FRANZ:*** High current LINAC combined with 1ns-bunch-compressor
- ***Test stand:*** Novel accelerator technology, high current beam diagnostics
- ***Applications:*** ⇒ Astrophysical (n, γ)-cross sections, TOF
  ⇒ Activation measurements, detector developments
  ⇒ Material sciences

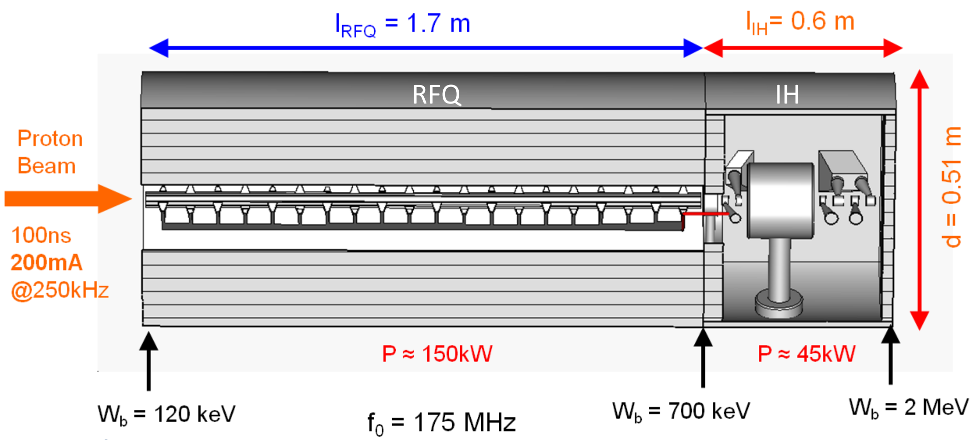
High current applications:

=> Where are the limits of conventional accelerator technologies?

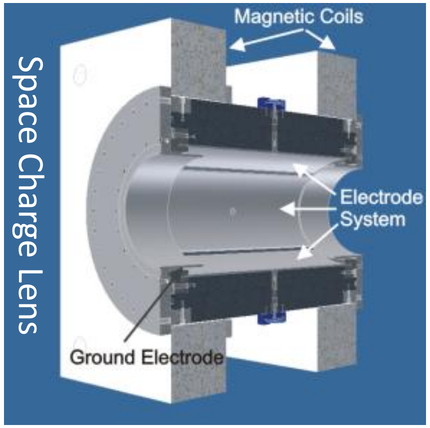
=> Are there alternative concepts?



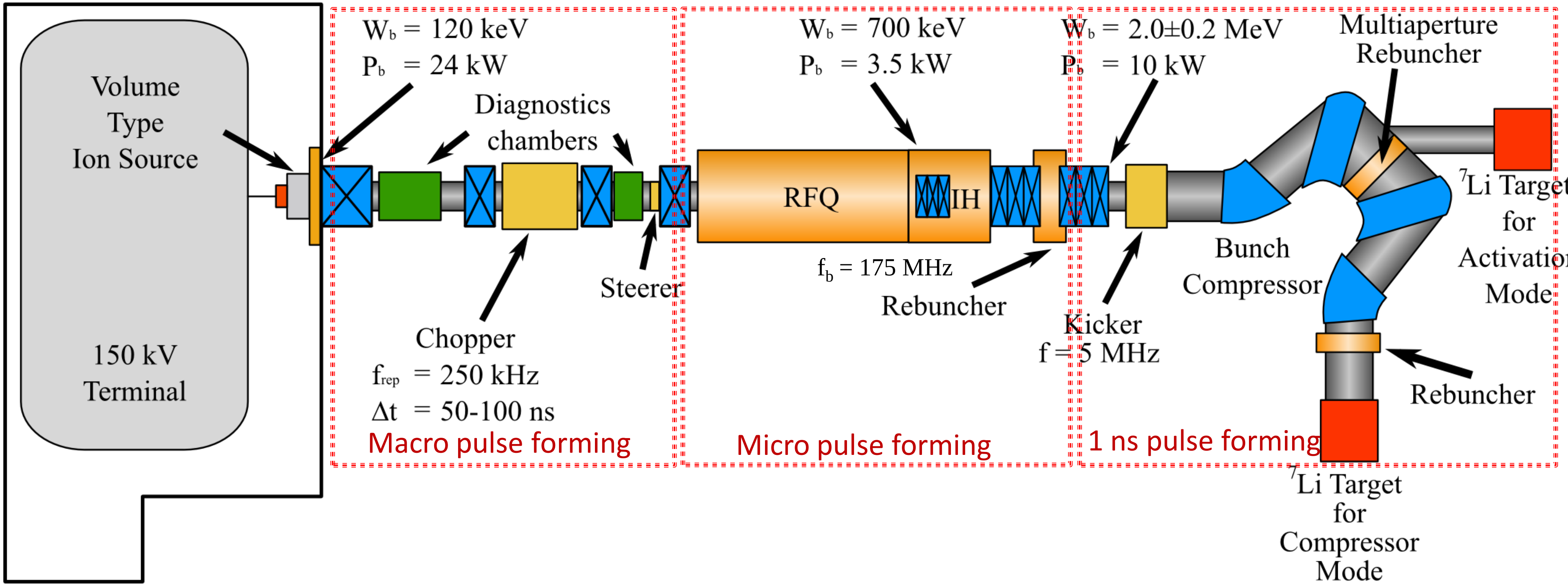
- Beam forming at high rep. rates: E×B chopper (C. Wiesner ,**THP071**)
- High current cw RFQ (A. Schempp, **TUP039**)
- Coupled RFQ-IH combination
- DTL concepts: IH, CH, Multi-Aperture Reb. (U. Ratzinger, H. Podlech, D. Noll: **MOP101**)



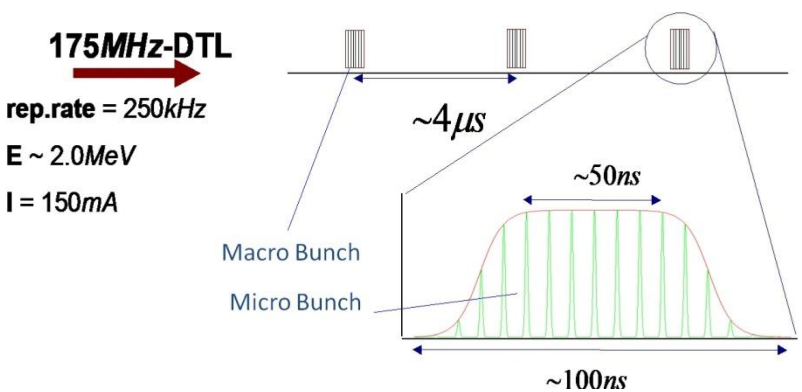
- Alternative beam dynamics: KONUS (U. Ratzinger)
- Alternative beam focusing device: Space Charge Lens (K. Schulte, O. Meusel, **MOP102**)
- Non destructive diagnostics: beam tomography (O. Meusel)



FRANZ: Bunch Compressor - Requirements



Pulse Structure at the Entrance



Requirements at the Final Focus

R	<	10 mm
ΔW/W	<	±5%
ΔT= 50-100 ns	=>	ΔT≈ 1 ns

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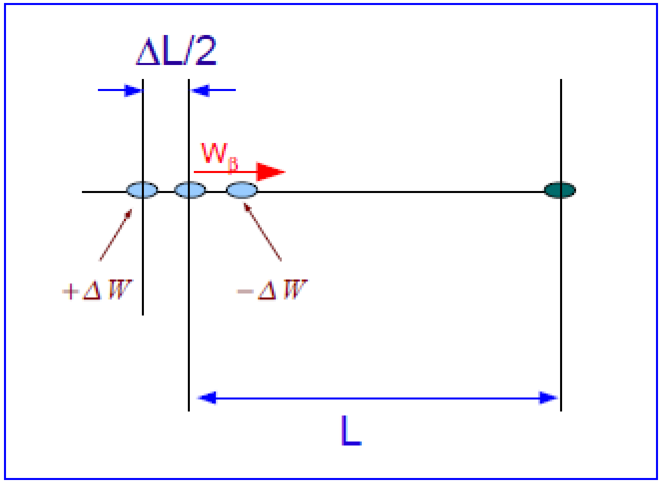
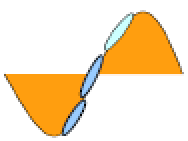
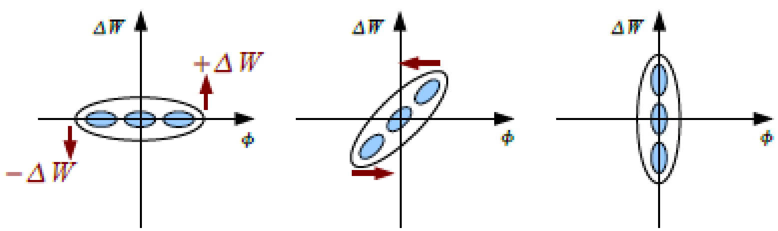
Bunch Compressor Concepts

Energy differences ⟵ **Transit time differences** ⟶ **Path length differences**

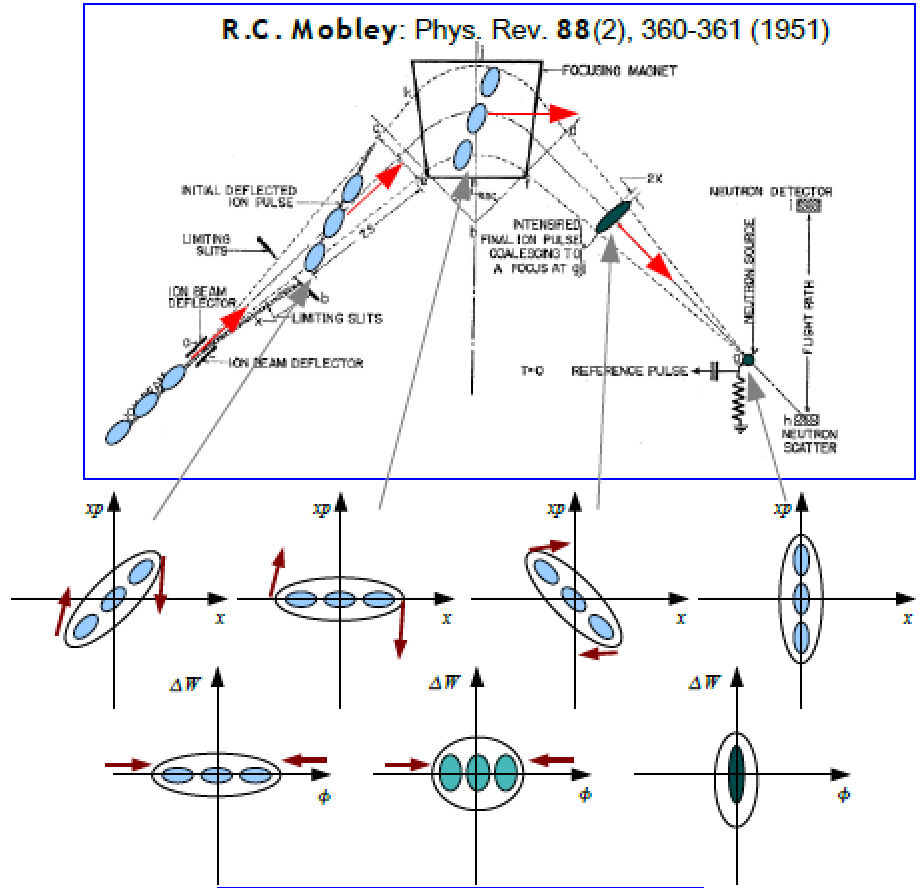




RF => de- / acceleration



Large energy spread (RF-cavity)



