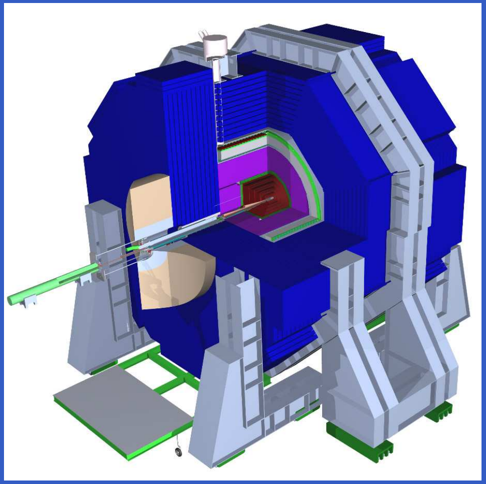
NMSSM $h_{1,2} \rightarrow 2a_1$ at the ILC



Chris Potter

University of Oregon

Next-to-Minimal Supersymmetric Model (NMSSM)

- The Next-to-Minimal Supersymmetric Model (NMSSM) is motivated to reduce the fine-tuning required for the term $\mu \hat{H}_u \hat{H}_d$ in the MSSM superpotential.
- One singlet superfield $\hat{S}$ is introduced to the MSSM. The NMSSM superpotential is

$$W_{NMSSM} = \lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\kappa}{3} \hat{S}^3 + W_{MSSM} \qquad (1)$$

- An effective μ term is generated $\mu_{eff} = \lambda < \hat{S} >$ at a natural scale.
