CERN Superbeam(s)

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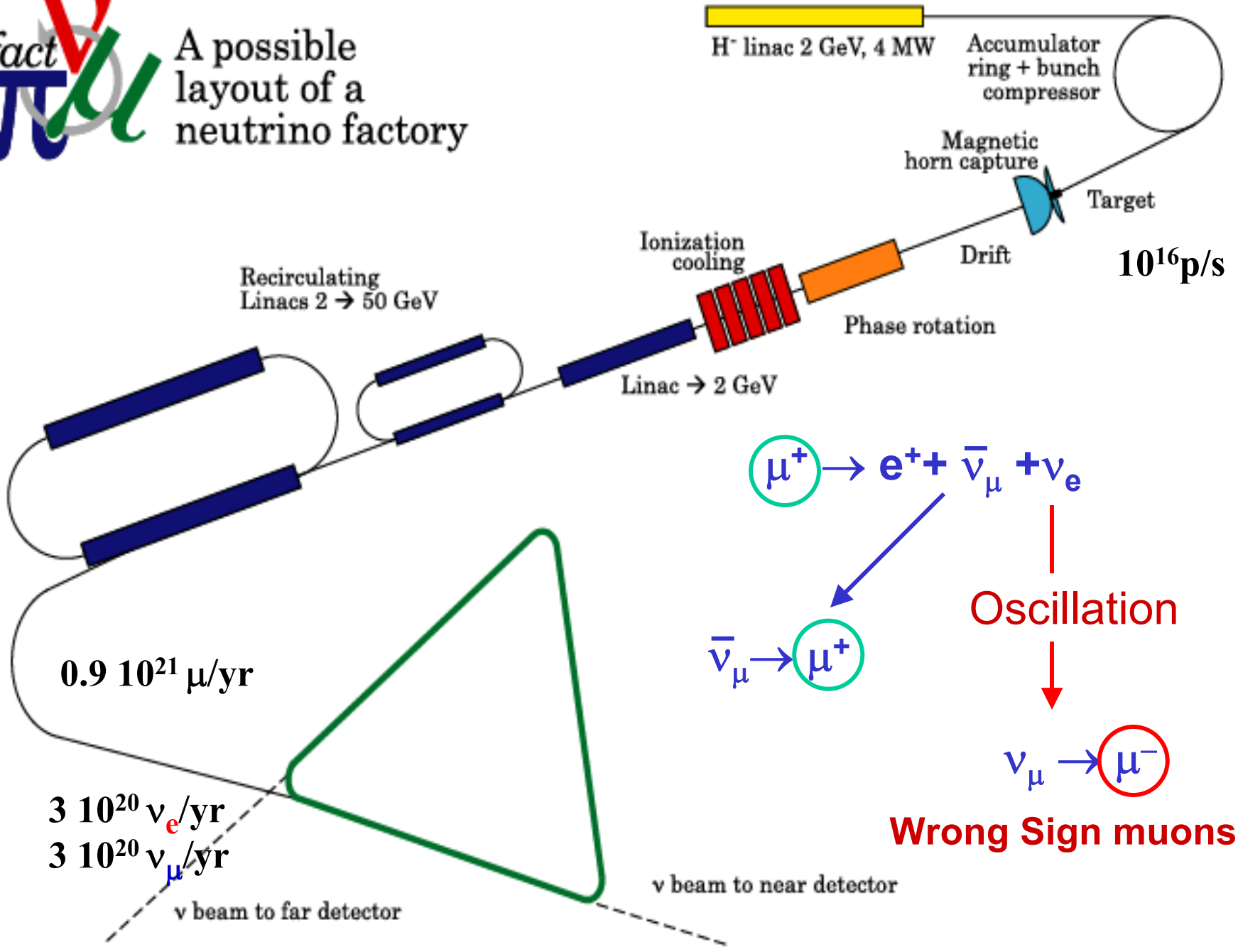
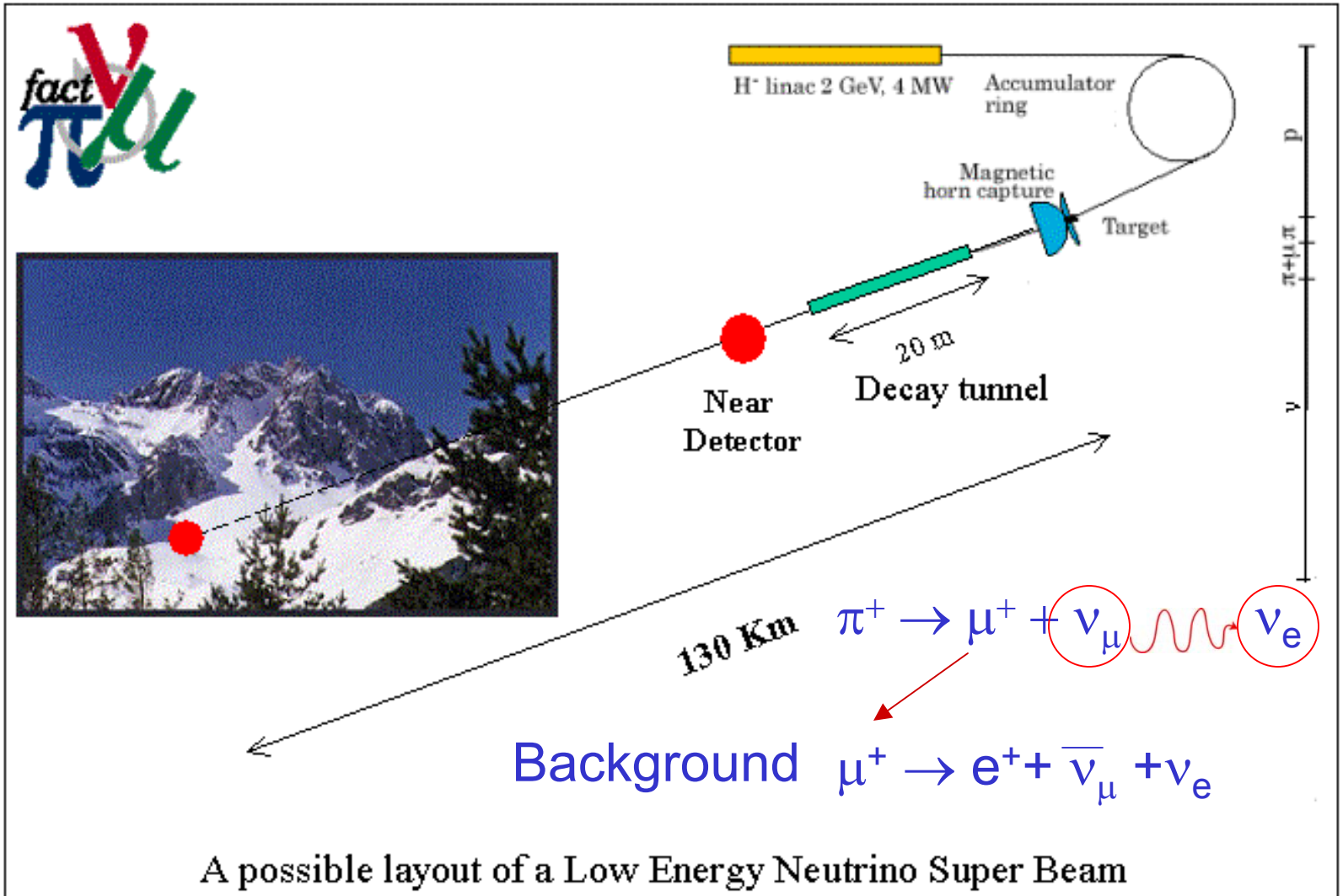
A possible layout of a neutrino factory



2000-06-16 • Peter Gruber, CERN-PS

Proposal for a CERN - Super Beam

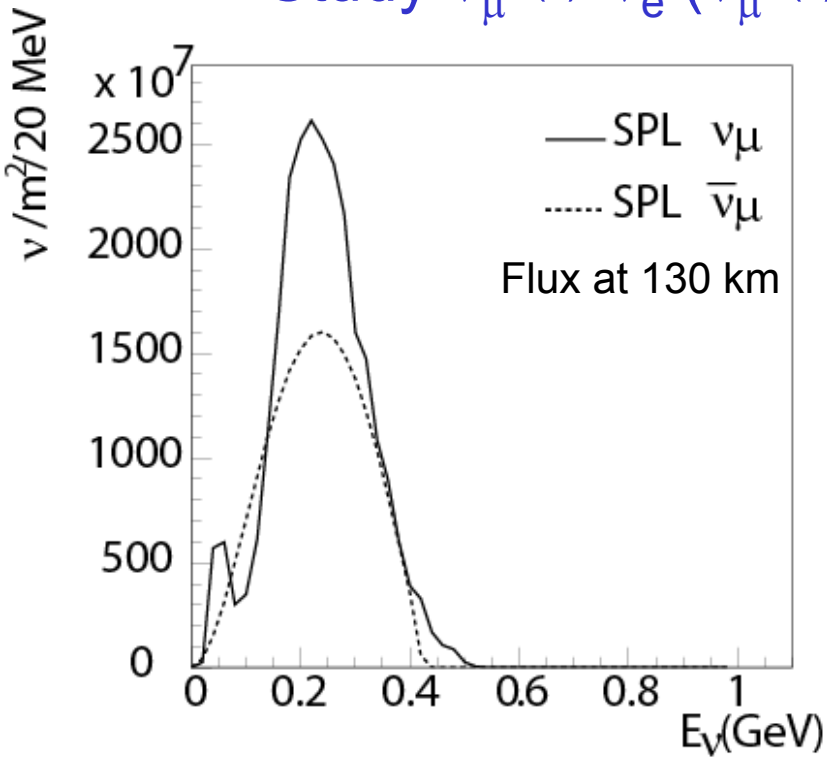


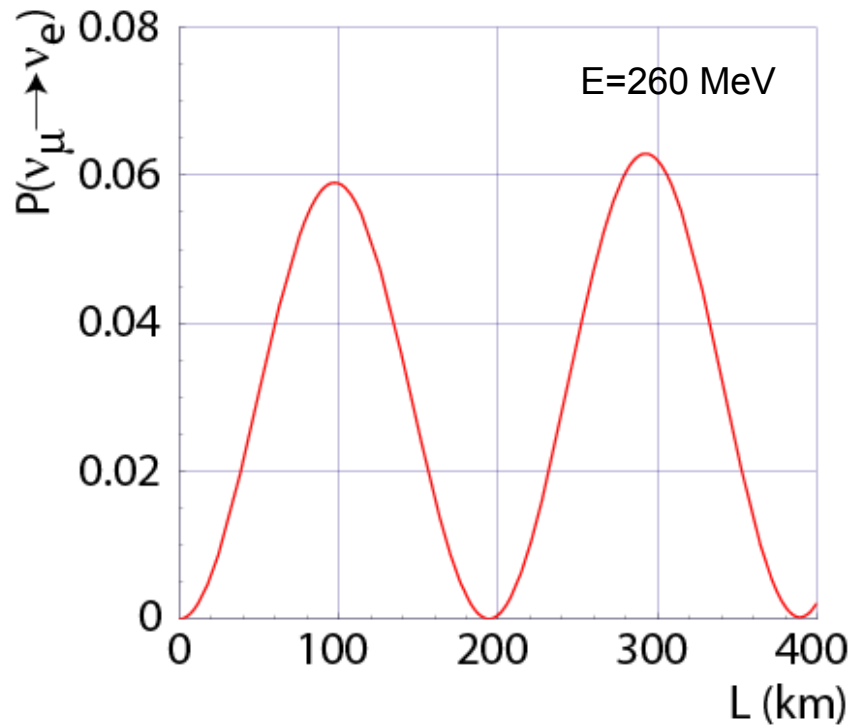
A possible layout of a Low Energy Neutrino Super Beam

Superbeam flux

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

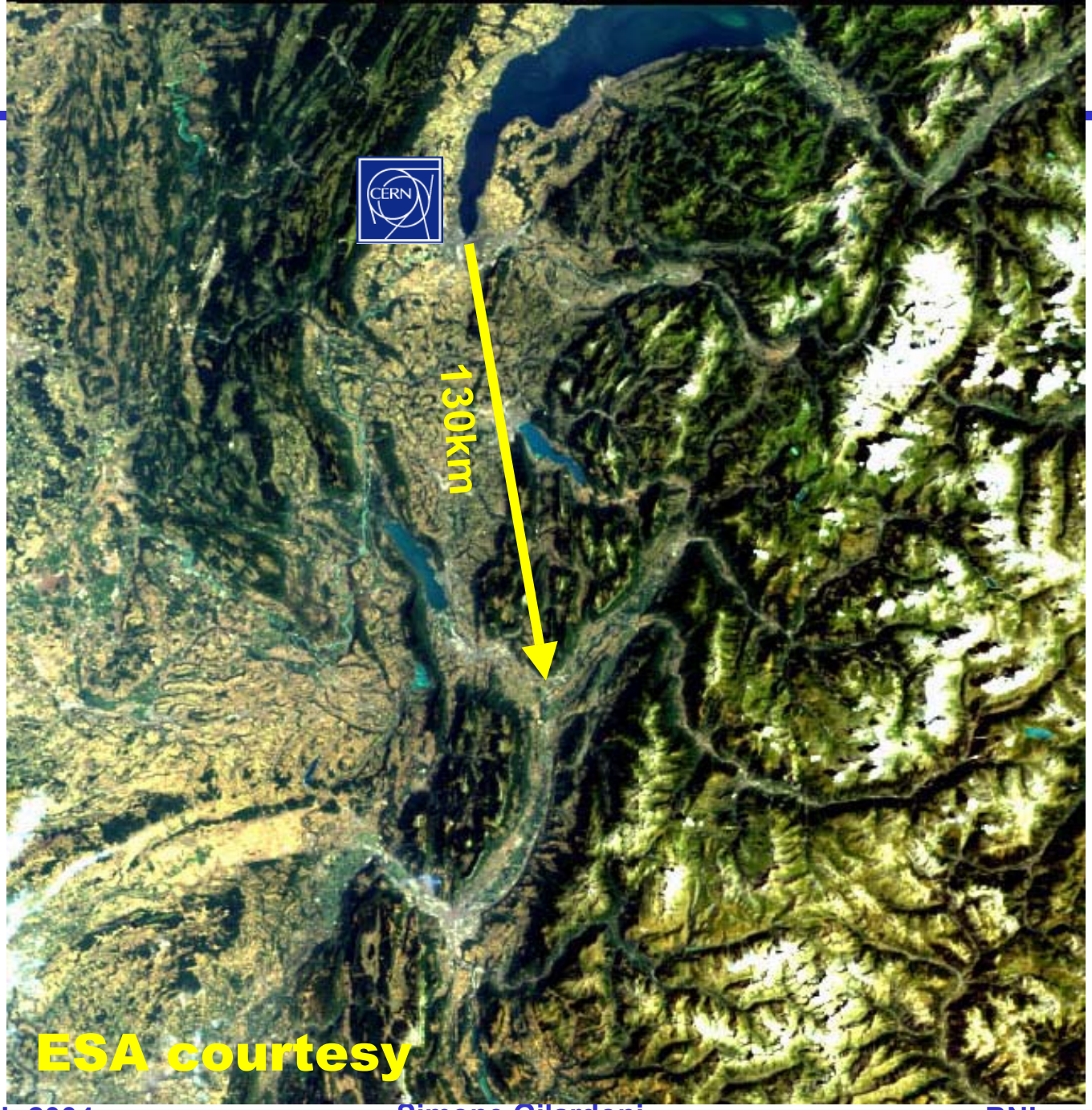
Study $\nu_\mu \leftrightarrow \nu_e$ ($\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$) oscillations at first maximum





