VMC: What has been done & future plans

Basic Validation of VMC

Reproduce Claudia's results (Geant4 stand alone) with VMC:

Same condition of simulation:
- -Beam described by gaussians (no correlation taken into account)
- -Geometry is simplified: only the target & S4
- -Same materials, same positions
- -Physics list used: QGSP_BERT

Compare elastic & quasi-elastic interactions , trigger bias estimation, cross sections

Quasi-Elastic Flag:

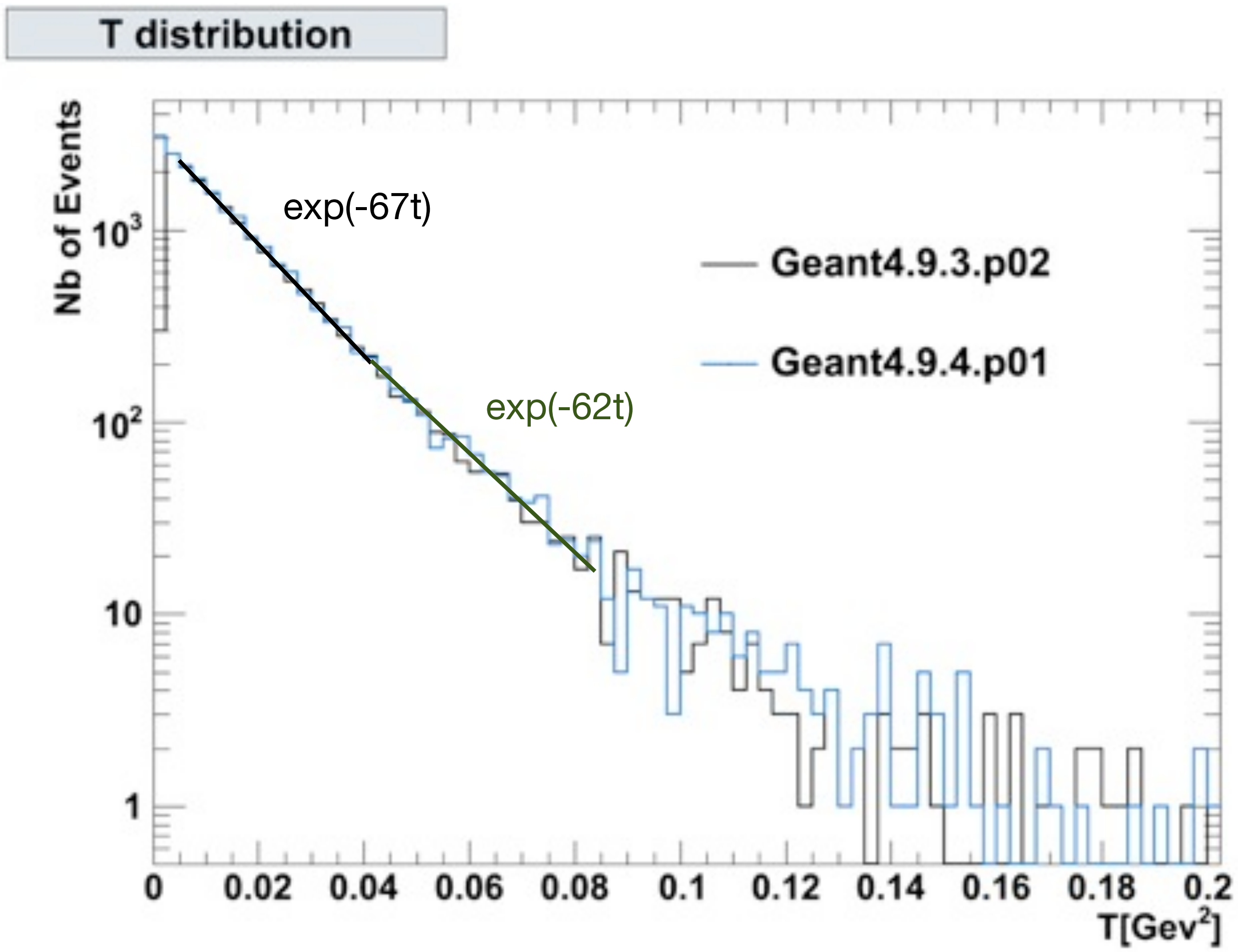
à la Claudia: interaction is labelled as inelastic, after the interaction 3 particles are propagated: proton with p>29.8GeV, a nucleon and the remaining nucleus.
à la VMC: Treatement of quasi-elastic interactions is model-depended: for some models, the use of relaxed cuts is needed: there are at least 3 particles propagated after the interactio, one of them being a proton with p>29.8GeV.

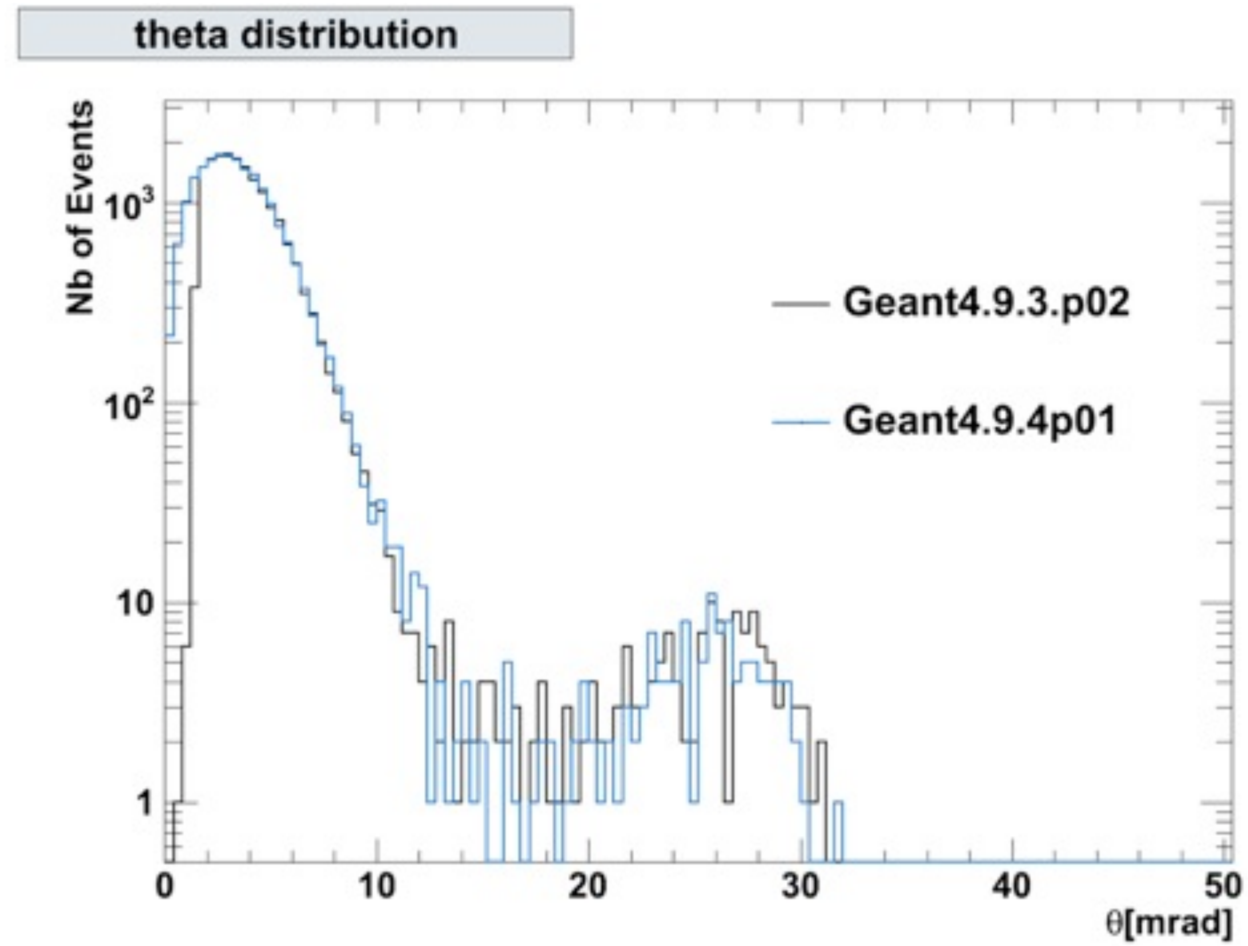
Elastic Flag: VMC's flag is supposed to be trustable

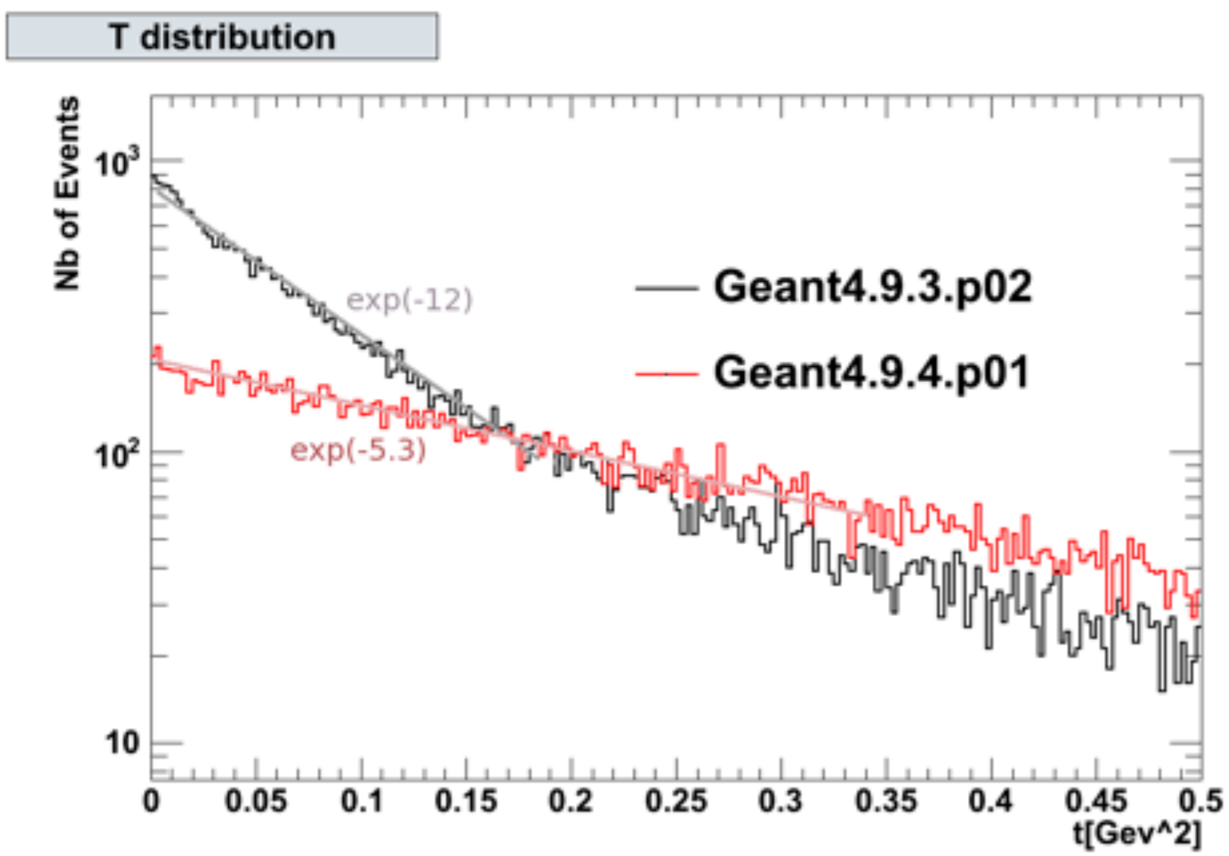
Treatement of those interactions are model-depended (for QE) and Geant4-version-depended!

