New Physics and Dark Matter at the ILC

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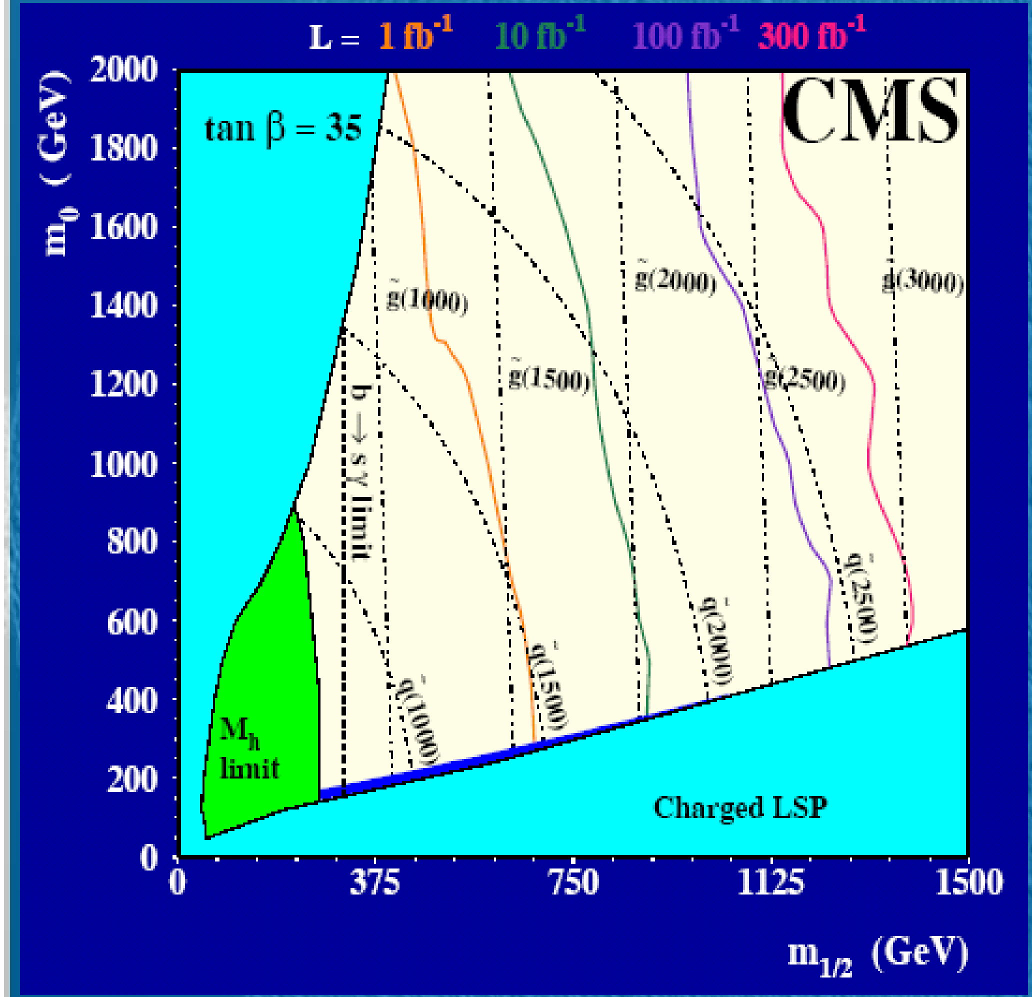
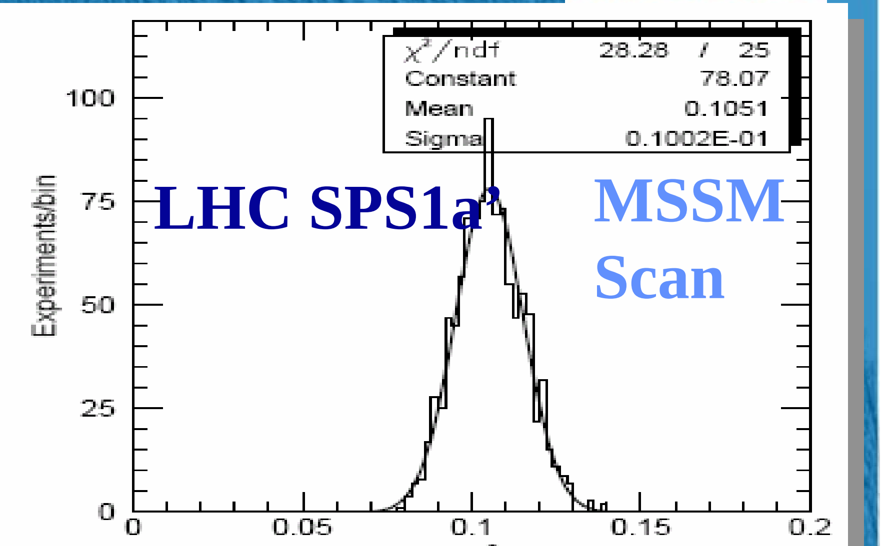
UC Berkeley and LBNL

Dark Matter Workshop
FNAL, May, 12 2007

Studying DM at LHC





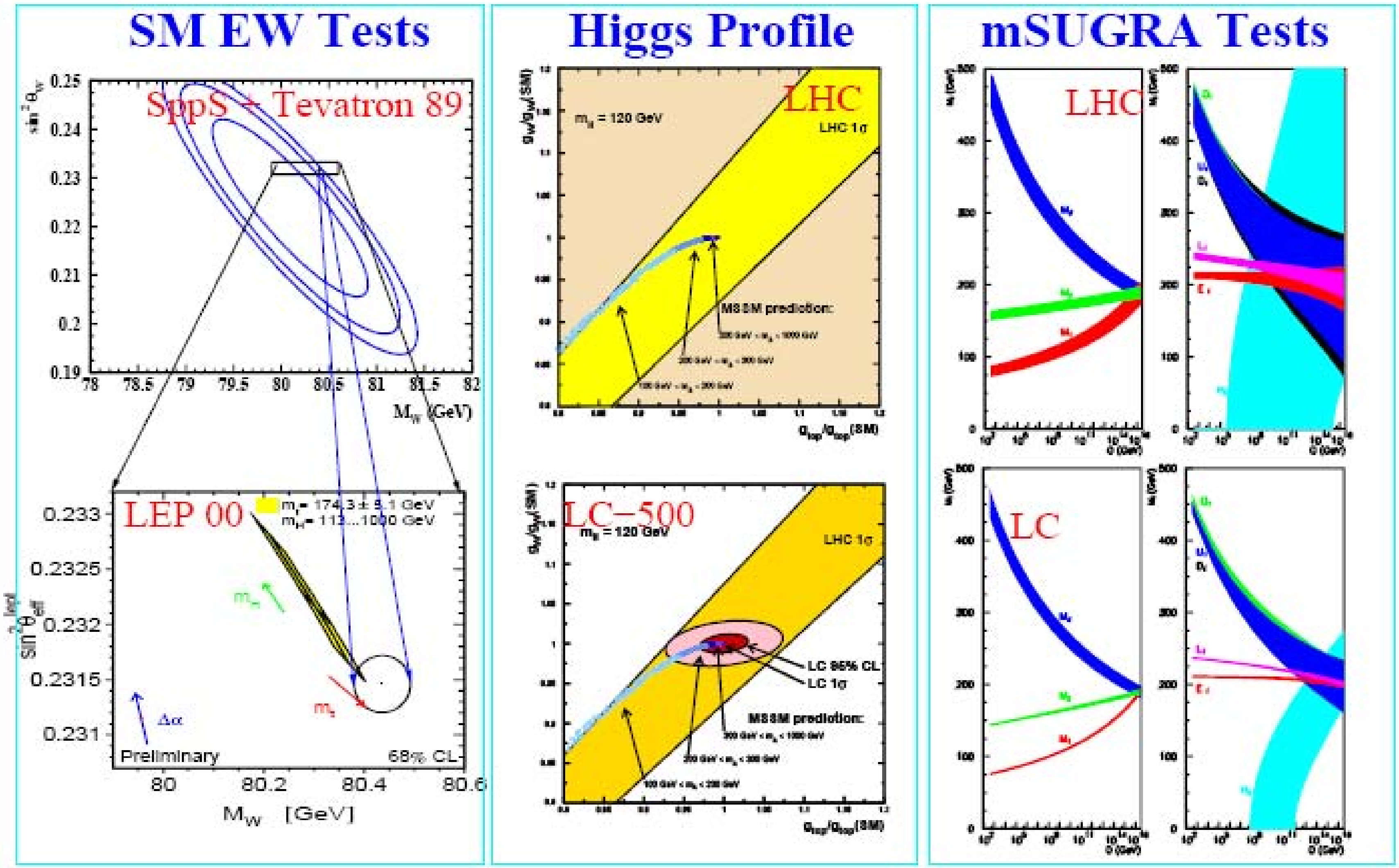
Nojiri, Polesello, Tovey, JHEP 0603 (2006)

LHC discovery reach independent of details of the model: $E_T^{missing}$+ jets and/or isolated leptons sufficient to ensure detection;

Consistency with DM requires a significant number of measurements;

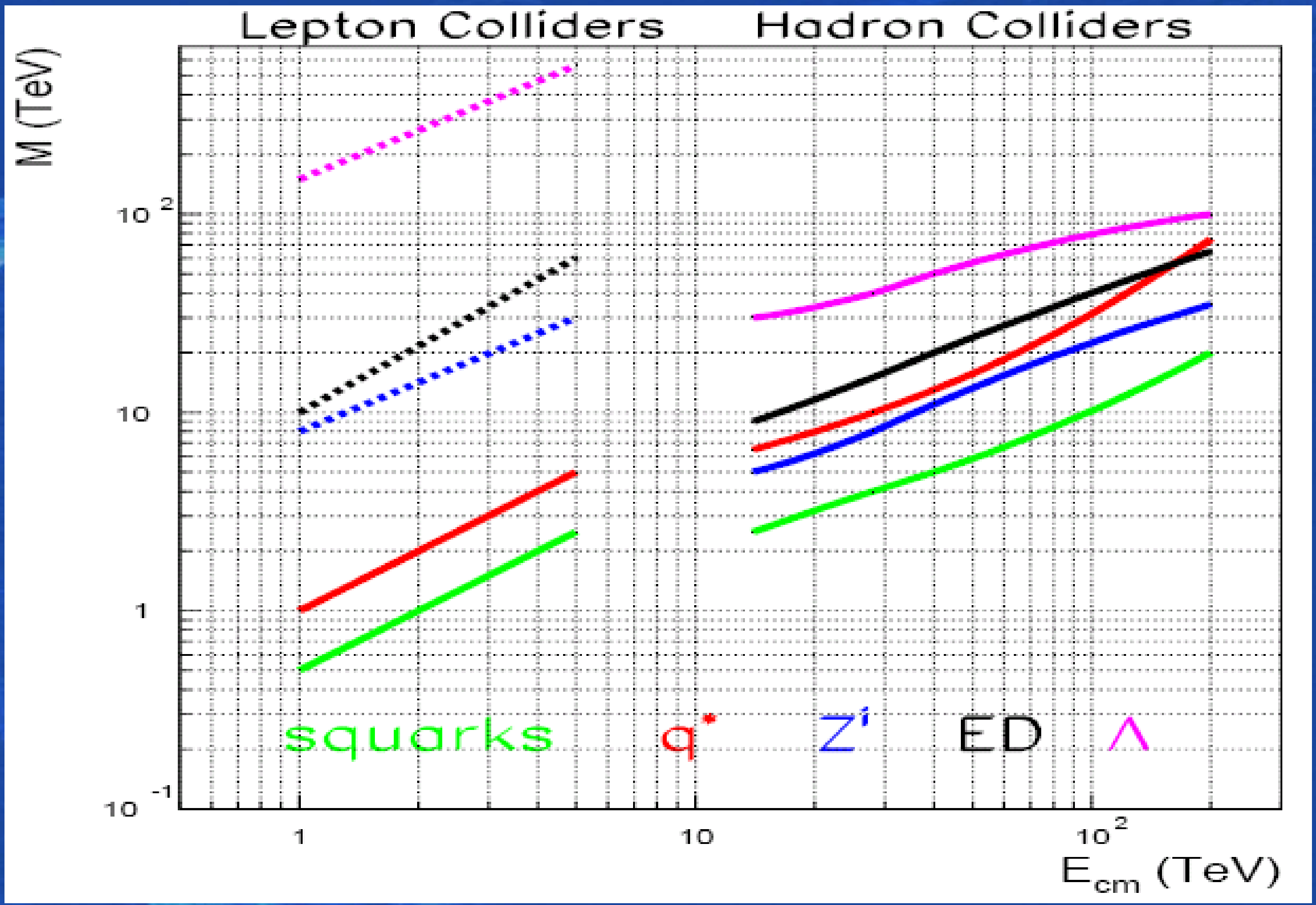
Perform tests first within context of specific model (cMSSM) and then reconstruct full decay chain enabling model-independent mass measurements;

