Updates on simulation

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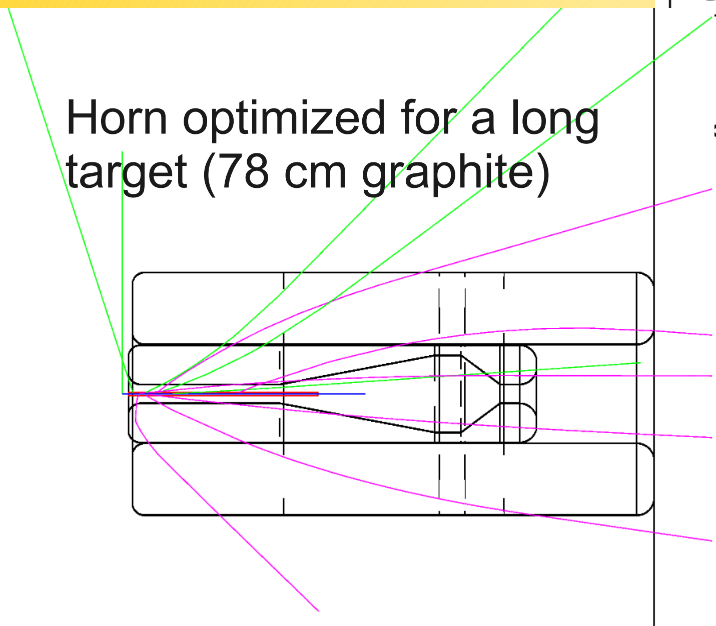
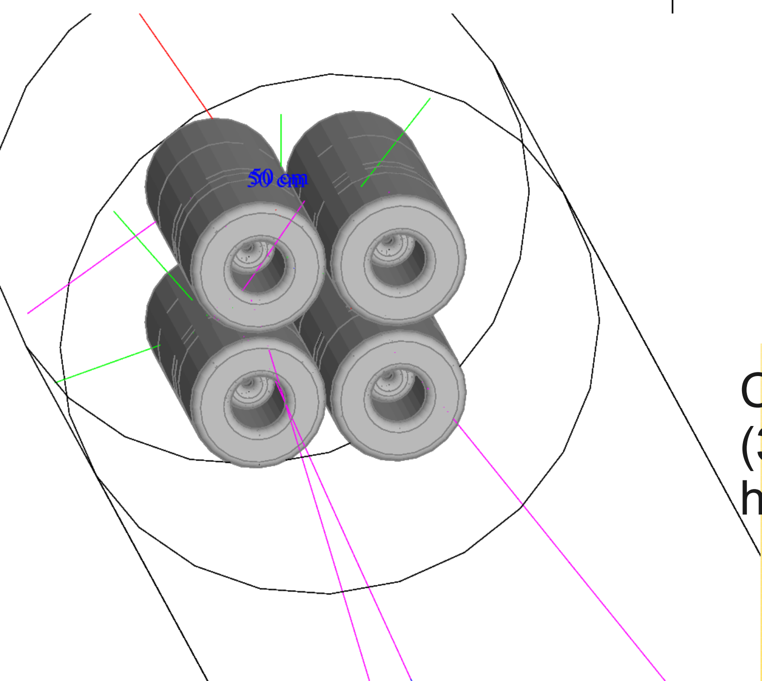
EUROnu WP2 meeting at CERN

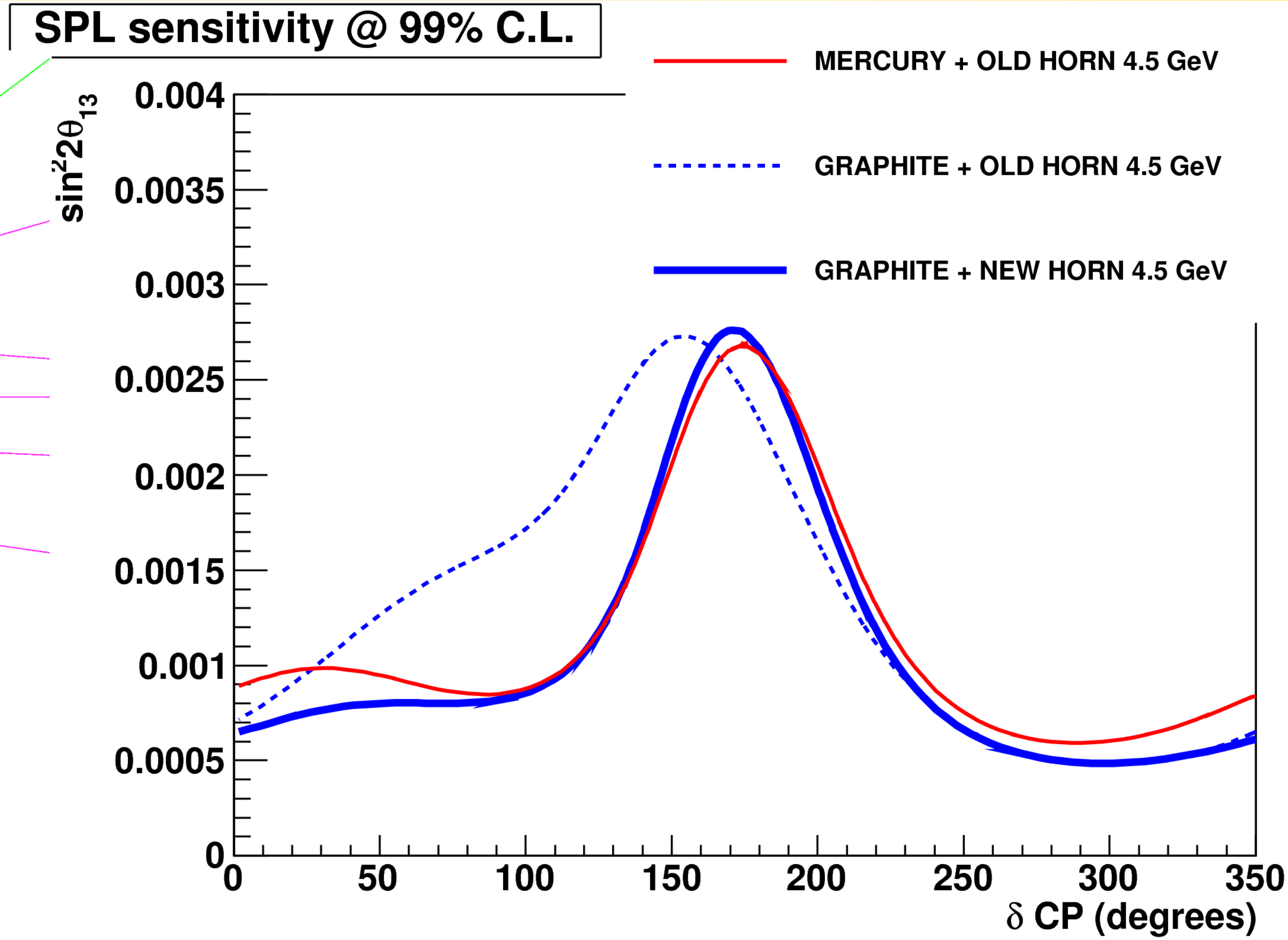
- **Previous results: reminder**
- **Software improvements**
- **Study of possible solutions w/o reflector**
- **Validation of G4 simulation as a general tool**
  - **Comparison with NovA (120 GeV p)**

Previous results (reminder)

Horn optimized for a long target (78 cm graphite)



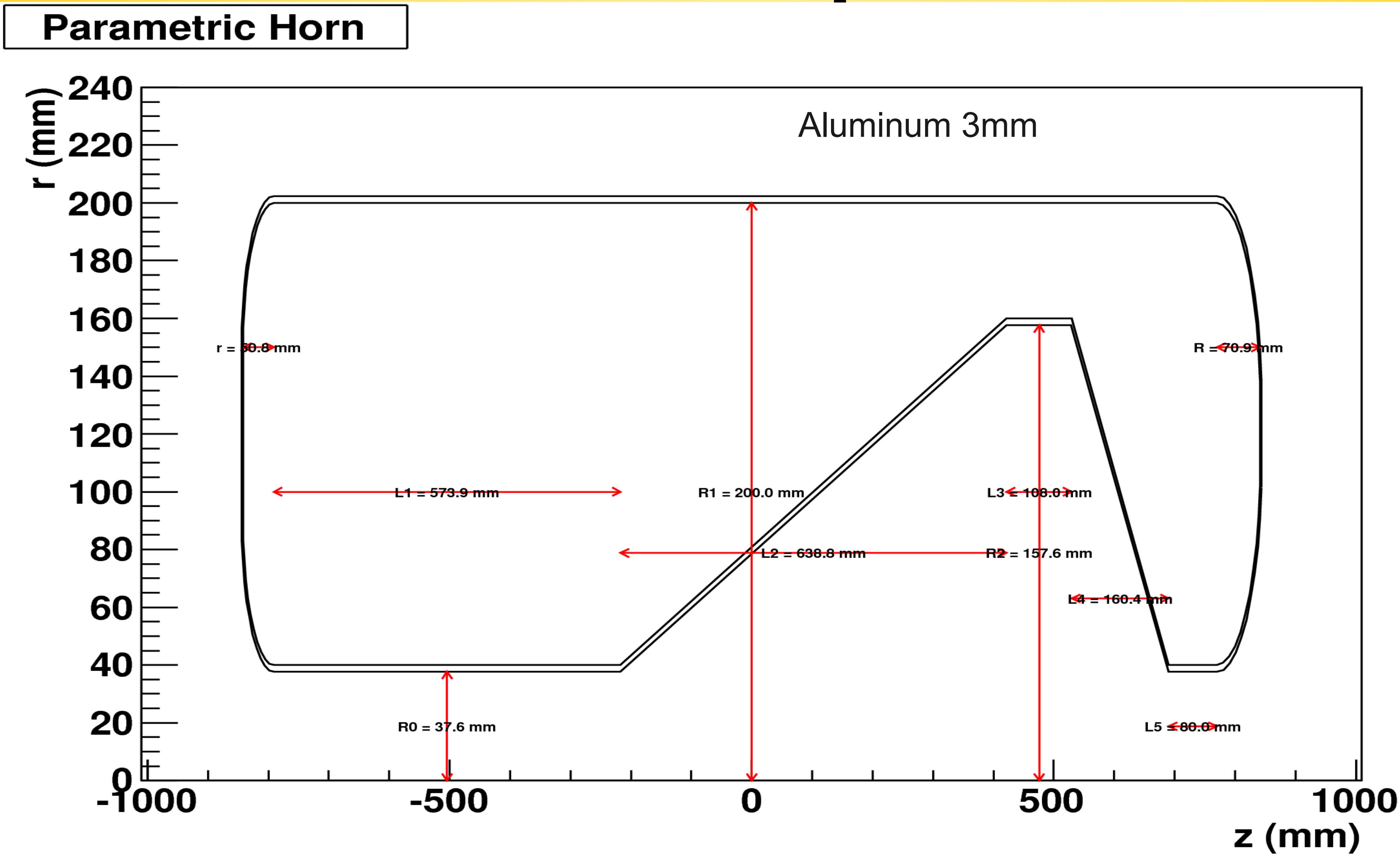




Currents as before (300 kA+600 kA for horn and reflector)

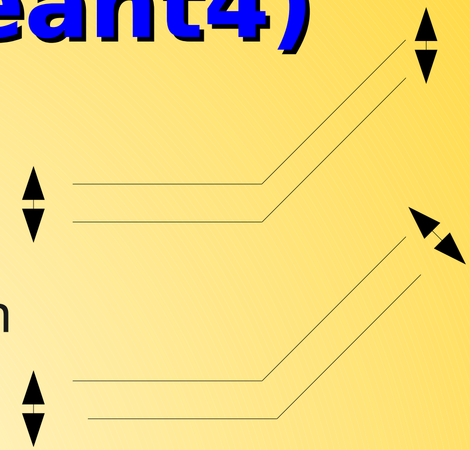
proceedings NUFACT09
et CERN EU strategy for future neutrino physics

Reference horn parameters



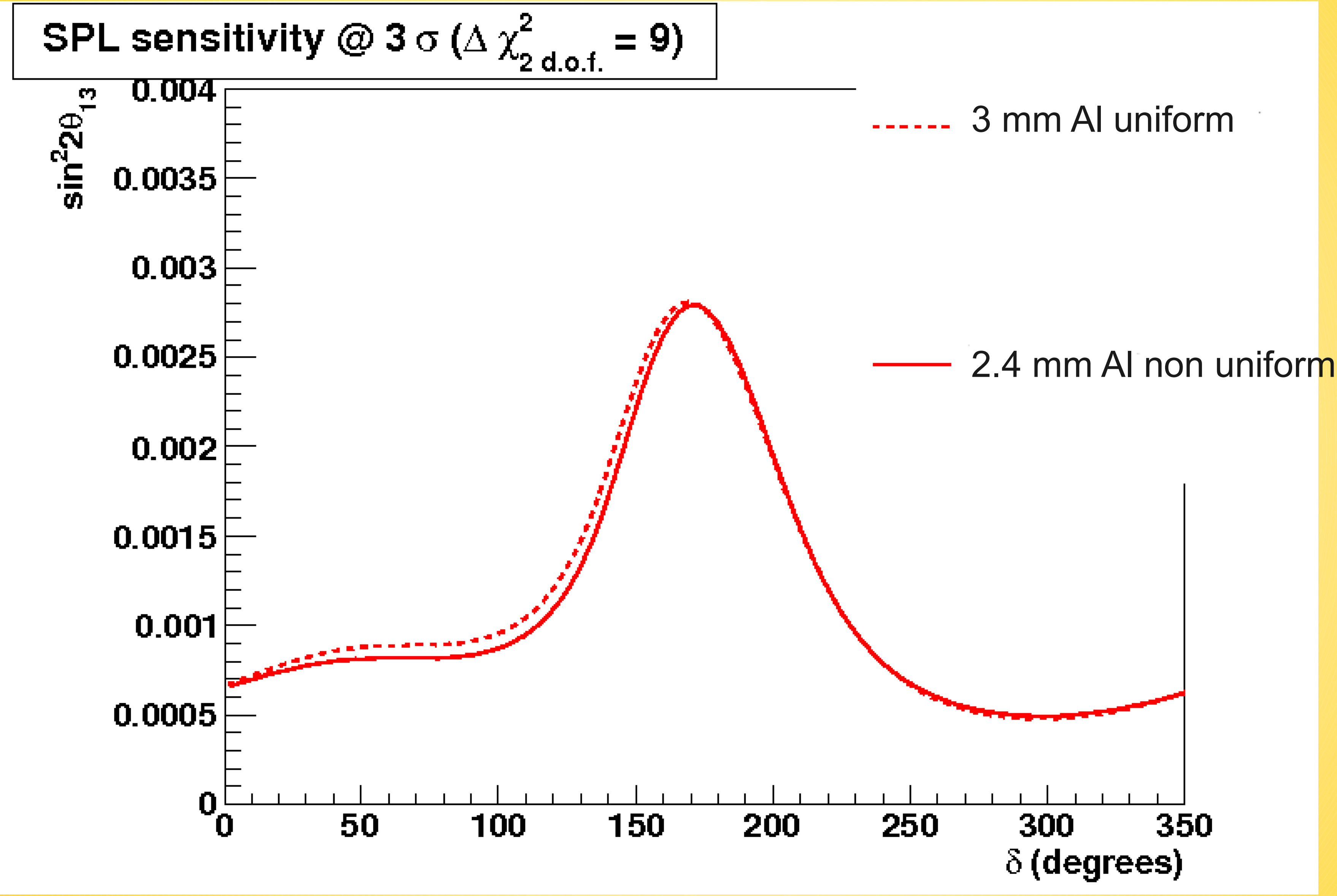
REFLECTOR R0 = 21.7 cm
R1 = 50. cm

Software updates (Geant4)

