Jet and photon signatures

R. Frey, University of Oregon

Physics Signature-II: Jet and Photon Energy Measurements - **Hornets Nest (WH8X) (13:30-17:00)**

- Conveners: FREY, Raymond; MAGILL, Stephen; PETRIELLO, Frank; RASPEREZA, Alexei; TAIT, Tim

time	title	presenter
13:30	Requirements for jet-energy resolution	BARKLOW, Tim
13:50	General Features of SUSY Signals at the ILC: Jet and Photon Resolution	BERGER, Carola
14:10	Jet reconstruction results I	MAGILL, Stephen
14:30	Jet reconstruction II - PFA Status & Results from Iowa	CHARLES, Matthew
14:45	Jet Reconstruction III: Studies with PandoraPFA	COWAN, Ray
15:00	break	
15:30	Higgs decaying to jets and photons	DOBRESCU, Bogdan FOX, Patrick
15:50	Prospects of using Z->jj for the decay independent detection of Higgs	RASPEREZA, Alexei
16:05	pi0 reconstruction in jets	WILSON, Graham
16:20	New Physics with photon signatures	MARTIN, Steve
16:35	H->gamma gamma: mini-review and effect of EM calorimeter resolution	PETRIELLO, Frank
16:50	photons in tau id and polarization	FREY, Raymond

our role

Are we neglecting or undervaluing important jet/photon considerations?

- Are there interesting physics processes we are neglecting?
- What are the signatures?

- Are there interesting physics signatures which can drive certain detector characteristics?
- Does this imply revised detector optimizations?

Bring theorists and experimenters together to discuss this.

Possible default benchmarks**

0. Single $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, π^{0}, $K^{\pm}$, K^{0}_{S}, γ, $0 < |\cos\theta| < 1$, $0 < p < 500$ GeV

1. $e^{+}e^{-} \to f\bar{f}$, $f = e, \tau, u, s, c, b$ at $\sqrt{s}$=0.091, 0.35, 0.5 and 1.0 TeV;

2. $e^{+}e^{-} \to Z^{0}h^{0} \to \ell^{+}\ell^{-}X$, $M_{h} = 120$ GeV at $\sqrt{s}$=0.35 TeV;

3. $e^{+}e^{-} \to Z^{0}h^{0}$, $h^{0} \to c\bar{c}, \tau^{+}\tau^{-}, WW^{*}$, $M_{h} = 120$ GeV at $\sqrt{s}$=0.35 TeV;

4. $e^{+}e^{-} \to Z^{0}h^{0}h^{0}$, $M_{h} = 120$ GeV at $\sqrt{s}$=0.5 TeV;

5. $e^{+}e^{-} \to \tilde{e}^{+}_{R}\tilde{e}^{-}_{R}$ at Point 1 at $\sqrt{s}$=0.5 TeV;

6. $e^{+}e^{-} \to \tilde{\tau}^{+}_{1}\tilde{\tau}^{-}_{1}$, at Point 3 at $\sqrt{s}$=0.5 TeV;

7. $e^{+}e^{-} \to \tilde{\chi}^{+}_{1}\tilde{\chi}^{-}_{1}/\tilde{\chi}^{0}_{2}\tilde{\chi}^{0}_{2}$ at Point 5 at $\sqrt{s}$=0.5 TeV;

**M. Battaglia, T. Barklow, M. E. Peskin, Y. Okada, S. Yamashita and P.M. Zerwas, ``Physics benchmarks for the ILC detectors,'' In the Proceedings of 2005 International Linear Collider Workshop (LCWS 2005), Stanford, California, 18-22 Mar 2005, pp 1602} [arXiv:hep-ex/0603010].

Jet *and* photon signatures

- There has been a lot of emphasis in the detector communities on jets and jet signatures
- There are very good reasons for this:
  - New Physics appearing in multi-jet final states is likely to be difficult/impossible to reconstruct at LHC $\Rightarrow$ an ILC imperative.
  - Furthermore, “LEP-like” performance (e.g. W W $\rightarrow$ jets at LEP2) may not suffice when
    - signal/background is low
    - a well-resolved quantity is required (e.g. $M(2j)=M_Z$ vs $M(2j)=M_W$)
    - beam constraints are difficult/impossible, e.g. the New Physics may require reconstruction of j j j j $\nu\nu$
  - Implementing a solution is one of the critical drivers of detector design (and requires a lot of work) $\Rightarrow$ address this early

- Every physics process/analysis will have its own optimization.
- Detectors must be able to handle *both* jet *and* other (photon) signatures
- Because there is much more to the ILC physics than jets.

benchmarks – short list

0. Single $e^\pm$, $\mu^\pm$, $\pi^\pm$, π^0, $K^\pm$, K^0_S, γ, $0 < |\cos\theta| < 1$, $0 < p < 500$ GeV

1. $e^+e^- \to f\bar{f}$, $f = e, \tau, u, s, c, b$ at $\sqrt{s}$=0.091, 0.35, 0.5 and 1.0 TeV;

2. $e^+e^- \to Z^0h^0 \to \ell^+\ell^-X$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;

3. $e^+e^- \to Z^0h^0$, $h^0 \to c\bar{c}, \tau^+\tau^-, WW^*$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;

4. $e^+e^- \to Z^0h^0h^0$, $M_h = 120$ GeV at $\sqrt{s}$=0.5 TeV; ← **CAL**

5. $e^+e^- \to \tilde{e}^+_R\tilde{e}^-_R$ at Point 1 at $\sqrt{s}$=0.5 TeV;

6. $e^+e^- \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, at Point 3 at $\sqrt{s}$=0.5 TeV;

7. $e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1/\tilde{\chi}^0_2\tilde{\chi}^0_2$ at Point 5 at $\sqrt{s}$=0.5 TeV;

The larger list...

