# A Detector for TLEP: synergies with ILC/CLIC

**Mark Thomson**
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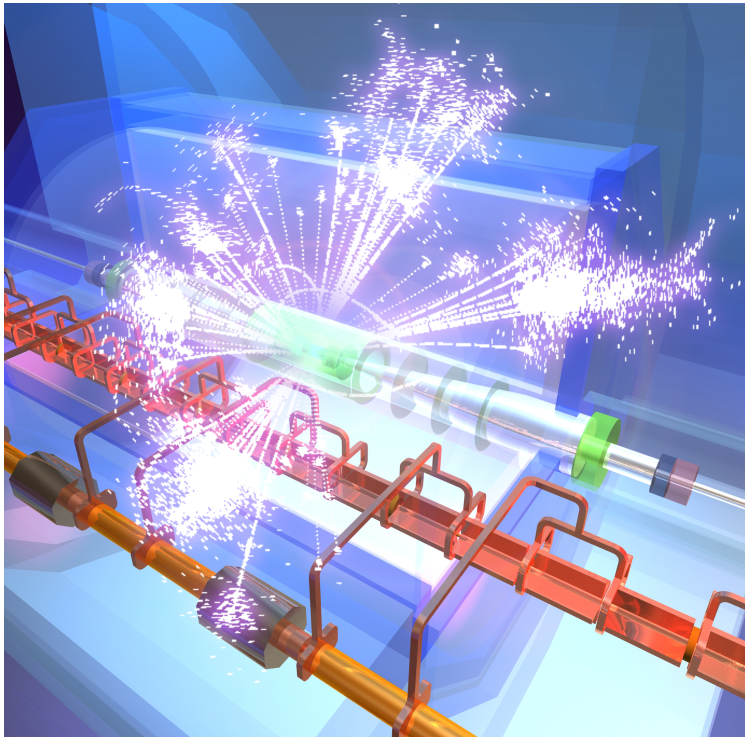


# or to paraphrase…

## Are LC detector concepts suitable for TLEP ?

# or to paraphrase…

YES

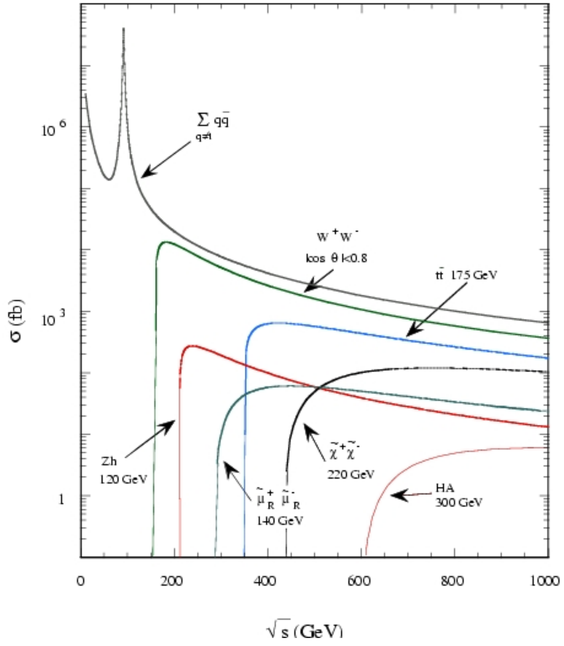
Are LC detector concepts suitable for TLEP ?

but with some caveats

# ILC/CLIC Physics

- Detector design is motivated by physics
- Full physics programme not fully defined until results from LHC
- Nevertheless, some clear candidates:

  e.g. Precision Studies/Measurements
  - Higgs sector
  - SUSY particle spectrum (if there)
  - Top physics
- Minimum detector requirements matched to "mandatory" physics programme



- Radiation hardness not a significant problem, e.g. 1st layer of vertex detector : $10^9$ $n$ cm$^{-2}$ yr$^{-1}$ c.f. $10^{14}$ $n$ cm$^{-2}$ yr$^{-1}$ at LHC
- Backgrounds also managable – shown in full simulation

**Bottom Line:**

**LC detector concepts developed to fully exploit physics in clean ILC/CLIC environment**

# LC Detector Requirements

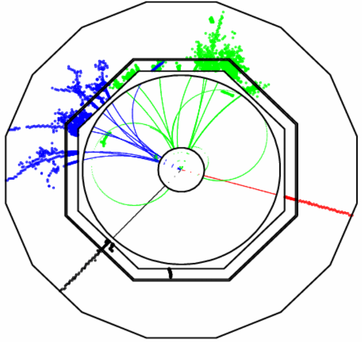
★ **momentum:** (1/10 x LEP)

