# Bunch Compressor for Intense Proton Beams

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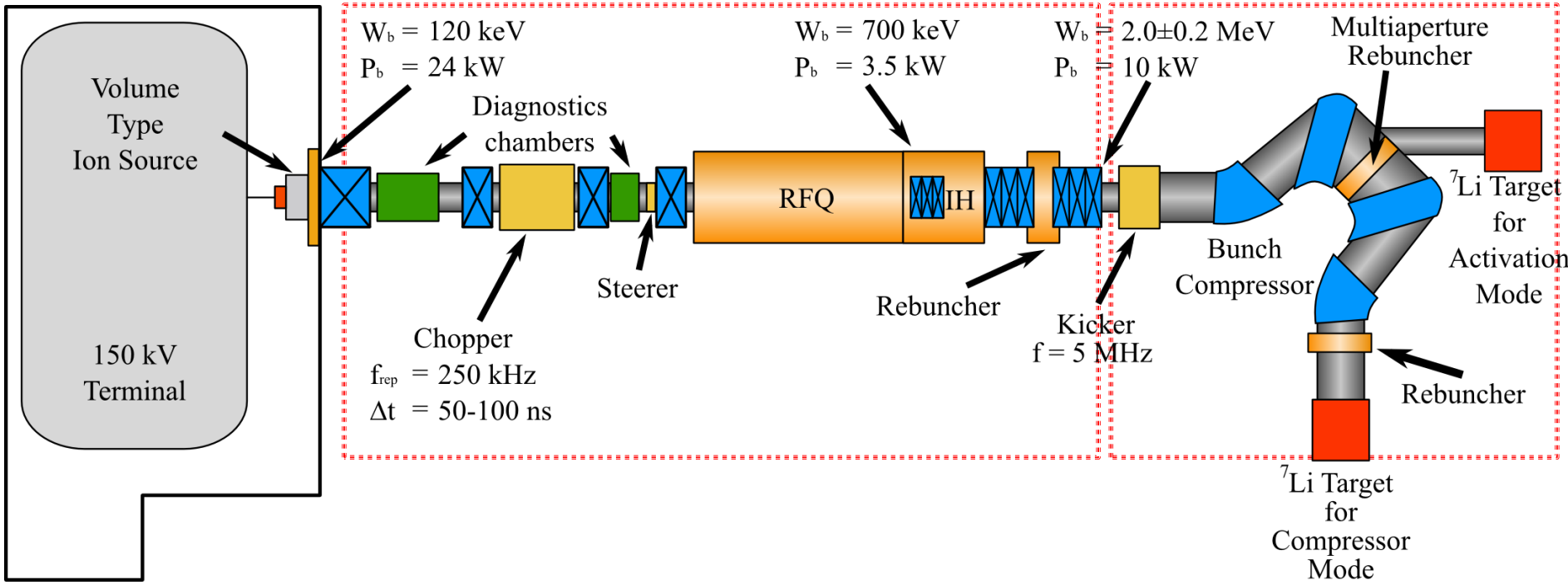
# Outlines:

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

# Frankfurt Neutron Source FRANZ




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

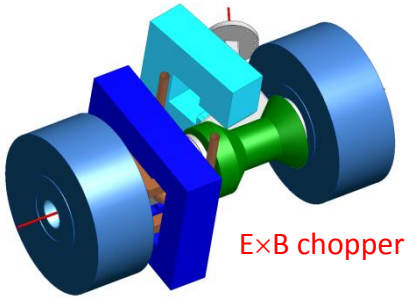
# FRANZ: Test Stand for Accelerator Technologies



***High current applications:***

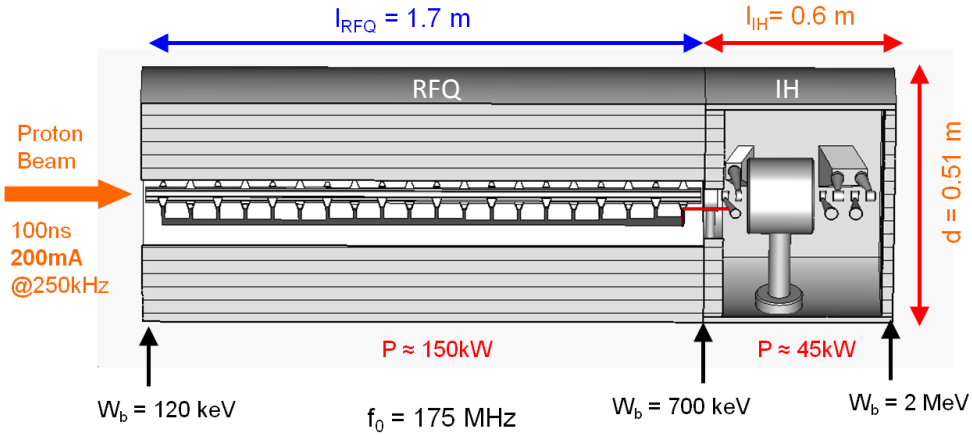
=> Where are the limits of conventional accelerator technologies?

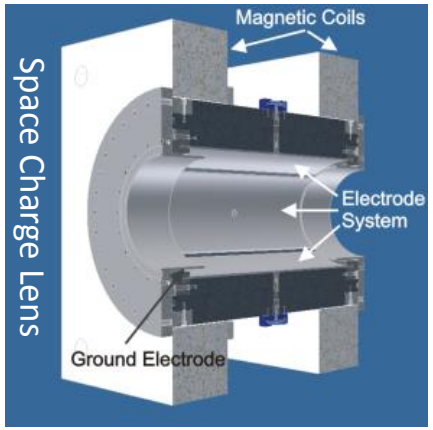
=> Are there alternative concepts?



E×B chopper

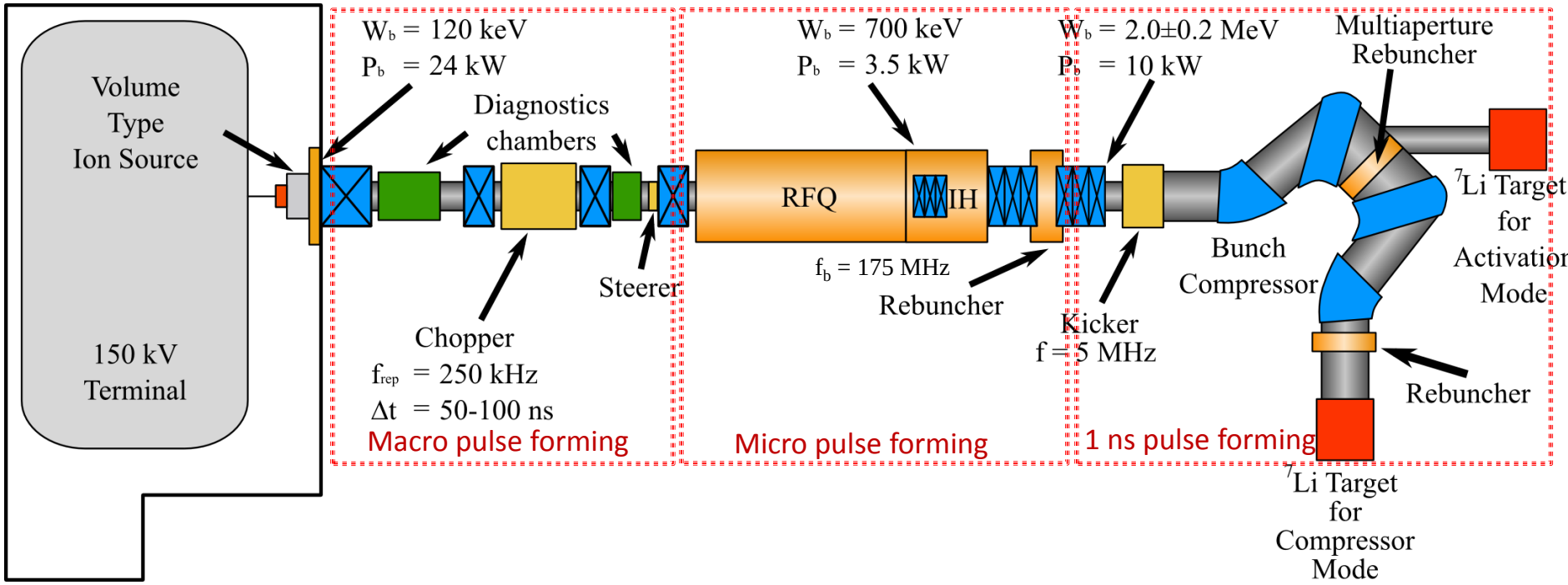
- Beam forming at high rep. rates: E×B chopper (C. Wiesner ,**THP071**)
- High current cw RFQ (A. Schempp, **TUP039**)
- Coupled RFQ-IH combination
- DTL concepts: IH, CH, Multi-Aperture Reb. (U. Ratzinger, H. Podlech, D. Noll: **MOP101**)
- Alternative beam dynamics: KONUS (U. Ratzinger)
- Alternative beam focusing device: Space Charge Lens (K. Schulte, O. Meusel, **MOP102**)
- Non destructive diagnostics: beam tomography (O. Meusel)



# FRANZ: Bunch Compressor - Requirements





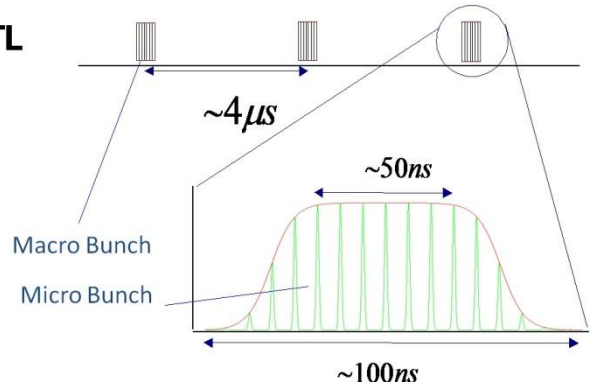

## Pulse Structure at the Entrance

**175MHz-DTL**

**rep.rate** = 250*kHz*

**E** ~ 2.0*MeV*

**I** = 150*mA*




## Requirements at the Final Focus

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

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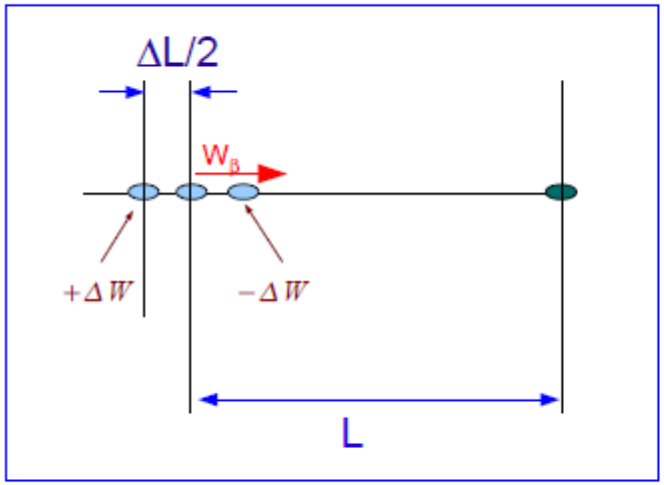
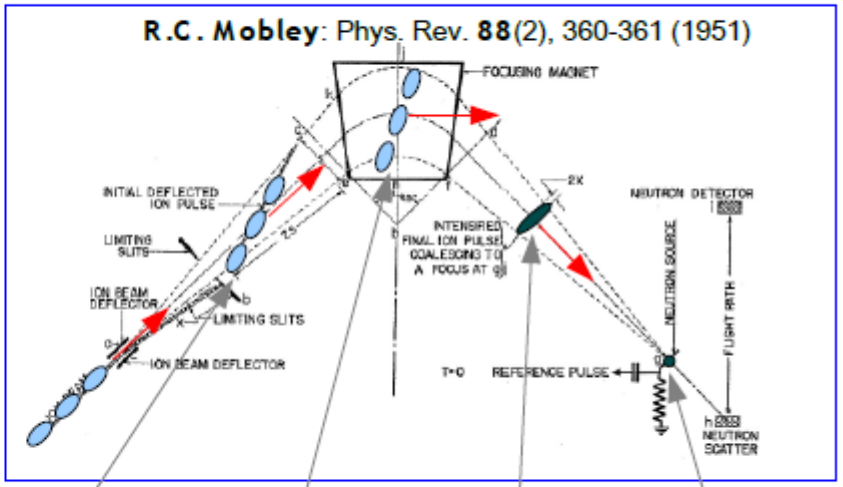
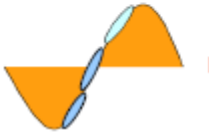
# Bunch Compressor Concepts



