Physics Benchmarks, Physics Signatures and Multi-TeV Lepton Colliders

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Muon Collider Workshop 2011, Telluride, CO

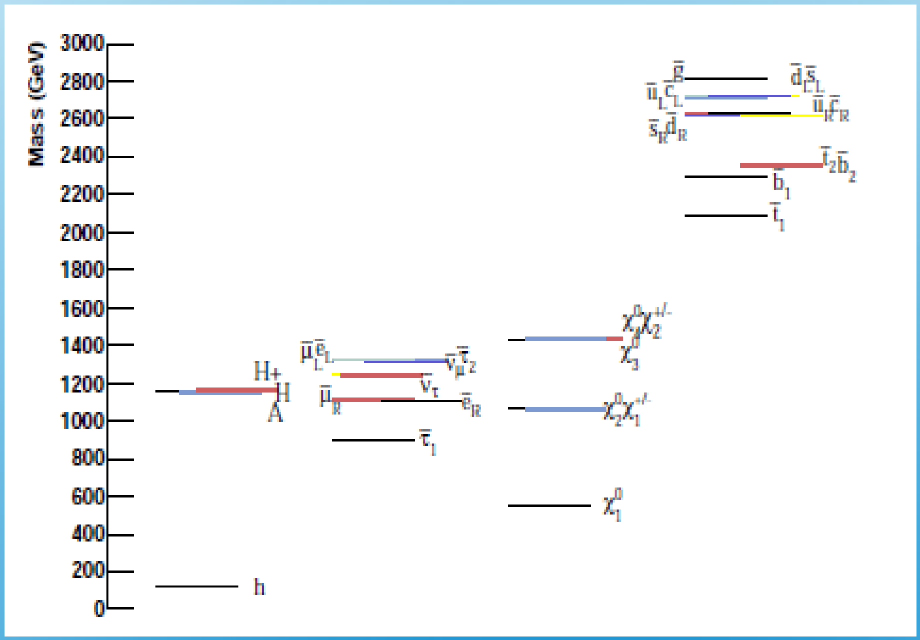
Physics Signatures	Higgs Sector	SUSY	SSB	New Gauge Bosons	Extra Dimensions
Resonance Scan		SUSY Thresholds	D-BESS	Z'	KK
EW Fits				A_{LR}, A_{FB}	$A_{FB}^{b\bar{b}}$
Multi-Jets	H^+H^- $t\bar{t}H$ $HH\nu\bar{\nu}$ HHZ $HHH\nu\bar{\nu}$ $HHHZ$		Techni-ρ		
E_{miss}, Fwd	He^+e^-	$\tilde{\ell}^+\tilde{\ell}^-$ $\tilde{\chi}^+\tilde{\chi}^-$	WW scattering		

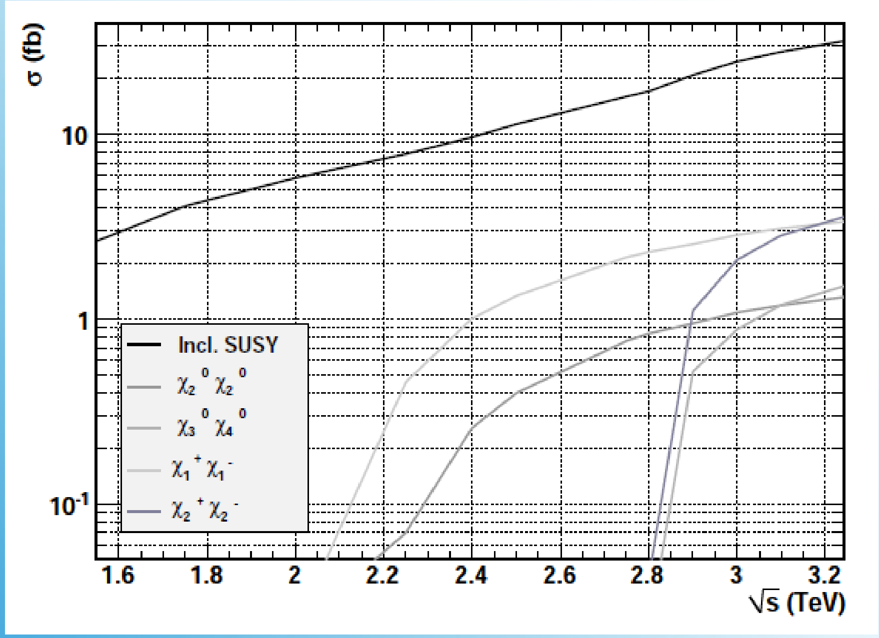
hep-ph/0103338

Physics Signatures

Multi-TeV lepton collisions likely to be required by new physics signals at the Tera-scale: essential to understand the intrinsic limitations of e+e- and μ+μ- in terms of practical collision energy (and luminosity);

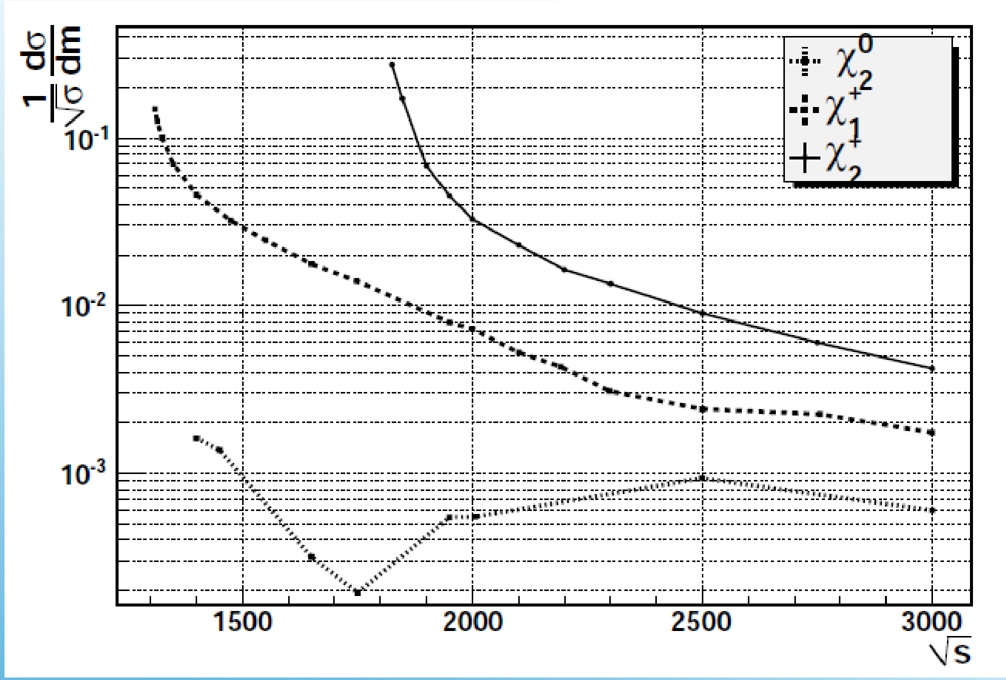
Several scenarios of new physics have thresolds for s-channel particle production extending over considerable energy span: need to evaluate achievable accuracy of measurements within realistic run plan;





