K. Long, 10 May, 2010

Imperial College London

The International Design Study for the Neutrino Factory

status, and plans

Acknowledgements:

- Based on recent IDS-NF plenary meeting at FNAL
  - See:
    - https://www.ids-nf.org/wiki/FrontPage
    - https://www.ids-nf.org/wiki/FNAL-2010-04-08

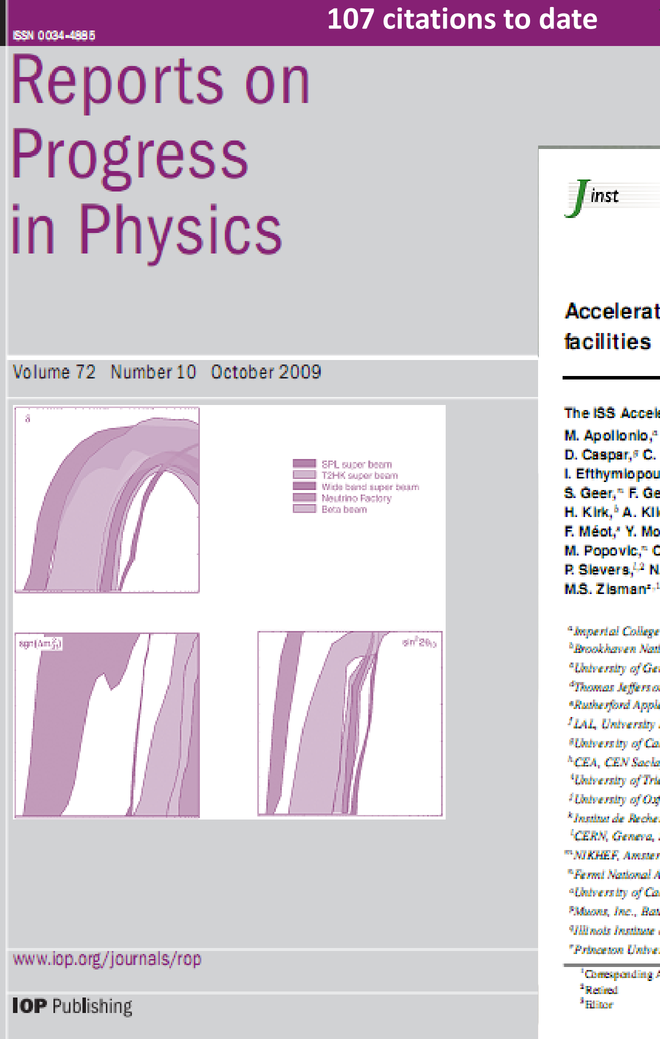
ABI

Contents:

- Timescale
- The IDS-NF baseline
- IDS-NF status and progress
  - Physics and performance evaluation group
  - Accelerator Working Group
  - Detector Working Group
- Opportunity and conclusions

Timescale

107 citations to date


ISSN 0034-4885

Reports on Progress in Physics

Volume 72 Number 10 October 2009

www.iop.org/journals/rop

IOP Publishing

Jinst
Published by IOP Publishing for SISSA
Received: October 2, 2008
Accepted: June 5, 2009
Published: July 2, 2009

Accelerator design concept for future neutrino facilities

The ISS Accelerator Working Group

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doi:10.1088/1748-0221/4/07/P07001

Jinst
Published by IOP Publishing for SISSA
Received: January 5, 2009
Accepted: February 25, 2009
Published: May 18, 2009

Technical Report

International Scoping Study (ISS) for a future neutrino factory and Super-Beam facility. Detectors and flux instrumentation for future neutrino facilities

The ISS Detector Working Group

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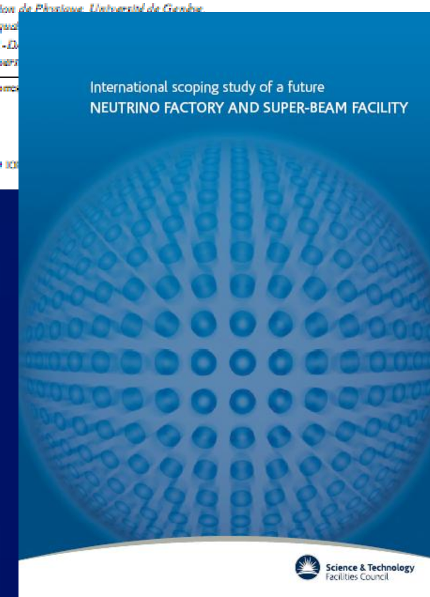
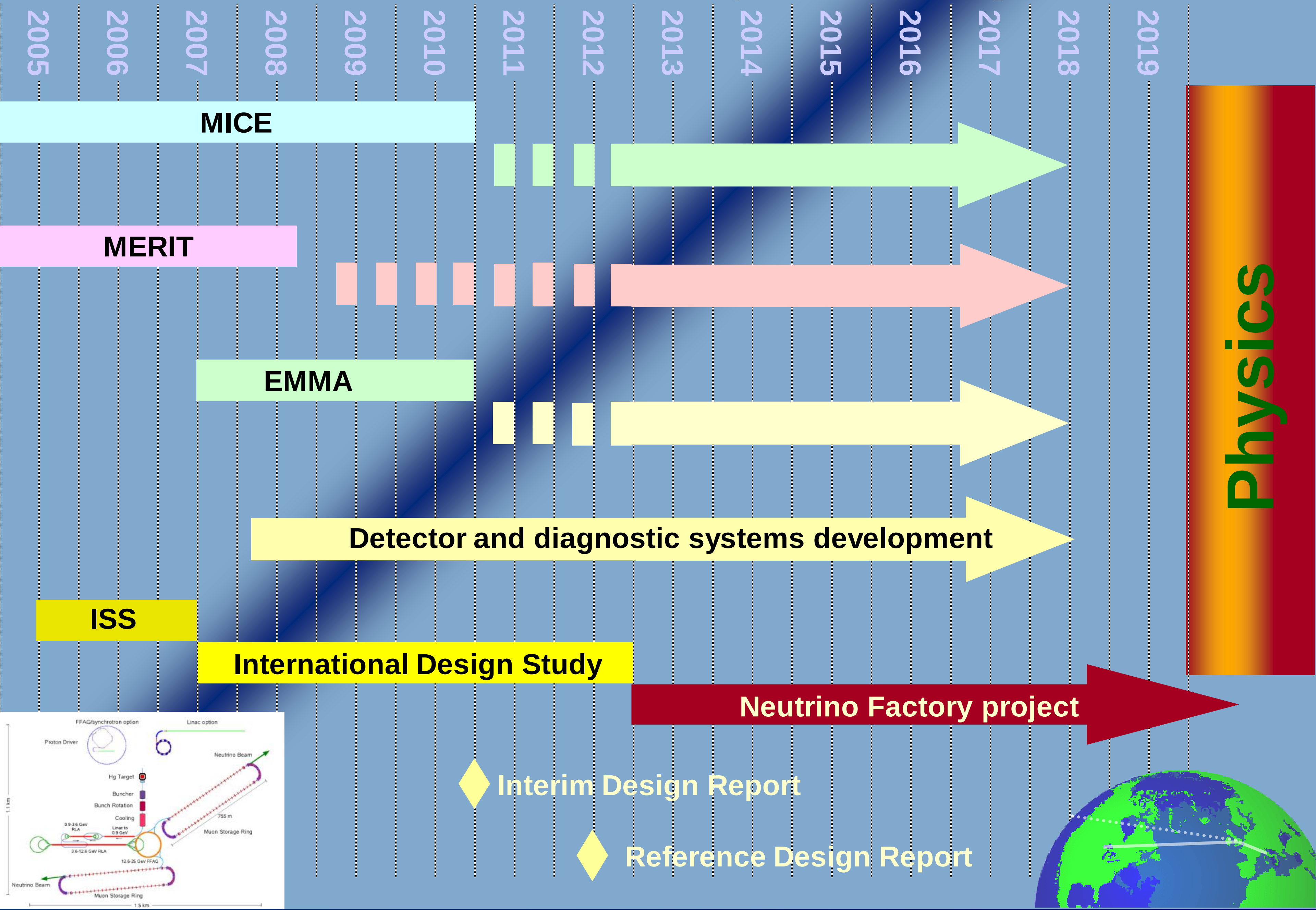
2009 JINST 4 T05001

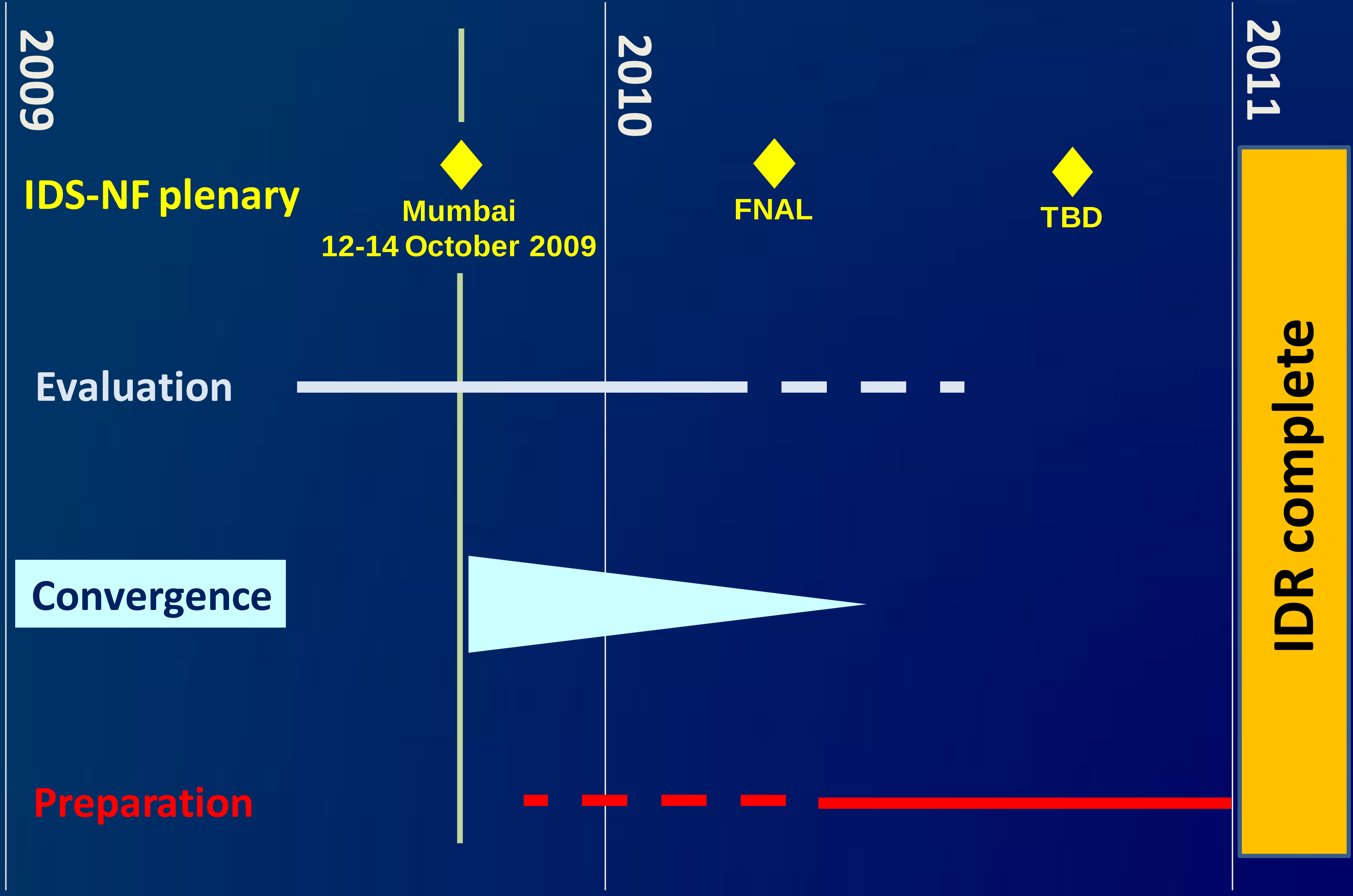


- **Published, a substantial achievement!**
  - **Physics Report: Rept.Prog.Phys.72:106201,2009.**
  - **Accelerator Report: JINST 4:P07001,2009.**
  - **Detector Report: JINST 4:T05001,2009**

