Long Baseline ν beams at CERN

I. Efthymiopoulos - CERN

EUCARD - Annual Meeting
Paris - May 12, 2011

Long Baseline ν beams at CERN

Possible

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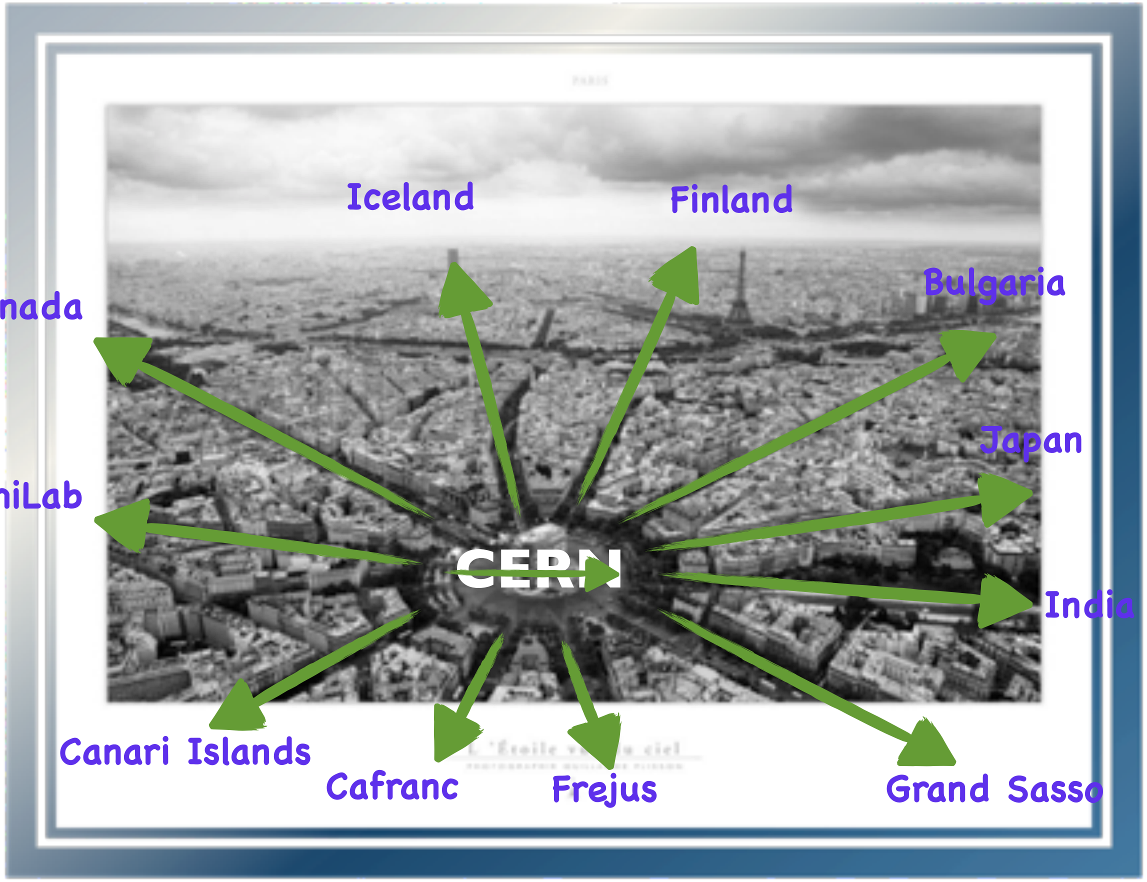

EUCARD - Annual Meeting
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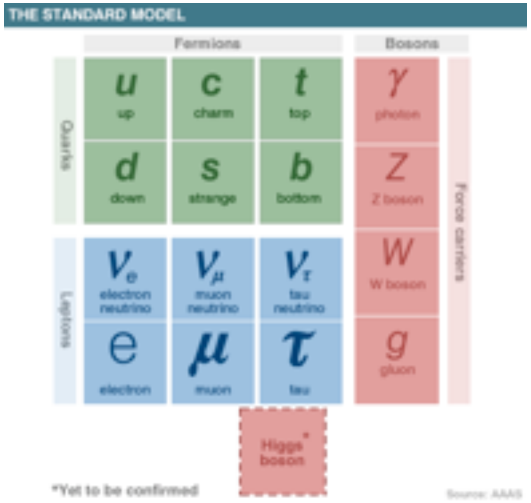
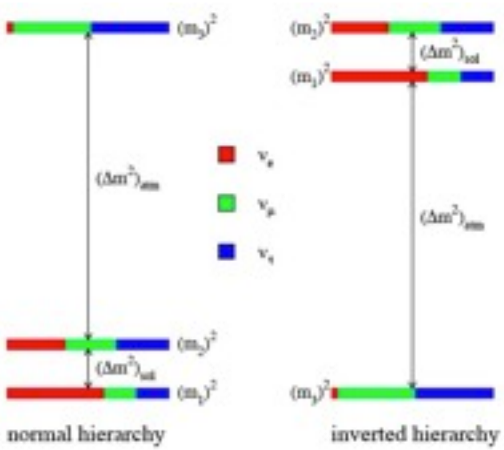
Why study ν physics & beams ?

- νs are part of the Standard Model (SM), yet the least understood particles
  - yet there are in large abundance around us: **6.5×10[10]** solar ν_s traverse 1 cm[2] per second in Earth
  - we know they have masses because they oscillate, but which and why (hierarchy)? are there only 3-neutrino families?



- νs call for an extension to the SM
  - as they seem to have (small) masses that is not foreseen
  - probe for physics beyond the SM but what type of extension is required? trivial of hints for a more fundamental theory?

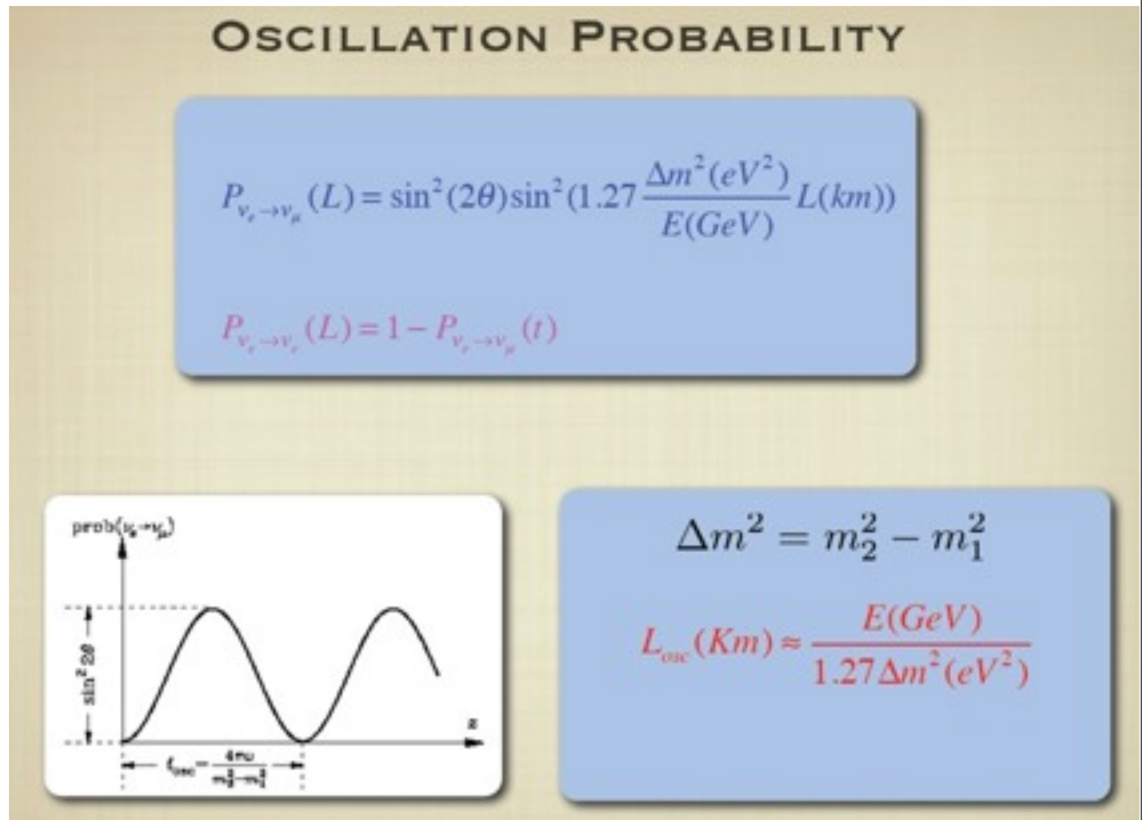


- is there CP-violation in the leptonic sector as observed for the quarks?
  - this could impact the cosmological models for the matter-antimatter asymmetry in the universe
- the ultimate theory of matter must include quarks and leptons
  - full understanding of the leptons/neutrinos is required
  - can't be done with LHC or ILC, CLIC

Why long baseline ν beams?

