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

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Overview

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 $\sqrt{s}$ = 500 GeV

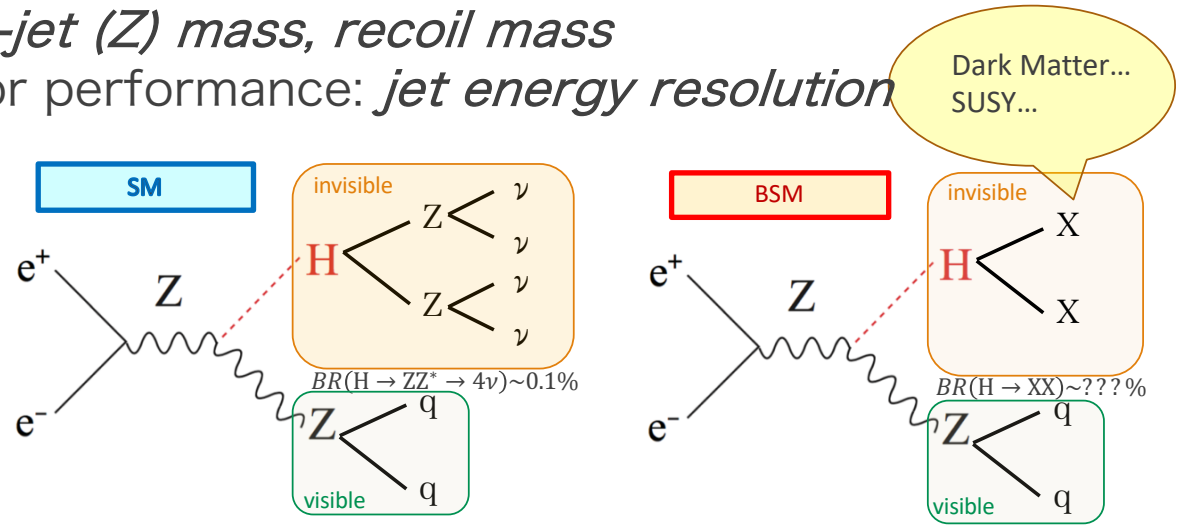
Final Observable

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*

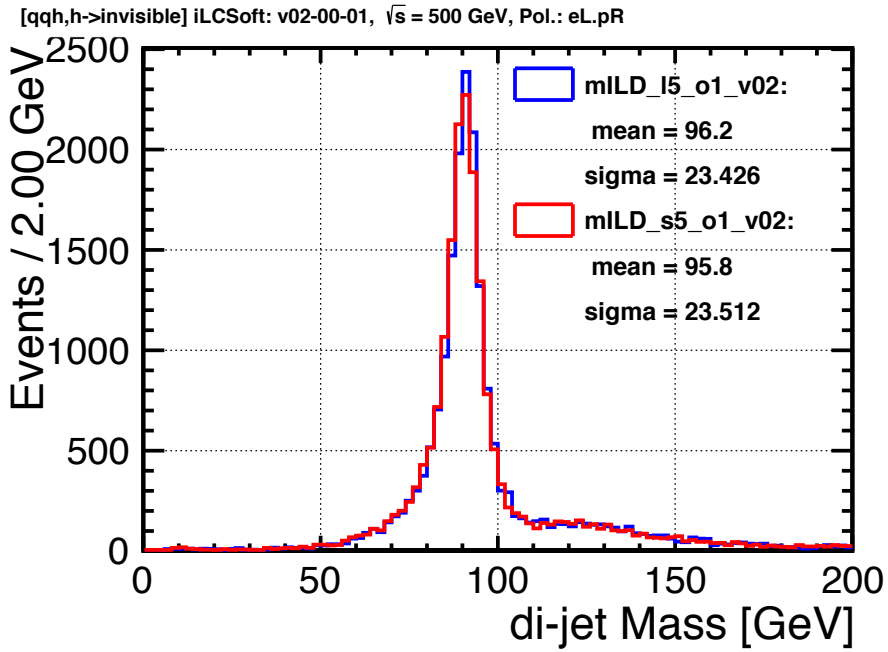
LHC result [%] (95% C.L.)	observed (expected)
CMS *1	26 (20)
ATLAS *2	26 (17)

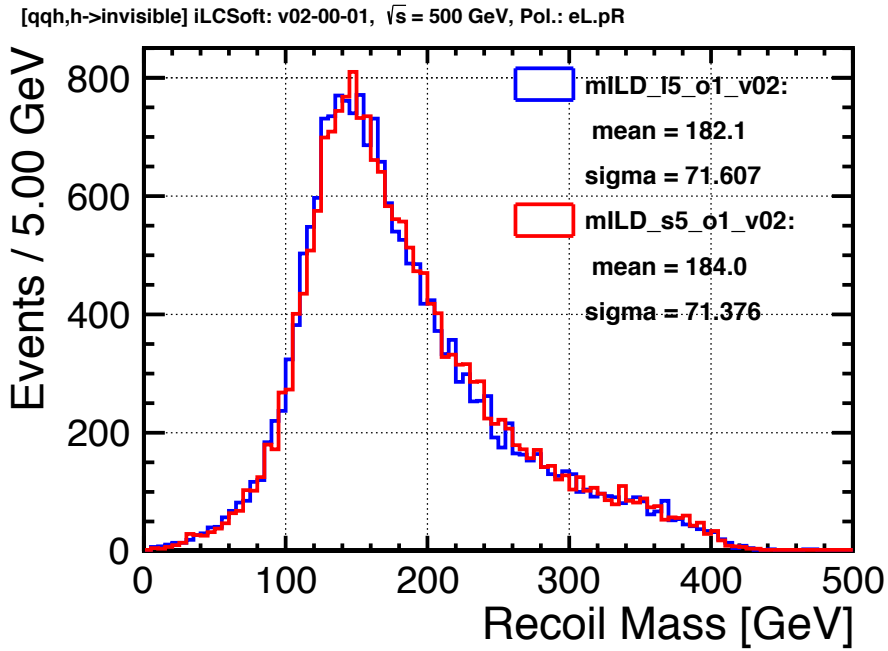


*1 Search for invisible decays of a Higgs boson produced through vector boson fusion in proton-proton collisions at $\sqrt{s}$= 13 TeV, CMS Collaboration
*2 Combination of searches for invisible Higgs boson decays with the ATLAS experiment, ATLAS Collaboration

