Updates on $h \to \mu^+\mu^-$ Analysis

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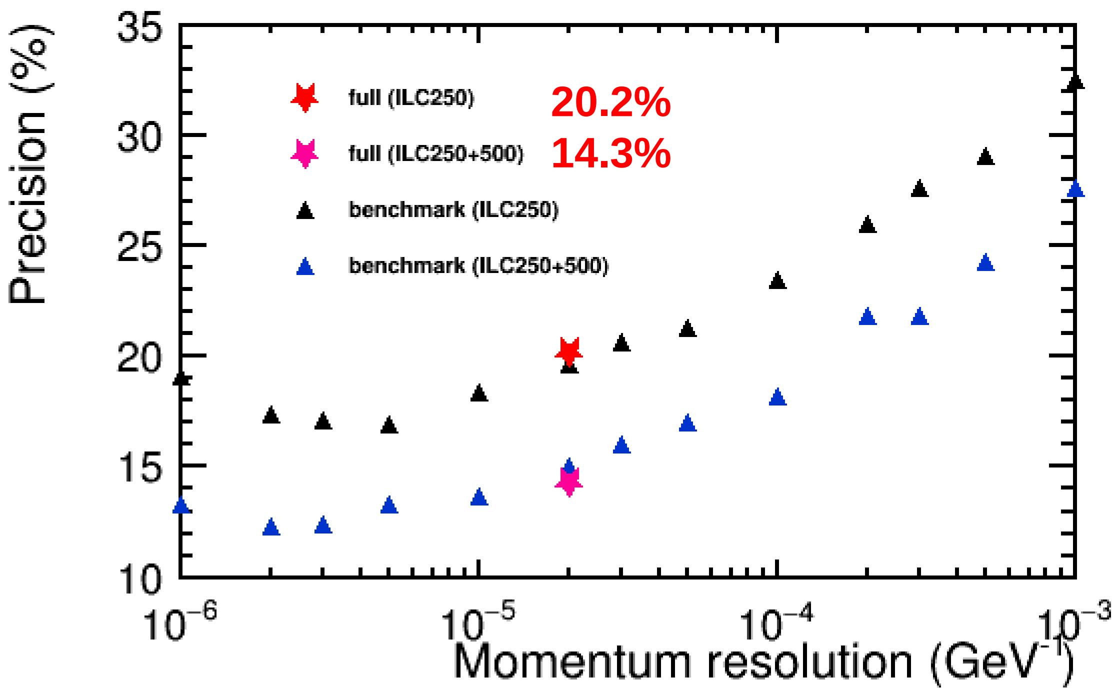
ILD Analysis/Software Meeting

Introduction

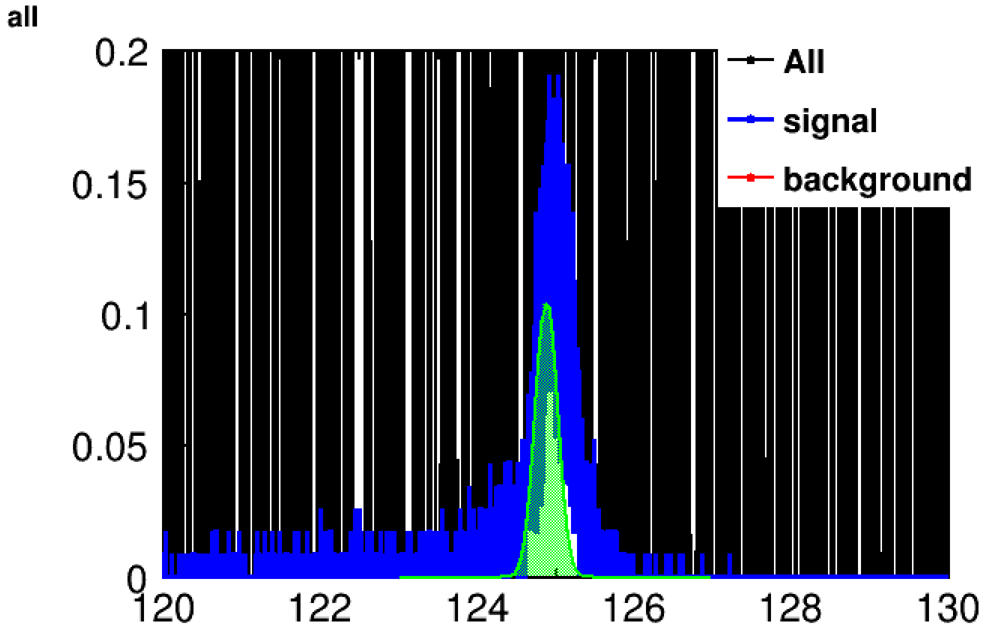
- Study of $h \to \mu^+\mu^-$ channel at the ILC
- Still playing around with DBD-world, did not touch new samples yet.
- But, this study will be finalized as a full paper in soon.

Impact of Momentum Resolution

- Shown in ALCW2018
  - used simple normalized Gaussian for signal modeling
  - sometimes zig-zag shape



Using Normalized Gaussian (nG)



please ignore black bars
blue: signal events
green: nG fit
2 MeV / bin

Definitely not good fit
- simple Gaussian cannot cover tail due to FSR
- peak is significantly underestimated
- fixed mean (125) is shifted by some magic

nG was not proper signal modeling function

need more suitable function for modeling the signal distribution

Signal Modeling

- Crystal Ball function (CB) would be a nice function
  - Traditionally used to describe the effect of radiative energy loss in an invariant mass
- ... and + Gaussian
  - for representing detector effect
- Use RooFit as a tool, and use CB + Gaussian for signal modeling
  - k*CB + (1-k)*Gaussian ($0 < k < 1$). I will write this as **CBG.**
  - CBG is also used in ATLAS study [ATLAS-PHYS-PUB-2018-006]

Study All Channels

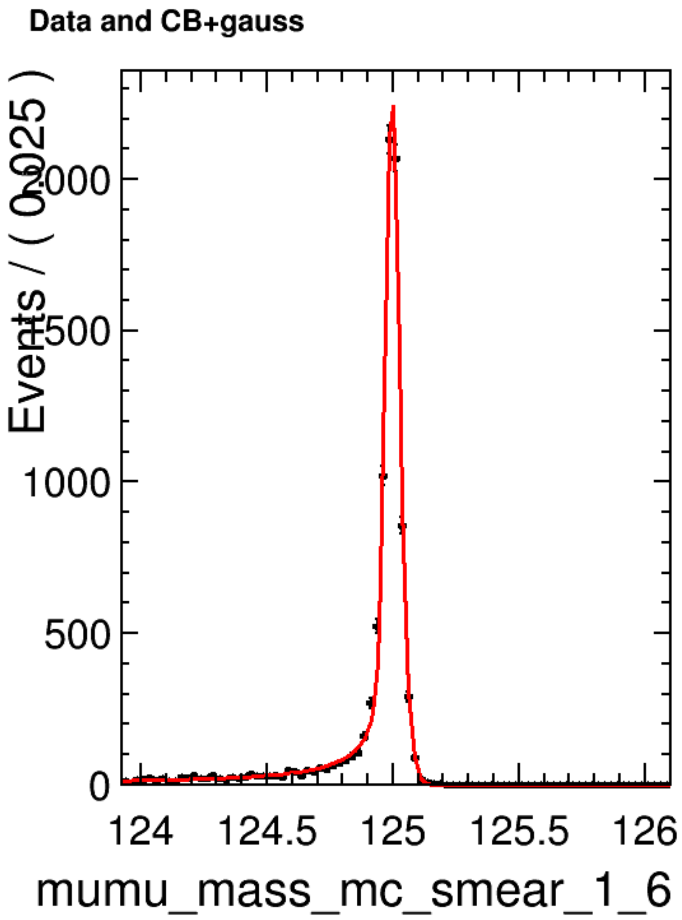
- Use **CBG** for signal modeling
- Use 1st order polynomial **[pol1]** for background modeling
- Have studied all cases: 250 GeV & 500 GeV, two beam polarizations, $q\bar{q}h$ & $\nu\bar{\nu}h$, full simulation & smeared momentum resolution cases, in total 8*14 = 112 cases
  - Signals are always smeared. Background is not smeared, which means I only used the fitting results in full simulation (template sample).
  - Because background distribution is expected to be almost flat. (flat) + (smearing) $\simeq$ (flat)

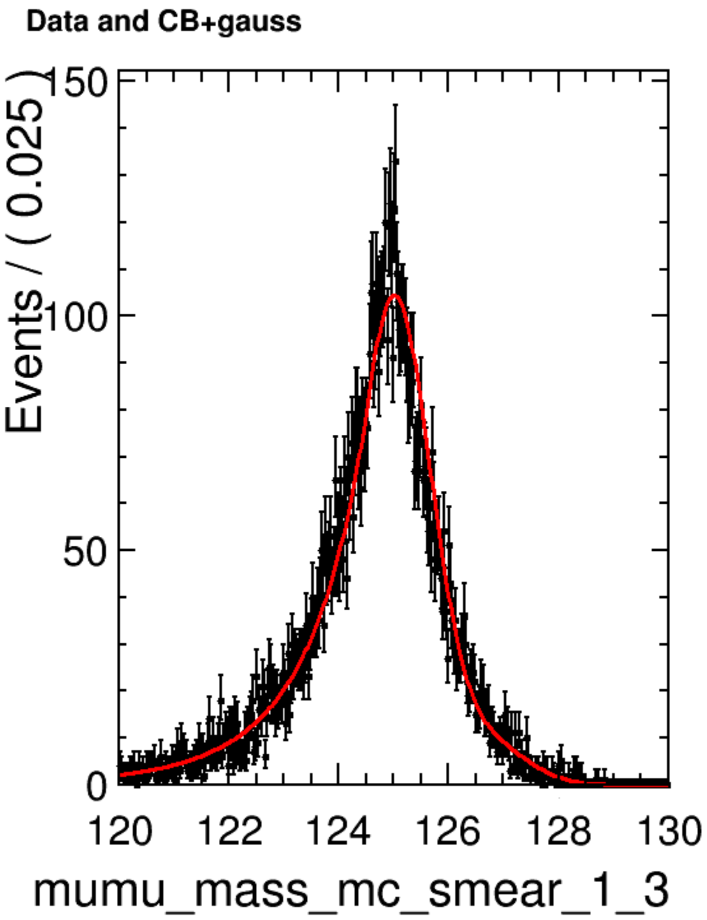
Detailed Procedure

- Binning: 25 MeV/bin at 250 GeV, and 50 MeV/bin at 500 GeV
- Fitting range: 120-130 GeV
- All fittings for modeling are using unweighted events
- Remove too bad fitting results