- easy(!!) way to produce ν and study their properties
    - alternatives: ν from reactors, beta-decay
- long, very long, or short beam lines depends on the value of the parameters

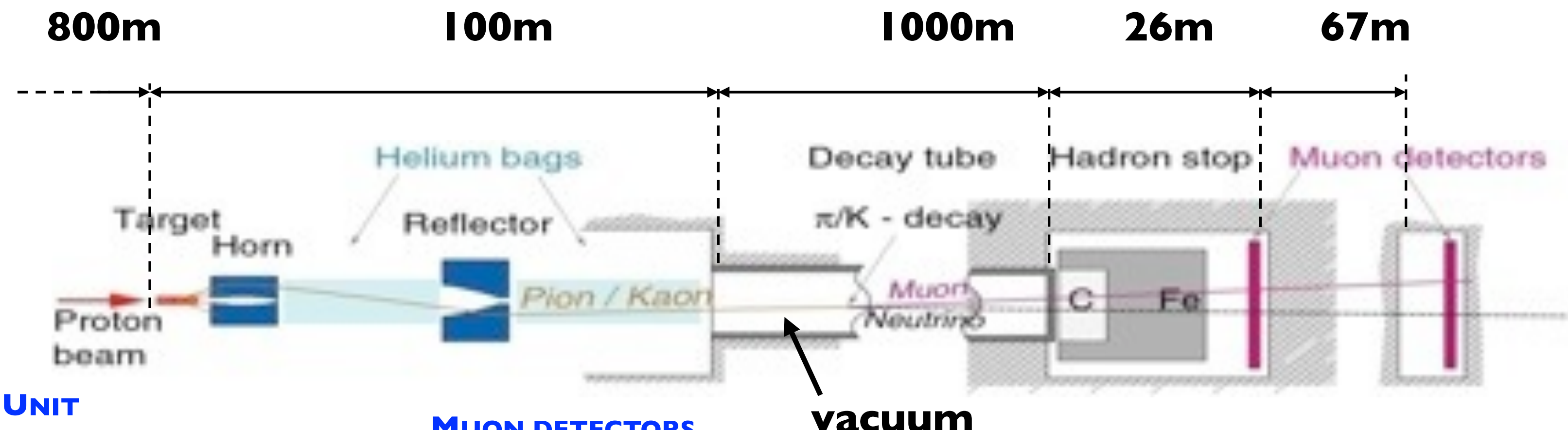
Courtesy JJ Gadenas



- **Typical configuration:**
    - **ν-source**: super beam, beta-beam, neutrino factory
    - **ν-detectors:**
        - near detector
        - far detector (one or many)
- long, very long, or short beam lines depends on the value of the parameters

Horn focused long baseline ν beam – CNGS

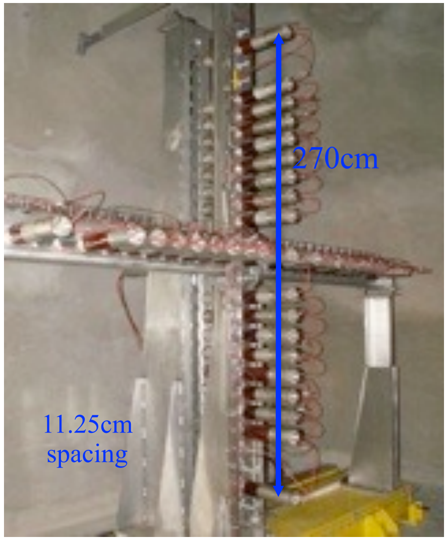
$p + C \rightarrow$ (interactions) $\rightarrow \pi^+, K^+ \rightarrow$ (decay) $\rightarrow \mu^+ + \nu_\mu$



TARGET UNIT

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

MUON DETECTORS



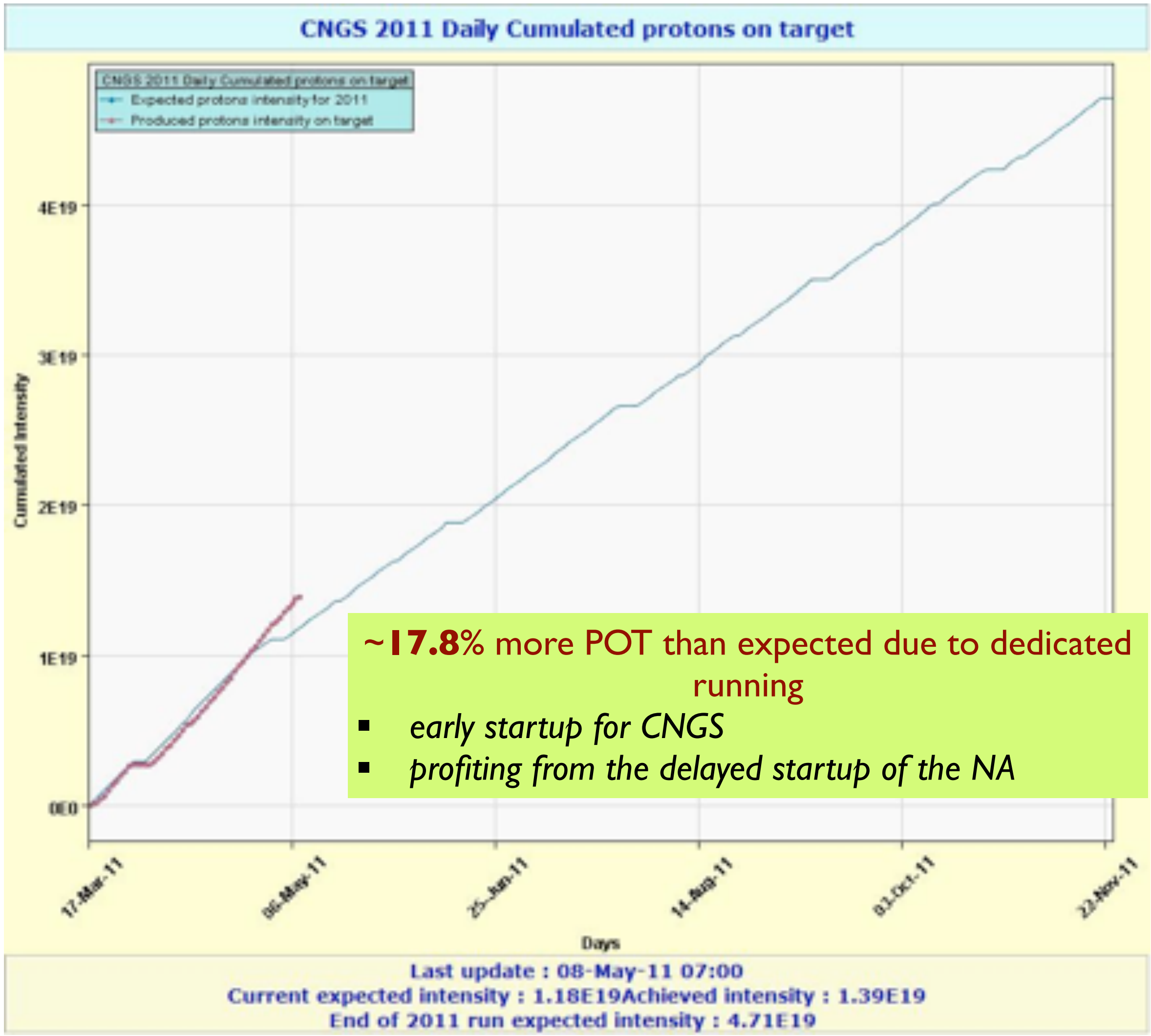
- 2 × 41 fixed monitors
- 2 × 1 motorized monitor

MAGNETIC HORNS

Why at CERN?

- CERN has a long **tradition** building ν beams
  - **Gargamelle** collaboration and discovery of the **neutral currents, horns** discovered at CERN by S. Van Der Meer
- CERN presently runs **CNGS** that is one of the three long baseline ν beams worldwide
  - CNGS offers a a valuable experience to build upon for future projects
- CERN has the possibility with the **(HP)-SPL** to provide the proton driver that is required for the high-power options of the ν-beams
- CERN has lot of **infrastructure** that is important asset for any project - also for ν beams!
- ν-physics is the size of the project that can run in // or interleaved with the LHC and its upgrades
  - interesting alternative physics program for a sizable EU ν-physics community; potential discoveries that should always be in the agenda of big labs!
- whatever program gets approved it must be in the GLOBAL perspective with international world-wide collaboration with other labs and institutes

CNGS ν-beam performance

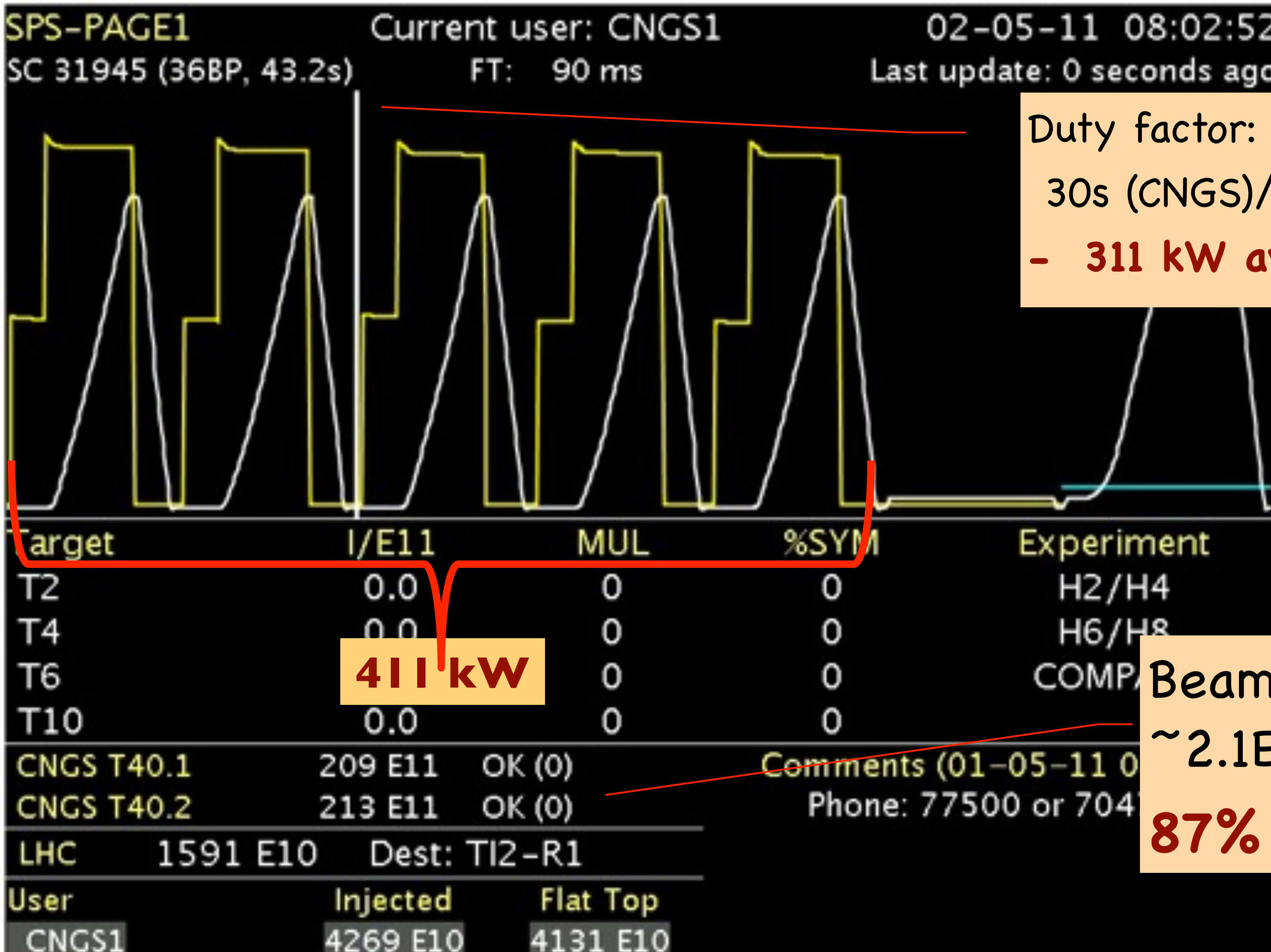


~**17.8**% more POT than expected due to dedicated running

- *early startup for CNGS*
- *profiting from the delayed startup of the NA*

Year	POT
2008	1.78×10^{19}
2009	3.52×10^{19}
2010	3.48×10^{19}
2011	1.39×10^{19} **(4.7×10^{19})**
Total	**10.17×10^{19} (13.48×10^{19})**