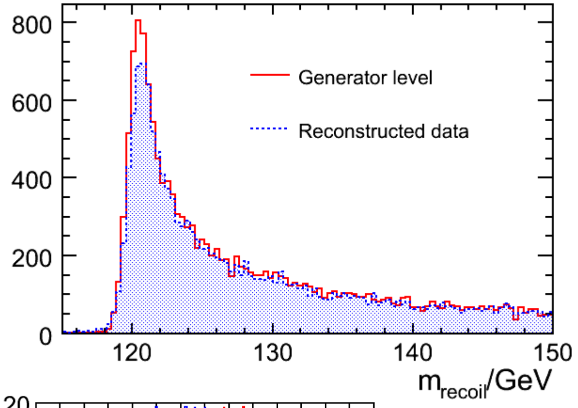
e.g. Muon momentum

Higgs recoil mass

$$\boxed{\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}}$$

$e^+e^- \to \mathrm{HZ}$



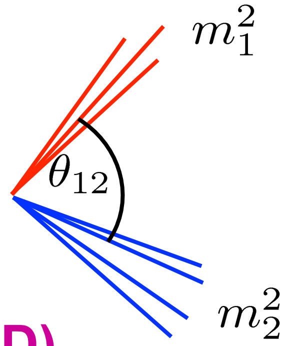


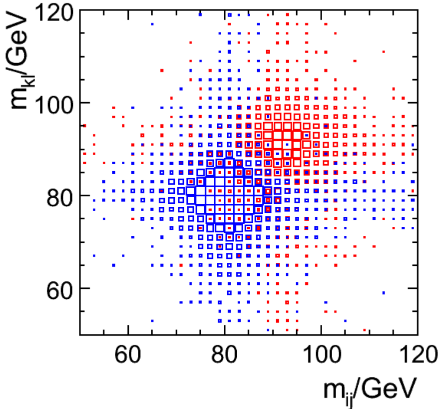
★ **jet energy:** (1/3 x LEP/ZEUS)

e.g. W/Z di-jet mass separation

EWSB signals

$$\boxed{\frac{\sigma_E}{E} \approx 3-4\,\%}$$



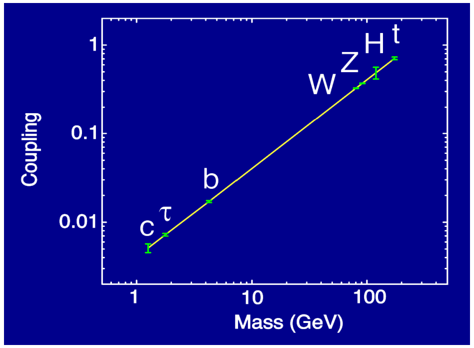


★ **impact parameter:** (1/3 x SLD)

e.g. c/b-tagging

Higgs BR

$$\boxed{\sigma_{r\phi} = 5 \oplus 10/(p\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}}$$

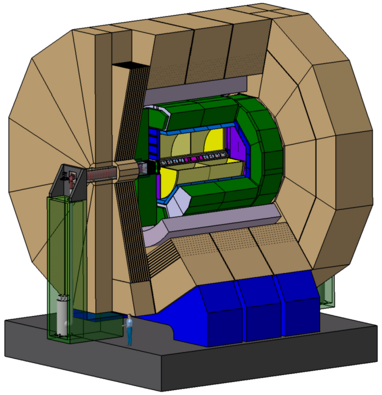


★ **hermetic:** down to θ = 5 mrad

e.g. missing energy signatures in SUSY

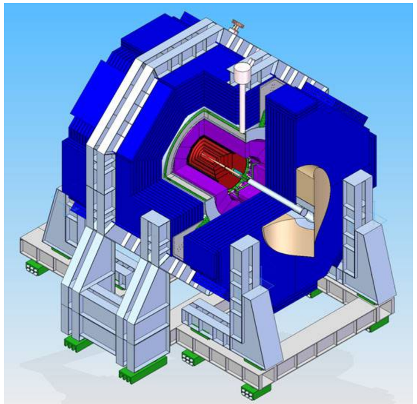
# ILC Detector Concepts

## ILD: International Large Detector



"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid

## SiD: Silicon Detector



"Small" : tracker radius 1.2m
B-field : 5 T
Tracker : Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid

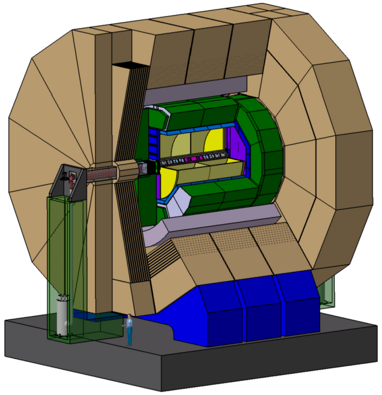
- ★ Both concepts "validated" by IDAG (independent expert review)
- ★ Detailed GEANT4 studies show ILD/SiD meet ILC detector goals
- ★ Fairly conventional technology – although many technical challenges

