Benchmark Analysis Study of Higgs→invisible at $\sqrt{s}$ = 500 GeV

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ILD Analysis and Software Meeting
Dec. 19, 2018

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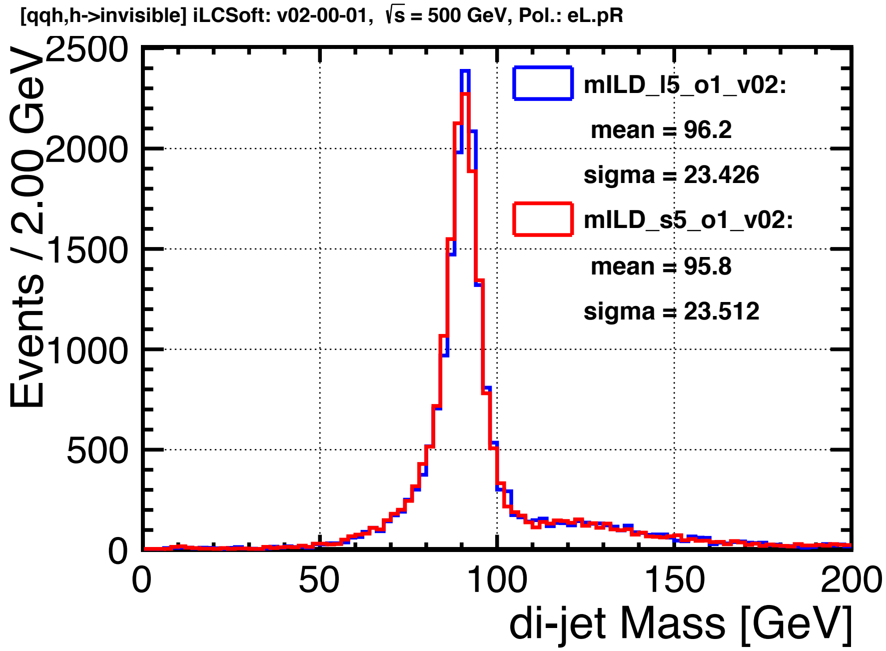
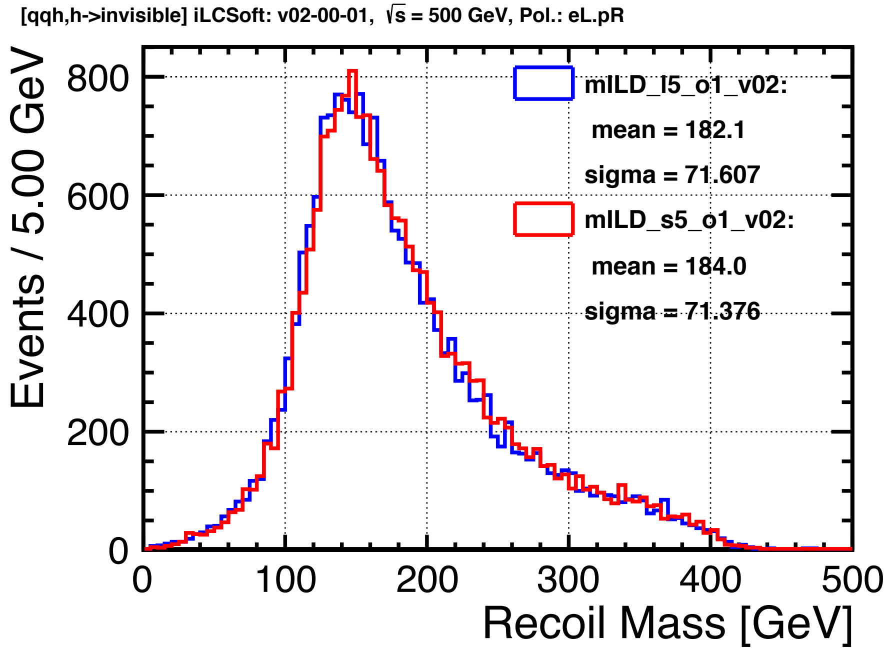
Status

- Apply cheating; w/o ISR, BS, Overlay, Z->bb/cc
- Check di-jet mass & recoil mass distribution of signal
- **Get result of l5/s5 w/ cheat**
- **Fit signal/bkg distribution**
- **Understand how ΔMrec and ΔEjj are related**
- **Understand why Mrec can't be fitted by single Gaussian**
  - Mrec dist. is consisted of multiple Gaussian overlaps because of energy dependence of JER
  - And also energy and JER of 2 jets are not equivalent
- Considering how to relate ΔMrec and JER
  - How we produce performance plot
- Produce performance plot
  - benchmarks: scaled sigma of fitted Mrec and use toyMC

Comparison Large/Small

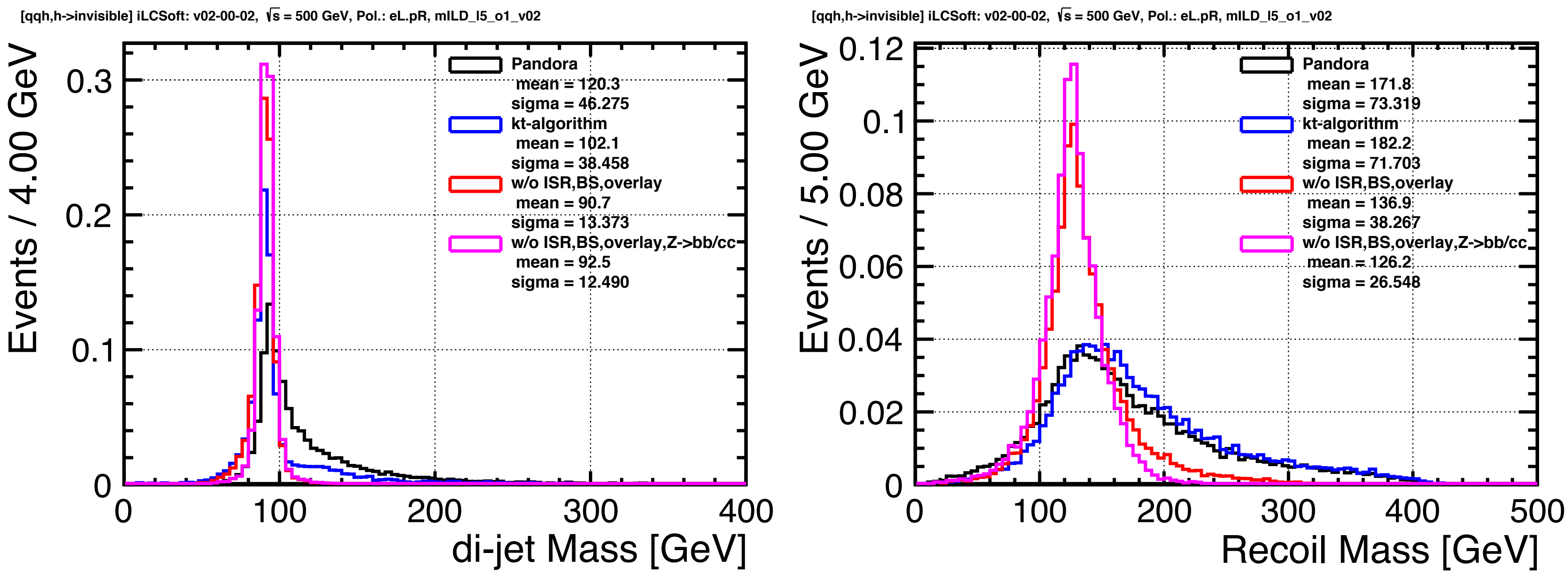




- There seems to be no big difference... why?
  →The effect other than detectors may be too large.
  ISR, beam effect, γγ- overlay, Z->bb/cc, etc...
- Apply cheating to isolate these effects

