Particle ID Away from the Bragg Peak using $\frac{dE}{dx}$

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2 August 2019

μBooNE

Kansas State University

Outline

1. What are neutrinos? What is MicroBooNE?
2. Why are particle ID methods away from the Bragg peak useful?
3. How can we use $\frac{dE}{dx}$ to create such a technique?
4. How does the technique work?
5. What are its results?

What Are Neutrinos?

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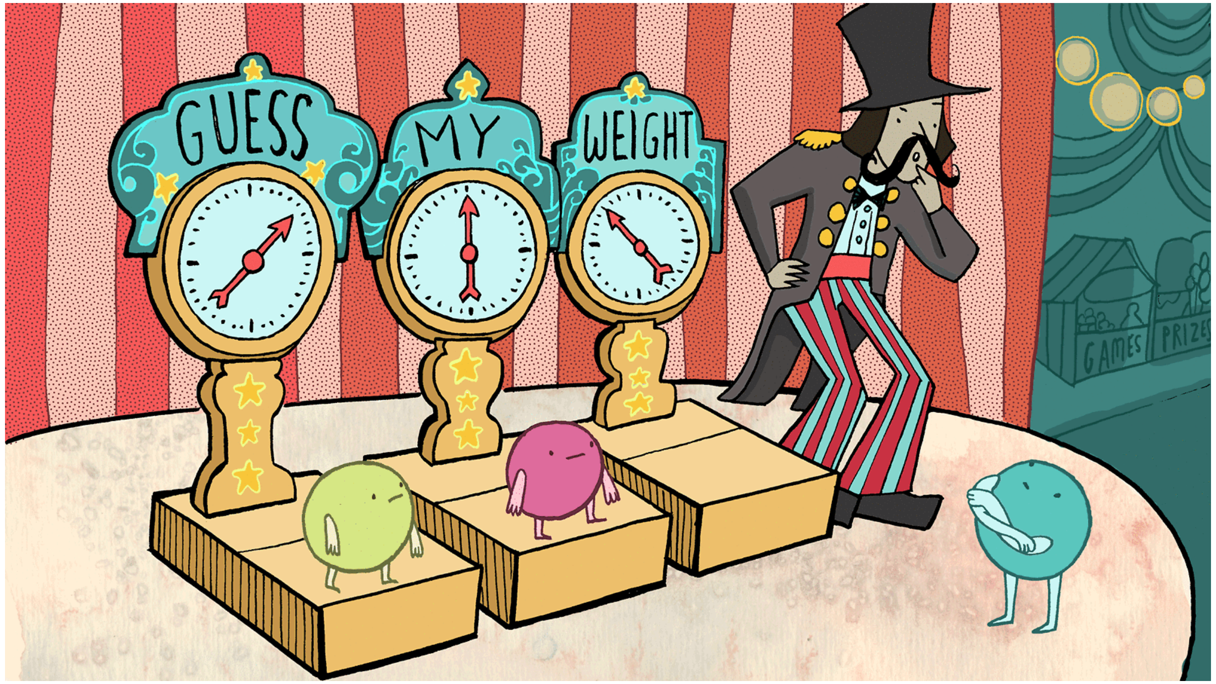
- Small ($m < 2\ eV/c^2$)!



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What Are Neutrinos?

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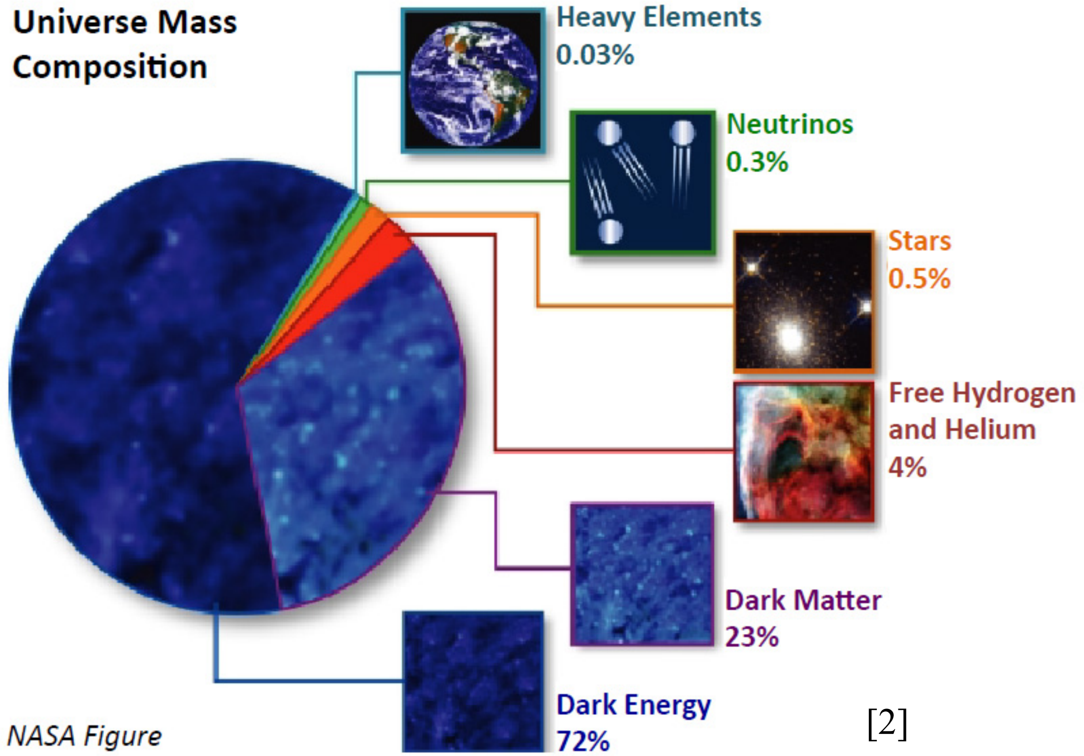
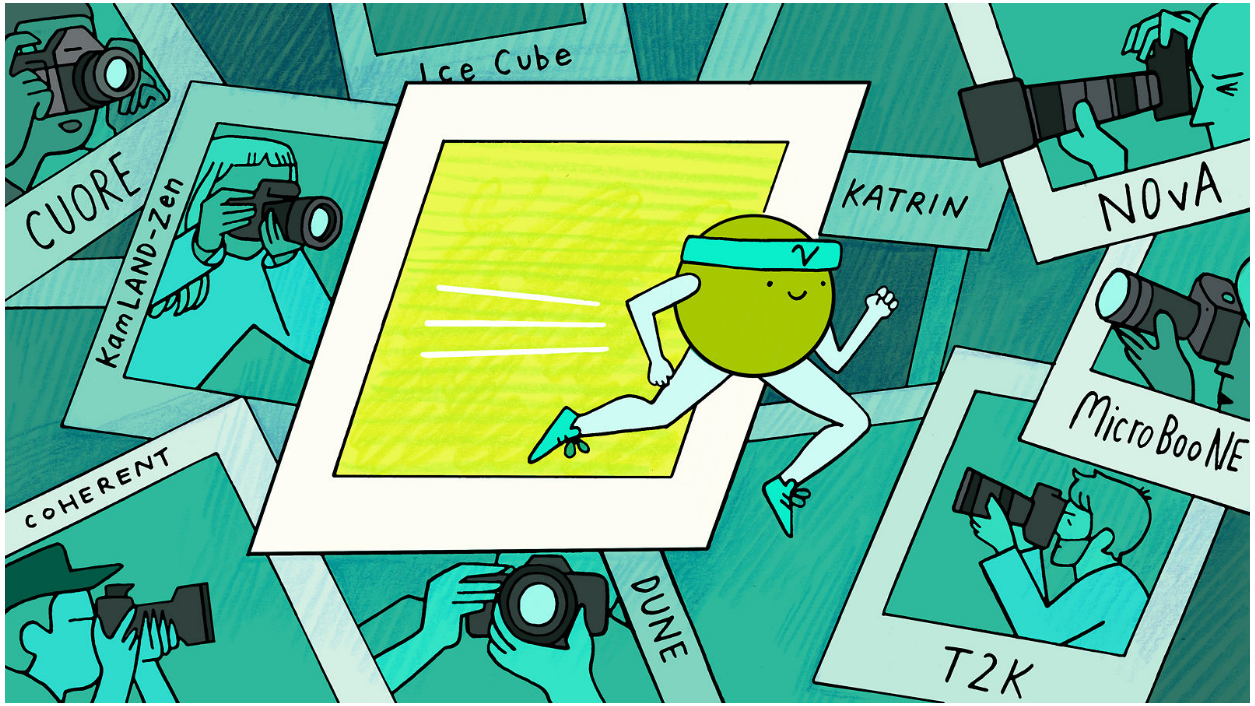
- Abundant!



[2]

What Are Neutrinos?

- Small ($m < 2\ eV/c^2$)!
- Abundant!
- Fascinating!



