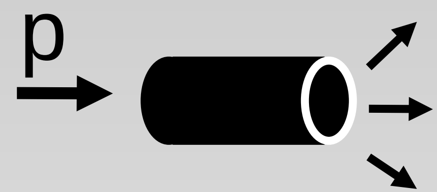
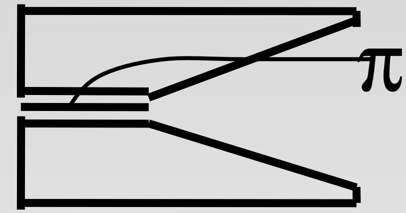
EUROnu Super-Beam studies

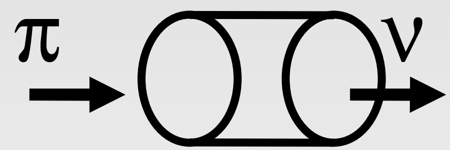
Andrea Longhin

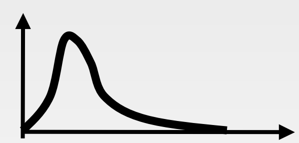
CEA Saclay





- **SPL-Fréjus Super Beam overview**
- **New studies within EURONU:**
  - **Solid target studies**
    - **Energy deposition**
    - **Pion/kaon yields**
    - **Neutrino fluxes and sensitivities**
    - **Focusing optimization**
- **Conclusions and Perspectives**





Acknowledments
(incomplete!)
A. Cazes. J-E. Campagne,
M. Mezzetto, M. Zito

NUFACT 2009

Chicago, 24 July 2009

EUROnu

A High Intensity Neutrino Oscillation Facility in Europe

EUROnu is a european union Framework Programme 7 Design Study which started on 1st September 2008 and will run for 4 years. The primary aims are to study three possible future neutrino oscillation facilities for Europe

- **CERN to Fréjus Super-Beam ← this talk**
- **Neutrino Factory**
- **Beta Beam with higher Q isotopes**

performance of the detectors for and physics reach cost and performance comparison.

close collaboration with related international activities like the Design Study for a Neutrino Factory, IDS-NF

Work Packages

WP1: Management and Knowledge Dissemination
WP2: Super-Beam
WP3: Neutrino Factory
WP4: Beta-Beam
WP5: Detector Performance
WP6: Physics

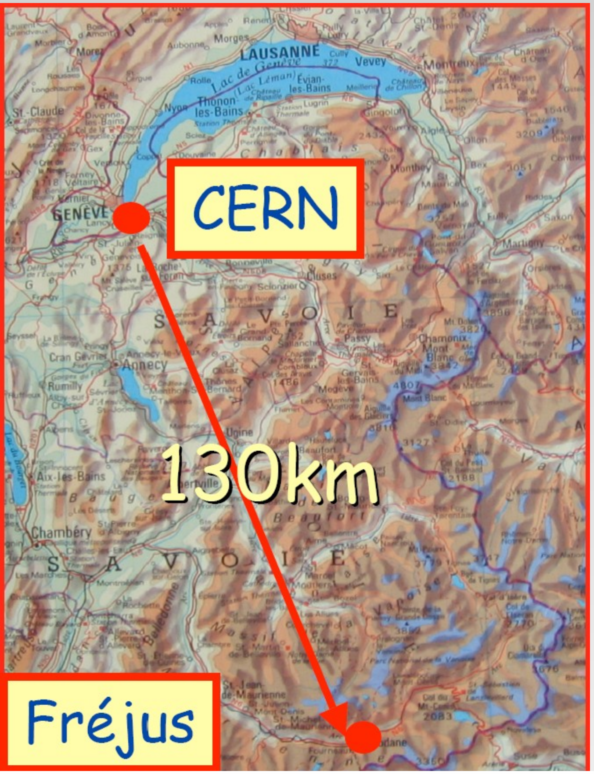
More info: **www.euronu.org**

Annual meeting held in CERN in march 2009:
http://indico.cern.ch/conferenceDisplay.py?confId=42846

The SPL-Fréjus Super-Beam

Being studied in EUROν WP2 (beam), LAGUNA (far site) and MEMPHYS (detector)

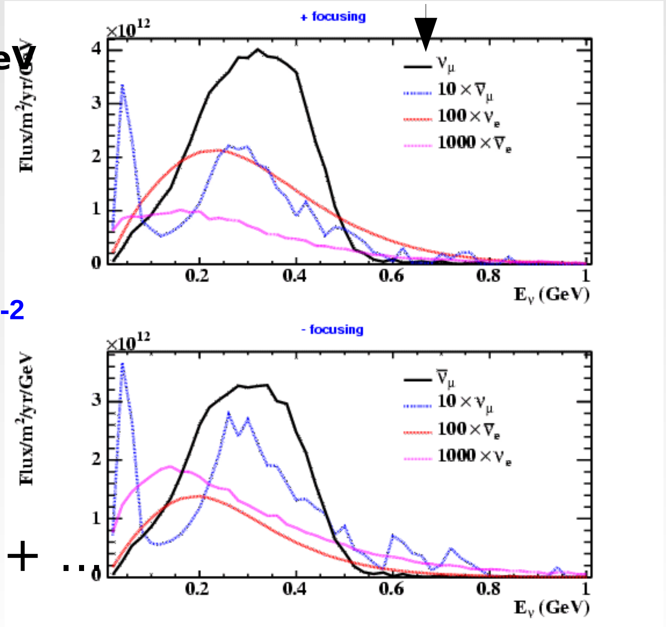
REFERENCES
- hep-ph/0105297v1
- EPJ C45:643-657,2006
- JHEP 0704:003,2007, hep/ph-0603172v3



- SPL p driver @ **4MW** (H- linac **E_k~ 5 GeV**)
- **L = 130 Km**
- Far Detector: **0.44 Mton Water Cerenkov**
- 1^{st} oscillation maximum **E_ν ~ 260 MeV**

- **Low E**
  - **:) Negligible ν_e from K**
  - **:) Compact horn and tunnel**
  - **:) Good reconstruction in WC**
    - **~ all elastic**
    - **σ_E: 43 MeV : [0.2-0.3] GeV**
    - **easier π^0 rejection**
- **small L**
  - **:) High flux**

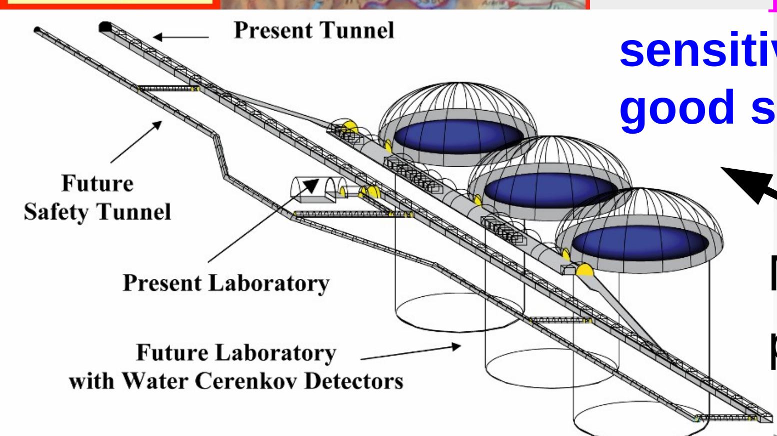
"Narrow band"



$\sin^2 2\theta_{13}$:

sensitivity limit @ ~ 10^{-3}

good sensitivity to δ @ ~ 10^{-2}



MEMPHYS also
p decay, atm.&SN ν + ...

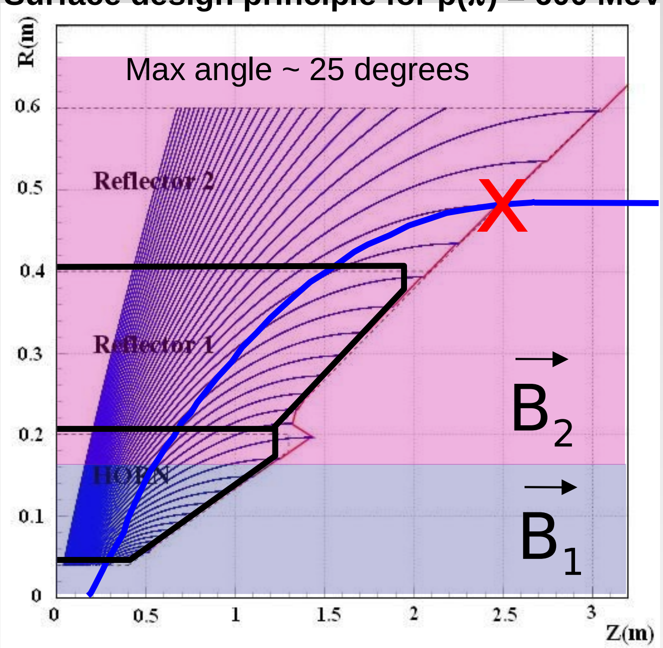
The focusing system

- Due to the low energy proton beam pions are mildly forward boosted ($<\theta_{\pi}> = 55°$)
  - -> Target inside the horn to recover collection efficiency

$$E_{\nu} \approx 260 \text{ MeV}$$

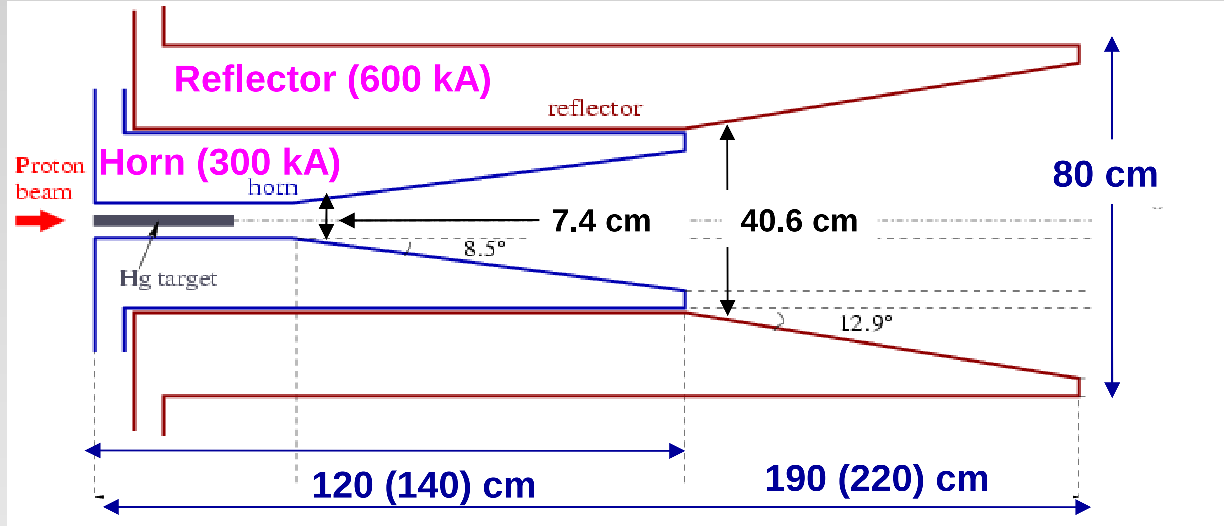
$$\Rightarrow p_{\pi} \approx 600 \text{ MeV/c}$$