Comparison Large/Small

full simulation @ILD Benchmark Days





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

Setup

- **Simulation**
  - ILCSoft: v02-00-01
  - Samples: new optimization samples @ 500 GeV
  - Detector: ILD full simulation (ILD_{l5,s5}_o1_v02)
- **Analysis**
  - ILCSoft: v02-00-02
  - $\sqrt{s}$ = 500 GeV, $\int Ldt$ = 1600 fb^{-1} , $(P_{e^-}, P_{e^+}) = \overset{\text{"Left"}}{(-0.8, +0.3)}, \overset{\text{"Right"}}{(+0.8, -0.3)}$
- **Flow of analysis**
  0. **Particle flow reconstruction** (PandoraPFA)
  1. **Isolated lepton tagging**: to remove in stage of Eve. Sel.
  2. **Remove $\gamma\gamma$-overlay:** using kt_algorithm (FastJet)
  3. **Durham jet finder**: forced 2 jets clustering
  4. **Event selection**
     - Optimized assuming signal BR(H→invisible) = 10%
  5. **Estimate upper limit(UL) of BR (95% C.L.)**

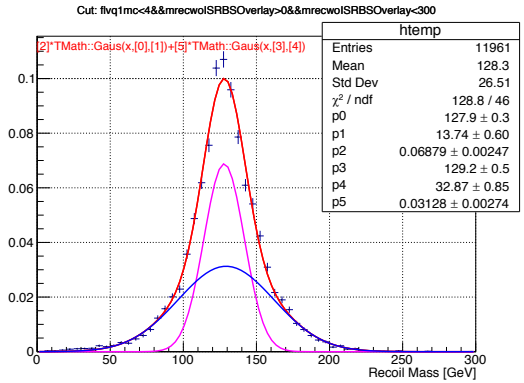
$$UL(\%) \equiv \frac{10(\%)}{N_S(10\%)} \times 1.65\sqrt{N_B}$$

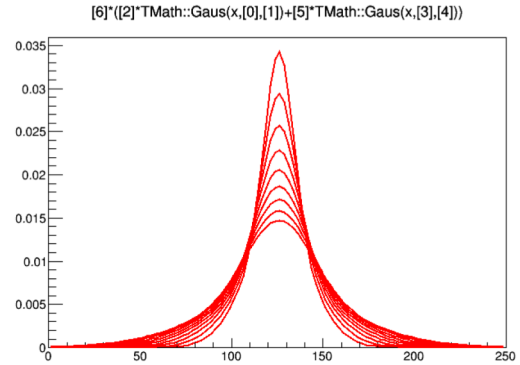
Strategy to evaluate JER benchmark

1. Apply cheating to make Mrec dist. as symmetrical as possible
2. Fit signal dist. by double-Gaussian and get p.d.f.
   - ΔMrec should be almost related to ΔEjj linearly in ideal case

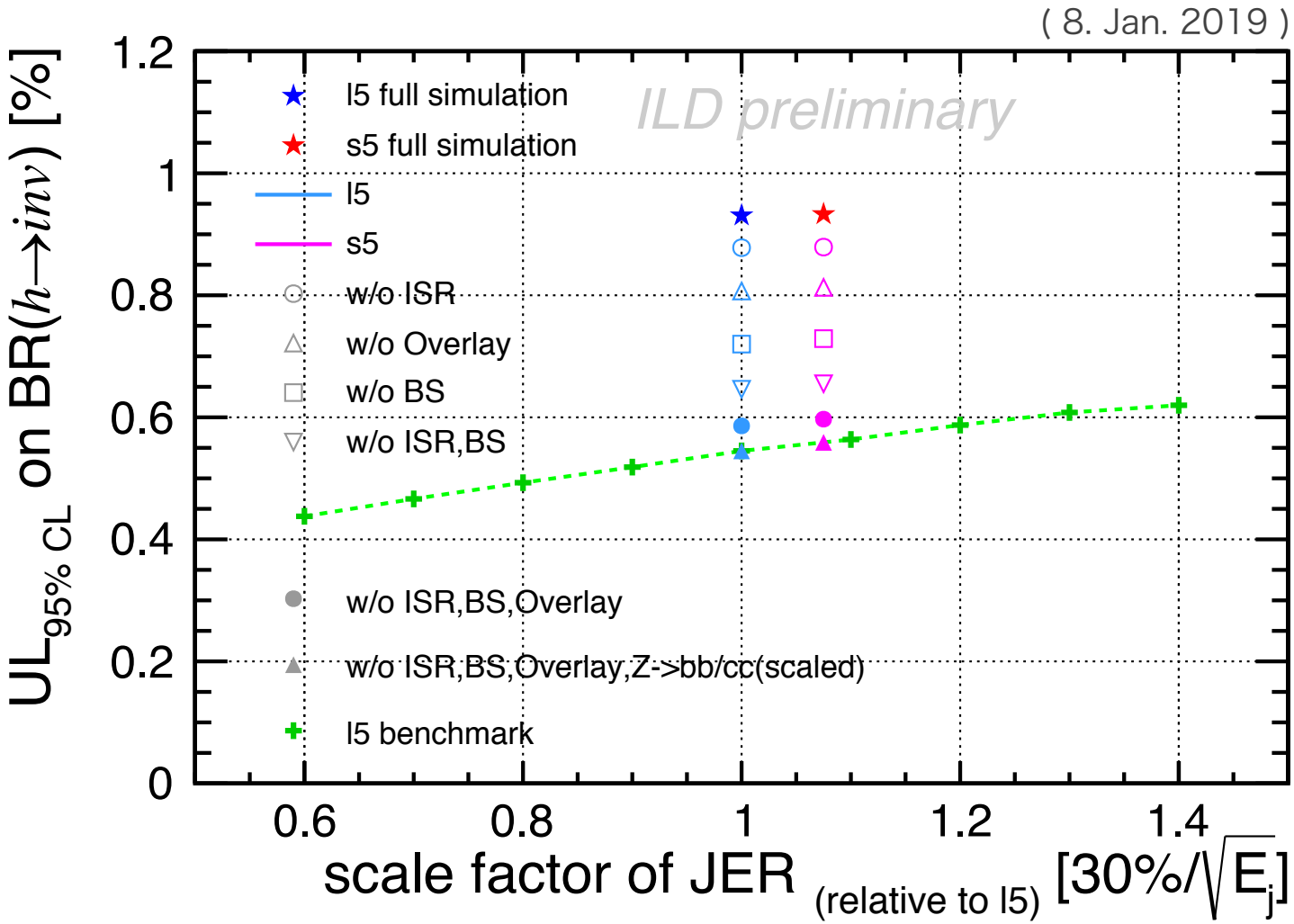
$$\Delta M_{rec} \sim \frac{\sqrt{s} - (1-\beta^2)E_{jj}}{M_{rec}} \Delta E_{jj}$$
$$\sim 4\Delta E_{jj} \ (when \ \sqrt{s} = 500 \ \mathrm{GeV})$$

   - However in practical situation, it can't be fitted by single-Gaussian
3. Make template function by adjusting sigma of fitted Gaussian
4. Do toy-MC
5. Evaluate upper limit on BR(H→inv.)

