Signal resolution requirements for muon to electron conversion experiments

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Introduction

- $\mu \to e$ conversion sensitivity
  - muon statistics
  - detector performance
- Detector performance
  - signal efficiency (statistics multiplier)
  - background rejection
- Backgrounds
  - intrinsic (DIO): momentum resolution is the only handle
  - other backgrounds—can be reduced by other means
- This work: quantify the relationship between
  - experiment sensitivity
  - stopped muon statistics $\times$ signal efficiency
  - detector momentum resolution

Approach

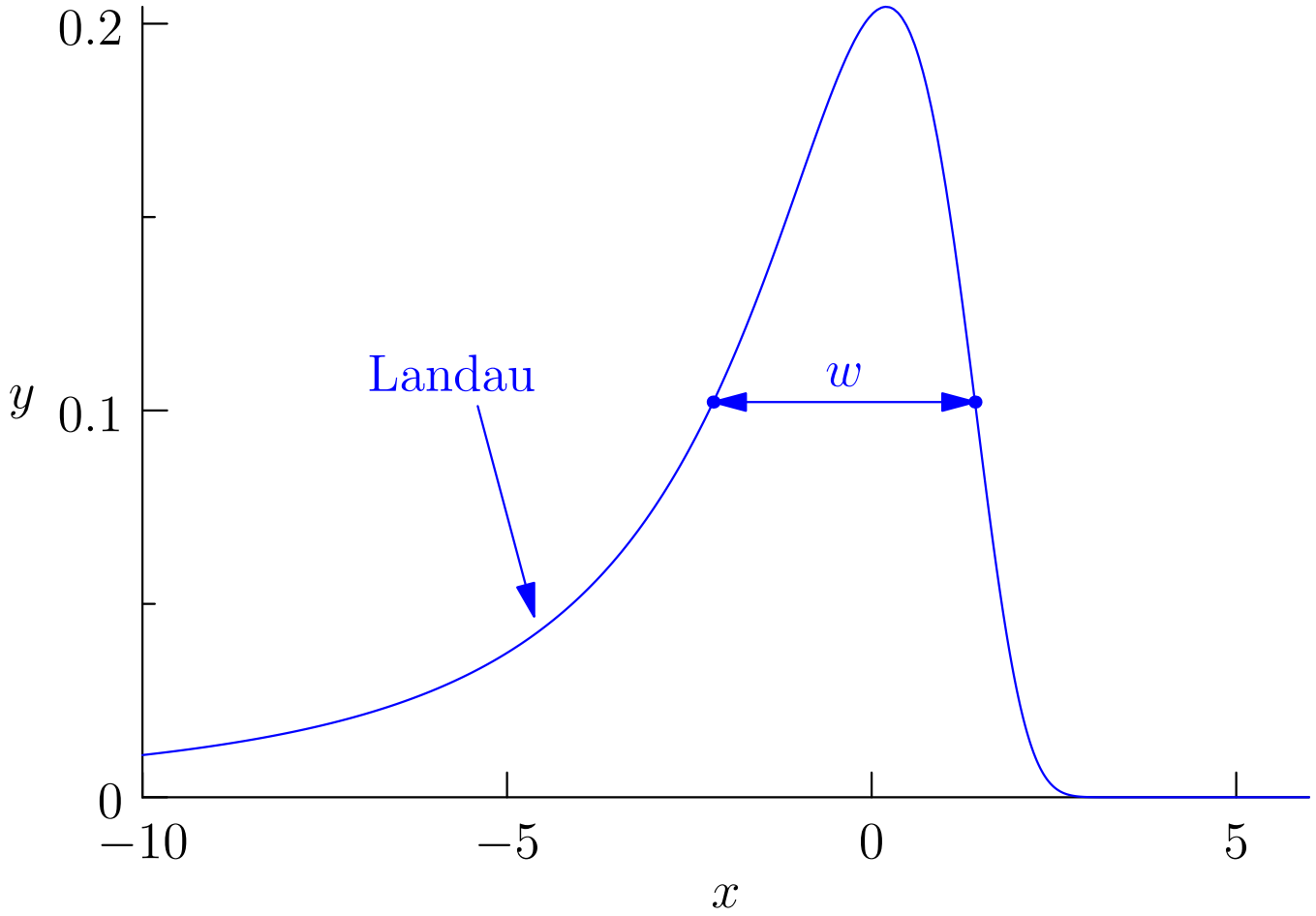
- Assume other backgrounds to be zeroed by other means
- Just two processes to consider: conversion signal and DIO
- Use tree level physics spectra: neglect $\mathcal{O}(10\%)$ effect
- For a given detector resolution and stopped muon statistics, optimize the signal momentum cut in a cut-and-count analysis
- Show the best possible experiment sensitivity under the above assumptions

