Large Aperture Superconducting Dipoles for the Beta-Beam Decay Ring

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Outline

- The Decay Ring Optics Requirements
- The Main Dipole
- Heat Deposition
- Further Work
- Conclusion

The Optics Requirements

The Main Parameters of the Dipole:

$B\rho$ = 1000 Tm

ρ = 156 m

θ = Pi/86 rad

L = 5.7 m

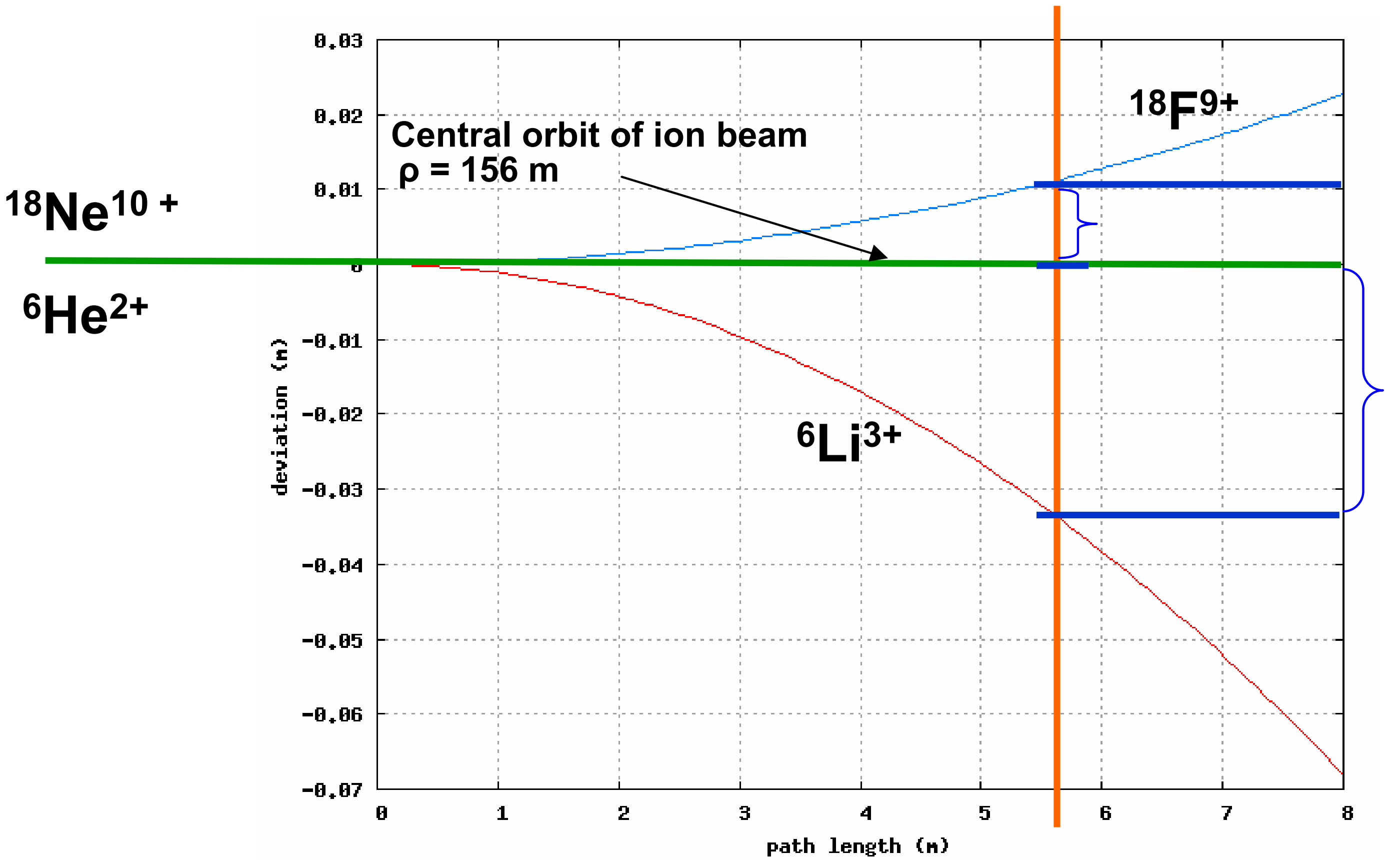
which gives a required dipole field of 6 T

Total Beam Size < 4 cm

Based on:

"A. Chance J. Payet: Simulation of the Beam Losses by Decay in the Decay Ring for the Beta Beams", 28 April 2006