Surface design principle for p(π) = 600 MeV



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

all pions of a certain momentum from a pointlike source are focused

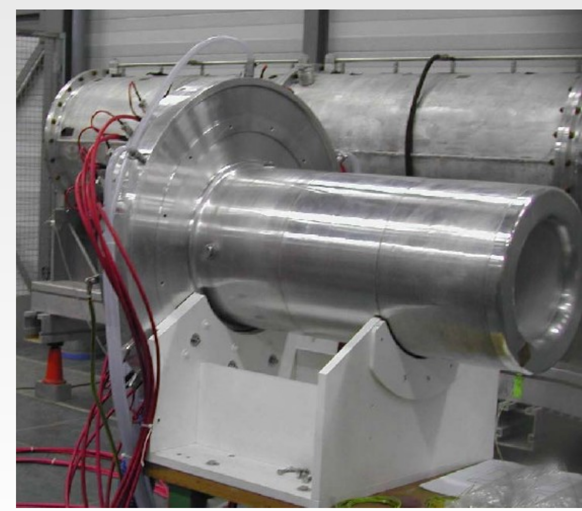


Higher length (in parenthesis) refer to a horn optimized for a higher E_{ν} ~ 350 MeV

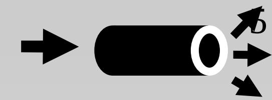
"350 MeV"-horn (longer one) as central choice. Better sensitivity to θ_{13}

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

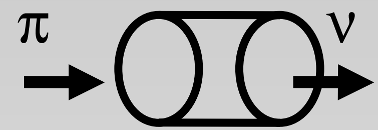
Horn prototype at CERN (detailed geometry implemented in the Geant simulation)



Simulation parameters

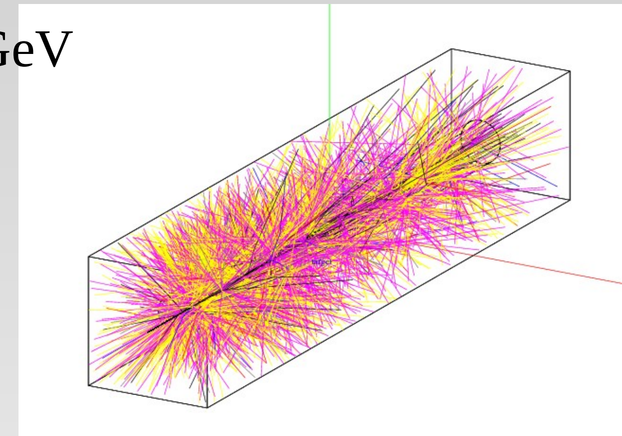


Production in target **FLUKA 2008.3** new next



(FLUKA 2002.4 and MARS in former studies)

- Proton beam: tested $E_k(p)$ = **2.2, 3.5, 4.5, 6.5, 8** GeV
- Cylindrical target (~ 2 λ_I long)
  - **Liquid mercury**: L = 30 cm, r = 0.75 cm
  - **Carbon** : L = 78 cm, r = 0.75 cm new next



Decay Tunnel

- Cylinder. Tested values: L=10-20-40-60 m / r =1-1.5-2 m
  - L = 40 m , r =2 m chosen as central value
  - Based on sensitivities. L>40 m gives ν_e contaminations from μ decay which spoil gain given by increase of ν_μ statistics

Decay lengths (m) @ 600 MeV

π	33.7
μ	3766
$K^{+/-}$	4.5
K^0_S	3.2
K^0_L	18.5

Meson focusing + decay: GEANT3 and **GEANT4** new next

ν fluxes: probabilistic approach. Each decay is weighted with the probability of the ν to reach the far detector. Event duplication+ weighting for μ and K decays.

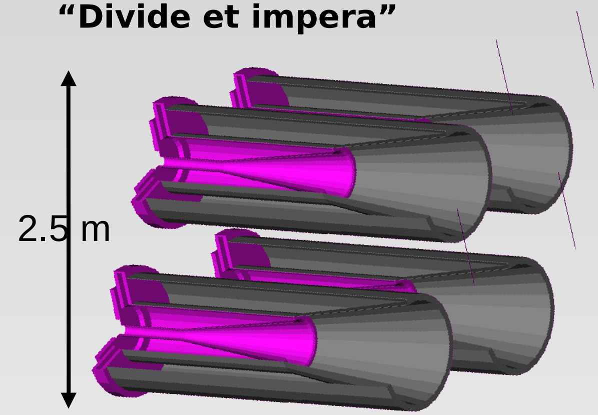
Sensitivities

GloBES 3.0.14 (Apr 2009)

Recent investigations: solid target(s) ?

- The liquid jet mercury target assumed in previous SPL simulations
- SPL electromagnetic horn (toroidal field): NO strong axial magnetic field for jet containment (MERIT): integration of horn and target is critical
- Viability of a solid target has thus been investigated
- Further motivation from
  - the experience being gained with the T2K graphite He cooled target which is about to operate at 0.75 MW.
  - The compactness of the horn and tunnel size makes the possibility of using multiple horns appealing

"Divide et impera"



M. Dracos

- As a starting point a "minimal change" approach wrt to the previous setup
  - **Mercury -> Carbon** ρ = 1.85 g/cm3 (as in the T2K target – IG43 by ToyoTanso)
  - **Target length: 30 -> 78 cm** (i.e. sticking to a ~ $2\lambda_I$ prescription)

- Items covered: **Power dissipation / mesons yield / pi+ collection / ν fluxes / sensitivities**

FLUKA 2008.3 + GEANT4	FLUKA 2008.3	GEANT3/(4)	GEANT3/(4)	GloBES 3.0.14

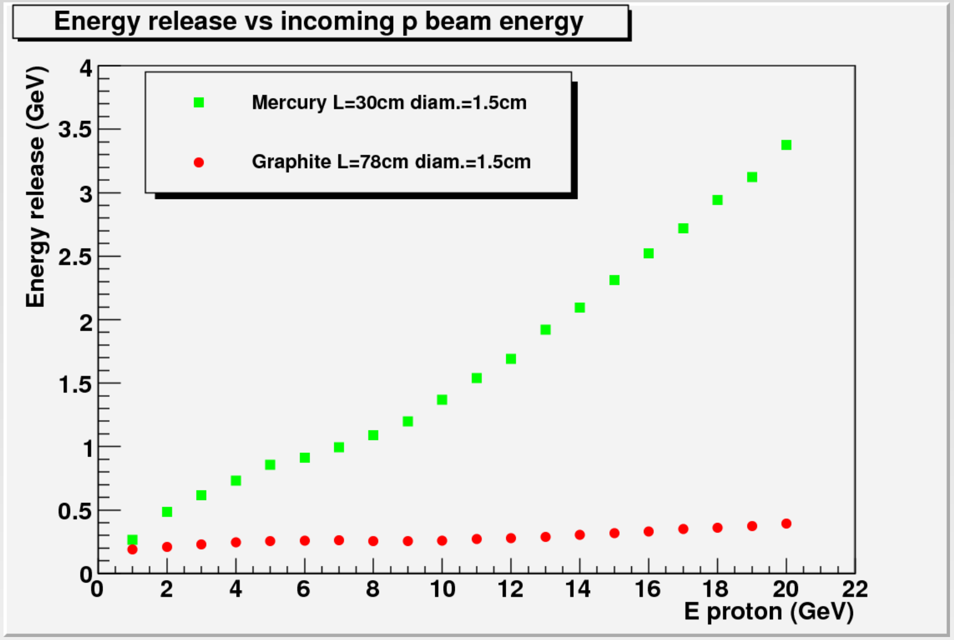
A note submitted to http://www.euronu.org

Study of the performance of the SPL-Fréjus Super Beam using a graphite target (A.L.)

