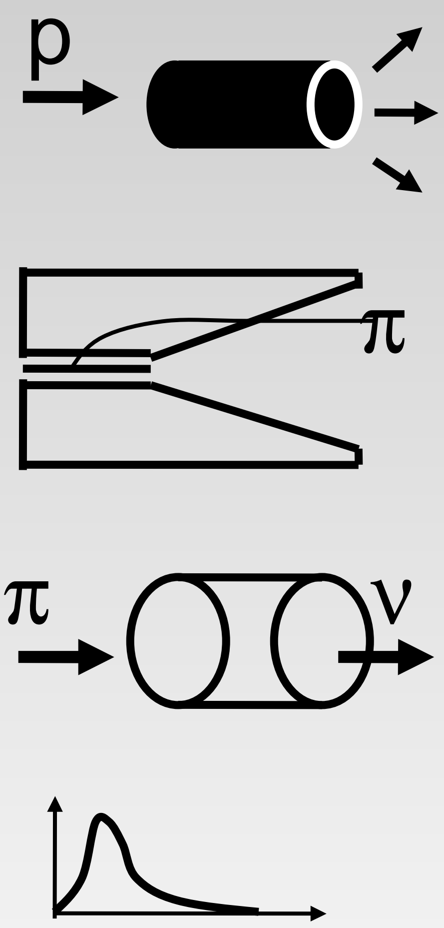
SPL-Fréjus studies: status report



Andrea Longhin

CEA Saclay

EUROnu WP2 EVO meeting

14 September 2009

Short summary of previous results

Graphite target option investigations presented in previous meetings have been documented in a note available at www.euronu.org (Documents -> WP2-> *Study of the performance of the SPL-Frèjus Super Beam using a graphite target*)

- much lower energy deposition in the target (FLUKA08+GEANT4)
- much lower neutron flux (~x15 FLUKA08)
- pion yields more asymmetric but comparable
- neutrino fluxes less E dependent similar
- higher antinu contamination
- sin22th13 sensitivities better for delta =0
- limit more delta dependent (worse in some regions) probably due to higher antinu and shape of flux (high energy tail is more relevant)

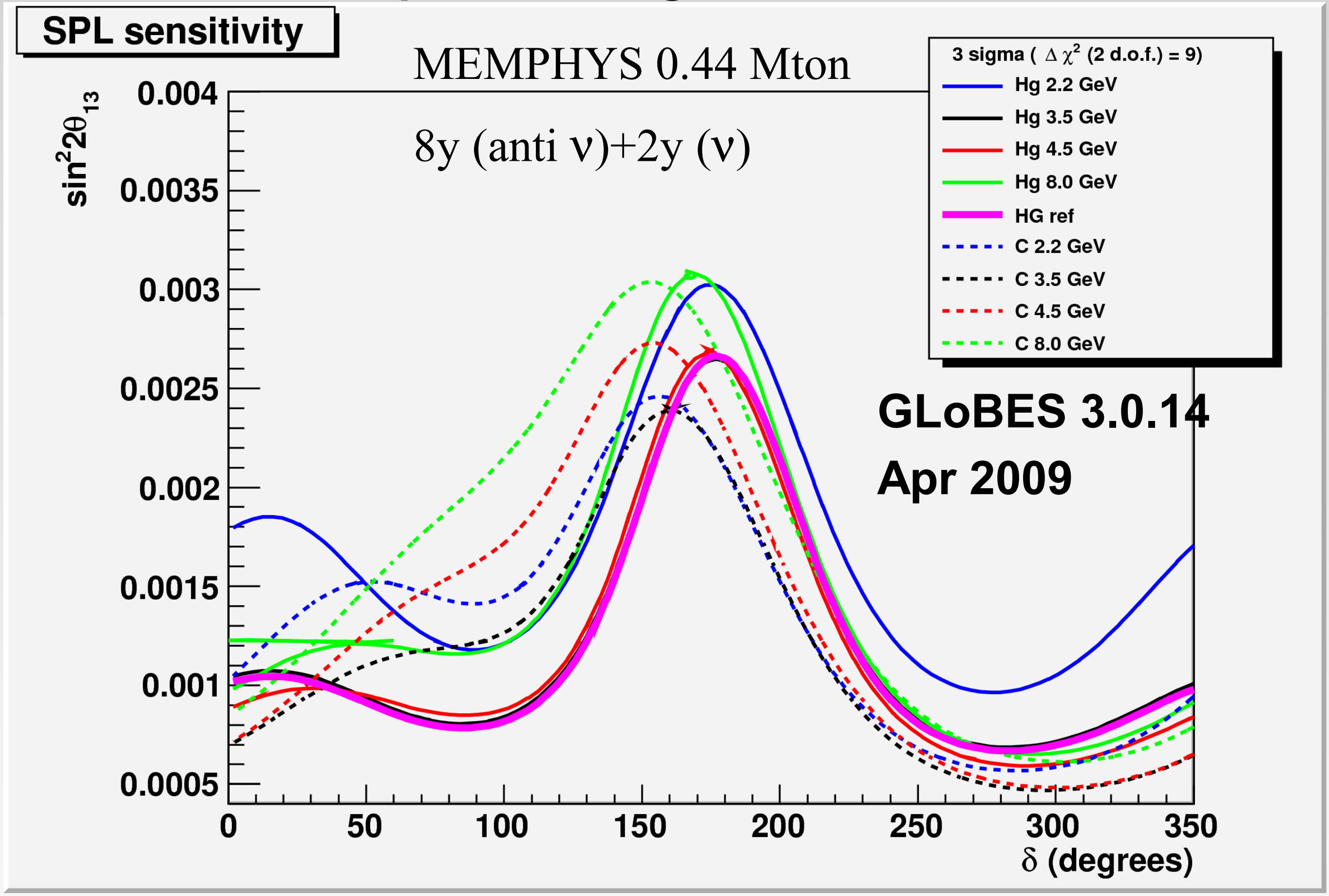
3 sigma sensitivity C-Hg comparison

Carbon (- - - - - -)   Mercury (———)

Color codes: proton energies

Presented at NUFACT09 in July

"Minimal change" scenario i.e. same horn and simulation (geant3) 78 cm long graphite target in place of 30cm mercury



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

Carbon limit (dashed) more δ dependent than for Mercury (continuous). Nevertheless quite competitive.

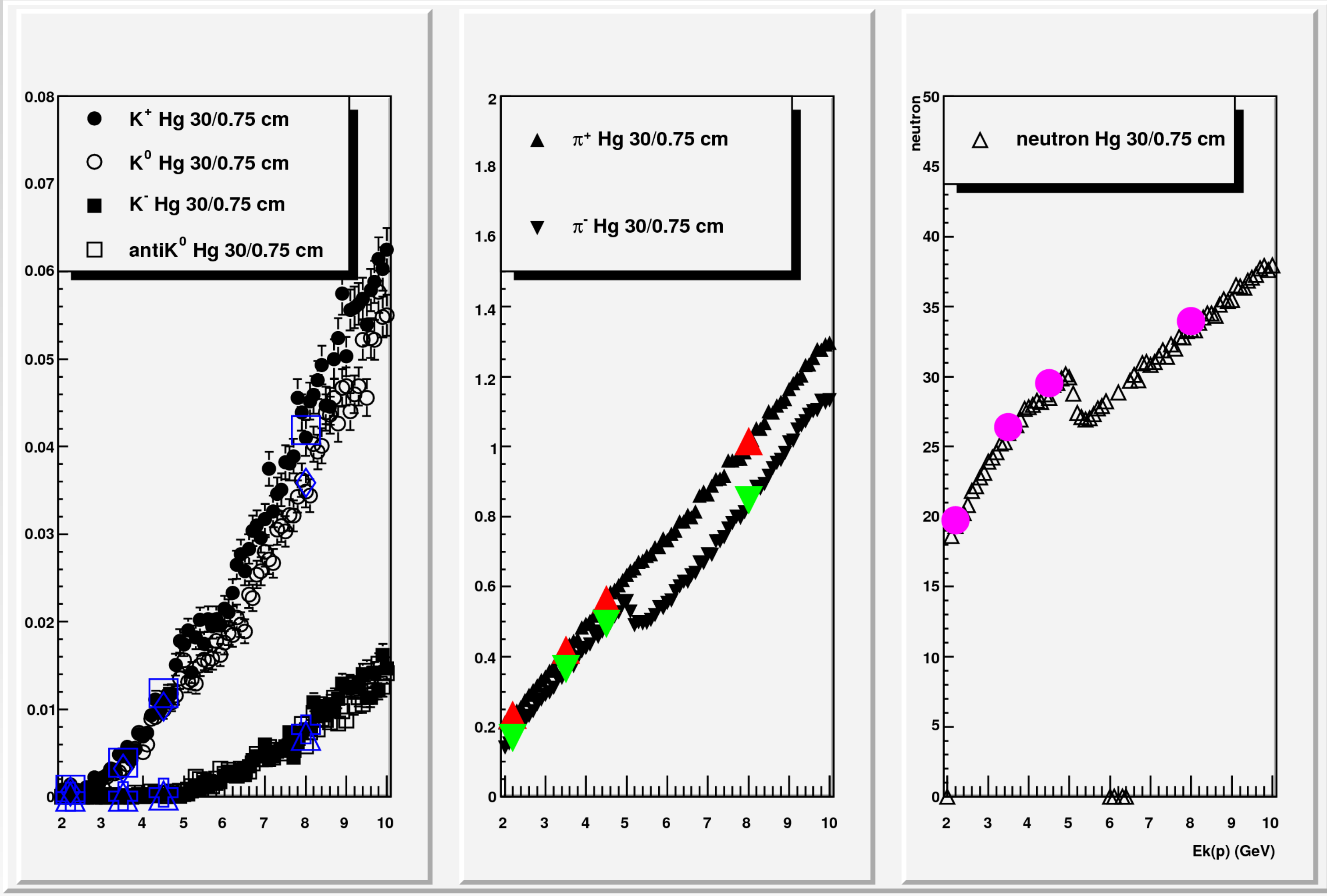
News since last EVO meeting (15 July 09)

* Comparison of FLUKA results with Christoph Bobeth

* Rewriting of the full simulation chain in GEANT4: ~ finished
* Implementation of nu_e fluxes from muon and K 3 body decays into GEANT4
* Detailed comparison of GEANT3 and new GEANT4 with standard horn geom.
* First preliminary results on sensitivity with an upgrade of the horn shape

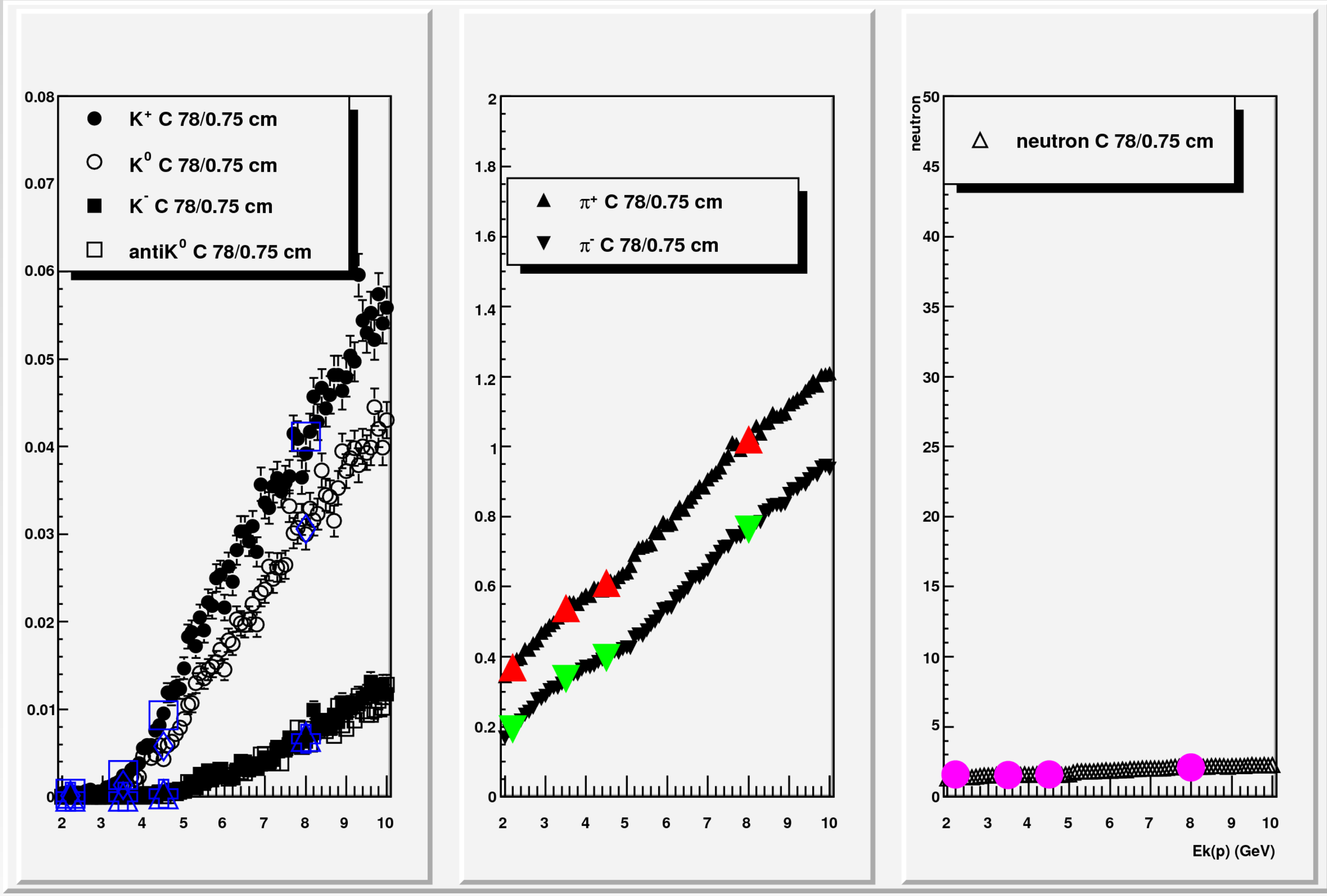
FLUKA multiplicities X-check: Mercury

Test points by Christoph superimposed in colors



Fluka multiplicities X-check: Carbon

Test points by Christoph superimposed in colors



GEANT4

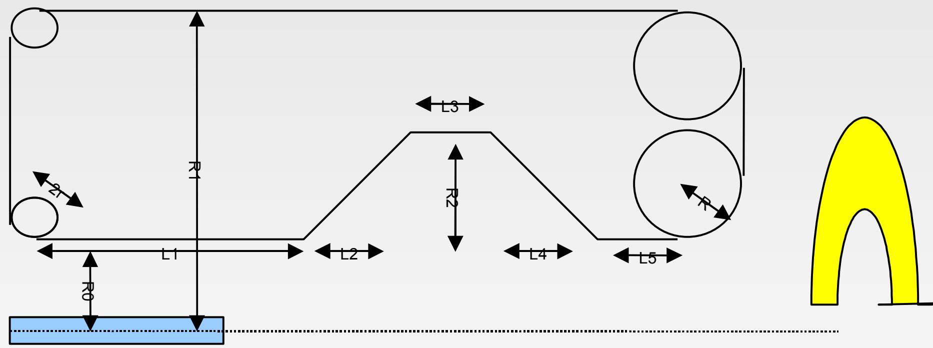
- GEANT4: modern, updated tool (C++)
- more flexible in view of the wish of studying many different geometries and optimize horn for a longer target

