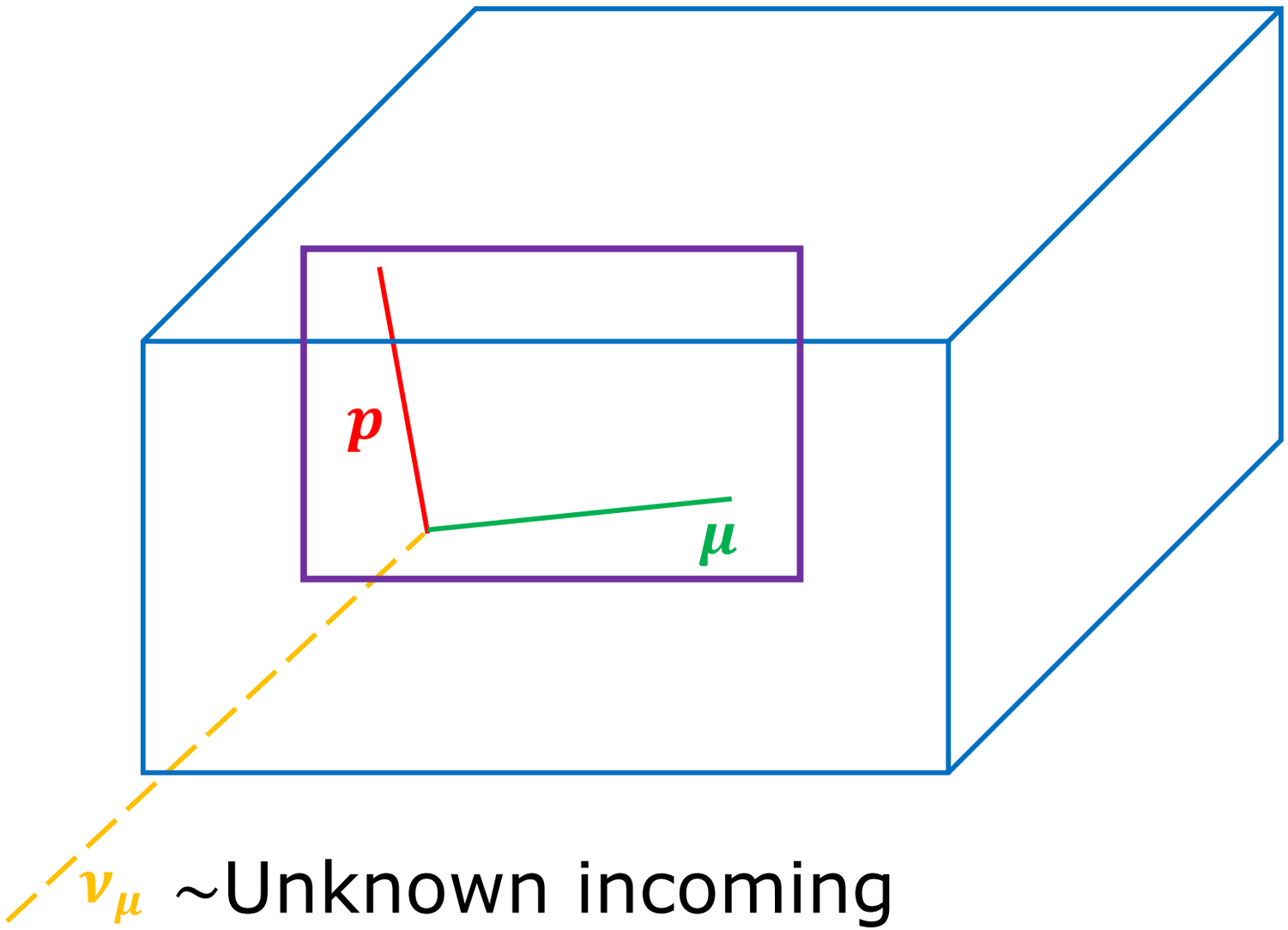
The Developing $\mu 4\nu$ Initiative

NuSTEC Workshop on Charged Lepton Scattering

by Josh Barrow, MIT-TAU, Zuckerman Postdoctoral Scholar

QE-like $\nu_\mu \mathrm{Ar} \rightarrow 1\mu 1p$

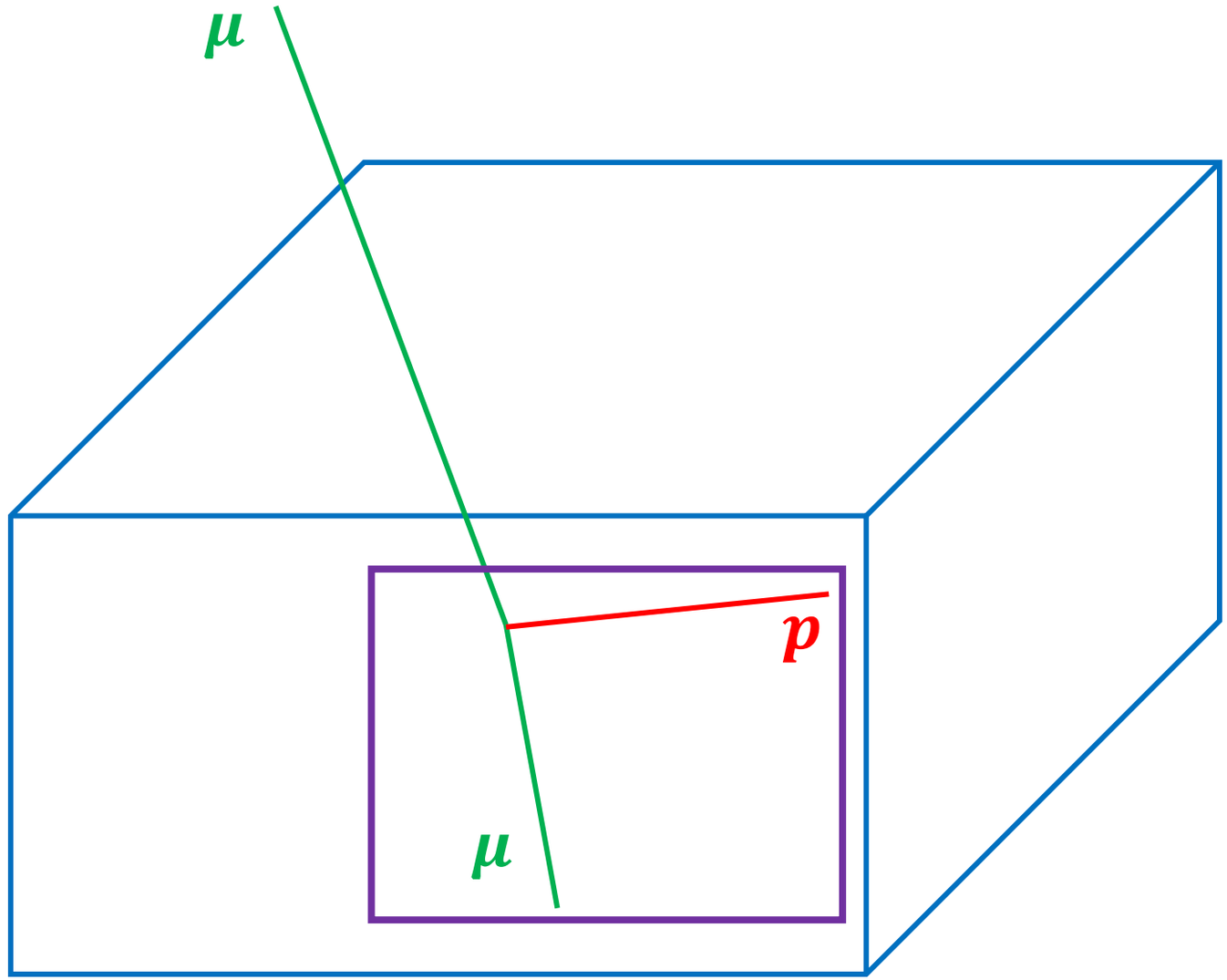
Definitive energy transfer
knowledge limited



ν_μ ~Unknown incoming
neutrino energy

QE-like $\mu\mathrm{Ar} \rightarrow 1\mu 1p$

Energy transfer knowledge not limited to only final state particles



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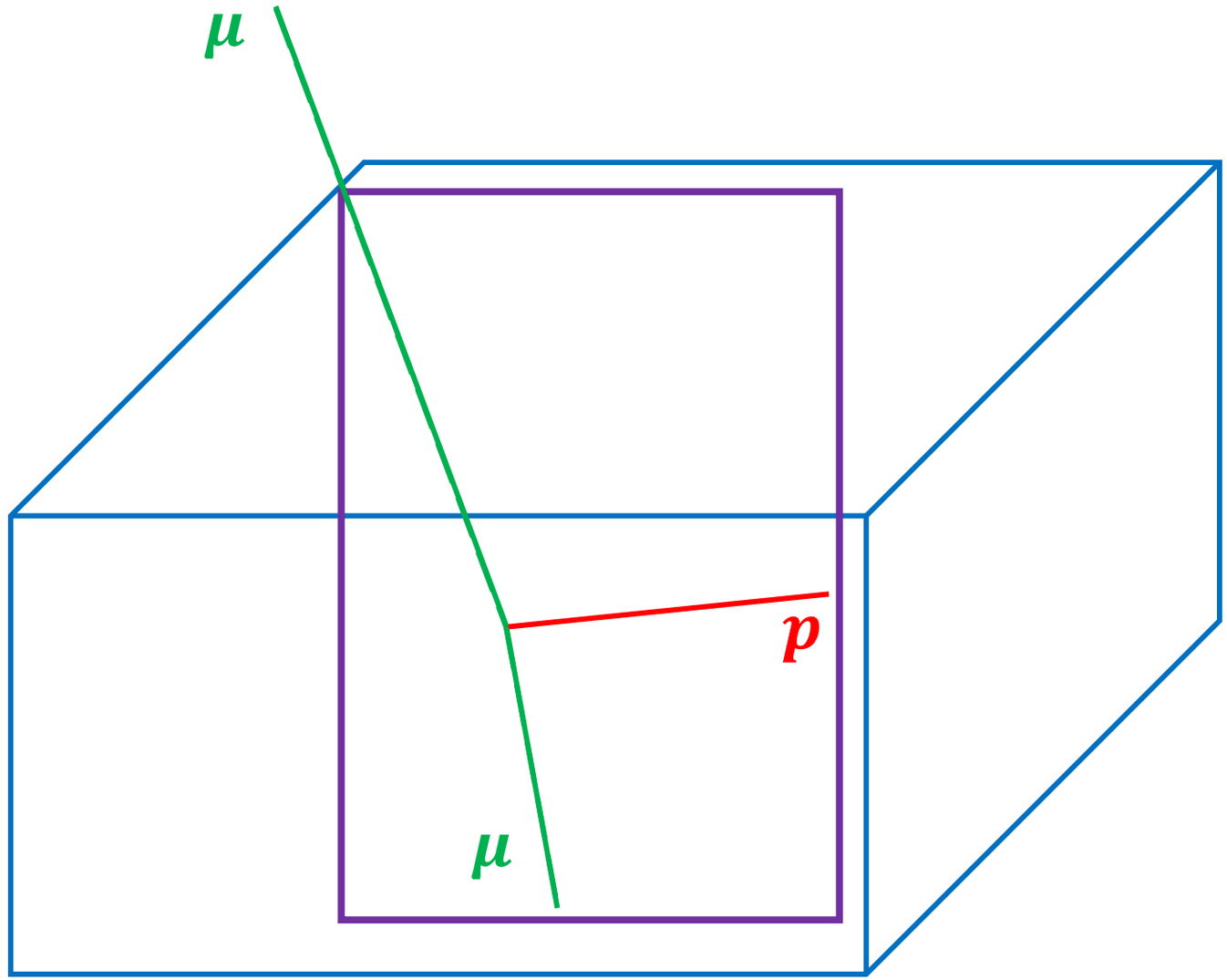


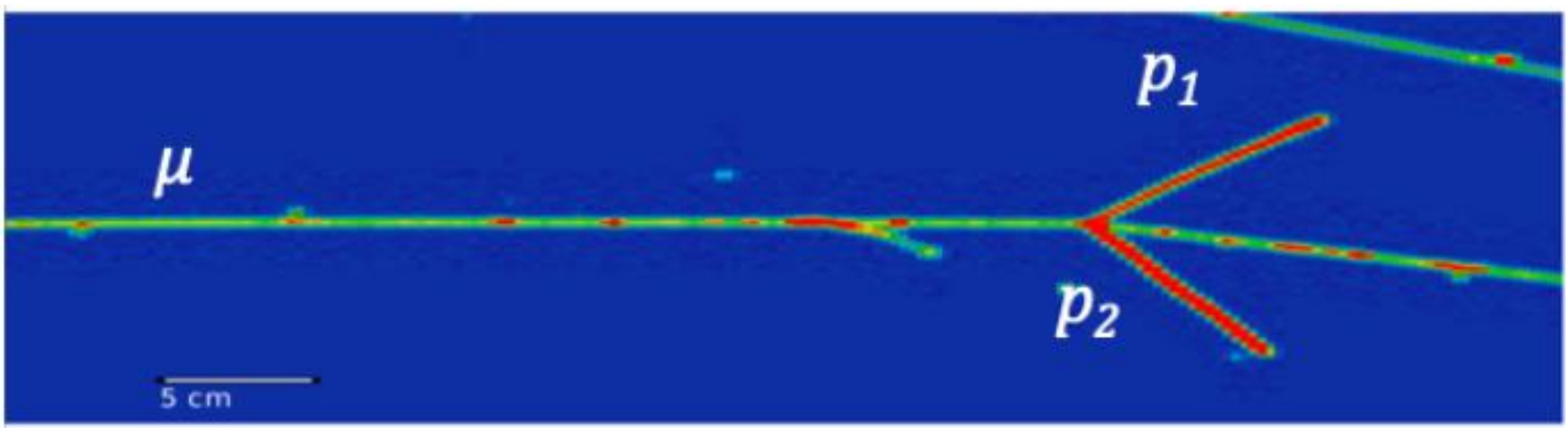
More information about kinematics given initial track leg