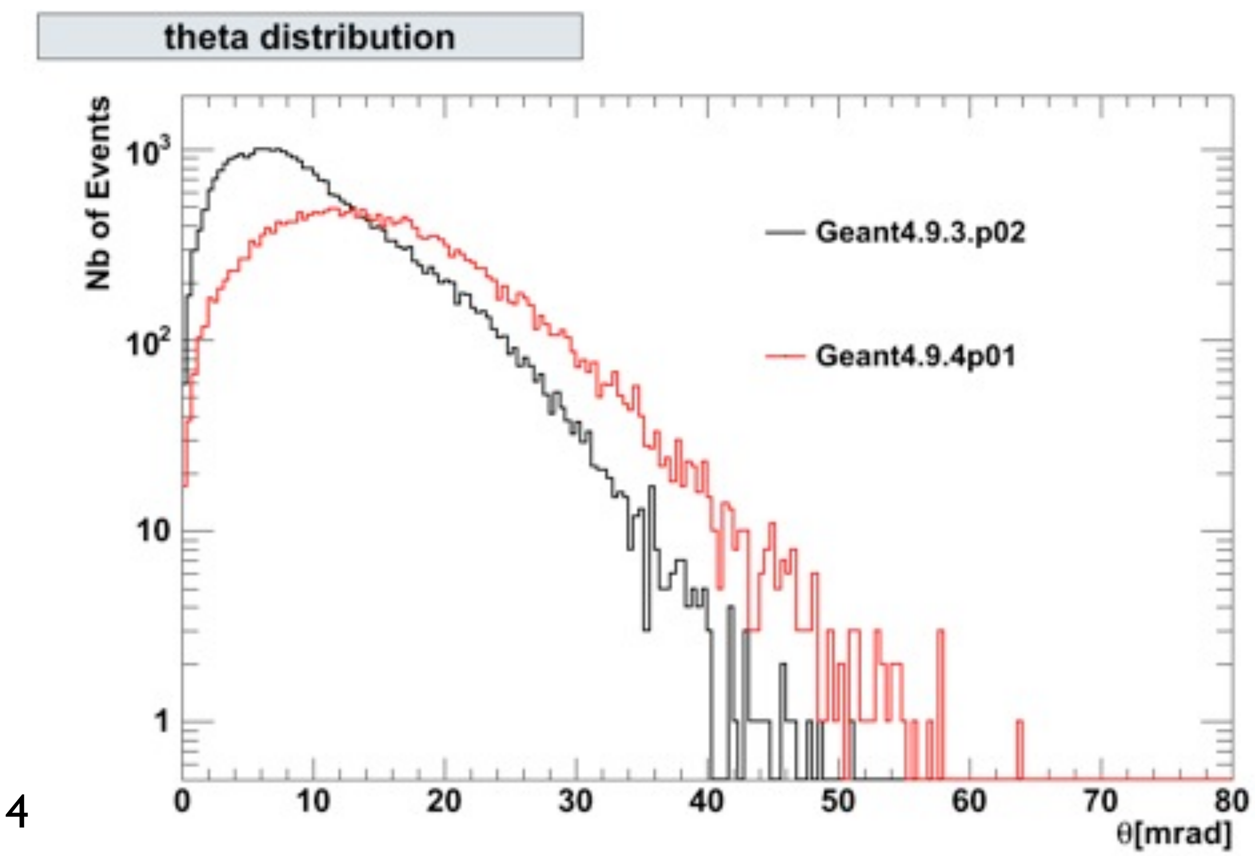
Elastic scattering: A cut at low T-low θ is seen for geant4.9.3.p02
Quasi-elastic: T slope is divided by a factor of 2 for geant4.9.4.p01

Elastic & Quasi-Elastic scattering, angular & T distributions

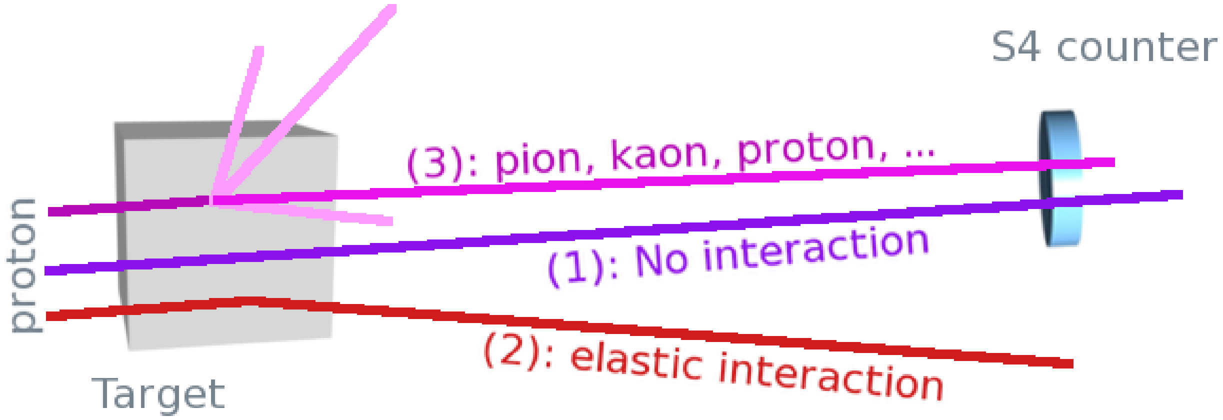








Cross section calculation



Measurement of inelastic cross section:

(1) : Rough estimation of the number of interaction:

$N_{int} = N_{POT} - N_{prot.\ on\ S4} \rightarrow \sigma_{trig}$

→This measurement has to be corrected from trigger bias

(2): Substract the number of event where the proton missed the S4 counter (mainly elastic interaction) $\rightarrow \sigma_{el}$

(3): Add the number of event where an inelastic interaction occured, one of the daughter hit the S4 counter : π or K $\rightarrow \sigma_{loss-\pi/K}$, or a proton (mainly from QE) $\rightarrow \sigma_{loss-p}$

Then:

$$\sigma_{inel} = \sigma_{trig} + \sigma_{loss-p} + \sigma_{loss-\pi/K} - \sigma_{el-outS4}$$

$$\sigma_{prod} = \sigma_{inel} - \sigma_{QE}$$

From data: $\sigma_{trig} = 298.1 \pm 1.9 \pm 7.3$ mbarn

Elastic & Quasi-Elastic

mbarn	Claudia	VMC geant4.9.3p02		VMC geant4.9.4p01	
$\sigma_{el\ tot}$	71.9±0.2	61.6±0.5		72.0±0.5	
$\sigma_{el\ out\ of\ S4}$	47.2±0.2±5.0 [65.6%]	45.4±0.5±2 [73.7%]		46.3±0.6±2.2 [64.3%]	
		regular cuts	relaxed cuts	regular cuts	relaxed cuts
$\sigma_{qe\ tot}$	27.6±0.1	26.3±0.3	28.1±0.3	26.2±0.3	28.0±0.3
$\sigma_{qe\ out\ of\ S4}$	25.7±0.2 [93.3%]	24.3±0.3±0.2 [92.4%]	26.1±0.3±0.2 [92.8%]	25.5±0.3±0.07 [96.9%]	27.2±0.3±0.07 [97.2%]