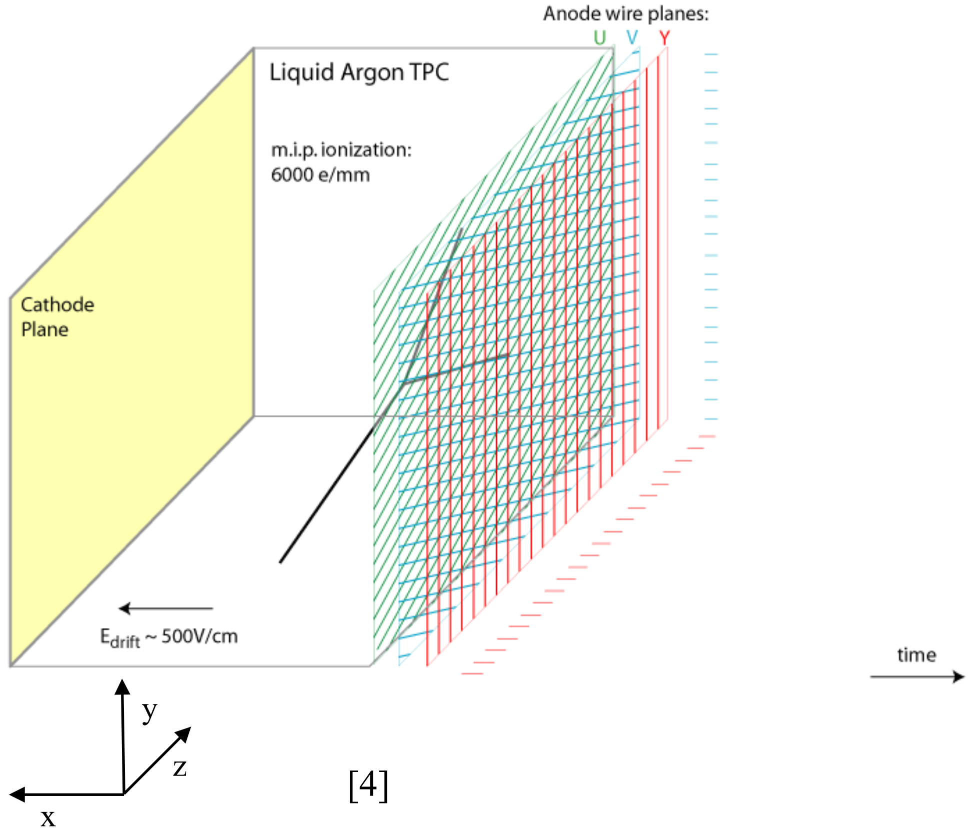
[3]

MicroBooNE

- Large liquid argon time projection chamber (LArTPC) experiment
- Previous experiment MiniBooNE found a significant excess of neutrino interactions producing lower energy photons and/or electrons
- <u>MicroBooNE's goal</u>: to probe the cause of this excess

μBooNE

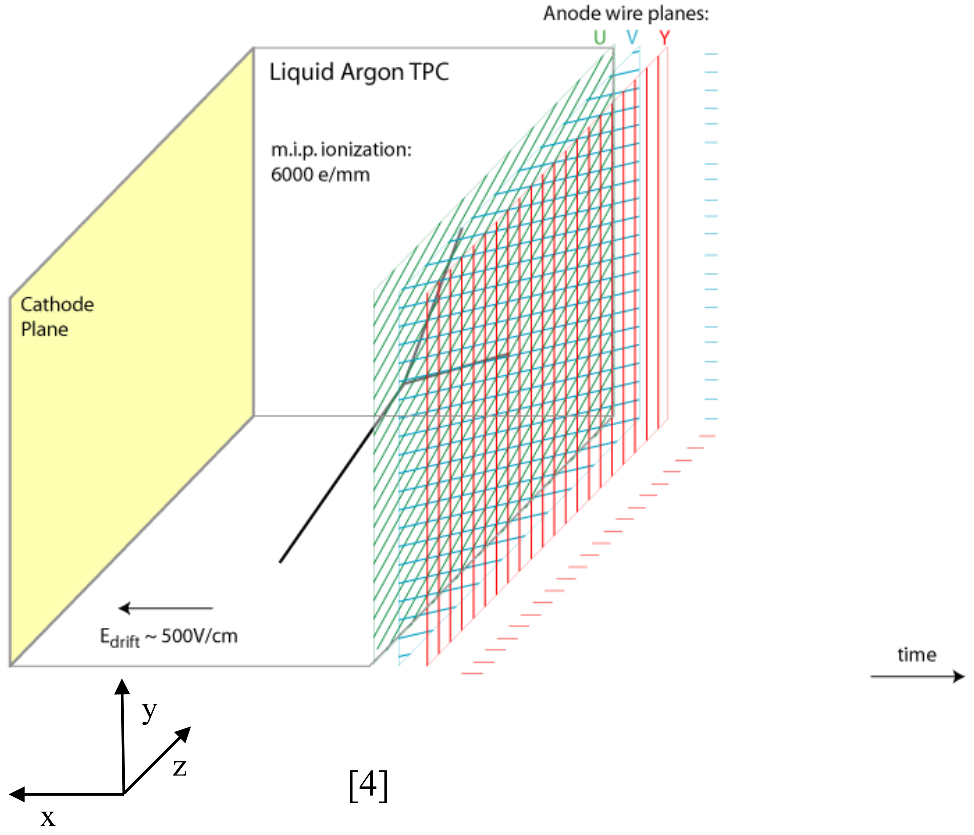
MicroBooNE Detector



[4]

MicroBooNE Detector

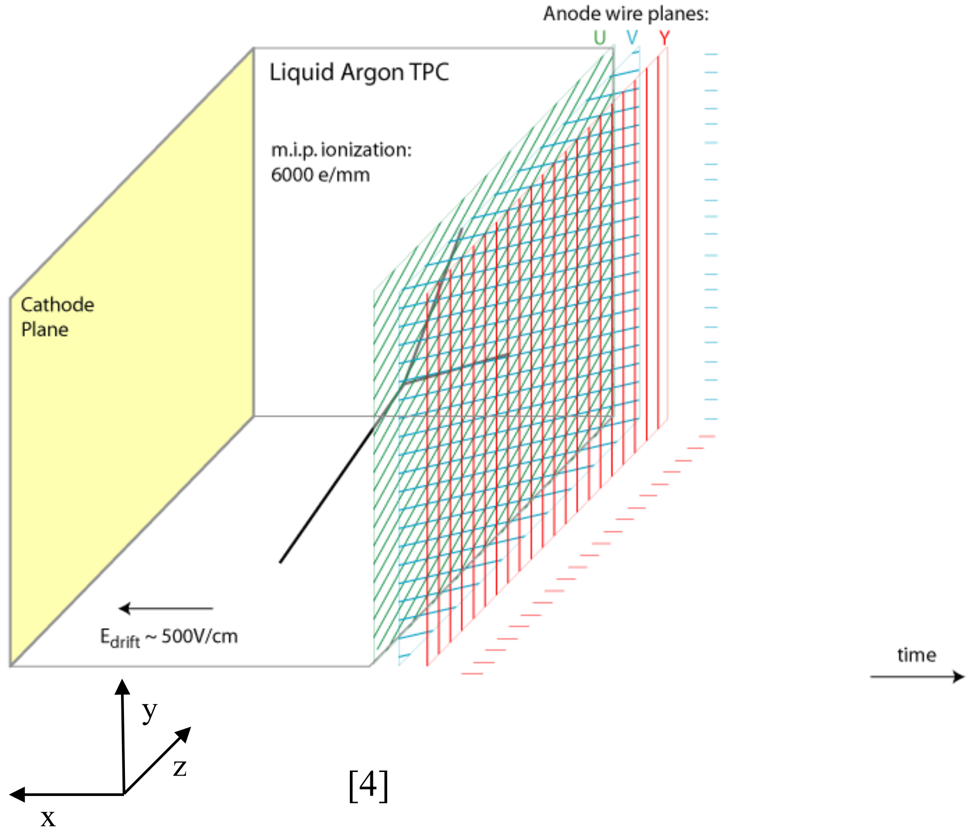
- Contains 90 tons of liquid argon
- Cathode has a potential of -100 kV
- Light produced from the interaction is collected by PMTs and gives start time
- Wire planes give y-z spatial resolution
- Time ionized electrons take gives x spatial resolution



[4]

MicroBooNE Detector

Important question: how do we identify the particles created in the detector?



