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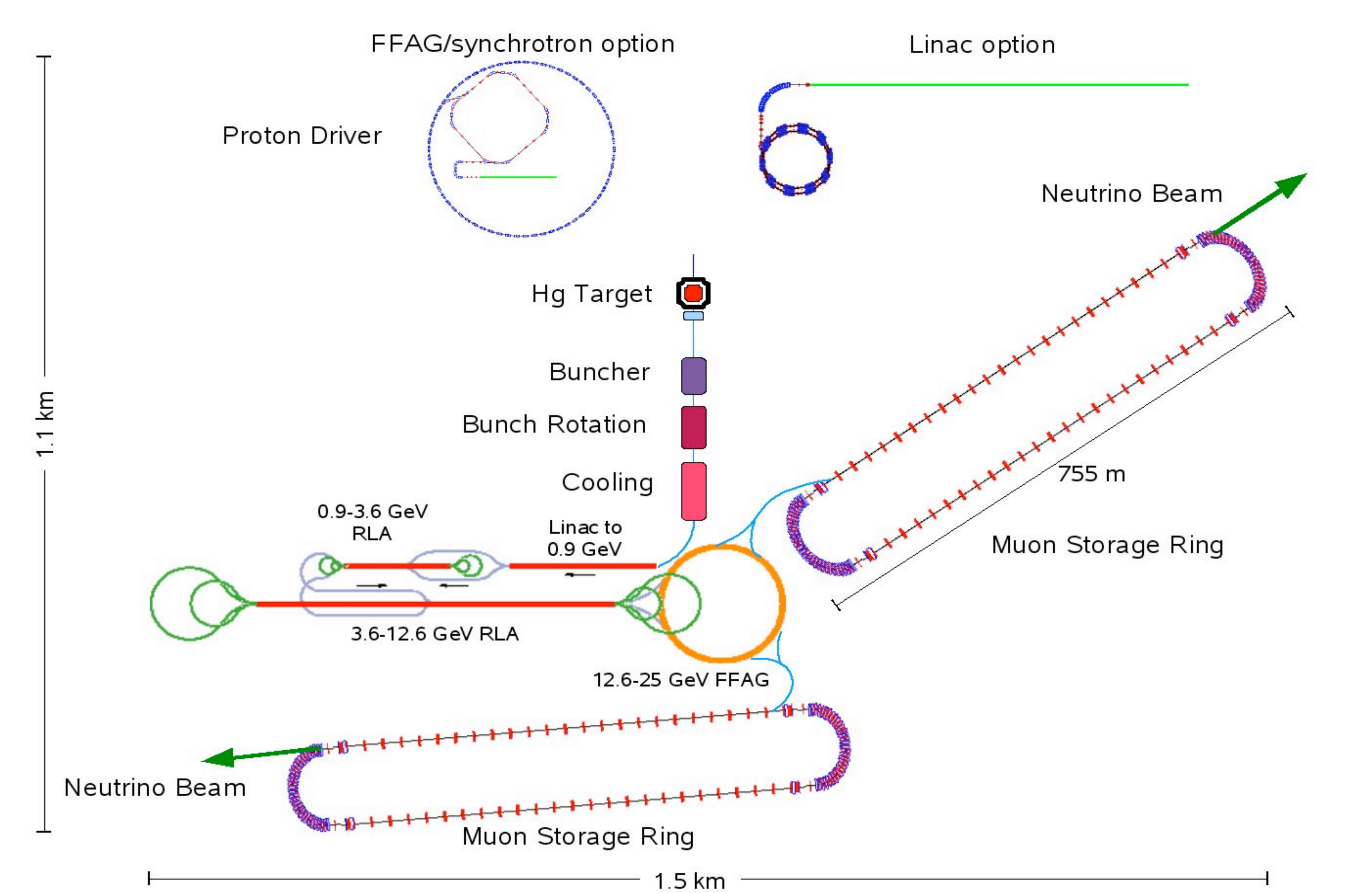
# Accelerator WG summary
# and
# Preparations for the IDR

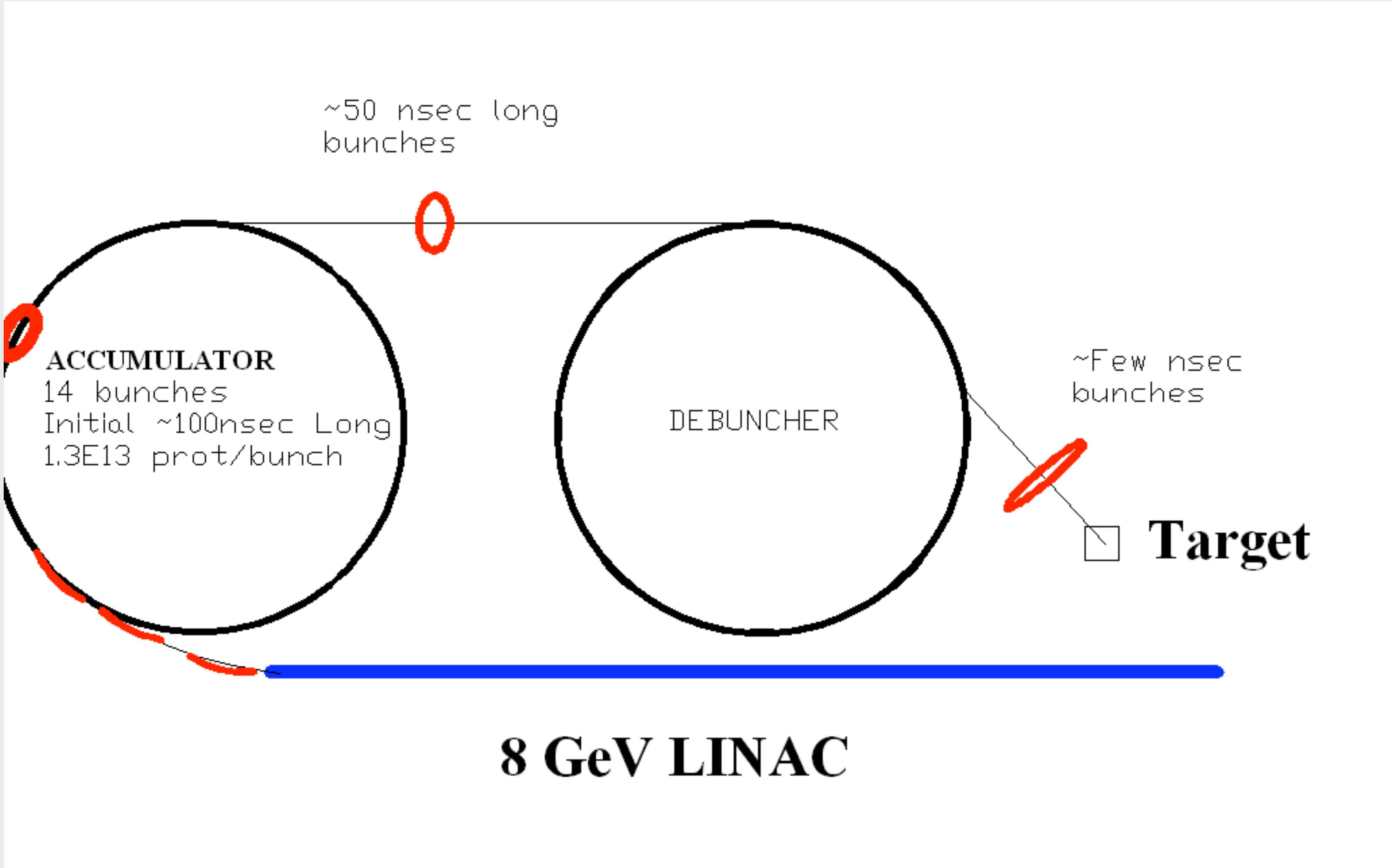
# Overview



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

# Proton driver - Project X

Chuck Ankenbrandt



# Illustrative Staging Scenario

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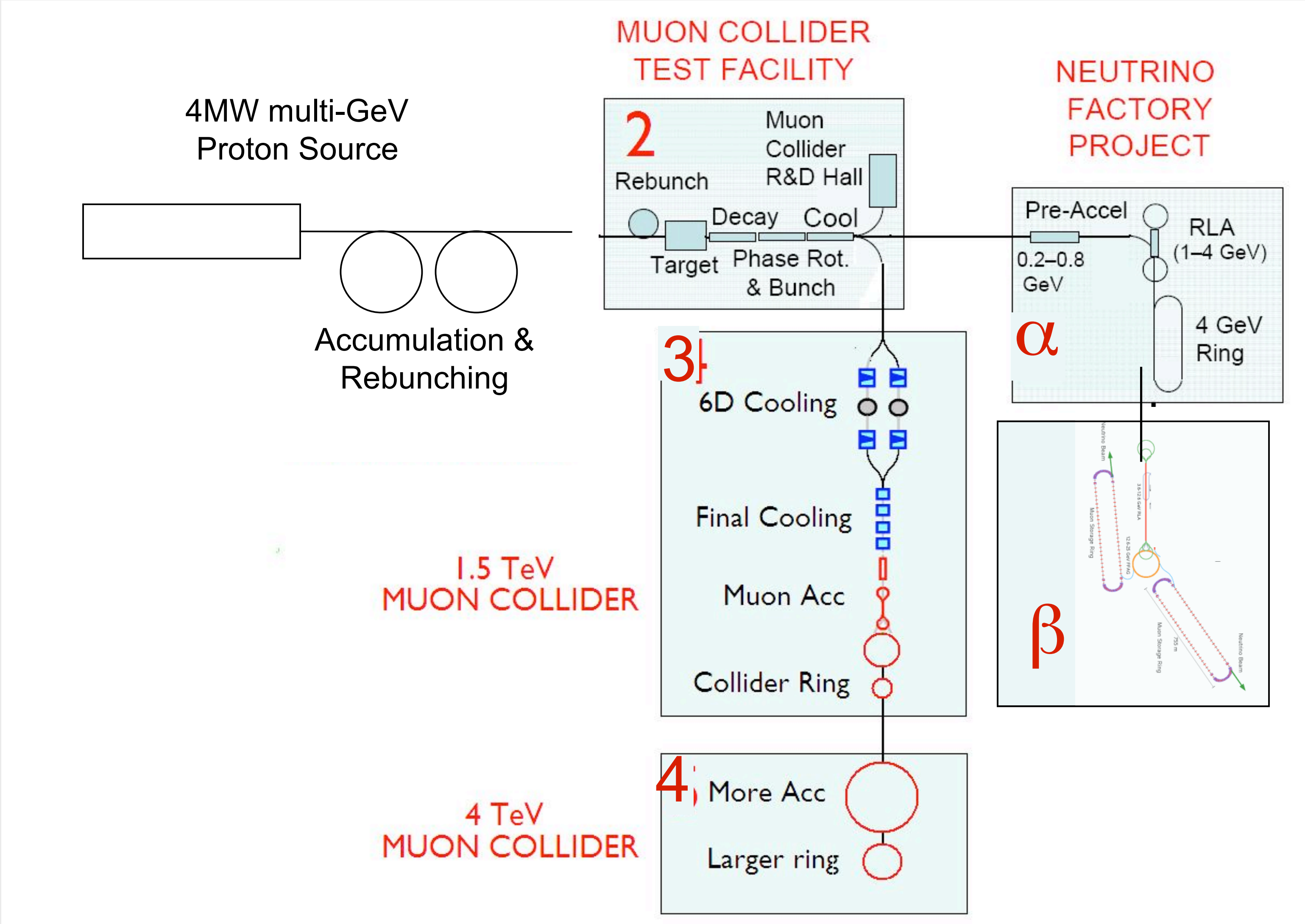
Chuck Ankenbrandt




4 GeV
NF

25 GeV
NF

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# Conclusions & Recommendations

Chuck Ankenbrandt

The most promising design approach for a proton driver consists of a full-energy $H^-$ linac, a pair of storage rings, and an external bunch combiner.

A kinetic energy of 6 GeV is high enough to support the 4-MW proton driver capabilities required for NF and MC applications.

The linac should be hybrid (if IC-2.2 is adopted):

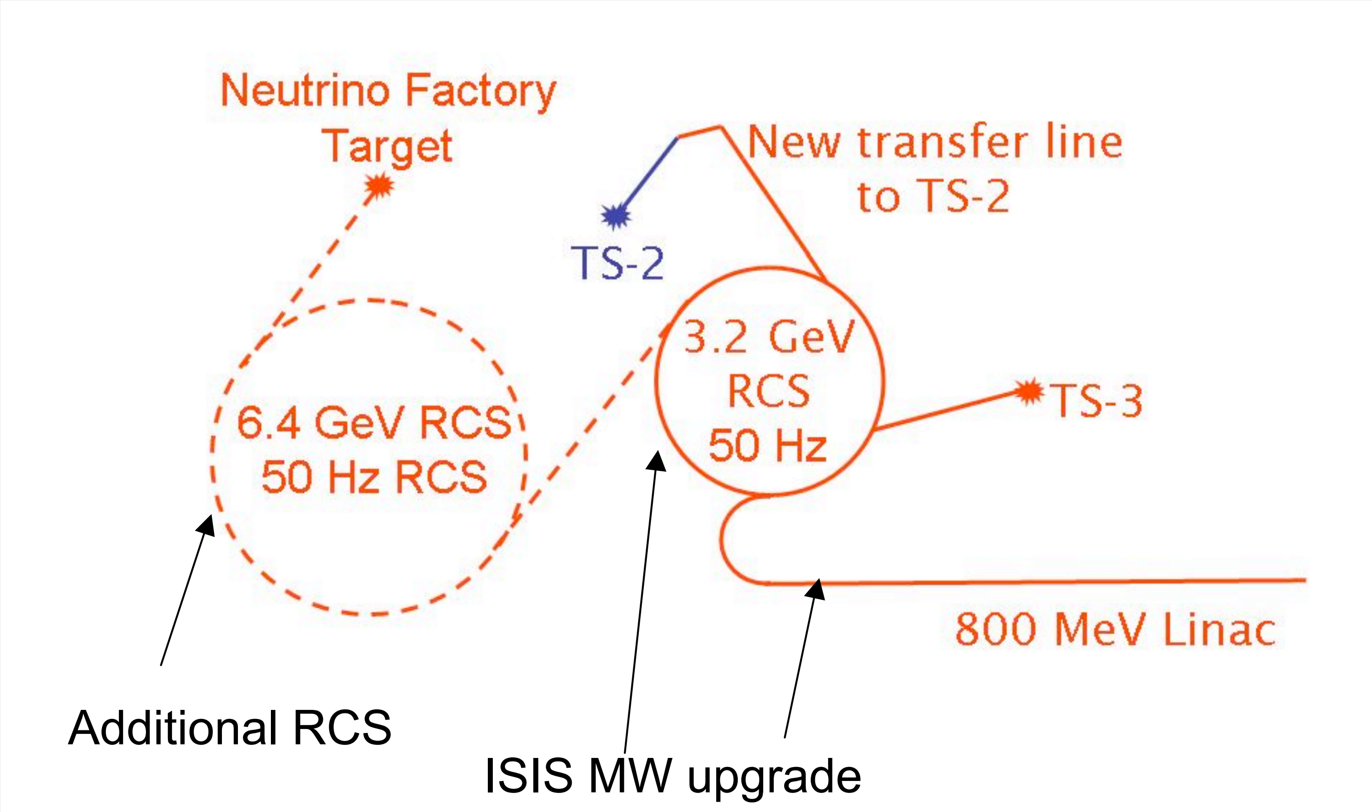
- **the RF power should be CW;**
- **the beam current should be pulsed at a high frequency.**

The proton driver complex can be staged:

- **the first stage supporting a modest neutrino factory,**
- **the second stage supporting the ultimate NF,**
- **the third stage supporting a high-luminosity muon collider.**

