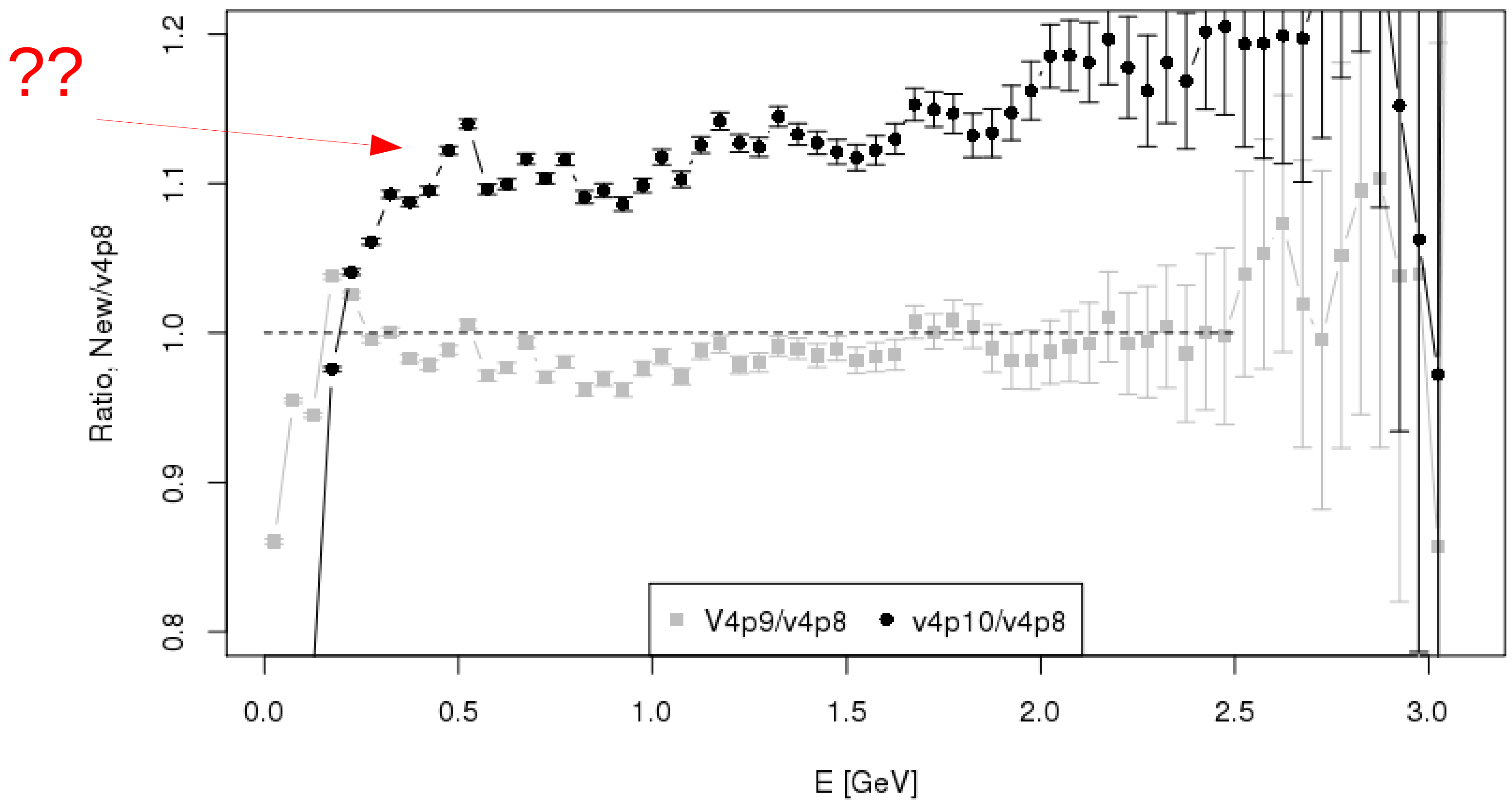
BNB, status, April 14/29 2016.

Onto more analysis:

About the sharp difference between the ν_μ from π^+ decay, v4p10 vs v4p8

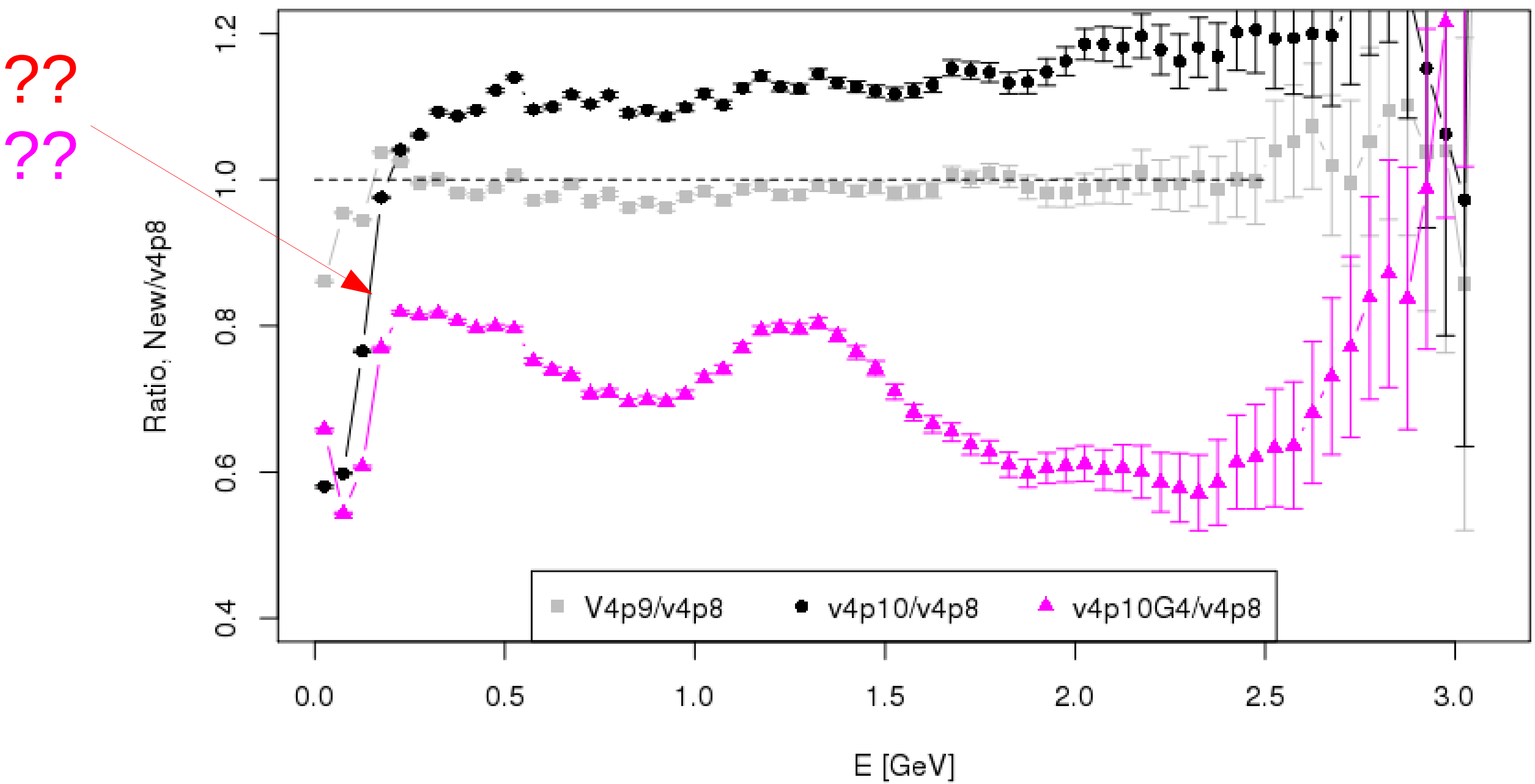
Neutrino flux, from $\pi^+ \rightarrow \mu^+ \nu_\mu$



The ~ 10% at large energy comes from in part from an increase in the targeting efficiency: Less proton elastic scattering, less diffusion.. But what about the low energy deficit? Also, the effective rate at which pions are absorbed could have changed.

