Neutrino factory design study R&D projects in Europe

J. Pozimski

EUROν - WP 3 and the IDS

The EUROν - WP 3 is an integral part of the international design effort IDS-NF

- To integrate additional EU partners into IDS
- End to end simulation (target to decay rings) for performance and cost evaluation.
- Proton beam handling after target & safety issues
- Input of new ideas from new members……

IDS - aims

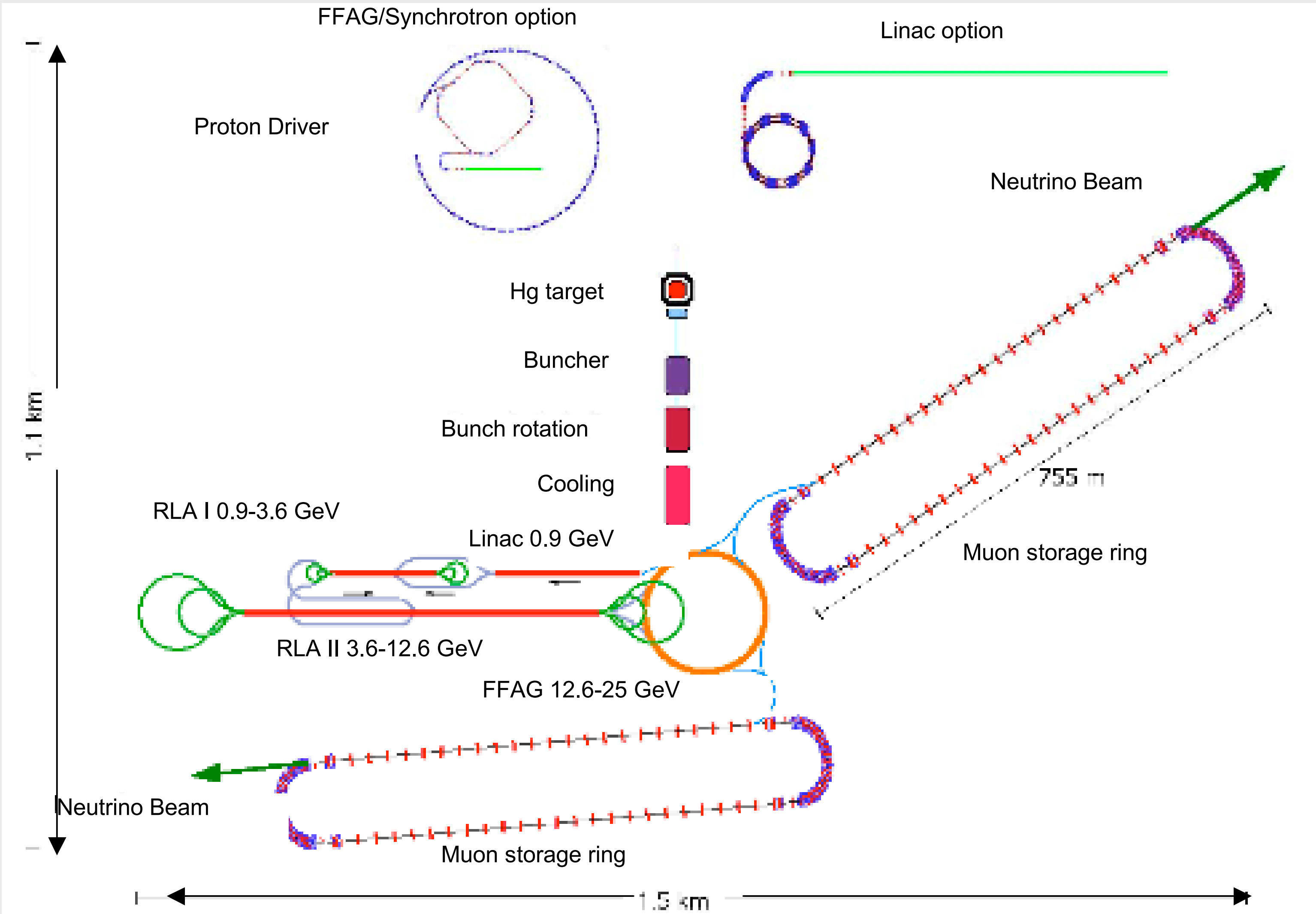
- To deliver an interims design report until 2010
  with a first costing to be 50-70% accurate

- To deliver an reference design report until 2012
  End to end simulations of muon linac
  Performance evaluation of facility
  costing to be 30-50% accurate

Organisation of the working group

System Sub-system	Task list Performed	 Required	Coordinators	Comments
Target	Optics Tracking 1 Tracking 2	CDR IDR costing	C.Densham (RAL), H.Kirk (BNL)	Particle production must be revisited when HARP results are included in MARS/Geant4
Muon front-end			C.Rogers (ASTeC), D.Neuffer (FNAL)	
Capture	Optics Tracking 1	Tracking 2 CDR IDR costing		
Bunching and phase rotation	Optics → Tracking 1 →	Tracking 2 CDR IDR costing		Risk mitigation: evaluate to what extent minor lattice revisions are required if it is demonstrated that the baseline gradient can not be achieved in the magnetic field.
Cooling	Optics → Tracking 1 →	Tracking 2 CDR IDR costing		Risk mitigation: evaluate to what extent minor lattice revisions are required if it is demonstrated that the baseline gradient can not be achieved in the magnetic field.
Acceleration ***Linear accelerators***	Optics	Tracking 1 Tracking 2 CDR IDR costing	A.Bogacz (JLab), J.Pozimski (ICL)	
FFAG	Optics → Tracking 1 →	Tracking 2 CDR IDR costing	S.Berg (BNL), S.Machida (RAL)	While initial optics and tracking work has been done, the fact that an injection and extraction scheme has not been proposed implies that it is necessary to revisit both the optics analysis and the tracking.
Storage ring		Optics Tracking 1 Tracking 2 CDR IDR costing	C.Prior (ASTeC), ANO	Present lattices store muons of a single charge only. A modification of the optics is required to allow positive and negative muons to be stored simultaneously.

The IDS baseline-overview



Proton driver and target baseline

Sub-system	Parameter	Value
Proton driver	Average beam power (MW)	4
	Pulse repetition frequency (Hz)	50
	Proton kinetic energy (GeV)	10±5
	Proton rms bunch length (ns)	2±1
	Number of proton bunches per pulse	3
	Sequential extraction delay (μs)	≥17
	Pulse duration, liquid-Hg target (μs)	≤40
Target: liquid-mercury jet	Jet diameter (cm)	1
	Jet velocity (m/s)	20
	Solenoidal field at interaction point (T)	20
Pion collection	Tapered solenoidal channel Length (m)	12
	Field at target (T)	20
	Diameter at target (cm)	15
	Field at exit (T)	1.75
	Diameter at exit (cm)	25

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.

Proton driver projects:

