Physics beyond the Standard Model at the ILC

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[1]DESY
Hamburg

Presentation at the SFB seminar, Zeuthen, February 2008

Outline

Project leaders: J. Haller, J. List, and P. Zerwas

Five sub-projects:

1. Measurements of basic SUSY parameters.
2. Dark Matter scenarios in SUSY.
3. Higgs and SUSY particles beyond the MSSM.
4. Reconstruction of the fundamental SUSY theory and its breaking mechanism.
5. Multi-loop precision studies in SUSY.

This talk will concentrate on the experimental side, ie. sub-project 2.

Currently active people: The project leaders, the speaker, P. Bechtle, D.Käfer and:

C. Bartels, I. Marchesini, P. Schade, N. d'Ascenzo (PhD students) and O. Stempel (Diploma student)

Why New Physics at the Terascale ?

- Theoretically
  - SM will have problems if no Higgs below that scale: Unitarity bound in WW scattering, triviality, $M_h \leq \Gamma(H)$ ....
  - Fine-tuning: New physics can't be too far from the EW-scale to solve the problem.
  - $t\bar{t}$ threshold, v=246 GeV ...
- Experimentally
  - LEP: The Higgs must be just around the corner.
  - g-2: 3σ deviation from SM would like something with mass $\mathcal{O}$(100 GeV) in the loops.
  - WMAP, EGRET, ... : We need dark matter, and something with mass $\mathcal{O}$(100 GeV) looks most likely.

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EGRET and the WMAP Haze

EGRET : excess of γ:s with E $>$ 1 GeV.

WMAP haze : excess of microwaves from the centre of the galaxy,

Fits well with $\tilde{\chi}^0$ annihilation, with $M_{\tilde{\chi}^0}$ $\mathcal{O}$(100 GeV).

The EGRET γ:s are from π^0 decays, the WMAP microwaves are from syncrotron radiation of e:s in the galactic B-field.

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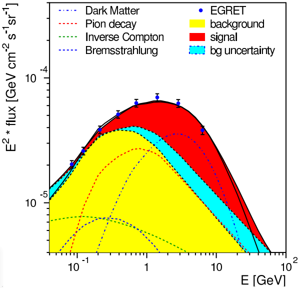

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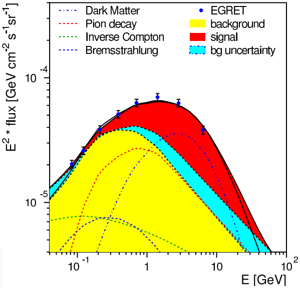

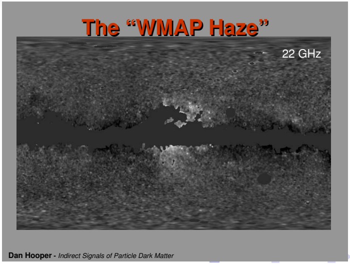

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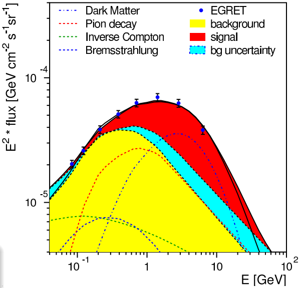

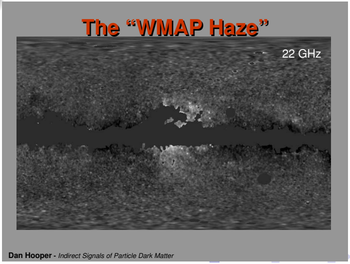

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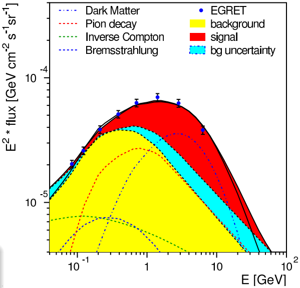

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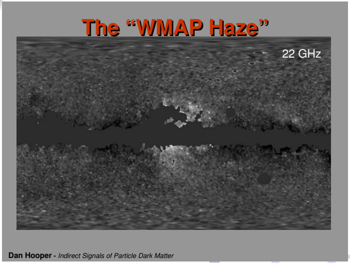

Accelerators

Two lines of approach

1. Highest possible energy: Explore as much as possible of new the landscape → LHC.
2. Highest possible precision: Make a detailed map of parts of the new landscape → ILC.