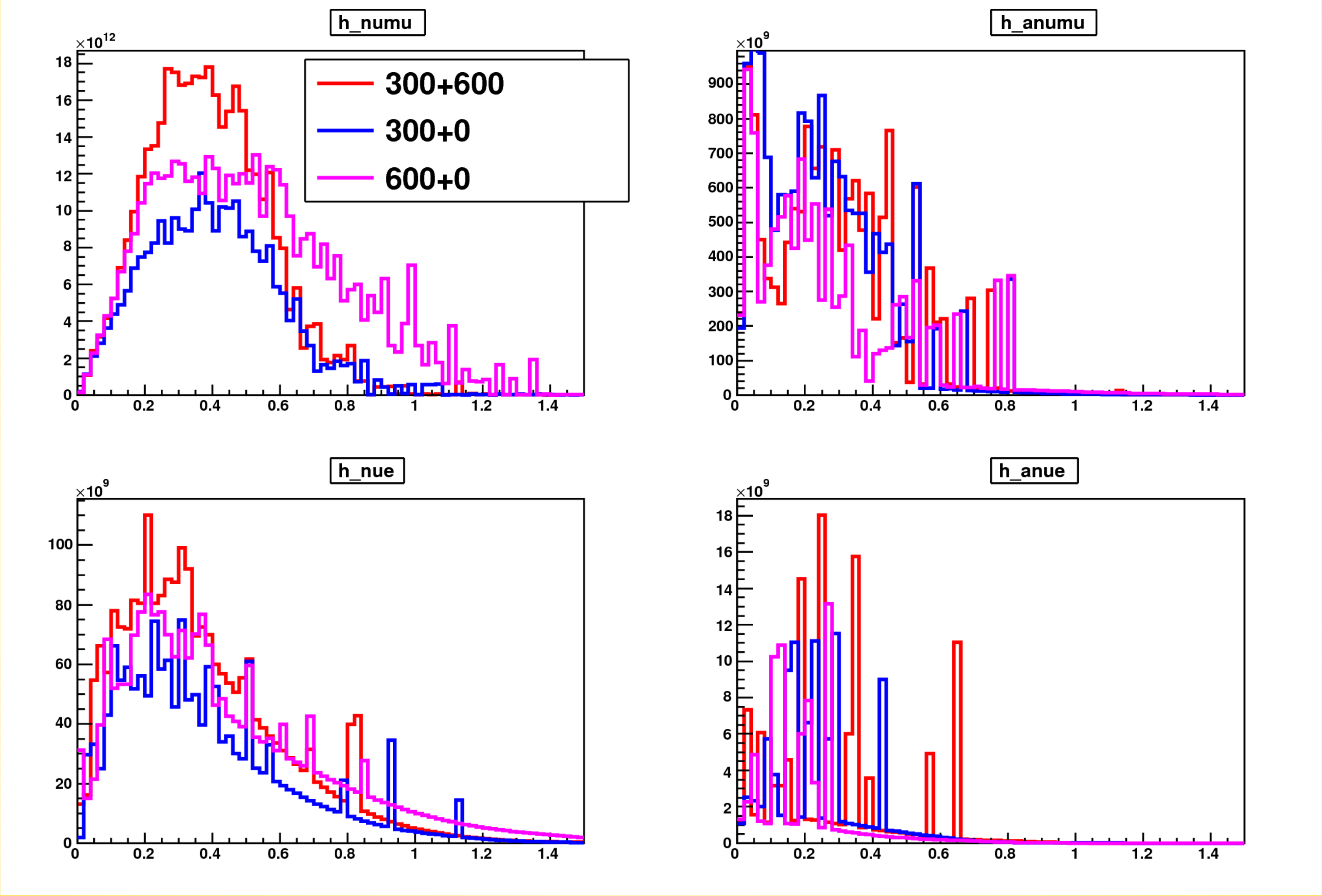


* Uniform horn aluminum skin depth
  - formerly thickness was constant in the radial direction
  - underestimation of material
  - small effect on sensitivity → see
* off-axis option implemented → `/SB/det/setOA 0.0146 rad`
* ν spectra from "direct counting" for cross check
  - probability weighting formulas
  - off-axis treatment
* fluxes from K decays:
  - weighting correction
  - replication implemented
* $\mu^{+/-}$ $e^{+/-}$ γ, π^0 killed before further propagation
  - gain of ~ x 2 in speed (at 120 GeV) !

Correction in the Al skin sim.

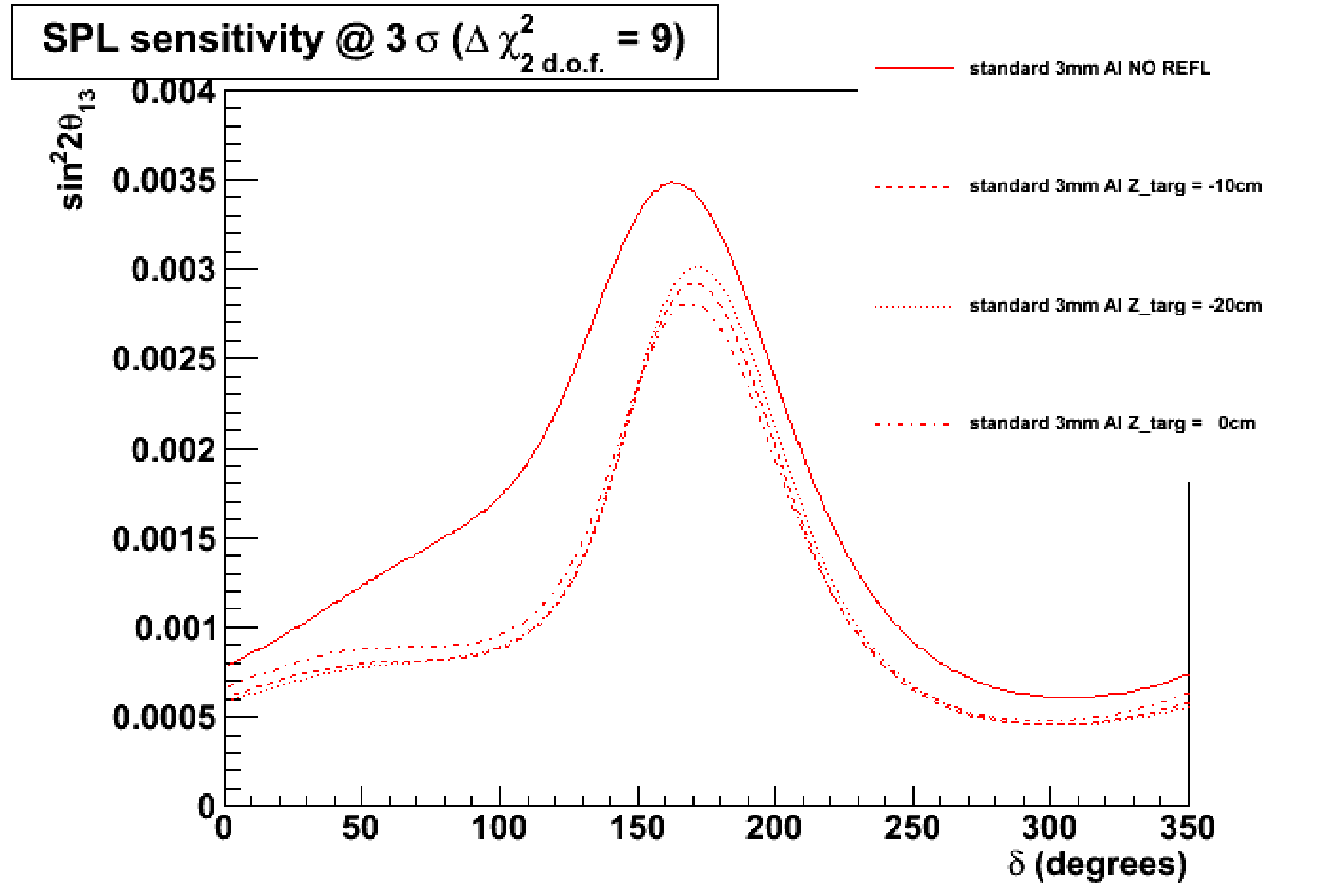


Fluxes without the reflector



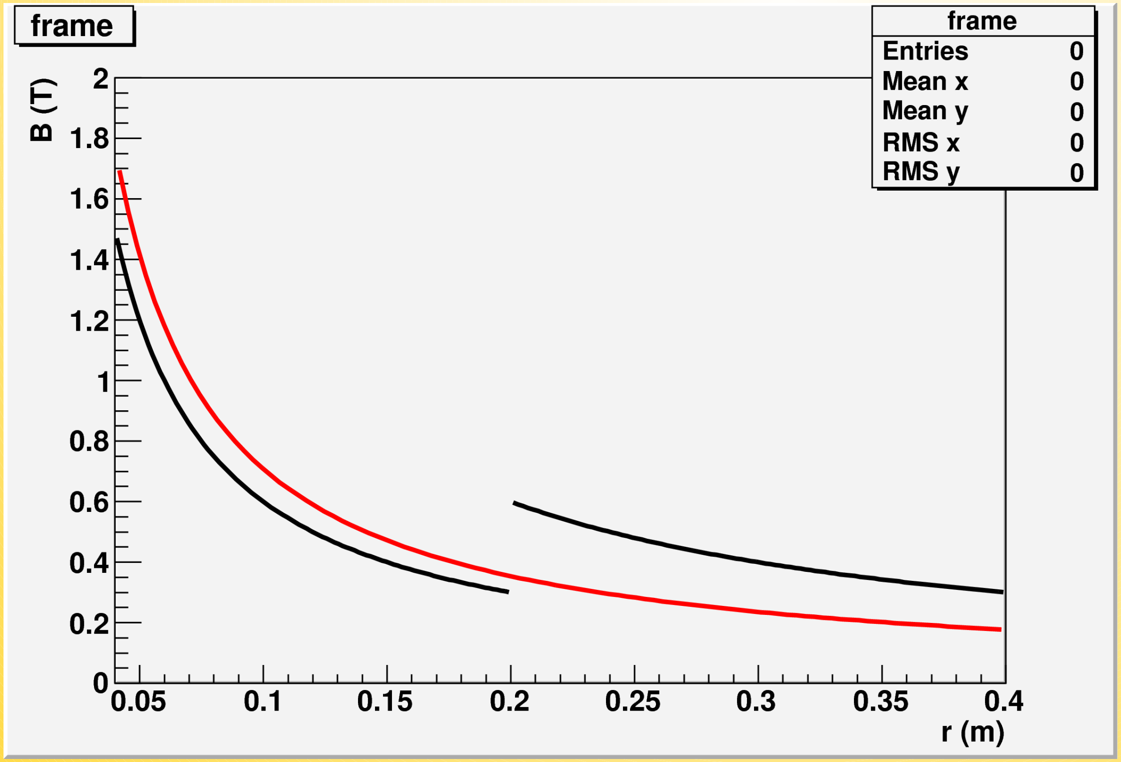
* Significant loss
* some recovery increasing i_horn to 600 kA (especially at high E) but
* 600 kA through a 4 cm radius cylinder probably not realistic

Sensitivity w/o reflector



Optimization w/o reflector

* Random sampling of parameters with the parametric model
* Allow larger outer radius and larger currents (up to 400 kA)
* Vary also position of target wrt horn and tunnel dimensions
* Introduced ranking based on sensitivities on θ_{13}
* 10k events/configuration

