International Linear Collider
Physics and Experiments

Physics
Detector Design
Detector Development
Conclusions

Klaus Desch
University of Freiburg
HEP2005
Lisboa, 25/07/2005

Challenges at the TeV Scale

Many of our most burning questions will be addressed if we explore the TeV energy regime:

Origin of mass and electro-weak symmetry breaking

Hierarchy between m_{weak} and m_{Planck}

Matter content in the Universe

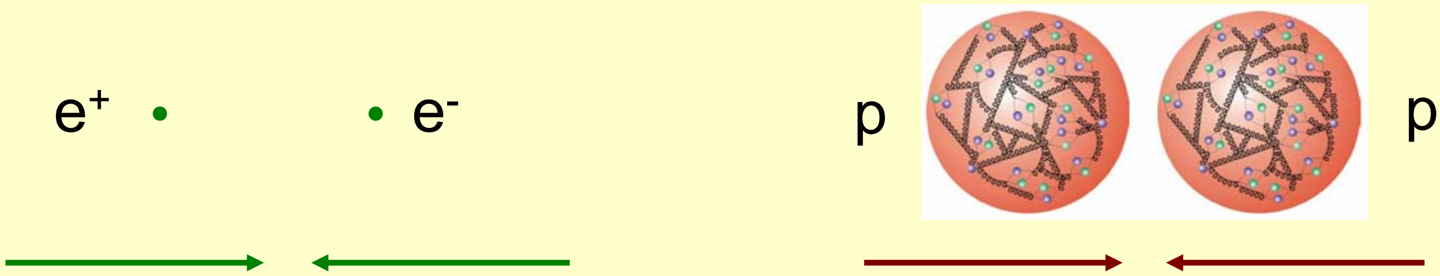
and maybe many more…

Tevatron is starting to open a window into this regime

LHC allows for a broad view on phenomena at the TeV scale!

Will this be sufficient?

Electron Positron Collisions



Electron positron collisions at high energy provide a unique tool to explore TeV-scale physics complementary to the LHC

Due to their point-like structure and absence of strong interactions

there are clear advantages of e^+e^- collisions:

- known and tunable centre-of-mass energy
- clean, fully reconstructable events
- polarized beams
- moderate backgrounds

→broad consensus for a 500-1000 GeV Linear Collider

The ILC

Technology decision in 2004: use superconducting RF

The International Linear Collider ILC

The baseline:

- $e^+ e^-$ LC operating from M_Z to 500 GeV, tunable energy
- e^- polarization
- at least 500 fb^{-1} in the first 4 years
- upgradable to ~ 1 TeV 500 fb^{-1} /year

Options :

- e^+ polarization , transverse polarization
- GigaZ (high luminosity running at M_Z)
- e-e-, $\gamma\gamma$, $e\gamma$ collisions

(ICFA parameter document, Heuer et al.)

A lot of flexibility!

Global Design Effort (GDE) started ⇨ Barish

ILC physics case

Explore new Physics through precision at high energy

microscopic

$$e^+e^- \to X_{new}(+Y_{SM})$$

Study the properties of new particles (cross sections, BR's, Quantum numbers)

⇨ Discovery through precision

telescopic

$$e^+e^- \to SM$$

Study known SM or new processes to look for tiny deviations through virtual effects (needs ultimate precision of measurements and theoretical predictions)

new physics reach deep into multi-TeV region

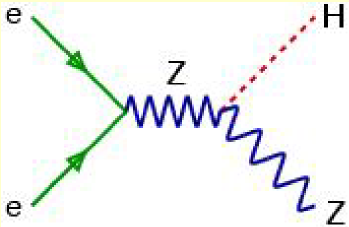
ILC Physics Case

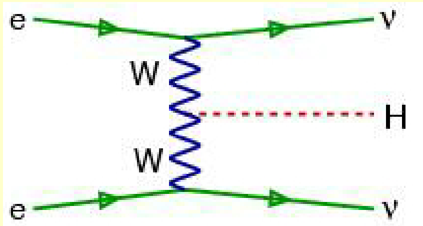
Whatever LHC will find, ILC will have a lot to say!
'What' depends on LHC findings: (TESLA TDR, Snowmass01, ACFA report, …)

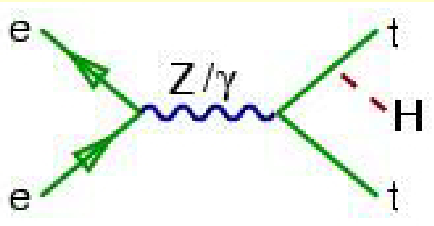
1. If there is a 'light' Higgs (consistent with precision EW)
   ⇨ verify the Higgs mechanism is at work in all elements
2. If there is a 'heavy' Higgs (inconsistent with precision EW)
   ⇨ verify the Higgs mechanism is at work in all elements
   ⇨ find out why prec. EW data are inconsistent
3. 1./2. + new states (SUSY, XD, little H, Z', …)
   ⇨ precise spectroscopy of the new states
4. No Higgs, no new states (inconsistent with precision EW)
   ⇨ find out why precision EW data are inconsistent
   ⇨ look for threshold effects of strong/delayed EWSB

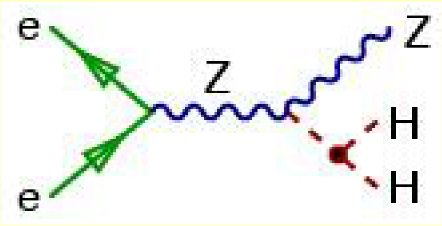
Early LHC data likely to guide us the direction
LHC + ILC data analysed (and taken) simultaneously ⇨ synergy!
(LHC/ILC study group, `Weiglein et al.)

