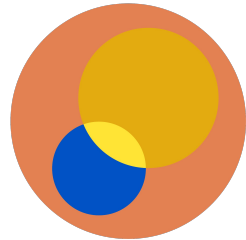
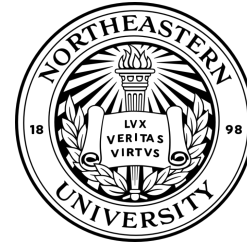


Particle Reconstruction in a Future Muon Collider

Sarah Douglass
Partikeldagarna 2026

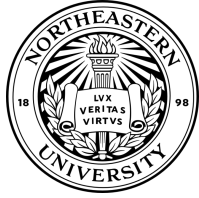
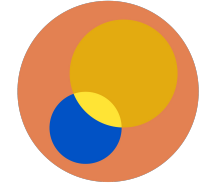
Questions to Answer

1. What is a muon collider?
2. Why do we want to build one?
3. What are the challenges?

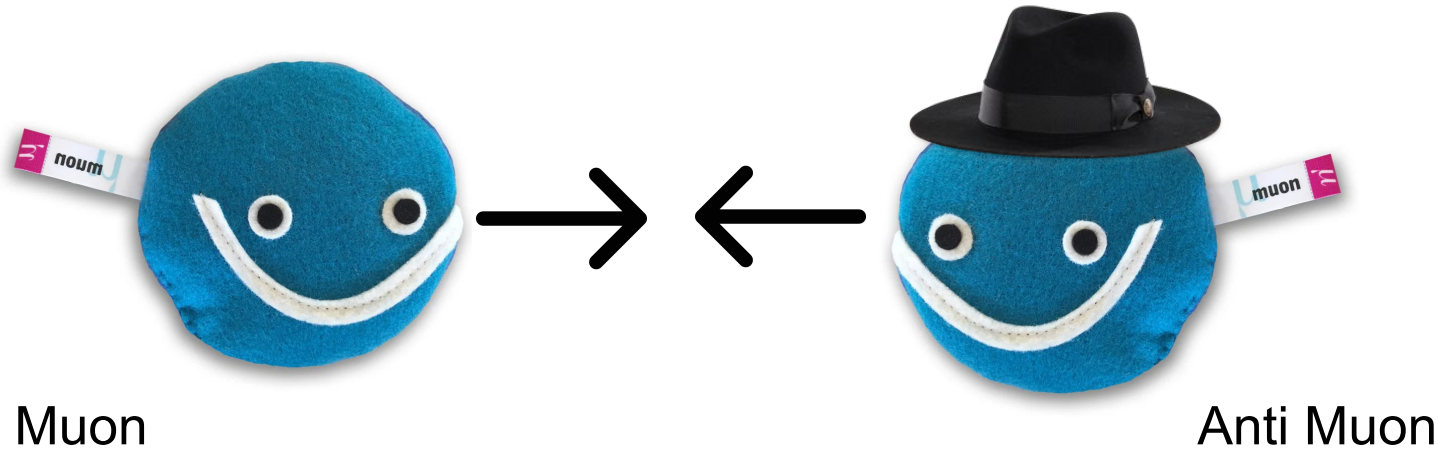
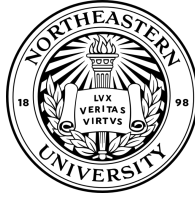
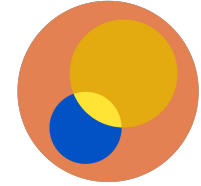


Sarah DeGross
Partikeldagarna 2026

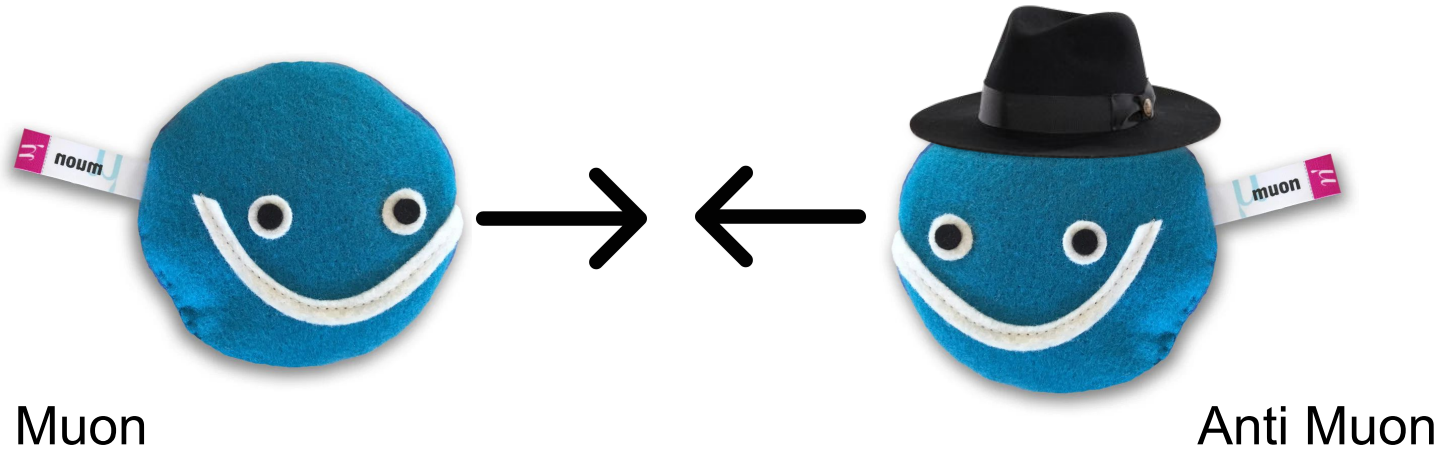
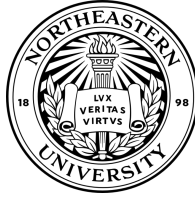
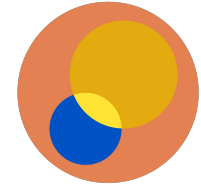
What is a Muon Collider?



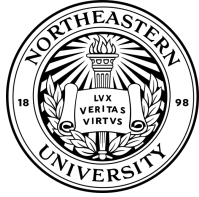
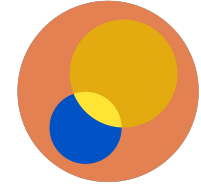
What is a Muon Collider?



~~What is a Muon Collider?~~ Why

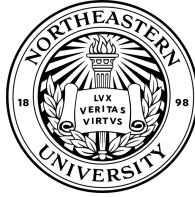
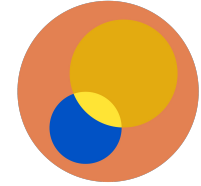


Why a Muon Collider?

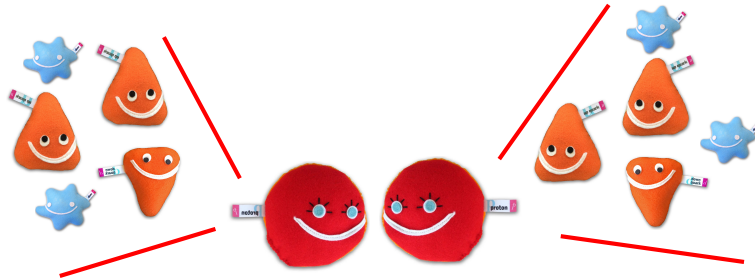


Higher energy $\rightarrow$ smaller ring

Why a Muon Collider?



