Analysis of $h \to \mu^+\mu^-$ at 500 GeV ILC with ILD detector

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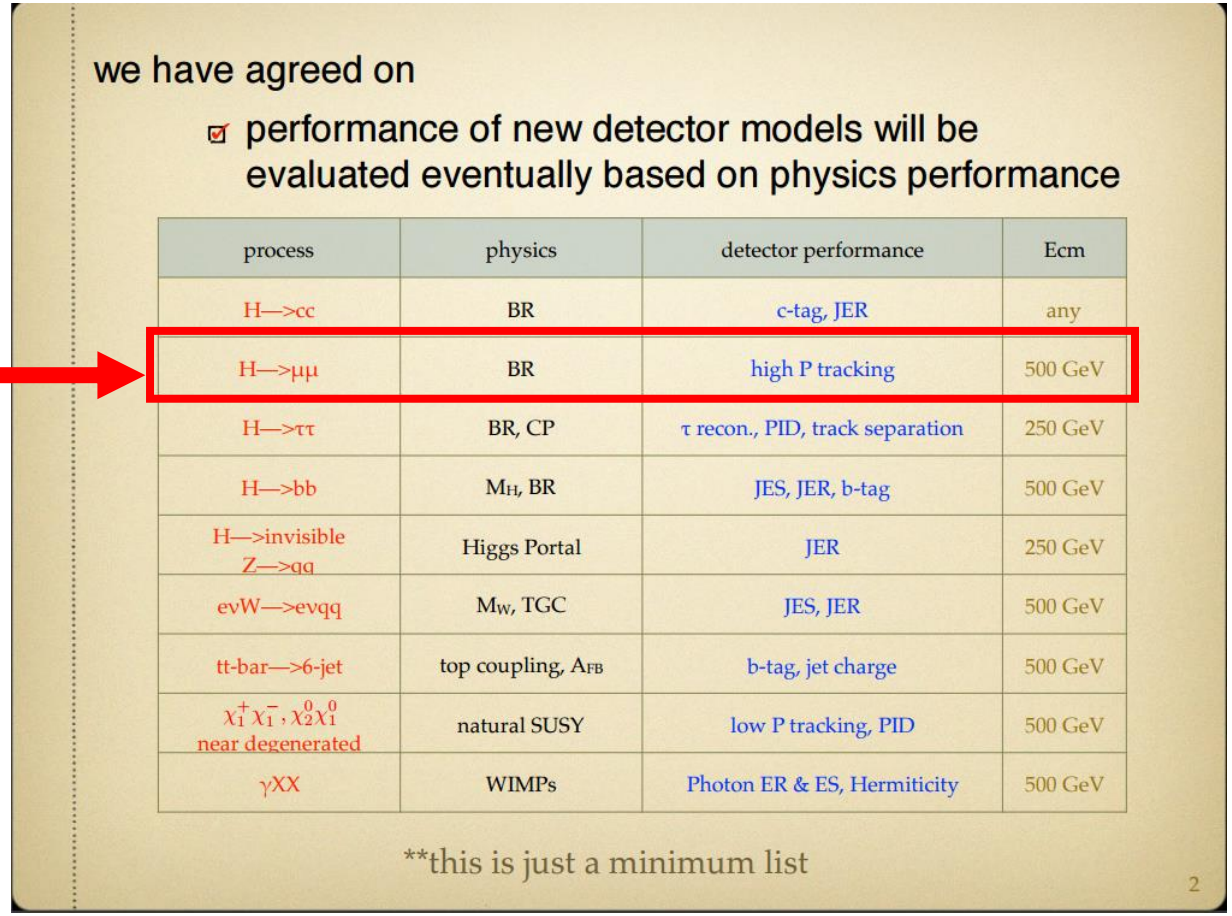
Quick Introduction

- This process is selected as one of the physics benchmark process of ILD optimization.



we have agreed on

- ☑ performance of new detector models will be evaluated eventually based on physics performance

process	physics	detector performance	Ecm
H—>cc	BR	c-tag, JER	any
H—>μμ	BR	high P tracking	500 GeV
H—>ττ	BR, CP	τ recon., PID, track separation	250 GeV
H—>bb	M_H, BR	JES, JER, b-tag	500 GeV
H—>invisible Z—>qq	Higgs Portal	JER	250 GeV
evW—>evqq	M_W, TGC	JES, JER	500 GeV
tt-bar—>6-jet	top coupling, A_{FB}	b-tag, jet charge	500 GeV
$\chi_1^+\chi_1^-$, $\chi_2^0\chi_1^0$ near degenerated	natural SUSY	low P tracking, PID	500 GeV
γXX	WIMPs	Photon ER & ES, Hermiticity	500 GeV

**this is just a minimum list

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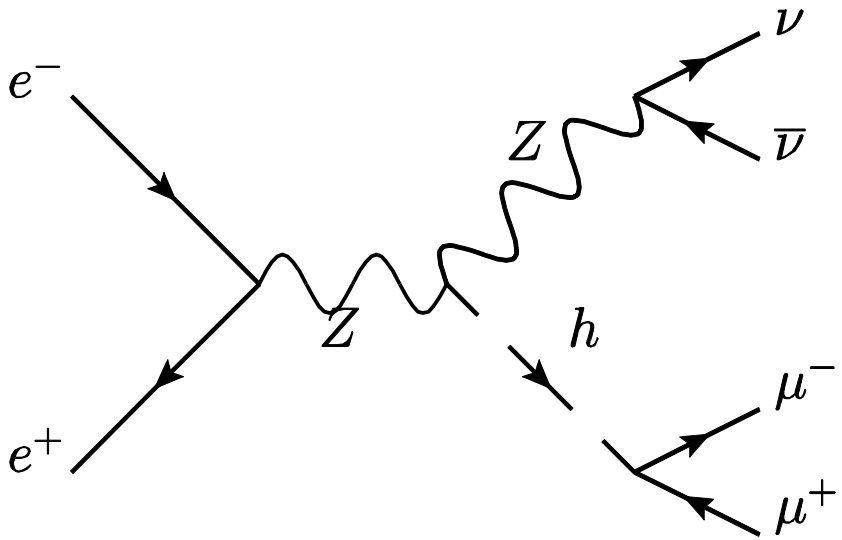
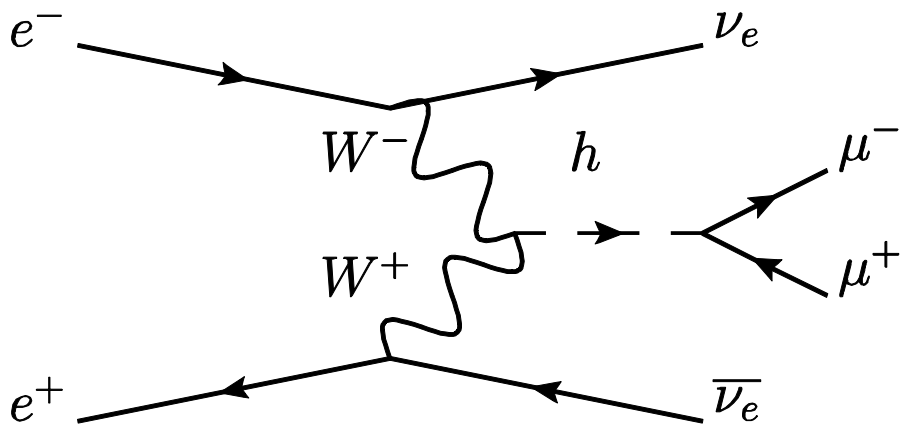
talk by J. Tian
ILD software and optimization workshop
(2016/Feb./22-26)

