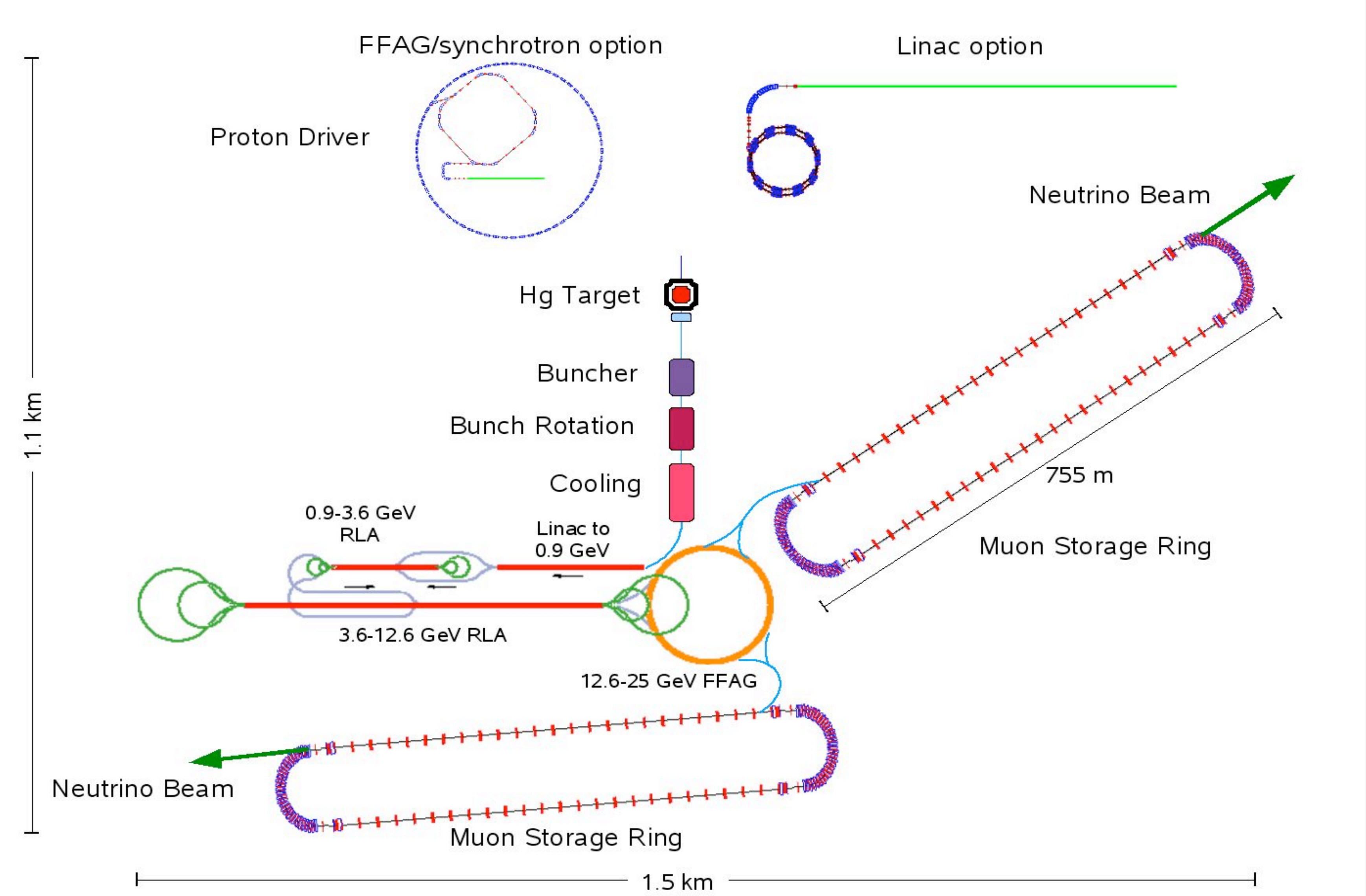
WP3 summary

J. Pozimski, Imperial College @ 2nd annual Euroν meeting 1-4 June 2010, Strasbourg

Overview


FFAG/synchrotron option
Linac option
Proton Driver
Neutrino Beam
Hg Target
Buncher
Bunch Rotation
Cooling
755 m
Muon Storage Ring
0.9-3.6 GeV RLA
Linac to 0.9 GeV
3.6-12.6 GeV RLA
12.6-25 GeV FFAG
Neutrino Beam
Muon Storage Ring
1.1 km
1.5 km

Proton driver

R&D for the proton driver is decoupled from IDS as a hosting lab specific solution is assumed,………but required beam parameters on target have been defined. Within Euroν the proton driver is part of the super beam work package. As the proton driver costing is strongly related to the hosting lab the following conveners have agreed to contribute:

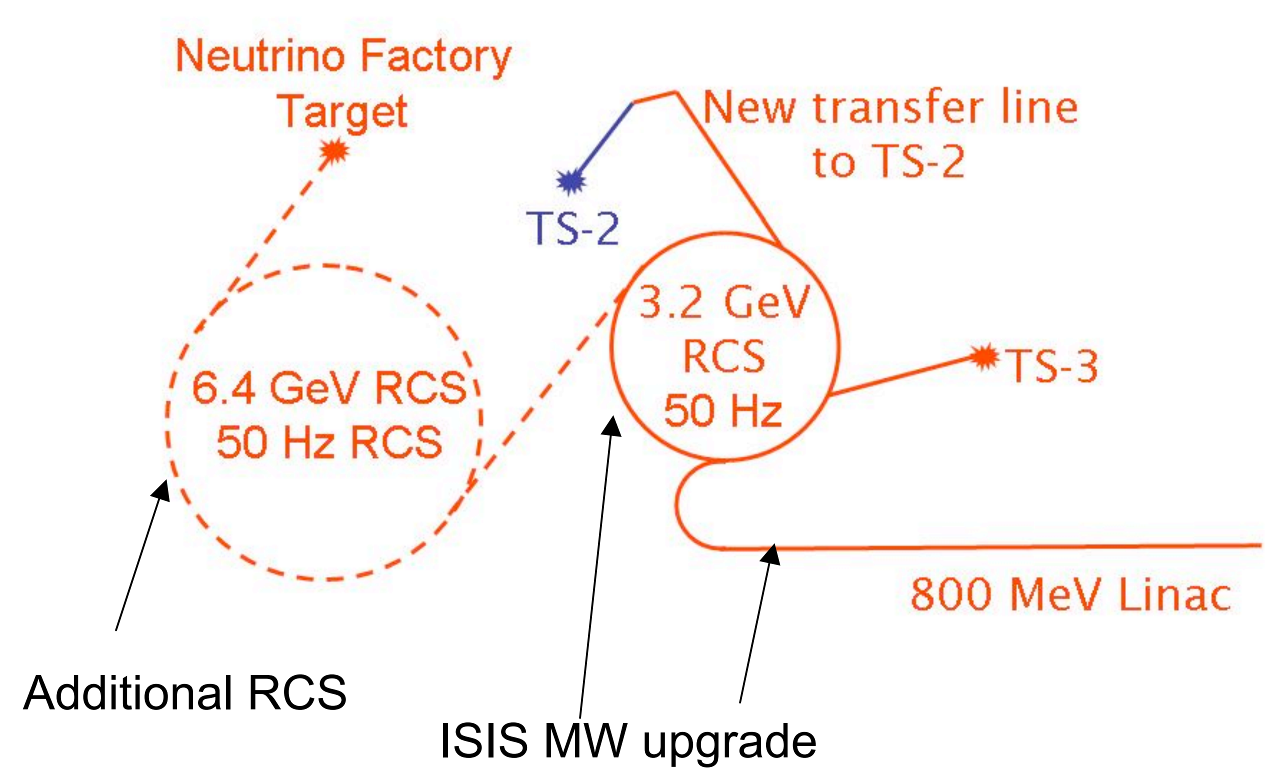
CERN LINAC 4 / SPL : Roland Garoby

Fermilab Project X : Keith Gollwitzer

RAL - ISIS upgrade : John Thomason

NF- Proton driver and ISIS upgrade

Jaroslaw Pasternak / John Thomason



- Based on MW ISIS upgrade with 0.8 GeV linac and 3.2 GeV RCS.
- Assumes a sharing of the beam power at 3.2 GeV between the two facilities
- Requires additional RCS machine in order to meet the power and energy needs of the Neutrino Factory
- Both facilities can have the same ion source, RFQ, chopper, linac, H^- injection, accumulation and acceleration to 3.2 GeV

Proton driver at CERN

High power SPL could be the proton driver for a NF.

Lattice design for accumulator and bunch compressor available.

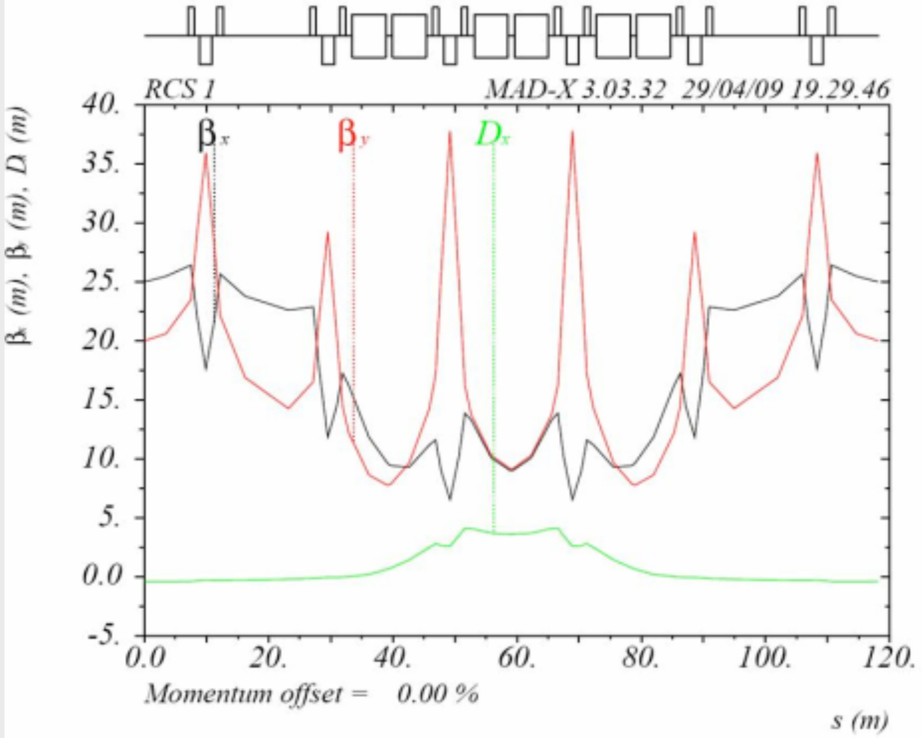
Detailed particle dynamics studies of accumulator and bunch compressor successfully performed.

3 bunch scenario is able to fulfil NF requirements.

Costing for SPL finished, this has also to be performed for the rings.

Preliminary design of the second RCS

Jaroslaw Pasternak

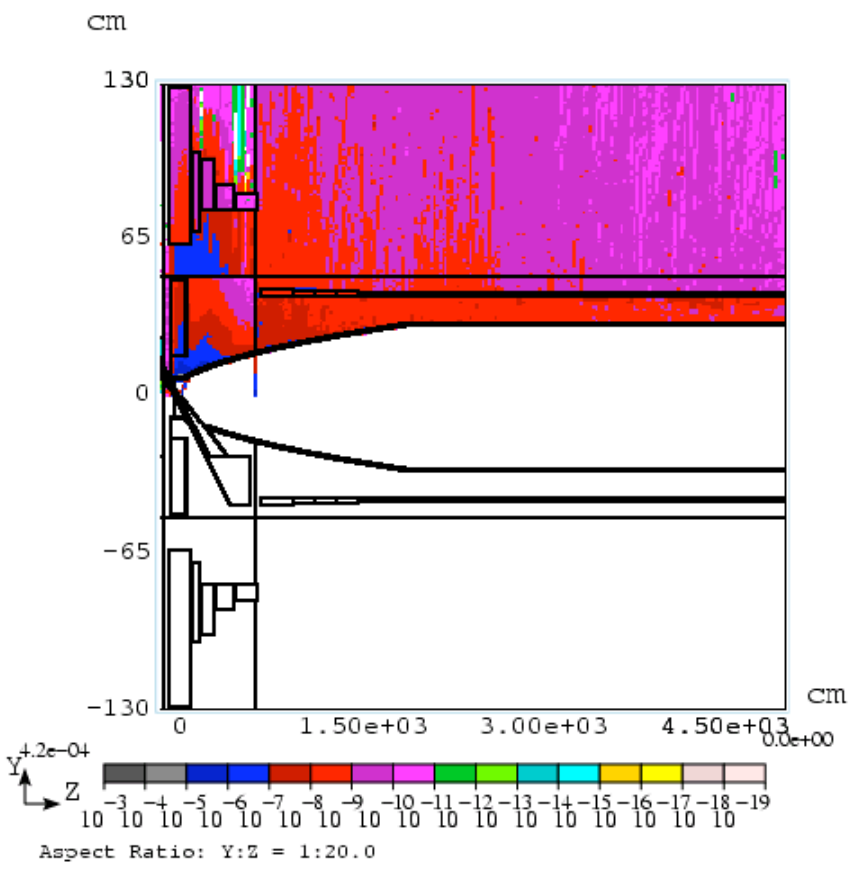


- Lattice may allow for flexibility in gamma transition choice (even with beam).
- Ring is overdesigned in order to allow for 10.3 GeV.
- Optimised solution for 6.4 GeV is in preparation!

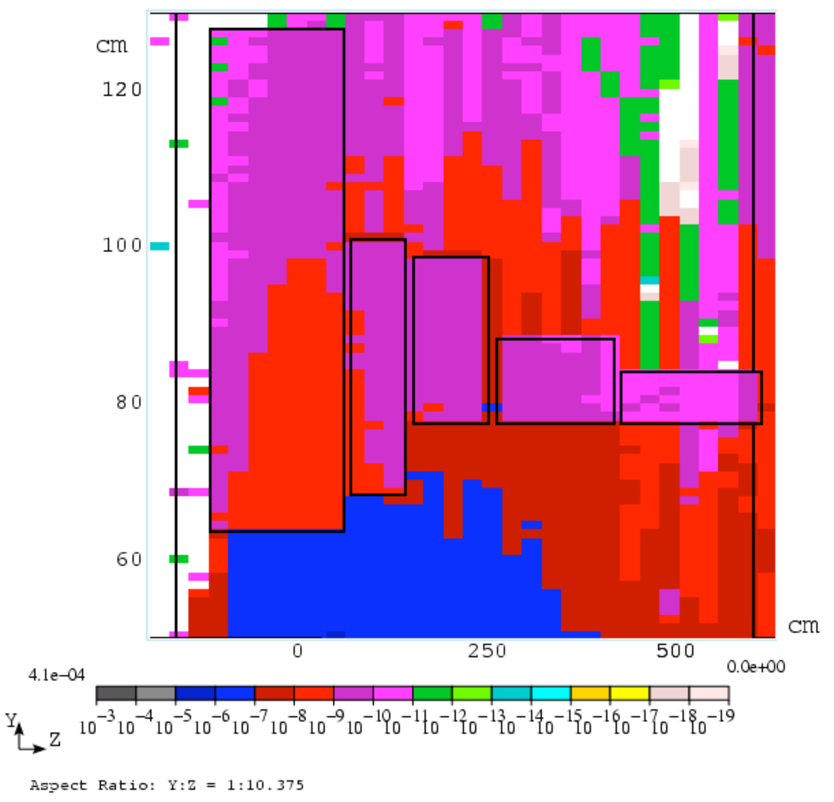
Number of superperiods	6
Circumference	708.788 m
Harmonic number	6
RF frequency	2.4717-2.5289 MHz
Betatron tunes (Q_H, Q_V)	(7.81, 7.78)
Gamma transition	7.9056
Beam power at 6.4 GeV	4 MW for 2 bunches
Bunch area	1.8 eVs
Δp/p at 3.2 GeV	$5.3\ 10^{-3}$
Injection / extraction energy	3.2 / 6.4 [10.3] GeV
Repetition rate	50 Hz
Max B field in dipoles	1.2 T (at 10.3 GeV)
Length of long drift	12 m

