Status of $h \to \mu^+\mu^-$ Analysis

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2019/August/28

ILD Group Meeting

$h \to \mu^+\mu^-$ Work: General Status

- DBD-paper, transverse momentum resolution: today's topic
- LCWS2019: plan to go
- IDR benchmark analysis: FINISHED!
- IDR note: PUBLISHED! (ILD-PHYS-PUB-2019-002, see at https://confluence.desy.de/display/ILD/ILD+notes)
- IDR ($h \to \mu^+\mu^-$ part only): made comments long time ago

Quick Reminder of Analysis Procedure

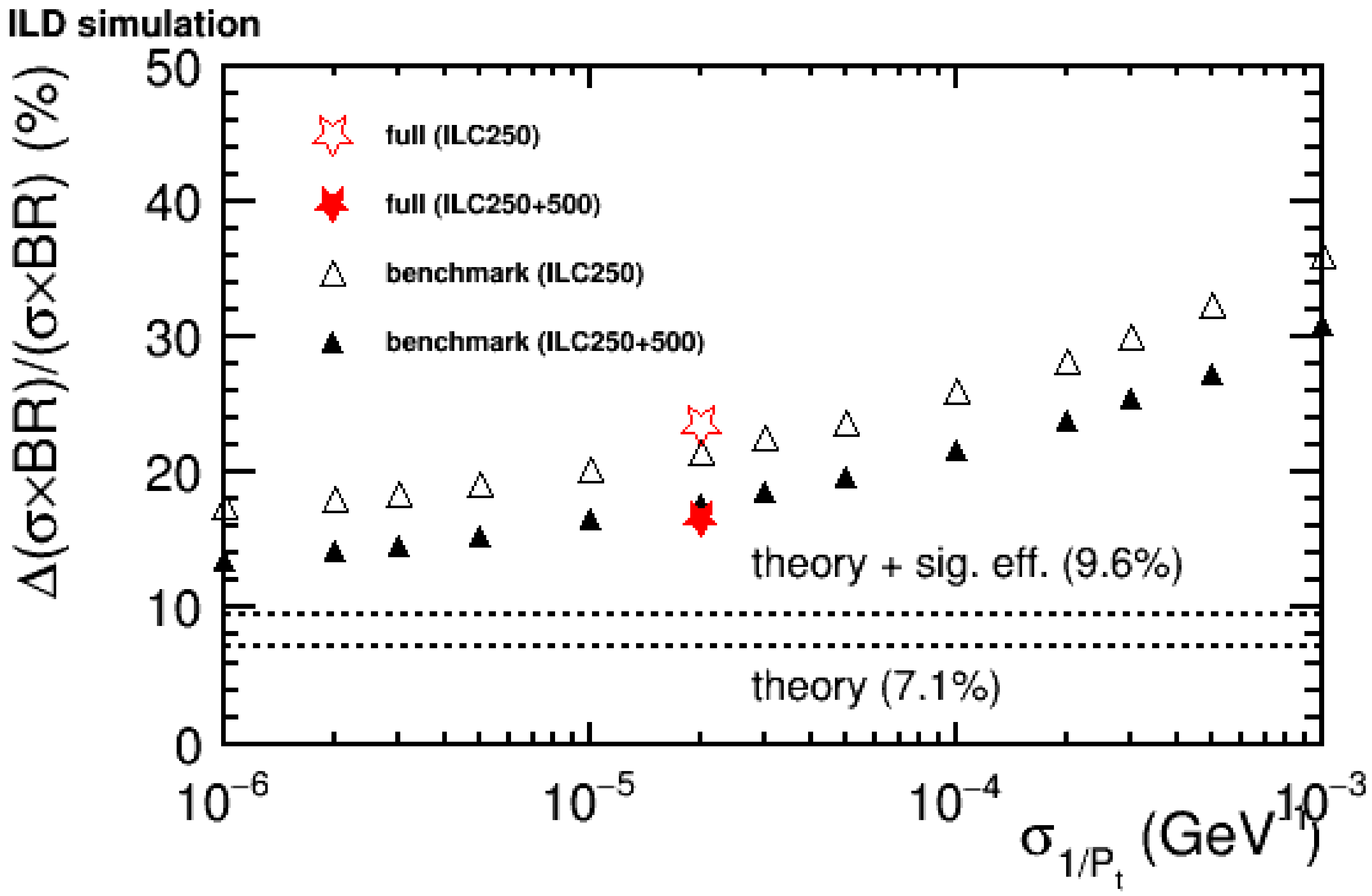
- IsolatedLeptonTagging and cut on $h \to \mu^+\mu^-$ candidate
- channel-specific reconstruction ($q\bar{q}h$ and $\nu\bar{\nu}h$) and cut-based analysis (preselection)
- TMVA (BDTG) analysis
- toy MC
    - Crystal Ball (CB) + Gaussian for signal modeling
    - 1st order polynomial for background modeling
    - 50000 times pseudo-experiments
    - optimization with toy MC by changing BDTG score cut

Transverse Momentum Resolution

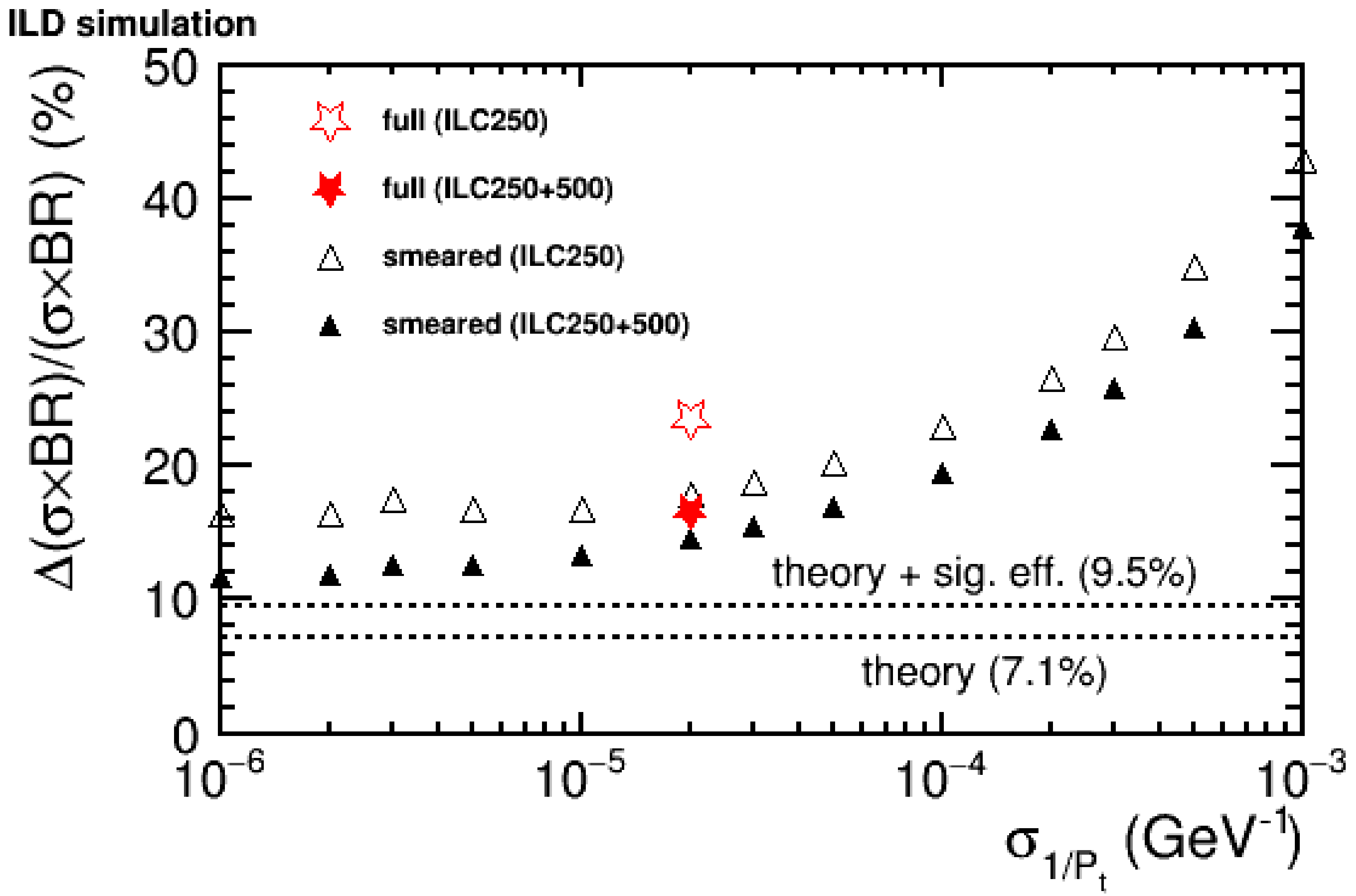
- Find a mistake in the part of smearing (details in backup)
  - caused some overestimate, especially at 500 GeV; this is the reason why full sim. gives significantly better result than smeared which assume a constant number of transverse momentum resolution everywhere

- New Plots have been made
  - red stars: full simulation results
  - triangles: assume certain transverse momentum resolution ($1*10^{-3}$ to $1*10^{-6}$) and do smearing to MC truth momentum of $h \to \mu^+\mu^-$
  - dotted-lines
    - theory (100% sig. eff. + no bkgs. + no det. eff.)
    - theory + sig. eff. (sig. eff. from full sim. + no bkgs. + no det. eff.)