# NF- Proton driver and ISIS upgrade

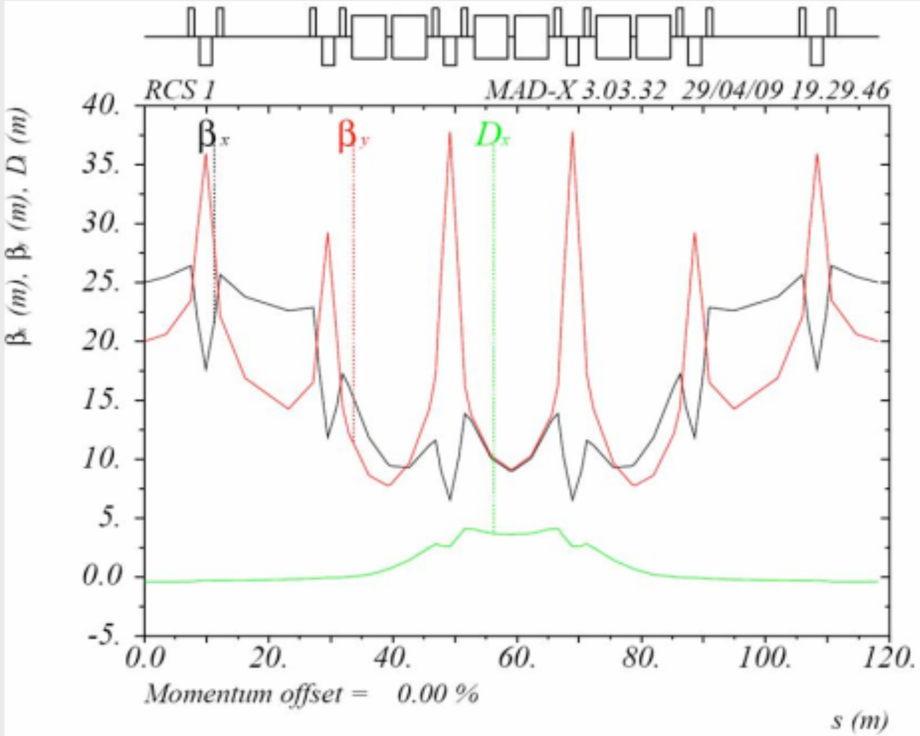
Jaroslaw Pasternak




- 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

# 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

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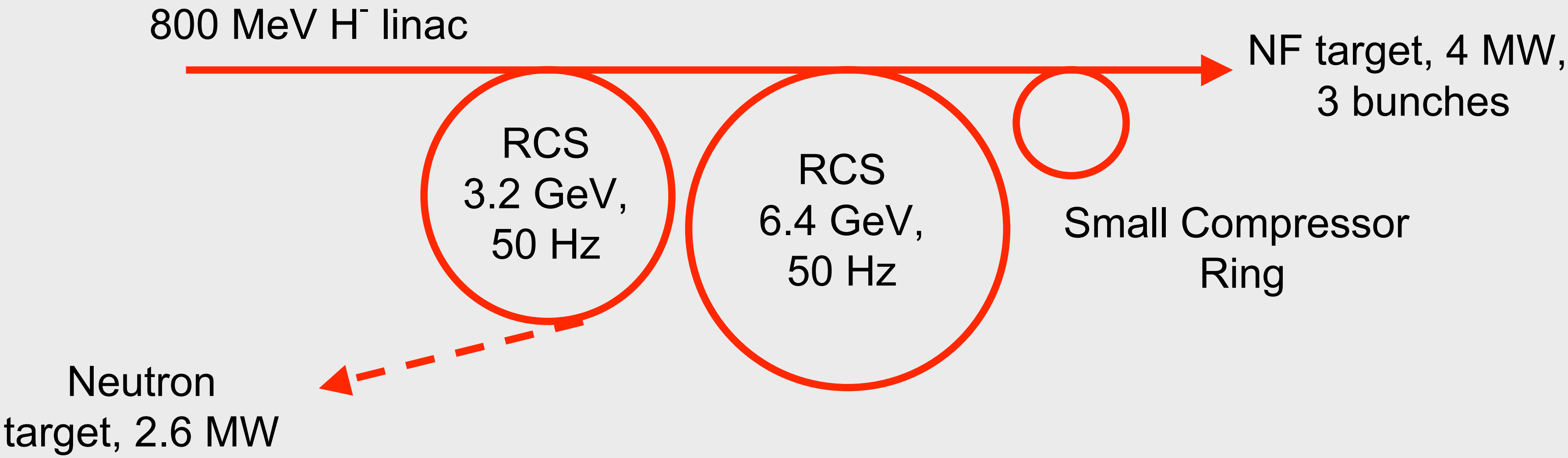
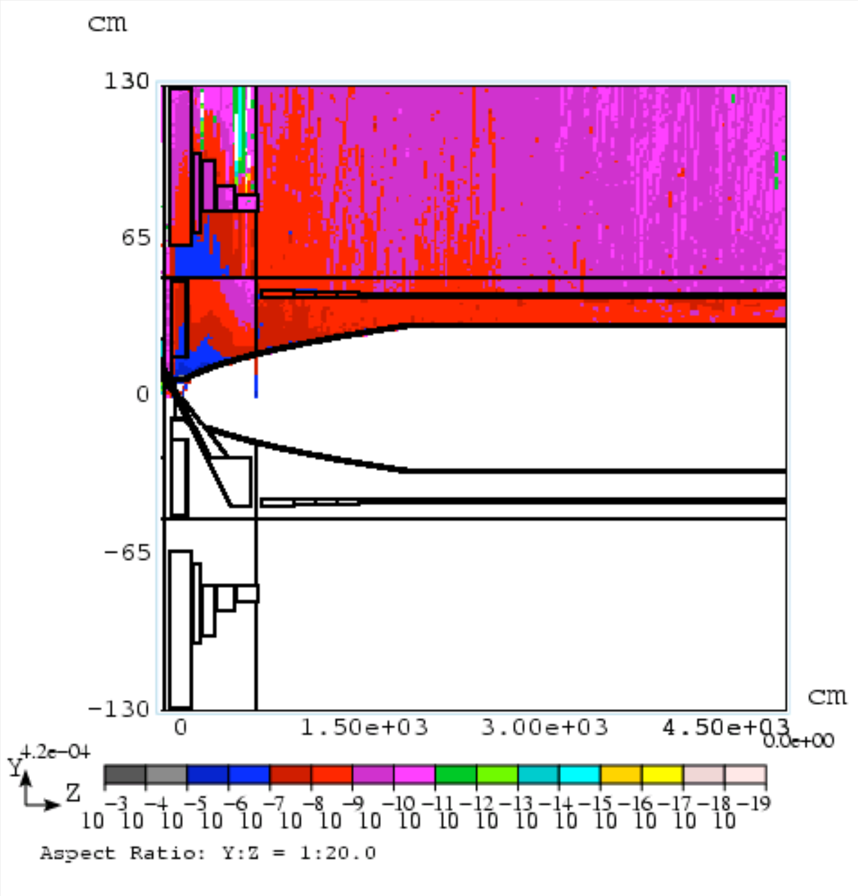
# Proton driver & bunch compression

Jaroslaw Pasternak

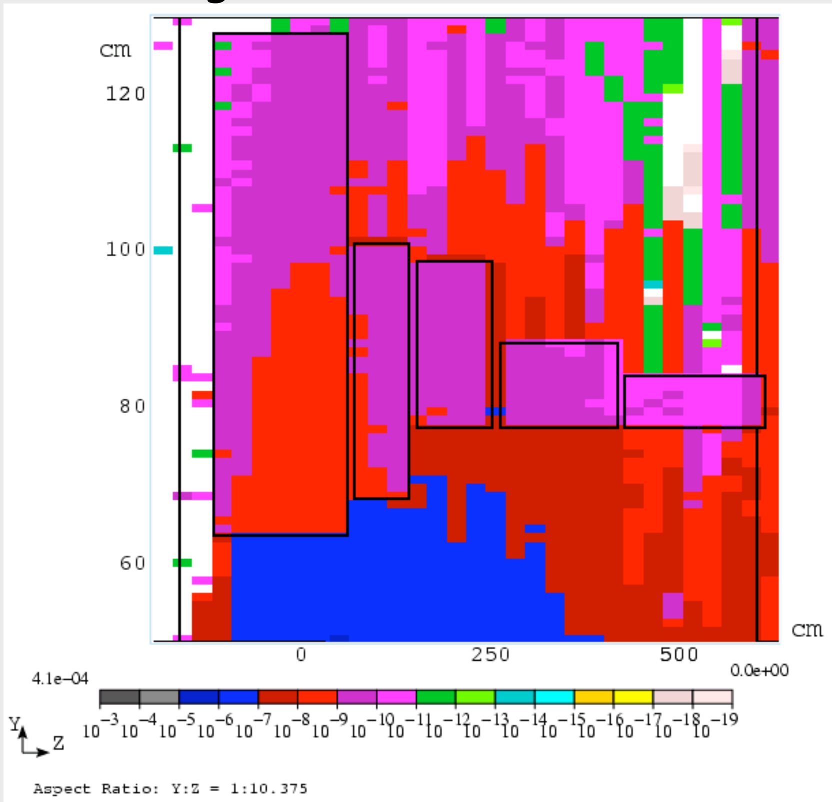



- Fast phase rotation in the dedicated compressor ring (most economic from the RF point of view, but another ring is needed).
- Bunches will be extracted one by one from the RCS.
- Compressor ring works above transition, but the rotation is very fast.
- The bunches in the RCS will wait uncompressed for 200 us, but they will come with different energies.
- We do not have a design for the compressor ring at the moment, but CERN design can be adopted.

# 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 Hardware design

## -Liquid mercury target -Hg Circulation System

V. Graves

Windows

Mercury dump and drain

Mercury vapour and condensation

Waste disposal

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# Liquid mercury target -Nozzle Development

R. Ladeinde

STONY BROOK

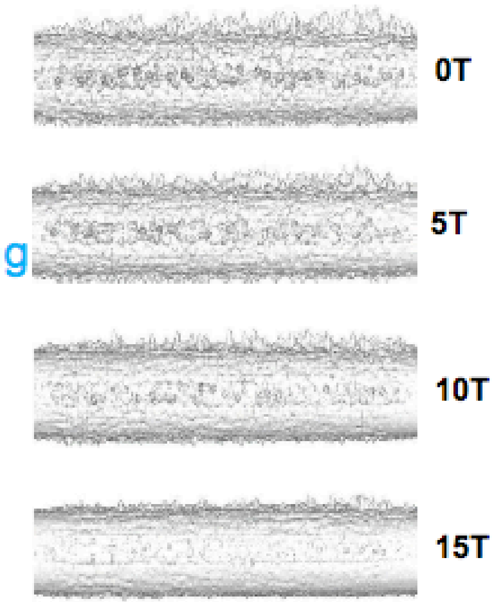
## Previous Work -Jet Flow

- 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

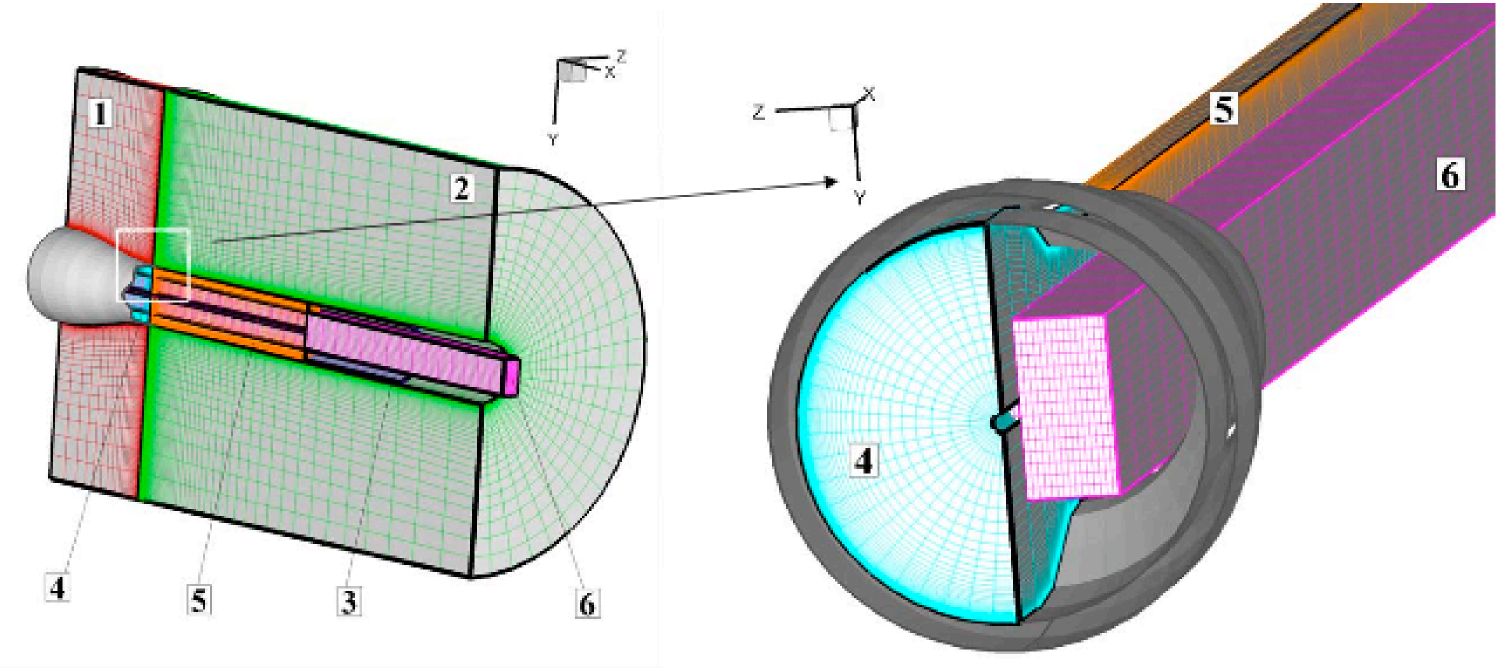
# Liquid mercury target -Nozzle Development

R. Ladeinde

STONY BROOK

## Our Numerical Approach

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



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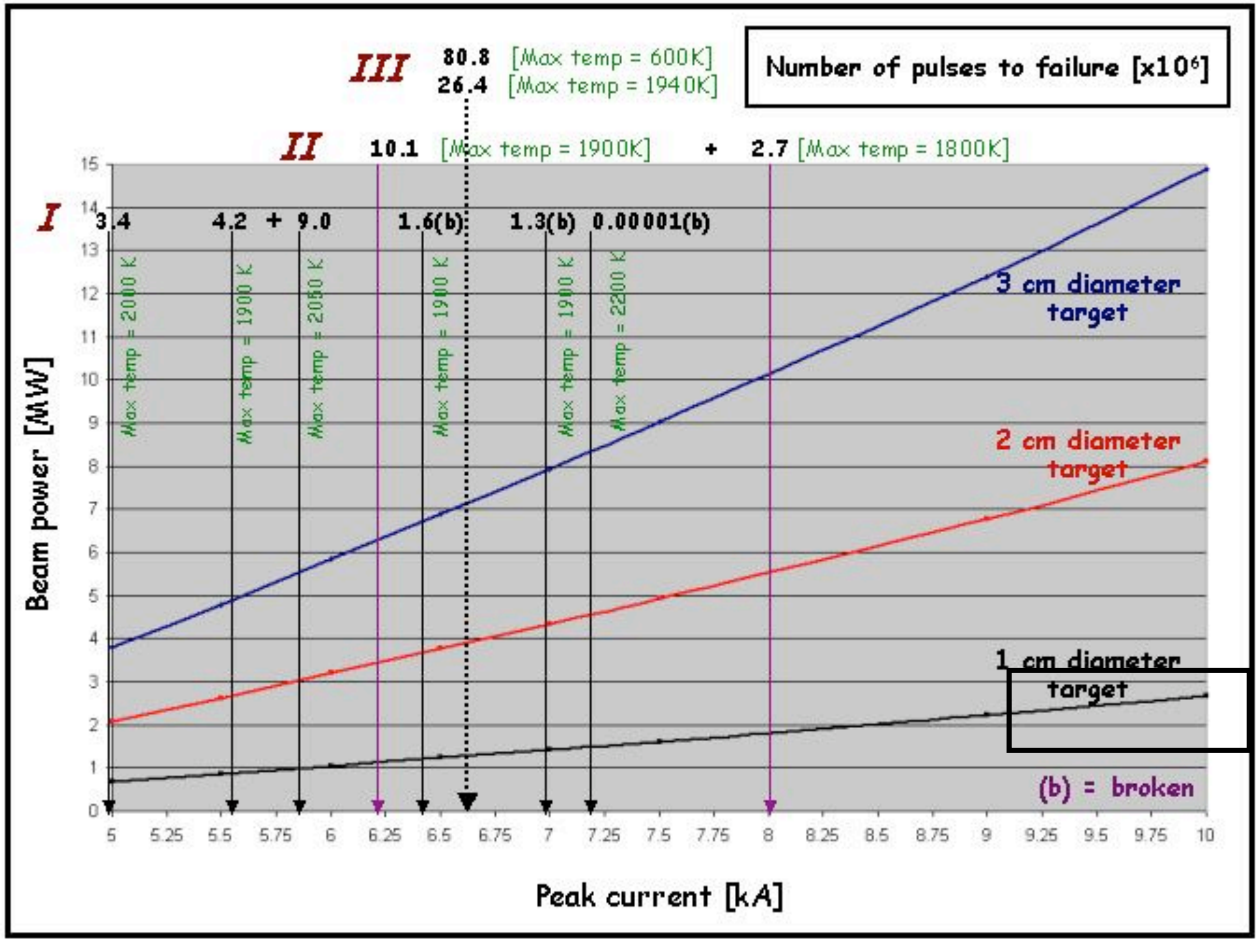
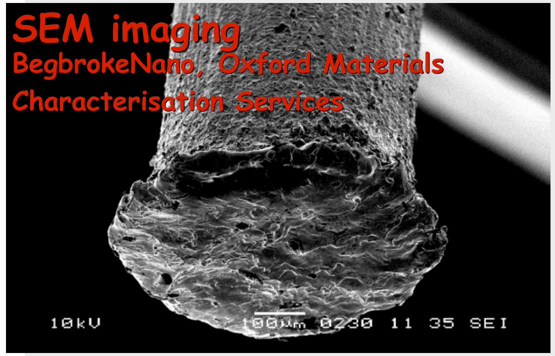
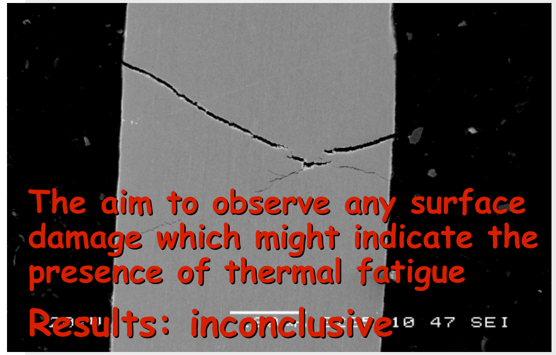
# Solid target- lifetime tests

Rob Edgecock




› 10 years for 2cm diameter target

› 20 years for 3cm diameter target

Focus now:

Measure stress;

Confirm modelling.