Energy and Luminosity

Physics Signatures: Threshold Scans

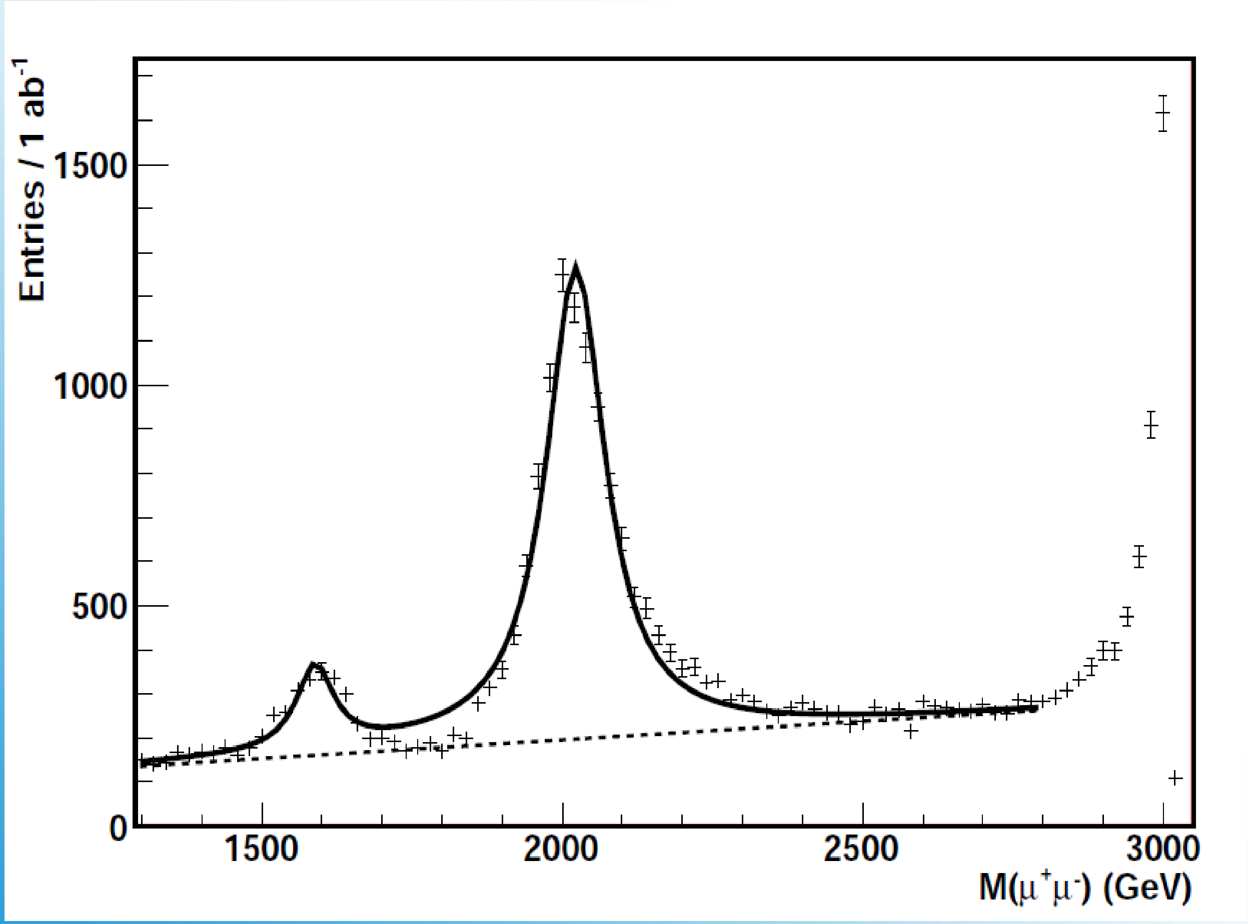


Particle	Mass (GeV)	Born	ISR	ISR+BS	ISR+BS +Bkg	w/ Pol (+0.8/0)	w/ Pol (+0.8/-0.6)
Model I							
$\chi_1^\pm$	643.2	$\pm$ 0.6	$\pm$ 0.6	$\pm$ 0.7	$\pm$ 0.7	$\pm$ 0.5	$\pm$ 0.4
χ_2^0	643.1	$\pm$ 4.3	$\pm$13.8	$\pm$24.1	$\pm$25.6	$\pm$23.9	$\pm$18.1
$\chi_2^\pm$	916.7	$\pm$ 0.8	$\pm$ 0.9	$\pm$ 1.3	$\pm$ 1.4	$\pm$ 1.1	$\pm$ 0.9

