

Branching ratio measurement of $h \rightarrow \mu^+ \mu^-$ at the ILC

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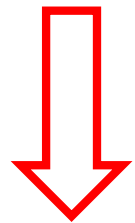
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Introduction

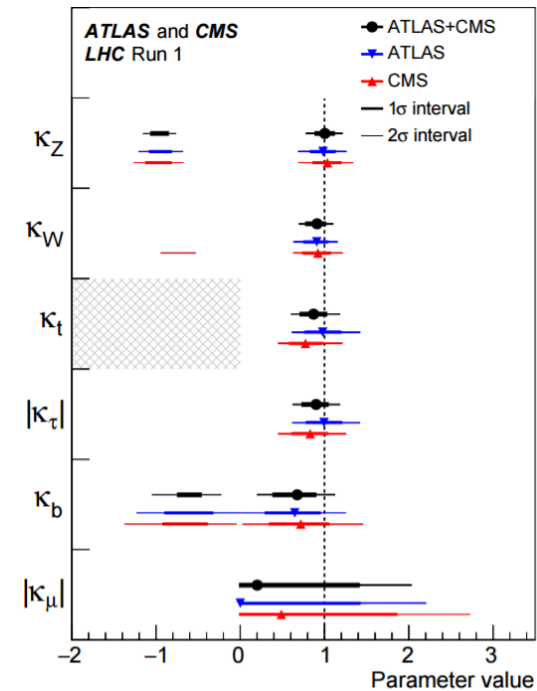
Discovery of Higgs-like boson at the LHC
--> Last particle of SM? Or beyond SM?

Goal: **model-independent** determination of
EWSB sector with **precise** measurements

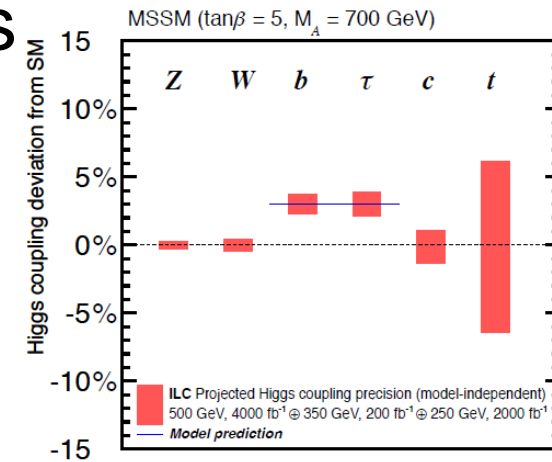
- mass-coupling relation
- any deviation shows the existence of BSM



ILC



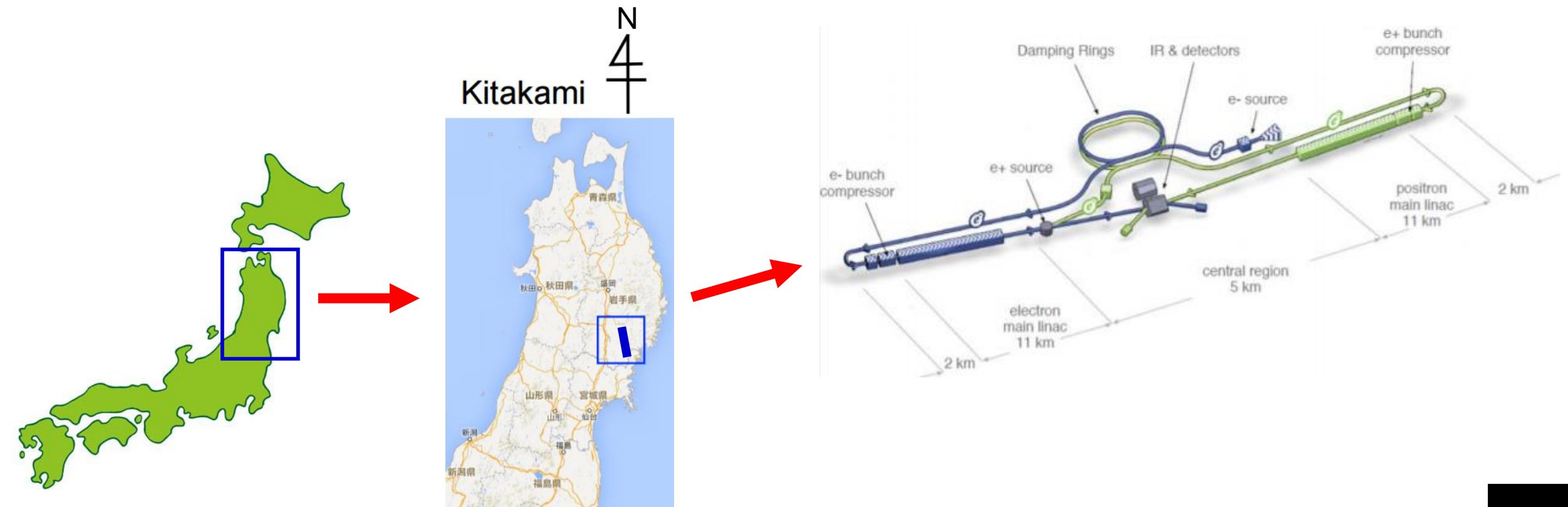
JHEP 08
(2016) 045



arXiv:
1506.05992
[hep-ex]

The International Linear Collider

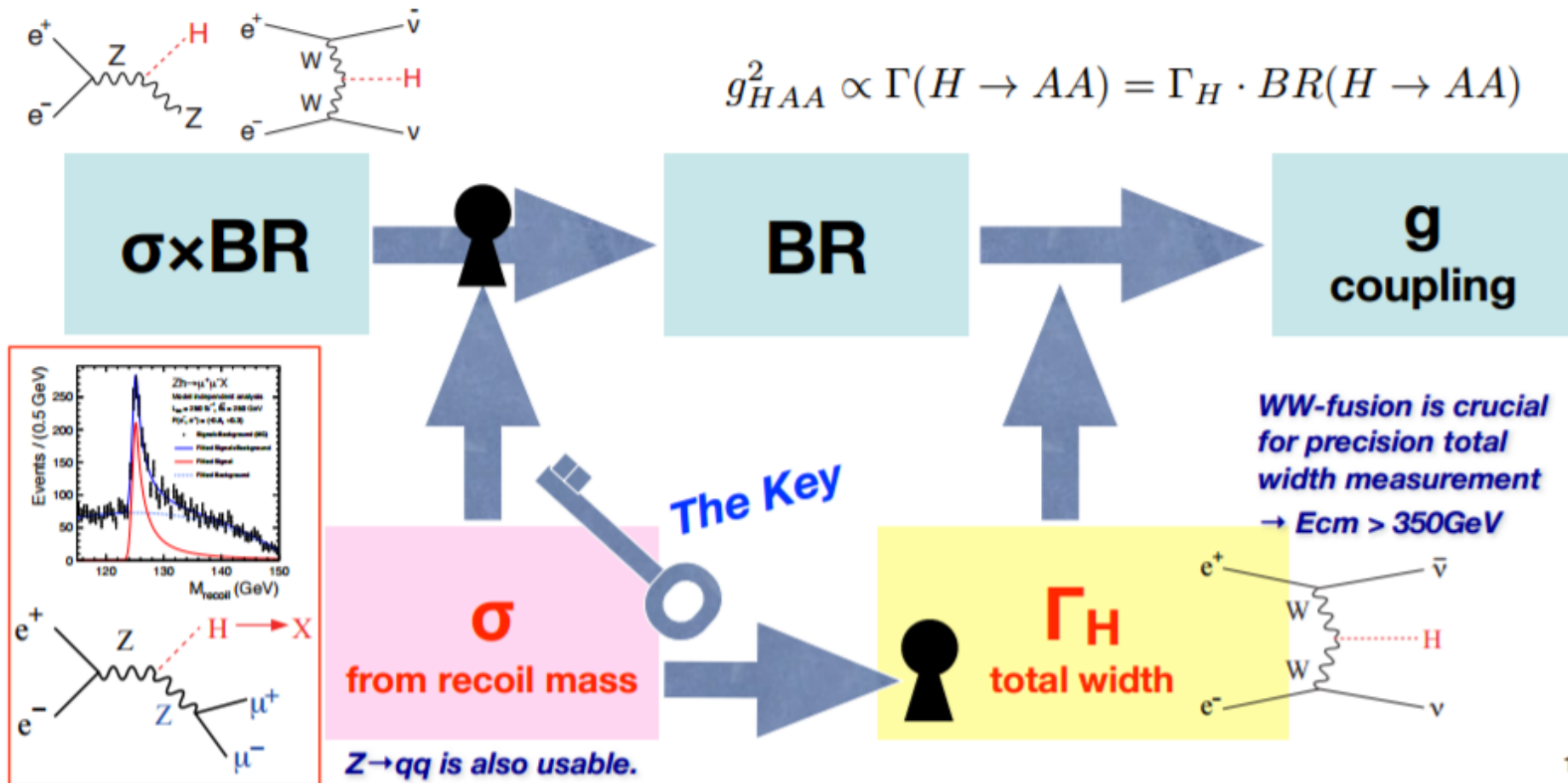
- e^+e^- collider, $E_{CM} = 250 - 500$ GeV (upgradable to 1 TeV)
- polarized beam (e^- : 80%, e^+ : 30%)
- clean environment, known initial state