Higher energy $\rightarrow$ smaller ring



$$\sqrt{s} = 13 \text{ TeV}$$

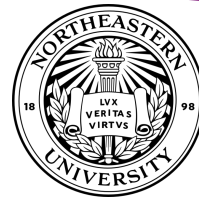
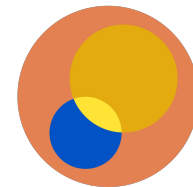
$pp \rightarrow \text{GeV} - \text{Low TeV}$



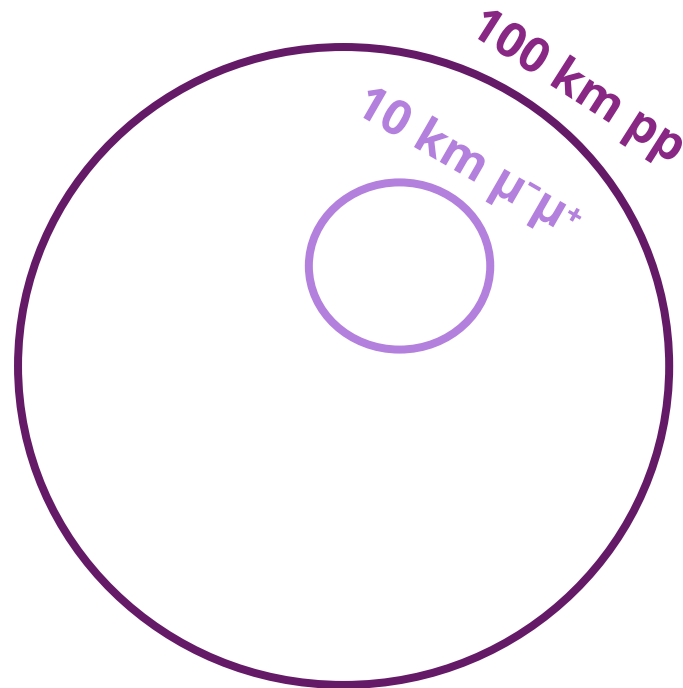
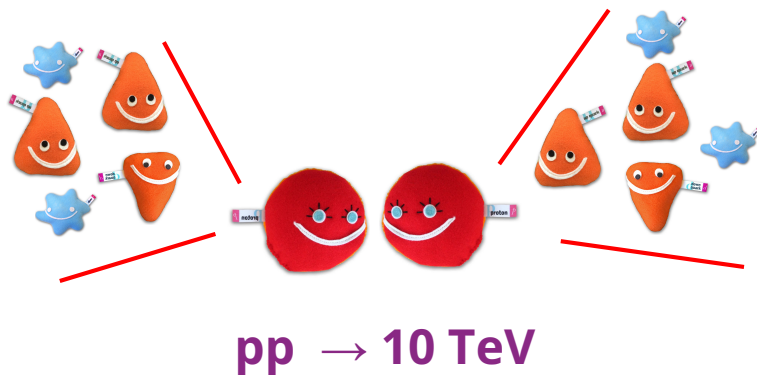
$$\sqrt{s} = 10 \text{ TeV}$$

$\mu^-\mu^+ \rightarrow 10 \text{ TeV}$

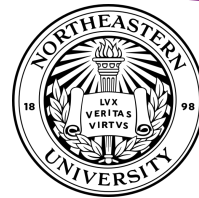
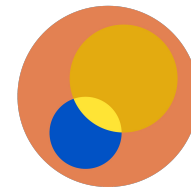
Why a Muon Collider?



Higher energy $\rightarrow$ smaller ring



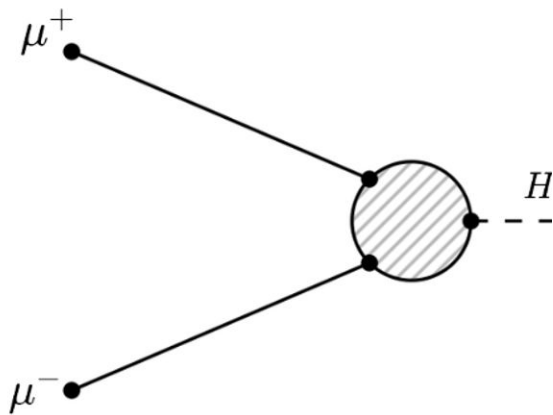
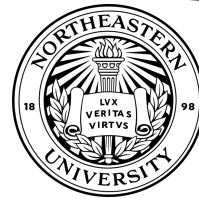
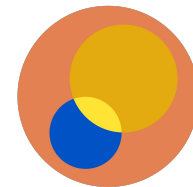
Why a Muon Collider?



Higher energy $\rightarrow$ smaller ring

Higher rate of Higgs production

Why a Muon Collider?



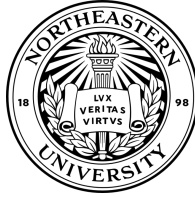
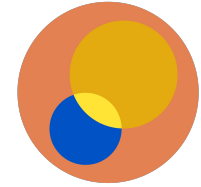
Think of FCCe⁻e⁺

207x mass of an electron -> Yukawa coupling scales directly with mass

Higher rate of Higgs production

Resonant rate scales with YC squared, would be 10⁴ x higher than in e⁻e⁺

Why a Muon Collider?

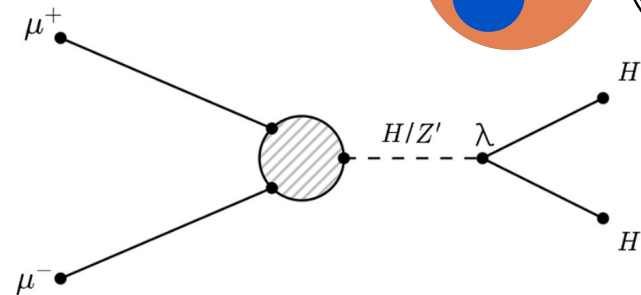
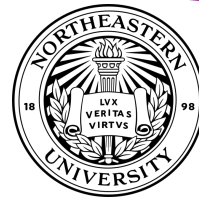
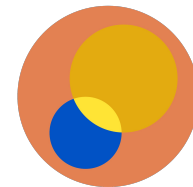


Higher energy $\rightarrow$ smaller ring

**Higher rate of higher order
Higgs production**

Higher rate of Higgs production

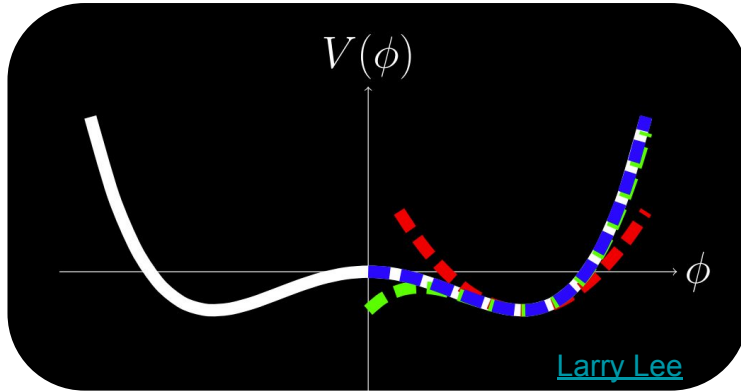
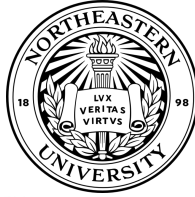
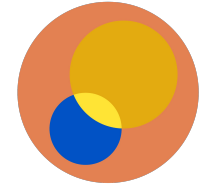
Why a Muon Collider?