Neutrino Factory roadmap

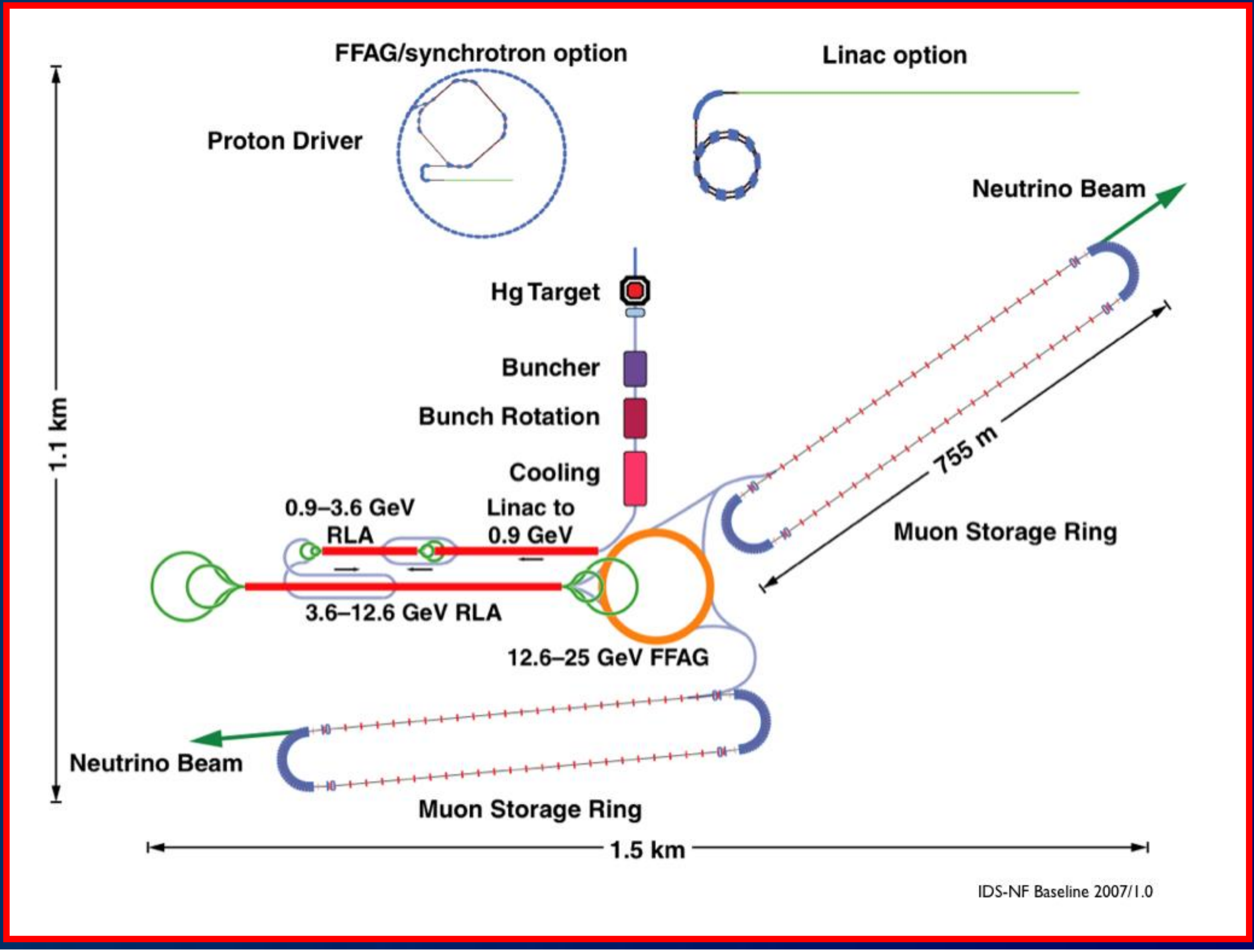


IDS-NF Interim Design Report roadmap



The IDS-NF baseline

Neutrino Factory: accelerator facility:



IDS-NF-002: https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=view&target=IDS-NF-002-v1.1.pdf

IDS-NF: status and progress:

International Design Study for the Neutrino Factory

IDS-NF-017

First progress report

The IDS-NF collaboration

Abstract

The International Design Study for the Neutrino Factory (the IDS-NF) collaboration has been established by the Neutrino Factory community to deliver a Reference Design Report (RDR) for the facility by 2012/13. This, the first progress report, summarises the status of the study in early 2010. The baseline design for the facility will provide 10^{21} muon decays per year from 25 GeV stored muon beams. The facility will serve two neutrino detectors; one situated at source-detector distance of between 3 000 km and 5 000 km, the second at 7 000–8 000 km. The work of the IDS-NF is carried out in three working groups: the Physics and Performance Evaluation Group; the Accelerator Working Group; and the Detector Working Group. The status of the work of each of these working groups is summarised in the report. In addition to developing the baseline configuration, the IDS-NF is active in exploring alternative configurations that may offer performance or cost advantages or may lower the technical risk of particular sub-systems. The Low Energy Neutrino Factory, in which a 4–5 GeV muon beam matched to a source-detector distance of $\sim$ 1500 km, which is discussed in the report, has emerged as a potentially attractive option should θ_{13} be large ($\sin^2 2\theta_{13} > 0.01$).

- **Much progress, can only skim highlights in short talk. So, …**
  - **Best to refer to the progress report**

https://www.ids-nf.org/wiki/FrontPage/Documentation

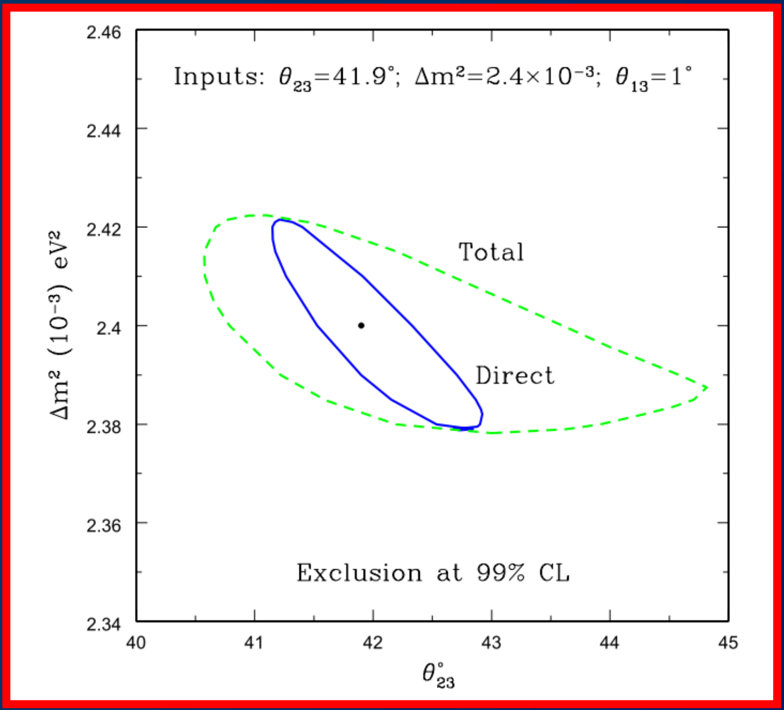
Physics and Performance Evaluation

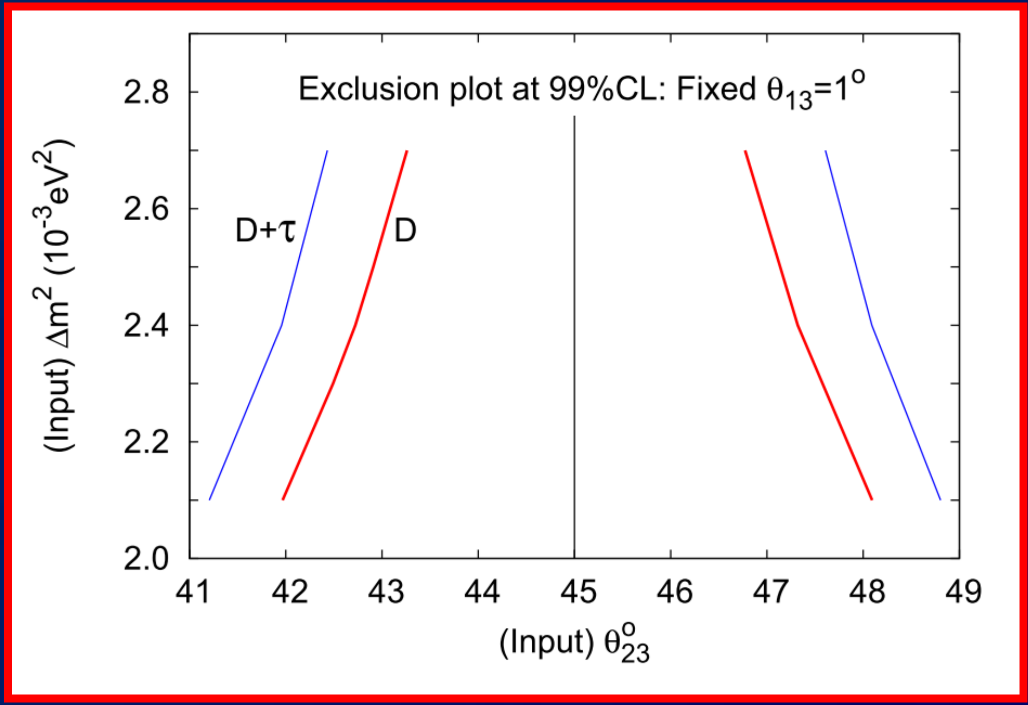
IDS-NF: status and progress:

PPEG: precision; effect of contamination:

P. Huber et al.

- Large θ_{13} (1°):
  - Deviation of θ_{23} from 45°:
    - τ s produced in ν_e and ν_μ CC interactions may be mis-identified as golden muons





- One 'figure of merit' for precision comparison?

Accelerator facility

IDS-NF: status and progress:

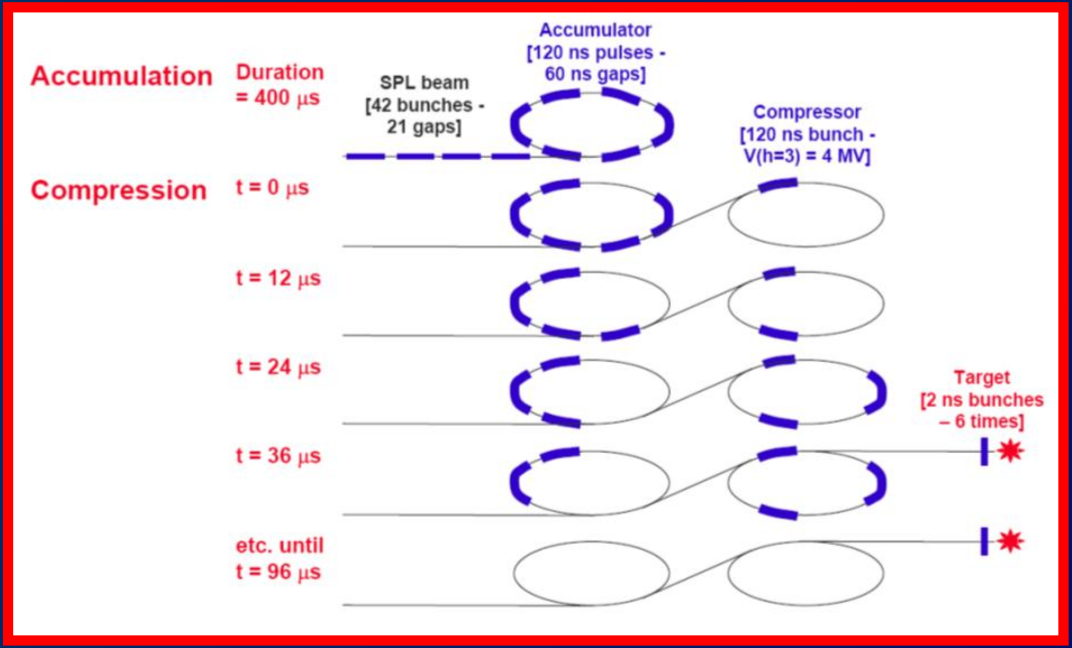
Proton driver:

Parameter	Value	Comment
Beam power	4 MW	Production rate
Beam energy	5-15 GeV	Optimum pion production
Bunch length	1-2 ns	Pion/muon capture

- Proton driver is the accelerator system most likely to be constrained by requirements of host-site
- IDS-NF approach:
  - Consider two 'generic' options:
    - LINAC:
      - Possible development option for SPL (CERN) or Project-X (FNAL)
      - Requires accumulator/compressor rings
    - Rings:
      - Development option for J-PARC or RAL or possible 'green-field' option
      - Requires bunch compression
- For Interim Design Report:
  - Envisaged as considering 'example sites' to be studied further in preparation of the Reference Design Report
    - Will require some effort from example sites

CERN SPL as proton driver:

- Accumulator and compressor ring scheme:
  - Two options: 6 bunches or 3 bunches

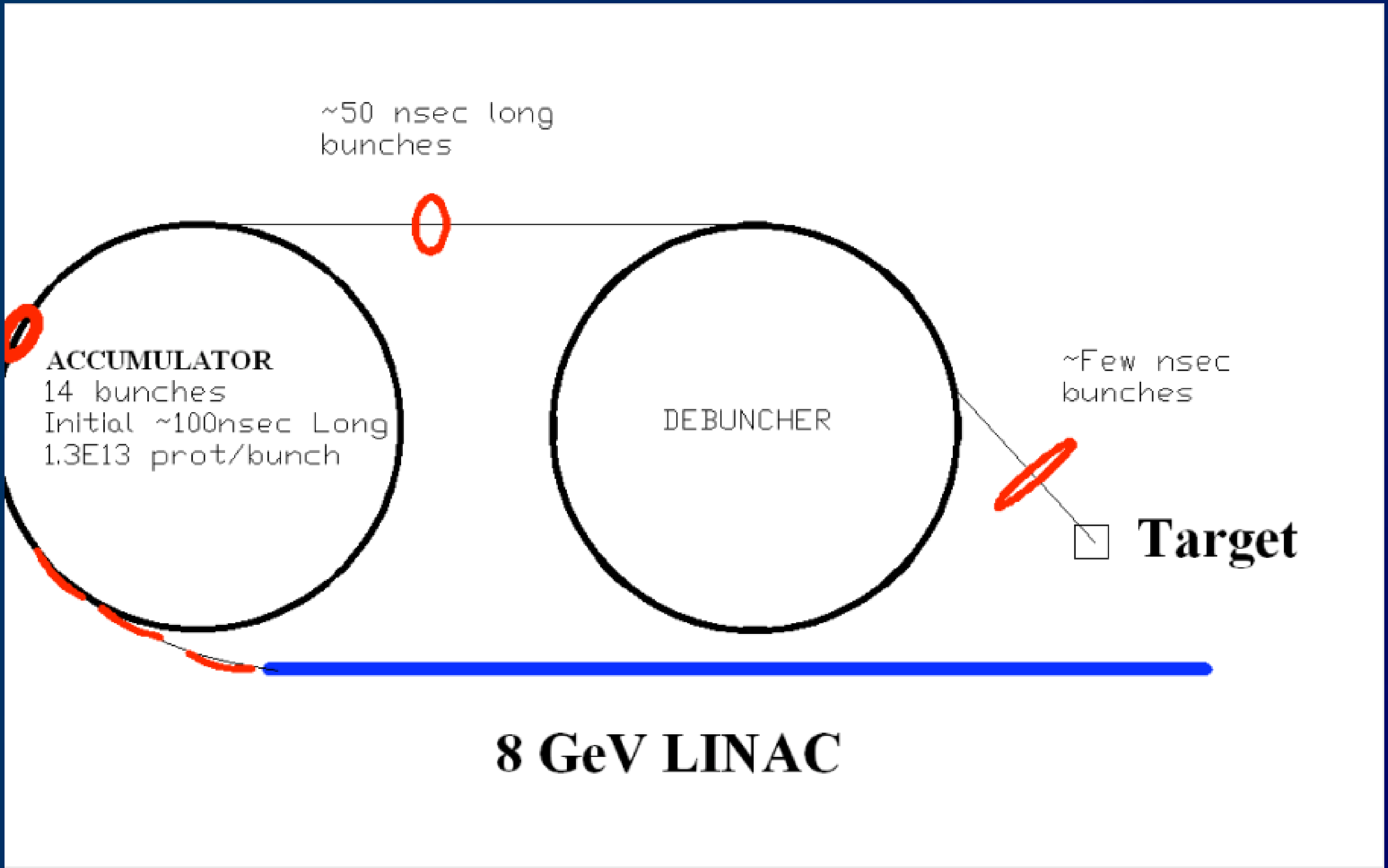


- SPL:
  - Staged scenario under consideration (Myers):
    - Low power SPL to serve LHC
    - High power SPL to serve applications such as Neutrino Factory
  - We seek to ensure upgrade path to high power stays open