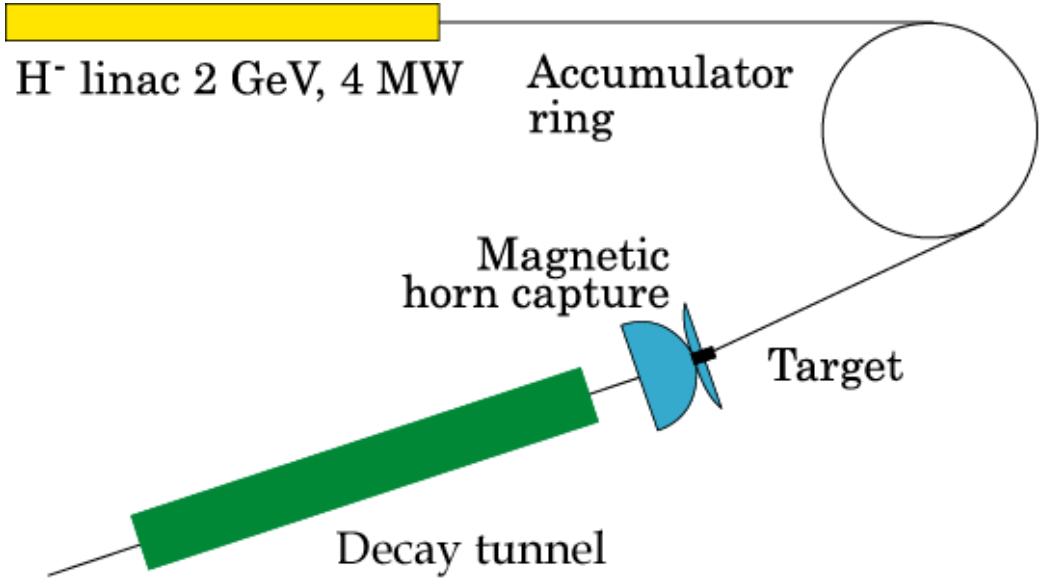
	ν_μ	$\bar{\nu}_\mu$
Neutrino flux ($\nu/\mathrm{m}^2/\mathrm{yr}$)	4.78 10^{11}	3.33 10^{11}
Neutrino average Energy	0.27 GeV	0.25 GeV
CC events	36698 (2 yrs)	23320 (8 yrs)
Oscillated	1279	774

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


CERN
130km
ESA courtesy

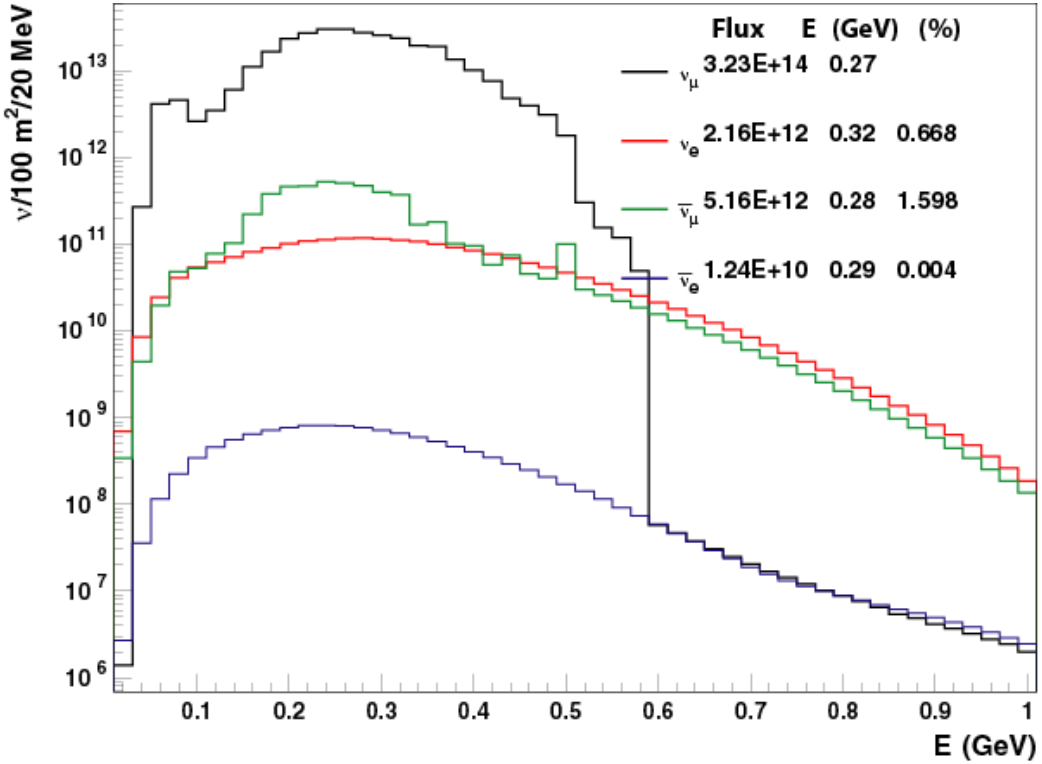
SuperBeam parameters

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



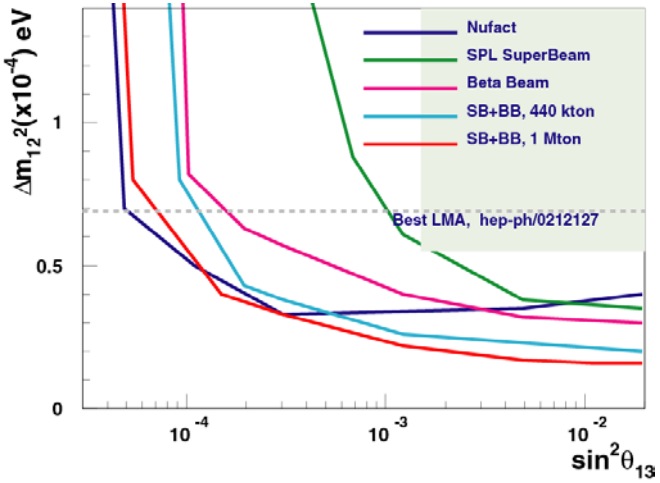
- Low energy pion beam: ≈ 500 MeV
  - proton energy below kaon threshold
  - Short decay channel < 100 m
- Low energy neutrino beam: ≈ 250 MeV

SPL neutrino beam



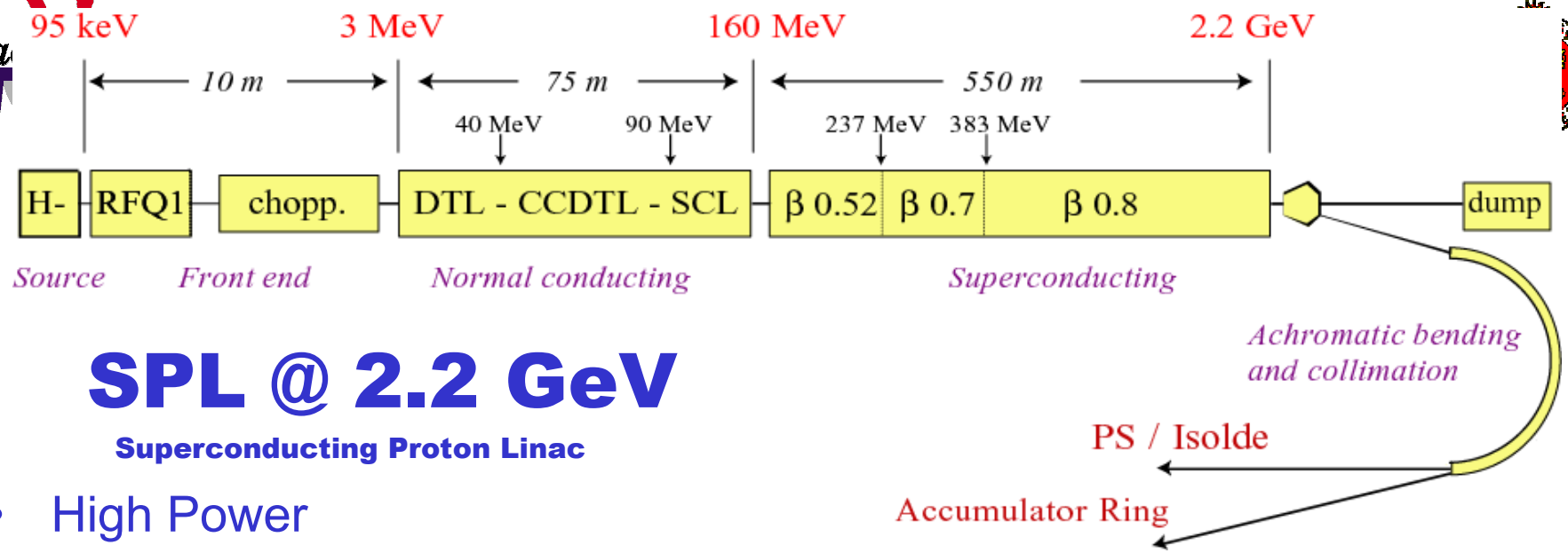
Flux intensities at 50 km from the target

Flavour	Absolute Flux (ν/ 10^{23}pot/ m^2)	Rel. Flux (%)	E (GeV)
ν_μ	$3.2 \cdot 10^{12}$	100	0.27
$\bar{\nu}_\mu$	$2.2 \cdot 10^{10}$	1.6	0.28
ν_e	$5.2 \cdot 10^{9}$	0.67	0.32
$\bar{\nu}_e$	$1.2 \cdot 10^{8}$	0.004	0.29



Flux computed by:

MARS for particle production+HORN
Nubeam standalone program

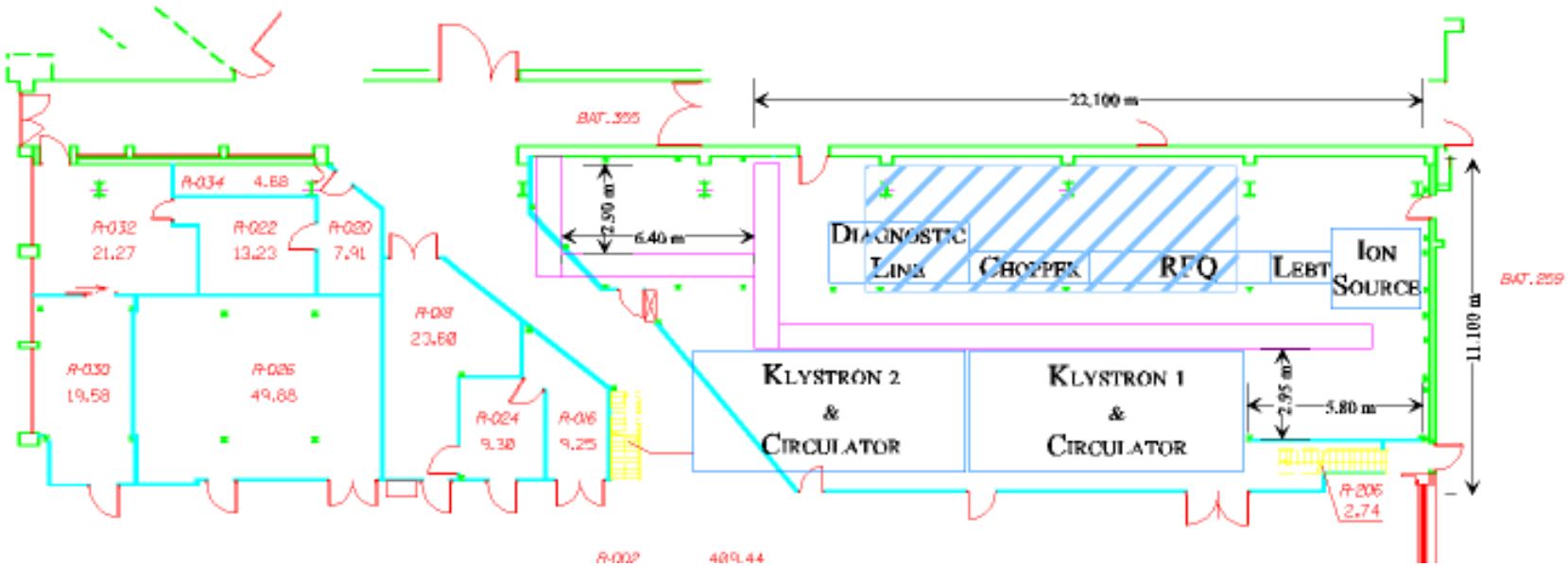


SPL @ 2.2 GeV

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)
- Accumulator ring to reduce the pulse length
- SPL also valuable 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)
- 3MeV pre-injector: approved

3 MeV and RF test place



- 3 MeV Test Stand to be installed in the PS South Hall (in place for linac 4)
- Purpose: test essential front-end issues (hardware & beam dynamics)
- Made of IPHI RFQ + CERN chopper line + IN2P3 diagnostics line + 2 LEP klystrons (1 for the RFQ + 1 for testing other RF structures).
- Initial use of a standard CERN proton source, to be replaced by an H- source.
- The elements will be placed in the exact position foreseen for Linac4.
- ***Operation with beam: 2007***

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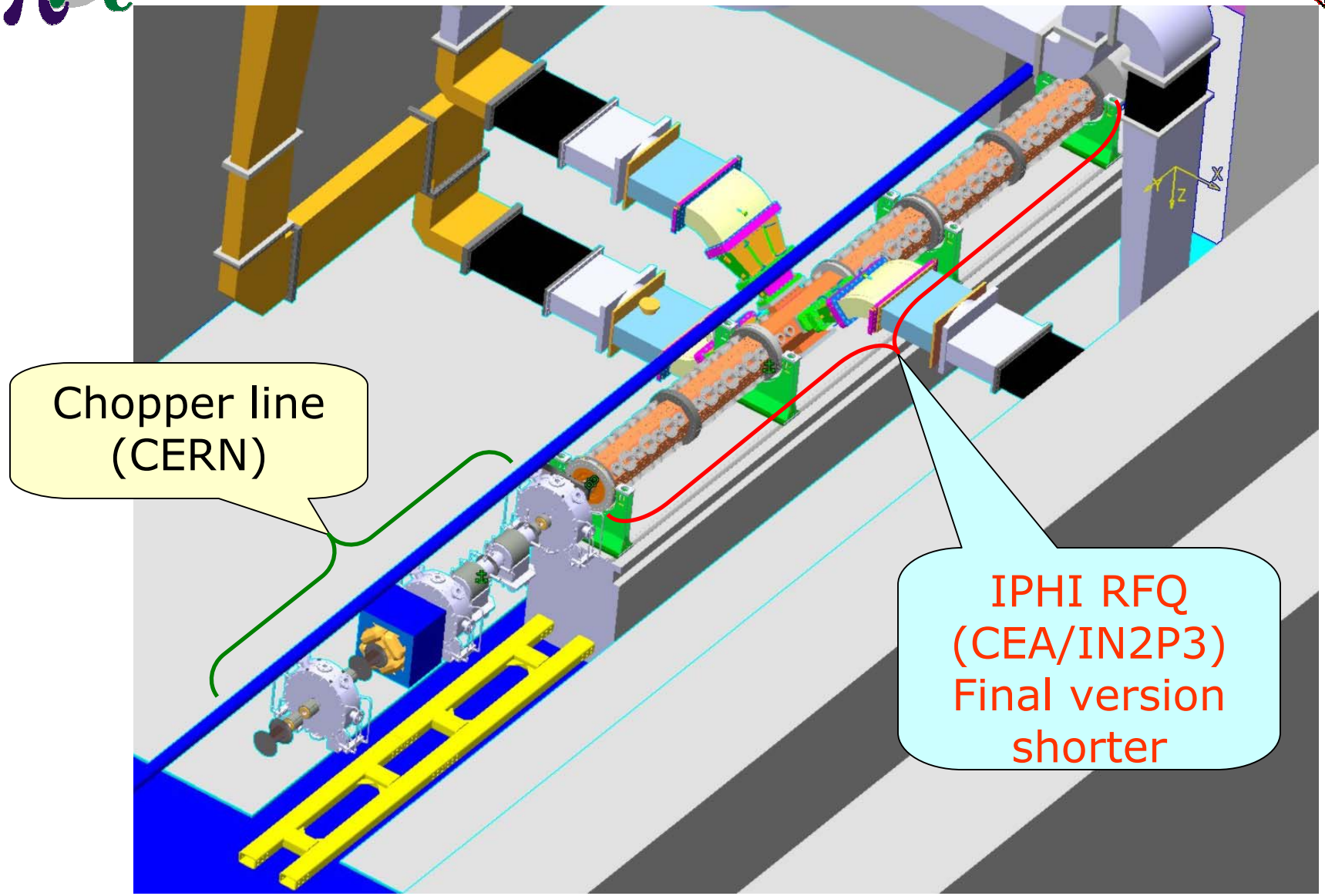
3 MeV test place – Preliminary layout



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IPHI-SPL Collaboration

IPHI = Injecteur de Protons de Haute Intensite

Goal of the IPHI-SPL collaboration: modify the design of the IPHI-RFQ for 3 MeV, finish construction, test in CW with 100 mA beam current at Saclay in 2006 **and deliver at CERN at the end of 2006 for the 3 MeV test place (pre-injector of the future linac 4 & SPL).**

- **Recent achievements:**
  - **Adaptation of French equipment design to the revised parameters**
  - **Strengthening of the CERN effort (3 MeV Technical Coordination Committee, integration in EDMS, analysis of control needs…)**
  - **1rst module of IPHI brazed at CERN last October**
  - **"Avenant" of agreement to be signed soon (formally declaring that the IPHI RFQ is for use at CERN)**
  - **Strong support by the IN2P3 management**

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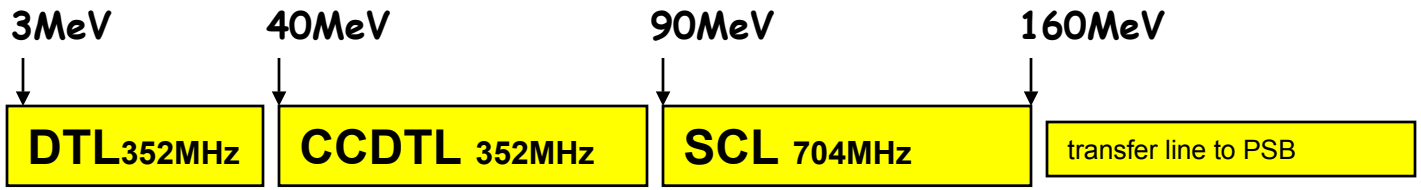
Technical Progress Evolution of the SPL Design

- **Linac 4**



  - Energy is increased to 160 MeV
  - High energy section (> 90 MeV) operates at **704 MHz** to fit inside the available space (higher gradients & higher power pulsed klystrons) and to prepare for a superconducting linac section at that frequency.