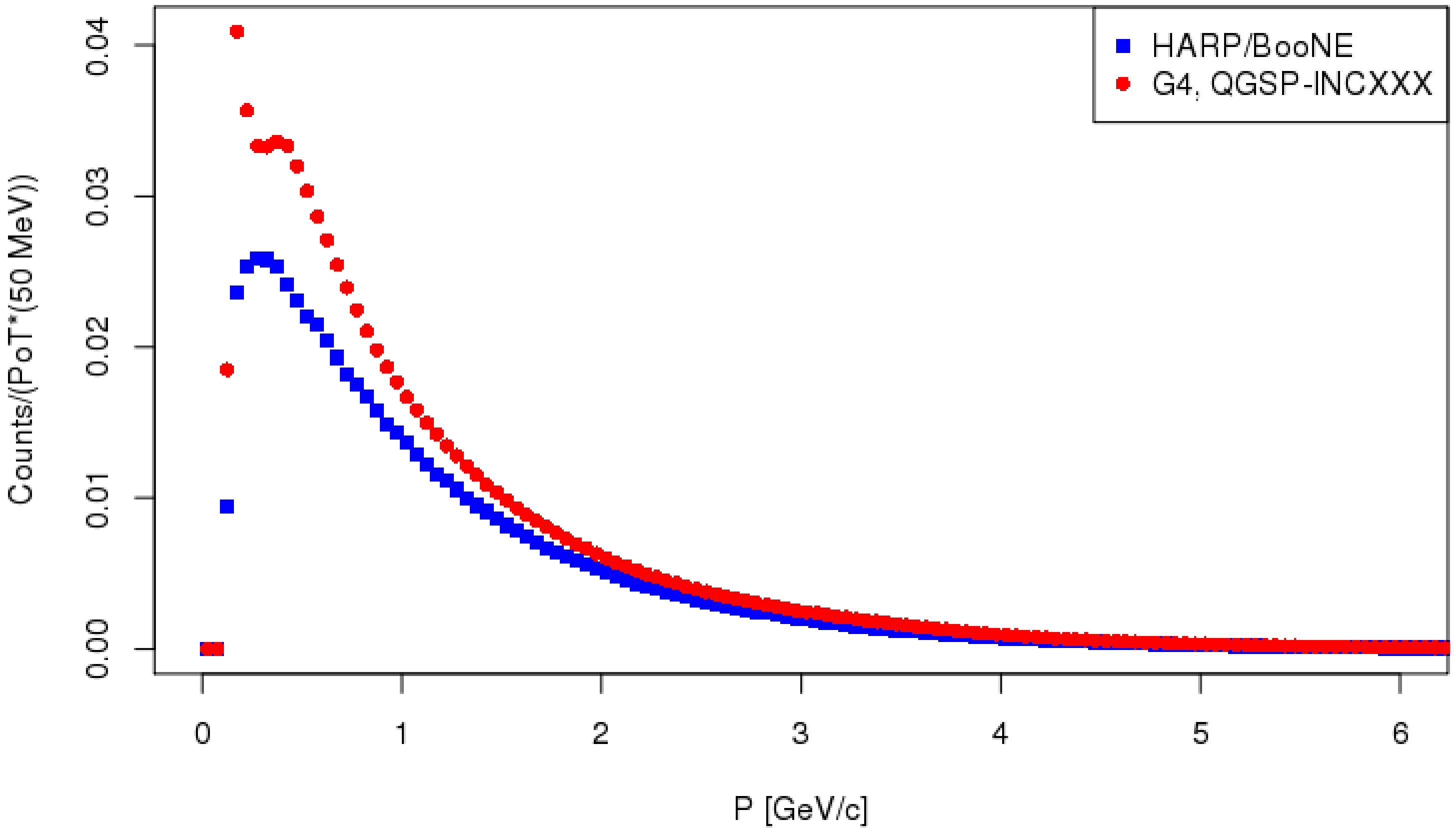
The version based on Geant v4.10.1.p03 also runs and produce a neutrino flux. However, the results are a bit distressing...

Neutrino flux, from $\pi^+ \rightarrow \mu^+ \nu_\mu$



The inelastic production of pions, proton on Be, seems quite a bit different, HARP/BooNE vs QSGSP_INCXX physics list.

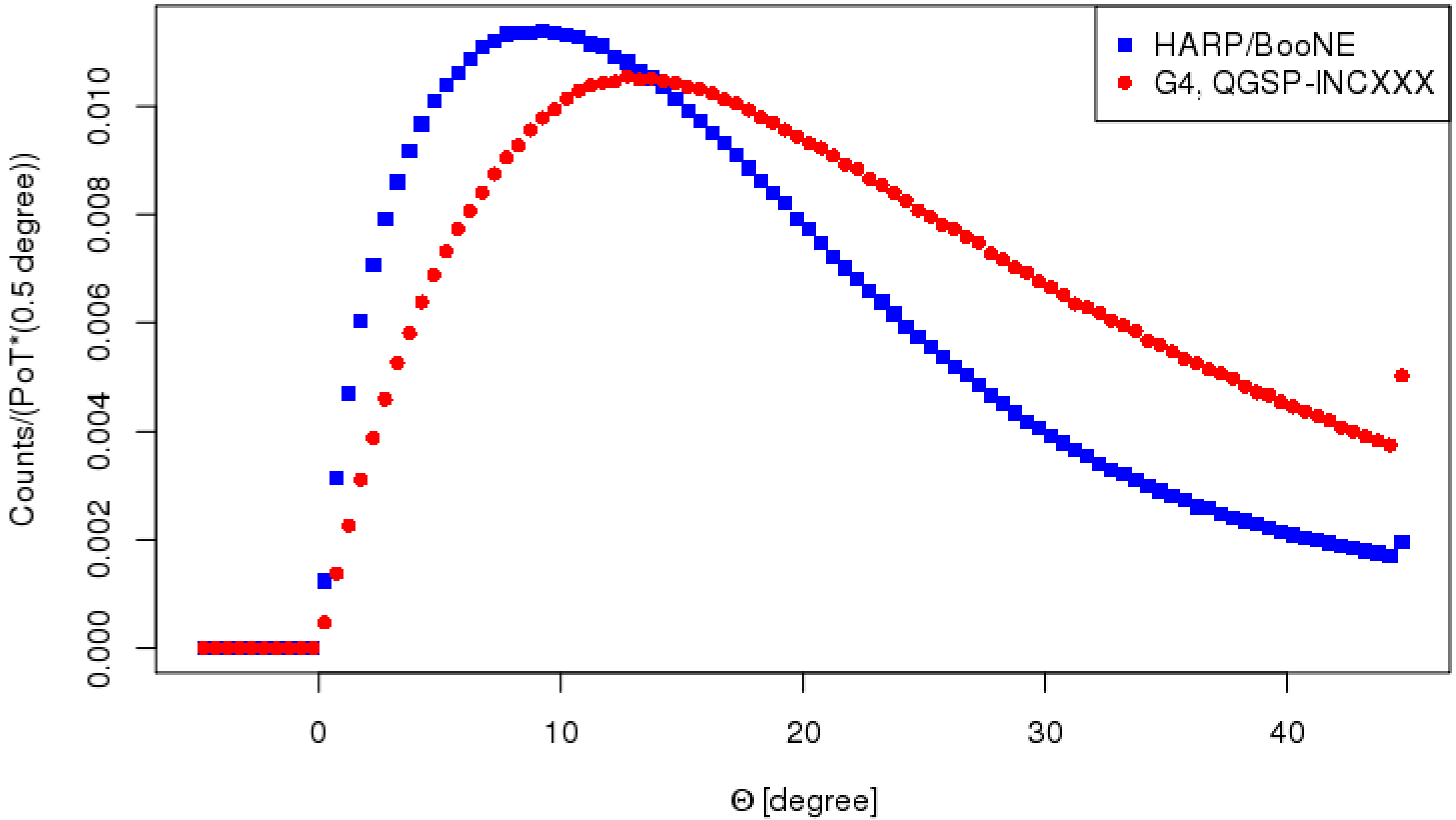
π^+ From p → Be



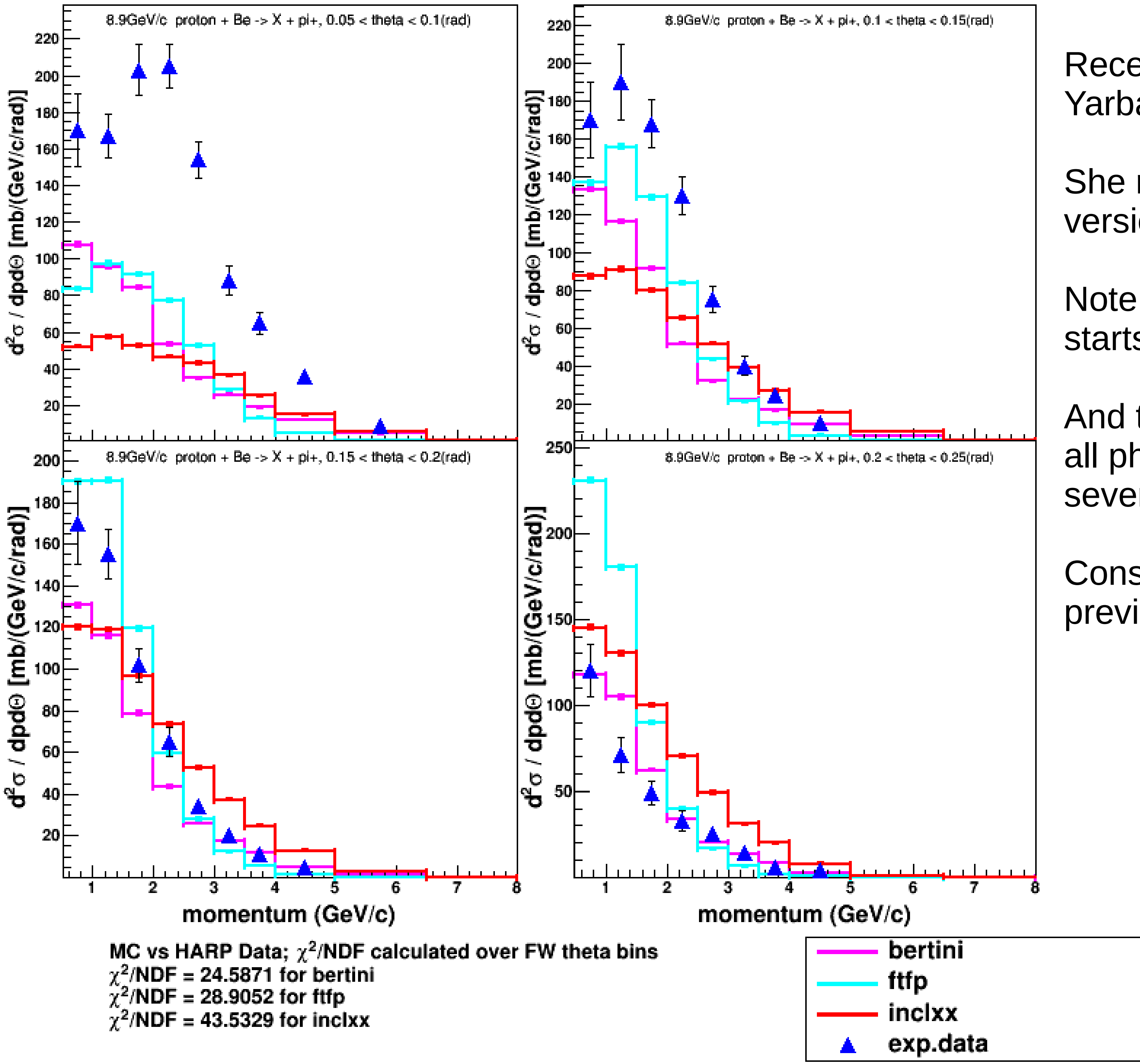
Geant4 GQSP-INCXX (recommended, Hand W. et al) produced a lot more soft pions
So why do we have a deficit of neutrinos ?