Parameters of 6.4 (10.3) GeV RCS

Liquid mercury target -Energy deposition in the target area



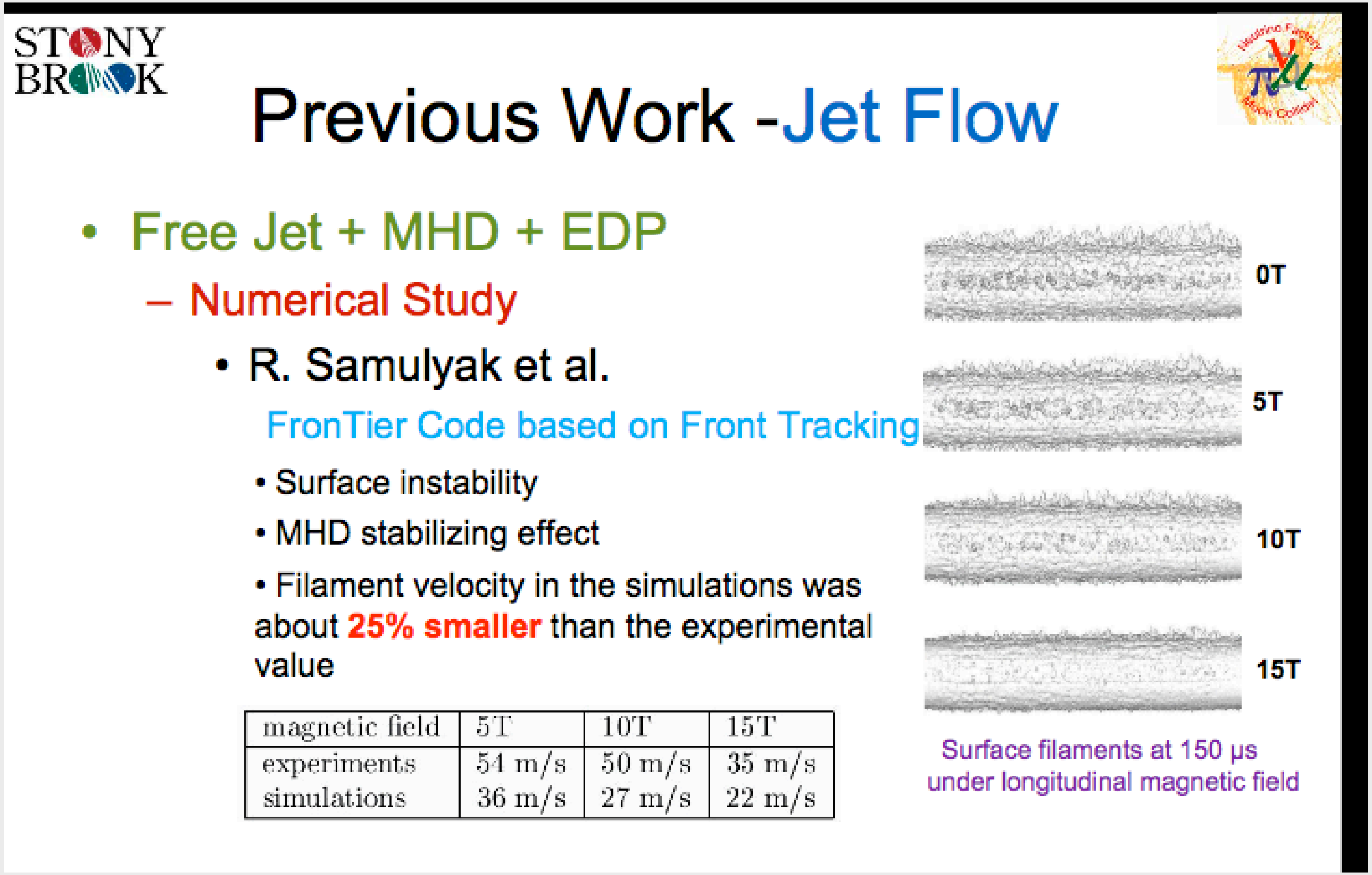
X. Ding



Enhanced shield can decrease the power deposition in SC1 coil from 22.1kW to 4.8kW. By replacing the Res Sol by WC shield, the power deposition in SC1 coil can be decreased further to 1.3kW.

Liquid mercury target - Nozzle Development

R. Ladeinde



STONY BROOK

Previous Work -Jet Flow

- Free Jet + MHD + EDP
  - Numerical Study
    - R. Samulyak et al.

FronTier Code based on Front Tracking

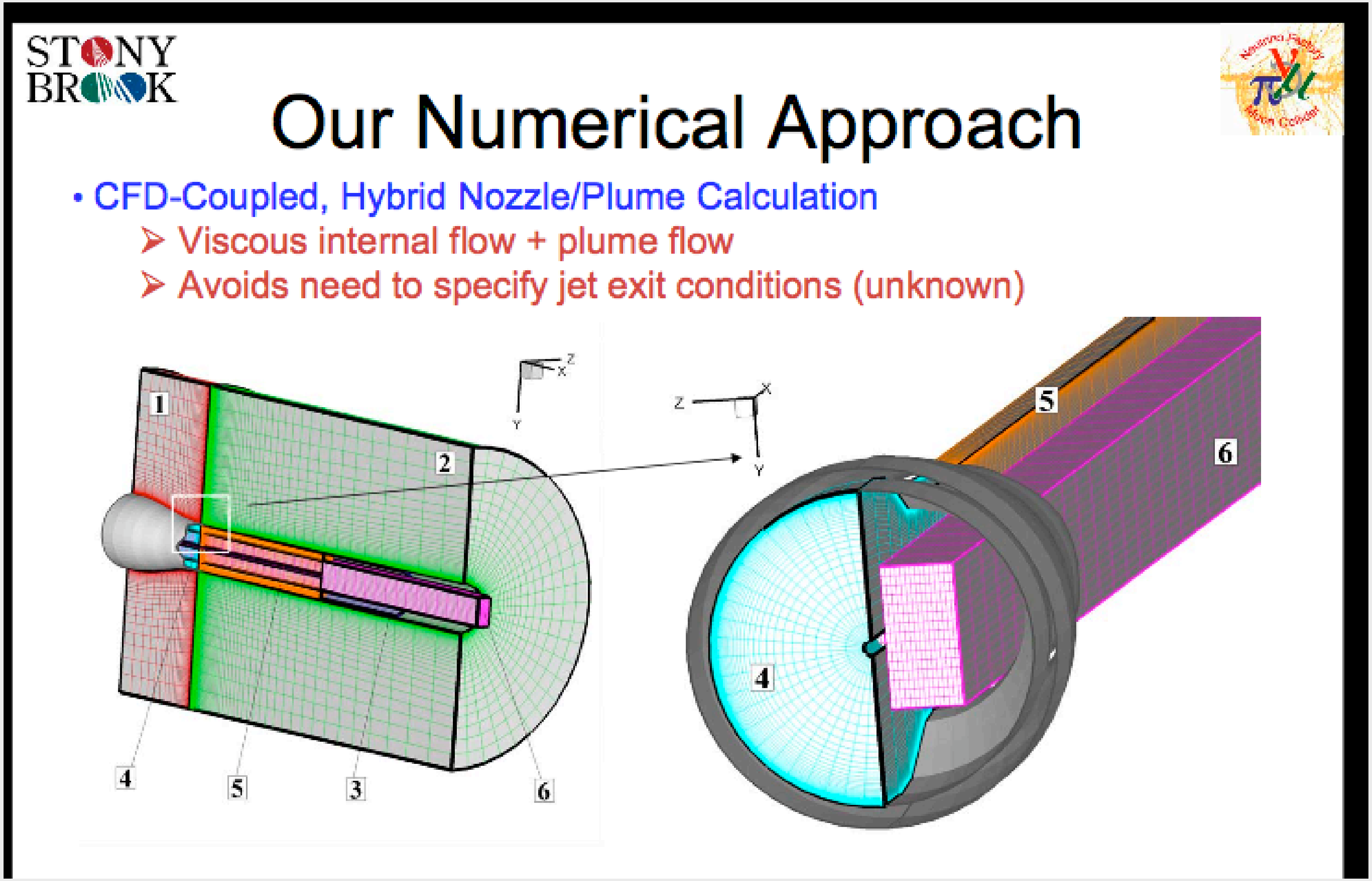
- Surface instability
- MHD stabilizing effect
- Filament velocity in the simulations was about **25% smaller** than the experimental value

magnetic field	5T	10T	15T
experiments	54 m/s	50 m/s	35 m/s
simulations	36 m/s	27 m/s	22 m/s

Surface filaments at 150 μs under longitudinal magnetic field

Liquid mercury target-Nozzle Development

R. Ladeinde

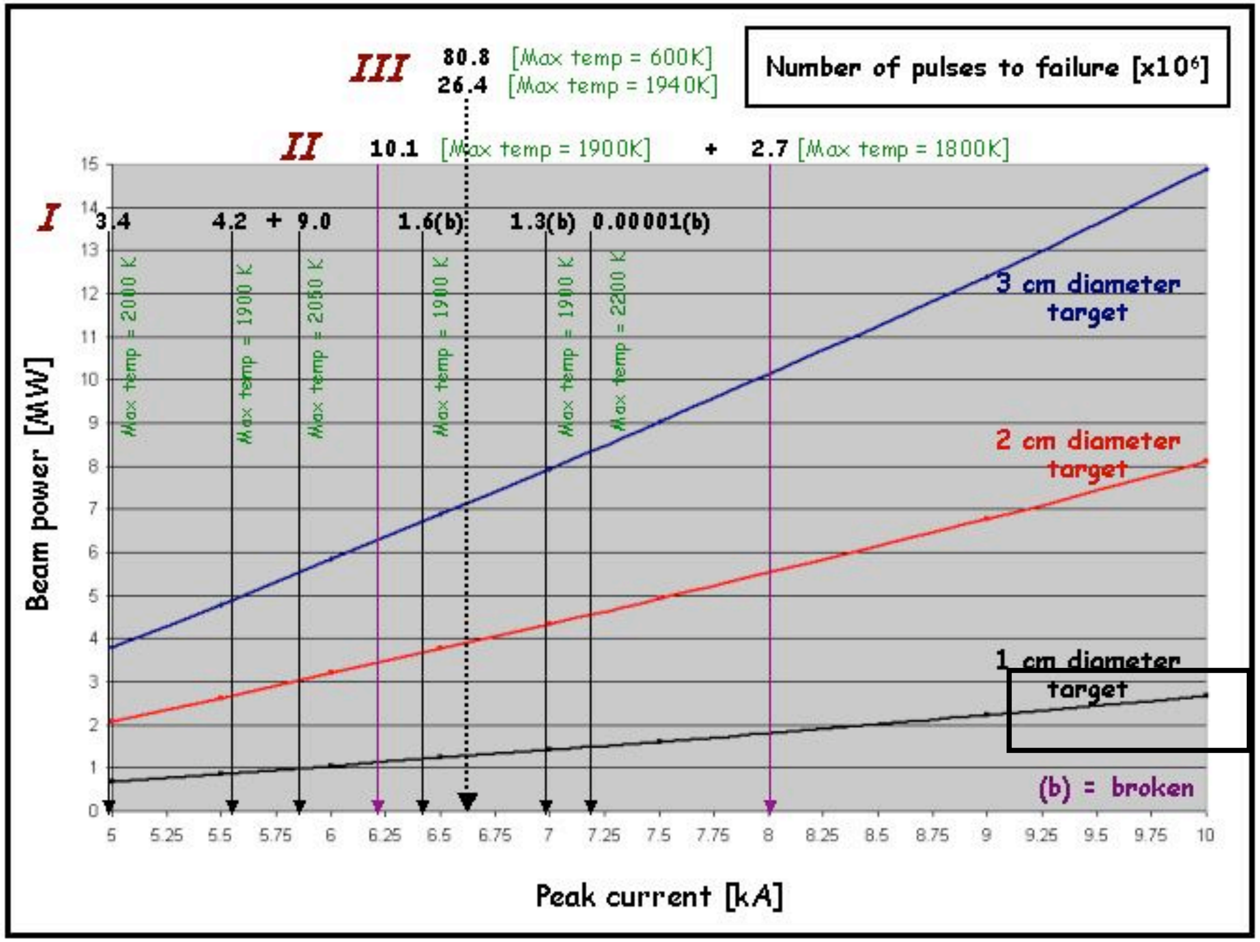


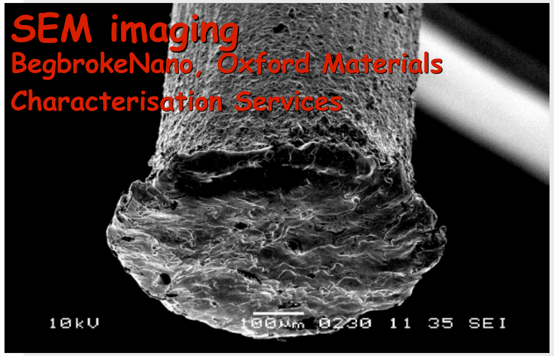
Our Numerical Approach

- CFD-Coupled, Hybrid Nozzle/Plume Calculation
  - ➢ Viscous internal flow + plume flow
  - ➢ Avoids need to specify jet exit conditions (unknown)

Solid target- lifetime tests

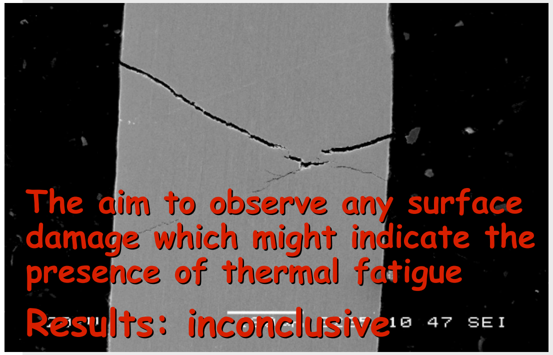
Rob Edgecock





SEM imaging

BegbrokeNano, Oxford Materials Characterisation Services



The aim to observe any surface damage which might indicate the presence of thermal fatigue

Results: inconclusive

> 10 years for 2cm diameter target

> 20 years for 3cm diameter target

Focus now:

Measure stress;

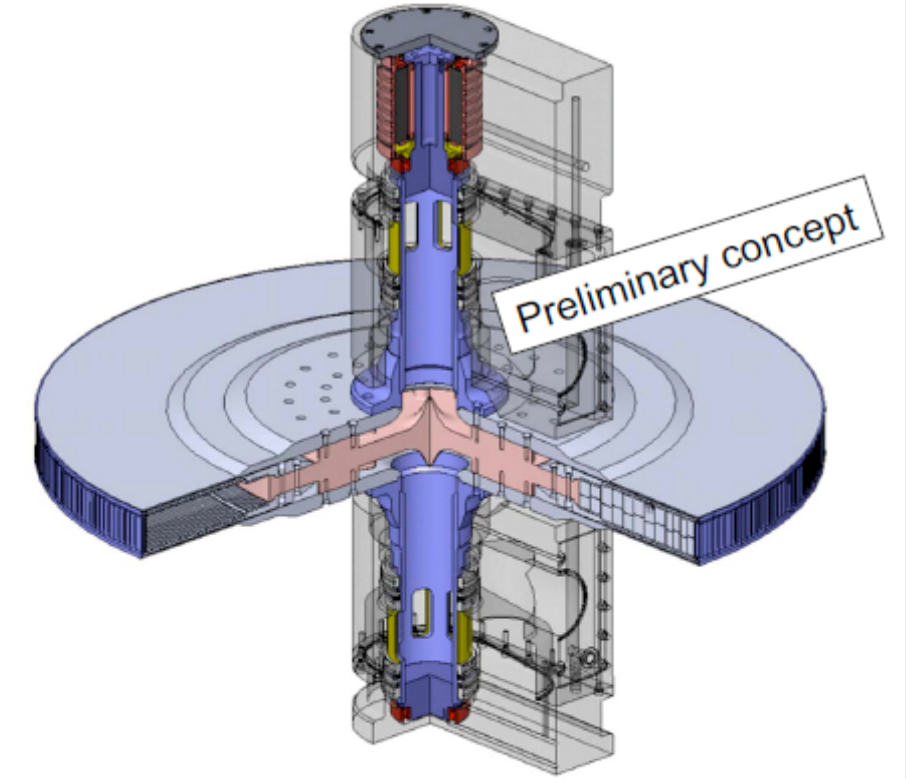
Confirm modelling.

Better at lower temperature!