● Apply cheating; w/o ISR, BS, Overlay, Z->bb/cc

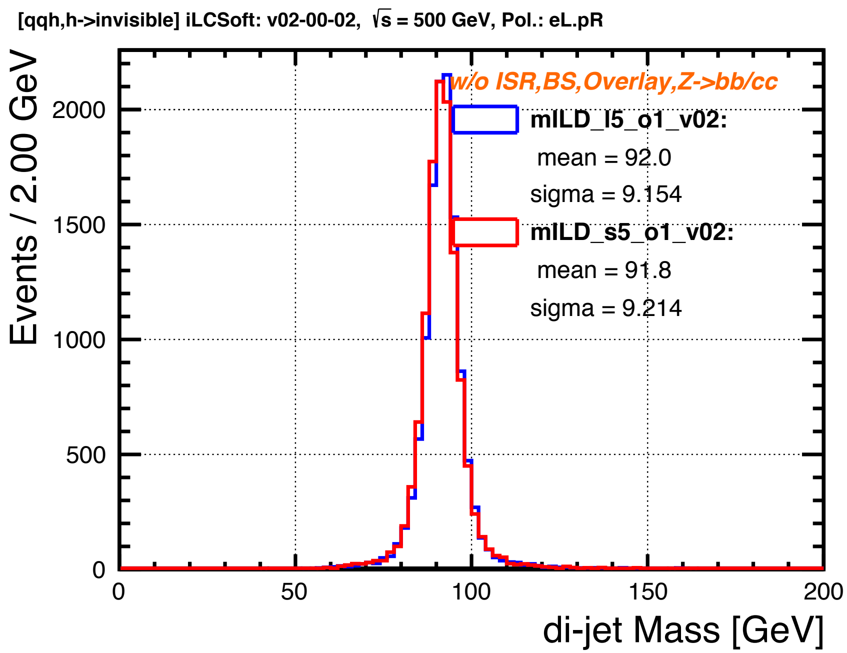
Comparison Pandora/kt-algorithm/cheat

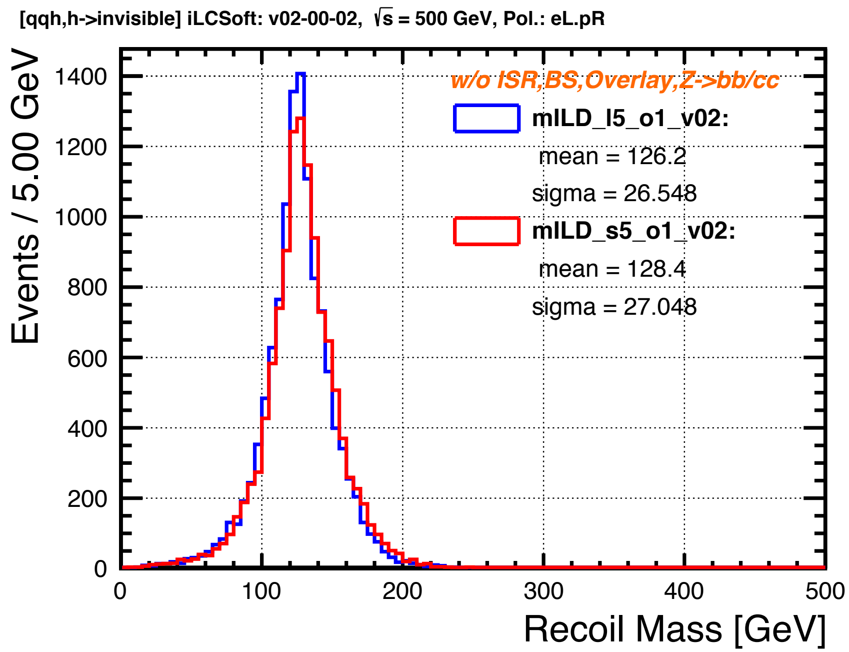


- used MCTruth information to apply cheating
- Magenta looks symmetrical

Check di-jet mass & recoil mass distribution of signal

Comparison Large/Small w/o ISR, BS, Overlay, Z->bb/cc



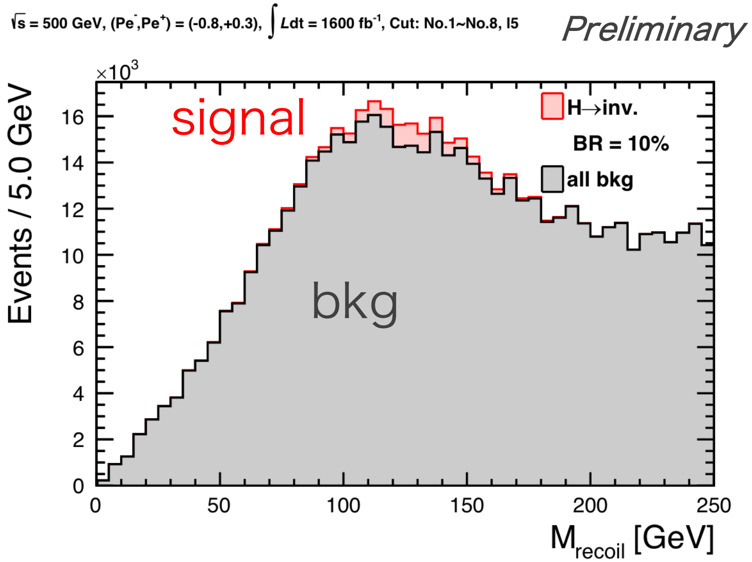


- Get result of l5/s5 w/ cheat

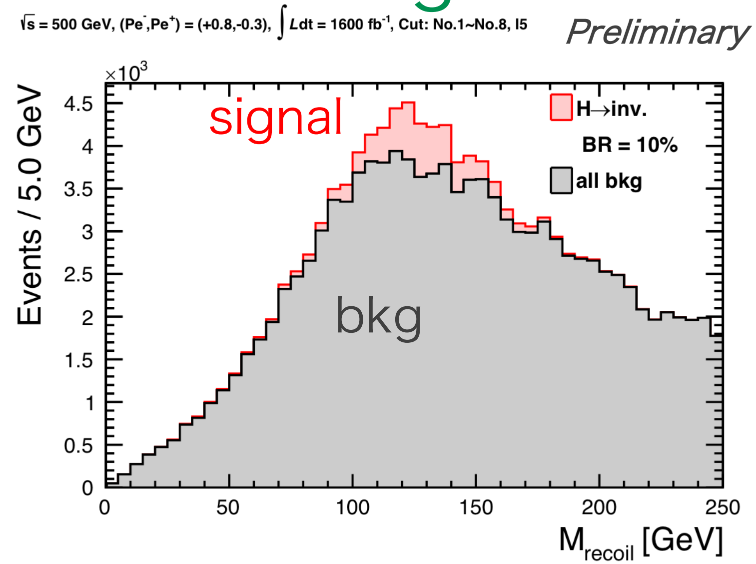
ILD_l5_o1_v02

Result w/ cheat [$\sqrt{s}$ = 500 GeV, 1600 fb^{-1},BR(H->inv.)=10%]

Left



Right



signal: w/o ISR, BS, Overlay, Z→bb/cc(scaled)

ILD_l5_o1_v02 w/ cheat [$\sqrt{s}$ = 500 GeV, 1600 fb^{-1}]	$(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$	$(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$	combined
significance assuming BR(H->inv.)=10%	18.184	23.563	29.764
UL on BR (95% C.L.)	0.907 %	0.700 %	0.554 %
Full Sim Result (l5)	1.569 %	1.156 %	0.931 %

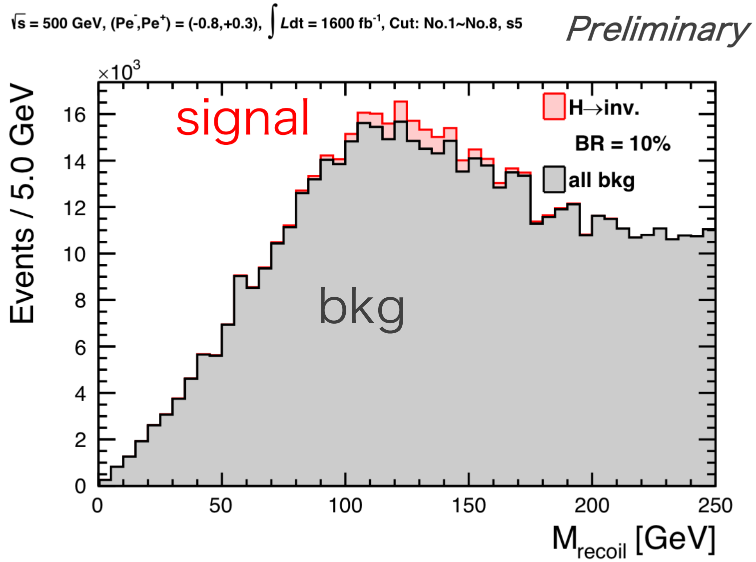
Preliminary

- Get result of l5/s5 w/ cheat

ILD_s5_o1_v02

Result w/ cheat [√s = 500 GeV, 1600 fb^{-1},BR(H->inv.)=10%]

Left



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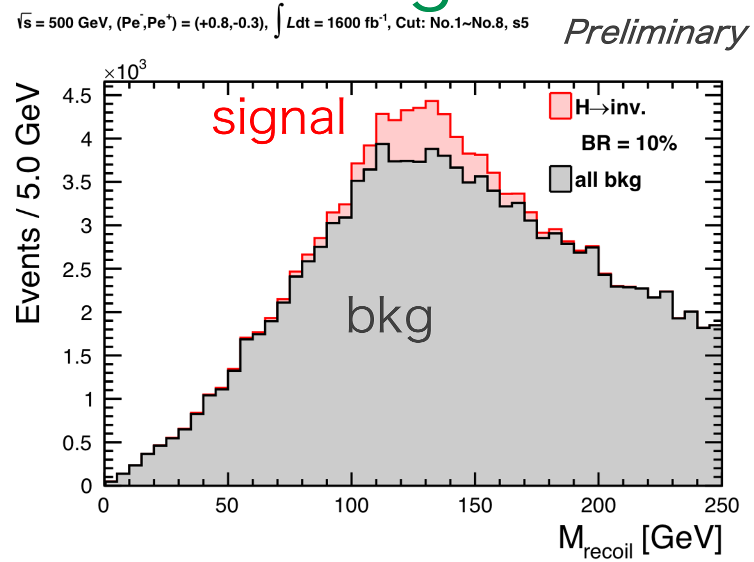
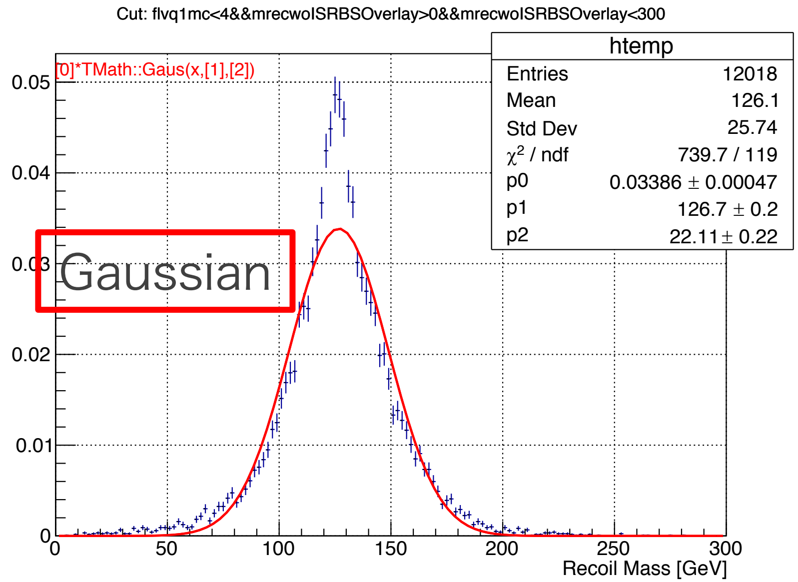
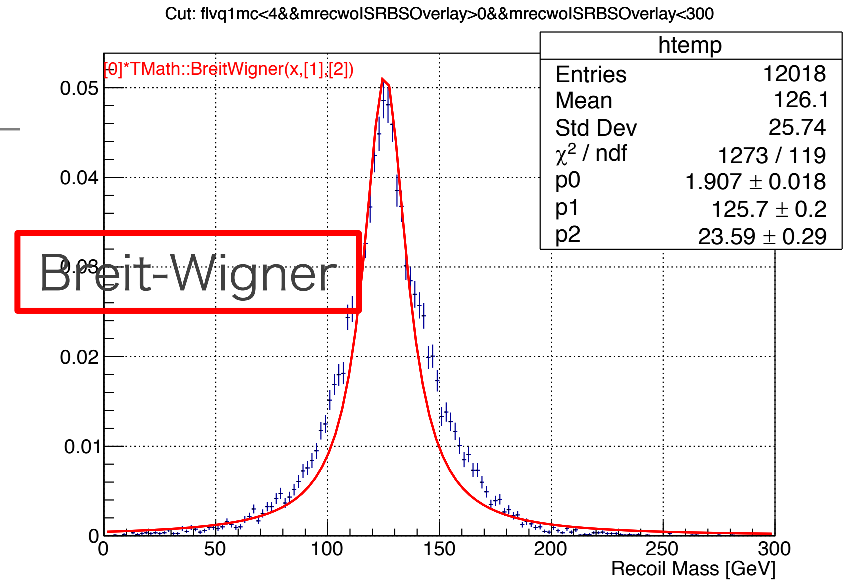