TABLE II: Benchmark reactions for the evaluation of ILC detectors

	Process and Final states	Energy (TeV)	Observables	Target Accuracy	Detector Challenge	Notes
Higgs	$ee \to Z^0h^0 \to \ell^+\ell^- X$	0.35	$\mathrm{M}_{\mathrm{recoil}}$, σ_{Zh}, BR_{bb}	$\delta\sigma_{Zh} = 2.5\%$, $\delta\mathrm{BR}_{bb} = 1\%$	T	{1}
	$ee \to Z^0h^0,\ h^0 \to b\bar{b}/c\bar{c}/\tau\tau$	0.35	Jet flavour , jet $(E, \vec{p})$	$\delta\mathrm{M}_h$=40 MeV, $\delta(\sigma_{Zh} \times \mathrm{BR})$=1%/7%/5%	V	{2}
	$ee \to Z^0h^0, h^0 \to WW^*$	0.35	M_Z, M_W, σ_{qqWW^*}	$\delta(\sigma_{Zh} \times \mathrm{BR}_{WW^*})$=5%	C	{3}
	$ee \to Z^0h^0/h^0\nu\bar{\nu},\ h^0 \to \gamma\gamma$	1.0	$M_{\gamma\gamma}$	$\delta(\sigma_{Zh} \times \mathrm{BR}_{\gamma\gamma})$=5%	C	{4}
	$ee \to Z^0h^0/h^0\nu\bar{\nu},\ h^0 \to \mu^+\mu^-$	1.0	$M_{\mu\mu}$	5σ Evidence for $M_h = 120$ GeV	T	{5}
	$ee \to Z^0h^0, h^0 \to invisible$	0.35	σ_{qqE}	5σ Evidence for $\mathrm{BR}_{\mathrm{invisible}}$=2.5%	C	{6}
	$ee \to h^0\nu\bar{\nu}$	0.5	$\sigma_{bb\nu\nu}$, M_{bb}	$\delta(\sigma_{\nu\nu h} \times \mathrm{BR}_{bb}) = 1\%$	C	{7}
	$ee \to t\bar{t}h^0$	1.0	σ_{tth}	δg_{tth}=5%	C	{8}
	$ee \to Z^0h^0h^0,\ h^0h^0\nu\bar{\nu}$	0.5/1.0	σ_{Zhh}, $\sigma_{\nu\nu hh}$, M_{hh}	δg_{hhh}=20/10%	C	{9}
SSB	$ee \to W^+W^-$	0.5		$\Delta\kappa_\gamma, \lambda_\gamma = 2 \cdot 10^{-4}$	V	{10}
	$ee \to W^+W^-\nu\bar{\nu}/Z^0Z^0\nu\bar{\nu}$	1.0	σ	$\Lambda_{*4}, \Lambda_{*5} = 3$ TeV	C	{11}
SUSY	$ee \to \tilde{e}^+_R\tilde{e}^-_R$ (Point 1)	0.5	E_e	$\delta M_{\tilde{\chi}^0_1}$=50 MeV	T	{12}
	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 1)	0.5	E_π, $E_{2\pi}$, $E_{3\pi}$	$\delta(M_{\tilde{\tau}_1} - M_{\tilde{\chi}^0_1})$=200 MeV	T	{13}
	$ee \to \tilde{t}_1\tilde{t}_1$ (Point 1)	1.0		$\delta M_{\tilde{t}_1}$=2 GeV		{14}
-CDM	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 3)	0.5		$\delta M_{\tilde{\tau}_1}$=1 GeV, $\delta M_{\tilde{\chi}^0_1}$=500 MeV,	F	{15}
	$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 2)	0.5	M_{jj} in $jj\not{E}$, $M_{\ell\ell}$ in $jj\ell\ell\not{E}$	$\delta\sigma_{\tilde{\chi}_2\tilde{\chi}_3} = 4\%$, $\delta(M_{\tilde{\chi}^0_2} - M_{\tilde{\chi}^0_1})$= 500 MeV	C	{16}
	$ee \to \tilde{\chi}^+_1\tilde{\chi}^-_1/\tilde{\chi}^0_i\tilde{\chi}^0_j$ (Point 5)	0.5/1.0	$ZZ\not{E}$, $WW\not{E}$	$\delta\sigma_{\tilde{\chi}\tilde{\chi}}$=10%, $\delta(M_{\tilde{\chi}^0_3} - M_{\tilde{\chi}^0_1})$ =2 GeV	C	{17}
	$ee \to H^0A^0 \to b\bar{b}b\bar{b}$ (Point 4)	1.0	Mass constrained M_{bb}	δM_A=1 GeV	C	{18}
-alternative SUSY breaking	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$ (Point 6)	0.5	Heavy stable particle	$\delta M_{\tilde{\tau}_1}$	T	{19}
	$\tilde{\chi}^0_1 \to \gamma + \not{E}$ (Point 7)	0.5	Non-pointing γ	$\delta c\tau$=10%	C	{20}
	$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$ (Point 8)	0.5	Soft $\pi^\pm$ above $\gamma\gamma$ bkgd	5σ Evidence for $\Delta\tilde{m}$=0.2-2 GeV	F	{21}
Precision SM	$ee \to t\bar{t} \to 6\ jets$	1.0		5σ Sensitivity for $(g-2)_t/2 \leq 10^{-3}$	V	{22}
	$ee \to f\bar{f}$ $(f = e, \mu, \tau; b, c)$	1.0	$\sigma_{f\bar{f}}$, A_{FB}, A_{LR}	5σ Sensitivity to $M_{Z_{LR}} = 7$ TeV	V	{23}
New Physics	$ee \to \gamma G$ (ADD)	1.0	$\sigma(\gamma + \not{E})$	5σ Sensitivity	C	{24}
	$ee \to KK \to f\bar{f}$ (RS)	1.0			T	{25}
Energy/Lumi Meas.	$ee \to ee_{fwd}$	0.3/1.0		δM_{top}=50 MeV	T	{26}
	$ee \to Z^0\gamma$	0.5/1.0			T	{27}

Jet reconstruction: ZHH study

Tim Barklow

$BR(H \to b\bar{b}) = 0.678$

$e^+e^- \to ZHH$

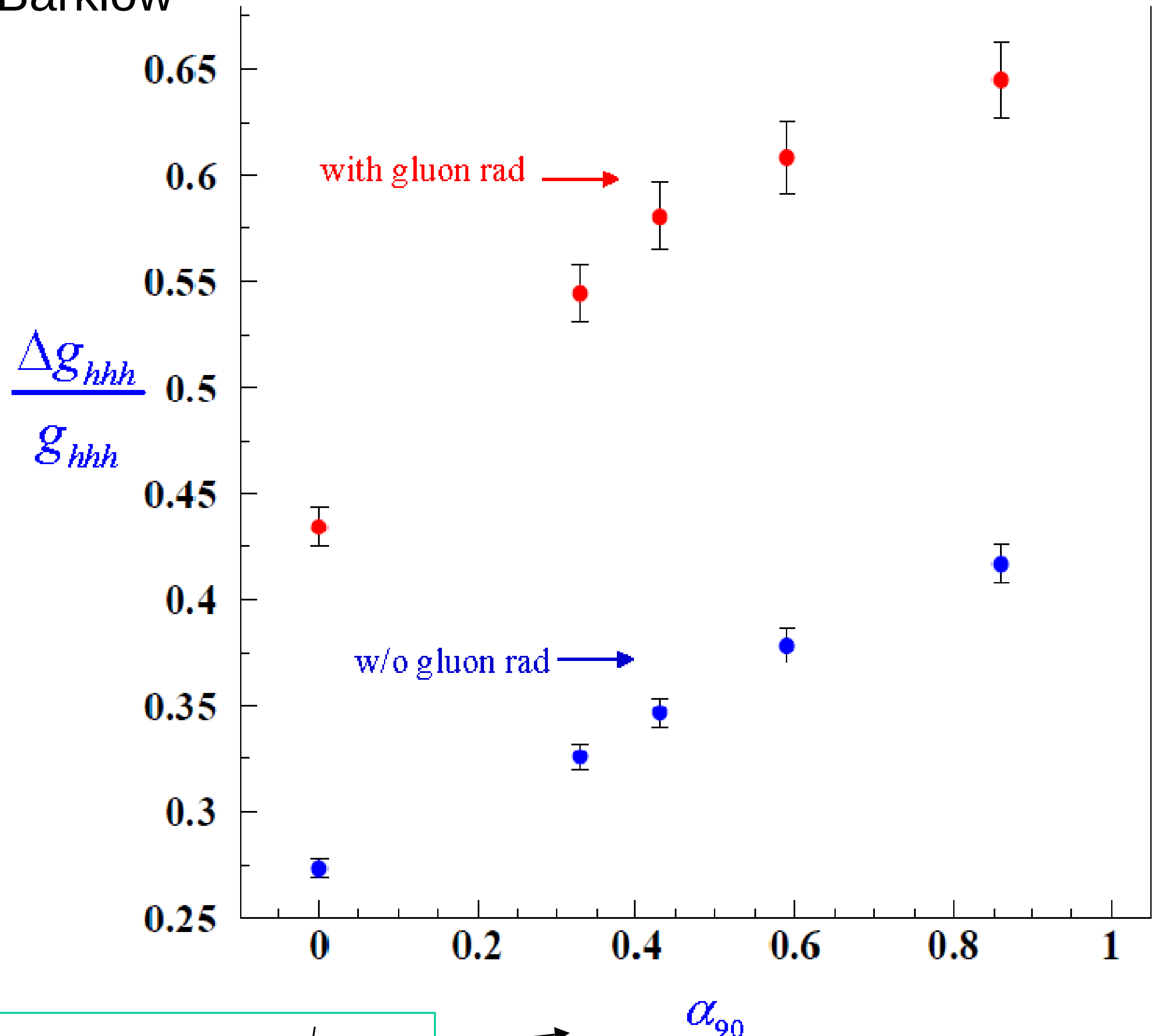
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\,GeV$