Solid target station

Rob Edgecock

- **Current option: a wheel – being investigated now**
- **Several already used, but most relevant: design study**

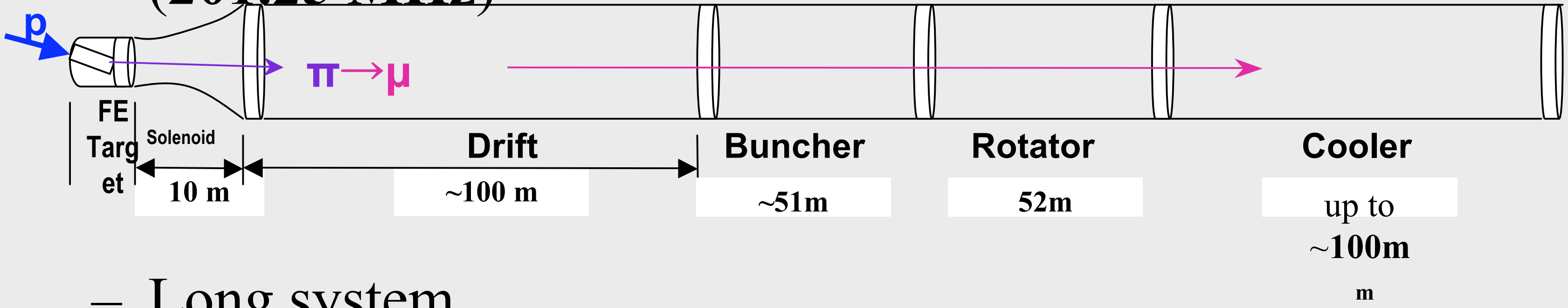


Horizontal for compatibility with baseline target station

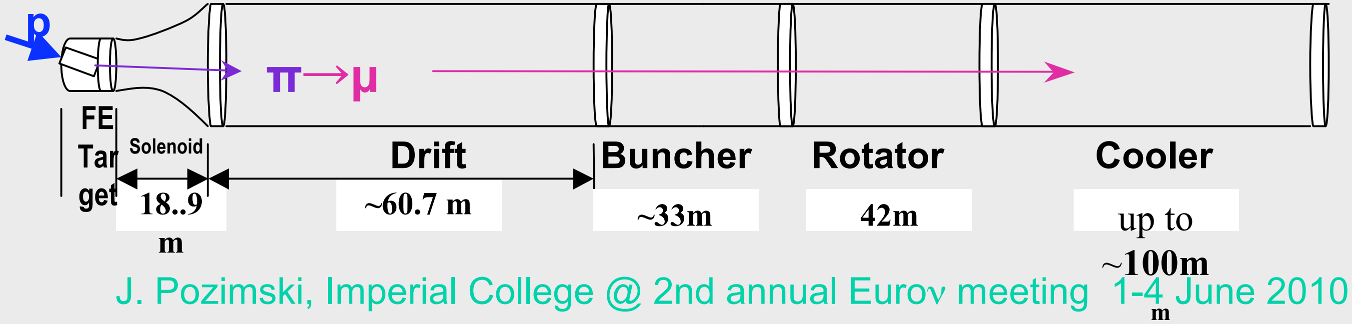
Compact Muon front end

D. Neuffer

- ISS study based on $n_B = 18$ (280 MeV/c to 154 MeV/c)
  - Buncher 0 to 12MV/m; Rotator 12.5MV/m, B=1.75T **(201.25 MHz)**



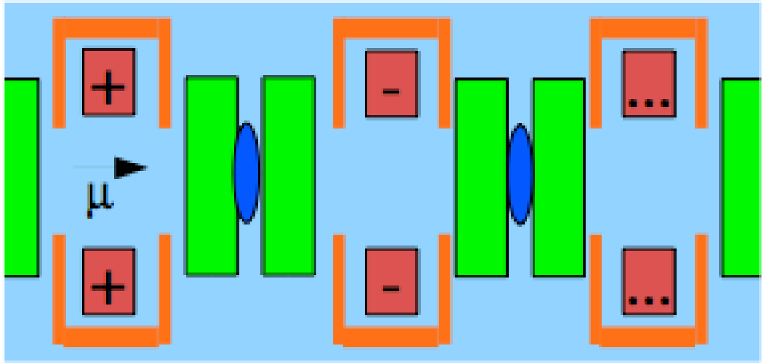
  - Long system,
- Try shorter version - $n_B = 10$ (233 MeV/c to 154 MeV/c)
  - slightly lower fields (1.5T, 15MV/m)
  - Buncher 0 to 9 MV/m, Rotator 12MV/m
  - Shorter bunch train

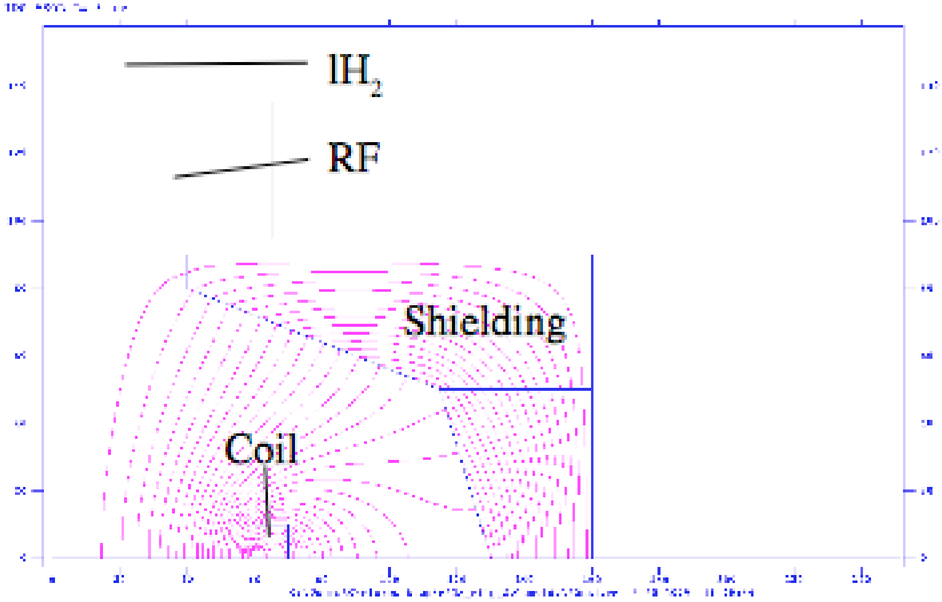


Shielded RF cooling lattice

C. Rogers

- Increase cell length to remove RF from fringe fields
  - Add shielding using iron or bucking coils
- Look at cooling section
  - This is where the RF is most limited
  - This is where optics are most demanding
- How well can we cool in this shielded scenario?
- How well can we optimise the cooling lattice?
- Try to keep RF cavities in < 0.1 T fields
- Liquid Hydrogen absorbers

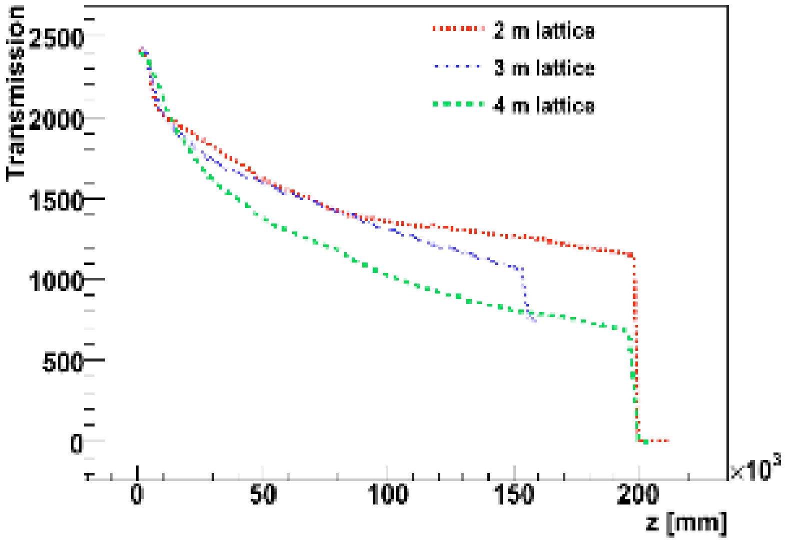


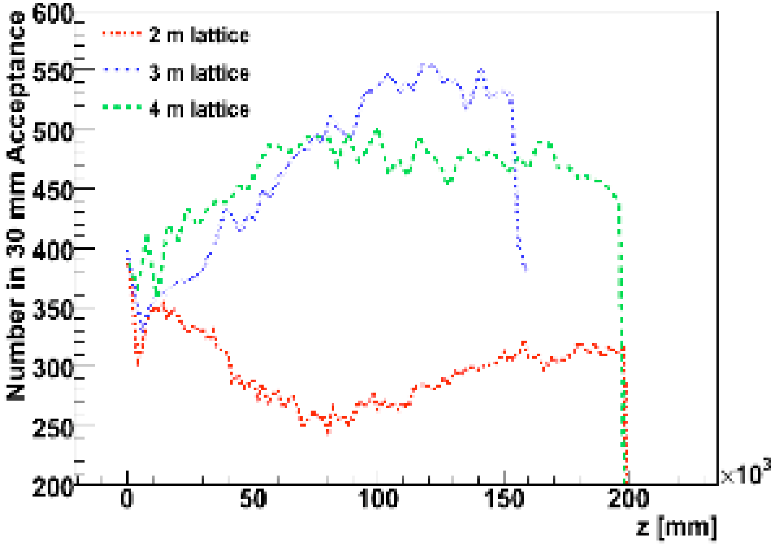


Shielded RF cooling lattice

C. Rogers

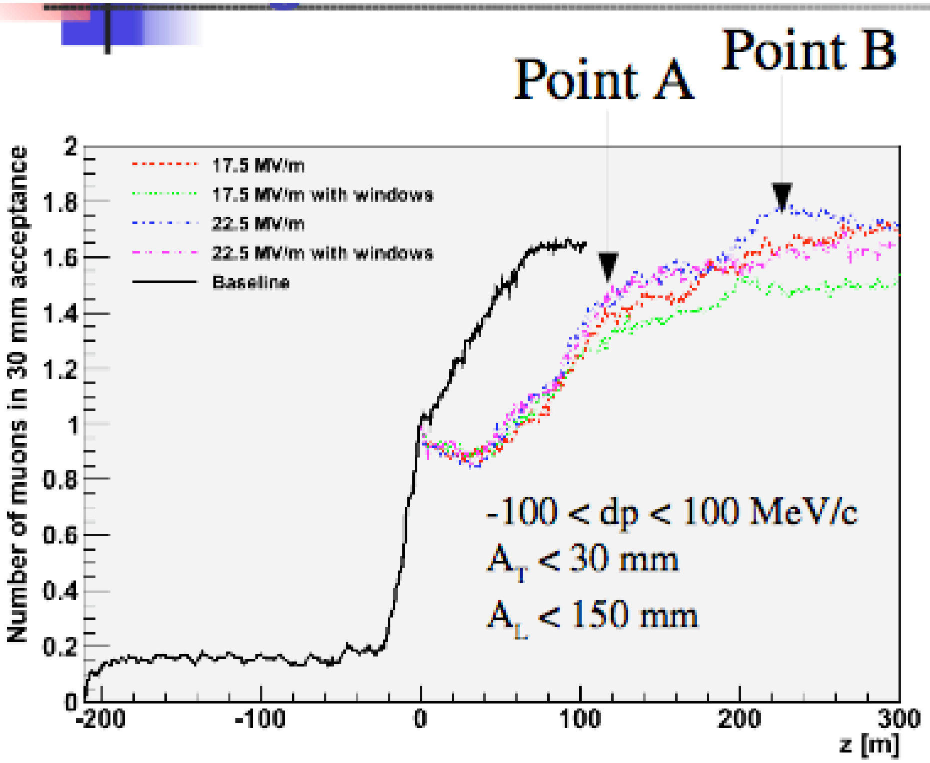
- Cell length optimisation
  - Simulated using long coil option
  - Race between RF packing fraction and β function
  - Higher RF packing => quicker cooling
  - Shorter lattice => lower β function (better equilibrium emittance)
- 3m lattice is optimal
  - Worry about initial beam loss
  - Nb low statistics
  - Get ~ 40 % with long coil (a bit more optimisation is possible)
- Case for beta tapering?





Higher momentum beam

C. Rogers



- Fairly large transmission losses
  - >~ 50%
- Most of the remaining beam is inside the 30 mm acceptance
- Getting increase in rate of ~ 70 %
  - But with more hardware
  - Performance quite similar to baseline
- If I stop at point A - I use roughly the same amount of hardware as the baseline (RF packing fraction ~ 1/2 that of the baseline)
  - And lose a few muons
- I can recover baseline performance if I go to Point B
  - But those last few muons are expensive!

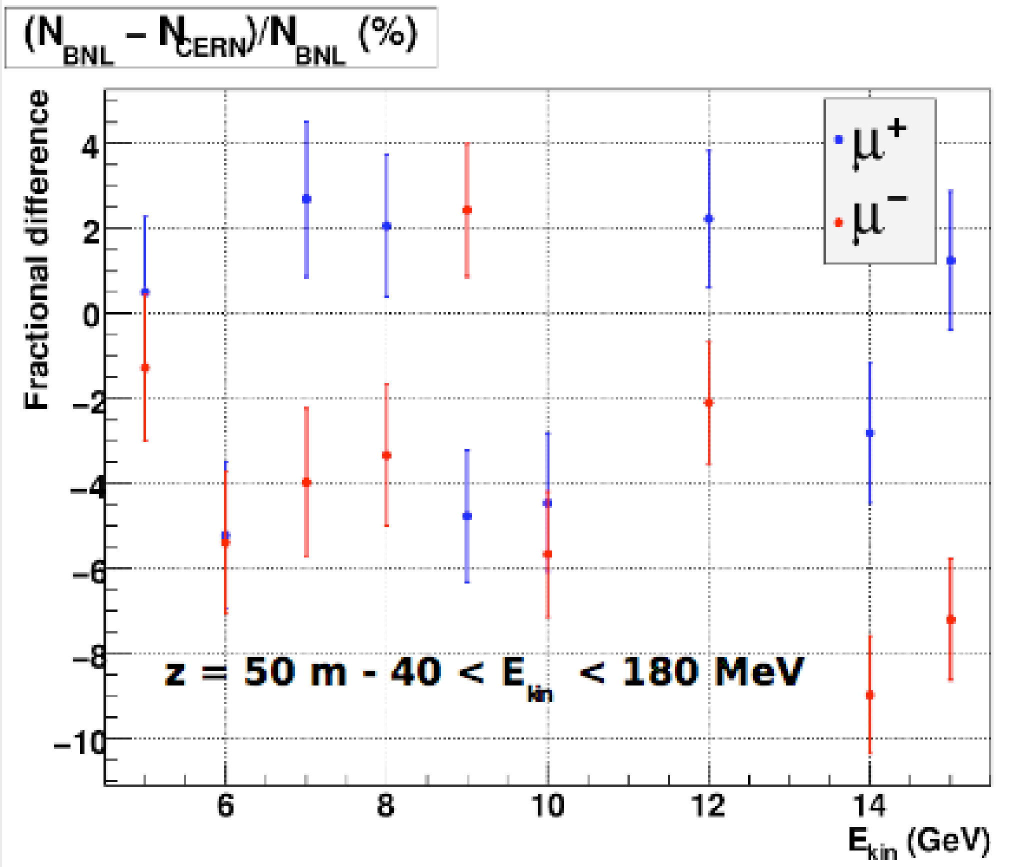
Front end work at CERN

G. Prior

Particles production (coll. with BNL)

Tested the exact same input files on 2 different machines:

- **SL4 2.6.9-89.0.11.EL.smp - 32x - little endian (BNL)**
- **SLC4 2.6.9-89.0.18.EL.cern - 32x - little endian (CERN)**

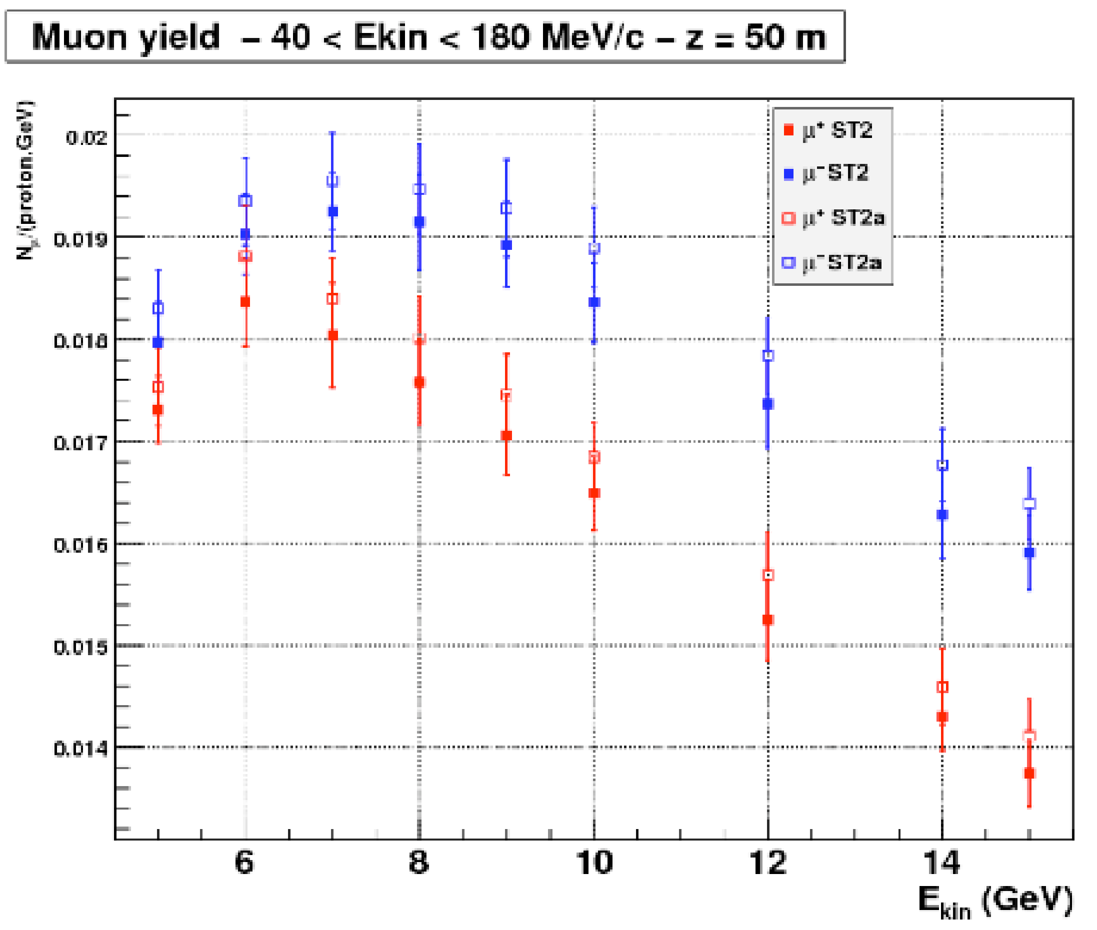


$$Error = \sqrt{(N.s_2 - s_1^2)/(N-1)}$$

$$s_2 = \sum w_i^2 \qquad s_1 = \sum w_i$$

Difference in the yield HAS to come from different code versions: need to be confirmed by the MARS developers as we don't have access to the source files.

