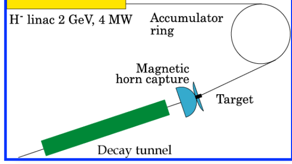
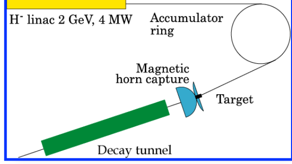


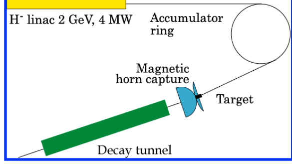
EUROν
Super Beam studies

Marcos Dracos
IPHC-IN2P3/CNRS, Strasbourg

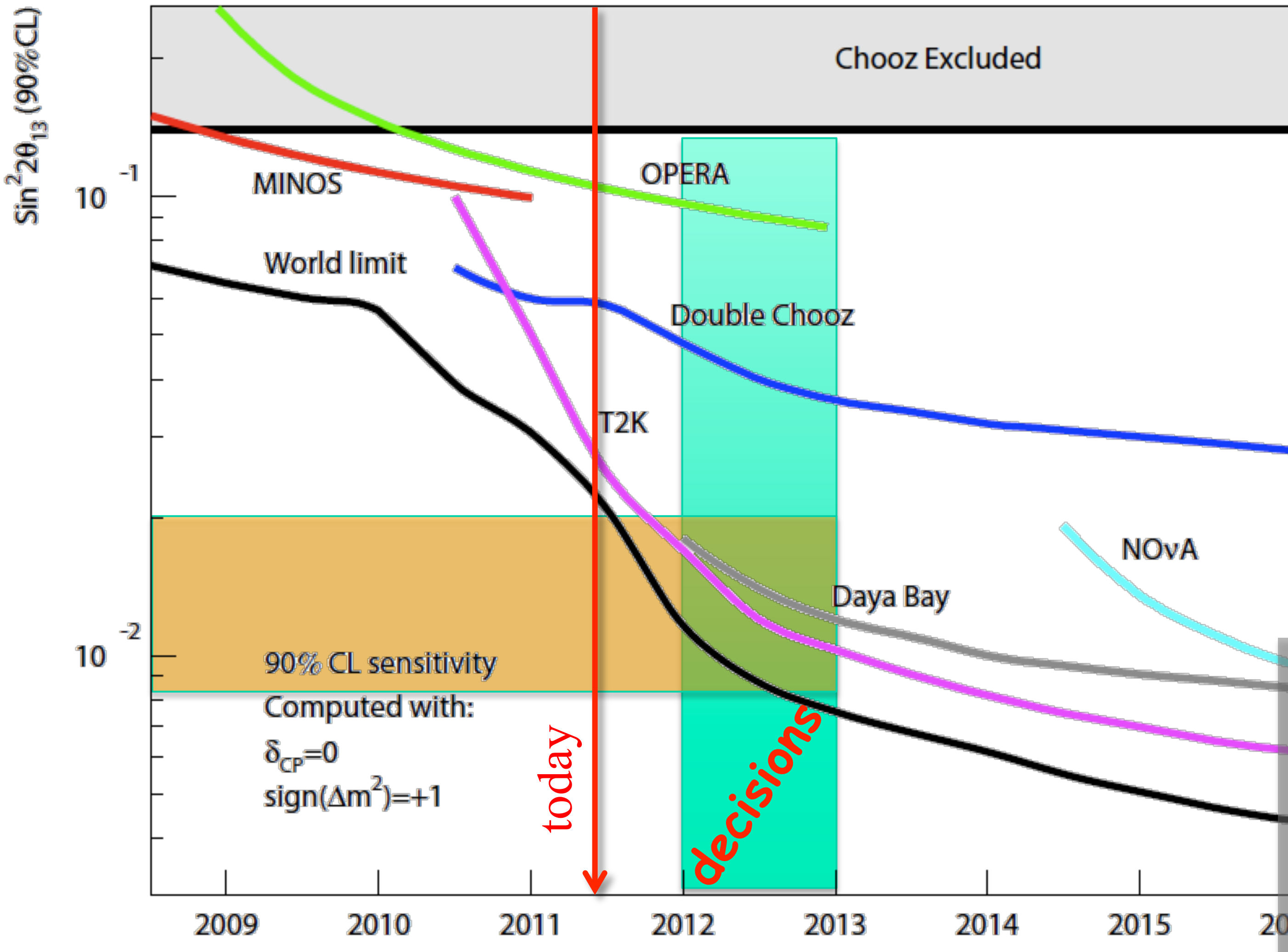


EUROν
Super Beam studies

- Motivation
- Where we have started
  - previous studies
- Achievements
  - target
  - collector
  - physics performance
- Where we are going



θ_{13} limit expectations up to 2016



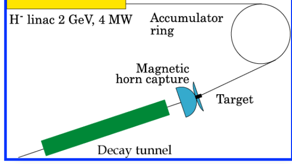
never forget that these projects could also observe the 1→3 oscillation

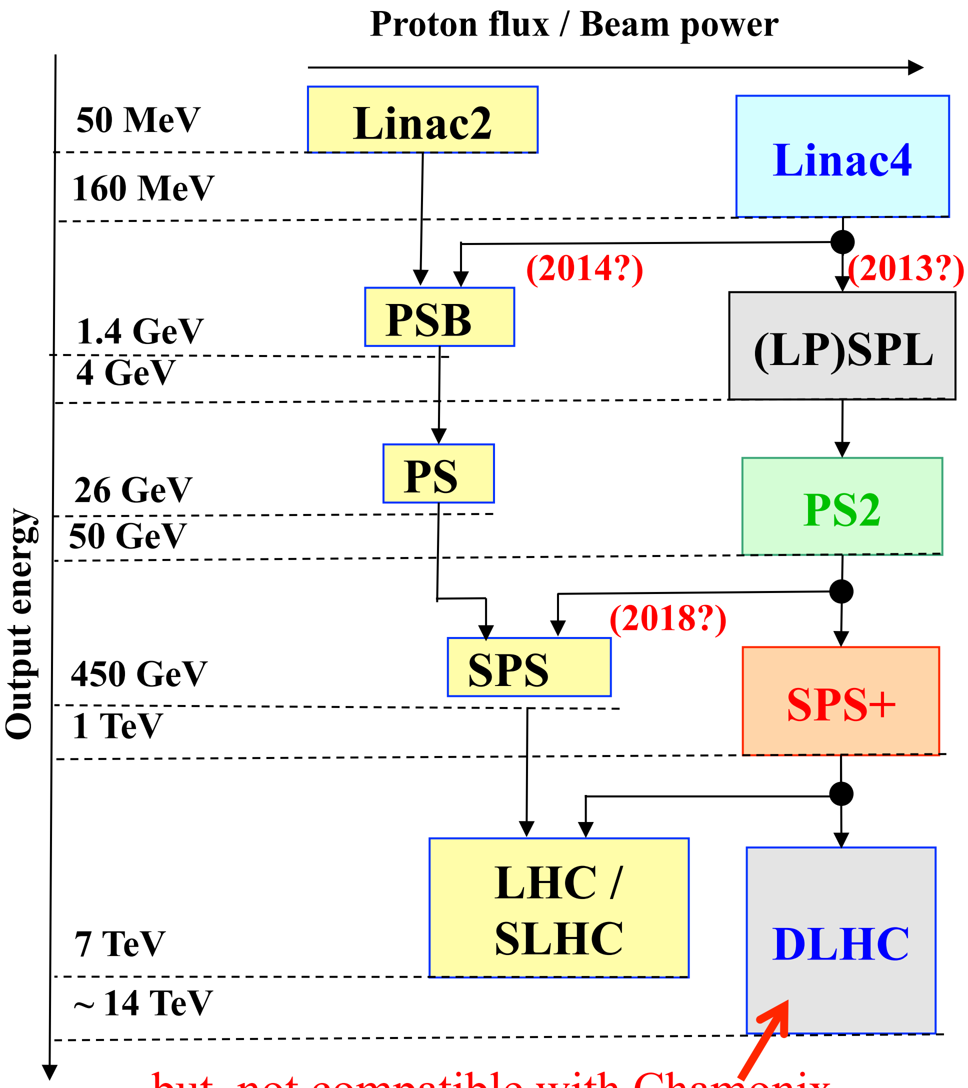
⇒ in this case precision measurements have to be done by the next projects

future facilities

(can we propose a neutrino facility technologically feasible and not too expensive?)

Take profit of an upgrade of CERN accelerator complex





Proton flux / Beam power

Output energy

50 MeV
160 MeV
1.4 GeV
4 GeV
26 GeV
50 GeV
450 GeV
1 TeV
7 TeV
~ 14 TeV

Linac2
Linac4
(2014?)
(2013?)
PSB
(LP)SPL
PS
PS2
(2018?)
SPS
SPS+
LHC / SLHC
DLHC

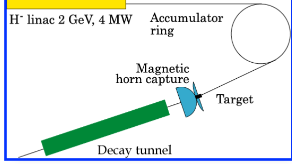
but, not compatible with Chamonix workshop conclusions (final?)

Motivation

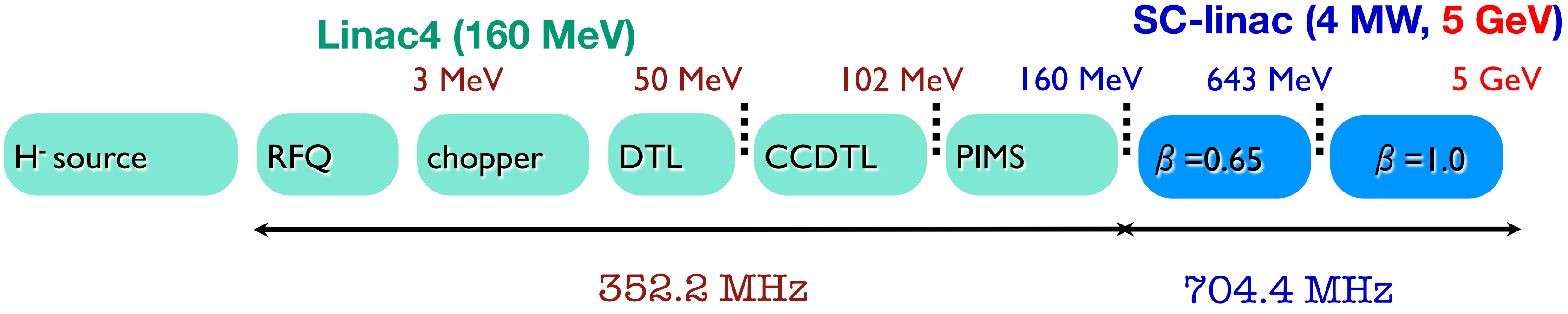
1. **Reliability: Present CERN accelerators too old ⇒ need for new accelerators designed for the needs of SLHC**
2. **Performance: Increase of brightness of the beam in LHC to allow for phase 2 of the LHC upgrade. ⇒ need to increase the injection energy in the synchrotrons**

LP-SPL: Low Power-Superconducting Proton Linac (4-5 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)

HP-SPL for Neutrino Beams



- CDR for 2.2 and 3.5 GeV HP-SPL already published (CERN 2000-012, CERN 2006-006)



Linac4 (160 MeV)

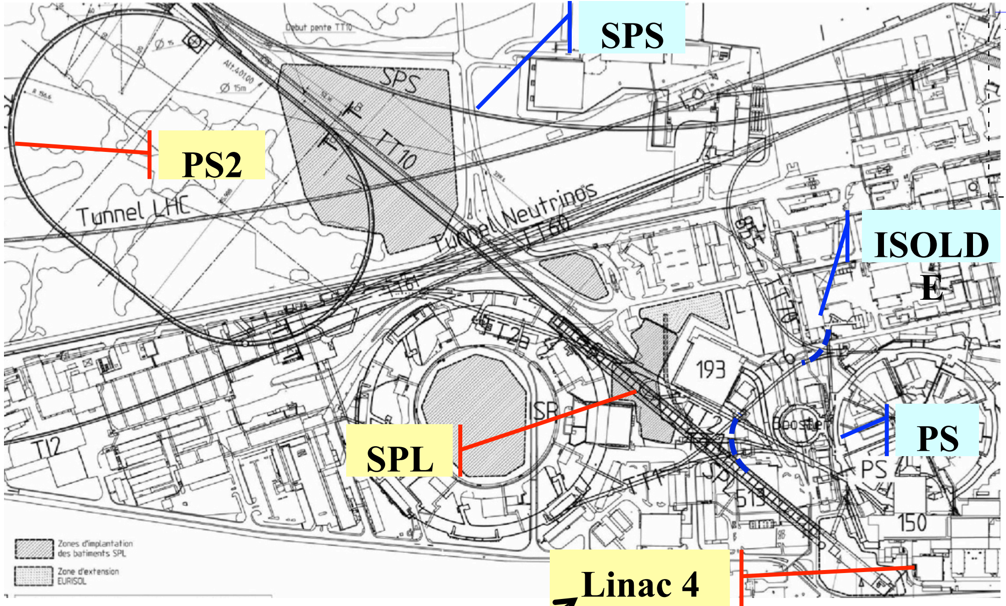
SC-linac (4 MW, 5 GeV)

3 MeV | 50 MeV | 102 MeV | 160 MeV | 643 MeV | 5 GeV

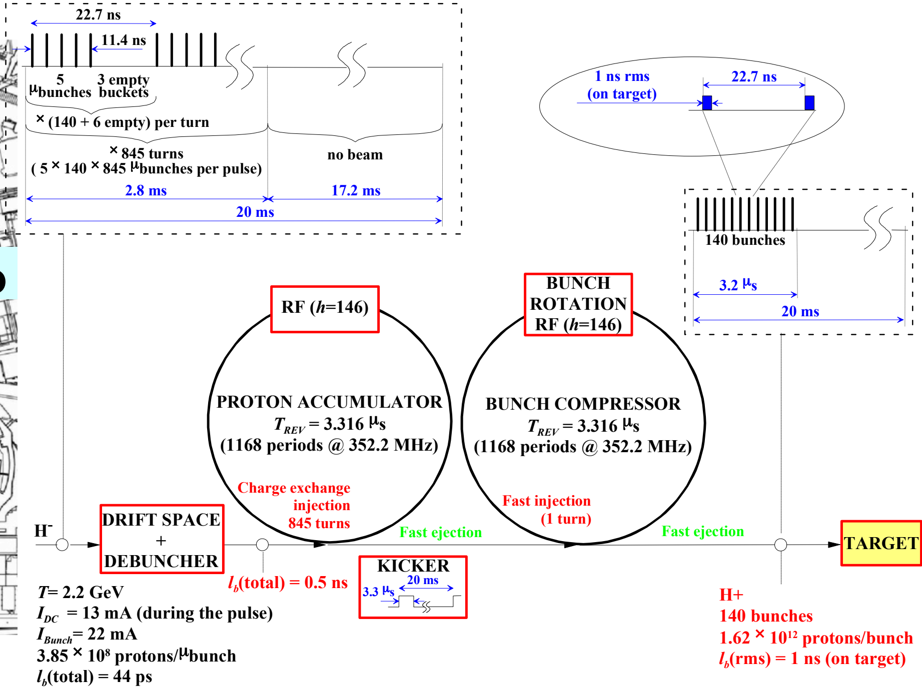
H⁻ source → RFQ → chopper → DTL → CCDTL → PIMS → β =0.65 → β =1.0

352.2 MHz

704.4 MHz

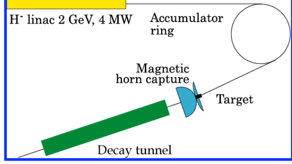


under construction
(high power already foreseen)