Key Point

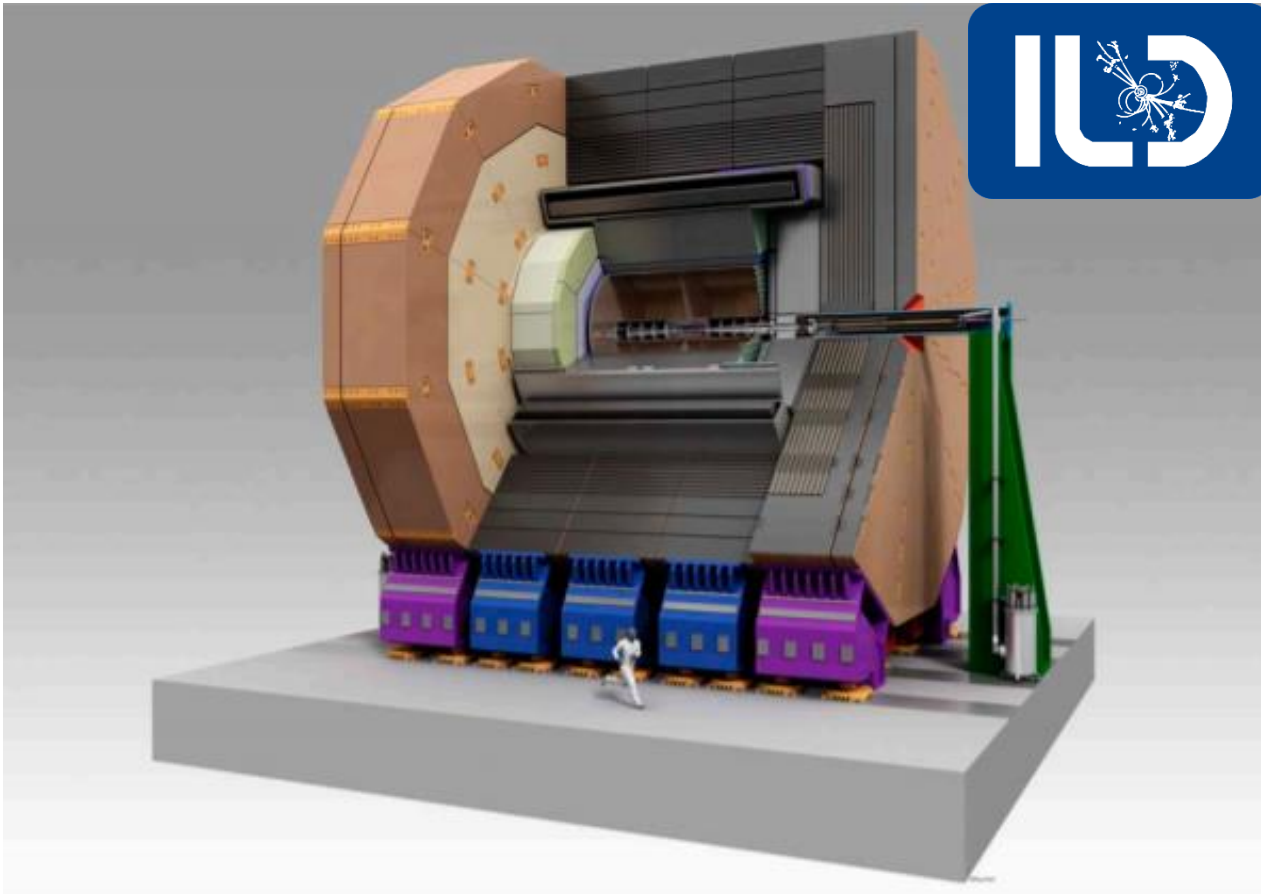
LHC: all measurements are $\sigma \times BR$

ILC: $\sigma \times BR$ measurements + σ measurement



Detector Concept at the ILC

ILD (International Large Detector)



Tracker: Vertex, TPC
Calorimeter: ECAL, HCAL
3.5T magnetic field
Yoke for muon, Forward system

Requirements:

- Impact parameter resolution

$$\sigma_{r\phi} < 5 \oplus \frac{10}{p \sin^{3/2} \theta} \mu\text{m}$$

- **Momentum resolution**

$$\sigma_{1/p_T} < 2 \cdot 10^{-5} \text{ GeV}^{-1}$$

- Energy resolution

$$\sigma_E/E = 3 - 4\%$$

In This Talk: $h \rightarrow \mu^+ \mu^-$

- Can be used for testing:
 - $y_f \propto m_f$
 - mass generation mechanism between 2nd/3rd leptons (κ_μ/κ_τ) and 2nd lepton/quark (κ_μ/κ_c)
- Good benchmark for detector optimization
- Challenging: tiny branching ratio ($\text{BR}(h \rightarrow \mu^+ \mu^-) = 2.2 \cdot 10^{-4}$)

Previous Studies

Everything performed at ≥ 1 TeV, or not realistic

Reference	E_{CM}	beam pol. $P(e^-, e^+)$	$\int L dt$	$\frac{\Delta(\sigma \times \text{BR})}{(\sigma \times \text{BR})}$	comment
LC-REP-2013-006	1 TeV	(-0.8, +0.2)	500 fb ⁻¹	44%	ILC/ILD
arXiv:1306.6329 [hep-ex]	1 TeV	(-0.8, +0.2)	1000 fb ⁻¹	32%	ILC/SiD
arXiv:1603.04718 [hep-ex]	1 TeV	(-0.8, +0.2)	500 fb ⁻¹	36%	ILC/ILD used TMVA
Eur. Phys. J. C73 (2), 2290 (2013)	3 TeV	unpol.	2000 fb ⁻¹	15%	CLIC_SiD $M_h = 120$ GeV used TMVA
Eur. Phys. J. C75 , 515 (2015)	1.4 TeV	unpol.	1500 fb ⁻¹	38%	CLIC_ILD used TMVA
		(-0.8, 0)		25%	
arXiv:0911.0006 [physics.ins-det]	250 GeV	(-0.8, +0.3)	250 fb ⁻¹	91%	ILC/SiD $M_h = 120$ GeV

