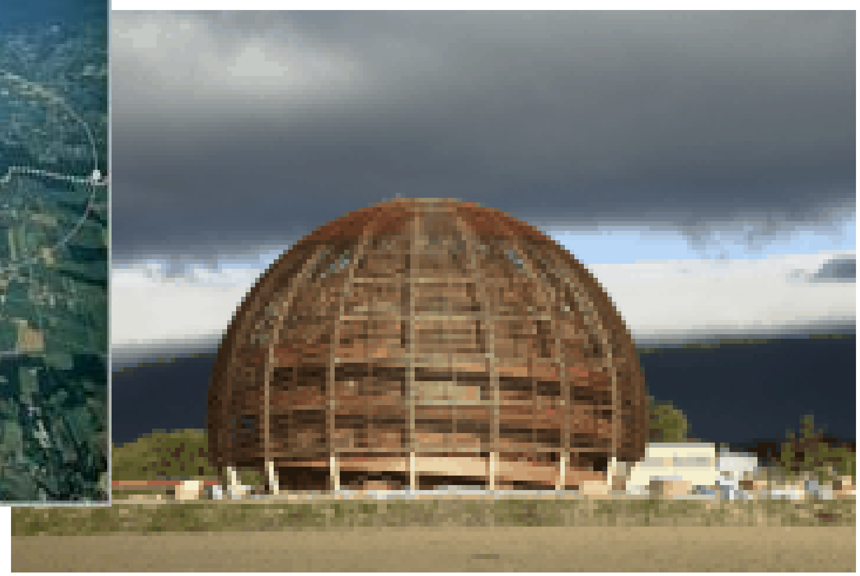
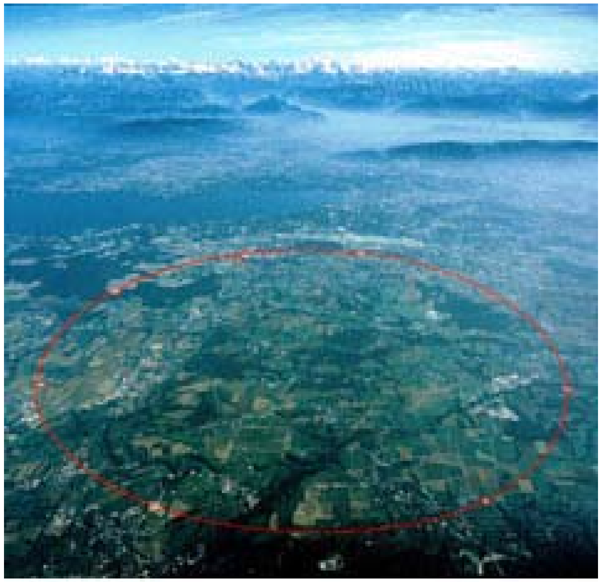
Accsim-FLUKA simulation of the DR arcs and concepts for dipoles + protection

Elena Wildner,
Accelerator Technology Dpt,
CERN



Outline



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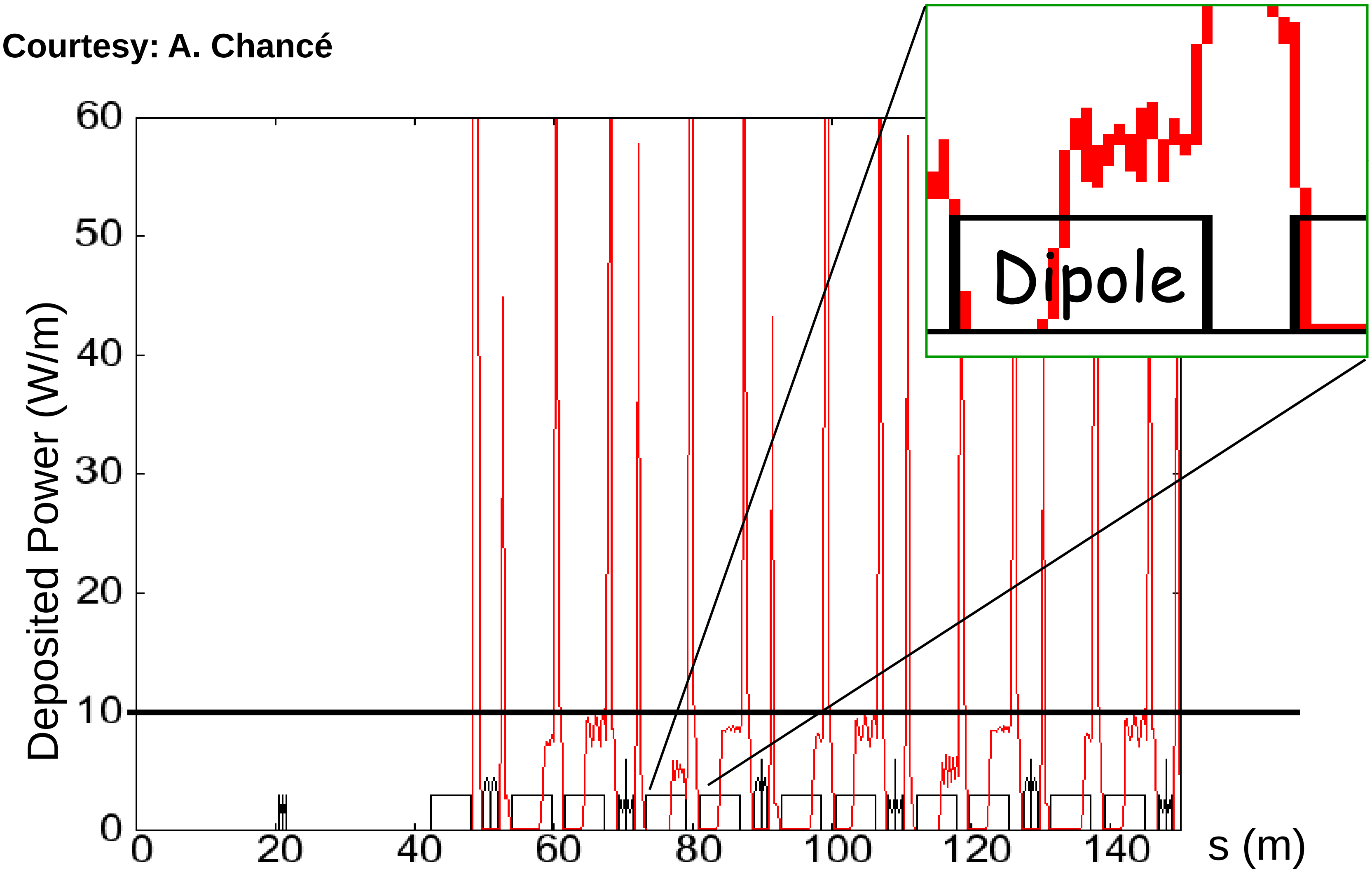
1. Review of the design
2. Building the model
3. ACCIM/FLUKA
4. Results
5. Continuation

