Highlights from NUFACT'08

Contents

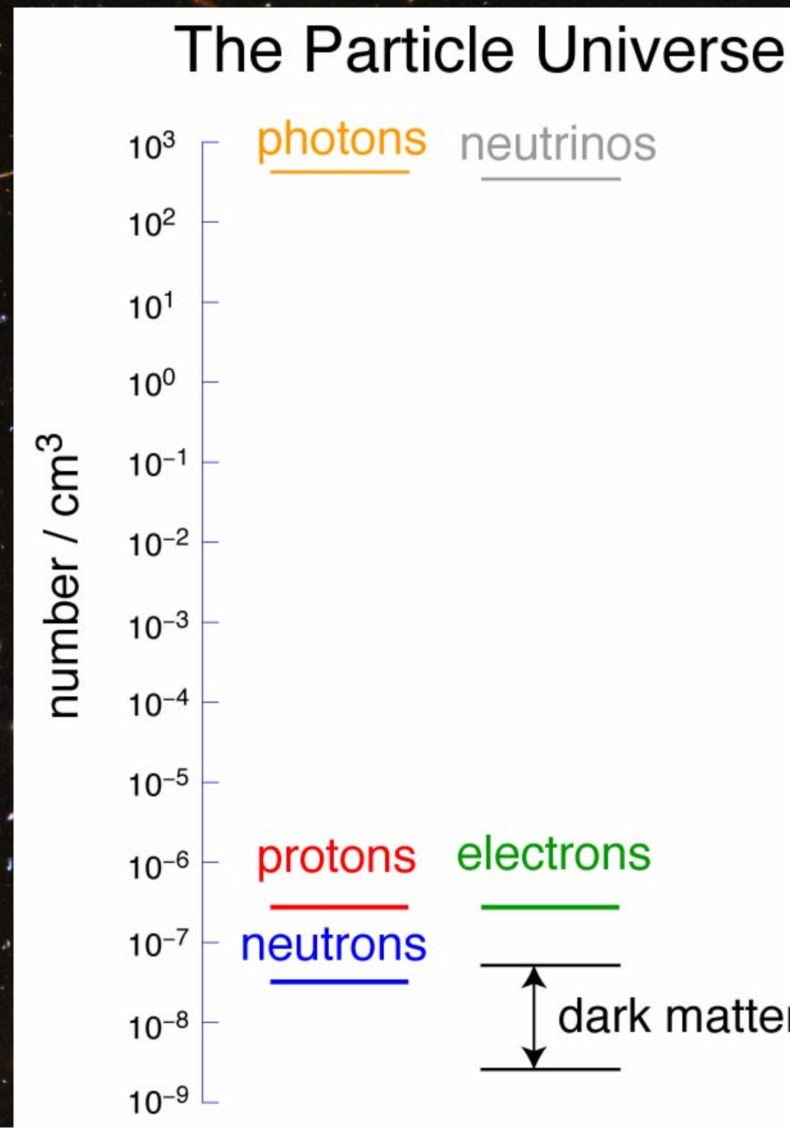
- ✓ Neutrinos in the Standard Model and Beyond
- ✓ International Scoping Study
  - Superbeams
  - Neutrino Factory
  - Beta Beams
  - Neutrino Factory Roadmap?
- ✓ Accelerator Working Group Summary
  - Proton Drivers
  - Capture
  - Target
  - Cooling
  - Acceleration

NUFACT08 - Valencia, Spain
30 June - 5 July 2008

MICHEL MARTINI

Neutrinos in the Standard Model and Beyond

There are a lot of neutrinos out there



HITOSHI MURAYAMA
IPMU TOKYO & BERKELEY

Neutrinos in the Standard Model…

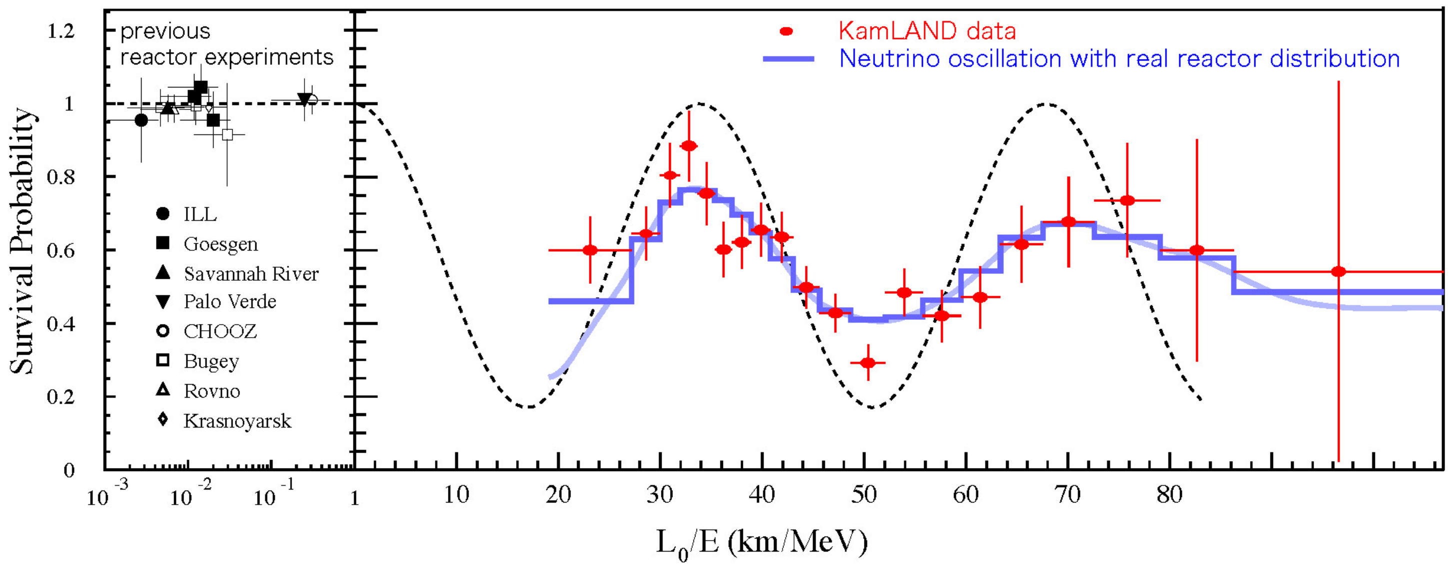
✓ Neutrinos left-handed (negative helicity) ⇒ massless in the Standard Model

– Finite mass of neutrinos imply the Standard Model is incomplete! And probably a lot more profound

✓ Neutrinos do oscillate ⇒ have a non-zero mass

– Neutrinos appear to have tiny but finite mass

✓ Discovery of neutrino mass: Revolution!