Note: This is a bit disappointing.. I would have expected a better agreement...

π^+ From p → Be



The angular distribution differ even more.. Pions produced at large angle may be not be focused enough to go through the collimator.. And we have a serious deficit (almost a factor 2 at ~ 5 degrees) of pions in QGSP-INCXXX .



Received from Julia Yarba,April 14 2016.

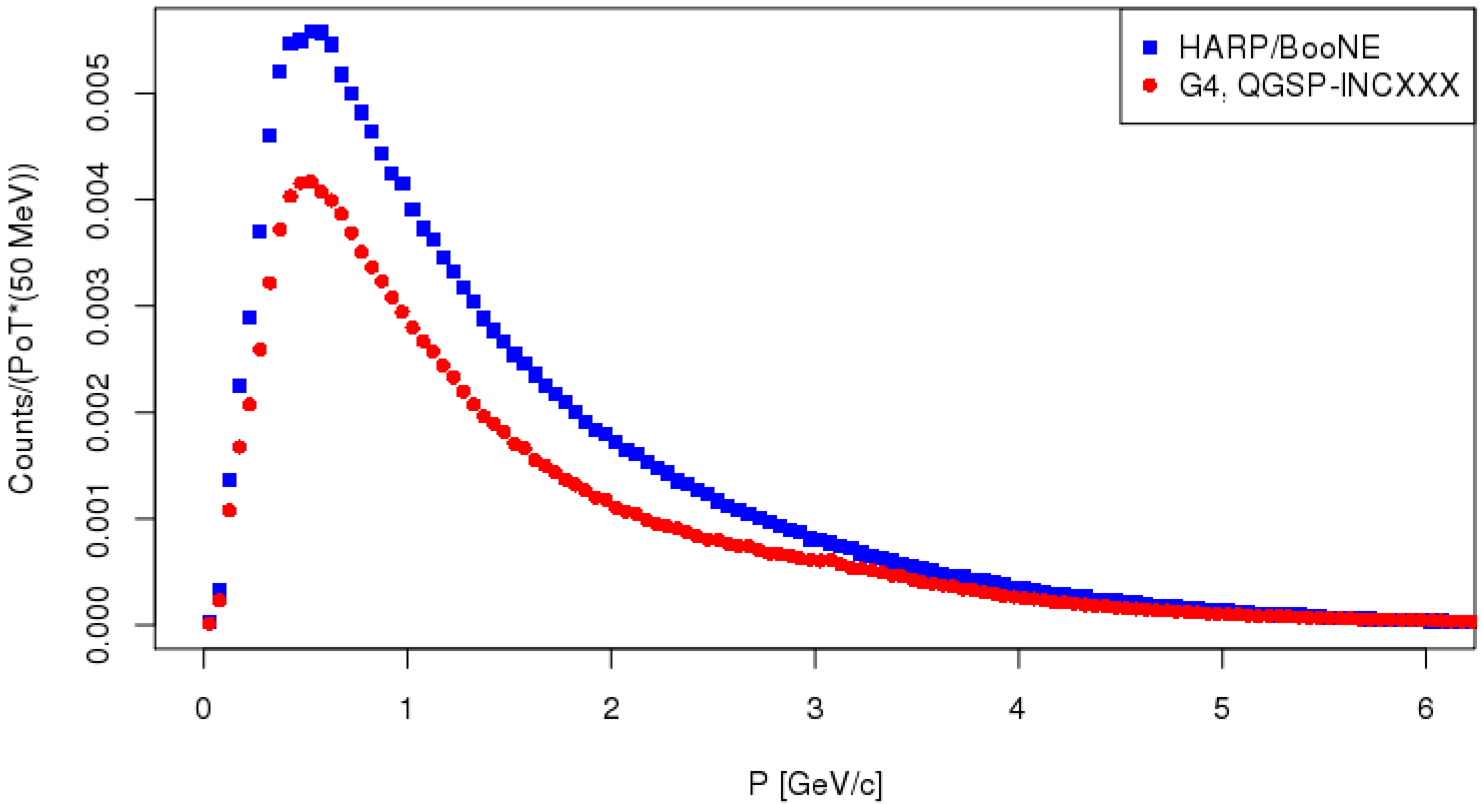
She ran the same G4 version..

Note that the comparison starts at 50 mRad.

And the G4 MC deficit (for all physics list do show a severe deficiency.

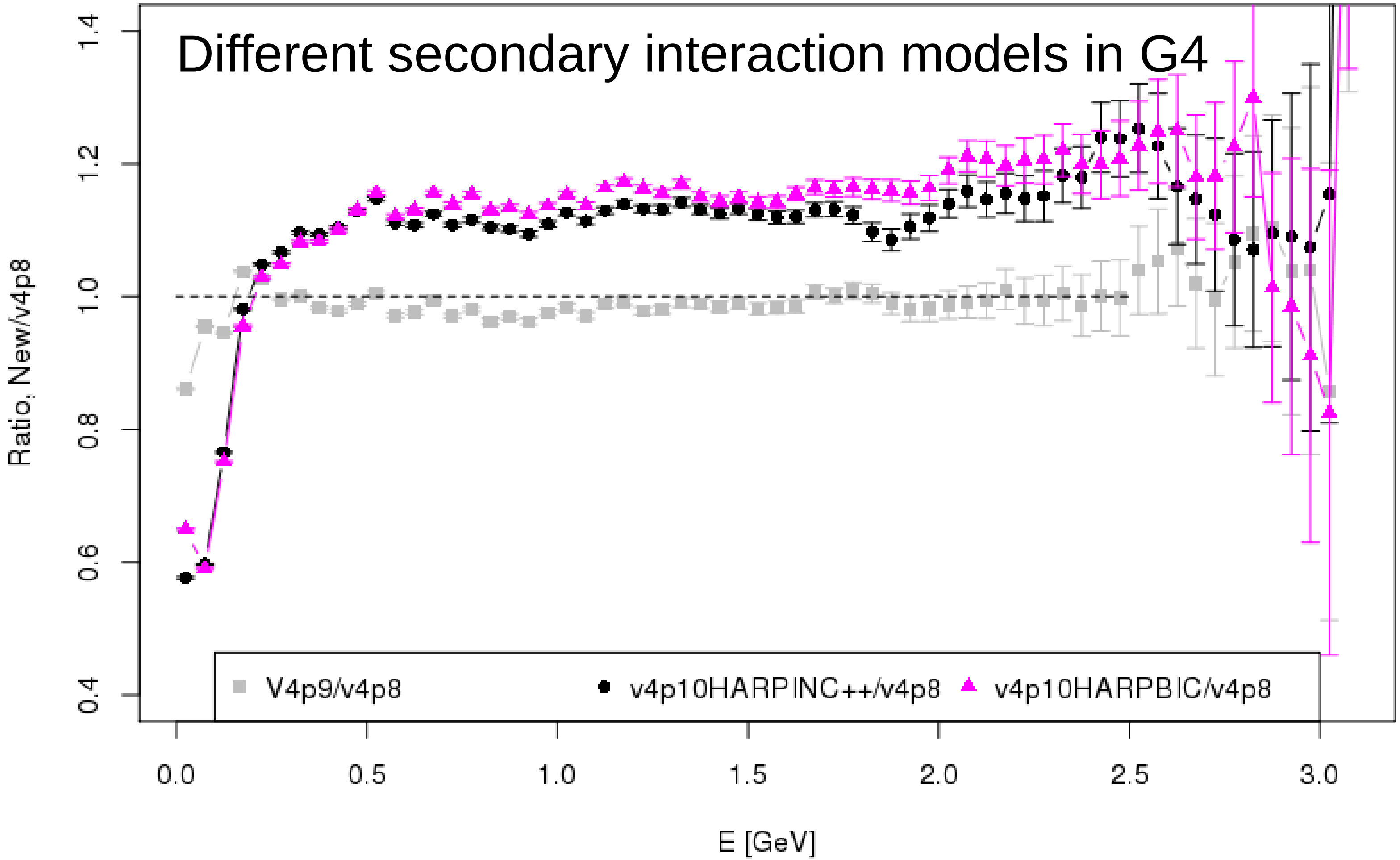
Consistent with the previous slides.