- Do 50000 toy MC to extract final precision
  - Use unbinned fit and f: $f \equiv Y_S f_S + Y_B f_B$, only Y_S is a free parameter

Example: qqh250-L (25 MeV/bin)

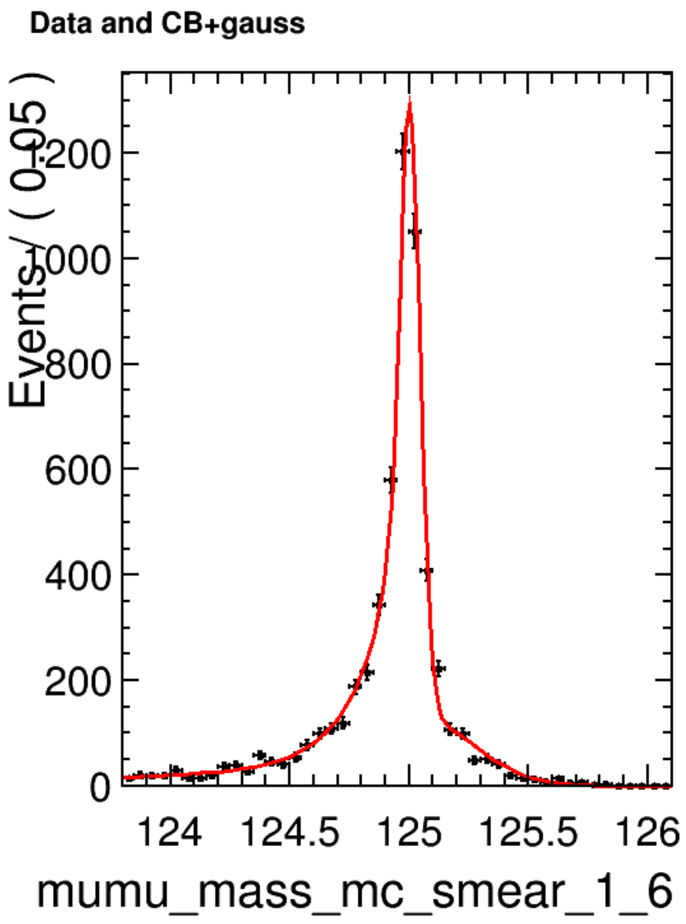




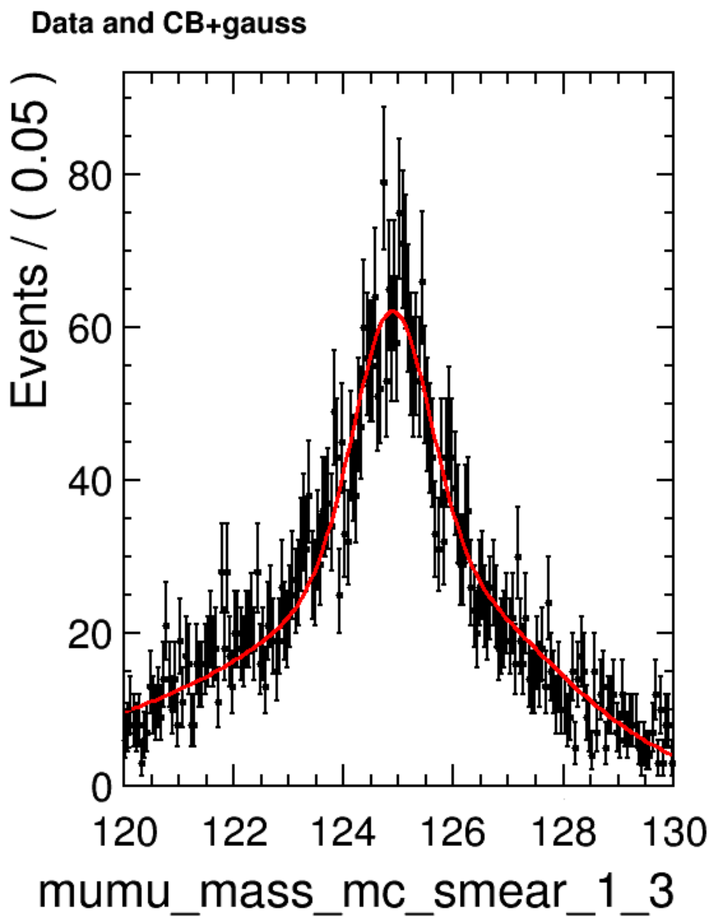
$1*10^{-6}$, zoom-up peak region
chi2/ndf = 1.11

$1*10^{-3}$, chi2/ndf = 0.90
MINOS says “PROBLEMS”,
but shape itself looks good

Example: nnh500-L (50 MeV/bin)

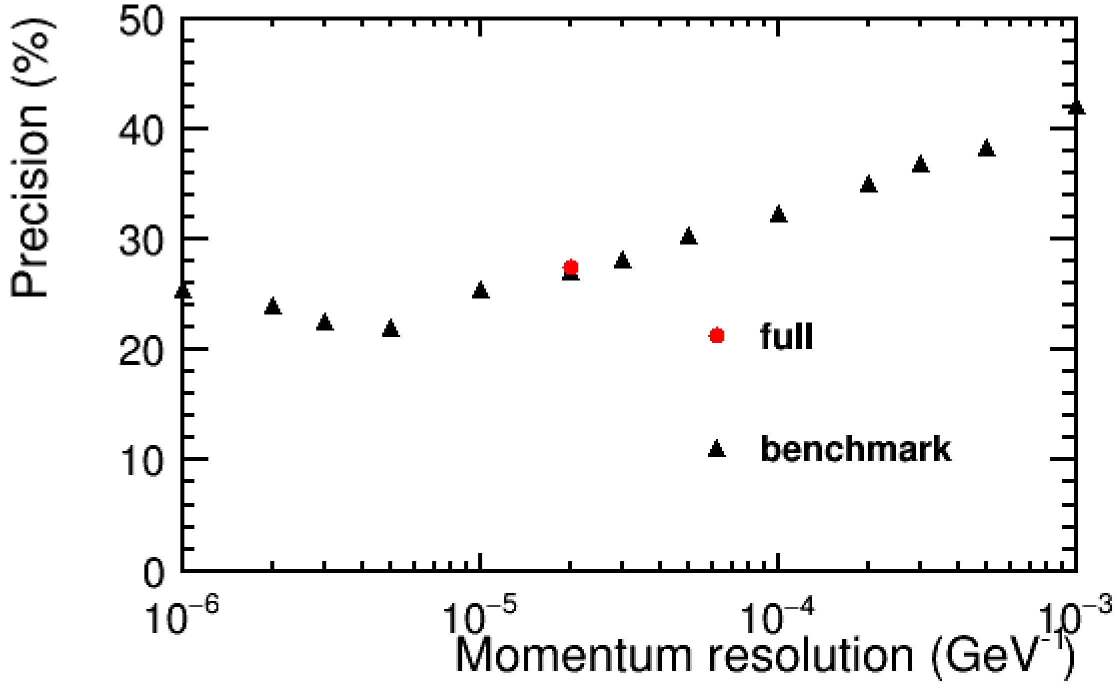


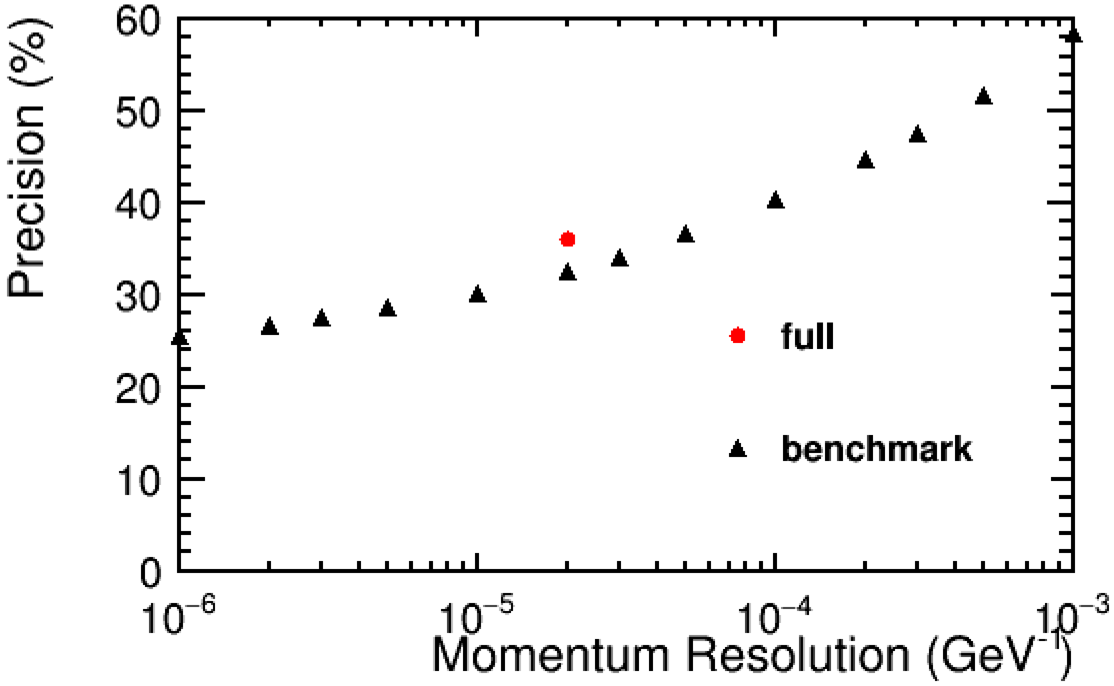
1*10^{-6}, zoom-up peak region
chi2/ndf = 1.42