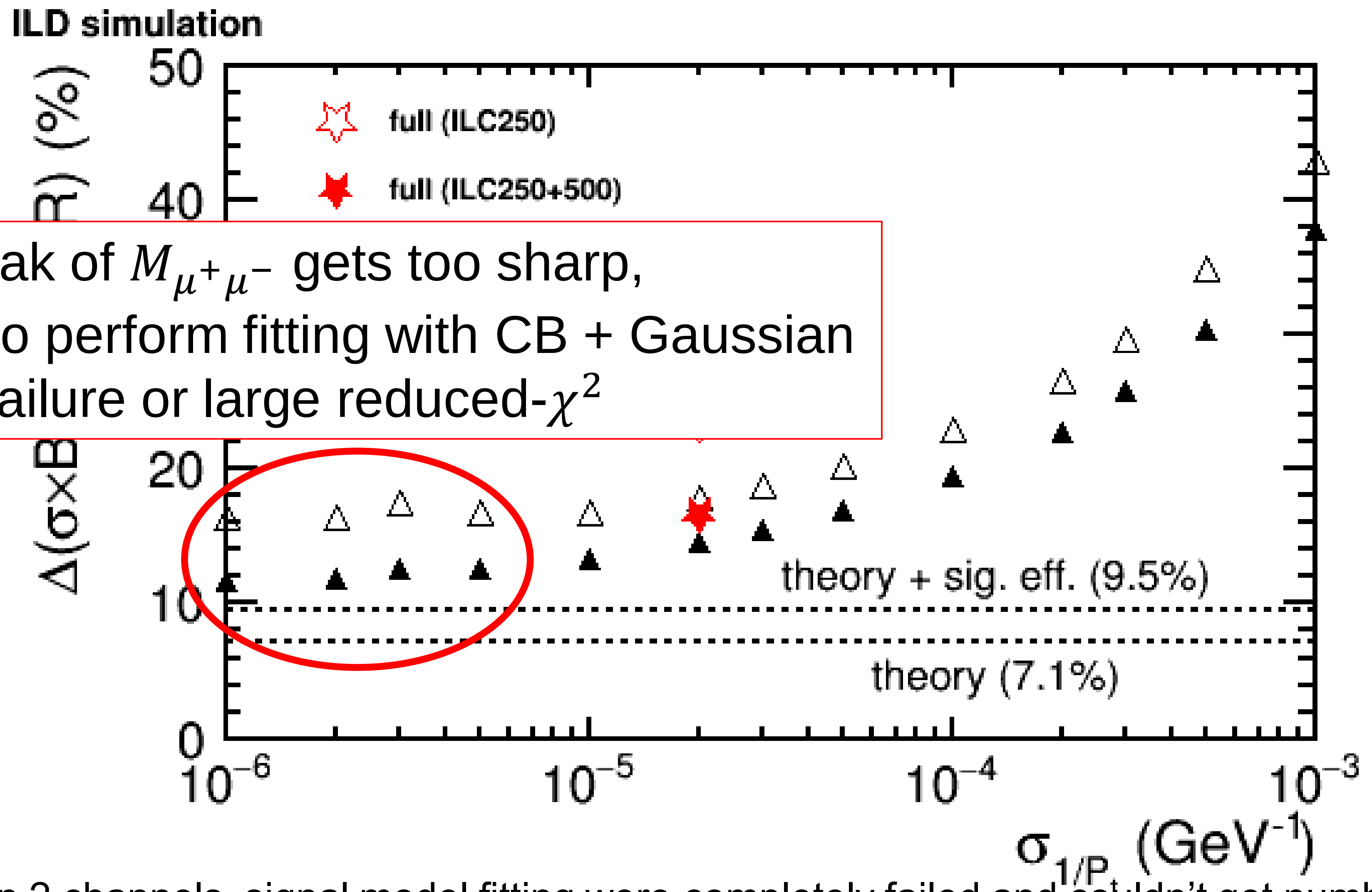
Previous Plot (ILC250+500)



New Plot (ILC250+500)



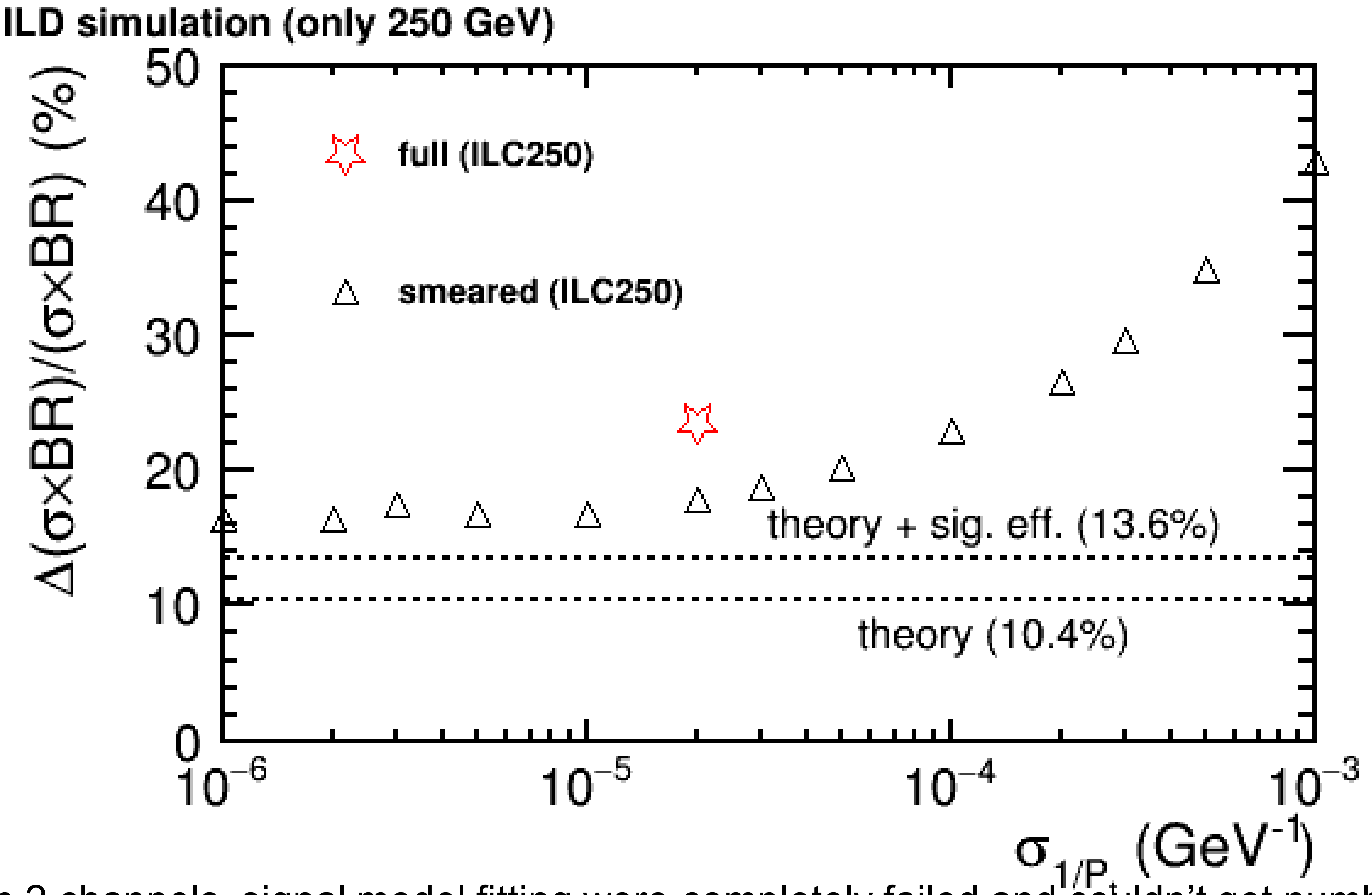
New Plot (ILC250+500)



since the peak of $M_{\mu^+\mu^-}$ gets too sharp,
it is difficult to perform fitting with CB + Gaussian
completely failure or large reduced-χ^2