Project-X as proton driver:

C. Ankenbrandt

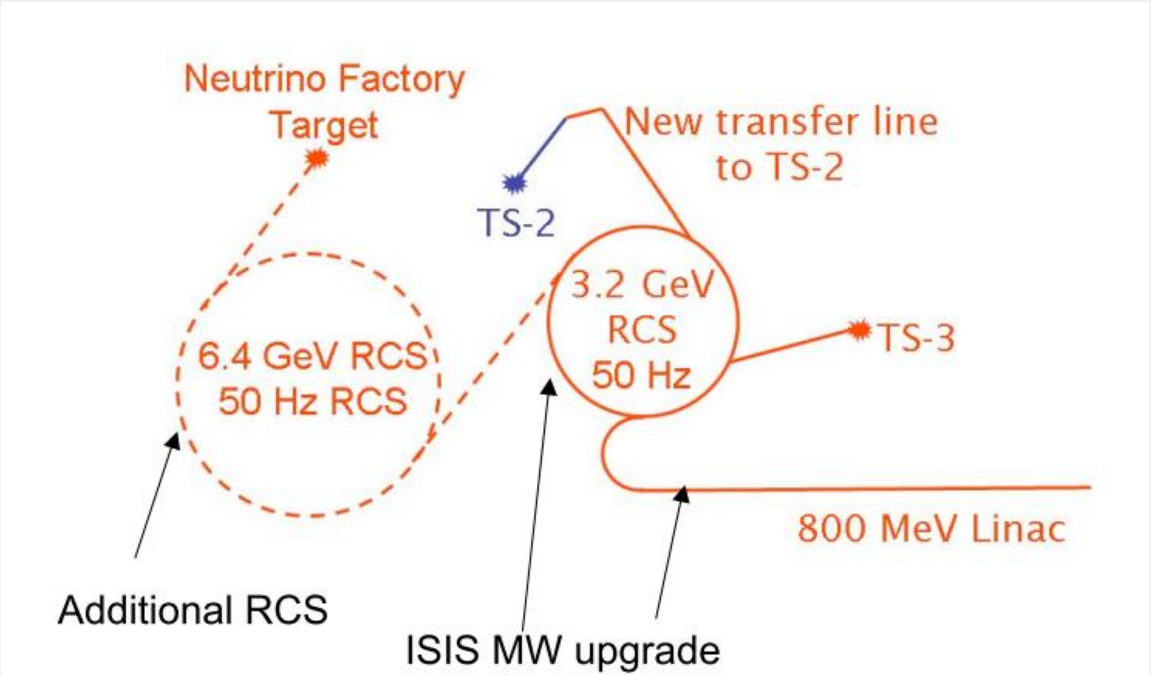
- Project-X linac with accumulator/compressor rings:
  - Linac:
    - 325 MHz to 420 MeV
    - 1.3 GHz to 8 GeV



Ring-based proton driver:

- ISIS upgrade options:
  - ISIS upgrade:
    - MW class, short pulse neutron spallation source
  - J-PARC upgrade:
    - Upgrade to 1.66 MW planned

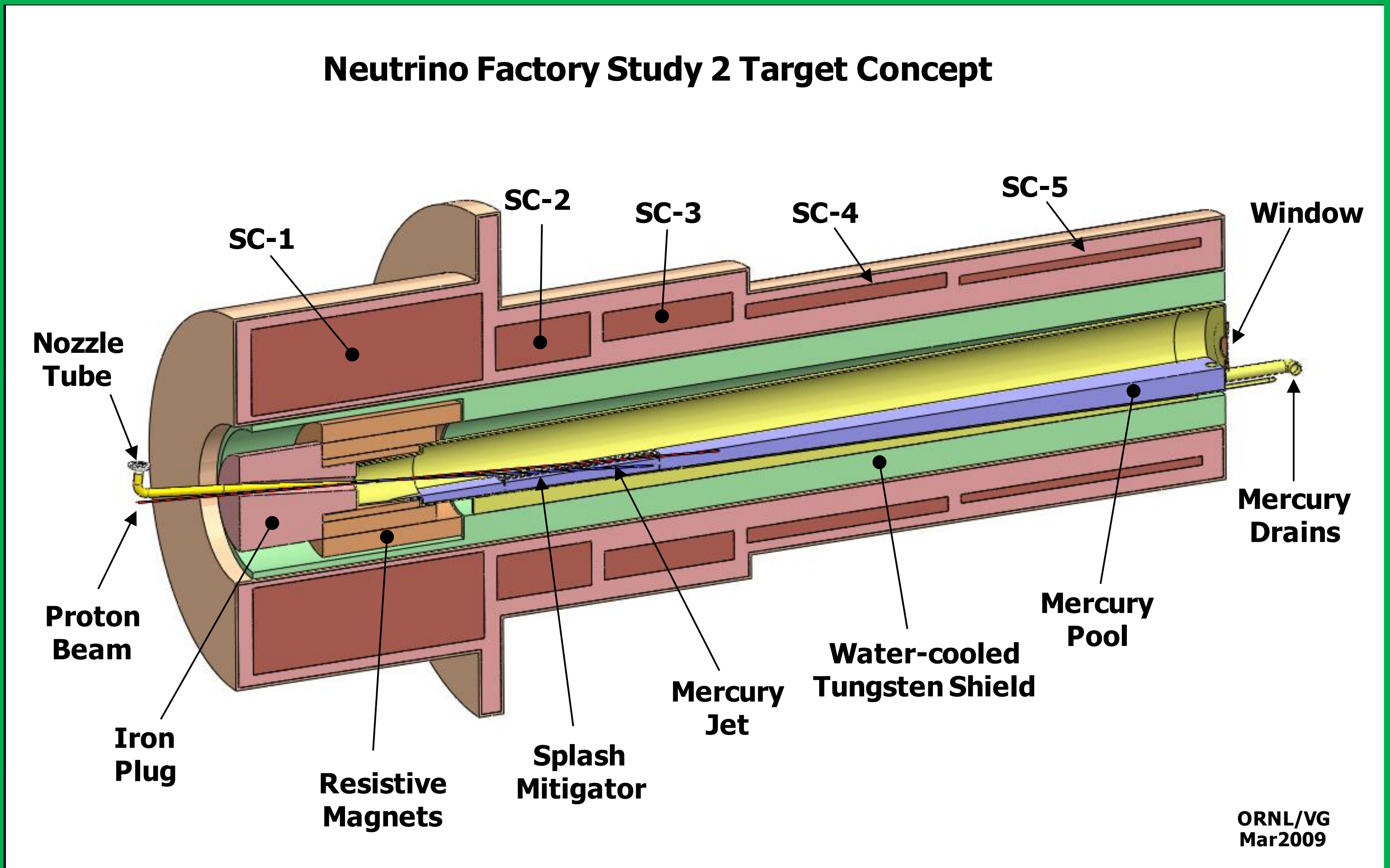
J. Pasternak



- 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

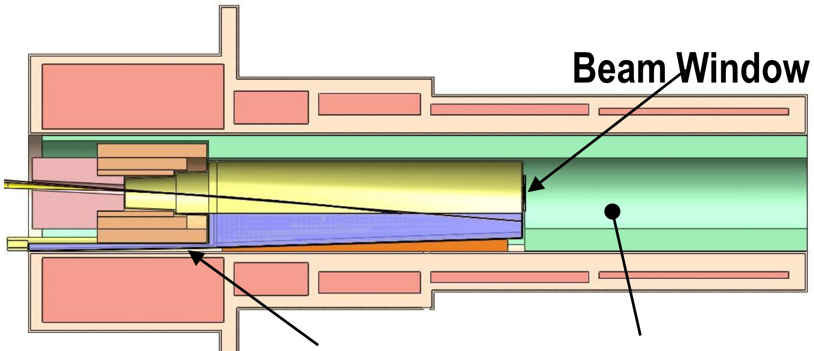
Target/capture:

Parameter	*Value*	*Comment*
Jet velocity	20 m/s	Reformation of jet
Field at i/p	20 T	Pion collection
Field at exit of capture	1.75 T	Pion focusing



- **Baseline: mercury jet, tapered solenoid for pion capture:**
  - 20 T tapering to 1.75 T in ~13 m

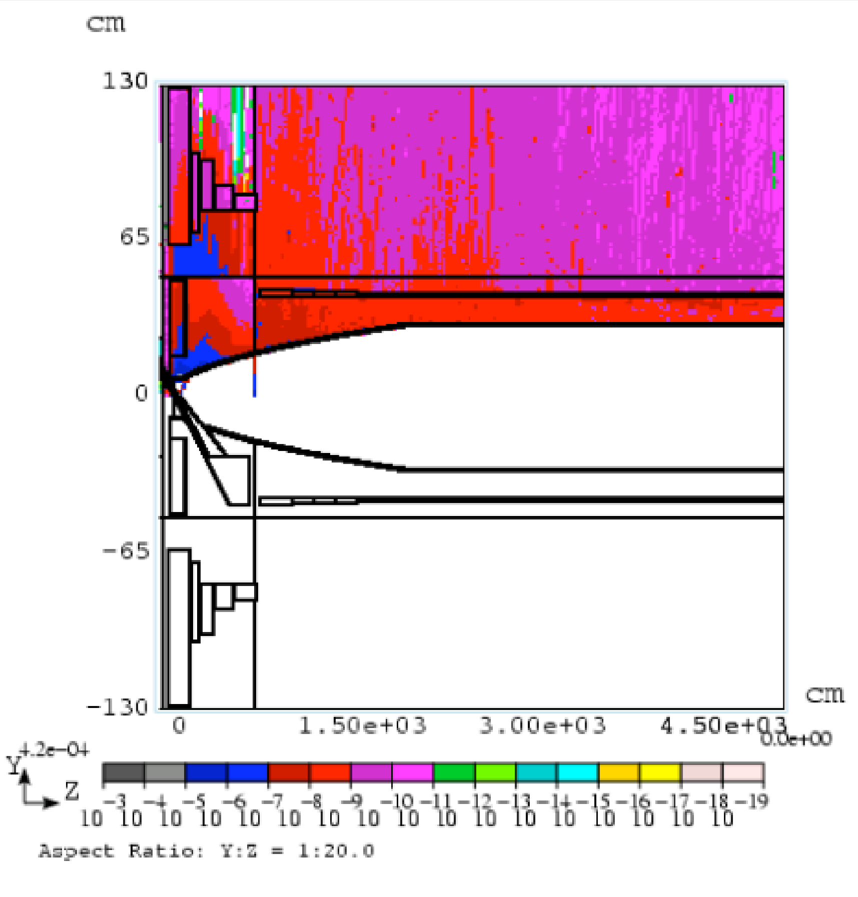
Heat Removal



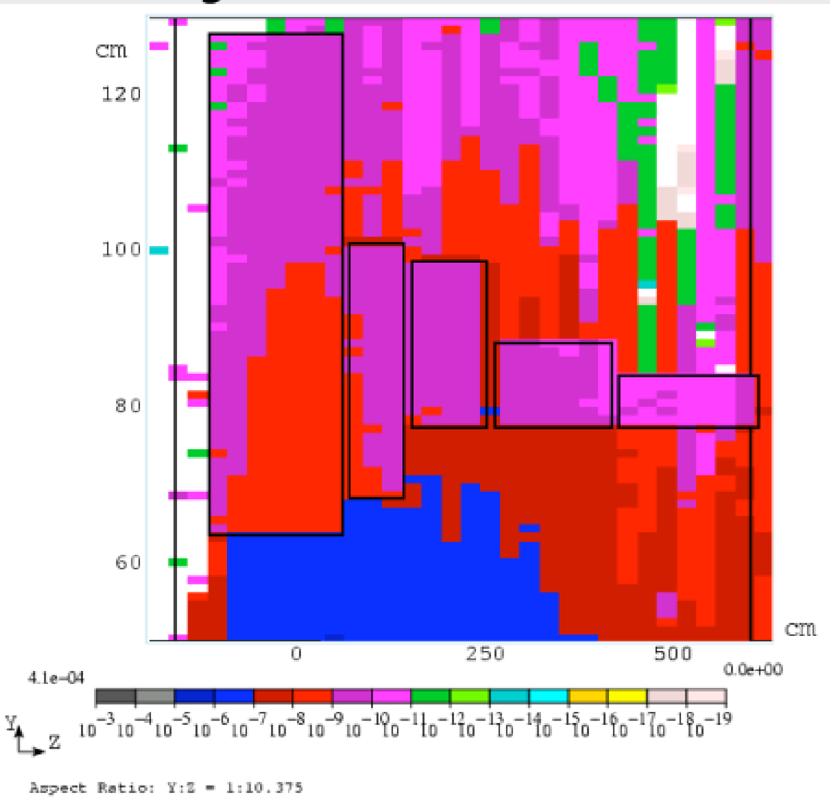
Element/Compound	Density (g/cm^3)
Hg	13.5
W	19.3
WC	15.8