CERN LINAC 4 / SPL

Fermilab Project X

RAL - ISIS upgrade

Good contacts between the projects

Linac/compressor ring option at CERN & Project X

Beam power (MW) 4

Beam energy (GeV) 5

Repetition rate (Hz) 50

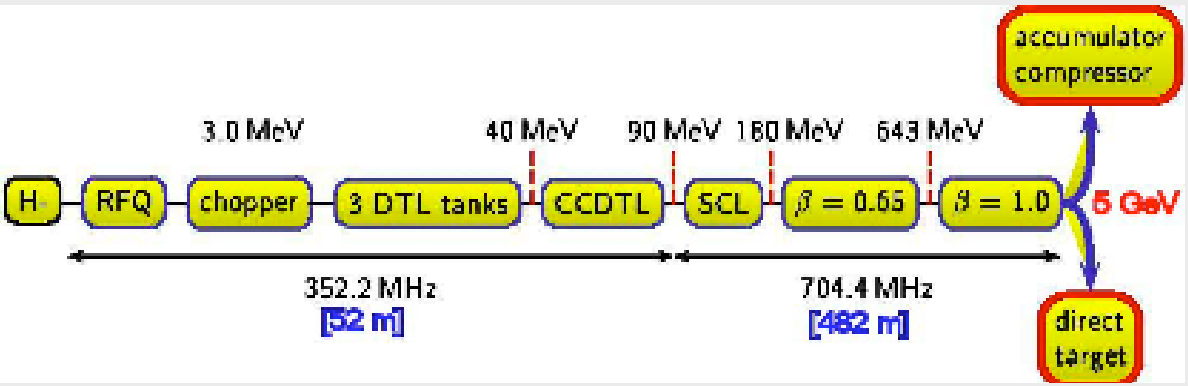
Average current (mA) 40

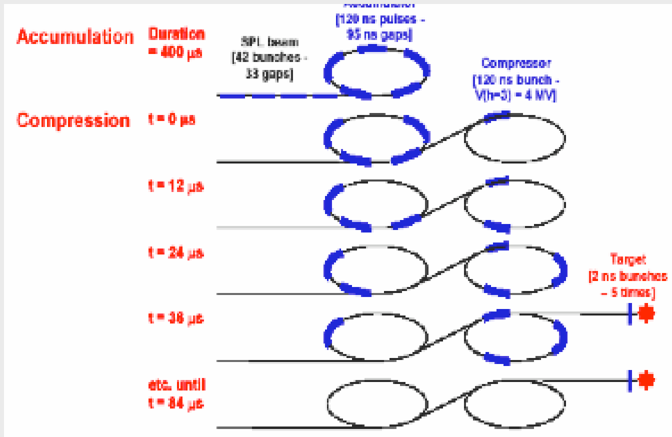
Beam power (MW) 200 kW/2.3 MW

Beam energy (GeV) 8 / 120

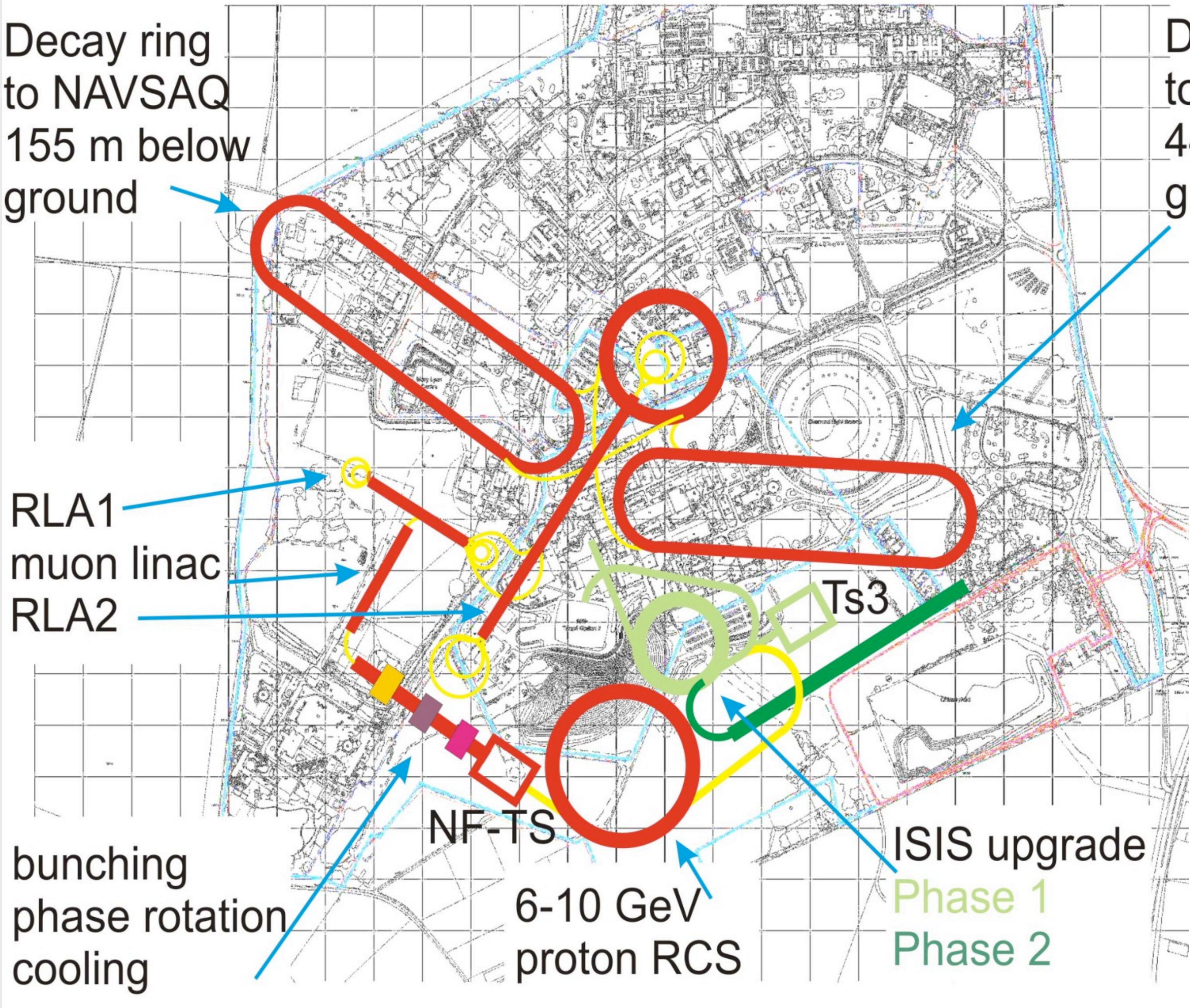
Repetition rate (Hz) <1

Average current (mA) 30





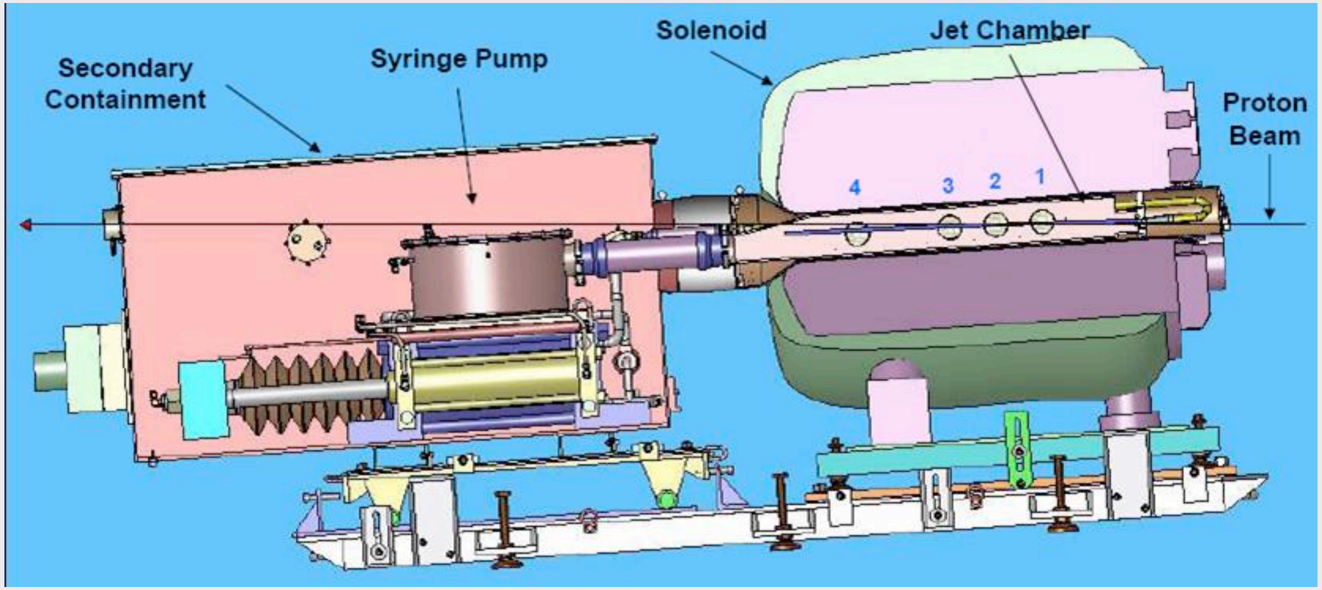
The Linac & RCS option (ISIS upgrade)

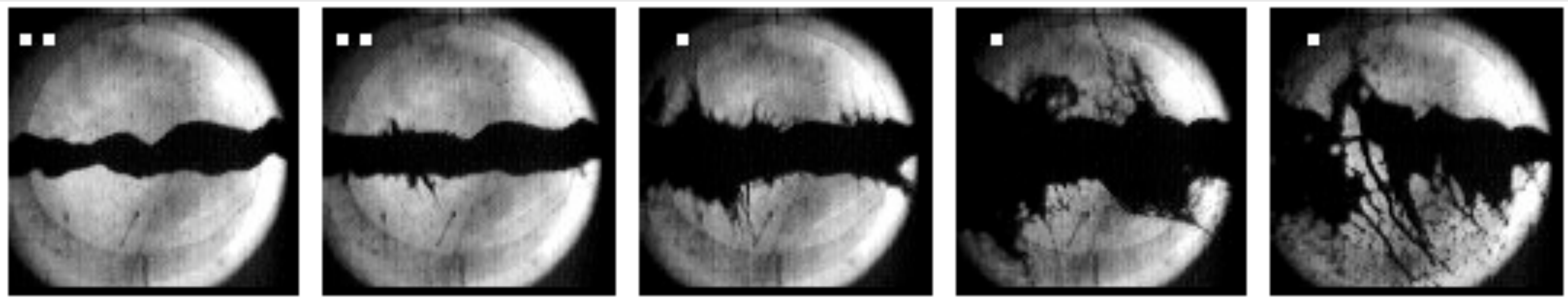


1) RCS from 800 MeV to 3.2 GeV (~1 MW)
2) Linac (800MeV) to replace old ISIS RCS (~ 2+2 MW)
3) RCS from 3.2 GeV to 6-10 GeV (4 MW)

Target R&D Mercury target

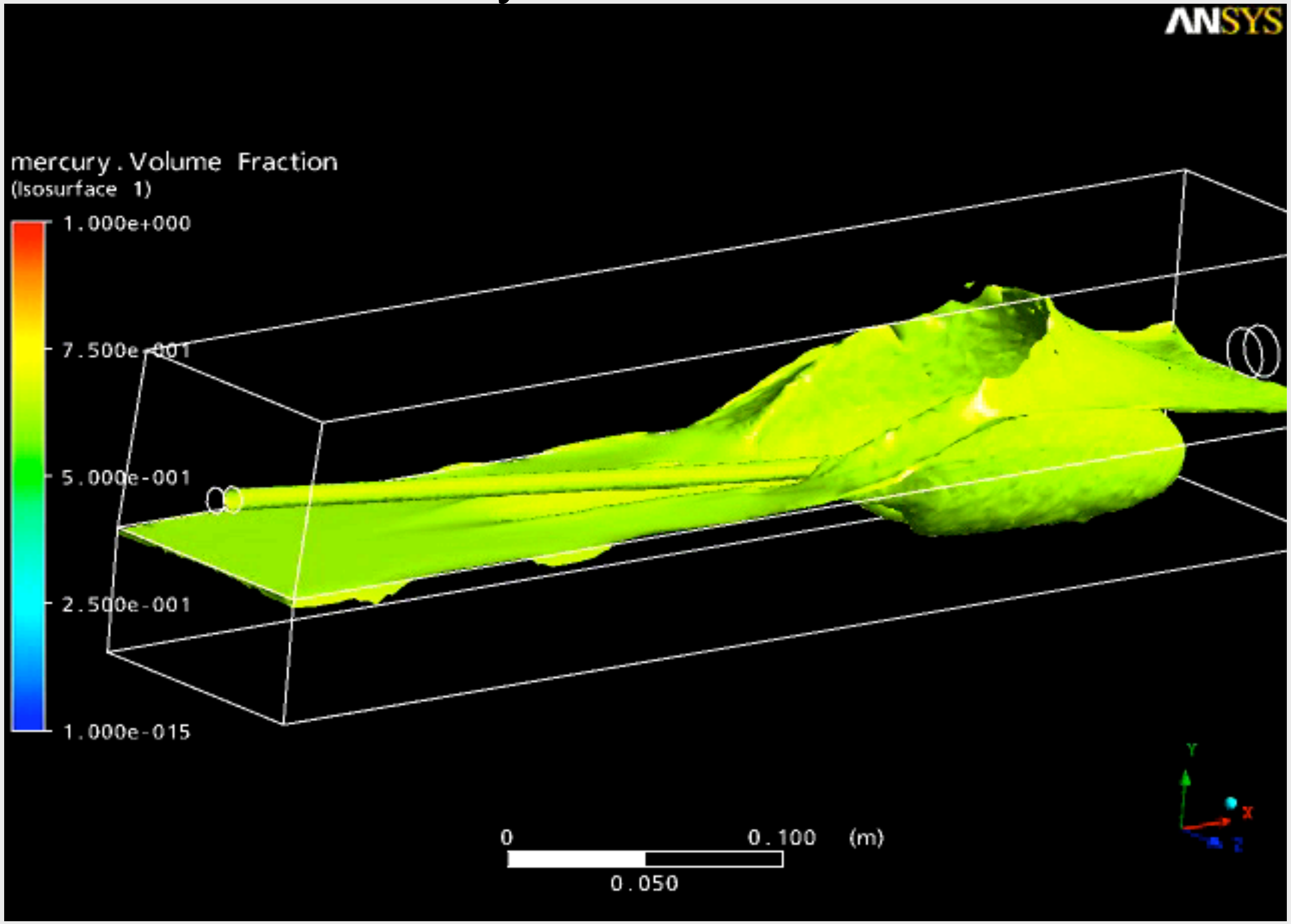
The Merit experiment : IDS baseline target



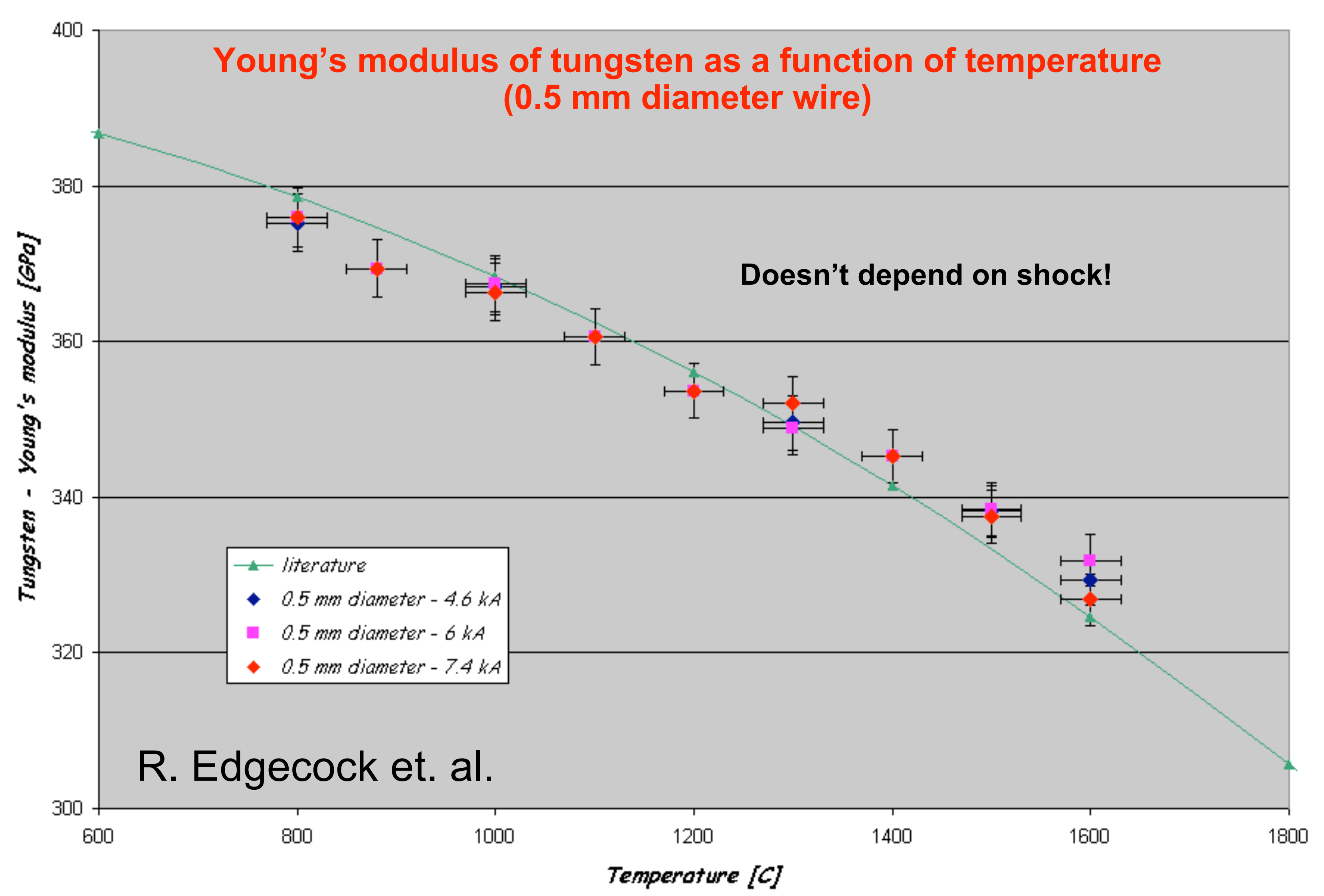


Target R&D Mercury target

CFD simulation of mercury jet interaction with beam dump
by Tristan Davenne



Target R&D - Solid target



Target R&D - Solid target

- **Shock:**

  We've done this to death!

