Super-Beam studies for an European Oscillation Facility within the EURONu framework

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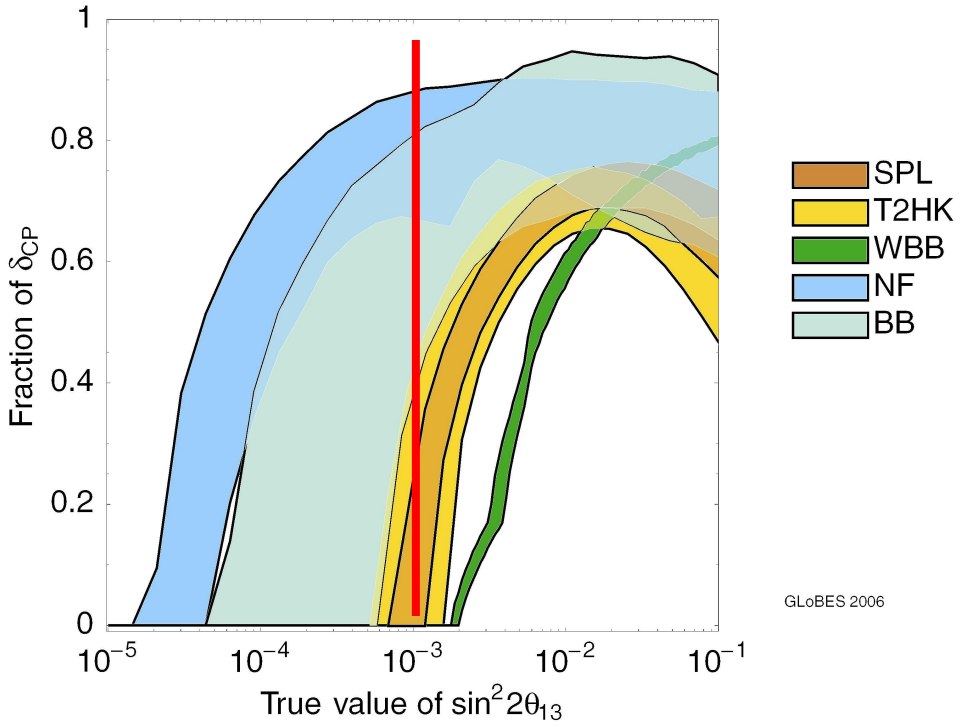
NEU2012 RAL 14/4/2010

Outstanding questions in neutrino physics

- Discover the last oscillation channel θ_{13} (T2K, Double Chooz ...)
- Measurement of neutrino mass
- Dirac or Majorana? (Neutrinoless Double Beta Decay)
- Mass hierarchy
- CP violation in the leptonic sector (leptogenesis!)

Super Beam features

- "Conventional" technology
- Competitive CP sensitivity down to $\sin^2(2\theta_{13}) \sim 10^{-3}$



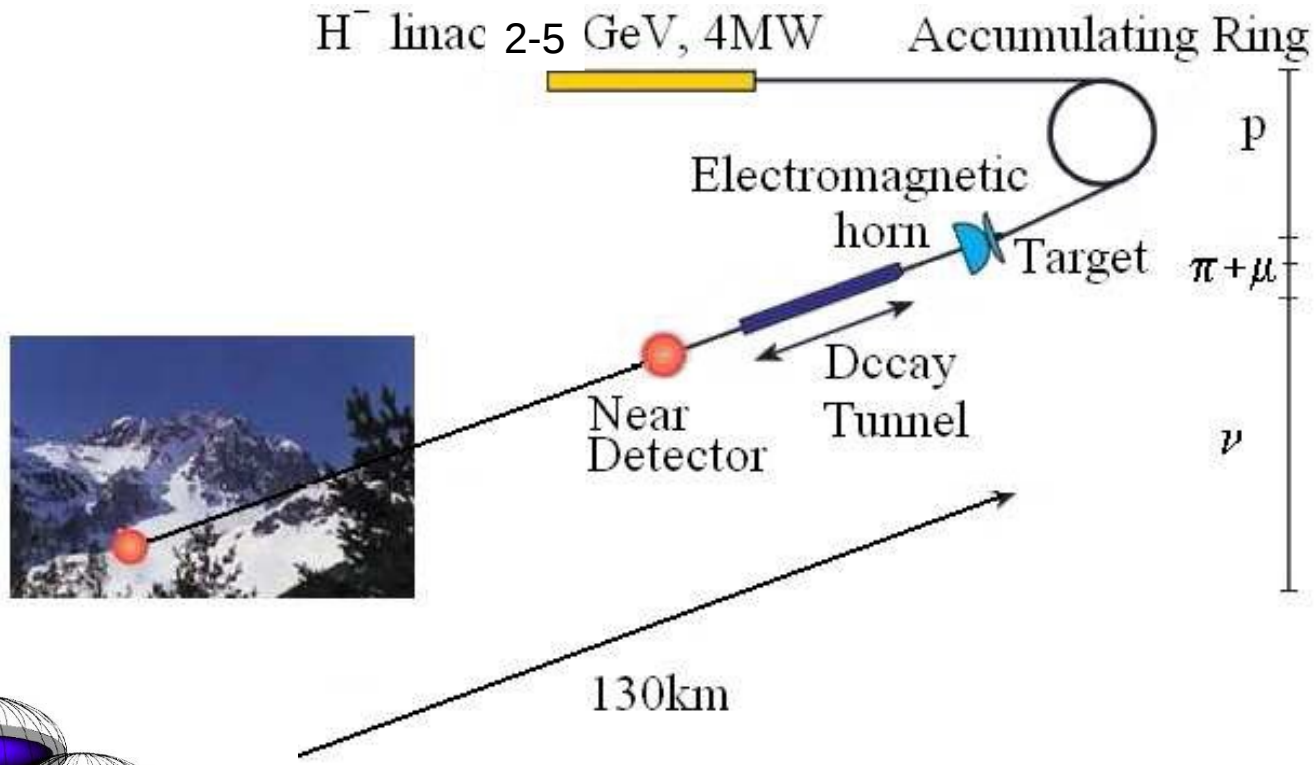
First indications about $\sin^2(2\theta_{13})$ in 2010-2011 (T2K+...) eagerly expected!