- From Study 2, the mercury jet/pool receive < 10% of beam energy; 50-60% goes into WC shielding (~2.4MW for 4MW beam)
  - Currently assumed to be WC spheres cooled by water
  - Much larger heat exchanger needed to cool shielding
- Considering that both W and WC must be water-cooled, their effective densities will approach that of Hg.
- Consequently, IF a Hg target is selected, the infrastructure will be in place to support use of Hg as a solenoid shield.
  - Would probably be a separate loop due to vastly different flow/pressure requirements, but could share a storage tank

Target engineering: heat deposition:



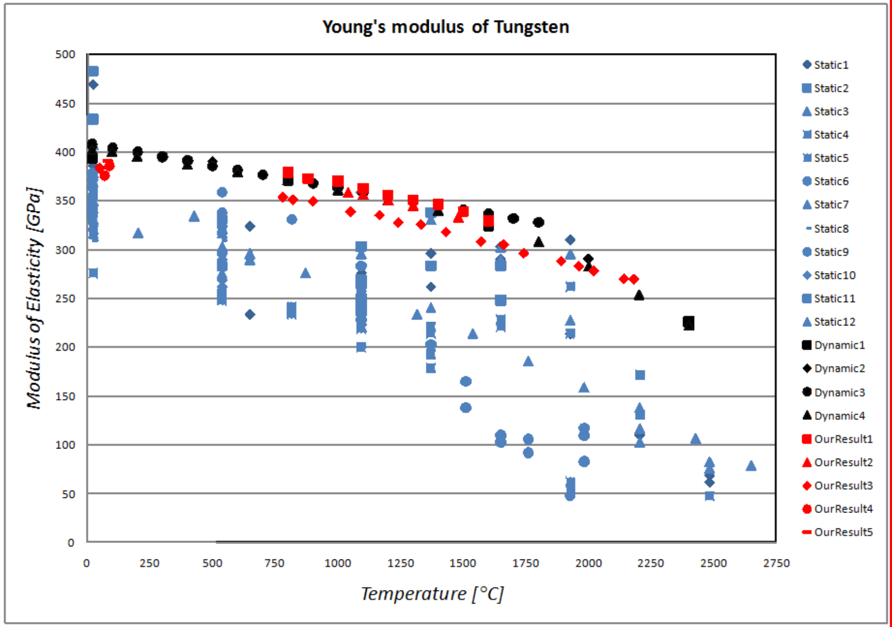
X. Ding



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.

Target: alternatives:

- Solid targets (R. Edgecock et al.):
  - Issues:
    - Shock:
      - Extensive studies with high-current pulse indicate that tungsten can survive shock at Neutrino Factory for extended period
    - Replacing target at appropriate rate:
      - Wheel-based target concept now under development
- Powder jet target (C. Densham et al.):
  - Combine advantages of solid and liquid jet
  - First studies of first proof-of-principle system encouraging



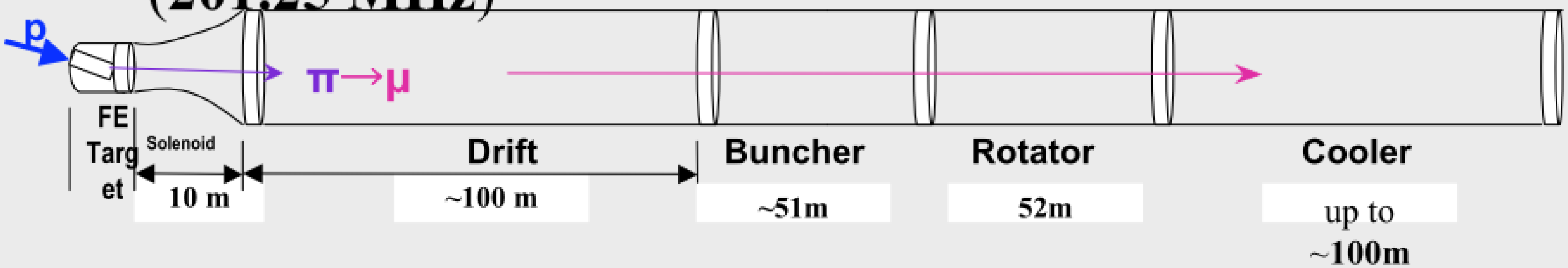
Re-circulating tungsten powder plant

Parameter	*Value*	*Comment*
E-spread after P.R.	10%	Subsequent accel.
Freq. after P.R.	201.25 MHz	
Emittance at exit	7.4 mm rad	Subsequent accel.

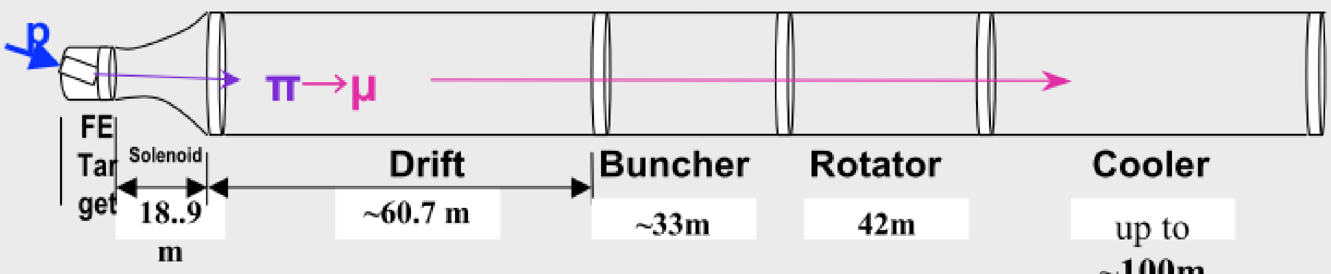
Muon front-end:

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

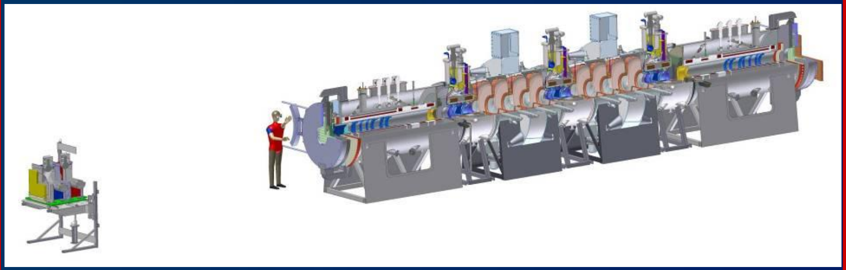


Mitigation of RF gradient risk:

C.Rogers

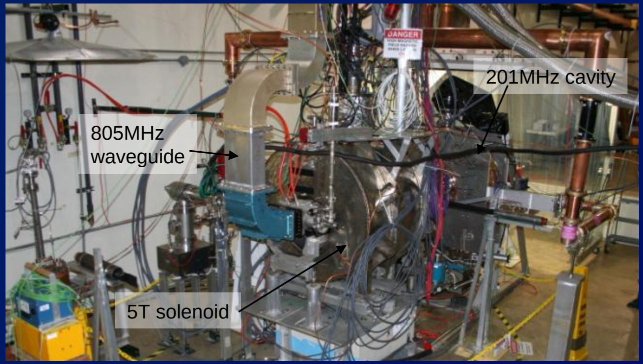
- Various options being considered:
  - Modified lattices, magnetic return, bucking coils, gas filled cavities…
  - Studies emphasise:
    - Priority: expedite MICE and MuCool programmes!

- Ionisation cooling



MICE
(under construction at RAL)

- RF cavity development

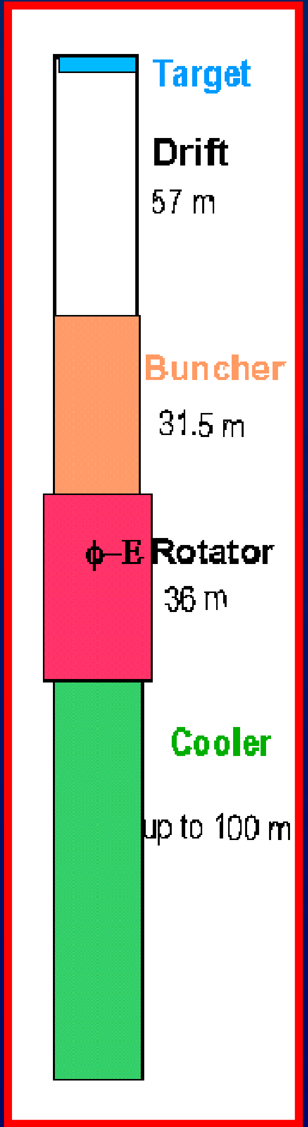


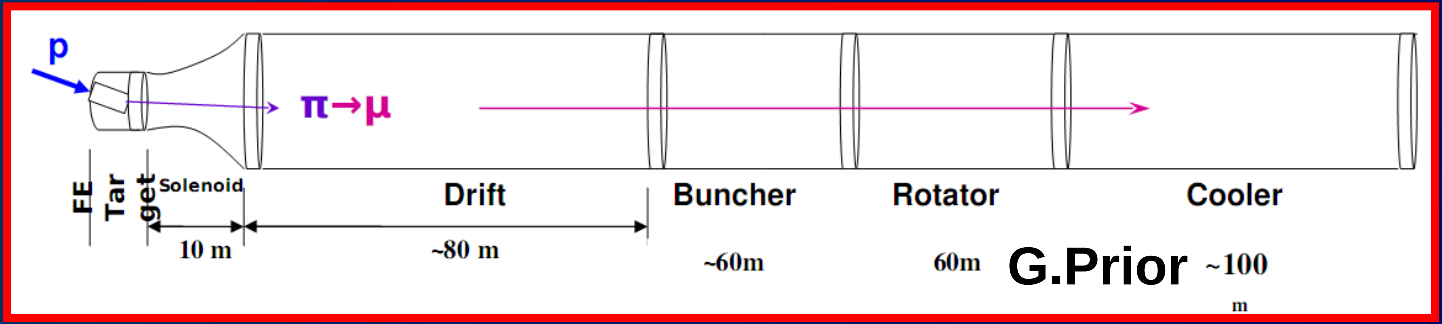
MuCool (part of US NFMCC)

– Interim Design Report will contain discussion of alternative configurations by which technical risk can be mitigated

Alternative front-end schemes:

- Shorter phase rotation and bunching sections:
  - Improved yield, but higher gradients required
- Re-visit 44/88 MHz scheme:
  - Outline:
    - Bunching , phase rotation, intial cooling, and acceleration to 280 MeV at 44 MHz, ~ 2 MV/m
    - Cooling and acceleration to 1 GeV at 88 MHz, ~10 MV/m
  - Issues:
    - Longer channel, larger cavities
    - Gradients high for low frequency cavities
      - Effect of magnetic fields?
    - May require reconsideration of other parts of complex





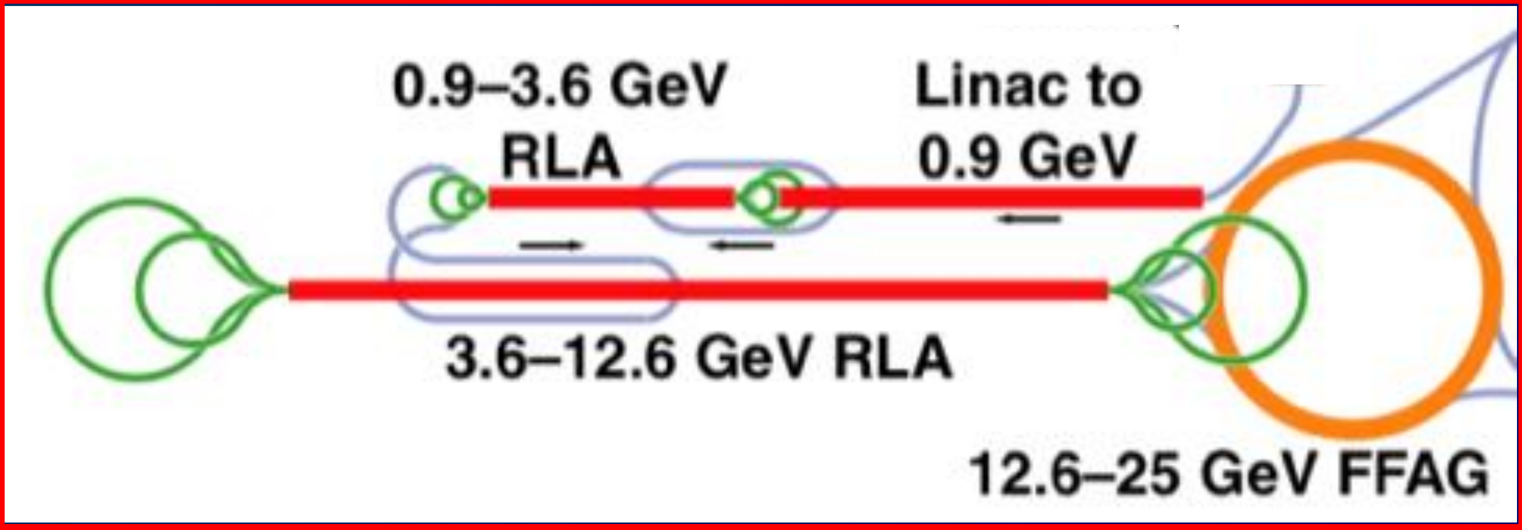
G.Prior

Muon acceleration:

	E_{fin} (GeV)	*Comment*
Pre-accel. Linac	0.9	Change in γ
RLA I	3.6	Switch-yard congestion
RLA II	12.6	Switch-yard congestion
FFAG	25.0	Large acceptance, use of RF

- **Linac/RLAs:**
  - Development of optics
    - Graded focussing
  - Tracking with OPTIM and MAD-X
  - Error-tolerance analysis for droplet arcs
  - Ready for end-to-end tracking

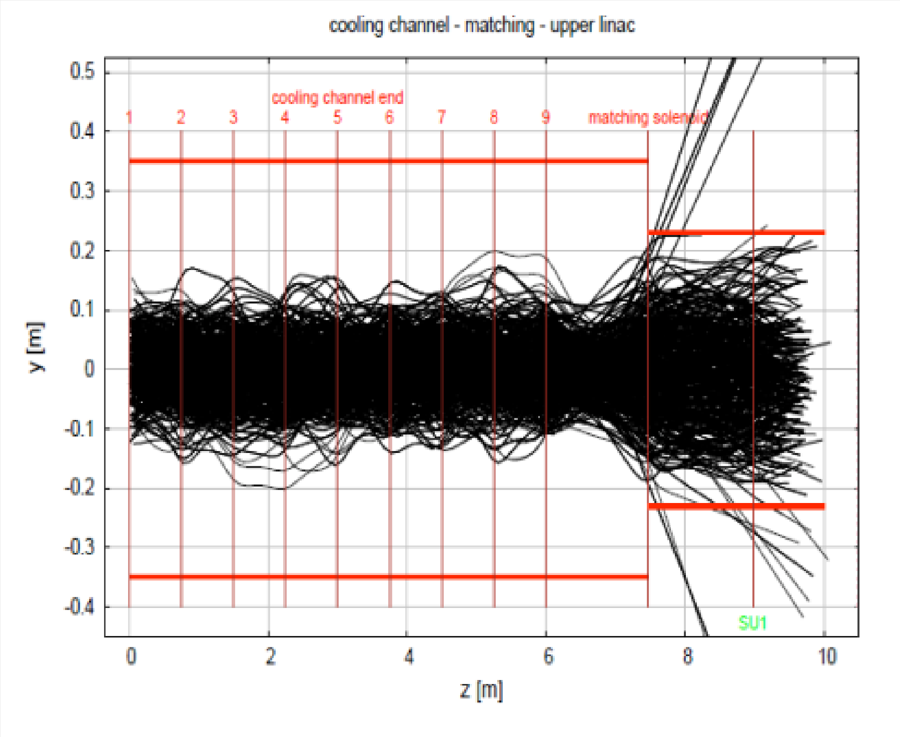
- **FFAG:**
  - Lattice specification update
  - Analysis of distortions & chromaticity
  - Evaluation of injection and extraction systems



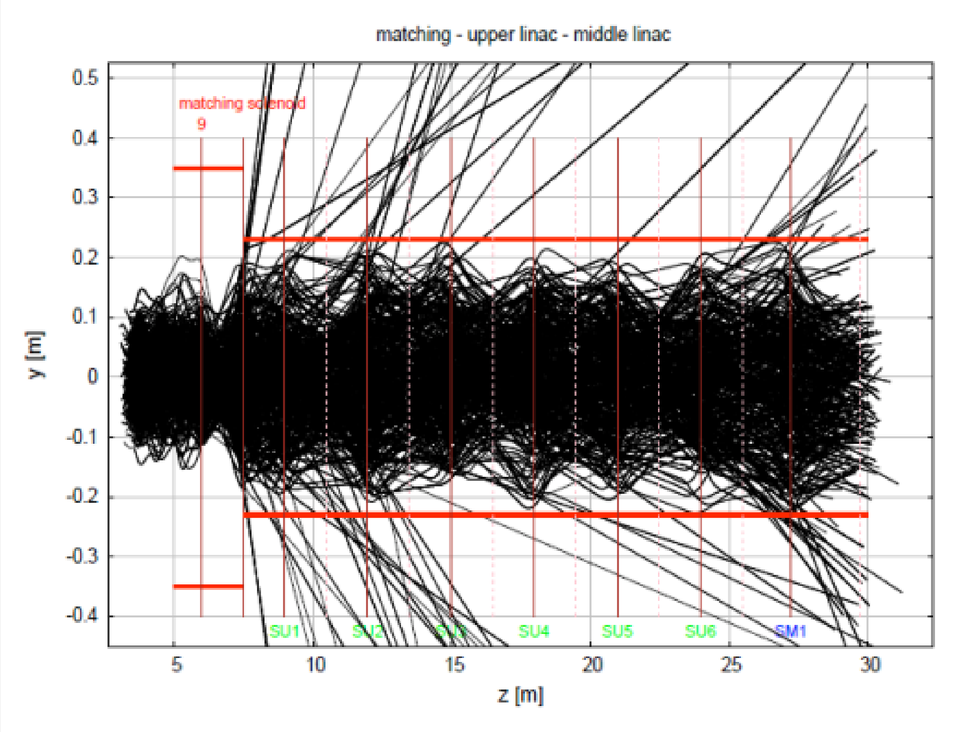
A.Bogacz

Pre-accelerator, RLA I & II:

cooling -> upper linac

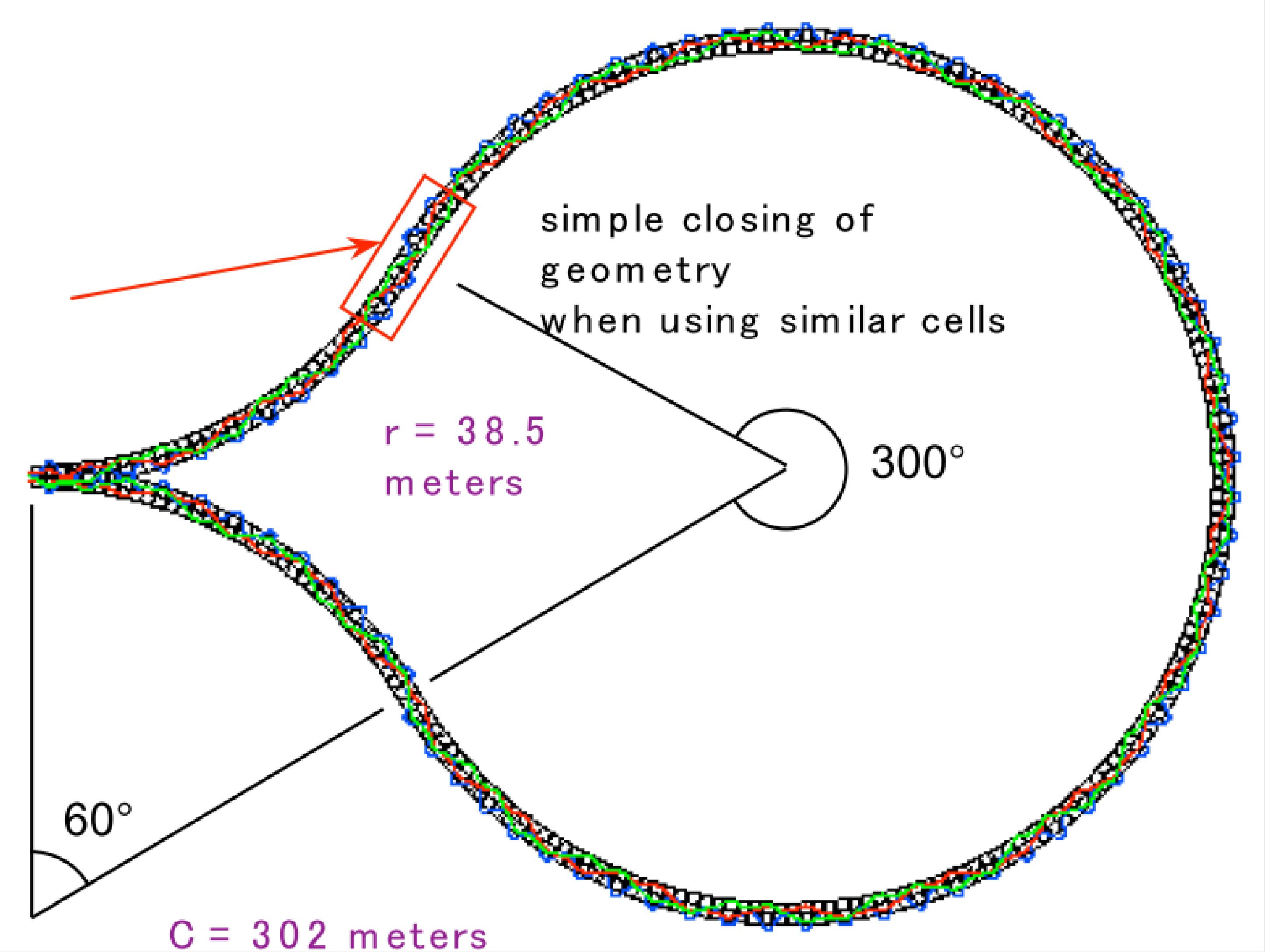


upper -> middle linac



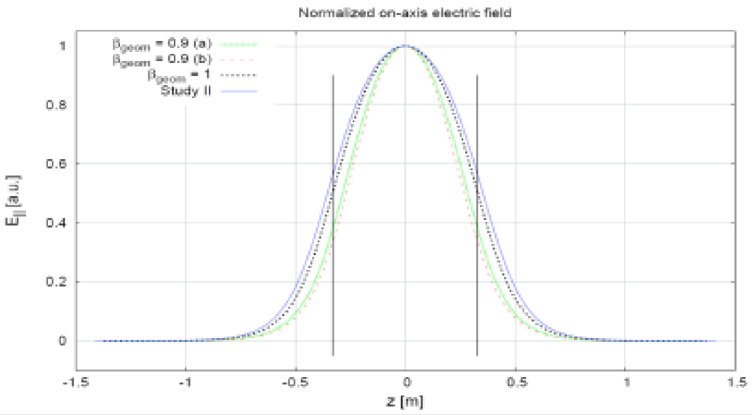
Droplet arcs:

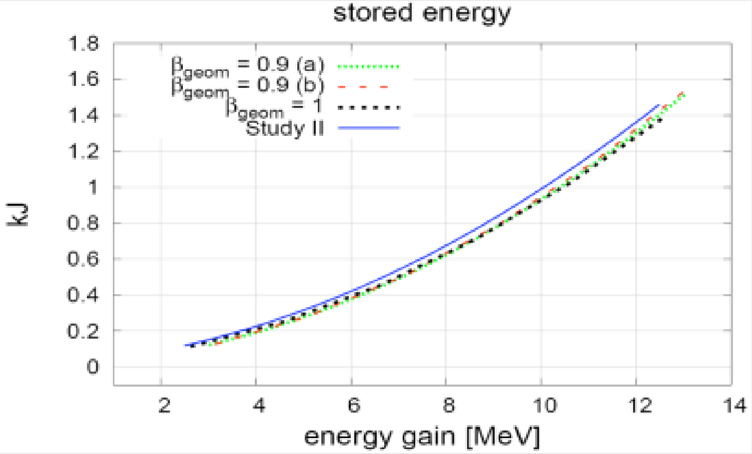
Vasiliy Morozov



Element design consideration:

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[ω 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





C. Bontoiu, J. Pozimski

T. Planche

Alternative for RLAs:

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.