Negligible energy spread (RF-deflector)

$L \approx 4$ m => $\Delta W \approx \pm 500$keV

Bunch Compressor Concepts

Transit time differences → **Path length differences**

Mobley-Buncher: (µA-Proton Beams)

Kicker

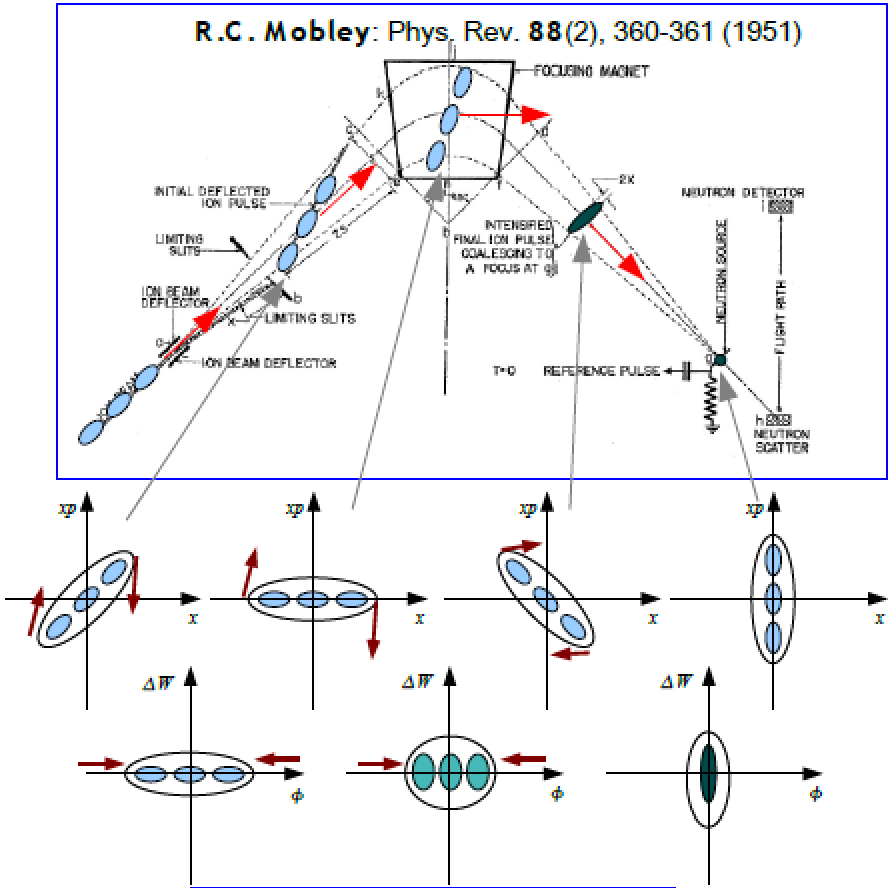
→ separation of the micro bunches

Bending system (1 Dipole)

→ "weak" focusing

→ path length differences

→ longitudinal compression



Negligible energy spread (RF-deflector)

Bunch Compressor Concepts

ARMADILLO – Arc Magnetic Dipole Chicane with Large Aperture Longitudinally Focusing Cavities

Mobley-Buncher: (μA-Proton Beams)

Kicker

→ separation of the micro bunches

Bending system (1 Dipole)

→ "weak" focusing

→ path length differences

→ longitudinal compression

Improvements for 150mA Proton Beams:

2 main dipoles (gradient)

→ more parameters for beam dynamics

2 auxiliary dipoles (homogeneous)

