Impact of Momentum Resolution on BR($h \to \mu^+\mu^-$) Measurement

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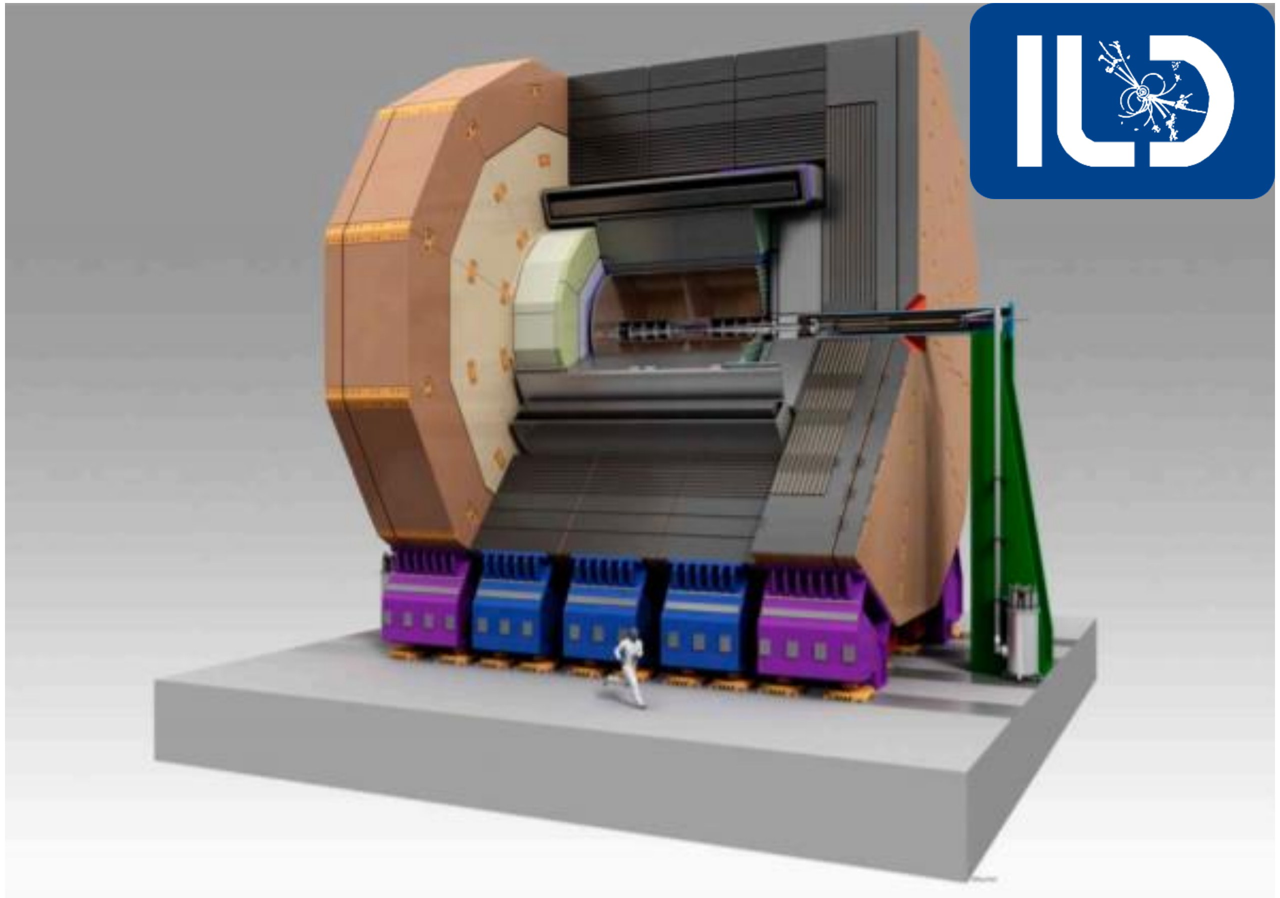
ILD Meeting @ Ichinoseki

Detector Concept at the ILC

ILD (**I**nternational **L**arge **D**etector)



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

Requirements:

- Impact parameter resolution

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

- **Momentum resolution**

  σ_{1/p_T} < 2*10^{-5} GeV^{-1}

- Energy resolution

  σ_E/E = 3 - 4%

ATLAS-PHYS-PUB-2013-004
CERN-LHCC-2015-10

This Talk: $h \to \mu^+\mu^-$

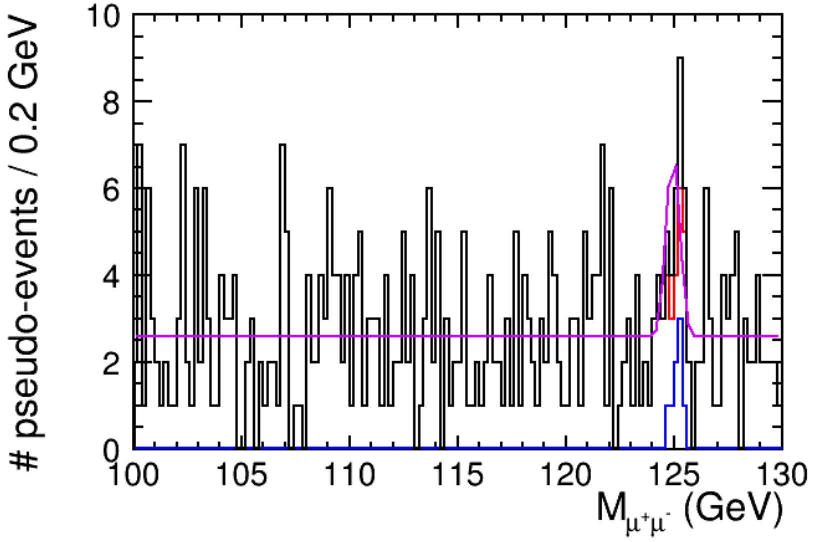
- Challenging analysis: tiny branching ratio (BR($h \to \mu^+\mu^-$) = **2.2*10^{-4}** at M_h = 125 GeV)
- Can be used for testing:
  - $y_f \propto m_f$
  - mass generation mechanism between 2nd/3rd leptons (κ_μ/κ_τ) and 2nd lepton/quark (κ_μ/κ_c)
- HL-LHC prospects (3000 fb^{-1}): ~21% (ATLAS), ~10% (CMS) for cross section times branching ratio $\frac{\Delta(\sigma\times\mathrm{BR})}{(\sigma\times\mathrm{BR})}$
- Good benchmark process for detector optimization

arXiv:1801.07966 [hep-ex]

Brief Summary of Analysis

- Geant4-based full detector simulation with ILD model
- DBD-style MC samples
- Included all possible SM backgrounds

1. Select $h \rightarrow \mu^+\mu^-$ candidate using IsolatedLeptonTagger
2. Channel-specific analysis
   - jet clustering, overlay removal...
3. Multivariate analysis
4. Toy MC using $M_{\mu^+\mu^-}$ distribution



Results

250 GeV	qqh	nnh
L	32.5%	108.6%
R	28.1%	110.4%

500 GeV	qqh	nnh
L	44.5%	37.0%
R	49.5%	74.5%

ILC250 combined = 20.5% (“theoretical limit” = 10.4%)
ILC250+500 combined = **15.4%** (“theoretical limit” = 7.1%)
HL-LHC: 10-21%

now working on further improvements...