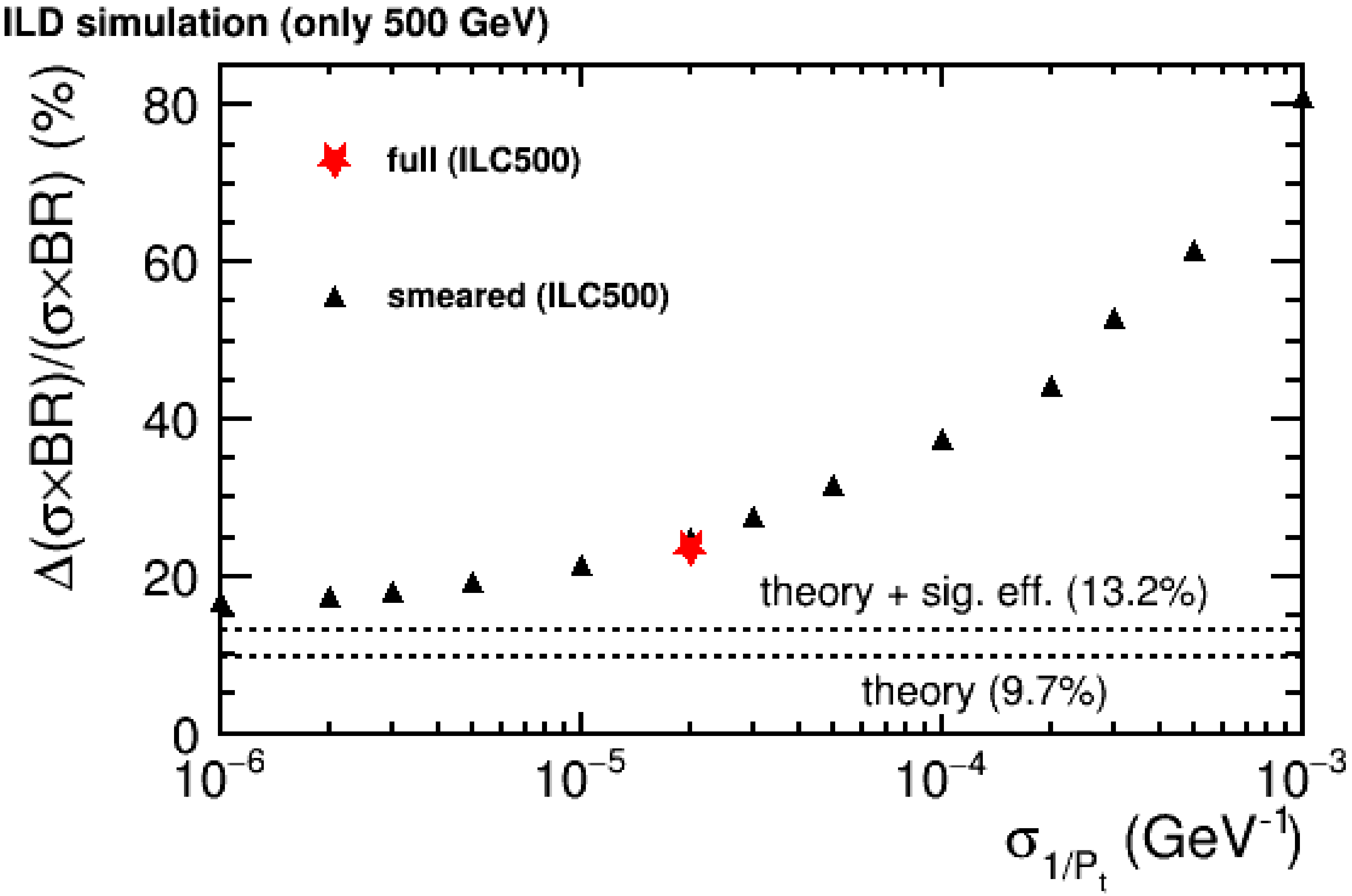
※In 2 channels, signal model fitting were completely failed and couldn't get numbers.
In the plot, some interpretation has been made at 5*10^{-6}. (see backup)

New Plot (ILC250 only)



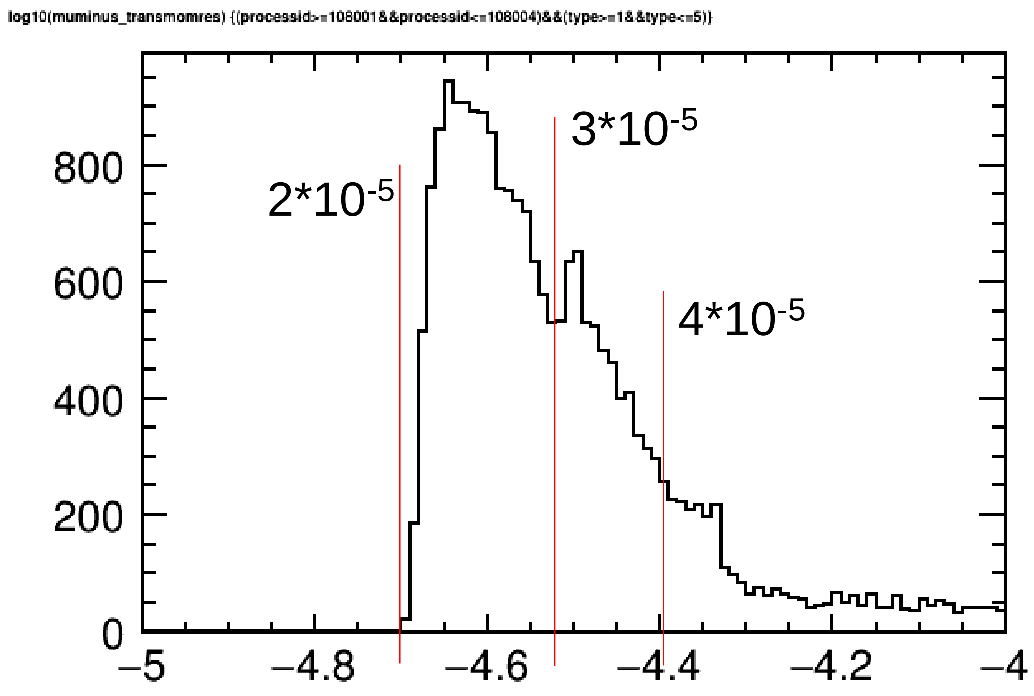
※In 2 channels, signal model fitting were completely failed and couldn't get numbers.
In the plot, some interpretation has been made at $5*10^{-6}$. (see backup)

New Plot (ILC500 only)