- A tool for "exploring" interesting geometries has been developed within G4:

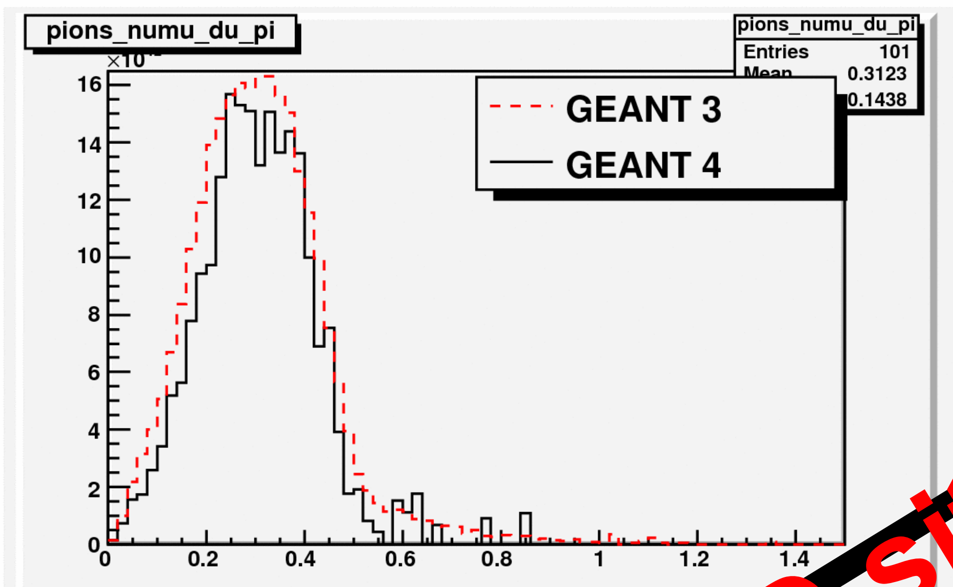
Parametric model implemented in GEANT4 simulation (MINIBOONE inspired) with 9 parameters

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



GEANT 4-3 early comparison



Implemented already:

- geometry
  - Parametric with some alternative options and accessible easily with input cards
- neutrino flux computation for the
  - pi->mu nu & K-> mu nu chains

OLD situation

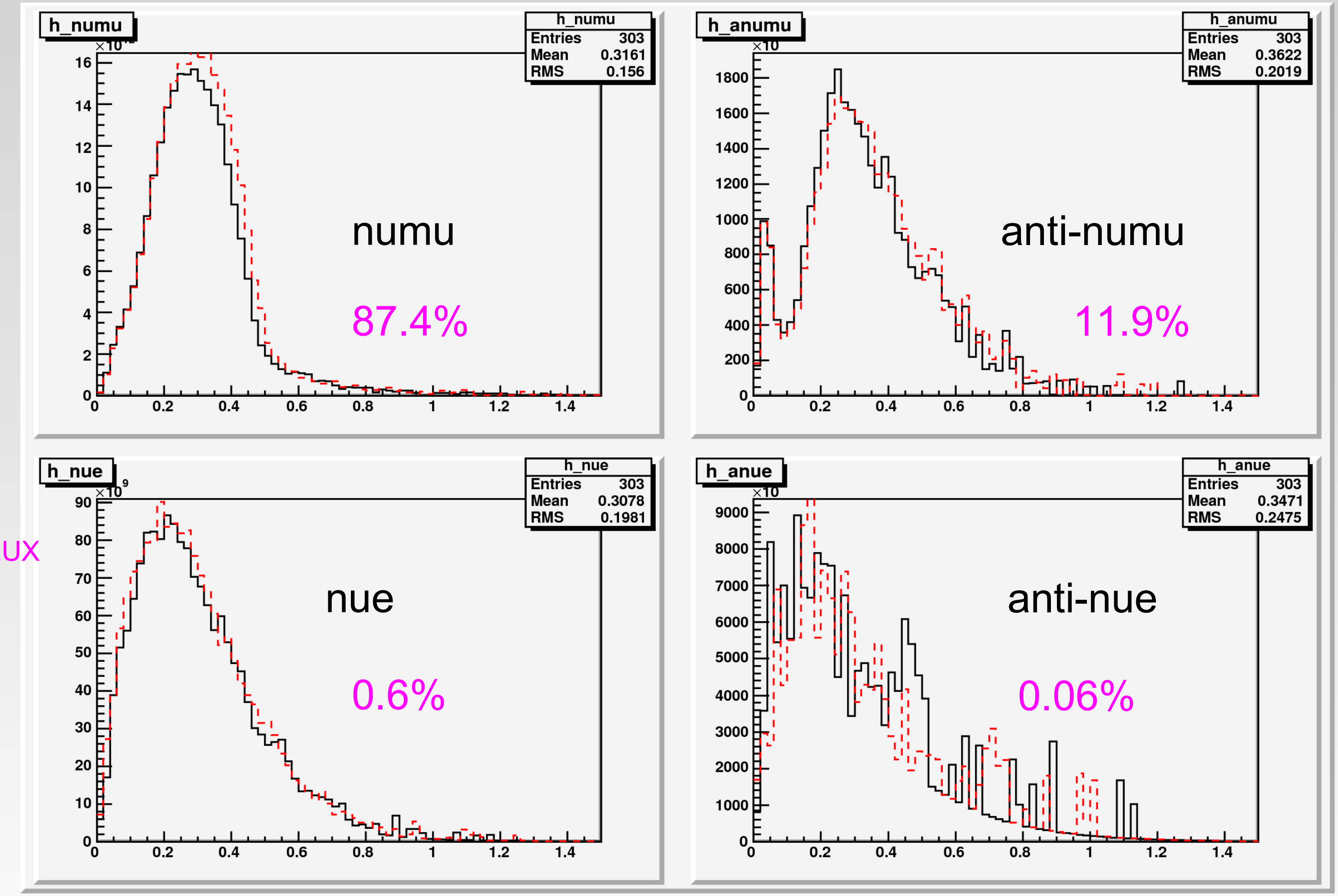
Not too bad at this (early) stage

More checks needed

ensure geometry is correctly reproduced and also handling of pion decay in flights

GEANT 4-3 "mature" comparison: total fluxes

GEANT3 (dashed)
GEANT4



% TOT FLUX (G4)

Ek(p) = 4.5 GeV

Fluxes contributions

Internal numbering scheme

	$K^{\pm}$		K_L^0		K_S^0	
1-2	$\mu^{\pm}\nu_{\mu}$	13	$\pi^-e^+\nu_e$	19	$\pi^+\pi^-$	68.61%
3-4	$\pi^{\pm}\pi^0$	14	$\pi^+e^-\bar{\nu}_e$	20	$\pi^0\pi^0$	31.39%
5-6	$\pi^{\pm}\pi^+\pi^-$	15	$\pi^-\mu^+\nu_{\mu}$	13.5%		
7-8	$e^{\pm}\nu_e\pi^0$	16	$\pi^+\mu^-\bar{\nu}_{\mu}$	13.5%		
9-10	$\mu^{\pm}\nu_{\mu}\pi^0$	17	$\pi^0\pi^0\pi^0$	21.5%		
11-12	$\pi^{\pm}\pi^0\pi^0$	18	$\pi^+\pi^-\pi^0$	12.38%		