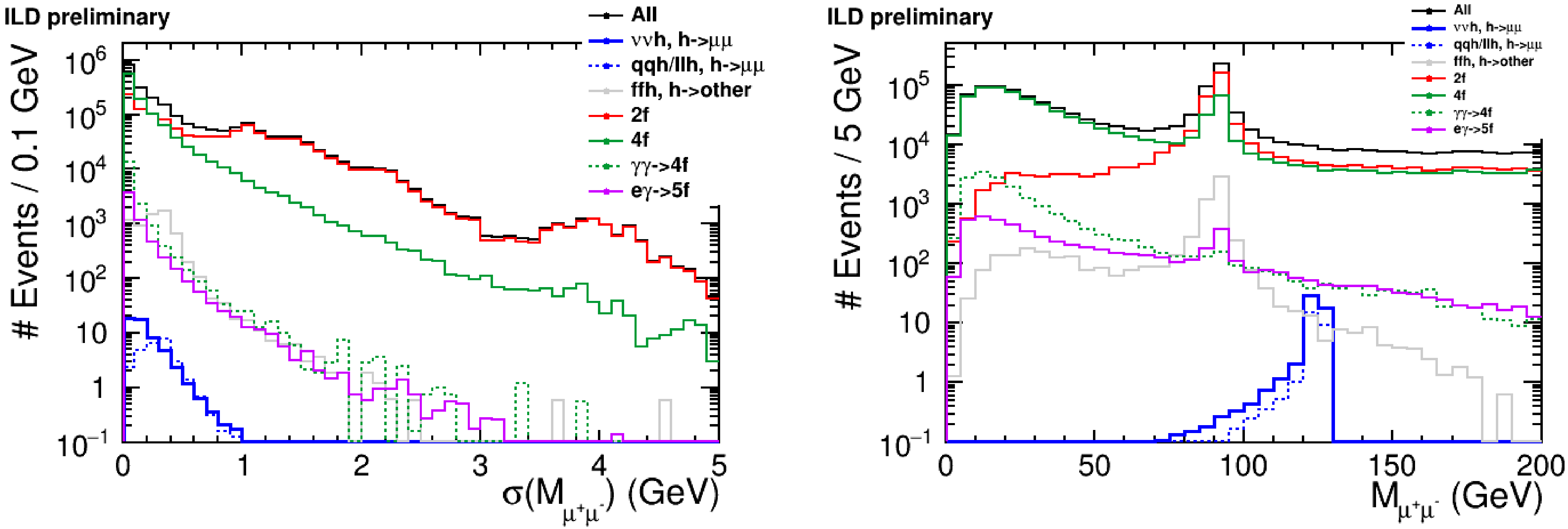
Impact of Momentum Resolution

- In this analysis, the **momentum resolution (P_t resolution)** is most important.
  - For high P_t muons
  - This affects $M_{\mu^+\mu^-}$ which is most important variable for physics analysis.

signal

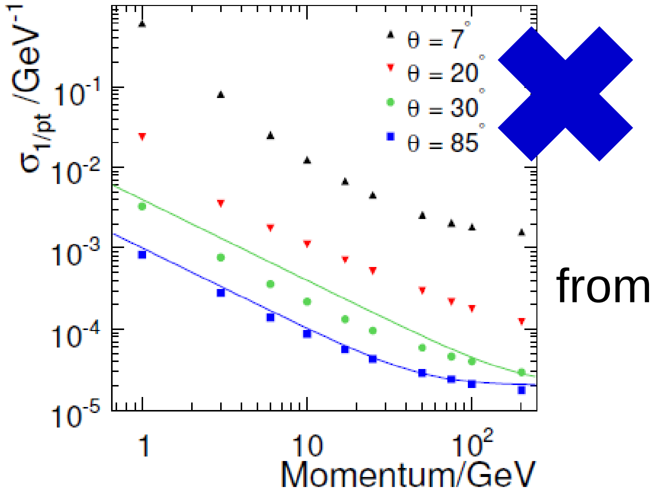
other colors: SM background

plots from nnh500-L



Impact of Momentum Resolution

- Studied what happens when we change momentum resolution artificially
  - 6 benchmark numbers
  - Smeared MCParticle momentum of isolated muon
  - Gaussian-smeared with **constant number**
    - no angular effects, no momentum dependencies



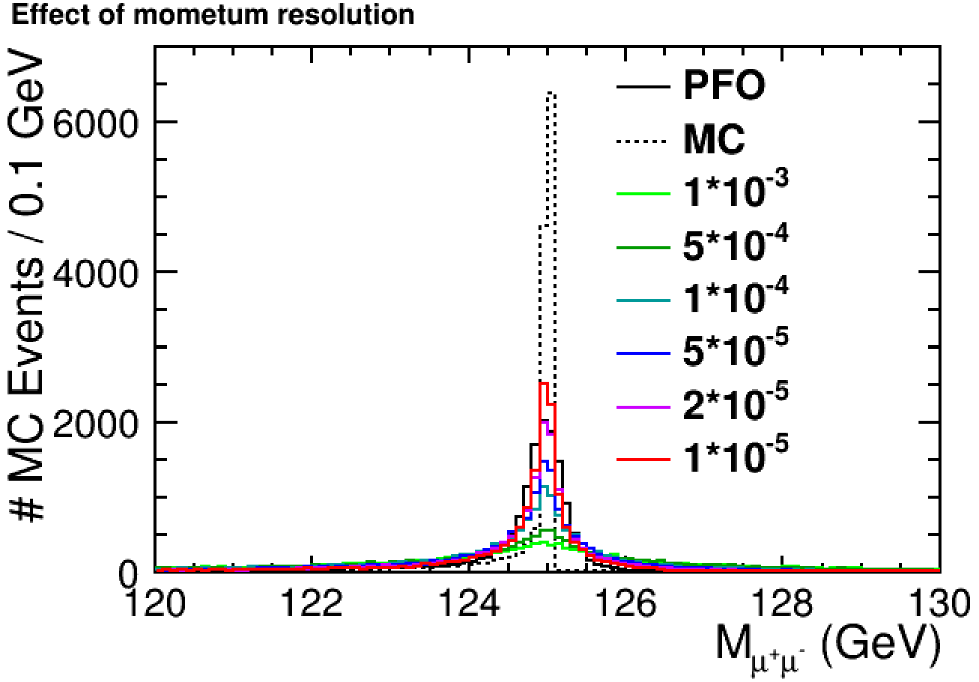
from DBD

Resolution (GeV^{-1})
$1 * 10^{-3}$
$5 * 10^{-4}$
$1 * 10^{-4}$
$5 * 10^{-5}$
$2 * 10^{-5}$
$1 * 10^{-5}$