Detector resolution

- Need physics resolution of the apparatus that includes everything. (Not just the "tracker" resolution that ignores effects of the stopping target, for example.)
- The shape is complicated, but includes "core" and "tails".
- Model used in this study
  - Landau distribution for the core and low tail:
    effects from particle passage through detector material.
  - Power law for the high momentum tail:
    ad hoc distribution to account for "miscreconstructed" tracks, same as used in Mu2e.

Resolution function

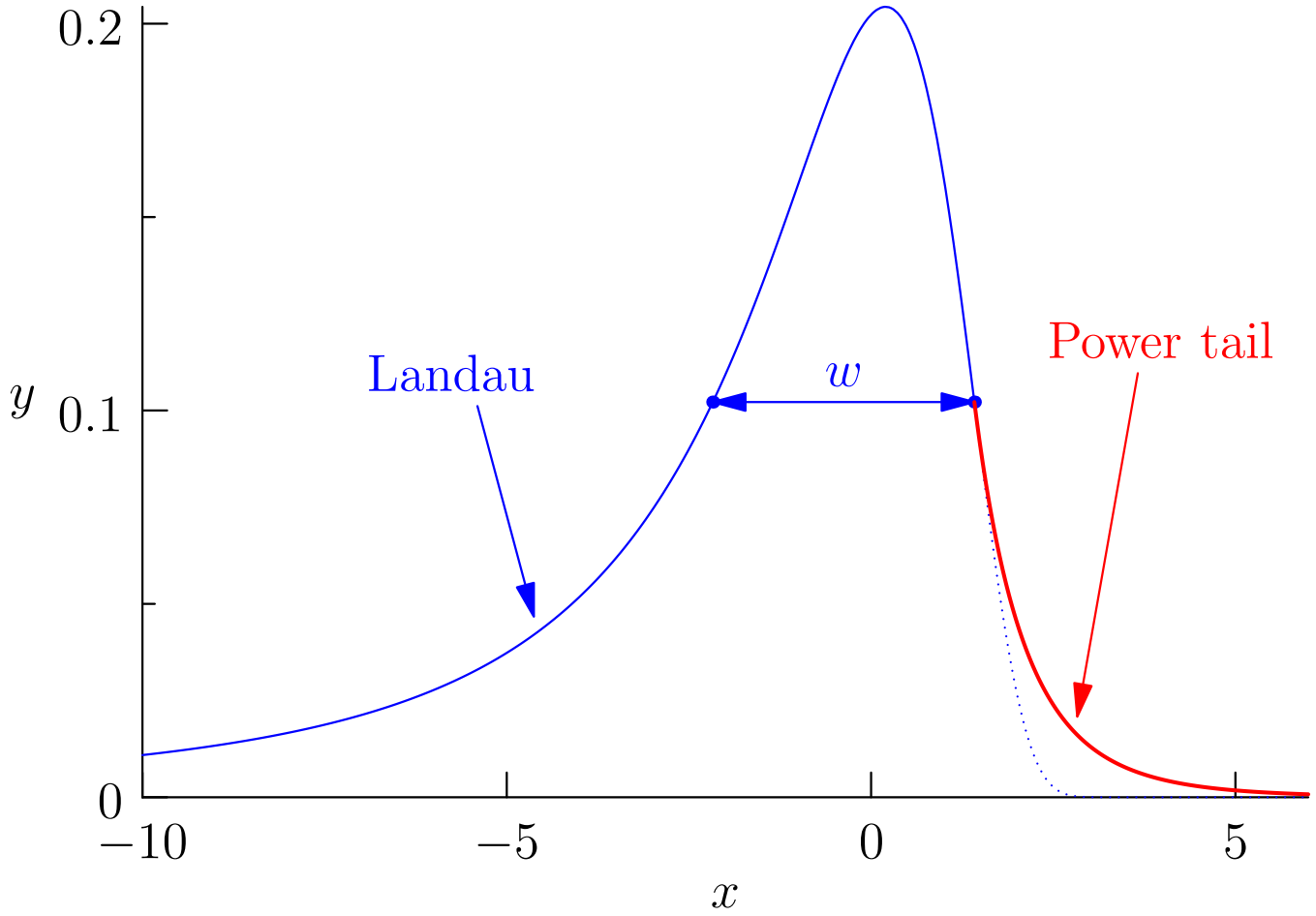
Start with Landau



Equivalent σ through FWHM: $\sigma = \frac{w}{2\sqrt{2\ln(2)}}$

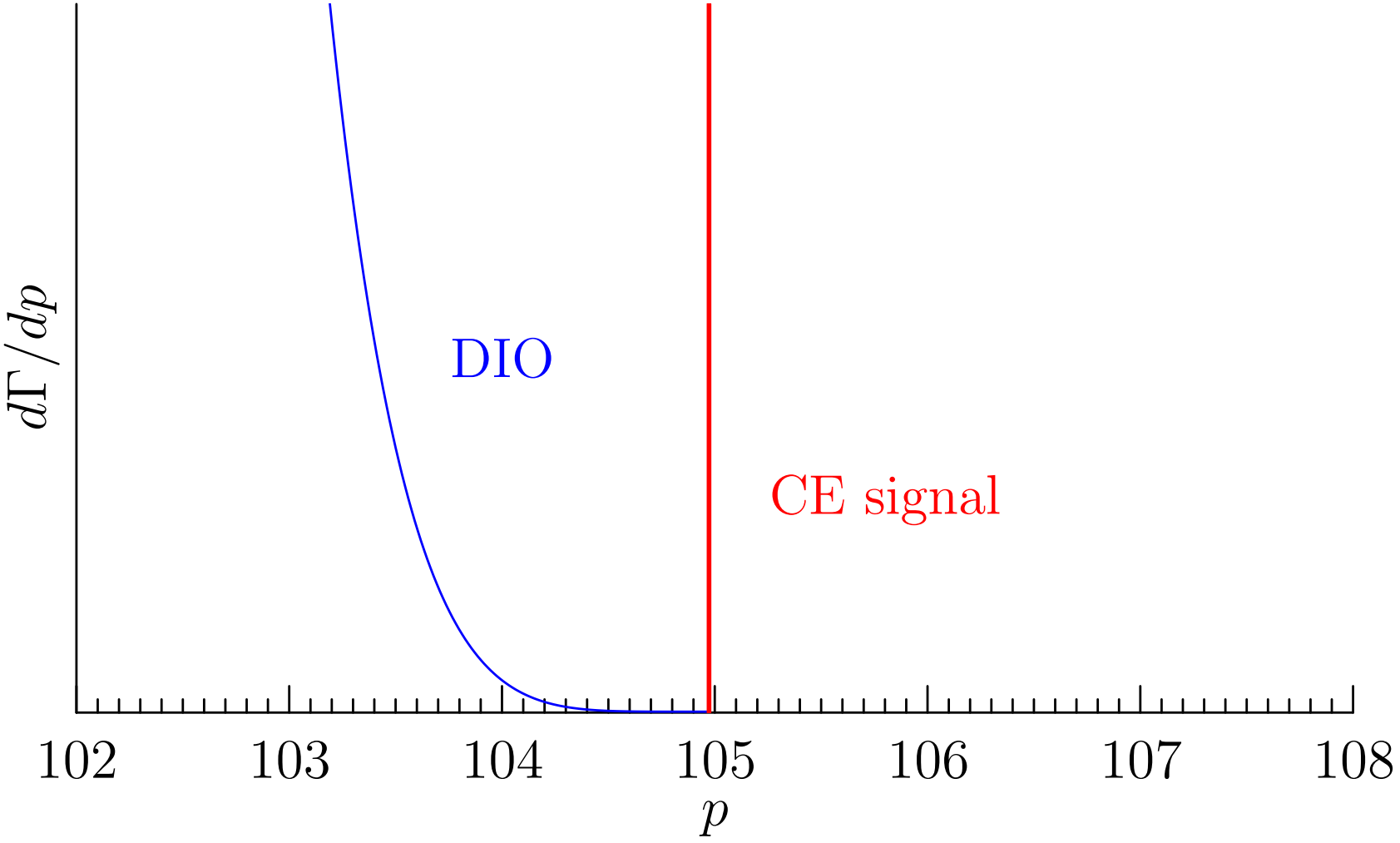
Resolution function

Add power tail



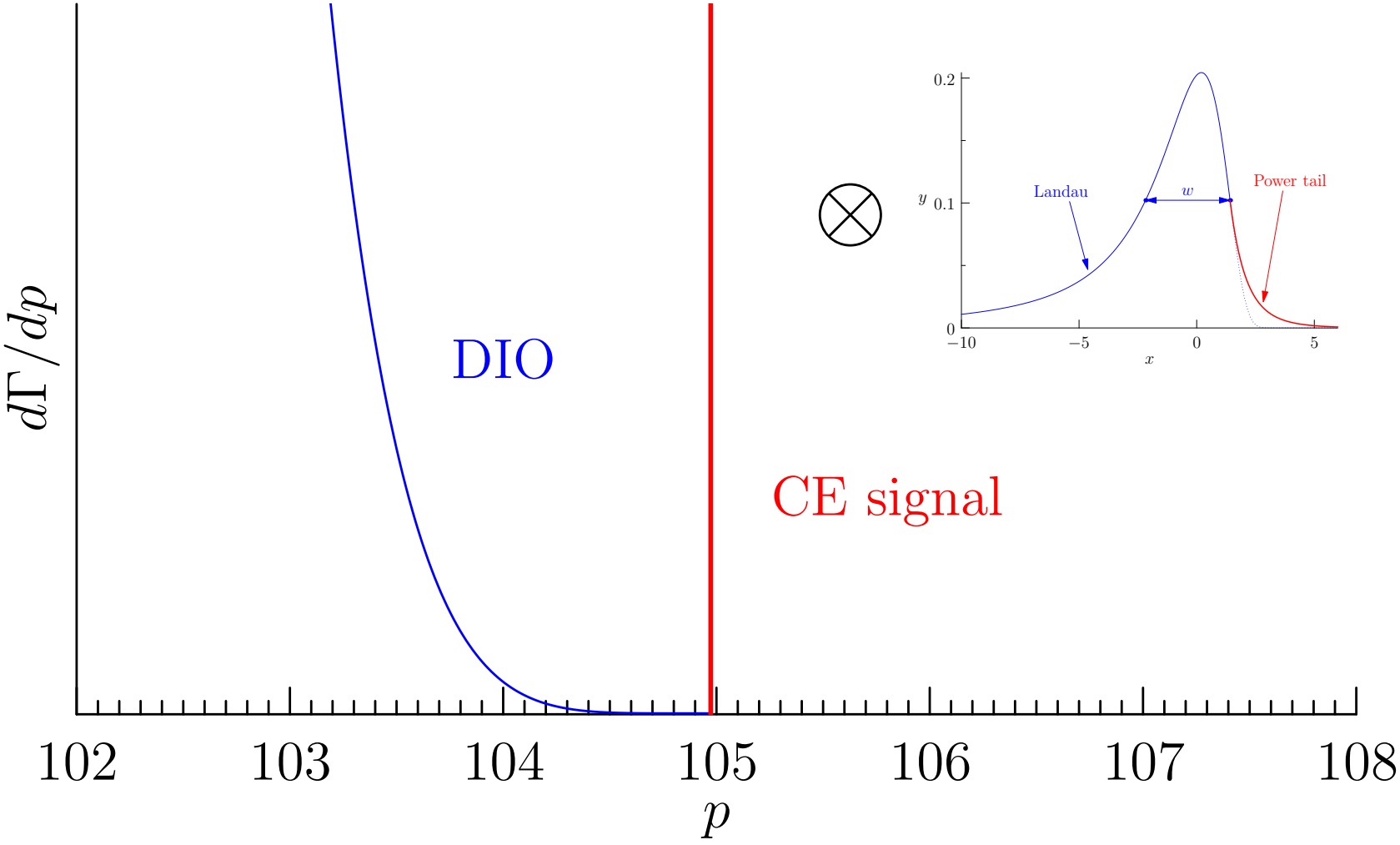
This is a two parameter model: σ and tail power s