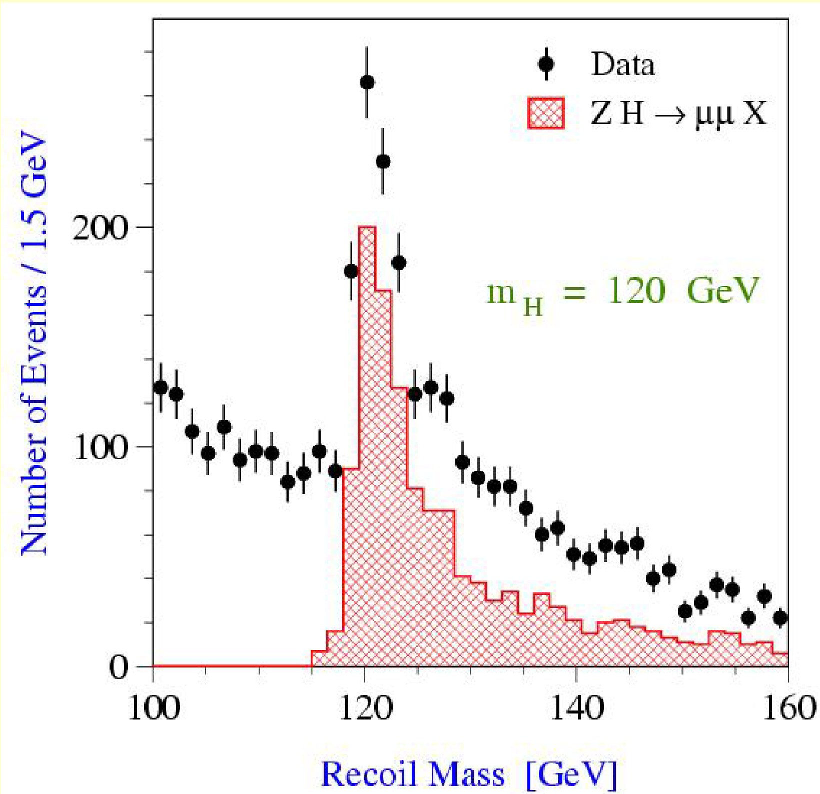
Precision Higgs physics











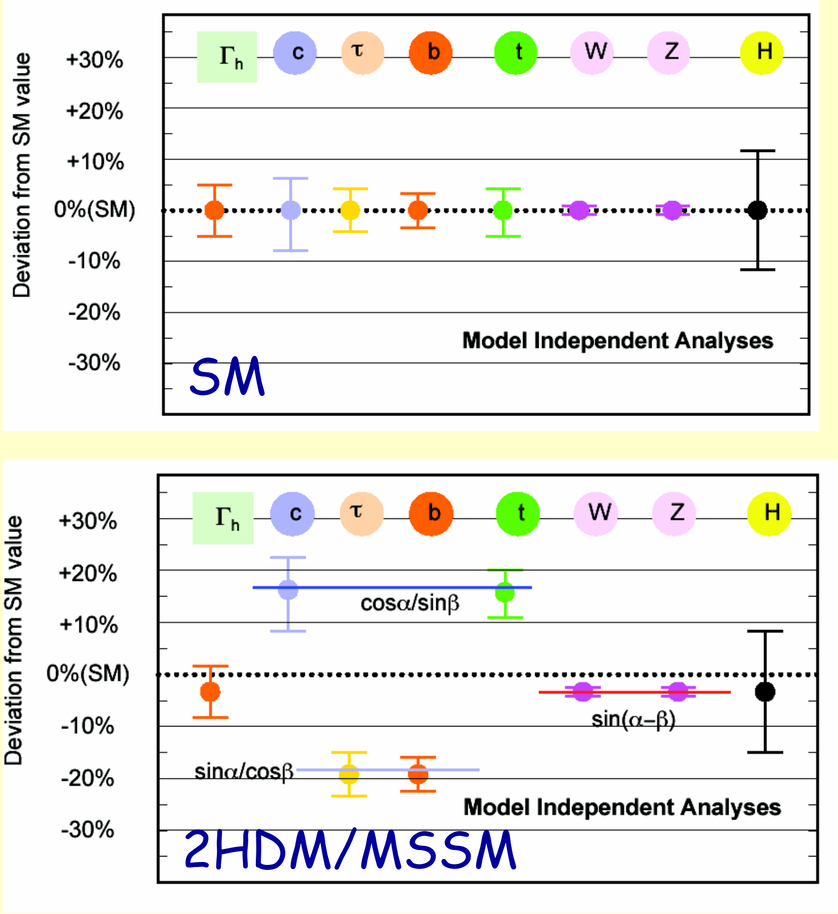
Garcia-Abia et al

- model-independent observation
- mass
- absolute branching ratios
- total width (mod.indep.)
- spin, *CP*
- top Yukawa coupling
- self coupling

most measurements at the precent level!

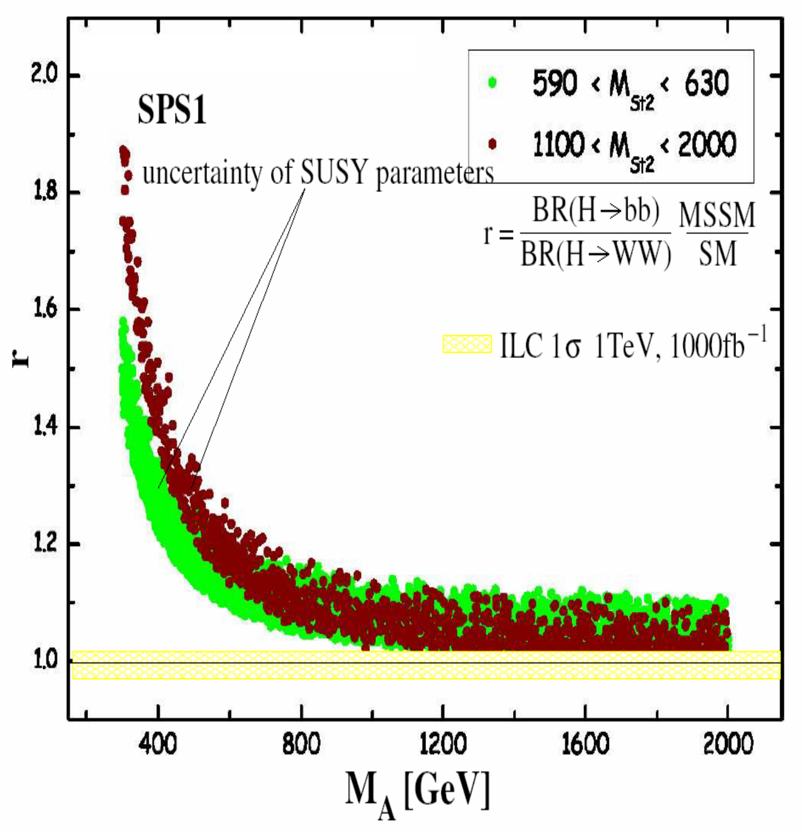
Precision Higgs physics

Precision allows us to learn about the underlying model, e.g.:



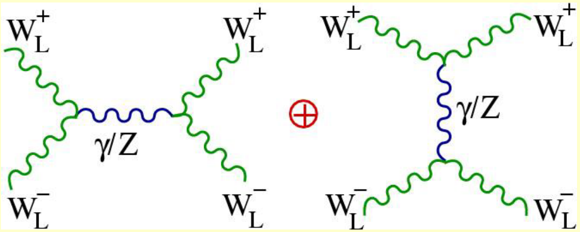
Yamashita et al

or constrain the masses of heavy particles (e.g. m_A)



Zivkovic et al

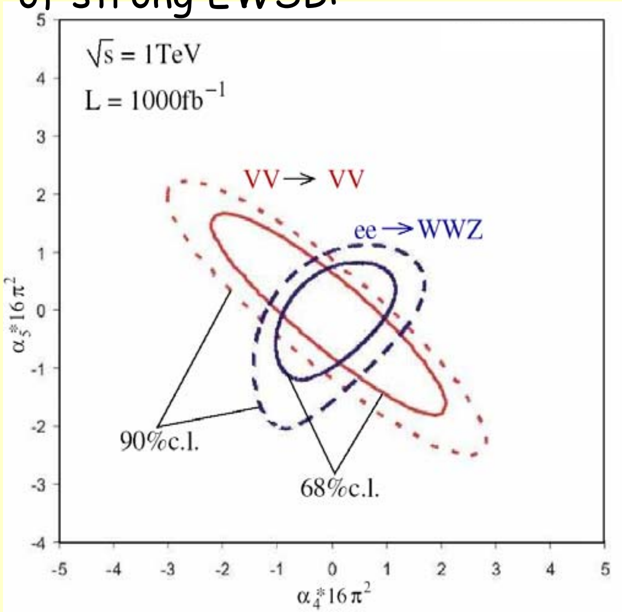
No elementary Higgs?



Cross section for vector boson scattering violates unitarity at ~1.2 TeV, if forces remain weak and no new resonances appear

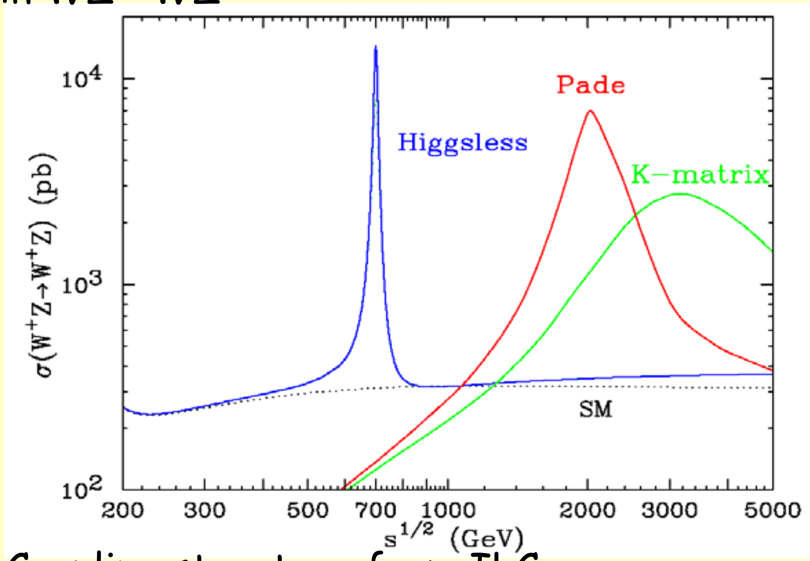
ILC sensitivity deep into multi-TeV region from VB final states

eff. Lagrangian parameters of strong EWSB:



Krstonosic et al.

Higgsless model: new resonance in WZ→WZ



Coupling structure from ILC if resonance seen by LHC

Birkedal et al.

Supersymmetry

After SUSY discovery at the LHC many burning questions will arise:

• is it really SUSY? (measurement of quantum numbers)

• how is it realized? (MSSM, NMSSM, …)

• how is it broken?