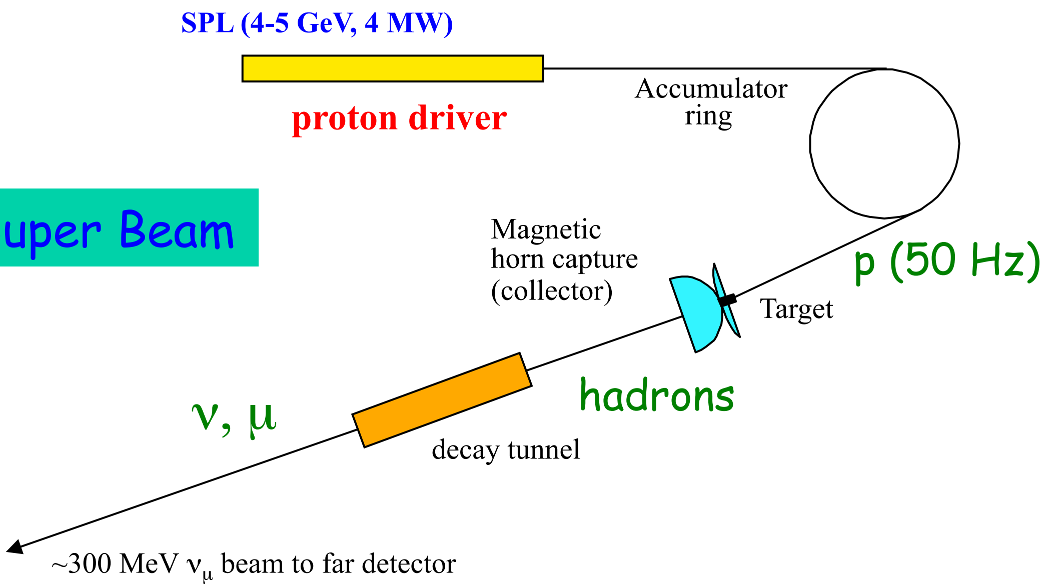


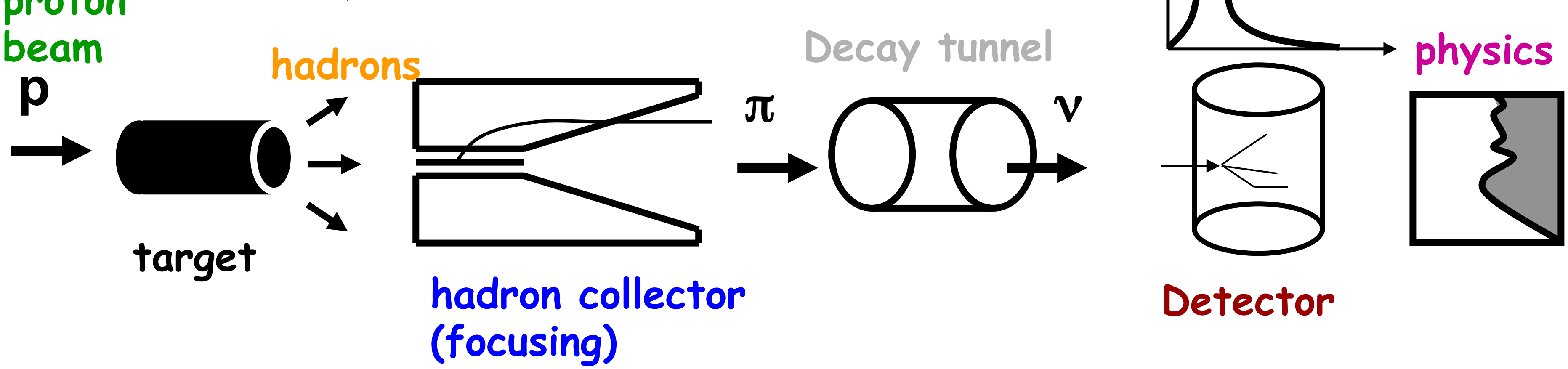
+ accumulator (and compressor for NF)

Super Beam: conventional MW power neutrino beam

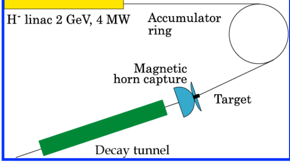


SPL Super Beam

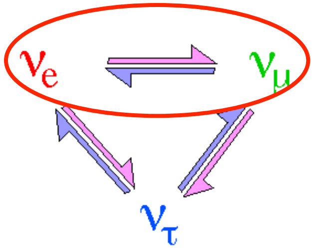




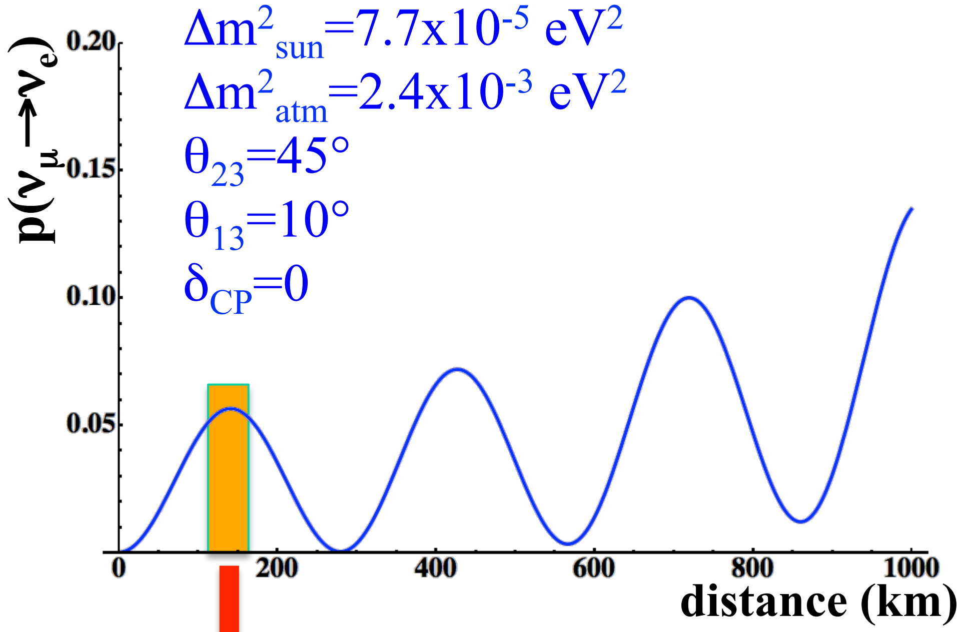
Neutrino Super Beam from HP-SPL



SPL proton kinetic energy: ~4 GeV



Neutrino energy: ~300 MeV

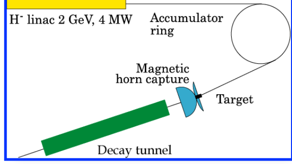


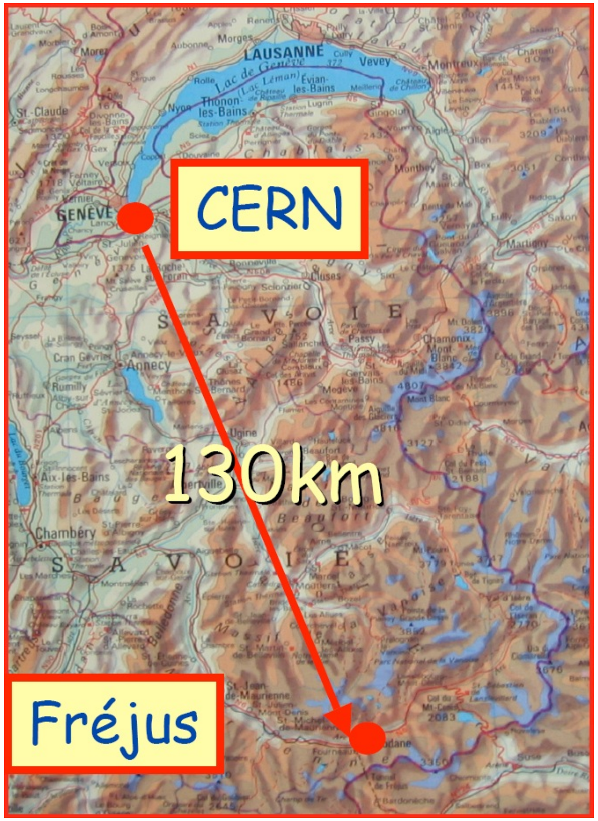
$\Delta m^2_{sun}=7.7\text{x}10^{-5}\ eV^2$
$\Delta m^2_{atm}=2.4\text{x}10^{-3}\ eV^2$
$\theta_{23}=45°$
$\theta_{13}=10°$
$\delta_{CP}=0$

~130 km

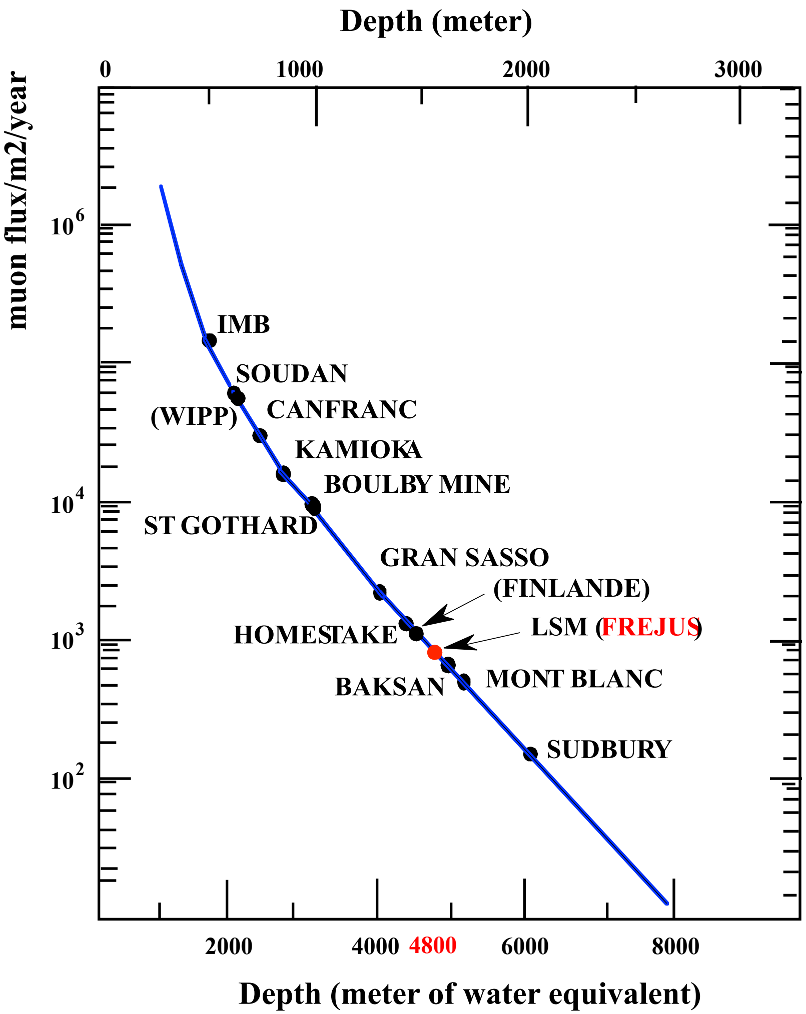
Fréjus tunnel

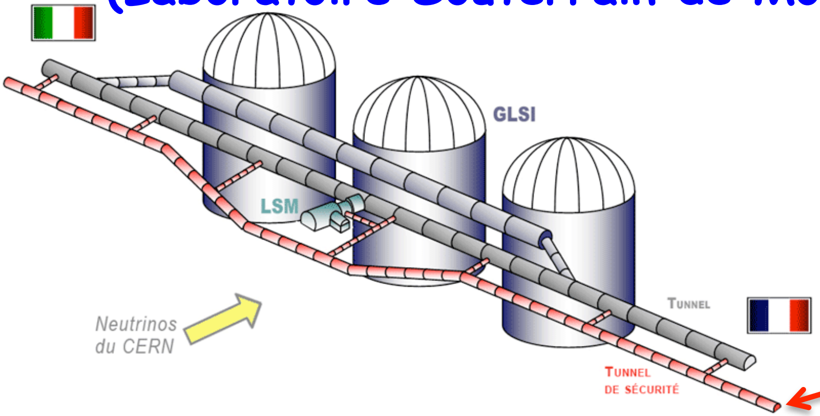
Fréjus underground laboratory



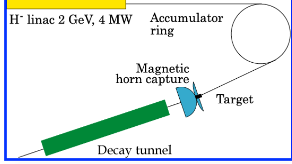


(Laboratoire Souterrain de Modane)

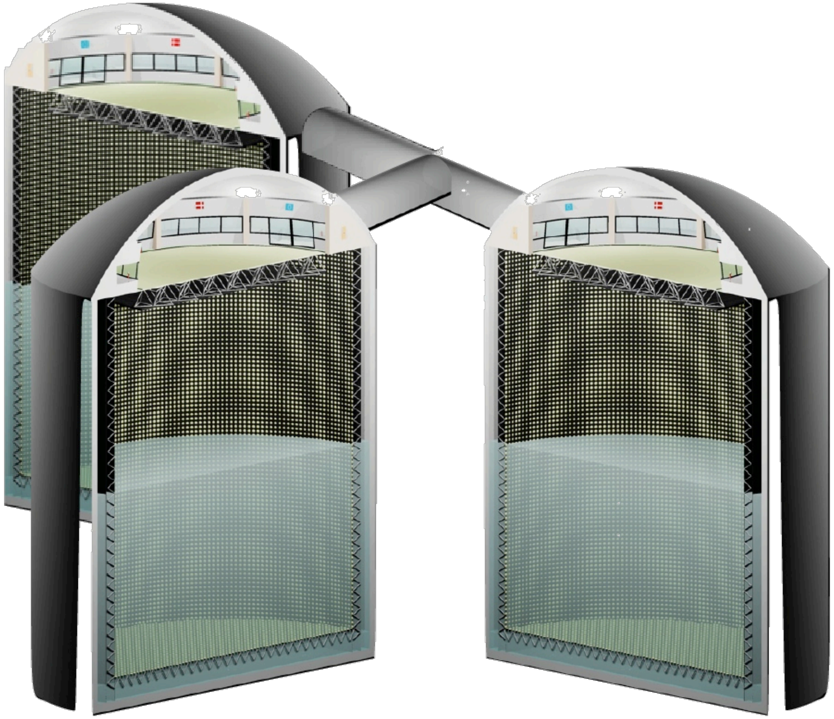




new safety gallery under construction, take profit of this opportunity to enlarge LSM



The MEMPHYS Project
(within FP7 LAGUNA DS)

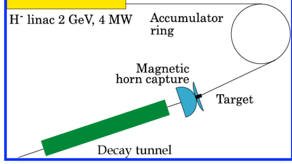


Mainly to study:

- **Proton Decay (GUT)**
  - **up to ~10^{35} years lifetime**
- **Neutrino properties and Astrophysics**
  - **Supernovae (burst + "relics")**
  - **Solar neutrinos**
  - **Atmospheric neutrinos**
  - **Geoneutrinos**
  - **neutrinos from accelerators (Super Beam, Beta Beam)**