Represent plausible/high-performance designs for an ILC detector

# CLIC Detector Concepts

**CLIC_ILD: International Large Detector**

"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



**CLIC_SiD: Silicon Detector**

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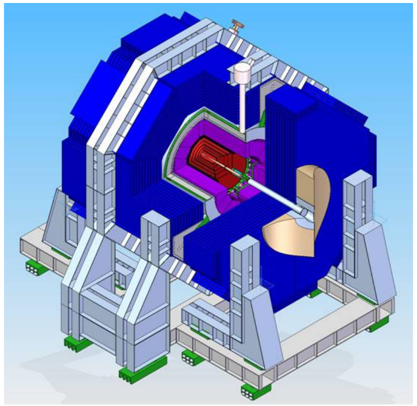
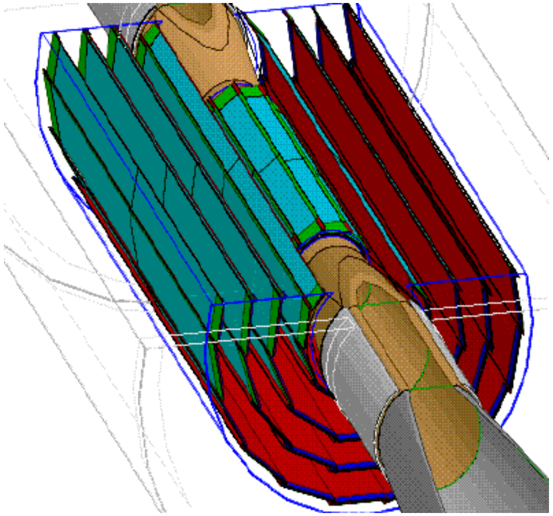


★ Basic design the same
- "thicker" HCAL – with W absorber for compactness
- modified forward region – backgrounds and machine interface
- timing requirements on detector systems

# Detector sub-systems

# LC Vertex detector

- ★ILD and SiD assume Silicon pixel based vertex detectors (5 or 6 layers)



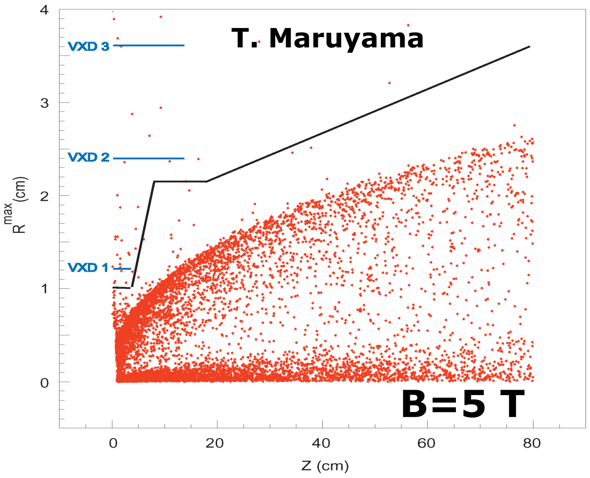
**Main design considerations:**

- ★ Inner radius: as close to beam pipe as possible for impact parameter resolution 15-30  mm
- ★ Layer thickness: as thin as possible to minimize multiple scattering

$$\boxed{\sigma_{r\phi} = 5 \oplus 10/(p\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}}$$

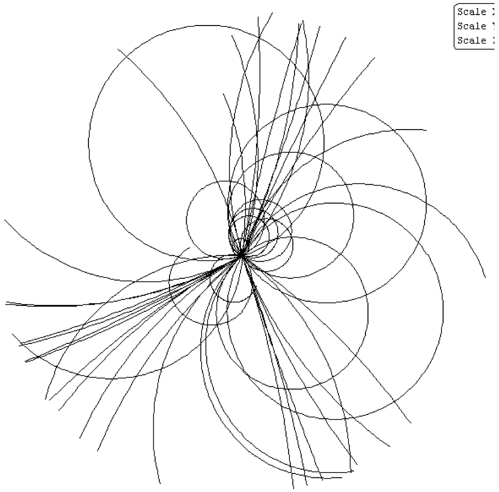
**Constraints:**

- ★ Inner radius limited by pair background depends on machine + detector B-field
- ★ Layer thickness depends on technology
- ★ Some time-stamping capability required

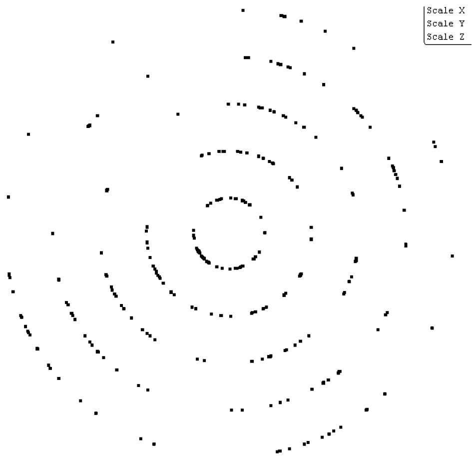


# Tracker Options

- **ILD:** Time Projection Chamber



- **SiD:** Silicon tracker (5 layers)



- Large number of samples
- Few very well measured points

★ Studies show that both result in :

- Very high track reconstruction efficiency
- Excellent momentum resolution: $\sigma_{1/p_\mathrm{T}} \sim 2 \times 10^{-5}\,\mathrm{GeV}^{-1}$ (high p tracks)

★ Main issues

- Robustness to background/Pattern recognition ?
- Material budget for Si tracker ?