ILC Running Scenario

optimized scenario with considering

- Higgs precise measurements
- Top physics
- New physics search

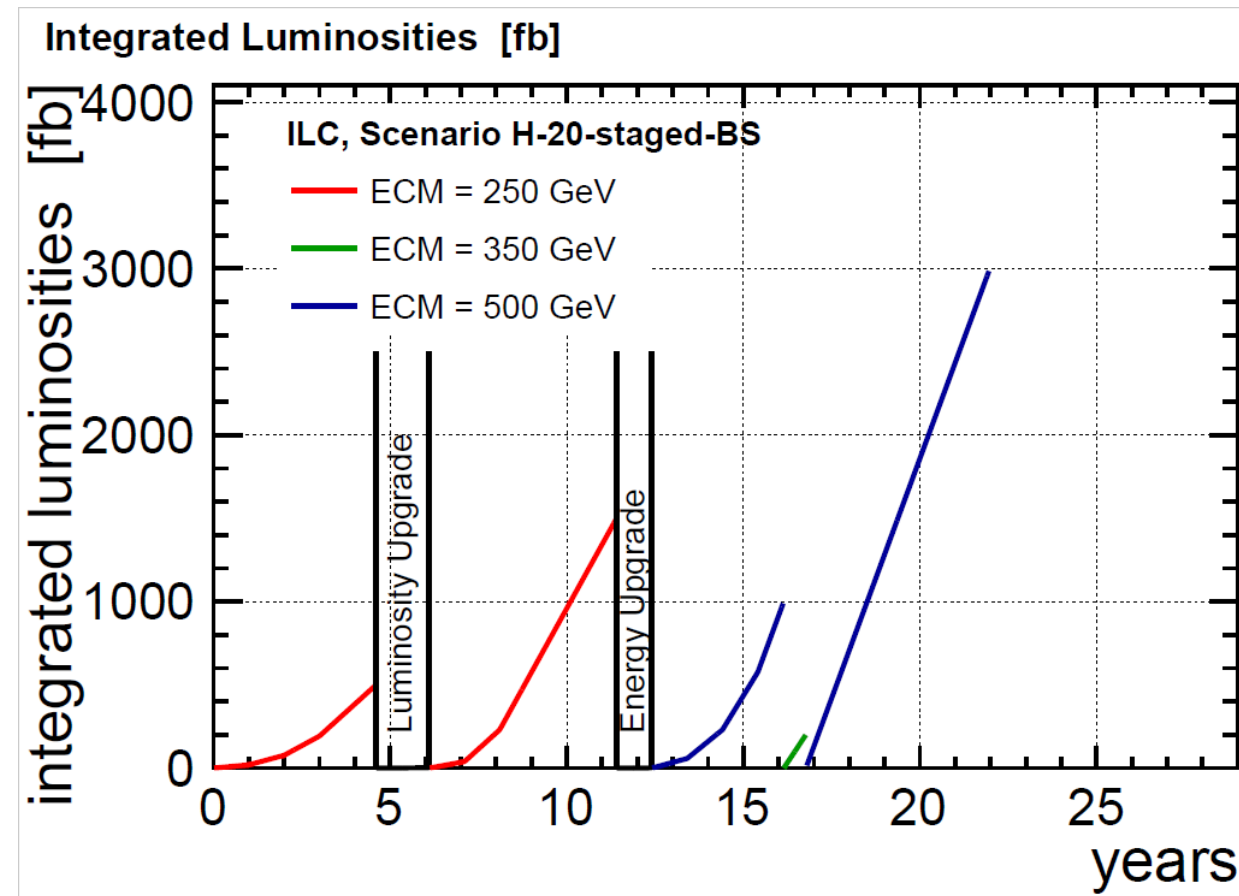
~20 years running with
energy range [250-500] GeV,
beam polarization sharing
---> then possible 1 TeV upgrade

preferred scenario:

2000 fb⁻¹ @ 250 GeV

200 fb⁻¹ @ 350 GeV

4000 fb⁻¹ @ 500 GeV



staging running scenario

Single Higgs Production

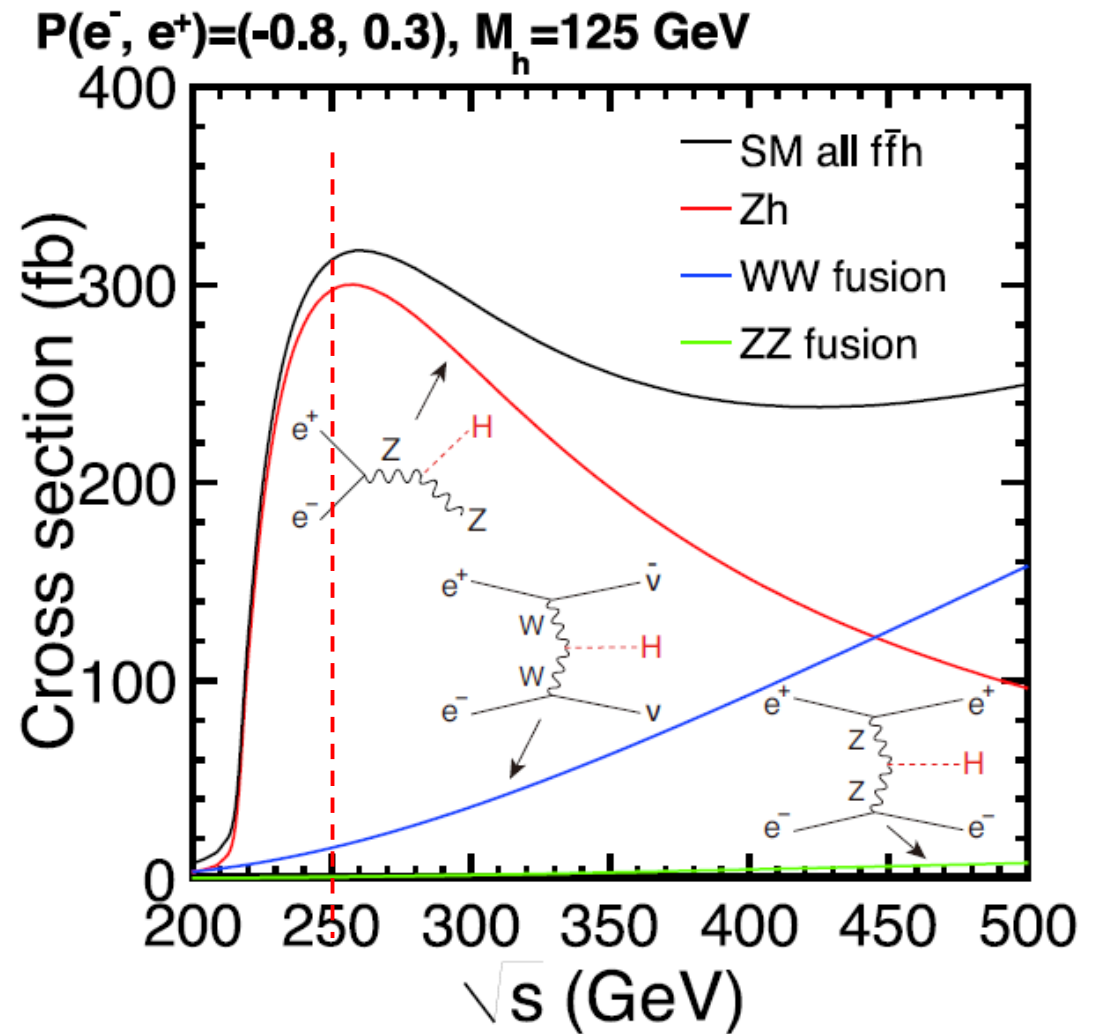
$\sqrt{s} = 250 \text{ GeV}$

Higgs-strahlung (Zh) dominant

$\sqrt{s} = 500 \text{ GeV}$

WW-fusion dominant

E_{CM}	process	beam pol.	$\int L dt$ (fb $^{-1}$)	# events
500	$\nu\bar{\nu}h$	L	1600	58
		R	1600	8
	$q\bar{q}h$	L	1600	25
		R	1600	16
250	$\nu\bar{\nu}h$	L	900	28
		R	900	8
	$q\bar{q}h$	L	900	41
		R	900	15



L: $(e^-, e^+) = (-0.8, +0.3)$

R: $(e^-, e^+) = (+0.8, -0.3)$

Analysis Settings

- Geant4-based full detector simulation with ILD model
- Included all possible SM backgrounds
 - Used DBD-style samples, a first look of newly generated MC samples will be given in Thursday (joint Sim/Rec/DetPerf/Vertex/Tracking)
 - Performed toy MC in the end to extract the precision, because some SM background processes have not enough MC statistics

