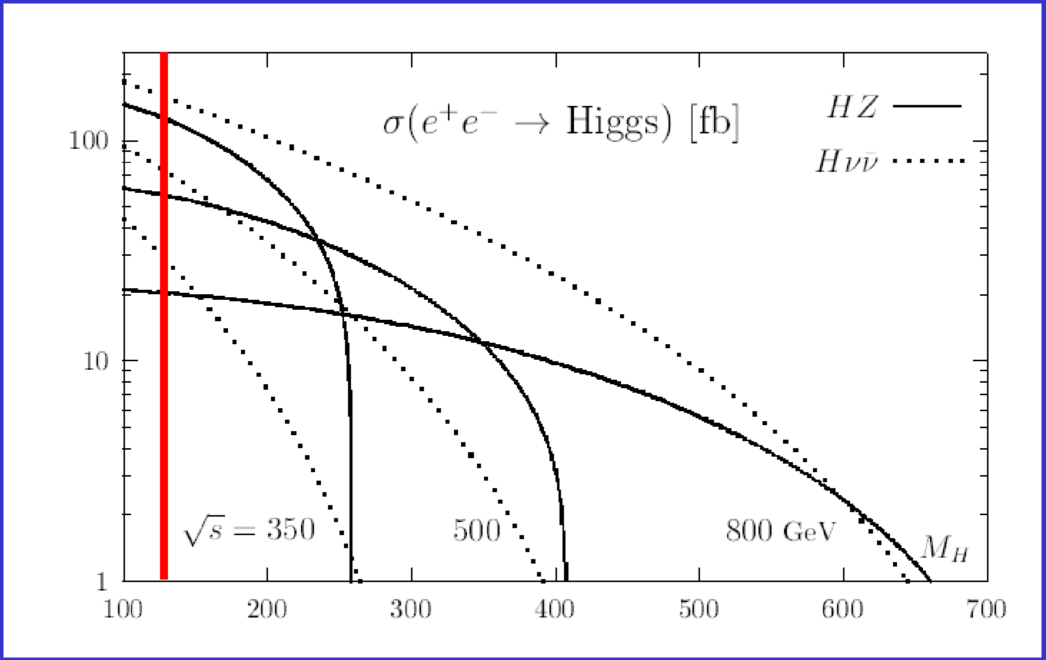
Higgs $B_{\gamma\gamma}$ and ECAL Resolution

Understand how much of a constraint measuring $B_{\gamma\gamma}$ well puts on the ECAL.

(see backup slides related to the physics impact of this and related measurements)



Are "Higgs-factory" type measurements best done at low √s optimized for Higgs-strahlung, OR much higher √s optimized for WW-fusion "the WW collider" ?

[If all you have is 500 GeV, then near threshold is best for light Higgs.]

Graham W. Wilson, University of Kansas

Higgs → γγ

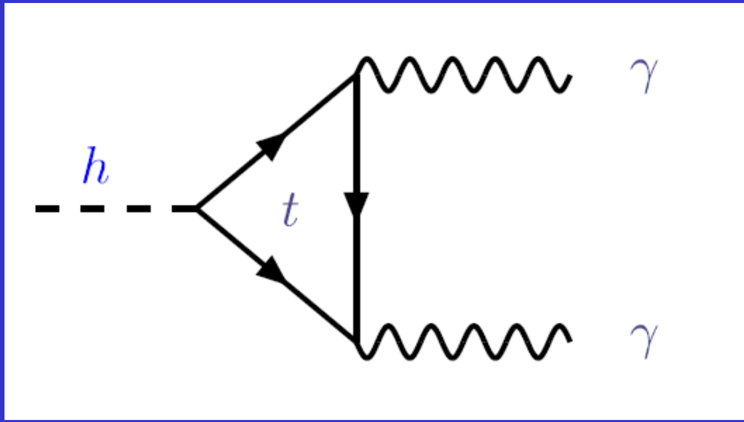
- This was reviewed by F. Petriello at ALCPG07.

- Studies done with $1\,\mathrm{ab}^{-1}$ at $\sqrt{s} = 350, 500, 1000$ GeV

  Boos et al., hep-ph/0011366; Barklow, hep-ph/0312268

- For $m_h = 120$ GeV:

$$\sqrt{s} = 350\,\mathrm{GeV} \Rightarrow \Delta BR(\gamma\gamma) = 12.1\%$$
$$\sqrt{s} = 500\,\mathrm{GeV} \Rightarrow \Delta BR(\gamma\gamma) = 9.6\%$$
$$\sqrt{s} = 1000\,\mathrm{GeV} \Rightarrow \Delta BR(\gamma\gamma) = 5.4\%$$



Any charged particle that gets its mass from the Higgs mechanism will affect the γγ width (but not necessarily by an observable amount !)

If this is really worth doing well (some think γγ collider), we need to make sure the detector is well adapted to measuring it at high √s.

Will a detector designed for PFA be good enough ?

It is also an area where the ILC could complement highly visible LHC measurements.

$H \rightarrow \gamma\gamma$ Study

- 4-vector level study using (old) WHIZARD 1.2 files generated by Tim Barklow at √s=1 TeV (NLC beamsstrahlung)
  - m_H = 120 GeV
    - Signal and background files have no additional ISR photons with p_T.
- Motivation I:
  - Should be able to do ***much*** better $B_{\gamma\gamma}$ measurement than at low √s as studied previously. Maybe even competitive with γγ collider option.
  - At high √s, Higgs cross-section ***increases*** with √s.
    - Dominated by WW fusion. So final state mainly, $\nu_e \nu_e \gamma \gamma$
  - ILC luminosity should be ***higher*** at higher √s (L ~ √s).
  - WW fusion production. So can use polarized beams to ***triple*** signal (and background) cross-section.
- Motivation II:

  This is supposed to be one of the channels which **helps constrain** the ECAL design. (It very much drove the CMS and ATLAS designs.)

Study parameters

- Used favorable $P(e^-) = -80\%$, $P(e^+) = +60\%$.
- Assumed 2 ab^{-1} at $\sqrt{s}=1$ TeV.
- $B_{\gamma\gamma}$ set to 0.220% (HDECAY value)
- Only considered $\nu\nu\gamma\gamma$ for signal and background.
- => Polarized signal cross-section = 1.23 fb

Pre-selection of Higgs $\rightarrow \gamma\gamma$ candidates

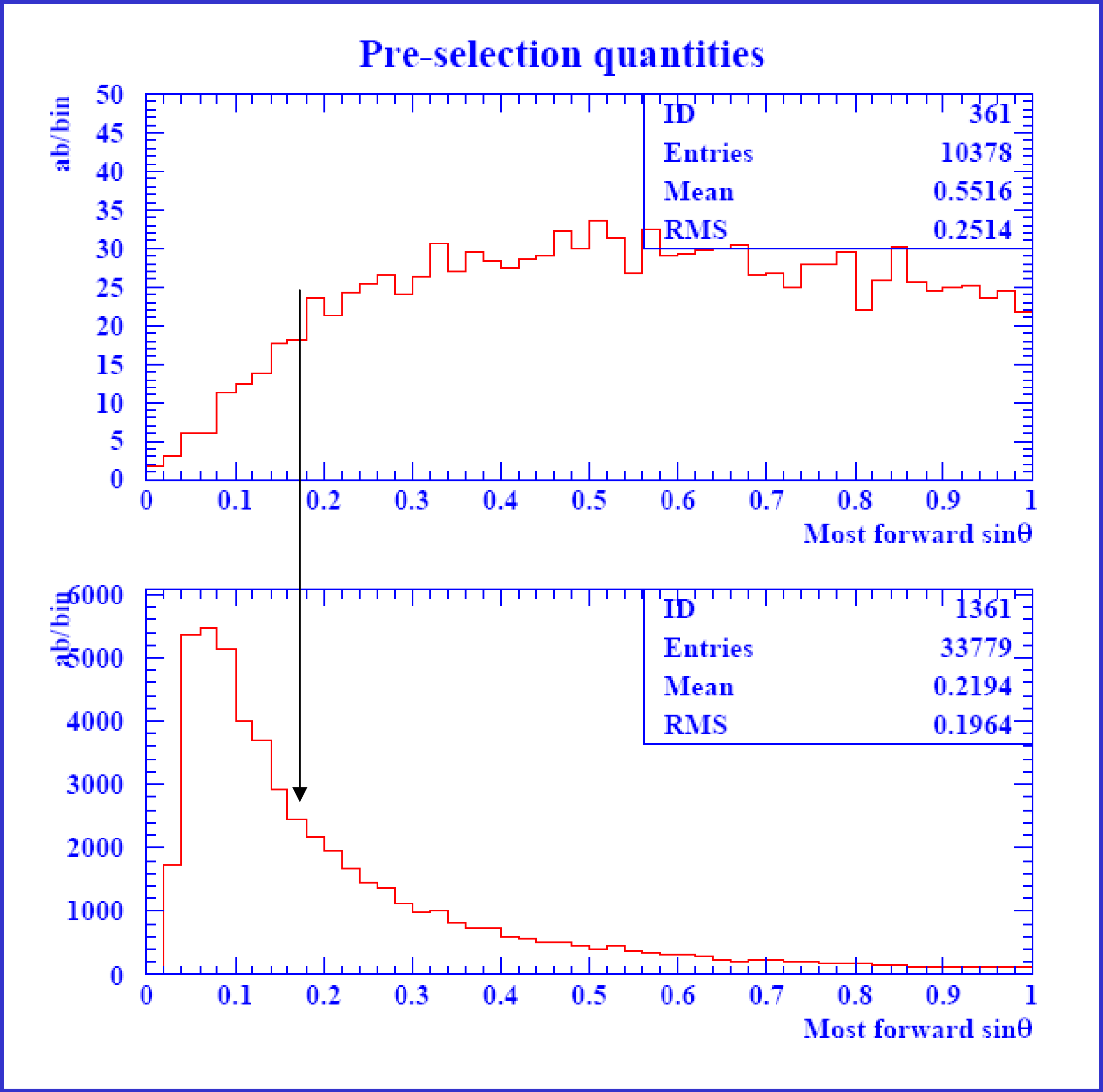
- Require that the two highest p_T photons, have polar angle, $|\cos\theta| < 0.985$ defined by edge of endcap acceptance in LDC.
  (I explored using more forward photons but it does not appear to be warranted in this physics channel).
- Missing p_T: $p_T(\gamma\gamma)/E_{beam} > 0.025$.
  - (driven by forward acceptance)
- Energy asymmetry, $a \equiv |E_1-E_2|/(E_1+E_2) < 0.90$.
- $100 < m_{\gamma\gamma} < 140$ GeV
- Pre-selection efficiency = 91.8% (of 1.23 fb)
  - (currently neglect photon reconstruction issues (conversions etc))
- Pre-selection bkgd level = 0.572 fb/GeV.