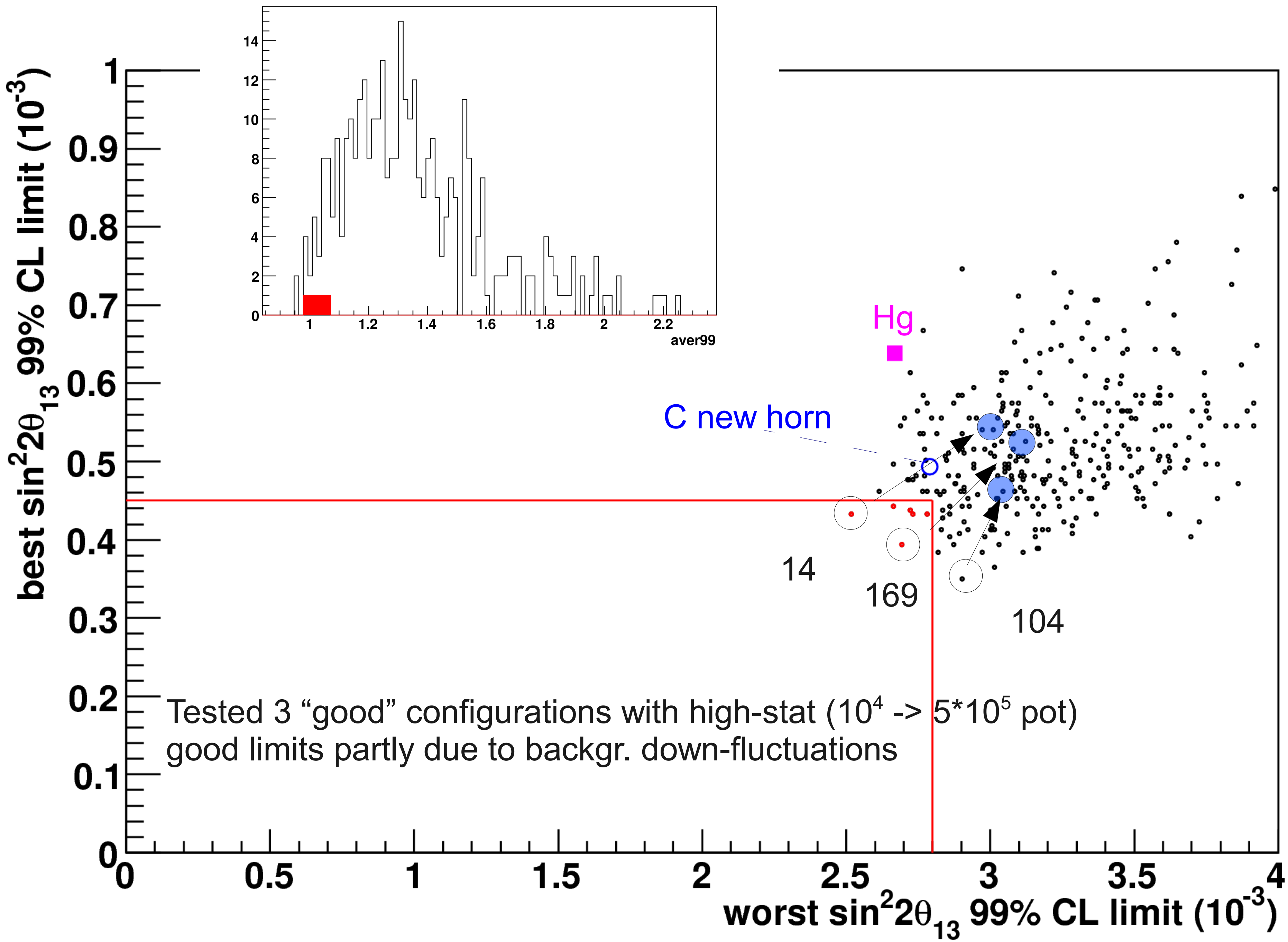


B vs r

Horn 300 kA
Refl 600 kA

thicker horn with
intermediate current

Optimisation w/o reflector



Selected configurations

conf_000104

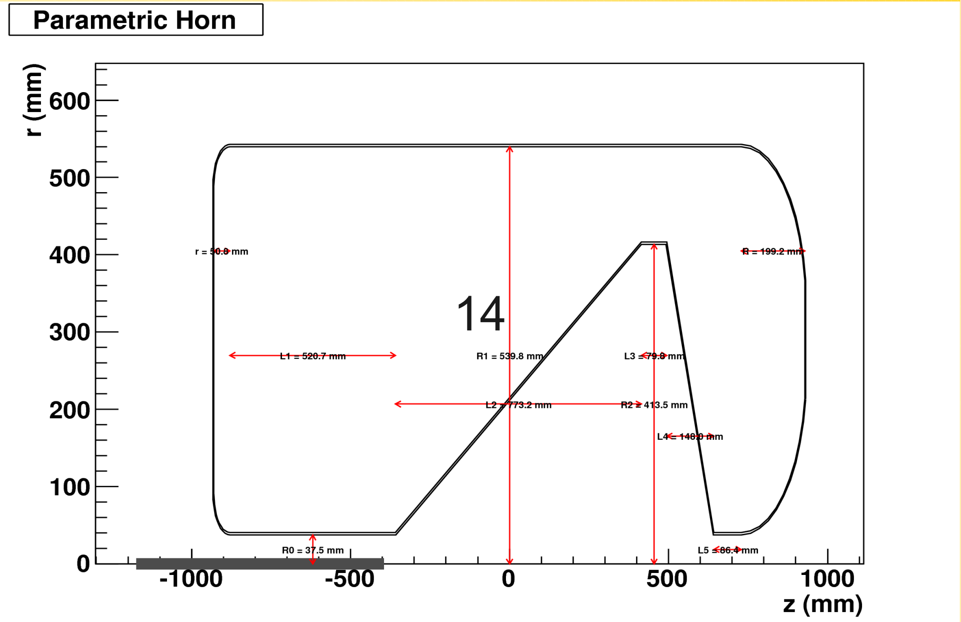
/SB/det/setTunLen 39.25 m
/SB/det/setTunRad 1.85054 m
/SB/det/Target_DZ -0.271037 m
/SB/det/SkinThick1 3. mm
/SB/det/SkinThick2 3. mm
/SB/det/Horn_L1 130.269 cm
/SB/det/Horn_L2 9.69801 cm
/SB/det/Horn_L3 37.6085 cm
/SB/det/Horn_L4 35.0146 cm
/SB/det/Horn_L5 2.50632 cm
/SB/det/Horn_R 20.0991 cm
/SB/det/Horn_r 5.08 cm
/SB/det/Horn_R0 4.58477 cm
/SB/det/Horn_R2 31.6614 cm
/SB/det/Horn_R1 74.2263 cm
/SB/det/Horn_I1 389952 ampere

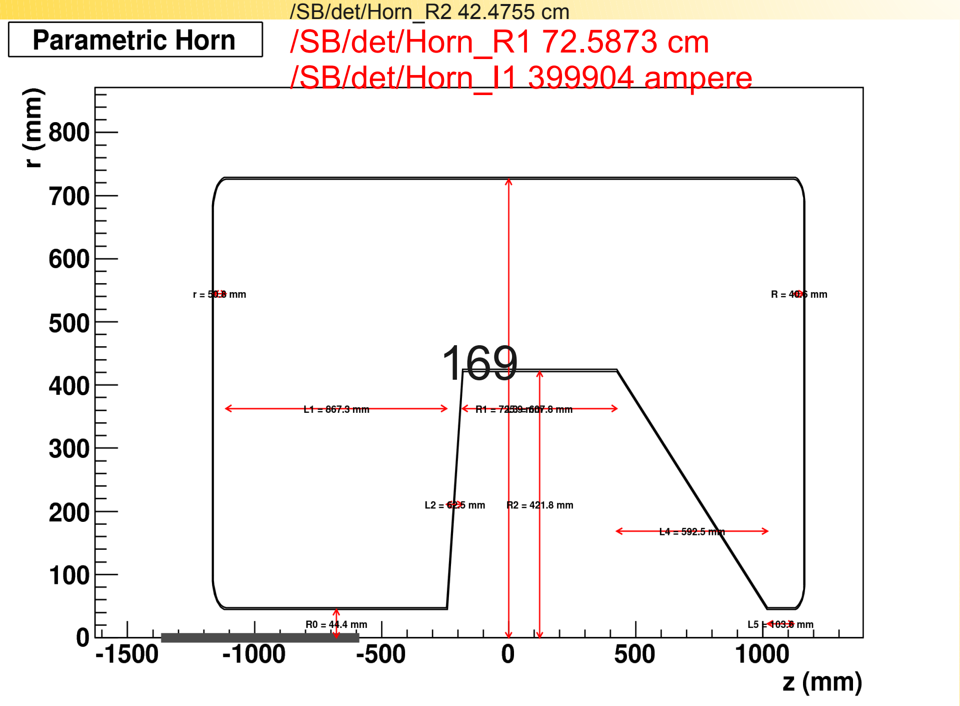
conf_000014

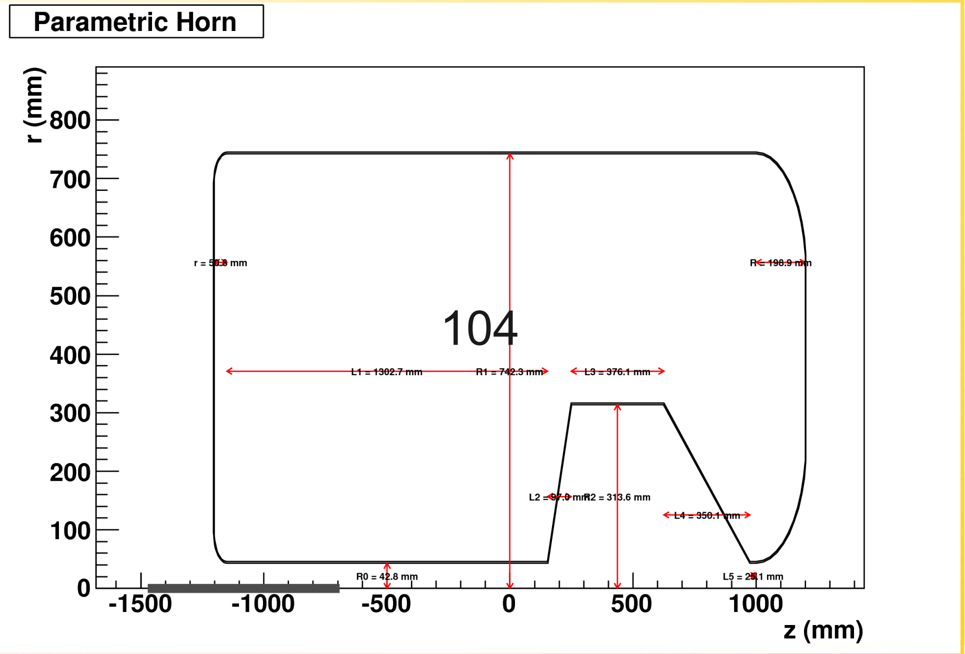
/SB/det/setTunLen 37.1594 m
/SB/det/setTunRad 1.83639 m
/SB/det/Target_DZ -0.244246 m
/SB/det/SkinThick1 3. mm
/SB/det/SkinThick2 3. mm
/SB/det/Horn_L1 52.0707 cm
/SB/det/Horn_L2 77.3249 cm
/SB/det/Horn_L3 7.98467 cm
/SB/det/Horn_L4 14.8029 cm
/SB/det/Horn_L5 8.64337 cm
/SB/det/Horn_R 20.1237 cm
/SB/det/Horn_r 5.08 cm
/SB/det/Horn_R0 4.05147 cm
/SB/det/Horn_R2 41.652 cm
/SB/det/Horn_R1 53.9759 cm
/SB/det/Horn_I1 353759 ampere

conf_000169

/SB/det/setTunLen 39.9763 m
/SB/det/setTunRad 1.80538 m
/SB/det/Target_DZ -0.204846 m
/SB/det/SkinThick1 3. mm
/SB/det/SkinThick2 3. mm
/SB/det/Horn_L1 86.7322 cm
/SB/det/Horn_L2 6.25182 cm
/SB/det/Horn_L3 60.7768 cm
/SB/det/Horn_L4 59.251 cm
/SB/det/Horn_L5 10.3558 cm
/SB/det/Horn_R 4.09709 cm
/SB/det/Horn_r 5.08 cm
/SB/det/Horn_R0 4.74328 cm
/SB/det/Horn_R2 42.4755 cm
/SB/det/Horn_R1 72.5873 cm
/SB/det/Horn_I1 399904 ampere