- The trilinear soft SUSY breaking terms in the NMSSM Lagrangian are

$$\mathcal{L}_{soft}^{trilinear} = \lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3. \qquad (2)$$

- Six parameters determine the NMSSM Higgs sector at tree level: $\lambda, \kappa, A_\lambda, A_\kappa, \tan\beta$ and μ_{eff}.
- The NMSSM Higgs sector includes neutral CP-odd a_1, a_2, neutral CP-even h_1, h_2, h_3 and charged H^+, H^-.

NMSSM Point: $(m_{a_1}, m_{h_1}, m_{h_2})$=(10.3,91.6,124.5) GeV

NMSSMTools_3.2.4

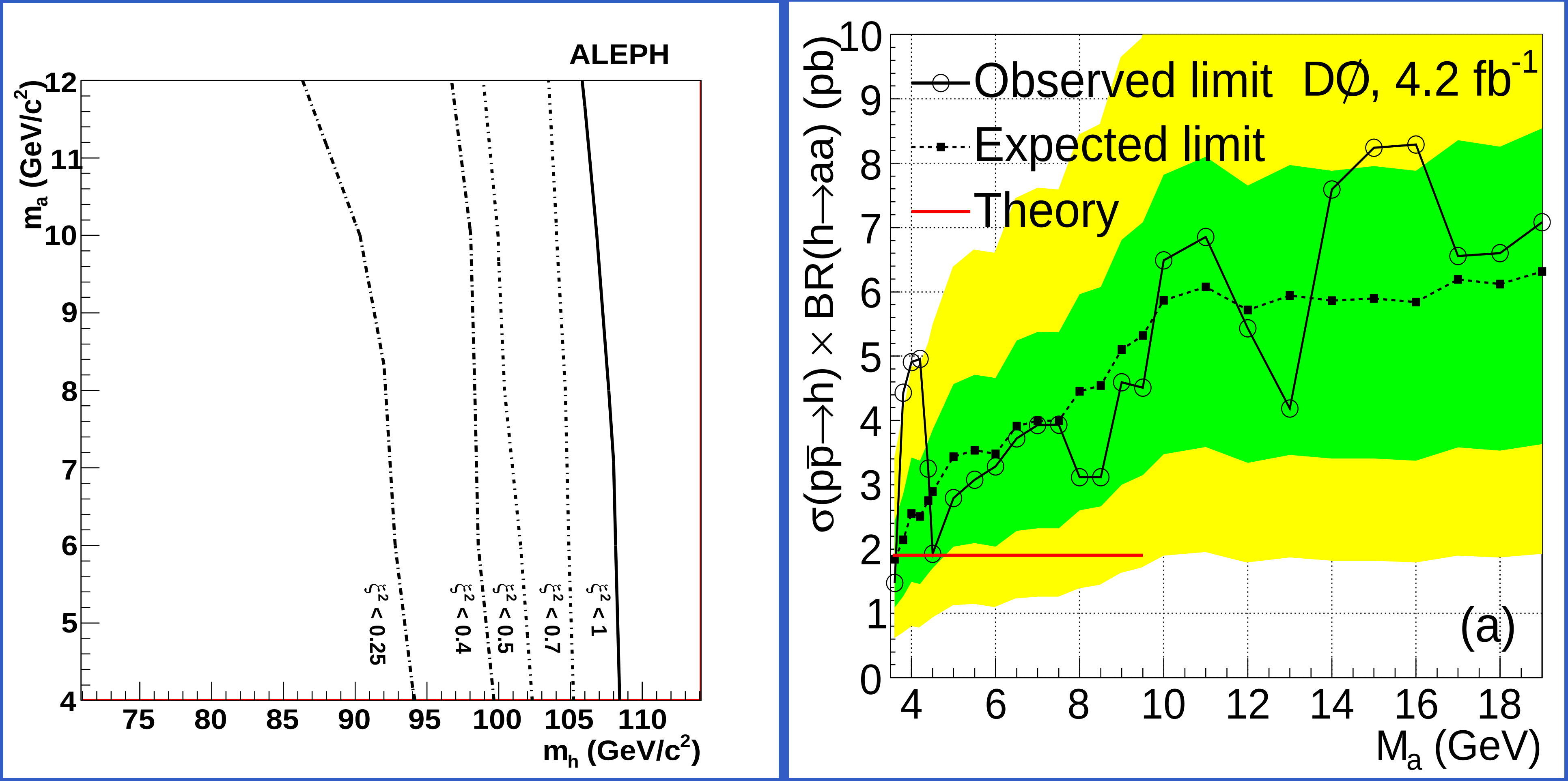
Target: $m_\Upsilon < m_{a_1} < 2m_B$, $m_{h_1} \approx 98$ GeV, $m_{h_2} \approx 125$ GeV.