[Multiple Coulomb scattering]

In Situ μ + Ar

- Cosmic muon tracks deposit energy in ~understood ways
- Incoming $\ell^{\pm}$ energy can be reconstructed
  - Find energy *just before* $\ell^{\pm}$ interaction
    - Multiple Coulomb scattering (MCS)
    - Fast timing from veto systems (in principle)
- Use "normal" ν_{ℓ} methods to assess final state
  - Can similarly constrain outgoing $\ell^{\pm}$ with MCS
- **Chief goals for $\mu 4\nu$ via cosmics:**
  - **Determine bias in $E_{\nu_{\mu}}$ (mis)reconstruction**

Courtesy of A. Furmanski

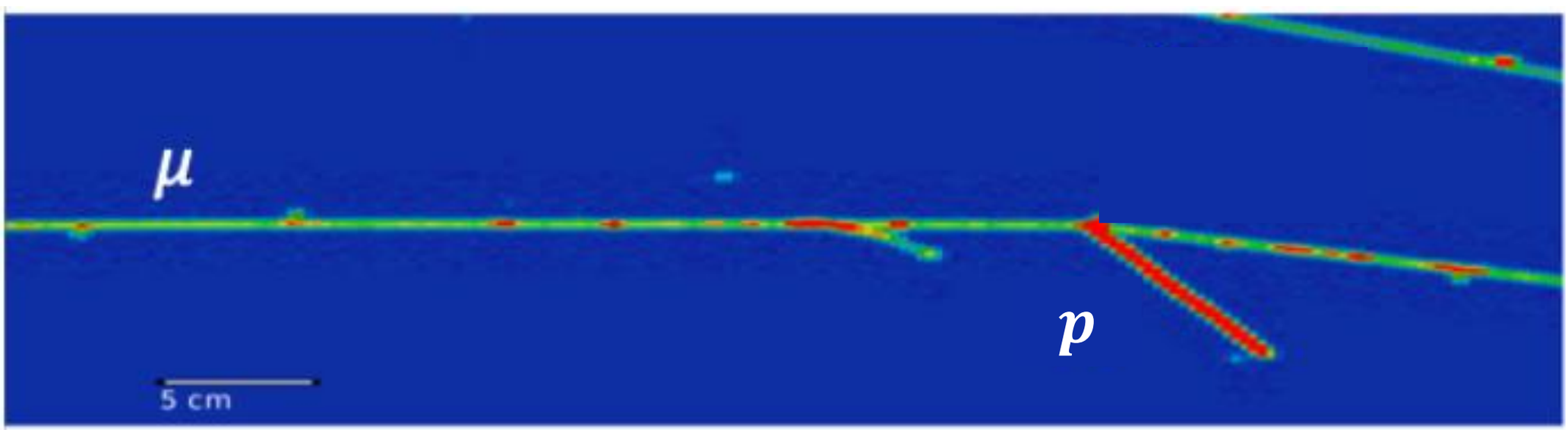


Multiprong (4) QE-like candidate

[Reconstructing cosmic muon scatter events in MicroBooNE]

Courtesy of A. Furmanski

Current focus of my own studies



Multiprong (3) QE-like candidate

[Reconstructing cosmic muon scatter events in MicroBooNE]

Expected QE-like Data Rates

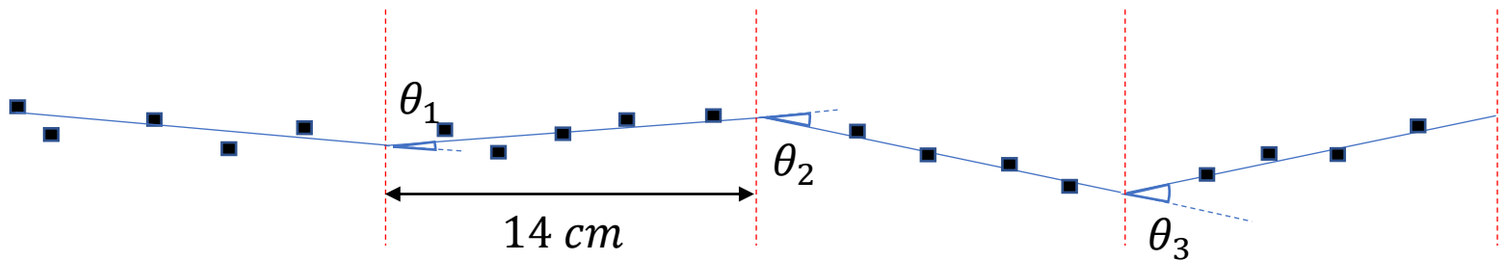
- QE-like proton ($\mu + \mathrm{Ar} \rightarrow p + \mu + X$) candidates
  - Estimate from **CORSIKA flux and** $\boldsymbol{\sigma_{e\mathrm{Ar}}^{\mathrm{QE,EM}}}$**:**
    - ~ 4000 cosmic μ per second
    - $\gtrsim 1\mathrm{Hz}$ true QE-like interactions above threshold

- Full analysis for estimation underway
  - Utilize MicroBooNE EXT unbiased data

Courtesy of A. Ashkenazi and W. Van De Pontseele

Measuring p_μ Using MCS in LArTPCs

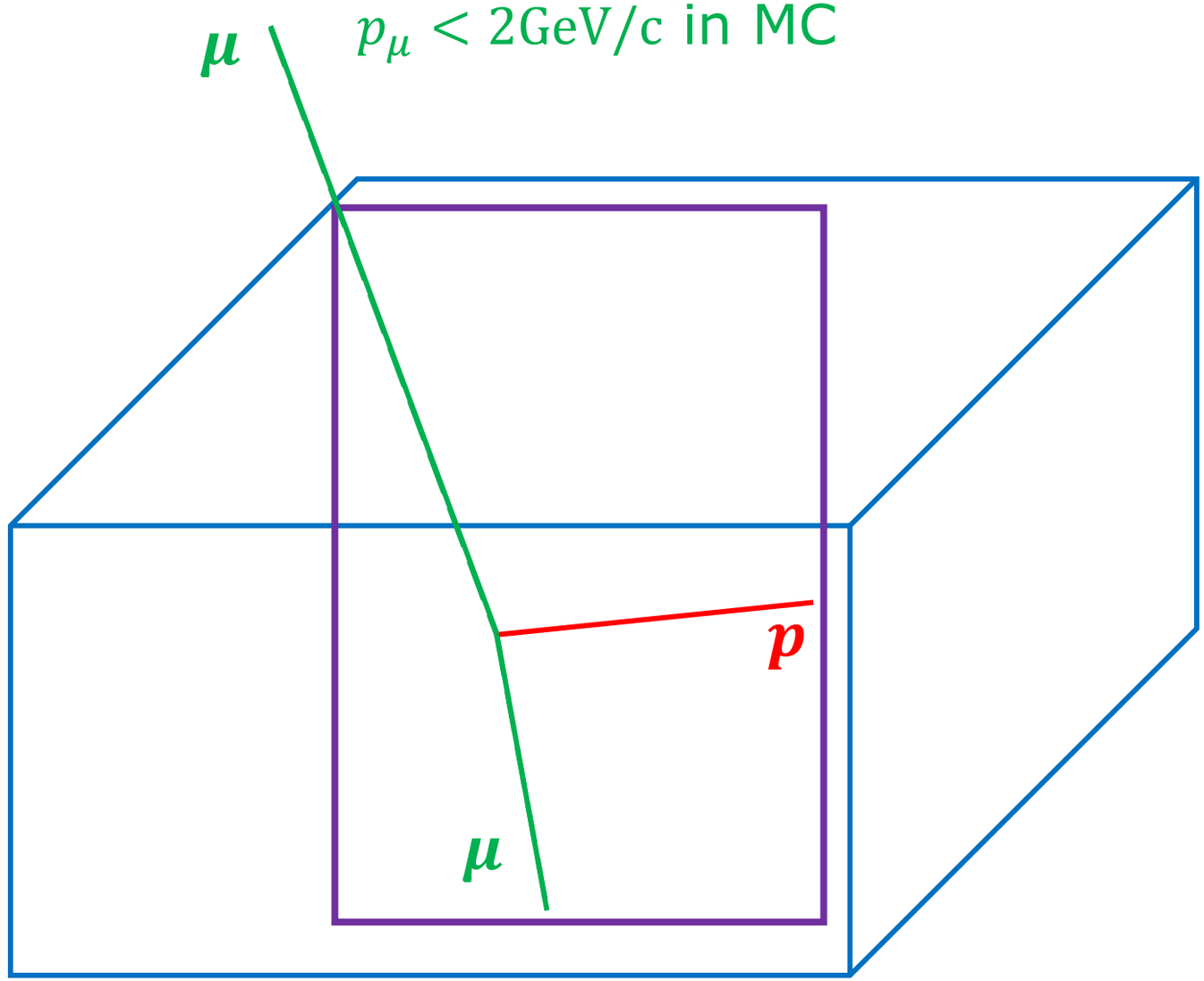
- Muons traverse a medium, are scattered off nuclei



- Tracks divided into segments
  - Scattering angles between consecutive segments measured
  - Particle momentum calculated from likelihood method

Amir Gruber

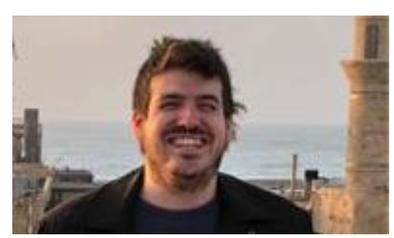
MCS momentum resolution is ~15% for $p_\mu < 2\mathrm{GeV/c}$ in MC