Synergy of Hadron and Lepton Colliders

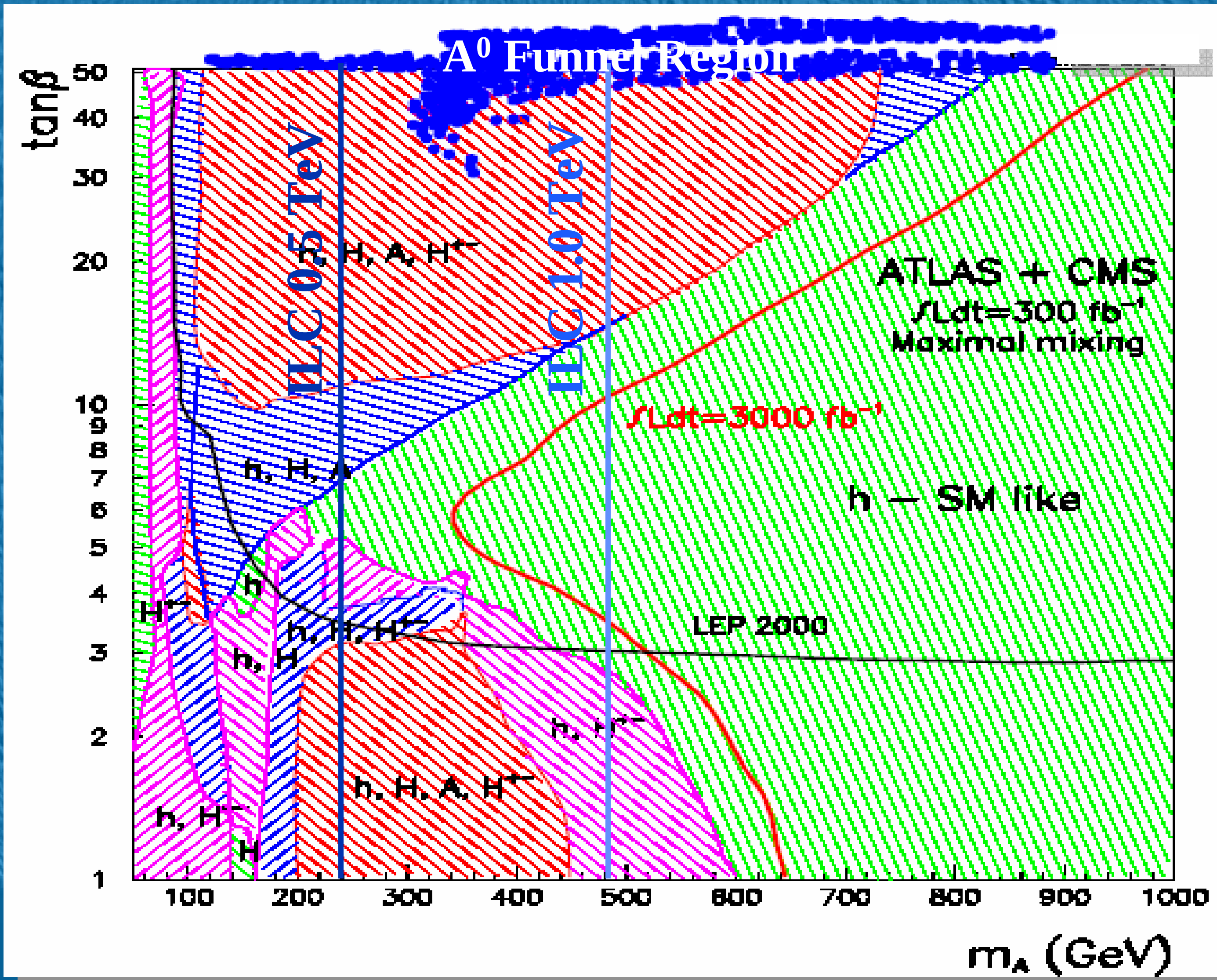


Synergy of Hadron and Lepton Colliders

Mass scale sensitivity vs. centre of mass energy



Studying DM in Higgs Sector

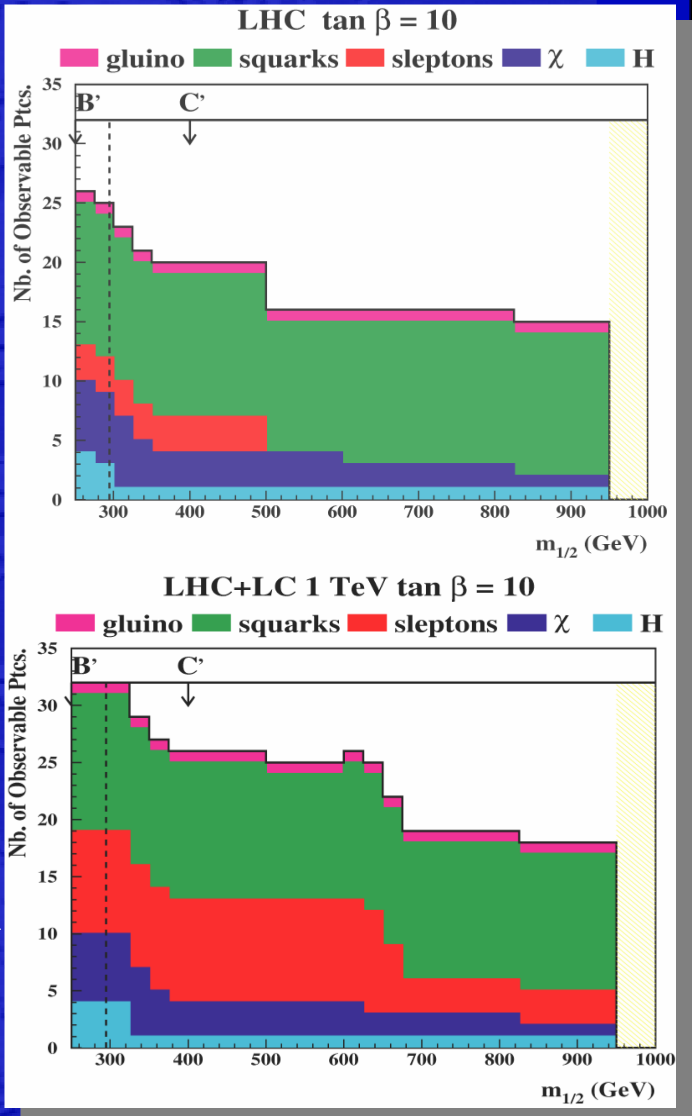


ILC-LHC Complementarity

ILC precision and versatility crucial in extending discoveries and fully testing nature of physics at the new frontier first explored by the LHC:

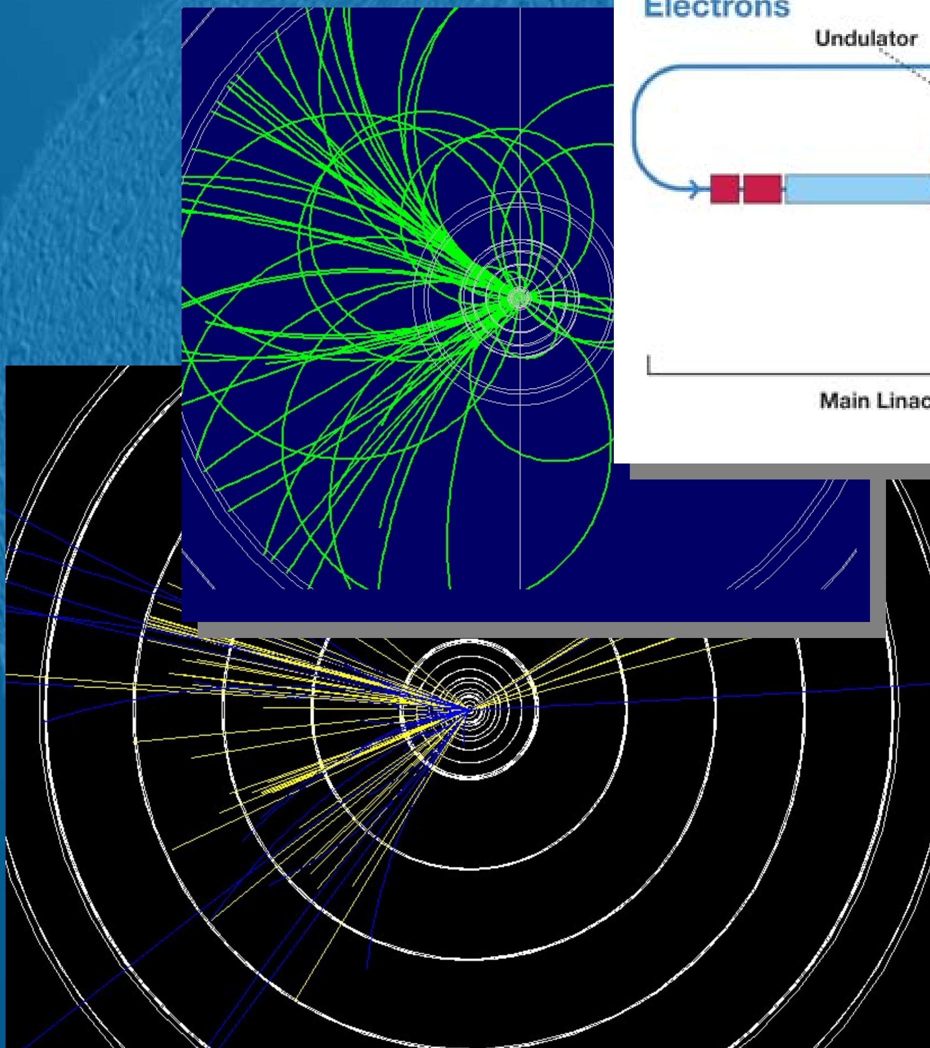
SUSY offers interesting template for complementarity in new particles to be discovered at LHC and ILC, but also for higher sensitivity to Cosmology-motivated scenarios at edges of phase space;

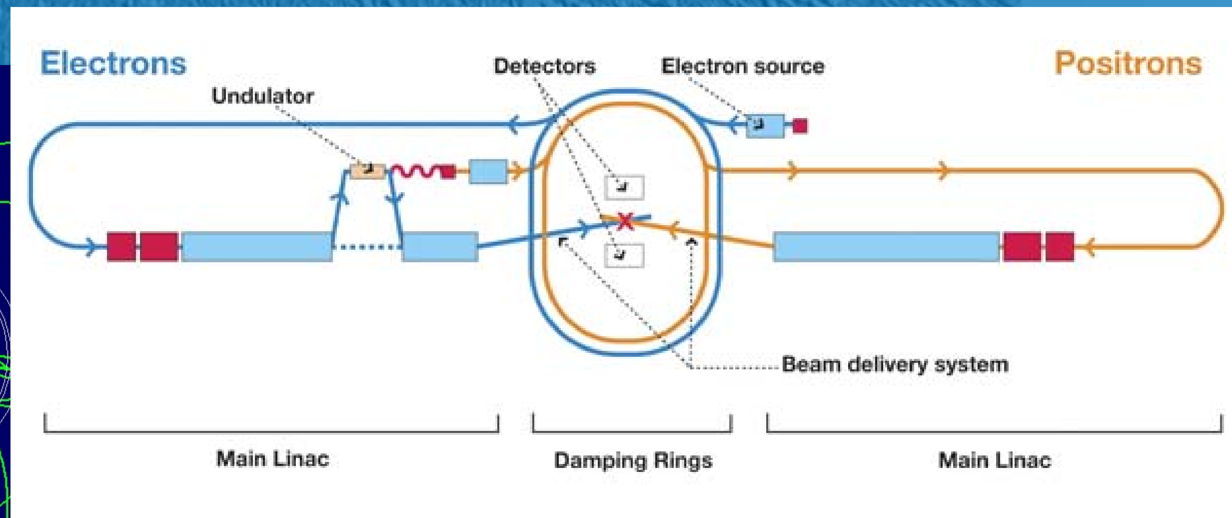
ILC offers unique probe in measuring quantum numbers and coupling and thus unravel relation of new signals to Supersymmetry, Extra Dimensions and other scenarios



hep-ph/0306219

Studying NP at Colliders beyond LHC





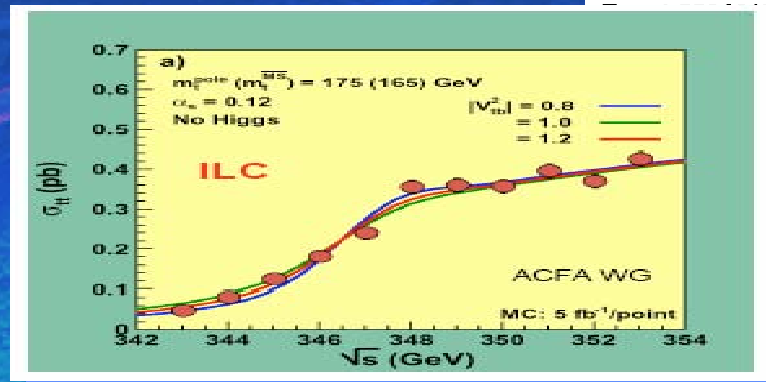
ILC to provide point-like particle collisions from 0.3 TeV up to ~ 1 TeV with tunable centre-of-mass energies, particle species and polarization states;

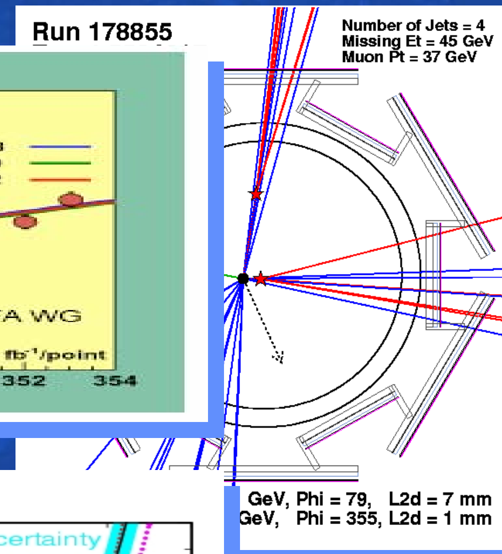
In a farther future, CLIC multi-TeV e^+e^- collider may further push energy frontier up to 3 – 5 TeV.