- **SPL**
  - Considering that the LEP cavities and their technology are aging, that CERN management does not support it anymore and that the corresponding know-how is disappearing, while bulk Nb is supported by other laboratories and provides higher gradients, the choice has been made to base the future design of the SPL on **704 MHz bulk Nb resonators**.
    No superconducting LEP cavities will be used anymore.
  - A new conceptual design will be prepared in 2004.
    The energy will be optimized as a function of the physics goals.

ISTC supported projects

2 years projects to demonstrate the capability of the Russian Nuclear Cities to build equipment for linacs (mostly accelerating structures).

1. BINP + VNIITF
   - *Subject: "Development of the technological basis for serial production of CCDTL structures in the energy range of 40-100 MeV for the SPL project. Feasibility study of effective application of normal conducting CCL structures up to the energy of 150-180 MeV. "*
   - **Cost: k$ 550**
   - **Status: approved (21/10/2003) & starting**
2. ITEP + VNIIEF
   - *Subject: "Development of Alvarez-type accelerating structures for the room-temperature part of the CERN SPL project."*
   - **Cost: k$ 498**
   - **Status: pending approval (March 2004)**
3. IHEP + VNIIEF
   - *Subject: "Design and manufacture of DTL-RFQ focusing and accelerating structure prototype for a 3-40 MeV H- linac of the SPL project."*
   - **Cost: k$ 500**
   - **Status: pending approval (March 2004)**

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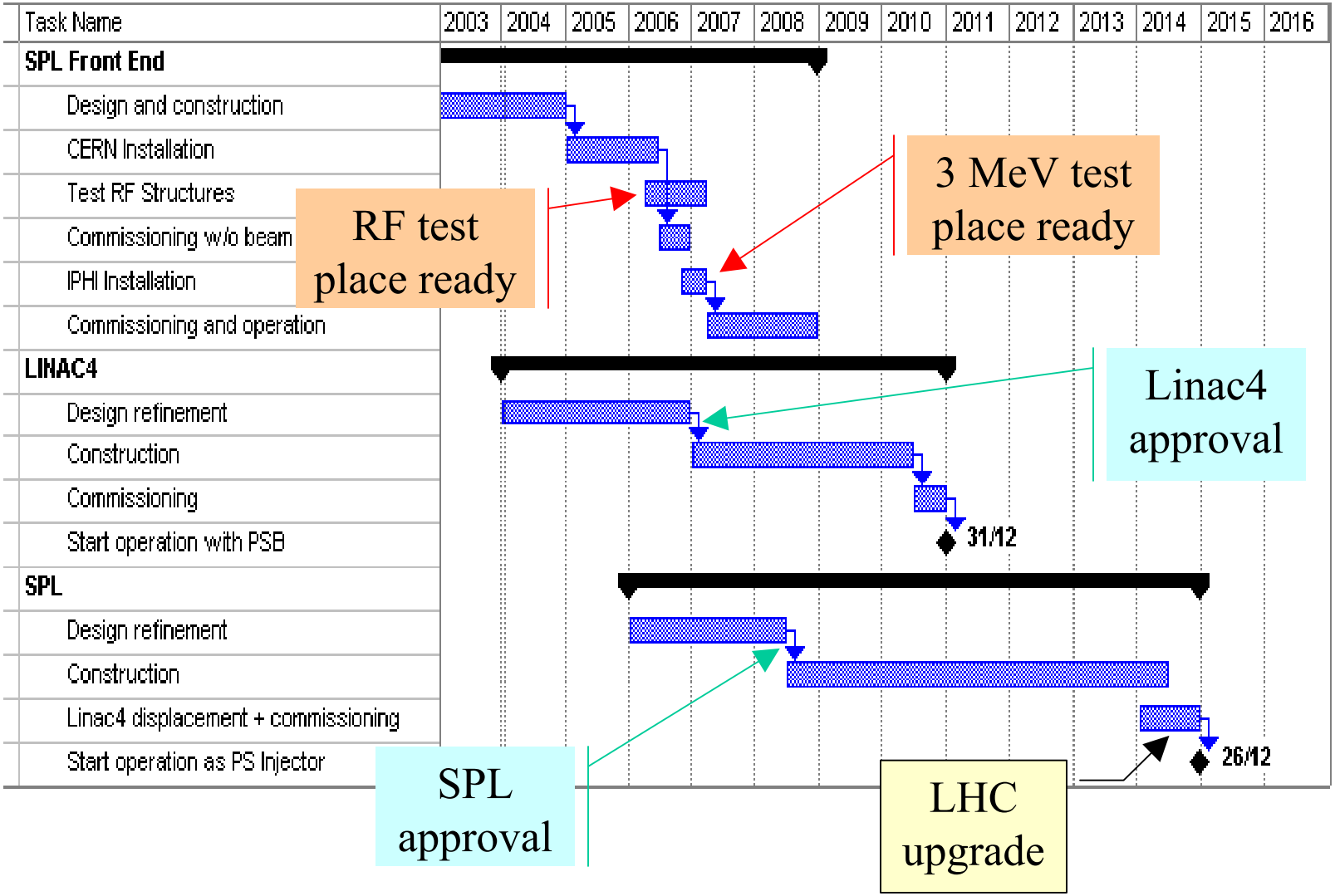
Multi-year planning



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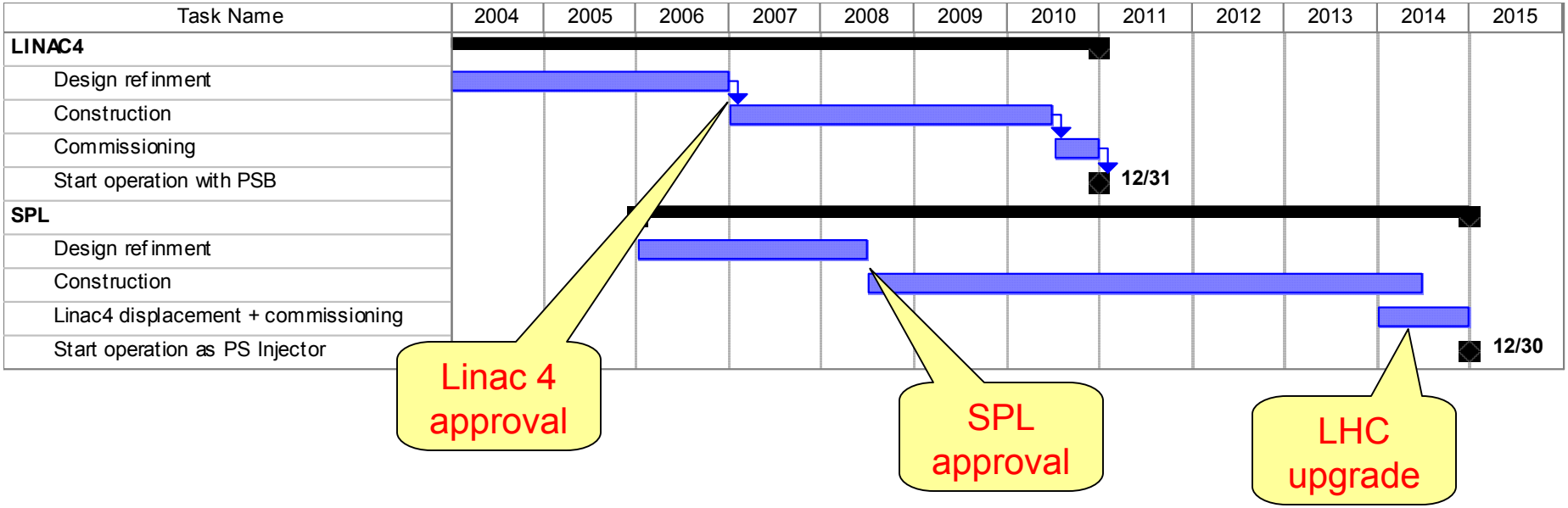
Proposed Roadmap

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)*



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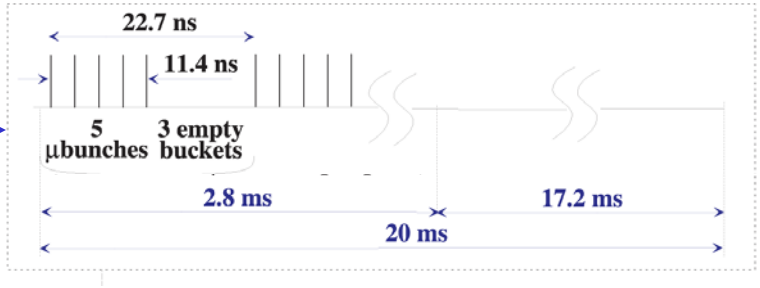
Accumulator and Compressor

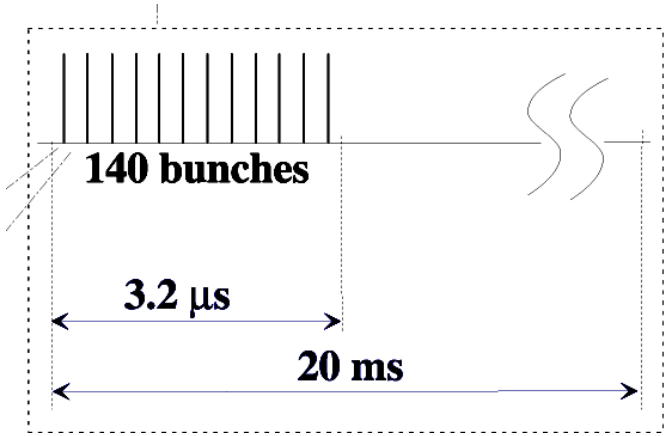
- Accumulator
  - *Macro*bunch with internal 23 ns structure (44 MHz) **MUON BUNCHES KEEP THIS STRUCTURE**
  - *Macro*bunch Rep. rate: 20 ms (50 Hz)

- 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





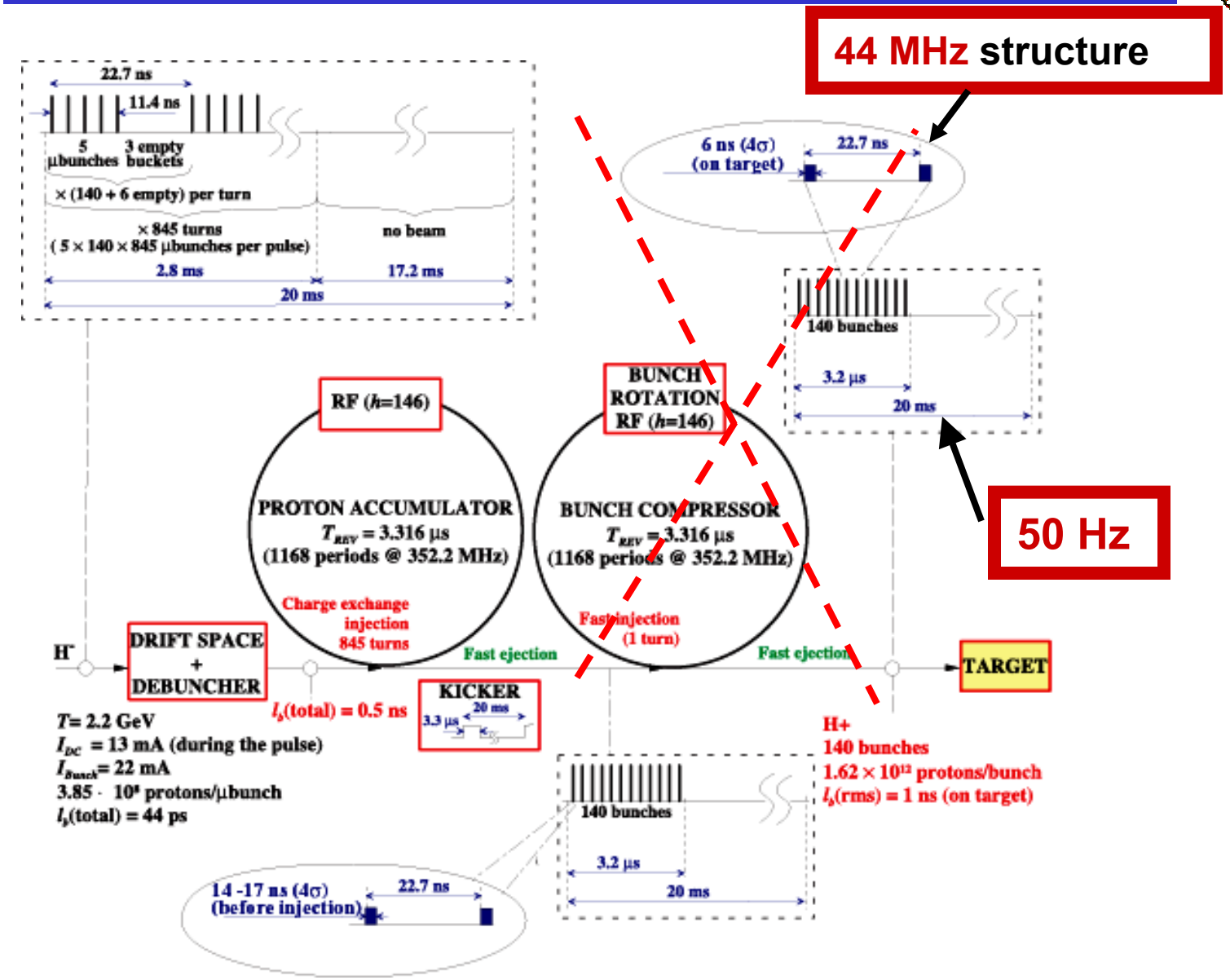
Beam from Accumulator

Atmospheric background: 100 evt/kton/y

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

From the SPL:	20 ms/1.2 ms	≈ 17
From the accumulator:	20 ms/3.2 μs	≈ 6250

PDAC time scheme



Target Nufact

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

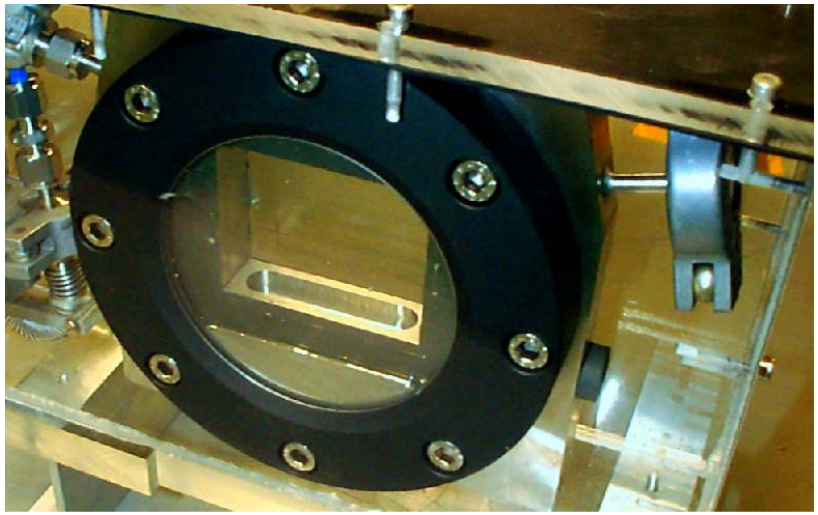
→ 4 MW of proton into more or less a pint of beer