1*10^{-3}, chi2/ndf = 0.88
MINOS says “PROBLEMS”,
but shape itself looks good

Results: qqh250-L

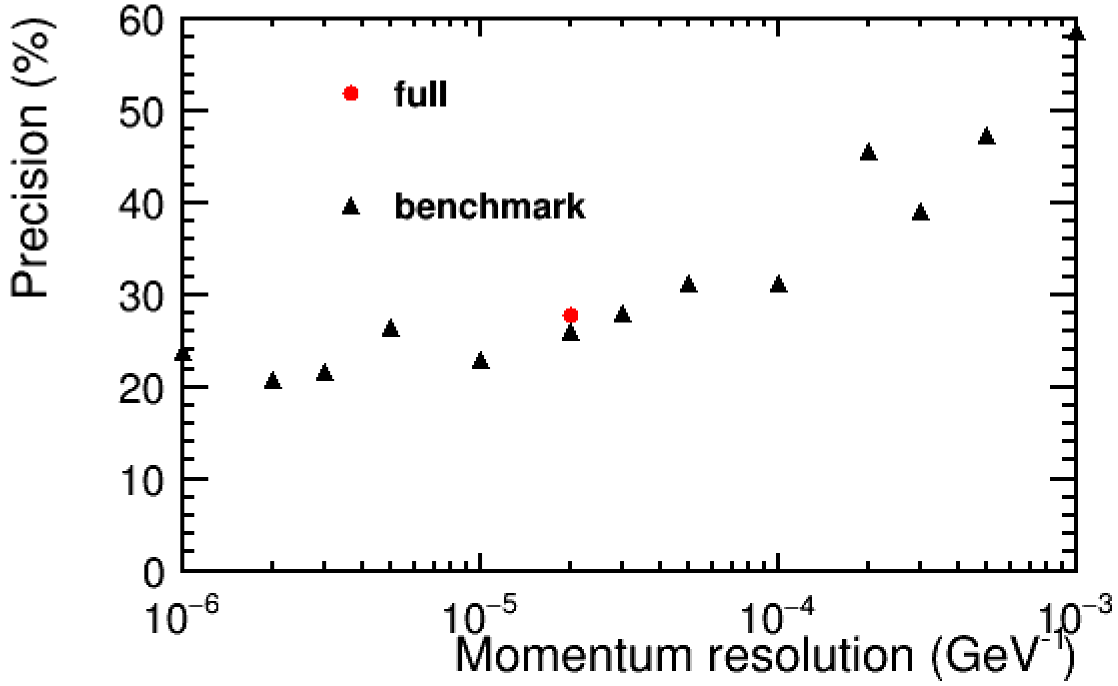


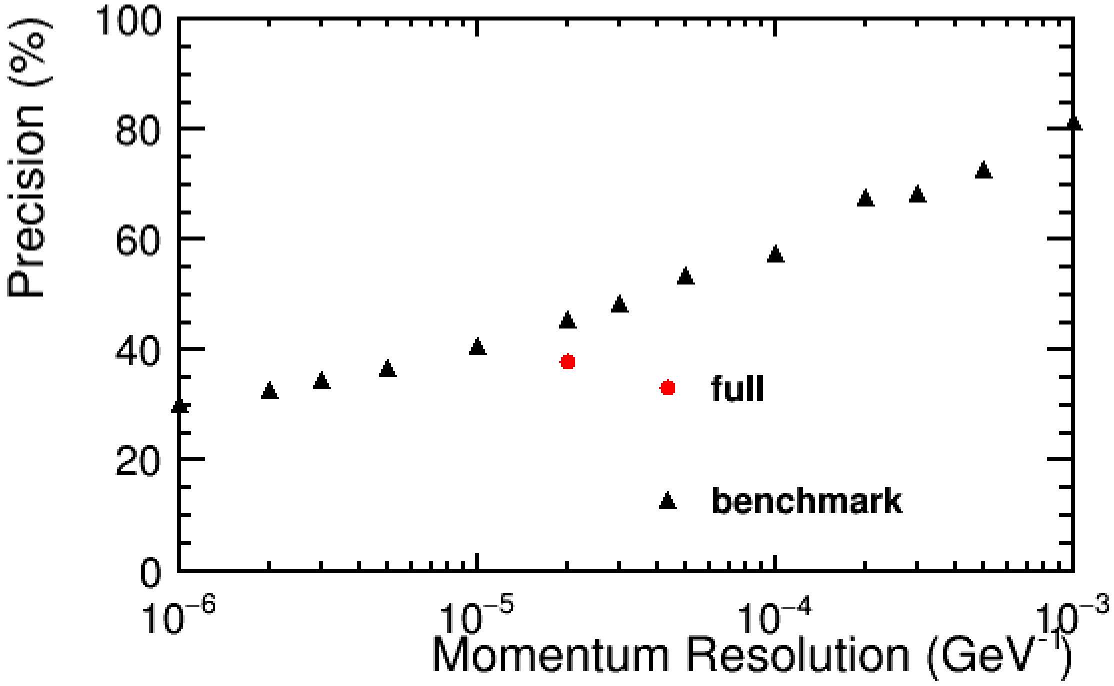


ALCW
full: 27.6%

CBG
full: 36.15%

Results: nnh500-L

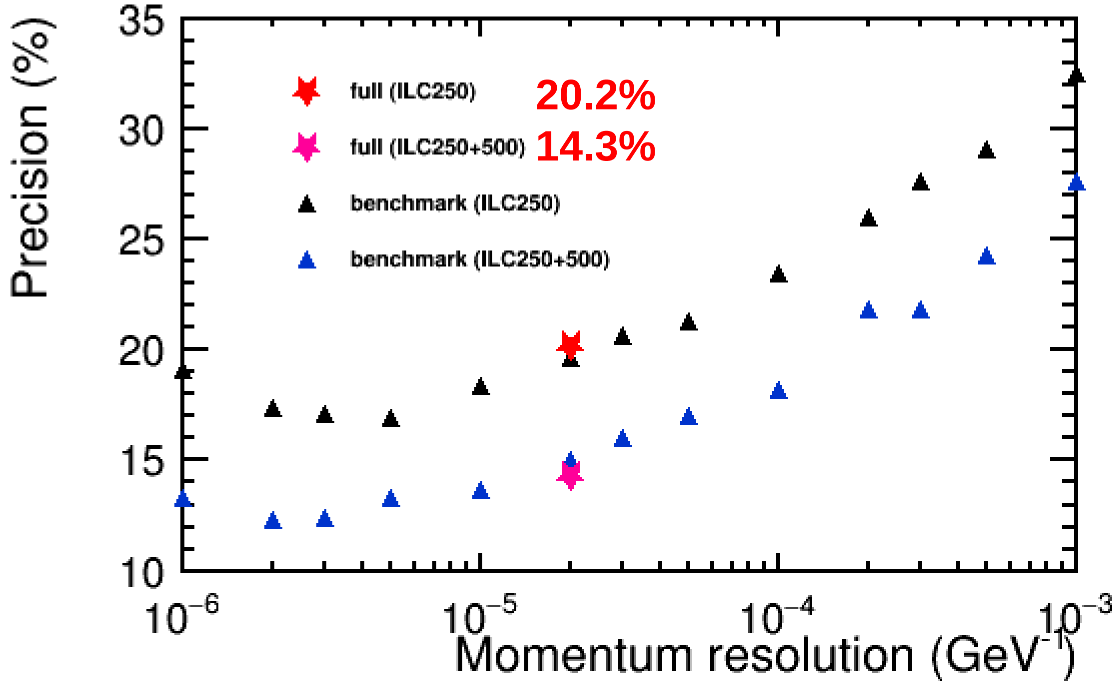


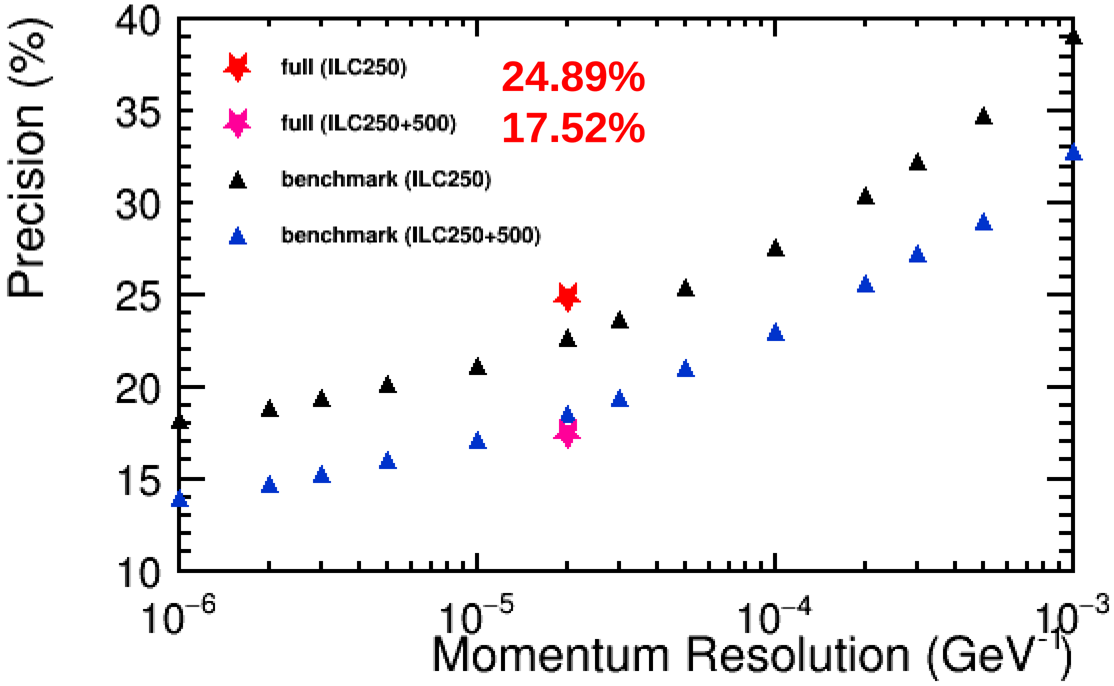


ALCW
full: 27.8%

CBG
full: 37.88%

Combined Results





ILC250:
~17-20% precision
ILC250+500:
~12-15% precision

ILC250:
~18-22% precision
ILC250+500:
~14-18% precision

Discussion (1)

- I think previous numbers were too good. And previous results in better resolution cases always had some problems in the fitting. At least CBG results are much more reliable.
- No bad results in better resolution cases!
- Zig-zag shape is gone!
- Basically 10-30% relative worse than previous for each channel, and ~20% relative worse for combined results in full simulation.