Energy transfer knowledge not limited to only final state particles

MCS permits knowledge of approximate incoming μ energies

MCS improvements being codeveloped

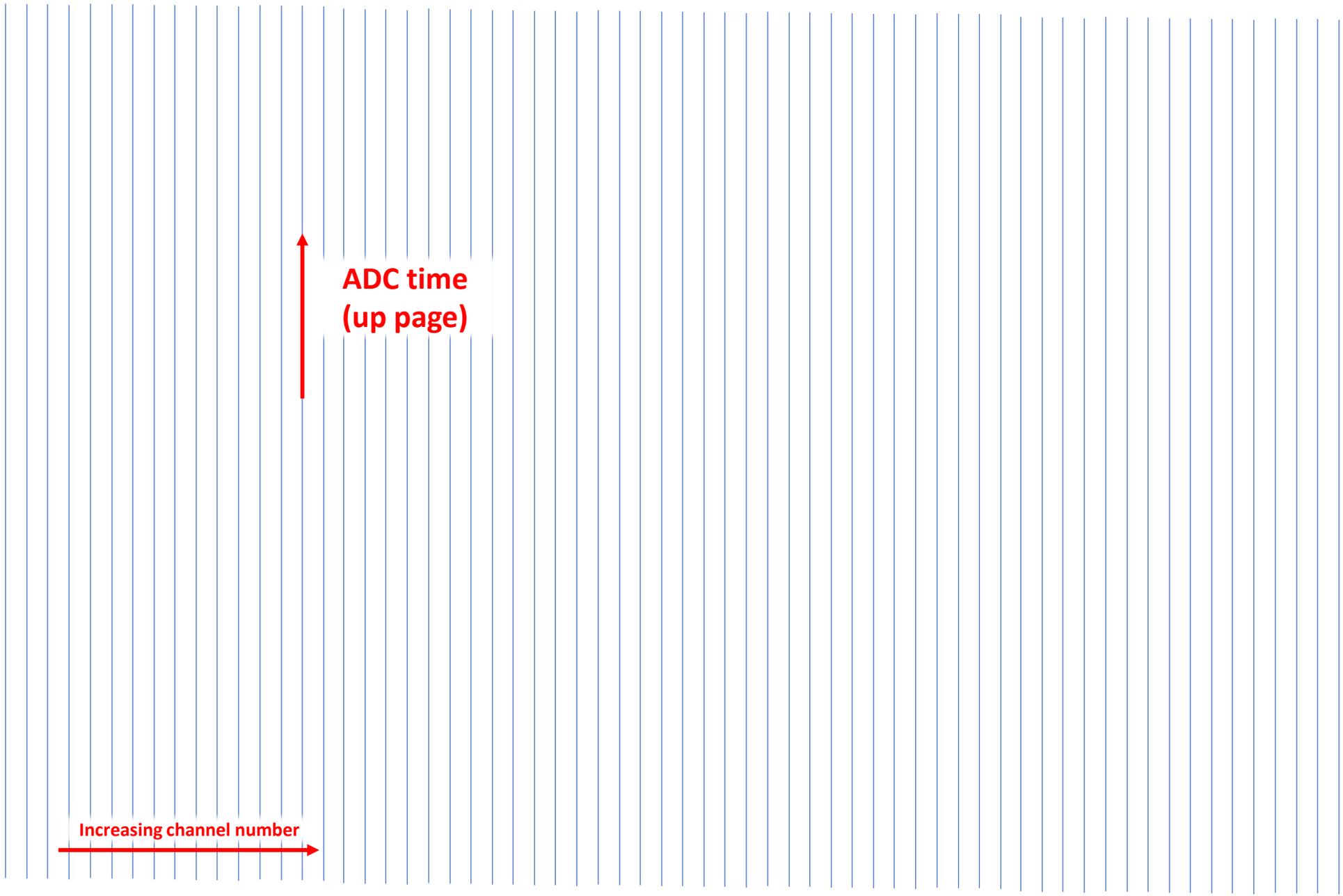


Amir Gruber

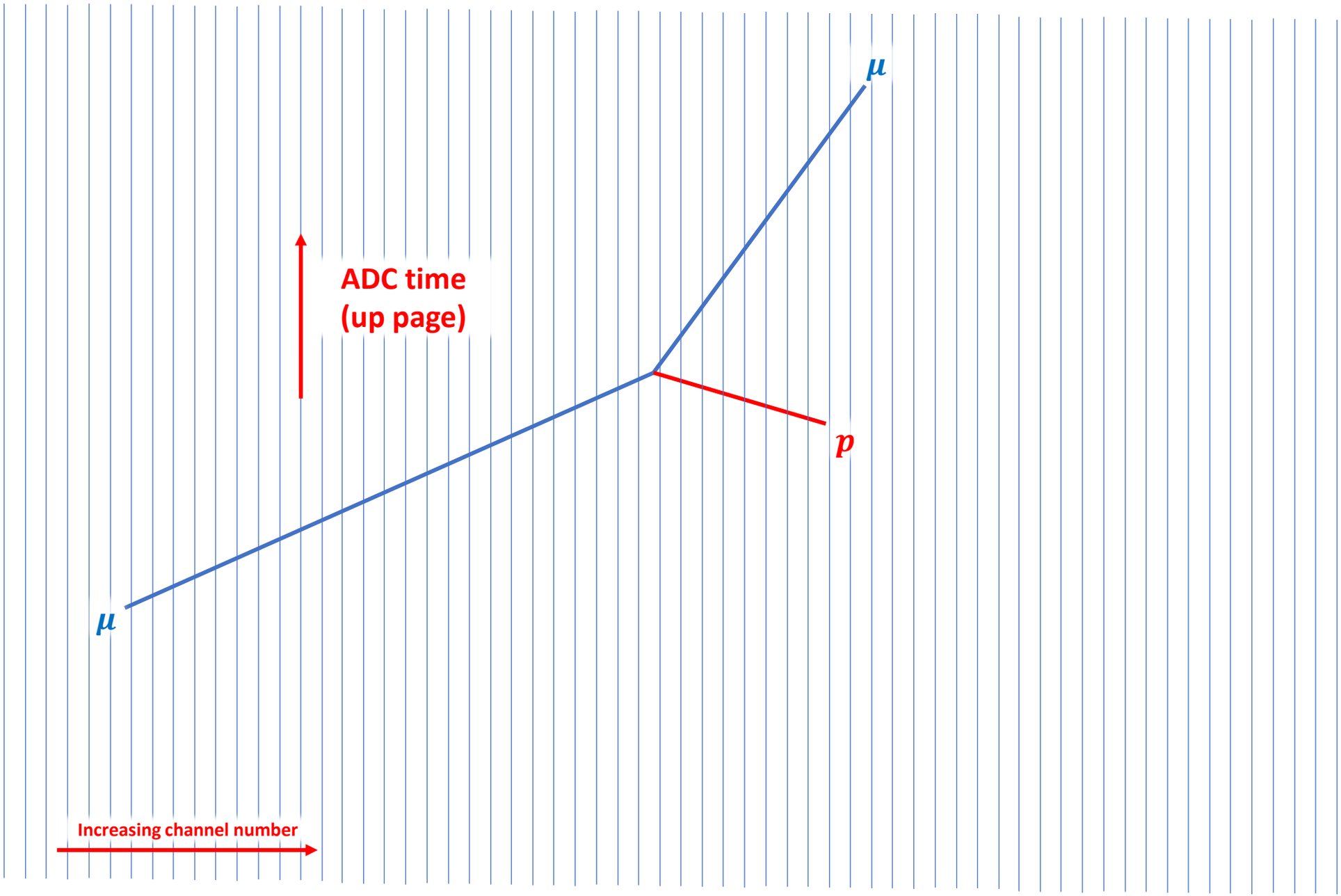
Multiple Coulomb scattering

A Simplified View of LArTPC

A single plane can be studied as a facsimile



Trigger Primitives Access Waveforms Directly



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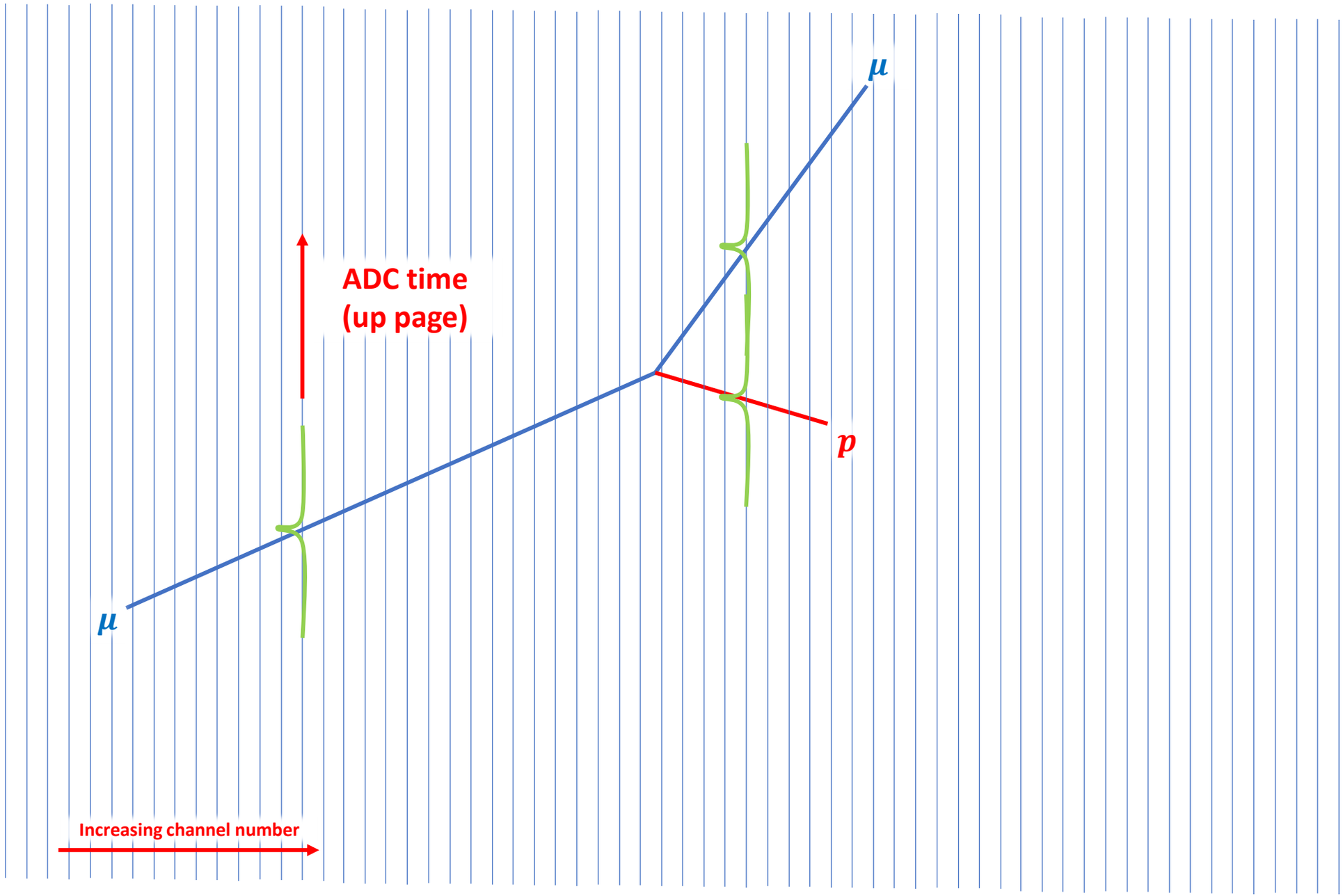

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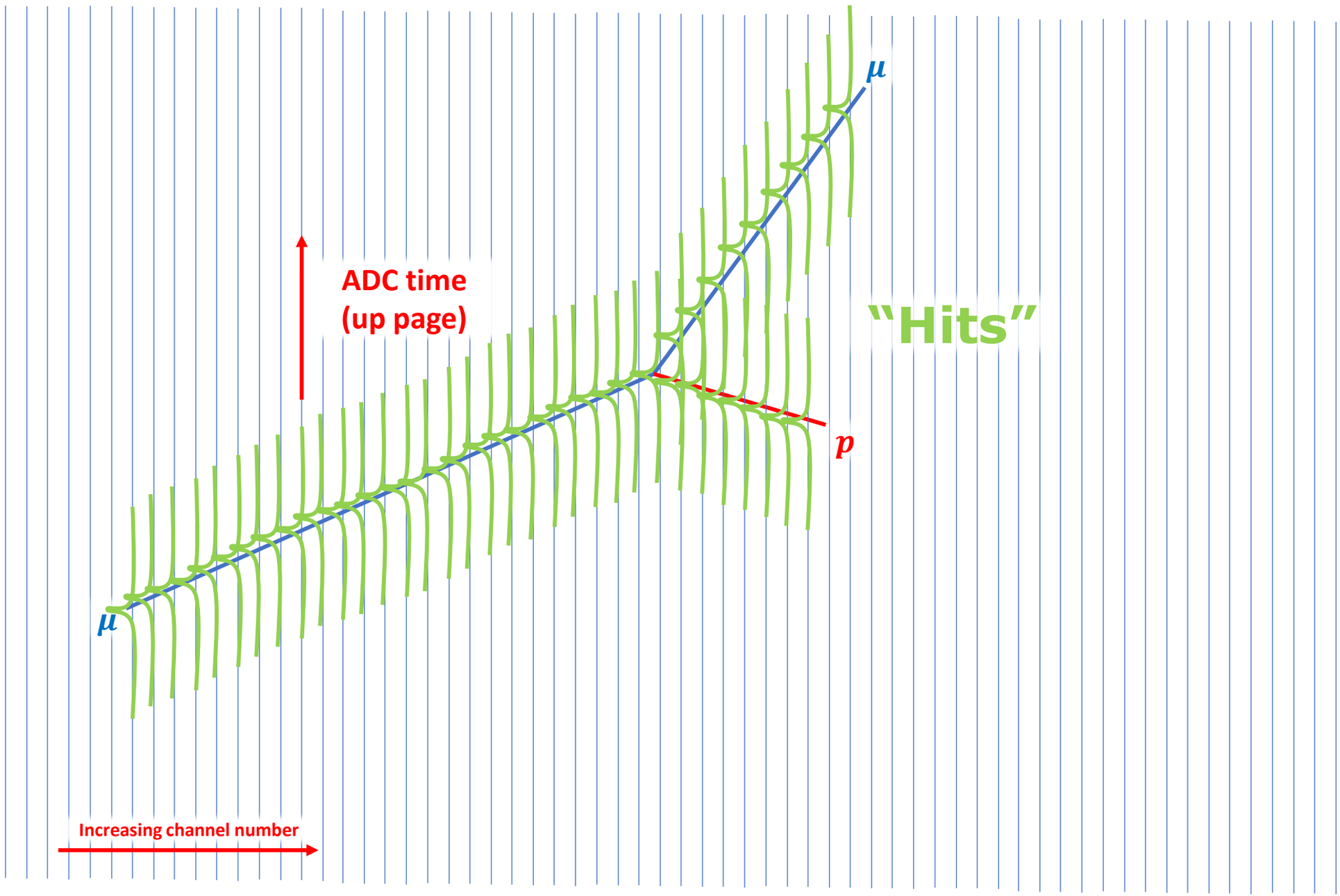
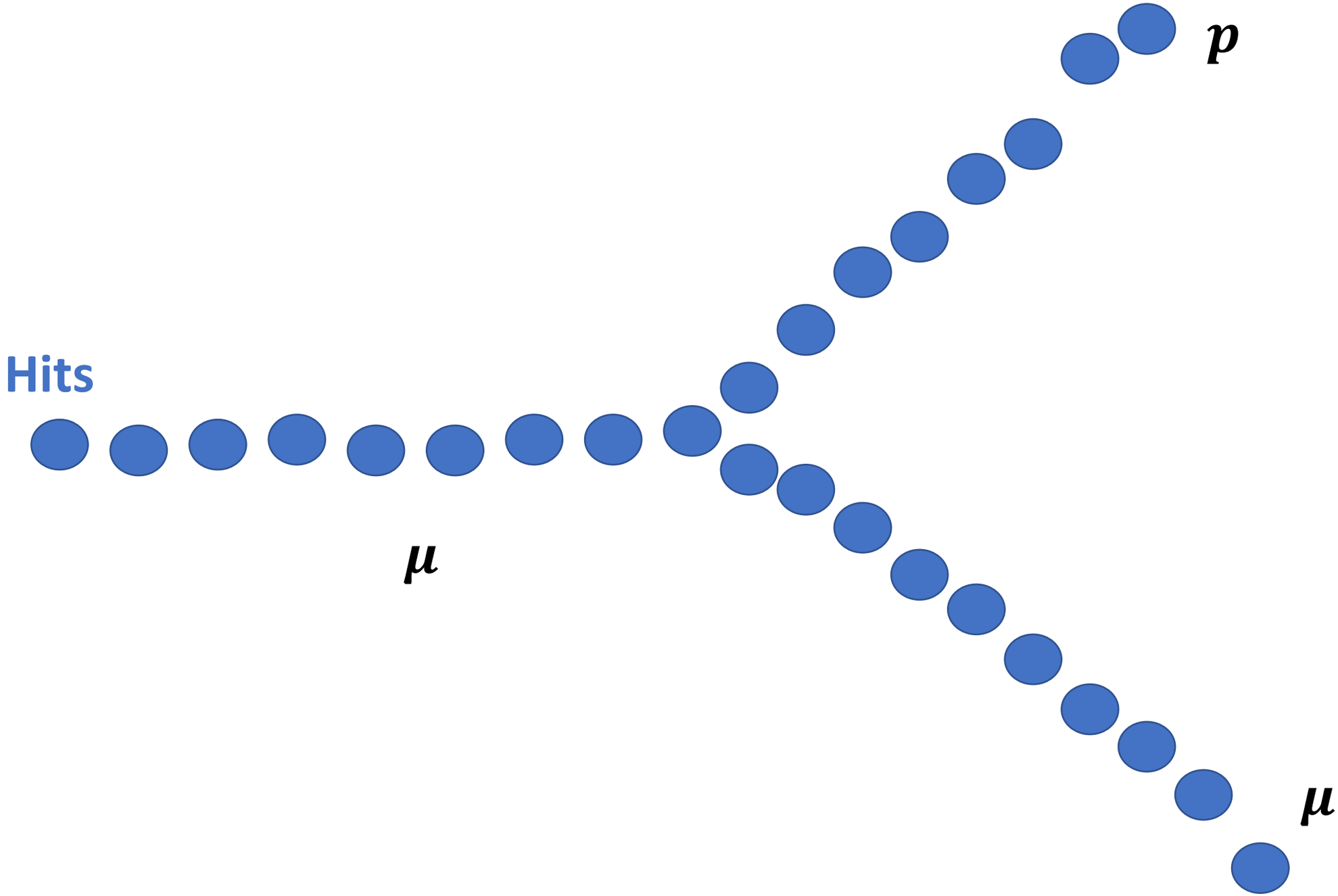