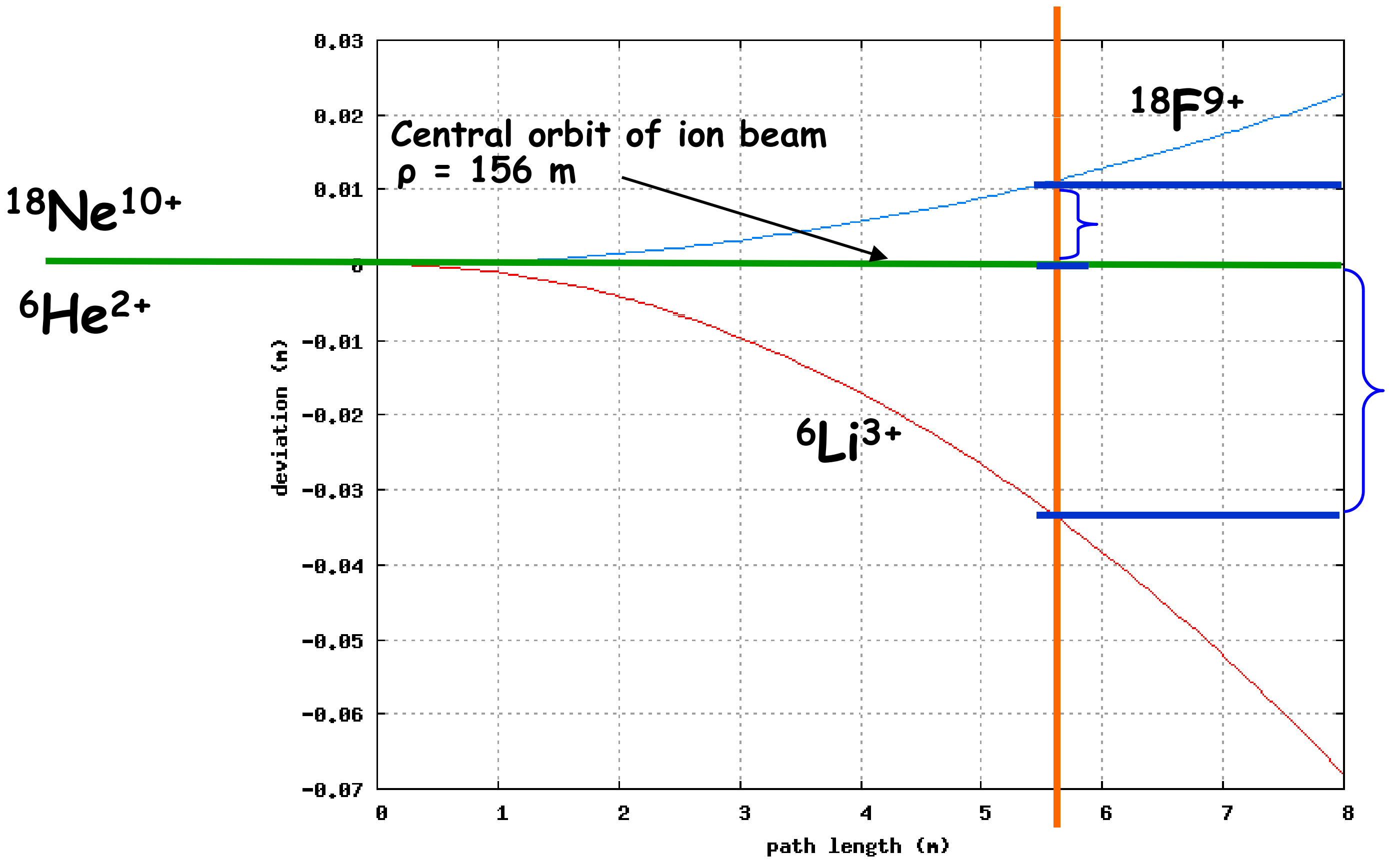
How to Set up the Model: Power Loss in Arc

Courtesy: A. Chancé



Arc, repetitive pattern

The beam Loss in the 6 m long Dipole

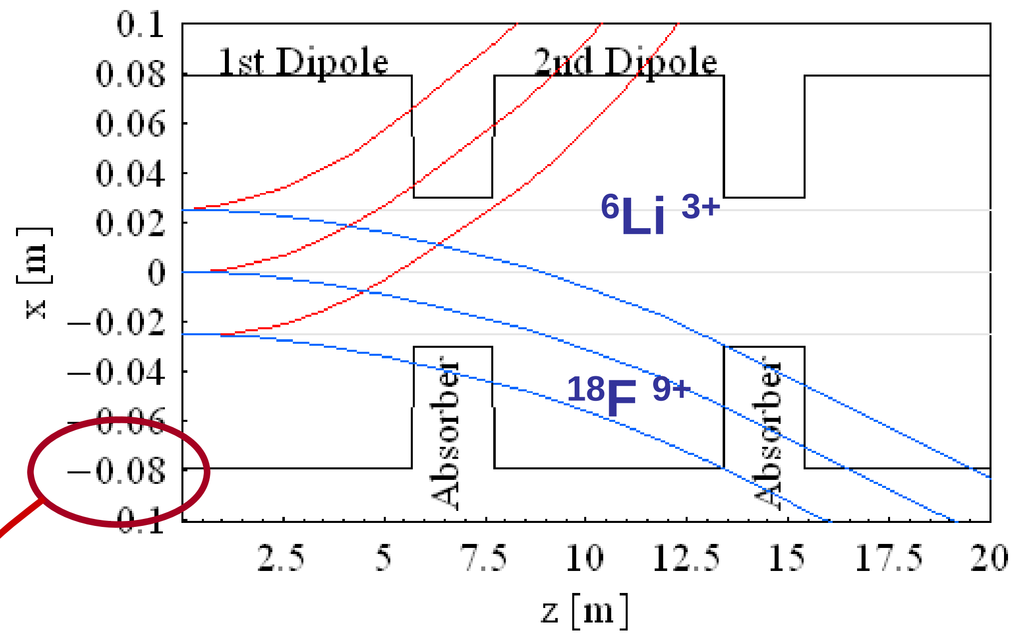


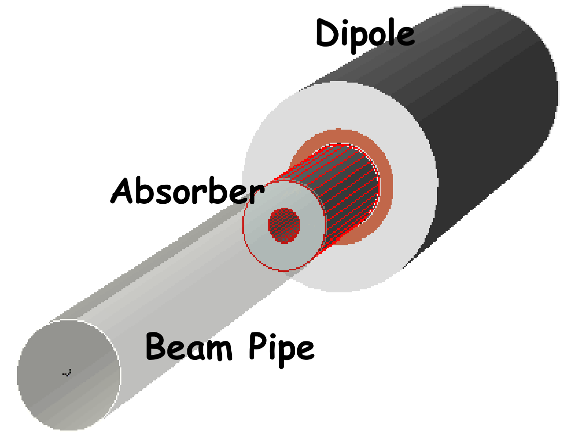
Deviation from central orbit of ion beam:

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 $^{18}F^{9+}$

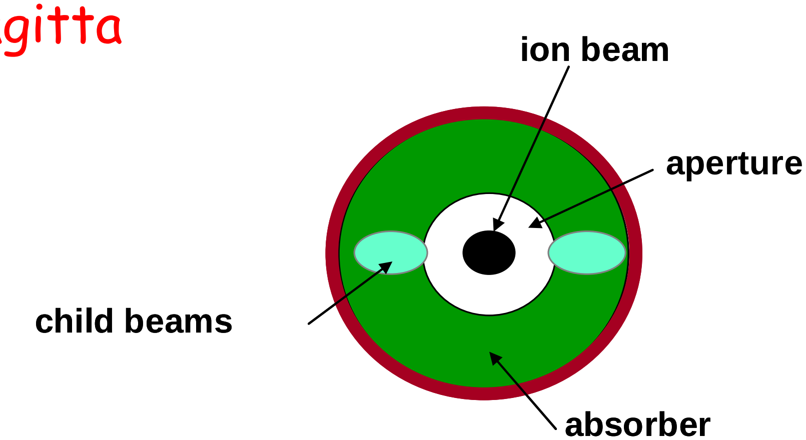
Large Aperture Requirements





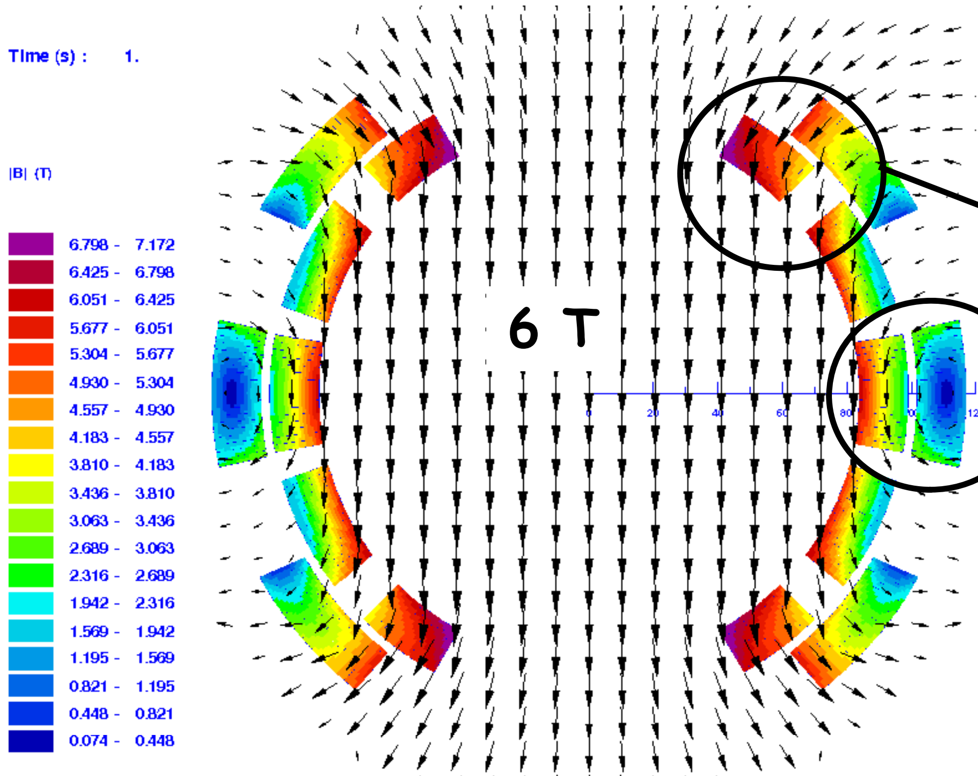
8 cm radius needed for the horizontal plane where the decay products cause daughter beams + 1 cm for the sagitta (no curved magnet)

4 cm for the vertical plane



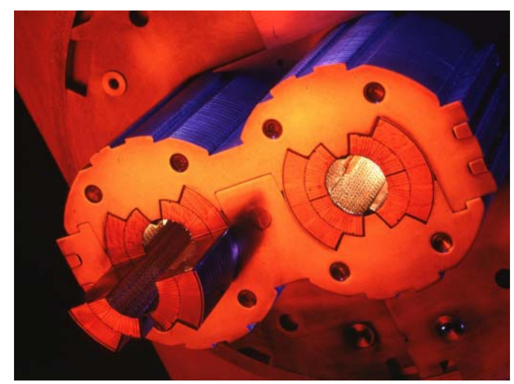
The Large Aperture Dipole, first feasibility study

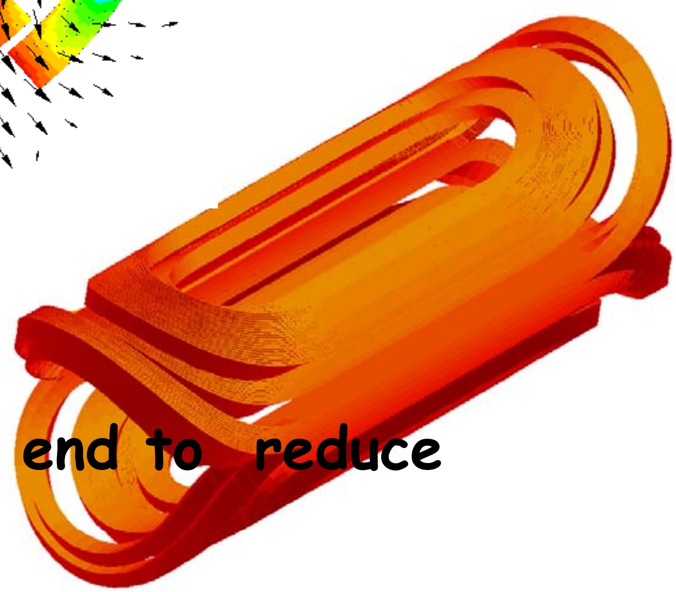
Courtesy Christine Vollinger



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

LHC "costheta" design





Compact coil end:
Aim is a compact coil end to reduce impinging particles

Fields used

Field maps exist for magnet with 16 cm aperture (diameter).

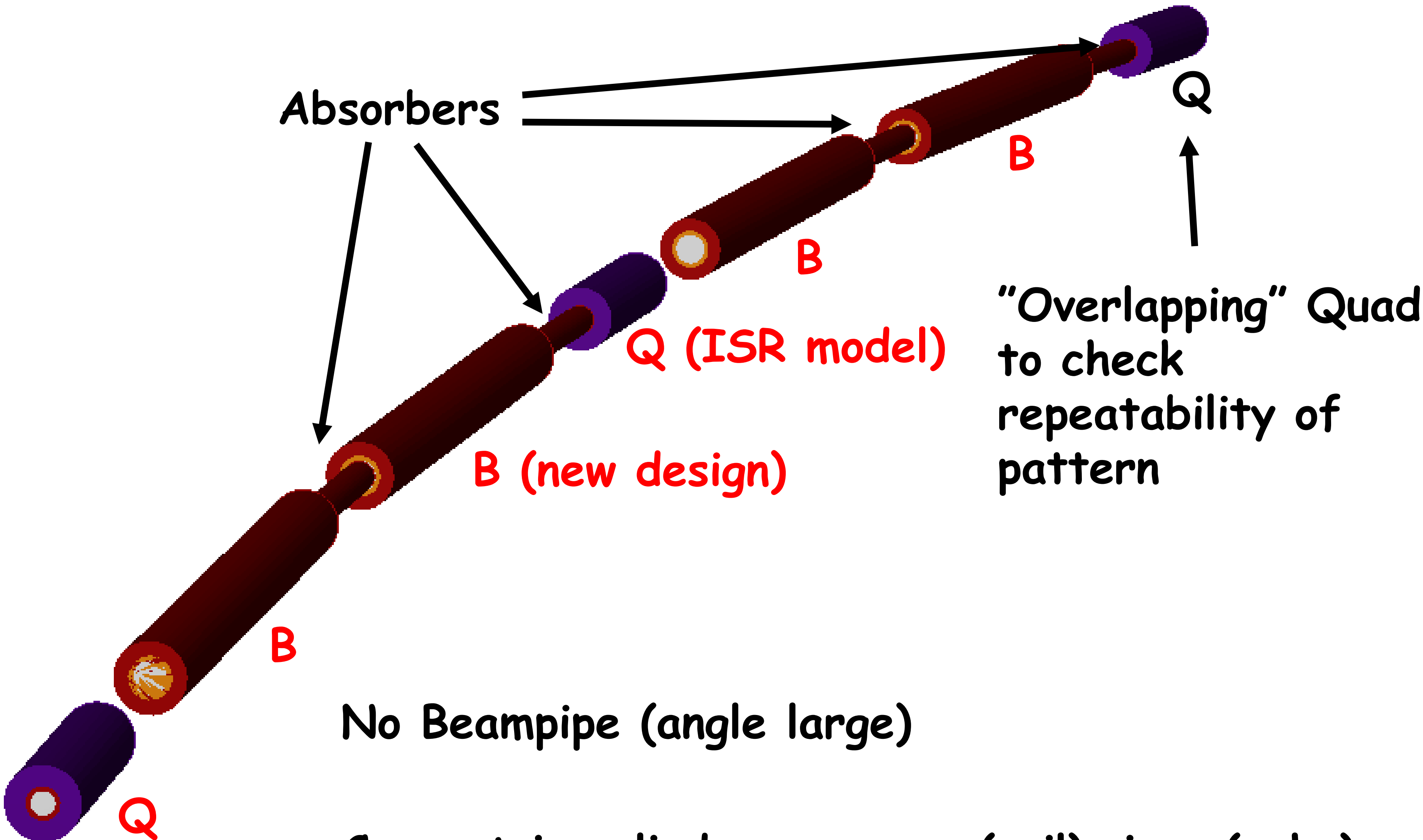
The sagitta was not taken into account. Considerations of bending this magnet (too short) made us decide on a 2 cm larger aperture.

Lack of time to re-calculate the fieldmap: an analytical field was used.

This should not change the situation considerably.

The field is being recalculated for the moment.

Heat Deposition Model, one cell



No Beampipe (angle large)

Concentric cylinders, copper (coil), iron (yoke)

Modelling: the beam code ACCIM I

Accsim, developed at TRIUMF, is a multiparticle tracking and simulation code for synchrotrons and storage rings.

- Some applications: CERN (S)PS(B), KEK PS, J-PARC, SNS, ...
- Incorporates simulation tools for injection, orbit manipulations, rf programs, foil, target & collimator interactions, longitudinal and transverse space charge, loss detection and accounting.
- Interest for Betabeam: to provide a comprehensive model of decay ring operation including injection (orbit bumps, septum, rf bunch merging), space charge effects, and losses (100% !)