LHC :

- Circular $p\bar{p}$ collider.
- Length 27 km.
- E_{CMS} = 14 TeV
- $\mathcal{L} = 10^{34}$
- Collides extended objects.

ILC :

- Linear e^+e^- collider.
- Length 31 km.
- E_{CMS} = 500 GeV
- $\mathcal{L} = 2\ 10^{34}$
- Collides point-like objects.

Accelerators

Why is LHC circular and ILC linear ?

$$\Delta(E) \sim \frac{E^4}{m^4} R \text{ and } (m_e/m_p)^4 \approx 10^{-13}$$
$$\text{Cost : circular} \propto aE + b\Delta(E)$$
$$\text{linear} \propto L \propto E$$

$R \sim E$ (at fixed B field)

For a proton machine, $\Delta(E) \approx 0$, so the circular always wins.

For an electron machine, sooner or later the the $\Delta(E)$ term will dominate, and then the linear finaly machine wins.

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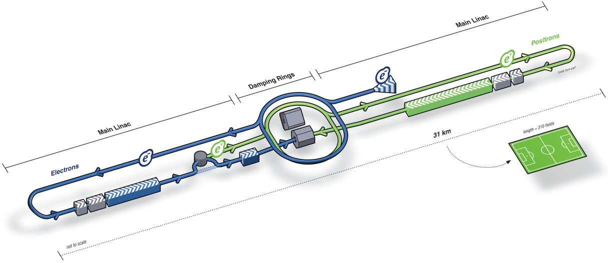
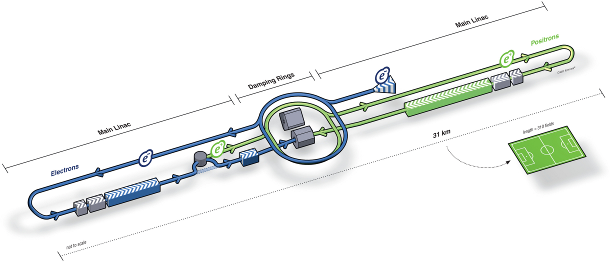


- E_{CMS} tunable between 200 and 500 GeV.
- Total length 31 km
- $\int \mathcal{L} \sim 500\ \mathrm{fb}^{-1}$ in 4 years
- Upgradeable to 1TeV
- Polarisation e^-: 80% (e^+: 60%)
- 2 experiments, but (possibly) only one interaction region.
- Concurrent running with the LHC

The ILC: Political & financial situation



- End of 2007, both the US[1] and the UK withdraw their support.
- In view of this, the schedule for the machine has changed, partly only in terminology.
- The detector LOI has been delayed 6 month (early 2009).
- More than 2 detectors will still be considered after the LOI.

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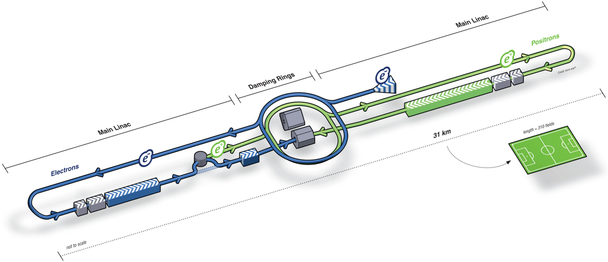

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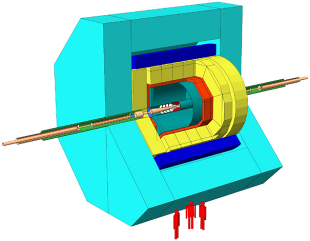

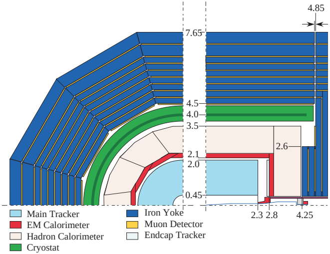

ILD: Merge the (mostly European) LDC and the (mostly Asiatic) GLD !

First meeting in January in Zeuthen. ≈ 150 participants.

Our main work till the LOI: Detector optimisation.

- Massive simulation of many detectors: LDC, GLD, 2 intermediate.
- Start ∼ now, done ∼ end of this summer.
- Single particles of all kinds.
- SM and beyond SM bench-marks.
- "strange" channels.