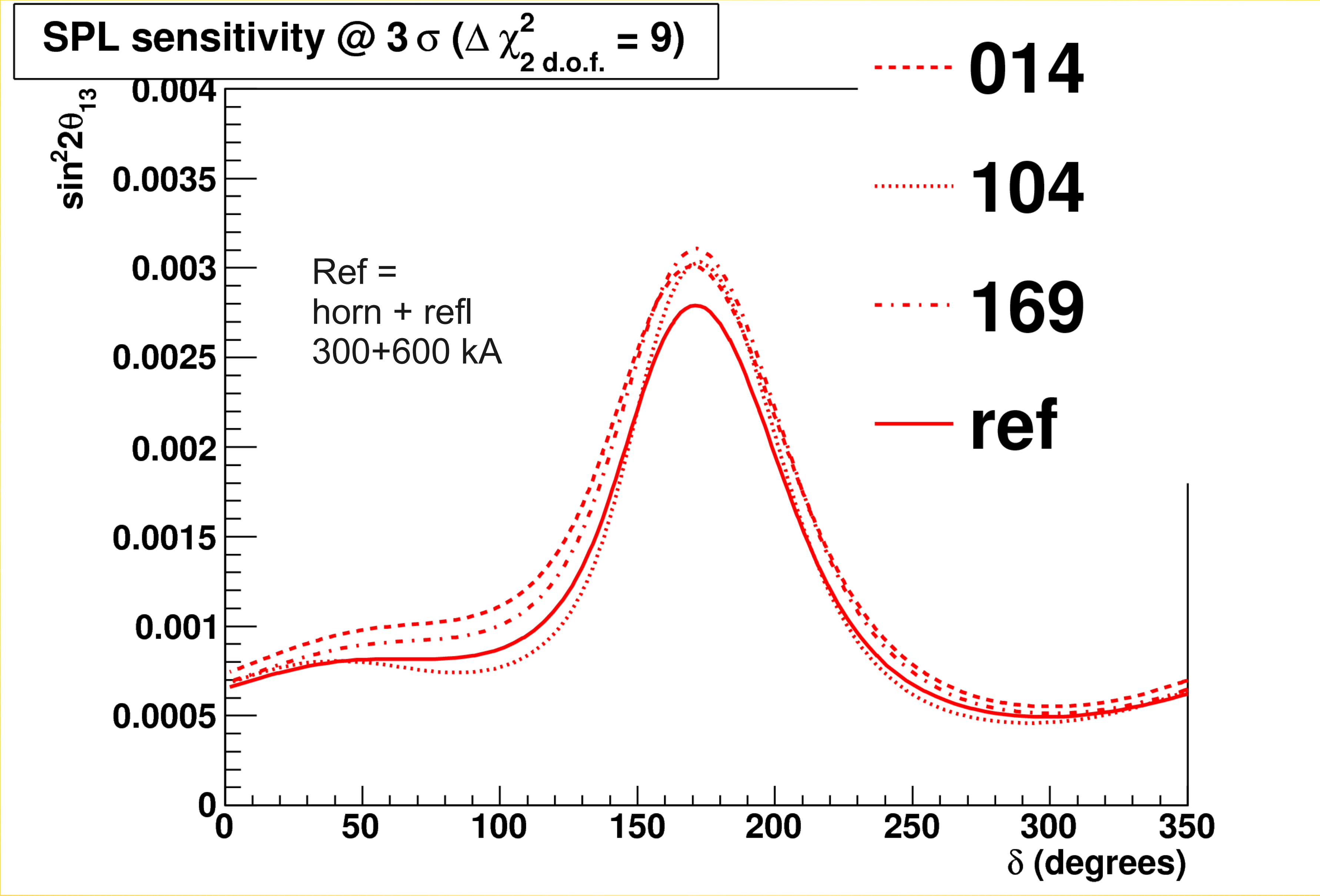






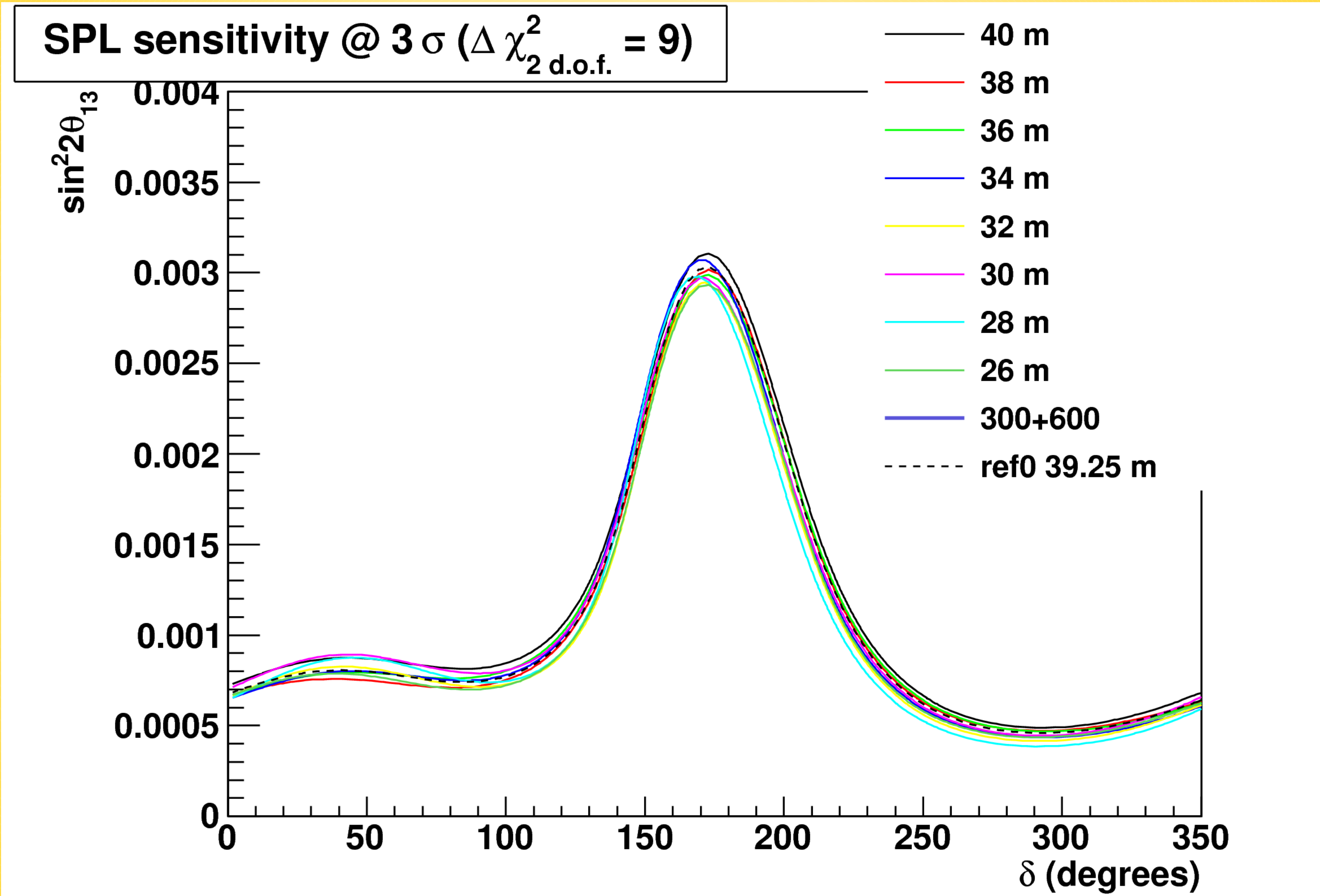
A

Sensitivity curves for the selected configurations

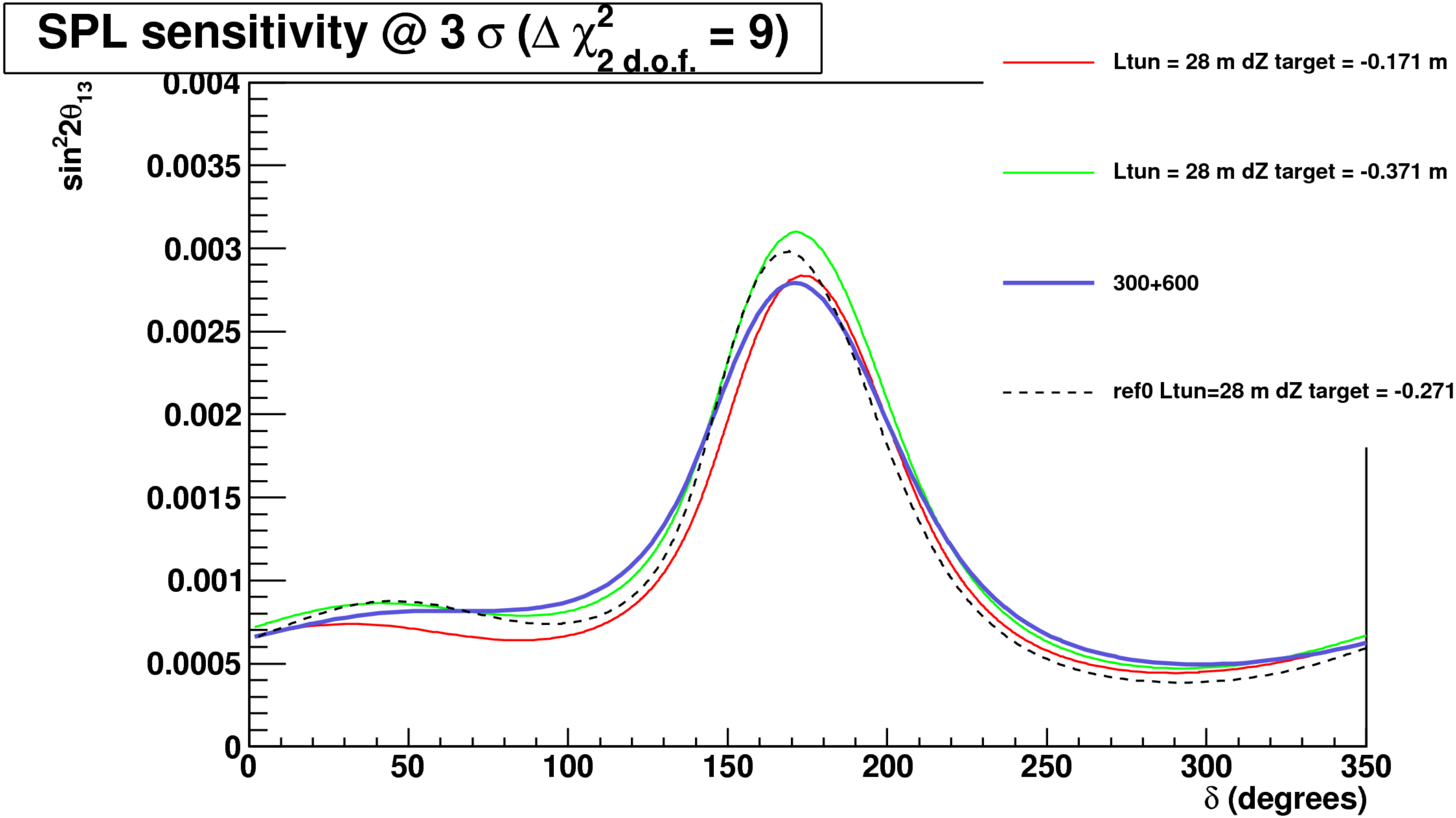


Further optimization (one parameter at a time, L tunnel, Z target) for conf 104 →

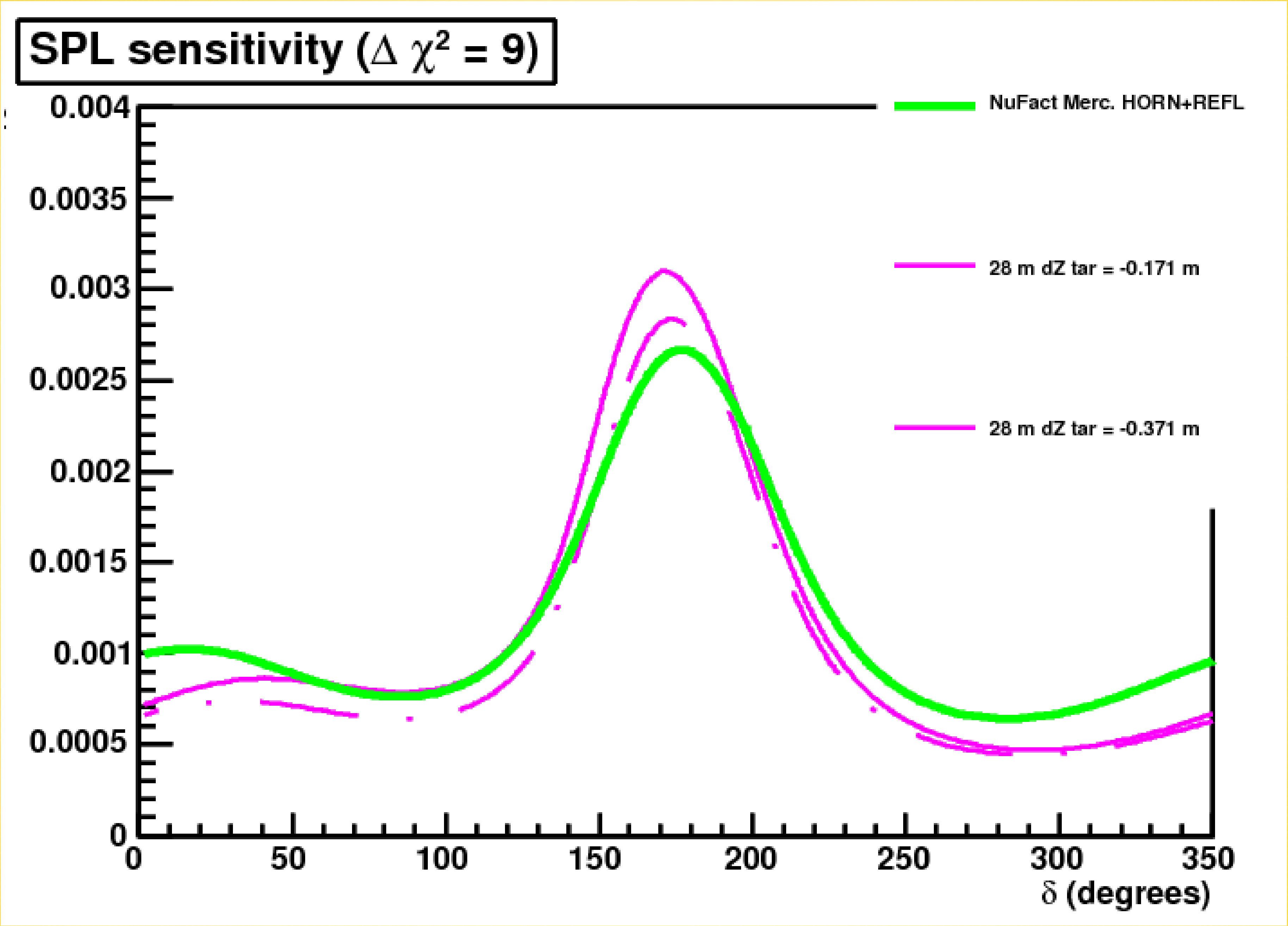
Conf 104: tunnel length variations



Conf 104: target position variations



Final results of this optimization



Conclusions 1: no-reflector study

Increasing the current (~ 400 kA) and the radius of the horn (~70cm) found configurations w/o reflector improving on the previous horn+reflector (300+600 kA) setup

Some (small) further improvement tuning L_tunnel al z_target

feasibility of such large currents though a small bore?

option: fix 300 kA and redo the exercise
(see Christoph study with the conical horn)

Validation of the GEANT4 simulation as a general tool

goal: investigate also other options with a coherent set of tools

cross check with other simulations at higher proton energy

Benchmark: NOvA

Tried to reproduce the NOvA fluxes with:

http://enrico1.physics.indiana.edu/messier/off-axis/spectra/

1) the GEANT4 simulation
2) the BMPT fast parametrization used in previous studies on PS2/CNGS based superbeams

doing comparisons is useful !

“Discovered”:

1) possible problem with K fluxes implementation for SPL not a big effect at 4.5 GeV – to be checked

2) some BMPT limitations

The NOvA setup:

E = 120 GeV
O.A. = 0.8365 deg
L = 810 Km
Al thickness 2 mm
Z_target = -1.4 m
Z_horn1 = 0
Z_horn2 = 19 m
L_tunnel = 677 m
r_tunnel = 1 m
power = 700 kW
target: graphite
L_target 1.2 m
r_target = 1.6 mm

primary production: GEANT4 QGSP

Benchmark: NOvA

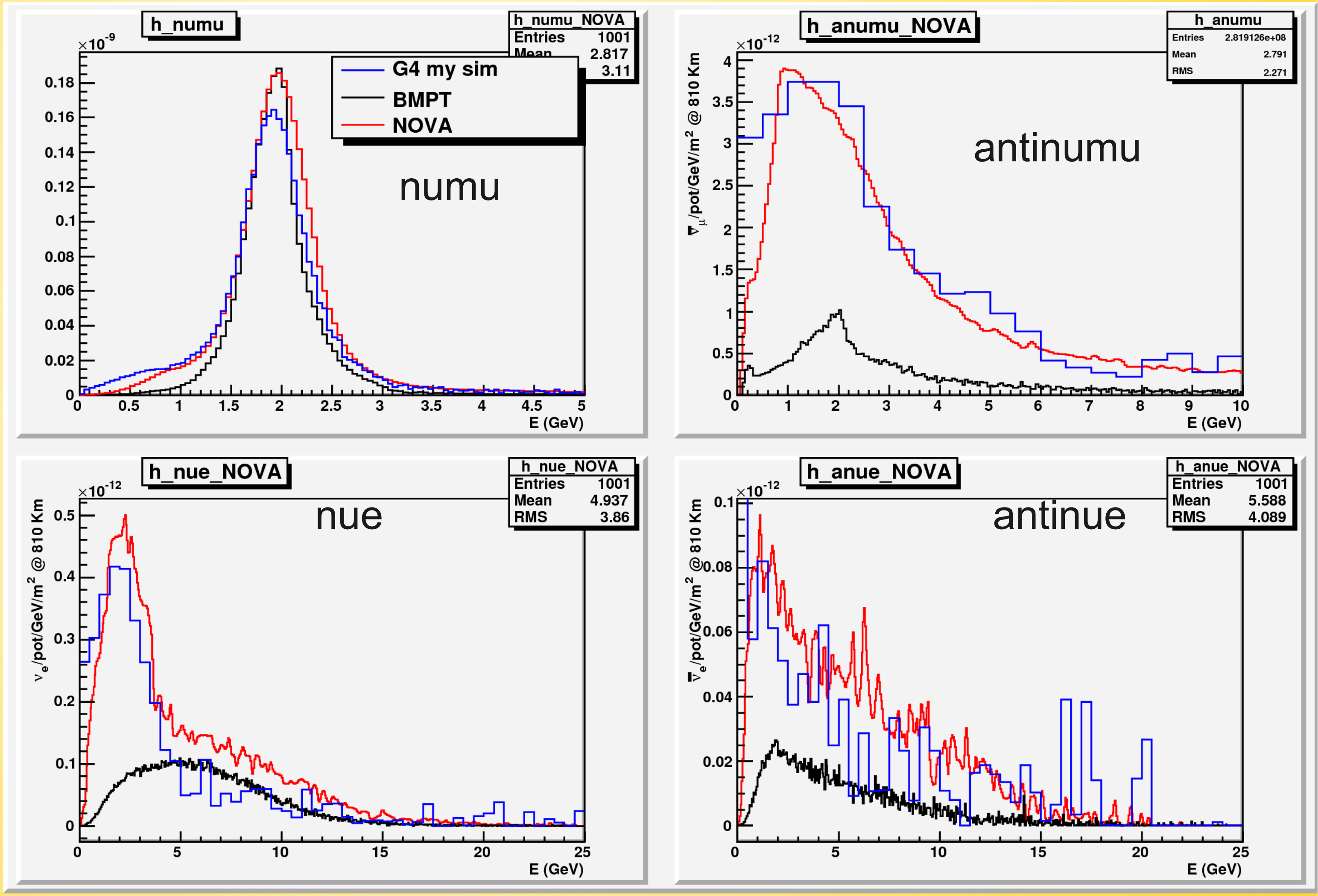
conf_91000N.mac
N=0,30
tot pots = 210K

Fair agreement with G4 simulation

apparently BMPT

understimates antinue, antinumu and nue from muons (low energy bump)