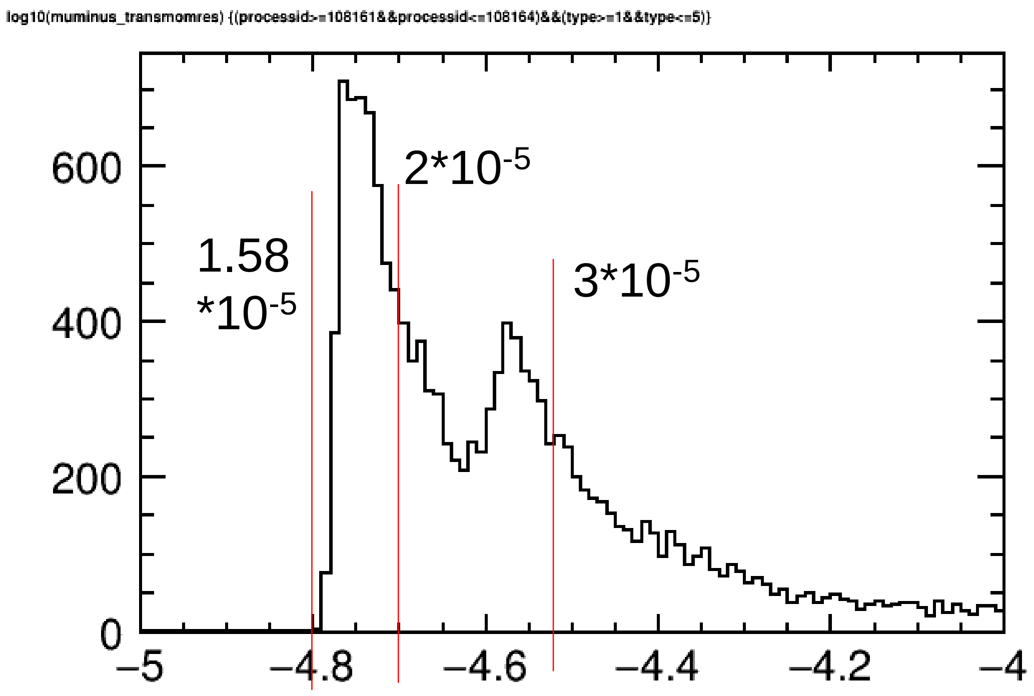


Actual Transverse Momentum Resolution

qqh250-L



qqh500-L

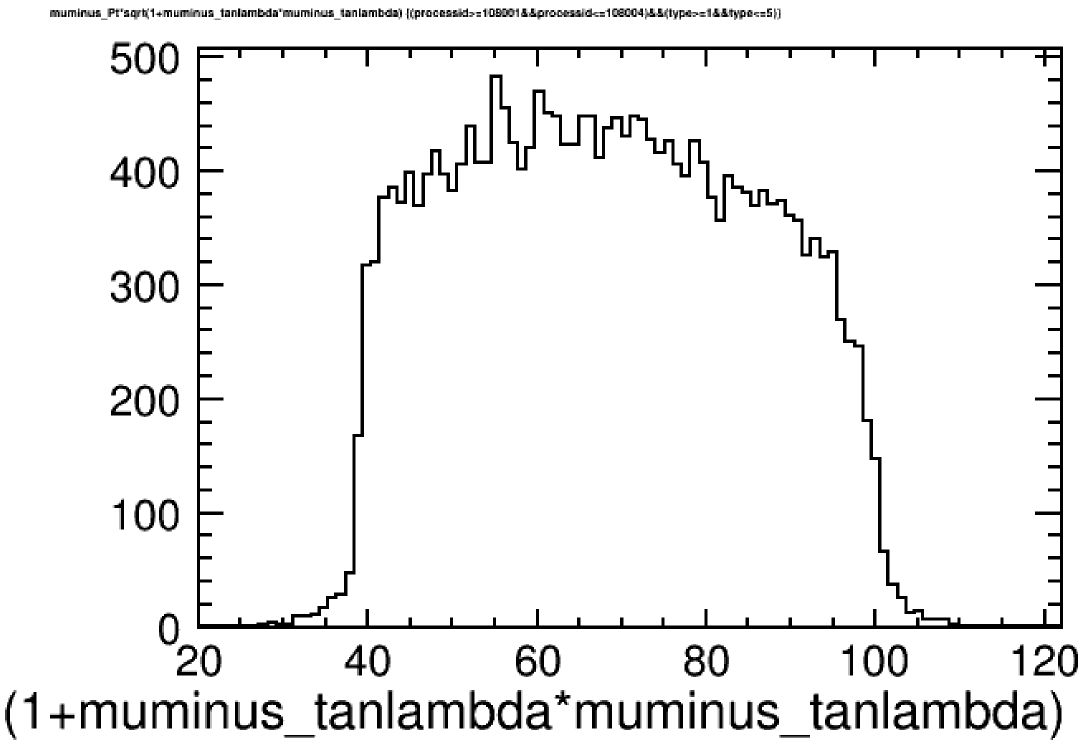


plotted $\log_{10}\left(\sigma_{1/p_T}(\mu^-)\right)$

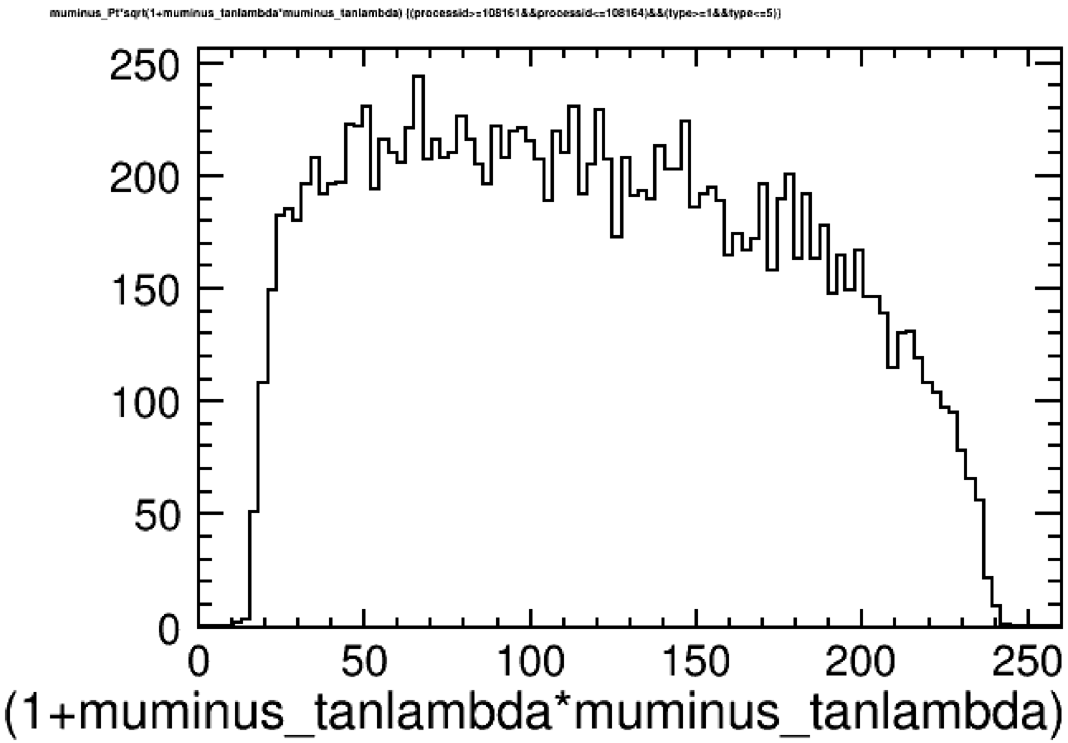
full sim. events, not lumi-weighted, before BDTG cut

Actual Magnitude of Momentum

qqh250-L



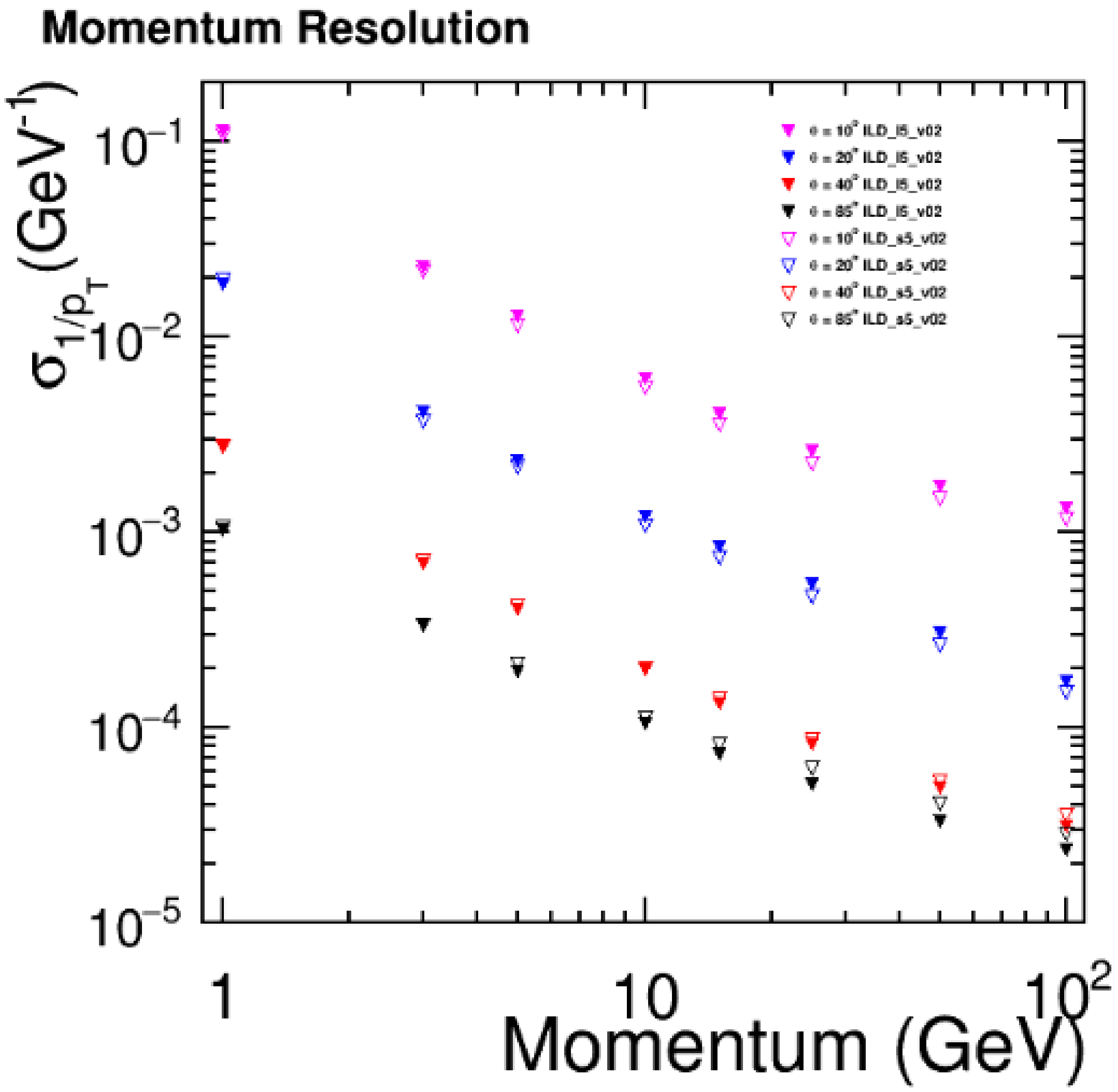
qqh500-L



plotted $p(\mu^-) = P_t\sqrt{1 + \tan^2\lambda}$

full sim. events, not lumi-weighted, before BDTG cut

copy-and-pasted from IDR



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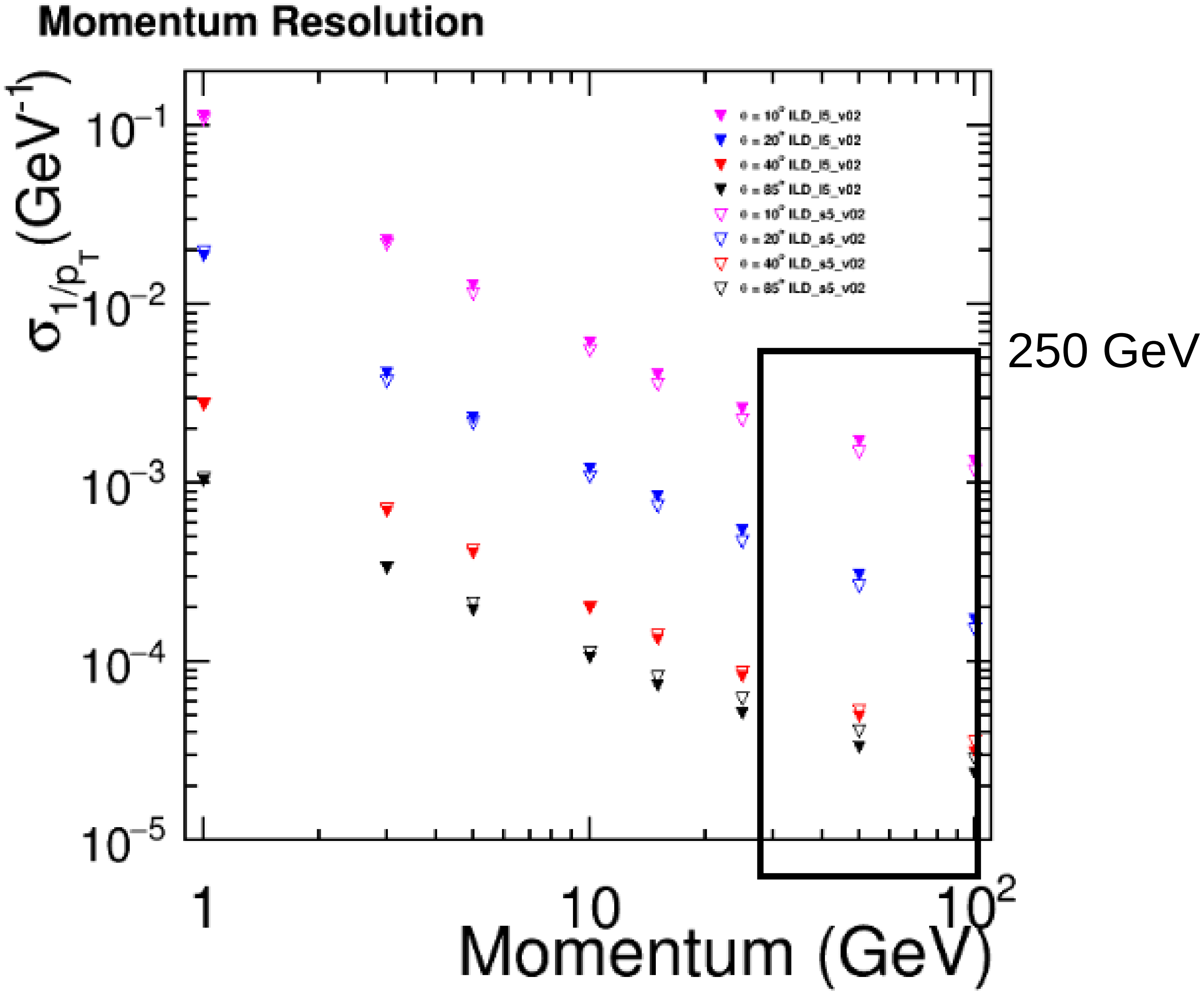