π^+ Yield After the Collimator...



Consequently, we have a serious deficit of pion filtering through the collimator...

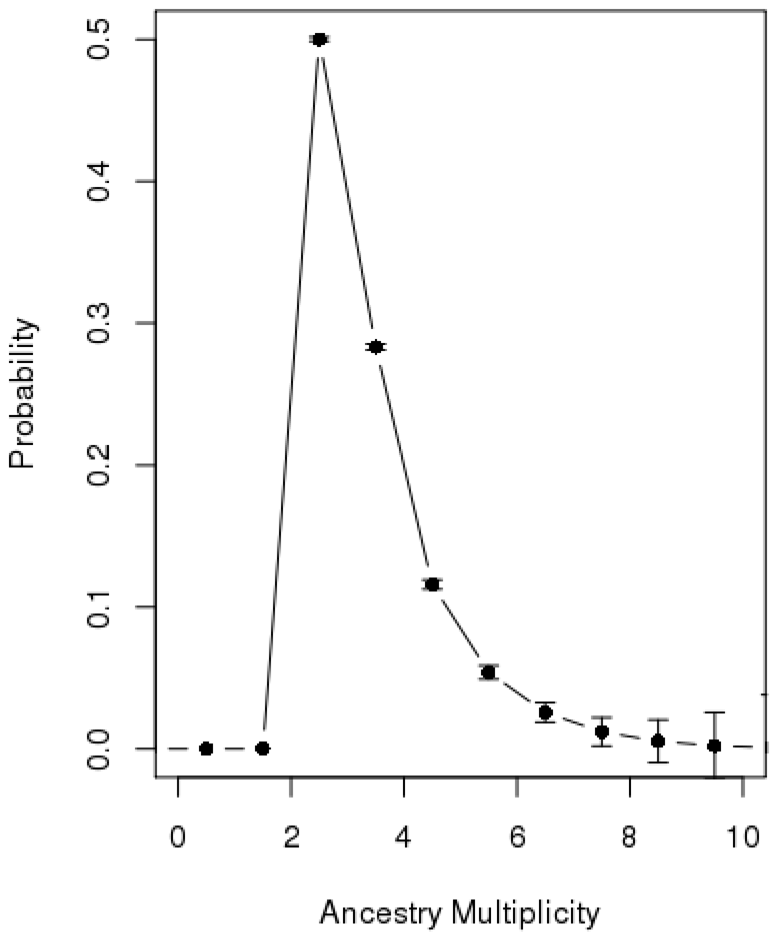
Neutrino flux, from $\pi^+ \rightarrow \mu^+ \nu_\mu$



In all three cases, the S_W HARP/BooNE inclusive production model is used,
But we have different scattering models for proton on Be, and pion on Be, Al, Steel, etc...

Back to the HARP/BooNE generator for 1rst generation of pions.

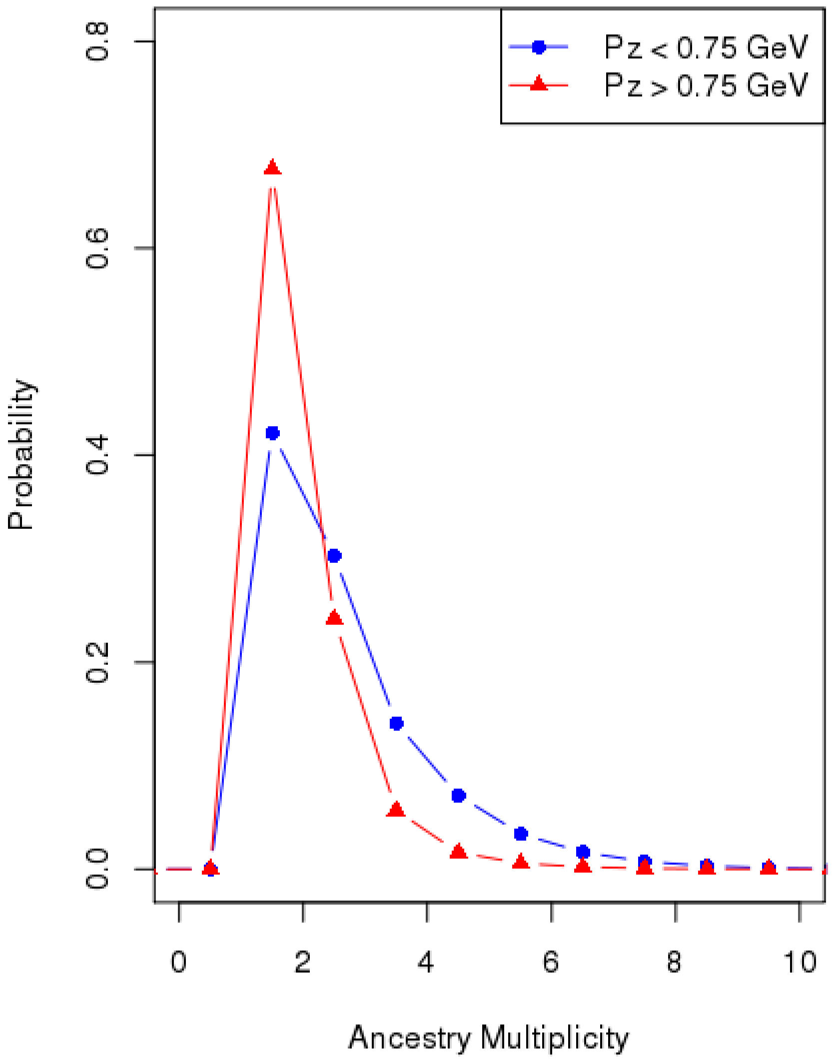
The Dk2nu ancestry has been ugraded to include both inelastic and elastic collisions, as these can induce significant change in the transverse momentum of the pion, thereby compromising proper focusing.



First, we select all the pions in the Dk2nu ntuple that are (I) positively charged (ii) and will decay to $\mu^+ \nu_\mu$ Then, ask the depth of the ancestry tree of the out coming neutrino. The minimum is 2, as the primary does not decay into a neutrino, but counts in the ancestry. These are the "easy" cases" proton comes in, create π^+ (HARP/BooNE) model, and this π^+ decays without scattering at all.

This is only 50% of the neutrinos that appear in the Dk2nu ntuple. This ancestry multiplicity is shown on the plot on the left.

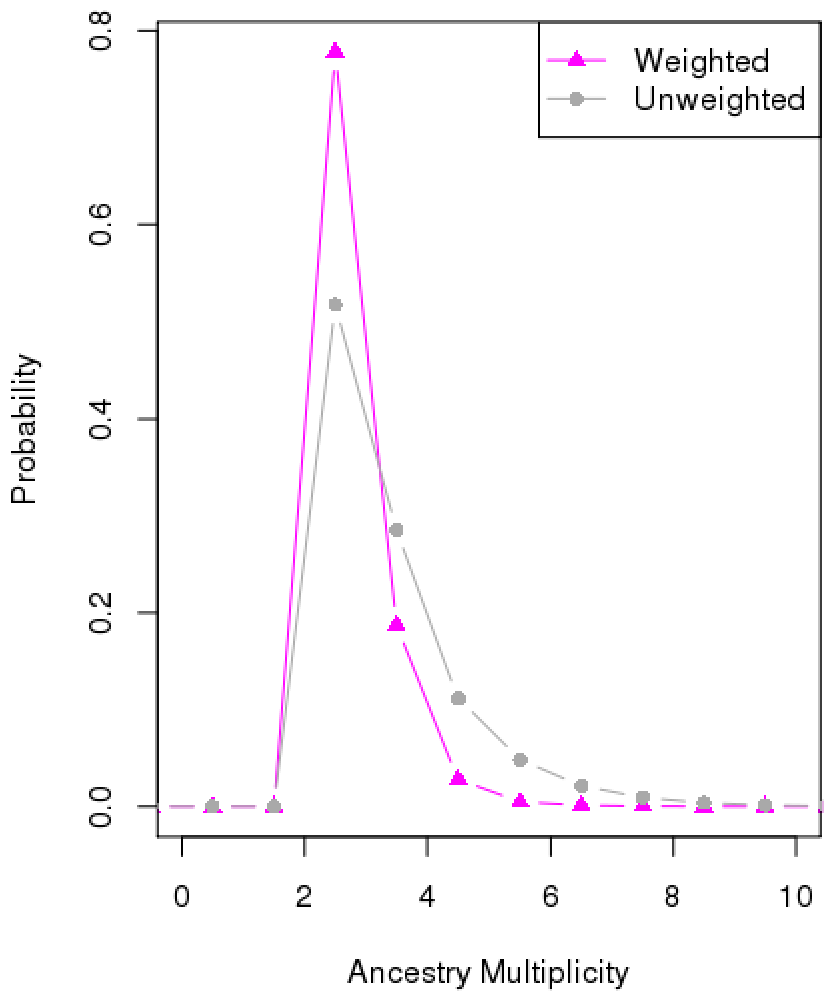
(At high multiplicity, Gaussian-based uncertainties are incorrect, overestimated, but mostly irrelevant, due to low fluxes.)