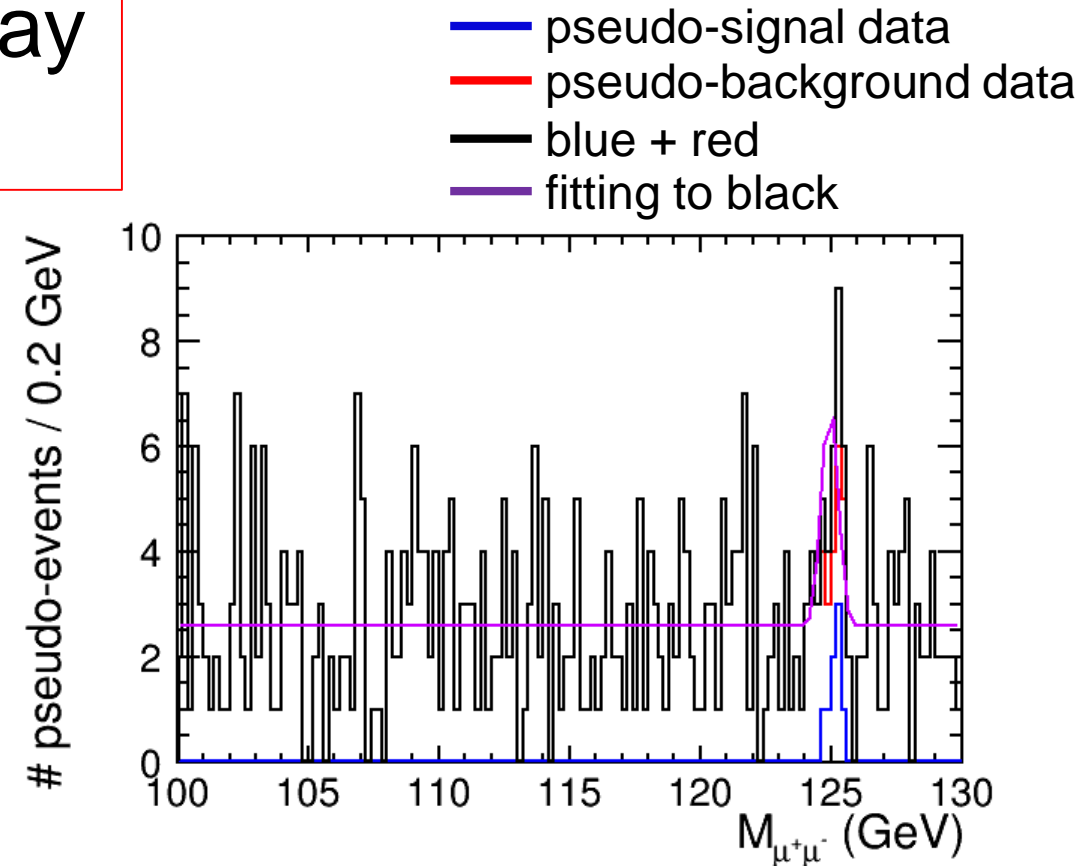
E_{CM}	# total MC events
500 GeV	$1.4 \cdot 10^7$
250 GeV	$7.1 \cdot 10^7$

Brief Summary of Analysis

Analysis is structured in the same way for all channels.

1. select $h \rightarrow \mu^+ \mu^-$ candidate
2. channel-specific analysis
3. multivariate analysis
4. toy MC with $M_{\mu^+ \mu^-}$ →

- extract final precision
- (for experts) 200 MeV/bin \rightarrow 2 MeV/bin



Results

precision for $\frac{\Delta(\sigma \times \text{BR})}{(\sigma \times \text{BR})}$

250 GeV	$q\bar{q}h$	$\nu\bar{\nu}h$	500 GeV	$q\bar{q}h$	$\nu\bar{\nu}h$
L	27.6%	97.5%	L	38.4%	27.8%
R	32.9%	94.7%	R	53.9%	92.5%

ILC250 combined = 20.2% (“theoretical limit” = 10.4%)

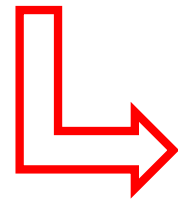
ILC250+500 combined = **14.3%** (“theoretical limit” = 7.1%)

HL-LHC: 10-21%

⌘ theoretical limit = 100% efficiency, no backgrounds, no detector effects

Impact of Momentum Resolution

- The variable $M_{\mu^+\mu^-}$ is most important and essential for this analysis. Thus, the momentum resolution (P_t resolution) has a crucial role.
- Studied what will happen when we change the momentum resolution artificially
 - 13 benchmark points



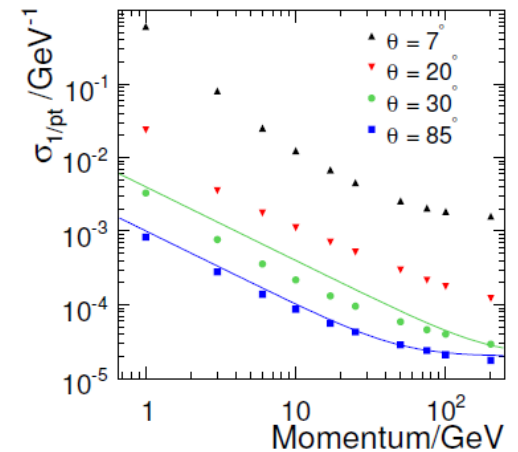
Resolution (GeV ⁻¹)			
1*10 ⁻³	5*10 ⁻⁴	5*10 ⁻⁵	5*10 ⁻⁶
	3*10 ⁻⁴	3*10 ⁻⁵	3*10 ⁻⁶
	2*10 ⁻⁴	2*10 ⁻⁵	2*10 ⁻⁶
	1*10 ⁻⁴	1*10 ⁻⁵	1*10 ⁻⁶

Impact of Momentum Resolution

- smeared MCParticle momentum of $h \rightarrow \mu^+ \mu^-$ candidate
 - Gaussian-smeared with **constant number**
 - no momentum/angular dependencies
 - Not 100% correct, but muons will fly everywhere. On average, this is still good approximation.
 - replace $M_{\mu^+ \mu^-}$ to $M_{\mu^+ \mu^-}^{\text{smear}}$ in toy MC
 - (for specialist) 200 MeV/bin \rightarrow 2 MeV/bin

Studied the impact to final number:

$$\frac{\Delta(\sigma \times \text{BR})}{(\sigma \times \text{BR})} \text{ in this study}$$



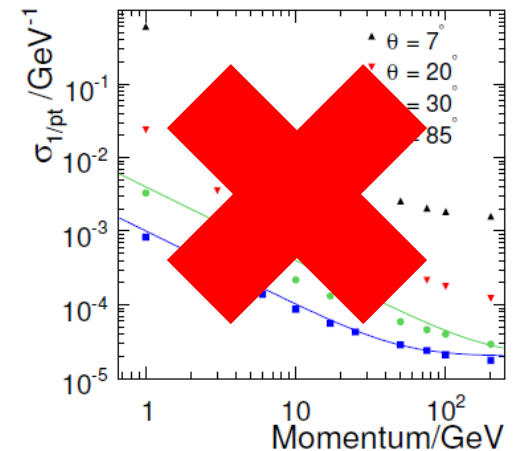
arXiv:1306.632
[physics.ins-det]

