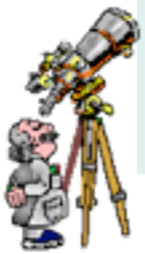
Possibilities for future ν beams at CERN



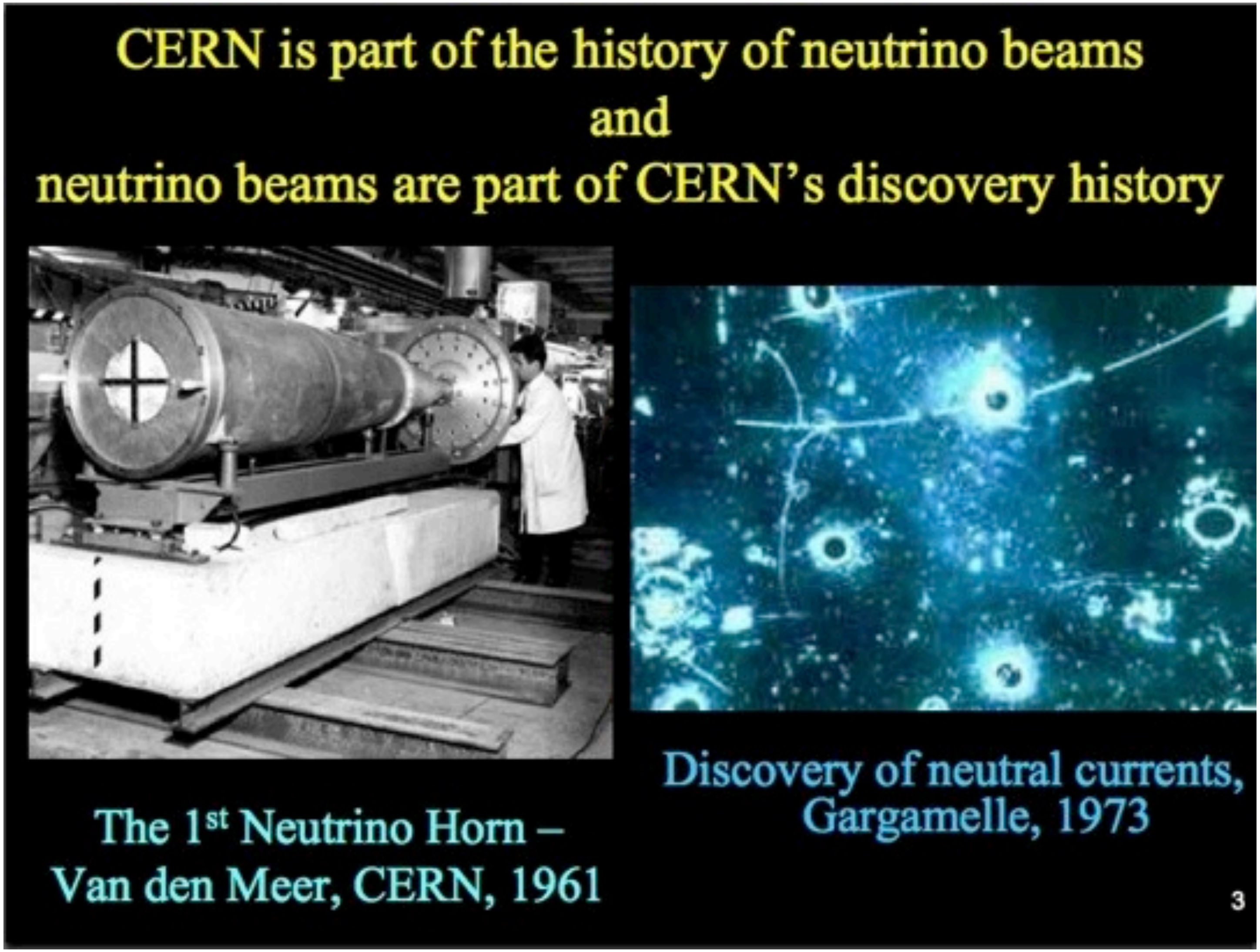
I. Efthymiopoulos - CERN

Many thanks to: M. Dracos, R. Garoby, E. Gschwendtner,, A. Guglielmi, K. Long, F. Pietropaolo, A. Rubbia, R. Steerenberg, E. Wildner

XIV International Workshop on "Neutrino Telescopes"
Venice - March 17, 2011

ν beams and CERN

Courtesy: C. Touramanis – CERN Neutrino Strategy Workshop



ν beams at CERN – The present

CERN Neutrinos to Grand Sasso, IT - CNGS

ν beams at CERN – The present

- **CNGS** is THE neutrino oscillation facility in Europe
- ν_τ **appearance** optimized detectors: **OPERA**(1.2kt) **ICARUS** (0.6kt)

- Installation completed in **June 2006**
- In physics operation since **2007**

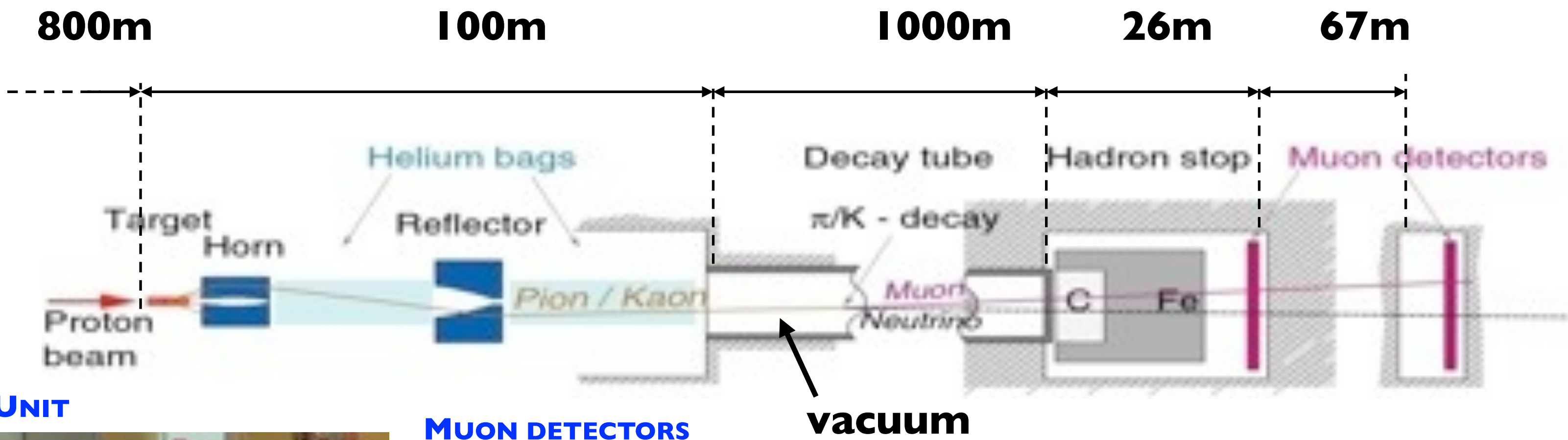
Proton beam parameters	
Energy	400 GeV/c
Cycle length	• 6 seconds • 2 extractions/cycle, 50ms apart
Extraction	• 2.4 x 10^{13} protons • 10.5 μs long pulse
Beam power	• **500 kW**

Approved program:

- **4.5 × 10^{19} protons/year** – 5 year program
- ~3.5 × 10^{11} ν_μ/year at Grand Sasso
- ~3000 CC ν_μ interactions/kt/year at the experiment
- **~2÷3 ν_τ interactions detected/year** (OPERA)

CNGS - Conventional ν beam

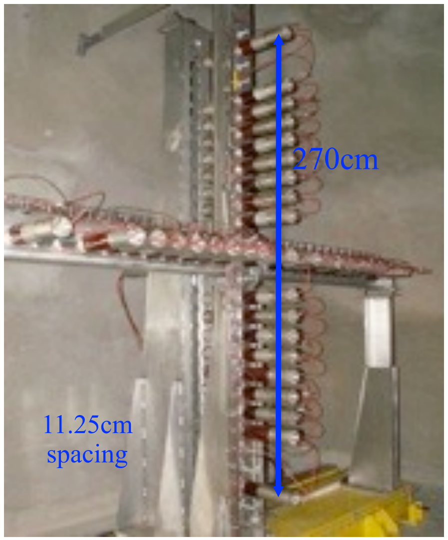
$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay)} \rightarrow \mu^+ + \nu_\mu$