The decayed ions in the Dipole

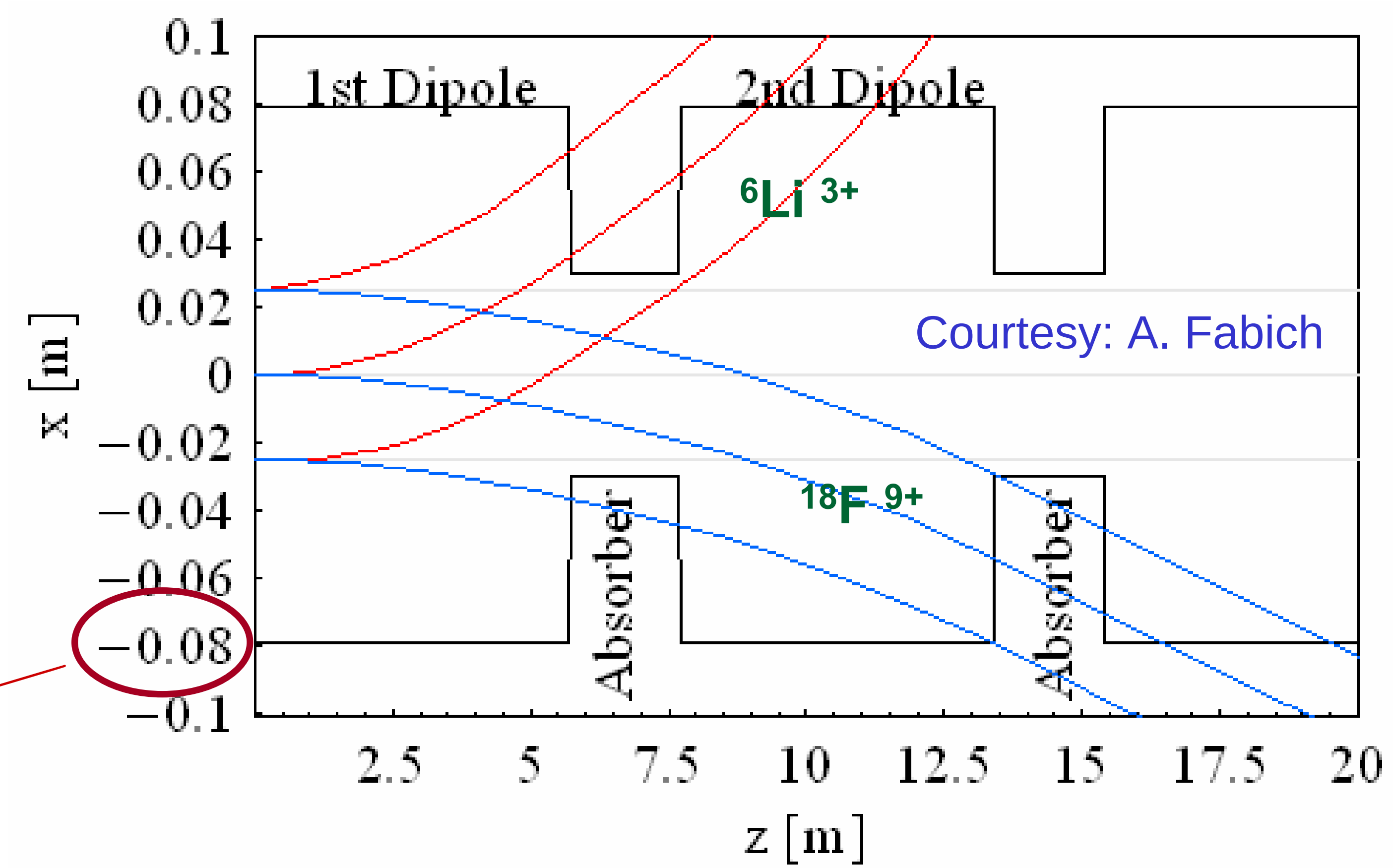


Deviation from central orbit of ion beam:

Dipole aperture has to be adapted.

Deviation of the trajectory of the decay products from central orbit of the ion beam vs dipole length for the decay products $^{6}Li^{3+}$ and $^{18}F^{9+}$

The Dipole Coil Size



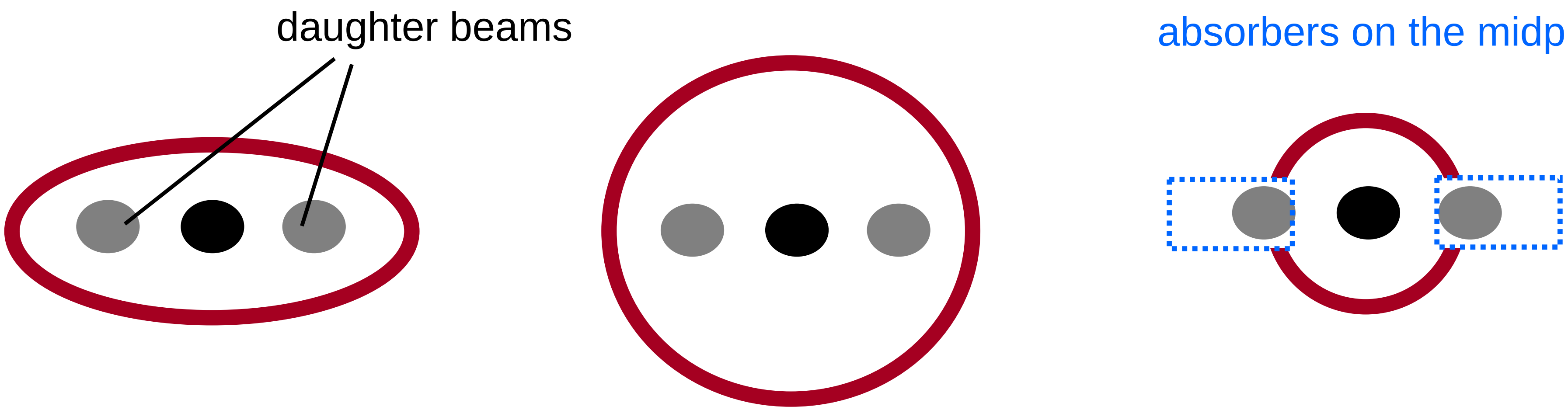
8 cm radius needed for the horizontal plane where the decay products cause daughter beams

4 cm for the vertical plane

The Alternatives

Depending on the severity of the heat-deposition and on construction constraints, several options are possible:

Eventually, we can put absorbers on the midplane



Elliptic coil cross section more adapted to the total beam size but may have mechanical constraints