Signal Diagram, Expected Number of Events

signal: $e^+e^- \to \nu\bar{\nu}h, h \to \mu^+\mu^-$





expected events: **~60**

with 1600 fb^{-1}, $P(e^-, e^+)$ = (-0.8, +0.3) (“H20” scenario)

BR($h \to \mu^+\mu^-$) ~ **2.2*10^{-4}**

Numbers of $h \to \mu^+\mu^-$

We only have extrapolated numbers for 500 GeV ILC.

ref.: ILC operating scenario (arXiv:1506.07830 [hep-ex])

$\int \mathcal{L}dt$ at $\sqrt{s}$	250 fb^{-1} at 250 GeV		330 fb^{-1} at 350 GeV		500 fb^{-1} at 500 GeV		
$P(e^-,e^+)$	(-80%,+30%)						
production	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$t\bar{t}h$
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$						
$h \to \mu^+\mu^-$ [45]	72%	-	76%	140%	88%	72%	-

[45] C. Calancha, private communication.

scale to 1600 fb^{-1}:
~40% expected

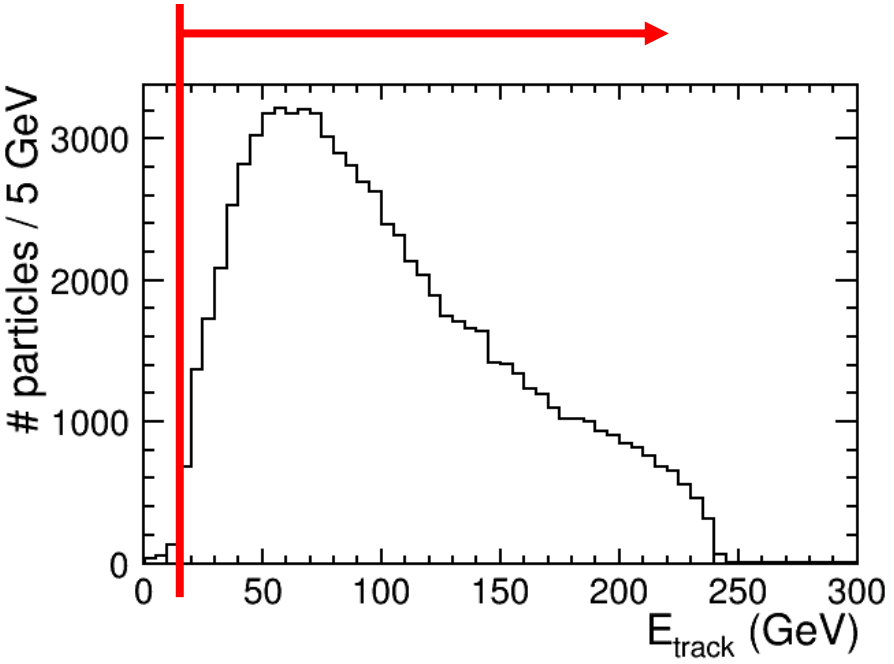
We have...
1 TeV ILC (DBD study by C. Calancha, using TMVA by M. F. Giannelli)
1.4 TeV CLIC (by G. Milutinovic-Dumbelovic et al.)

MC Samples & Analysis Setting

- Signal
  - STDHEP files were already generated
  - limited fully-simulated samples, we used SGV-simulated samples instead
  - SGV can be used many different types of detector configurations ---> good tool for detector optimization study
- Background
  - DBD samples
    - 2f, 4f (except WW/ZZ-hadronic), 5f, aa_4f, higgs_ffh
- ILCSOFT: v01-17-09

