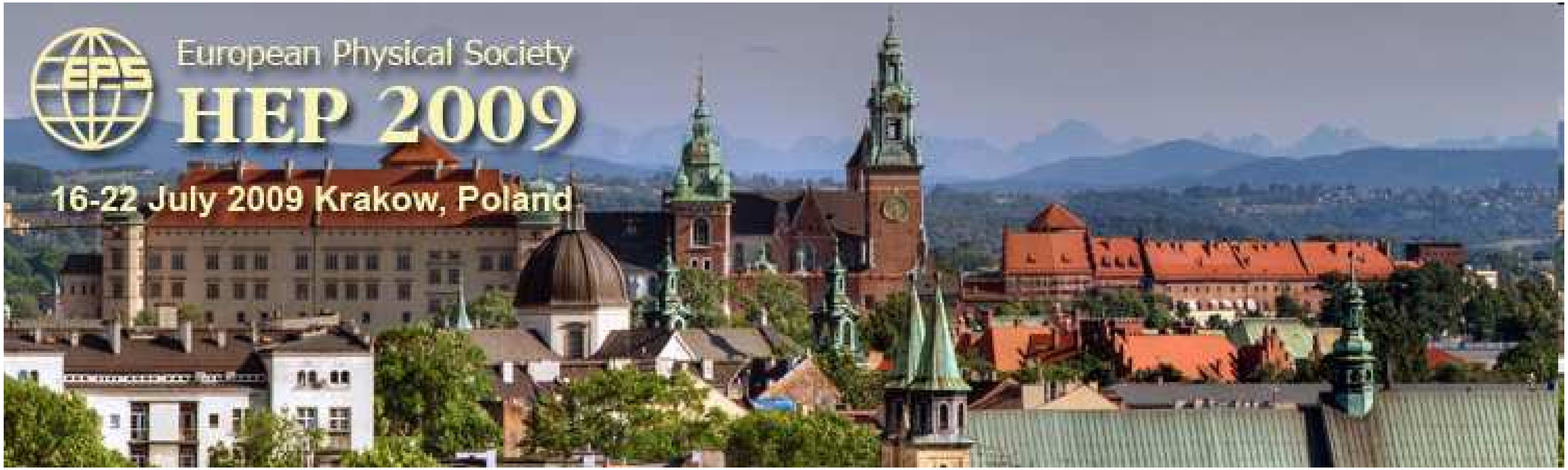
Future Neutrino Oscillation Facilities



A. the status and CP violation

B. Beyond the approved program:
options in Europe and elsewhere

- B1 Elsewhere
  - B1.1 in Japan
  - B1.2 In the US
- B2. in Europe
  - B1.1 LAGUNA and liquid detectors
  - B1.2 EURONU future neutrino facility and the SPL
  - B1.3 Super-beam options
  - B1.4 Beta beam
  - B1.5 Neutrino Factory

C. Conclusions and outlook

Status of neutrino oscillations in a few words

1. **We know that there are three families of active, light neutrinos** ***(LEP)***
2. **Solar neutrino oscillations are established**
3. ***(Homestake+Gallium+Kam+SuperK+!SNO(2002)!+KamLAND)***
3. **Atmospheric neutrino (ν_μ –>) oscillations are established**
   (IMB+Kam+Macro+Sudan +!SuperK(1998)!+K2K+MINOS)
3. **At that frequency, electron neutrino oscillations are small** ***(CHOOZ)***

4. **Indication of possible higher frequency oscillation (LSND) is not confirmed (miniBooNe)**

This allows a consistent picture with 3-family oscillations

$\theta_{12} \sim 34^0$ $\Delta m_{12}^2 \sim 7.6\ 10^{-5} eV^2$, $\theta_{23} \sim 45^0$, $\Delta m_{23}{}^2 \sim \pm 2.4\ 10^{-3} eV^2$, $\theta_{13} <\sim 10^0$

with 3 unknown θ_{13}, phase δ , sign of Δm^2_{13}

BUT many basics full scheme and unitarity still untested:

=> an exciting experimental program for at least 25 years *)

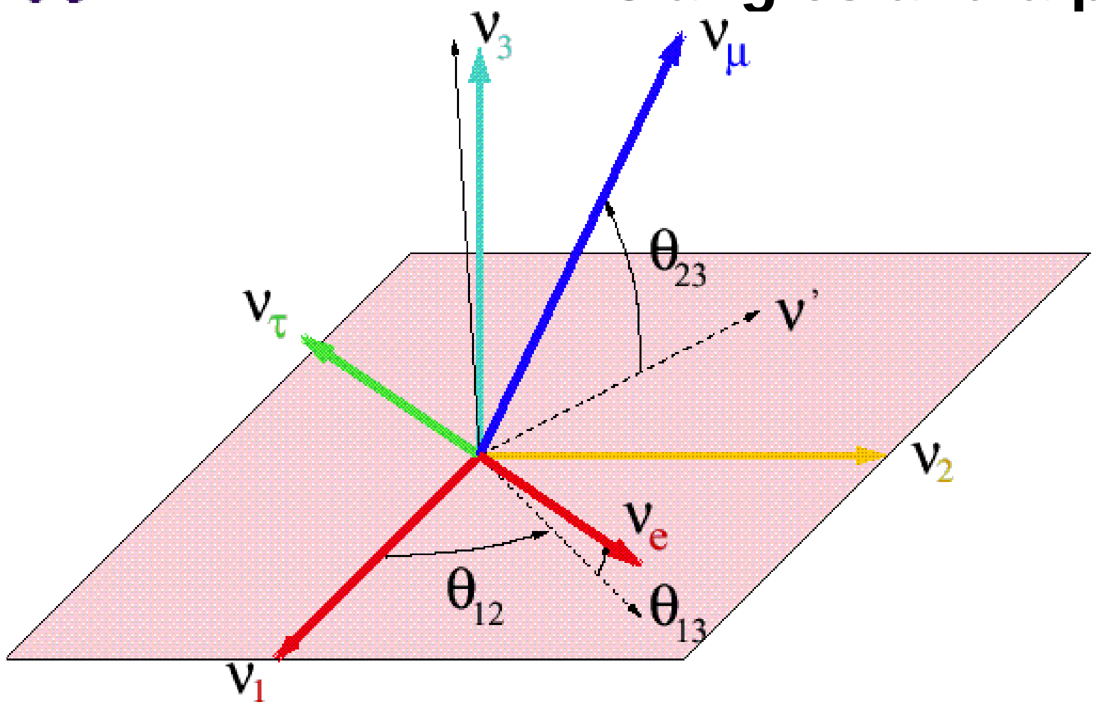
including leptonic CP & T violations

***) to set the scale: CP violation in quarks was discovered in 1964**
and there is still an important program (LHCb, K0pi0, superB, Neutron EDM, NA63….)
to go on for 10+ years…i.e. a total of ~50+ yrs. and we have not discovered leptonic CP violation yet

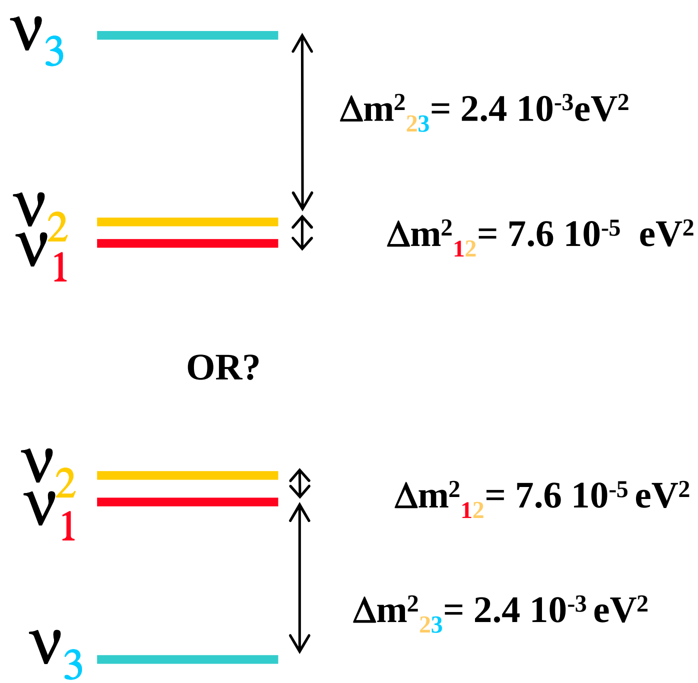
5. Several experiments are prepared/starting to go further:
OPERA, T2K, D-CHOOZ, RENO, Daya Bay, NOvA

and the future program is being discussed

The neutrino mixing matrix: 3 angles and a phase δ

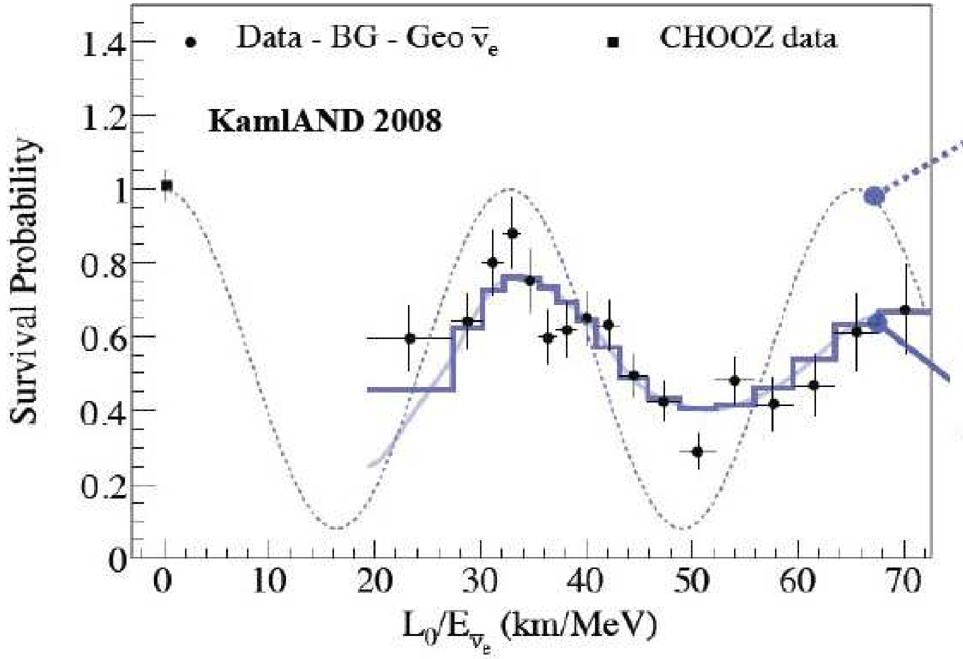


θ_{23} (atmospheric) = 45^0, θ_{12} (solar) = 32^0, θ_{13} (Chooz) < 13^0



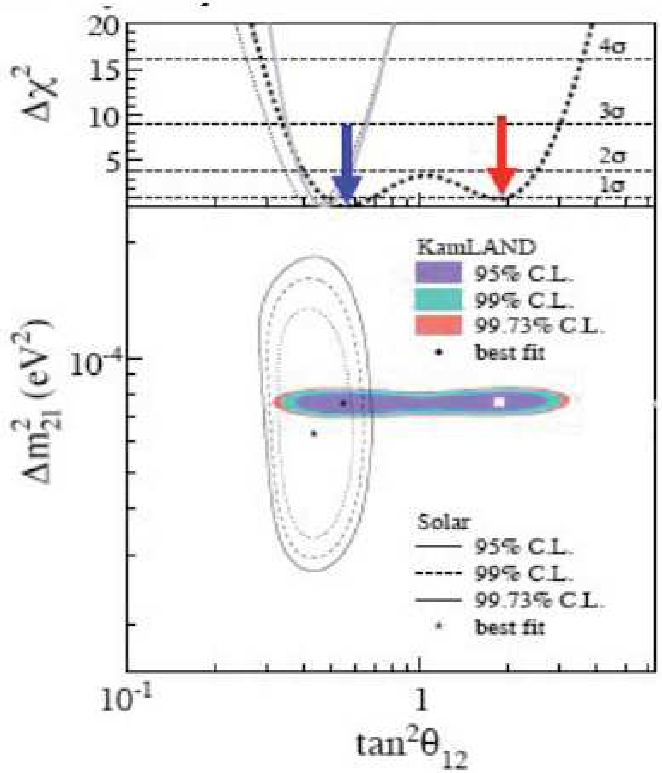
$$U_{MNS}: \begin{pmatrix} \sim \frac{\sqrt{2}}{2} & \sim -\frac{\sqrt{2}}{2} & \sin\theta_{13}\, e^{i\delta} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim -\frac{\sqrt{2}}{2} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim \frac{\sqrt{2}}{2} \end{pmatrix}$$

Unknown or poorly known
θ_{13}, phase δ, sign of Δm_{13}^{2}

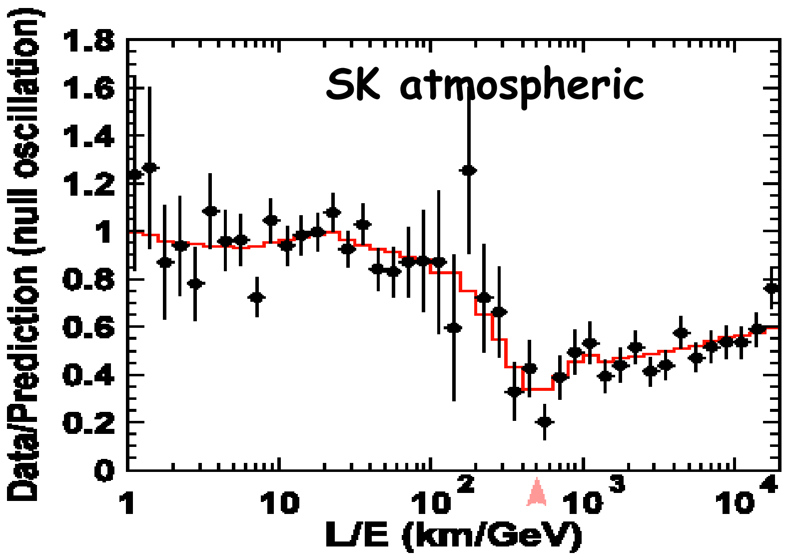


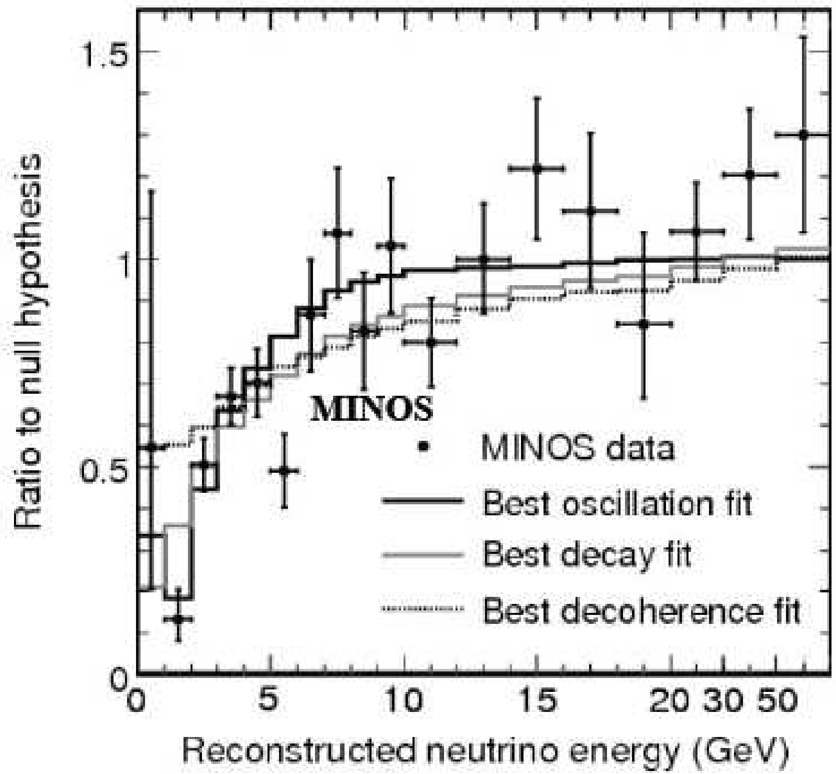
Oscillation pattern for a mono-energetic $\overline{\nu}_e$ at one baseline

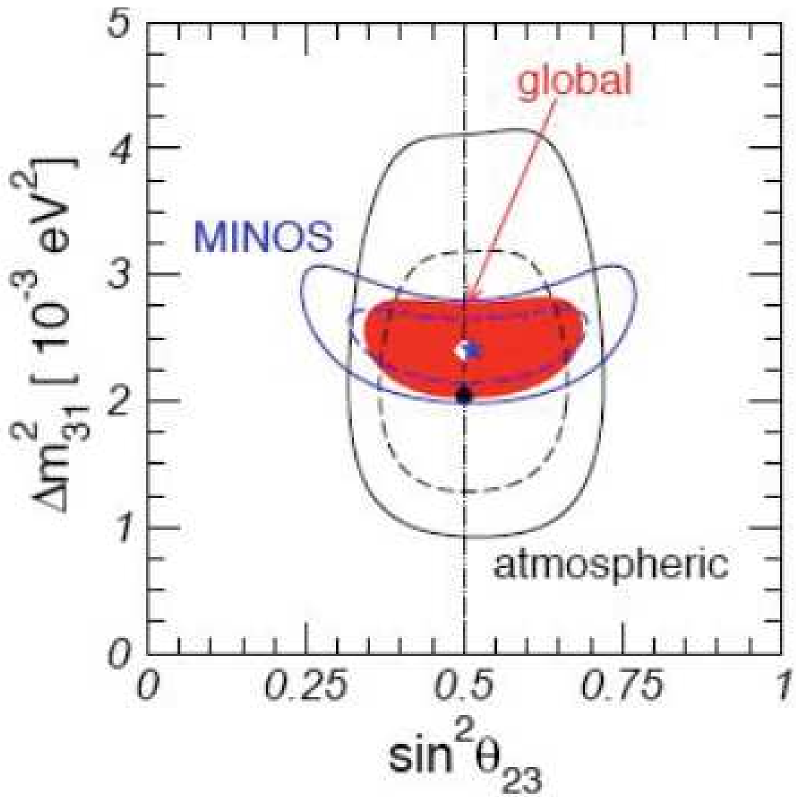
Best-fit oscillation



KamLAND+Solar: $\Delta m^2 = 7.59^{+0.21}_{-0.21} \times 10^{-5}\,\mathrm{eV}^2$ $\quad \tan^2\theta = 0.47^{+0.06}_{-0.05}$







arxiv:0806.2237, 3.4×10^{20} pot

$$\sin^2\theta_{23} = 0.50^{+0.07}_{-0.06}$$

$$|\Delta m^2_{31}| = 2.40^{+0.12}_{-0.11} \times 10^{-3}\,\mathrm{eV}^2$$

There are today THREE compelling and firmly established observational facts that the Standard Model fails to account for:

-- neutrino masses
-- the existence of dark matter
-- the baryon asymmetry of the universe

