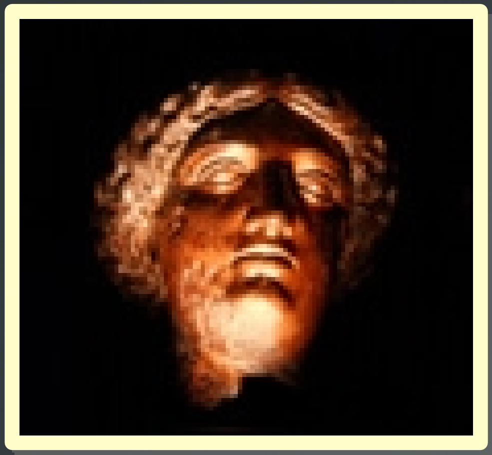

MINERvA-MINOS muon energy scale in CC inclusive events

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Overview

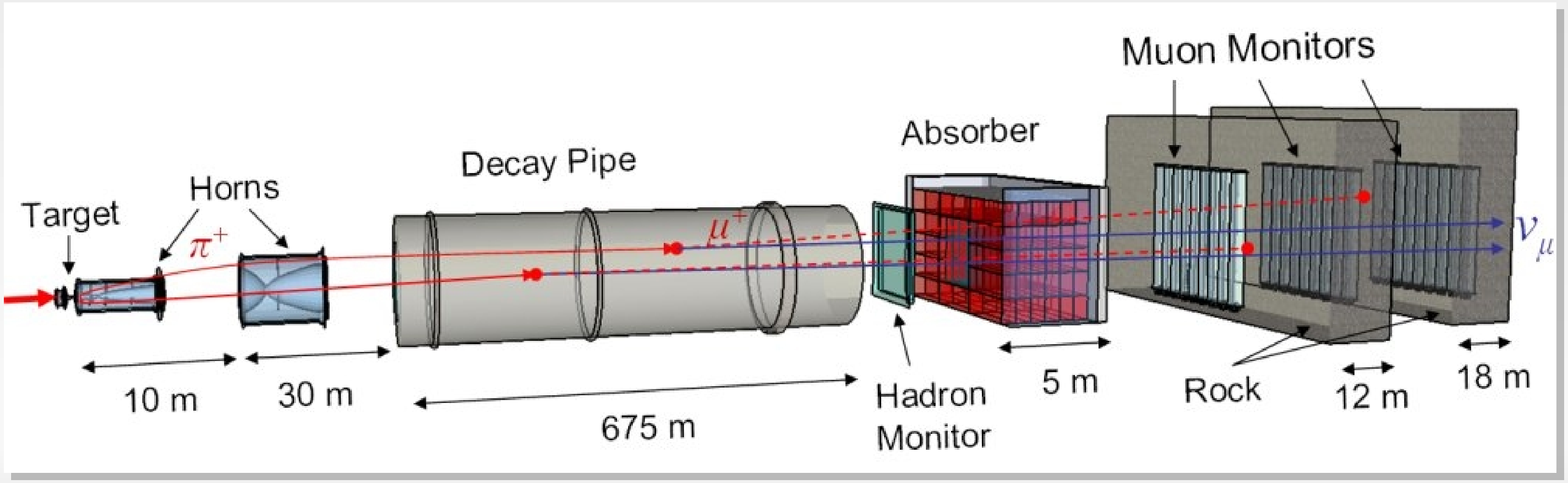
- The MINERvA experiment
- MINERvA detector
- MINOS near detector
- Motivation for this work
- Event selection
- Muon Energy Scale calculation
- Systematic Uncertainties results
- Conclusions

Main INjector ExpeRiment v-A

MINERvA is a neutrino scattering experiment located underground at the NuMI beamline at Fermilab.

Pions and kaons are produced by the interaction of 120 GeV protons from the Main Injector into a graphite target, and neutrinos are created when those pions and kaons decay.

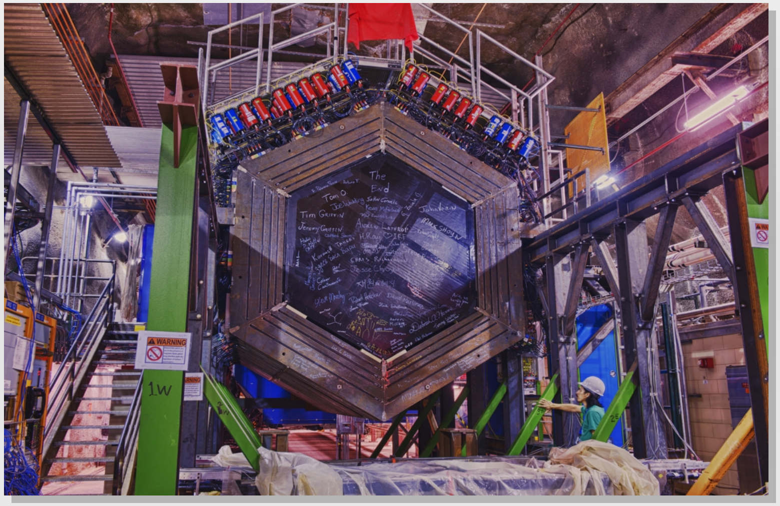
The principal goal is to measure neutrino-nucleus cross sections in the neutrino energy range from 1 to 10 GeV.

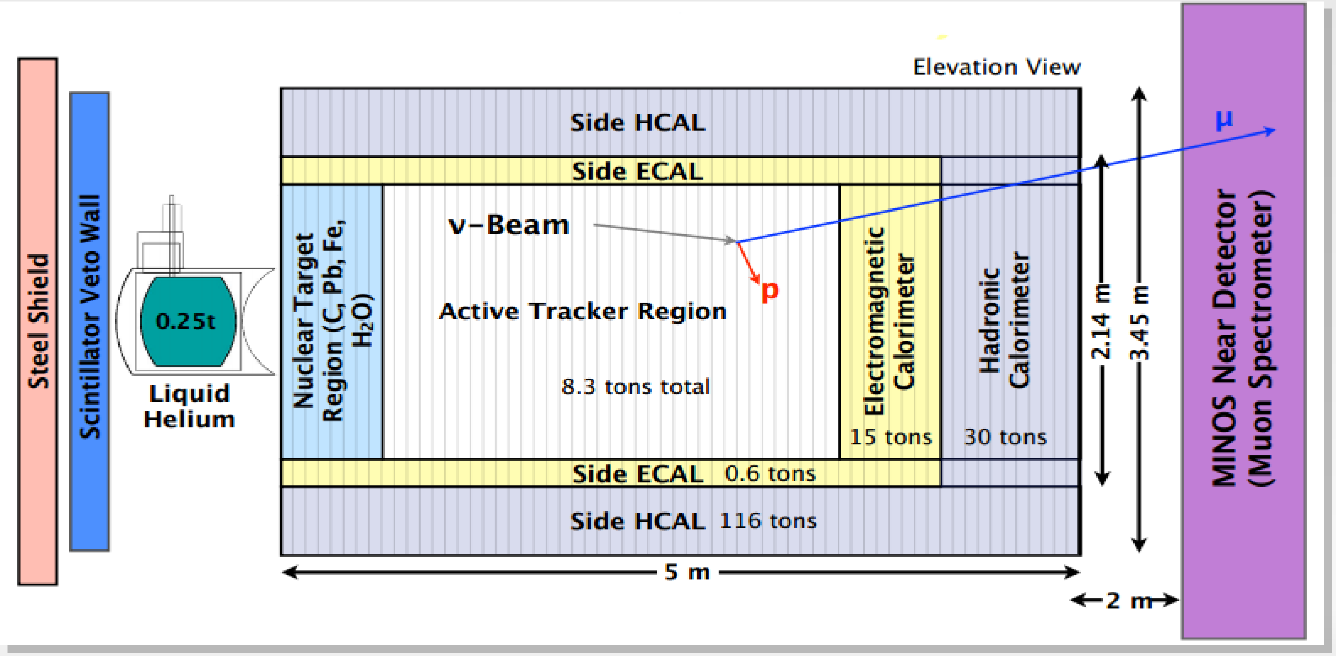


MINERvA detector

The detector is composed of 200 hexagonal scintillator planes finely segmented (around 32000 readout channels) and has four fundamental parts:

- Nuclear target region.
- Active tracker region.
- Calorimeter region: ECAL (lead sheets) and HCAL (steel plates).
- Outer detector: side ECAL (lead collars) and side HCAL (steel frames) that envolve radially.

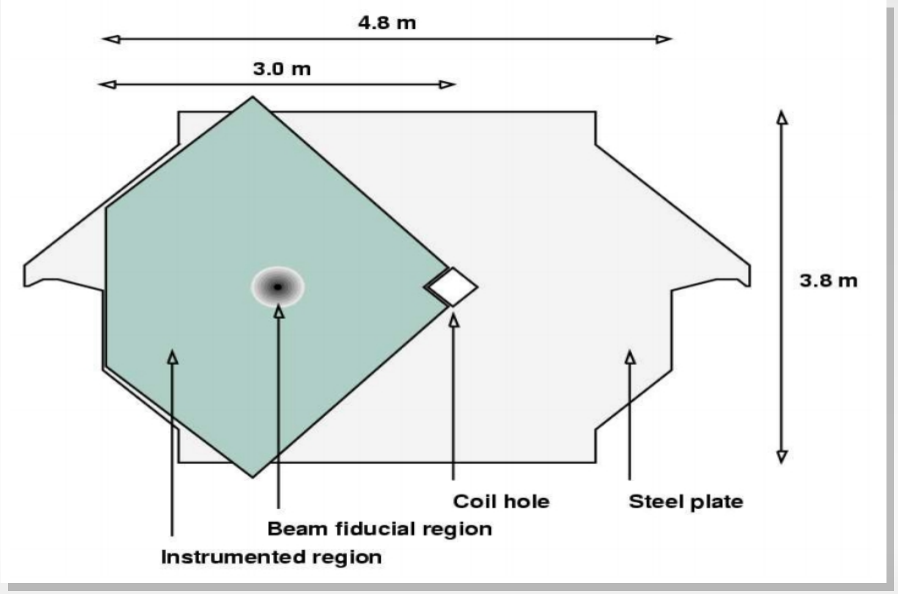




MINOS near detector

- Located downstream of the MINERvA detector and composed of 282 octogonal planes.
- Serves as MINERvA magnetic muon spectometer characterizing muon charge and momentum.
- Upstream part (first 120 planes): calorimeter fully instrumented.
- Downstream part (remaining 162 planes): spectrometer instrumented every 5 planes.
- Has an electromagnetic coil that passes around the center and generates a magnetic field inside.

