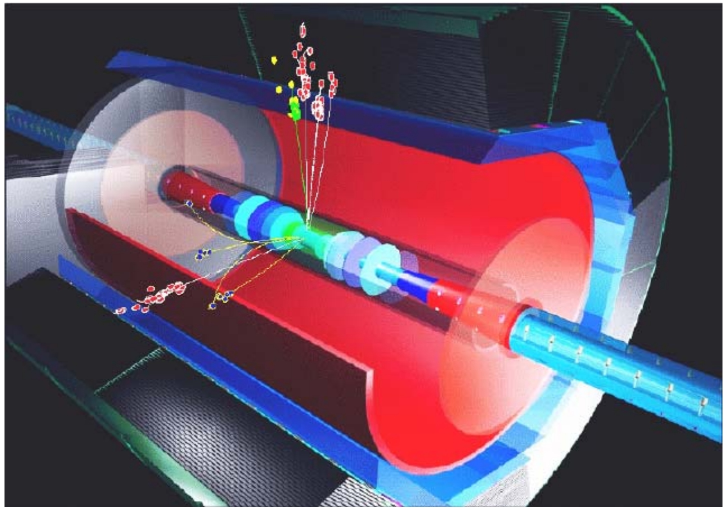


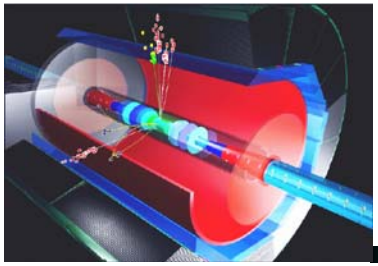
Physics and Experiments at the International Linear Collider

Felix Sefkow
DESY

ICFA Instrumentation School

Special thanks to my colleagues for helping me with their material: T.Behnke, K.Desch and many others

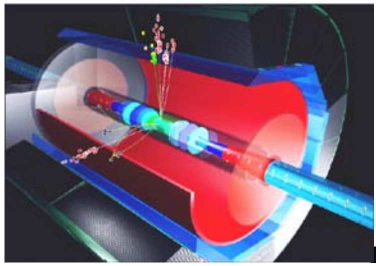
Istanbul, September 8, 2005



Plan

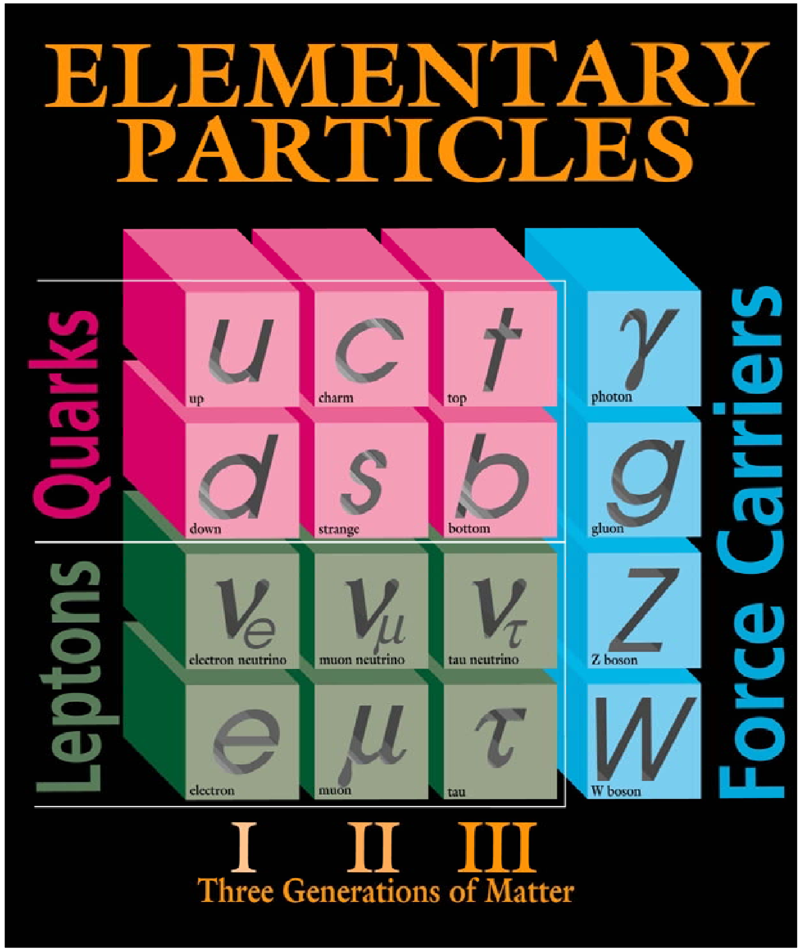
1. Physics case for the ILC
2. The accelerator, timeline
3. Standard Model physics: Higgs
4. Beyond: Supersymmetry and more
5. The detector challenge

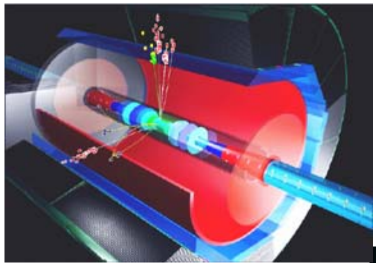
1. Physics Case



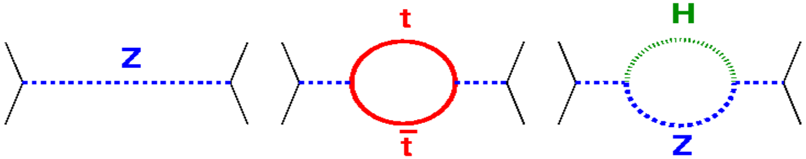
The Standard Model

- A unified and precise (0.1%) description of all known subatomic phenomena
- Down to 10^{-18} m
- Back to 10^{-10} s after the Big Bang
- Consistent at the quantum loop level



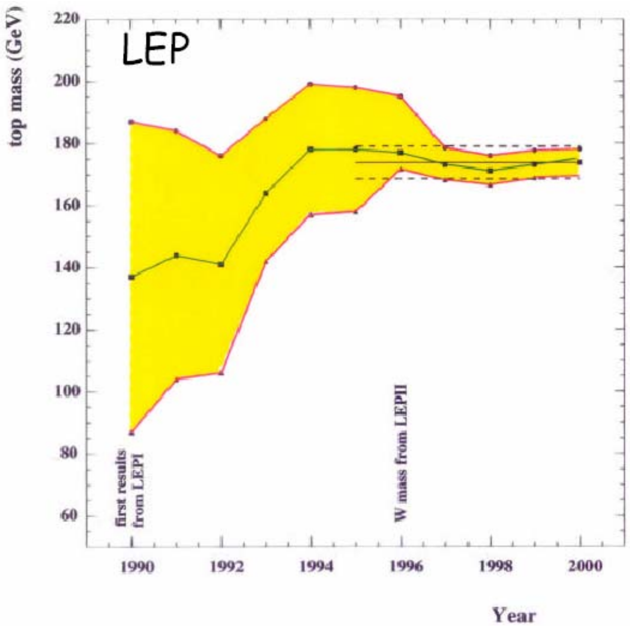


Radiative corrections



$$M_Z^2 = M_Z^{2\;\;0.Ordnung} \cdot (1 + \Delta)$$

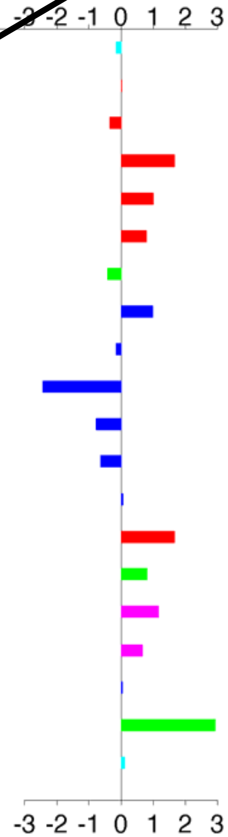
$$\Delta = \dots M_t^2 \dots + \dots \ln M_H \dots$$

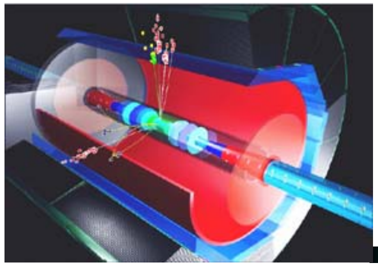


Winter 2003

0.002%

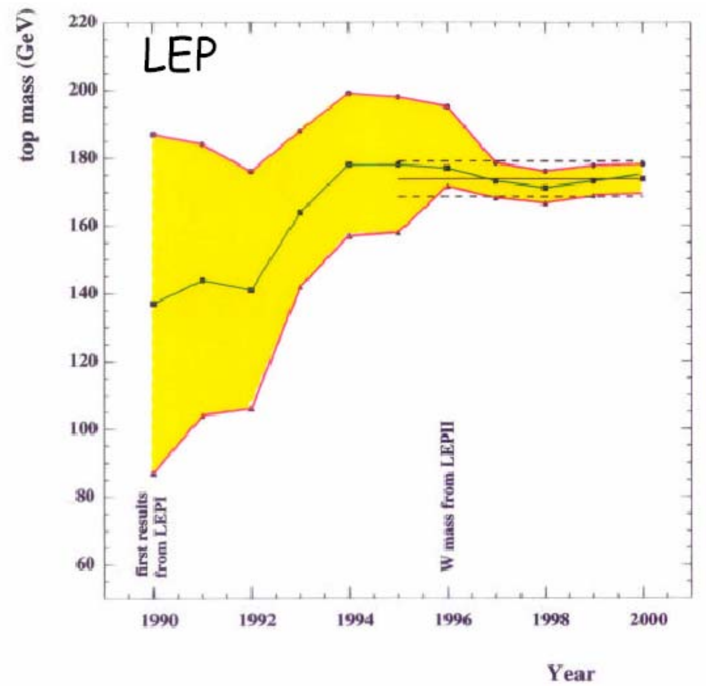
	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-0.16
m_Z [GeV]	91.1875 ± 0.0021	0.02
Γ_Z [GeV]	2.4952 ± 0.0023	-0.36
σ^0_{had} [nb]	41.540 ± 0.037	1.67
R_l	20.767 ± 0.025	1.01
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.79
$A_l(P_\tau)$	0.1465 ± 0.0032	-0.42
R_b	0.21644 ± 0.00065	0.99
R_c	0.1718 ± 0.0031	-0.15
$A^{0,b}_{fb}$	0.0995 ± 0.0017	-2.43
$A^{0,c}_{fb}$	0.0713 ± 0.0036	-0.78
A_b	0.922 ± 0.020	-0.64
A_c	0.670 ± 0.026	0.07
A_l(SLD)	0.1513 ± 0.0021	1.67
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.82
m_W [GeV]	80.426 ± 0.034	1.17
Γ_W [GeV]	2.139 ± 0.069	0.67
m_t [GeV]	174.3 ± 5.1	0.05
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	2.94
Q_W(Cs)	-72.83 ± 0.49	0.12

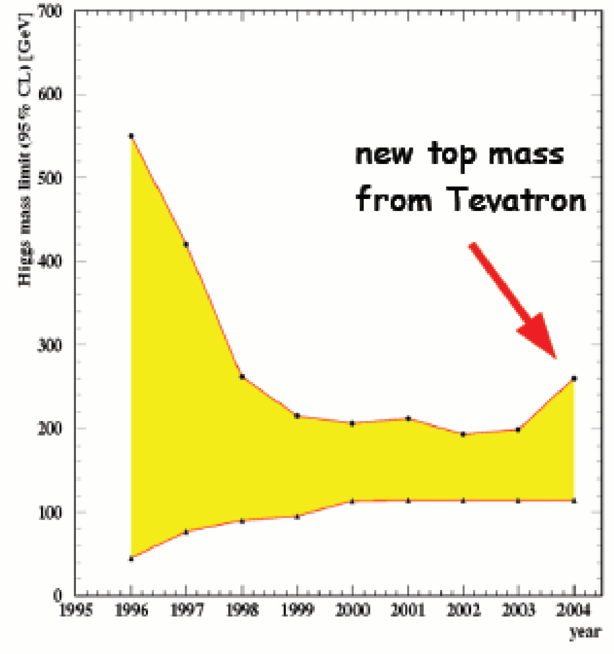




Anticipated discoveries

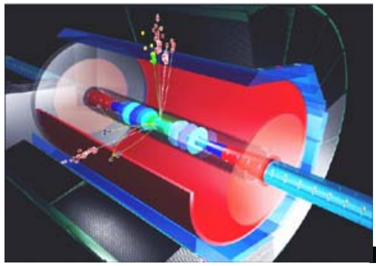
- The history of particle physics is full of predicted discoveries:
  - Positron, neutrino, pions, quarks, gluons, W, Z bosons, charm, bottom
  - Most recent example: **top** quark - still missing: the **Higgs** boson





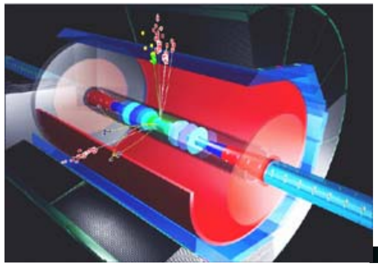
From quantum corrections with virtual top quarks

… with virtual Higgs bosons

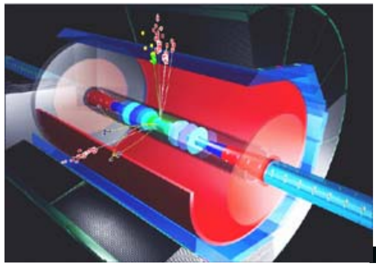


Standard Model deficiencies

- The Higgs particle – required to give masses to force carriers and matter constituents – has not yet been observed
- 25 or so free parameters: masses, couplings, mixing angles, which are not explained
- General stability / fine tuning problems above ~ 1 TeV
- Gravity is not included



What is the world made of?

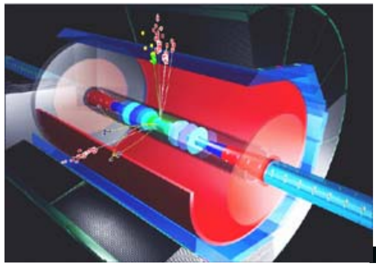


21^{st} century physics

- Fundamental questions on matter, energy, space and time:
  - How do particles acquire mass?
  - Is there a Higgs boson? Or something else taking its role?
  - What are its properties?
  - What is the origin of electroweak symmetry breaking?

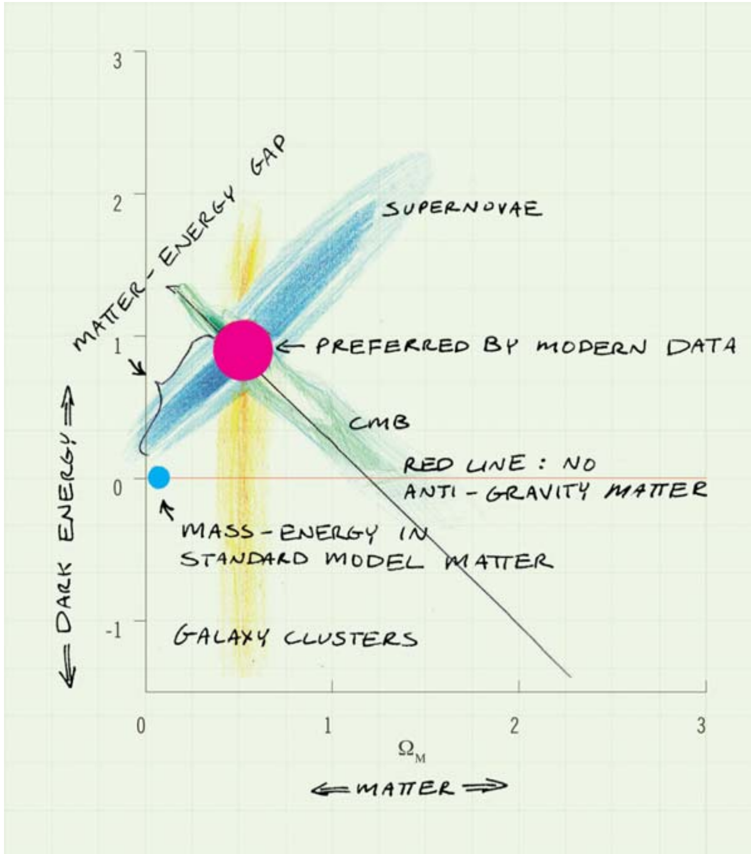
  - Do the fundamental forces unify?
  - How does gravity tie in?

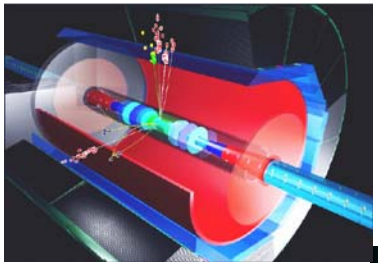
  - What is the universe made of? What is dark matter?
  - (What is dark energy? Maybe a 22^{nd} century question…)



Dark matter

- In many models dark matter is a "thermal relic" WIMP
- WIMPs are neutral, weakly interacting, massive particles
- Once in thermal equilibrium, then frozen out due to expansion of the universe
- Calculable density today
- Naturally appear in EW symmetry breaking models
  - Mass 100 GeV or so
  - Copiously produced at colliders



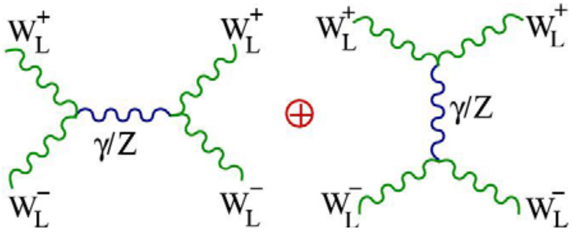


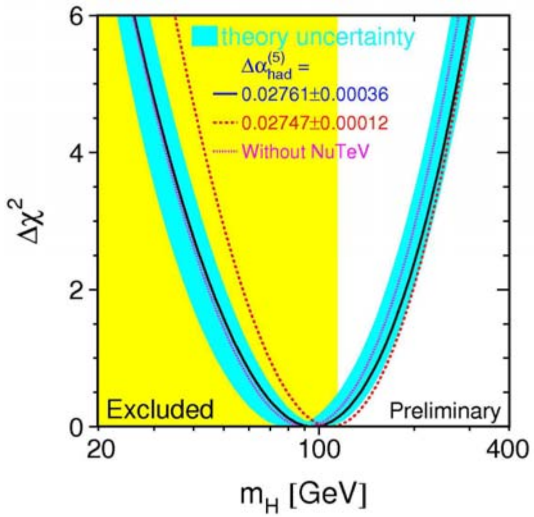
New physics around the corner

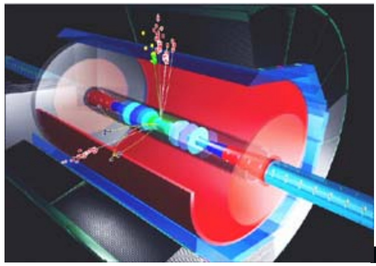
- We expect fundamental answers at the TeV scale
- I.e. from the immediate generation of new colliders

- For theoretical reasons:
  - SM w/o Higgs is inconsistent above ~ 1.3 TeV
  - Fine-tuning problem if nothing between m_W and m_{Planck} – must be near m_W to be relevant

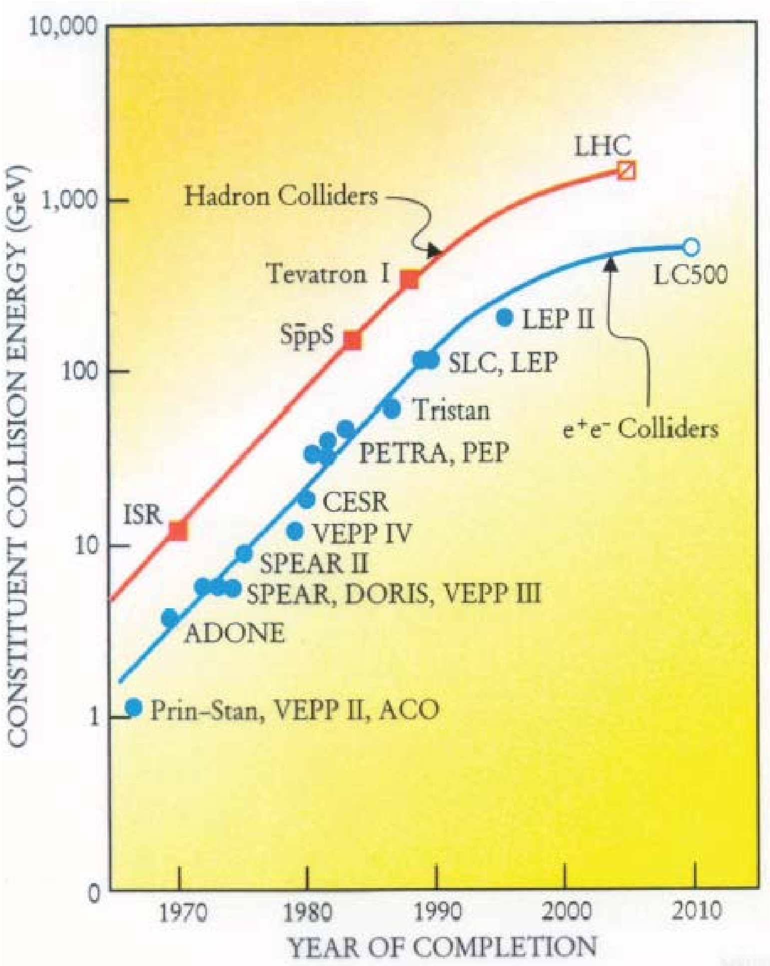
- For experimental reasons
  - Electroweak precision data want Higgs – or "something in the loops" - below 250 GeV
  - Astrophysics wants a dark matter particle with a few 100 GeV



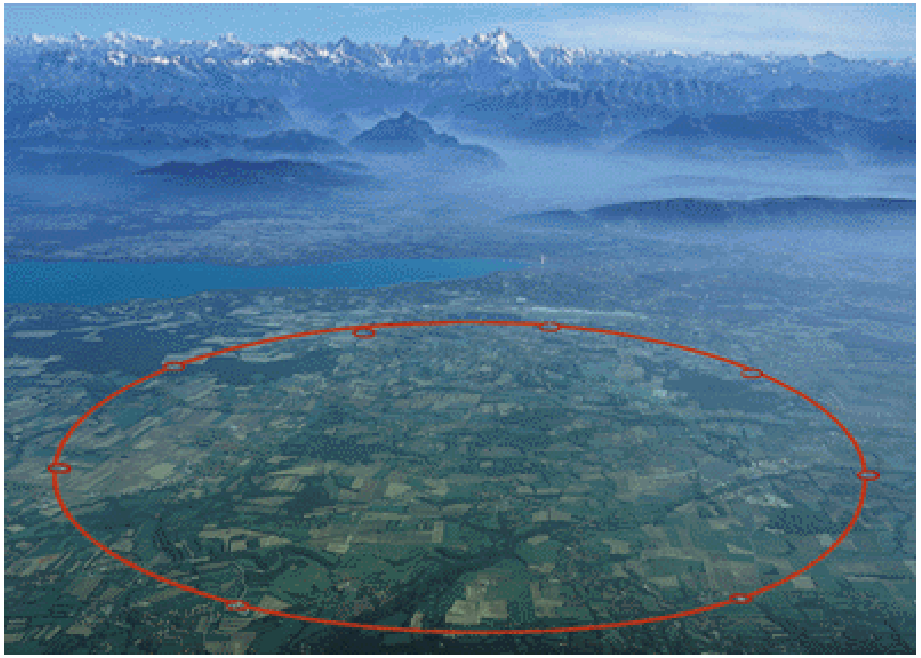


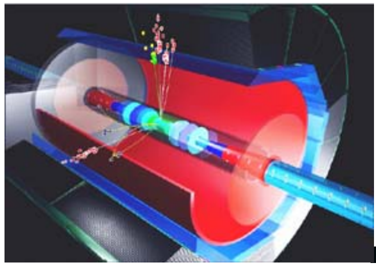


The energy frontier



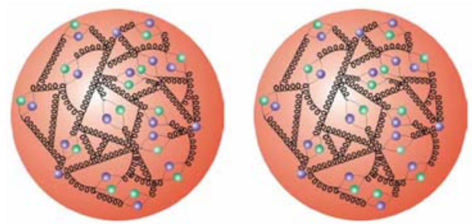
- The LHC with 14 TeV proton proton collisions will start up in 2007