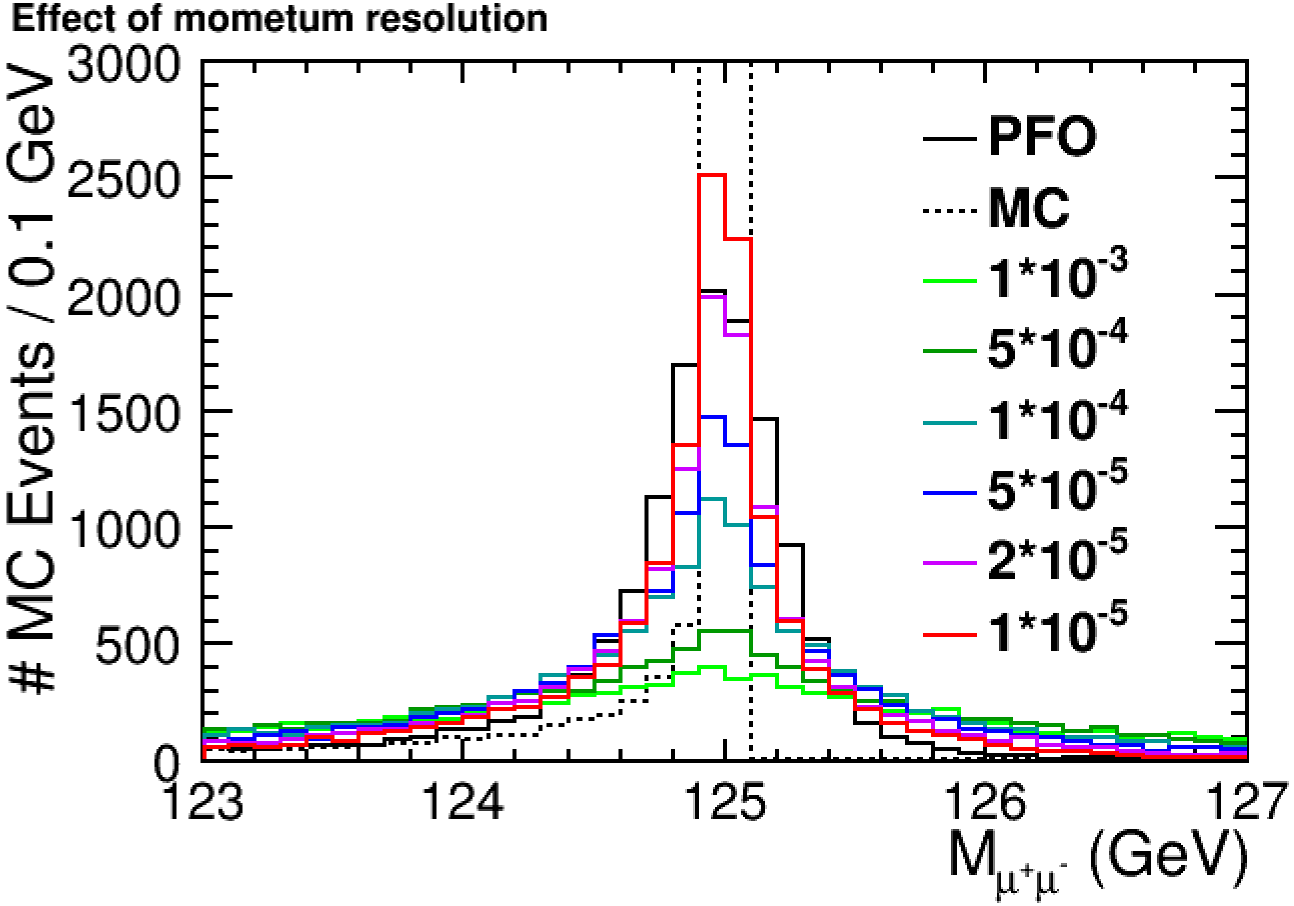
※not luminosity weighted

$M_{\mu^+\mu^-}$ Spectrum

overview

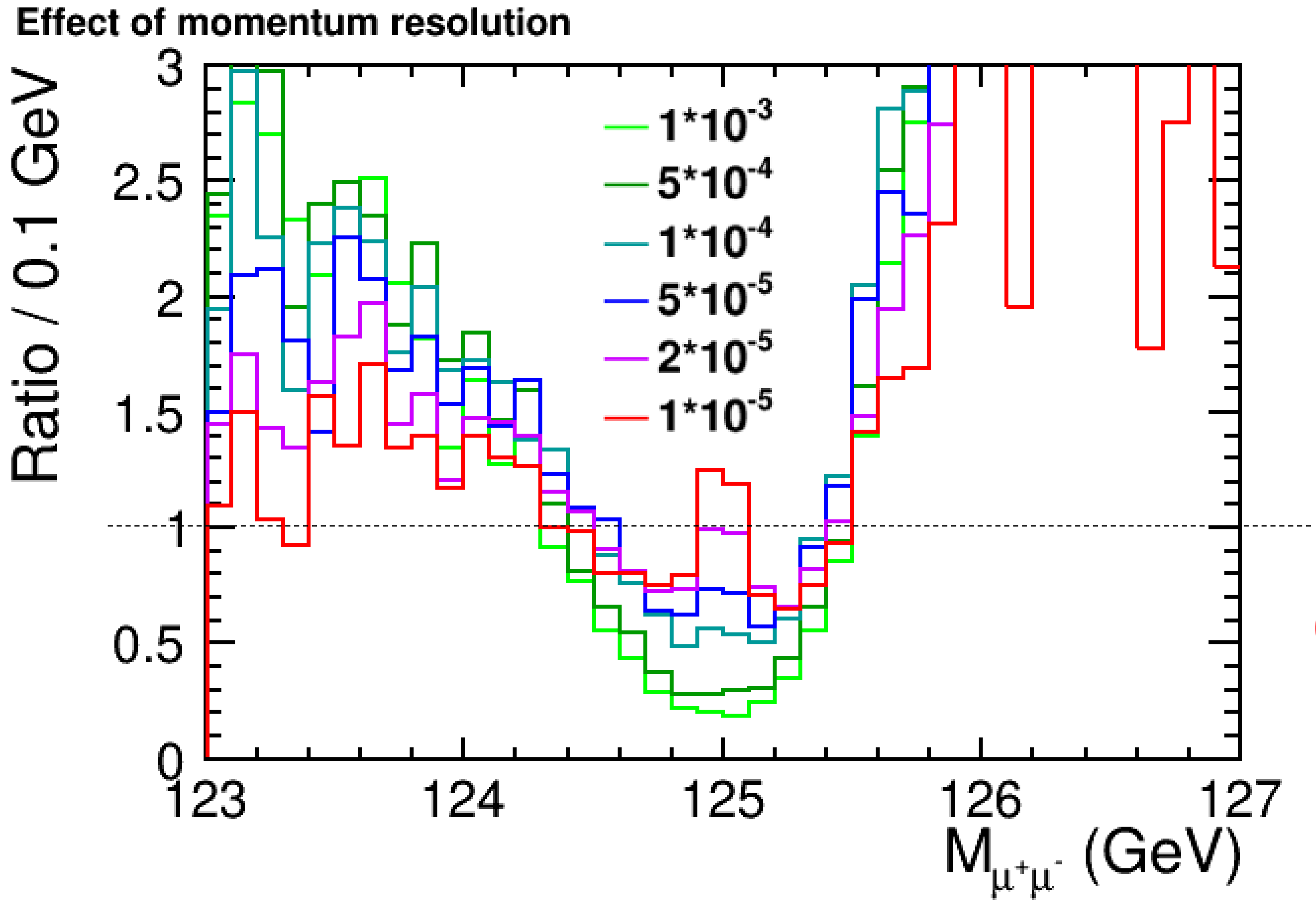


zoom up



※not luminosity weighted

Ratio Spectrum



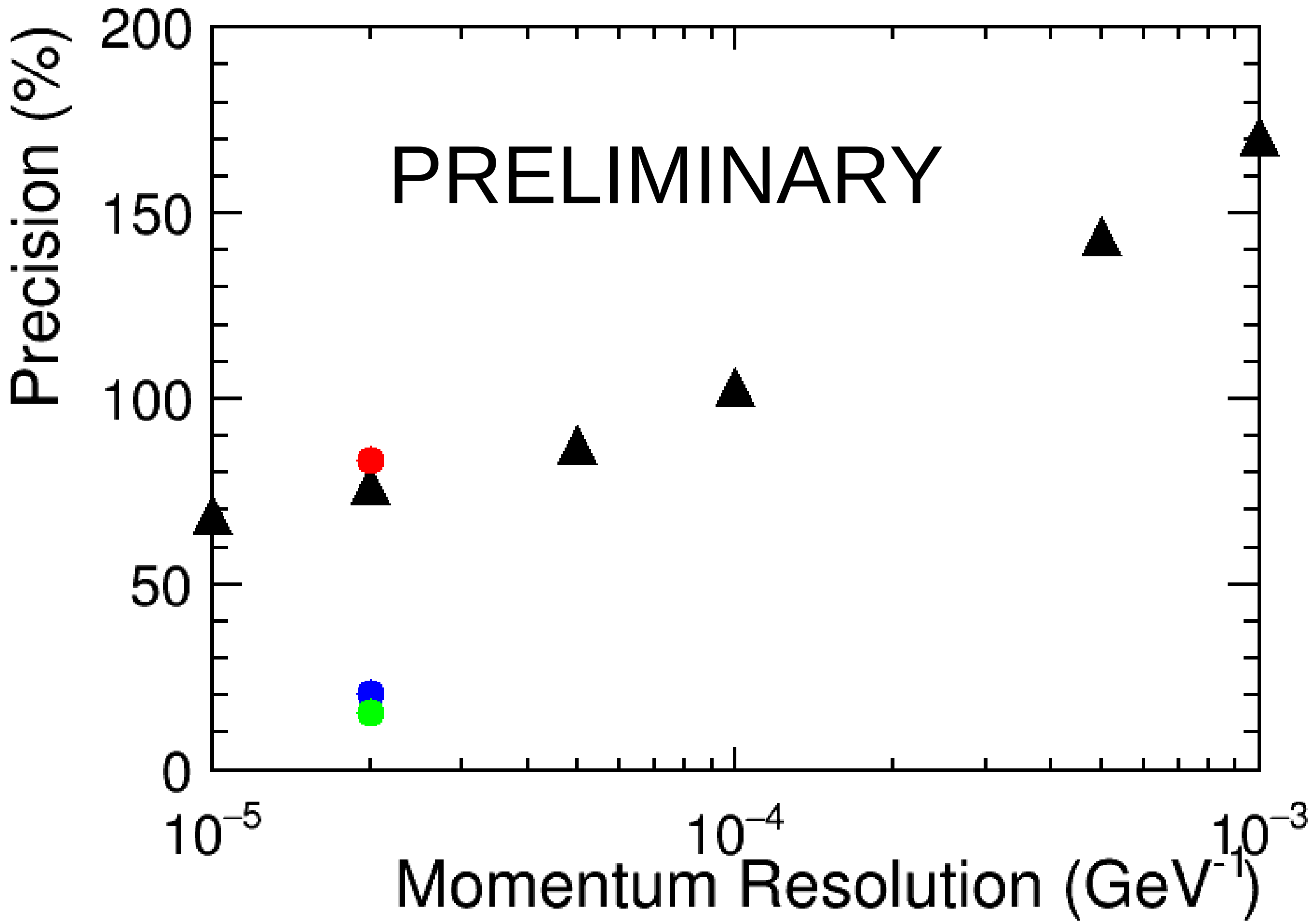
$$\text{Ratio} \equiv \frac{\text{smeared histogram}}{\text{PFO histogram}}$$

Clearly worse in bad momentum resolutions

Impact to Final Numbers

- It was only for $M_{\mu^+\mu^-}$, but in the end we are interested in the final precision numbers. $\frac{\Delta(\sigma\times\mathrm{BR})}{(\sigma\times\mathrm{BR})}$
- Studied final precision for various momentum resolution
  - Again 6 benchmark numbers (p8)
  - Just changed from $M_{\mu^+\mu^-}$ to $M_{\mu^+\mu^-}^{\mathrm{smear}}$ in toy MC
  - Studied only for nnh250-L, due to time limitation (and system problem)
    - clean channel: 2 muons + nothing, small $\gamma\gamma \to$ hadrons
    - new precuts are applied, pseudomass included in TMVA

Impact to Final Numbers (nnh250-L)



red: full analysis result 83.2%
black: benchmark points
($2*10^{-5}$: 76.9%)
blue: ILC250 20.5%
green: ILC250+500 15.4%

At $2*10^{-5}$:
black is ~10% better than red
angle/momentum dependencies?