Many thanks to the MINOS collaboration!!

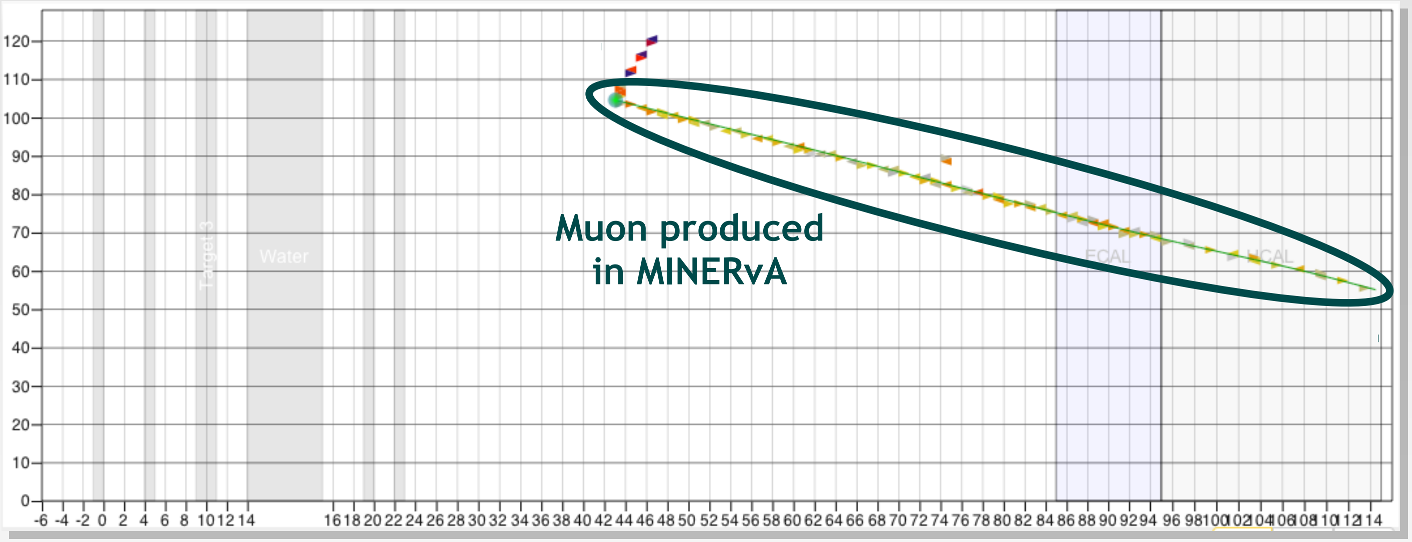


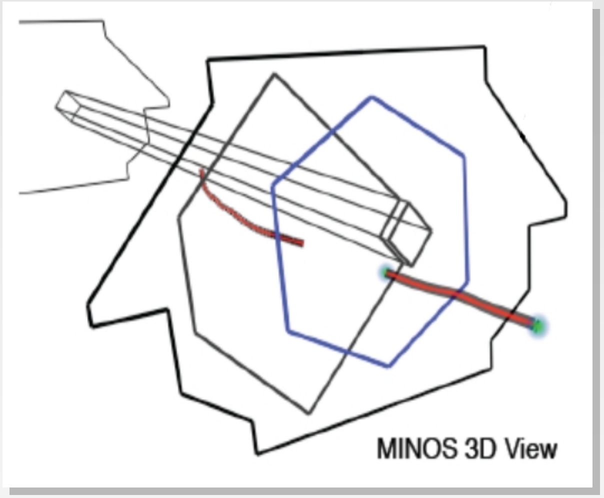
Motivation for this work

Depending of the type of a neutrino interaction inside MINERvA, a muon can be produced that goes through MINERvA and reaches MINOS. And an important task is to reconstruct the muon energy in the interaction vertex.

MINOS helps us by reconstructing the muon momentum when it enters in the upstream calorimeter, and there are two ways to make that:

- By **curvature**: Muon is not contained inside MINOS and scapes.
- By **range**: Muon stops in the calorimeter.





Thanks to the MINOS data, we know that the systematic error on the muon momentum due to the reconstruction by range is 2%.

But we also need to find the **systematic error due to the difference between the reconstructions of the muon momentum by range and by curvature!**

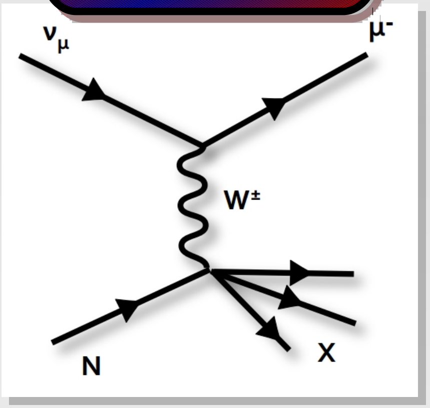
Event selection

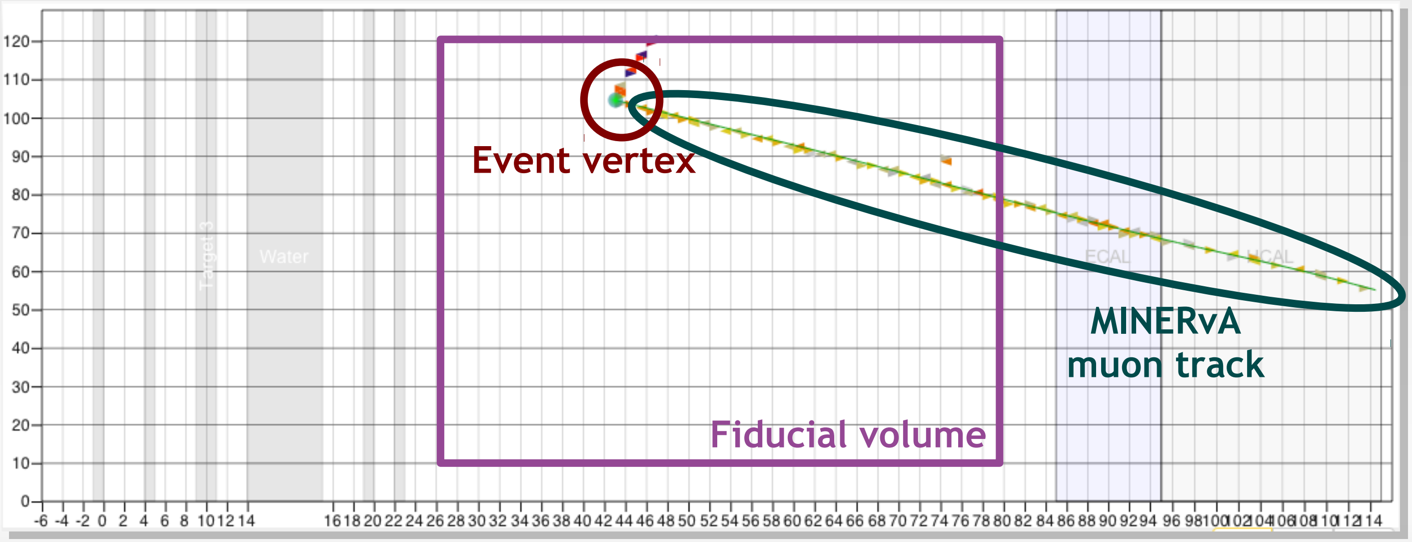
A neutrino interaction inside MINERvA could be neutral current or charged current.

This study is focused only in **charged current neutrino events** (CC inclusive) and applies these event cuts:

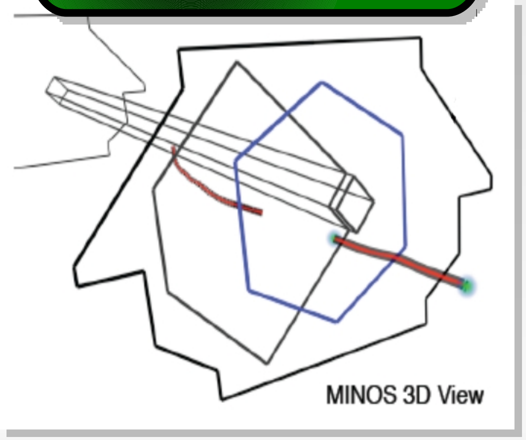
- Event vertex located inside fiducial volume.
- 'Clear' events: E_ν < 20 GeV and 1 MeV < E_{muon} < 20 GeV
- Muon **recognized with a negative charge by MINOS** detector.
- Muon **track in MINERvA must have a matched MINOS track**.
- Muon momentum in MINOS has to be **reconstrcted by range**.