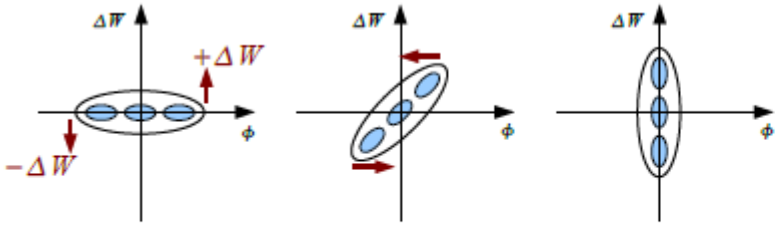
**Energy differences** ⟵ **Transit time differences** ⟶ **Path length differences**



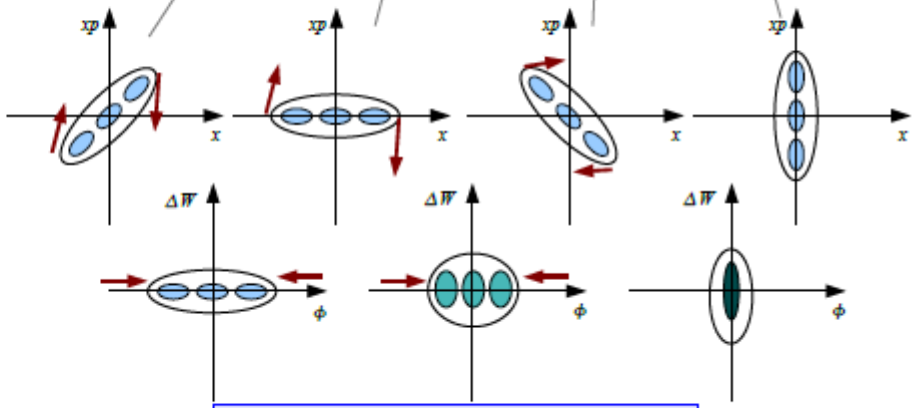



RF ⟹ de- / acceleration




**Large energy spread (RF-cavity)**




**Negligible energy spread (RF-deflector)**

L ≈ 4 m ⟹ ΔW ≈ ±500keV

**Transit time differences** → **Path length differences**

## Mobley-Buncher: (µA-Proton Beams)

***Kicker***

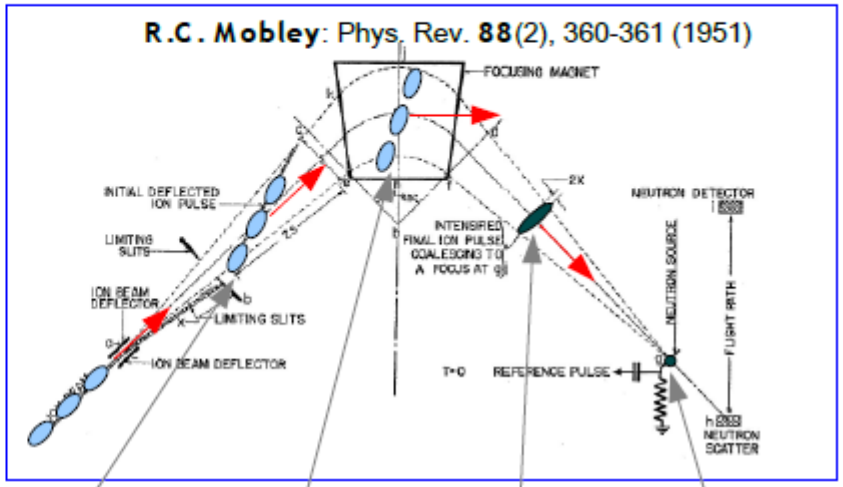
→ separation of the micro bunches

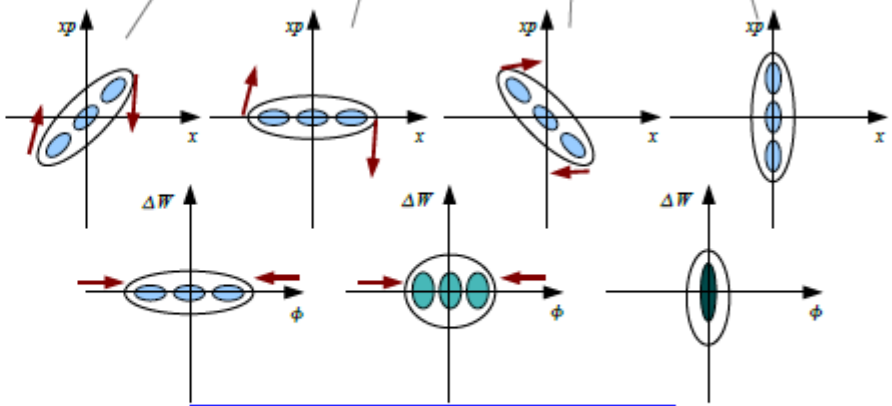
***Bending system (1 Dipole)***

→ "weak" focusing

→ path length differences

→ longitudinal compression




Negligible energy spread (RF-deflector)