# Tracker Options

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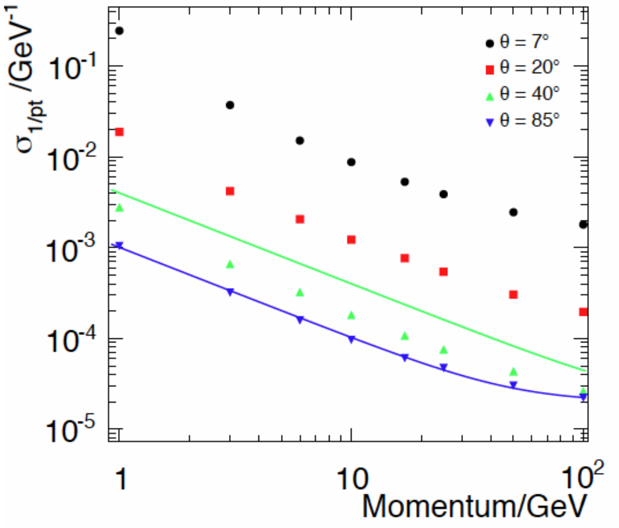

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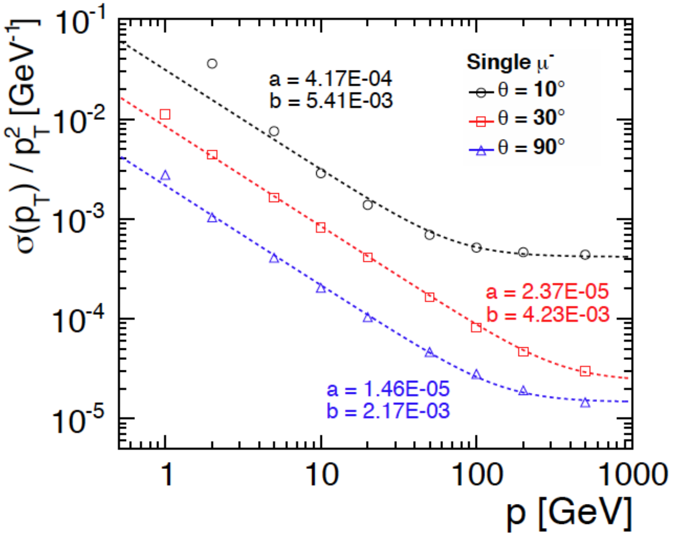

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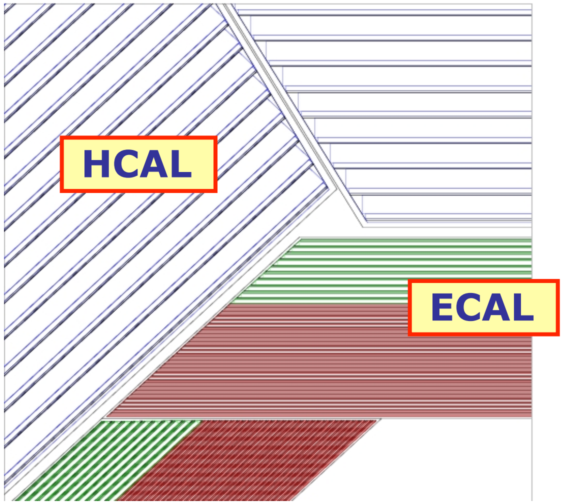
# LC Calorimetry

★ **ILD** and **SiD** concepts designed for **particle flow calorimetry,** e.g. ILD*

**ECAL:**

- SiW sampling calorimeter
- Tungsten: $X_0/\lambda_{had} = 1/25$, $R_{Mol.} \sim 9$mm
  - → Narrow EM showers
  - → longitudinal sep. of EM/had. showers
- longitudinal segmentation: **30 layers**
- transverse segmentation: **5x5 mm$^2$** pixels



**HCAL:**

- Steel-Scintillator sampling calorimeter
- longitudinal segmentation: **48 layers** (6 interaction lengths)
- transverse segmentation: **3x3 cm$^2$** scintillator tiles

**Comments:**

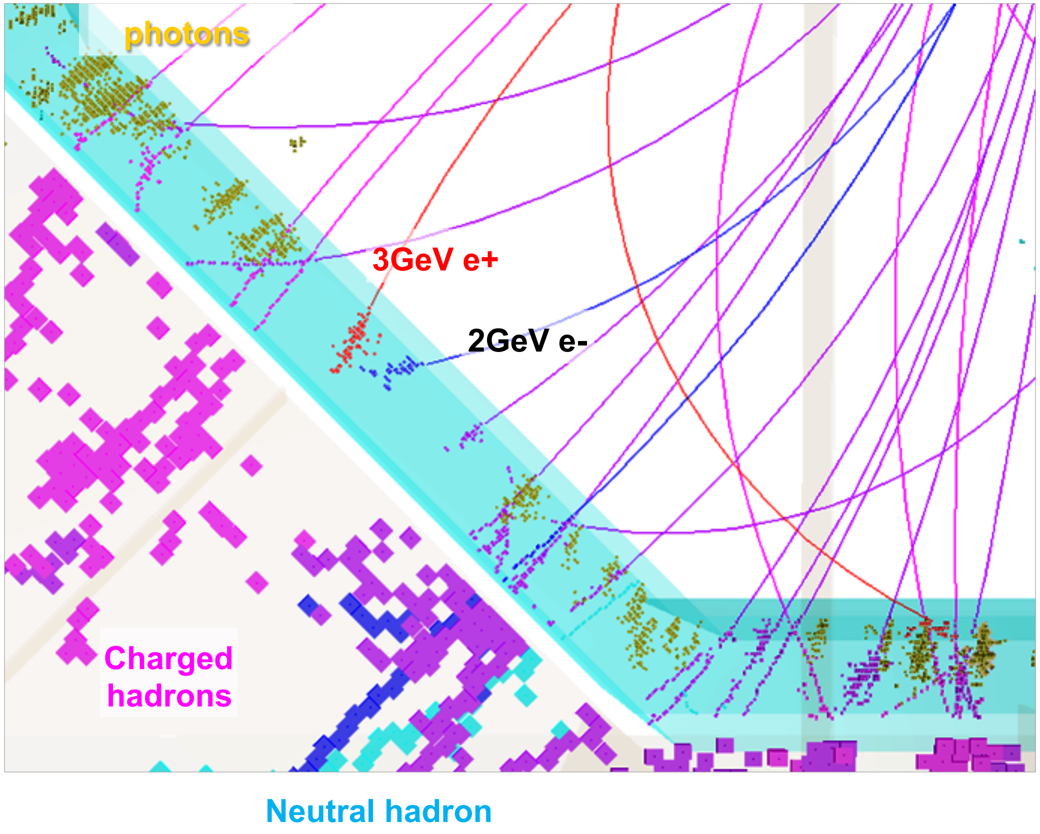
★ Technologically feasible (although not cheap)