Hitoshi Murayama
IPMU Tokyo & Berkeley

Neutrinos in the Standard Model…

- ✓ Matter oscillation results for three neutrinos:
  - The probability of measuring a specific flavor (electron, muon or tau) for a neutrino varies periodically as it propagates

$$P_{\nu_e\nu_\mu(\bar{\nu}_e\bar{\nu}_\mu)}(x) = P_1 + P_2 + P_3 + P_4$$

$$P_1 = s_{23}^2 \sin^2 2\theta_{13} (\Delta_{13}/B_\mp)^2 \sin^2 [B_\mp x/2]$$

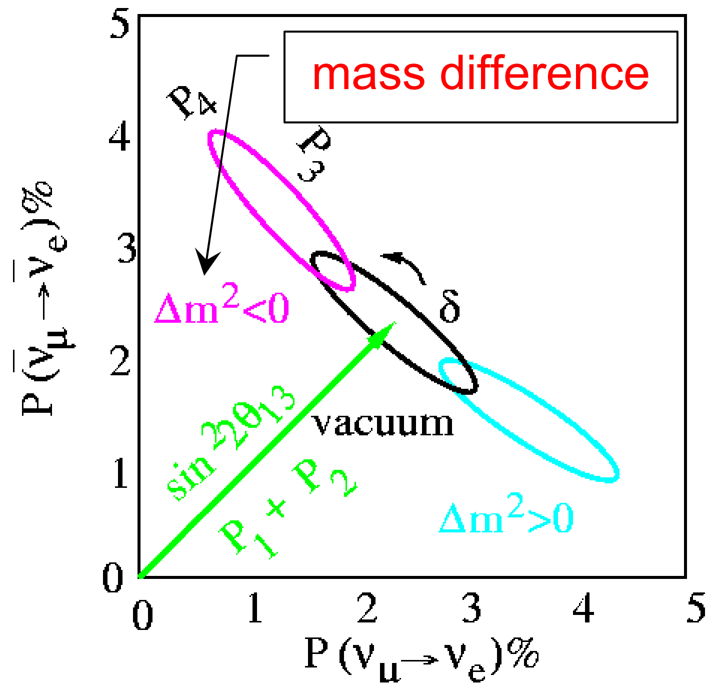
$$P_2 = c_{23}^2 \sin^2 2\theta_{12} (\Delta_{12}/A)^2 \sin^2 [Ax/2]$$

$$P_3 = \cos\delta \sin[Ax/2]\ldots \quad P_4 = \pm \sin\delta \sin[Ax/2]\ldots$$

$$\Delta_{ij} \equiv \Delta m_{ij}^2/2E$$

Magic baseline: only 1 term in equation

$$Ax/2 = \pi \Rightarrow x \approx 7300 - 7600 \text{ km}$$



- ✓ θ_{13} is crucial for the future of neutrino oscillation physics

Neutrinos in the Standard Model…

✓ Raised More Questions

- Now neutrino right-handed? Two ways to go:
  - Dirac neutrino: New particle, right-handed neutrino. Why not yet seen?
  - Majorana neutrino: No new particle, must be right-handed anti-neutrino. No essential difference between neutrinos and anti-neutrinos!
- Why is neutrino mass so small?
- CP Violation?

✓ Connections to big questions about the universe

- Did neutrinos affect galaxy formation?
- Why do we exist?
- Why does the Universe exist?

International Scoping Study

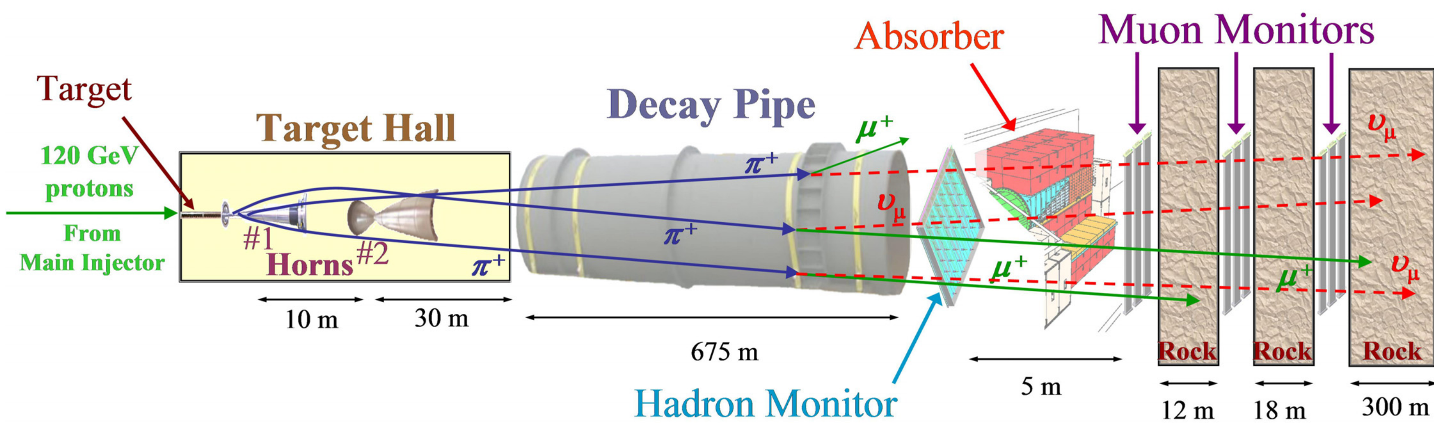
- ✓ The International Scoping Study (ISS) compared the physics performance and detector requirements for 3 possible facilities:
  - Super-beams: high powered conventional neutrino beams from the decay of pions
  - Neutrino Factories: neutrino beams from the decay of muons
  - Beta beams: neutrino beams from the decay of radioactive isotopes
- ✓ Also, the ISS defined the scope of the accelerator parameters for a:
  - Neutrino Factory
  - Beta beam facility (in collaboration with the Eurisol beta beam design study)

Superbeams

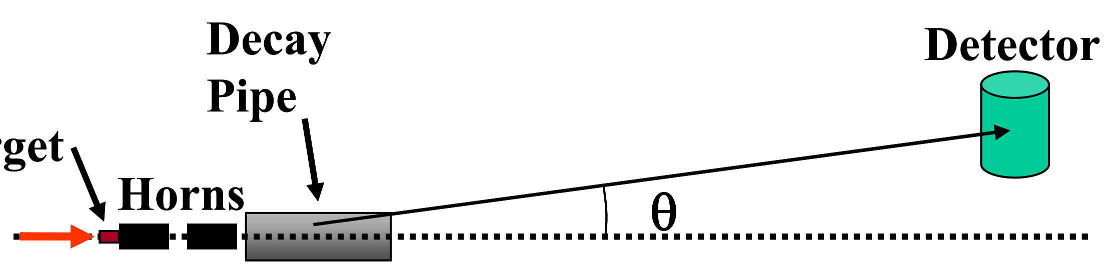
- ✓ Super-beams: 1-4 MW proton intensity to generate beam of neutrinos from the decays of pion and kaons.