Charged current interaction





MINERvA track matches MINOS track



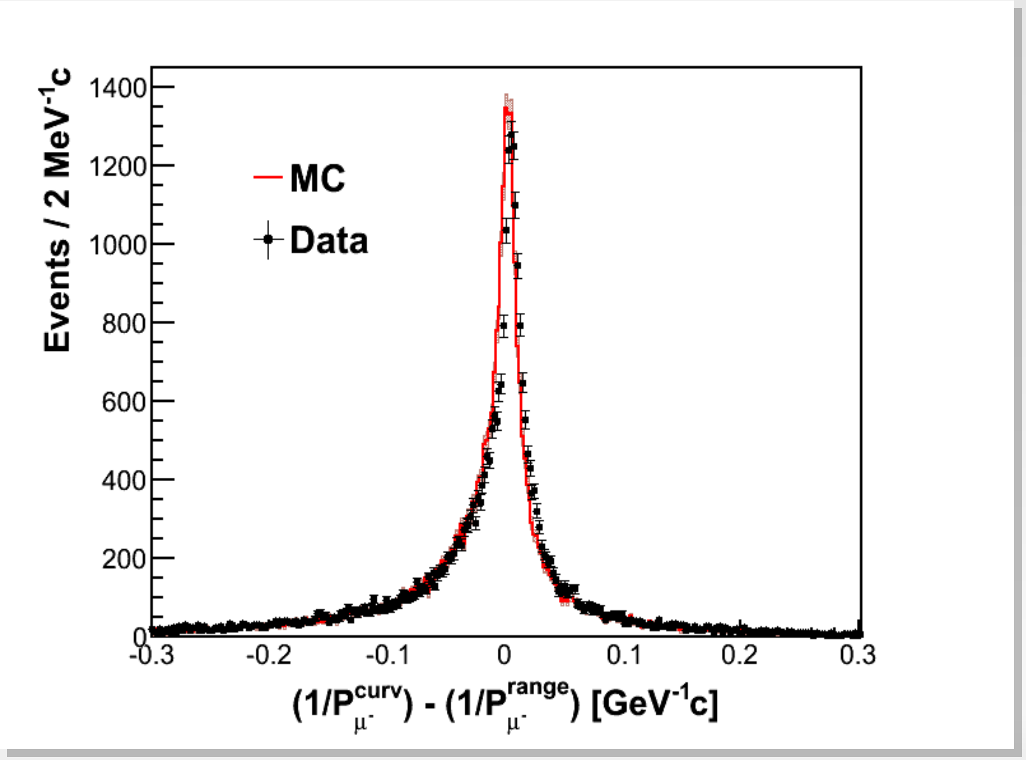
Muon Energy Scale calculation

An event whose muon has a momentum reconstructed by range also has a momentum reconstructed by the curvature (**K**) of its track.

$$K \propto \frac{1}{P}$$

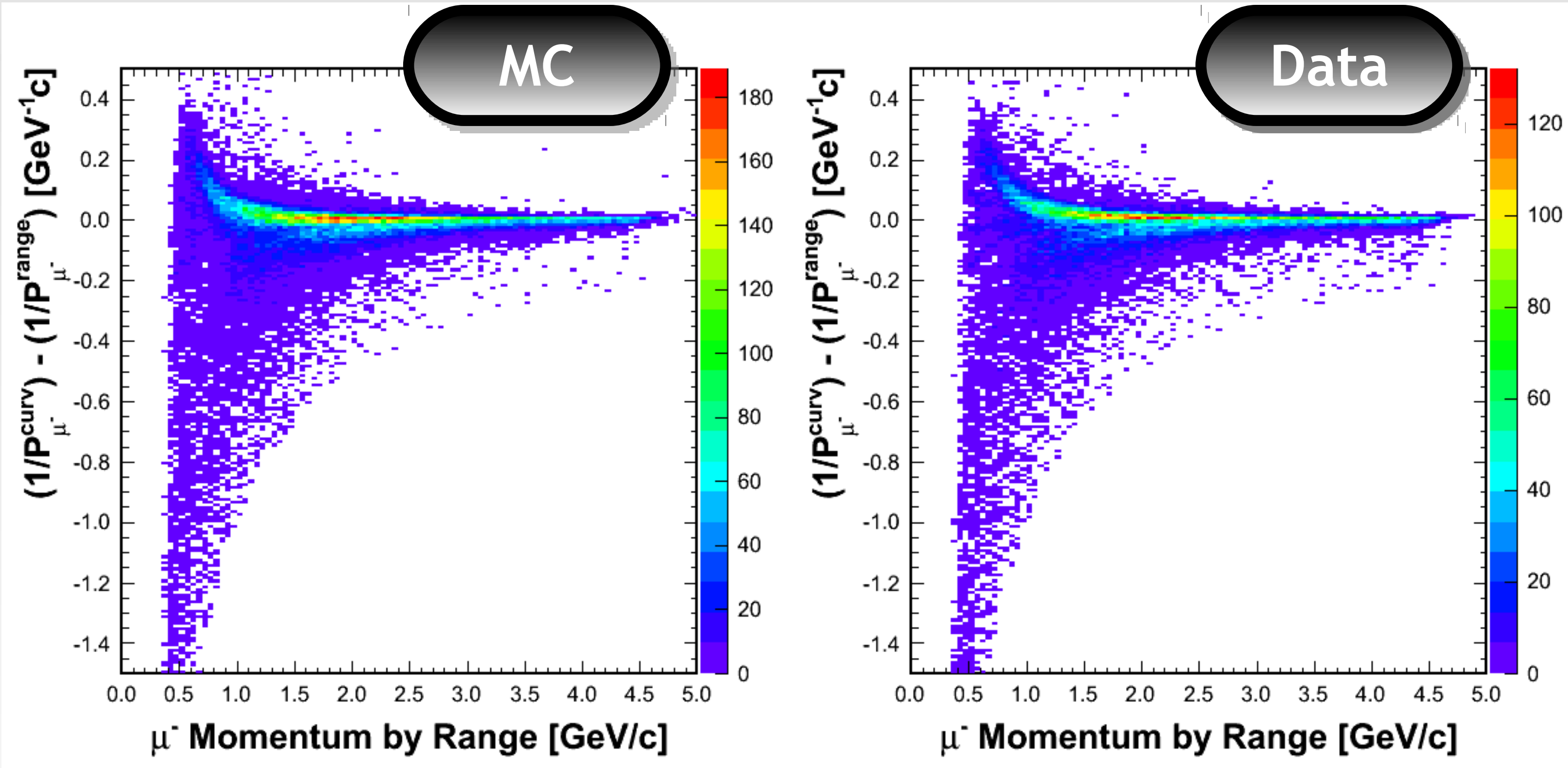
Additionally, **the importance of measuring the curvature of a muon track is that we actually are measuring 1/P**.

The difference between momentum by range ($\mathbf{P}_{range}$) and momentum by curvature ($\mathbf{P}_{curv}$) is expressed as an inverse residual momentum, so the systematic error will come from the difference of this inverse residual in Data and Montecarlo:



Muon Energy Scale calculation

Now, we look at the dependance of the inverse residual momentum distribution in terms of the muon momentum by range.

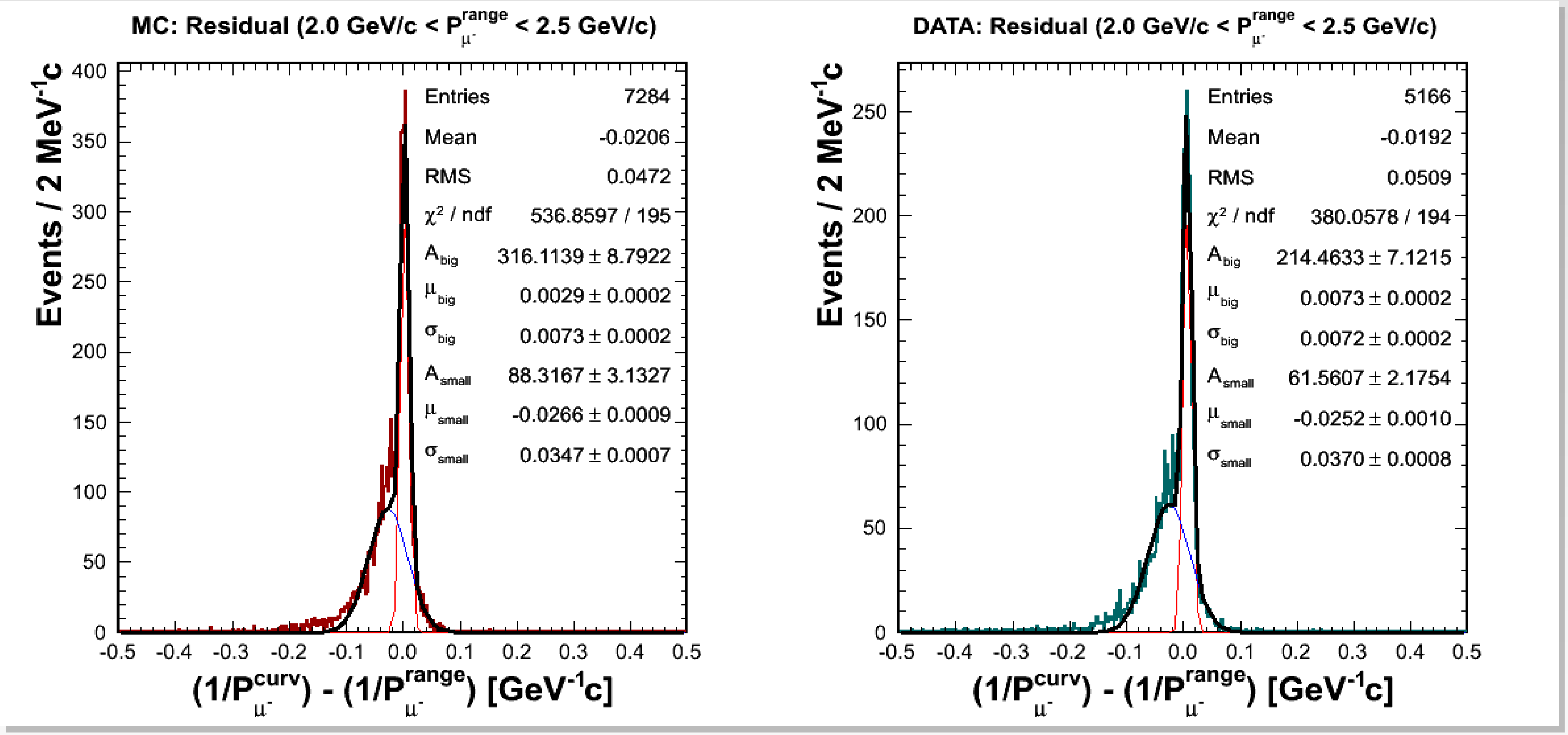


There's a strong dependance: **the higher the momentum by range, the less the inverse residual**.