Theoretical spectra



Czarnecki, Tormo PRD84(2011)013006

Theoretical spectra



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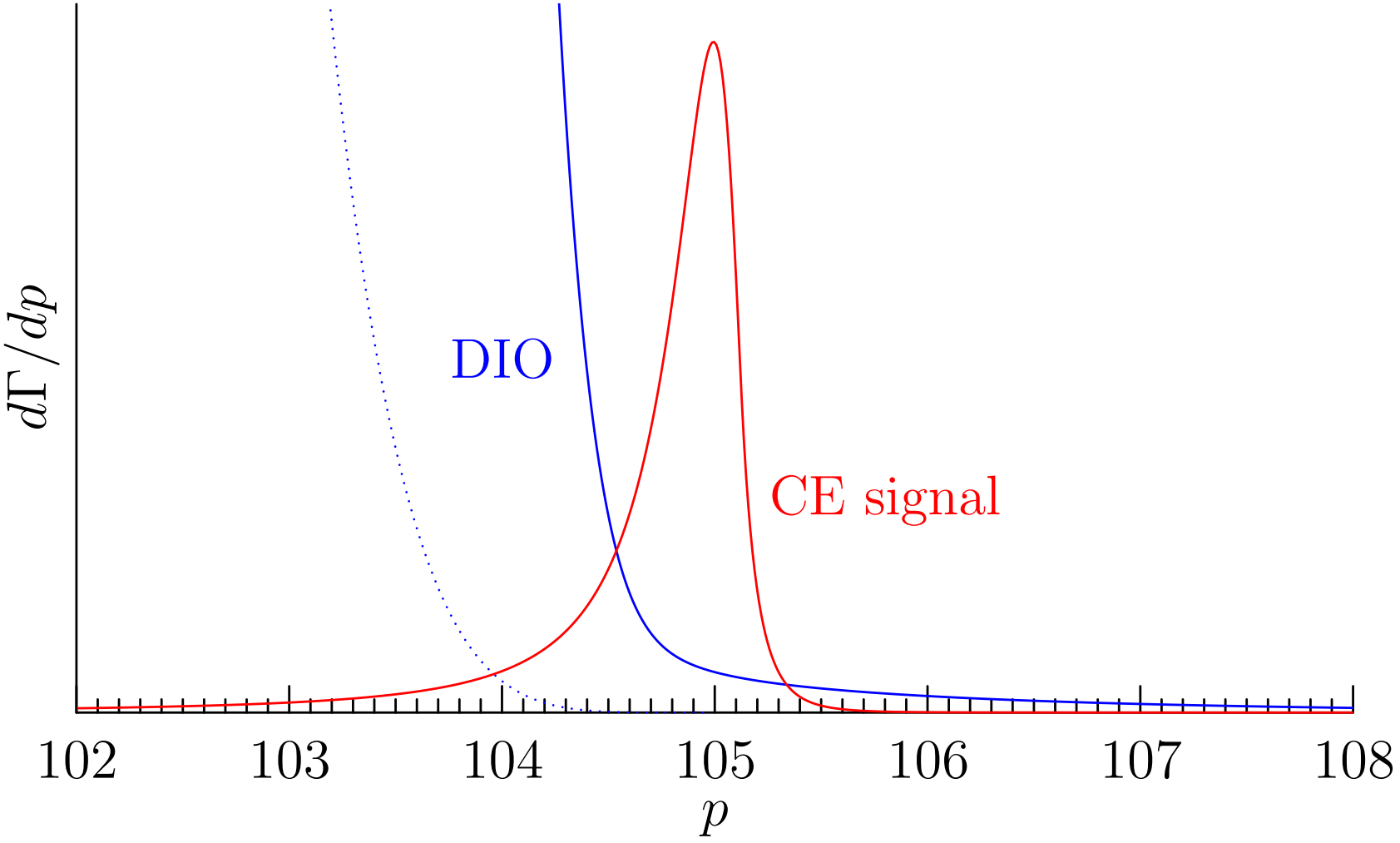
“Reconstructed” spectra