Discussion (2)

- Full250 is worse than $2*10^{-5}$ benchmark but Full250+500 is better than $2*10^{-5}$ benchmark.
  - One reason I think this is the effect of magnitude of momentum.
  - Main production process at 250 GeV is Zh. Higgs boson has an energy of ~125 GeV, the produced muons have ~60 GeV.
  - However at 500 GeV, main production process is $\nu\bar{\nu}h$. Higgs boson has an energy greater than 125 GeV and up to 500 GeV due to WW-fusion. Then energy of produced muons will be ~60-250 GeV, thus the average is more than 100 GeV.
  - For higher momentum charged particles, momentum resolution is better. In 500 GeV, the actual momentum resolution is better than $2*10^{-5}$.
  - Also angle dependencies are there. This is a kind of mixed results. Still need to discuss for better understanding.

Discussion (3)

- Even we can develop ultimate precision detector system, it is not so beneficial anymore, especially 10^{-5} or better resolution cases.
  - Only ~10% relative improvement
  - Similar tendency is also found at CLIC study (next page)

Another Study: 1.4 TeV CLIC $h \rightarrow \mu^+\mu^-$

Eur. Phys. J. C (2015) 75:515

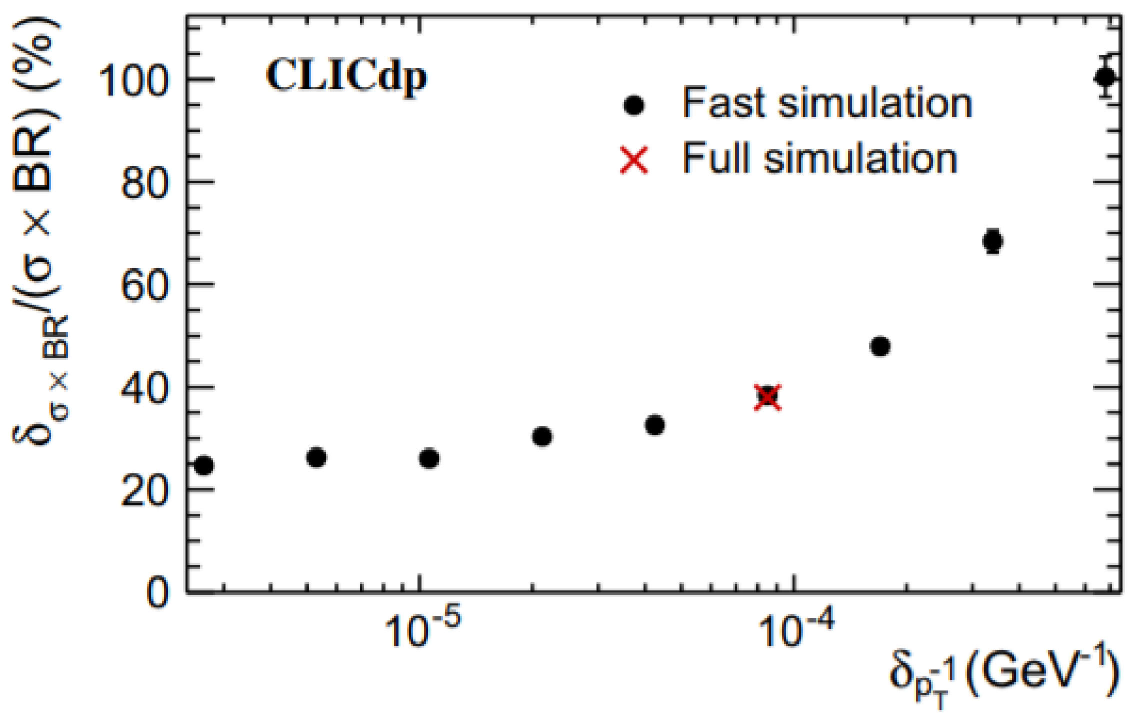


Fig. 11 Dependence of the relative statistical uncertainty of the $\sigma(H\nu\bar{\nu}) \times BR(H \rightarrow \mu^+\mu^-)$ on the transverse momentum resolution, δ_{1/p_T}, averaged over the signal sample in the whole detector

From paper:
To estimate the benefit of a better p_T resolution, the analysis was repeated by substituting the muon four-momenta reconstructed in the full simulation of the signal by the four-momenta obtained by a parametrisation of the momentum resolution for several different values of the detector resolution.

Full: 38%

- ➢ Similar tendency with us
- ➢ Performance will saturate around $1*10^{-5}$ (~25%)

Discussion (4)

- Full vs Theoretical limit (100% signal eff., no background)
  - ILC250: 24.89% vs 10.4%
  - ILC250+500: 17.52% vs 7.1%
- Factor ~2.5 far away from theoretical limit
  - Major contribution: **irreducible background**
    - (# irreducible background after all cuts) = (# signal after all cuts)***(~10-50)**
    - most of remaining backgrounds are irreducible **(~80-100%)**
  - ~5% signal loss during isolated muon selection
  - ~20-30% signal loss after precuts
  - ~30-70% signal loss after all cuts

Summary & Future

- CBG fitting works so well
- ILC250: 24.89%, ILC250+500: 17.52%
- Beautiful benchmark curve
- Time to summarize into full paper!

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

Shin-ichi Kawada, Jenny List, Mikael Berggren

Abstract

We study the prospects of measurement of the branching ratio of $h \to \mu^+\mu^-$ at the International Linear Collider. The study is performed at the center-of-mass energies of 250 GeV and 500 GeV, using fully-simulated MC samples assuming International Large Detector model. For both center-of-mass energies, 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 250 GeV and 4 ab^{-1} at 500 GeV, corresponding to its staging running scenario, the combined precision on $\sigma \times \mathrm{BR}(h \to \mu^+\mu^-)$ is estimated to be 16.6%, which is similar precision can be achieved at the prospects of High Luminosity Large Hadron Collider. We also study the impact of momentum resolution to this analysis.

BACKUP

Detailed Procedure (Modeling)

- Binning: 25 MeV/bin at 250 GeV, and 50 MeV/bin at 500 GeV
- Fitting range: 120-130 GeV
- All fittings are using unweighted events

1. Apply BDTGoutput cut
2. Do fitting using CBG or pol1 with MINOS option
   - If MINOS says “SUCCESSFUL”, then accept it and go further toy MC (only 1 exceptional case, too high chi2/ndf).
   - If MINOS says “FAILURE” or “PROBLEMS” in pol1 fit, then throw away and forget it.
   - If MINOS says “PROBLEMS” in CBG fit, then check chi2/ndf. If chi2/ndf is in the range of 0.5-1.5, then accept it and go further toy MC. If not in the range, throw away it.
3. Change BDTGoutput cut and repeat 2.
4. Repeat 1., 2., and 3. for all analyze case.

Integration Check

- To be honest, it is difficult to check it. Since CBG and pol1 are the P.D.F., and its normalization is automatically considered by RooFit. This means the integral of CBG/pol1 is always 1, by definition.
- I tried to get normalization factor which should be corresponding to # MC events used for fitting, but couldn’t find it.
- This time, I only confirmed the good chi2/ndf value.

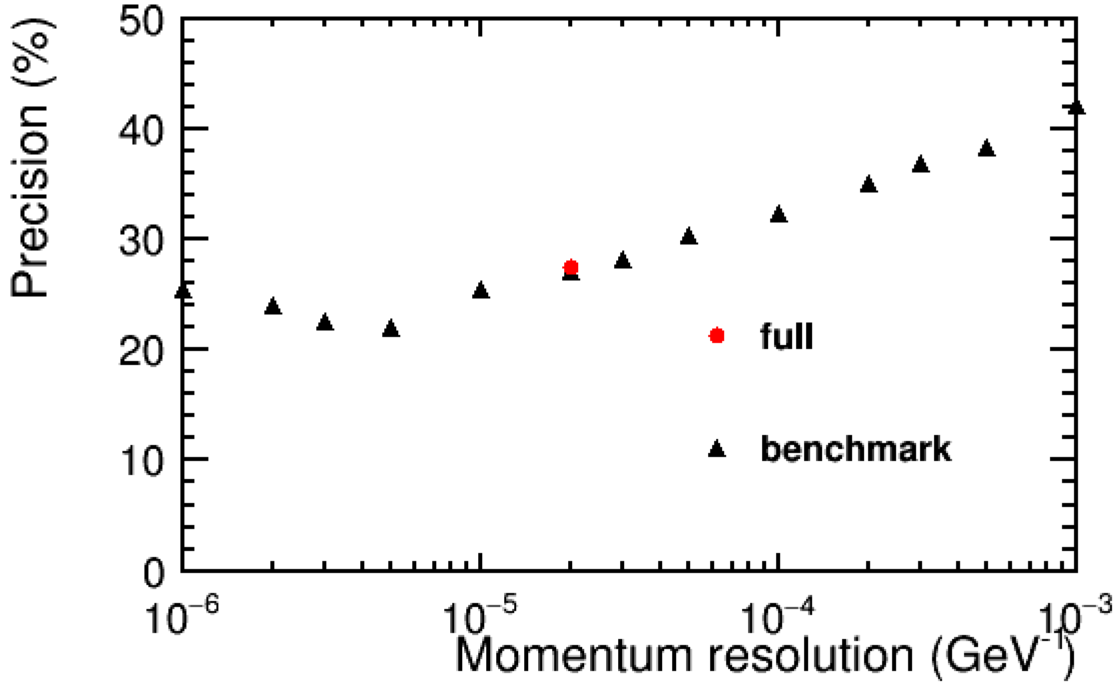
Detailed Procedure (Toy MC)