From Glauber calculations: σ_{qe} = 28 mbarn

Systematical uncertainties: position/size of S4

Cross section: results

Inelastic & production cross section

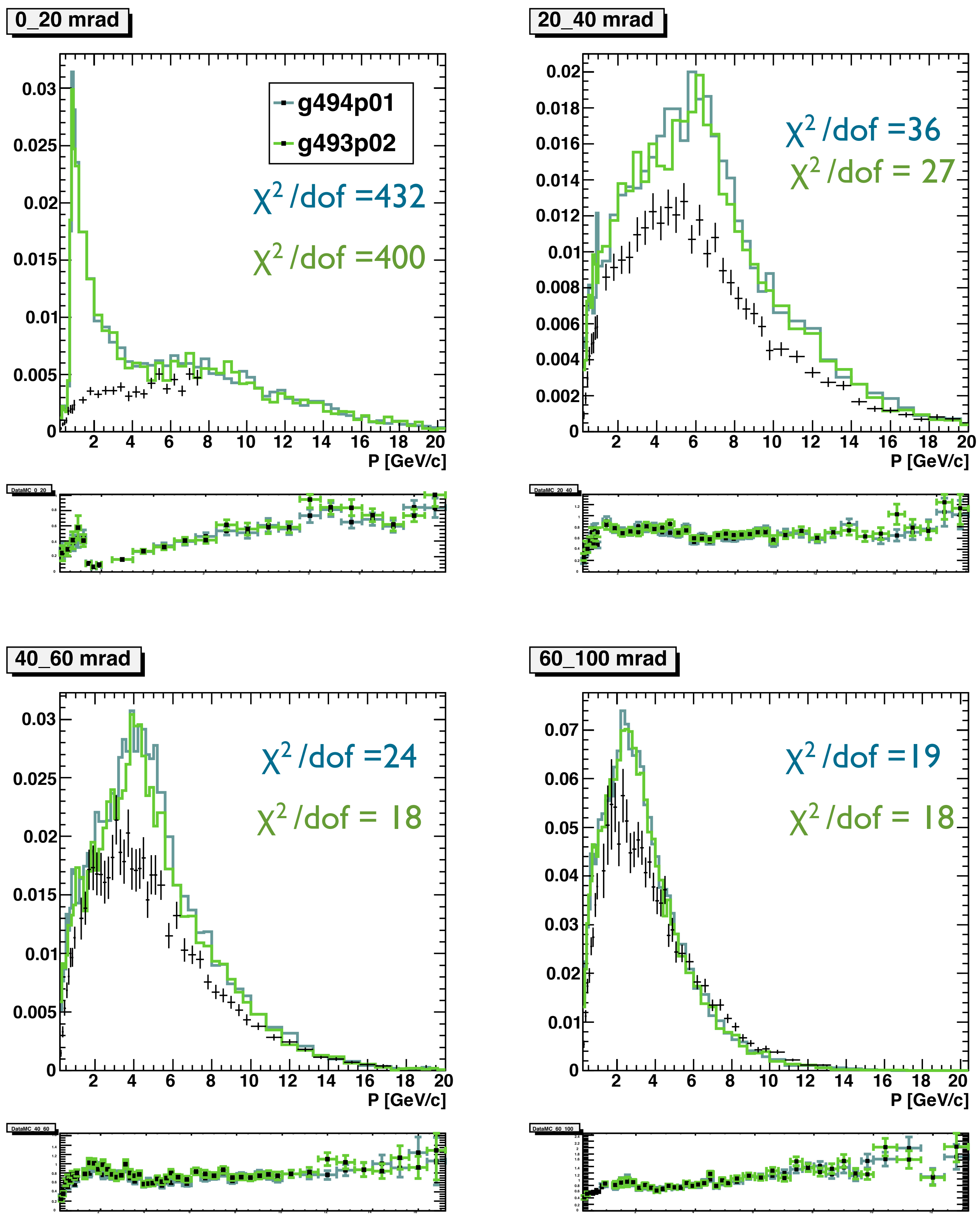
σ_{trig} = 298.1±1.9±7.3 mbarn

Systematical uncertainties: position/size of S4

(mbarn)	Claudia *[geant4.9.3p02 à priori]*	VMC	
		geant4.9.3p02	geant4.9.4p01
+ σ_{loss-p}	5.7±0.2±0.5	4.6±0.04±0.7	4.5±0.1±0.7
+ $\sigma_{loss-\pi/K}$	0.57±0.02±0.35	0.5±0.1±0.07	0.45±0.04±0.05
- $\sigma_{el\ out\ of\ S4}$	47.2±0.2±5.0	45.5±0.4±3.5	45.2±0.4±3.6
σ_{inel}	257.2±1.9±8.9	257.7±1.9±8.1	257.9±1.9±8.2
σ_{prod}	229.2±1.9±9.0	229.6±1.9±8.1	229.9±1.9±8.2

Results are compatible

Comparison between data & MonteCarlo



Agreement between data and MC, with QGSP_BERT is very bad, in both version of geant4

Must improve the simulation:

- Better description of the geometry : re-interaction are taken into account
- Search for the best physics list to describe data

Toward a better simulation of NA61-thin target

A lot physics list were tested, only the most interesting is presented: FTFP_BERT, FTF_BIC, QGSP_BERT, GFLUKA

Elastic & Quasi-elastic cross sections:

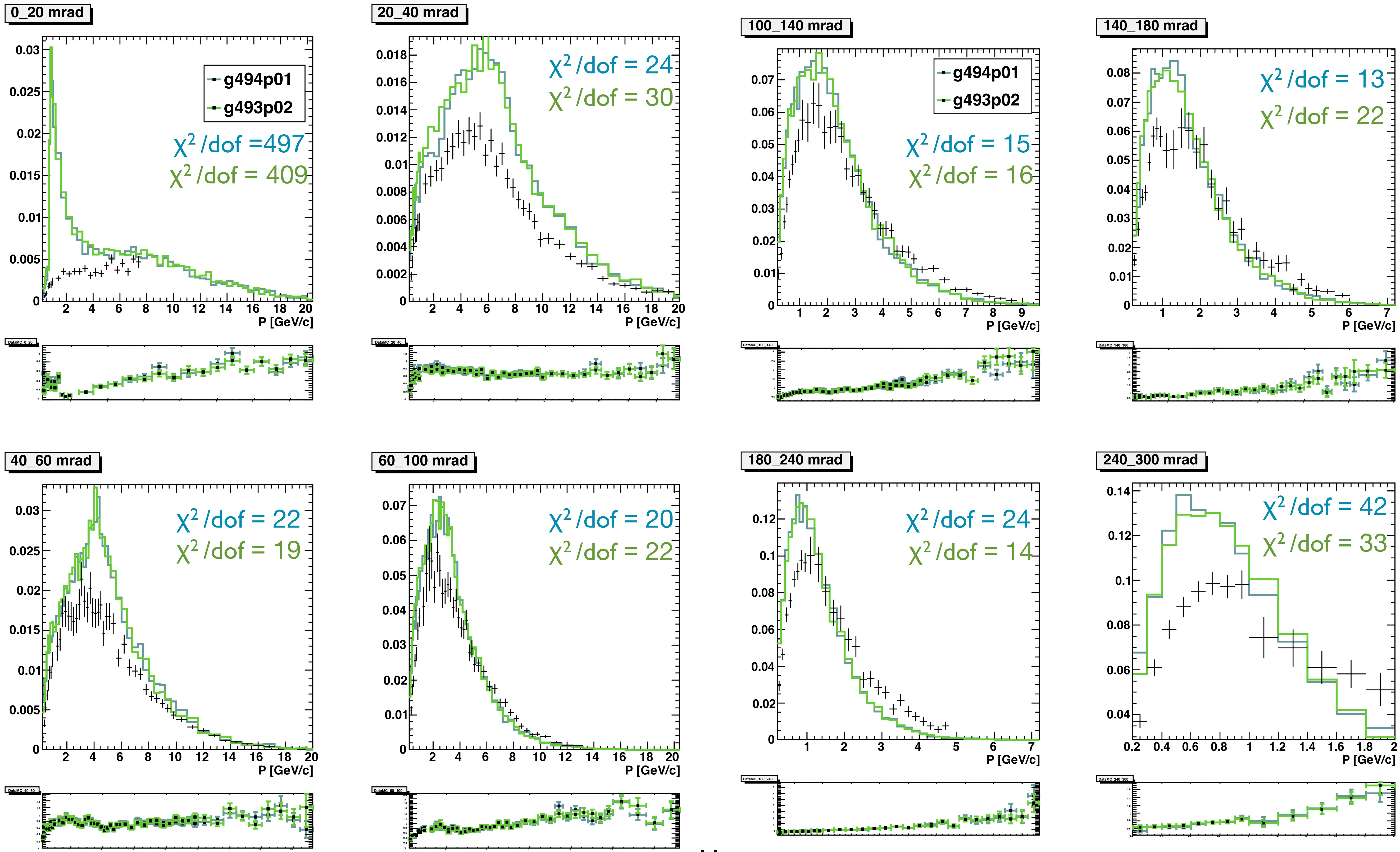
	mbarn	$\sigma_{el\ tot}$	$\sigma_{el\ out\ of\ S4}$	$\sigma_{qe\ tot}$	$\sigma_{qe\ out\ of\ S4}$
QGSP_BERT	g493p02	61.5±0.5	44.8±0.5±1.8 [73%]	28.1±0.3	26.1±0.3±0.2 [92.8%]
	g494p01	72.3±0.5	46.4±0.6±2 [64.2%]	28.4±0.4	27.6±0.3±0.1 [97.1%]
FTF_BIC	g493p02	61.9±0.5	45.7±0.5±1.9 [73.9%]	30.8±0.3	28.8±0.3±0.2 [93.5%]
	g494p01	71.5±0.5	46.2±0.6±2.2 [64.6%]	32.6±0.3	30.9±0.3±0.2 [94.8%]
FTFP_BERT	g493p02	62.1±0.5	45.6±0.5±2 [73.4%]	33.5±0.3	31.1±0.4±0.2 [92.9%]
	g494p01	71.7±0.5	46.1±0.6±1.9 [64.3%]	34.2±0.3	32.2±0.4±0.2 [94.2%]
GFLUKA	geant321	-	57.0±0.5±3.4	14.9±0.2	14.8±0.2±0.03 [99.4%]

Inelastic & production cross section

	mbarn	$+\sigma_{loss\text{-}p}$	$+\sigma_{loss\ \pi/K}$	$-\sigma_{el\ out\ of\ S4}$	σ_{inel}	σ_{prod}
QGSP_BERT Empty geometry	g493p02	4.6±0.1±0.8	0.5±0.04±0.07	45.5±0.4±3.5	257.7±1.9±8.1	229.6±1.9±8.1
	g494p01	4.5±0.1±0.7	0.45±0.04±0.05	45.2±0.4±3.6	257.9±1.9±8.2	229.9±1.9±8.2
QGSP_BERT	g493p02	5.7±0.1±0.7	0.5±0.04±0.06	44.2±0.4±3.8	260.2±1.9±8.3	232.1±1.9±8.3
	g494p01	4.4±0.1±0.8	0.53±0.04±0.05	47.3±0.4±4.2	255.8±1.9±8.5	227.4±1.9±8.5
FTF_BIC	g493p02	2.7±0.1±0.2	0.3±0.03±0.03	46.8±0.4±4	254.3±1.9±8.3	223.5±1.9±8.3
	g494p01	2.5±0.01±0.2	0.4±0.04±0.05	46.7±0.4±4.2	254.4±1.9±8.4	221.8±1.9±8.5
FTFP_BERT	g493p02	3.2±0.1±0.3	0.3±0.03±0.02	46.9±0.4±3.9	254.7±1.9±8.3	221.2±1.9±8.3
	g494p01	3.0±0.1±0.3	0.3±0.03±0.04	46.8±0.4±4.3	254.6±1.9±8.5	220.4±1.9±8.5
GFLUKA	geant321	0.8±0.06±0.1	0.8±0.05±0.1	57±0.4±4.1	242.7±1.9±8.4	227.8±1.9±8.4