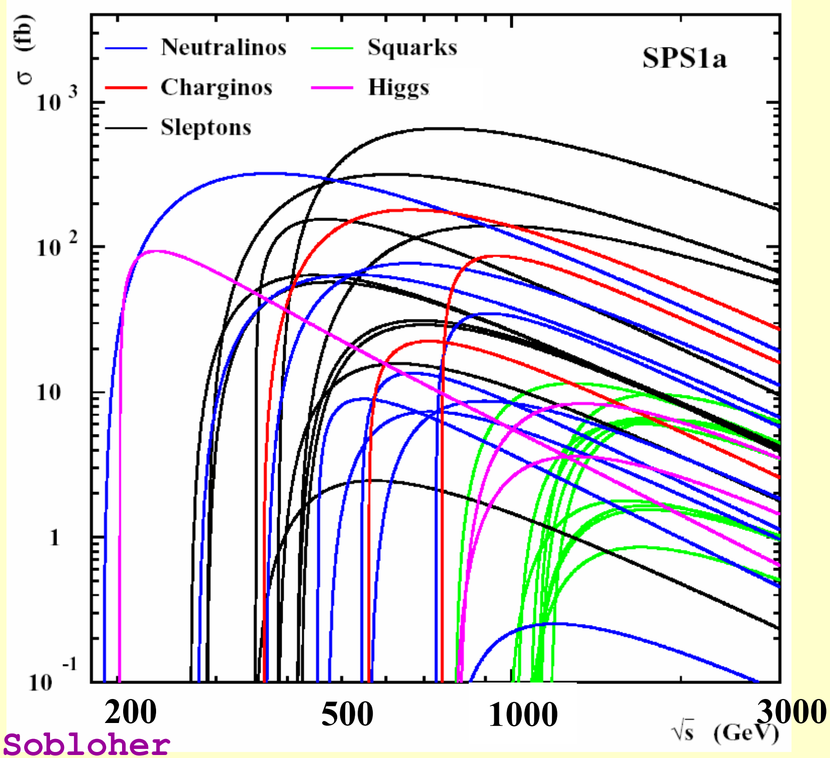
ILC will be indispensable to answer these questions!

Make full use of the flexibility of the machine:

- tunable energy

- polarized beams

- possibly e^-e^- and $\gamma\gamma$ collisions

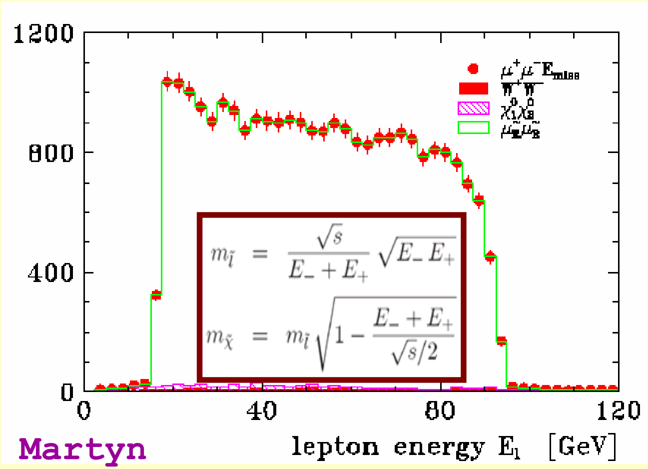


Sobloher

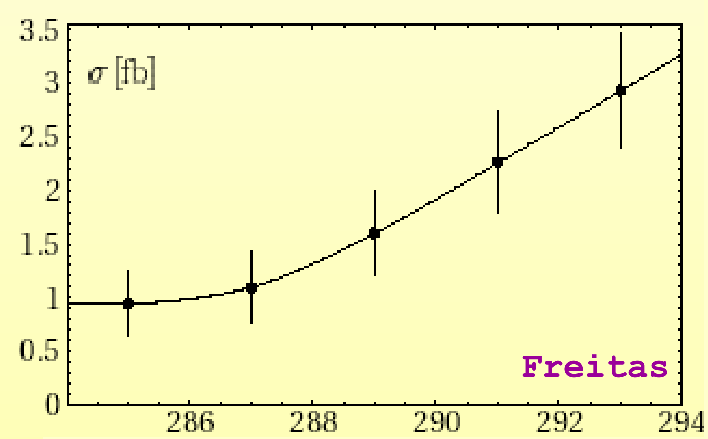
Supersymmetry

Two methods to obtain absolute sparticle masses:

in the continuum:



at the kinematic threshold:



mass precision $^0/_{00}$ – $^0/_0$

many more observables than just masses:

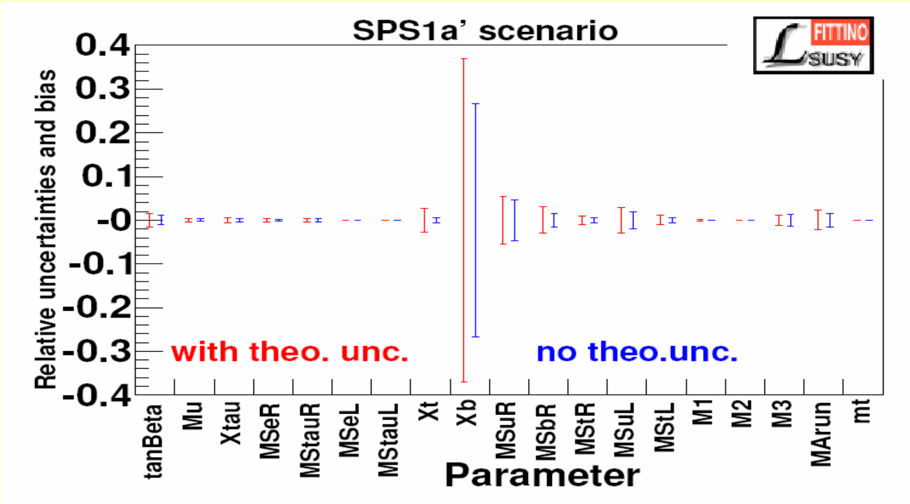
- angular distributions, FB-asymmetries
- cross sections
- LR-asymmetries
- ratios of branching ratios

→ possibility to determine SUSY parameters without many model assumptions

Supersymmetry

What ILC precision + LHC mass reach for squarks/gluinos does:

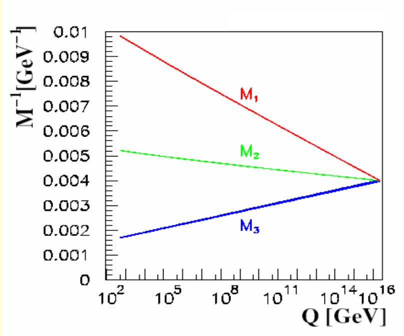
errors of a 19-parameter fit using ILC+LHC:

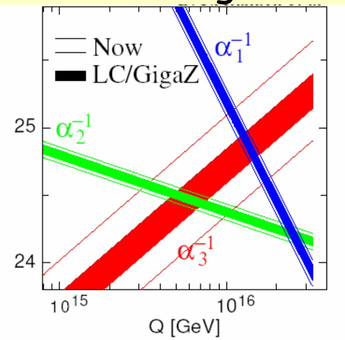


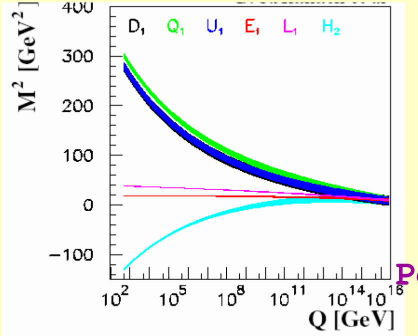
note: this will not be possible will either LHC or ILC alone – need both!