ST2/ST2a comparison



Yield = MEAN

Error = STD

ST2a slightly better than ST2 (within the errors bars).

Advantage of a higher field at end of taper but ST2 magnet configuratior in a more mature design.

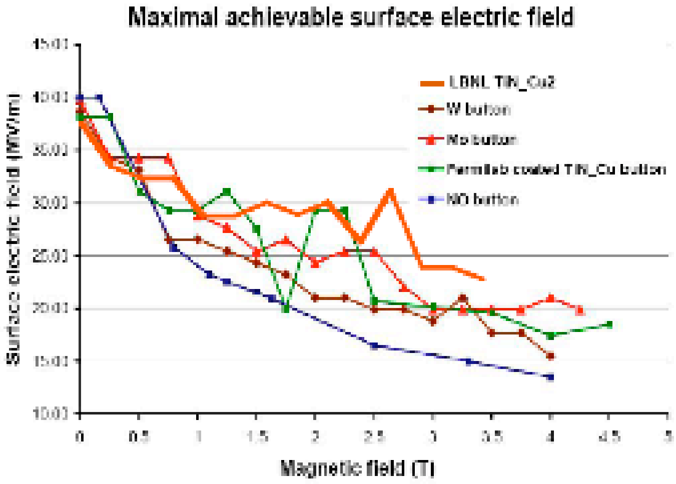
Optimum at 7-8 GeV and yield difference between muon signs is likely to be model dependent.

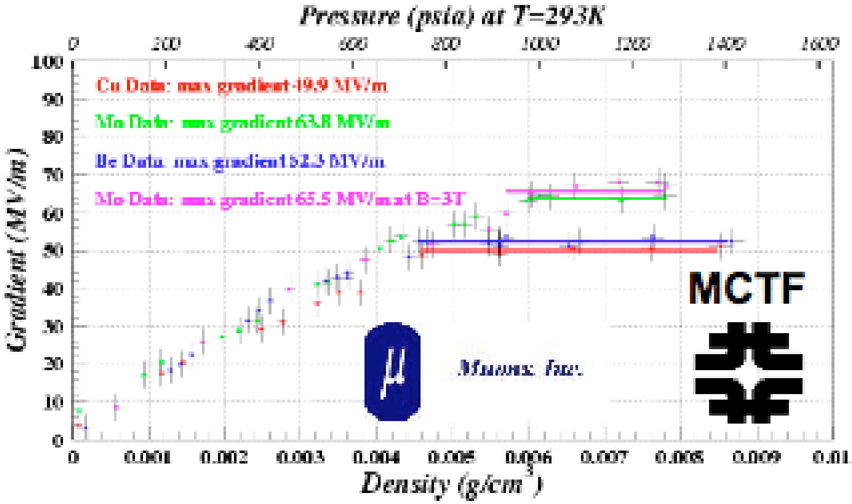
High pressure RF

M. Zisman

- **We have evidence that vacuum RF cavity gradient performance degrades in a strong magnetic field**
  - alternative approach of HPRF does not
    - though it has other potential issues

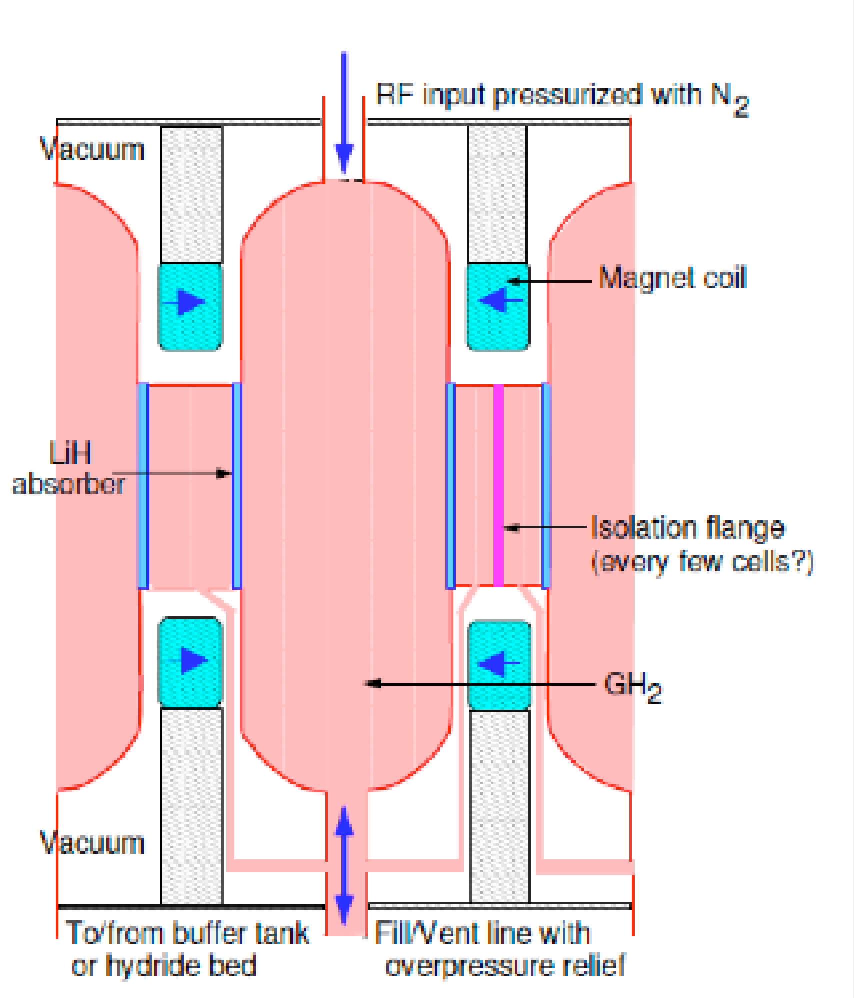
- **It seems prudent to begin investigating the technical aspects of implementing HPRF in a linear cooling channel**
  - minimizes changes in cooling channel layout and hardware

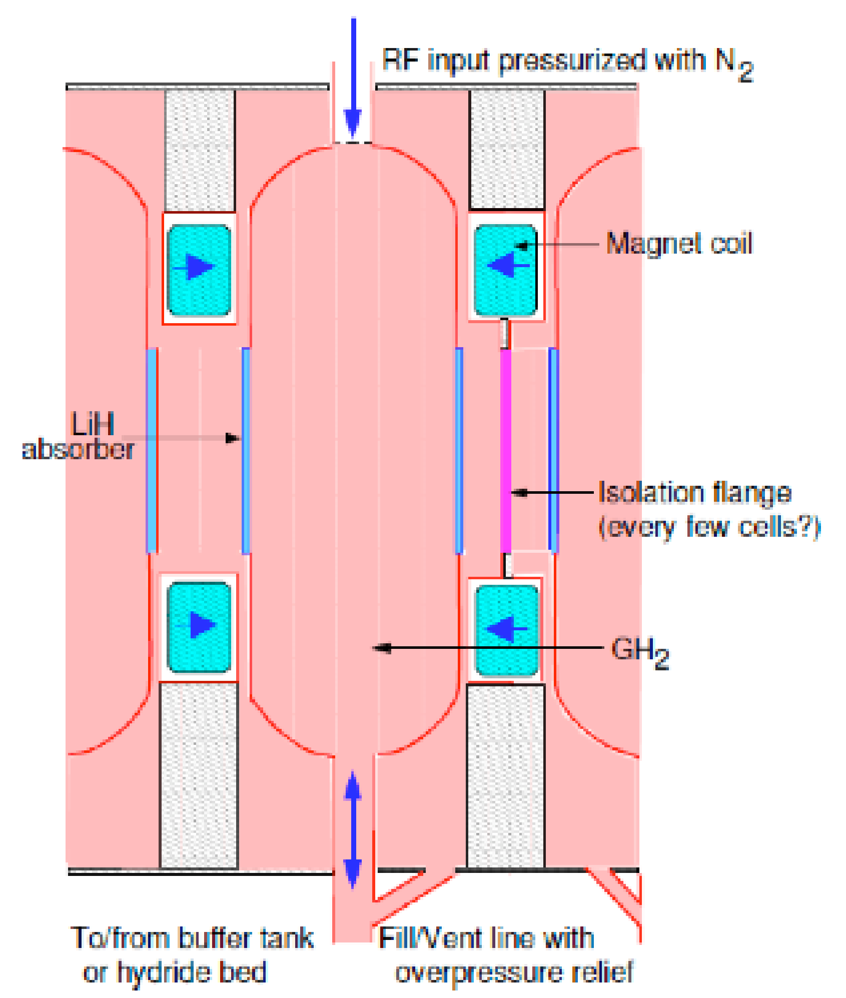




High pressure RF implementation

M. Zisman

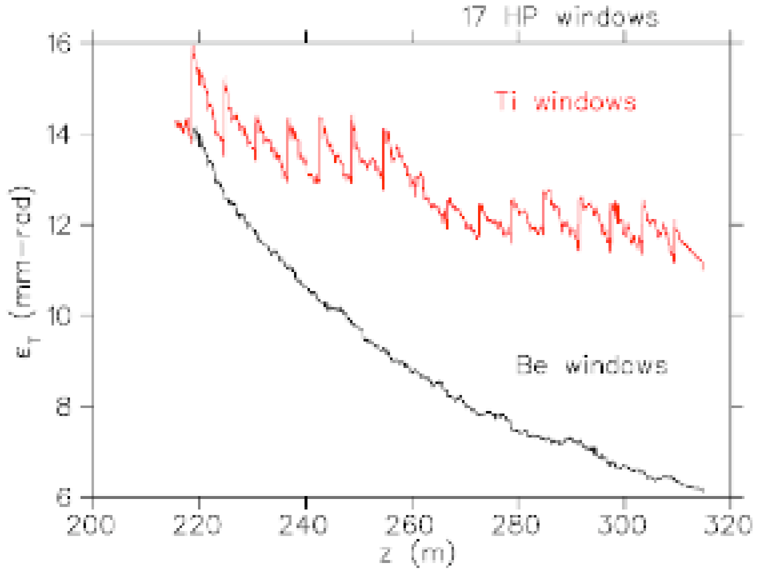


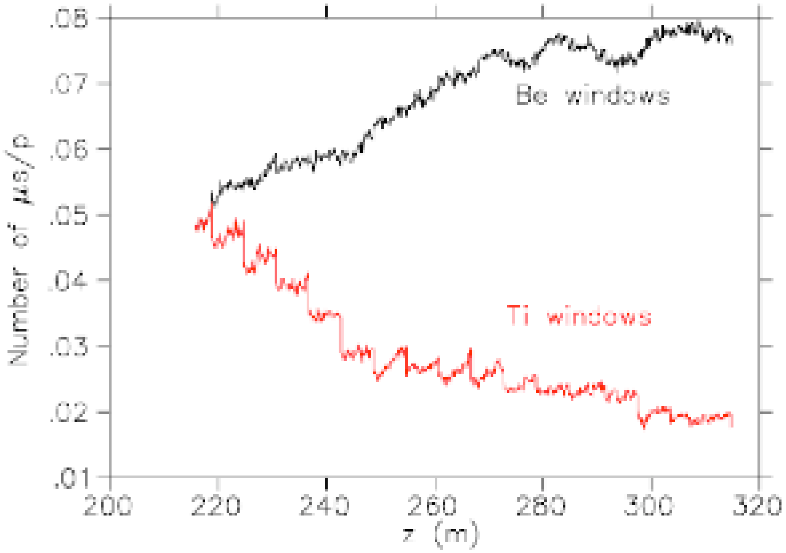


High pressure RF - window material

M. Zisman

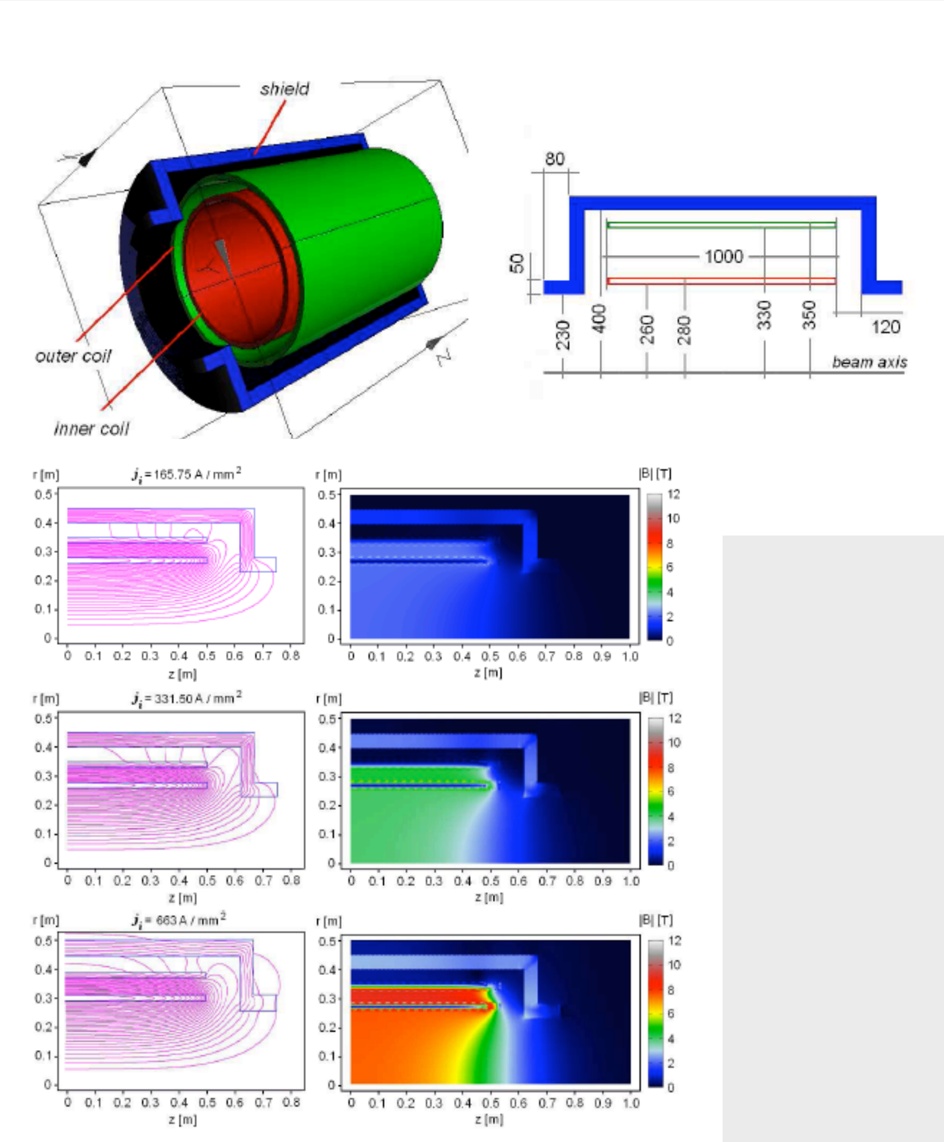
- To make sure we were not fooling ourselves, ran cases with both Be and Ti
  - the difference is obvious
- Will next look at Al and AlBeMet windows as time permits
  - Al is okay in terms of hydrogen embrittlement; not yet sure about other materials