Context/strategy

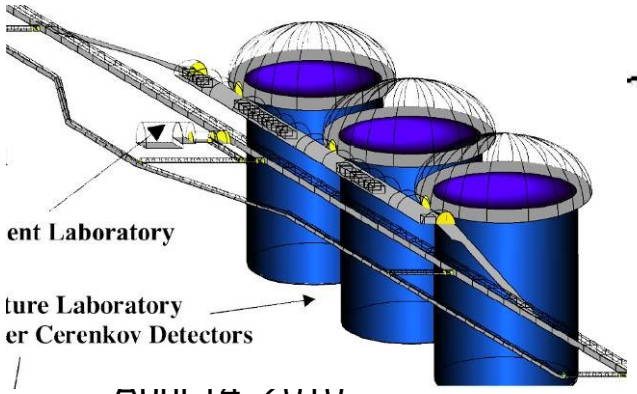
- Aggressive quest for theta_13 by accelerator and reactor experiments
- Preparation of strategy for the next steps in neutrino physics
- Coupled with changing landscape of european accelerators
- What can be achieved with an European Superbeam ?

What can be achieved with an European Superbeam ? From Euronu ...

- We started studying the SPL to Fréjus proposal



MEMPHYS



… to LAGUNA

underground laboratory

Candidate sites

1. Boulby, UK
2. Canfranc, Spain
3. Fréjus, France
4. Pyhäsalmi, Finland
5. Sieroszowice, Poland
6. Slanic, Romania
7. Caso, Italy

LAGUNA is studying a rich number of European options

EUROnu Super Beam studies

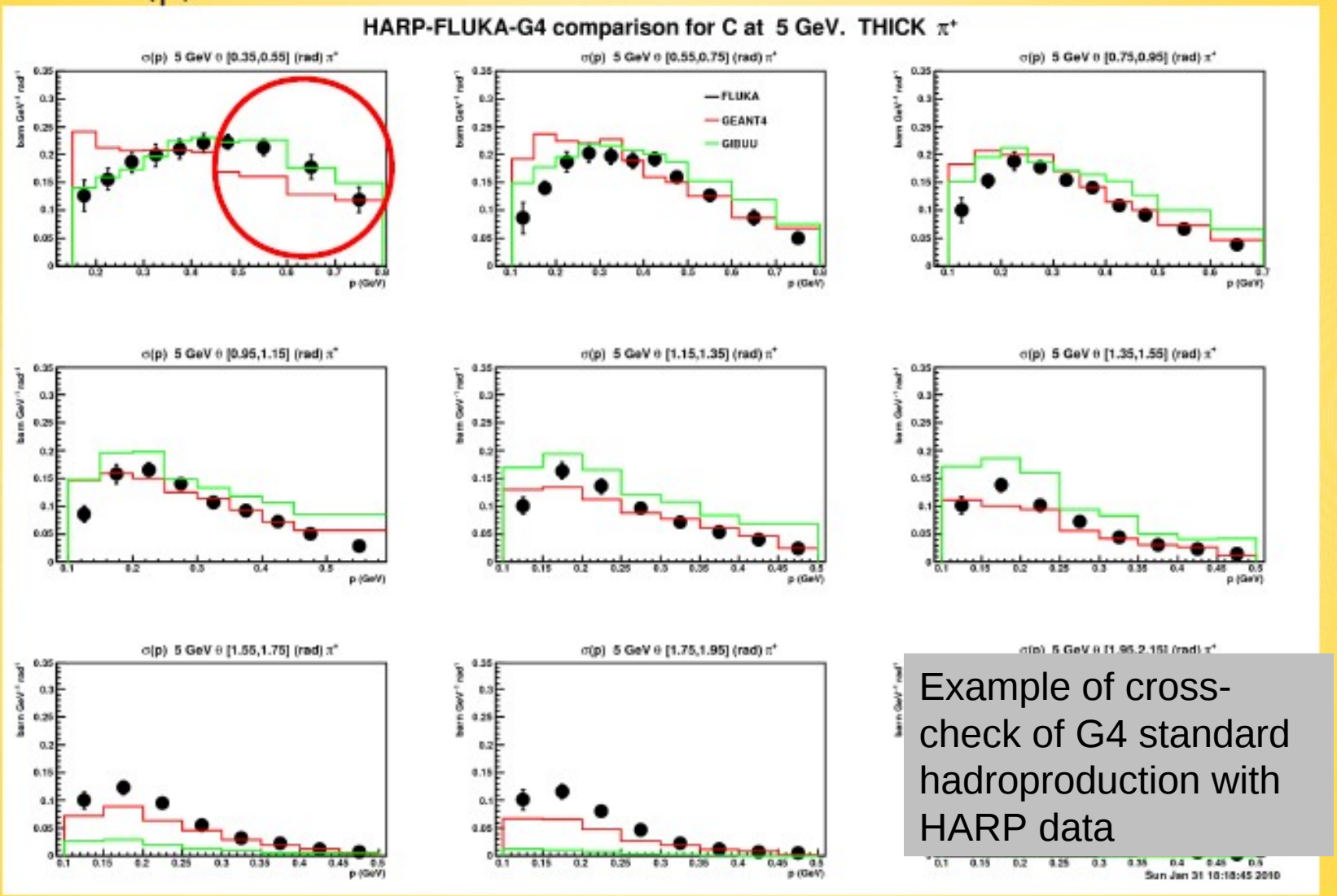
- Optimizing a Super Beam presents peculiar technical challenges