- Needed developments for Betabeam:
  - Arbitrary ion species, decay, secondary ions.
  - More powerful and flexible aperture definitions (for absorbers)
  - Tracking of secondary ions off-momentum by >30% (unheard of in conventional fast-tracking codes)
  - Detection of ion losses: exactly where did the ion hit the wall?

-- a challenge for tracking with the usual "element transfer maps"

Modelling: the beam code ACCIM (II)

Secondary ion tracking (the key to effective simulation)

- Different charge state ⇨ ions "severely mismatched" to ring optics

- A "matrix scaling" technique was implemented.

- Allows computation of symplectic dipole and quadrupole maps that are accurate for ions widely off-momentum and off-center from the reference orbit. In essence, makes a custom map for each particle.

Modelling: the beam code Accsim (II)

Accsim as event generator for FLUKA*

- Identify "region of interest": sequence of Accsim elements corresponding to the representative arc cell modelled in FLUKA.
- Tracking 100000 macro-particles representing fully populated ring (9.66×10^{13} He or 7.42×10^{13} Ne), with decay.
- Detect and record two types of events:
  1. Ions that decayed upstream of the cell and have survived to enter the cell.
  2. Ions that decay in the cell.

For each event the ion coordinates and reference data are recorded for use as source particles in FLUKA.

* **"FLUKA: a multi-particle transport code", A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala,** CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
"The physics models of FLUKA: status and recent developments", A. Fasso`, A. Ferrari, S. Roesler, P.R. Sala, G. Battistoni, F. Cerutti, E. Gadioli, M.V. Garzelli, F. Ballarini, A. Ottolenghi, A. Empl and J. Ranft, Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003

Modeling the heat deposition with FLUKA

FLUKA uses cartesian coordinates

Survey data from optics code needed:

"Beam-Optics" * (Mathematica) used

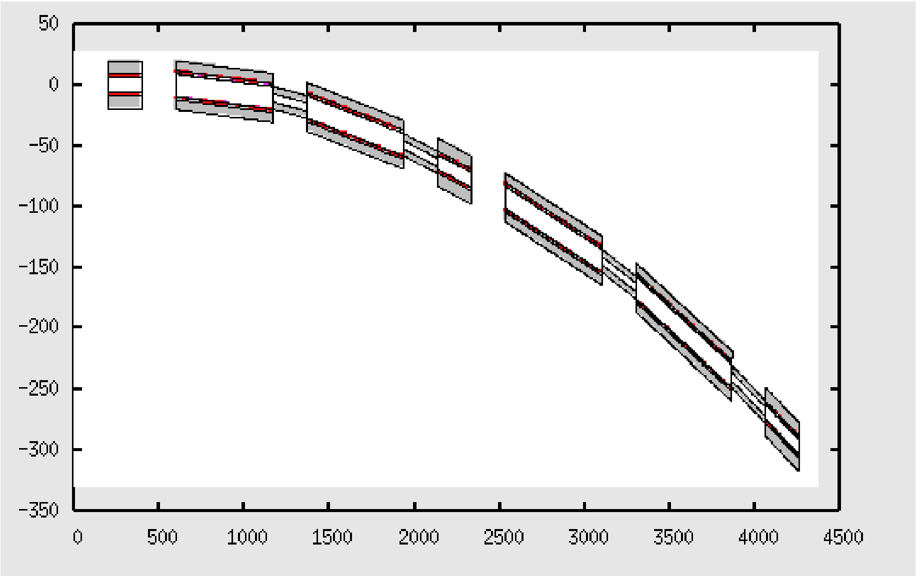
Cross-checked with DIMAD

FLUKA input generated from this,
knowing the magnetic length of the elements

Should be included in ACCIM to, optimally, generate FLUKA cards.

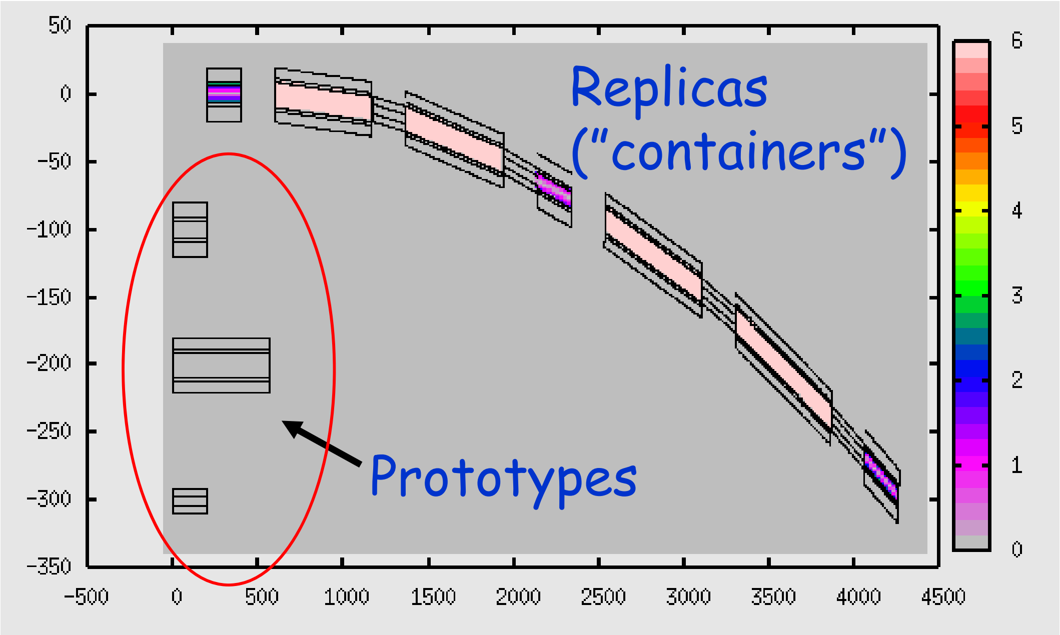
*** "Beam Optics : a program for analytical beam optics"**
Autin, Bruno; Carli, Christian; D'Amico, Tommaso Eric; Gröbner, Oswald; Martini, Michel; Wildner, Elena;
Geneva: CERN, 1998.- 129 p.- CERN-98-06

Modelling



Repeated insertion of complete magnets. Important for the total summing up on regions automatically made by fluka (overall cryogenics)
"Material" option switched on

Lattice model:
Binning for deposition scoring in coordinates adapted to magnet layout
Important for detailed analysis of local heat deposition in coils
"Magnetic field" option swithed on in figure