[4]

PID at the Bragg Peak

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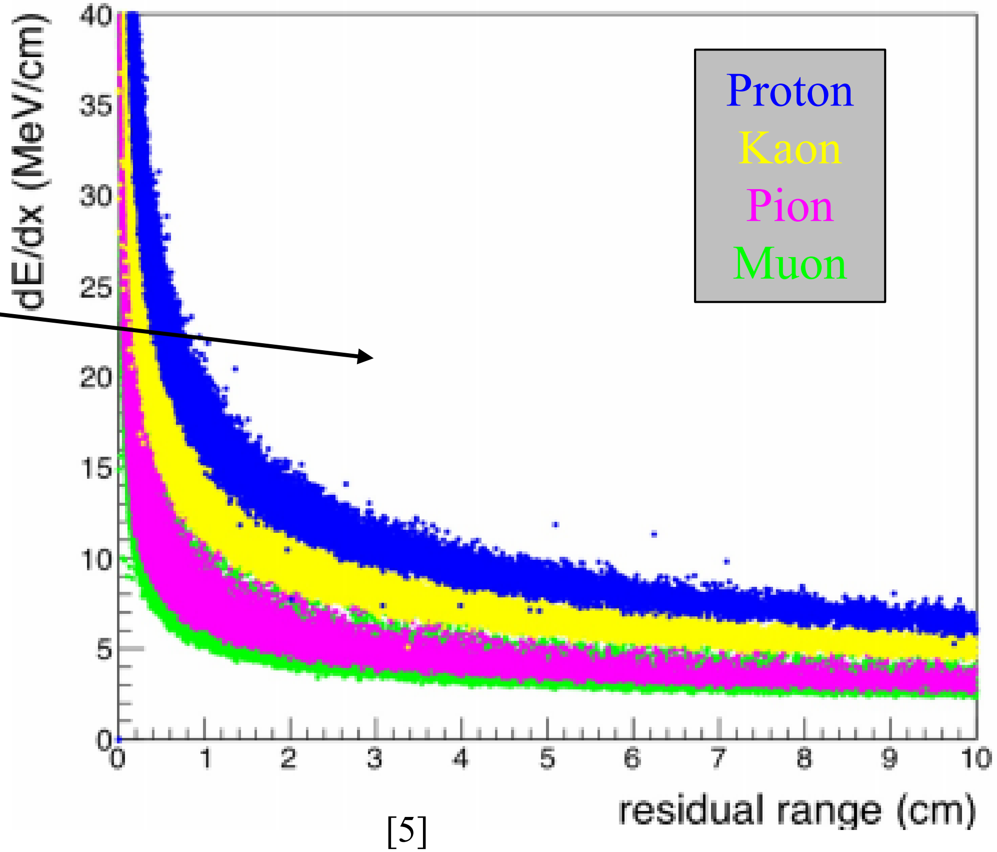
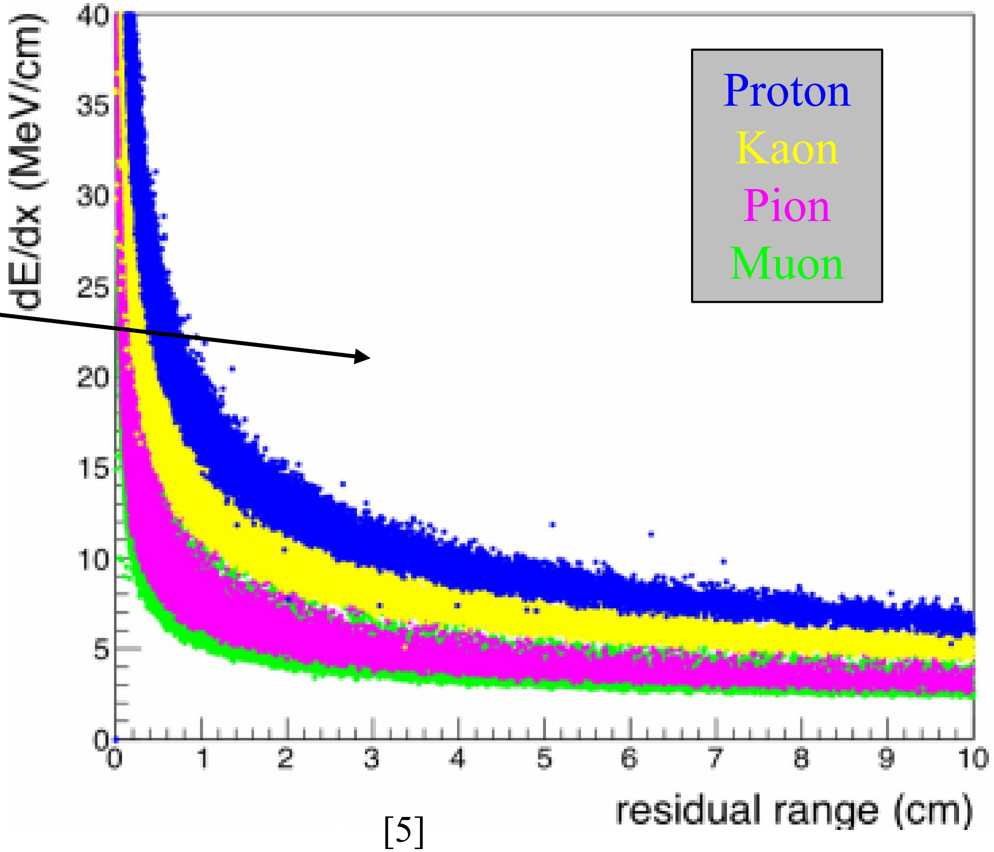


[5]

PID at the Bragg Peak

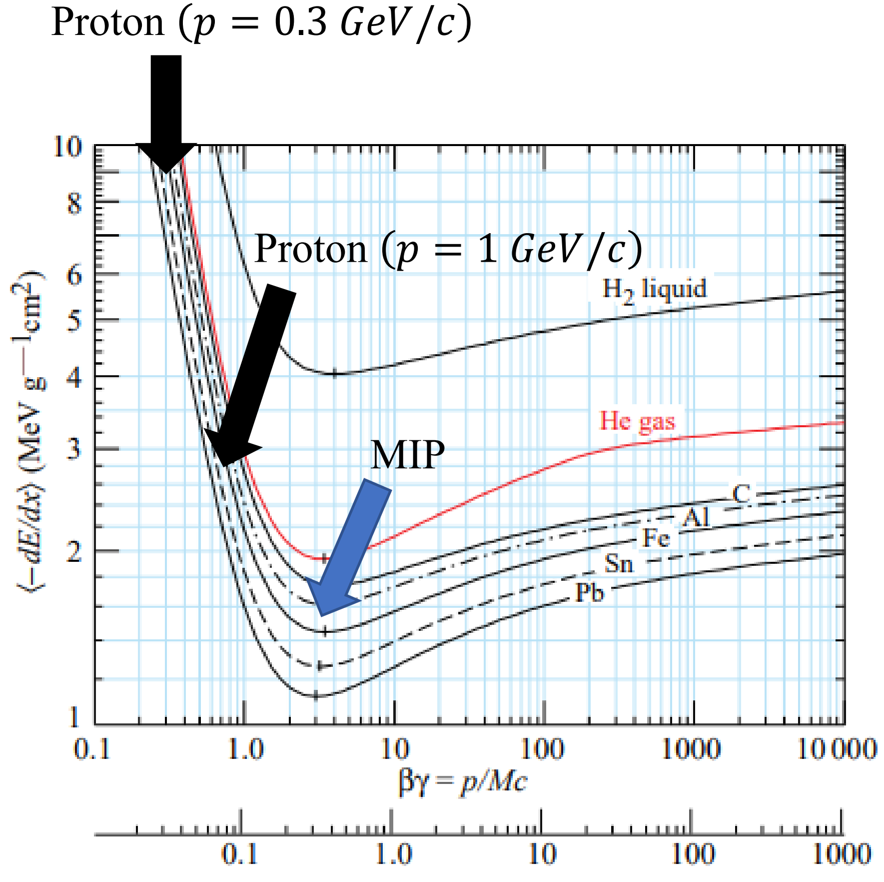
- Relies on two important quantities:
    1. Pattern of energy losses
    2. Track of particle (especially end)

Big problems! The particle would need to come to a gradual stop in the detector for the method to work!



[5]

PID Away from the Bragg Peak

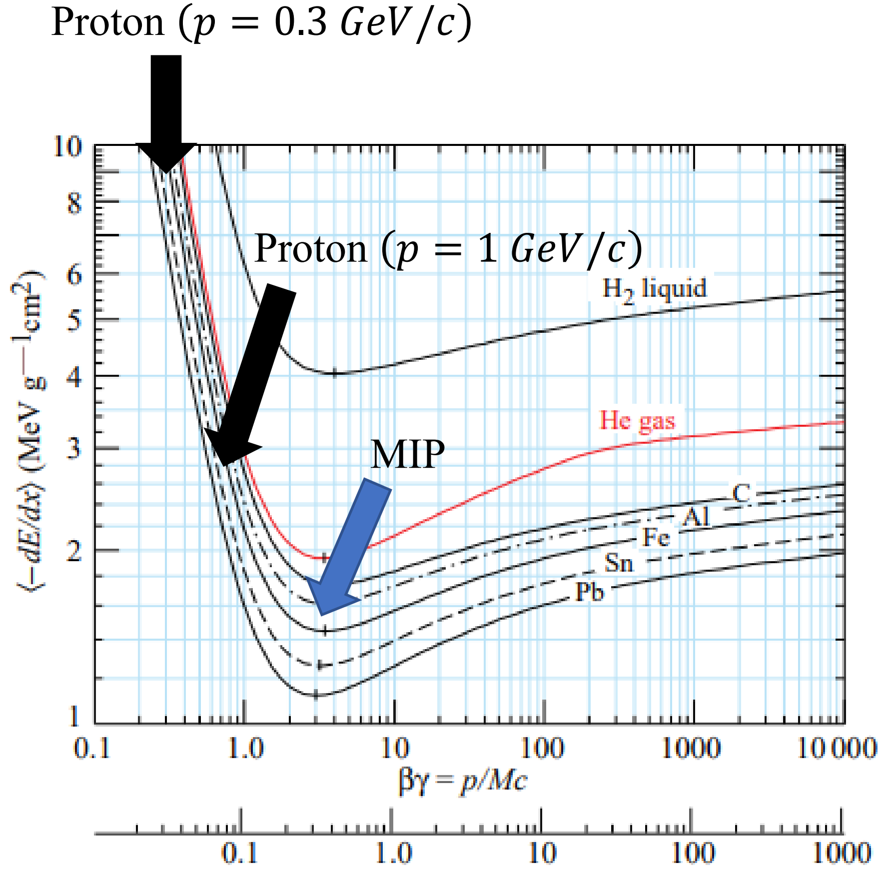


[6]