(LHC: signal = 30 fb,
bkgd = 180 fb/GeV)

So ILC intrinsic s/b is higher by a factor of 12

SIGNAL

BACKGROUND



Most plots show the cross-section per bin since they are summed over lots of different samples

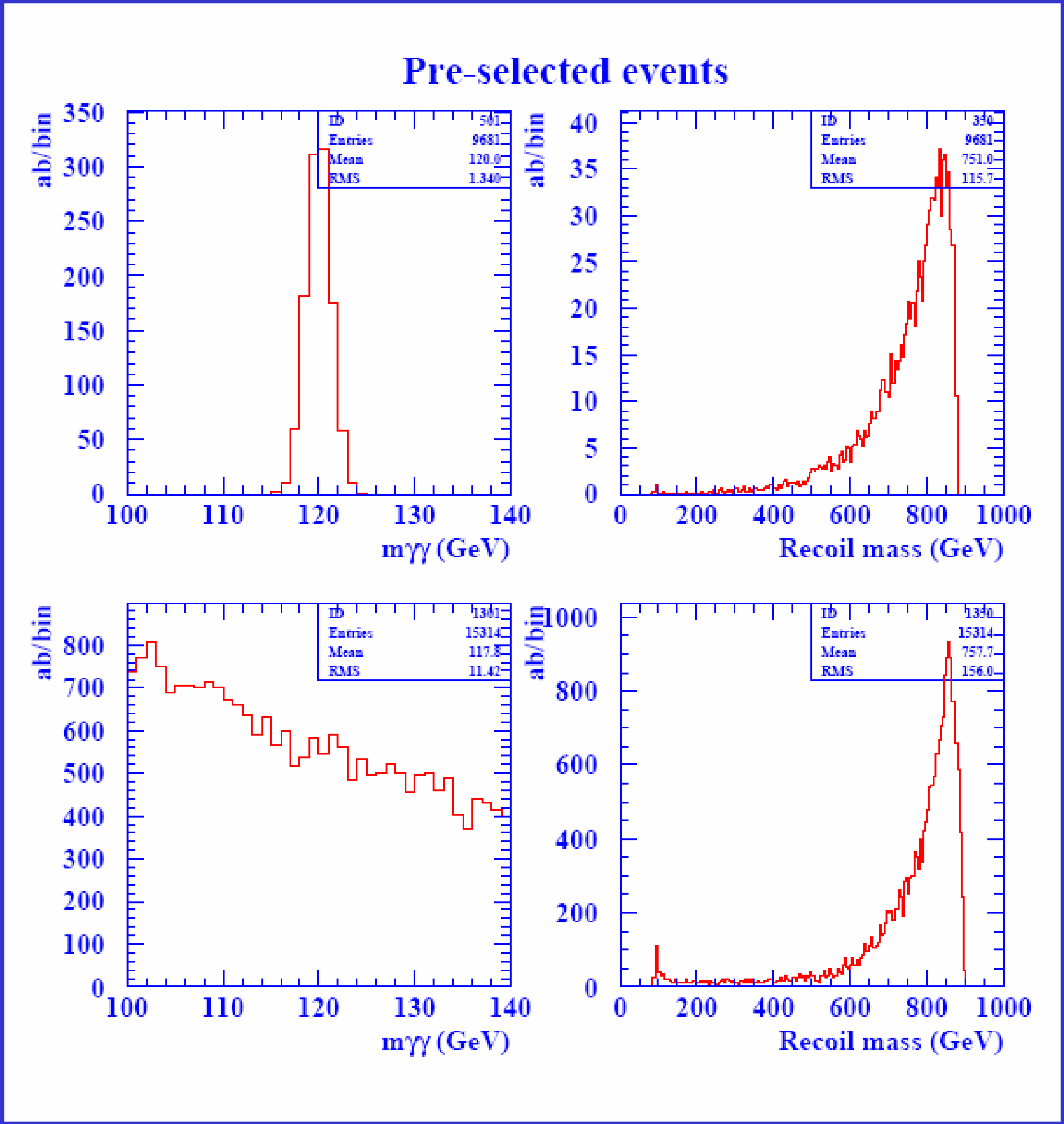
(also – stays away from generator cuts at low angle)