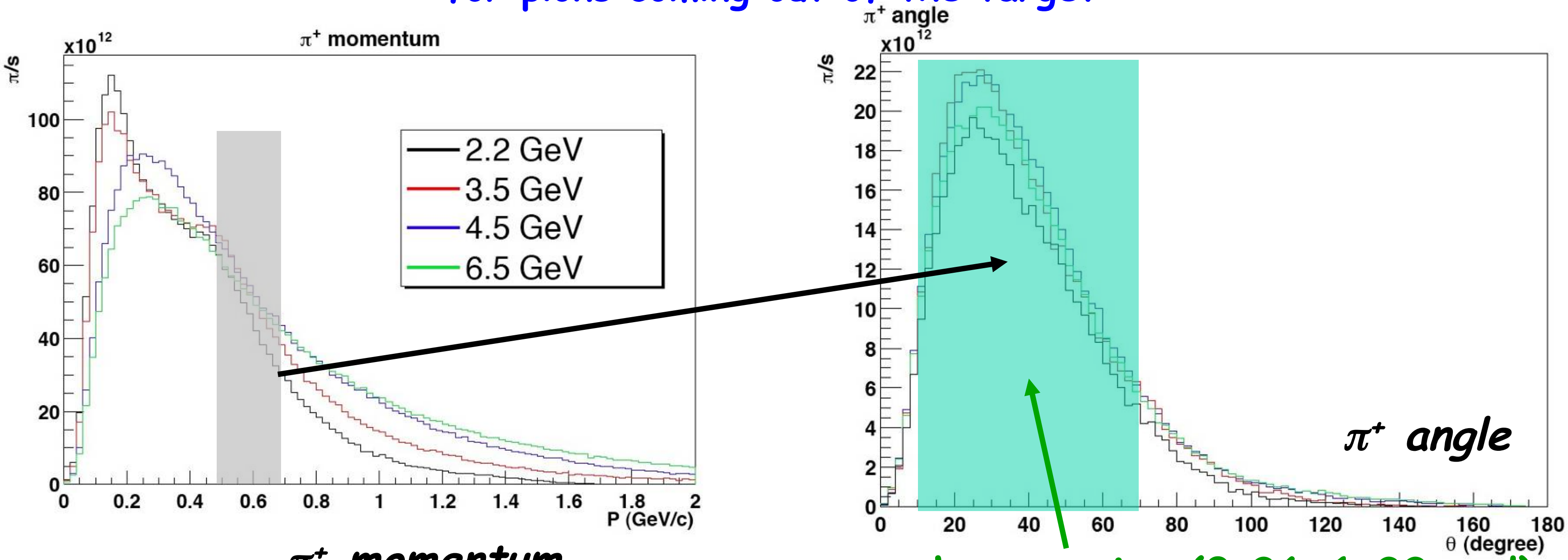
Water Cerenkov Detector with total fiducial mass: 440 kt:
- **3 Cylindrical modules 65x65 m**
- **Readout: 3x81k 12” PMTs, 30% geom. cover.**
  (#PEs =40% cov. with 20” PMTs).

(arXiv: hep-ex/0607026)



Proposed design for HP-SPL

for pions coming out of the target



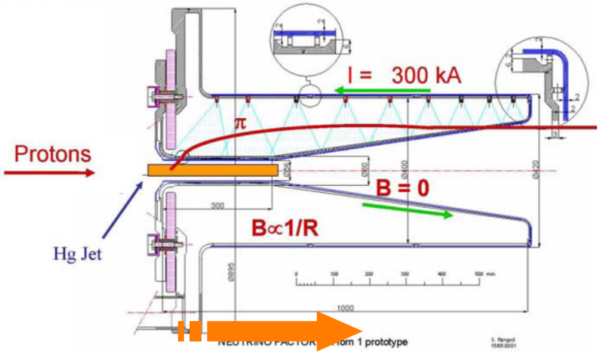
π^+ momentum

horn region (0.26-1.22 rad)

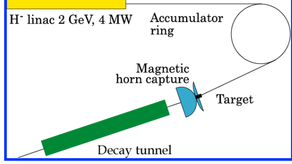
the target must be inside the horn

for a Hg target, 30 cm length, ∅15 mm
($N_{particles}$x10^{16}/sec, FLUKA)

E_k (GeV)	p	n	γ	e^+	e^-	π^+	π^-	μ^+	μ^-	K^+	K^0
2.2	1.4	17	5.0	0.08	0.17	0.24	0.18	4	1	7	6
3.5	1.8	23	7.0	0.15	0.28	0.41	0.37	10	3	35	30
4.5	2.3	25	7.7	0.21	0.35	0.57	0.39	11	3.3	93	68
8	3.1	33	11.0	0.41	0.63	1.00	0.85	30	9.5	413	340



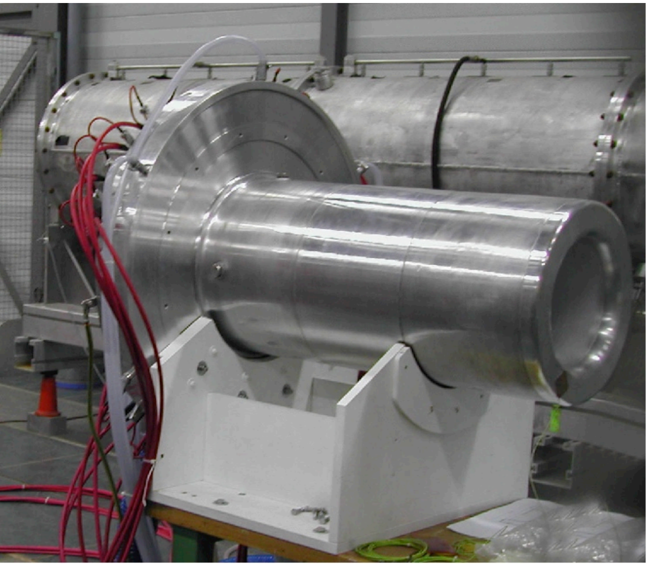
severe cooling conditions



Horn prototype (CERN)

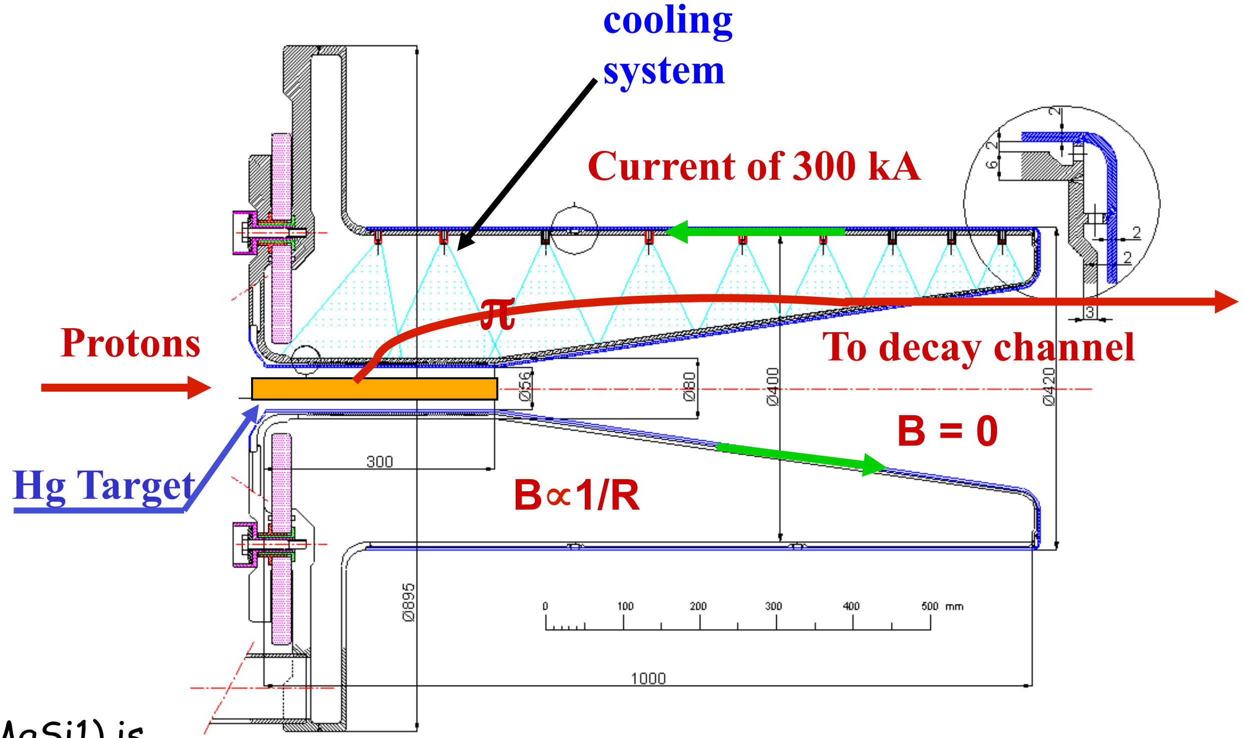
First studies with old SPL characteristics:

- 2.2 GeV proton beam



For the horn skin AA 6082-T6 / (AlMgSi1) is an acceptable compromise between the 4 main characteristics:

- Mechanical properties
- Welding abilities
- Electrical properties
- Resistance to corrosion
- Same for CNGS



cooling system

Current of 300 kA

Protons

π

To decay channel

Hg Target

B = 0

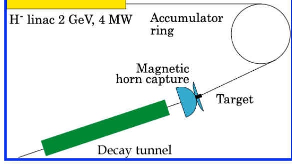
B∝1/R

initial design satisfying both, Neutrino Factory and Super Beam

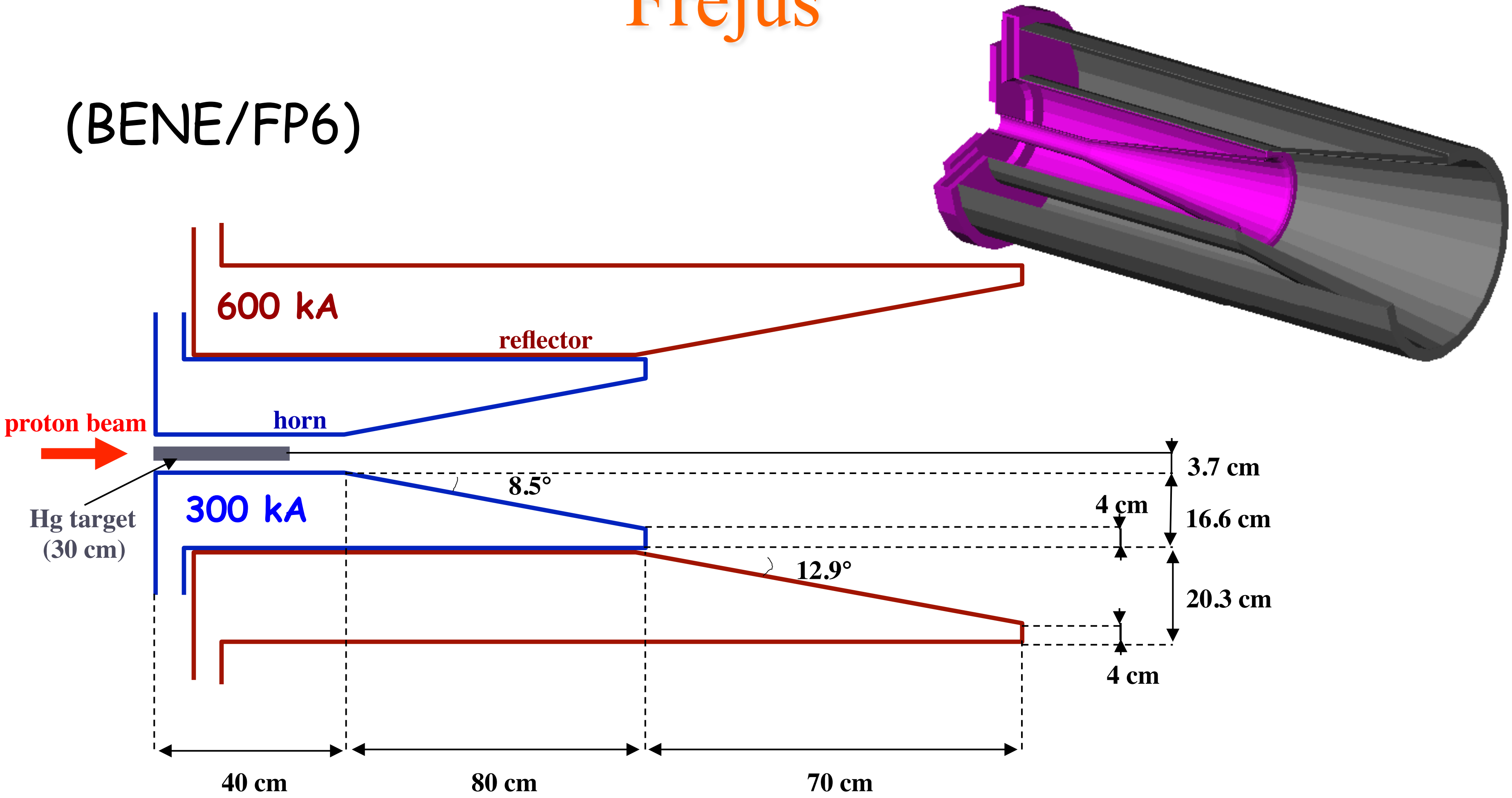
(see S. Gilardoni's thesis)

…but Al is not compatible with Mercury!

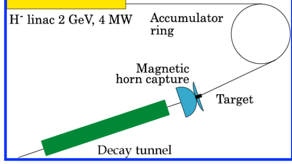
New design for SPL (3.5 GeV) to Frèjus



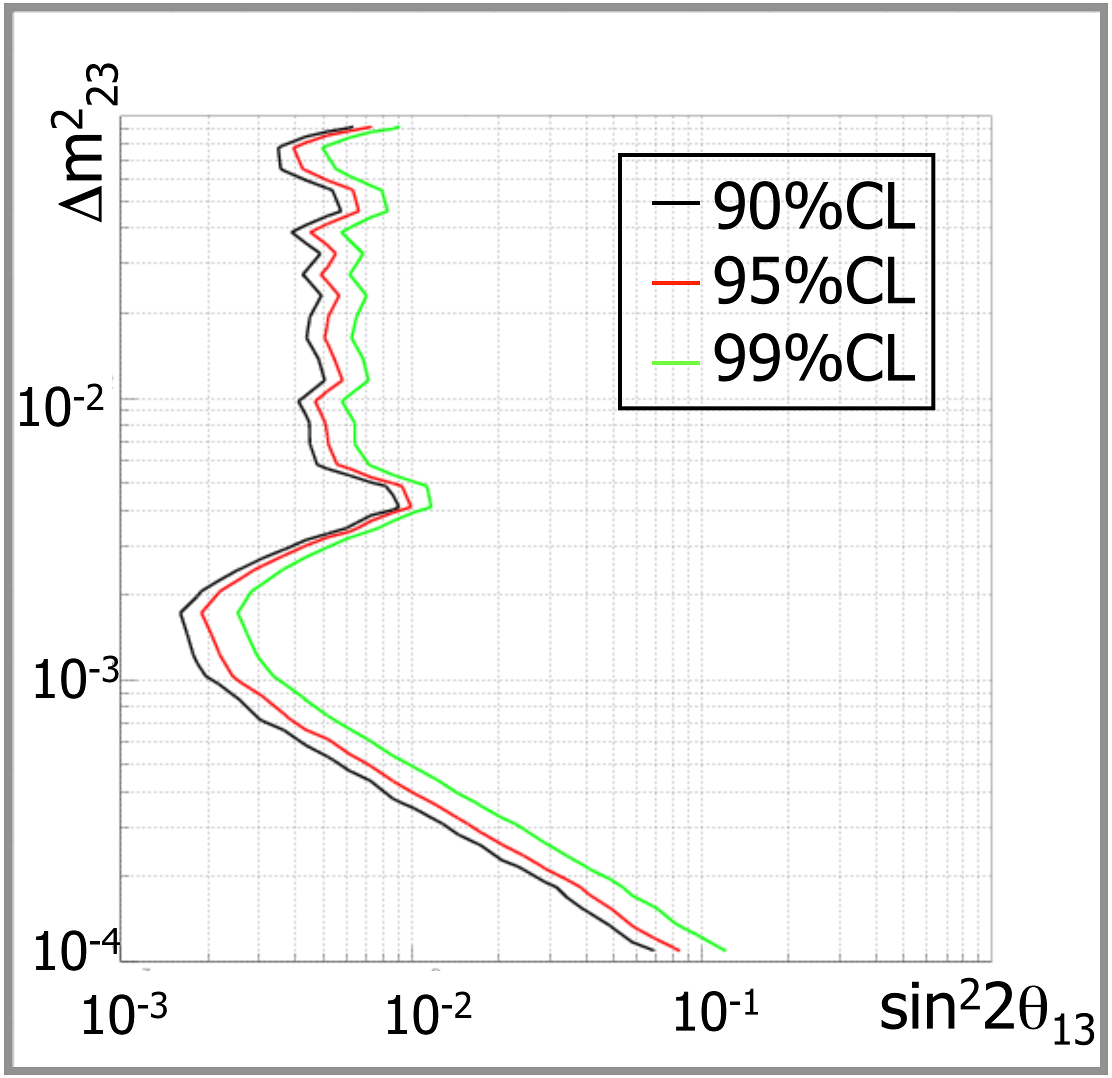
(BENE/FP6)