Hadron and electron machines

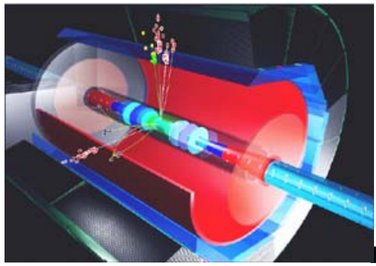
… are complementary like X-rays and microscope

p  p

e^+ • • e^-

- Proton (anti-) proton colliders:
  - Energy range higher (limited by magnet bending power)
  - Composite particles, different initial state constituents and energies in each collision
  - Hadronic final states difficult
- Discovery machines
- Excellent for some precision measurements

- Electron positron colliders:
  - Energy range limited (by RF power)
  - Point-like particles, exactly defined initial state quantum numbers and energies
  - Hadronic final states easy
- Precision machines
- Discovery potential, but not at the energy frontier

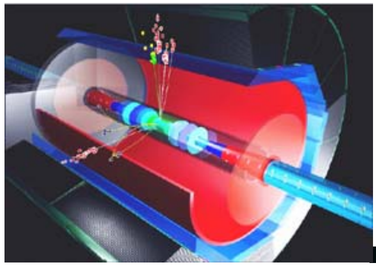


Independent physics case

- Whatever the discoveries at the LHC will be - an e+e- collider with 0.5 - 1TeV energy will be needed to study them

  - Light Higgs: verify the Higgs mechanism
  - Heavy Higgs: ditto, and find out what's wrong in EW precision data
  - New particles: precision spectroscopy
  - No Higgs, no nothing: This is beyond SM! find out what is wrong, and measure the indirect effects with max precision

- Case has been worked out and well documented (e.g. TESLA TDR)
- See also answers to ITRP questions: hep-ph/0411159

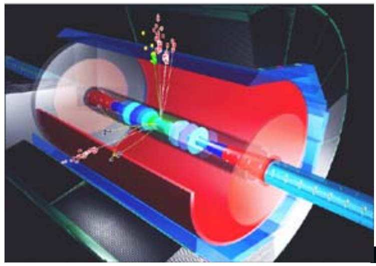


ILC Physics case

- New physics at the origin of electroweak symmetry breaking is expected to be discovered at the next generation of collider experiments
- The case for an e+ e- collider with 500 GeV – 1 TeV energy rests on general grounds and is excellent in different scenarios.
- Cosmological arguments favor this energy region, too.
- The ILC case holds independent of LHC findings; LHC and ILC complement each other.

2. Accelerator

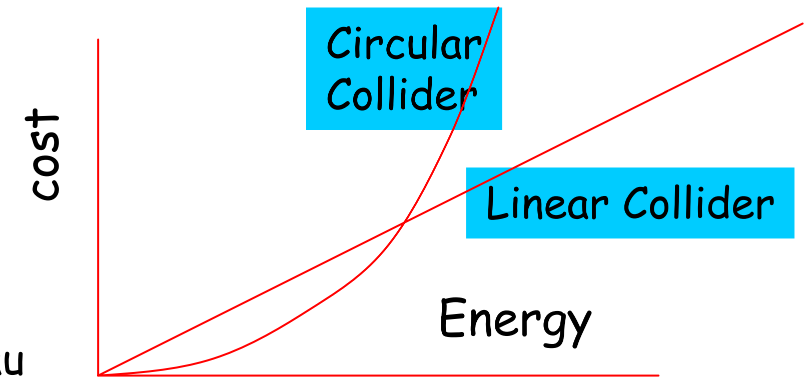
(a fascinating topic in itself;
here only a few facts for the experimentalist)



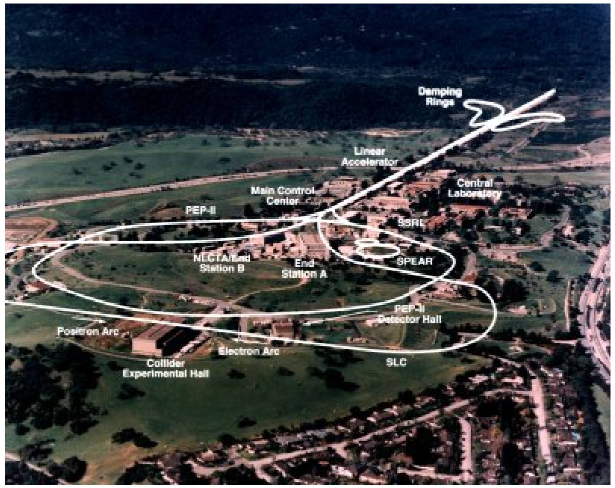
Linear vs. circular

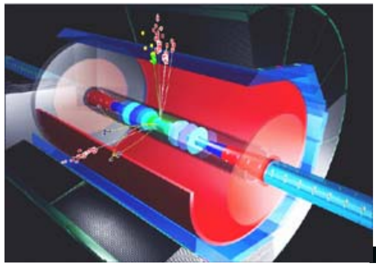
- Synchrotron radiation
  - $\Delta E \sim (E^4 / m^4 R)$ per turn; 2 GeV per beam at LEP2 (200 GeV)
- Cost
  - circular $\sim a R + b\, \Delta E \quad \sim a R + b\, (E^4 / m^4 R)$
    - Optimization $R \sim E^2 \quad \Rightarrow$ Cost $\sim E^2$
  - linear $\sim L$, where $L \sim E$

SLC at SLAC: 100 GeV



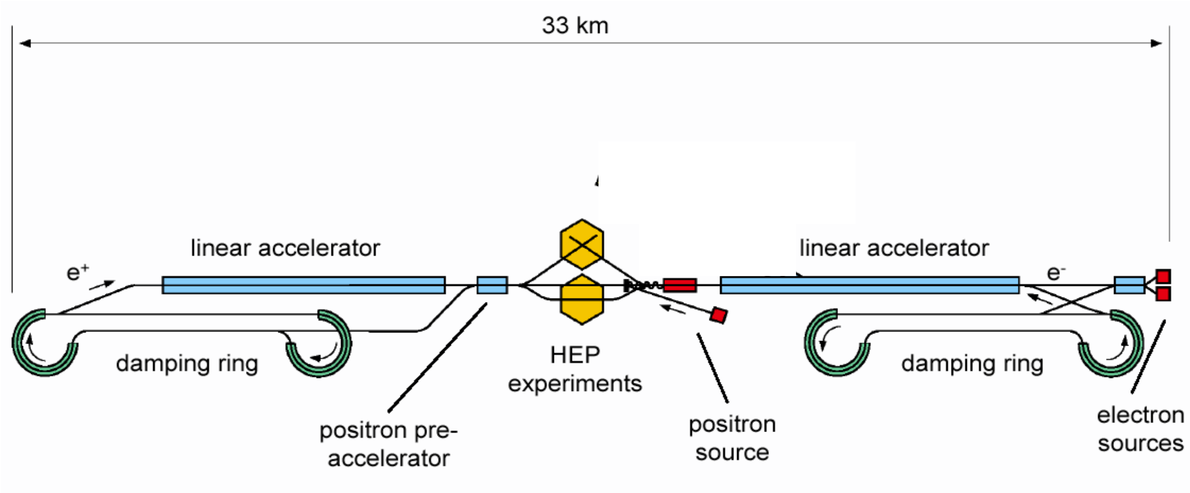
From J.Brau

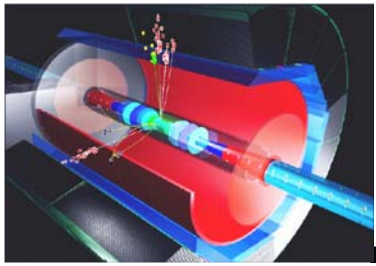




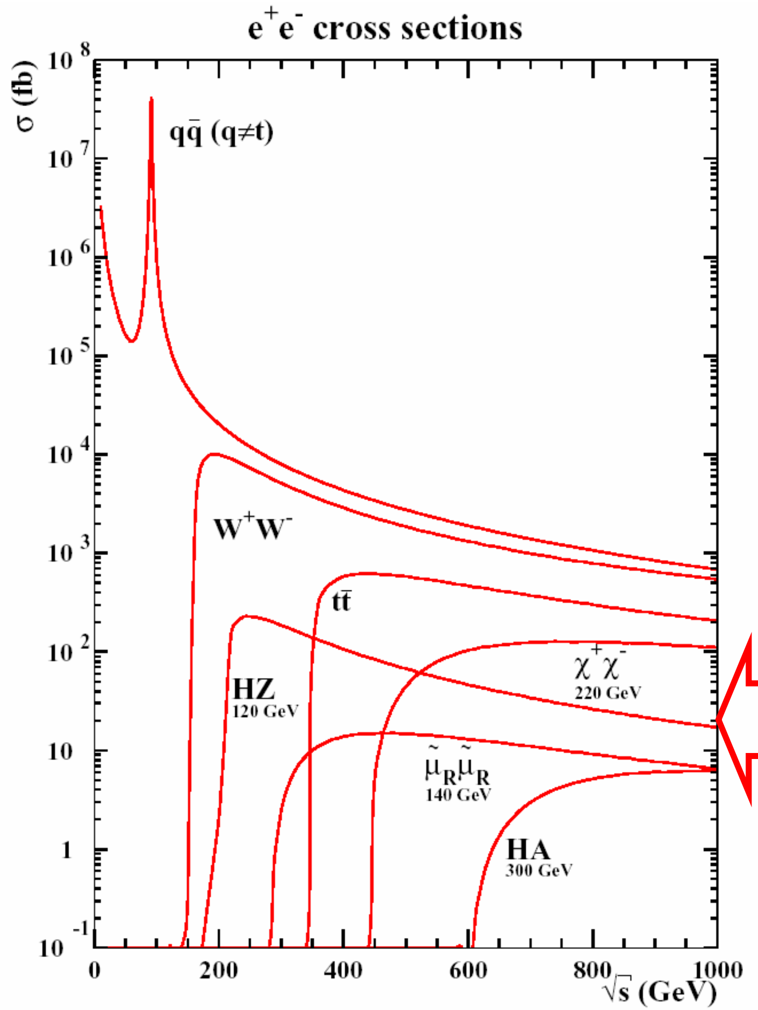
The Linear Collider consensus

- 200 GeV < $\sqrt{s}$ < 500 GeV
- Integrated luminosity ~ 500 fb^{-1} in 4 years
- Upgrade to 1TeV
- 2 interaction regions
- Concurrent running with the LHC

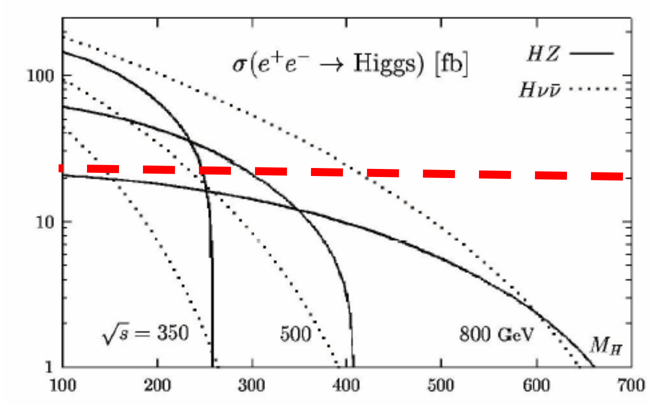




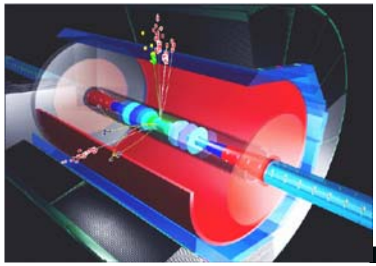
Luminosity



- 1/s calls for high luminosity



1% precision – 10’000 events
for cross-section of 20 fb
and integrated luminosity of 500 fb^{-1}
= 100 days at 5*10^{34}cm^{-2}s^{-1}



RF power

Ties Behnke: Linear Collider Projects

Introduce the centre of mass energy, E_{cm}:

$$L = \left(\frac{E_{cm}}{E_{cm}}\right) \frac{n_b N^2 f_{rep}}{4\pi\sigma_x\sigma_y} H_D$$

$$n_b N f_{rep} E_{cm} = P_{beams} = \eta_{RF\rightarrow beam} P_{RF}$$

η_{RF} is RF to beam power efficiency.

Luminosity is proportional to the RF power for a given E_{cm}

$$L = \frac{\eta_{RF\rightarrow beam} P_{RF} N^2}{4\pi\sigma_x\sigma_y E_{CM}} H_D$$

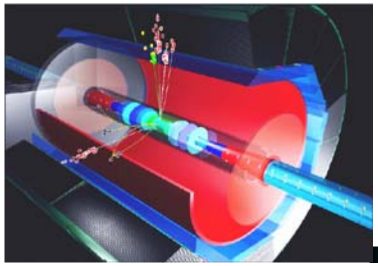
Some numbers:

E_{cm}	= 500 GeV
N	= 10^{10}
n_b	= 1000
f_{rep}	= 10 Hz

P = 8 MW x eff
eff ~ 10%
dep on technology

LEP f_{rep} = 44 kHz

- Need to push beam sizes at IP -> tolerances, beam-beam effects



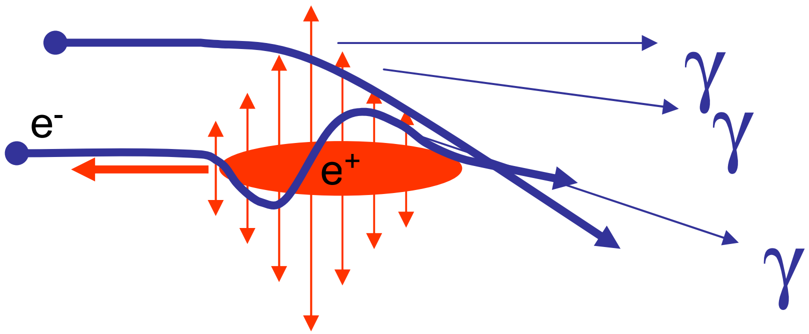
Beamstrahlung

- Lower bunch rate than in storage ring - need intense beams at IP
- Energy loss

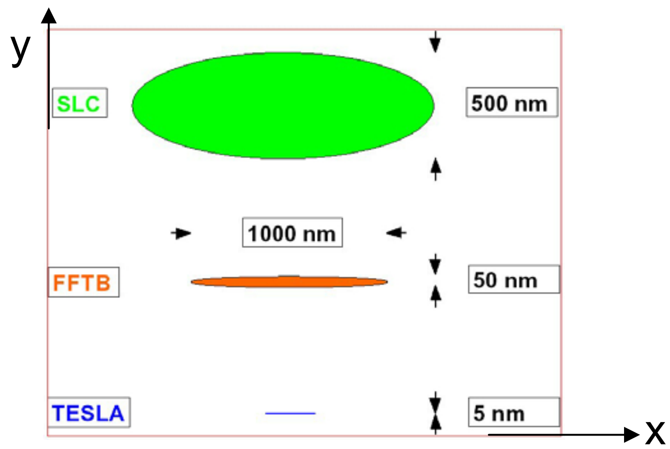
$$\delta_{BS} = \frac{\Delta E}{E} \propto \frac{E_{cm}}{\sigma_z}\left(\frac{N}{\sigma_x^* + \sigma_y^*}\right)^2$$

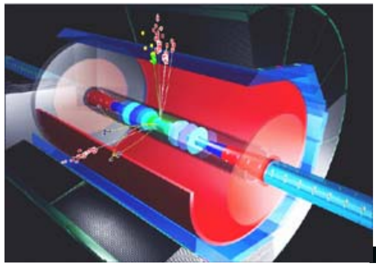
but L~ 1 / $\sigma_x^*\sigma_y^*$ ➒ chose flat beams

Hard photons radiated in field of colliding bunch



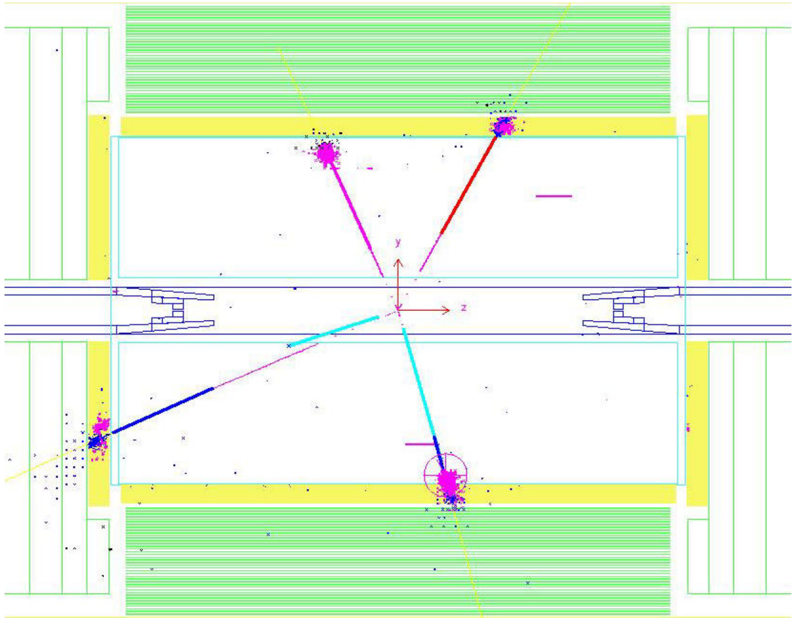
- 1.5% reduction of collision energy
  - > 5% for 10% of events
- 140'000 e+e- pairs / BX
  - Machine detector interface challenging
- γγ background



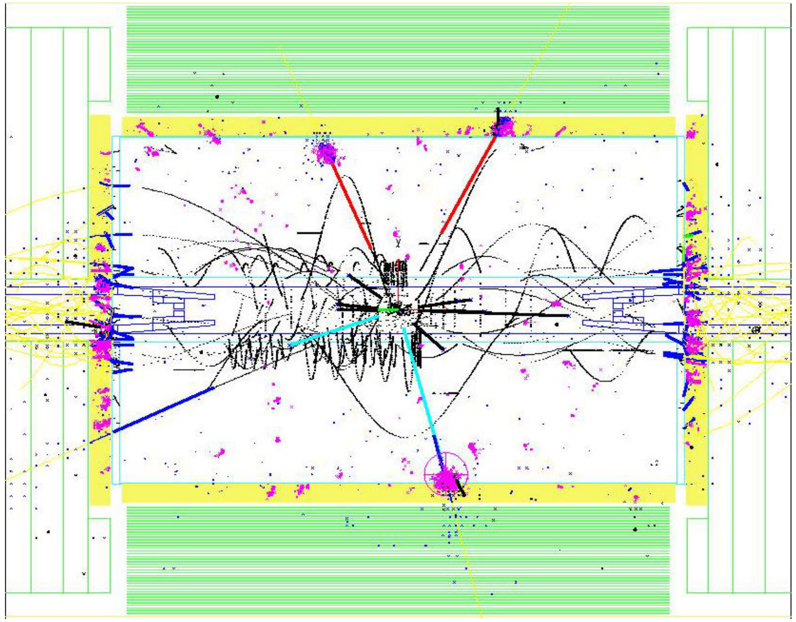


Two photon background

$HZ \to \tau\tau ee$ event (no background)

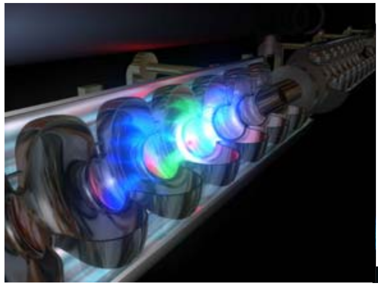


Same event + ~60 BX pileup



TESLA / ILC: BX every 337 ns, 3000 BX / train (1ms), 5 trains /s

Occupancies small, but need fast enough time-stamping



Time line*

2004: superconducting (TESLA) technology chosen

- Unanimously endorsed by ICFA

2005: Global design initiative (GDI) starts

- B.Barish chairs, distributed effort (no host)

2006: Reference design report

- Ambitious, must start from TESLA, NLC, GLC proposals
- Sample site specific, include rough **detector concept and costing**

2008: Technical design

- Ready for political approval
- Site selection, international organization, collaboration forming

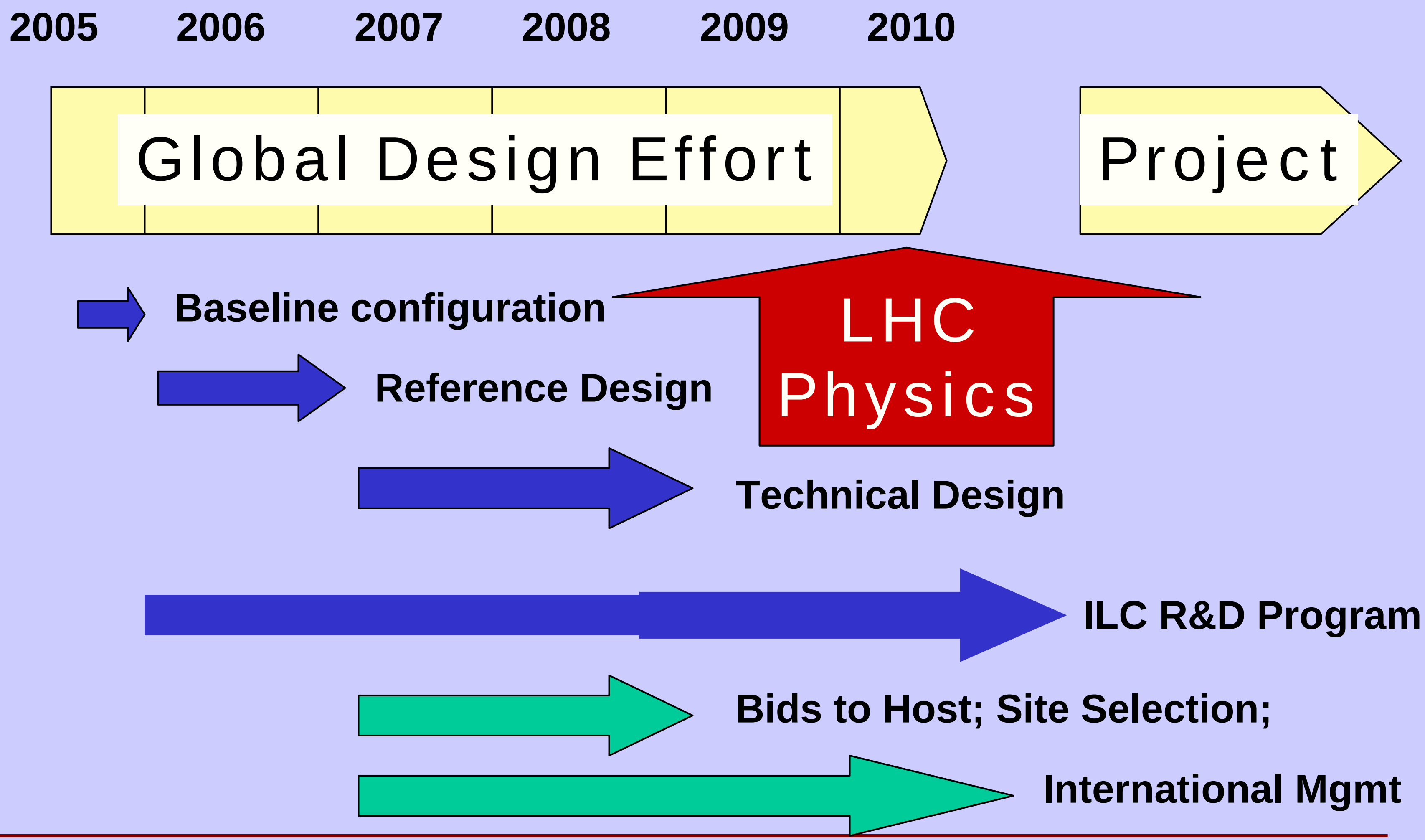
2009/10: possibility to react to first LHC results