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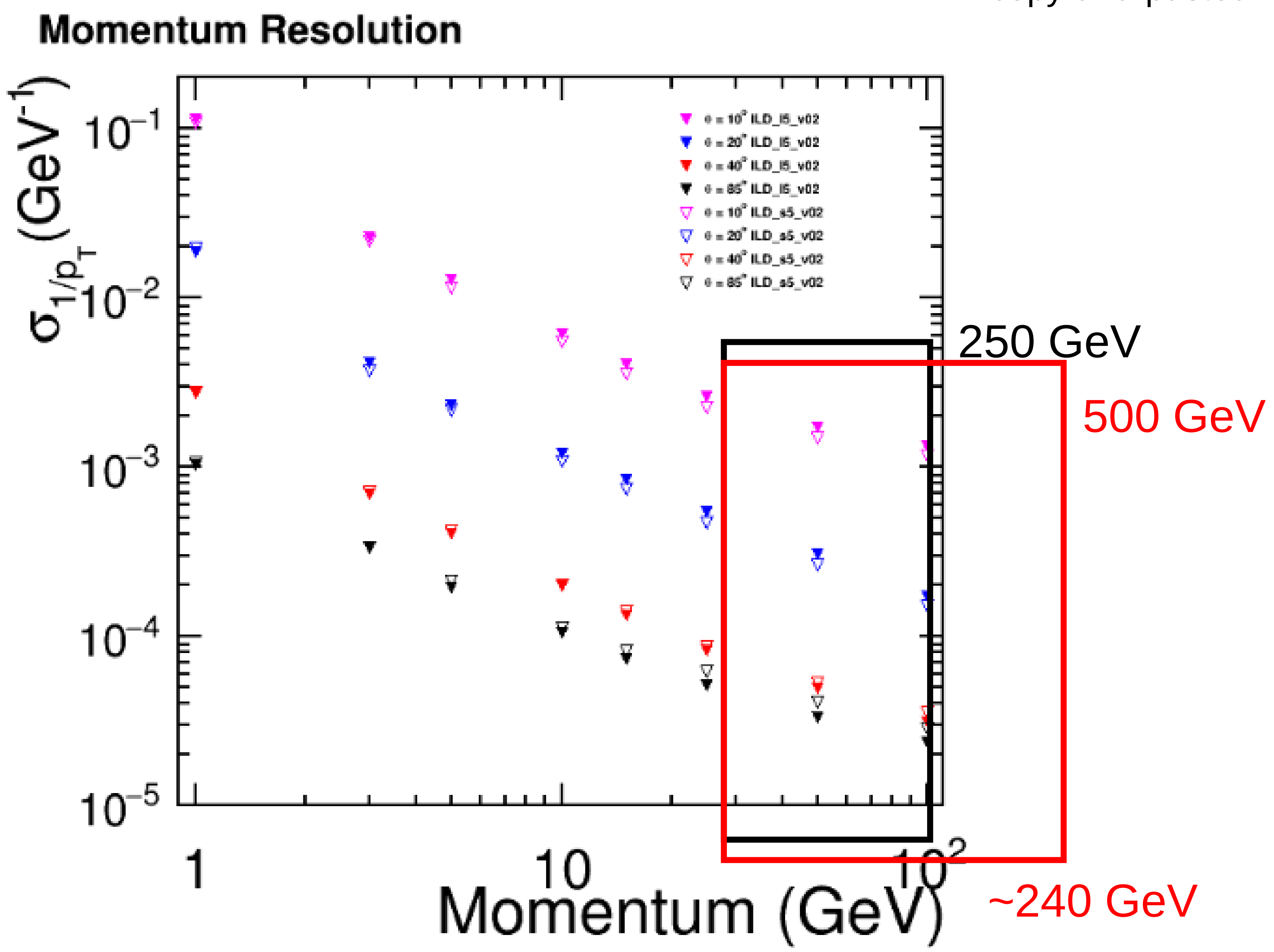

Results and Discussion

- CB + Gaussian signal modeling works until certain point but will not work properly in extremely good resolution cases, because the shape of $M_{\mu^+\mu^-}$ gets like Breit-Wigner function (+ FSR tail).
- It is important archive ILD goal for transverse momentum resolution for this analysis.
- Developing ultimate precision detector system and more proper modeling function will not improve the results anymore. It will reach to the limit (dotted-lines).
- Possible limiting factor for this analysis is listed up (next page).

Limiting Factor For This Analysis

Limiting Factor	Reason	How To Improve
small # signal events	- physics - analysis	- more luminosity and more money - keep high signal efficiency
remaining background $q\bar{q}\mu^+\mu^-$ for $q\bar{q}h$ $\nu\bar{\nu}\mu^+\mu^-$ for $\nu\bar{\nu}h$	- physics - analysis	- develop more advanced technique - keep high background rejection rate
momentum resolution σ_{1/p_T}	- detector (hardware) - algorithm (software)	- more developments (only be the problem when σ_{1/p_T} is very bad)
FSR	- physics - analysis	- develop more sophisticated technique (only be the problem when σ_{1/p_T} is very good)

DBD-Paper Full Draft: How It Looks Like

Prospects of measuring Higgs boson decays into muon pairs at the International Linear Collider

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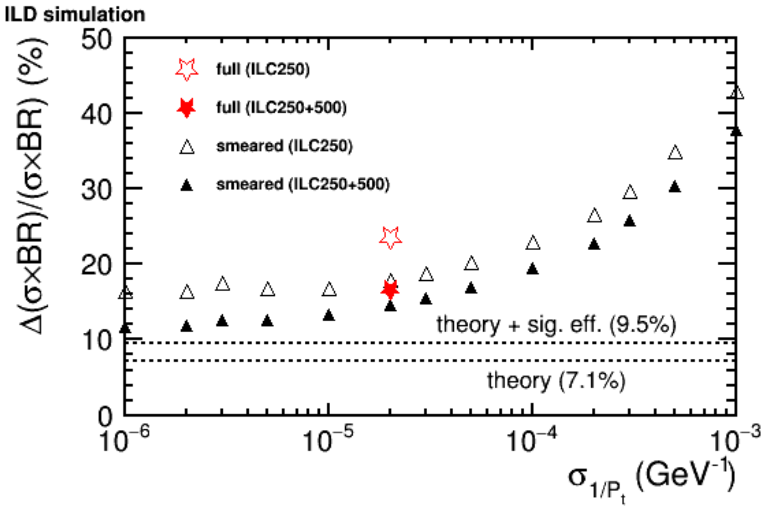
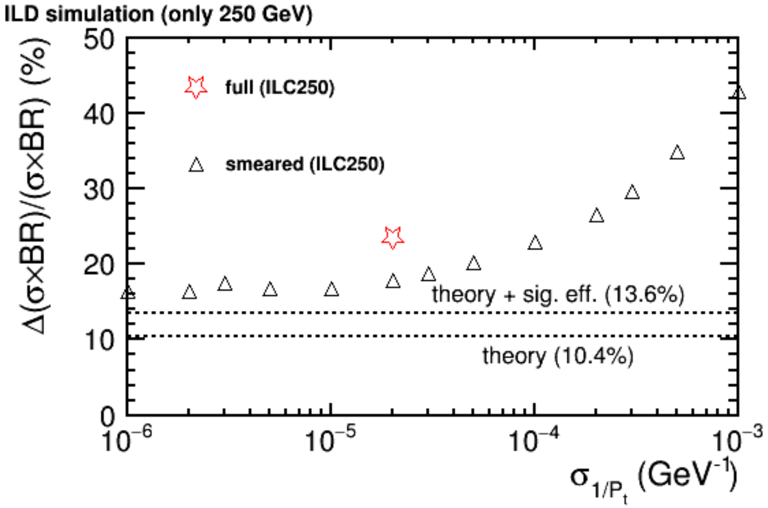
Abstract