ν_μ's: $\pi^+ \rightarrow \mu^+ \nu_\mu$
$K^+ \rightarrow \mu^+ \nu_\mu$

ν_e's: $\mu^+ \rightarrow e^+ \nu_e \nu_\mu$
$K^+ \rightarrow \pi^0 e^+ \nu_e$



- ✓ Off-axis for better determination neutrino energy. Nova off-axis (~750 km) or T2K (~250 km)



PAUL SOLER - UNIVERSITY OF GLASGOW

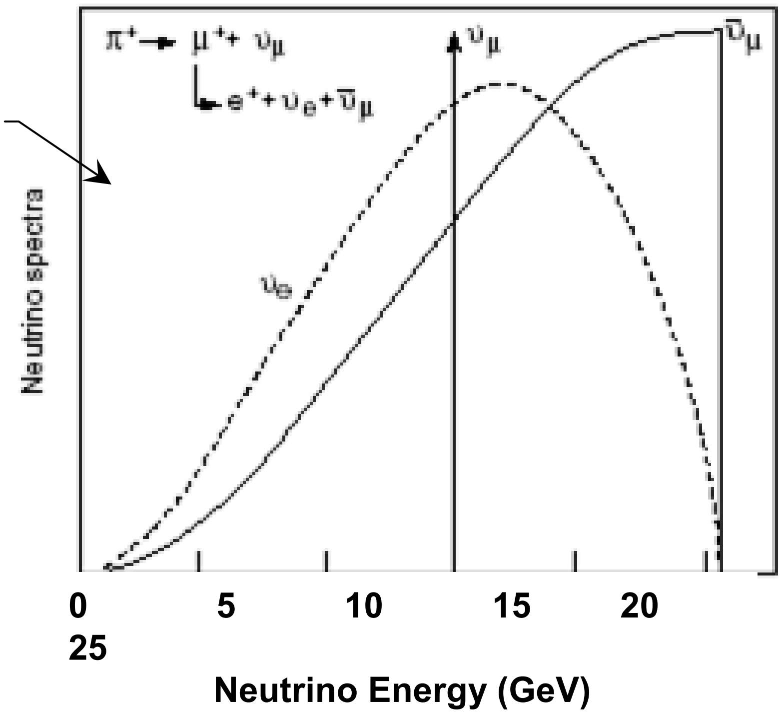
Neutrino Factory

- ✓ Neutrino Factories produce neutrinos from muon decays in a storage ring.
- ✓ Rate calculable by kinematics of decay

e.g. if μ^+ accelerated to 25 GeV

$$\mu^+ \rightarrow e^+ + \overline{\nu}_\mu + \nu_e$$

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$$

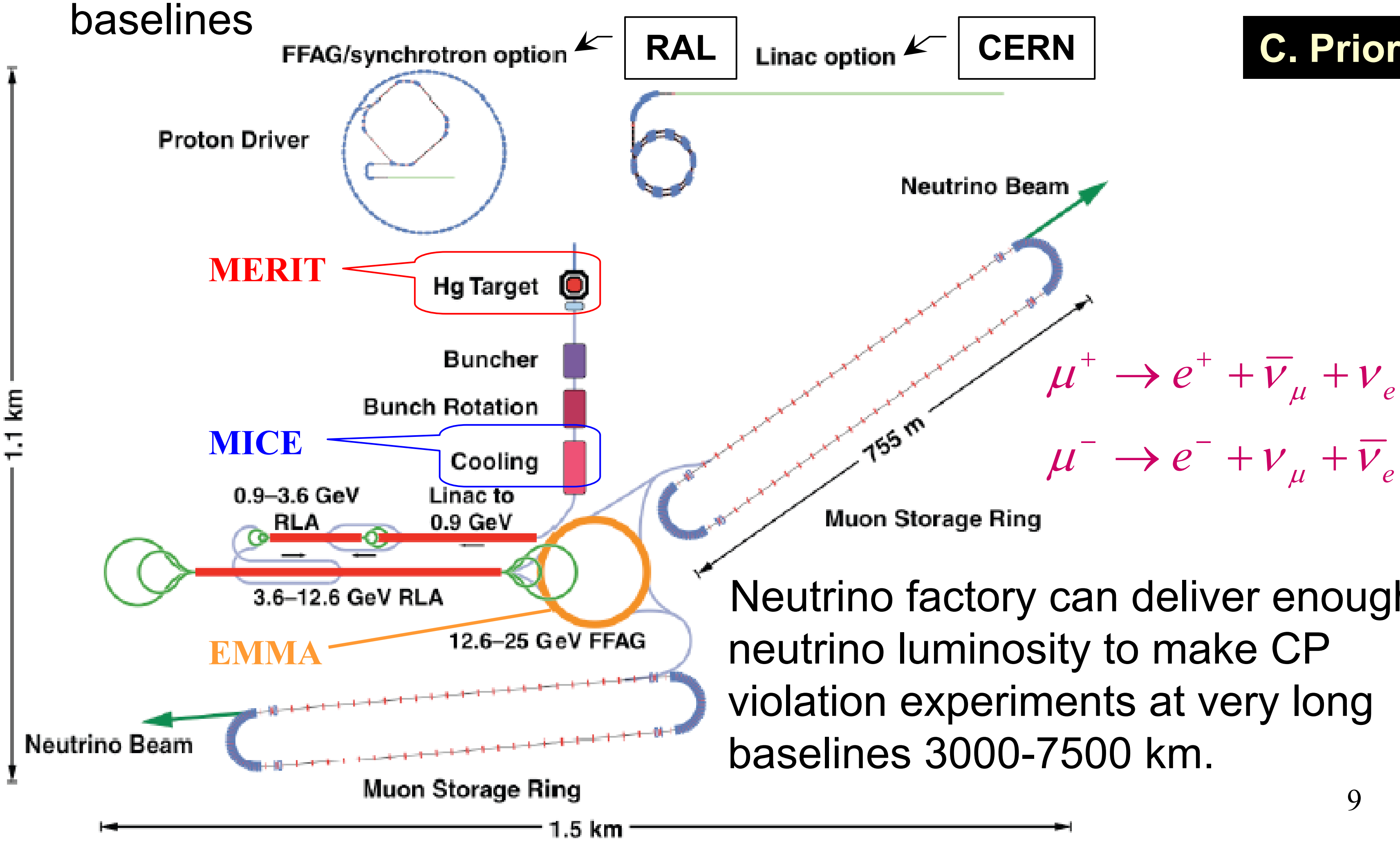


- ✓ Defines detector needs:
  - Muon and electron neutrino and anti-neutrino species being produced concurrently we need to determine the charge and lepton identity to separate from background ⇒ Magnetic detectors

Neutrino Factory

- ✓ Baseline design for a Neutrino Factory from International Design Study
- ✓ Design can fire neutrino beams to 2 different detectors at 2 different baselines