## 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

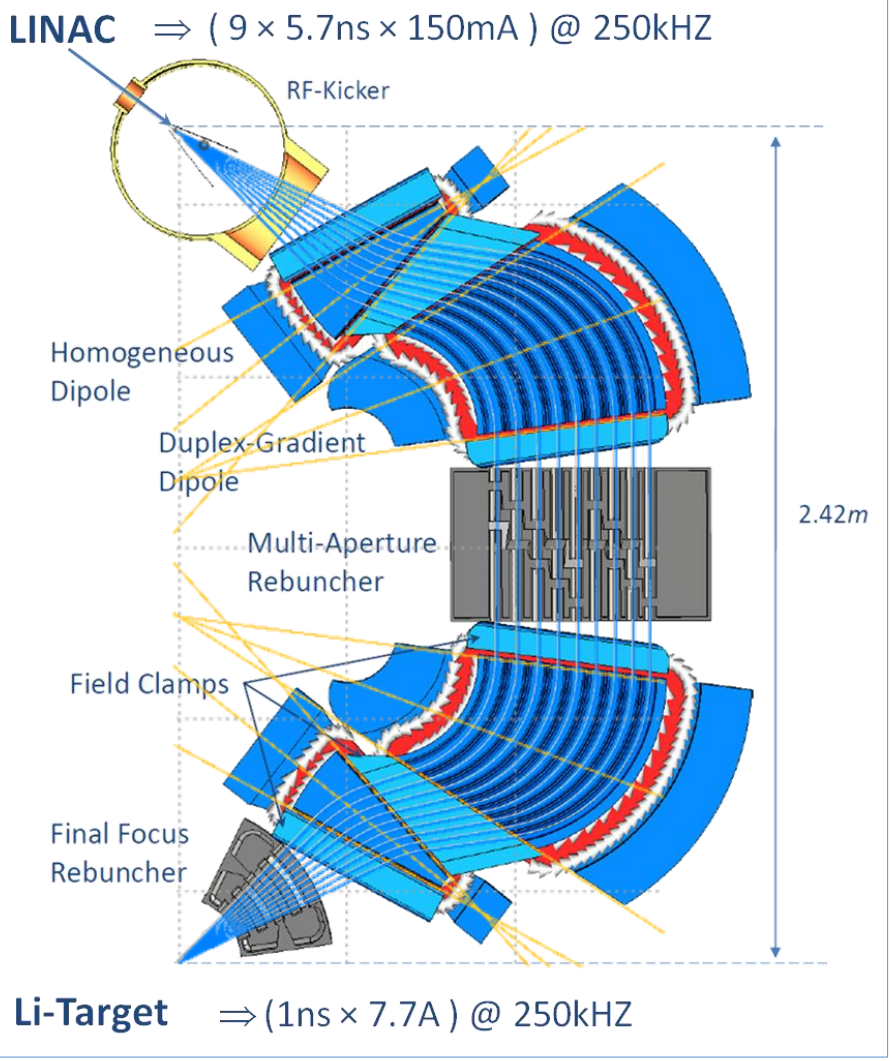
***2 auxiliary dipoles (homogeneous)***

→ linear separation of the trajectories

→ momentum exchange in trans. plane

***2 rebuncher cavities***

→ longitudinal beam dynamics





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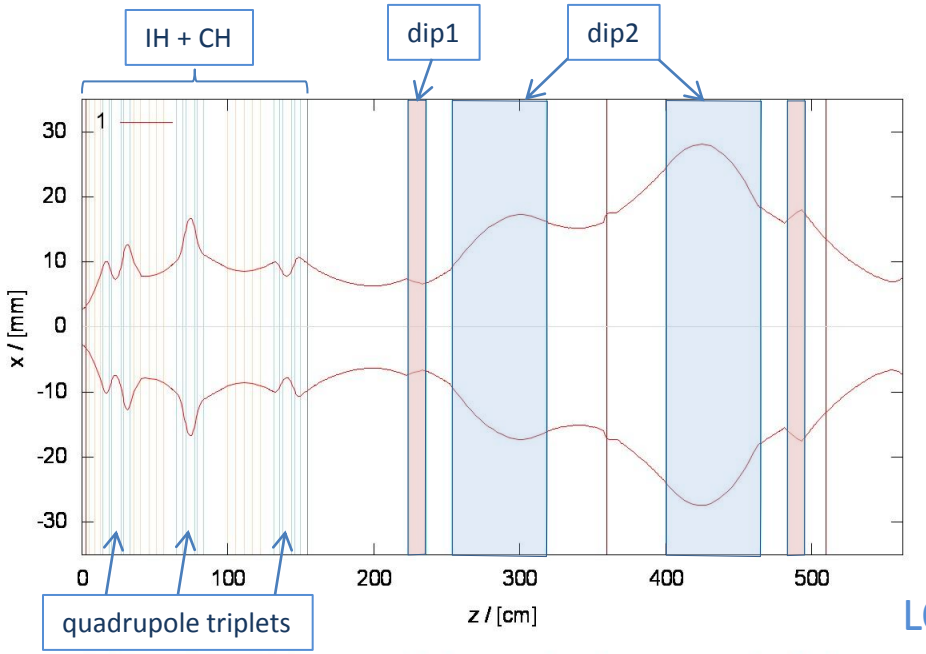
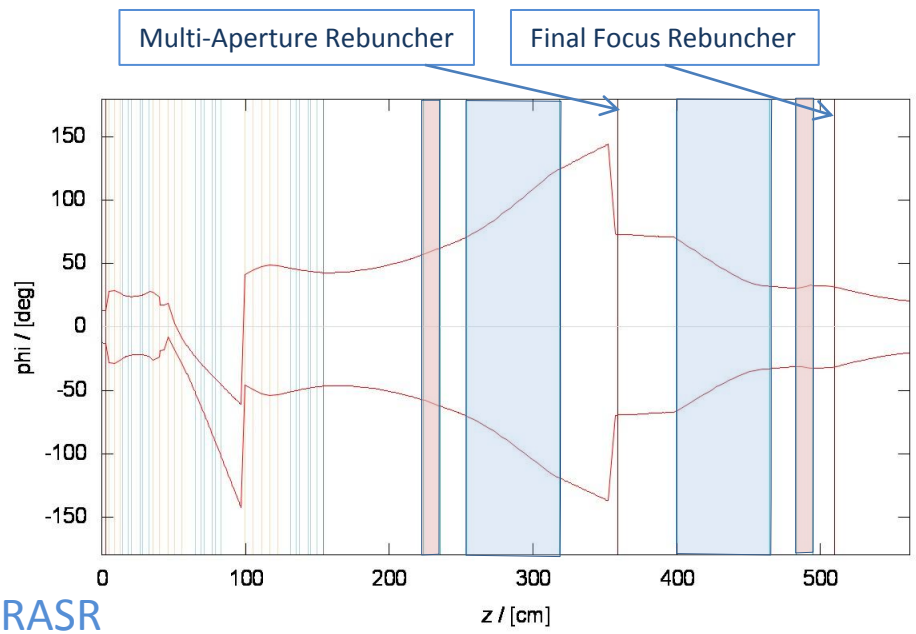
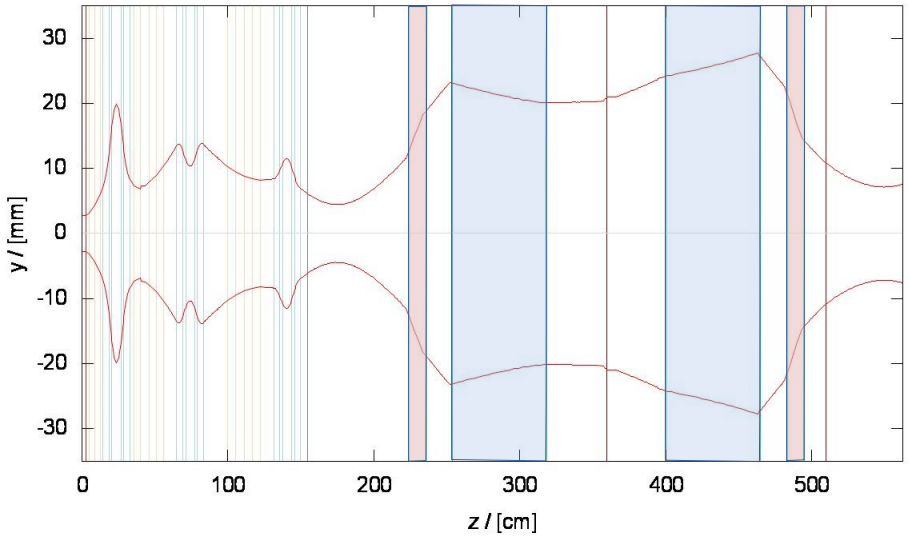
# Single Bunch Beam Dynamics: 95% Envelope

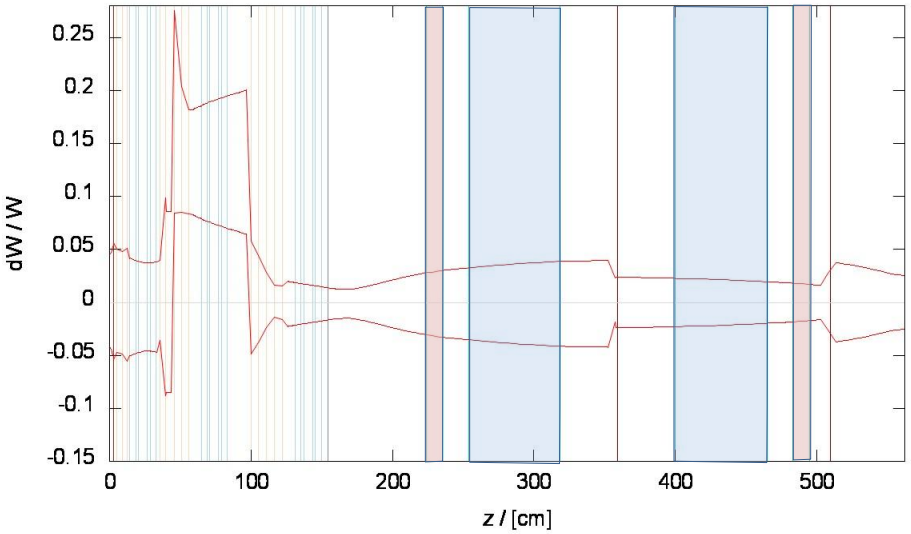





LORASR

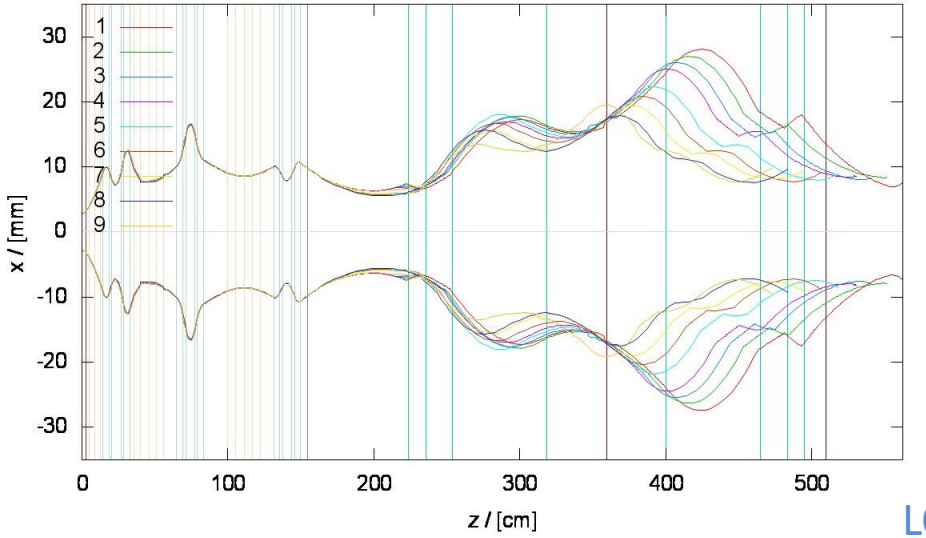


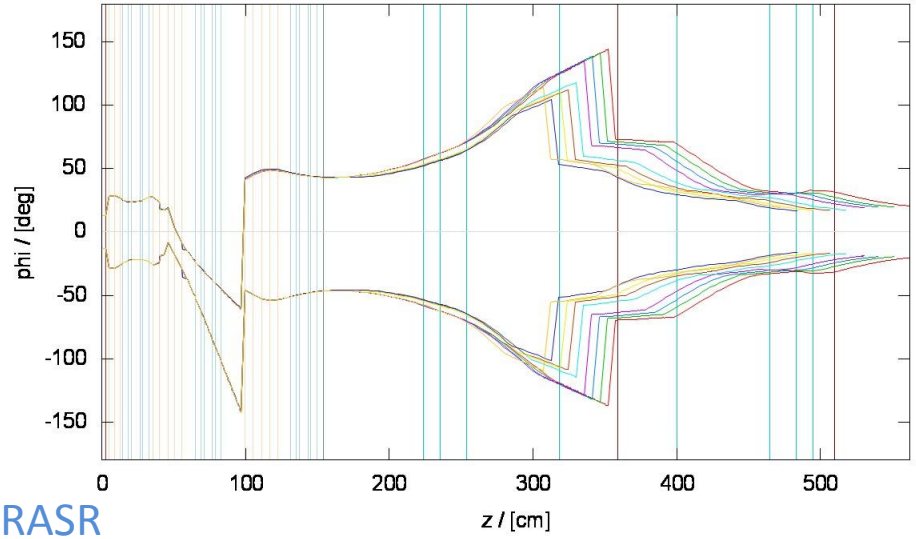



# Single Bunch Beam Dynamics



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

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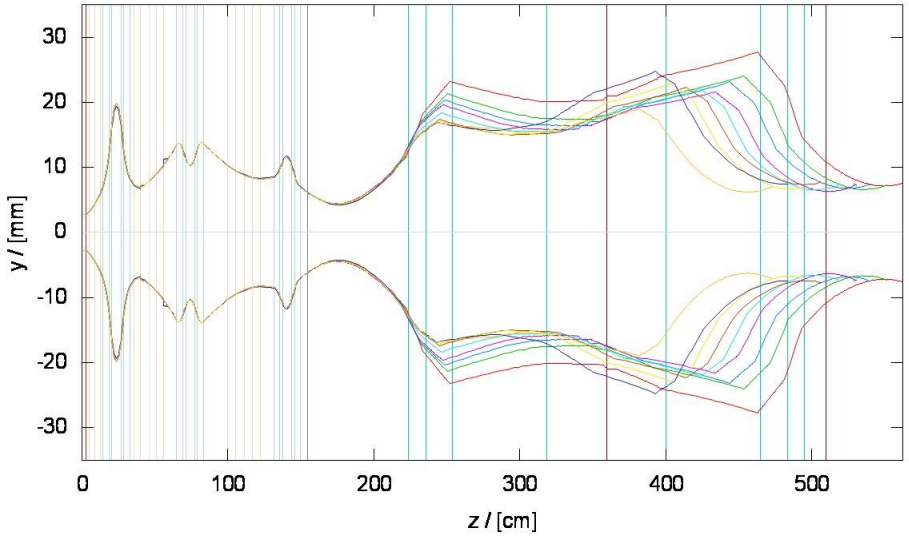
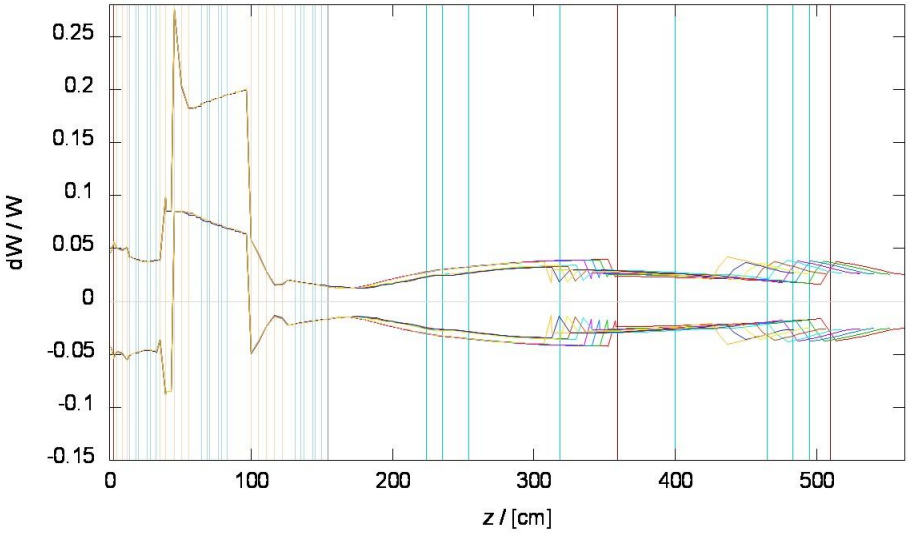
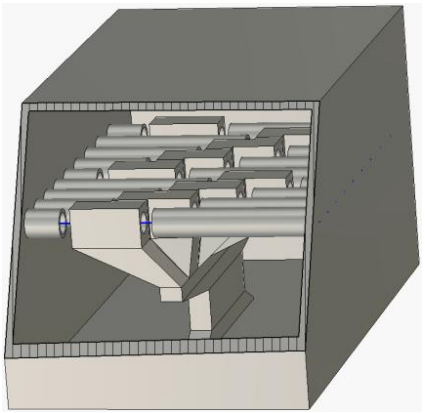
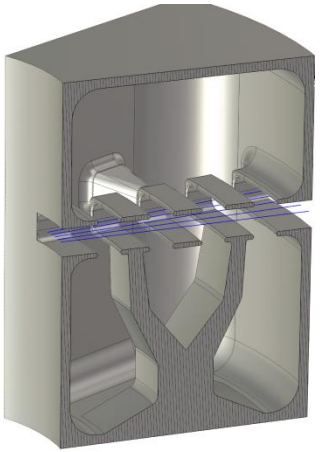