- very high current in reflector inducing severe problems
- building and operating one object inside the other in severe conditions (radiations, cooling, vibrations etc.) is extremely difficult



Sensitivity 3.5 GeV

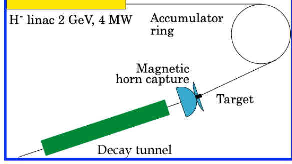


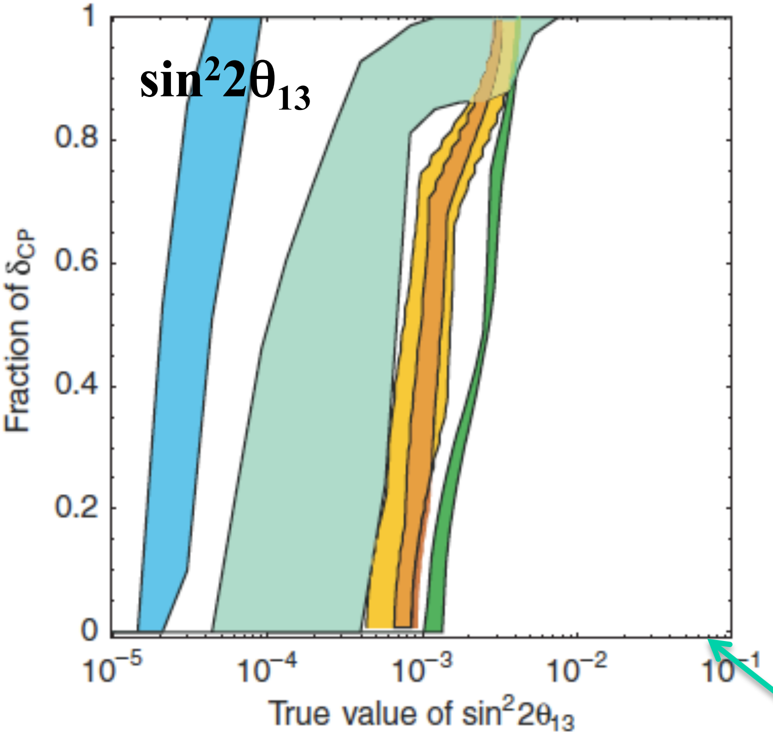
(A.Cazes' thesis)

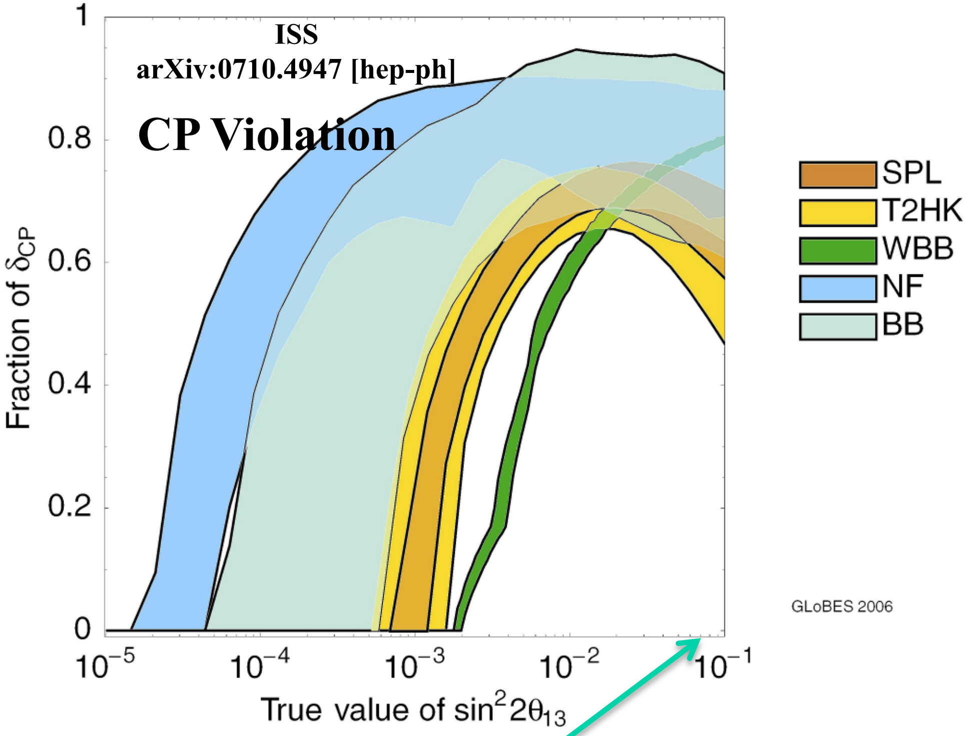
Minimum:
$\theta_{13} = 1.2°$
(90%CL)

no strong dependence on proton energy for 2.2<p<5 GeV

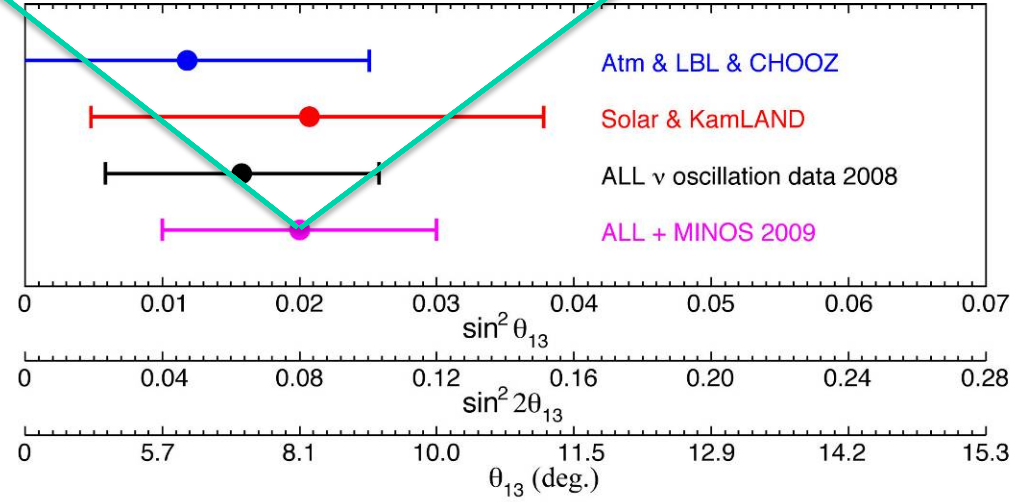
Sensitivity of future projects (ISS)







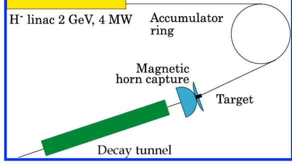
http://www.iop.org/EJ/toc/0034-4885/72/10



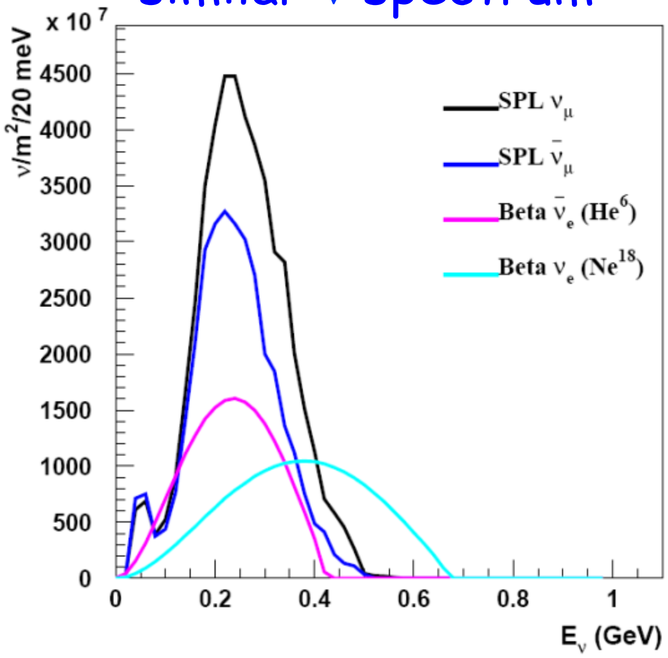
Hints (~1σ) for relatively large θ_{13} by combining all results

G. Fogli et al., [*http://arxiv.org/abs/0905.3549*](http://arxiv.org/abs/0905.3549)

Combination of Super Beam with Beta Beam

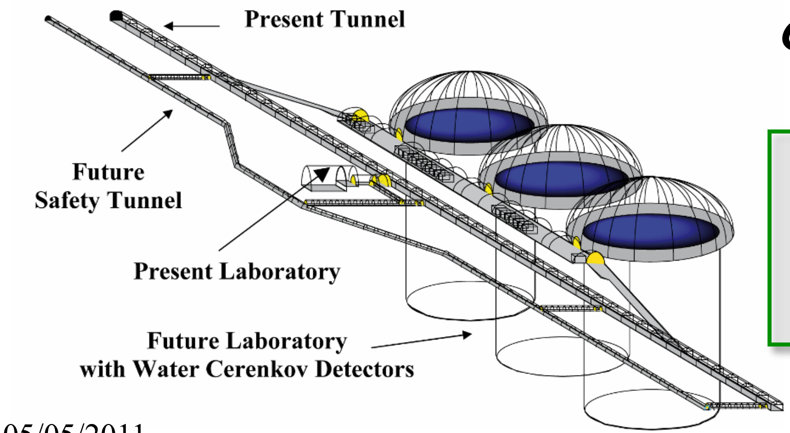


similar ν spectrum



Beta Beam (γ~100)		Super Beam
$\nu_e \rightarrow \nu_\mu$ (β+)	(T)	$\nu_\mu \rightarrow \nu_e$ (π^+)
(CP)	(CPT)	(CP)
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ (β-)	(T)	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ (π^-)

combination of CP and T violation tests

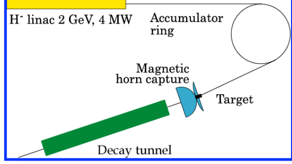


2 beams

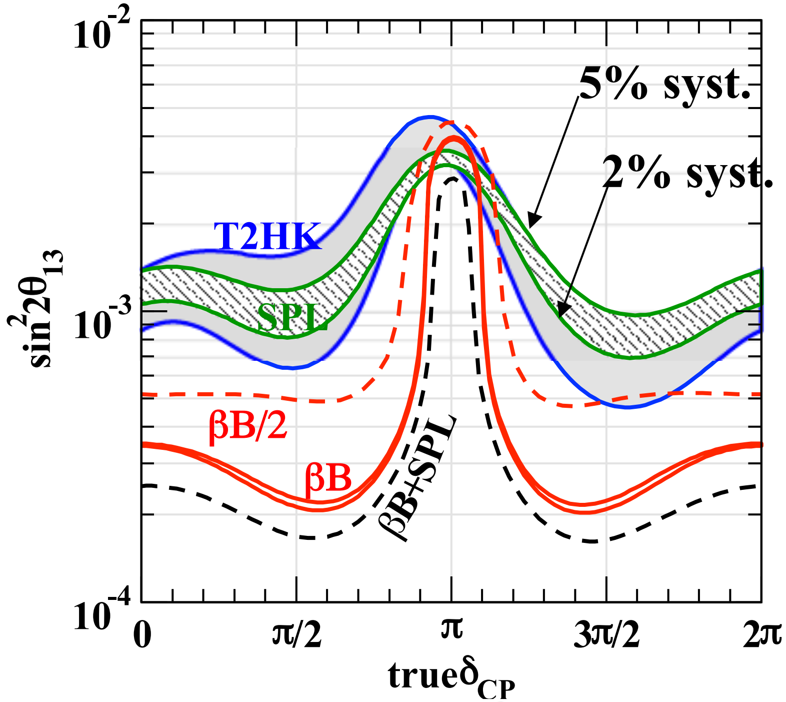
1 detector

Bonus: the unoscillated neutrinos of one facility can be used to well study the efficiencies of the other one

Performance and Comparisons



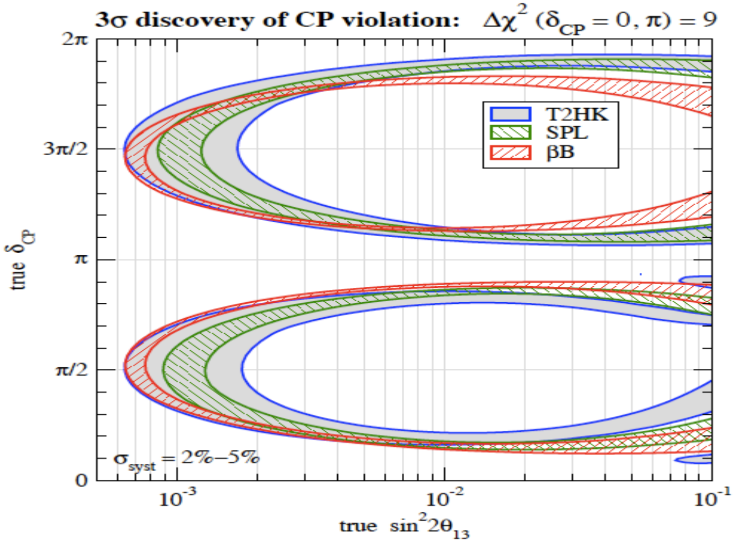
arXiv:hep-ph/0603172v3



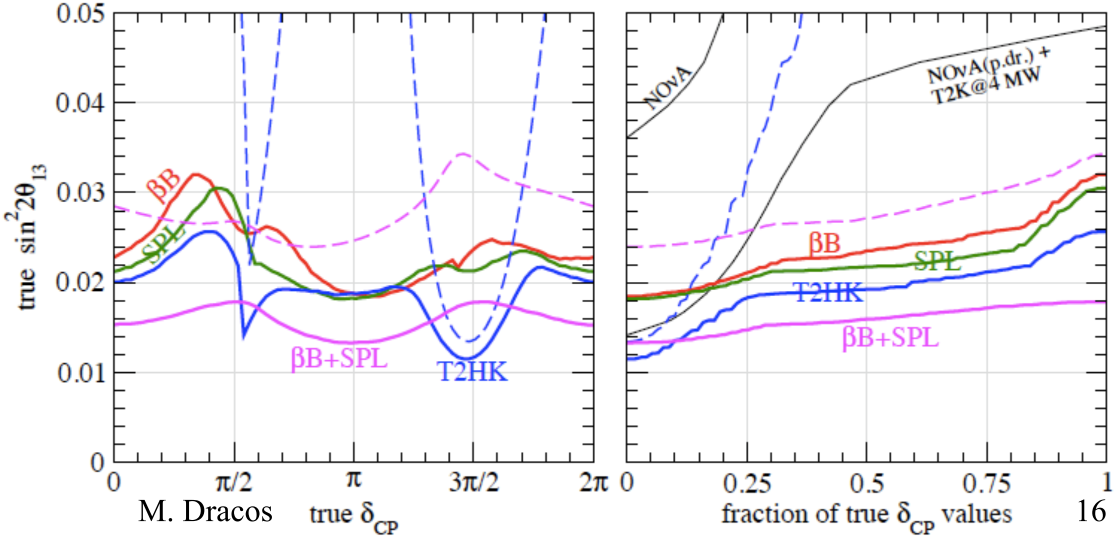
	βB	SPL	T2HK
Detector mass	440 kt	440 kt	440 kt
Baseline	130 km	130 km	295 km
Running time $(\nu + \bar{\nu})$	5 + 5 yr	2 + 8 yr	2 + 8 yr
Beam intensity	$5.8\,(2.2) \cdot 10^{18}$ He (Ne) dcys/yr	4 MW	4 MW
Systematics on signal	2%	2%	2%
Systematics on backgr.	2%	2%	2%