Bechtle et al

allows for model-independent investigation of GUT/Planck scale features of the theory:







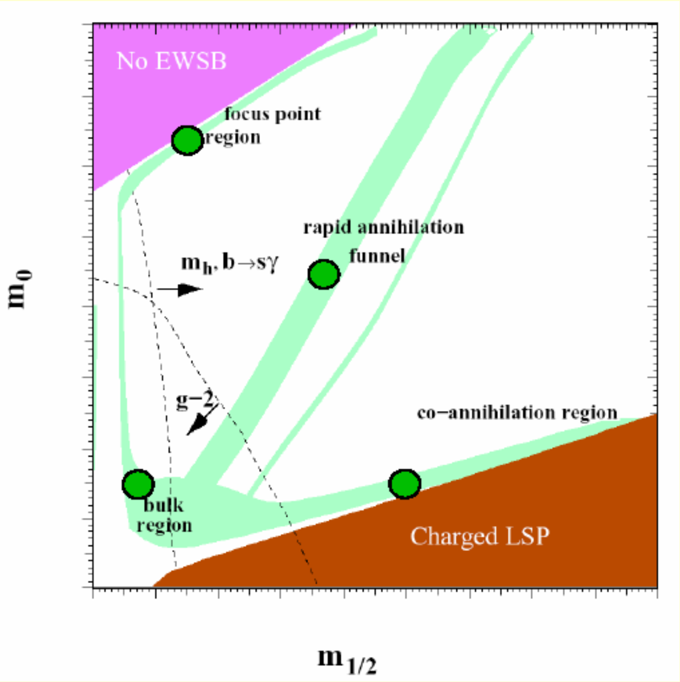
Porod et al

The Cosmic Connection

SUSY provides excellent candidate for dark matter (LSP)

Other models also provide TeV-scale WIMPs

How well can the properties of the DM-candidates (to be found at accelerators) be compared to the properties of the real DM (inferred from astrophysical measurements) ?



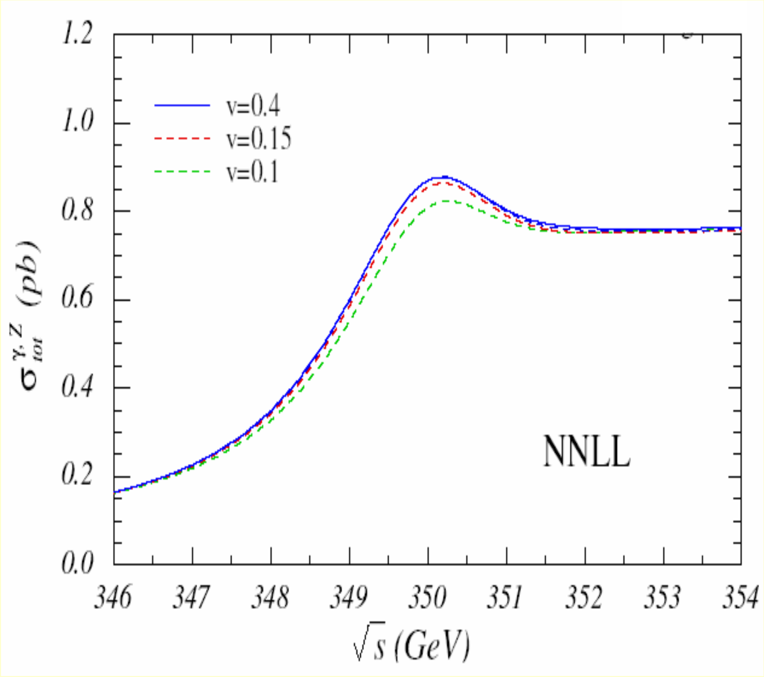
ALCPG study/prel.

	$\Delta\Omega_{DM}/\Omega_{DM}$	main sensitivity
bulk	3.5%	$\tilde{\chi}^0_1, \tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_1$
focus	1.9%	$\tilde{\chi}^0_1, \tilde{\chi}^0_2 - \tilde{\chi}^0_1, \tilde{\chi}^0_3 - \tilde{\chi}^0_1, \tilde{\chi}^+_1 - \tilde{\chi}^0_1, \sigma(\tilde{\chi}^+_1 \tilde{\chi}^-_1)$
co-ann.	6.5%	$\tilde{\chi}^0_1, \tilde{\chi}^0_1 - \tilde{\tau}_1$
funnel	3.1%	$A^0, \tilde{\chi}^0_1, \tilde{\tau}_1$

matches precision of future CMB exp.

Top

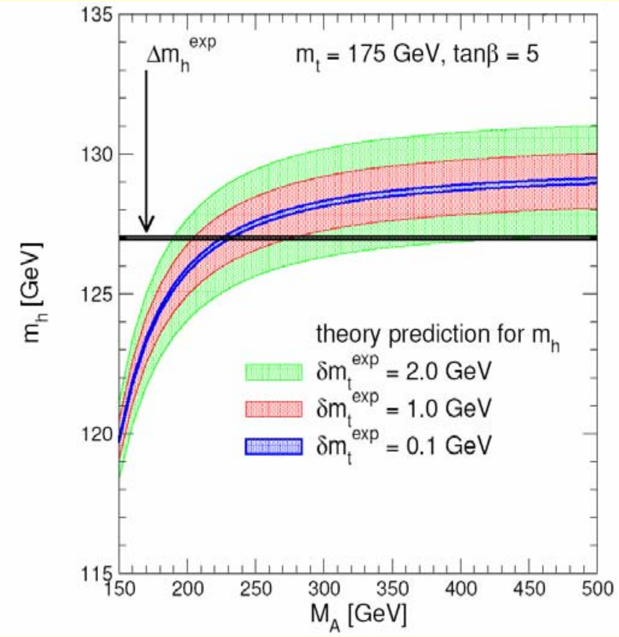
it's there for sure!
Threshold scan provides excellent mass measurement
Theory (NNLL) controls $m_t(\overline{MS})$ to 100 MeV



Hoang et al

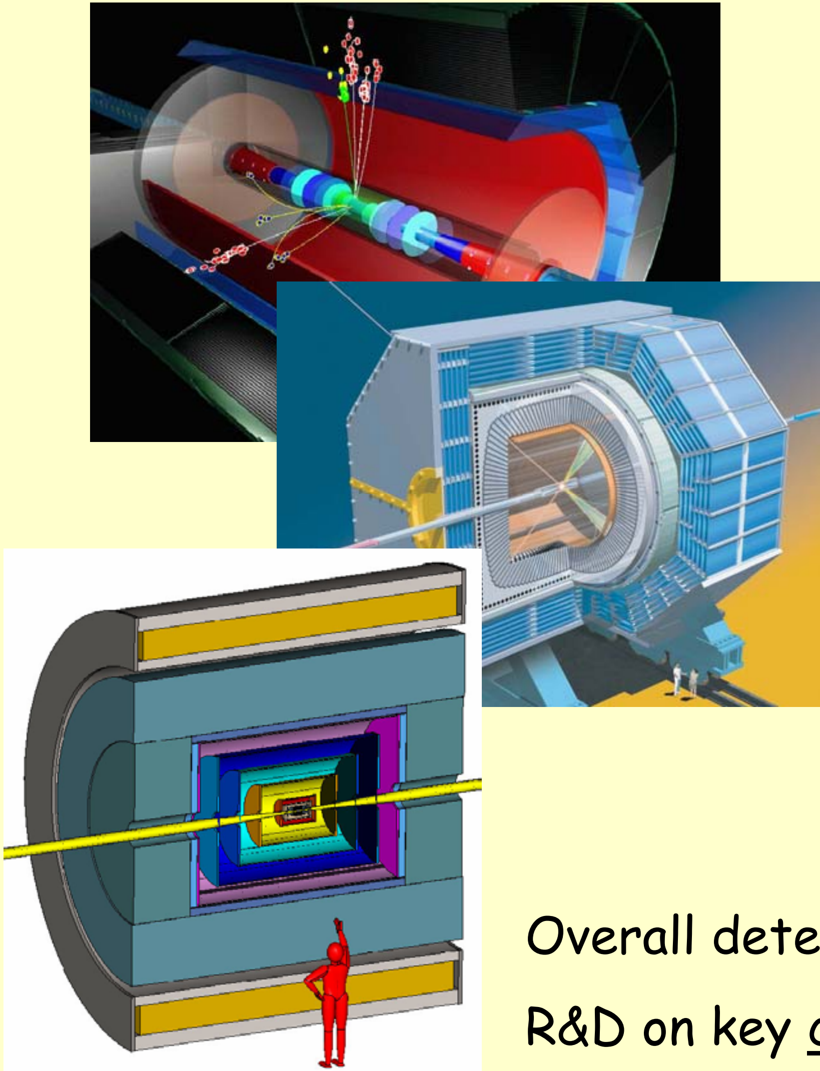
precise m_{top} vital for

- improved SM fits
- MSSM (m_h prediction)
- DM-density in mSugra
- ...