  Don't believe it is a problem

  Tests with beams to come (anyone offers a beam ?)

- **Radiation damage:**

  Lots of local experience exists

  Needs to be applied to our case

- **Target wheel:**

  Structure looks feasible – detailed study underway

  Integration with magnets being studied

  60% of Study II pion capture achievable now

  Ideas to increase to 100% being investigated

Target R&D - Powder jet

O.Caretta, P.Loveridge and C.J.Densham

Achieved a dense and coherent jet:
- Estimated 42% +-5% v/v i.e. ~8000 kg/m^3
- 1m long, 20mm diameter pipe generating a 300 mm long jet.

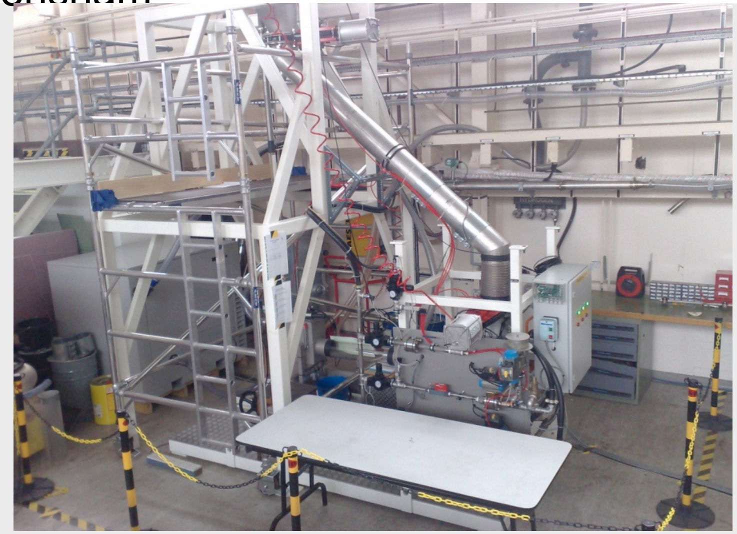
Little erosion of dense phase conveying components:
- no scratching of glass discharge pipe

Moving components (i.e. valves) removed from the proximity of the beam

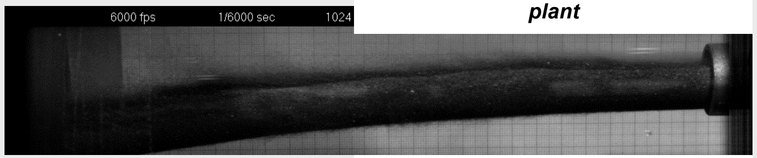
Steady flow was achieved in pipe:
- flow restarts even with a packed nozzle

Particle Image Velocimetry analysis of the high speed video of the jet is in progress

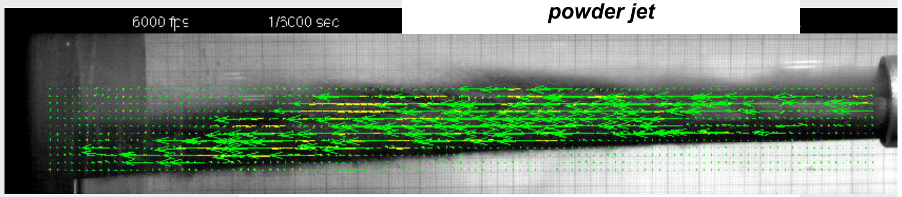
Plant has reliably conveyed 4.5 tonne of tungsten powder so far



Re-circulating tungsten powder plant



High speed image: tungsten powder jet



Particle Image Velocimetry applied to the jet

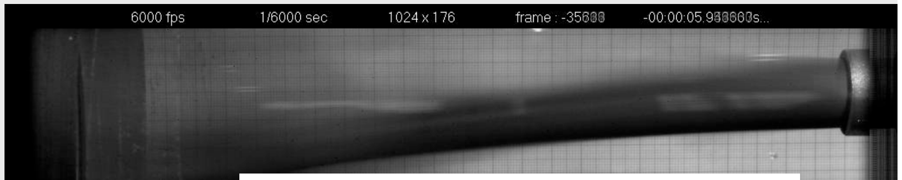
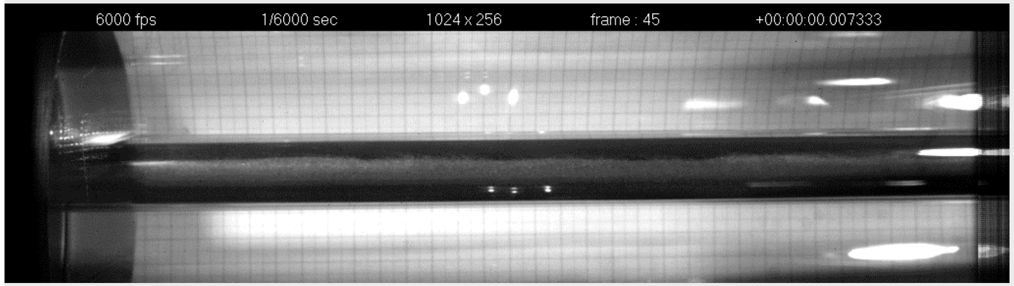


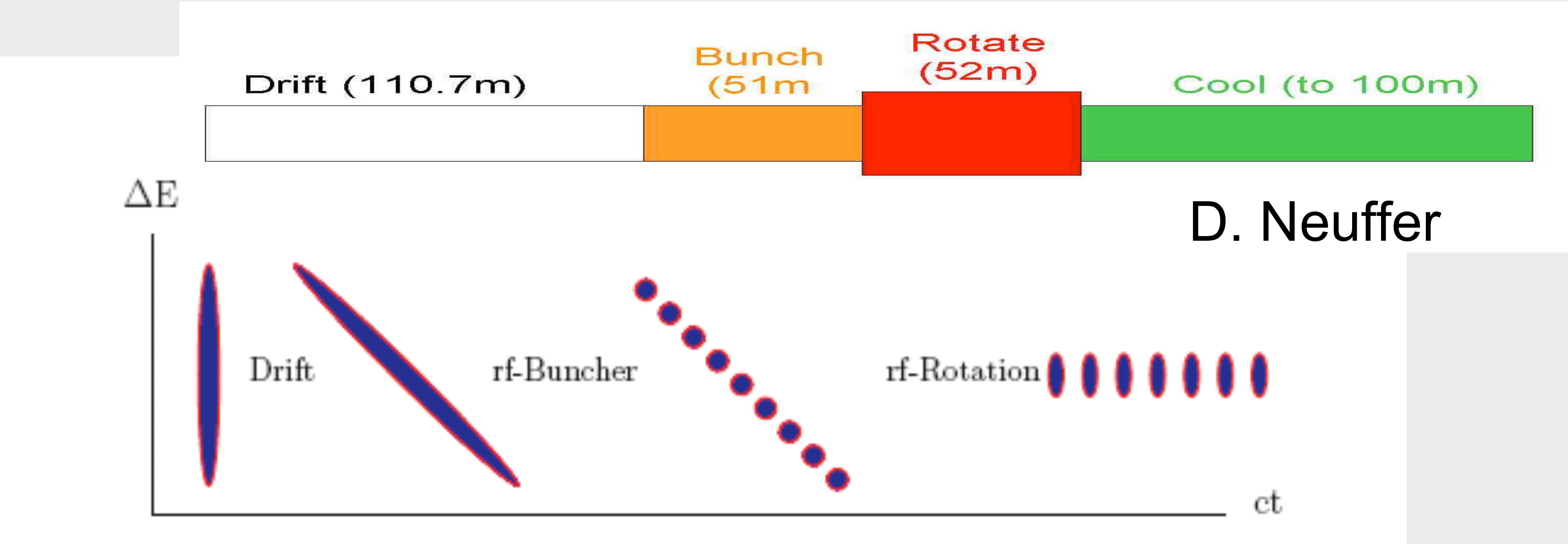
Image analysis: average jet



High speed image: tungsten powder flow in a pipe

The muon front end layout

- **Goal is capture and cool as many μ's as possible**
  - Capture within rf buckets
  - f=200MHz
  - p= 200 MeV/c $\delta p_{r,s}$= 10%
- **High Frequency buncher/rotation**
- **Common for ν-Factor and μ^+-μ Collider**



D. Neuffer

The IDS baseline-muon front end

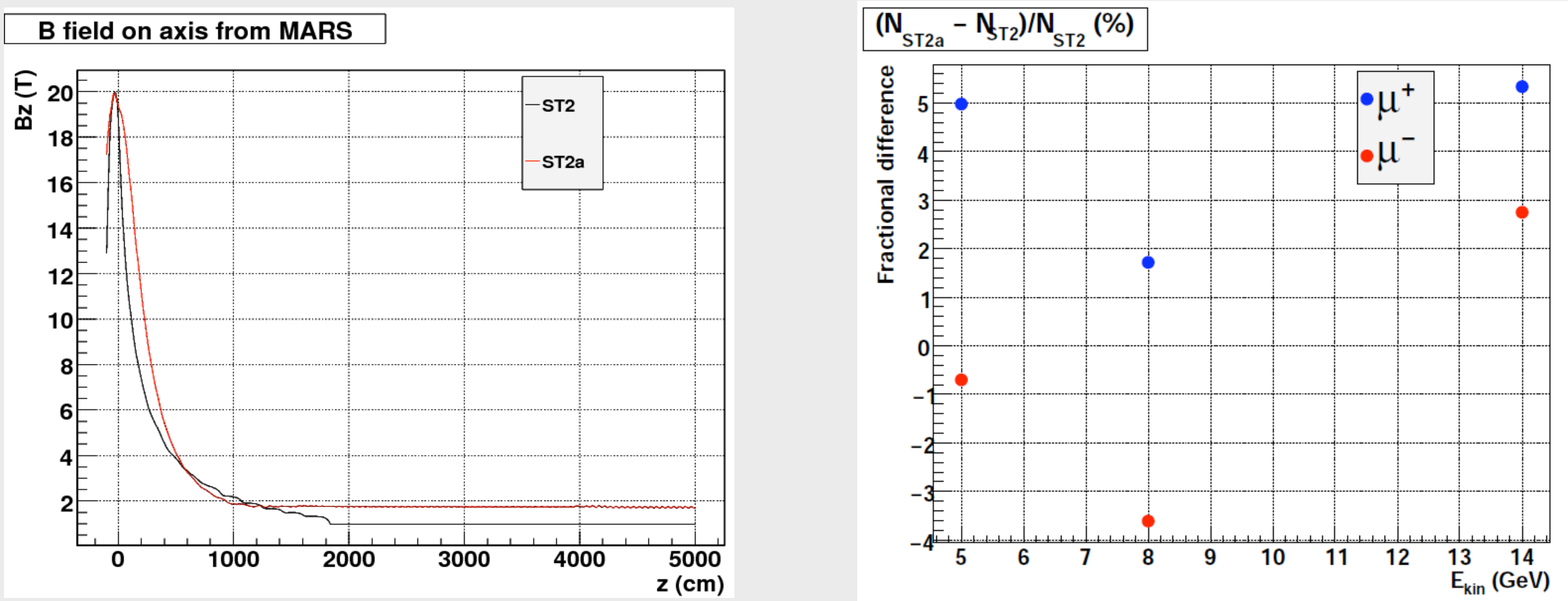
Sub-system	Parameter	Value
Decay channel	Length (m)	100
Adiabatic buncher	Length (m)	50
Phase rotator	Length (m)	50
	Energy spread at exit (%)	10.5
Ionisation cooling channel	Length (m)	80
	RF frequency (MHz)	201.25
	Absorber material	LiH
	Absorber thickness (cm)	1
	Input emittance (mm rad)	17
	Output emittance (mm rad)	7.4
	Central momentum (MeV/c)	220
	Solenoidal focussing field (T)	2.8

Pions production @target from MARS

Comparison at z = 50 cm, 40 < E_{kin} < 180 MeV for 5-8-14 GeV:

- with different code version the muon yield varies by 1-7%

- with different field maps the muon yield varies by 1-6%



G. Prior

(Previous study was giving a 10% increase).