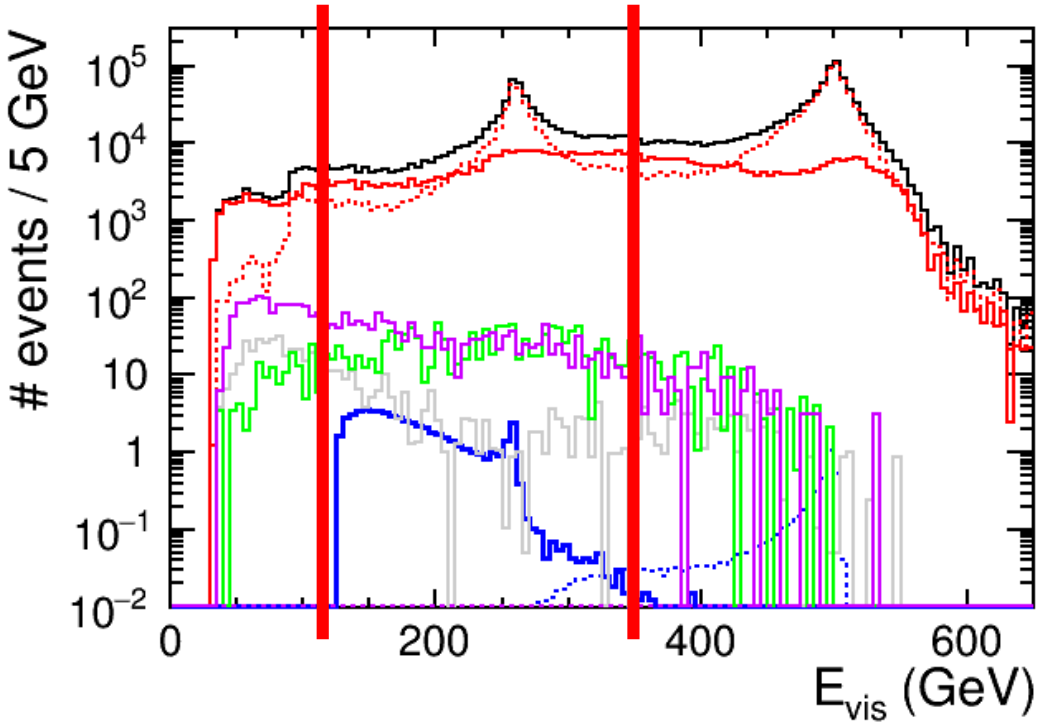
Muon Reconstruction

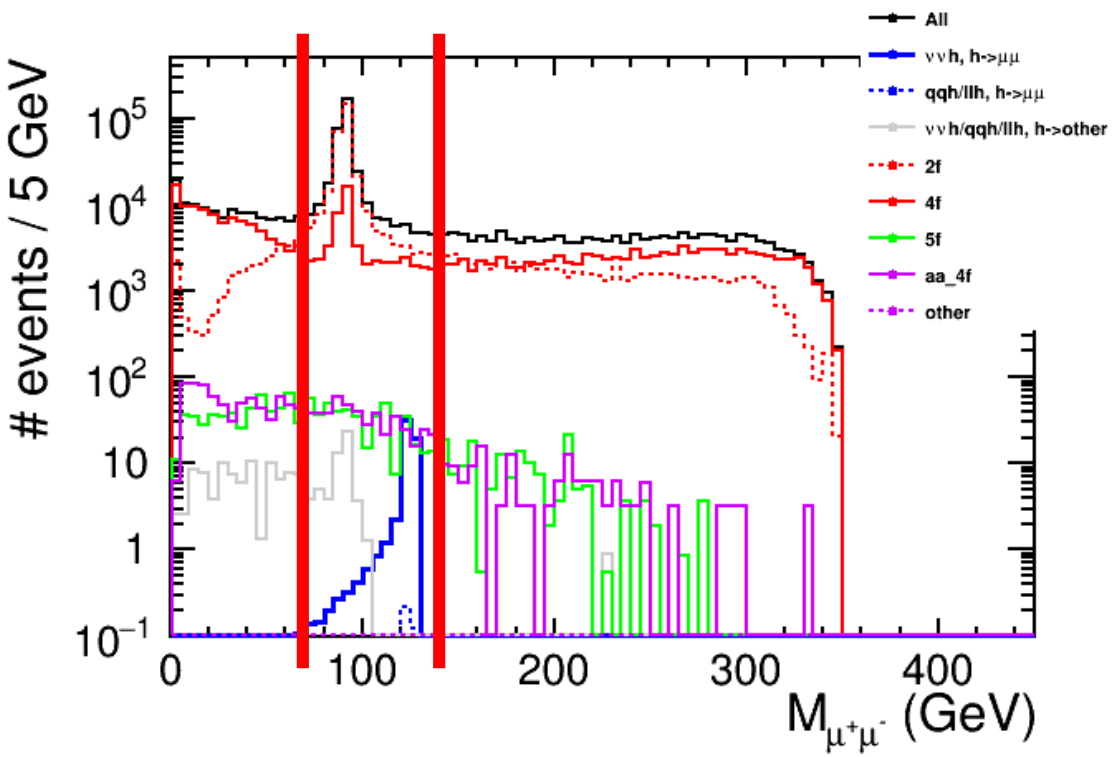
- Isolated muon selection is highly optimized in other studies, and further improvement is expected with using full PID. But does not work in SGV samples... ---> future work using fully-simulated samples
- Current: applied simple method
  - energy of charged track E_{track} > 15 GeV
  - E_{ECAL} / (E_{ECAL}+E_{HCAL}) < 0.5
  - (E_{ECAL}+E_{HCAL}) / P_{track} < 0.3
  - $\left|\frac{d_0}{\Delta d_0}\right|$ < 3



Precuts

one μ^+ && one μ^-, # tracks <= 4,
120 GeV < E_{vis} < 350 GeV, 70 GeV < $M_{\mu^+\mu^-}$ < 140 GeV