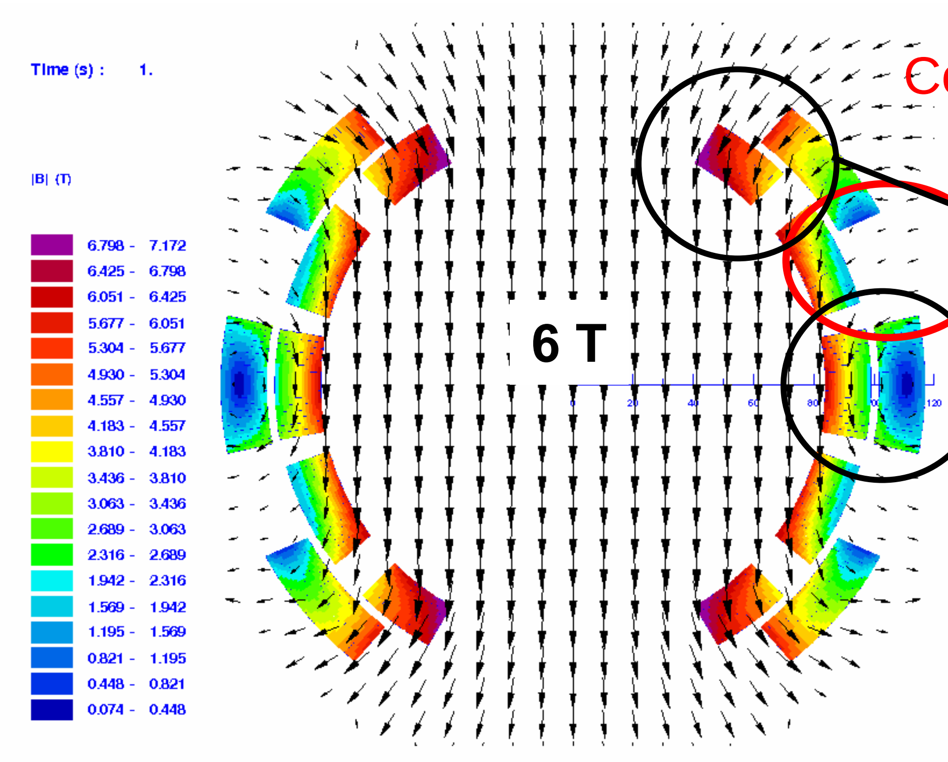
Circular coil cross section is a "safe" solution for first estimate

"Open Mid Plane" if the coil cannot stand the heat deposition from the decay products in the mid plane

The Dipole

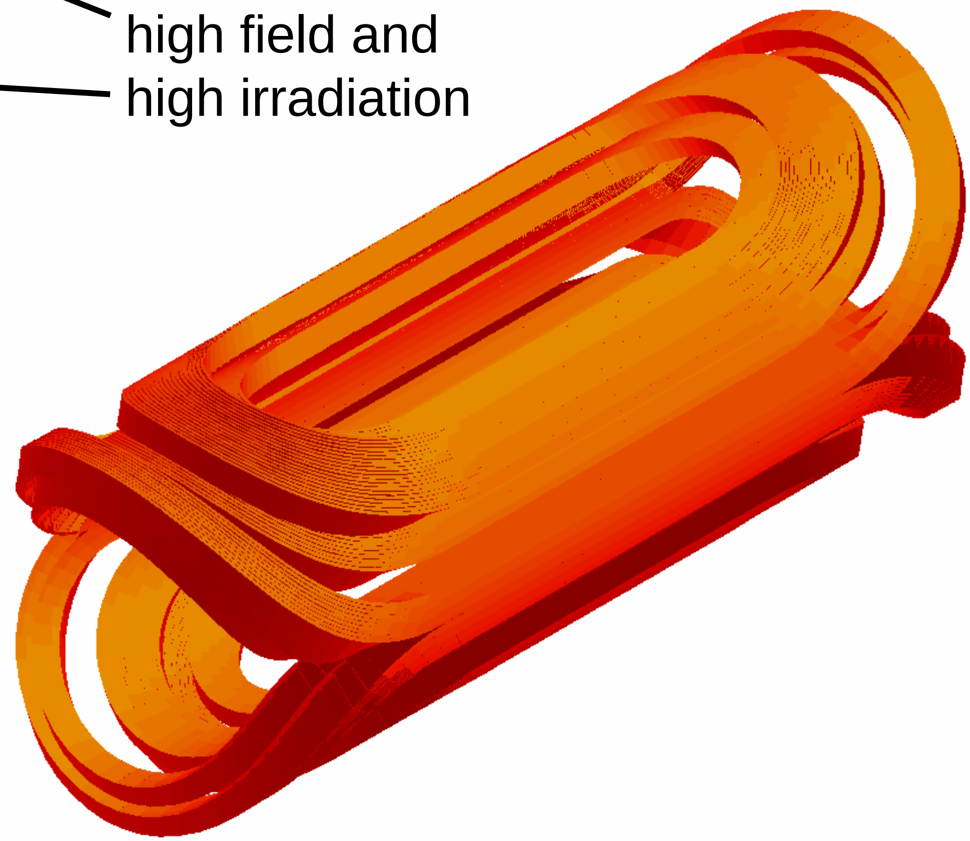
- Classical LHC technology (wellknown):
  - NiTi cable
  - Cable Size: 15.1 mm x 1.73 mm
- Double Layer
- 1.9 K, Superfluid Helium (leaves large margin on sc critical surface)
- Required beam pipe size: 16 cm diameter
- Length 6 m
- Compact coil end

Cross section and Coil Ends



Cooling channel for inner layer can be added if needed.