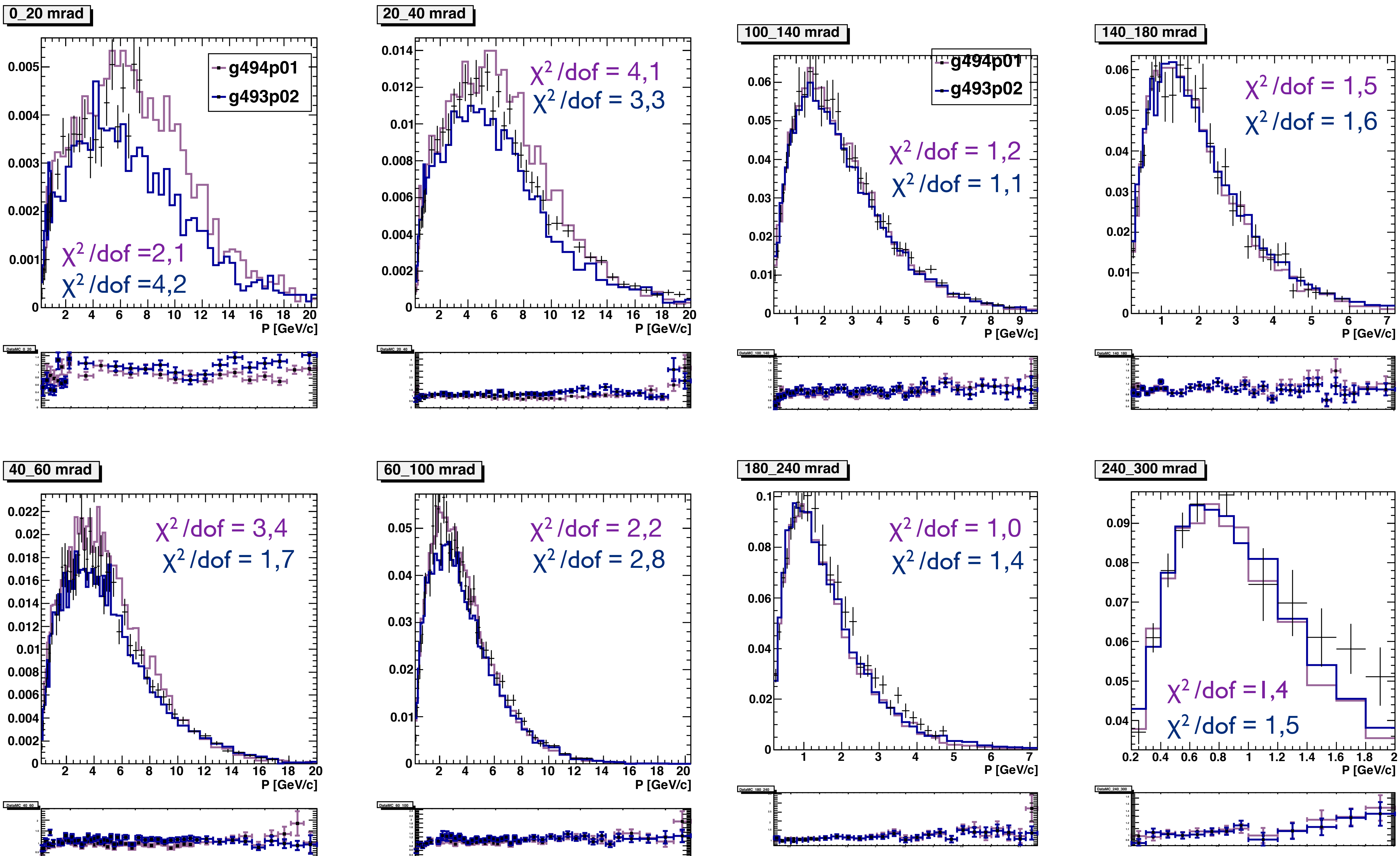
Toward a better simulation of NA61-thin target

QGSP_BERT



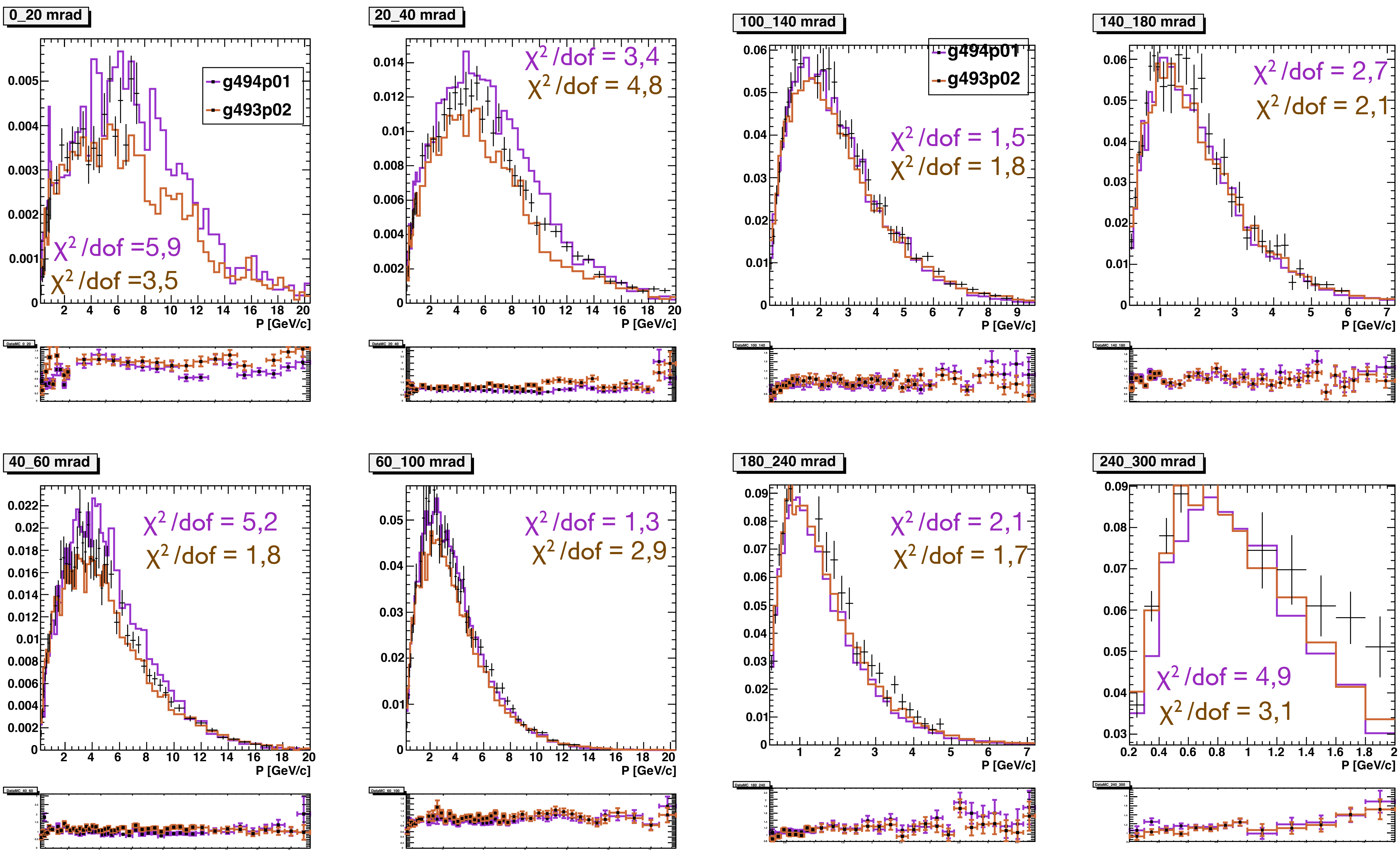
Toward a better simulation of NA61-thin target

FTFP_BERT



Toward a better simulation of NA61-thin target

FTF_BIC



Tuning of FTFP_BERT with FTFP_BERT

In V. Uzhinsky, arXiv : 1109.6768v1 paper, NA61-pion data are used to tune Fritiof-derived models

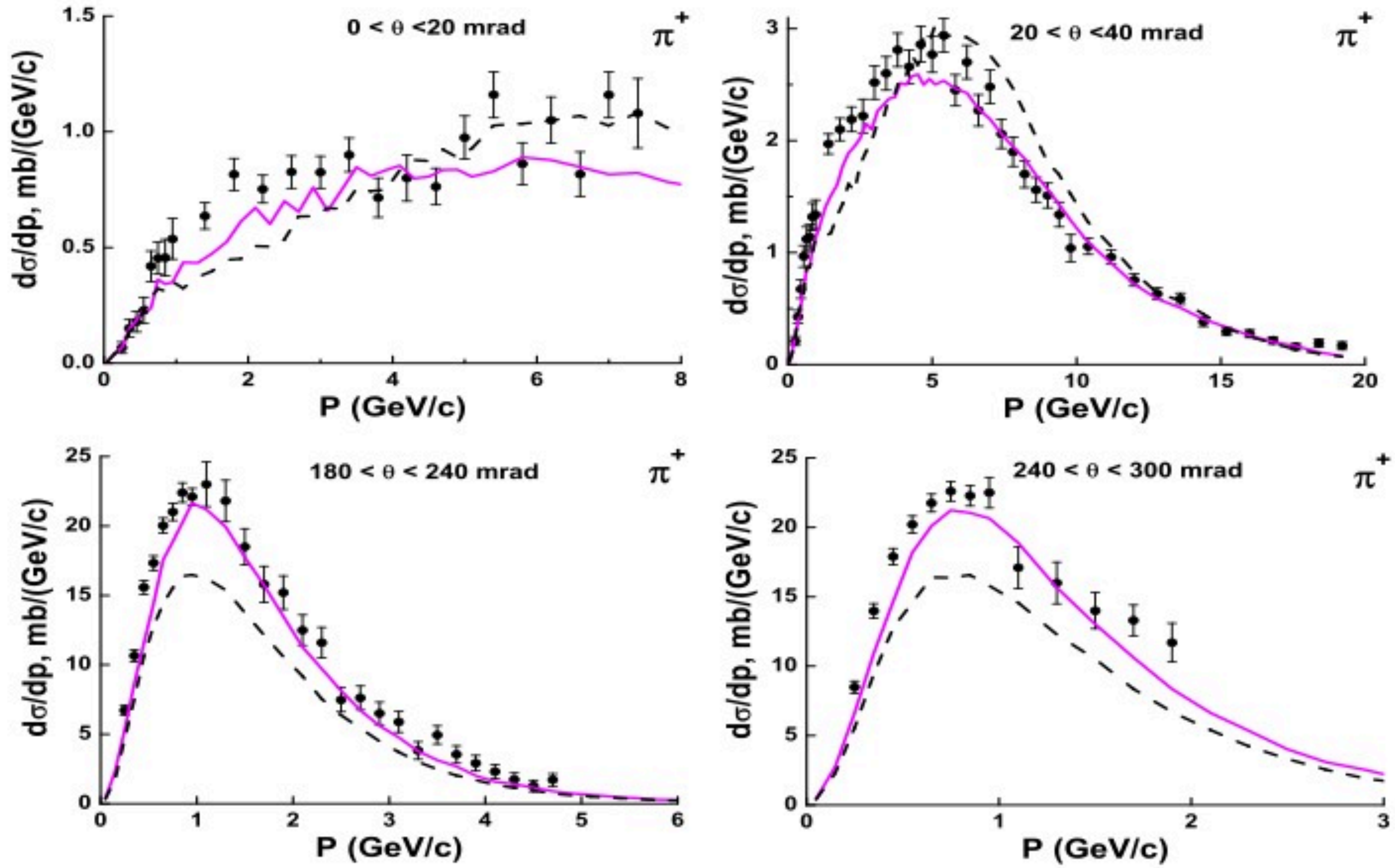
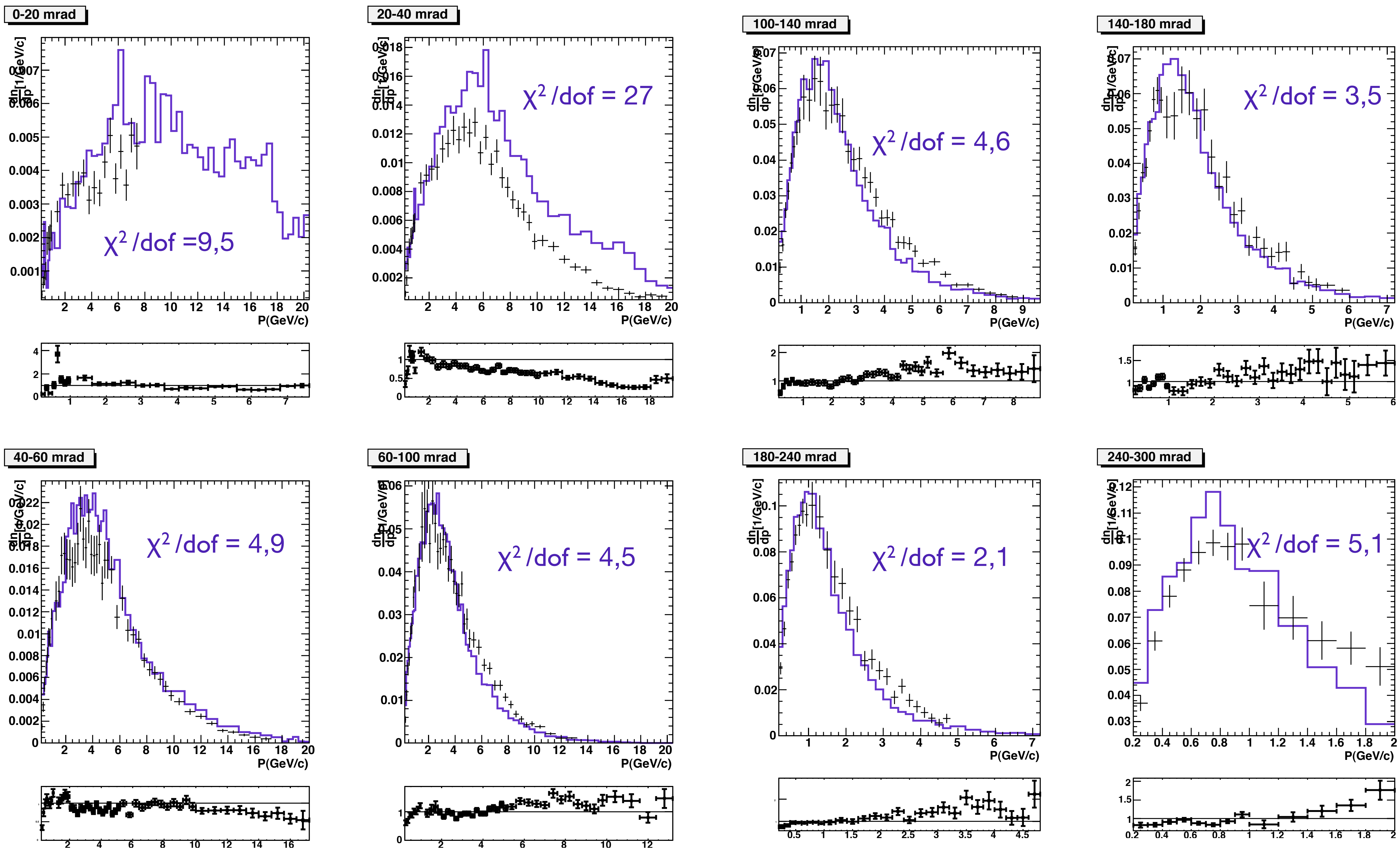