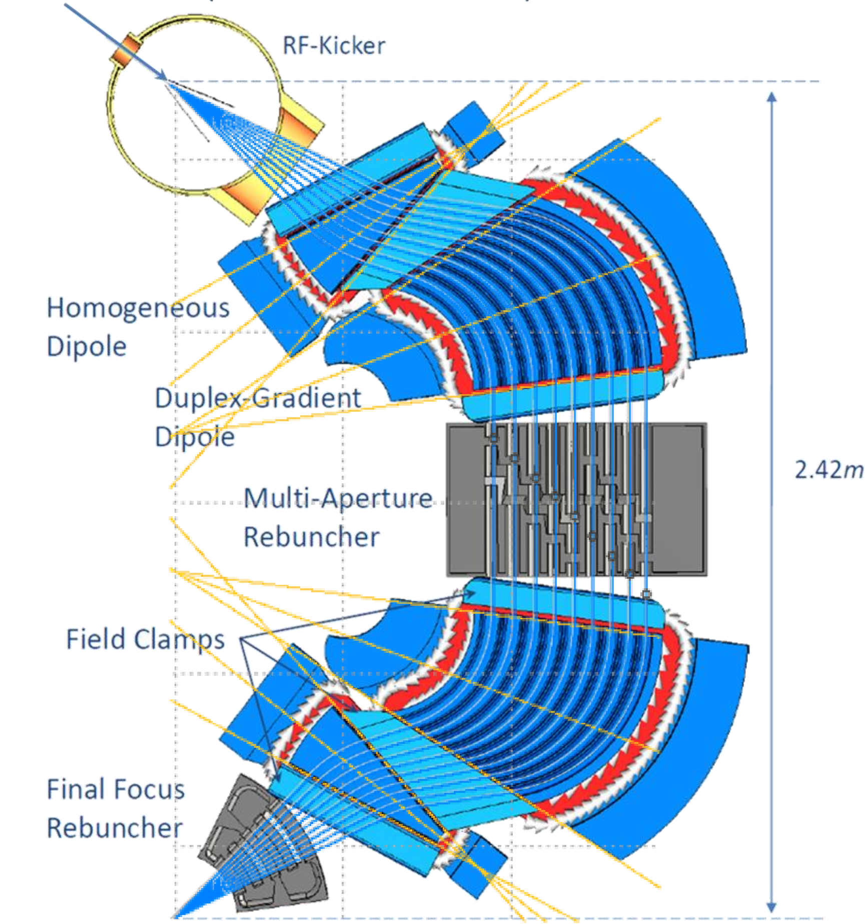
→ linear separation of the trajectories

→ momentum exchange in trans. plane

2 rebuncher cavities

→ longitudinal beam dynamics

LINAC ⇒ (9 × 5.7ns × 150mA) @ 250kHZ



Li-Target ⇒ (1ns × 7.7A) @ 250kHZ

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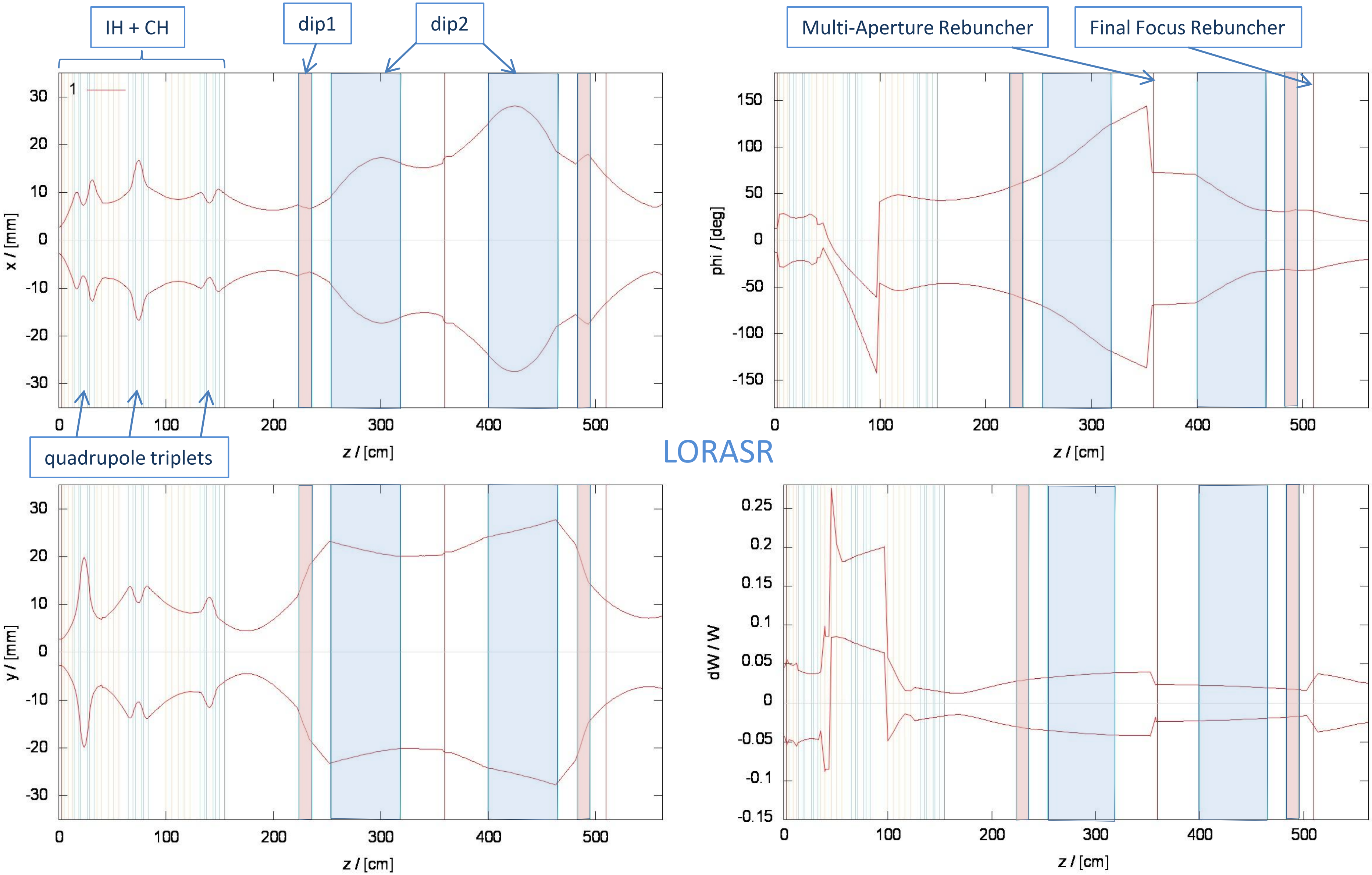
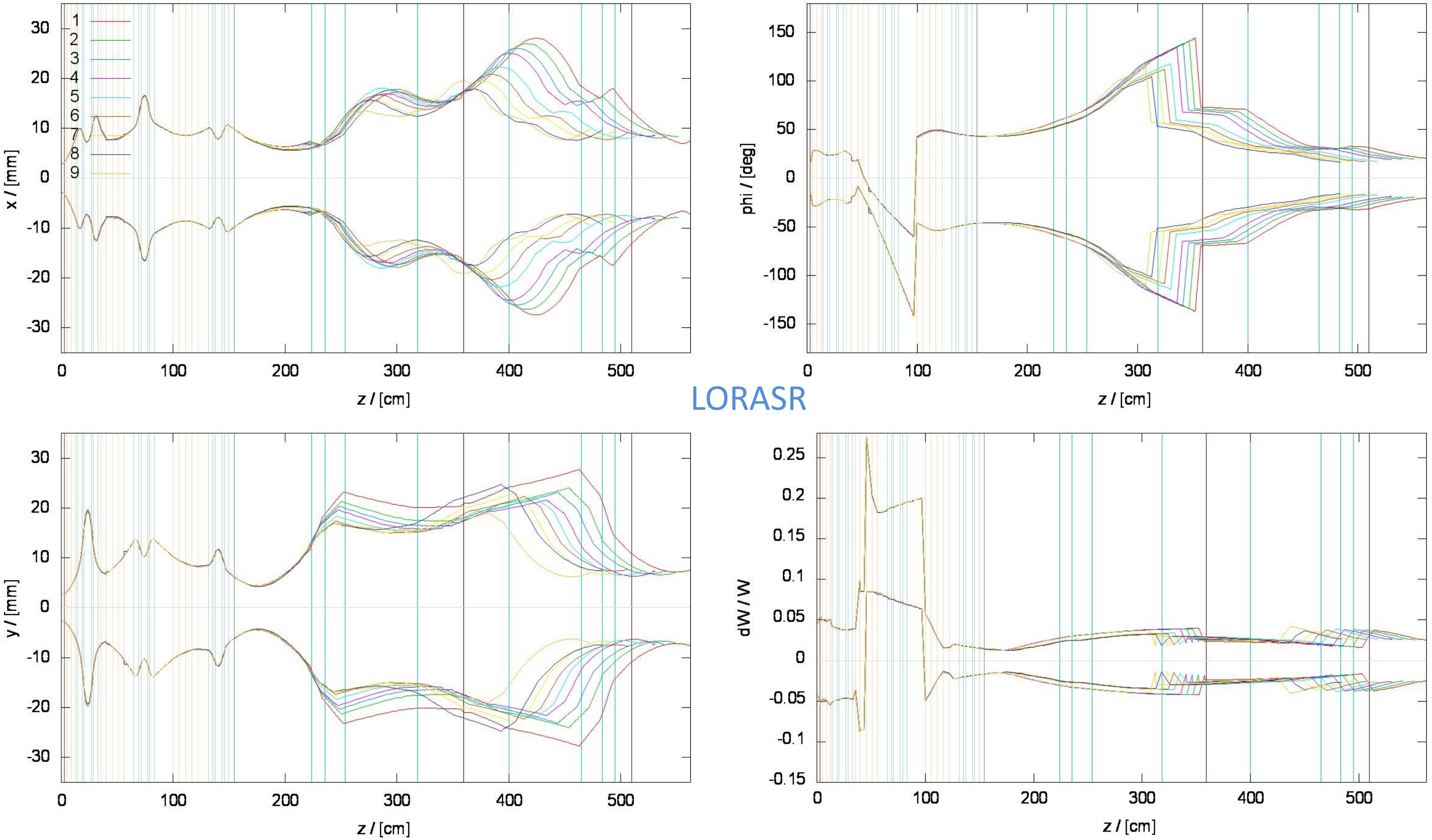
Single Bunch Beam Dynamics: 95% Envelope



- Beam dynamics solutions for all bunches can be found by manual optimization!



Single Bunch Beam Dynamics

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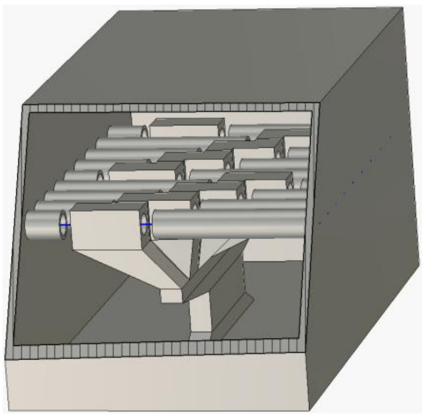
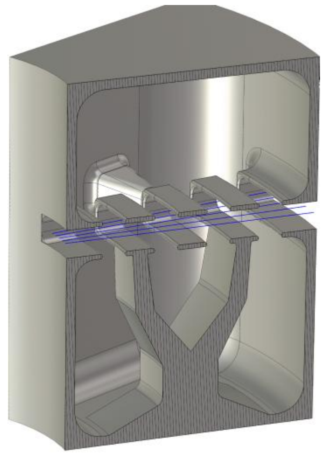
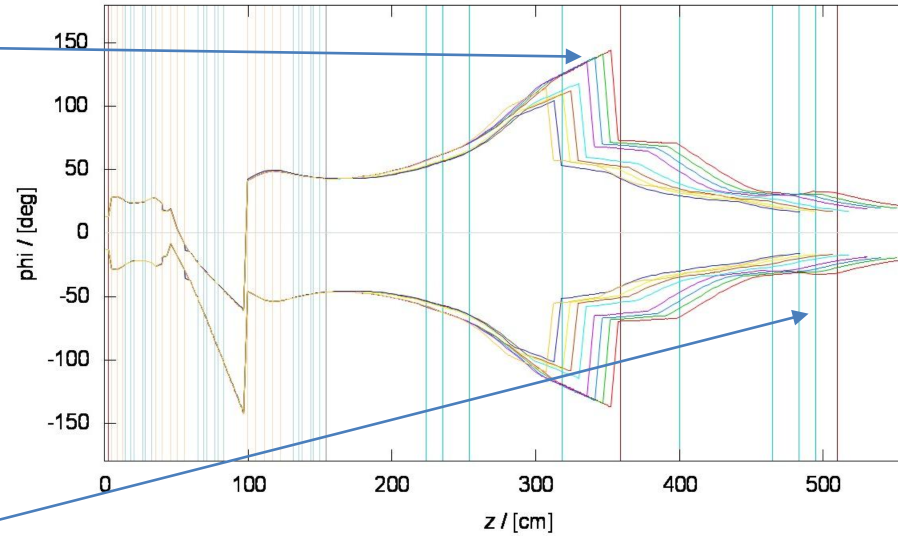


Multi-Aperture Rebuncher



Final Focus Rebuncher



- Smarter solution was proposed by ***D. Noll***: using "Particle Swarm Optimization" (PSO)*

**[J. Kennedy, R. Eberhart, 1995, Proceedings of IEEE International Conference on Neural Networks. IV. pp. 19421948.]*

- Cavity design: Multi-Aperture + Final Focus Rebuncher ⇒ ***D. Noll, MOP101***

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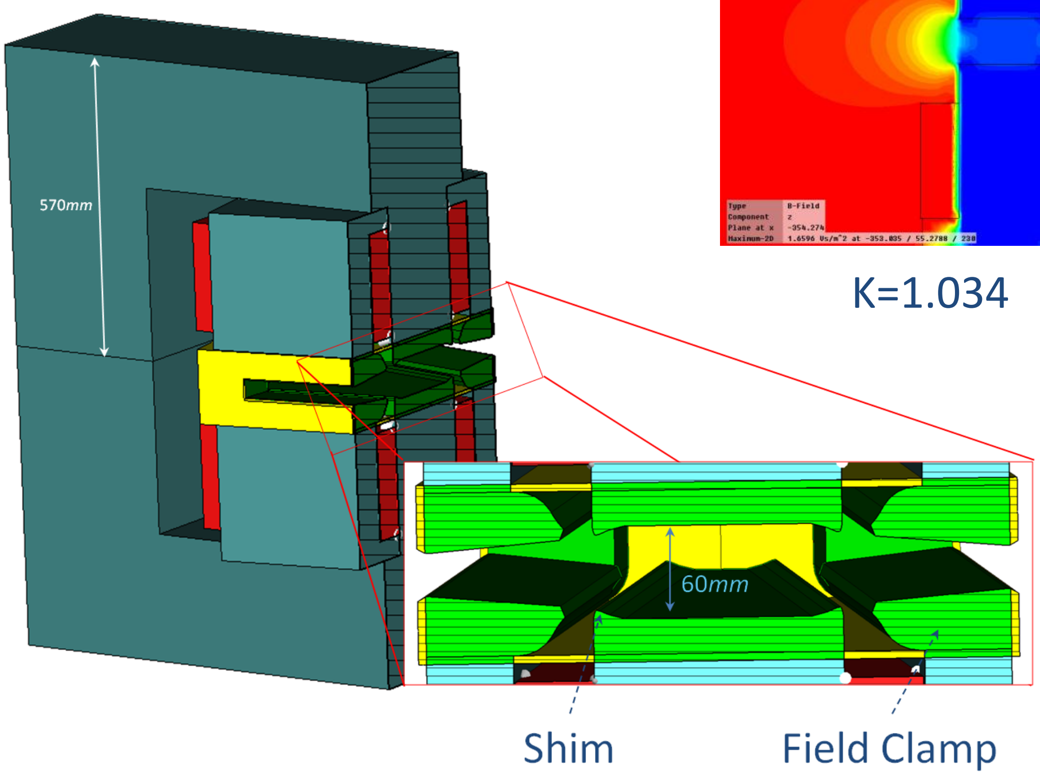
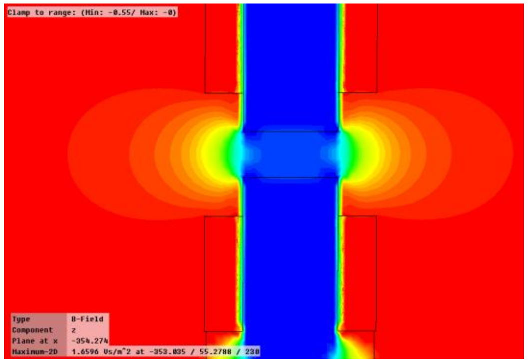
Magnet Design: Improvement for Beam Dynamics

- Beam dynamics solutions for all bunches can be found by manual optimization!
- Is it possible to design a magnet with the required parameters?