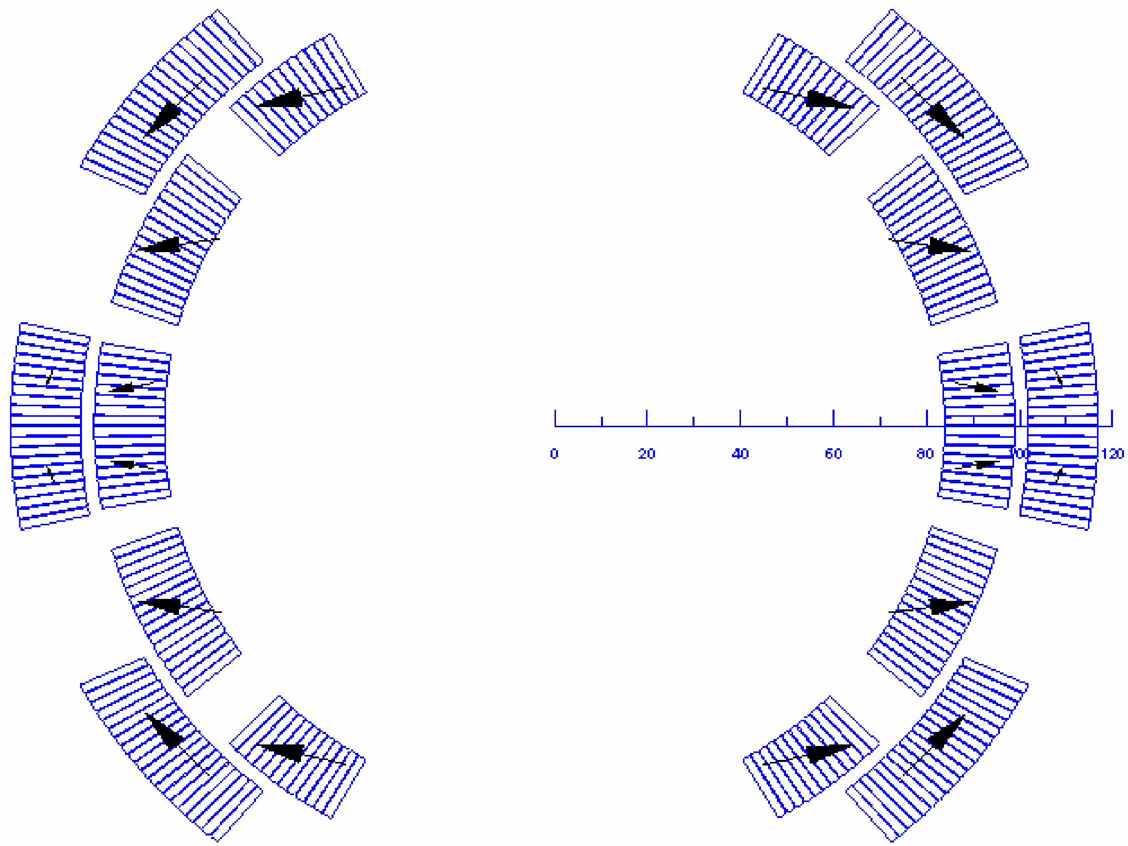
2 critical regions in coil cross-section:
high field and
high irradiation



- **Aim is a compact coil end to reduce impinging particles**

Force and Stress in the Cross-section

- LHC: ~52 MPa on midplane in each layer
- We need ~10 MPa for prestress
- We have ~64 MPa (47 MPa) from em forces in inner (outer) layer,
- Good Margin! (acceptable: at least 150 MPa)

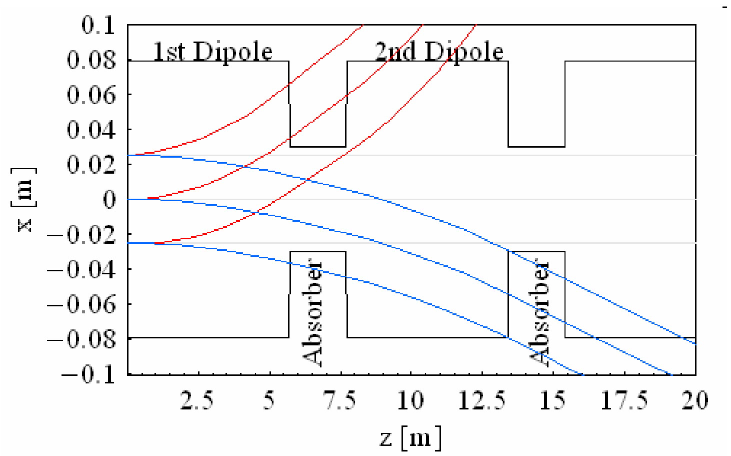


Field Imperfections

- Field imperfections larger far from the center
- Field good for the circulating beam.