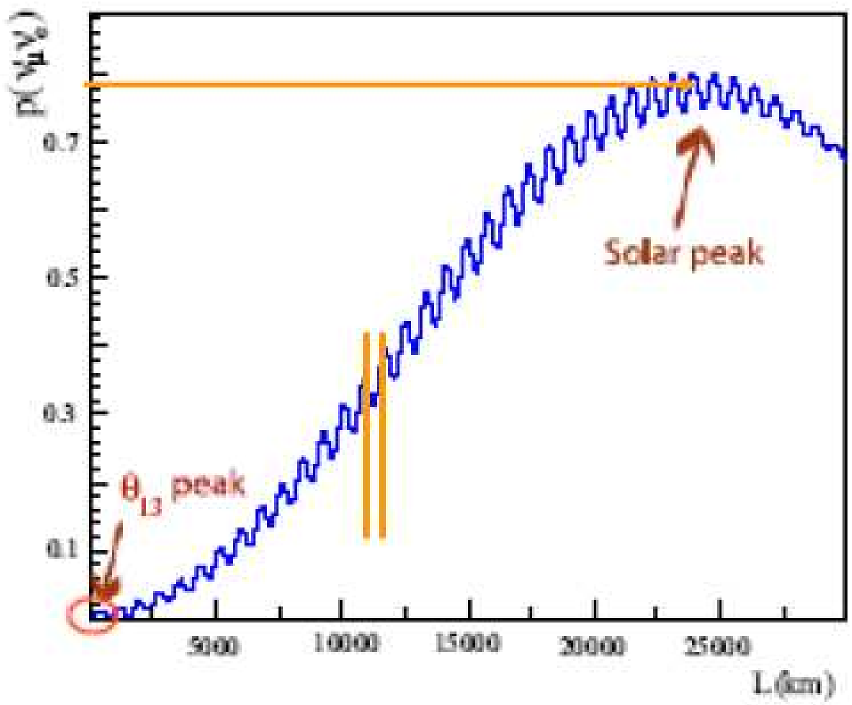
The fact that neutrino have masses and mix is established by neutrino oscillations

The neutrino masses offer a chance to explain the baryon asymmetry in the most natural way via

*** LEPTOGENESIS ***

by a combination of
-- fermion number violation (authorized by neutrino masses and GUT)
-- three families of neutrinos ==> leptonic CP violation
(authorized by the mixing of three families with large mixing angles)

Fermion number violation → neutrino less double beta decay
CP violation → neutrino oscillations (today)



$$P(\nu_e \to \nu_\mu) = |A|^2 + |S|^2 + 2\,A\,S\ \sin\delta$$

$$P(\bar{\nu}_e \to \bar{\nu}_\mu) = |A|^2 + |S|^2 - 2\,A\,S\ \sin\delta$$

$$\frac{P(\nu_e \to \nu_\mu) - P(\bar{\nu}_e \to \bar{\nu}_\mu)}{P(\nu_e \to \nu_\mu) + P(\bar{\nu}_e \to \bar{\nu}_\mu)} = A_{CP} \ \alpha \ \frac{\sin\delta \ \ \sin(\Delta m^2_{12} L/4E) \ \ \sin\theta_{12} \sin\theta_{13}}{\sin^2 2\theta_{13} + \text{solar term}\ldots}$$

… need large values of sin θ_{12}, Δm^2_{12} (LMA-- we have it!) but *not* large $\sin^2\theta_{13}$

… need APPEARANCE … $P(\nu_e \to \nu_e)$ is time reversal symmetric (reactors or sun are out)

… can be large (100%) for suppressed channel (one small angle vs two large)

at wavelength at which ‘solar’ = ‘atmospheric’ and for $\nu_e \to \nu_\mu$, ν_τ

… asymmetry is opposite for $\nu_e \to \nu_\mu$ and $\nu_e \to \nu_\tau$

NOTES:

Asymmetry can be very large.

Stat. sensitivity in absence of bkg is ~independent of θ_{13} down to $\sin^2 2\theta_{13} = 10^{-3}$

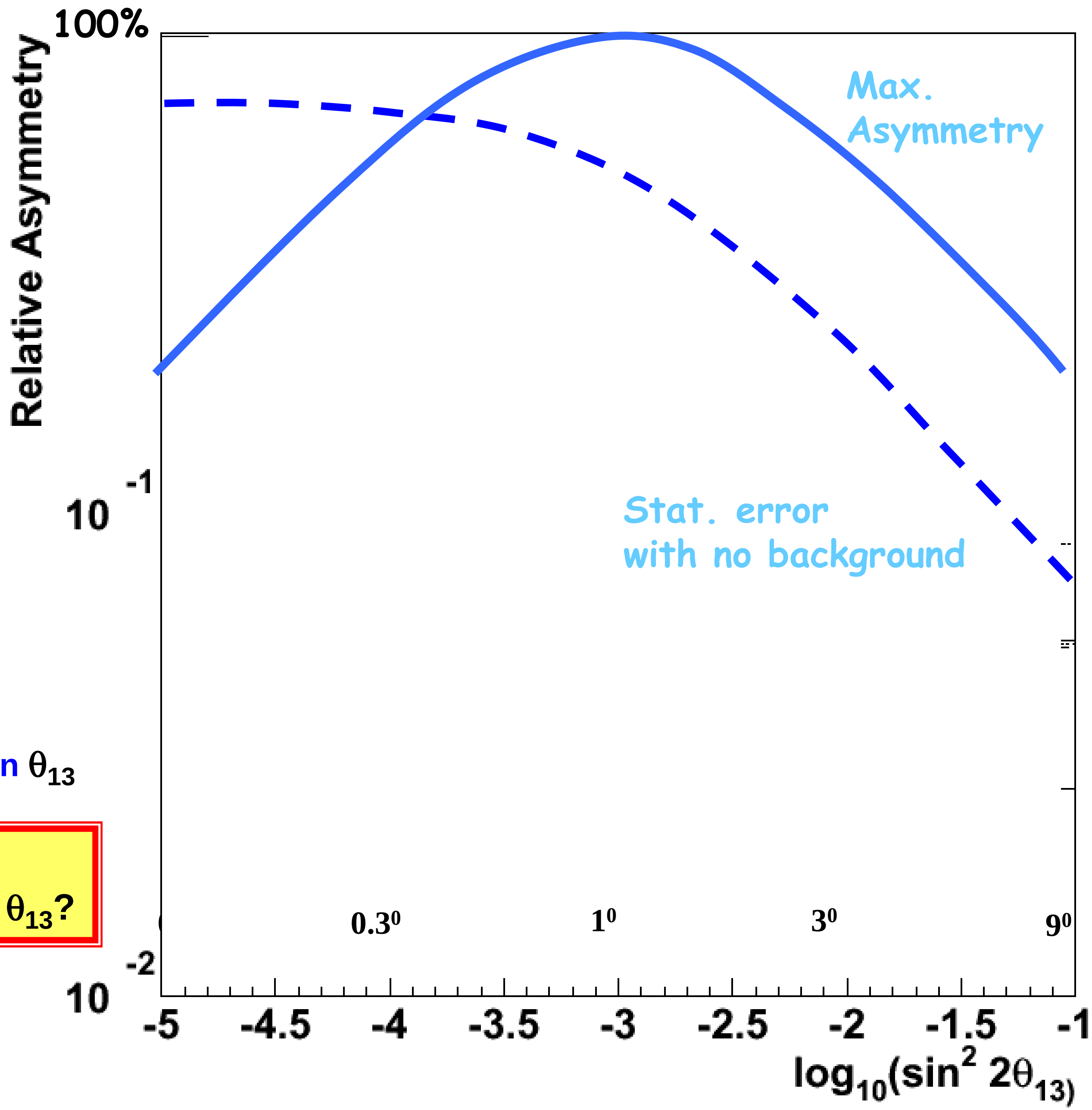
Asymmetry changes sign from one max. to the next.

Sensitivity at low values of θ_{13} is better for short baselines, sensitivity at large values of θ_{13} is better for longer baselines (2d max or 3d max.)

Optimal experiment depends on θ_{13}

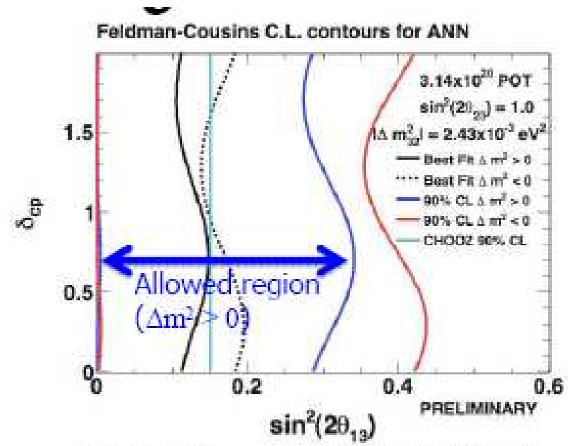
→First step: what is the value of θ_{13}?

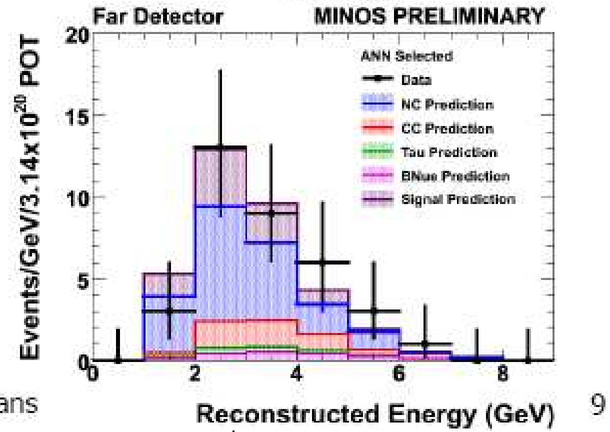
T asymmetry for sin δ = 1

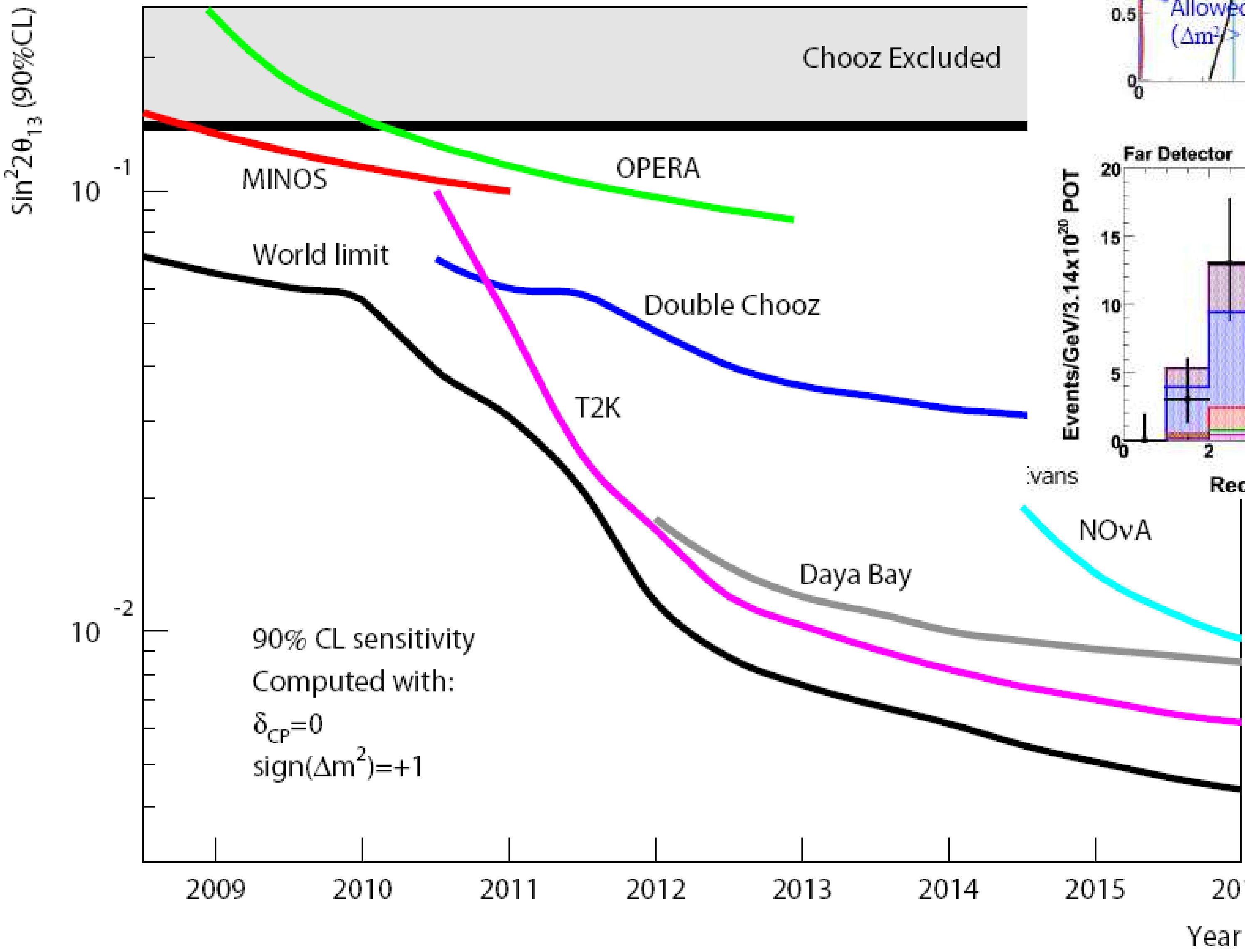


Future project	$\mathrm{Sin}^2 2\theta_{13}$, sign ($\Delta m^2_{13}$) CP	methods
DCHOOZ (2010) RENO DAYA BAY(2012)	0.03 - 0.01 no no 0.03 – 0.01 no no 0.02-0.008 no no	Reactor + scintillator Near + far (1km) baselines up to 1.8km
T2K (2010) T2K+	0.01 no no 0.001? Yes? ?	Near (scint. + TPC) Far (Water Ckov)50kt Far= 250-500 kt WC a/o 100kt Larg TPC?
3. NOvA (2012) 4. DUSEL	0.01 W/T2K? no 0.001 Yes? ?	Active Scintillator WC, (TASD, Larg)?
5. CERN -- SB to ?F-lab -- BB to ?F-lab	Combination allows 0.001 no? yes	SB or BB + 500 kt WC or Larg?
-- neutrino factory	0.0001 Yes Yes	muon decay beam magnetized Fe Mag MECC/Larg/TASD

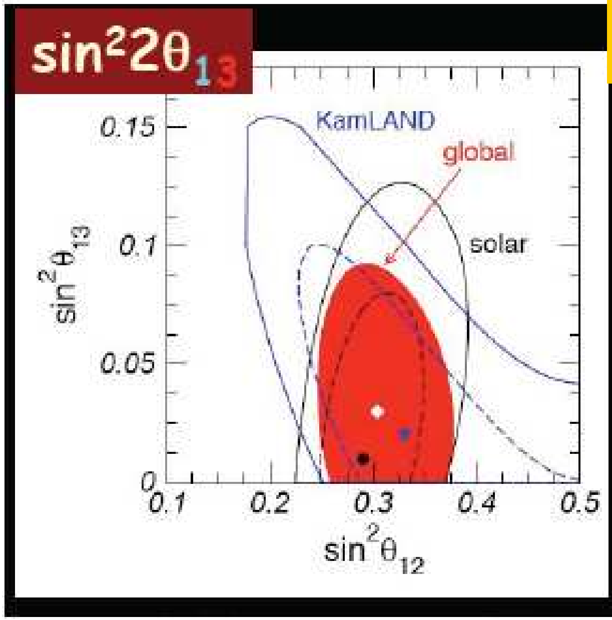
The quest for $\sin 2\theta_{13}$



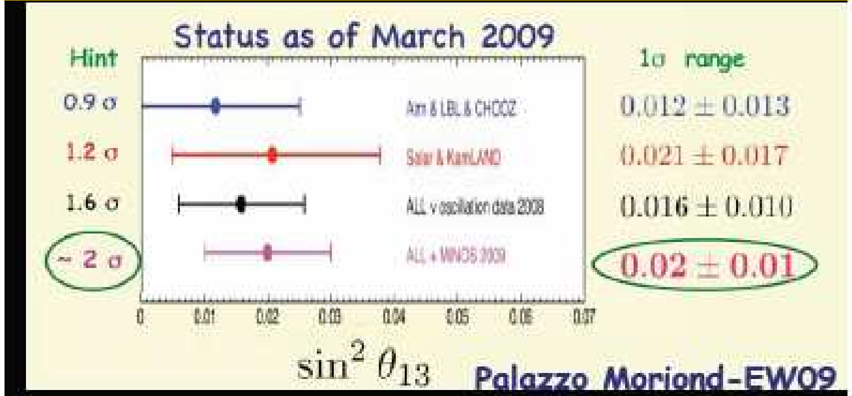




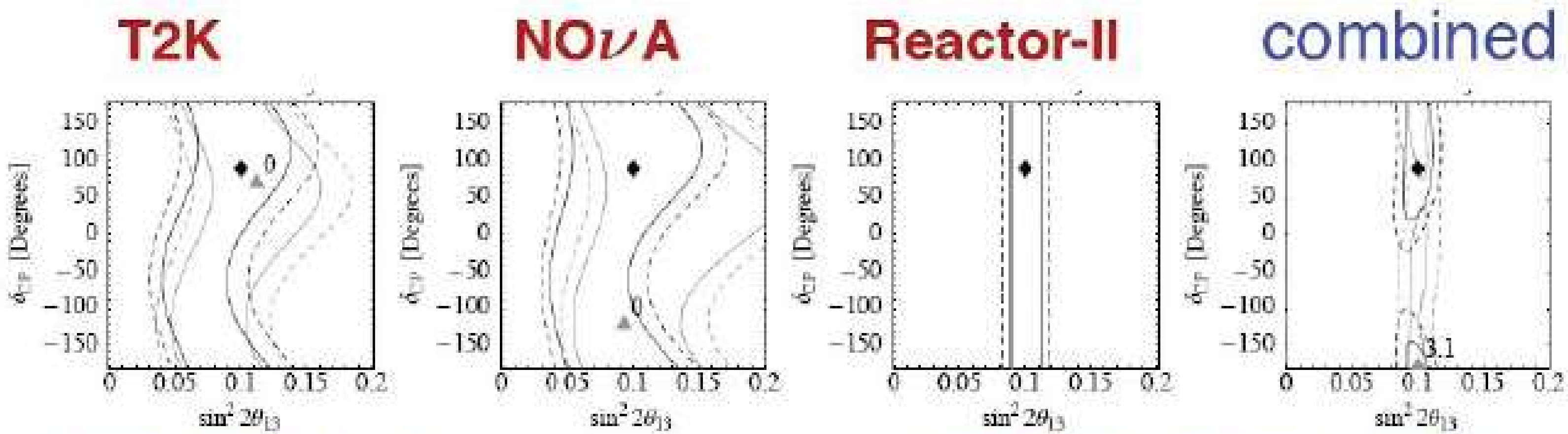
MINOS 2009



θ13 as of spring 2009



Situation after approved program if $\sin 2\theta_{13}$ is close to present limit:



input: $\sin^2 2\theta_{13} = 0.1$ (Huber et al, hep-ph/0403068)

Very scant possibility of 2σ if both sinδ and $\sin^2\theta_{13}$ are at the limit.
Otherwise nothing is known! obvioulsy we must go beyond this and prepare for it!