arXiv:1104.0523

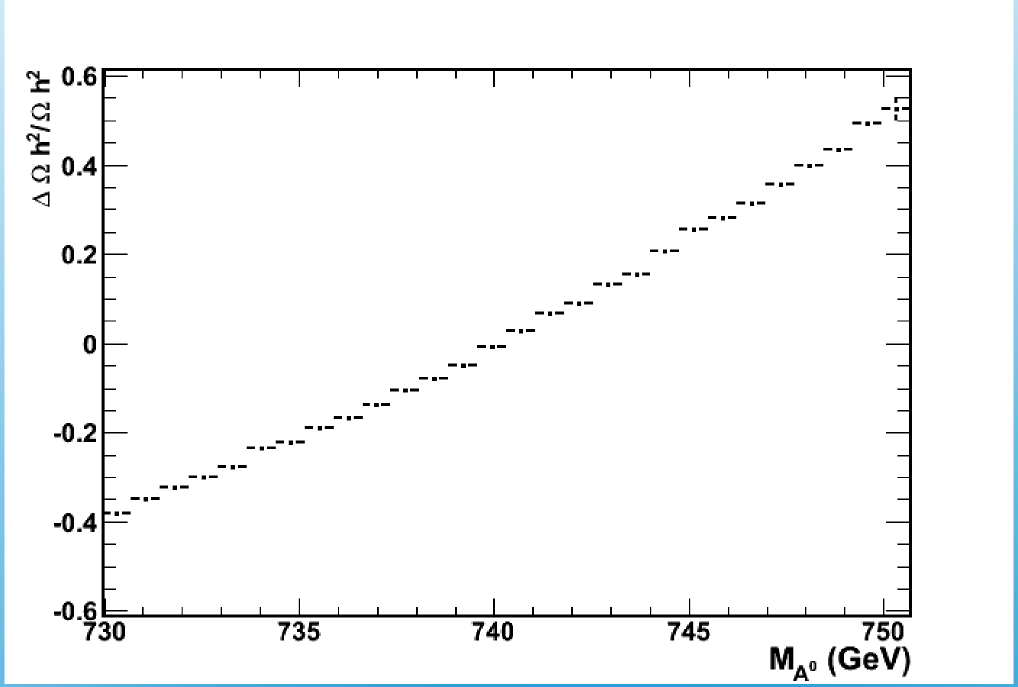
Autoscan using beam radiation (ISR+Beamstrahlung at CLIC, ISR at MuC)

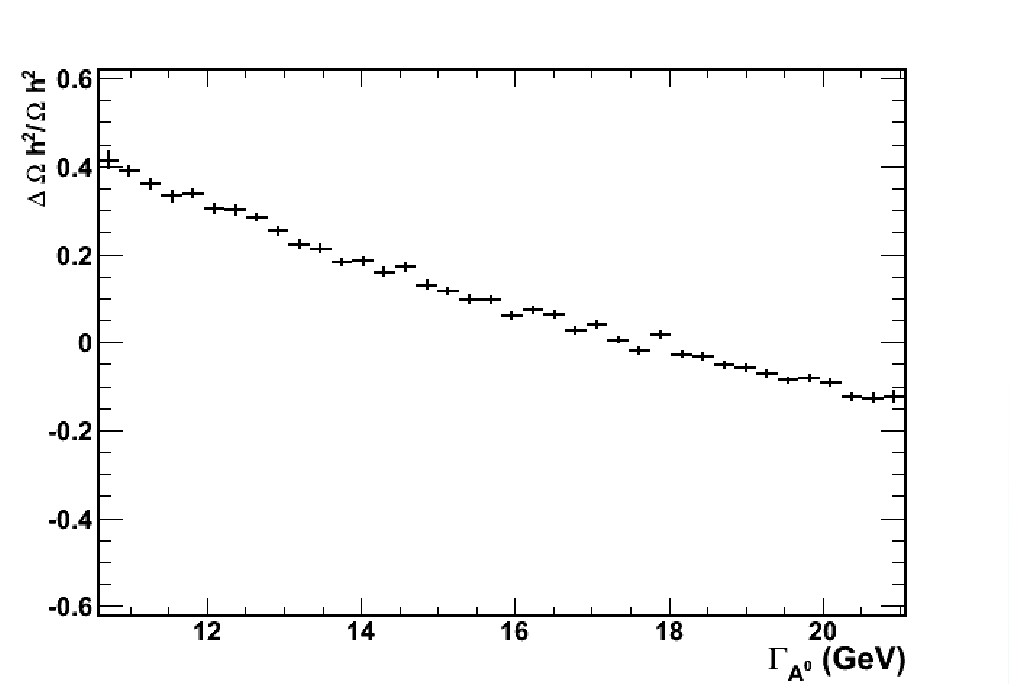
Perform scan to determine nature of resonances from EW observables (A_{FB}, A_{LR})



Physics Signatures:
s-channel Resonance Production

Mass and width of CP-odd A^0 boson of special importance in neutralino WIMP DM scenarios since the $\chi\chi$ annihilation and the WIMP scattering cross section receives large contributions from the A^0 channel





SuperIso+FeynHiggs Simulation

Physics Signatures:
s-channel Resonance Production

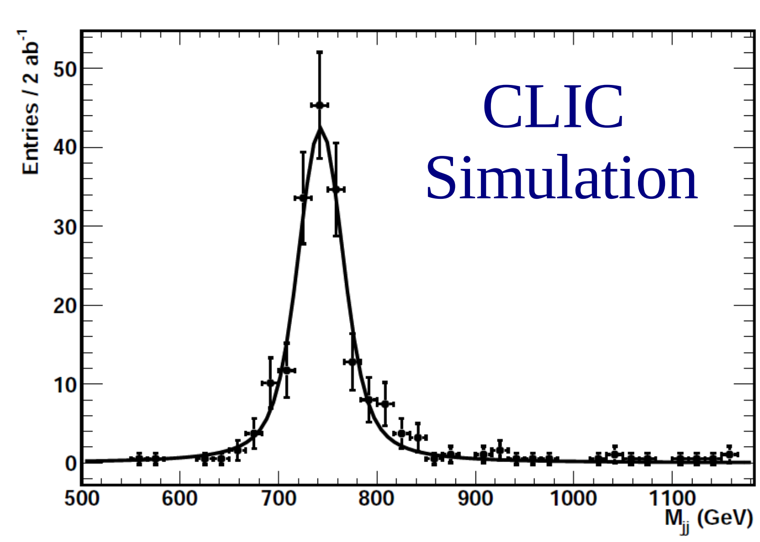
$e^+e^- \to H^0A^0 \to bbbb$ at 3 TeV gives accuracies $\sigma M_A/M_A \sim 0.002\text{-}0.005$ and $\sigma\Gamma_A/\Gamma_A \sim 0.10\text{-}0.15$