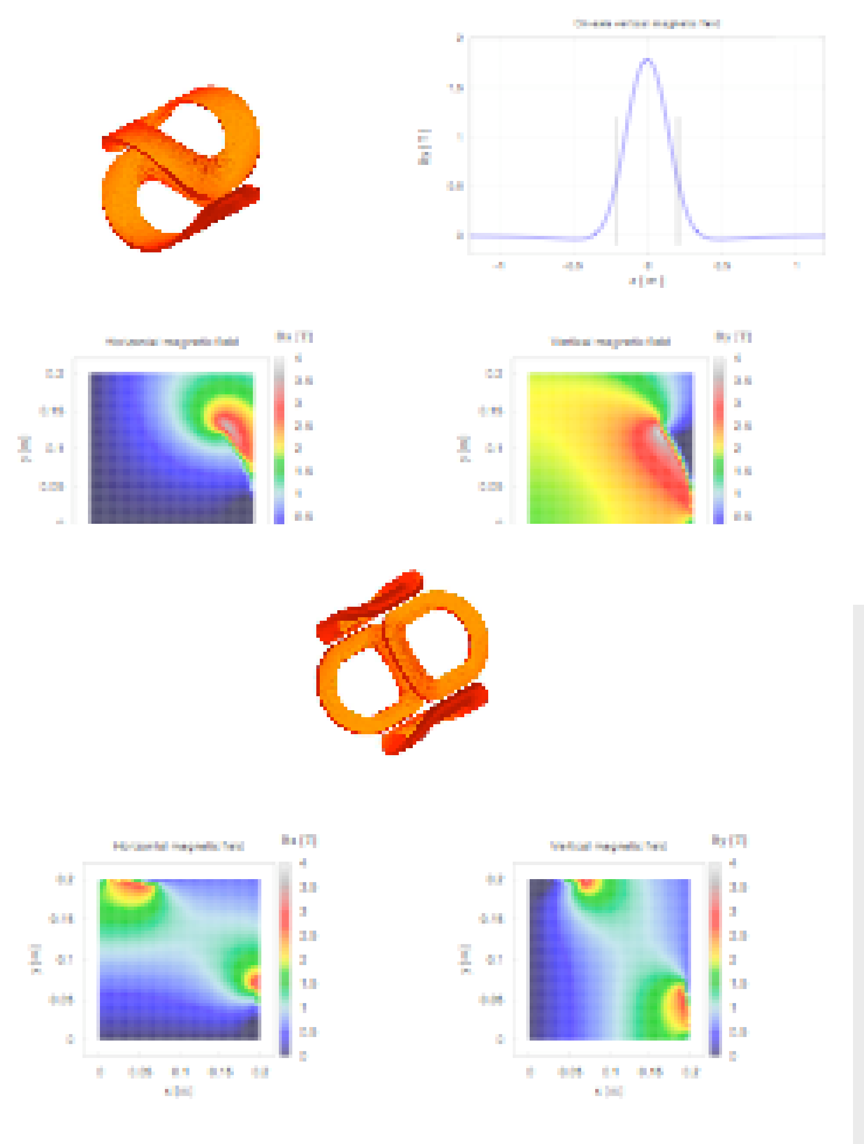




Hardware design magnets

C. Bontoiu

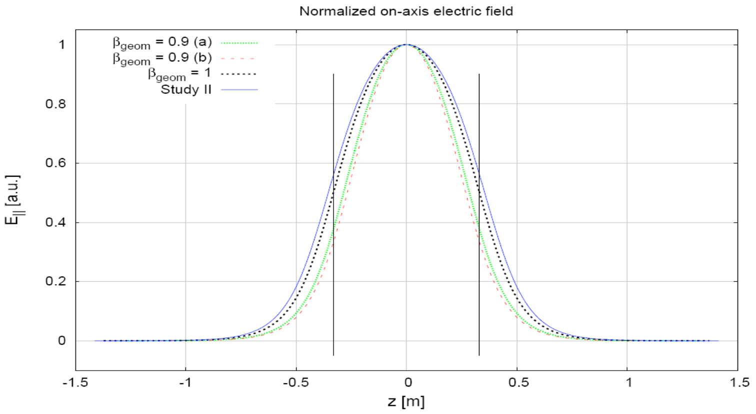


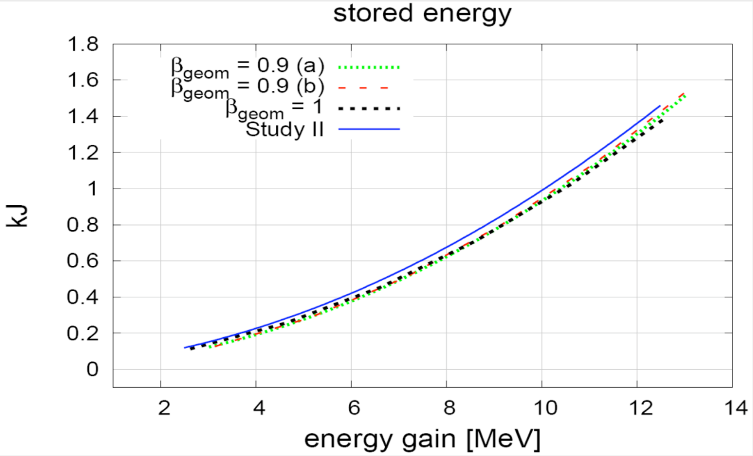


Hardware design RF cavities

C. Bontoiu / J. Pozimski

Parameter	$\beta_{geom} = 1$	$\beta_{geom} = 0.9$ (a)	$\beta_{geom} = 0.9$ (b)	Study II
l_{cav} [m]	0.7448	0.67034	0.67034	0.8282
r [m]	0.6854	0.7042	0.6804	0.6641
f_0 [MHz]	201.247	201.251	201.255	198.575
Q [10^9]	24.67	19.6	18.8	26.7
T	0.650	0.716	0.726	0.591
$\hat{E}$ [MV/m]	26.17	27.19	27.83	26.38
$\bar{E}$ [MV/m]	20.62	20.81	20.53	20.42
$\lvert E\rvert^{max}_{surface}$ [MV/m]	21.70	24.87	29.45	19.75
$\lvert H\rvert^{max}_{surface}$ [kA/m]	48.06	58.53	61.92	45.00
U [J]	712	772	797	747
$\int_{-\infty}^{+\infty} \mathrm{E(0,z)cos}[\omega\ \mathrm{t(z)]dz}$	8.6142	9.0081	9.1336	8.8466
$\int_{-l_{cav}/2}^{+l_{cav}/2} \mathrm{E(0,z)cos}[\omega\ \mathrm{t(z)]dz}$	10.0000	10.0000	9.9999	10.0000
$\int_{+l_{cav}/2}^{+\infty} \mathrm{E(0,z)cos}[\omega\ \mathrm{t(z)]dz}$	-0.69204	-0.49594	-0.43320	-0.75676
correction [%]	-13.841	-9.9188	-8.6639	-15.135