$\sigma_E/E =$

$10\%/\sqrt{E(GeV)} \oplus 1\%$

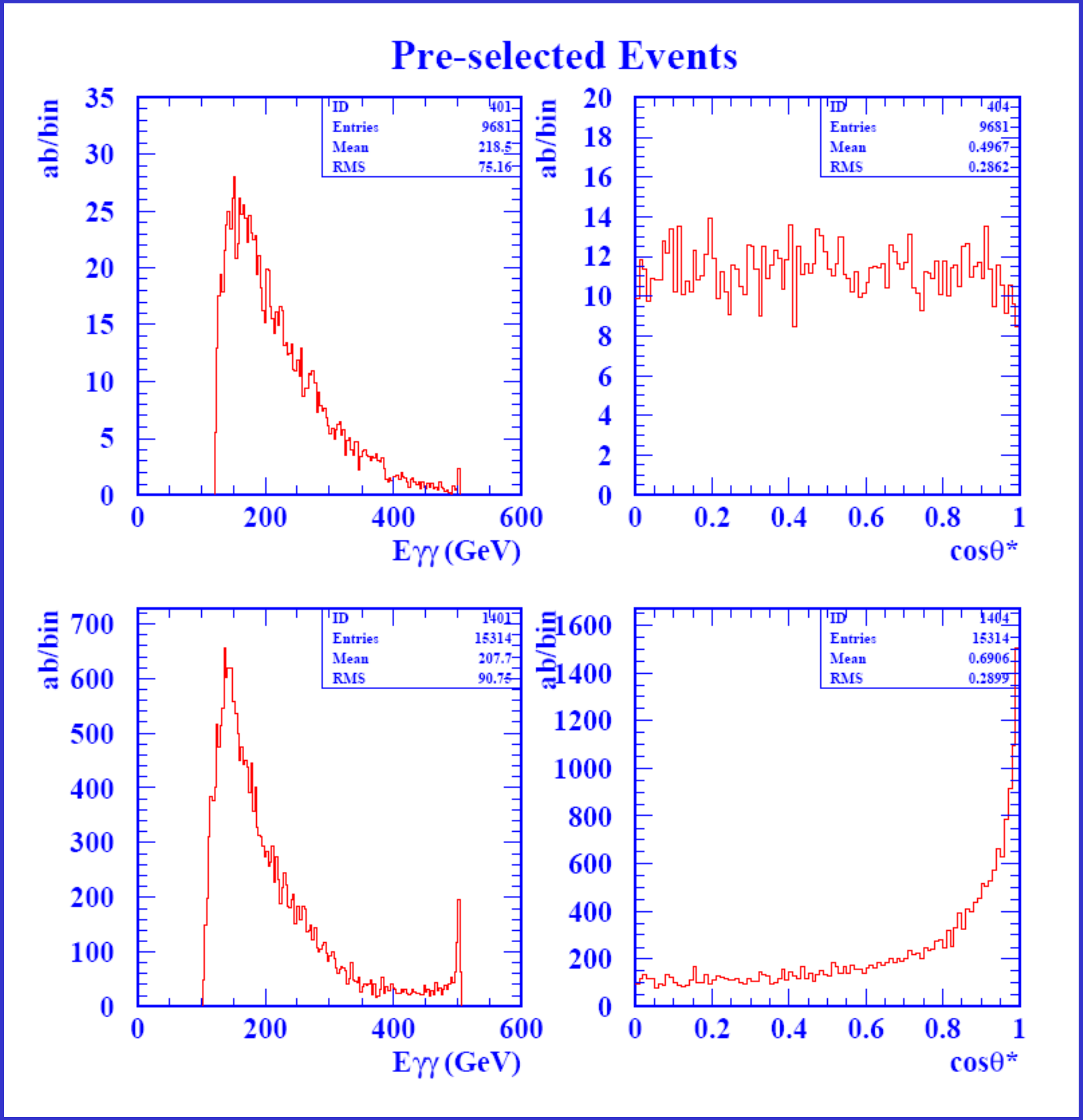
SIGNAL

BACKGROUND



SIGNAL

BACKGROUND

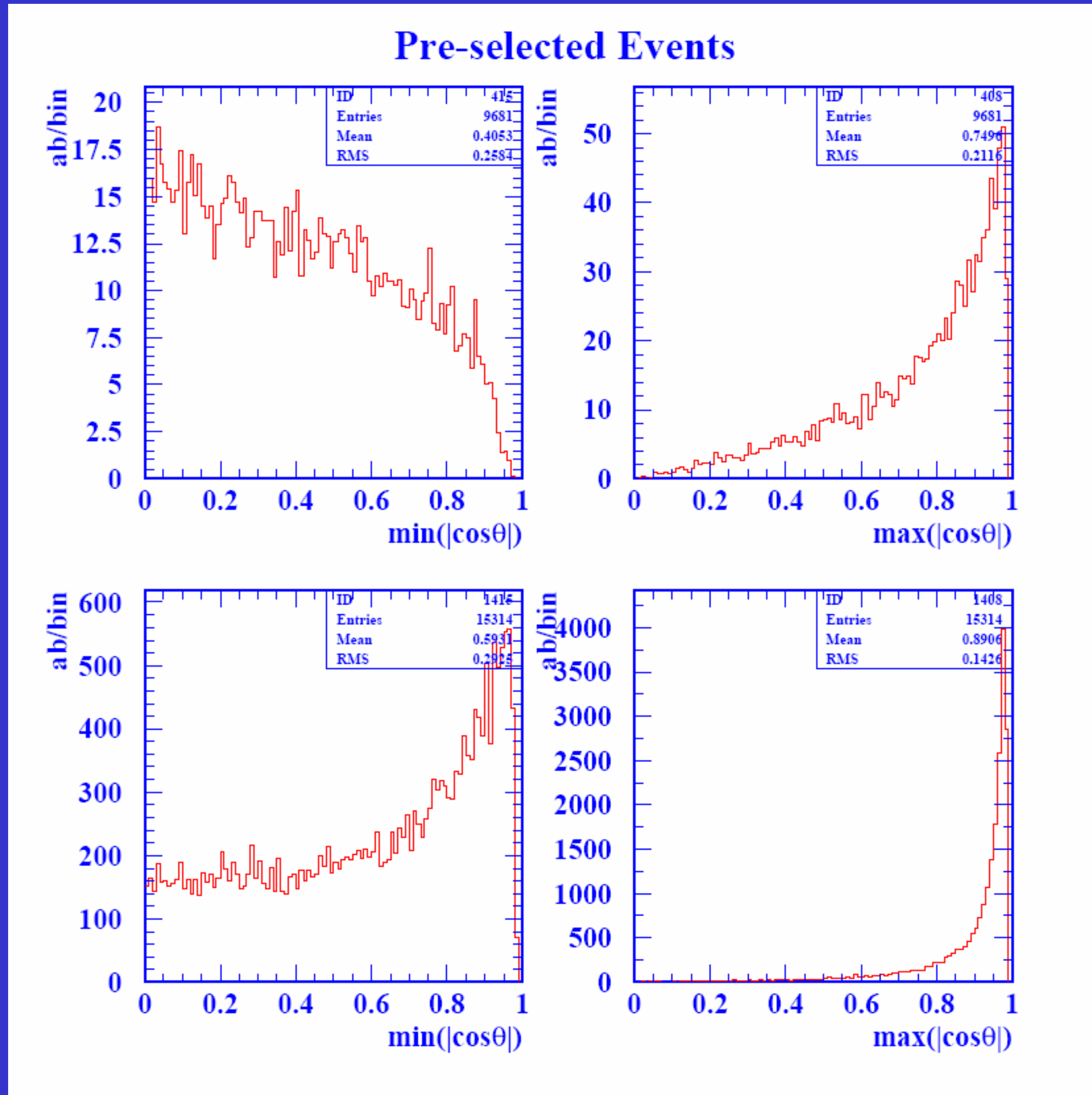


Uniform as expected for spin 0

Note modest energy of $\gamma\gamma$ system

SIGNAL

BACKGROUND



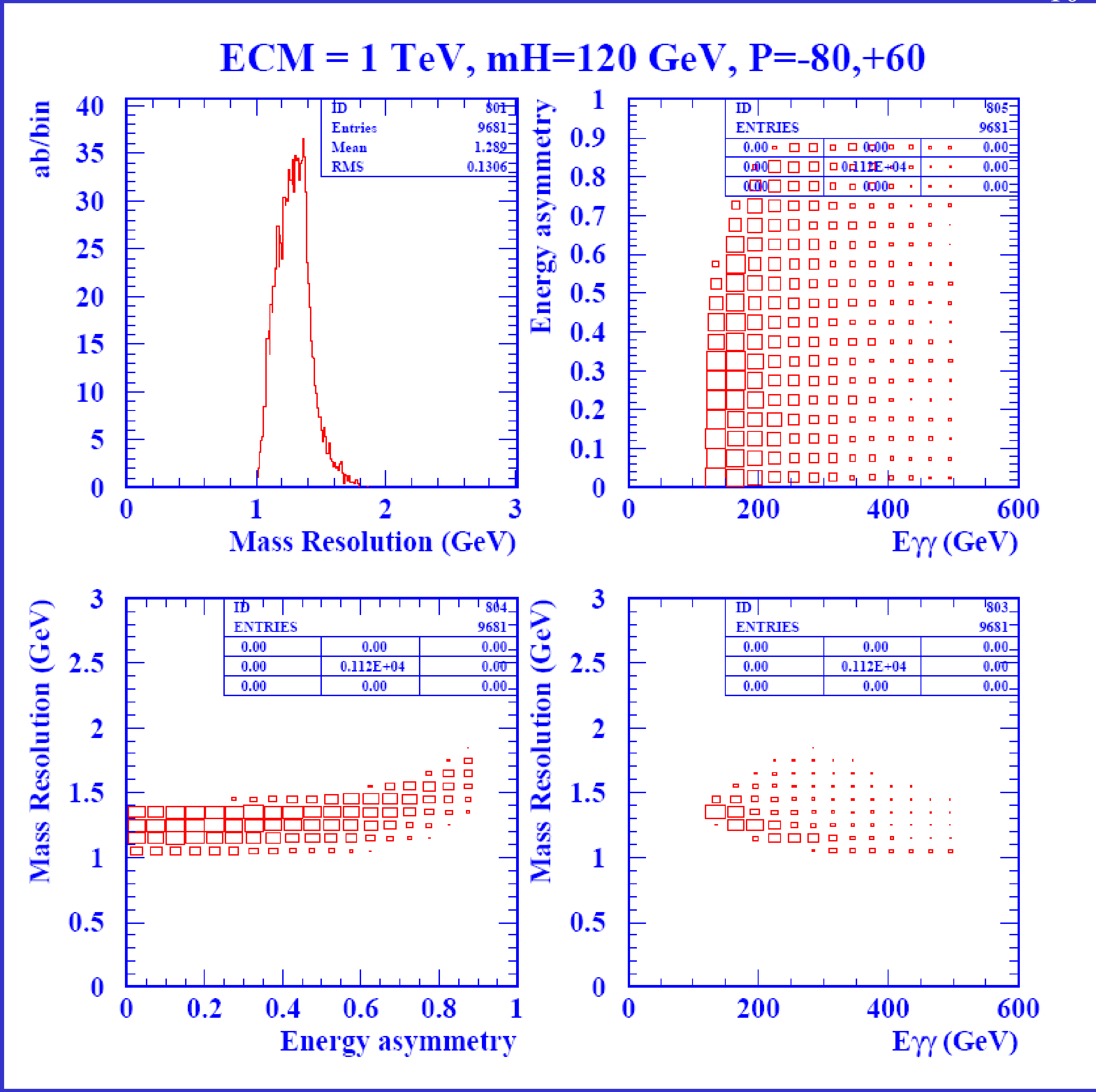
=> Need endcap acceptance too

$\sigma_E/E =$

$10\%/\sqrt{E(GeV)} \oplus 1\%$

Leads to

$\sigma_m \approx 1.25$ *GeV.*



Mass resolution depends on $(a, E_{\gamma\gamma})$

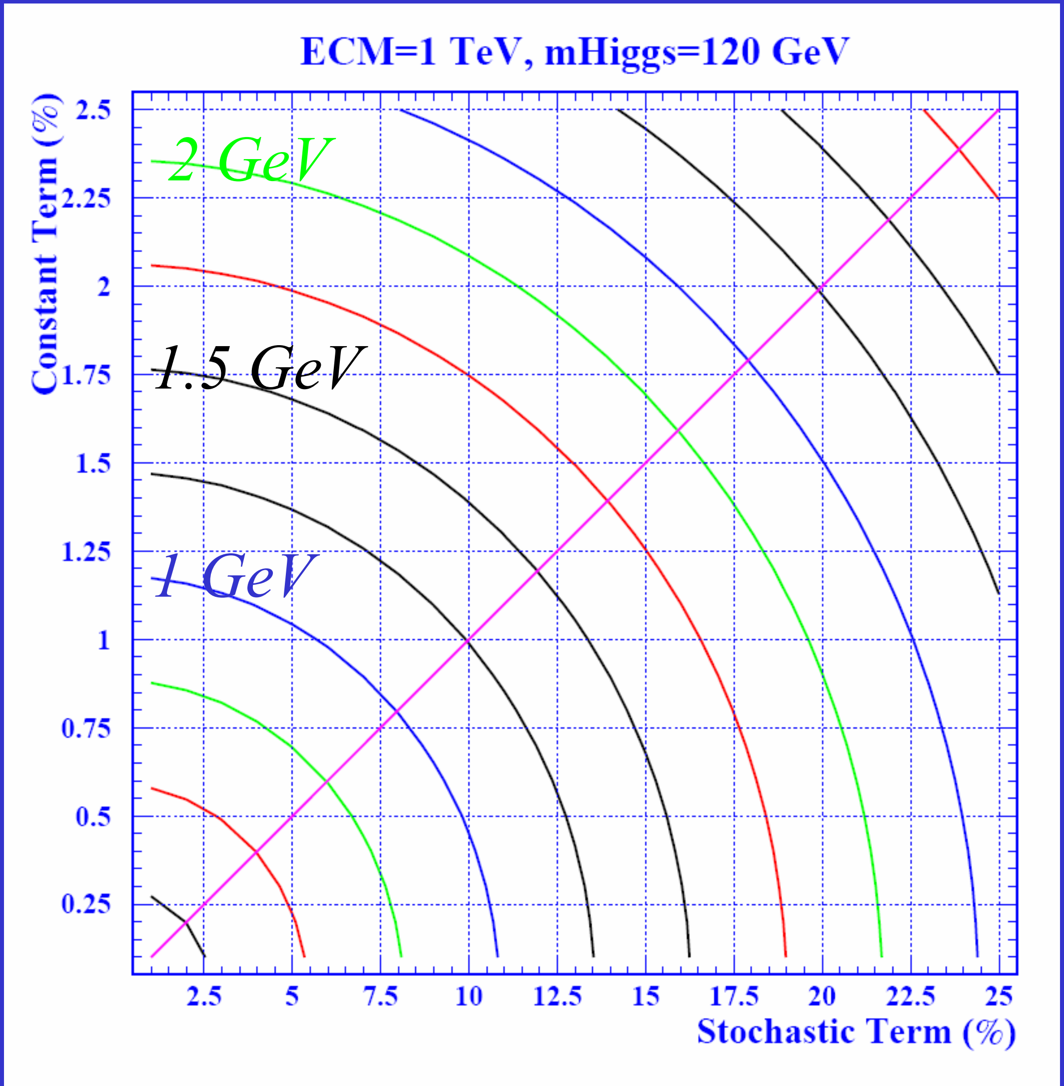
$a = |E_1 - E_2|/E_{\gamma\gamma} = \beta|\cos\theta^*|$

$\sigma_m/m =$

$C_S/\sqrt{(1-a^2)E_{\gamma\gamma}} \oplus C_C/\sqrt{2}$

At $\sqrt{s}$*=1 TeV, the Higgs energy is modest (220 GeV average). WW fusion dominates.*

ECAL Resolution effects on m_H resolution in γγ channel



Contours of average mass resolution (0.25 GeV steps). Uses the (a,$E_{\gamma\gamma}$) distribution expected for Higgs events.