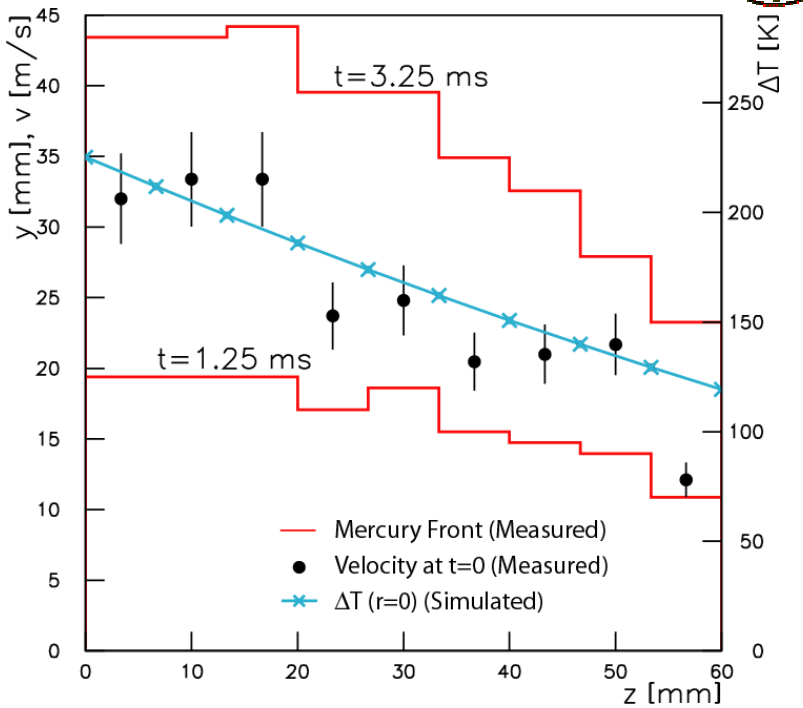
4 MW

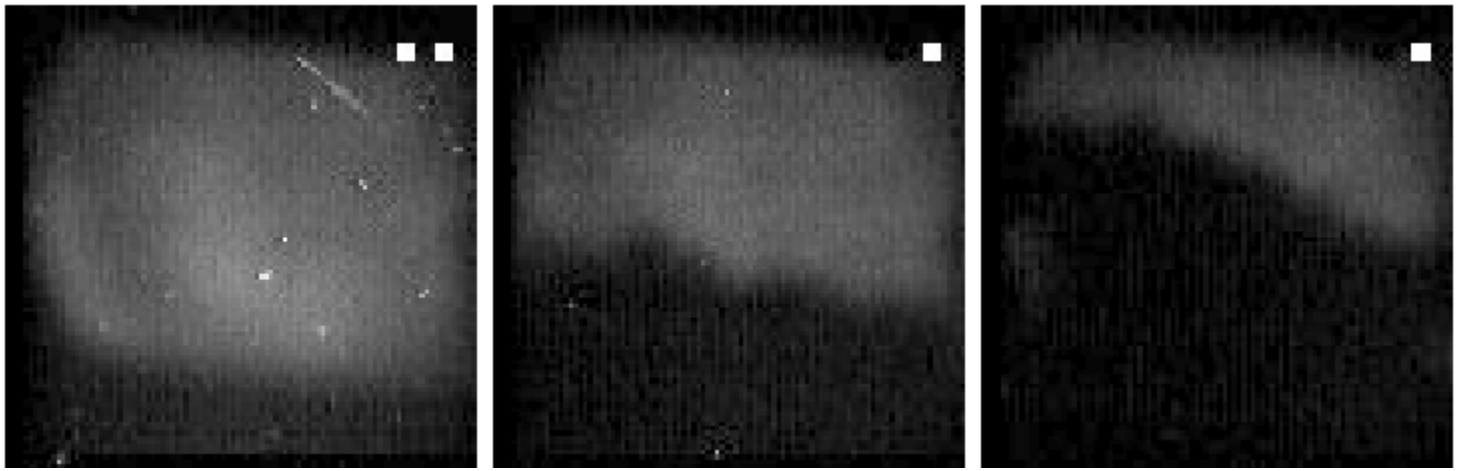
=

40000 ×

Trough experiment @ ISOLDE





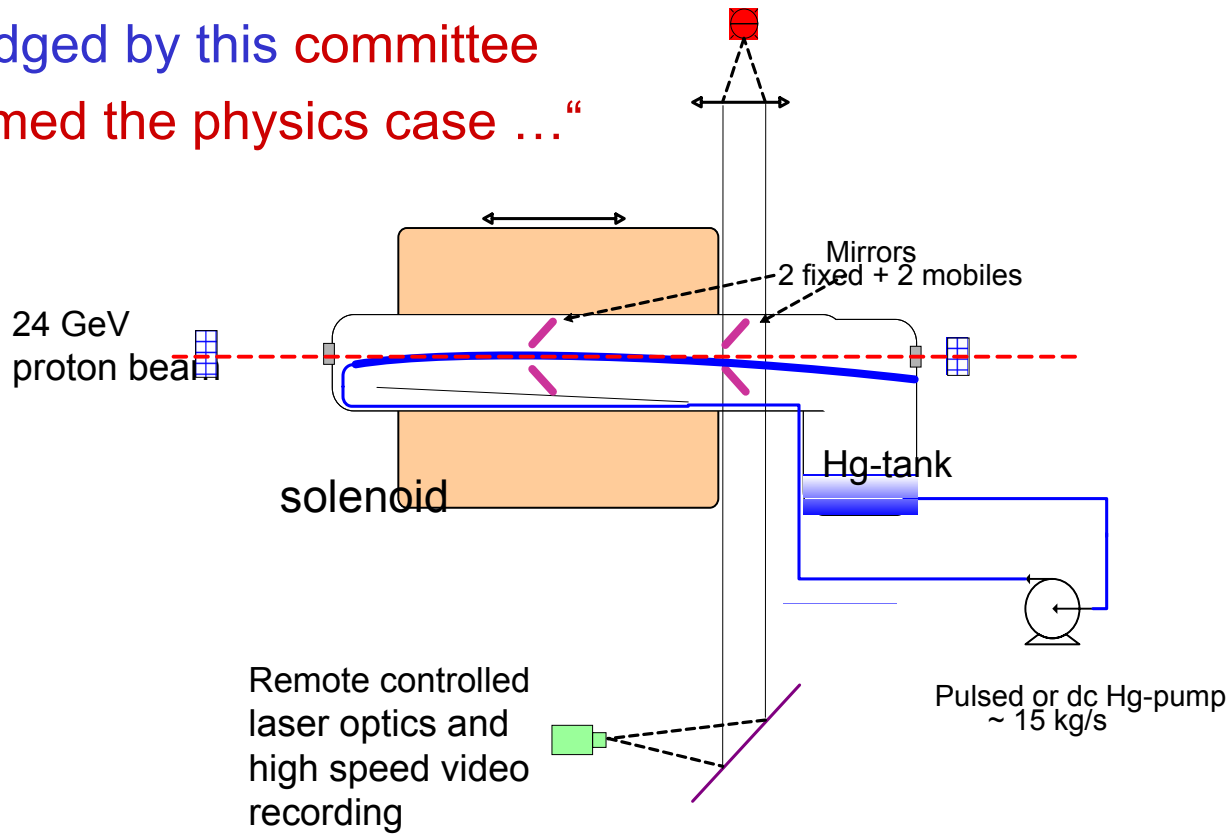


Liquid Target Test for high intensity proton beams

Not exactly for the CERN Superbeam but for general understanding of liquit target with high intensity proton beams

- Oct 2003 LOI submitted to INTC
  - positively acknowledged by this committee

    "… welcomed the physics case …"



Proposal in preparation

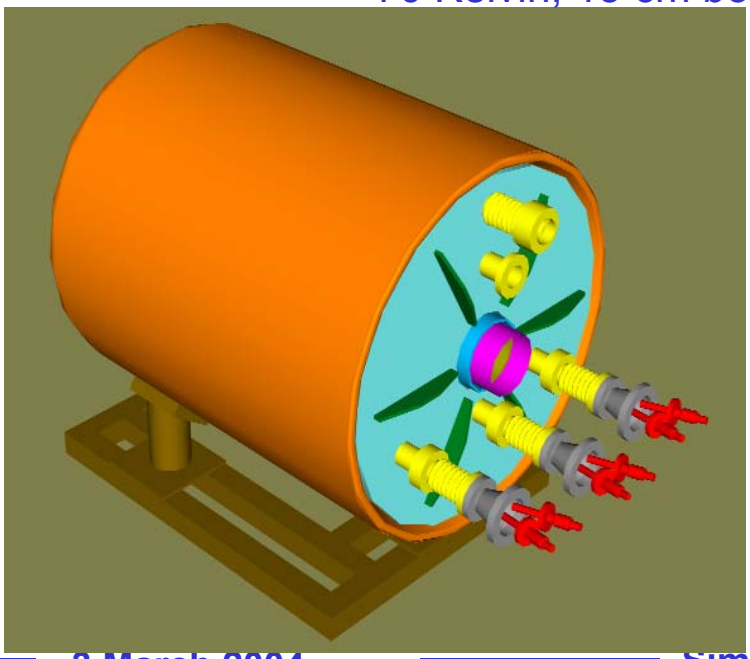
Collaboration: BNL, CERN, Princeton University, RAL

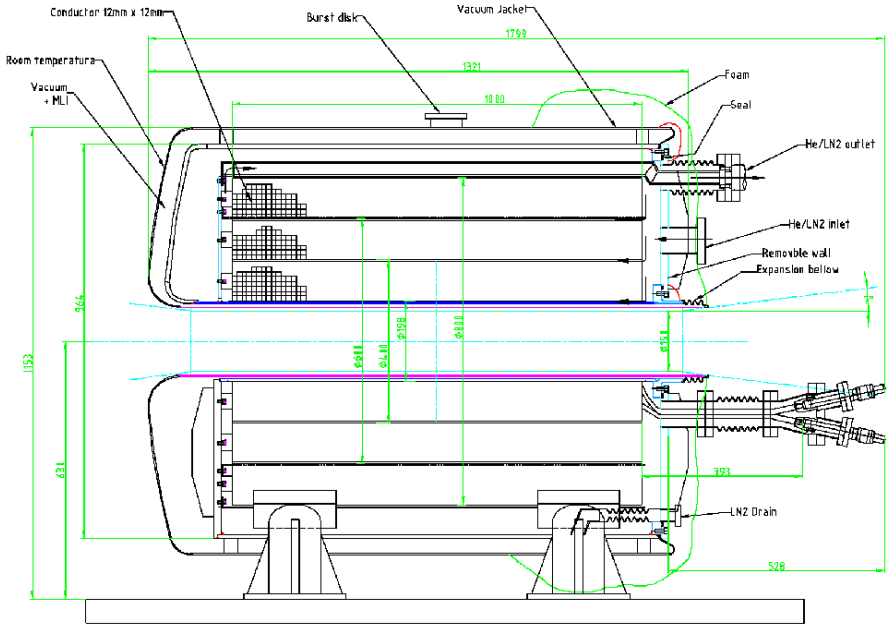
- proposed site: CERN TT2A tunnel, upstream of nToF
- Beam time: spring 2006
  - Proton Synchrotron (PS) beam:

    p=24 GeV/c

    Intensity <$3*10^{13}$ protons/pulse , 4 bunches, single turn extraction
- Nominal mercury jet target: d = 1 cm, v = 15-20 m/s
- pion collection system: 15 Tesla “warm” solenoid

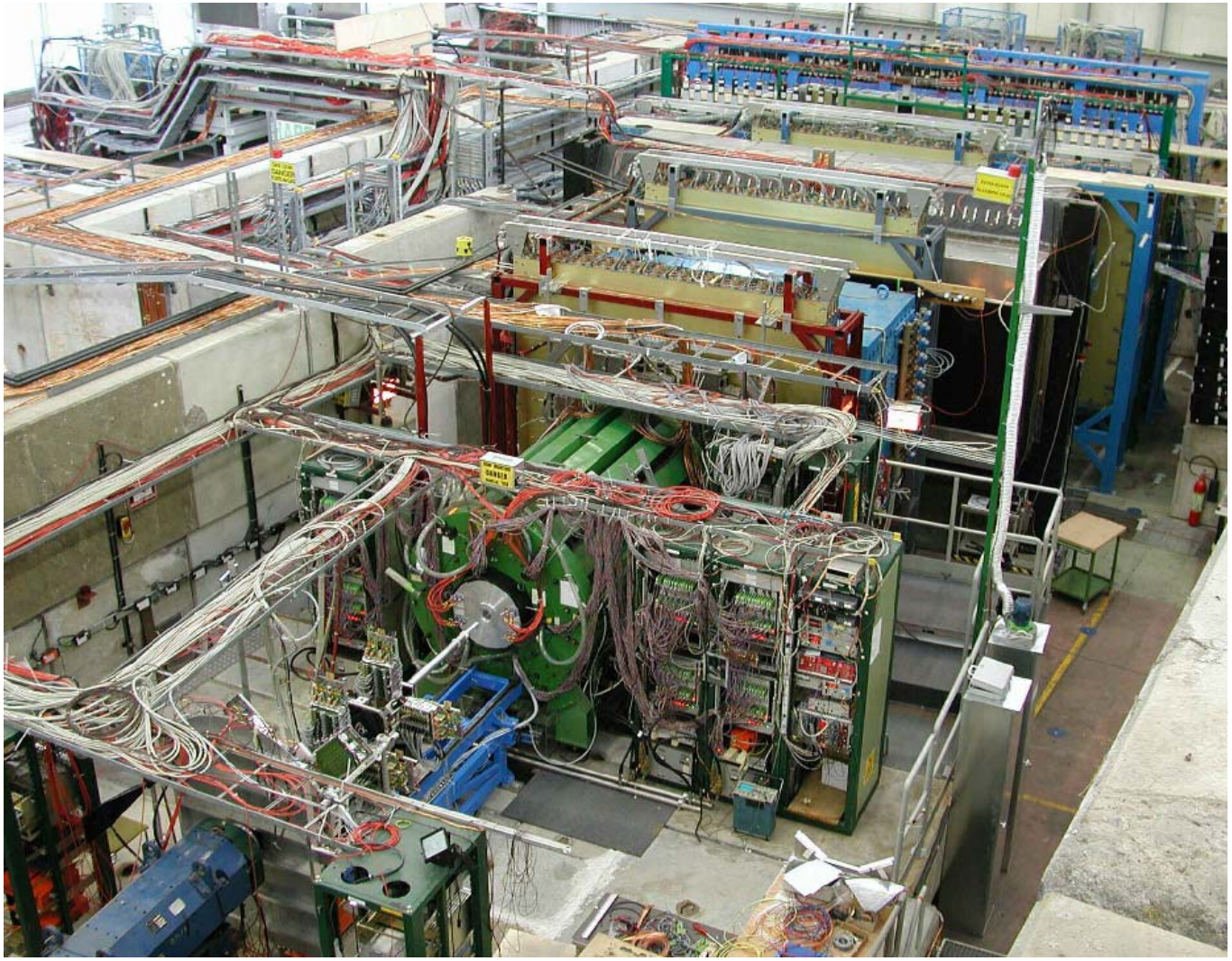
  70 Kelvin, 15 cm bore





The Harp experiment

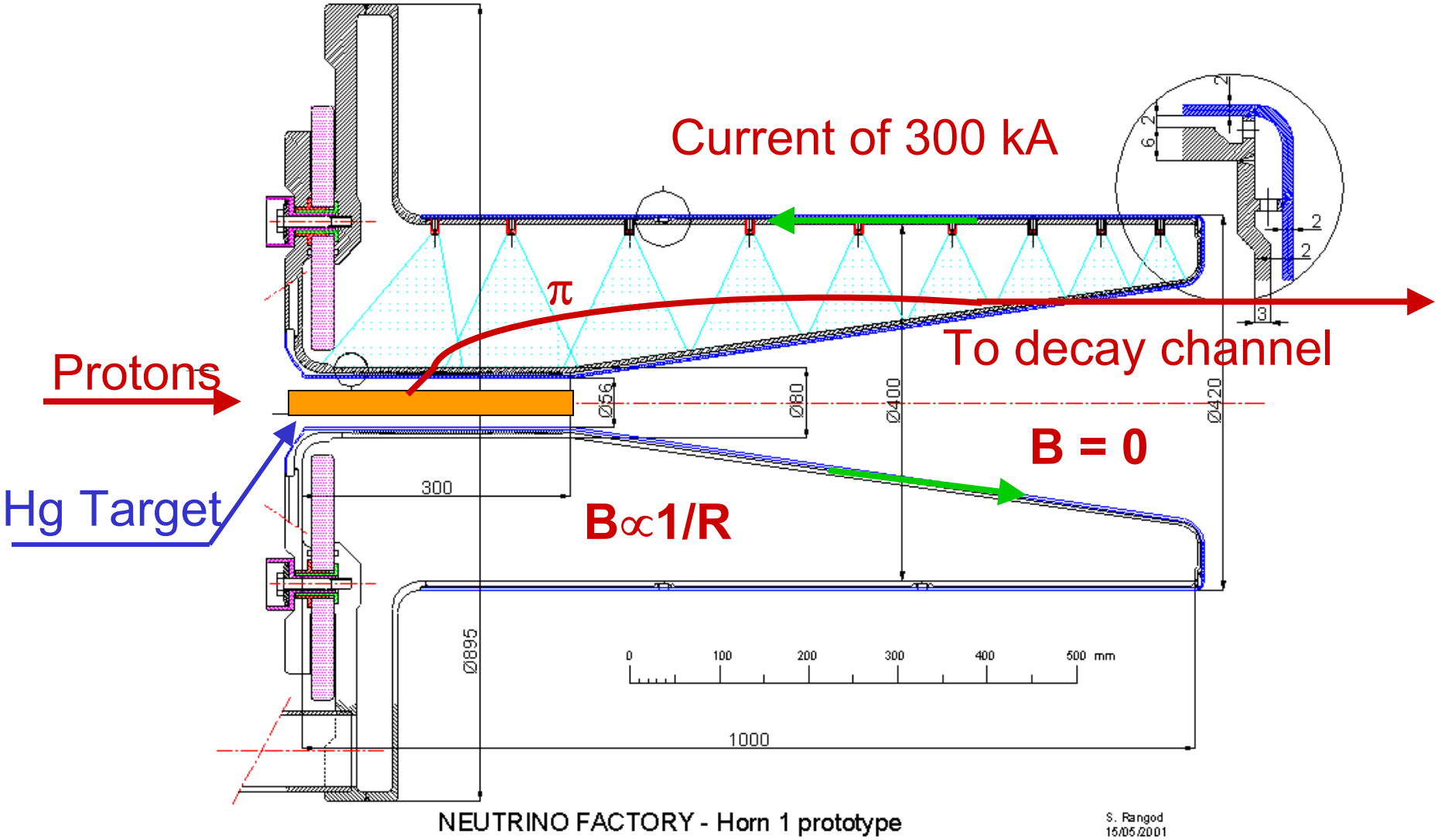
Hadron production cross section measurement