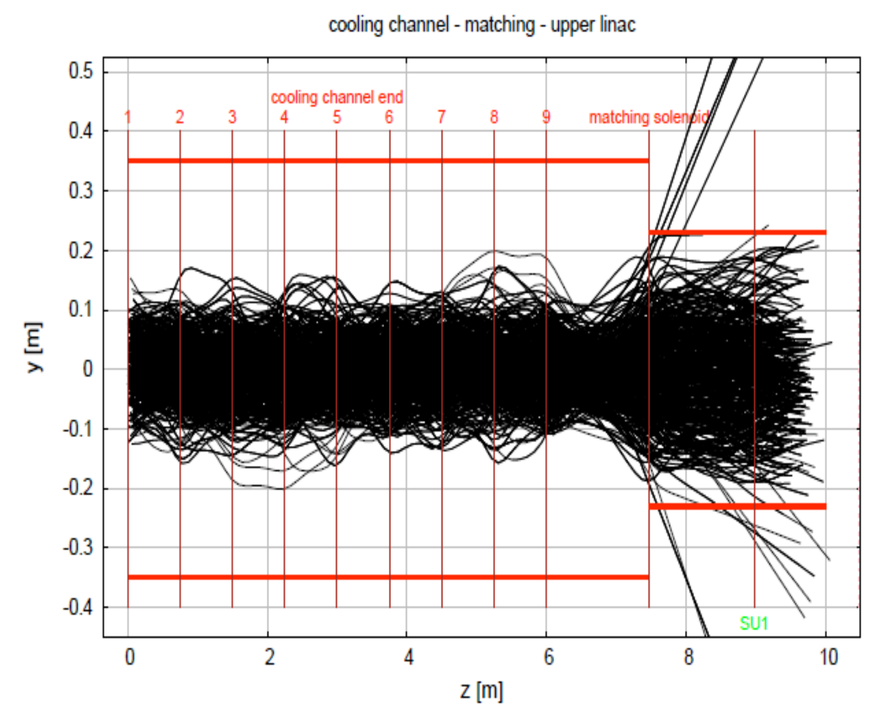


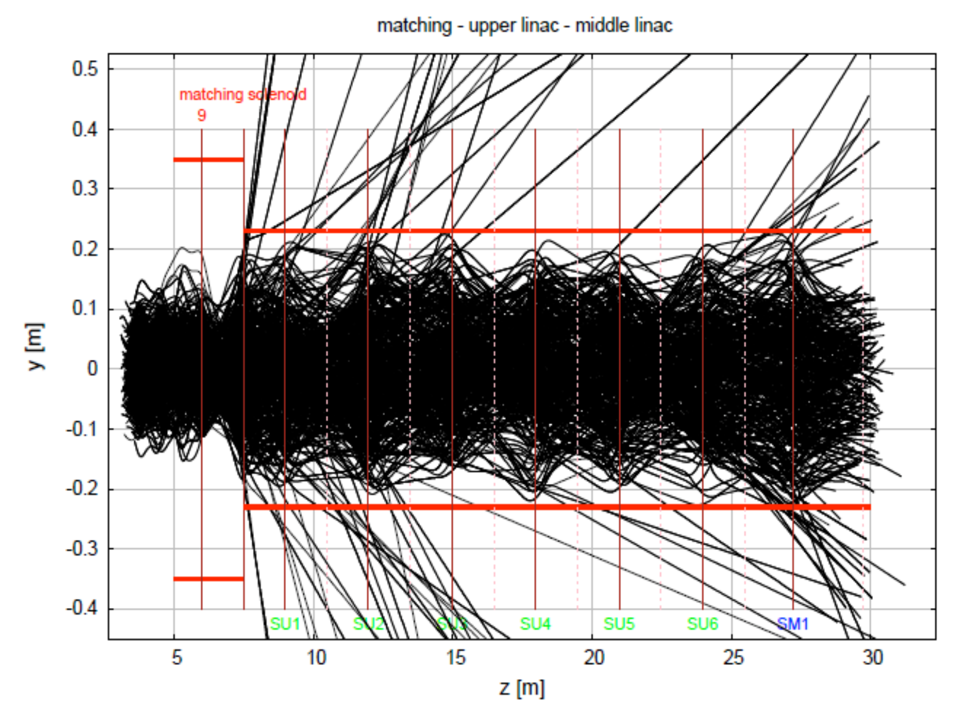
Matching from cooling to linac

C. Bontoiu

cooling -> upper linac

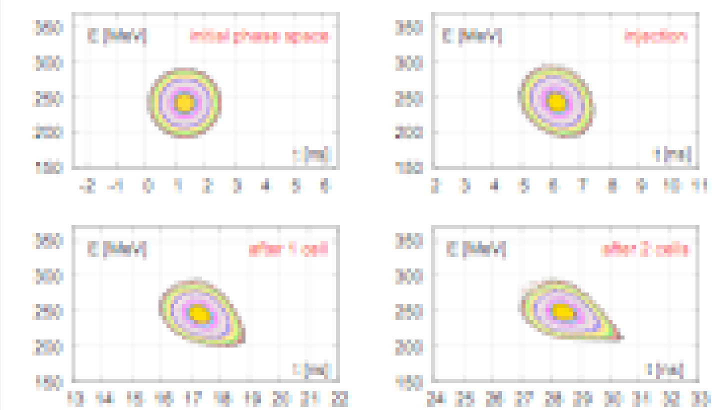
upper -> middle linac

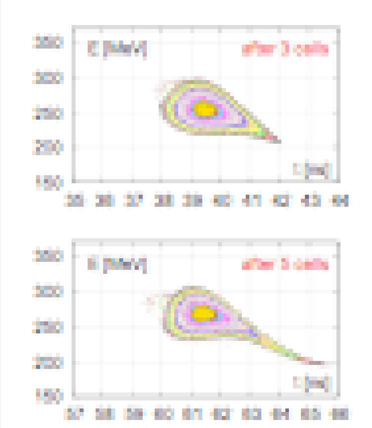




Particle tracking - Linac

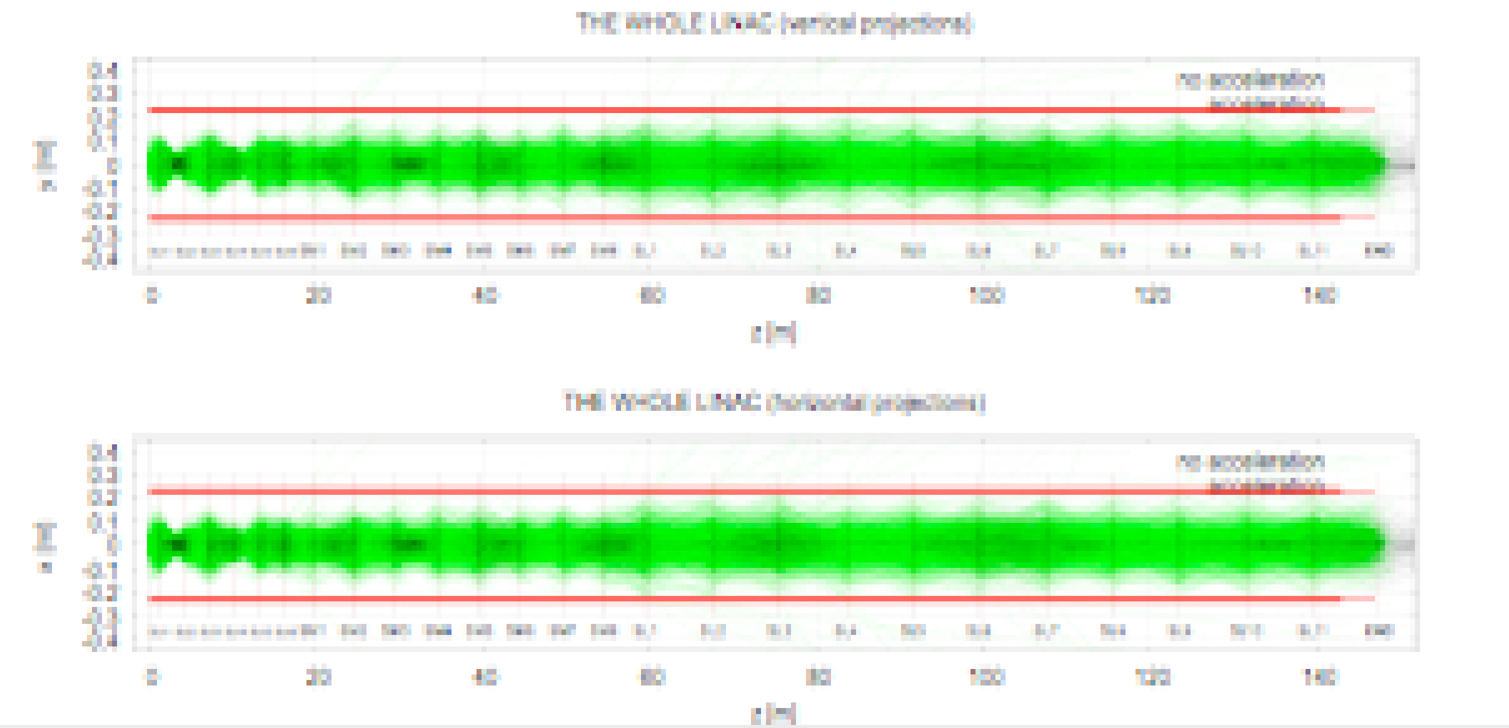
C. Bontoiu





Longitudinal phase space

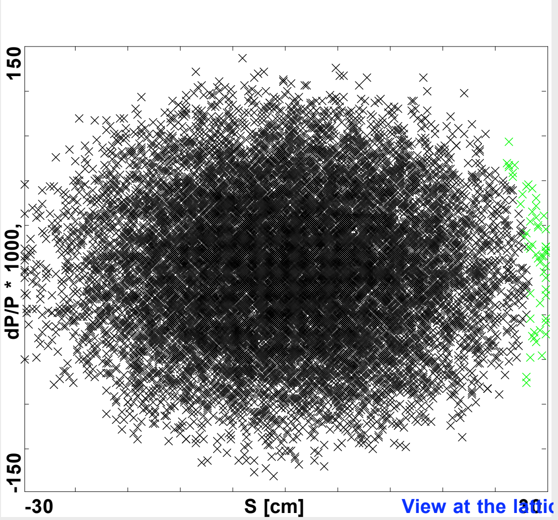
Transversal projections

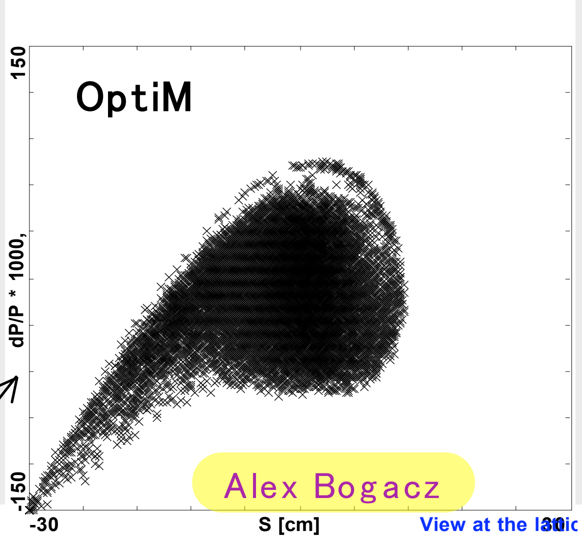


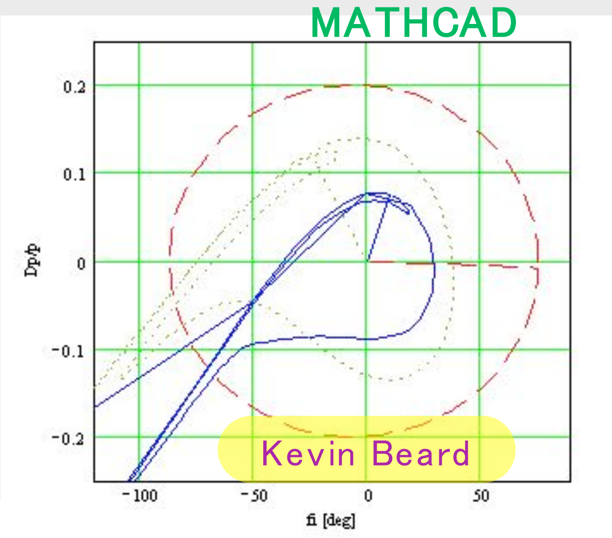
Longitudinal phase space

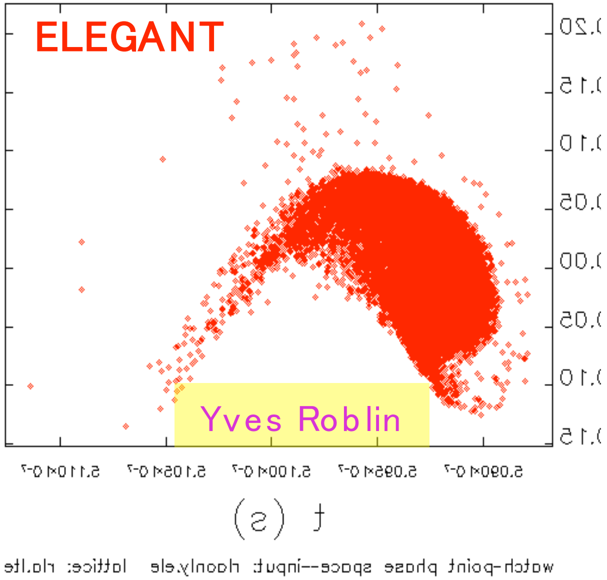
A. Bogacz

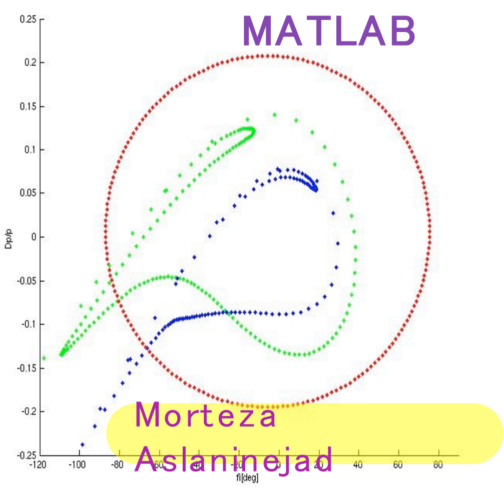
Initial distribution







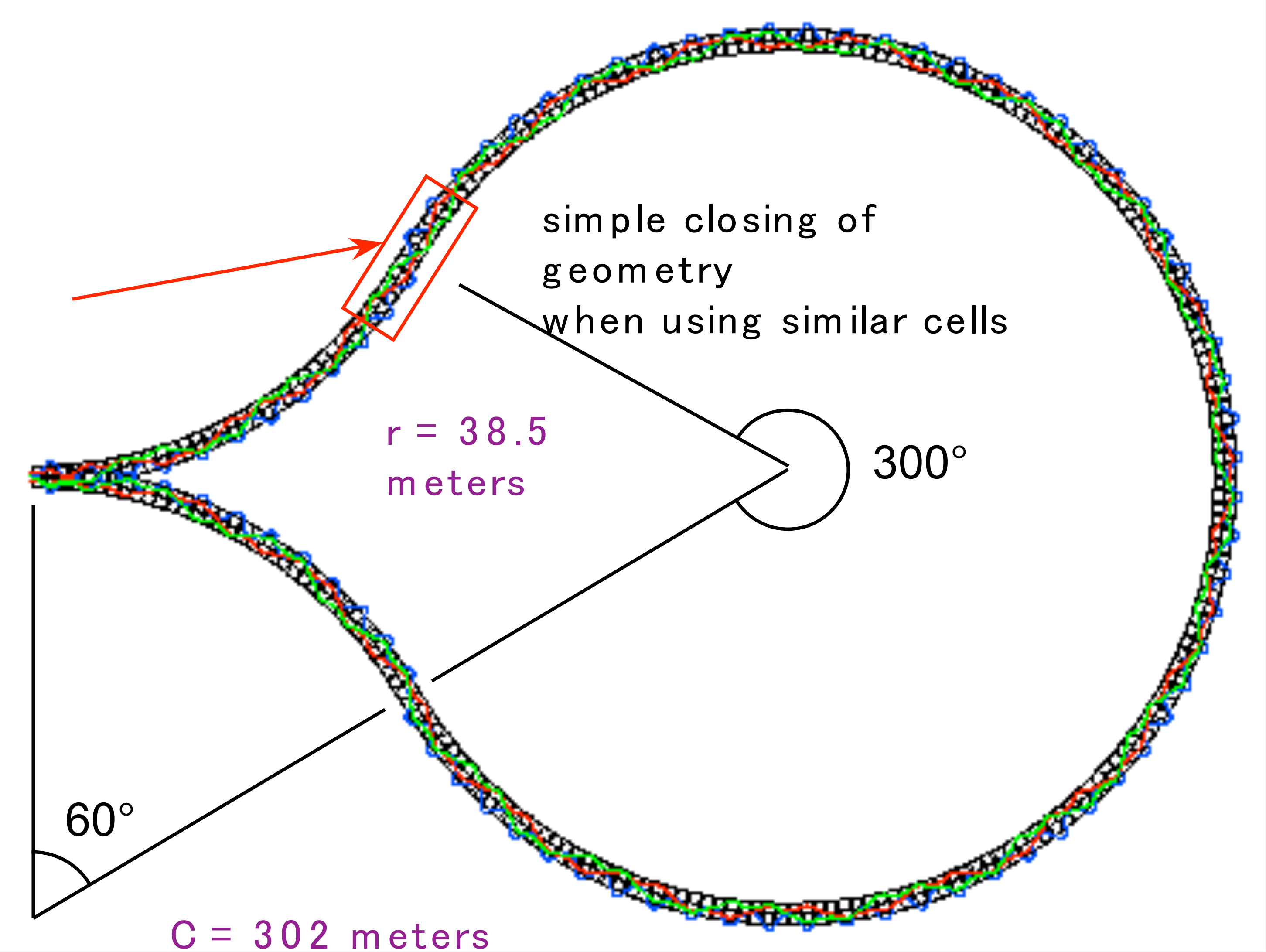




Multipass FFAG arc

A. Bogacz

Vasiliy Morozov



simple closing of geometry
when using similar cells

r = 38.5 meters

C = 302 meters

Scaling FFAG alternative for RLA 2

T. Planche

Parameters of a 3.6 to 12.6 GeV muon ring

Lattice type	FDF triplet
Injection/extraction energy	3.6/12.6 GeV
RF frequency	200 MHz
Number of turns	6
RF peak voltage (per turn)	1.8 GV
Synchronous energy	8.04 GeV
Mean radius	~160.9 m
B_{max}(@ 12.6 GeV)	3.9 T
Field index k	1390
Total orbit excursion	14.3 cm
Harmonic number h	675
Number of cells	225
Long drift length	~1.5 m
Horiz. phase adv. per cell	85.86 deg.
Vert. phase adv. per cell	33.81 deg.

Table 1 - Example of 3.6 to 12.6 GeV muon scaling FFAG ring parameters.

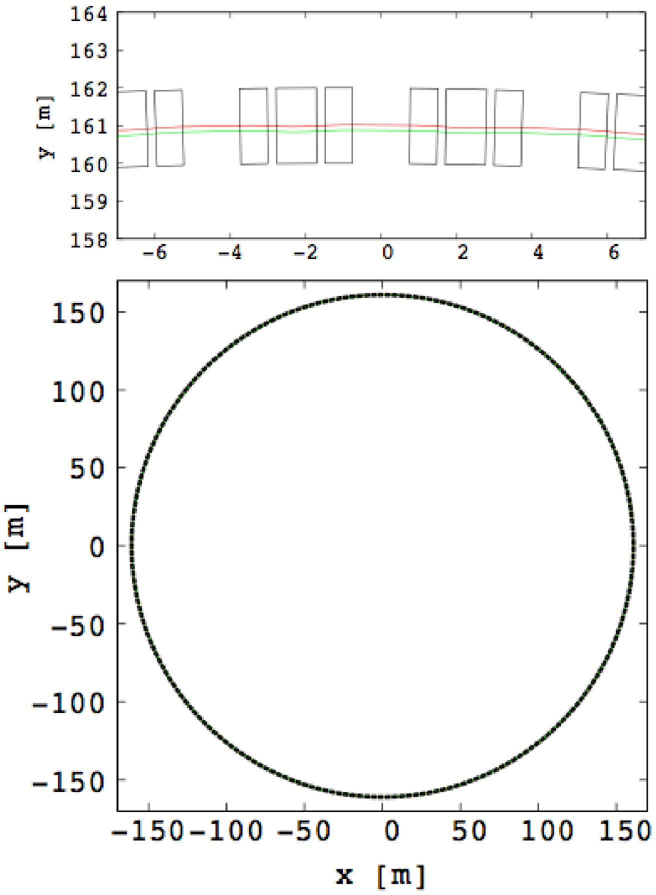


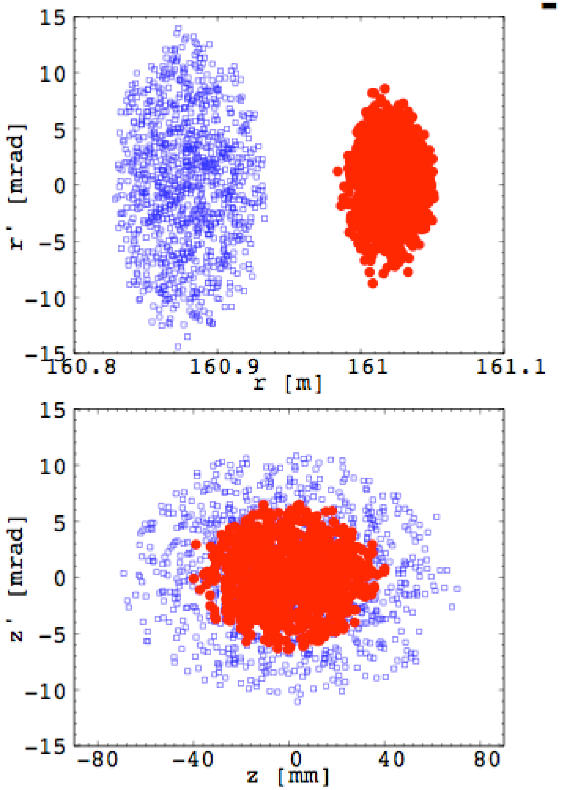
Figure 2 - Ring layout.