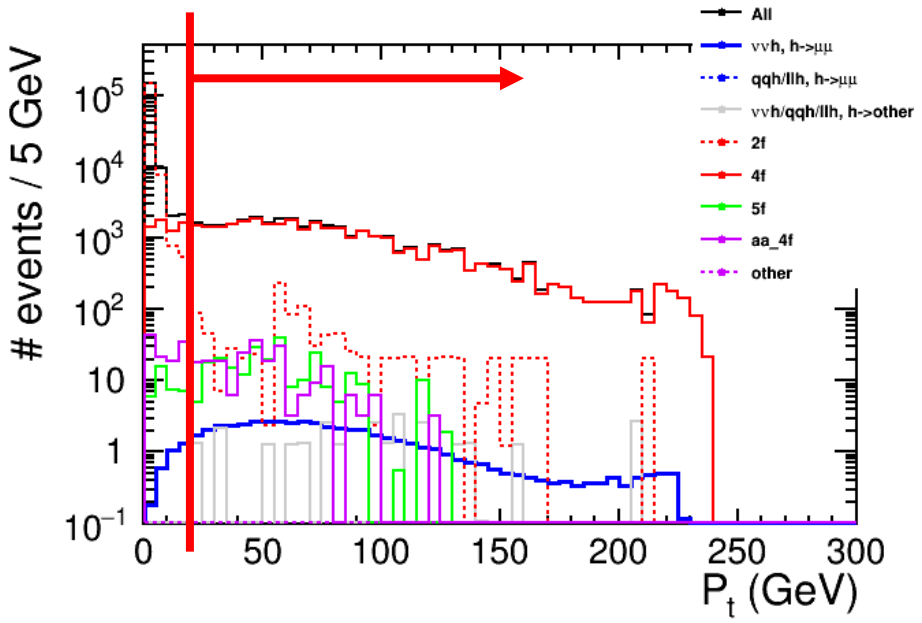


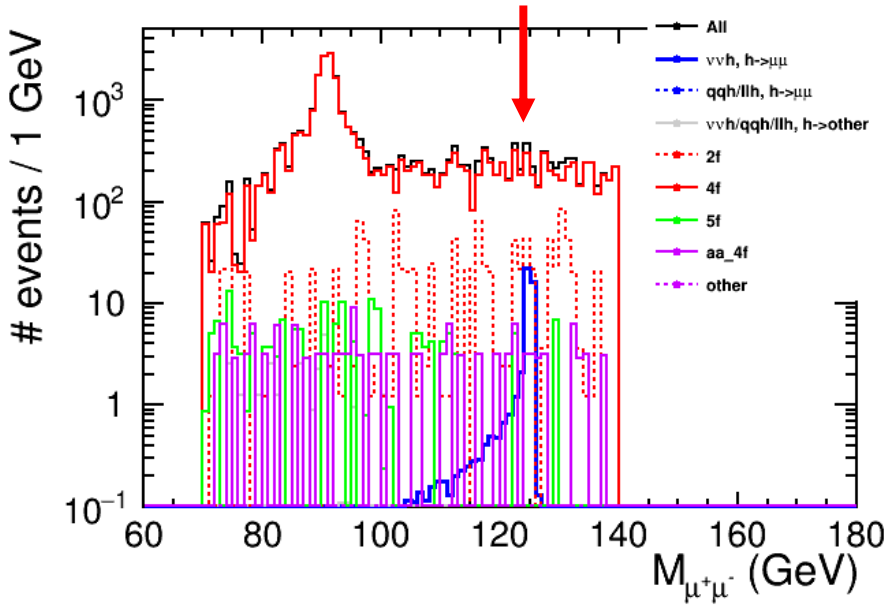


selection efficiency of signal: 97.4%

First Trial

- 125 GeV < E_{vis} < 260 GeV
- P_t > 20 GeV
- $|\cos\theta_{\mathrm{thrustaxis}}| < 0.94$
- 124 GeV < $M_{\mu^+\mu^-}$ < 126 GeV





First Trial

500 GeV, 1600 fb^{-1}, $P(e^-, e^+)$ = (-0.8, +0.3)

	signal $\nu\nu h$	qqh $\ell\ell h$	ffh, $h \nrightarrow \mu\mu$	2f	4f	5f	aa_4f
No cut	60.0	20.2	$4.120*10^5$	$4.273*10^7$	$3.802*10^7$	$2.208*10^5$	$3.356*10^5$
Precuts	58.5	0.4	54.3	$2.994*10^5$	$5.170*10^4$	442.1	468.0
Cut	38.6	0.02	0	64.2	482.4	0	6.3

signal efficiency = 64.3%

significance $\frac{S}{\sqrt{S+B}}$ = 1.6, precision $\frac{\Delta(\sigma\times\mathrm{BR})}{(\sigma\times\mathrm{BR})}$ = 63%

major bkg.: 2f_z_l, 4f_ww_l, 4f_zzorww_l

※weight (= 1600/generated lumi.) is really high! (~20)

For Further Improvement: $\sigma\left(M_{\mu^+\mu^-}\right)$

error of measured $M_{\mu^+\mu^-}$:

$$\sigma^2\left(M_{\mu^+\mu^-}\right) = \frac{1}{M^2_{\mu^+\mu^-}}\left[P_1^T \Sigma_2 P_1 + P_2^T \Sigma_1 P_2\right]$$

P: a matrix filled with 4-momentum of muon

$$P_i: \begin{pmatrix} E_i \\ p_{xi} \\ p_{yi} \\ p_{zi} \end{pmatrix}$$

$$P_i^T: \begin{pmatrix} E_i & -p_{xi} & -p_{yi} & -p_{zi} \end{pmatrix}$$

Σ_i: covariance matrix in momenta space of muon i

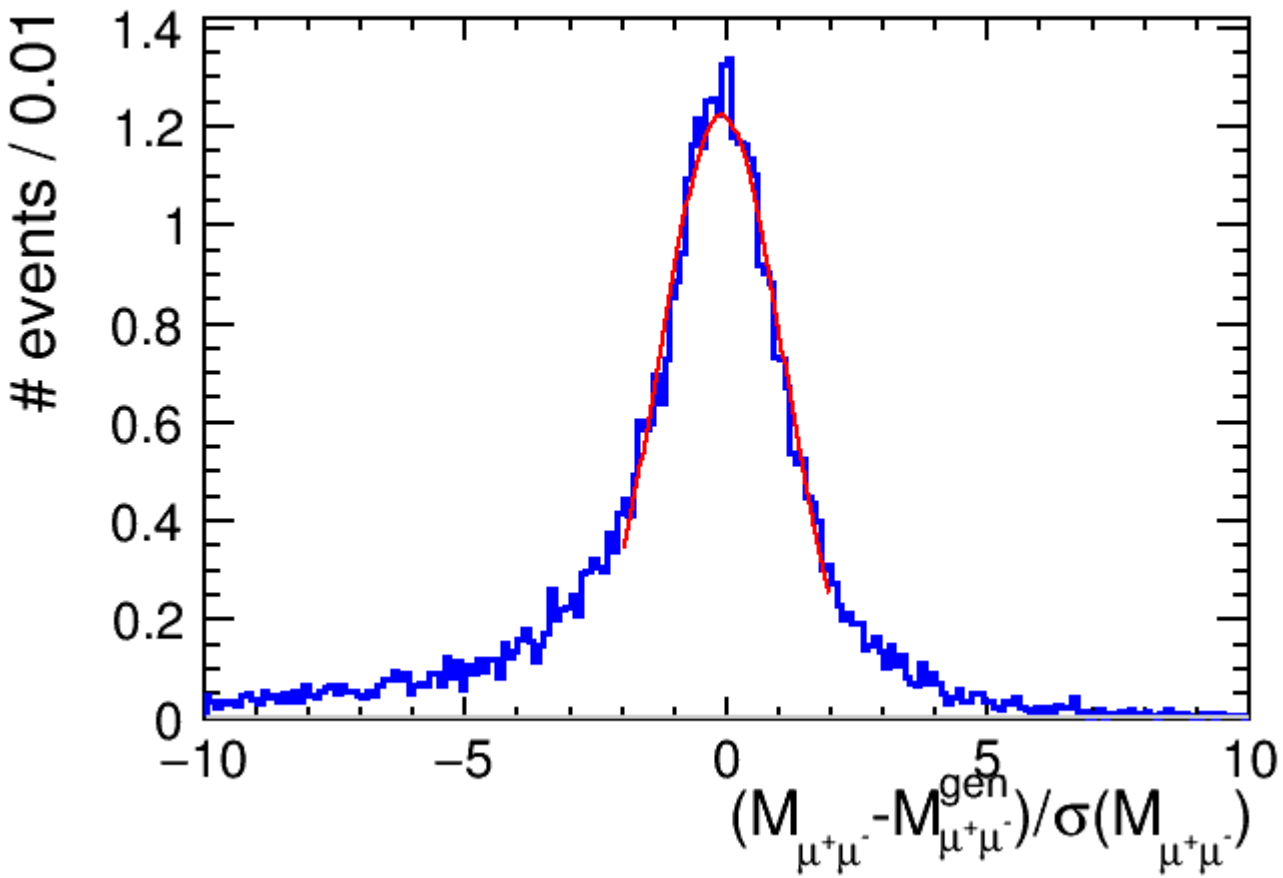
$$\Sigma_i \equiv \begin{pmatrix} \mathrm{cov}[E,E] & \mathrm{cov}[E,p_x] & \mathrm{cov}[E,p_y] & \mathrm{cov}[E,p_z] \\ \mathrm{cov}[E,p_x] & \mathrm{cov}[p_x,p_x] & \mathrm{cov}[p_x,p_y] & \mathrm{cov}[p_x,p_z] \\ \mathrm{cov}[E,p_y] & \mathrm{cov}[p_x,p_y] & \mathrm{cov}[p_y,p_y] & \mathrm{cov}[p_y,p_z] \\ \mathrm{cov}[E,p_z] & \mathrm{cov}[p_x,p_z] & \mathrm{cov}[p_y,p_z] & \mathrm{cov}[p_z,p_z] \end{pmatrix}$$