Target Unit

- C rods
- 5(4) mm Ø
- 5 in-situ spares

Muon detectors

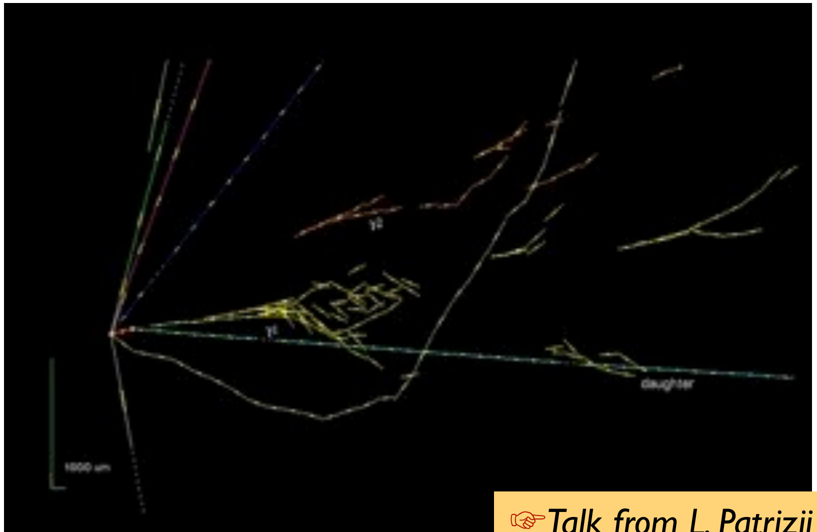


- 2 × 41 fixed monitors
- 2 × 1 motorized monitor

Magnetic Horns

CNGS - Performance

First ν_τ **event** from OPERA

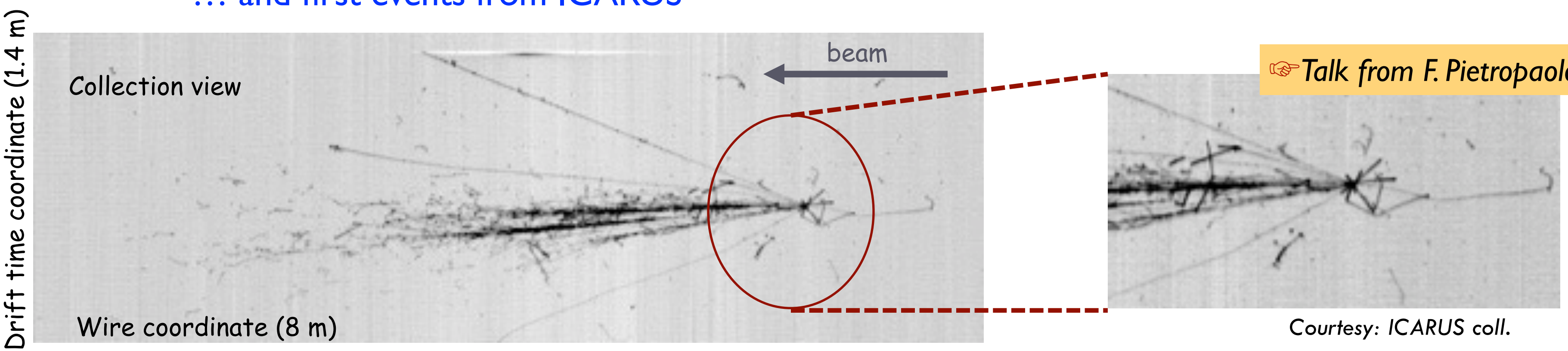


☞*Talk from L. Patrizii*

Courtesy: D. Autiero

	Protons on Target
2006 (commissioning)	*0.09×10^{19}*
2007 (commissioning- HI)	*0.08×10^{19}*
2008 – physics run	1.79×10^{19}
2009 – physics run	3.58×10^{19}
2010 – physics run	4.04×10^{19}
Total	**9.41×10^{19}**
2011 – physics run (221d)	**4.7×10^{19}**

… and first events from ICARUS



☞*Talk from F. Pietropaolo*

Courtesy: ICARUS coll.

CNGS – Operation

- The design and operation of a **high-intensity**, **high-power** (0.3-0.5MW of beam power) facility is always very challenging

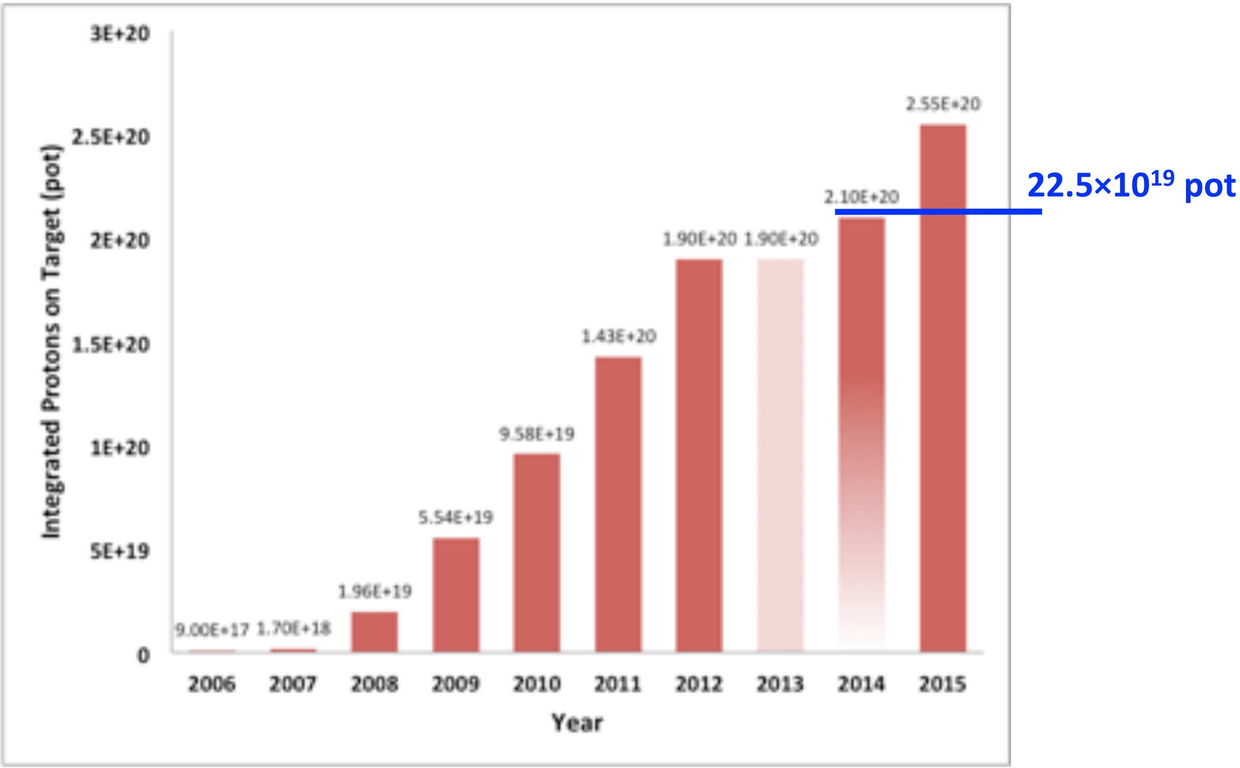
- **Design:**
  - Choice of **materials**, facility **layout**, **shielding**, **radiation** environment
  - Technical challenges during **construction**

- **Operation :**
  - Possibility for **early repairs** must be included in the design
  - Radiation effects on **proximity electronics** should be looked at
  - The **ventilation system is a key element** that has a double challenge: temperature/humidity control, and management of radioactive air
  - **H-3** creation (air, water) should not be forgotten !

- Important lessons, in view of future facilities with (M)**MW** of beam power !

CNGS – Planning

- The presently approved program will be completed by 2014-2015
  - assuming **4.7 × 10^{19} pot/y** for 2011, 2012



ν beams at CERN – The Future

- predicting the future is an old story

  .... but with questionable efficiency !

Aegeus, King of Athens consulting the Delphic Oracle, Greek Vase, Altes Museum - Berlin, Ge

- Strong participation of European Labs in accelerator ν physics programs worldwide
  - **T2K** neutrino beam
  - International Design Study

    for a Neutrino Factory (**IDS-NF**)

- CERN/Europe plays and can/should continue playing a leading role in the Neutrino Physics

Courtesy: T. Hasegawa
CERN Neutrino Strategy Workshop

Accelerator ν Physics in Europe (besides CNGS)

- EC funded design studies
  - **EUROnu** – Design Study for Super-beam, β-beam, ν-factory
  - **EUCARD** – Neu2012 (network activity) – MICE (transnational access)
  - **LAGUNA** – Water Cherenkov, LArgon, Scintillator Detectors
    - **LAGUNA-LBNO(proposal)** - Detectors + beams from CERN
- R&D Activities – prototypes
  - **MERIT@CERN** - high-power targetry experiment
  - **MICE@RAL** - muon ionization cooling experiment

ν beams at CERN – a possible roadmap

ν beams at CERN – a possible roadmap

Short timescale

- Conventional LBL ν-beams from SPS (400 GeV)
  - Exploit the CNGS technology, sub-MW class facility
    - **CNGS+** : intensity upgrade, new focusing scheme for low ν-beam energies
- Conventional SBL ν-beam from PS (20 GeV) – **PSNF**
  - Dedicated experiment on sterile neutrinos
  - Test bed for detector and targetry R&D, x-section measurements

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Medium timescale

- Conventional LBL ν-beams from SPS (400 GeV)
  - 750kW beam to a new site (**CN2?**)
- Upgrade using LP-SPL as proton driver, new HPPS (30 GeV)
  - ~MW class facility (**CN2?-HP**)

ν beams at CERN – a possible roadmap

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The BIG picture – ultimate facilities

- Super beams, β-beams, Neutrino Factory
  - HP-SPL and new accelerators, MMW class facilities

CNGS Upgrade Possibilities

- **Limitations:**
  - key elements of the secondary beam line: target, horns, beam windows
  - layout and RP considerations, SPS RF and beam extraction system
- **CNGS upgrade ⇔ SPS upgrade:**
  - Possibilities will be studied within the LHC Injector Upgrade project (**LIU**) and followed in **LAGUNA-LBNO**
    - **750kW** may be reachable, going beyond would require substantial consolidation of the facility

Int. per PS batch	# PS batches	Int. per SPS cycle	200 days, 100% efficiency, no sharing	200 days, 55% efficiency, no sharing	200 days, 55% efficiency, 60% CNGS sharing
		[prot./6s cycle]	*[pot/year]*	*[pot/year]*	*[pot/year]*
2.4×10^{13} - Nominal CNGS	2	4.8×10^{13}	**1.38×10^{20}**	**7.6×10^{19}**	**4.56×10^{19}**
3.5×10^{13} - Ultimate CNGS	2	**7.0×10^{13}**	2.02×10^{20}	1.11×10^{20}	6.65×10^{19}