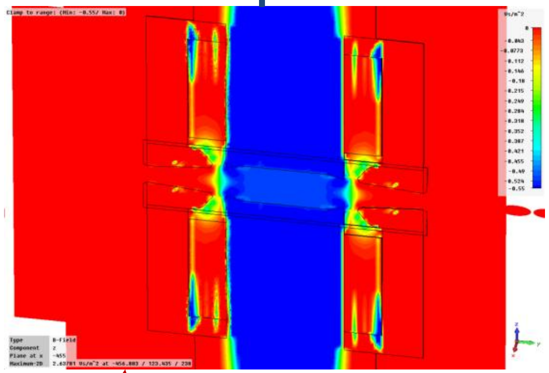


Without Modifications

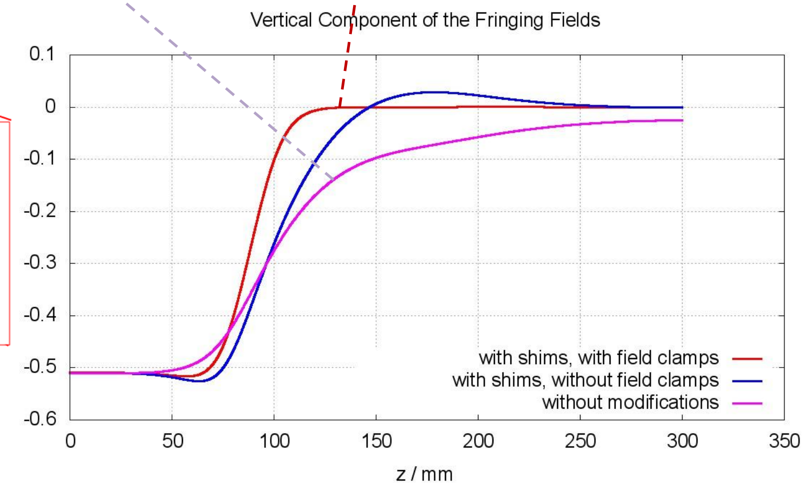


K=1.034

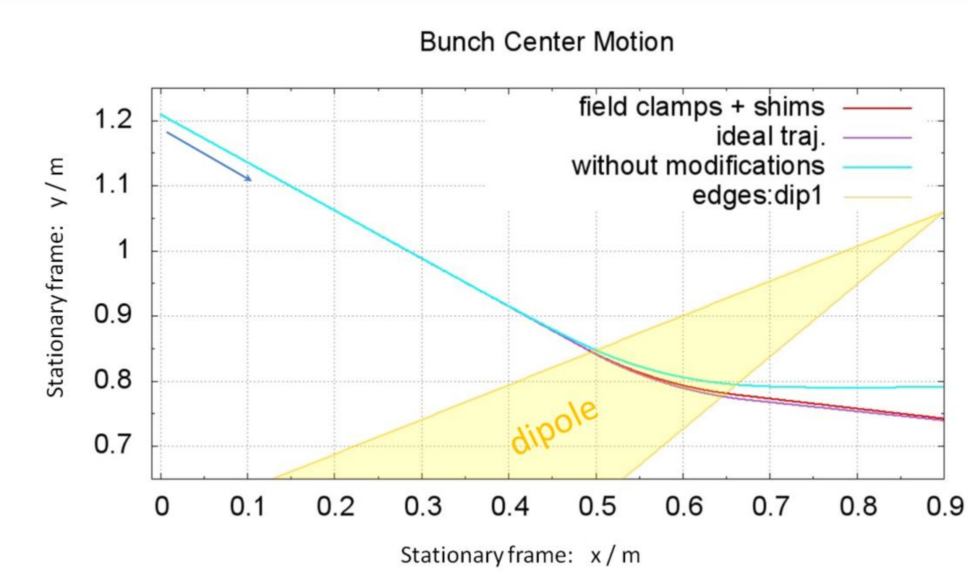
Field Clamps + Shims

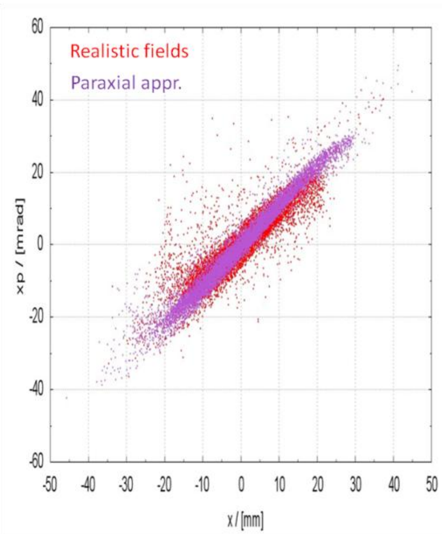


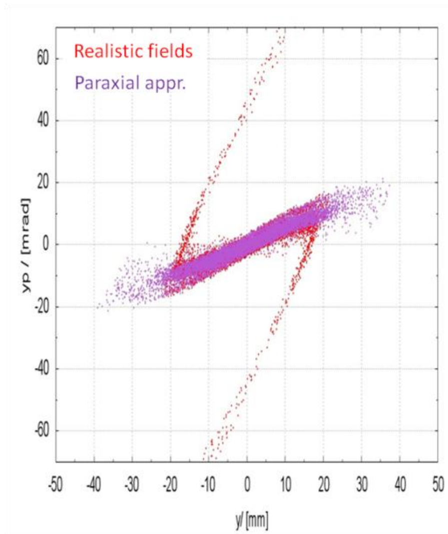
K=0.098



Magnet Design: Improvement for Beam Dynamics





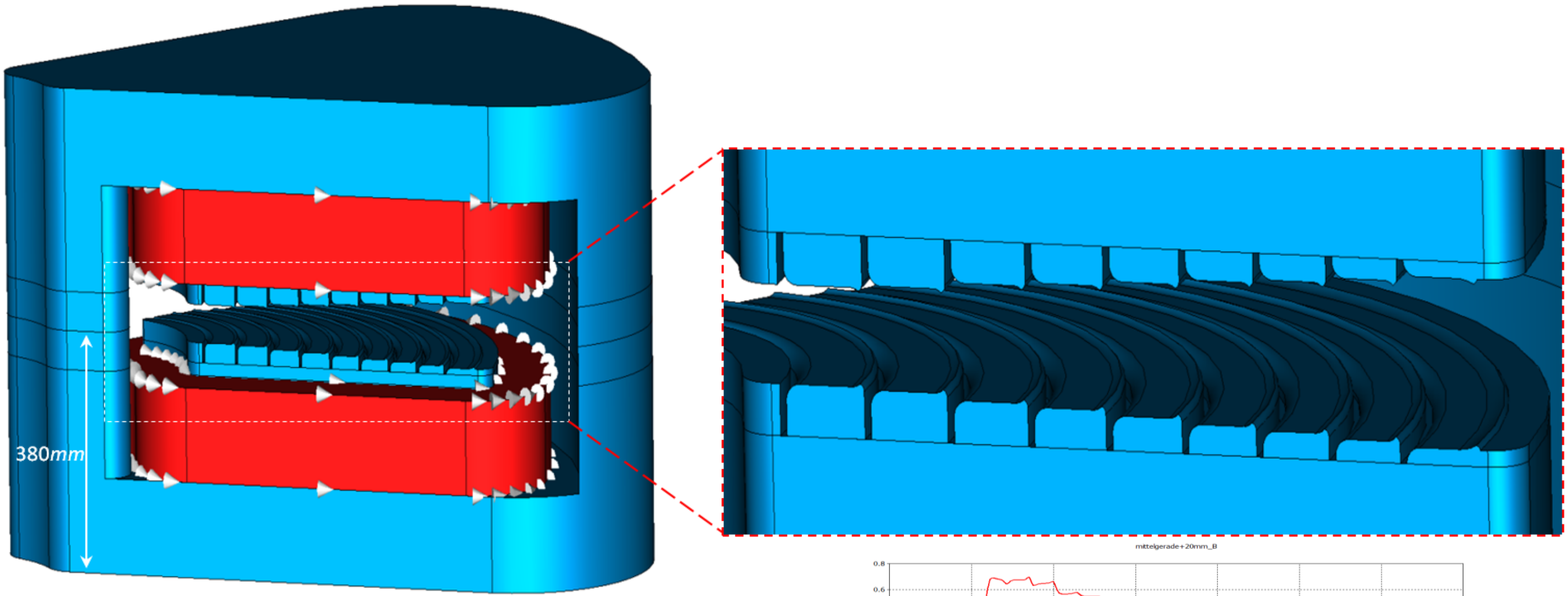


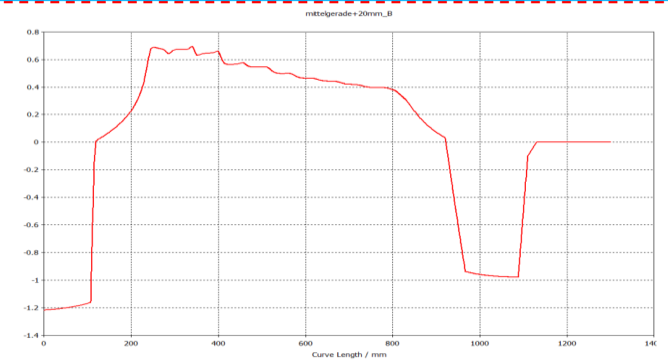
- Particle in Cell (PIC) transport with realistic fields compared to 1st order paraxial approach with given fringe field integral and edge angles.
- Ideal traj. ≡ const. fields + hard edges.
- Convergence to the ideal trajectory.
- Slope and core of distributions fit very well.
- Aberration caused by field gradients near shimmed edges.

⇒ Single bunch beam dynamics with 1st order paraxial approach is good enough for geometrical design.

⇒ Magnet design is possible!