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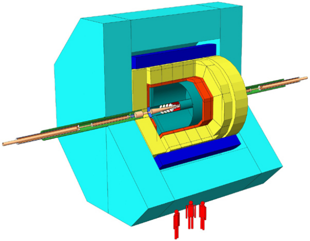

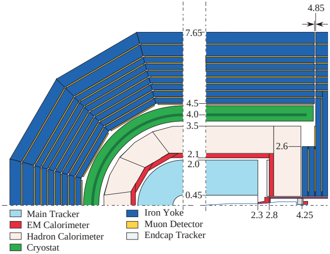

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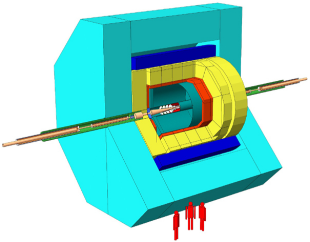

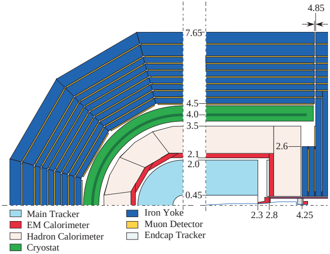

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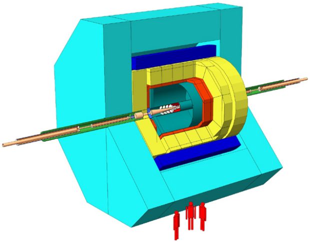

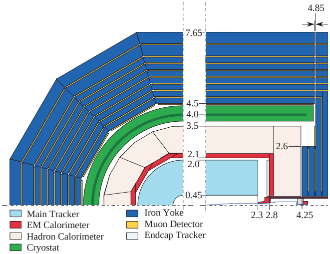

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Detector optimisation ? Isn't an ILC detector $\approx$ LEP detector ? No.

- LEP was a Z factory. σ_Z is huge. At ILC, physics is in small σ processes (Higgs, SUSY, gauge boson self-couplings, ...)
- Higher energy.
- Beam-strahlung.
- New technologies makes a better detector possible!

OK, then just do whatever todays technology allows for.
Not that simple ...

- Better resolution $\Rightarrow$ Higher cost.
- Better performance in one aspect might mean worse in another: Eg. More points $\rightarrow$ Tracking better. But More points $\rightarrow$ more material $\rightarrow$ worse calorimetry. Or: Higher granularity $\rightarrow$ better calorimetry. But Higher granularity $\rightarrow$ more cables $\rightarrow$ worse hermiticity, ...

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Detector optimisation

... can be

- Purely technological: What can be done in terms of point-resolutions, power-consumtion, sampling rate, ...

  Typically bench-marks on single particles or jets.
- Physics-driven: What implications does various choices have on the physics we want to do.

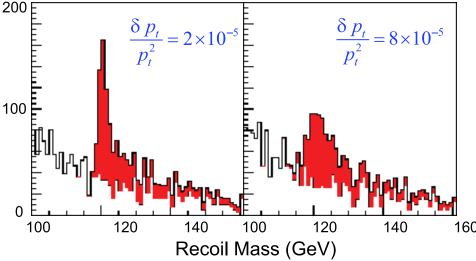
  Bench-marks on full physics simulation.

Project B1-ii is heavily committed to the second item.

Physics driven detector optimisation

First three (very important) non-B1 examples:

1. Total Higgs cross-section: Study *ee* $\rightarrow$ *ZH* $\rightarrow \mu\mu X$, (*Z* going to $\mu\mu$). Study recoil-mass $\Rightarrow$ Higgs cross-section independent of decay-mode- momentum resolution !
2. Higgs Branching ratios: Separate $H \rightarrow bb$ or *cc* or *qq* - micro-vertex detector !
3. Gauge boson self-couplings: Separte *ZZ* and *WW* fully hadronic events - Calorimetry !