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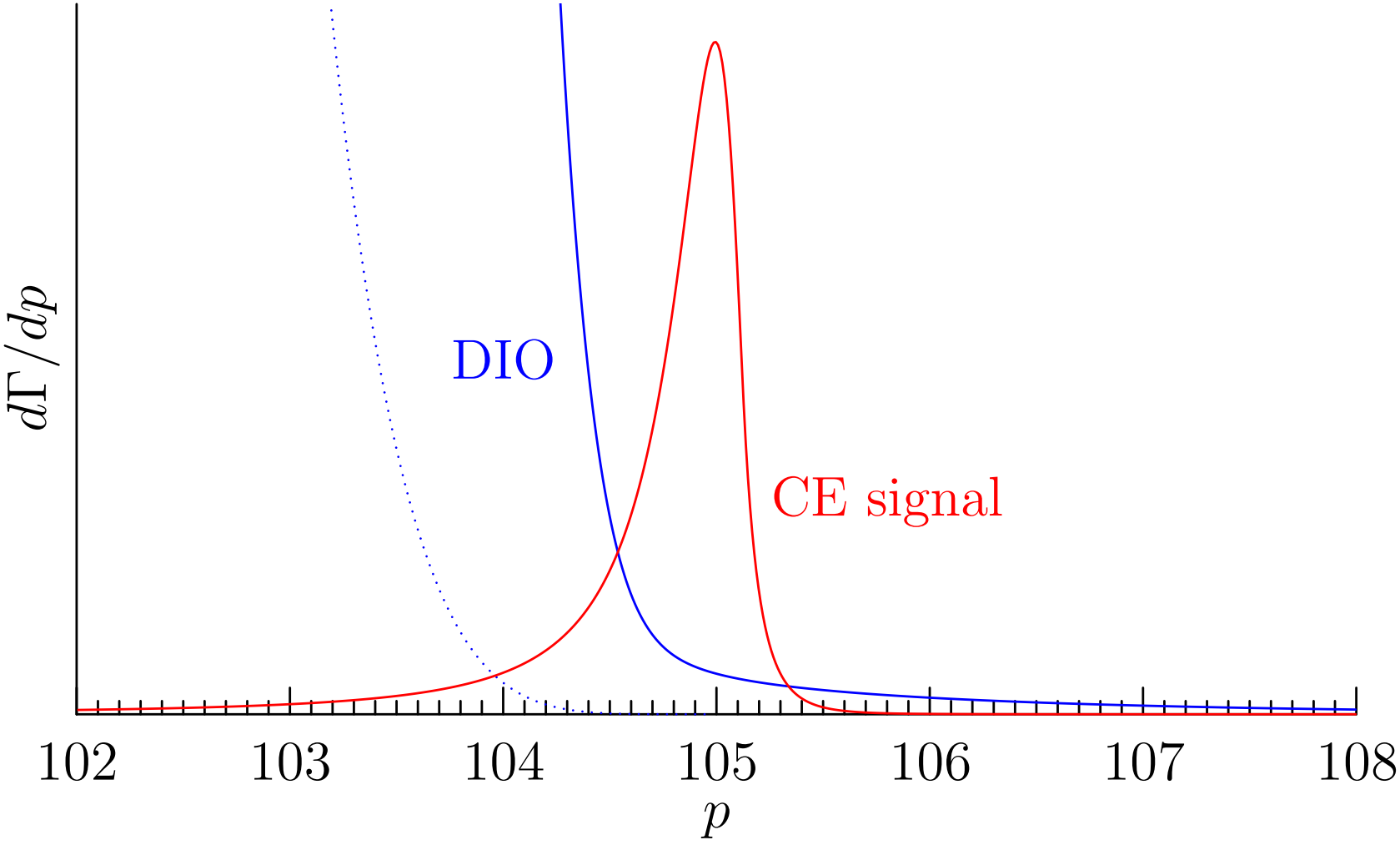
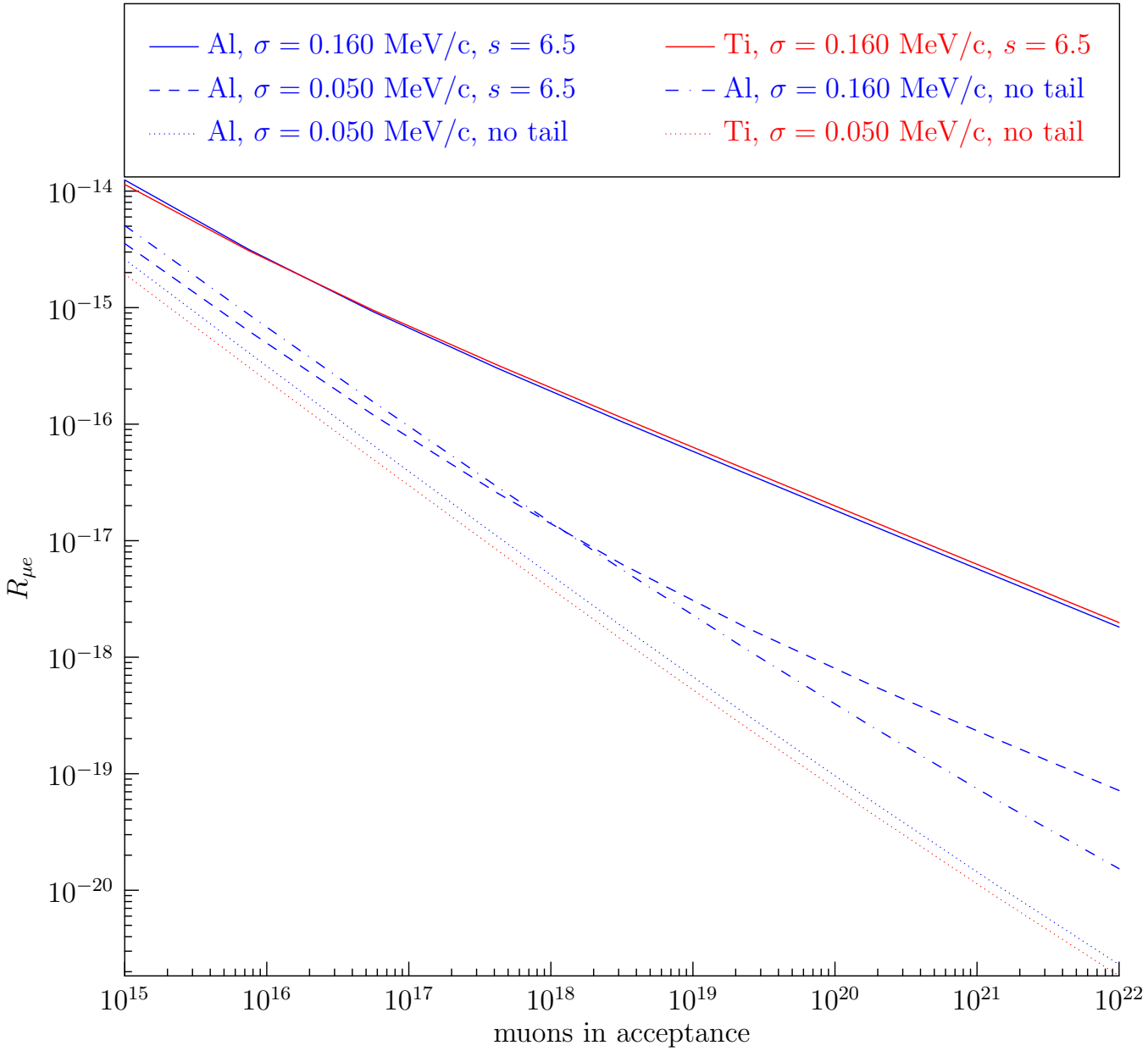


Signal momentum cut to optimize median 5σ discovery sensitivity

Median 5σ discovery sensitivity scaling



Muons in acceptance $= N_{\mu\ \text{stops}} \times A \times \varepsilon$ where ε includes all cuts except the signal momentum cut

Summary

- Developed an approach to estimate required momentum resolution for future muon to electron conversion experiments
- Core vs tail resolution example
  - for 10^{17} statistics improving core 0.050 MeV$/c \Rightarrow 0.160$ MeV$/c$ wins over getting rid of the tail
  - but for 10^{19} tail is more important than core
- FERMILAB-PUB-22-117-PPD will eventually contain a write up of this work