But, perhaps, it is only the wimpy pions that do scatter, and those are not likely to get enough boost to point towards the neutrino detector.

Actually, this what we see. But this effect is not large: we still have ~32% of the pion with large (> 0.75 GeV/c) that are subjected to secondary interactions or scattering (ancestry multiplicity > 2).

Note that these are the probability for a ν_μ to be emitted, not necessarily towards a specific detectors.

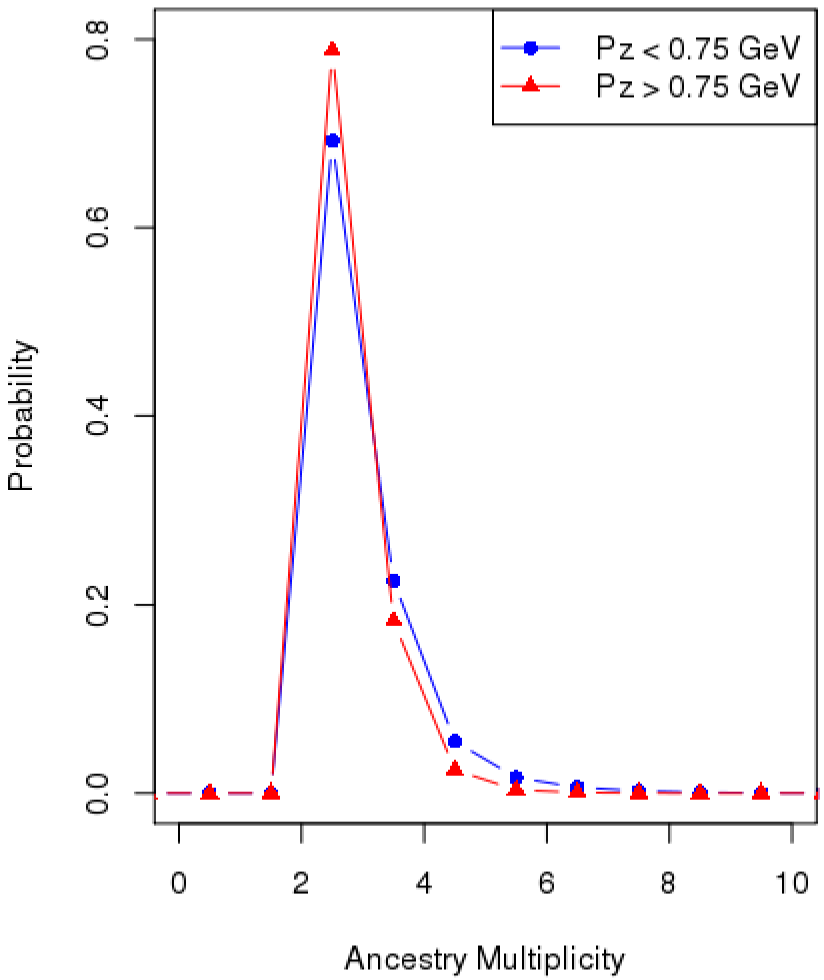


Since we keep comparing neutrino fluxes at the MiniBoone detector, a more realistic determination of the ancestry multiplicity distribution is the one corrected for the MiniBoone “detector weights”

Computed the “MiniBooNE/T2k” way..

22% of the pions that produced a ν_μ towards MiniBoone have did scatter, or were produced by by secondary interactions.

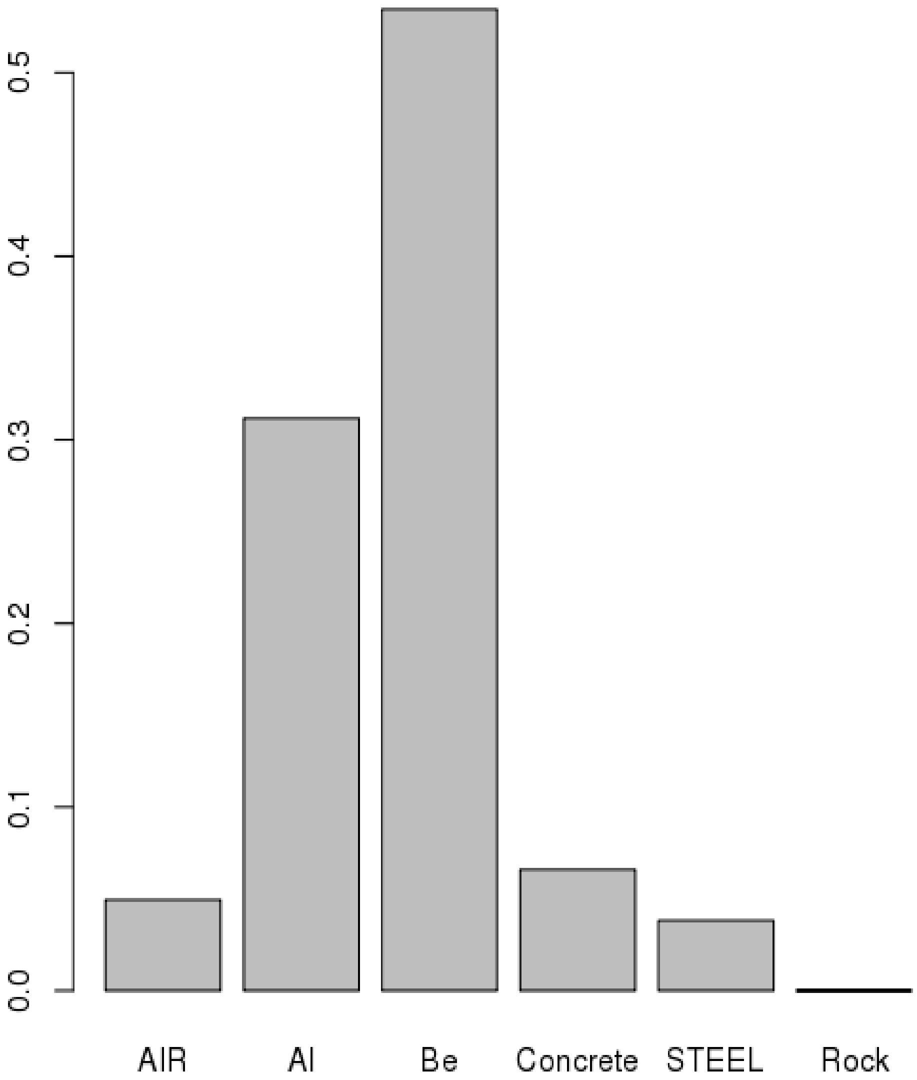
(The grey curve is the black curve on slide 11.)



For sake of completeness, here are the same curves as presented before (slide 12) , but corrected by the MiniBoone detector weights.

Pz here refers to the longitudina lmomentum of the pion that produced the neutrino.

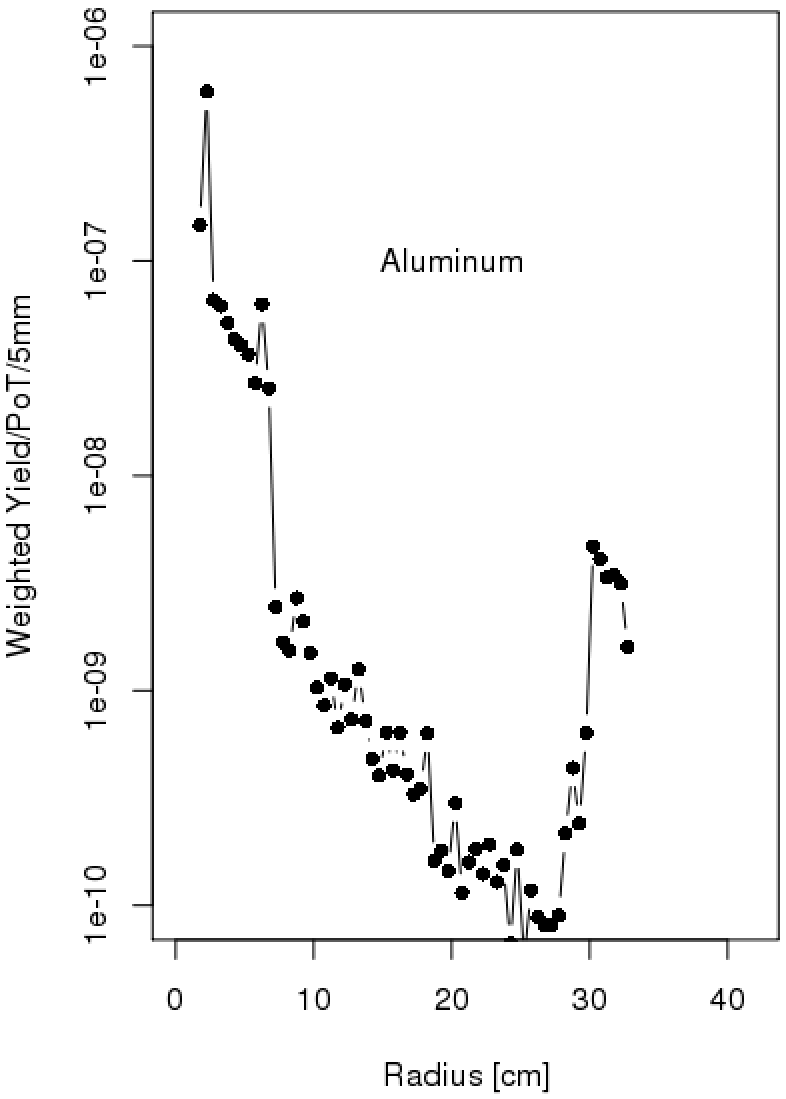
For the following part of this talk, we will always used these MiniBooNE detector weights.