- Not waiting, but preparing defined "escape lane"

2014/15: first beams

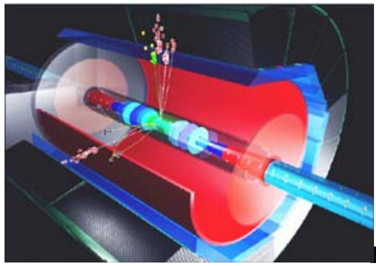
** "adopted" by funding agencies*

The GDE Plan and Schedule



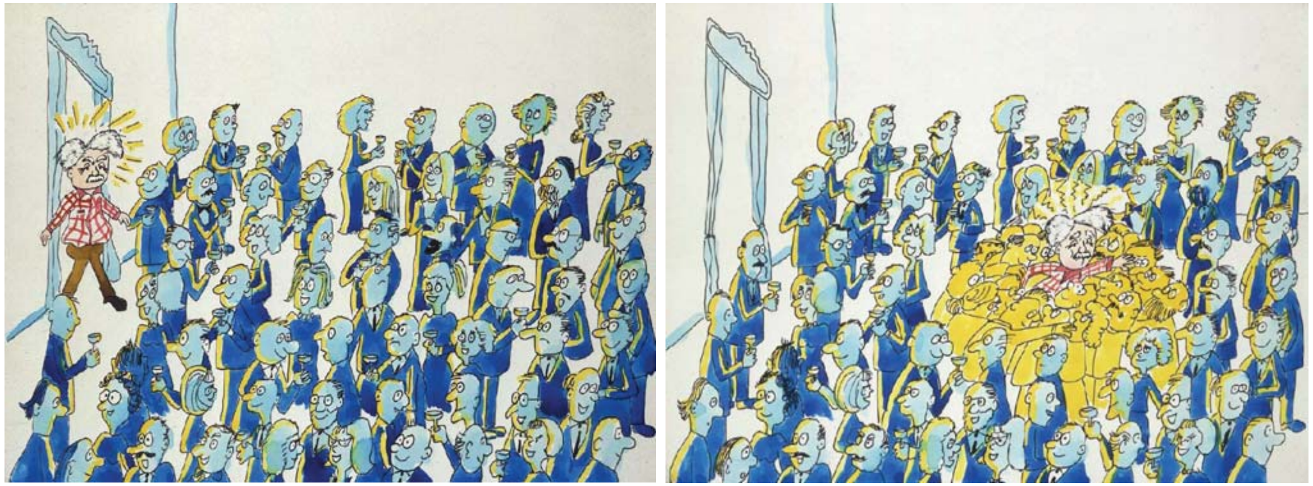
B.Barish

3. Higgs physics

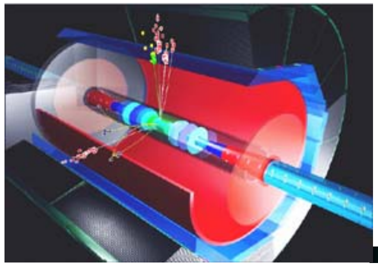


The Higgs particle

- The last missing ingredient to the Standard Model
- Essential to keep theory finite
- Weak gauge bosons and all quarks and charged leptons are originally massless; they acquire mass through interaction with the Higgs field

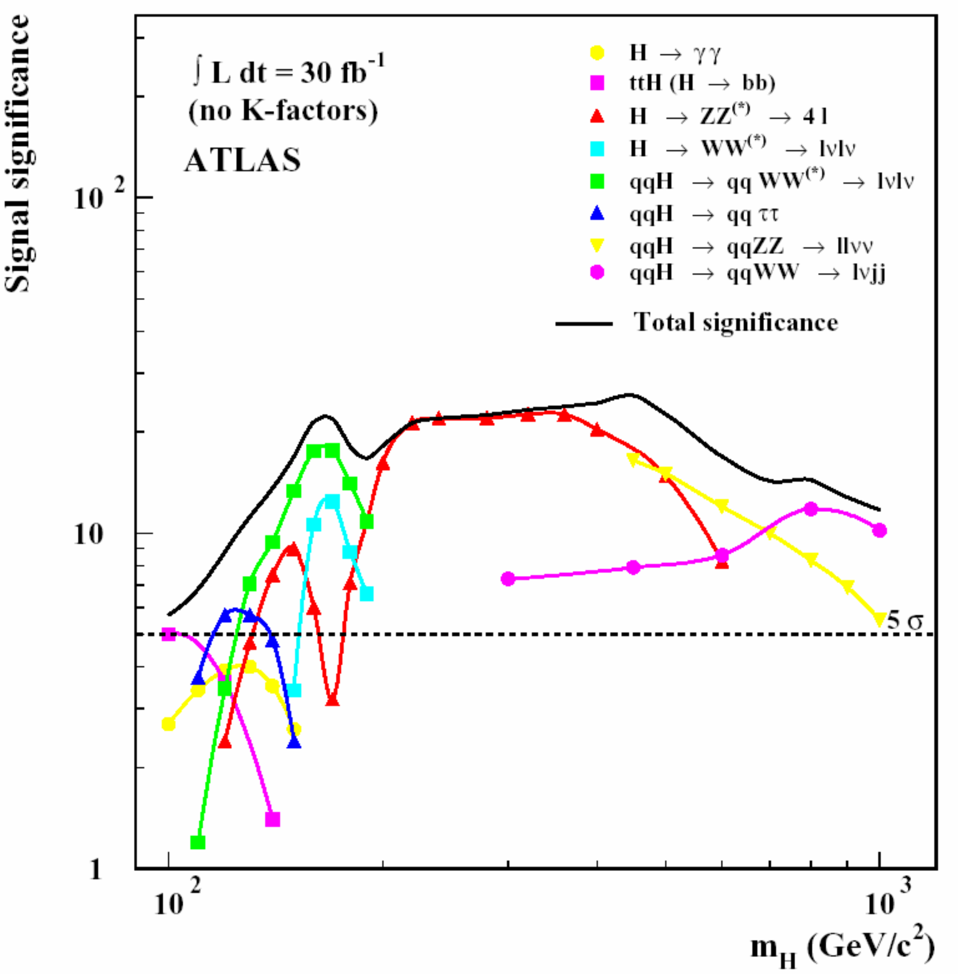


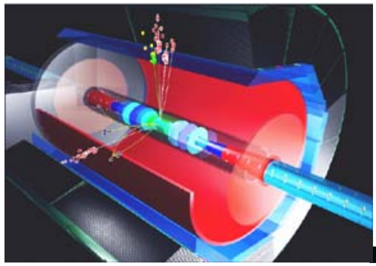
- New form of matter: fundamental scalar field
- A new force which couples proportional to mass



Higgs discovery

- At the LHC after about 1 year
- Measure some properties
  - Mass
  - Ratios of couplings
- 1 year LHC = 1 day LC
  - LC can discover Higgs-like particle even if rate is 1/100 of SM

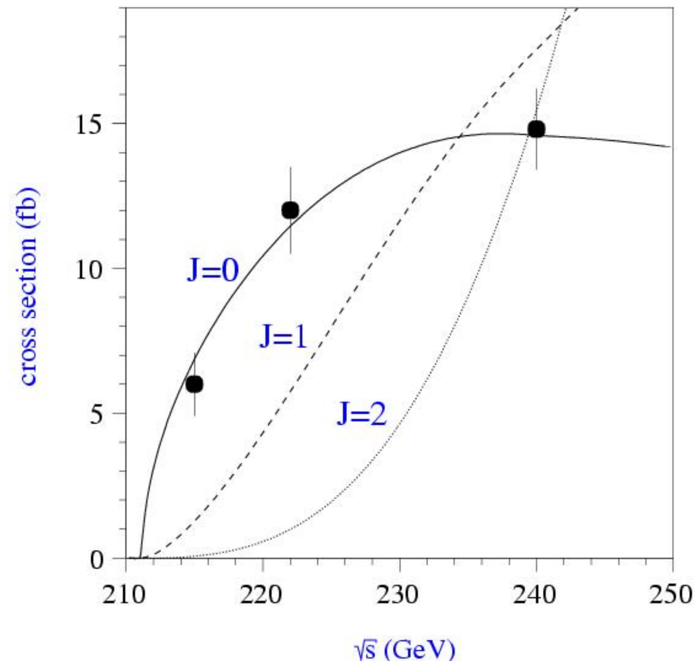


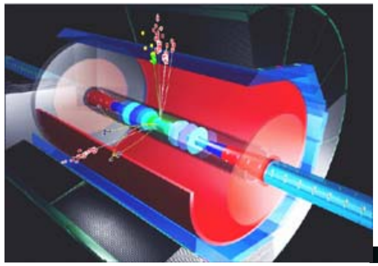


Higgs at the ILC

- Measure the Higgs profile
  - Mass and width
  - Quantum numbers
  - Couplings to fermions
  - Couplings to gauge bosons
  - Self coupling
- Prove that the Higgs **is** the Higgs
  - Establish the Higgs mechanism
- Do Higgs precision physics
  - Deviations from SM, admixtures, SUSY Higgs

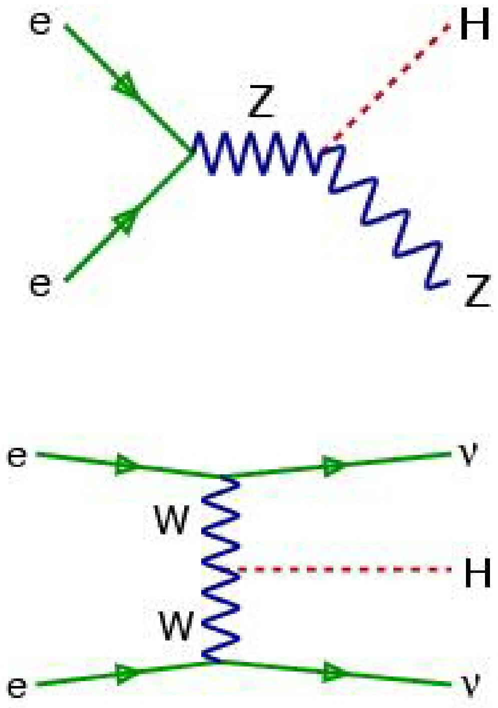
e.g. spin

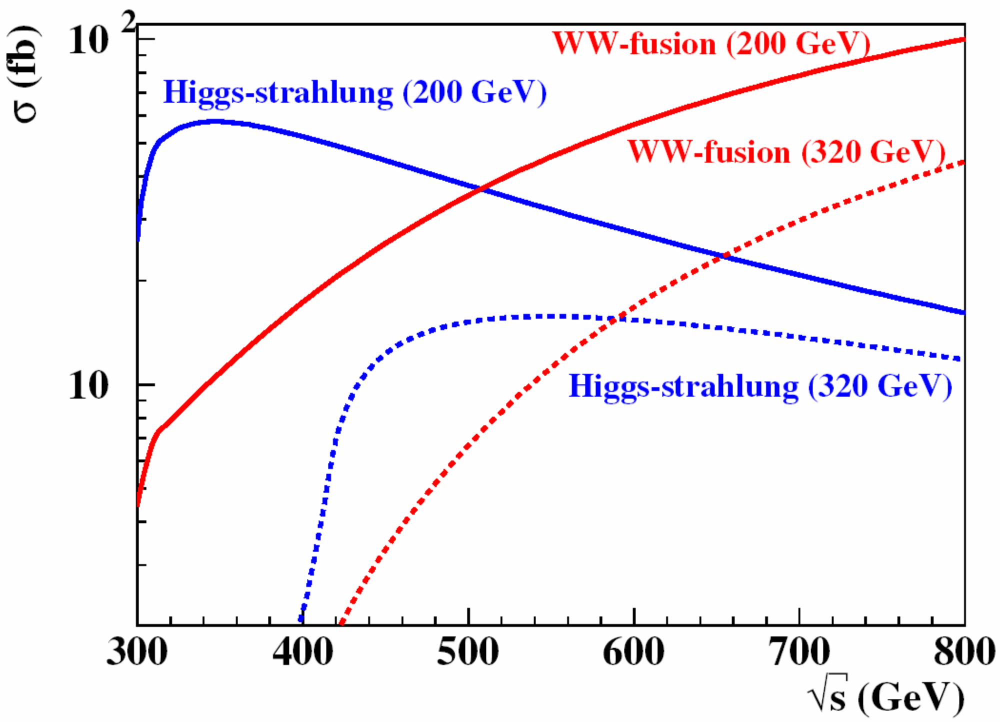


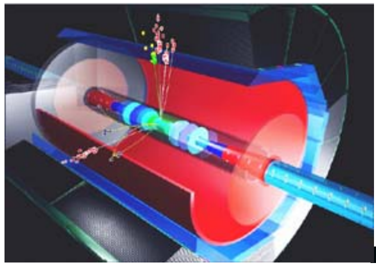


Higgs production

- Higgs strahlung and WW fusion

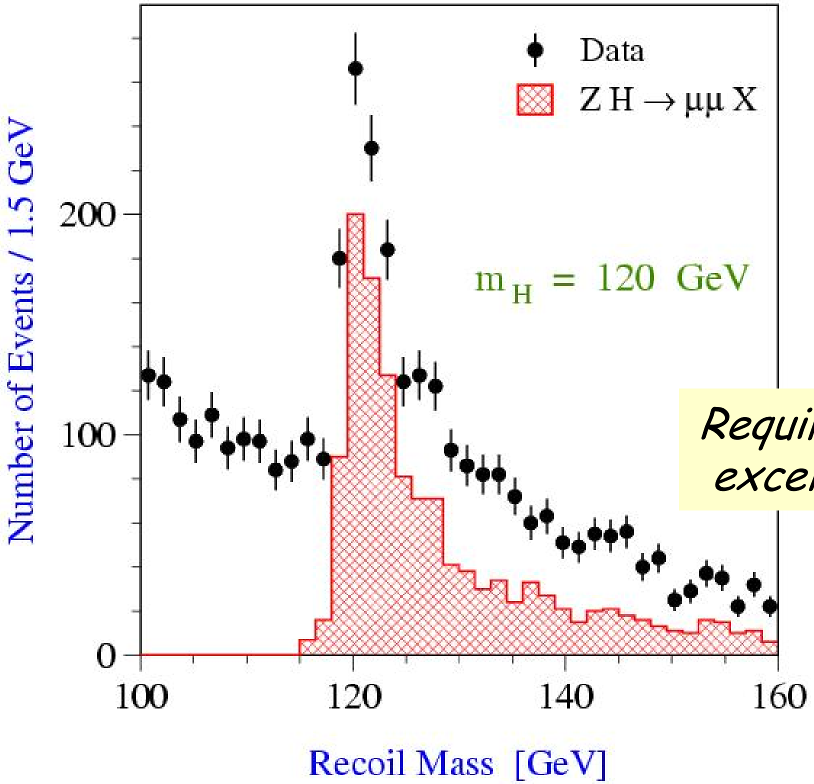




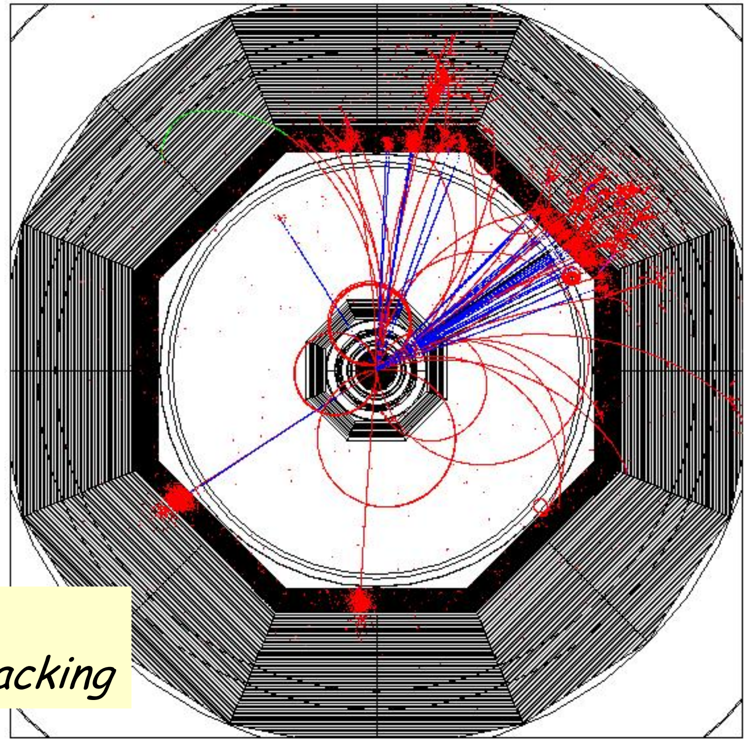


Higgs signature

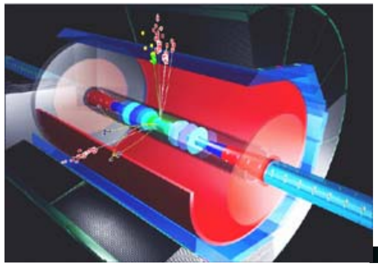
- Model independent
- Independent of decay mode



Requires excellent tracking



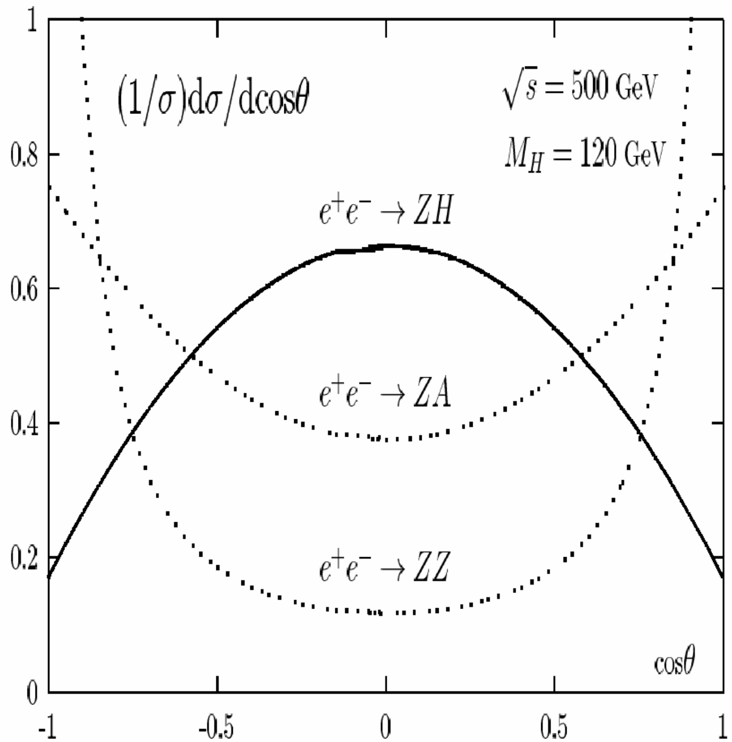
- Provides absolute normalization for decay rates



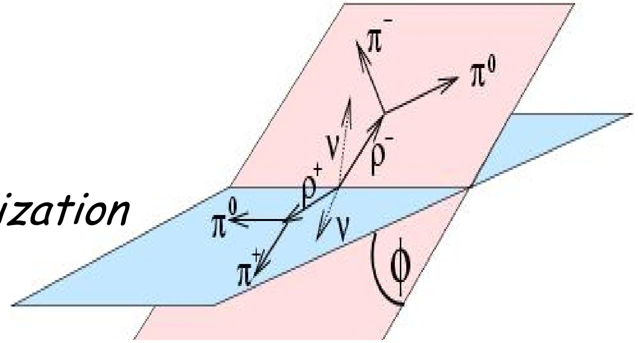
Determine CP

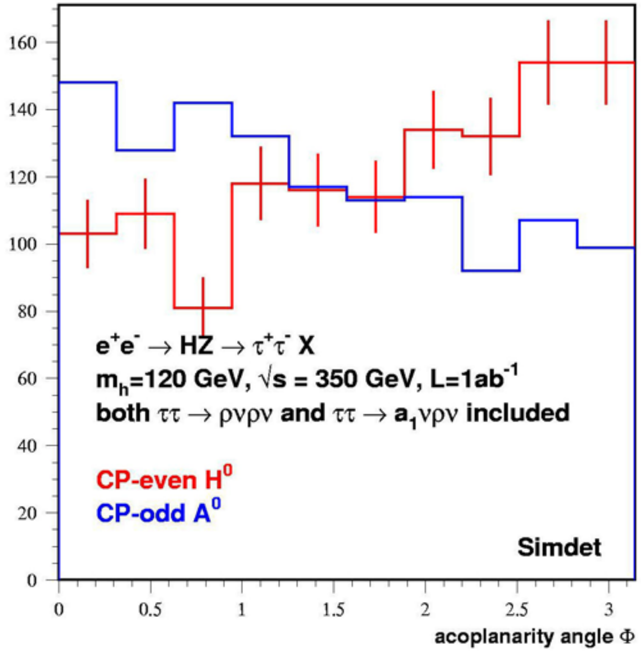
- Many models have two Higgs doublets
  - H^+, H^-, and even H and h, odd A