CNGS ν-beam performance



Duty factor:

30s (CNGS)/43.2s (total) = **69%**

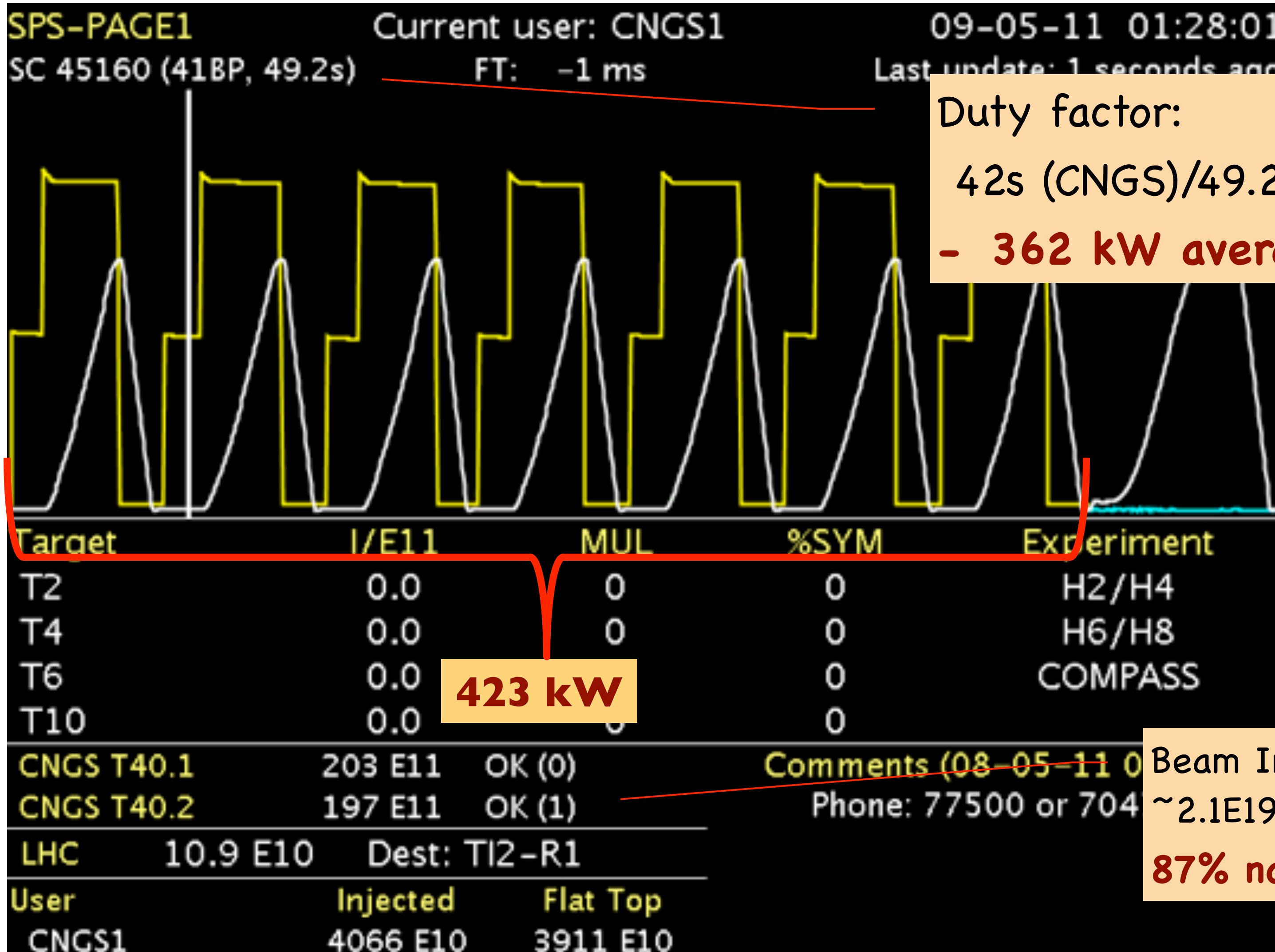
- **311 kW average power**

Beam Intensity:

~2.1E19 pot/extr

87% nominal

CNGS ν-beam performance



Duty factor:

42s (CNGS)/49.2s (total) = **85%**

- **362 kW average power**

423 kW

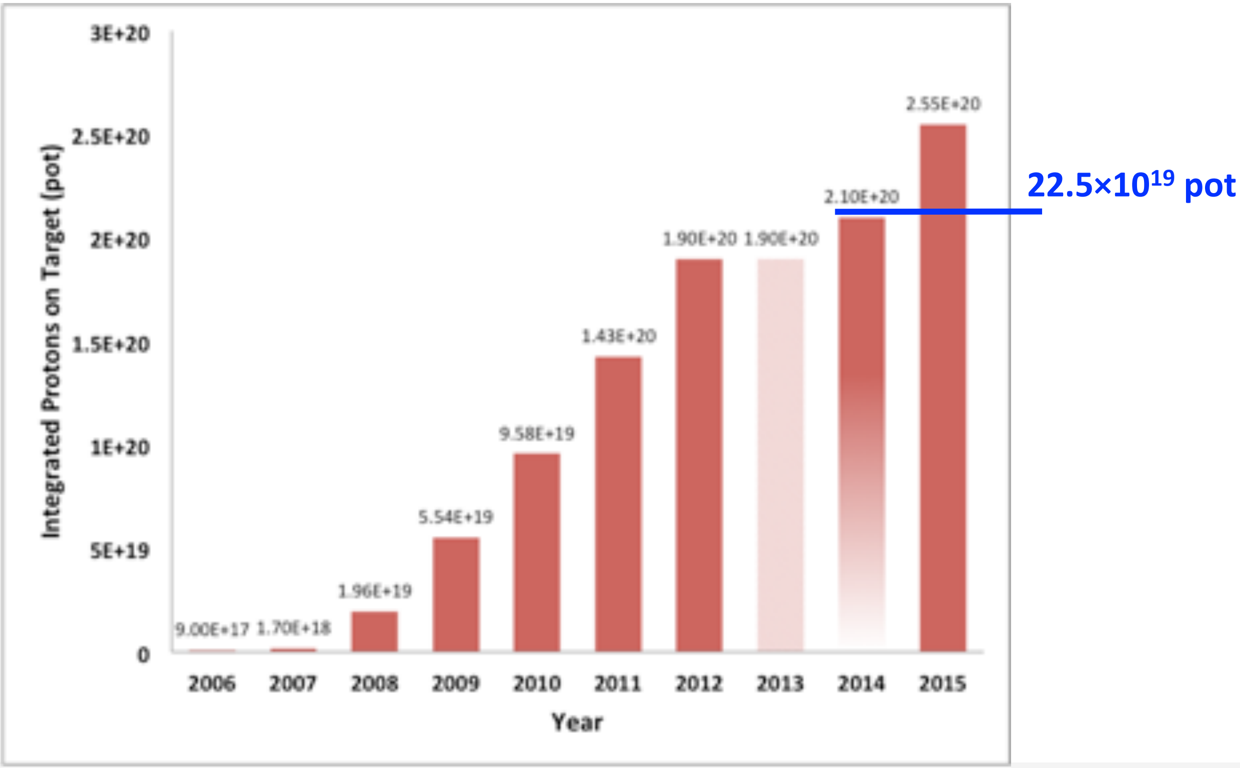
Beam Intensity:

~2.1E19 pot/extr

87% nominal

CNGS - Planning

- The presently approved program will be completed by 2014-2015
  - assuming **4.7×10^{19} pot/y** for 2011, 2012
- However by 2013 we could reach **~19×10^{19}** which depending on the results obtained may call for an early stop of the facility



CNGS Technology 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

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
    - WP3 = **IDS-NF** - the **GLOBAL** effort
  - **EUCARD** – Neu2012 (network activity) – MICE (transnational access)
  - **LAGUNA** – Water Cherenkov, LArgon, Scintillator Detectors
    - **LAGUNA-LBNO(new!)** - Underground detectors + beams from CERN
- R&D Activities – prototypes
  - **MERIT@CERN** - high-power targetry experiment
  - **MICE@RAL** - muon ionization cooling experiment