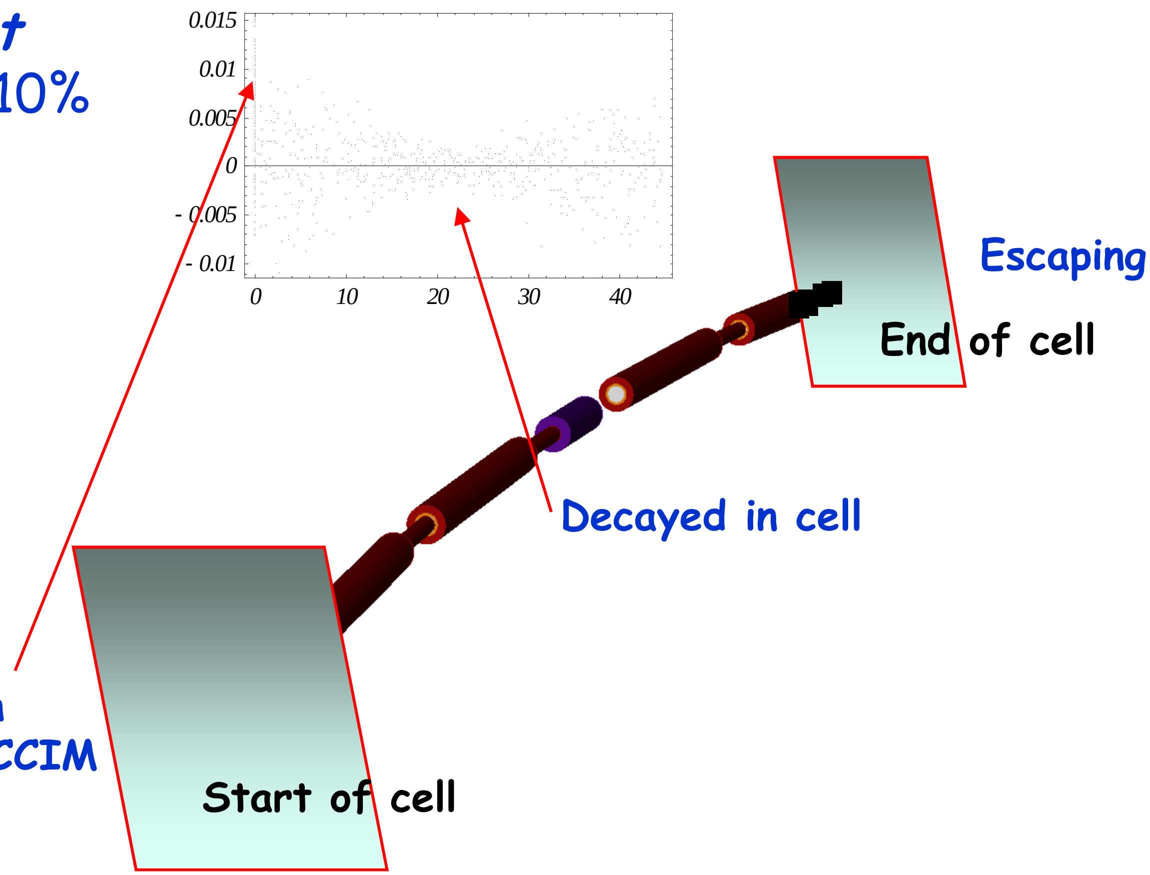


Particle generation and treatment

1. ACCSIM tracks 6Li and 18F particle ***decaying in the ring*** up to cell entry (10 % of total)

2. ACCSIM gives coordinates and momentum vectors of particles ***just decayd*** in cell

3. Particles ***escaping out*** are detected by Fluka (10% for both Li and F)

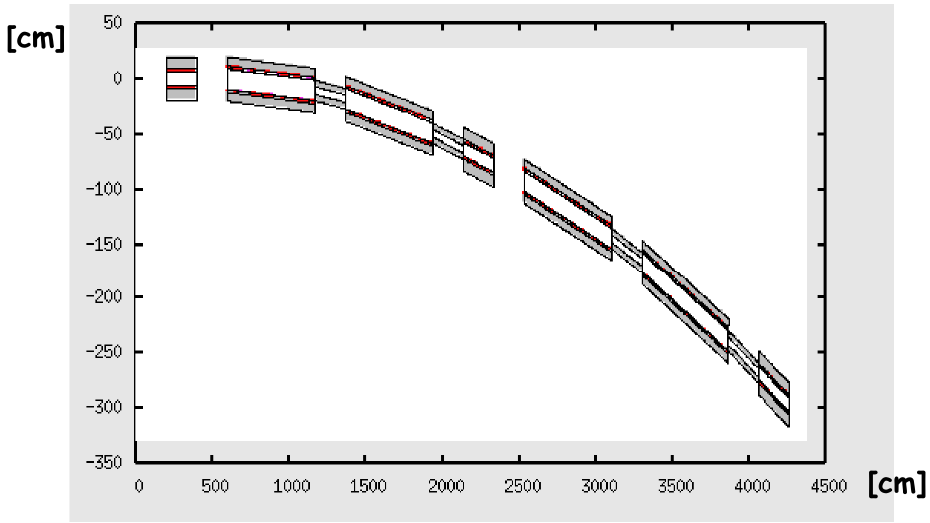


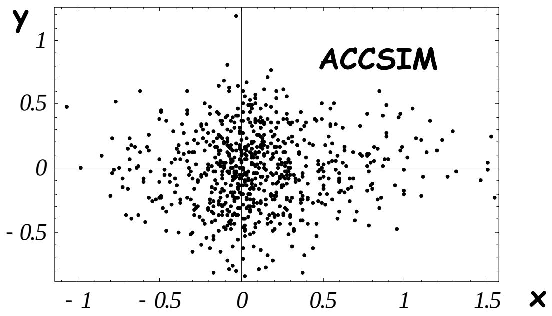
Coordinate transformation

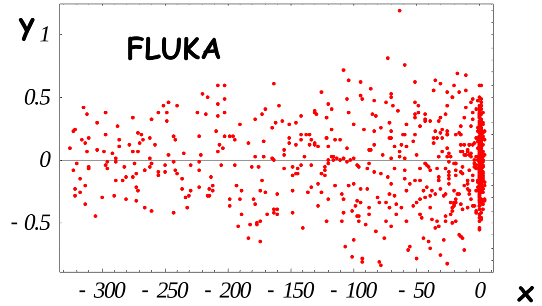
ACCSIM/FLUKA and inverse

We used Mathematica based on the survey options of "BeamOptics" to generate FLUKA Particle file

Useful if ACCSIM could integrate the transformation code



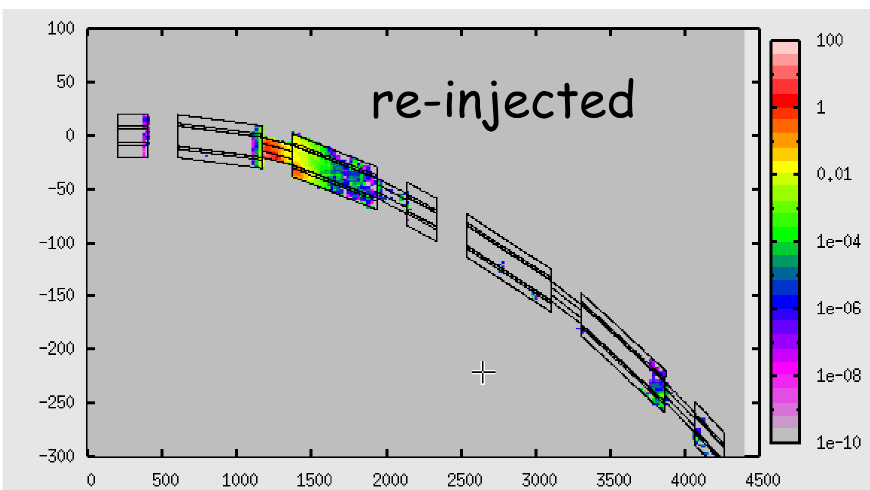


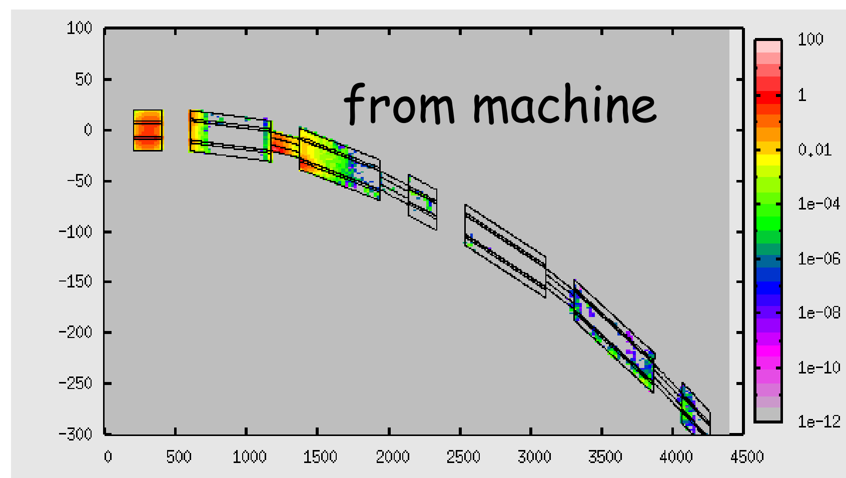


Tuning of model

Fields, momenta, particle masses carefully ***checked by tracking*** of the original particle (6He) with Fluka and ACCIM for comparison. Momentum not like data base but we are using Data from: A. Chancé and J. Payet, EURISOL DS/TASK12/TN-06-05

The, from the cell, escaping particles (FLUKA) reinjected to the cell, were compared to the incoming particles (ACCSIM) and the ***energy deposition pattern is similar***