Hits
p
μ
μ

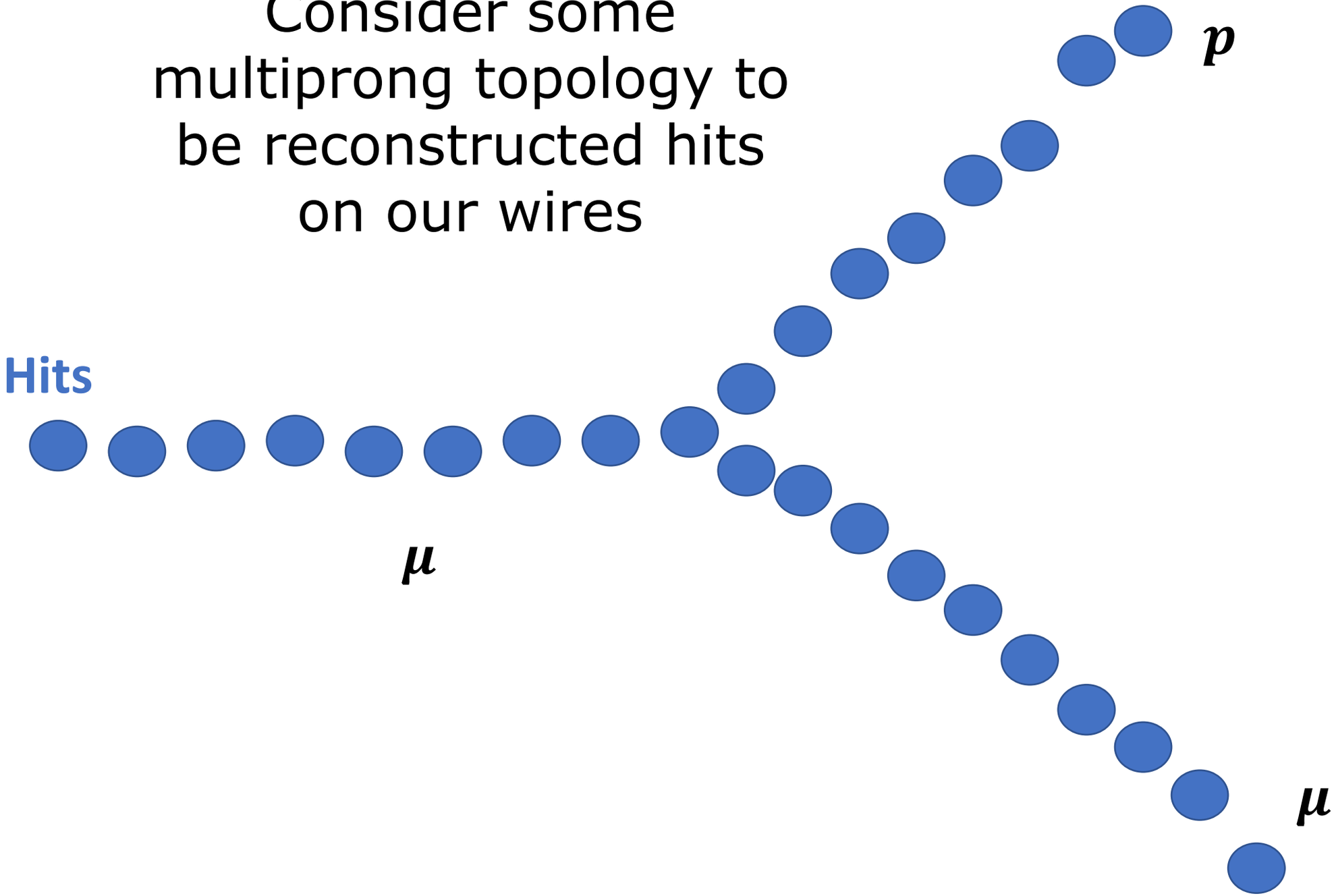
Multiprong Trigger Design

- Considers “hits” of trigger primitives
  - Locations in time and wire number
  - Effectively a “cartesian” plane

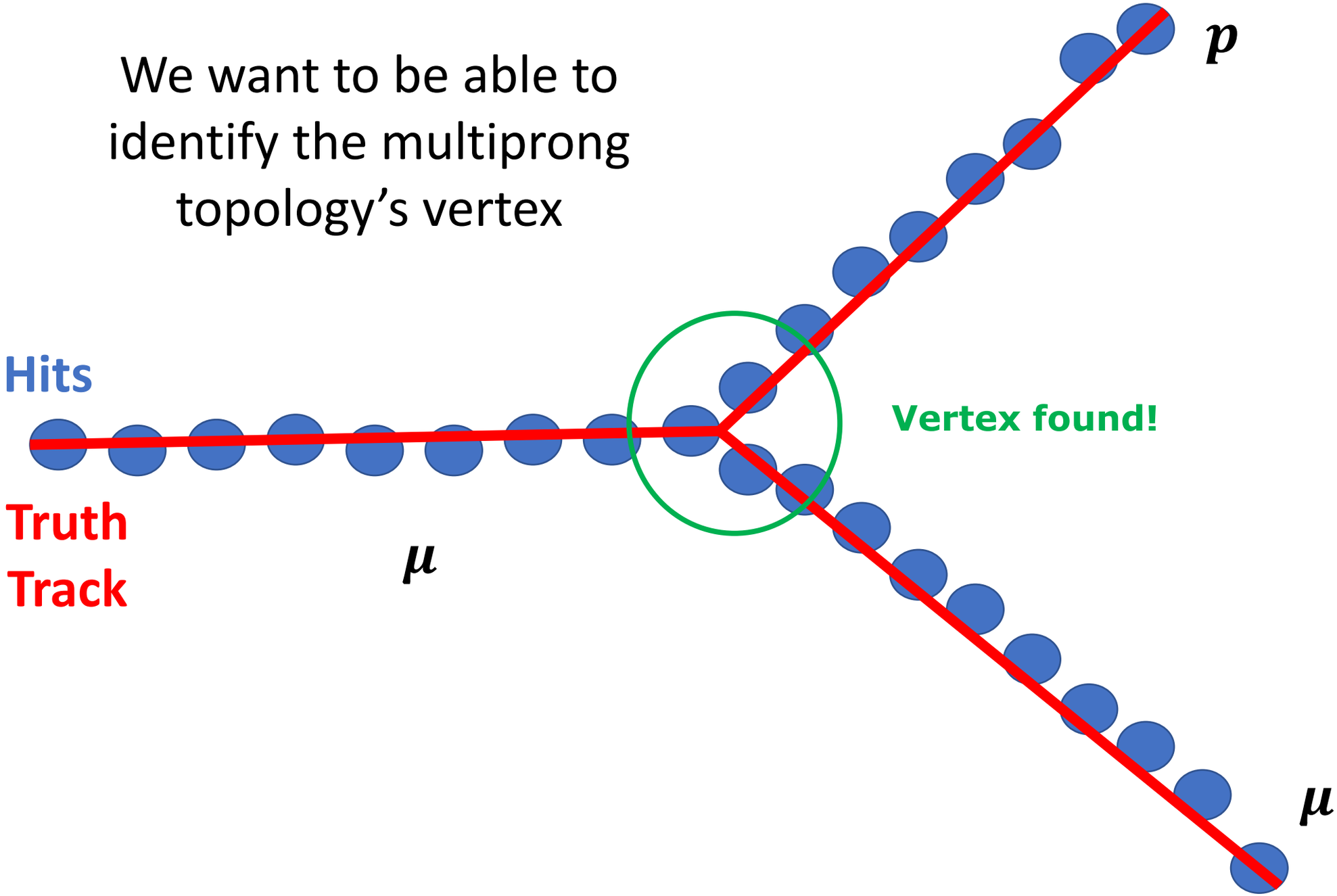
- Treat every hit as a potential vertex
  - Consider surrounding hits only to try and find “tracks”
  - Outer box/“radius” of activity

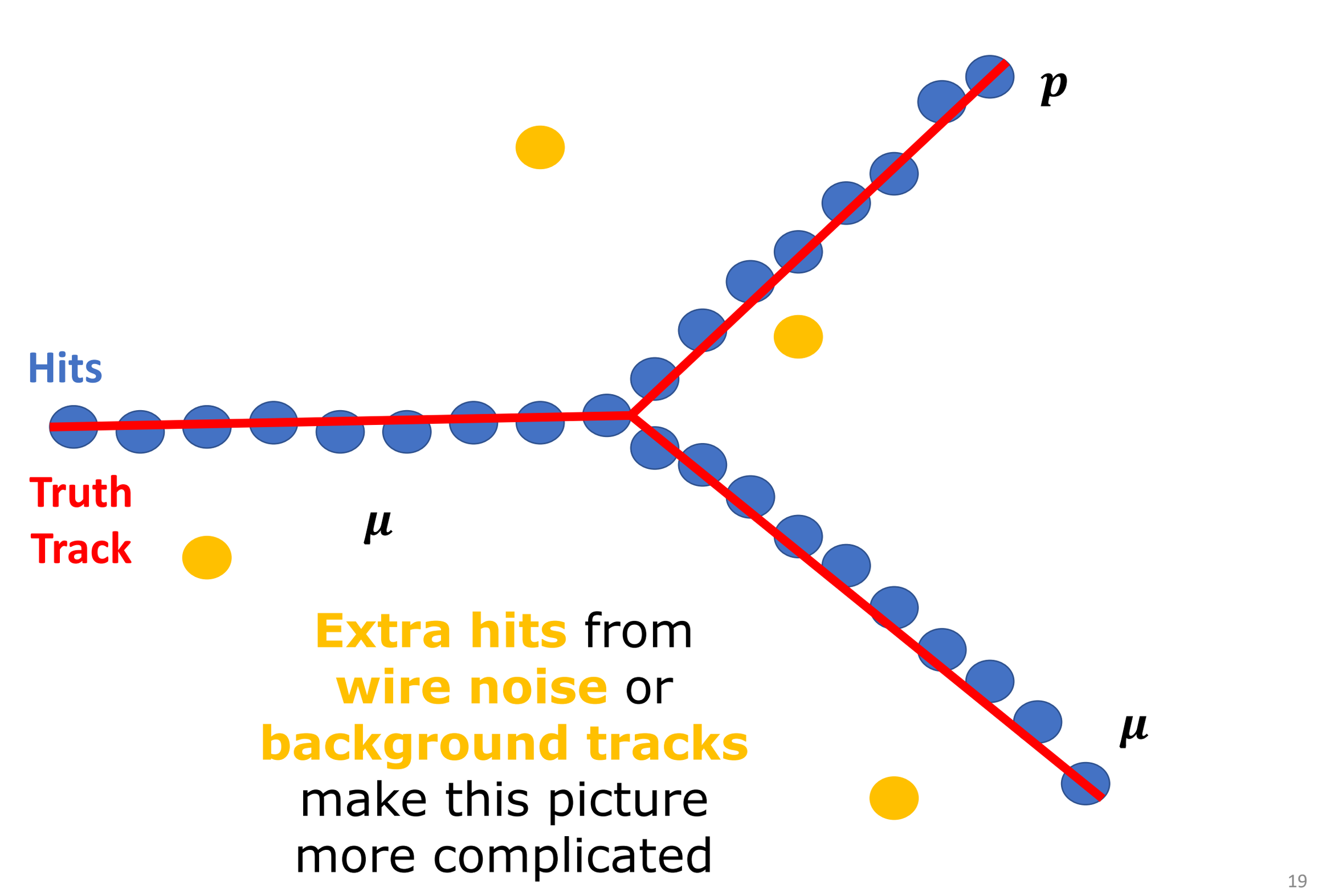
- Transform: semi-*cylindrical* coordinates
  - Use θ to differentiate “tracks” from one another from

