Low Energy SPL Superbeam

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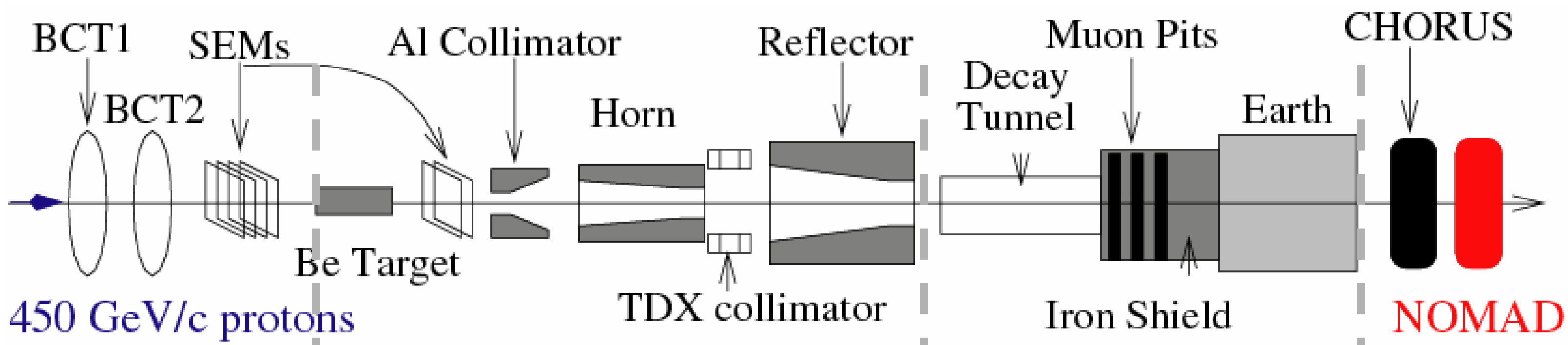
SuperBeam Definition

Example of **conventional neutrino beam**: WANF



Protons | Pions and kaons | Pions, Muons and Neutrinos | Neutrinos

Superbeam basic ingredients: Multi-MegaWatt proton source to produce a high intensity neutrino beam directed to a Multi-100 kTon neutrino detector.

Aim: Study the the oscillation of $\nu_\mu \rightarrow \nu_e$ to get θ_{13} and possibly to have a first hint of leptonic CP violation with a LBL experiment

Neutrino's beam future

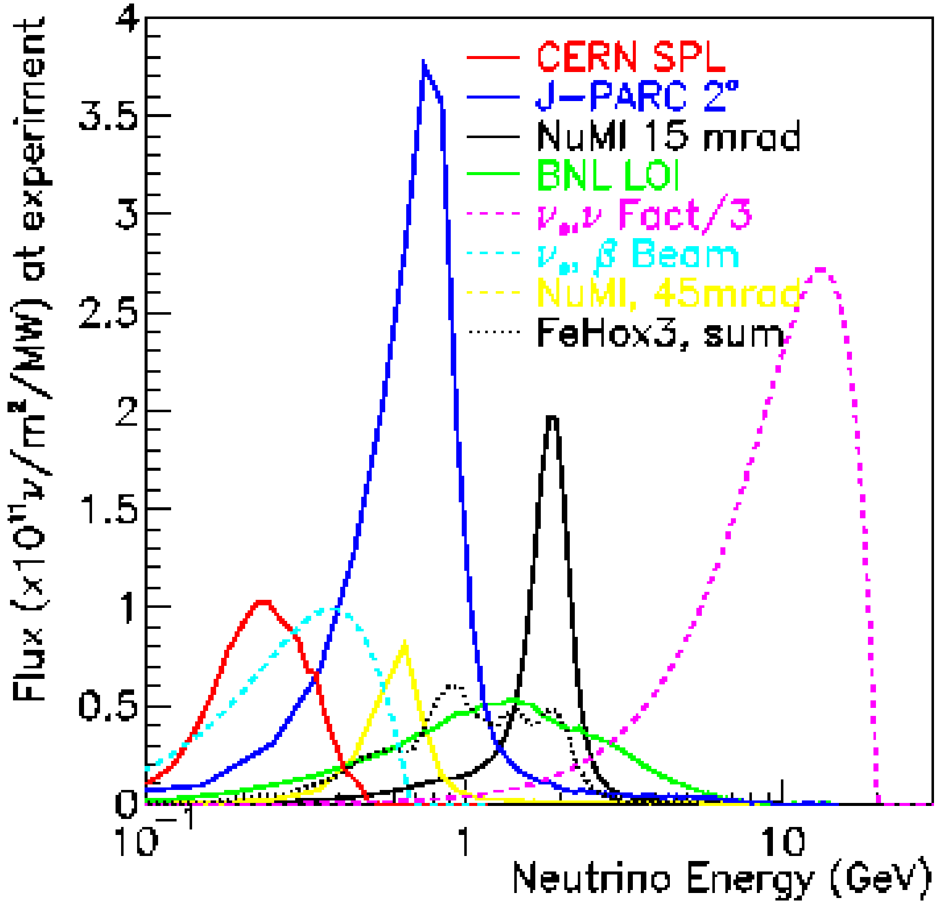
From: Takashi Kobayashi, Paris 2004

	E_p (GeV)	Power (MW)	Beam	$\langle E_\nu \rangle$ (GeV)	L (km)	M_{det} (kt)	ν_μCC (/yr)	ν_e @peak
K2K	12	0.005	WB	1.3	250	22.5	~50	~1%
MINOS(LE)	120	0.4	WB	3.5	730	5.4	~2,500	1.2%
CNGS	400	0.3	WB	18	732	~2	~5,000	0.8%
T2K-I	50	0.75	OA	0.7	295	22.5	~3,000	0.2%
NOνA	120	0.4	OA	~2	810?	50	~4,600	0.3%
C2GT	400	0.3	OA	0.8	~1200	1,000?	~5,000	0.2%
T2K-II	50	4	OA	0.7	295	~500	~360,000	0.2%
NOνA+PD	120	2	OA	~2	810?	50?	~23,000	0.3%
BNL-Hs	28	1	WB/OA	~1	2540	~500	~13,000	
SPL-Frejus	2.2	4	WB	0.32	130	~500	~18,000	0.4%
FeHo	8/120	"4"	WB/OA	1~3	1290	~500	~50,000	

Different experiment

Different approaches to have a
Low Energy Neutrino Beam

- Energy range ~100 MeV – 1 GeV
- OFF-axis beam: neutrino energy is selected by 2-body decay kinematics
- WB at low energy like the SPL



D. Harris. Nufact04

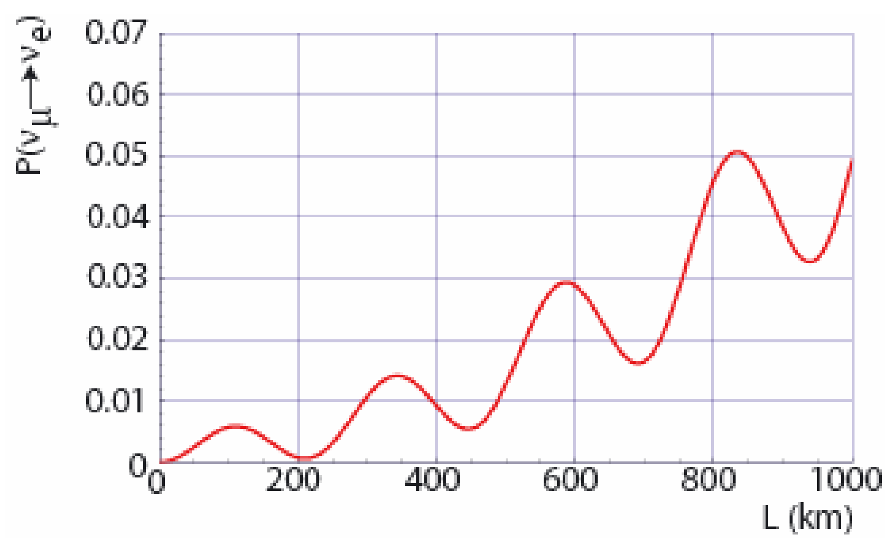
A brief recall about oscillation parameters

$$P(\nu_\mu \to \nu_e) = 4(s_{23}^2 s_{13}^2 c_{13}^2 + J_{CP}\sin\Delta_{21})\sin^2\frac{\Delta_{31}}{2}$$
$$+2(s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - s_{12}^2 s_{23}^2 s_{13}^2 c_{13}^2)\sin\Delta_{31}\sin\Delta_{21}$$
$$+4(s_{12}^2 c_{12}^2 c_{23}^2 c_{13}^2 + s_{12}^4 s_{23}^2 s_{13}^2 c_{13}^2 - 2s_{12}^3 s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - J_{CP}\sin\Delta_{31})\sin^2\frac{\Delta_{21}}{2}$$
$$+8(s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - s_{12}^2 s_{23}^2 s_{13}^2 c_{13}^2)\sin^2\frac{\Delta_{31}}{2}\sin^2\frac{\Delta_{21}}{2}$$

$$J_{CP} \equiv s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2\sin\delta$$

Missing parameter in the neutrino oscillation probability:

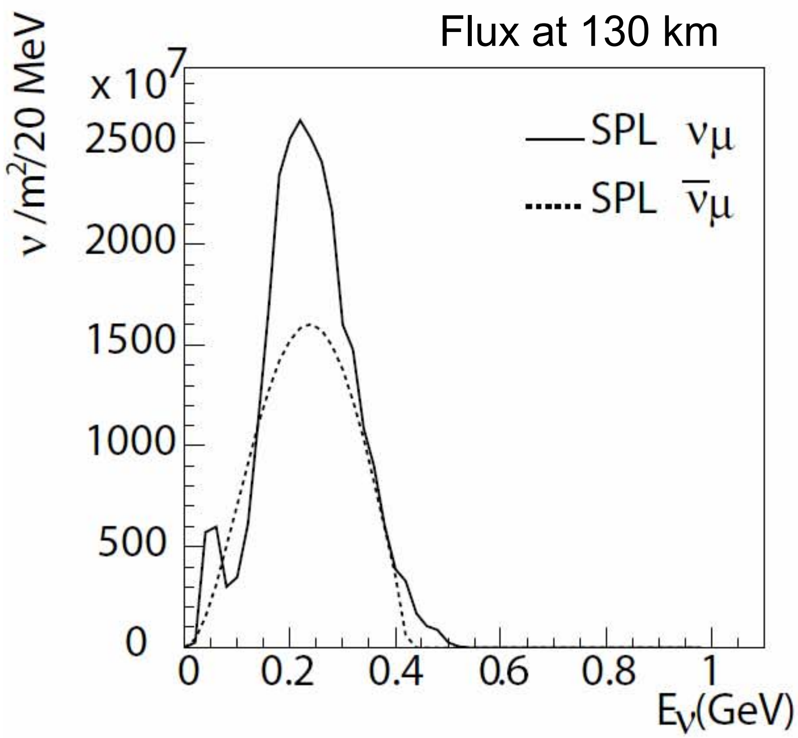
- θ_{13}
- CP δ phase

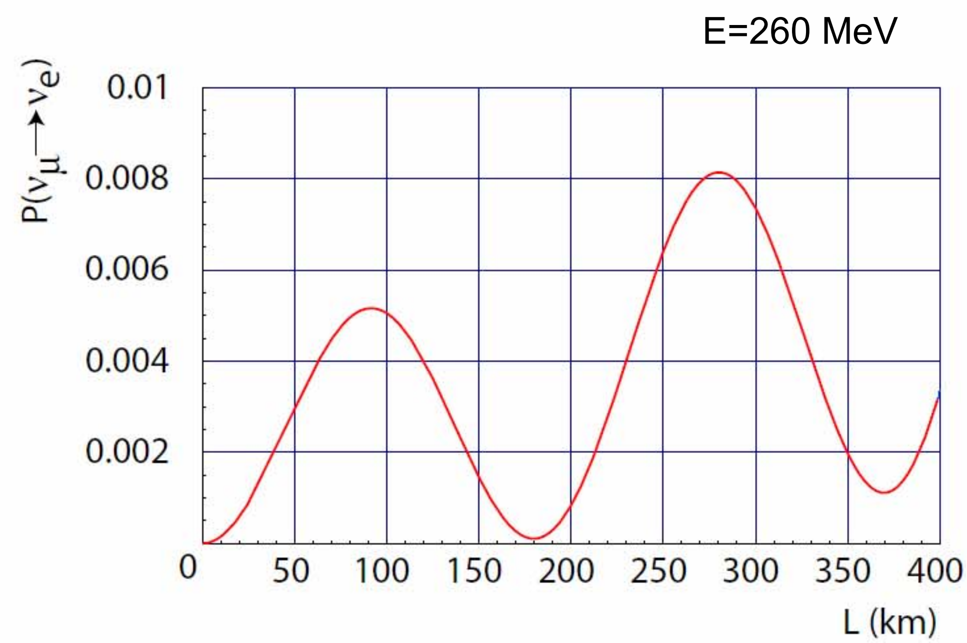


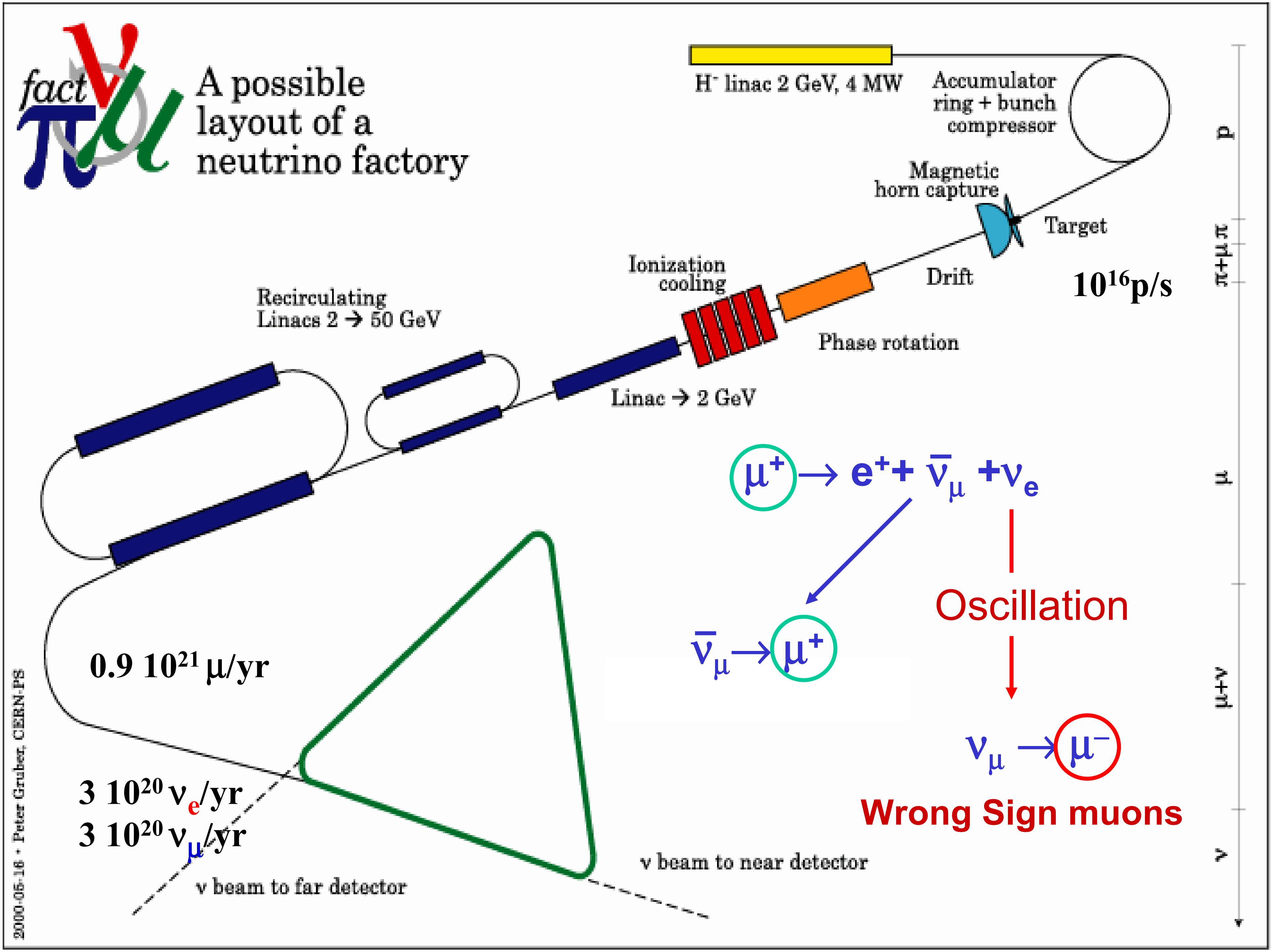
Superbeam flux

How to make a first step to measure θ_{13} and δ ?

Study $\nu_\mu \rightarrow \nu_e$ ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) oscillations at first maximum

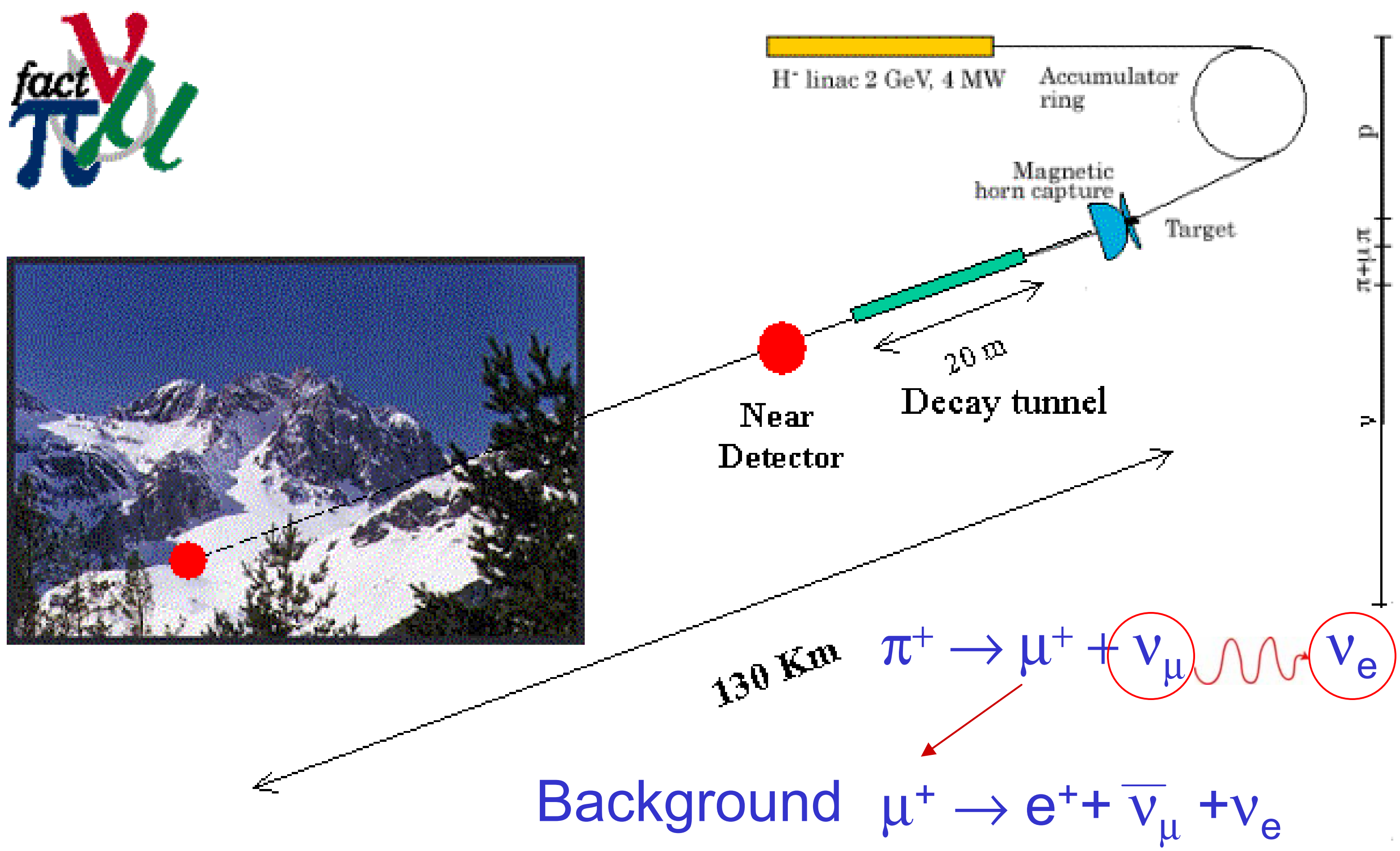






factvπμ
A possible layout of a neutrino factory
H⁻ linac 2 GeV, 4 MW
Accumulator ring + bunch compressor
Magnetic horn capture
Target
Drift
10^{16}p/s
Ionization cooling
Phase rotation
Recirculating Linacs 2 → 50 GeV
Linac → 2 GeV
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$
$\bar{\nu}_\mu \rightarrow \mu^+$
Oscillation
$\nu_\mu \rightarrow \mu^-$
Wrong Sign muons
$0.9\ 10^{21}\ \mu$/yr
$3\ 10^{20}\ \nu_e$/yr
$3\ 10^{20}\ \nu_\mu$/yr
ν beam to far detector
ν beam to near detector
2000-05-16 • Peter Gruber, CERN-PS
p
π+μ
μ
μ+ν
ν

Proposal for a CERN - Super Beam

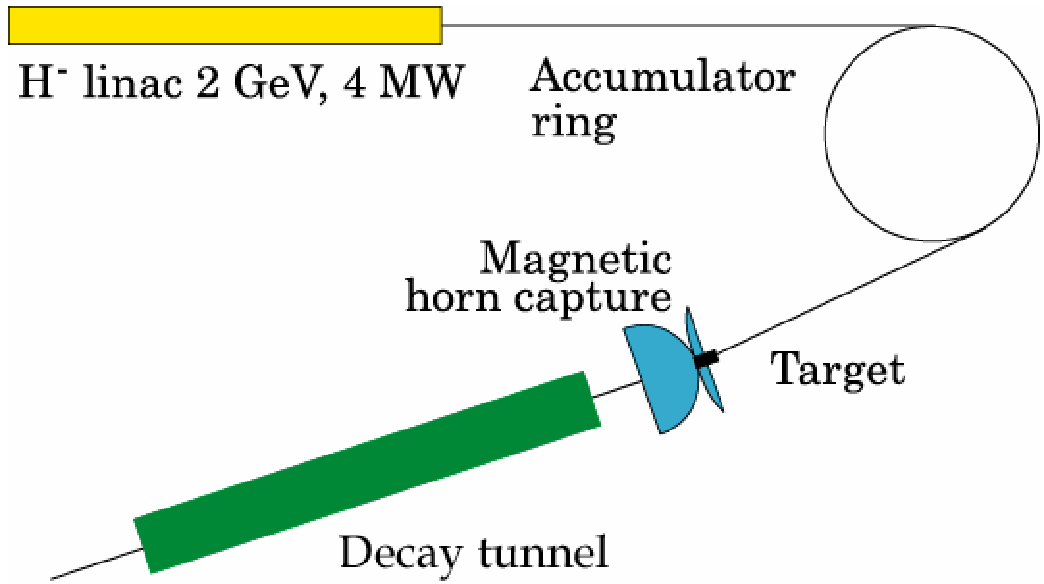


A possible layout of a Low Energy Neutrino Super Beam

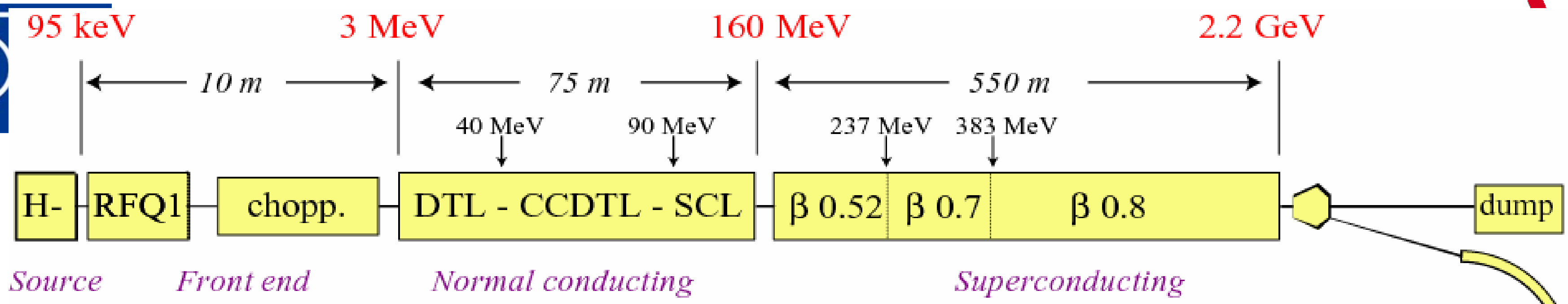

CERN
130km
ESA courtesy

SuperBeam parameters

- Proton beam
  - 2.2 GeV
  - 4 MW
  - 50 Hz rep. rate
- Accumulator ring
- Mercury target
- Horn focusing
  - First horn 300 kA
  - Reflector 600 kA

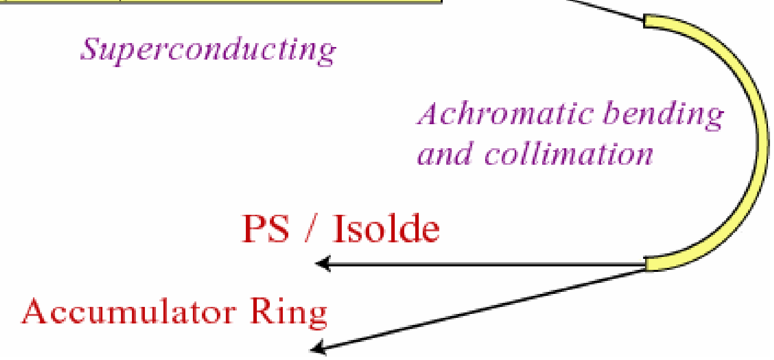


- Low energy pion beam: ≈ 500 MeV
  - proton energy below kaon threshold
  - Short decay channel < 100 m
- Low energy neutrino beam: ≈ 250 MeV