ILC Energy

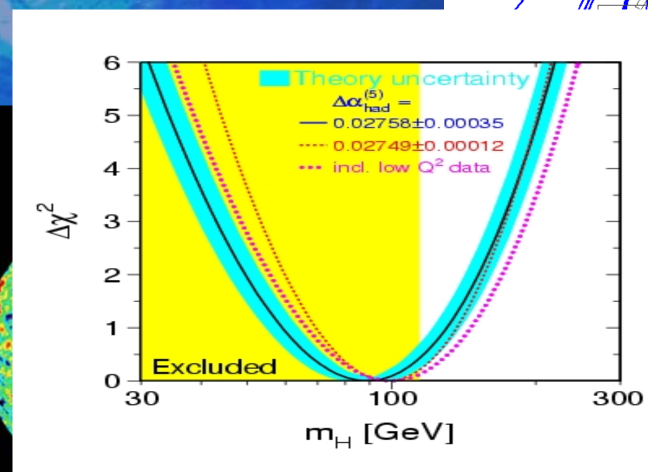
Physics to define next thresholds beyond 100 GeV:

Top Quark pair production threshold:



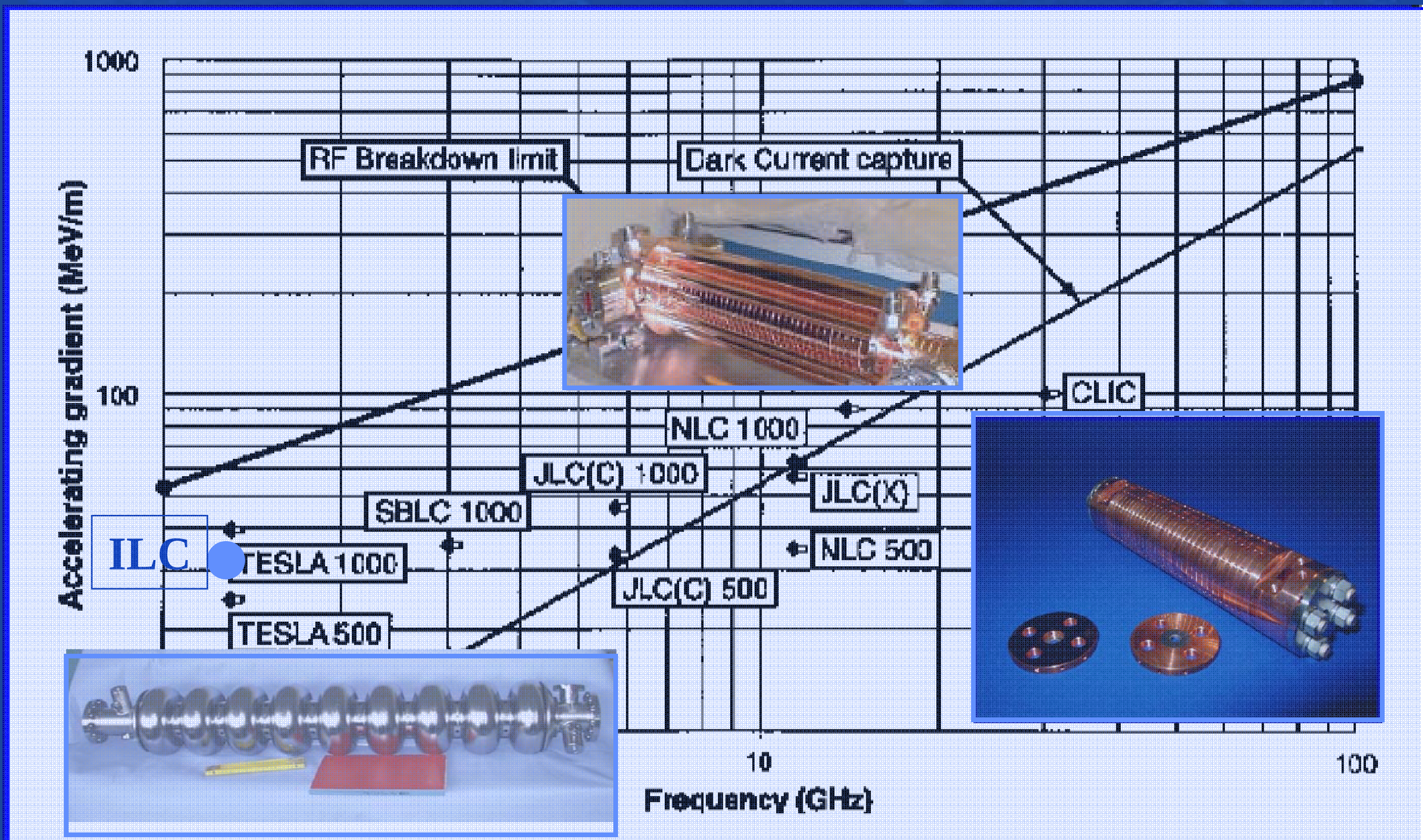


Strong prejudice (supported by data) on **Higgs** and **New Physics** thresholds between EW scale and ~ 1 TeV:



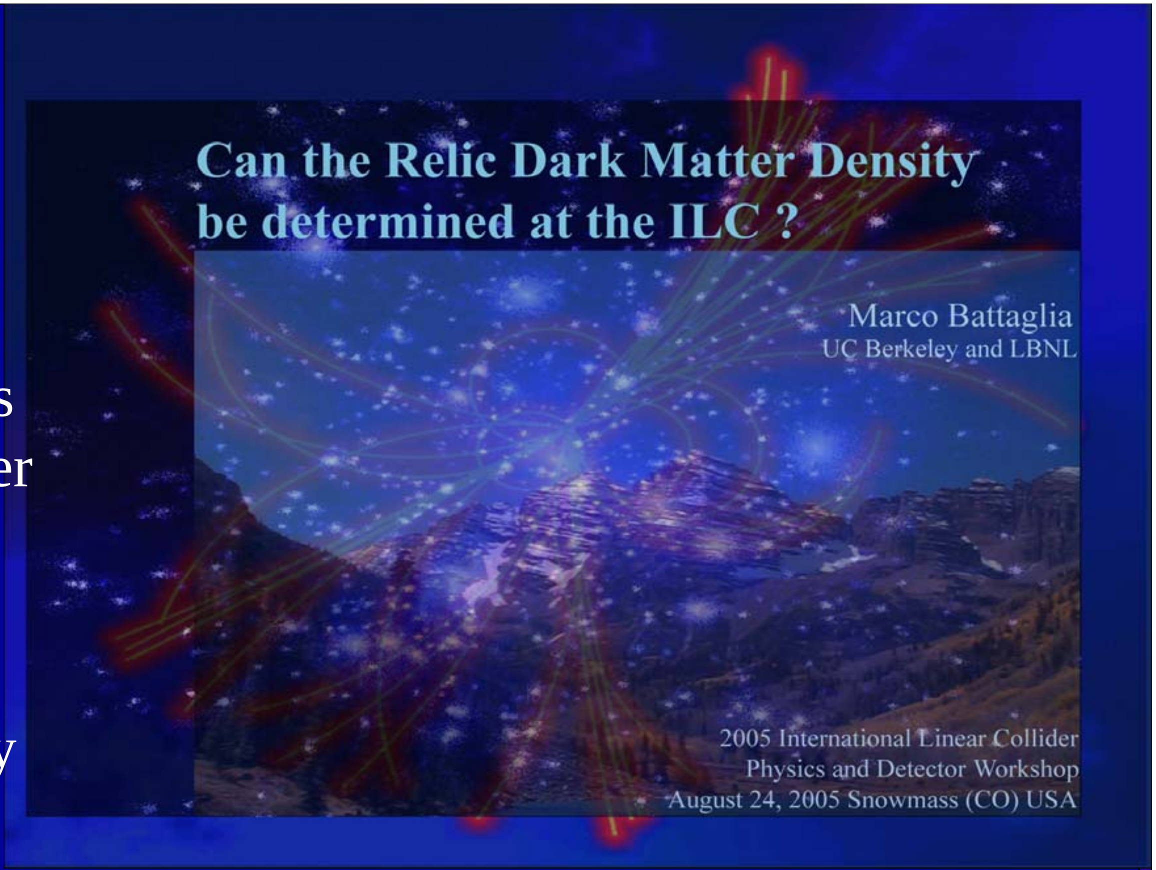
ILC Energy

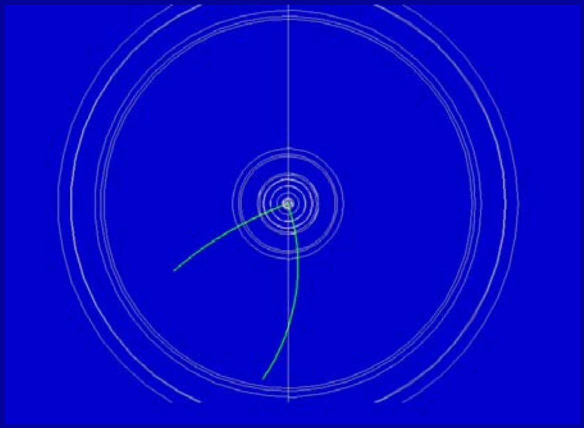
Accelerating Gradient vs. RF Frequency: [ILC 0.5 – 1.0 TeV]

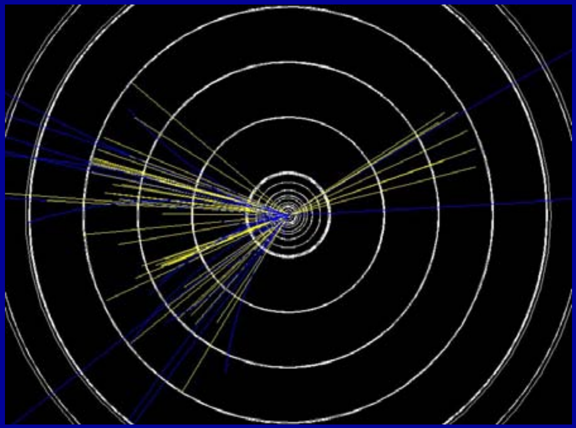


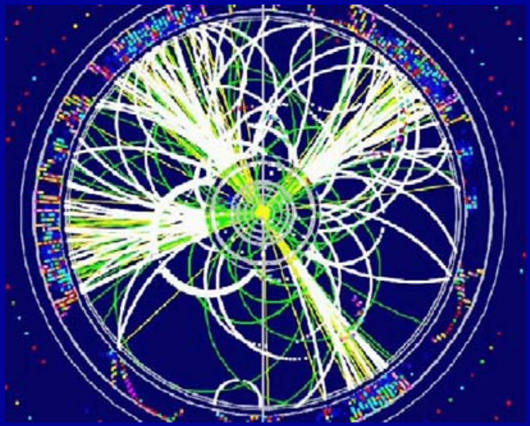
ILC-Cosmology Connections

ILC connection to Cosmology through WIMP CDM motivates re-analysis of ILC potential over a variety of signatures of New Physics and offers a major driver on detector accuracy to match precision on relic density from satellites:

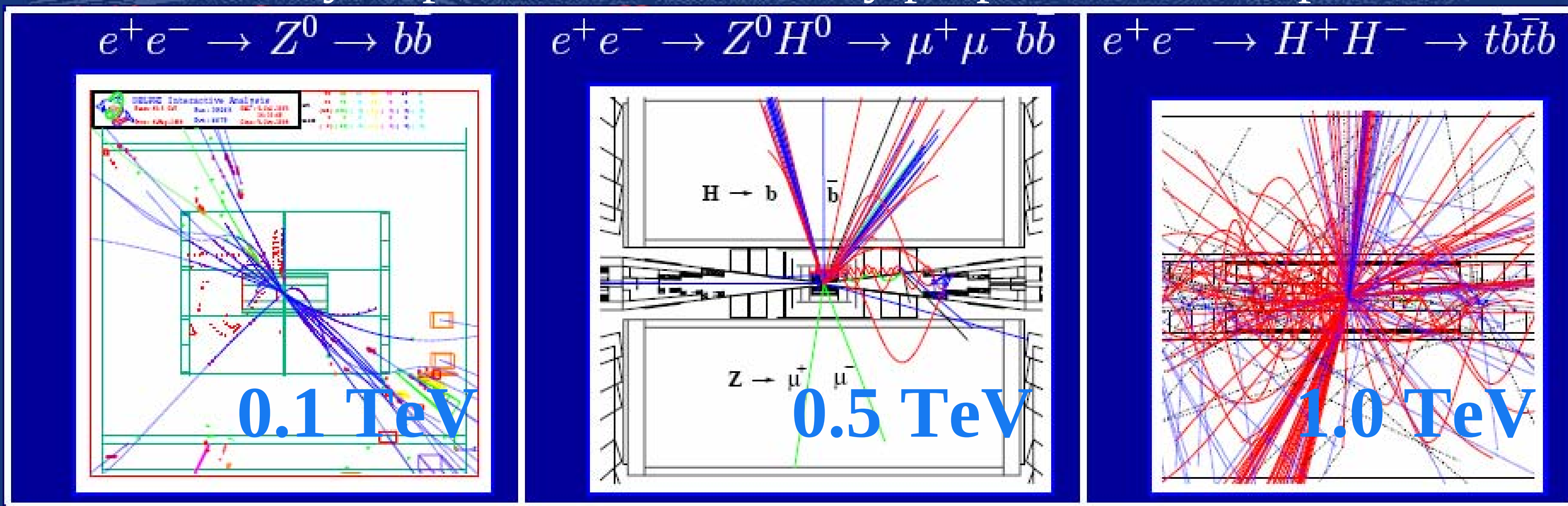






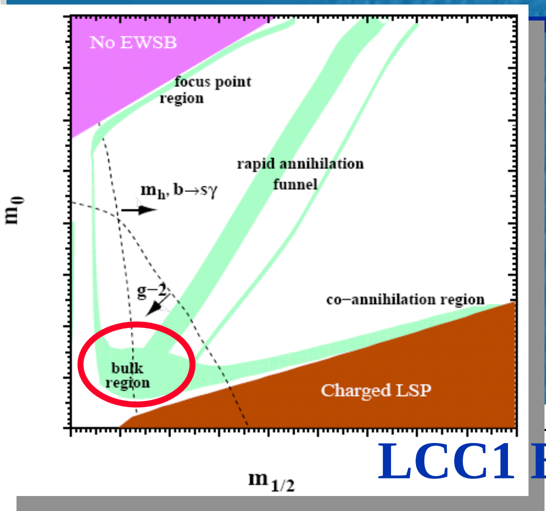


ILC has potential to cover widest energy range of any accelerator; Physics program spans from high-precision EW tests of SM to search of new phenomena up to and above the scale accessed by LHC and detailed study of production and decay properties of new particles;

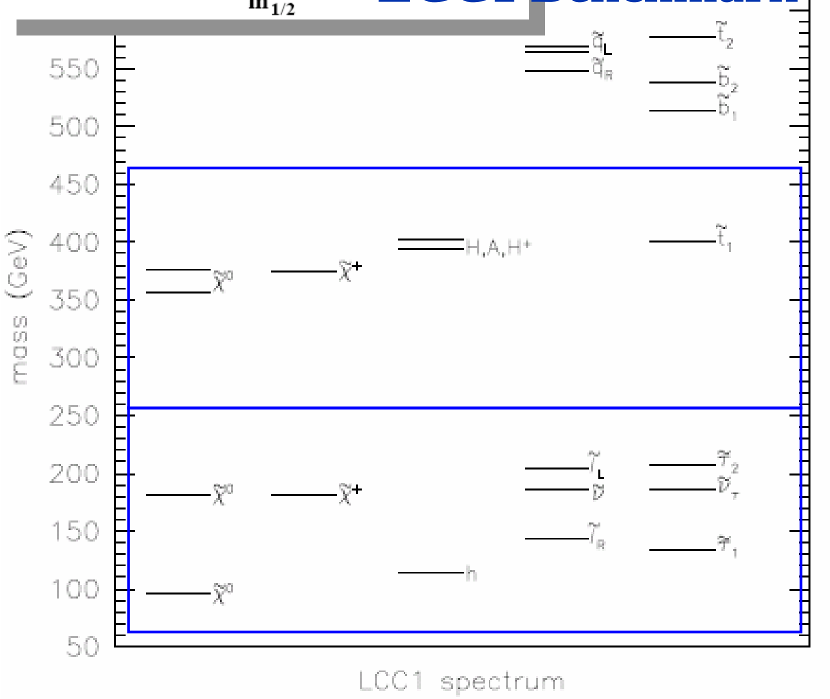


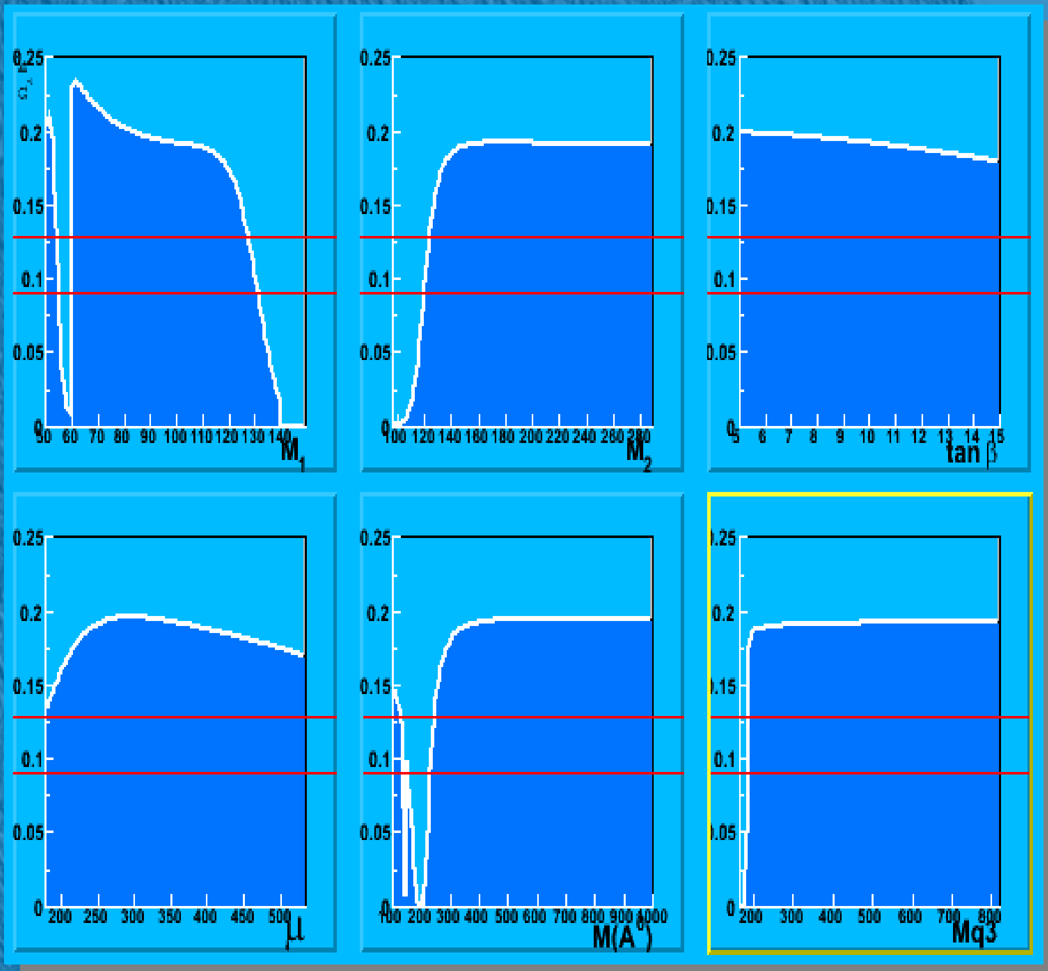
This relies on efficient **identification** of fermion flavours, accurate **reconstruction** of multi-partons and availability of different **beam** particles, energy and polarization **configurations**.

SUSY Bulk Region



LCC1 Benchmark





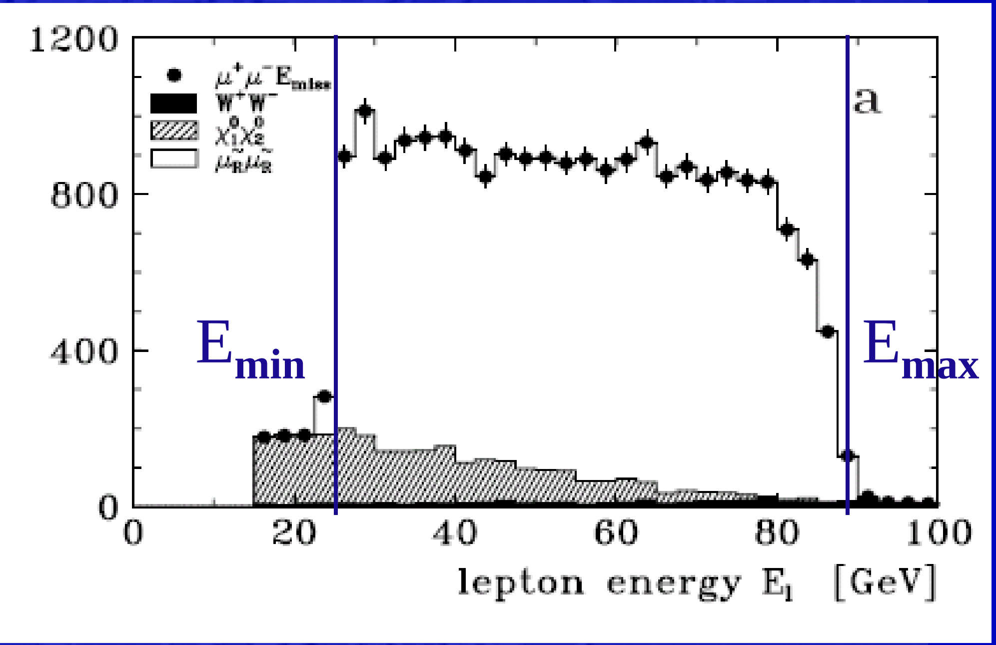
Momentum End Points

In two body decay $\tilde{q} \longrightarrow q\tilde{\chi}_1^0$ $E_{squark} = E_{beam}$ if pair produced, χ escapes unobserved and energy of only particle left (q) can be related to mass difference (ratio) between squark particle and LSP :

$$E_{\max,\min} = \frac{E_b}{2}\left(1 \pm \sqrt{1 - \frac{m_{\tilde{q}}^2}{E_b^2}}\right)\left(1 - \frac{M_{\tilde{\chi}_1^0}^2}{m_{\tilde{q}}^2}\right)$$

Method originally introduced for squarks applies also to sleptons $\tilde{\ell}^- \longrightarrow \ell^- \tilde{\chi}_i^0$ and allows to determine slepton mass once χ known or determine relation between masses and get LSP mass if slepton can be independently measured;

Accuracy limited by beamstrahlung, not δp/p.



Threshold Scan

Determine signal cross section at threshold as function of centre-of-mass energy, fit data to extract mass and width of pair-produced particles;