C. Prior



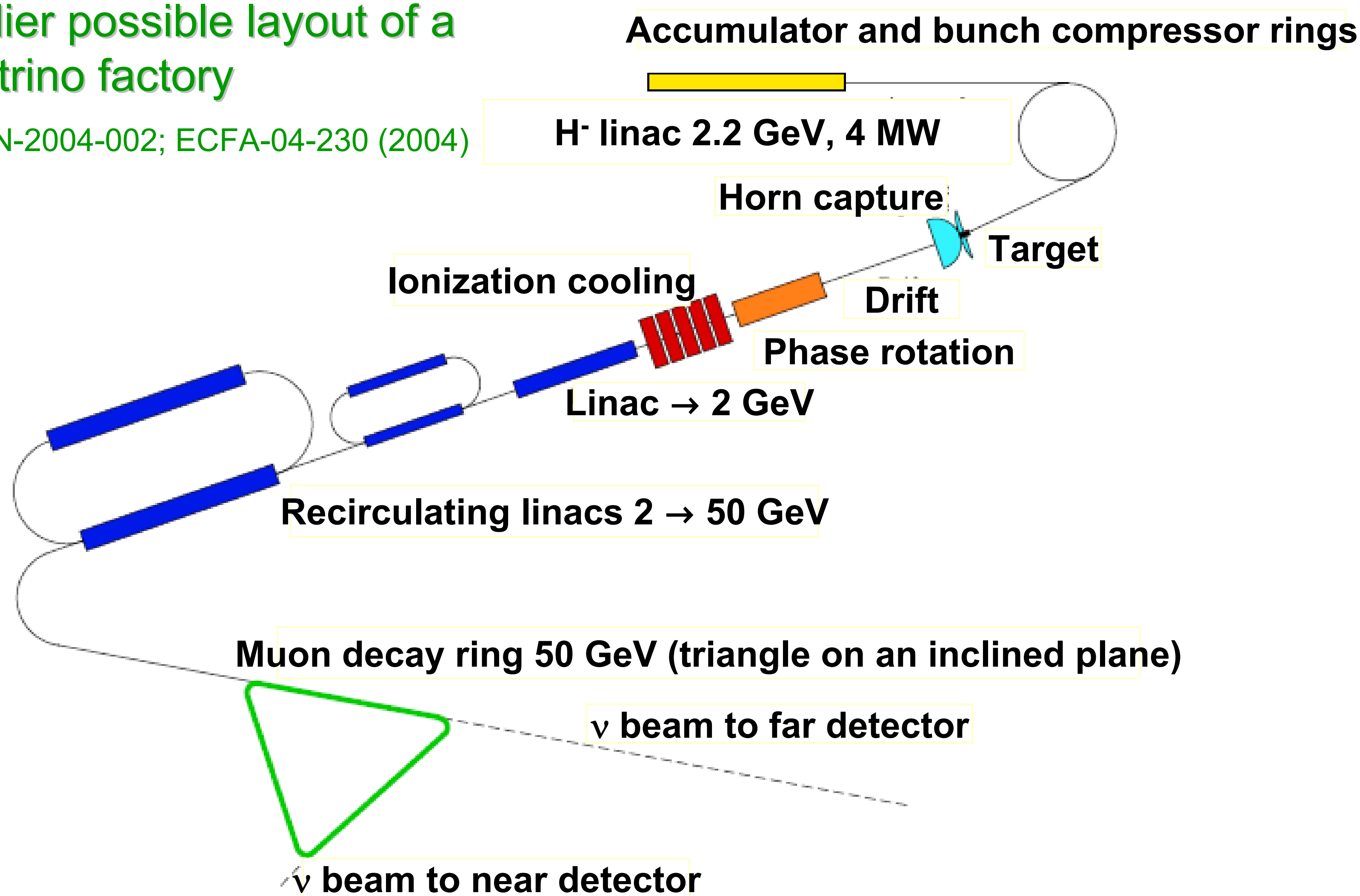
Neutrino factory can deliver enough neutrino luminosity to make CP violation experiments at very long baselines 3000-7500 km.

PAUL SOLER - UNIVERSITY OF GLASGOW

Neutrino Factory

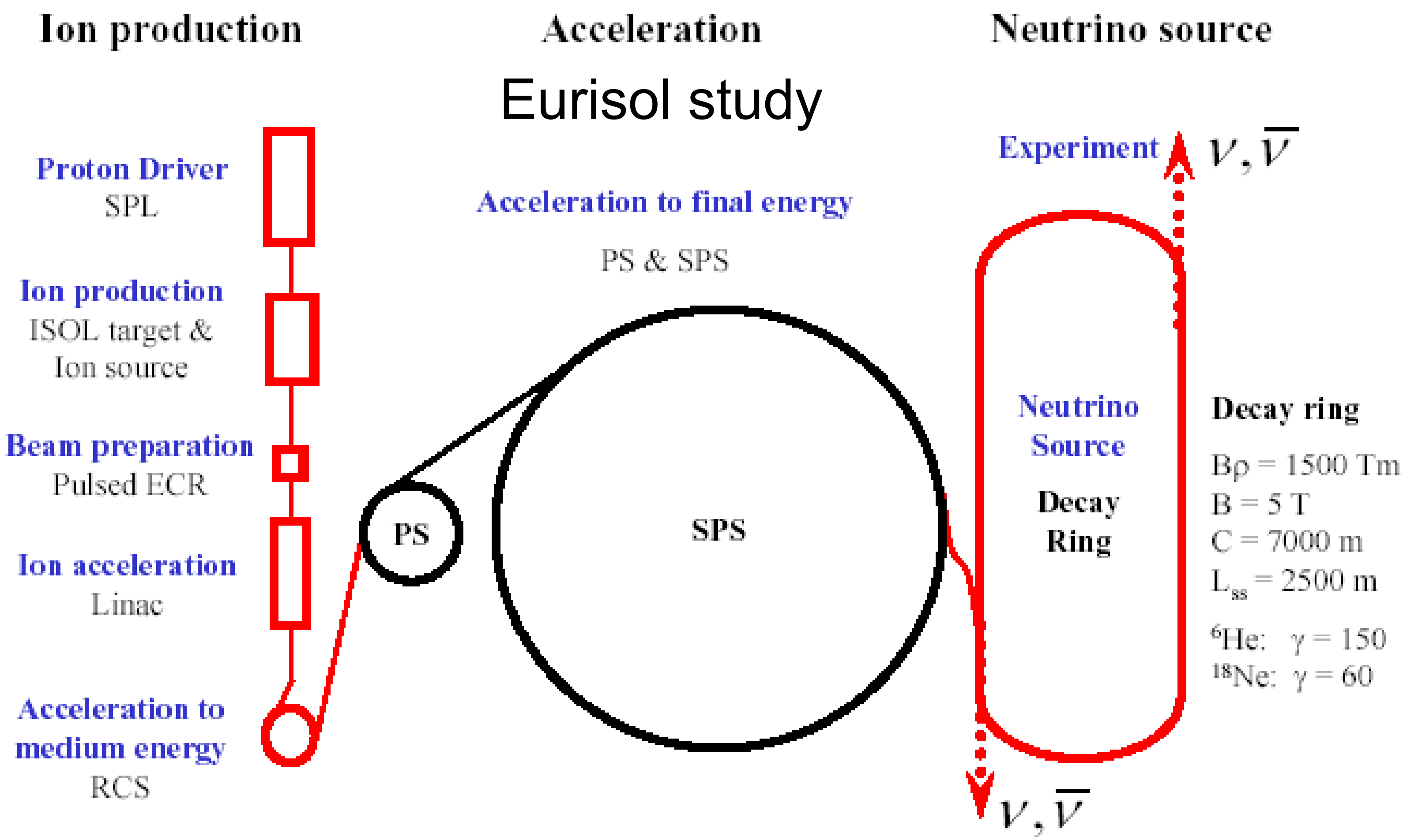
Earlier possible layout of a neutrino factory

CERN-2004-002; ECFA-04-230 (2004)



Beta Beams

- ✓ **Beta beam:** beta decay of accelerated radioactive nuclei
  - He-6 for neutrino production: γ ~ 100 $\quad {}^{6}_{2}He \rightarrow {}^{6}_{3}Li + e^{-} + \overline{\nu}_{e}$
  - Ne-18 for antineutrino production: γ ~ 60 $\quad {}^{18}_{10}Ne \rightarrow {}^{18}_{9}F + e^{+} + \nu_{e}$