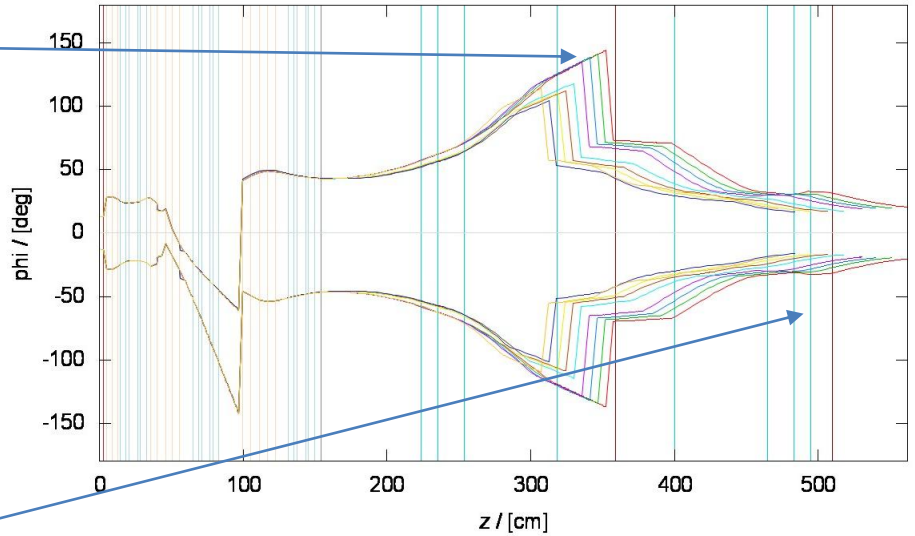
- Beam dynamics solutions for all bunches can be found by manual optimization!



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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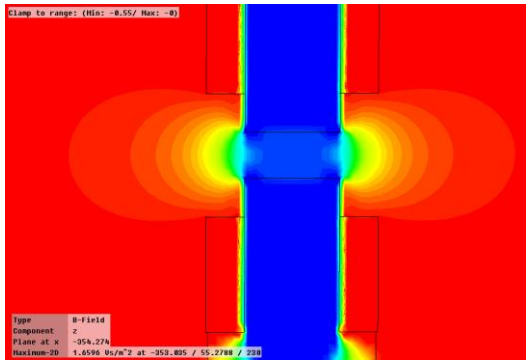
# Magnet Design: Improvement for Beam Dynamics



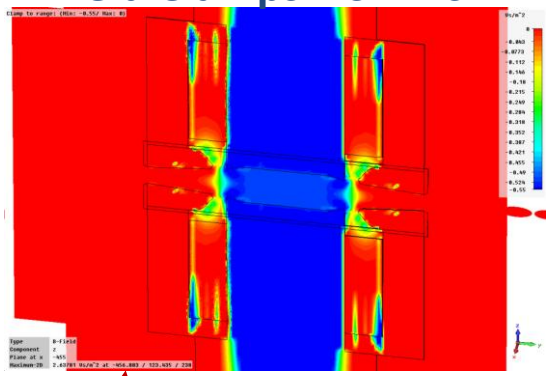
- Beam dynamics solutions for all bunches can be found by manual optimization!
- Is it possible to design a magnet with the required parameters?