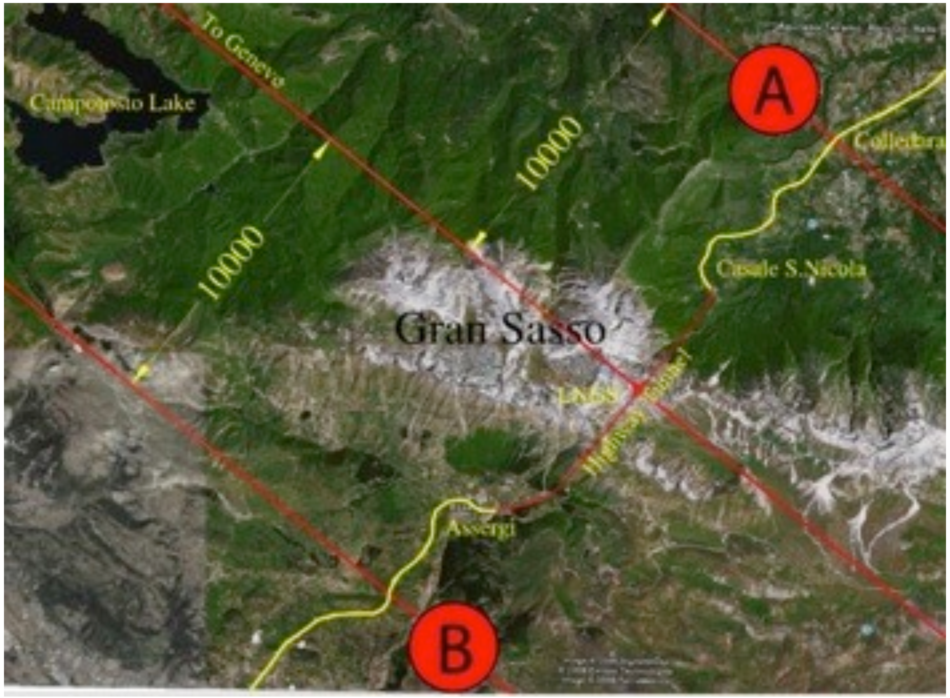
750kW design limit for the target

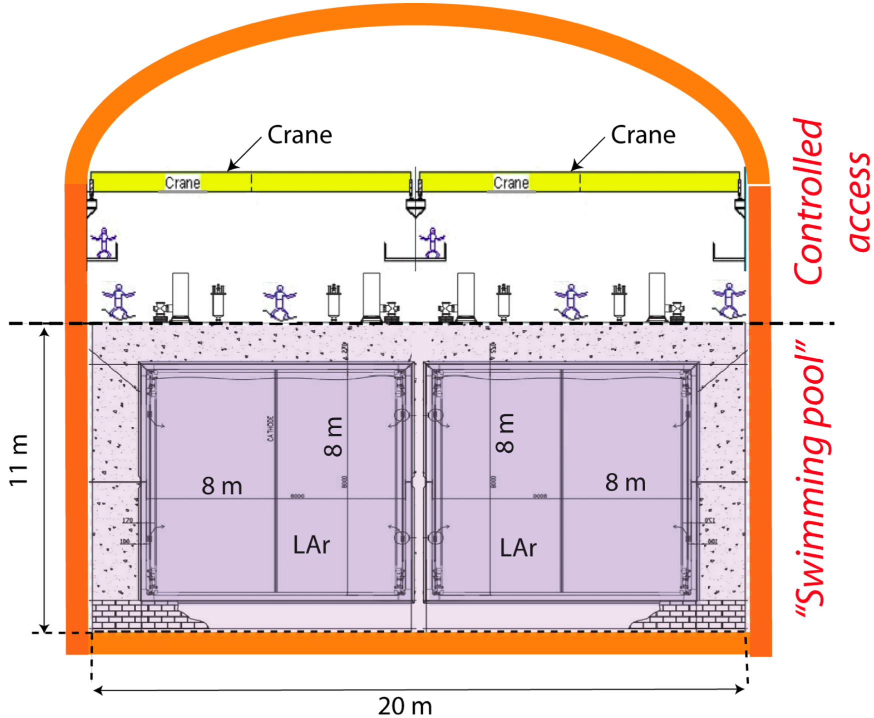
working hypothesis for RP calculations

M.Meddahi, E.Schaposnicova - CERN-AB-2007-013 PAF

Future CNGS experiments?

- **MODULAR proposal** APJ 29 (2008) 174
  - New 10km off-axis experiment
    - 20kt(4×5kt) LArgon-TPC based on the ICARUS-T600 technology (× 2.66 scale-up)
- MODULAr/CNGS (400 GeV, 1.2 10^{20} pot/yr) ~ NOvA/NUMI (120 GeV, 6.5 10^{20} pot/yr)





Event rates in MODULAR

- 20 kt, 5 y, 1.2 10^{20} pot/y, $\sin^2(2\theta_{13})=0.1$

ν_μ CC	bkg	Signal	S/√(bkg)
5700	28	250	47

From conventional to super ν-beams

- A staged approach to intensity

JPARC	**T2K (300km)** – **0.11MW** operation in 2010	**T2K (300km)** – expected **0.75MW** gradually ~2014	**T2K (300km) T2O(658km)** – expected **1.66MW** operation, by >2014
FNAL	**NUMI/MINOS (700km)** – **0.3MW** sustained operation	**NUMI/NOVA (700km off-axis)** – **0.75MW** upgrade (~2013)	**LBNE/DUSEL (1300 km)** – **2MW** operation requires Project-X
CERN	**CNGS (732km)** – **0.3MW** sustained operation, **0.5MW** if no beam sharing	**CNGS+ (732km) or CN2PY (2300km)** – **0.75MW** "ultimate", requires SPS and injector upgrade	**CN2PY(2300km) CN2FR(130km)** – **2MW** operation requires LP-SPL+HPPS, or HP-SPL+Accumulator

LAGUNA-LBNO, EUROν FP7 Design Studies

LAGUNA/LAGUNA_LBNO FP7 Study

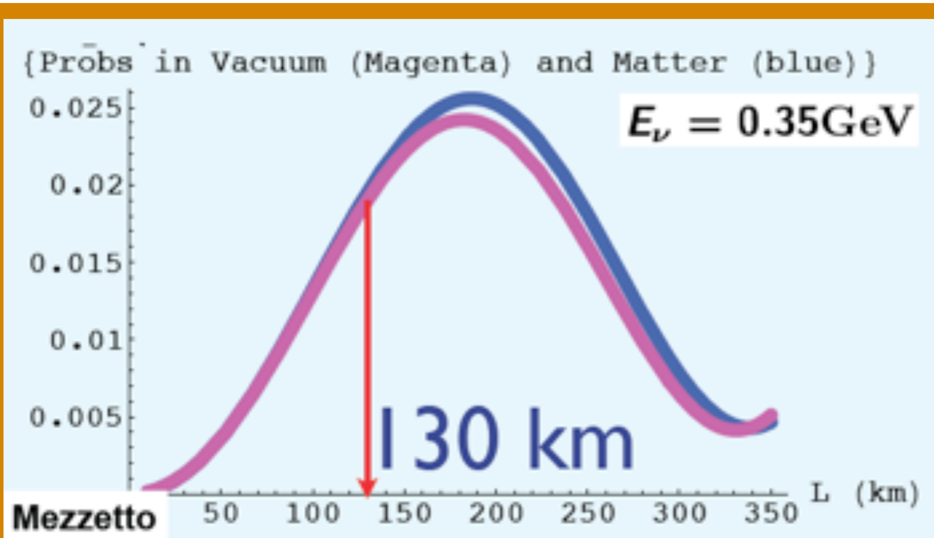
Courtesy: A. Rubbia, LAGUNA

☞*Talk from A Rubbia*

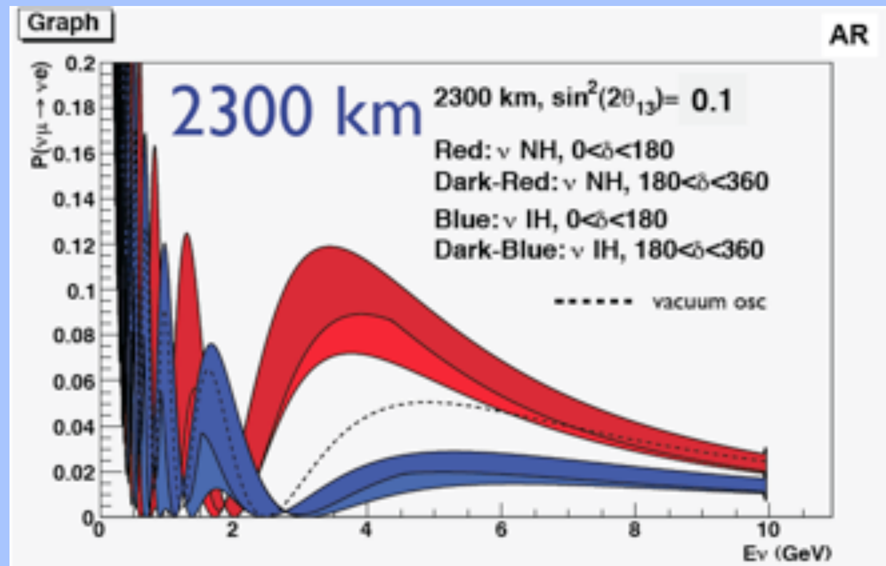
Conventional ν-beams from CERN

Courtesy: A. Rubbia, LAGUNA

- CERN-Frejus (130km) & CERN-Pyhasalmi(2300km): Very short/very long baseline combination for unique physics opportunities in Europe



