From LHC to Linear Colliders:

Physics and Detectors

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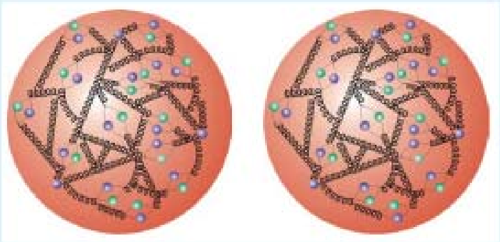
Outline

- **Introduction**

- **LHC**
  - **design & challenges**
  - **machine & detectors**
  - **physics examples**

- **Linear Collider (ILC)**
  - **design & challenges**
  - **machine & detectors**
  - **physics motivation**

Comparison Proton and Electron Colliders

p  p

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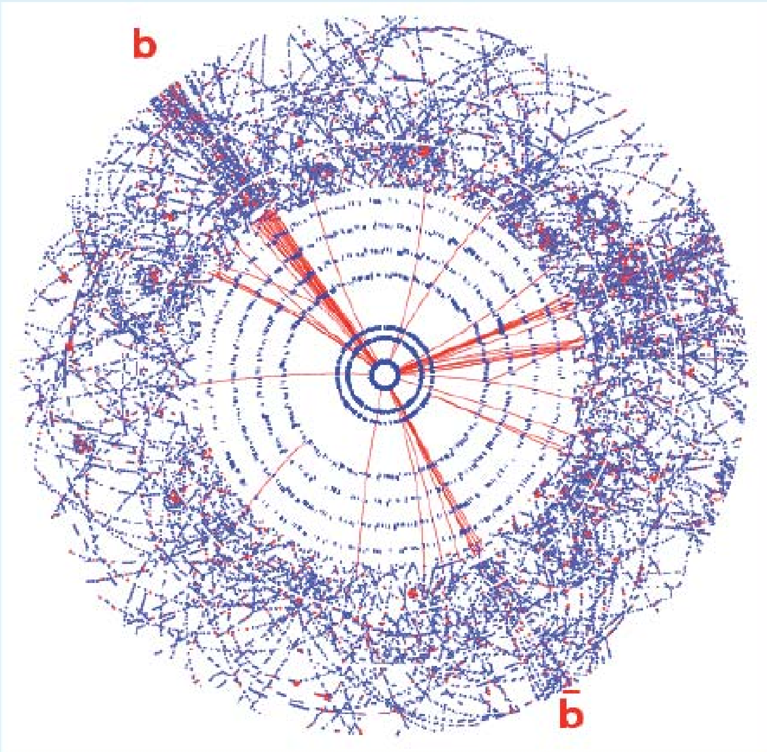
- Proton (anti-) proton colliders:
  - Energy range higher (limited by magnet bending power)
  - Composite particles, different initial state constituents and energies in each collision
  - Hadronic final states difficult
- Discovery machines
- Excellent for some precision measurements