Example:
$1*10^{-4}$ ---> $2*10^{-5}$: ~25% improvement

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

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

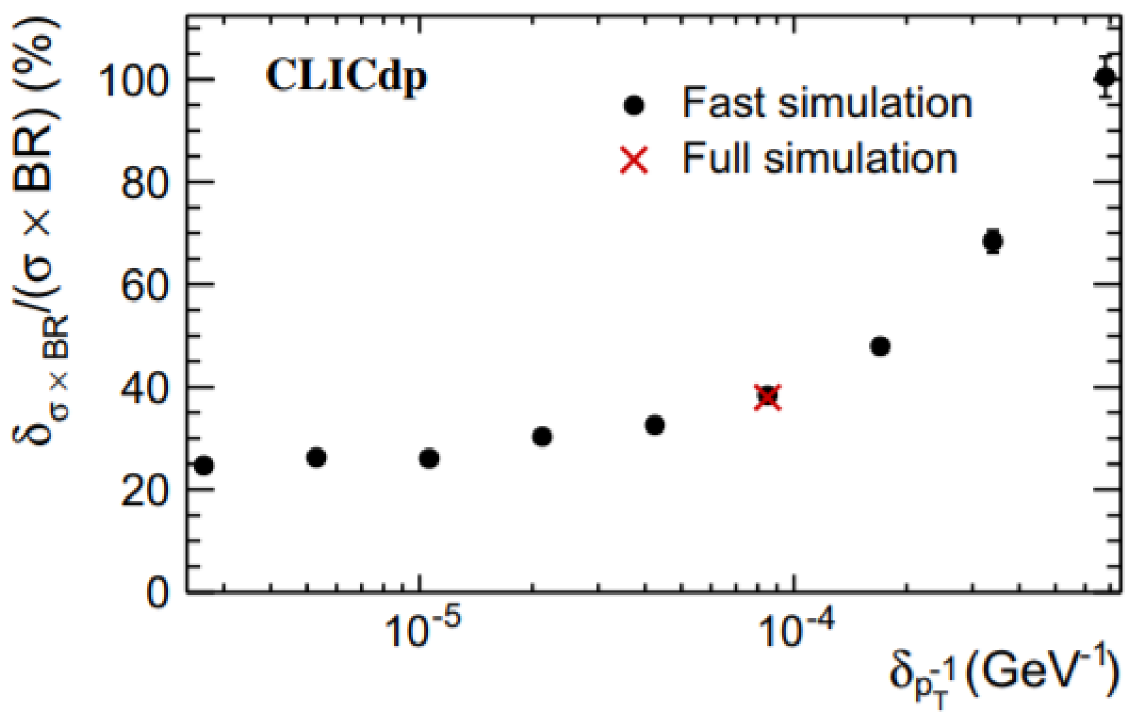


Fig. 11 Dependence of the relative statistical uncertainty of the $\sigma(H\nu\bar{\nu}) \times BR(H \to \mu^+\mu^-)$ on the transverse momentum resolution, δ_{1/p_T}, averaged over the signal sample in the whole detector

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%)

Summary & Plan

- Studied for impact of momentum resolution in BR($h \to \mu^+\mu^-$) measurement
  - similar tendency with CLIC, but saturation is not observed currently

- study more benchmark points and other channels
- work for further improvement and write a paper

BACKUP

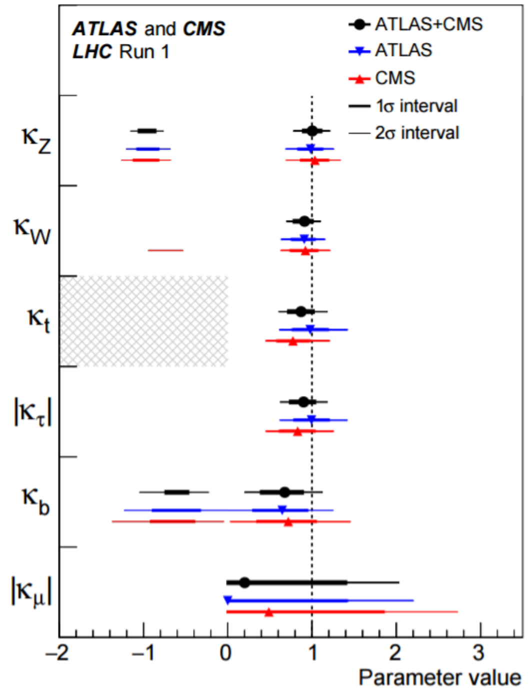
Introduction

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

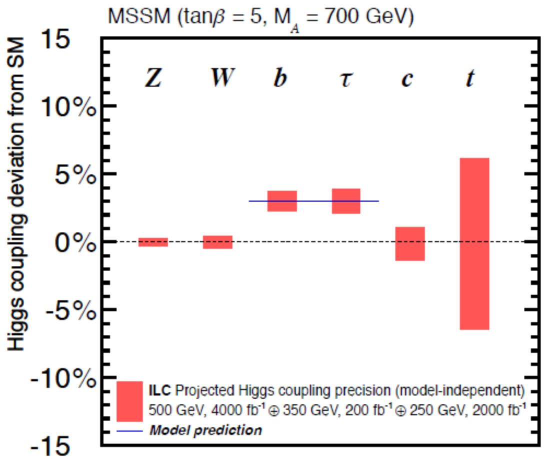
Goal: model-independent determination of EWSB sector with precise measurements
- mass-coupling relation
- any deviation shows the existence of BSM

⇩

ILC



JHEP **08** (2016) 045



arXiv: 1506.05992 [hep-ex]

Previous Studies

Everything performed at >= 1 TeV, or not realistic

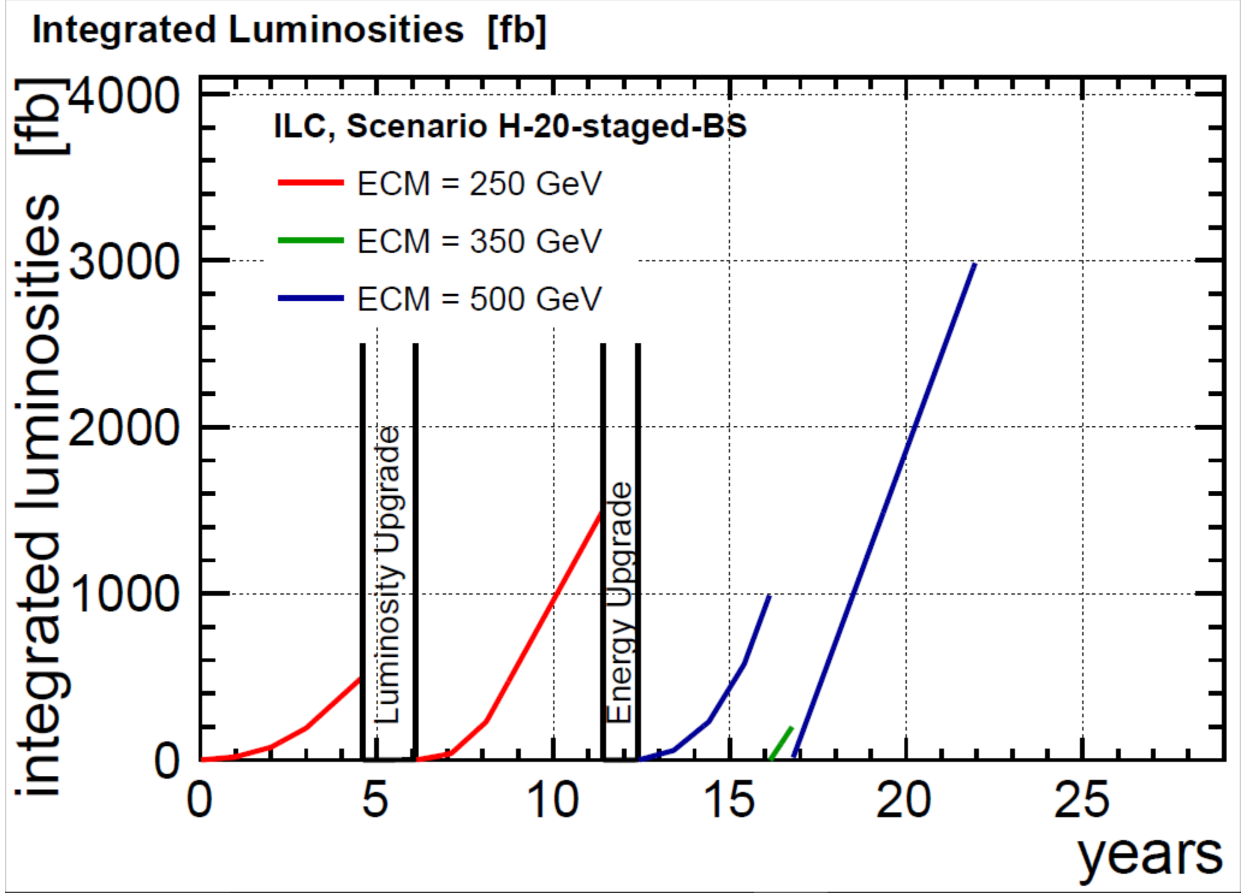
Reference	E_{CM}	beam pol. $P(e^-, e^+)$	$\int Ldt$	$\frac{\Delta(\sigma \times BR)}{(\sigma \times BR)}$	comment
LC-REP-2013-006	1 TeV	(-0.8, +0.2)	500 fb^{-1}	44%	ILC/ILD
arXiv:1306.6329 [hep-ex]	1 TeV	(-0.8, +0.2)	1000 fb^{-1}	32%	ILC/SiD
arXiv:1603.04718 [hep-ex]	1 TeV	(-0.8, +0.2)	500 fb^{-1}	36%	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