Heinemeyer et al

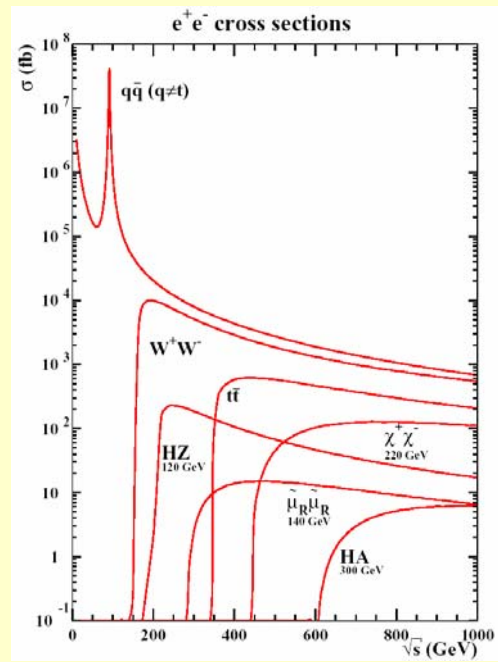
Detector Design for the ILC



Match detector resolution
to high statistical power of ILC

Limit systematic errors

Requirements different
from LHC detectors



Overall detector concept

R&D on key components

The Particle Flow Detector

ILC physics allows for and requires complete reconstruction of complex final states (multi-jets, tau's) – often accompanied by miss-E

Require best possible energy resolution for jets

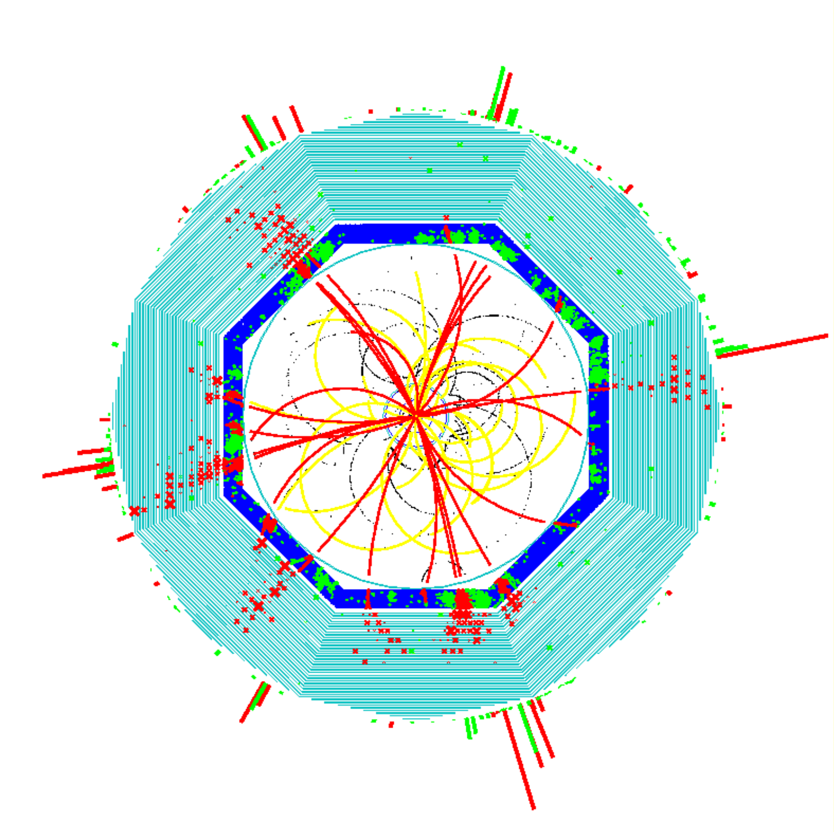
Generally accepted paradigm: Particle flow

Particle flow is:

- a philosophy!

- an algorithm!

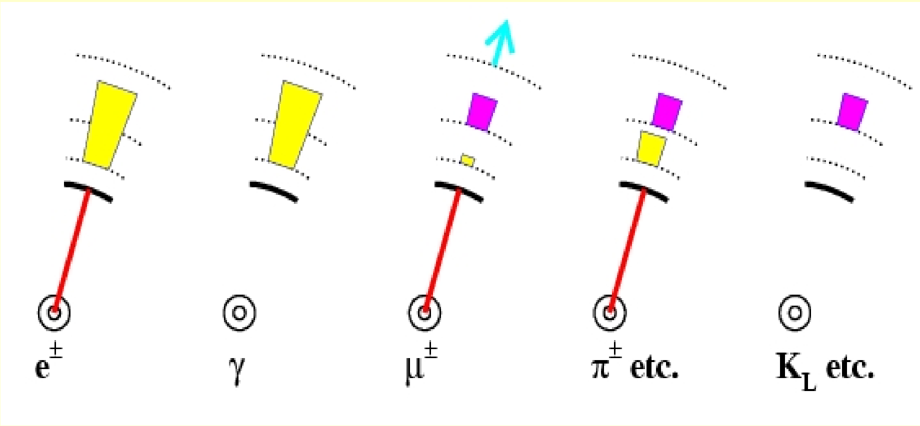
- a detector concept!



The Particle Flow Detector

Basic idea: reconstruct every single particle in the event

for each particle species use the detector which can do that best!

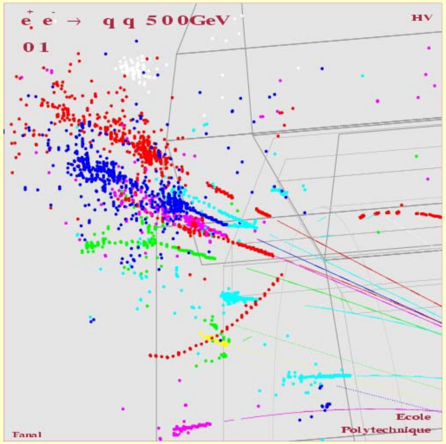


65% charged → tracker

25% photons (from π^0) → ECAL

10% neut. hadrons → HCAL

sounds simple
challenge: separate them!



Separate

charged from neutral: B, R, trans. granularity, material

EM from HAD: trans. + long. granularity ("shower tracking")

Detector concept studies

3 different incarnations of a PF detector studied

They have a lot in common:

- both ECAL+HCAL inside coil
- highly-granular calorimeter
- precision pixel vertex detector
- common R&D on components!

concepts, but no closed 'collaboration'

They differ in:

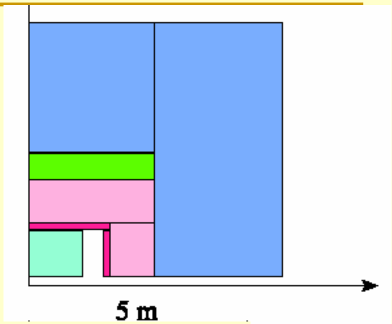
choice of tracking: TPC vs. Si

magnetic field 3 – 5 T

inner radius of ECAL

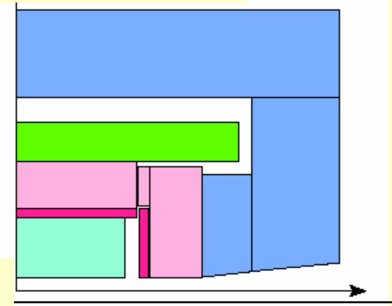
choice of ECAL readout Si vs Sc

SiD



www-sid.slac.stanford.edu

LDC



www.ilcldc.org

GLD

ilcphys.kek.jp/gld/

Design Issues and Detector R&D

Detector integral part of ILC Design – meet schedule of GDE

Concept optimisation & R&D now!

Key components:

1. Vertex Detector
2. Charged Particle Tracking
3. Calorimetry
4. Muon system
5. Forward Region
6. Machine Detector Interface

no time to cover 4.-6.