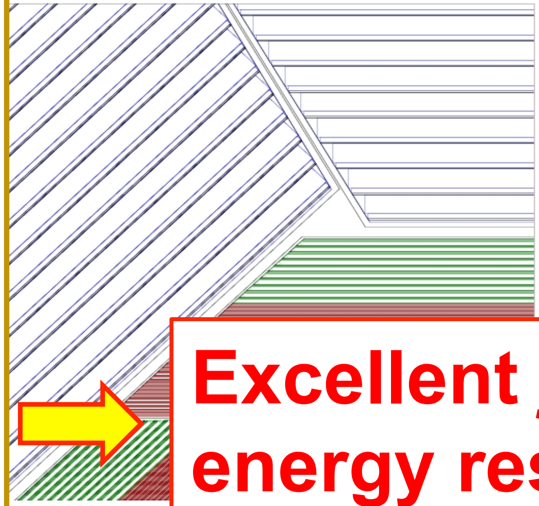
★ Ongoing test beam studies (CALICE collaboration)

# LC Calorimetry

- ★ **ILD and SiD concepts designed for particle flow calorimetry, e.g. ILD***

**Typical 250GeV Jet in ILD:**





**Excellent jet-energy resol.**

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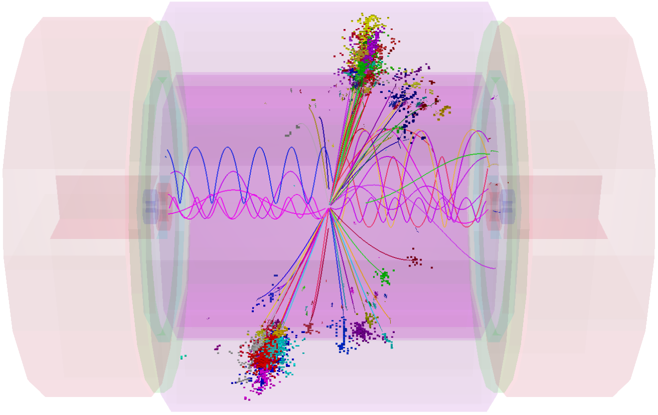
# Performance

★ **Recall:** motivation for high granularity PFlow Calorimetry

⇨ Jet energy resolution: $\boxed{\sigma_E/E < 3.5\%}$

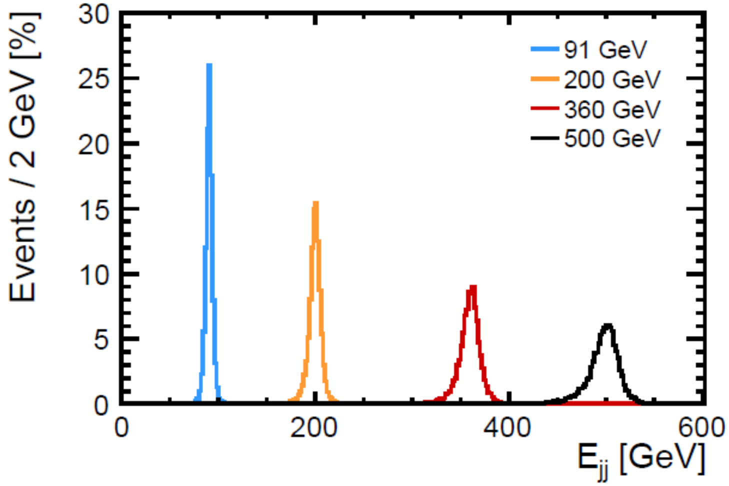


★ **Benchmark** performance using jet energy resolution in Z decays to light quarks

★ Use total energy to avoid complication of jet finding (mass resolutions later)

★ Current performance (PandoraPFA + ILD)

- uds jets (full GEANT 4 simulations)



rms$_{90}$

| $E_{JET}$ | $\sigma_E/E_j$ |
|---|---|
| 45 GeV | 3.7 % |
| 100 GeV | 2.8 % |
| 180 GeV | 2.9 % |
| 250 GeV | 2.9 % |

→ **GOAL MET !**

★ Factor 2-3 better than traditional calorimetry !