Not covered in this talk!

- The EUROnu SB group has devoted a large effort to :
  - Prepare the simulation tools (FLUKA, GEANT4, horn optimization ...)
  - Establish realistic technical solutions for the target and collection system
- We are now in a position to use these tools to study and optimize various SB scenarios
- Simulation-optimization studies performed mainly by Andrea Longhin (CEA-Saclay)

Simulation tools and validation

$\sigma(p)$ in θ bins



Example of cross-check of G4 standard hadroproduction with HARP data

tends to underestimate production at large angles

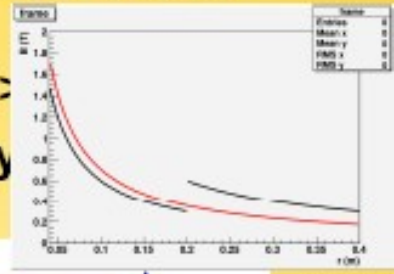
GIBUU rather good in the interesting region (high-p, small θ)

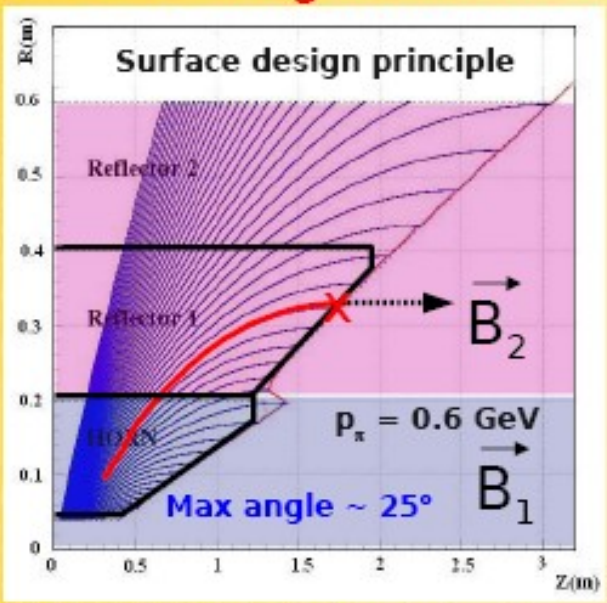
SB optimization examples

- SPL optimized horn (SPL 5 GeV, 4 MW, 440kt, 2+8 years)
- SPL various baselines
- SPL and PS2 with various LAGUNA baselines (PS2 50 GeV, 2.4MW NOVA focussing, optimization to be done, work in progress)

The standard focusing system

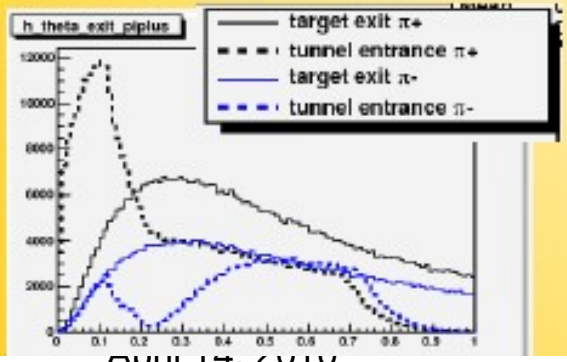
- Due to the low energy proton beam pions are mildly forward boosted (<θ_π>
  - -> **Target inside the horn** to recover collection efficiency