$h \to \mu^+\mu^-$: small σ when $M_{\mu^+\mu^-} \sim M_h$

background: no peak in small σ when $M_{\mu^+\mu^-} \sim M_h$

see backup for details

Pull distribution ($\nu\nu h, h \to \mu^+\mu^-$)



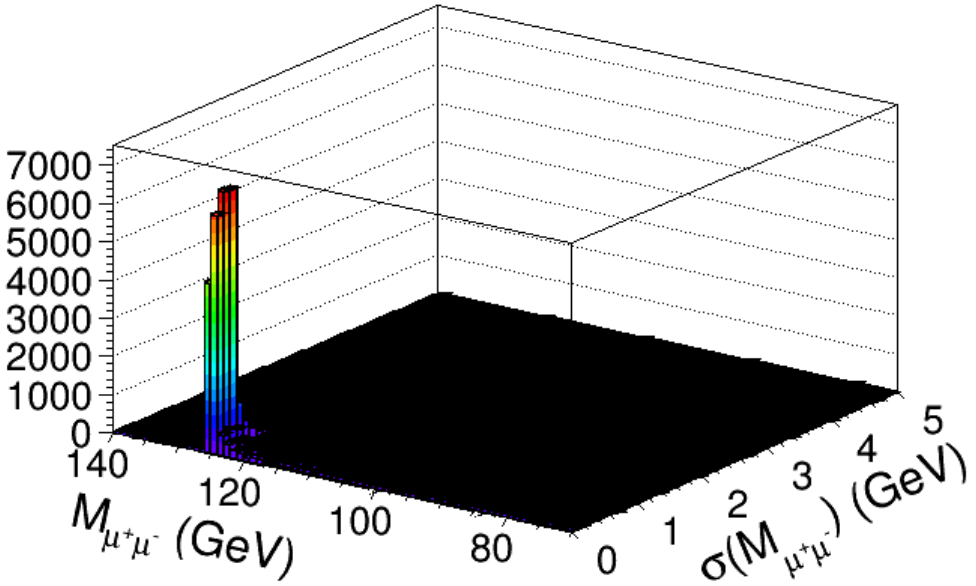
after precuts (in p7)
Gaussian fit: [-2,2]
sigma = 1.18 +- 0.03

- first analysis-level application of FourMomentumCovMat
- width of pull distribution looks fine
- tails need to be studied, FSR?

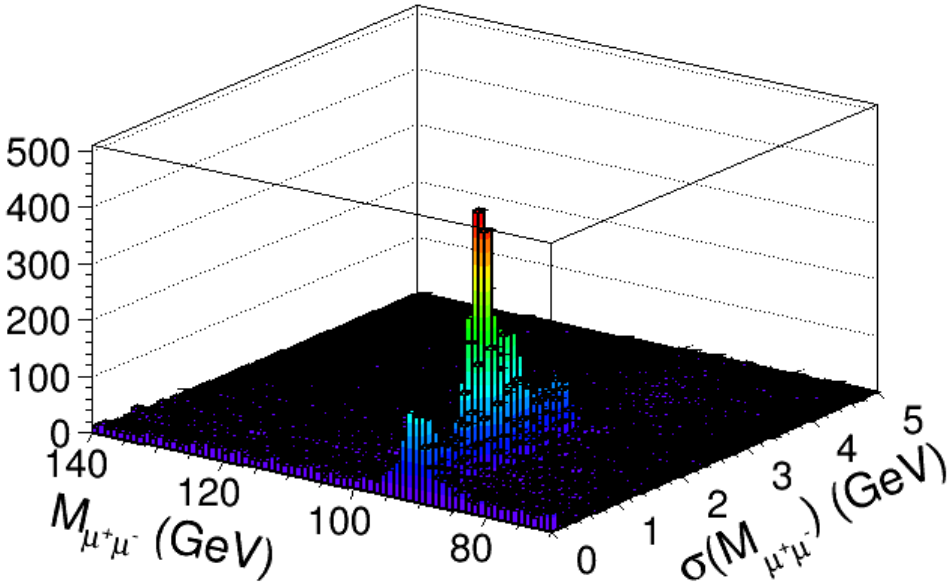
$M_{\mu^+\mu^-}$ v.s. $\sigma\left(M_{\mu^+\mu^-}\right)$