**Without Modifications**

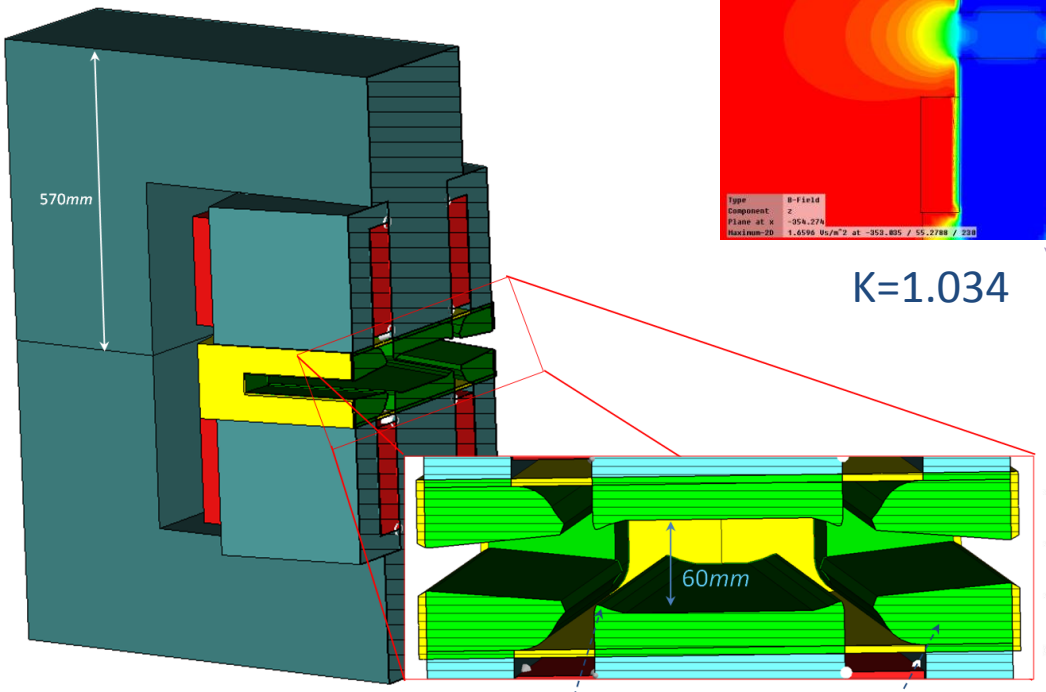


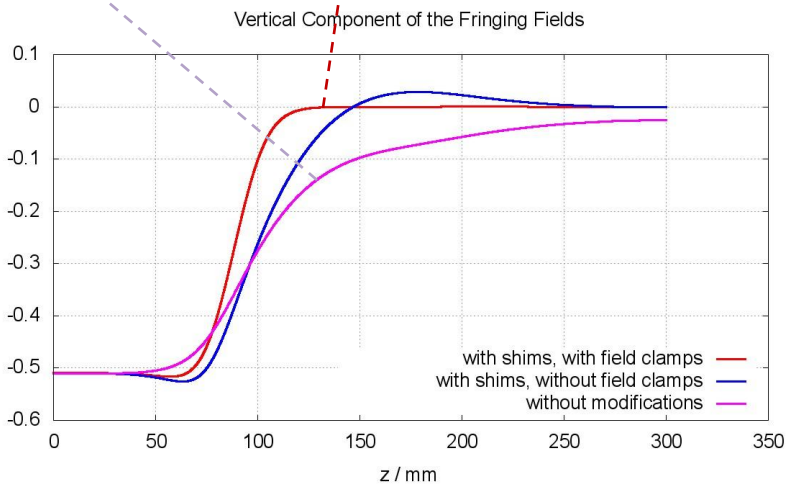
K=1.034

**Field Clamps + Shims**



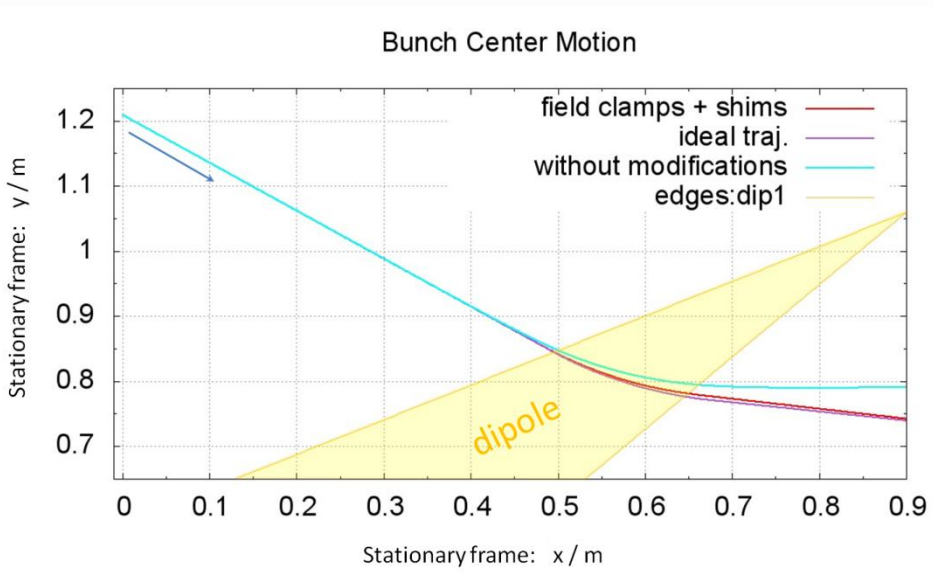
K=0.098

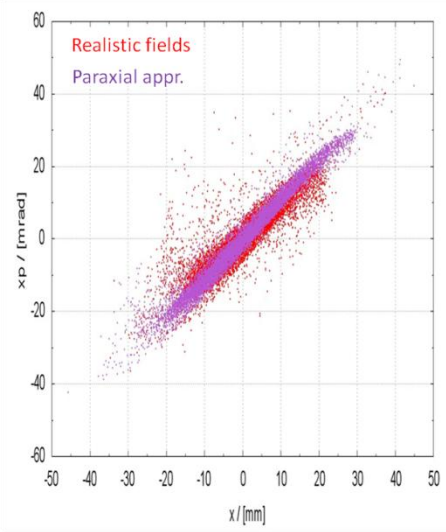


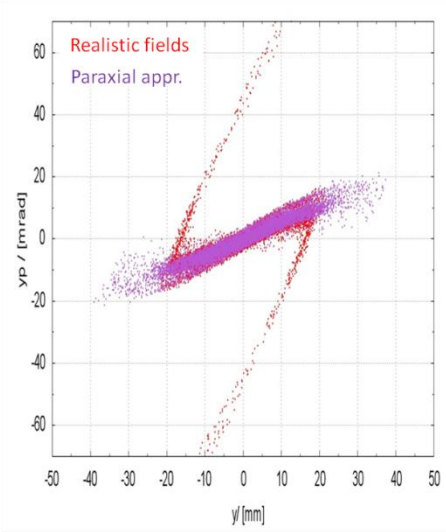



# Magnet Design: Improvement for Beam Dynamics





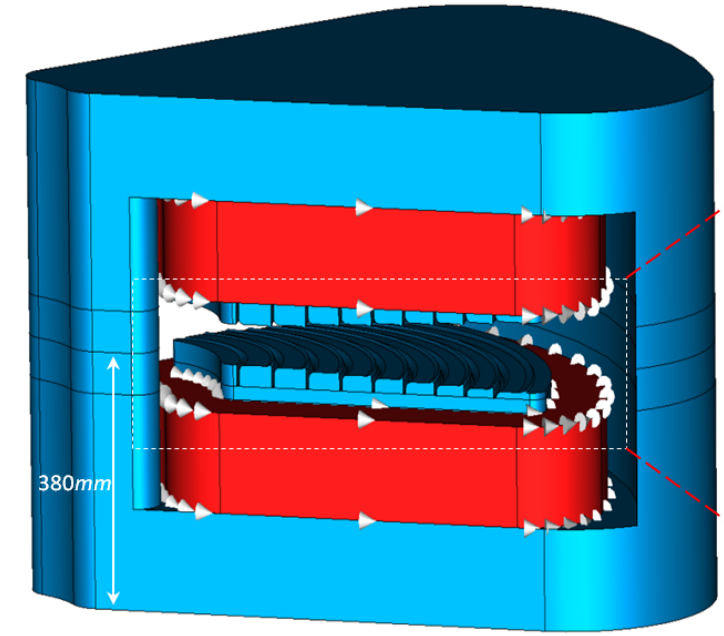



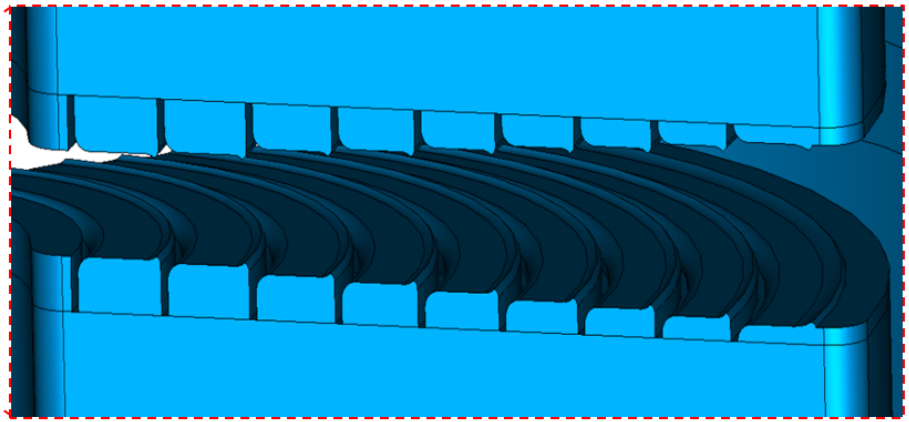

- Particle in Cell (PIC) transport with realistic fields compared to 1st order paraxial approach with given fringe field integral and edge angles.
- Ideal traj. ≡ const. fields + hard edges.
- Convergence to the ideal trajectory.
- Slope and core of distributions fit very well.
- Aberration caused by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

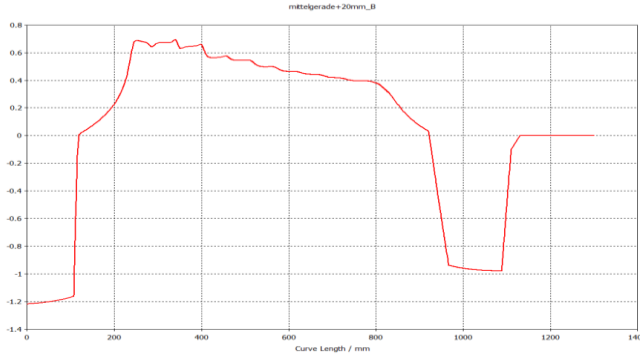
⇒ Single bunch beam dynamics with 1st order paraxial approach is good enough for geometrical design.

⇒ 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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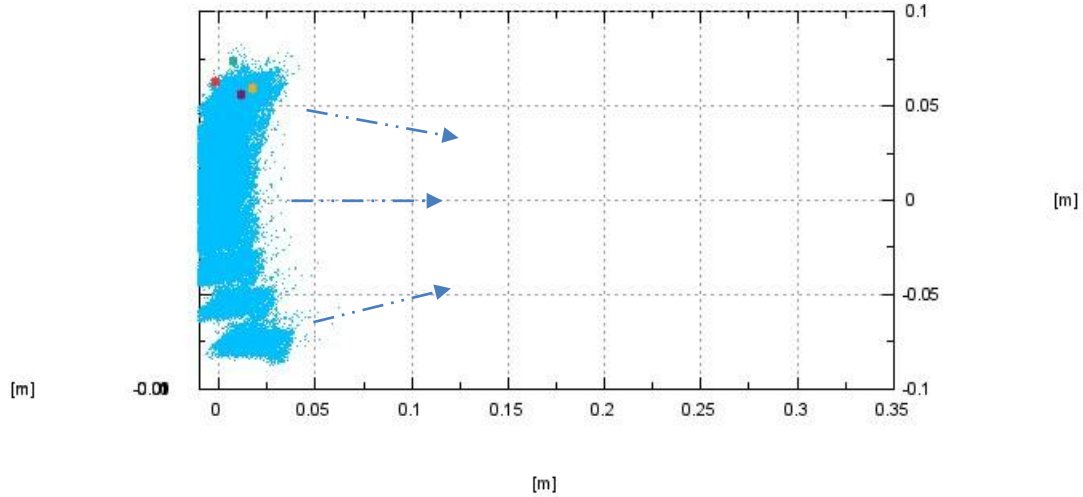
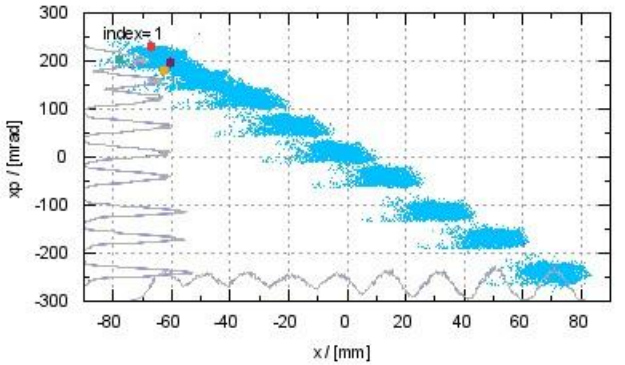
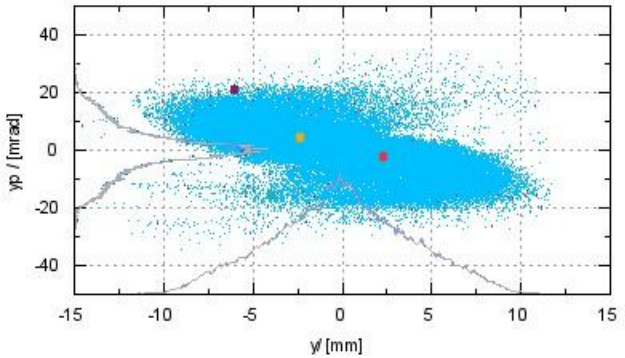
# Multi Bunch Beam Dynamics: Effects of Space Charge

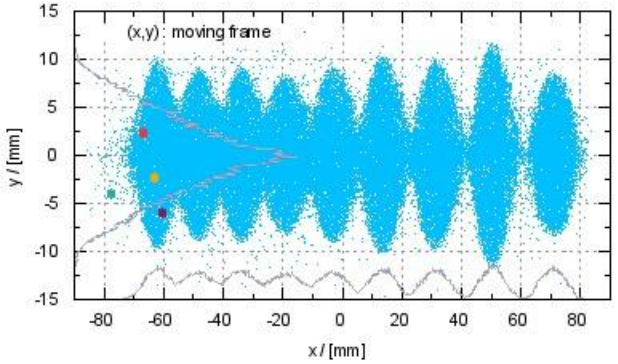


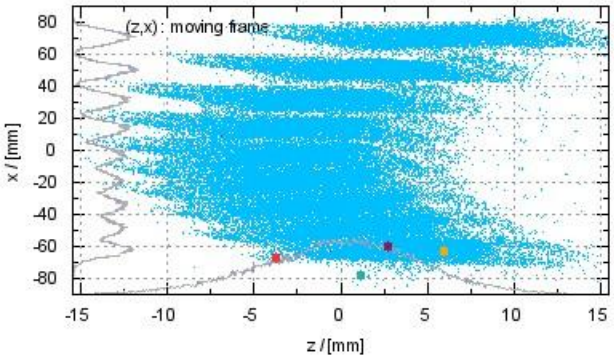
- Merging along **last 300 mm to the final focus**: realistic distributions from single bunch beam dynamics.
- Full Space Charge Forces (FSCF, red + purple).
- Space Charge Compensated transport (SCC, blue),
  e.g. provided by Space Charge Lens => K. Schulte, **MOP102.**

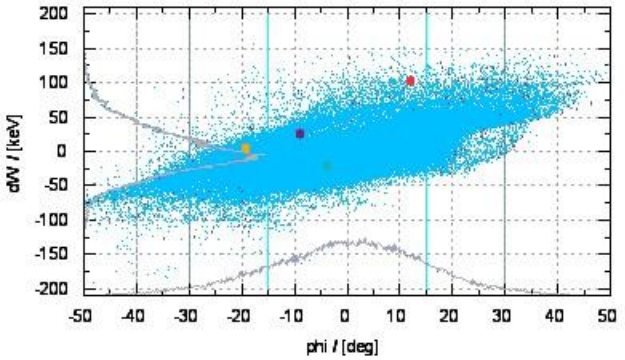


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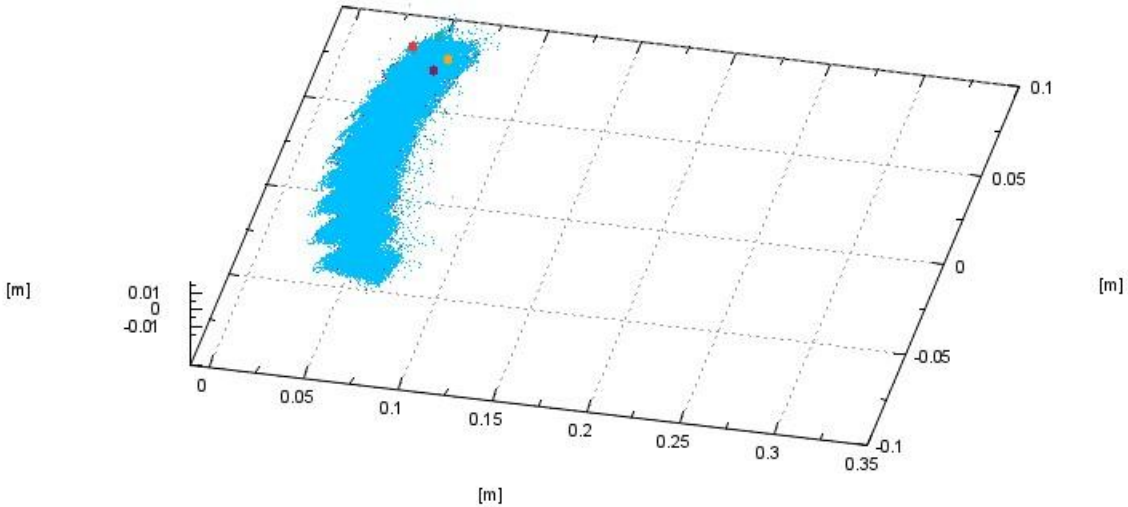