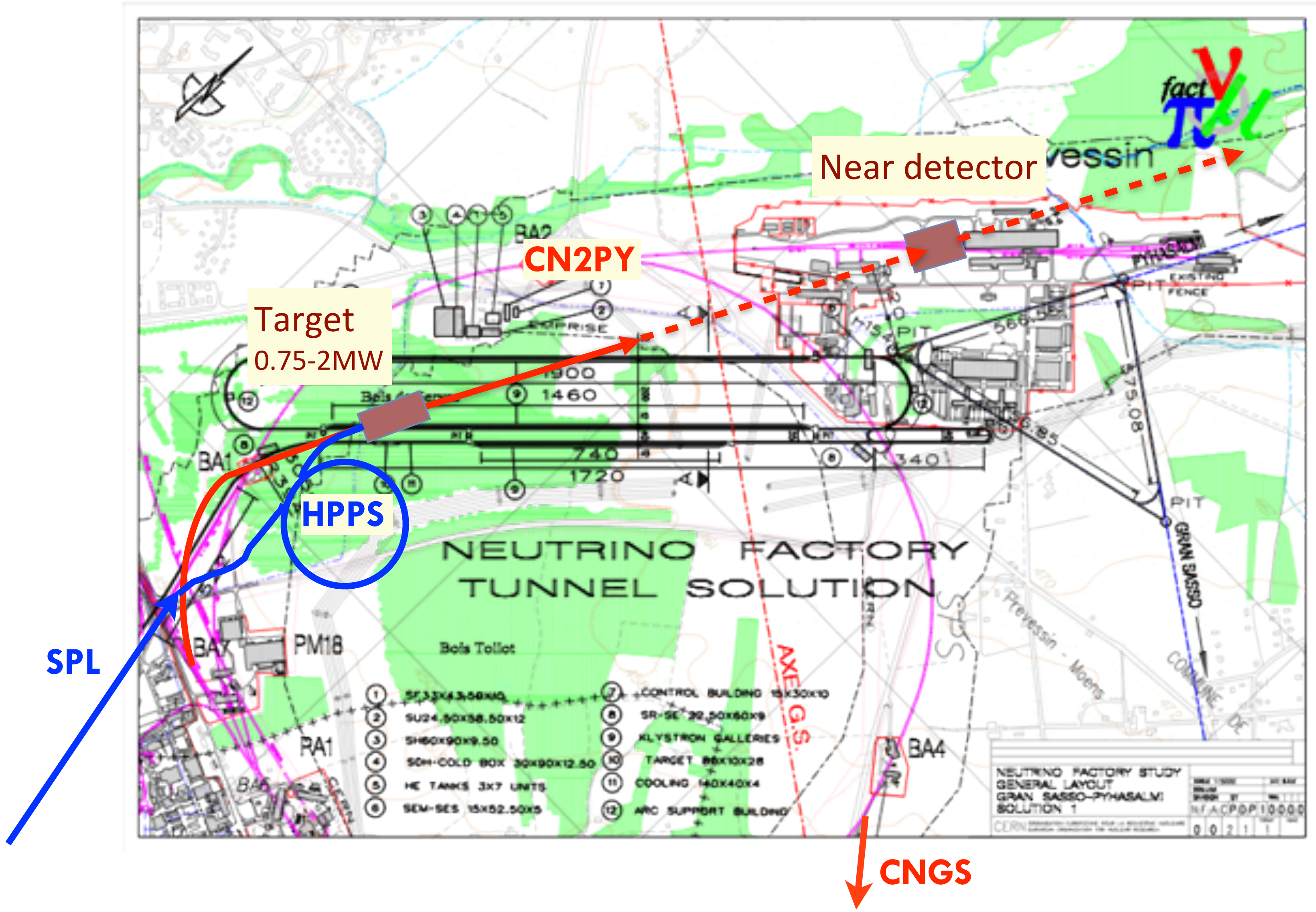
- Determine CP-violation by comparison of ν/anti-ν in absence of competing matter effects
- Very low energy beam, huge (WC) detector



- Determine CP-violation and mass degeneracy by spectrum measurement and resolve degeneracies and so called "π-transit" effect
- arXiv:0908.3741.v1 for "Magic distance"

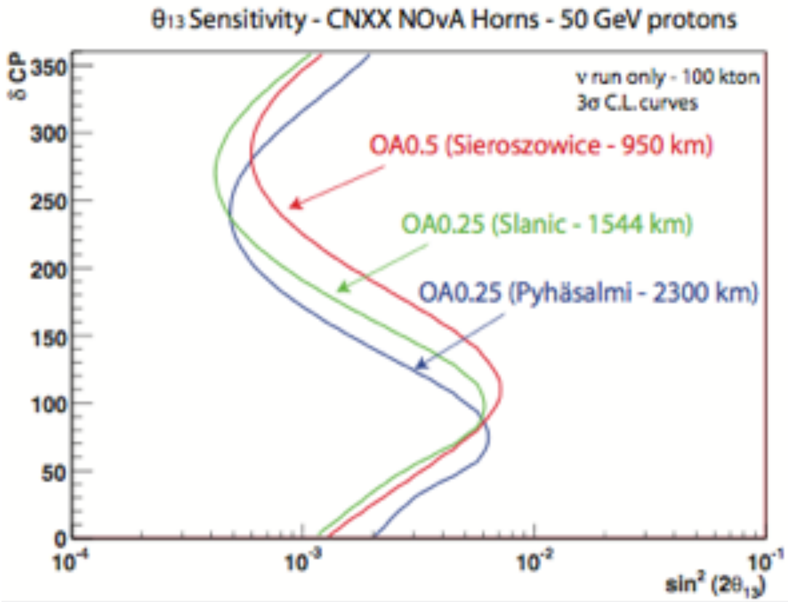
- … and synergies:
  - **CERN-Frejus** : adequate baseline/energy for β-beam
  - **CERN-Pyhasalmi** : adequate baseline for Neutrino-Factory