30	$\pi^+ \to \mu^+ \nu_{\mu}$
31	$\pi^- \to \mu^-$ antiν_{μ}

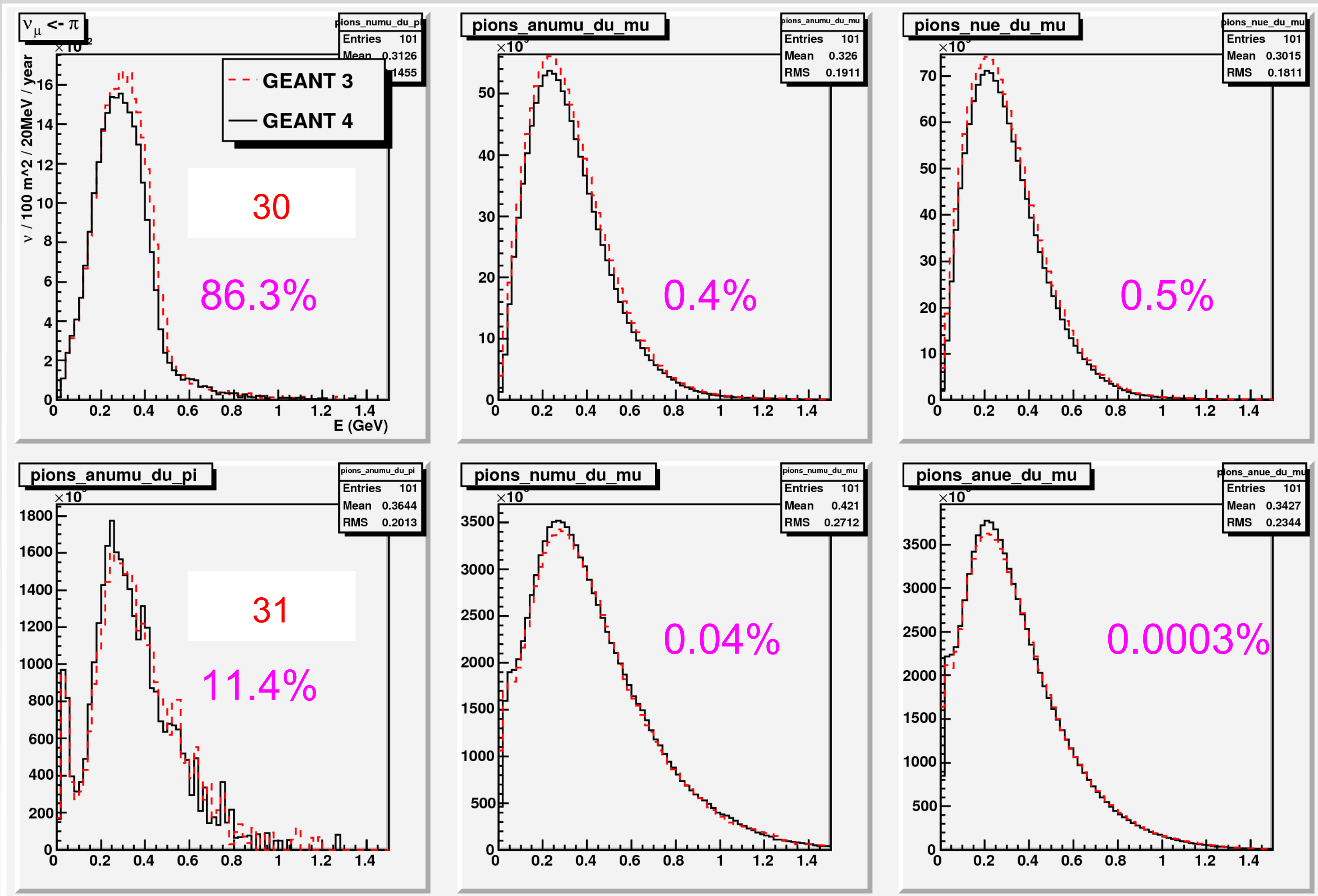
GEANT 4-3: nu from primary pions

30	$\pi^+ \to \mu^+ \nu_\mu$
31	$\pi^- \to \mu^-$ antiν_μ

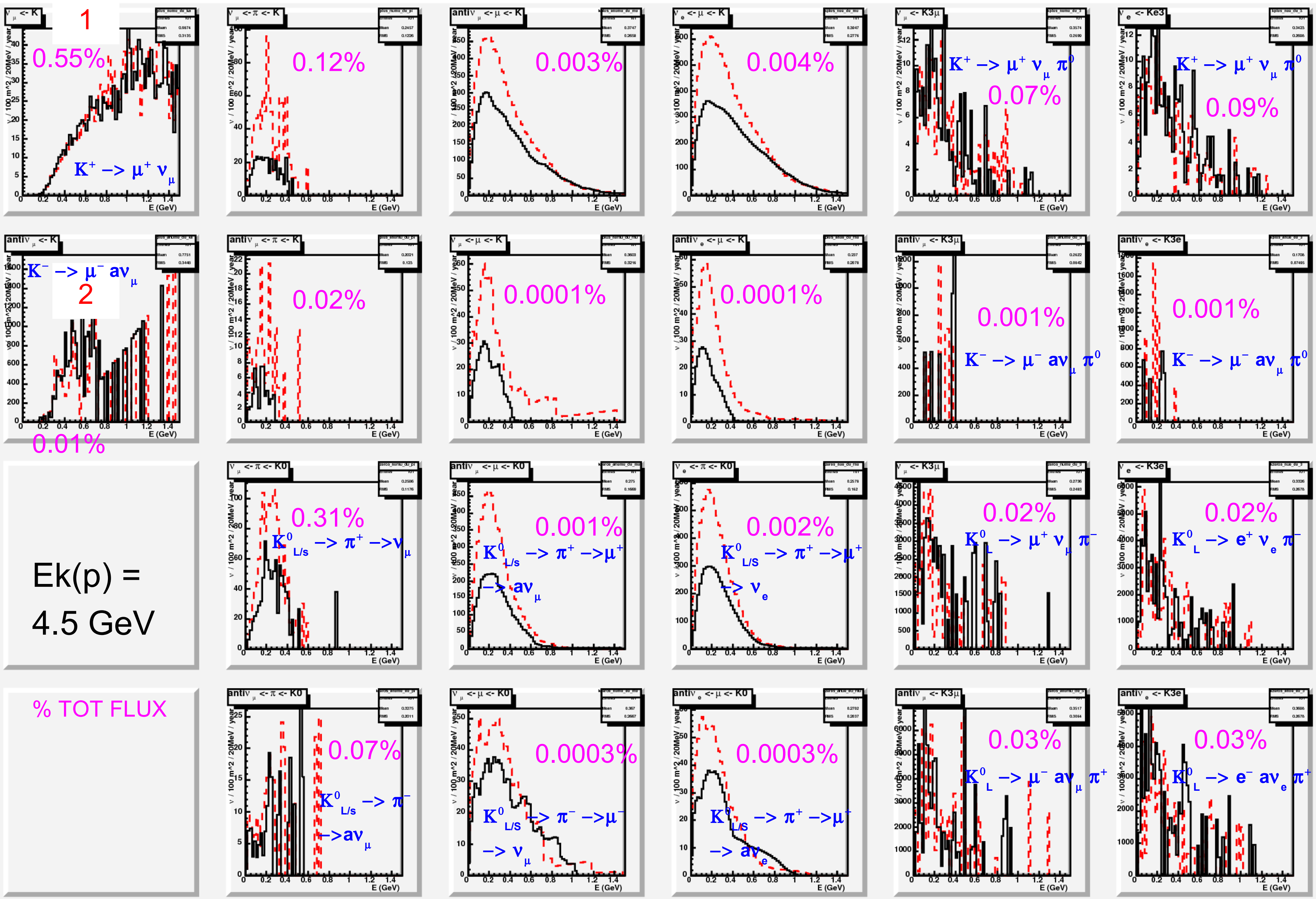
Pion chain

Ek(p) = 4.5 GeV

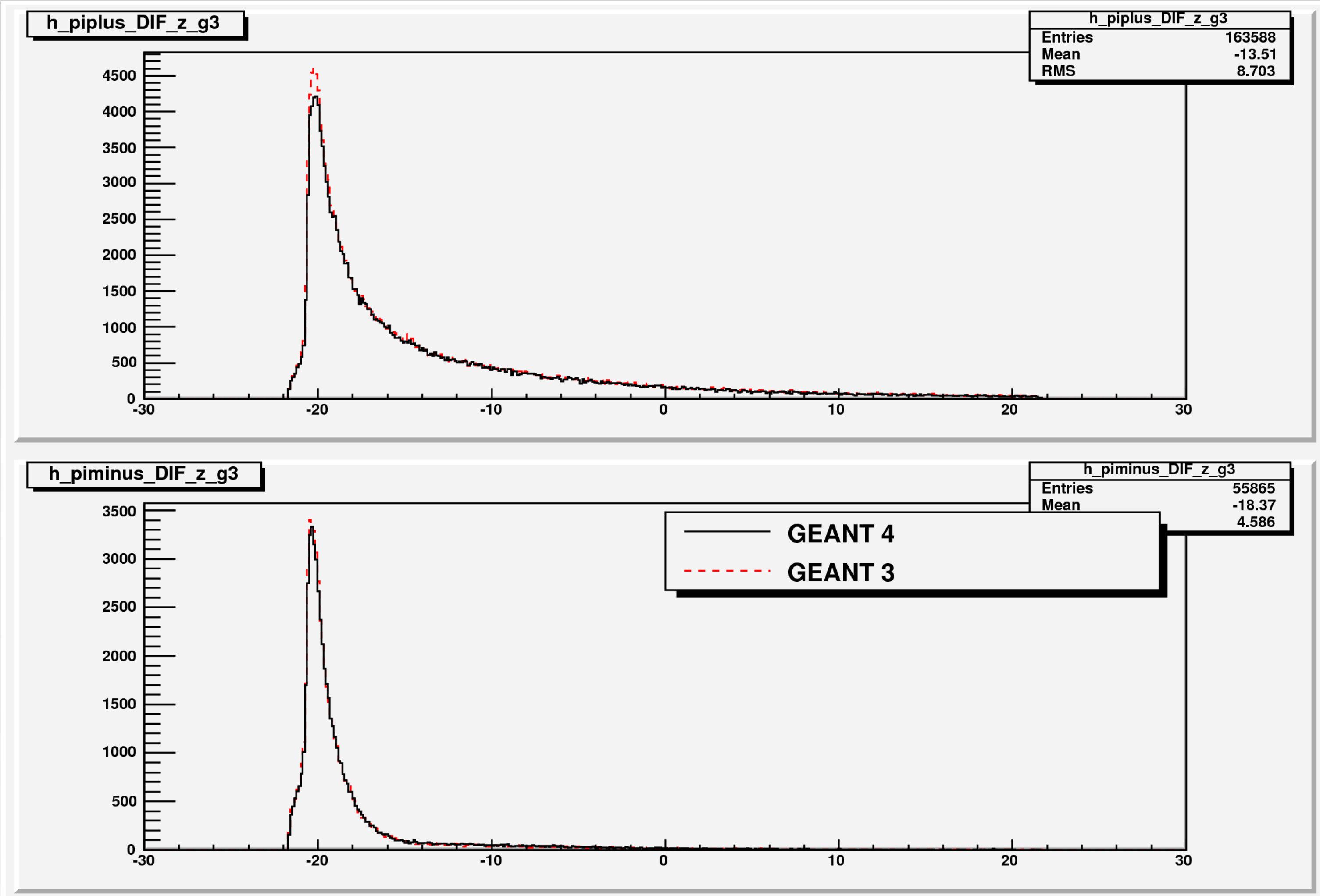
% TOT FLUX



GEANT 4-3: nu from K+/- and K0



GEANT 4-3: decays in flight z

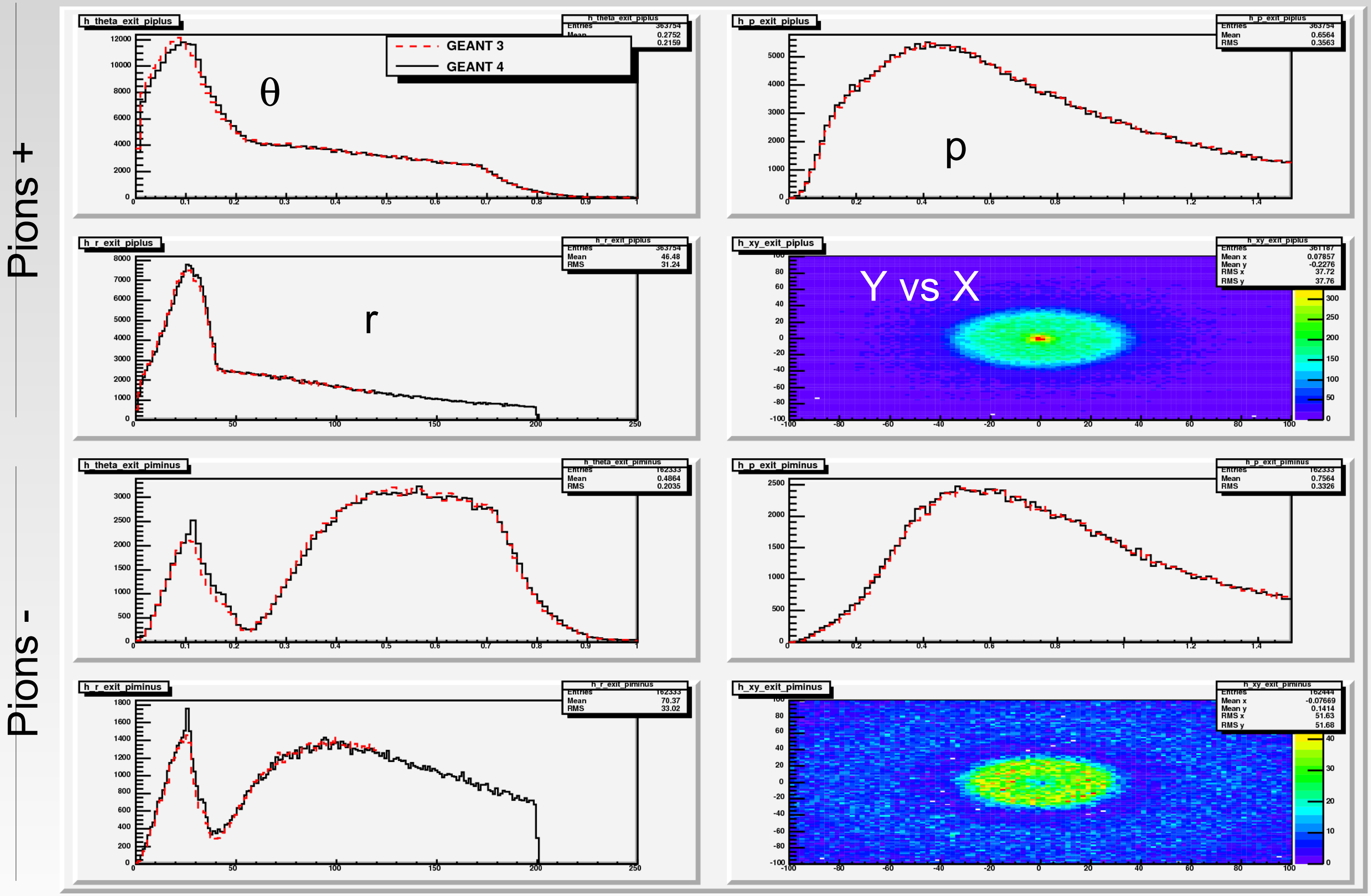


Ek(p) = 4.5 GeV

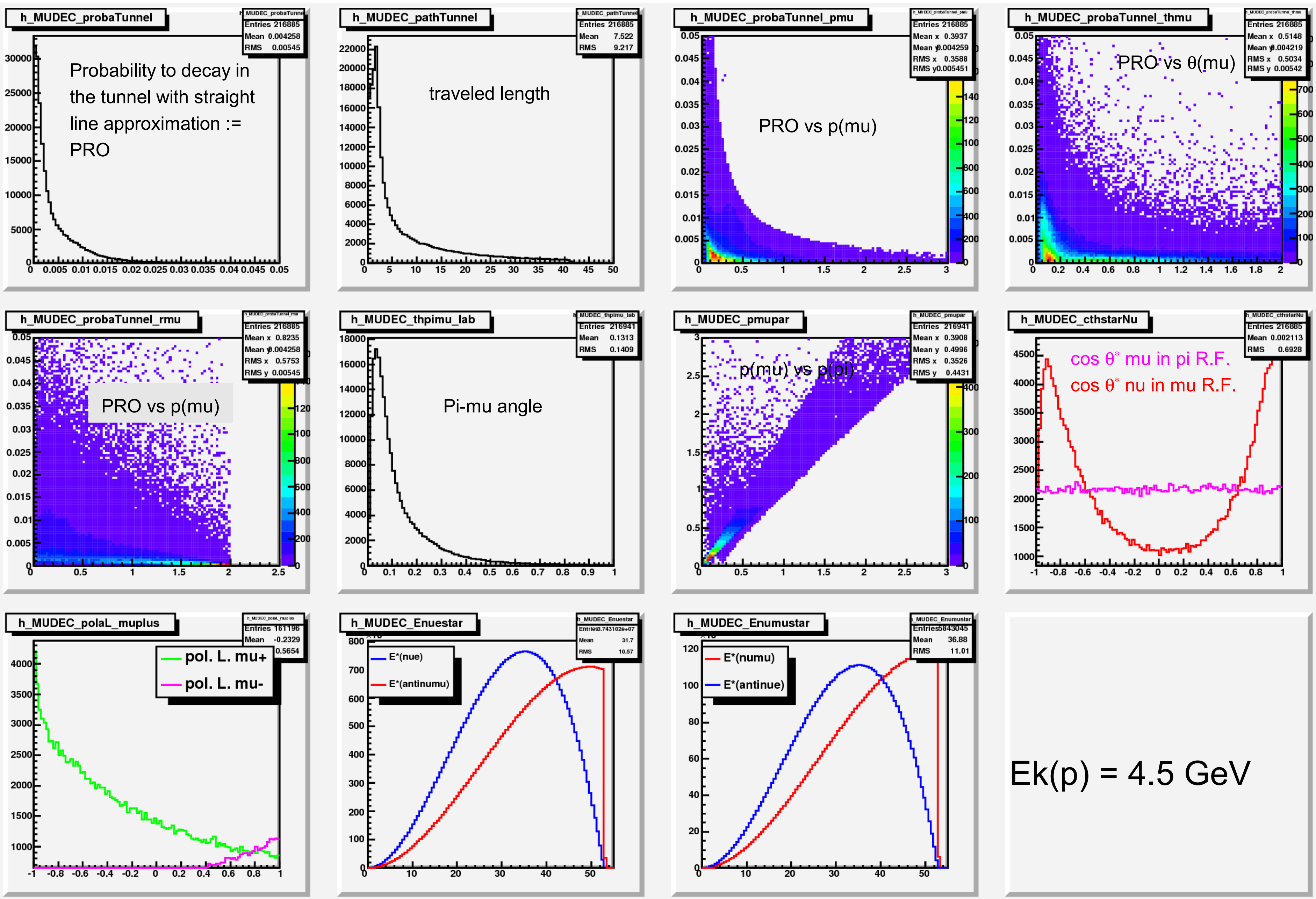
GEANT 4-3: pi+/- at tunnel entrance

GEANT3 (dashed)
GEANT4

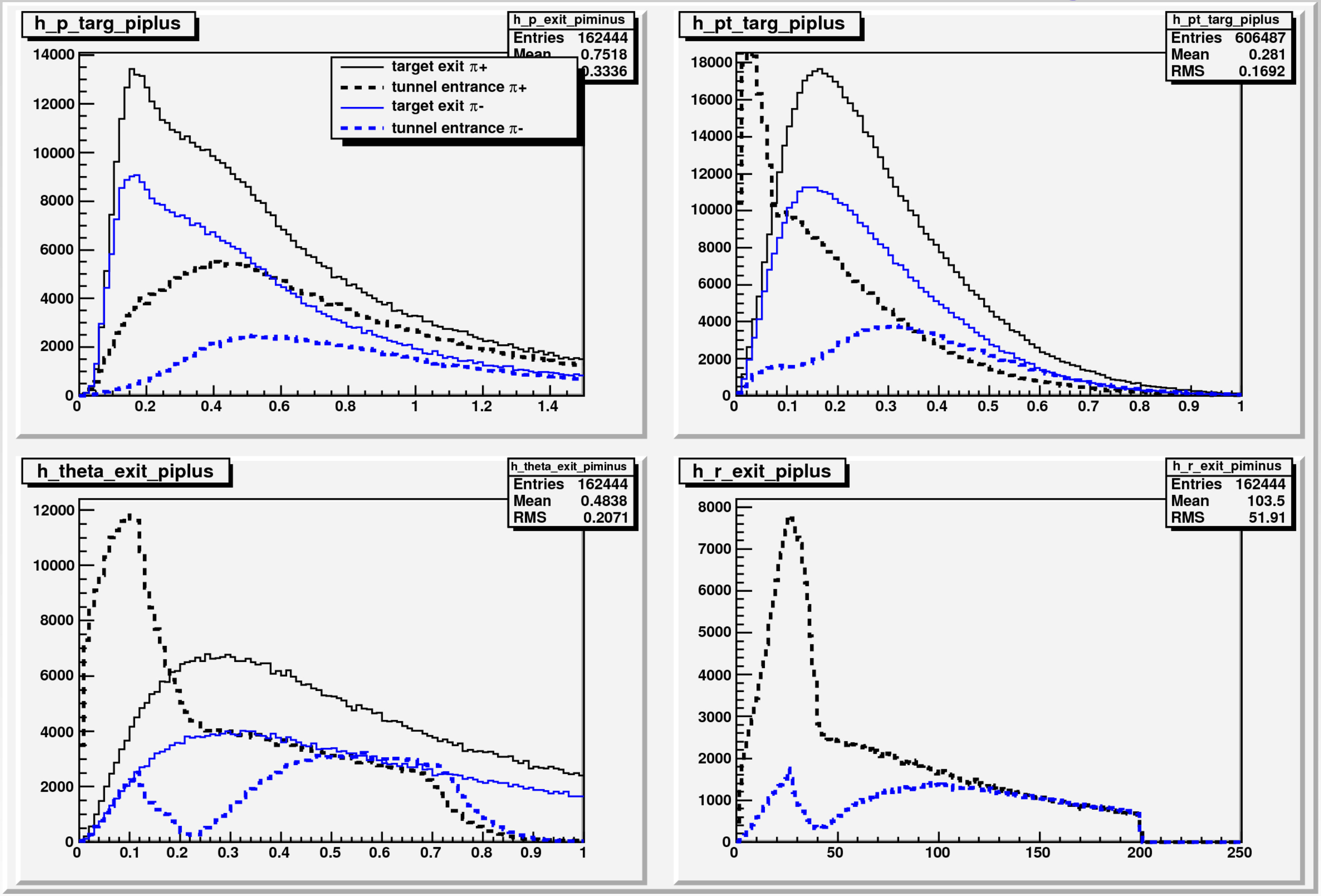
Ek(p) = 4.5 GeV



GEANT 4 control plots for muon decay neutrino fluxes



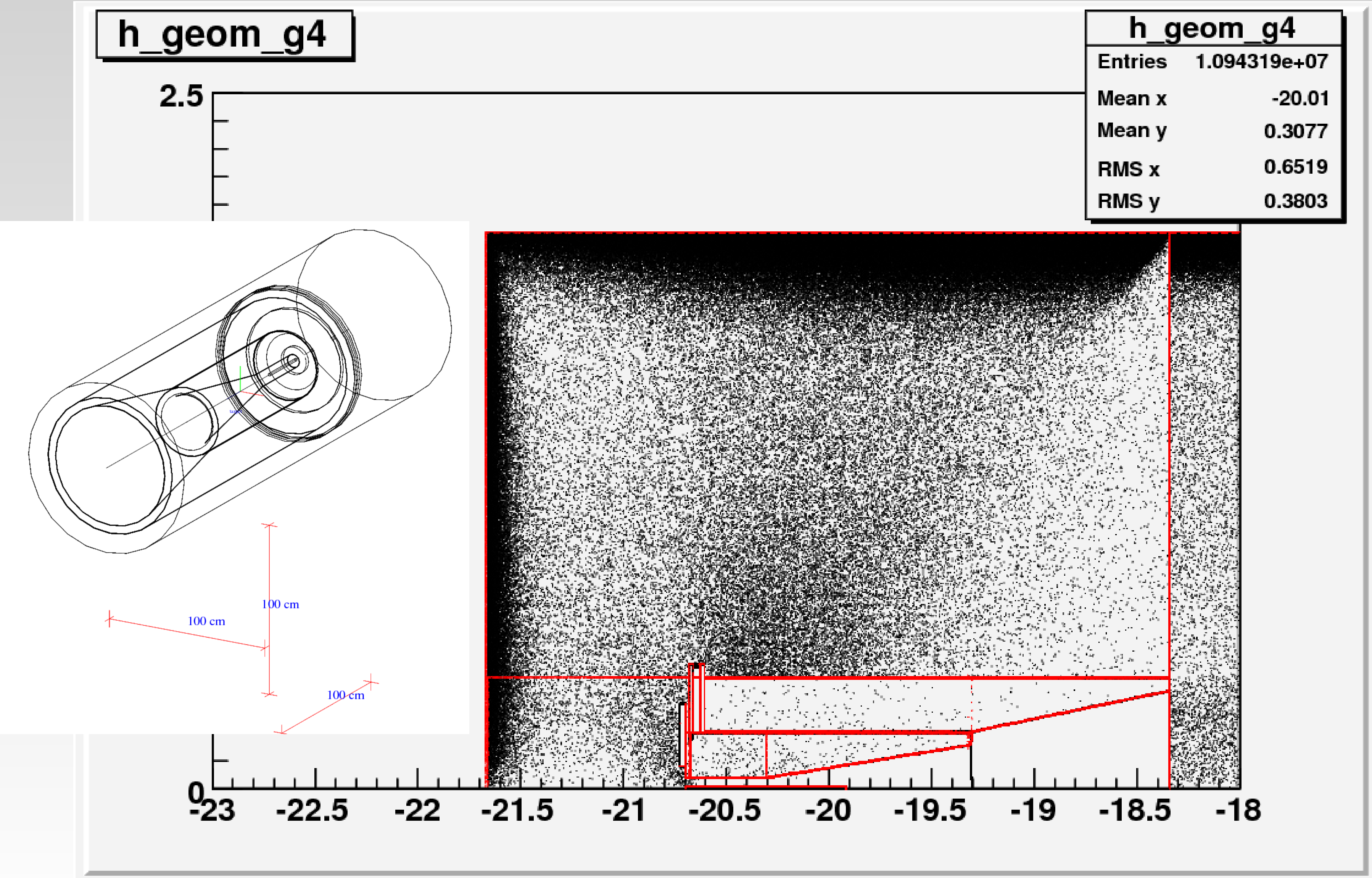
GEANT 4 control plots for pion focusing



Ek(p) = 4.5 GeV

GEANT 4 control plots for geometry

The **geant4** and **geant 3** hit maps are superimposed in the (r,z plane)



GEANT 4 control plots for branching ratios