For instance, the sum of the detector weights for the pions that generate a neutrino are not directly coming from the primary vertex, normalized to the the sum of the detector weights for the entire sample, is about 22%, as previously mentioned.

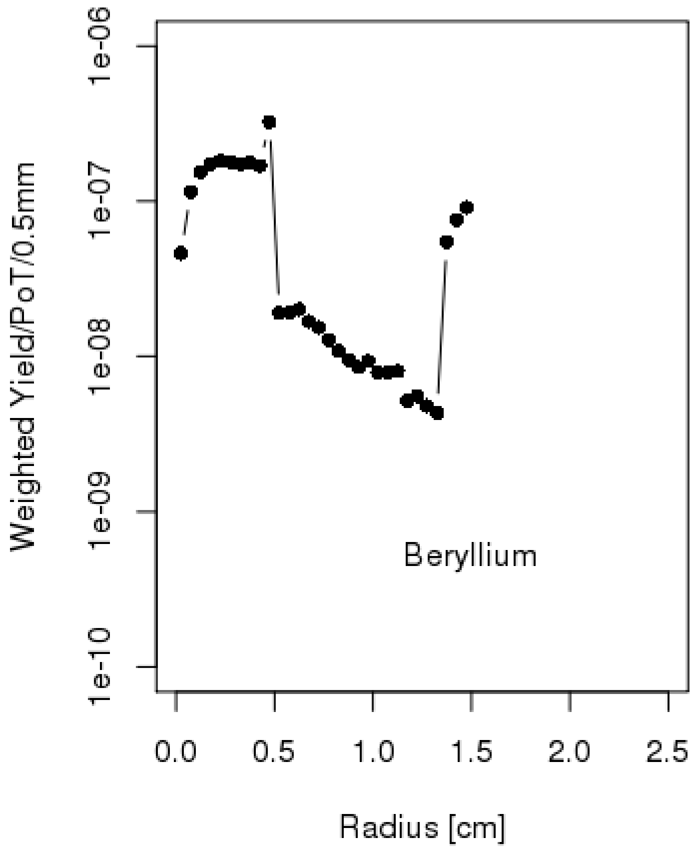
Consider not this ~ 22% sample, look at the relative weight for these pions that produced the neutrino and did interact in some material. This barplot shows the relative importance of these materials in determining the neutrino flux when pion interact with the material in the beam.

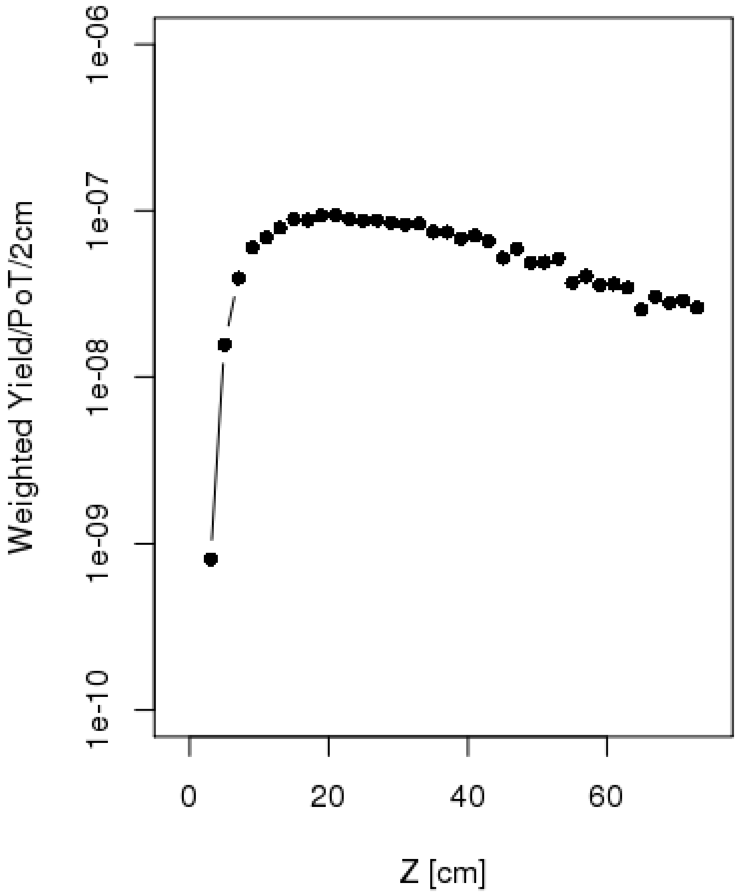
Again, this chart will be different for ICARUS, ND/SBN, etc...



The Dk2nu ancestry records for every hadronic interaction (elastic or inelastic) the incoming/ougoing momenta of the particle in the ancestry, as well as the X-YZ position of the vertex. Therefore, one ca easily check the geometry, and the relative importance of a given region. the 3d position .

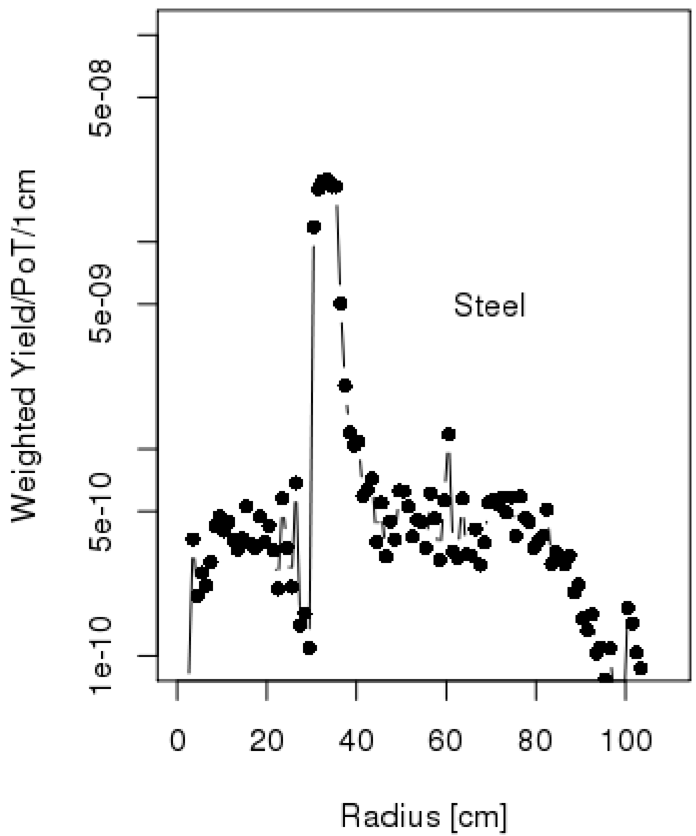
Here is a MiniBooNE detector weighted histogram of the radial position of the pions that undergoes scattering in conductors of the horn (material is aluminum)

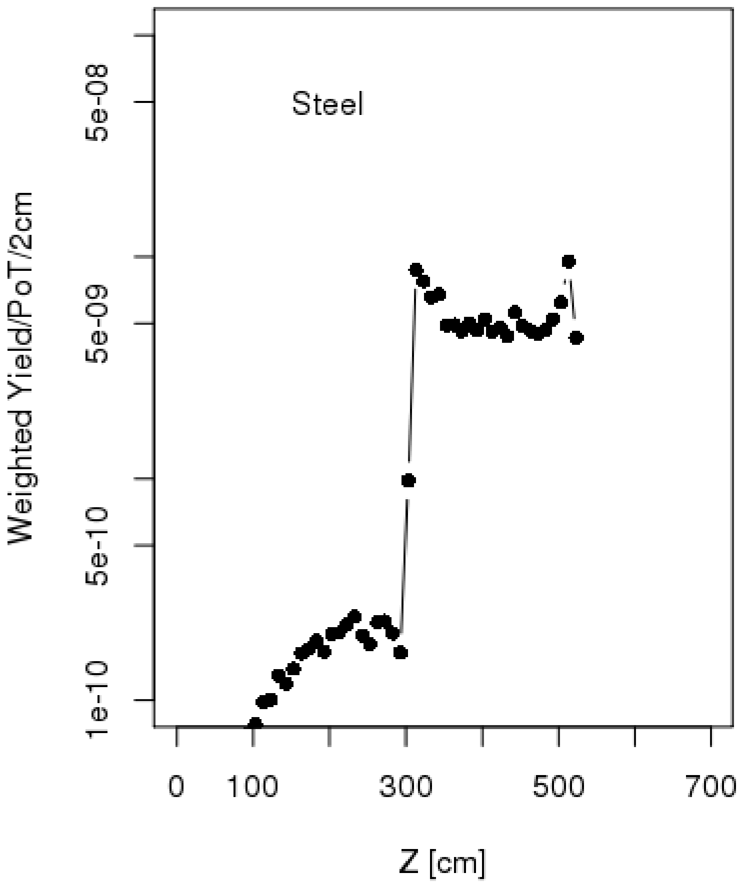




Same for Beryllium. The tracking step size is quite often larger than the radius of the Be slugs, hence, this radial plot is not very accurate.