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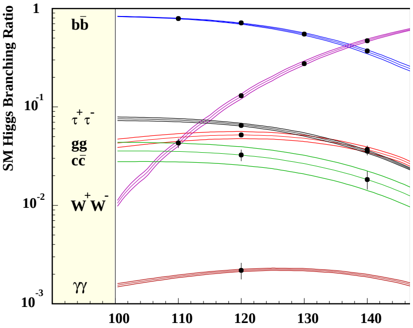

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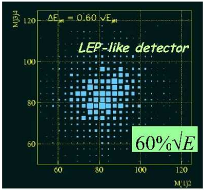
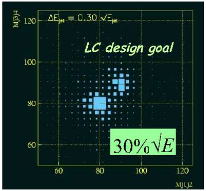




Physics driven detector optimisation: B1

On-going or just started analyses

1. Low $\Delta(M)$ SUSY - forward region
2. Model independent WIMP search - photon detection
3. Gravitino LSP with extremely long-lived NLSP - Entire HCAL concept

Up-coming analyses

1. $\tilde{\tau}$ polarisation
2. $\tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \mu\mu$

Low $\Delta(M)$ SUSY

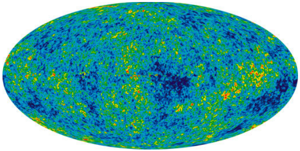
WMAP $\Rightarrow$ Dark Matter (DM) of $\sim$ 25% established with an error $\sim$ 10%.

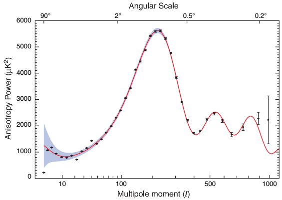
$\Rightarrow$ Strong constraints on SUSY.

Co-annihilation region: Too keep the dark matter content within limits, the NLSP must be close to the LSP (cross-section and number density)

$\Rightarrow$ Low $\Delta(M)$ SUSY

In this region, the NLSP is the $\tilde{\tau}$.





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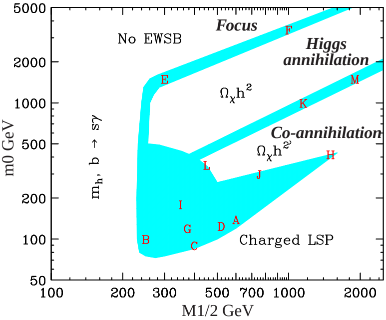

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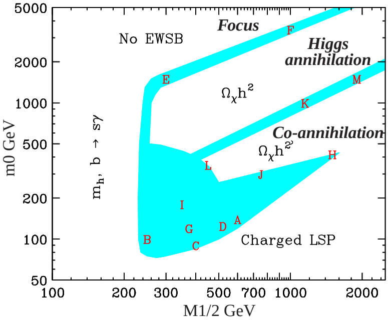

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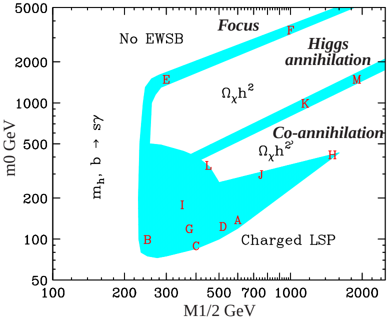

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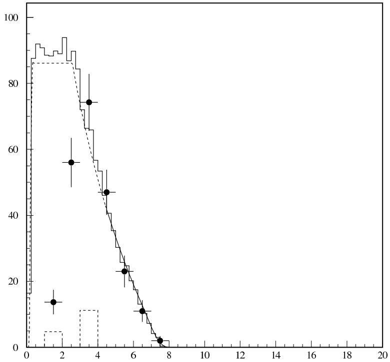

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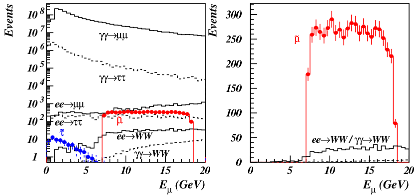

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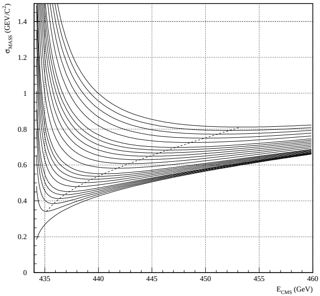

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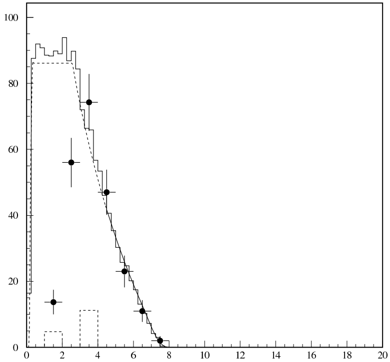
Low $\Delta(M)$ SUSY: Detector optimisation

Statistics dominated, ie. extremely good $\Delta(p)$ not needed.