Beyond the Approved program

Neutrino Intensity Upgrade

Quest for the Origin of Matter Dominated Universe

One of the Main Subject of
KEK Roadmap

T2K (2009~) → Discover ν_e app. → Neutrino Anti-Neutrino meas. → CPV search Proton decay

Intensity Upgrade → CPV search Proton decay

Detector R&D → Tech. Choice → Huge det. Construction → CPV search Proton decay

Possible Timeline

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	4	4	4	4	4	4	4	4	4	4
Linac(400MeV)		?			? → 400MeV					
T2K										
MR Intensity Upgrade					?		?	→ 1.66MW		
Detector R&D										

Presented by KEK DG at KEK Roadmap Review Committee 9,10-March 2008

First Protons on Target!

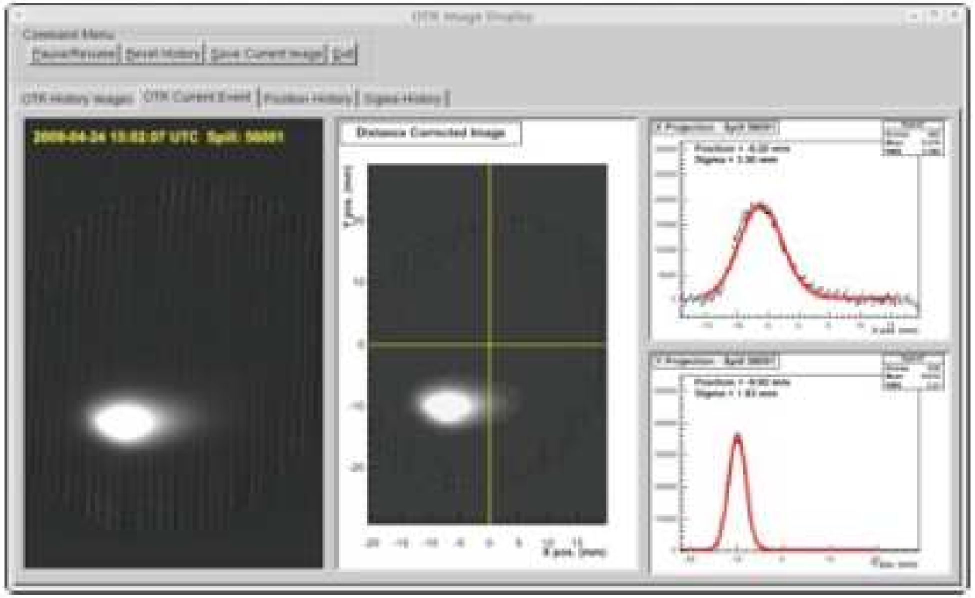
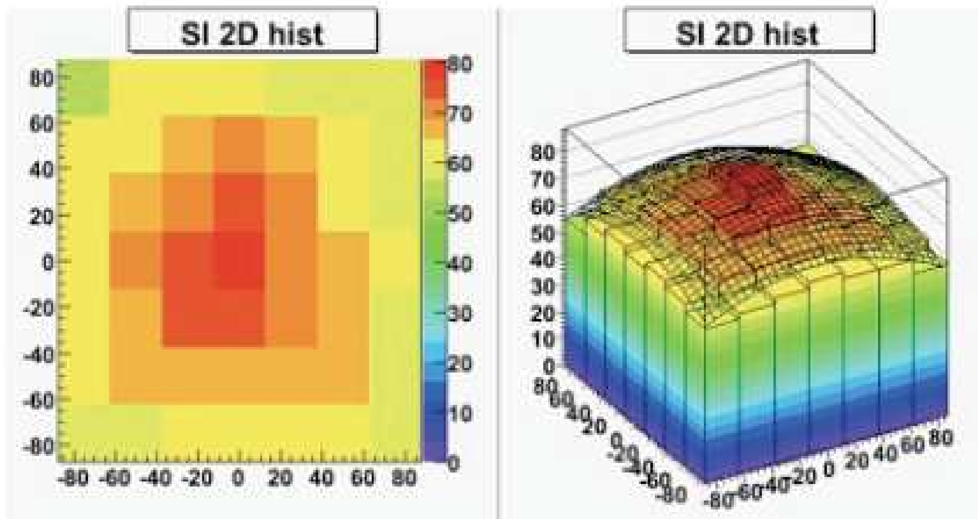


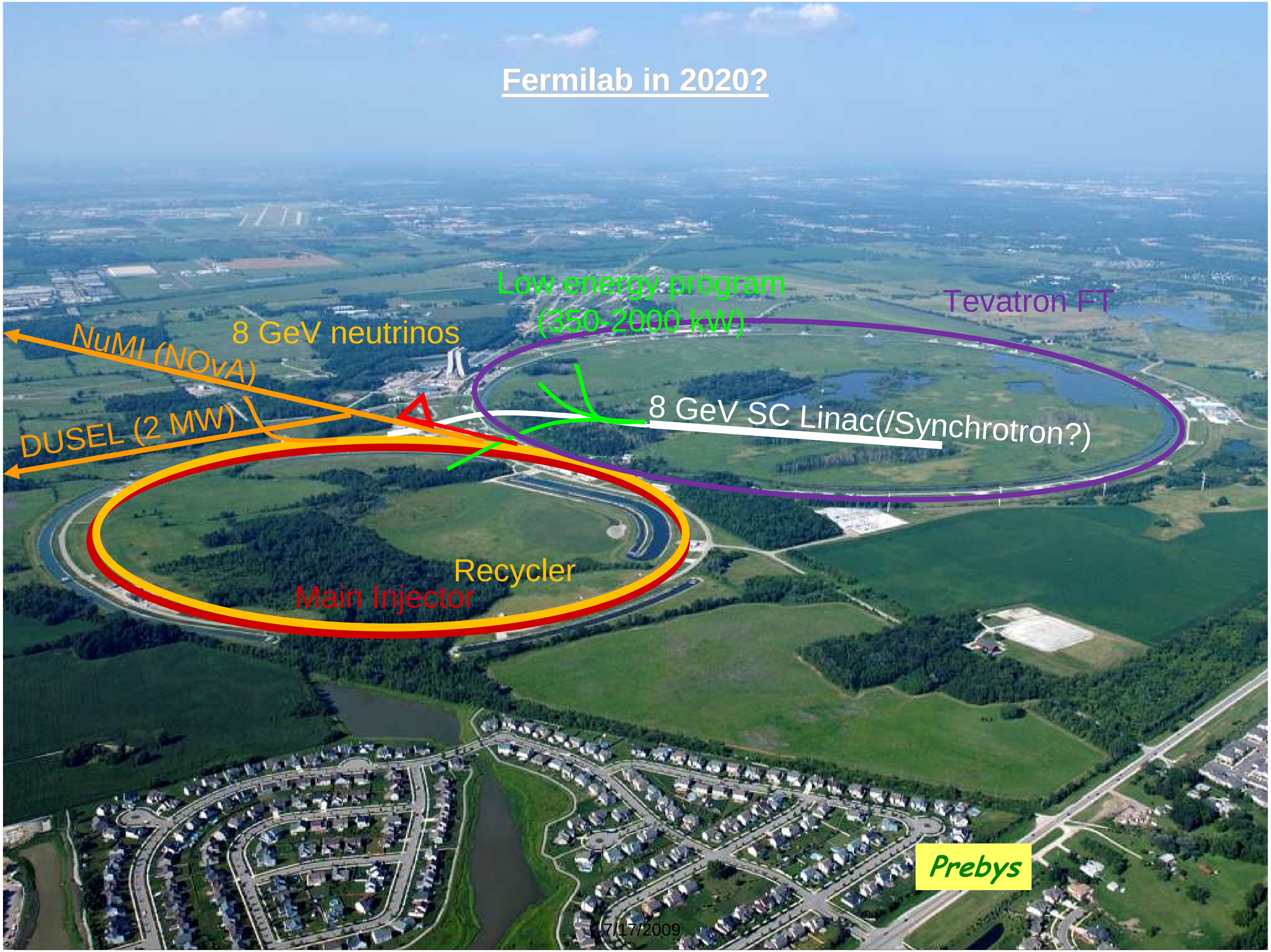
Image in proton beam position monitor 30 cm before target

- First **protons on target** April 24, 2009!

Signal in Muon Monitor at end of decay volume

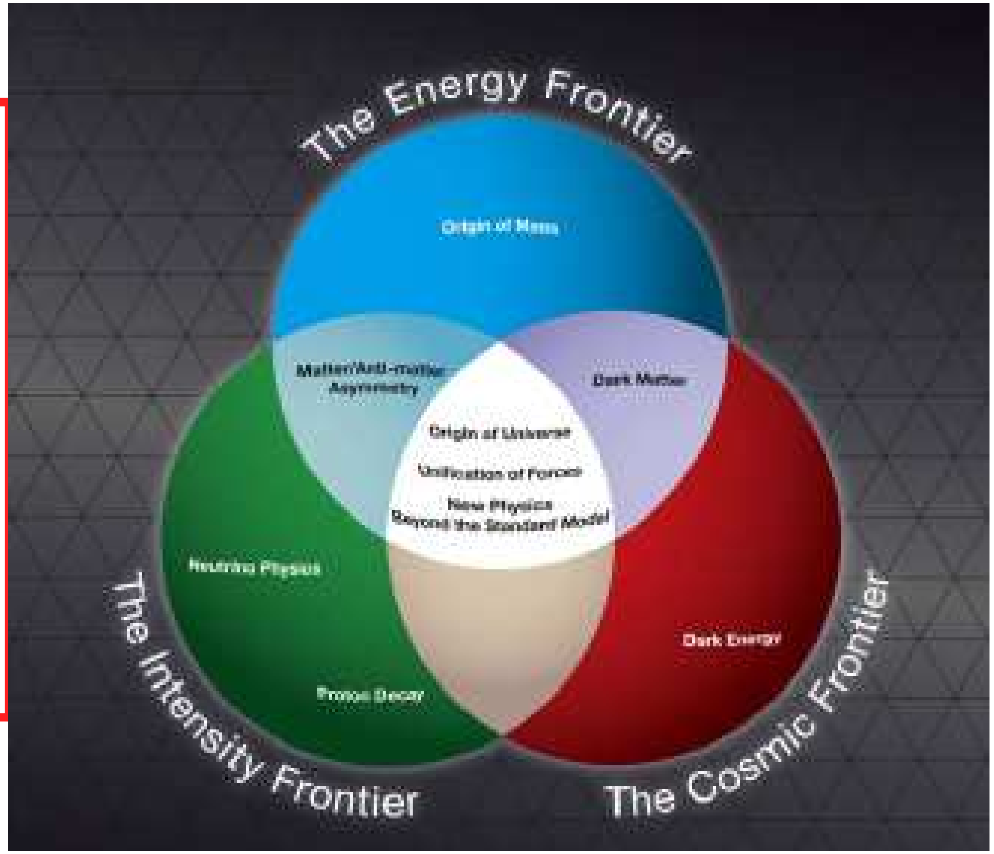


Three Possible Scenario Studied at NP08 Workshop


Fermilab in 2020?
Low energy program
(350-2000 kW)
Tevatron FT
8 GeV neutrinos
NuMI (NOvA)
DUSEL (2 MW)
8 GeV SC Linac(/Synchrotron?)
Recycler
Main Injector
Prebys
7/17/2009

What Next? Excerpts from P5 major findings*

- **An opportunity exists for the U.S. to become a world leader at the Intensity Frontier**
  - Central is an intense neutrino beam and large underground long-based line detector
  - Building on infrastructure at Fermilab and partnering with NSF
  - Develops infrastructure that positions the U.S. to regain Energy Frontier (Muon Collider)



- **HEP at its core is an accelerator based experimental science**
  - Accelerator R&D develops technologies needed by the field and that benefit the nation

*as reported by Dennis Kovar at the Fermilab Users' Meeting, June 2008

Possibilities in EUROPE

1. The community

the active participants in
- CNGS (OPERA + ICARUS)
- T2K (250 = about half of the collaboration)
- MINOS
- DCHOOZ
- R&D for future neutrino beams and detectors
  (MICE MERIT, EUROnu, LAGUNA, ISS…)
- Ancillary experiments such as HARP, NA61

This represents of the order of >~ 500 European physicists.
Diverse but very motivated!

2. CNGS

OPERA is THE neutrino accelerator experiment in Europe today.
Design limitations:
  Intensity due to SPS and due to radiation environement
  No near detector.
  High energy suitable for tau appearance but far from osc. maximum requires redesign
Proposals exist (MODULAR , 20 kton liquid argon TPC) and should be evaluated

3. Advanced neutrino beams

References and Links

Original ideas in 1970's (Amaldi, Budker)

Neutrino Beams From Muon Storage Rings: Characteristics And Physics Potential
S. Geer Phys.Rev.D57:6989-6997,1998, Erratum-ibid.D59:039903,1999]

Prospective study of muon storage rings at CERN, ECFA-CERN CERN 99-02 (1999)

Study IIA Neutrino Factory and Beta Beam Experiments and Development,
C. Albright et al, BNL-72369-2004, FNAL-TM-2259, LBNL-55478,

ECFA-CERN study of a Neutrino Factory Complex
A. Blondel et al., eds. CERN-2004-002.- ECFA-04-230 March 2004.

ISS (ECFA supported) reports
Accelerator design concept for future neutrino facilities. arXiv:0802.4023
Detectors and flux instrumentation for future neutrino facilities. JINST 4:T05001,2009.
Physics at a future Neutrino Factory and super-beam facility. arXiv:0710.4947 [hep-ph]

ISS study
-- Performed comparison between proposed facilities
-- defined the baseline parameters.
to be followed-up quantitatively (R&D, feasibility, cost) ➔ International Design Study

Towards a high-intensity neutrino programme

EP2010:

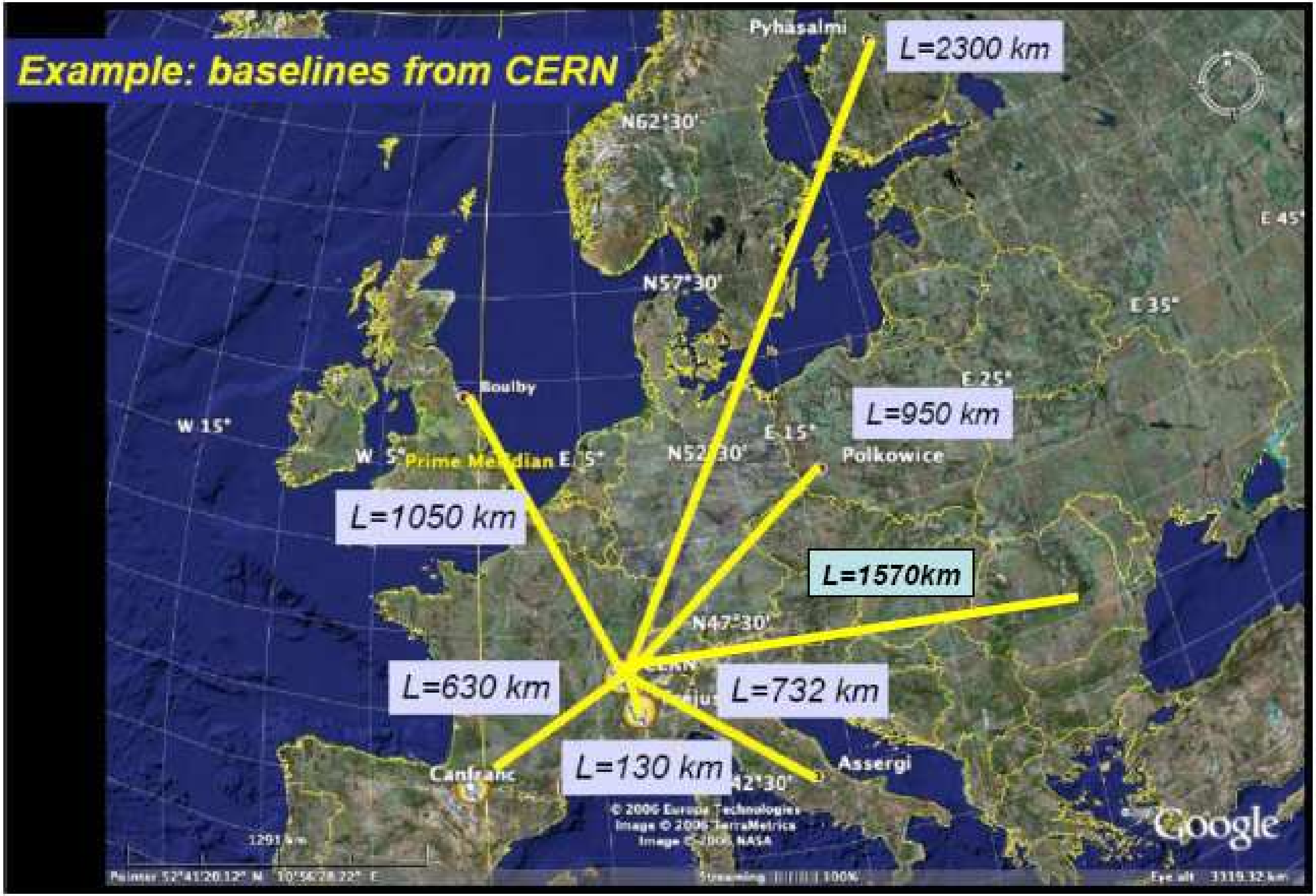
« pursue an internationally coordinated, staged program in neutrino physics »

CERN-SG:

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.