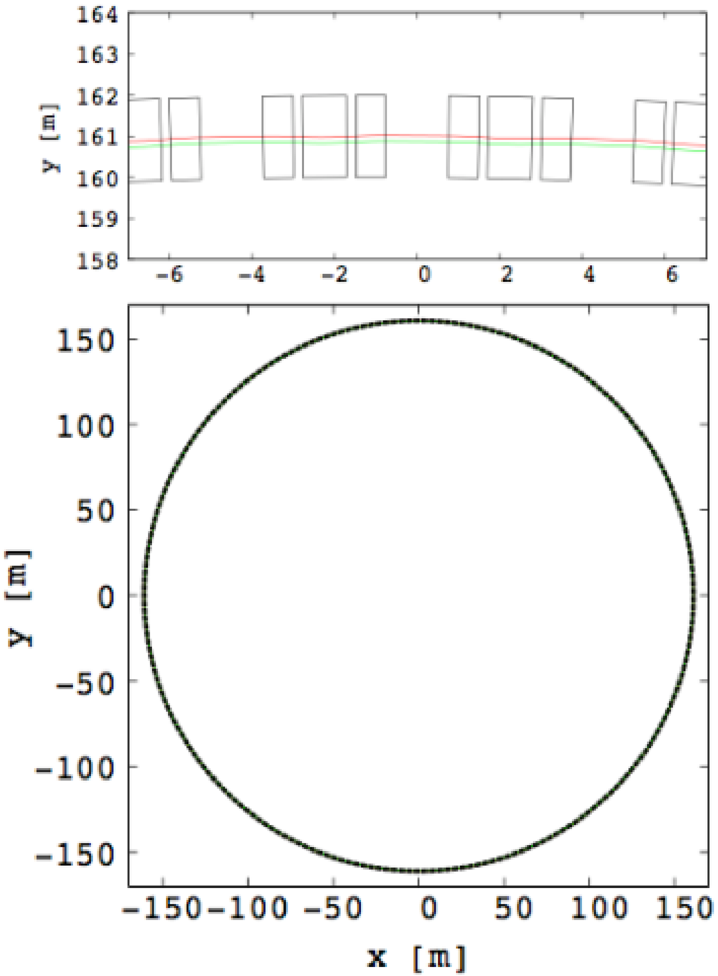


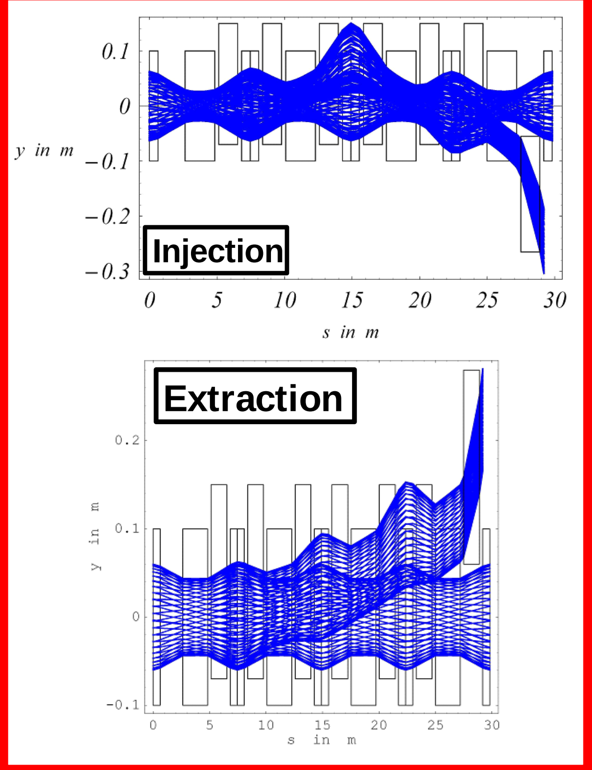
Figure 2 - Ring layout.

S.Berg, J.Pasternak, D.Kelliher

Muon FFAG:

- Lattice revision required to:
  - Provide drift spaces for installation of kickers
- Various options:
  - Doublet, triplet, FODO, single and 'doublet' of cavities
  - Some indicative estimate of cost
    - How to converge on a single, optimised design?
- Kicker schemes under development:

FODO case	Inject 6	Inject 10	Extract
Kickers	6	10	6
Kicker field (T)	0.12	0.08	0.10
Septum field (T)	2.5	2.5	4.0



- Orbit distortions related to magnet apertures in injection and extraction sections under study

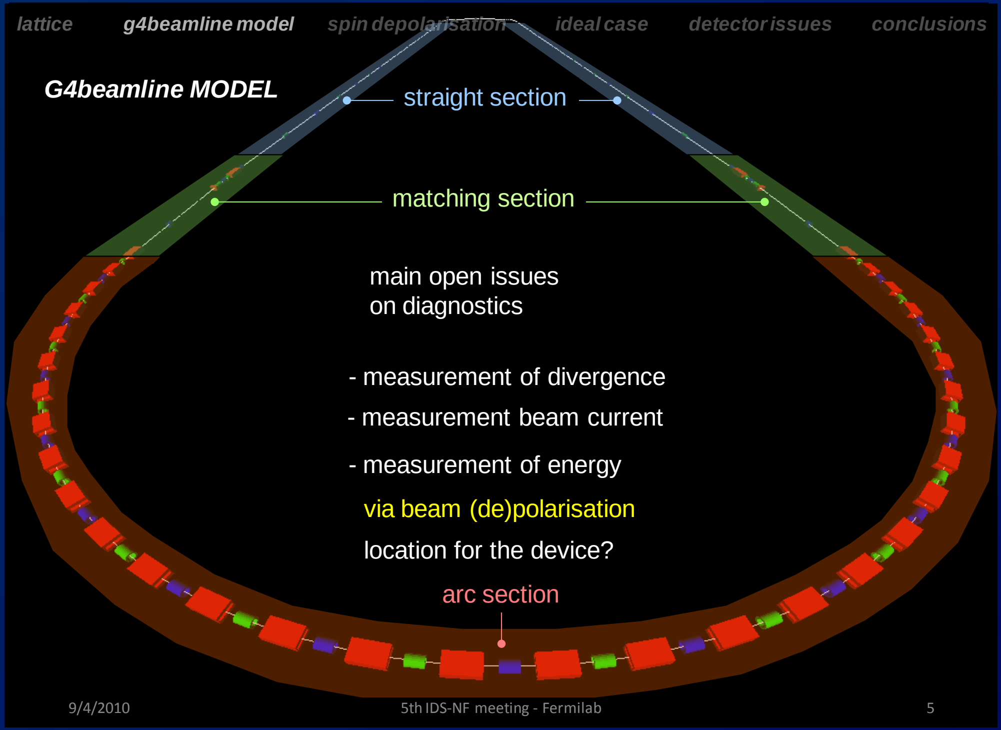
- Chromaticity (sextupole) corrections required to mitigate time-of-flight differences

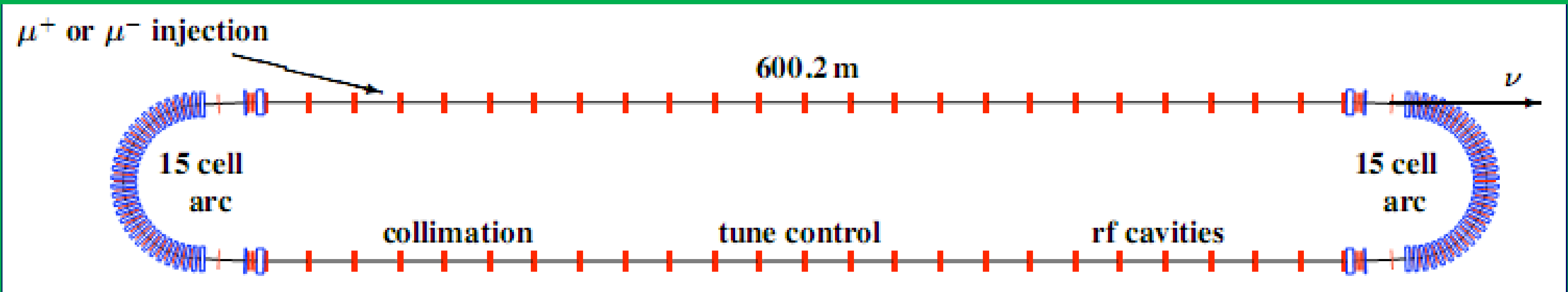
Storage rings:

M. Apollonio, D. Kelliher

Parameter	E_{fin} (GeV	Comment
Type	Race track	Triangle as backup
N_{decays} /b.l. /yr	5×10^{20}	Baseline flux (10^{21} / yr total)
Min, bunch spacin	100 ns	Event separation

- **Detailed tracking studies:**
  - Ring issues
  - Instrumentation





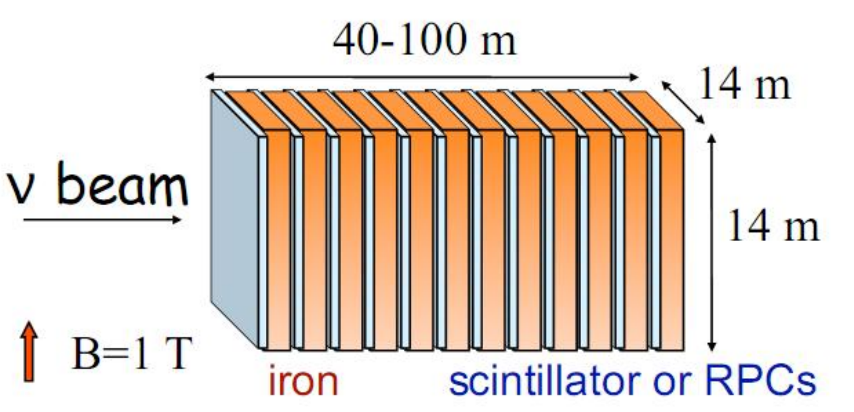
Long baseline neutrino detectors, near detector

IDS-NF: status and progress:

Measurement of oscillation parameters:

- Essential, golden channel:
  - ν_μ appearance
    - Wrong sign muon
      - Magnetic detector
- Baseline:
  - Magnetised Iron Neutrino Detector (MIND)
    - Known technology, straightforward to magnetise

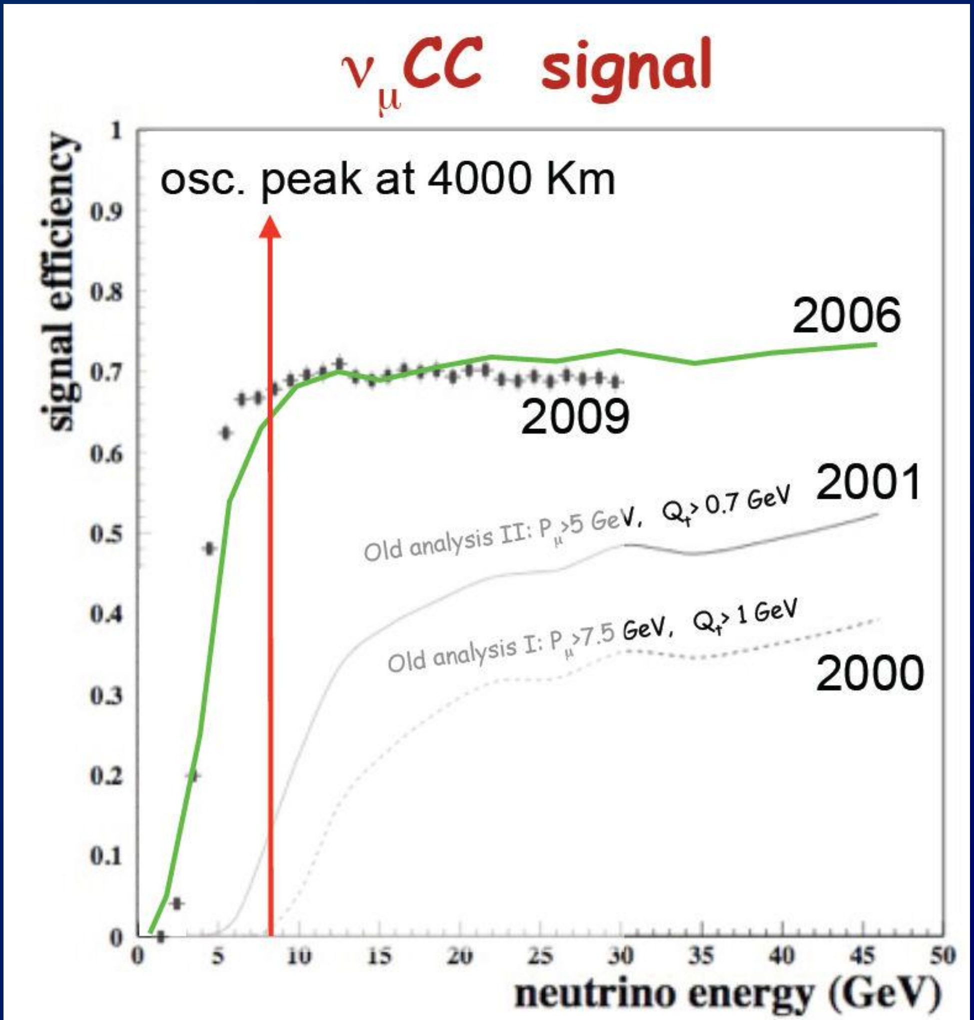
Stored $\mu^- \to e^- \nu_\mu \bar{\nu}_e$	
Disappearance	Appearance
$\bar{\nu}_e \to \bar{\nu}_e \to e^+$	$\bar{\nu}_e \to \bar{\nu}_\mu \to \mu^+$
	$\bar{\nu}_e \to \bar{\nu}_\tau \to \tau^+$
$\nu_\mu \to \nu_\mu \to \mu^-$	$\nu_\mu \to \nu_e \to e^-$
	$\nu_\mu \to \nu_\tau \to \tau^-$



MIND performance:

A. Cervera, A. Laing,
J. Martin-Albo, and P. Soler

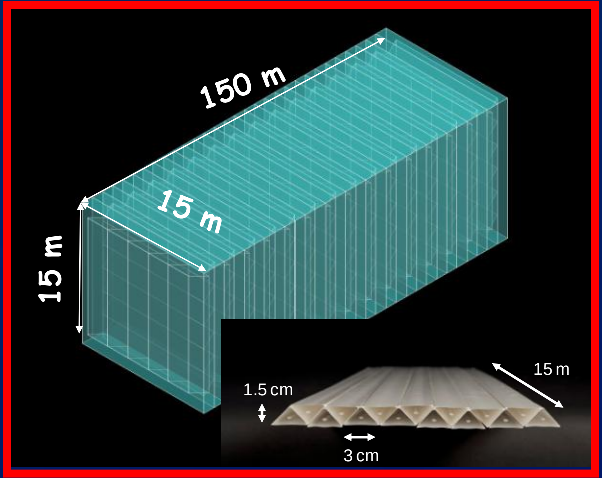
- The baseline MIND
  - Better En threshold turn-on
    - Still room for improvement based on MINOS data
  - 100 kT
- Required R&D is well defined
  - Scintillator
    - Existing Technology OK
    - Photodetector
      - SiPM
    - Magnet
  - Inputs for costing well understood
- Improvements in simulation in analysis:
  - Turn on at ~3 GeV
  - Further improvements (inclusion of QE) expected