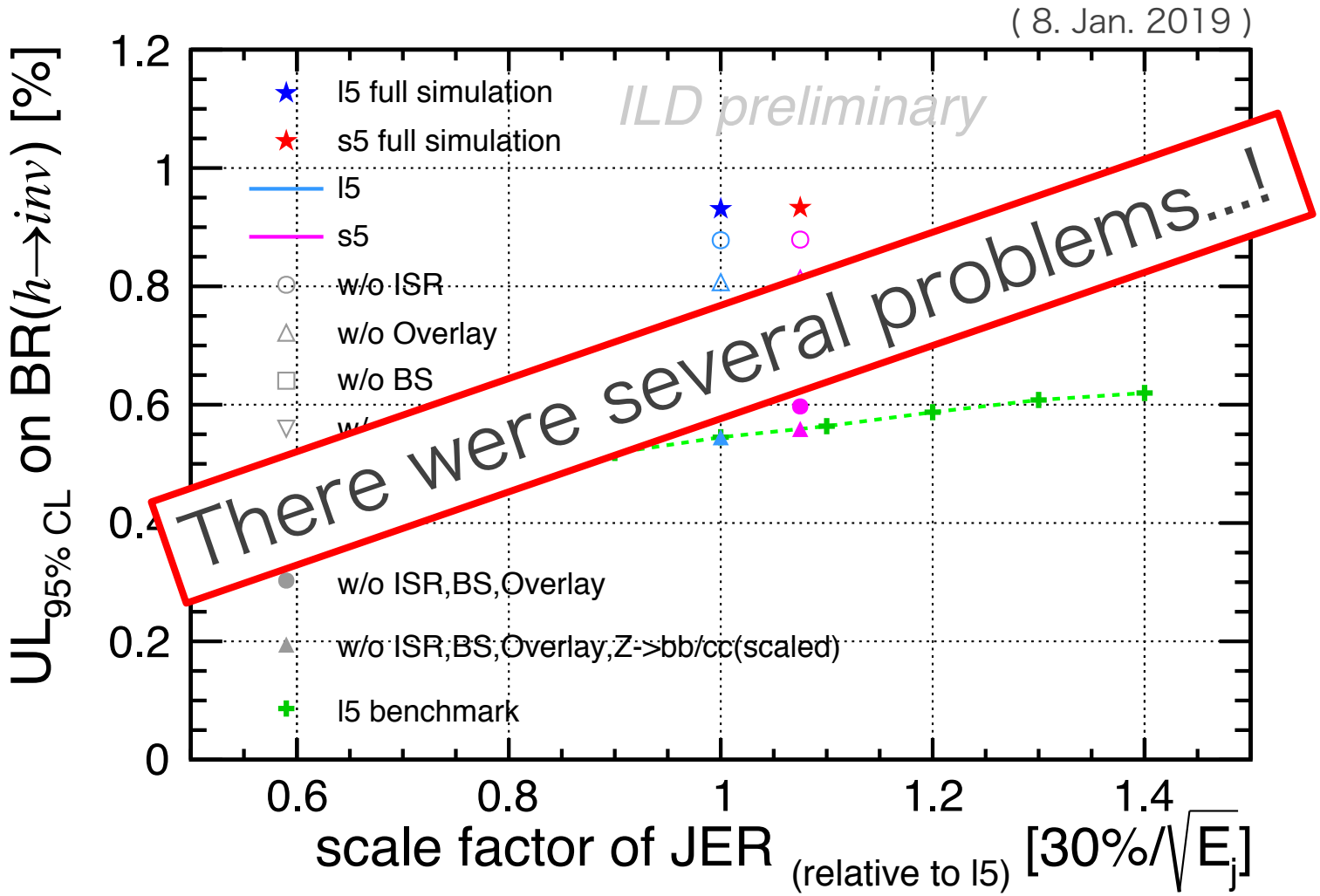




Previous Result



Previous Result



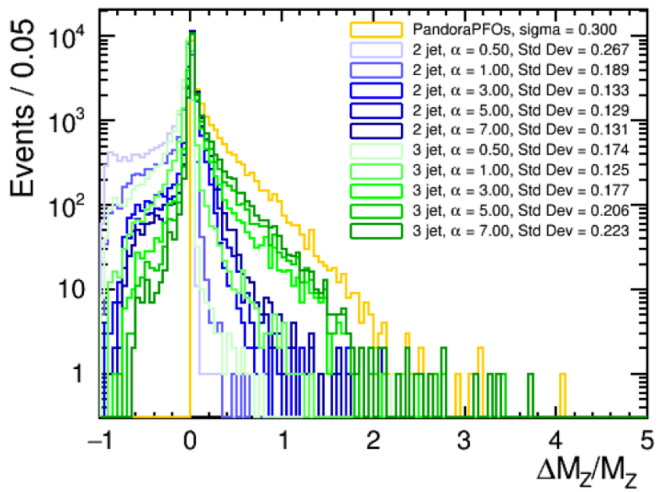
Problems

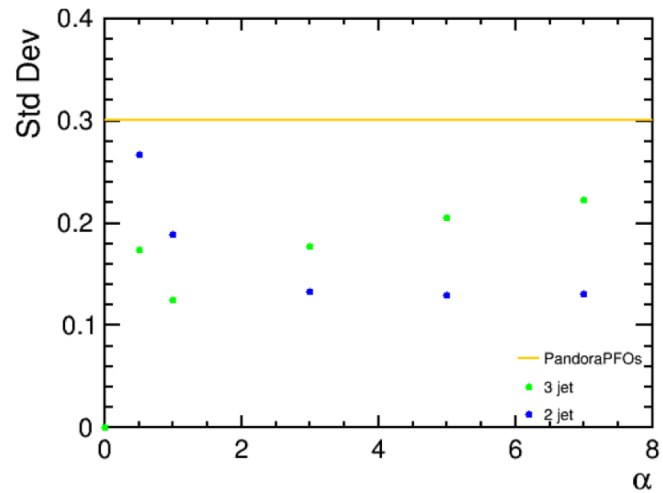
- Overlay removal was not optimized.
  - kt algorithm which parameters are not optimized was used.
- The definitions of w/o { ISR, BS } were wrong.
  - w/o ISR: PFOs w/o ISR & Overlay removal & **Pecm = 500**
  - w/o BS: **Pecm = Ph + Pqq**
- The weights which is to convert generated evts. to expected evts. were not correct.
  - I chose generated evts. as evts. which is passed Processor selection.
  - Processor selection has no skips without "# of jets = 2", but parts of bkg evts. are interpreted as less than 2 jets.