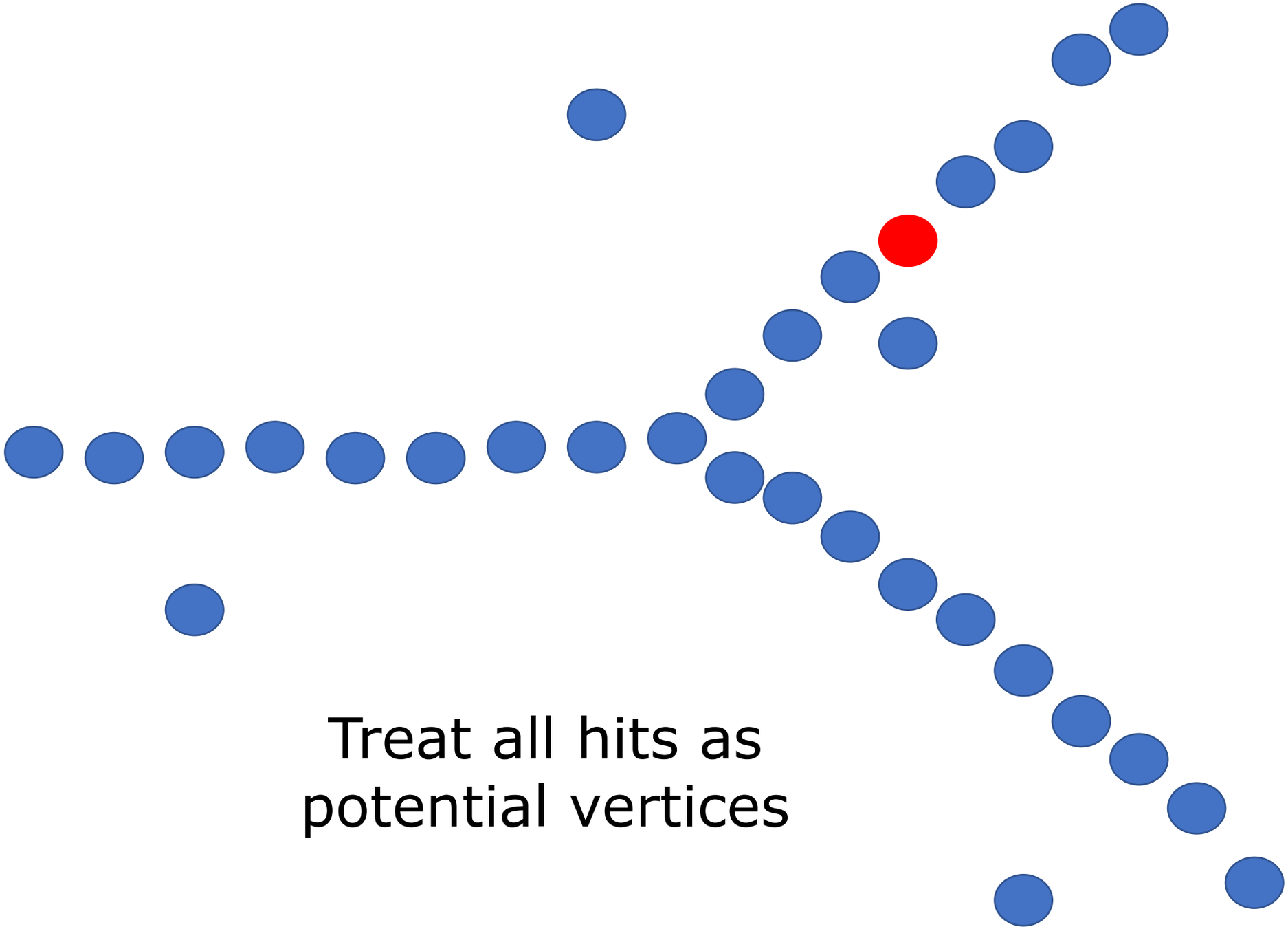
Consider some multiprong topology to be reconstructed hits on our wires



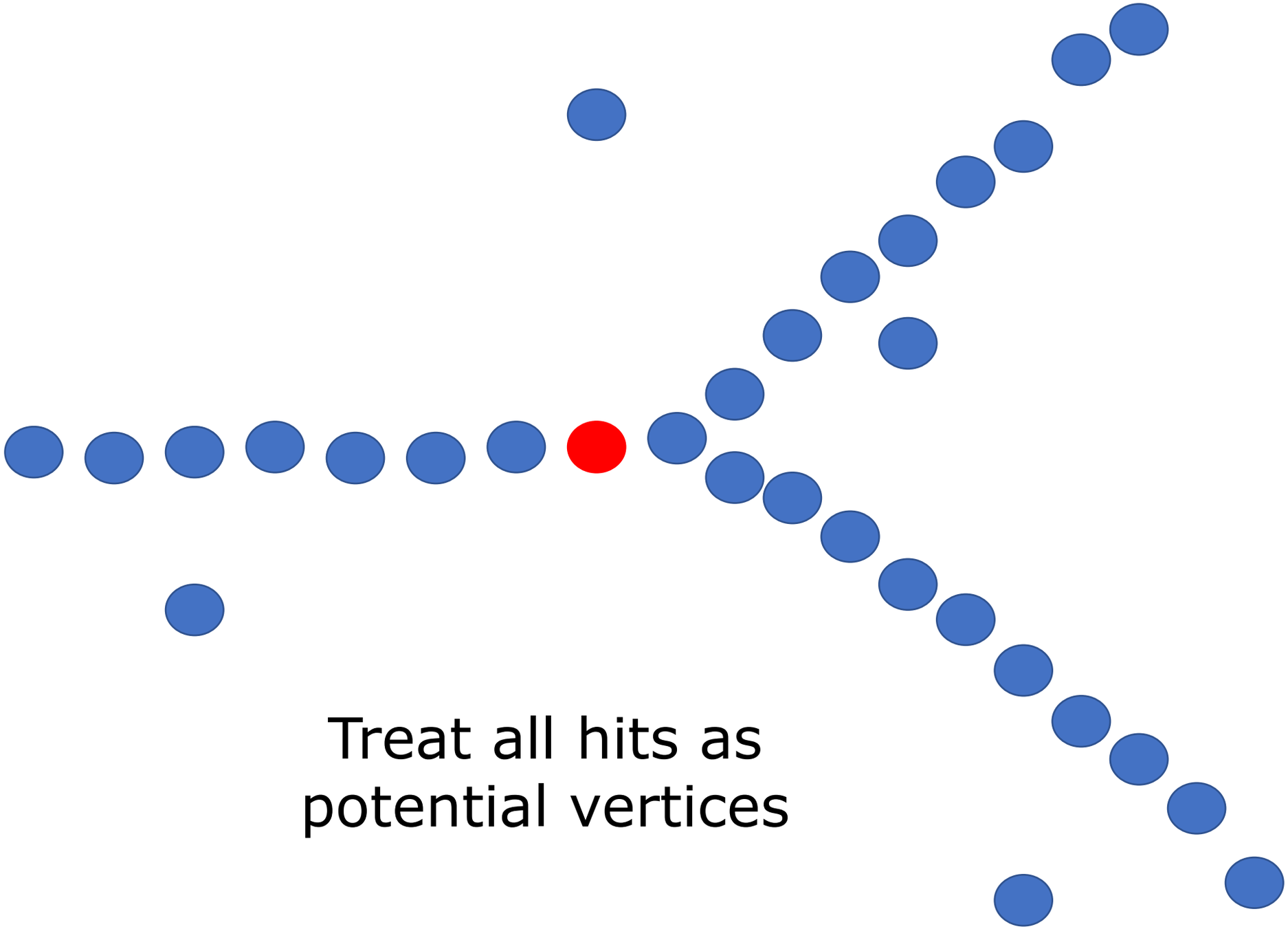
We want to be able to identify the multiprong topology's vertex




p
Hits
Truth
Track
μ
μ
Extra hits from
wire noise or
background tracks
make this picture
more complicated



Treat all hits as
potential vertices



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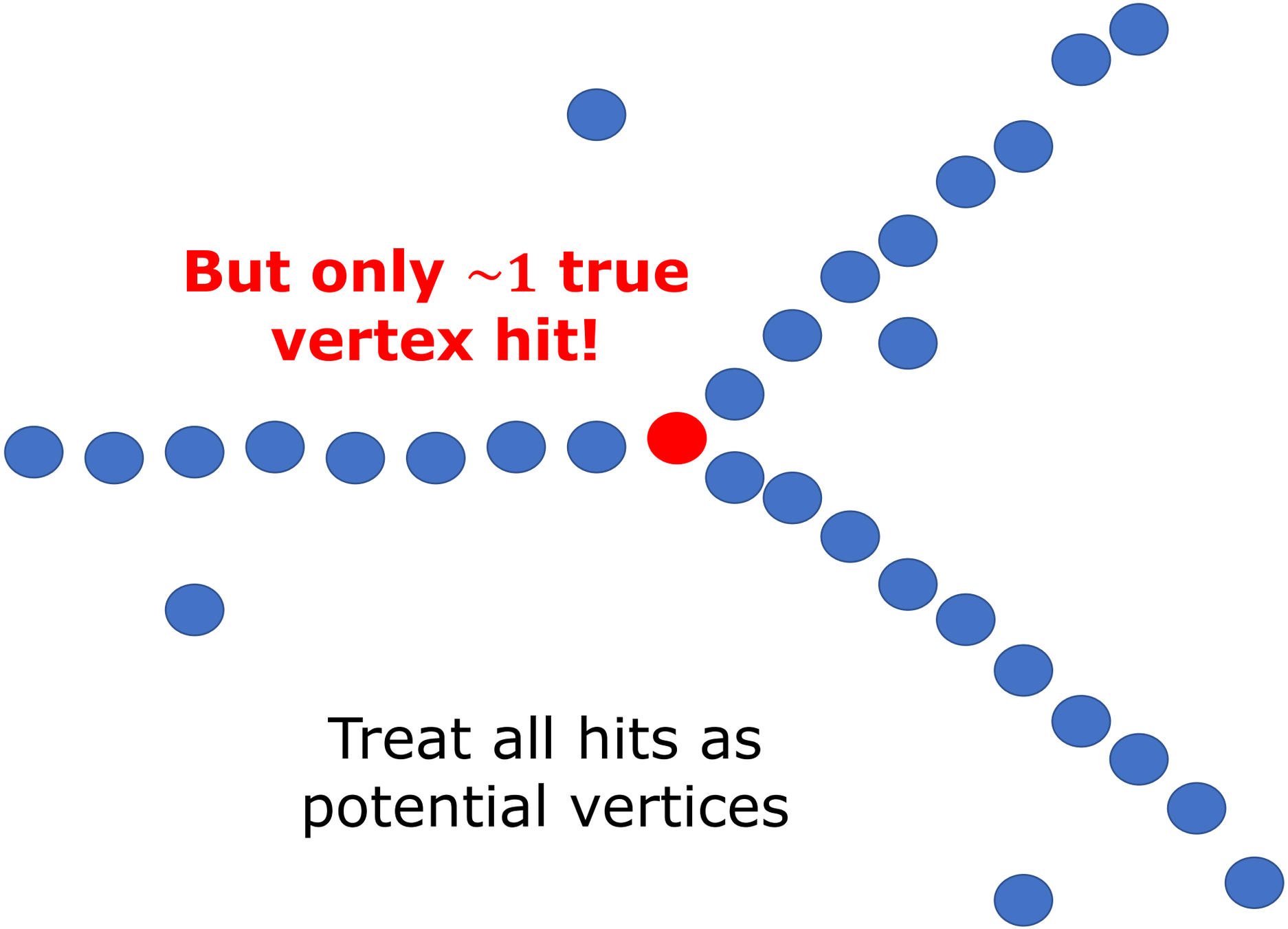