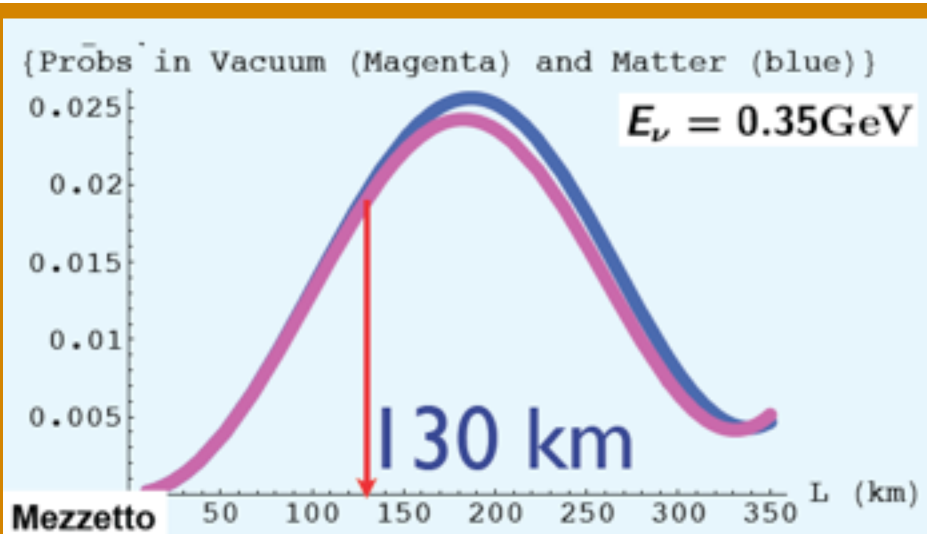
LAGUNA/LAGUNA_LBNO FP7 Study

Courtesy: A. Rubbia, LAGUNA

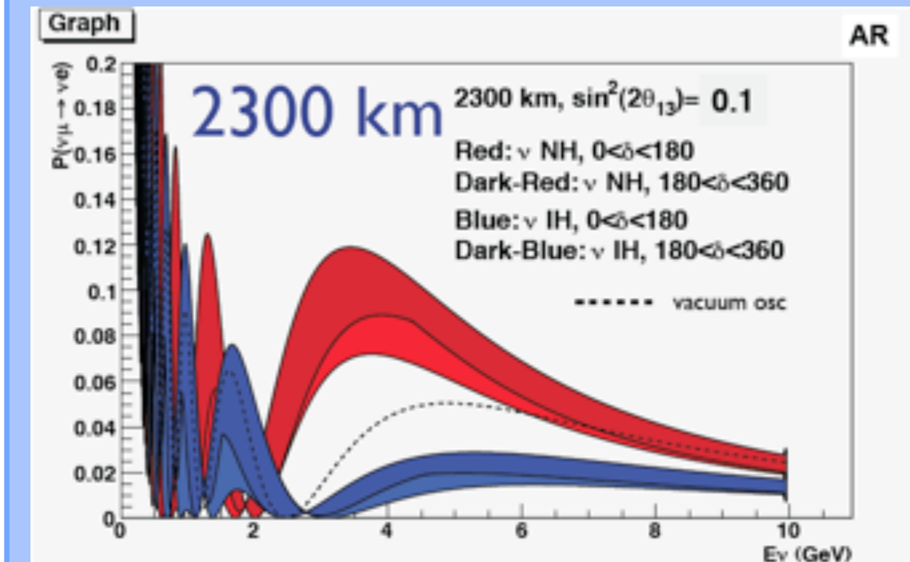
☞Talk from A Rubbia

Long-Baseline ν-beams from CERN

- **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"

A. Rubbia, LAGUNA

- **... and synergies:**
  - **CERN-Frejus** : adequate baseline/energy for β-beam
  - **CERN-Pyhasalmi** : adequate baseline for Neutrino-Factory from CERN or other labs (~7'000 km)

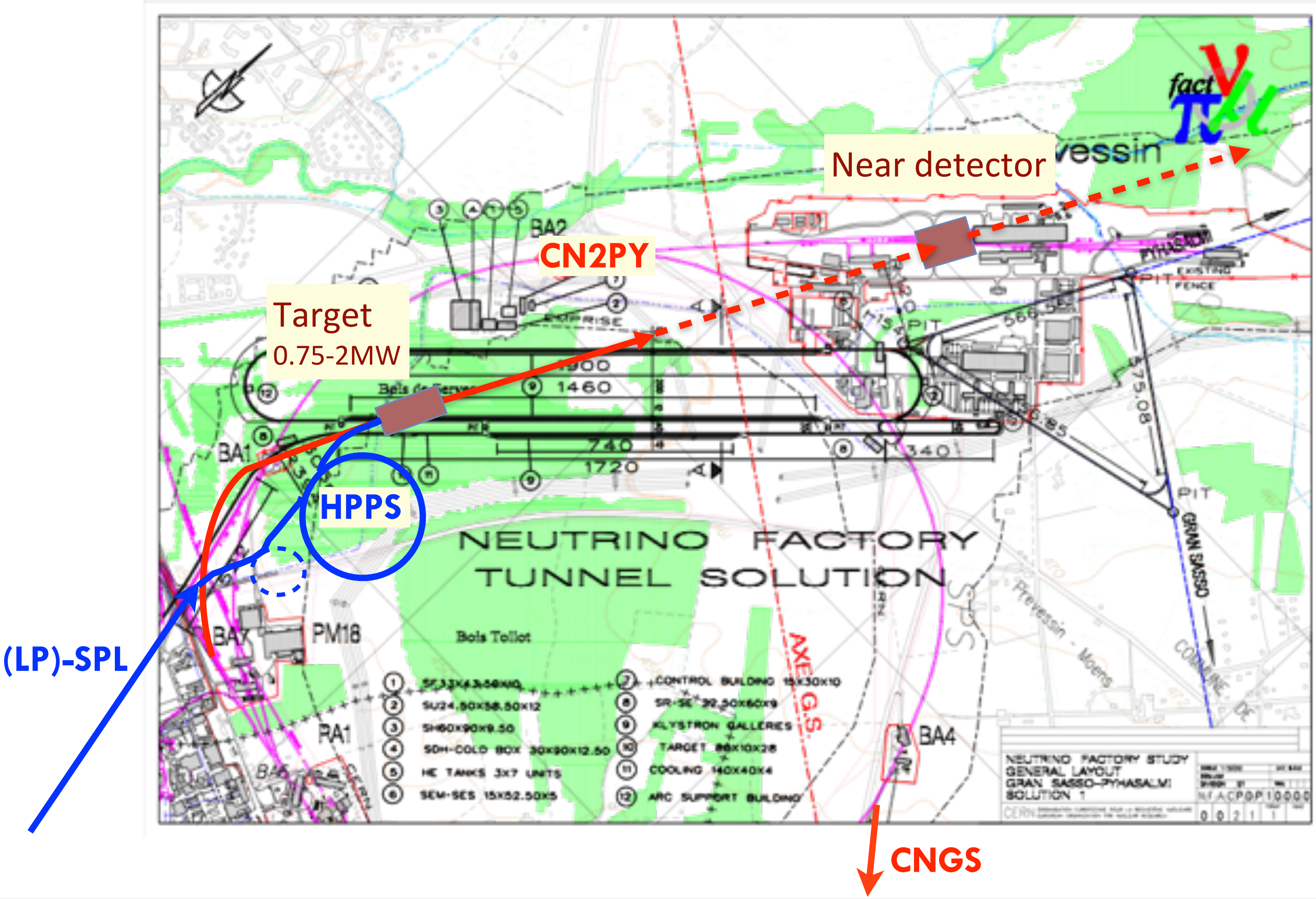
A staged approach towards high-intensity facilities

- ~1MW an important (necessary) barrier

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+Accum

LAGUNA-LBNO, EUROν FP7 Design Studies

CERN ν-beam to Pyhasalmi - CN2PY

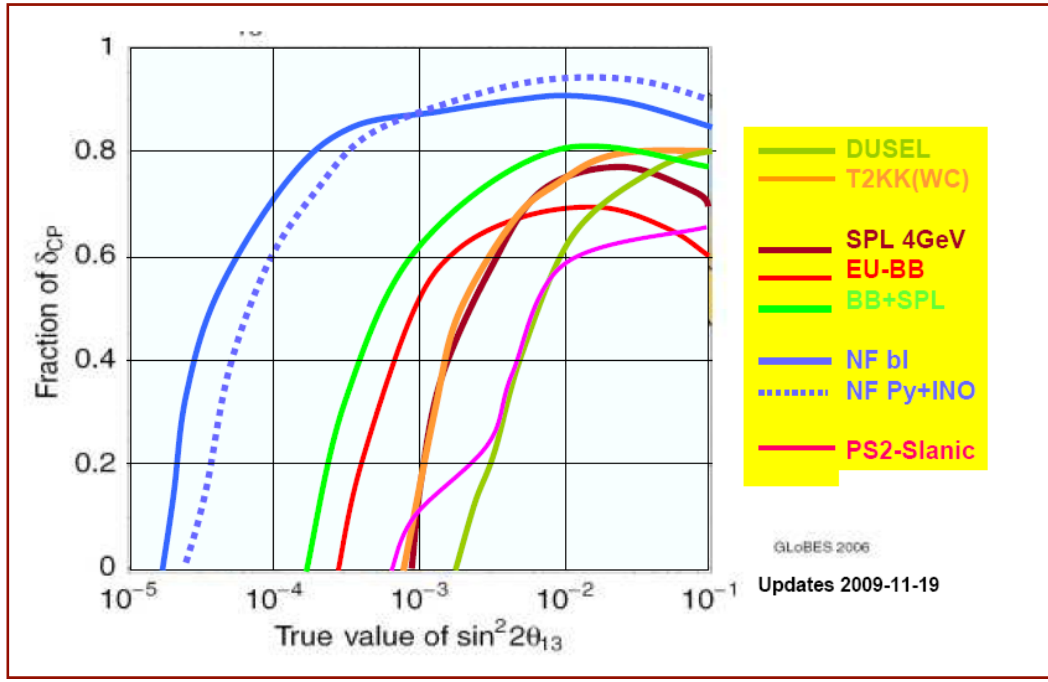


CN2PY - Technical challenges

- 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 April 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?