SPL @ 2.2 GeV

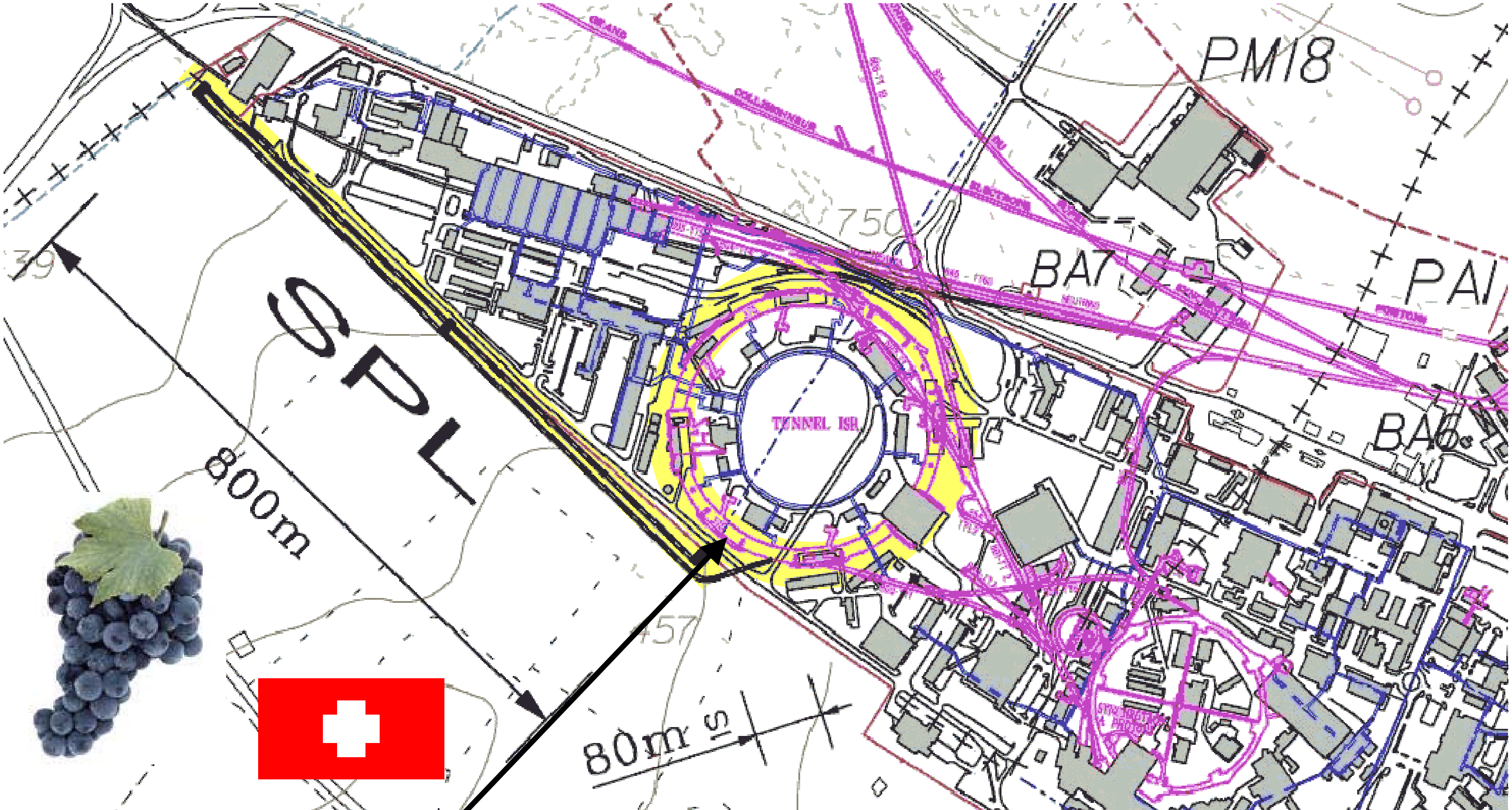
Superconducting Proton Linac



- High Power
  - LINAC @ 4 MW
  - Rep. Rate 50 Hz
  - 2.27 10^{14} p/pulse (1.2 ms burst with 352 MHz bunching & 44 MHz time structure)
- SPL followed by an accumulator ring to reduce the pulse length

- SPL needed for LHC luminosity upgrade and next generation radio-active ion beam facility in Europe (EURISOL)
- 160 MeV linac ("Linac 4") justified as new PSB injector for LHC (ultimate luminosity and beyond) and ISOLDE (higher flux)
- 3 MeV pre-injector: approved (see Garoby talk yesterday)

Proposed site



Old ISR tunnel, site of accumulator
Radius = 150 m

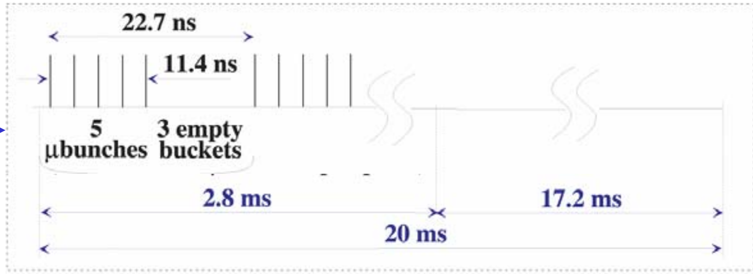
Accumulator and Compressor

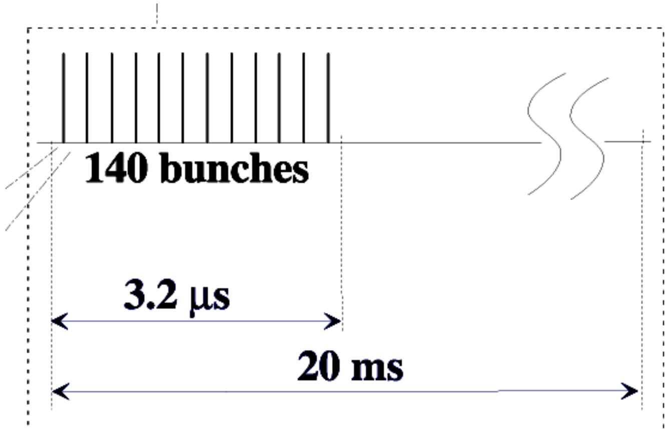
- Accumulator
  - *Macro*bunch with internal 23 ns structure (44 MHz)
  - *Macro*bunch Rep. rate: 20 ms (50 Hz)
  - The energy remain fixed to the LINAC energy: 2.2 GeV
  - Necessary to reject atmospheric background with timing

- Compressor
  - *Micro*bunch length reduction from 3.5 ns to 1 ns
  - This is not required for the Superbeam

Why the accumulator?

Beam from SPL





Beam from Accumulator

Atmospheric background: 100 evt/kton/y

Detector (40 kton per 5 y): Atmospheric 20000 evts
Superbeam ~ 10 evts

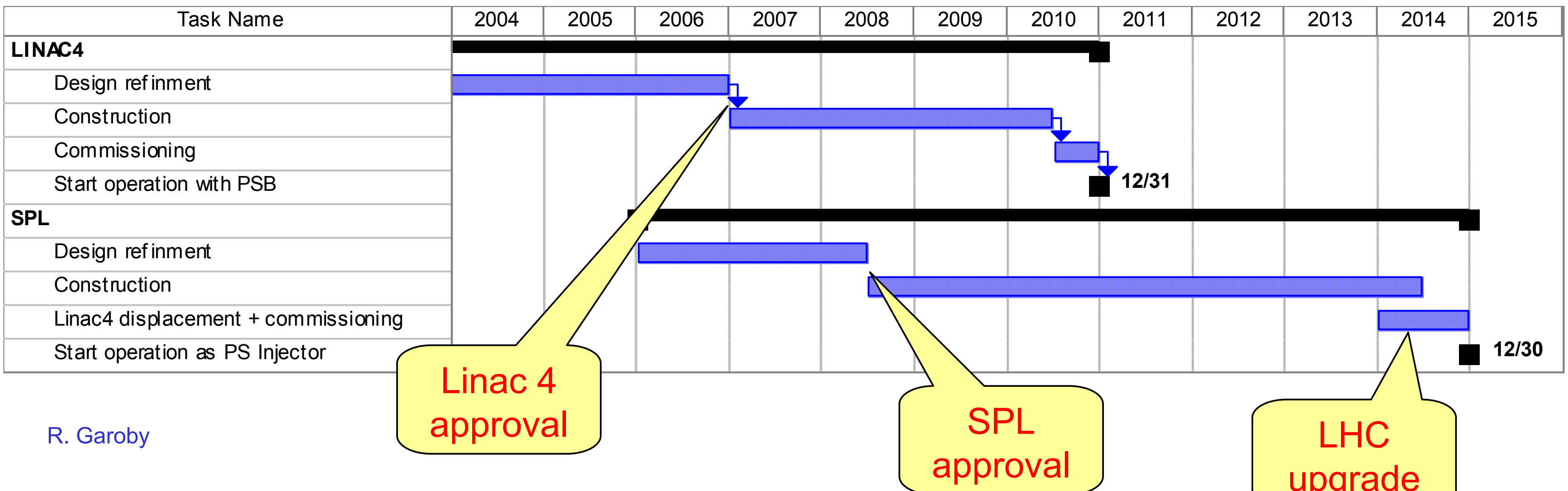
From the SPL: 20 ms/2.8 ms $\approx$ 17
From the accumulator: 20 ms/3.2 μs $\approx$ 6250

SPL Proposed Roadmap

Consistent with the content of a talk by L. Maiani at the "Celebration of the Discovery of the W and Z bosons". Contribution to a document to be submitted to the December Council *("CERN Future Projects and Associated R&D").*

Assumptions:

- construction of Linac4 in 2007/10 *(with complementary resources, before end of LHC payment)*
- construction of SPL in 2008/15 *(after end of LHC payments)*



R. Garoby

Warning: Compressor ring and detector (8 years) are not quoted

Protons from the SPL ready in 2015

Target SuperBeam/Nufact

- Target:
  - Mercury: Z = 80 $\rightarrow$ short target
    Liquid $\rightarrow$ easy to replace
    ($v_{//} \approx$ 20 m/s)
  - Dimensions: L $\approx$ 30 cm, R $\approx$ 1 cm

$\rightarrow$ 4 MW of proton into more or less a pint of beer

4 MW

=

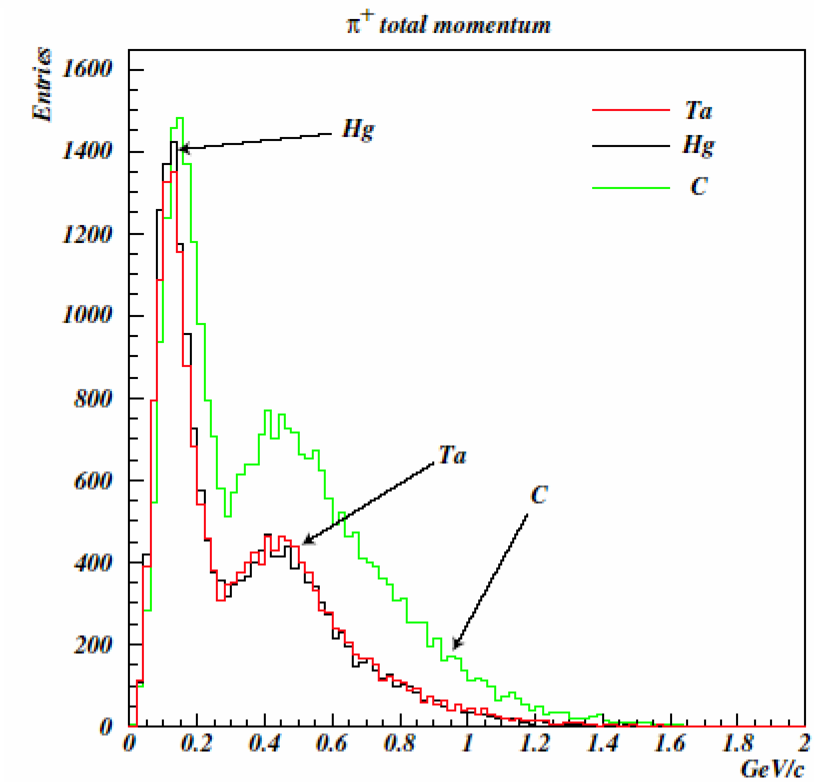
40000 $\times$

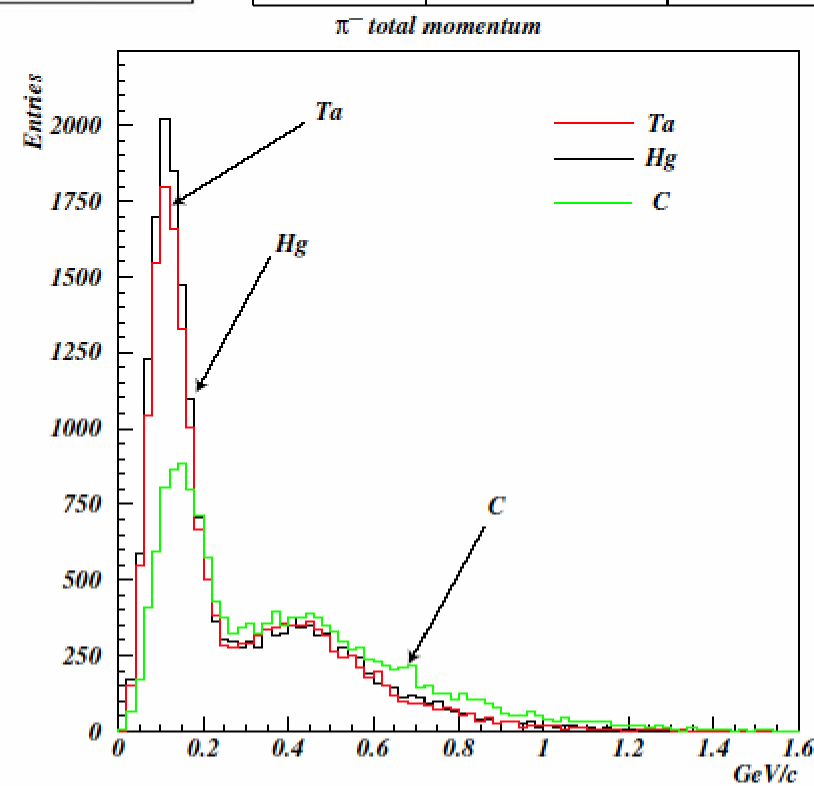
Pion yield from 2.2 GeV

- Different material pion production simulated with MARS
- Obs: Carbon will not survive at 4 MW

Material	Z	A	Melting point (°K)	λ_I(cm)	density(g/cm^3)
C	6	12	3800	38.1	2.265
Ta	73	180	3290	10.4	16.650
Hg	80	200	628	13.0	13.570

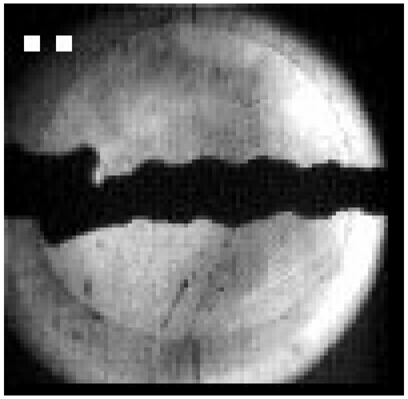
Material	π^+ per p.o.t.	π^- per p.o.t.
C	0.30	0.153
Ta	0.183	0.174
Hg	0.185	0.186