Better at lower temperature!

# Solid target - Youngs modulus

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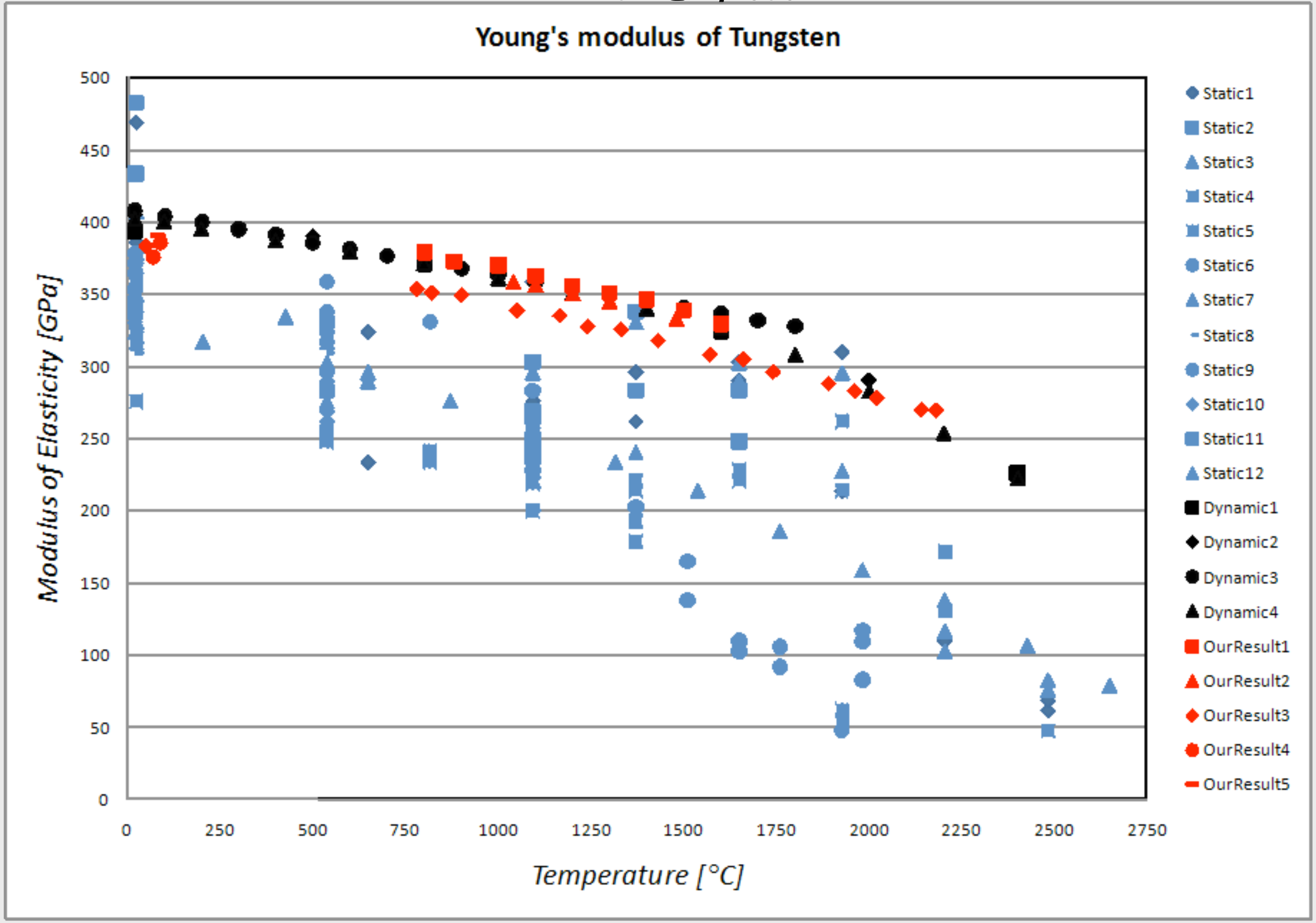
Rob Edgecock



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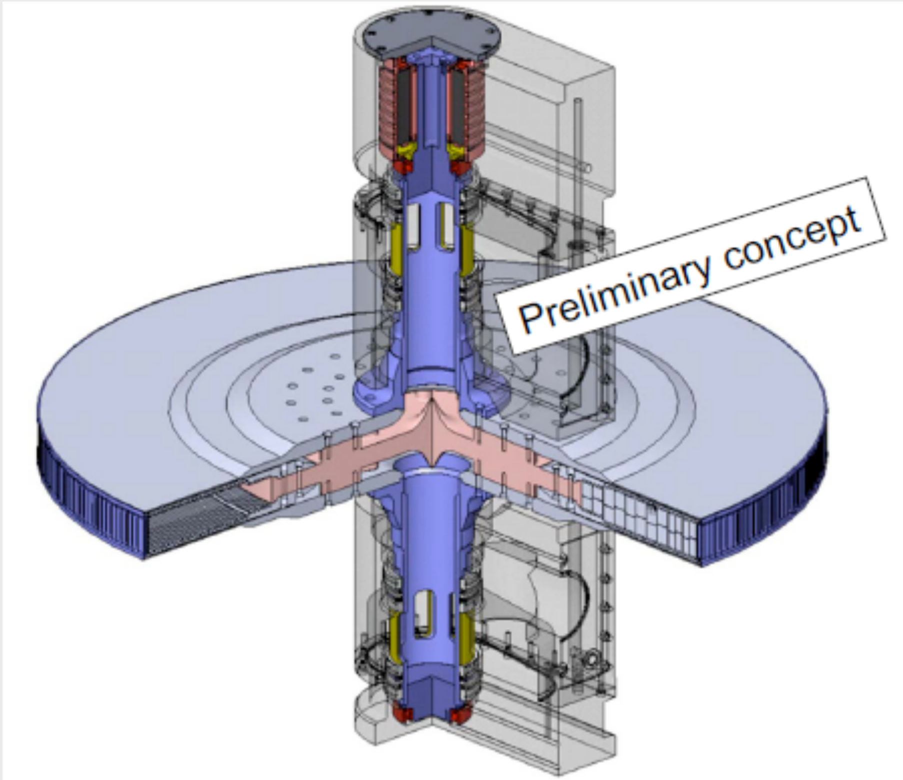
# Solid target station

Rob Edgecock

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

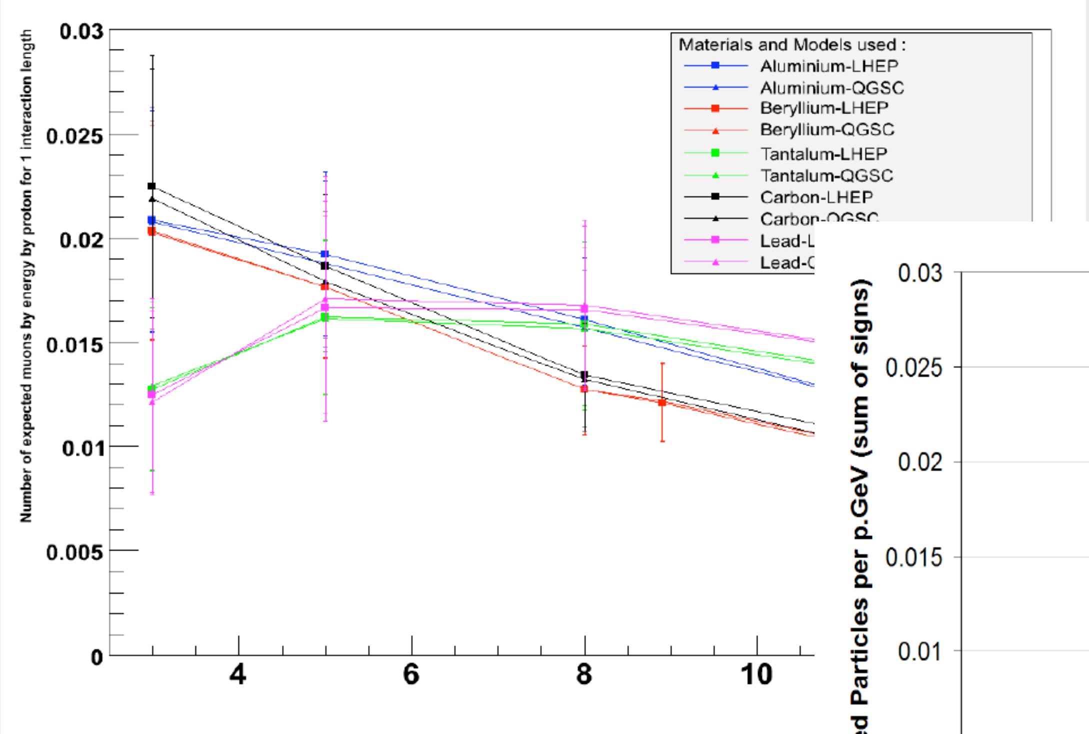



**Horizontal for compatibility with baseline target station**

# Harp data comparison

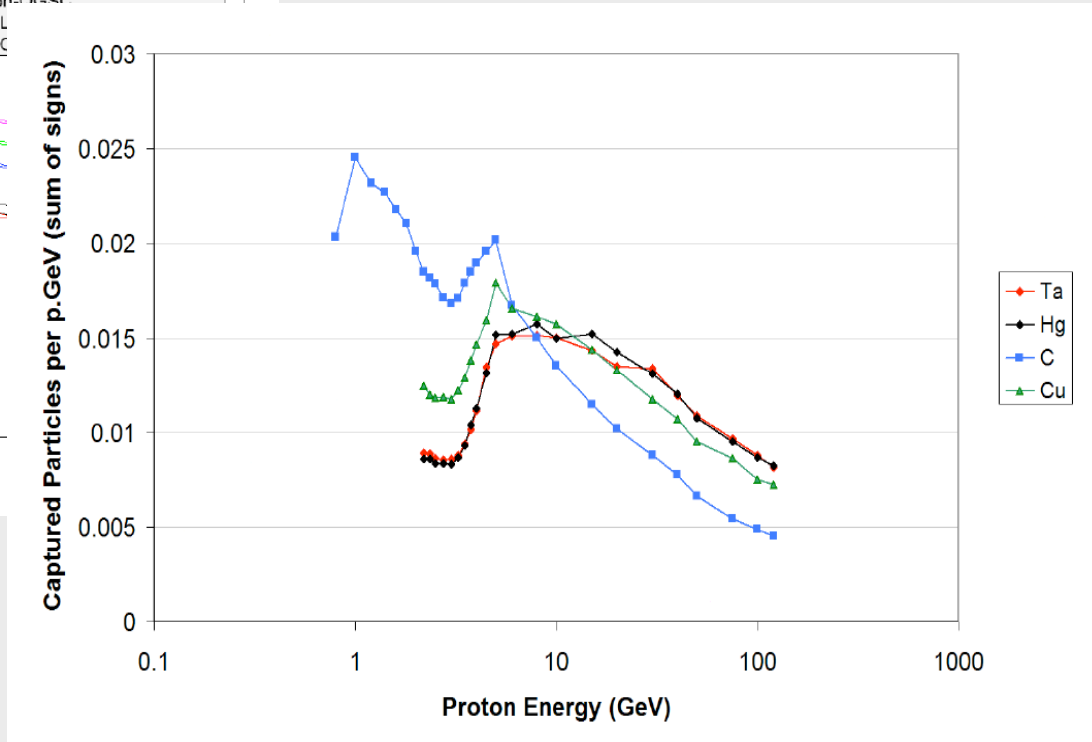
P. Soler

Reweighted Harp results




**Includes NF muon aceptance!**

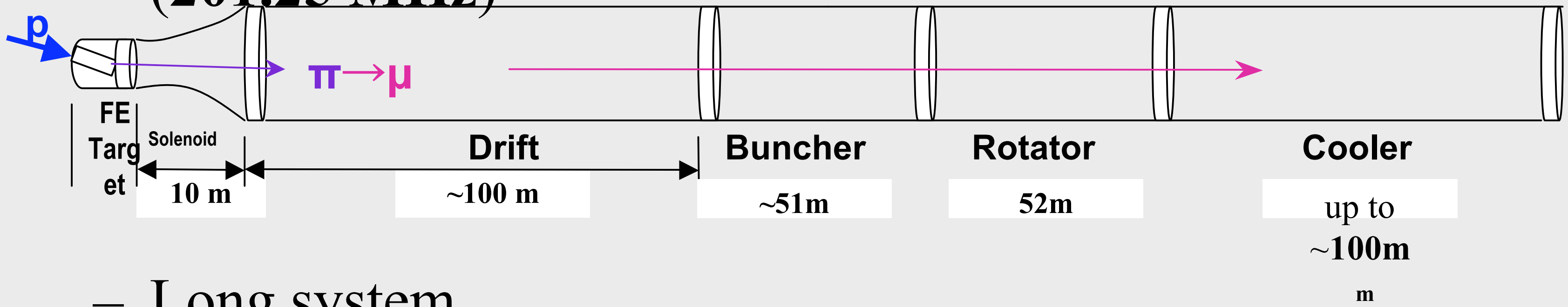
Comparison to MARS simulations (S.Brooks)



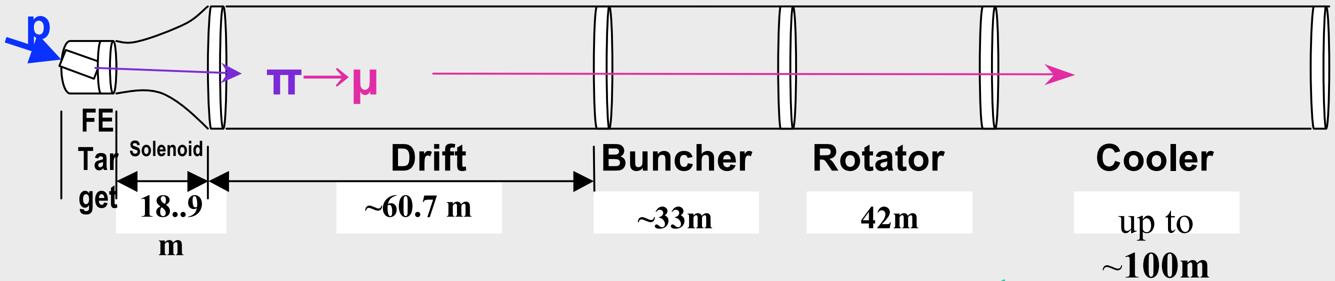
# Muon front end

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



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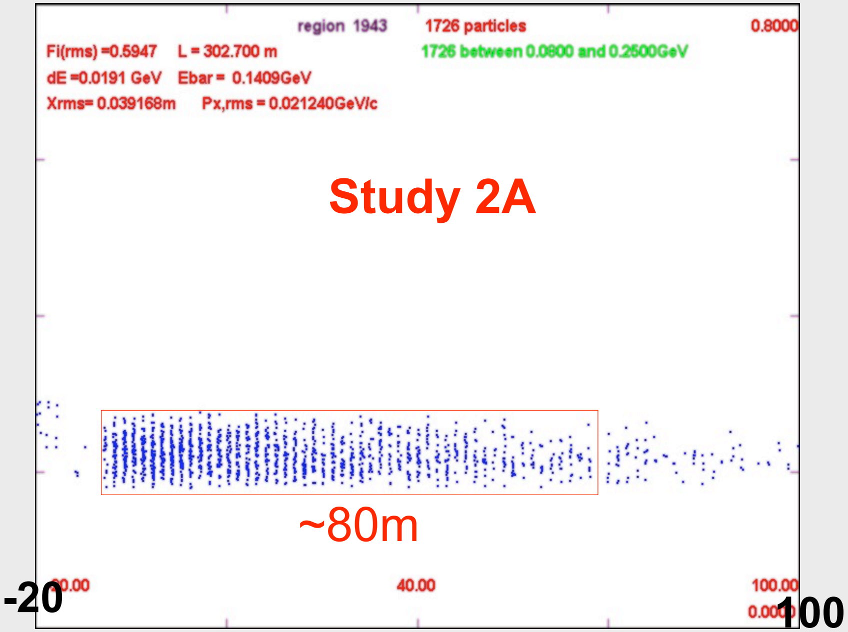
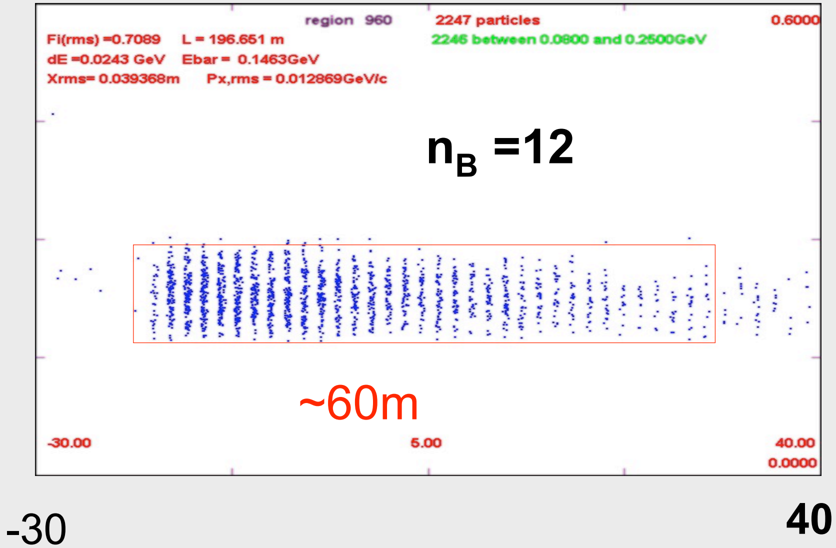
# Muon front end - bunch train length