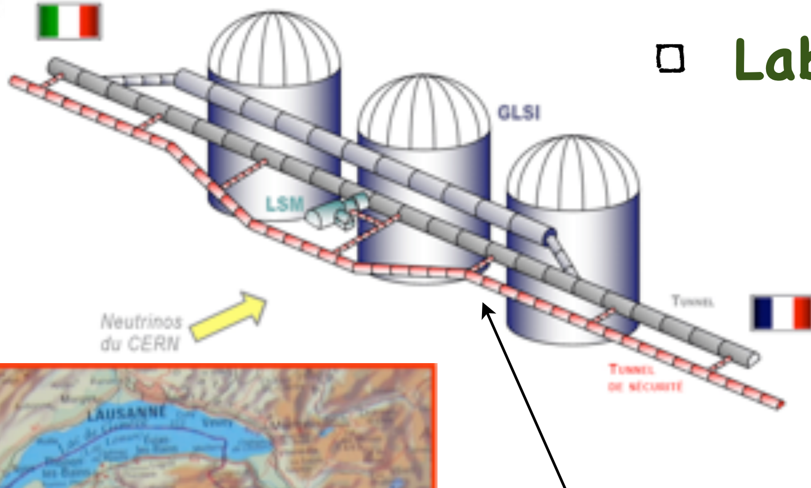


- **Possible options:**
  - **Option-I** : super-beam & beta-beam from CERN to Frejus
  - **Option-II** : LBL from SPS (power-beam) followed by Neutrino Factory

Super-beam to Frejus

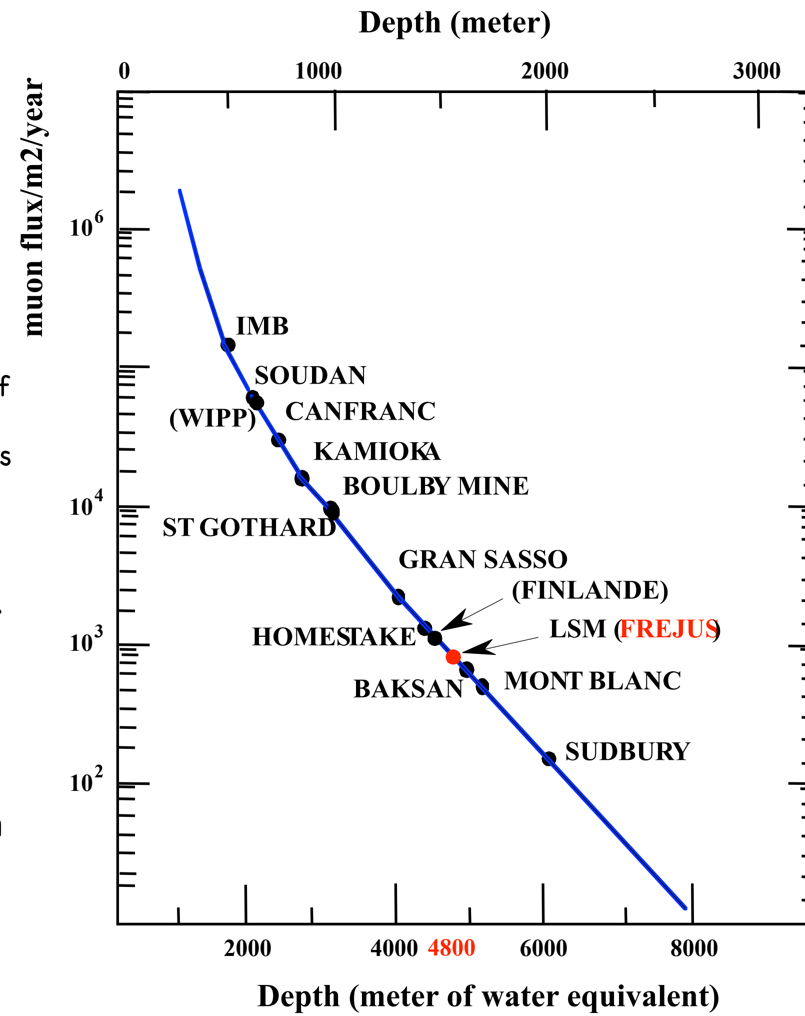
Courtesy: M. Dracos, EUROnu

- **Laboratoire Souterrain de Modane**

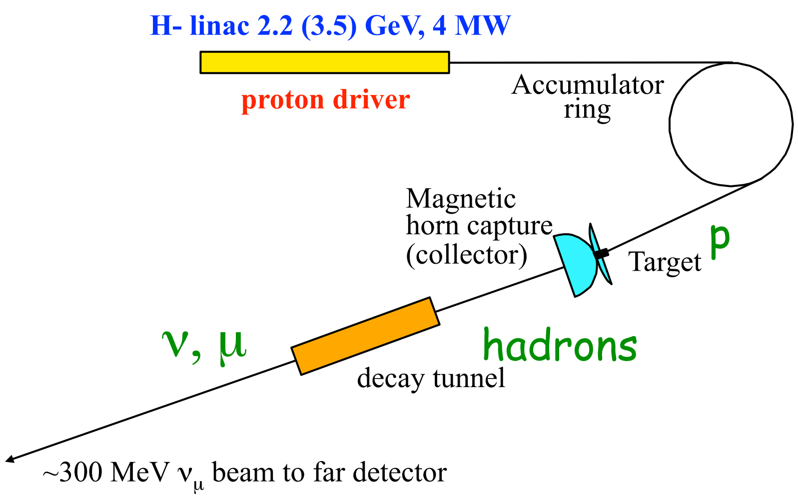


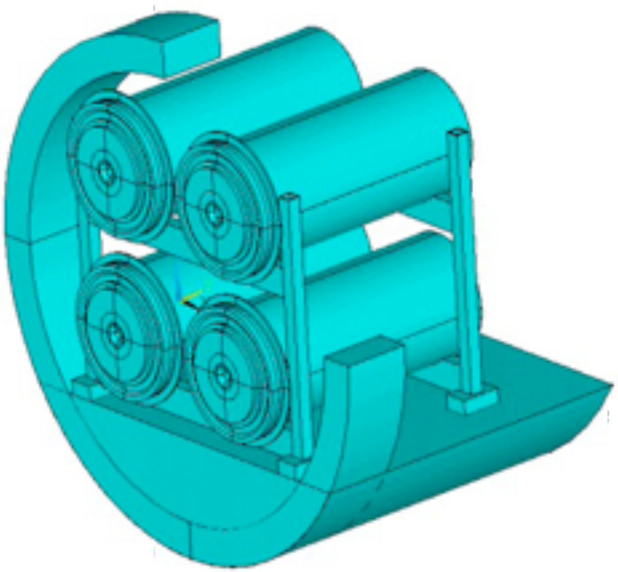
Profit from the excavation of the new safety gallery to prepare the detector caverns

- 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

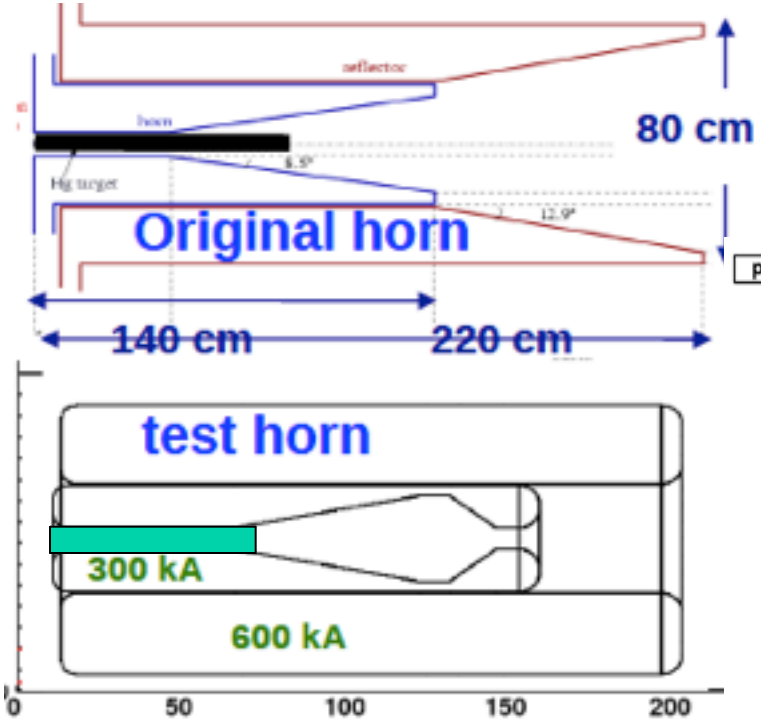


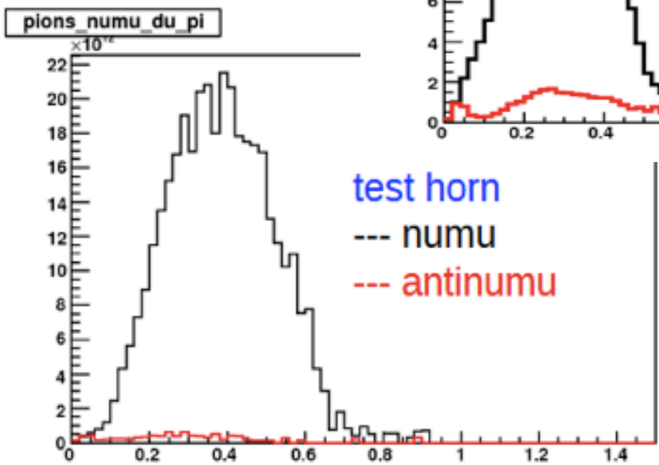


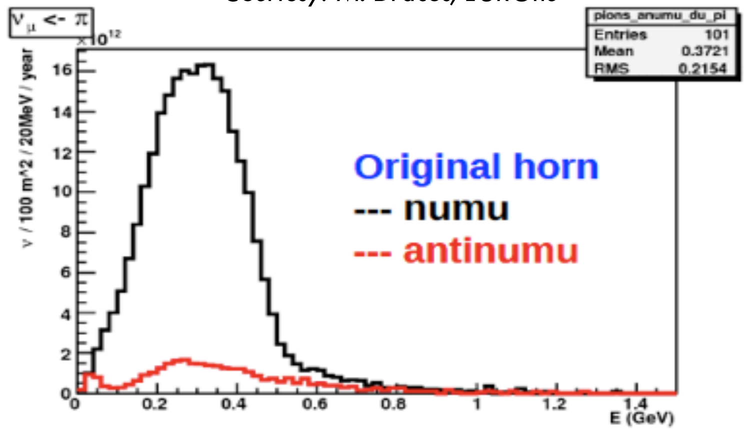
- **Technical challenges:**
  - **Target design**
    - impact of the 4MW beam
  - **Horn design**
    - high current, mechanical constraints due to physics requirements, radiation, high-current (heating), pulsing
- **Solution:**
  - **4 × 1 MW = 4 MW !!!!**
  - four target/horn assemblies mounted together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