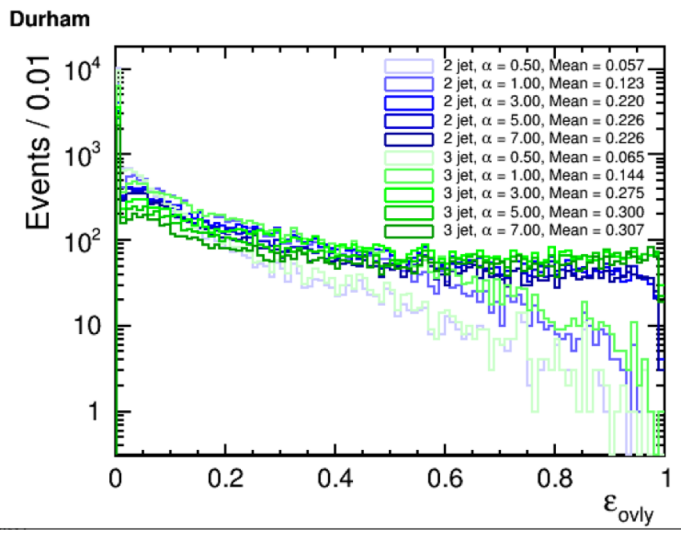
Status

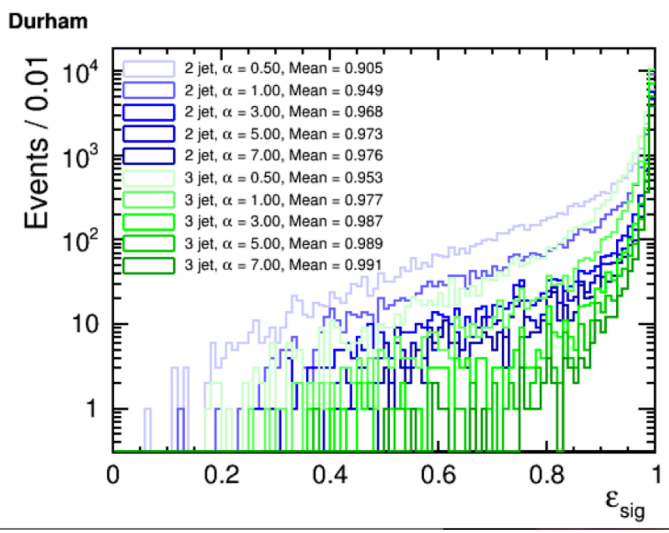
- Several problems were found.
- Updates
  - Overlay removal: kt → Durham
  - Definition of “w/o ISR”: PFOs w/o ISR & Overlay removal & Pecm = 500 **- Pisr**
  - Definition of “w/o BS”: Pecm = Ph + Pqq **+ Pisr**
  - Definition of “w/o Z→bb/cc”: Pjj = Pvis + Pmis
  - Fix # of generated events
  - Add DBD 250 GeV result
    - Event selection is not optimized yet.

Durham : {Njet=2, α=5.0} seems to be the best.