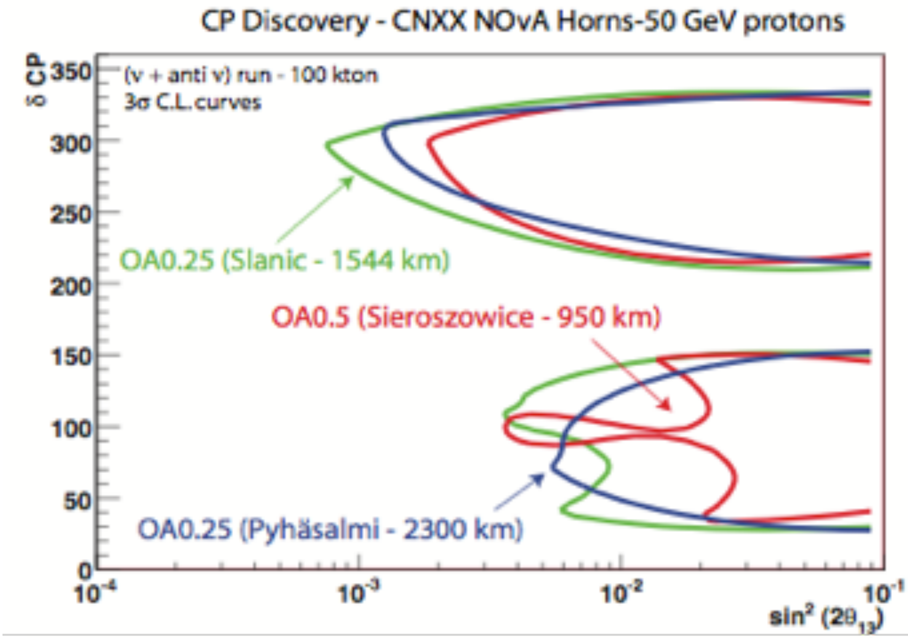
CERN ν-beam to Pyhasalmi - CN2PY

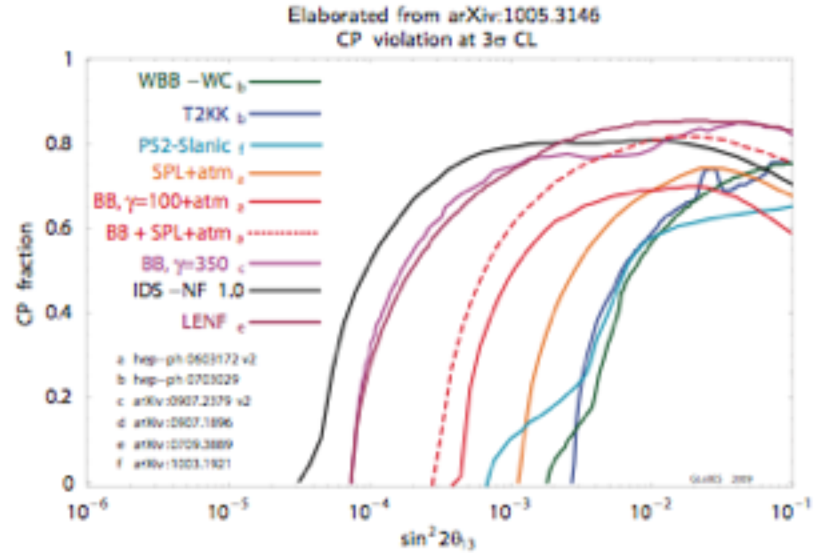


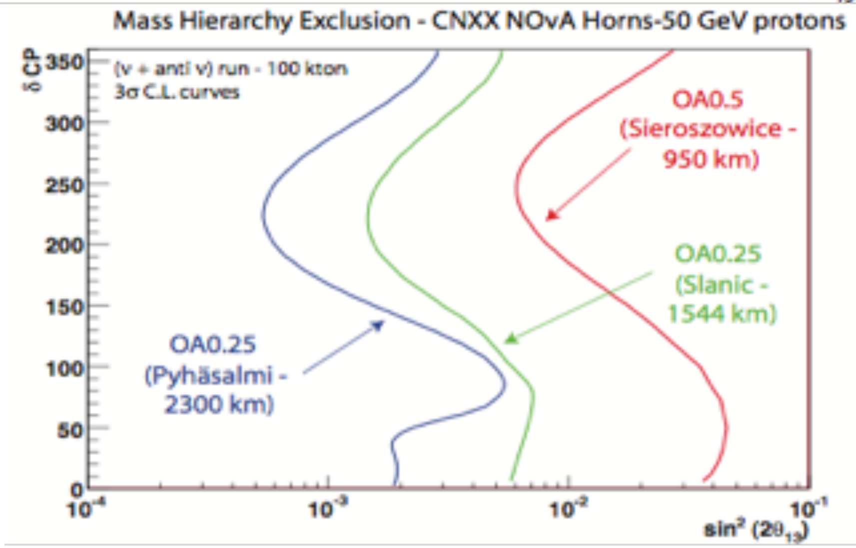
CN2PY-HP - Physics Reach

Courtesy: A. Rubbia, LAGUNA







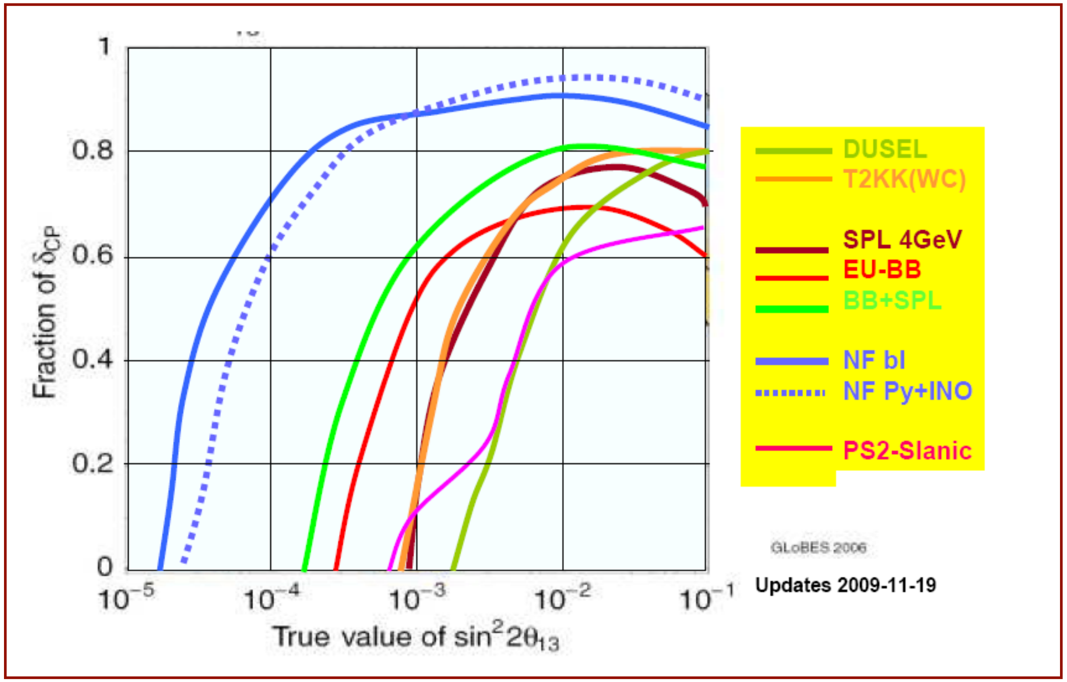


CN2PY - Technical challenges

- CN2PY will profit from the CNGS experience but can't be just a "copy"
- **Key issues to address:**
  - Target station design: 0.75 - 2 MW
    - investigate the option for a future upgrade to MMW use as target station for a NeutrinoFactory
  - Optimized target/horn secondary beam optics for low energy neutrinos
  - SPS extraction system for high-intensity beams using the existing extraction channel (TI2) for LHC
  - Decay tube and **near detector with 10-deg slope**
- Enhance synergies and collaboration with teams working on neutrino beam lines in Japan and US
  - **NBI workshop March 2012 @ CERN - NBI2012**

The BIG picture - Ultimate Facilities

- **Precision measurements**
  - Mass hierarchy
  - CP-violation
  - θ_{13} - if only limits until then
  - Understand and measure the ν-mixing parameters
  - Understand the differences between the quark and lepton sectors
  - Physics beyond the SM?

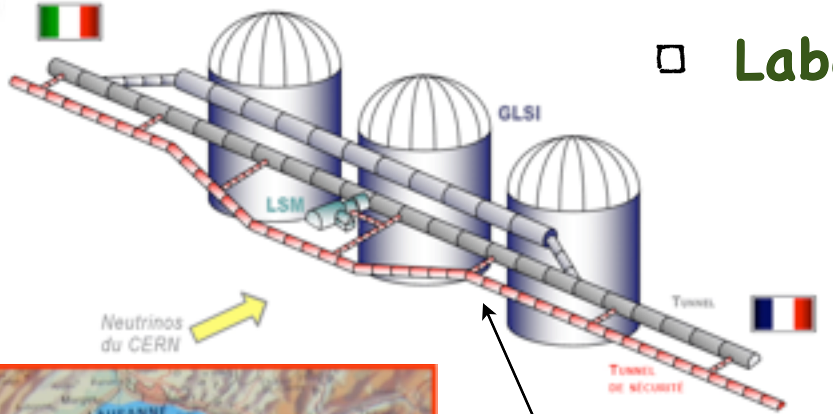


- **Possible options:**
  - **Option-I** : super-beam & beta-beam from CERN to Frejus
  - **Option-II** : LBL from SPS (power-beam) followed by Neutrino Factory

Super-beam to Frejus

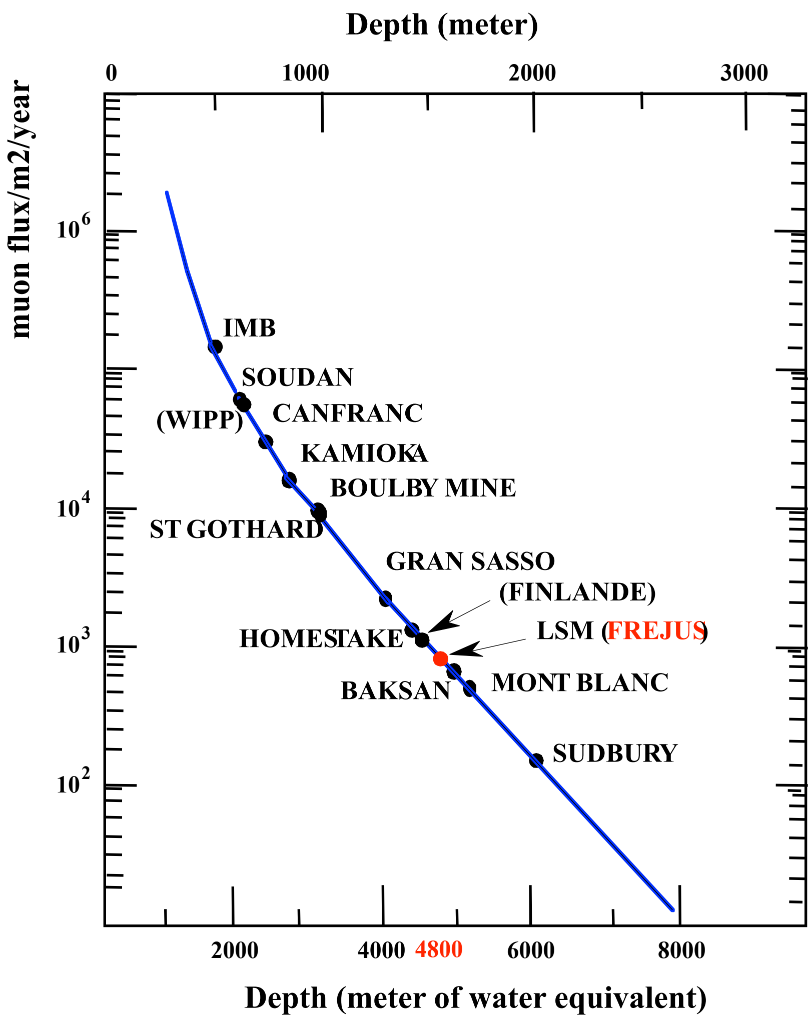
Courtesy: M. Dracos, EUROnu

- Laboratoire Souterrain de Modane

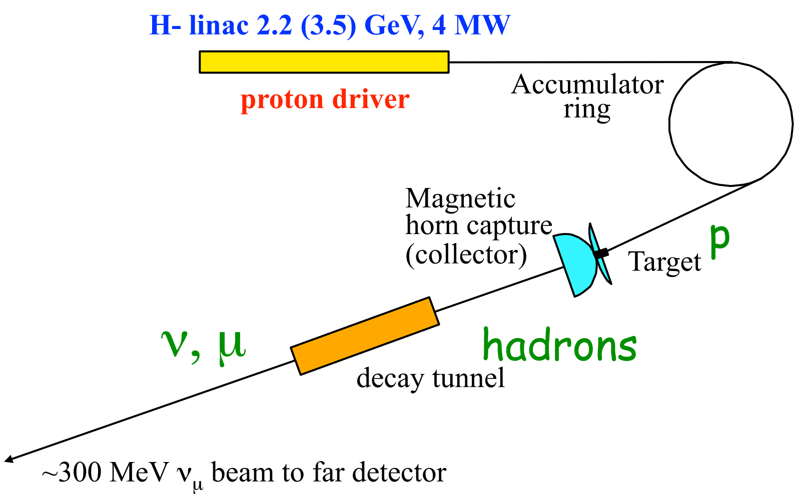


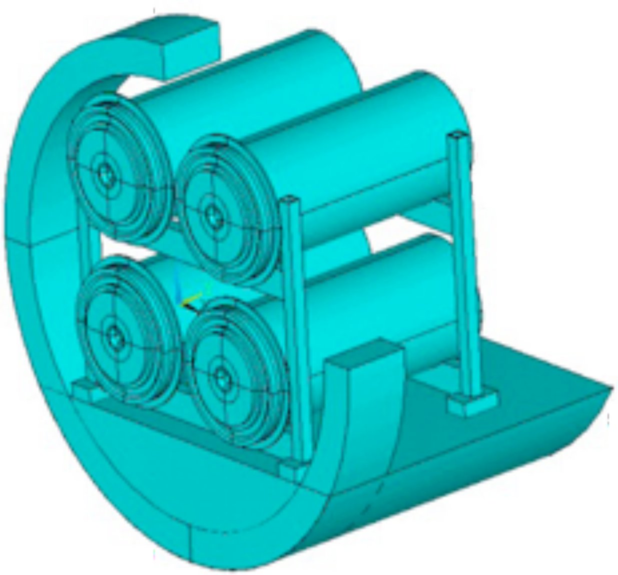
Profit from the excavation of the new safety gallery to prepare the detector caverns