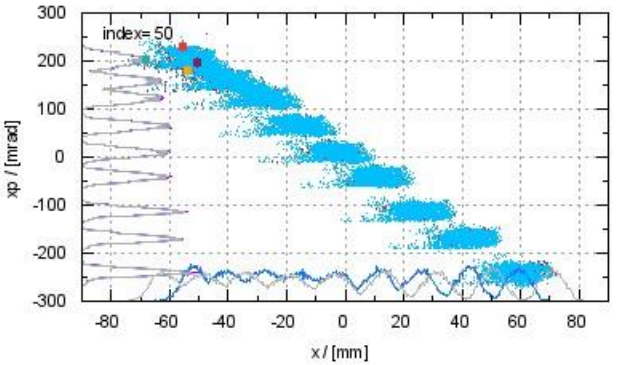


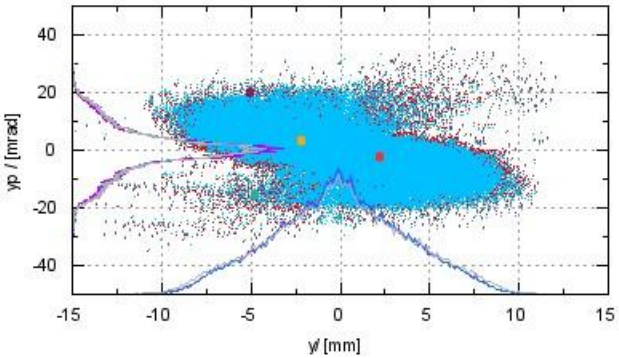


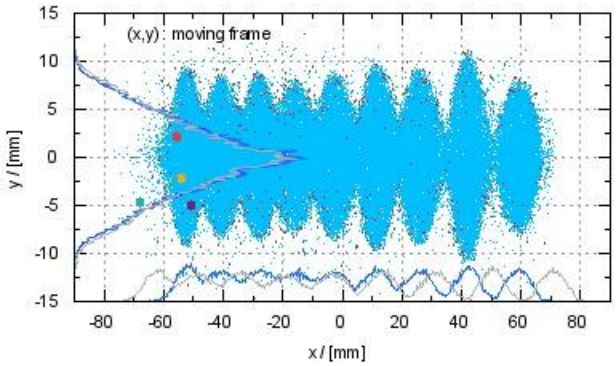


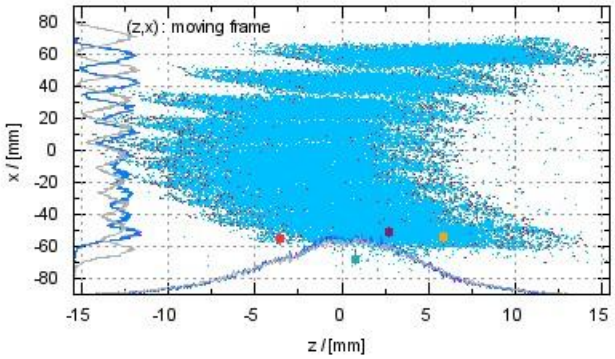


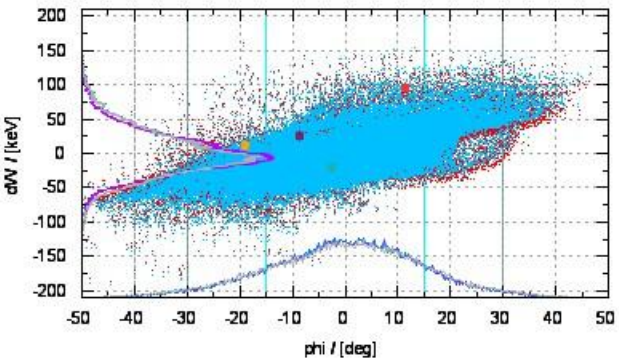

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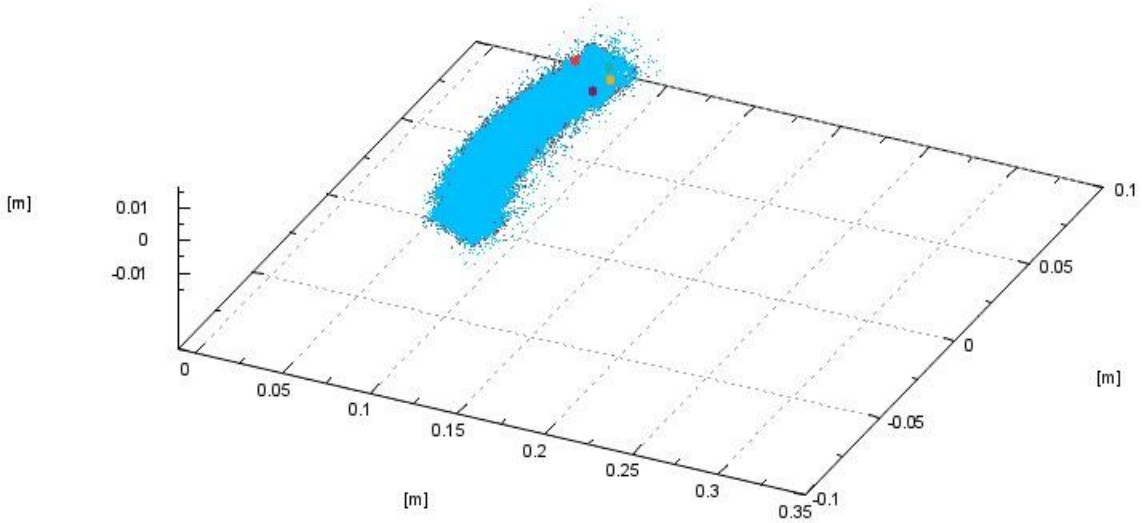


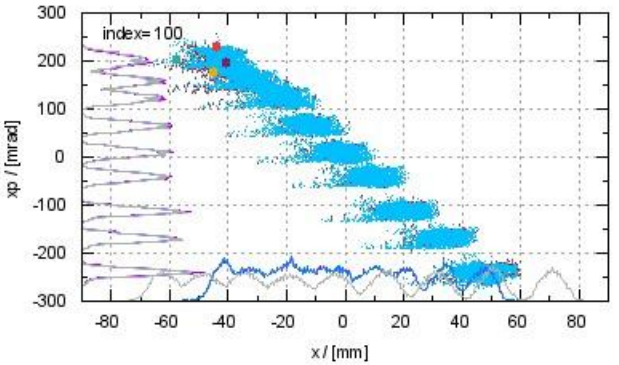


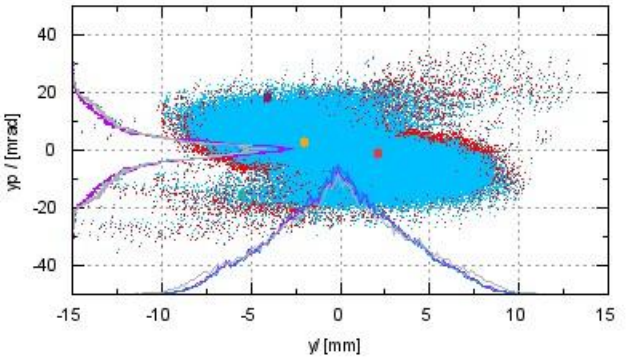


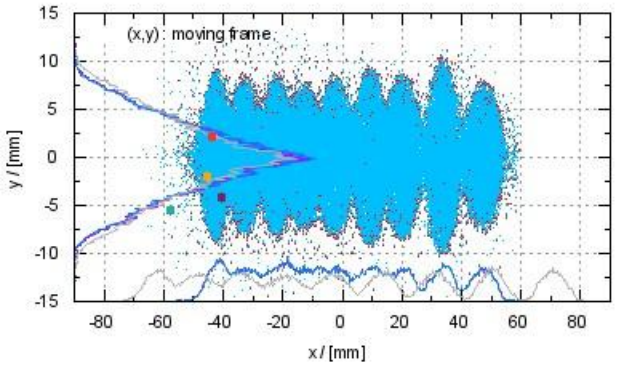


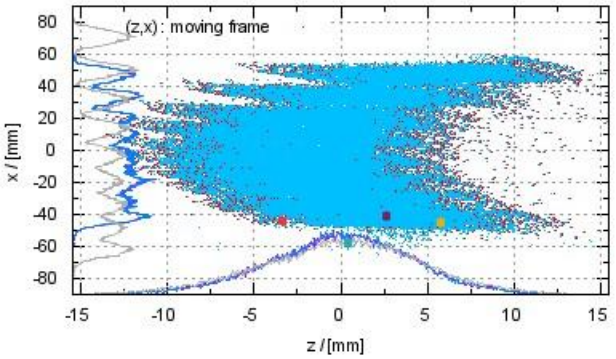


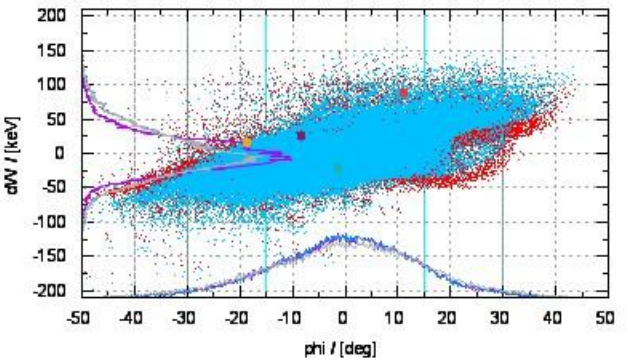

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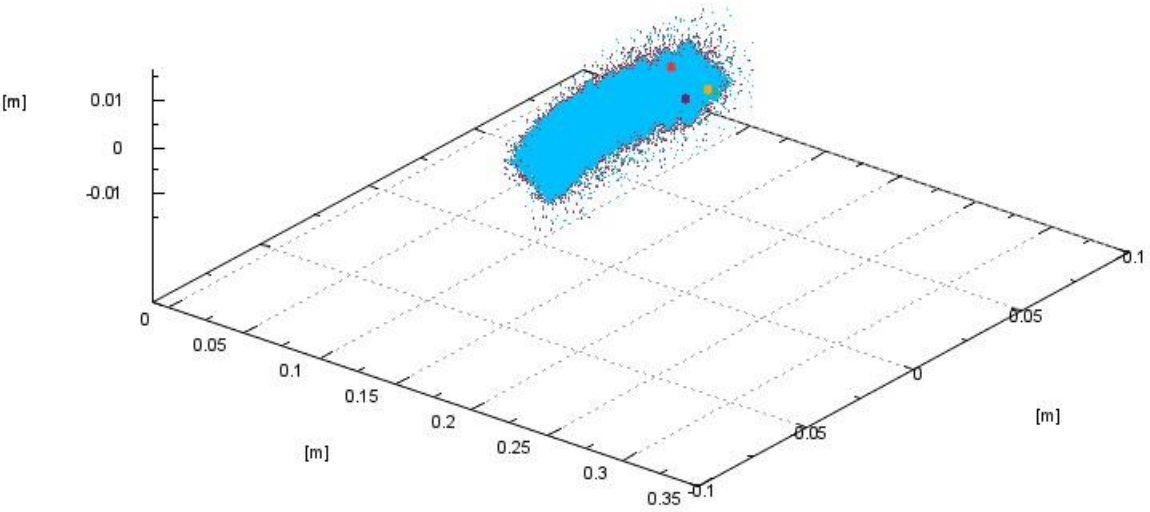