PID Away from the Bragg Peak

MIPs and HIPs have different average energy losses even in the middle of their tracks!!!*

*This still depends on the starting KE of the particles though



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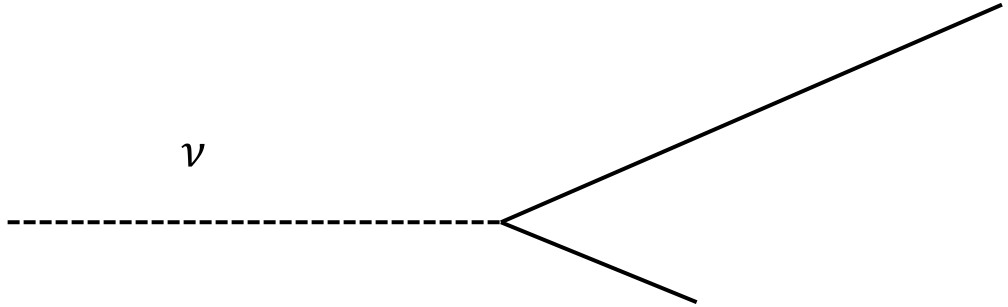

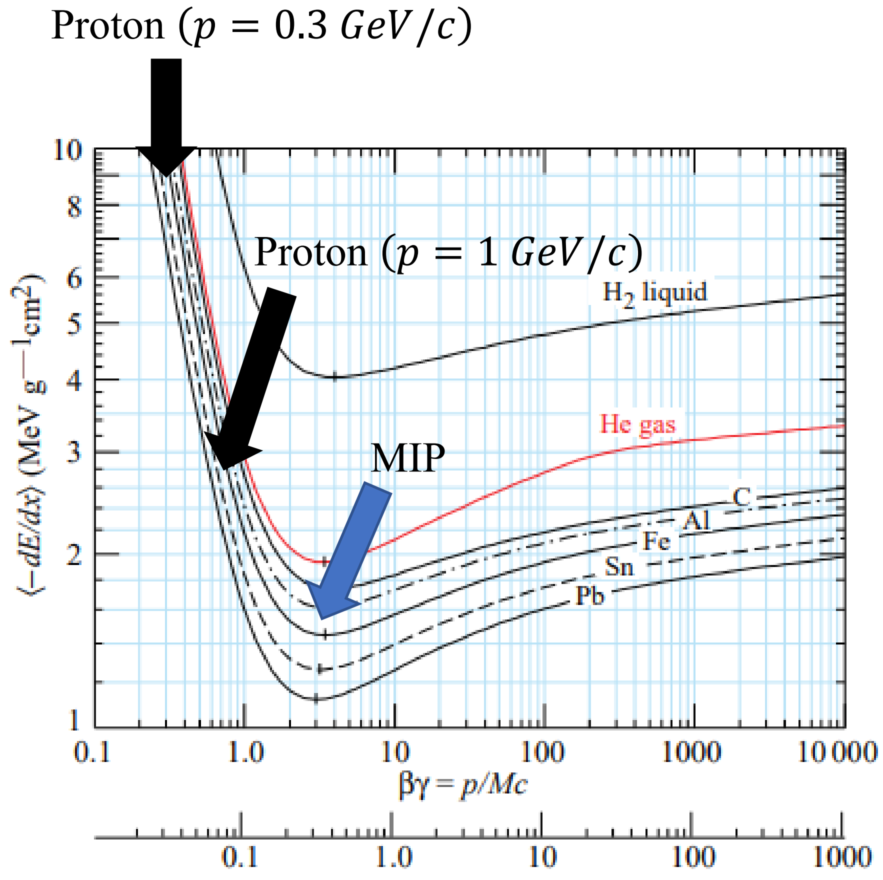

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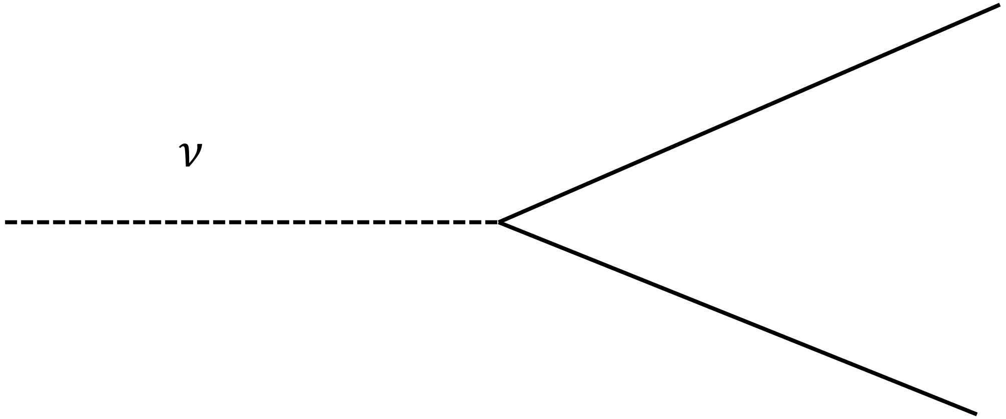

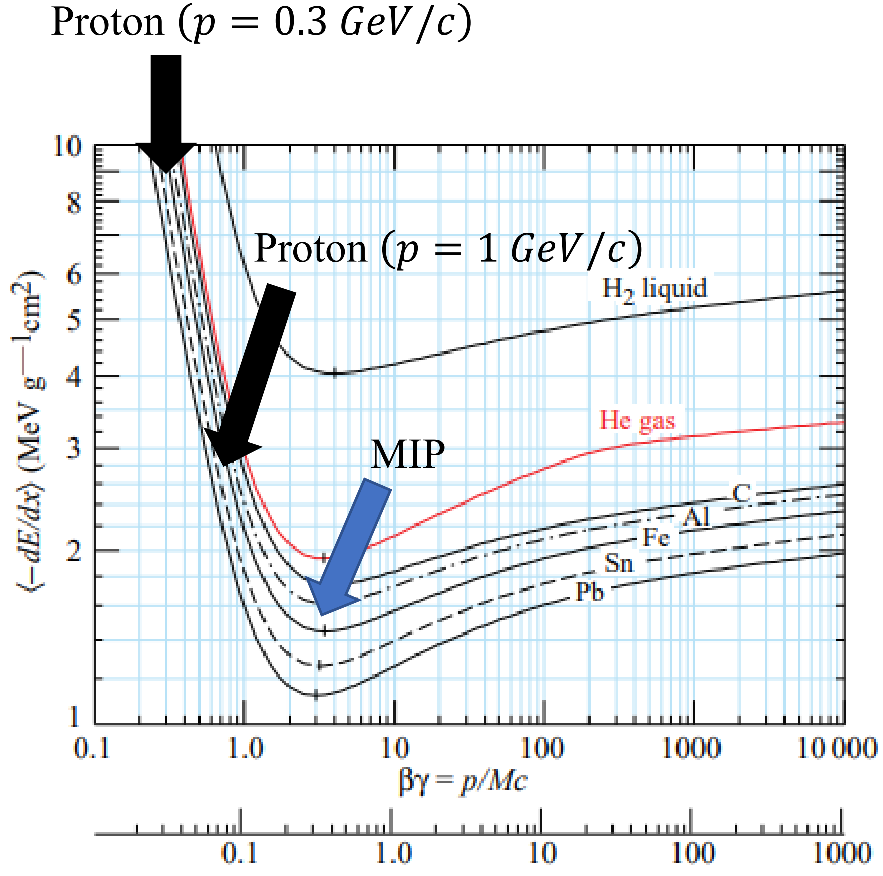

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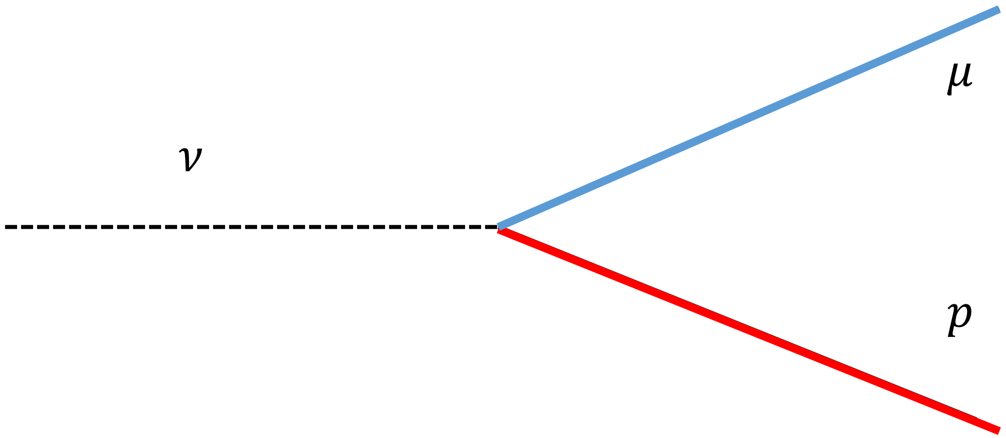