lower K/pi ratio in GEANT4-QGSP wrt BMPT



Benchmark: NOvA

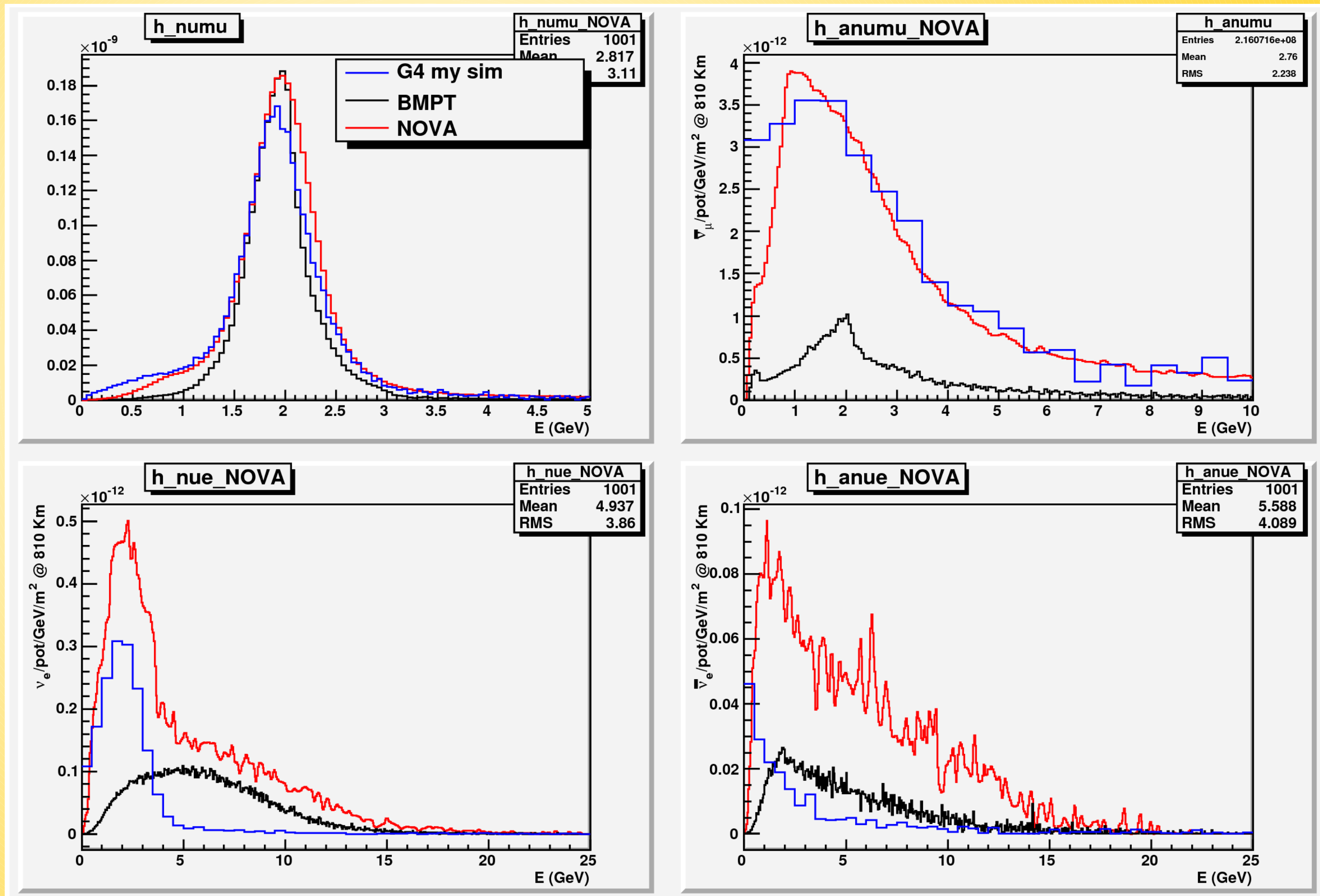
160K pots

Before correction for Kaons

new version assumes a 2 body decay formula even in the case of a 3 body decay (as in BMPT)

yields better agreement with NOVA and BMPT than previous formalism

validation with direct counting technique? feasible?
see →



Cross-check: nu counting

To validate: 1) probability approach 2) off-axis treatment

Select neutrinos generated by GEANT4 decays in narrow cones around the forward direction and off axis direction

Easier with high energy beam. Done for the NOvA configuration.

Use numu spectrum to understand the maximal cone aperture cone which allows to have a realistic spectrum shape (at sufficient statistics)

$\Omega = 1 / (4\pi L^2)$ ($1\ m^2$ at 810 Km) ~ 1.5 prad

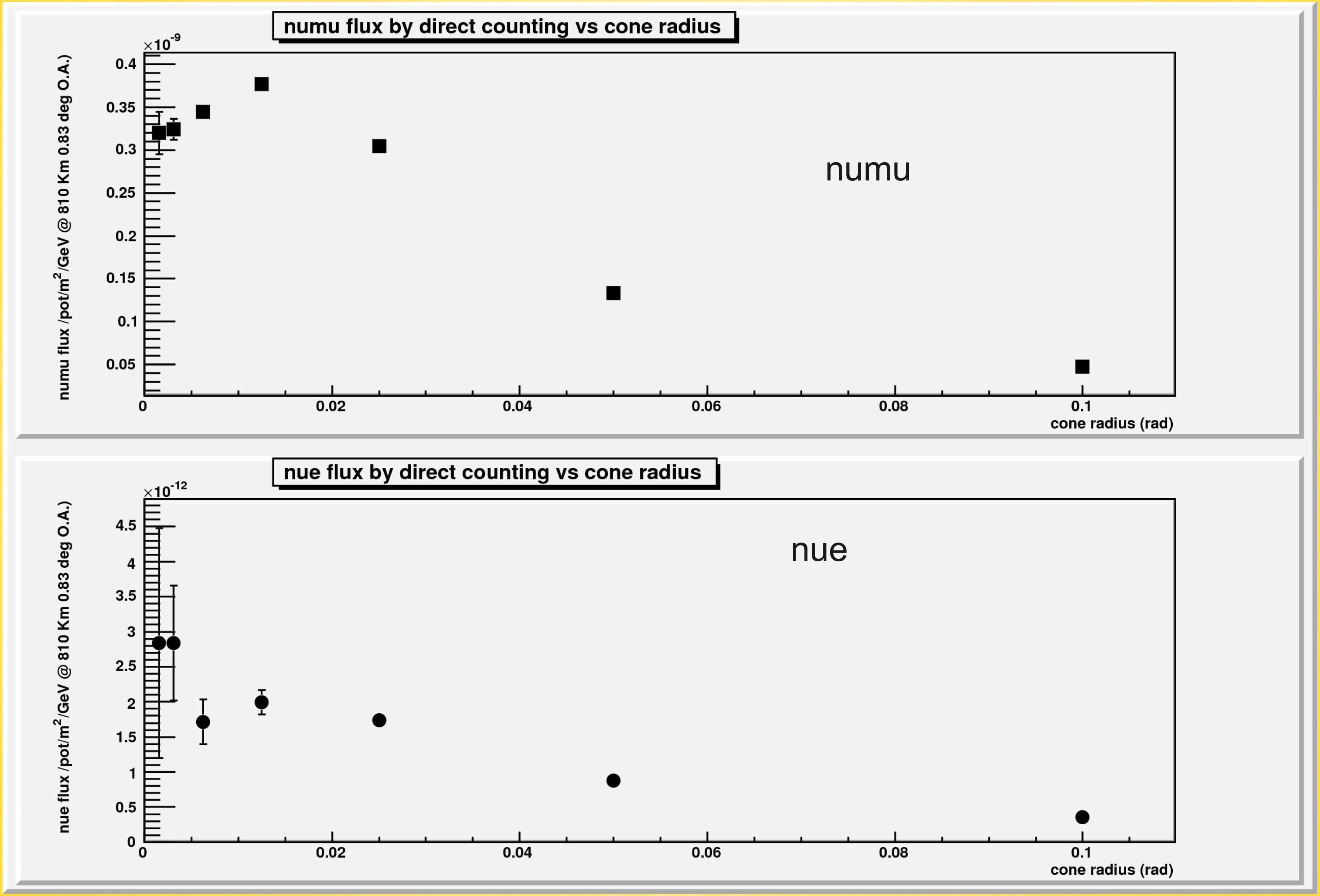
considered 7 cones of semi-aperture:
α =0.1 - 0.05 - 0.025 - 0.0125 - 0.00625 - 0.003125 - 0.0015625

solid angles Ω' (prad): 3.1e10 - 7.8e9 - 2.0e9 - 4.9e8 - 1.2e8 - 3.1e7 - 7.7e6
$\Omega' = 2\pi (1 - \cos \alpha)$

last cone ~ a detector ~ 2.2 Km x 2.2 Km

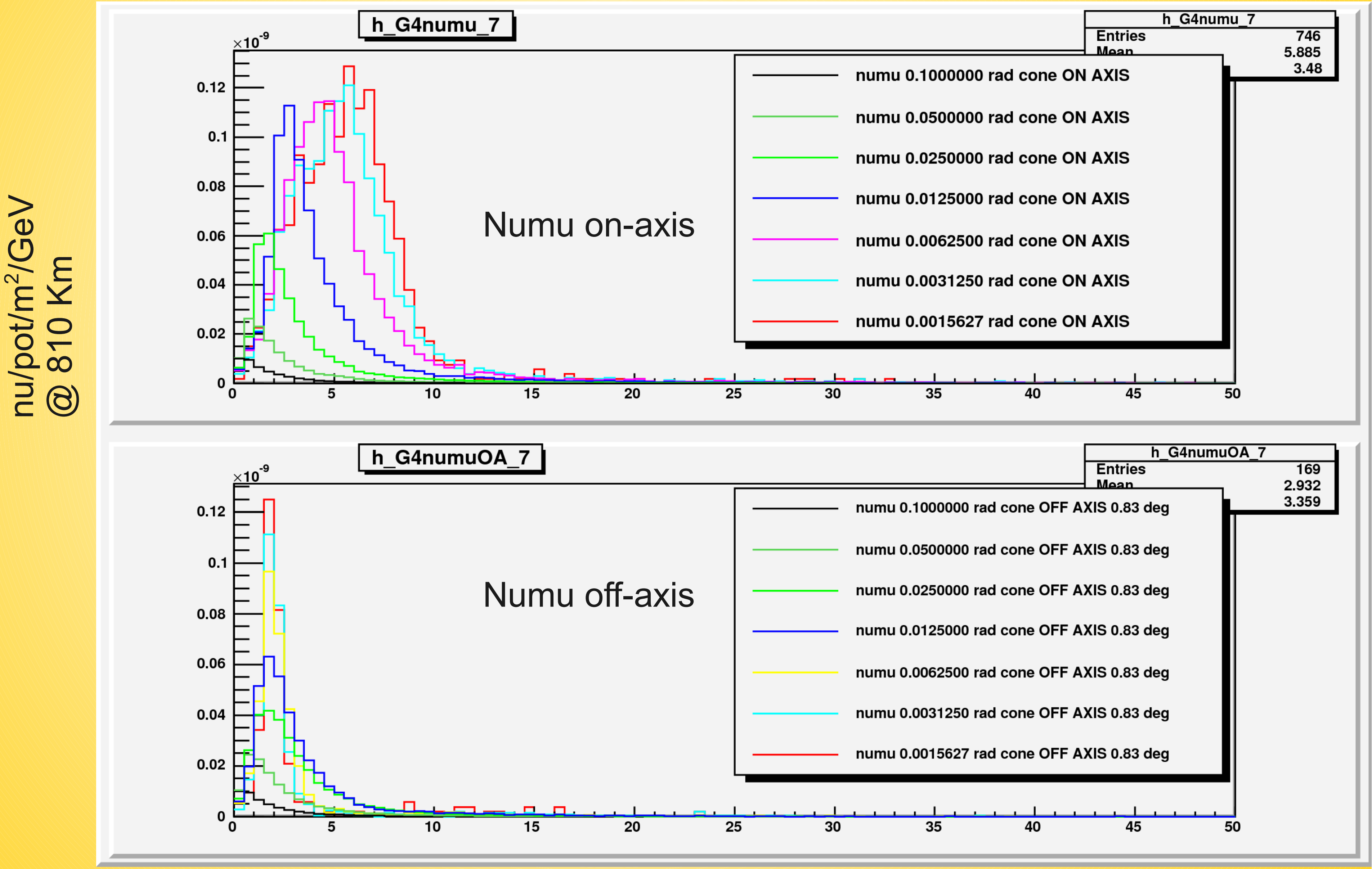
scale fluxes obtained with counting neutrinos in the cone by Ω/Ω'