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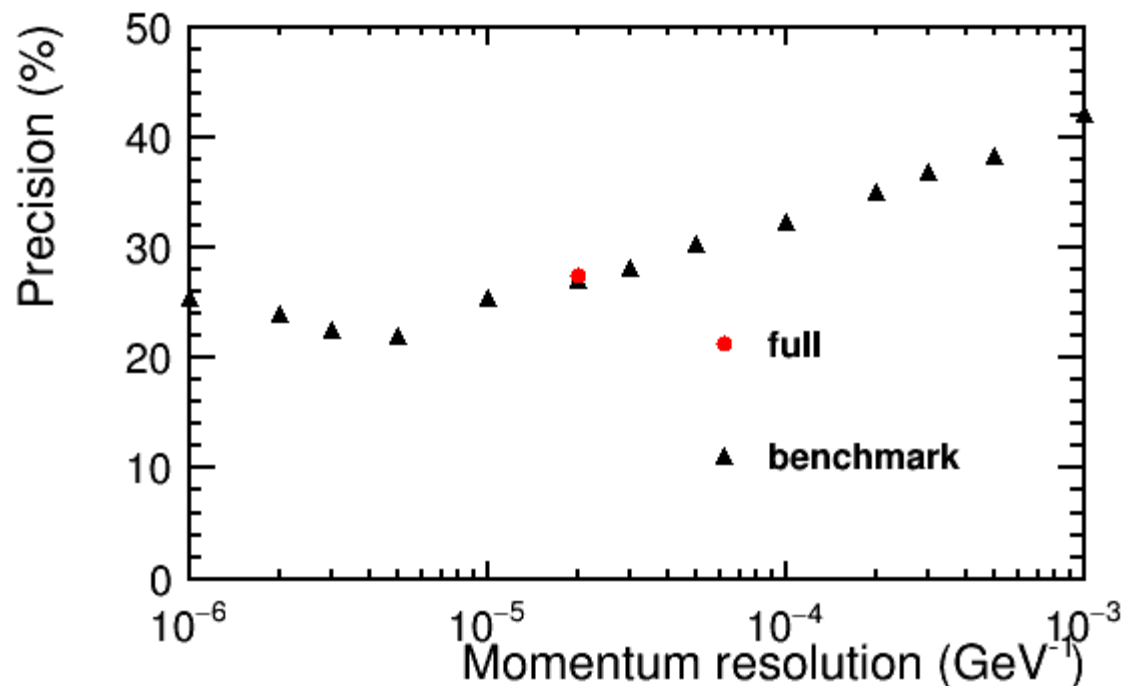
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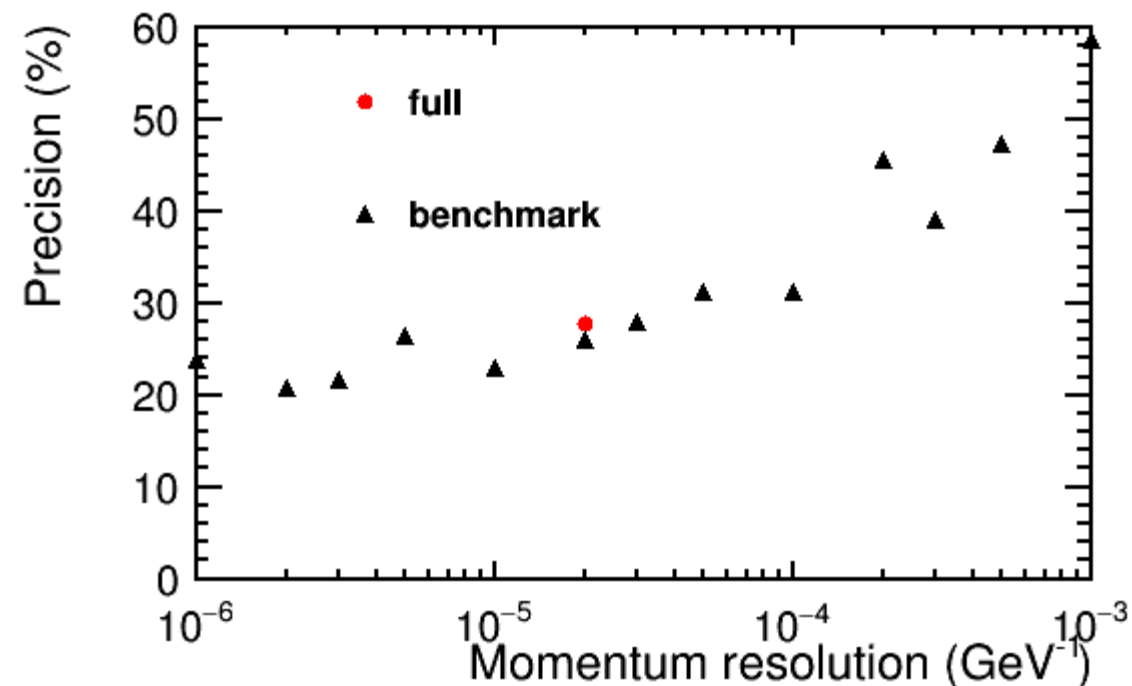


arXiv:1306.632
[physics.ins-det]

Results (Major Channel)

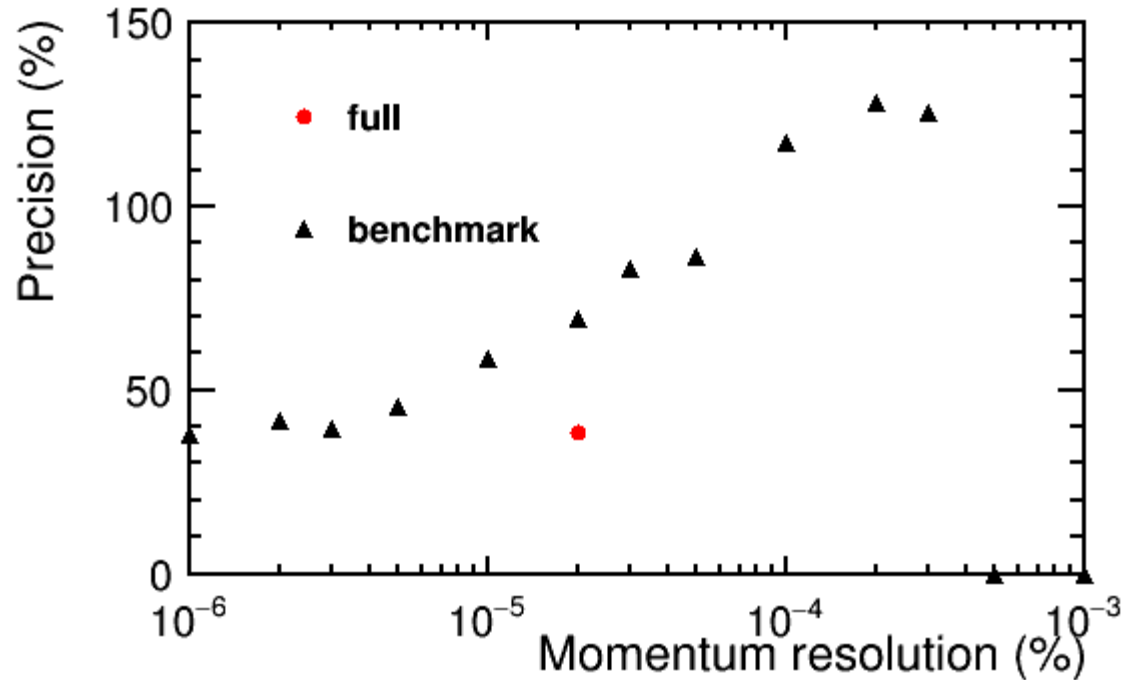


qqh250-L
full: 27.6%



nnh500-L
full: 27.8%

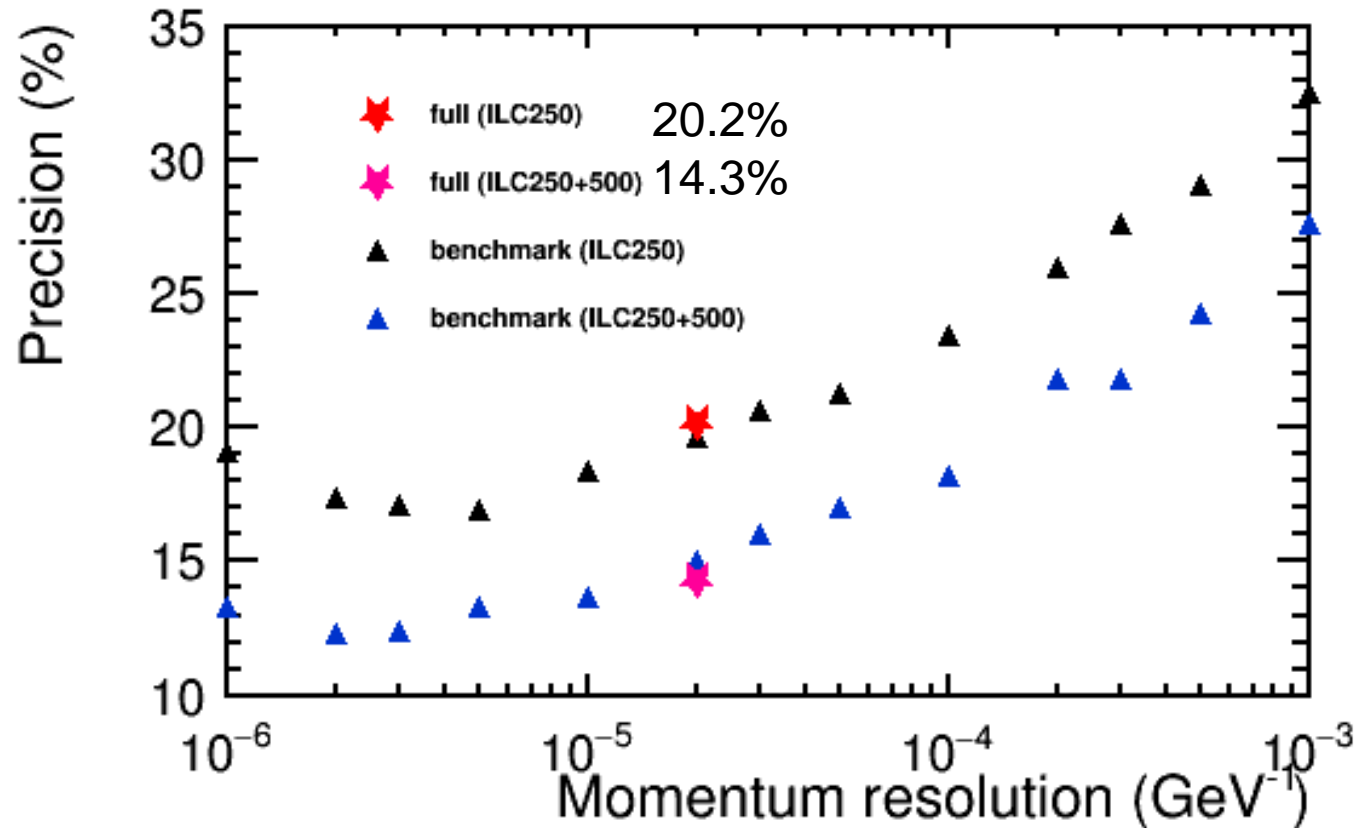
Results (???)