Accuracy on particle mass m

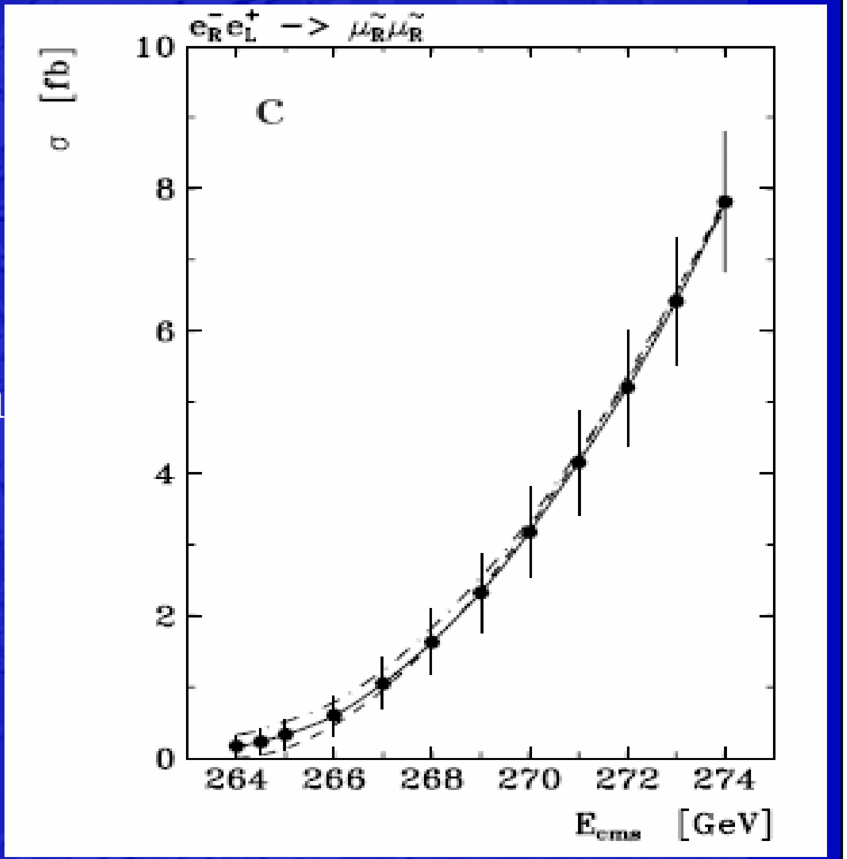
S-wave process = β rise of cross section

$$\delta m \approx \Delta E(1+0.36/\sqrt{N})/\sqrt{18N\mathcal{L}\sigma_u}$$

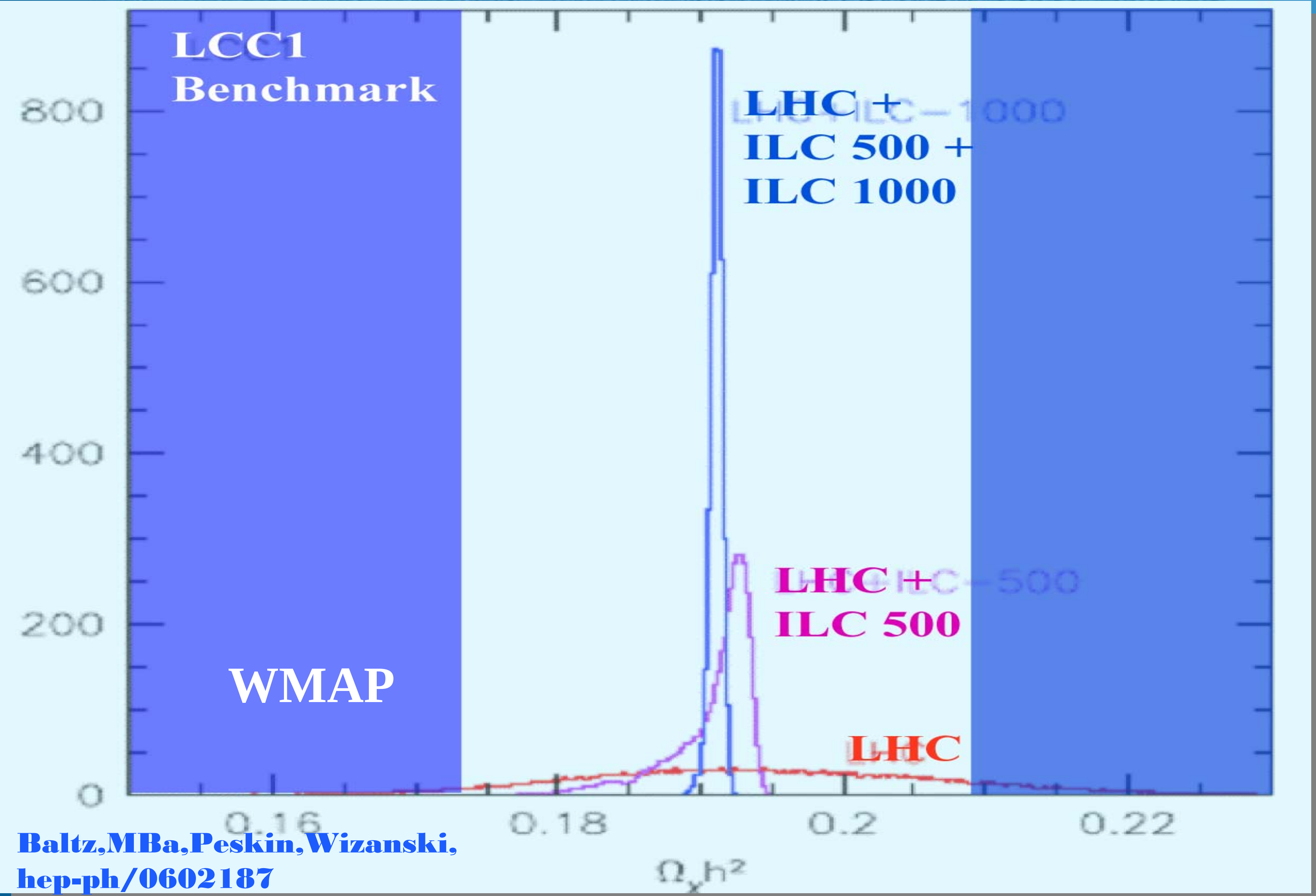
P-wave process = β^3 rise of cross section

$$\delta m \approx \Delta E N^{-1/4}(1+0.38/\sqrt{N})/\sqrt{2.6N\mathcal{L}\sigma_u}$$

Weak dependence of δm accuracy on nb. of scan points N, optimal scan with luminosity concentrated at 2 or 3 points

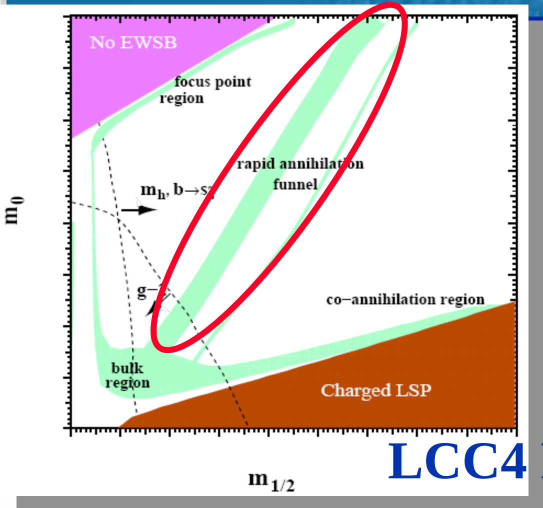


A Comparison of DM density accuracy at LHC and ILC in Bulk Region

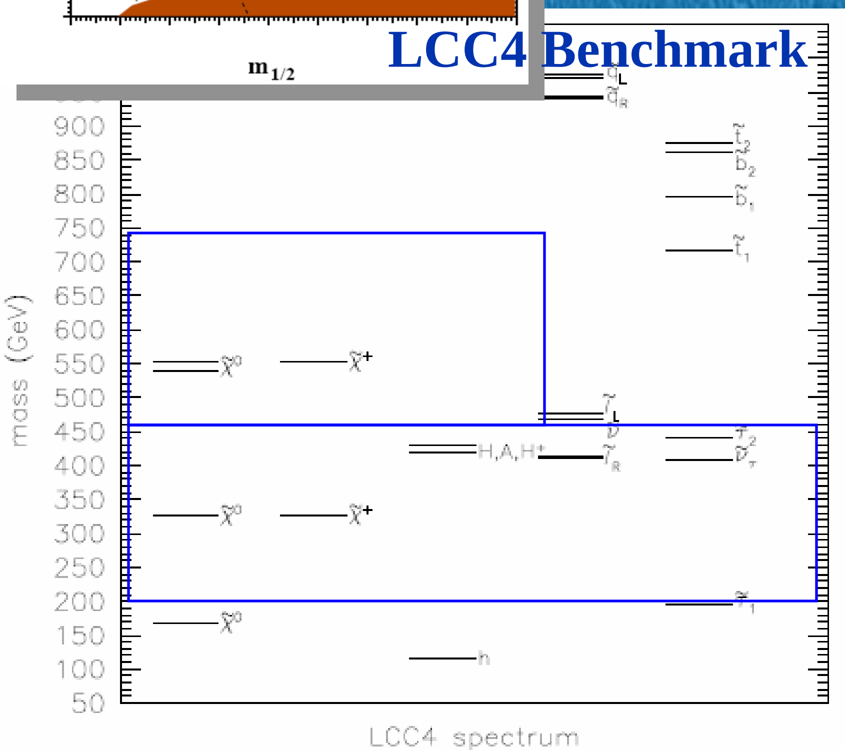


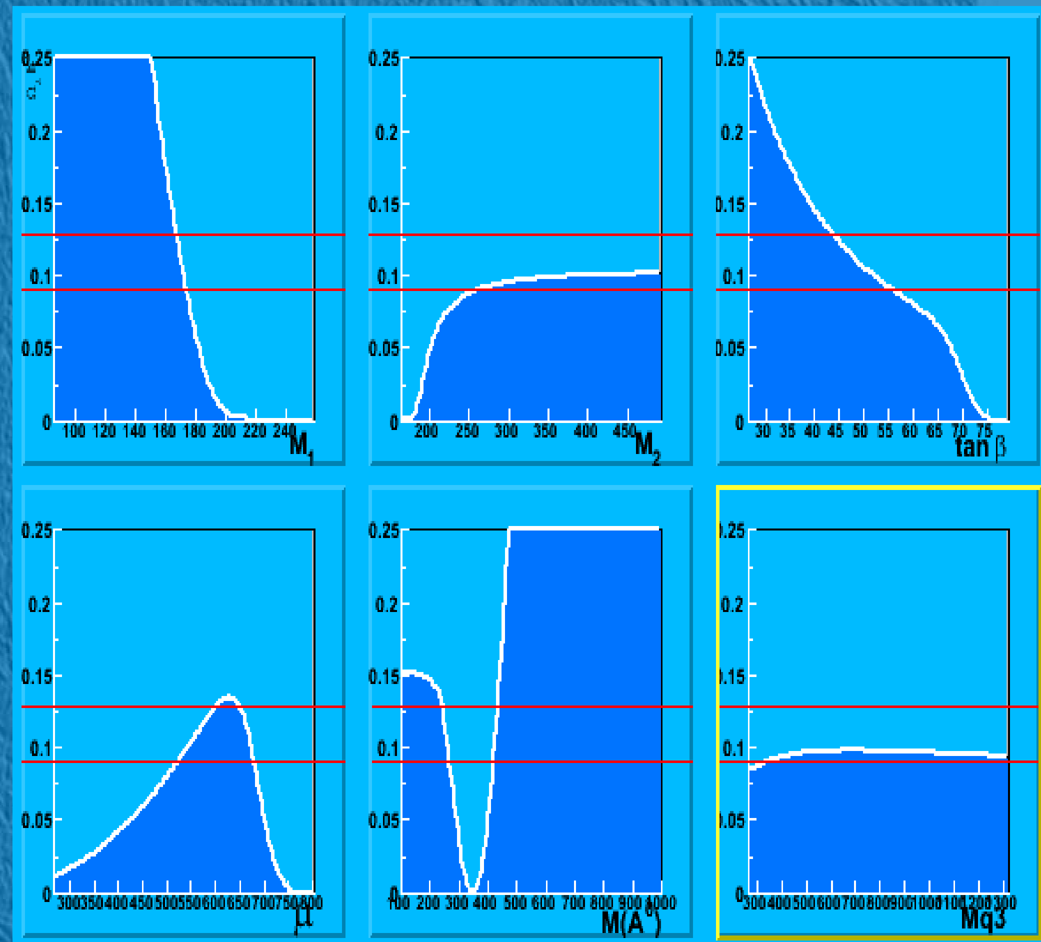
Baltz,MBa,Peskin,Wizanski, hep-ph/0602187