Muon Energy Scale calculation

We separate from all events those whose muon momentum by range is between 0.5 and 3.5 GeV/c, and later we make 6 subgroups of 0.5 GeV/c range momentum each one.

In each of these intervals over all events contained, we make inverse residual plots on Data and MC and fit those distributions using a double gaussian fit:

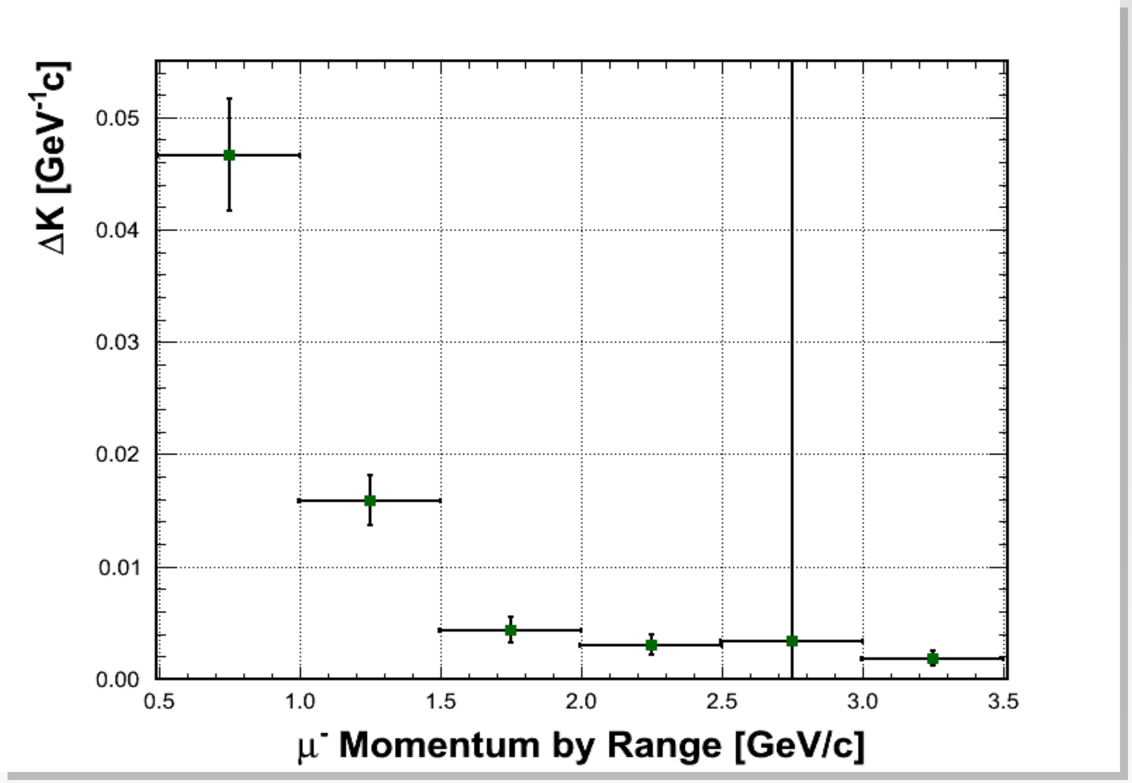


And we register the value of the histogram mean and the gaussian fit peak, and their corresponding uncertainties.

Muon Energy Scale calculation

For both, histogram mean and gaussian big peak, we substract the MC from the Data. And later we make one final substraction between these both residuals on each one of the six intervals.

The absolute value of those substractions is a number that we call **ΔK**, it's the maximum difference between **$1/P_{curv}$** and **$1/P_{range}$**, and has units of inverse momentum:



In other words, **ΔK is a systematic error range-curvature but on $1/P_{range}$**.

Muon Energy Scale calculation

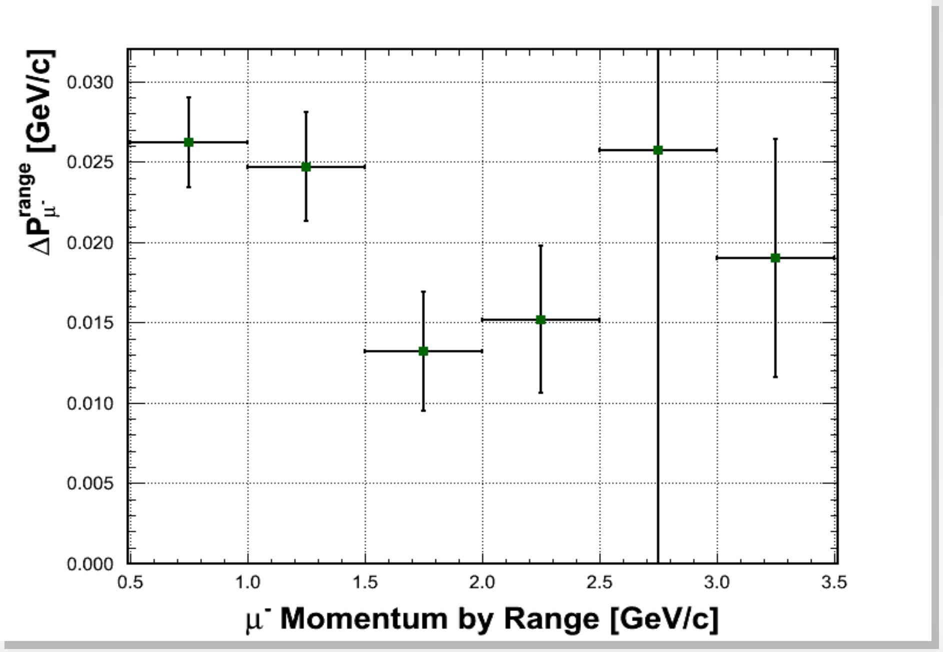
The shift in $1/P_{range}$ is according to:

$$\frac{1}{P_{range}} \Rightarrow \frac{1}{P_{range}} \pm \Delta K = \frac{1}{P_{range}} (1 \pm P_{range}\, \Delta K)$$

So, the variation on P_{range} will be:

$$P_{range} \Rightarrow \frac{P_{range}}{1 \pm P_{range}\, \Delta K} \approx P_{range} (1 \pm P_{range}\, \Delta K) = P_{range} \pm (P_{range})^2\, \Delta K = P_{range} \pm \Delta P_{range}$$

With this, we realize that **the systematic error between momentum by range and momentum by curvature is** $\Delta P_{range} = (P_{range})^2\, \Delta K$. Due to we are working with momentum intervals, we use the mean value of the interval as a P_{range} to make the calculation.



Range-Curvature Systematic Uncertainties results

Due to the errors must be the maximum possible, the final calculation of them for each slice of P_{range} is made rounding the values of ΔP_{range} to its maximum possible.

Therefore, our final results are:

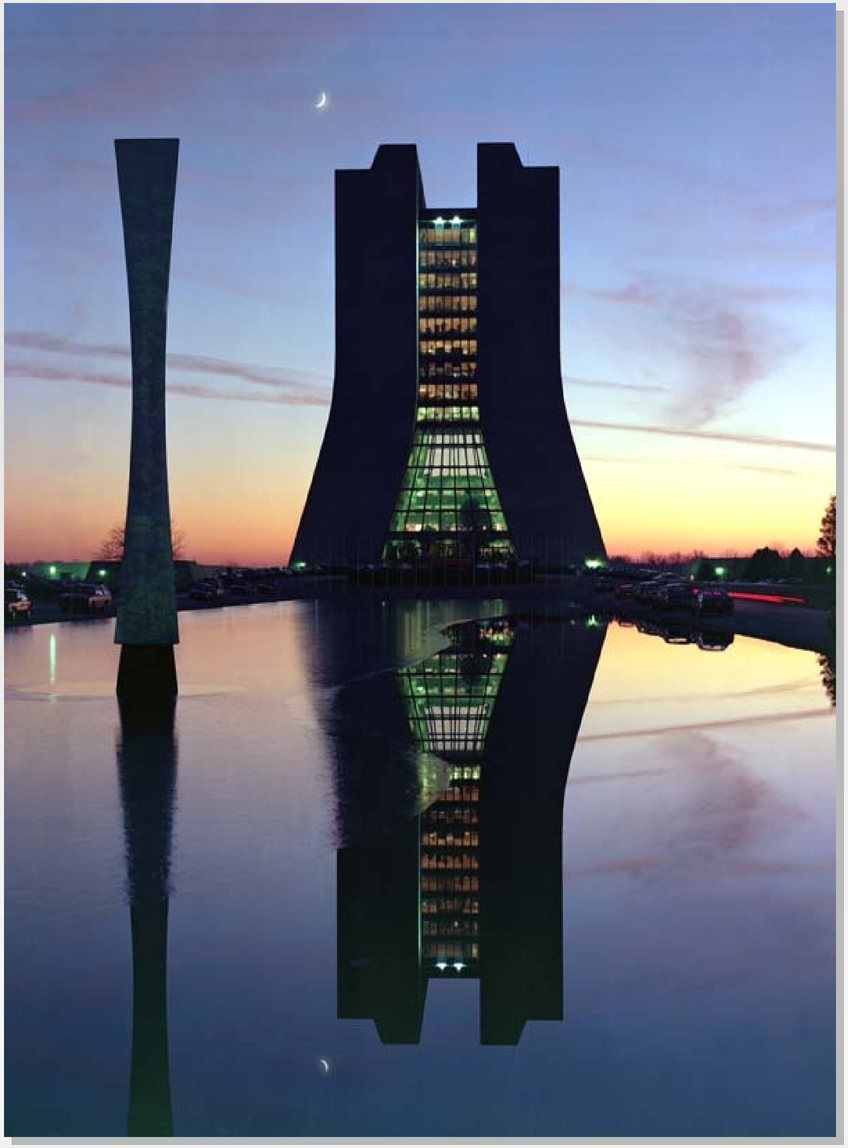
P_{range} [GeV/c]	Maximum possible error in P_{range} [MeV/c]	Maximum possible percentage error in P_{range}	Percentage error used by MINERvA this summer
0.5 to 1.0	29.0	3.87 %	5.00 % for any P_{range} < 1.5 GeV/c
1.0 to 1.5	28.1	2.81 %	
1.5 to 2.0	16.9	1.13 %	3.00 % for any P_{range} > 1.5 GeV/c
2.0 to 2.5	19.8	0.99 %	
2.5 to 3.0	*Bad fitting*	*Bad fitting*	
3.0 to 3.5	26.4	0.88 %	