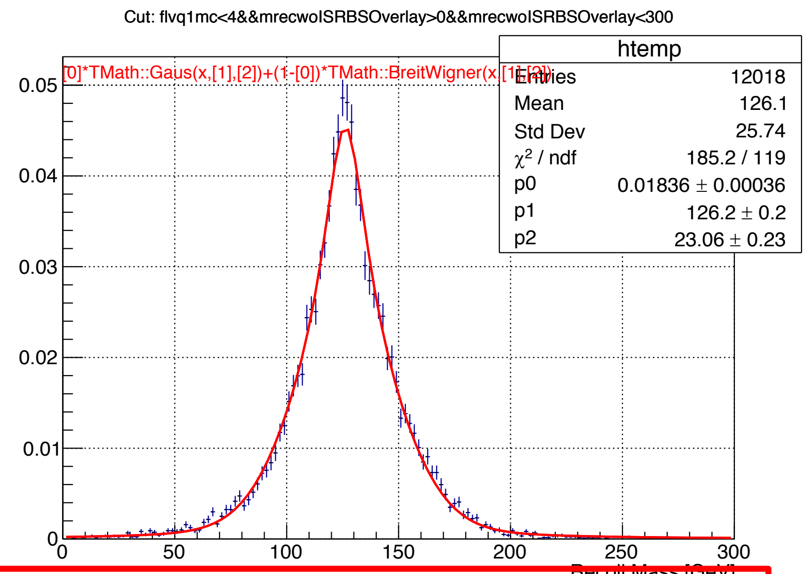
signal: w/o ISR, BS, Overlay, Z→bb/cc(scaled)

ILD_s5_o1_v02 w/ cheat [√s = 500 GeV, 1600 fb^{-1}]	$(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$	$(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$	combined
significance assuming BR(H->inv.)=10%	17.718	23.027	29.054
UL on BR (95% C.L.)	0.931 %	0.717 %	0.568 %
Full Sim Result (s5)	1.579 %	1.157 %	0.933 %