Given the modest Higgs energies, the stochastic term and constant term are of about equal importance on the relative scales displayed here.

$10\%/\sqrt{E} \oplus 1\% \approx 14\%/\sqrt{E} \approx 1.4\%$

Estimating analysis performance

Use multi-channel method (see Favara, Pieri, hep-ex/9706016 and CMS TDR) to sub-divide the selected events into different analysis bins with varying s/b.

Use simple counting experiments within each analysis bin, with a mass window optimized for signal significance, assuming that background level can be measured from sidebands/predicted with negligible error.

Here use bins in D, where

$$D^2 \equiv \sin\theta_1 \sin\theta_2 (1-|\cos\theta^*|)$$

graham@heplx2:/raidslow/graham/work/htogg/Hgg_tests

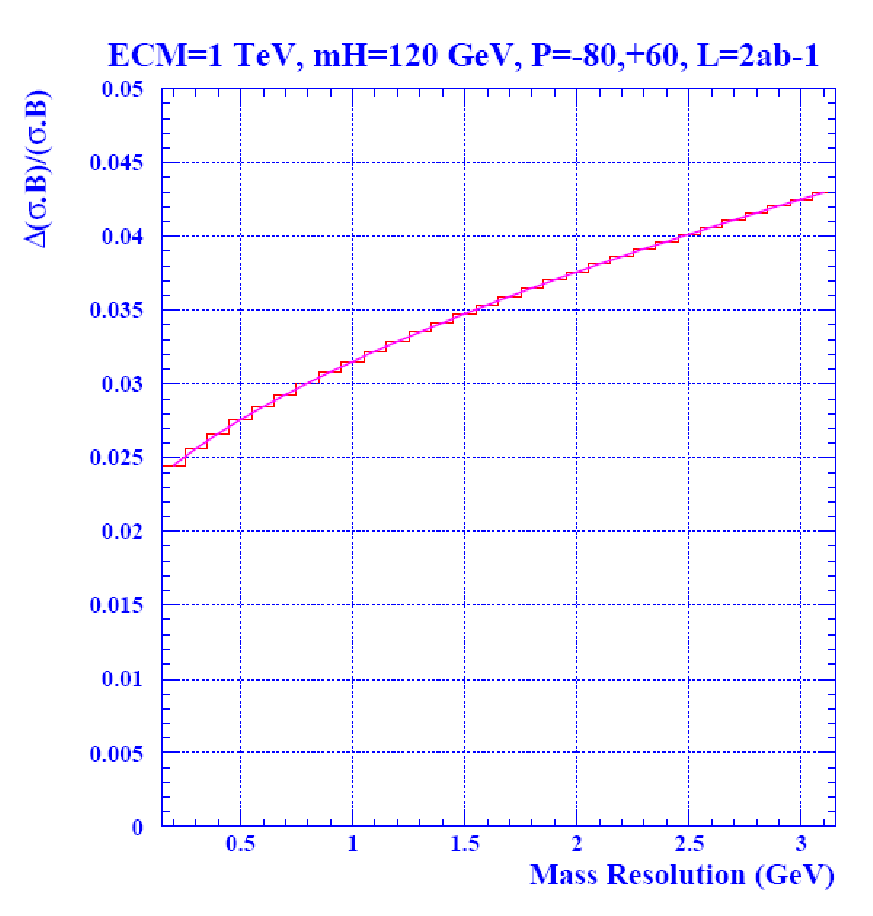
```
[graham@heplx2 Hgg_tests]$ more optimize_d_final.txt
   Performance assuming average mass resolution of 1.25 GeV.
   Each bin uses an optimized cut in mass window width assuming a Gaussian signal.
   Uses polarized beams (80% e-L), (60% e+R) and 2 inv ab.
```

D-bin	+- DM	(sigma, GeV)	eff_rel	S	B	S/B	Significance	Error
[0.0,0.1]	1.42	1.775	0.844	41.4	913.9	0.045	1.34	0.747
[0.1,0.2]	1.46	1.825	0.856	129.4	925.0	0.140	3.98	0.251
[0.2,0.3]	1.53	1.9125	0.874	270.4	857.3	0.315	8.05	0.124
[0.3,0.4]	1.61	2.0125	0.893	369.8	690.0	0.536	11.36	0.088
[0.4,0.5]	1.68	2.1000	0.907	349.8	462.3	0.757	12.27	0.081
[0.5,0.6]	1.79	2.2375	0.927	324.4	267.6	1.212	13.33	0.075
[0.6,0.7]	1.85	2.3125	0.936	251.1	164.8	1.523	12.31	0.081
[0.7,0.8]	1.92	2.4000	0.945	175.0	91.2	1.919	10.72	0.093
[0.8,0.9]	1.96	2.4500	0.950	99.5	46.4	2.143	8.24	0.121
[0.9,1.0]	1.97	2.4625	0.951	30.6	13.8	2.221	4.59	0.218
SUMMED							29.92	0.0334

[graham

Improves over simple cut on D (from 27.8σ to 30.1 σ using 100 bins)

Physics Performance vs σ_m

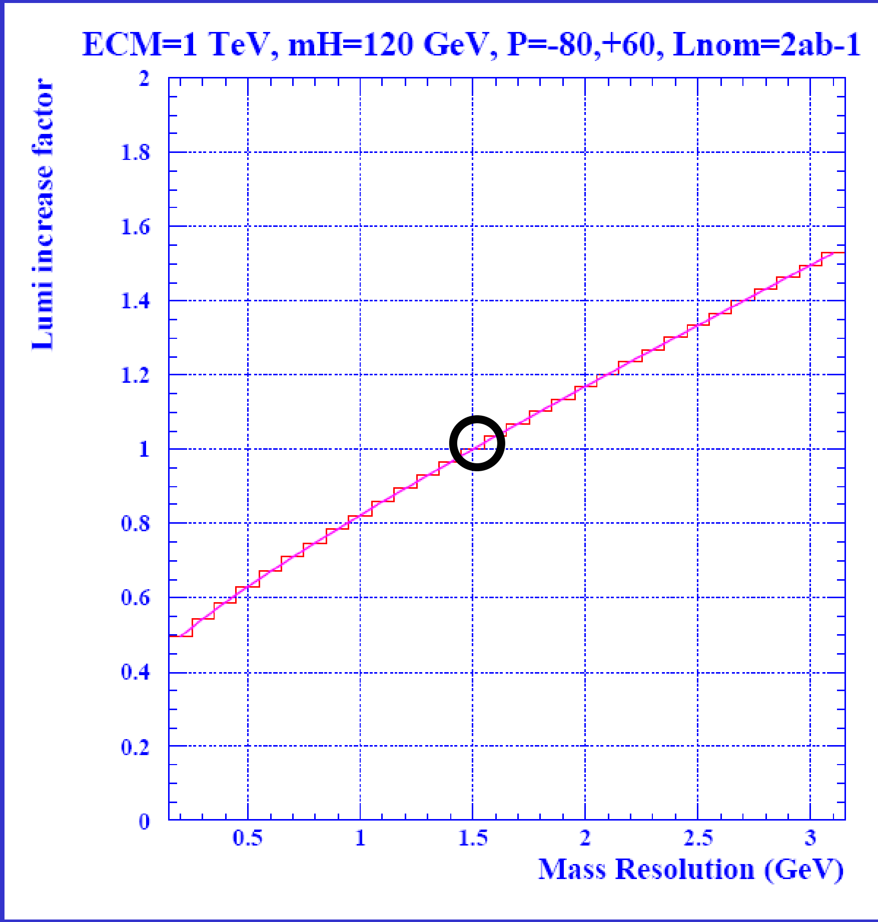


For very good mass resolution, the performance tends to the background free limit.

If the S/B was really poor the measurement error would worsen by a factor of √2 as the resolution degrades by a factor of 2 (ie. a factor of 2 in lumi equivalent).
→ NOT THE CASE

3.3% for 1.25 GeV (nominal 10%/√E⊕1%)

ECAL Mass Resolution Dependence



Same plot as before, but now showing the factor of increase in integrated lumi necessary to achieve the same performance (3.5% on $\sigma.B$) as with $L=2ab^{-1}$ and $\sigma_m=1.5$ GeV