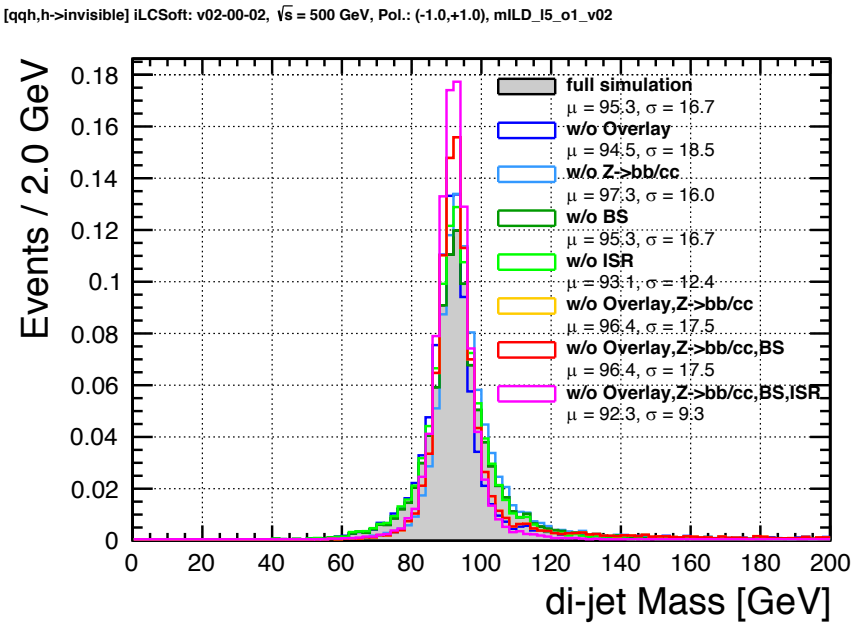


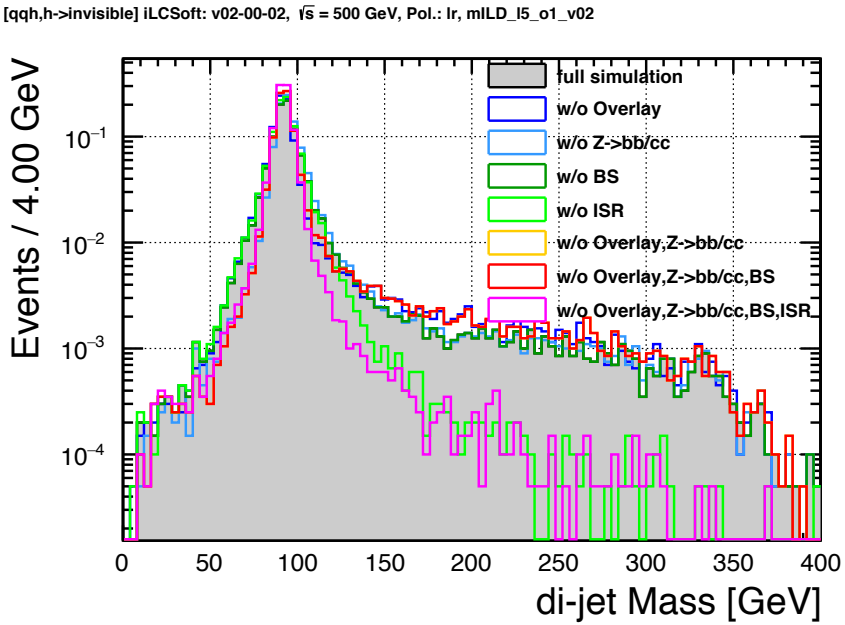






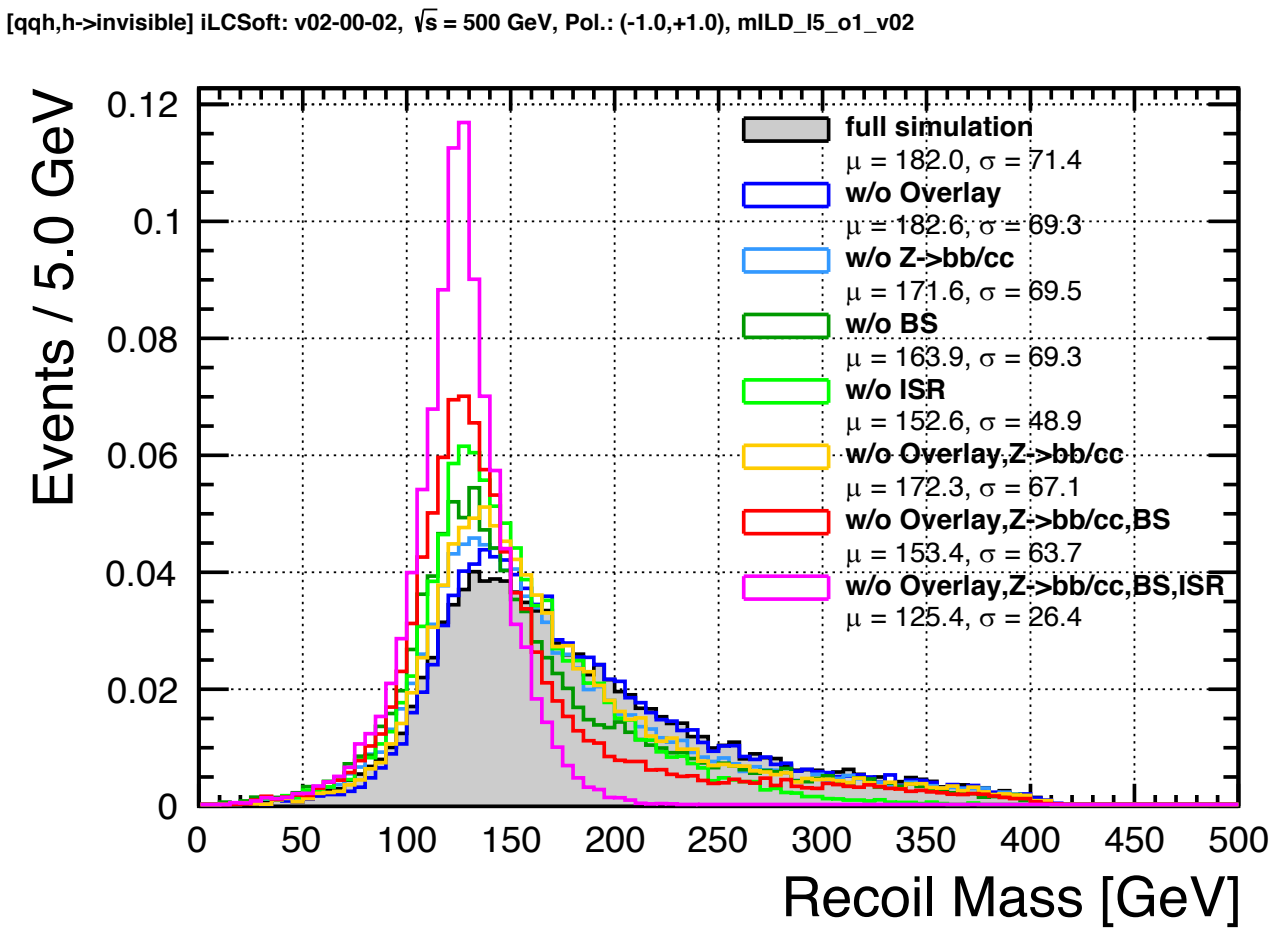
Comparison full sim./cheating





- Std Dev of w/o Overlay is larger than full sim → over-removal
- w/o BS is same as full sim because of the definition
- High energy tail is removed by w/o ISR
- Low energy region is recovered by w/o Z→bb/cc