Higher rate of higher order
Higgs production

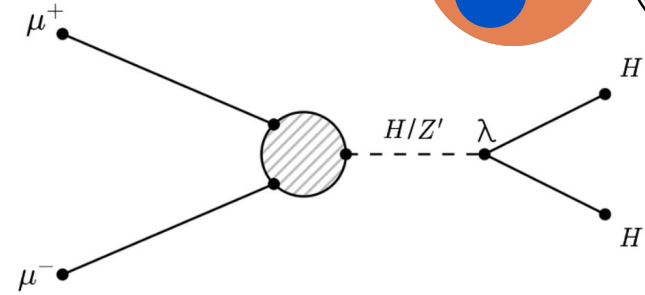
Direct measurement of
the self coupling λ

Why a Muon Collider?



[Larry Lee](#)

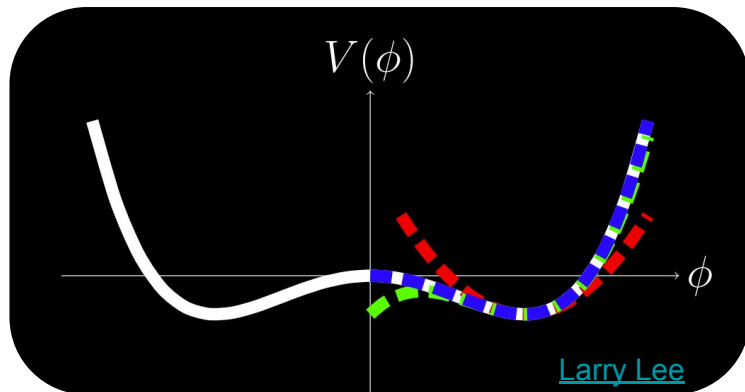
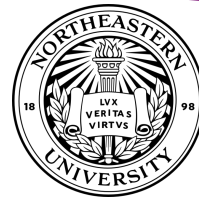
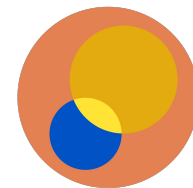
$$O(H^2) + O(H^3) + O(H^4)$$



Higher rate of higher order
Higgs production

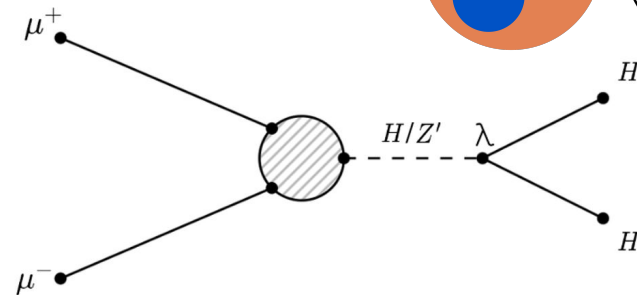
Direct measurement of
the self coupling λ

Why a Muon Collider?



$$O(H^2) + O(H^3) + O(H^4)$$

$$\mathcal{L} = -\frac{1}{2}\mu^2\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 \\ - \lambda H^4 - A\lambda H^3 - \dots$$

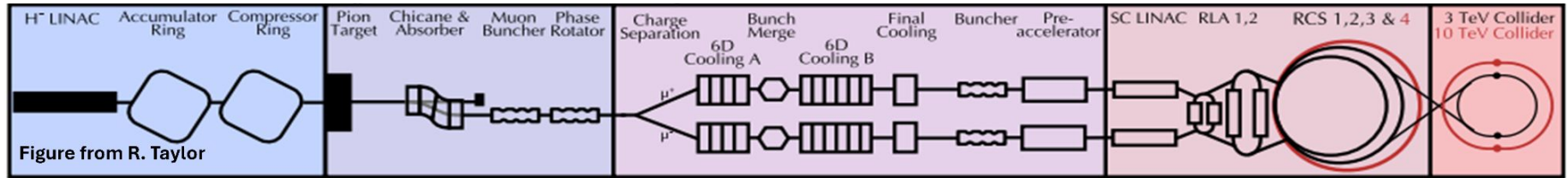
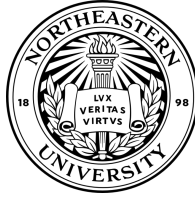
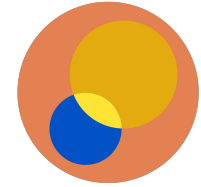


Higher rate of higher order
Higgs production

Direct measurement of
the self coupling λ

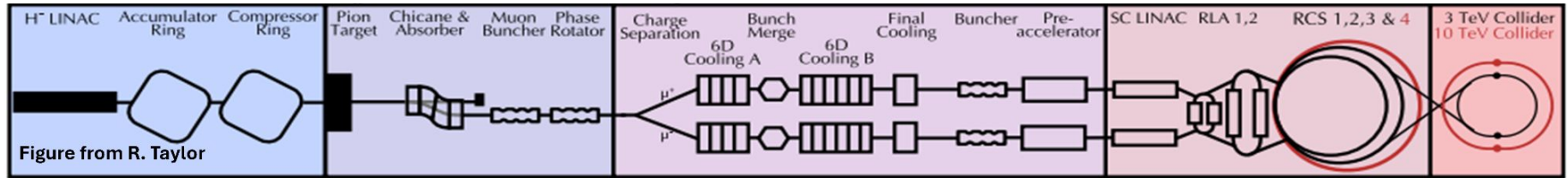
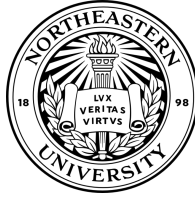
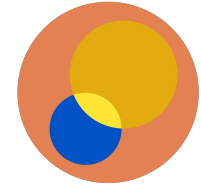
$2.2 \mu s$

Technical Problems



$2.2 \mu s$

Technical Problems



New Target Tech

10T/ms ramping

40T??

Magnet Magnitude

6D Cooling

MW proton beam

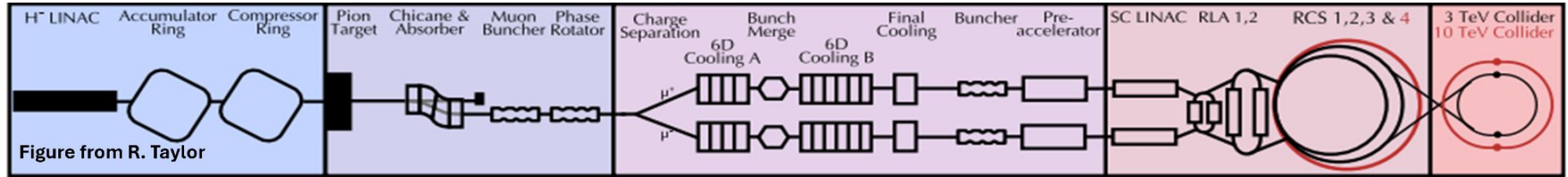
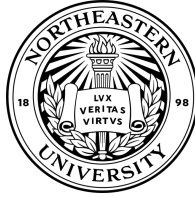
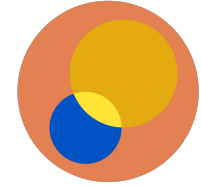
Dense BIB

COST

20T?