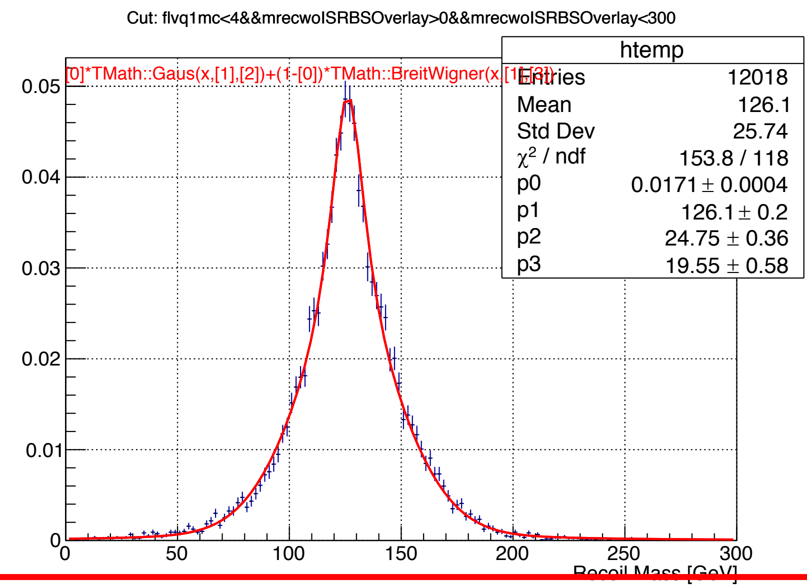
Fit signal distribution







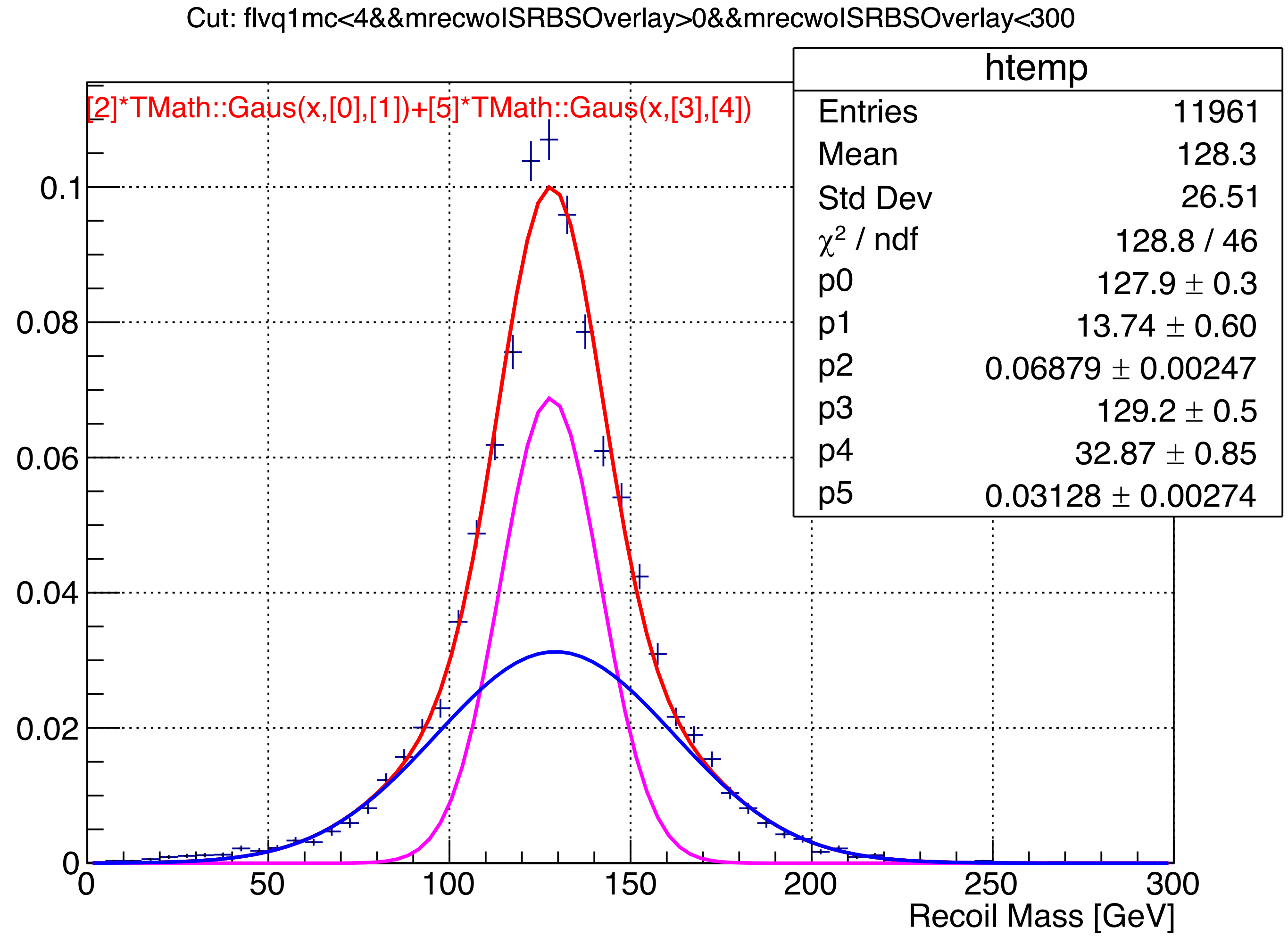
p0×Gaus+(1-p0)×BW same sigma



p0×Gaus+(1-p0)×BW different sigma

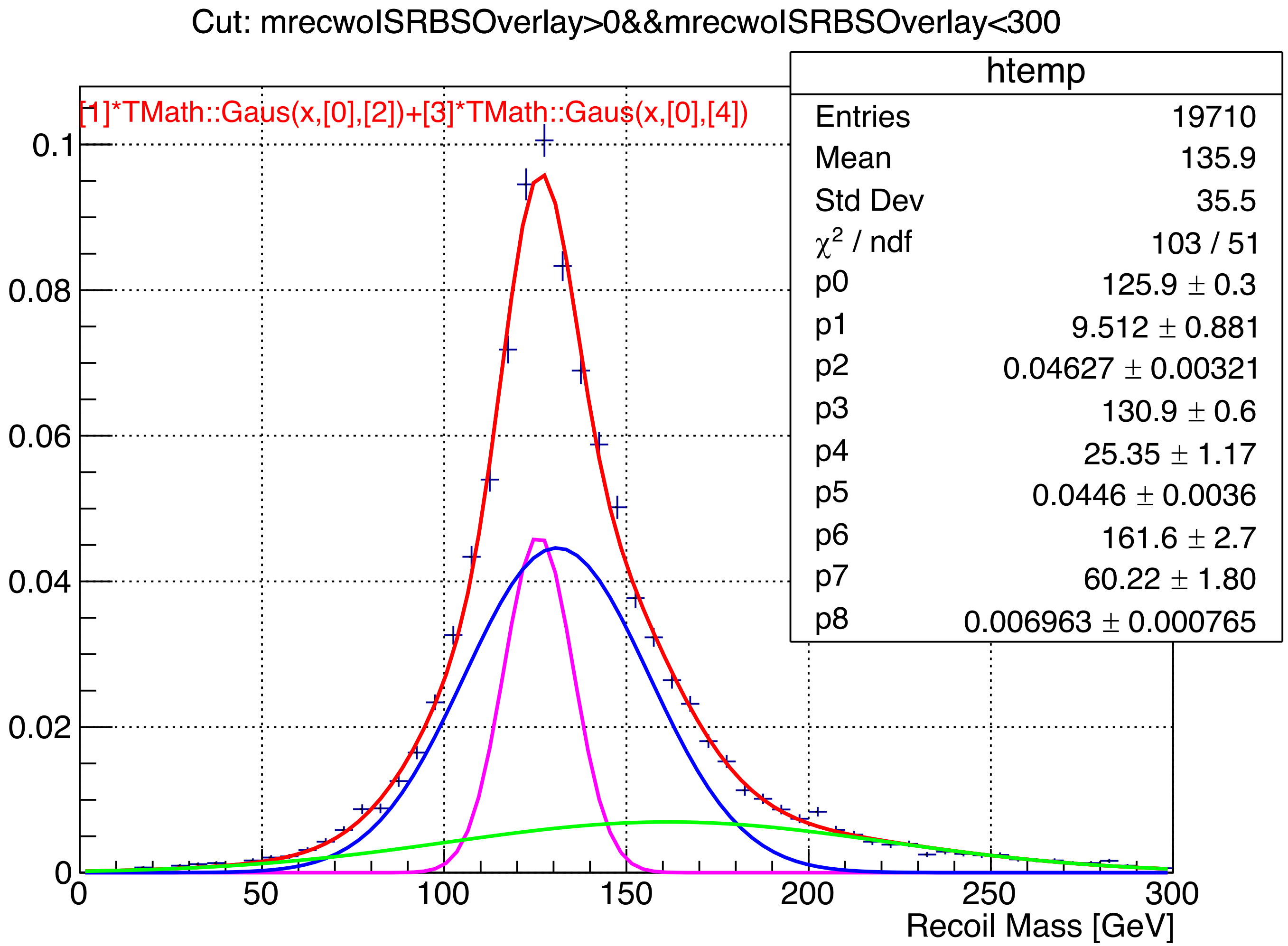
●Fit signal distribution

double-Gaussian fit w/o Z->bb/cc



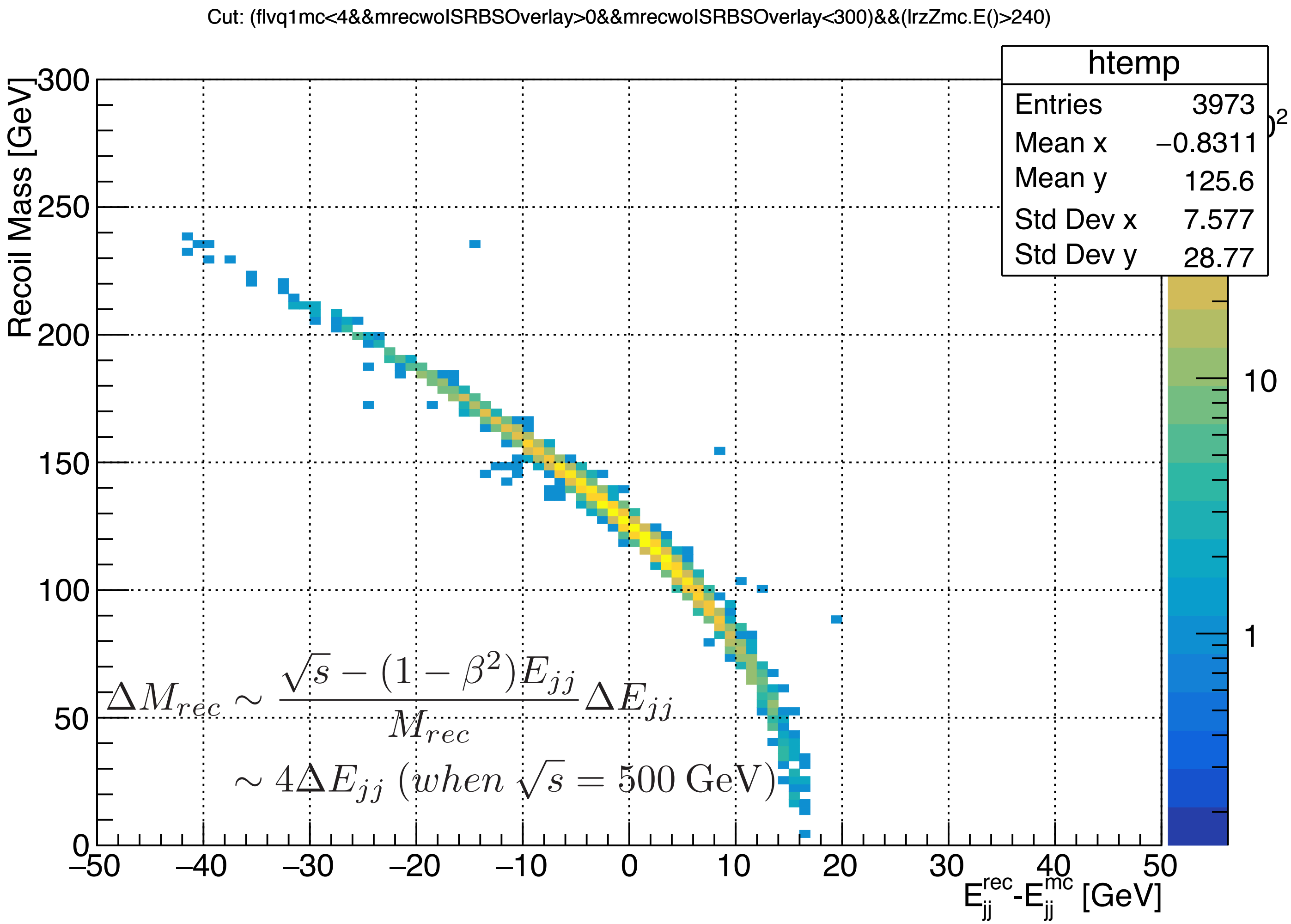
● Fit signal distribution

triple-Gaussian fit w/ Z->bb/cc



● Understand how ΔMrec and ΔEjj are related

ΔEjj vs ΔMrec

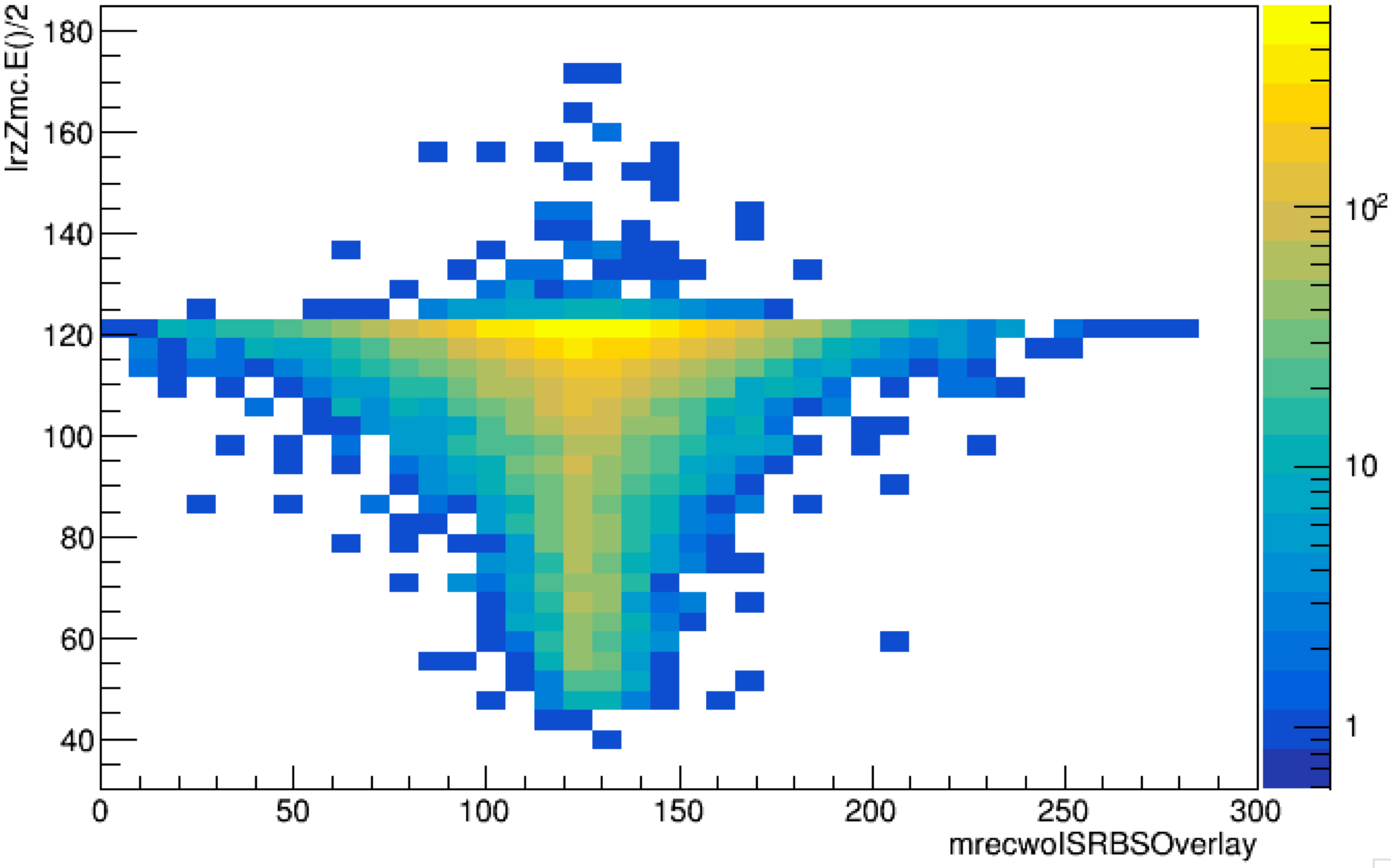


$$\Delta M_{rec} \sim \frac{\sqrt{s} - (1-\beta^2)E_{jj}}{M_{rec}} \Delta E_{jj}$$

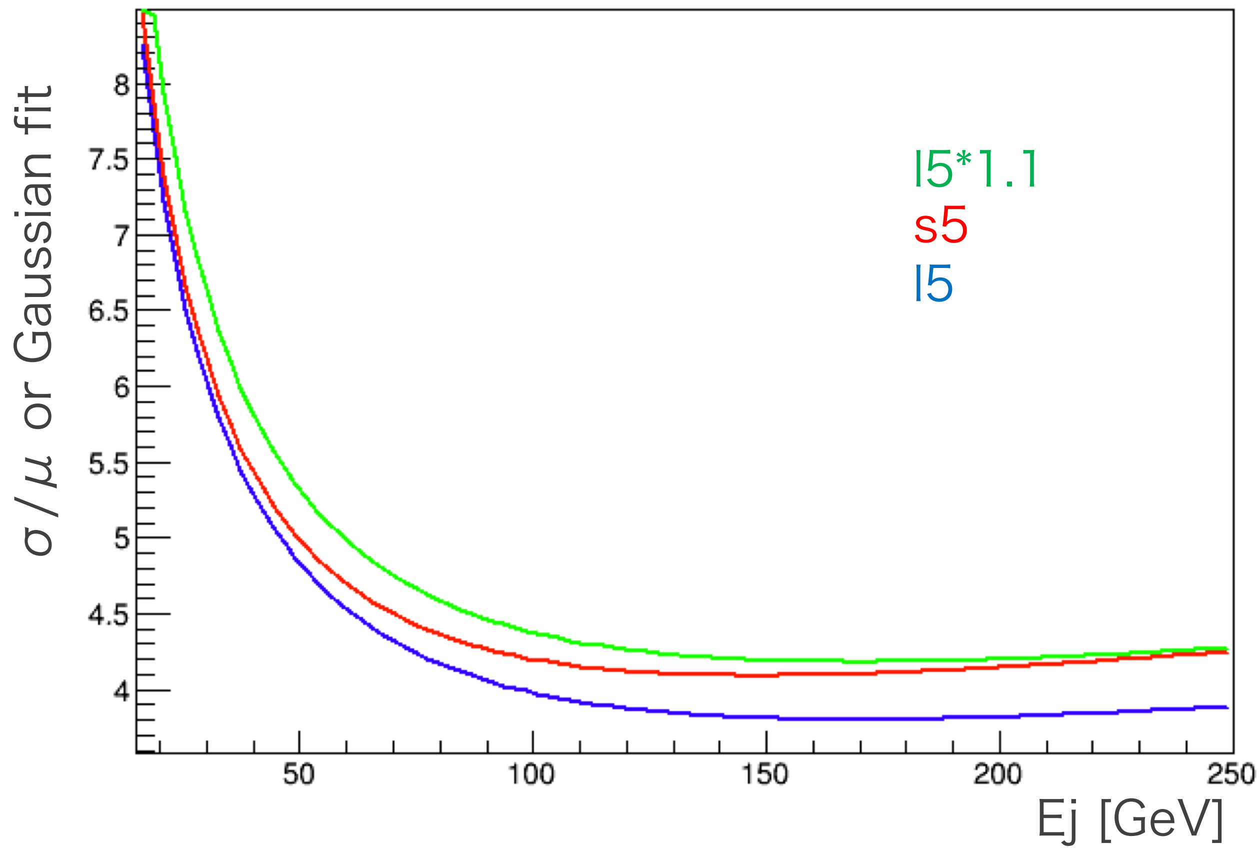
$$\sim 4\Delta E_{jj}\ (when\ \sqrt{s} = 500\ \mathrm{GeV})$$