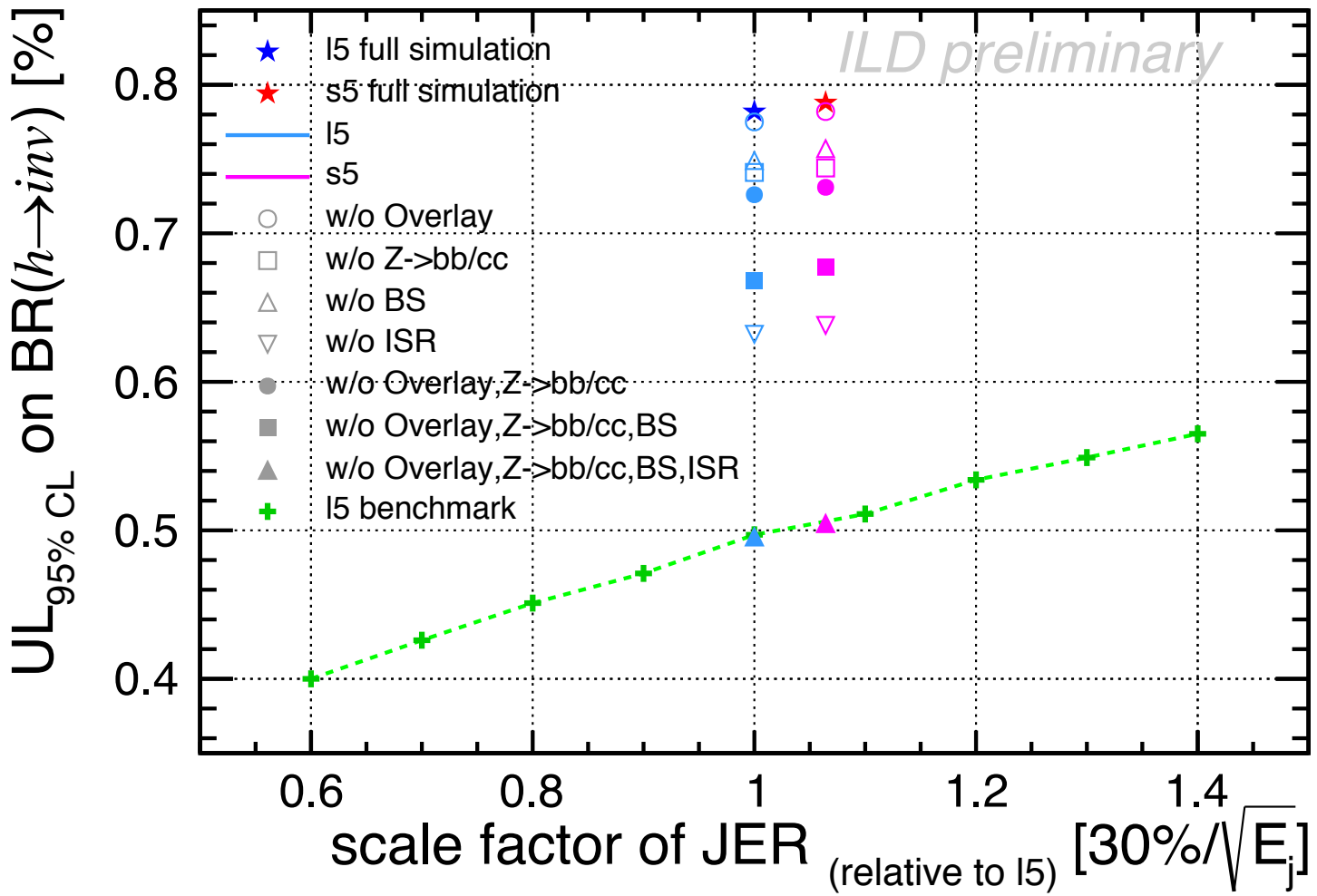
Comparison full sim./cheating



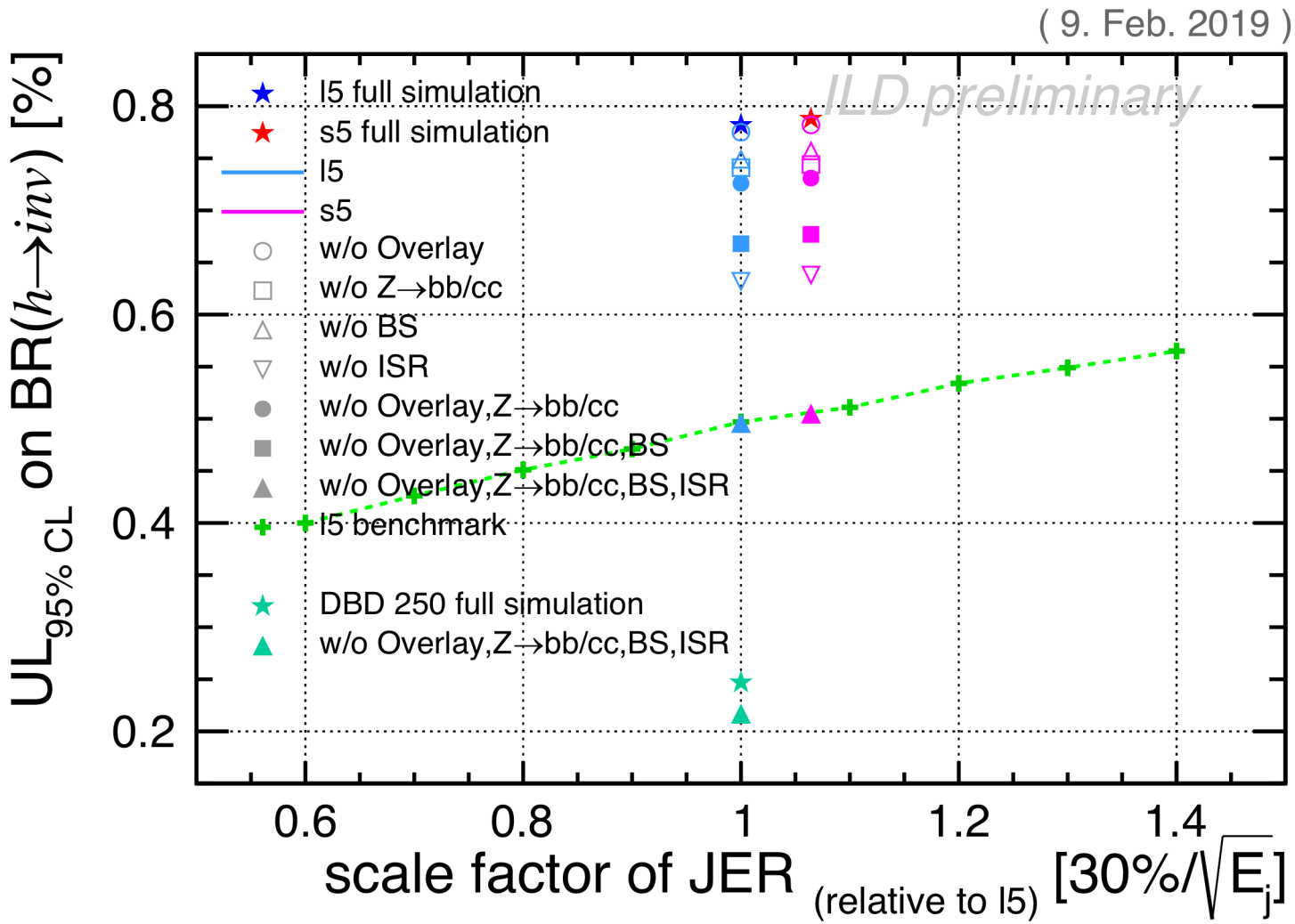
- The effect of w/o Overlay is not so large.
- ISR is effective.
- Magenta looks almost symmetrical.

Latest Results

(8. Feb. 2019)