But it is this case, it is the Z location of the re-interaction that matters.





Same for Steel. The lip of the collimator clearly stands out. In this calculation, it is pure steel, not rust at all. The low probability for R < 30 cm. are due to the few neutrino from pions decay downstream of the start of the absorber.

The Ancestry in the Dk2Nu package does not tell the whole story, as, for a given entry in the ROOT ntuple to be uploaded, there ought to be a neutrino to start with.

This does not occur if the pion is absorbed, or scattered away into the collimator, etc,.. de facto lost...

To study this, besides “screen Ntuple”, located after the collimator and after the horn, a new (with respect to v4p8) set of Ntuples has been added, MesonScatteringAfterHorn, MesonScatteringAfterCollimator. They are filled when, for any given G4 step, the process name is “hadElastic”, or “hIon”, with hadronic activity, the v4p8 corresponding process “PionPlusInelastic” (for propagated π^+)

The location and the change of momenta are recorded.

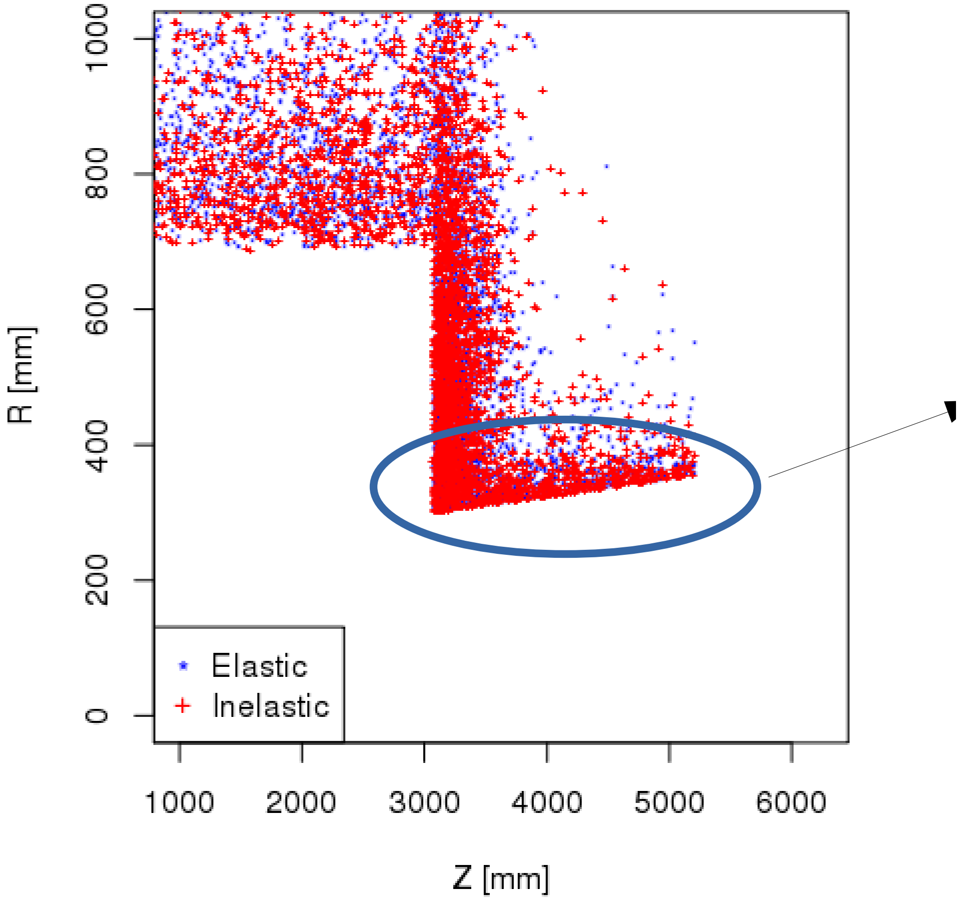
For instance, selecting the π^+ in the beam line, that make it to the end of the horn, the probability to find such a that scattered elastically on an Aluminum nuclei is about 7.0% per PoT. The corresponding number for Beryllium is 2.3%.

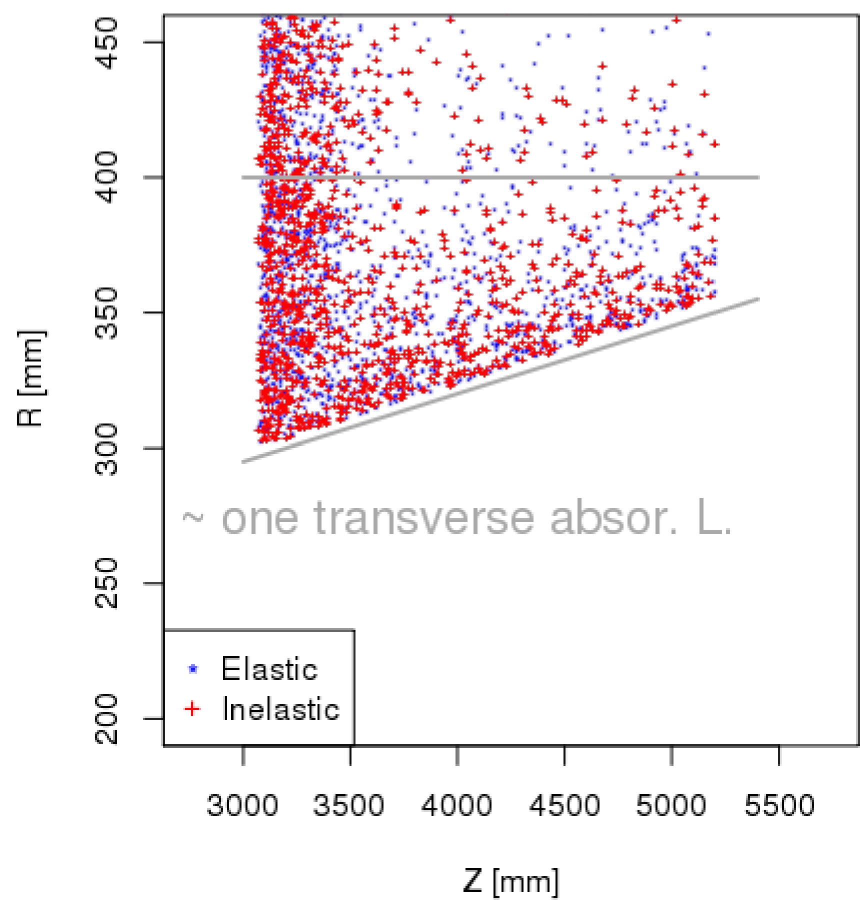
To this, one must add the inelastic channels as well. The distinction between a "Quasi-elastic" and an inelastic scattering process is of course model dependent, and thereby G4 Physicslist dependent..

Selecting the π^+ in the beam line, that make it to the end of the horn, the probability to find such a that scattered inealstically and produced an additional hadron with a kinetic energy greater than 50 MeV, on an Aluminum nuclei is about 4.1% per PoT. The corresponding number for Beryllium is 1.7%.

Of course, we have to add the steel from the collimator. For elastic π^+ on iron (no rust!), the corresponding number is 53.7%. For inelastic, it is 38.8%

Again, per PoT: It make sens: a lot of pions are lost in the collimator...