arXiv:1710.07621 [hep-ex]

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



staging running scenario

preferred scenario:
2000 fb^{-1} @ 250 GeV
200 fb^{-1} @ 350 GeV
4000 fb^{-1} @ 500 GeV

arXiv:1506.05992 [hep-ex]

Single Higgs Production

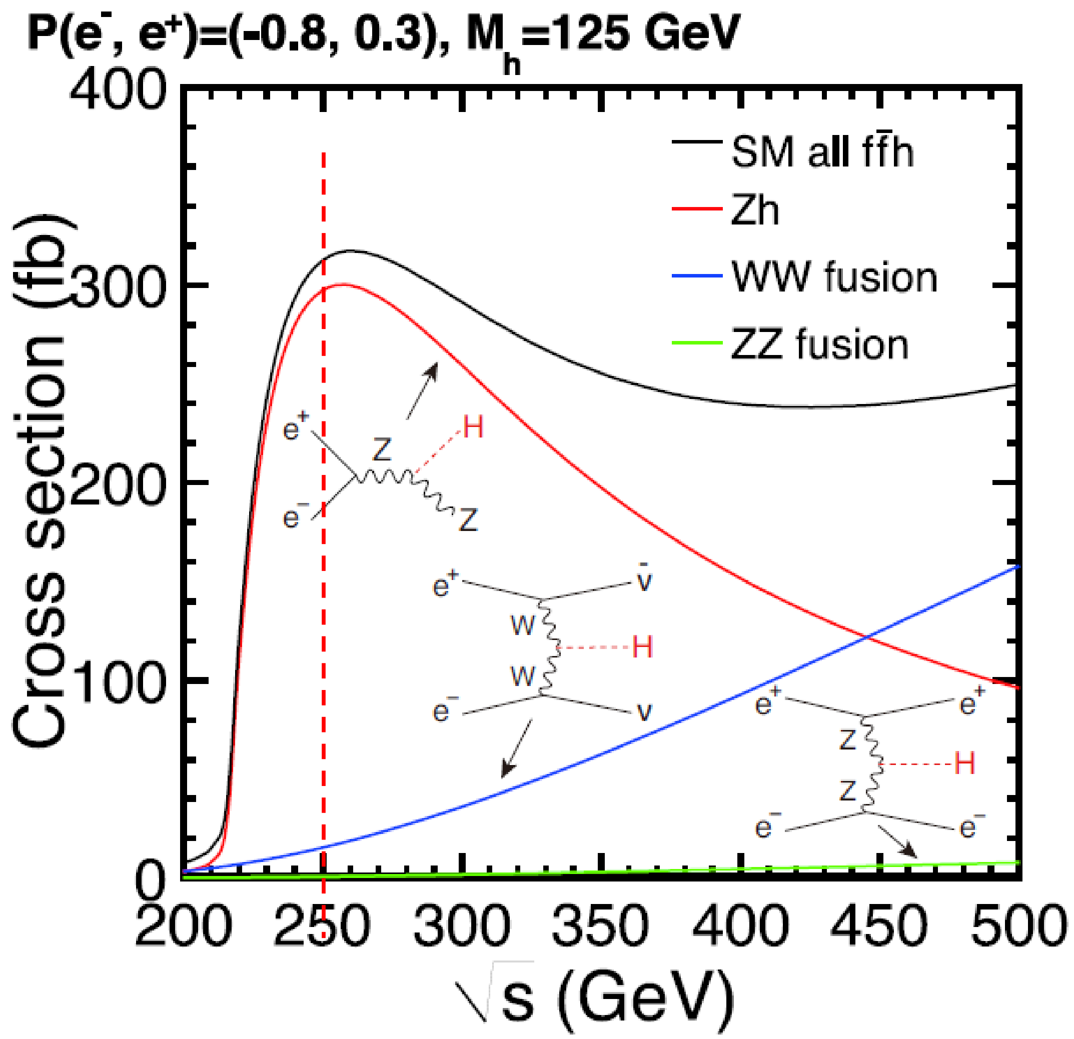
$\sqrt{s}$ = 250 GeV

Higgs-strahlung (Zh) dominant

$\sqrt{s}$ = 500 GeV

WW-fusion dominant

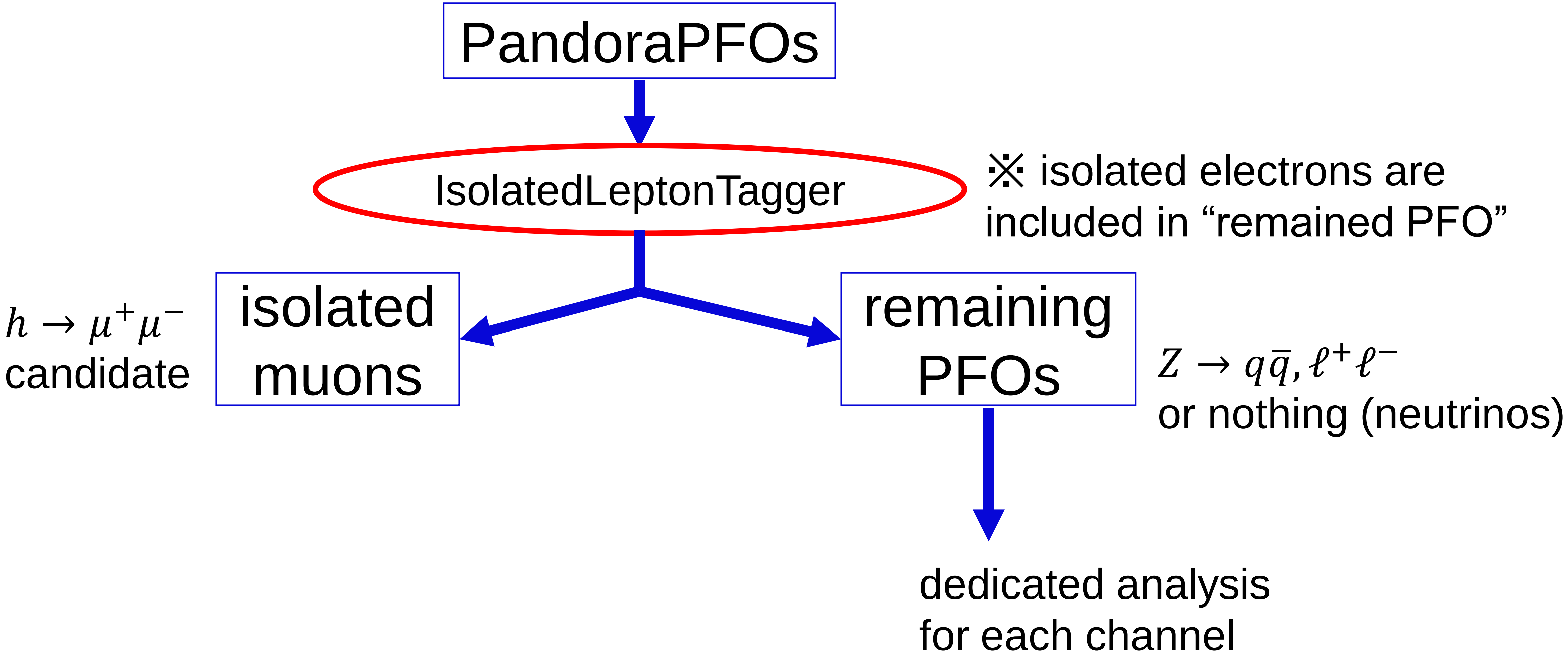
E_{CM}	process	beam pol.	$\int Ldt$ (fb^{-1})	# events
500	$\nu\bar{\nu}h$	L	1600	58
		R	1600	8
	$q\bar{q}h$	L	1600	25
		R	1600	16
250	$\nu\bar{\nu}h$	L	900	15
		R	900	8
	$q\bar{q}h$	L	900	41
		R	900	28