Implementation of Branching rations in Geant4 checked a posteriori

For decays of charged pions, kaons, neutral kaons

$K^{\pm}$		K_L^0		K_S^0	
$\mu^{\pm}\nu_{\mu}$	63.51%	$\pi^-e^+\nu_e$	19.35%	$\pi^+\pi^-$	68.61%
$\pi^{\pm}\pi^0$	21.17%	$\pi^+e^-\bar{\nu}_e$	19.35%	$\pi^0\pi^0$	31.39%
$\pi^{\pm}\pi^+\pi^-$	5.59%	$\pi^-\mu^+\nu_{\mu}$	13.5%		
$e^{\pm}\nu_e\pi^0$	4.82%	$\pi^+\mu^-\bar{\nu}_{\mu}$	13.5%		
$\mu^{\pm}\nu_{\mu}\pi^0$	3.18%	$\pi^0\pi^0\pi^0$	21.5%		
$\pi^{\pm}\pi^0\pi^0$	1.73%	$\pi^+\pi^-\pi^0$	12.38%		

19
20

Decay channel numbering (internal convention)

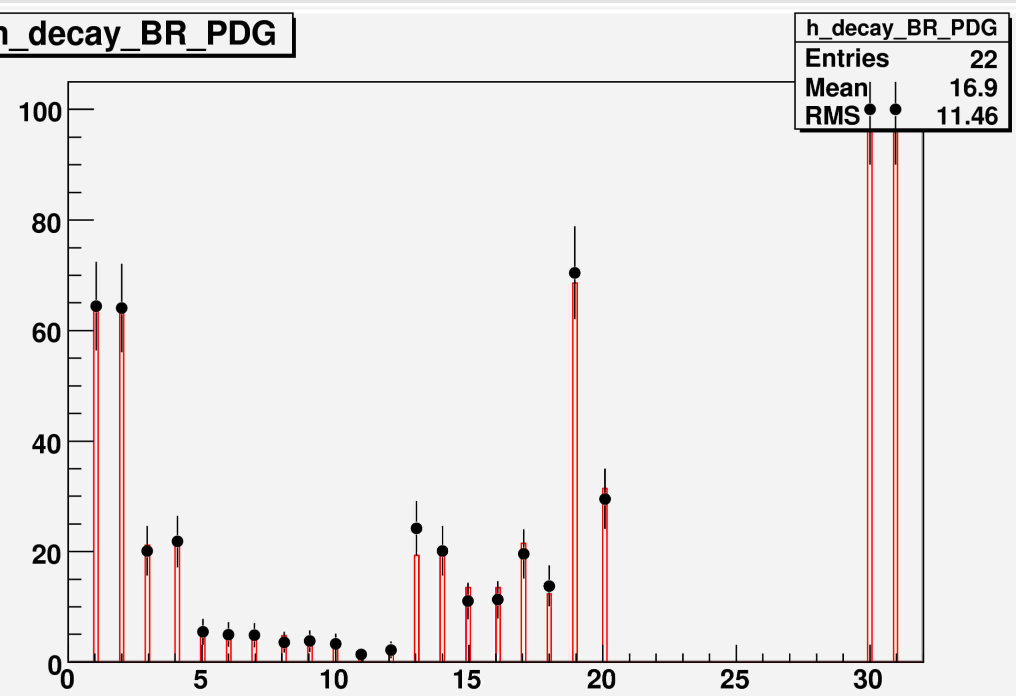
1-2
3-4
5-6
7-8
9-10
11-12

13
14
15
16
17
18

30
31

$\pi^+ \to \mu^+ \nu_{\mu}$
$\pi^- \to \mu^-$ antiv$_{\mu}$

B.R. (%)

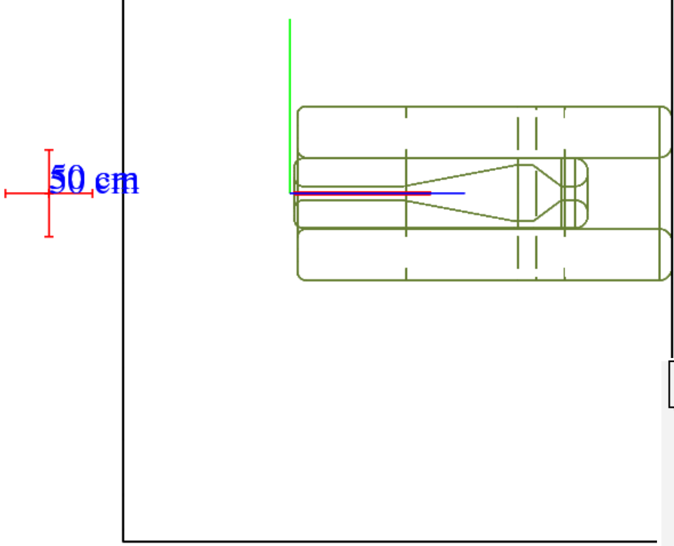


|| PDG values

● values obtained by counting

decays to i-th channel / # decays

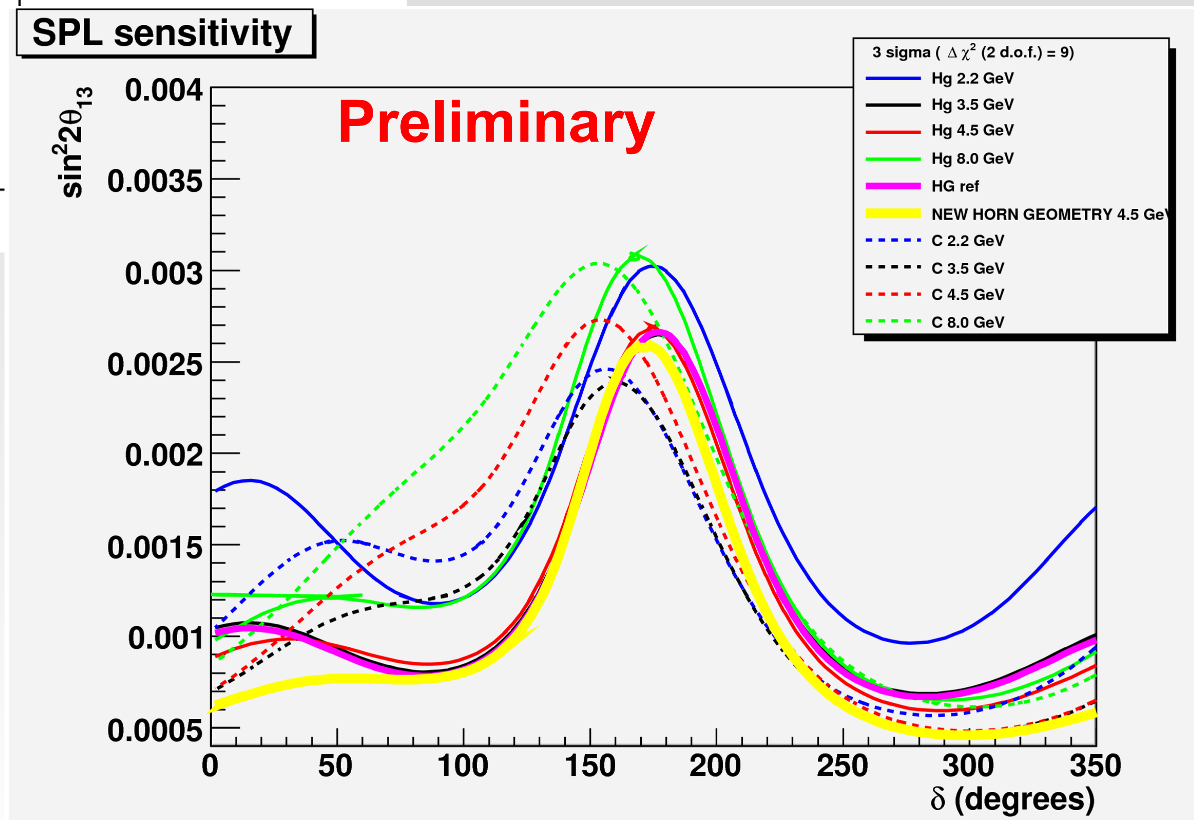
Preliminary sensitivity with a new horn shape