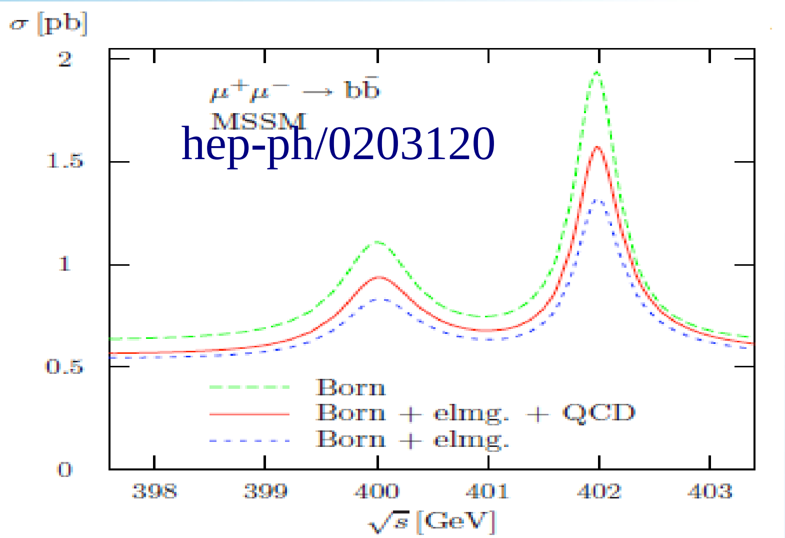
$\sigma(e^+e^- \to H^0A^0) \sim 1\text{-}10$ fb

$M_A = 743$ GeV, $\tan\beta = 51$

$M_A = 903$ GeV, $\tan\beta = 24$

$\mu^+\mu^- \to A^0 \to bb$ at M_A should in principle give competitive accuracies on M_A and Γ_A with $\sigma(\mu^+\mu^- \to A^0) \sim 0.1 - 1$ pb





Physics Signatures:
s-channel Resonance Production

- $e^+e^- \rightarrow \chi_2^0\chi_2^0 \rightarrow h^0\chi_1^0 h^0\chi_1^0;\, h \rightarrow b\bar{b}$,

Identification and determination of mass of χ^0 and χ^+ through decays into bosons highlights the need of excellent parton energy resolution and b-tagging:

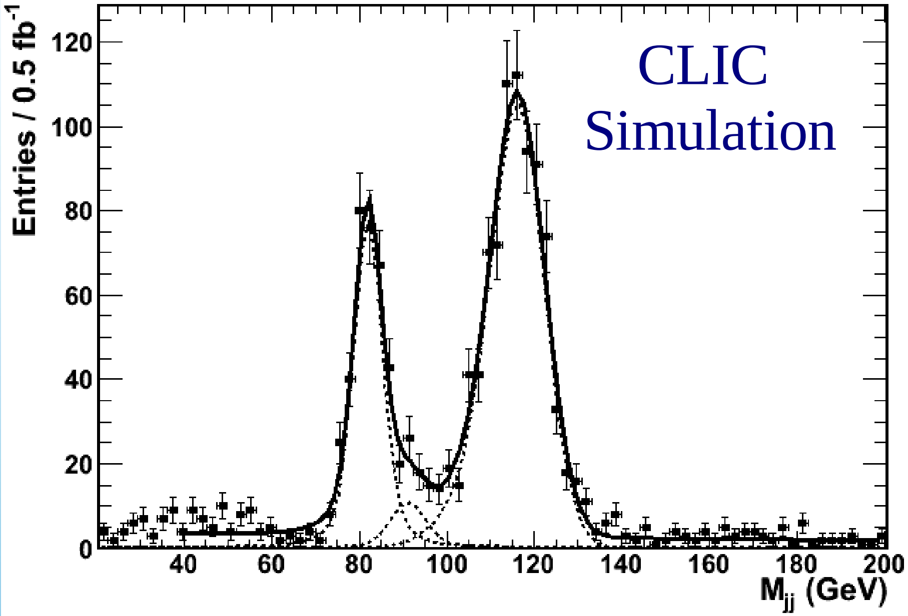
Particle	Mass (GeV)	No Rad	ISR	ISR+BS $\delta E/E$=0	ISR+BS =0.025	ISR+BS =0.05
Model I χ_2^0	643.2	$\pm$ 1.01	$\pm$ 1.17	$\pm$ 2.58	$\pm$ 3.59	$\pm$ 4.54