D. Neuffer



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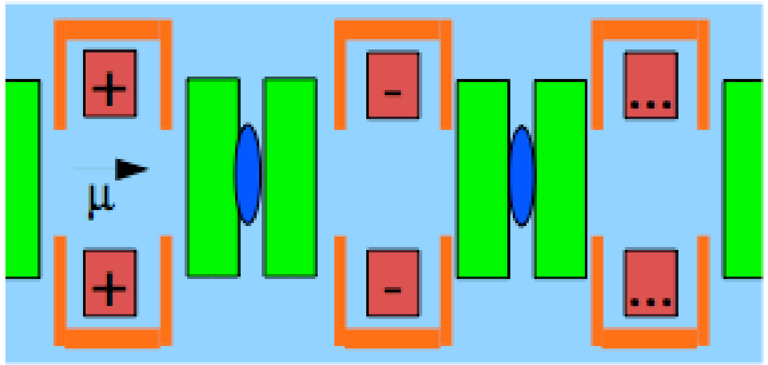
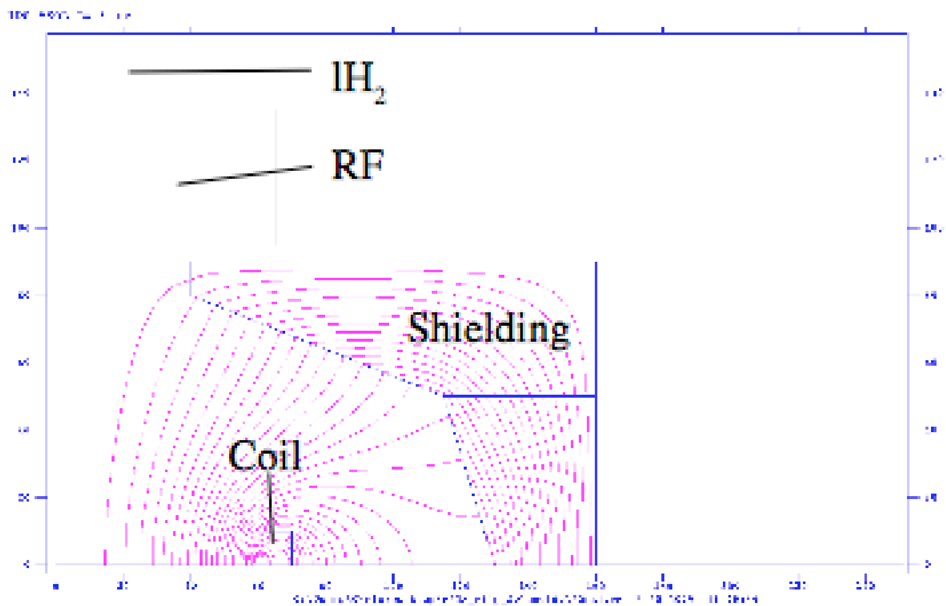
# Shielded RF cooling lattice

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

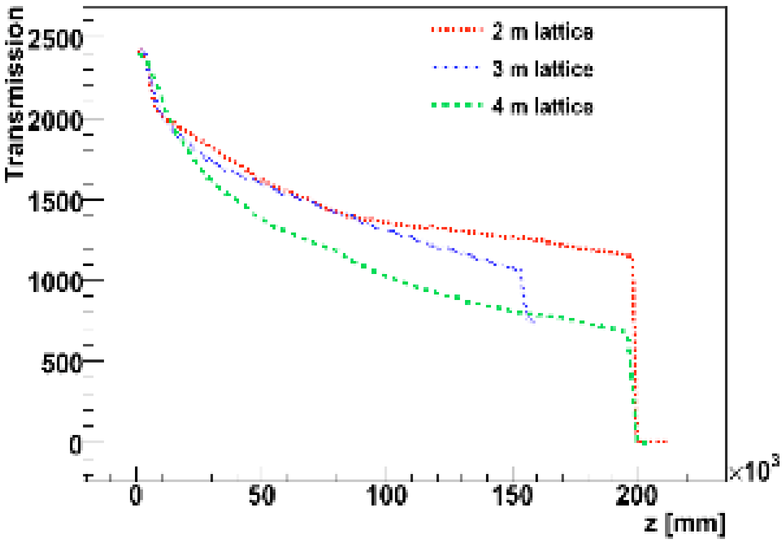


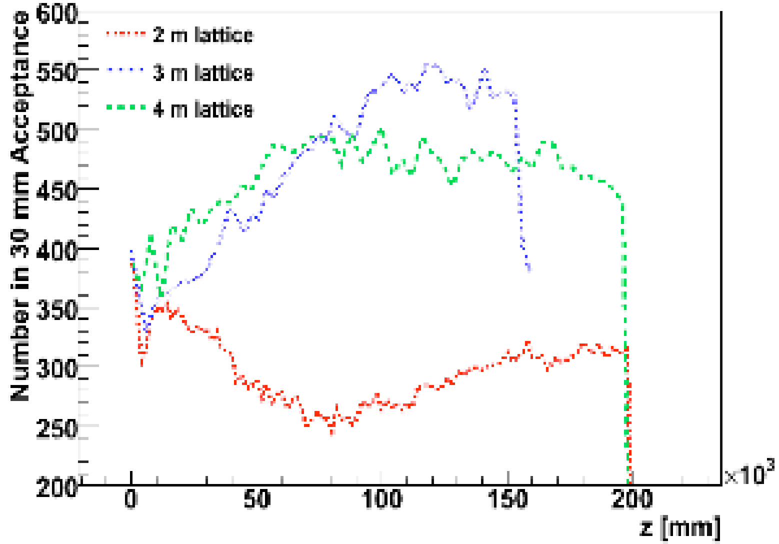



# Shielded RF cooling lattice

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?



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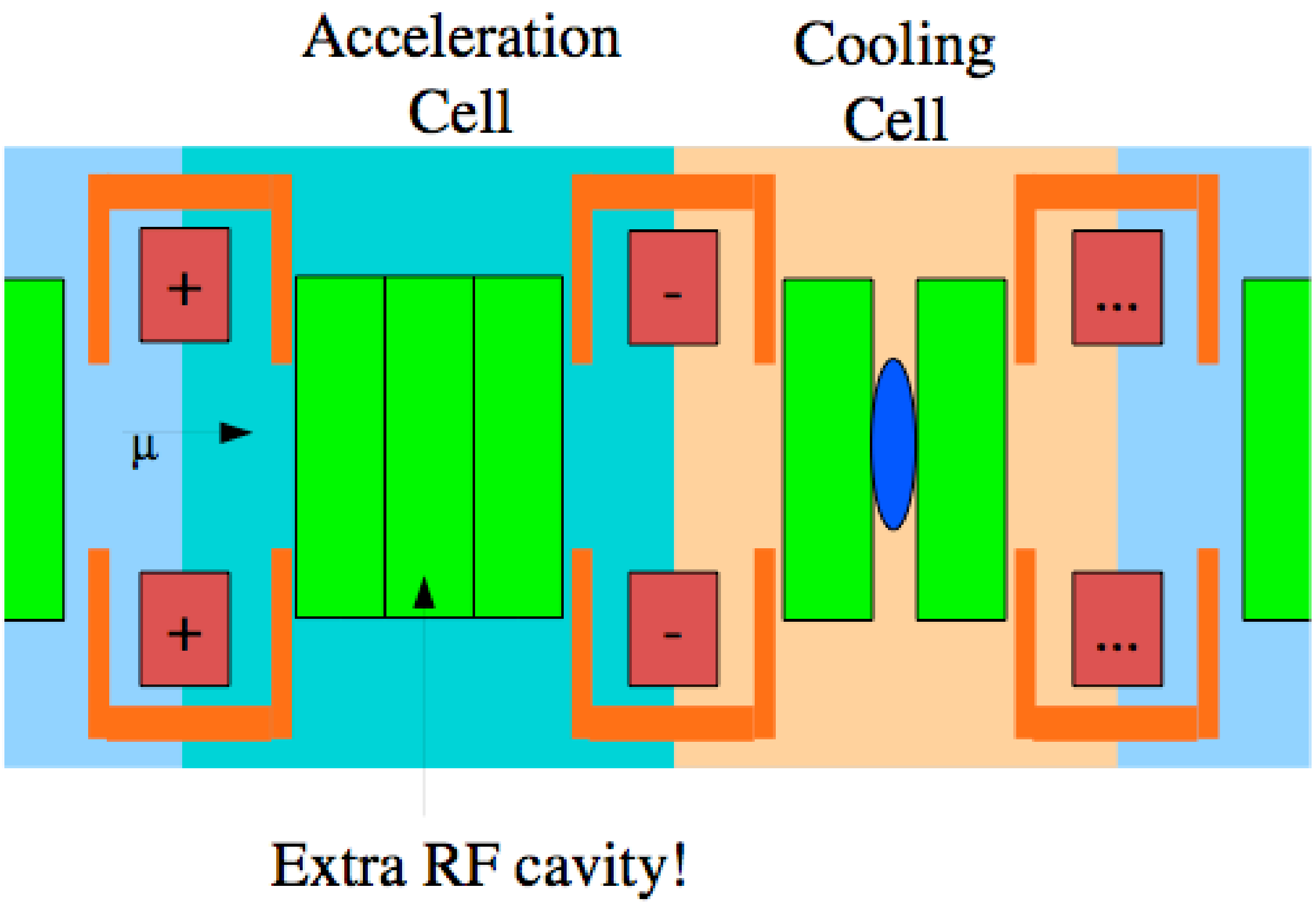
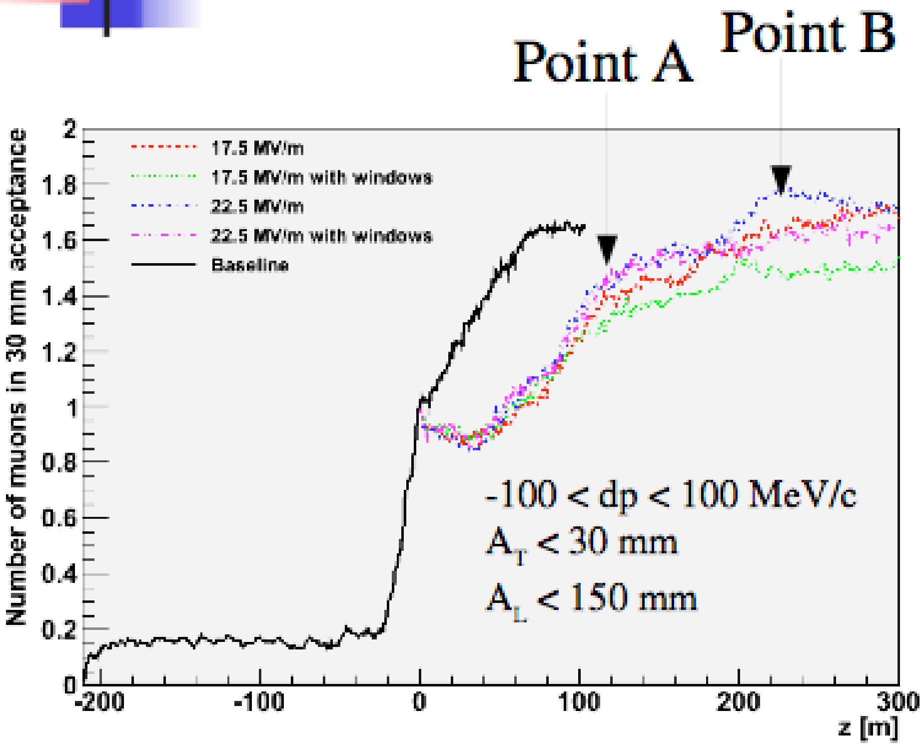
# Higher momentum beam

C. Rogers



# 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!

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# 44 / 88 MHz lattice

G. Prior

**Pion production: 2 GeV proton beam on a 26 cm-long Hg target in 20 T field.**

**Drift: 30 m decay in 1.8 T field.**

**Rotation: 30 1m-long cavities at 44 MHz (2 MV/m) in 1.8 T solenoid. Phasing by 1 degree shift from -121 to -4 deg.**
**(energy spread reduction by 2)**

**Cooling I: 44 MHz RF + $H_2$ absorbers. ($\varepsilon_\perp$ reduced by 40%)**

**Acceleration: 88 MHz (4 MV/m) RF provide acceleration to 300 MeV/c.**

**Cooling II: 88 MHz RF + $H_2$ absorbers. ($\varepsilon_\perp$ reduced by 30%)**

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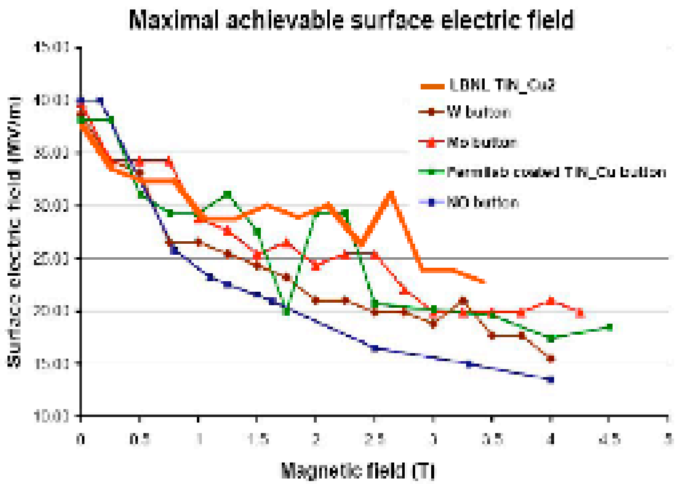
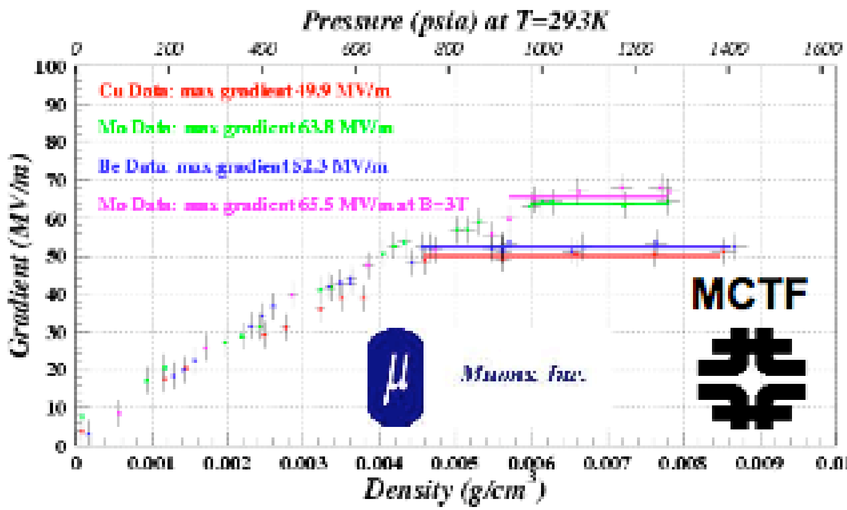
# High pressure RF

M. Zisman

- We have evidence that vacuum RF cavity gradient performance degrades in a strong magnetic field
  - alternative approach of HPRF does not
    - o 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