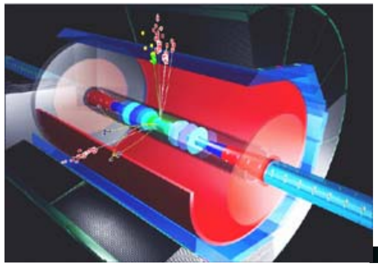
Production angle



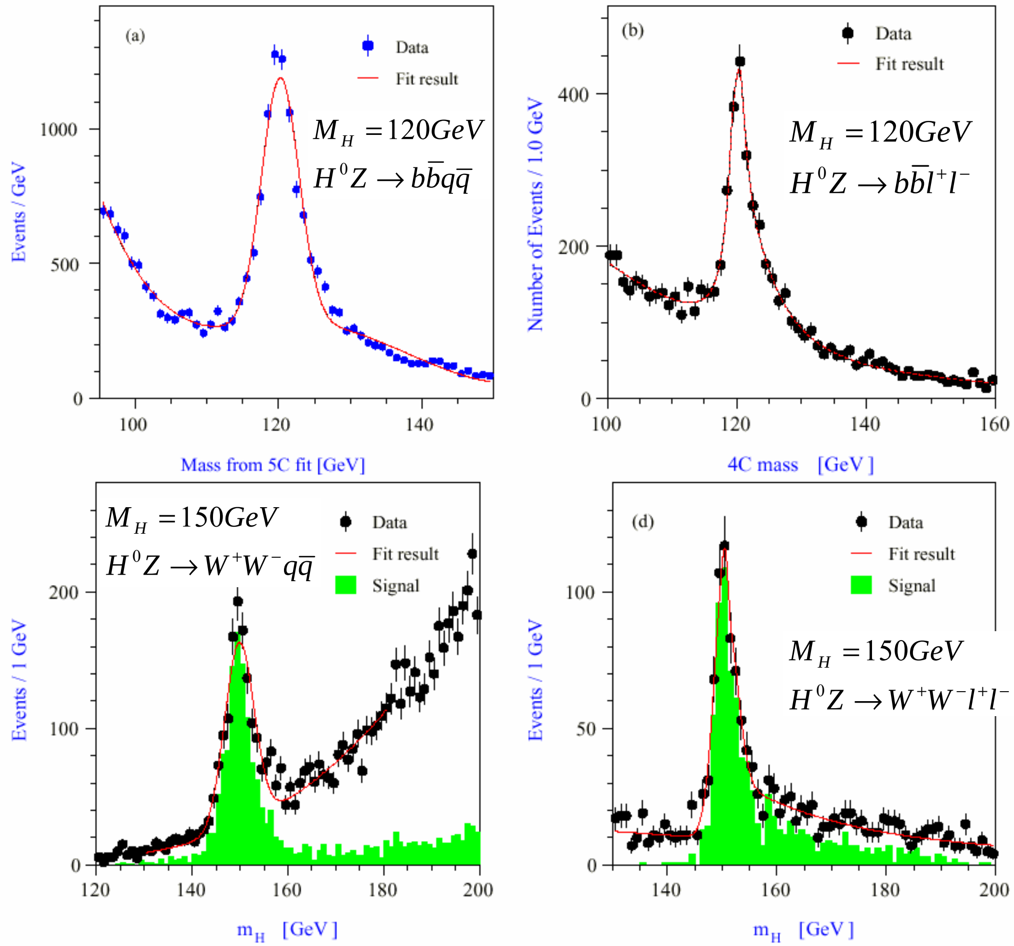
Tau polarization





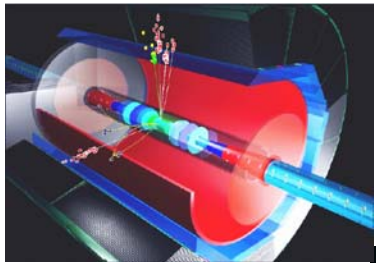


Higgs mass

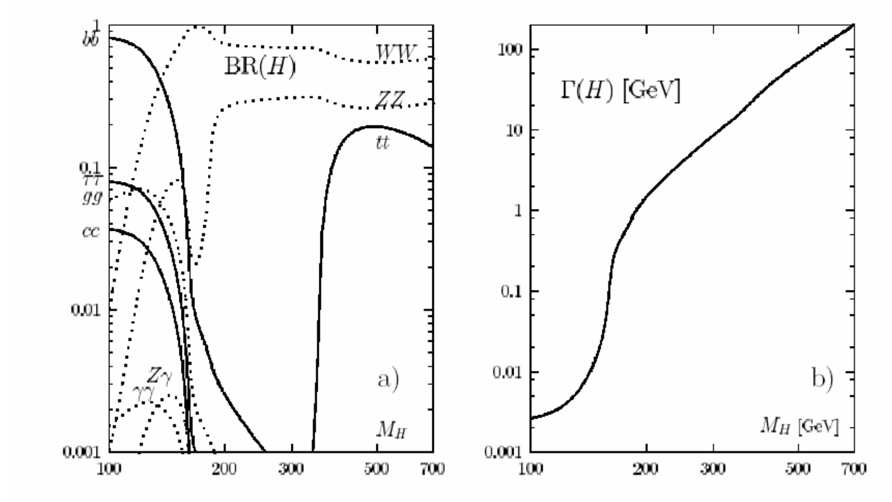


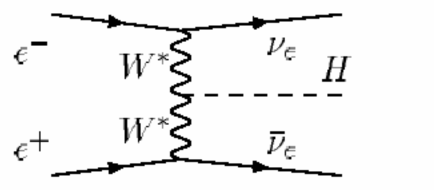
- Use kinematic constraints
  - Detector resolution still matters
- Precision below 0.1%

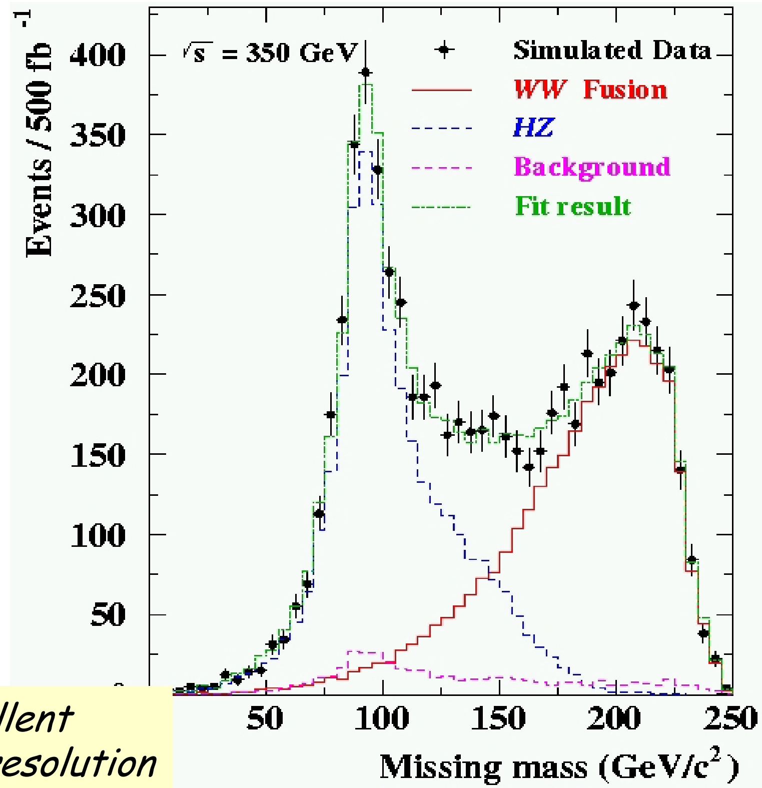
M_H (GeV)	Channel	δM_H (MeV)
120	$\ell\ell qq$	±70
120	$qqbb$	±50
120	Combined	±40
150	$\ell\ell$ Recoil	±90
150	$qqWW$	±130
150	Combined	±70
180	$\ell\ell$ Recoil	±100
180	$qqWW$	±150
180	Combined	±80



The Higgs boson total width

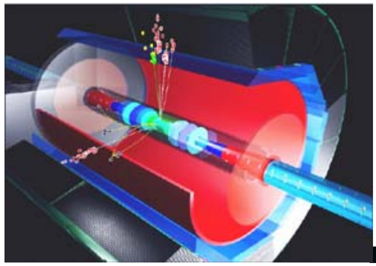






- For large M_H use line shape
- for low M_H from σ (WW fusion) and BR ($H \rightarrow WW^*$) = $\Gamma_{H \rightarrow WW^*} / \Gamma_{total}$
- gives access to all couplings

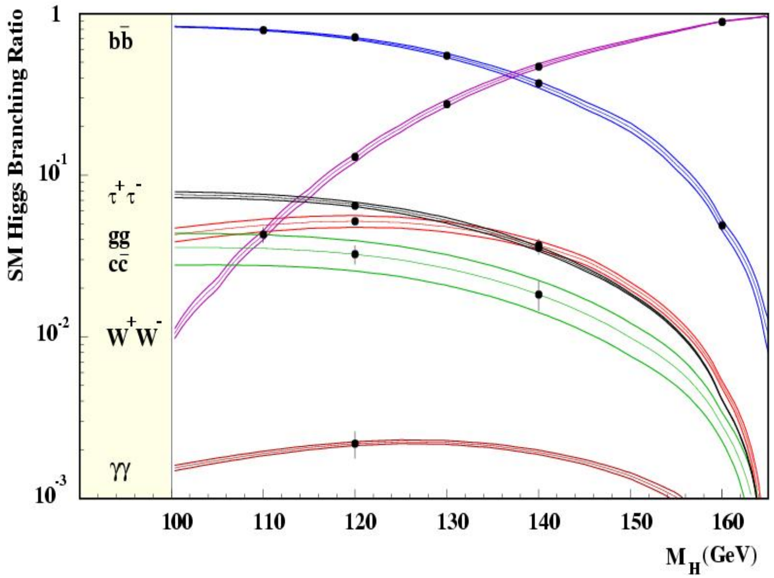
Needs excellent jet energy resolution



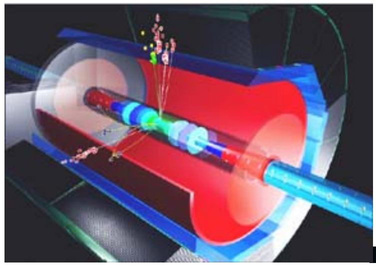
Higgs boson couplings

- The Higgs mechanism at work
  - coupling ~ mass
- HWW, HZZ: production cross section
- Yukawa couplings to fermions
  - Most challenging: disentangle bb, cc and gg
  - Beauty <u>and charm</u> tagging

Higgs branching ratios (absolute!)



Requires excellent vertex detector



Top Yukawa coupling

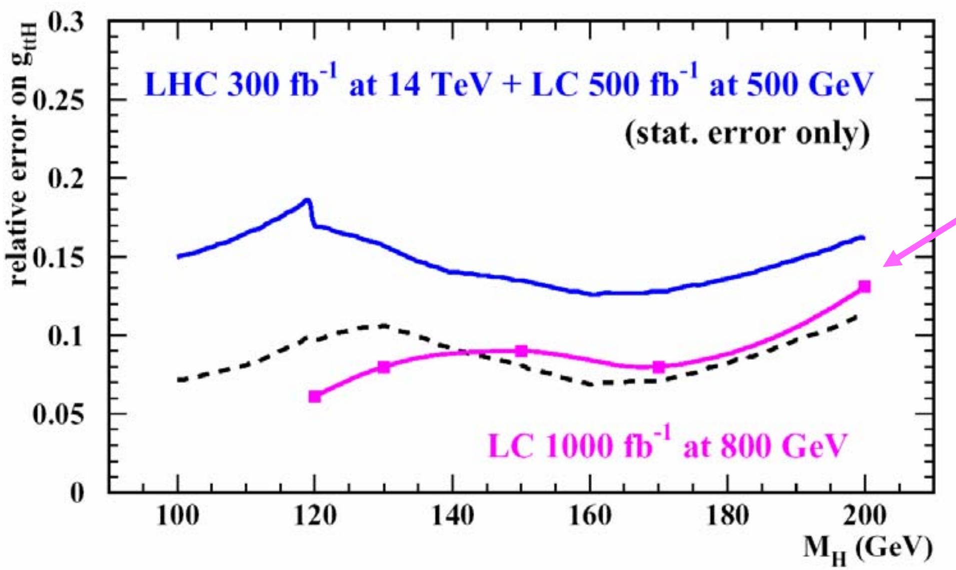
- Example for LHC ⊕ LC synergy: Common interpretation:

  absolute top Yukawa coupling from

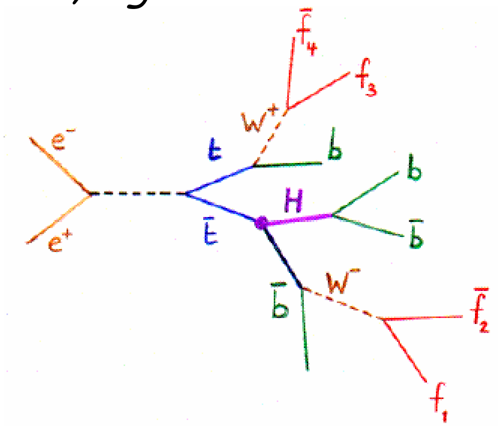
  $gg,qq \to ttH$ $(H \to bb, WW)$ (@LHC) (rate ~ $(g_t\, g_{b/W})^2$)

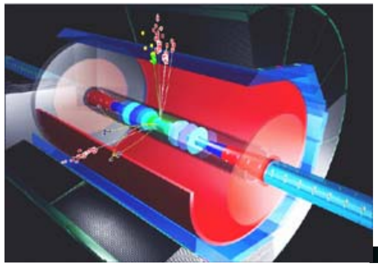
  and

  $BR(H \to bb, WW)$ (@LC) (absolute measurement of $g_{b/W}$)



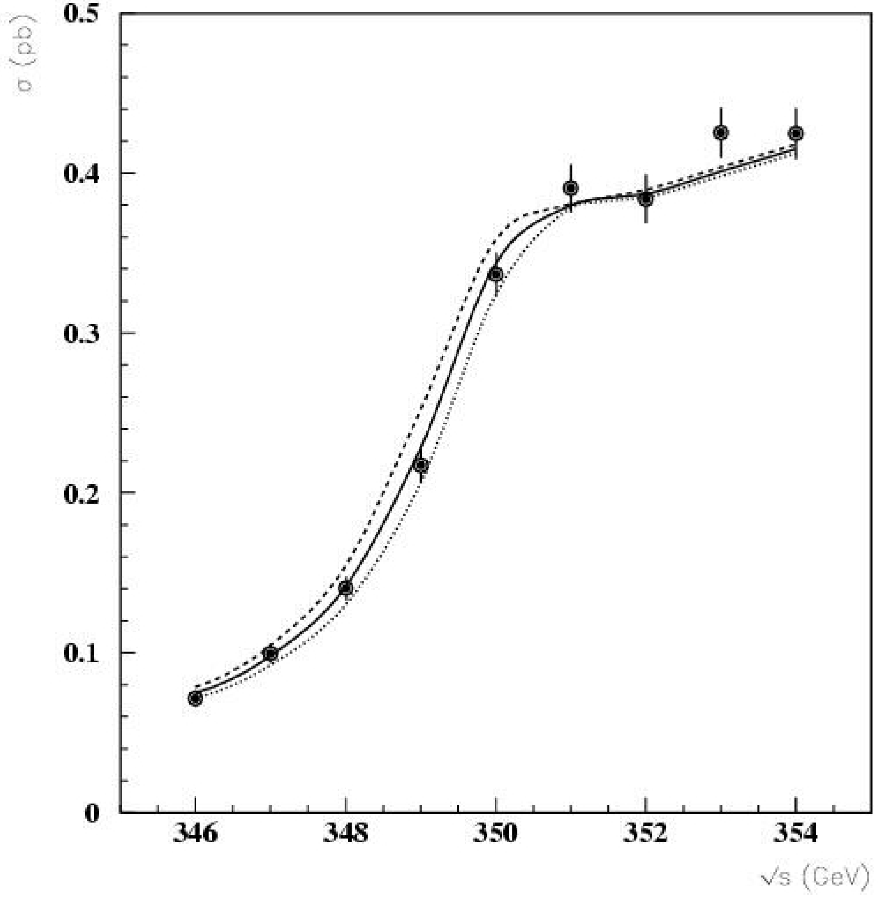
At the ILC (alone), need highest energy and combine many channels, e.g.:

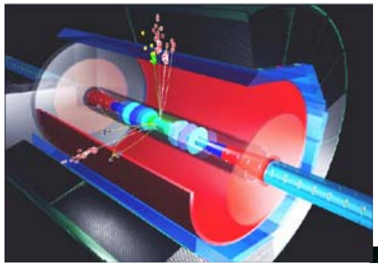




Top mass

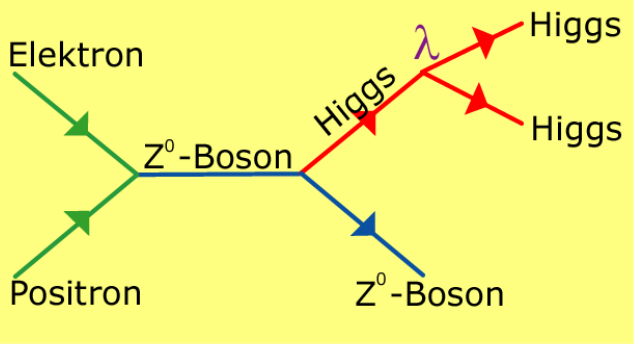
- Best method: threshold scan at the ILC
- Presently largest source of uncertainties for calculation of many SM observables
- Precision 50-100 MeV
- width to 3-5%



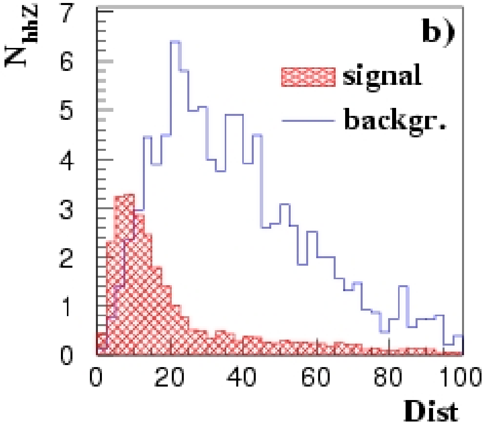


The Higgs self-coupling

- *Is* the Higgs the Higgs?
- Check $\lambda = M^2_H/2v^2$



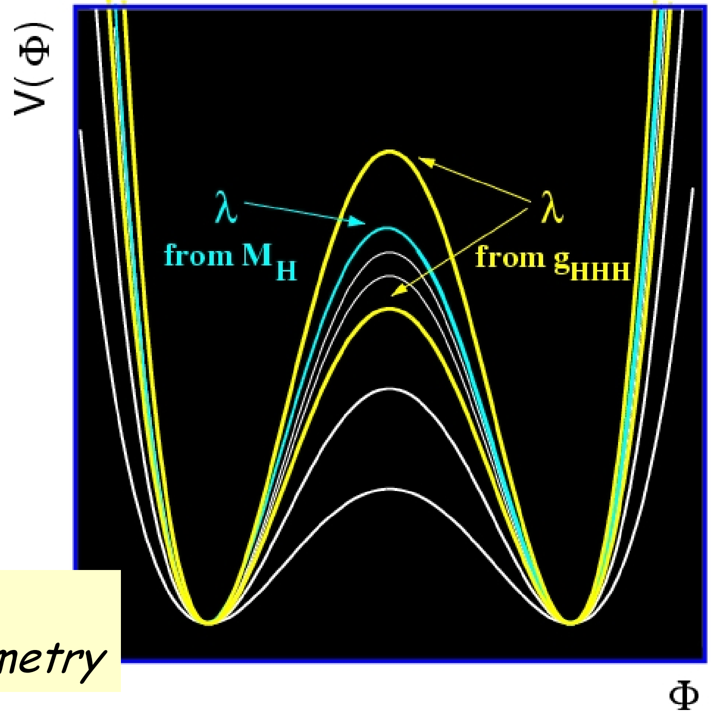
6 jets



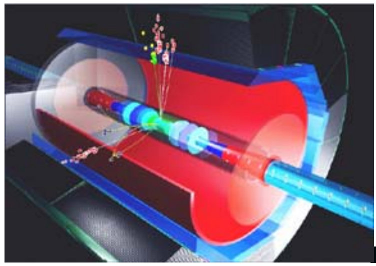
6-jet observable

Requires excellent calorimetry

Higgs potential

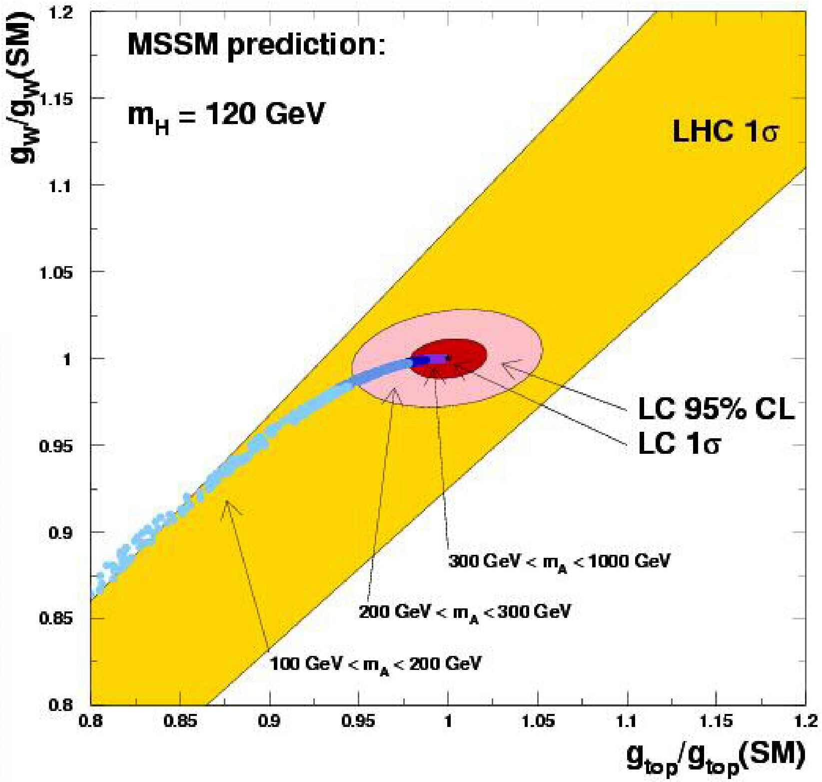


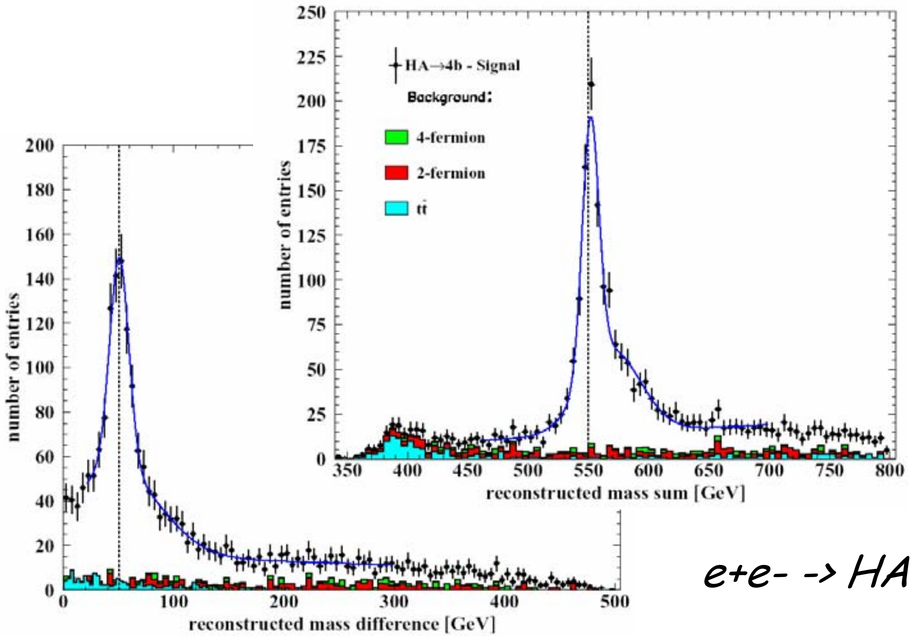
$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$



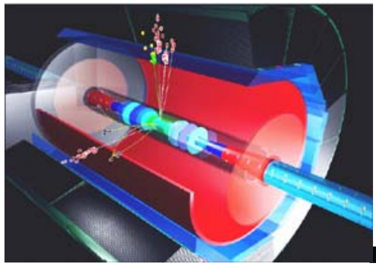
Higgs profile analysis

- Global fit using all measured properties
- SM Higgs or MSSM Higgs?