Concepts for Main Dipole





- modular pole face
- global gradient => longitudinal focusing of the macro bunches
- individual reverse gradient => horizontal focusing of the micro bunches
- individual edge angles => vertical focusing of the micro bunches

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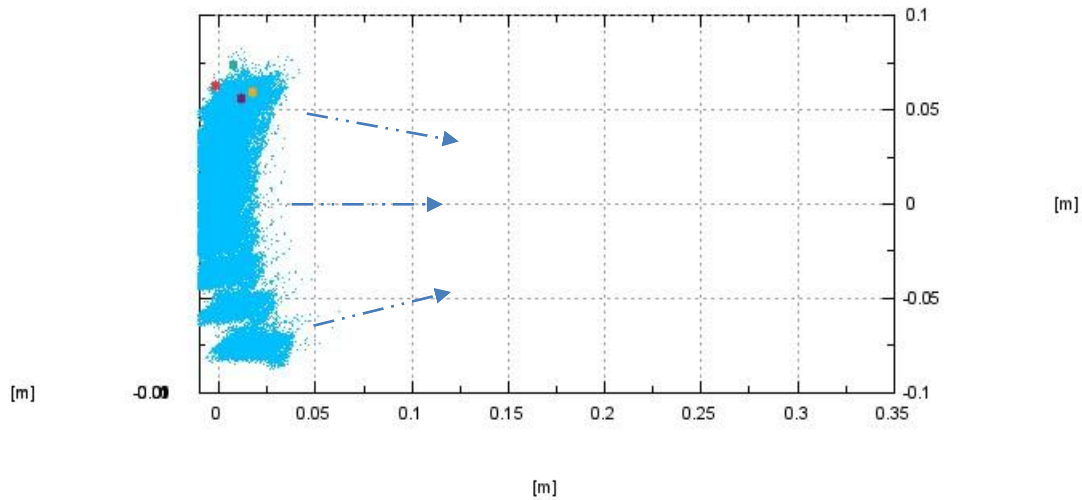
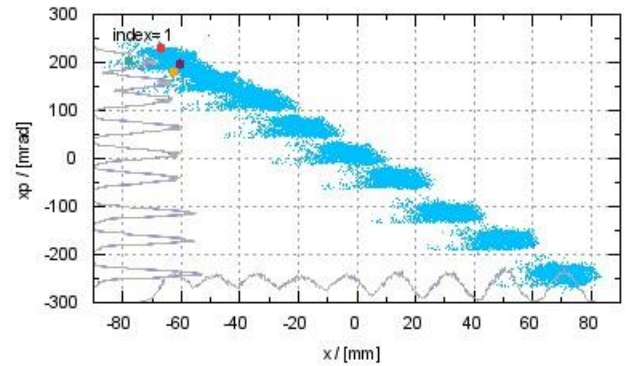
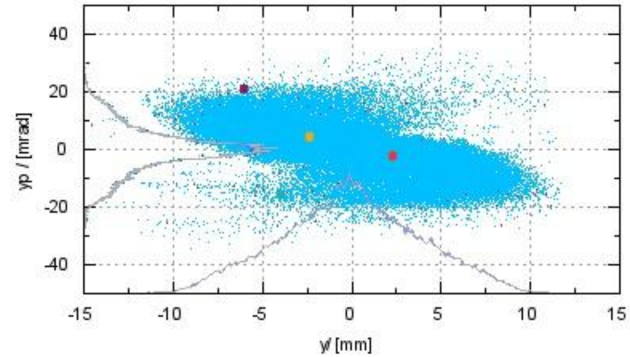
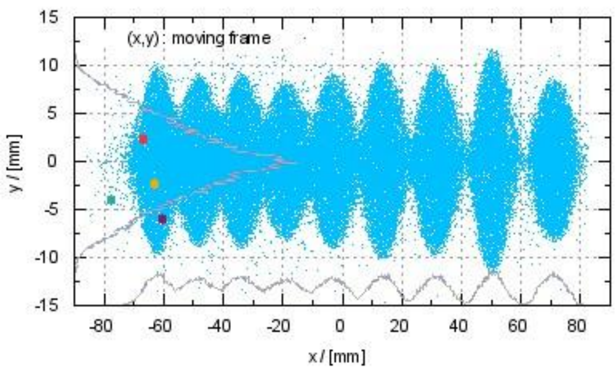
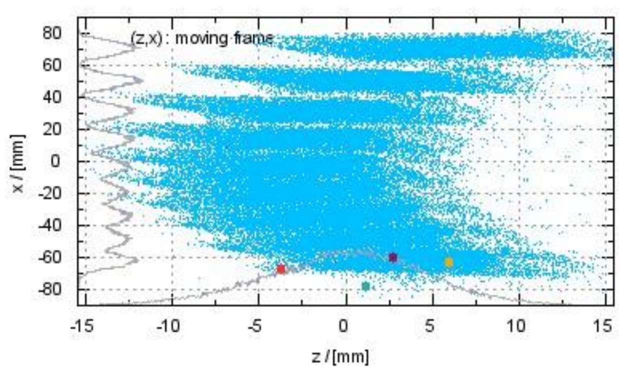
  e.g. provided by Space Charge Lens => K. Schulte, **MOP102.**

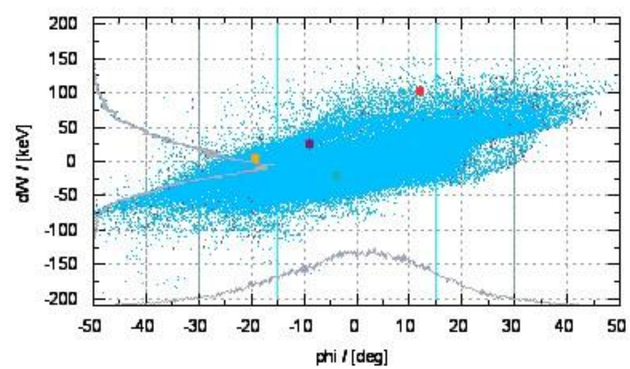












Multi Bunch Beam Dynamics: Effects of Space Charge

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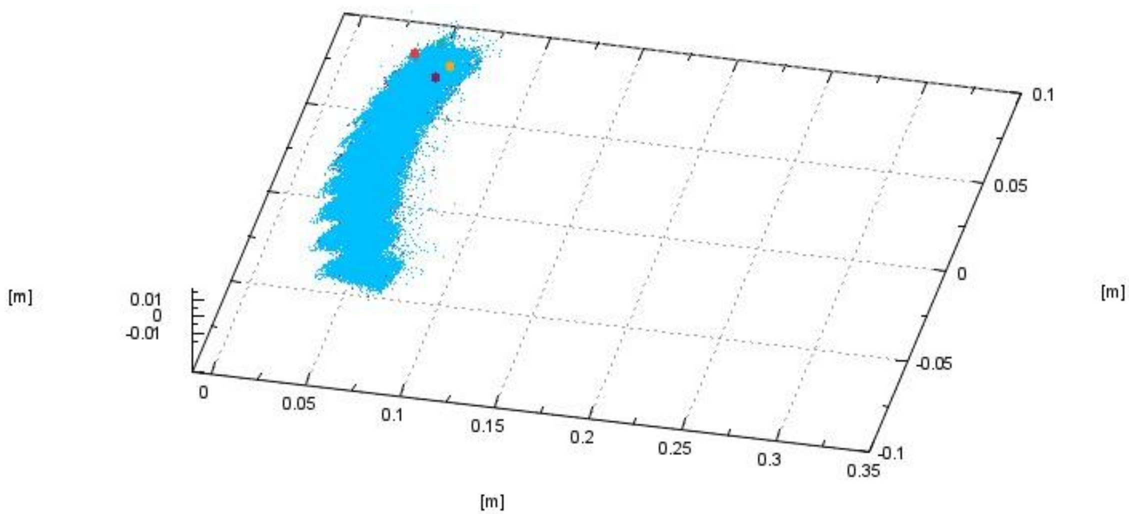