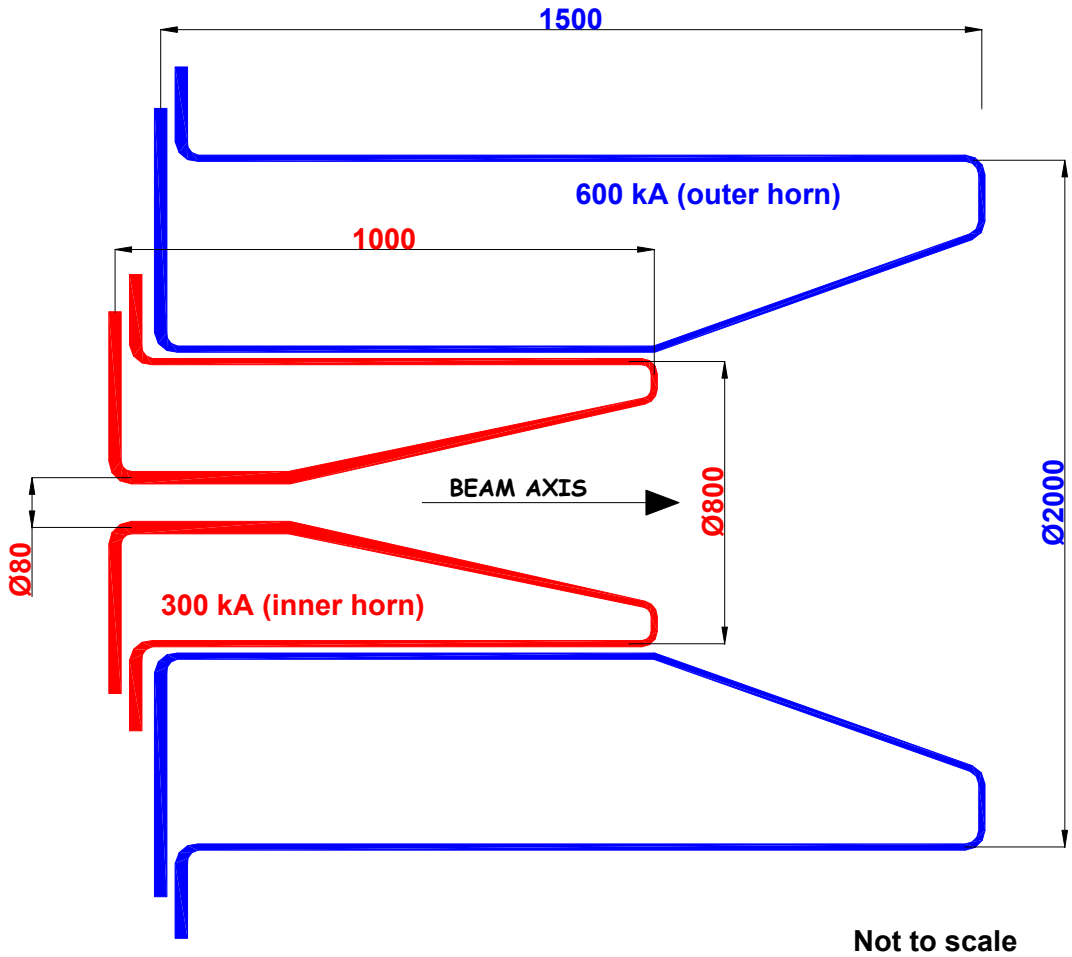
Harp results coming soon ...

- Which energy for the proton beam?
  - SPL design, ring design, focusing
  - Maximum energy with linac $\rightarrow$ 4 GeV
- kaon threshold to be measured
  - background evaluation
- pion production cross section
  - best material, pi+/pi- ratio, beam normalization