Parameter	Value	Scalar	Mass [GeV]	Decay	BR [%]
λ	0.3	a_1	10.3	$h_1 \to 2a_1$	85.4
κ	0.1	h_1	91.6	$h_1 \to b\bar{b}$	11.9
A_κ	11.6	h_2	124.5	$h_1 \to \tau^+\tau^-$	1.2
m_A	465 GeV	a_2	465.2	$a_1 \to \tau^+\tau^-$	73.2
$\tan\beta$	3.1	h_3	469.2	$a_1 \to 2g + c\bar{c}$	22.3+3.1
μ_{eff}	165 GeV	$H^\pm$	465.7	$h_2 \to 2a_1$	87.2

The generated particle spectrum and decay tables are saved in SLHA files and passed to e^+e^- or pp generators.

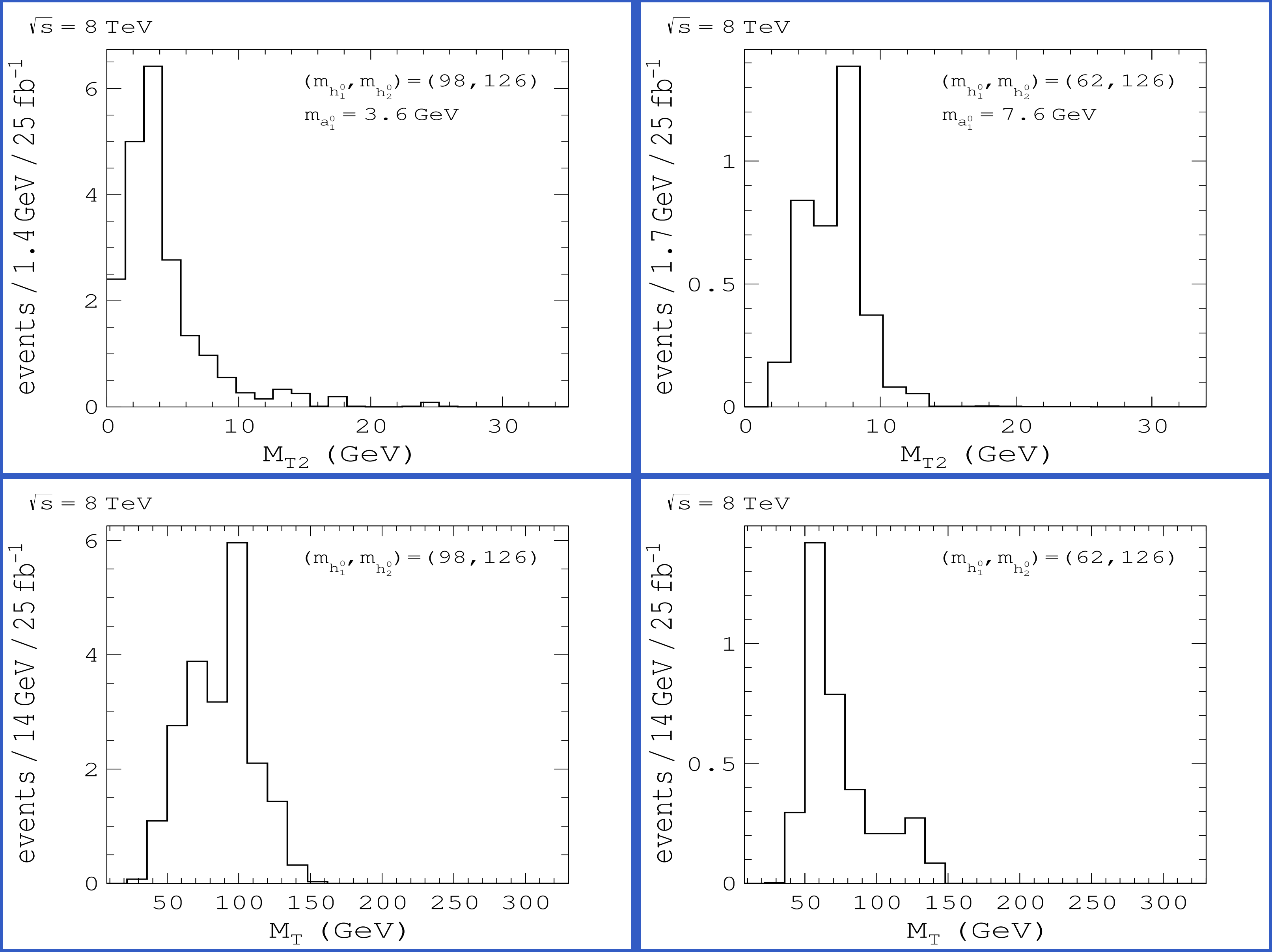
This Scenario at LEPII and the Tevatron

$$\xi^2 = \sigma/\sigma_{SM} \times B(h \rightarrow 2a) \times B(a \rightarrow 2\tau)^2$$



JHEP 1005:049,2010 (left), PRL 103, 061801,2009(right)