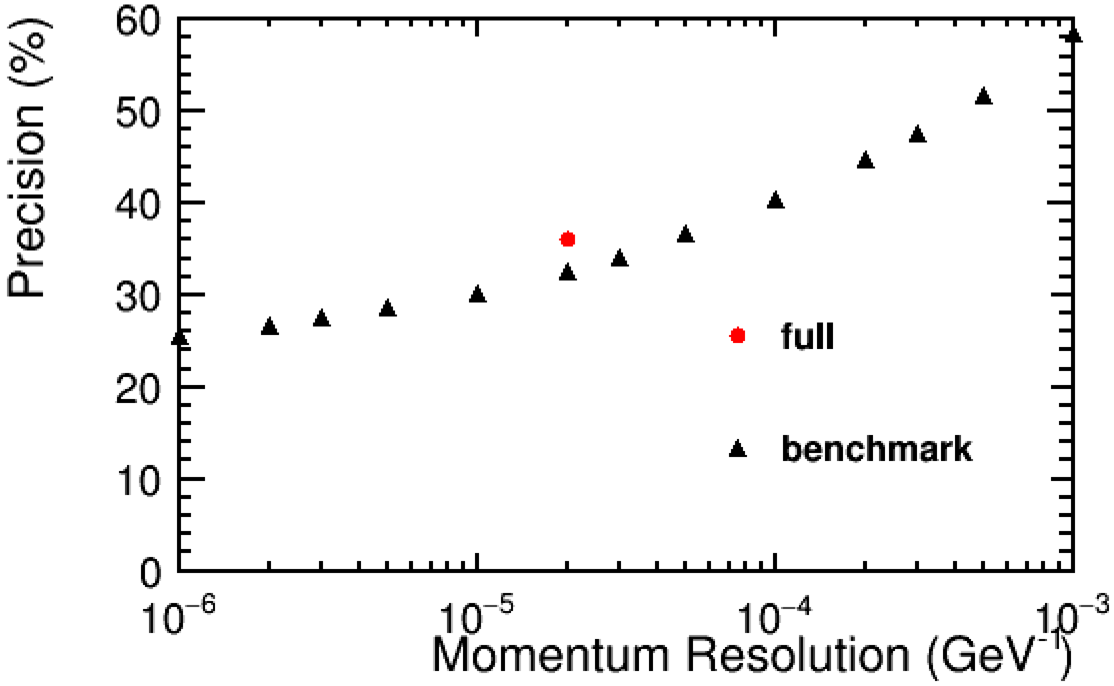
1. Generate pseudo-signal data based on parametrized CBG. Number of generated events are determined by the template sample with Poisson fluctuation.
   - parametrized = all parameters in a function are fixed as the numbers I obtained in p3 modeling
2. Same for pseudo-background, except based on parametrized pol1 using the result of template sample.
3. Sum up above 2 pseudo-data, and do unbinned fitting using f: $f \equiv Y_S f_S + Y_B f_B$, only Y_S is a free parameter. Obtain Y_S and store it.
   - f_S: parametrized CBG, f_B: parametrized pol1, Y_B: fixed as the number of background events in template sample, f is of course P.D.F.
4. Repeat 1., 2., and 3. for 50000 times.
5. Calculate final precision by Gaussian fitting in final Y_S distribution.
   - Precision = (width of Gaussian fitting) / (mean of Gaussian fitting)

Observation In This Experiment

- In “SUCCESSFUL” cases of CBG fitting, the range of chi2/ndf was ~0.3-2.0.
- Even CBG fitting was “PROBLEMS” in worse resolution cases, the fit itself looks fine (based on my limited number of tests). Typically this happens in [10^{-3}-10^{-4}] at 500 GeV and 10^{-3} at 250 GeV. Typically, the parameter “n” was not good (allowed range of n: 0-10, but fitting result says n is nearly or equal to 10).
- Sometimes many iteration have performed. In such cases, chi2/ndf have huge number [10^5 or higher up to 10^{13}], and just throw away.