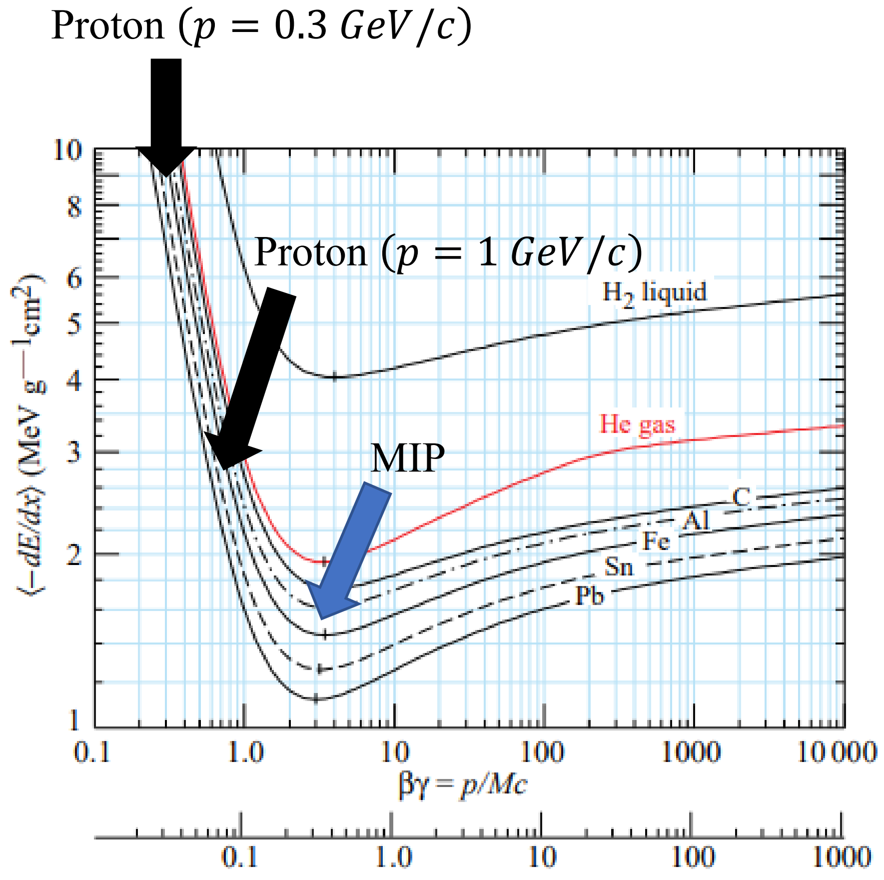

[6]

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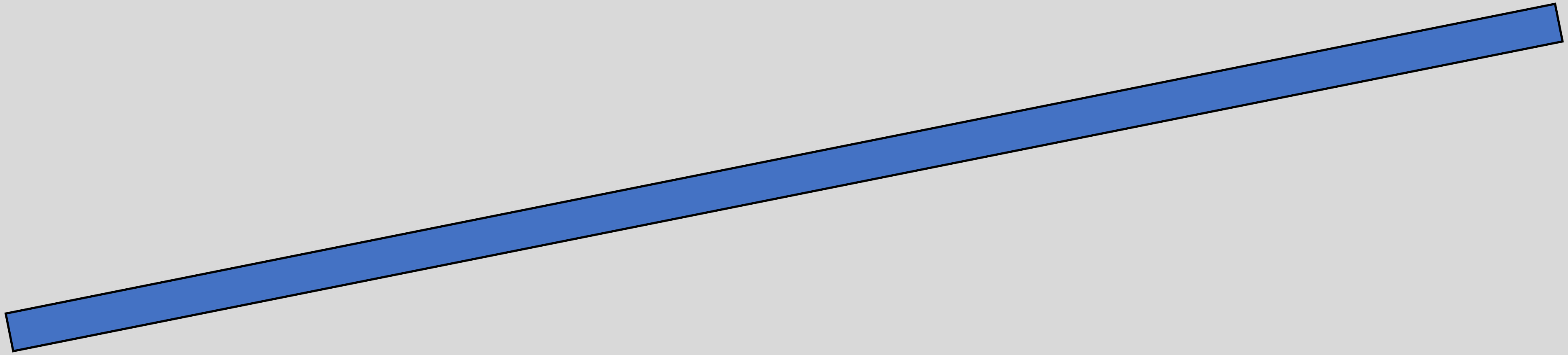
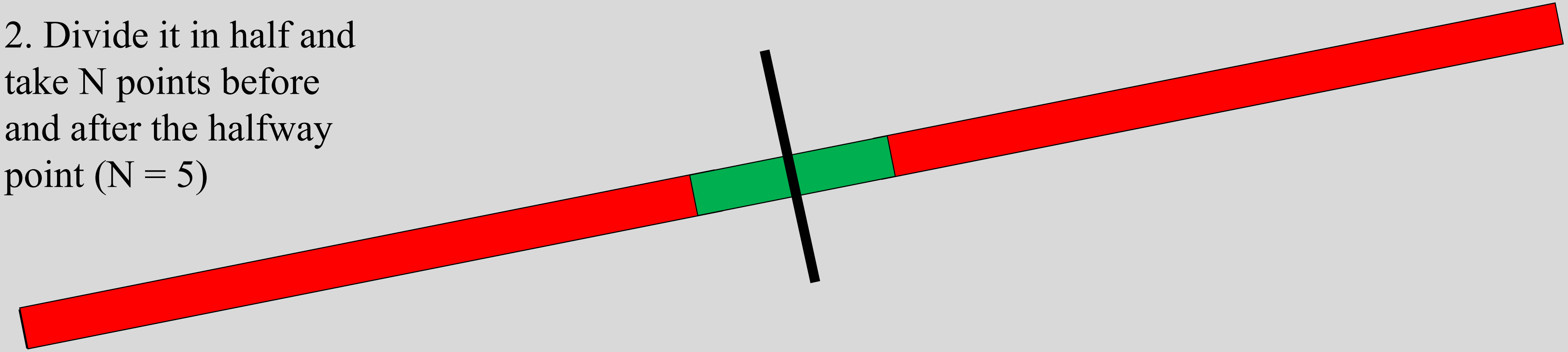


How does it work?

1. Take a track

2. Divide it in half and take N points before and after the halfway point (N = 5)



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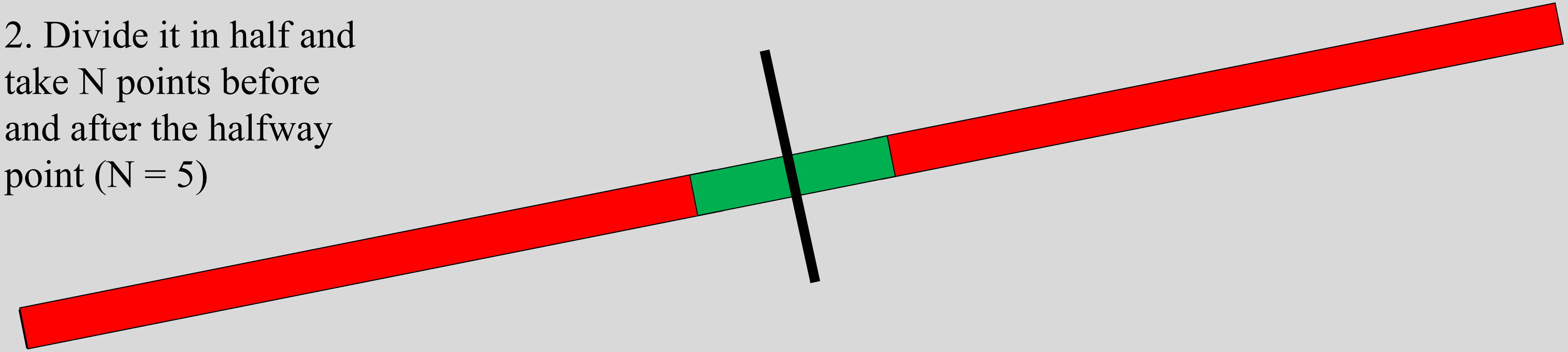