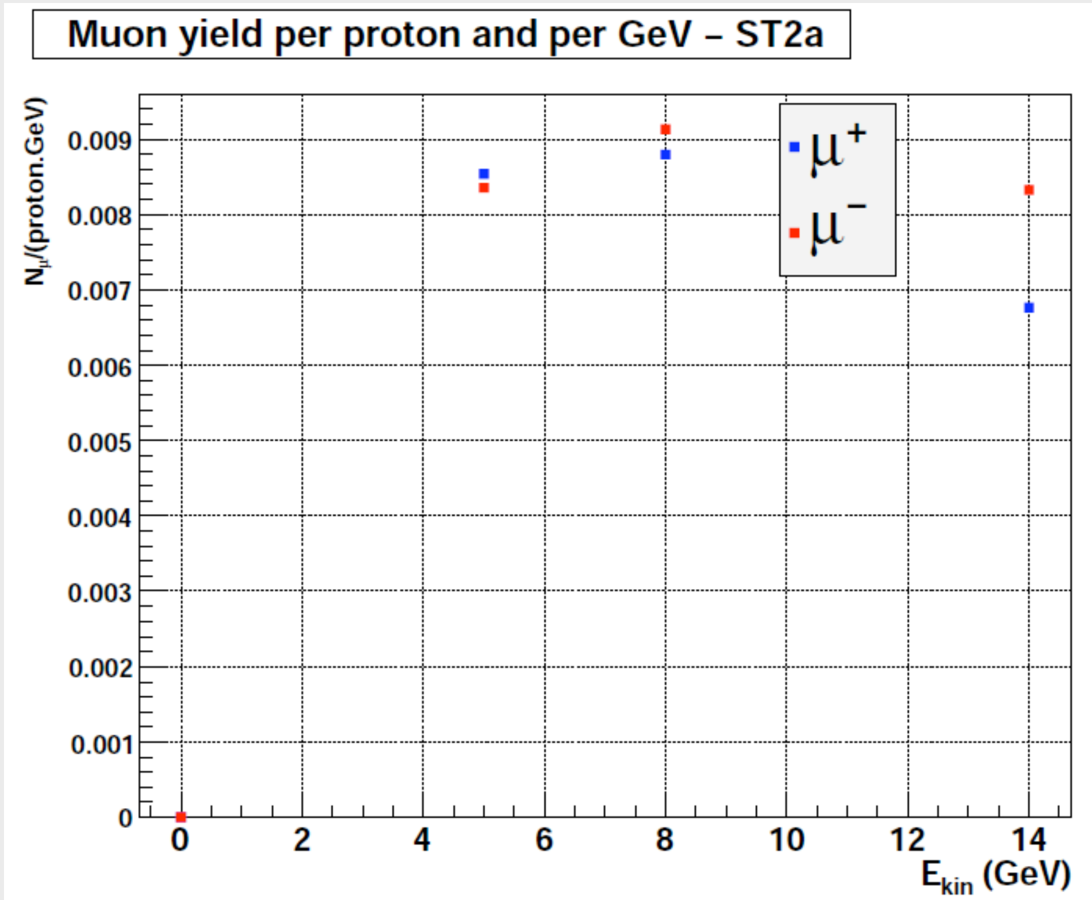
Pion/Muon tracking in ICOOL

At the end of the cooling channel with the acceptance cuts:

$A_{¤¤}$ = 150 mm

$A_{^}$ = 30 mm

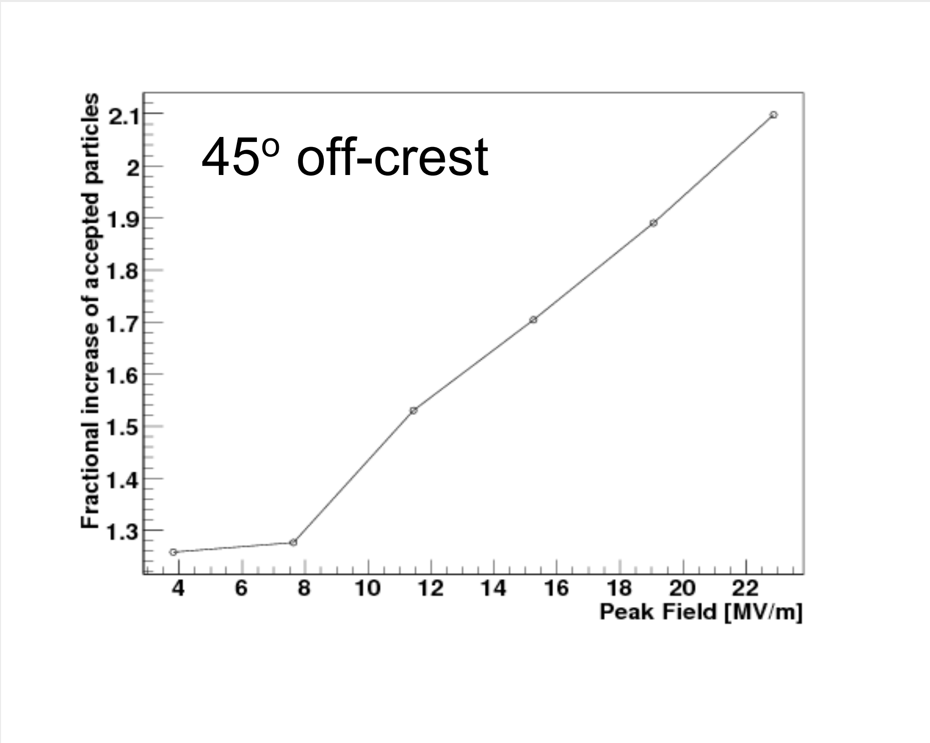
50 < p < 400 MeV/c

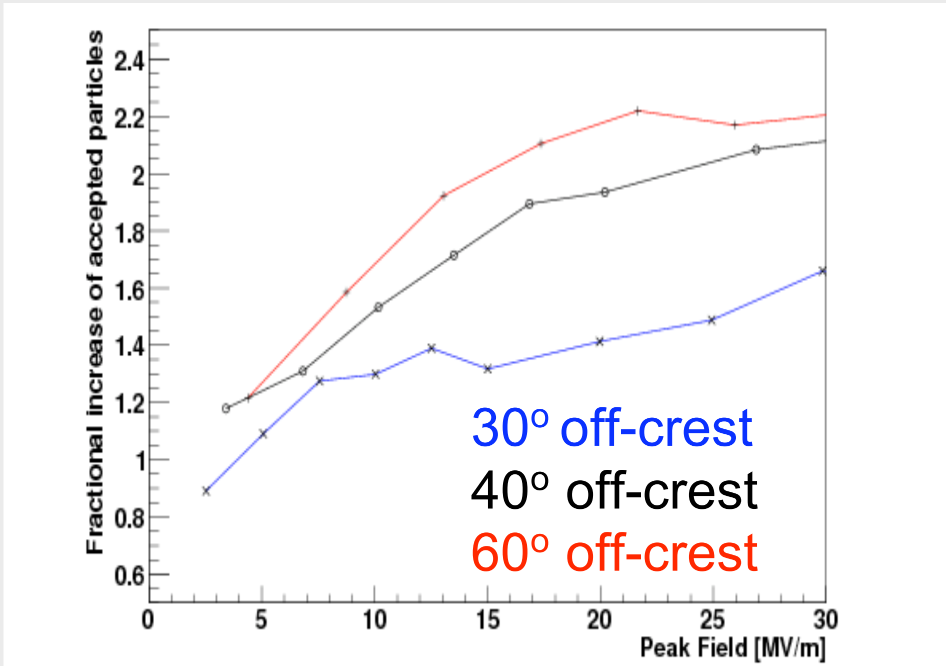


8 GeV still favored but may change with the new MARS generator (LAQGSM)

Cooling performance with reduced gradients

ICOOL code (left) and G4MICE code (right):

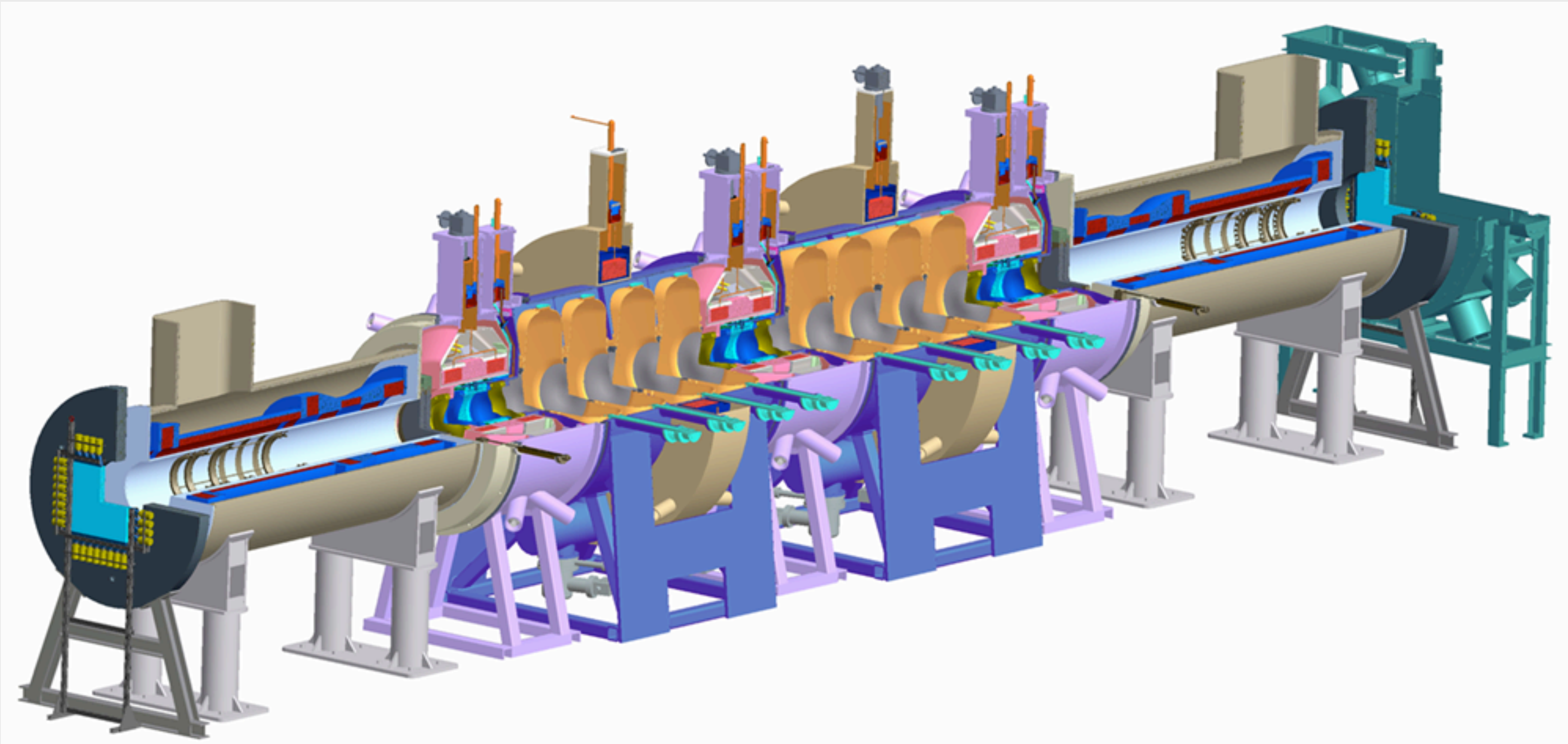




Difference in performance likely due to differences in LiH modelling.