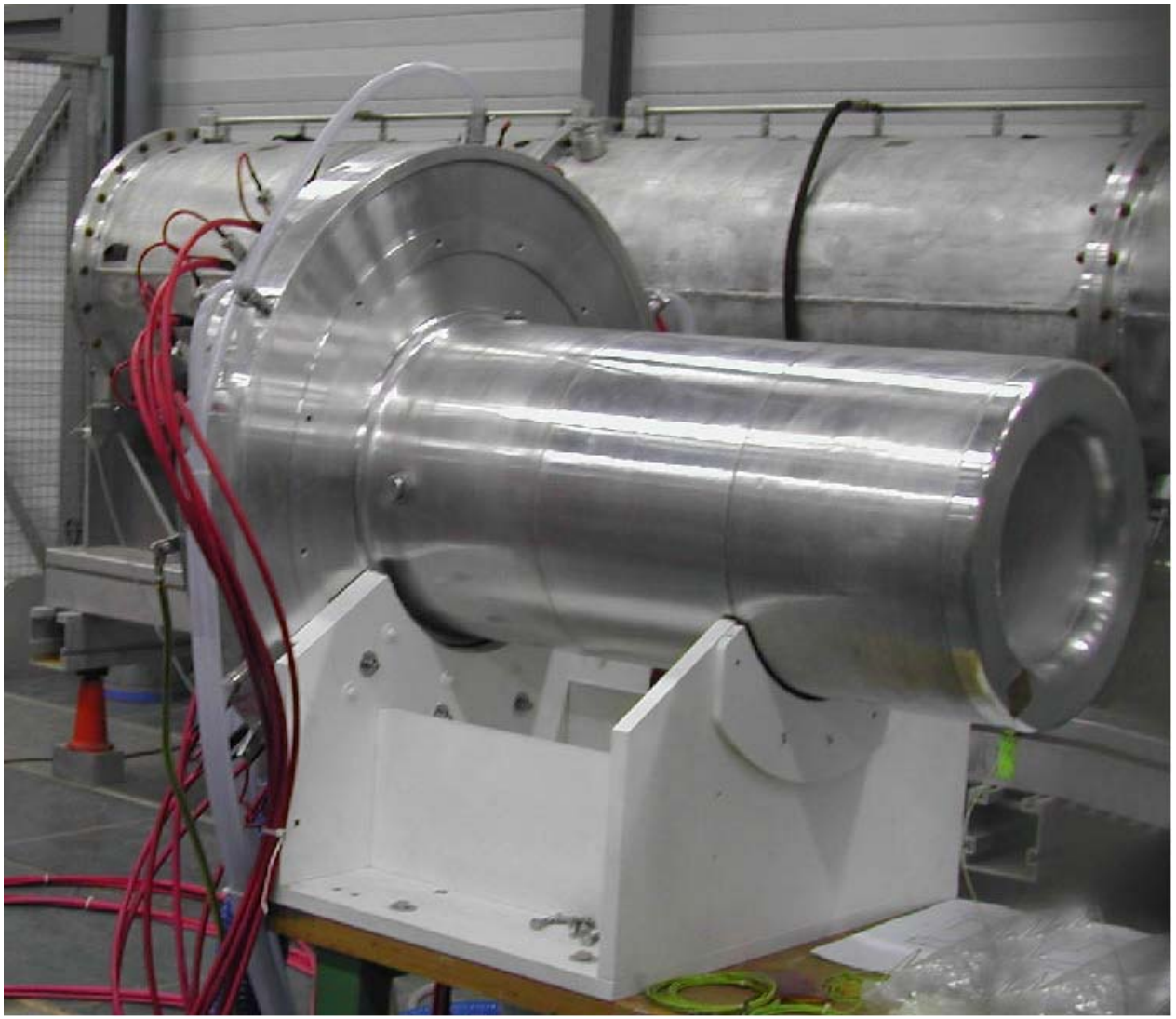
Magnetic horn



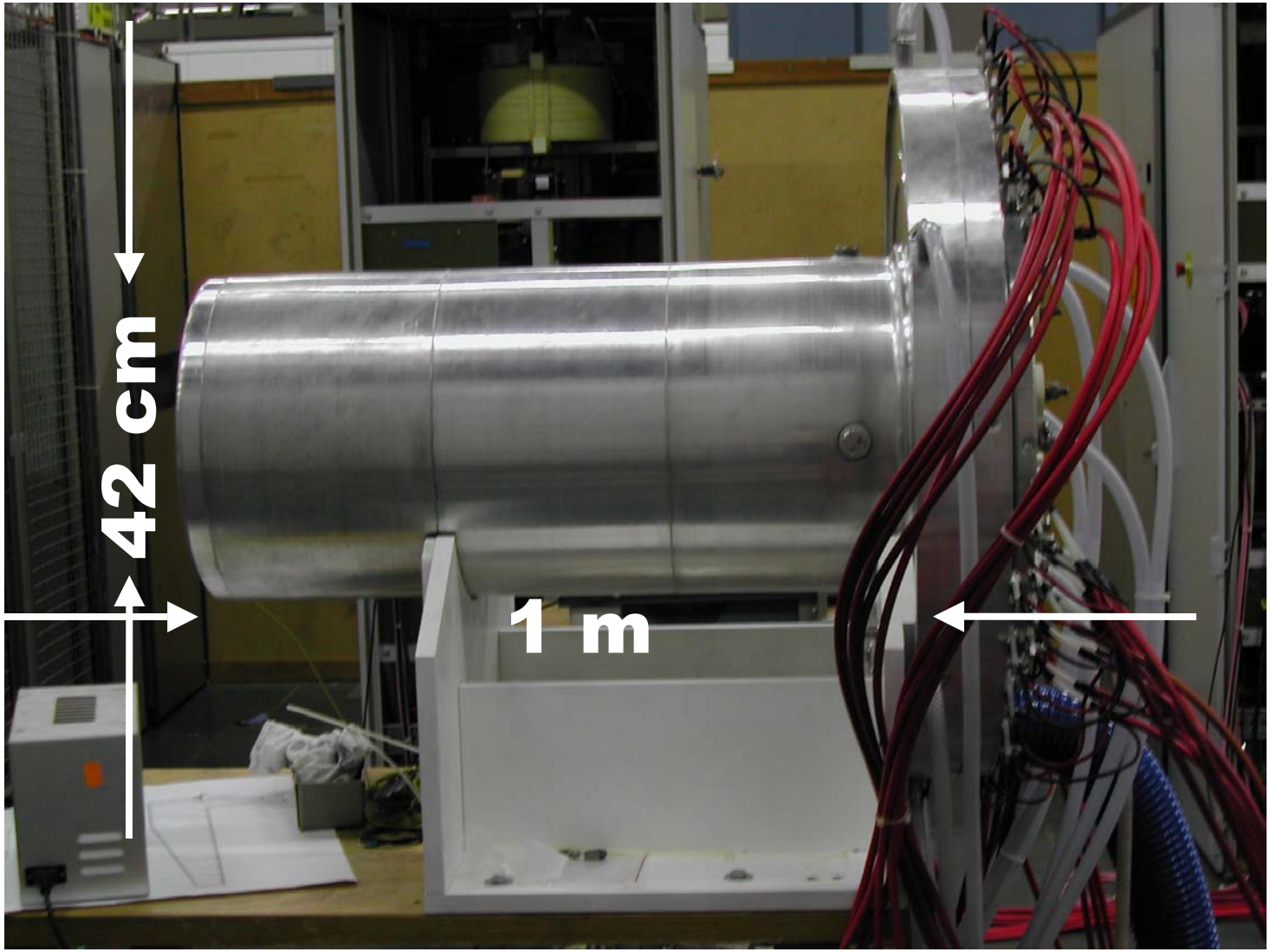
Double horn concept



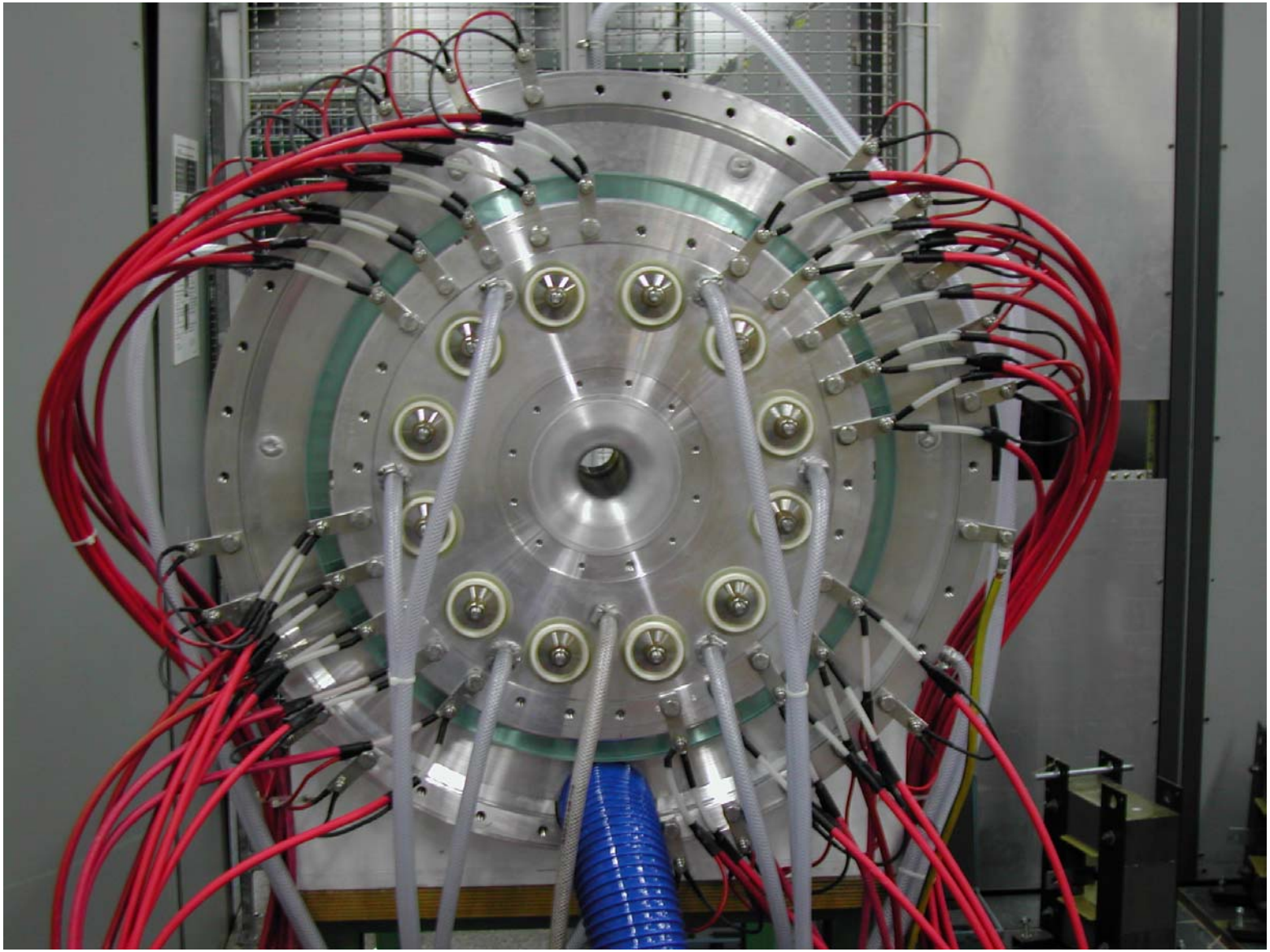
Horn prototype ready for tests



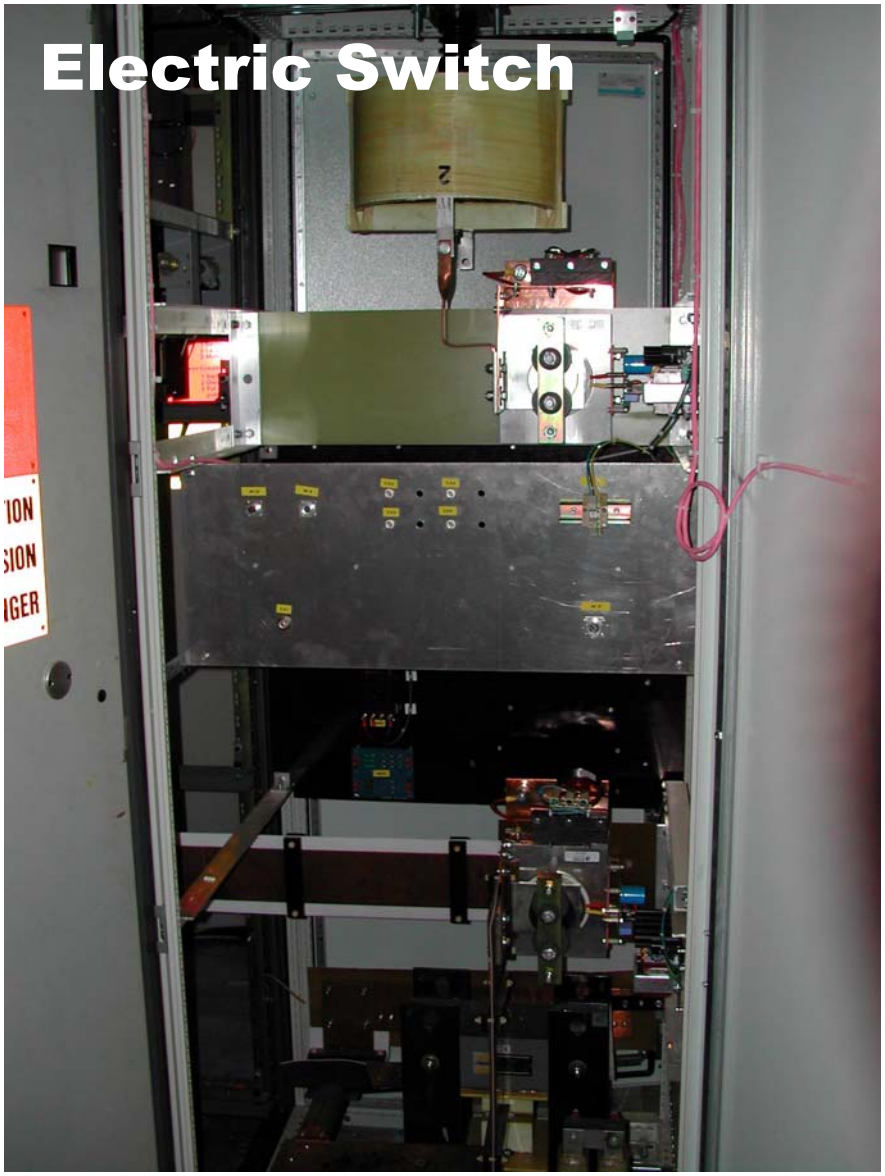
Lateral view



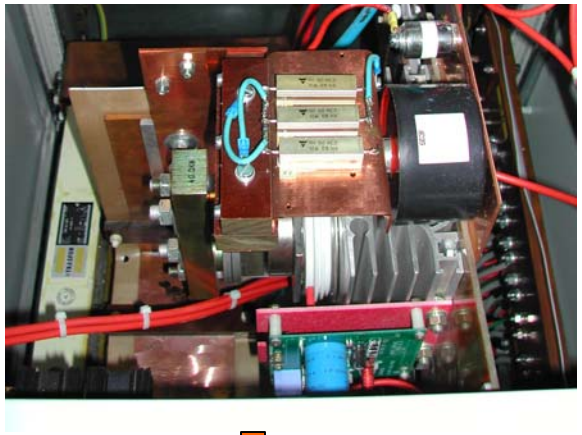
Electrical and water connections

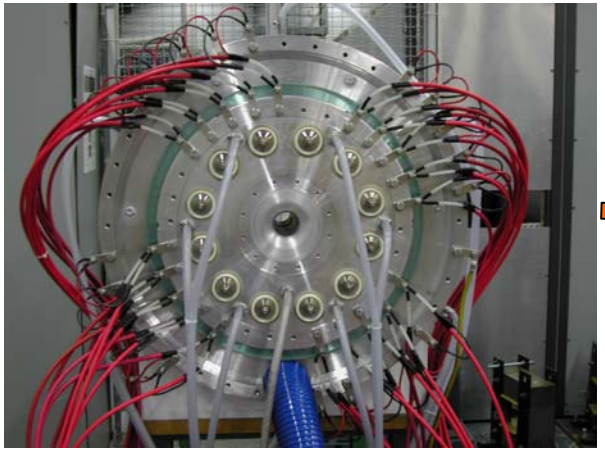


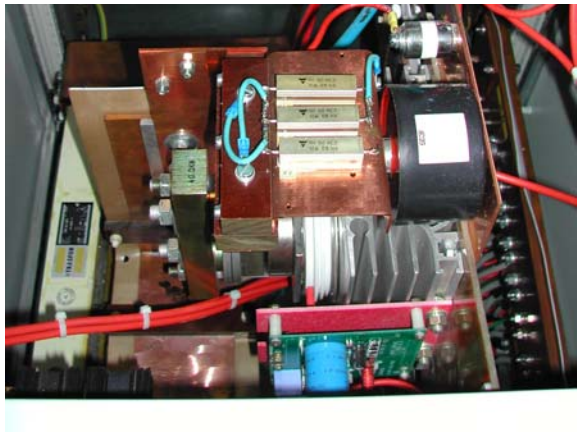
Discharger unit : 2 units in parallel



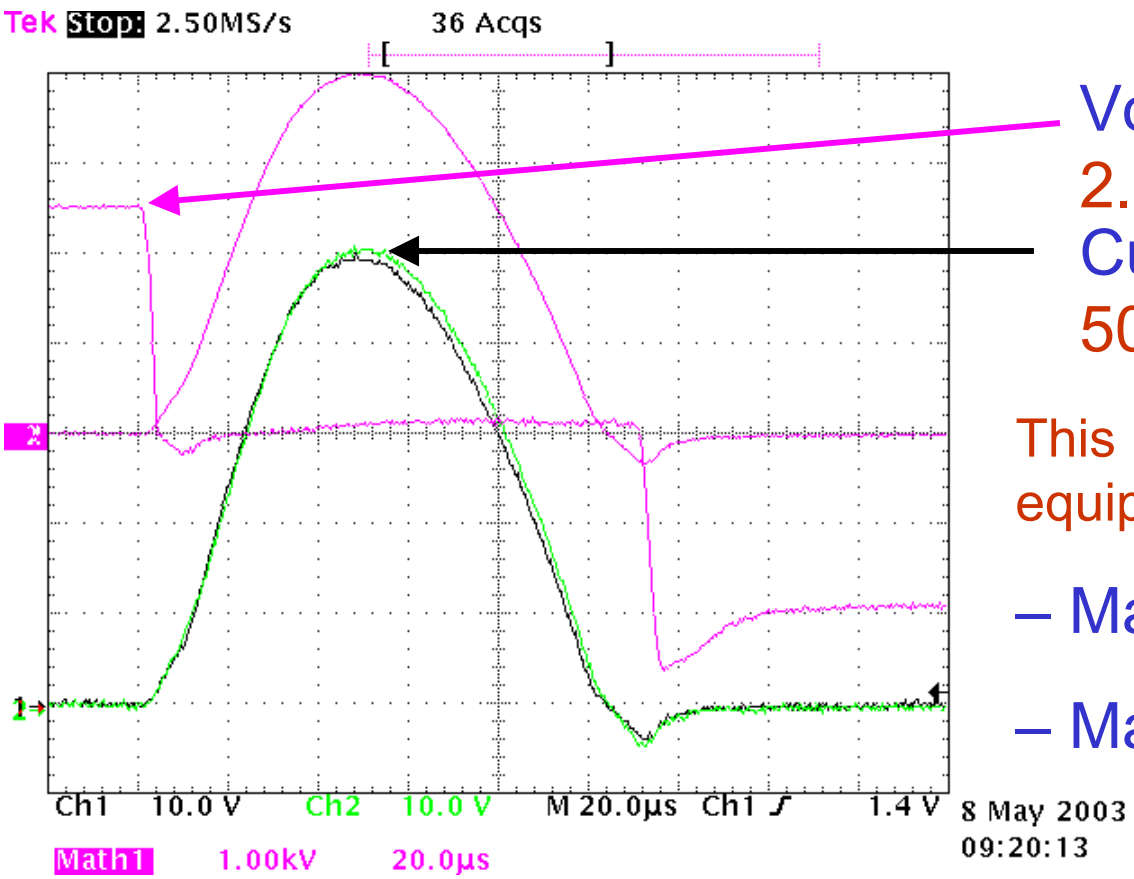
From scheme to reality







Current tests: 100 kA – 0.5 Hz



Voltage on horn/thyristor: 2.5 kV

Current first/second unit 50 kA

This is the Limit for the existing equipment:

– Max voltage on thyristor

– Max rep rate for resistors

Ch1: Current of unit one measured with current transformer. (10kA/div)
Ch2: Current of unit two measured with current transformer. (10kA/div)
M1: Voltage across thyristor. (1kV/div)
M2: Sum of both currents. (25kA/div)

Horns available from the shelf

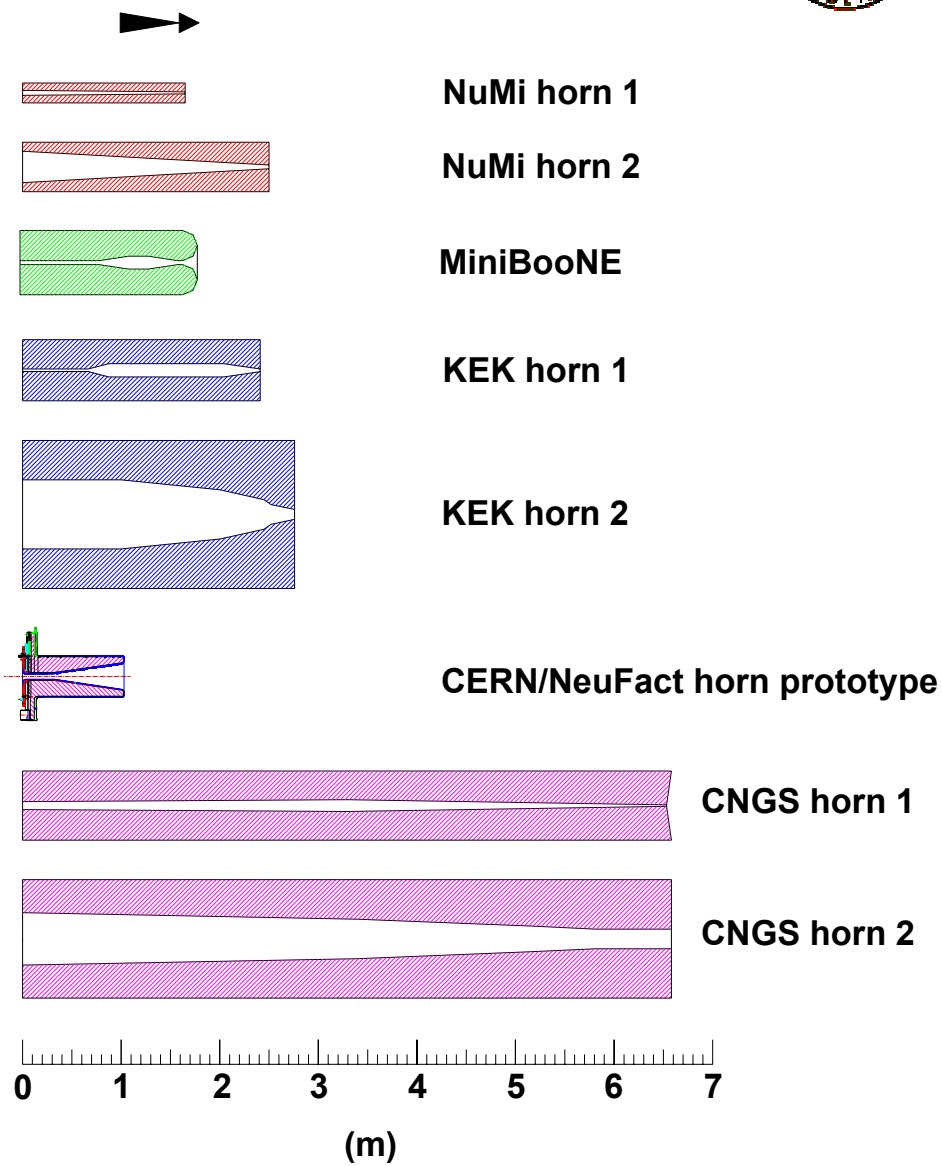
Numi: 200 kA, 0.5 Hz, 6M pulses
1 year

MinibooNe: 170 kA, 5 Hz, 11M pulses
1 year

K2K: 250 kA, 0.5 Hz, 11M pulses
1 year

Nufact: 300 kA, 50 Hz, 200 M pulses
6 weeks

CNGS: 150 kA, 2 pulse/6s, 42 M pulses
4 years



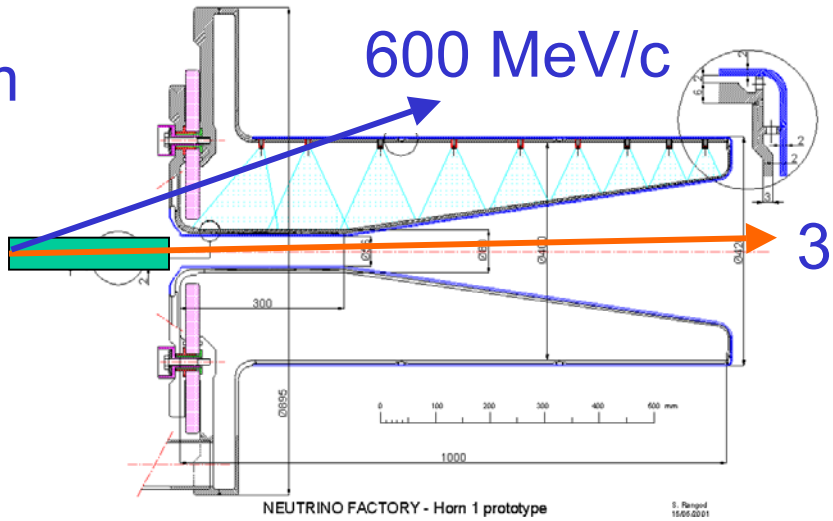
Target inside or outside ?