# Performance

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**PARTICLE FLOW DICTATES DESIGN OF ~$500M LC DETECTORS**

rr

| | |
|---|---|
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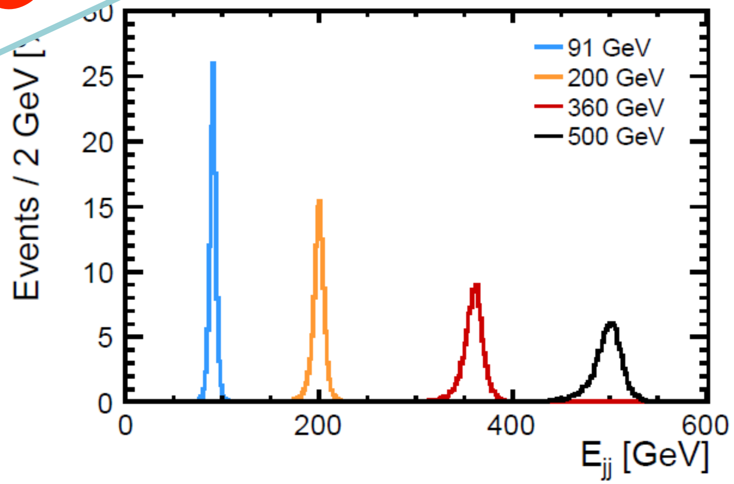

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# LC Detector Requirements

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  - e.g. Muon momentum
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- **jet energy:** (1/3 x LEP/ZEUS)
  - e.g. W/Z di-jet mass separation
  - EWSB signals

$$\frac{\sigma_E}{E} \approx 3-4\,\%$$

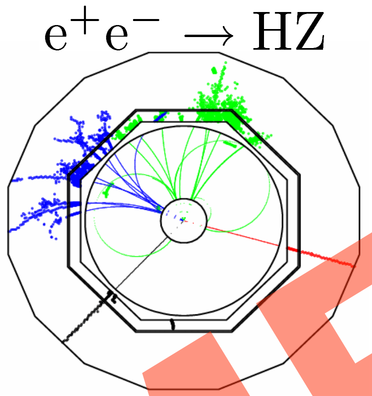
- **impact parameter:** (1/3 x SLD)
  - e.g. c/b-tagging
  - Higgs BR

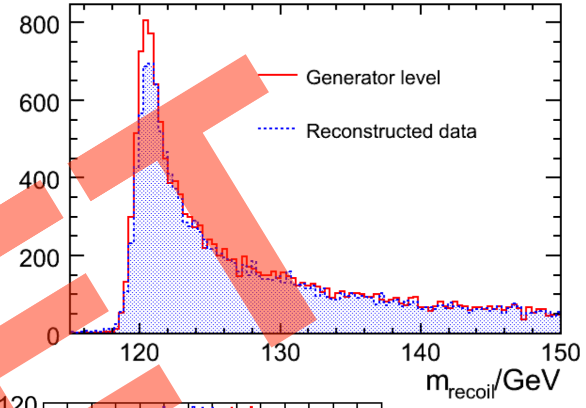
$$\sigma_{r\phi} = 5 \oplus 10/(p\,si \;\; \mu m$$

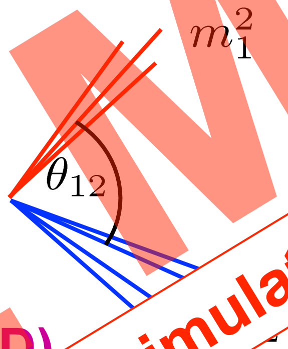
- **hermetic:** down to θ = 5 mrad
  - e.g. missing energy signatures in SUSY

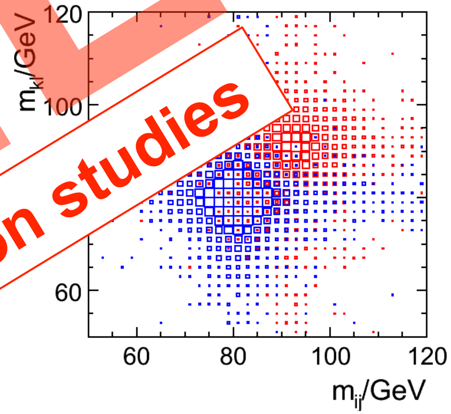
ALL MET

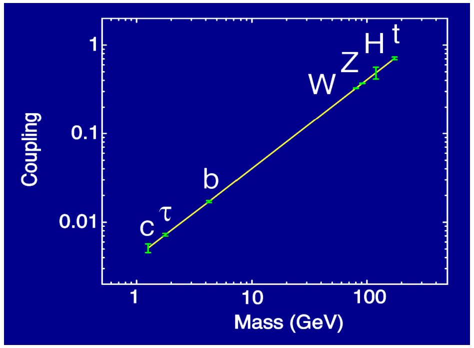
In very detailed simulation studies











# Issues for TLEP?

- ★ Break down into:
  - ▪ machine related issues
  - ▪ physics performance-related issues

# TLEP Issues

- **Machine-related questions** (assuming LC perf. goals):
  - ILC bunch operates with bunch trains ~ 5 Hz
  - Inter-bunch gaps are a good thing:
    - Power-pulsing of electronics, off ~99 % of time
    - Reduces need for cooling-related services
  - Si-Trackers:
    - Without power-pulsing, ultra-low material budget may be an issue
    - Impact on viability of low-mass central Si tracker?
    - Impact on VTX detector design?
    - Time-stamping (more power + technology)
  - Calorimeters:
    - Without power-pulsing, cooling of high-granularity calorimeters – very challenging due to # of channels
    - Pushes towards significantly less segmentation?