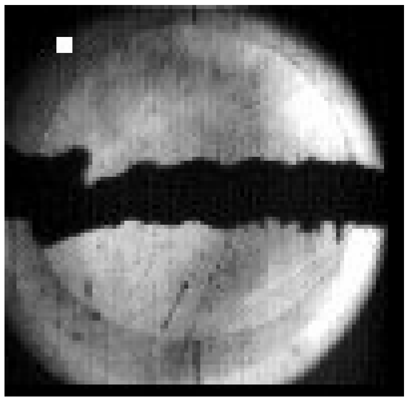


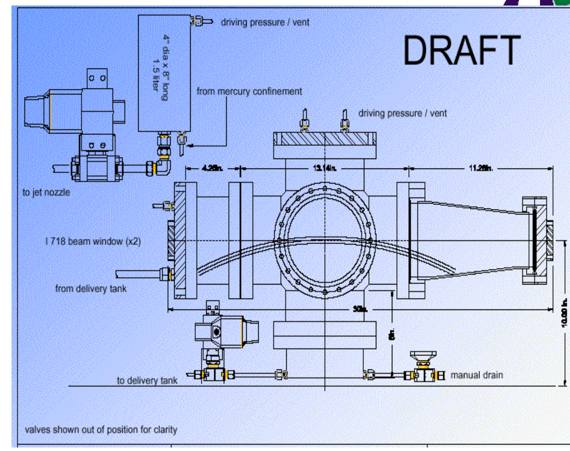
Hg Jet test a BNL E-951

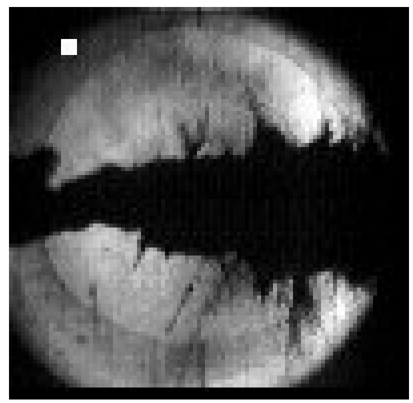
Event #11   25th April 2001

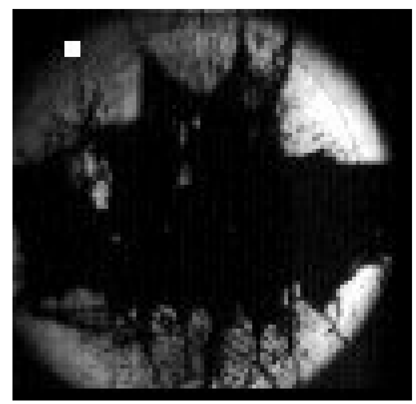


Protons ←









Picture timing [ms]
0.00
0.75
4.50
13.00

P-bunch: 2.7×10^{12} ppb
100 ns
t_o = ~ 0.45 ms

Hg- jet : diameter 1.2 cm
jet-velocity 2.5 m/s
perp. velocity ~ 5 m/s

K. Mc Donald, H. Kirk, A. Fabich

Proposed experiment @ CERN

- Target Experiment proposed at TT2A @ CERN for proof-of-principle test of a liquid jet target for high power proton beams

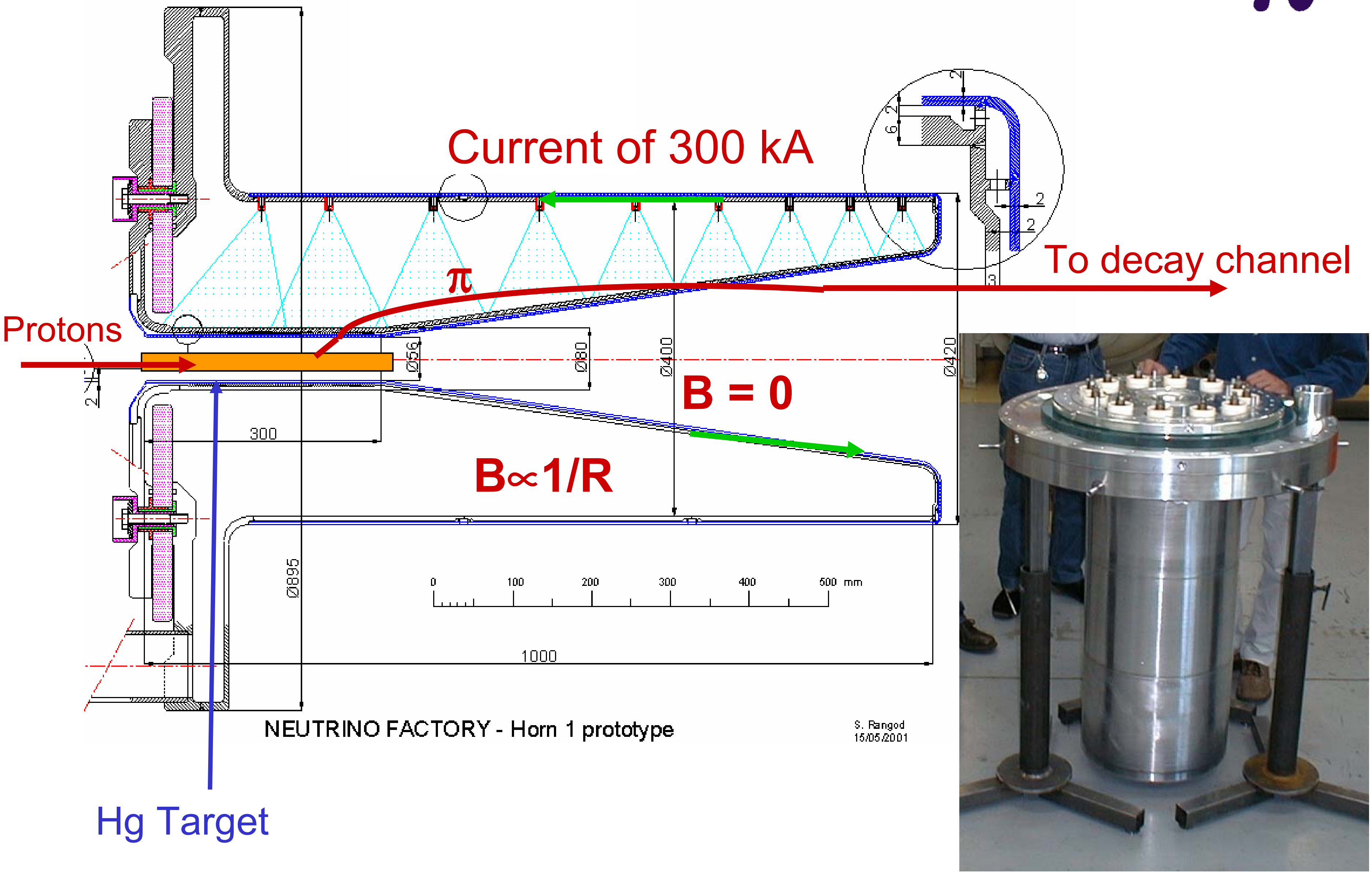
- Completion of the target R&D for final design of the Hg-Jet

	ISOLDE	GHMFL	BNL	TT2A	SuperB/NuFact
p+/pulse	$3\ 10^{13}$	----	$0.4\ 10^{13}$	$2.5\ 10^{13}$	$3\ 10^{13}$
B [T]	---	20	---	0 or 15	0 or 20 T
Hg target	static	15 m/s jet (d=4mm)	2 m/s jet	20 m/s jet	20 m/s jet (d=10mm)
	DONE	DONE	DONE	OPTION	DESIGN

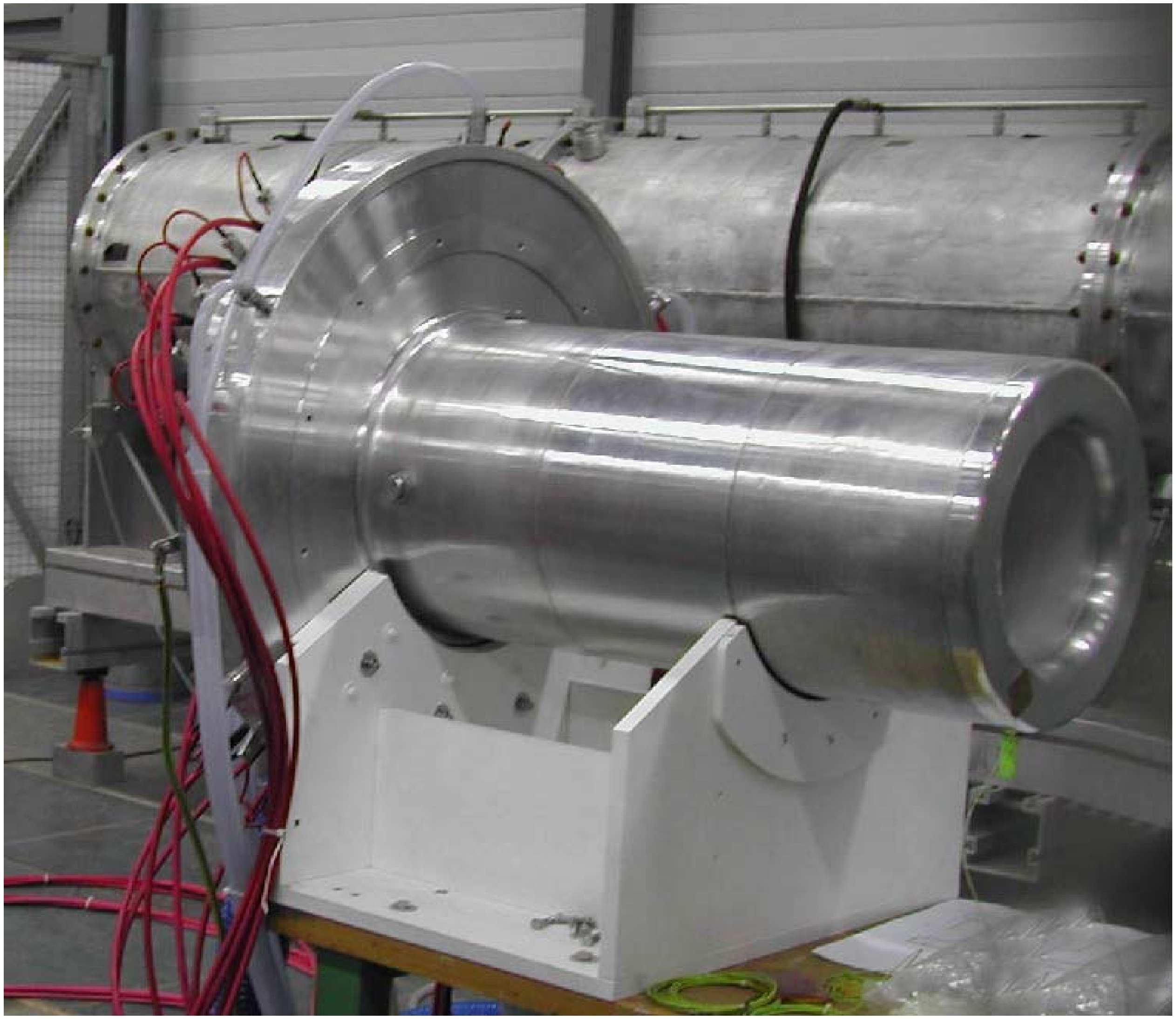
Experimental setup: 15 T solenoid + Mercury Jet + PS beam

IMPORTANT: This experiment with the SOLENOID OFF is fundamental to understand jet disruption in the HORN neck

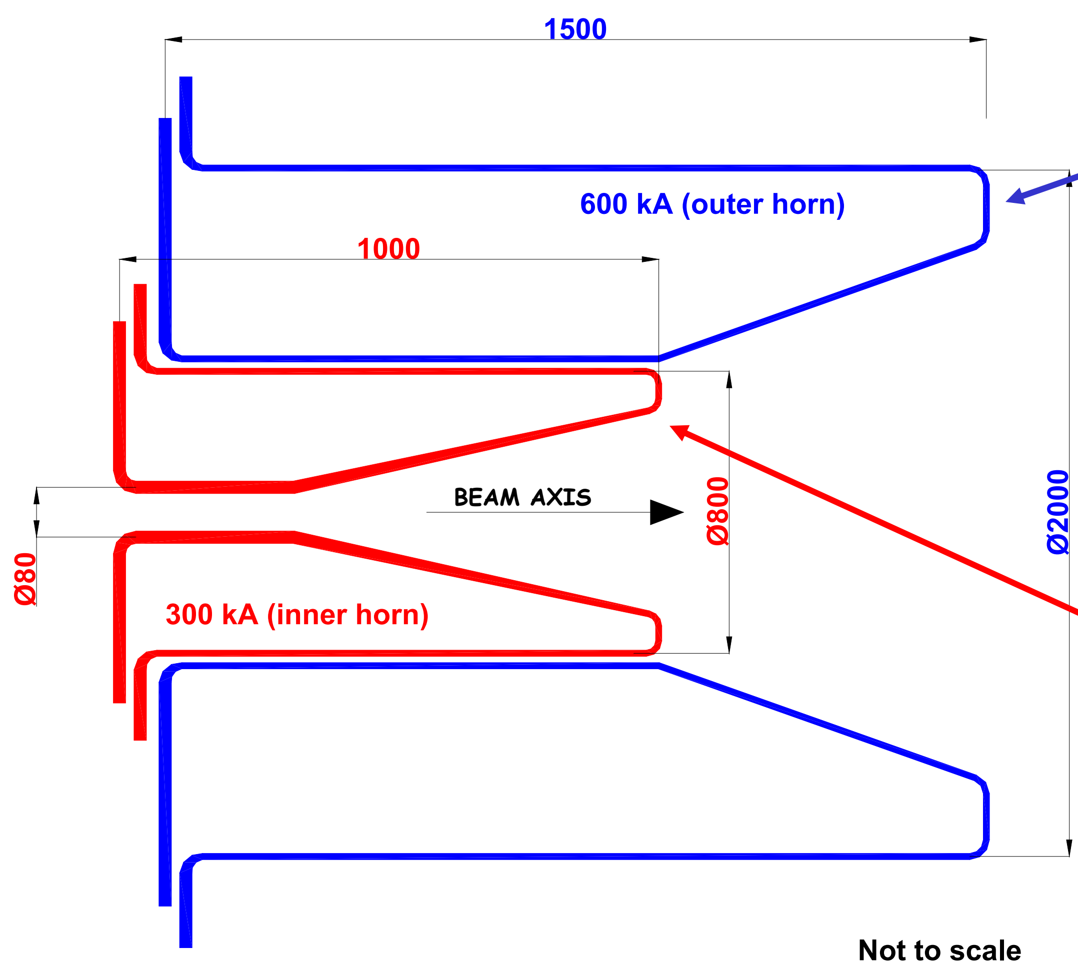
Magnetic horn



Horn prototype @ CERN



Horn typical design



Outer horn
Reflector like
Optimized for
SuperBeam

Inner horn
Same as Nufact

Horn design strategy

- Useful pions:
  - $E_k = 500$ MeV
  - Max Neutrino Energy ≈ 270 MeV
  - Max point-to-parallel production angle
    - I = 300 kA ⇒ θ_{max}= 12 degrees
    - I = 600 kA ⇒ θ_{max}= 17 degrees