qqh500-L
full: 38.4%

- Fittings are failed many times
- Probably related too small number of events, or too small number of bkg MC events after all cuts.
- Smearing is applied signal and bkg.
- Planning to test: fix bkg, and smear only signal

Combined Results



ILC250:

~17-20% precision

ILC250+500:

~12-15% precision

- relatively up to ~15% better results compare to full
- not drastic differences among better resolution cases

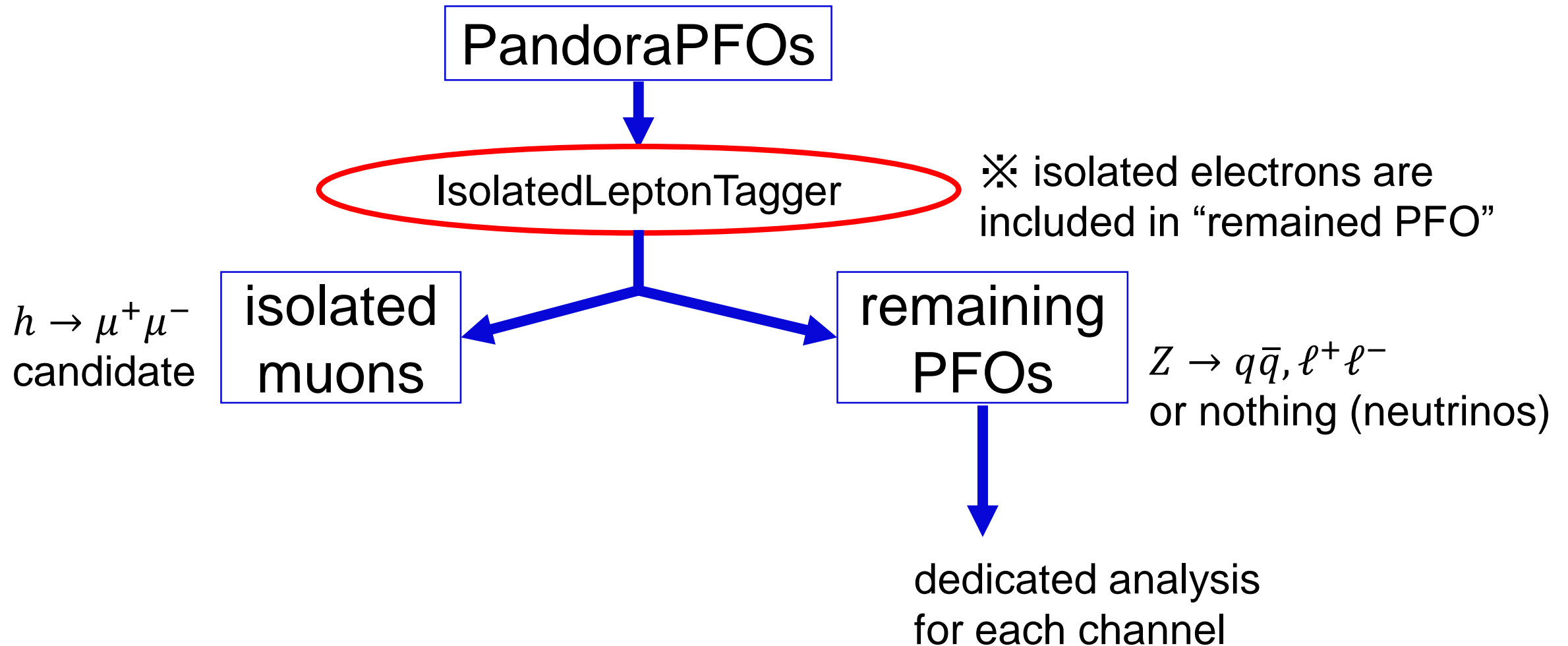
Summary

- Precise measurements and extracting absolute Higgs couplings are possible at the ILC
- Studied $h \rightarrow \mu^+ \mu^-$ channel with $E_{\text{CM}} = 250/500$ GeV at the ILC
 - Can reach 14.3% combined precision for $\frac{\Delta(\sigma \times \text{BR})}{(\sigma \times \text{BR})}$
- Studied the impact of momentum resolution
 - Precision will not change dramatically around $\sim 1 \cdot 10^{-5}$ momentum resolution
 - More studies needed