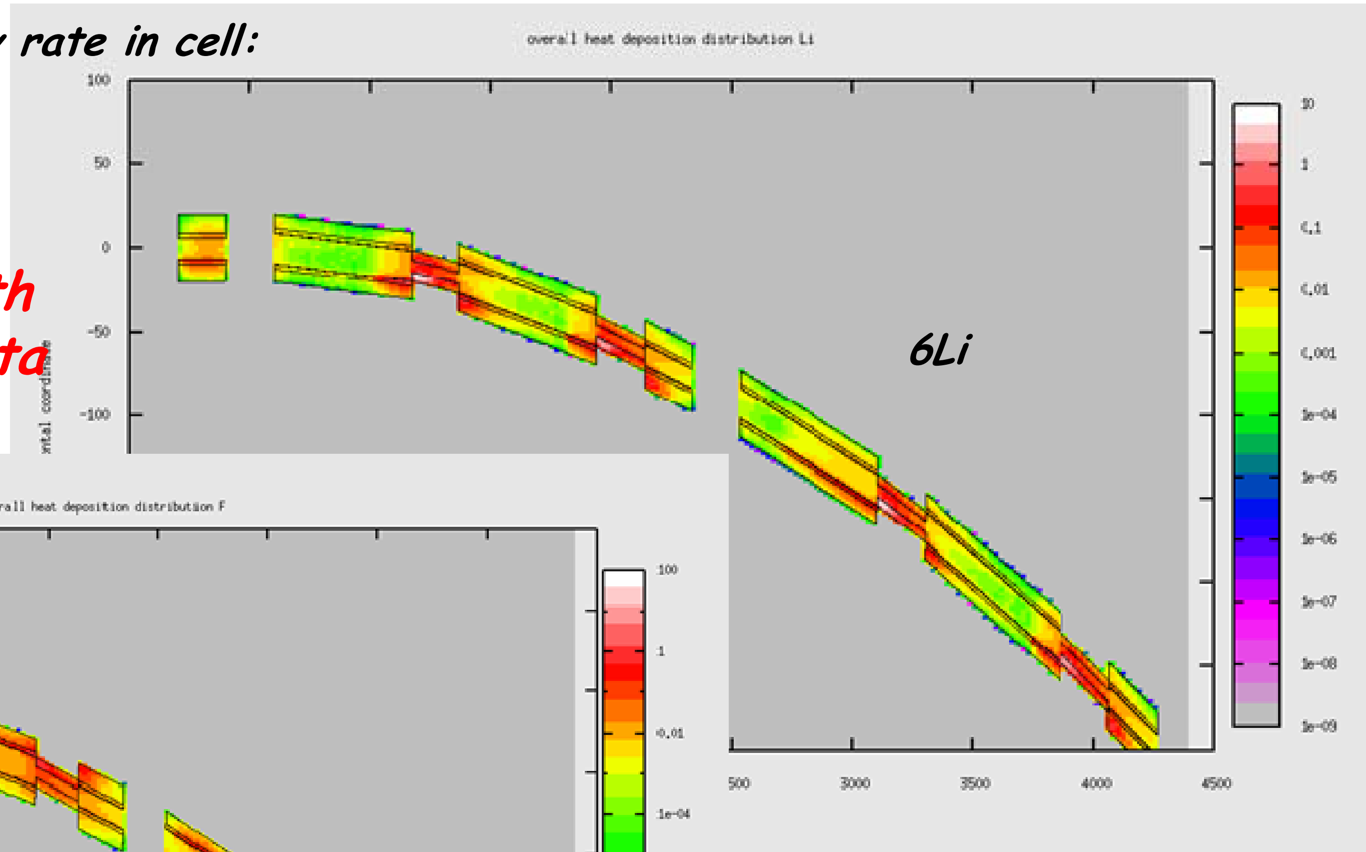


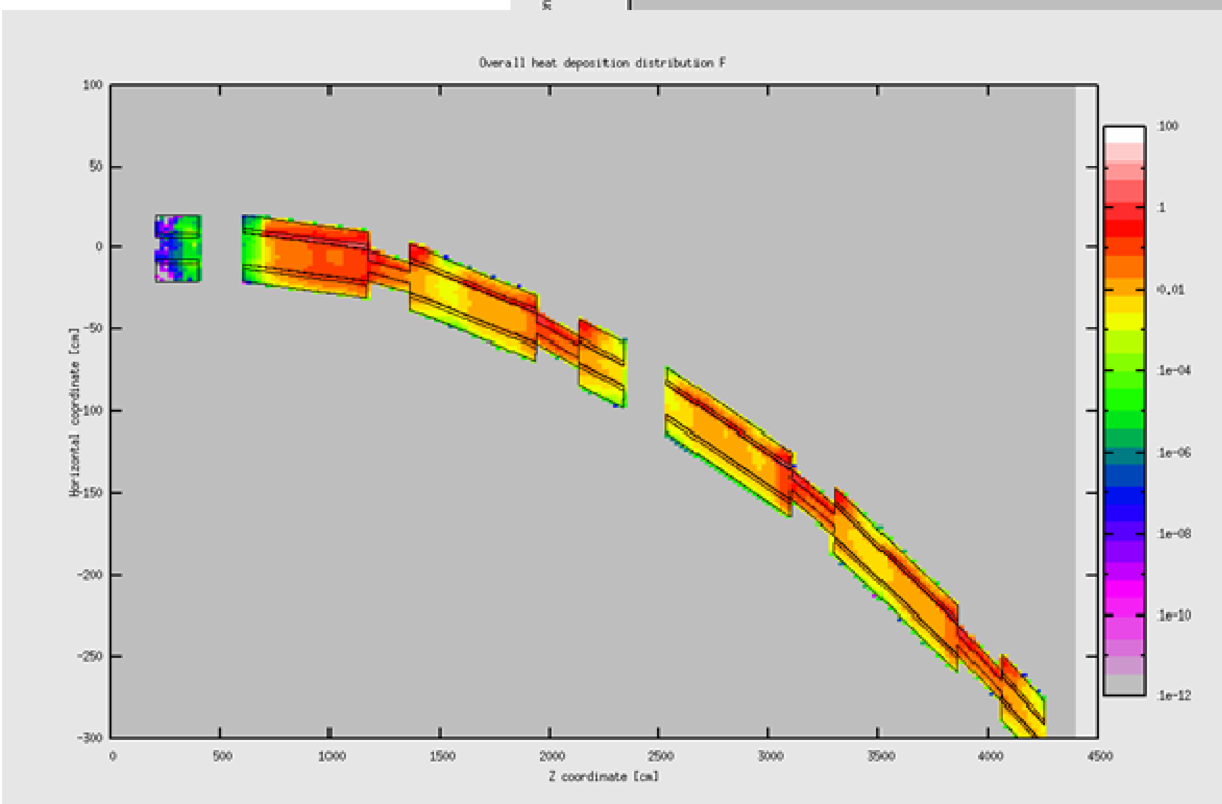


Overall Power Deposition

Normalized to a decay rate in cell:
He: 5.37 10^9 decays/s
Ne: 1.99 10^9 decays/s