Reflector thicker by 10cm, ~same length

Usual 300/600 kA for Horn/Reflector

more “closed”, lower antinumu contamination

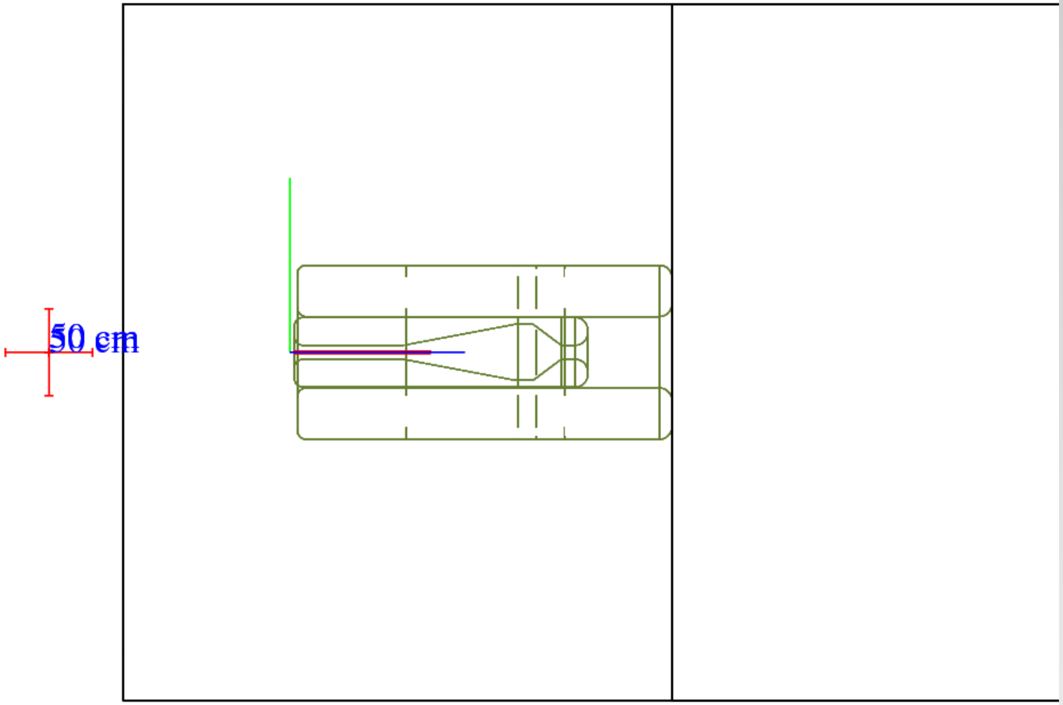


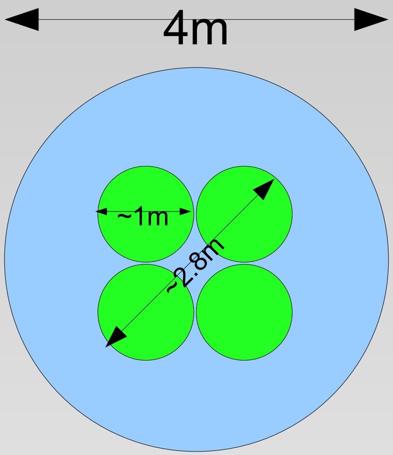
Caveats.

no aluminum cage at present

nu_e almost but not completely reproduced with g4

Conclusions and Outlook (I)





GEANT4 simulation reproduces quite well previous results, some refinements still needed. Work in progress ...

TODO after GEANT4 setup validation:

* finalize characterization of a new shape for the horn

* Implement multiple-horn configuration and study the impact on fluxes and sensitivities. Expected effects:

- each horn sees an “off-axis tunnel (~on axis with lower effective radius)

  interference among horns for high angle tracks in terms of material (and B field depending from proton injection-horn pulsing strategy)

Outlook (II)

Presentations/documentation :

* Abstract for poster CERN workshop 1-3 October to be submitted (today)
* EURONU technical note: “geant3-4 comparison”. Being written.

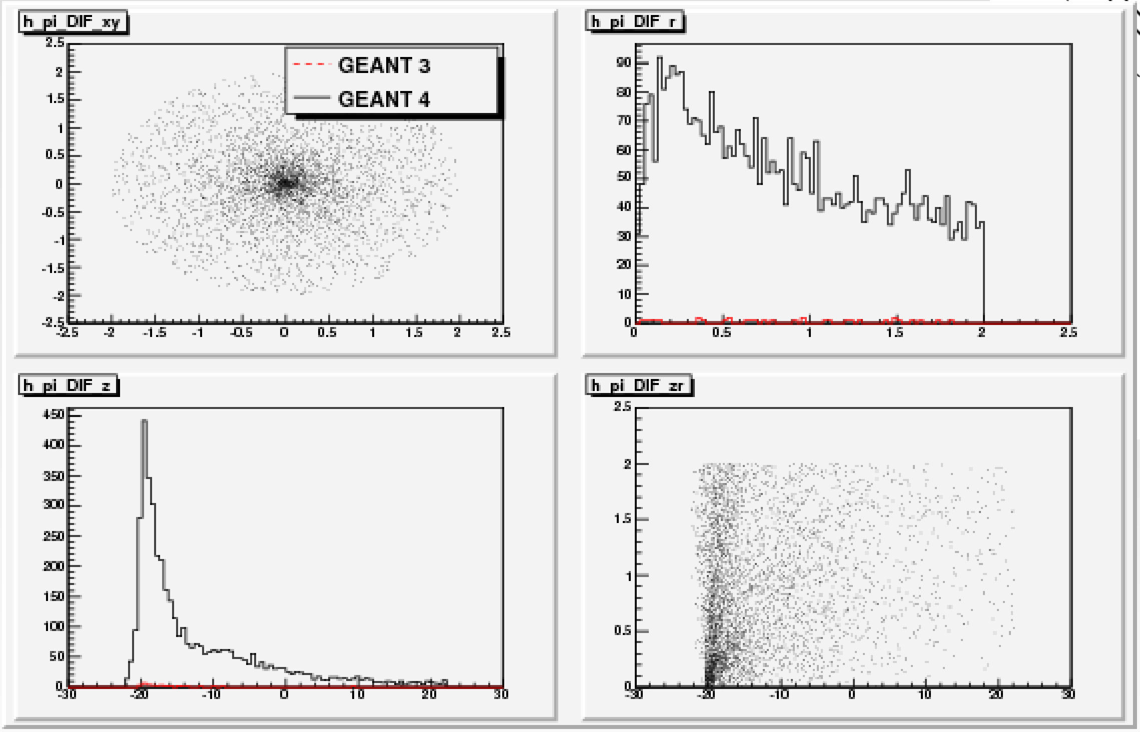
Also:

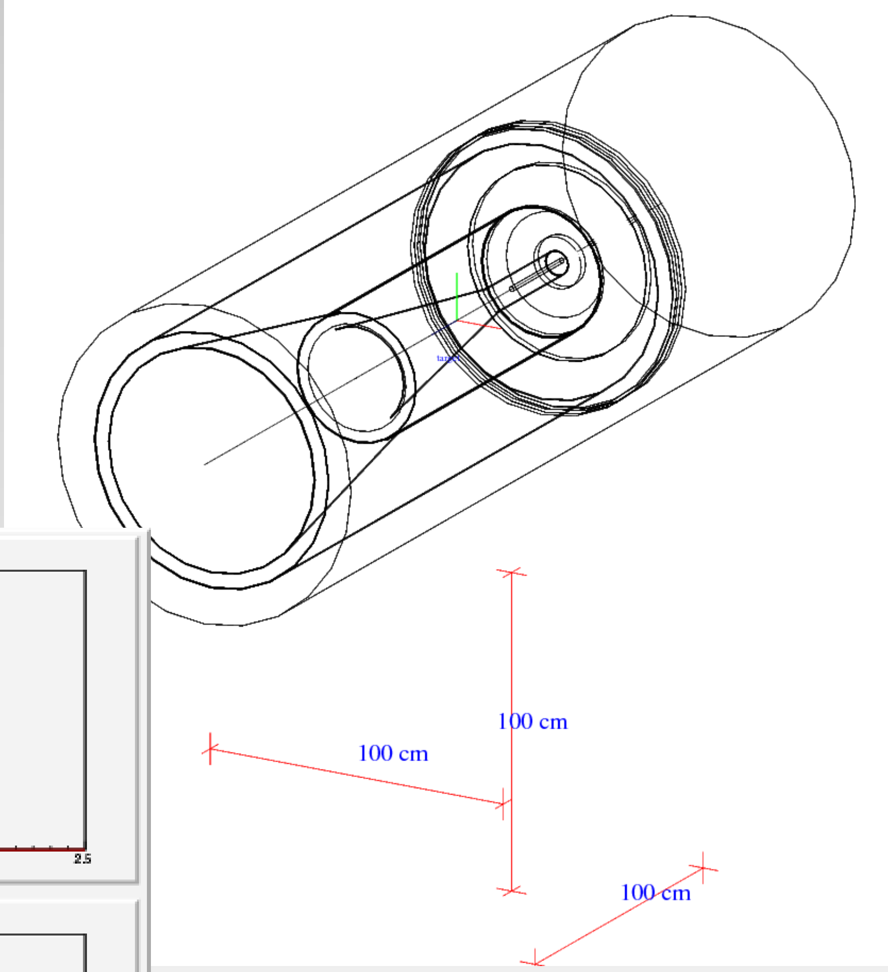
HARP data -> FLUKA comparison to validate results on carbon target

BACK-UP

GEANT4

Example of a set of control plots automatically generated by the main simulation program