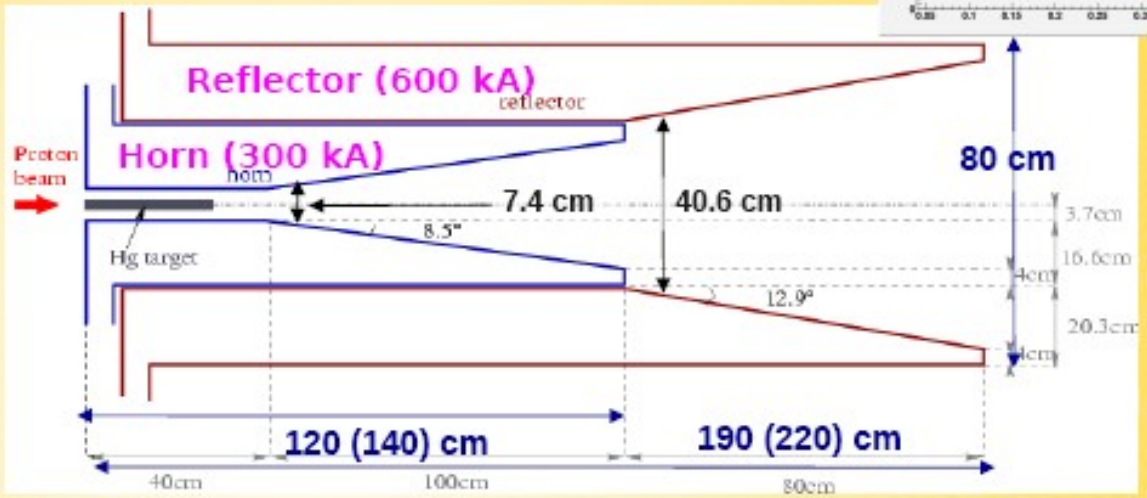




The outer conductor is placed where the slope becomes // to the beam (dr/dz =0)

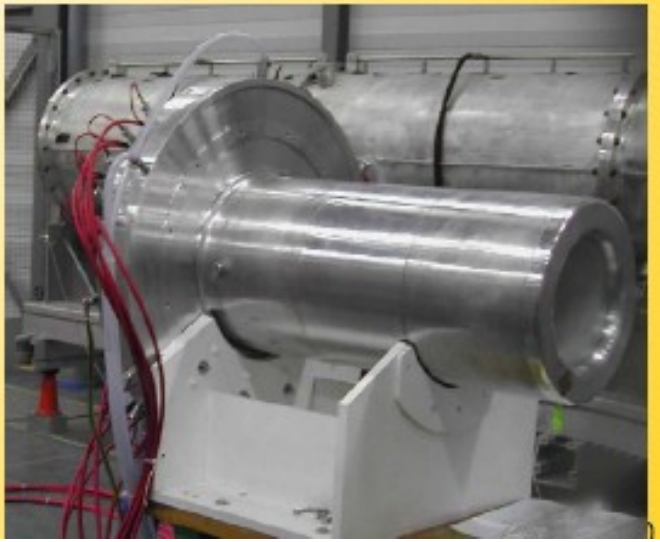
all π of a certain p from a point-like source focused



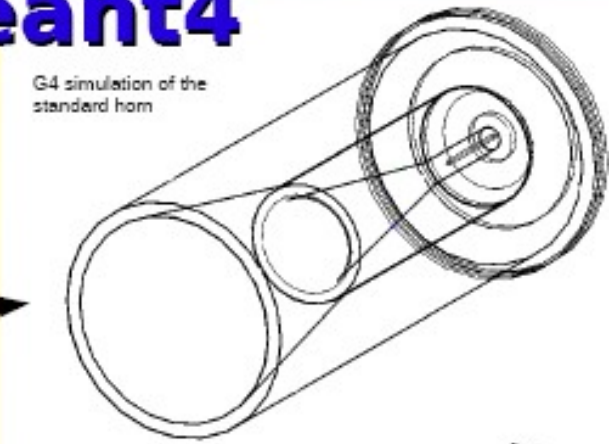


- i(h/r) = 300/600 kA
- pulsed @ 50 Hz
- Toroidal |B| ~ i / r
- B_1^{MK} =1.5 T, B_2^{MK} = 0.6 T
- 3 mm thick Al

Horn prototype at CERN (detailed geometry implemented in the Geant simulation)



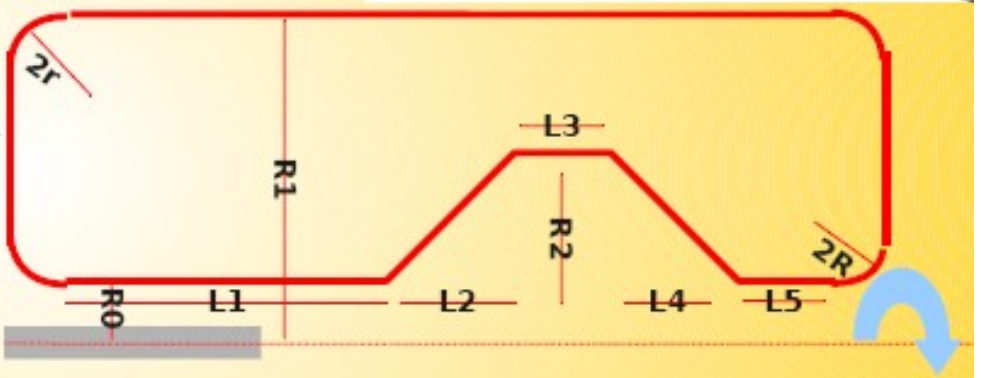
New simulation with Geant4



The full simulation has been migrated
Geant3 ~> Geant4

2 geometry implementations:

- **1) the standard horn reproducing the existing CERN prototype**
- **2) a new parametric model implemented (MINIBOONE inspired)**



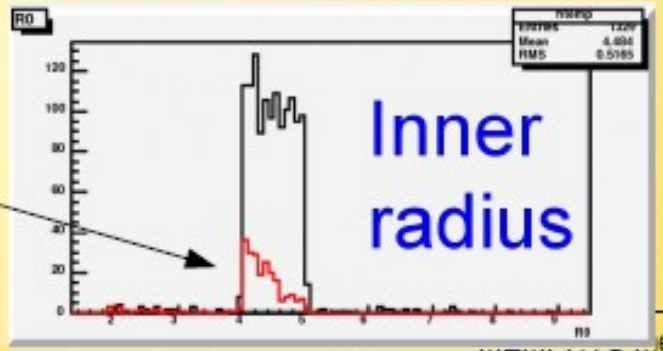
Better wrong charge pion rejection (more "forward closed") and higher mean neutrino energy

Flexible enough to reproduce also standard conical geometry

"Heuristic" approach to find favorable geometries based on the generation of random configurations using the horn parametric model

The resulting fluxes are selected according to quality parameters (ν_μ normalization, $\overline{\nu}_\mu$ contamination, mean energy, energy spread)

Randomly generated
Accepted after cuts on spectra



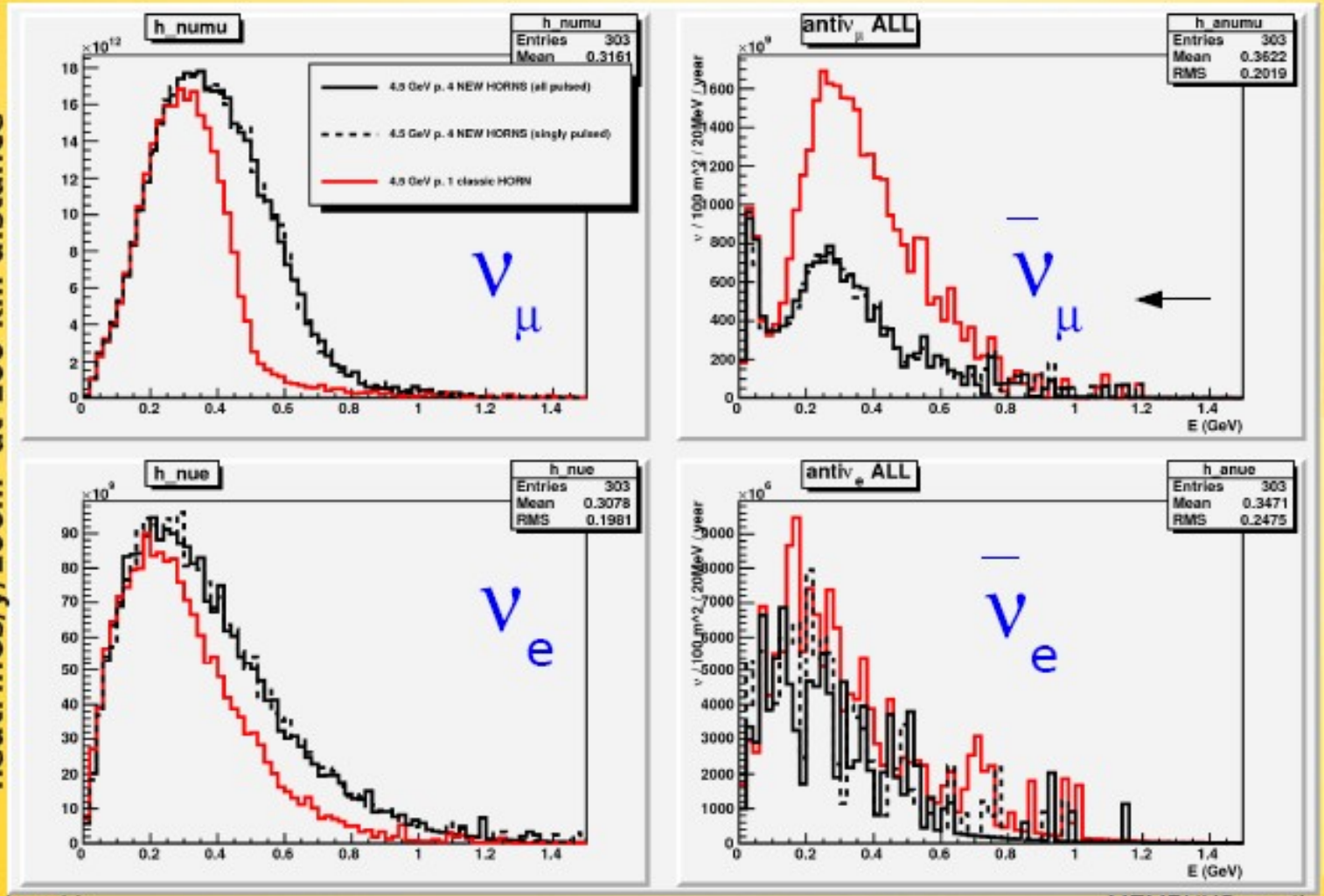
9 parameters fully accessible from external macro file

```
#
/SB/det/HornDesign 2
/SB/det/Horn_L1 57.3895 cm
/SB/det/Horn_L2 63.8771 cm
/SB/det/Horn_L3 10.797 cm
/SB/det/Horn_L4 16.0441 cm
/SB/det/Horn_L5 8 cm
/SB/det/Horn_R 7.16565 cm
/SB/det/Horn_r 5.08 cm
/SB/det/Horn_R0 4. cm
/SB/det/Horn_R1 20. cm
/SB/det/Horn_R2 16. cm
/SB/det/Horn_I1 300000 ampere
```