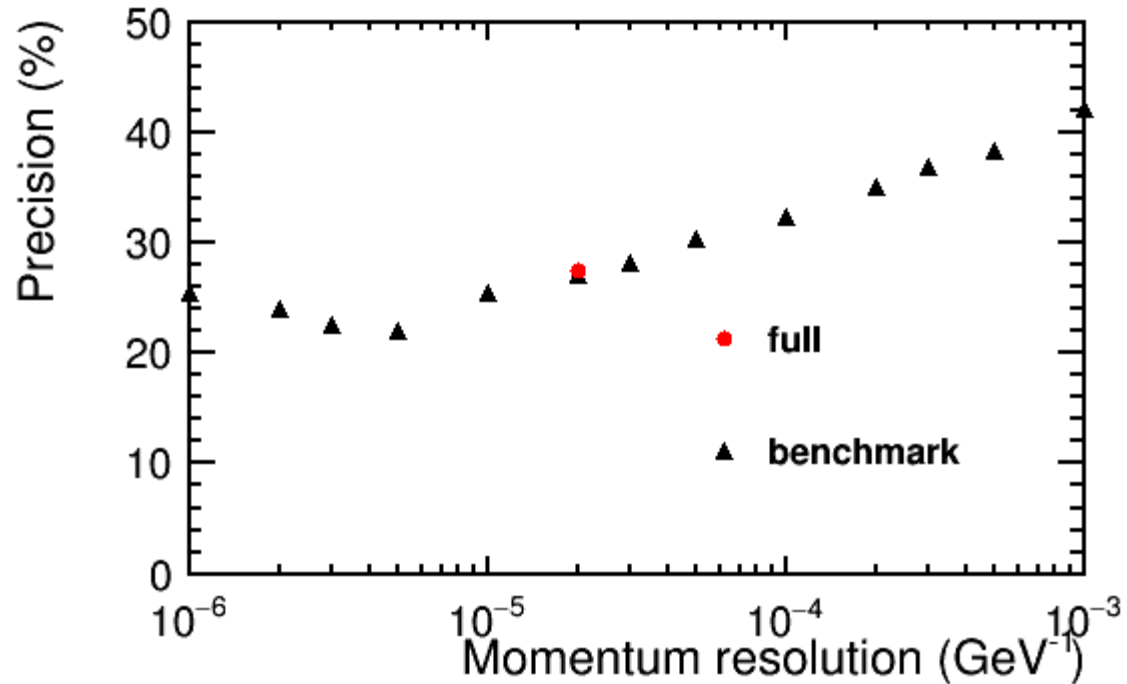
BACKUP



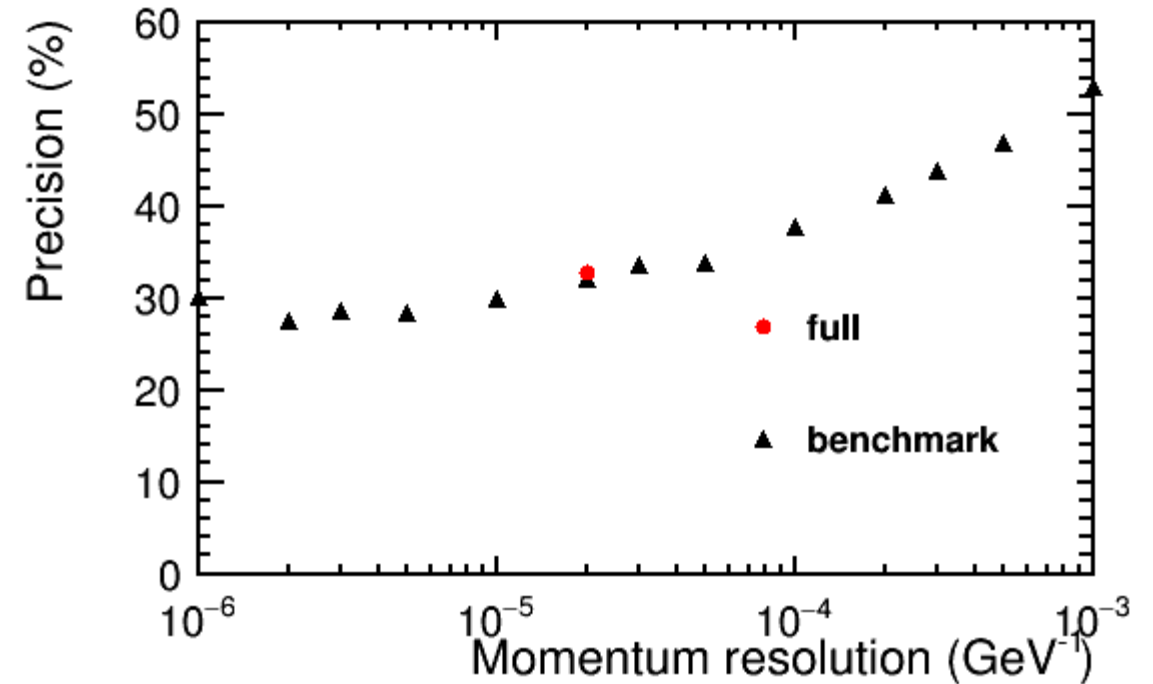
General Event Reconstruction



Results: qqh250

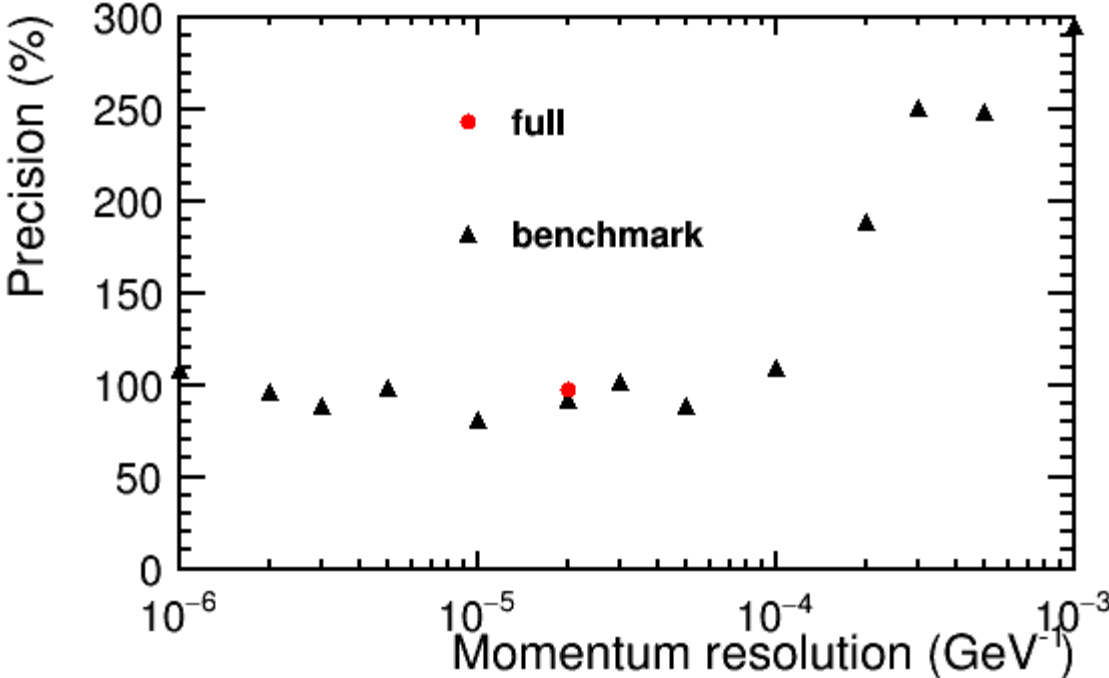


qqh250-L
full: 27.6%

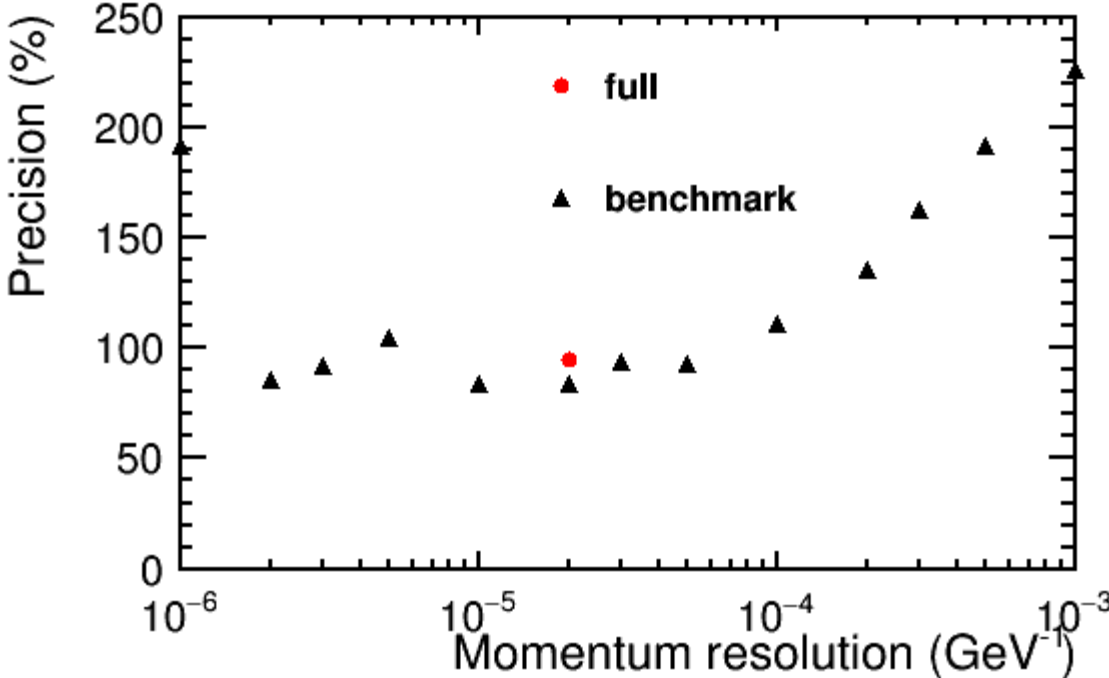


qqh250-R
full: 32.9%

Results: nnh250

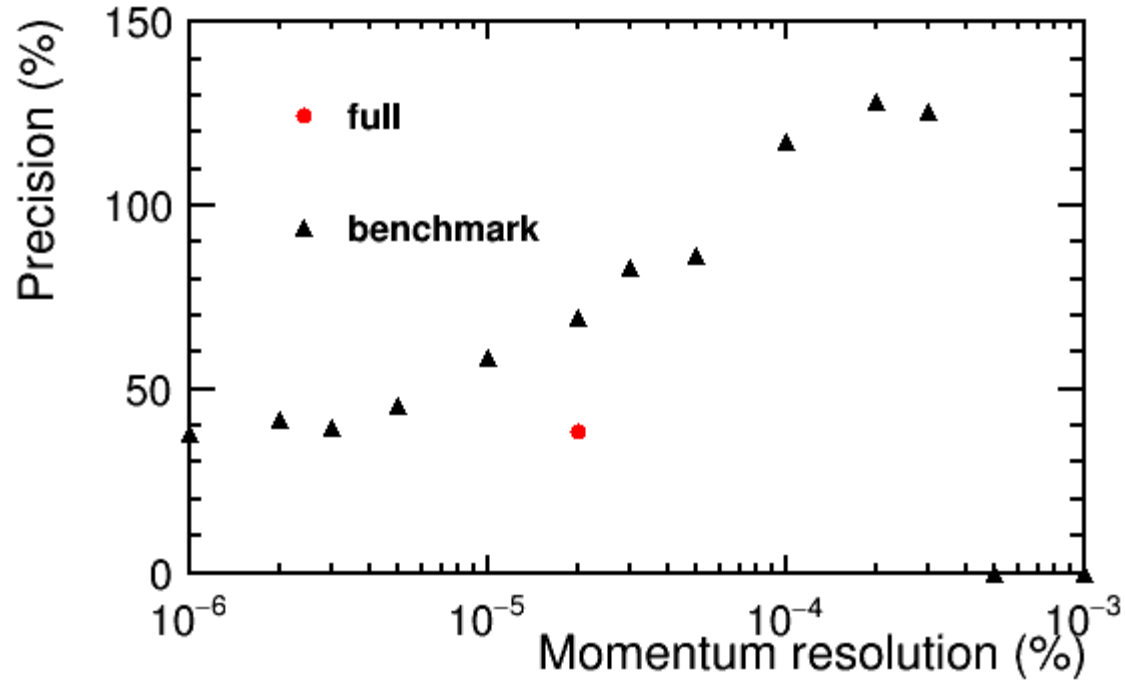