Latest Results

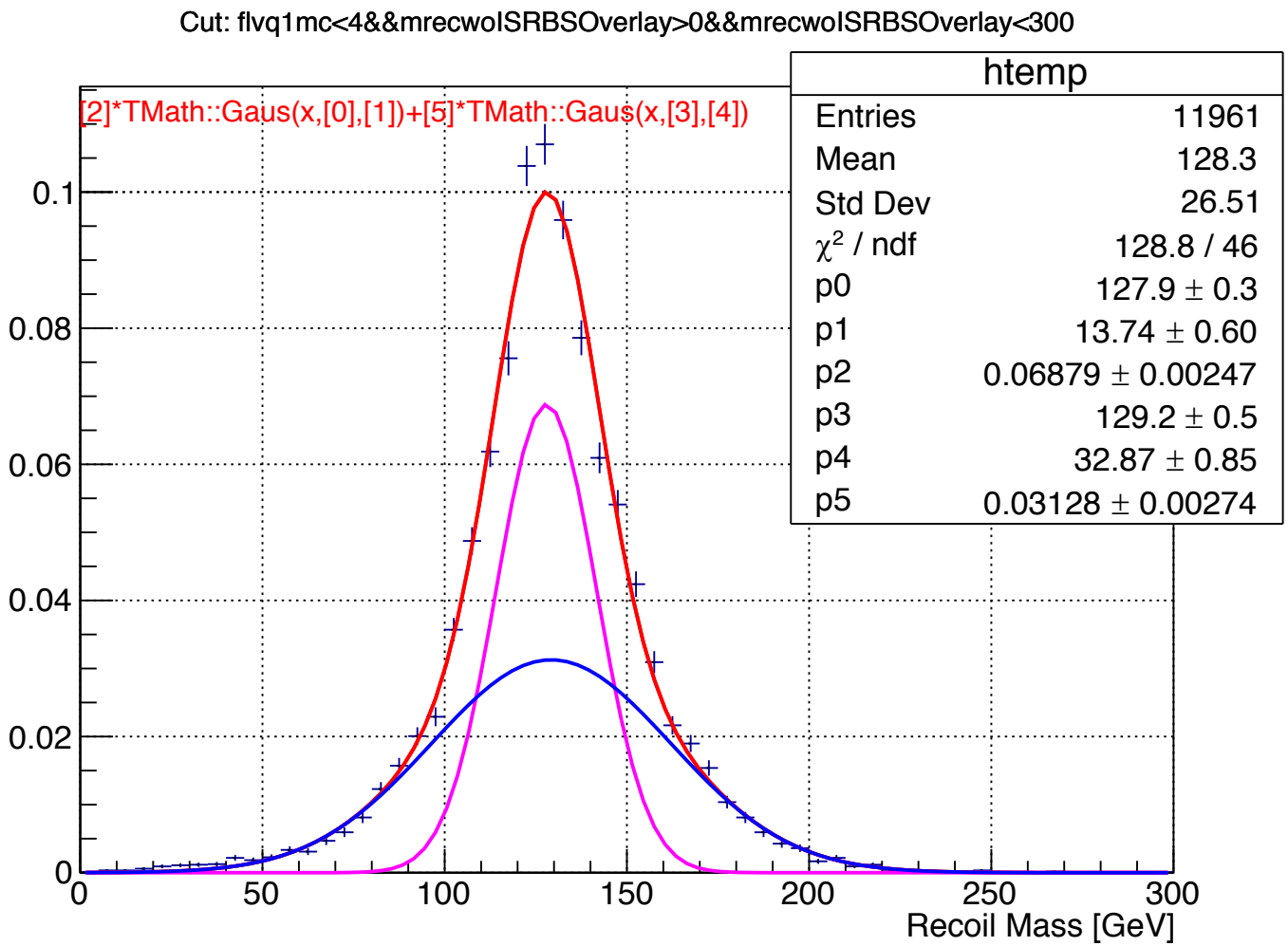


backup

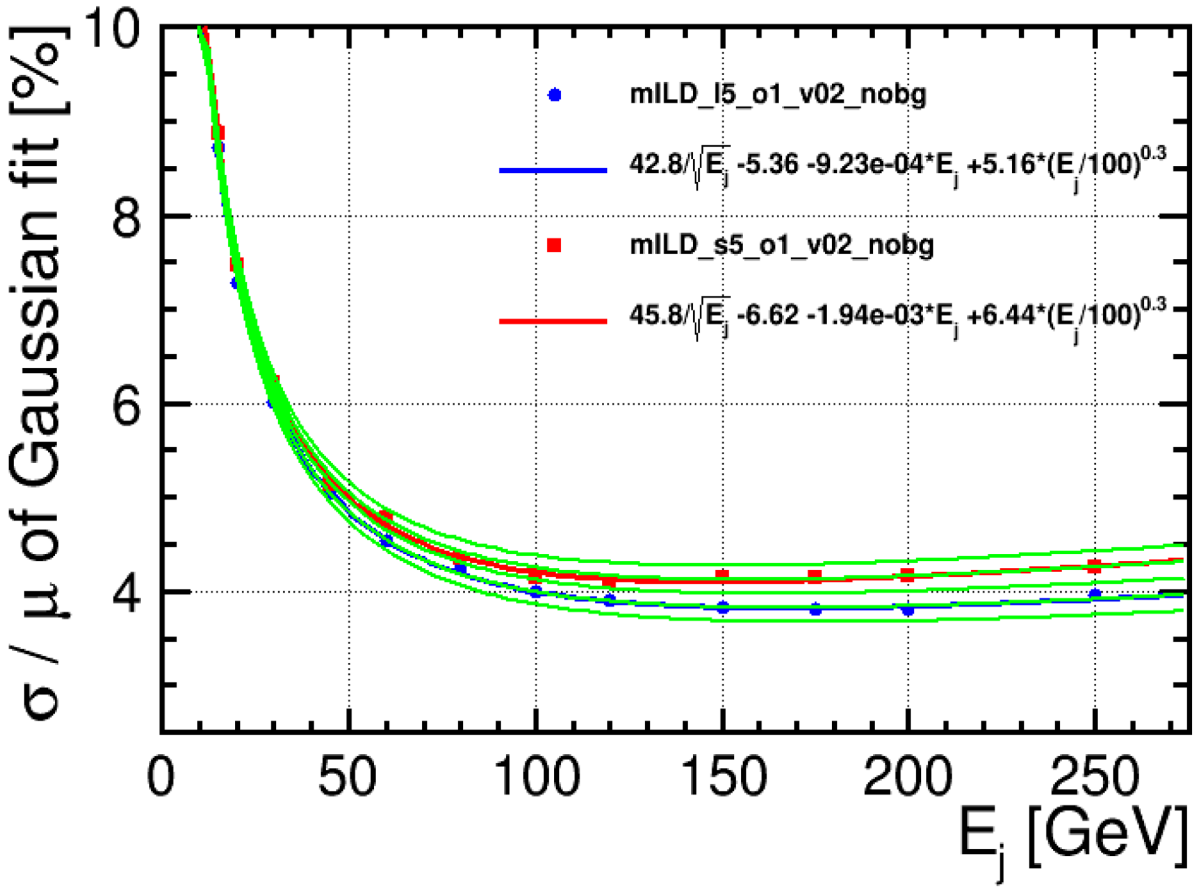
Latest Results

condition	l5/s5	lr sig	rl sig	comb sig	lr UL [%]	rl UL [%]	comb UL [%]	(s5-l5)/l5
full simulation	l5	12.7281	16.8409	21.1097239	1.29634431	0.97975761	0.782	
(mrec80-330,bw=5GeV)	s5	12.6195	16.7247	20.9515482	1.3075003	0.98656478	0.788	0.755%
w/o OZ	l5	13.8243	18.0503	22.7359759	1.19355049	0.91411223	0.726	
(mrec80-330,cut7,bw=5)	s5	13.6816	17.9548	22.5734583	1.2059993	0.91897431	0.731	0.720%
w/o OZB	l5	15.1501	19.4869	24.6832899	1.08910172	0.84672267	0.668	
(mrec50-300,cut7,bw=5)	s5	14.9165	19.2874	24.382489	1.10615761	0.85548078	0.677	1.234%
w/o OZBI	l5	20.5951	26.1507	33.2868931	0.80116144	0.63095825	0.496	
(mrec0-250,cut7,bw=5)	s5	20.1449	25.7104	32.6625422	0.81906587	0.64176364	0.505	1.912%
scaled JER template								
0.6	l5	25.9253	32.07	41.2384054	0.63644394	0.51449953	0.400	
0.7	l5	24.1576	30.2919	38.7451783	0.68301487	0.54470007	0.426	
0.8	l5	22.7874	28.6655	36.6193458	0.72408436	0.57560482	0.451	
0.9	l5	21.6818	27.4943	35.0148109	0.76100693	0.60012439	0.471	
1	l5	20.632	26.0433	33.2254857	0.79972858	0.63356026	0.497	
1.1	l5	19.8347	25.4684	32.2808724	0.83187545	0.64786166	0.511	
1.2	l5	18.9812	24.4043	30.9169179	0.86928118	0.67611036	0.534	
1.3	l5	18.484	23.7114	30.0647426	0.89266393	0.69586781	0.549	
1.4	l5	18.0108	22.9787	29.196054	0.916117	0.71805629	0.565	
w/o Overlay	l5	12.8777	16.9561	21.2918878	1.2812847	0.97310113	0.775	
(80-330,cut7,bw=5)	s5	12.7443	16.8147	21.0986094	1.29469645	0.98128423	0.782	0.916%
w/o Zbbcc	l5	13.5141	17.7139	22.2803311	1.22094701	0.93147189	0.741	
(80-330,cut7,bw=5)	s5	13.4247	17.6601	22.1833654	1.22907774	0.93430955	0.744	0.437%
w/o BS	l5	13.4427	17.4392	22.0188982	1.22743199	0.94614432	0.749	
(80-330,cut7,bw=5)	s5	13.2565	17.2976	21.7931585	1.24467242	0.95388956	0.757	1.036%
w/o ISR	l5	15.9292	20.6605	26.0882286	1.03583356	0.7986254	0.632	
(50-300,cut7,bw=5)	s5	15.7793	20.486	25.8585093	1.04567376	0.8054281	0.638	0.888%