Fluxes: new VS old horn

Carbon target
new horns / old horn

- gain ν_μ at higher energies
- Effectively suppressed contributions from wrong charge pions (more than a factor 2 less anti-ν_μ, lower anti-ν_e +c.c.)



GEANT4

@ 4.5 GeV positive focusing

	OLD (%)	NEW (%)
+ FOCUSING		
ν_μ	88.9	-> 95.55
$a\nu_\mu$	10.5	-> 3.9
ν_e	0.6	-> 0.56
$a\nu_e$	0.052	-> 0.025
- FOCUSING		
ν_μ	26.1	-> 11.2
$a\nu_\mu$	73.4	-> 88.4
ν_e	0.17	-> 0.09
$a\nu_e$	0.34	-> 0.35

3σ sensitivity on θ_{13} with the new horn

Color codes: proton energies

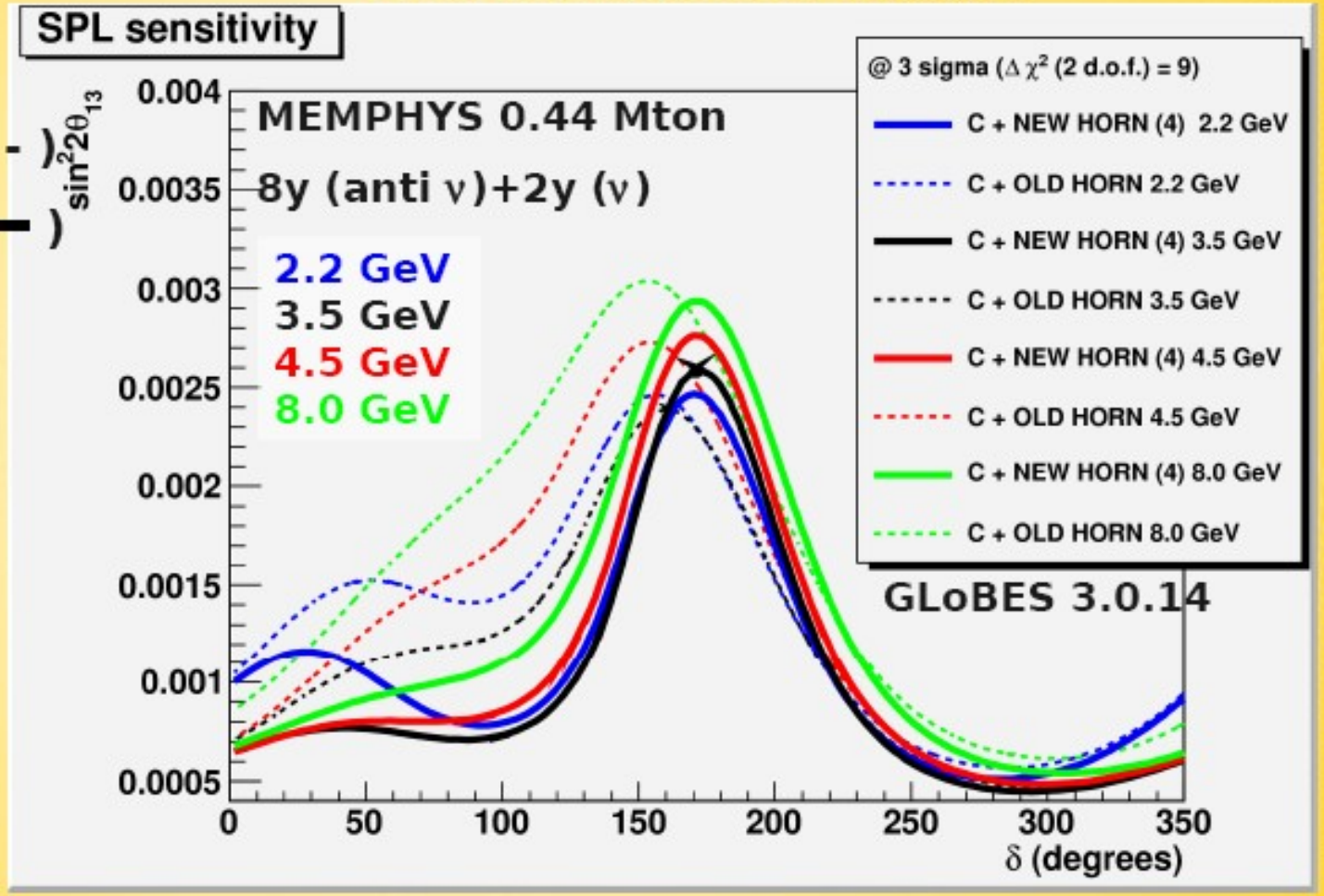
Carbon target

old horn (- - - - - -)