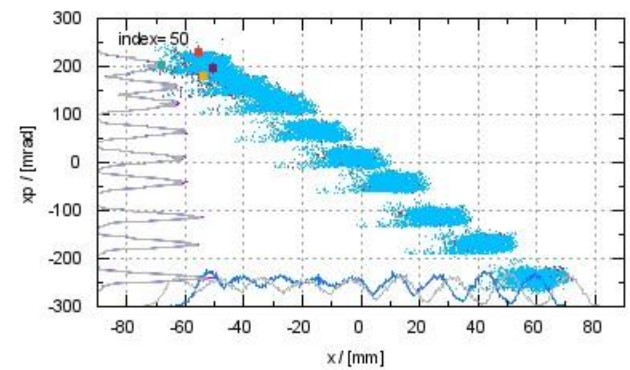

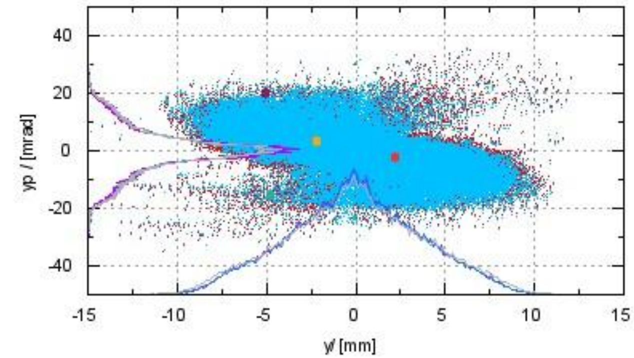

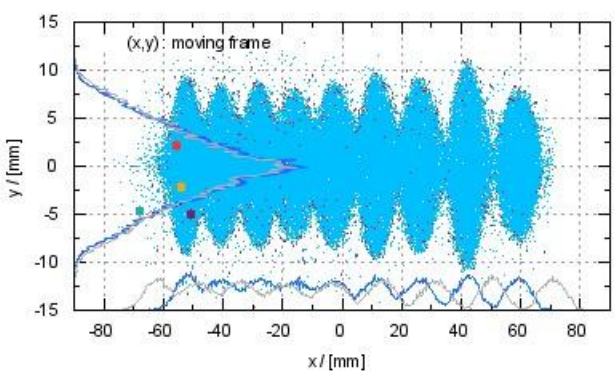

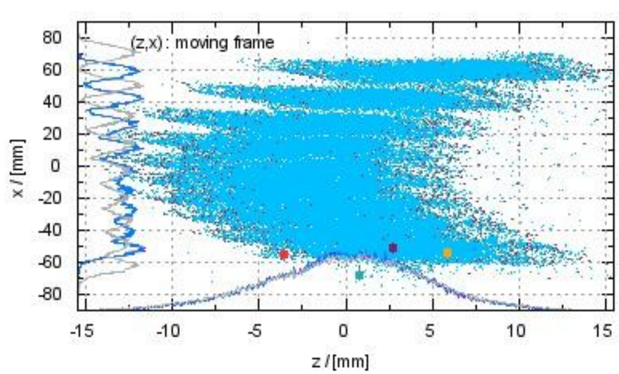

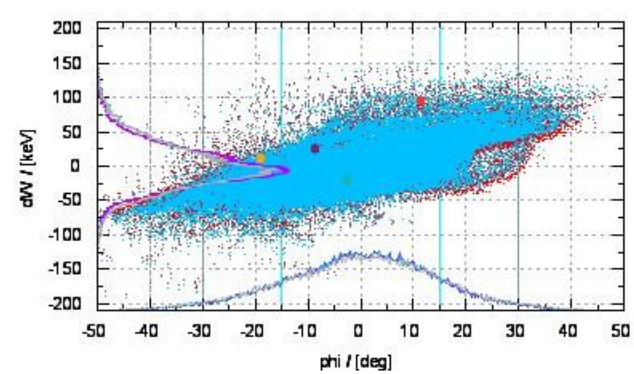

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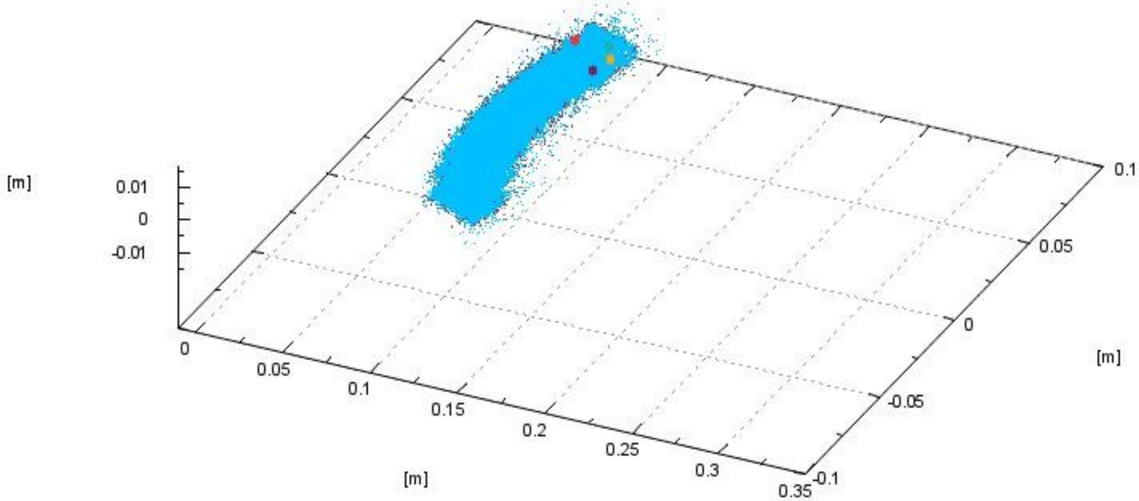

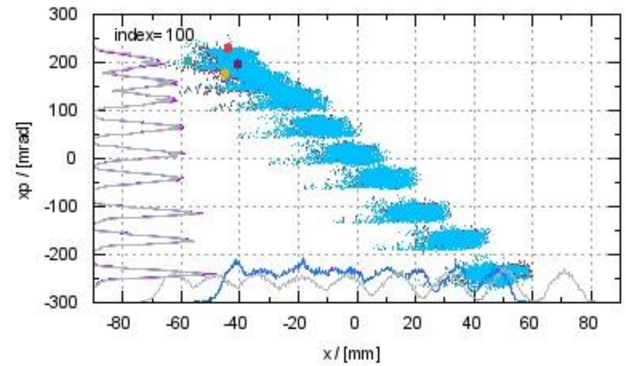

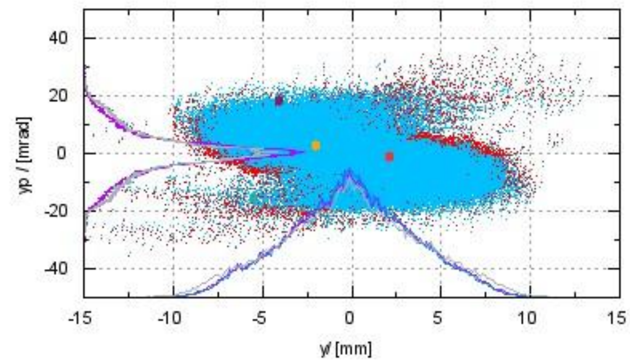

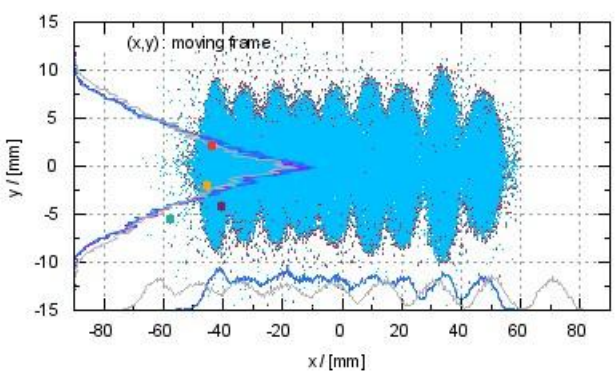

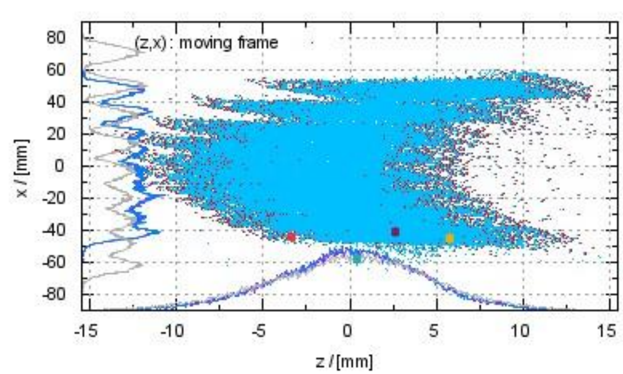

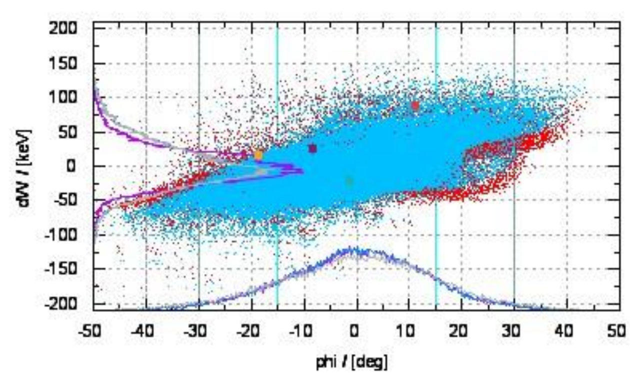

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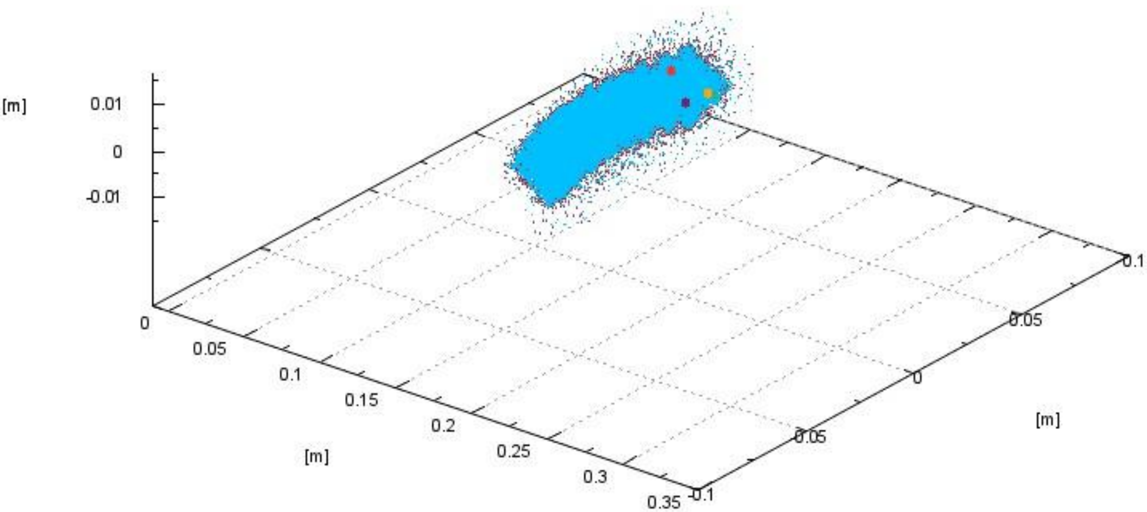