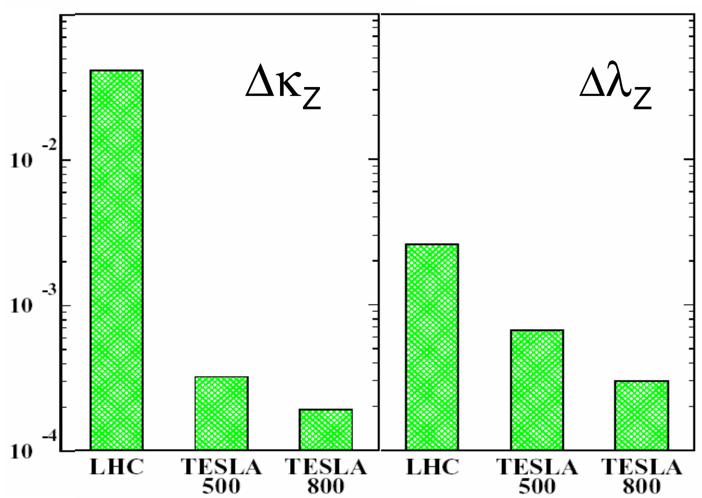
e+e- -> HA signal

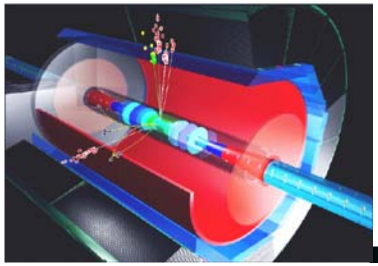


If there is a heavy (or no) Higgs

- This is physics beyond the Standard Model
- Something **must** be in the loops
- Exploit precision potential of LC (tune energy, polarization, eγ option)
  - Really nothing overlooked at LHC?
  - Probe virtual effects
- E.g. sensitivity of triple / quartic gauge couplings reaches far into the TeV range

	LHC Λ [TeV]				LC Λ [TeV]			
model	LL	RR	LR	RL	LL	RR	LR	RL
eeqq: Λ_+	20.1	20.2	22.1	21.8	64	24	92	22
Λ_-	33.8	33.7	29.2	29.7	63	35	92	24
ee$\mu\mu$: Λ_+					90	88	72	72
Λ_-					90	88	72	72
eeee: Λ_+					44.9	43.4	52.4	52.4
Λ_-					43.5	42.1	50.7	50.7

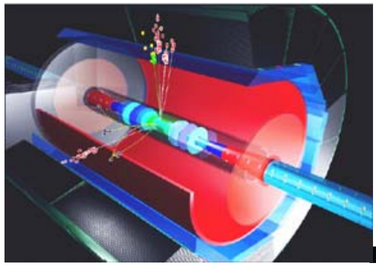




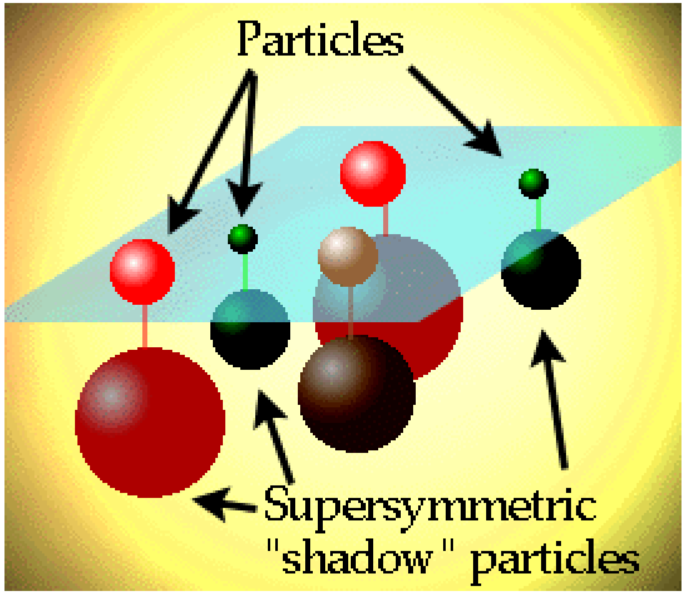
Higgs summary

- The Higgs boson (or something taking its role) will be discovered at the LHC.
- Its profile can be fully determined at the ILC with precision.
- This can fully establish – or falsify – the Higgs mechanism by which particles acquire mass in the Standard Model.
- If the Higgs is different from SM expectation, or if there is no Higgs at all, we will obtain important clues to New Physics.

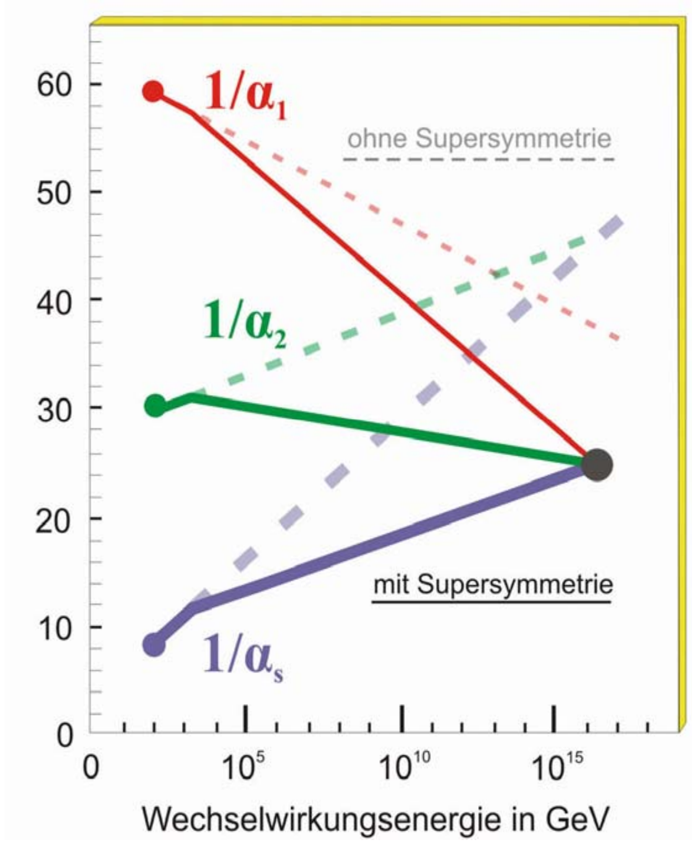
4. Beyond the Standard Model



One candidate for new physics: Supersymmetry

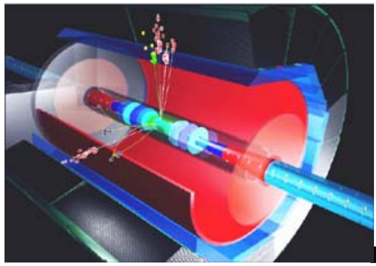


- Unification
- Solves fine-tuning problems
- Light Higgs
- Dark matter candidate
- Link to gravity



This is achieved for $\sin^2\theta_W^{SUSY} = 0.2335(17)$

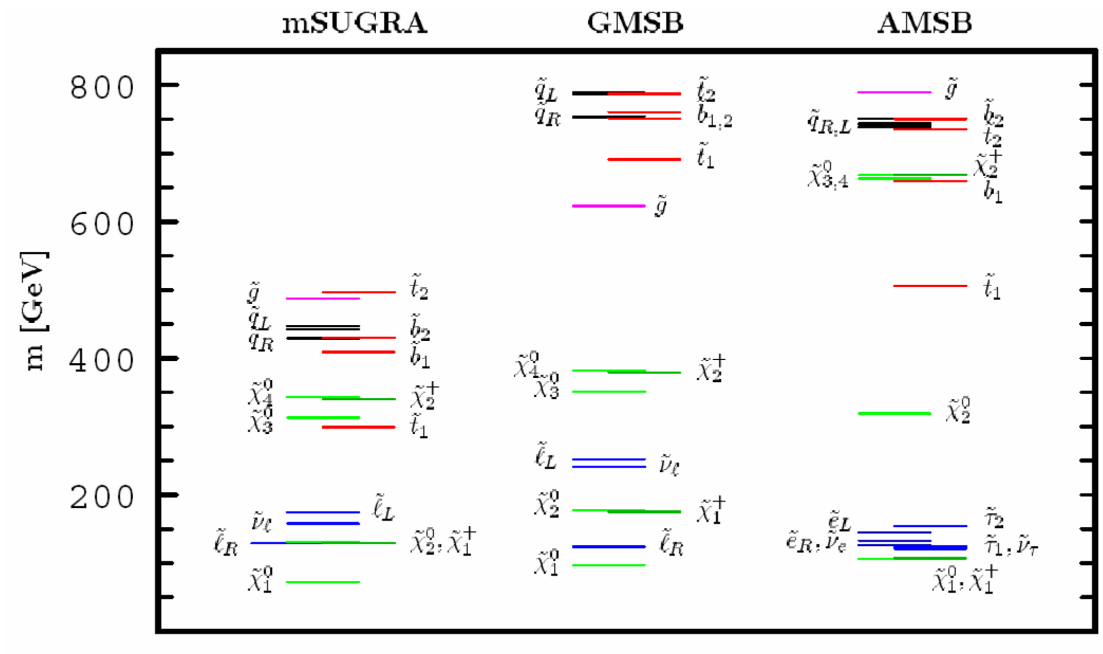
Experiment: $\sin^2\theta_W^{exp.} = 0.2315(2)$

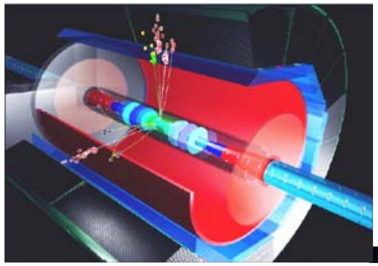


SUSY particles

- SUSY partners with spin differing by ½
  - Sfermions, (Gauginos, Higgsinos) -> (Neutralinos, Charginos)
- SUSY must be broken – particles are heavy

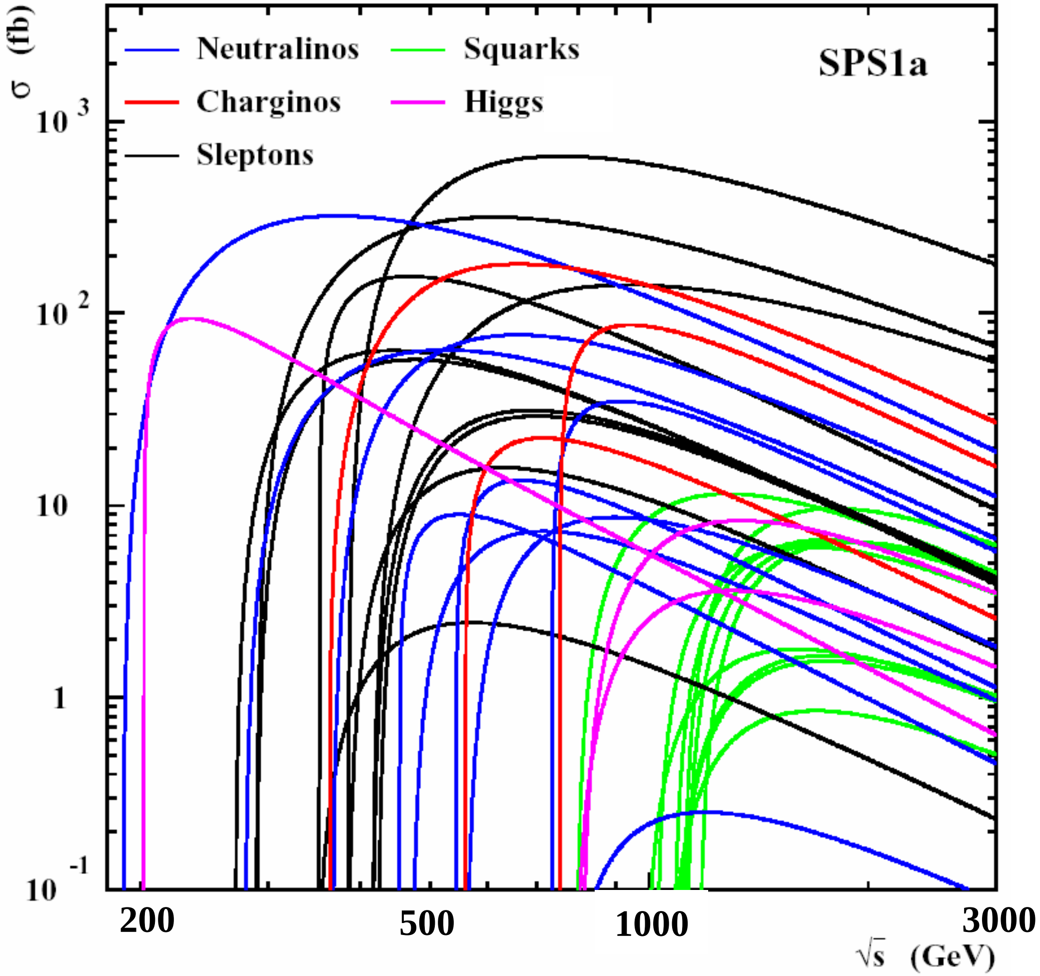
- >100 free parameters
- unknown due to ignorance of breaking mechanism
- Spectroscopy provides the key

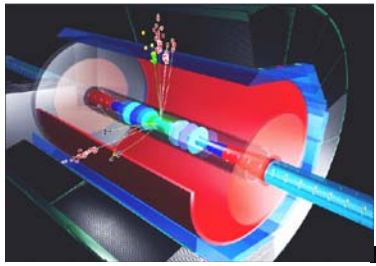




SUSY particle production

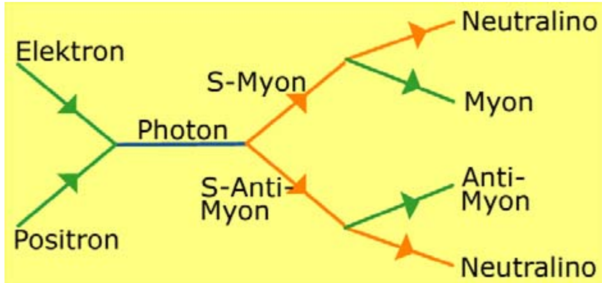
- In “all” scenarios several new states within ILC energy range
- Tunable energy and polarization help to disentangle the chaos

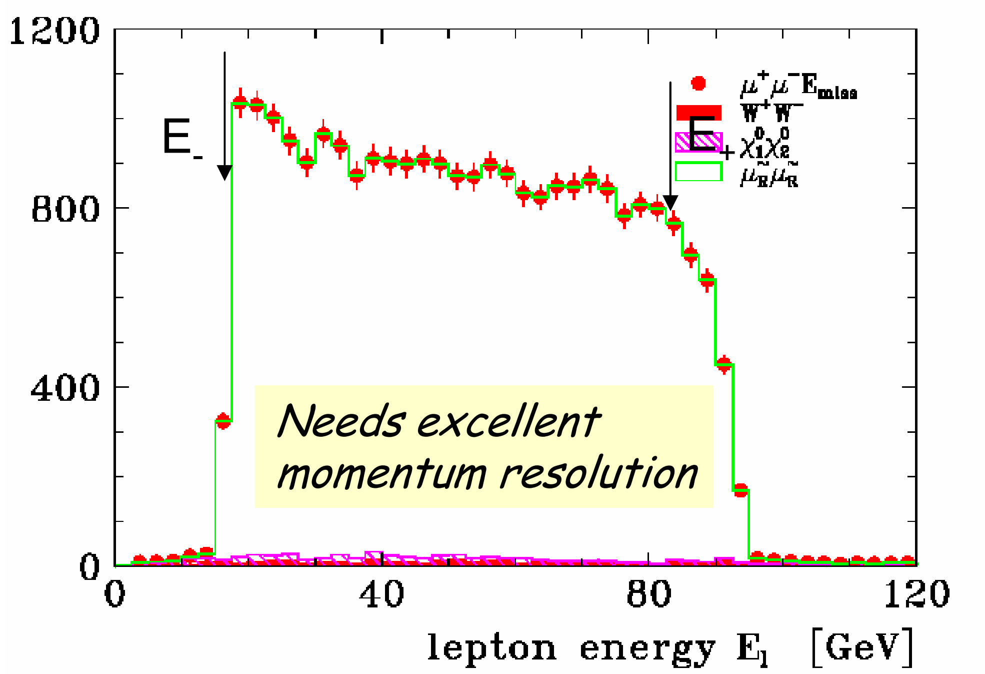




Sleptons

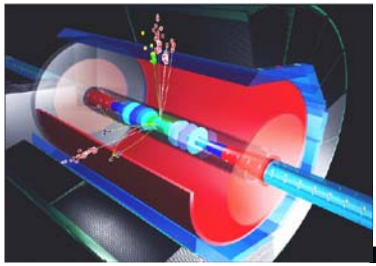
- Pair production, example smuon
- 2 body kinematics, beam energy constraint -> masses of smuon and lightest neutralino





$$
\begin{aligned}
m_{\tilde{l}} &= \frac{\sqrt{s}}{E_- + E_+}\sqrt{E_- E_+} \\
m_{\tilde{\chi}} &= m_{\tilde{l}}\sqrt{1 - \frac{E_- + E_+}{\sqrt{s}/2}}
\end{aligned}
$$

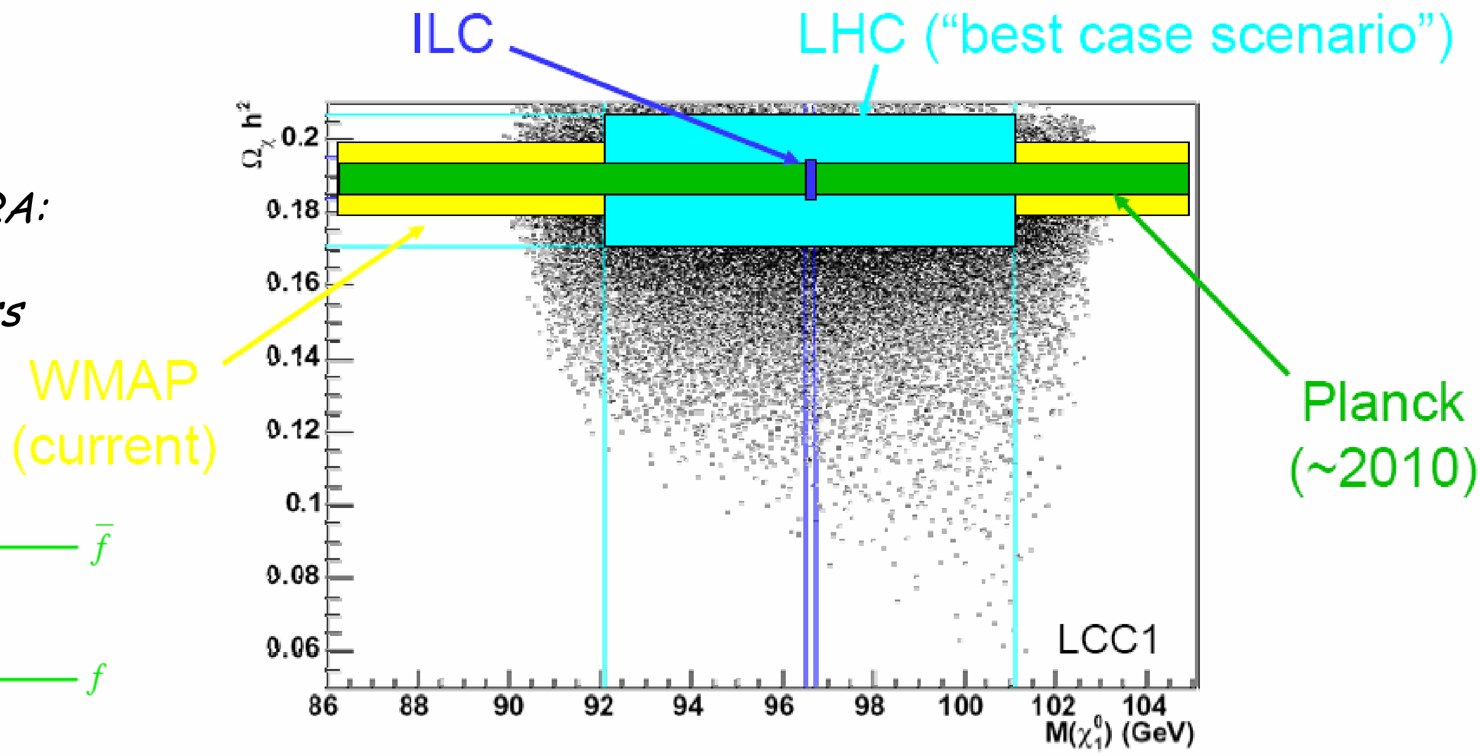
(For LSP many other methods possible)

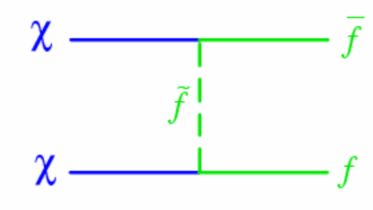


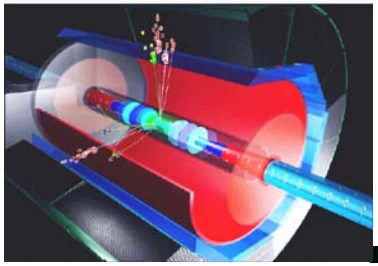
Dark matter interpretation

- LHC will see DM candidate as jets + missing energy, LSP = χ_1^0 ??
- To claim dark matter discovery, need to establish model; annihilation cross section to precisely calculate relic density, match with cosmology

E.g. mSUGRA: Depends on slepton mass

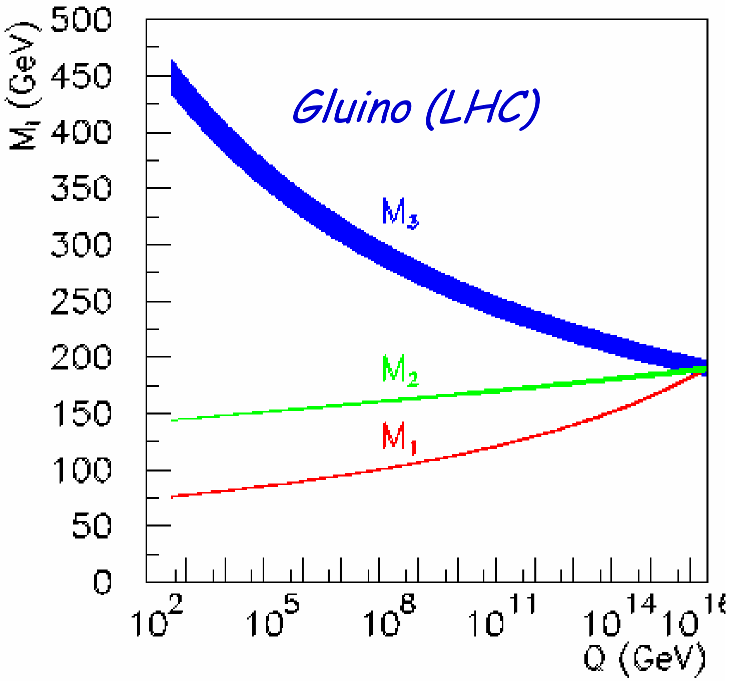




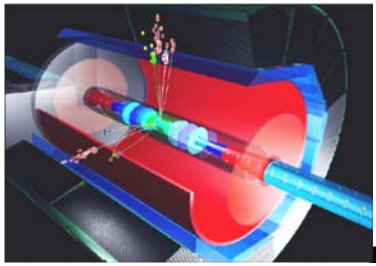


Reconstruct fundamental theory

- Example Supersymmetry
  - Precision measurements of SUSY particle masses and couplings
    - E.g. neutralino mass: δm/m ~ 10-3
  - Disentangle SUSY breaking mechanism
- Extrapolate to Grand unification scale
- Needs both LHC and ILC highest possible precision
- Maybe only experimental clue to GUT scale physics