Scaling FFAG alternative for RLA 2

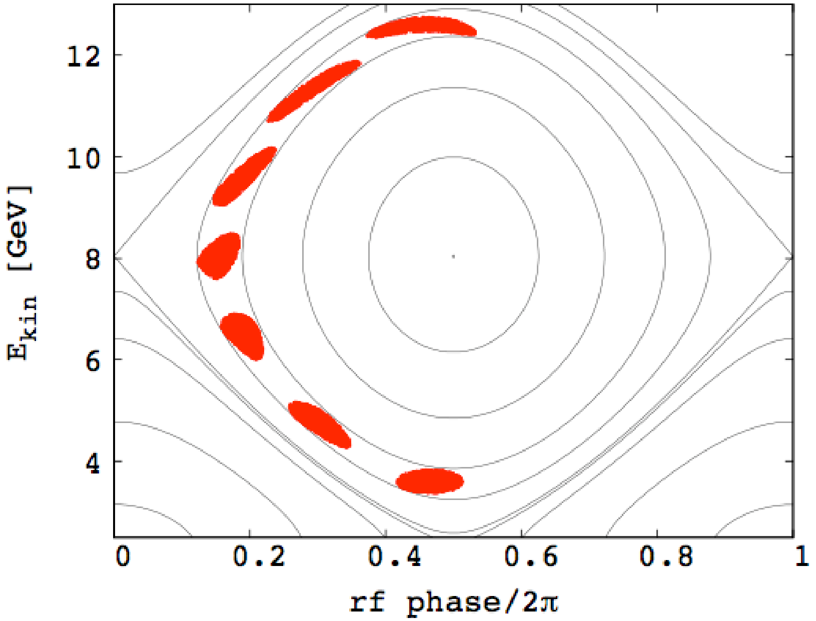
T. Planche

Full acceleration cycle - 6D tracking

- Tracking results -



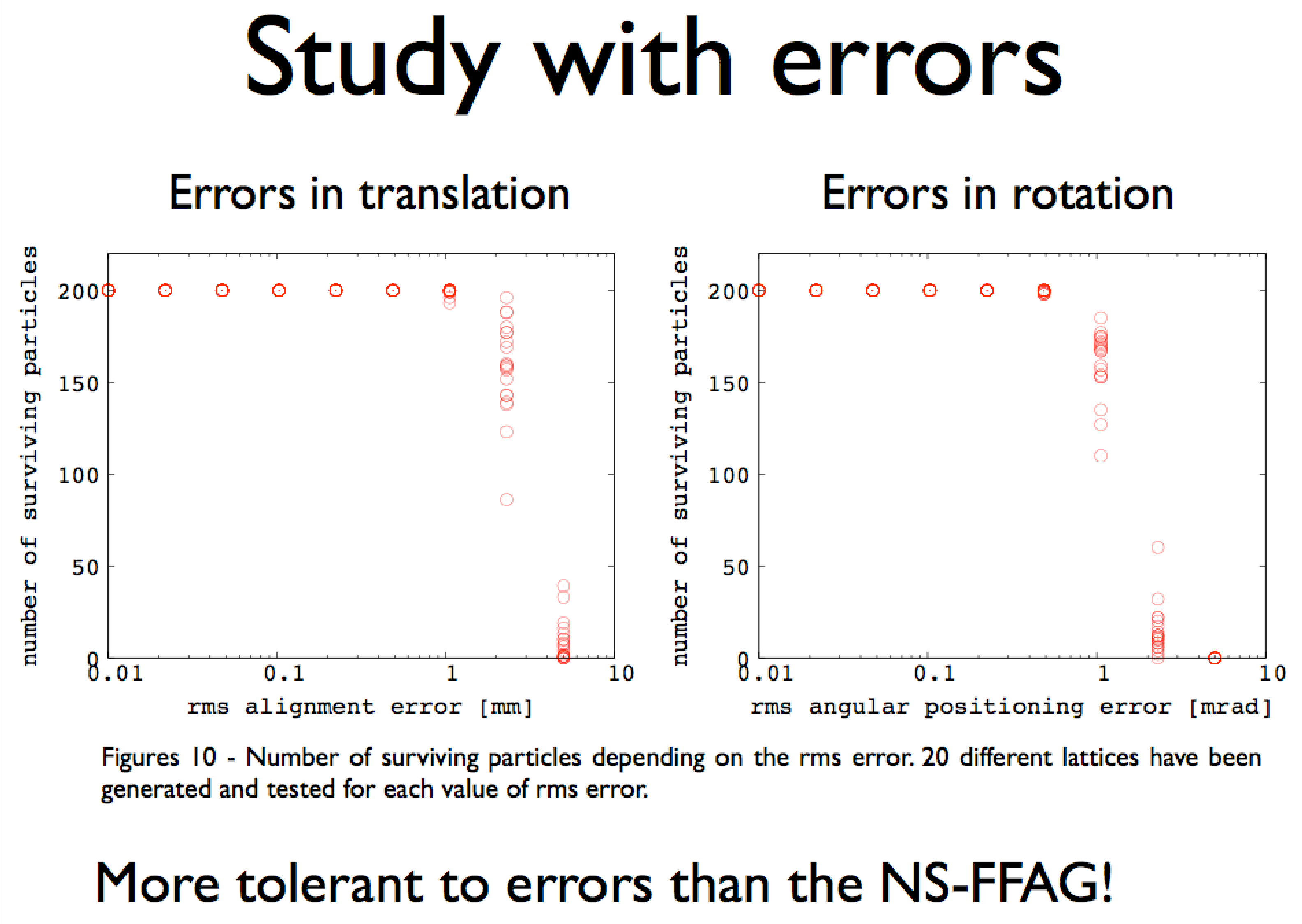
Figures 8 - Initial (blue) and final (red) particles distribution in the horizontal (top), and vertical (bottom) phase space.



Figures 9 - longitudinal phase space plot showing a 6-turn acceleration cycle. Hamiltonian contours are superimposed.

Scaling FFAG alternative for RLA2

T. Planche



Study with errors

Errors in translation

Errors in rotation

Figures 10 - Number of surviving particles depending on the rms error. 20 different lattices have been generated and tested for each value of rms error.

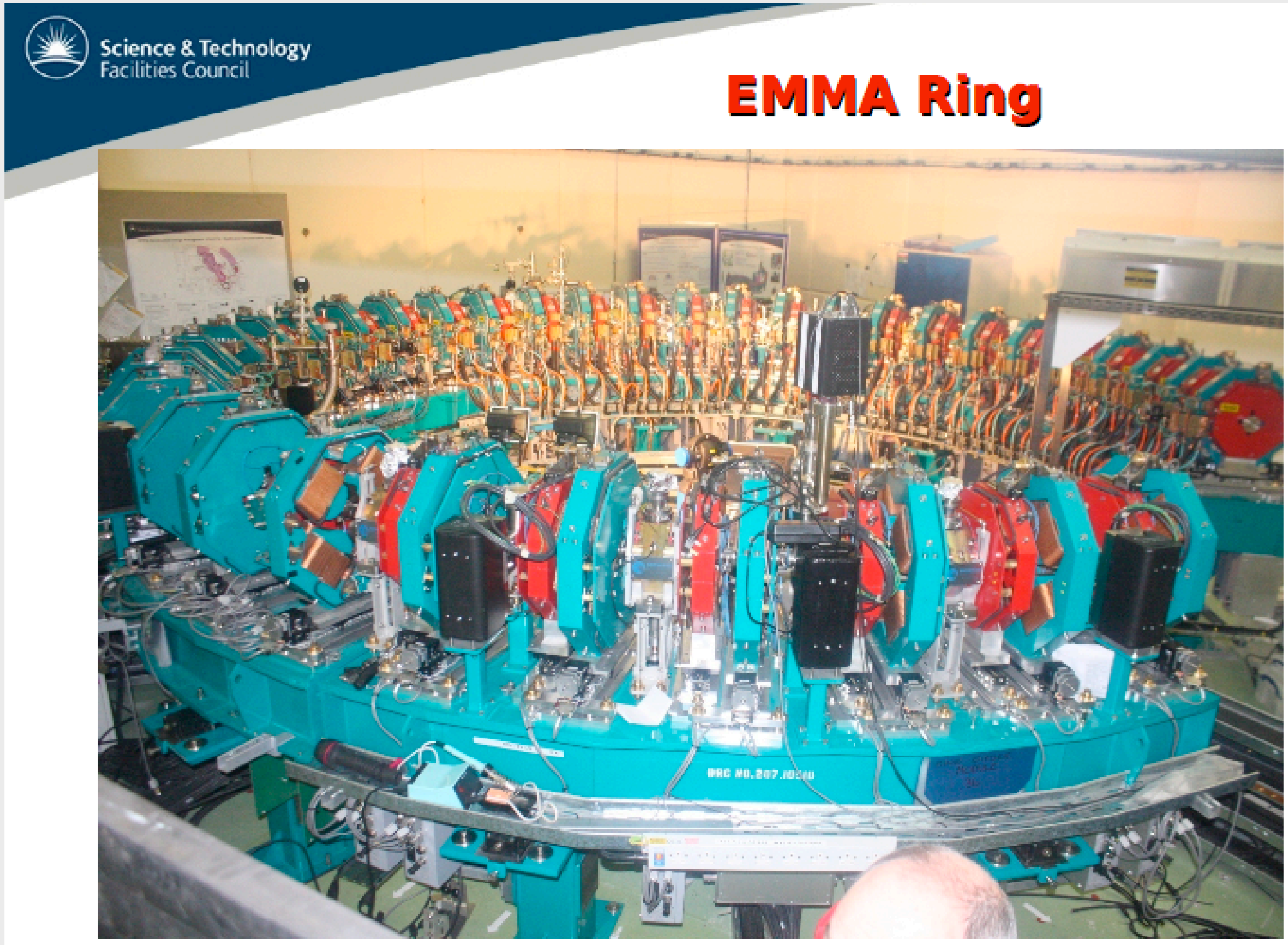
More tolerant to errors than the NS-FFAG!

FFAG Lattice & EMMA

S. Berg / R. Edgecock / F. Meot

Most promising due to longer drifts for RF and kickers : FDFCC

Minimum E 12.6 GeV
Maximum E 25 GeV
Cells 64
Circumference 546 m
Cavity cells 88
RF Voltage 1119 MV
Decay 5.6%
Turns 11.8
D Radius 11.5 cm
F Radius 15.3 cm
D Field 6.5 T
F Field 3.6 T
D Length 1.96 m
F Length 1.29 m
Long drift 3 m
Short drift 0.5 m



Science & Technology Facilities Council

EMMA Ring

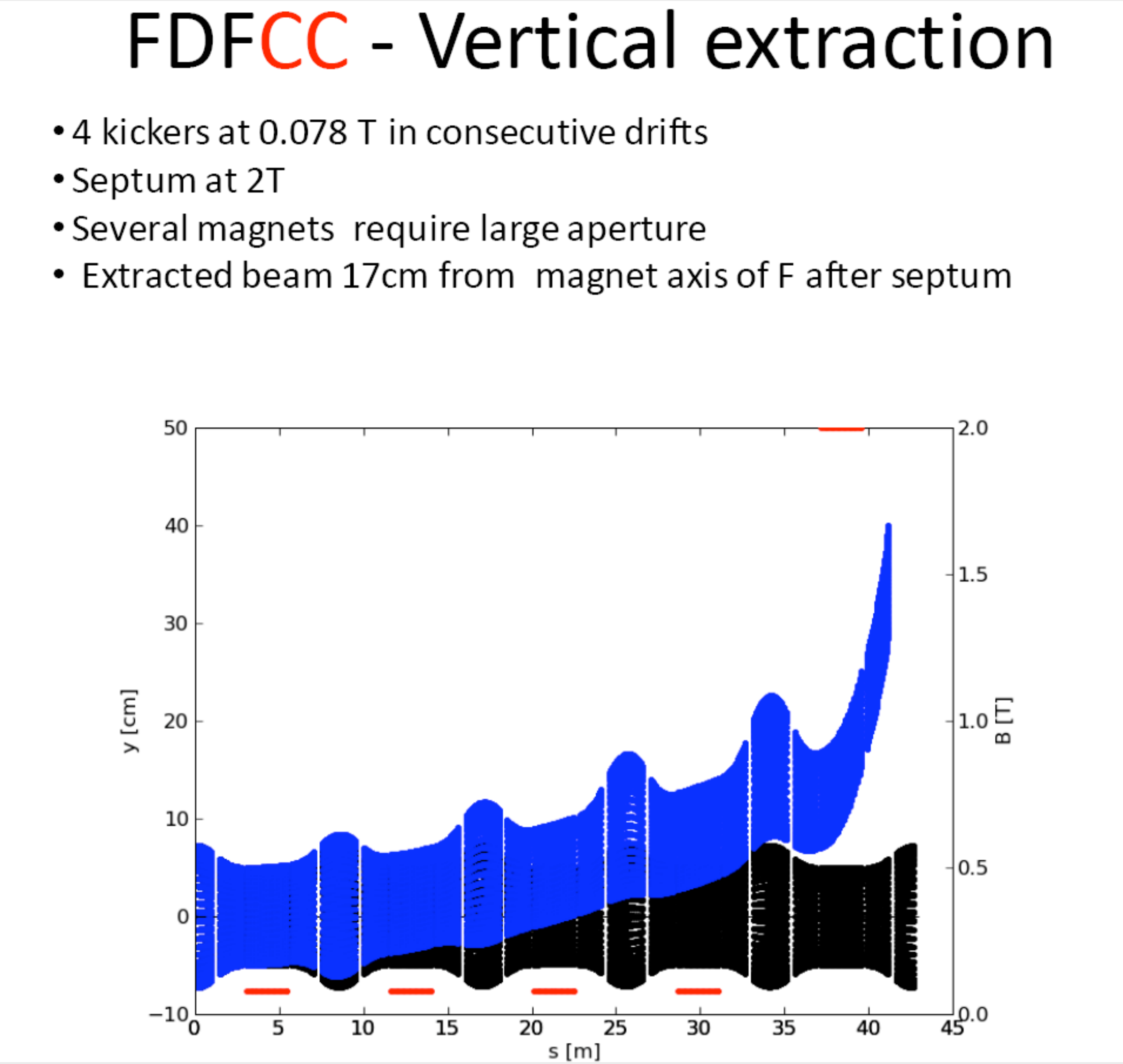
NS-FFAG cromaticity correction

S. Machida

- Reduces time of flight dependence on transverse amplitude
- Downsides
  - Reduction in dynamic aperture
  - Increase in magnet aper tures (cost)
  - Modification of time of flight vs. energy
- Still studying optimal choice for this
  - Some modest correction likely included

Extraction particle dynamics

J. Pasternak / D. Kelliher

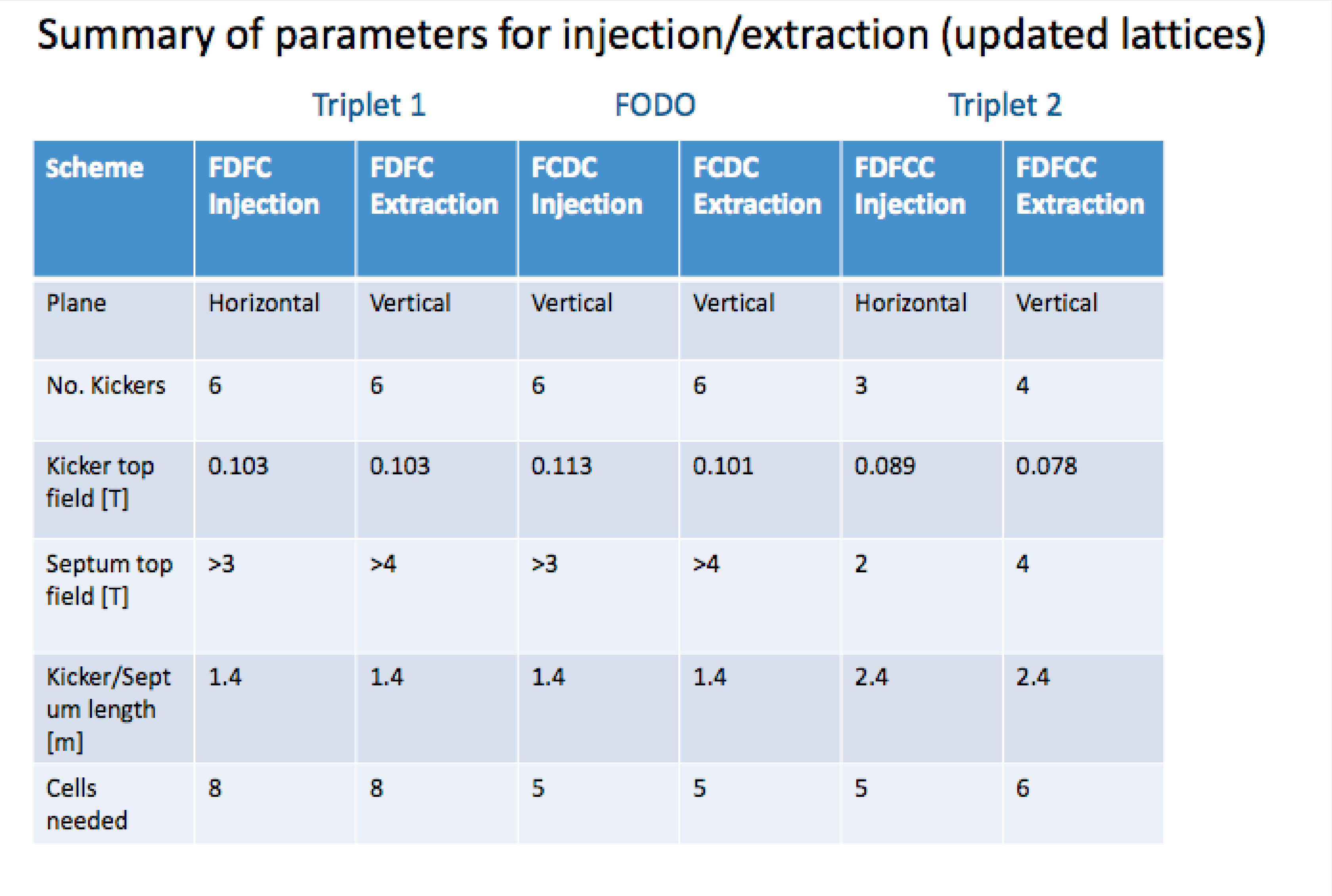


FDFCC - Vertical extraction

- 4 kickers at 0.078 T in consecutive drifts
- Septum at 2T
- Several magnets require large aperture
- Extracted beam 17cm from magnet axis of F after septum