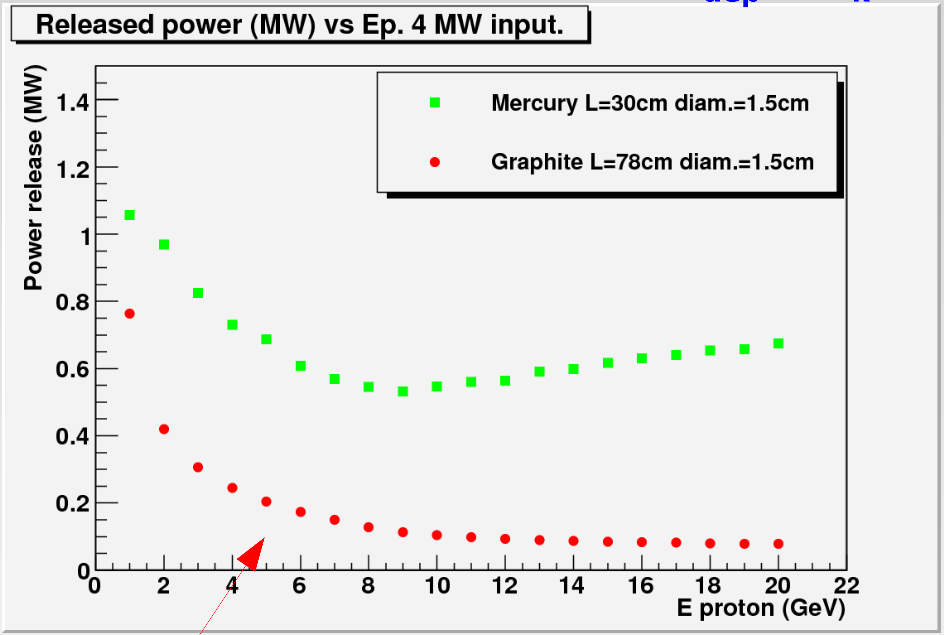
Graphite-Mercury energy deposition

GEANT4 (hadronic “QGSP physics list”)

Mean energy deposition vs Ek(p)



Power release: 4 MW * $\langle E_{dep} \rangle / E_k(p)$



Power released in target:

at 5 GeV ~ 200 kW deposited in the carbon target

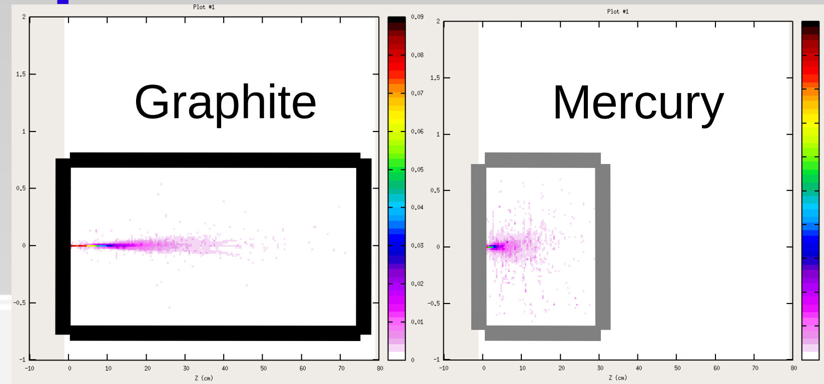
Hg: ~ 1 - 0.6 MW

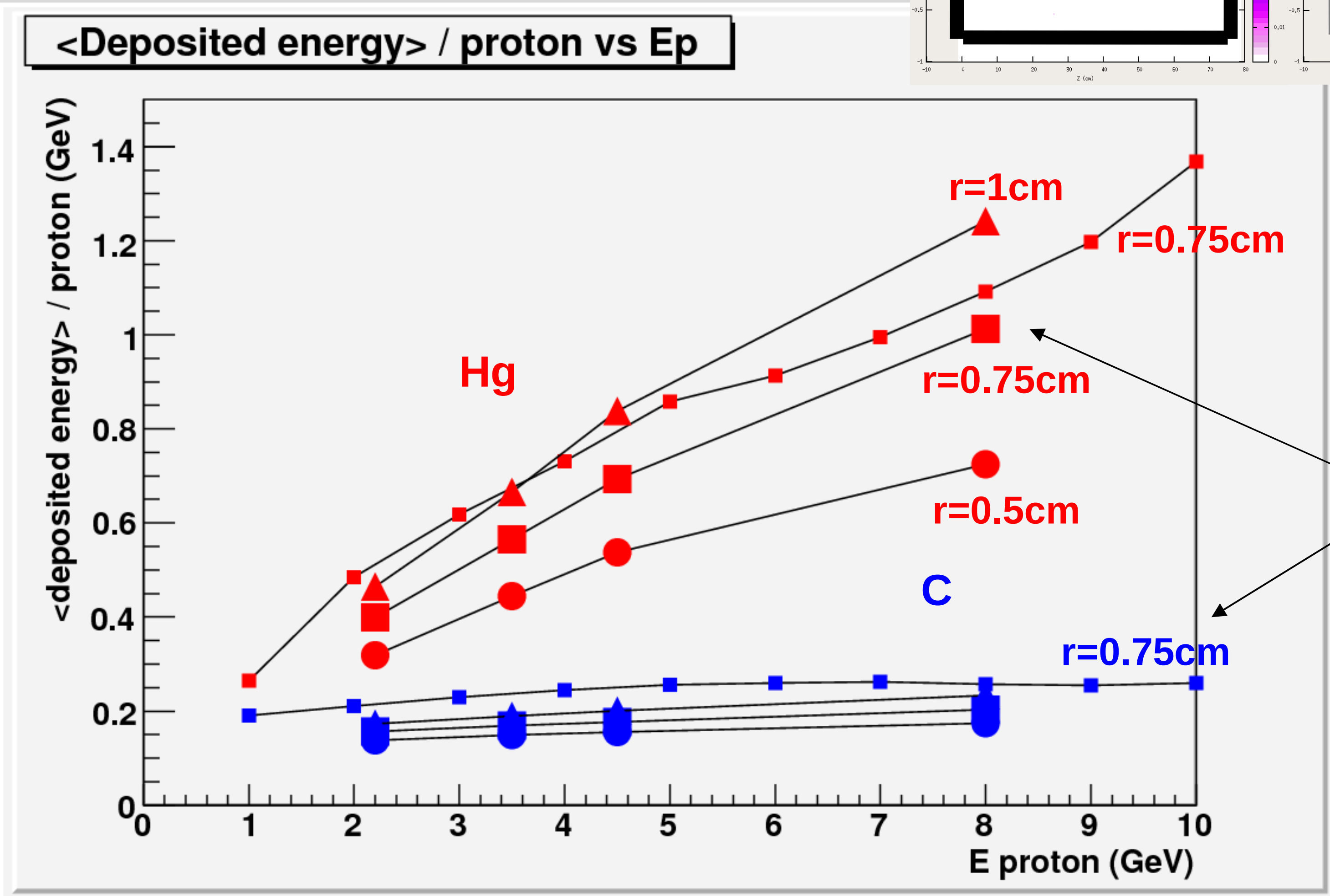
C : ~ 0.8 - 0.1 MW

considerably lower for Carbon !

Graphite-Mercury energy deposition: G4/FLUKA08

- G4 larger than FLUKA. ~ +10% for Mercury
- General trend is confirmed
- r = 0.5 / 0.75 / 1.0 cm





markers:

FLUKA large

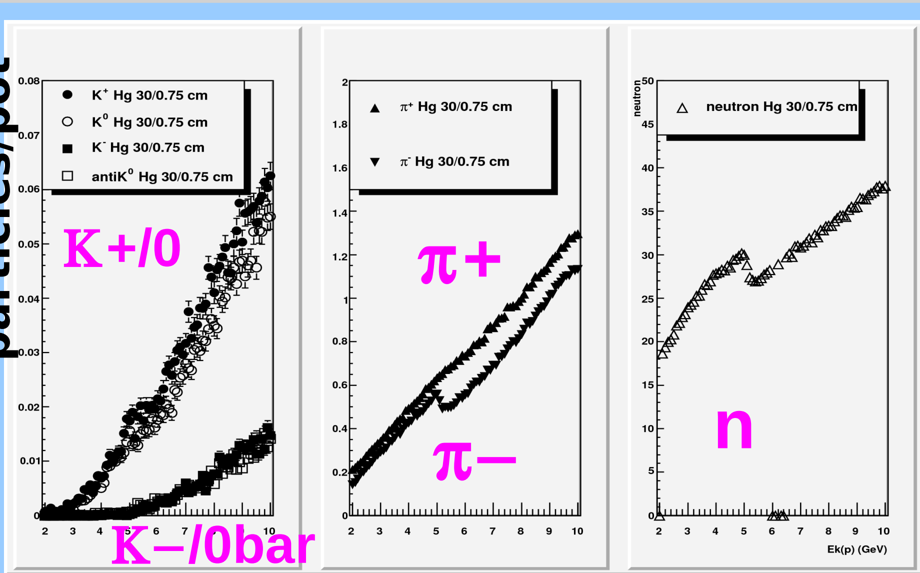
GEANT4 small

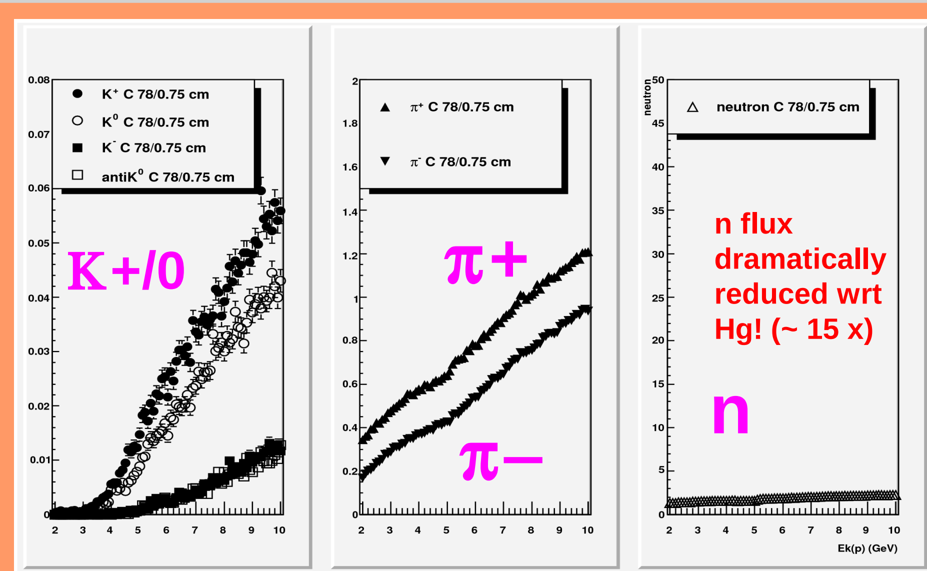
Particle multiplicities FLUKA 2008 vs proton kinetic energy [2-10] GeV

Normalization to fixed power (~E x i):

- 1.13×10^{16} pot/s at 2.2 GeV
- 0.71×10^{16} pot/s at 3.5 GeV
- 0.55×10^{16} pot/s at 4.5 GeV
- 0.31×10^{16} pot/s at 8.0 GeV