Flux vs cone radius



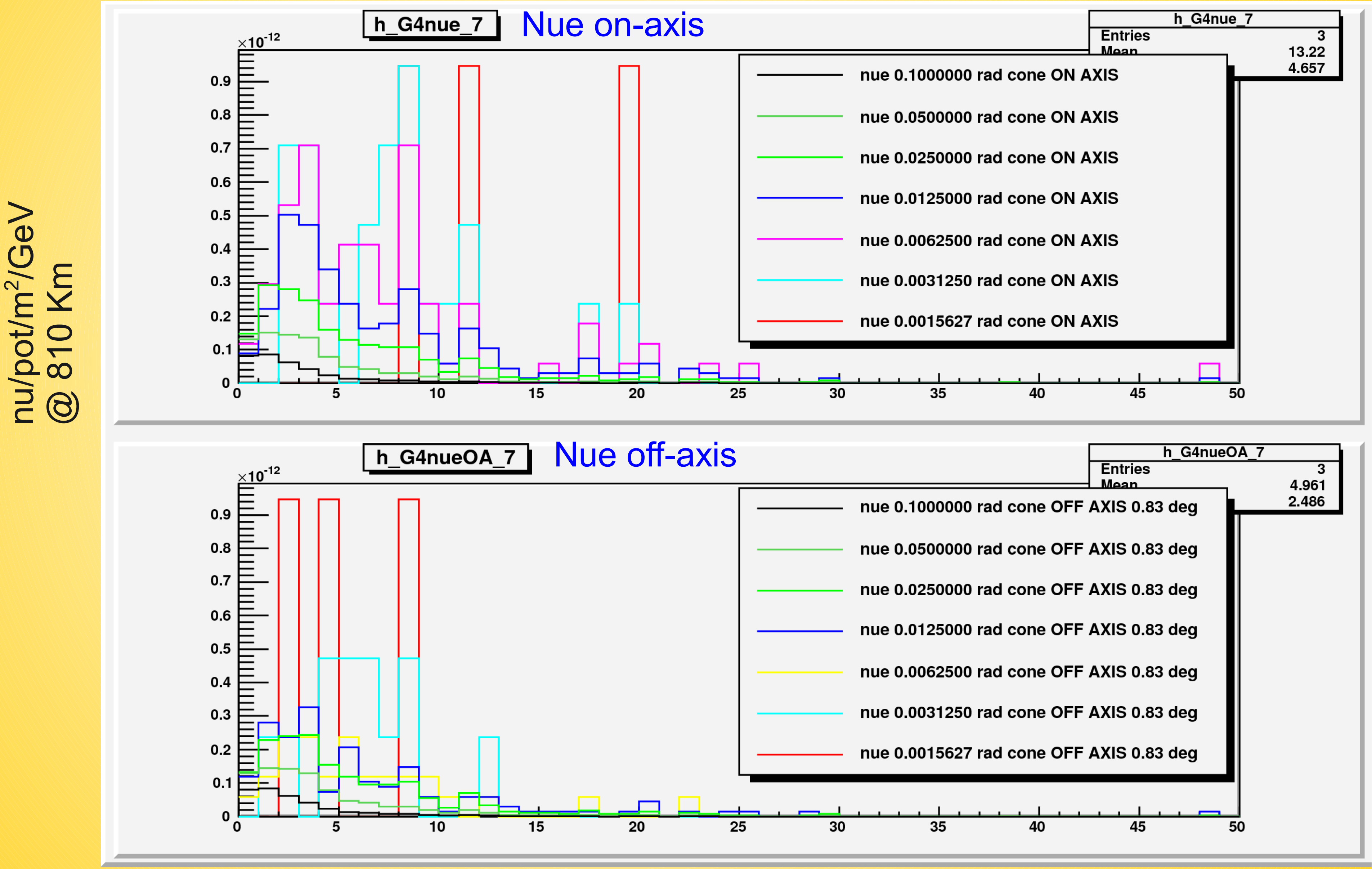
Spectra dependence on cone r: numu

Numu fluxes spectra for different cone's radii



Spectra dependence on cone r: nue

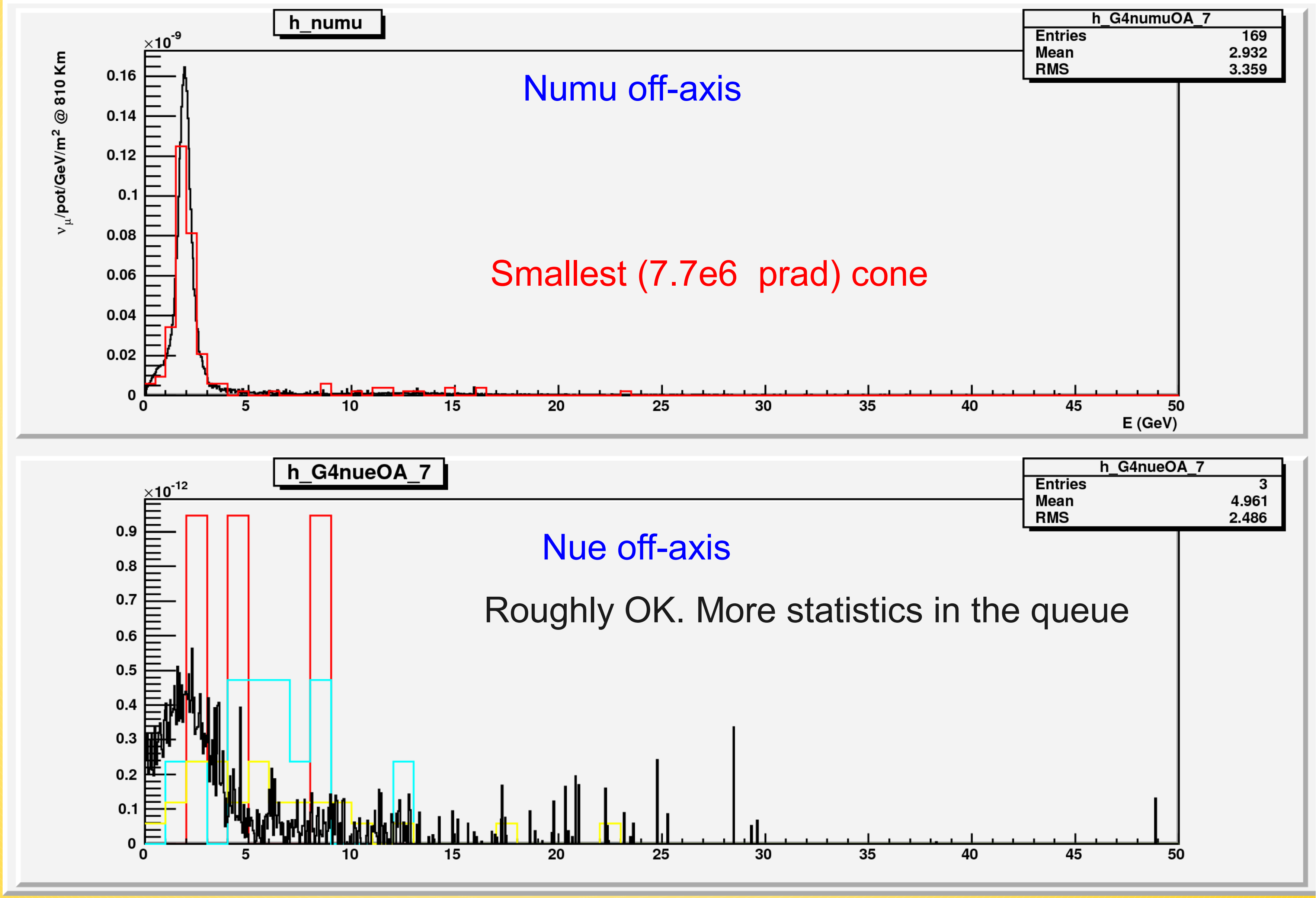
Nue fluxes spectra for different cone's radii



Counting<-> probability

Comparison of direct counting and probability weighting

nu/pot/m^2/GeV
@ 810 Km



Conclusions 2: G4 for high-E

Looks fairly good, need to better understand kaon 3 body decays proper treatment

Direct nu counting: seems an interesting way to cross check, need to increase stats.

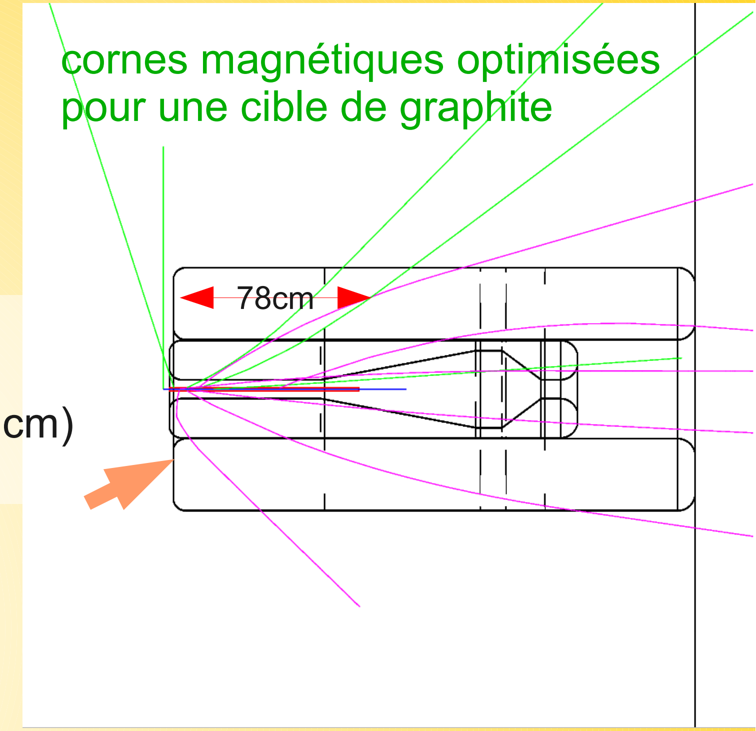
Proceed towards simulation of other possible configurations in Europe

Back-up

Solid target results

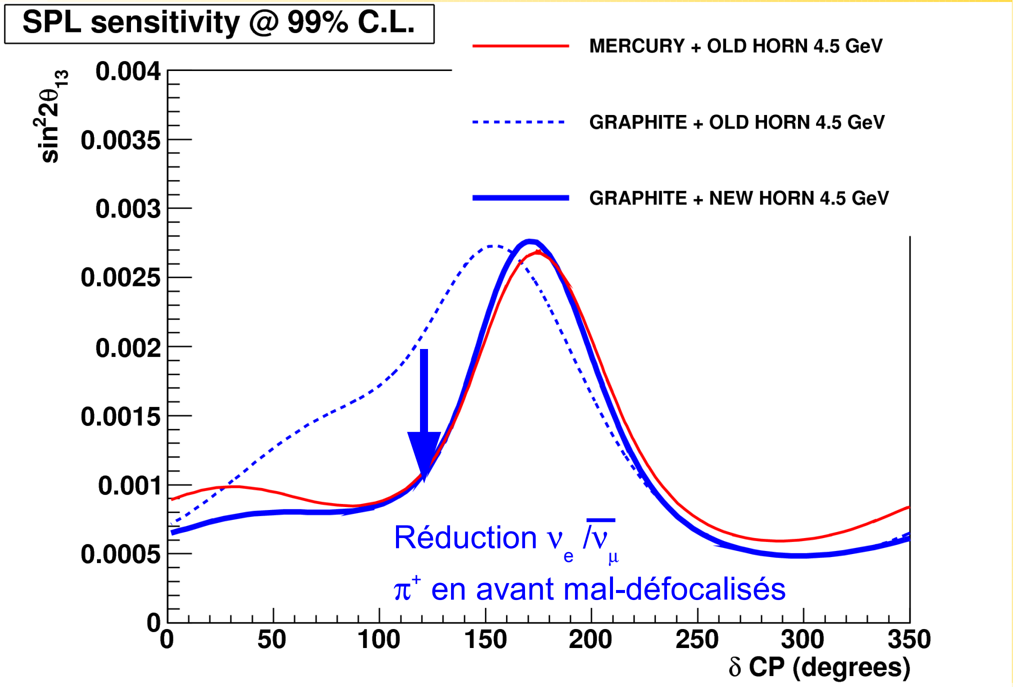
Idée: vérifier l'impact d'employer des cibles en graphite au lieu d'une cible de mercure liquide.
des aspects techniques jusqu'à la physique

Actions:
* Réécriture de la simulation en GEANT4. Dernière version de FLUKA
* Optimisation des cornes magnétiques pour une cible longue (30→78 cm)
  utilisation d'un modèle paramétrique flexible

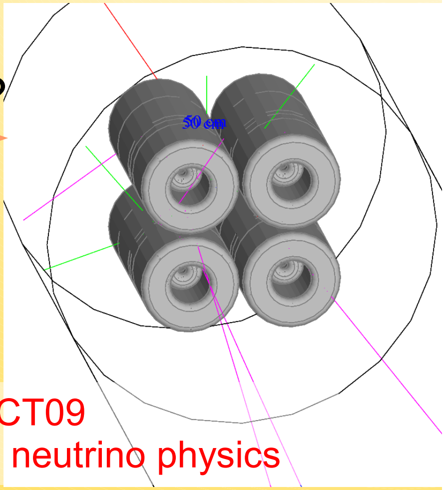


Resultats:
* amélioration des limites sur $\sin^2 2\theta_{13}$

+ un cadre plus réaliste:
  - pas de problème d'intégration du mercure liquide
  - déposition d'énergie et flux de neutrons plus favorables