- Water Cherenkov detector with **440kt** total fiducial mass
- 3 cylinders 65x65m
- Conventional ν-beam with **HP-SPL as the proton driver**



CERN ν-sbeam to Frejus - CN2FR

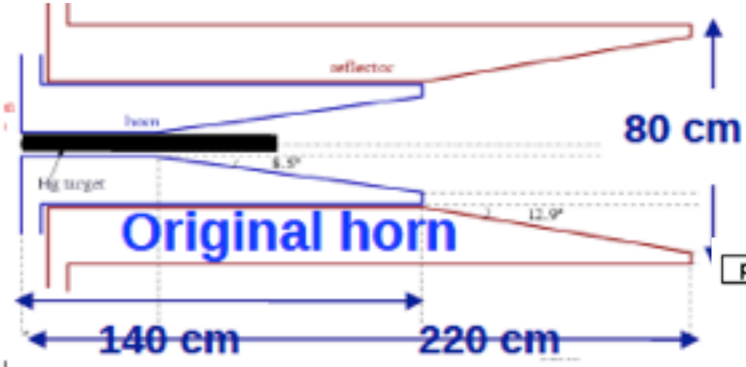


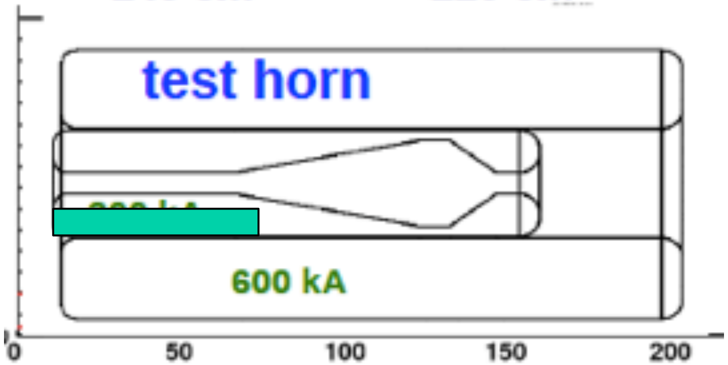


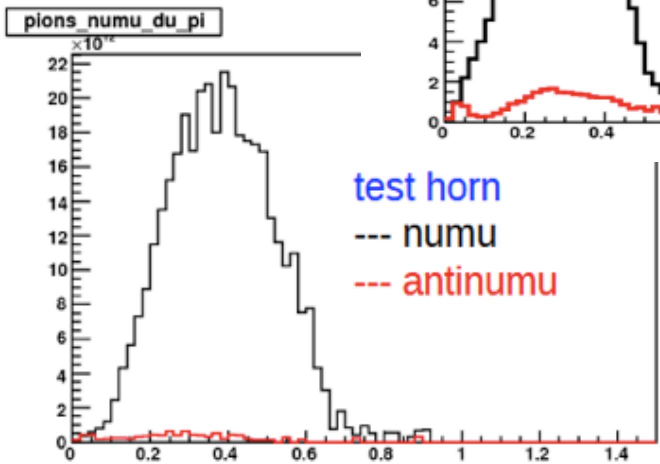
- **Technical challenges:**
  - **Target design**
    - impact of the 4MW beam
  - **Horn design**
    - high current, mechanical constraints due to physics requirements, radiation, high-current (heating), pulsing
- **Solution:**
  - **4 × 1 MW = 4 MW !!!!**
  - four target/horn assemblies mounted together in a mechanical structure

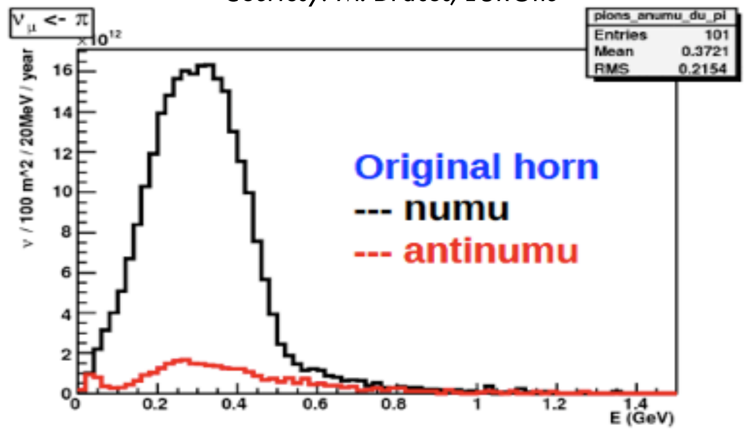
CN2FR - horn optimization

Courtesy: M. Dracos, EUROnu

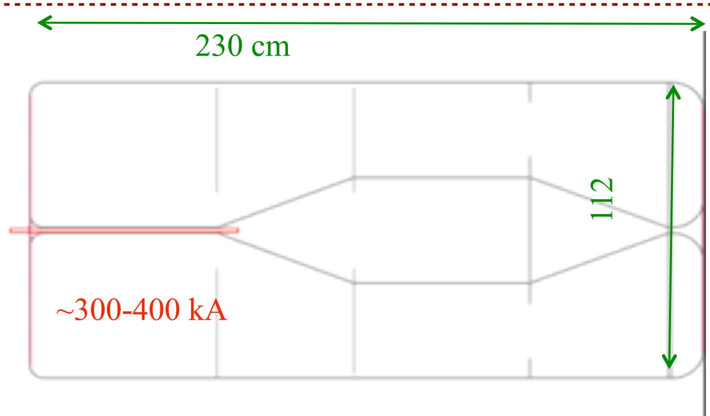








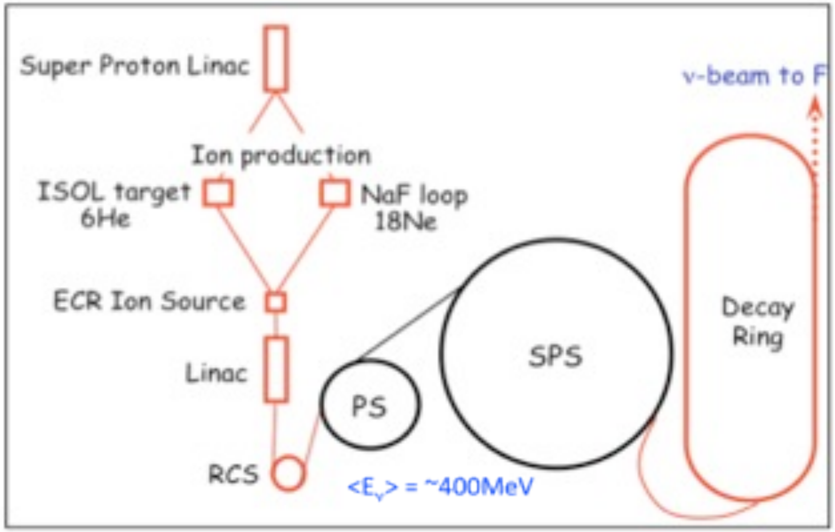
- **Latest design**
  - single horn with reduced current
- **Target**
  - solid C(Be?) rod inserted into the horn or Be pebble



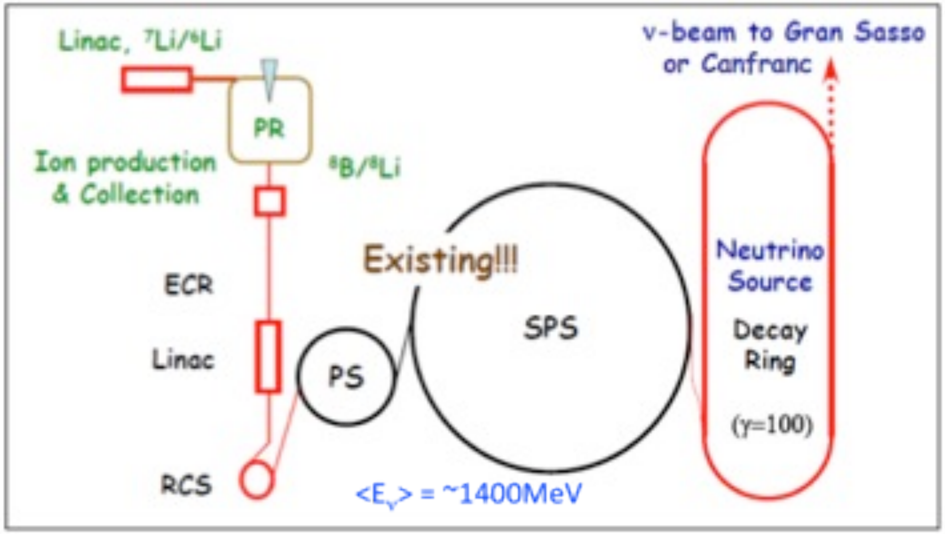
β-beam : Pure $\nu_e, \bar{\nu}_e$ beams from CERN