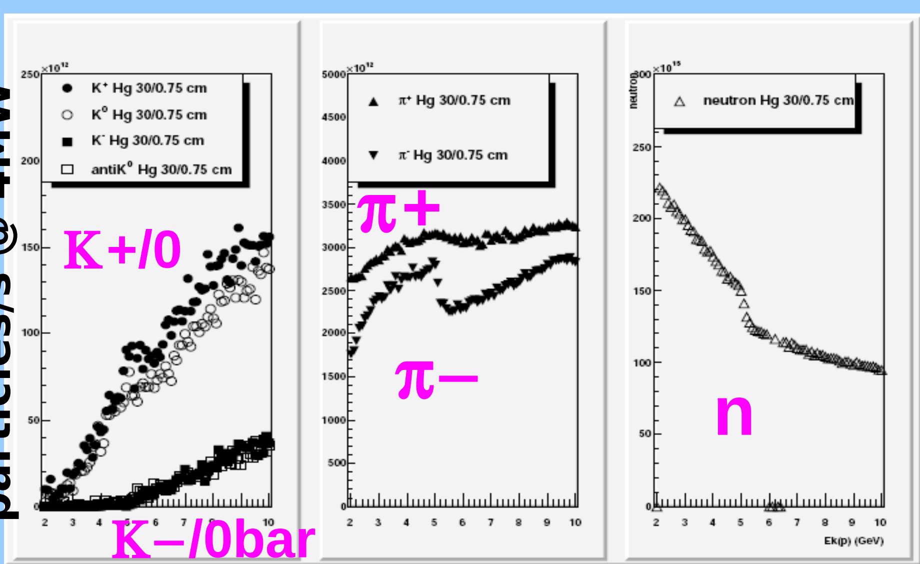
particles/pot

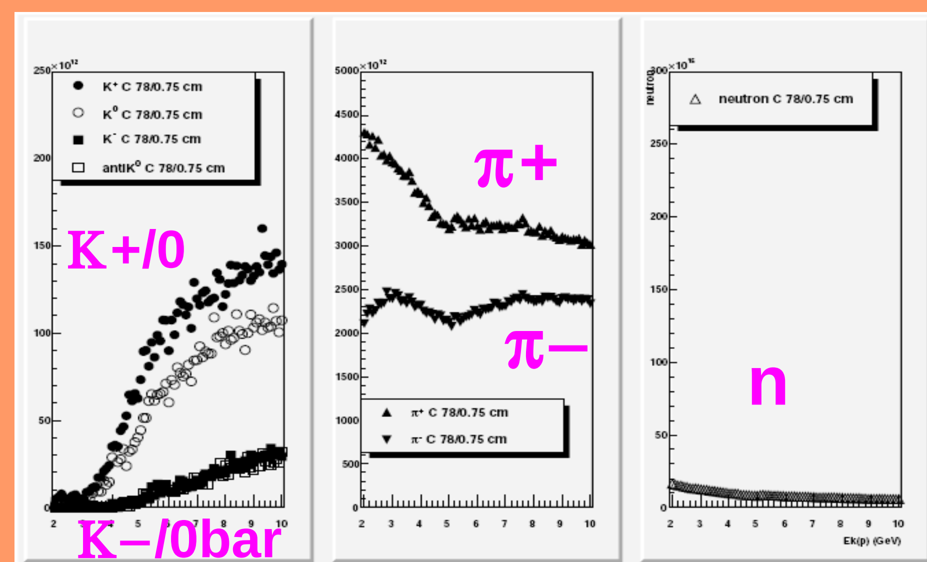




... and yields **Mercury** Same vert. scale **Carbon**

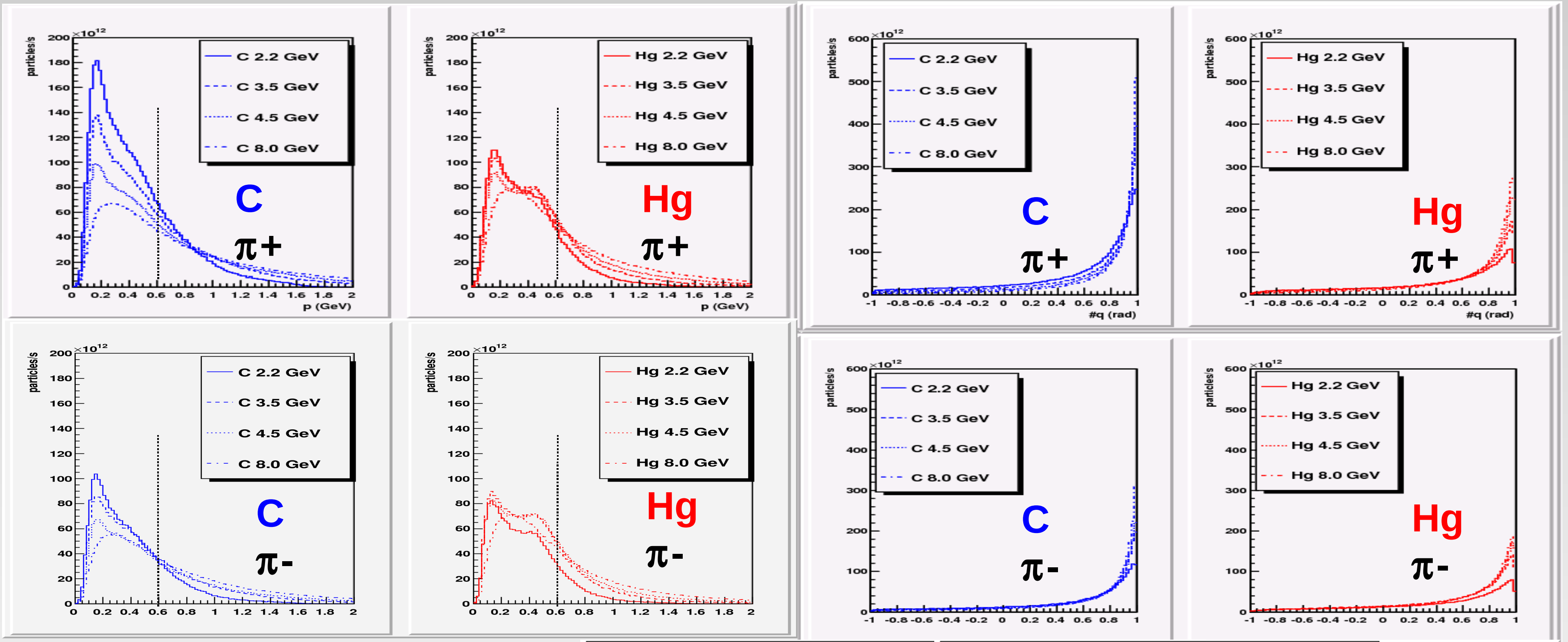
particles/s @ 4MW

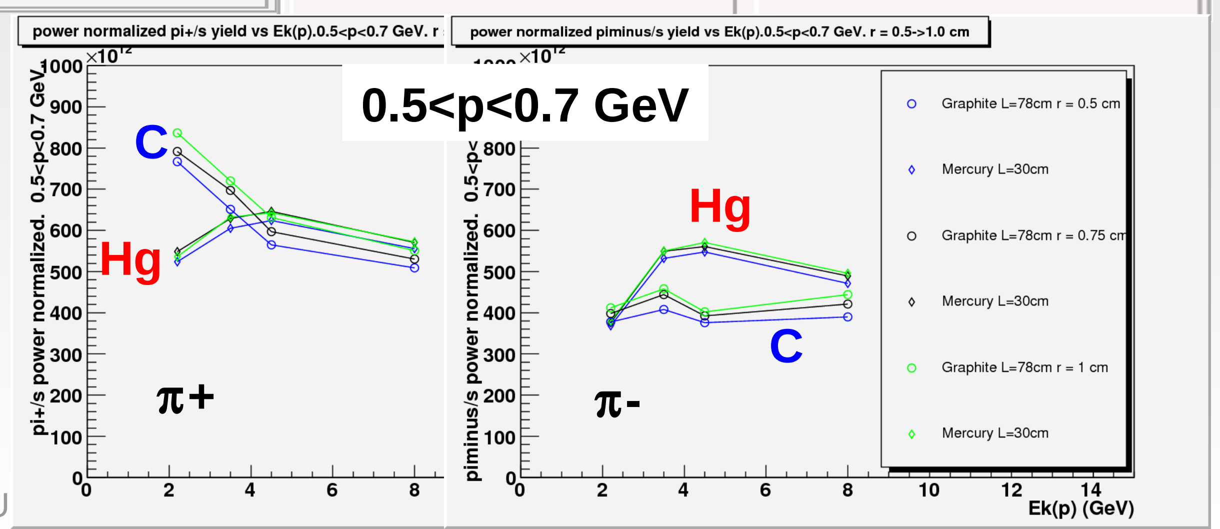




Impulse and angular spectra: FLUKA 2008

E (GeV) : 2.2-3.5-4.5-8.0   pions/s @ 4MW



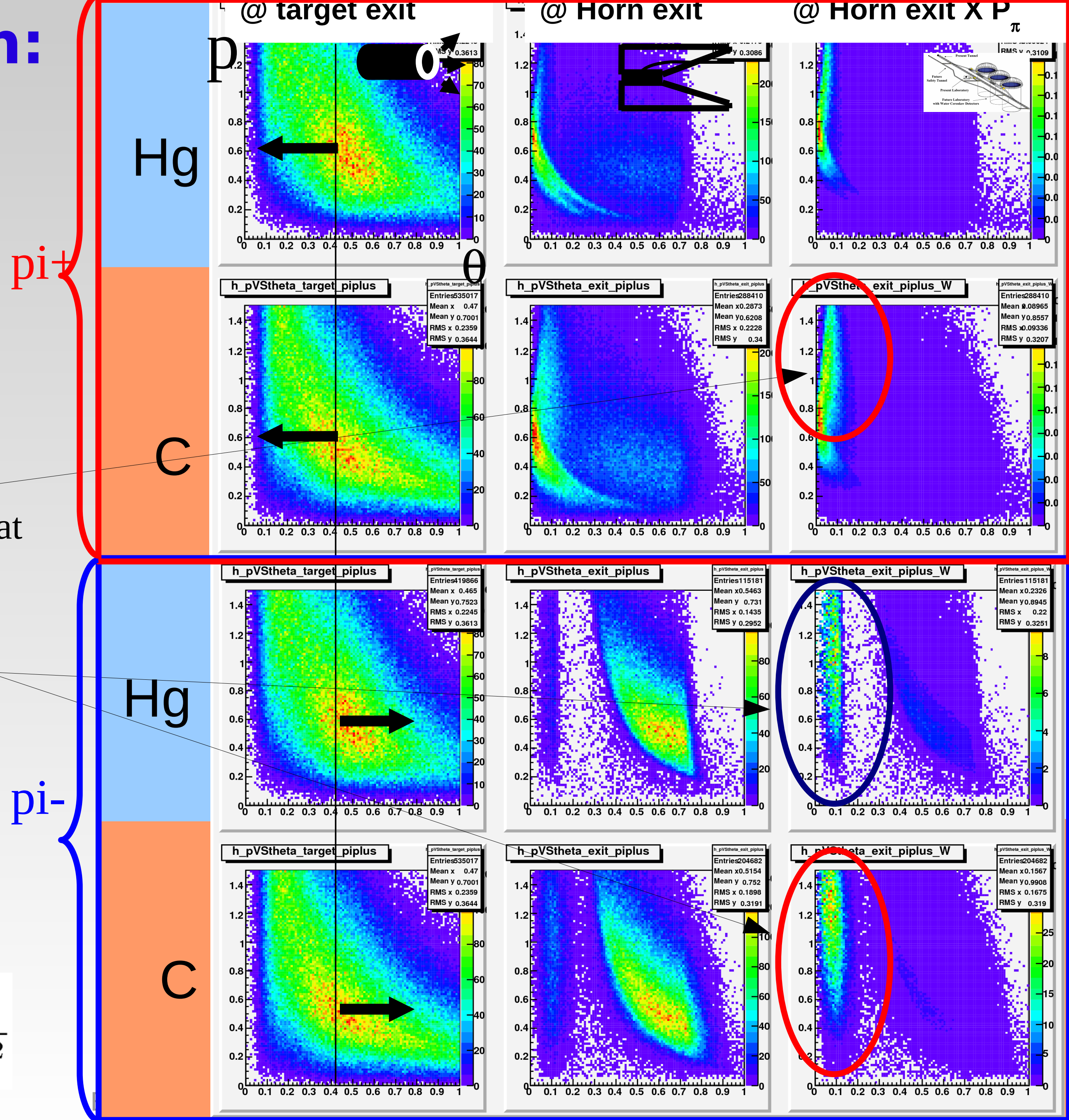


Carbon

* more abundant at low energies for pi+ (becoming similar as E increases)
* more forward peaked

Pi collection: Hg-C

- P vs θ plots
- Positive focusing (negative defocusing)
- Carbon:
  - focused pi+ less “monochromatic” (tail at high momentum)
  - larger fraction of not defocused pi-
- 4.5 GeV



P_π := probability to reach the detector