SUSY A^0 Funnel Region



LCC4 Benchmark



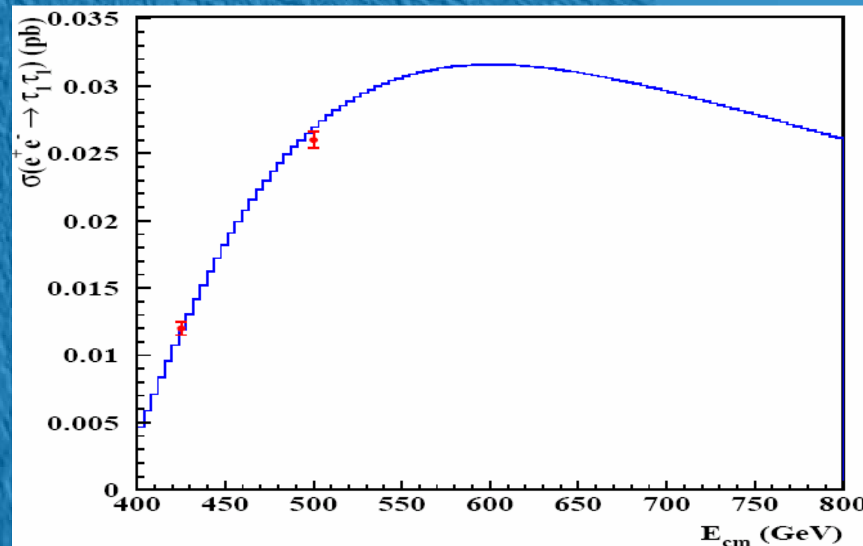


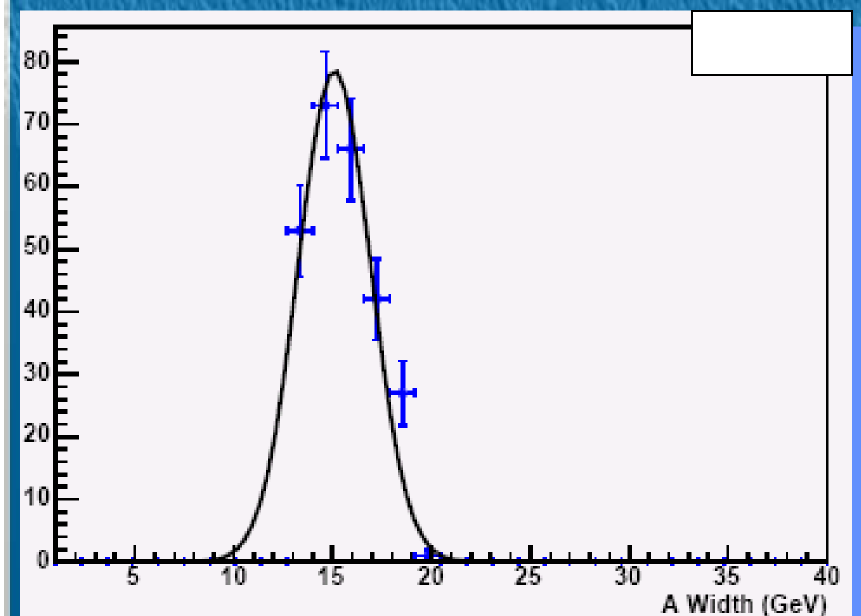
A^0 Funnel Region at ILC 0.5 TeV

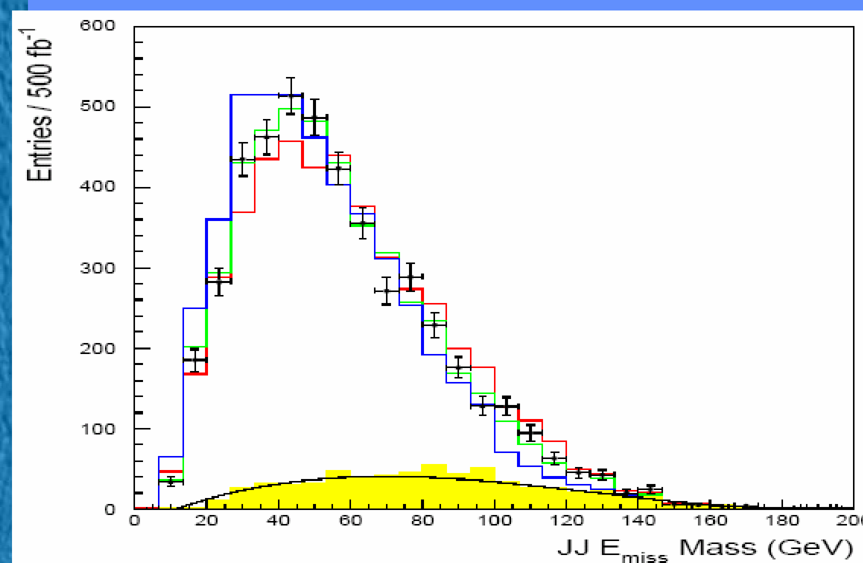
Determine $M(\tau_1)$ and $M(\tau_1) - M(\chi_1{}^0)$ from stau threshold scan and decays;

Estimate $\Gamma(A^0)$ from precise $BR(h^0 \rightarrow bb)$ at 0.35/0.5 TeV;

$$\Gamma(A^0) = \frac{\mathrm{BR}(h^0 \to b\bar{b})}{\mathrm{BR}(A^0 \to b\bar{b})} \times \Gamma(h^0) \times \tan^2\beta$$





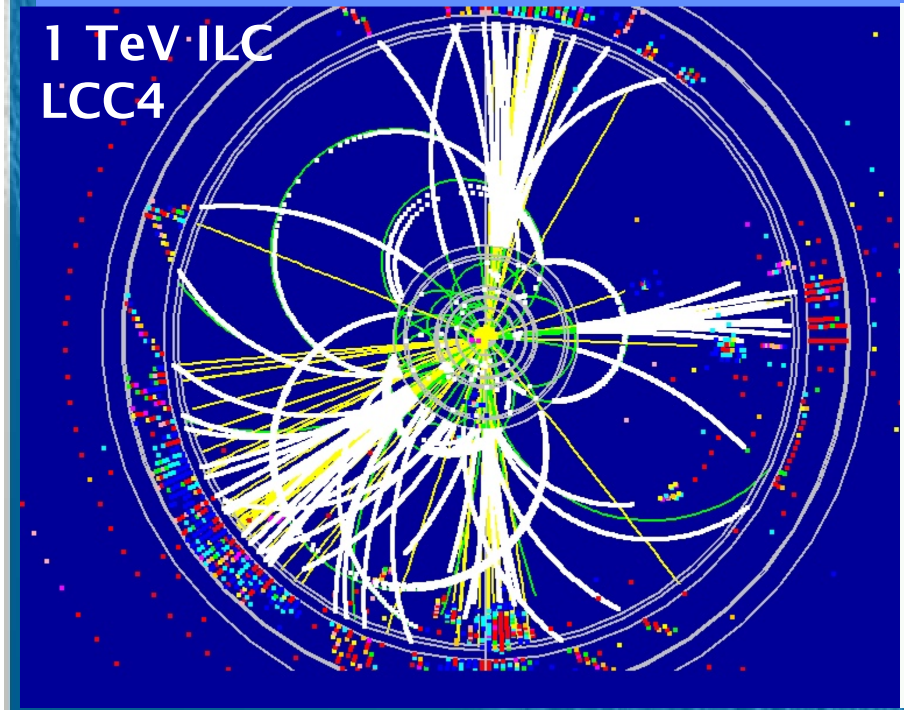


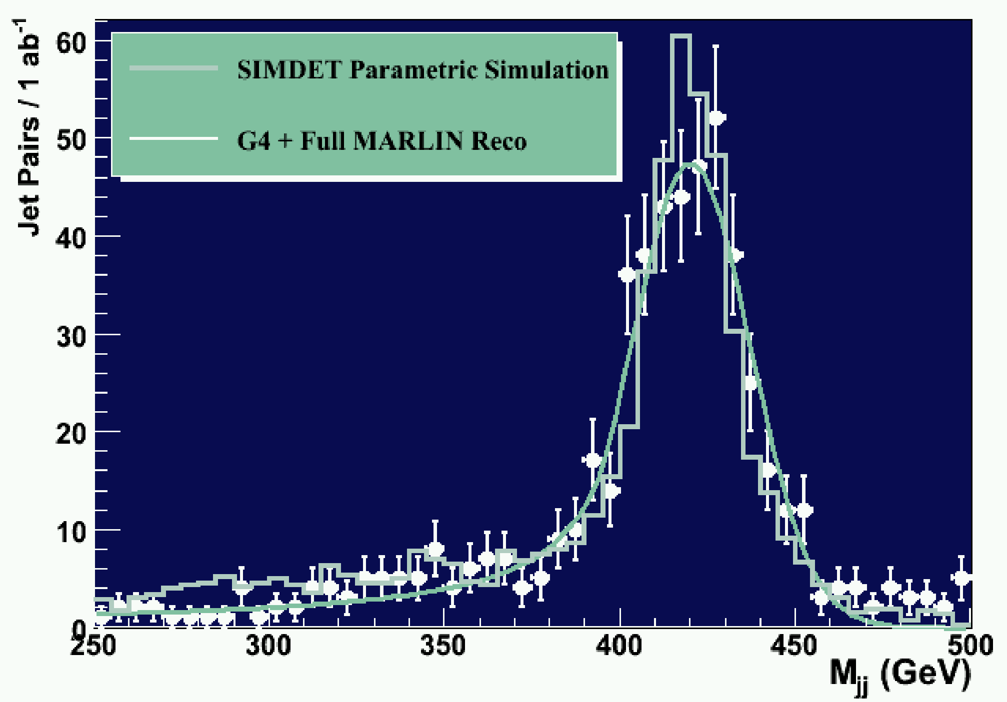
A^0 Funnel Region at ILC 1 TeV

Determine M_A from $e^+e^- \rightarrow H^0A^0$

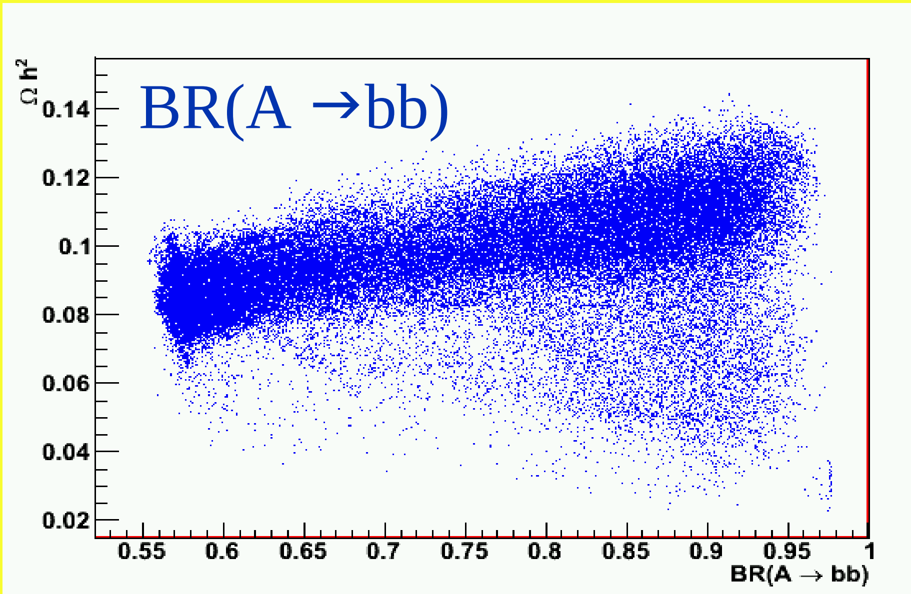
Apply 4C constraints and determine M_A and Γ_A from 5-par fit to M_{jj} spectrum using $BW \oplus Gauss$ signal+quadratic background term:

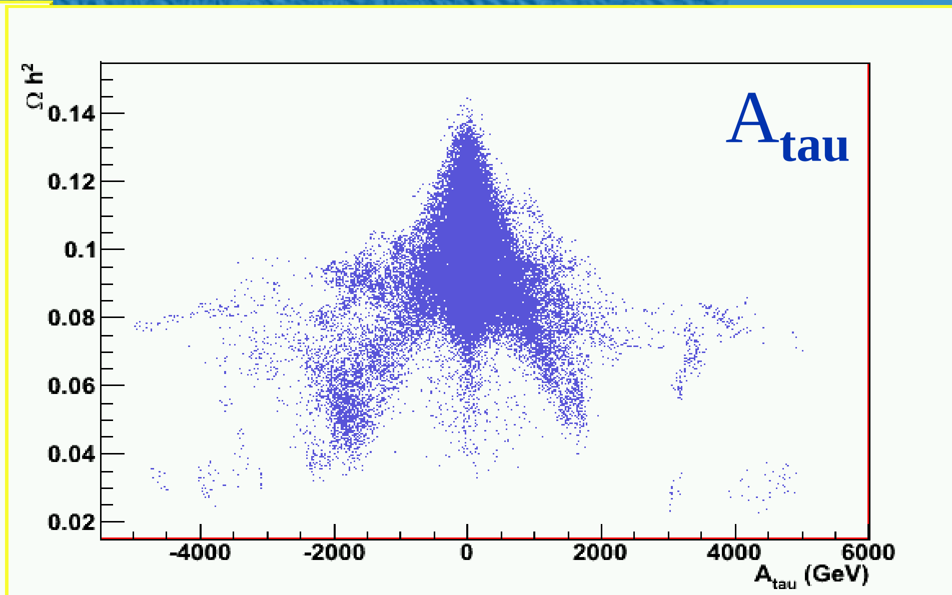
ILC 1 TeV	5-par Fit
$M(A)$ (GeV)	418.9±0.8
$\Gamma(A)$ (GeV)	16.1±2.7
$M(H) - M(A)$ (GeV)	1.4 (Fixed)