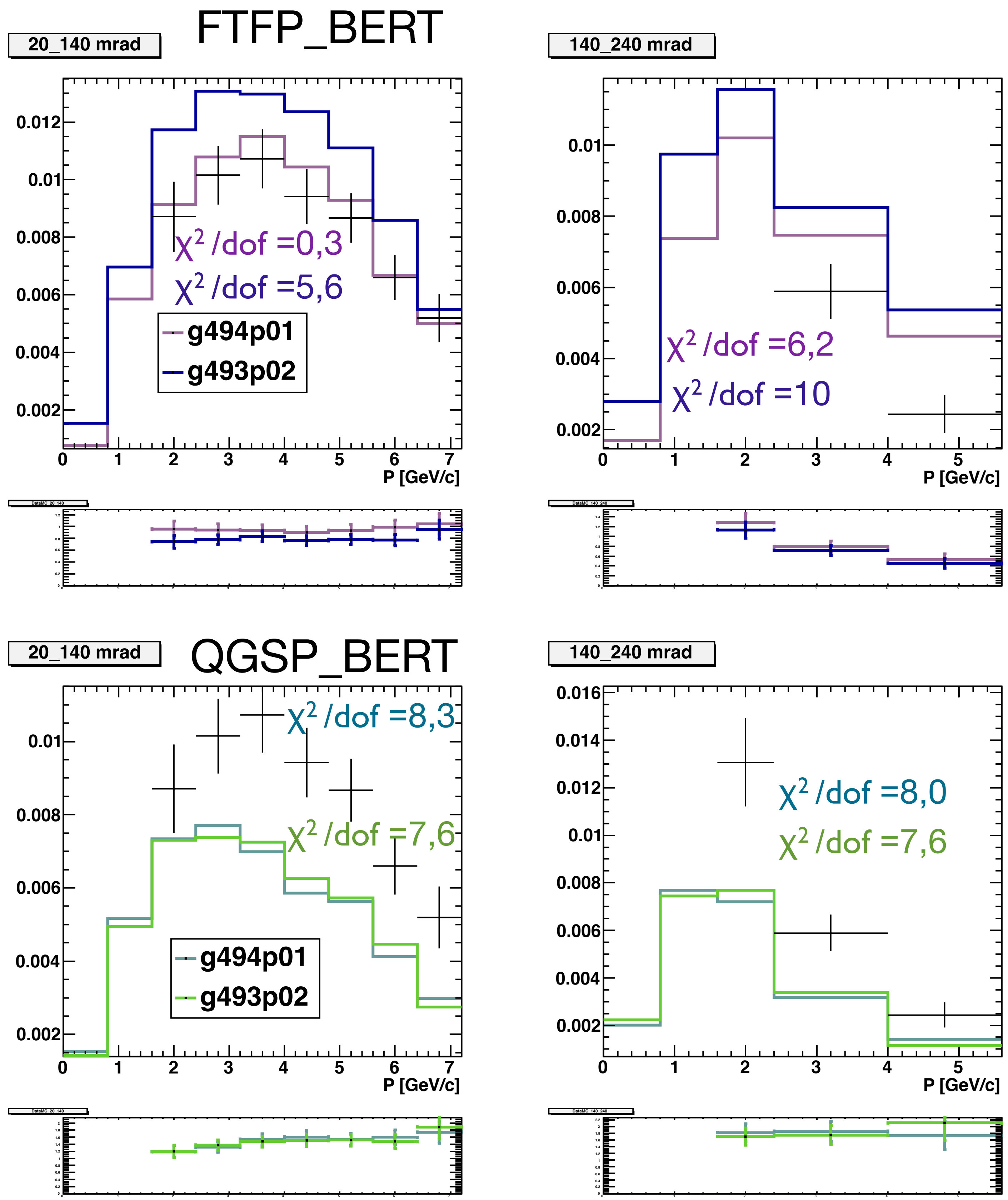
Figure 5: Inclusive cross sections of π^+ meson production. Points are experimental data [1]. Solid and dashed lines are the FTF model calculations with flat and $1/P$ distributions, respectively.

Toward a better simulation of NA61-thin target

GFLUKA



Toward a better simulation of NA61-thin target



So far, the best physics list to be used to describe NA61 data is fritiof-derived models, like FTFP_BERT

Same conclusion for the Geant4-team: A Dotti *et al* 2011 *J. Phys.: Conf. Ser.* **293** 012022
doi:10.1088/1742-6596/293/1/012022

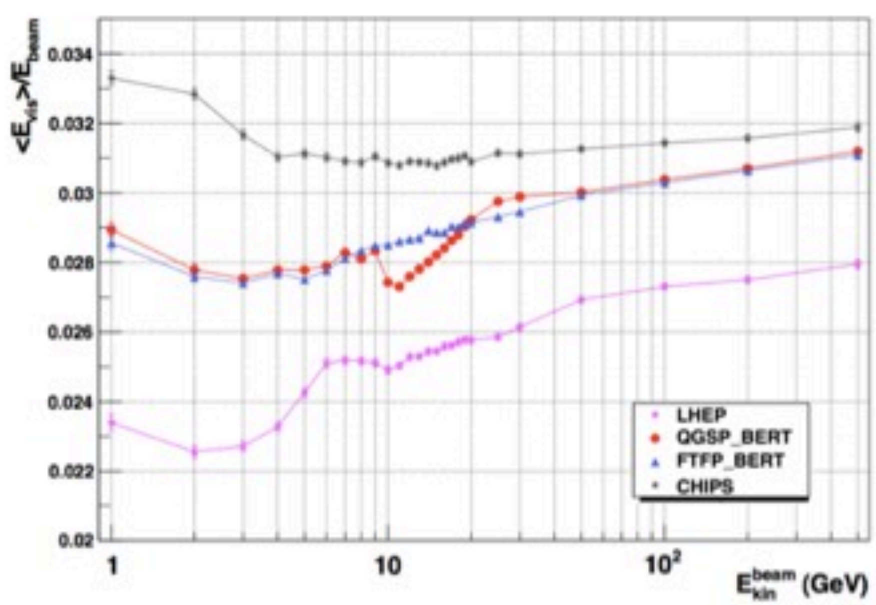


Figure 1. Simulated response in a simplified scintillator/iron sampling calorimeter for negatively charged pions as a function of primary kinetic energy. Different Geant4 Physics Lists are shown for comparison. Statistical and systematic errors are also shown, in many cases they are smaller than the symbol size.