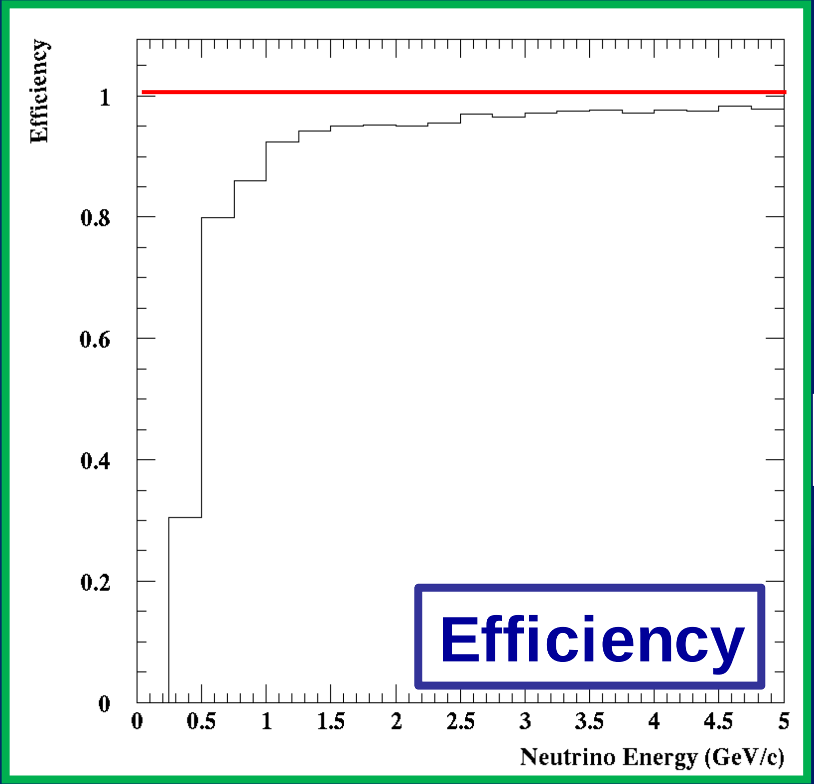


M.Ellis, S. Zlobin,
P. Rubinov

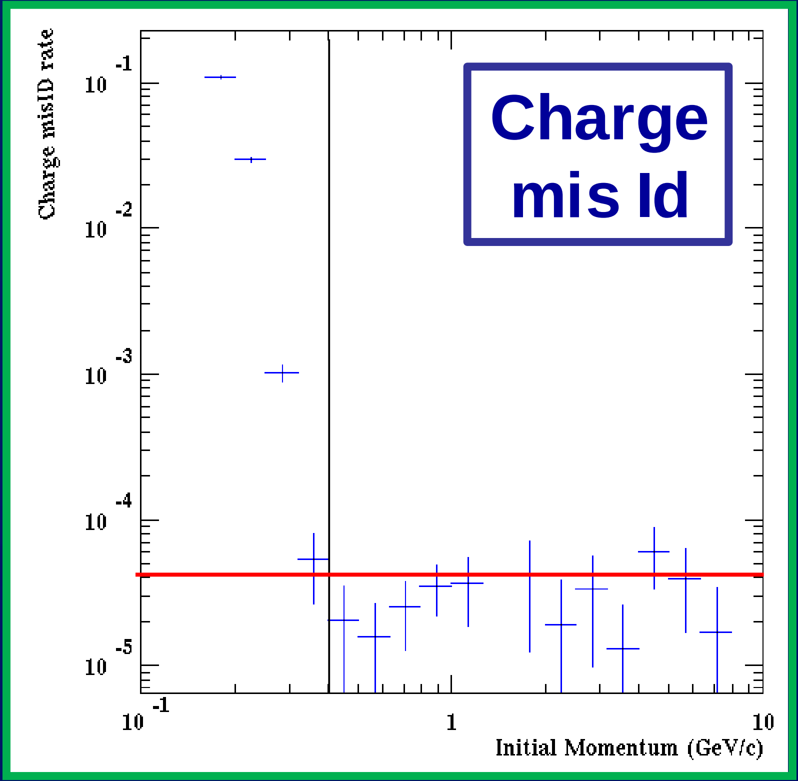
TASD: performance update:

- Assume:
  - 35 kT *total* mass
  - 0.5 T field
  - Simulation using 'NOvA' concept





Muon



Summary - Detector Options

- TASD
  - Still baseline for LENF
  - R&D Well defined & rather limited
    - Magnetic Volume
      - No Progress due to lack of resources
- LAr
  - Aggressive R&D Program underway
  - Technical challenges well defined and all are being investigated
  - We will have to wait and see, but
    - "First LAr talk that left us with the impression that it might be possible (multi-kT detectors)"

Near Detector Requirements

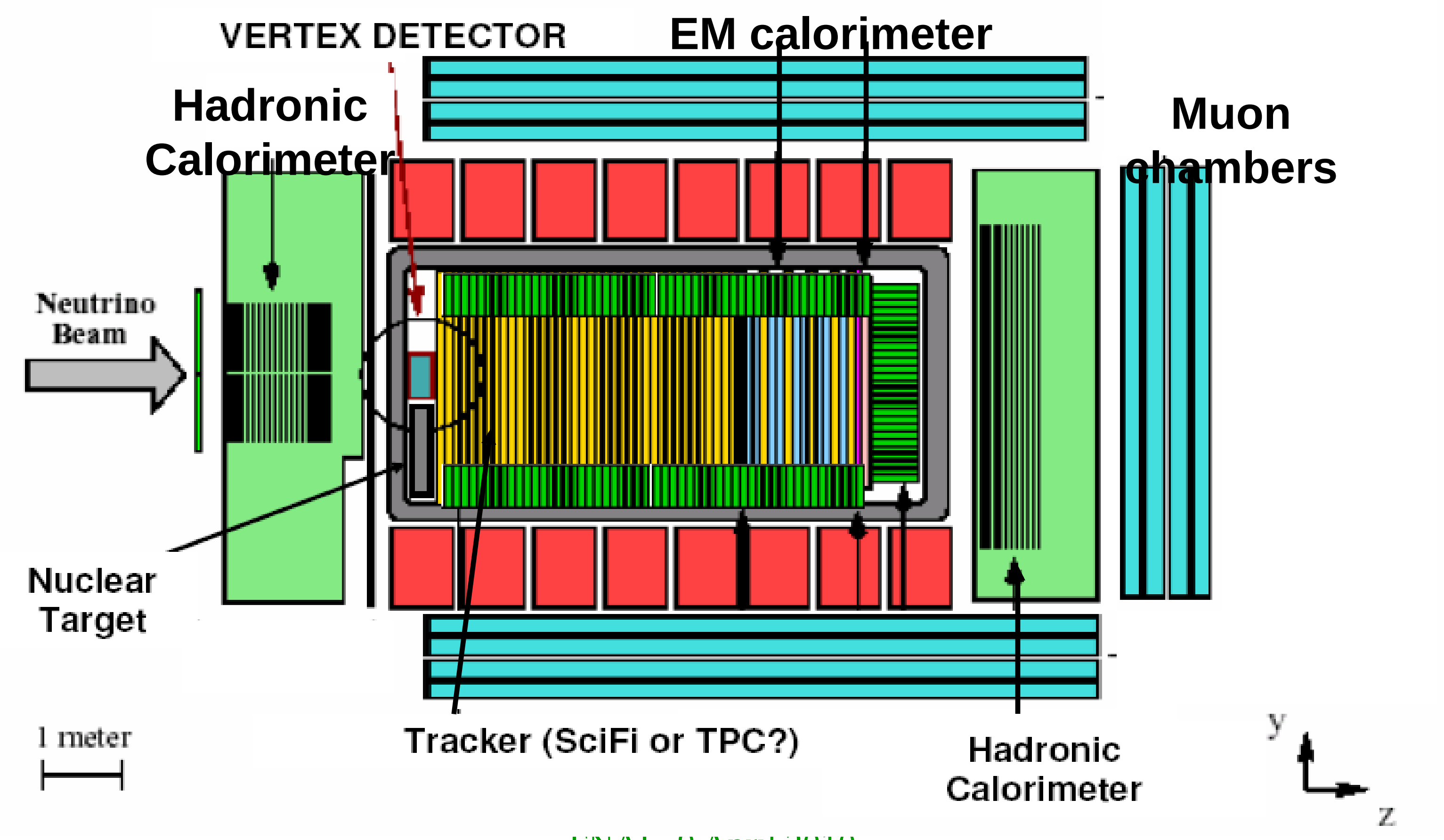
- Need high resolution (low-Z) target for accurate measurement of angles of muons for flux determination and resolution of hadronic final states for cross section measurements.
- Need good identification and accurate momentum measurement of the muon – a magnetic field with muon identification.
- Very good hadron energy determination for flux and cross section measurements.
- Need excellent vertex resolution for charm production and ν_τ detection for indications of NSI.

Near Detector Aims

- Currently there is no near detector baseline
- At the Mumbai meeting we decided that the near detector would be part of the baseline but not what it looks like, nor how far away it should be from the decay ring
- We have decided on some of the essential measurements that a Near Detector needs to do to reduce the neutrino oscillation systematics:
  - Measurement of neutrino flux and extrapolation to Far Detector
  - Measurement of charm (main background to oscillation signal)
  - Cross-section measurements: DIS, QEL, RES scattering
- Other desirable measurements with Near Detector
  - Fundamental electroweak and QCD physics (ie PDFs)
  - Search for Non Standard Interactions (NSI) from taus

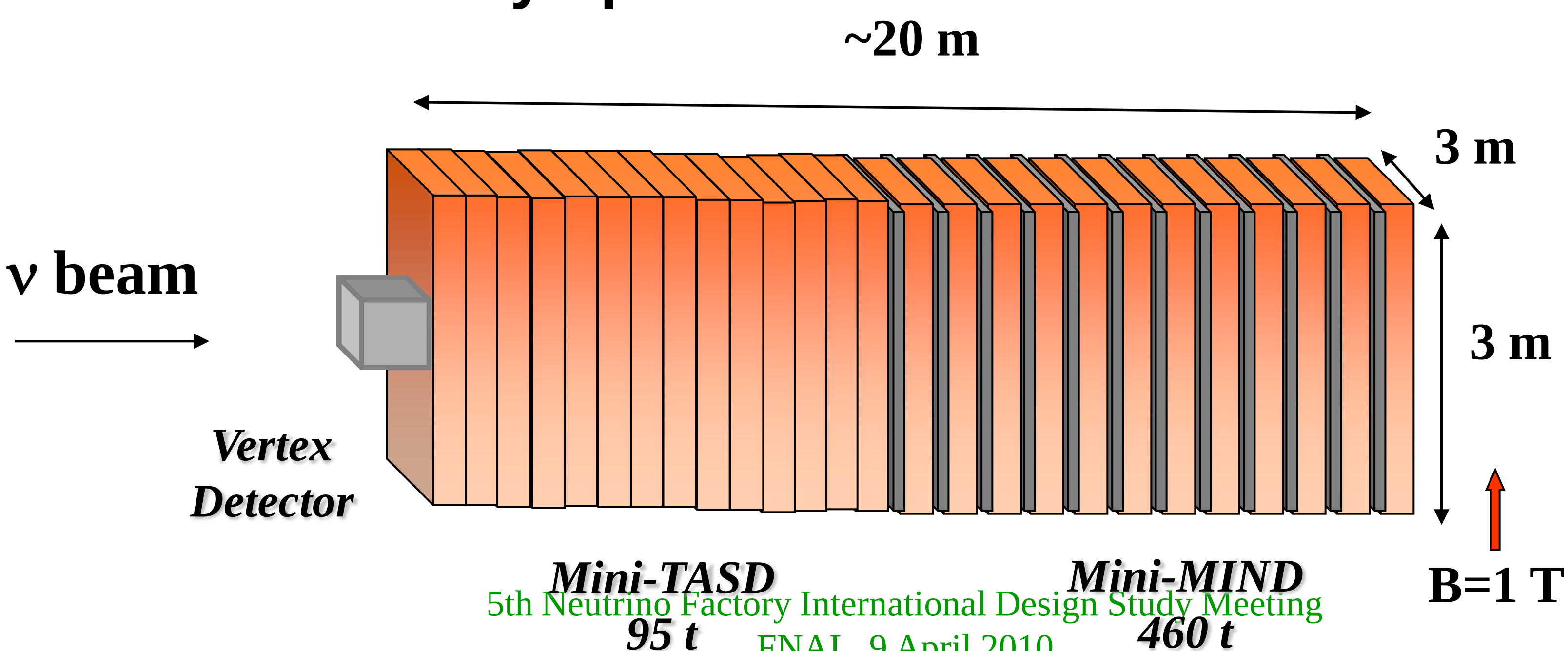
One possible design

- I have shown this possibility before:
  - Based on NOMAD experience
  - Also similar to T2K