$L = 2000\ fb^{-1}$

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to $1.4\times$ Lumi



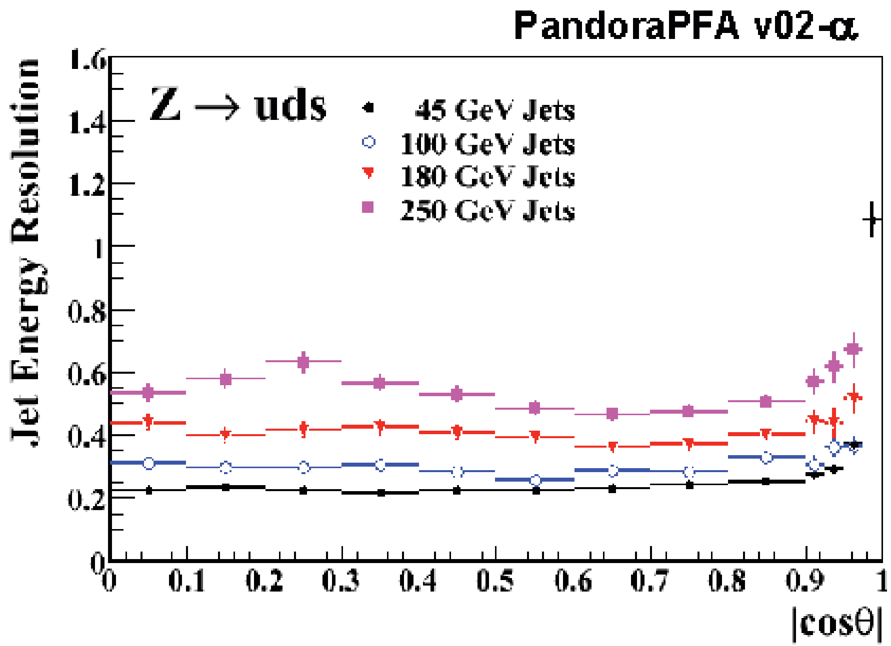
$\Delta E/ E)_{jet} = \alpha_{90}/\sqrt{E_{jet}}$

Jet reconstruction: Particle Flow Algorithm talks

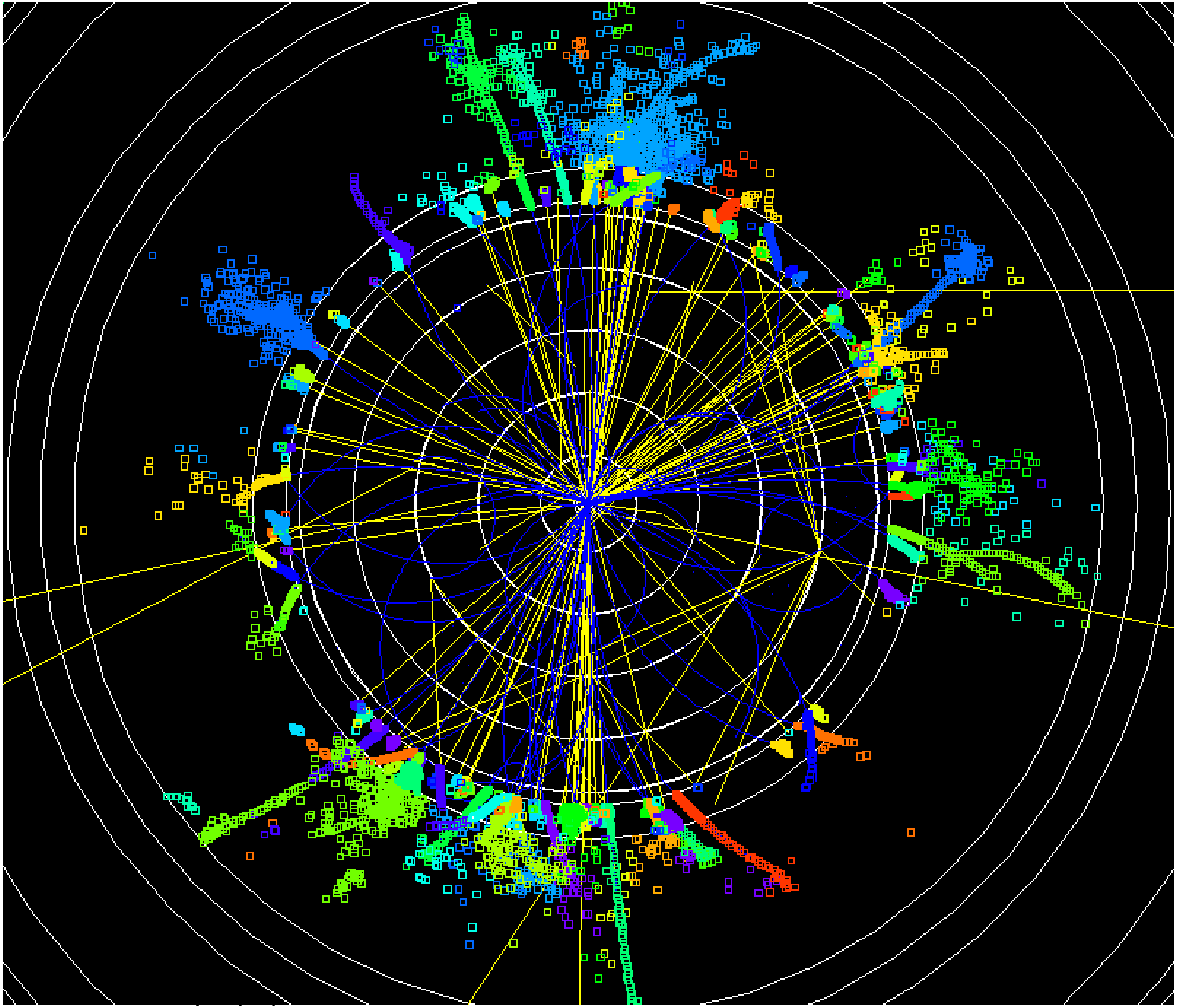
- Steve Magill and Mat Charles: Illustrations of PFA technique – successes and pitfalls
- Ray Cowan + Marcel Stanitzki: Running Mark Thomson's PandoraPFA on different detector configurations

PandoraPFA v02-α

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\|\cos\theta\|<0.7$	σ_E/E_j
45 GeV	0.227	3.4 %
100 GeV	0.287	2.9 %
180 GeV	0.395	2.9 %
250 GeV	0.532	3.4 %