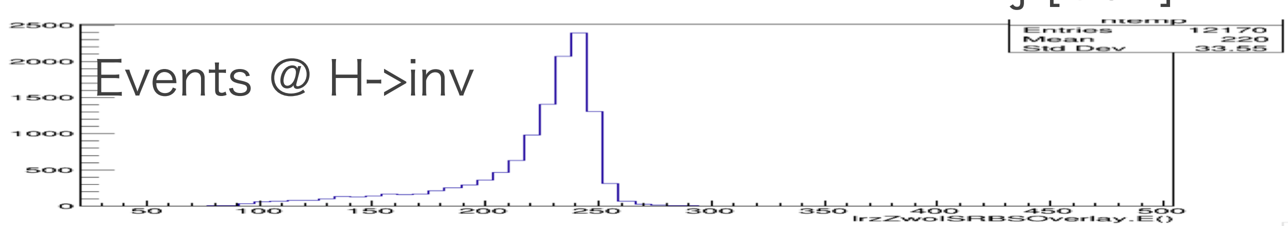
ΔMrec vs Ej^{mc}

- Understand why Mrec can't be fitted by single Gaussian
  - Mrec dist. is consisted of multiple Gaussian overlaps because of energy dependence of JER
  - And also energy and JER of 2 jets are not equivalent



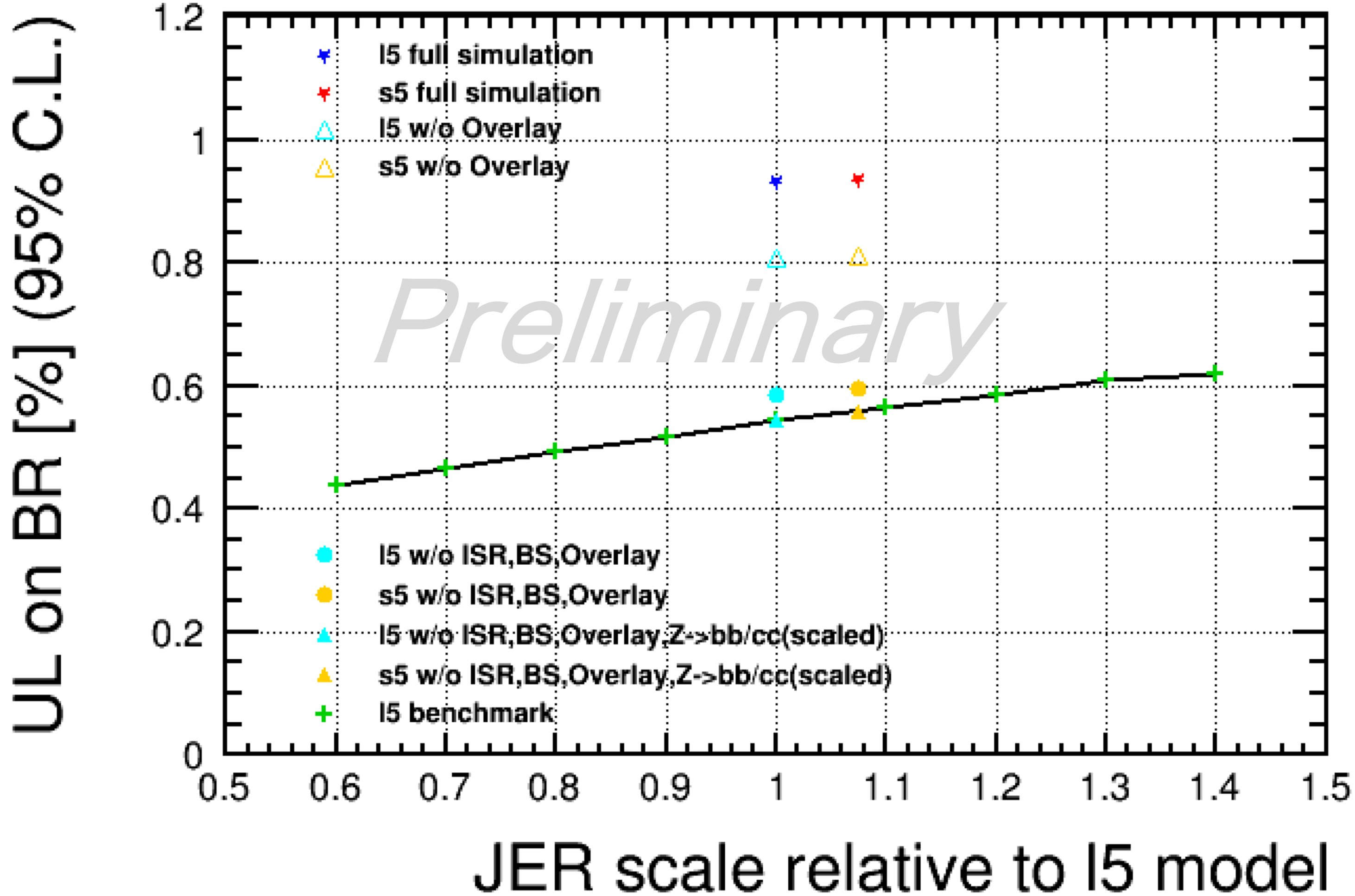
How to relate ΔMrec and JER...?





- Produce performance plot
  - benchmarks: scaled sigma of fitted Mrec and use toyMC

Results



backup

Motivation

Physics Motivation

Higgs can decay invisibly into final states
as candidate dark matter particles ($m_{DM} < m_H/2$),
if there is *a hidden sector which couples to Higgs field.*

Search Channel

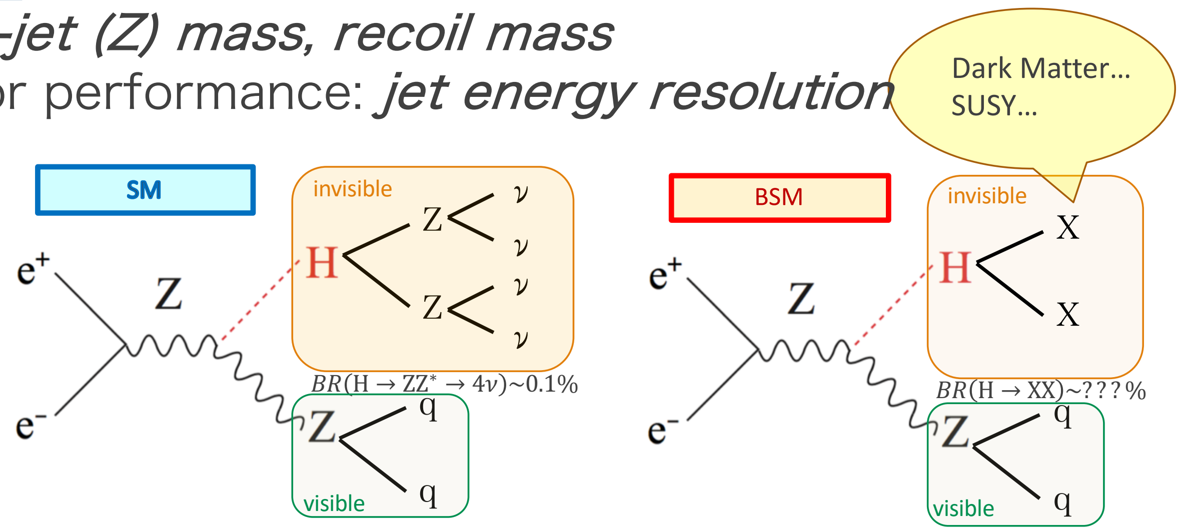
e+e- → ZH, Z→qq, H→invisible, at √s = 500 GeV

Final Observable

95% C.L. upper limit on Branching Ratio of H→invisible.

Detector Benchmark

main variables: *di-jet (Z) mass, recoil mass*
influential detector performance: *jet energy resolution*

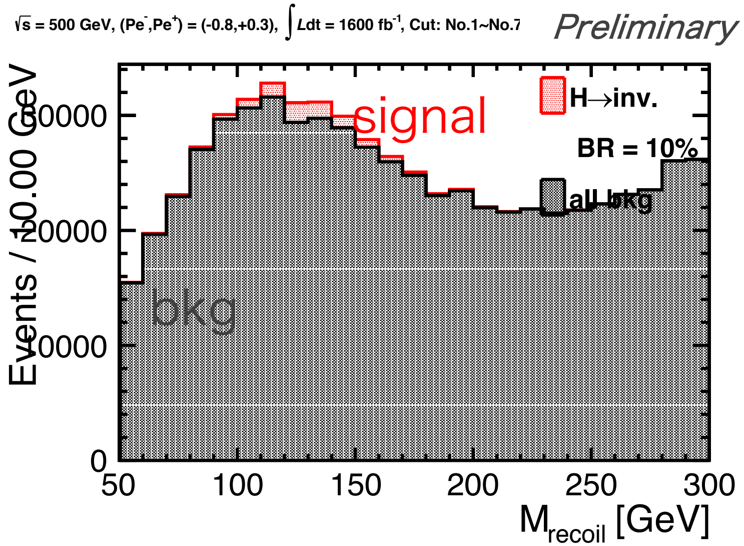


Preliminary

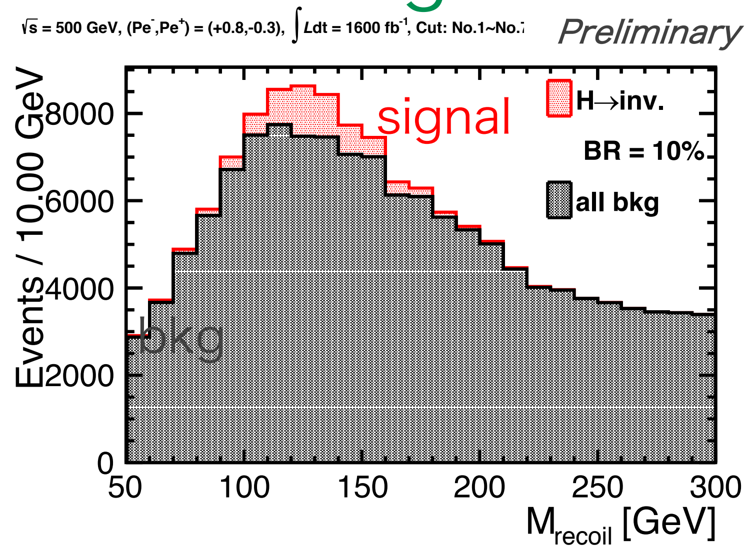
ILD_l5_o1_v02

Result w/ cheat [√s = 500 GeV, 1600 fb^{-1},BR(H->inv.)=10%]