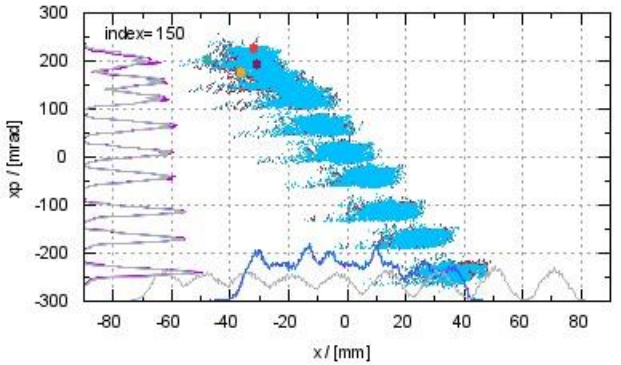


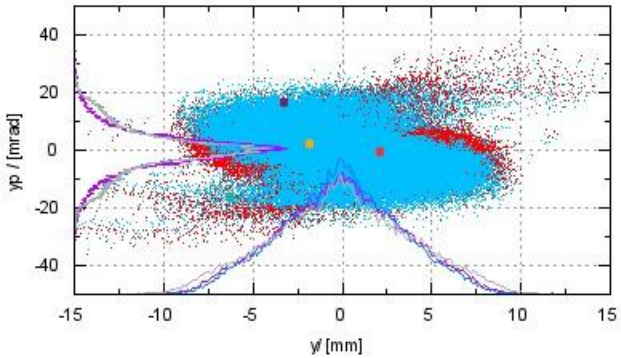


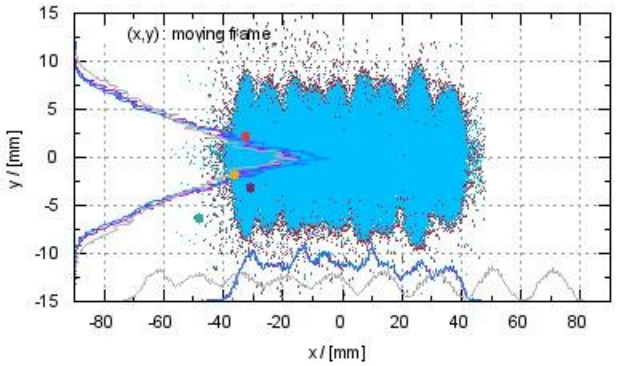


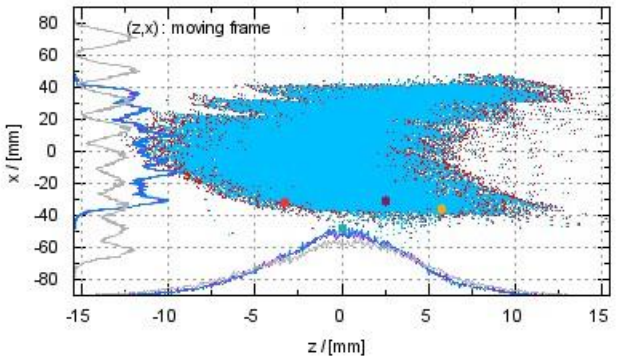


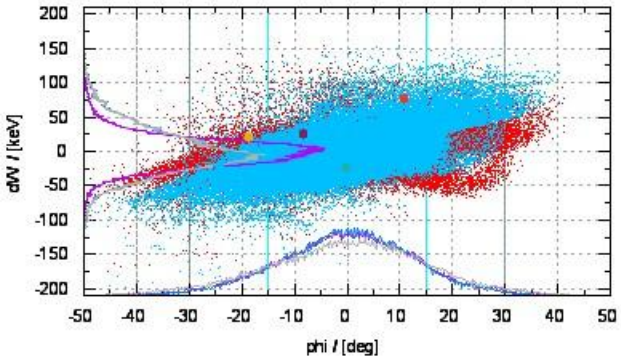

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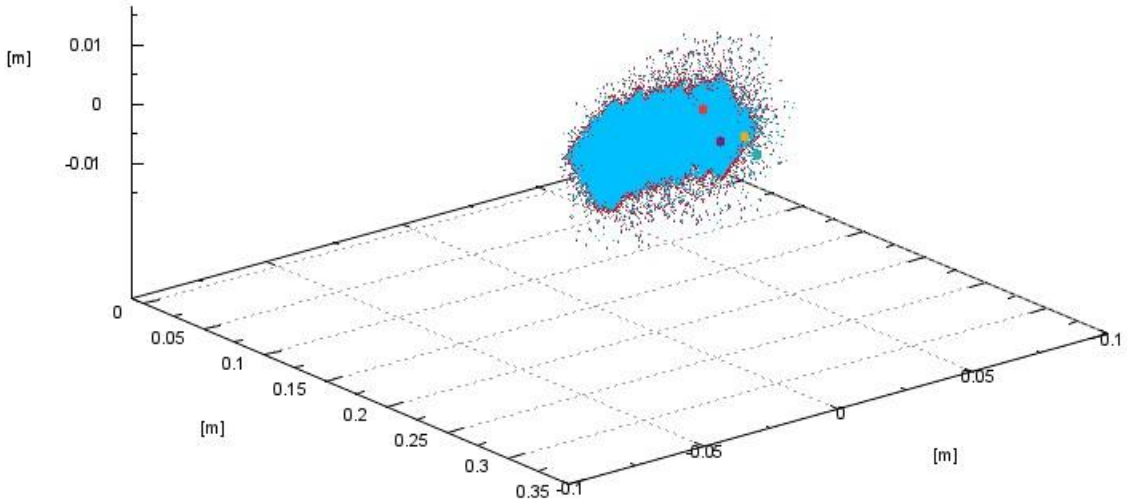


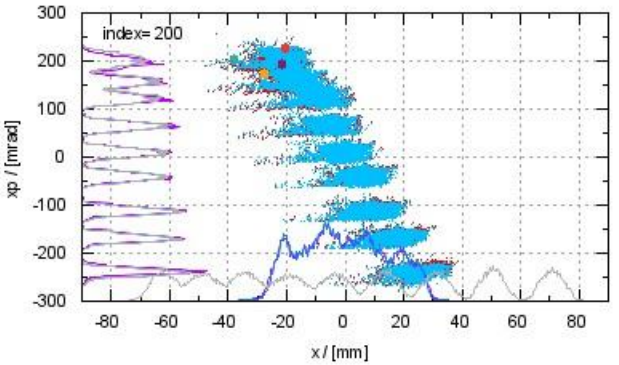


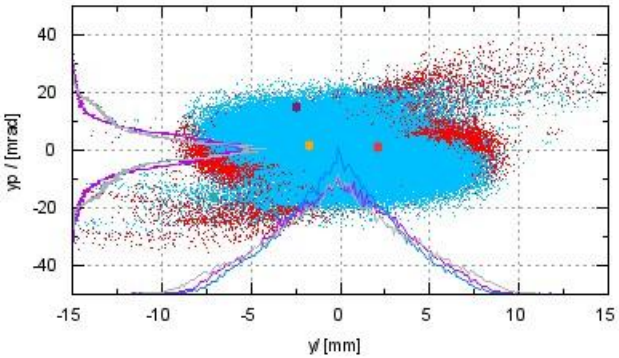


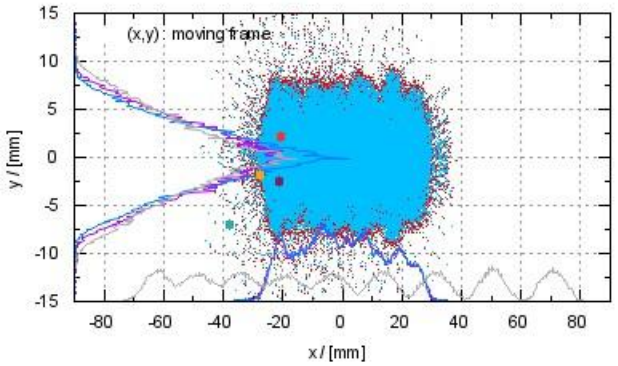


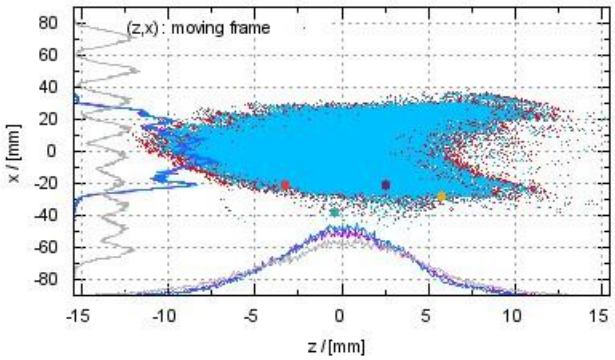


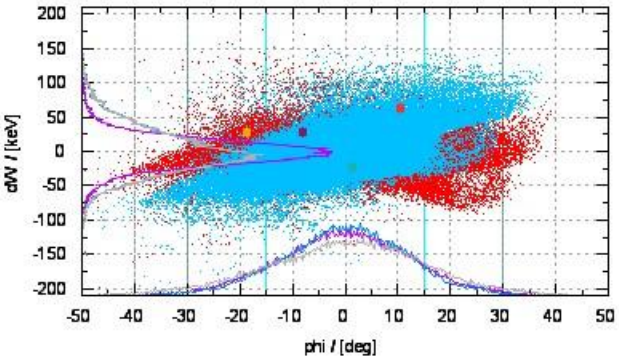

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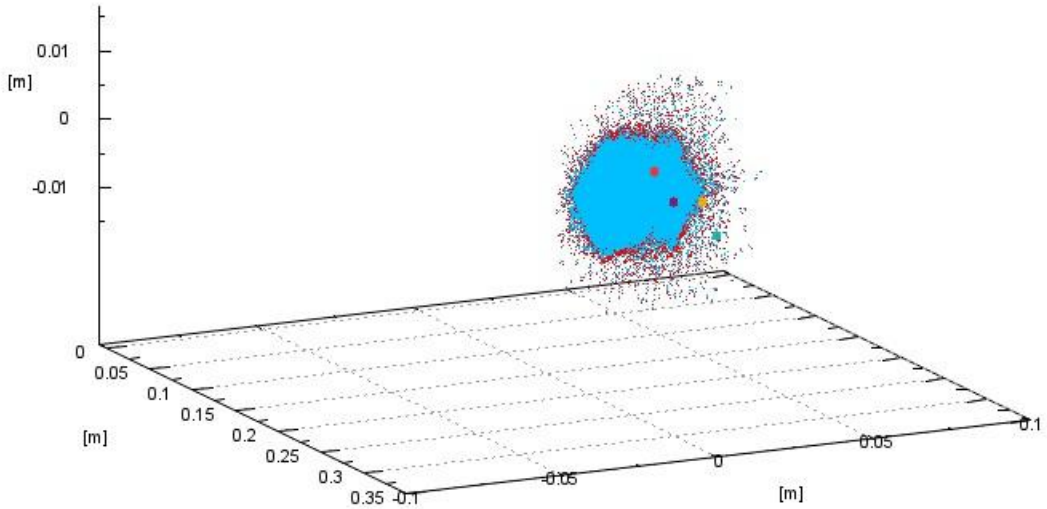