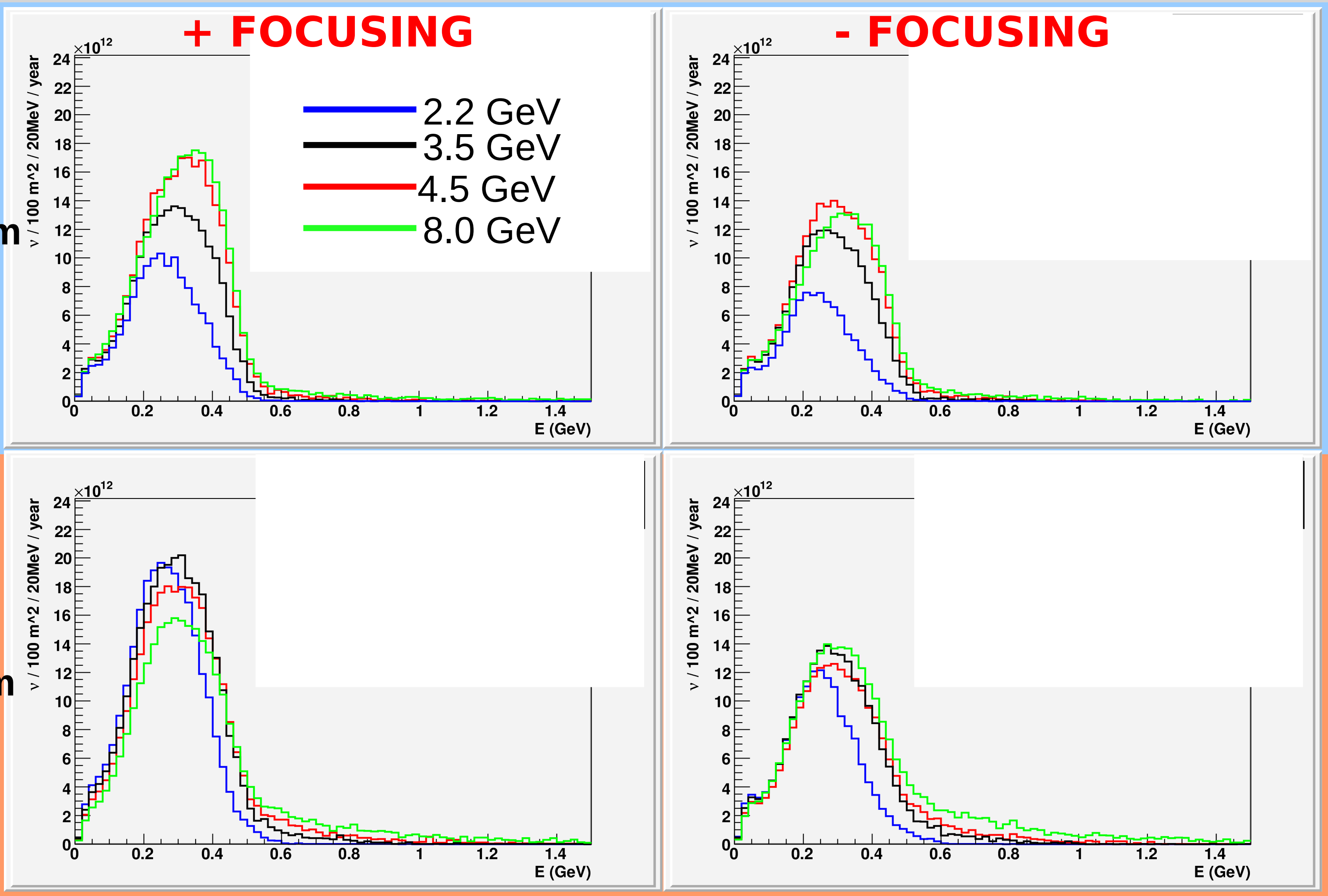
$$\mathcal{P}_\pi = \frac{1}{4\pi}\frac{A}{L^2}\frac{1-\beta^2}{(\beta\cos\alpha - 1)^2}$$

$\nu_{\text{ALL FLAVOURS}}$ fluxes: Mercury-Graphite

- pion yield trends are reflected in fluxes despite non optimized focusing for long Graphite target
- Fluxes intensities are similar
- higher high energy tail for Graphite (not optimized focusing)

Mercury 30/0.75 cm

Graphite 78/0.75 cm



3 sigma sensitivity C-Hg comparison

- Carbon limit (dashed) more δ dependent than for Mercury (continuous).
- Improvement over asymmetry on δ observed after reducing ("by hand" for the moment) anti ν_μ and anti ν_e contamination to ν_μ beam (+cc). Marked beneficial effect also seen for δ determination.
- Both reduced minimizing wrong charge pions !