Assuming 500 fb^{-1}/yr,

Factor=0.5 = 2 years

Factor=1.0 = 4 years

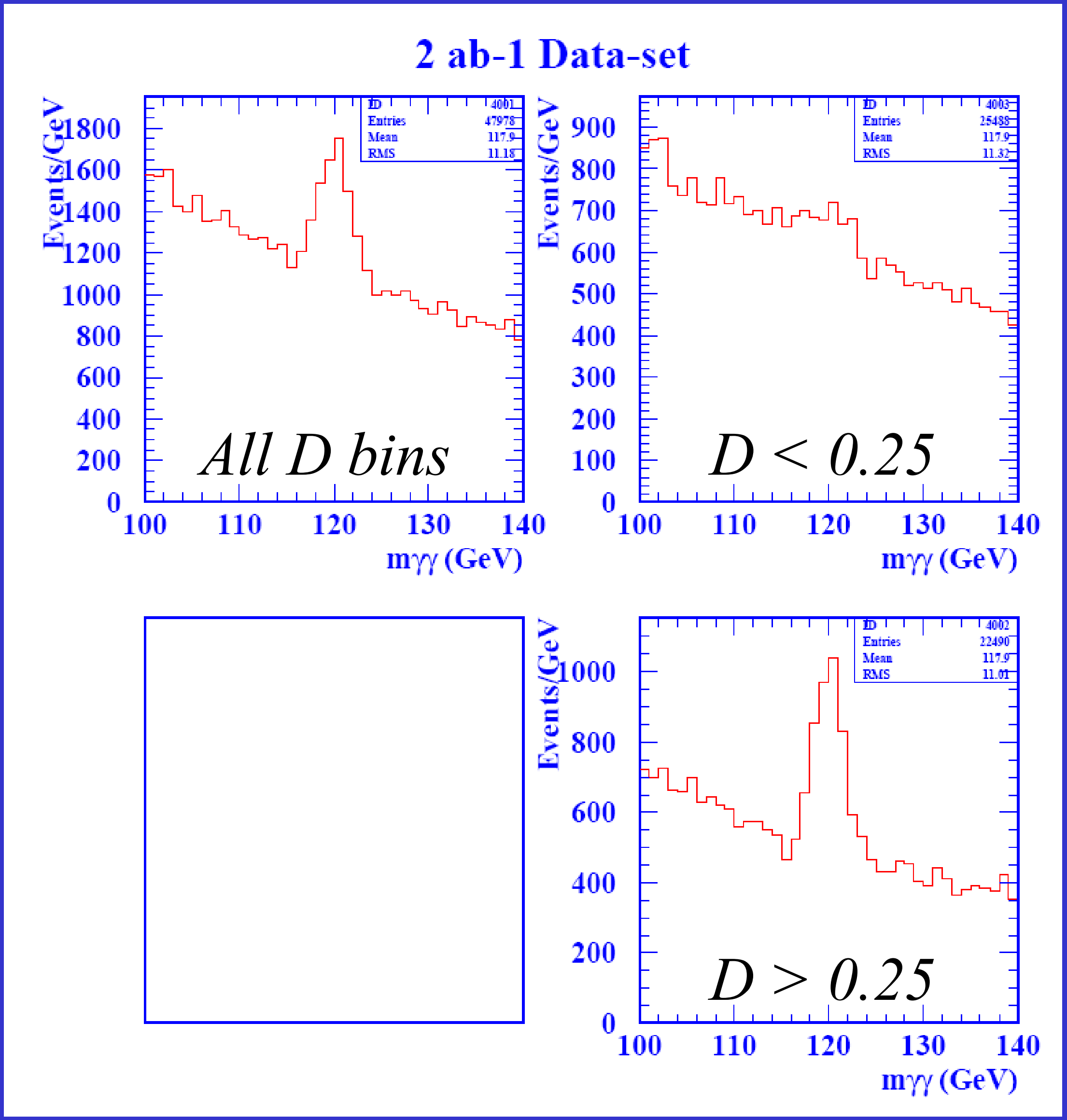
Factor=1.5 = 6 years

Sample Experiment

Used

$10\%/\sqrt{E} \oplus 1\%$

($\sigma_m = 1.25$ GeV)

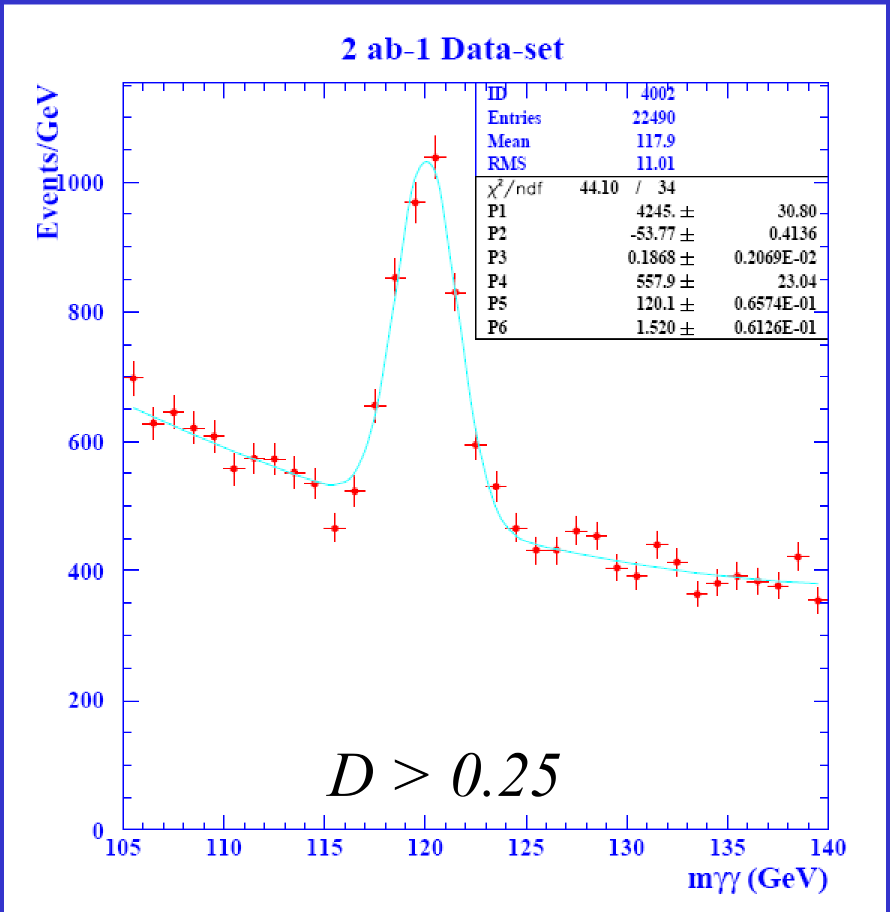


Sanity checks of sensitivity including background for this "experiment".

Expect 27.8 σ measurement from counting experiment in 1 bin with known background.

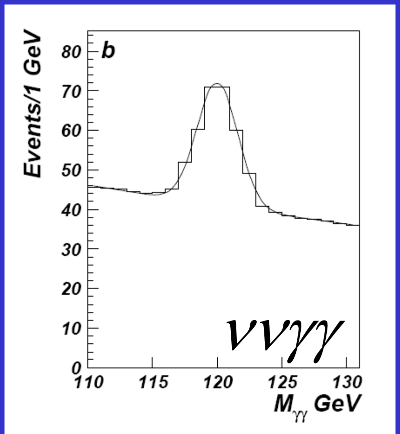
Fit with 6 free parameters (with Gaussian signal shape) → 24.3 σ.

Fit with signal and background shapes fixed, and S, B normalization floating → 27.2 σ. (measure bkgd to 0.8%)



1900 signal events

3.5%



Boos et al., √s=500 GeV unpolarized.

1 ab^{-1}, Sig = 6.1σ

16.4%

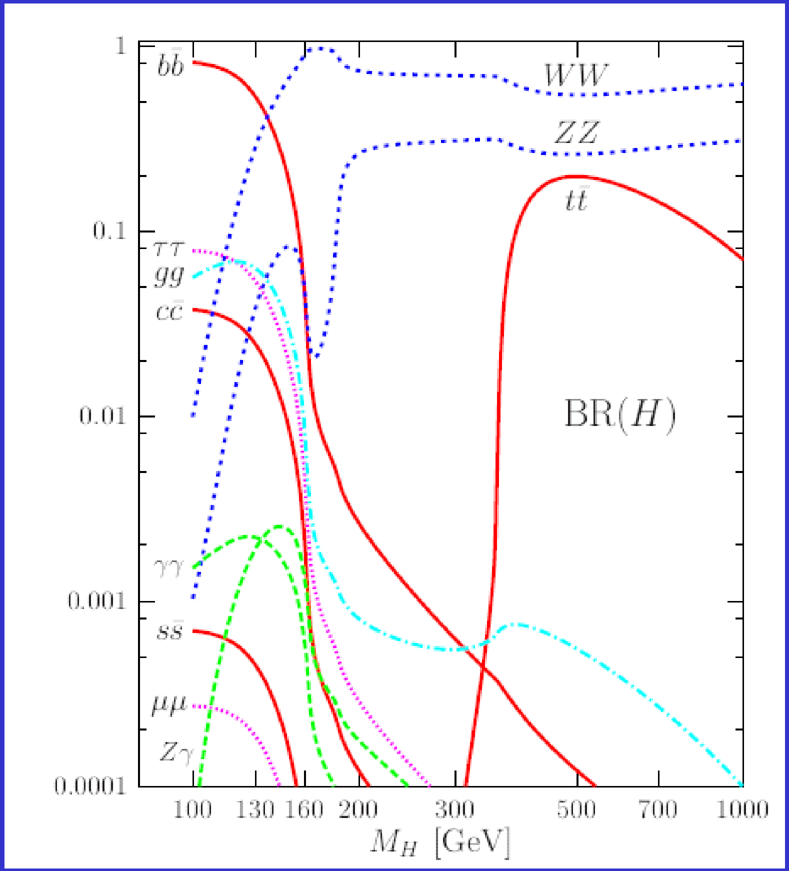
$H \rightarrow \gamma\gamma$ conclusions

- Main conclusions
  - This is ***not*** a "high energy" constraint even if the best measurement is done at the highest $\sqrt{s}$.
    - Stochastic term and constant term both important.
  - Emphasizes ***forward*** acceptance at high $\sqrt{s}$.
  - Even here, analysis improvements can increase the sensitivity.
- A sensible goal for a PFA-based calorimeter may be mass resolution better than 1.5 GeV. (need double the L compared to a perfect calorimeter)
  - (ie better than $16\%/\sqrt{E} \oplus 0\%$ or $12\%/\sqrt{E} \oplus 1.2\%$)
- Working on checking performance of current models with Mokka / Marlin et al
  - (Mokka working. Still have issues with stdhep and Marlin based reconstruction)

- Subsidiary conclusion: interpreting a $B_{\gamma\gamma}$ measurement without being above the new physics threshold is tough …
- If this really is important, we should also be trying to measure $H \rightarrow Z\,\gamma$ (this may be quite a challenge for any calorimeter).