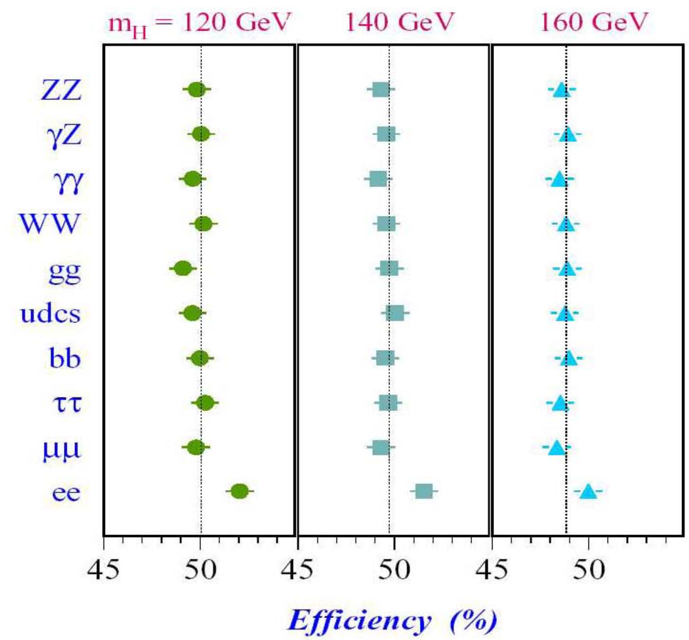
- "Technical" and physics benchmarks for PFA development (Steve Magill)
  - $e^+e^- \to ZZ \to qq\nu\nu$
  - $e^+e^- \to ZZ \to qqqq$ vs $e^+e^- \to HZ \to qqqq$
  - $e^+e^- \to$ t tbar $\to$ jets
  - $e^+e^- \to qq$ at 500 GeV



ZH, H→X with Z→jets ?

Alexei Raspereza

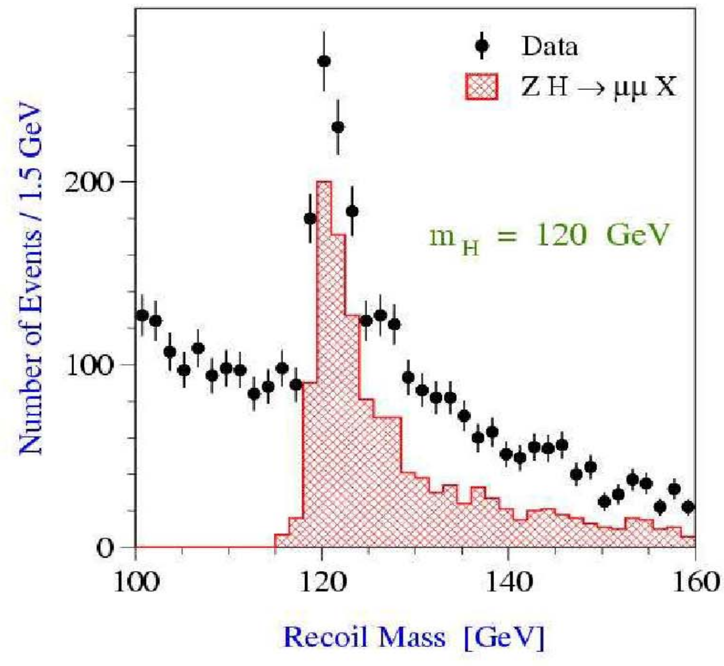
At ILC Higgs boson can be detected independent of its decay mode, even if it decays into invisible particles $H \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$



ILC „golden" channel : $ZH \rightarrow (ee, \mu\mu)X$

Peak in $(ee, \mu\mu)$ *recoil mass spectrum*

⇒ model independent extraction of ZZH coupling : $\sigma(ZH) \propto g^2_{HZZ}$



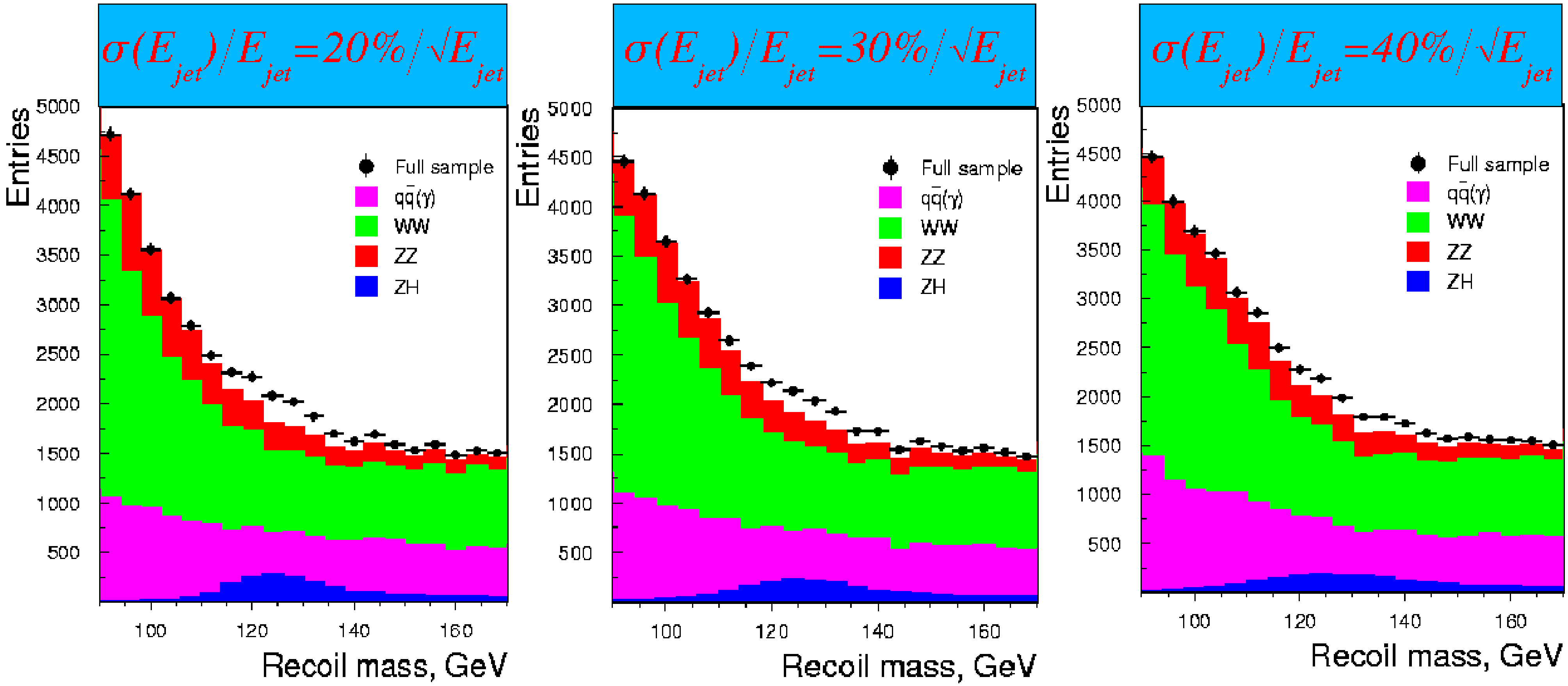
- $\sqrt{s} = 350\ GeV,\ L=500\ fb^{-1},\quad Z \rightarrow ee,\ \mu\mu$

⇒ $\delta\sigma/\sigma = 2.6(3.1)\%\ \ m_H = 120(160)\ GeV$

[P.Garcia-Abia, W.Lohmann, EPJDirect C2 (2000)]

Can we also exploit *Z→jj* decays?