- Geometrical constraints:
  - Nothing in front of the primary proton halo
  - Nothing along the mercury direction
  - Maximum energy stored in the magnetic volume

Decay tunnel

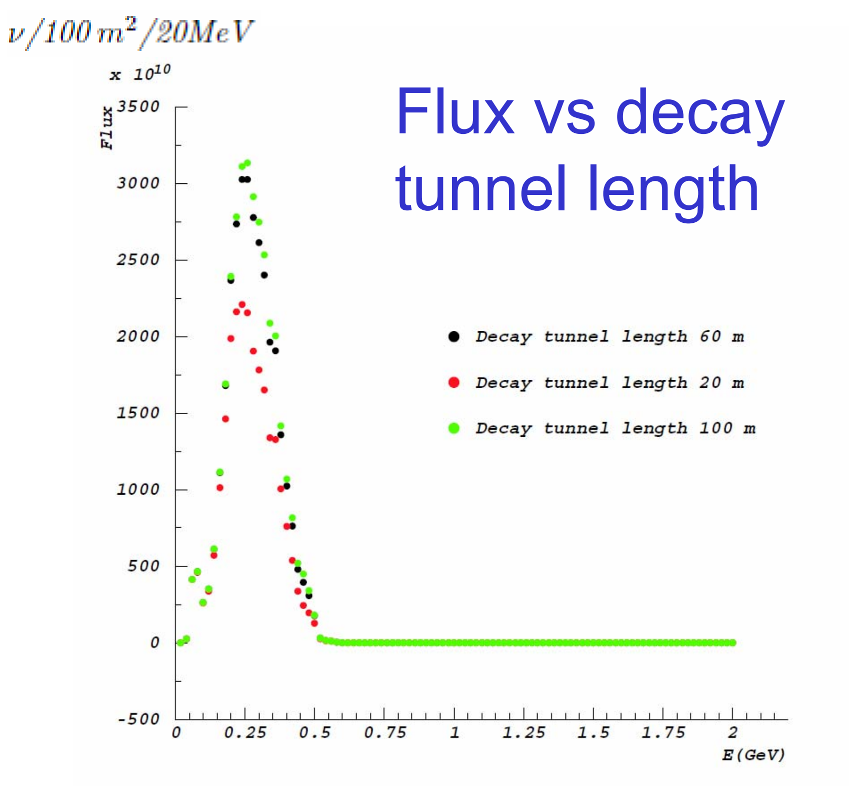
- Decay channel used to control the beam related background
  - muon decay
  - wrong sign pions
- Length of typical 20 to 100 m since low energy pions
- Radius of 1 or 2 m tuned to cut the beam background
- Studies about activation of shielding/earth around decay channel already published using CNGS experience
  - Is it possible to have a 4 MW target station in the CERN area? YES

Neutrino beam optimization

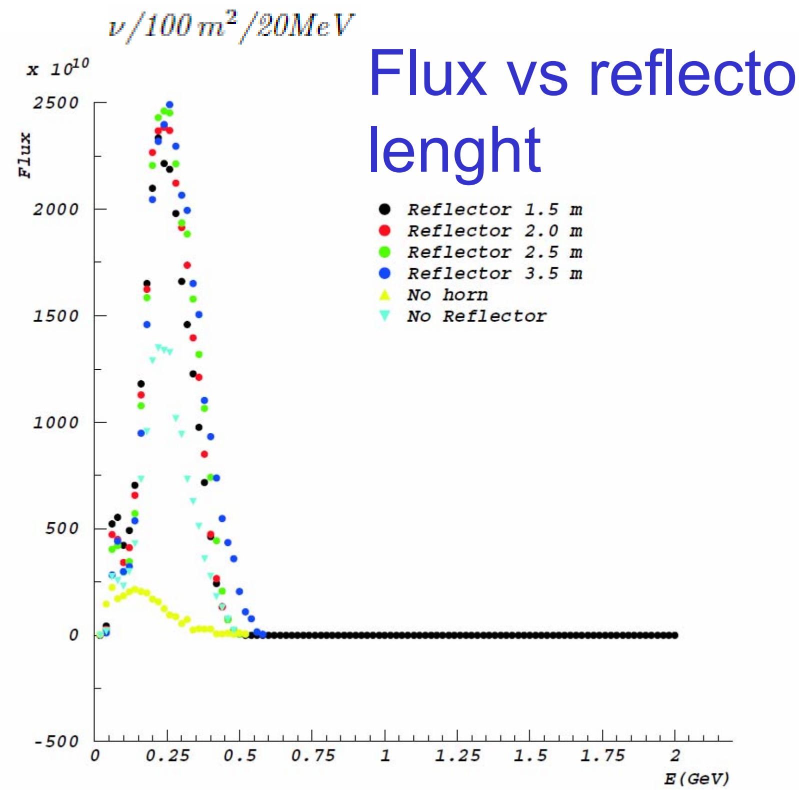
Flux computed by:

MARS for particle production+HORN
Nubeam standalone program (M. Donega)

Flux vs decay tunnel length



Flux vs reflector lenght



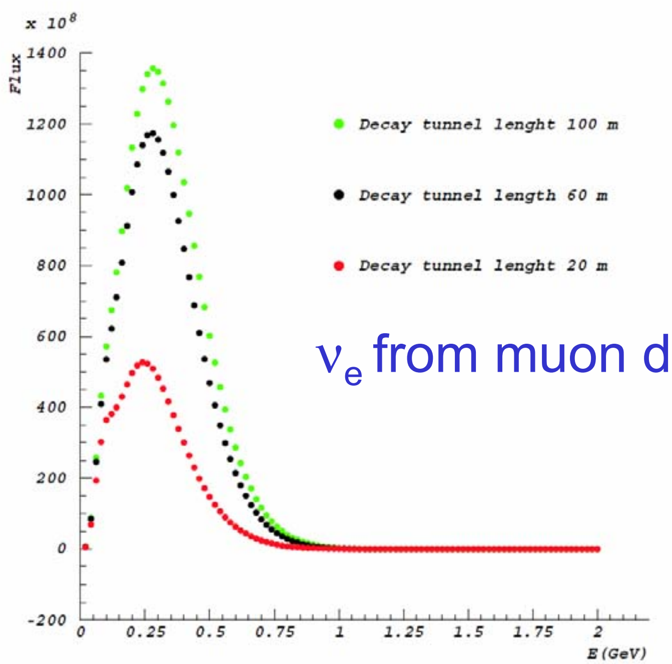
Chosen conditions

Maximum neutrino flux $\rightarrow$ longer decay channel

Beam background sources:

1. ν_e from muon decay $\rightarrow$ controlled with decay tunnel geometry
   Typical content 0.004 at peak

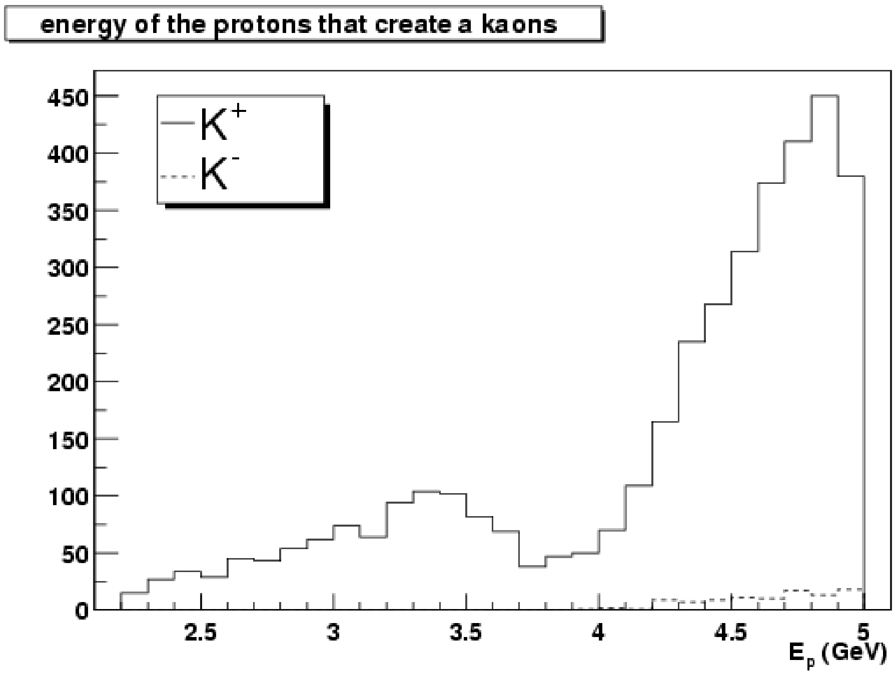
2. ν_e from kaon decay $\rightarrow$ kaon production not too relevant, low energy proton