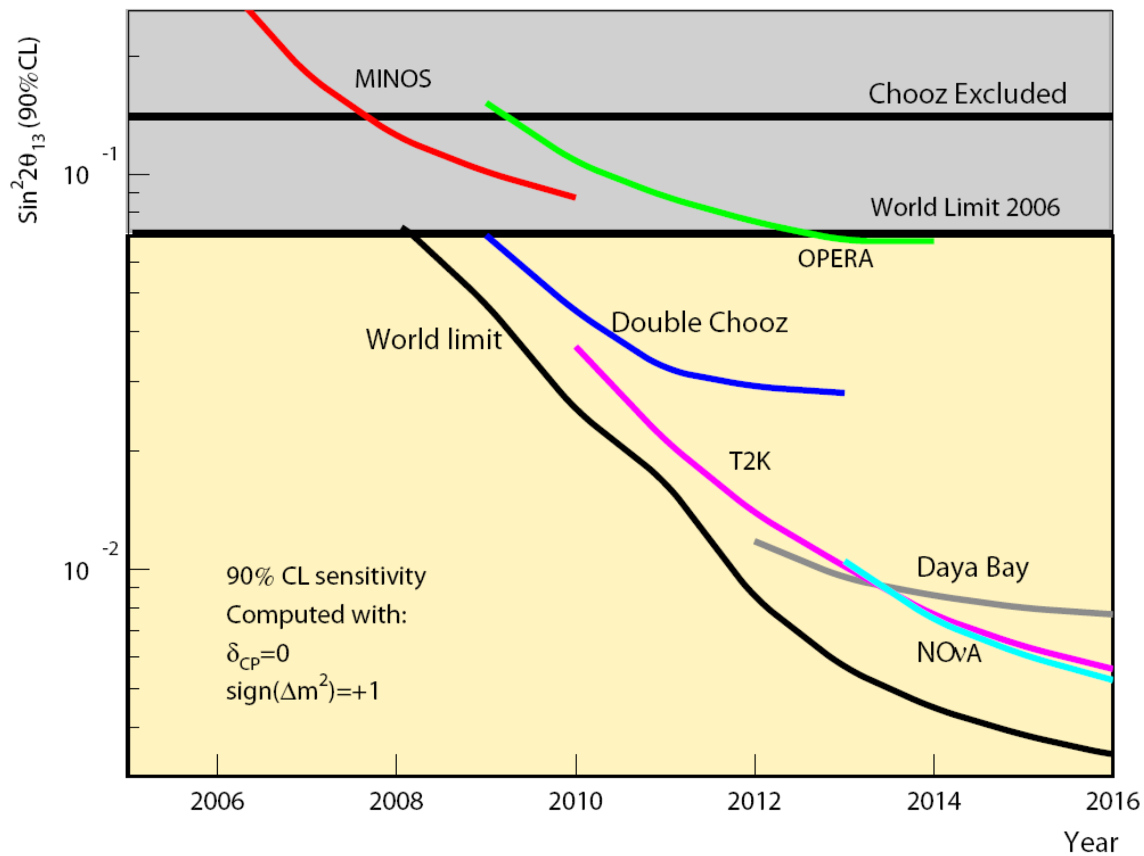
PAUL SOLER - UNIVERSITY OF GLASGOW

Neutrino Factory Roadmap?

- ✓ Roadmaps for Neutrino Factory and Neutrino Oscillation measurements:
  - The ISS studied options for future facilities and narrowed the list of detector options for each facility
  - Launch of Neutrino Factory International Design Study (IDS)
  - Developed an internationally agreed baseline for the Neutrino Factory accelerator complex and for the Neutrino Factory neutrino-detection system
  - Goal: to produce a 'Reference Design Report' for the Neutrino Factory by 2012:
    - document that will allow the to consider initiating the Neutrino Factory project
    - Emphasis on engineering to demonstrate technical feasibility and evaluate cost

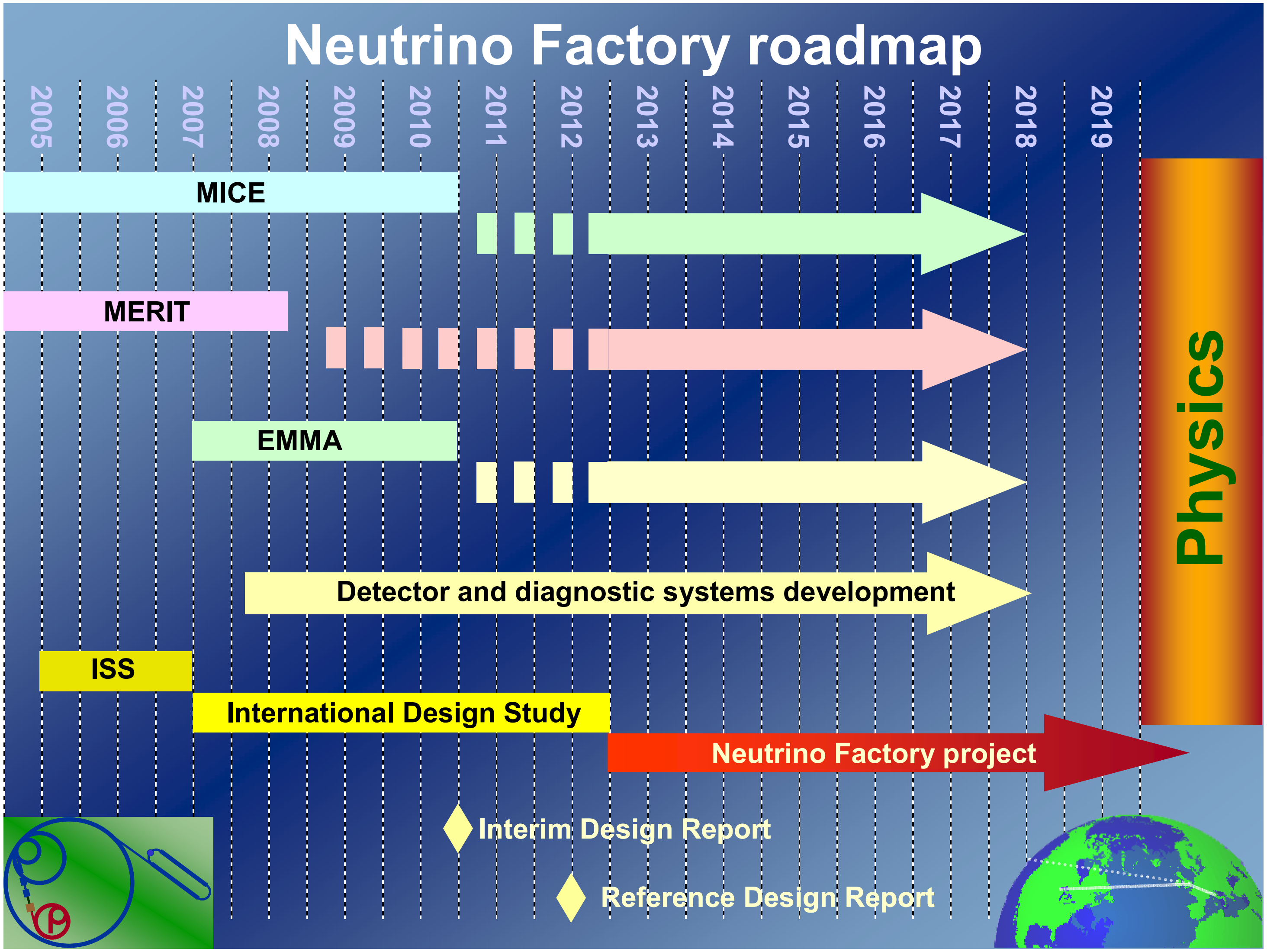
Neutrino Factory Roadmap?