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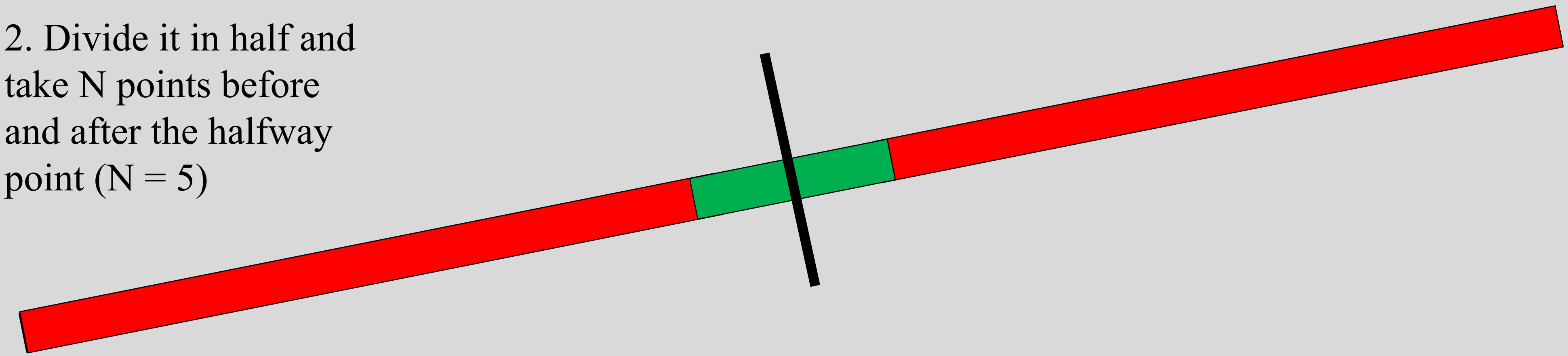

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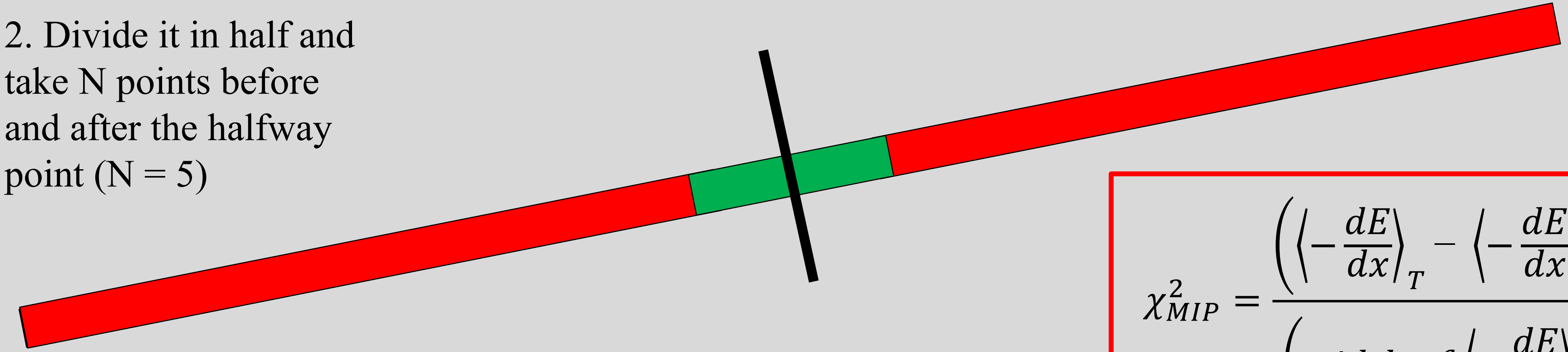

$$\chi^2_{MIP} = \frac{\left(\left\langle -\frac{dE}{dx}\right\rangle_T - \left\langle -\frac{dE}{dx}\right\rangle_{T_{MIP}}\right)^2}{\left(width\ of\ \left\langle -\frac{dE}{dx}\right\rangle_{T_{MIP}}\right)^2}$$

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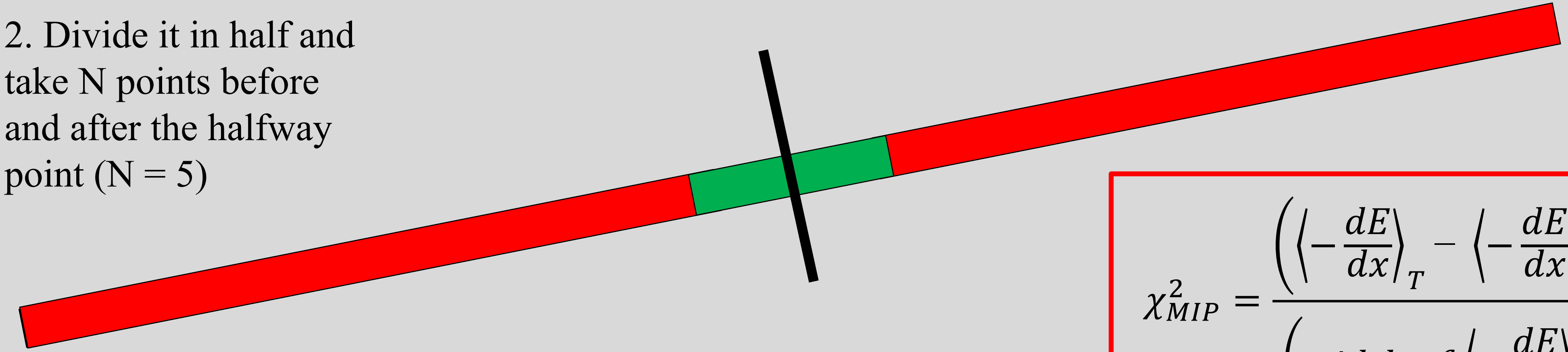

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$\left\langle -\frac{dE}{dx}\right\rangle_T$ and the width of $\left\langle -\frac{dE}{dx}\right\rangle_T$ come from a MIP Monte Carlo simulation

How does it work?

Why compare to MIP data? There is excellent MIP calibration throughout the detector [7]!

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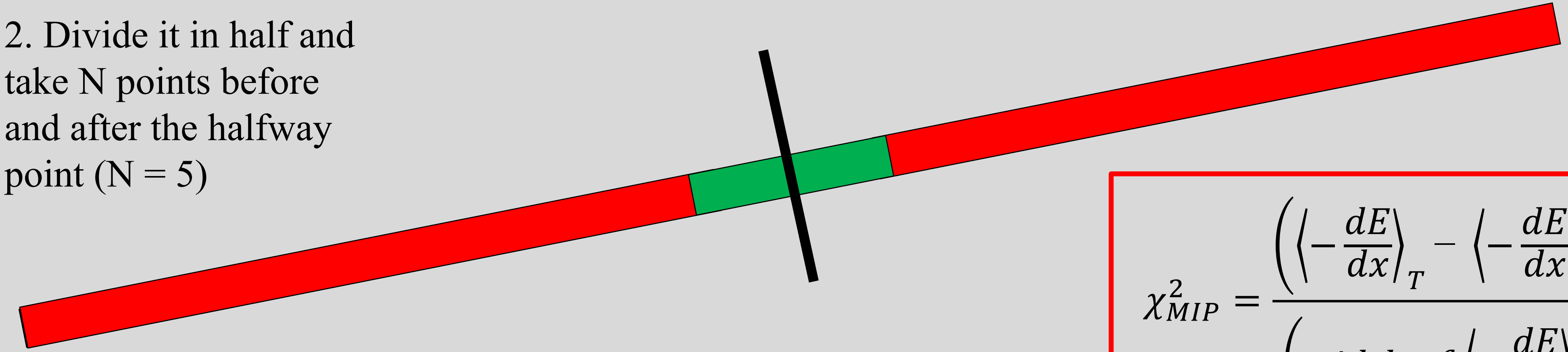