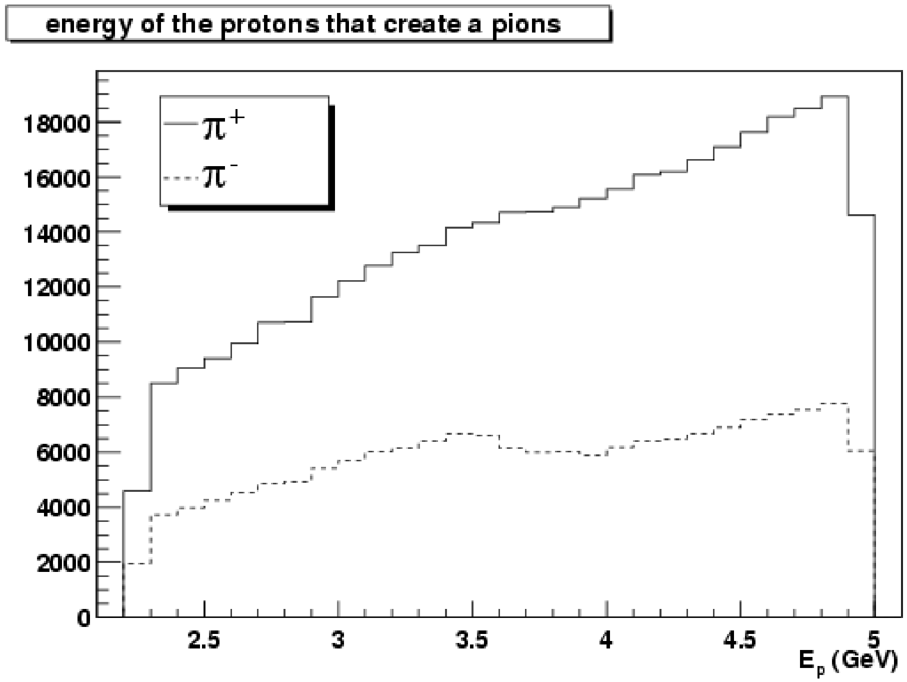


ν_e from muon decay

Kaon Contamination

Number for 500 000 pot

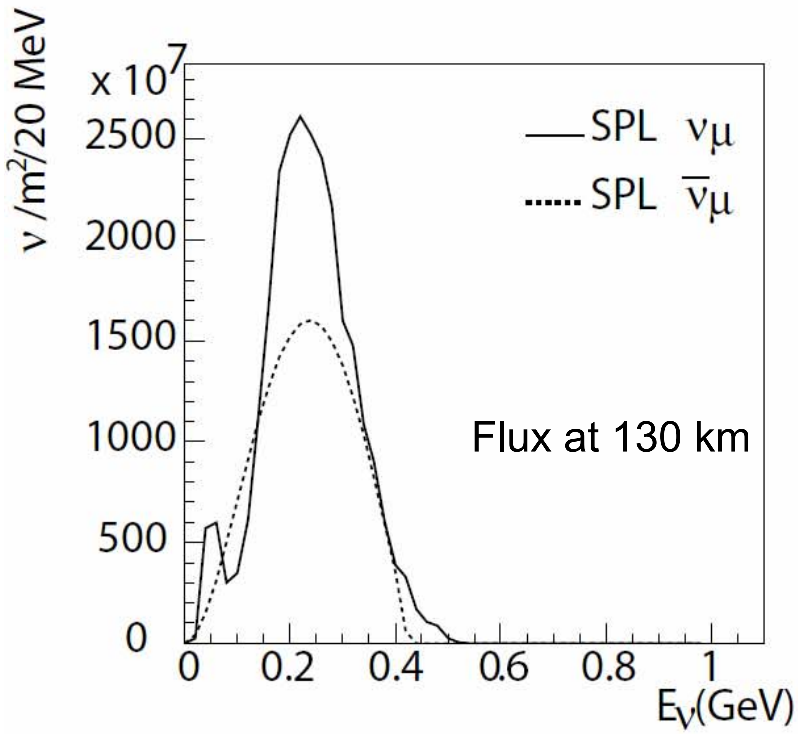


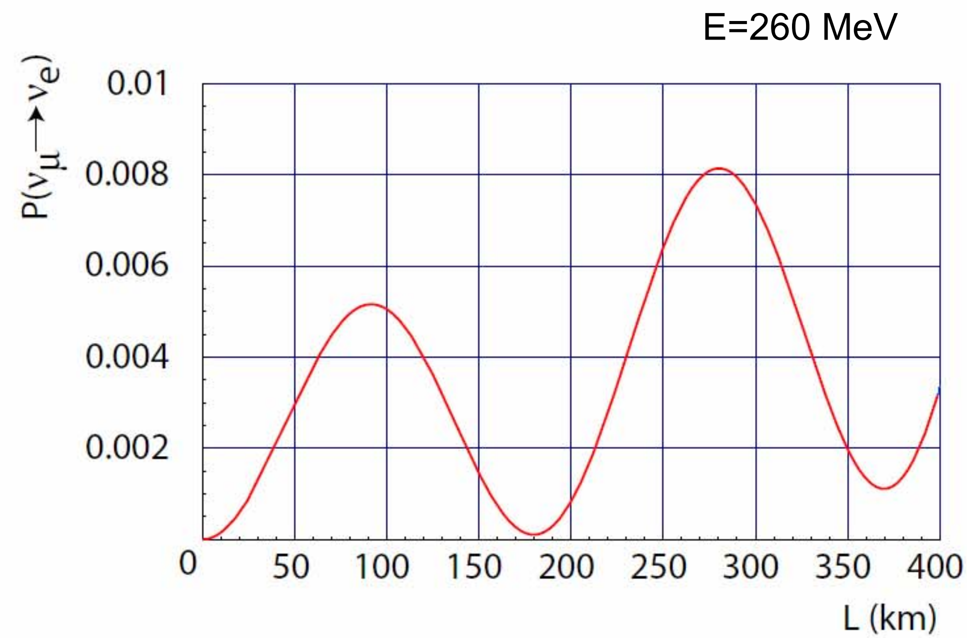


- Two production processes (origin to be investigated in MC-Fluka)
- Anyway below 4 GeV, K^+ production < 300 times the π^+ production.
- neutrino production associated to K^+ seems to be negligible at 2.2 GeV

A. Cazes - LAL

Superbeam flux





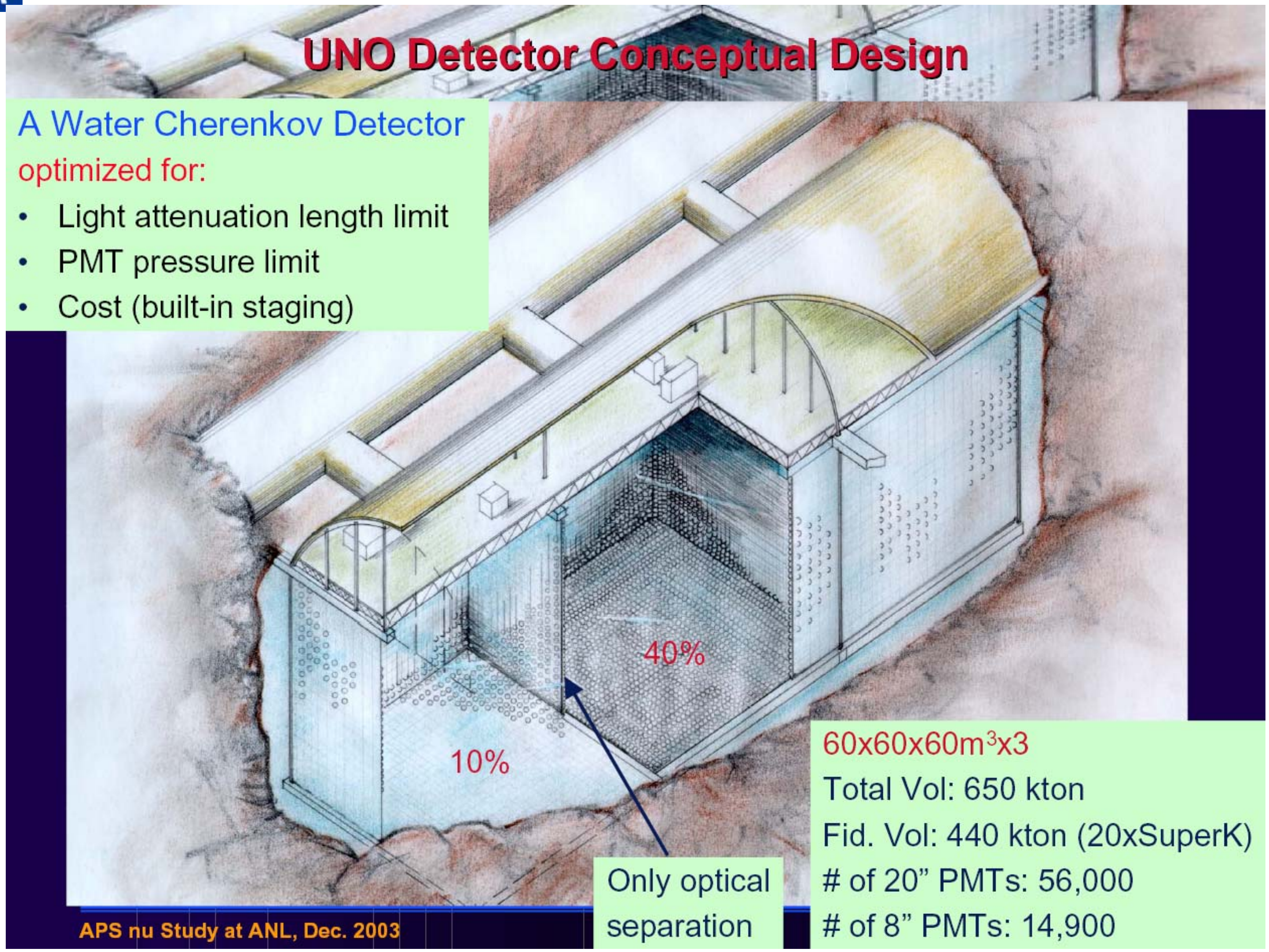
	ν_μ	$\bar{\nu}_\mu$
Neutrino flux ($\nu/\mathrm{m}^2/\mathrm{yr}$)	4.78 10^{11}	3.33 10^{11}
Neutrino average Energy	0.27 GeV	0.25 GeV
CC events	36698 (2 yrs)	23320 (8 yrs)
Oscillated	1279	774

$$\theta_{12} = 31.7^\circ \qquad \Delta m^2_{12} = 7\,10^{-5}\,eV^2$$
$$\theta_{23} = 45^\circ \qquad \Delta m^2_{23} = 2.5\,10^{-3}\,eV^2$$
$$\theta_{13} = 10^\circ$$

2 years of π^+ 8 years of π^-

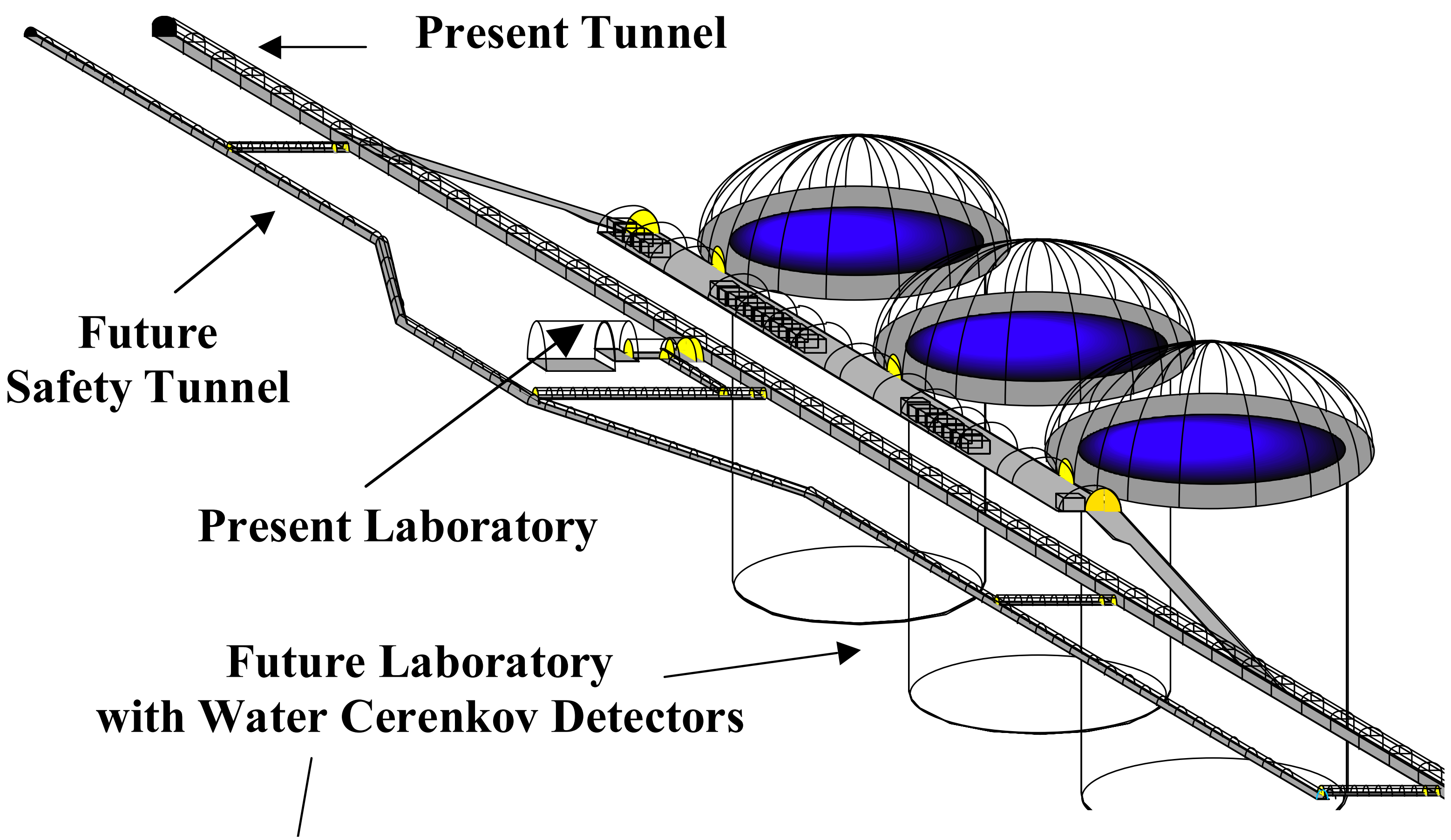
M. Mezzetto, NuFact 03

UNO-like detector



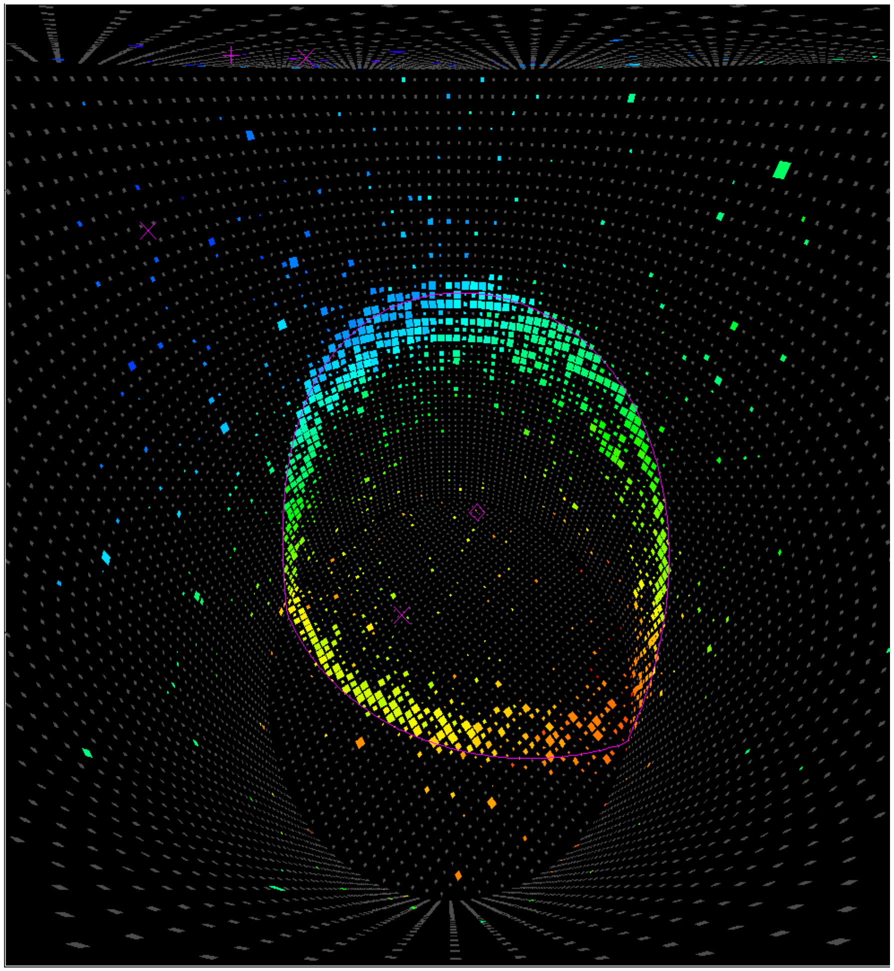
Obs: SuperBeam as a "customer" of a multipurpose detector