Target INSIDE for low energy

- Max p_t more or less independent from the energy
  - p_t = 250 MeV/c

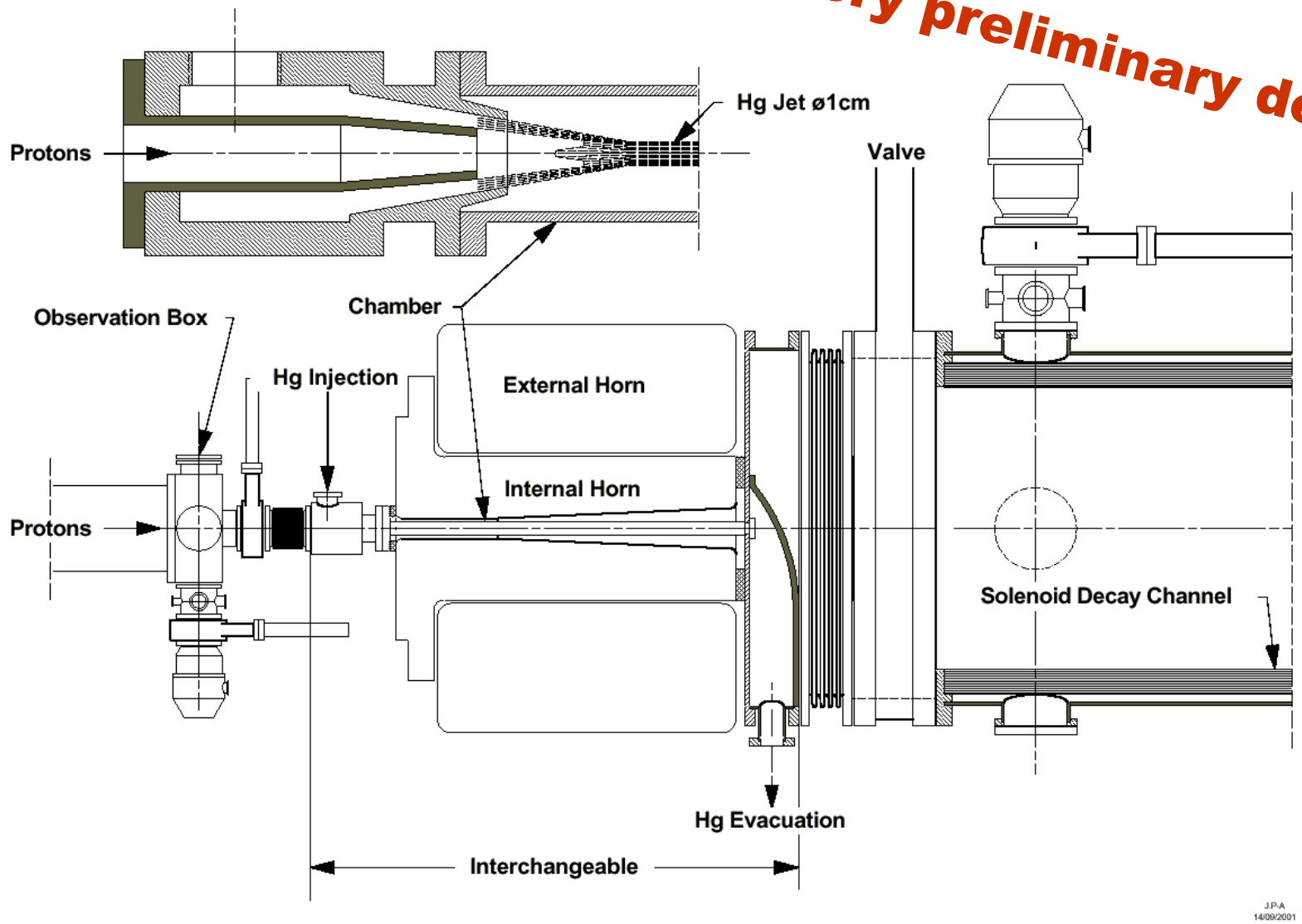
p_{tot}= 600 MeV/c
θ = 24º
R(z=30 cm)= 13 cm

p_{tot}= 30 GeV/c
θ = 0.47º
R(z=30 cm)= 0.25 cm

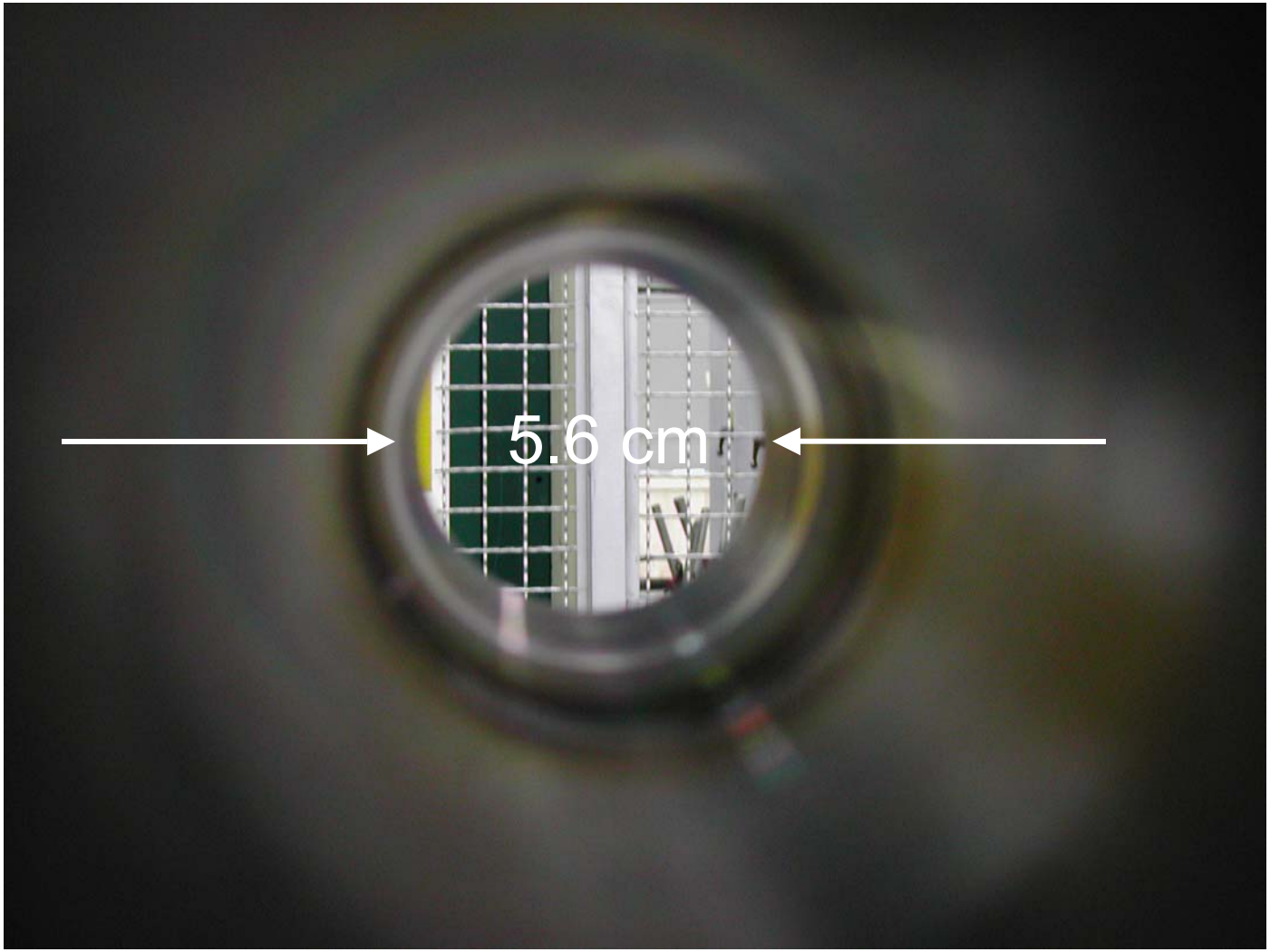


Target and Horn integration

Very preliminary design



Inside the neck

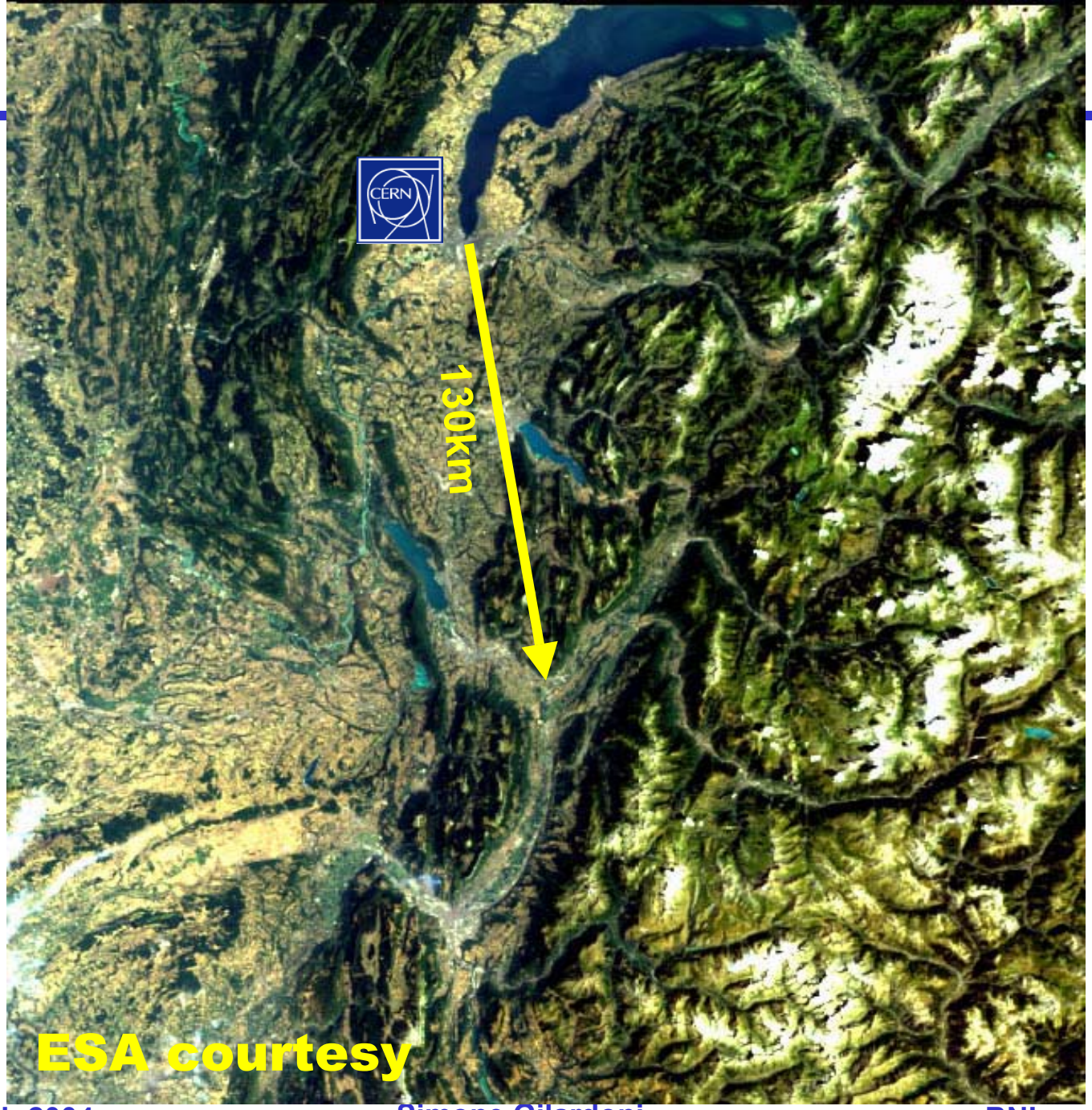


Decay tunnel

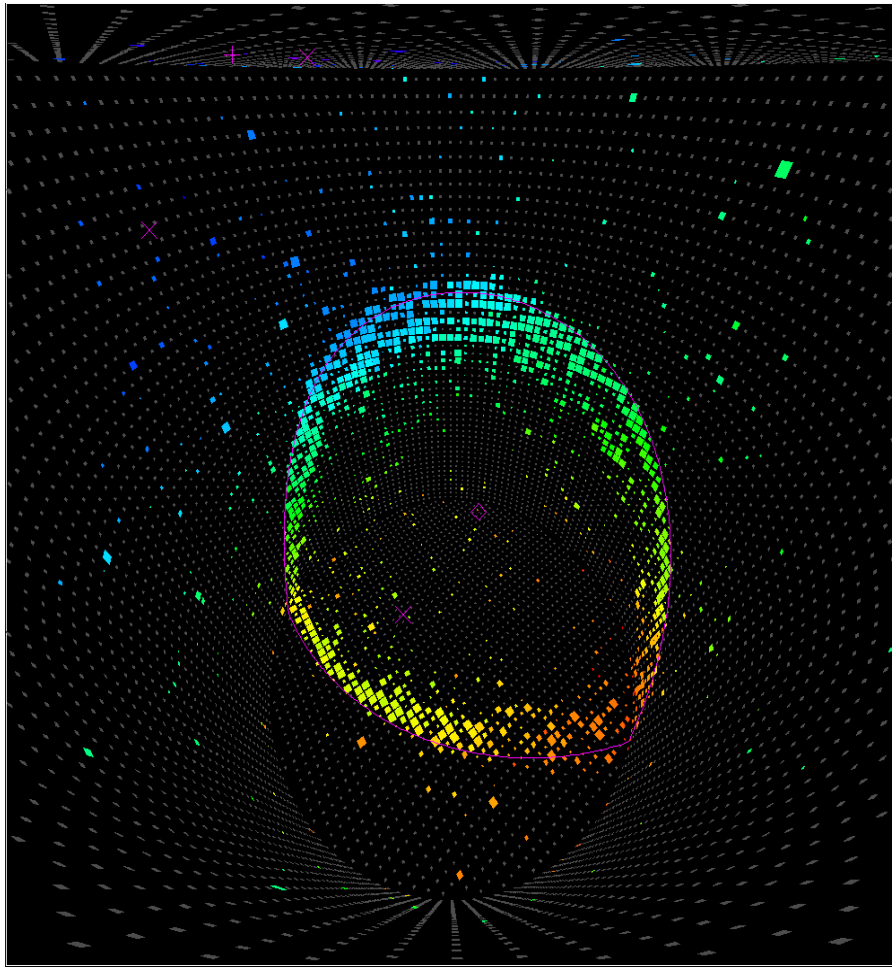
- Decay channel used to control the beam related background
  - muon decay
  - wrong sign pions

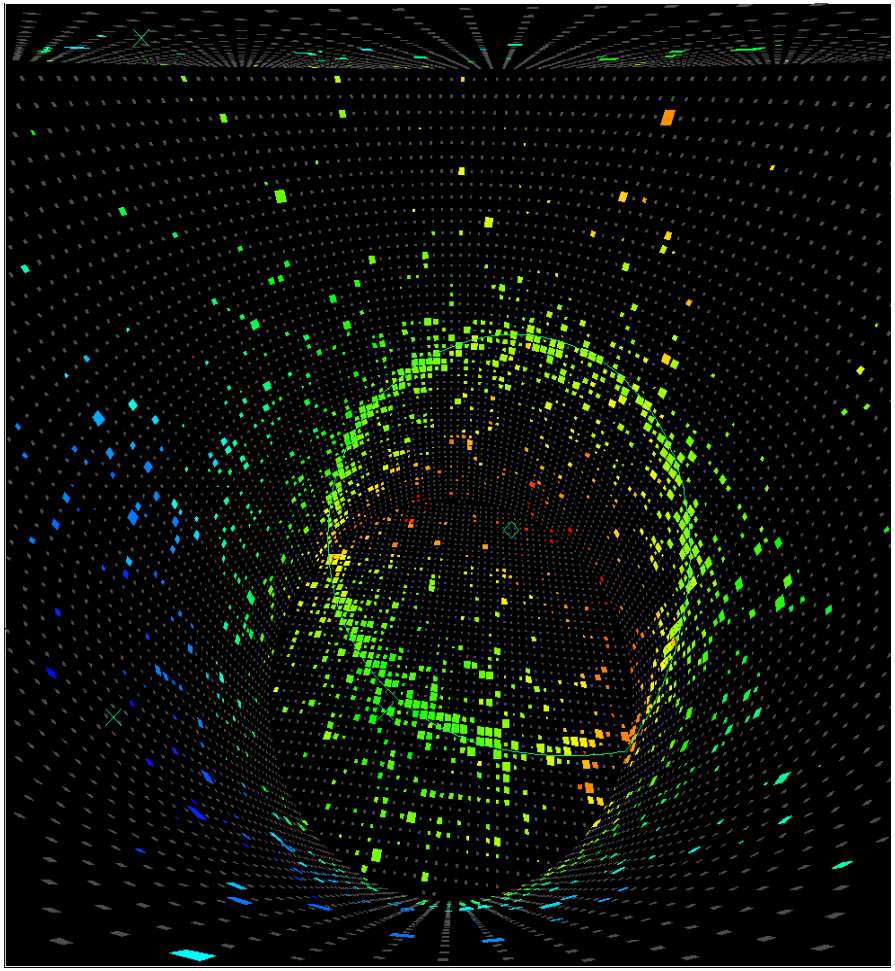
- Length of typical 100 m
- Radius of 1 m