Conclusions

- This analysis helps MINERvA to characterize in a first approach one of the many but important systematic errors, that is the MINOS muon energy scale, in the reconstruction of CC Inclusive events in MINERvA.
- Even when the momentum errors I've calculated have a minor value than the errors MINERvA uses to present its results this summer, it's important to note that my systematic errors have a high degree of uncertainty due to some errors on the reconstruction, the gaussian fits that aren't 100% accurate and the use of an 'average' value on the calculation of ΔP_{range}.
- The next step on this topic is to find the way to minimize these errors using more accurate fits and better momentum cuts.

Stay tuned for more MINERvA results!

Acknowledgements



The MINERvA collaboration:

University of Athens
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Universidad de Guanajuato
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Institute for Nuclear Research of Moscow
Massachusetts College of Liberal Arts
Northwestern University
Otterbein College
University of Pittsburgh
Pontificia Universidad Católica del Perú
University of Rochester
Rutgers University
Tufts University
University of California at Irvine
Universtiy of Minnesota at Duluth
Universidad Nacional de Ingeniería
Universidad Técnica Federico Santa María
College of William and Mary

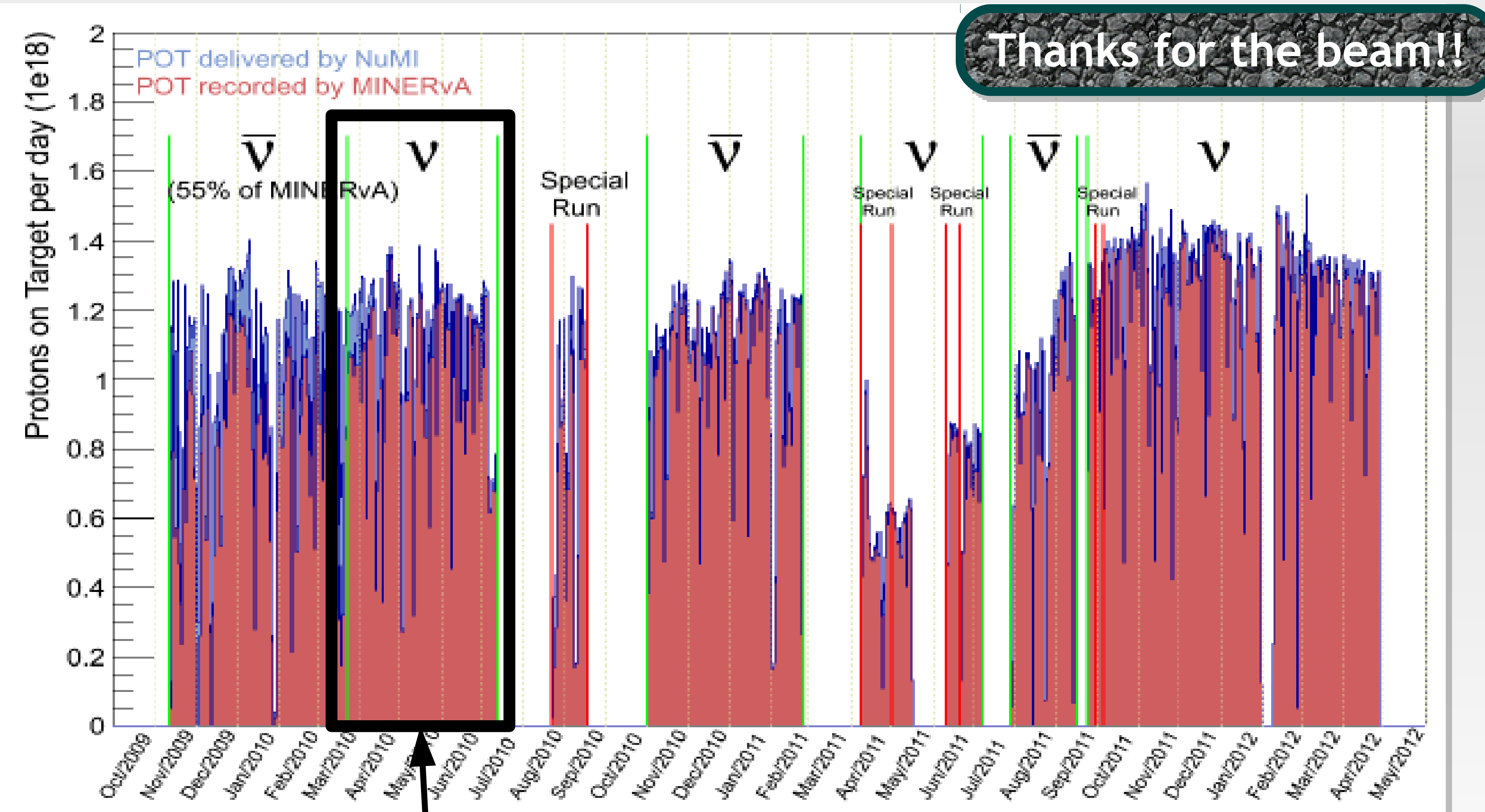
Muchas gracias!

Backup slides

NuMI beam specs

- **POT used**: 9.52×10^{19}
- **POT timeline**: March 2010 – July 2010
- **Beam configuration**: Low energy
- **Horn configuration**: Forward horn current (FHC)

POT used from NuMI beam

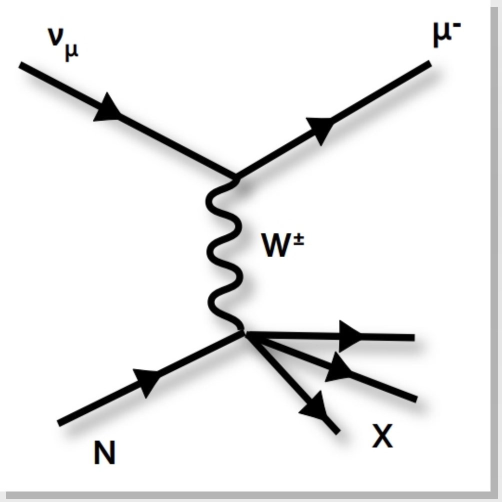


POT used in this analysis

CC Inclusive in MINERvA

- **Charged current**: Interaction mediated by W^+ and W^- bosons.
- **Inclusive**: Not all final particles of the interaction are known and only one of them is detected.

$$\nu_\mu + N \rightarrow \mu^- + X$$



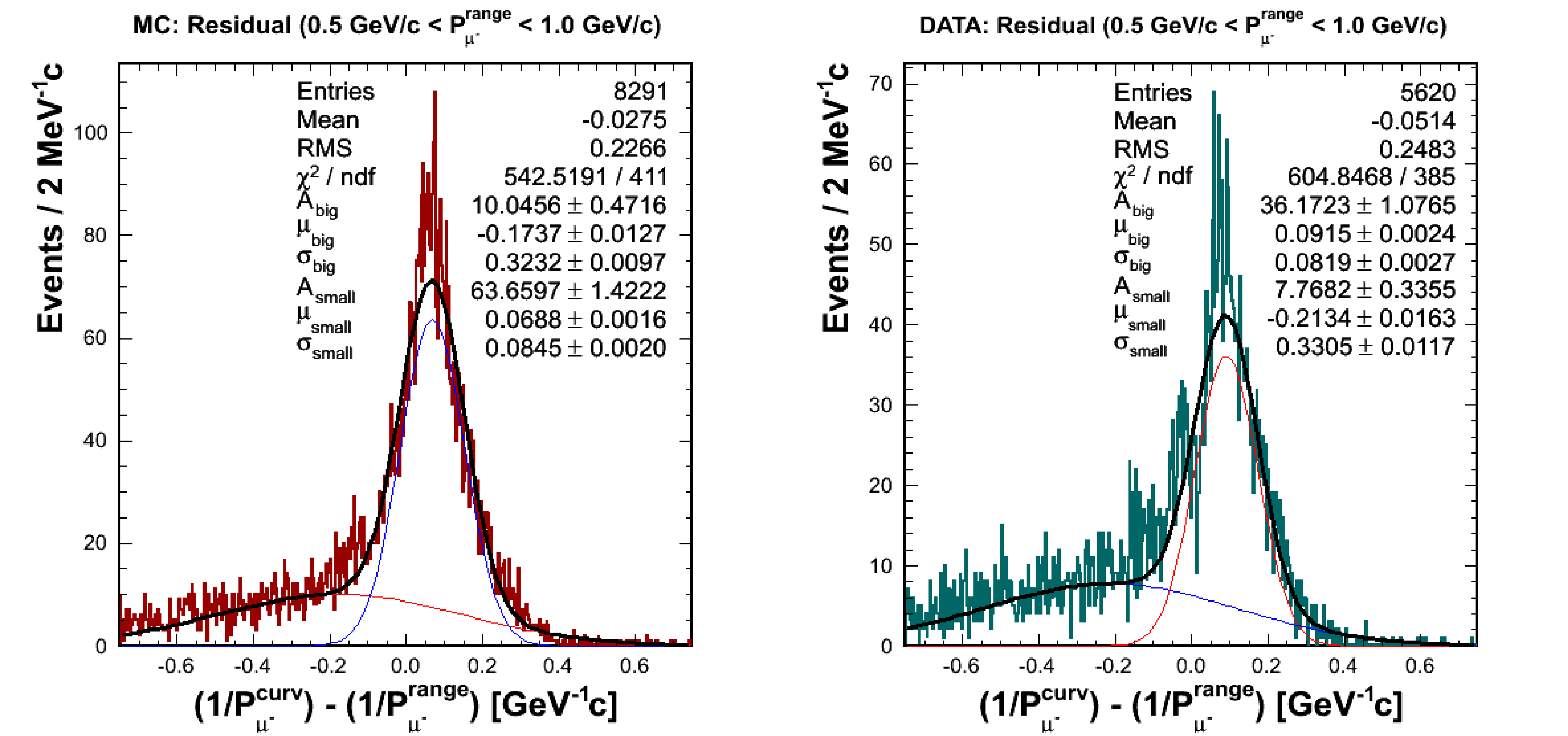
Four CC Inclusive interactions in MINERvA:

- CC Quasi-Elastic: $\nu_\mu + n \rightarrow \mu^- + p$
- CC Coherent Pion: $\nu_\mu + N \rightarrow \mu^- + \pi^+ + N'$
- CC Resonant Pion: $\nu_\mu + n \rightarrow \mu^- + \Delta^+ \quad ; \quad \Delta^+ \rightarrow n + \pi^+$

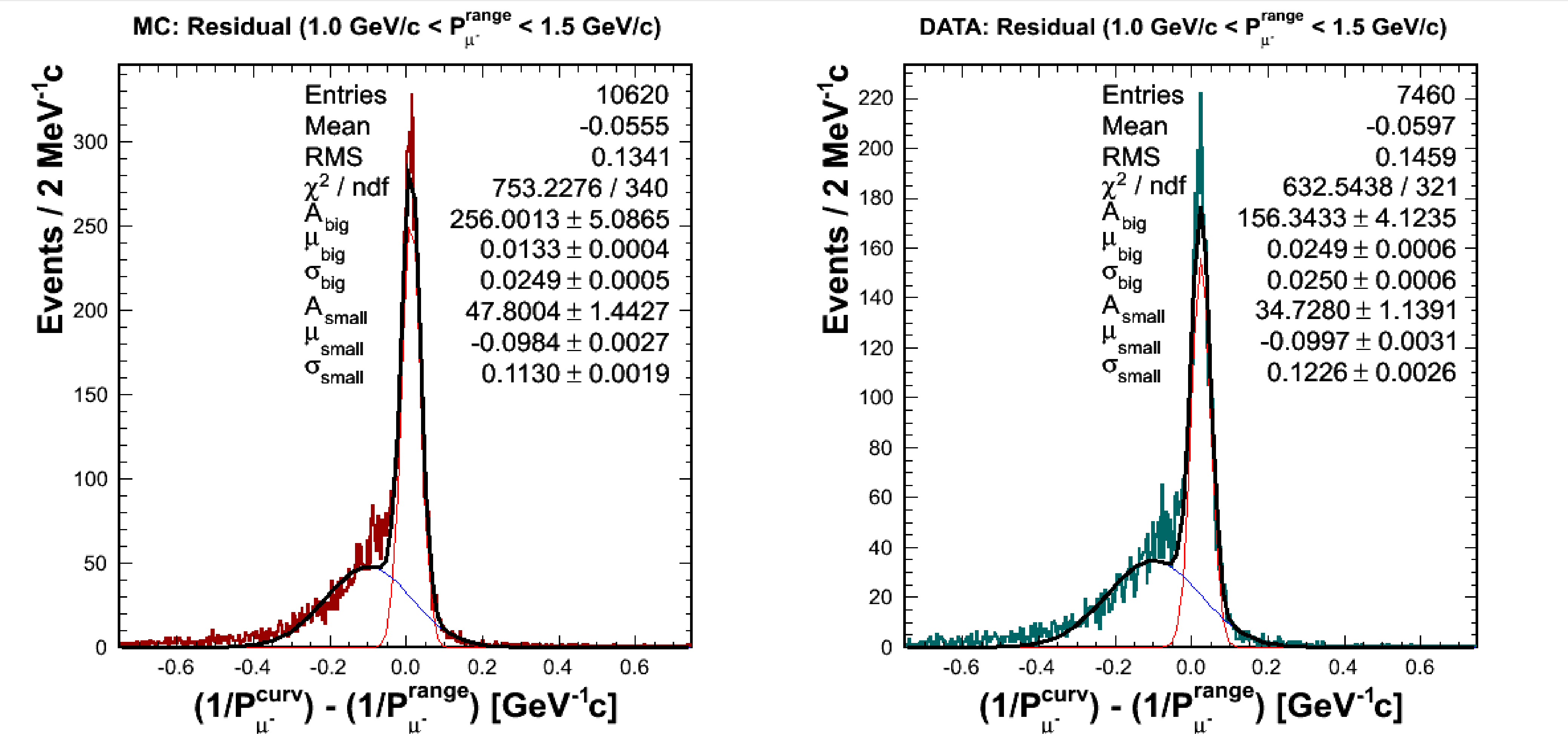
$$\nu_\mu + p \rightarrow \mu^- + \Delta^{++} \quad ; \quad \Delta^{++} \rightarrow p + \pi^+$$