# Physics Issues

- ★ **Are the LC detector goals appropriate for TLEP physics?**
  - ▪ **Would a less performant detector do the job?**

# Vertex Detector

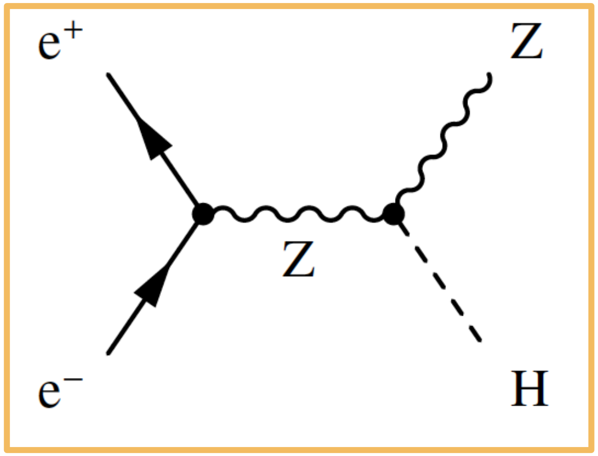
- **Main argument is H →bb, H →cc, H →gg BRs**
  - **Still holds at TLEP at both 250 GeV and 350 GeV**
  - **Challenge will be keeping material budget down**
    - **Lack of power-pulsing may be an issue…**

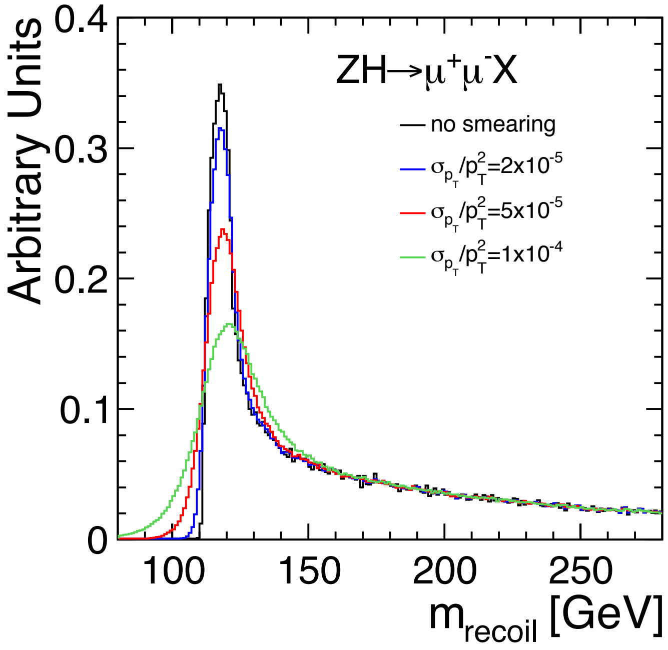
# Track Momentum

- ★ **Argument is Higgs recoil analysis**
  - Sharpness of peak given by:
    - Beam energy spread
    - Momentum resolution
  - Degraded resolution:
    - Degrades $m_H$ resolution
      - not clear if this matters?
    - Less impact on HZ cross section measurement
      - the important meas.