2.2 μ s

Technical Problems



New Target Tech

10T/ms ramping

40T??

Magnet Magnitude

6D Cooling

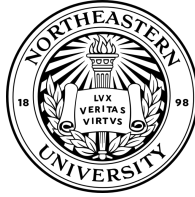
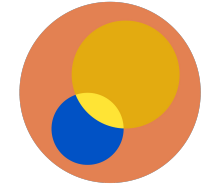
MW proton beam

Dense BIB

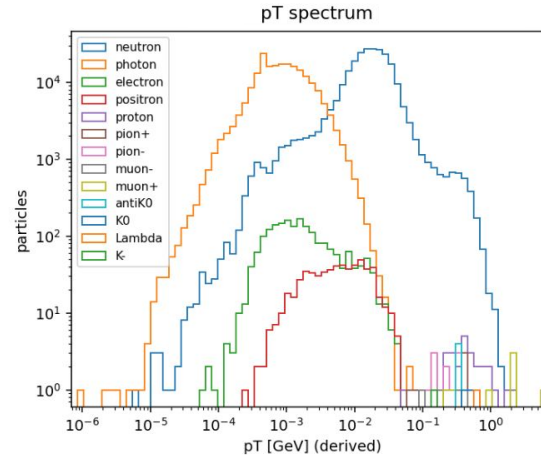
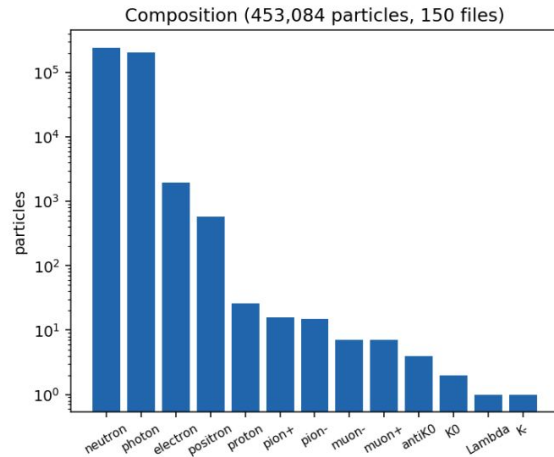
COST

20T?

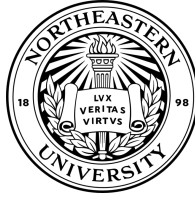
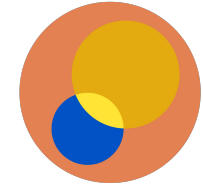
What is BIB?



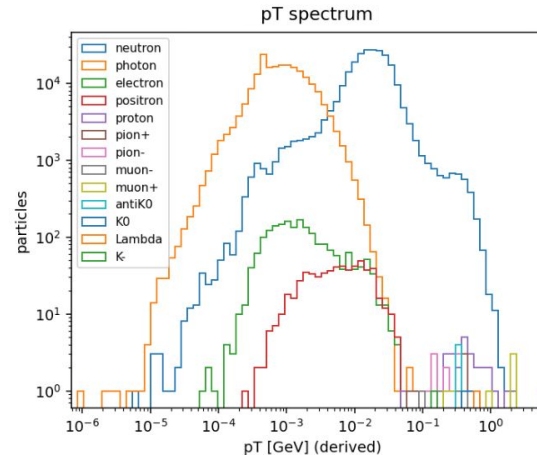
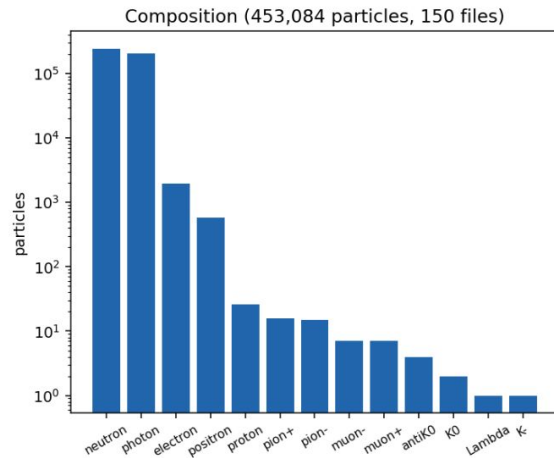
- Beam Induced Background
- Generated using FLUKA (with MAIA), computationally expensive
- Samples with “Full BIB” can take over a month to produce



What is BIB?

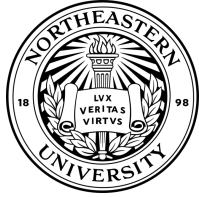
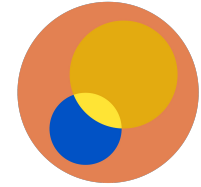


- Beam Induced Background
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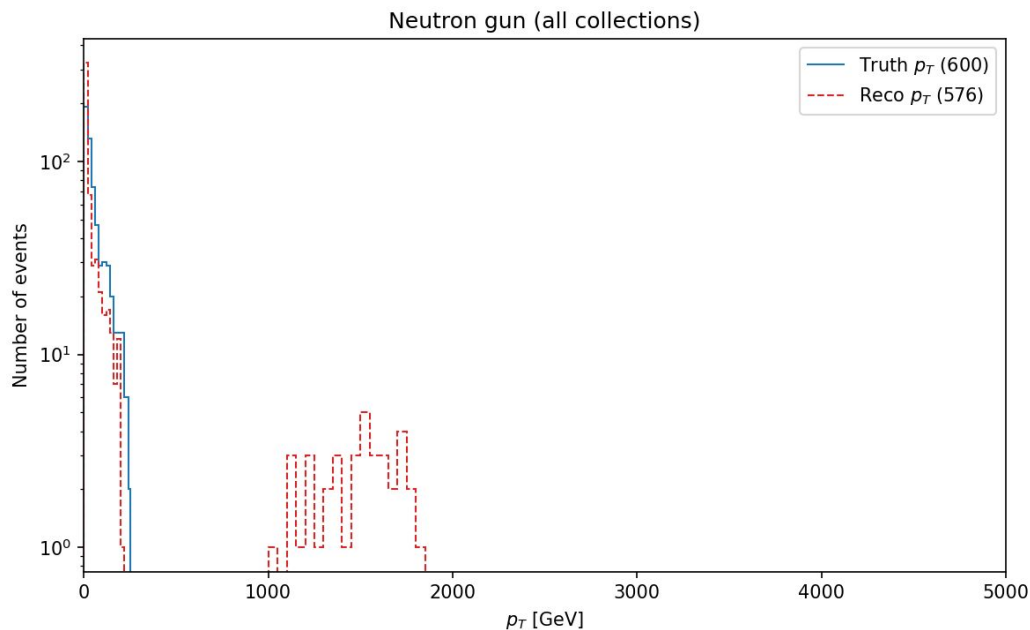
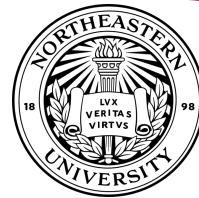
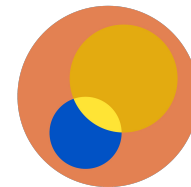


Produces a ton of
reco related
issues!