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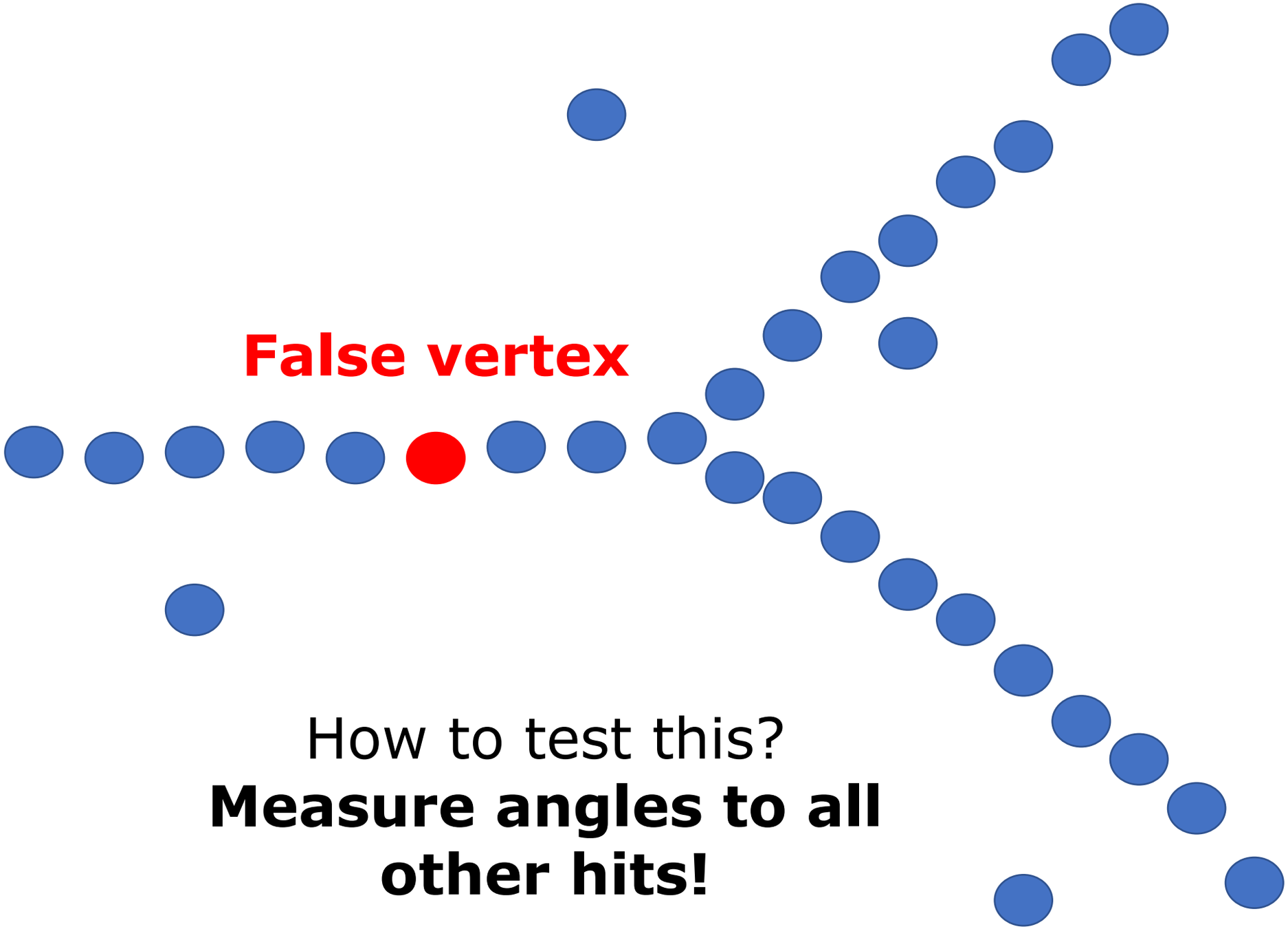
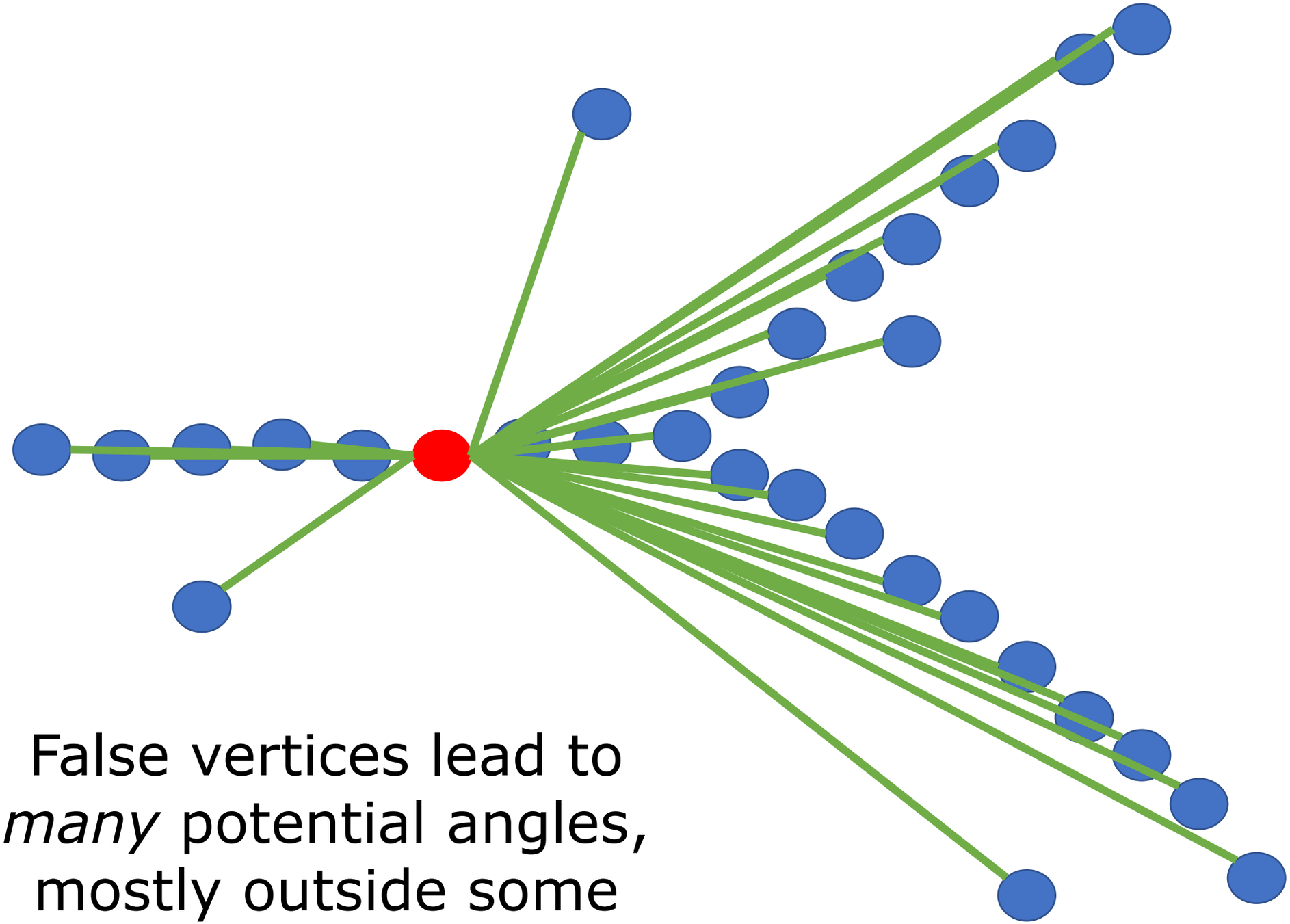
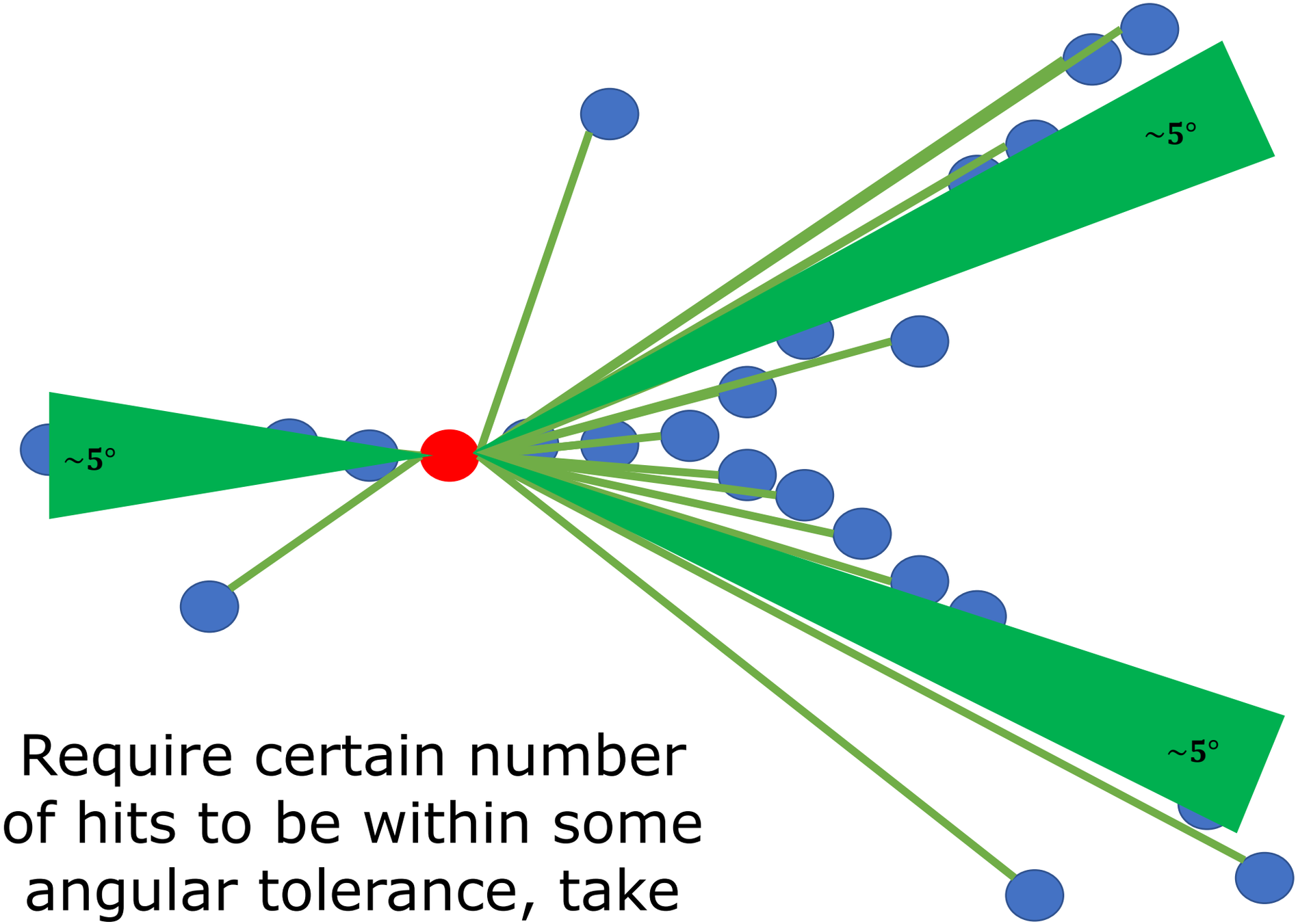


How to test this?

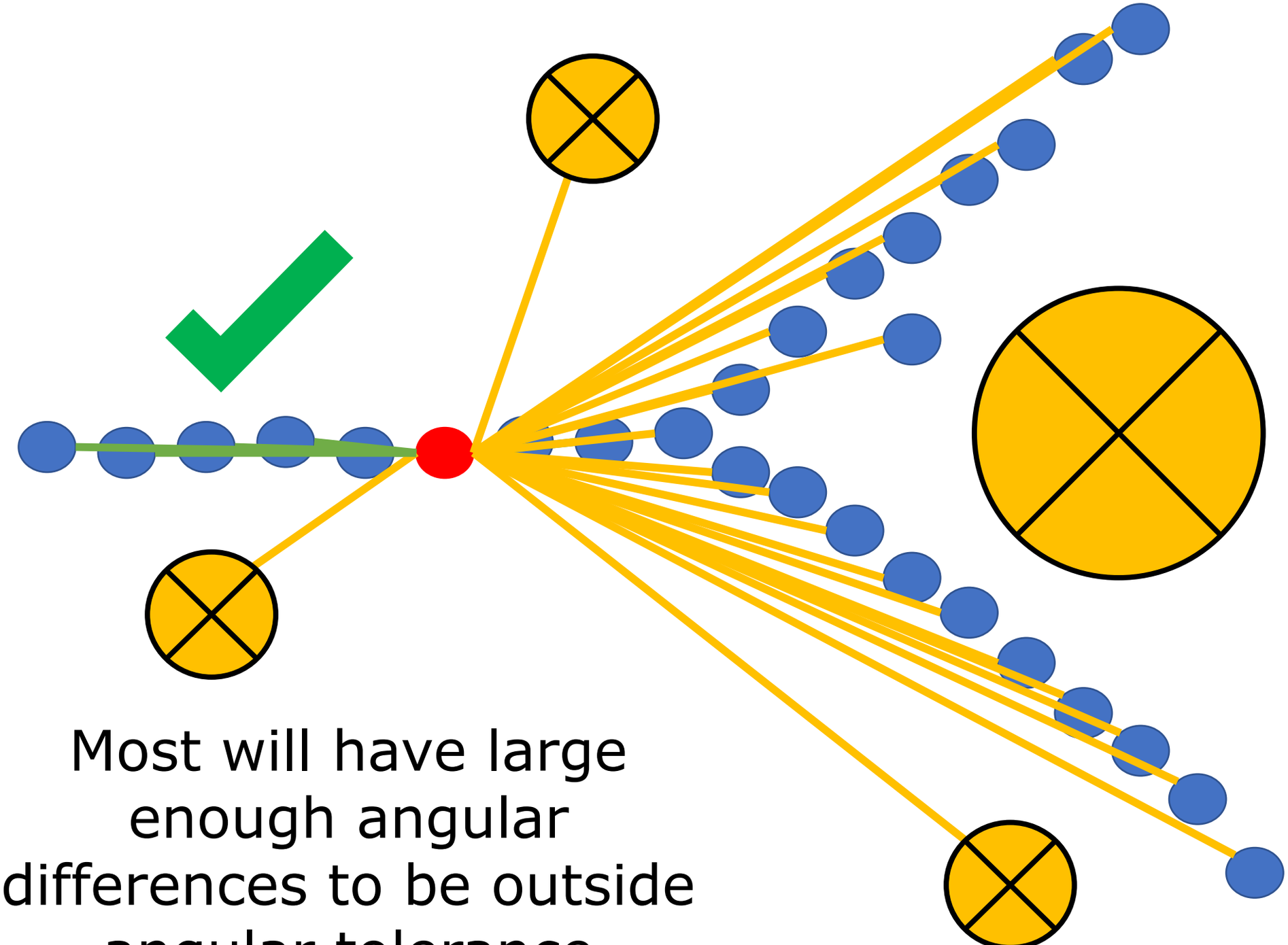
Measure angles to all other hits!