CN2FR – horn optimization

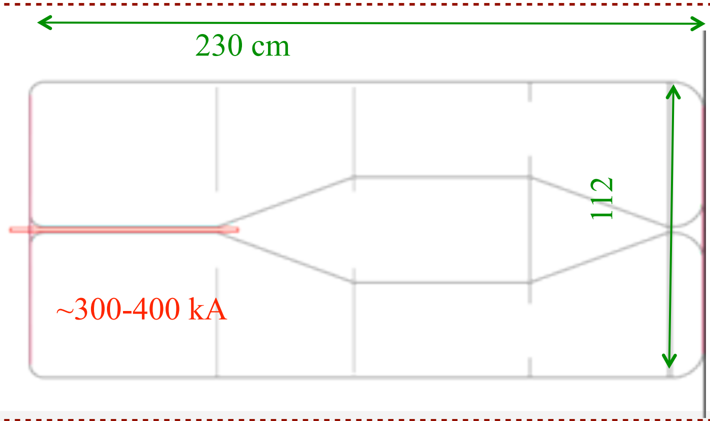
Courtesy: M. Dracos, EUROnu







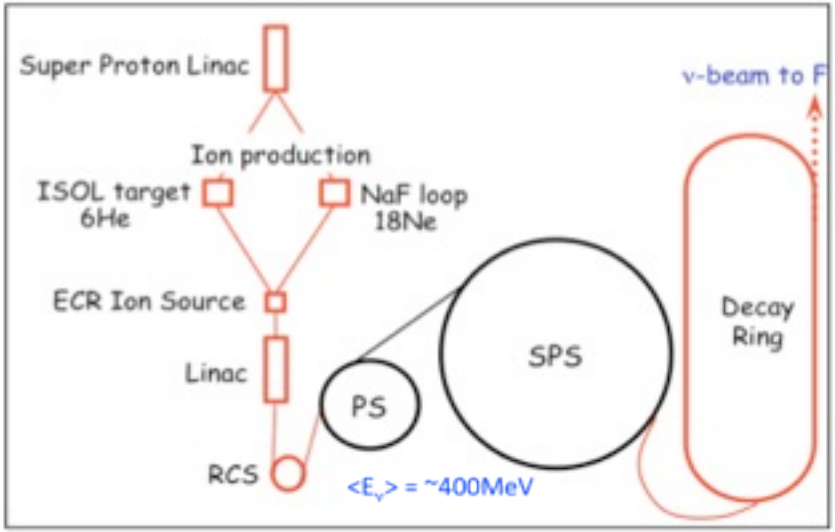
- **Latest design**
  - single horn with reduced current
- **Target**
  - solid C(Be?) rod inserted into the horn or Be pebble



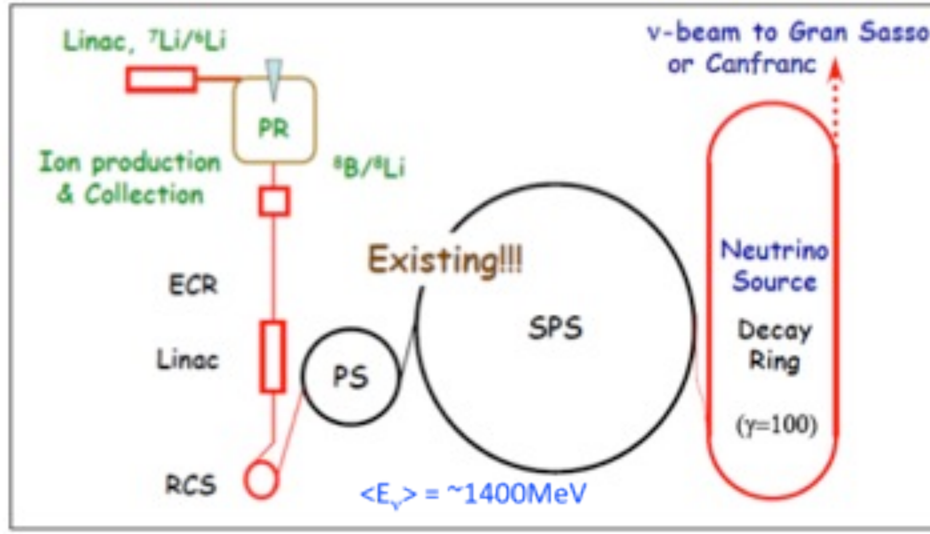
β-beam : Pure ν_e,$\bar{\nu}_e$ beams from CERN

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*

β-beam: isotope production

Courtesy: E. Wildner, EUROnu

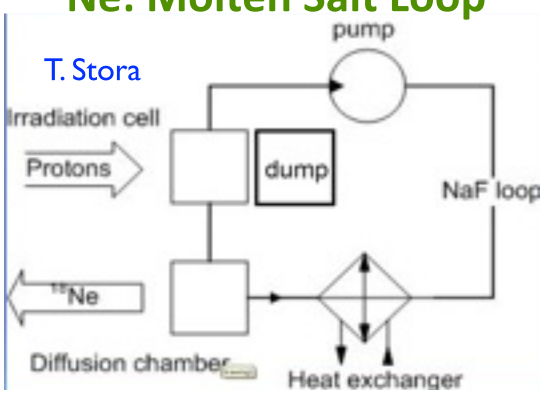
Type	Accelerator	Beam	I_{beam} mA	E_{beam} MeV	P_{beam} kW	Target	Isotope	Flux s^{-1}	Ok?
ISOL & n-converter	SPL	p	0.1	2 10^3	200	W/BeO	6He	5 10^{13}	
ISOL & n-converter	Saraf/GANIL	d	15	40	600	C/BeO	6He	5 10^{13}	
ISOL	Linac 4	p	6	160	700	19F Molten NaF loop	18Ne	1 10^{13}	
ISOL	Cyclo/Linac	p	10	70	700	19F Molten NaF loop	18Ne	2 10^{13}	
ISOL	LinacX1	3He	> 170	21	3600	MgO 80 cm disk	18Ne	2 10^{13}	
P-Ring	LinacX2	7Li	0.160	25	4	d	8Li	?1 10^{14}	
P-Ring	LinacX2	6Li	0.160	25	4	3He	8B	?1 10^{14}	

Experimentally OK
On paper may be OK
Not OK yet

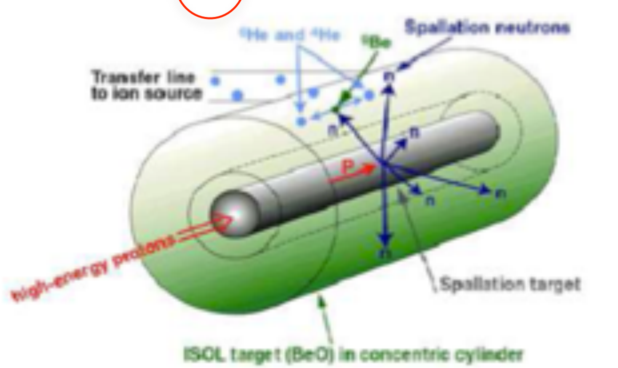
Baseline option (^{6}He and ^{18}Ne). ^{18}Ne production experiments in 2011.