Software Challenge



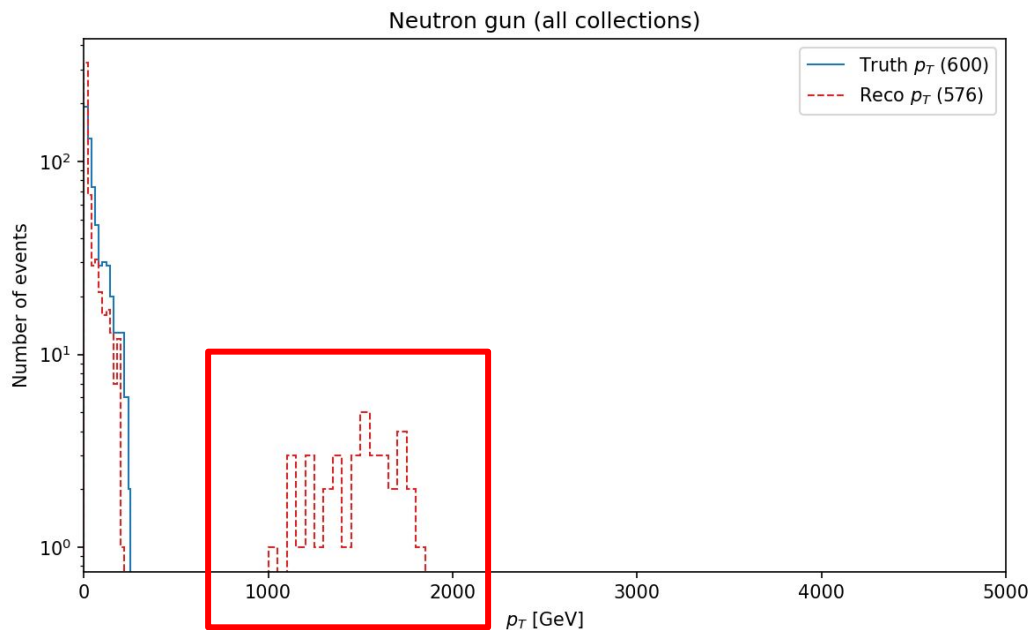
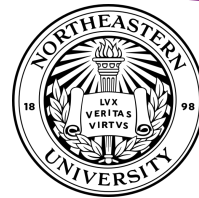
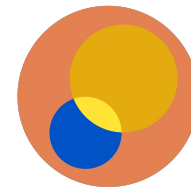
Software Challenge



BIB neutrons < 1 GeV

Gun Sample neutrons 0
to 250 GeV

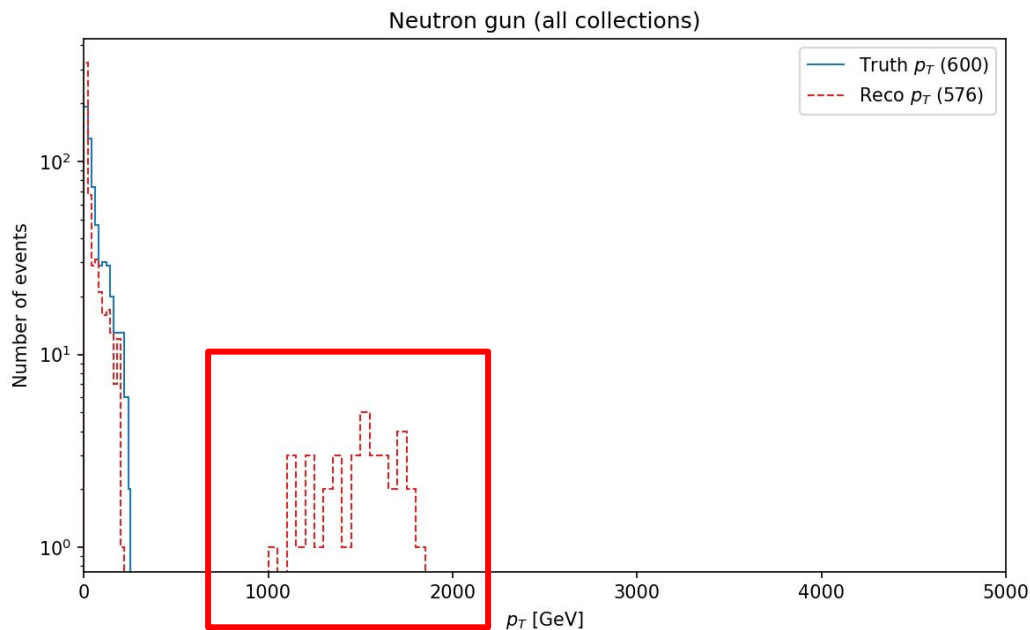
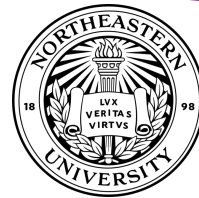
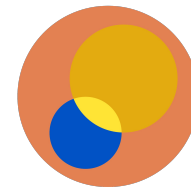
Software Challenge



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Software Challenge

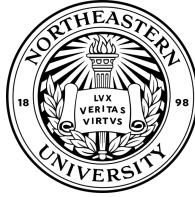
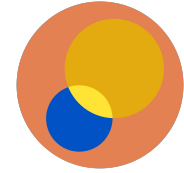


BIB neutrons < 1 GeV

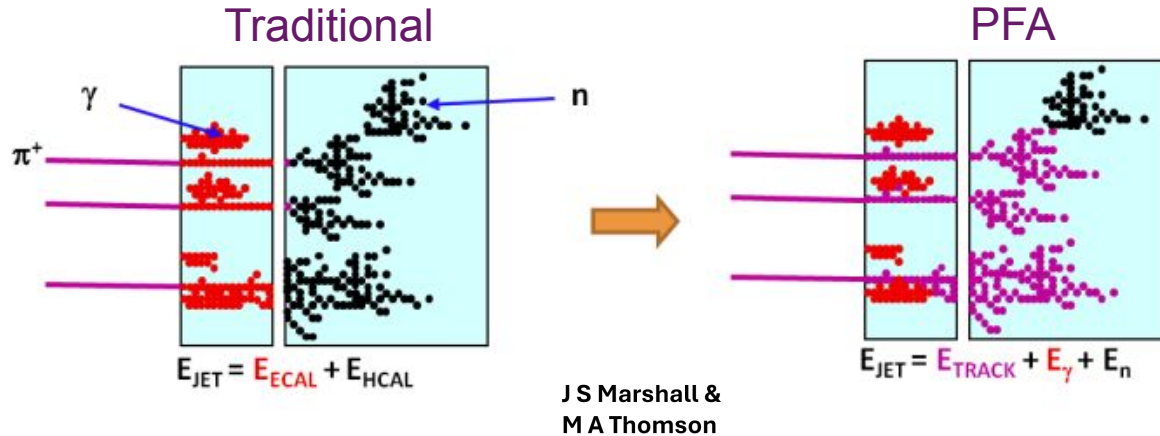
Gun Sample neutrons 0
to 250 GeV

TeV scale neutrons? No! Pandora clustering problem

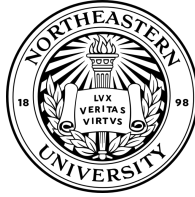
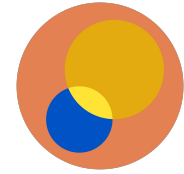
What is Pandora