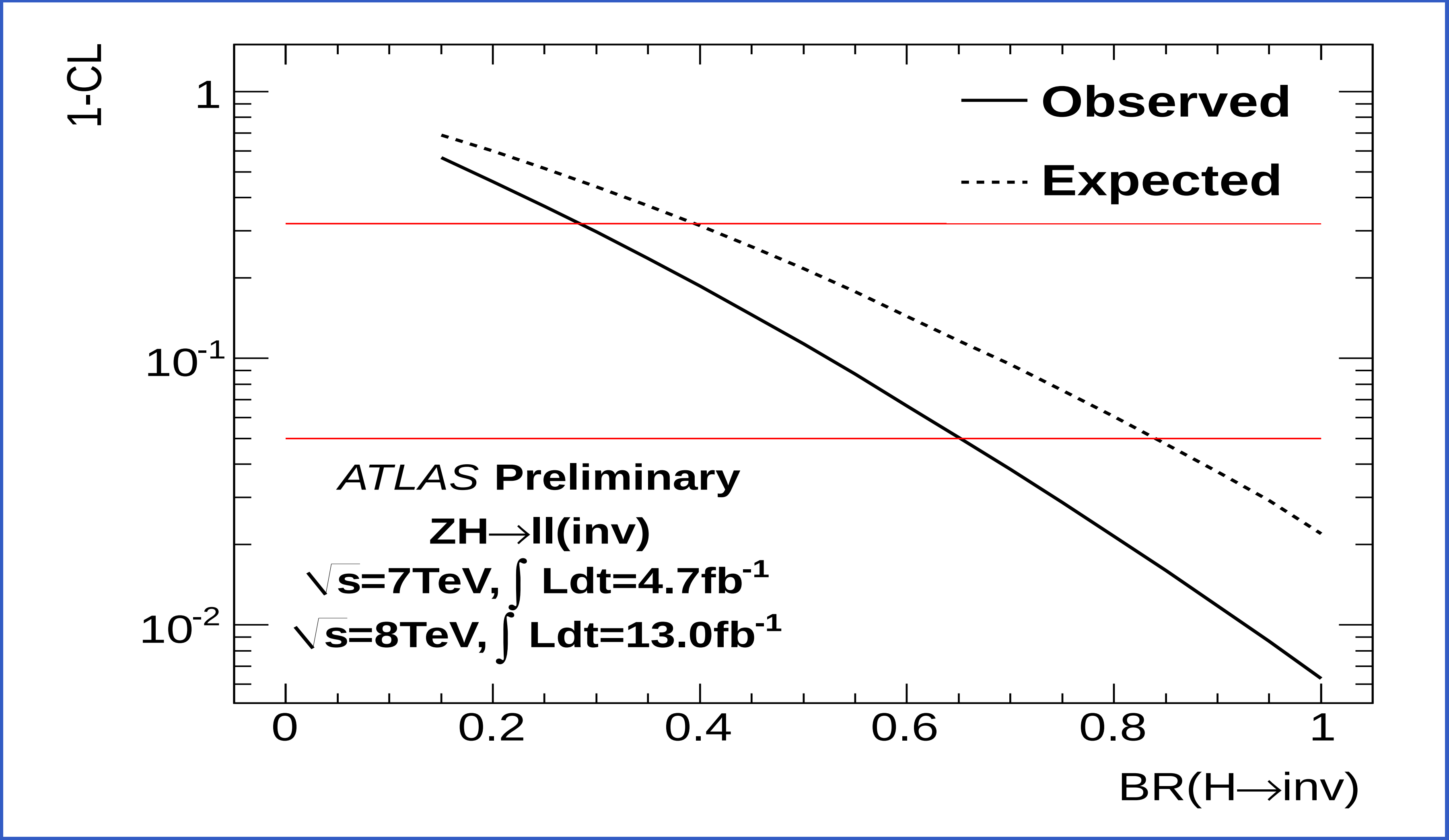
This Scenario at the LHC ($\sqrt{s} = 8$ TeV, 25 fb^{-1})



Cerdeno, Ghosh and Park (arXiv:1301.1325v3)