ZH, Z→jets (contd)



Obtains σ(ZH) with errors approx. 9% (stat) ⊕ 4% (sys)

for 350 GeV, 50 fb^{-1}

Take results of these studies with caution

- Simple toy MC analysis used, no full simulation of detector response, no realistic event reconstruction
- Not all backgrounds are considered [$e^+e^- \rightarrow Zee, We\nu$ ...]
- Not all Higgs decays studied [$H\rightarrow\gamma\gamma$, γZ, *invisible*...]
- Analysis is far from optimal : unsophisticated procedure of jet assignment for the *Z* decay exploited, simple cut-based selection applied

Observability of SUSY processes for a panoply of SUSY models

Carola Berger (with Gainer, Hewett, Lillie, Rizzo)

1. Models with staus accessible at 500 GeV

$$e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^- \rightarrow \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

- Include SM backgrounds, beamstrahlung, etc
- Pipe through org.lcsim fast Monte Carlo for SiD detector concept

- Of 28 models, only 18 (11) are visible with tau id B (A)
- Detection issue: 2 photon background $\rightarrow$ confusion with tau id:

$$e^+e^- \rightarrow \gamma\gamma ee \rightarrow \mu(\mu)e(e) \quad \text{vs} \quad \tau\tau \rightarrow \mu e \ \ (4\nu)$$

Need tracking for $50 < \theta < 200$ mrad

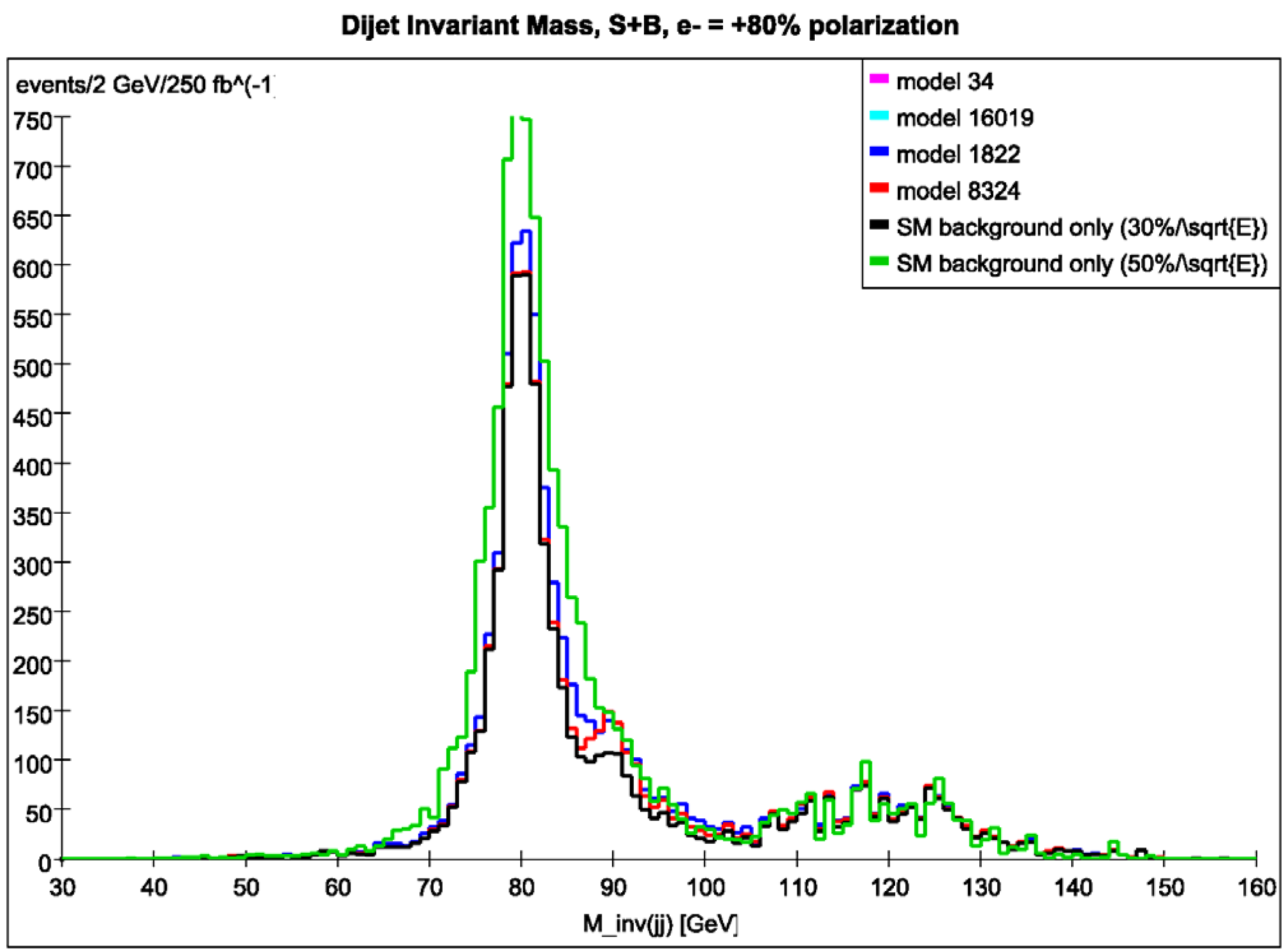
SUSY observability (contd)

2. Associated neutralino production:

e+e- $\rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0 \rightarrow Z/H \tilde{\chi}_1^0 \tilde{\chi}_1^0, \; Z/H \rightarrow jj, l^+ l^-$

or $\tilde{\chi}_2^0 \tilde{\chi}_1^0 \rightarrow W^{\pm} \tilde{\chi}^{\mp} \tilde{\chi}_1^0, \; W \rightarrow jj, \; \tilde{\chi}^{\pm} \rightarrow \tilde{\chi}_1^0 +$ **very soft jets**

Requires very good di-jet mass resolution

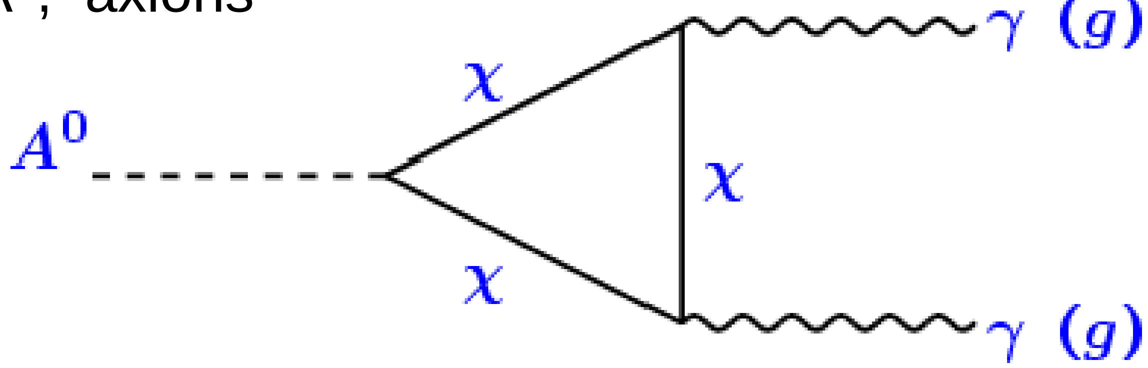


Only 5 of 46 accessible models are seen

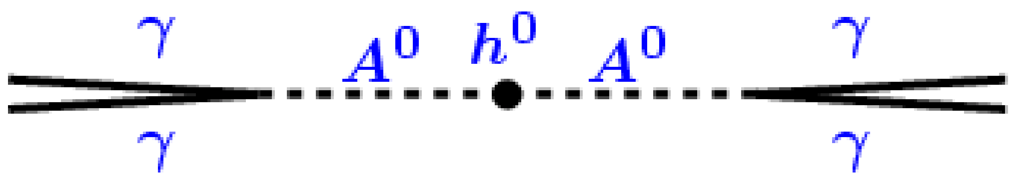
non-standard Higgs decays to jets or photons