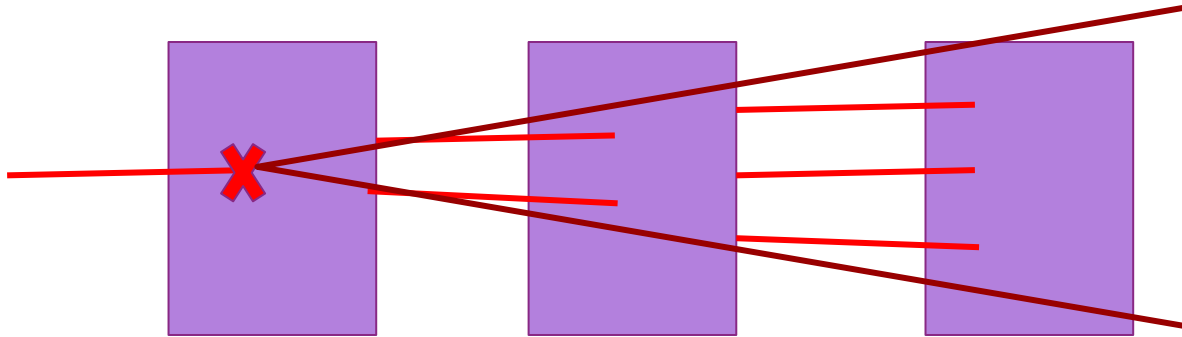
- Software framework that uses particle flow algorithm (PFA) to reconstruct particle-flow objects (PFOs) from raw hits



Clustering Problem



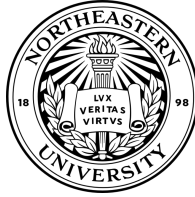
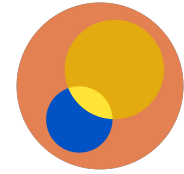
Pandora registers a hit -> looks in the forward region and surrounding area for more hits -> makes connections -> classifies as 2112



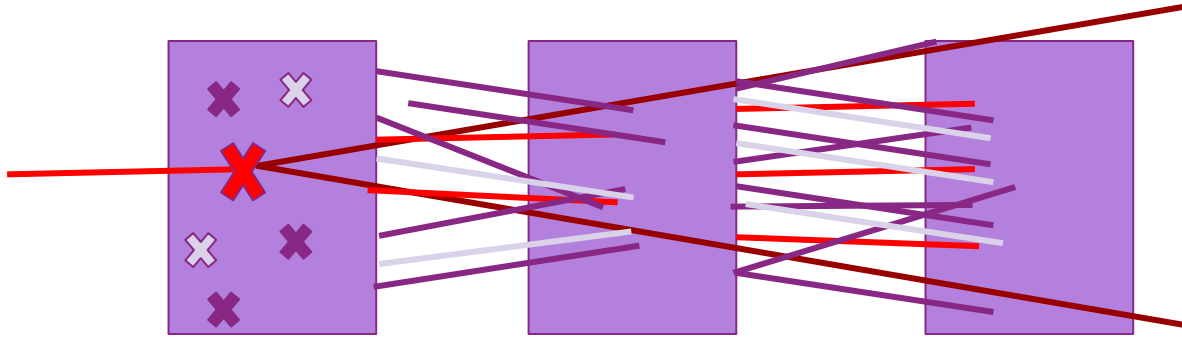
1 PFO
type: 2112

Works great in a clean environment

Clustering Problem



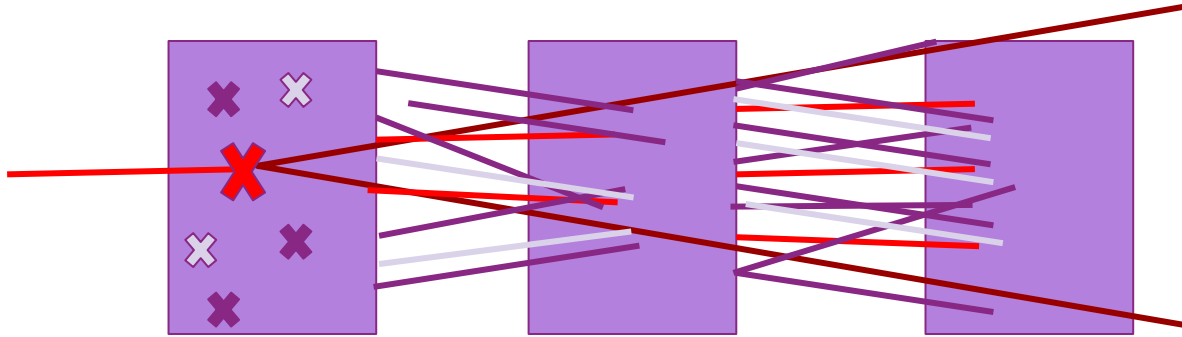
Pandora registers a hit -> looks in the forward region and surrounding area for one hits -> forms clusters -> merges -> classifies as 2112



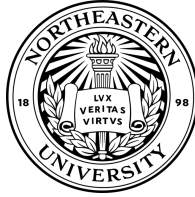
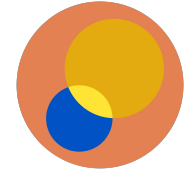
Works great in a clean environment - but add the BIB

Still 1 PFO: type 2112, but with a much greater reco pT

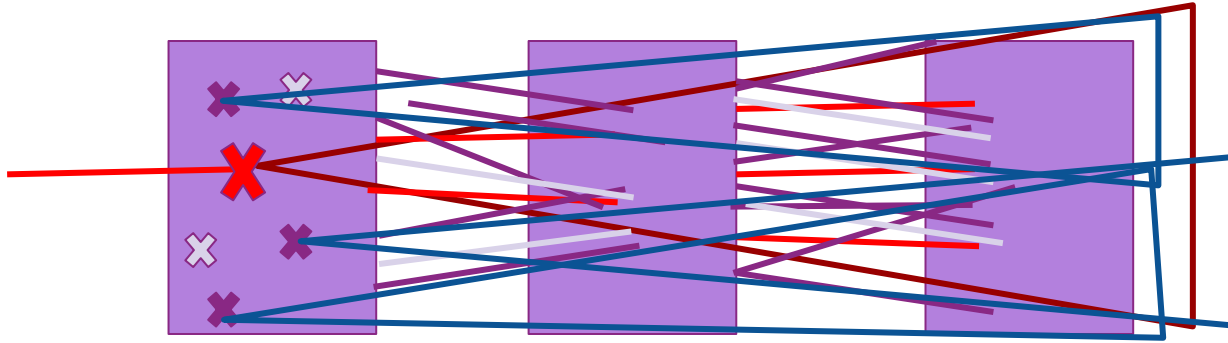
Not just BIB getting lumped in during the clustering stage, a load of tiny clusters are formed, then marked as soft, then merged together



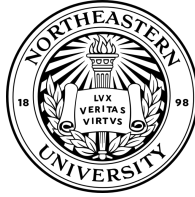
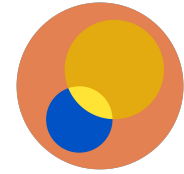
Clustering Problem