Motivation ($h_2 \to a_1 a_1$): ATLAS Limits on $h_{125} \to invisible$

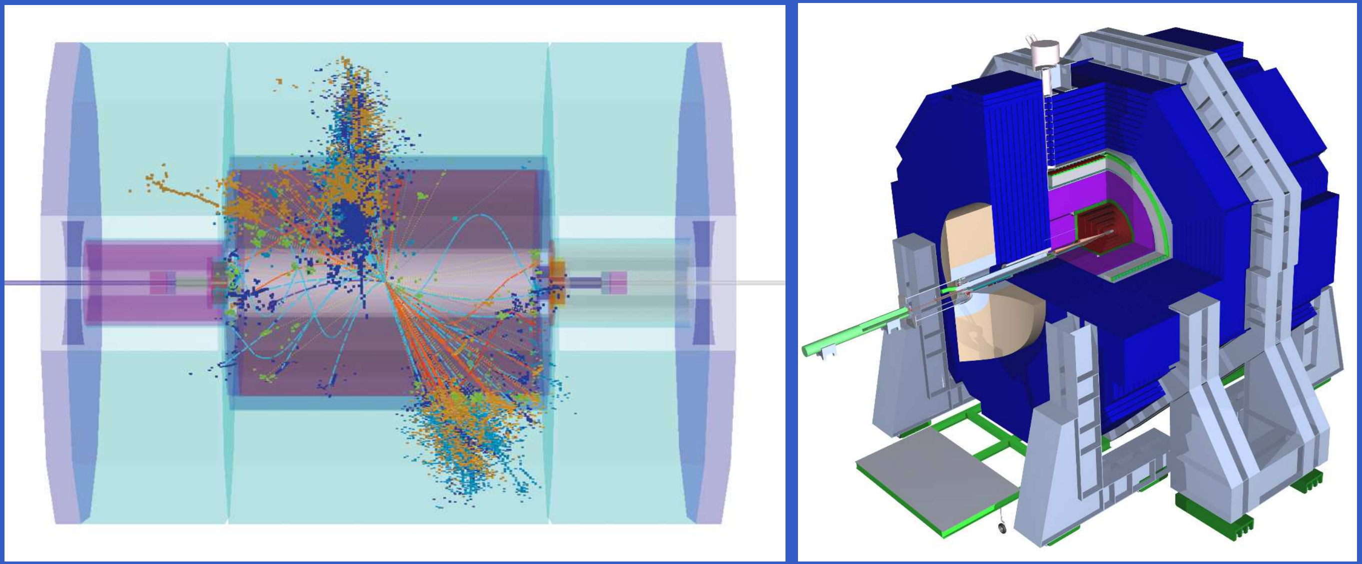
ATLAS-CONF-2013-011



1 - Confidence level (CL) for the SM scalar with 125 GeV mass. The red solid lines indicate the 68% and 95% CL for (a). The expected 95% C.L. upper limit on $\mathcal{B}(H \to inv.)$ at 125 GeV is 84%, the observed limit is 65%.

SiD Detector (see Ch. 3 of the ILC DBD)

http://www.linearcollider.org/ILC/physics-detectors/Detectors/Detailed-Baseline-Design



- Silicon pixel vertex detector extends radially $1.4 < r < 6.0$cm in five layers around the beamline and five disks on both sides of the IP.
- Silicon strip main tracker occupies $21.7 < r < 122.1$cm and consists of five cylinders and four disks on both sides of the IP, all instrumented with 10×10 cm^2 silicon sensors
- Silicon Tungsten ectromagnetic calorimeter occupies $126.5 < r < 140.9$cm and includes 26 radiation lengths and one nuclear interaction length.
- Glass RPC/Steel hadronic calorimeter extends radially $141.7 < r < 249.3$cm. and includes 4.5 nuclear interaction lengths.
- Scintillator muon system instrumented on the iron flux return of a 5T solenoidal magnet.