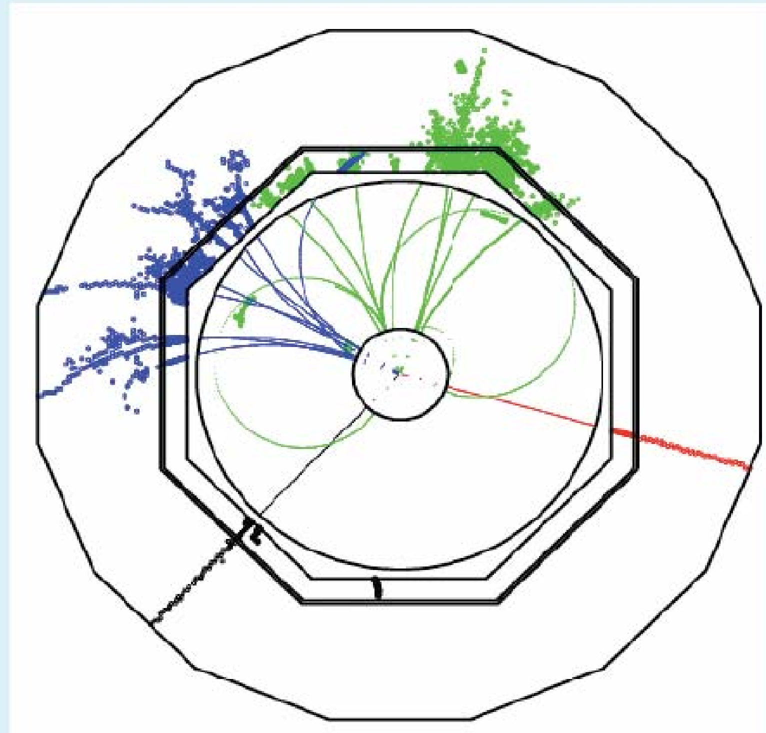
- Electron positron colliders:
  - Energy range limited (by RF power)
  - Point-like particles, exactly defined initial state quantum numbers and energies
  - Hadronic final states easy
- Precision machines
- Discovery potential

- **Precision is main motivation for a new electron positron collider**
- **Complementarity to proton machines, e.g. SppS/Tevatron and LEP**

Comparison Proton and Electron Colliders



$pp \rightarrow H + X$

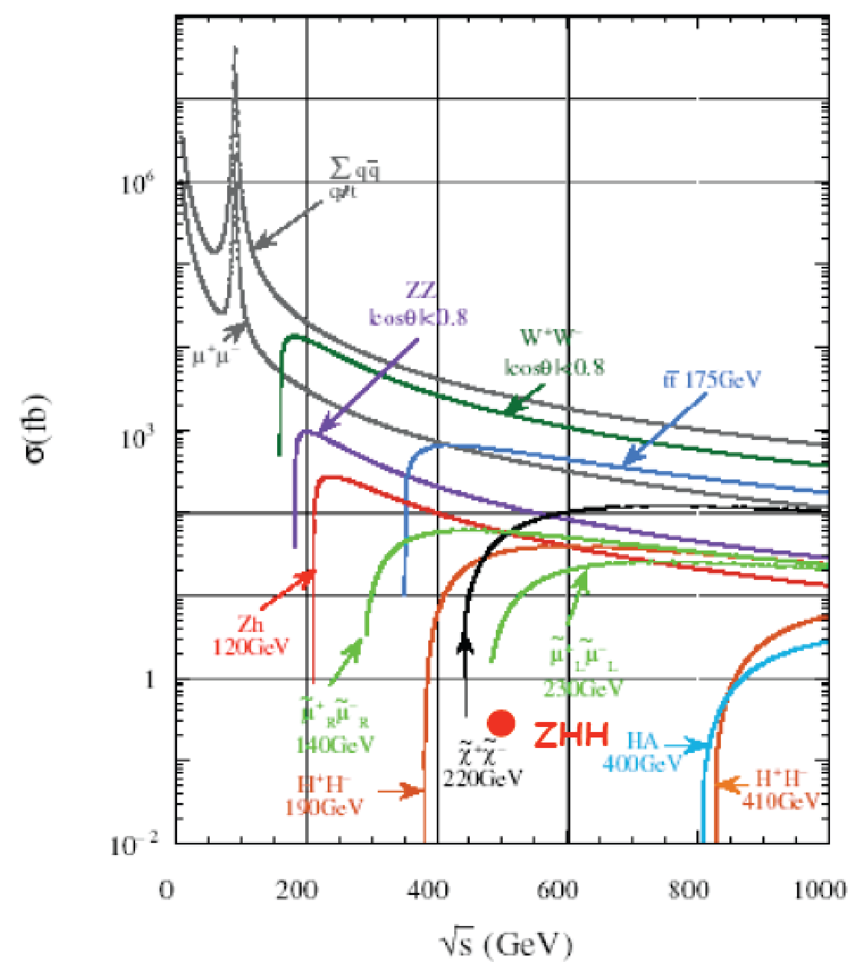


$e^+e^- \rightarrow HZ$

Electron Positron Collider

- The e+e- cross section drops ~1/√s
- The key parameters for a com-petitive e+e- machine are
  - energy reach
  - luminosity