The issue is the $\gamma\gamma$ background:

1. Detect beam-remnant to low Θ: Very forward calorimetry and beam-delivery (the holes)
2. $\sigma(\gamma\gamma) \approx 35$ nb, signal a few fb $\Rightarrow$ very rare $\gamma\gamma$ configurations must be vetoable: eg $ee \rightarrow ee\mu\mu$ with one e and one μ at low angles: m.i.p.'s at low angles ? $ee \rightarrow eeqq \rightarrow eeXK^0$: K^0 at low angles ?



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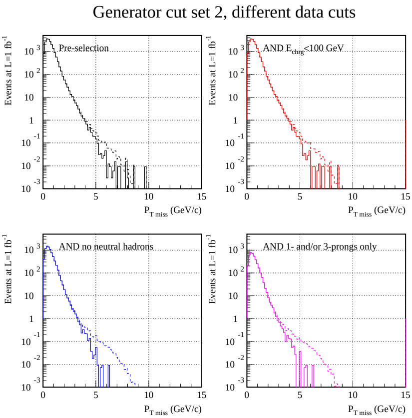

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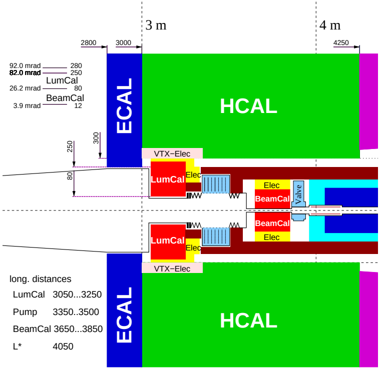

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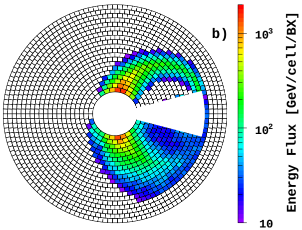

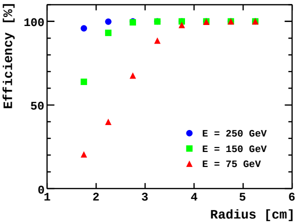

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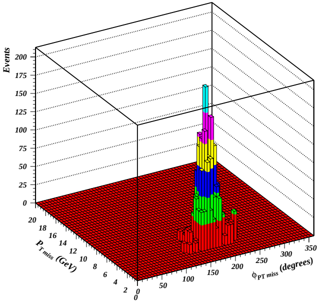

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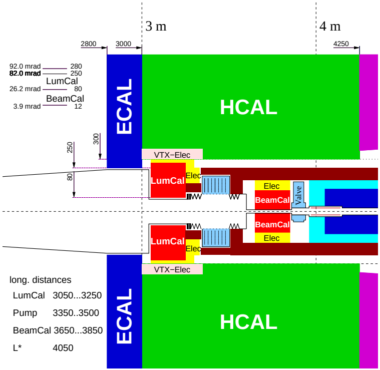

Model independent WIMP search

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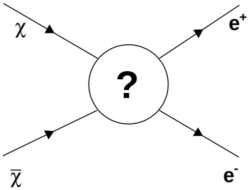

Vary

- κ_e annihilation fraction to electrons
- Lorentz structure ($1-\gamma_5$, 1 or $1+\gamma_5$).
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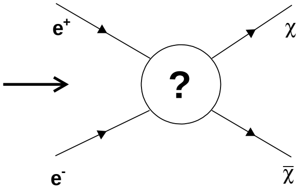

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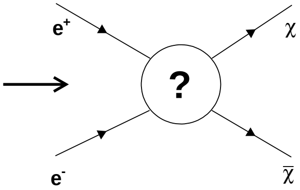

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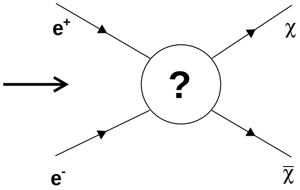