new horn (———)

Significant improvement achieved by the new horn design mainly in the anti-ν region as needed.

Limits gets even better than mercury ones with standard horn

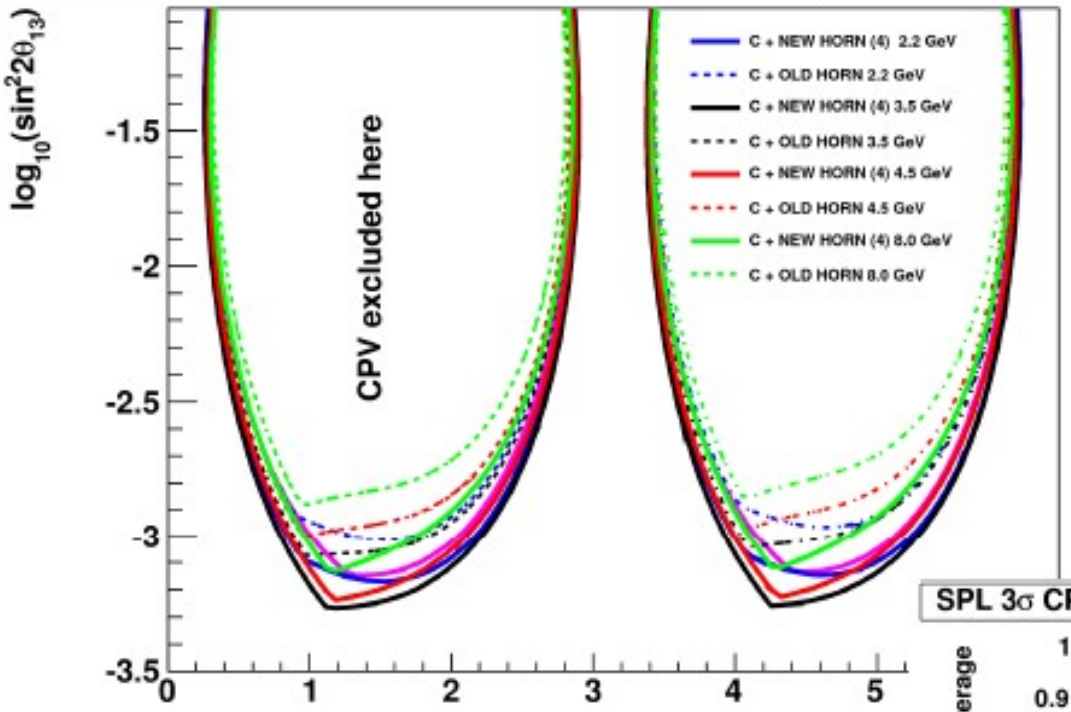


GEANT4

AEDL file SPL.glb in GloBES (with M=0.44Mton)
J. Phys. G29 (2003),1781-1784

3σ CP violation discovery coverage

SPL 3σ sensitivity to CPV ($\Delta\chi^2(\delta_{CP} = 0 \,||\, \pi) = 9$)



Color codes: p energies

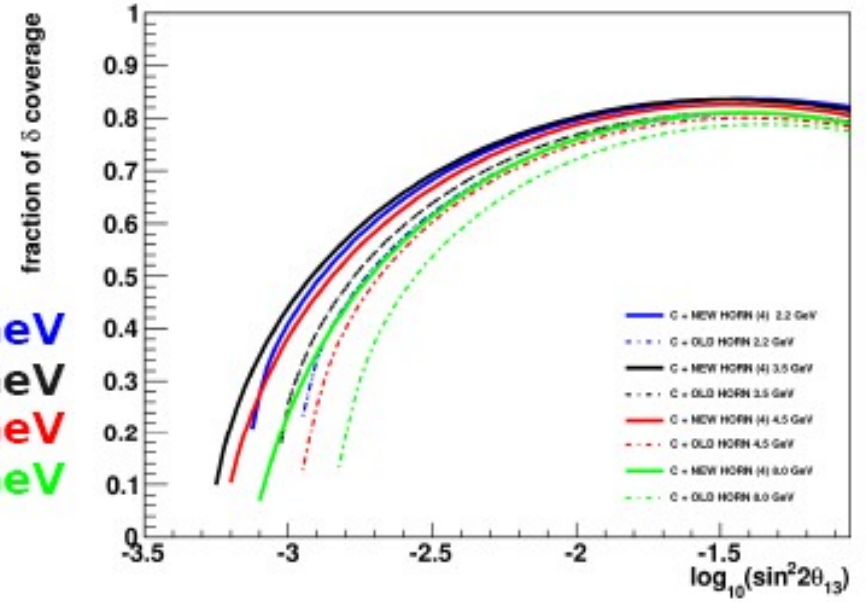
Carbon target

old horn (- - - - - -)

new horn (———)

Significant improvement achieved by the new horn design.