The MICE experiment

PoP experiment for muon ionisation cooling essential for NF and muon collider



THE MICE COLLABORATION -130 collaborators -

Universite Catholique de Louvain , Belgium

University of Sofia, Bulgaria

The Harbin Institute for Super Conducting Technologies PR China

INFN Milano , INFN Napoli , INFN Pavia, INFN Roma III , INFN Trieste , Italy

KEK, Kyoto University, O saka University , Japan

NIKHEF , The Netherlands

CERN

Geneva University, Paul Scherrer Institut Switzerland

Brunel , Cockcroft/Lancaster, Glasgow, Liverpool, ICL London, Oxford, Darsbury, RAL, Sheffield UK

Argonne National Laboratory , Brookhaven National Laboratory , Fairfield University ,
University of Chicago , Enrico Fermi Institute , Fermilab , Illinois Institute of Technology ,
Jefferson Lab , Lawrence Berkeley National Laboratory , UCLA , Northern Illinois University ,
University of Iowa , University of Mississippi , UC Riverside ,
University of Illinois at Urbana -Champaign, Muons Inc. USA

RF cavities in magnetic fields

Problem :

To contain the beam within the acceptance of the cooling channel transversal focussing (solenoids 5T) is required together with an field gradient in the cavities of ~ 15 MV/m

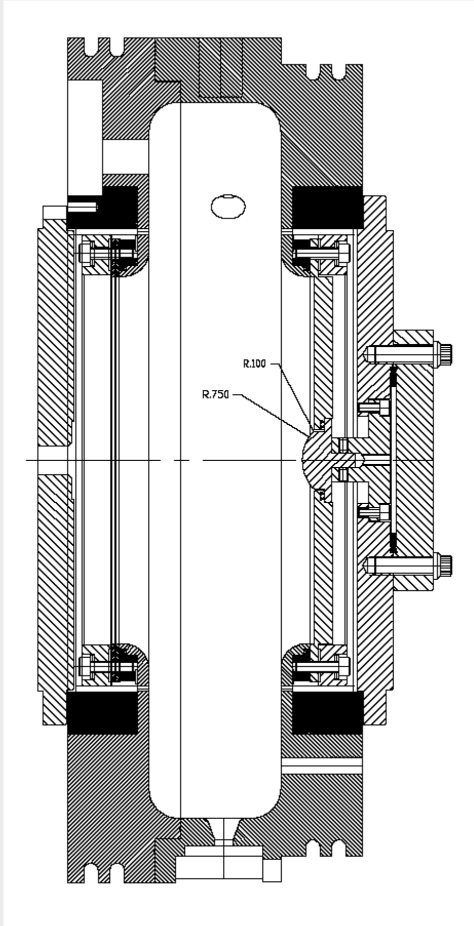
High magnetic fields degrades the available accelerating voltage (dark currents, RF breakdown) to below 10 MV/m and causes damage of RF cavities

Extensive experimental program underway to investigate this problem (surface roughness, coating, magnetic isolation)

=> Achievable gradient will strongly influence the design of muon front end.

MuCool Button Test

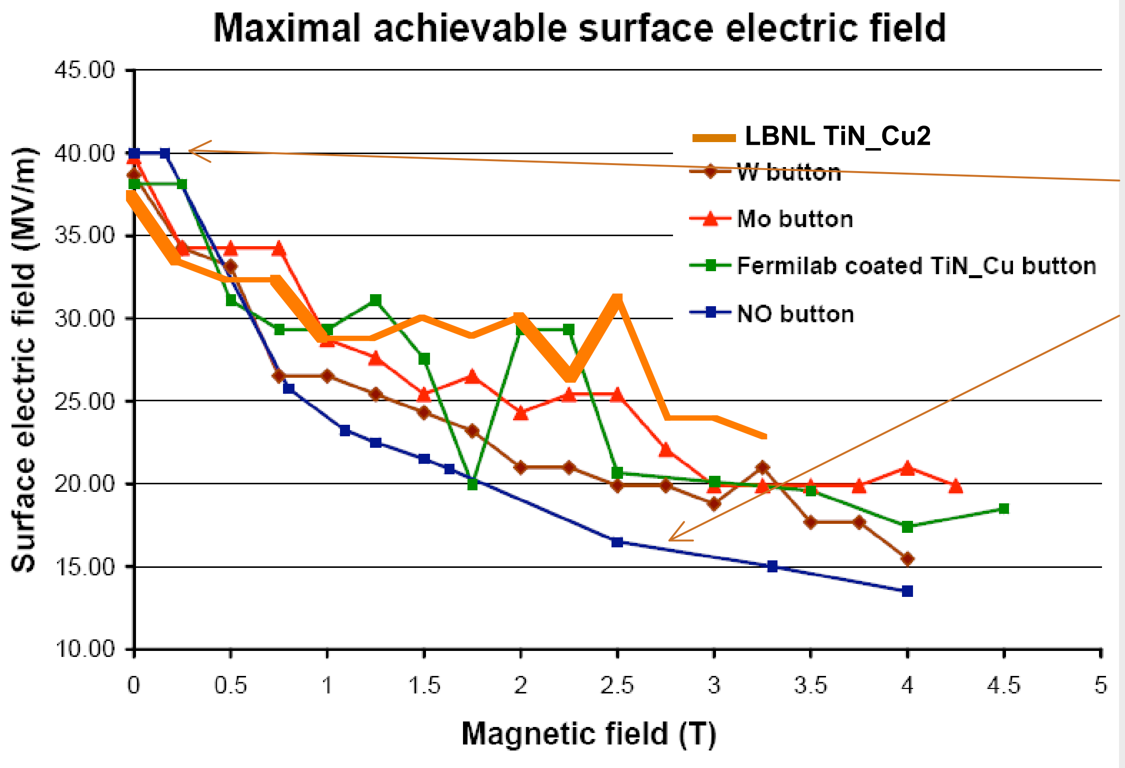
MTA Testing Area



805 MHz Cavity

Much of the effort has gone towards evaluating various material and coatings

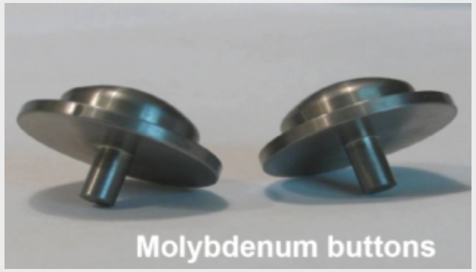
Button Test Results



No Button

40 MV/m no field

16 MV/m @ 2.8 T



D. Huang – MUTAC 08

Performance is considerably improved by using stronger material and better coatings

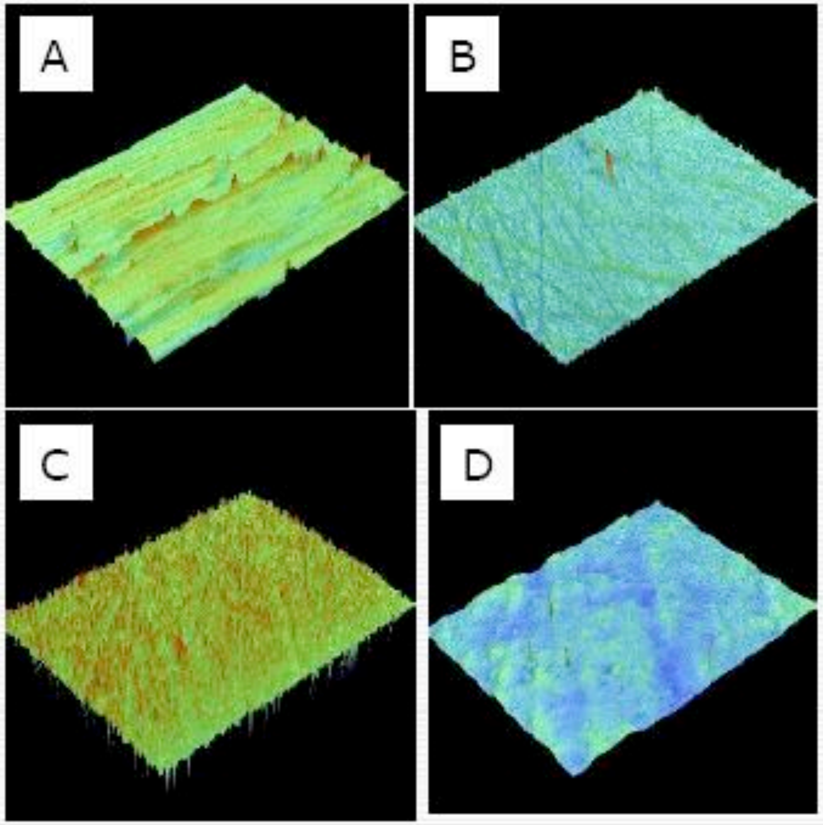
Main question:

- Reliability & reproducibility of existing results

INTERFEROMETER RESULTS

		RA (nm)	RQ (nm)
Flat Samples			
	As Received	106	143
	After Hand polish	140	194
	After Chemical etch	252	362
	After Electro polish	93	121
Button Samples			
	As Received	356	459
	After Hand polish	180	240
	After Chemical etch	220	292
	After Electro polish	98	120

Matthew Stable - 2008

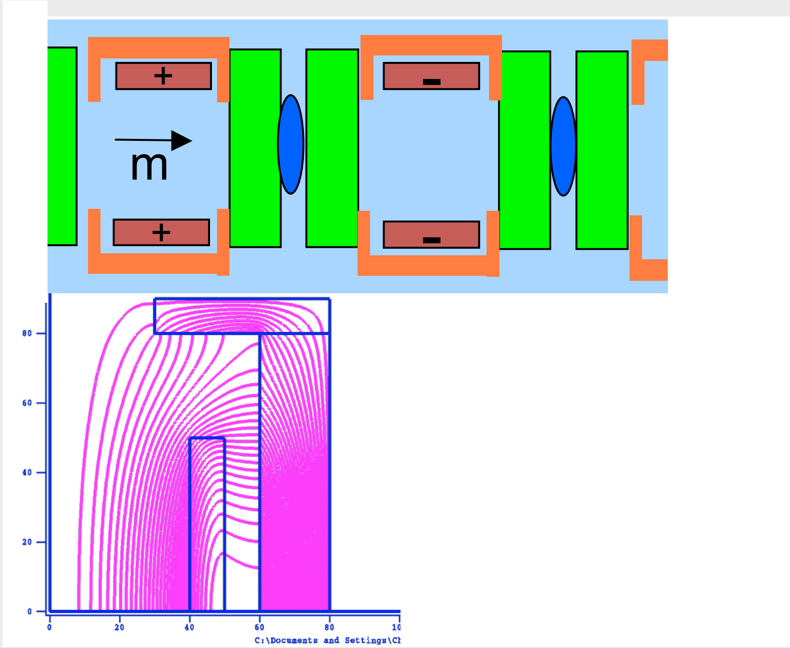


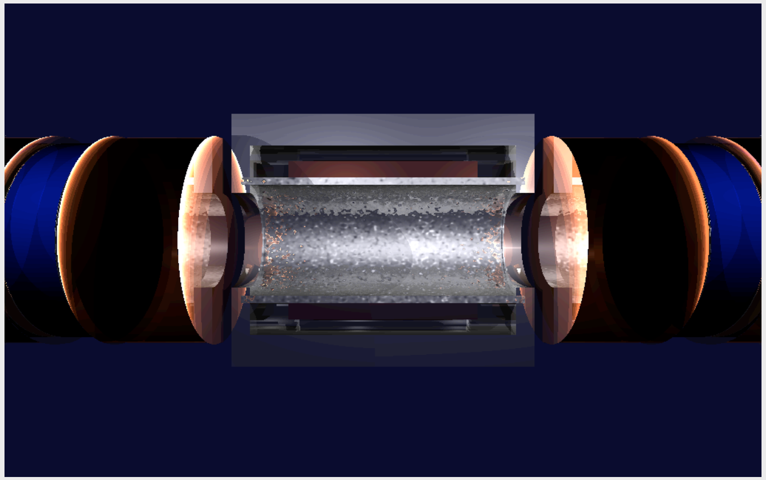
Mechanical polish and chemical etch remove deep scratches while EP reduces the average roughness