Neon treated with scaling of momenta

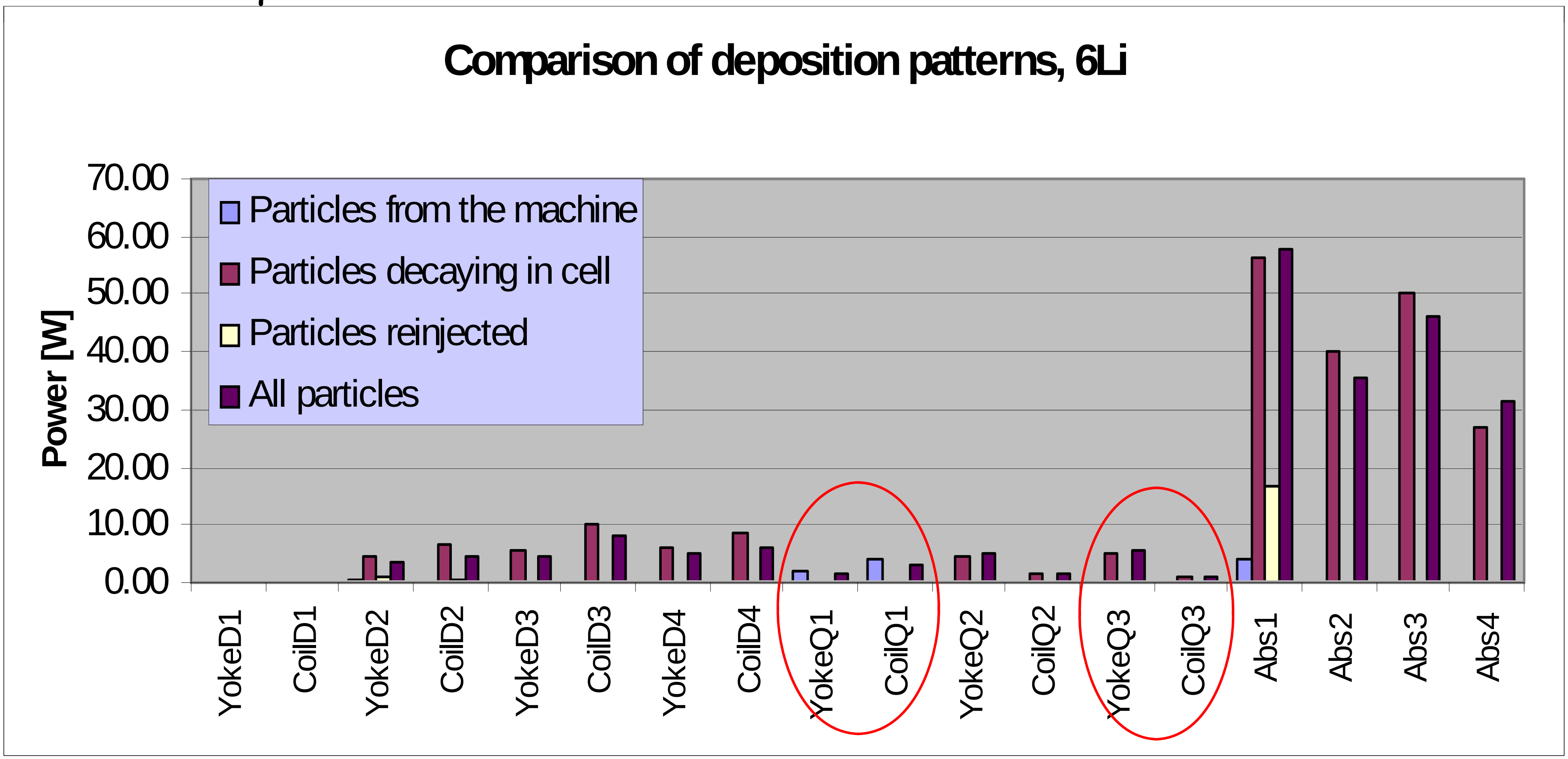




Overall Power Deposition

Normalized to a decay rate in cell:
He: 5.37 10^9 decays/s
Ne: 1.99 10^9 decays/s

Limit for quench 10W/m

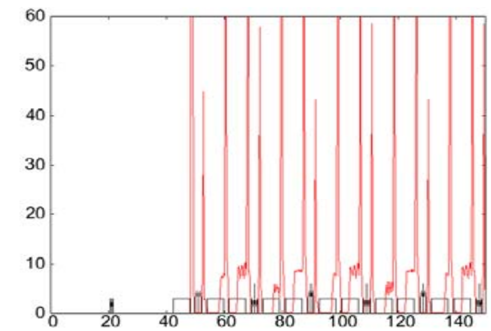


18F give 2 times these values in the dipole coils

Overall Power Deposition

Two aspects of the global heat eposition:

1. Compare to Loss Pattern: similar (A.Chancé)
2. Compare to Limits (10W/m): On limit



Dipole	YokeD1	CoilD1	YokeD2	CoilD2	YokeD3	CoilD3	YokeD4	CoilD4
Average [W]	0.2	0.1	3.7	4.8	4.4	8.2	5.1	5.9
Stdev [W]	0.1	0.0	0.7	0.9	0.9	1.7	0.6	0.6

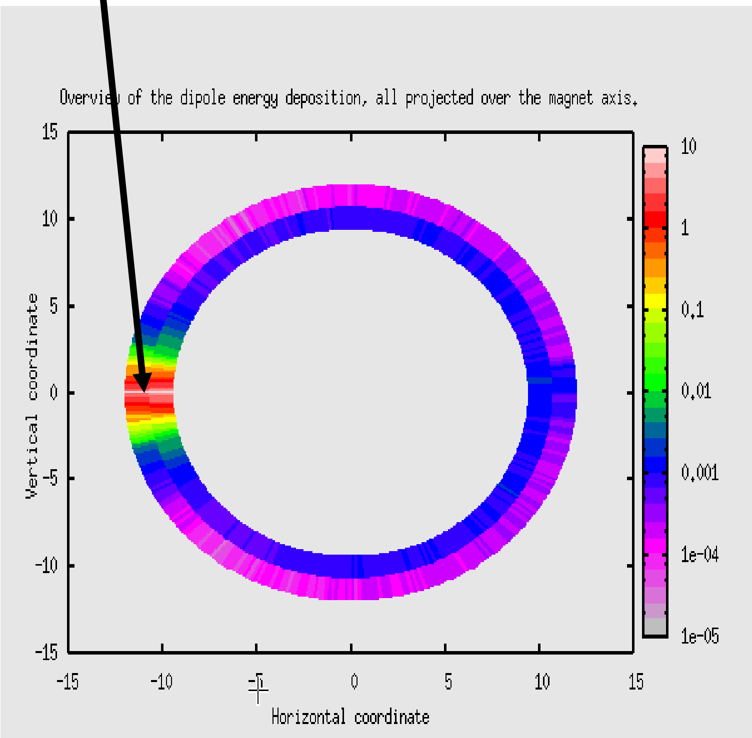
Quadrupole	YokeQ1	CoilQ1	YokeQ2	CoilQ2	YokeQ3	CoilQ3
Average [W]	1.7	3.1	4.8	1.5	5.8	1.2
Stdev [W]	0.6	1	0.9	0.2	1.6	0

Absorber	Abs1	Abs2	Abs3	Abs4
Average [W]	57.8	35.7	45.9	31.3
Stdev [W]	4.3	2.5	2.5	2.1

Normalized to a decay rate in cell:
He: 5.37 10^9 decays/s
Ne: 1.99 10^9 decays/s

Local Power Deposition

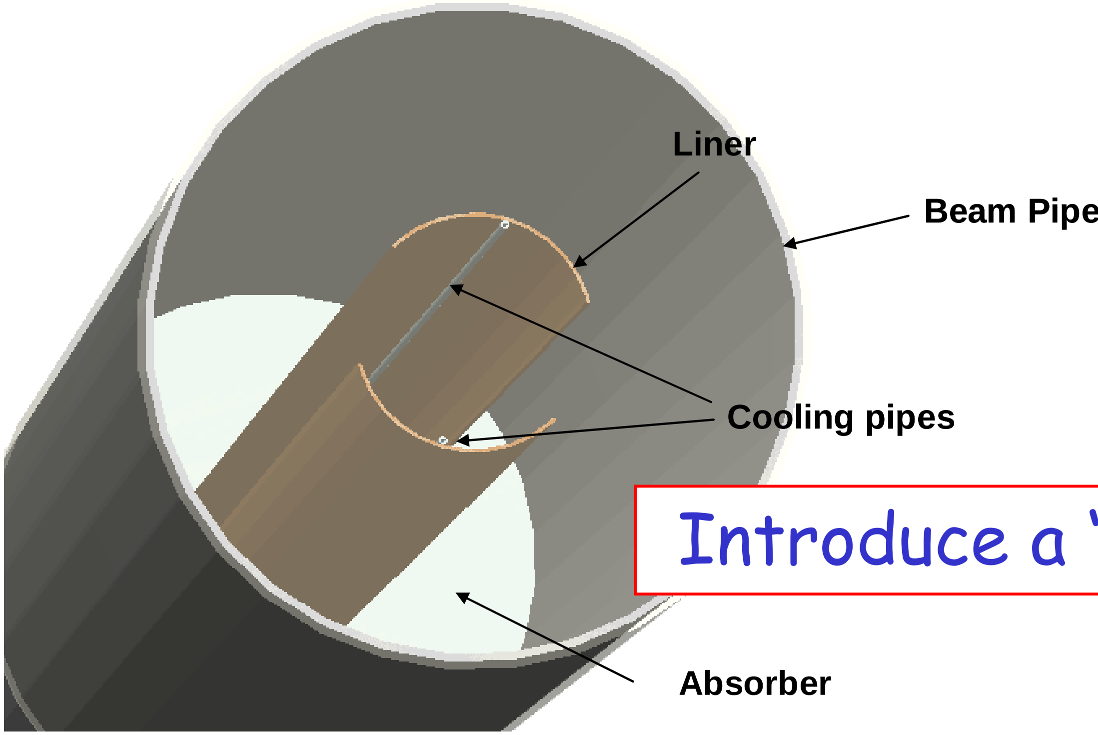
Local power deposition concentrated around the mid plane (scoring in cable corresponds to cable dimensions and heat transport properties)