$\pi^+ \rightarrow \mu^+ \nu_\mu$

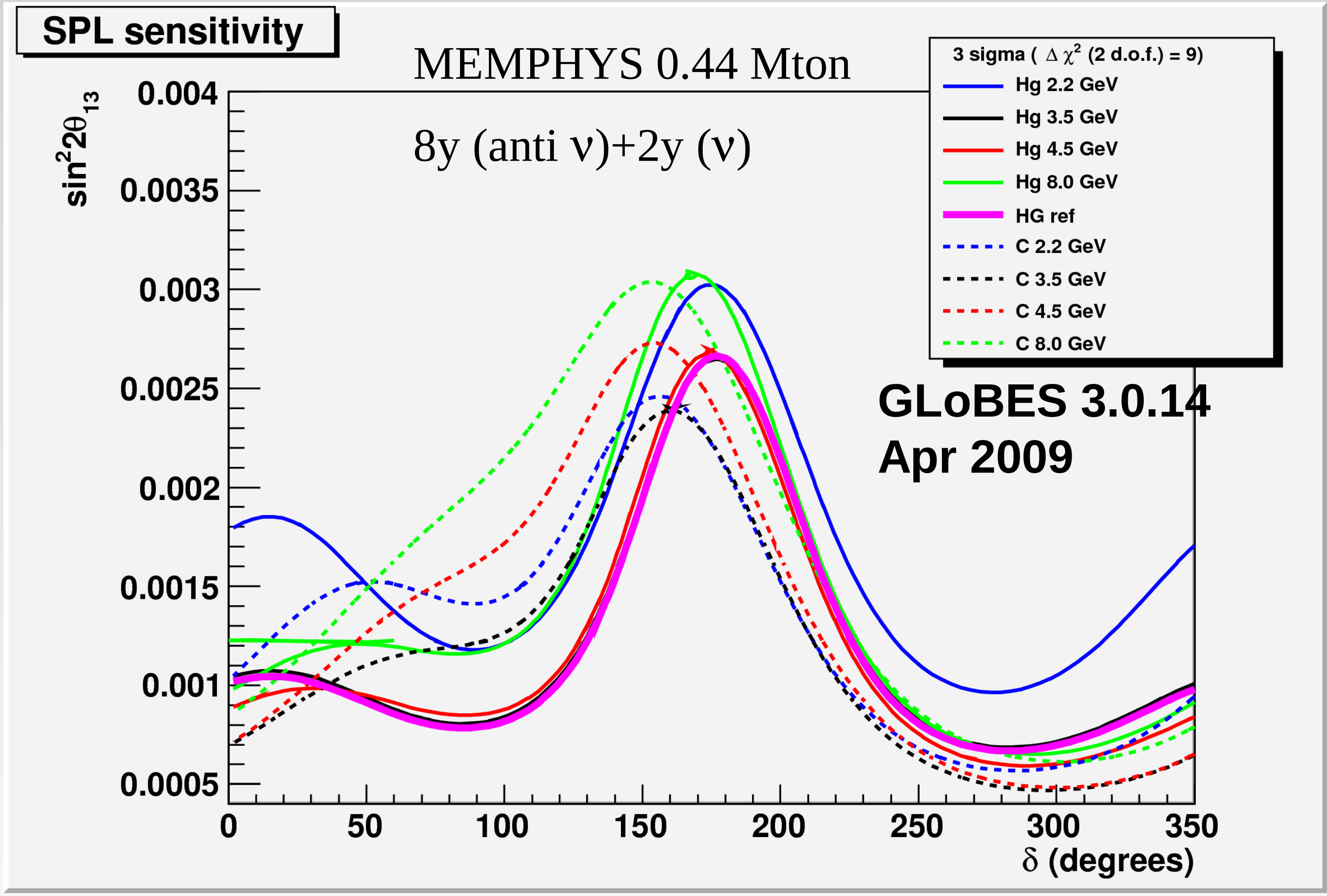
↘ $e^+ \nu_e$ anti ν_μ

$\pi^- \rightarrow \mu^-$ anti ν_μ

↘ e^- anti ν_e ν_μ

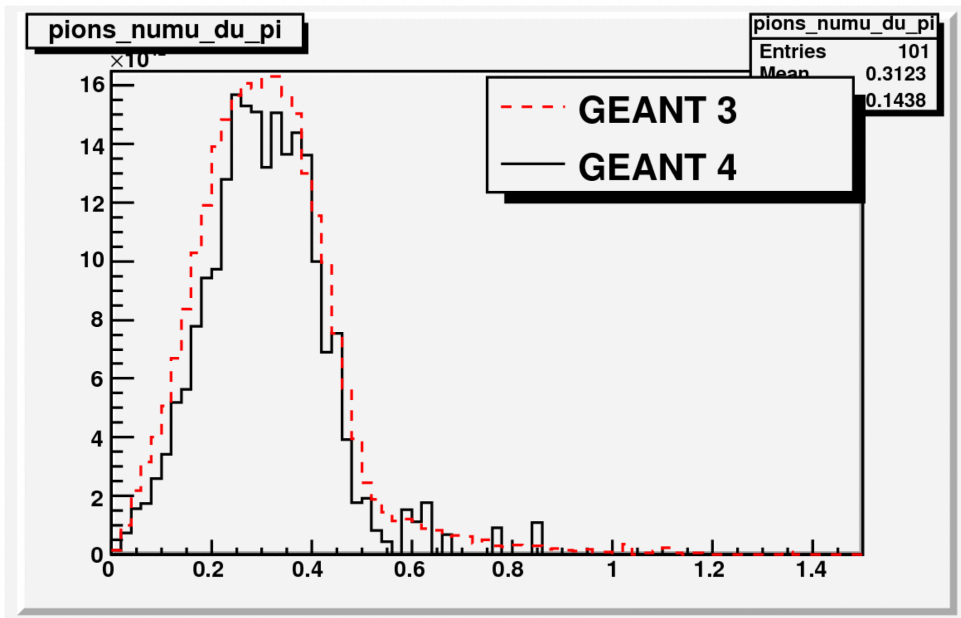
Carbon (- - - - - -) Mercury (———)

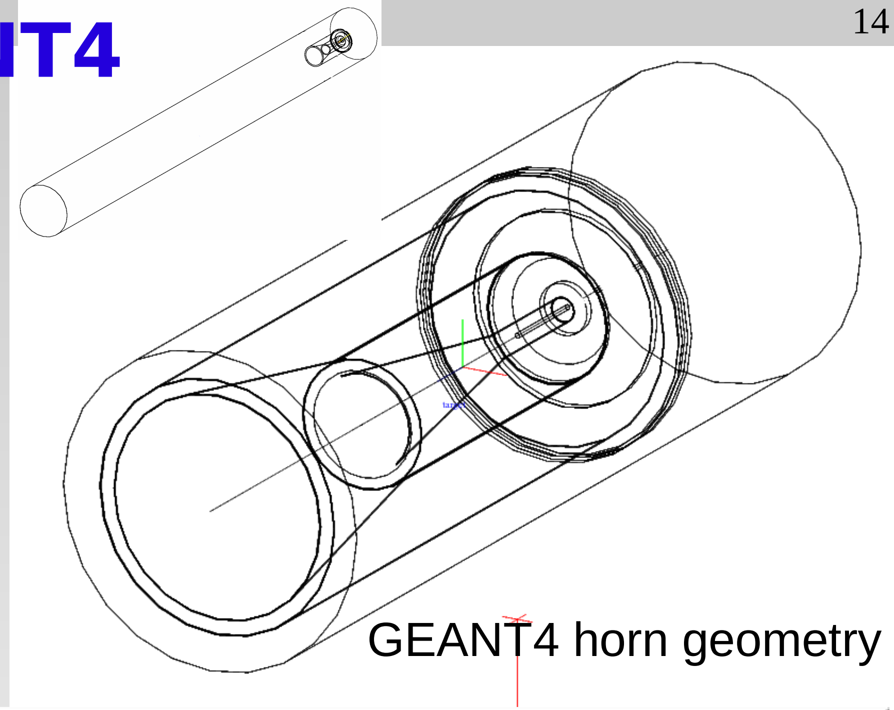
Color codes: proton energies



AEDL file SPL.glb developed by M.Mezzetto et al.

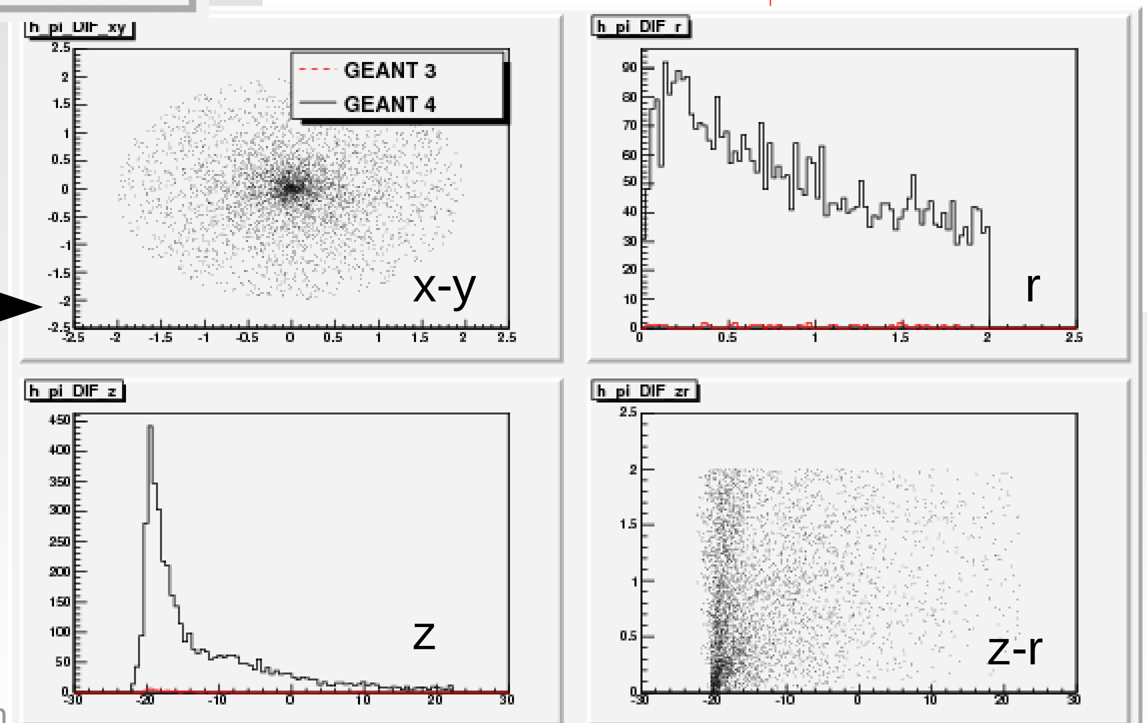
Software updates: GEANT4

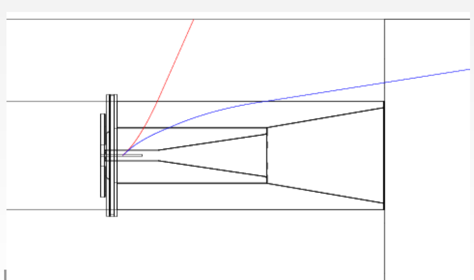




- Not too bad at this (early) stage
- Finalization ongoing

Example of a set of control plots automatically generated by the main simulation program for pion decay in flights positions