※# of MC events after precuts (in p7), not luminosity weighted

$h \to \mu^+\mu^-$ samples



background

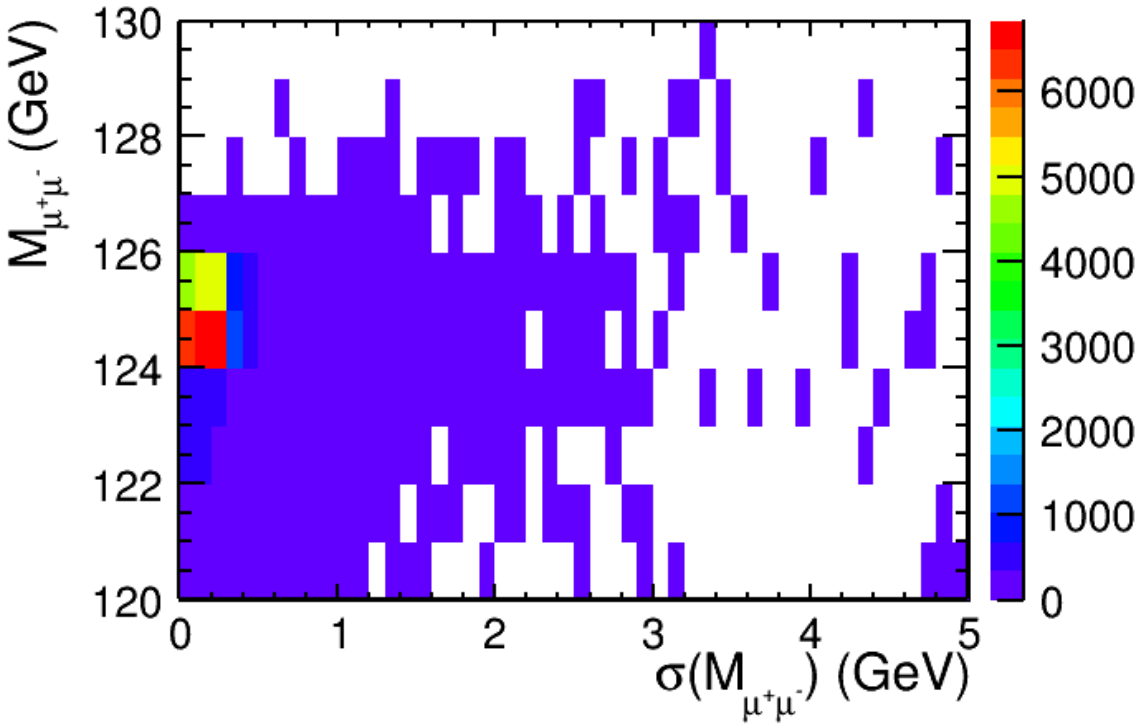


- hot spot in small $\sigma\left(M_{\mu^+\mu^-}\right)$ around $M_{\mu^+\mu^-} \simeq M_h$ in $h \to \mu^+\mu^-$ samples, as expected
- peak around M_z with larger $\sigma\left(M_{\mu^+\mu^-}\right)$ in background (probably going forward) and no peak in signal region

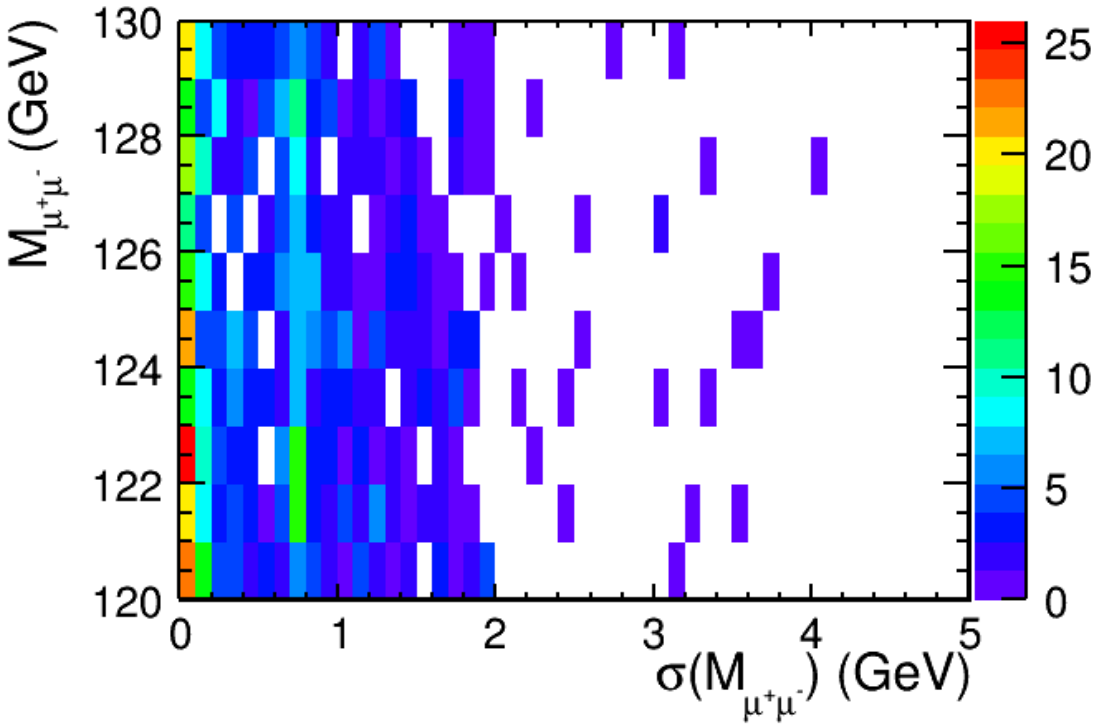
Zoom: $M_{\mu+\mu-}$ v.s. $\sigma\left(M_{\mu+\mu-}\right)$

※# of MC events after precuts (in p7), not luminosity weighted
zoom in M_h region