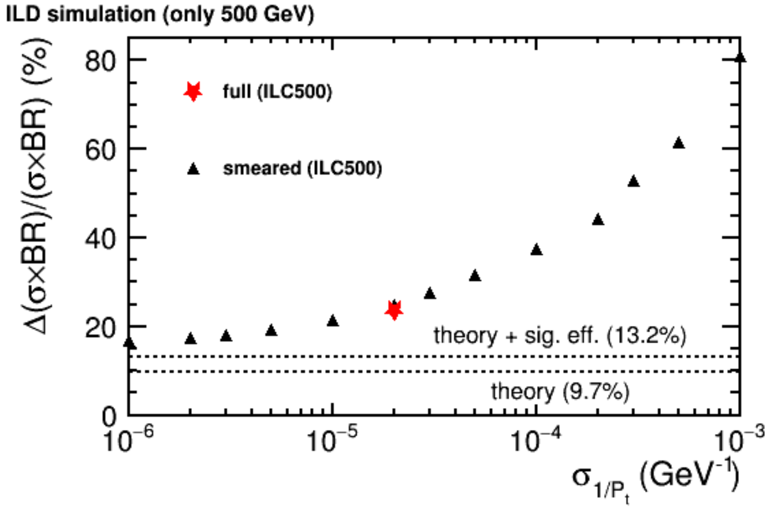
We study the prospects for measuring the branching ratio of $h \to \mu^+\mu^-$ at the International Linear Collider (ILC). The study is performed at center-of-mass energies ($\sqrt{s}$) of 250 GeV and 500 GeV based on a full detector simulation of the International Large Detector (ILD) concept. For both $\sqrt{s}$ cases, the two final states $q\bar{q}h$ and $\nu\bar{\nu}h$ have been analyzed. For an integrated luminosity of 2 ab^{-1} at $\sqrt{s} = 250$ GeV and 4 ab^{-1} at $\sqrt{s} = 500$ GeV, the combined precision on the cross section times branching ratio of $h \to \mu^+\mu^-$ is estimated to be 16.7%. The impact of the transverse momentum resolution for this analysis is also studied. It is very important to achieve the detector requirement of the ILD for the transverse momentum resolution, but an ultimate resolution will not improve the results anymore, and the results will be limited by other factors.

Summary

- DBD-analysis is done.
- DBD-paper is now close to final editing, will circulate to internal reviewers (Ivanka and Filip) in soon.
- I will also give a talk on Sep./3 (ILD group meeting).







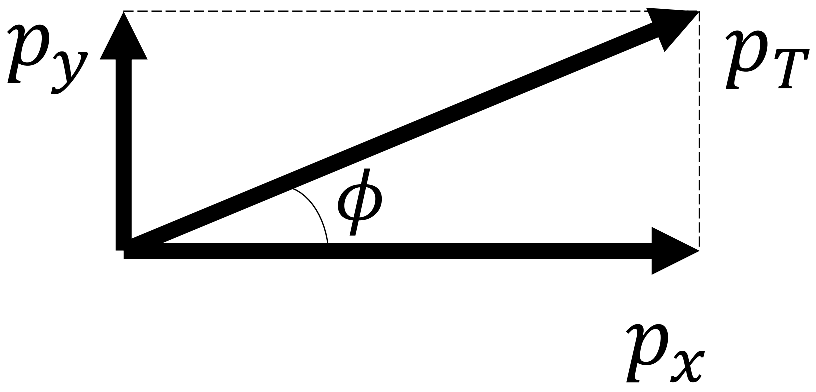
BACKUP

DBD Re-Re-do Analysis

- Re-do Analysis
  - Some unphysical cuts are removed, then do analyze again from scratch.
  - Added missing 6f samples at 500 GeV.
  - Some optimization for BDTG input variables is performed.
- Re-Re-do Analysis
  - THE FINAL PROBLEM: why benchmark dots are significantly worse than full simulation in 500 GeV?
    - I checked transverse momentum resolution of single muon was not the reason; similar between 250 GeV and 500 GeV.
  - THE MASTER FORMULA: $\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$

Before Smearing

(from $h \to \mu\mu$ candidate)
μ MC-truth 4-momentum
(p_x, p_y, p_z, E)



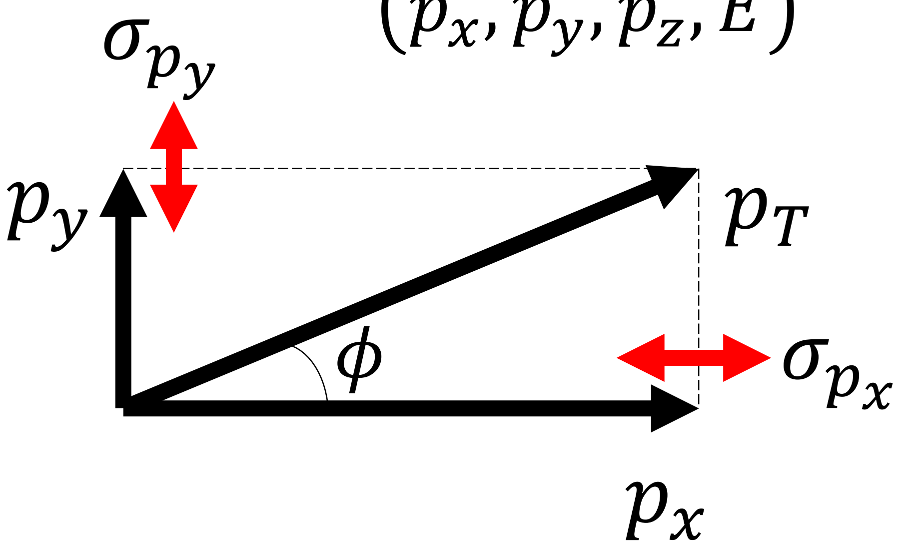
master formula

$$\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$$

σ_{1/p_T} is just a constant

Previous (1)

(from $h \to \mu\mu$ candidate)
μ MC-truth 4-momentum
(p_x, p_y, p_z, E)



master formula

$$\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$$

σ_{1/p_T} is just a constant

I interpreted as:

$$\sigma_{p_x} = \sqrt{\sigma_{p_T}}, \sigma_{p_y} = \sqrt{\sigma_{p_T}}$$

and simulate each with gRandom->Gaus(0, $\sqrt{\sigma_{p_T}}$).

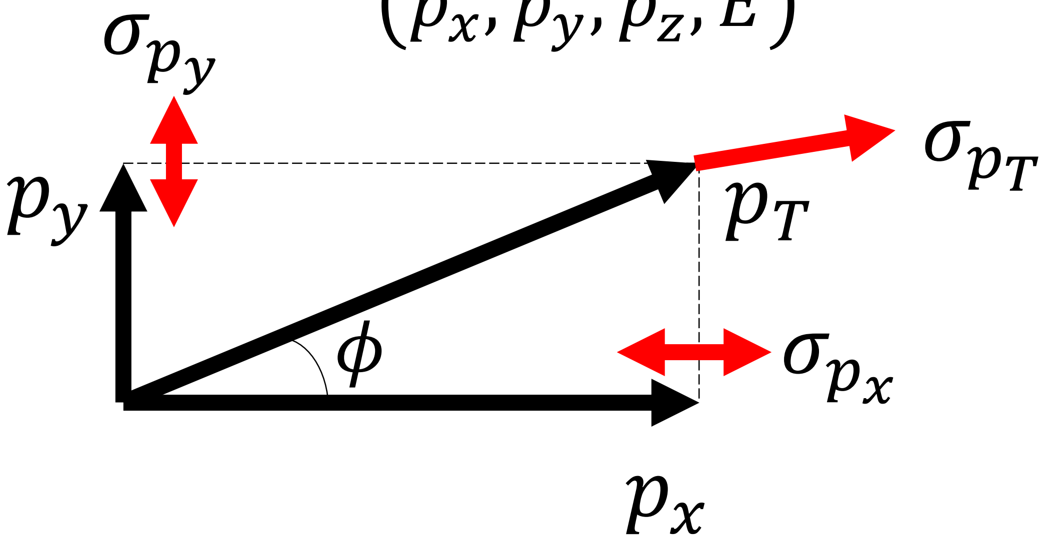
Obtain $\sigma_{p_x}(\mathrm{sim})$ and $\sigma_{p_y}(\mathrm{sim})$.

Smearing vector is:

$$\left(\sigma_{p_x}(\mathrm{sim}), \sigma_{p_y}(\mathrm{sim}), 0, 0\right)$$

Previous (2)

(from $h \to \mu\mu$ candidate)
μ MC-truth 4-momentum
(p_x, p_y, p_z, E)



master formula

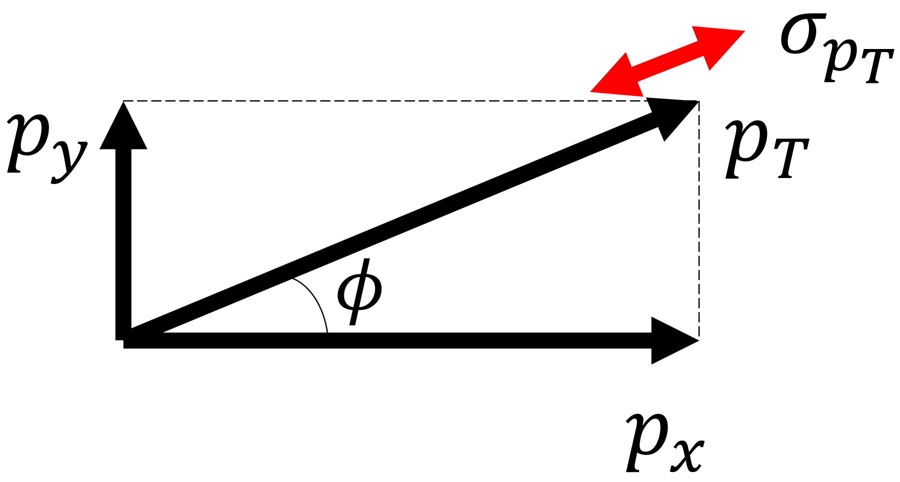
$$\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$$

σ_{1/p_T} is just a constant

However:
(1) σ_{p_T}-vector will not parallel to p_T-vector
(2) simulating not correct variable
-> can overestimate $\sigma_{p_T}(\mathrm{sim})$ up to factor $\sqrt{2}$
-> more terrible in 500 GeV because higher p_T

Now (1)

(from $h \to \mu\mu$ candidate)
μ MC-truth 4-momentum
(p_x, p_y, p_z, E)



master formula

$$\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$$

σ_{1/p_T} is just a constant

simulate σ_{p_T} directly with gRandom->Gaus(0, σ_{p_T}), obtain $\sigma_{p_T}(\mathrm{sim})$.