R&D Panel established by world-wide LC study to promote and coordinate detector R&D for the ILC

Keeps a register of R&D activities around the world at

https://wiki.lepp.cornell.edu/wws/

Talks in parallel sessions:

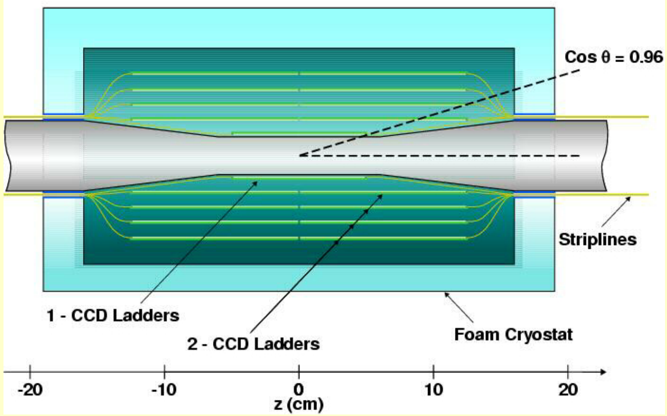
062,720 (MAPS)
803 (CCD)
817 (TPC)

Plenary talk: F.Sauli

Vertex Detector

Driving physics: Higgs BR's
(but also Higgs self coupling, tt, charged Higgs, …)

Aim for unprecedented flavor (b,c,τ) tagging performance



- 4-5 layers (inner radius 12-15 mm)
- 3-hit coverage to $\cos\Theta < 0.96$
- pixel size at most $(20\ \mu m)^2$
- $< 0.1\%\ X_0$ per layer!

Design issues:

thin detectors
readout-speed (column parallel r/o)
power consumption (material!)
backgrounds (1^{st} layer)
beam pickup

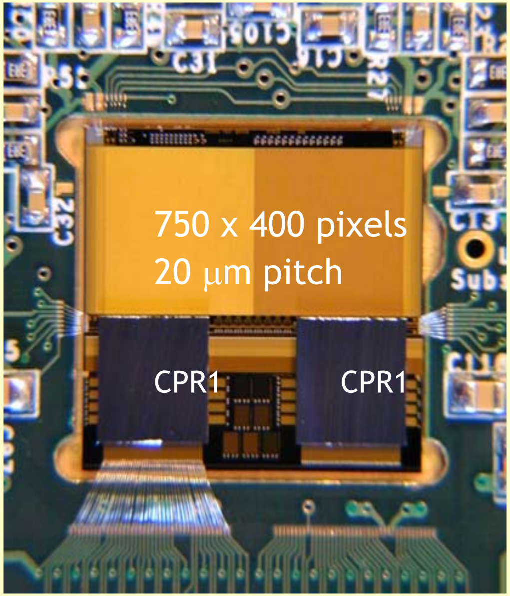
common to
SiD, LDC, GLD

Vertex Detector

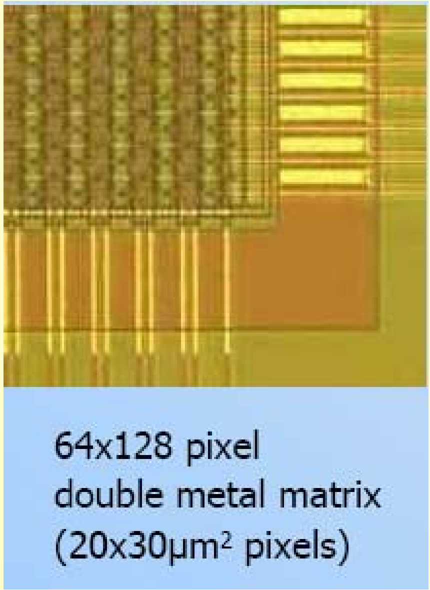
Many technologies under study – very active field

CCD
DEPFET
MAPS
and many others…

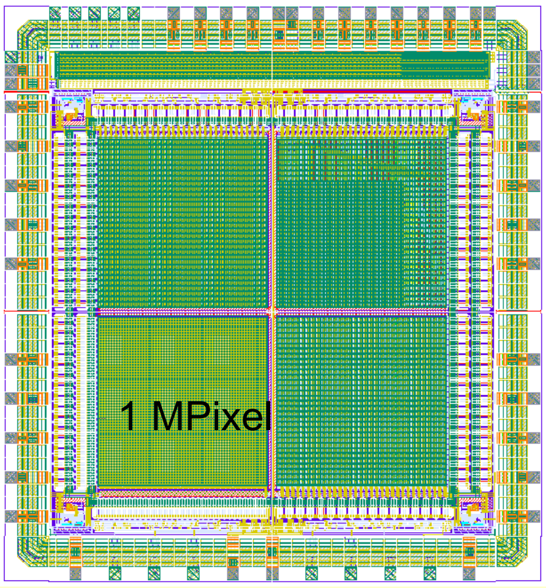
CCD with column par. r/o



DEPFET



Mimosa 9 (MAPS)

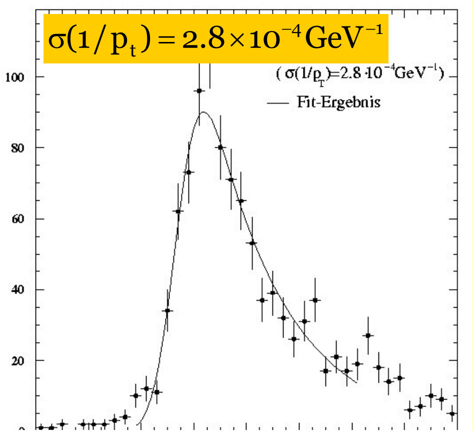


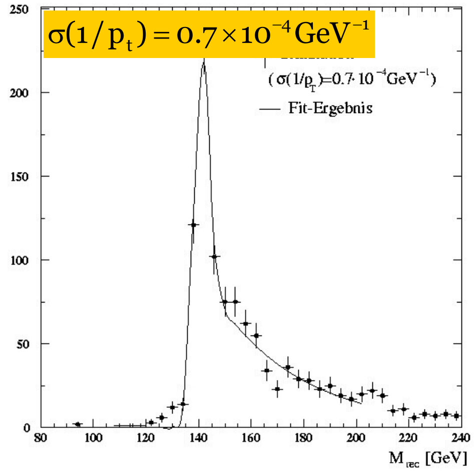
Central Tracking

__Driving Physics:__

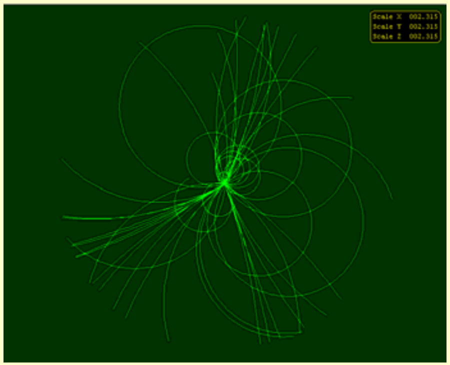
Particle Flow: robustness+efficiency, resolution less important

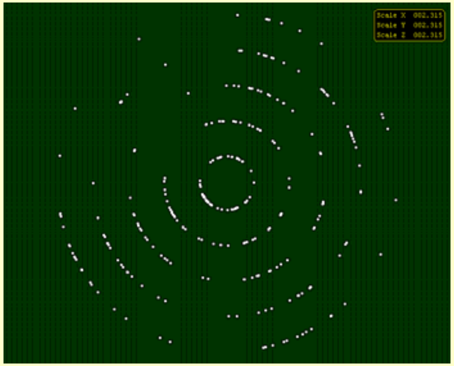
Higgs recoil mass, SUSY di-lepton endpoints: momentum resolution





Two options: Gaseous or Silicon tracker?