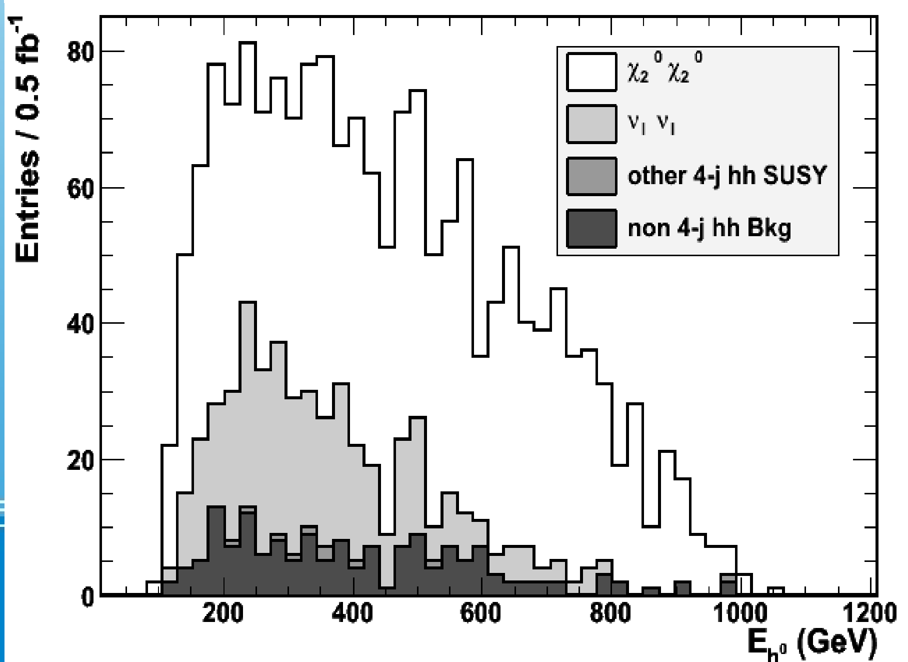
at 0.5 TeV

$\sigma M_\chi/M_\chi$ ~ 0.005-0.01 for M ~ 200 GeV

at 3 TeV

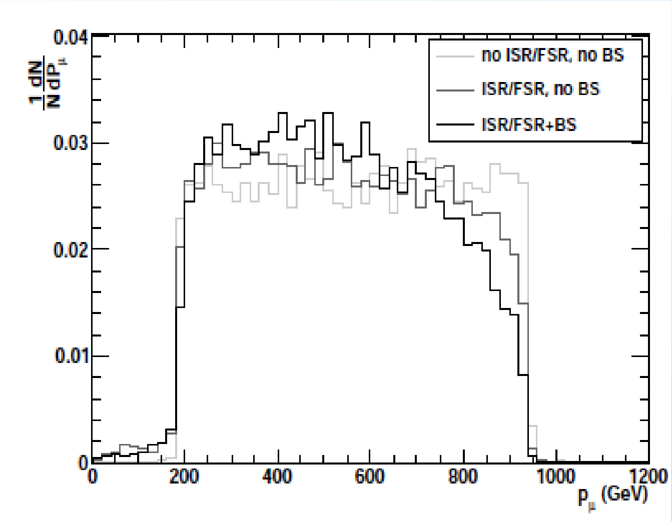
$\sigma M_\chi/M_\chi$ ~ 0.01-0.05 for M = 600-900 GeV