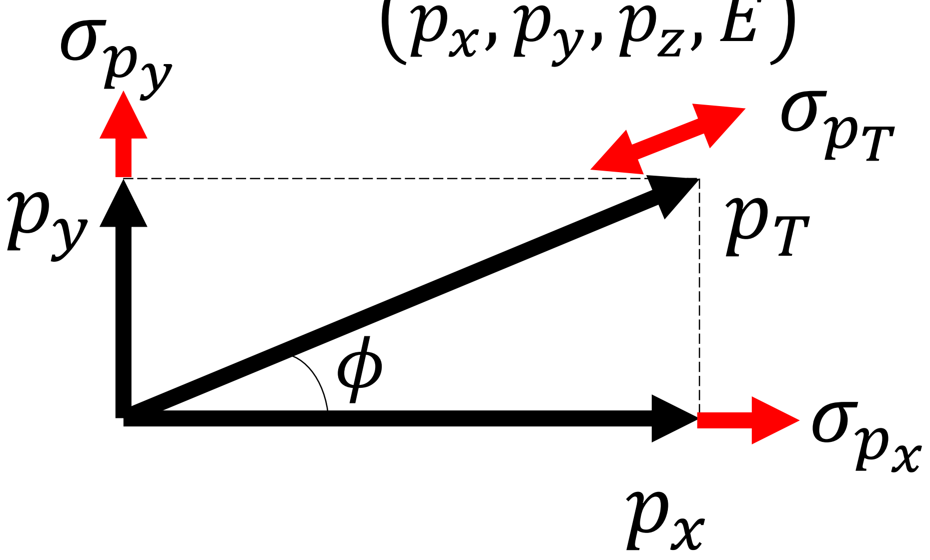
Then the smearing vector is:

$$\sigma_{p_x}(\mathrm{sim}) = \sigma_{p_T}(\mathrm{sim}) \times \cos\phi$$

$$\sigma_{p_y}(\mathrm{sim}) = \sigma_{p_T}(\mathrm{sim}) \times \sin\phi$$

Now (2)

(from $h \to \mu\mu$ candidate)
μ MC-truth 4-momentum
(p_x, p_y, p_z, E)



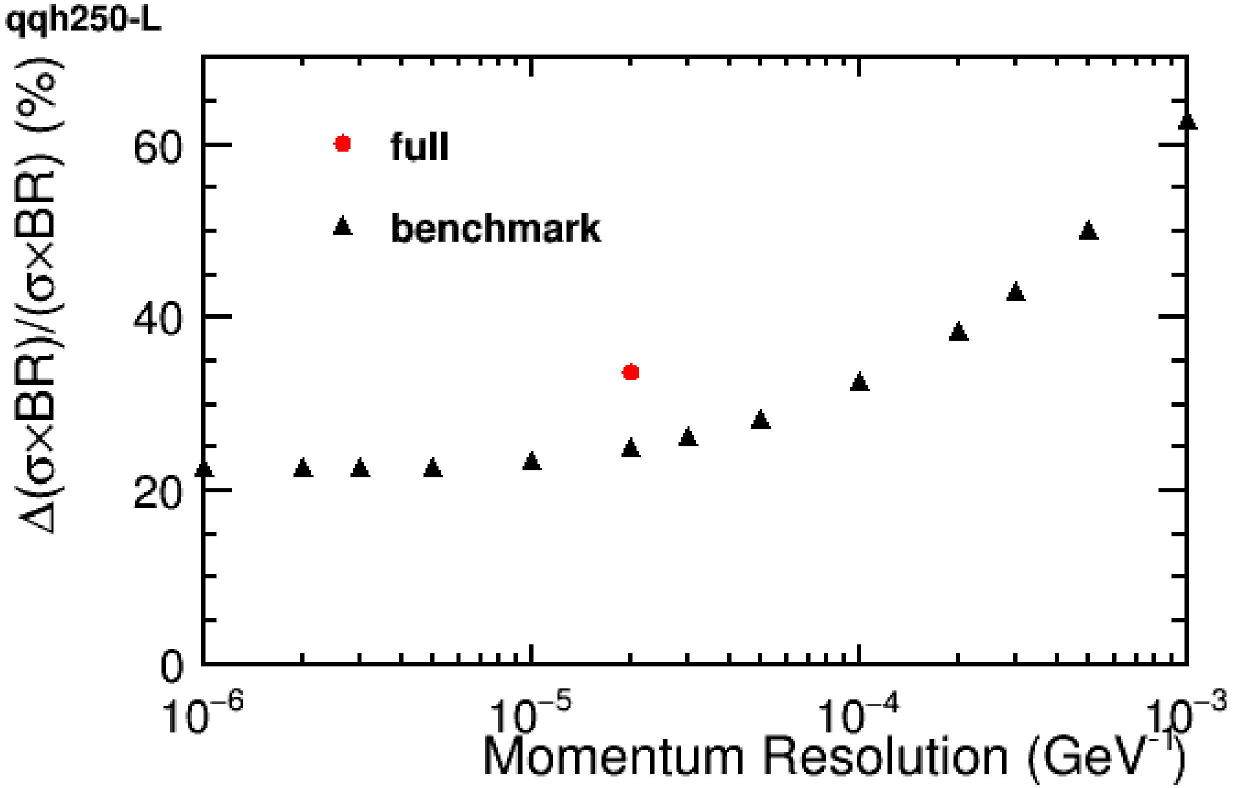
master formula

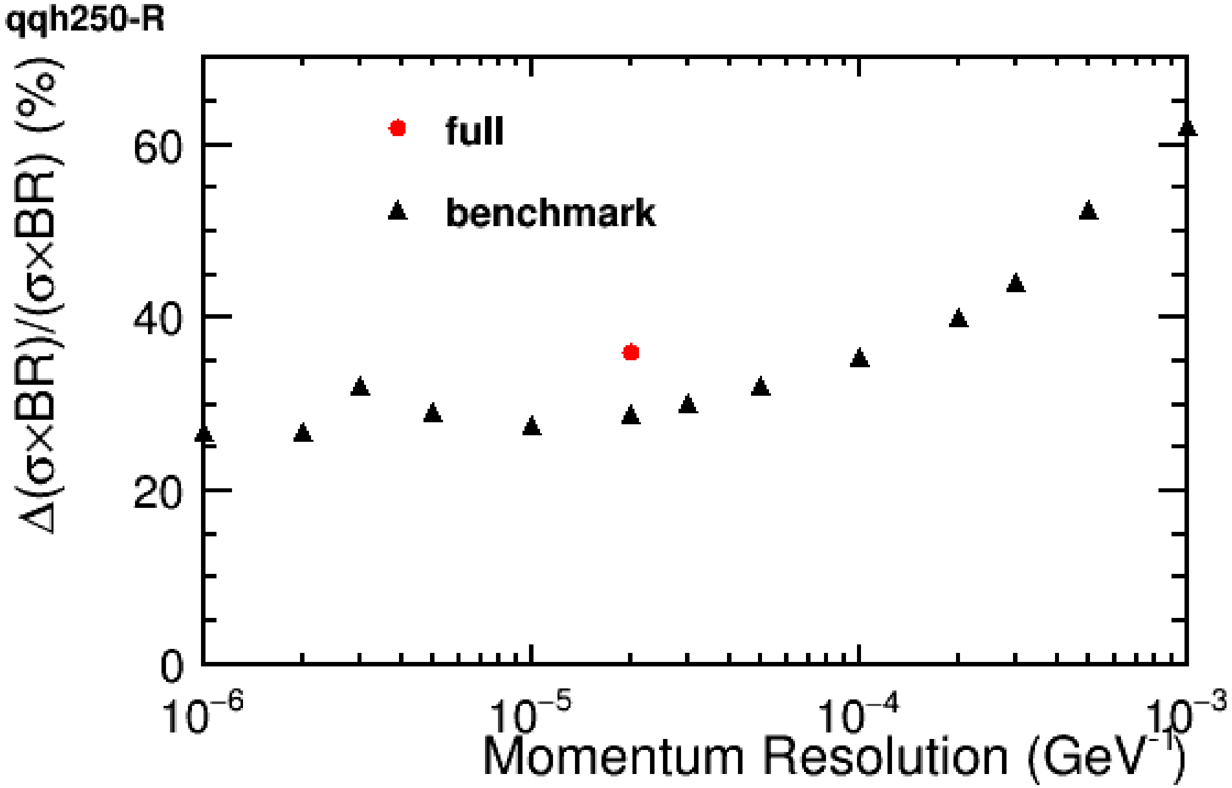
$$\sigma_{p_T} = \sigma_{1/p_T} \times p_T^2$$