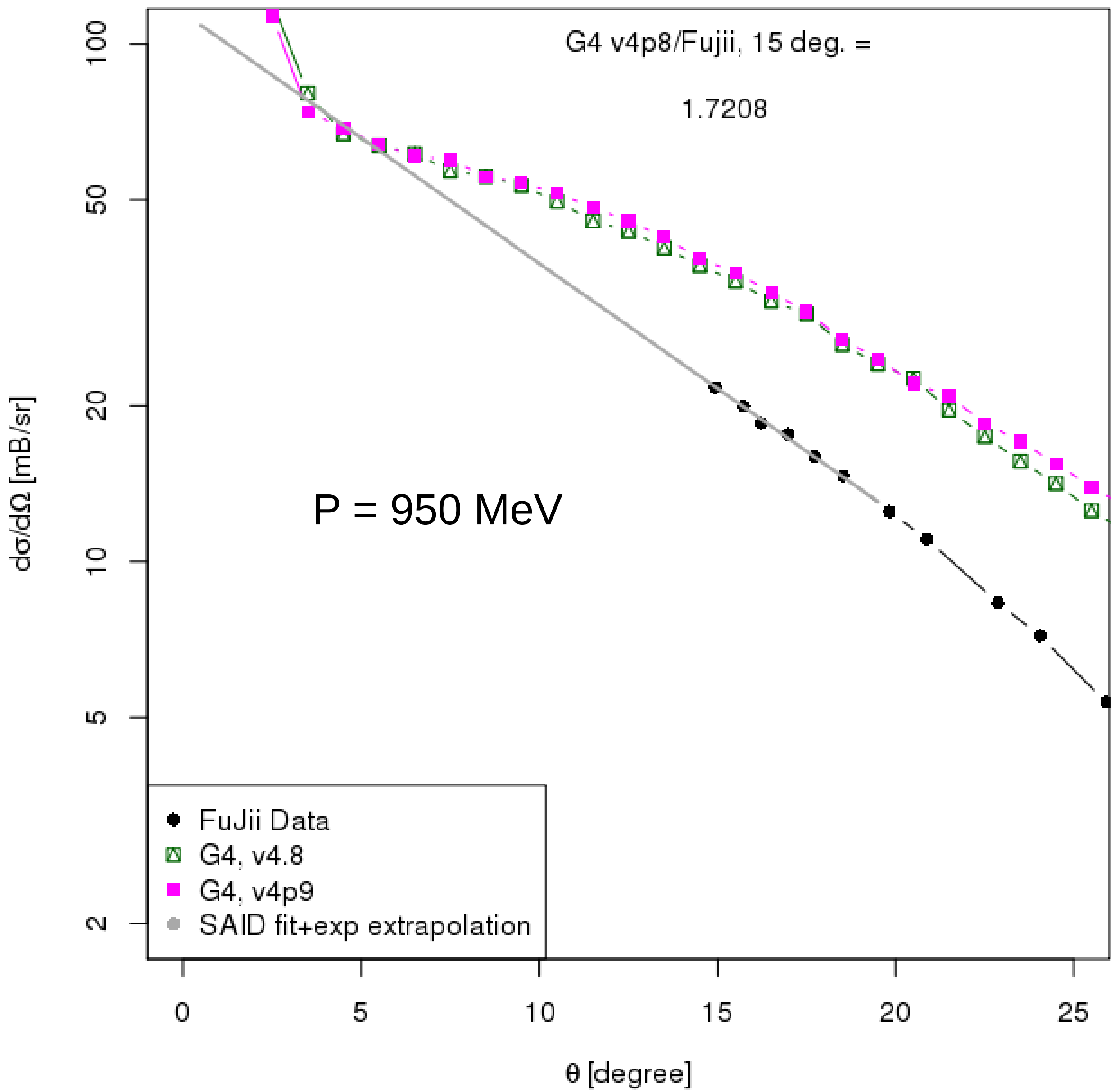
The scatter plot of long. Vs transverse coordinates of the scattering occurrence shows enhanced activity at the front face of the collimator, and around the first ~ 10 cm (~ 1 Nucl. coll. Length), going out radially. The probabilities to get a scattering occurrence, per PoT in this region is about 12. % (Elastic) and 10. % (Inelastic).

So, regarding estimates of the "effective absorption rate", uncertainties from hadron - Beryllium scattering differential cross-section is not our biggest problem. We have to consider the other materials as well.

→ HARP – thick target data is not the end of the story.

If we add up the approximate relative (per PoT) rate at which we could loose pions if they scatter too much going through the target, the horn, the lip of the collimator, we reach ~30%

Not negligible. Again, this information does not directly come from the neutrino ancestry analysis, but from a new diagnostic Ntuple in BooNE MC/G4 v4.10



Wrote a small standalone G4 application that simply "measures" the differential cross-section(s) for a thin target, with a perfect detector.

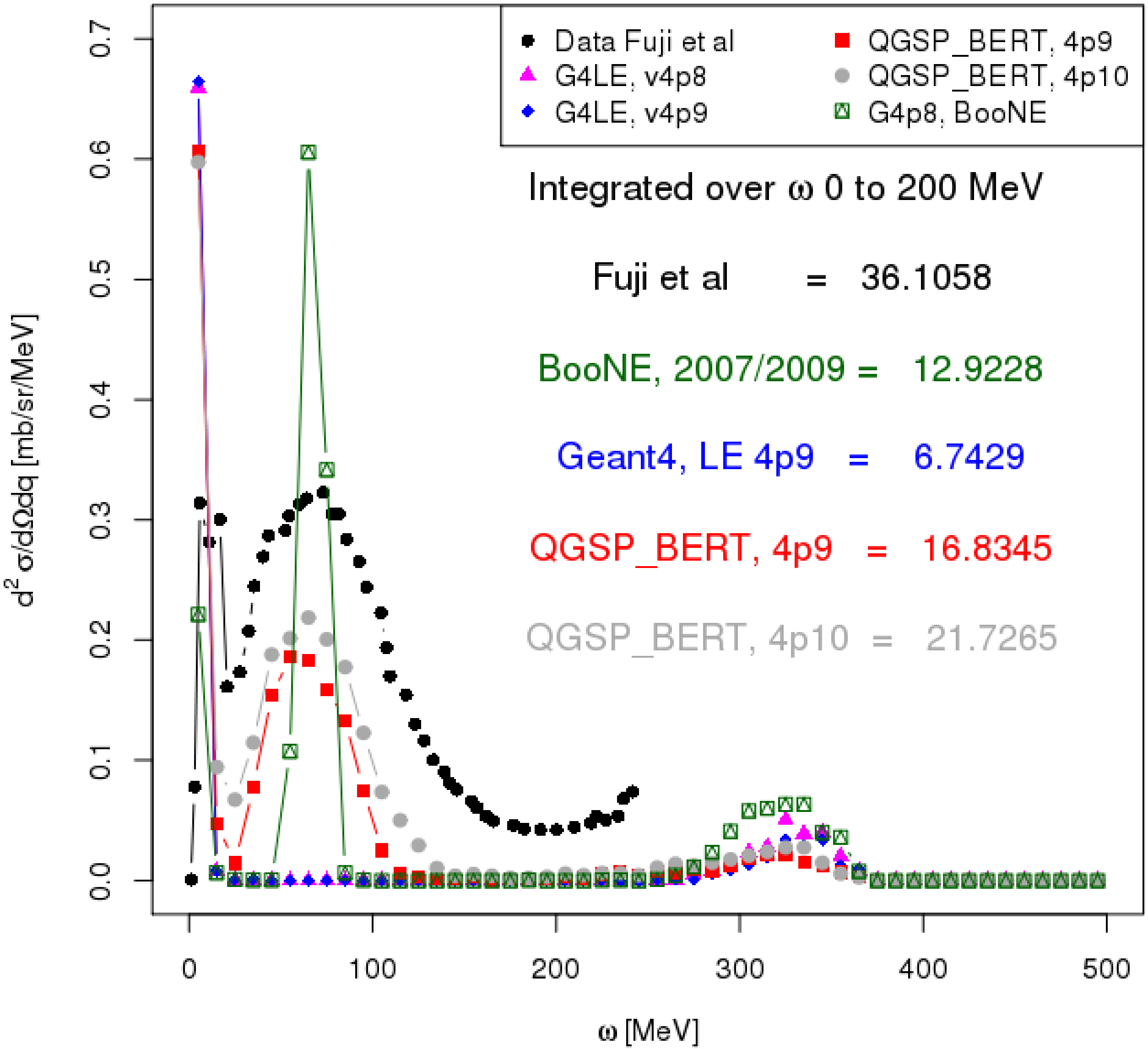
Easily portable across G4 versions (No private, custom, Physics lists or hadron scattering..)

On Hydrogen, ignoring the second kinematic variable, the pion energy loss in the lab frame, not much difference.

Good fit at a few degree (ignoring multiple scattering below ~ 3 degree). Worse at higher angle.

Shown on Jan 6 2016..

Shown on Jan 6 2016 meeting...



Summary plot for the study on pion-Carbon scattering Quasi Elastic scattering.

Large difference between models and data..

In this context, seeing 5~10% in difference in neutrino flux between v4p8 and v4p10, using the same HARP model to generate pions, is not surprising....

Discussion..Where to go next ?

Could do more studies, for instance, repeat the 3-slugs, no other materials, runs done previously on v4.9. A good exercise for the upcoming MicroBooNE student ?..

Met with Krzysztof genser, CD/Simulation, on how to improve the G4 physics generator. I learned: (I) There is an ongoing effort to provide interfaces such that some parameters in the various Physicst list can be modified by the user. (ii) the name of some proponents of various hadronic generator.. (iii) Some (many?) have their "stake holders" working on high energy colliders, not neutrino physics. The emphasis is placed on, for instance, overall energy conservation for calorimetry purposes, not details of the double differential cross-section, angle energy, which matters a lot for neutrino flux predictions.

I suggested to Krzysztof that I summarize the status of the BooNE MC and write a few slides for his team. And share it with adhoc G4 Hadronic team, for instance Denis Right (SLAC/G4). Krzusztof will give a heads-up to Dennis in the next few week.

Perhaps we can collaborate, to build a Physics List with improved hadronic models..

Of course, I (personal opinion) that we should design a single particle, limited aperture, “portable/movable” spectrometer with particle I.D., which can be installed at a test beam with adhoc momentum range, or, even better, at the BooNE-25 m. location, or downstream of DUNE HornC...

And develop the Booster, SBN proton beam instrumentation to handle ~ 10^6, 10^7 ppp. Such that we can measure the pion/kaon/muon flux in-situ...