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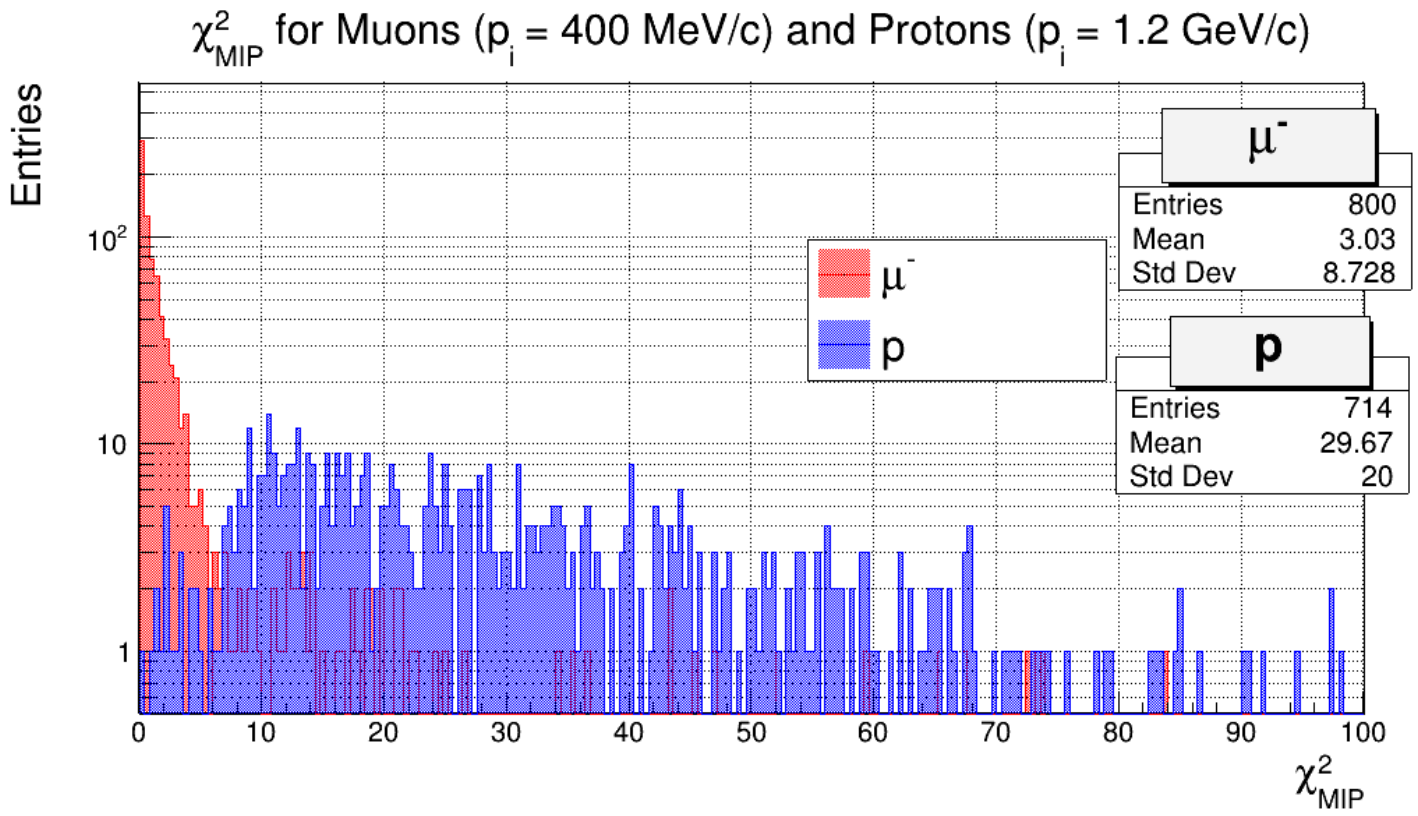
Algorithm results on MC-Truth simulation data with 800 muons ($p_i = 400\ MeV/c$) and 800 protons ($p_i = 1.2\ GeV/c$) and $\theta = \phi = 0$

χ^2_{MIP} Cut	Muon Efficiency from Muon Sample	Proton Efficiency from Proton Sample
1	55.9%	99.7%
4	87.1%	97.8%
9	93.1%	91.9%
16	95.6%	74.2%

$$\chi^2_{MIP} < (\chi^2_{MIP}\ \boldsymbol{Cut}) \rightarrow \mu$$

$$\chi^2_{MIP} > (\chi^2_{MIP}\ \boldsymbol{Cut}) \rightarrow p$$

$$efficiency = \frac{(\#\ of\ correctly\ identified\ particles)}{(total\ \#\ of\ particles)}$$



Summary

- PID techniques away from the Bragg peak are useful!
- The technique compares the truncated mean $\frac{dE}{dx}$ of a particle in the middle of its track to a MIP
- It is effective for one test track with a length around 130 cm
- Future inquiry: how does the method behave at different track lengths?

Acknowledgements

- Dr. Tim Bolton
- Dr. Glenn Horton-Smith
- Harry Mayrhofer
- Norman Martinez
- The MicroBooNE Collaboration
- Kansas State University*
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*Thank you Blet Frandels and Norlen Greman!

References

[1] Mucha, C., and Sandbox Studio Chicago (2017), “How Heavy is a neutrino?” Online; accessed July 27, 2019.

[2] Universe Review, (2019), “Mass composition of the universe,” Online; accessed July 27, 2019.

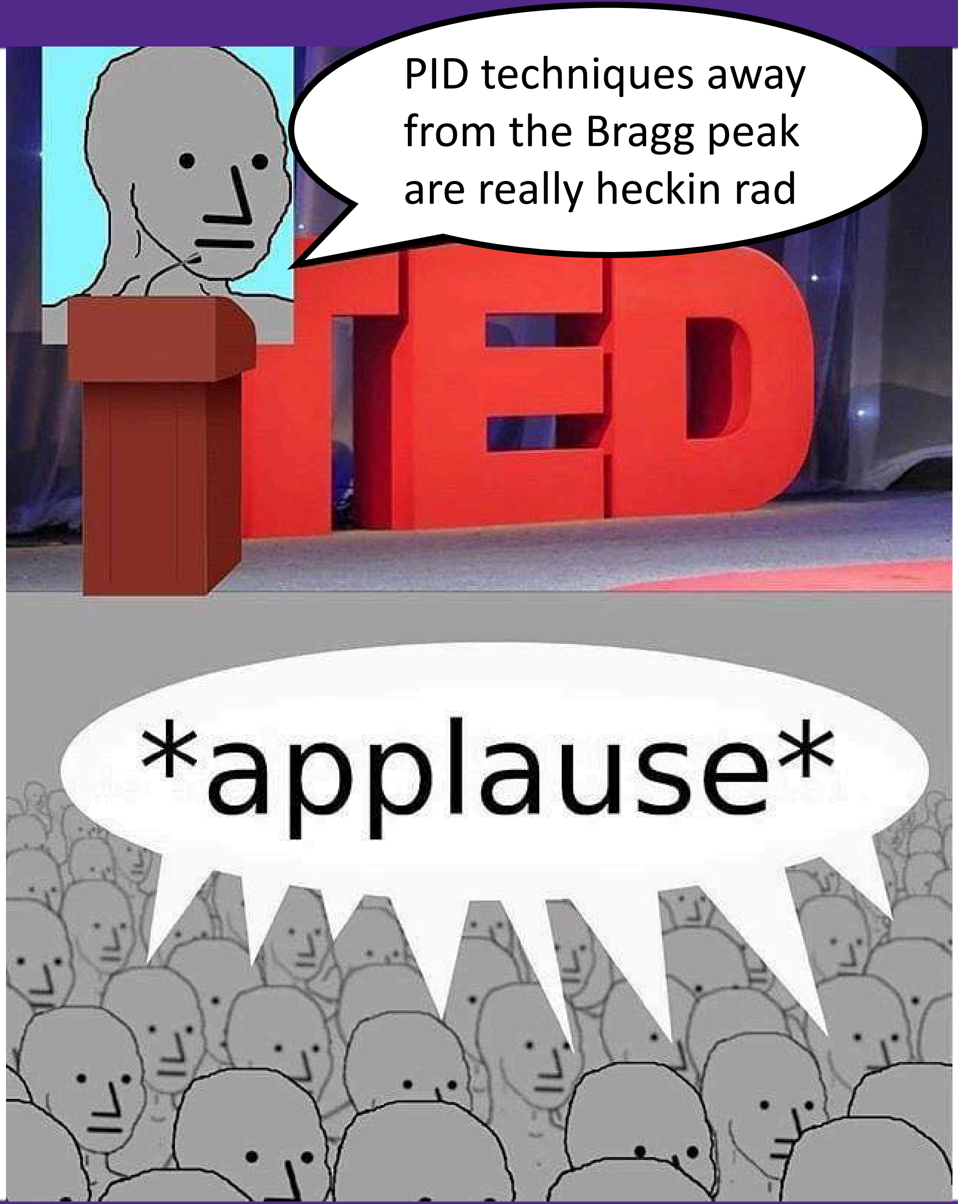
[3] Mucha, C., and Sandbox Studio Chicago (2018), “Game-changing neutrino experiments,” Online; accessed July 27, 2019.

[4] Brookhaven National Laboratory, (2019), “LArTPC Signal,” Online; accessed June 7, 2019.

[5] MicroBooNE Collaboration, “Selection of ν_μ charged-current induced interations with N>0 protons and performance of events with N=2 protons in the final state in the MicroBooNE detector from the BNB,” MICROBOONE-NOTE-1056-PUB (2018).

[6] Tanabashi, M., *et al.* (Particle Data Group) (2018), Phys. Rev. D **98**, 030001.