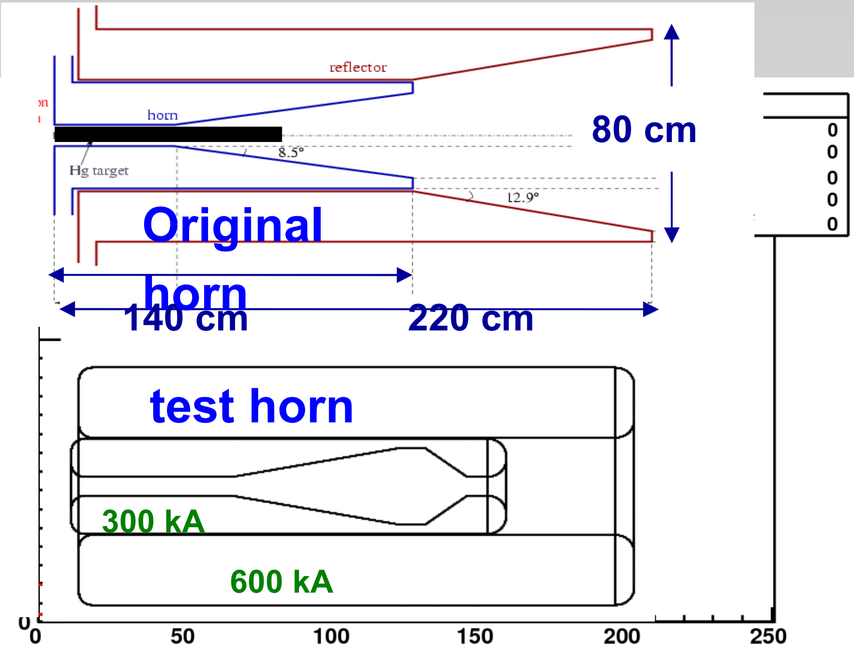


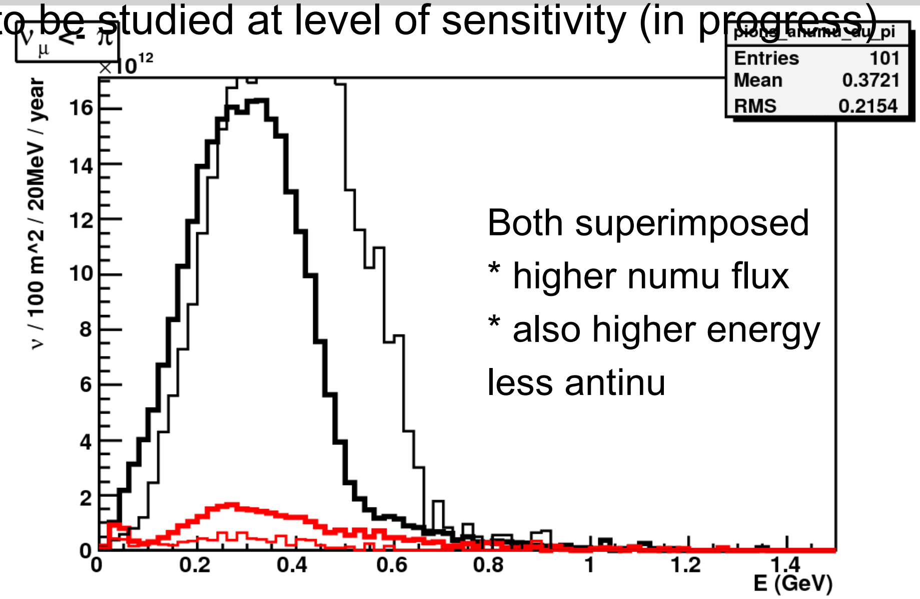


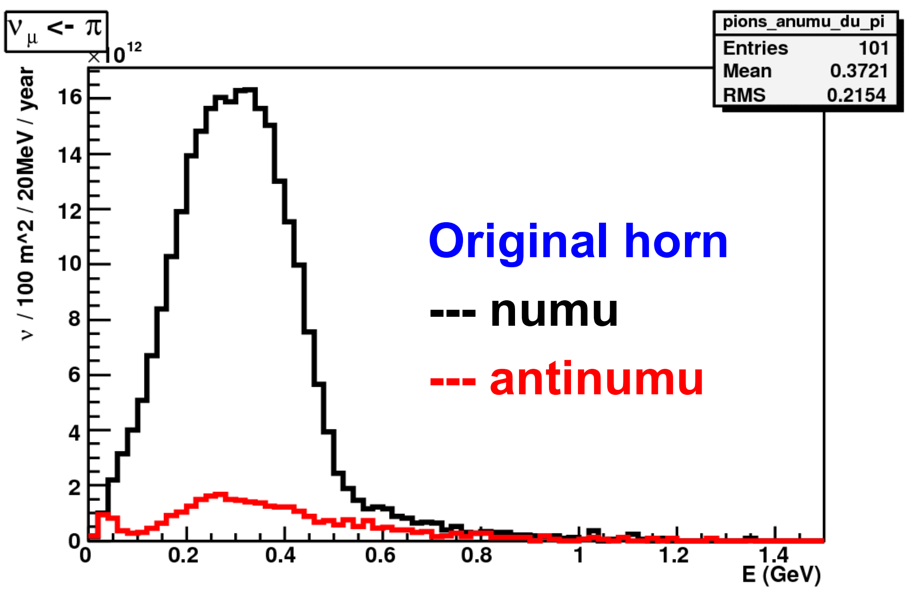
A “promising” configuration

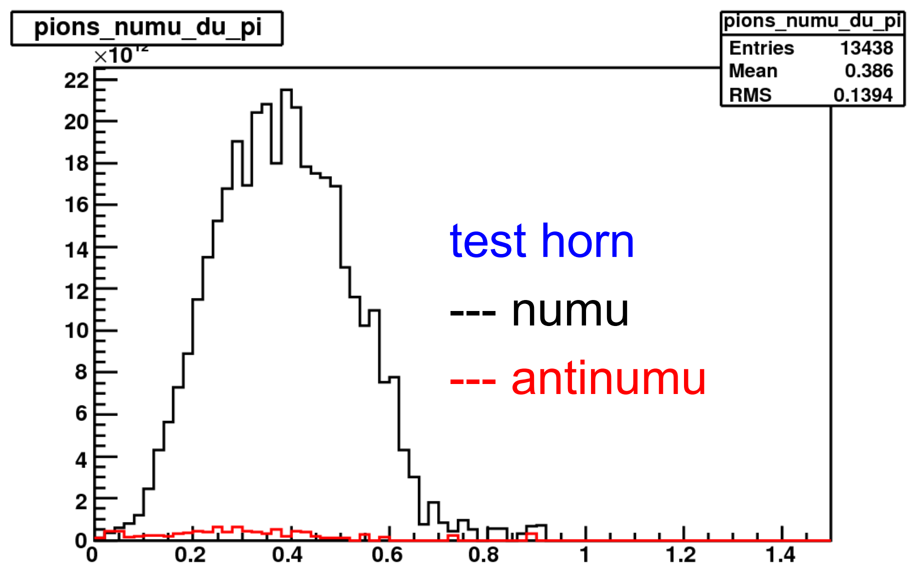
No fine tuning tried

* much less antinumu! -> CPV :)
* higher flux (+10cm for reflector, forward “plug”)
* to be studied at level of sensitivity (in progress)









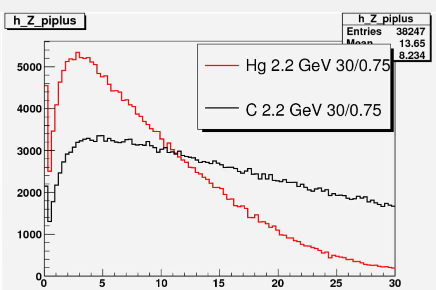
Horn shape and long target

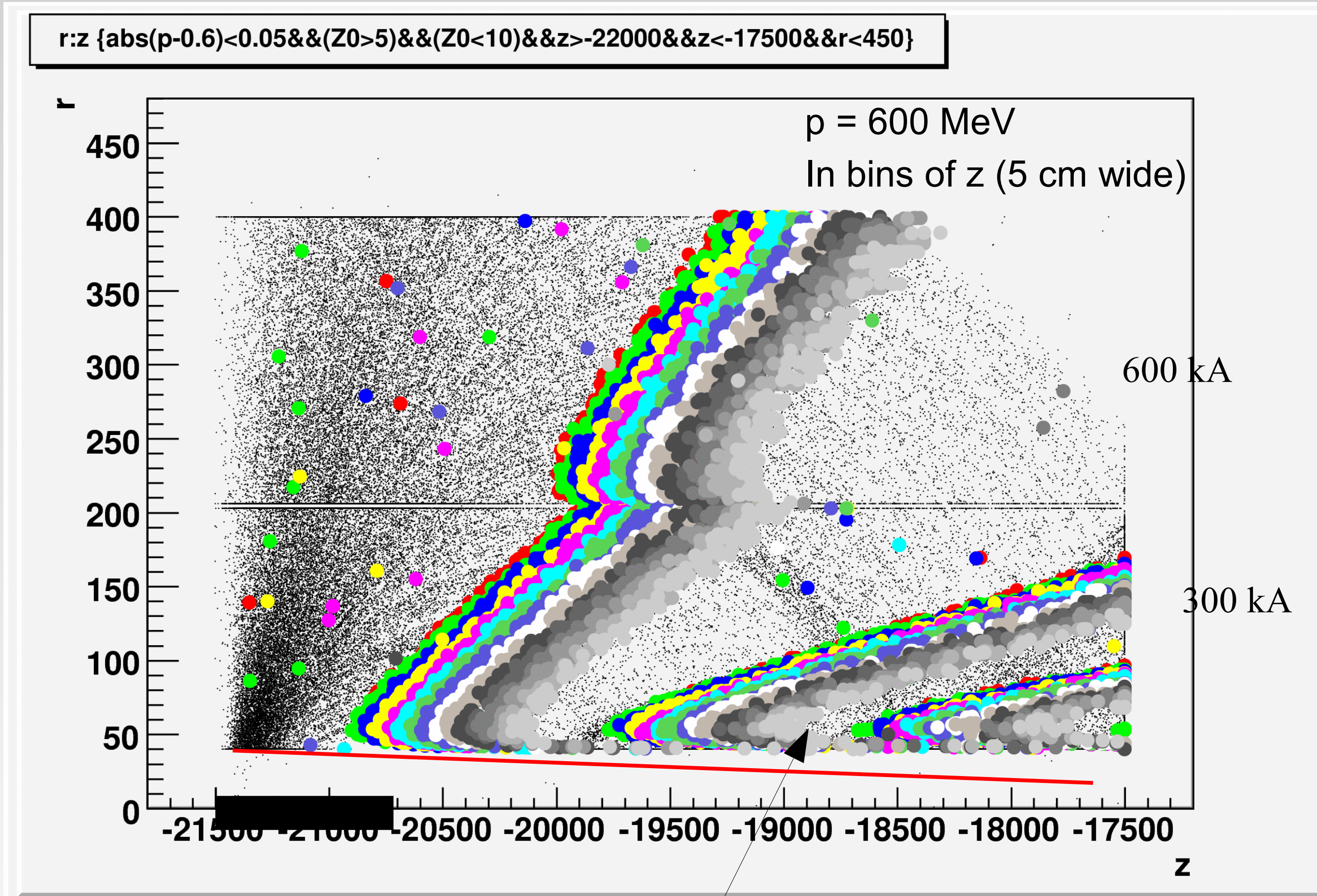
Original study by J-E. Campagne redone with GEANT4 and realistic graphite source.

Colored dots marks the optimal shape in bins of z of production for a pion of 600 MeV. (r,z) at with dr/dz = 0.

Each z sample requires “its” shape to focalize “monochromatic pions”

Some “shrinkage” of optimal shapes is obtained by using a small negative slope for the inner conductor (not fully studied yet) (idea is to equalize region of magnetic field crossed by pions created at different z)





“Bouncing” pions (cylinder with 1/r field). Not present when conductors are in place

black thin points are pion trajectories in the z~0 bin

Horn parametric model

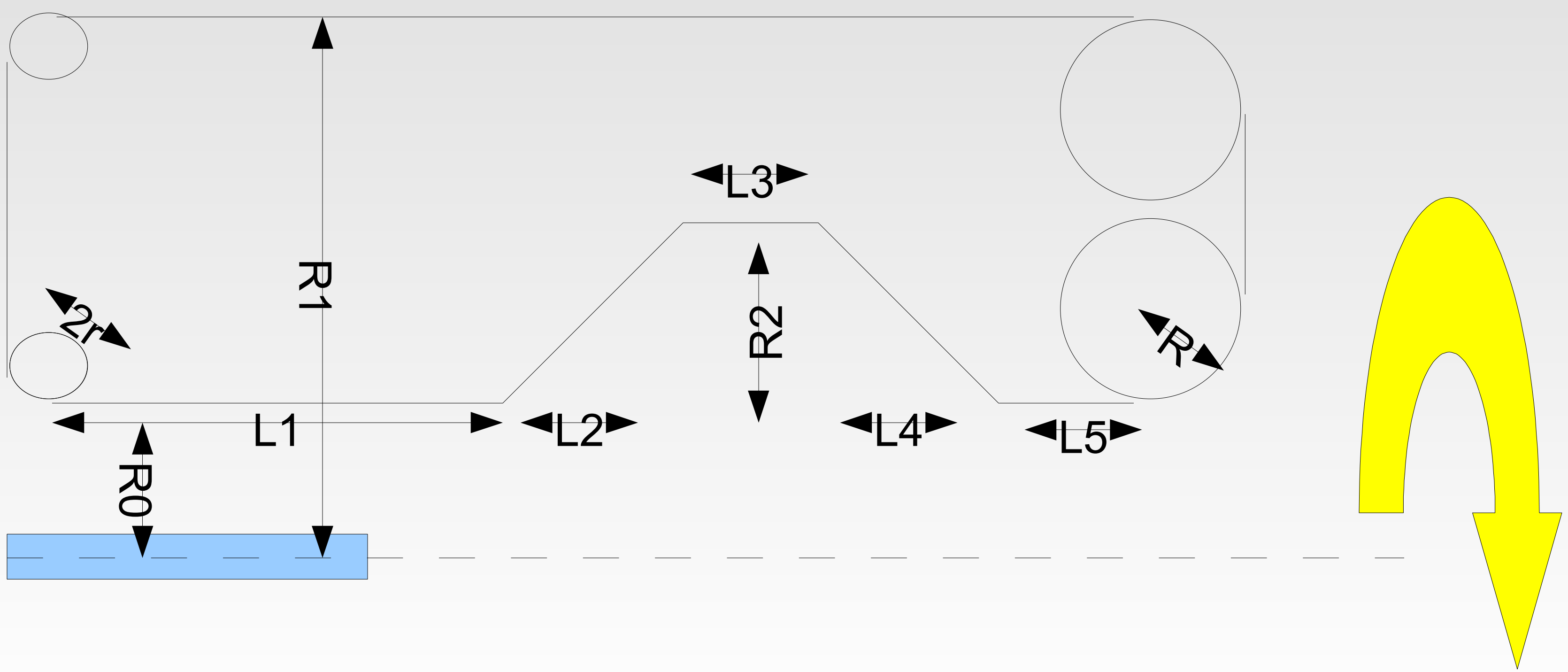
Miniboone horn - inspired

in general with this shape better antinumu rejection (more “forward closed”) and conversely higher mean energy