TPC:

>200 3D space points with 'moderate' point-res o(100μm) (LDC, GLD)

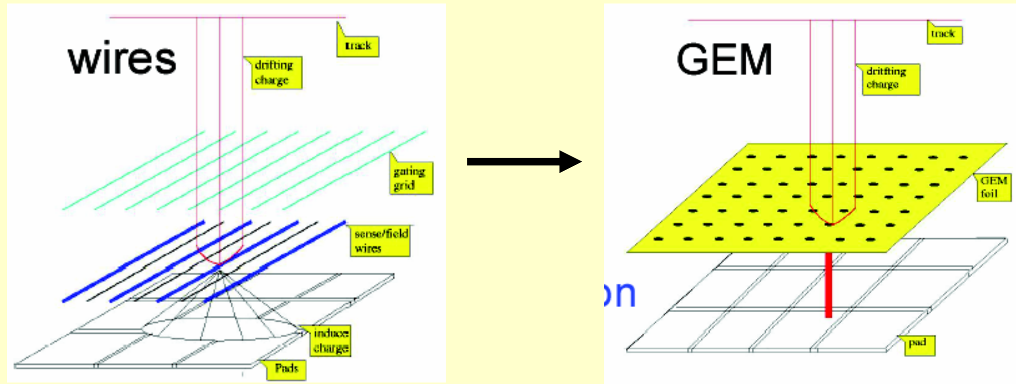
Si:

5 (pix) + 5 (strips) high-res points point-res o(few μm) (SiD)

TPC R&D

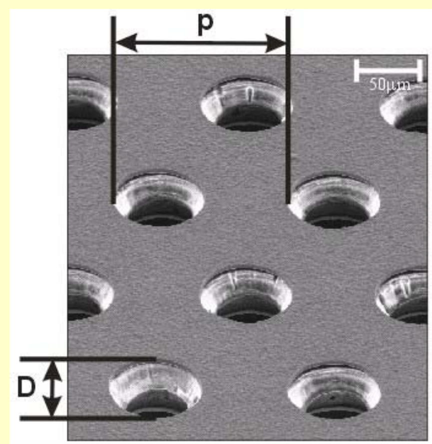
Use Micro Pattern Gas Detectors (GEMs, MicroMegas) for gas amplification

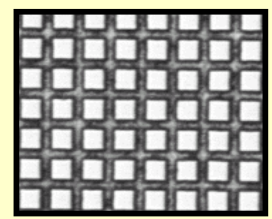
- inherent 2D structure
- natural ion-feedback suppression
- low material budget in end-plate

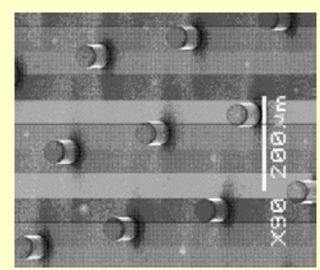


R&D issues:

- stable operation on large scale
- optimize resolution/pad geometry
- pad or pixel readout?
- operation in magnetic field
- field cage design







Significant effort worldwide
LC-TPC collaboration

Central Tracking: Silicon Tracker

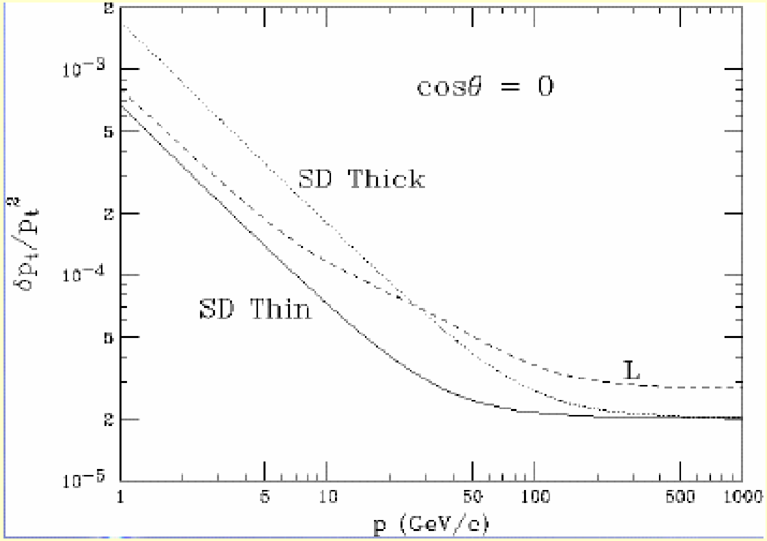
SiLC collaboration

<u>Design issues:</u>

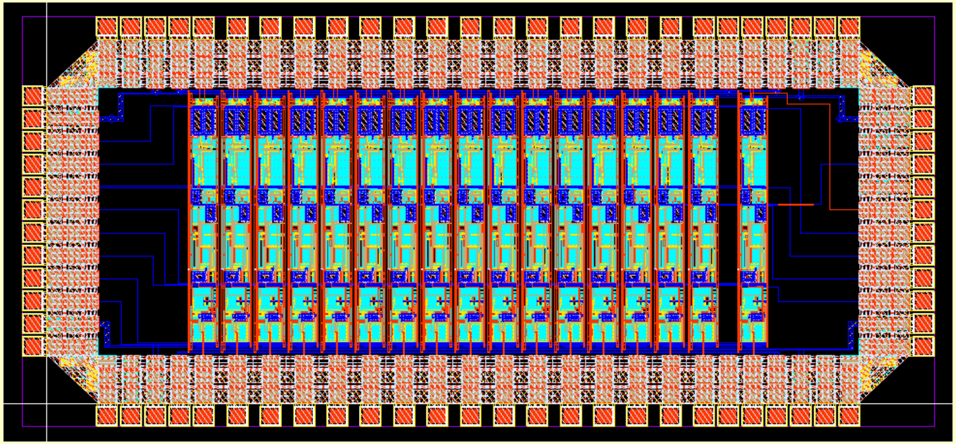
long ladders (minimize material)
limit noise → long shaping time
develop r/o chips
pattern recognition → use VTX as seed

aim for testbeam in 2006

momentum resolution: simulation



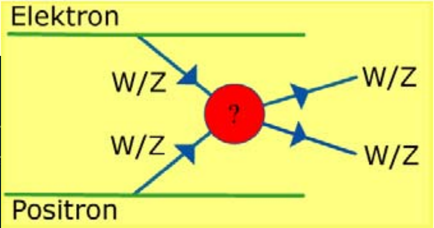
FE prototype ASIC

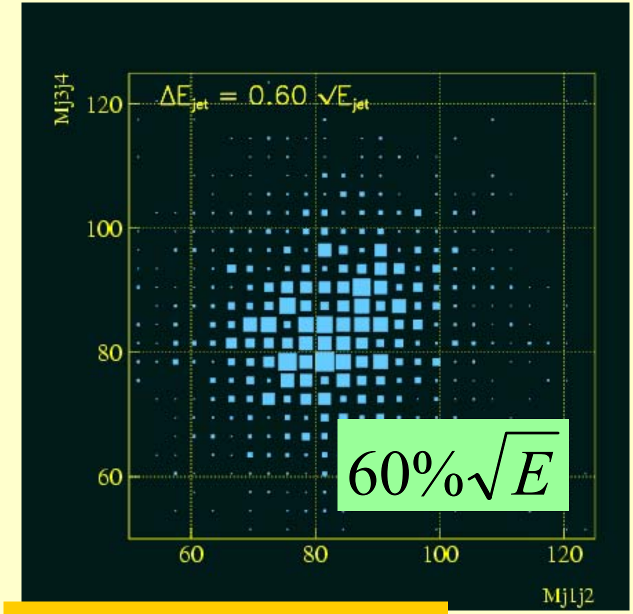


Calorimetry

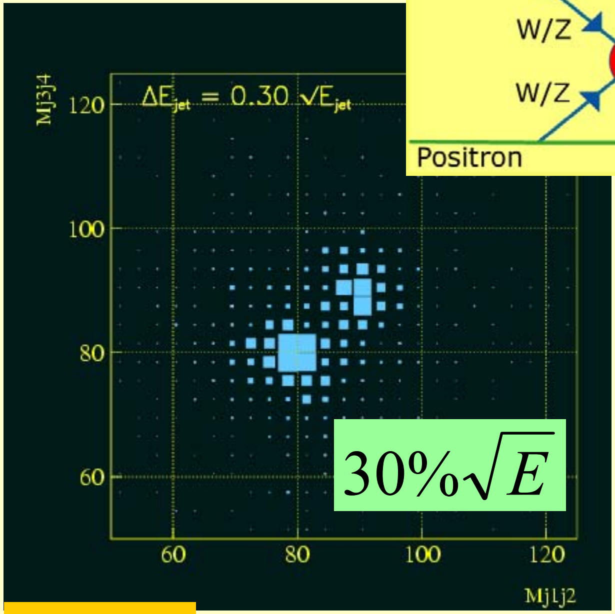
Driving physics: Jet energy resolution in multi-jet (6,8,..) events
tau reconstruction
non-pointing photons

Example: Strong EW symmetry breaking
distinguish W and Z in their hadronic decays
w/o kinematic constraints