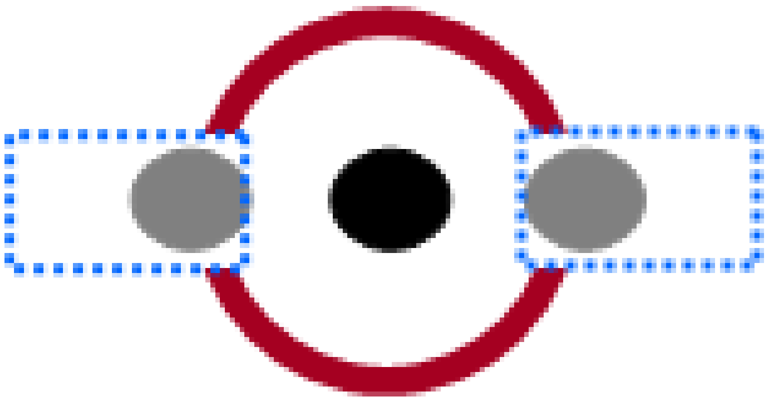
Limit for quench 4.3mW/cm3
(LHC cable data including margin)

For ^{18}F we attain values above this limit:
12 mW/cm^3

Too High Impedance: Possible Solutions



Introduce a "Beam Screen"



Open Mid Plane Magnet a better solution

Summary

A ***protocol*** between the beam code Accsim and the material tracking code (FLUKA)   has ben developed for the beta beam studies. ACCIM to be used for ***the whole accelerator chain***, for decay data production. New ACCIM model installed at CERN.

Accim now to be complemented with the packages made for model creation and for coordinate transformation (Accim->FLUKA->Accim)

First results indicate that the ***deposited power is exceeding*** the limits ***locally, but they are on the limit globally***. Optimisation or another magnet design needed.

The structure with absorbers would need ***special arrangements*** for the impedance induced.

To do:

Data Base to be checked, we have used data from A. Chancé and J. Payet, EURISOL DS/TASK12/TN-06-05. This should not be of any importance, scaling for Ne with database values for Brho. Ne runs to be repeated.

Check why F has large energy deposition in first dipole, maybe wrong emittance?

Open midplane design ongoing. Not yet ready to use in simulations with FLUKA.

Liner to protect the coil to be checked: A thick protection may solve the problem.

Complete Accsim with coordinate transformation for deposition models (normally cartesian systems, fix in space). New first version of reference manual available, should be published.

Acknowledgements

F. Cerutti, CERN, has helped with many aspects of FLUKA for the simulations of the heat deposition.

Decay Ring Top Parameters

	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	100	100
Bρ (T.m)	938	563
τ (s) at rest	0.8	1.67
$N_{Injected}$ (ions/batch)	$9.05\ 10^{12}$	$4.26\ 10^{12}$
N_{Stored} (ions/batch)	$9.71\ 10^{13}$	$7.4\ 10^{13}$

Parameters

Lattice

Name	Calculated	Symbol	Value	Unit	Source	Comments	Last modified	History
Betatron tune hor.	No	Qx	22.23		AC, 2nd bb meeting		17-Mar-06 18:13	
Betatron tune ver.	No	Qy	12.16		AC, 2nd bb meeting		17-Mar-06 18:15	
gamma at transition	No	$\gamma_{transition}$	27.00		AC, 2nd bb meeting		17-Mar-06 18:13	
β hor. average	No	$<\beta_{hor}>$	148.25		mathematica nb		04-Dec-06 11:53	1
β ver. average	No	$<\beta_{ver}>$	173.64		mathematica nb		04-Dec-06 11:53	1
1/β hor. average	No	$<1/\beta_{hor}>$	0.02		mathematica nb		04-Dec-06 11:53	1
1/β ver. average	No	$<1/\beta_{ver}>$	0.01		mathematica nb		04-Dec-06 11:53	1
Dispersion average	No	D average	-0.60		mathematica nb		04-Dec-06 11:53	1
Transverse emittance blow-up	No		0.00				19-Oct-06 15:53	
Longitudinal emittance blow-up	No		0.00				19-Oct-06 15:53	
Harmonic number at injection	No	h	1848		version2		26-Oct-06 15:09	1
Bunch-to-bucket ratio	No		0.80				20-Mar-06 11:46	

Parameters

Beams

Parameter	Symbol	Unit	Calculated	6He	18Ne	19Ne	proton
Cycle							
Accumulation time/cycle		s	in Mathematica	0.	0.	0.	
Bunching time		ms	in Mathematica	0.			
Acceleration time		s	in Mathematica	2.5419			
Flat top length		s	in Mathematica	0.			
dead time		ms	no				
Cycle rate		Hz	on the fly	0.17	0.28	0.28	
Cycle time		s	in Mathematica	6.00	3.60	3.60	
Repetition time		s	in Mathematica				
E_{tot}/nucleon at transition		GeV	on the fly	25.23	25.15	25.15	25.36
p/nucleon at transition		GeV/c	on the fly	25.21	25.13	25.13	25.34
bunch merges			no	15	20	20	

Parameters

Injection							
Relativistic gamma			in Mathematica	100.00	100.00	100.00	298.41
Relativistic beta			in Mathematica	1.00	1.00	1.00	1.00
Relativistic beta*gamma			in Mathematica	99.99	99.99	99.99	298.41
Half-life time		s	in Mathematica	81.00	167.00	1730.00	
Magnetic rigidity			on the fly	934.93	559.26	590.21	934.93
E_{kin}/nucleon		eV	in Mathematica	9.25E+10	9.22E+10	9.22E+10	2.79E+11
E_{kin}/ion		eV	in Mathematica	5.55E+11	1.66E+12	1.75E+12	2.79E+11
E_{tot}/nucleon		eV	in Mathematica	9.34E+10	9.32E+10	9.31E+10	2.80E+11
E_{tot}/ion		eV	in Mathematica	5.61E+11	1.68E+12	1.77E+12	2.80E+11
p/nucleon		eV/c	in Mathematica	9.34E+10	9.31E+10	9.31E+10	2.80E+11
p/charge		eV/c	in Mathematica	2.80E+11	1.68E+11	1.77E+11	2.80E+11
Revolution time		μs	on the fly	23.06	23.06	23.06	23.05
Revolution frequency		kHz	on the fly	43.37	43.37	43.37	43.38
Norm. horizontal emittance (1 σ)		pi mm mrad	no	11.3	11.3	11.3	11.3
Norm. vertical emittance (1 σ)		pi mm mrad	no	6.0	6.0	6.0	6.0
Phys. hor emittance (1 σ)		pi mm mrad	on the fly	0.11	0.11	0.11	0.04
Phys. vert. emittance (1 σ)		pi mm mrad	on the fly	0.06	0.06	0.06	0.02
Longitudinal emittance (full)		eVs	no	15.00	44.00	44.00	
Bunch length (full)		s	on the fly	9.981E-09	9.981E-09	9.981E-09	9.980E-09
Bunch length (full)		m	on the fly	2.992	2.992	2.992	2.992
Pulse length		μs	no				
Momentum spread (full)			no	0.00	0.00		