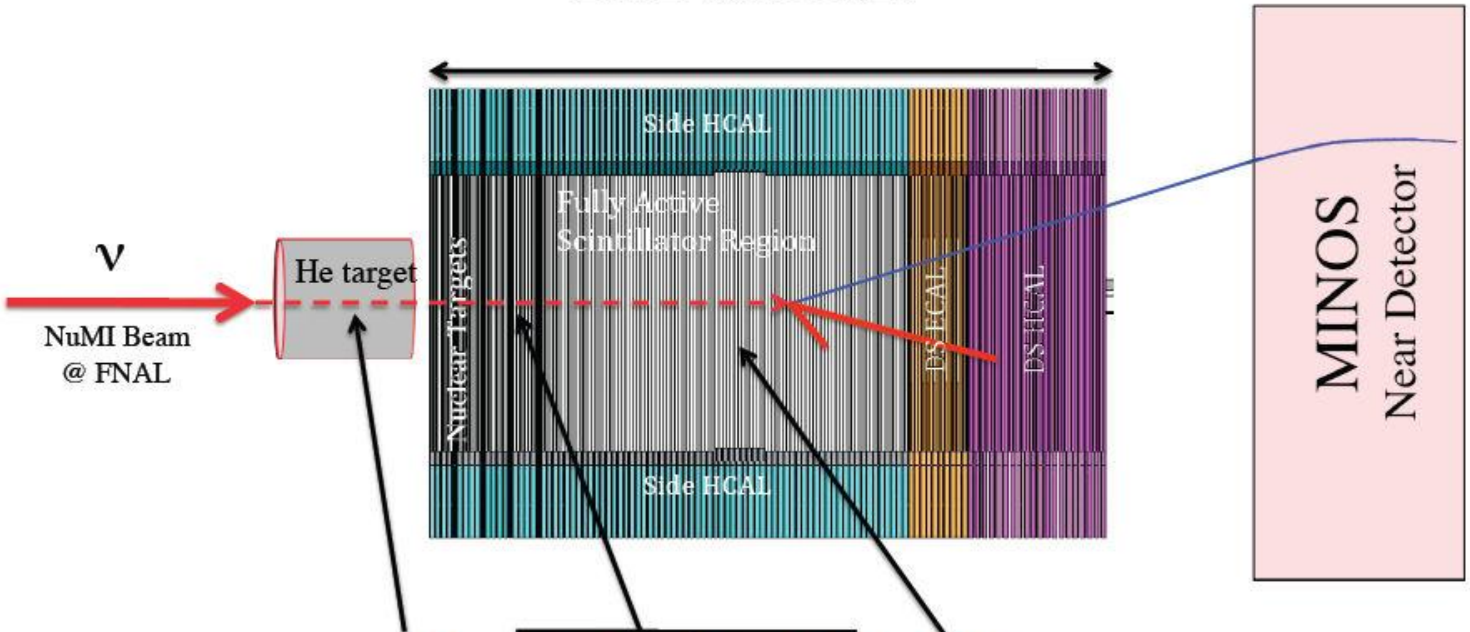
Another possibility

- Make design more similar to Far Detector:
  - Can have a high resolution Mini-TASD for leptonic measurement and a mini-MIND for flux and muon measurement
  - Vertex detector for charm measurement at the front.
  - Need to study options with detailed simulations



LBNE ND1: MINERνA Detector Concepts

Finely segmented, fully active scintillator tracking region surrounded by ECAL and HCAL,



nuclear targets (He, C, Fe, Pb, H_2O, CH)

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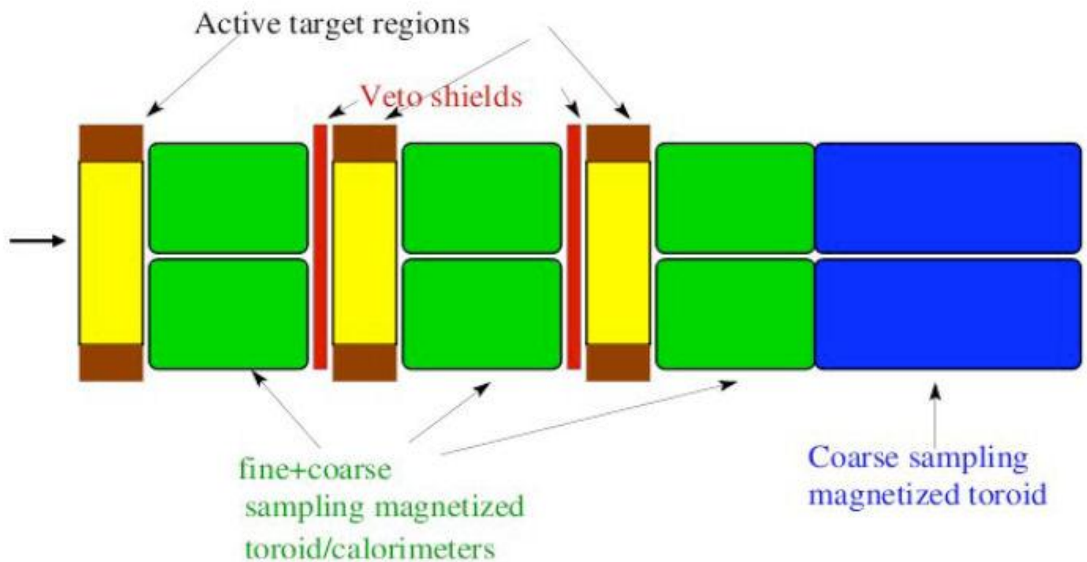
Hybrid Design based on MINERνA concept

Bob Bradford (U of Rochester) – Detector session PS3 tomorrow AM



- Downstream of the entire group of 3 is a coarser muon ranger for the highest energy muons.

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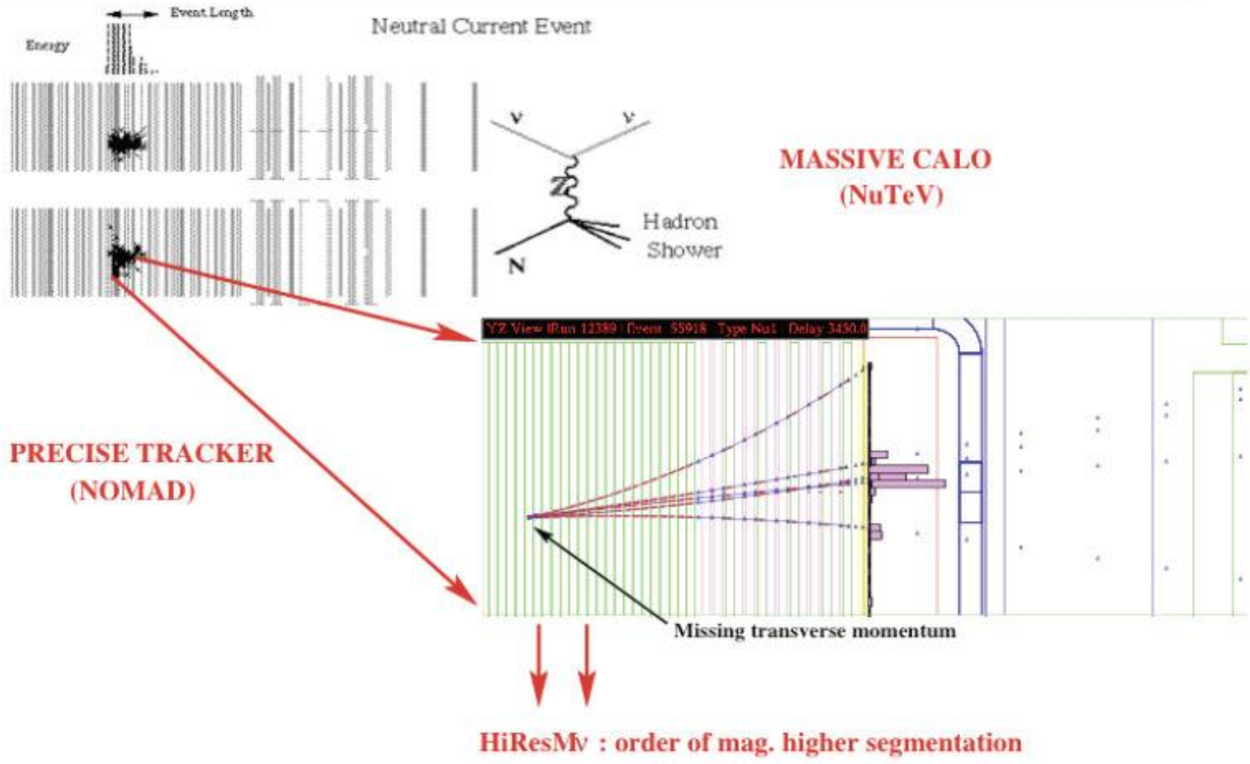
LBNE ND2: High Resolution STT Concepts



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Opportunity and conclusions:

Physics, not 'stamp collecting':

- Neutrino oscillations established

- $\nu_\mu \to \nu_\tau$ and $\bar{\nu}_\mu \to \bar{\nu}_\tau$ — atmospheric experiments ["indisputable"];
- $\nu_e \to \nu_{\mu,\tau}$ — solar experiments ["indisputable"];
- $\bar{\nu}_e \to \bar{\nu}_{\text{other}}$ — reactor neutrinos ["indisputable"];
- $\nu_\mu \to \nu_{\text{other}}$ from accelerator experiments ["indisputable"].

De Gouvea, NuFlavour09

Lepton Flavor Number NOT a good quantum number.

- Sign post for Physics at highest energy scale:
  - New symmetries?
    - E.g. family symmetry?
  - New particles?
    - E.g. heavy, Majorana neutrinos?
  - New forces?
    - E.g. SUSY?

$$m_\nu \propto \frac{1}{M_N}$$

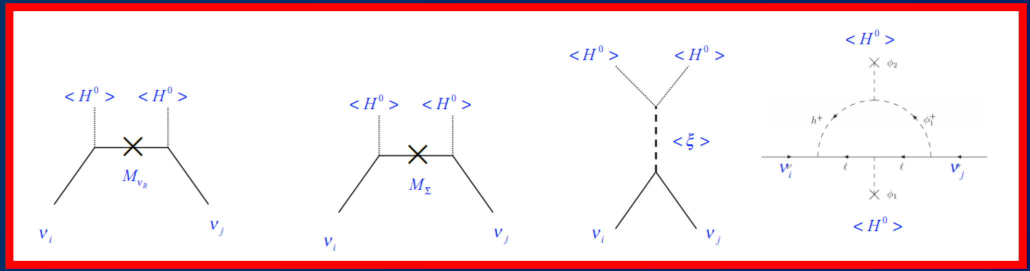
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

TB angles $\theta_{12} = 35^\circ, \quad \theta_{23} = 45^\circ, \quad \theta_{13} = 0^\circ.$

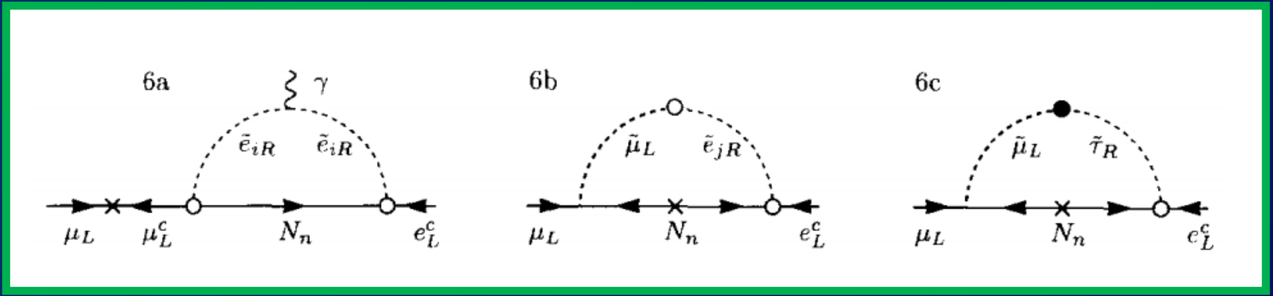
c.f. data $\theta_{12} = 34.5^\circ \pm 1.4^\circ, \theta_{23} = 43.1^\circ \pm 4^o, \; \theta_{13} = 8^\circ \pm 2^o$

Opportunity:

- Neutrino oscillations:



- Charged lepton flavour violation:



- Related processes!
  - Greatest benefit:
    - Neutrino oscillations, CLFV searches, LFV at colliders
- Can we articulate a ‘muon programme’?
  - Definitive CLFV programme
  - Definitive neutrino oscillations programme
  - The route to the energy frontier in lepton-antilepton collisions

Conclusions:

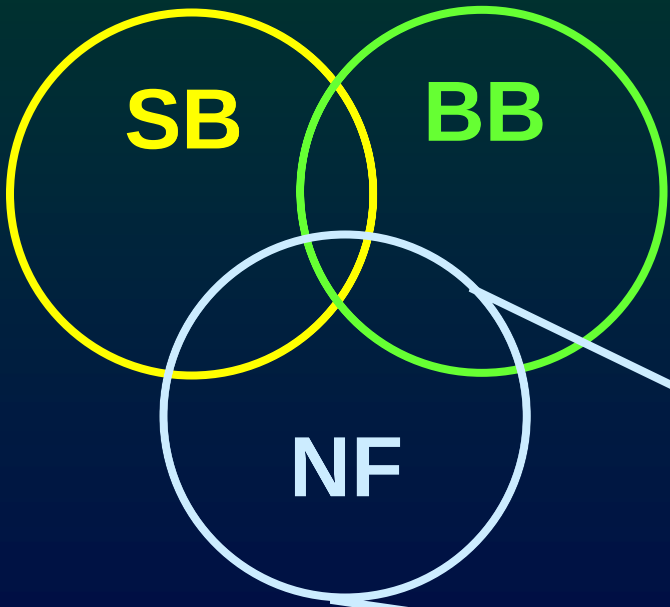
- The Neutrino Factory, the 'facility of choice':
  - Best discovery reach
  - Best precision:
    - But define agreed figure of merit
  - Best sensitivity to non-standard interactions:
- The IDS-NF baseline established and, so far, robust
  - Alternatives to the baseline, addressing particular issues (e.g., Low Energy Neutrino Factory), are under discussion
- The IDS-NF collaboration:
  - Energetic and ambitious, working towards IDR 2010/11 and RDR 2012/13
- Scientific imperative remains to make the Neutrino Factory an option for the field
  - Join us in Mumbai! Together we'll make the weather!

Backup:

EUROnu and the IDS-NF

- EUROnu *is* the European contribution to the IDS-NF

EUROnu



IDS-NF

- The Americas
  - Canada
  - USA
- Asia
  - Japan
  - India
  - (in the future: China …)
- Europe
  - EUROnu