Signal Simulation and Analysis Selection

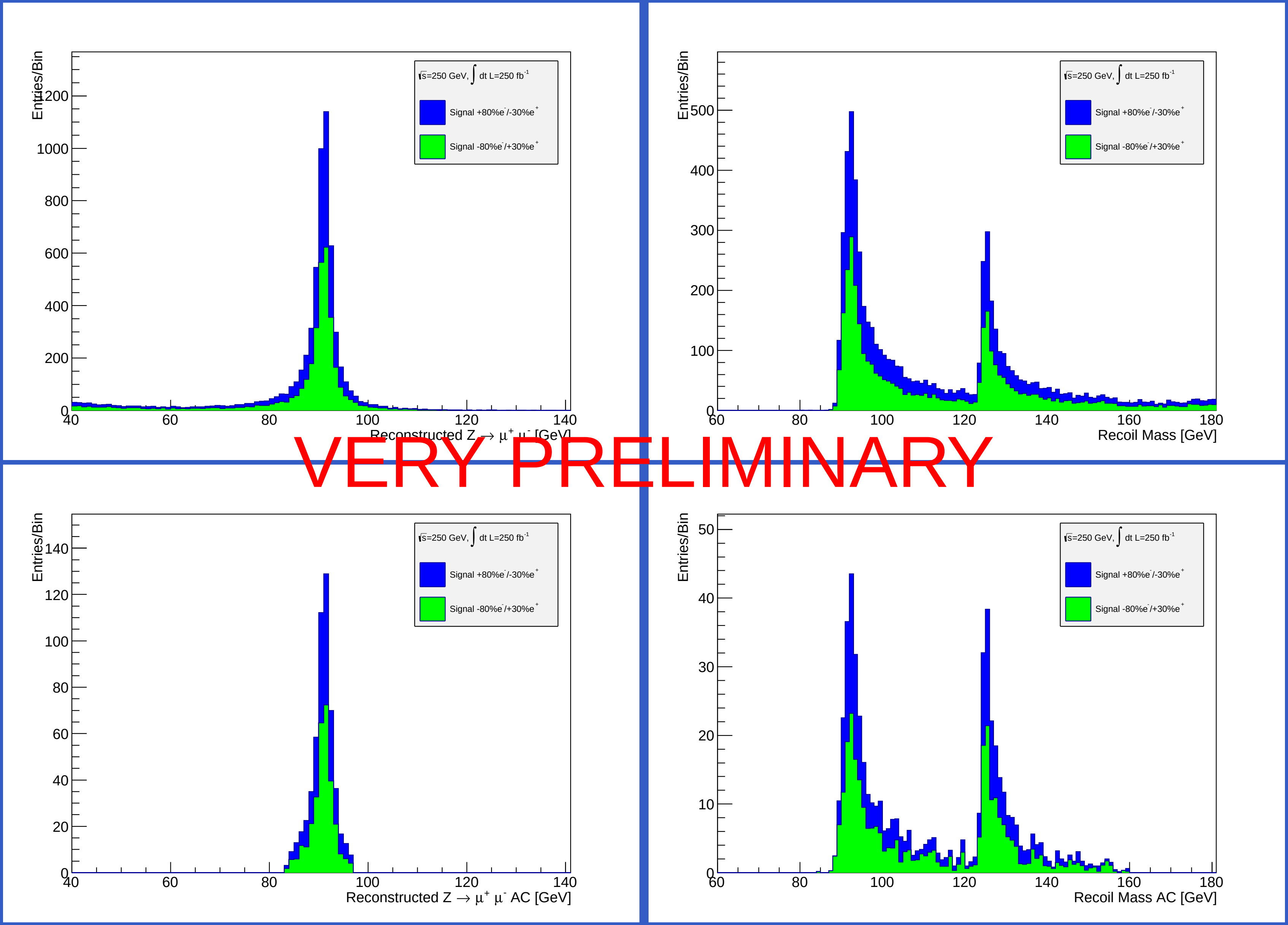
Signal Simulation

- Simulation of the signal process $e^+e^- \to Zh_{1,2} \to f\bar{f}a_1a_1$ was performed with the Whizard event generator, which has a full implementation of the NMSSM.
- Whizard interfaces the NMSSM model with the SLHA file generated by NMSSMTools
- Signal events are weighted by $Zh_{1,2}$ production cross section multiplied by the branching ratio for $Z \to f\bar{f}$.
- Thanks to Tim Barklow for generating the Whizard events and Norman Graf for SiD detector simulation and event reconstruction.

Analysis Selection: Search for $\tau^+\tau^- \to \tau_{1-pr}\tau_{1-pr}$

- Require two muons with $pT > 5$ GeV (using MC truth PID for now)
- Reconstruct $Z \to \mu^+\mu^-$ and calculate recoil mass
- Require reconstructed Z mass within 3σ of m_Z
- Require four tracks with $p_T > 1$ GeV in recoil of the Z
- Require zero charge in recoiling tracks with $p_T > 1$ GeV.
- Veto events with good 3-prong candidate from $\tau \to a_!(1260)\nu$