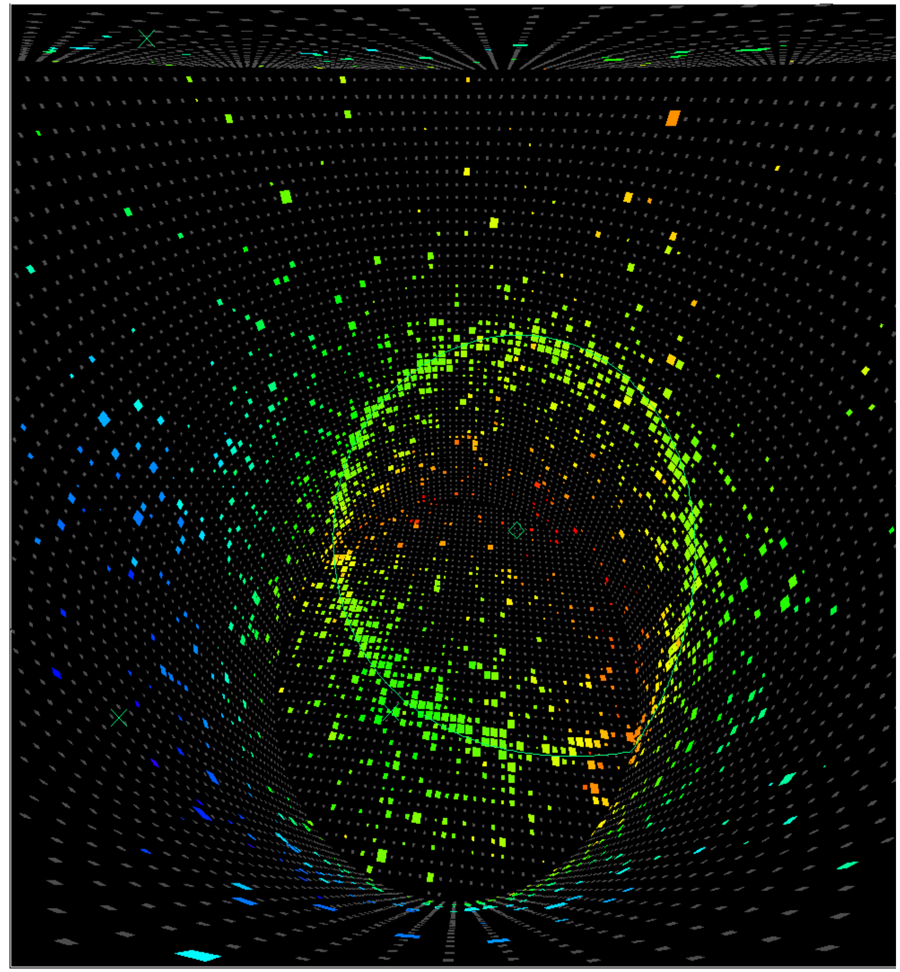
Frejus lab/tunnel location



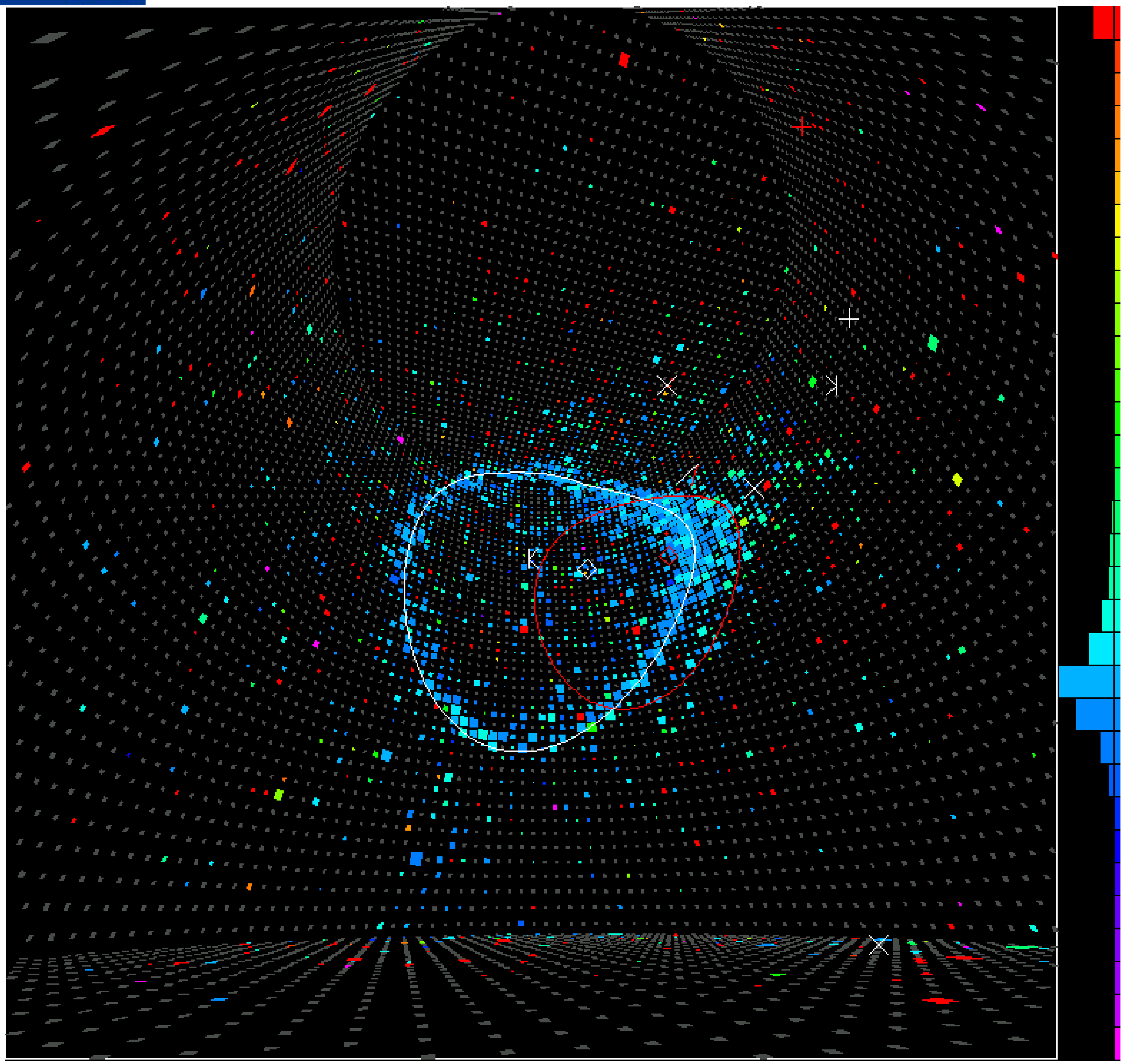
See Mosca talk

μ/e Background Rejection

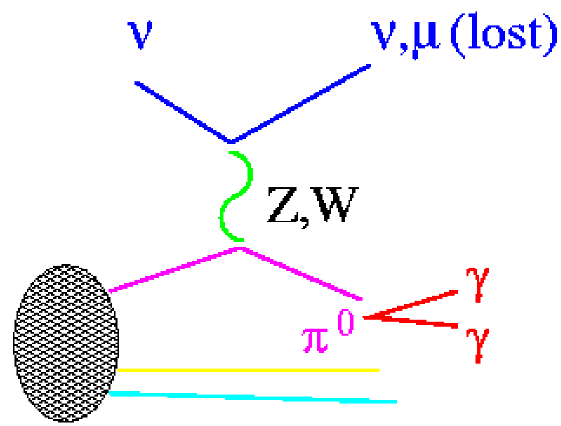




π^0 event from K2K



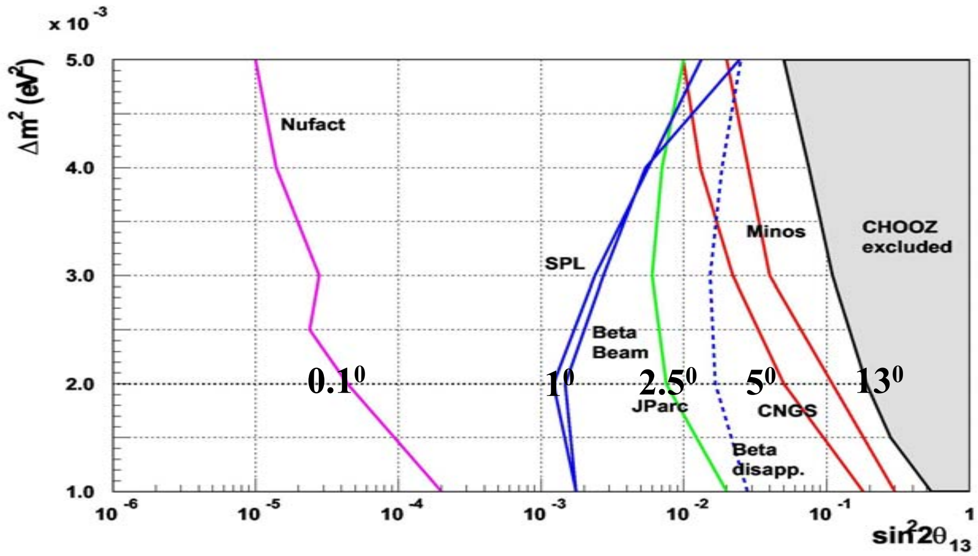
Two rings similar to ν_e events due to small two ring separation



π^0 production suppressed because of low energy neutrinos

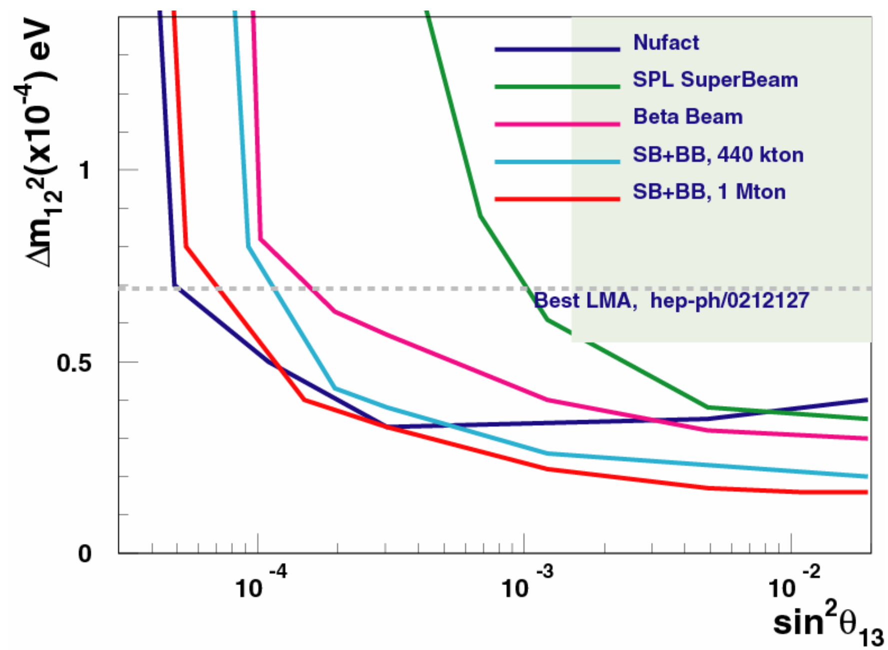
Not the case for J-PARC

Superbeam results



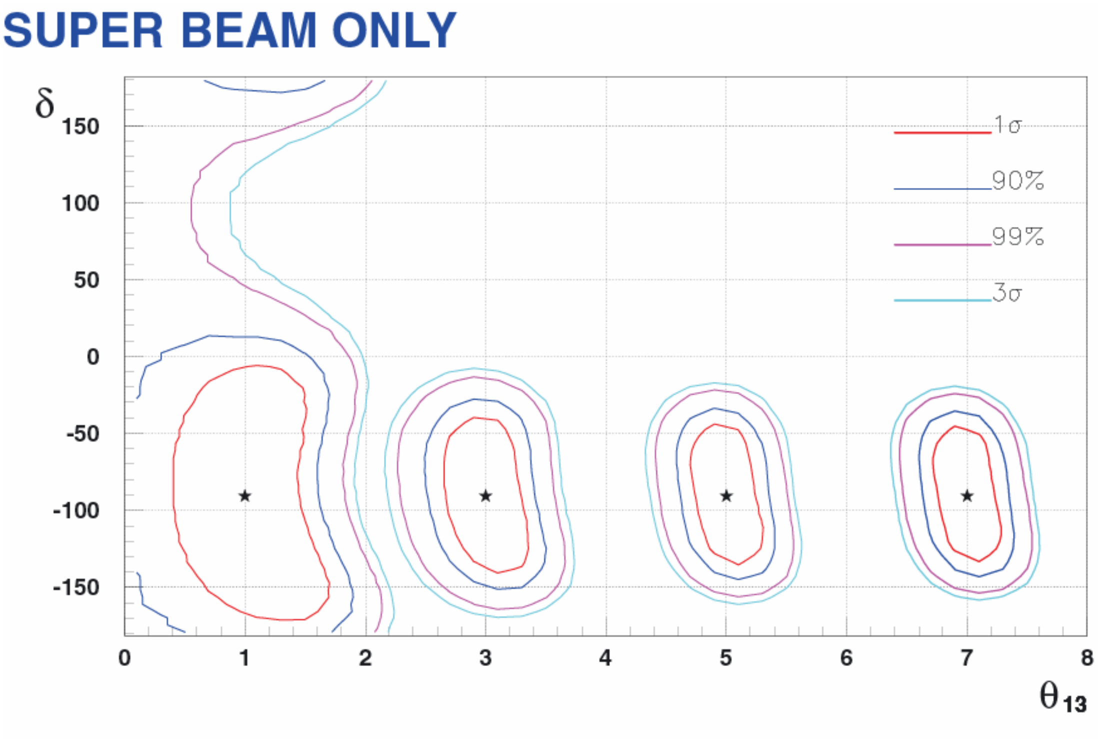
The CERN Superbeam would be able to measure θ_{13} down to ~1°