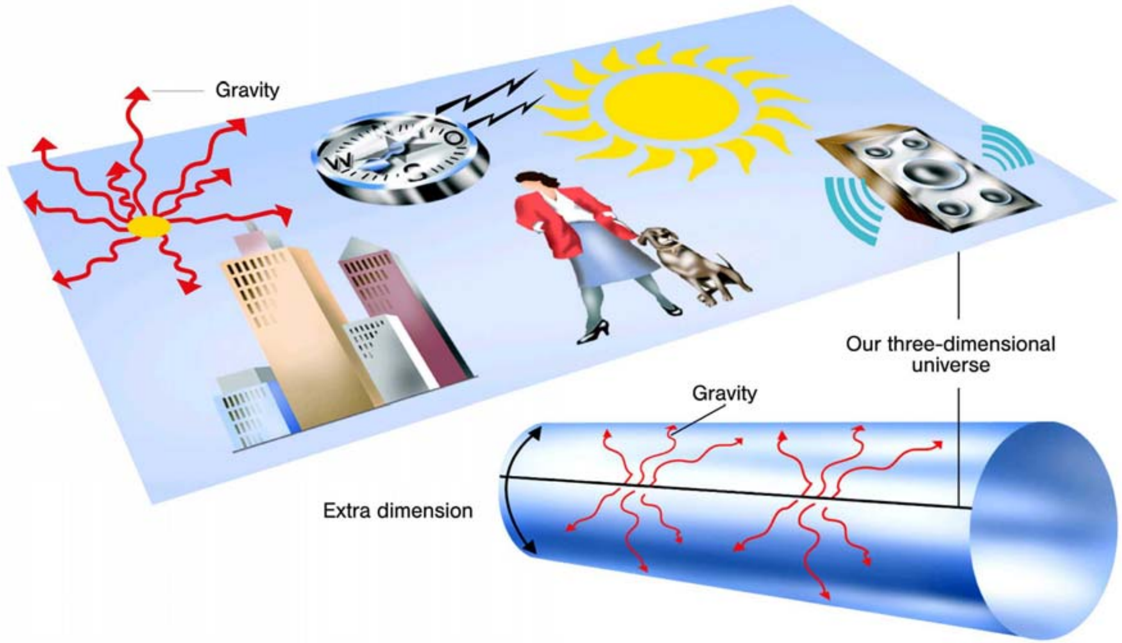


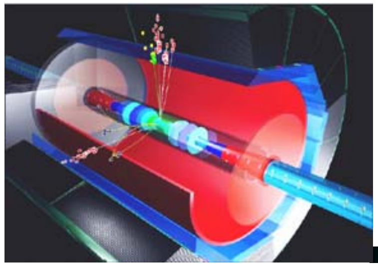
(in mSUGRA model)



Or: extra dimensions

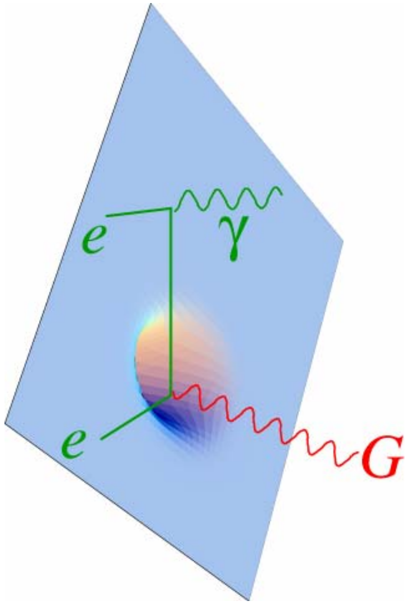
- “Solves” the hierarchy problem
- Gravity lives in 4 + δ dimensions, δ dimensions curled (radius R)
- Modifies Newton’s law for r<R, lowers Gravity scale
  - E.g. δ = 2, R = 0.1 mm gives $M_{Gravity}$ = 1 TeV

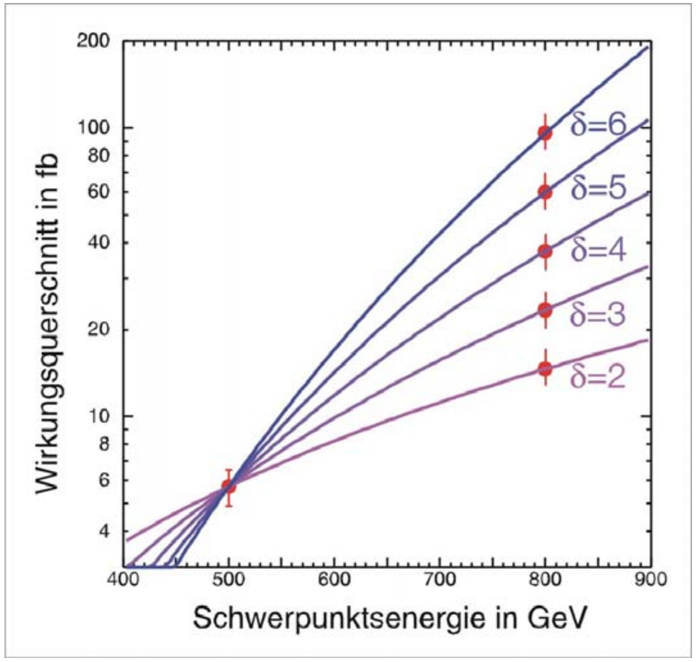


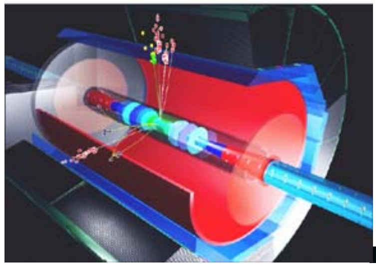


Extra dimensions signature

- Measure the number of extra space dimensions
  - Via single photon production



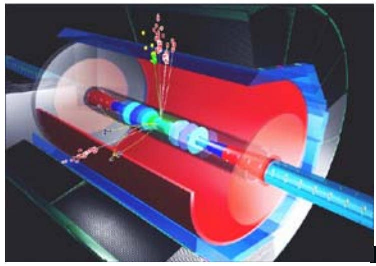




New Physics:

- New Physics – related to electroweak symmetry breaking – is likely to appear below the TeV scale
- Supersymmetry – as a generic case study – opens up a new spectroscopy.
- Precision measurements provide the clues to the underlying highest scale theories.
- There are clear cosmological questions which can be addressed at the ILC.

5. The detector challenge

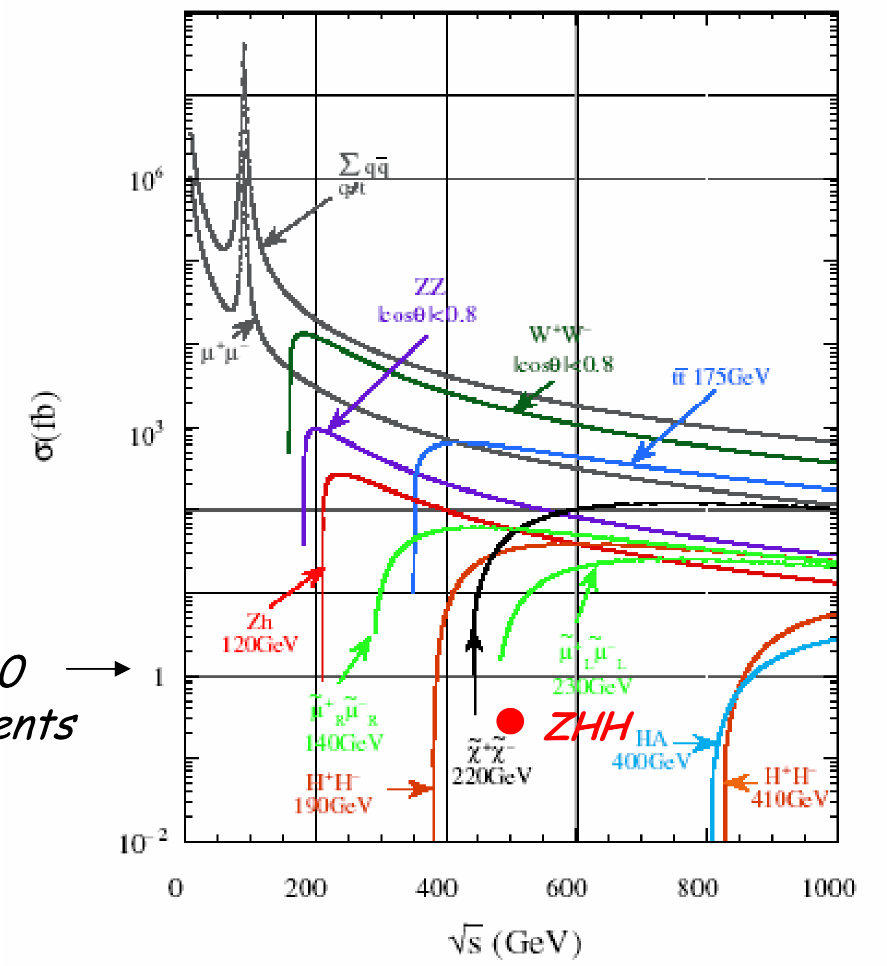


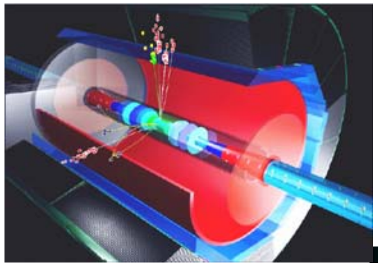
Precision physics

- Discoveries **and** precision measurements

- rare processes
- often statistics limited
- final states with heavy bosons **W, Z, H**
- need to reconstruct their hadronic decay modes, **multi-jet events**
- Excellent track resolution
- Flavor tagging

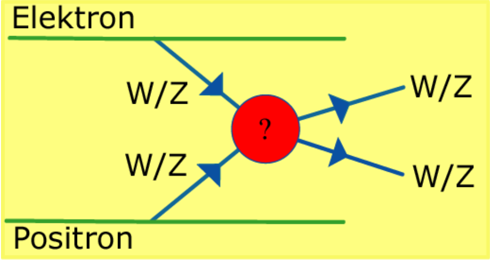
500 events →

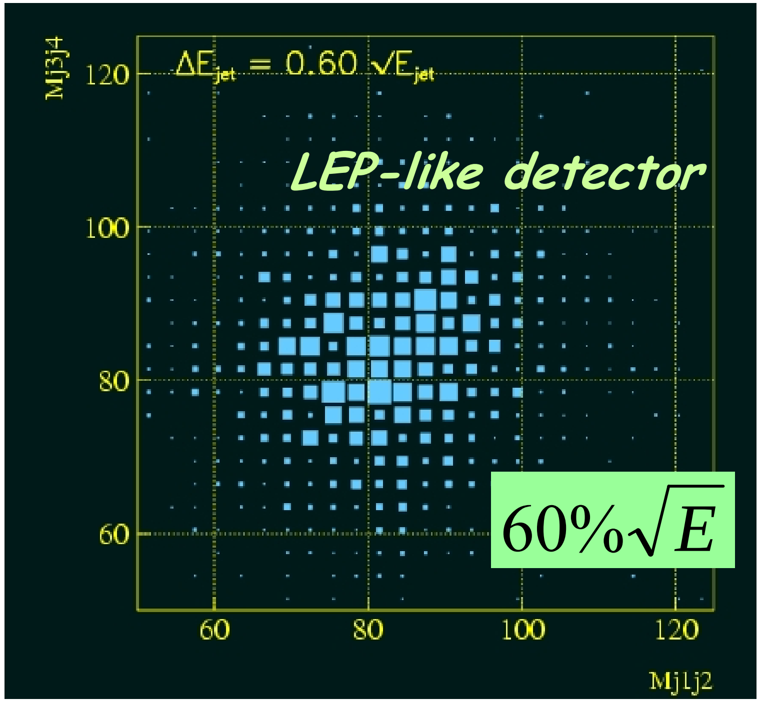


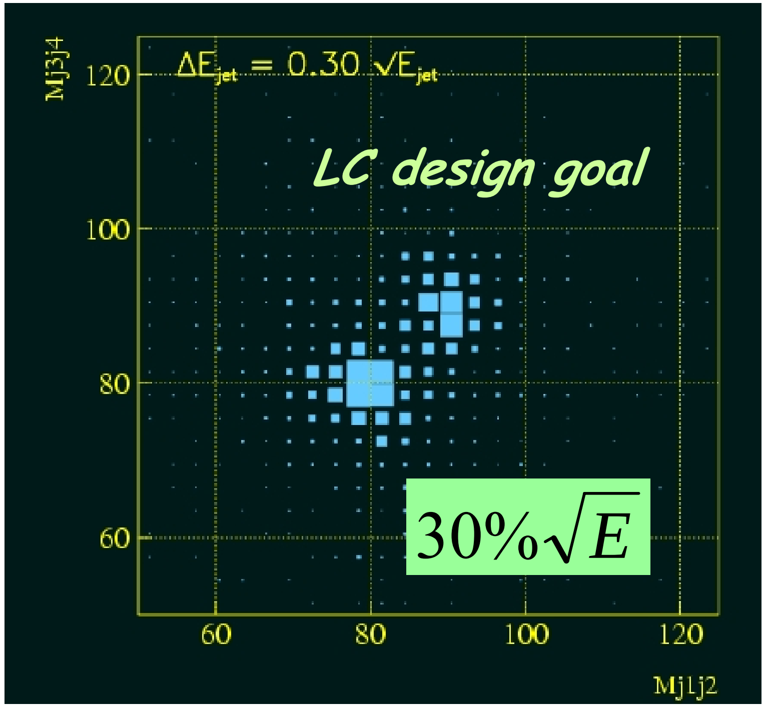


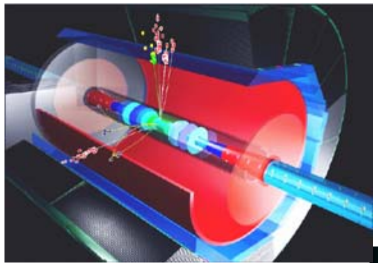
Jet energy resolution

- Challenge: separate W and Z in the hadronic mode
- E.g.: WW scattering, violates unitarity if no Higgs; irreducible background: ZZ
- Dijet masses in WW, ZZ events:



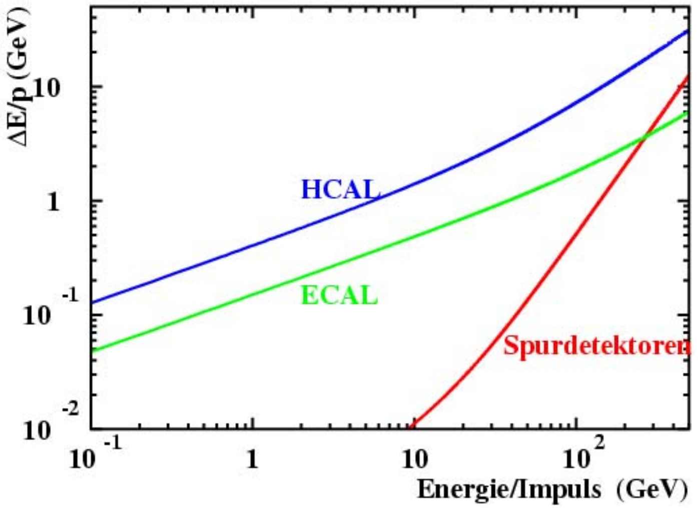






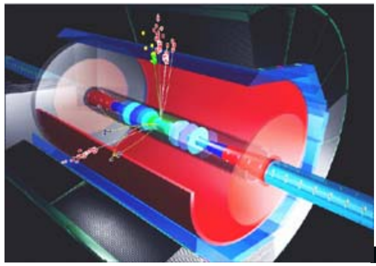
Particle Flow Algorithms

- Optimize jet energy resolution by using the best possible detector component
  - tracking detectors to measure energy of charged particles (**65%** of the typical jet energy)
  - EM calorimeter for photons (**25%**)
  - EM and HAD calorimeter for neutral hadrons (**10%**)



$$E_{\text{jet}} = E_{\text{charged}} + E_{\text{photons}} + E_{\text{neut. had.}}$$

$$\sigma^2_{E\text{jet}} = \sigma^2_{E\text{charged}} + \sigma^2_{E\text{photons}} + \sigma^2_{E\text{neut.had.}} + \sigma^2_{\text{confusion}}$$



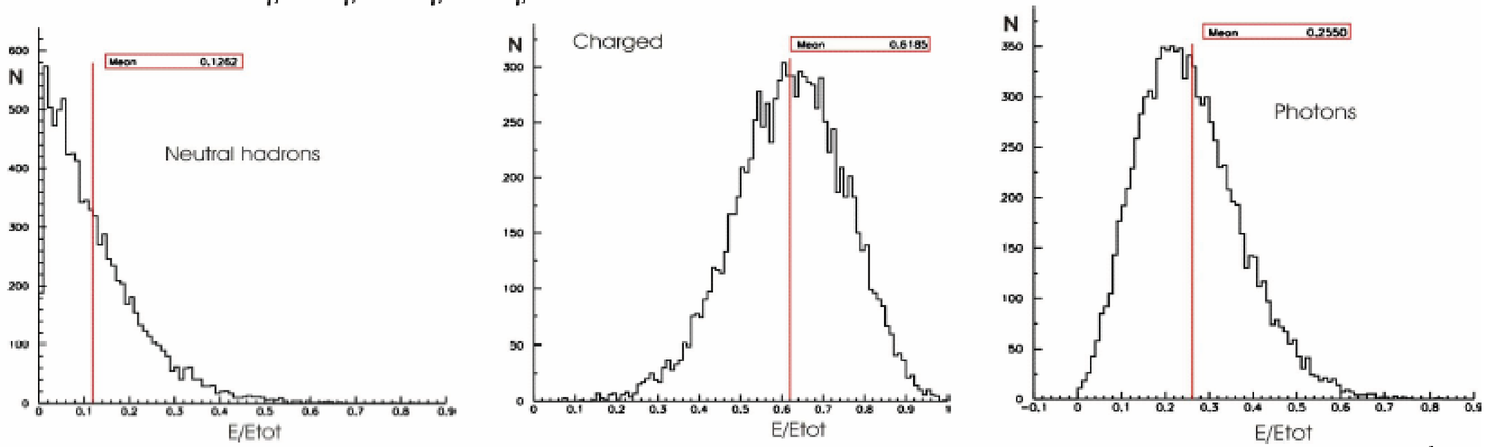
PFLOW in theory

- Jet energy resolution
  $\sigma^2(E_{jet}) = \sigma^2(ch.) + \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Excellent tracker :
  $\sigma^2(ch.) << \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Perfect PFA : $\sigma^2(conf.) = 0$
- $\sigma^2(E_{jet}) = A_\gamma^2 E_\gamma + A_h^2 E_{h0} = w_\gamma A_\gamma^2 E_{jet} + w_{h0} A_h^2 E_{jet}$
  $\sigma(E_{\gamma,h})/E_{\gamma,h} = A_{\gamma,h}/\sqrt{E_{\gamma,h}}$

Typically $w_\gamma = 25\%$; $w_{h0} = 13\%$

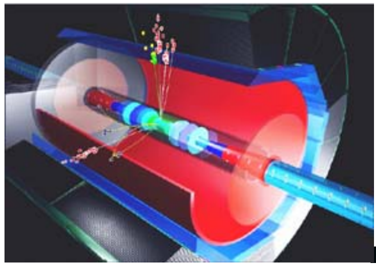
$A_\gamma = 11\%$; $A_{h0} = 34\%$
=> $\sigma(E_{jet})/E_{jet} = 12\%/\sqrt{E_{jet}}$

$A_\gamma = 11\%$; $A_{h0} = 50\%$
=> $\sigma(E_{jet})/E_{jet} = 17\%/\sqrt{E_{jet}}$



Alexei Raspereza DESY ILC Workshop Snowmass August 22 2005

4



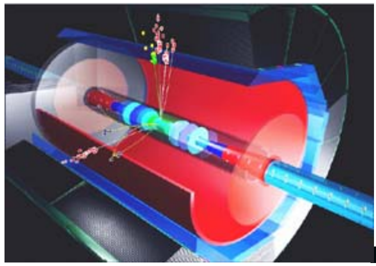
More realistically

- Toy experiment: just smear momenta, no confusion

$e^+ e^- \rightarrow Z^0 \rightarrow q\bar{q}$ at 91.2GeV

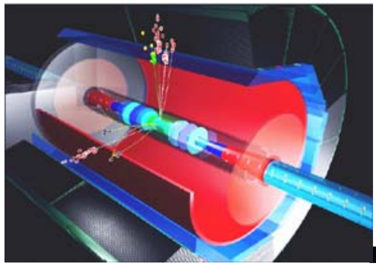
Studies by P.Krstonosic

Effect	σ [GeV] separate	σ [GeV] not joined	σ [GeV] total ($\%/\sqrt{E}$)	σ to total
$E_\nu > 0$	0.84	0.84	0.84 (8.80%)	12.28
$Cone < 5^o$	0.73	1.11	1.11(11.65%)	9.28
$P_t < 0.36$	1.36	1.76	1.76(18.40%)	32.20
σ_{HCAL}	1.40	1.40	2.25(23.53%)	34.12
σ_{ECAL}	0.57	1.51	2.32(24.27%)	5.66
M_{neutral}	0.53	1.60	2.38(24.90%)	4.89
M_{charged}	0.30	1.63	2.40(25.10%)	1.57