- CC Deep Inelastic Scattering: $\nu_\mu + N \rightarrow \mu^- + X'$

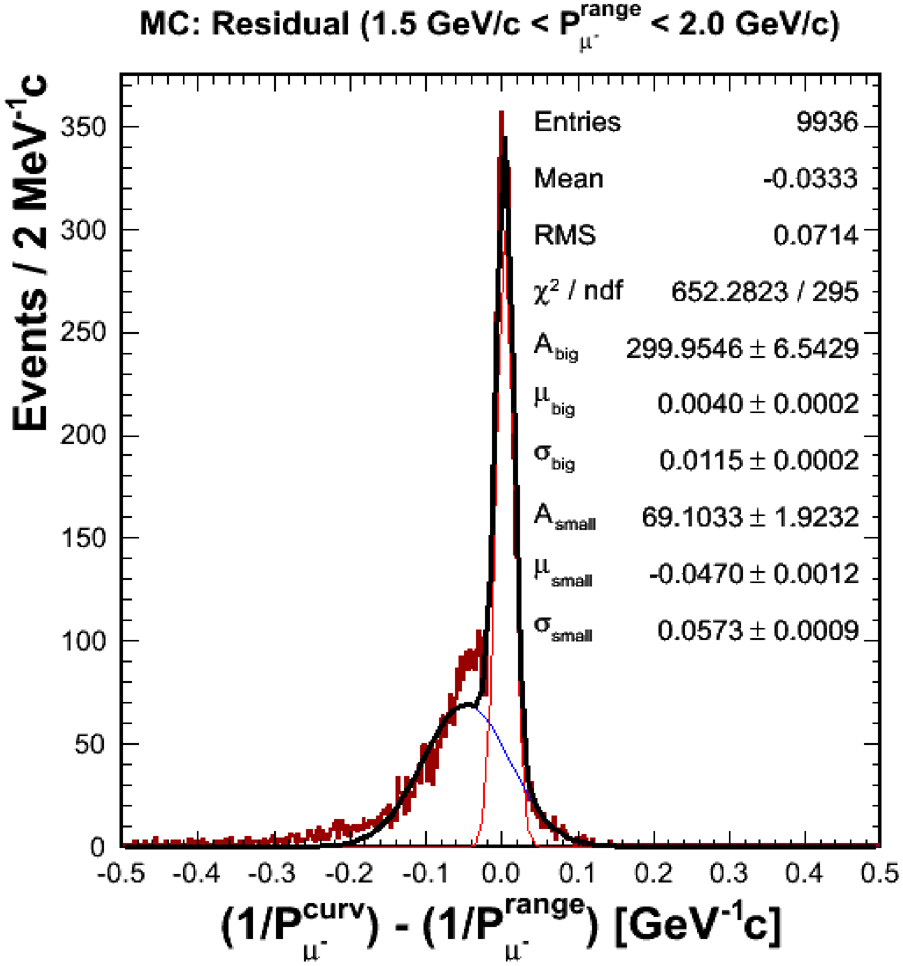
Fits on the 1st interval of P_{range}

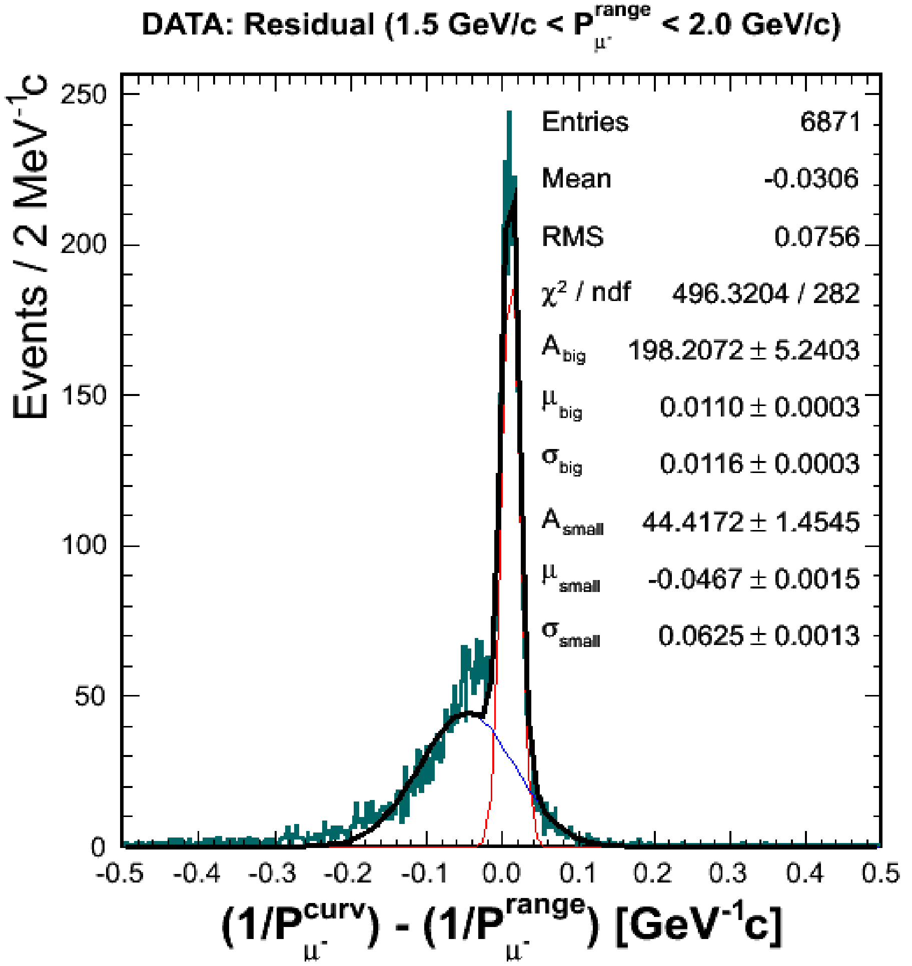


Fits on the 2nd interval of P_{range}

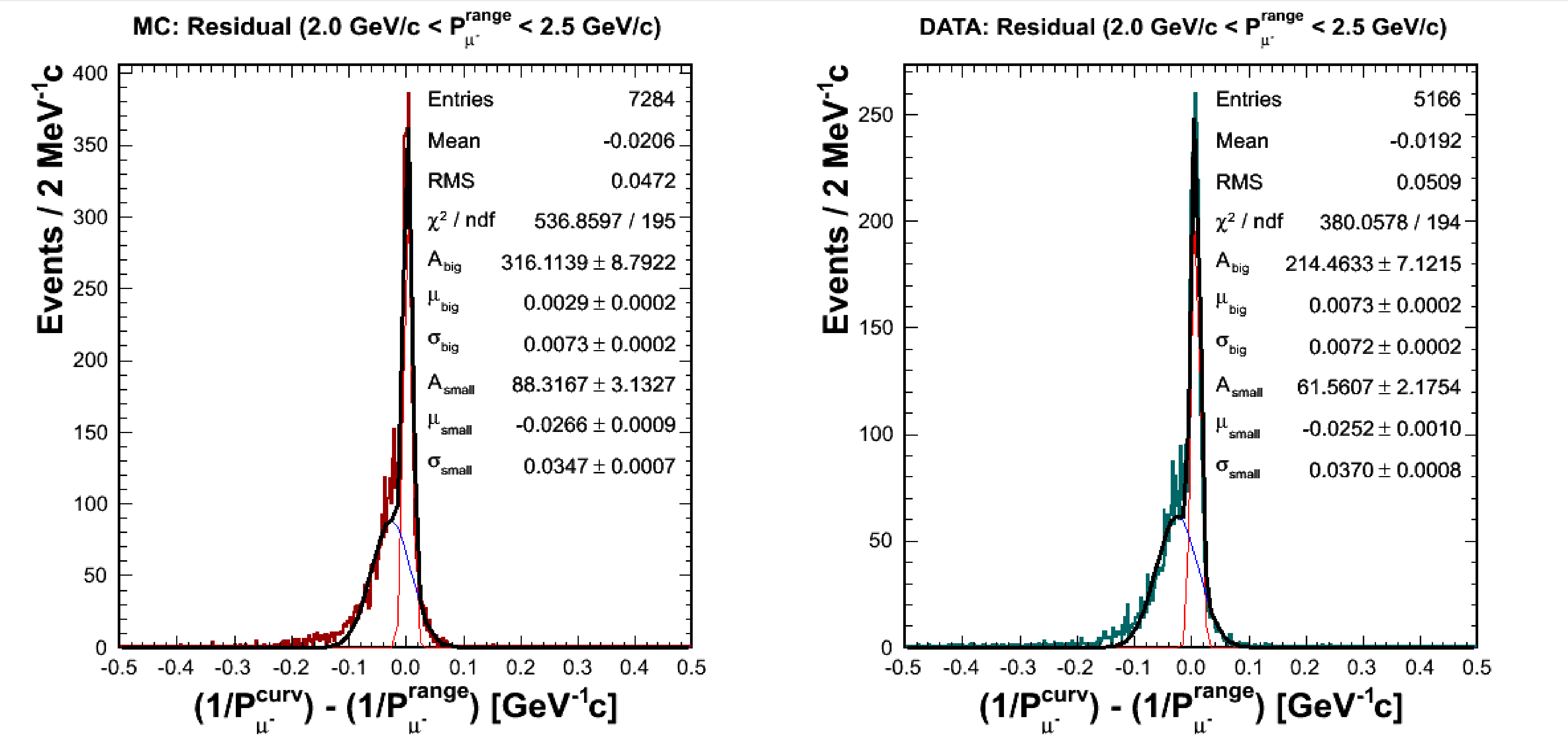


Fits on the 3rd interval of P_{range}

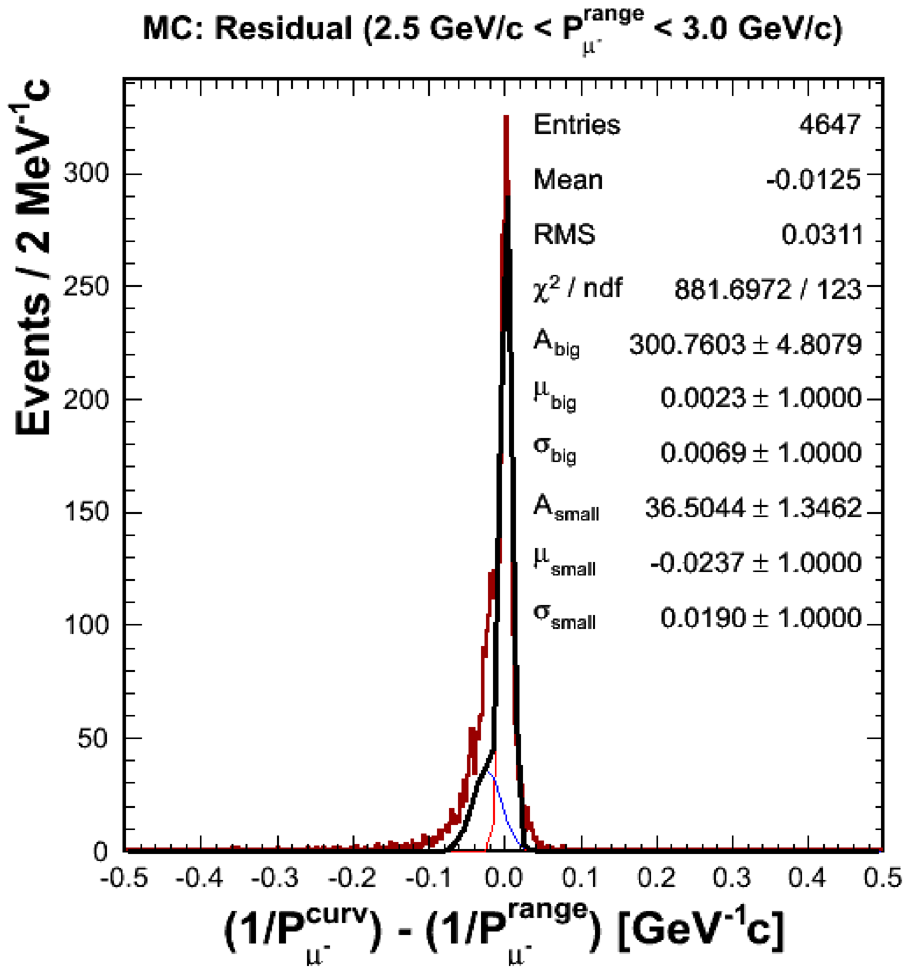


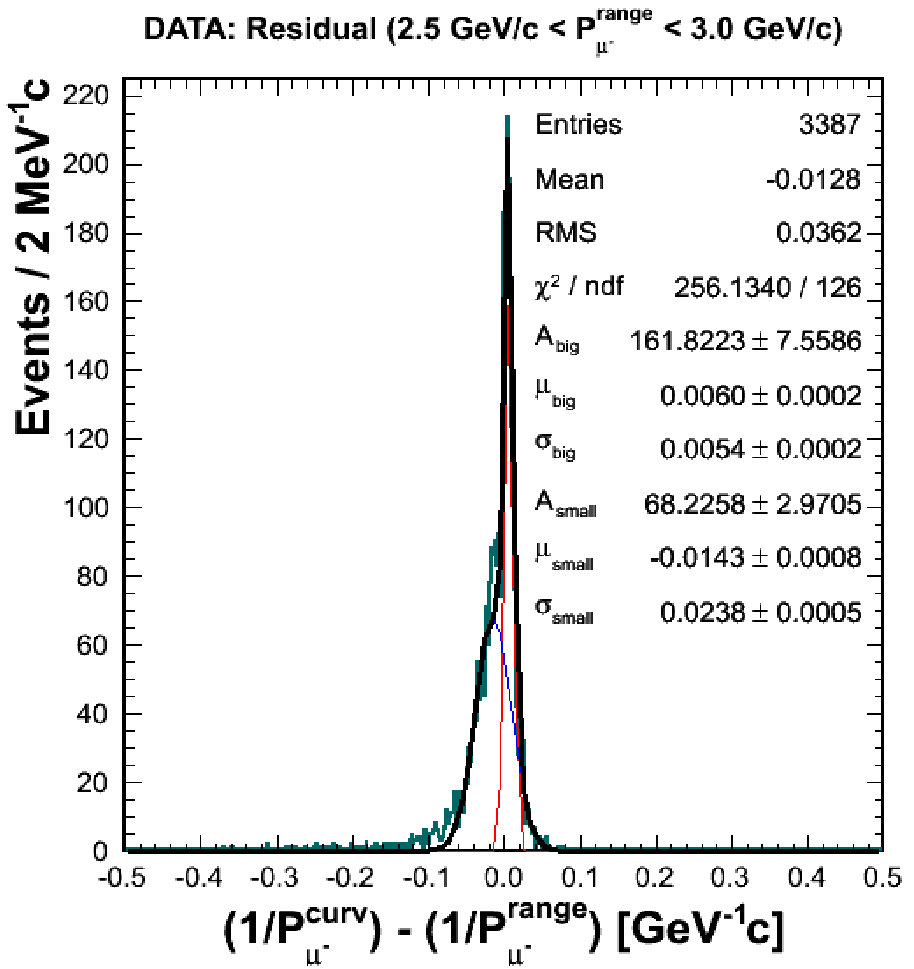


Fits on the 4th interval of P_{range}

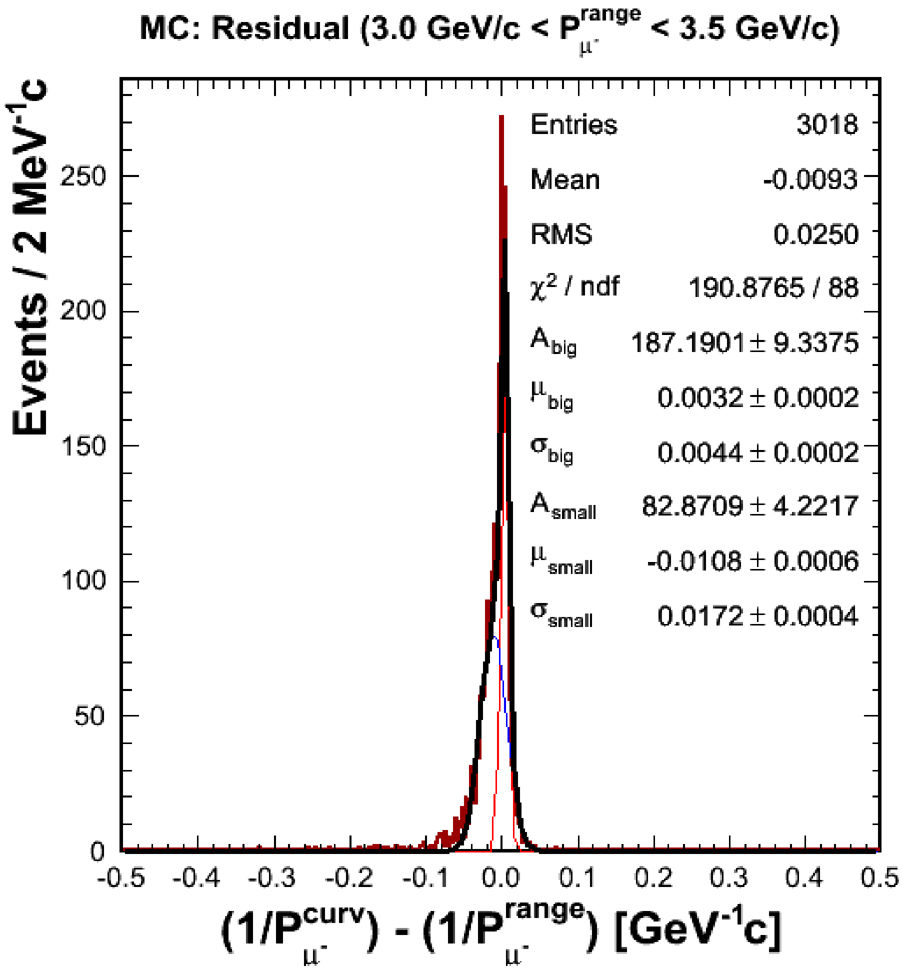


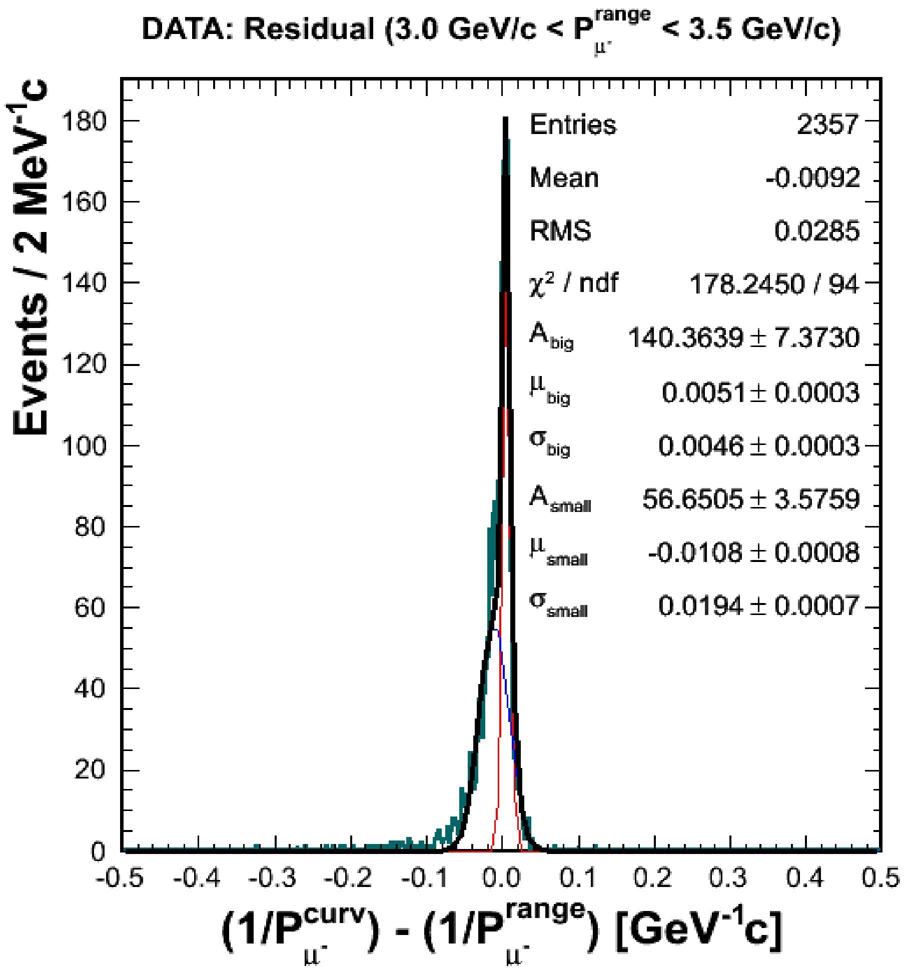
Fits on the 5th interval of P_{range}





Fits on the 6th interval of P_{range}





Details about the calculation of ΔK

P_{range} [GeV/c]	Histogram mean		Gaussian big peak	
	Data [c/GeV]	MC [c/GeV]	Data [c/GeV]	MC [c/GeV]
0.5 to 1.0	-0.0514 ± 0.0033	-0.0275 ± 0.0025	0.0915 ± 0.0024	0.0688 ± 0.0016
1.0 to 1.5	-0.0597 ± 0.0017	-0.0555 ± 0.0013	0.0249 ± 0.0006	0.0133 ± 0.0004
1.5 to 2.0	-0.0306 ± 0.0009	-0.0333 ± 0.0007	0.0110 ± 0.0003	0.0040 ± 0.0002