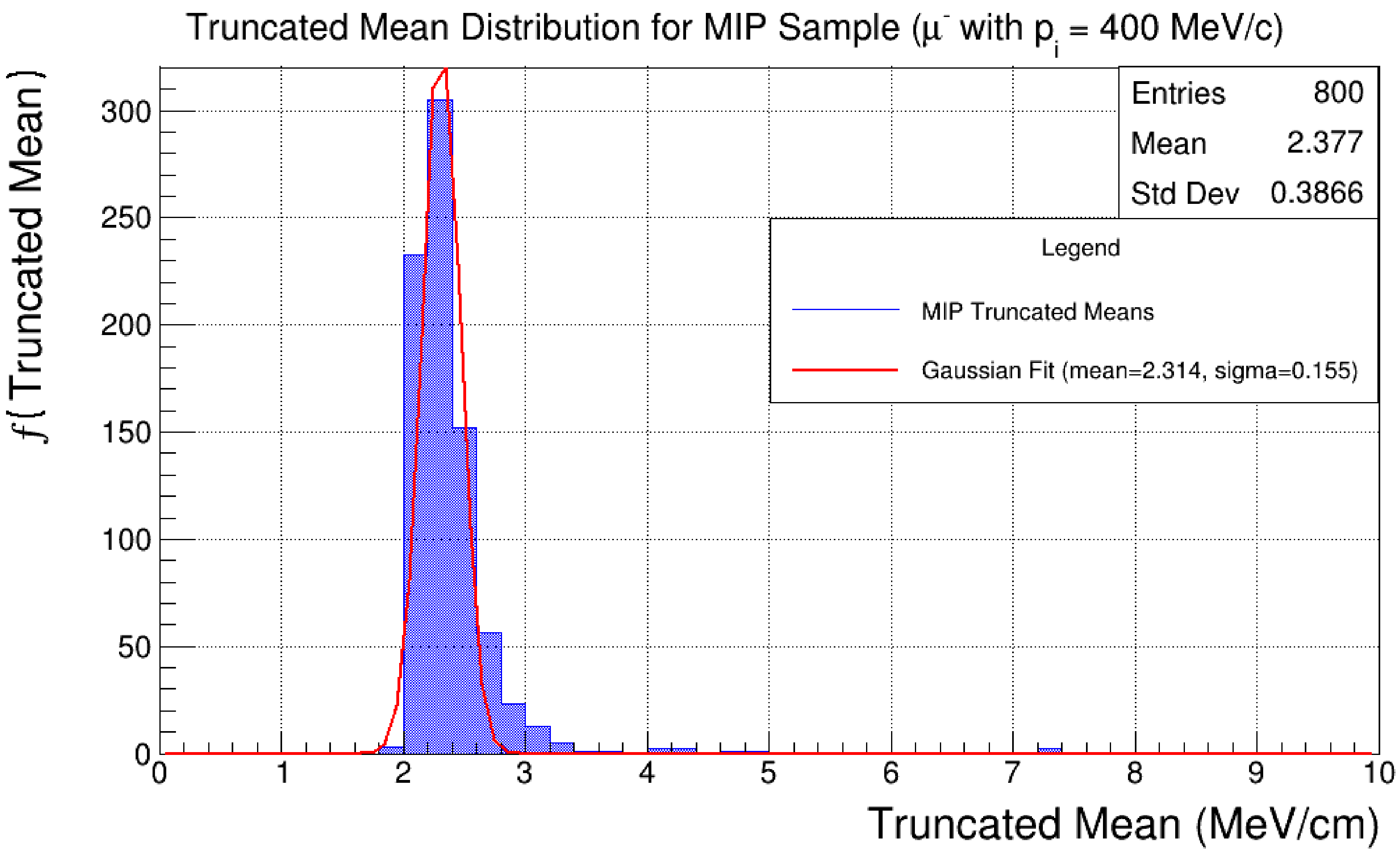
[7] MicroBooNE Collaboration, “Detector calibration using through going and stopping muons in the MicroBooNE LArTPC,” MICROBOONE-NOTE-1048-PUB (2018).


PID techniques away from the Bragg peak are really heckin rad
TED
applause

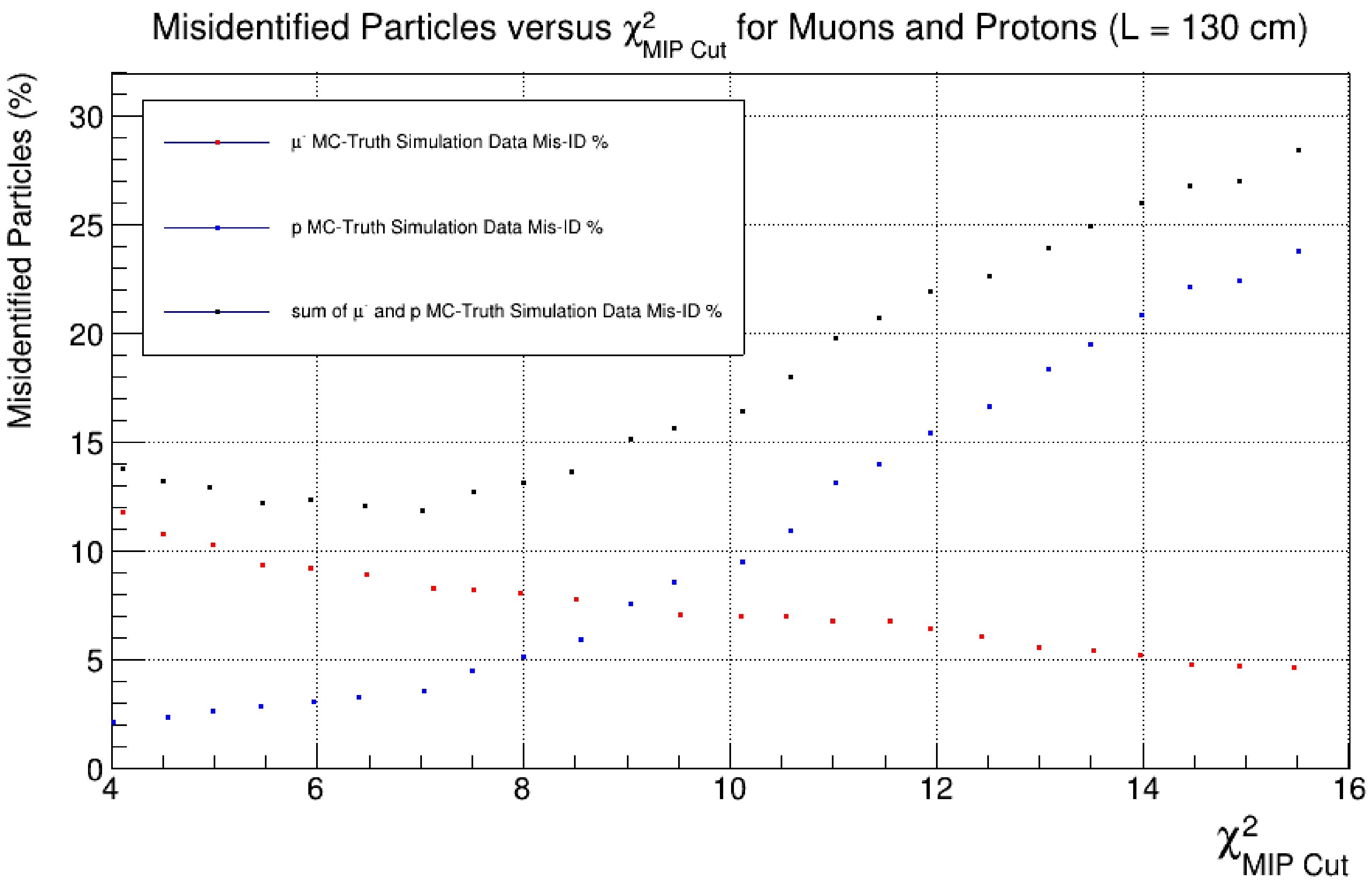
Extra Slides

Definitions

- MIP: minimum ionizing particle (practically speaking, μ^- with $p_i = 400\ MeV/c$)
- HIP: highly ionizing particle (practically speaking, protons)
- $\left\langle -\frac{dE}{dx} \right\rangle_T$: truncated mean from track data
- $\left\langle -\frac{dE}{dx} \right\rangle_{T_{MIP}}$: mean of Gaussian fit of MIP truncated mean distribution
- Width of $\left\langle -\frac{dE}{dx} \right\rangle_T$: standard deviation of Gaussian fit of MIP truncated mean distribution



Truncated Mean Distribution for MIP Sample (μ^- with p_i = 400 MeV/c)
Entries 800
Mean 2.377
Std Dev 0.3866
Legend
MIP Truncated Means
Gaussian Fit (mean=2.314, sigma=0.155)
f(Truncated Mean)
Truncated Mean (MeV/cm)
0
50
100
150
200
250
300
0
1
2
3
4
5
6
7
8
9
10


Misidentified Particles versus $\chi^2_{MIP\ Cut}$ for Muons and Protons (L = 130 cm)
Misidentified Particles (%)
μ^- MC-Truth Simulation Data Mis-ID %
p MC-Truth Simulation Data Mis-ID %
sum of μ^- and p MC-Truth Simulation Data Mis-ID %
0
5
10
15
20
25
30
4
6
8
10
12
14
16
$\chi^2_{MIP\ Cut}$