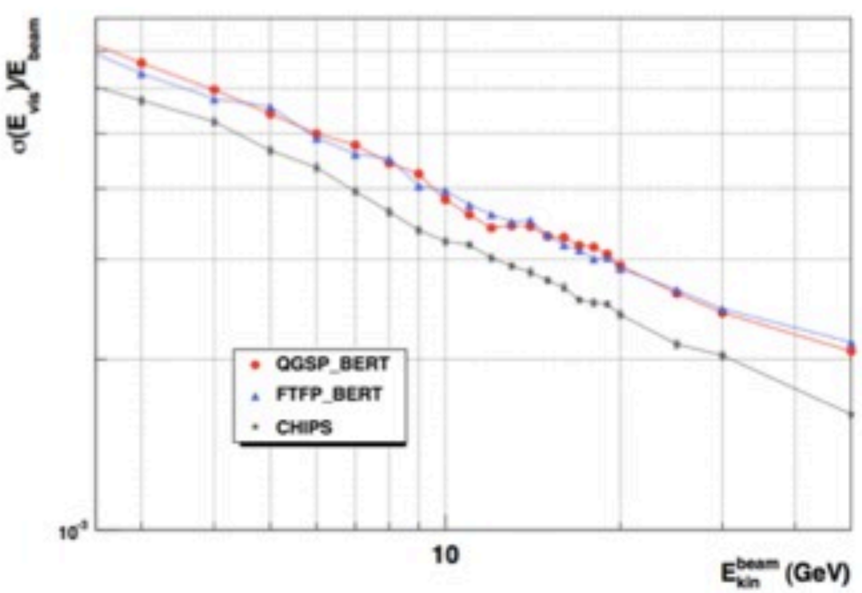


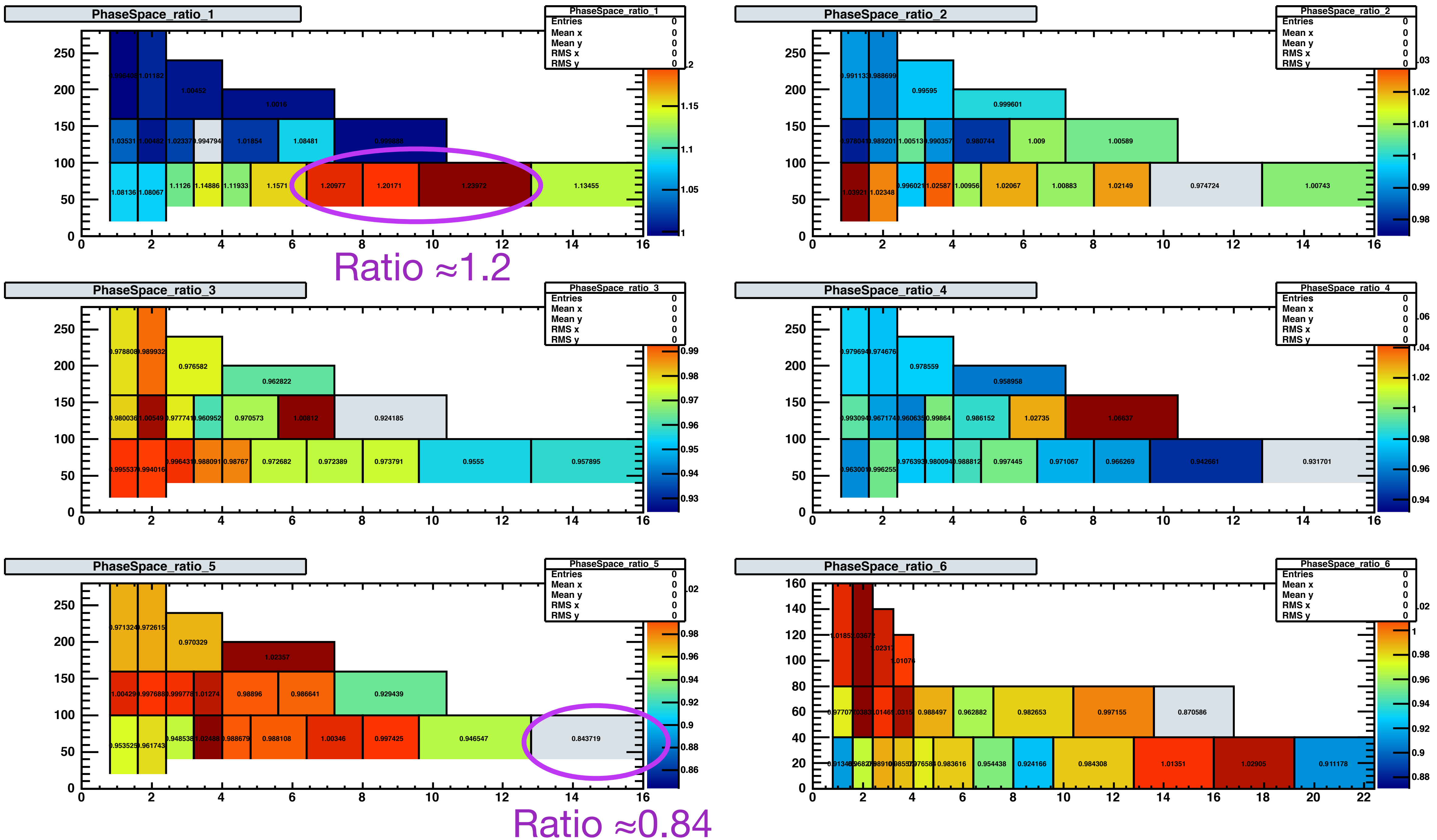
Figure 2. Simulated normalized response width in a simplified scintillator/iron sampling calorimeter for negatively charged pions as a function of primary kinetic energy (the interesting region at E_{beam} = 10 GeV is shown). Different Geant4 Physics Lists are shown for comparison.

Study of the long target: impact of the tilted target

For all long target studies, beam is simulated according to the data

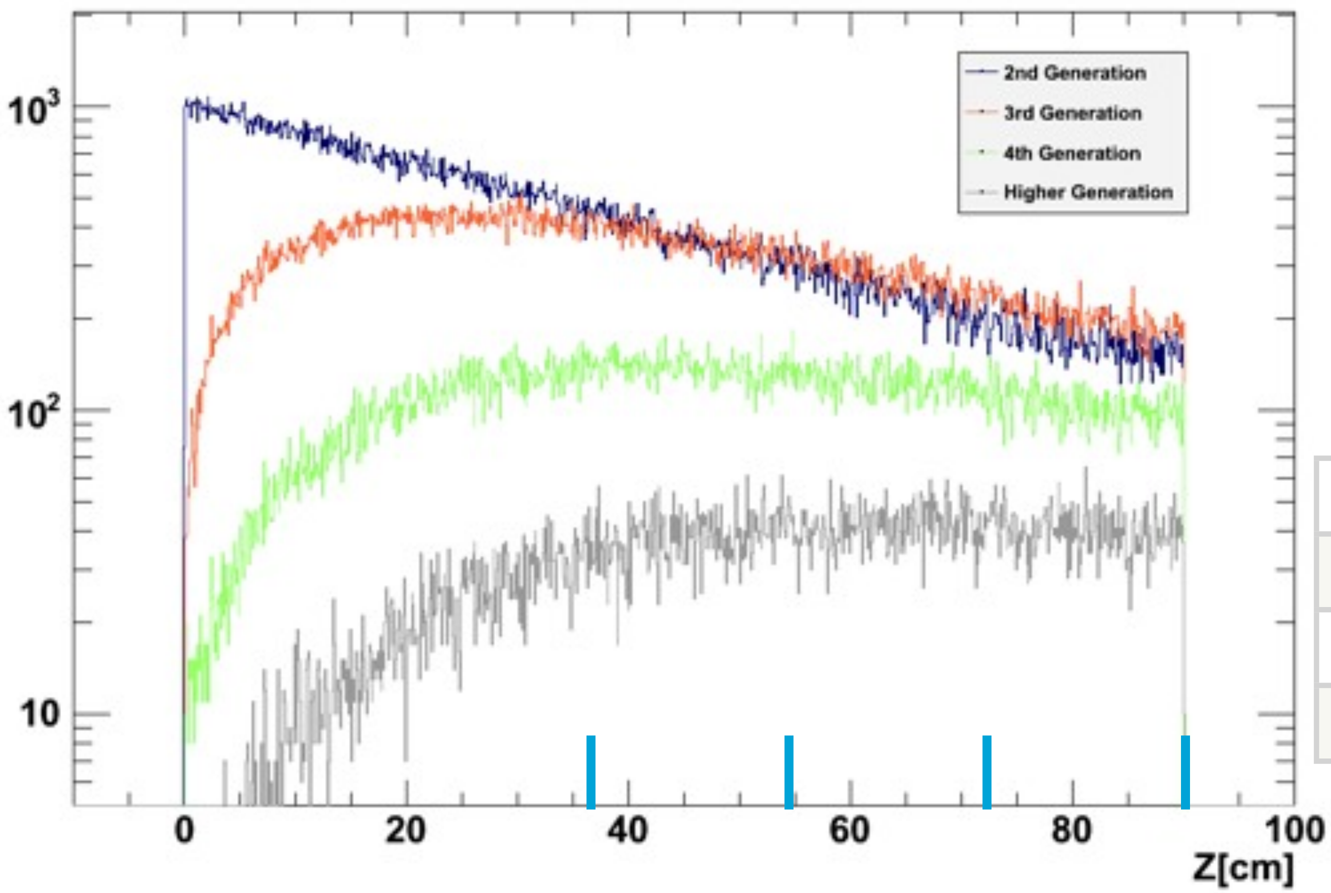
Ratio: PS of aligned target/PS of tilted target, only proton who see an effective length of 90 of carbon are selected.