Shielded RF Lattice

- Aim is to shield RF cavities from solenoid fringe field
- Shorter solenoids have big spherical aberrations
- Requirements for big acceptance and tight focussing difficult to achieve
- Race between RF packing and optics performance

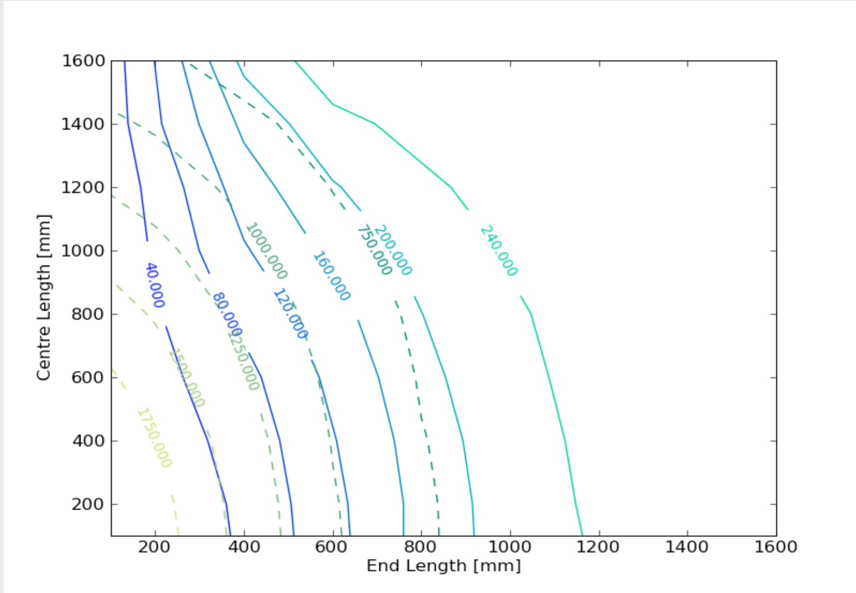
C. Rogers

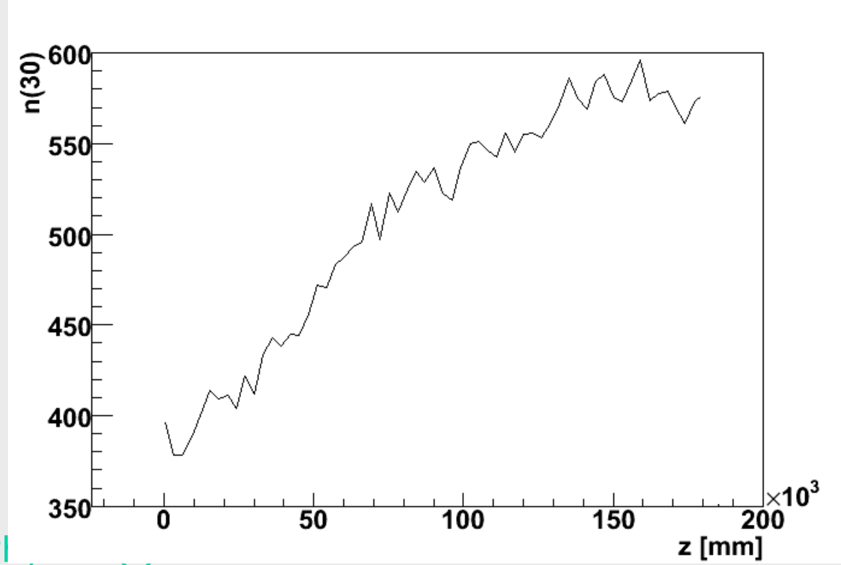




Cell Length

- Cell length optimisation
  - **Higher RF packing => quicker cooling, larger RF bucket**
  - **Shorter lattice => lower b function (better equilibrium emittance)**
- 3m lattice is optimal
  - **Get ~ 50 % improvement in muon rate**
    - *Still not as good as the IDS baseline*
    - *Probably more practical*
  - **Some "toy" magnet design started**
- Further optimisation on muon momentum in progress



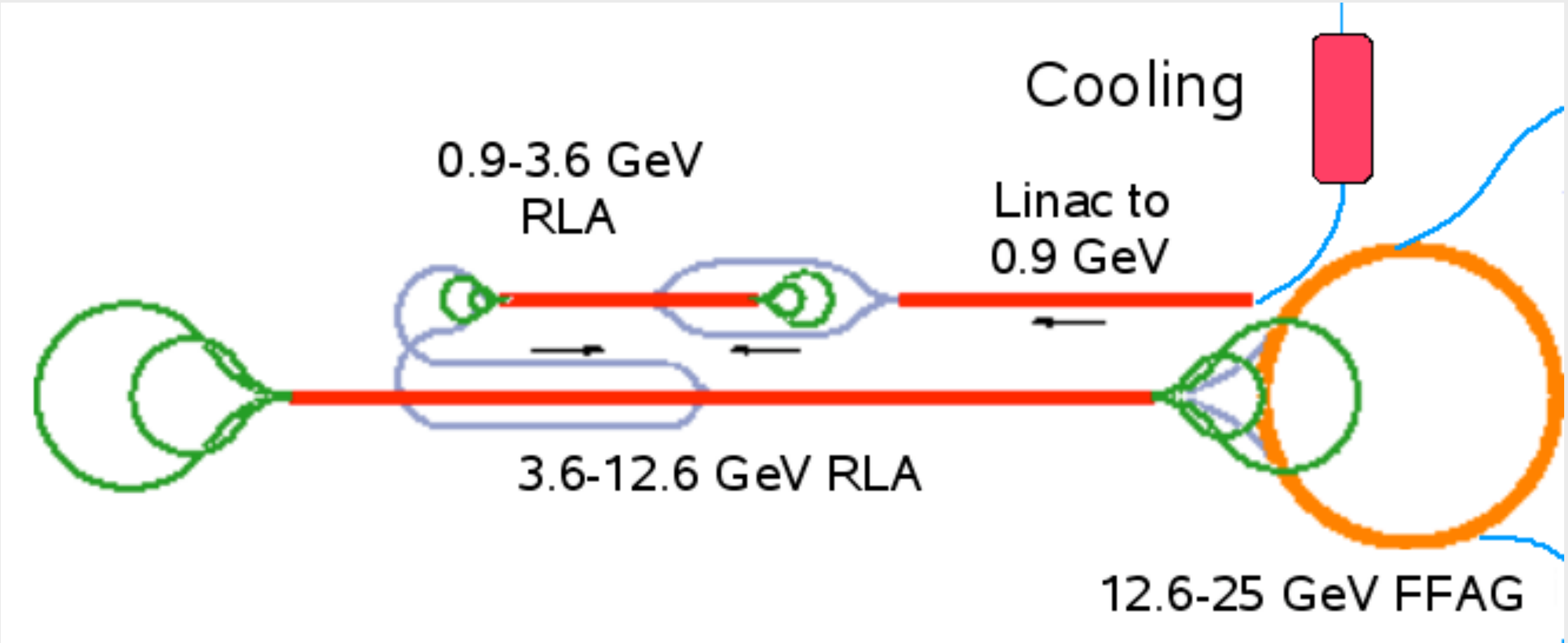


The IDS baseline-muon accelerator

Sub-system	Parameter	Value
Acceleration system	Total energy at input (MeV)	244
	Total energy at end of acceleration (GeV)	25
	Input transverse acceptance (mm rad)	30
	Input longitudinal acceptance (mm rad)	150
Pre-acceleration linac	Final total energy (GeV)	0.9
RLA(1)	Final total energy (GeV)	3.6
RLA(2)	Final total energy (GeV)	12.6
NFFAG	Final total energy (GeV)	25
Decay rings	Ring type	Race track
	Straight-section length (m)	600.2
	Race-track circumference (m)	1,608.80
	Number of rings (number of baselines)	2
	Stored muon energy (total energy, GeV)	25
	Beam divergence in production straight (γ-1)	0.1
	Bunch spacing (ns)	≥100
	Number of μ decays per year per baseline	$5*10^{20}$

Fast acceleration – Linac & RLA

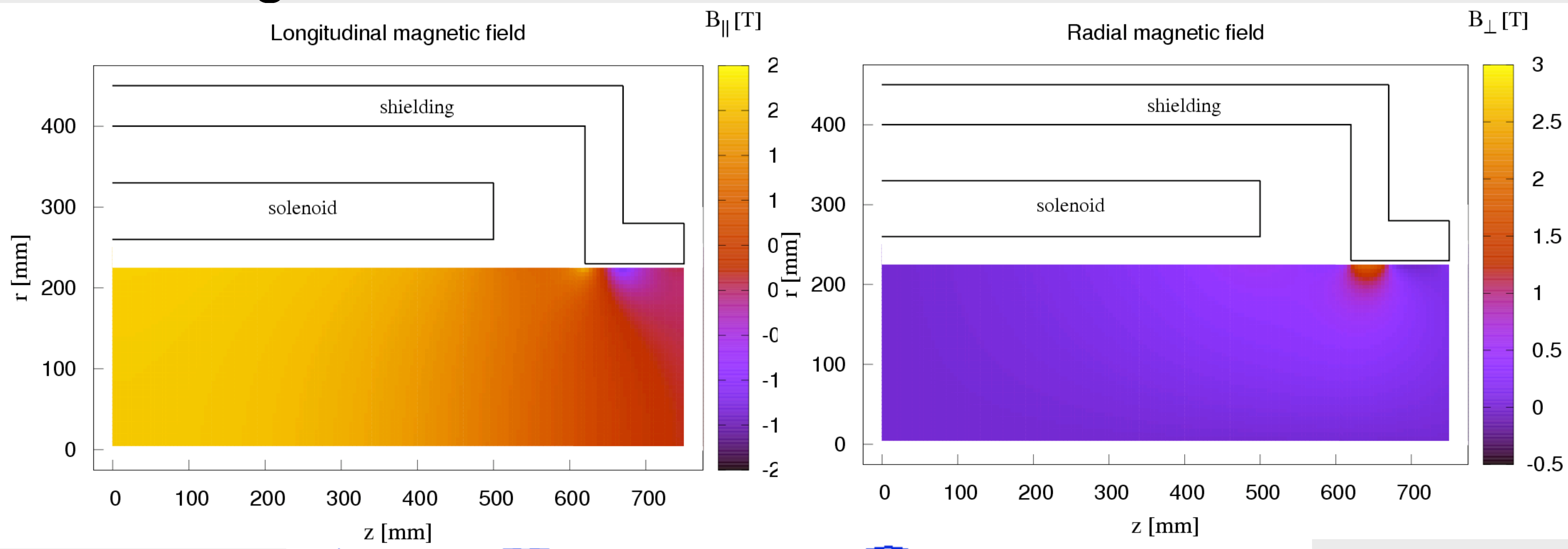
Initial design by A. Bogacz (Jefferson)

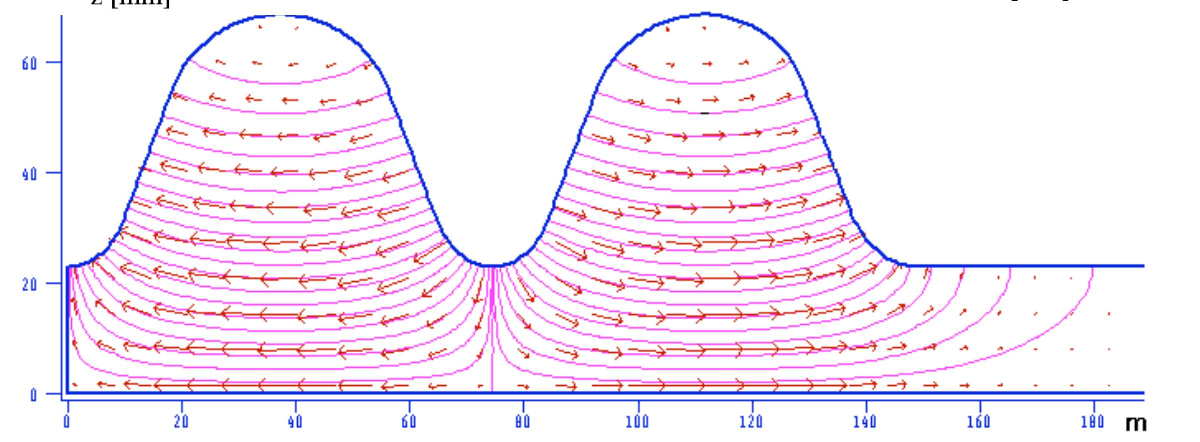


•Benchmarking of OPTIM design with MADX and confirmation of lattice (M. Aslaninejad).