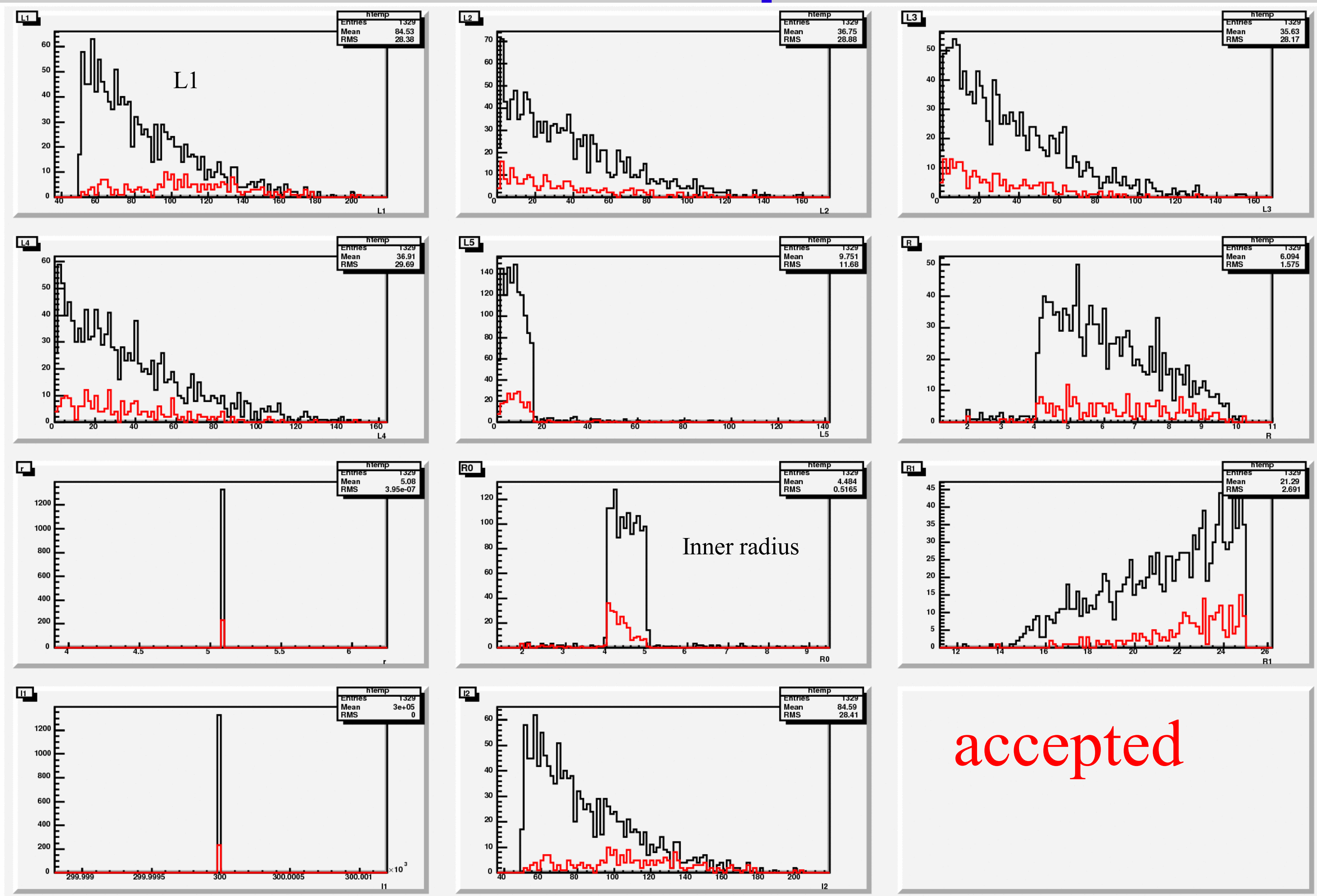
9 parameters + constraints

governed with external input card

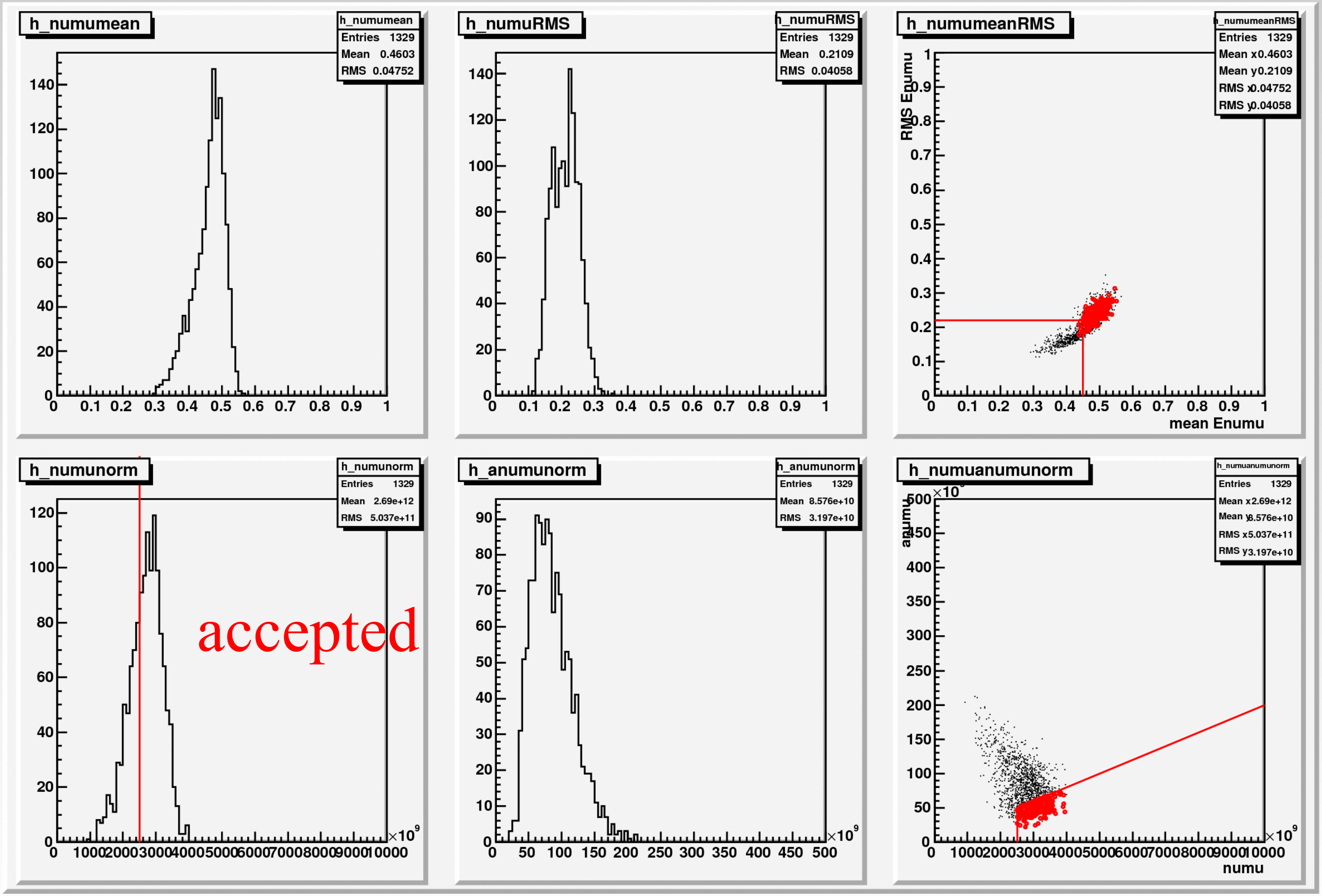
flexible enough to reproduce also current setup (anyway also already implemented “faithfully”-replica of GEANT3 previous setup)



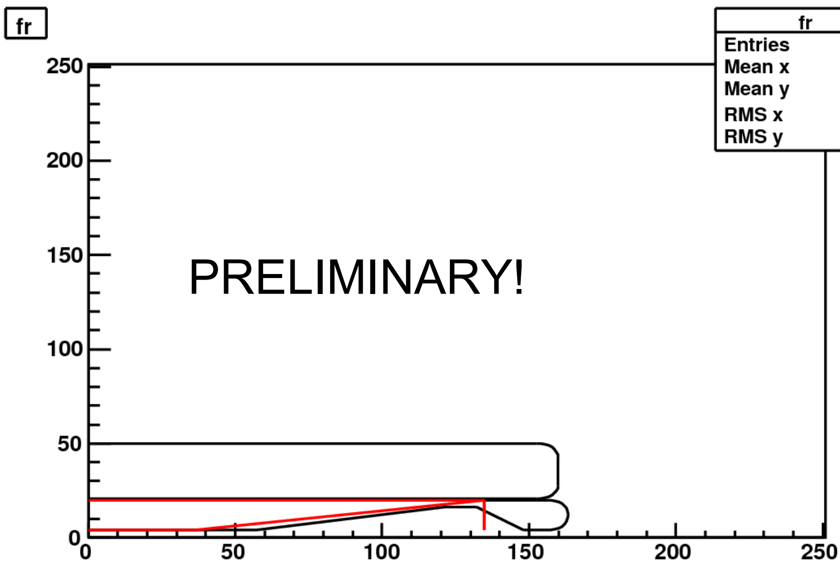
Distribution of the parameters

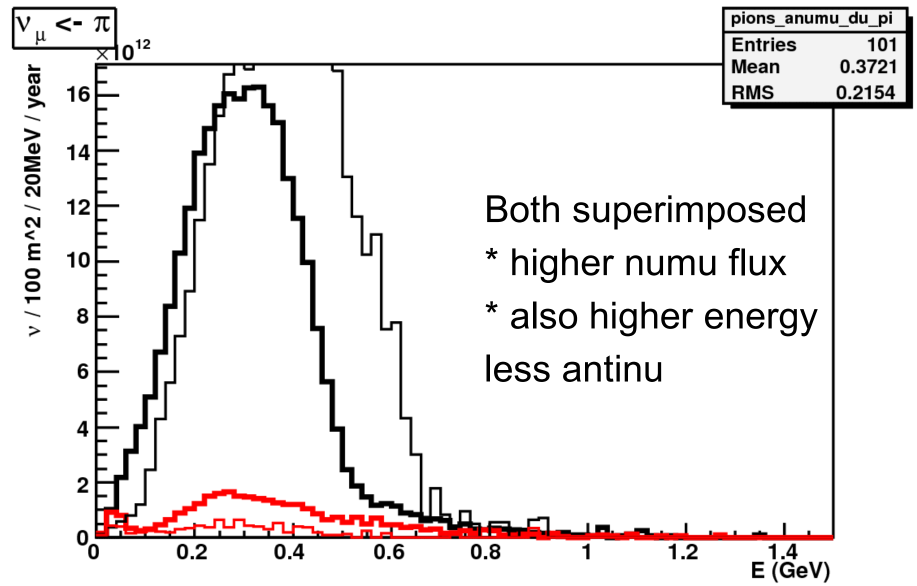


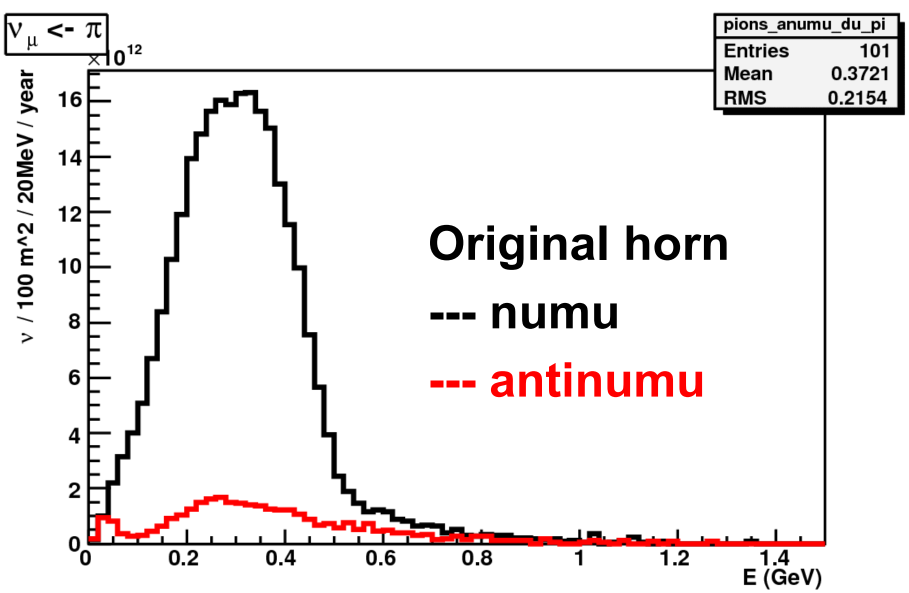
Numu spectra results over configurations

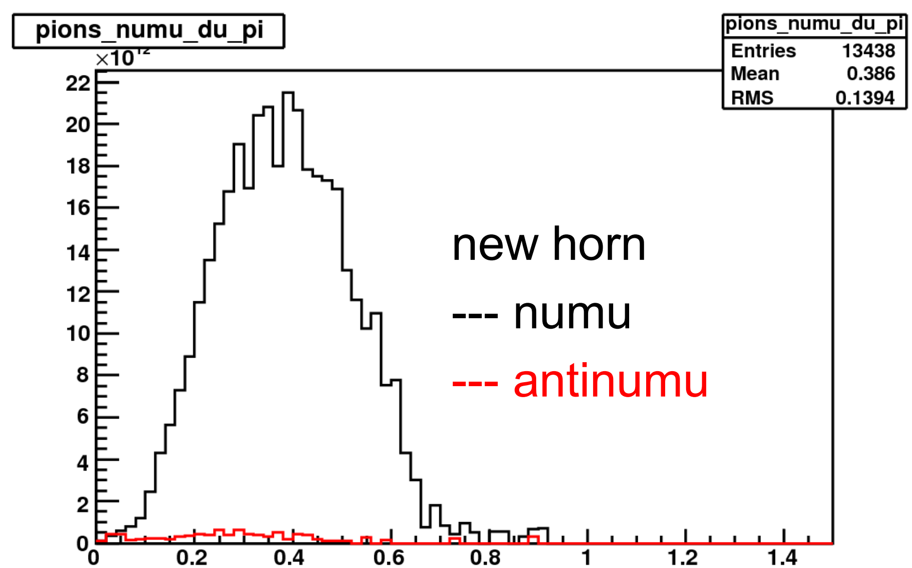


A “good” configuration

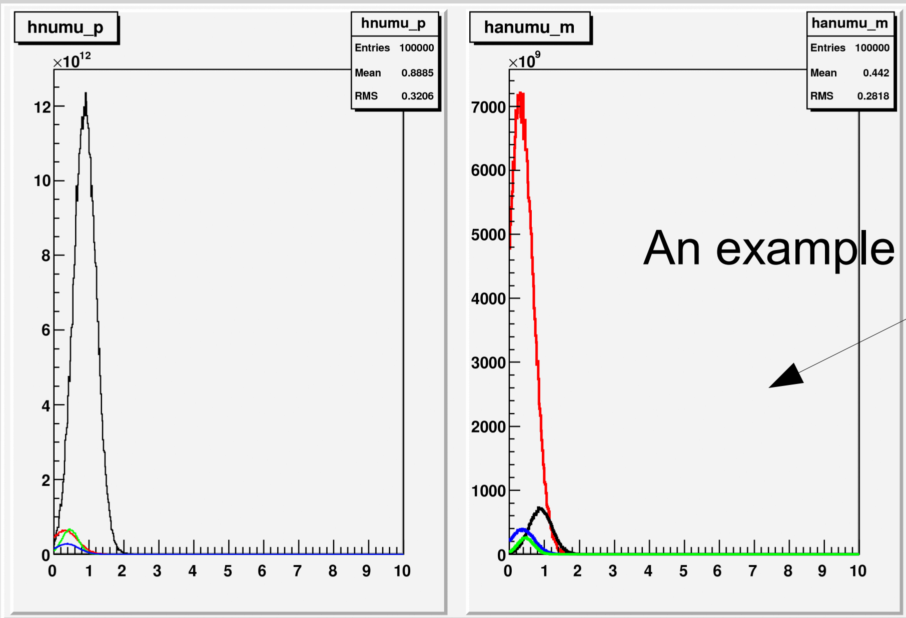








Dependence of sensitivity (GloBES) on nu spectra characteristics

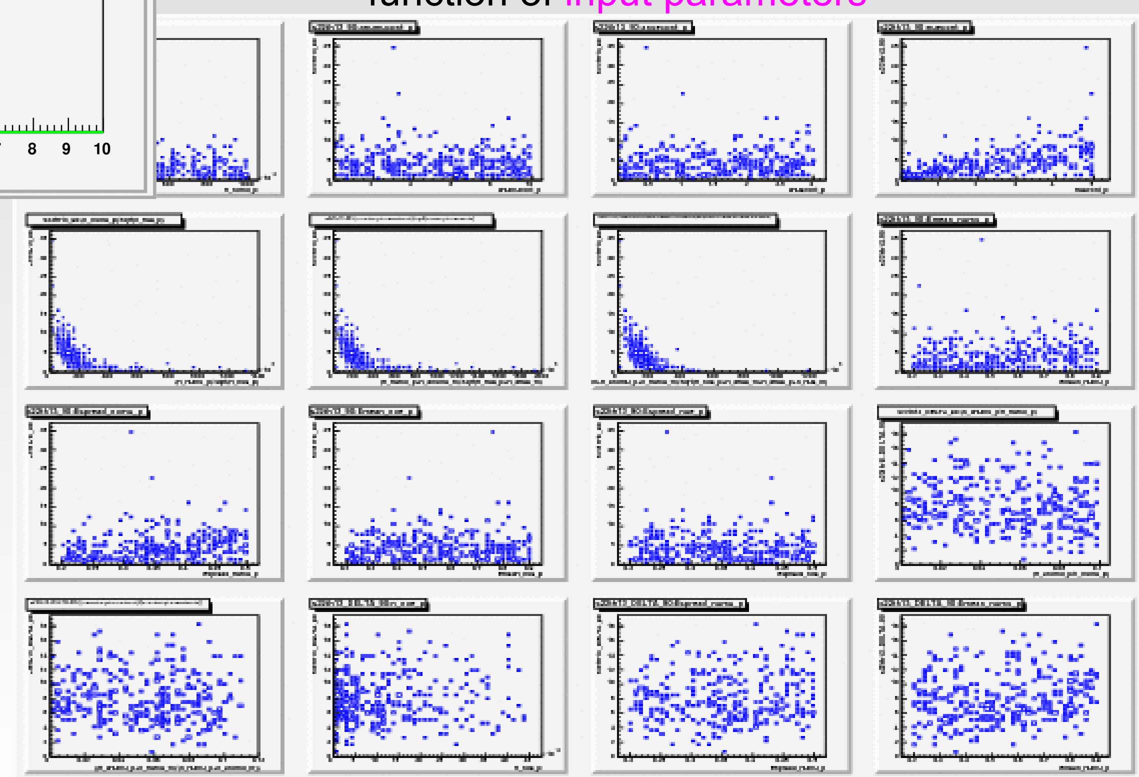


Fluxes modelized with simple gaussians.