✓ Roadmap for Neutrino Oscillation measurements:



– Knowledge of θ_{13} and technical feasibility dictates high intensity neutrino facility for high-precision required "second half next decade"

Neutrino Factory Roadmap?



Accelerator Working Group Summary

✓ Organization

– Proton drivers	chair	M. Zisman
– Capture	chair	K. Yoshimura
– Muon source - end to end simulation	chair	E. Keil
– Target	chair	J. Pozimski
– Front-end	chair	B. Palmer
– Acceleration	chair	Y. Mori
– Experiences from operating facilities	chair	T. Nakaya
– Beta beams	chair	M. Lindroos
– Beta beams and NF optimization	chair	E. Wildner

M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory

Proton Drivers

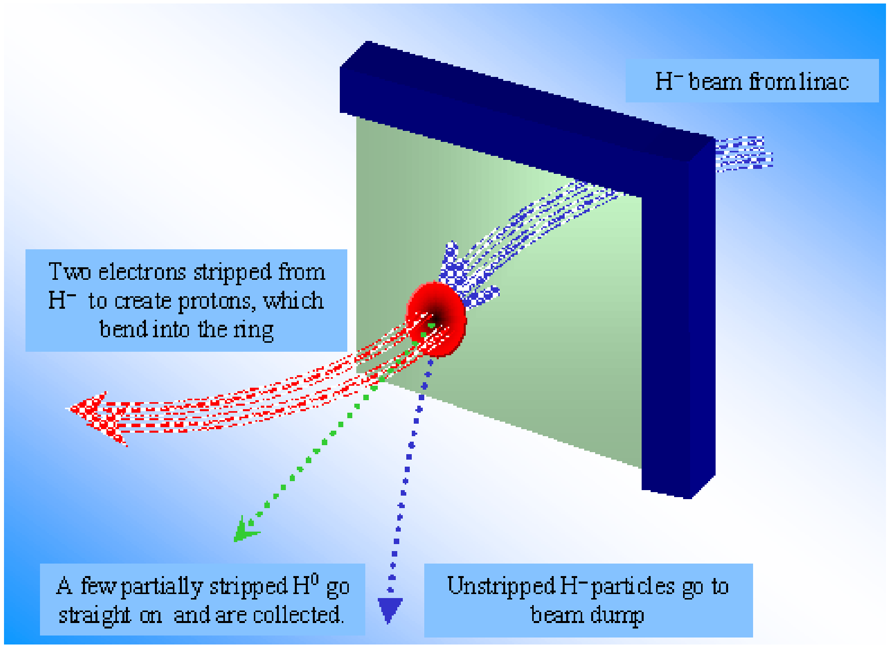
- ✓ Challenging!
- ✓ 4 MW ->2500 Amps in 1 ns bunch
- ✓ Issues: Beam chopper, injection, bunch compression

⇒ **To-Do list**

Injection

– Foil issues. Use of painting techniques. Inject energy varying beam in dispersion region to change transverse positions: gives free painting!

– Laser stripping: Promising work at SNS - may be solution for the future.



M. Meddahi and D. Li *

CERN, Lawrence Berkeley National Laboratory

C. Prior

Proton Driver: ν-Factory PD updates?

NF- IDS 01-08

C. Prior
J. Pozimski
M. Aiba

✓ Mean beam power	4 MW
✓ Pulse repetition rate	50 Hz
✓ Proton kinetic energy	5-10-15 GeV
✓ Bunch duration at target	1-3 ns rms
✓ Number of bunches per pulse	1-3
✓ Separated bunch extraction delay	≥ 17 μs
✓ Pulse duration:	
– liquid mercury target	≤ 40 μs possibly ≤ 150 μs ?
– Solid metal target	≥ 70 μs

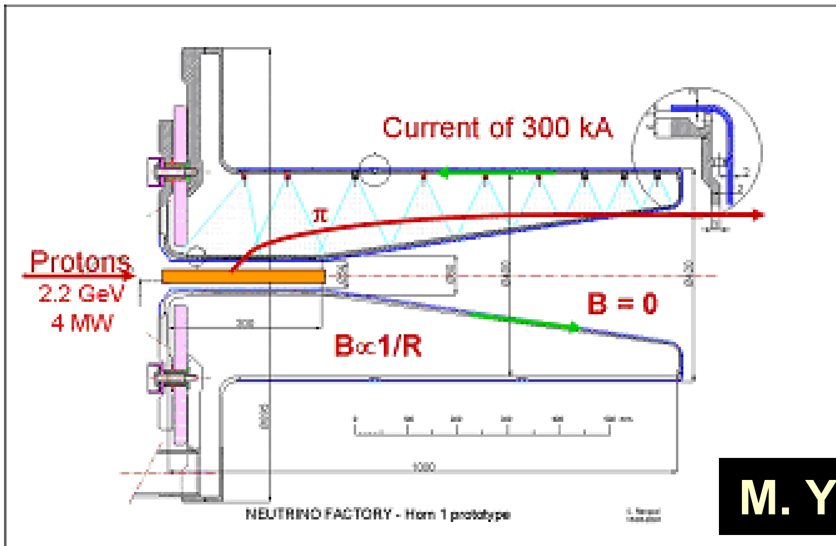
Should we update the baseline parameters?

Too premature: Require first to study consequences in each system and perform end-to-end assessment. **To-Do list**

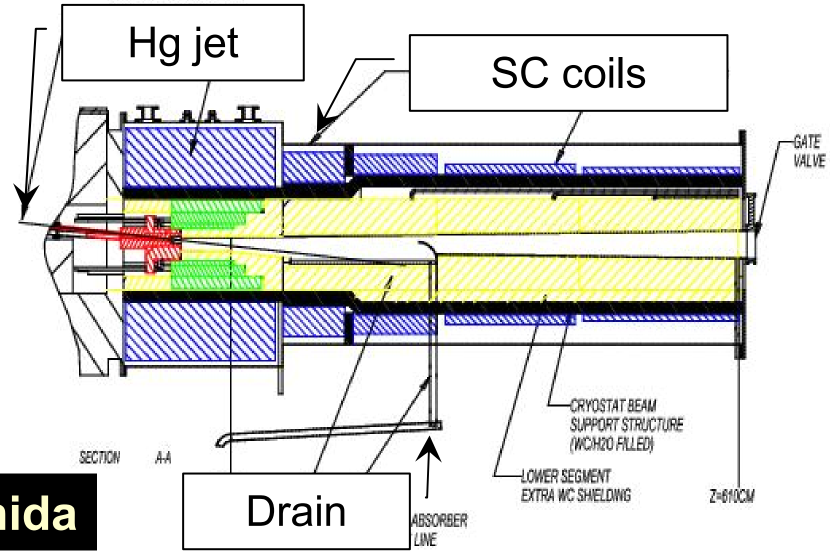
M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory

Capture - Horns vs Solenoids

Horn in Neutrino Factory



Solenoid in Neutrino Factory



M. Yoshida

- ✓ Solenoid option: lifetime limited by radiation damage
  ⇒ R&D on radiation damage of insulator **To-Do list**
- ✓ Horn option: Lifetime limited by mechanical fatigue
  ⇒ Need to overcome ~10^9 pulses/yr at 50 Hz **To-Do list**
- ✓ Beam dump & radiation dose in target station are an issue ⇒ Maintenance scenario **To-Do list**