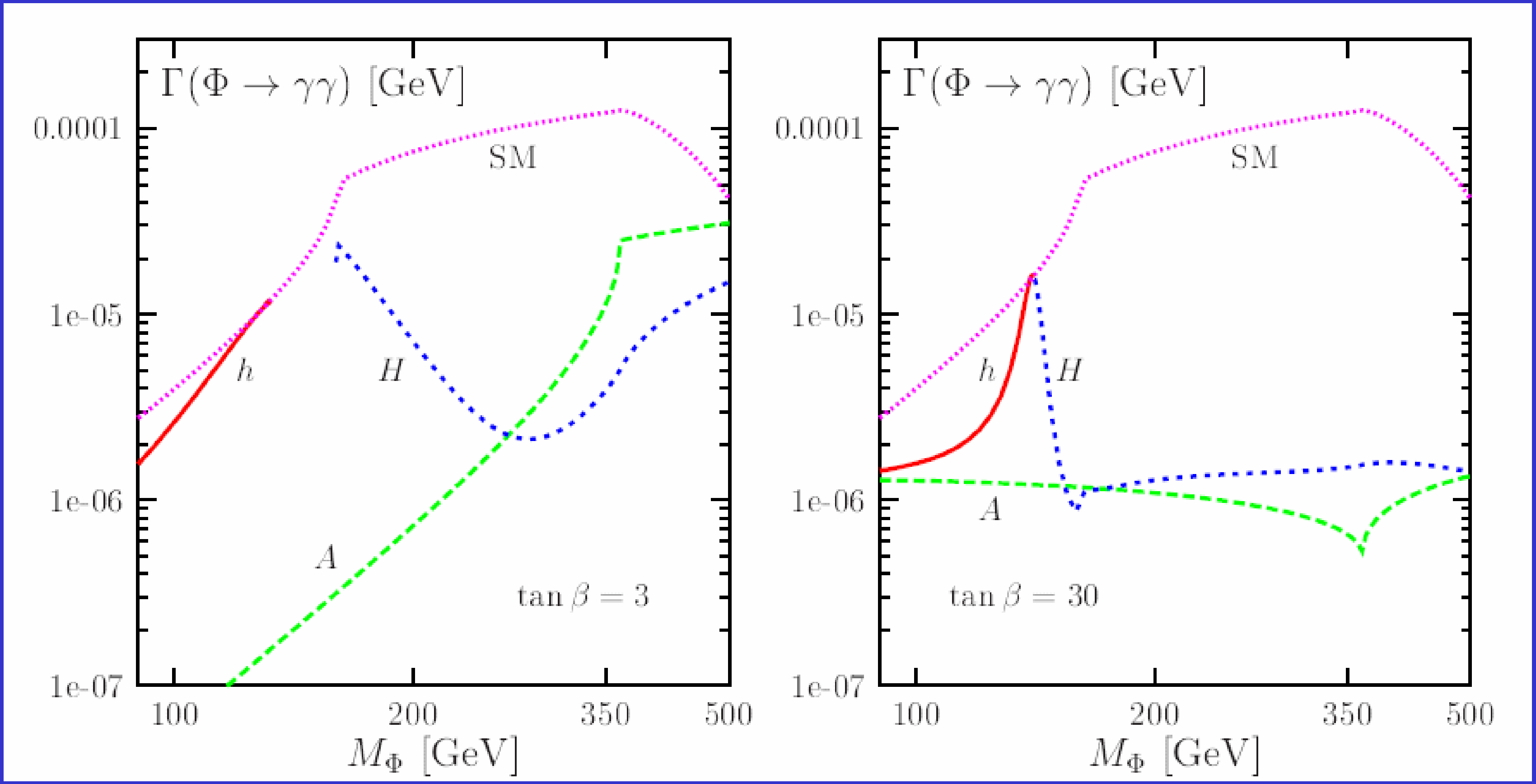
Backup Slides

SM Higgs Decays



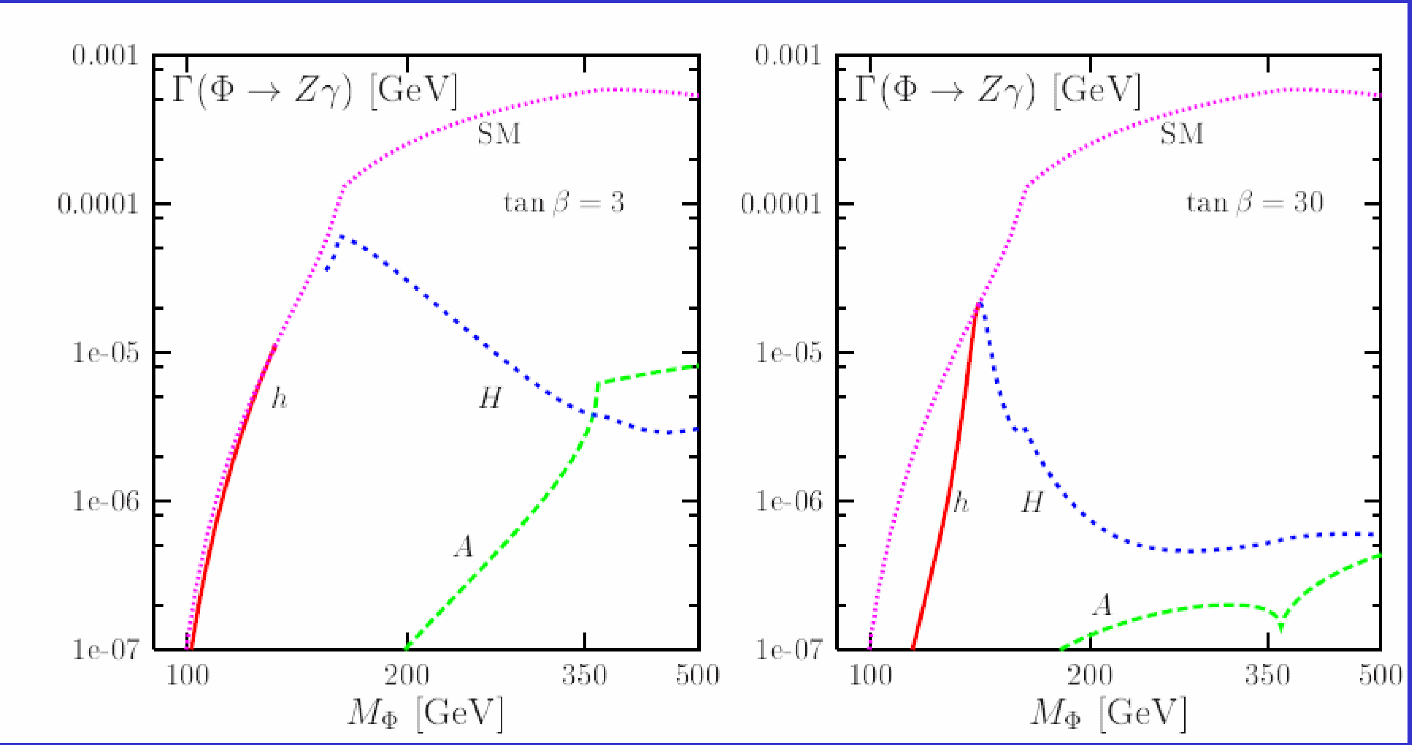
Djouadi

Higgs Loop Decays (γγ)



(It is hard for SUSY-like new physics to escape actual detection and show up in this kind of observable, typically 10% effects at most. However other types of physics eg heavy W' would presumably be much more amenable to huge deviations)

Higgs Loop Decays (Zγ)



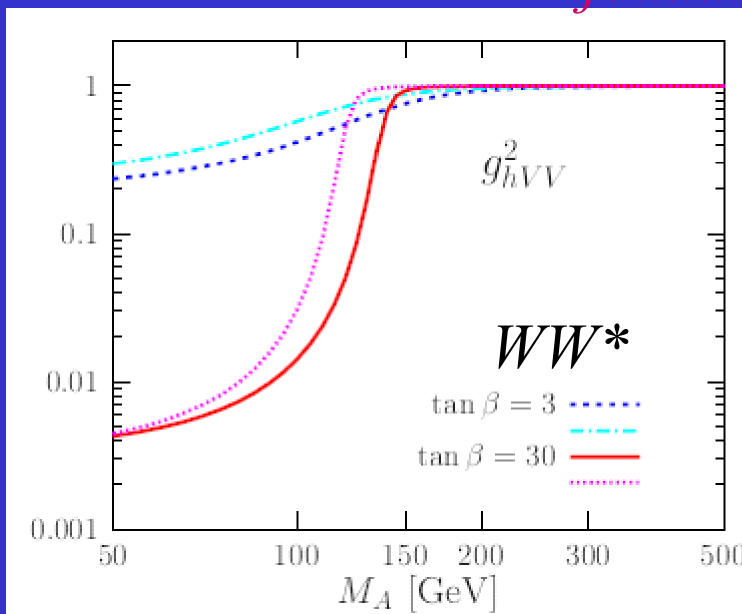
Any effects of new physics here are similar to γγ, but tend to be smaller in BR effect (of order 5%, not 10%).

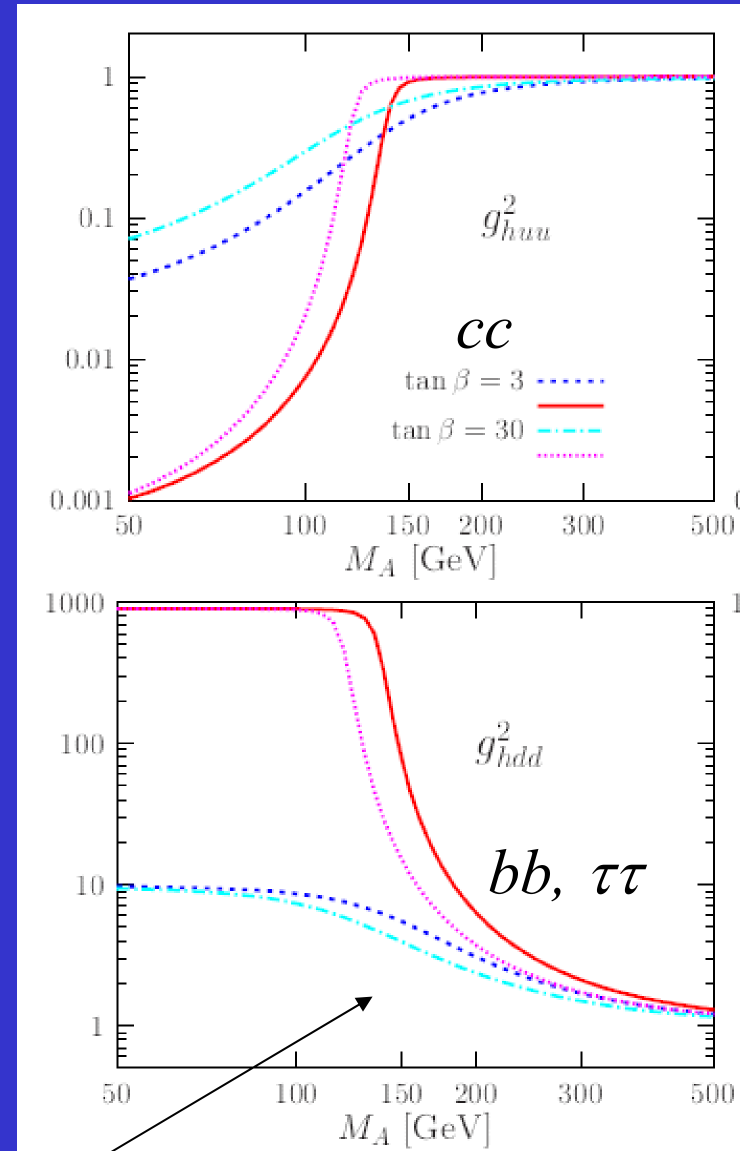
So far don't know of a study on H→ Zγ. It looks hard but not impossible and will challenge jet+γ calorimetry. Maybe useful in context of eg. WWγ and QGCs.