Left



Right



signal w/o ISR, BS, Overlay

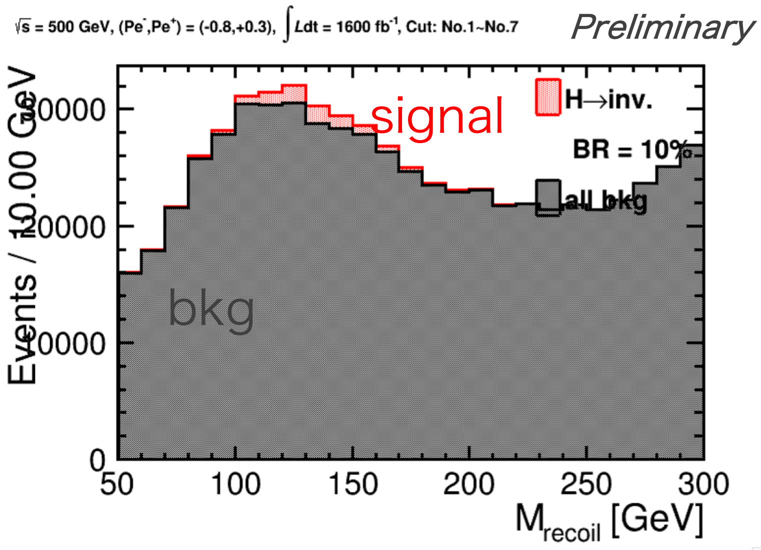
ILD_l5_o1_v02 w/ cheat [√s = 500 GeV, 1600 fb^{-1}]	$(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$	$(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$	combined
significance assuming BR(H->inv.)=10%	17.127	22.334	28.145
UL on BR (95% C.L.)	0.963 %	0.739 %	0.586 %
Full Sim Result (l5)	1.569 %	1.156 %	0.931 %

Preliminary

ILD_s5_o1_v02

Result w/ cheat [√s = 500 GeV, 1600 fb^{-1},BR(H->inv.)=10%]

Left



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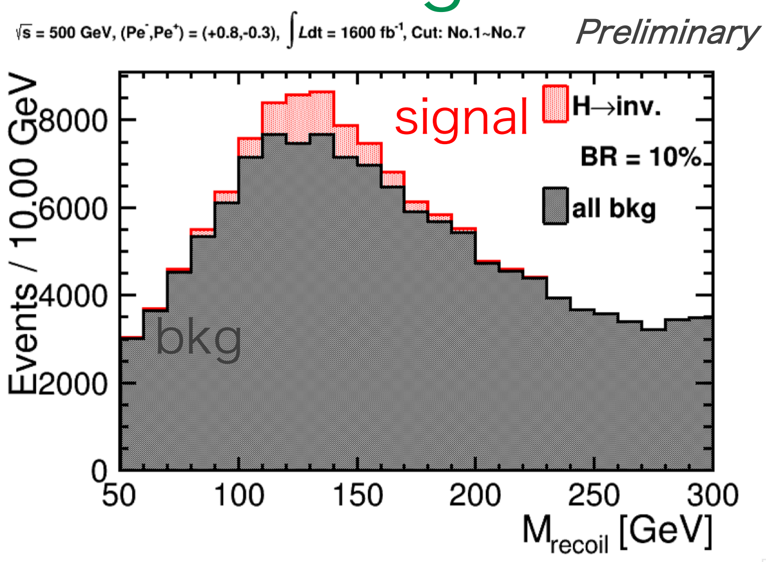
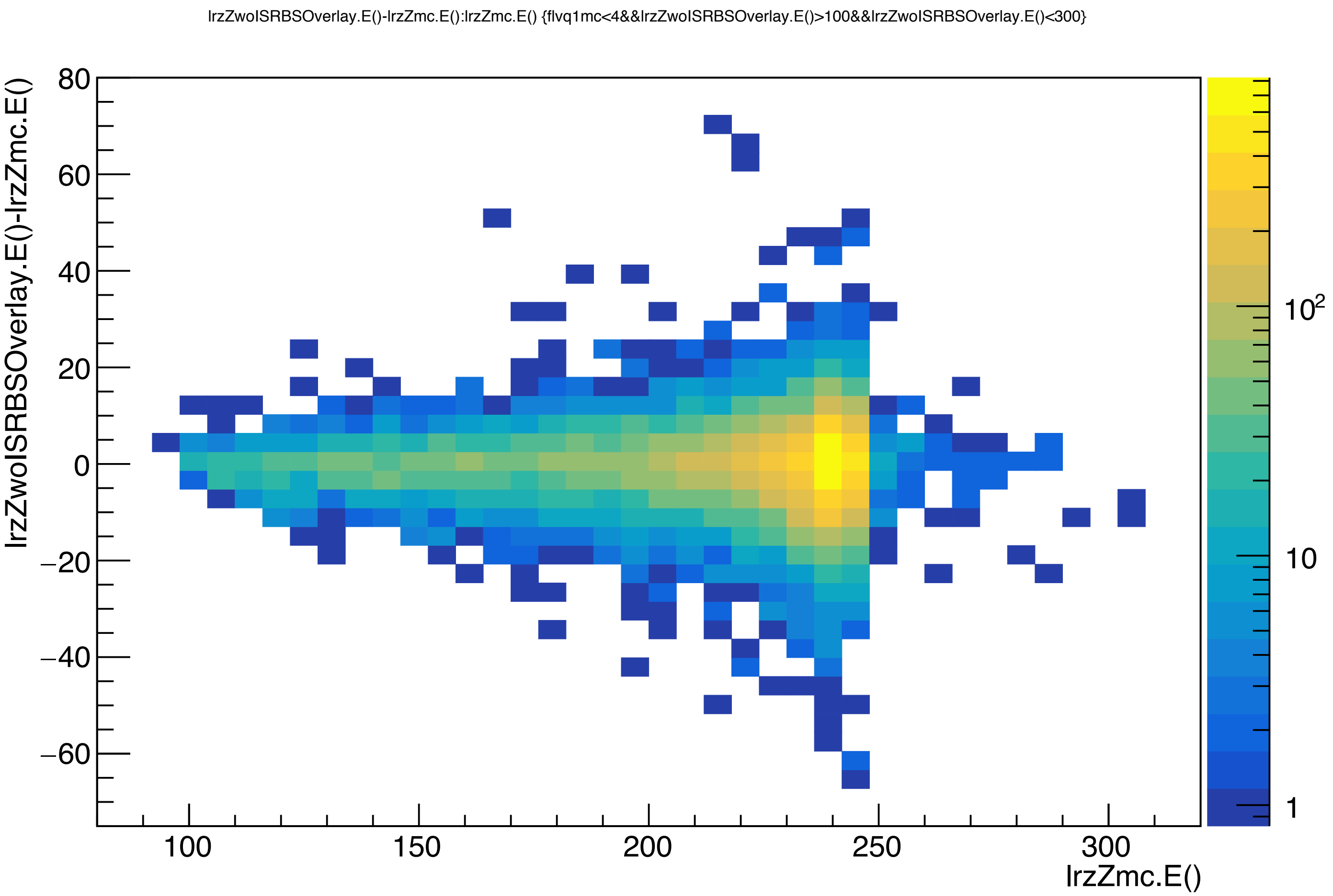


signal w/o ISR, BS, Overlay

ILD_s5_o1_v02 w/ cheat [√s = 500 GeV, 1600 fb^{-1}]	$(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$	$(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$	combined
significance assuming BR(H->inv.)=10%	16.817	21.947	27.649
UL on BR (95% C.L.)	0.981 %	0.752 %	0.597 %
Full Sim Result (s5)	1.579 %	1.157 %	0.933 %