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

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

General Event Reconstruction



signal
other colors: SM background
plots from nnh500-L

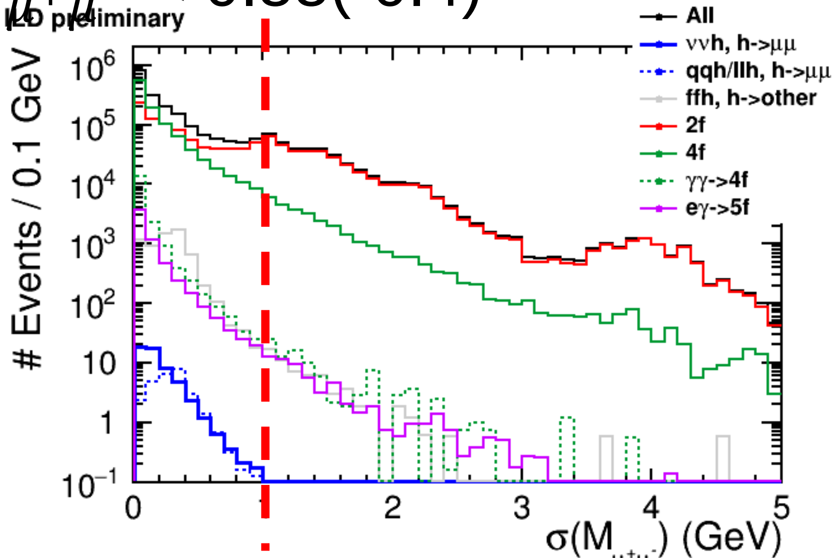
General Event Selection

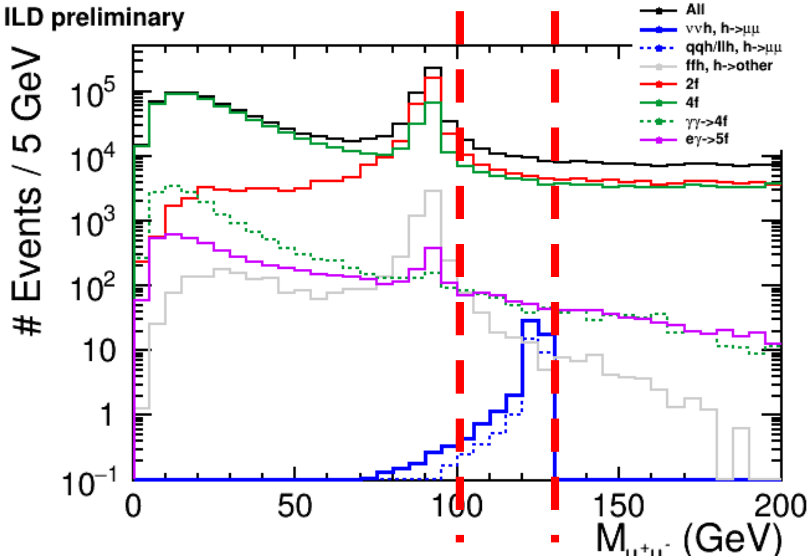
Selections at 500(250) GeV:

- $\# \mu^+ == 1$, $\# \mu^- == 1$
- $0.5 < \chi^2(\mu^\pm)$/Ndf < 1.5 → only select well-measured tracks
- $\sigma(M_{\mu^+\mu^-})$ < 1(0.5) GeV → only select well-measured muon pair
- $|d_0(\mu^\pm)|$ < 0.02 mm, $|d_0(\mu^-) - d_0(\mu^+)|$ < 0.02 mm
- $|z_0(\mu^\pm)|$ < 0.5 mm, $|z_0(\mu^-) - z_0(\mu^+)|$ < 0.5 mm