M. MEDDAHI AND D. LI *

CERN, LAWRENCE BERKELEY NATIONAL LABORATORY

Target

✓ **HARP** results below 15 GeV are essential for future neutrino facilities

To-Do list

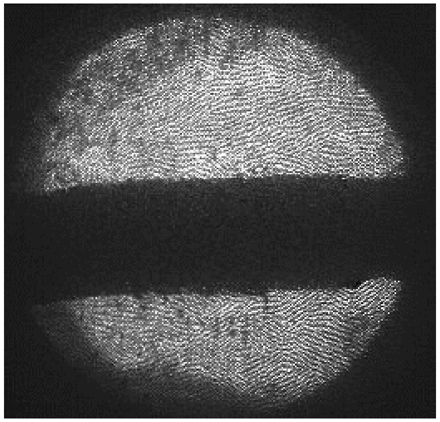
– Take advantage of the HARP data
  Revisit the estimates made in the past
– Any other questions from new facility designers which need to be answered?
– Requests for more experiments?

M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory

Target - Free Liquid Jet Targets

MERIT: The Neutrino Factory/Muon Collider target concept of a free liquid jet has been validated for 4 MW operation

H. Kirk



H. Kirk

To-do List

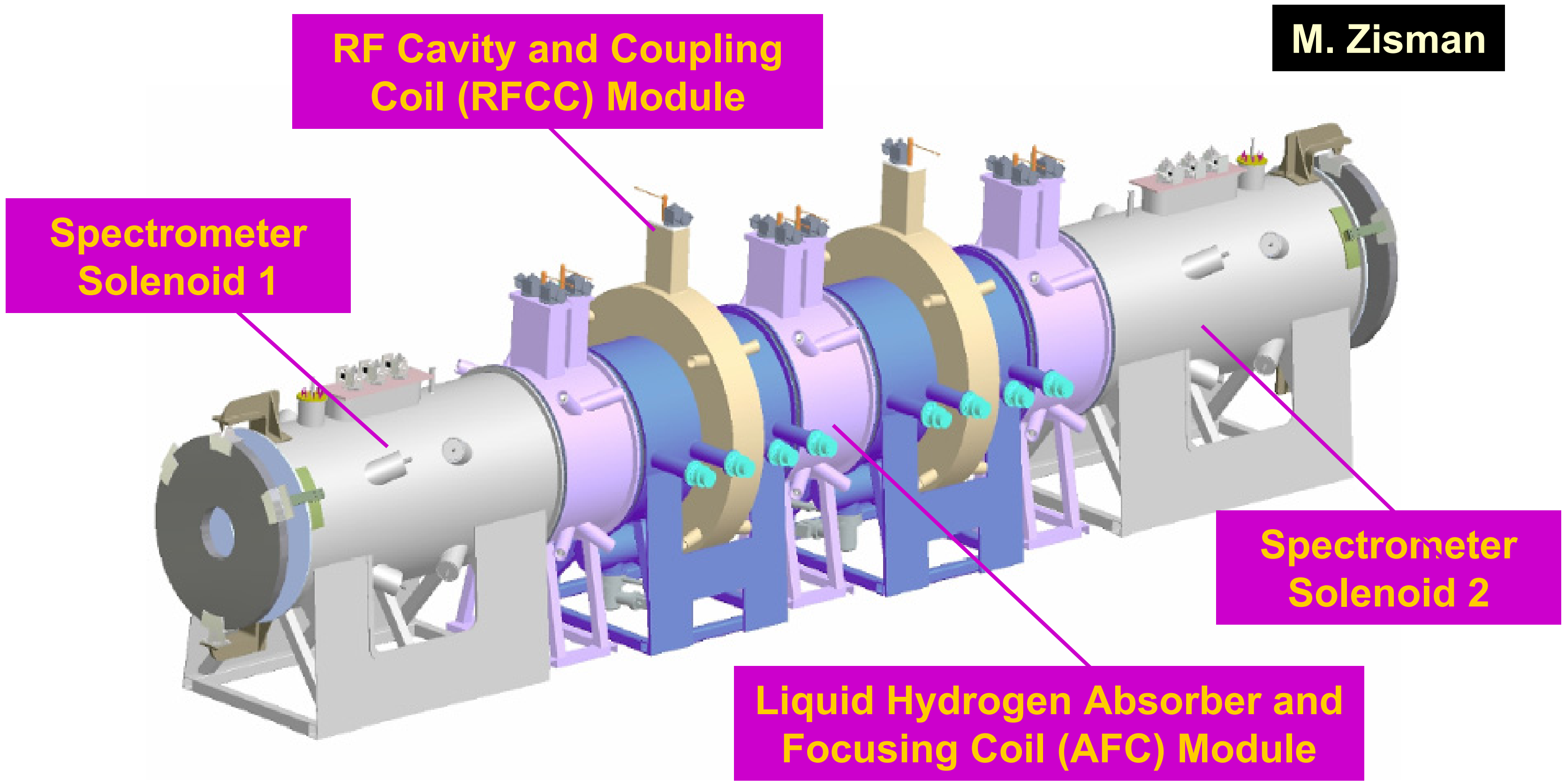
- More R&D to improve the jet quality and to advance understanding of systems design issues

✓ Baseline updates?

- Keep Liquid Jet target as baseline for Neutrino Factories and Muon Colliders
- For Superbeams that will be limited in beam power to less than 2 MW –TBC- static solid targets continue to be appealing. Results to be followed-up closely

M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory

Muon Ionization Cooling: MICE

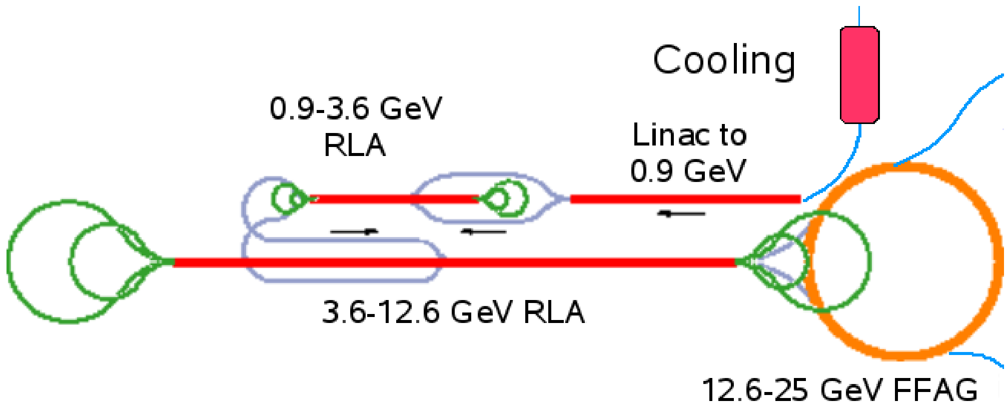


Aim: Demonstrate the technology required to reduce the produced muon phase space

Trans. emittance reduction (cooling) ~10% for 200 MeV/c muons

Acceleration: IDS Baseline

A. Bogacz



- ✓ Linear Pre-accelerator
  - 244 MeV to 900 MeV
- ✓ RLA I (1 Linac, 4 arcs)
  - 4½ pass, 0.9 GeV to 3.6 GeV, 0.6 GeV/pass
- ✓ RLA II (1 Linac, 4 arcs)
  - 4½ pass, 3.6 GeV to 12.6 GeV, 2 GeV/pass
- ✓ Non scaling FFAG
  - 12.6 GeV to 25 GeV