Physics Signatures: Energy Resolution in Multi-Jet Final States

$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$



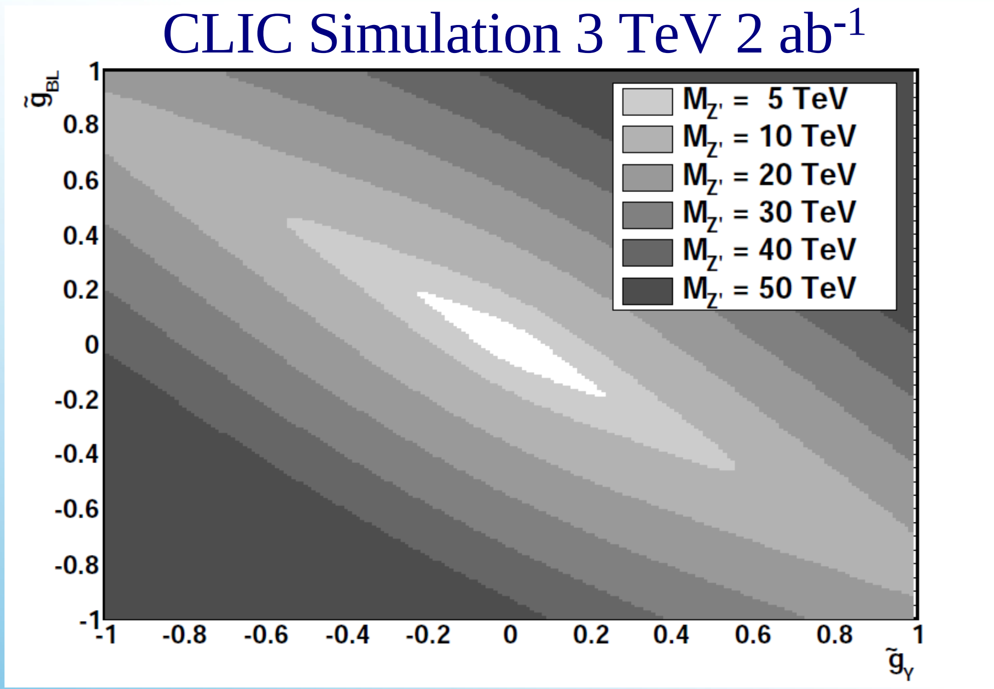
arXiv:1006.2547

Smuon Mass reconstruction accuracy for different assumptions

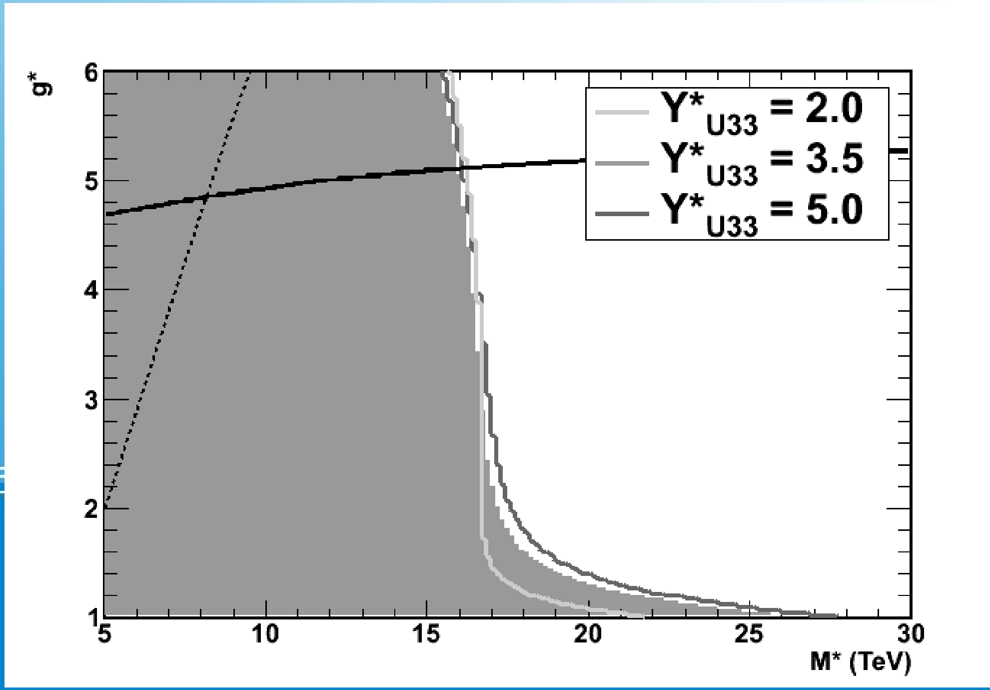
$\delta p_t/p_t^2$ ($\times10^{-5}$ GeV^{-1})	$\sqrt{s}>$ (GeV)	Data Set	Pol (e^-/e^+)	BX	(M$\pm\sigma_M$) (GeV) $\tilde{\mu}_R^\pm$	$\tilde{\chi}_1^0$
0.	2950	S	0/ 0	0	1106.3± 2.9	558.8 ± 1.3
0.	2500	S	0/ 0	0	1098.8± 2.6	555.4 ± 1.2
0.	2500 (ISR only)	S	0/ 0	0	1109.2± 3.2	555.4 ± 1.2
0.	2500	S (No FSR Cor)	0/ 0	0	1095.3± 3.2	557.7 ± 1.3
2.	2500	S	0/ 0	0	1104.6± 2.9	560.0 ± 1.7
2.	2500	S (G4+Reco)	0/ 0	0	1107.1± 2.8	560.1 ± 1.5
4.	2500	S	0/ 0	0	1102.8± 2.9	557.2 ± 2.8
6.	2500	S	0/ 0	0	1098.8± 3.1	559.1 ± 3.6
8.	2500	S	0/ 0	0	1101.0± 3.4	564.2 ± 4.0
20.	2500	S	0/ 0	0	1107.5± 4.2	575.7 ± 5.3
2.	2500	S+B (0.8)	0/ 0	0	1107.5±15.5	542.5 ± 11.3
2.	2500	S+B (0.9)	0/ 0	0	1107.5±14.4	551.2 ± 12.0
2.	2500	S+B (0.8)	80/ 0	0	1107.7± 8.7	542.6 ± 4.6
2.	2500	S+B (0.8)	80/60	0	1118.5± 6.1	551.3 ± 3.0
2.	2500	S+B (0.8)	80/60	5	1105.7± 6.3	549.4 ± 3.9
2.	2500	S+B (0.8)	80/60	20	1113.2± 6.8	550.3 ± 3.4

Physics Signatures:
Energy Resolution in Leptonic Final States

EW observables (σ, A_{FB}, A_{LR}) with beam polarization in e+e- $\rightarrow$ $\mu\mu$, bb, tt sensitive to virtual contribution of new particles with M >> E_{cm}



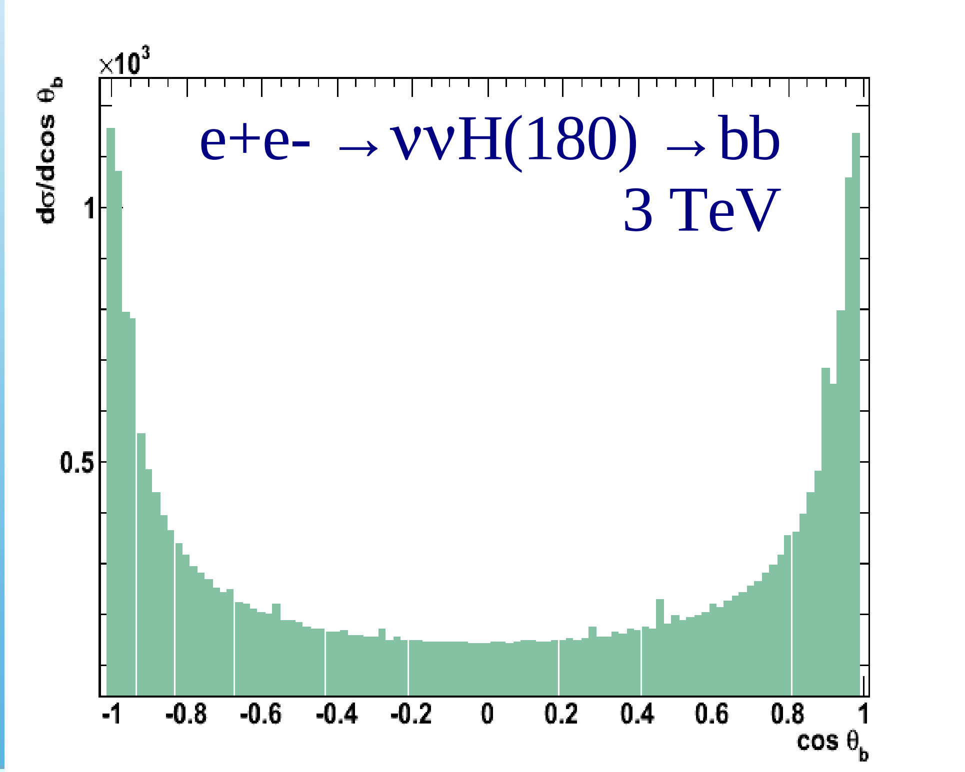
EW fits emphasise efficient flavour tagging, quark charge determination in highest energy jets and beam polarization