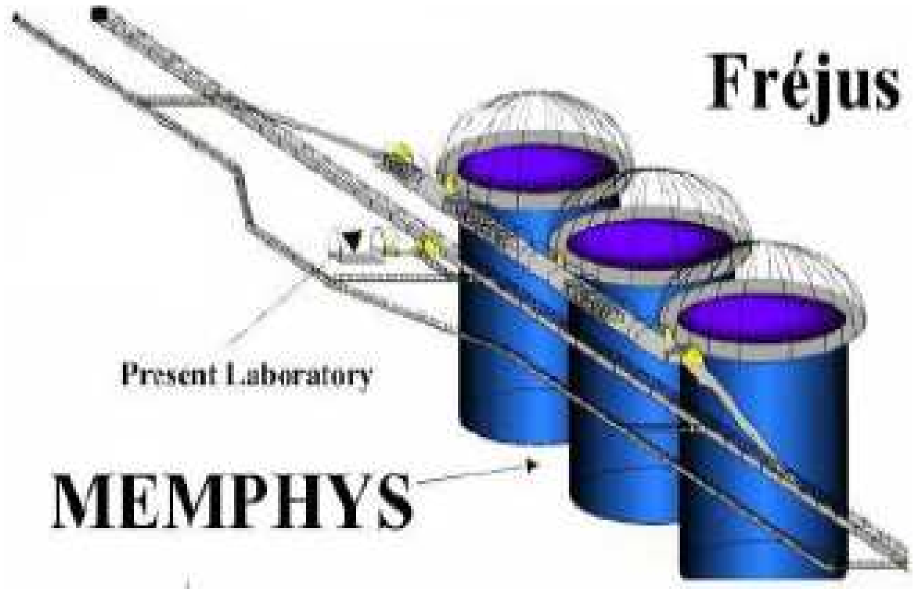
LAGUNA: considered underground sites

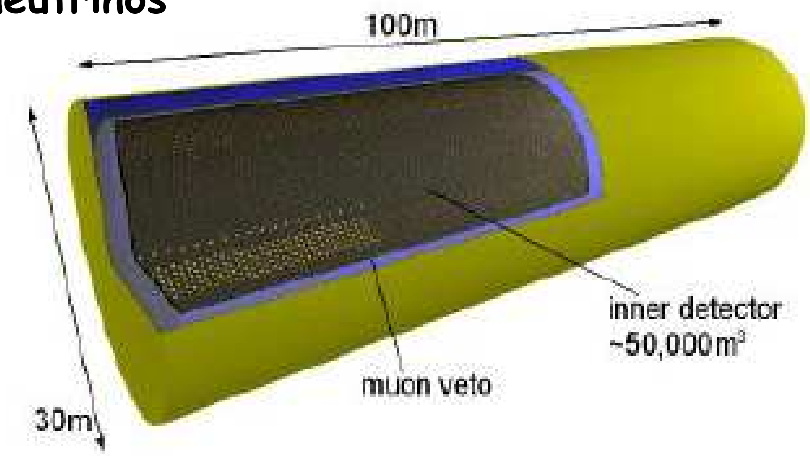


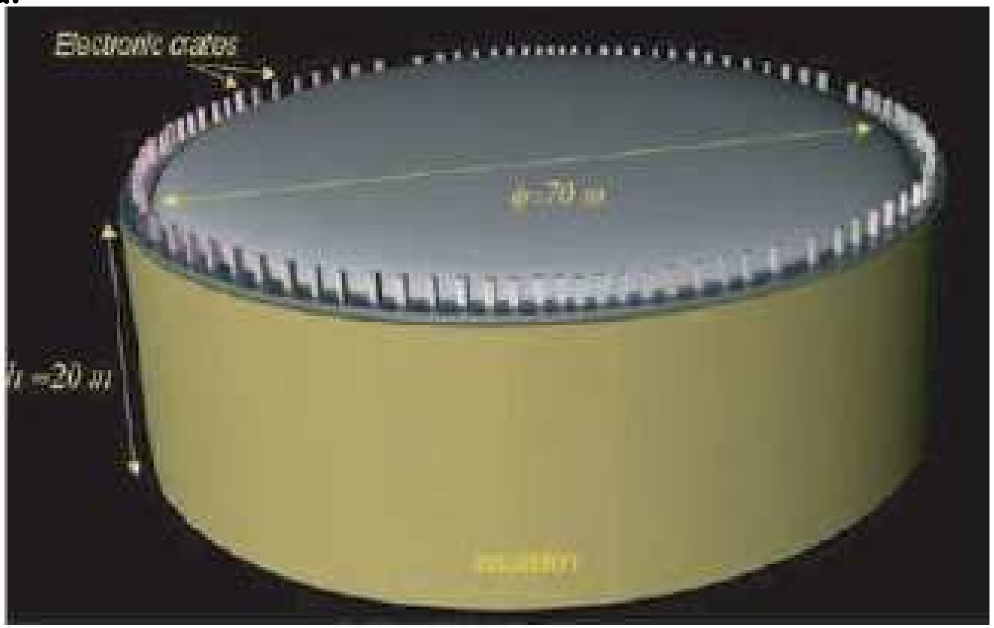
Detectors envisaged in Laguna

Large Water Cherenkov (160 kton per tank)
Giant Liquid Argon TPC (100 kton)
30ton Liquid Scintillator à la Borexino

Non magnetic.
Suitable for superbeam and/or Beta beam,
but not with neutrino factory.
Synergy with proton decay and astropysical neutrinos



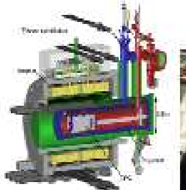




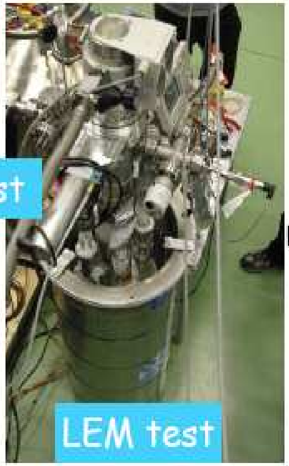
Steps towards GLACIER

ETH Institute for Particle Physics

Small prototypes ➡ ton-scale detectors ➡ 1 kton ➡ ?



B-field test



LEM test

proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale

➡ **LEM readout on 1x1 m² scale** UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale

we are here

➡ **direct proof of long drift path up to 5 m**

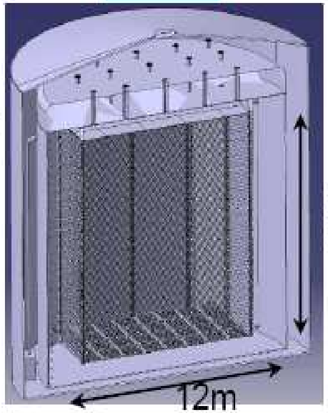
ArgonTube: long drift, ton-scale

➡ **Application of LAr LEM TPC to neutrino physics**: particle identification (200-1000 MeV electrons), optimization of readout and electronics, cold ASIC electronics, possibility of neutrino beam exposure

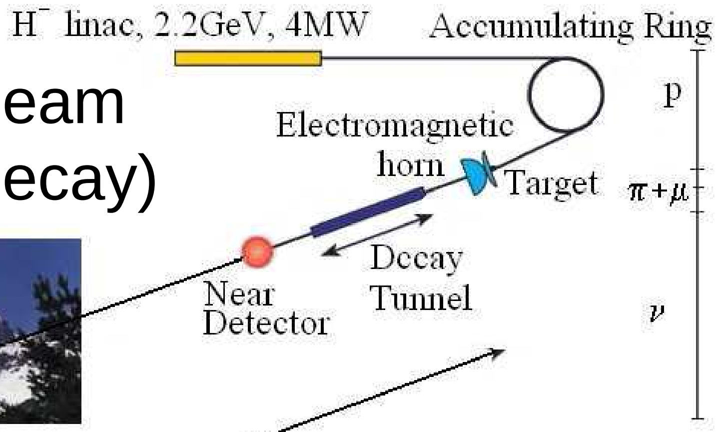
Test beam
1 to 10 ton-scale

➡ **full engineering demonstrator for larger detectors**, acting as near detector for neutrino fluxes and cross-sections measurements, ...

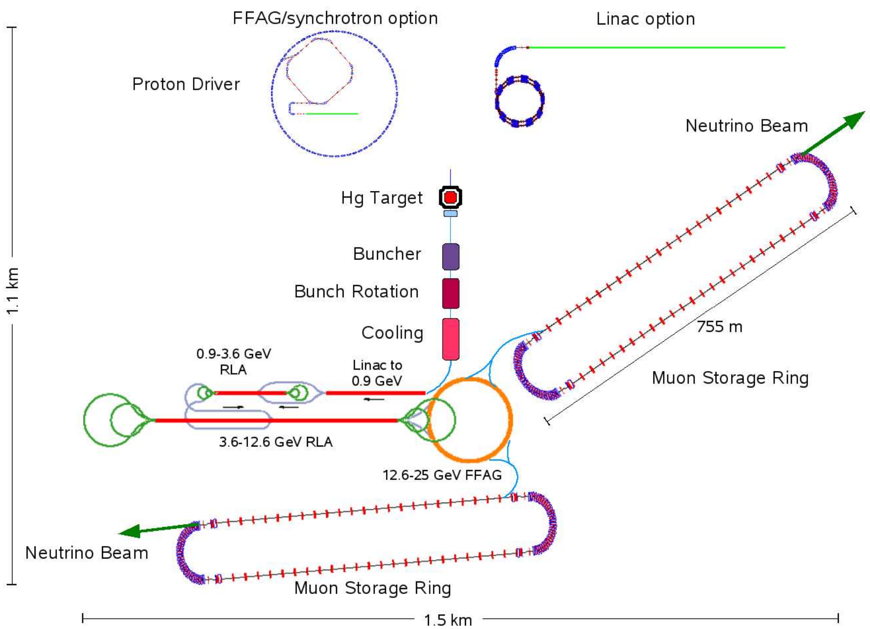
1 kton



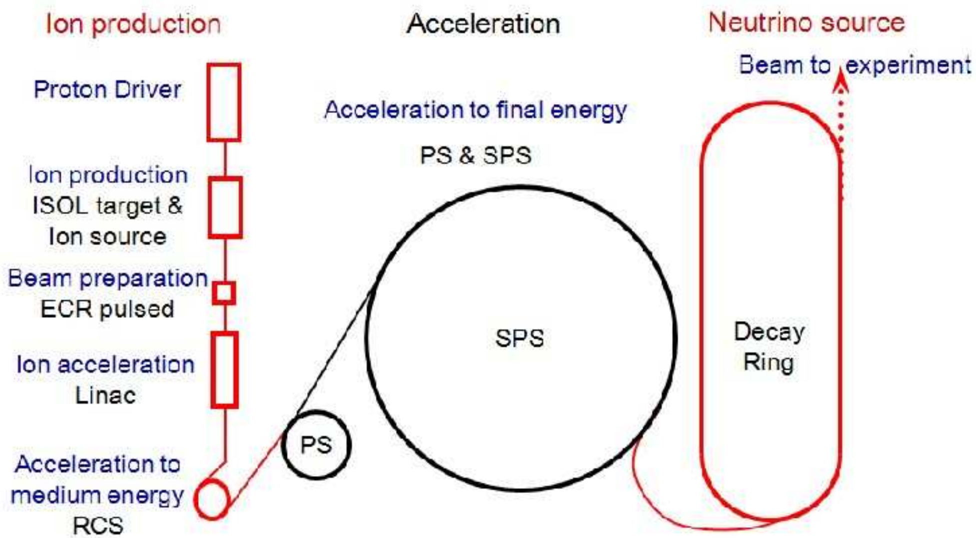
EUROν



superbeam
(pion decay)



Neutrino Factory
(muon decay)

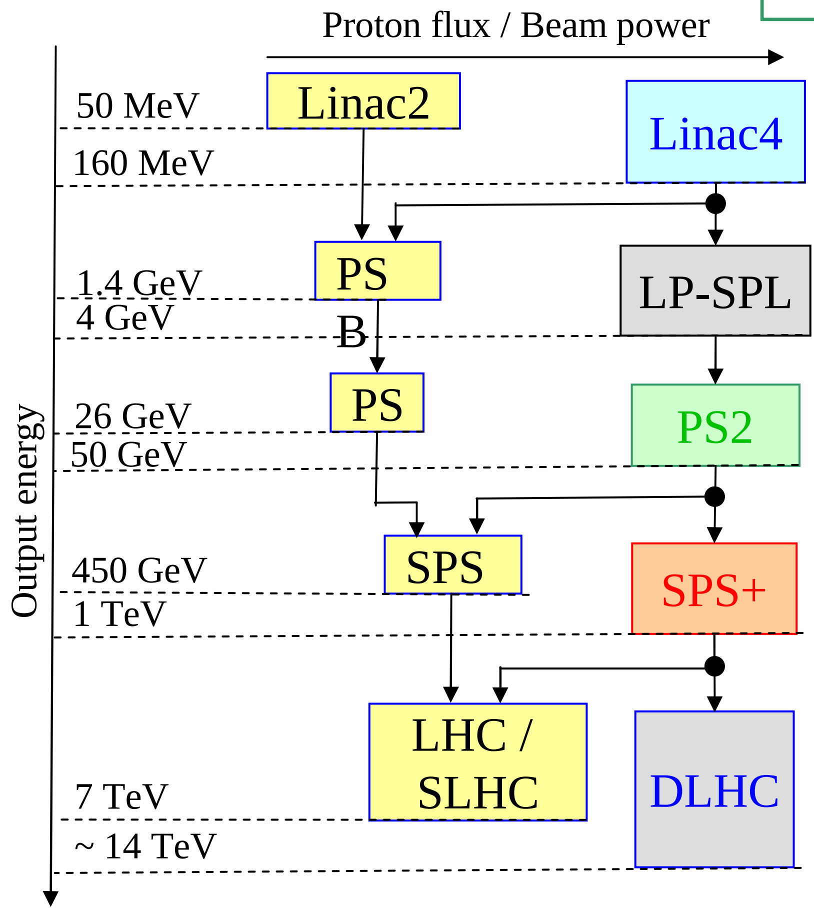


Beta-beam
rad-ion decay

Can any of this be at CERN?
Elsewhere in Europe?

Main possibilities connected to LHC injector upgrade

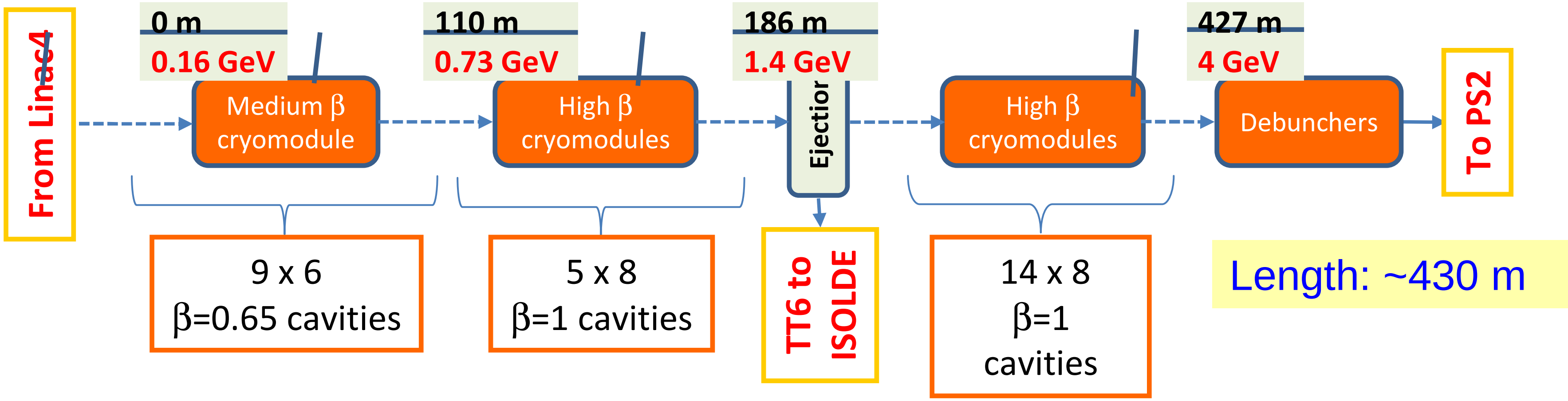
LP-SPL: Low Power-Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
sLHC: "Super-luminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

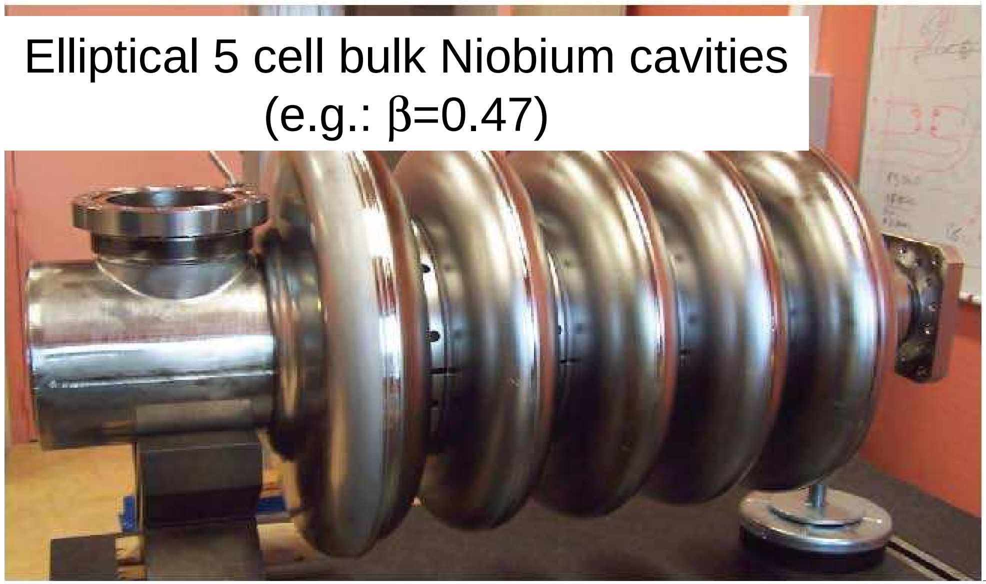


Main requirements of PS2 on its injector:

Requirement	Parameter	Value
2.2 x ultimate brightness with nominal emittances	Injection energy	4 GeV
	Nb. of protons / cycle for LHC (180 bunches)	6.7×10^{13}
Single pulse filling of SPS for fixed target physics	Nb. of protons / cycle for SPS fixed target	1.1×10^{14}

The preferred possibility for high power : the SPL
SC-linac (160 MeV → 4 GeV) with ejection at intermediate energy



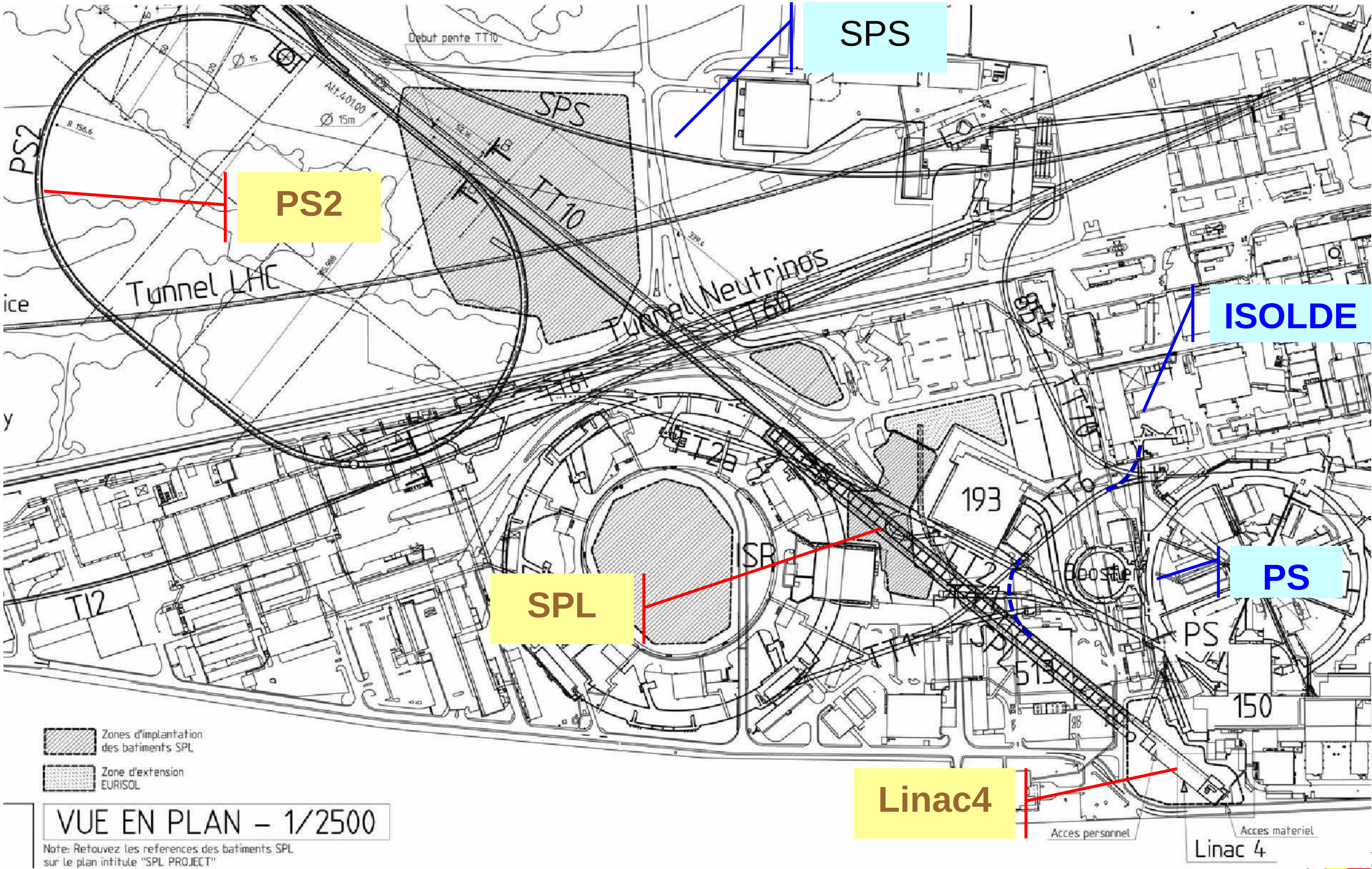


Elliptical 5 cell bulk Niobium cavities
(e.g.: β=0.47)