ALEPH like resolution



ILC goal

Calorimetry

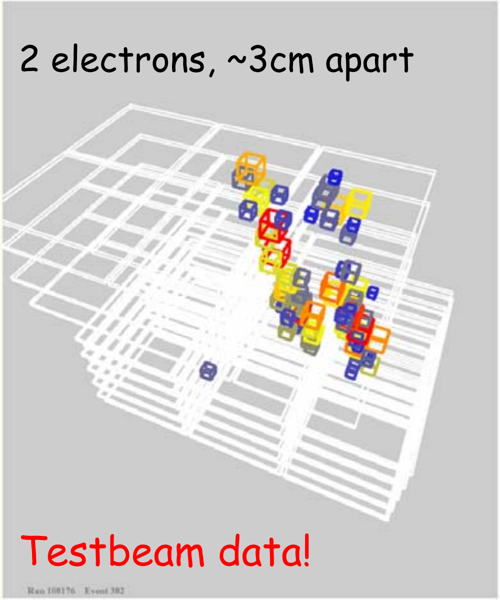
Calorimeter and Particle Flow algorithm are a real challenge

Present technologies under study:

EM calorimeter: Si W (SiD,LDC), Sc W (GLD)

HAD calorimeter: scintillating tiles ('analog')

RPC, GEM, tiles ('digital')



addressed by a world-wide R&D effort

e.g. CALICE: 26 Institutes, 9 Countries in 3 Regions

ECAL

1st testbeam at DESY

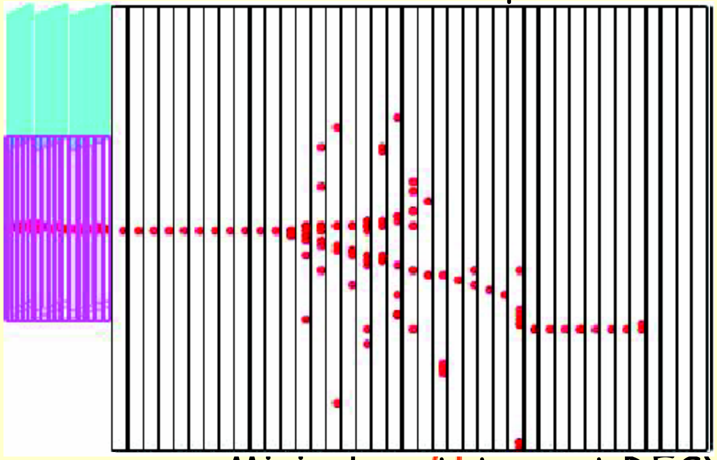
HCAL

HCAL issues:

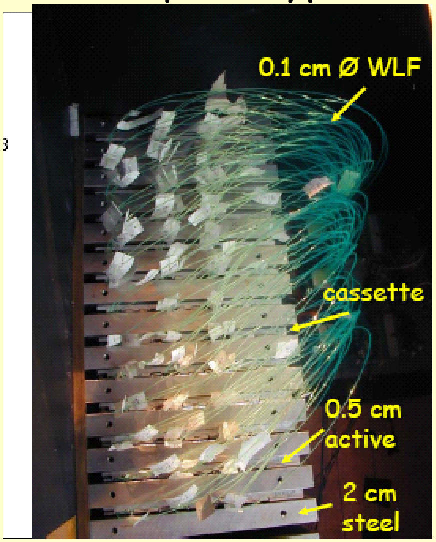
active medium gaseous or scintillator?

- Understand hadron showers
- Scintillator: new possibilities with small photo-sensors ("SiPMs")
- Prototype construction under way

Fluctuations of hadronic showers
Simulation of same 6 GeV pion:

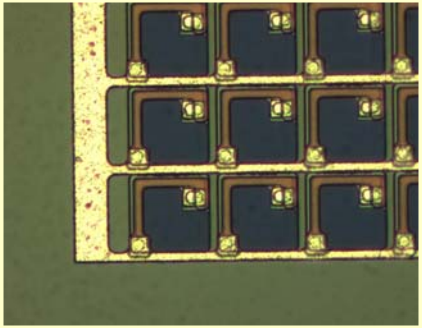


Minical prototype at DESY



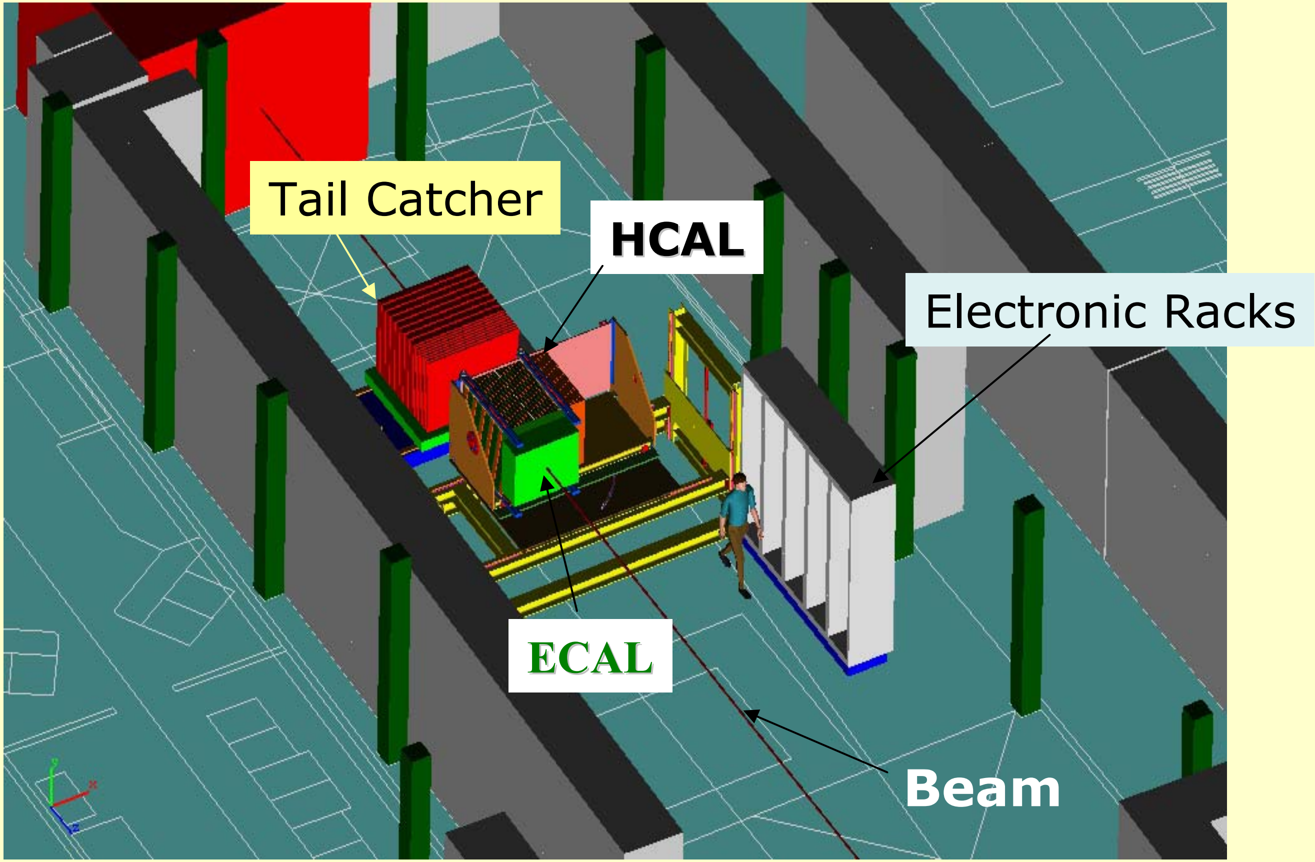
Scintillator plane with SiPM r/o

Detail of SiPM



ECAL+HCAL joint testbeam

1m^3 prototype testbeam planned for 2006
detailed understanding of el-mag and hadronic showers in a highly-granular Calorimeter



Next Steps

Aug. 2005 (Snowmass) - optimize detector parameters.
Prepare inputs to machine.

End 2005 - A detector R&D document to go with the machine baseline configuration document.

End 2006 - Detector Concept Report (one document with multiple concepts, costed) to go with the machine reference design report.

2008 Detector Concept will be part of
ILC Technical Design report

Conclusions

- Physics case for the ILC is compelling and independent of LHC findings
- LHC and ILC are highly complementary
  Joint analyses of LHC and ILC data yields additional benefit
  Overlapping running can feedback on LHC analysis and data taking
- Development of the detectors is an integral part of GDE
- Ambitious time schedule – detector concepts and subdetector R&D are proceeding at good pace. Still time to join!