$h \to \mu^+\mu^-$ samples



background



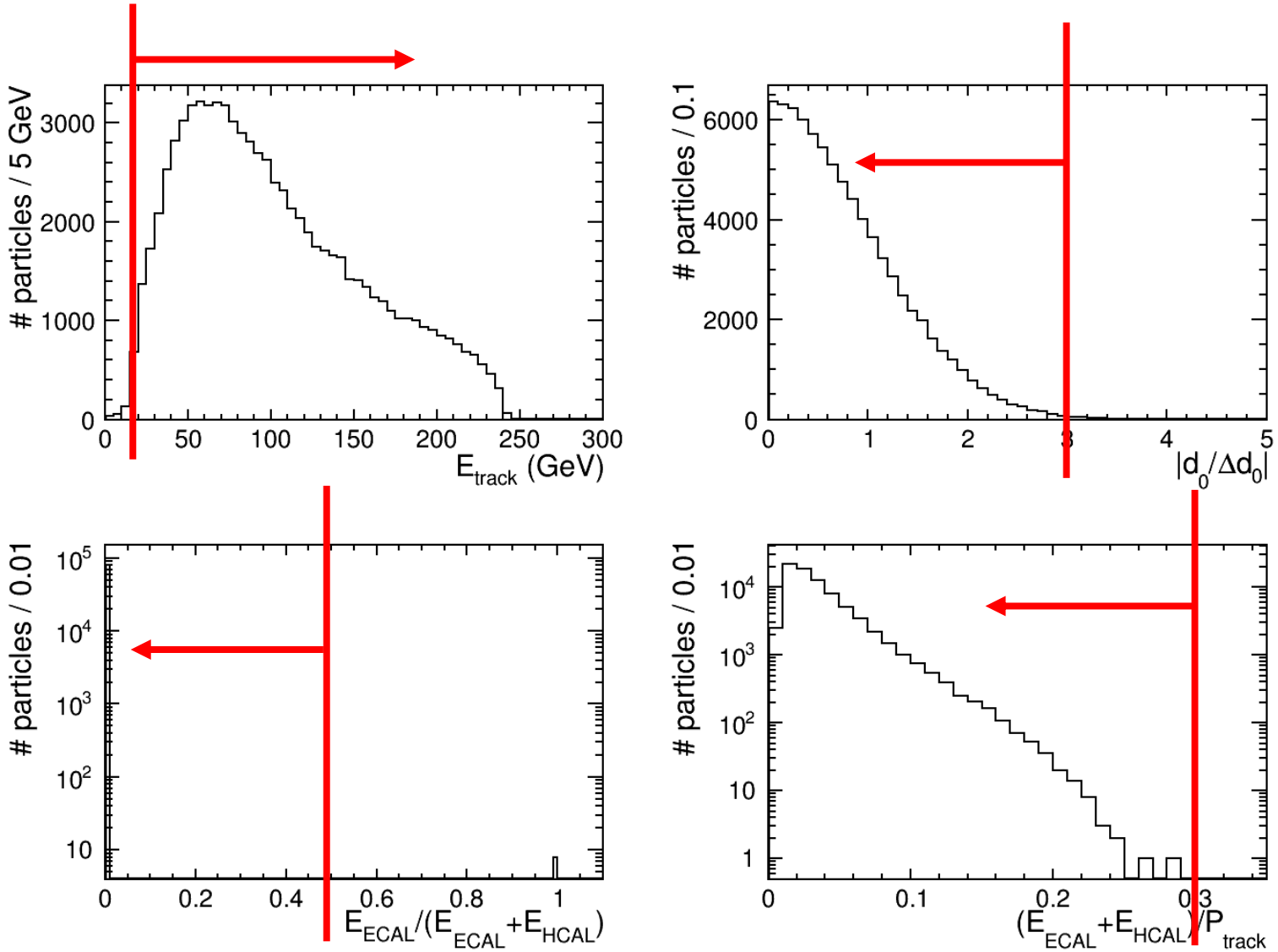
Summary & Next Step

- Analysis of $h \to \mu^+\mu^-$ at 500 GeV is just started.
- $\sigma\left(M_{\mu^+\mu^-}\right)$ using covariance matrix in momenta space is calculated, and to be included in analysis.

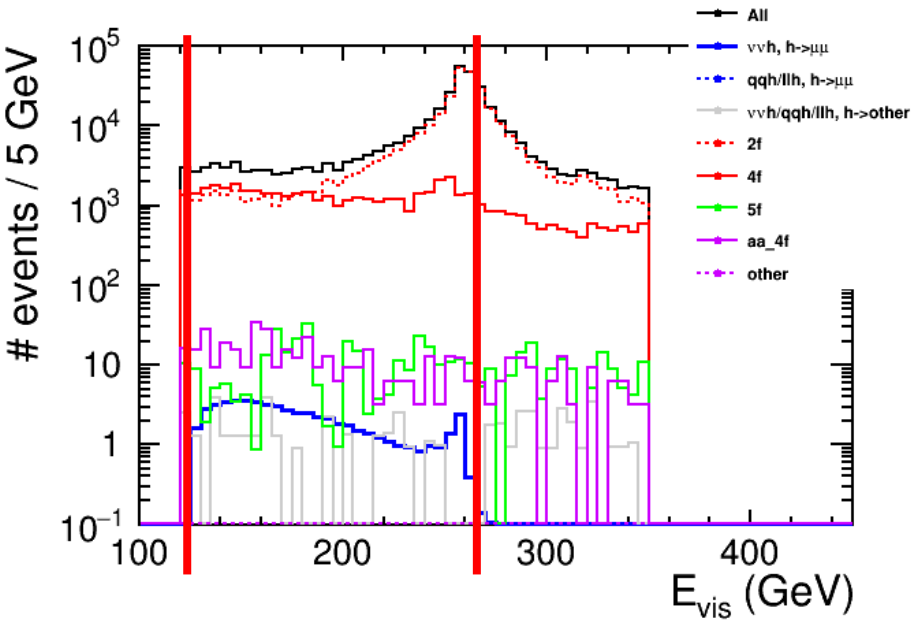
- This process is a good benchmark of tracking, and can be studied using SGV for various detector configuration.
- Later: full simulation study with selected detector configuration