Results: qqh250-L

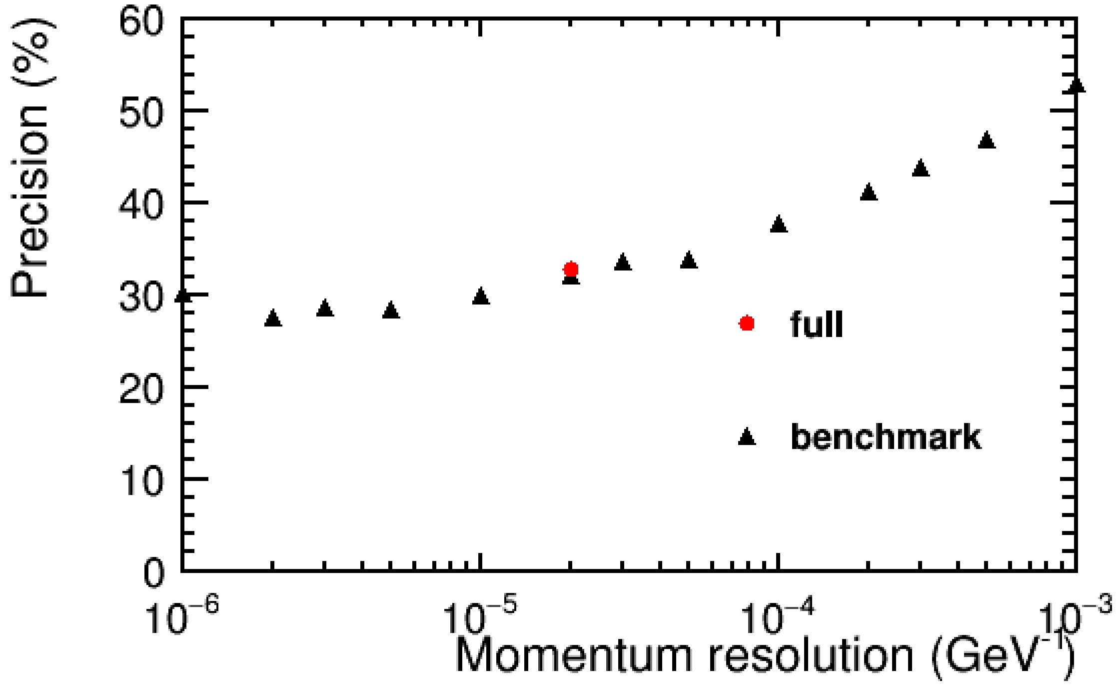


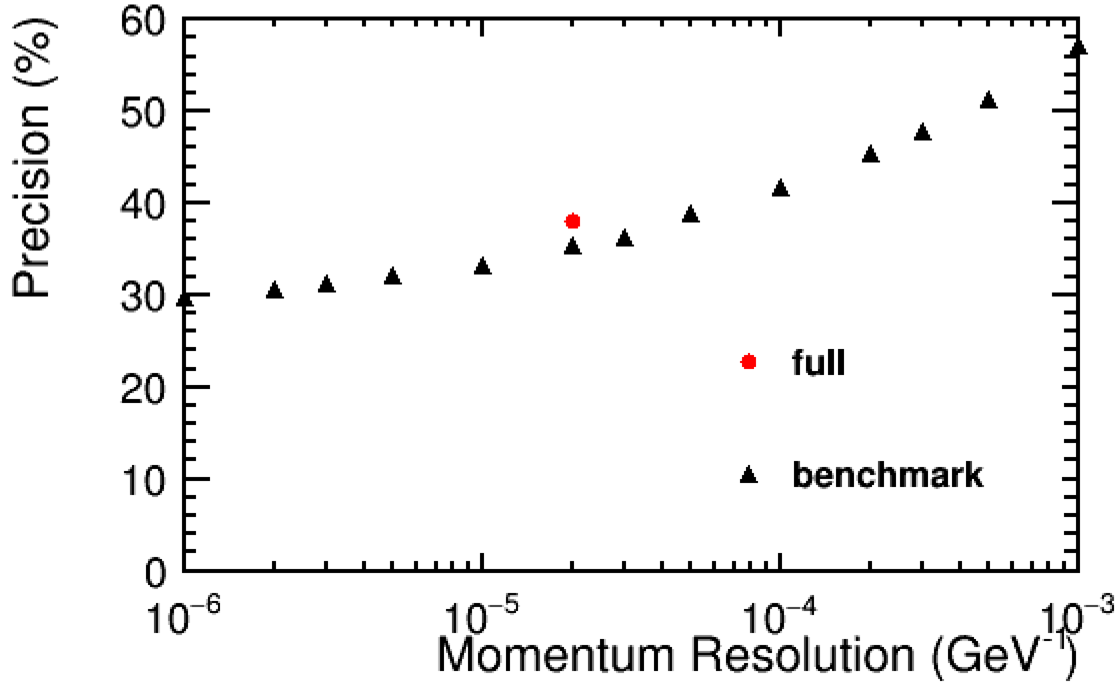


ALCW
full: 27.6%

CBG
full: 36.15%

Results: qqh250-R

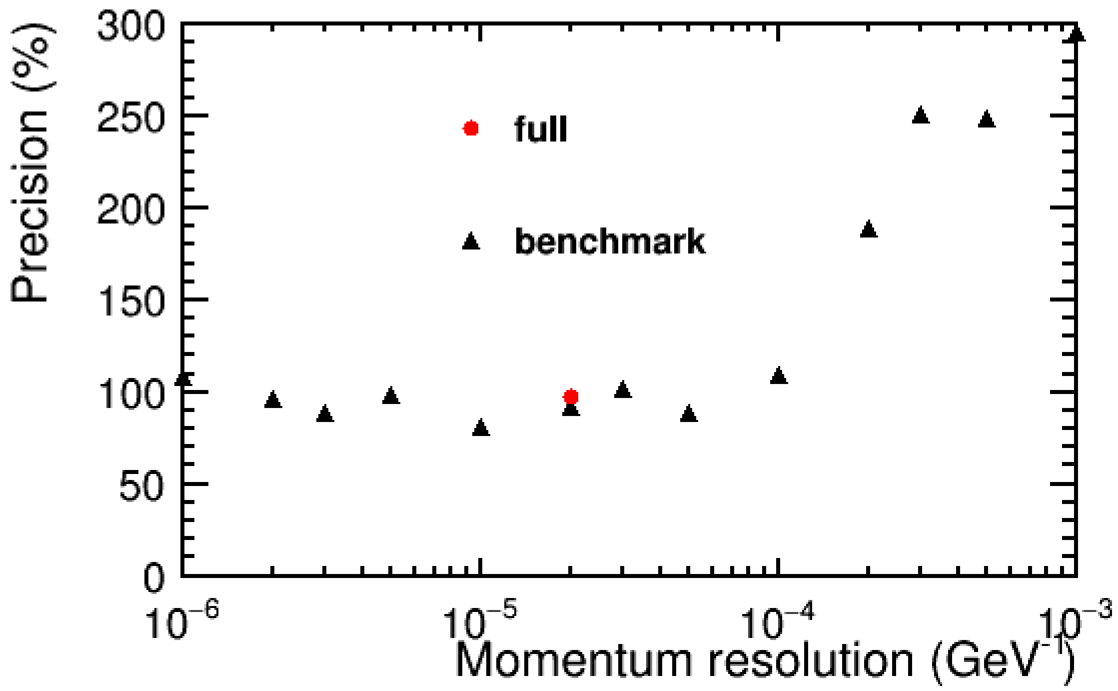


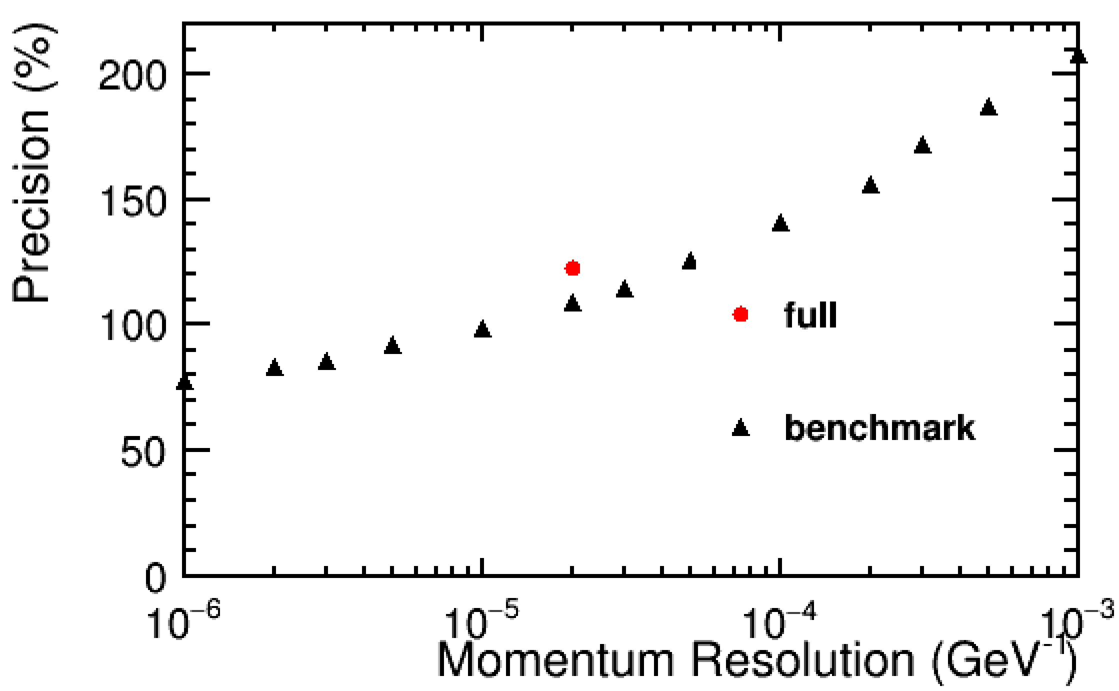


ALCW
full: 32.9%

CBG
full: 38.04%

Results: nnh250-L

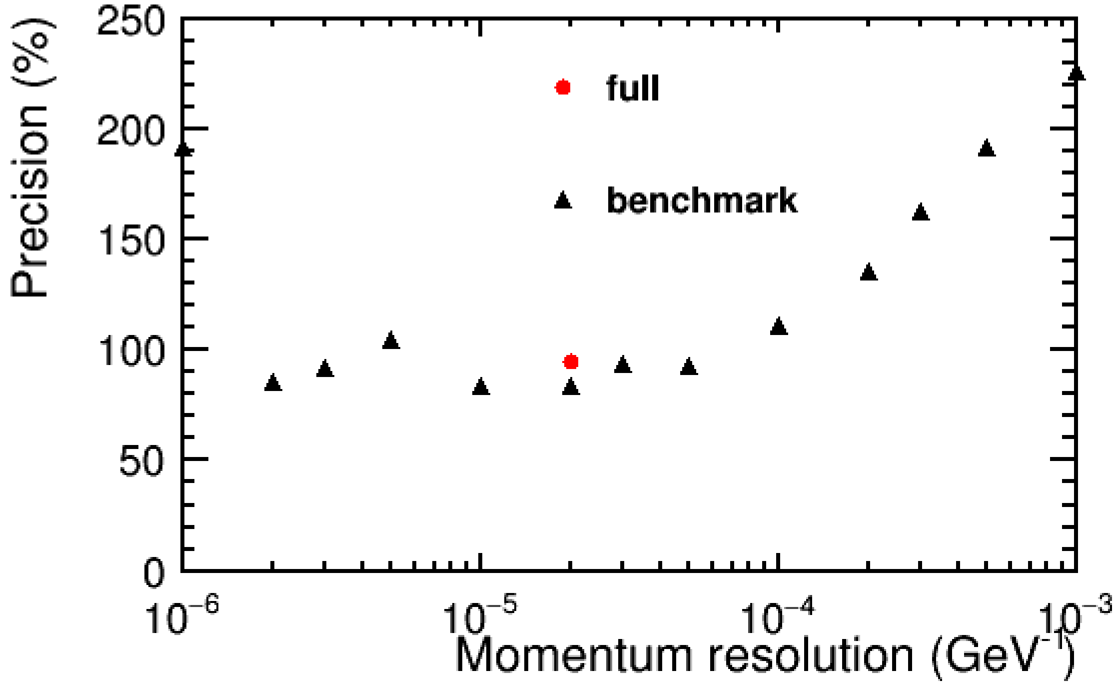