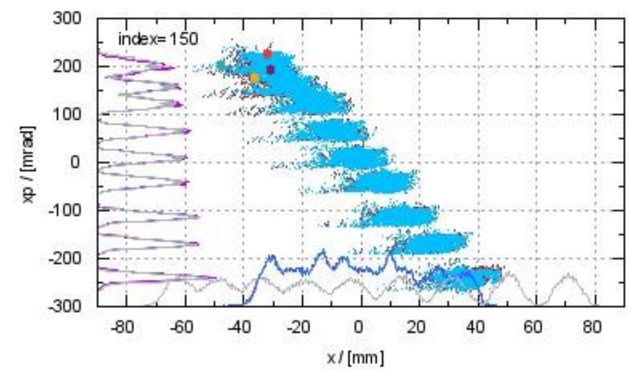

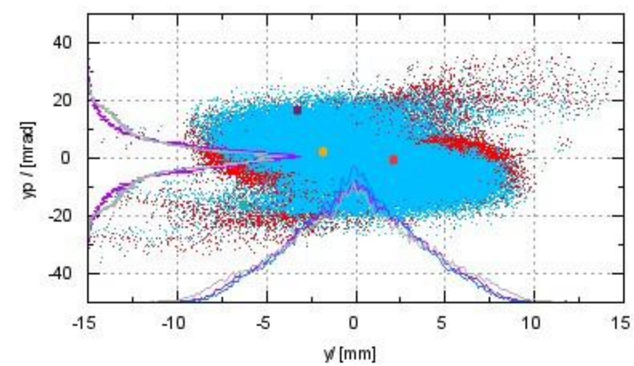

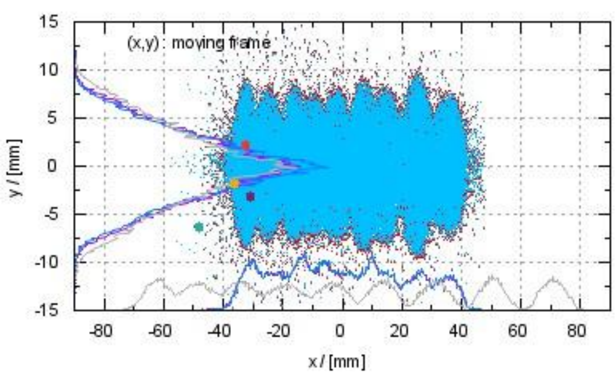

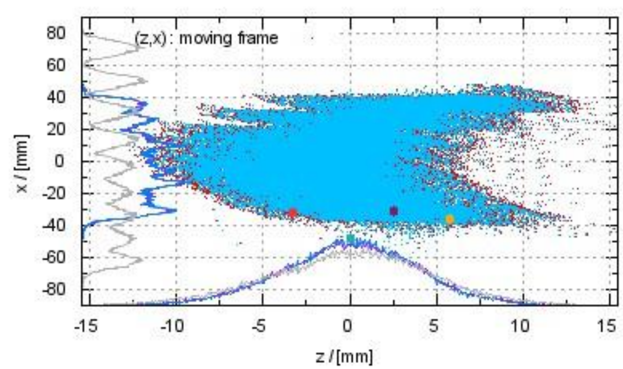

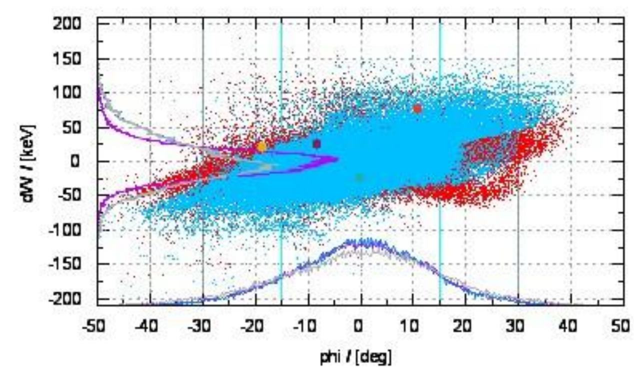

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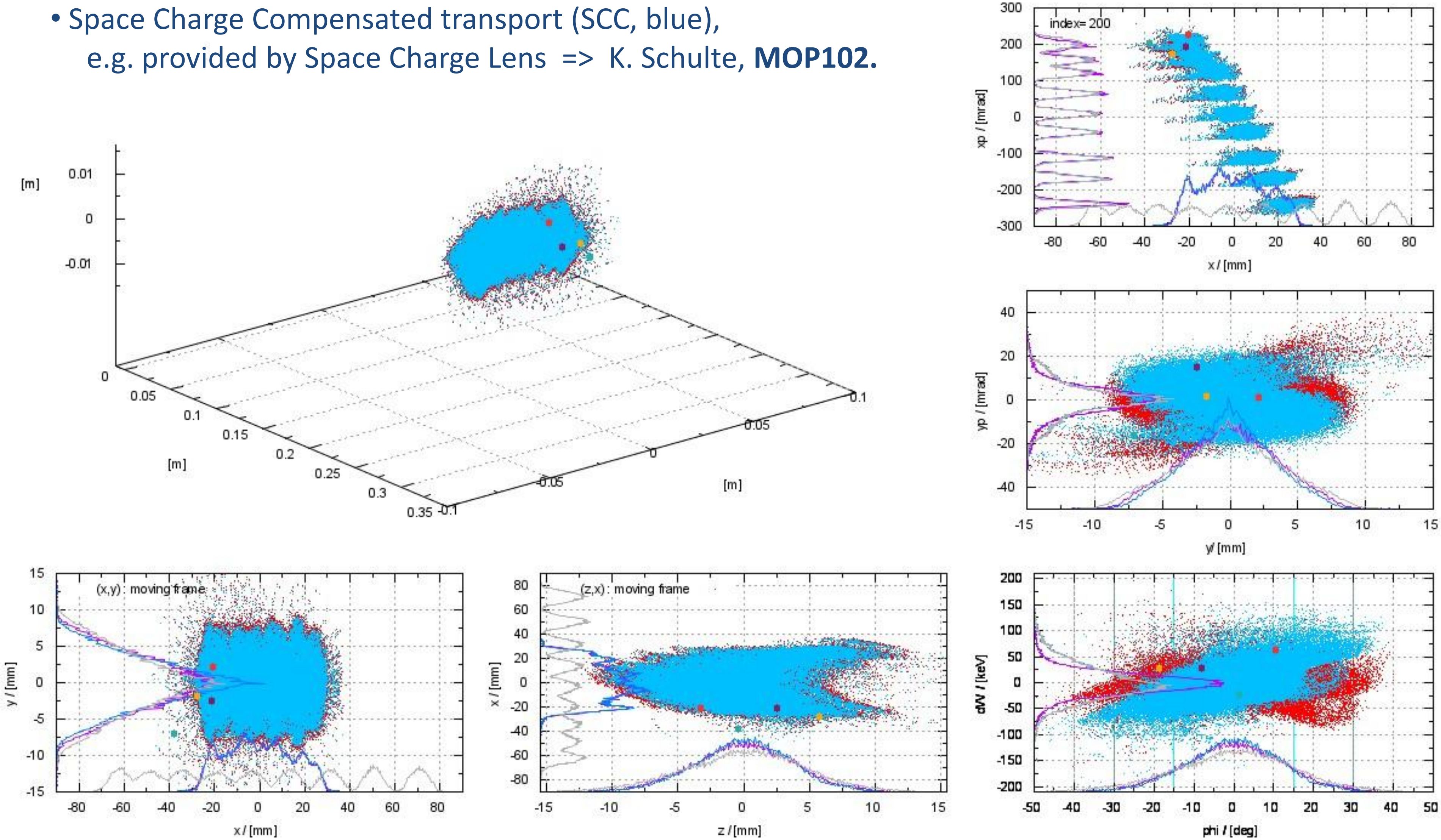

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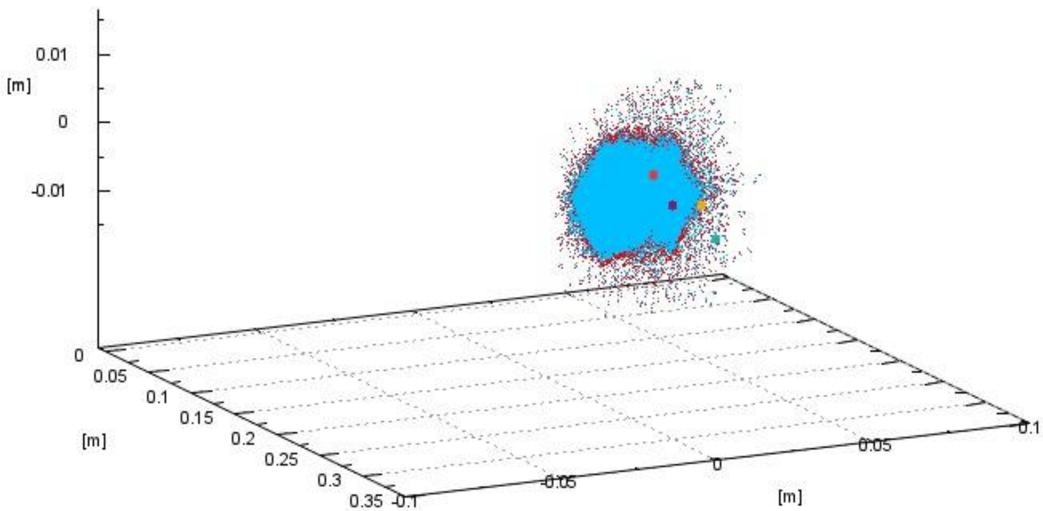