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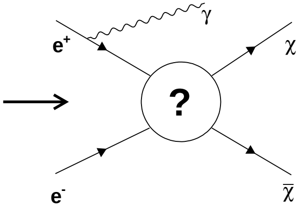

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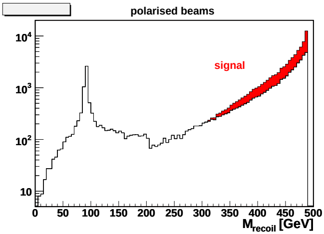

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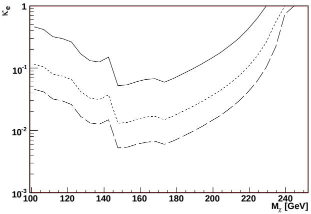

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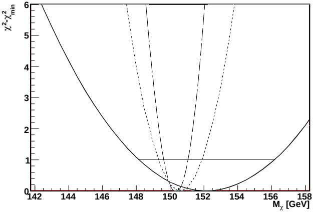

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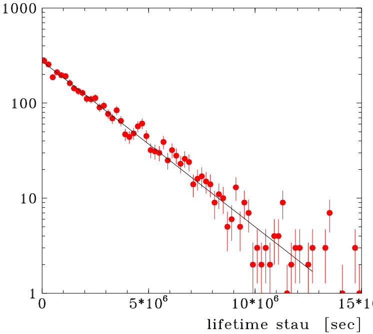

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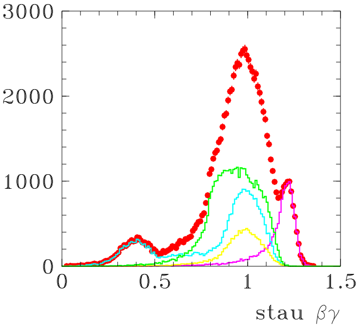

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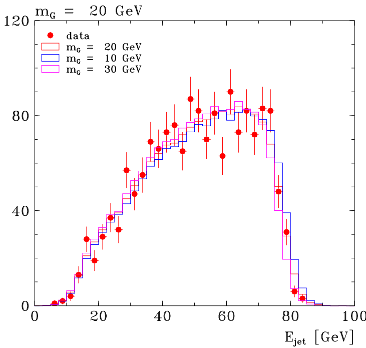

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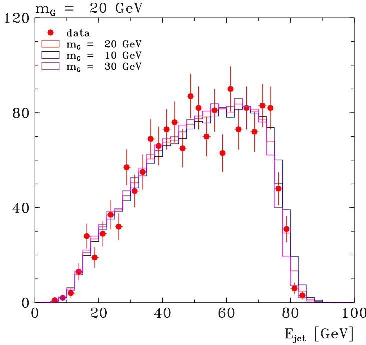

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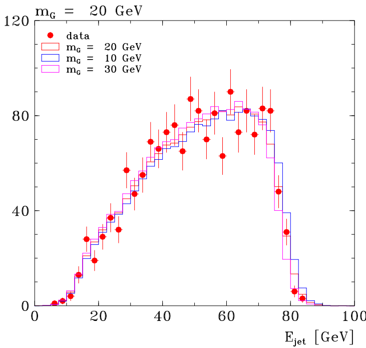

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Detector issues:

- dE/dx in the TPC, and the resulting sensitivity.
- The HCAL is pulsed, ie. it is powered off between bunches, in order to keep power-consumption low, and to avoid the need for liquid cooling. Do we need to re-think the entire design ?
- What input from LHC/cosmology would trigger such a decision?

Conclusions

- Despite the current political/economical problems in some contributing countries, the ILC is still on track.
- The detector LOI has only been delayed by 6 months.
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  - Model independent WIMP search : On track. C. Bartels
  - Low $\Delta(M)$ SUSY : Starting (fastsim analysis existing.) O. Stempel, MB
  - Gravitino LSP with extremely long-lived NLSP : Starting (fastsim analysis existing.) D. Käfer
  - $\tilde{\tau}$ polarisation : Starting P. Schade
  - $\tilde{\chi}^0_1\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1\mu\mu$: Starting. N. d'Ascenzo
  - Beam polarisation studies. Starting I. Marchesini