- solid line: LBL+atm.
- dashed line: LBL

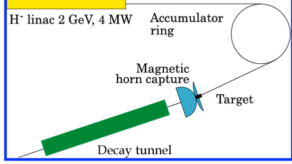
weak point: mass hierarchy



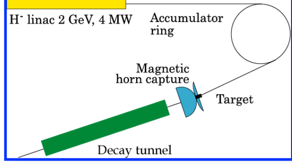
2σ sensitivity to normal hierarchy from LBL + ATM data



M. Dracos



From BENE (FP6) to EUROν (FP7, 2008-2012)

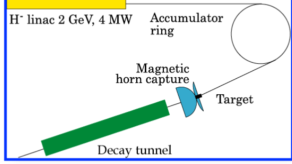


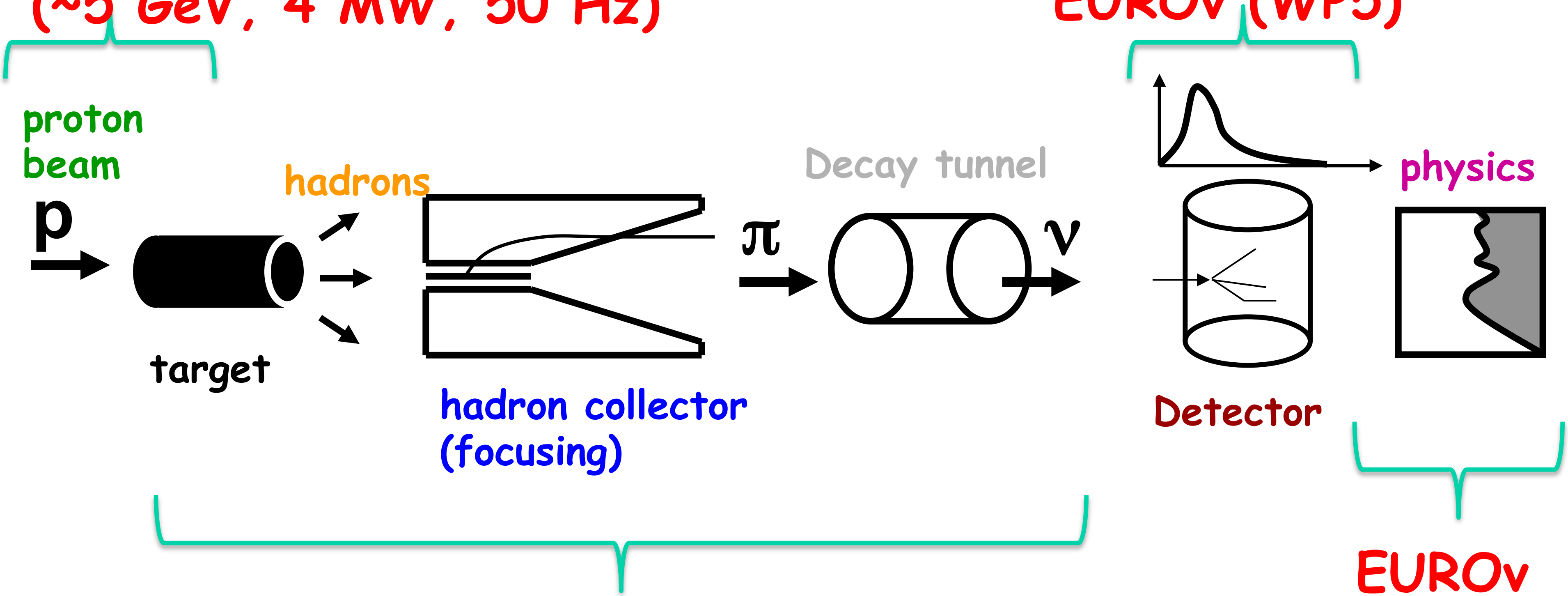
The WP2 team

- Cracow University of Technology
- STFC RAL
- IPHC Strasbourg
- Irfu-SPP, CEA Saclay
- external partners

E. Baussan, O. Besida, C. Bobeth, O. Caretta, P. Cupial, T. Davenne, C. Densham, M. Dracos, M. Fitton, G. Gaudiot, M. Kozien, B. Lepers, A. Longhin, P. Loveridge, F. Osswald, P. Poussot, M. Rooney, B. Skoczen, G. Vasseur, N. Vassilopoulos, A. Wroblewski, J. Wurtz, V. Zeter, M. Zito

EURUν-WP2 studies





HP-SPL (CERN)
(~5 GeV, 4 MW, 50 Hz)

LAGUNA
EUROν (WP5)

proton beam

p

hadrons

target

hadron collector (focusing)

π

Decay tunnel

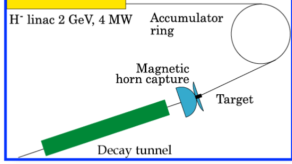
ν

Detector

physics

EUROν (WP2)

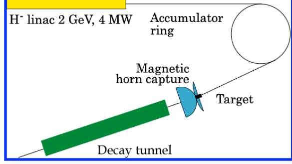
EUROν (WP6)



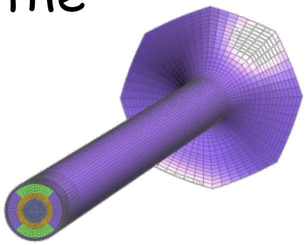
WP2 activities

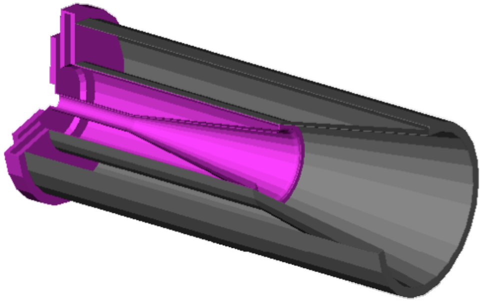
- Beam simulation and optimization, physics sensitivities
- Beam/target interface
- Target and target station design
- Horn design
- Target/horn integration
- Cost
- Safety

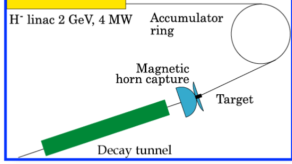
Technological Challenge



- Can we conceive a neutrino beam based on a multi-MW proton beam ?
- At the start of EUROν, no proven solution for the target and collector was proposed for this facility !
- Can we design a target for a multi-MW proton beam ?
- Can we do it with a reliable design without compromising the physics reach ?
- **Target**
  - 300-1000 J/cm^3/pulse
  - Severe problems from: sudden heating, stress, activation
  - Solid versus liquid targets
  - cooling
- **Horn**
  - horn+reflector integration
  - pulser (up to 600 kA)
- **Safety**
- **Lifetime** (supposed to run for 10 years)

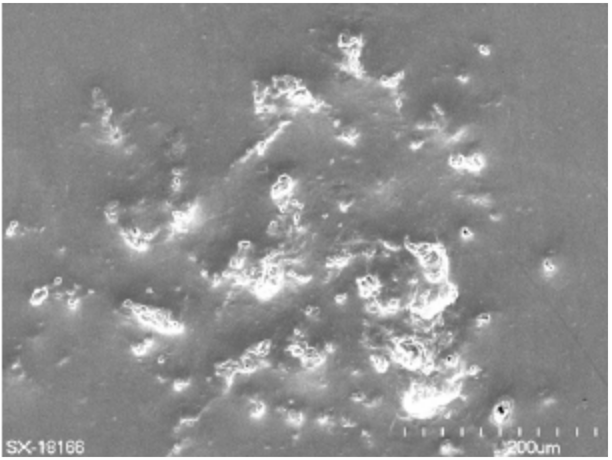






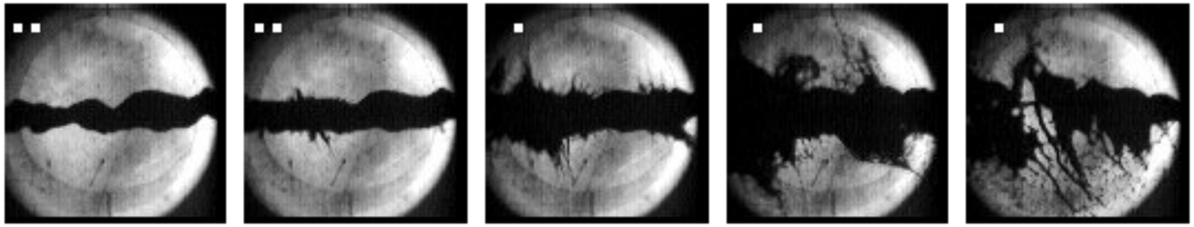
Studies on Hg targets

Contained mercury



Cavitation damage in wall of Hg target container after 100 pulses of 19 J/cc proton beam (WNR facility at LANL)

Free mercury jet

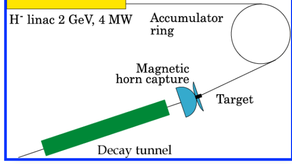


MERIT experiment: Beam-induced splashing of mercury jet (c.200 J/cc)

- Damping of splashes due to magnetic field observed as predicted

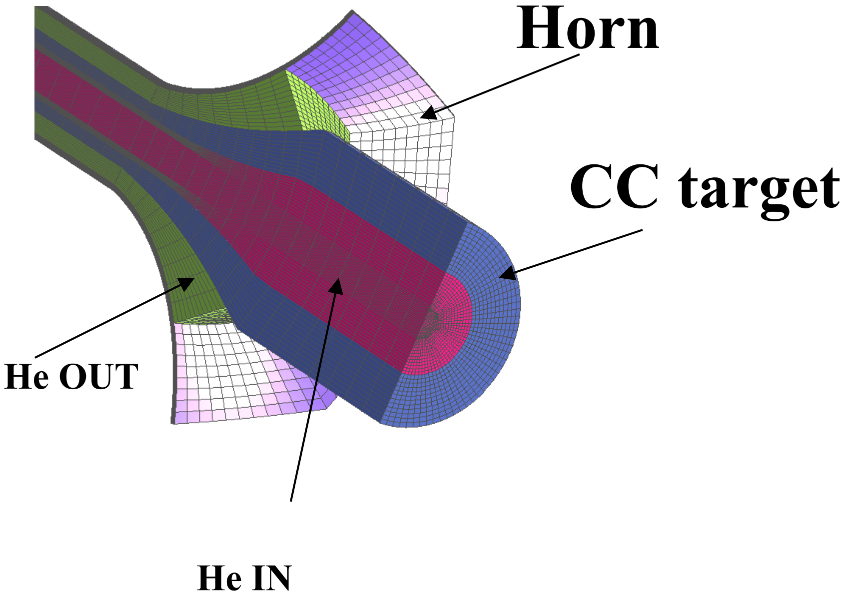
no problem with target cooling but…

- Magnetic horns are typically manufactured from aluminium alloy not compatible with Hg (severe and rapid erosion in addition to the shock wave problem).
- Necessity to protect the horn with a layer of material compatible with liquid Hg (lifetime?).
- B=0 inside horn, ie no magnetic damping of mercury jet as in MERIT experiment.
- Combination of a mercury jet with a magnetic horn appears to be extremely difficult.

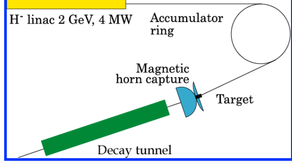


Solid Targets?

- Graphite (or other solid targets) is conventional and already used for neutrino beams
- Easier to combine with a magnetic horn (e.g. T2K target)
- Questions:
  - How does particle production for C compare with Hg?
  - Can a static graphite target dissipate heat from a 4 MW beam?
  - What is the expected lifetime for a graphite target in a 4 MW beam?
  - According to studies done at BNL, no problem with 1-1.5 MW proton beam.



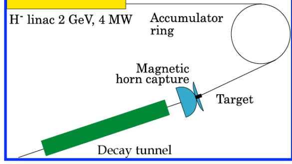
cooling is a main issue…



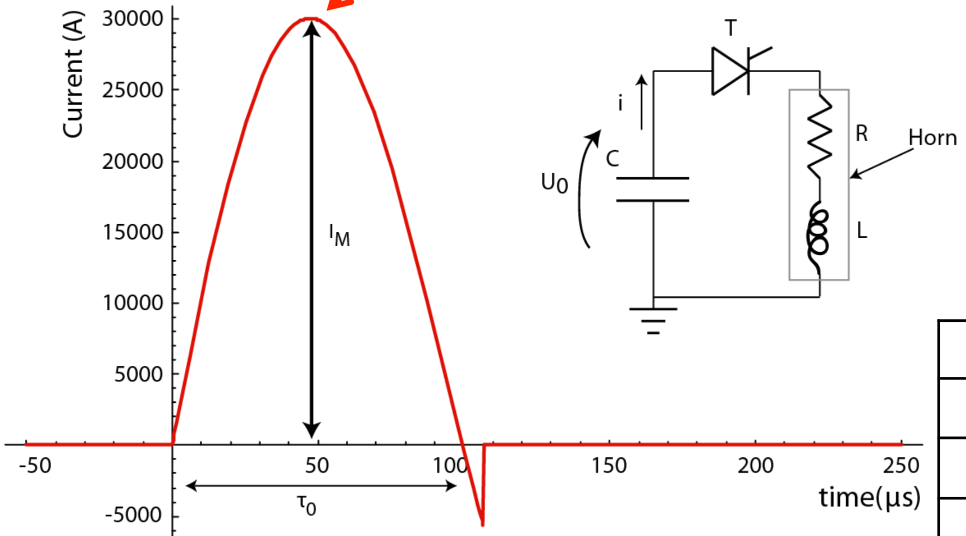
Main Collector Challenges

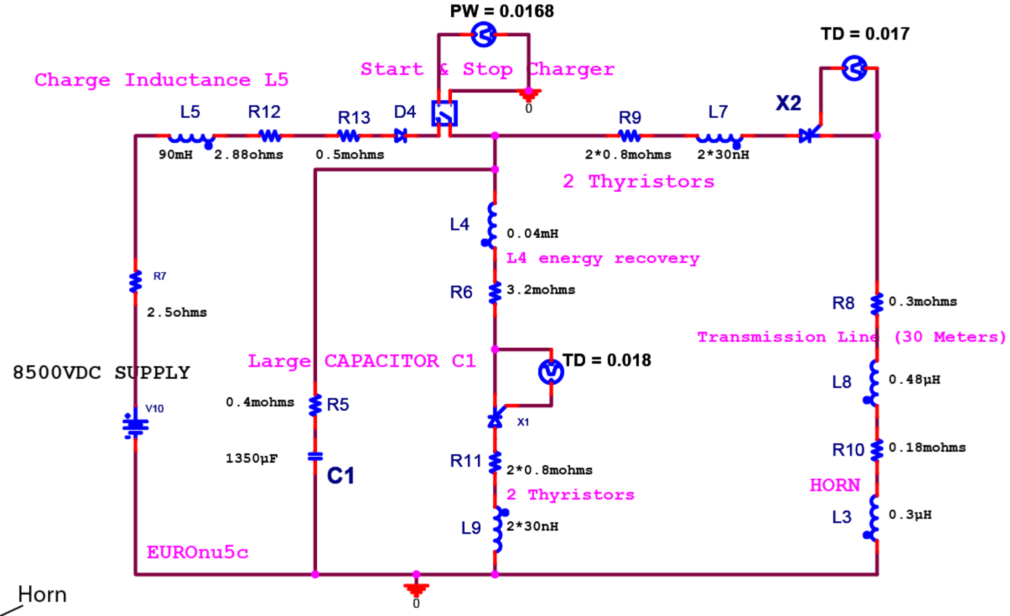
- Horn : as thin as possible (few mm) to minimize the energy deposition.
- Pulsing repetition rate: 50 Hz (vs a few Hz up to now).
- Large electromagnetic wave, thermo-mechanical stress, vibrations, fatigue, radiation damage (multiphysics studies needed).
- Currents: 300 kA (horn) and 600kA (reflector),
  - design of a high current pulsed power supply.
- Cooling system in order to maintain the integrity of the horn.
- Definition of the radiation tolerance.
- Integration of the target and horn.
- Longevity in a high power beam.