Réduire le stress d'irradiation?
* 4 cornes:
validé par la simulation des flux



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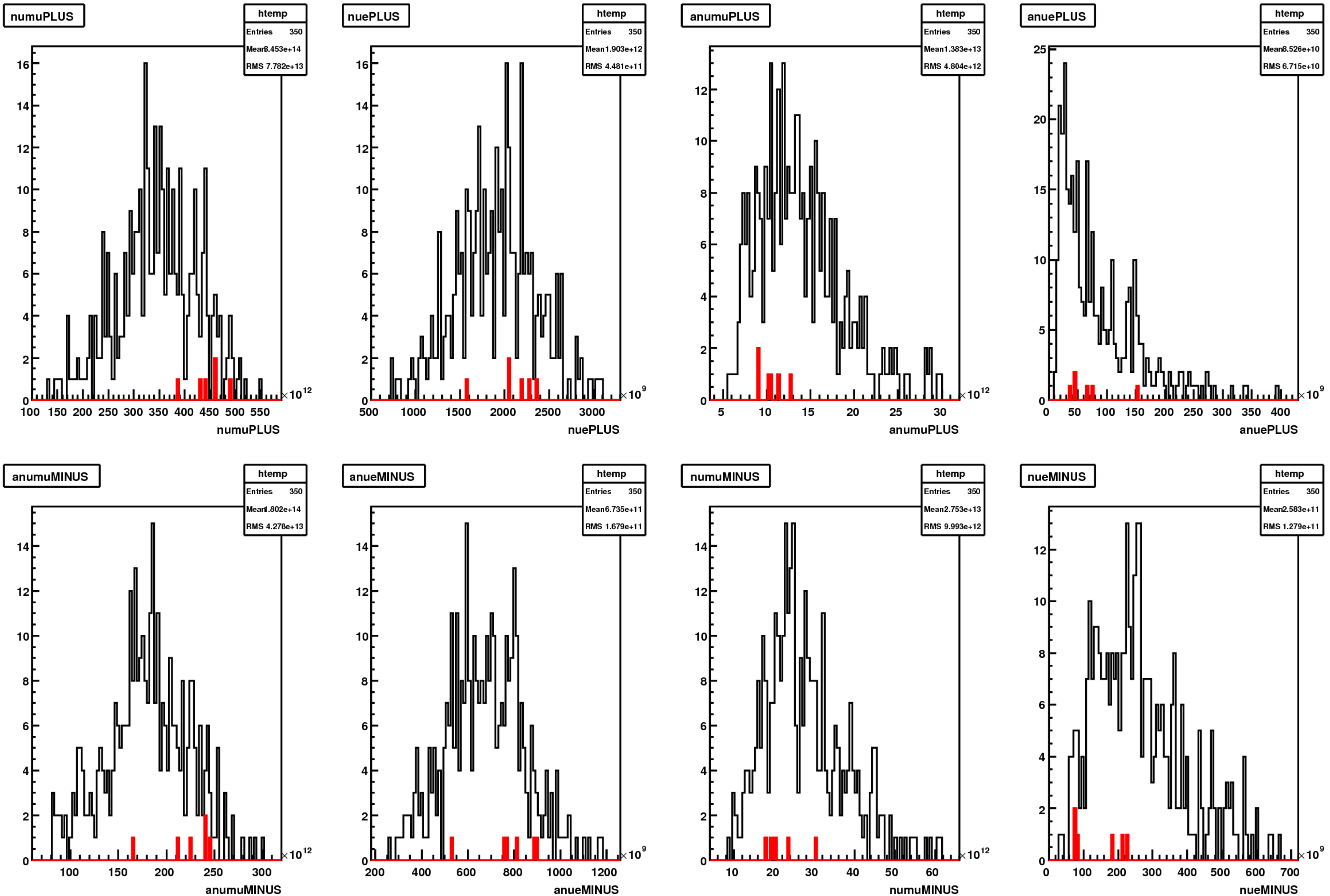
numuPLUS
htemp
Entries 350
Mear8.453e+14
RMS 7.782e+13
numuPLUS
nuePLUS
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Entries 350
Mean 1.903e+12
RMS 4.481e+11
nuePLUS
anumuPLUS
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Entries 350
Mean 1.383e+13
RMS 4.804e+12
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Entries 350
Mean 8.526e+10
RMS 6.715e+10
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Mean 1.802e+14
RMS 4.278e+13
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Entries 350
Mean 6.735e+11
RMS 1.679e+11
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Entries 350
Mean 2.753e+13
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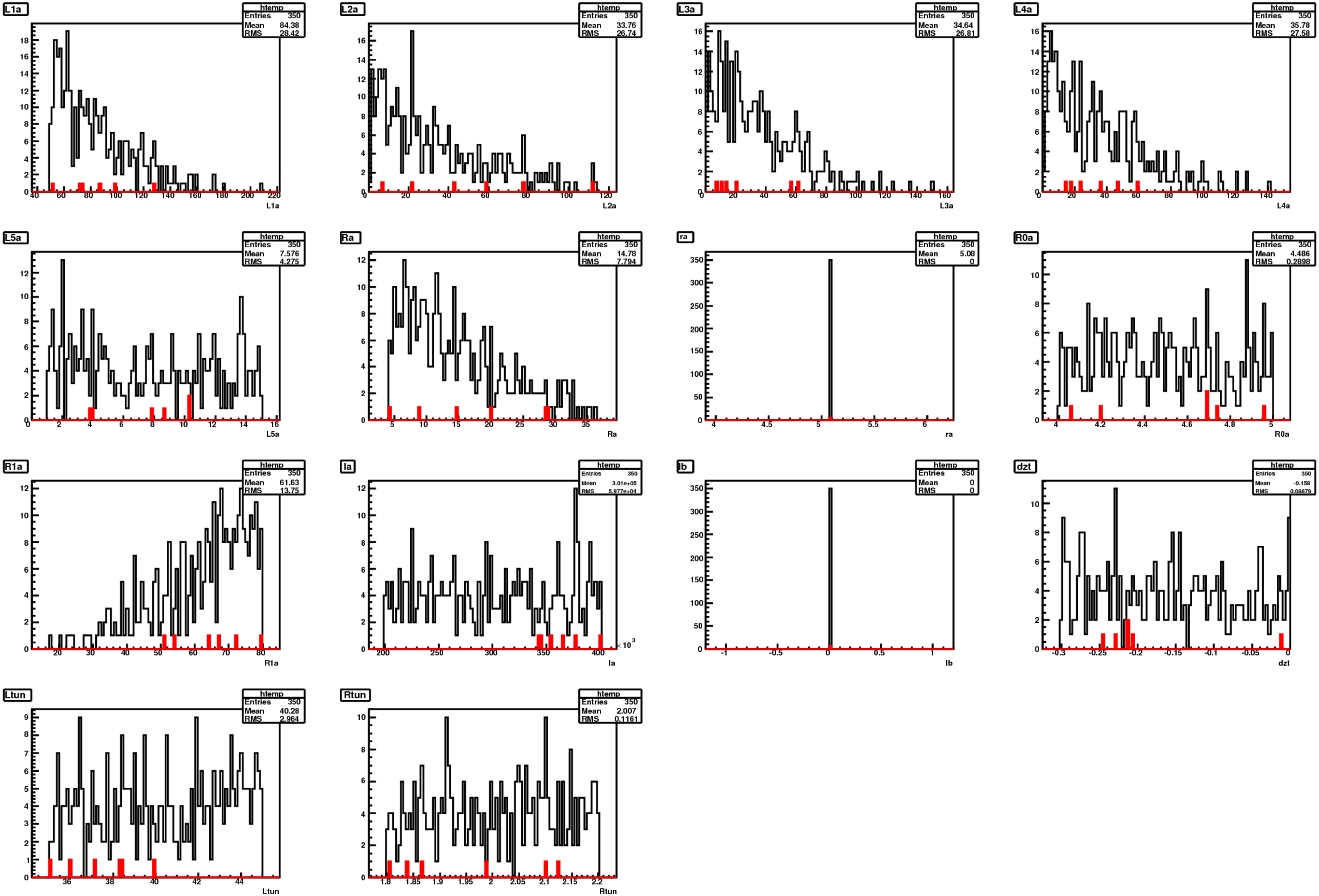
RMS 1.279e+11
nueMINUS