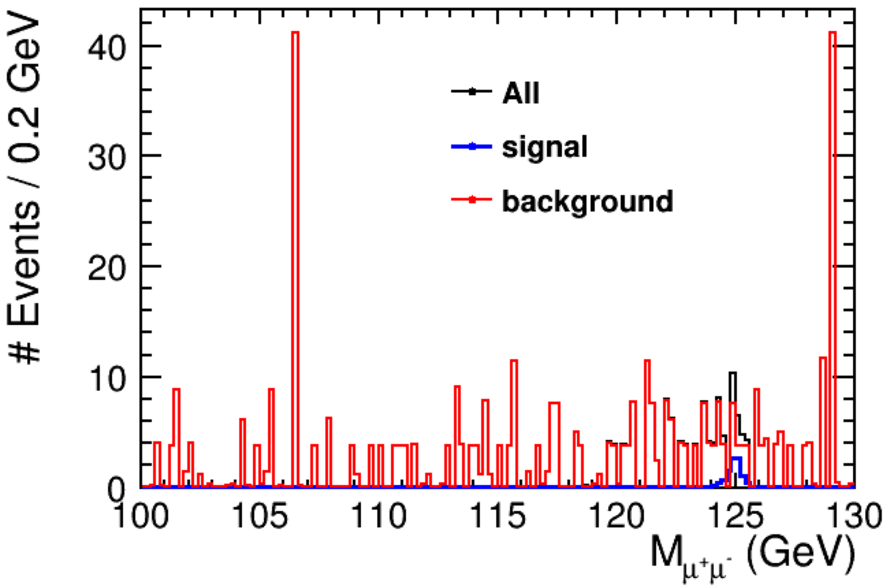
} only select prompt muons

- $100 < M_{\mu^+\mu^-}$ < 130 GeV → $h \to \mu^+\mu^-$ candidate
- $\cos\theta_{\mu^+\mu^-}$ < 0.55(-0.4)

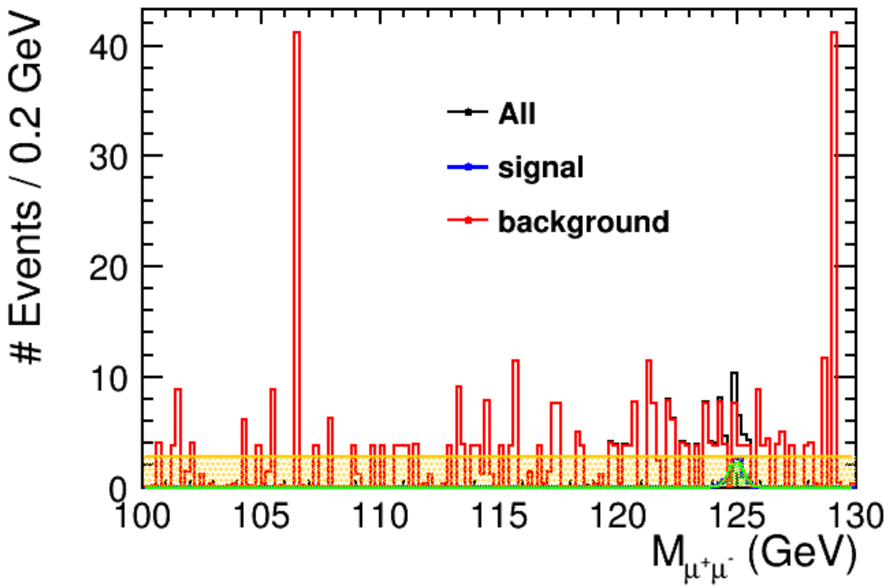




Toy MC Study (1)

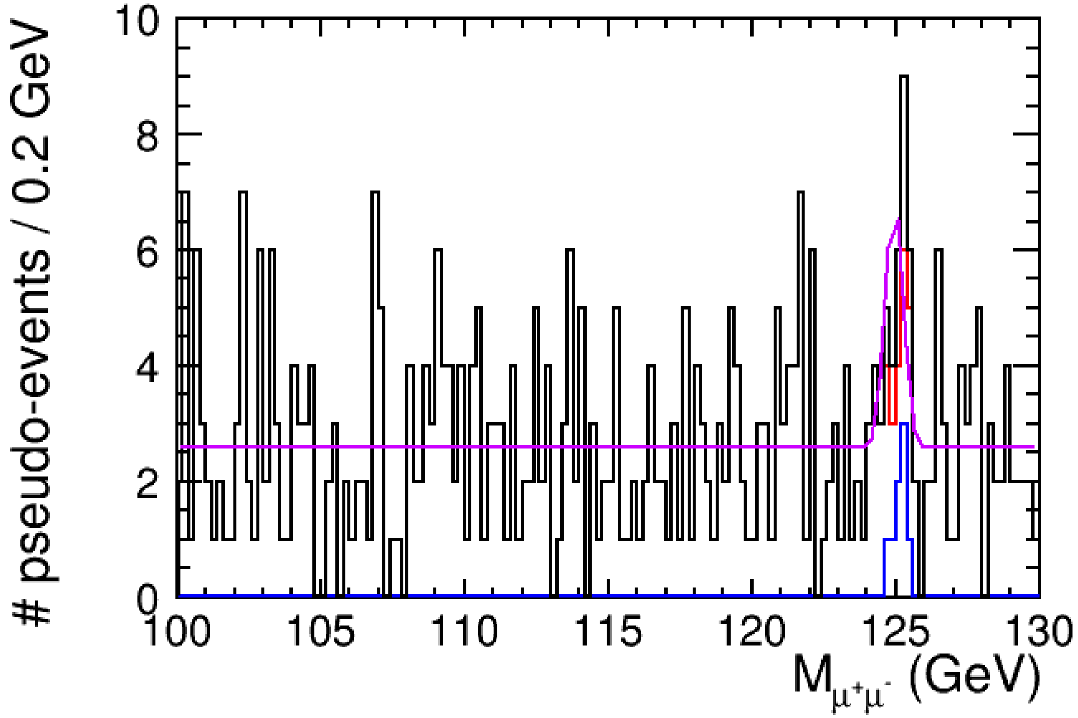


$M_{\mu^+\mu^-}$ spectrum after all cuts
spiky due to low MC statistics



fitting for toy MC
f_S: normalized Gaussian (green)
f_B: constant (yellow)

Toy MC Study (2)



pseudo experiment
blue: signal pseudo data
red: background pseudo data
black = blue + red
purple: result of fit with $f = Y_S f_S + Y_B f_B$
normalization considered

(1) both Y_S and Y_B free
(2) fix Y_B, Y_S is free

repeat 200000 times
obtain Y_S distribution

For Further Improvement

- ISR study (especially qqh and high energy case)
- Pseudomass for nnh
  - Used in OPAL experiment (EPJC **26**, 321-330 (2003))
  - Determine W mass in $W^+W^- \to \ell^+\nu\ell^-\nu$ process

$$M_\pm^2 = \frac{2}{|\overrightarrow{p_{\ell'}} + \overrightarrow{p_\ell}|^2}\left[(P\overrightarrow{p_{\ell'}} - Q\overrightarrow{p_\ell})(\overrightarrow{p_{\ell'}} + \overrightarrow{p_\ell}) \pm \sqrt{|\overrightarrow{p_{\ell'}} \times \overrightarrow{p_\ell}|^2\{|\overrightarrow{p_{\ell'}} + \overrightarrow{p_\ell}|^2(E_{\mathrm{beam}} - E_\ell)^2 - (P+Q)^2\}}\right]$$

$$P \equiv E_{\mathrm{beam}}E_\ell - E_\ell^2 + \frac{1}{2}m_\ell^2$$

$$Q \equiv -E_{\mathrm{beam}}E_{\ell'} - \overrightarrow{p_{\ell'}} \cdot \overrightarrow{p_\ell} + \frac{1}{2}m_{\ell'}^2$$

M_+ is sensitive to M_W