The CERN Superbeam can approach the measurement of the CP violation



From M. Mezzetto

CP violation

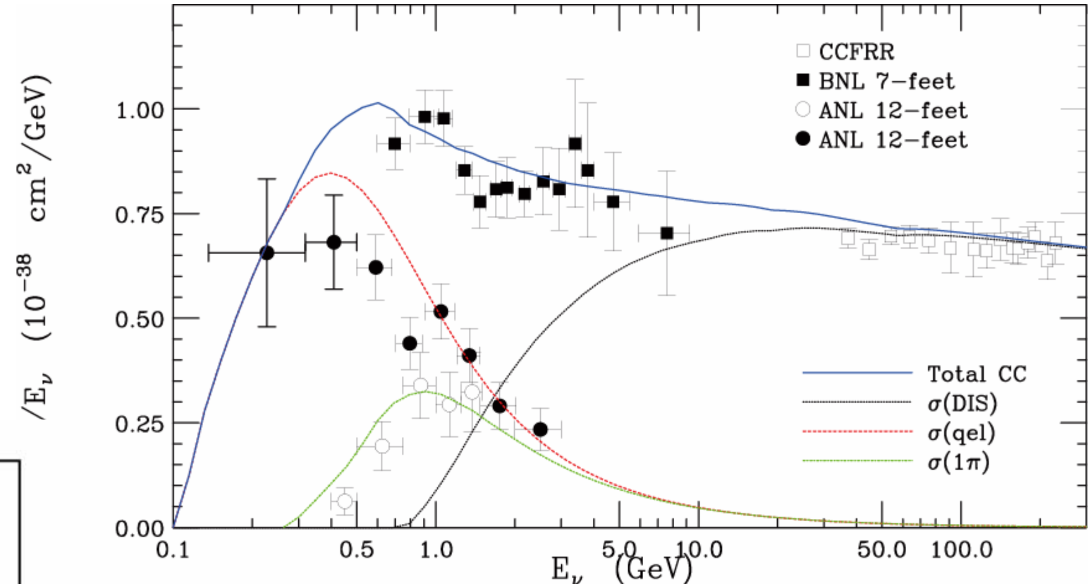


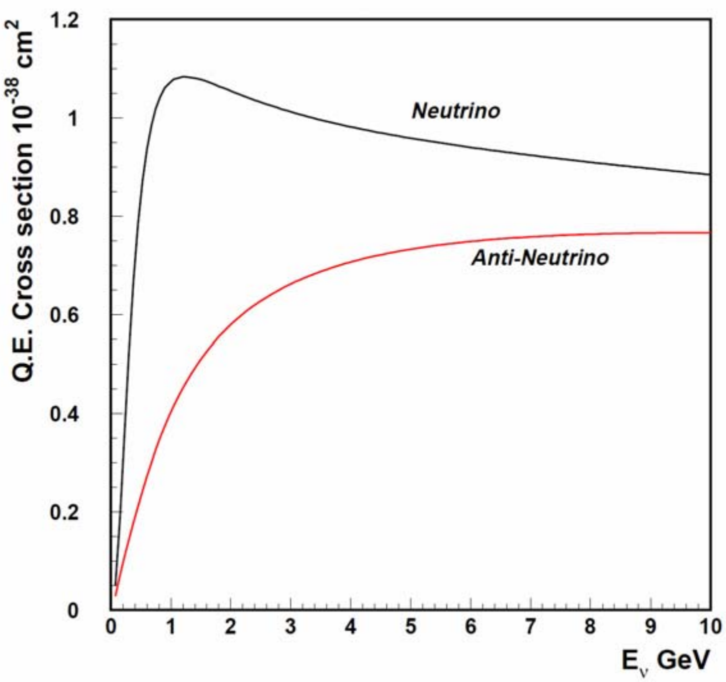
CP violation measurement limited by the antineutrinos and the difference of the cross section at this energies where Q-E interaction dominates

Neutrino Interaction

Neutrino Cross section interaction

From Lipari





- Low energy is a limitation for antineutrinos
- Ratio of cross section is approx 5

$\rightarrow$ Trying to increase a bit neutrino energy

SPL SuperBeam FAQ

Q: Why 2.2 GeV for the proton driver?

A: First design of the SPL which used the LEP cavities.

Q: What about increasing the proton energy ?

A: Possible up to 3.5 GeV- 4 GeV with some caveats. Energy optimization to tune the proton beam energy is in working stage (see next slides).

Q: Is the SPL SuperBeam strongly connected with the Frejus?

A: Yes, due to low energy of proton beam no way to go further than 130 km.

Q: What if instead of a Cherenkov detector one wants to use a Liquid Argon TPC ?

A: Possible if the experts are interested in the location (meaning not going to Japan)

Q: Why proposing the SPL Superbeam if JHF will have similar results?

A1: Unique synergy with the Beta Beam

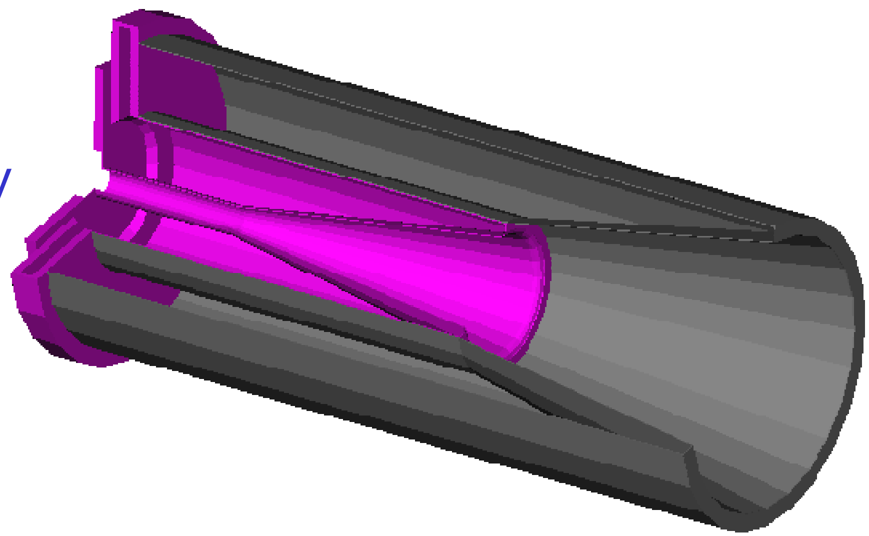
A2: Learned from the Japanese style of working, and also from CERN style, every step carries the know-how for the next step. The next could be a NuFact.

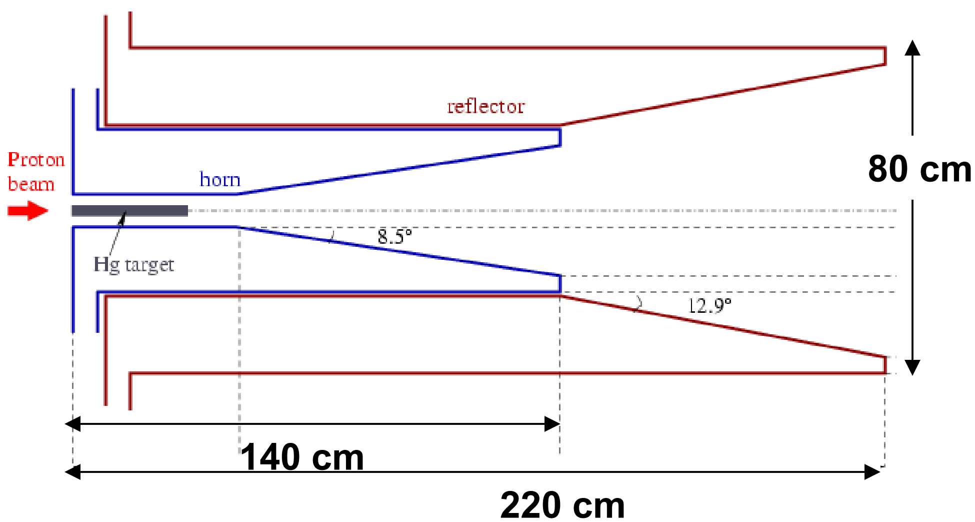
A3: Different condition to repeat the same measurement. In particular different background.

New study and optimisation

J.E. Campagne, A. Cazes   LAL, Orsay

- Horn shape optimisation for 260MeV or 350MeV neutrinos
- decay tunnel length and radius
  - 10m < L < 60m
  - 1m < R < 2m
- SPL energy optimisation
  - 2.2GeV, 3.5GeV, 4.5GeV → 8GeV



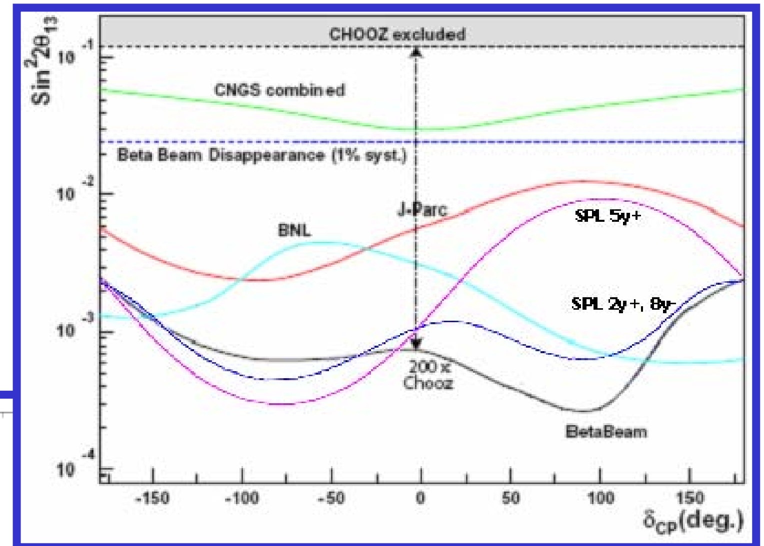


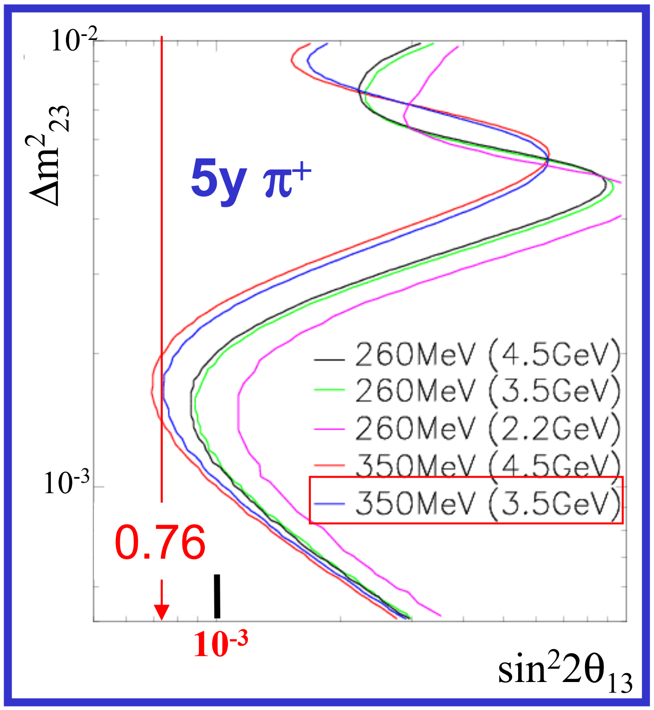
New simulation including kaons decays.

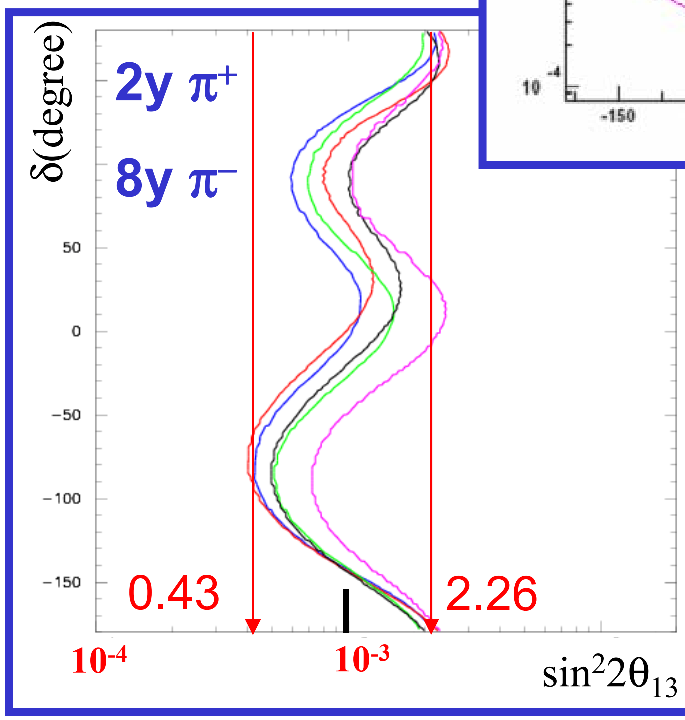
Target simulated with FLUKA

θ_{13} and δ_{CP} sensitivity

- Sensitivity computed thanks to Mauro Mezzetto's code.
- Best results for
  - SPL at 3.5GeV
  - Horn designed for 350MeV neutrinos
  - Decay tunnel : 40 m long, 2 m radius







440 kT, $\varepsilon_{syst} = 2\%$
130km from CERN

$\Delta m^2_{12} = 7.1\ 10^{-5}\ eV^2$, $\theta_{12} = 32°$
$\Delta m^2_{23} = 2.5\ 10^{-3}\ eV^2$, $\theta_{23} = 45°$

To be submited to Eur. Phys. J. C.

Conclusions

- The SPL SuperBeam would be the perfect user for a Megaton detector located in the Frejus tunnel

- The SPL SuperBeam can be very attractive to measure θ_{13} in different conditions (neutrino energy and beam contamination) than the T2K experiment

- The SPL SuperBeam + Beta Beam offer a unique opportunity for measuring CP and T violation

- Due to its design the SPL SuperBeam is the first step towards a CERN based-Neutrino Factory

Flux comparison with other experiment