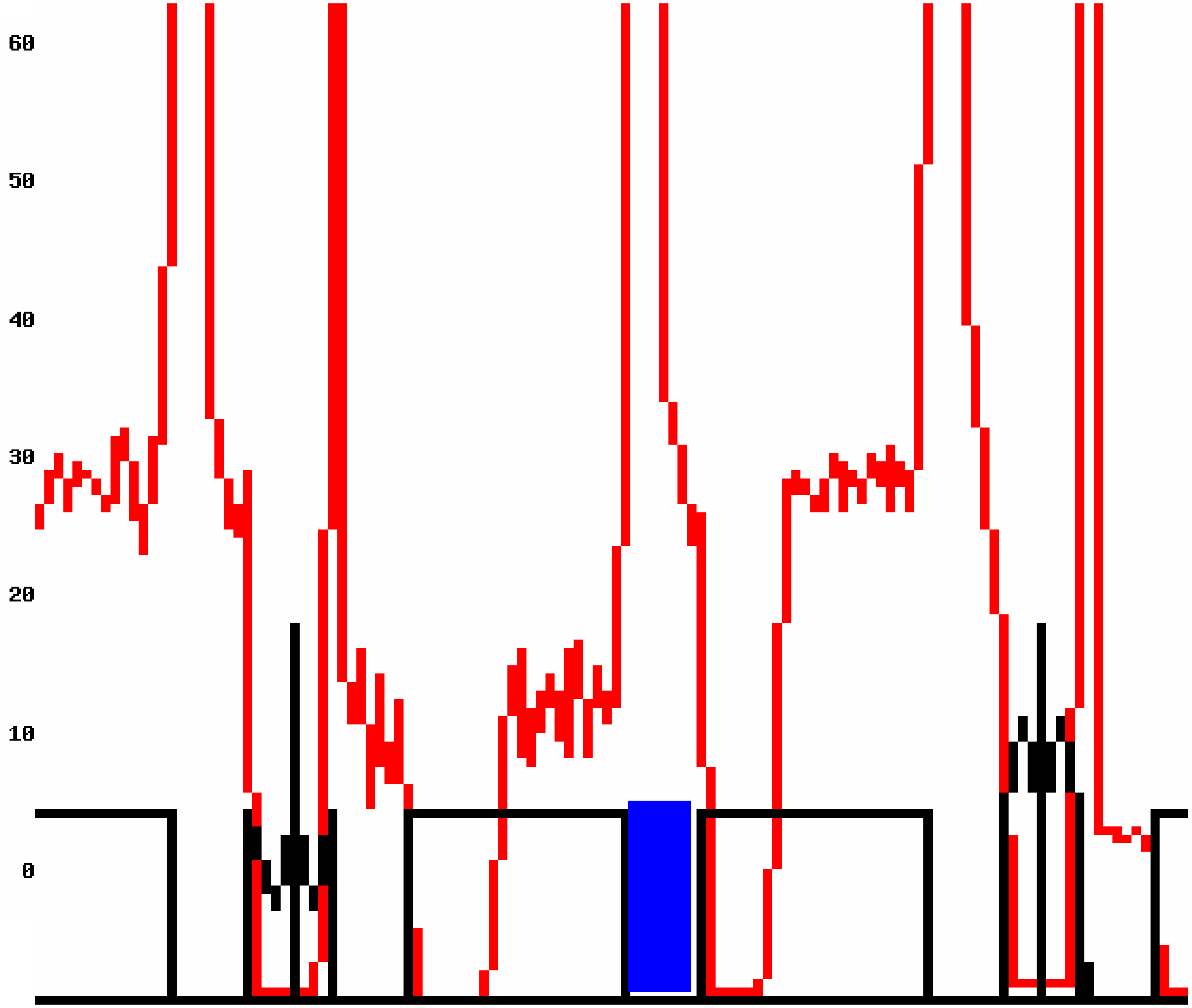
	Field errors in at 4 cm radius in units 10^{-4}	
	max. allowed	exist by design
b_2	50	0
b_3	10	8.5
b_4	3	0

Absorbers for Heat Deposition



- We need absorbers to intercept the decay products
- Absorber inside chamber
- Absorber outside chamber: space restrictions between magnets
- Non magnetic and non superconducting absorber material: avoid iron and lead

Lost Particles in Dipole



"A. Chance J. Payet: Simulation of the Beam Losses by Decay in the Decay Ring for the Beta Beams", 28 April 2006

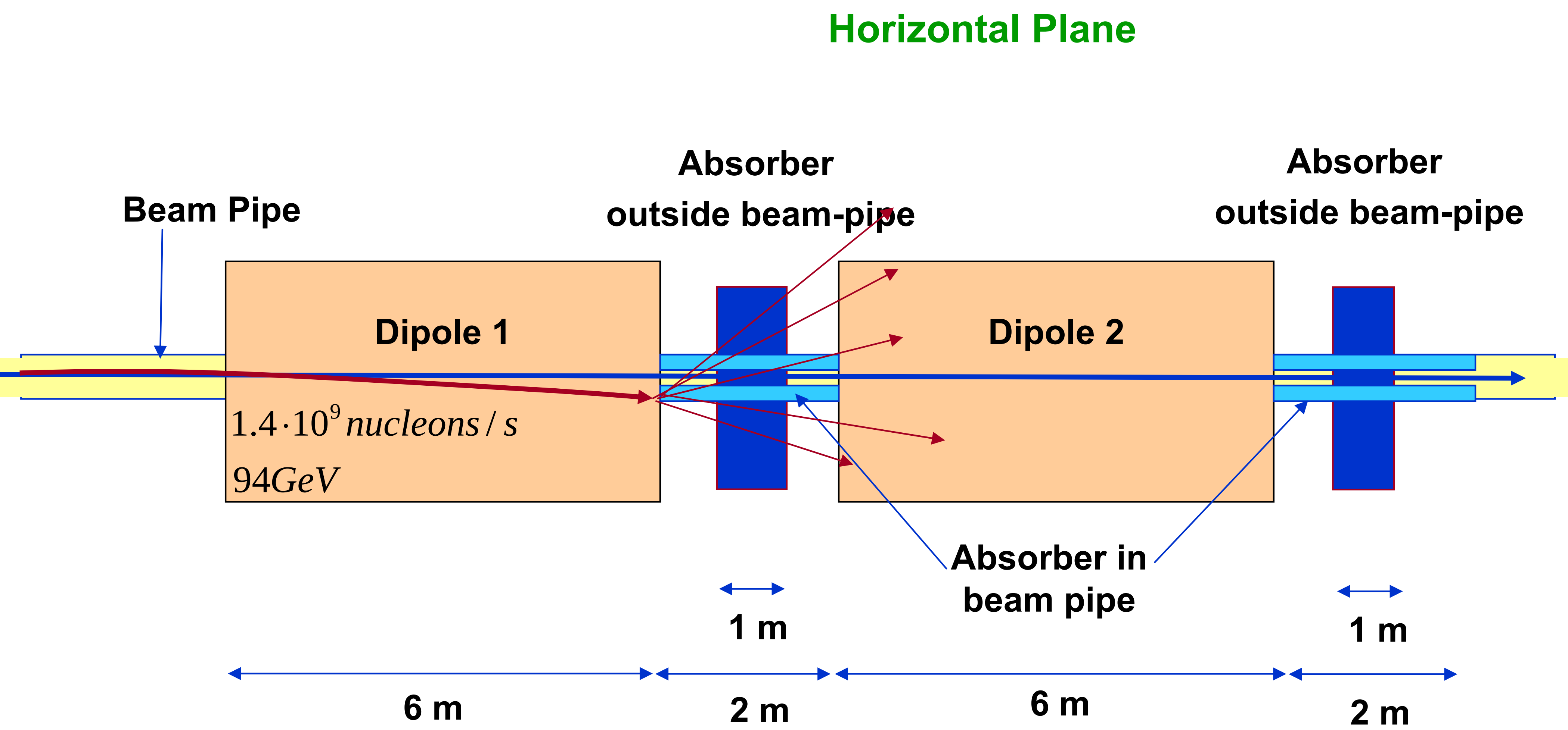
By design: Ions lost on absorber in beam pipe