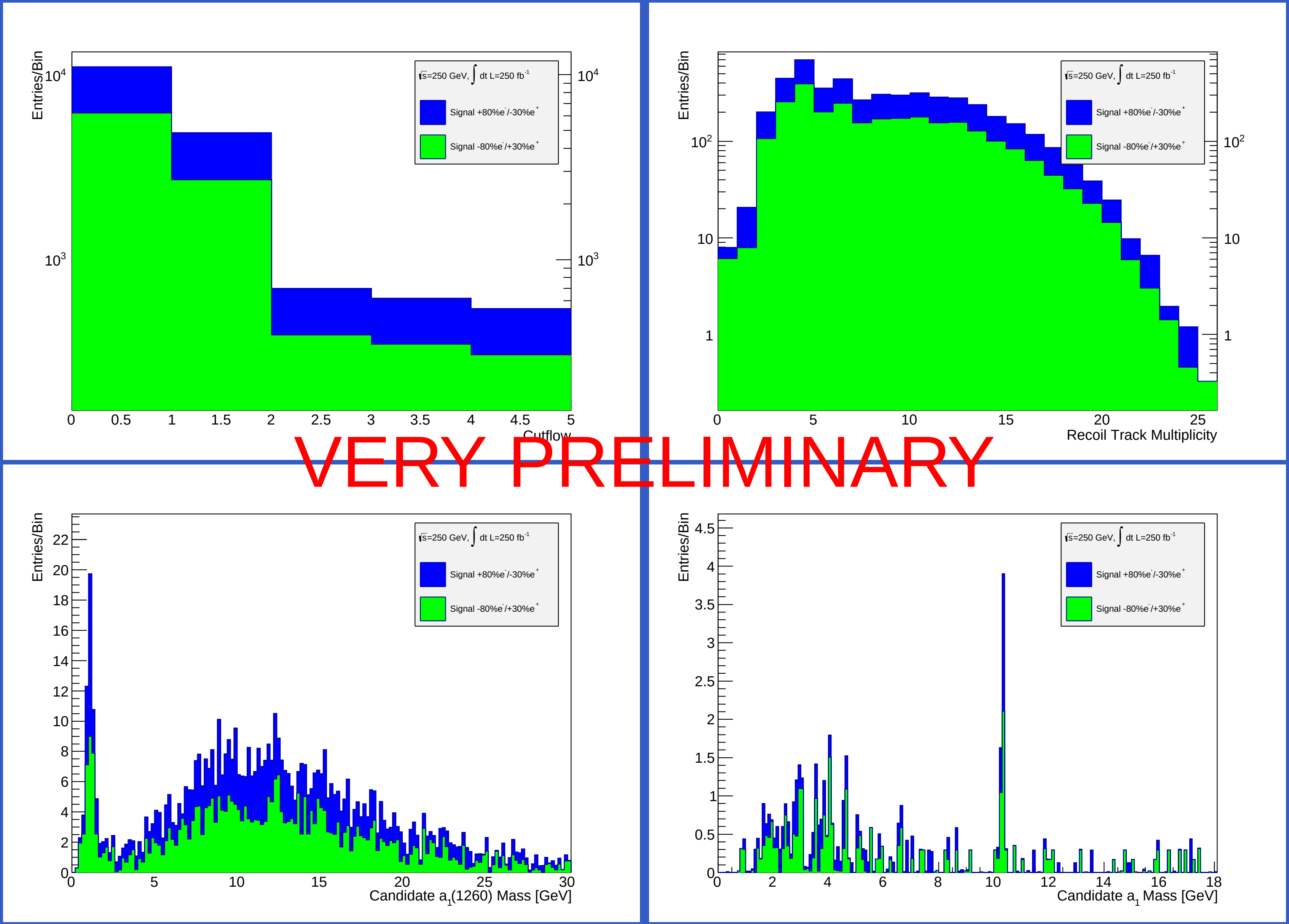
Signal $Z \to \mu^+\mu^-$ and Recoil Masses (SiD Full Sim.)



VERY PRELIMINARY

Reconstructed Z (left) and recoil (right) masses before (top) and after (bottom) full selection.

Signal Distributions (SiD Full Simulation)



VERY PRELIMINARY

Cutflow, recoil track multiplicity, best $a_!(1260)$ candidate and candidate $a_1 \rightarrow \mu^+\mu^-$.

Conclusions and Outlook

Conclusion

- The NMSSM is well motivated both theoretically and experimentally.
- One interesting scenario identifies the h_{125} with the h_2 of the NMSSM and allows an h_1 to escape LEPII bounds by decaying via $h_1 \to a_1 a_1$.
- For $2m_\tau < m_{a_1} < 2m_B$, this scenario has been studied both at LEPII (ALEPH) and at the Tevatron (DZero) but not at the LHC.
- For $m_{a_1} < 2m_\tau$, CMS has set strong limits.

To Do for Minneapolis

- Reduce the $e^+e^- \to ZZ \to \mu^+\mu^-\tau^+\tau^-$ background in which one τ decays to 1-prong and the other to 3-prong.
- Study the hadronic decays $a_1 \to gg, c\bar{c}$, which will allow direct mass measurement for the a_1.
- Evaluate the expected precision for branching ratios and masses for $h_{1,2} \to 2a_1$ and $a_1 \to \tau^+\tau^-, \mu^+\mu^-$.
- Include the $h_{1,2}Z \to h_{1,2}e^+e^-$ events.
- Repeat the study for $\sqrt{s} = 350$ GeV.