⇨ $g_{HZZ}$

- ★ **Could step back from LC perf. ?**
  - would need proper study



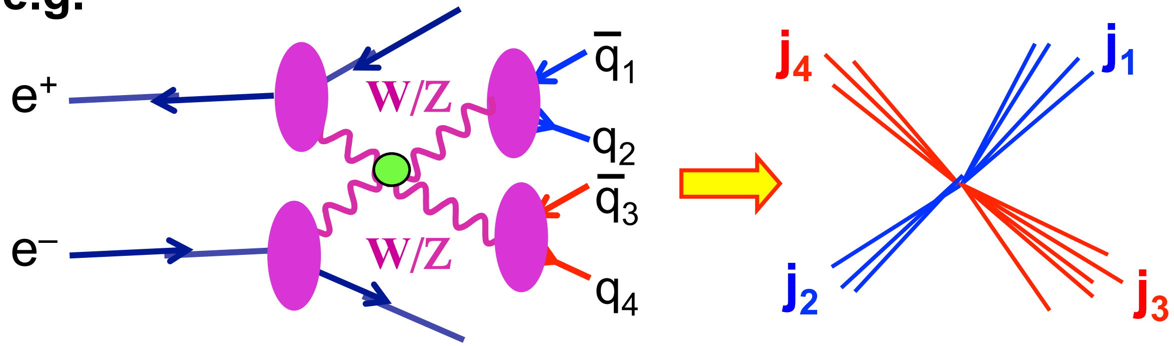


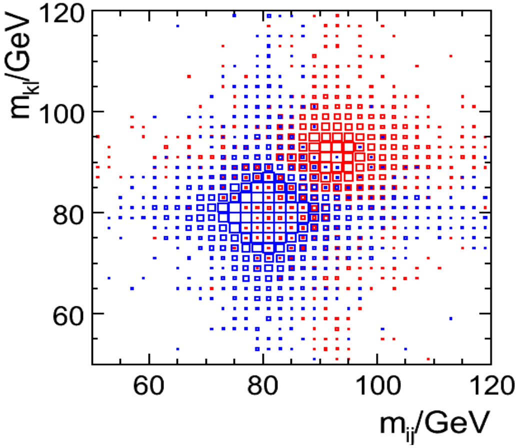
# Calorimetry

★ **"Traditional argument"**

- **Want to separate Ws/Zs - drives ~3.5 % jet E goal**

**e.g.**





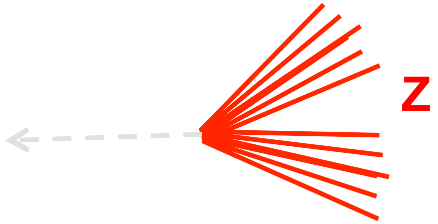
★ **Relevance at 250/350 GeV?**

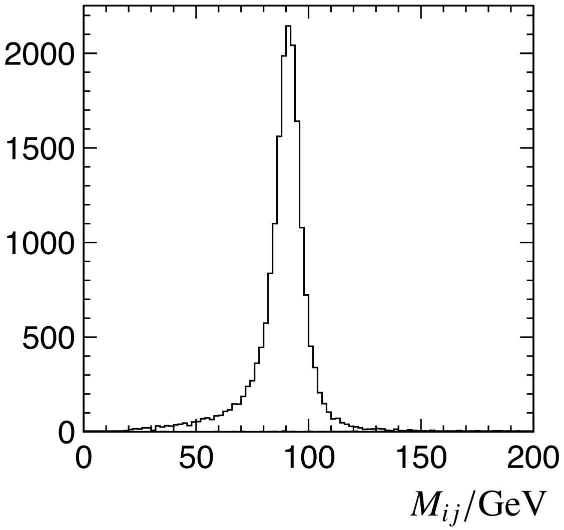
- **What is the key physics driver?**
- **Not studied in great detail, previous arguments focus on >500 GeV**

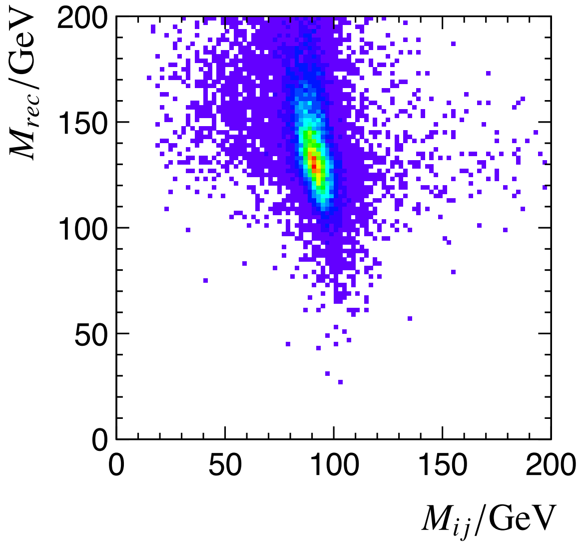
# Calorimetry

- ★ **Higgs physics**
  - Impact of jet E resolution on precision Higg physics not yet studied
  - But di-jet inv. mass is an important selection tool

**e.g.** Search for invisible Higgs decays in HZ production







- ★ **Jet E resolution likely to be valuable in many H analyses**
  - needs to be quantified

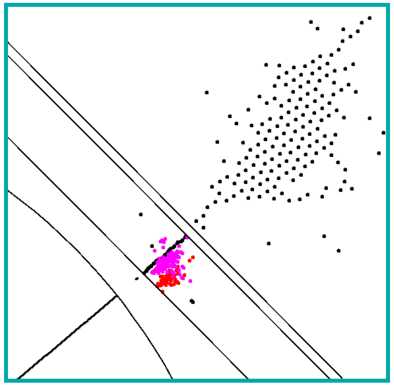
# Lower Energy

★ **What about TLEP as a Z and WW factory**

- Control of systematics likely to be driving factor
- Tried to identify possible benefits of LC-like detector

★ **One example:**

- precision tau physics at the Z
- high granularity calorimetry ideal for τ decay ID
- improved measurements of tau polarisation



| Mode | Efficiency | Purity |
|---|---|---|
| $e\nu\nu$ | 98.9 % | 98.9 % |
| $\mu\nu\nu$ | 98.8 % | 99.3 % |
| $\pi\nu$ | 96.0 % | 89.5 % |
| $\rho\nu$ | 91.6 % | 88.6 % |
| $a_1\nu$ (1-prong) | 67.5 % | 73.4 % |
| $a_1\nu$ (3-prong) | 91.1 % | 88.9 % |

ILD @ 500 GeV

★ May be other examples…

# Summary

★ Clear synergies between ILC/CLIC detectors and TLEP

★ Main caveat is lack of power-pulsing and impact on material budget

★ Could question whether all aspects of an LC detector are over-specified for TLEP physics
- needs proper study