^{8}Li can be produced in sufficient quantities with ISOL & n-converter

^{18}Ne: Molten Salt Loop

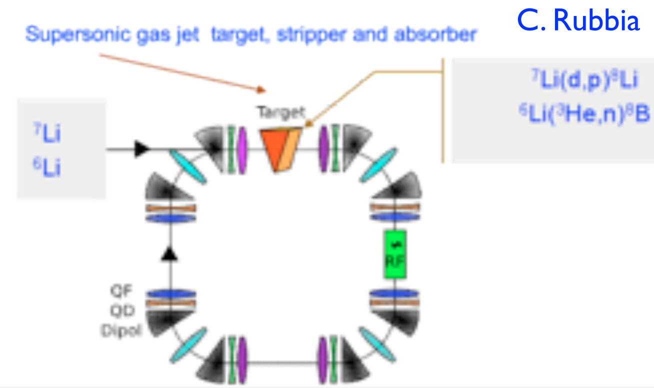


^{6}He & ^{8}Li : ISOL&n-converter



^{8}B & ^{8}Li : Production Ring

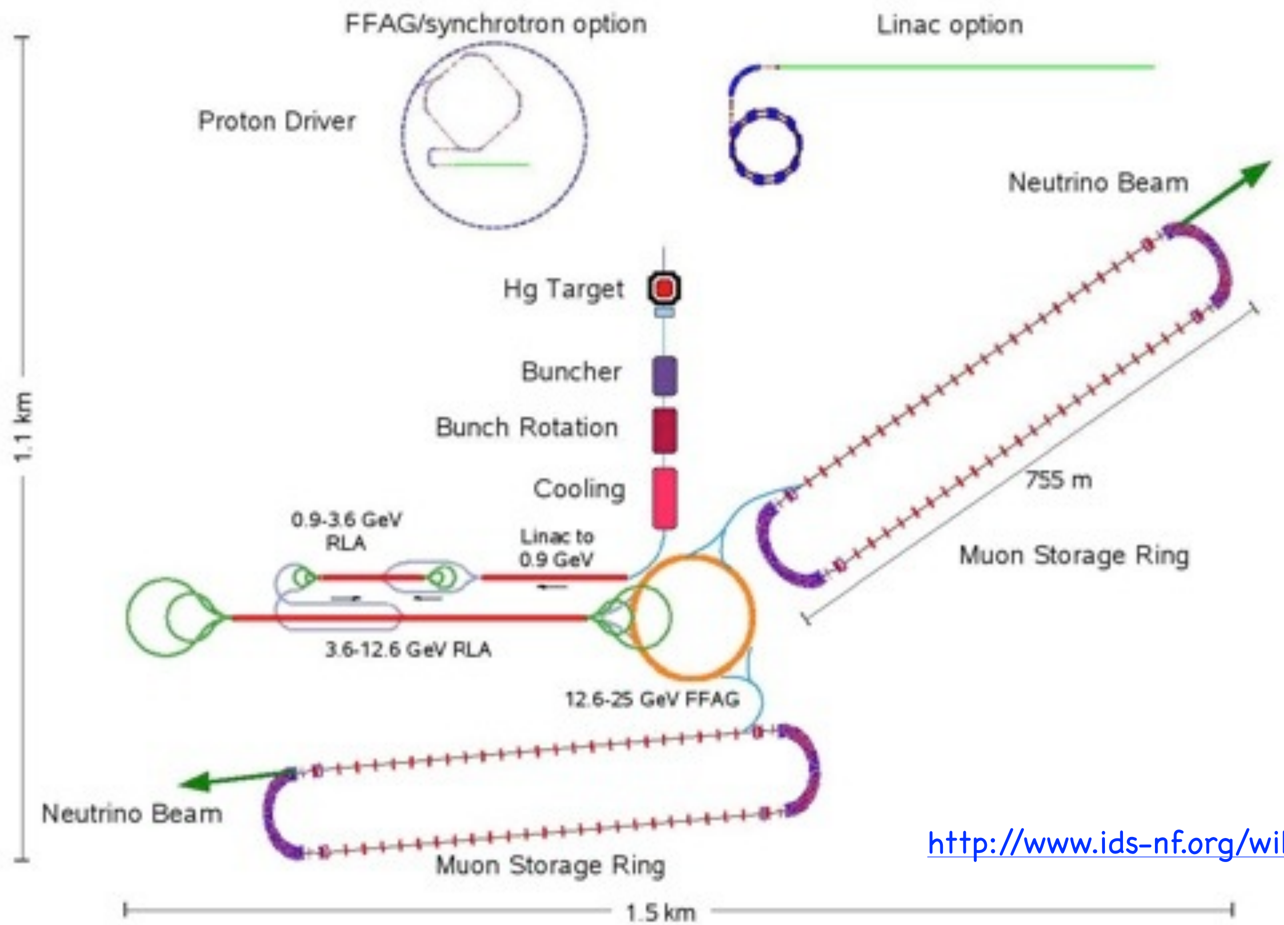
C. Rubbia



Neutrino Factory

Courtesy: EUROnu & IDS-NF

p+ C (int) → $\mu^{\pm}$ (capture, accelerate, store, decay) → ν_μ, ν_e

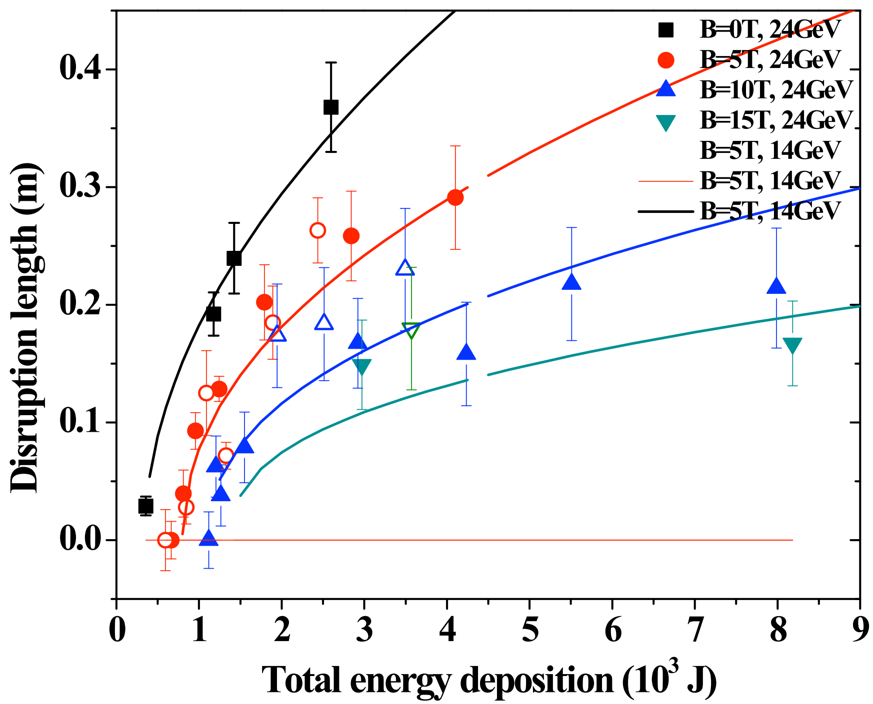


http://www.ids-nf.org/wiki

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



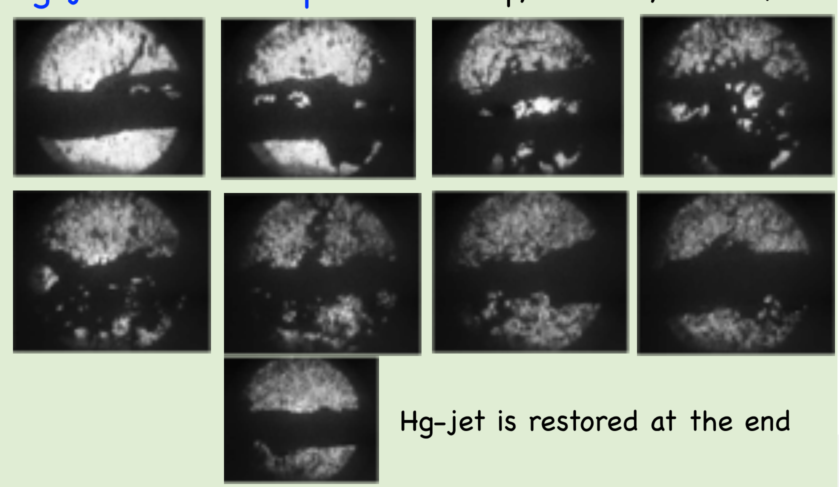
- **The MERIT Experiment @ CERN PS**

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



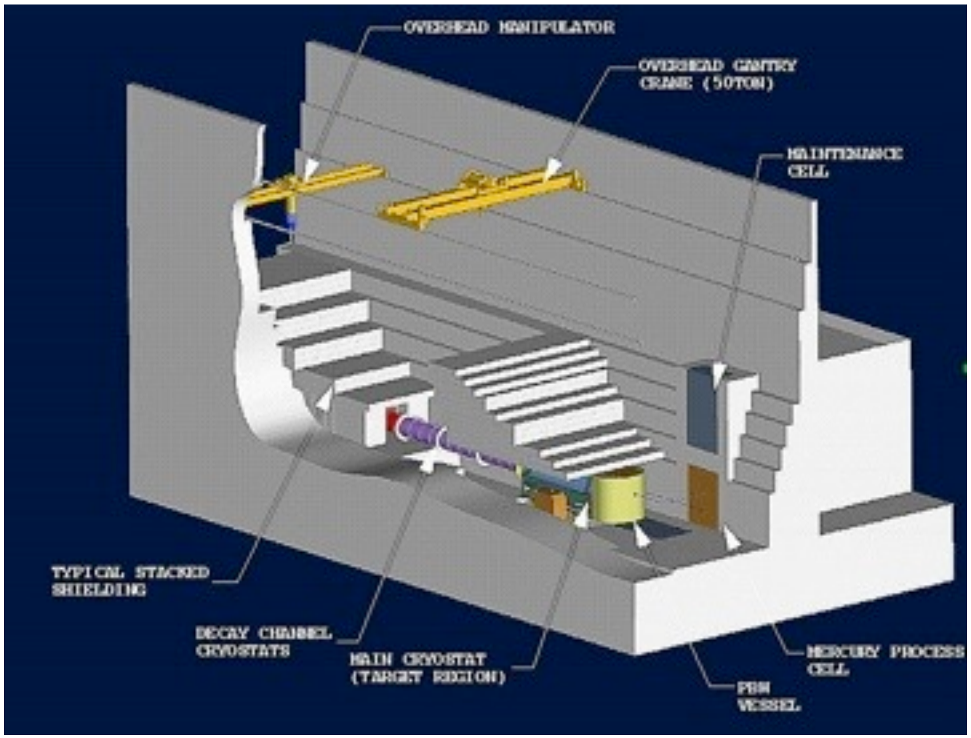
Hg-jet is restored at the end

Key results #2

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

High-power target station

- The future ....

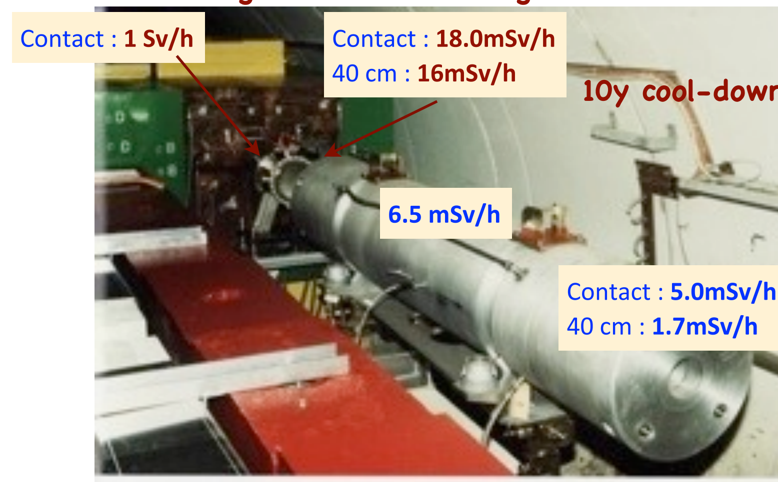


Courtesy: P. Spampinato, ORNL

- High-intensity (M)MW areas should be treated with respect !!!