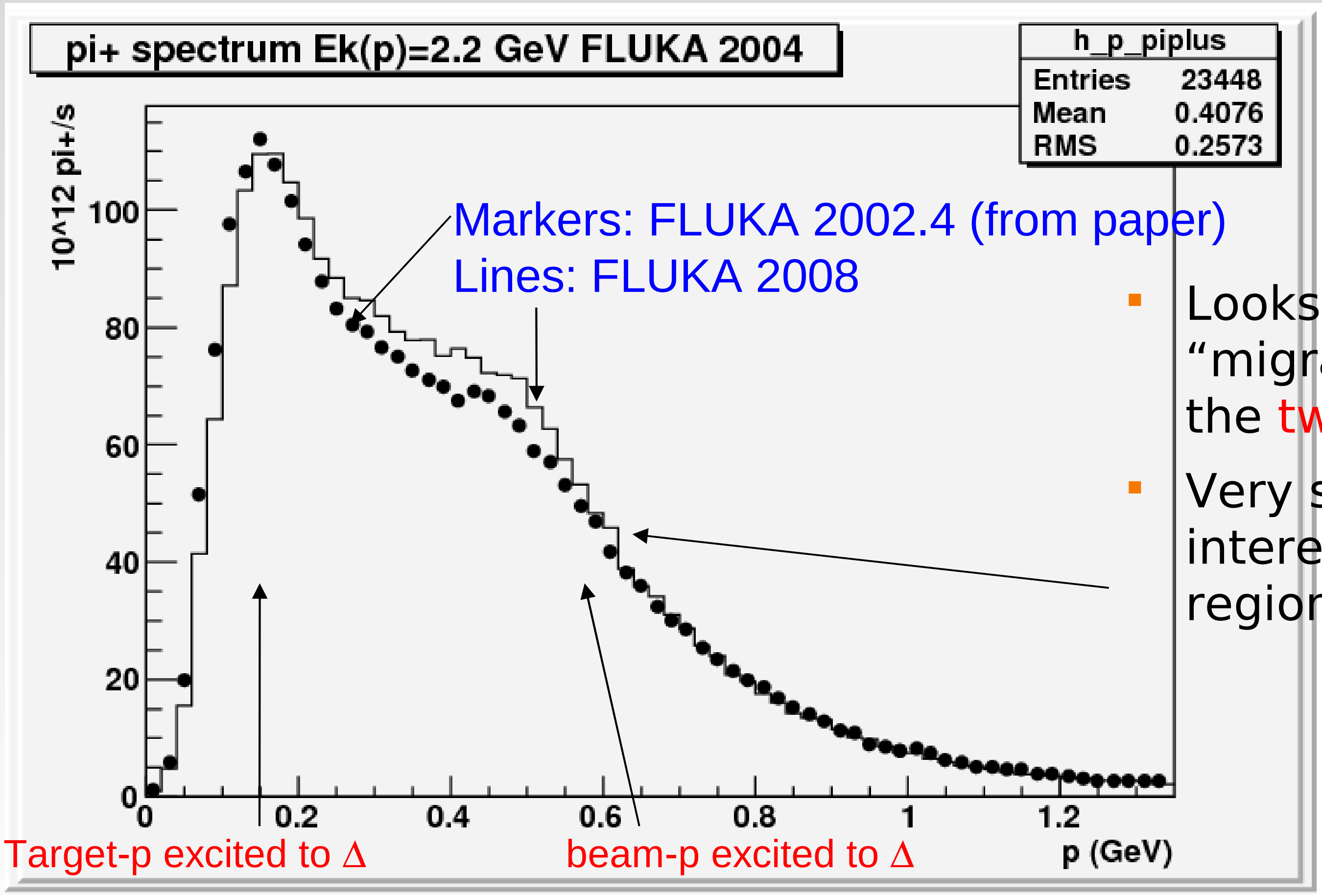




FLUKA 2008.3 vs FLUKA 2002.4

Momentum spectrum of π^+ exiting the target

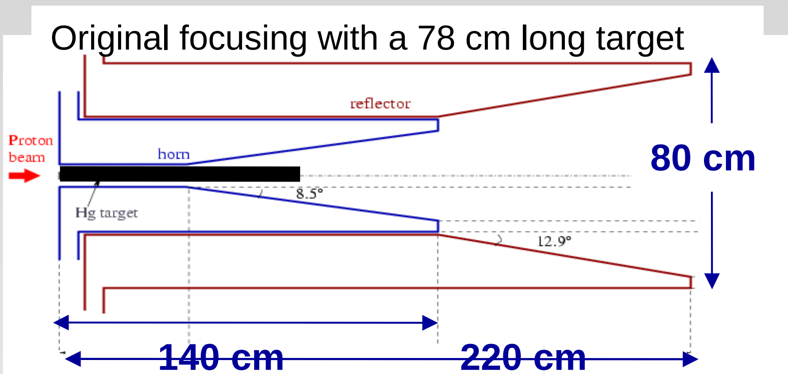
- $E_k(p)$ = 2.2 GeV, Hg cylinder L = 30cm, r = 0.75 cm
- Normalization + shape comparison

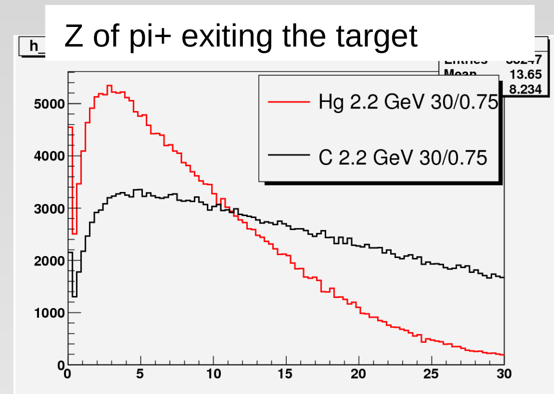


- Looks like a kind of "migration" between the two regions
- Very similar in the interesting momentum region at ~ 600 MeV

Horn shape optimization: first attempts with a long target

As we have seen the “minimal change configuration” already produces good results. To gain something more (especially with respect to the higher contamination from wrong charge pions) a campaign of optimization of the focusing system is ongoing.

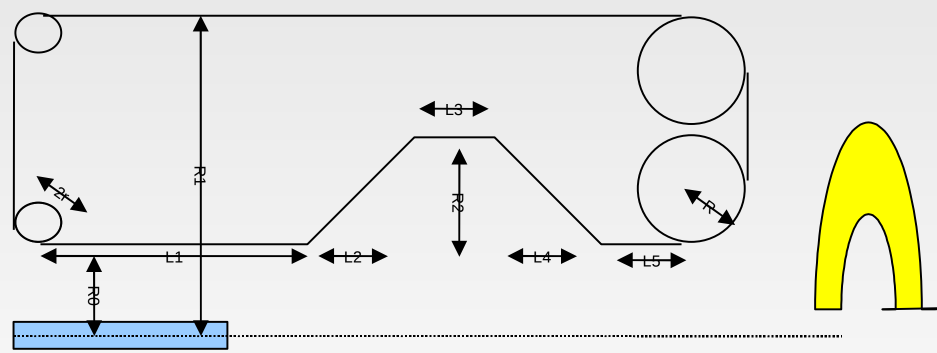




Parametric model implemented in GEANT4 simulation (MINIBOONE inspired) with 9 parameters

In general with this shape better wrong charge pion rejection (more “forward closed”) but conversely higher mean energy is obtained

Flexible enough to reproduce also standard conical geometry



Horn shape optimization (contd.)

Distribution of parametric horn geometrical parameters

“heuristic” approach to find favorable geometries

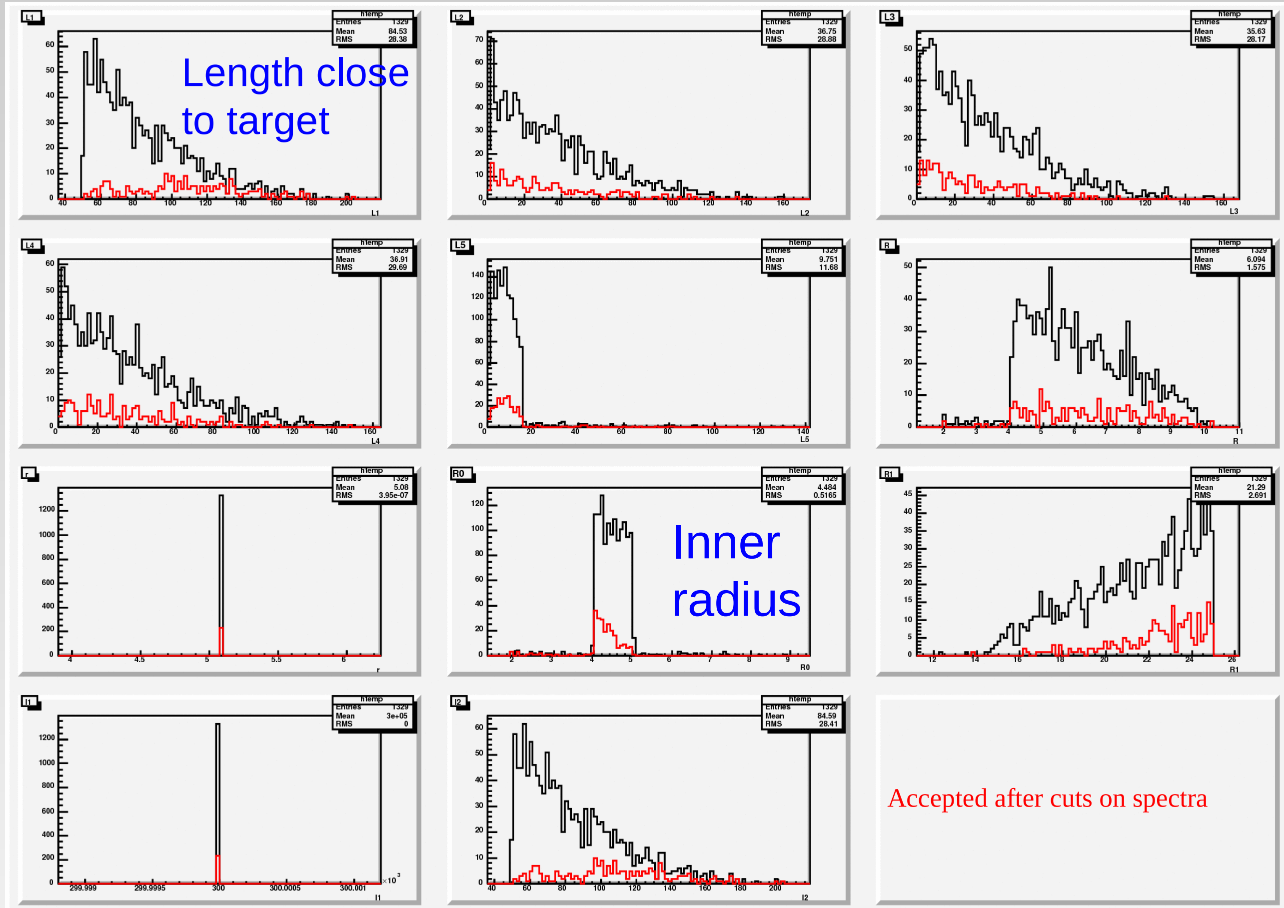
based on the generation of random configurations using the horn parametric model

The resulting fluxes are selected according to quality parameters (numu normalization, antinumu contamination, mean energy, energy spread) .