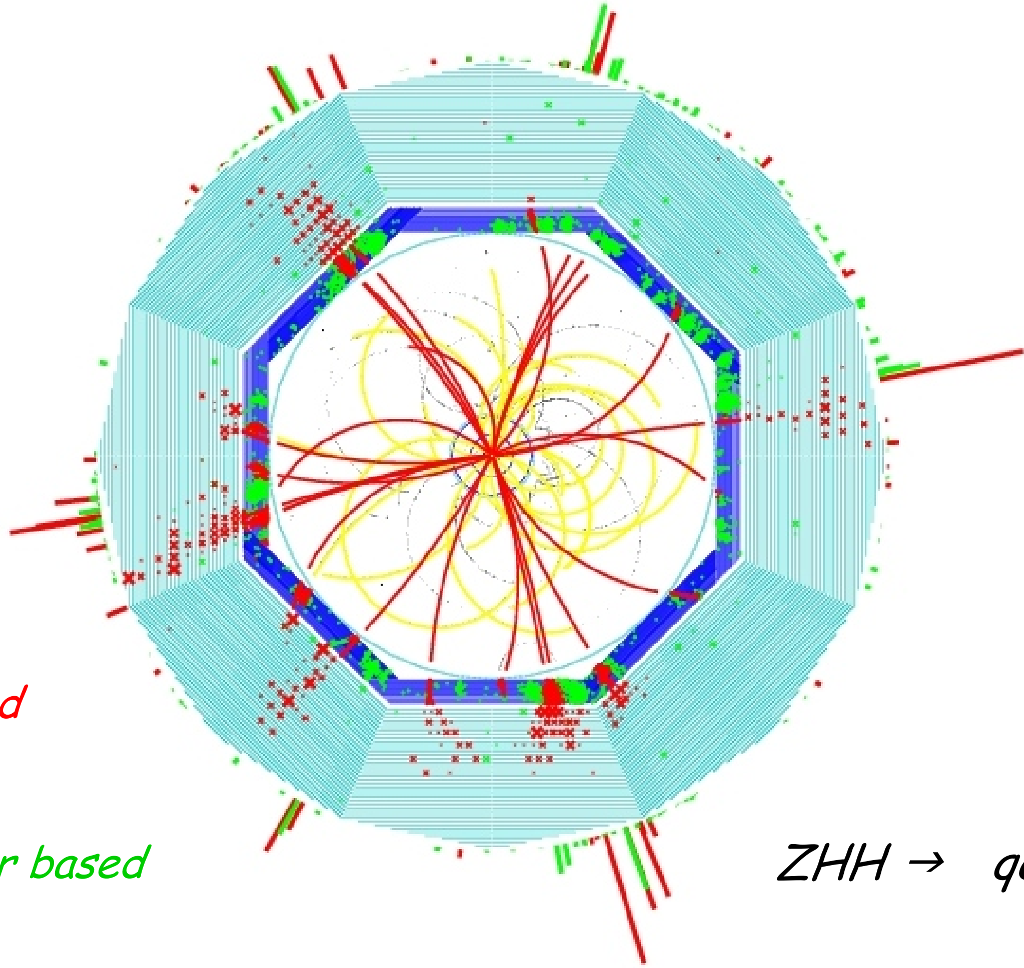
The PFLOW paradigm

- The confusion term dominates
- Each particle should be reconstructed and measured separately
- For the jet energy measurement spatial resolution / particle separation power is more important than energy resolution



Imaging calorimetry

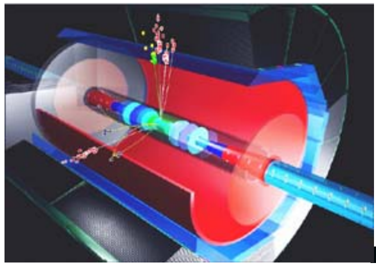
Reconstruct each particle individually



red: track based

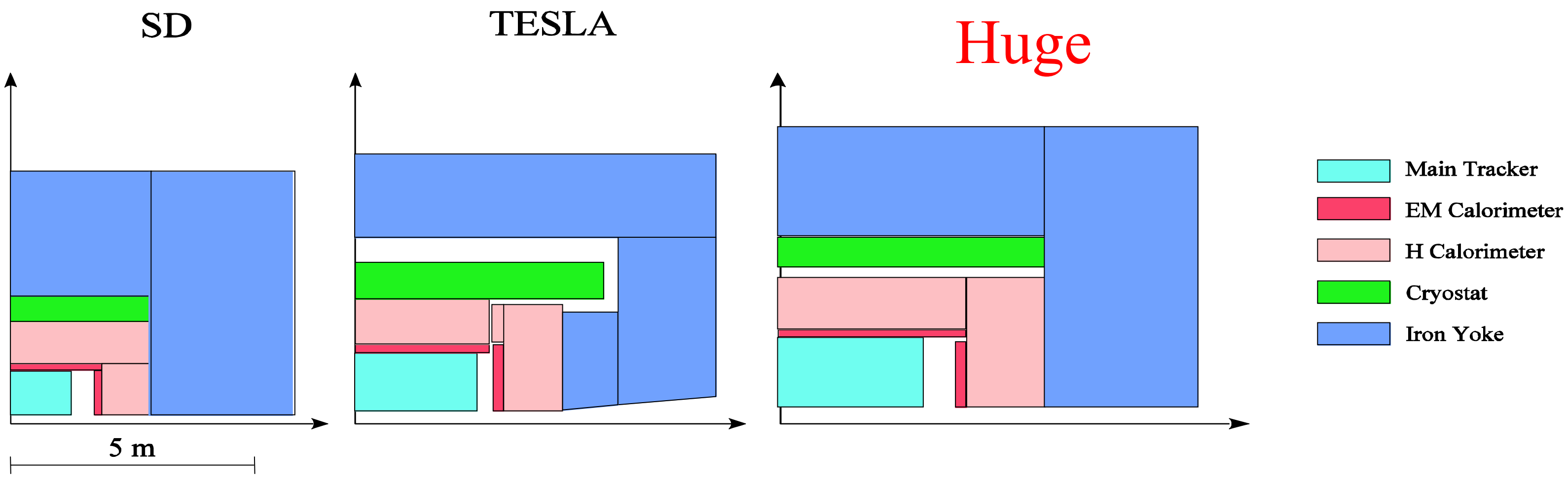
green: calorimeter based

ZHH → qqbbbb

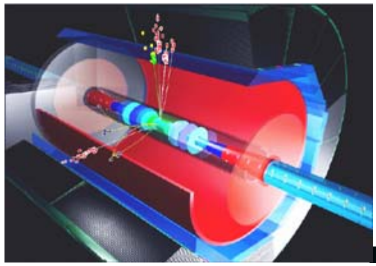


Detector concepts

- Sizes



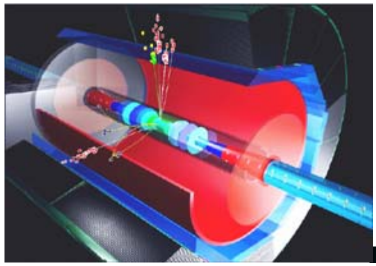
•	:5T	4T	3T
•	Si Tracker	Gasous Tracker (+Si?)	Gasous Tracker
•	SiW ECAL	SiW	Hybrid or Scint ECAL



Calorimeter concept

- large radius and length
  - to separate the particles
- large magnetic field
  - to sweep out charged tracks
- “no” material in front
  - stay inside coil
- small Moliere radius
  - to minimize shower overlap
- small granularity
  - to separate overlapping showers

- figure of merit: $B\ R^2_{calo} / (r^2_M + r^2_{cell})$

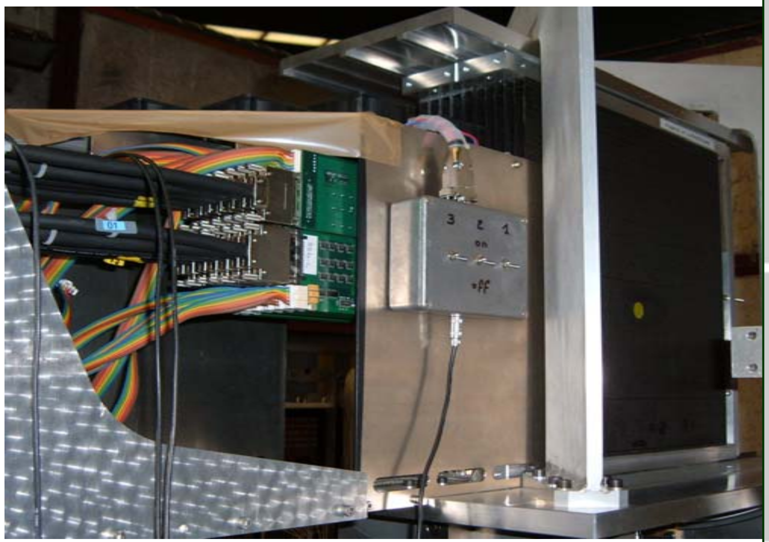


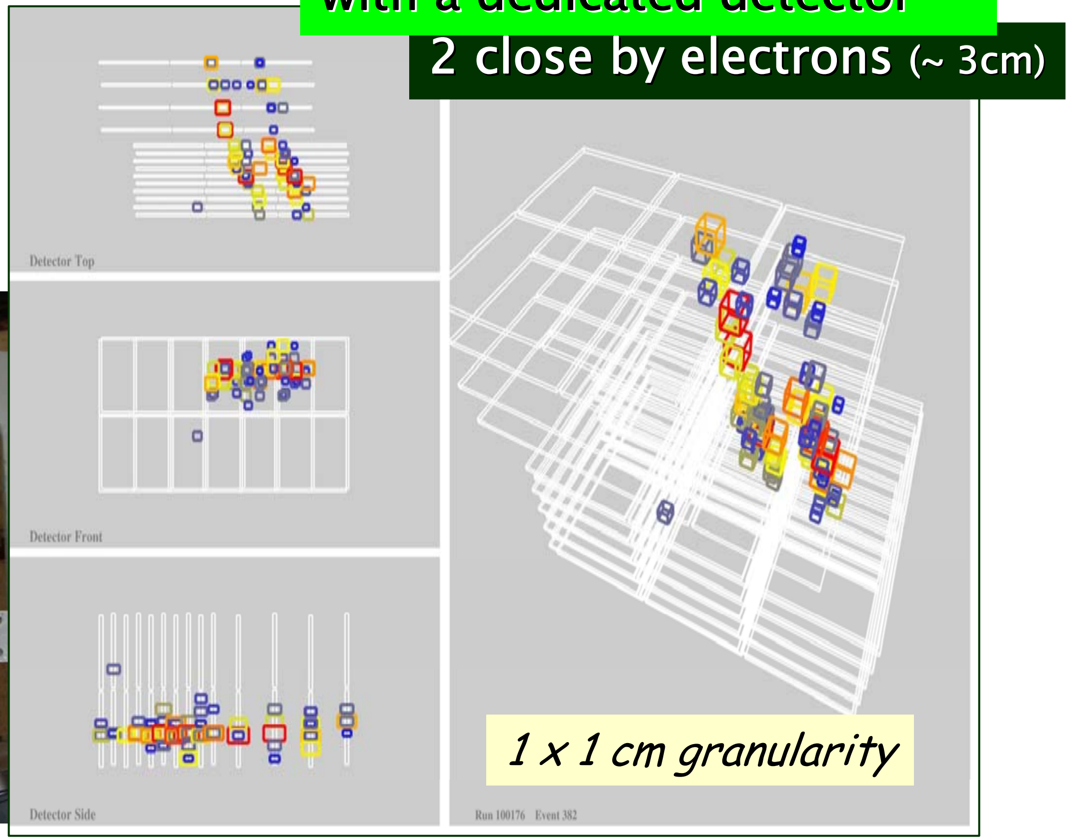
Electromagnetic Calorimeter

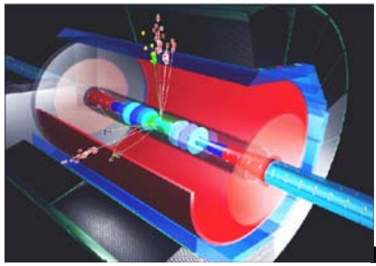
- ECAL: main option Si W
- Demonstrate feasibility of ultra-compact systems

First real test versus the « Particle Flow » method with a dedicated detector

Beam test at DESY

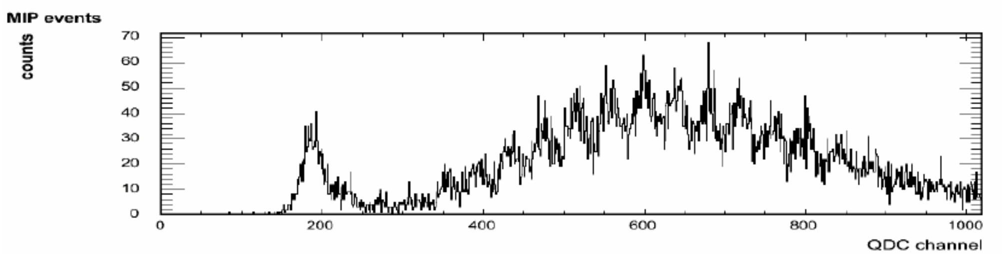




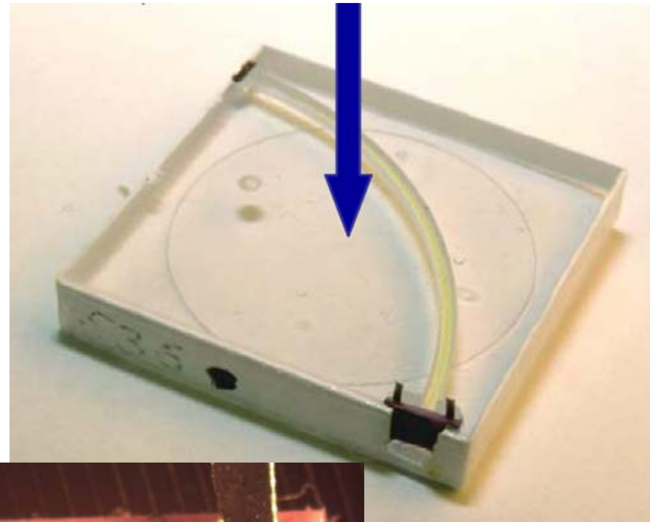


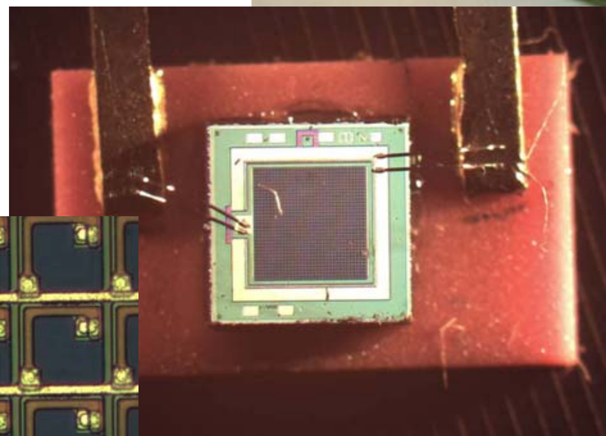
Silicon Photo-Multipliers

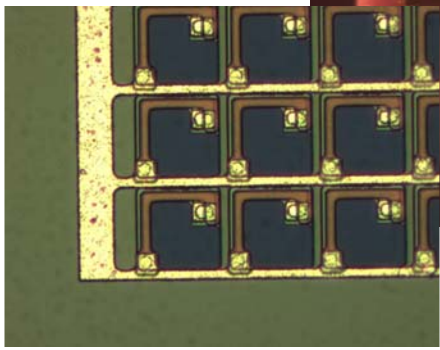
- Pixel Geiger Mode APDs
- Gain 10^6, bias ~ 50 V, size 1 mm^2



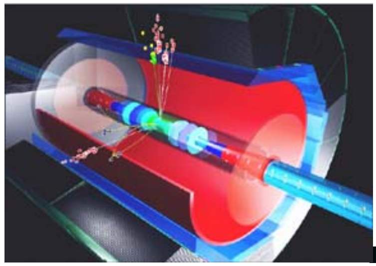
Auto-calibrating, but non-linear





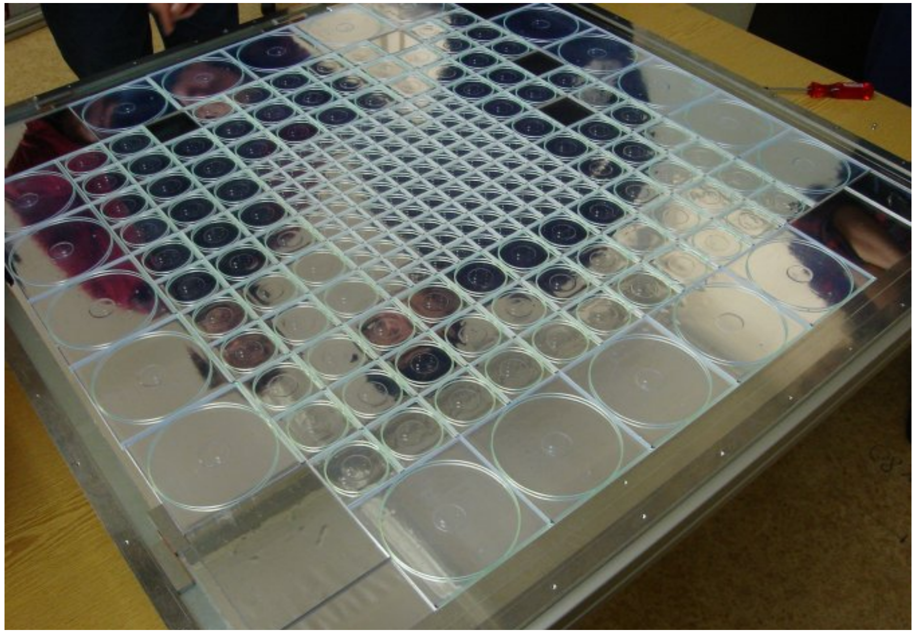


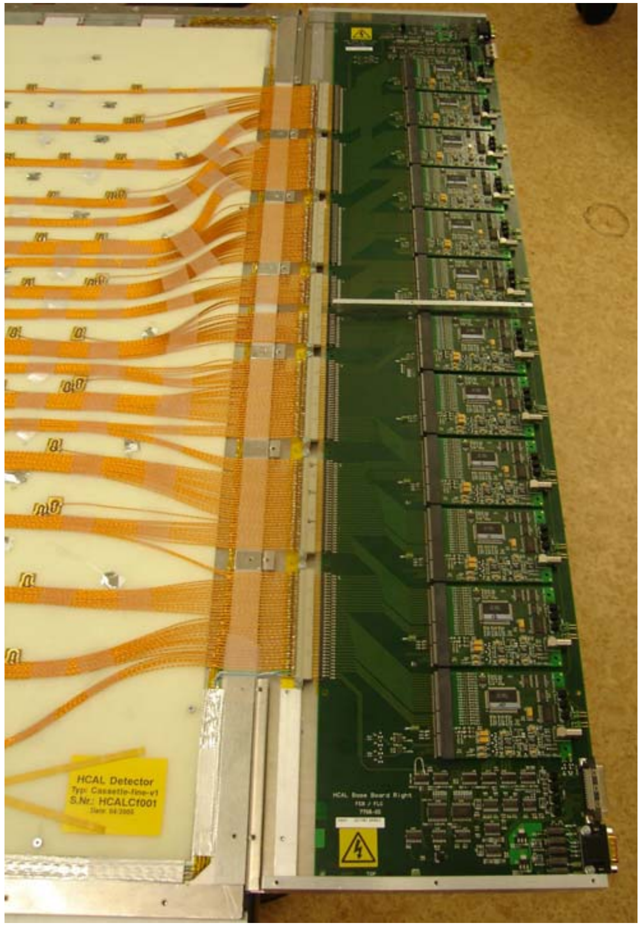
3 cm Scintillator tile



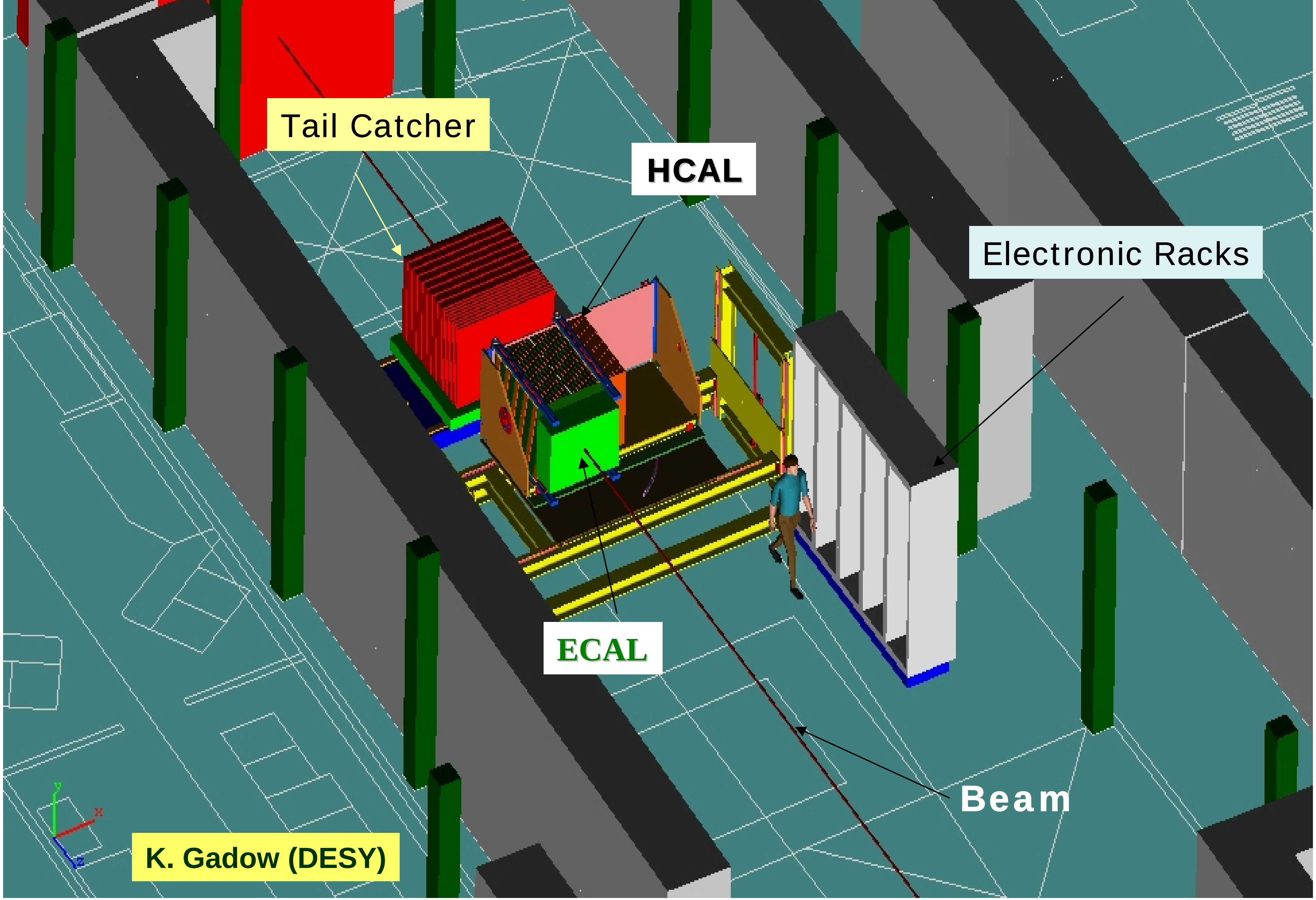
HCAL Testbeam prototype

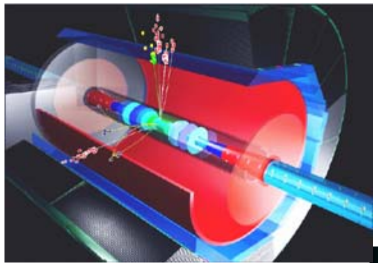
- Not a technical prototype
- Still to improve
  - Front end electronics
  - Readout boards
  - Calibration system