- ... and the past

Dismantling WANF - 2010: Target & collimator



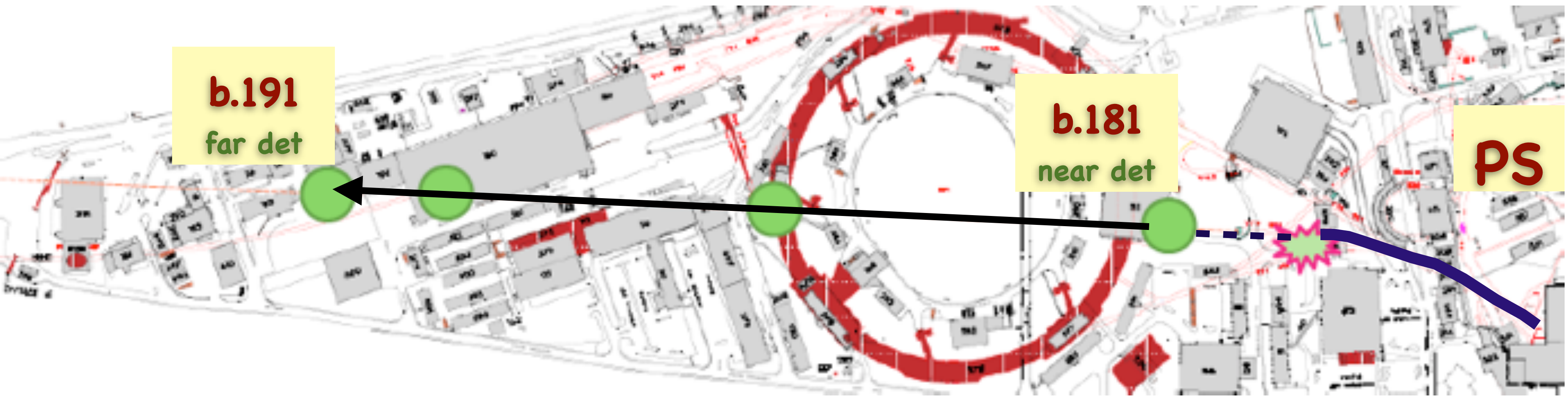
Dismantling WANF - 2010: Target & collimator

PS - Short Baseline ν-beam

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

☞ *Talk from C. Rubbia*

C. Rubbia et al



- 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

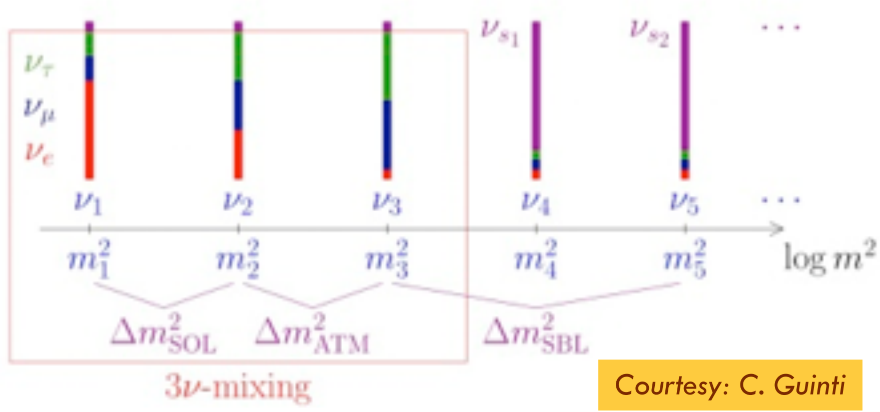
PS - SBL ν-beam for sterile ν's ?

Sterile neutrinos?

- Facts
  - we know from LEP that there are 3 SM neutrino families: ν_e, ν_μ, ν_τ
  - we know from experiments the neutrinos have mass (small) because they seem to oscillate, i.e. over a distance they transform from $\nu_a \rightarrow \nu_b$
- The problem:
  - some experiments (LSND, KAMLAND, MiniBooNe, MINOS,...) observed an anomaly in the oscillation pattern:
    - anti-neutrinos seem to oscillate differently than neutrinos, at least in some energy range
  - to explain the effect CP and even CPT-violation is required, or new physics → sterile neutrinos

The sterile neutrino hypothesis

- Imagine there are neutrinos into which the known ones can be transformed, but they don't transform back (or transform in a different rate), i.e. don't have SM interactions → sterile
- it turns out that a theory with 2 sterile neutrinos (3+2 theory) fits well (~)all of the present data
- Sterile neutrinos are not needed by the theory, but if found would be a great discovery !!!



Courtesy: C. Guinti

From design studies to projects

- The political picture

36 | The European strategy for particle physics

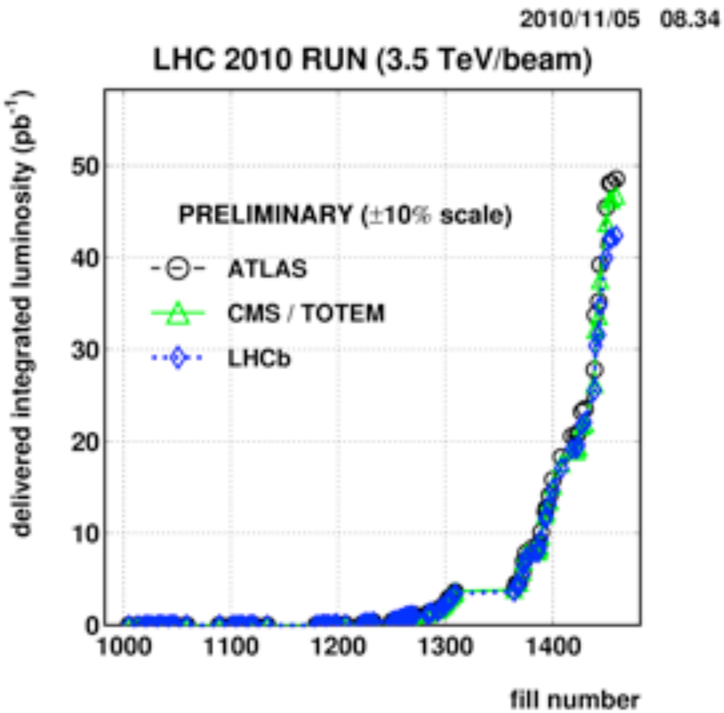
The European strategy *for particle physics*

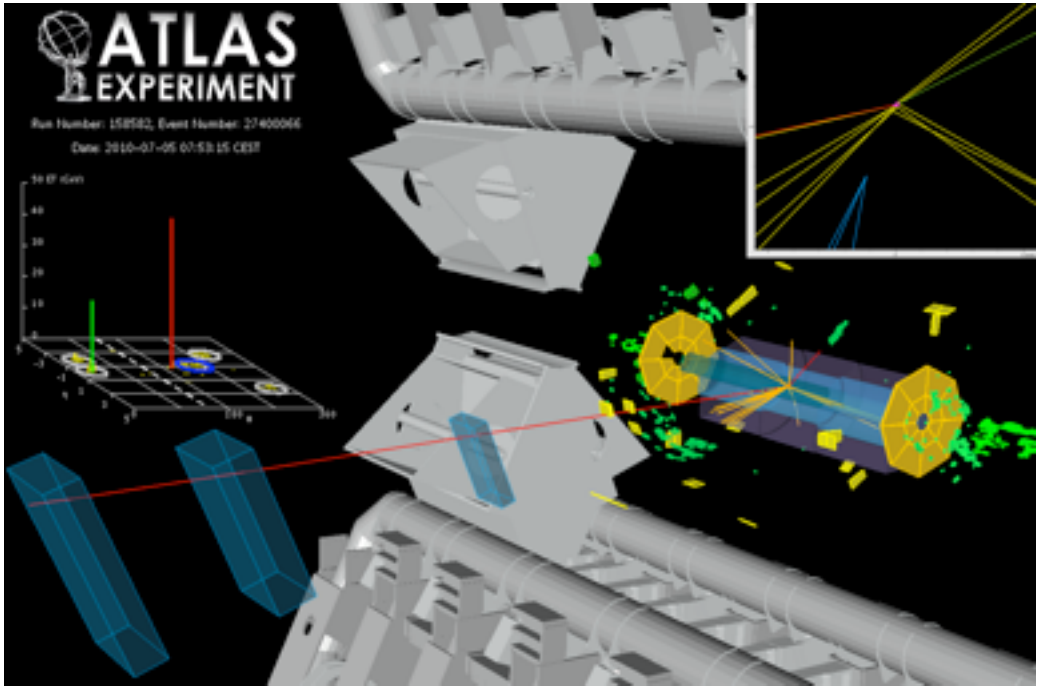
4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play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





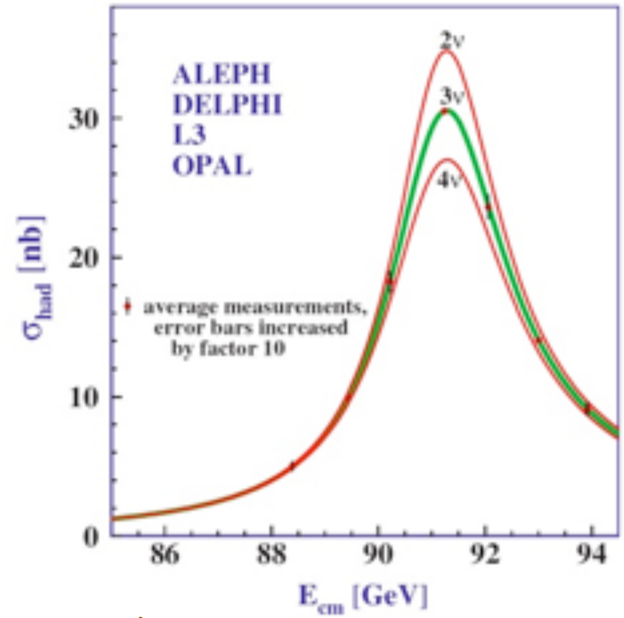
Begun probing physics at the TeV scale!!

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 accelerator technologies to be developed
  - **Collaboration** and **coordination** for accelerator and detector R&D at a **global** scale
  - The ν-physics and accelerator community defines a **prioritized roadmap** of facilities to **make ν-physics a valid option for the field and CERN/Europe in // to LHC and its upgrades**

ν beams at CERN – what future ?

- To know more about ν-beams and associated physics:

- **NUFACT11** Workshop @ CERN/ UniGe in **August 1-6, 2011**

- Neutrino Beam Instrumentation **NBI2012 @ CERN in April 2012**

- EUCARD workshops within WP3-Neu2012 WP