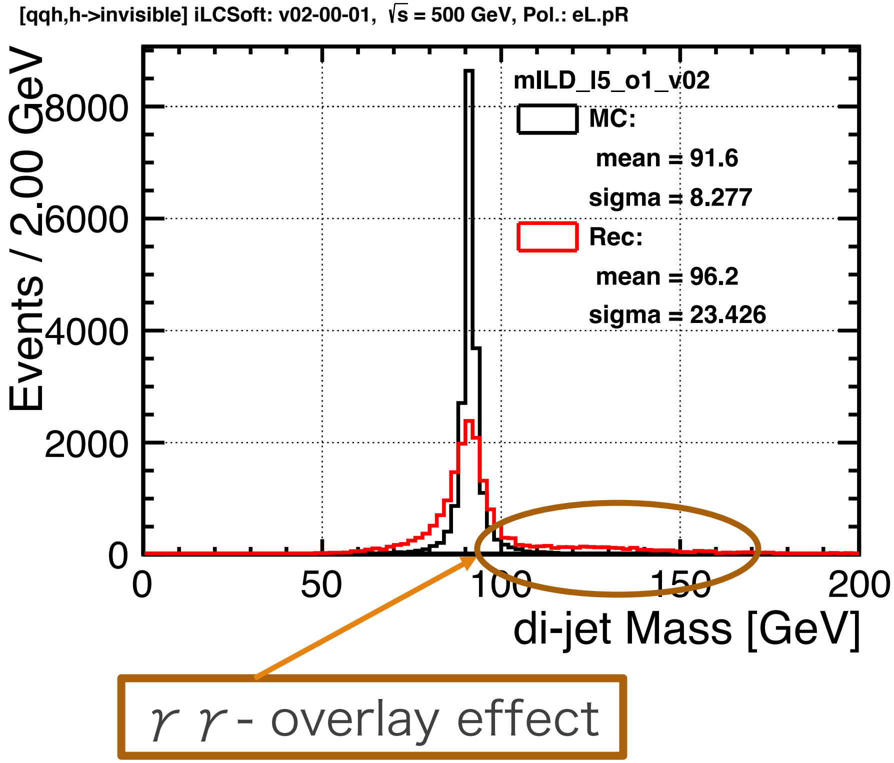
Preliminary

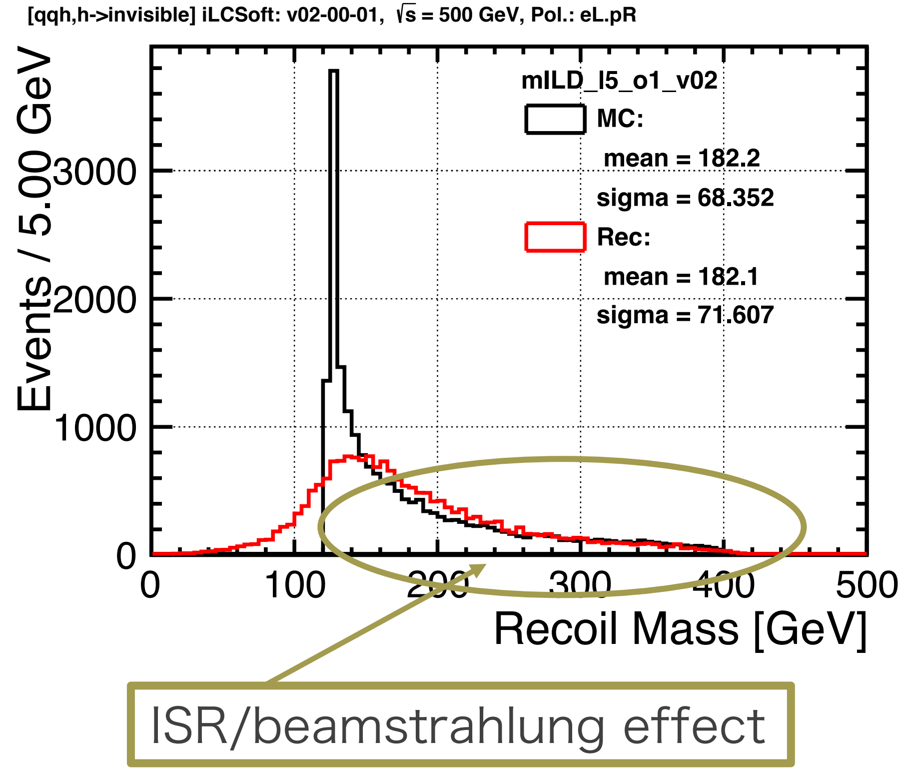
Ejj^{mc} vs ΔEjj



Distribution di-jet mass/Recoil mass

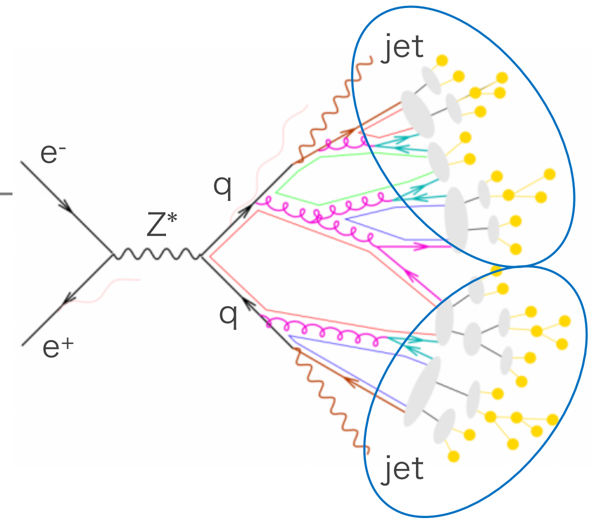
As a first step, I checked signal distribution.





Note: Event selection not applied.

Setting of Evaluation JER



ILCSoft & ILDConfig: v02-00-01

ILD models: ILD_{l5,s5}_{o1,o2}_v02

Samples:

mc-opt-3

uds samples: Z→di-jet, no bkg

√s = { 30, 40, 60 ,91, 120, 160, 200, 250, 300, 350, 400, 500 } GeV

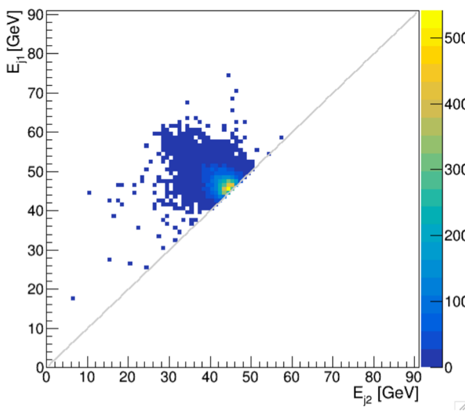
10,000 evts in each √s & models

Jet resolution definition:

[Total energy method] ※assuming $E_{j1} = E_{j2}$

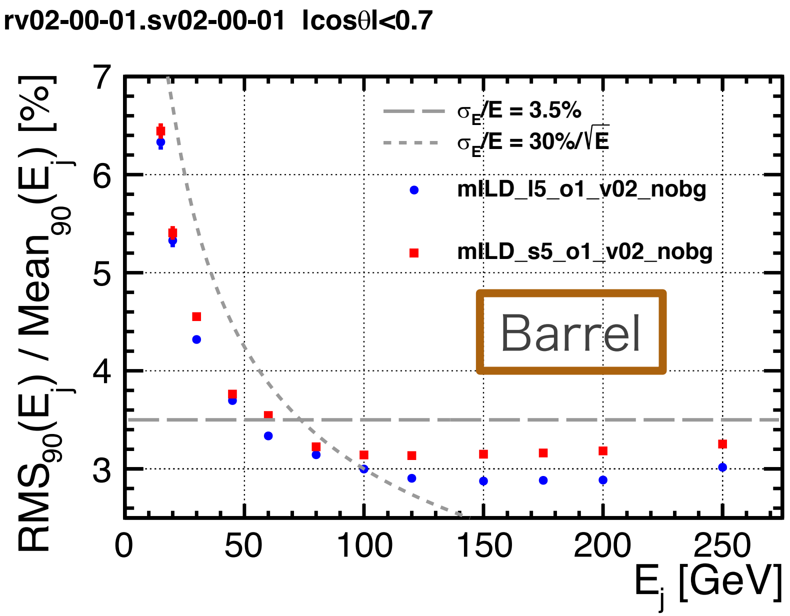
$$\frac{\sigma_{E_j}}{E_j} = \frac{\mathrm{RMS}_{90}(E_j)}{mean_{90}(E_j)} = \sqrt{2}\frac{\mathrm{RMS}_{90}(E_{jj})}{mean_{90}(E_{jj})}$$

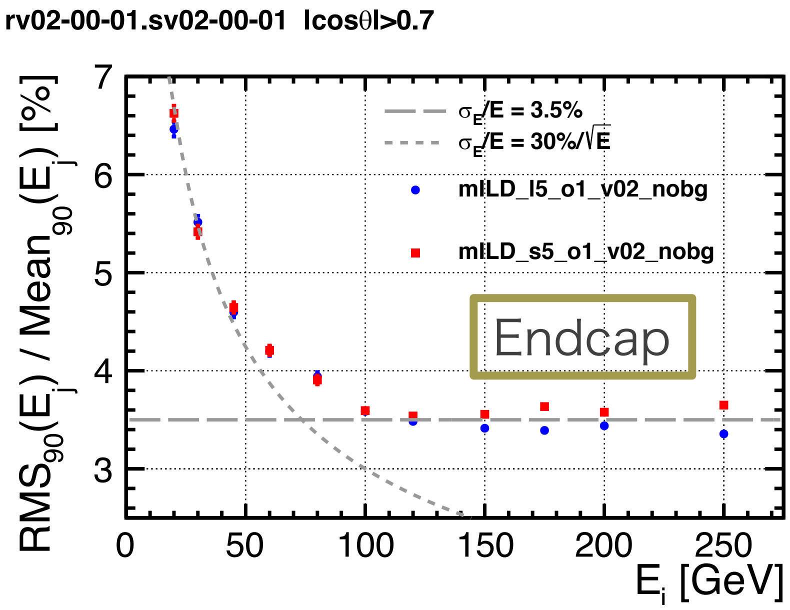
In realistic case, Ejet is not strictly same. →



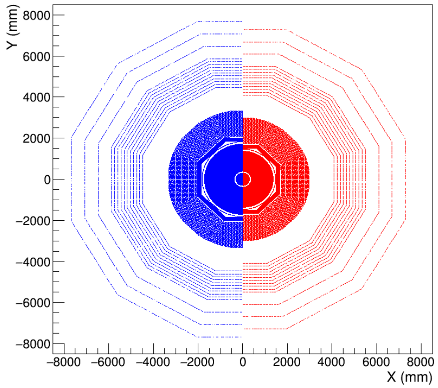
JER: Comparison Large/Small

The two detector models (large/small) were evaluated for comparison.





There are just a little, but significant difference.