Courtesy: E. Wildner, EUROnu

Detector @ Frejus (130 km)



Detector @ Canfranc/Gran Sasso (~ 700 km)



- **Beta Beams: acceleration of beta active isotopes**
- Unique facility for CERN:
  - Reuse of CERN existing accelerators and infrastructure ⇒ **cost reduction**
  - Known technologies
  - Ion Production: ISOL technique, ion production ring, molten salt loop
- Synergies with Super beam to Frejus for enhanced physics reach

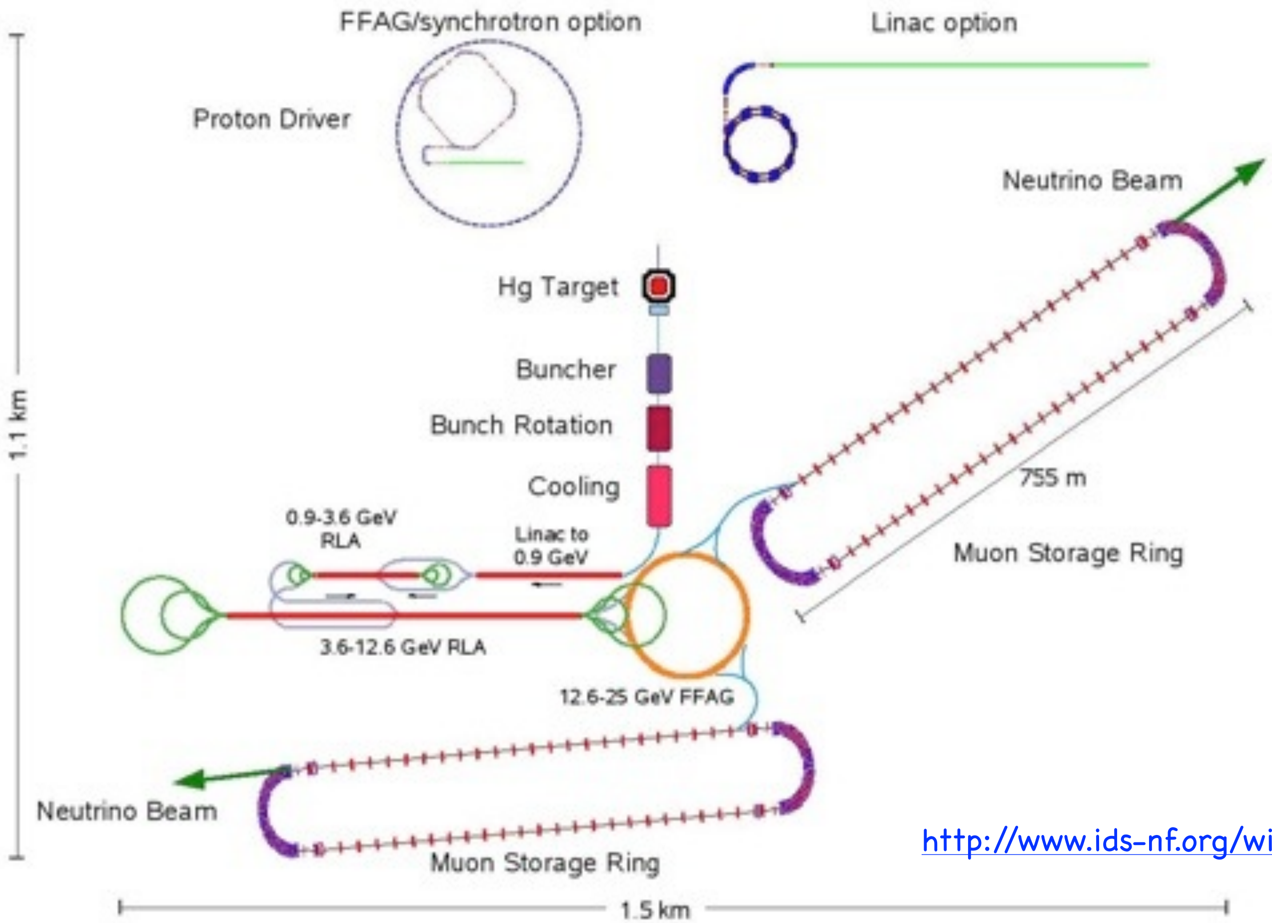
EURISOL Design Study

☞*Talk from E.Wildner*

Neutrino Factory

Courtesy: EUROnu & IDS-NF

p+ C (int) → $\mu^{\pm}$ (capture, accelerate, store, decay) → ν_{μ}, ν_{e}



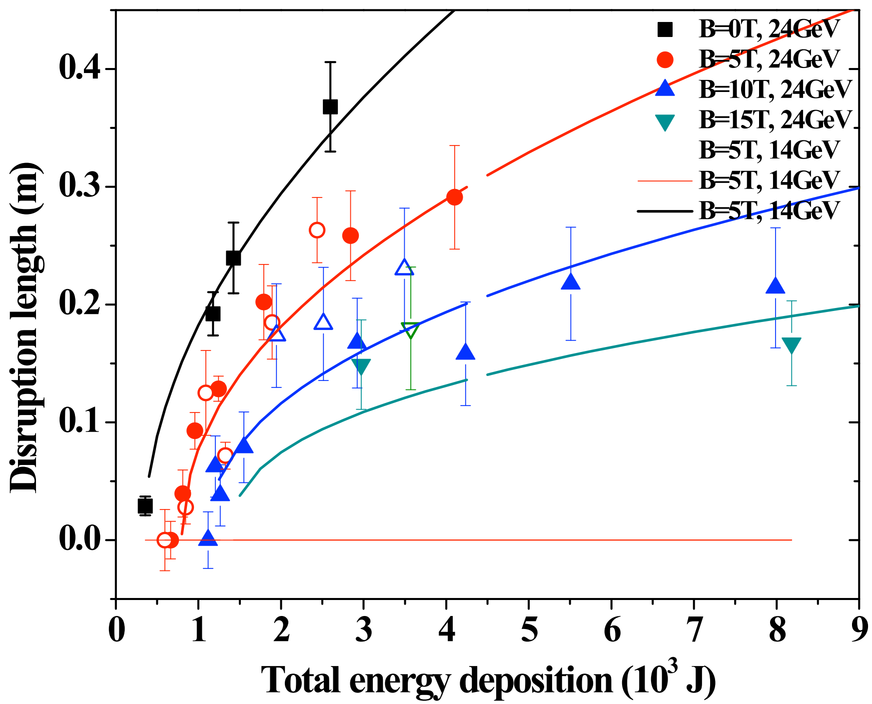
☞Talk from K. Long

http://www.ids-nf.org/wiki

Ultimate facilities – Technical challenges

- Design and operate MMW facilities is not trivial
- Key issues where present R&D effort is concentrated:
  - Production :
    - **Super-Beam**: secondary beam elements : target
    - **Neutrino Factory**: Front-end system : target
    - **β-beam** : ion production
  - Beam handling :
    - **Super-Beam**: horns
    - **Neutrino Factory**: capture, cooling channel, RF & absorbers Beam dump, fast acceleration
    - **β-beam** : collective effects, ion losses & radiation
  - Beam delivery :
    - **Super-Beam**: decay tunnel – dump
    - **Neutrino Factory**: storage ring slopes, beam monitoring
    - **β-beam** : decay ring
    - … and ν-beam monitoring & near detector

High-Power targetry



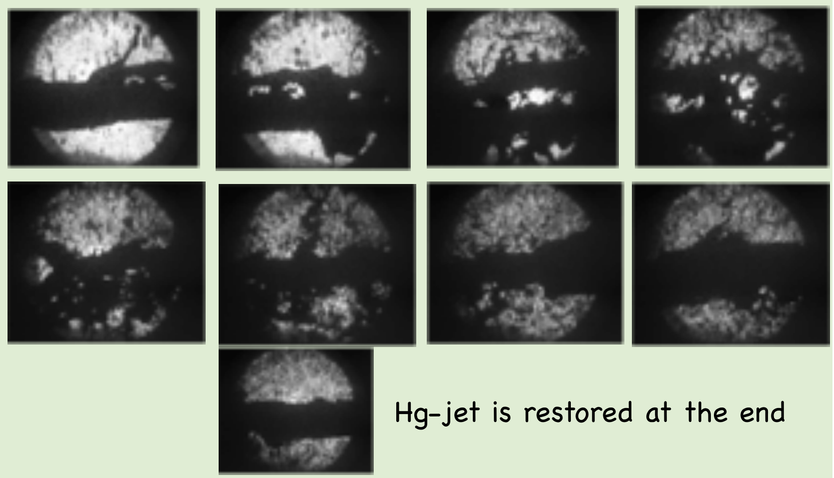
- **The MERIT Experiment @ CERN PS**

High-Power **Liquid Hg-jet** experiment, proof-of-principle of a target system for a ν-Factory or μ-collider

Key results #1

- Hg-jet disruption mitigated by magnetic field
  - 20 m/s jet operation allows up to **70Hz** operation with beam

Hg-jet - beam impact 16×10^{12} p, 5T field, 14 GeV/c



Hg-jet is restored at the end

Key results #2

- Disruption threshold: **>4×10^{12} protons@14 GeV, 10T field**
  - **115kJ** pulse containment demonstrated