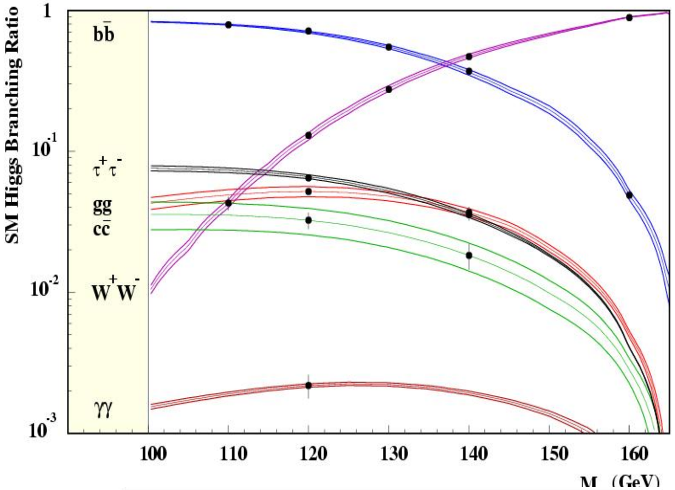
CALICE Setup V-Trial at FNAL MTBF

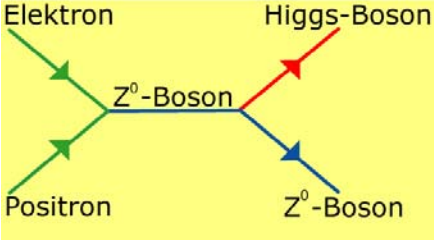




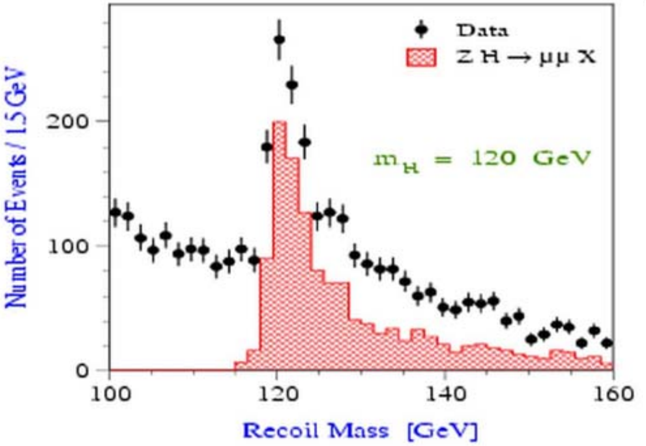
Vertexing and Tracking

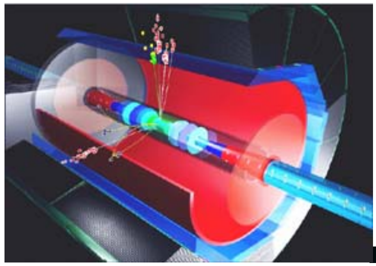
- Vertex detector
  - Charm tagging (!): $H \rightarrow cc$
  - Multi-jet combinatorics
  - Need $5\ \mu m \oplus 10\ \mu m / p$



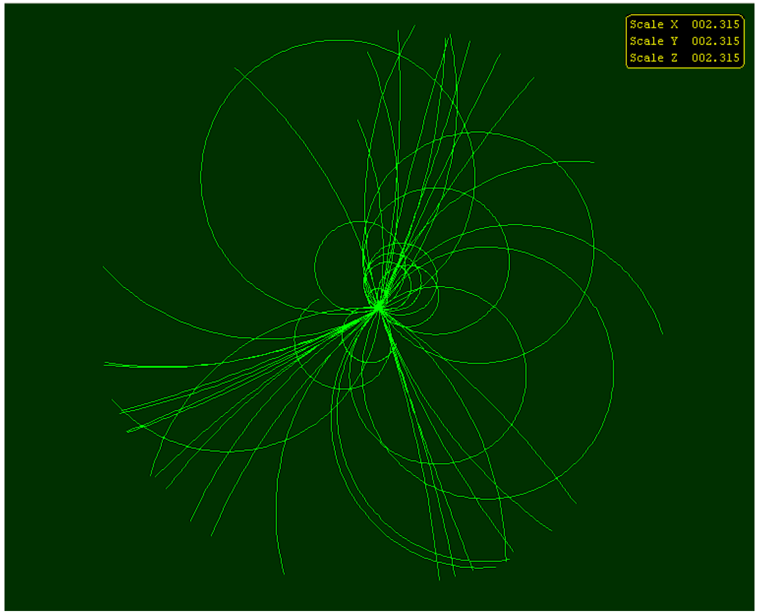


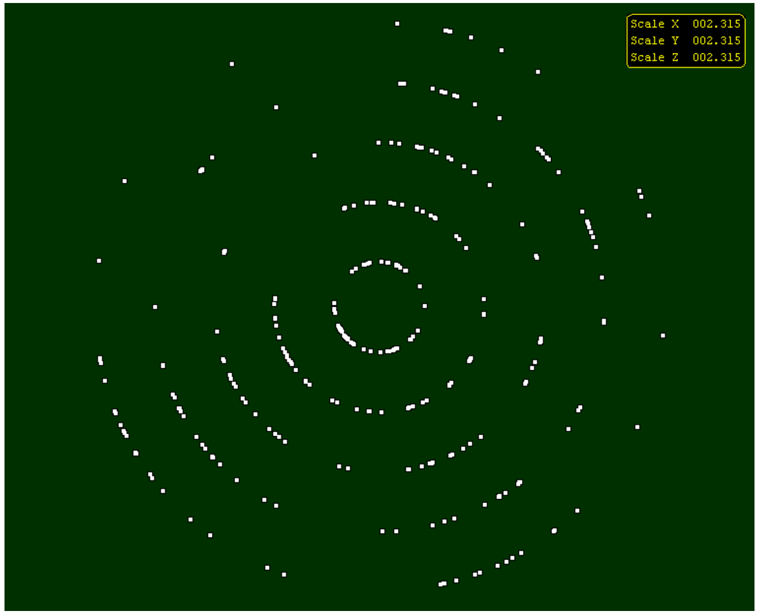
- Main tracker
  - Higgs recoil
  - Slepton decay momentum endpoint
  - Need to be 10x better than LEP TPCs





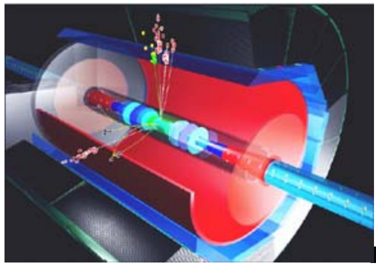
Main tracker: gaseous or Silicon?



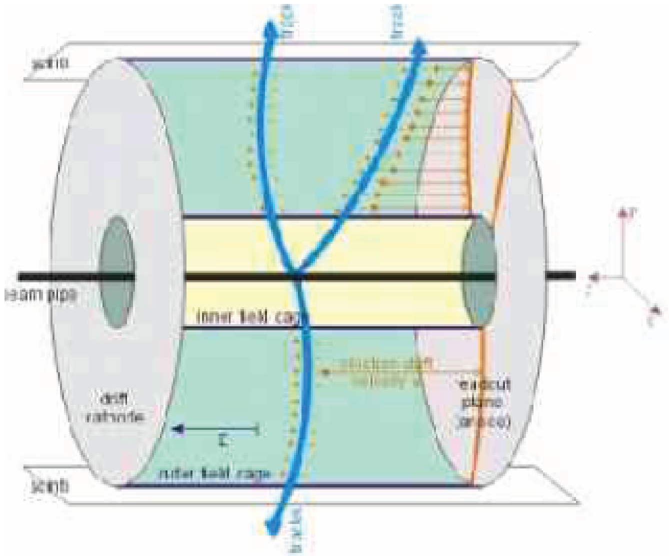


+ 3D: efficient pattern recognition
+ low material budget

+ robust and fast
+ no endplates, no HV

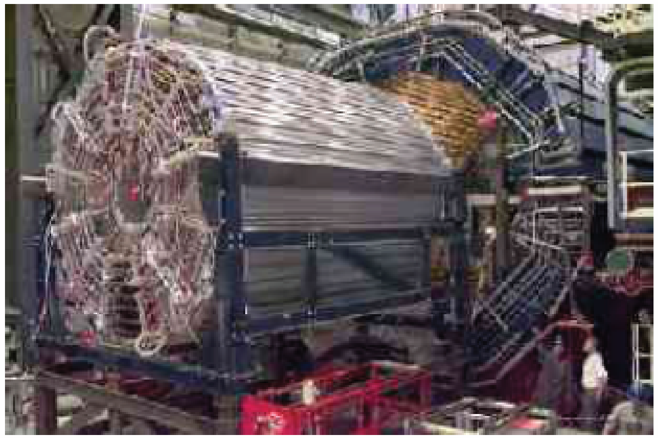


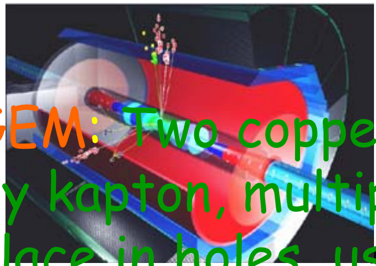
Time Projection Chamber



- Successful operation at LEP (Aleph, Delphi) and heavy ion experiments (Star, Alice)
- Ionisation tracks are dirfting several meters to the read out plane
- Diffusion limited through magnetic field
- Fast and clean gas
- Field homogeneity
- No space charge! No ion backdrift



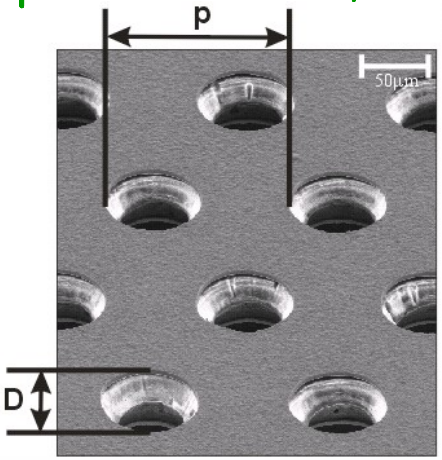




Gas-Amplification Systems: Wires & MPGDs→

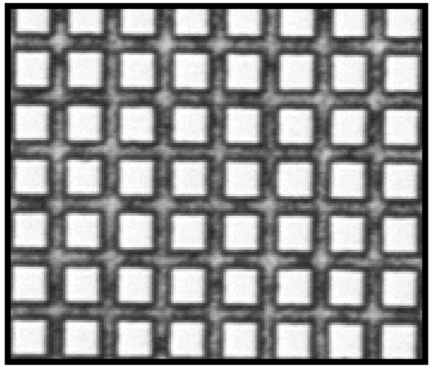
GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

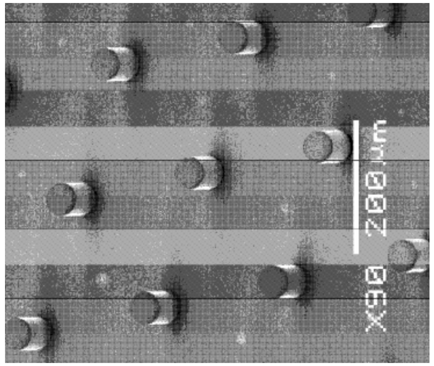
Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage



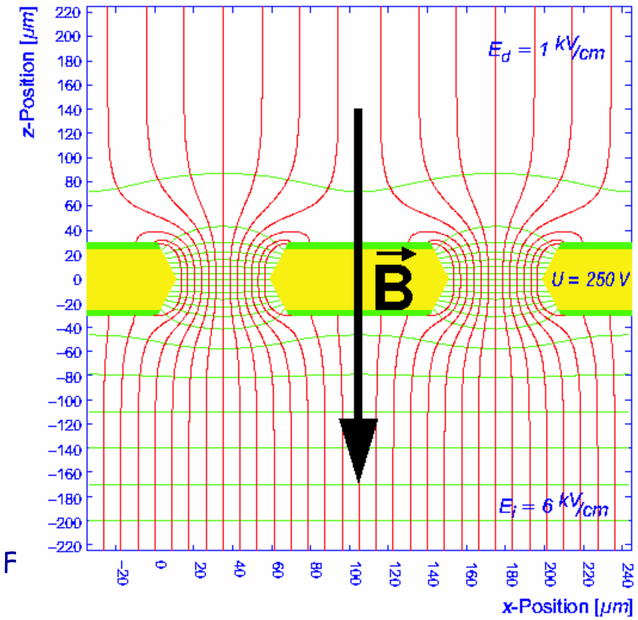
P~140 µm

D~60 µm

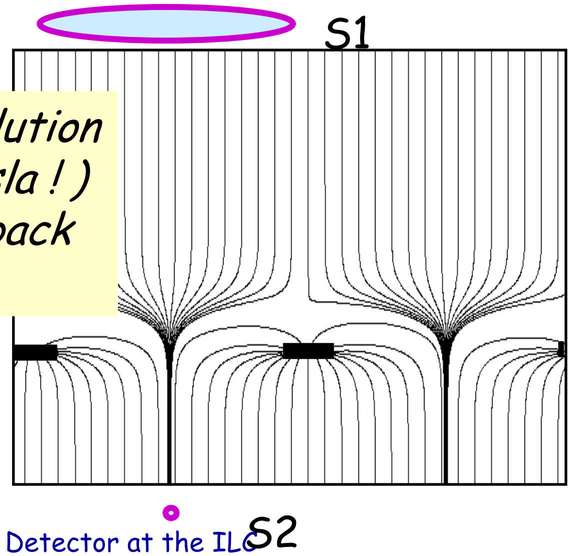


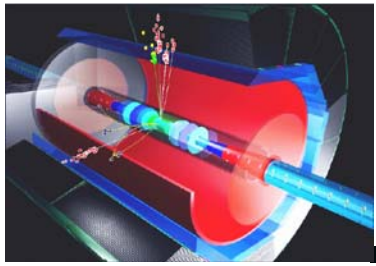


S1/S2 ~ Eamplif / Edrift



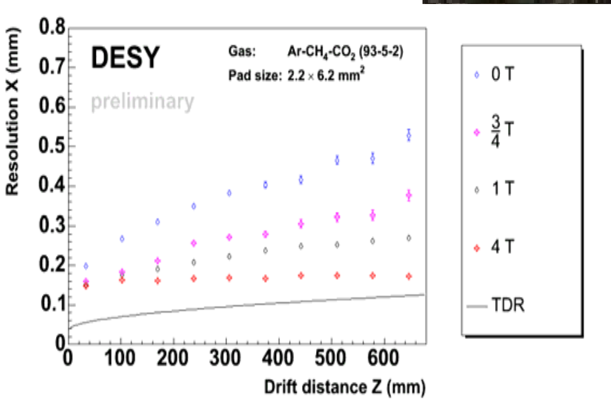
High intrinsic resolution
Avoid E x B (4 Tesla !)
Suppress ion feedback
Fast signals

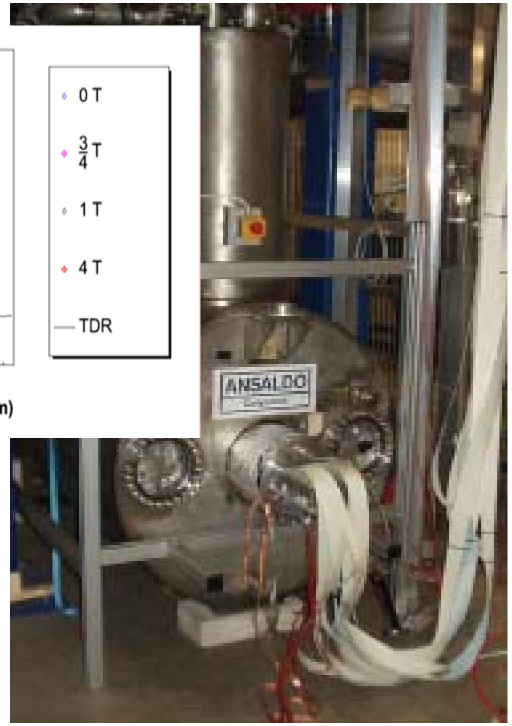


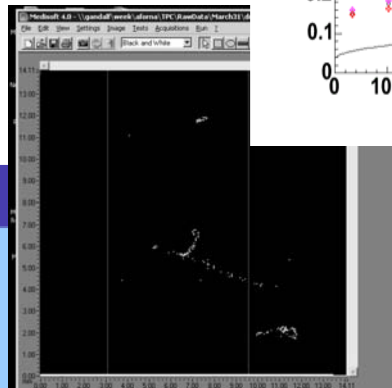


Understand GEM TPCs

- (and Micromegas)
- Tests in magnetic fields
  - Results from customers from all regions in DESY R&D magnet
- Pixel TPC







TPC Simulation

Independent from simulation packages

Simulation in three steps:

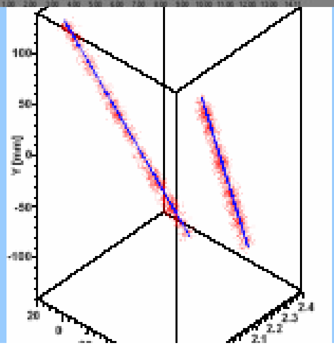
- Primary ionisation (blue)
- Drifting (red)
- Amplification with GEMs

Studies of:

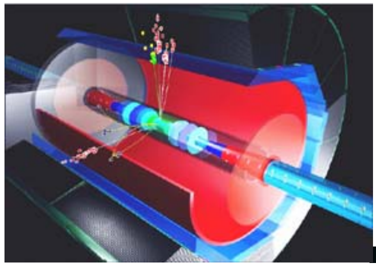
E & B fields, ion backdrift, pad geometry etc.

First results:

Agreement with TPC prototype



- Next: larger system(!)
- Electronics
  - DAQ kick-started since bunch structure known

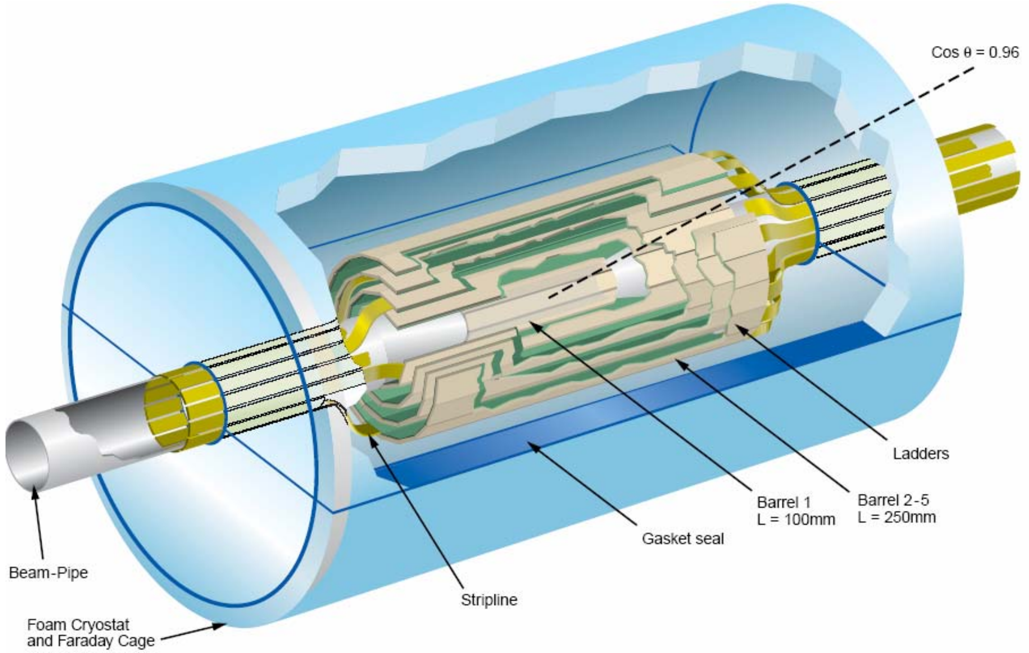


Vertex detector

Technologies

CAP
CPCCD
DEPFET
FAPS
FPCCD
HAPS
ISIS – edge readout
ISIS – distributed readout
MAPS – transverse readout
MAPS-digital
SoI
Macro-pixel/Micro-pixel sandwich

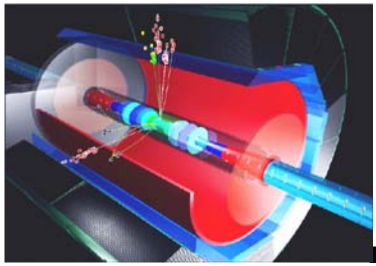
(probably incomplete!)



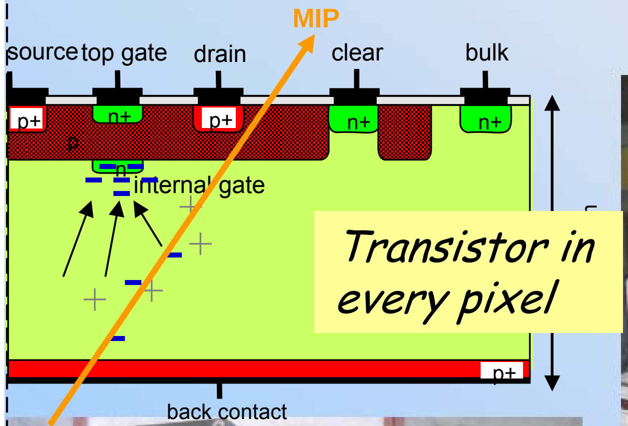
Giga pixel

- Thinner
- Faster
- Closer

than SLD



Beam tests at DESY



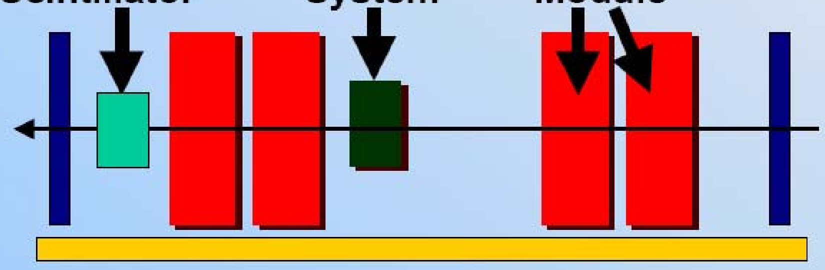
Transistor in every pixel

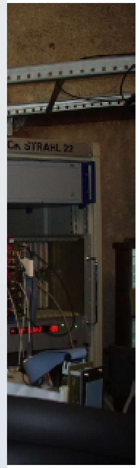
3 x 3 mm^2 Scintillator

DEPFET System

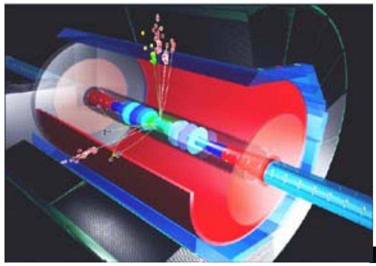
Telescope-Module

Scintillator





LCWS, Stanford 19.03.2005 - 10 - Marcel Trimpl, Bonn University



Summary

- There is a fascinating and compelling **physics case** for a (sub-) TeV e+e- collider running in parallel with the LHC
- The ILC will be ideally suited to map out the profile of the **Higgs** boson – or whatever takes its role – and provide a telescopic view to physics at highest energy scales.
- The **cosmic connection** is evident – we're entering exciting times.
- With the linac RF **technology decision** taken, time lines have become more realistic.
- The **detector** is a challenge. Conceptual detector design choices need to be made in few years time and must be prepared now.