σ_{1/p_T} is just a constant

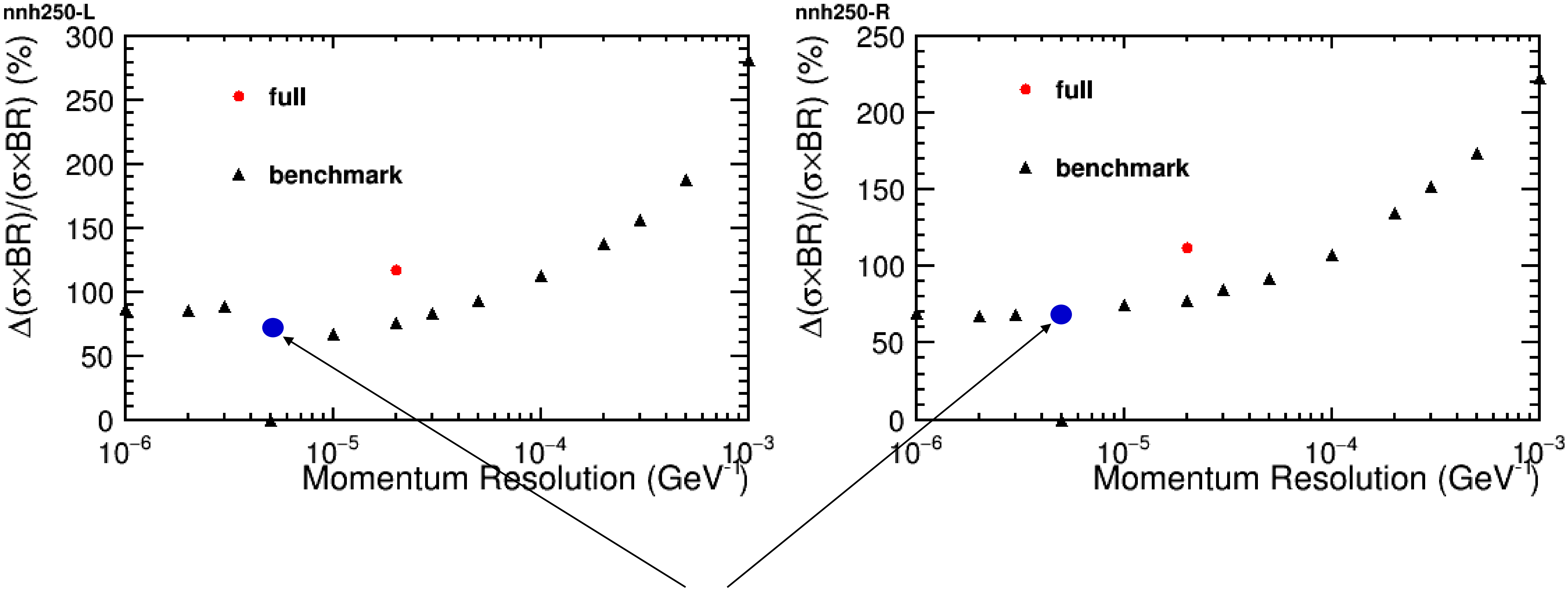
(1) keep parallel $p_T \parallel \sigma_{p_T}$
(2) no overestimating anymore

Individual Channel Plot (qqh250-L/R)



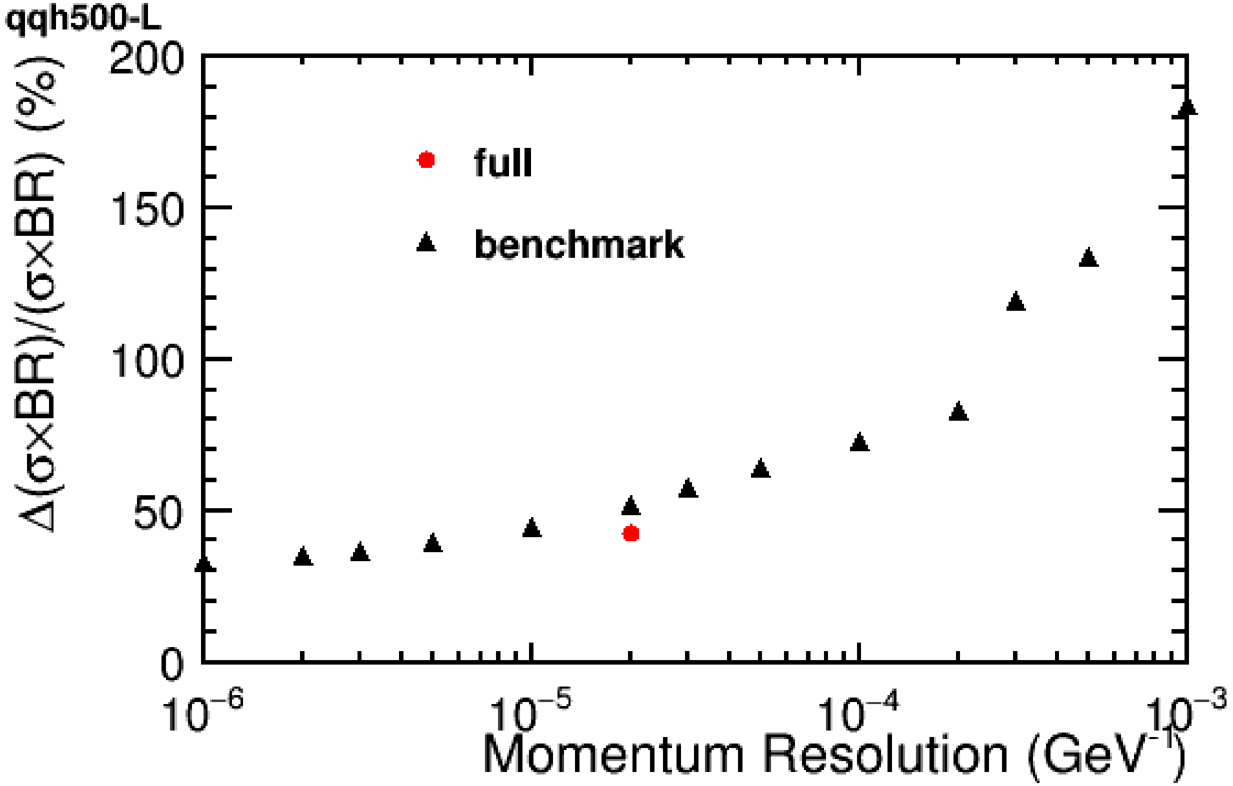


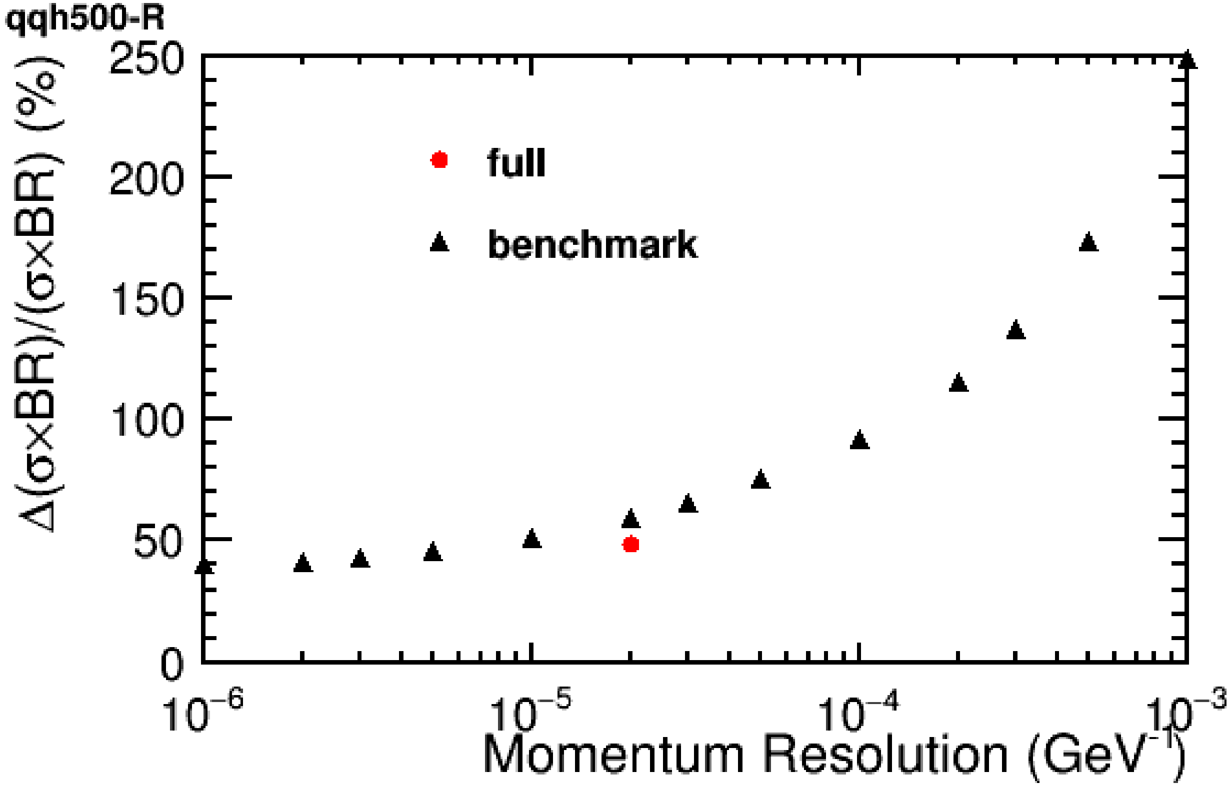
Individual Channel Plot (nnh250-L/R)



interpreted points because fitting failed completely

Individual Channel Plot (qqh500-L/R)





Individual Channel Plot (nnh500-L/R)