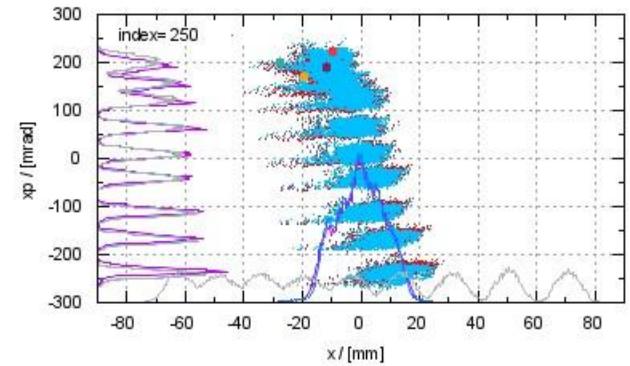

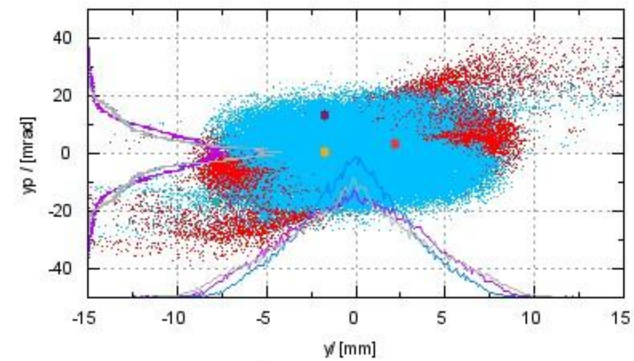

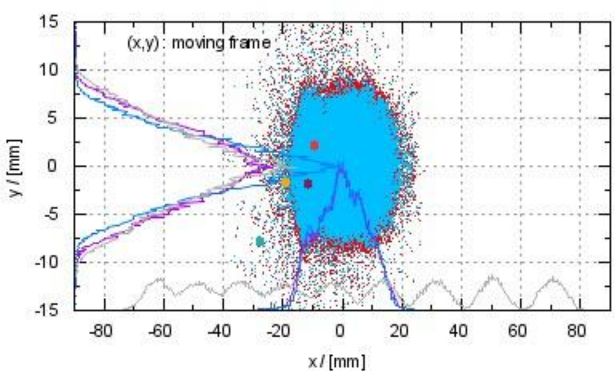

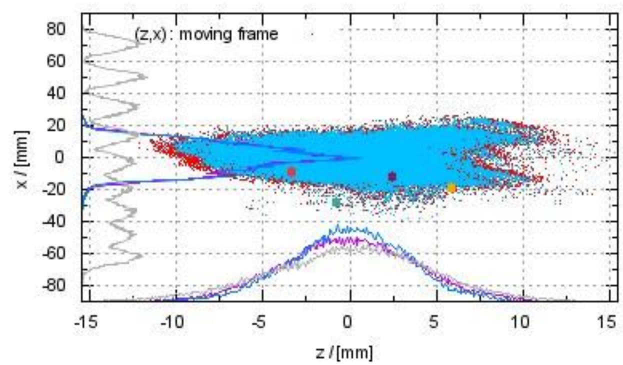

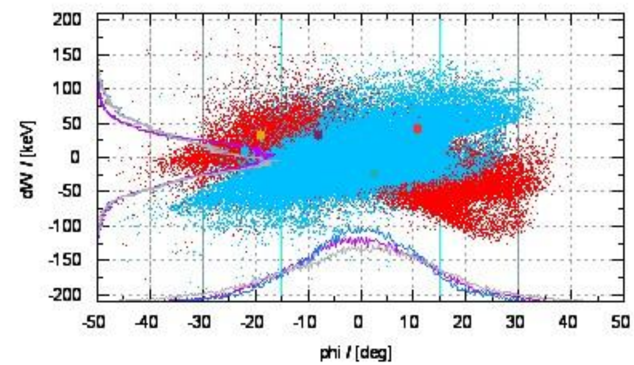

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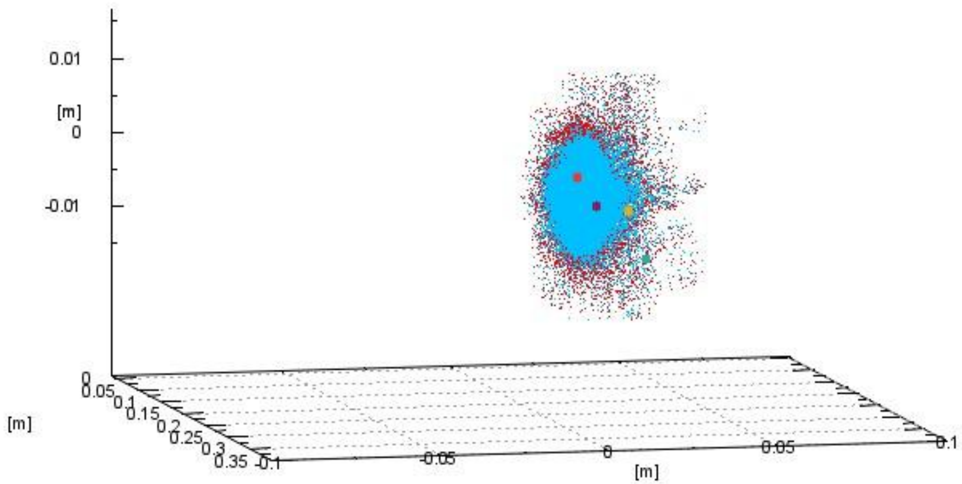
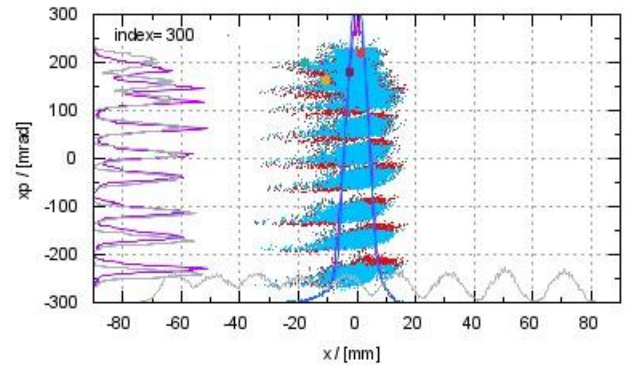
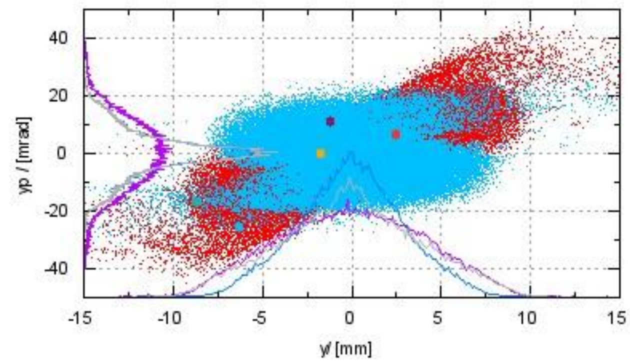
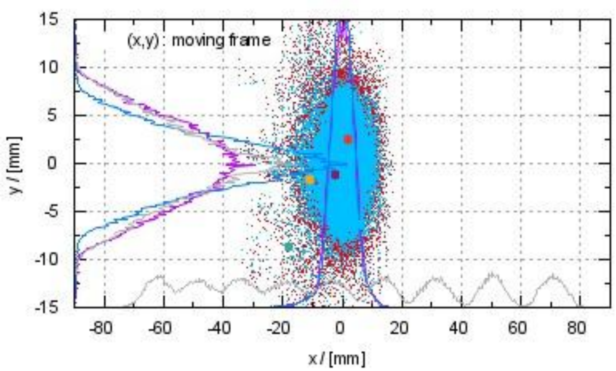
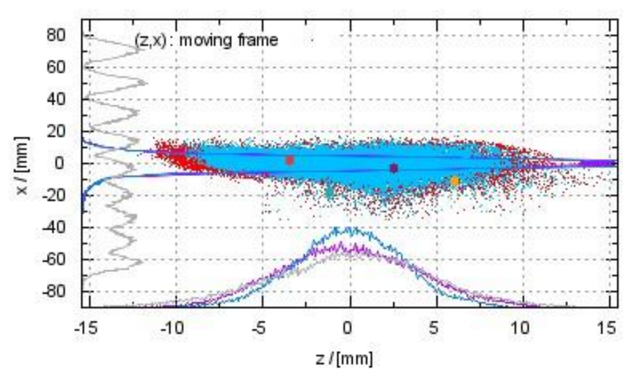


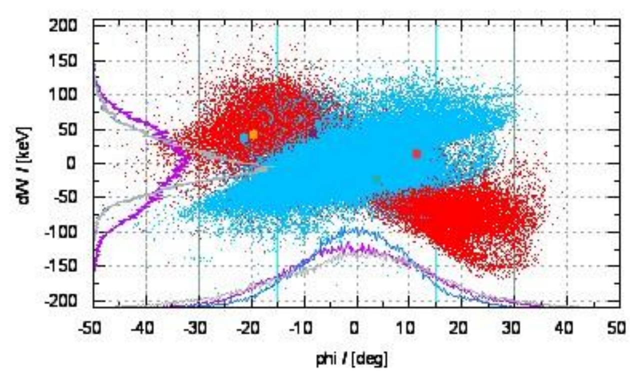




Beam spot at the target



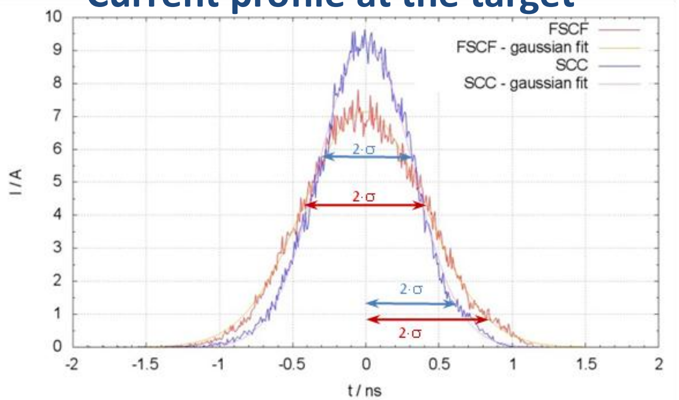




Multi Bunch Beam Dynamics: Effects of Space Charge

- Merging along **last 300 mm to the final focus**: realistic distributions from single bunch beam dynamics.
- Full Space Charge Forces (FSCF, red + purple).
- Space Charge Compensated transport (SCC, blue),
  e.g. provided by Space Charge Lens => K. Schulte, **MOP102.**

Current profile at the target



$I_{max,FSCF} = 7.1A$

$I_{max,SCC} = 9.2A$

$I_{average} < 2$ mA

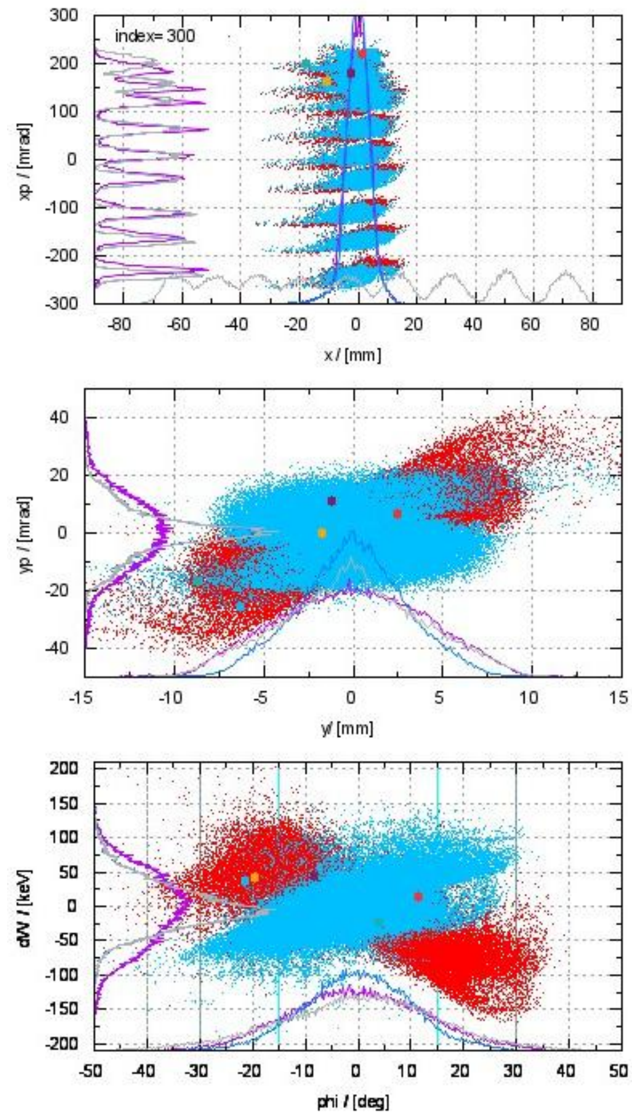
$(\Delta T)_{rms} \equiv 2\cdot\sigma$

Average $\pm 2\cdot\sigma \equiv 95.5\%$

Requirements

R	<	10 mm
ΔW/W	<	±5%
ΔT= 50-100 ns	=>	ΔT≈ 1 ns

		2·σ FSCF	2·σ SCC	Δ(2·σ)
x	*mm*	7.86	6.92	-12%
y	*mm*	8.90	7.02	-21%
z	*mm*	16.52	12.38	-25%
ϕ @87.5MHz	*deg*	26.46	19.80	-25%
ΔT	*ns*	0.84	0.63	-25%
ΔW	*keV*	104.6	55.0	-47%



Summary & Outlook

- **ARMADILLO** bunch compressor is presented.
- **Geometrical concept** is principally able to reach a long. compression ratio of 45.
- **Single bunch and multi bunch beam dynamics** results, even with full space charge forces, are promising to **satisfy the requirements**.
- Preliminary and **improved magnet designs** are proposed.
- **Optimization of hardware and complementary code** has to be continued.
- **Front to end simulations** with realistic fields have to be done.
- Detailed **error studies** have to be done.

Thank you for your attention

on behalf of

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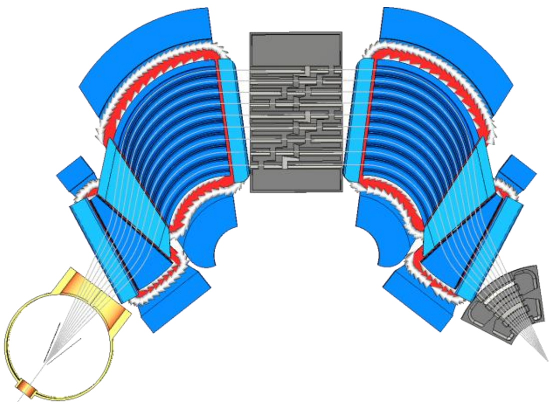

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M. Heil (GSI)

ARMADILLO
Arc Magnetic Dipole Chicane with Large Aperture Longitudinal Focusing Cavities

H. Klein, H. Podlech, A. Schempp, S. Schmidt, K. Schulte

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