Analysis Setup

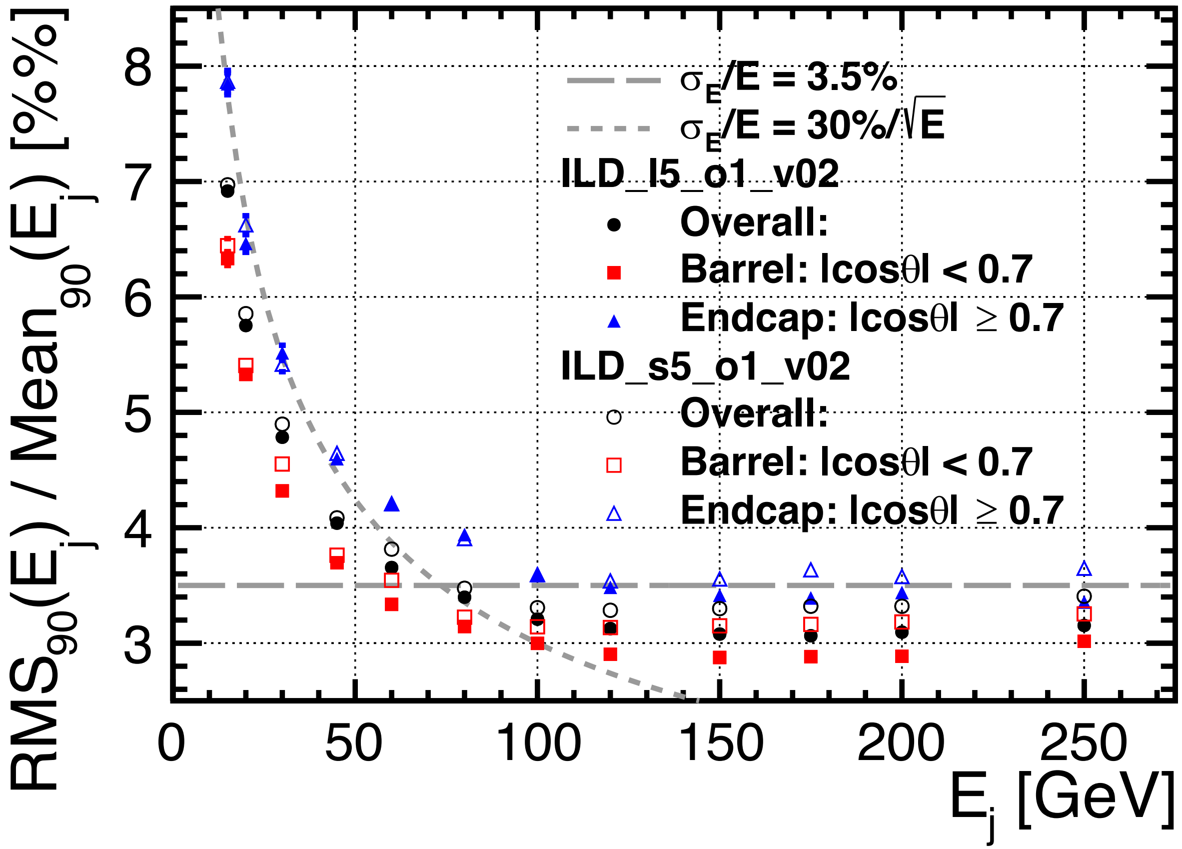
- Simulation
  - ILCSoft: v02-00-01
  - Samples: new optimization samples @ 500 GeV
  - Detector: ILD full simulation (ILD_{l5,s5}_o1_v02)
  - $\sqrt{s}$ = 500 GeV, $\int L dt$ = 1600 fb^{-1} , $(P_{e^-}, P_{e^+}) = (-0.8, +0.3), (+0.8, -0.3)$
    "Left" "Right"
- Flow of analysis
  1. **Particle flow reconstruction** (PandoraPFA)
  2. **Isolated lepton tagging**: to remove in stage of Eve. Sel.
  3. **Remove $\gamma\gamma$-overlay:** using kt_algorithm (FastJet)
  4. **Durham jet finder**: forced 2 jets clustering
  5. **Event selection**
     - Optimized assuming signal BR(H→invisible) = 10%
  6. **Estimate upper limit(UL) of BR (95% C.L.)**

$$UL(\%) \equiv \frac{10(\%)}{N_S(10\%)} \times 1.65\sqrt{N_B}$$

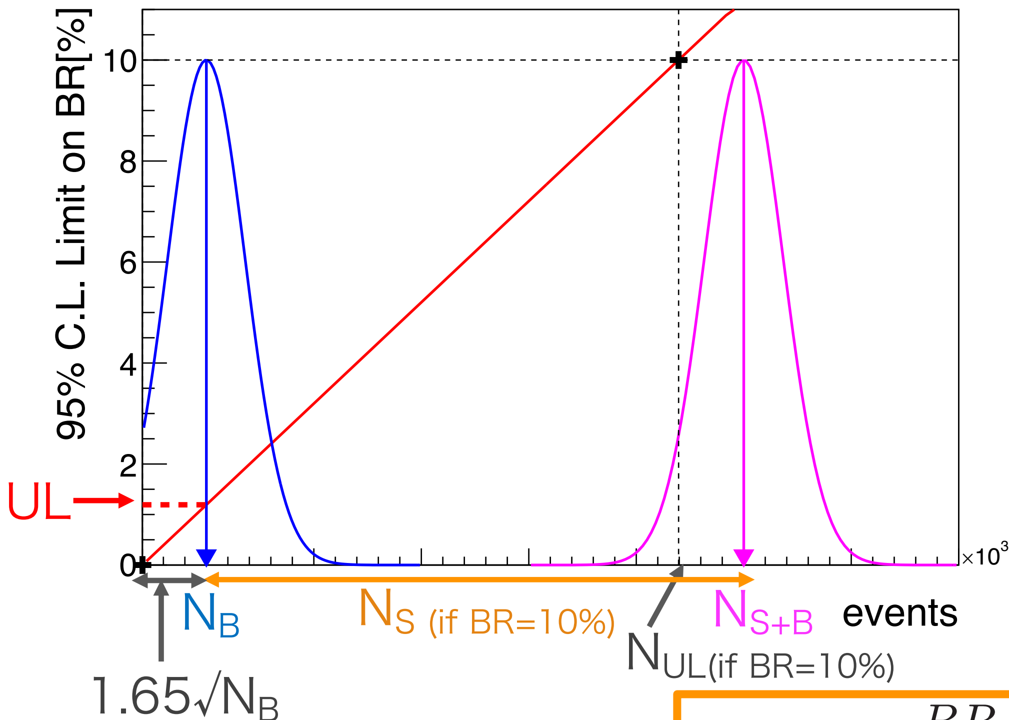
JER: Comparison Large/Small

The two detector models (large/small) were evaluated for comparison.

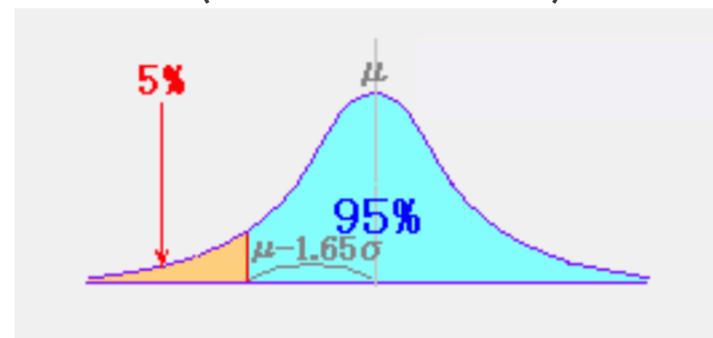
rv02-00-01.sv02-00-01



How to set Upper Limit

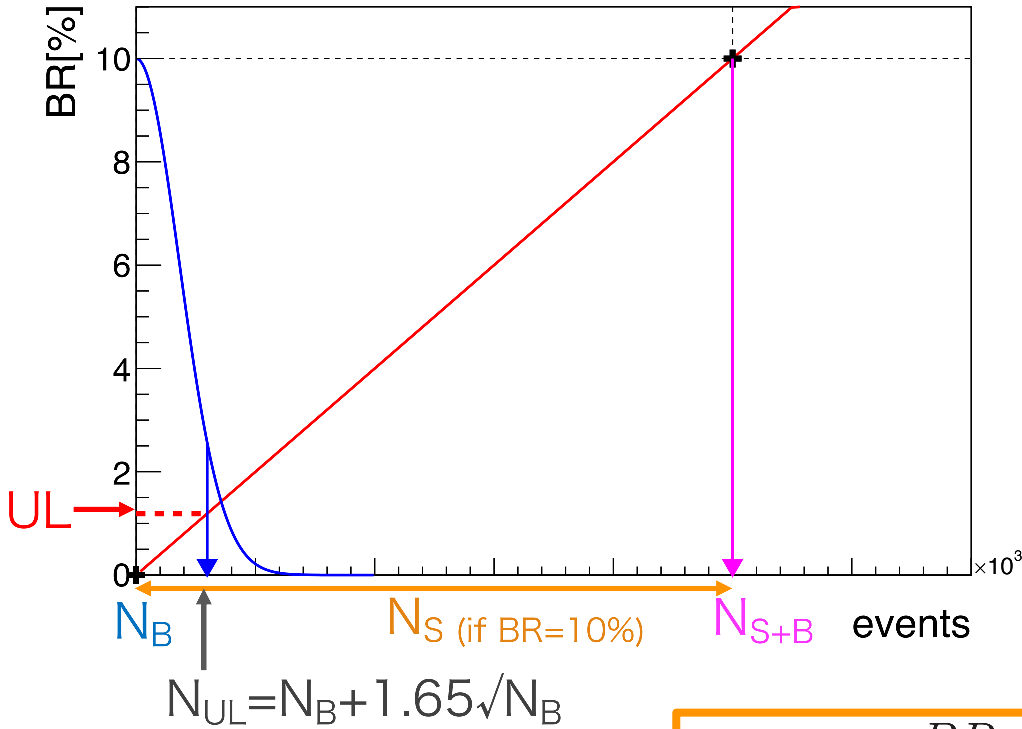


definition of 95% C.L.
(one-sided test)



$$\begin{aligned} UL(\%) &\equiv \frac{BR_{\mathrm{assumed}}[\%]}{N_S(BR_{\mathrm{assumed}})} \times \sigma(N_B, \mathrm{CL}) \\ &\cong \frac{10[\%]}{N_S(BR = 10[\%])} \times 1.65\sqrt{N_B}\ (\mathrm{CL} = 95\%) \\ &\simeq \frac{10[\%] \times 1.65}{significance(BR = 10[\%])} \end{aligned}$$

How to set Upper Limit



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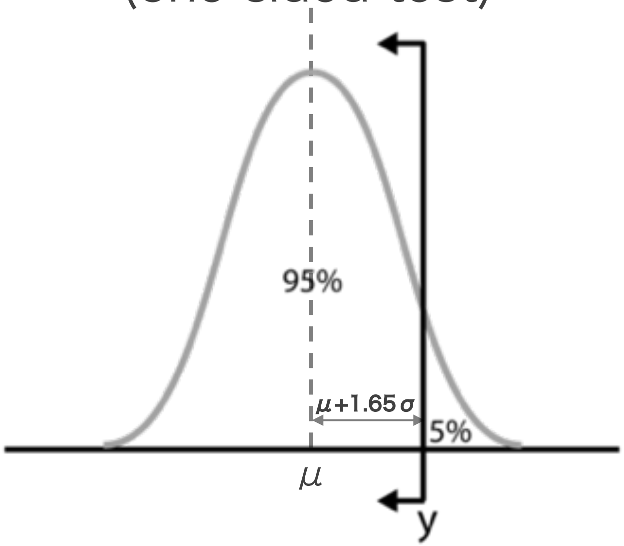

$$
\begin{aligned}
UL(\%) &\equiv \frac{BR_{\text{assumed}}[\%]}{N_S(BR_{\text{assumed}})} \times \sigma(N_B, \text{CL}) \\
&= \frac{10[\%]}{N_S(BR = 10[\%])} \times 1.65\sqrt{N_B}\ (\text{CL} = 95\%) \\
&\simeq \frac{10[\%] \times 1.65}{significance(BR = 10[\%])}
\end{aligned}
$$