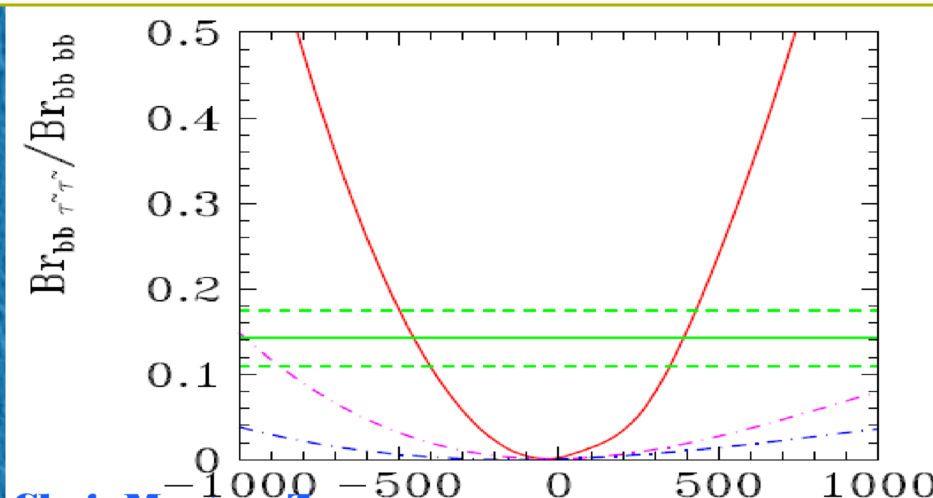


Further DM Constraints at ILC



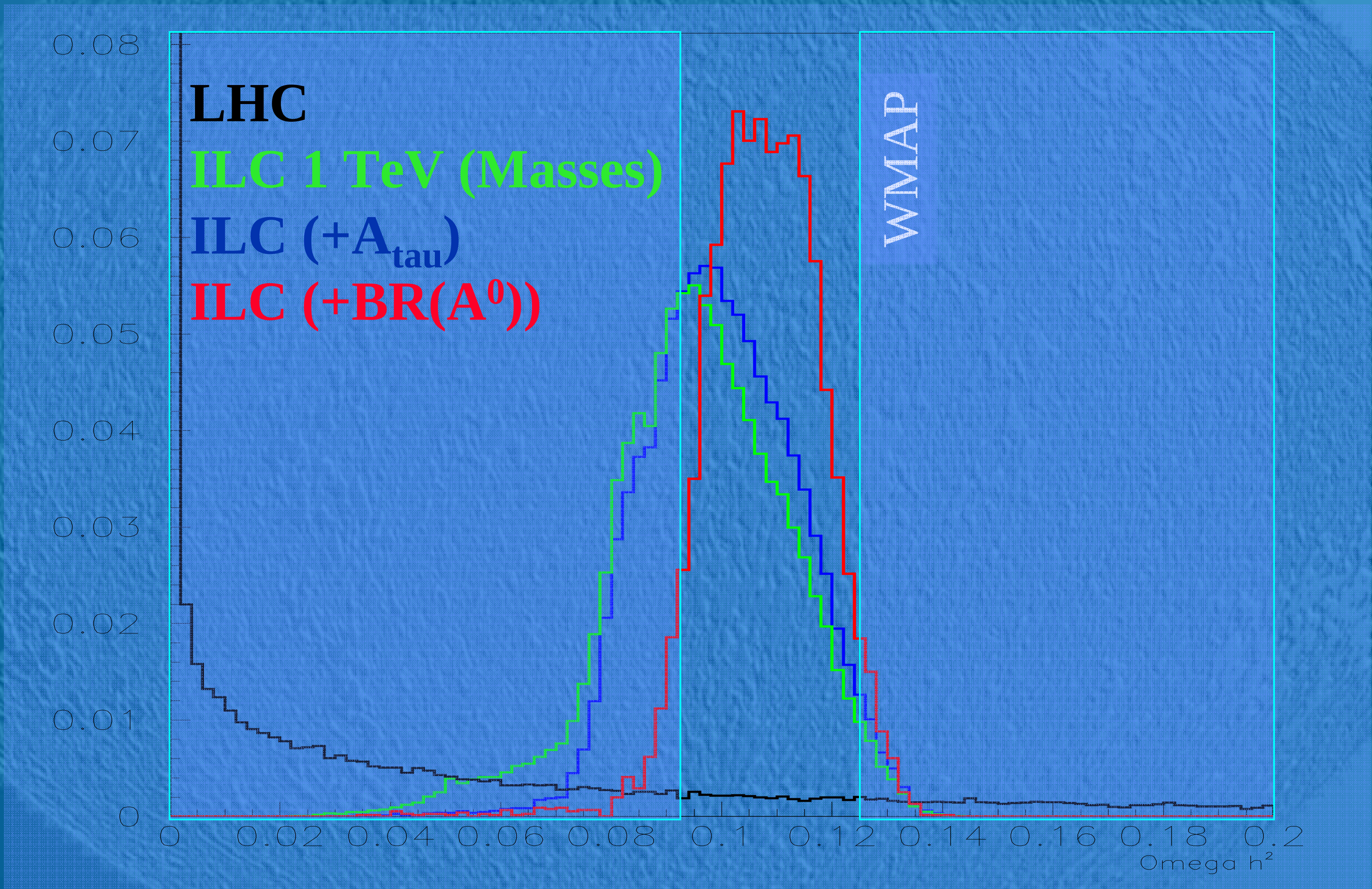


Study of heavy Higgs BRs may allow to further pin down the SUSY parameter range to further constrain $\Omega_{CDM}h^2$



Choi, Martyn, Zerwas, hep-ph/0508021

A Comparison of DM density accuracy at LHC and ILC in A Funnel Region



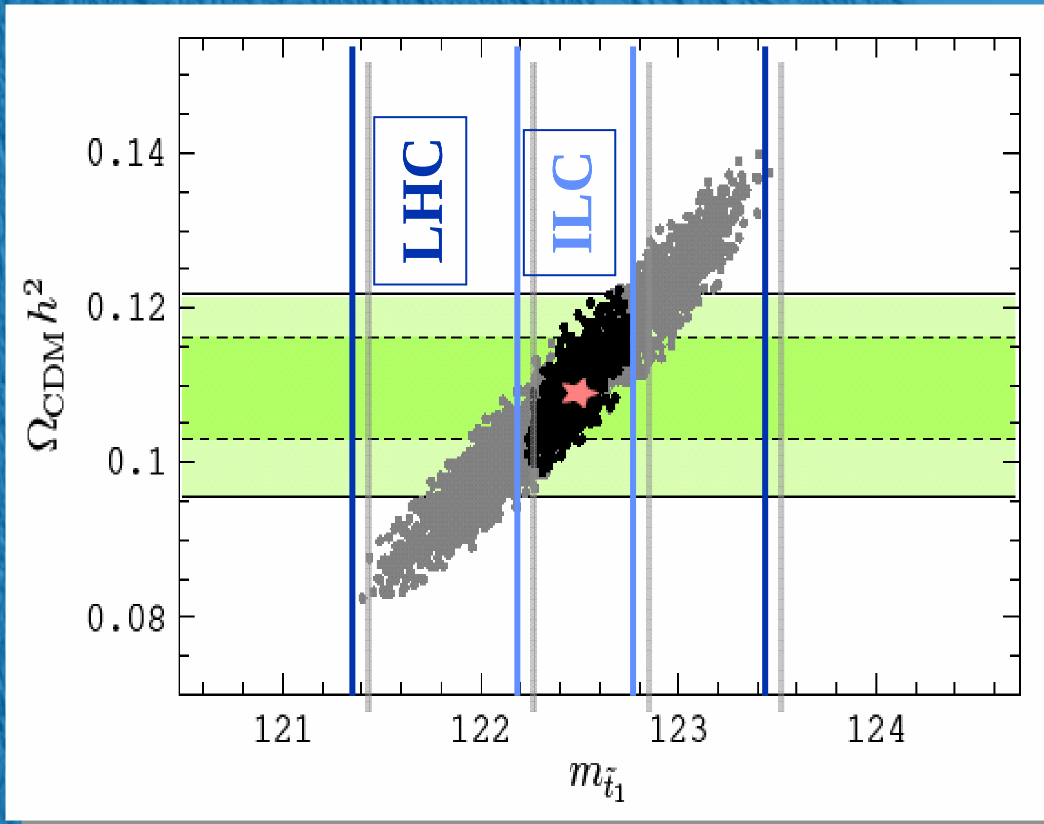
M.Ba, N. Kelley

Stop co-Annihilation in Baryogenesis motivated Scenarios

Light scalar top, nearly degenerate with neutralino, provides efficient co-annihilation and evades Tevatron searches due to small E_T.

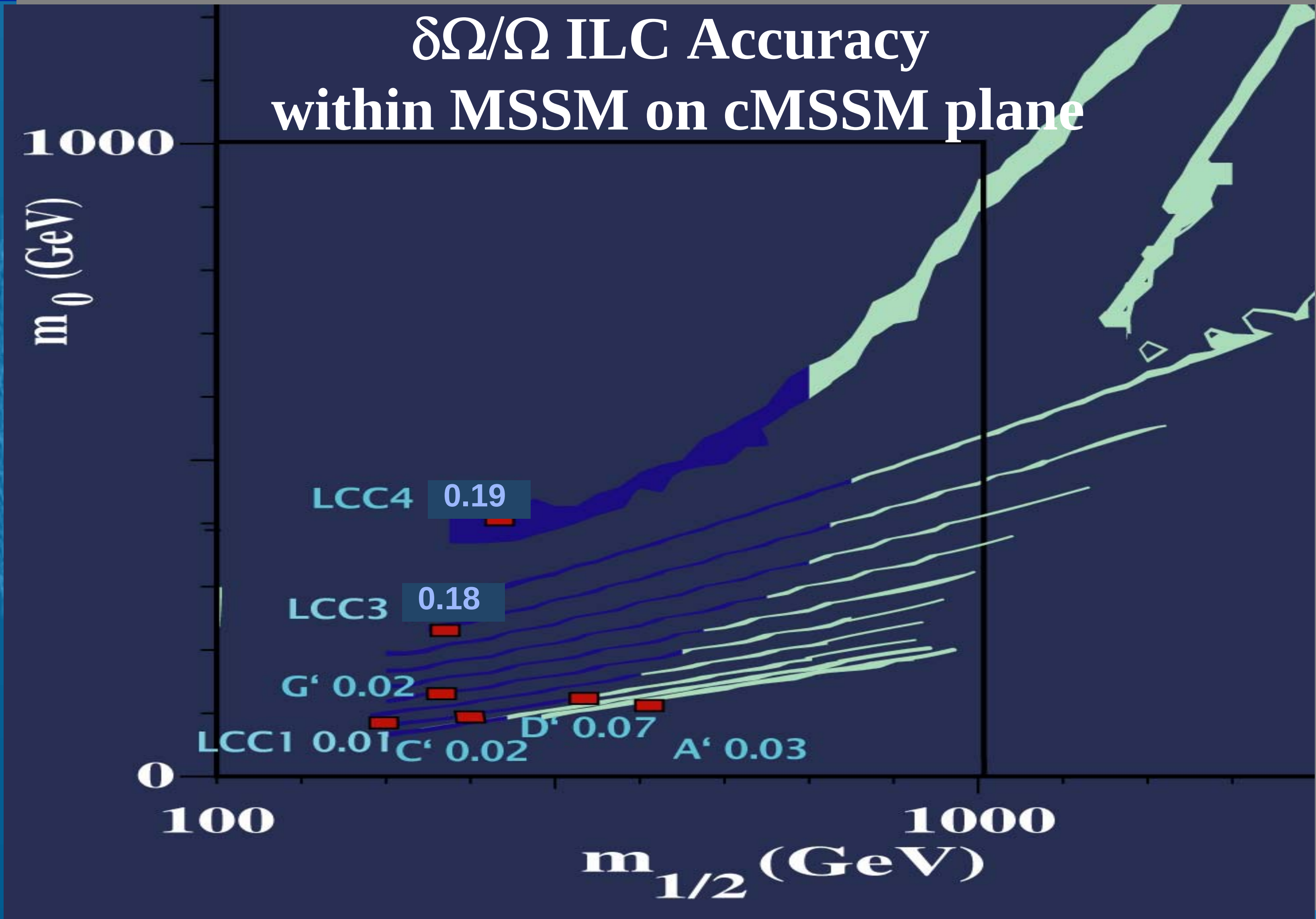
Baryogenesis constraints push towards heavy scalar and introduces CP-violating phase in μ.

Scenario shares several features characteristic of FP region but requires analysis of real Z^0 and light stops.