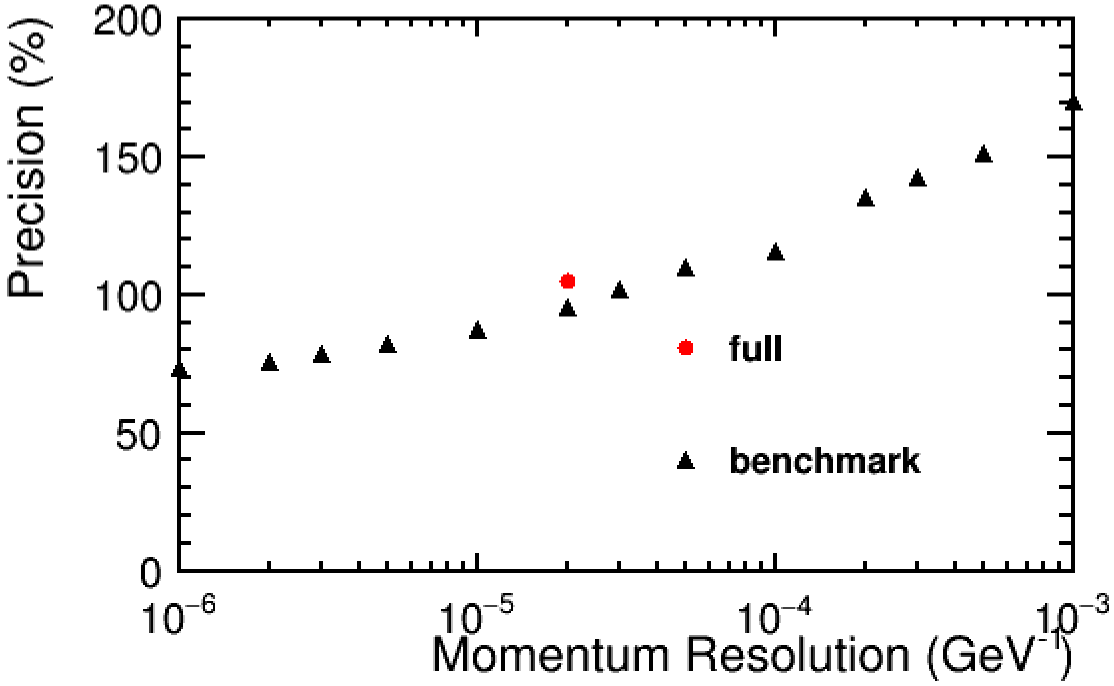


ALCW
full: 97.5%

CBG
full: 122.40%

Results: nnh250-R

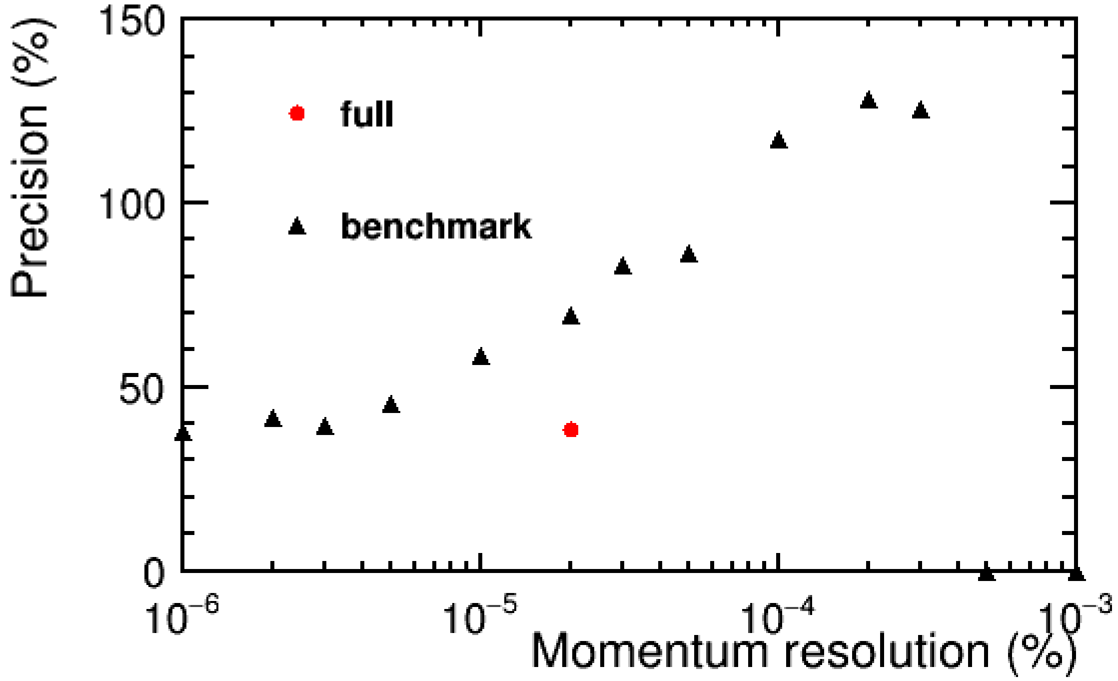


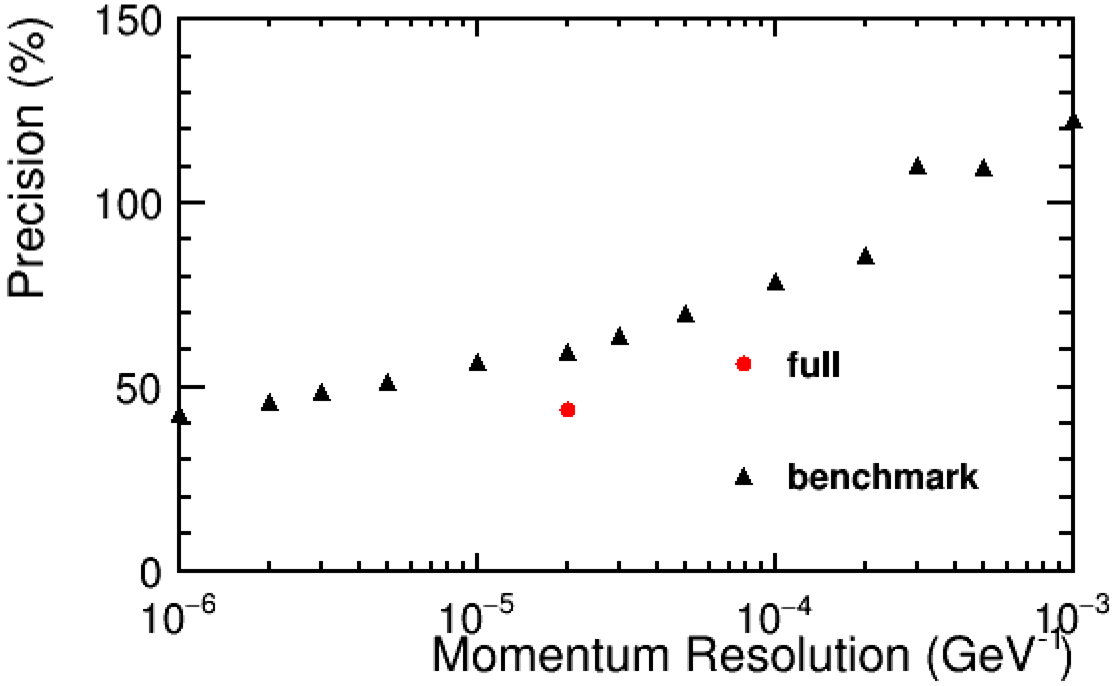


ALCW
full: 94.7%

CBG
full: 105.10%

Results: qqh500-L

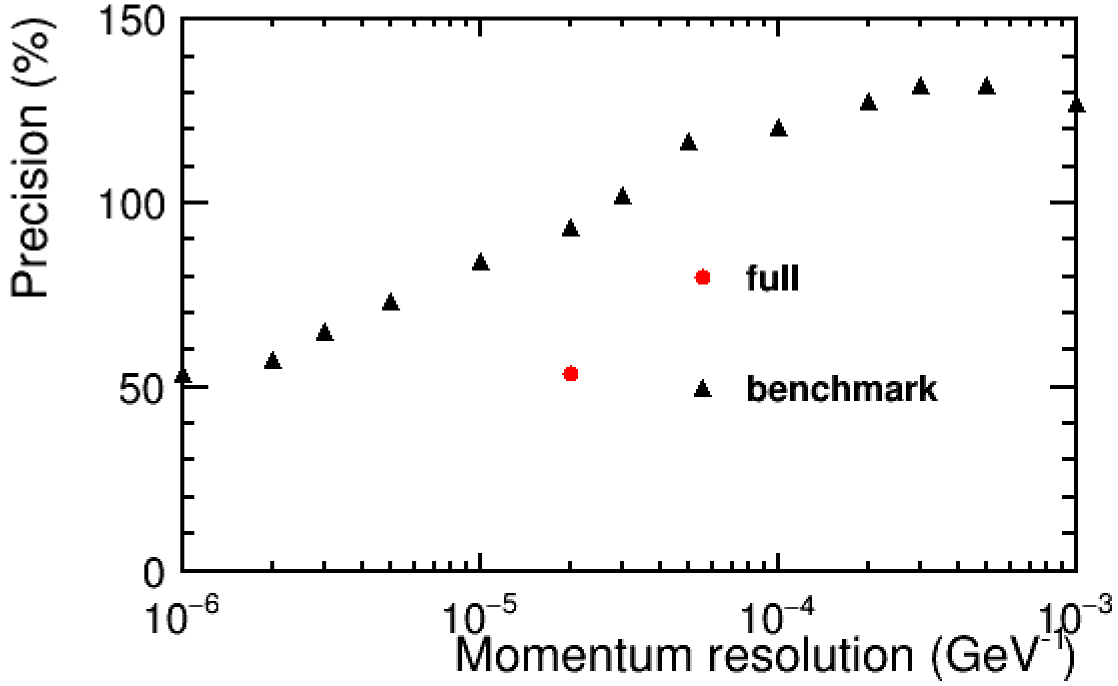


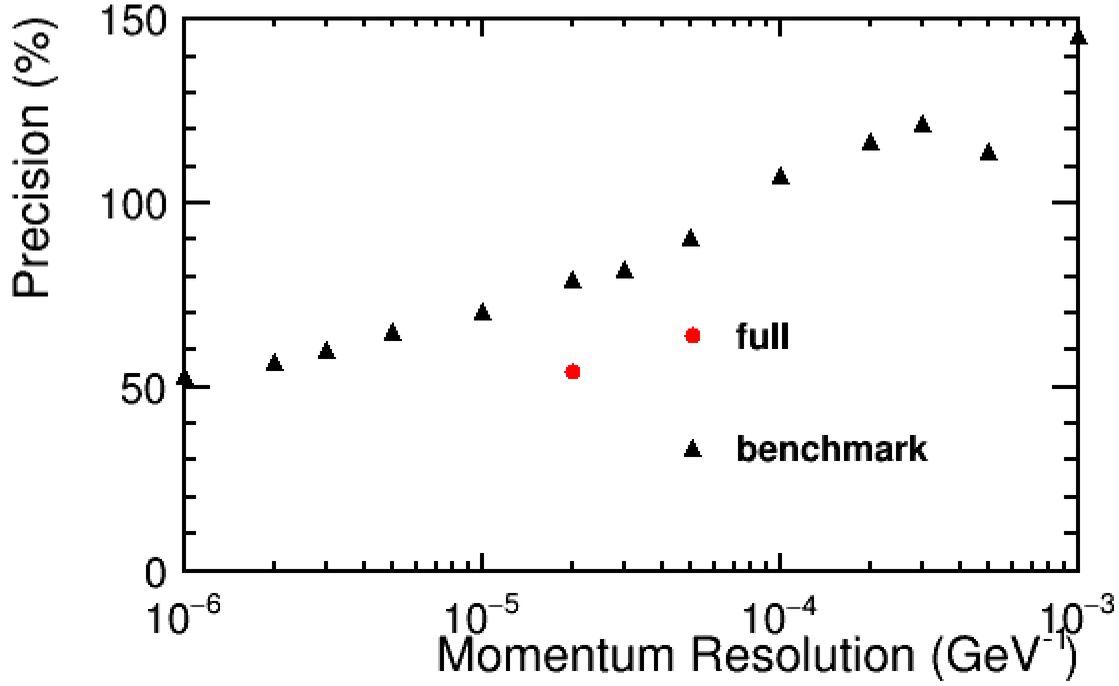


ALCW
full: 38.4%

CBG
full: 43.75%

Results: qqh500-R