Power Supply for horn pulsing



focusing done during
this "plateau"
proton pulse duration
must be limited (<5 µs)

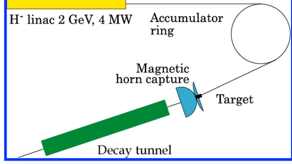




energy recuperation (>60%)
and reinjection

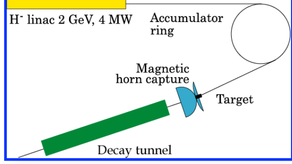
U_0	7 kV
I_M	300 kA (14.5 rms)
τ_0	100 µs
L	0.6 (0.4 Horn) µH
R	500 (180 Horn) µΩ
C	1500 µF

300 kA/50Hz
it's a real
challenge

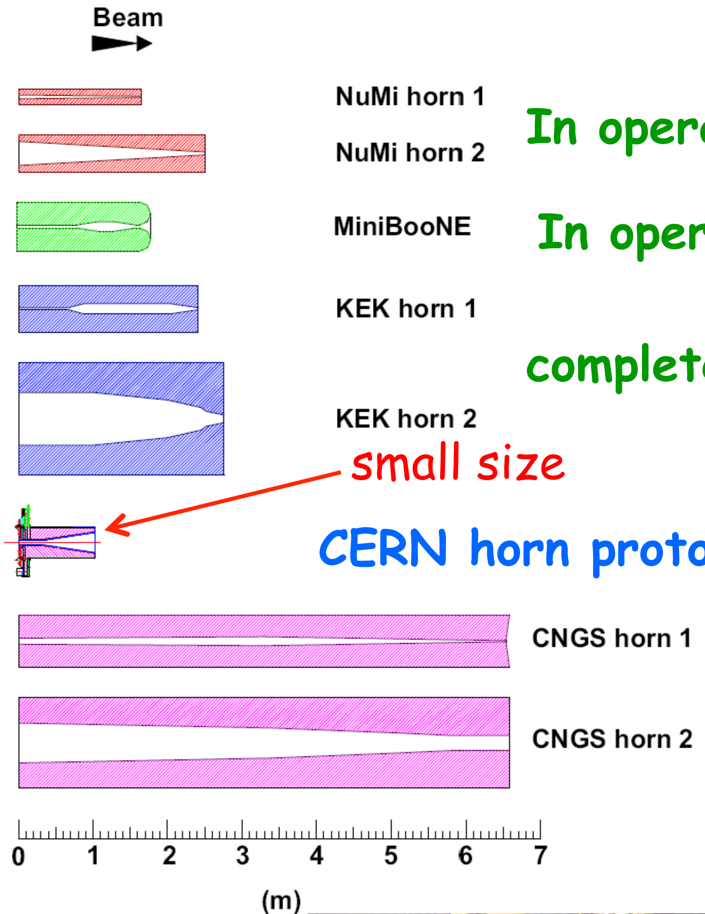


How to deal with all these problems?

Present Collectors



Experiment	Current	Rep. Rate	Pulses per time period
Numi (120 GeV)	200 kA	0.5 Hz	6 Mpulses 1 year
MiniBoone (8 GeV)	170 kA	5 Hz	11 Mpulses 1 year
K2K (12 GeV)	250 kA	0.5 Hz	11 Mpulses 1 year
Super-Beam (3.5 GeV)	300 kA	50 Hz	200 Mpulses 6 weeks
CNGS (400 GeV)	150 kA	2 pulses/ 6 sec	42 Mpulses 4 year



In operation

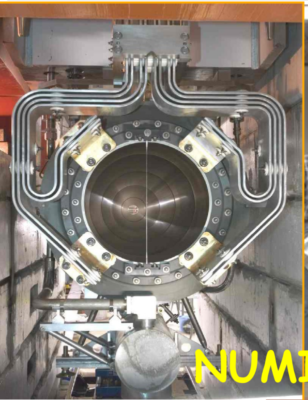
In operation

completed

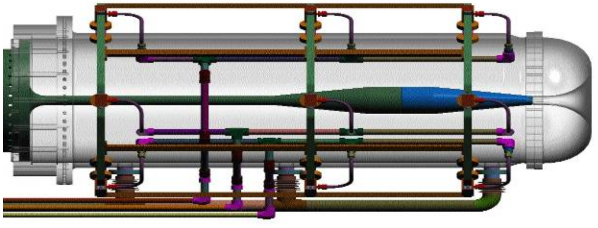
small size

CERN horn prototype for SPL

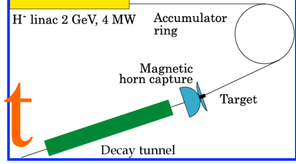
In operation



MiniBooNE

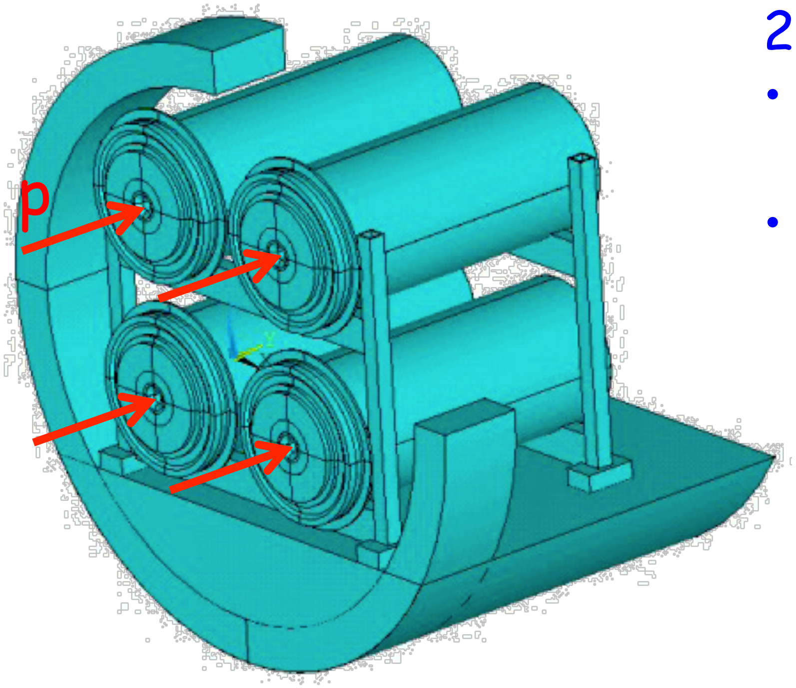


How to mitigate the power effect



4 target/horn system (4x4 m^2) with single decay tunnel (~30 m)

back to solid targets able to afford up to ~1.5 MW proton beam



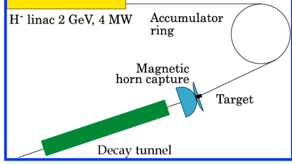
2 options (only one pulser?):

- send at the same time 1 MW per target/horn system
- send 4 MW/system every 50/4 Hz
  - in case of failure of one horn/target, continue with the 3 remaining ones sharing the 4 MW power

we get rid of Hg, but what about particle production?

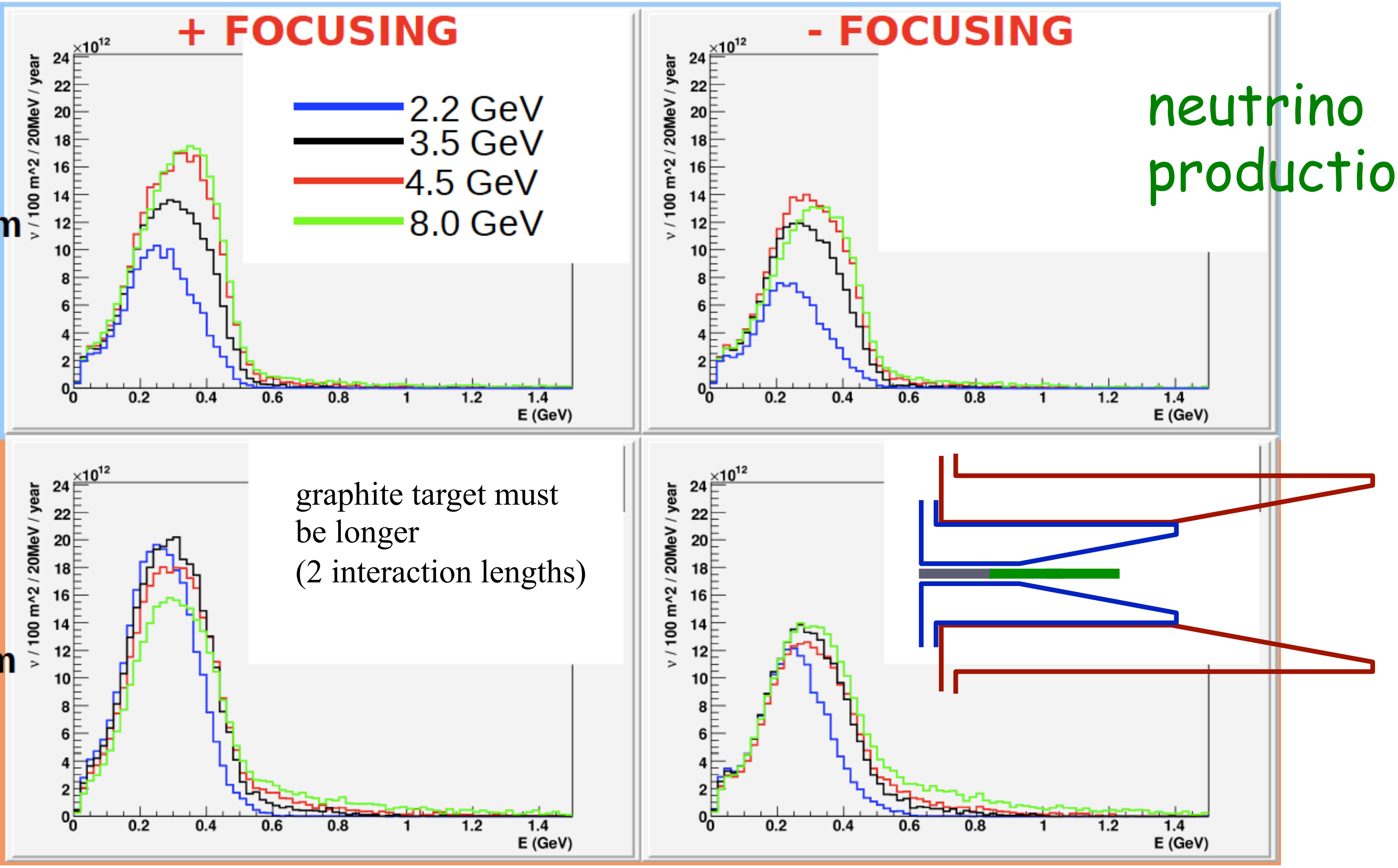
more expensive but more reliable system

Comparison Mercury/Carbon



Mercury
30/0.75 cm

Graphite
78/0.75 cm

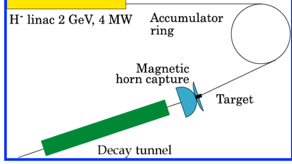


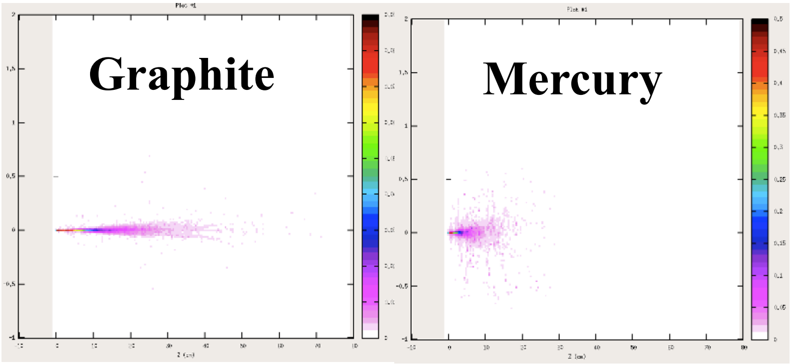
graphite target must be longer (2 interaction lengths)

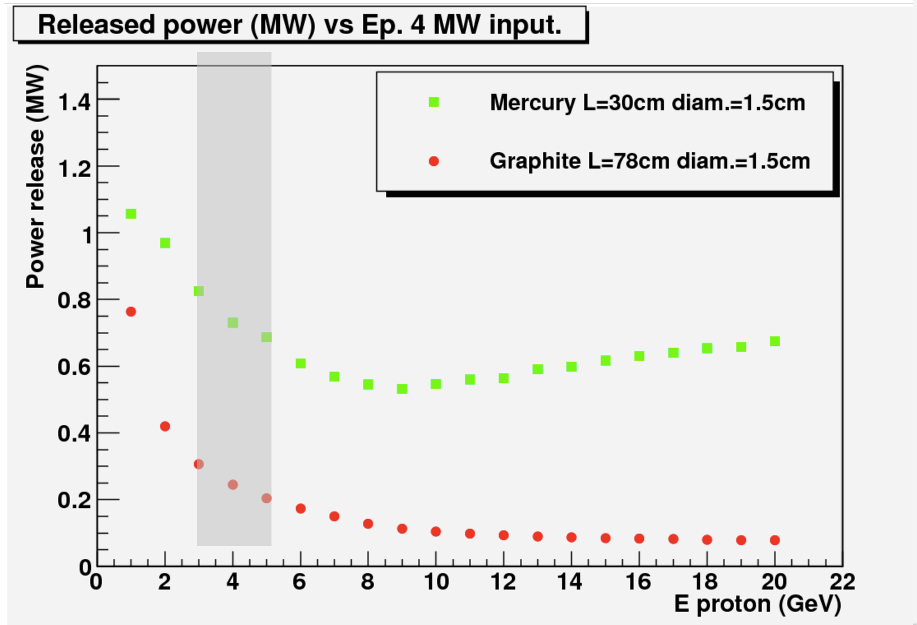
neutrino production

- neutrino intensities are comparable despite non optimized focusing for long Graphite target (very promising)
- high energy tail for Graphite is slightly more important (not optimized focusing)