Some are lost in the second half of the Dipole ~ 10W/m

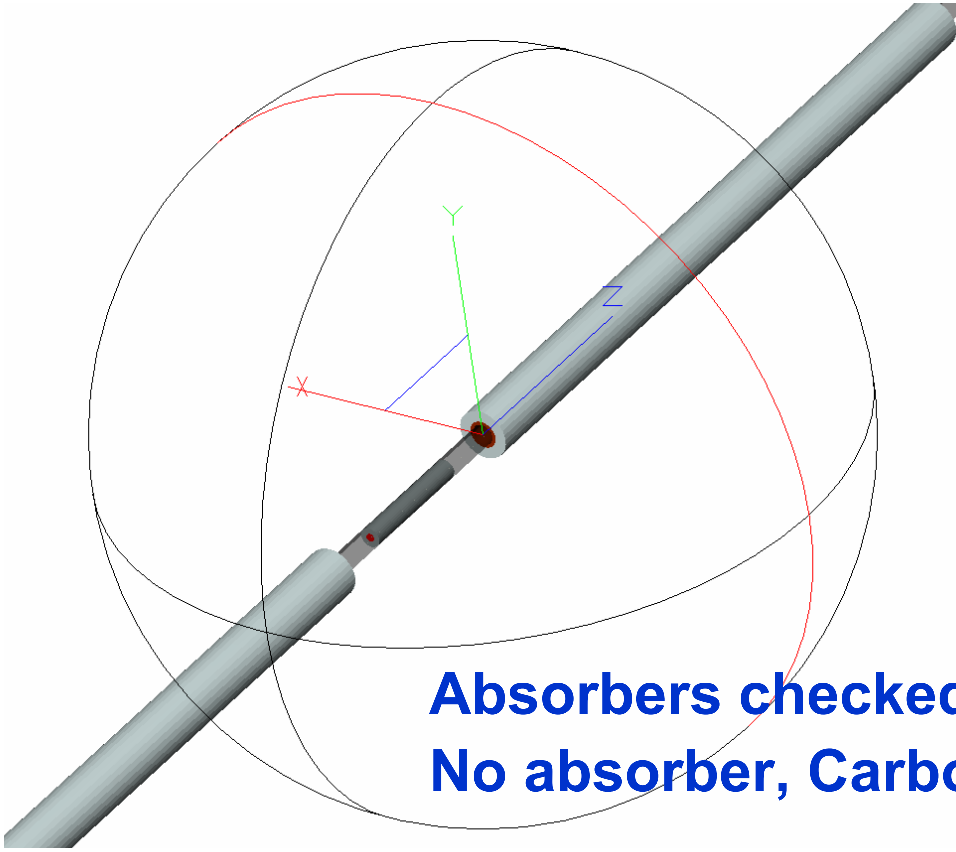
First scenario: Check the heat deposition from the beam decaying after quad, impinging on the absorber in the beam pipe.

Then make refined calculation including all decaying particles (tracking).

Simplified model of decay in Dipole



Model for heat deposition



Absorbers checked (in beam pipe):
No absorber, Carbon, Iron, Tungsten

Theis C., et al.:
"Interactive three dimensional visualization and creation of geometries for Monte Carlo calculations",
Nuclear Instruments and Methods in Physics Research A 562, pp. 827-829 (2006).

Results for heat deposition

Binning like cable dimension:

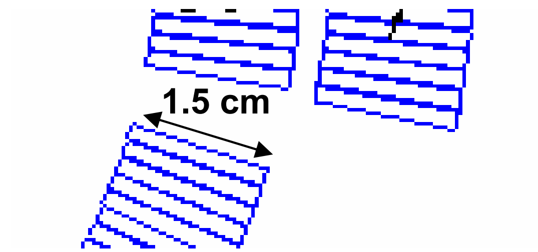
~1.5 cm radial bins

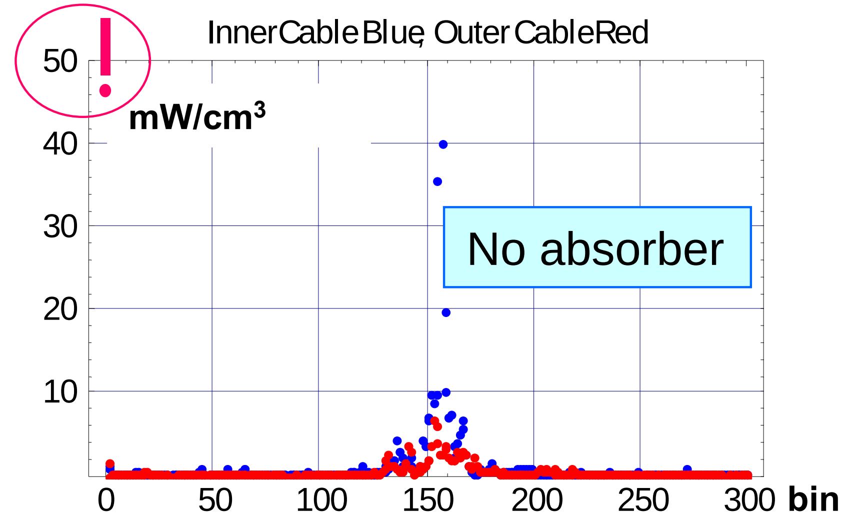
azimuthal bins

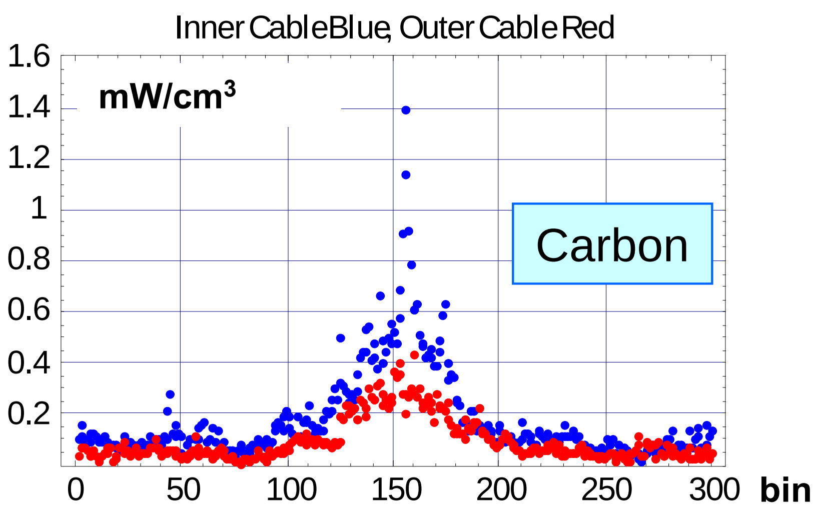
~1.5 mm wide inner,

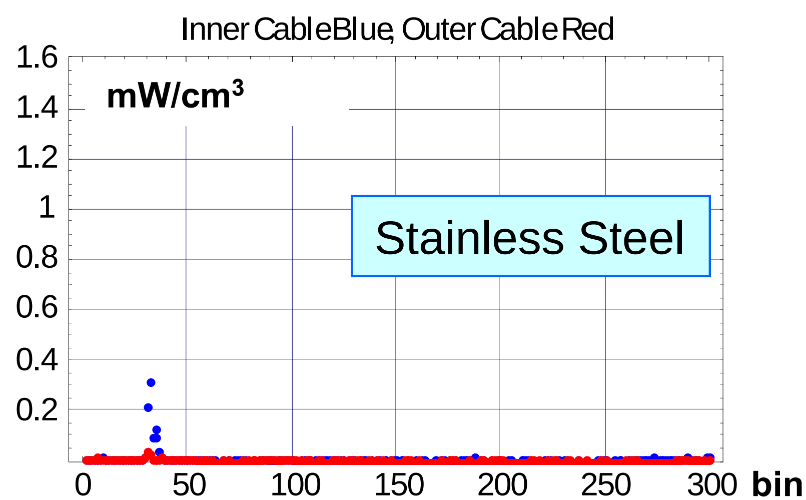
~2 mm wide outer

~ 2 cm long bins in z





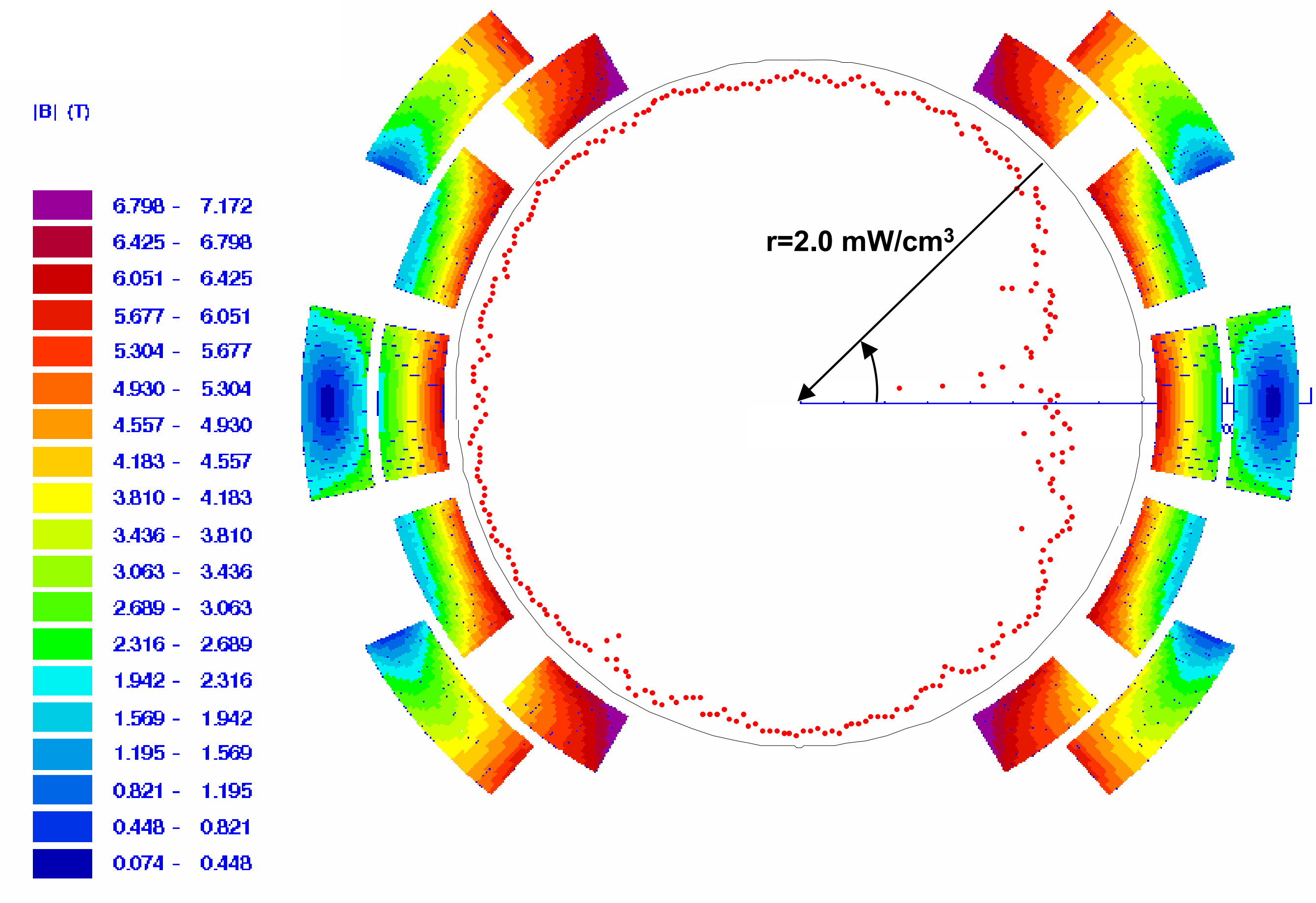




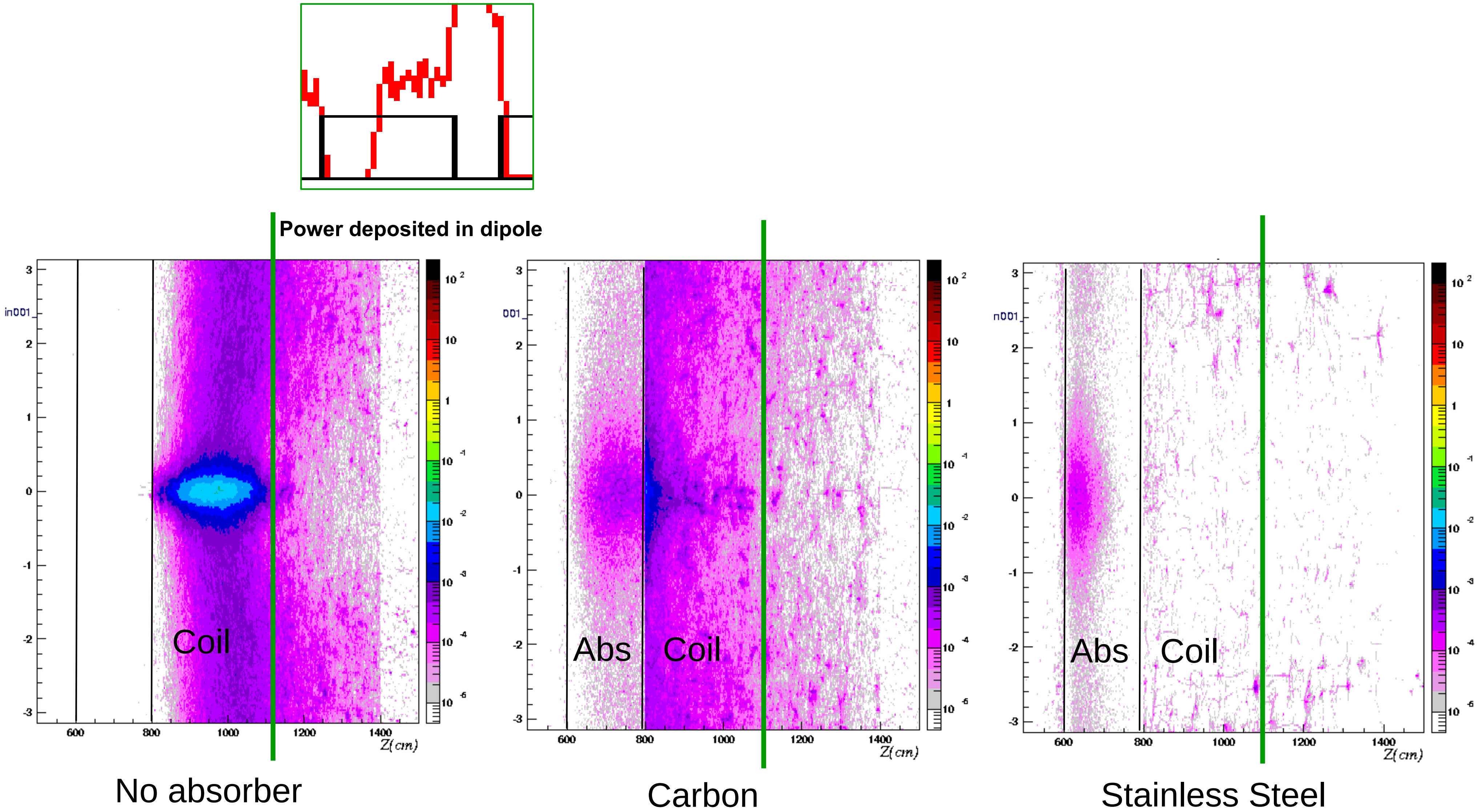
Results, Carbon

Display of heat deposition in the coil together with field strength:

Radius of black circle corresponds to 2.0 mW/cm^3



Longitudinal penetration, coil



Results for heat deposition

Quantity / Absorb material	Max Heat [mWatt/cm^3]	Dist from Dipole Entry [cm]	Angle for max [degrees]
Vacuum	> 30	~ 200	~ 0
Carbon	1.4	20	7
Stainless Steel	0.4 (stat)	-	-
Tungsten	0.2 (stat)	-	-

Value for LHC Magnet > 4.5 mWatt/cm^3 : we have margin, load line more favorable, cooling channels possible to introduce.

Next step: Complete heat deposition and shielding calculations with detailed decaying beam (tracking studies)

Future work

- Optimize magnet (field, 4.5K, cost considerations)
- Evaluate cryogenic aspects
- Coil end: reduced cooling, mechanical constraints
- Include total decay using decaying ion tracking code (ACCIM, F. Jones, Triumf)
- Refine heat deposition model
- Long term radiation effects
- Impedance aspects of absorber in pipe (beam)

Conclusion

- A first design of the dipole for the beta beam decay ring shows:
  - A large aperture dipole is feasible and fulfills requirements for the ion beam
  - Heat deposition can be mastered (no quench in steady state operation)
- Optimization of design, more heat deposition studies, study of cryogenic system, beam dynamics (impedance) and shielding remains