2.0 to 2.5	-0.0192 ± 0.0007	-0.0206 ± 0.0006	0.0073 ± 0.0002	0.0029 ± 0.0002
2.5 to 3.0	-0.0128 ± 0.0006	-0.0125 ± 0.0004	0.0060 ± 0.0002	0.0023 ± 1.0000
3.0 to 3.5	-0.0092 ± 0.0006	-0.0093 ± 0.0001	0.0051 ± 0.0003	0.0032 ± 0.0002

Details about the calculation of ΔK

P_{range} [GeV/c]	Difference: Data - MC	
	Histogram mean [c/GeV]	Gaussian big peak [c/GeV]
0.5 to 1.0	-0.0239 ± 0.0041	0.0227 ± 0.0029
1.0 to 1.5	-0.0042 ± 0.0021	0.0116 ± 0.0007
1.5 to 2.0	0.0027 ± 0.0011	0.0070 ± 0.0004
2.0 to 2.5	0.0014 ± 0.0009	0.0044 ± 0.0003
2.5 to 3.0	-0.0003 ± 0.0007	0.0037 ± 1.0000
3.0 to 3.5	0.0001 ± 0.0006	0.0019 ± 0.0004

Exact values of ΔK and ΔP_{range}

P_{range} [GeV/c]	ΔK [c/GeV]	ΔP_{range} [GeV/c]
0.5 to 1.0	0.0466 ± 0.0050	0.0262 ± 0.0028
1.0 to 1.5	0.0158 ± 0.0022	0.0247 ± 0.0034
1.5 to 2.0	0.0043 ± 0.0012	0.0132 ± 0.0037
2.0 to 2.5	0.0030 ± 0.0009	0.0152 ± 0.0046
2.5 to 3.0	*Bad fitting*	*Bad fitting*
3.0 to 3.5	0.0018 ± 0.0007	0.0190 ± 0.0074