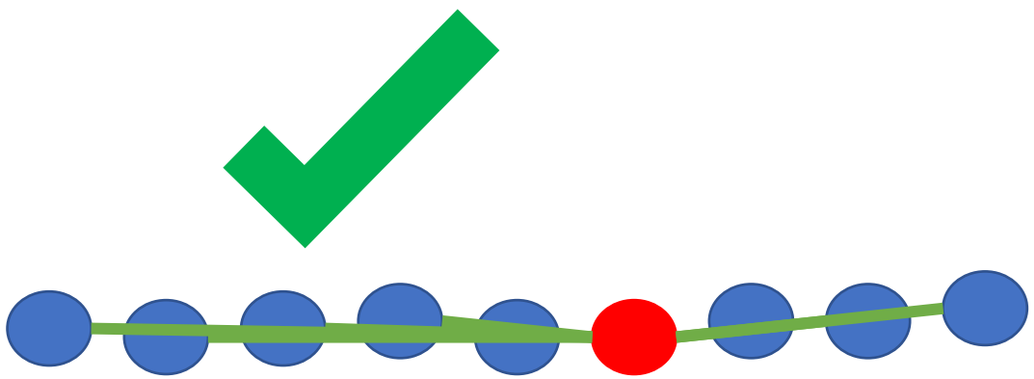
False vertices lead to *many* potential angles, mostly outside some angular tolerance



Require certain number of hits to be within some angular tolerance, take an average

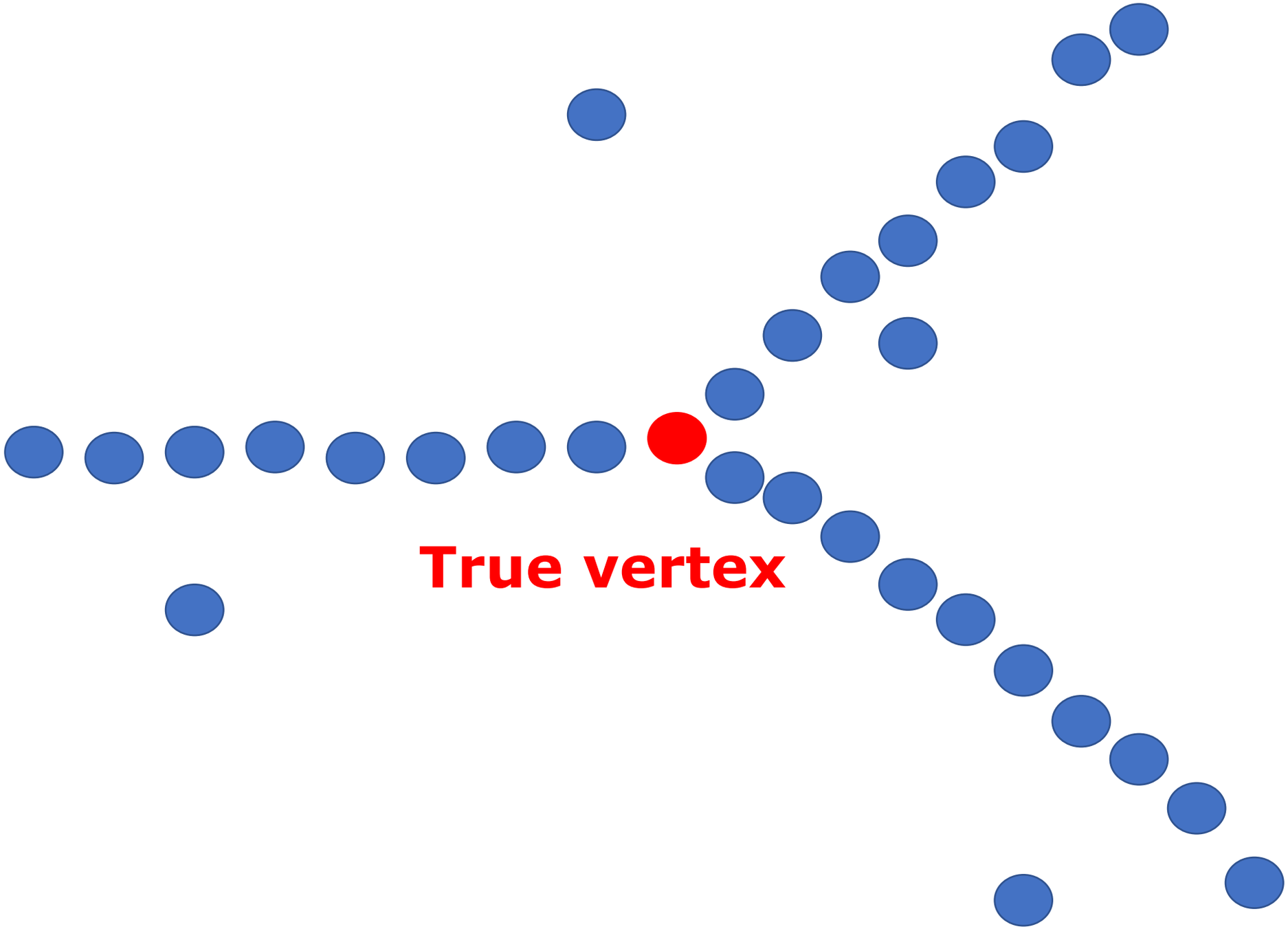


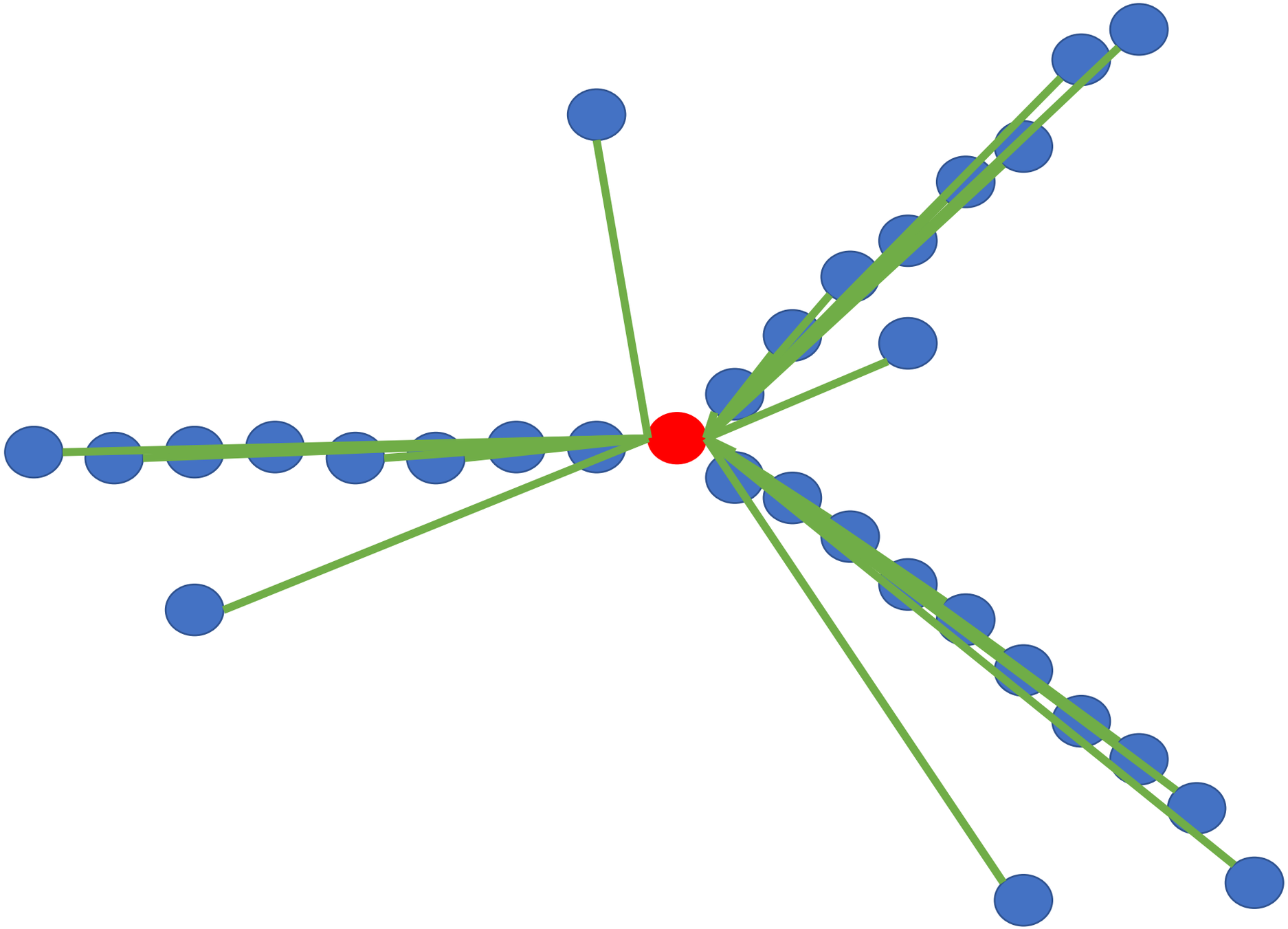
Most will have large enough angular differences to be outside angular tolerance