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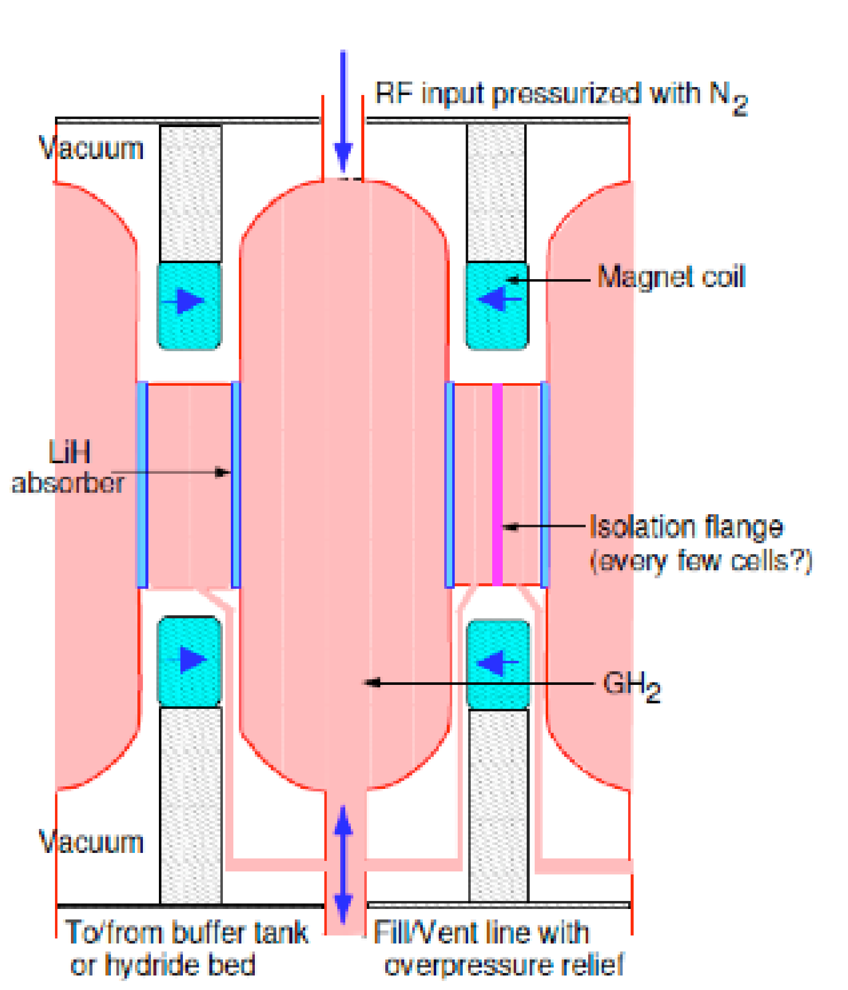
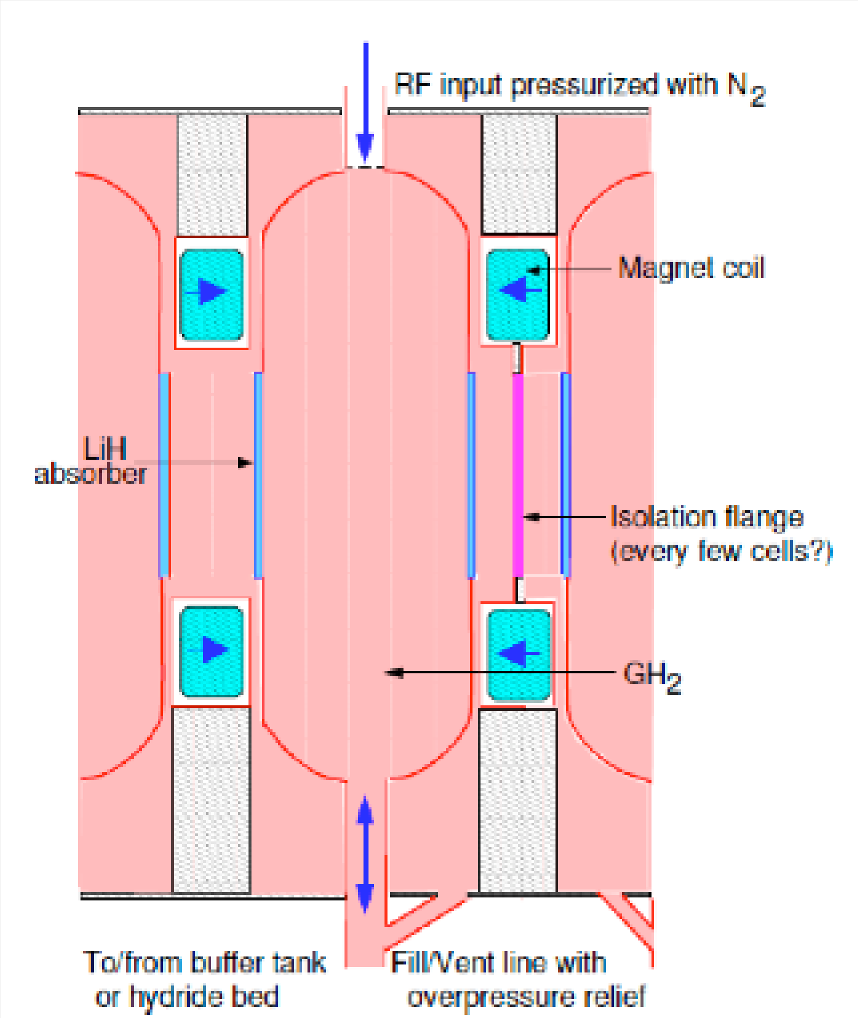
# High pressure RF implementation

M. Zisman

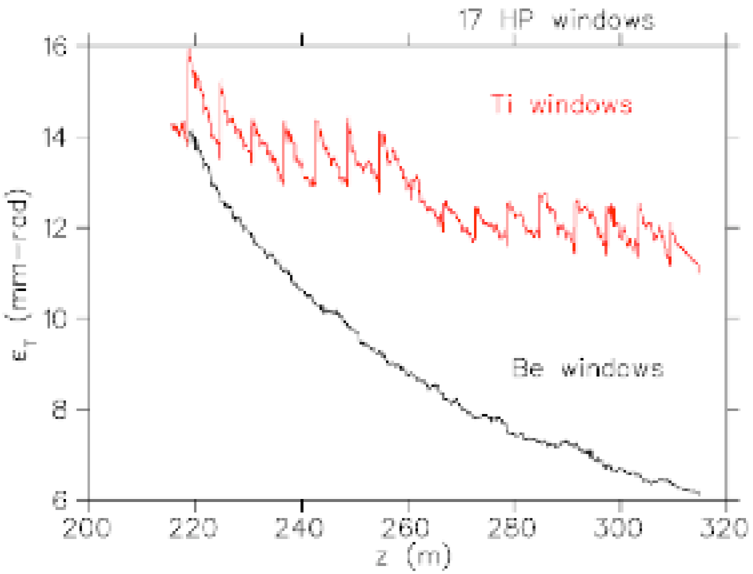


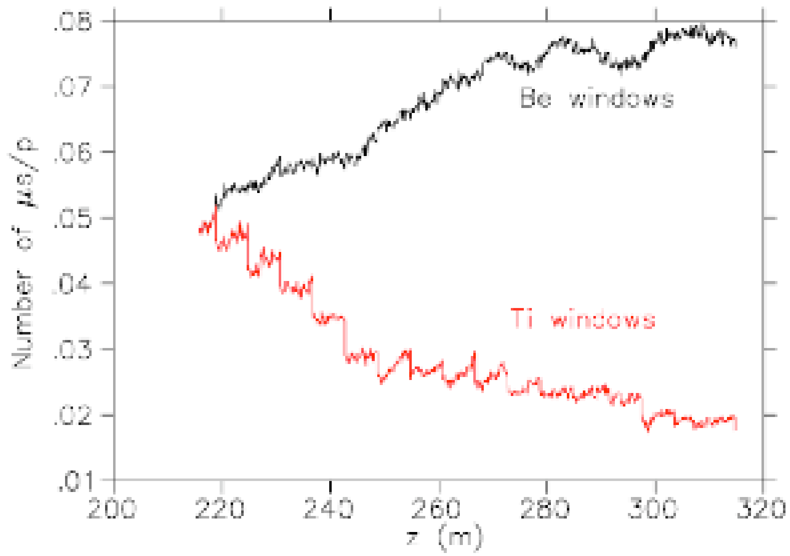



# High pressure RF - window material

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



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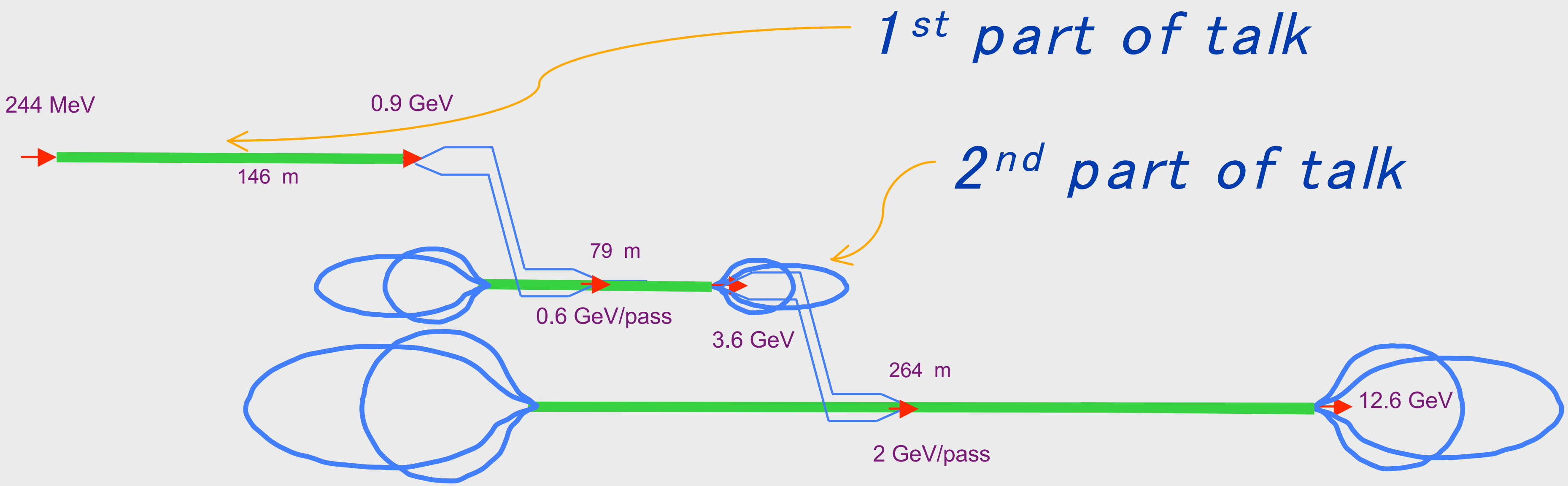
# Linac & RLA's

A. Bogacz

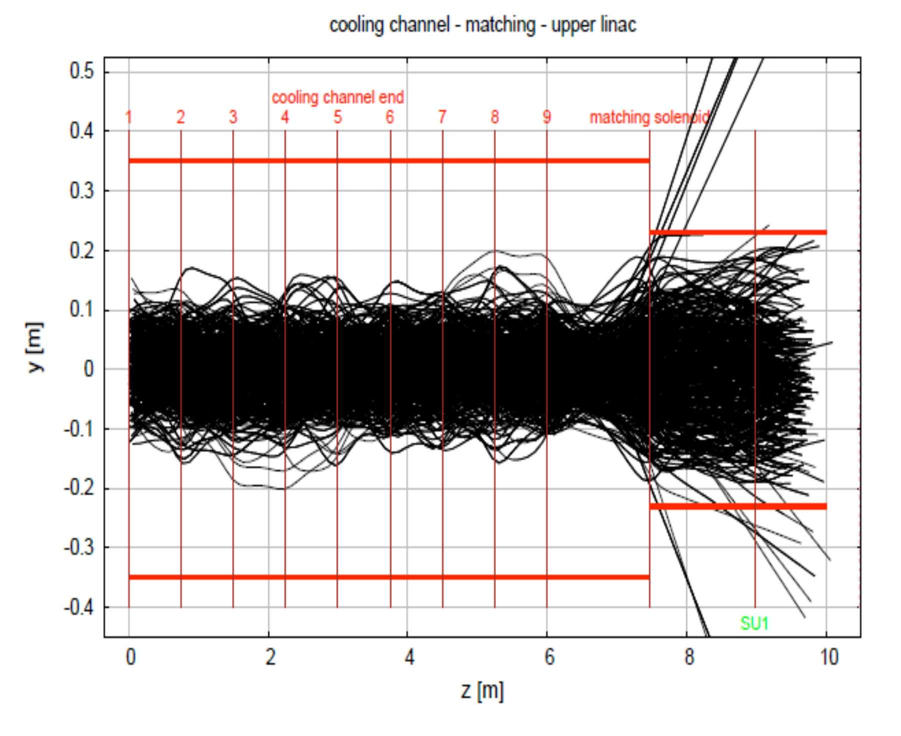



- IDS Goals:
  - Define beamlines/lattices for all components
  - Resolve physical interferences, beamline crossings etc
  - Error sensitivity analysis
  - **End-to-end simulation (machine acceptance)**
  - Component count and costing

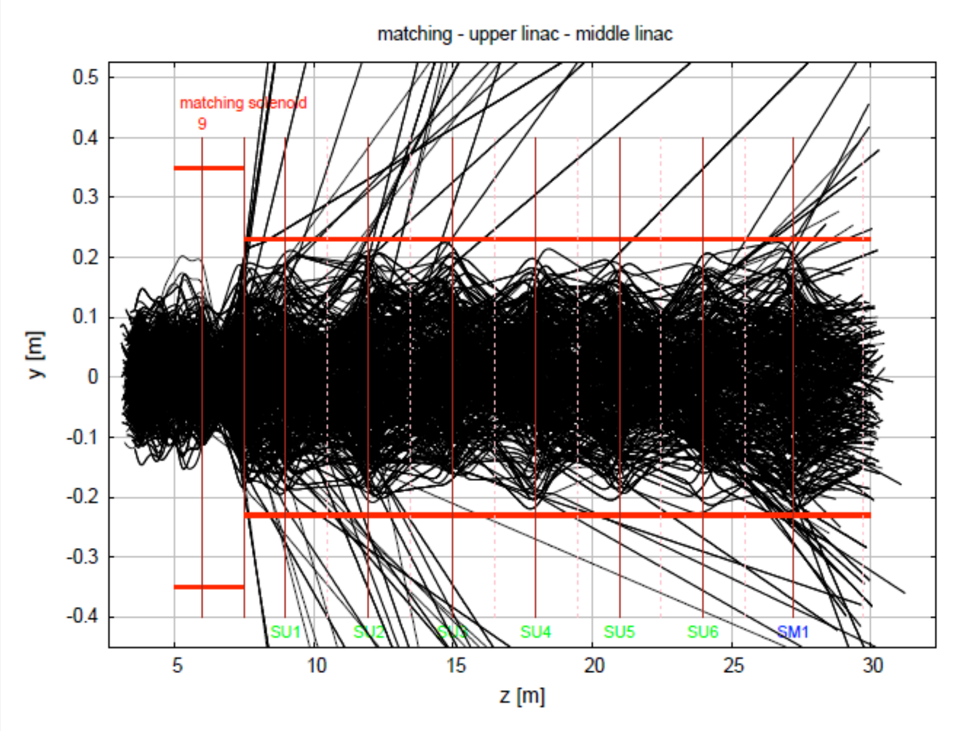
# Matching from cooling to linac

A. Bogacz

cooling -> upper linac




upper -> middle linac



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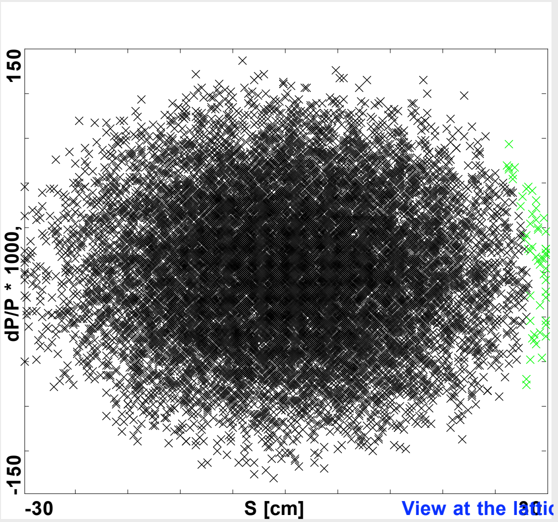
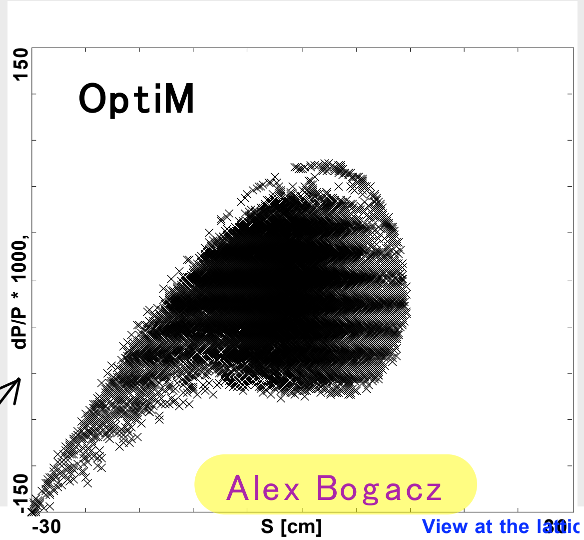
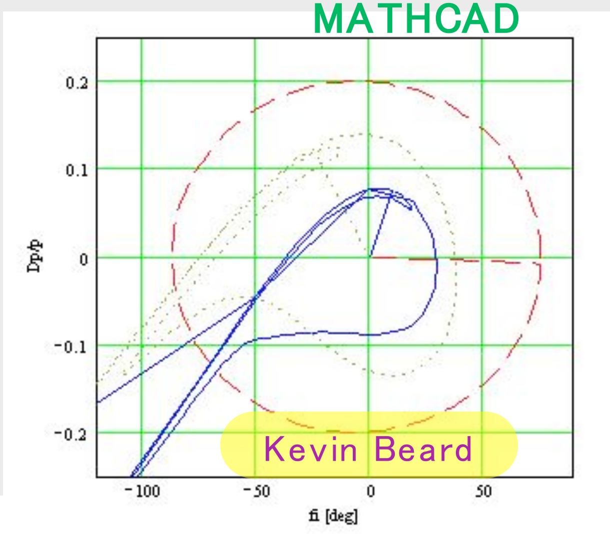
# Longitudinal phase space