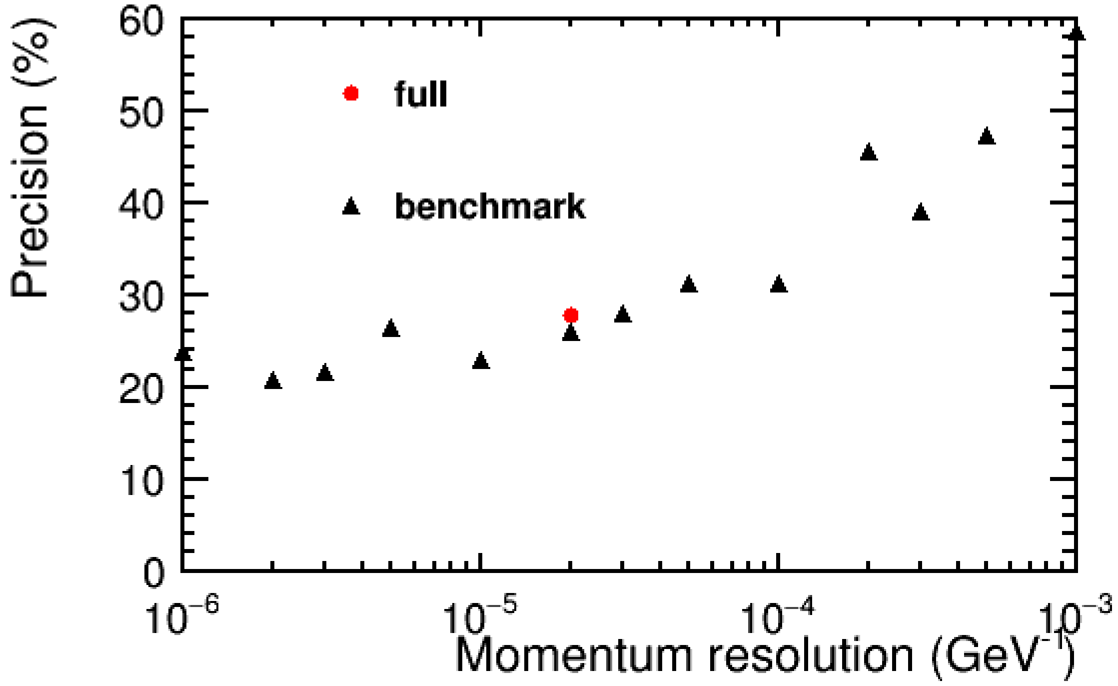




ALCW
full: 53.9%

CBG
full: 54.18%

Results: nnh500-L



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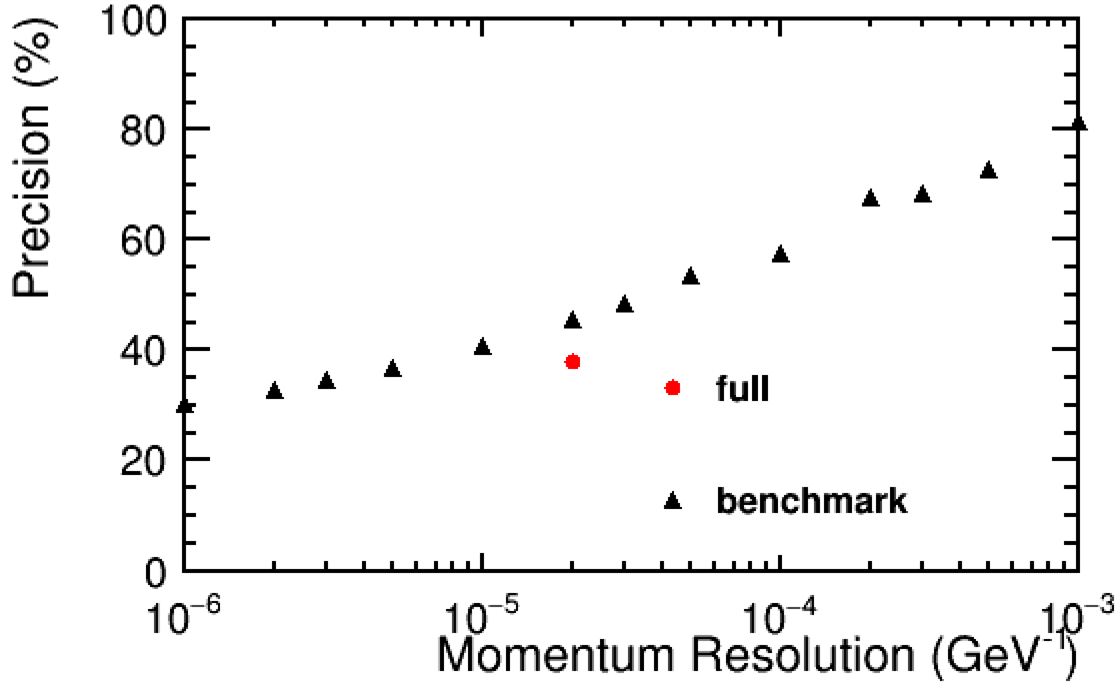
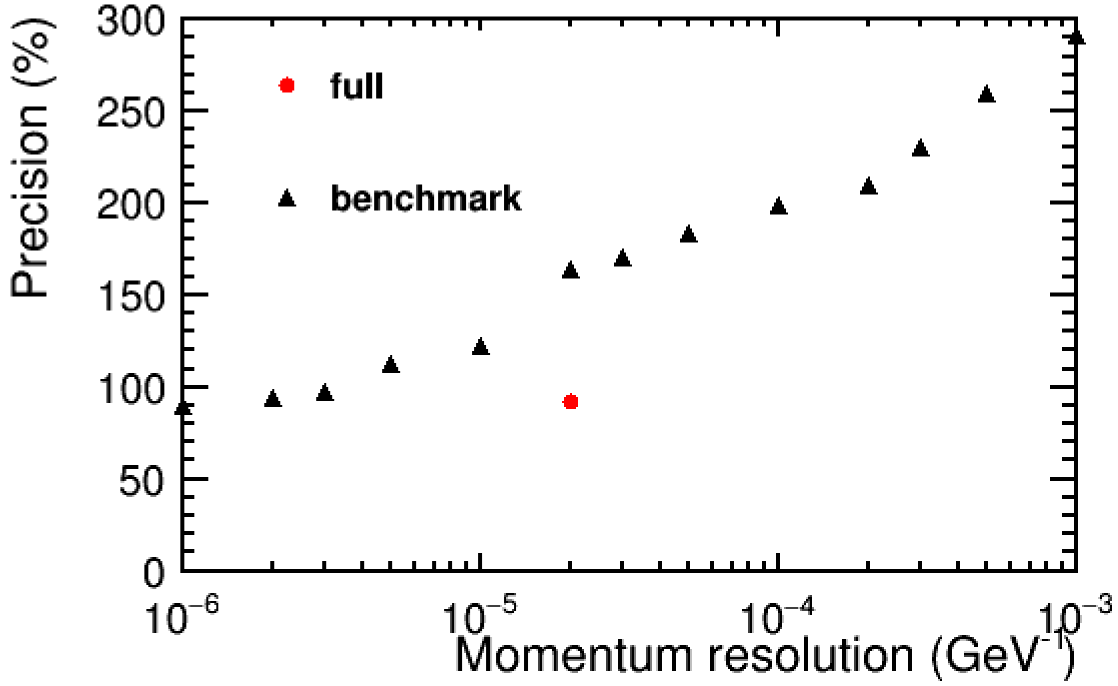
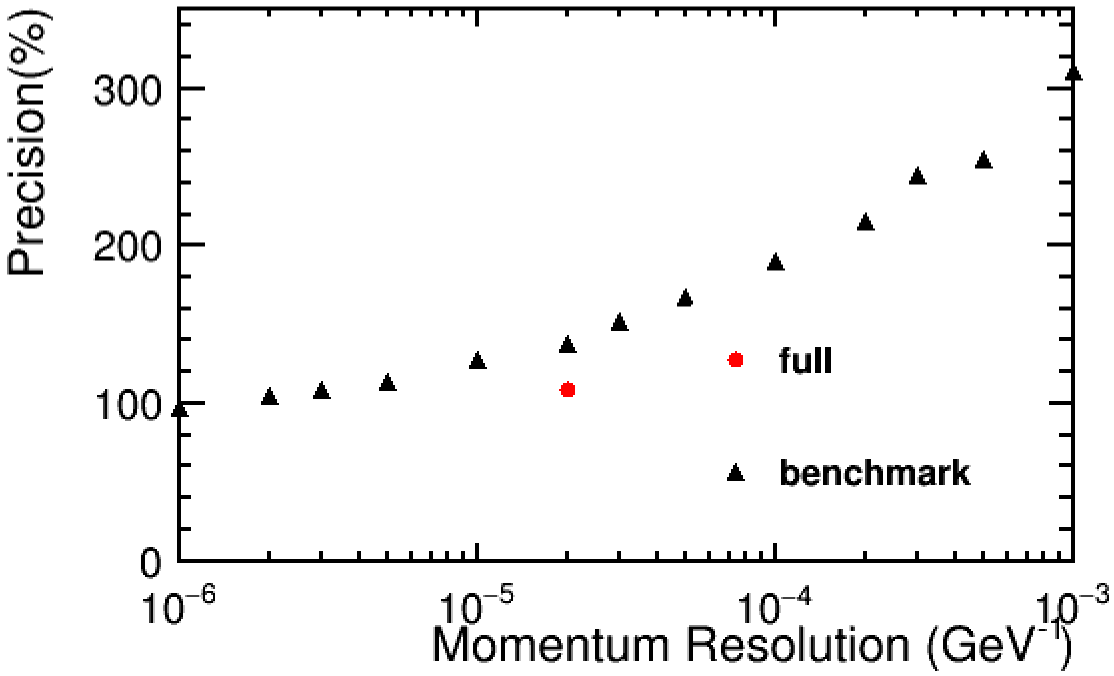
full: 27.8%



CBG
full: 37.88%

Results: nnh500-R





ALCW
full: 92.5%

CBG
full: 108.82%