Low Power - SPL beam characteristics at 4 GeV

Kinetic energy (GeV)	4
Beam power at 4 GeV (MW)	0.12
Repetition period (s)	0.6
Protons/pulse (x 10^{14})	1.1
Average pulse current (mA)	20
Pulse duration (ms)	0.9

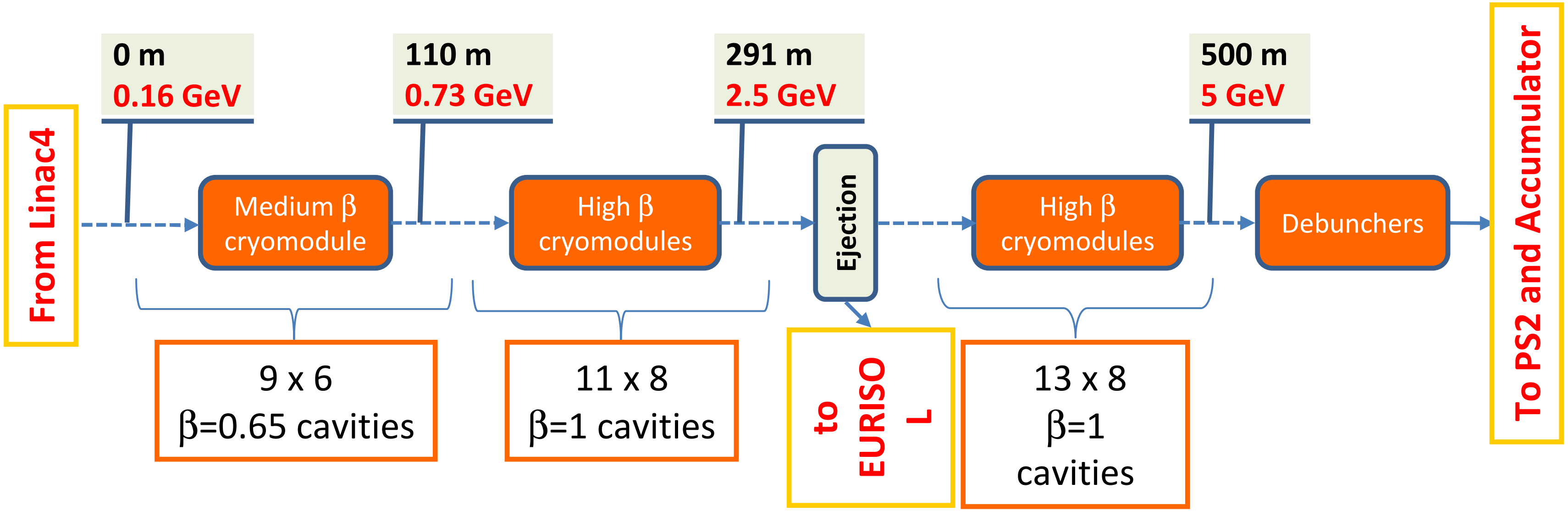
SPL Architecture



High Power proton beams (HP-SPL)

- Replacement of klystron power supplies, upgraded infrastructure (cooling & electricity, etc.)
- Addition of 5 high β cryomodules to accelerate up to 5 GeV (π production for ν Factory))

SC-linac (160 MeV → 5 GeV) with ejection at intermediate energy



Length: ~500 m

➔ **Up to 4MW at BOTH 2.5 GeV (For EURISOL, L.E. muons etc..) and 5 GeV (for neutrino production)**

A formidable power-horse!

High Power proton beams (HP-SPL) [2/2]

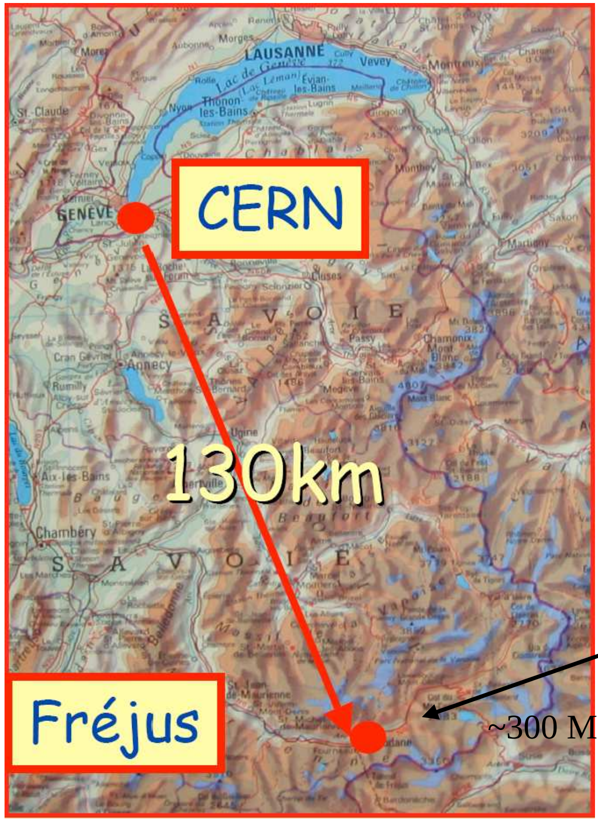
Beam characteristics of the main options

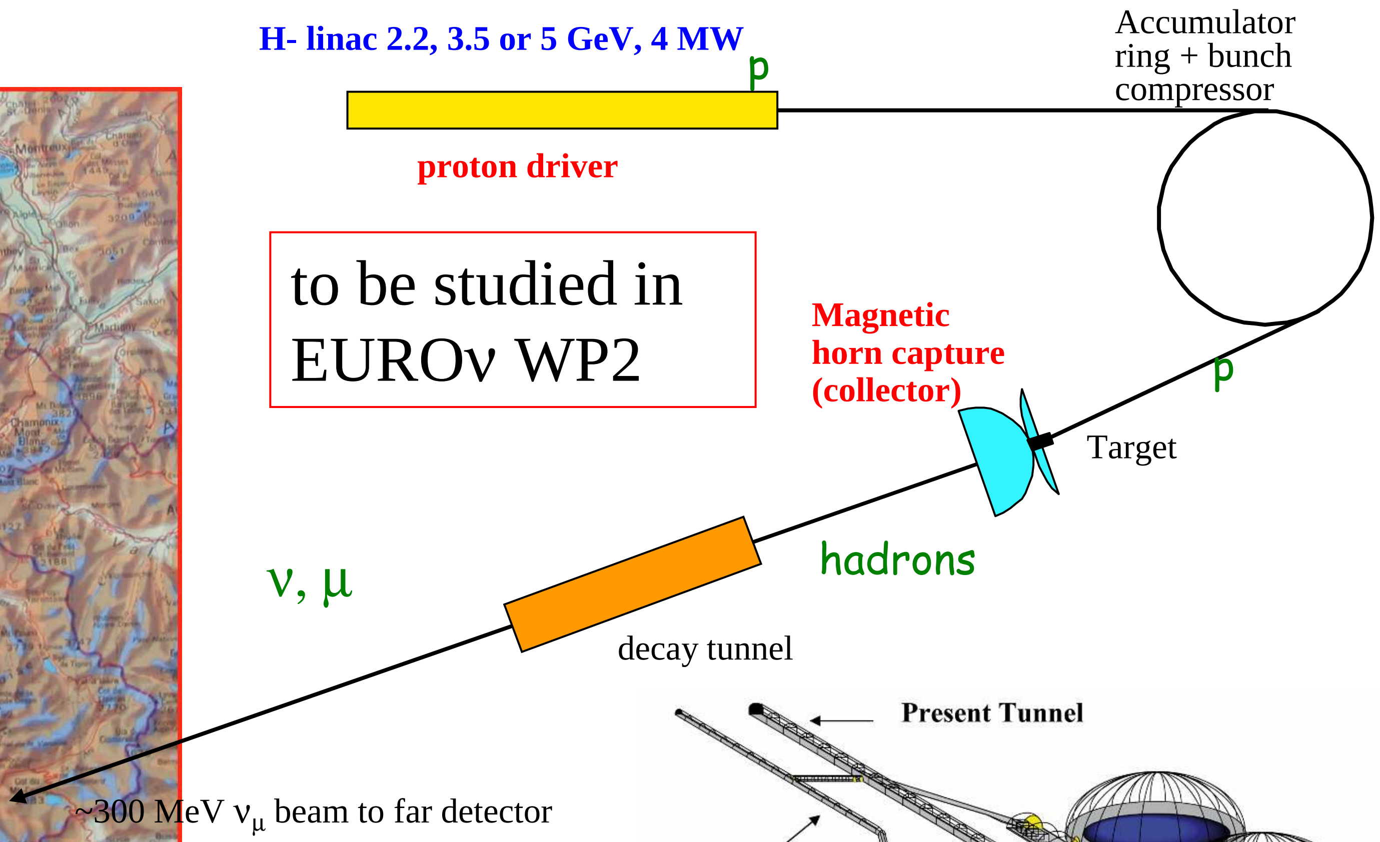
	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) or 4.5 MW (5 GeV)	4 MW (2.5 GeV) and 4 MW (5 GeV)
Rep. frequency (Hz)	50	50
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	0.8 (2.5 GeV) + 0.4 (5 GeV)

Faster rep. rate ⇒ new power supplies, more cooling etc.

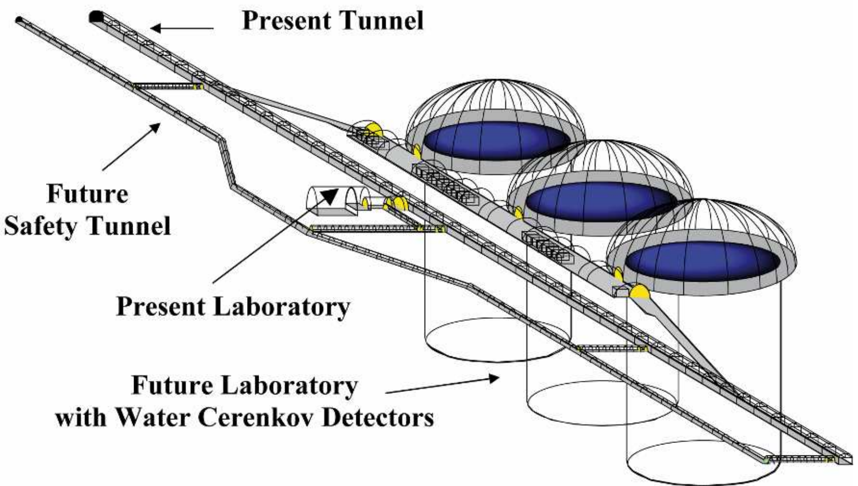
2 × beam current ⇒ 2 × nb. of klystrons etc .

SPL Super-Beam Project





to be studied in EUROν WP2



to be studied by LAGUNA

SUPERBEAM at SPL? 50 Hz 4 MW 4-5 GeV LINAC

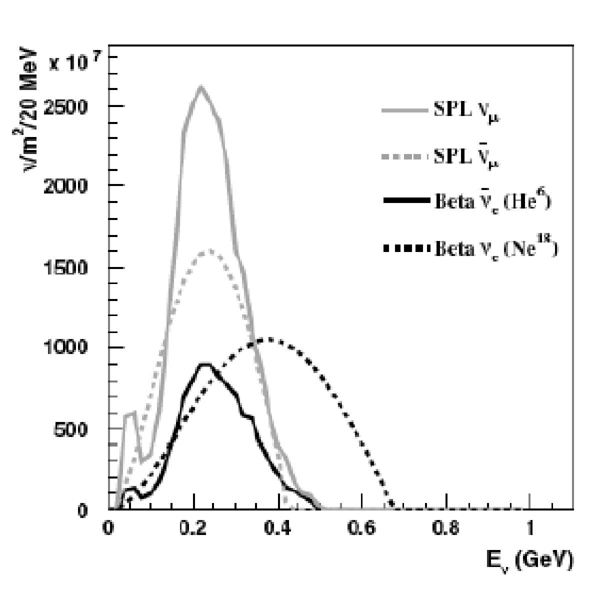
High beam power required (~4MW or more if possible)

Short duty cycle => accumulator ring is necessary

Pulsed Magnetic horns require duty cycle typically <10-3 (thermal constraint)
At 50 Hz operation this requires beam delivery within <20 microseconds.

Single Target? Liquid Hg target difficult to integrate in horn. Solid/powder target?

Proton Beam energy?
On axis pion decay Neutrino energy is typically < 10-15% of proton beam energy
SPL superbeam=> 400-500 MeV neutrino beam energy.
This is a good energy for the Water Cherenkov also
in search of proton decay.

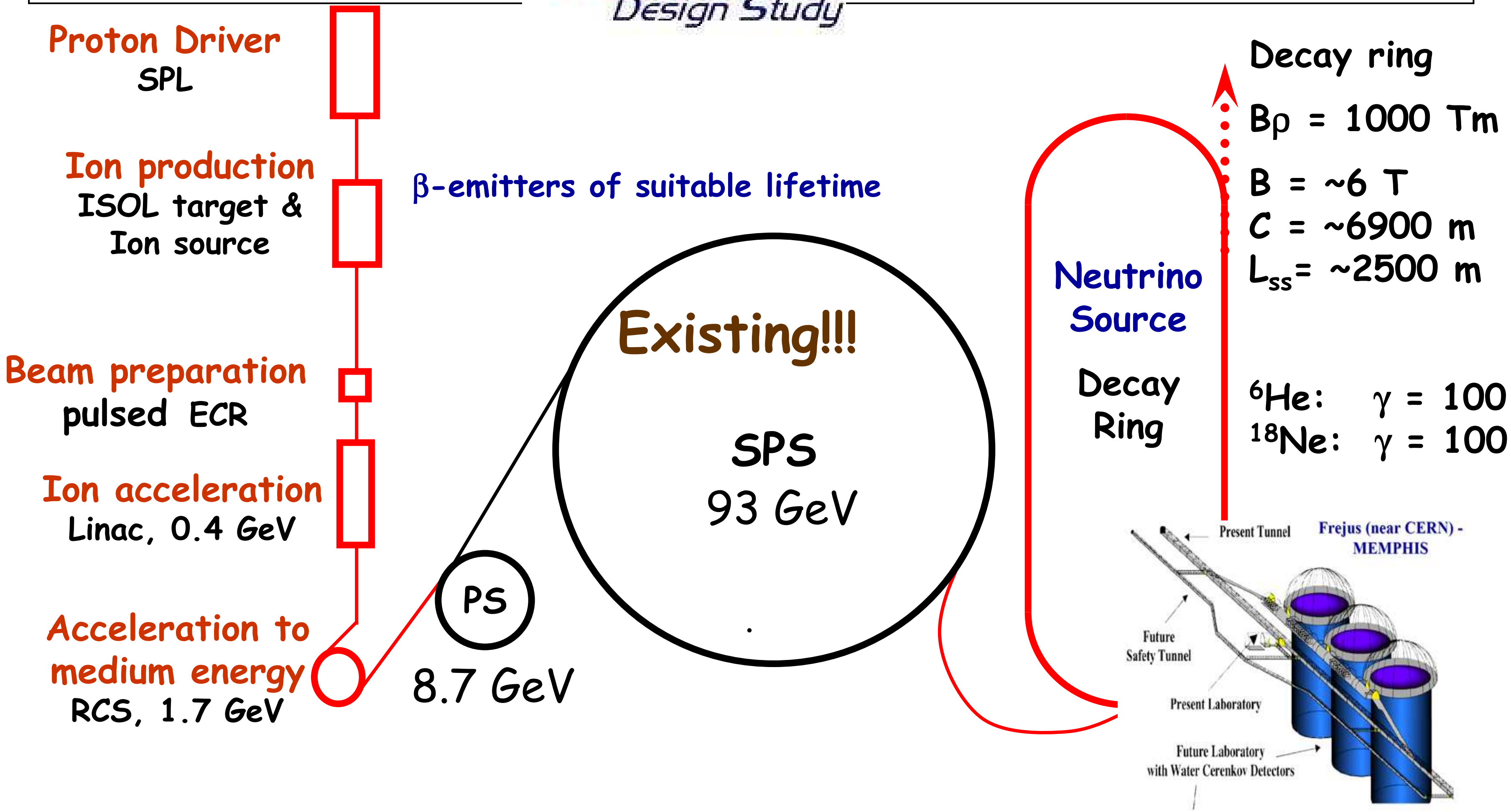


First oscillation maximum is situated at <250 km.
Second oscillation maximum at < 750 km.
(useful if $\sin^2 2\theta_{13}$ is small?)

Probably not very interesting if considered in isolation.
Advocated to be Interesting/important/necessary
if considered in conjunction to beta-beam.