MSSM in the Higgs decoupling regime

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$	$g_{\Phi AZ}$	$g_{\Phi H^\pm W^\mp}$
$H_{\rm SM}$	1	1	1	0	0
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	$\mp\cos(\beta-\alpha)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$	$-\sin(\beta-\alpha)$	$\pm\sin(\beta-\alpha)$
A	$\cot\beta$	$\tan\beta$	0	0	1

Djouadi





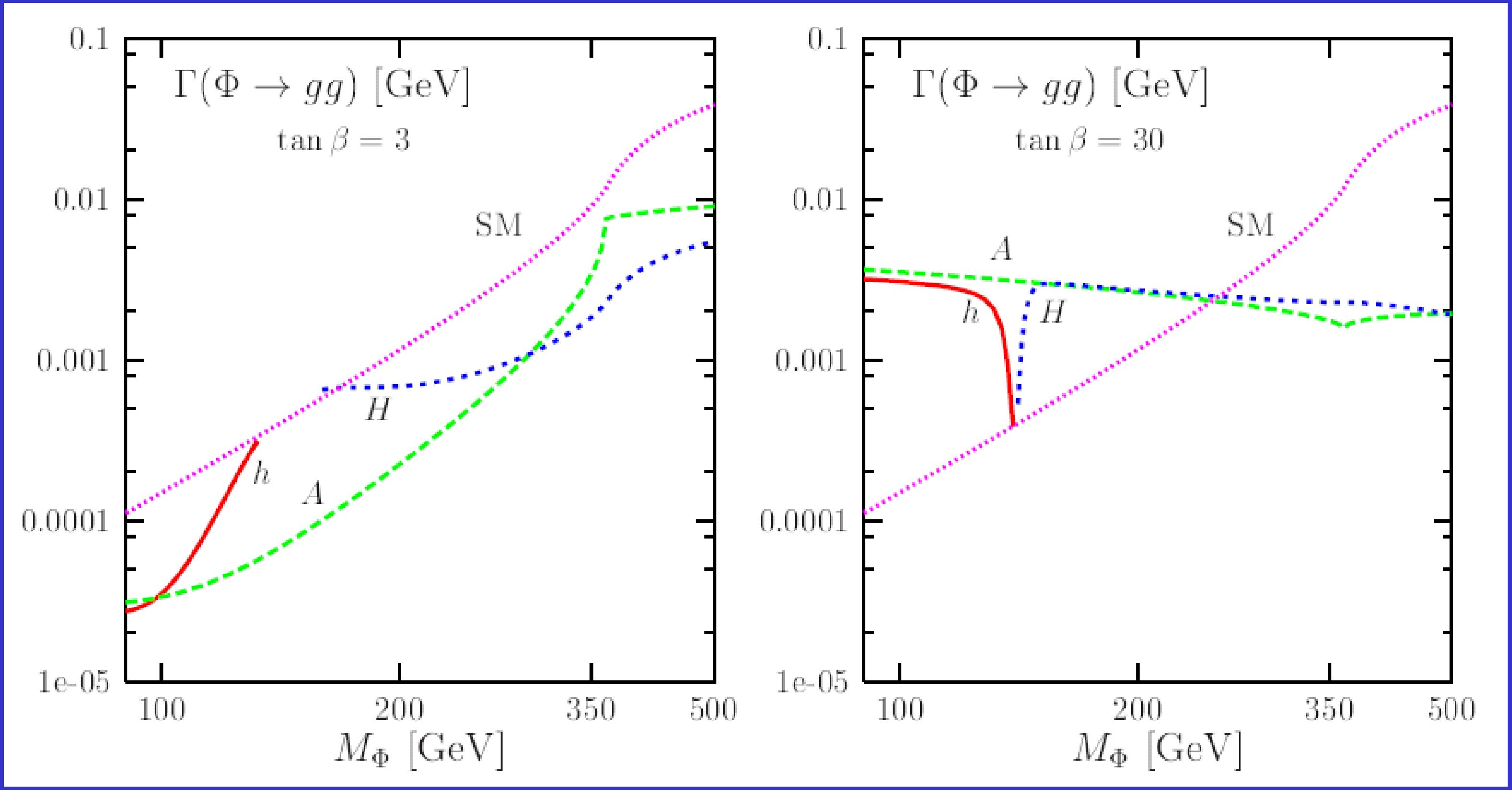
For $m_A \geq 200$ GeV, only the Higgs coupling to down-like fermions differs significantly from SM.

So, primary strategy for distinguishing is to measure bb/WW. (and ττ/WW)

For Higgs physics

- Studying H $\rightarrow$ WW* is very important. (By playing off $\nu\nu$h and Zh can test WW and ZZ couplings, and then get at partial widths.)
  - Existing studies look at qq qqlν
  - What about $\nu\nu$ qqqq etc.
- H $\rightarrow$ $\tau\tau$.
  - Is of similar interest to bb, but also as a CP analyzer. Looking at qq $\tau\tau$, would be very useful.

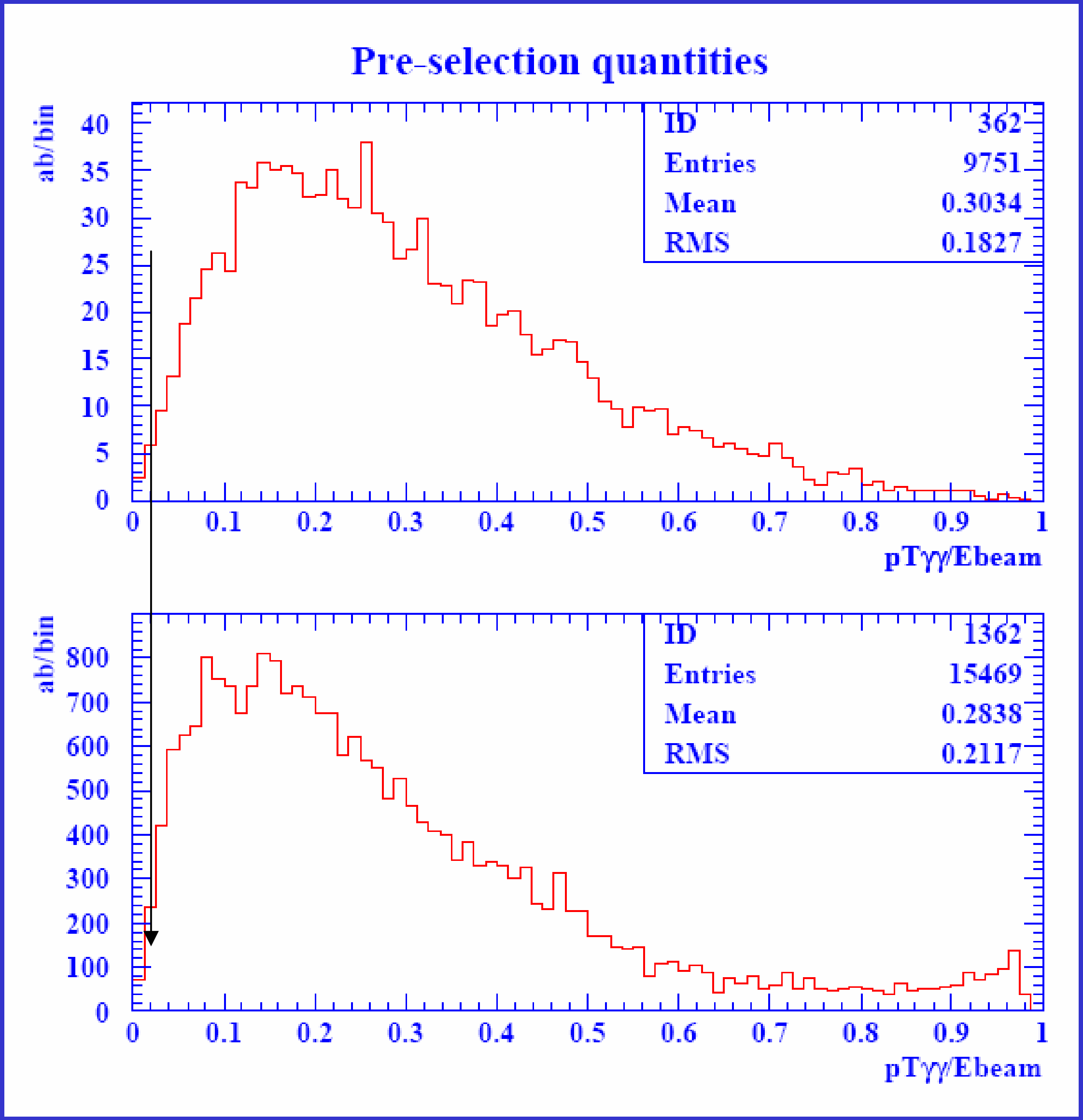
Higgs Loop Decays (gg)



Large QCD corrections in play. But effects are large. Can we identify gluon jets rather than just measuring "non-b,c jets" ?