FTFP_BERT, g494p01



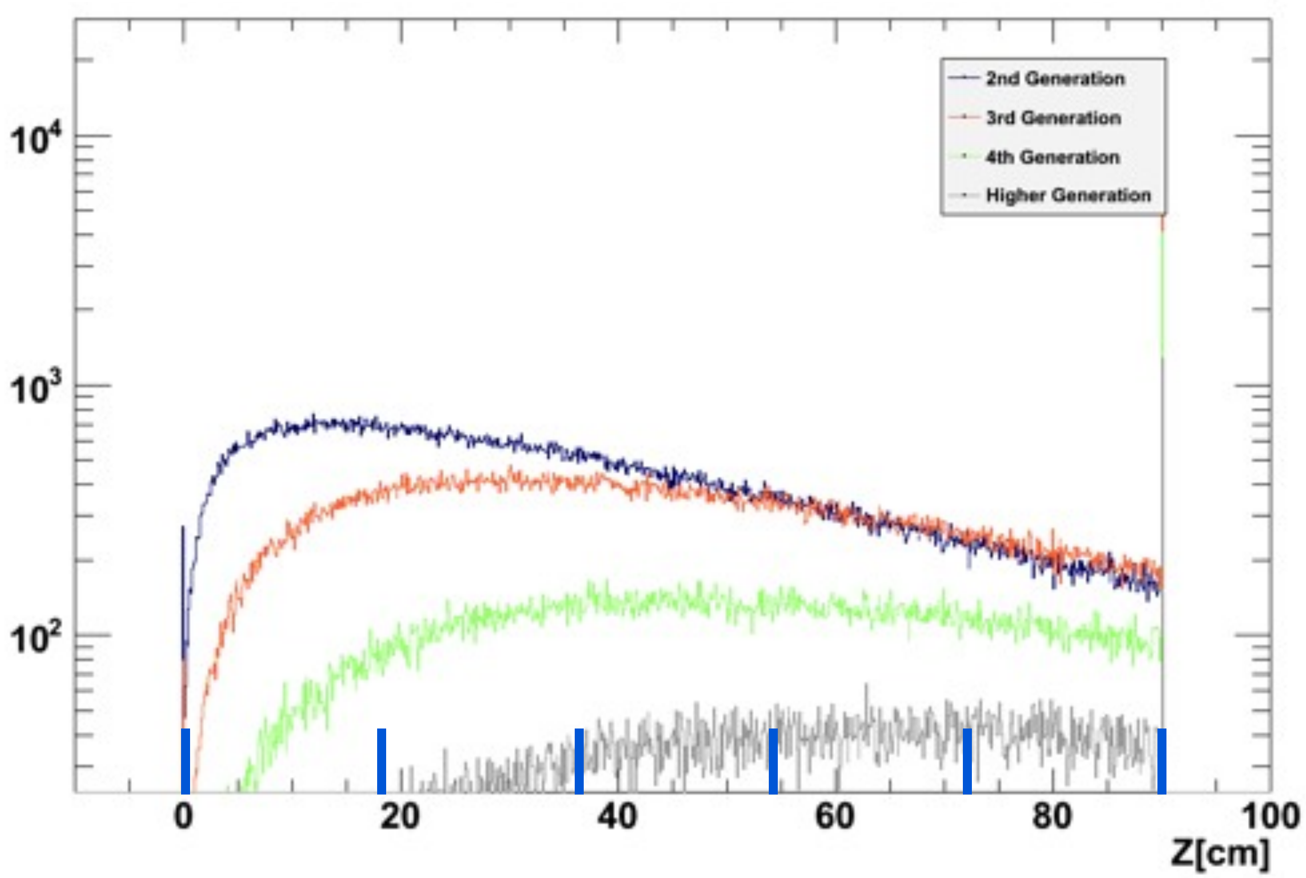
Study of the long target:

FTFP_BERT, g494p01, tilted target



Interaction point of π+ exiting the target

%	Bin #1	Bin #2	Bin #3	Bin #4	Bin#5
2nd Gen.	70.2	49.6	40.6	35.8	33.1
3rd Gen.	24.7	37.3	40.2	40.2	39.1
4th Gen.	4.5	10.7	14.9	18.0	20.0
High Gen.	0.6	2.3	4.2	6.0	7.8



Exiting point of π+

%	Bin #1	Bin #2	Bin #3
2nd Gen.	69.9	54.2	45.9
3rd Gen.	24.8	35.6	39.7
4th Gen.	4.8	8.8	11.9
High Gen.	0.6	1.5	2.4

%	Bin #4	Bin#5	Bin #6
2nd Gen.	41.0	39.2	54.6
3rd Gen.	40.9	40.8	34.4
4th Gen.	14.6	15.9	8.9
High Gen.	3.4	4.1	2.0

A new functionnality of VMC

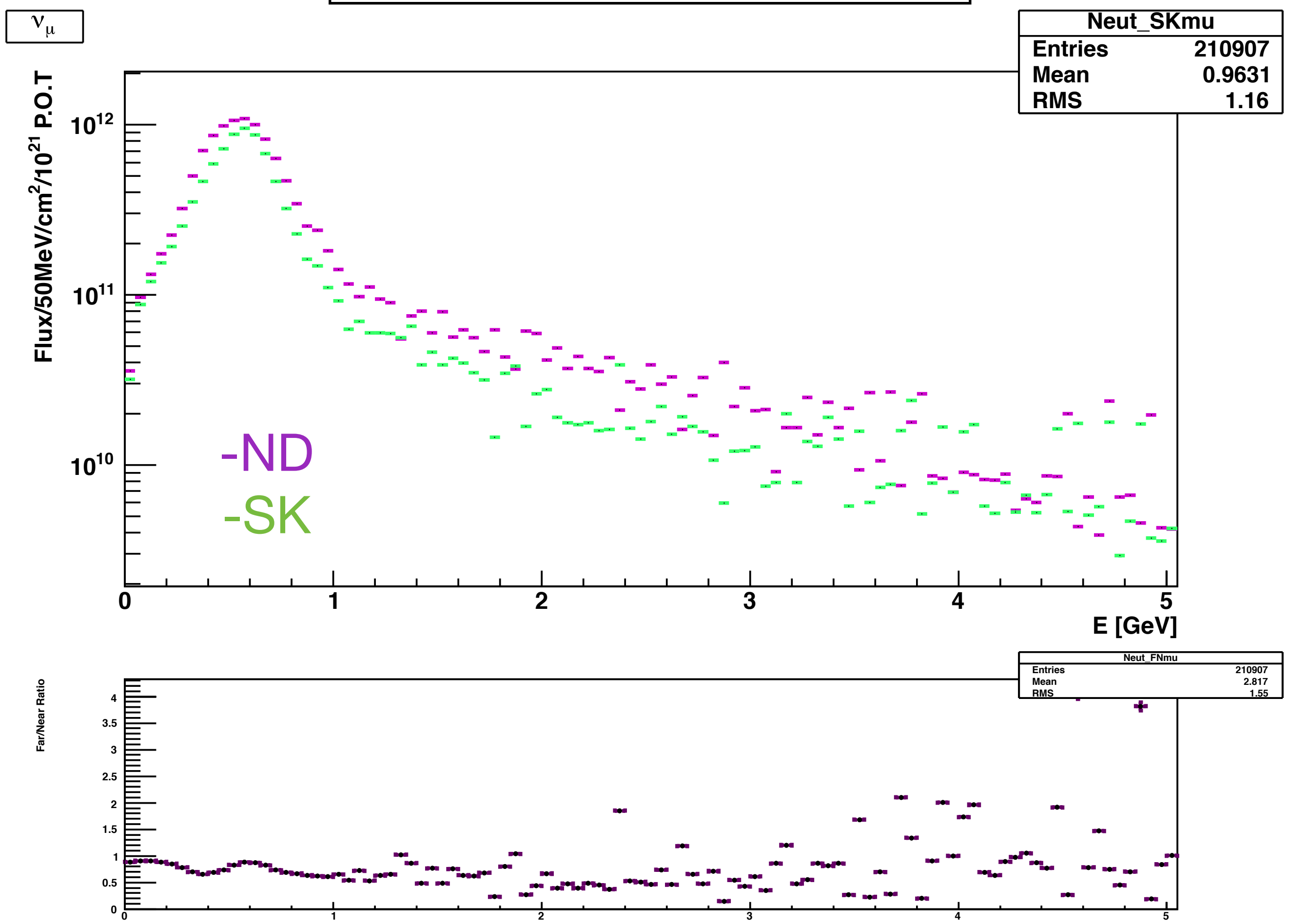
As in Jnubeam & GNA61, it is now possible to use an input file in VMC
E.g. Fluka stand alone is used to simulate interactions in the target. Every particle escaping the target, and its information (pid, momentum, vertex at production and escape, history) is stored in a root file read by VMC. The propagation through the geometry (NA61, T2K, ...) is then handled by VMC interfaced with the appropriate physics list.

In the final VMC output, the whole history of those particles is kept.

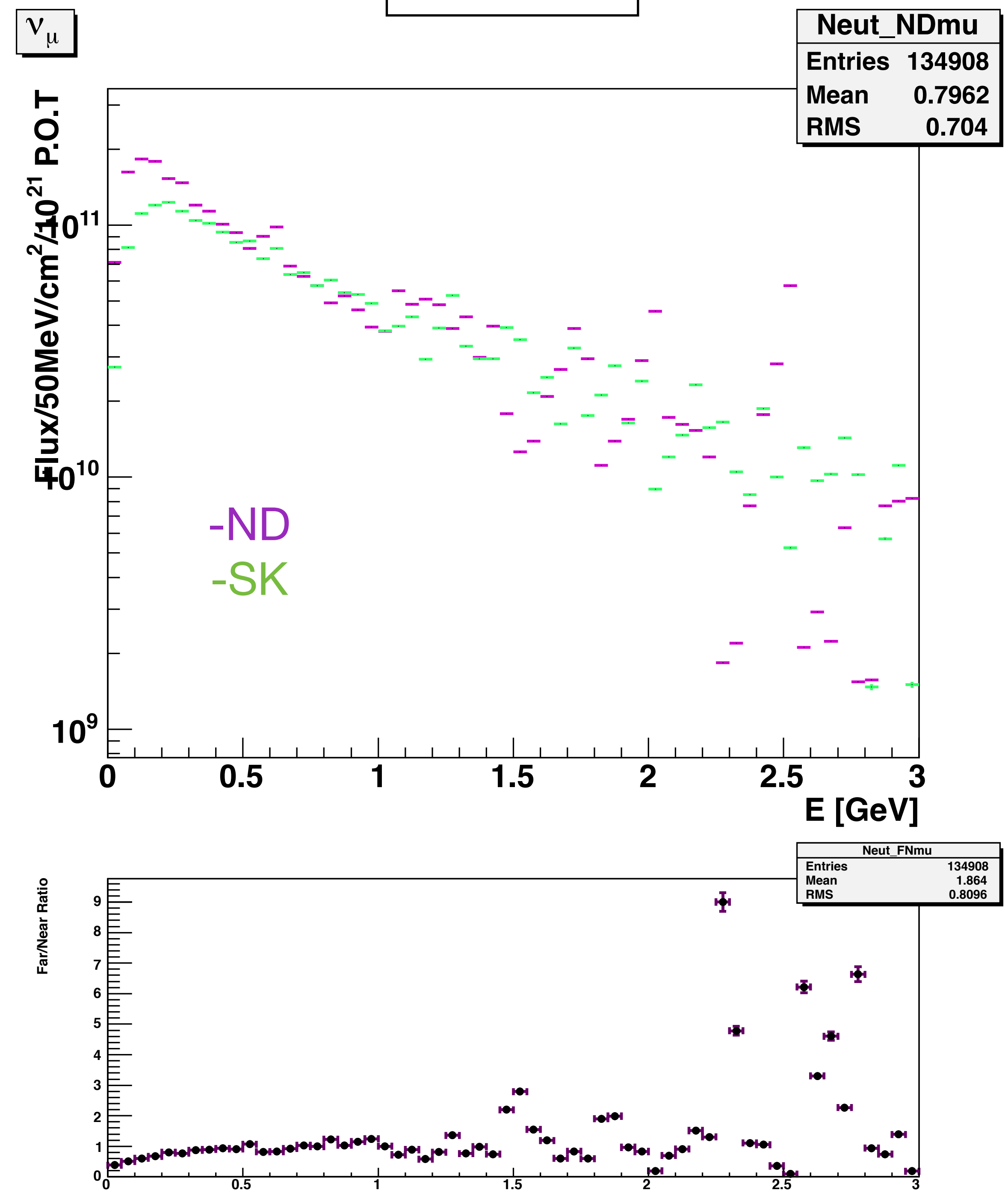
=>Could be a way to compare the VMC project with JNUBEAM for the neutrino flux prediction