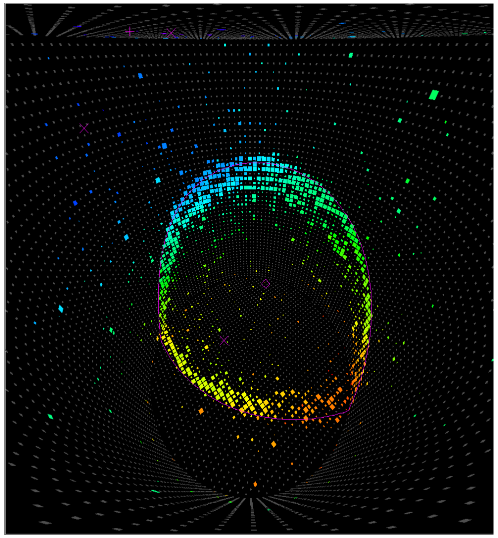
Recall of Beta Beam scenario, EURISOL

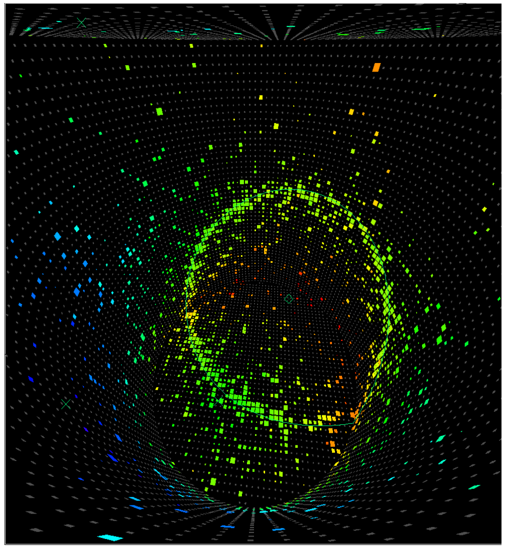
EURISOL Design Study



Detector in the Frejus tunnel

Combination of beta beam with super beam





combines CP and T violation tests

$\nu_e \rightarrow \nu_\mu$ (β+)	(T)	$\nu_\mu \rightarrow \nu_e$ (π^+)
(CP)		
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ (β-)	(T)	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ (π^-)

in addition, one beam provides cross-sections and topologies for the other in the near detector

Beta-beams

Aimed:
He 2.9 10^{18} (2.0 10^{13}/s)
Ne 1.1 10^{18} (2.0 10^{13}/s)

Original concept for the ion production is based on the SPL:
succesful for ^{6}He, well established production mechanism
Spallation production of ^{6}He on a BeO target from a powerful proton source
(~200 kw per target station)

For ^{18}Ne initial considerations using the same technique lead to a deficit
of a factor > 10 wrt to physics demands. (8 10^{11}/s).
Direct production using high power ^{3}He gun needed. Demonstration needed!

With SPS as final accelerator, typical maximal energy for (anti) neutrinos
is 400-600 MeV (i.e. can be matched to the SPL superbeam)

→EUROnu DS will investigate new production mechanisms using high Q isotopes:
^{8}Li, ^{8}B (C. Rubbia et al) which are less demanding on the proton source.
Higher energy neutrinos (factor 4-5) but correspondingly higher number of ions
will be required for same event rates. Flux goes as $1/Q^2$ and cross-section as Q.

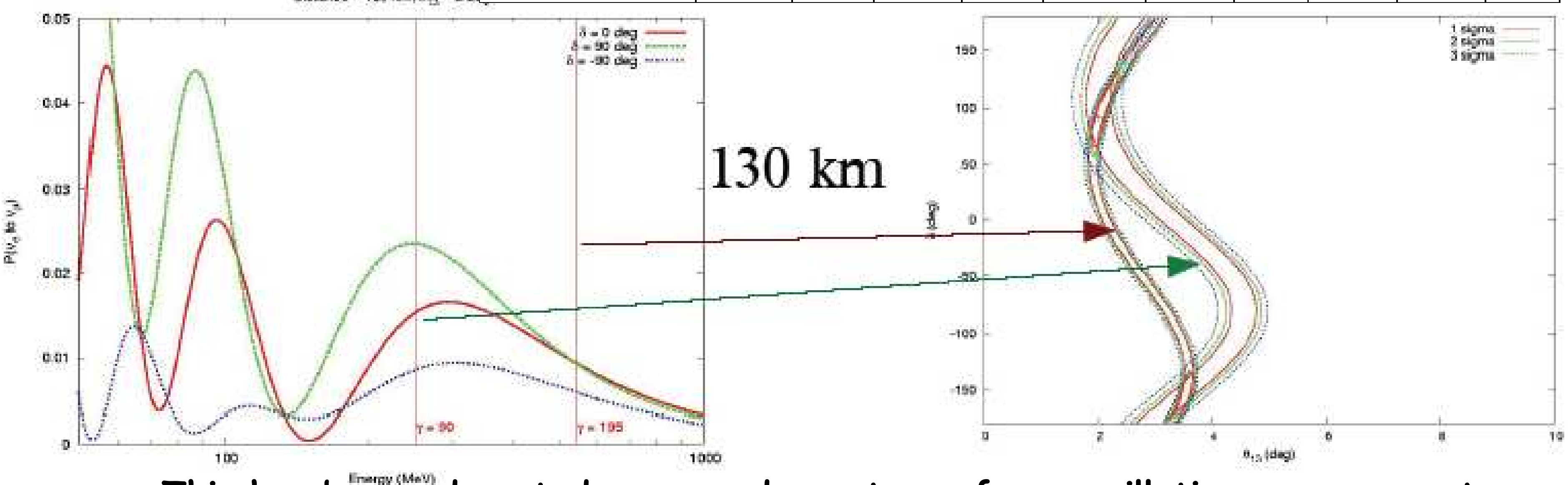
Exciting possibility also with e-capture ions (Dy for instance) $N+e^- \to N'+\nu_e$ which
produce monochromatic electron neutrino beams.
Spallation production; really needs high power SPL.

These new ion production schemes are object of the EUROnu design study.

A monochromatic neutrino beam

Electron Capture:
$N+e^- \rightarrow N'+\nu_e$

Decay	$T_{1/2}$	BR_ν	EC/ν	I^{β}_{EC}	B(GT)	E_{GR}	Γ_{GR}	Q_{EC}	E_ν	ΔE_ν
$^{148}Dy \rightarrow {}^{148}Tb^*$	3.1 m	1	0.96	0.96	0.46	620		2682	2062	
$^{150}Dy \rightarrow {}^{150}Tb^*$	7.2 m	0.64	1	1	0.32	397		1794	1397	
$^{152}Tm2^- \rightarrow {}^{152}E_T^*$	8.0 s	1	0.45	0.50	0.48	4300	520	8700	4400	520
$^{150}Ho2^- \rightarrow {}^{150}Dy^*$	72 s	1	0.77	0.56	0.25	4400	400	7400	3000	400



This has been advocated as a good way to perform oscillation measurements…

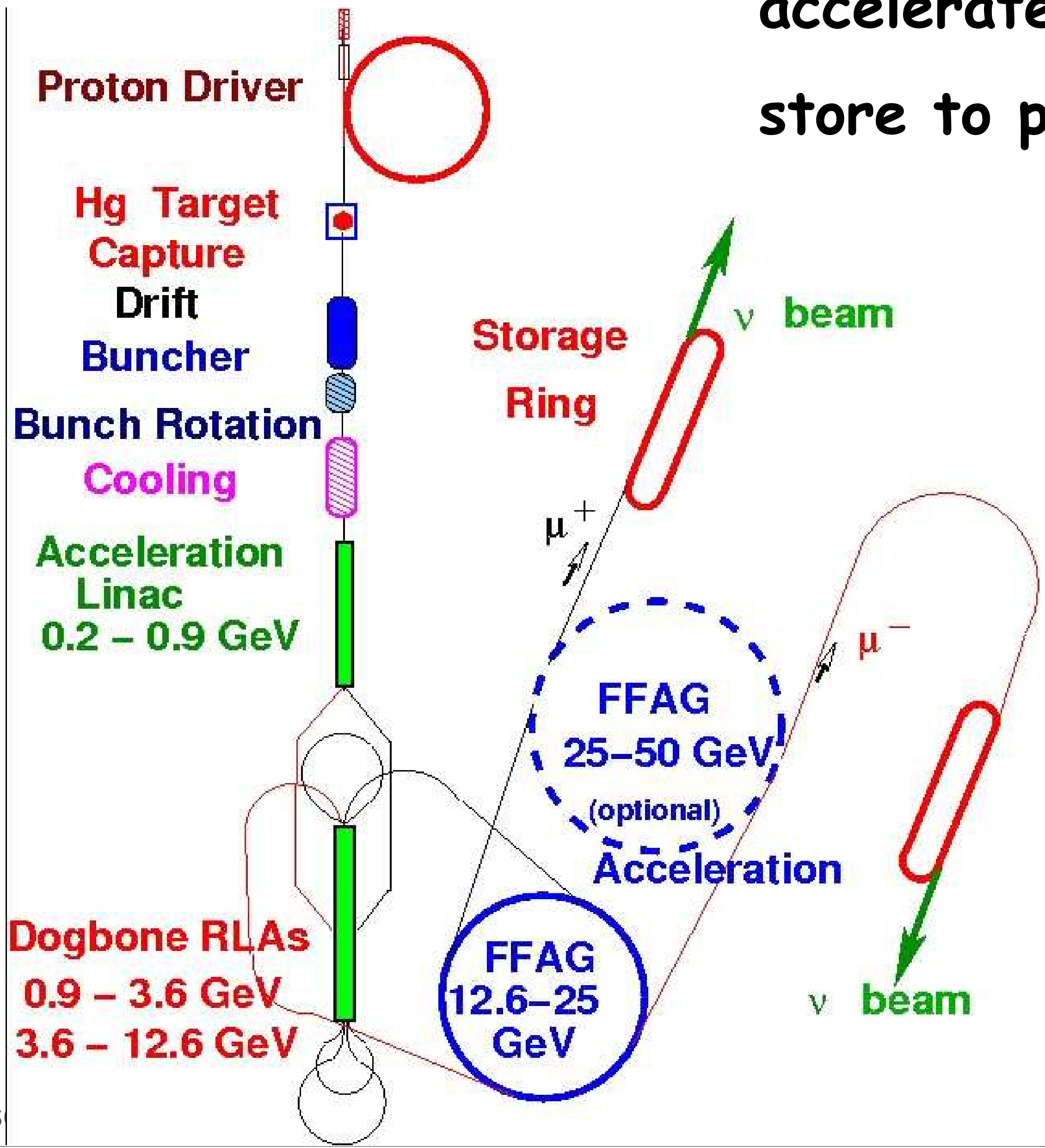
Unfortunately the decay rate of these isotopes is very long,
and the number of stored ions correspondingly lower
==> intensities likely to be too small for oscillation experiments.

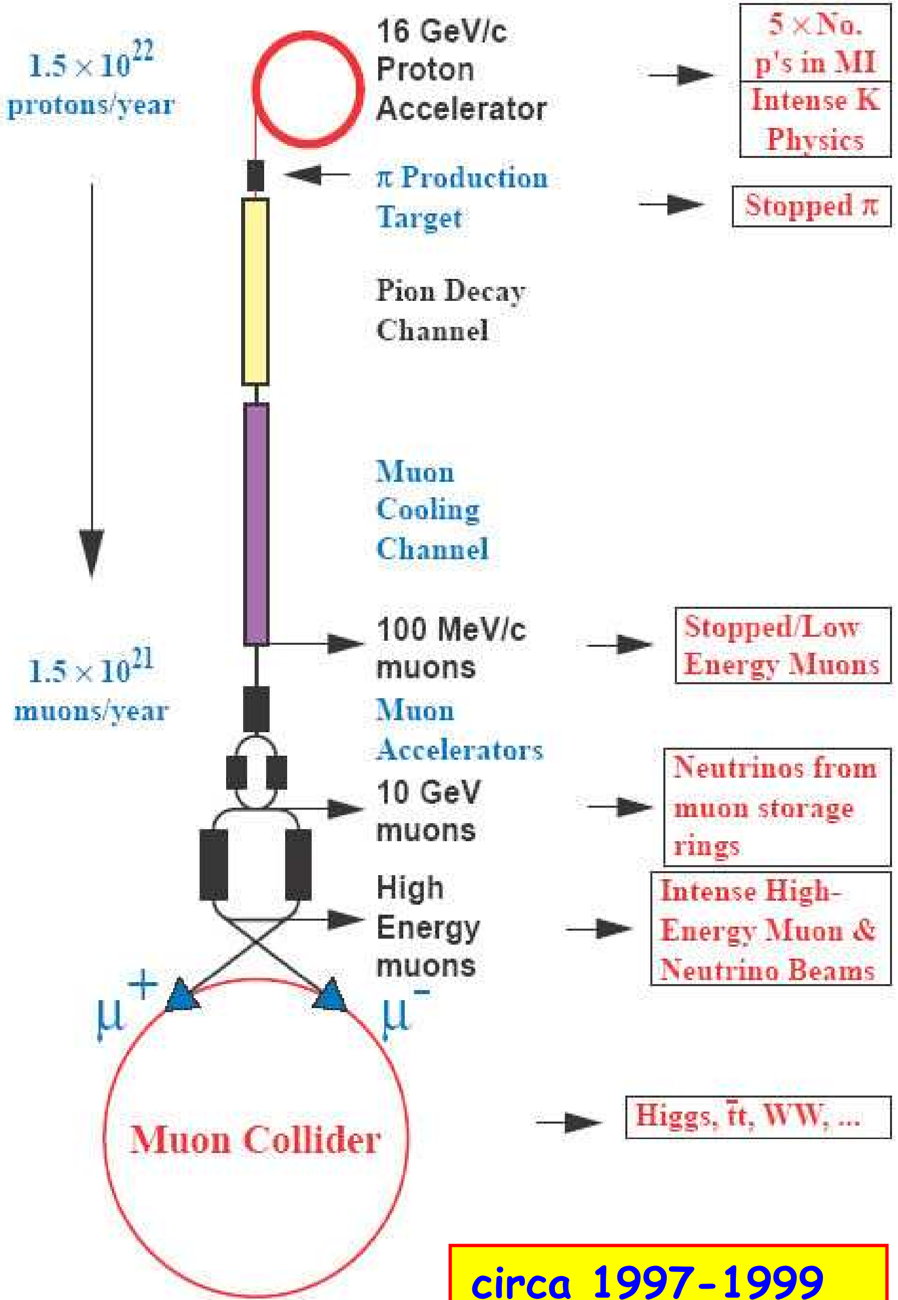
Tunable monochromatic beam for cross-section measts in near detector!

neutrino factory:

accelerate muons and

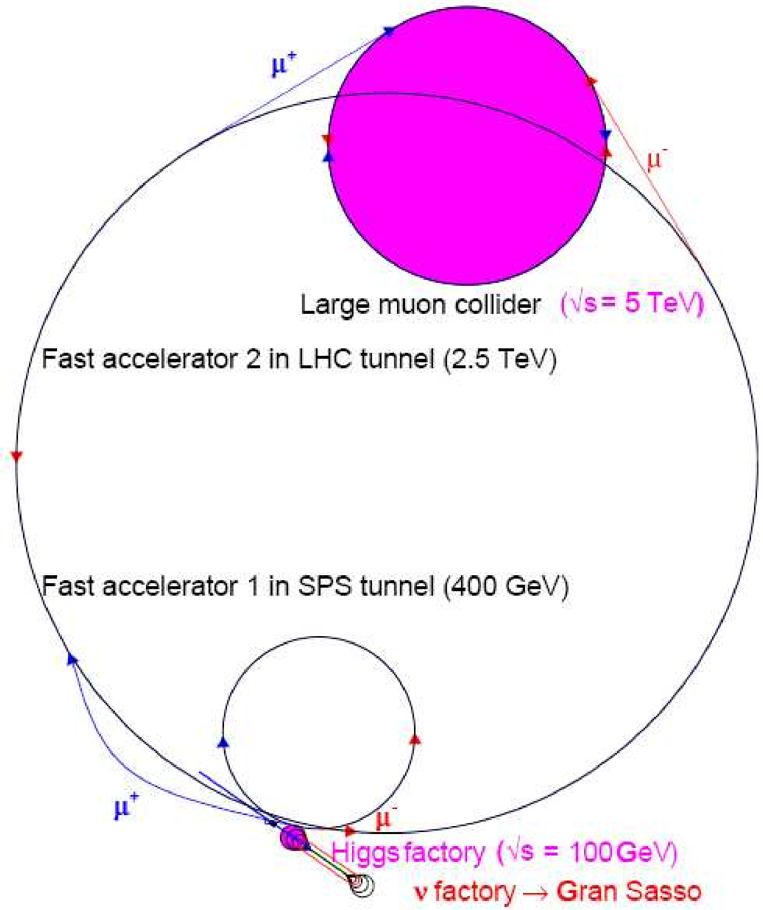
store to produce neutrinos





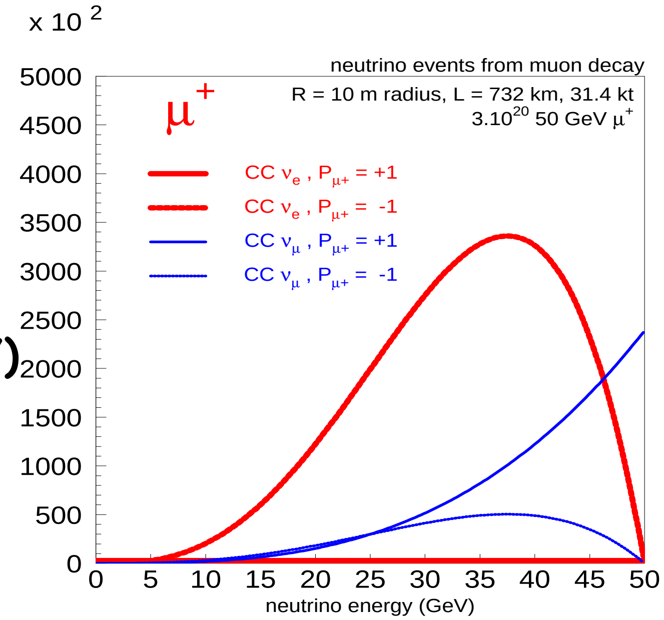
circa 1997-1999
US, Europe, Japan

Intense nucl. and hadr. physics
Intense Low-E muons
Neutrino Factory
Higgs(es) Factory(ies)
Energy Frontier -> 5 TeV



Possible layout of a muon complex on the CERN site.

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



Unique: High energy electron neutrinos, spectrum extends up to ~muon energyabove tau production threshold (3.5 GeV) and matter resonance (~12 GeV)

Flux well known (10^{-3})

Appearance oscillation signal: wrong sign muons:

Golden channel:

$$\nu_e \rightarrow \nu_\mu; \nu_\mu + N \rightarrow \mu^- + X$$

vs

$$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu; \bar{\nu}_\mu + N \rightarrow \mu^+ + X$$

Detection « easy » : LARGE (100kton) magnetized iron neutrino detector (MIND) baseline detector.