- ✓ Acceleration Goals: Large acceptance acceleration to 25 GeV and beam 'shaping'
- ✓ Various fixed field accelerators at different stages
- ✓ IDS Acceleration scenario optimized to take maximum advantage of appropriate acceleration scheme at a given stage

M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory

FFAG Acceleration

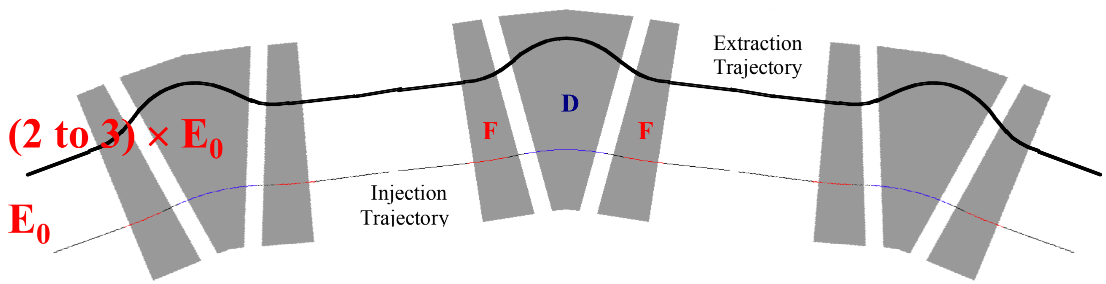
Fixed Focus Alternating Gradient Concept

H.G. Kirk

Why FFAGs ?

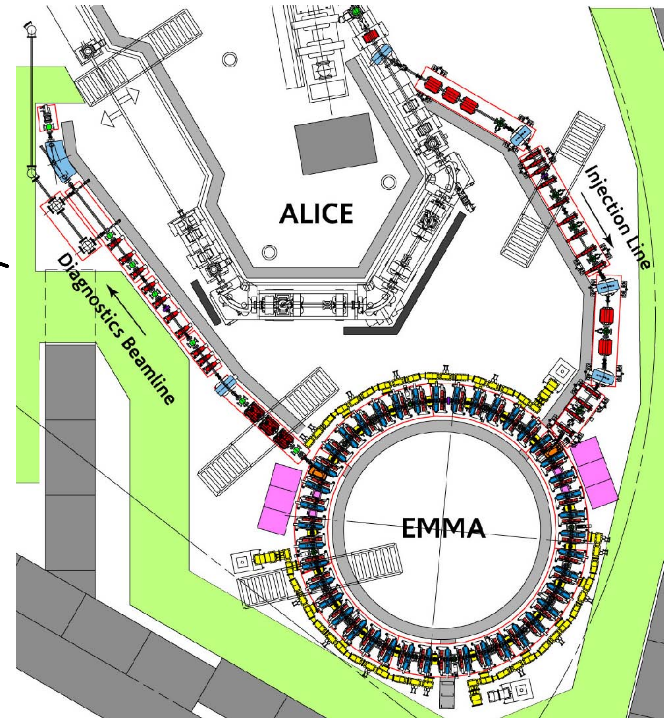
Large chromatic acceptance (2 to 3×)

No ramping → Fast acceleration



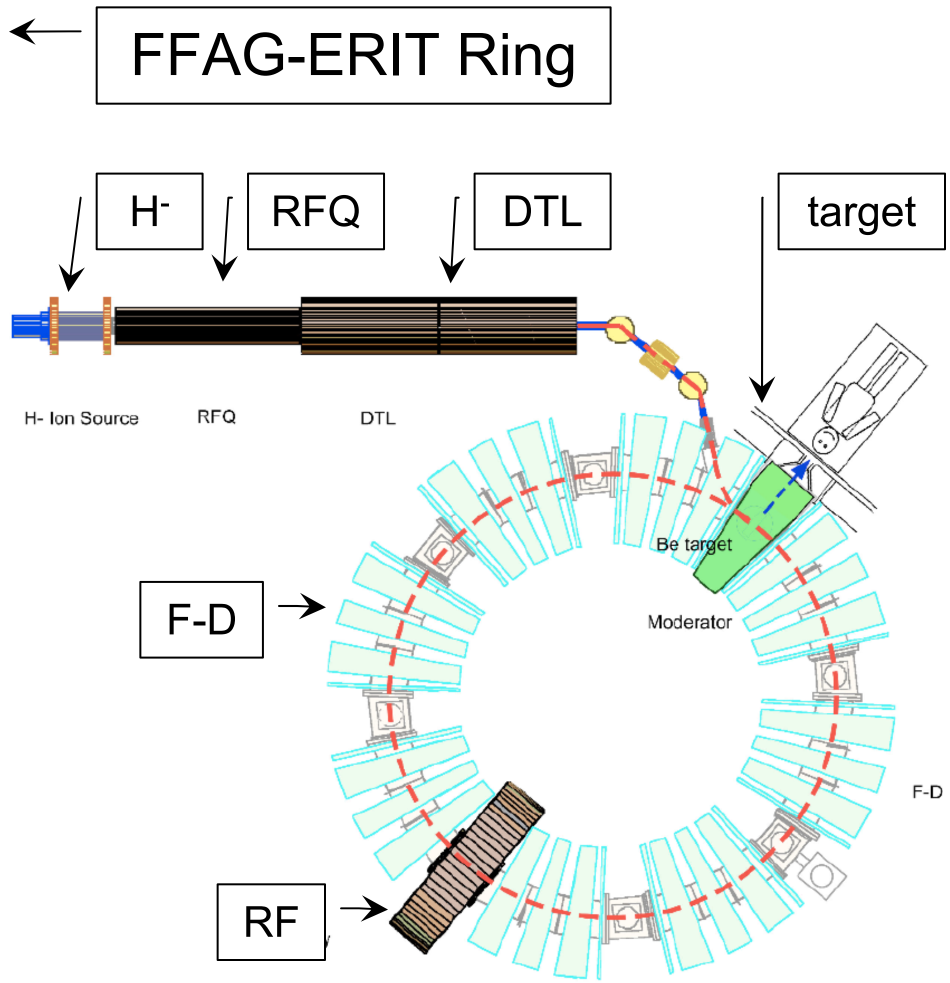
- ✓ **Scaling**
  - –**Tune independent of momentum**
  - –**Large magnets**
  - –**Low frequency RF**

- ✓ **Non-Scaling**
  - –**Momentum dependent tunes**
  - –**Smaller less expensive magnet**
  - –**Can use higher frequency RF**



EMMA (Darsbury) is an electron non scaling FFAG designed for 10-20MeV/c operation

FFAG Acceleration



Beam Energy: 11MeV
Beam Current: 70 mA
Beam Life-time: 500 - 1000 turns
Acceptance: A_v > 3000 mm.mrad
$\Delta p/p > \pm 5\%$ (Full)

M. Meddahi and D. Li *
CERN, Lawrence Berkeley National Laboratory