Bogdan Dobrescu and Patrick Fox

$h \to A^\circ A^\circ$, axions



for light axions



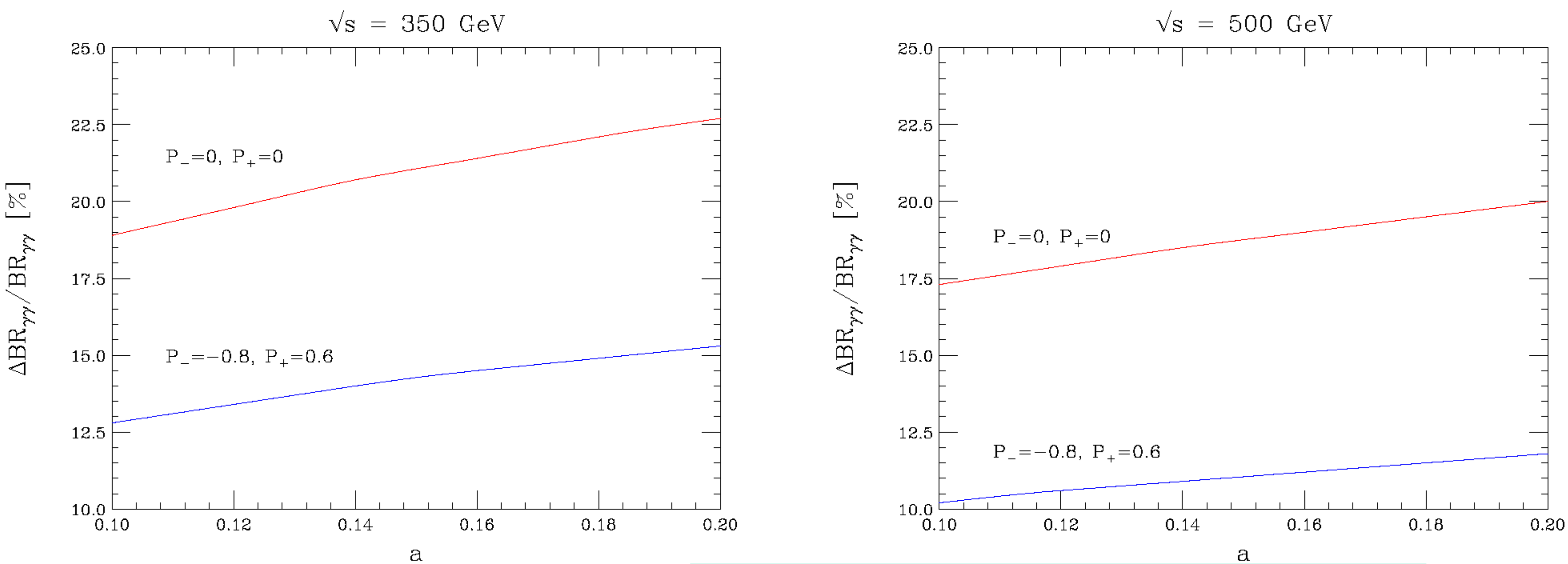
- $h \to A^\circ A^\circ \to 4\gamma$, 4j, $2\gamma 2j$ all possible
- Allows Higgs mass well below 115 GeV
- Depending on decay mode and characteristics, may be difficult or impossible to observe at LHC

Photon energy resolution

Frank Petriello

- Not a driver for jet energy resolution (if a <≈0.20, $\Delta E/E = a/\sqrt{E_\gamma}$)
- What about $h \rightarrow \gamma\gamma$?

- $h \rightarrow \gamma\gamma$ is sensitive to (other) new physics
- branching fraction measurements better than 20% are interesting
- background parameterized from Boos, et al., hep-ph/0011366



weak dependence on resolution

Isolated photon signatures

Steve Martin

I. GMSB

$$\tilde{N}_1 \to \gamma \tilde{G}$$

with a decay width:

$$\Gamma = 20\kappa \left(\frac{m_{\tilde{N}_1}}{100\ \mathrm{GeV}}\right)^5 \left(\frac{\sqrt{F}}{10\ \mathrm{TeV}}\right)^{-4} \ \mathrm{eV}$$

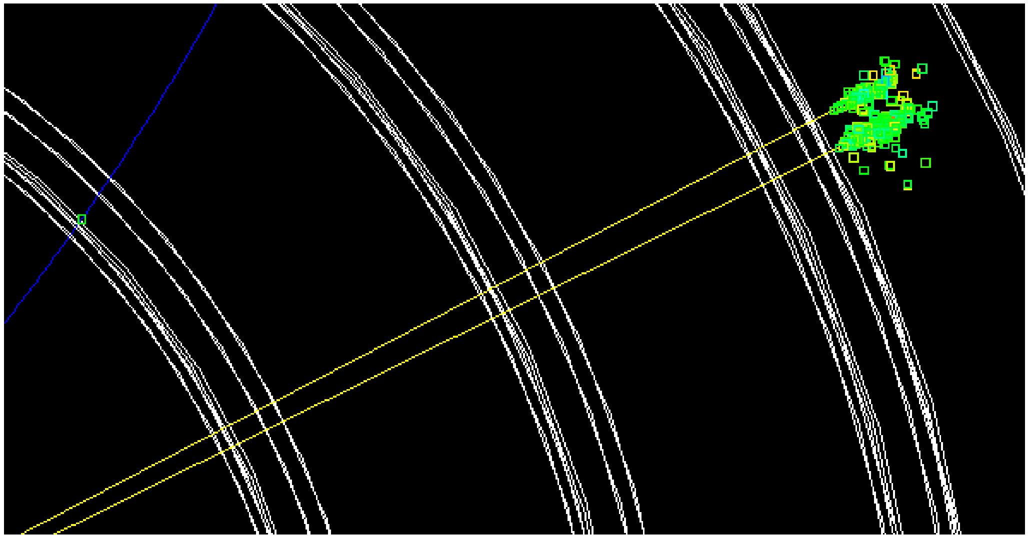
Here κ is a neutralino-photino mixing angle of order 1, and

$\sqrt{F}$ = mass scale of SUSY breaking

At ILC:

$$e^+e^- \to \tilde{N}_1 \tilde{N}_1 \to \gamma\gamma + \not{E}$$

is a possible process, with N1 decay lengths which could be ~1 m (or more; or less)