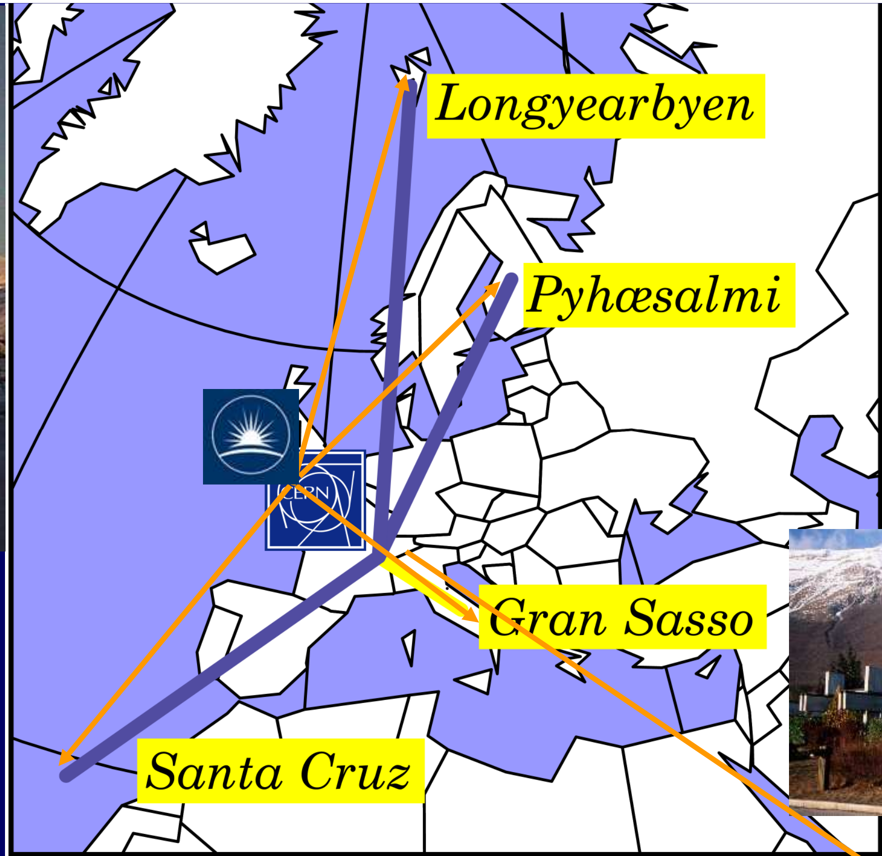
More difficult:

Silver channel: $$\nu_e \rightarrow \nu_\tau; \nu_\tau + N \rightarrow \tau^- + X$$ **wrong sign taus:**

Platinum channel: $$\bar{\nu}_\mu \rightarrow \bar{\nu}_e; \bar{\nu}_e + N \rightarrow e^+ + X$$ **wrong sign electrons:**

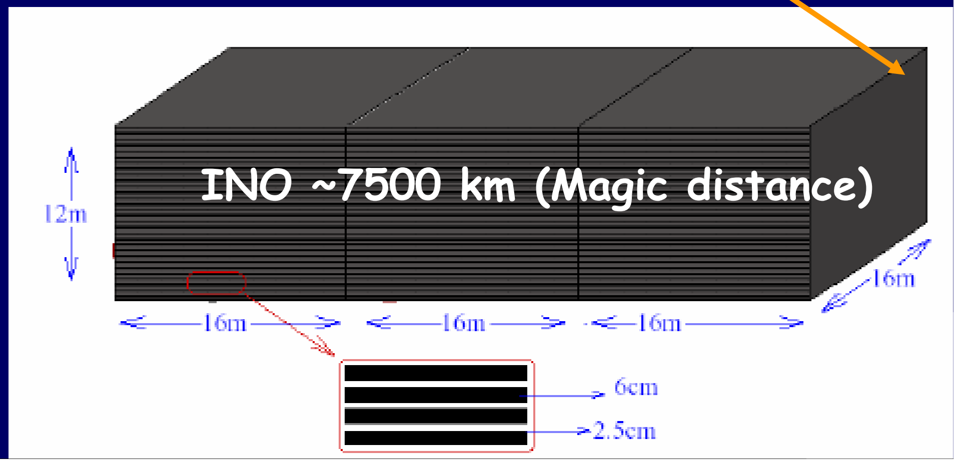
require emulsion or fine grain (Larg or TASD) detector in magnetic field – a challenge!

Explore neutrino factory
or muon collider
as an option for the future.
Feasibility, cost

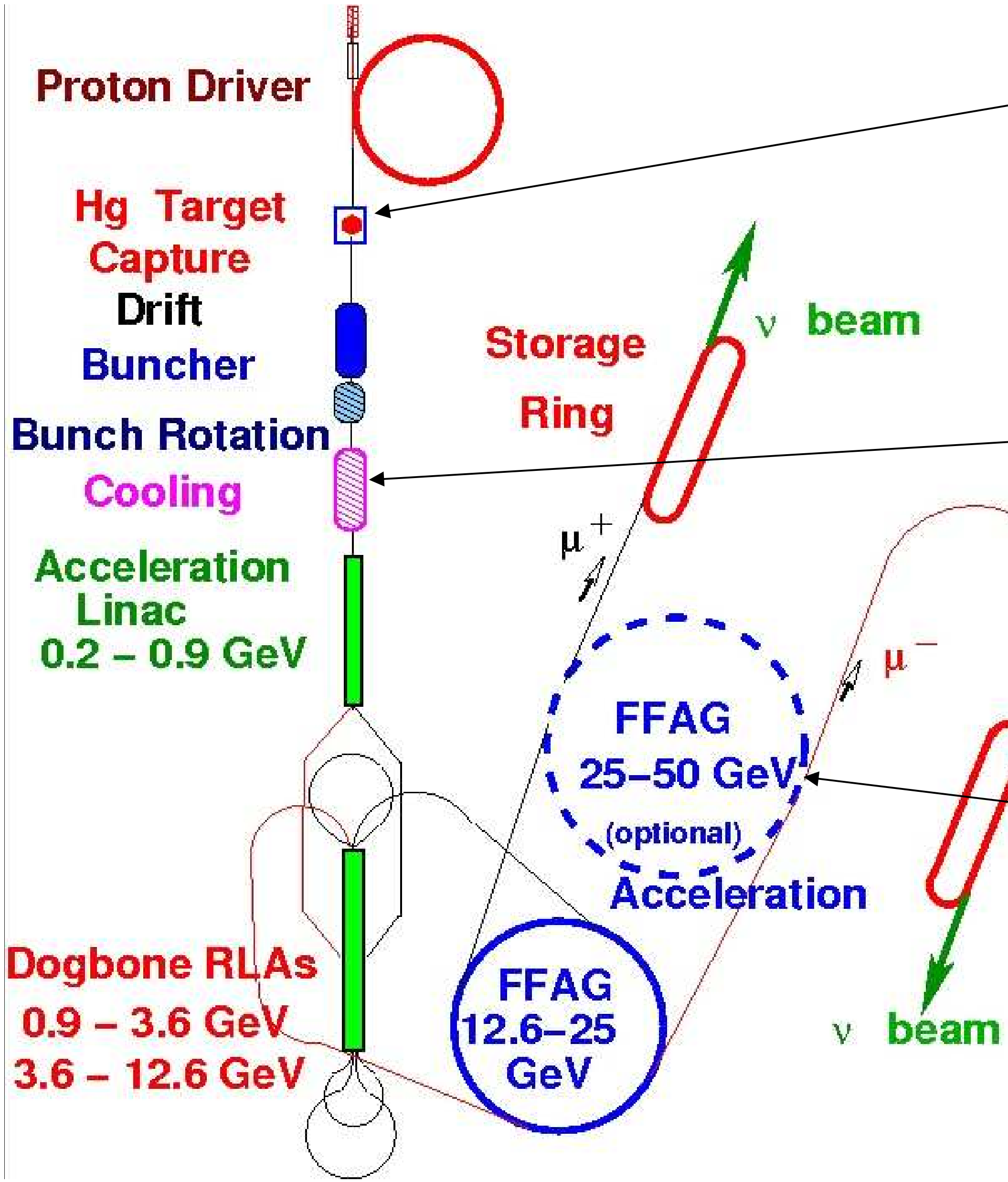


Laguna site!

Long baseline detectors: Magnetized Iron, emulsions, liquid argon
Good baselines are: ~3000-5000 depending on muon threshold + 7500 km



Major challenges tackled by R&D expts



High-power target
. 4MW
. good transmission
MERIT experiment
(CERN)

Fast muon cooling
MICE experiment
(RAL)

Fast, large aperture accelerator (FFAG)
EMMA (Daresbury)

ISS baseline

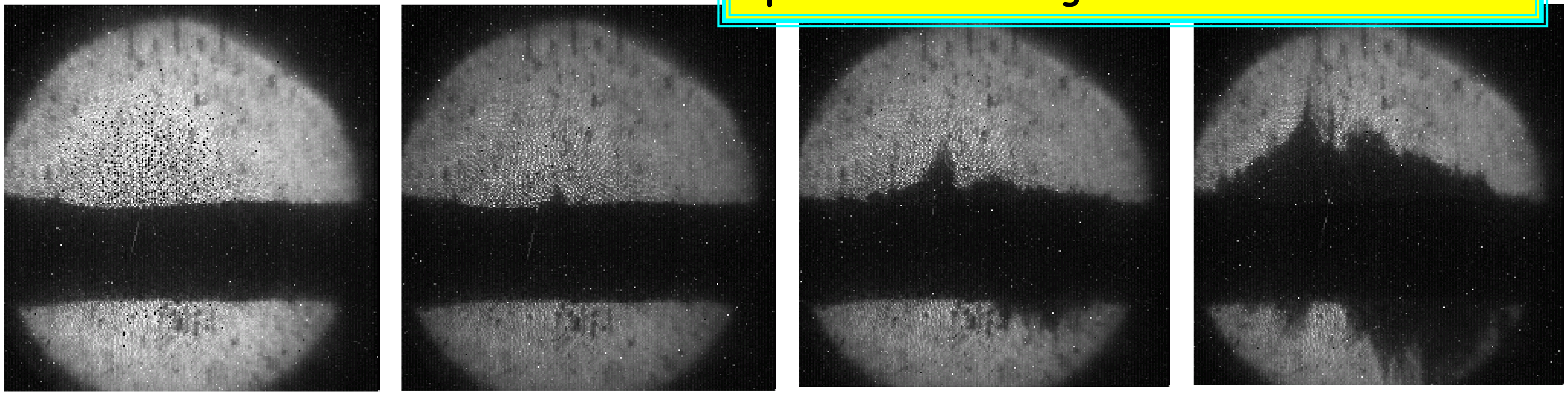
MERIT EXPERIMENT at CERN

BNL, MIT, ORNL, Princeton University CERN, RAL

Splash velocity – 24 GeV beam

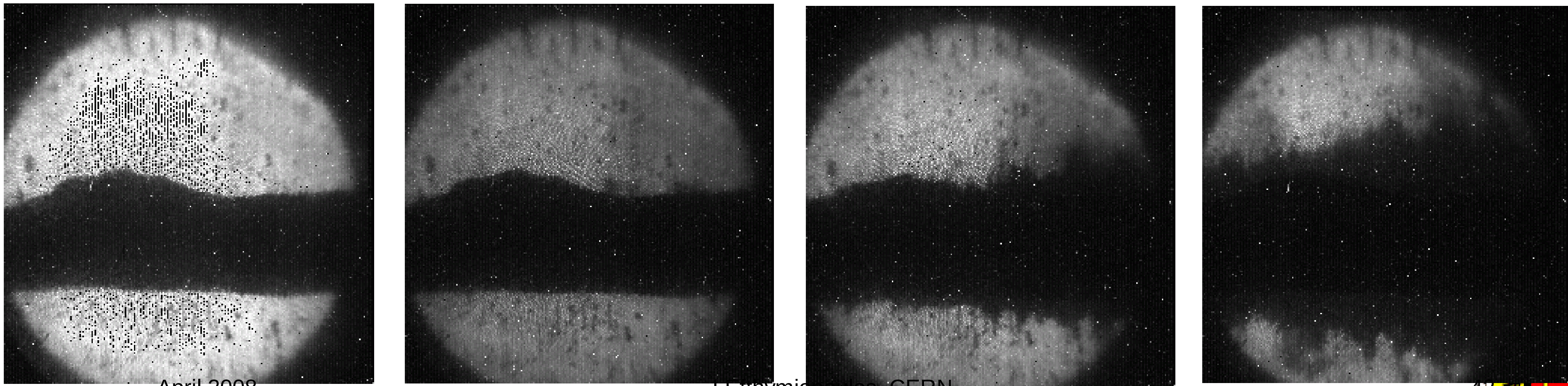
Demonstrated liquid mercury jet technology for neutrino factory and muon collider up to 8MW on target *Oct22-Nov12 2007*

10TP, 10T *V = 54 m/s*



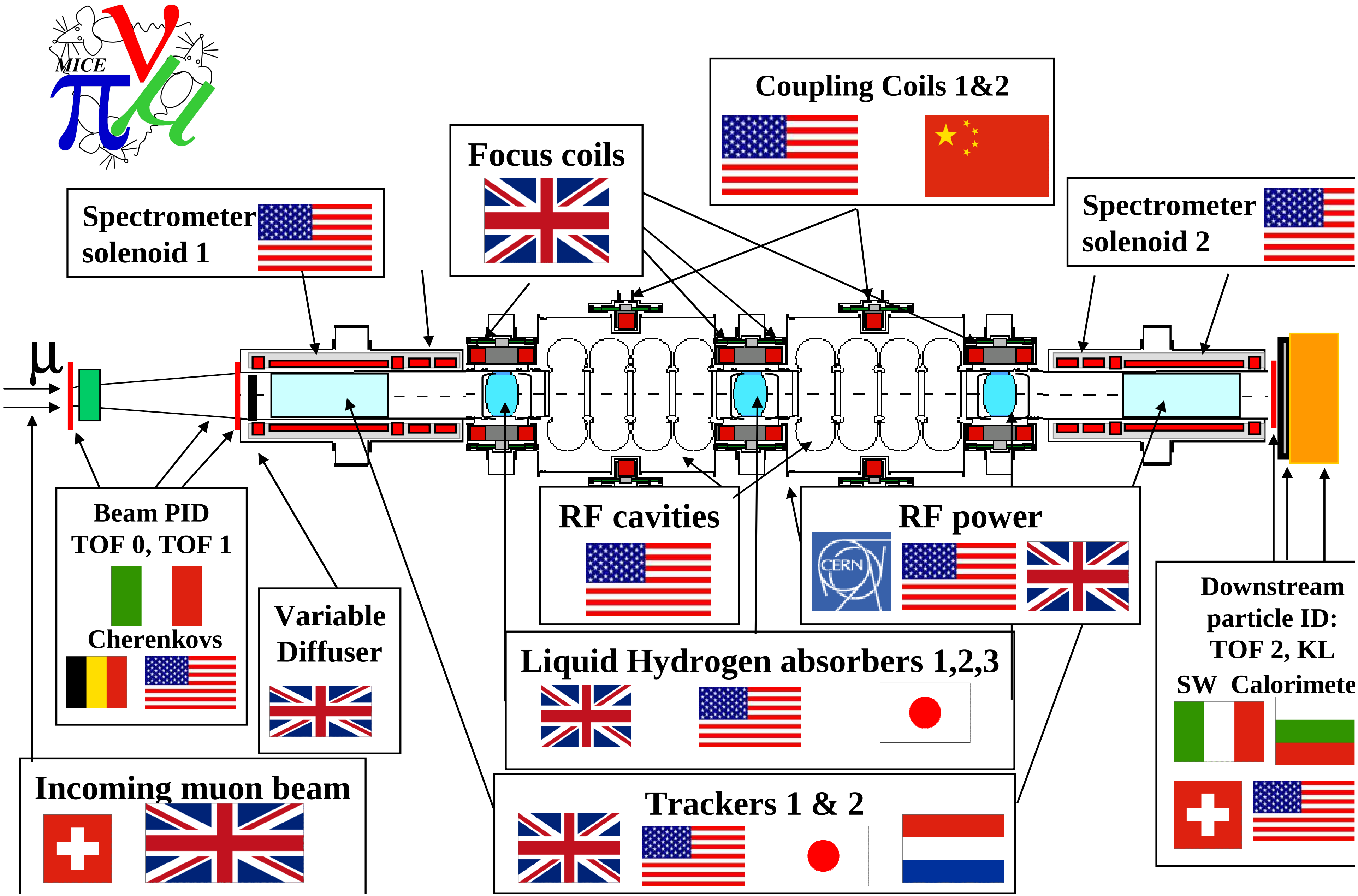
t=0 *t=0.075 ms* *t=0.175 ms* *t=0.375 ms*

20TP, 15T *V = 65 m/s*



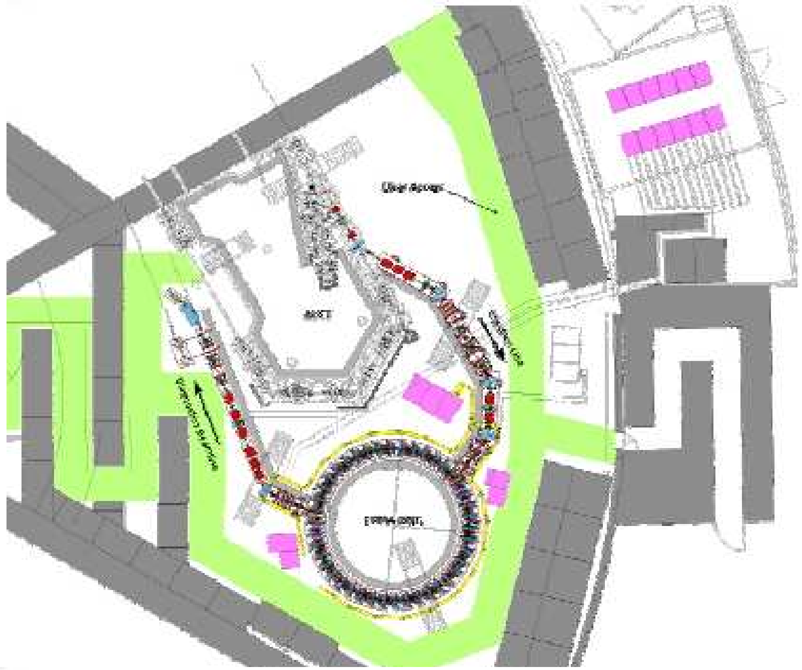
t=0 *t=0.075 ms* *t=0.175 ms* *t=0.375 ms*

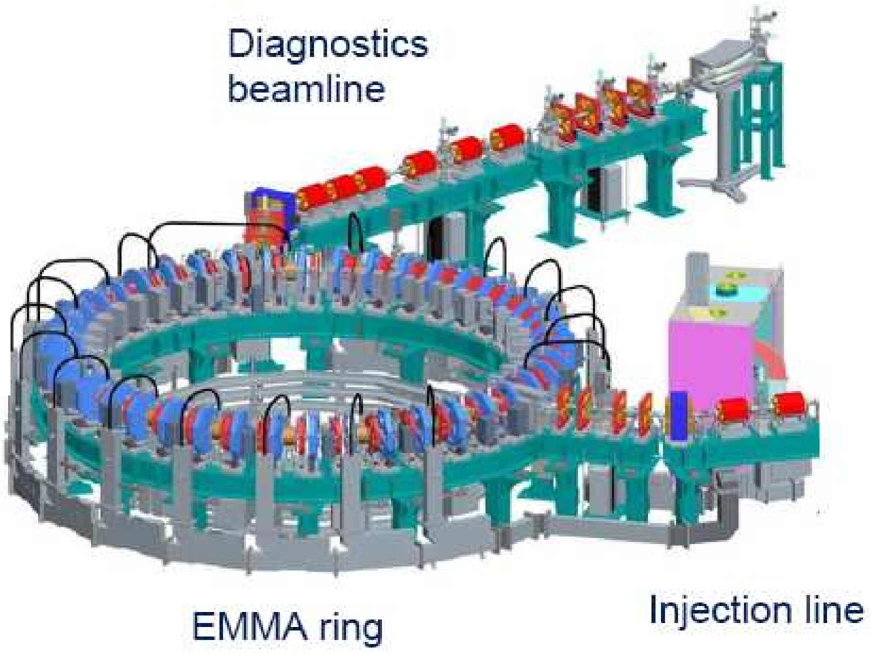
Muon Ionization Cooling Eexperiment (MICE) Collaboration