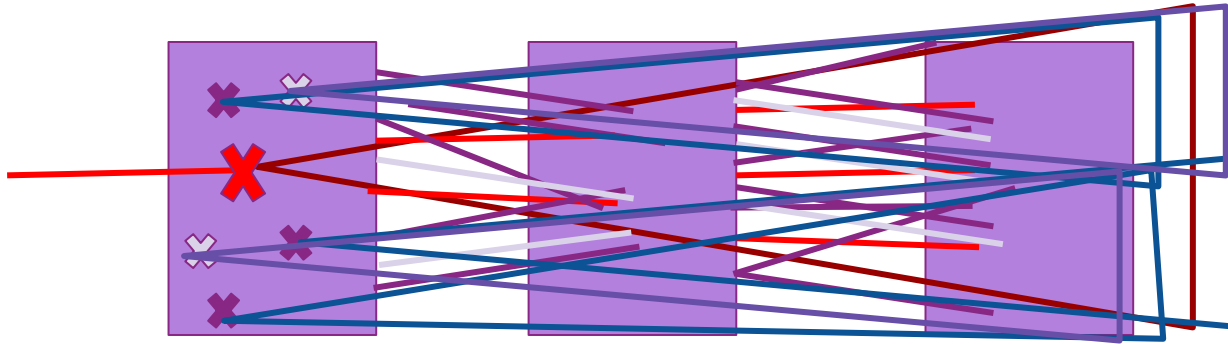
Not just BIB getting lumped in during the clustering stage, a load of tiny clusters are formed, then marked as soft, then merged together



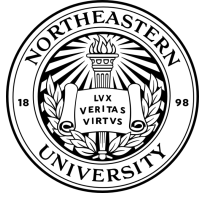
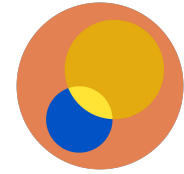
Clustering Problem



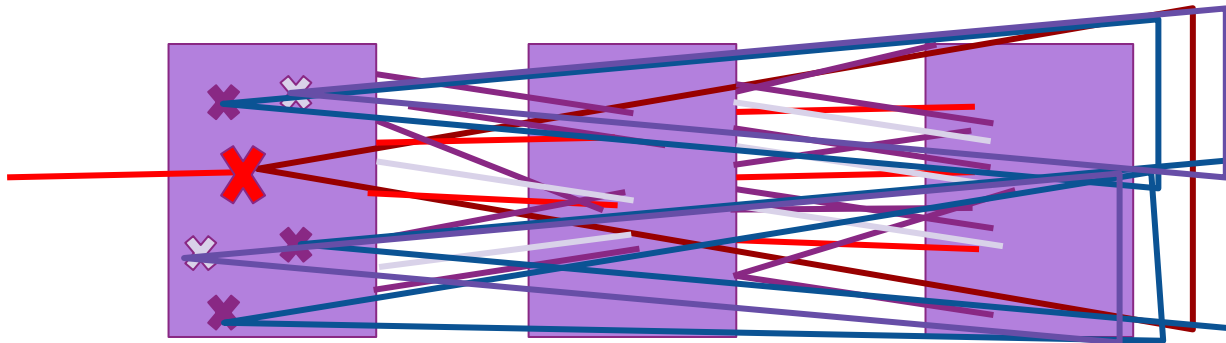
Not just BIB getting lumped in during the clustering stage, a load of tiny clusters are formed, then marked as soft, then merged together



Clustering Problem



Not just BIB getting lumped in during the clustering stage, a load of tiny clusters are formed, then marked as soft, then merged together

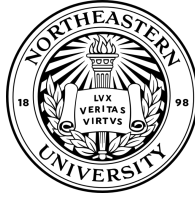
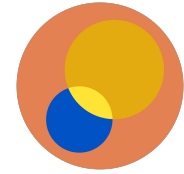


≤ 5 calorimeter hits

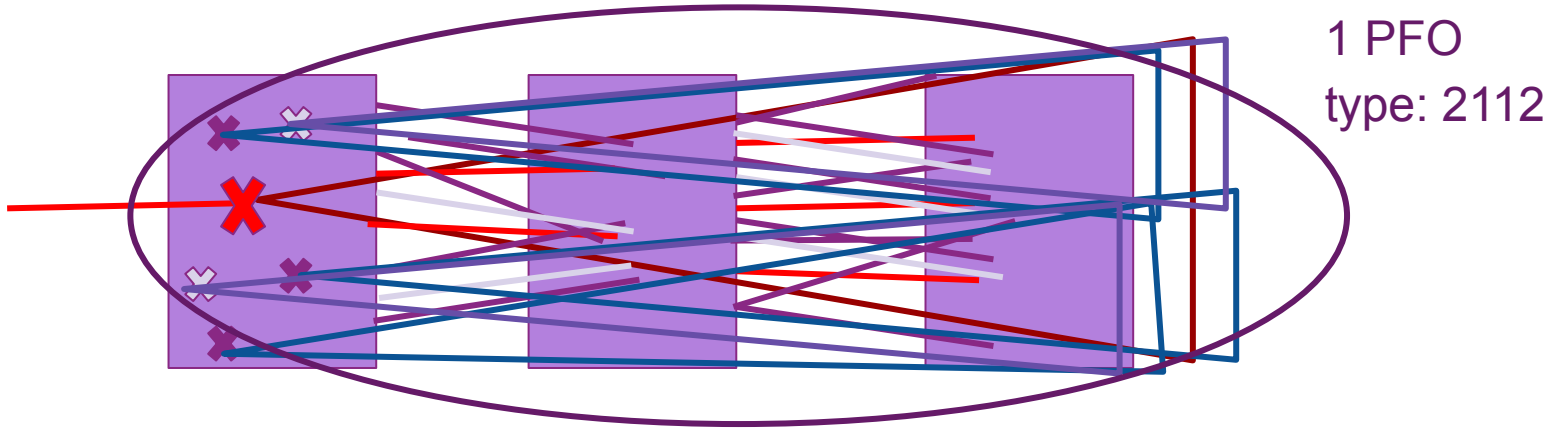
< 3 layers deep
(too shallow)

< 2 GeV hadronic
energy (too weak)

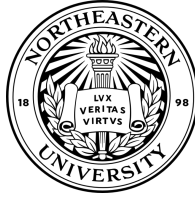
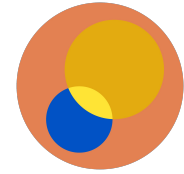
Clustering Problem



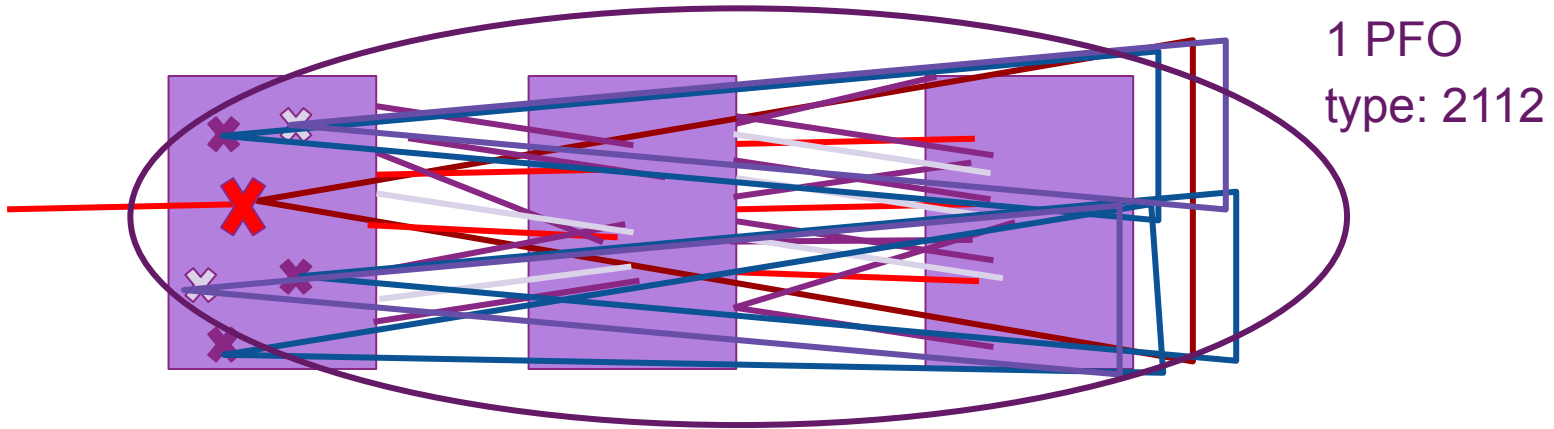
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Clustering Problem