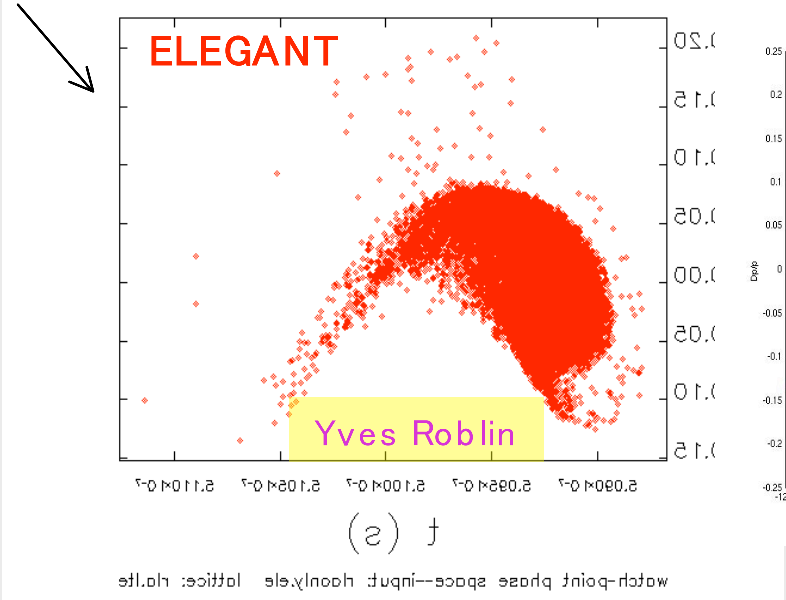
A. Bogacz

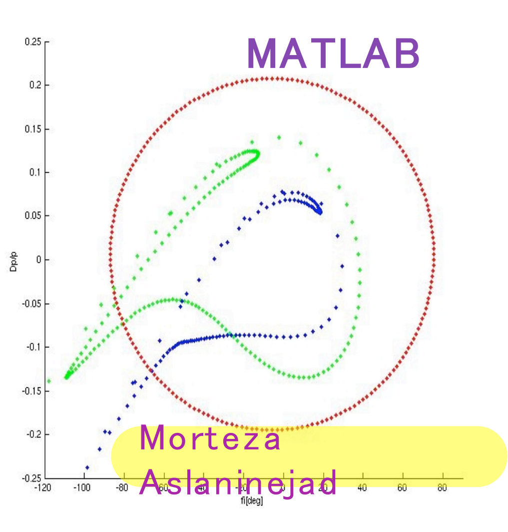
Initial distribution



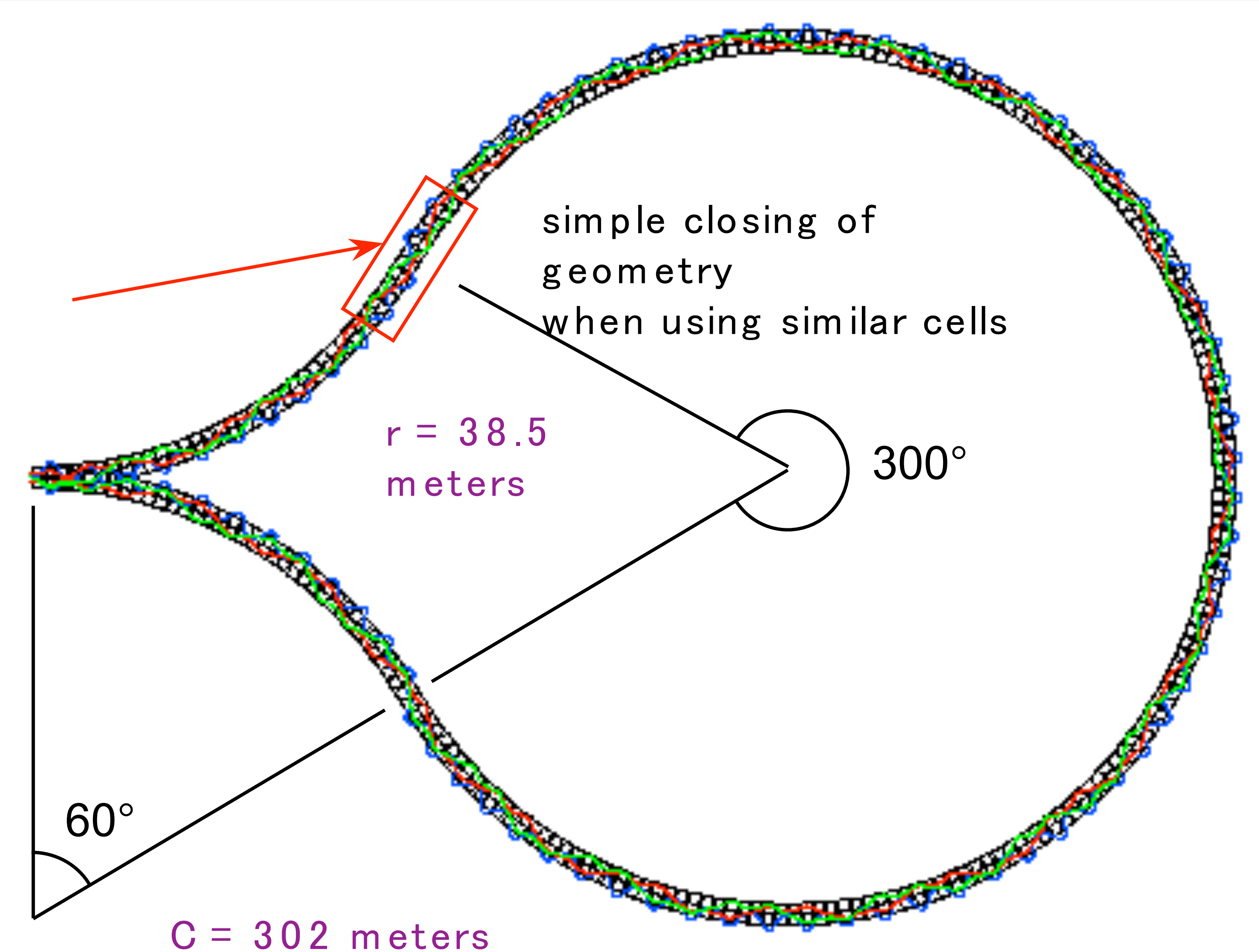



# Multipass FFAG arc

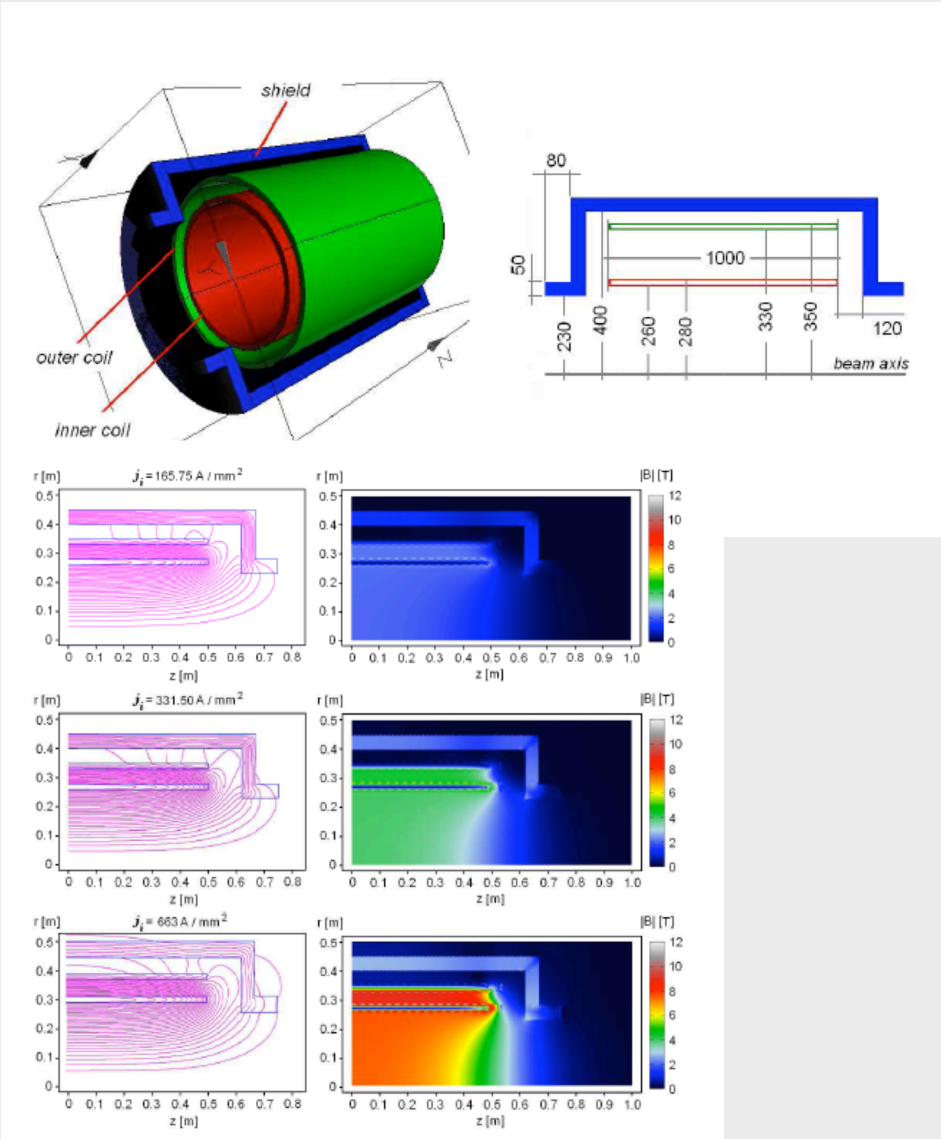
A. Bogacz

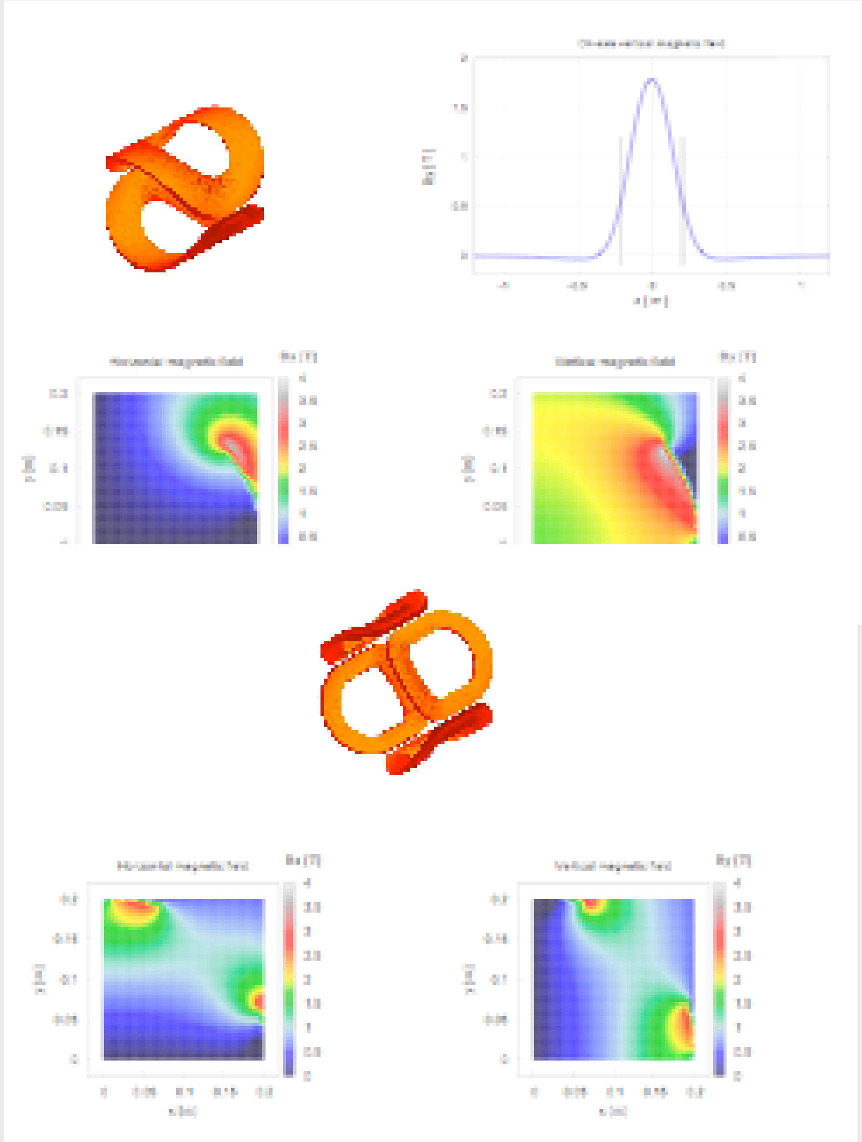
Vasiliy Morozov



# Hardware design magnets

C. Bontoiu

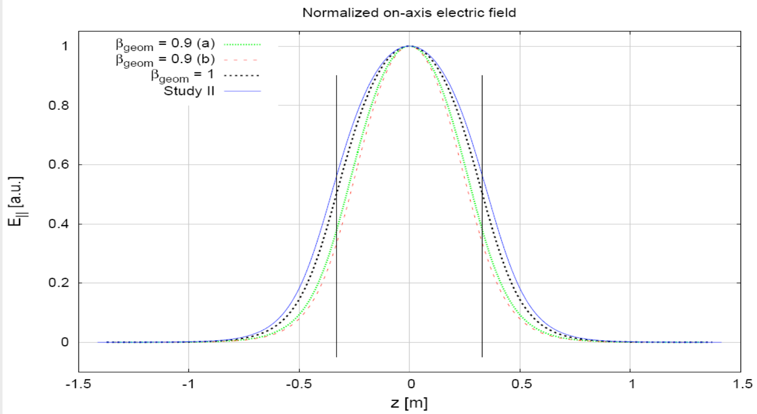


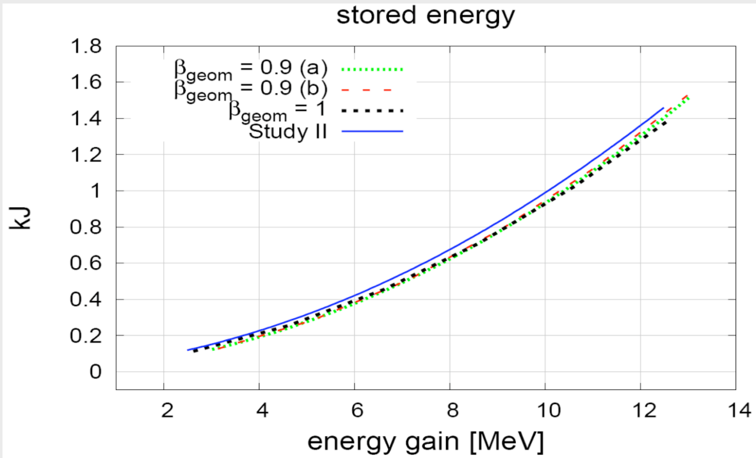



# Hardware design RF cavities

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 |
| $\int_{-\infty}^{+\infty} E(0,z)\cos[\omega\ t(z)]dz$ | 8.6142 | 9.0081 | 9.1336 | 8.8466 |
| $\int_{-l_{cav}/2}^{+l_{cav}/2} E(0,z)\cos[\omega\ t(z)]dz$ | 10.0000 | 10.0000 | 9.9999 | 10.0000 |
| $\int_{+l_{cav}/2}^{+\infty} E(0,z)\cos[\omega\ t(z)]dz$ | -0.69204 | -0.49594 | -0.43320 | -0.75676 |
| correction [%] | -13.841 | -9.9188 | -8.6639 | -15.135 |