Seems worth pursuing!

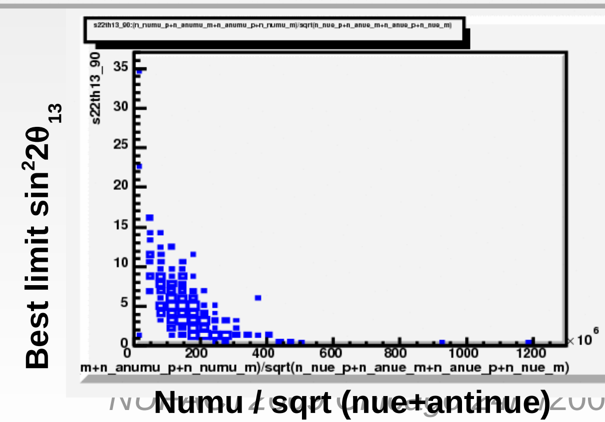
Preferred configurations have small inner radius and high length. (OK, as expected)

Performance at sensitivity level of configurations is next step.



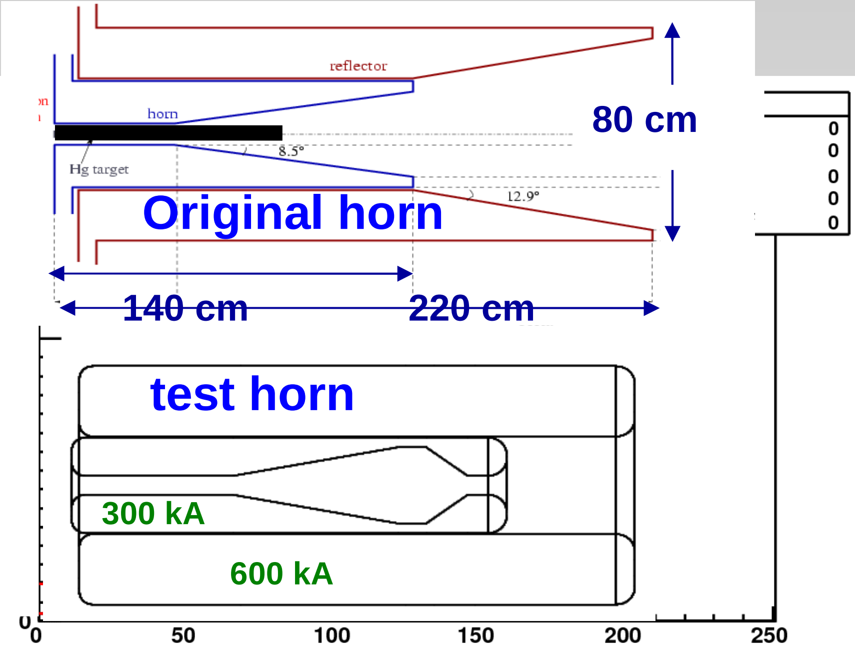
“fluxes optimization”

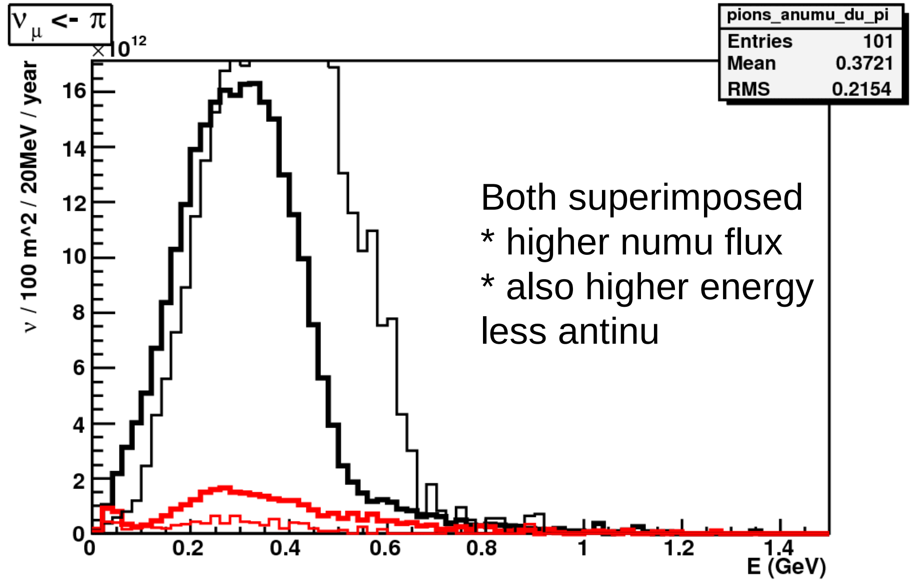
- Along a similar “philosophy” the study the effect of the global characteristics of neutrino fluxes (absolute/relative normalizations, mean energies, spread) on the sensitivity on θ_{13} attempted. Generate many configurations and look for general trends on a statistical basis. Strongest correlation found with numu/sqrt(nue+antinue) ~> “significance” as expected.

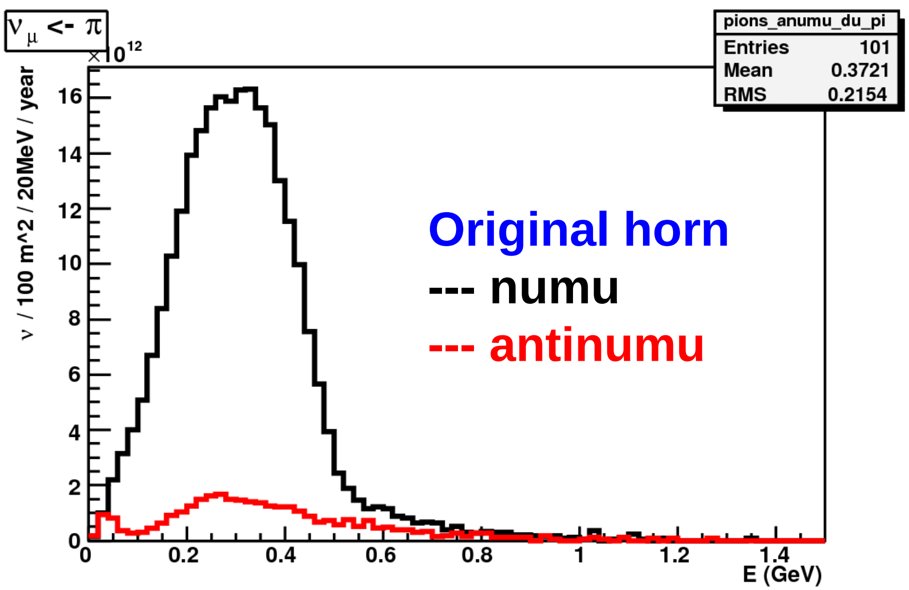


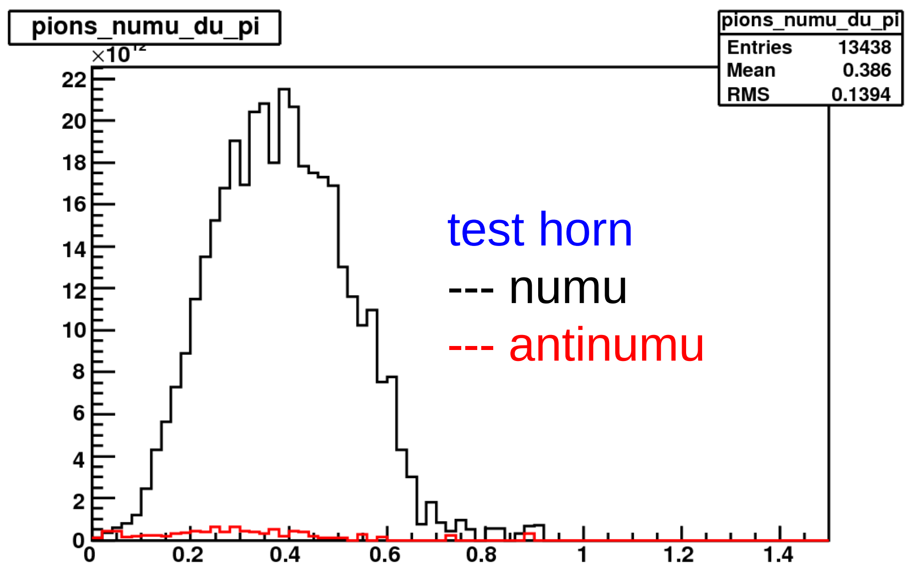
A “promising” configuration

No fine tuning tried
* much less antinumu! -> CPV :)
* higher flux (+10cm for reflector, forward “plug”)
* to be studied at level of sensitivity (in progress)









Conclusions

Activity on the SPL-Fréjus project revived within EUROnu. More "forces" joining the effort.

Simulation tools working and being updated (GEANT4-FLUKA2008.3-GLoBES 3.0.14)

Solid target option (in association with multiple horns): looks appealing !

Simulation indicate a much reduced energy deposition and neutron fluxes (-X 15), comparable neutrino fluxes and competitive performances at the level of θ_{13} sensitivities even before horn optimization for longer target.

A stronger dependence on δ of θ_{13} sensitivity for carbon target due to a higher occurrence on anti-ν_μ and anti-ν_e in the ν_μ beam (from wrong charge π) is being addressed by optimizing the focusing.

Promising horn configurations under test: room for improvement

... and Outlook

Verify FLUKA description with HARP "thick target" data (synergy with EURONU-WP3) and other models (i.e. MARS).

Finalize transition to GEANT4 and definition of optimized horn suited for a long target with full analysis up to sensitivity level (few steps missing).