Fast acceleration – Linac

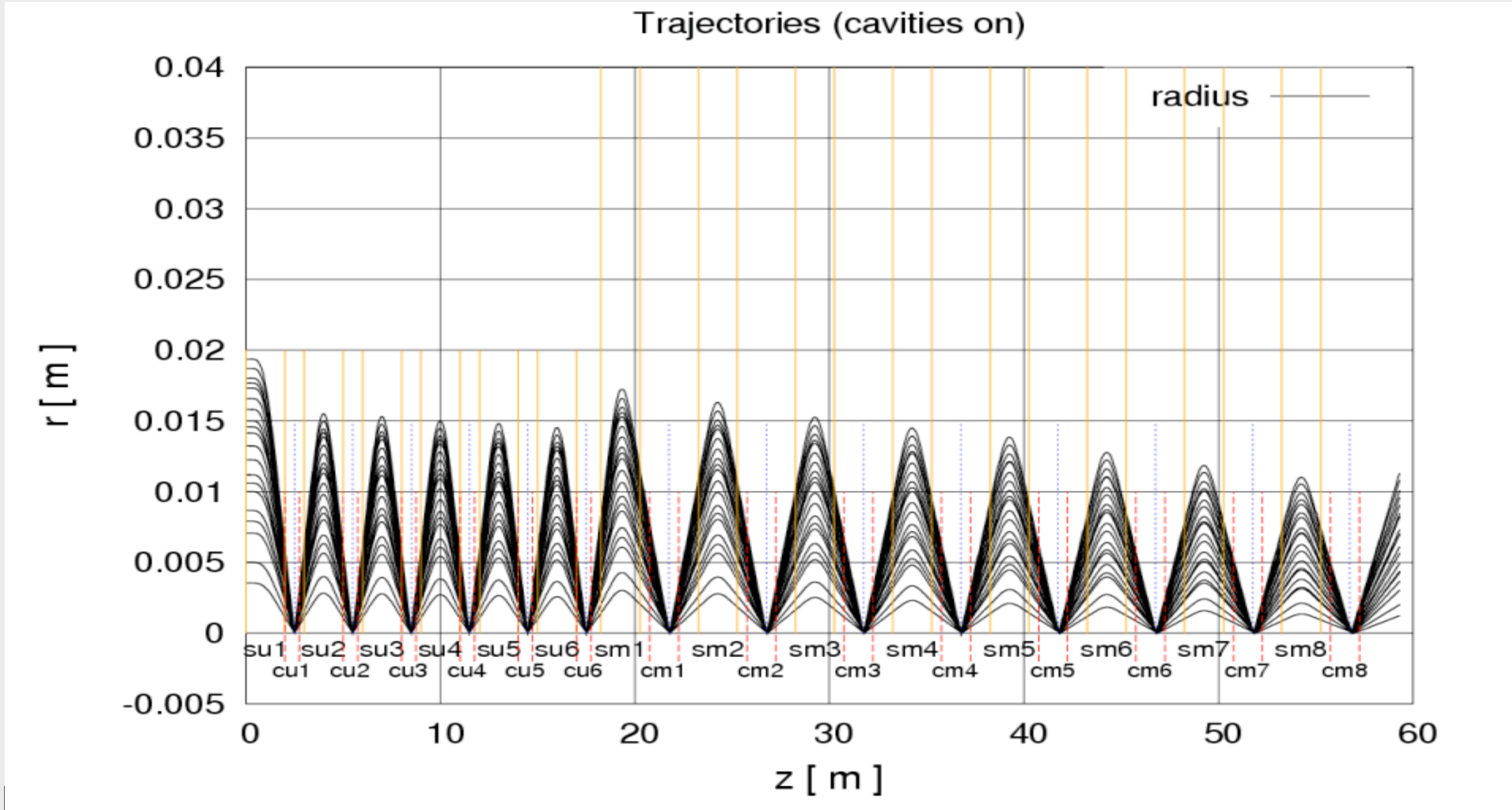
Modelling of solenoids and cavities





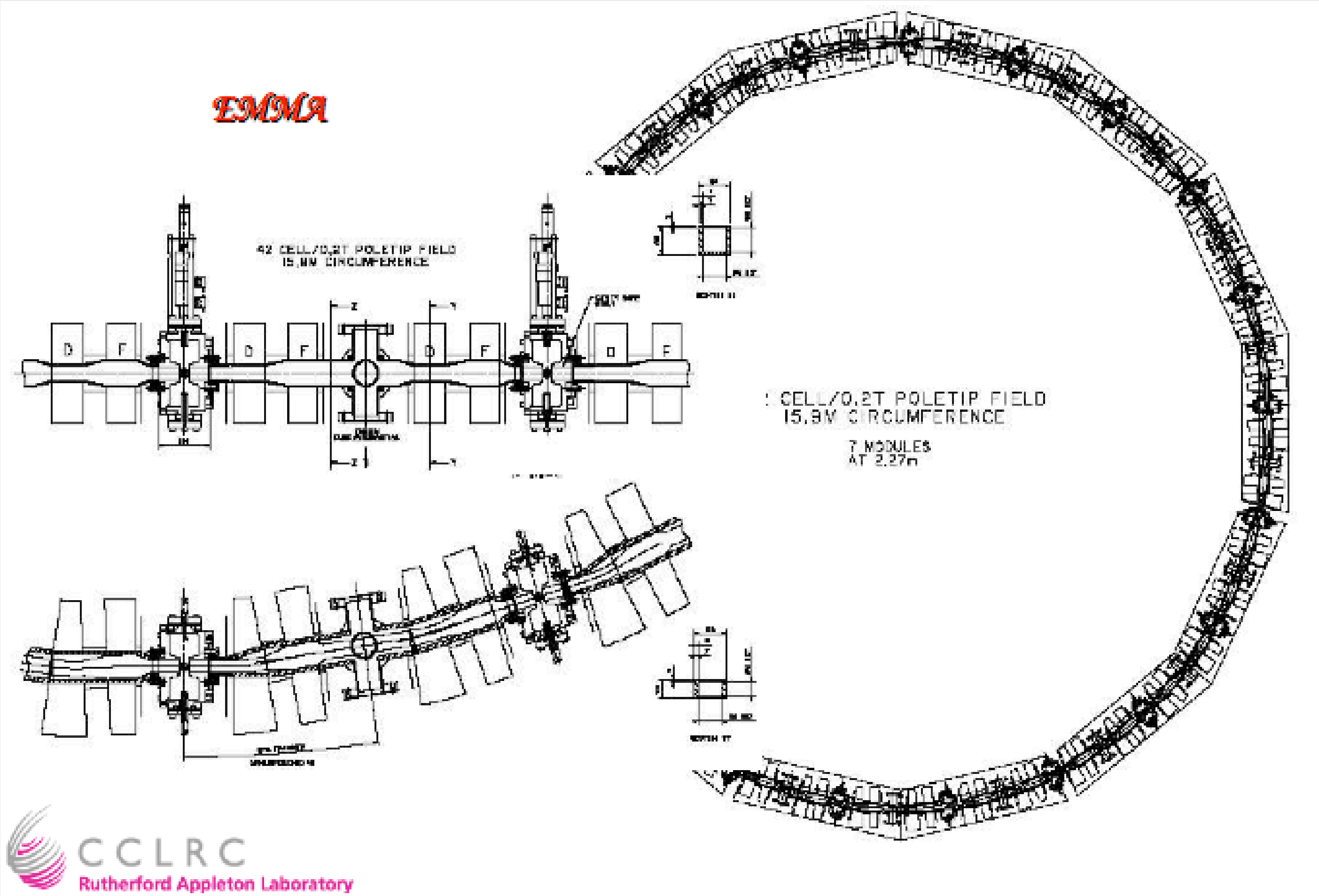
Fast acceleration – Linac

- Multiparticle tracking using field maps in GPT (C. Bontoiu)



- Benchmarking of droplet arcs with Zgoubi (F. Meot)

EMMA - first NS FFAG



1. Proof of principle
2. Electrons
3. 3 m inner radius
4. Acceleration from 10-20 MeV
5. Displaced quadrupoles

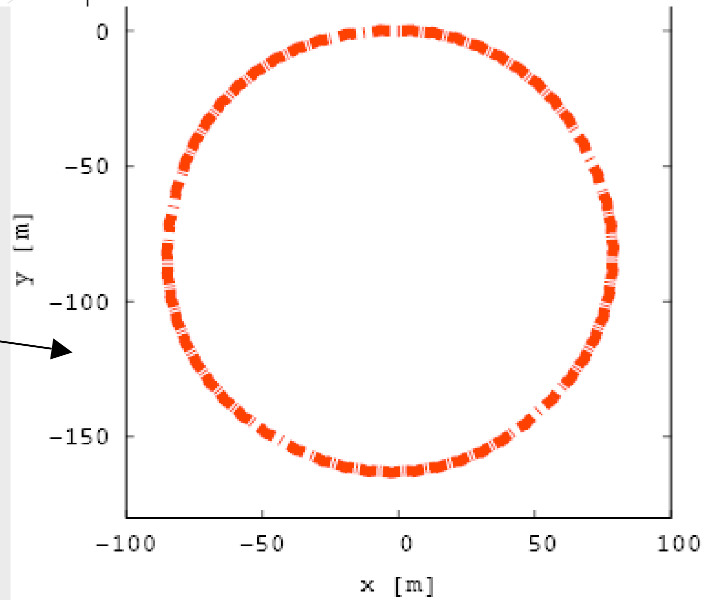
Fast acceleration - FFAG

- Quasi-Isochronus linear Non-Scaling FFAG was proposed for muon acceleration in the Neutrino Factory (12.6 – 25 GeV).
- It allows to use 200 MHz RF system and has a very large transverse acceptance.
- Beam dynamics in NS-FFAGs was studied using independent codes with a very good agreement.
- Lattice update was performed (Scott Berg).
- Alternative lattice with chromaticity correction and insertions was proposed (S. Machida).
- Schemes based on scaling FFAG are under study in Japan (Y. Mori *et al.).*

IDS-NF FFAG Parameters

	FCDC	FDFCC	FDFC
Cells	68	60	80
D radius (mm)	94	102	87
D field (T)	6.4	7.9	7.0
F radius (mm)	200	144	115
F field (T)	3.1	4.0	4.0
Average Gradient (MV/m)	2.8	2.6	1.6
turns	9.0	13.0	17.3
Length (m)	521	393	479
Cost (A.U.)	170	155	142