Injection & Extraction studies

J. Pasternak / D. Kelliher



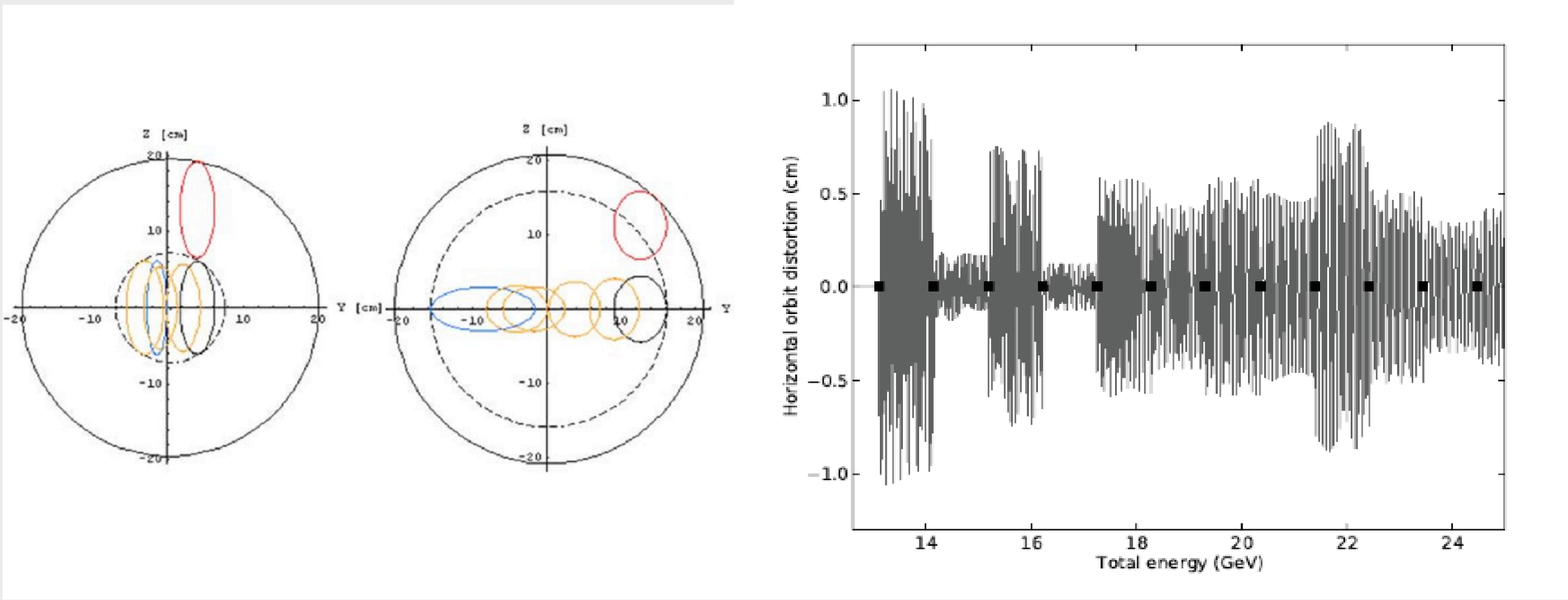
Summary of parameters for injection/extraction (updated lattices)

	Triplet 1		FODO		Triplet 2	
Scheme	**FDFC Injection**	**FDFC Extraction**	**FCDC Injection**	**FCDC Extraction**	**FDFCC Injection**	**FDFCC Extraction**
Plane	Horizontal	Vertical	Vertical	Vertical	Horizontal	Vertical
No. Kickers	6	6	6	6	3	4
Kicker top field [T]	0.103	0.103	0.113	0.101	0.089	0.078
Septum top field [T]	>3	>4	>3	>4	2	4
Kicker/Septum length [m]	1.4	1.4	1.4	1.4	2.4	2.4
Cells needed	8	8	5	5	5	6

Extraction particle dynamics

J. Pasternak / / D. Kelliher

Effects of special magnets

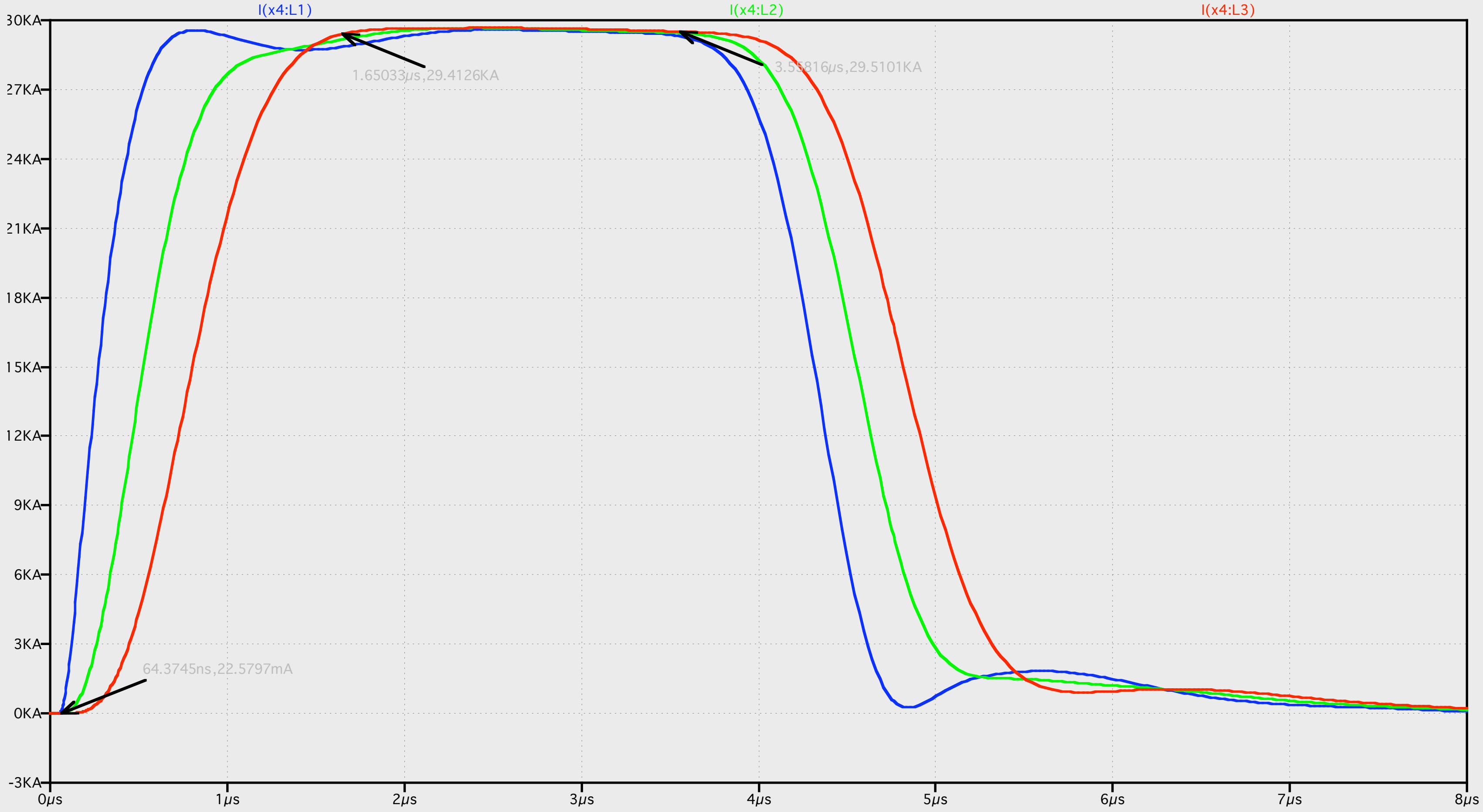


- Beams close to septum push the magnet aperture.
- Special magnets with higher aperture is needed in injection/extraction regions.
- Those magnets introduce the ring lattice symmetry breaking, which can cause accelerated orbit distortion.
- Current studies show that the effect is not dramatic, but more simulations are reqired.

Kicker electronics simulations

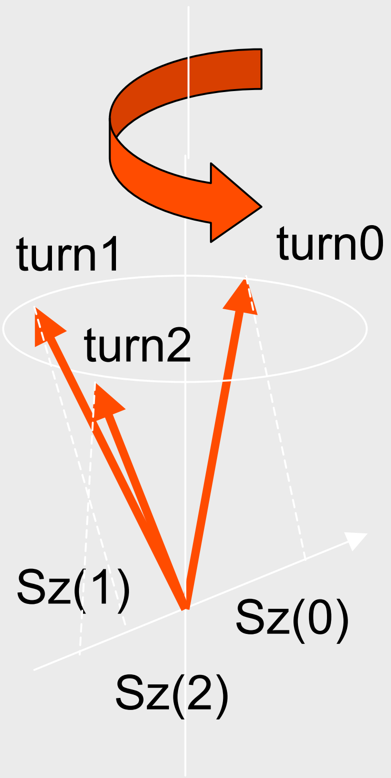
J. Pasternak

Current pulses in 3 kicker sections – „travelling wave" using PSPice



Ring instrumentation - Energy

M. Apollonio



- Energy can be measured using the *Polarisation of the Muon Beam* [Raja-Tollestrup – FERMILAB-Pub-97 / 402] IF some $\mathcal{P}$ is saved after all the massage in the machines ...

- Spin precesses in a ring due to coupling with magnetic fields (bending magnets).

- At every turn spin precession is determined by the *SPIN TUNE*:

$$\omega = \mathbf{2}\,\pi\,\gamma\,a$$

$$a = 1.16\mathrm{E}{-3}$$

This determines a modulation in $\mathcal{P}$

- NB: if $\Delta E/E = 0$ ➔ γ same for all muons ➔ $\mathcal{P}$ keeps oscillating
  if $\Delta E/E \,!\!= 0$ ➔ $\mathcal{P}$ goes to 0 after n turns

e+ spectrum from μ-decay is a function of $\mathcal{P}$:

$$d^2N/dx\, d\cos\theta = N0[(3-2x)x^2 - \mathcal{P}(1-x)x^2 \cos\theta] \qquad \text{(CM)}$$

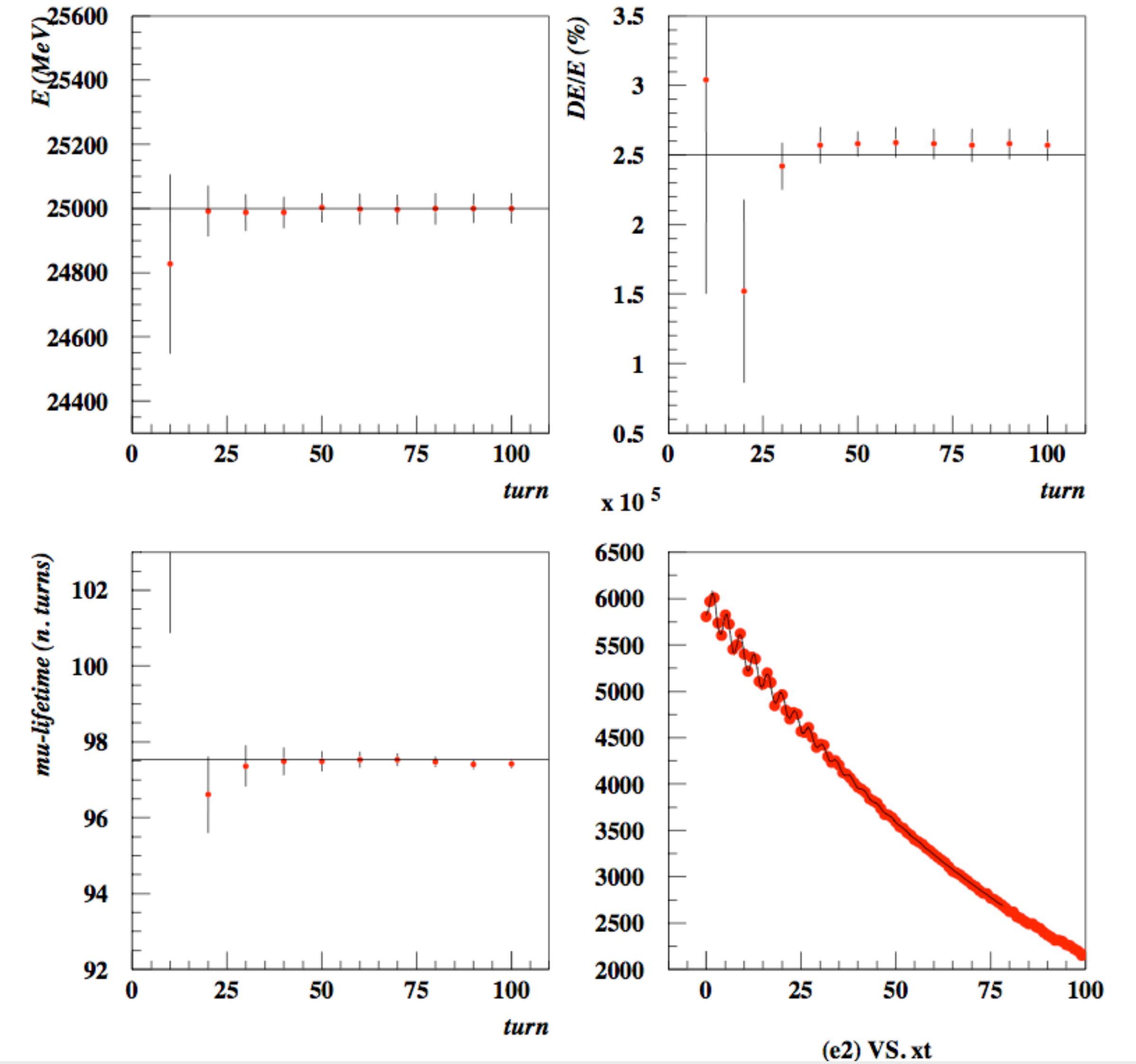
- I have modelled the behaviour of a beam (> 1E5 muons) all with their spin and energy ($\Delta E/E = [0.01\text{-}0.05]$)

- Lorentz Boost
- Modulation in $\mathcal{P}$ produces a modulation in E(e+)

- I assume $\mathcal{P}$ = 27% or 18% is left when filling the DK ring

Simulation results

M. Apollonio

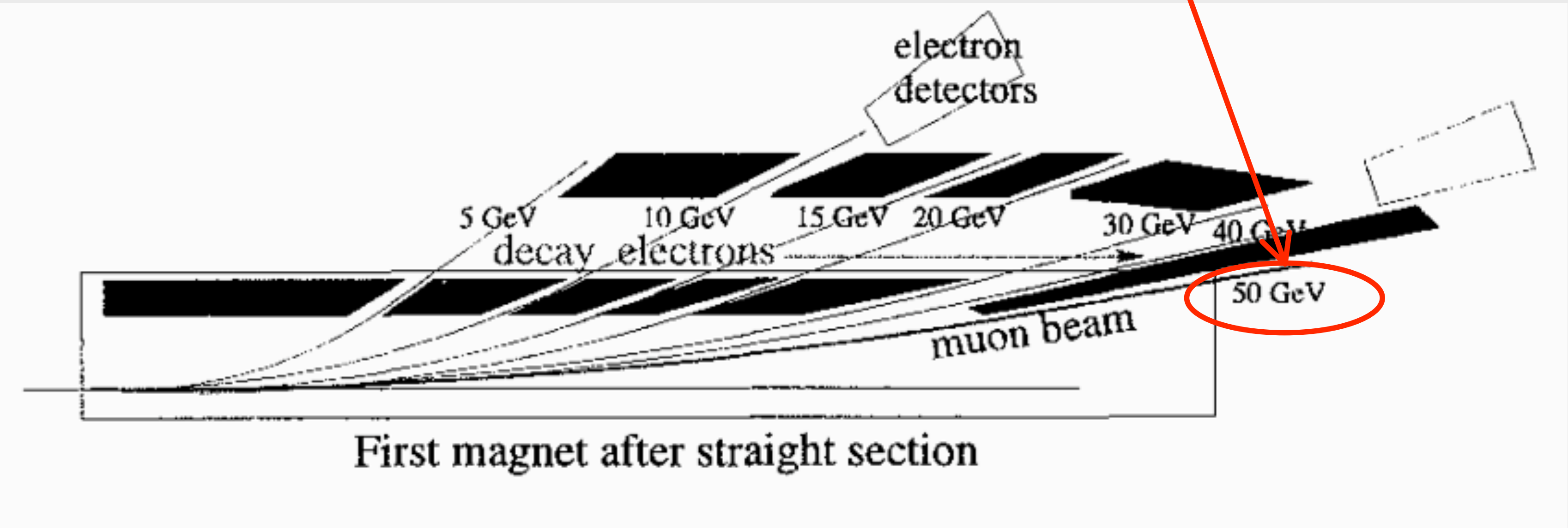


Implementation

M. Apollonio

It has been suggested [Blondel – ECFA 99-197(1999)] to use the *first bending magnet* after the decay straight section to SELECT electron energy bins: what does that mean today with a realistic lattice (25 GeV)?

In fact electron is emitted ~parallel to μ (due to the high γ)



First magnet after straight section

The spectral power of the 1st magnet depends on its *FIELD* and *LENGTH*

A *G4Beamline simulation* can tell us where electrons impinge after decaying somewhere along the orbit

IDR preparations

- Sub groups presented detailed plans for convergence.
- How do we organize the decision making process ?
- How do we handle alternatives and fall back options in the IDS ?
- IDR chapters should be prepared to be ready for submission to editors after RAL plenary (1st October)
- For IDS “mixed” costing according to readiness of the hardware design (global to detailed)