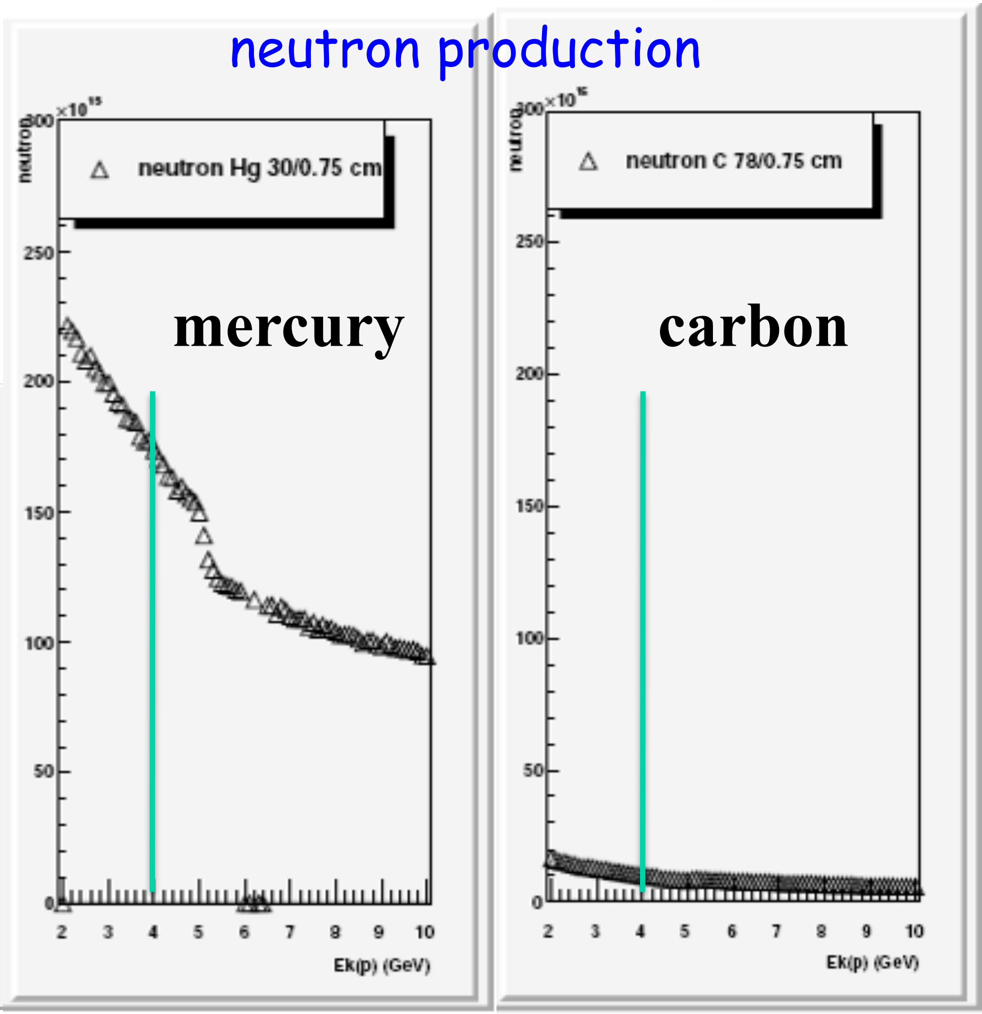
The Bonus…







neutron production

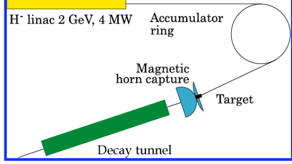


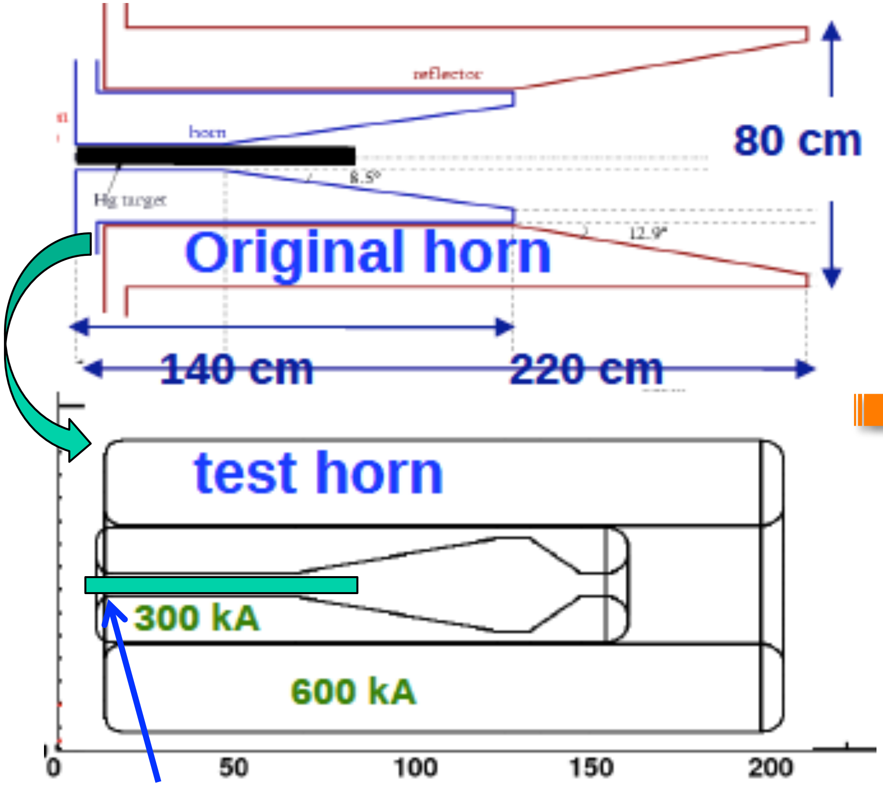
Released power:

- Hg: ~ 1 - 0.6 MW
- C : ~ 0.8 - 0.1 MW
- lower for Carbon !

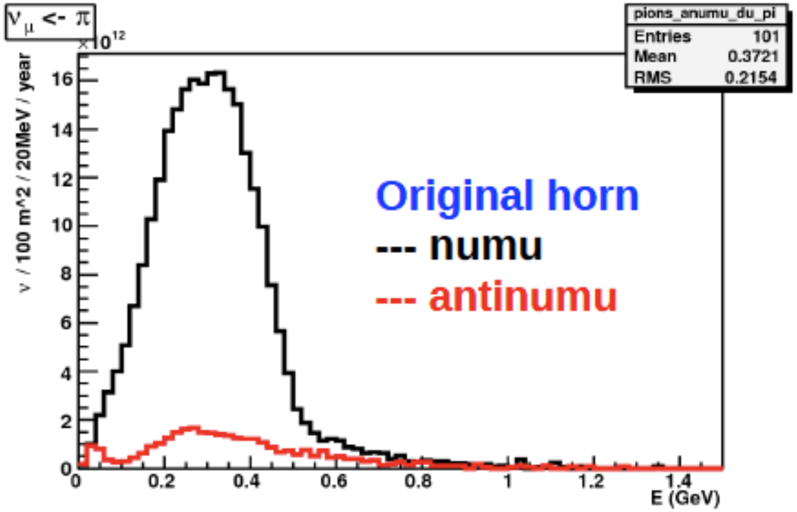
neutron flux dramatically reduced wrt Hg!
(~ x15)

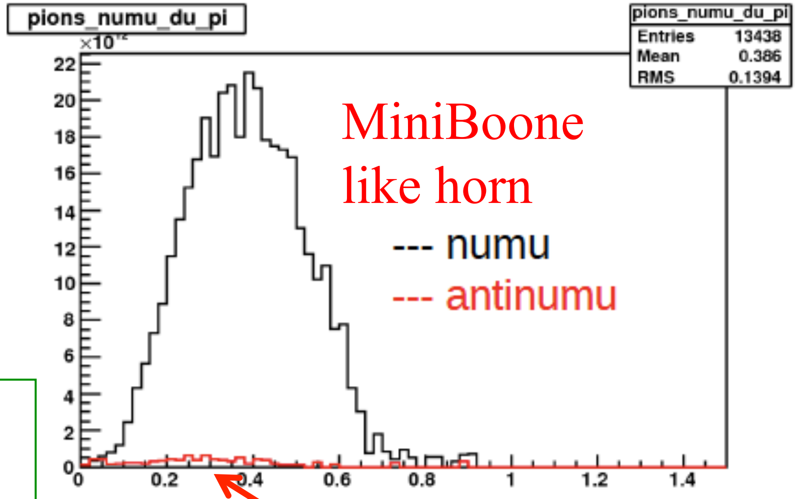
Can we optimize the horn shape for the solid target?





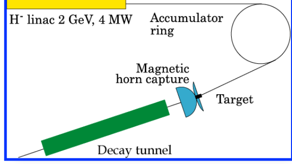
solid target (2 X0)



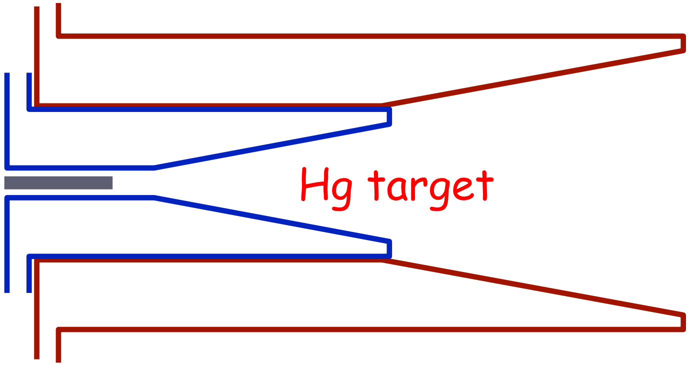


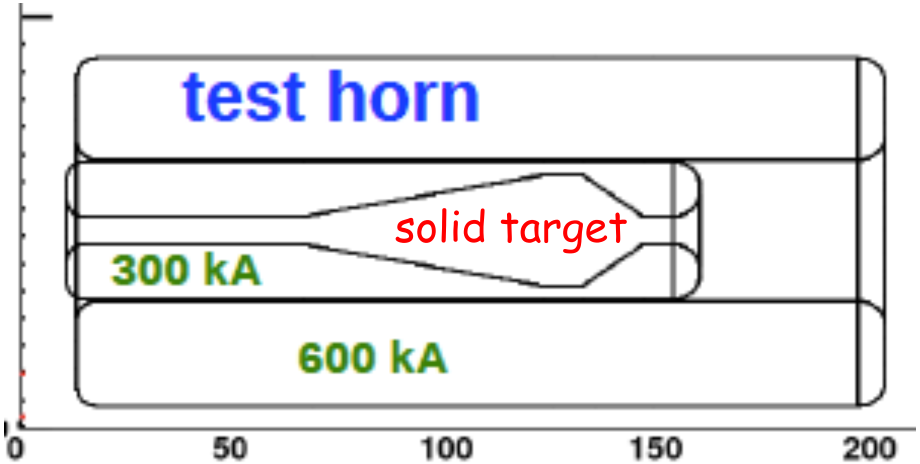
less contamination

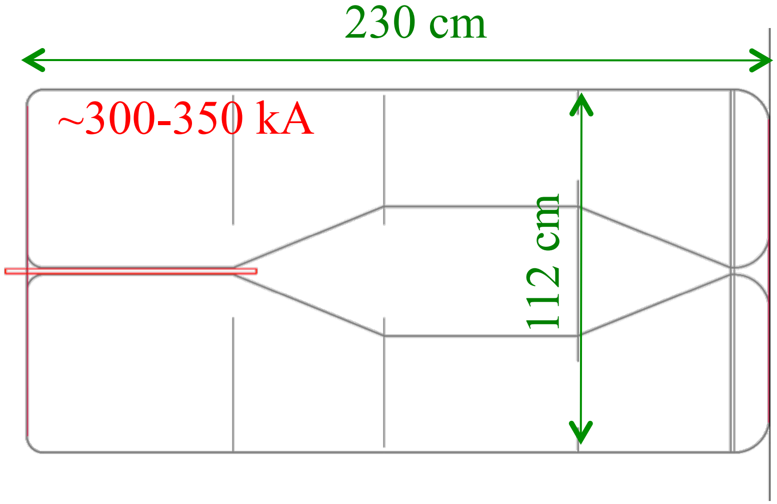
~simpler focalisation system without compromising with the physics performance (with even less contamination)



Can we get rid of the reflector?



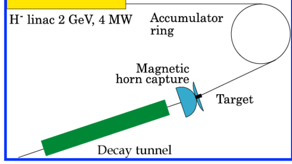


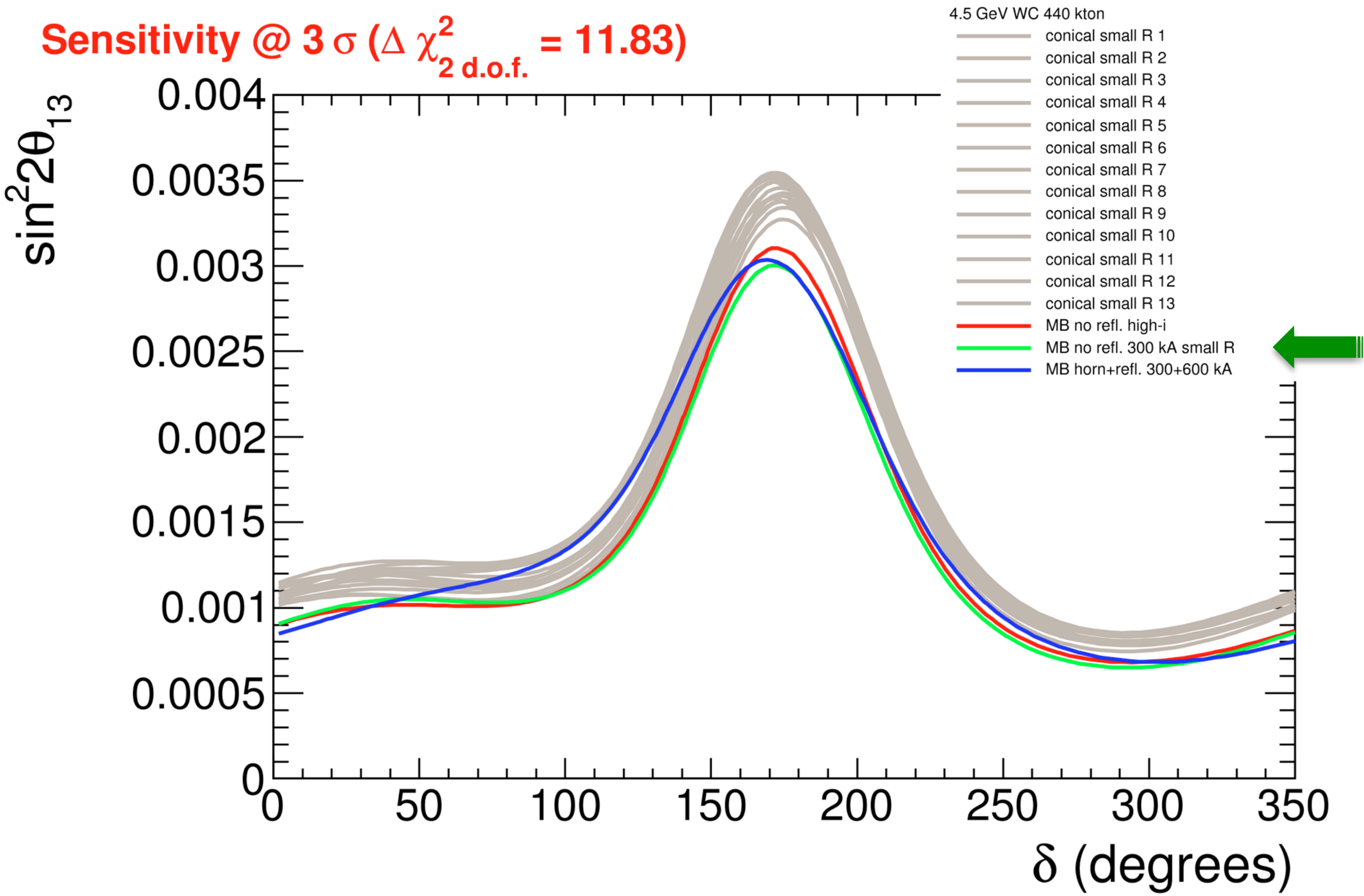


simple shape
with reduced
current!