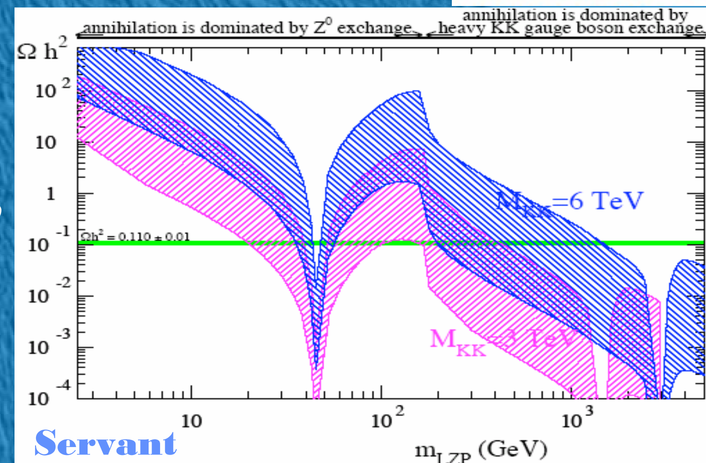
Carena, Freytas, hep-ph/0608255

δΩ/Ω ILC Accuracy within MSSM on cMSSM plane

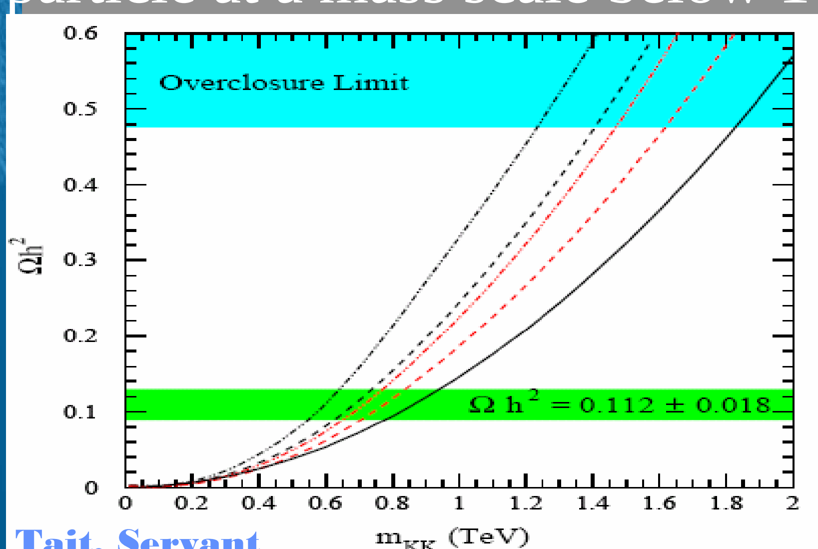


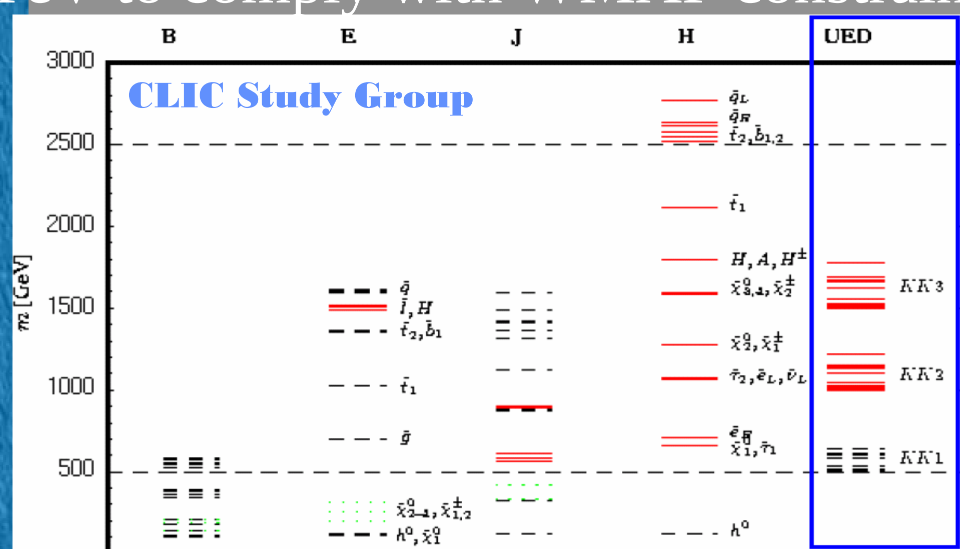
non-SUSY WIMP Dark Matter

Several scenarios of New Physics may include a symmetry protecting a cold DM candidate: Warped Extra Dimensions, Radions, **Universal Extra Dimensions**,...



UED interesting case study, with a phenomenology close to SUSY and particle at a mass scale below 1 TeV to comply with WMAP constraint.





non-SUSY WIMP Dark Matter

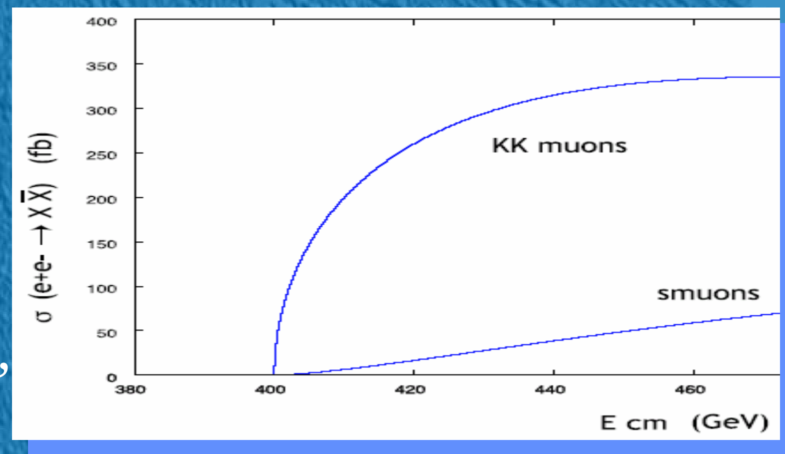
UED phenomenology

$$e^+e^- \rightarrow \mu_1^+\mu_1^- \rightarrow \mu^+\mu^-\gamma_1\gamma_1$$

closely resembles SUSY;

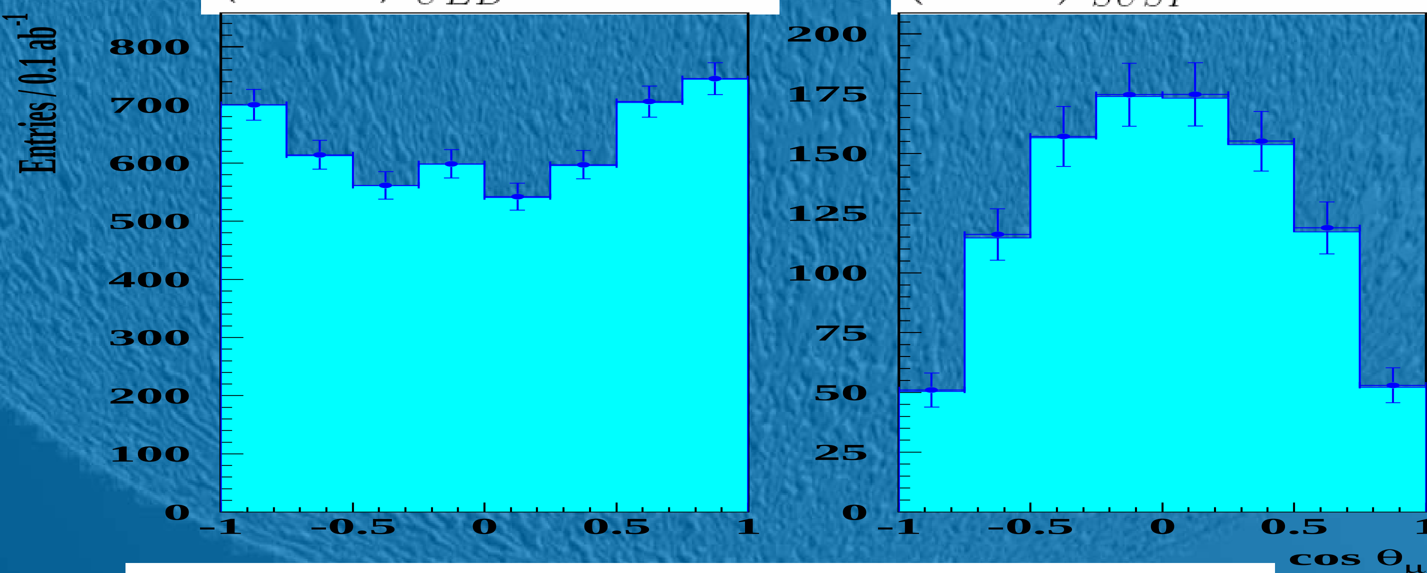
$$e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^- \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Nature of new particles can be clearly identified by a spin analysis, based on production properties and decay angles.



$$\left(\frac{d\sigma}{d\cos\theta}\right)_{UED} \sim 1+\cos^2\theta$$

$$\left(\frac{d\sigma}{d\cos\theta}\right)_{SUSY} \sim 1-\cos^2\theta$$

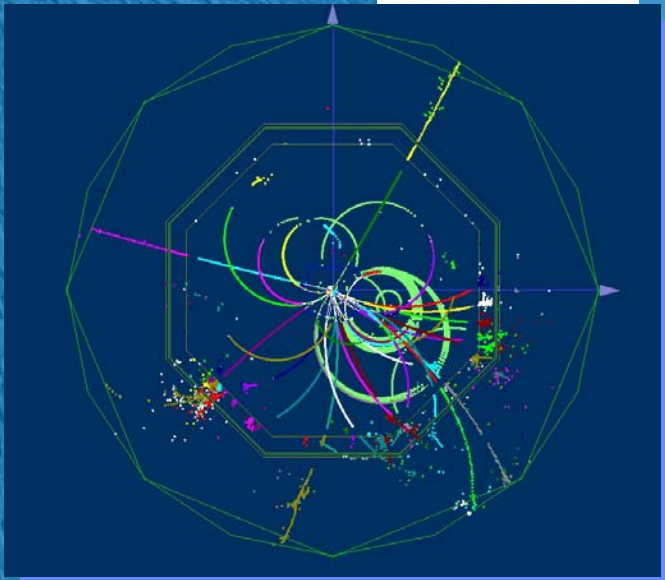


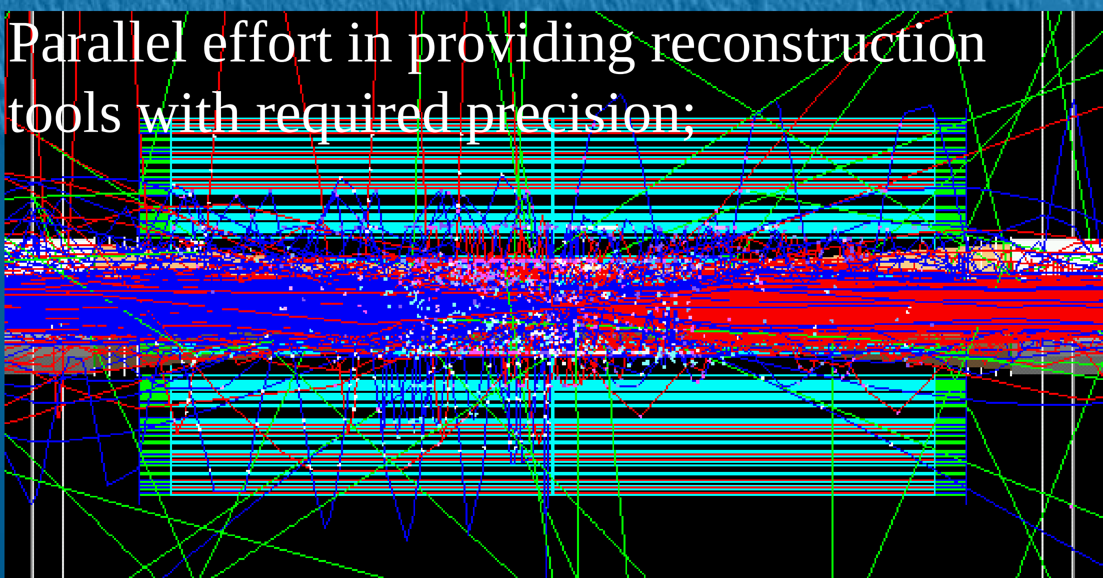
Towards Detailed ILC Analyses

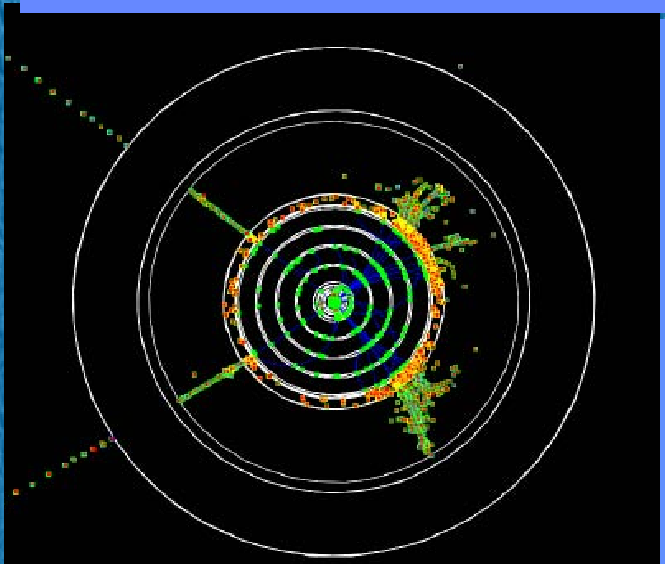
Essential to validate anticipated results with analyses based on full G4 simulation and reconstruction;

ILC program of New Physics studies offers significant challenges to detector design and machine-detector interface to preserve the signature e^+e^- clean event reconstruction;

Parallel effort in providing reconstruction tools with required precision;







Conclusion

Dark Matter likely to be first signal of New Physics at TeV scale;

Current and future collider experiment programs at Tevatron, LHC and ILC to better define model constraints, discover signature of new phenomena beyond SM and measure them with enough accuracy to test their compatibility with both CMB satellite surveys and ground based DM searches;

If results would agree, major triumph for both Cosmology and Particle Physics, detailed data on DM particle would enable precise studies of Cosmology;

Detailed event reconstruction, more than maximum centre-of-mass energy is key to obtain accelerator experiment data with accuracy needed to match that of satellite experiments and emphasis the importance of the ILC program complementing the LHC in this new scientific adventure.