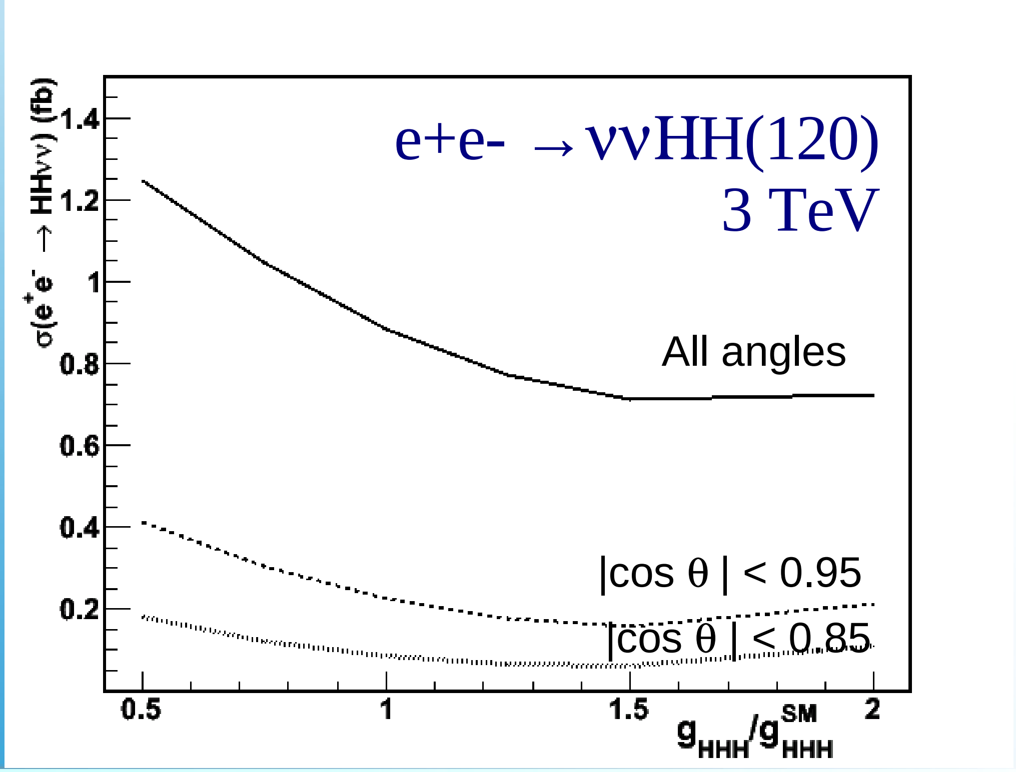


Physics Signatures: Electro-weak Fits

Complete the SM through t-channel/fusion channels

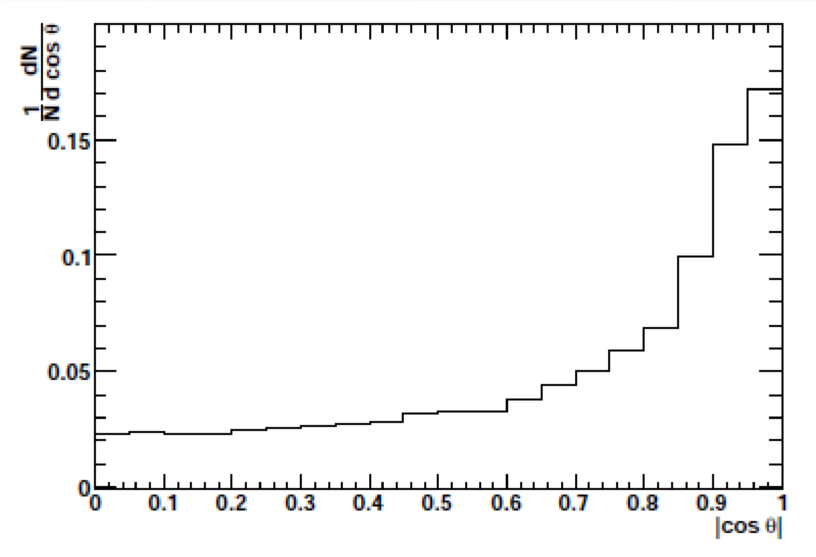
Suppressed SM processes (H(120) → μ+μ−, H(180) → bb, H → Zγ, HH production through g_{HHH}) become accessible at multi-TeV energies due to log s increase of WW fusion process and enhancement w/ polarised beams

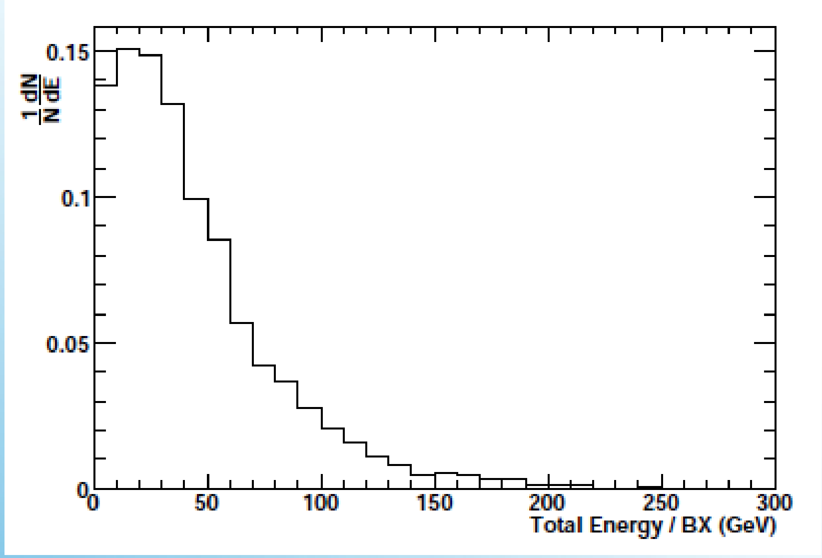




Physics Signatures:
Fwd Processes

$\gamma\gamma \rightarrow$ hadrons in multi-TeV collisions





At CLIC ~15 TeV/train dumped in detector (|cos θ| < 0.98)
Preserving accuracy in measurements requires special care (timing, LHC jet clustering algorithms, kinematic fits, …) effects studied on fully sim + reco events:

Nb. of BXs of overlayed $\gamma\gamma$	N_{bkg}	N_{signal}	M_A (GeV) 4-jet	M_A (GeV) semi-incl.
0	76	222±19	1137.4±3.3	1136.7±3.4
5	77	224±20	1144.4±3.8	1135.9±3.7
20	102	208±20	1160.7±6.9	1139.9±5.4
40	96	183±20	1167.2±8.2	1134.1±7.2

arXiV:1006.5659

Machine-induced backgrounds and benchmarks

Impact of LHC limits on lepton collider energy scale

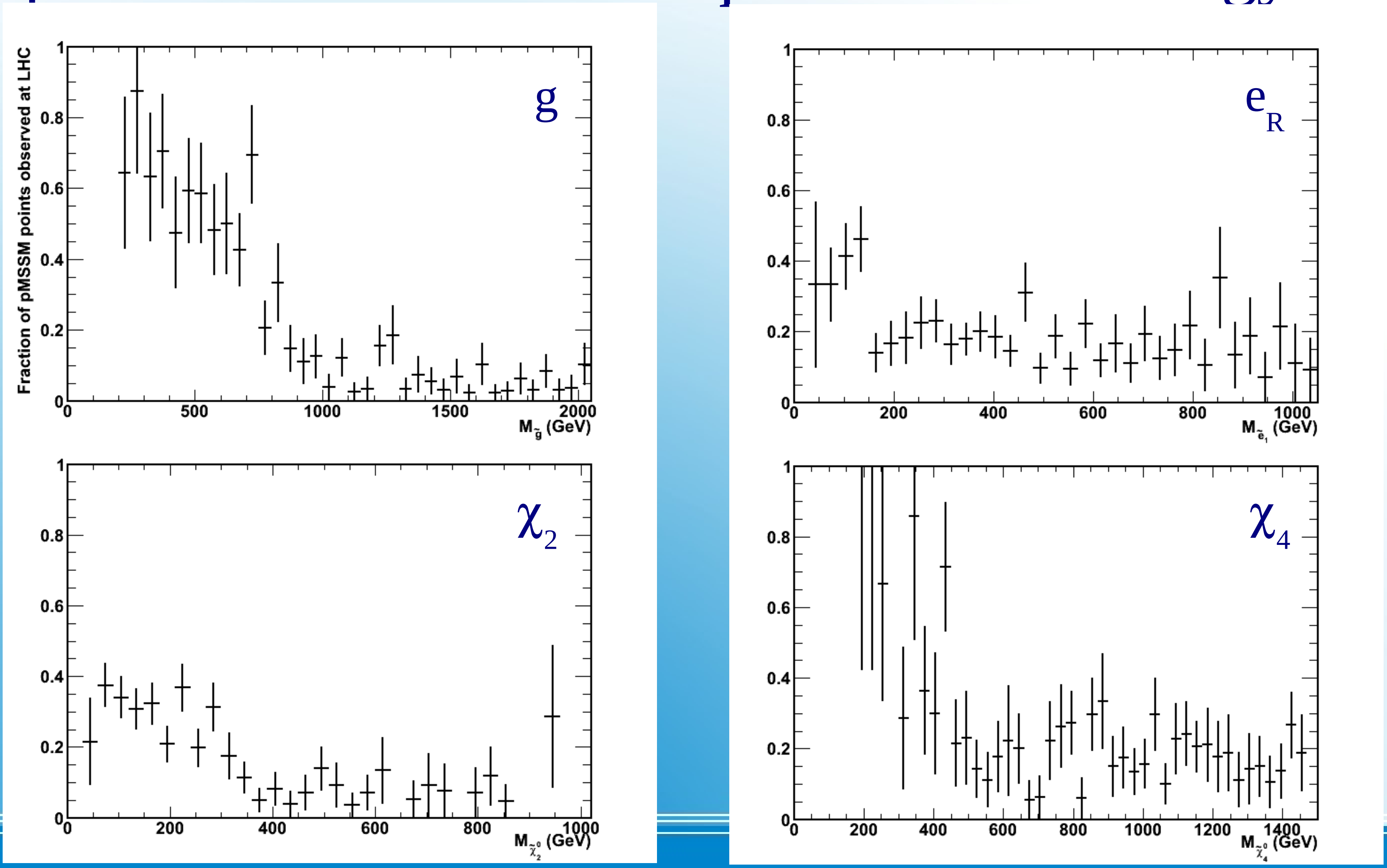
How are LHC limits on strongly interacting particles impacting the likely spectrum of the weakly interacting particles a lepton collider wants to access in SUSY ?

Coupling of MSUSY with slepton and gaugino masses is a prejudice derived from highly constrained models (cMSSM, mSUGRA, NUHM) used so far for benchmarking

In more generic MSSM models, such as the pMSSM, coupling becomes quite weak: (see also detailed analyses of Hewett *et al* arXiv:1103.1697)

Preliminary results of analysis imposing flavour constraints, Ωh^2 and LHC limits for 1 ab^{-1} (20000 pMSSM points of which 1300 accepted) (MB, A Arbey, N Mahoudi):

Impact of LHC limits on lepton collider energy scale



Energy and Luminosity:
SUSY Scale and LHC Limits

Process	Signature	Detector Challenges	Machine Challenges
H^0, $A^0 \rightarrow$ bb $H^+H^- \rightarrow$ tb	Multi-jets	b tagging δE_{jet} w/ kin fitting	δE_{beam}
Gaugino pairs, $\chi \rightarrow$ W/Z/h	Multi-jets+ $E_{missing}$	dEjets w/o kin fitting Jet clustering	δE_{beam}, bkg L vs E_{beam} Threshold scan
Slepton pairs	Leptons+ $E_{missing}$	Lepton id δE at high E	L vs E_{beam} Threshold scan Polarisation
Squark pairs	Multi-jets+ $E_{missing}$	δE_{jet} at highest E	
EW observables in $\mu\mu$, bb, tt	Multi-jets, Fwd	b tagging at highest E Quark charge, Fwd	Polarisation, bkg
$\nu\nu H \rightarrow \mu\mu$ $\nu\nu H \rightarrow$ bb	Fwd Fwd b jets	Fwd E reco Fwd b tagging	bkg
$\nu\nu HH \rightarrow$ bbbb	Fwd b jets	Fwd b tagging, Jet clustering	L, bkg, Polarisation
$\nu\nu WW$ / $\nu\nu ZZ$	Multi-jets Fwd	W/Z separation, Fwd	bkg