(see N. Vassilopoulos' presentation)

Physics Performance



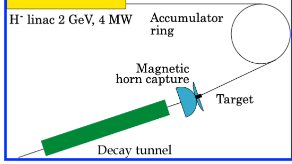

Sensitivity @ 3 σ ($\Delta \chi^2_{2\,d.o.f.} = 11.83$)

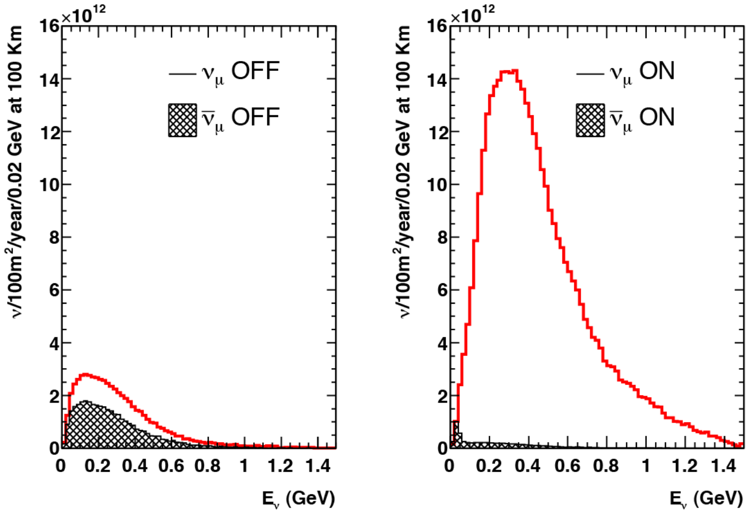
betters (best) results with the new horn geometry

➡

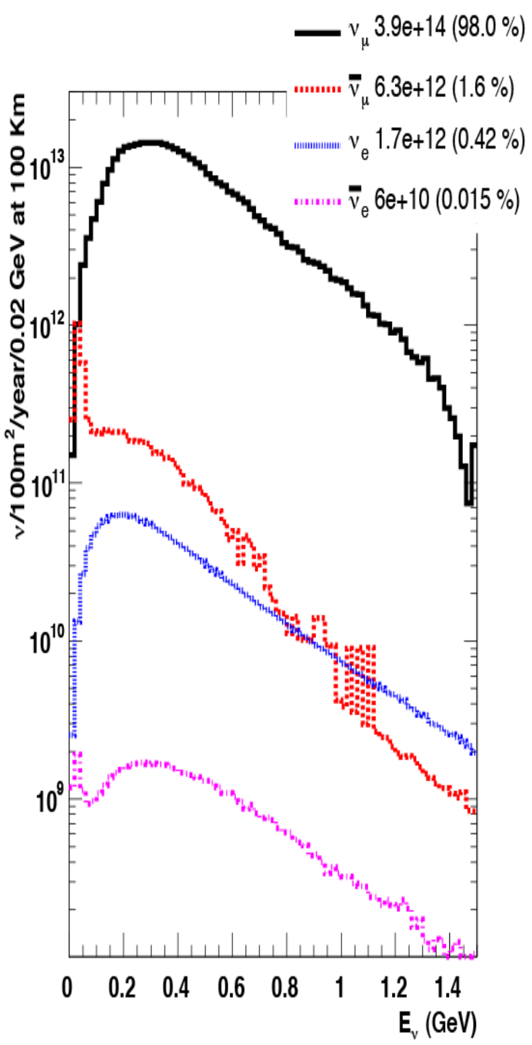
very promising (baseline)

Neutrino Spectra

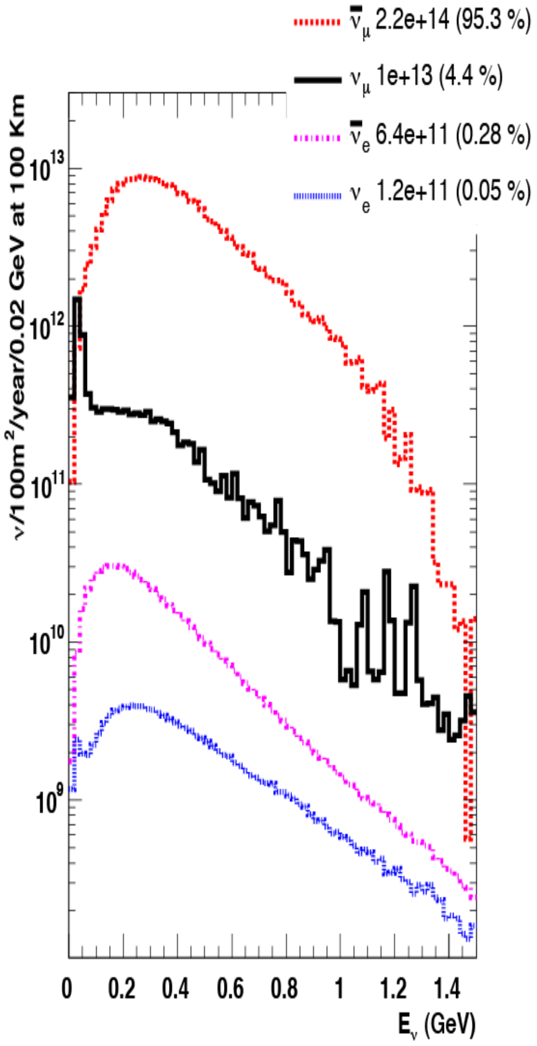




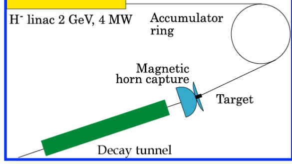
horn on/off



neutrinos



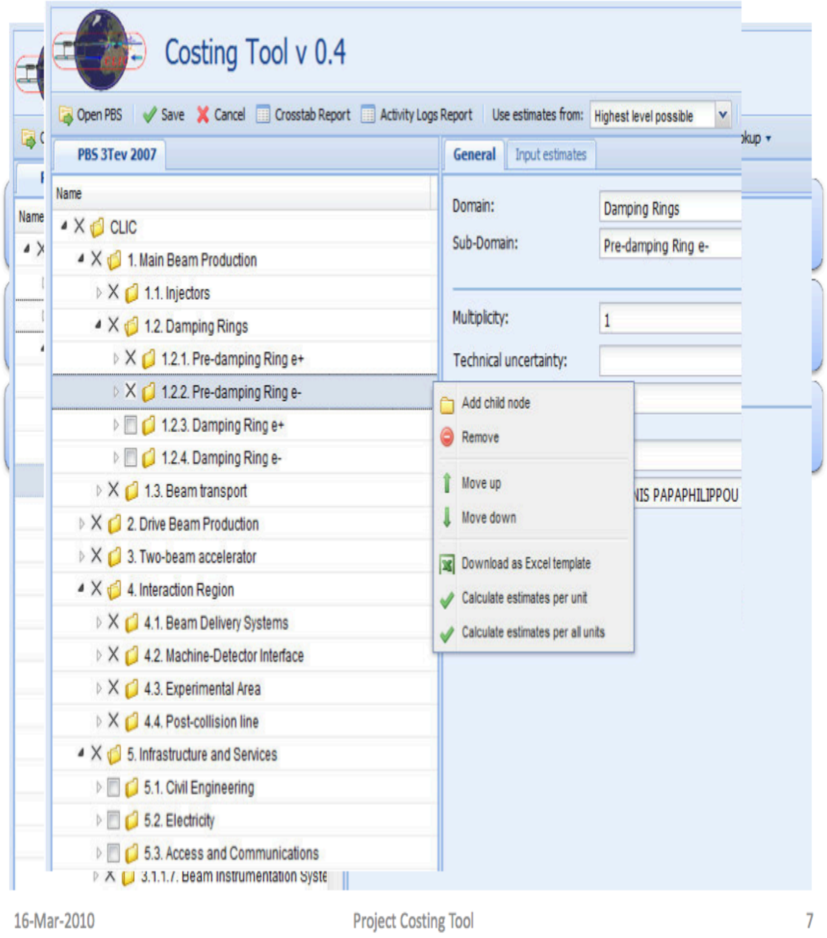
anti-neutrinos



Cost of the facilities

(CERN tool for project costing)

- The cost evaluation and safety issues of the proposed facilities are part of the design study.
- A first two days costing workshop has been organized at CERN in March 2010 (http://indico.cern.ch/event/EuroNuCostingMar2010)
    - presentation of the cost management techniques to the EURO ν participants towards defining a strategy for what needs to be done within the design study.
- Definition of the WP2 WBS underway (EUROν has also to cost HP-SPL, hopefully with the CERN help)

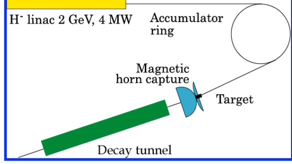


Use estimates from: Highest level possible

- CLIC
    - 1. Main Beam Production
        - 1.1. Injectors
        - 1.2. Damping Rings
            - 1.2.1. Pre-damping Ring e+
            - 1.2.2. Pre-damping Ring e-
            - 1.2.3. Damping Ring e+
            - 1.2.4. Damping Ring e-
        - 1.3. Beam transport
    - 2. Drive Beam Production
    - 3. Two-beam accelerator
    - 4. Interaction Region
        - 4.1. Beam Delivery Systems
        - 4.2. Machine-Detector Interface
        - 4.3. Experimental Area
        - 4.4. Post-collision line
    - 5. Infrastructure and Services
        - 5.1. Civil Engineering
        - 5.2. Electricity
        - 5.3. Access and Communications
        - 3.1.1.7. Beam instrumentation Syste

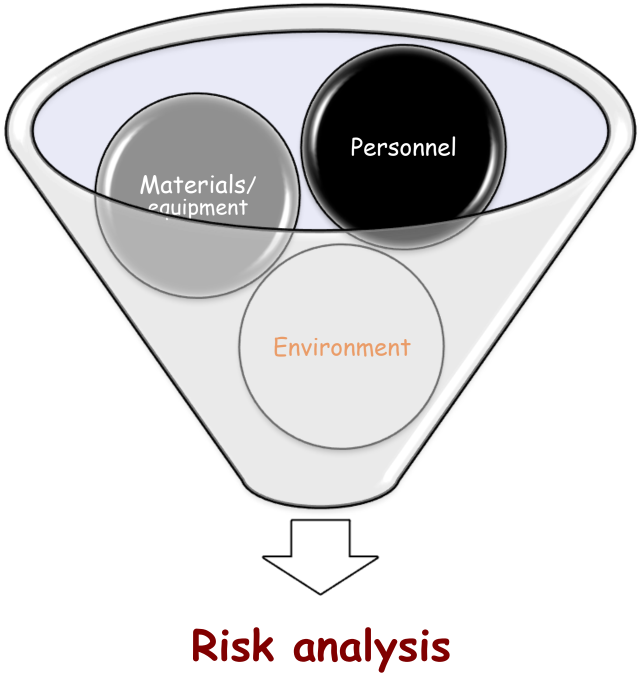
Domain: Damping Rings
Sub-Domain: Pre-damping Ring e-
Multiplicity: 1
Technical uncertainty:
IIS PAPAPHILIPPOU

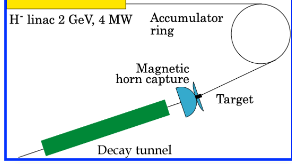
CERN costing tool



Safety
(workshop at CERN, 9-10 June)

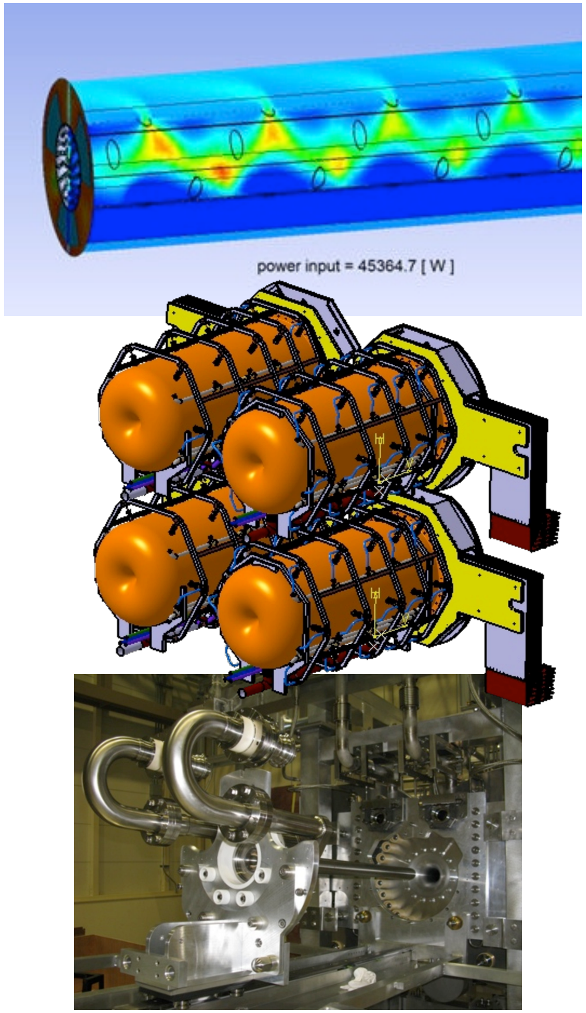
- ❑ Identify safety issues in the project
  - Safety of **personnel** during installation, operation, maintenance and dismantling actions.
  - Safety to **materials/equipment** – assure their operation as required by the specs.
  - Impact to the **environment** during installation, operation and dismantling of the facility.
- ❑ Do risk analysis for each identified safety issue
  - Ways to **mitigate** the risk → incorporate in the design, **include in the cost** estimate.
  - Classify the risks → setup the project risk register.

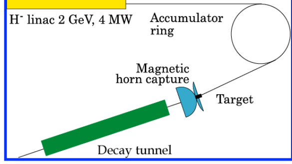




After EUROν

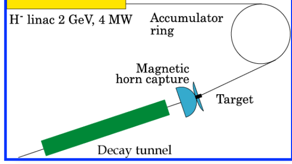
- R&D is needed for:
  - target
  - horn
  - horn pulsing system
- When?
  - next relevant EU call?





Conclusions

- The SPL to Fréjus Super Beam project is under study in FP7 EUROnu WP2:
  - Conventional technology
  - "Short" schedule
  - Cost effective
  - Many synergies with other projects
  - Competitive CP sensitivity down to $\sin^2(2\theta_{13})\sim10^{-3}$
- Work in EUROν:
  - physics performance has been improved (still room for improvements?).
  - the proposed system is now feasible and reliable
- We have started freezing all elements of this facility.
- Cost estimation soon.
- The physics potential of this project is very high (also for astrophysics) especially in case of SB/BB combination.
- R&D is needed.


H- linac 2 GeV, 4 MW
Accumulator ring
Magnetic horn capture
Target
Decay tunnel

End