SPL 3σ CPV discovery

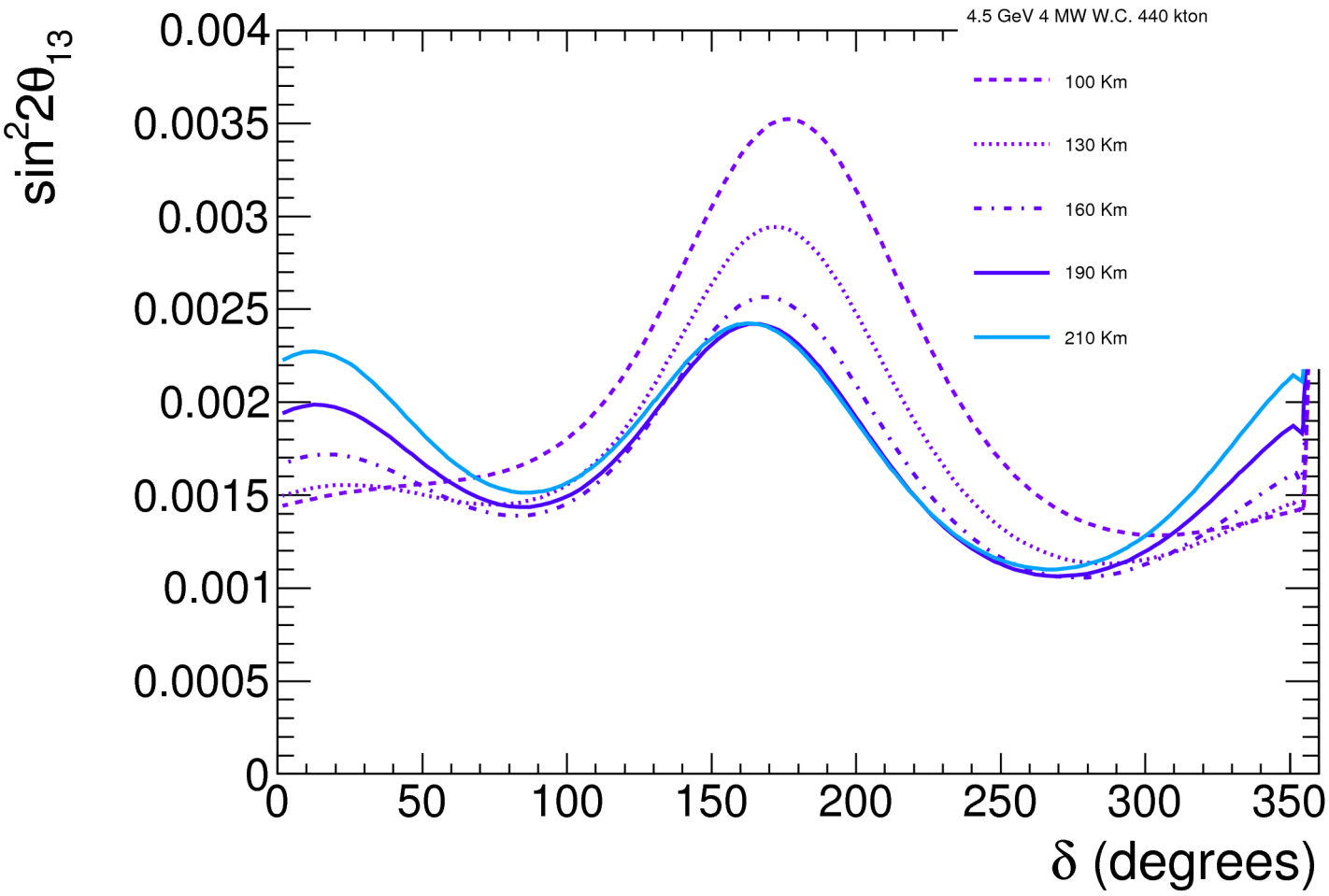


The change in the focusing does not alter the "ranking" of proton energies

3.5 and 4.5 GeV are preferred (in this order)

2.2 GeV
3.5 GeV
4.5 GeV
8.0 GeV

SPL: various baselines



Conclusions

- The EUROnu Super Beam group has prepared the tools for a systematic studies of the European SB scenarios
- The tools were benchmarked with previous simulations and experiments
- Optimization of the beams (energy, target, horn) still ongoing
- Preliminary results available for SPL
- Competitive performances for $\sin^2(2\theta_{13}) >$ few 10^{-3}