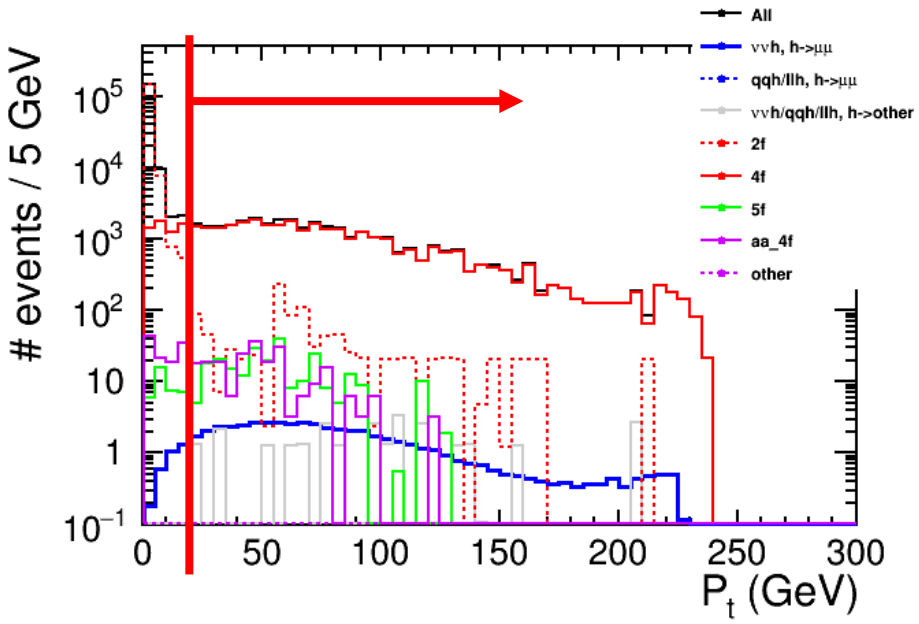
BACKUP SLIDES

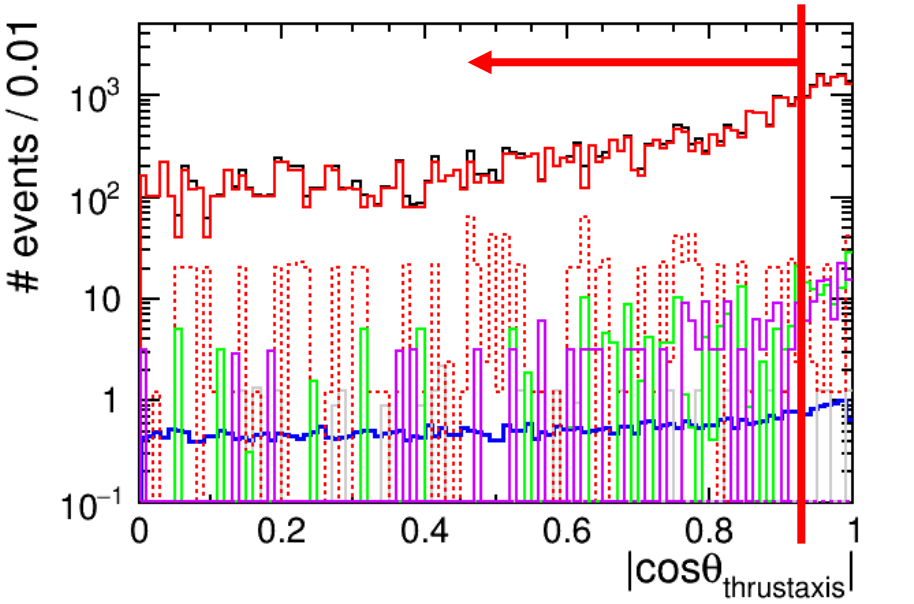
Muon Reconstruction

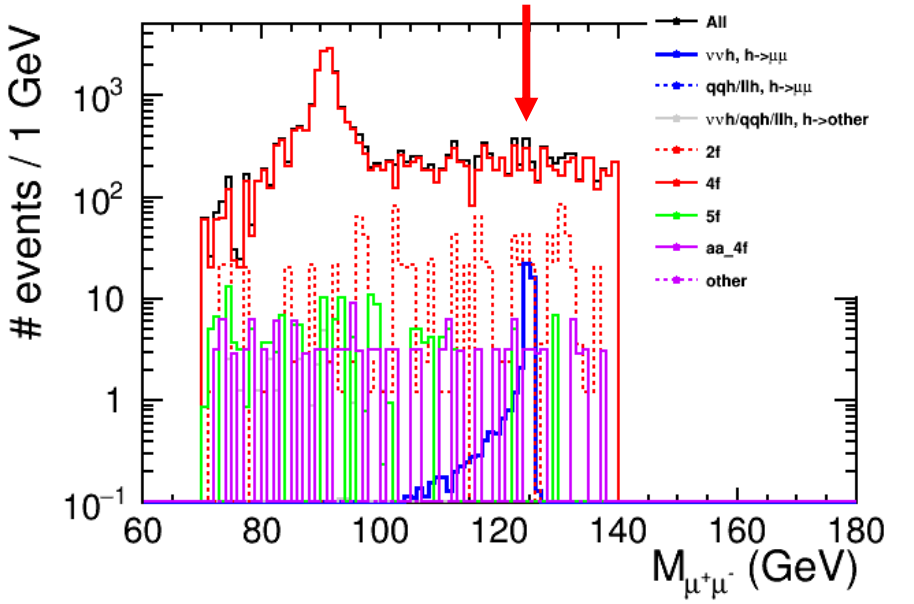


Cut


All
vvh, h->μμ
qqh/llh, h->μμ
vvh/qqh/llh, h->other
2f
4f
5f
aa_4f
other
events / 5 GeV
E_vis (GeV)


All
vvh, h->μμ
qqh/llh, h->μμ
vvh/qqh/llh, h->other
2f
4f
5f
aa_4f
other
events / 5 GeV
P_t (GeV)


events / 0.01
|cosθ_thrustaxis|


All
vvh, h->μμ
qqh/llh, h->μμ
vvh/qqh/llh, h->other
2f
4f
5f
aa_4f
other
events / 1 GeV
M_μ+μ- (GeV)

$\sigma\left(M_{\mu^+\mu^-}\right)$ Covariance Matrix in Momenta Space

- ref.: C. Calancha's talk
  - http://agenda.linearcollider.org/event/6315/contribution/1/material/slides/0.pdf
  - http://agenda.linearcollider.org/event/6343/contribution/2/material/slides/0.pdf
  - http://agenda.linearcollider.org/event/6361/contribution/10/material/slides/0.pdf
  - http://agenda.linearcollider.org/event/6372/contribution/4/material/slides/0.pdf