nnh250-L
full: 97.5%

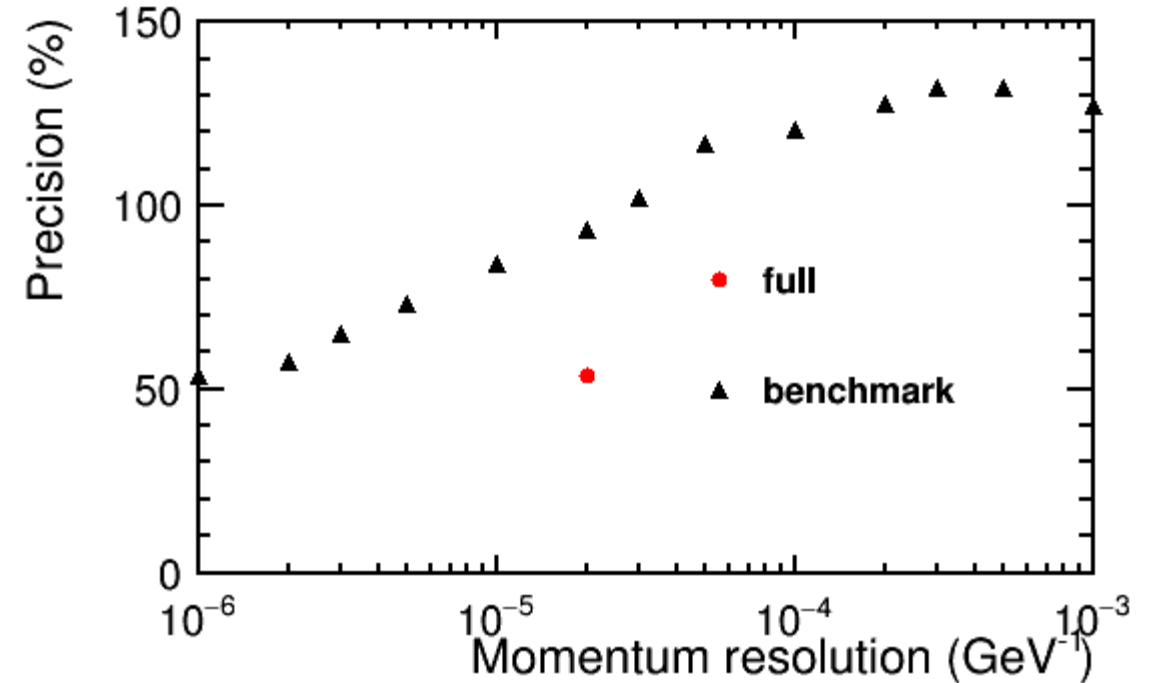


nnh250-R
full: 94.7%

Results: qqh500

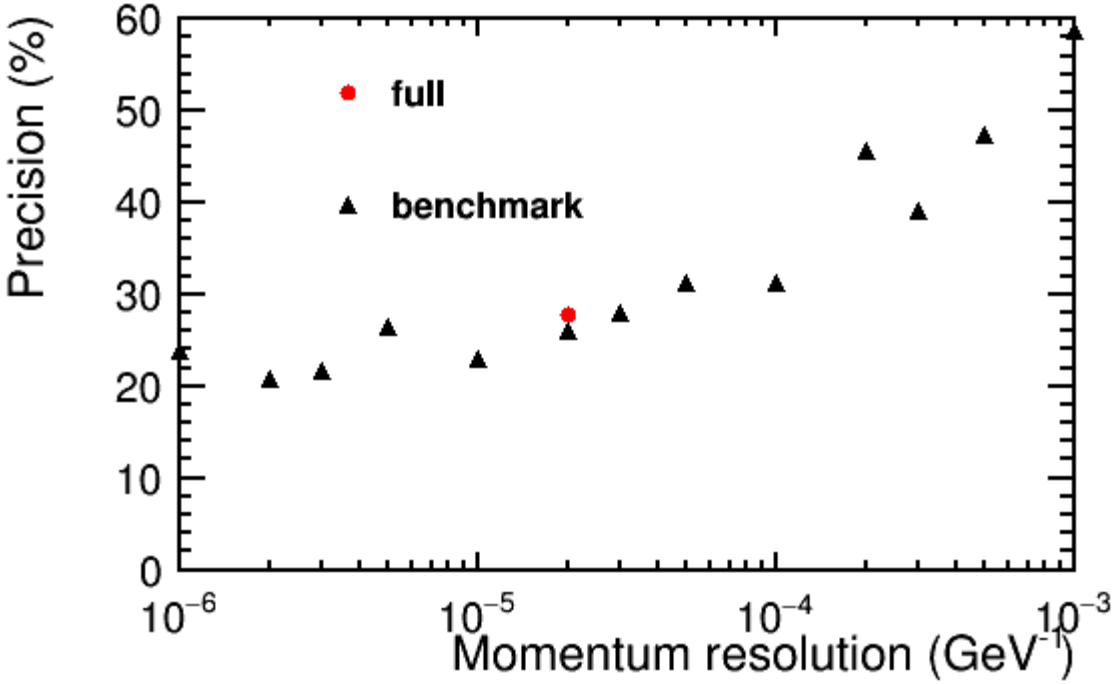


qqh500-L
full: 38.4%

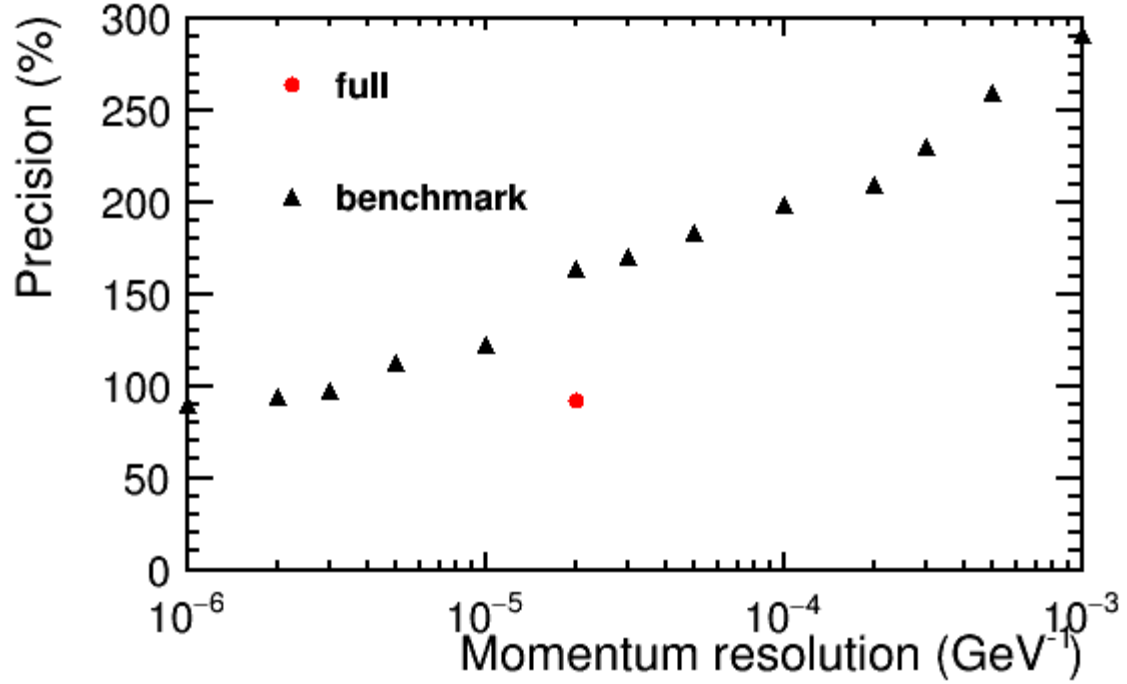


qqh500-R
full: 53.9%

Results: nnh500



nnh500-L
full: 27.8%



nnh500-R
full: 92.5%