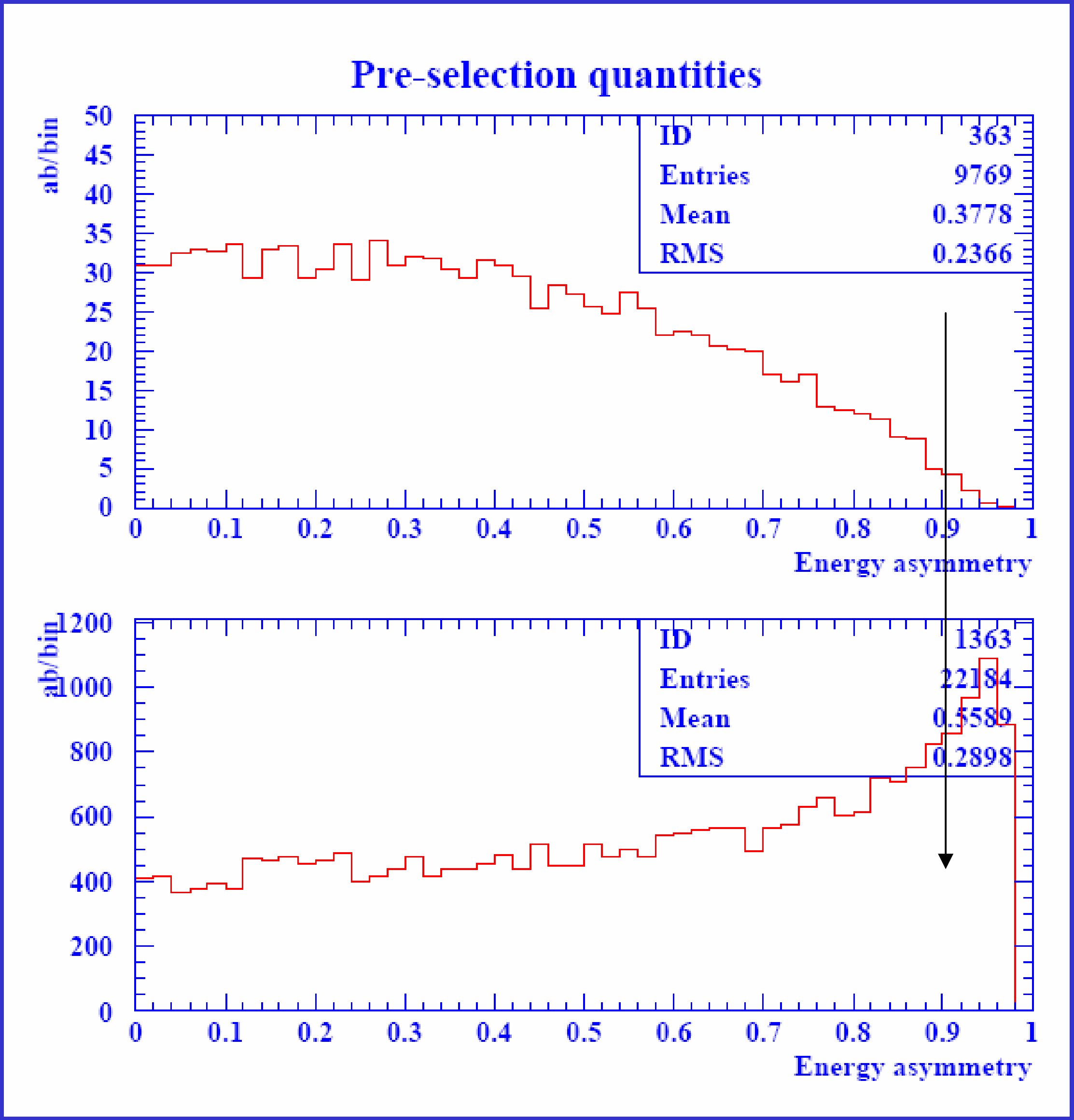
SIGNAL

BACKGROUND



SIGNAL

BACKGROUND

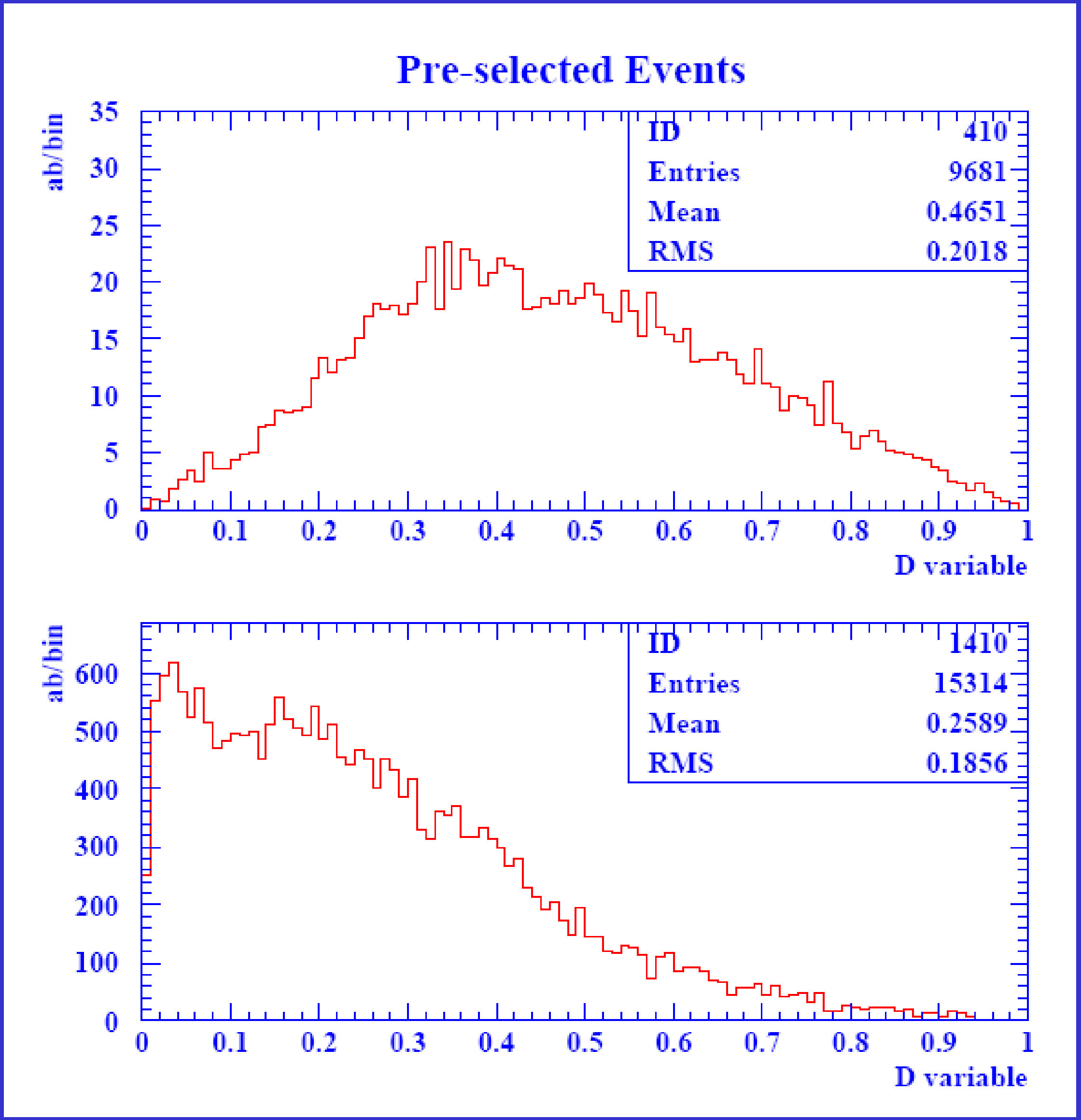


D variable, where

$$D^2 \equiv \sin\theta_1 \sin\theta_2 (1-|\cos\theta^*|)$$

SIGNAL

BACKGROUND



LDC ECAL Resolution

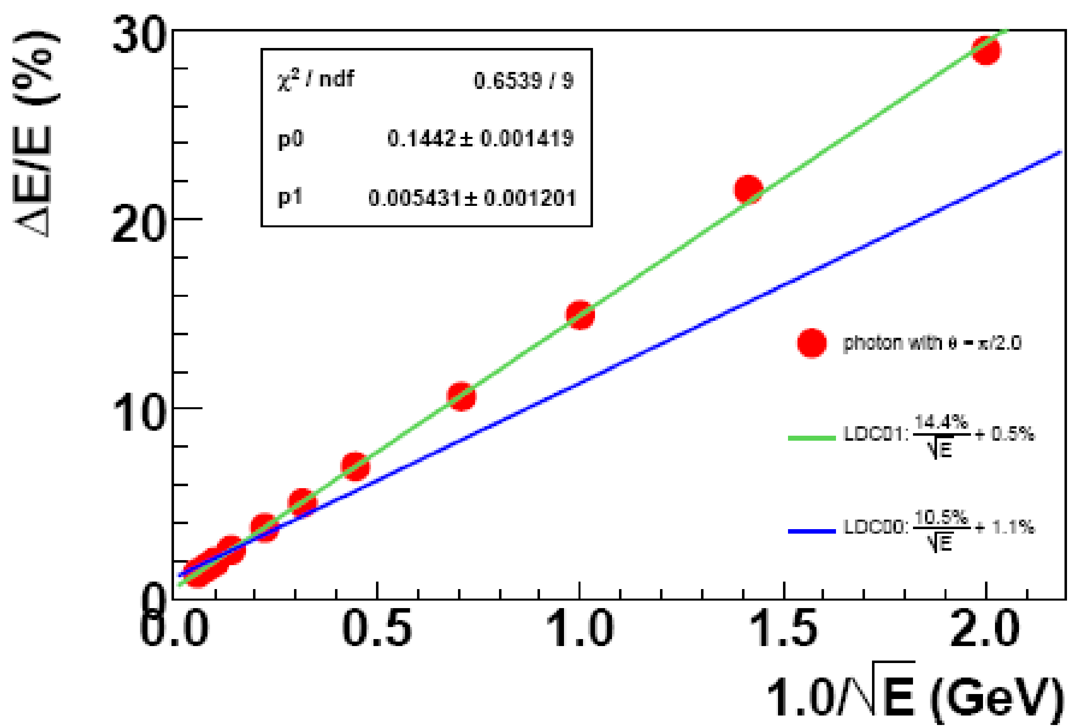


Figure 46 *Fractional energy resolution for photons at normal incidence to the Si-W ECAL as a function of $1/\sqrt{E}$. The resolution was derived from Gaussian fits to the peak of the response distribution. Results for the 40 layer LDC00 design are shown for comparison.*

LDC01 : Consistent with the 1.5 GeV target.
Is this representative of a realistic design ?