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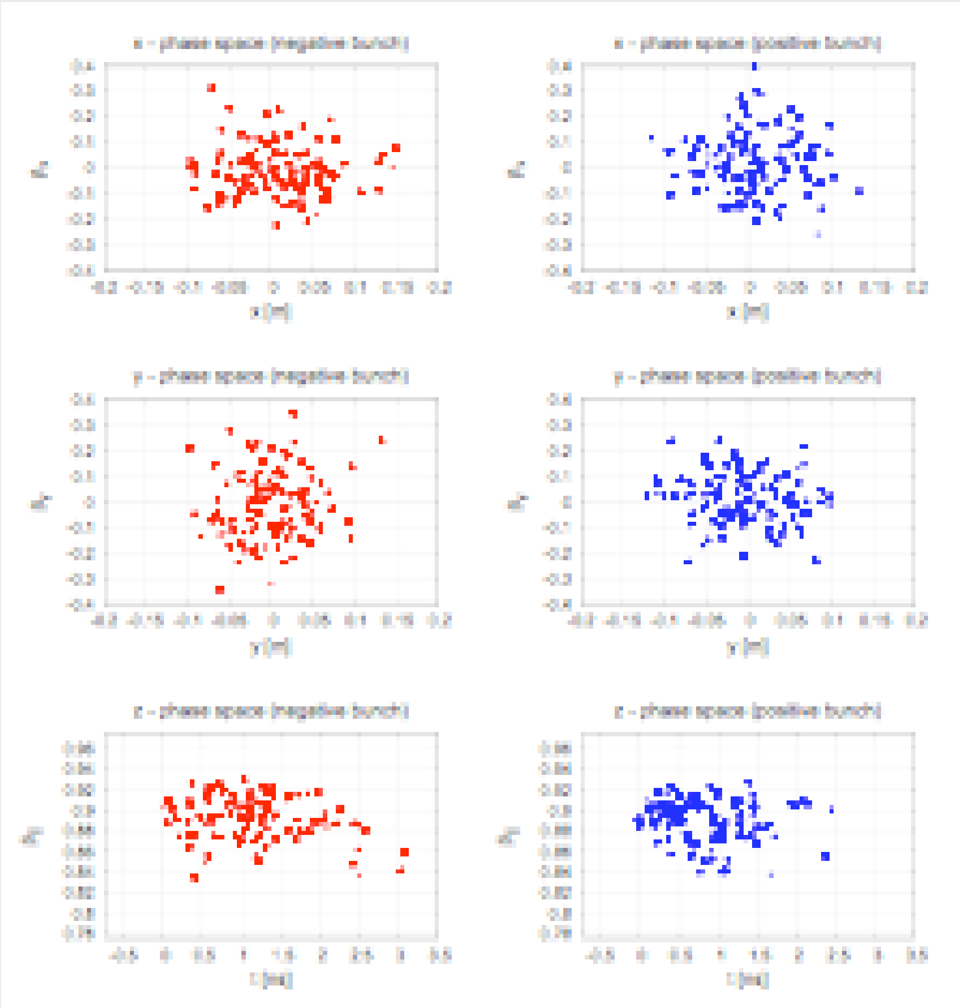
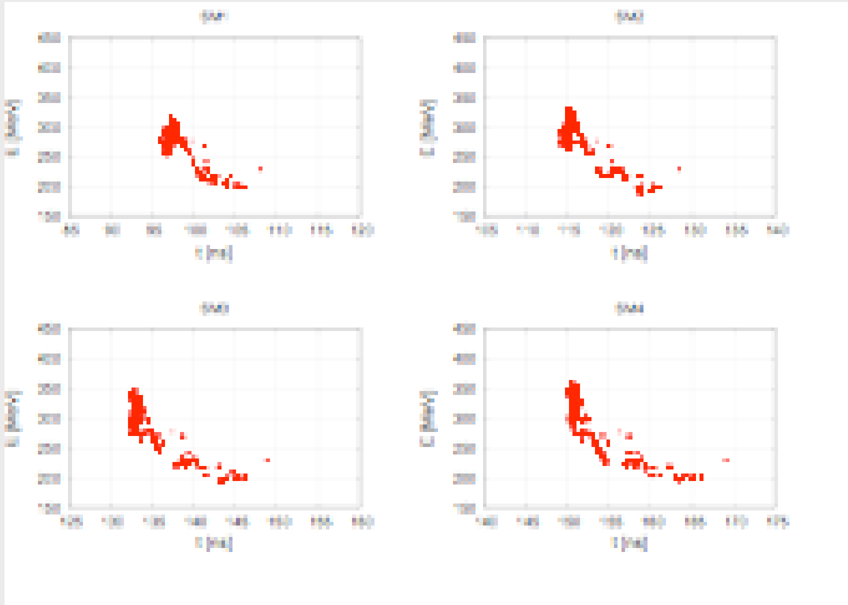
# Particle tracking

C. Bontoiu

Intital distribution from cooling channel




Energy spread in the linac



# 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.

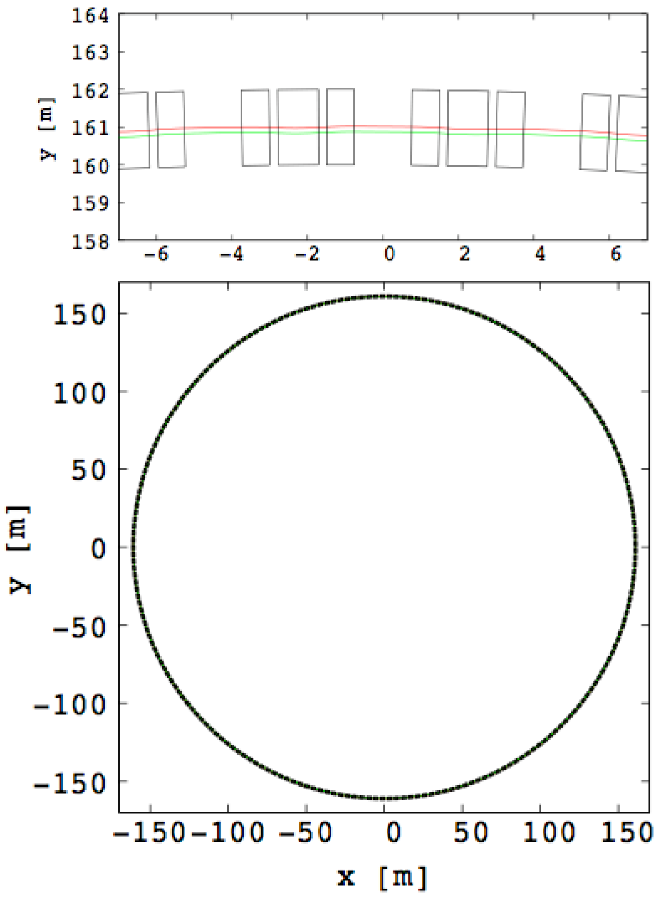



Figure 2 - Ring layout.

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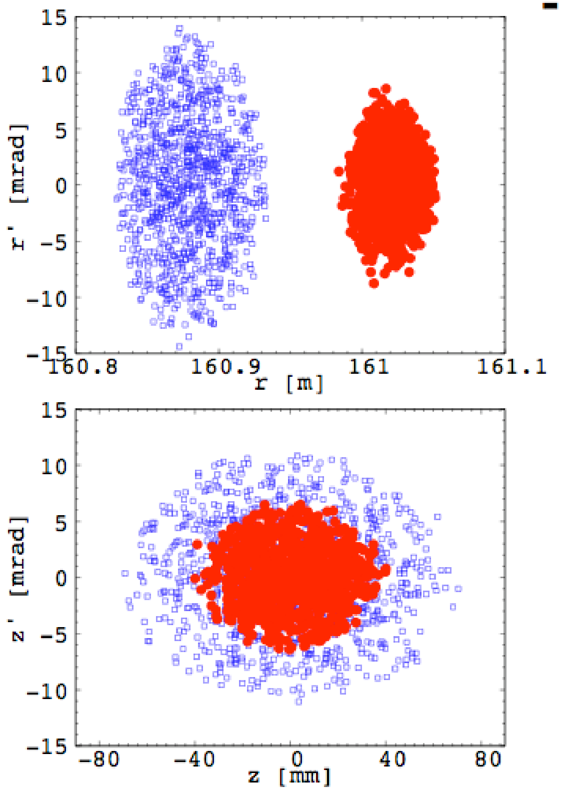
# Scaling FFAG alternative for RLA 2

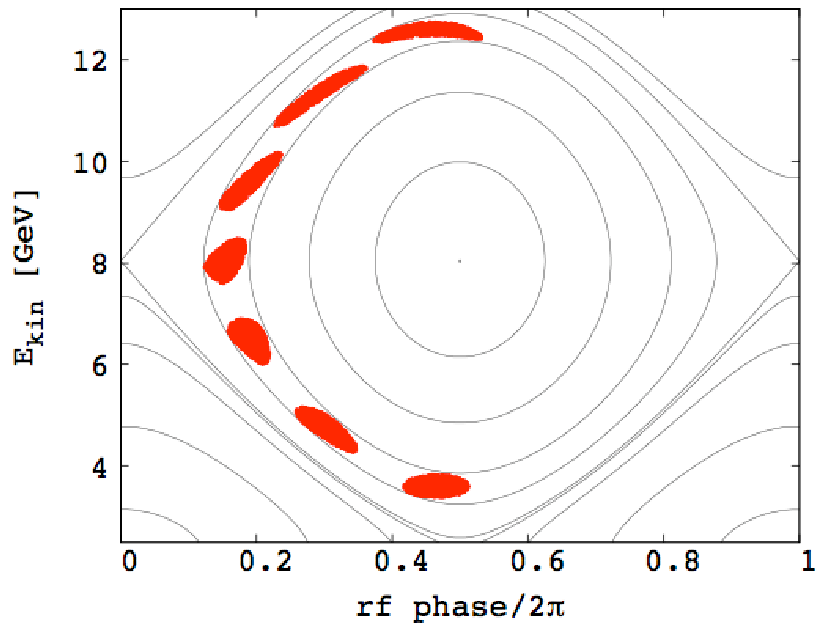
T. Planche

## 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.

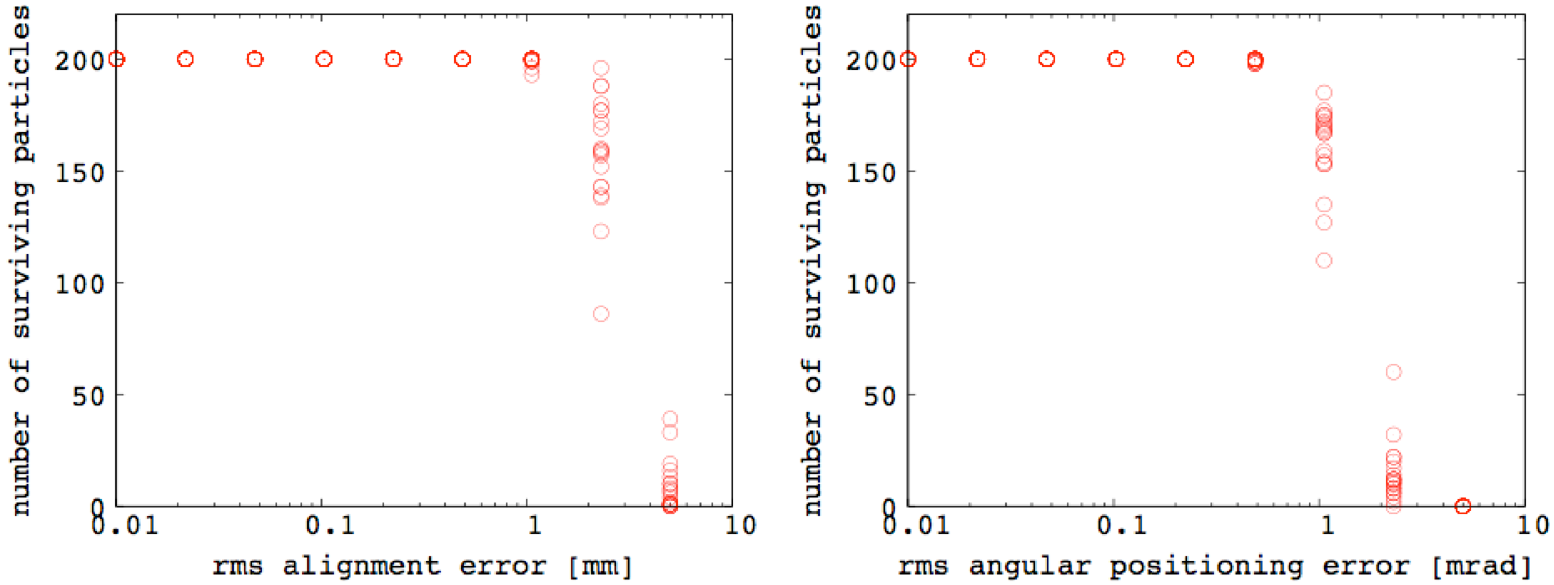
# Scaling FFAG alternative for RLA2

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!

# NS-FFAG Lattice parameters

S. Berg

Most promising due to longer dirfts 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

# NS-FFAG cromaticity correction

S. Berg

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

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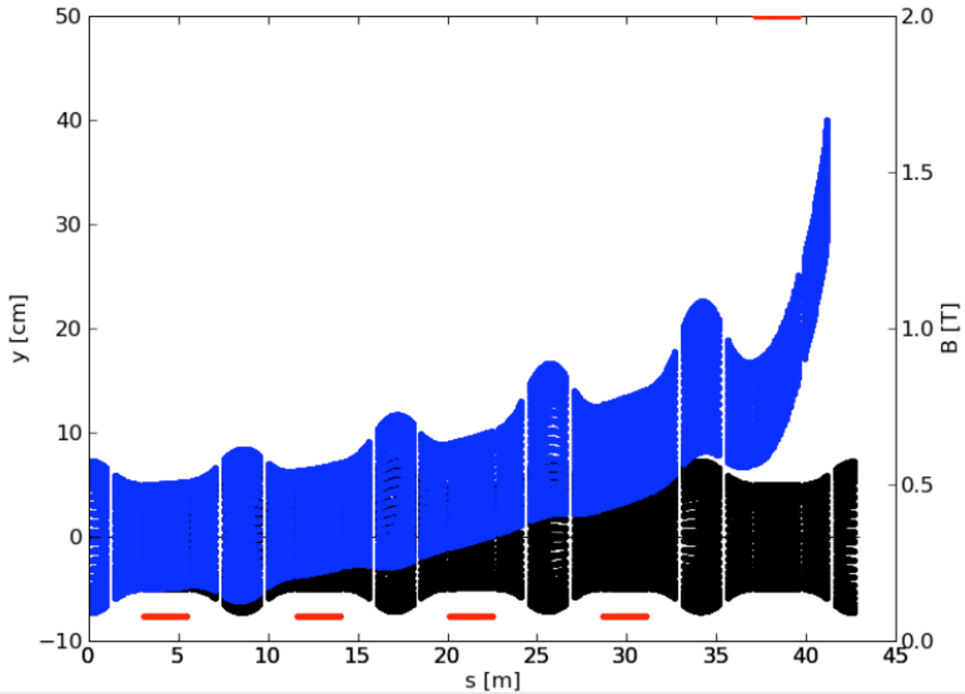
# Extraction particle dynamics