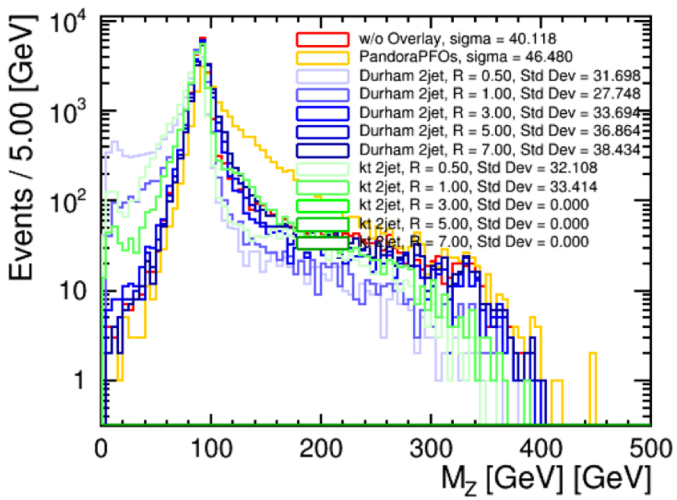
double-Gaussian fit w/o Z->bb/cc

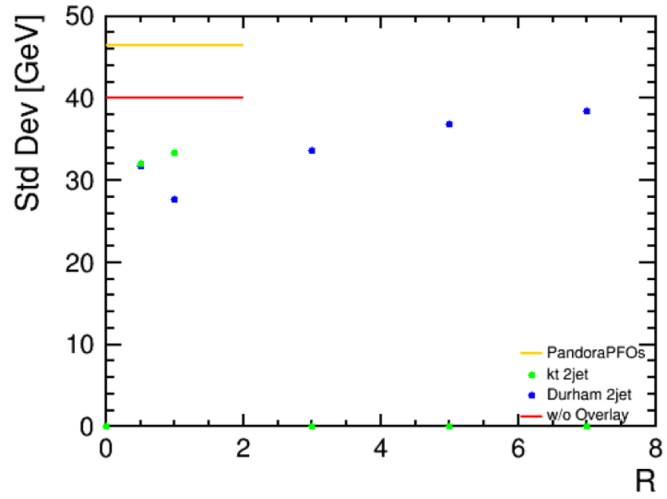


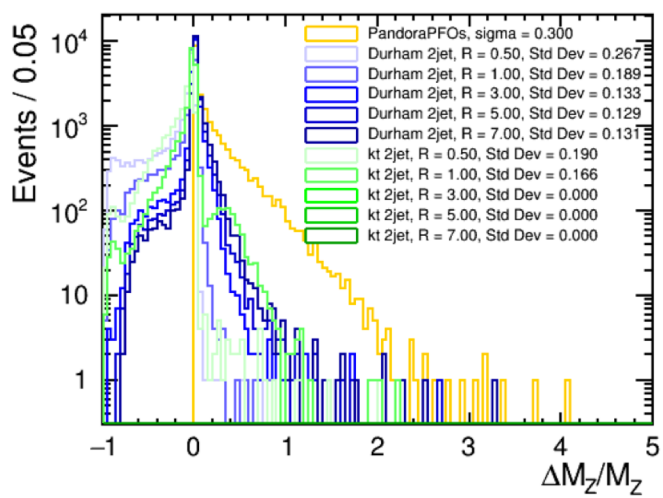
How to relate ΔMrec and JER...?

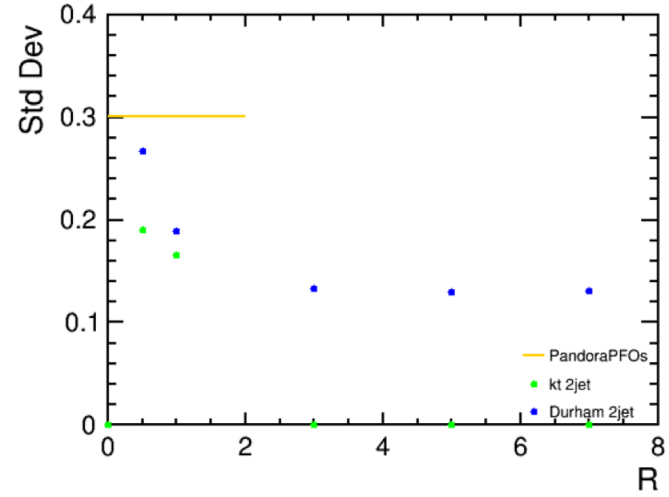


kt vs Durham


w/o Overlay, sigma = 40.118
PandoraPFOs, sigma = 46.480
Durham 2jet, R = 0.50, Std Dev = 31.698
Durham 2jet, R = 1.00, Std Dev = 27.748
Durham 2jet, R = 3.00, Std Dev = 33.694
Durham 2jet, R = 5.00, Std Dev = 36.864
Durham 2jet, R = 7.00, Std Dev = 38.434
kt 2jet, R = 0.50, Std Dev = 32.108
kt 2jet, R = 1.00, Std Dev = 33.414
kt 2jet, R = 3.00, Std Dev = 0.000
kt 2jet, R = 5.00, Std Dev = 0.000
kt 2jet, R = 7.00, Std Dev = 0.000
Events / 5.00 [GeV]
M_Z [GeV] [GeV]


Std Dev [GeV]
PandoraPFOs
kt 2jet
Durham 2jet
w/o Overlay
R


PandoraPFOs, sigma = 0.300
Durham 2jet, R = 0.50, Std Dev = 0.267
Durham 2jet, R = 1.00, Std Dev = 0.189
Durham 2jet, R = 3.00, Std Dev = 0.133
Durham 2jet, R = 5.00, Std Dev = 0.129
Durham 2jet, R = 7.00, Std Dev = 0.131
kt 2jet, R = 0.50, Std Dev = 0.190
kt 2jet, R = 1.00, Std Dev = 0.166
kt 2jet, R = 3.00, Std Dev = 0.000
kt 2jet, R = 5.00, Std Dev = 0.000
kt 2jet, R = 7.00, Std Dev = 0.000
Events / 0.05
ΔM_Z/M_Z


Std Dev
PandoraPFOs
kt 2jet
Durham 2jet
R