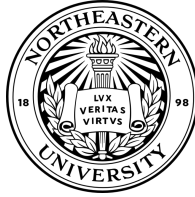
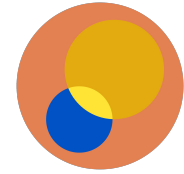


Not just BIB getting lumped in during the clustering stage, a load of tiny clusters are formed, then marked as soft, then merged together

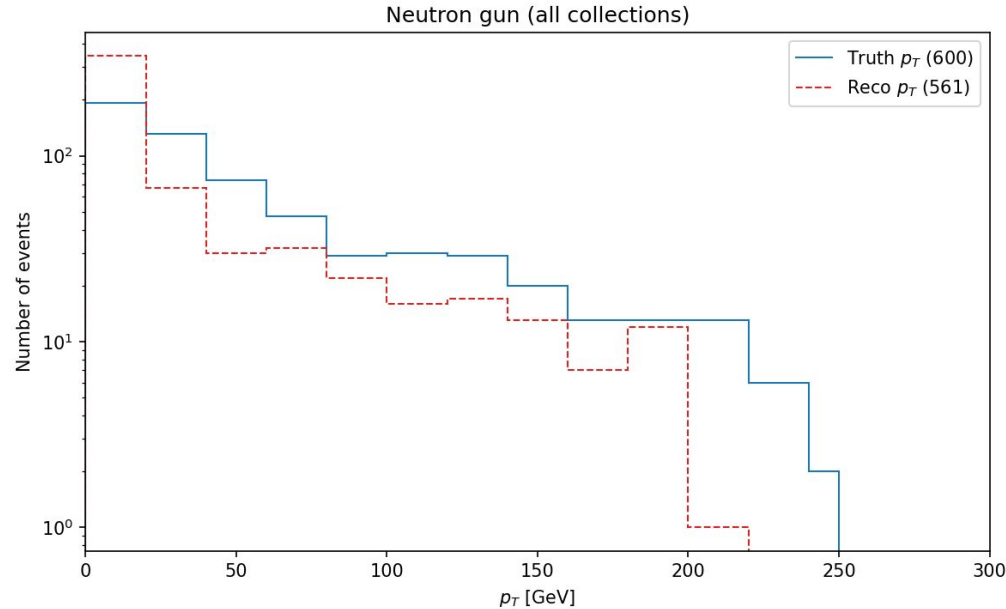


Ton of clusters in a list -> merge -> mega cluster

Neutron Issue Fixed?

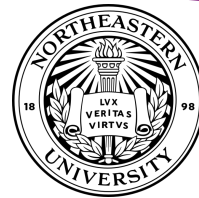
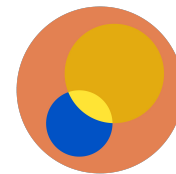


Impose a strict upper boundary



What happens when we want to analyze TeV scale neutrons?

Neutron Issue Fixed?



Impose a strict
upper

Neutron gun (all collections)

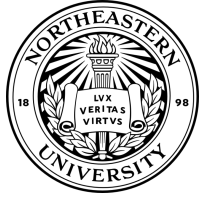
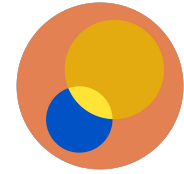
Truth p_T (600)

One of many BIB-induced issues...

0 50 100 150 200 250 300
 p_T [GeV]

What happens when we want to analyze TeV scale neutrons?

Conclusion



- Leaps and bounds of work to be done from an analysis and generator perspective
- Should we build a muon collider?
- Can we?



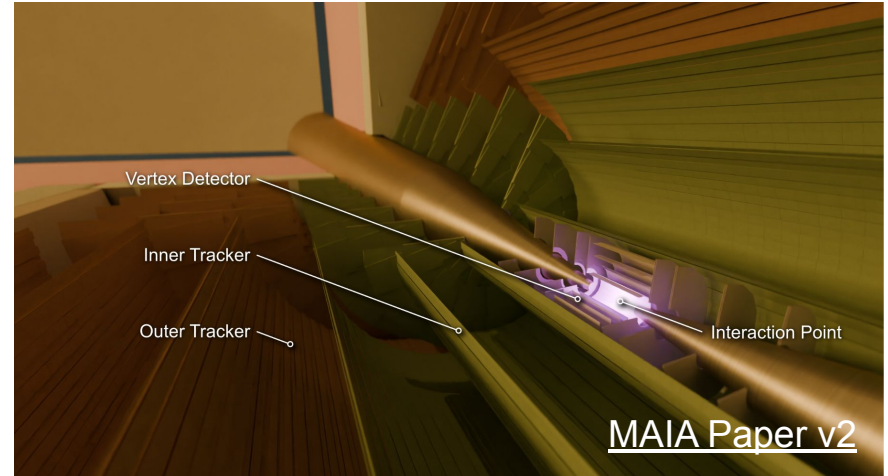
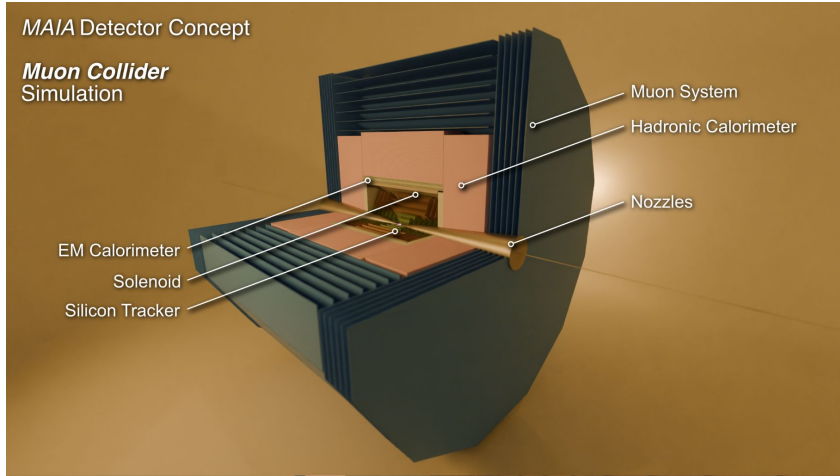


Thanks! Questions?

The background is white with several large, organic, wavy shapes in various shades of purple (light, medium, and dark) positioned around the edges. Scattered throughout the white space are small, solid purple circles of varying sizes.

Backup

Detector Design



Muon Accelerator Instrumented Apparatus