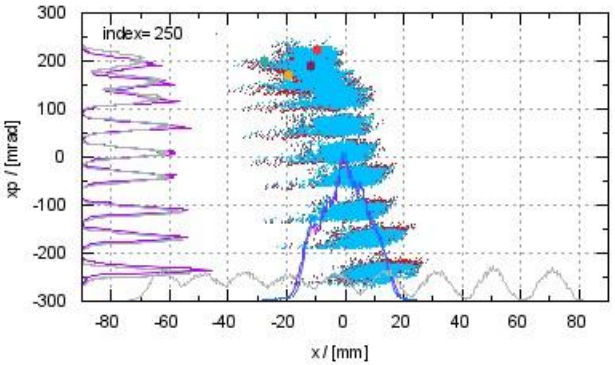


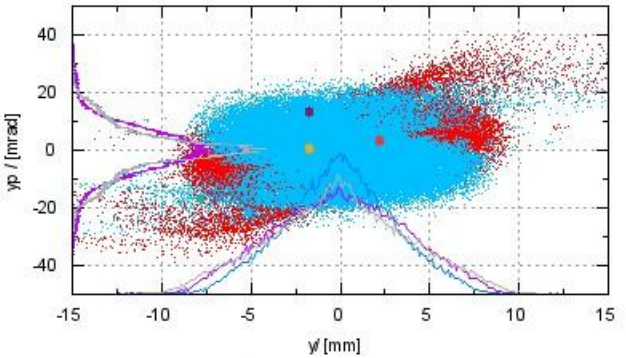


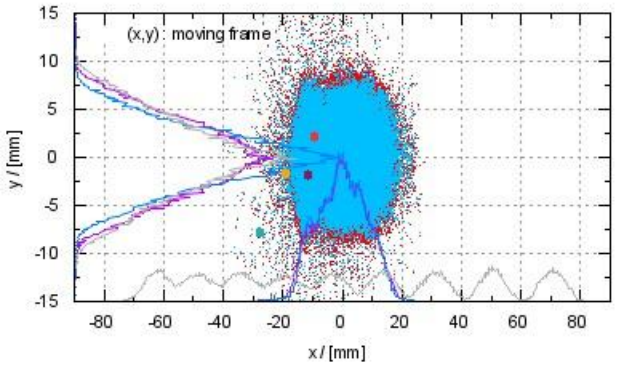


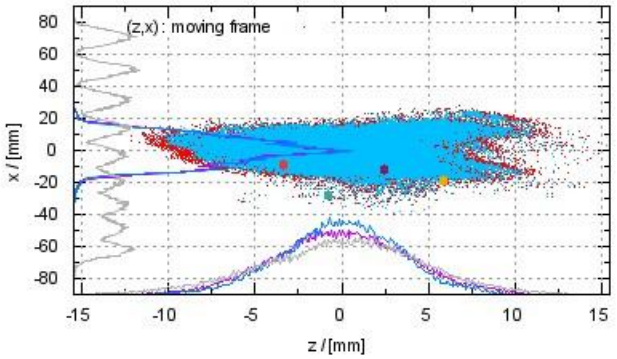


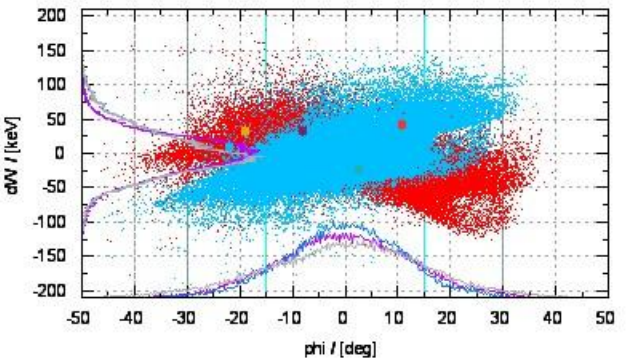

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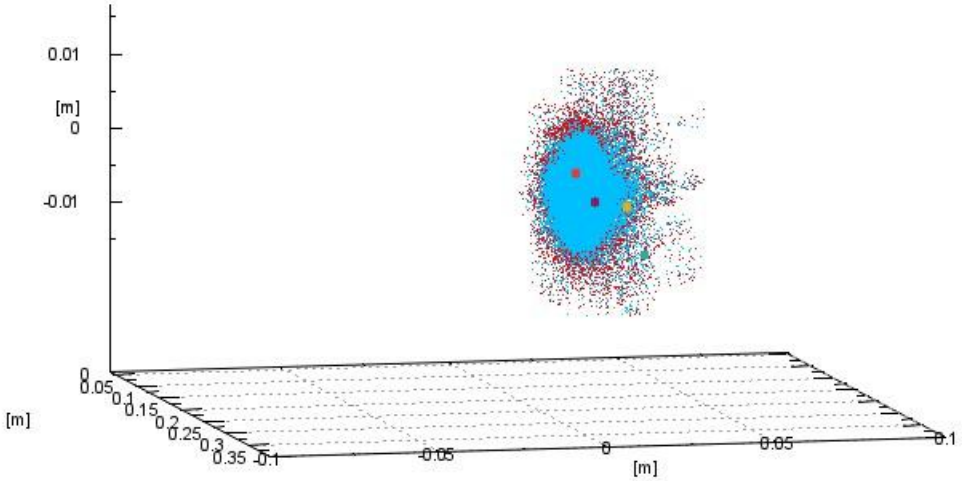
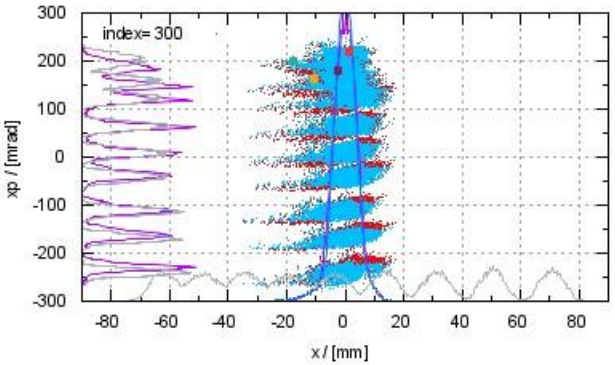
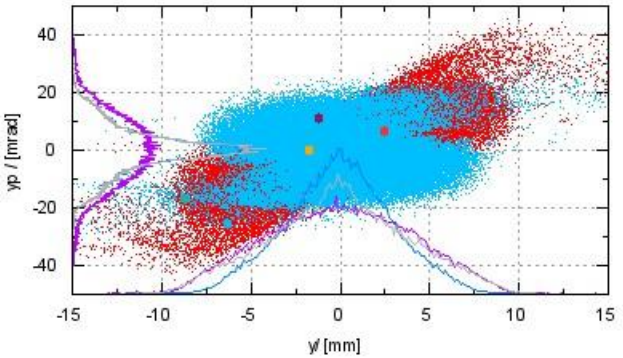
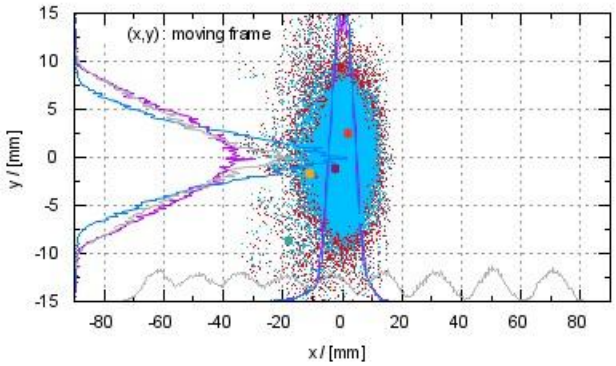
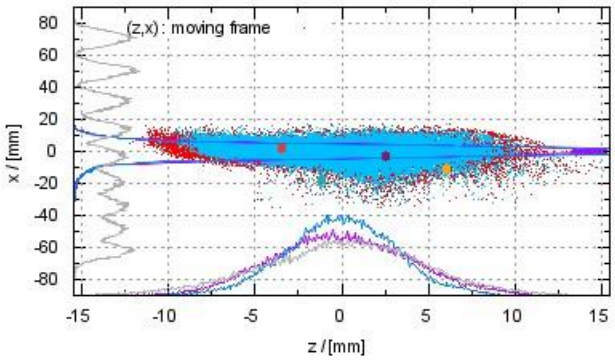


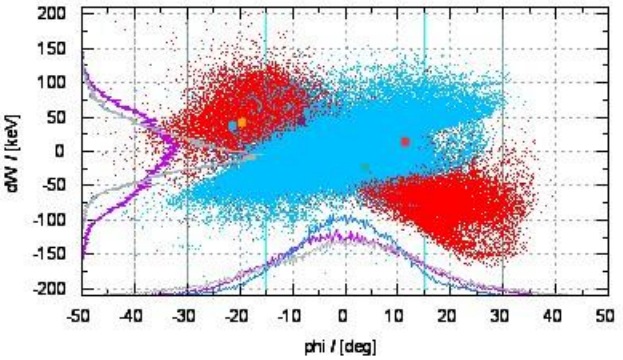




## Beam spot at the target



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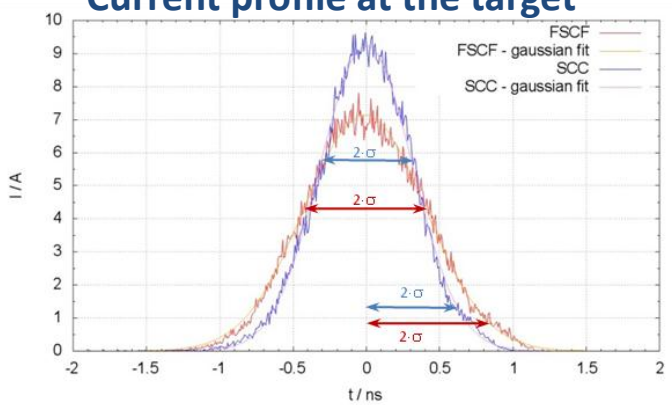
## Current profile at the target




$I_{max,FSCF} = 7.1A$

$I_{max,SCC} = 9.2A$

$I_{average} < 2$ mA

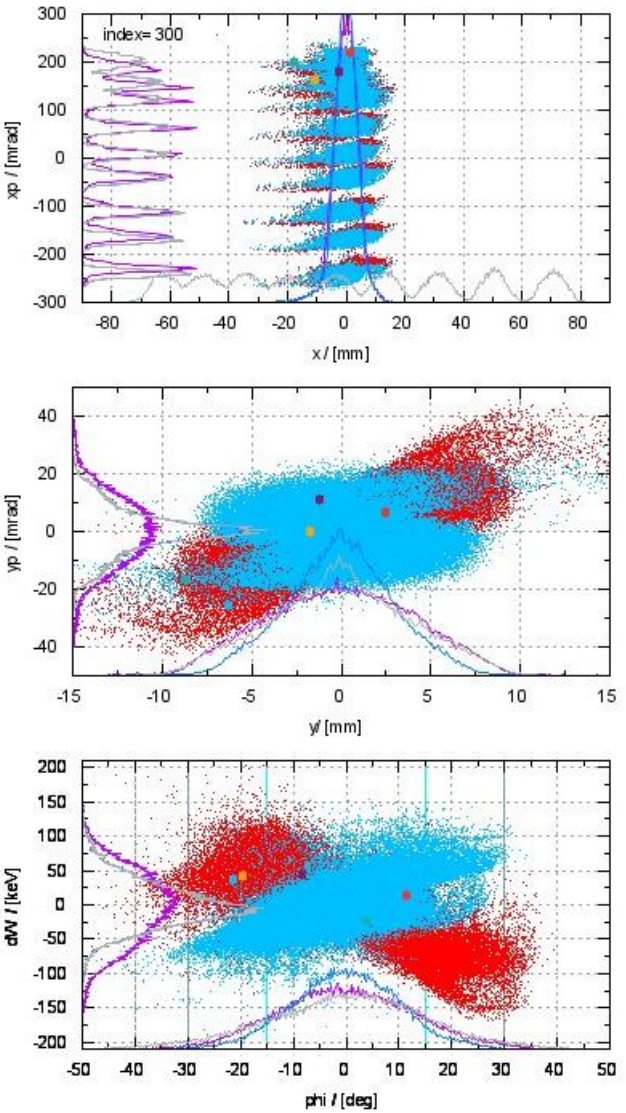
$(\Delta T)_{rms} \equiv 2\cdot\sigma$

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

| | | 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% |

### *Requirements*

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



# Summary & Outlook



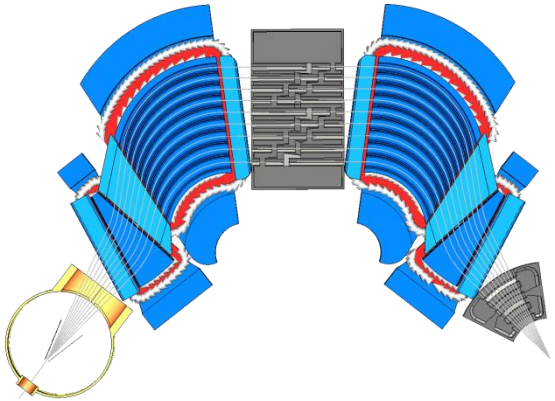
- **ARMADILLO** bunch compressor is presented.
- **Geometrical concept** is principally able to reach a long. compression ratio of 45.
- **Single bunch and multi bunch beam dynamics** results, even with full space charge forces, are promising to **satisfy the requirements**.
- Preliminary and **improved 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**

M. Droba, O. Meusel, D. Noll, U. Ratzinger, C. Wiesner

*IAP, Goethe University Frankfurt*



## Acknowledgment:

Franz Käppeler (FZK)
R. Reifarth (GSI / U. Frankfurt)
M. Heil (GSI)

ARMADILLO
Arc Magnetic Dipole Chicane with Large Aperture Longitudinal Focusing Cavities

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

*IAP, Goethe University Frankfurt*

| | |
|---|---|
| LINAC-AG | http://linac.physik.uni-frankfurt.de |
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