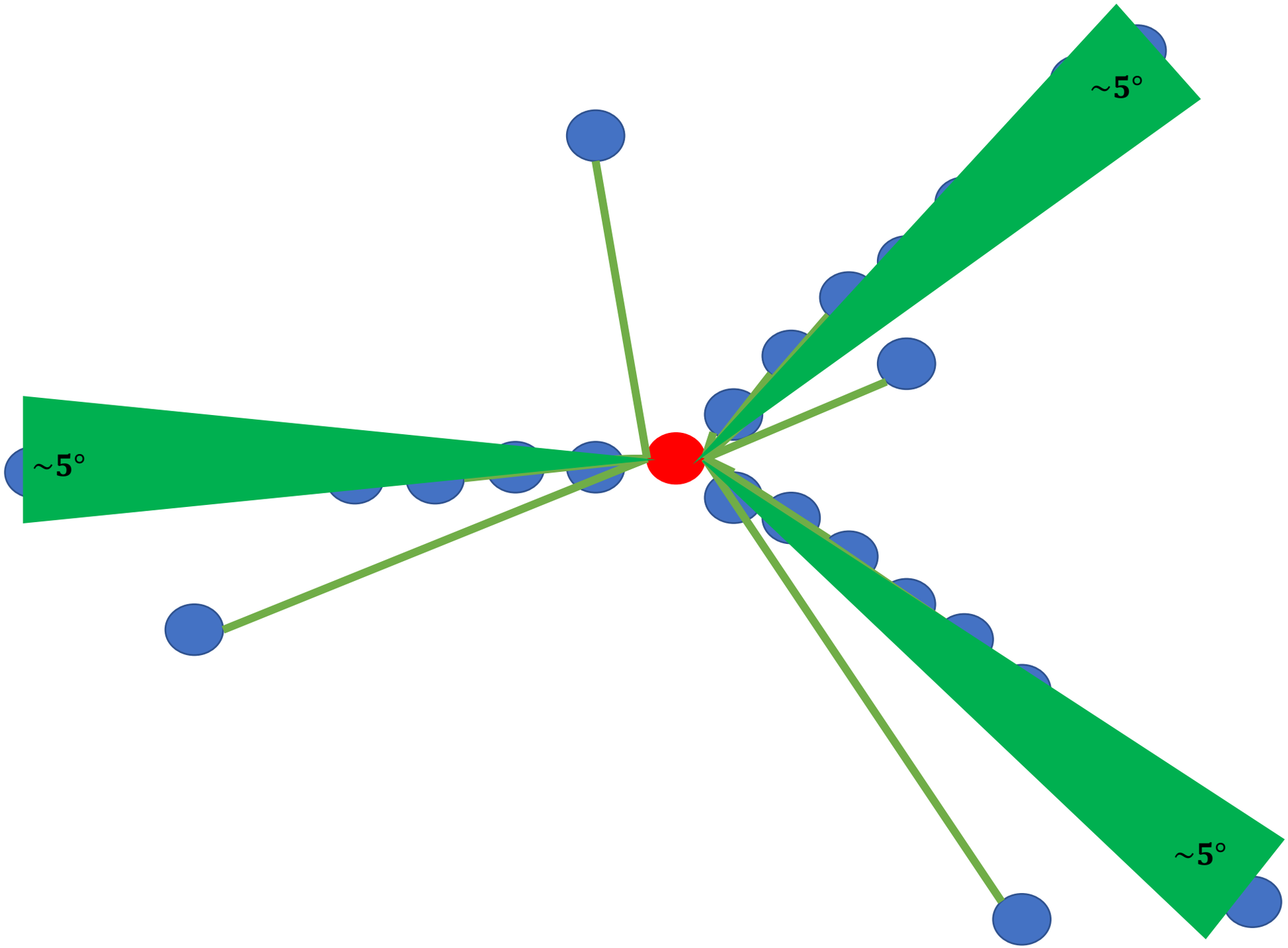


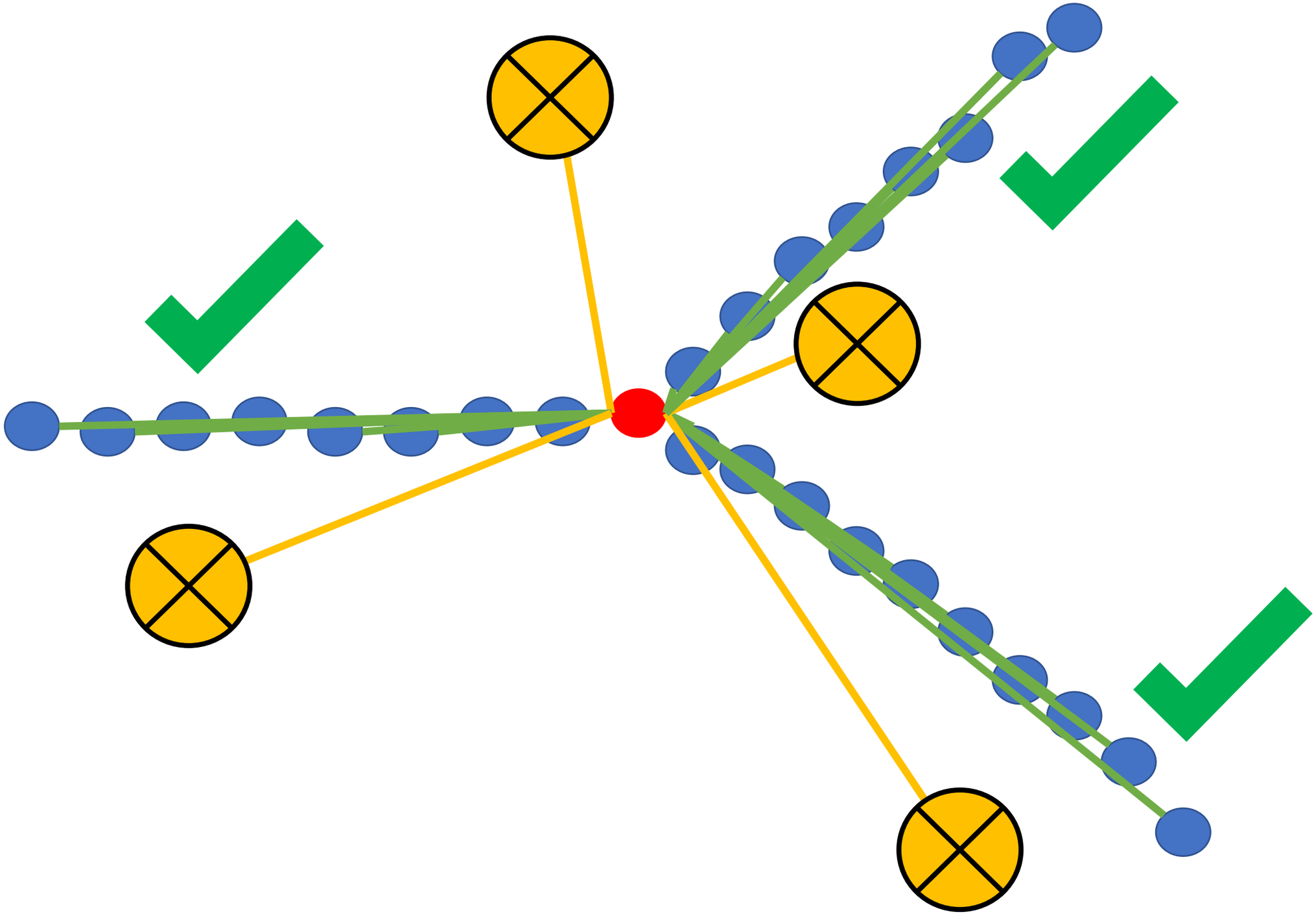
This greatly limits the number of possible tracks of particular angles which can be triggered on

→ **Require ≥ 3 for multiprong**!

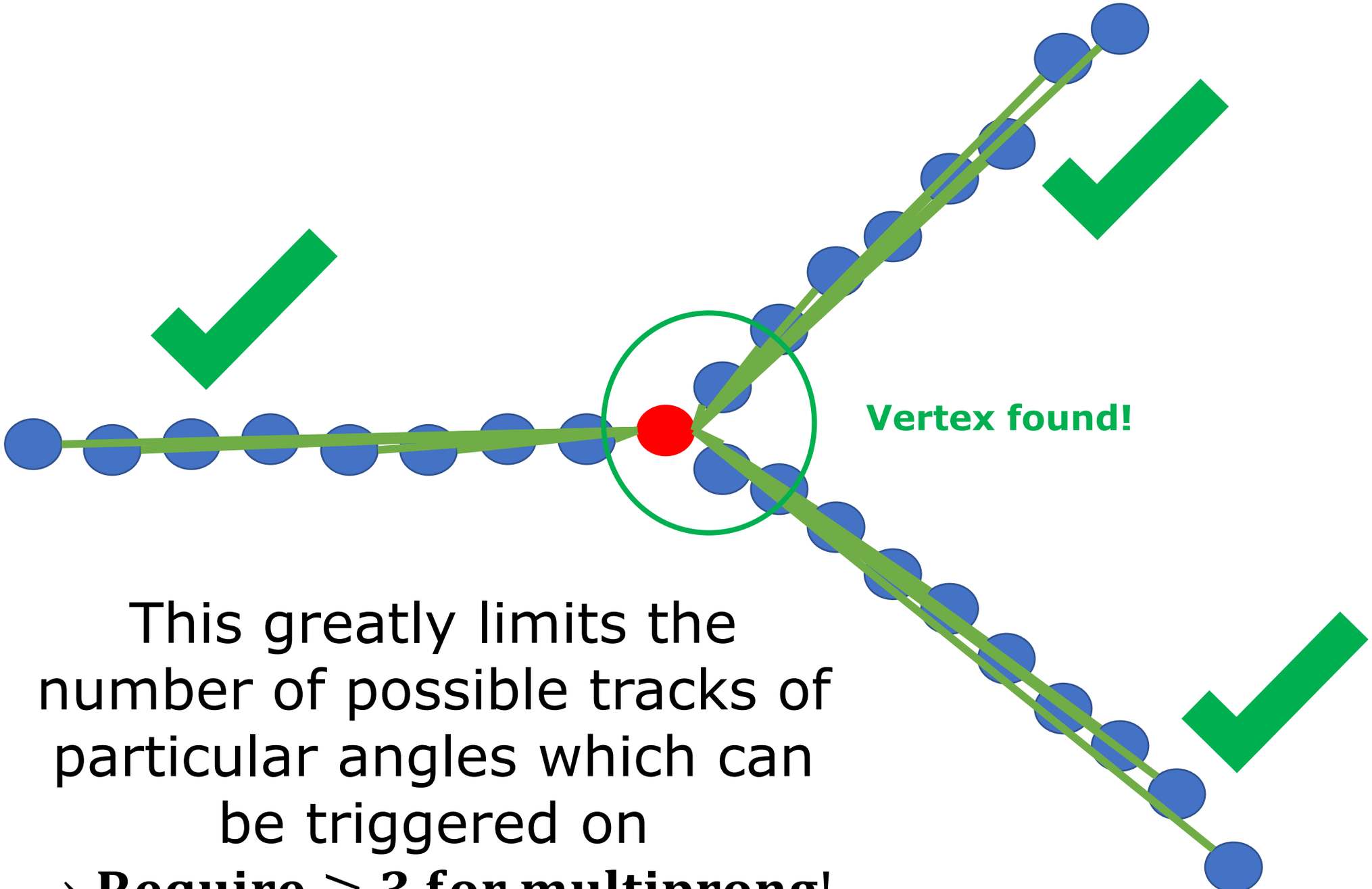

True vertex




~5°
~5°
~5°



Original idea developed in conversation with A. Ashkenazi



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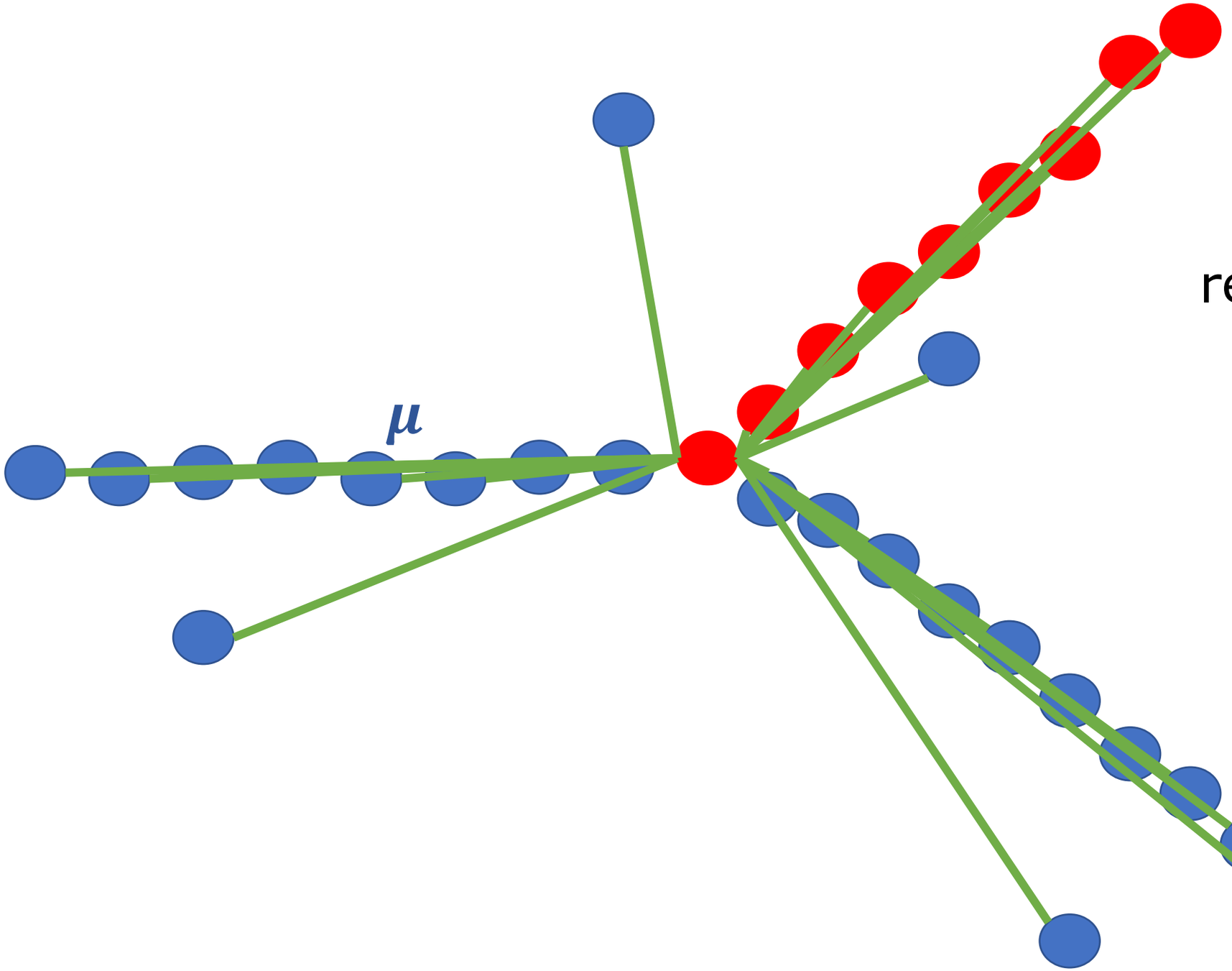


Including **high ADC** requirements makes this selection more pure

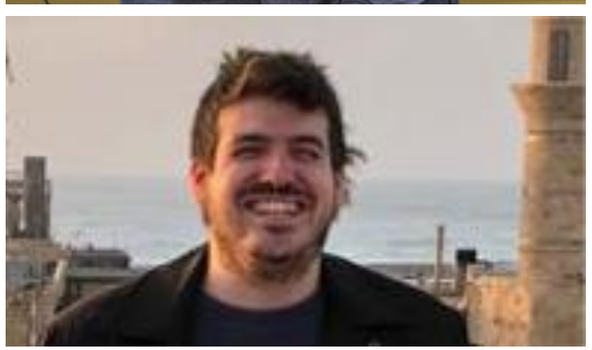
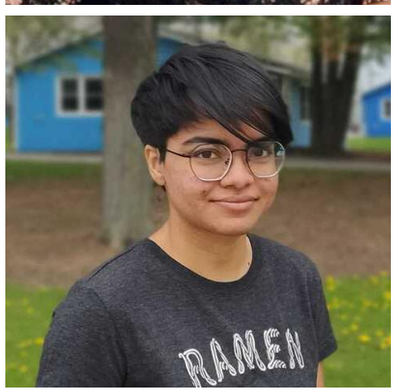
$\mu 4\nu$ Summary

- **Cosmic QE-like EM** events ($\mu + \mathrm{Ar} \rightarrow \mu + \mathrm{N}p + X$)
  - Offer powerful facsimile to ν_μ CC events
  - More information from incoming lepton
  - Final state can be studies as if from ν_μ interaction

- **Deliverables in $\mu 4\nu$ via cosmics:**
  - **Select $1\mu 1p$ via trigger algorithm on data**
  - **Determine bias in E_{ν_μ} (mis)reconstruction**
  - **Improve MCS for uncontained tracks**
  - **Apply as calibrations to ν_μ CC interactions**





Thanks to the team!

Clockwise from top left: G. Karagiorgi (Columbia), W. Ketchum (FNAL), A. Ashkenazi (TAU), D. Kalra (Columbia), M. Bhattacharya (FNAL), A. Gruber (TAU), M. Kirby (FNAL)