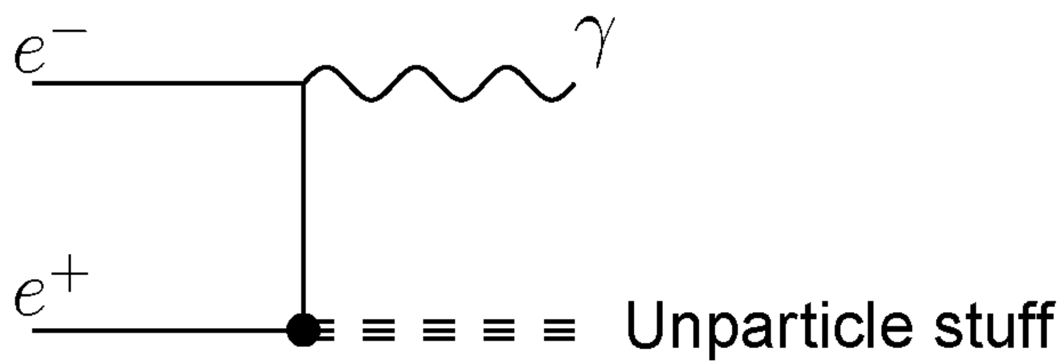


isolated photons (contd)

II. Unparticles

Monophoton signature from Unparticle Stuff

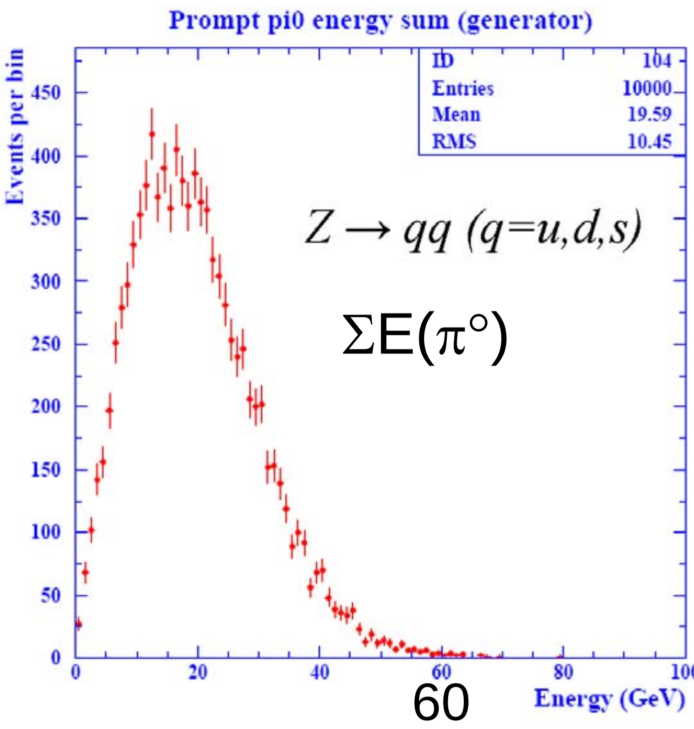
$$\sigma \propto \frac{\lambda^2}{\Lambda_{\mathcal{U}}^{2d_{\mathcal{U}}-2}}$$