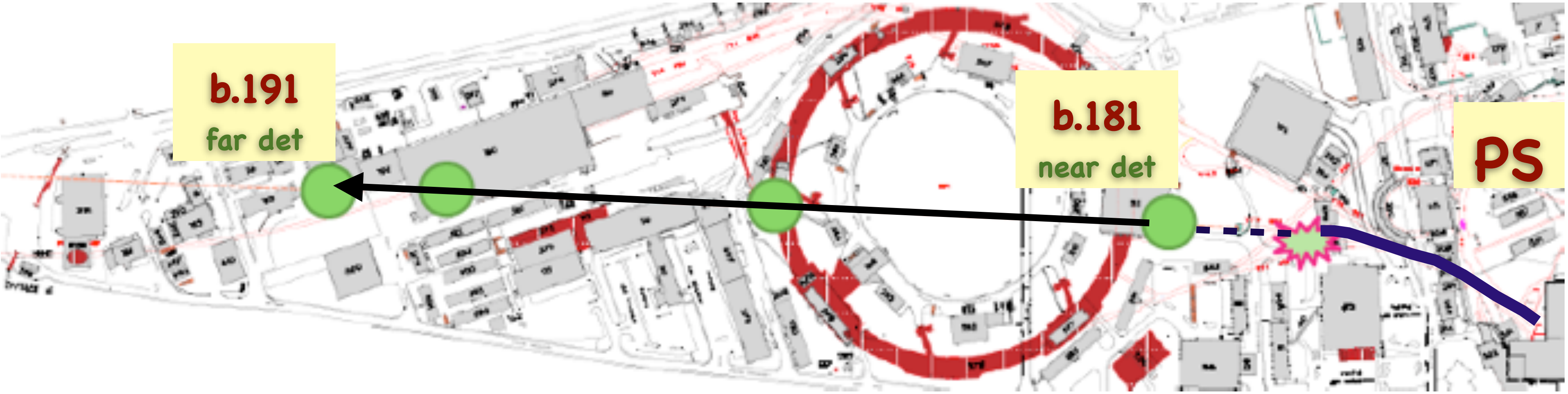
    8 MW capability demonstrated

PS – Short Baseline ν-beam

- A search for anomalous neutrino $\nu_\mu \rightarrow \nu_e$ oscillations at the CERN PS with LAr-TPC detectors

C. Rubbia et al

☞ *Talk from C. Rubbia*



- Beam line originally operated in early 80's for PS169, PS181, PS180(BEBC) experiments
- PS beam possibilities (180, 85% efficiency) :
  - $6.13\ 10^{19} \div 2.02\ 10^{20}$ from zero to max impact to PS users

	Old neutrino facility		New neutrino facility		
	PS dedicated Feb-Mar 1983	PS parallel 1983 - 1984	PS dedicated	PS parasitic	PS ultimate[2]
Proton Momentum	19.2 GeV/c	19.2 GeV/c	20 GeV/c	20 GeV/c	26 GeV/c
Protons/pulse	1.25×10^{13}	1.2×10^{13}	3×10^{13}	2.6×10^{13}	4×10^{13}
Max. rep. rate	1.2 s	14.4 s	1.2 s	1.2 s	1.2
Beam energy	38 kJ	38 kJ	96 kJ	84 kJ	166 kJ
Average beam power	32 kW	2.5 kW	80 kW	70 W	140 kW

Courtesy: R. Steerenberg – CERN

From design studies to projects

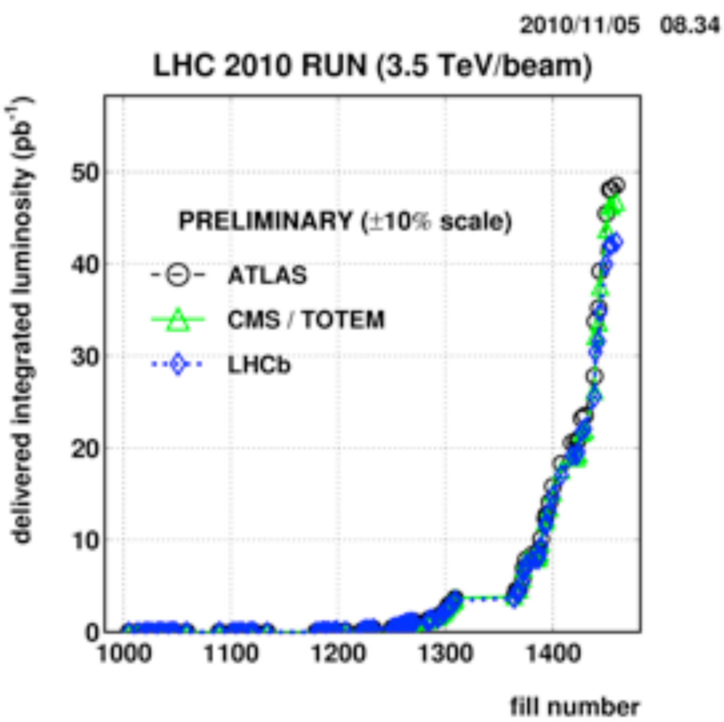
The European strategy for particle physics

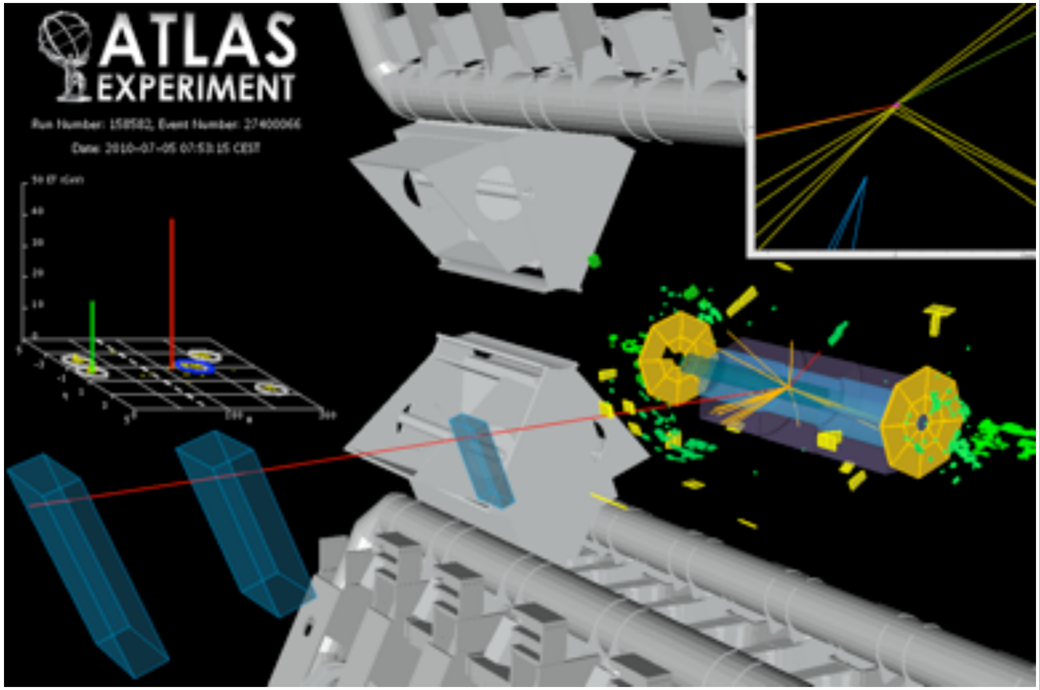
4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

6. 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.*

CERN – towards the energy frontier

- **LHC is the new world's high-energy machine**
- The first year of operation was just completed with excellent performance for **protons** and **ions**





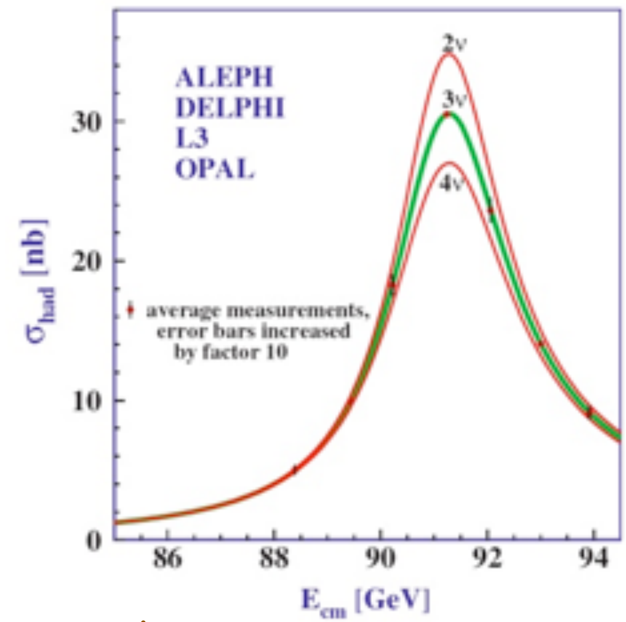
Begun probing physics at the TeV scale!!

ν beams at CERN – what future ?

The opportunity ...

- New results are expected soon to justify the physics case of a future ν-program in // or as a post-LHC project

- **LHC** : is physics beyond the SM?
- **CNGS**: # ν_τ events to expectations?
- **T2K**: θ_{13} measurement/new limits
- **Reactor** experiments
  - Θ_{12}, θ_{13} measurement/new limits



LEP's contribution to ν-physics ~21 years ago!

...and of course any unexpected physics !!!

ν beams at CERN – what future ?

… and the challenge

- Future ν-facilities will require:
  - Innovative ideas and new technologies to be developed
  - **Collaboration** and **coordination** for accelerator and detector R&D at a **global** scale
  - Define a **prioritized roadmap** of facilities to **make ν-physics a valid option for the field and CERN**
  - Support from a large and **focused** community to propose the ν-physics as an interesting physics program for CERN/Europe in // to LHC and its upgrades

CERN

UNIVERSITÉ DE GENÈVE

NuFACT-11 @ CERN / Univ. Geneva

1-6 August 2011

International Neutrino Summer School

Geneva 18-30 July 2011

EuCARD