- Studies about activation of shielding/earth around decay channel

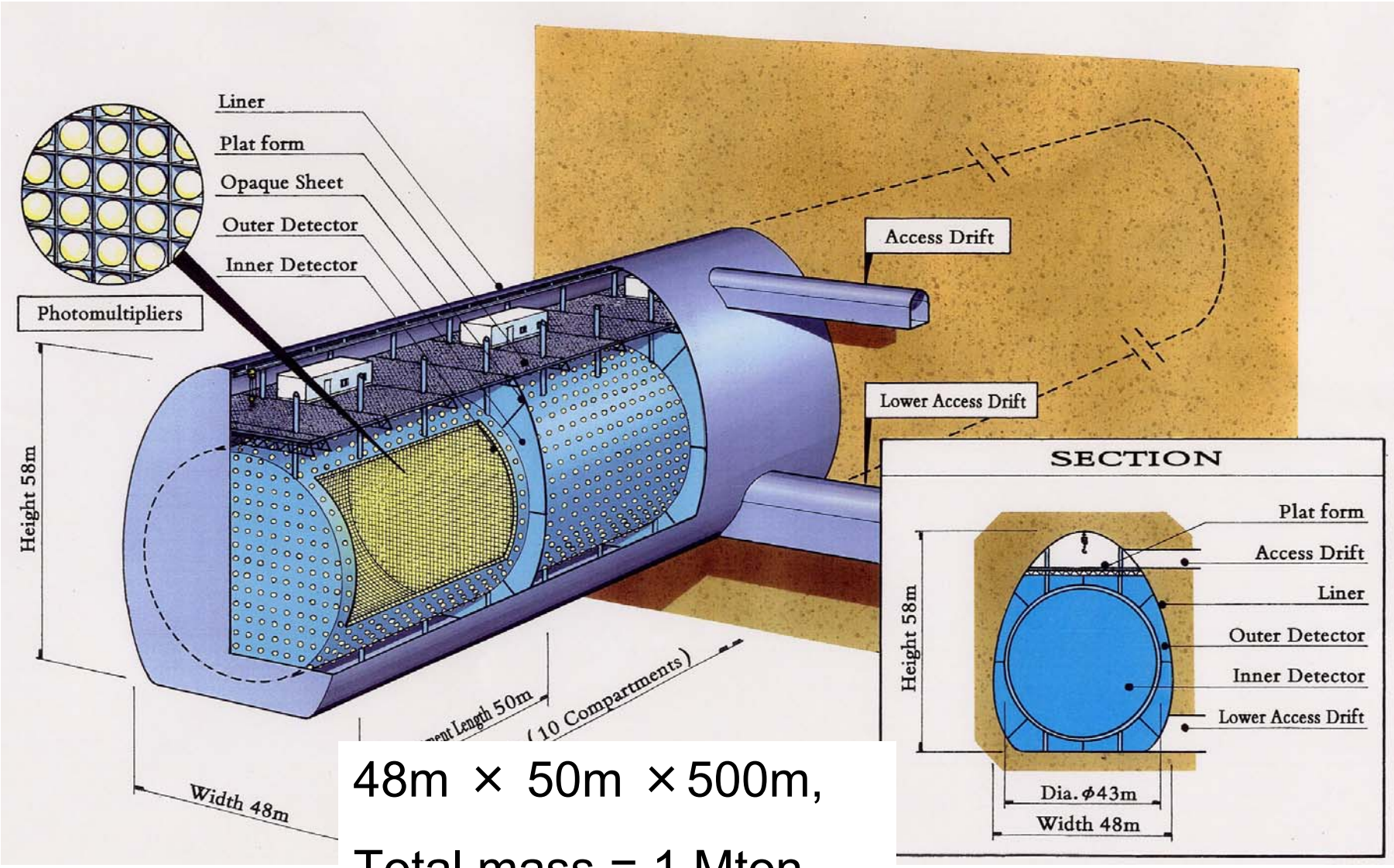

CERN
130km
ESA courtesy

μ/e Background Rejection





Far Detector(Uno/Hyperkamiokande)



48m × 50m × 500m,

Total mass = 1 Mton

Few words about the BETA-BEAM

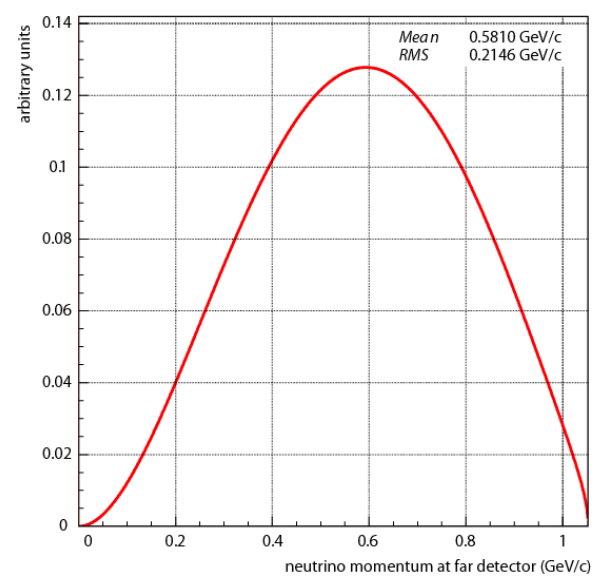
Basic principle: production low energy and pure ν_e ($\bar{\nu}_e$) beam from high energy ($\gamma \approx 100$) ion beta decays

Ingredients:

1. **Produce a Radioactive Ion with a short beta-decay lifetime**
2. **Accelerate ions in a conventional way (PS) to "high" energy ($\gamma \approx 100$)**
3. **Store the ion in a decay ring with straight sections.**
4. **It will decay. ν_e ($\bar{\nu}_e$) will be produced.**
5. **Some hundreds MeV spectrum → Detector at Frejus**

$$^{6}He \rightarrow {}^{6}Li + e^{-} + \bar{\nu}_e$$

- SINGLE flavour
- Known spectrum
- Known intensity
- Focussed
- Low energy
- "Better" Beam of $\bar{\nu}_e$ (ν_e)



P. Zucchelli

Superbeam + Beta beam

Two goals for the experiments: **1) measure θ_{13}**
2) search for CP violation
or T violation

Using only Superbeam:

run 3 years in neutrinos and 7 years in antineutrinos

compare $\nu_\mu \rightarrow \nu_e$ and anti-$\nu_\mu \rightarrow$ anti-ν_e

Caveat: measured limited by antineutrino low cross section
and lower negative pion production yields

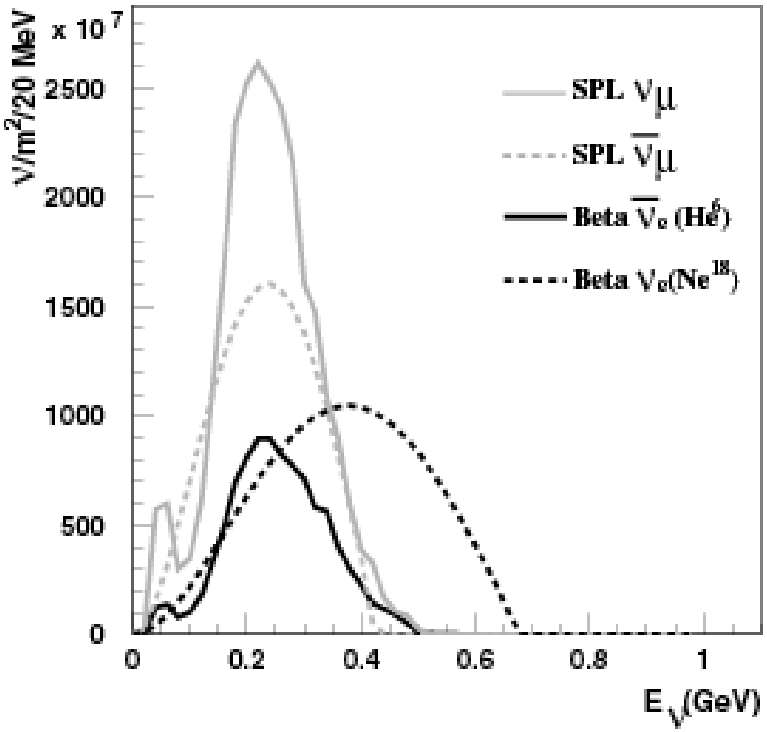
with Superbeam and Beta beam:

run 10 years and study simultaneously

$\nu_\mu \rightarrow \nu_e$ with the Superbeam
$\nu_e \rightarrow \nu_\mu$ with the beta beam (using ^{18}Ne)

T violation
(no antineutrinos limitation)

Superbeam vs betabeam



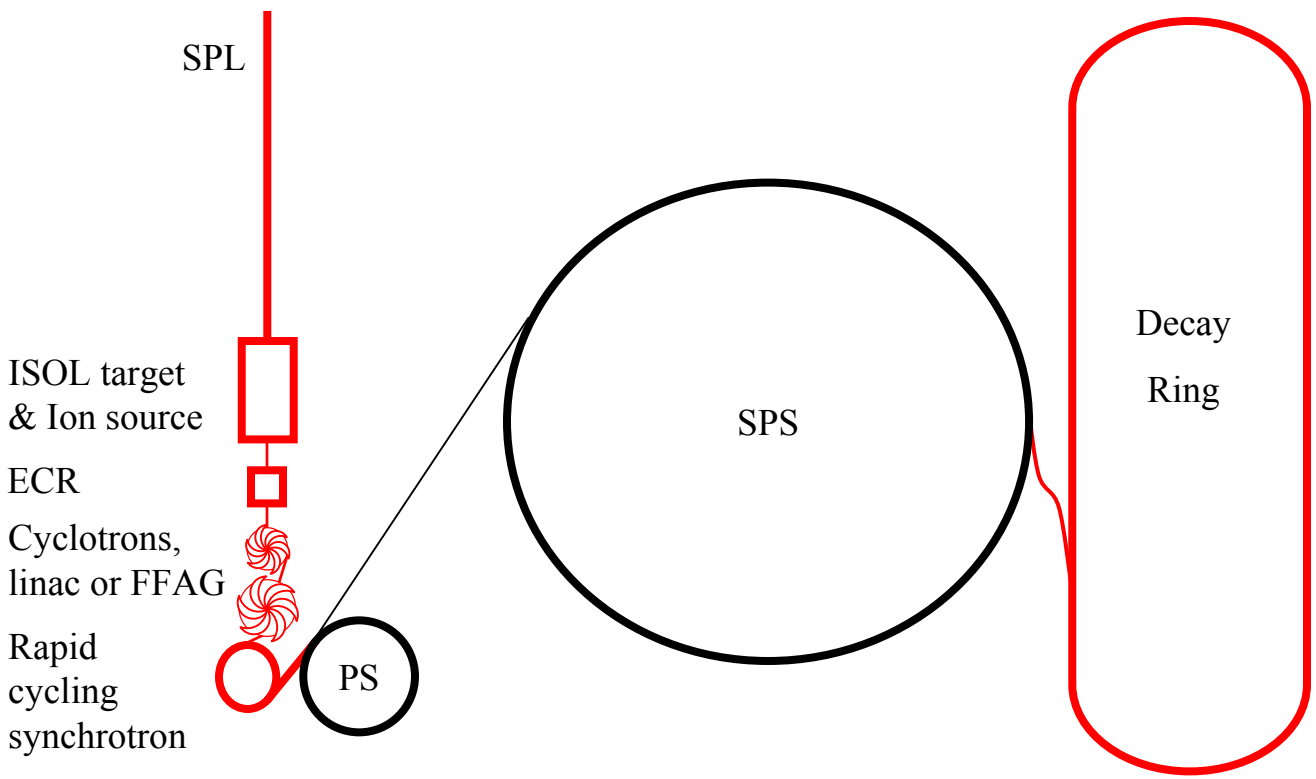
	Fluxes m^2 yr	E (GeV)
$\bar{\nu}_e(\gamma \sim 60)$	1 97 10^{11}	0.24
$\nu_e(\gamma \sim 100)$	1 88 10^{11}	0.36
ν_μ	4 78 10^{11}	0.27
$\bar{\nu}_\mu$	3 33 10^{11}	0.25

More details in J. Bouchez et al., NuFact03 Proc.

Working hypothesis

- Realistic scenario for a beta-beam facility:
  - Use known/existing technology (or reasonable extrapolations of known technology)
  - Any other innovation is used to increase the ions/neutrino flux
  - Re-use the CERN existing accelerators
- Use the SPL as proton injector
  - only less than 10% of the maximum power

Beta-beam baseline design



Decay ring

Brho = 1500 Tm

B = 5 T

L_{ss} = 2500 m

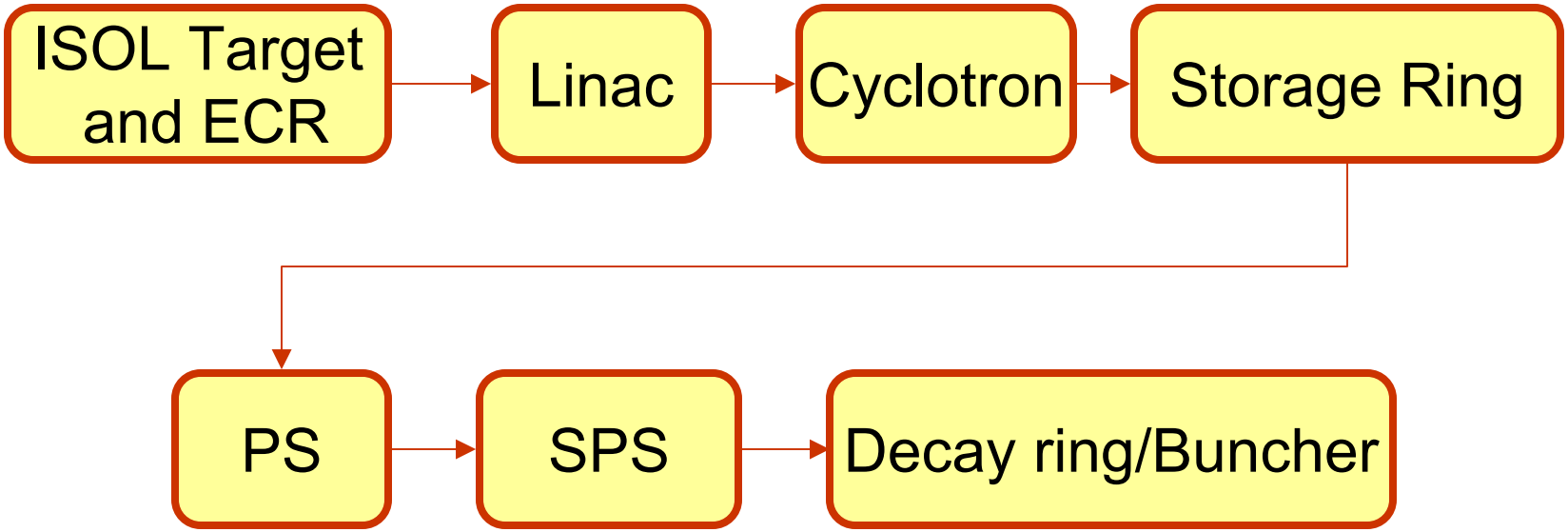
$^{6}_{2}He \rightarrow ^{6}_{3}Li\, e^{-}\, \bar{\nu}$

Average $E_{cms} = 1.937$ MeV

$^{18}_{10}Ne \rightarrow ^{18}_{9}Fe\, e^{+}\, \nu$

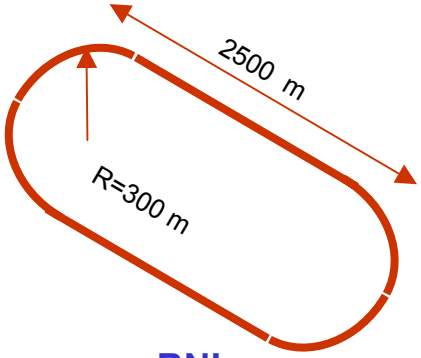
Average $E_{cms} = 1.86$ MeV

The Acceleration principle



Bunch rotation is the crucial issue for atmospheric background control!

Studies are made on EXISTING CERN machines. Why? Much more detailed knowledge exists, the best way to identify possible problems and limitations.



Beam parameters in the decay ring

^{6}Helium^{2+}

- Intensity: 1.0×10^{14} ions
- Rel. gamma: 60
- Rigidity: 1500 Tm

^{18}Neon^{10+} (single target)

- Intensity: 4.5×10^{12} ions
- Rel. gamma: 100
- Rigidity: 335 Tm

- The neutrino beam at the experiment should have the "time stamp" of the circulating beam in the decay ring.
- The beam has to be concentrated to as few and as short bunches as possible to maximize the number of ions/nanosecond.
  - Atmospheric background suppression

M. Lindroos

Conclusions

- Proton driver:
  - good development for the low energy part of the SPL
  - set of dead lines fixed by CERN management
  - international collaboration (Russia + Europe)
  - Superbeam design still under study
    - Beam optimization
- Physics:
  - Strong interest from community
  - Super beam, beta-beam and FREJUS: WORLD unique
  - Please attend the talk by V. Palladino this friday