23

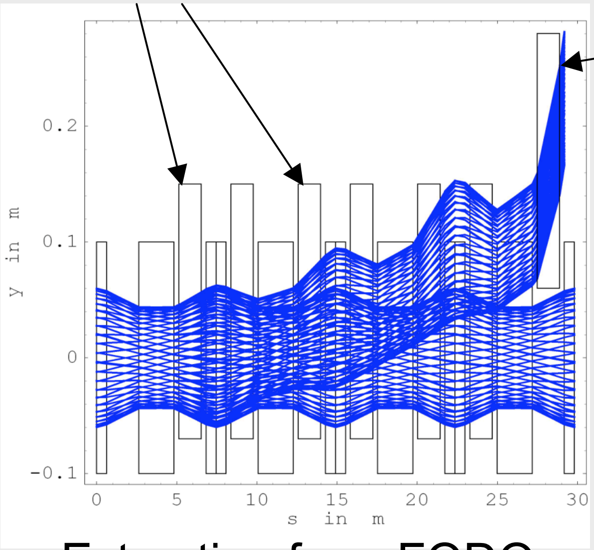


Fast acceleration - FFAG

- Injection and extraction schemes in the baseline triplet and FODO lattices have been evalueted (D. Kelliher, J. Pasternak)
- Triplet lattice seems to be easier due to the longer available drift length.
- All schemes require many kickers and large aperture magnets.
- Symmetry breaking effect due to those additional large aperture magnets is manageable.
- Parameters of the kicker magnets were estimated and are within the reach of the present technology

Kickers 0.1 T, 1.4 m

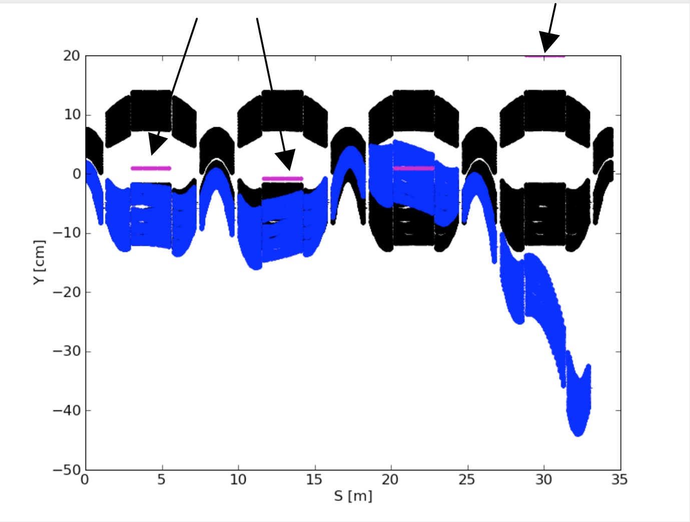
Septum



Extraction from FODO

Kickers

Septum



Injection into triplet lattice
(beam direction)

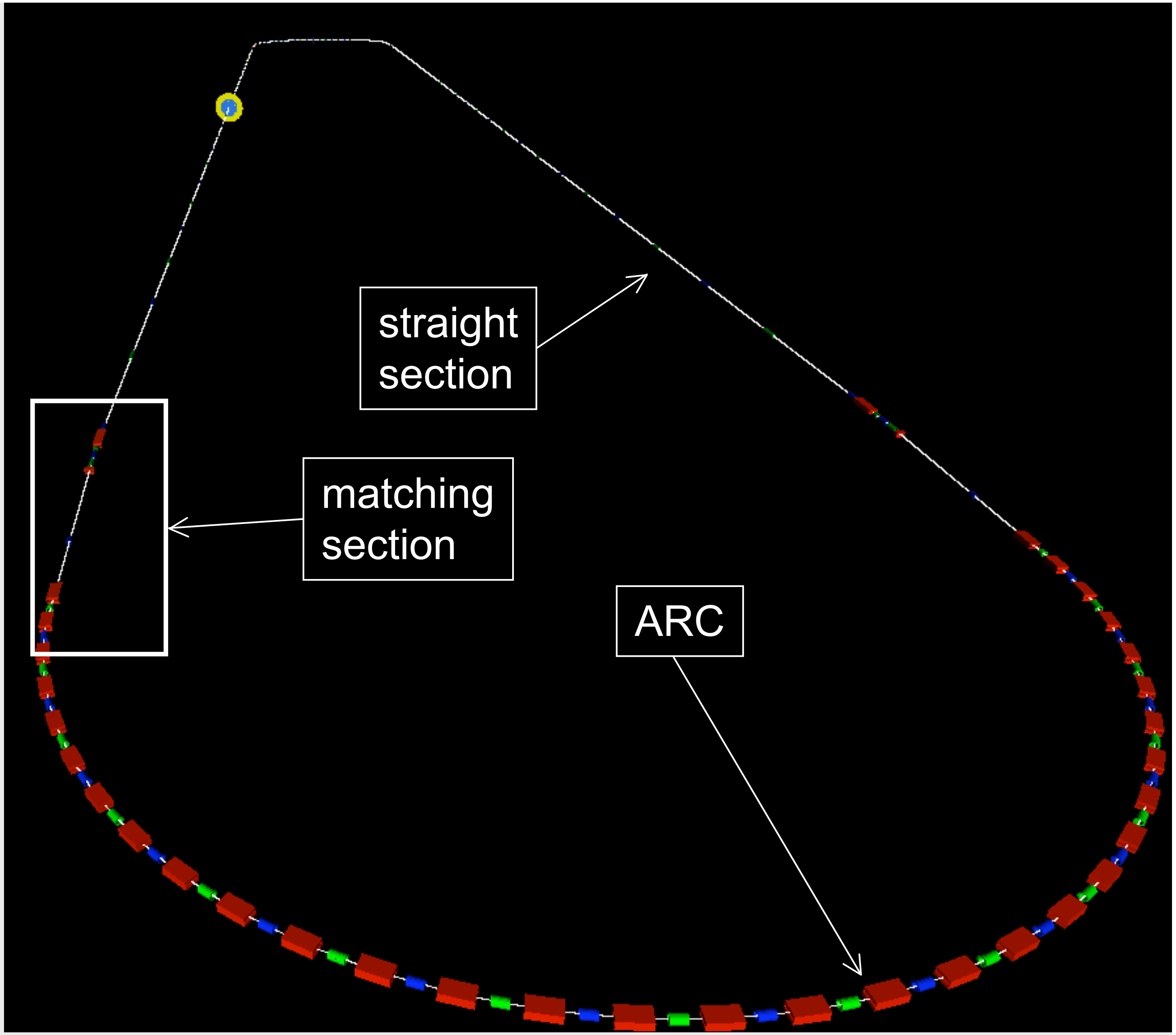
Decay rings

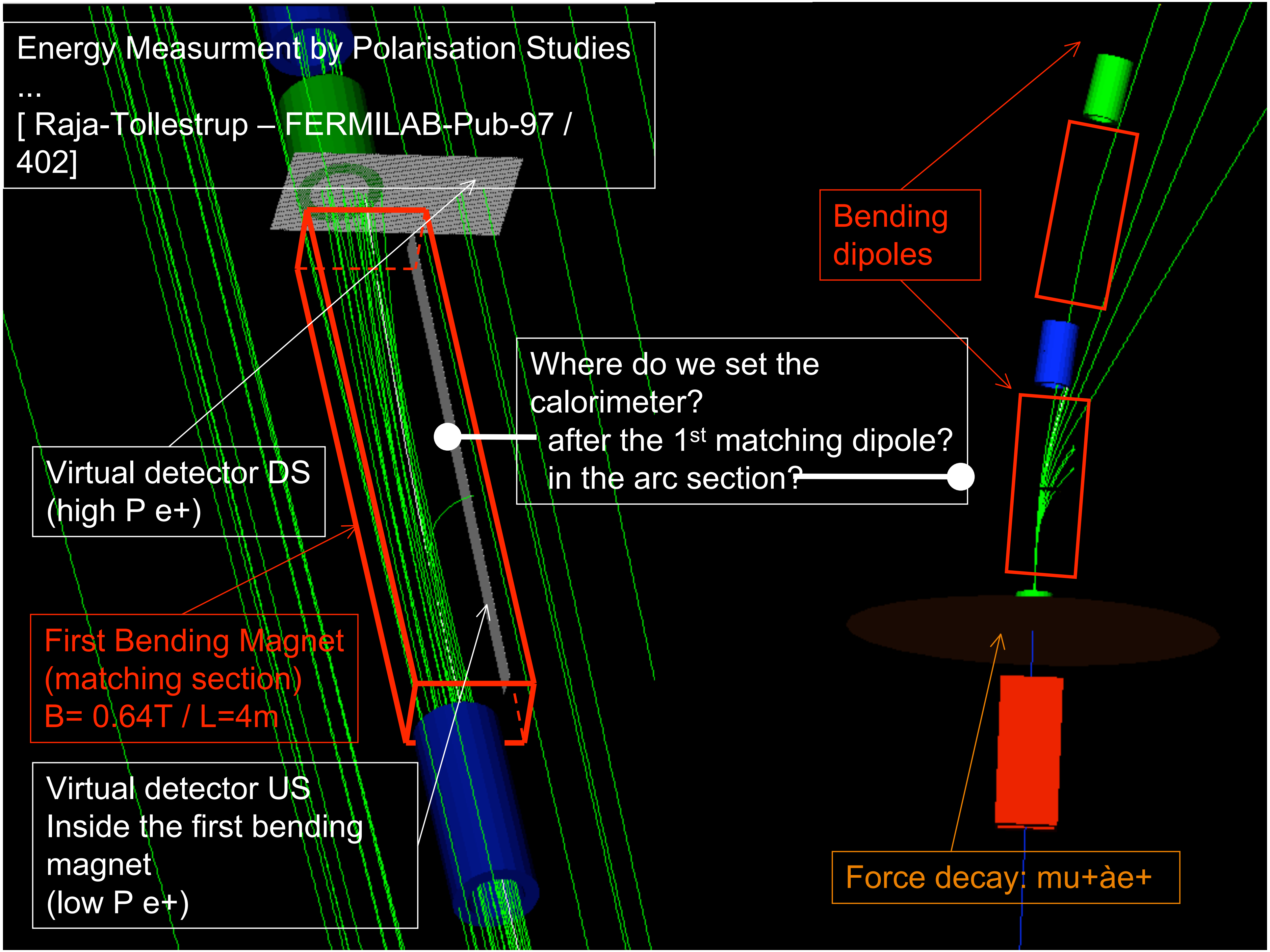
Lattice design of race track decay rings finished (25 GeV)

Particle tracking shows that presumably no rebunching is required.

Secondary particle production and investigation of beam diagnostics

C. Prior & M. Apollonio




Energy Measurment by Polarisation Studies
...
[Raja-Tollestrup – FERMILAB-Pub-97 / 402]
Bending dipoles
Where do we set the calorimeter?
after the 1st matching dipole?
in the arc section?
Virtual detector DS (high P e+)
First Bending Magnet (matching section)
B= 0.64T / L=4m
Virtual detector US Inside the first bending magnet (low P e+)
Force decay: mu+àe+

Proposal for increased contributions from CERN to future neutrino oscillation facilities via the EUROnu FP7 Design Study

The primary aim of EUROnu is to do a performance and relative cost comparison between the three facilities, as mandated by the CERN Strategy Group: *"Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; Council will play an active role in promoting a coordinated European participation in a global neutrino programme."…..*

…….EUROnu is the bulk of the European contribution to this - and we have many associate members from around the world. Nevertheless, we still lack the resources to meet the aims of the Strategy Group in full on the timescale of 2012/13.

Work Package	CERN FTEs	Total FTEs
Management	1.0	7.7
CERN to Frejus Superbeam		27.8
Neutrino Factory	6.2	23.5
Beta beam	6.7	24.6
Detector performance		16.6
Physics Reach	0.1	17.2

	2010	2011	2012	2013
Accelerator physicist	2	3	3	3
Engineer/technical support	3	4	5	5
Safety expertise	0.5	1	1	1
Costing expertise	0.5	0.5	1	1
Total	**6**	**8.5**	**10**	**10**

Summary

- EUROν started
  - in person WG3 meetings aligned with IDS
  - recruitment and coordination finished
  - first results available
  - request for additional resources for eng. & costing

- IDS
  - Tasks and partners identified
  - Main issues identified and work started
  - Work focuses on problems to be solved for a design report in 2010 / 2012