L1a
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Entries 350
Mean 84.38
RMS 28.42
L1a
L2a
htemp
Entries 350
Mean 33.76
RMS 26.74
L2a
L3a
htemp
Entries 350
Mean 34.64
RMS 26.81
L3a
L4a
htemp
Entries 350
Mean 35.78
RMS 27.58
L4a
L5a
htemp
Entries 350
Mean 7.576
RMS 4.275
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Entries 350
Mean 14.78
RMS 7.794
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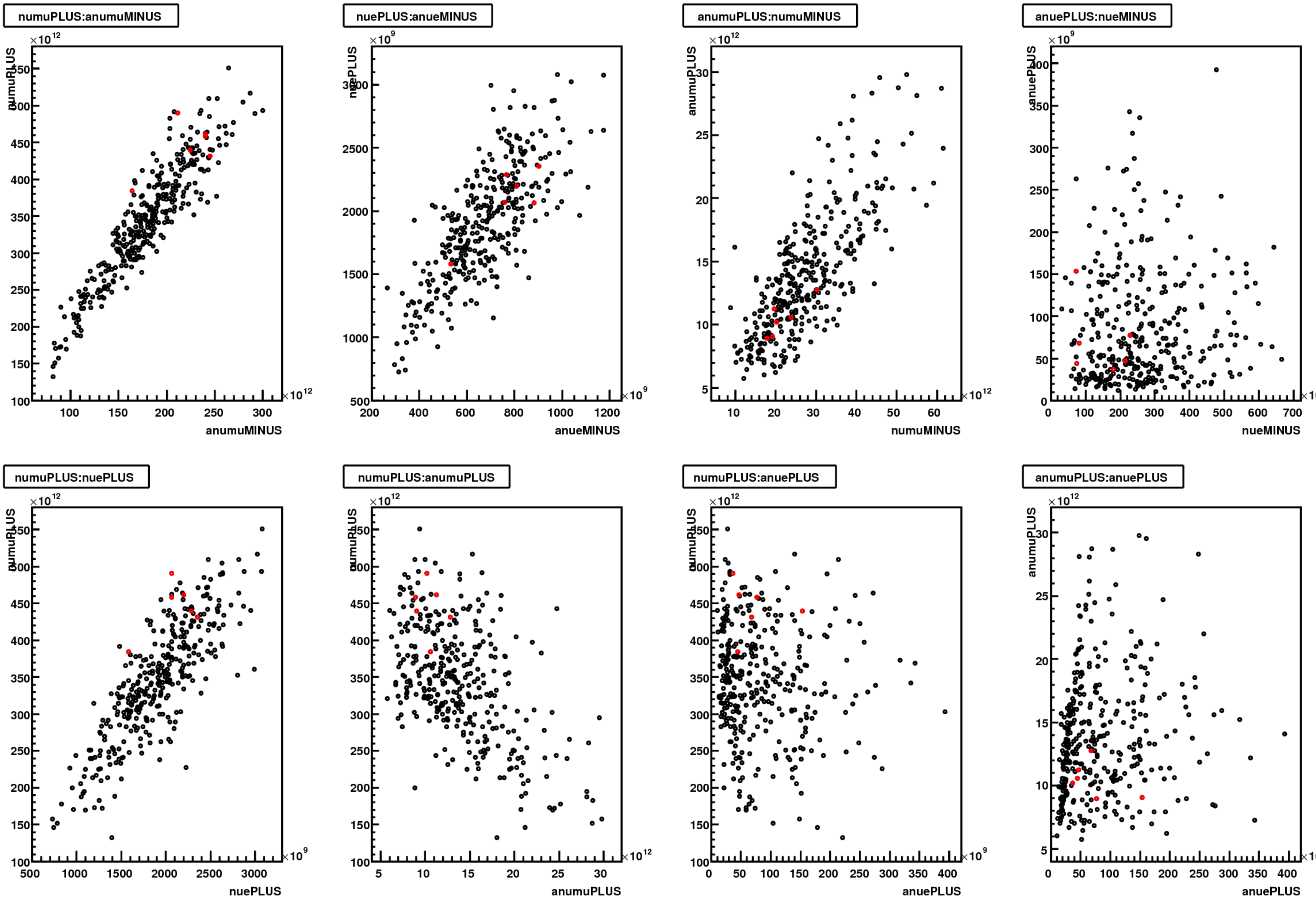
Entries 350
Mean 5.08
RMS 0
ra
R0a
htemp
Entries 350
Mean 4.486
RMS 0.2898
R0a
R1a
htemp
Entries 350
Mean 61.63
RMS 13.75
R1a
Ia
htemp
Entries 350
Mean 3.01e+05
RMS 5.977e+04
Ia
Ib
htemp
Entries 350
Mean 0
RMS 0
Ib
dzt
htemp
Entries 350
Mean -0.158
RMS 0.08879
dzt
Ltun
htemp
Entries 350
Mean 40.28
RMS 2.964
Ltun
Rtun
htemp
Entries 350
Mean 2.007
RMS 0.1161
Rtun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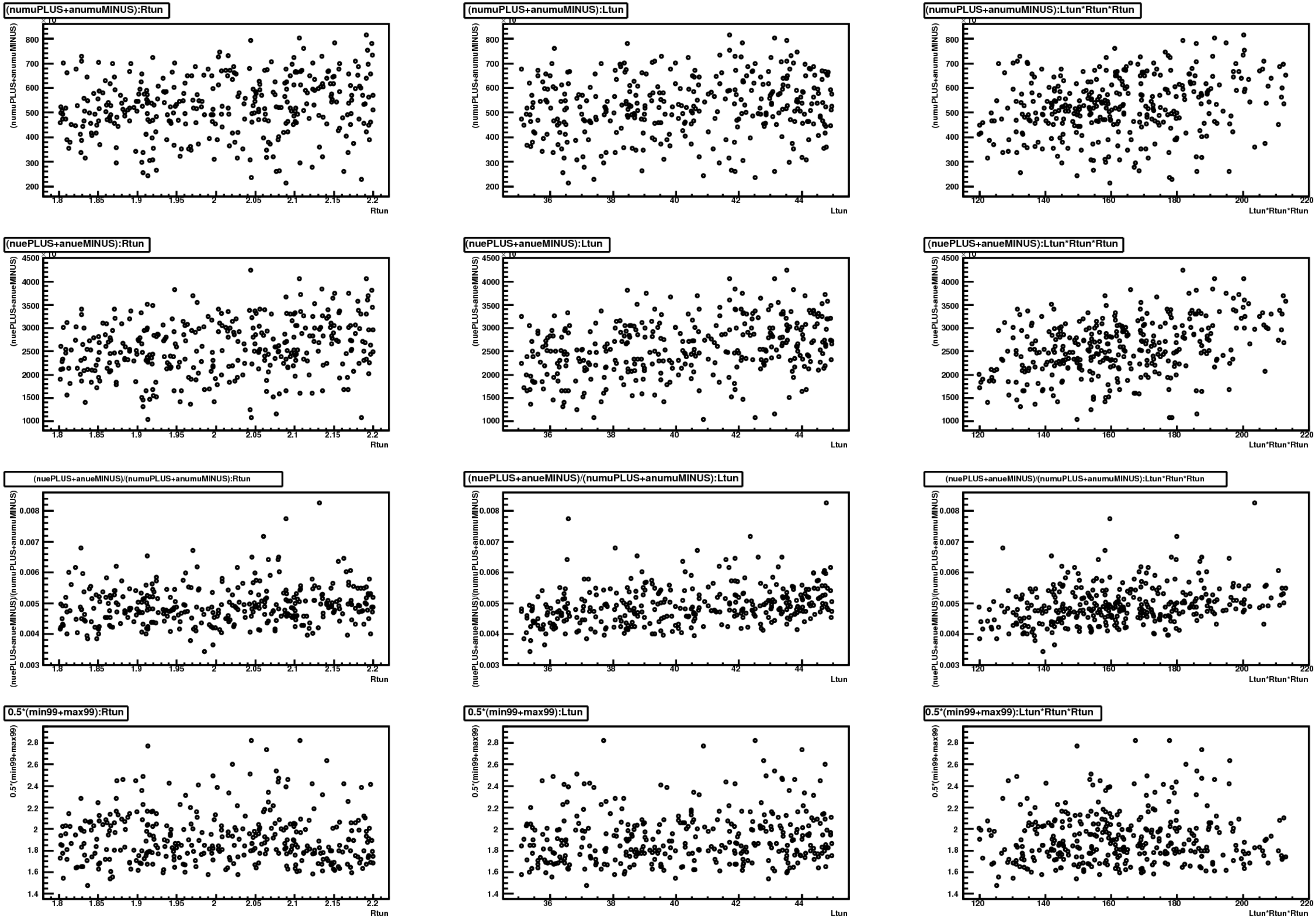
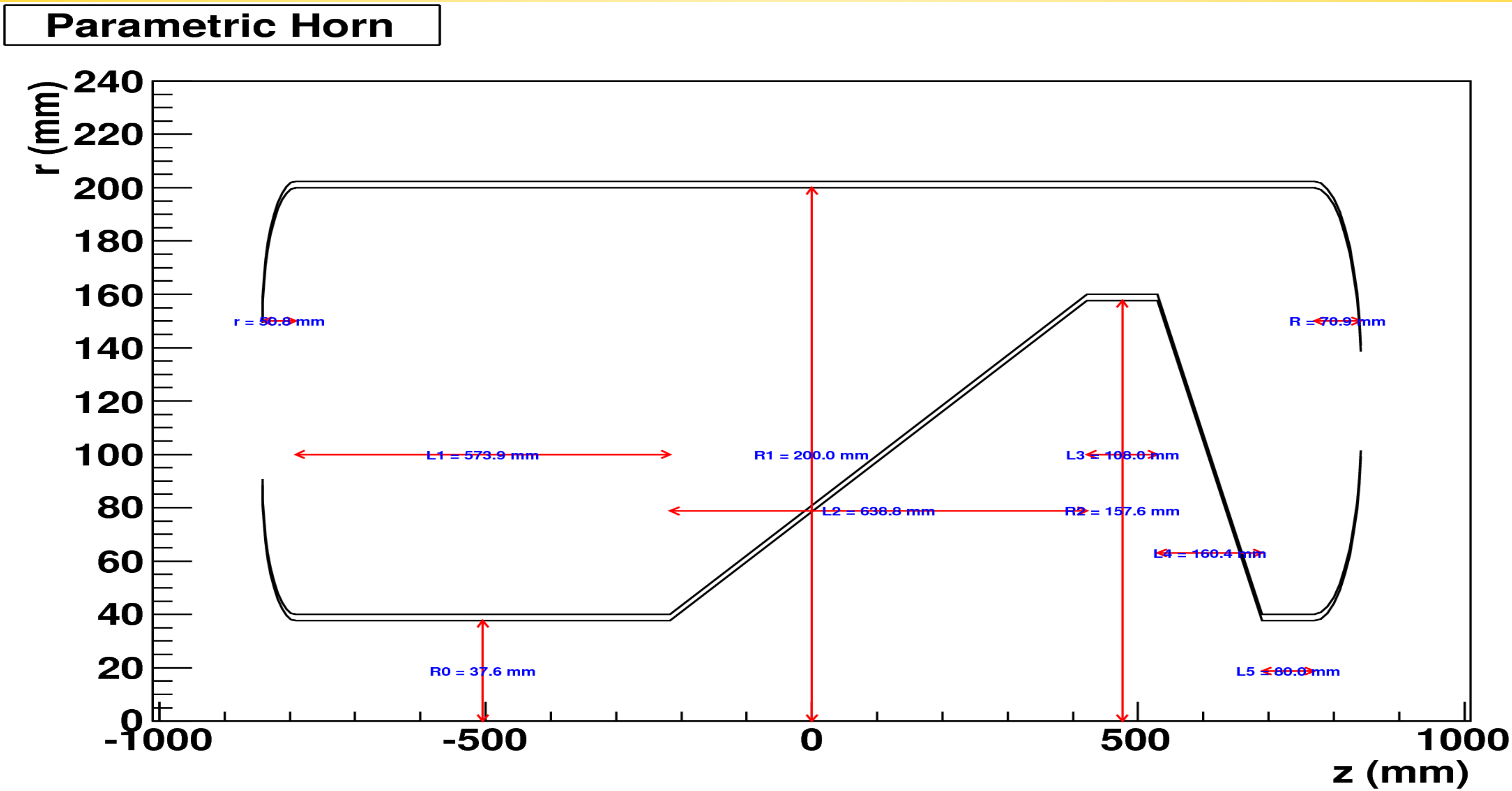
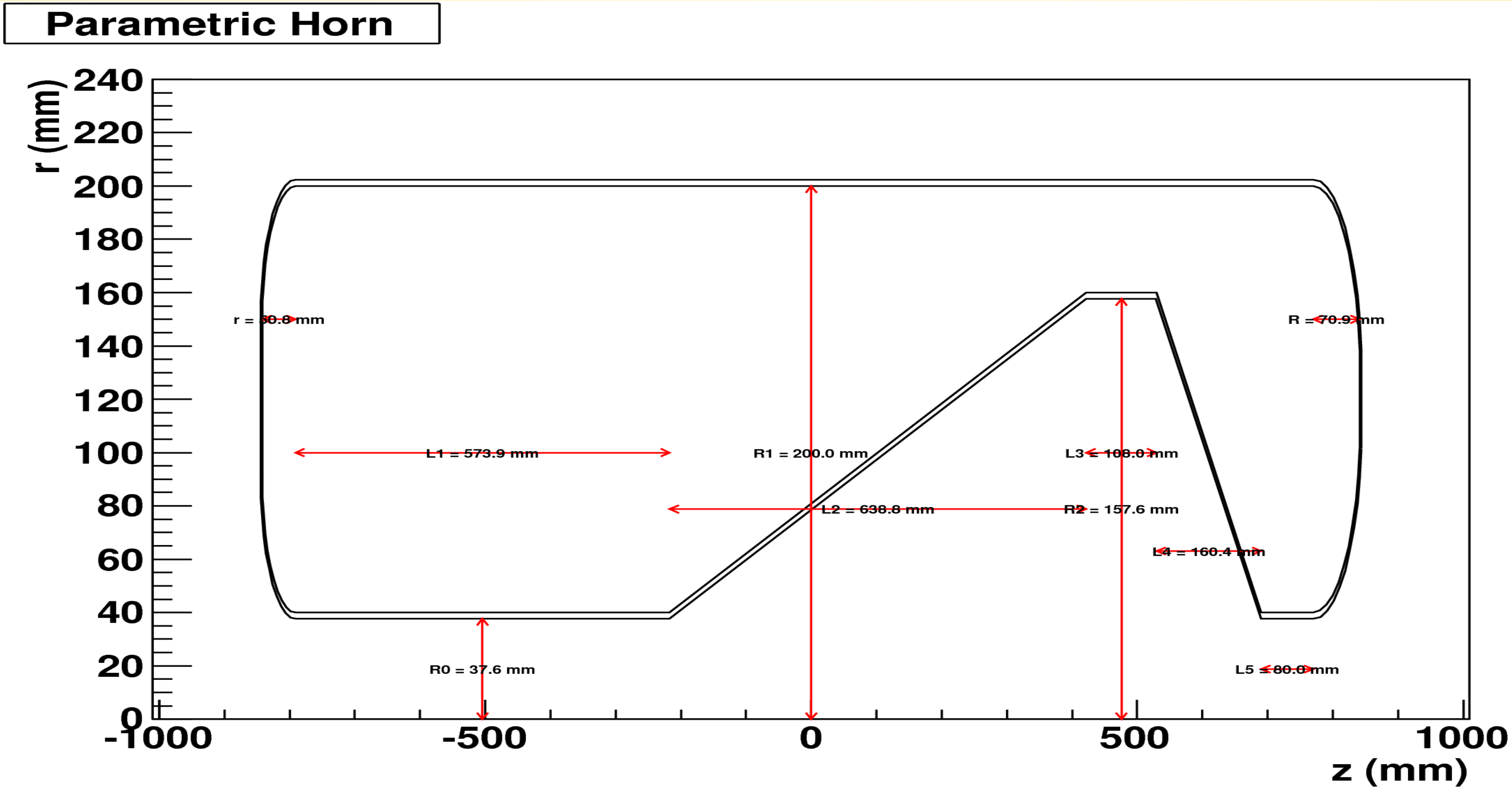

(numuPLUS+anumuMINUS):Rtun
(numuPLUS+anumuMINUS):Ltun
(numuPLUS+anumuMINUS):Ltun*Rtun*Rtun
(nuePLUS+anueMINUS):Rtun
(nuePLUS+anueMINUS):Ltun
(nuePLUS+anueMINUS):Ltun*Rtun*Rtun
(nuePLUS+anueMINUS)/(numuPLUS+anumuMINUS):Rtun
(nuePLUS+anueMINUS)/(numuPLUS+anumuMINUS):Ltun
(nuePLUS+anueMINUS)/(numuPLUS+anumuMINUS):Ltun*Rtun*Rtun
0.5*(min99+max99):Rtun
0.5*(min99+max99):Ltun
0.5*(min99+max99):Ltun*Rtun*Rtun
(numuPLUS+anumuMINUS)
(nuePLUS+anueMINUS)
(nuePLUS+anueMINUS)/(numuPLUS+anumuMINUS)
0.5*(min99+max99)
Rtun
Ltun
Ltun*Rtun*Rtun

Correction in the Al skin sim.

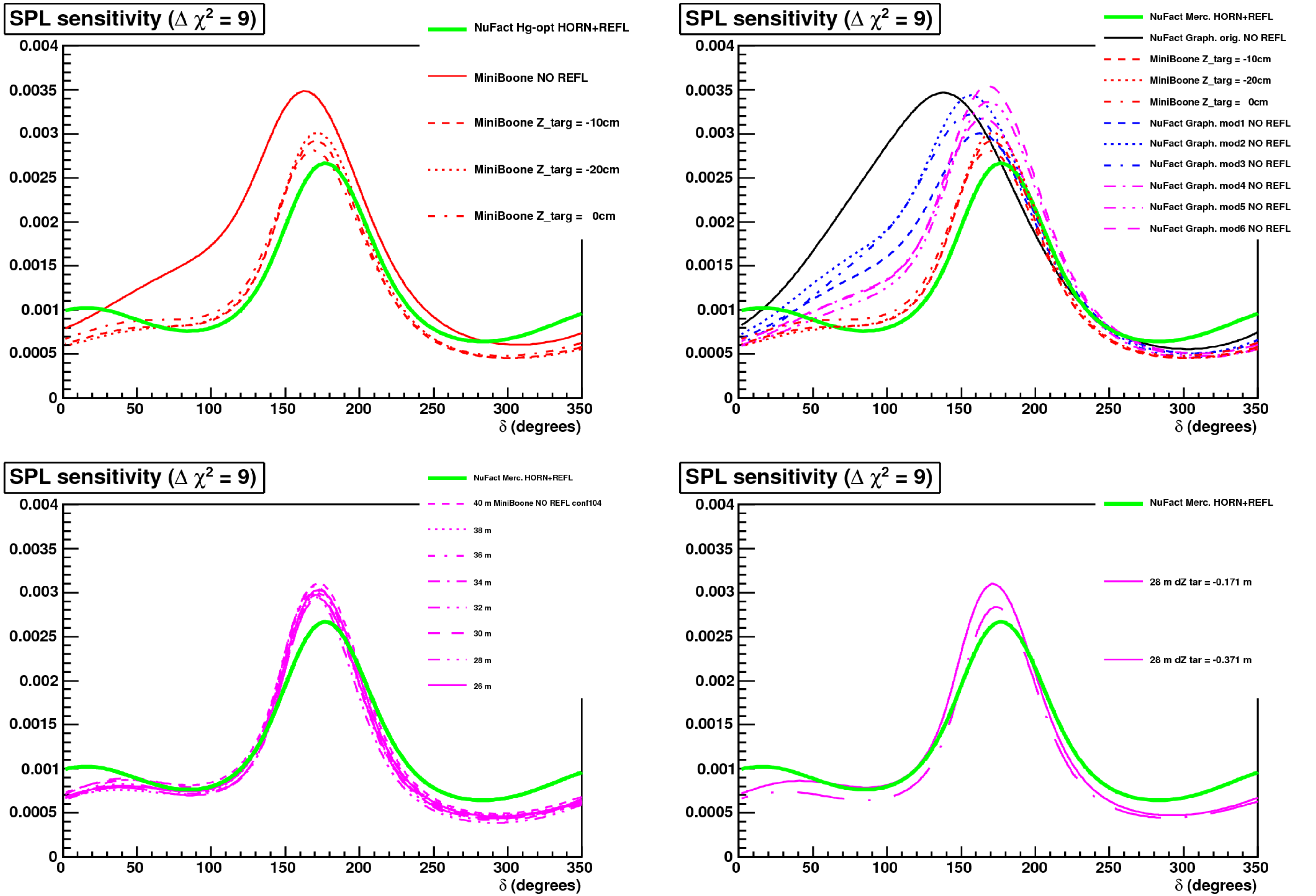


2.4 mm, no uniform Al thickness

Correction in the Al skin sim.



Correct geometry 3 mm uniform thickness Al


SPL sensitivity (Δ χ² = 9)
NuFact Hg-opt HORN+REFL
MiniBoone NO REFL
MiniBoone Z_targ = -10cm
MiniBoone Z_targ = -20cm
MiniBoone Z_targ = 0cm
δ (degrees)
SPL sensitivity (Δ χ² = 9)
NuFact Merc. HORN+REFL
NuFact Graph. orig. NO REFL
MiniBoone Z_targ = -10cm
MiniBoone Z_targ = -20cm
MiniBoone Z_targ = 0cm
NuFact Graph. mod1 NO REFL
NuFact Graph. mod2 NO REFL
NuFact Graph. mod3 NO REFL
NuFact Graph. mod4 NO REFL
NuFact Graph. mod5 NO REFL
NuFact Graph. mod6 NO REFL
δ (degrees)
SPL sensitivity (Δ χ² = 9)
NuFact Merc. HORN+REFL
40 m MiniBoone NO REFL conf104
38 m
36 m
34 m
32 m
30 m
28 m
26 m
δ (degrees)
SPL sensitivity (Δ χ² = 9)
NuFact Merc. HORN+REFL
28 m dZ tar = -0.171 m
28 m dZ tar = -0.371 m
δ (degrees)