ν_μ flux prediction at T2K

FTFP_BERT, g494p01



GCALOR

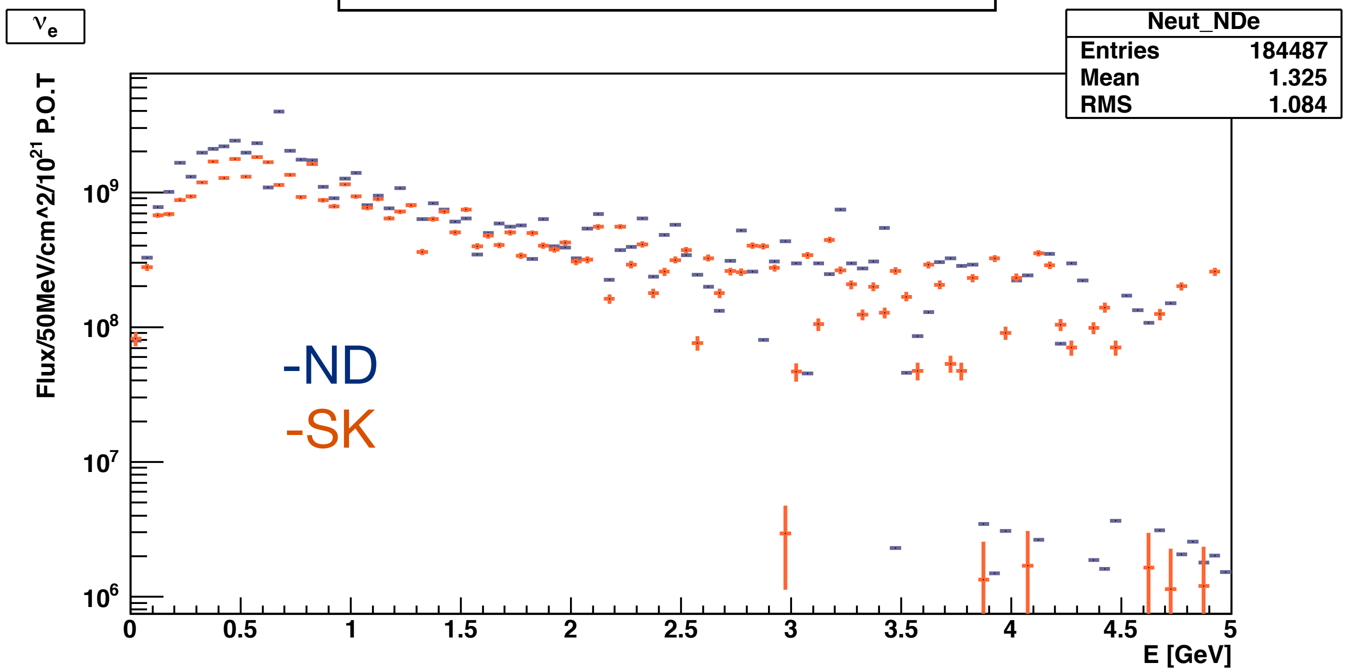


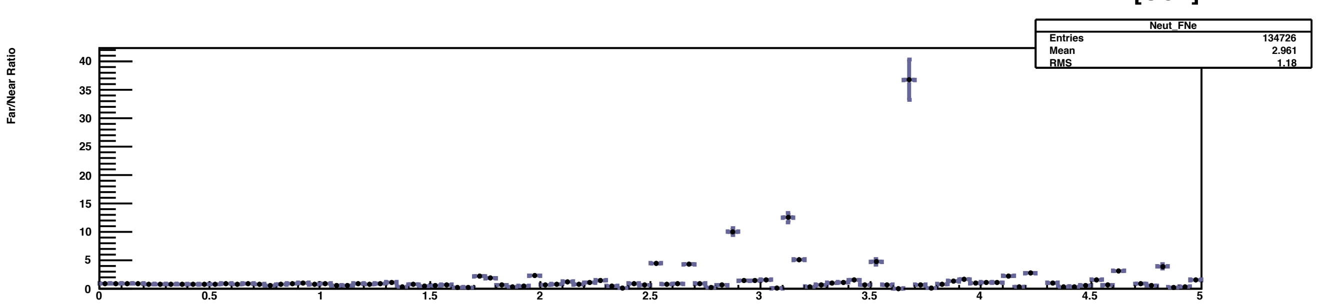
Simulation is done with full T2K geometry for FTFP_BERT.

For GCALOR, the simulation has been done with an empty geometry

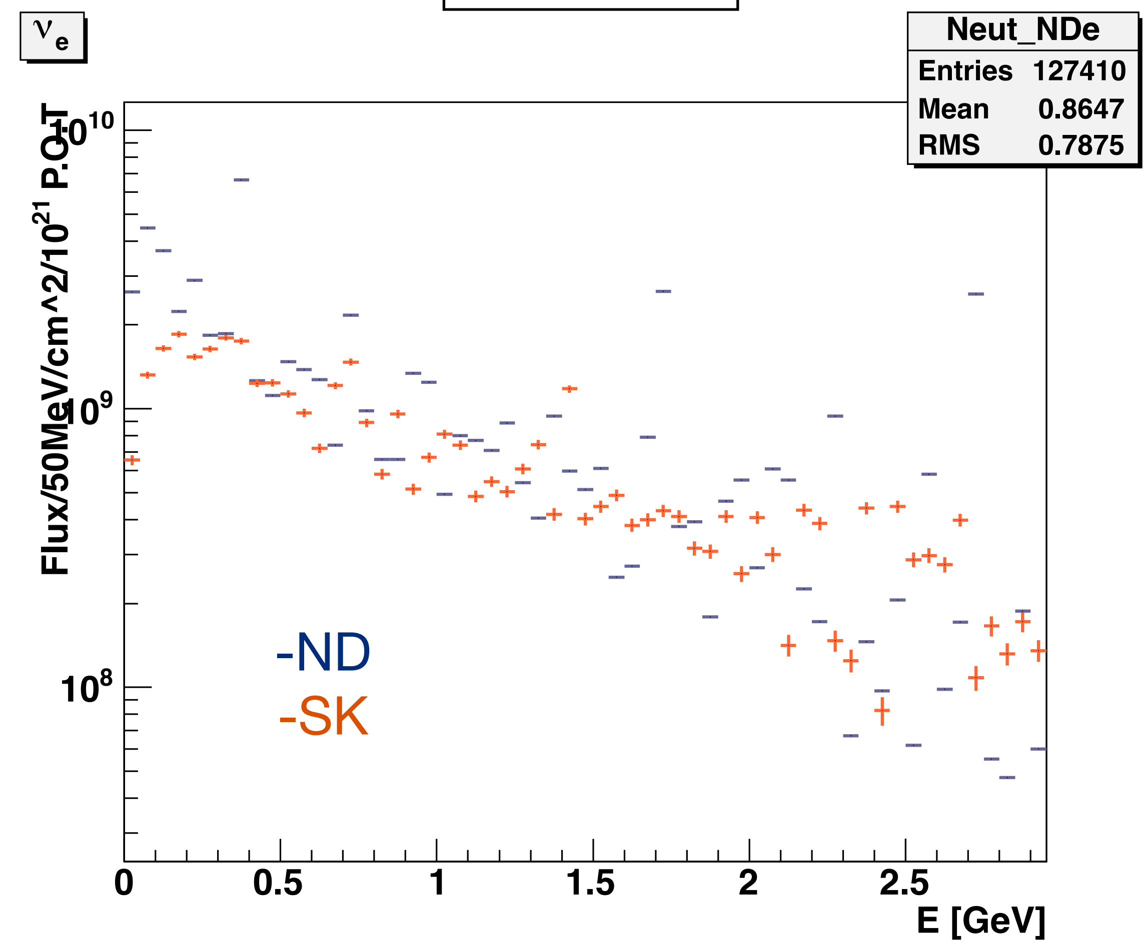
ν_e flux prediction at T2K

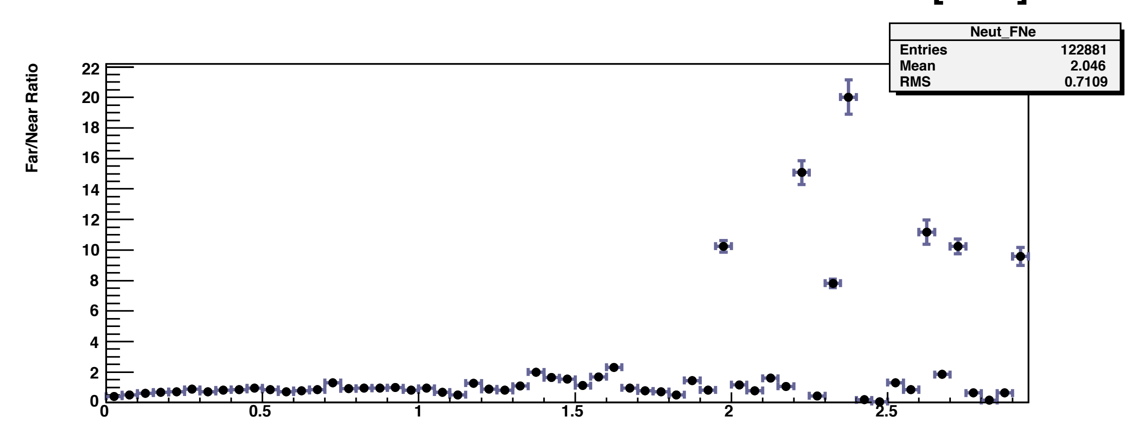
FTFP_BERT, g494p01





GCALOR





Simulation is done with full T2K geometry for FTFP_BERT.

For GCALOR, the simulation has been done with an empty geometry

Conclusion & perspective

Full use of the flexibility of VMC:
-various way to simulate beam (gaussians, from data, from input)
-different geometry implemented (NA61 thin/long target, T2K : to be improved)
-Comparison of physics list with data led to one prefered model: FTFP_BERT, observation confirmed by Geant4-team

Thin target: stuff to do
-Try new version of VMC & Geant4 (see effect of the tuning of FTFP_BERT) ?
-Try CHIPS physics list, as adviced by the Geant4-team
-Internal note in preparation!

Long target: stuff to do
-neutrino fluxes to be compared with JNUBEAM, with input (from Fluka)
-improve T2K simulation (geometry, treatement of decay)
-part of the luminance project?

kaons - FTF_BIC, GFLUKA