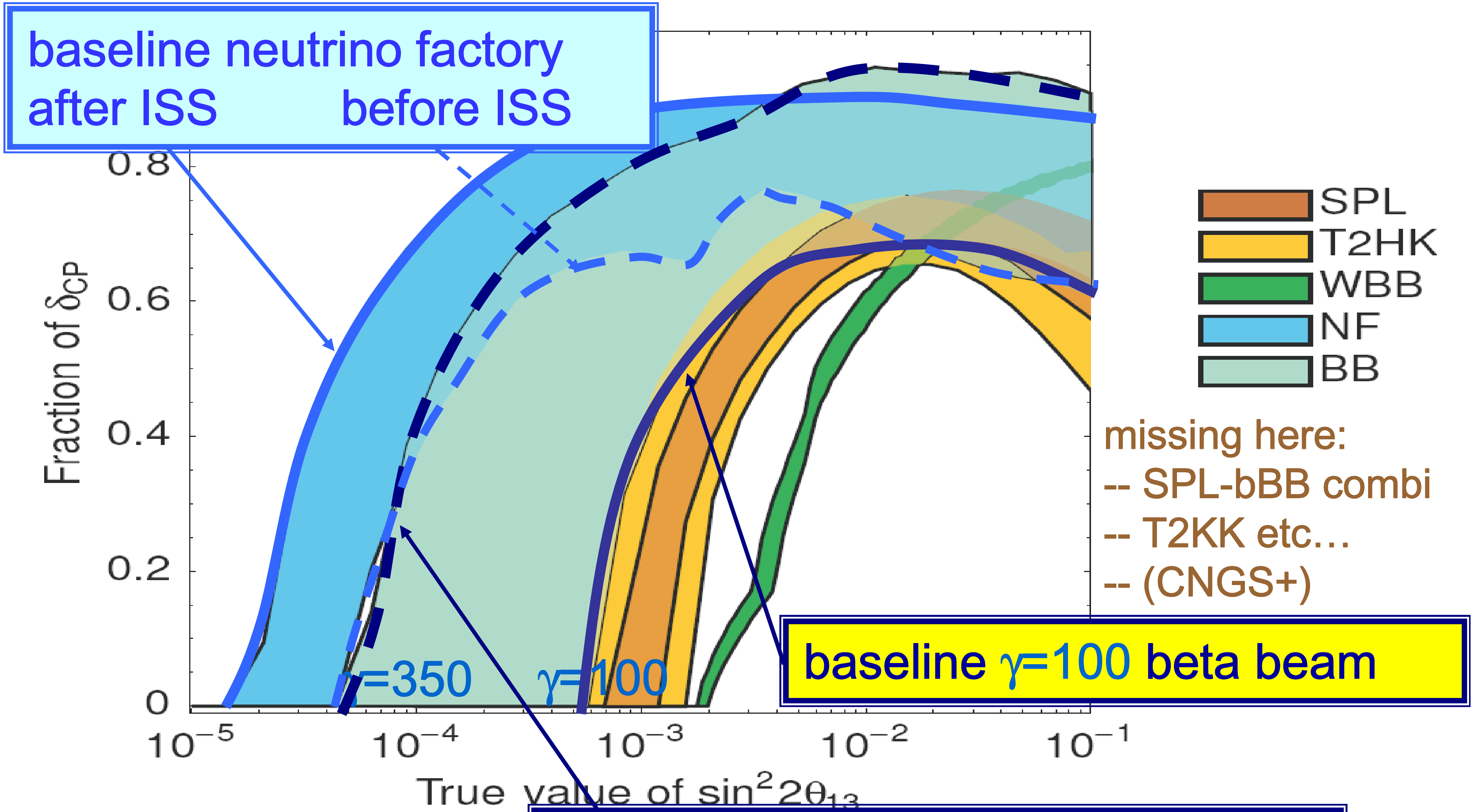


EMMA

- Model of muon FFAG accelerator(s) in NF – v. imp. R&D project
- Proof-of-principle non-scaling FFAG – variety of applications:
  - proton & light ion cancer therapy
  - ADSR
  - muon production for slow muons
  - etc
- Will study:
  - ns dynamics
  - large acceptance, 30πm mrad
  - bucketless acceleration
  - fast resonance crossing
  - very large momentum compaction
  - etc
- Comparison with tracking codes
- Parameters:
  - electrons, 10-20MeV
  - 42 cells, doublet lattice, 1.3GHZ RF
  - cell length 40cm → 16.5m circumference







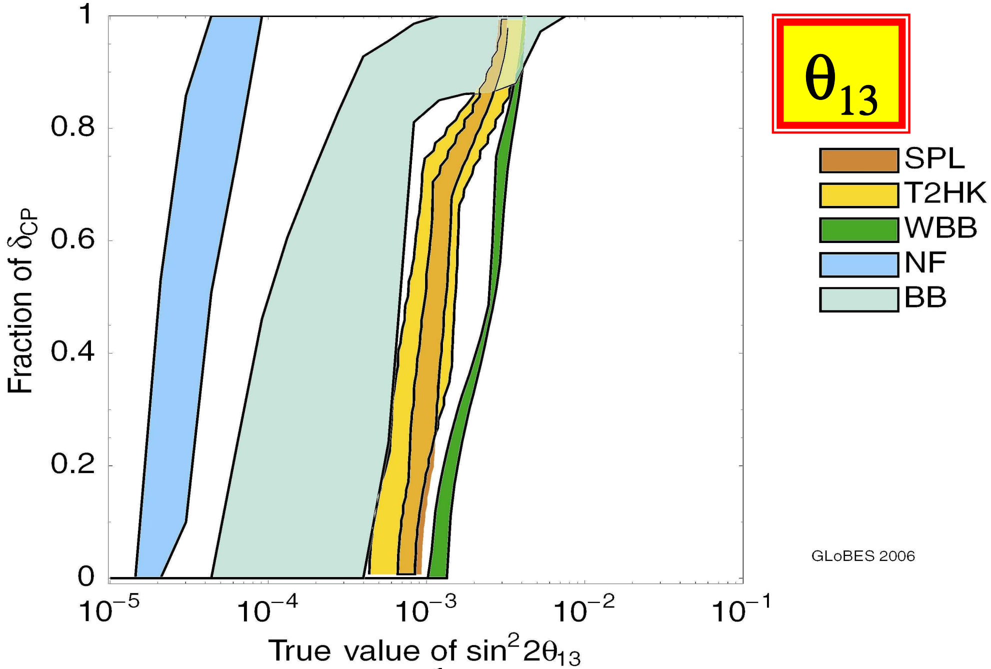
"aspirational" γ=350 beta beam

Neutrino factory is the most Powerful device for neutrino CP violation, matter effects, universality, precise measurements of Neutrino mixing parameters

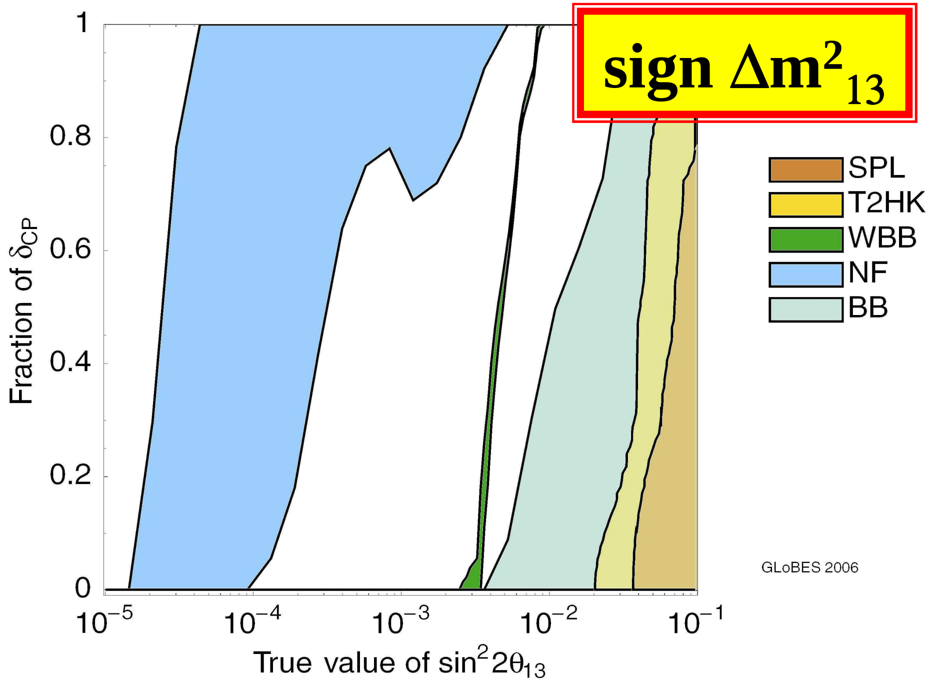
…he … he right
… excluded at the 3σ confidence level. The discovery limits are shown as a
… values of the true value of the CP phase δ ('Fraction of δ_{CP}') and the true
…ges of the bands correspond to the conservative set-ups while the left-hand
…-ups, as described in the text. The discovery reach of the SPL super-beam
… T2HK as the yellow band, and that of the wide-band beam experiment as
…f the beta-beam is shown as the light green band and the Neutrino Factory
…band.

Overall comparisons from ISS

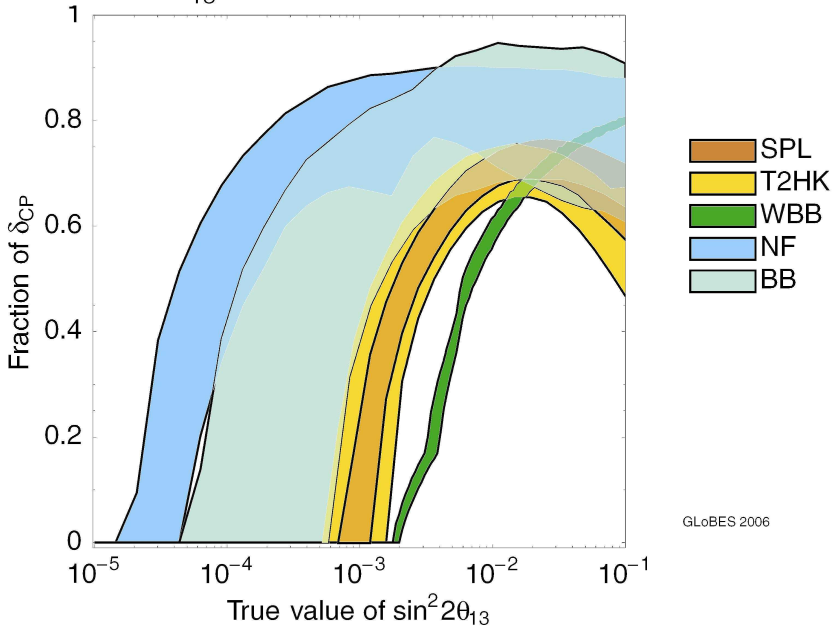
θ_{13}



sign Δm^2_{13}



CP phase δ



NuFACT does it all…
(+ univ. test etc…)
but <u>when</u> can it do it
and <u>at what cost</u>?

International Design Study IDS-NF

The collaboration

International Design Study of the Neutrino Factory

Steering Group

A.Blondel, K.Long (chair), M.Zisman, Y.Kuno

Physics and Performance Evaluation:
A.Donini, P.Huber, S.Pascoli, W.Winter

Accelerator:
S.Berg, Y.Mori, C.Prior, J.Pozimski

Detector:
A.Bross, A.Cervera, N.Mondal, P.Soler

https://www.ids-nf.org

EU component is part-funded via EUROnu

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Aim: produce CDR for 2012

'CDR' implies:
- Physics performance of *costed* scenario
- Conceived as input to cost/performance comparison required at C.E.R.N.
- Council Strategy Group 2012 decision point

Muon beams for rare muon decay physics

Rare decays searches: $\mu^+ \to e^+\gamma$, $\mu^+ \to e^+ee$, $\mu^- N \to e^- N$ are sensitive probes of Models with FCNC's. (SU-SY in particular). Very fundamental experiments!

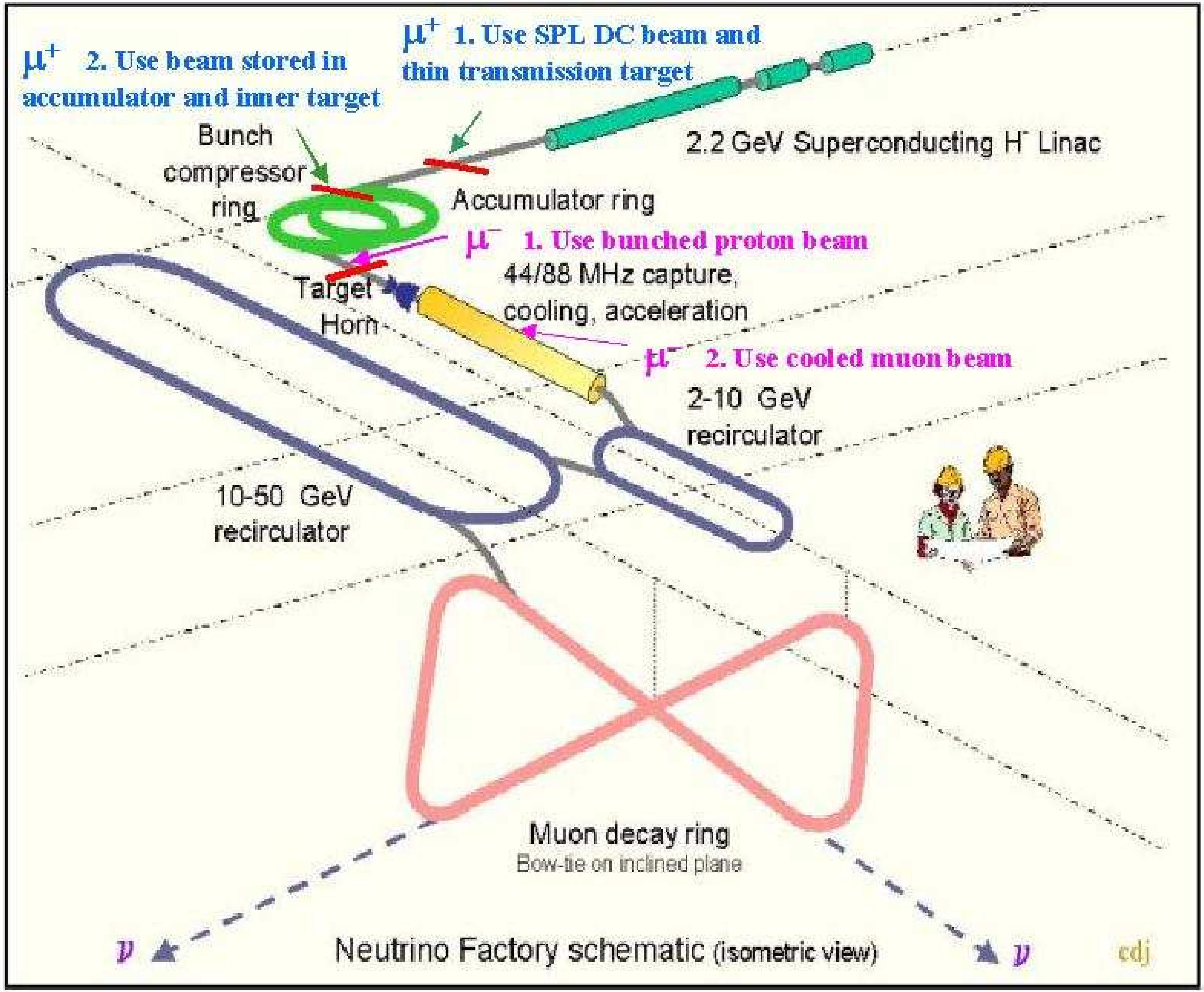
Leading experiment $\mu \to e\gamma$, MEG at PSI aims at 10^{-13} sensitivity.
1.5 MW proton beam at 590 MeV, 4% transmission target, surface muons.
(PSI Main user of protons is spallation source SINQ and low energy neutron source)

Can one gain 3 orders of magnitude over MEG?
Progress needed both on detector side and on beam intensity.

As was pointed out in early studies the SPL with accumulator ring provides (using an internal target of completely open design)
a very convenient DC beam for DC muon production. $\mu+ \to e+\gamma$, $\mu+ \to e+ee$,

It can also provide en excellent pulsed proton beam with short pulses using a target on the neutrino beam transfer line or its own fast extraction beam line.
μ-N$\to$e-N

No succesful idea (yet) to use the muons from the neutrino factory front end.


μ+ 1. Use SPL DC beam and
thin transmission target
μ+ 2. Use beam stored in
accumulator and inner target
Bunch
compressor
ring
2.2 GeV Superconducting H- Linac
Accumulator ring
μ- 1. Use bunched proton beam
44/88 MHz capture,
cooling, acceleration
Target
Horn
μ- 2. Use cooled muon beam
2-10 GeV
recirculator
10-50 GeV
recirculator
Muon decay ring
Bow-tie on inclined plane
ν
Neutrino Factory schematic (isometric view)
ν
cdj

Conclusions -- outlook

Neutrino Oscillation physics attracts a growing community on a step-wise programme

The ultimate goal is precision measurements of neutrino oscillation parameters with important potential for discoveries along the way.
Leptonic CP violation, mass hierarchy, unitarity etc..

NEUTRINO PHYSICS IS NEW, FUNDAMENTAL PHYSICS that is complemetary to the high energy frontier but cannot be addressed by it.

Substantial efforts are underway both on detectors and accelerators to establish feasibility of future steps; but the CERN involvement has remained marginal. The date of 2012 for deciding the next step is taken seriously.

Several options, many issues… and the way forward

-- How do we come to an agreed program?

-- How can efforts be optimized and enhanced where (sometimes badly) needed?

WILL BE EXPOSED AND DISCUSSED AT THE UPCOMING WORKSHOP

European Strategy for Neutrino physics -- 1-3 Oct09 at CERN

References and Links

Original ideas in 1970's (Amaldi, Budker)

Neutrino Beams From Muon Storage Rings: Characteristics And Physics Potential
S. Geer Phys.Rev.D57:6989-6997,1998, Erratum-ibid.D59:039903,1999]

***Prospective study of muon storage rings at CERN*, ECFA-CERN CERN 99-02 (1999)**

Study IIA Neutrino Factory and Beta Beam Experiments and Development,
C. Albright et al, BNL-72369-2004, FNAL-TM-2259, LBNL-55478,

ECFA-CERN study of a Neutrino Factory Complex
A. Blondel et al., eds. CERN-2004-002.- ECFA-04-230 March 2004.

ISS reports
***Accelerator design concept for future neutrino facilities.* arXiv:0802.4023**
***Detectors and flux instrumentation for future neutrino facilities.* JINST 4:T05001,2009.**
***Physics at a future Neutrino Factory and super-beam facility.* arXiv:0710.4947 [hep-ph]**

ISS study
-- Performed comparison between proposed facilities
-- defined the baseline parameters.
to be followed-up quantitatively (R&D, feasibility, cost) → International Design Study