Vary randomly:

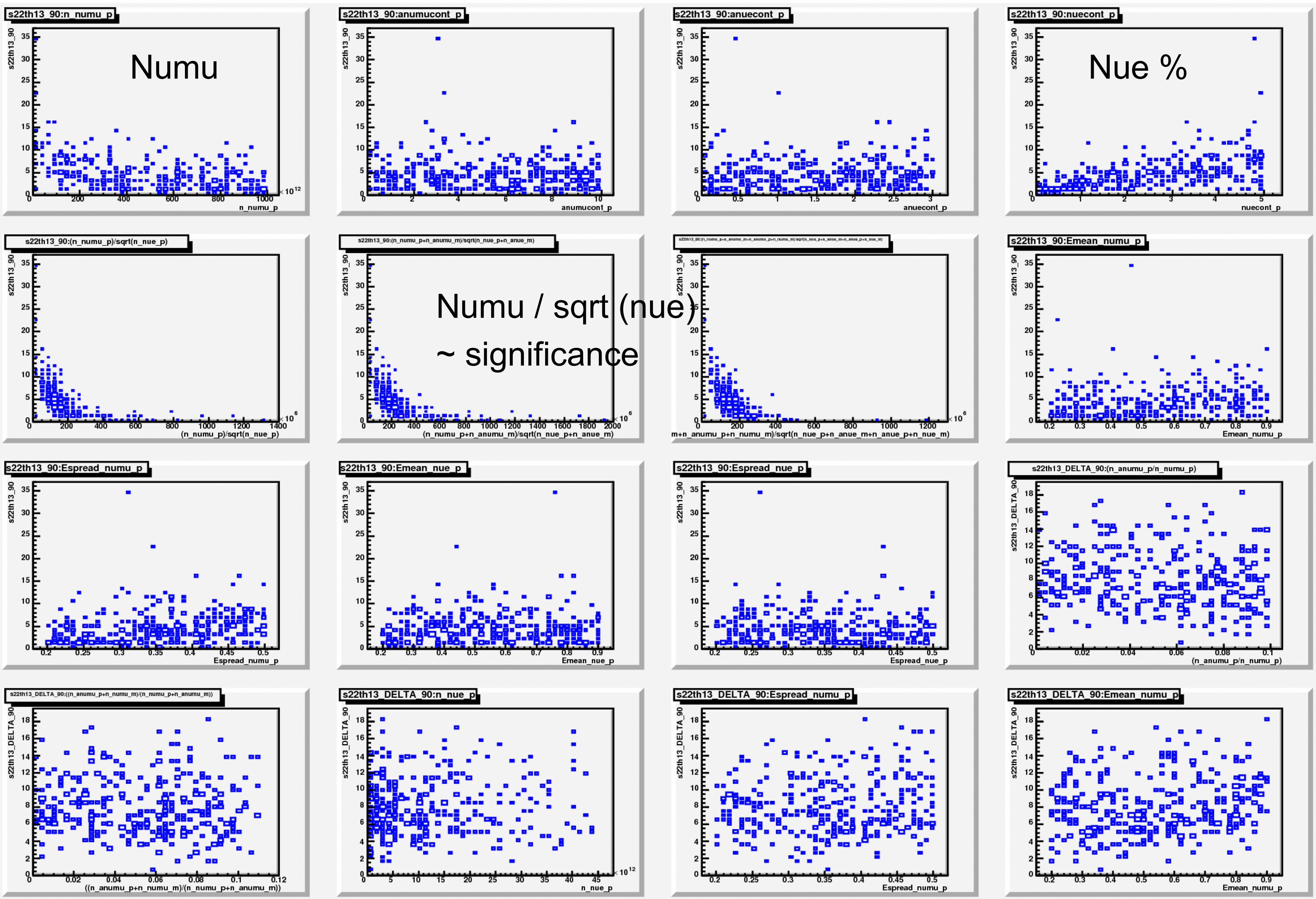
mean values, widths (same for +/- focusing), relative normalizations of lfavours, +/- focusing ratio.

within reasonable ranges -> feed to GloBES and get limits on sin22th13 as a function of input parameters

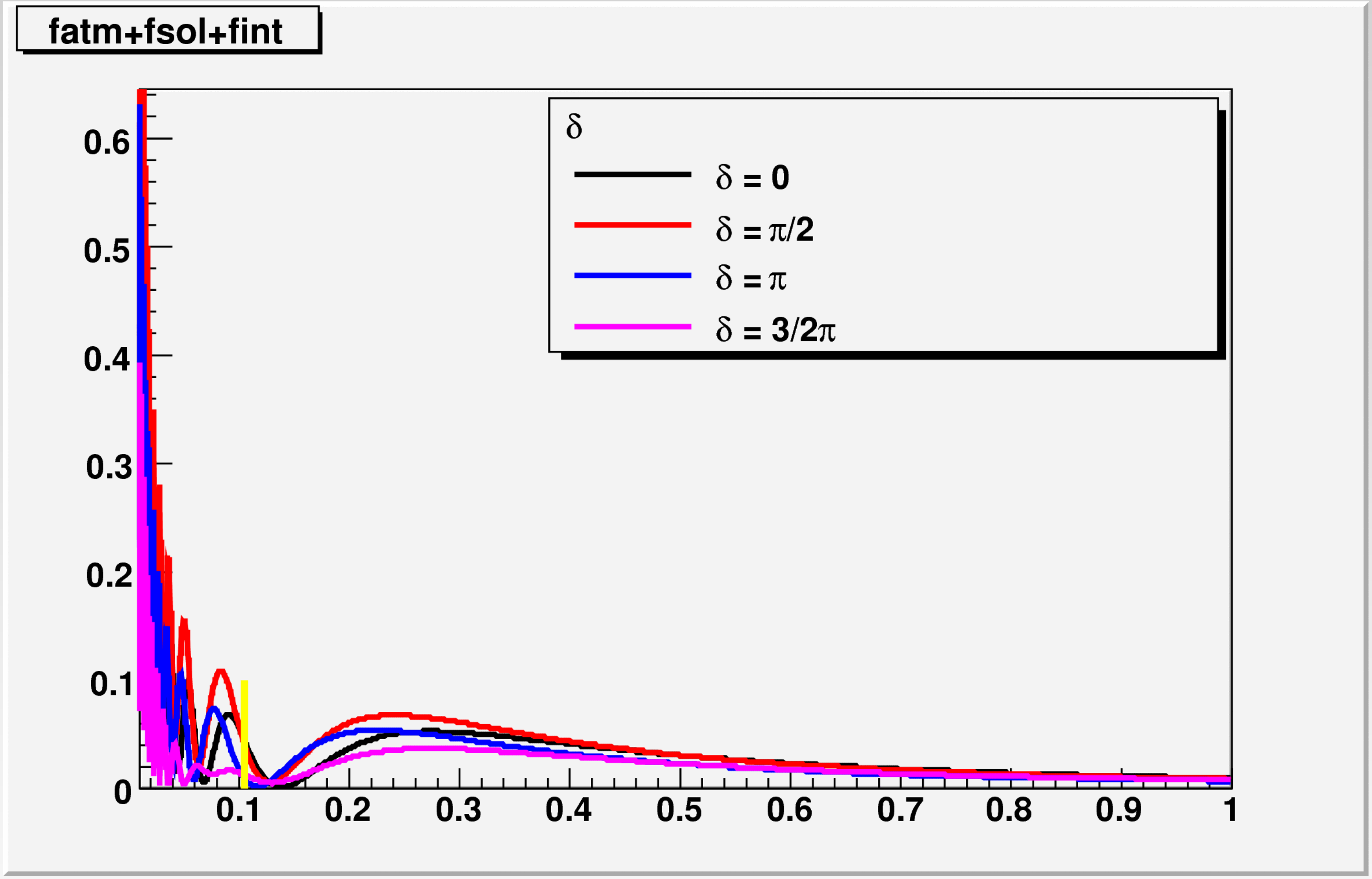


“Random” inputs, study on a statistical basis

Preliminary results: sin22th13 best limit @ 90% CL vs parameters

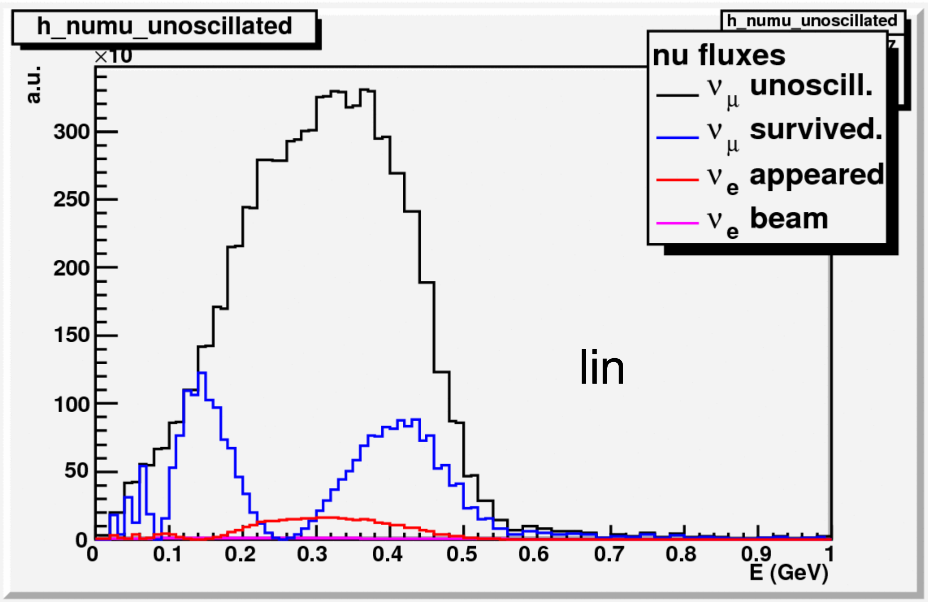


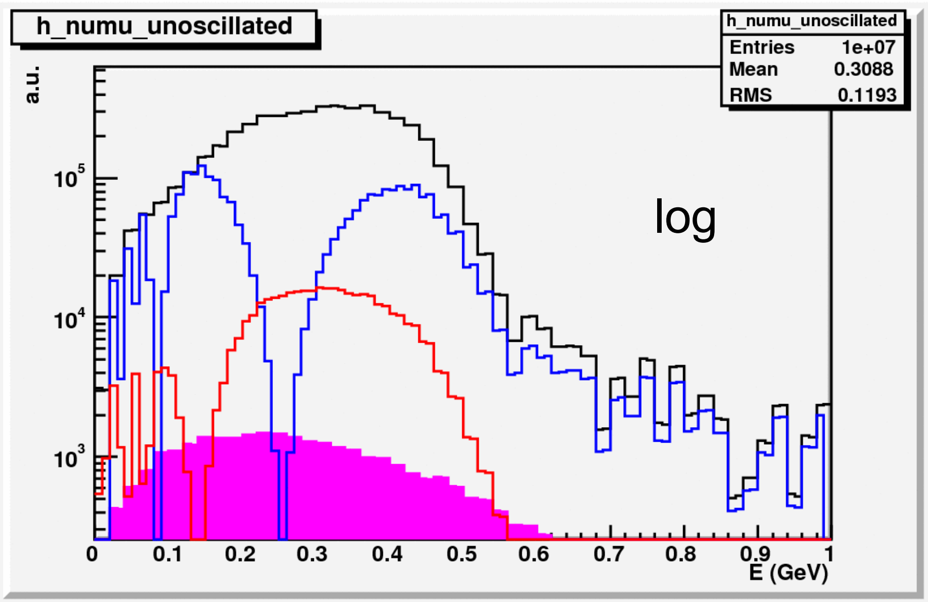
P(numu->nue) vs E with L=130 km

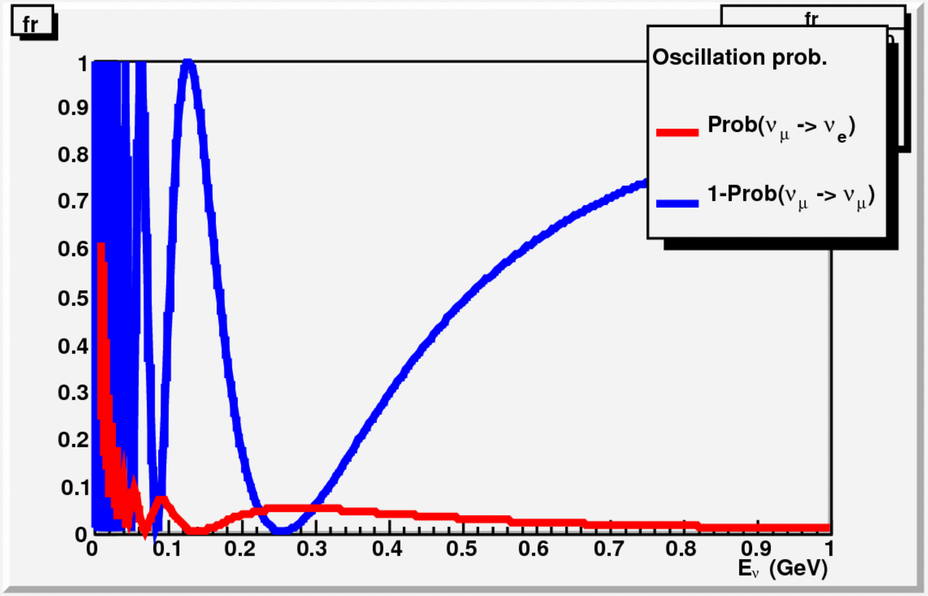


Colors: 4 delta values

P(numu->nue) x numu flux (a.u.)







Sin(2theta13)^2 = 0.01

numu survived

nue appeared

nue beam