J. Pasternak

## 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

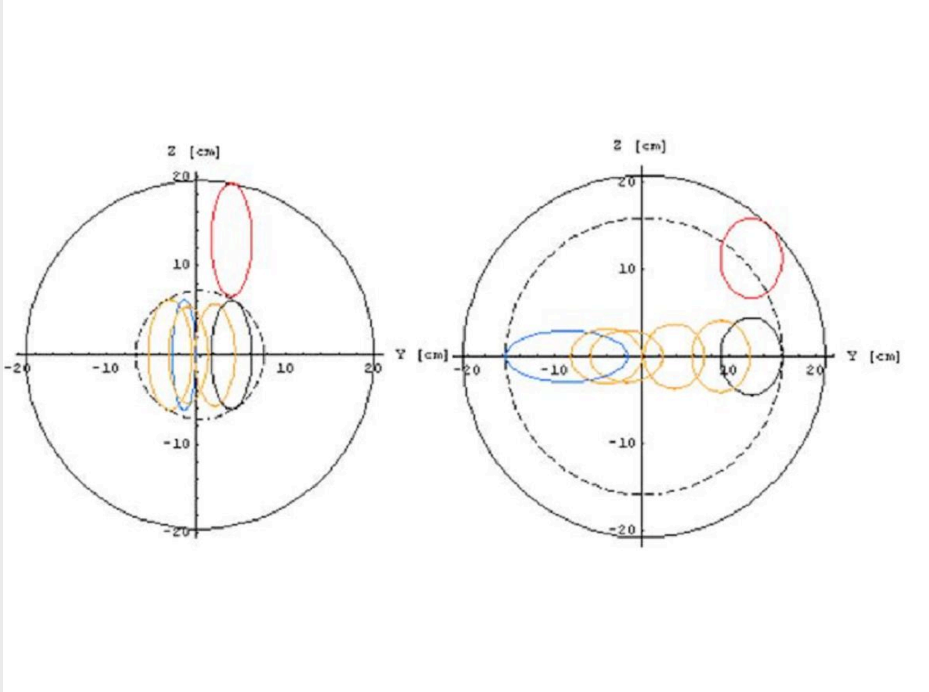


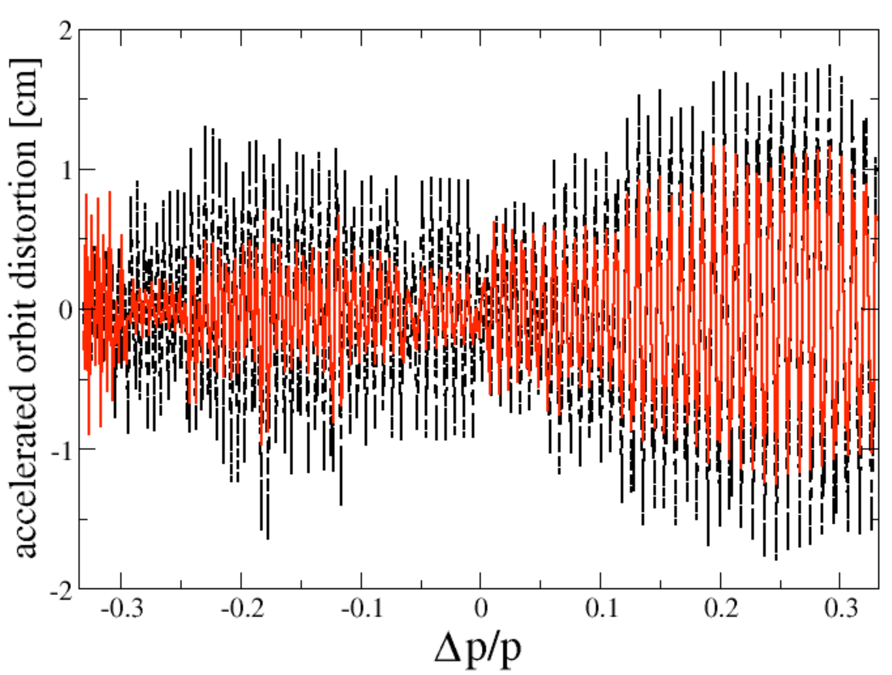

D. Kelliher

# Extraction particle dynamics

J. Pasternak

## Effects of special magnets



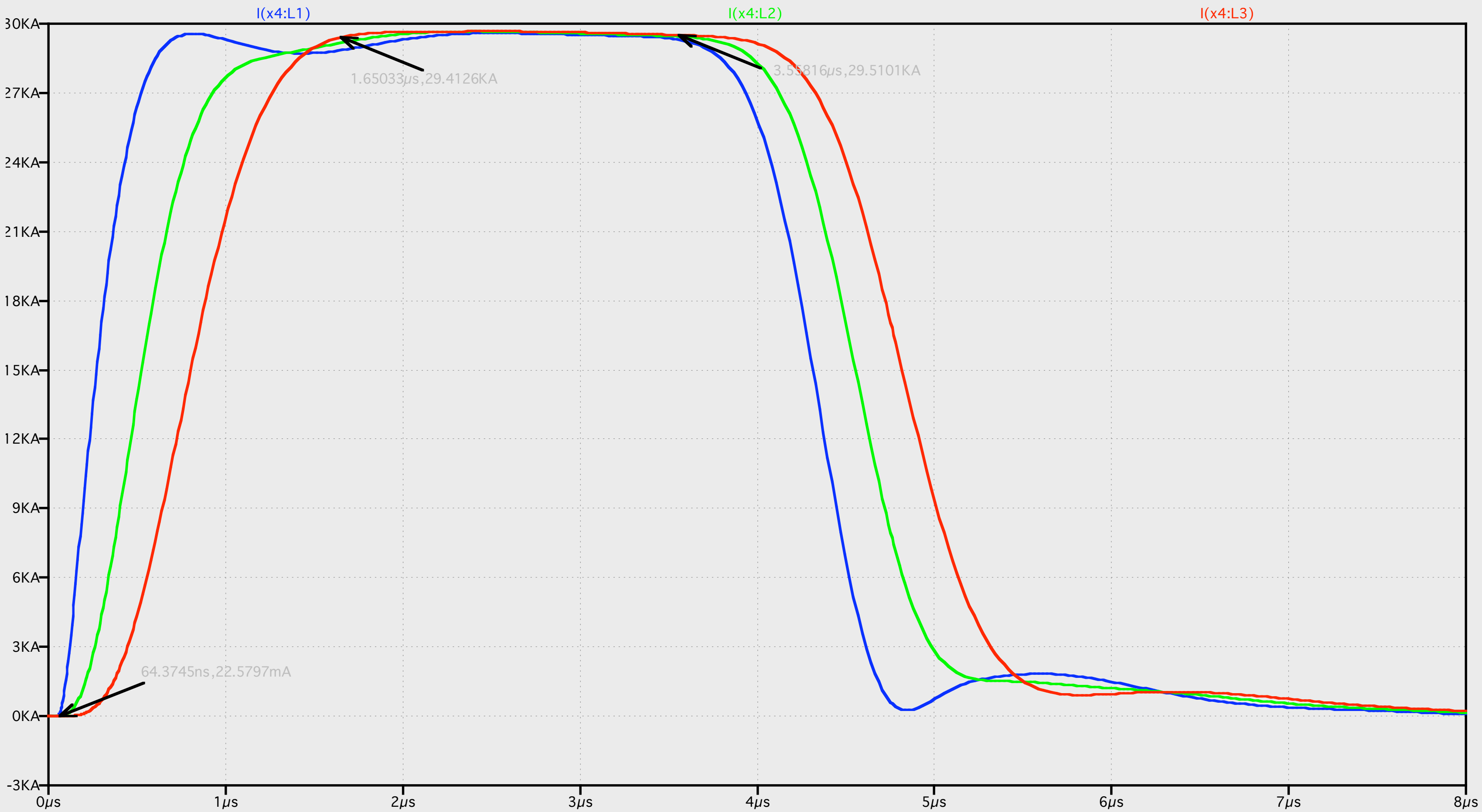




- Beams close to septum push the magnet aperture.
- Special magnets with higher aperture is needed in injection/extraction regions.
- Those magnets introduce the ring lattice symmetry breaking, which can cause accelerated orbit distortion.
- Current studies show that the effect is not dramatic, but more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

# Kicker electronics simulations

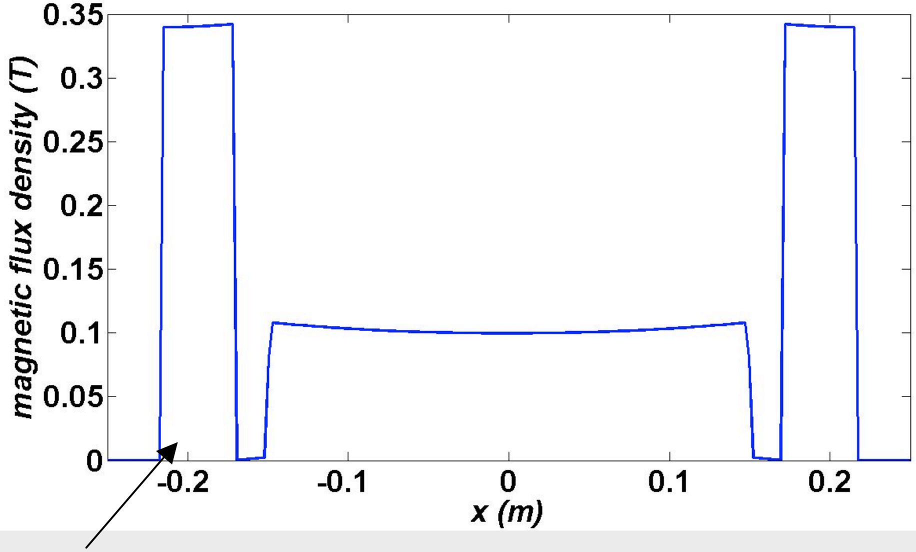
J. Pasternak

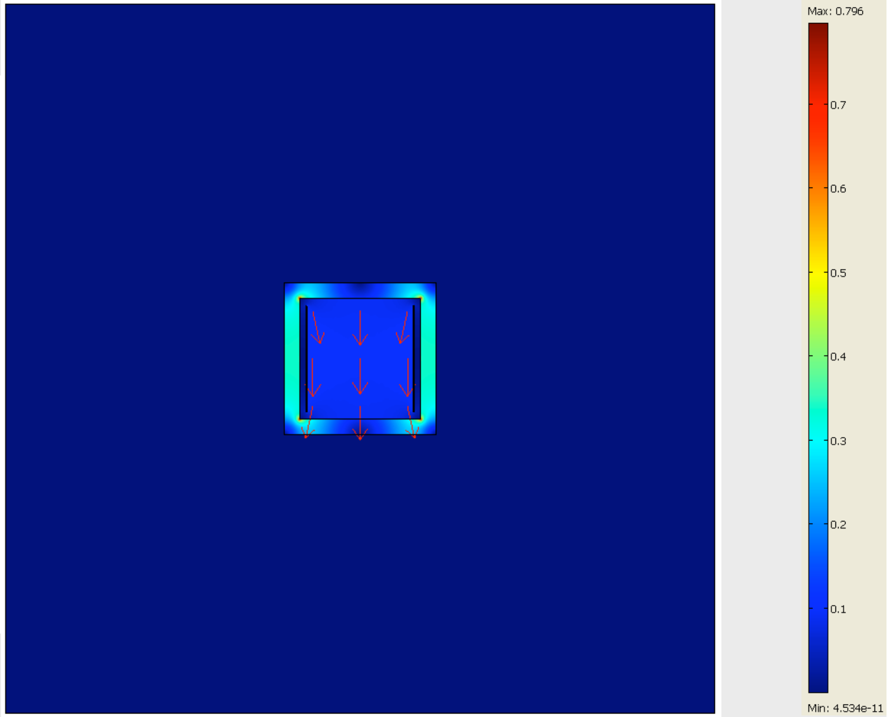
## Current pulses in 3 kicker sections – „travelling wave" using PSPice



# Kicker magnet simulations in COMSOL

J. Pasternak




- 2D simulation to estimate the current, which is needed.
- Ferrite 3c11 is assumed for the yoke.
- Field quality is OK and it can still be improved.

# Ring instrumentation - Energy

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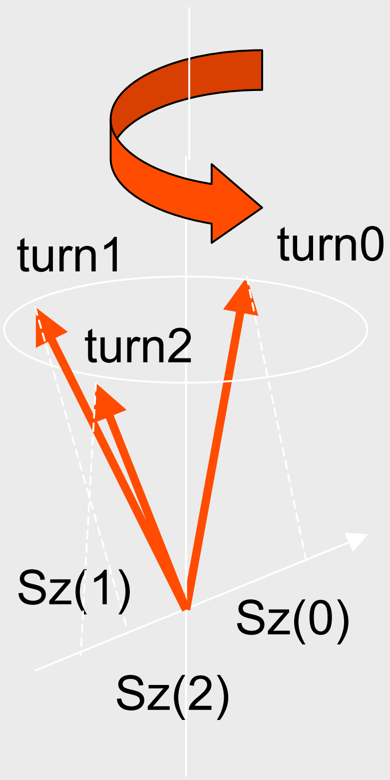
M. Apollonio




- 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*:

$\omega = 2\pi\gamma a$

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

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

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

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

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

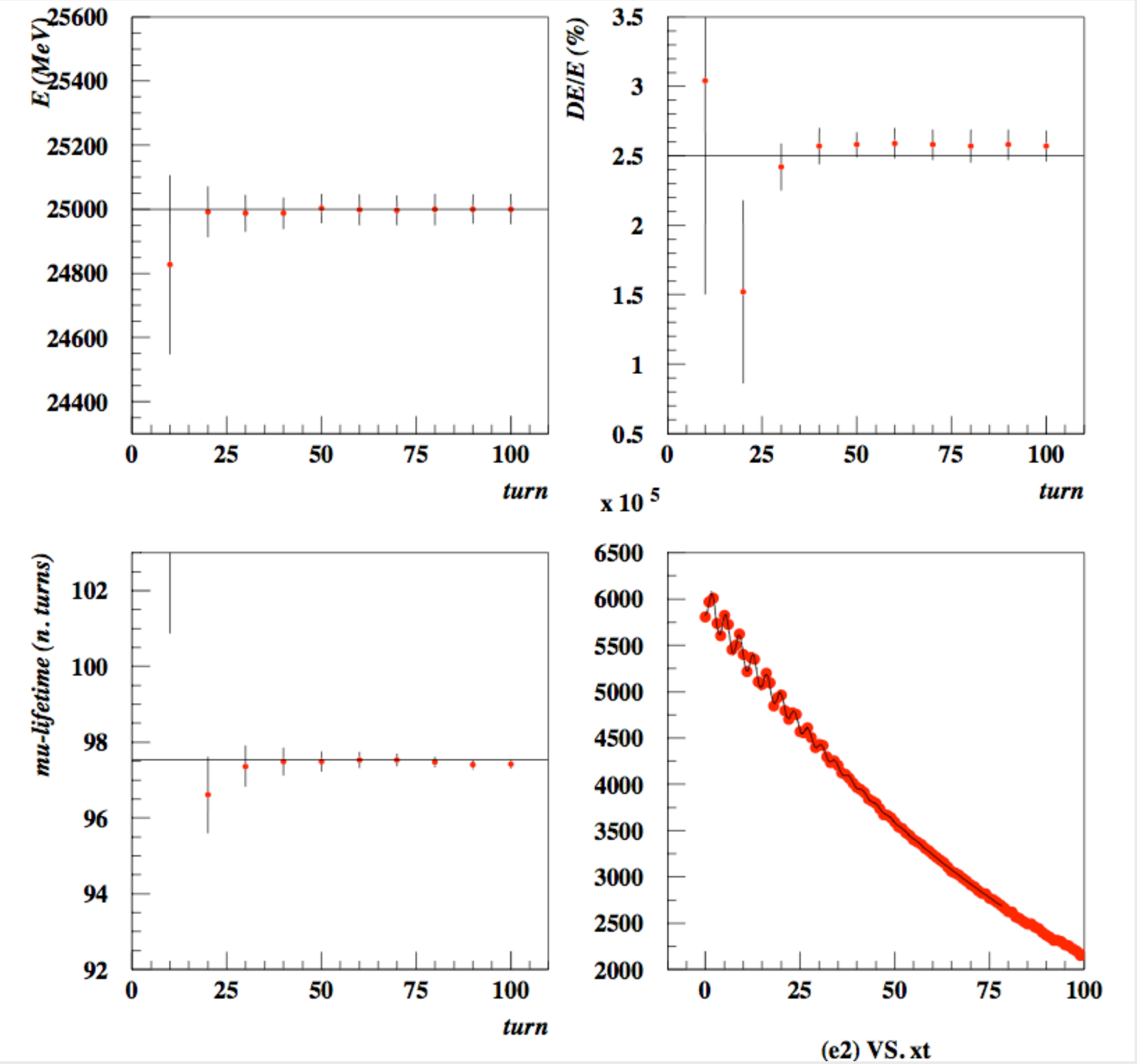
- I have modelled the behaviour of a beam (> 1E5 muons) all with their spin and energy ($\Delta E/E$ =[0.01-0.05])

- 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

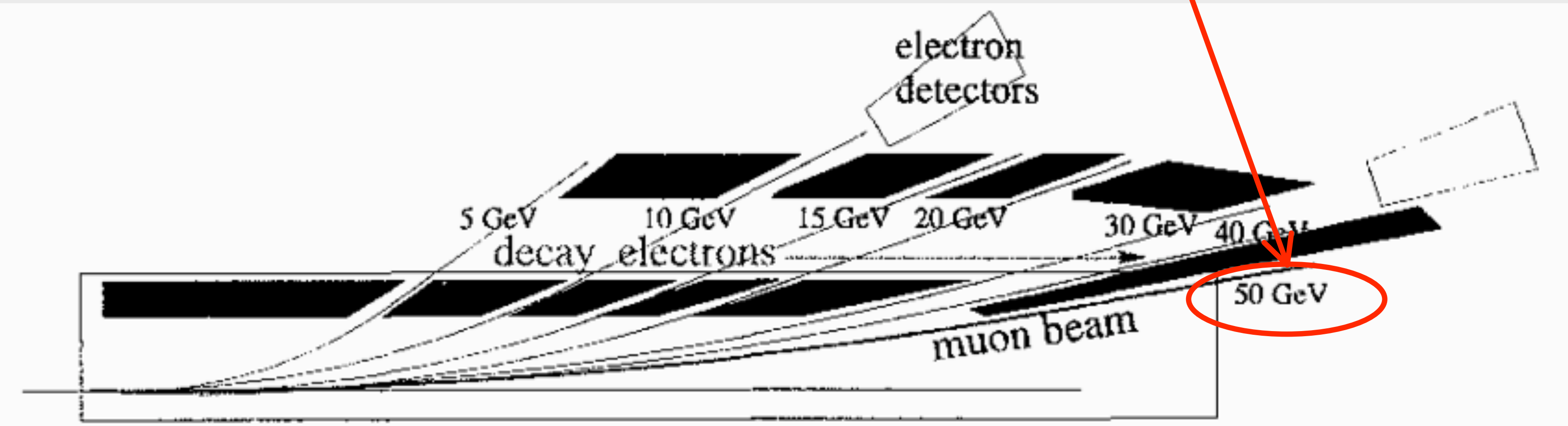


# Implementation

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

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# IDR preparations - status

- Define Reference Beam
- Redefine Solenoid Taper (for 1.25 T vs 1.5 T vs 1.75 T)
- Best Guess of achievable RF Voltage vs B @ 200 MHz
- Modified FS2A Front End
- Different Lithium Hydride mixtures, physics process model
- Tapering beta function
- Improved longitudinal and transverse matching
- Optimised buncher & phase rotation
- Buncher variations on a theme (shorter bunch train, etc)
- Buncher & rotator length vs gradient study
- Cooling performance degraded with different RF voltages
- Shielded cavities or Bucked coils
- High pressure RF
- Magnetically Insulated Lattice (BxE = 0)
- Low Frequency Scheme
- Helical FoFo Snake
- Helical Cooling Channel

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# IDR preparations - to do list

- Description of baseline
- ICOOL Optics Lattice
- 2D magnet designs
- Current densities, J vs B, tracking through field map
- 2D RF cavity designs
- Q-Factor for power supply costing
- LiH absorber heat load, decision on active cooling
- Description of one backup option for RF peak field mitigation?
- Optics only
- Costing
- Hardware inventory
- Cost scaling
- Preliminary estimate shielding/collimation issues + requirements
- Preliminary estimate civil engineering issues
- How does the requirement for a CERN design study match available manpower? CERN must provide resources...

# 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)