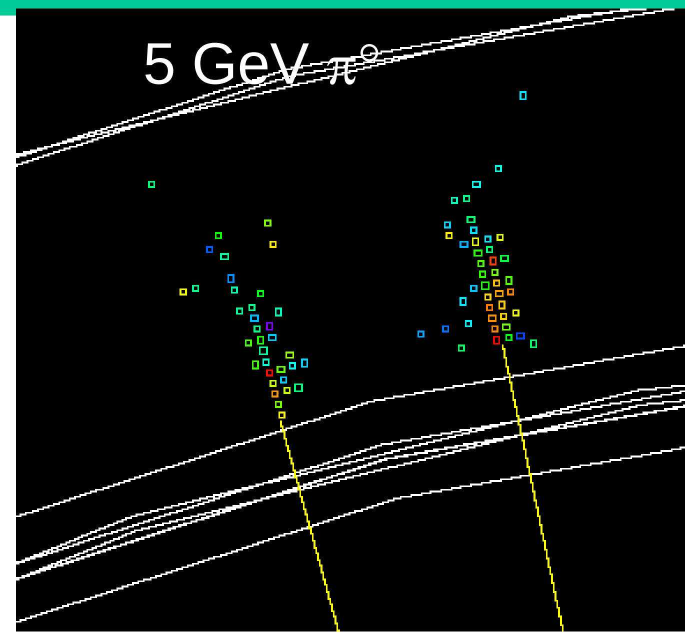


Constrained by LEP2 single photon results $\rightarrow$ ILC

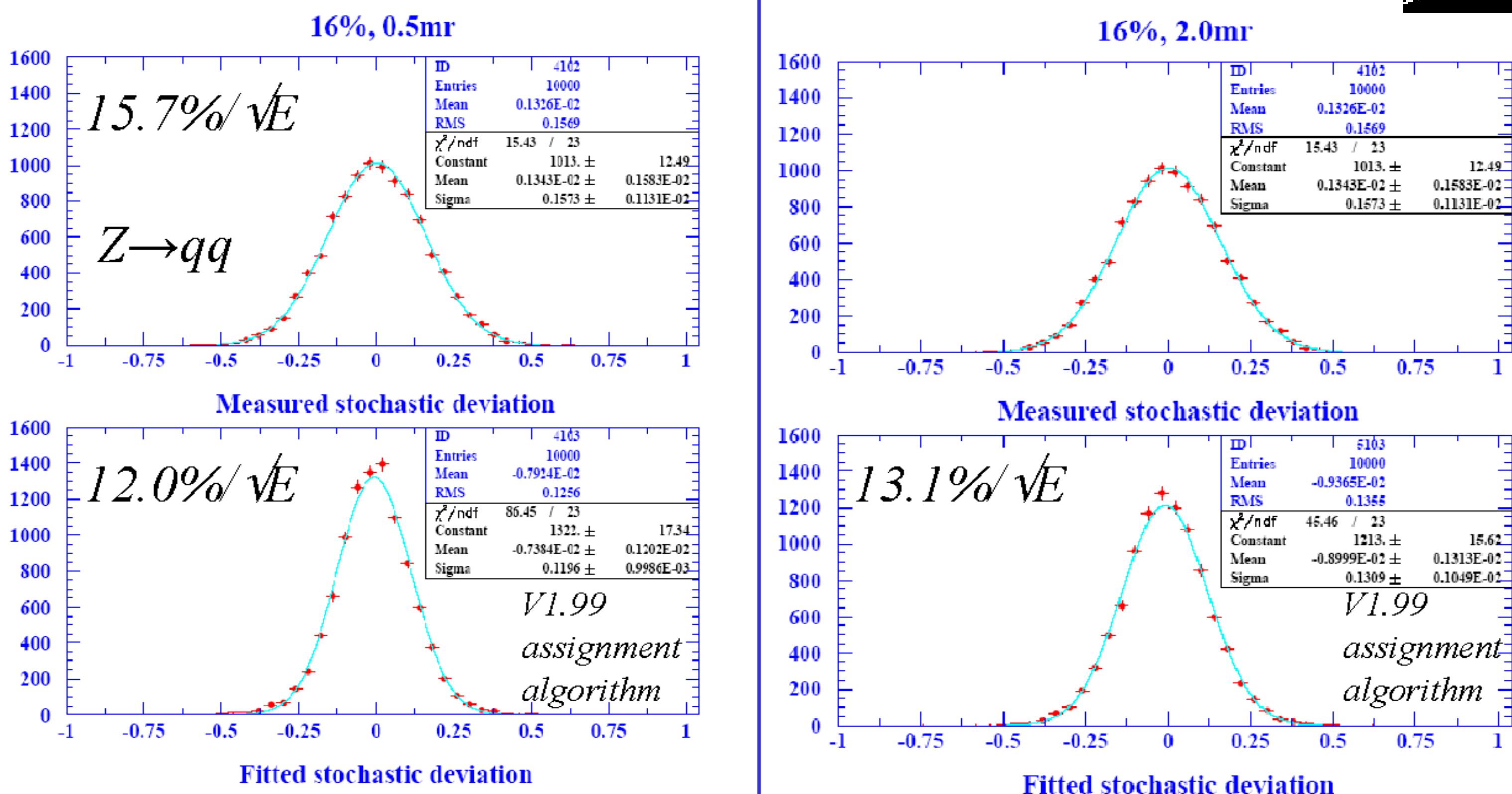
Improving jet resolution

Graham Wilson





Use $\pi°$ mass constraint to improve jet energy resolution



no constraint

with constraint

Photons for tau polarization

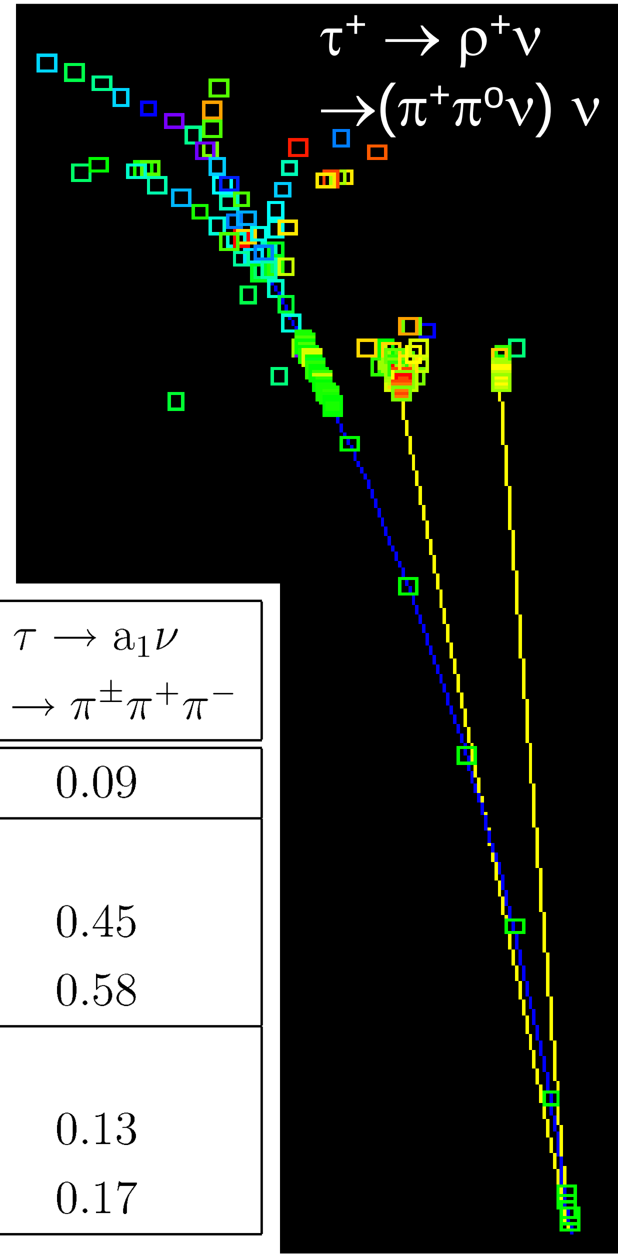
RF

Example from SUSY $e^+e^- \longrightarrow \tilde{\tau}_1^+\tilde{\tau}_1^-$, $\tilde{\tau}_1^\pm \longrightarrow \tilde{\chi}_1^0\tau^\pm$

$$\tilde{\chi}_1 = N_{11}\widetilde{\mathrm{B}} + N_{12}\widetilde{\mathrm{W}} + N_{13}\widetilde{\mathrm{H}}_1 + N_{14}\widetilde{\mathrm{H}}_2$$

- mSUGRA: $\tilde{\chi}_1 \sim \widetilde{\mathrm{B}} \Rightarrow P_\tau \approx +1$
- non-universal SUGRA: $\tilde{\chi}_1 \sim \tilde{\mathrm{H}} \Rightarrow P_\tau \approx \cos^2\theta_\tau - \sin^2\theta_\tau$
- AMSB: $\tilde{\chi}_1 \sim \widetilde{\mathrm{W}} \Rightarrow P_\tau \approx -1$
- GMSB: $\tilde{\tau}_1^\pm \rightarrow \widetilde{\mathrm{G}}\tau^\pm \Rightarrow P_\tau \approx \sin^2\theta_\tau - \cos^2\theta_\tau$

Godbole, Guchait, Roy, Phys Lett B (2005)



Phys.Rept.427:257,2006	$\tau \rightarrow \rho\nu$	$\tau \rightarrow \pi\nu$	$\tau \rightarrow e\nu\overline{\nu}$	$\tau \rightarrow \mu\nu\overline{\nu}$	$\tau \rightarrow a_1\nu$, $a_1 \rightarrow \pi^\pm\pi^+\pi^-$
Branching fraction	0.25	0.12	0.18	0.17	0.09
Maximum sensitivity:					
no 3D τ direction	0.49	0.58	0.22	0.22	0.45
with 3D τ direction	0.58	0.58	0.27	0.27	0.58
Normalised ideal weight:					
no 3D τ direction	0.44	0.30	0.06	0.06	0.13
with 3D τ direction	0.47	0.22	0.07	0.07	0.17

Summary

- It was great to bring theorists and experimentalists together to discuss common issues.

- Learned about
  - some interesting signatures for New Physics
  - some new twists on well-known signatures
  - some potential detector issues

- There are interesting cross-connections between jets+photons and other signature groups which should be explored
  - Tau id and analysis
  - Heavy flavor reconstruction
  - etc

theorist-experimenter interactions example

- Past studies: e+e- $\rightarrow$ t tbar $\rightarrow$ 4 jets, 6 jets

$\Rightarrow$ top neutral-current anomalous couplings ($\rightarrow$ TESLA TDR, etc)

- Found out that there now are predicted effects from various BSM models!

TESLA TDR

Form factor	SM value	$\sqrt{s} = 500\,\mathrm{GeV}$		$\sqrt{s} = 800\,\mathrm{GeV}$	
		$p = 0$	$p = -0.8$	$p = 0$	$p = -0.8$
F_{1V}^{Z}	1		0.019		
F_{1A}^{Z}	1		0.016		
$F_{2V}^{\gamma,Z} = (g-2)^{\gamma,Z}{}_t$	0	0.015	0.011	0.011	0.008
$\mathrm{Re}\, F_{2A}^{\gamma}$	0	0.035	0.007	0.015	0.004
$\mathrm{Re}\, d_t^{\gamma}$ $[10^{-19}$ e cm$]$	0	20	4	8	2
$\mathrm{Re}\, F_{2A}^{Z}$	0	0.012	0.008	0.008	0.007
$\mathrm{Re}\, d_t^{Z}$ $[10^{-19}$ e cm$]$	0	7	5	5	4
$\mathrm{Im}\, F_{2A}^{\gamma}$	0	0.010	0.008	0.006	0.005
$\mathrm{Im}\, F_{2A}^{Z}$	0	0.055	0.010	0.037	0.007
F_{1R}^{W}	0	0.030	0.012		
$\mathrm{Im} F_{2R}^{W}$	0	0.025	0.010		