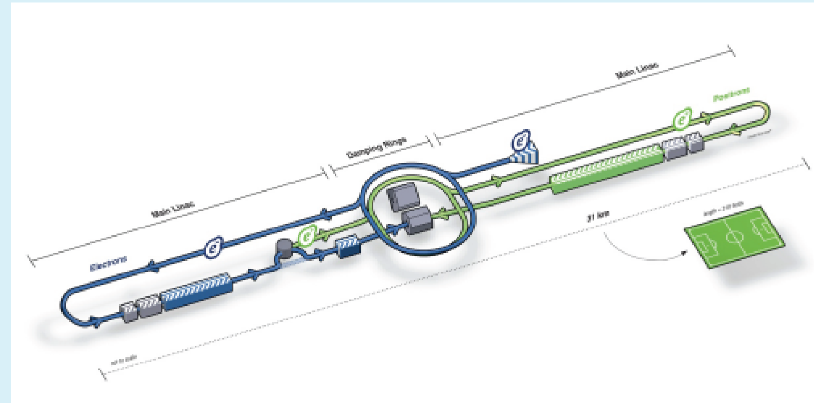
strive for few 10^{34}/cm^2/s (comparable to LHC)



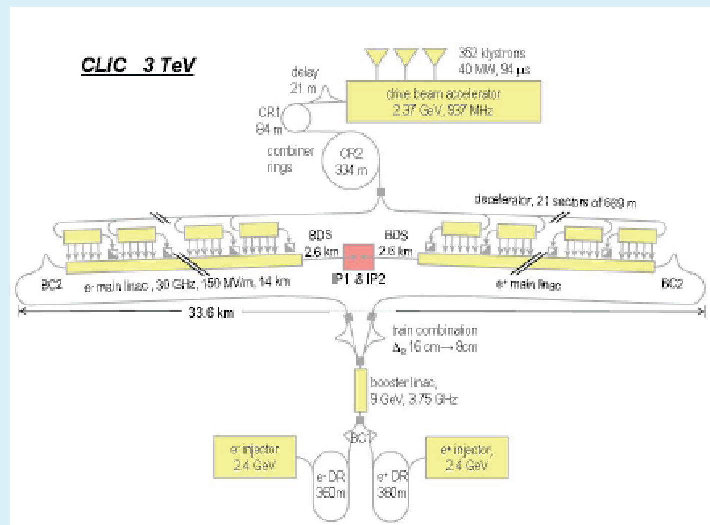
Recall: 10^{34}/cm^2/s corresponds to 100 fb^{-1} per year

Linear Collider Concepts

- International Linear Collider ILC
  - superconducting acceleration
  - 31.5 MeV/m, 1.3 GHz
  - advanced design (c.f. XFEL)
  - 500 GeV (→ 1TeV)
  - Luminsosity: 2 x 10^{34} cm^{-2} s^{-1}



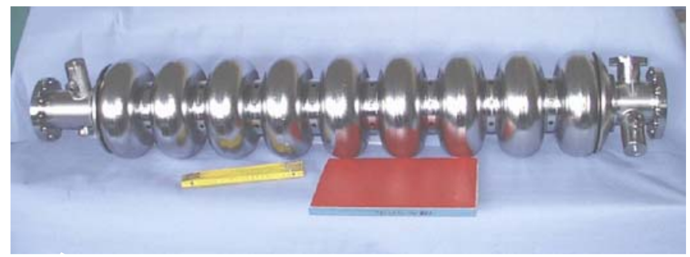
- Compact Linear Collider CLIC
  - normalconducting acceleration
  - 100 MeV/m, 12 GHz
  - two-beam acceleration principle
  - up to several TeV
  - still in fundamental R&D phase



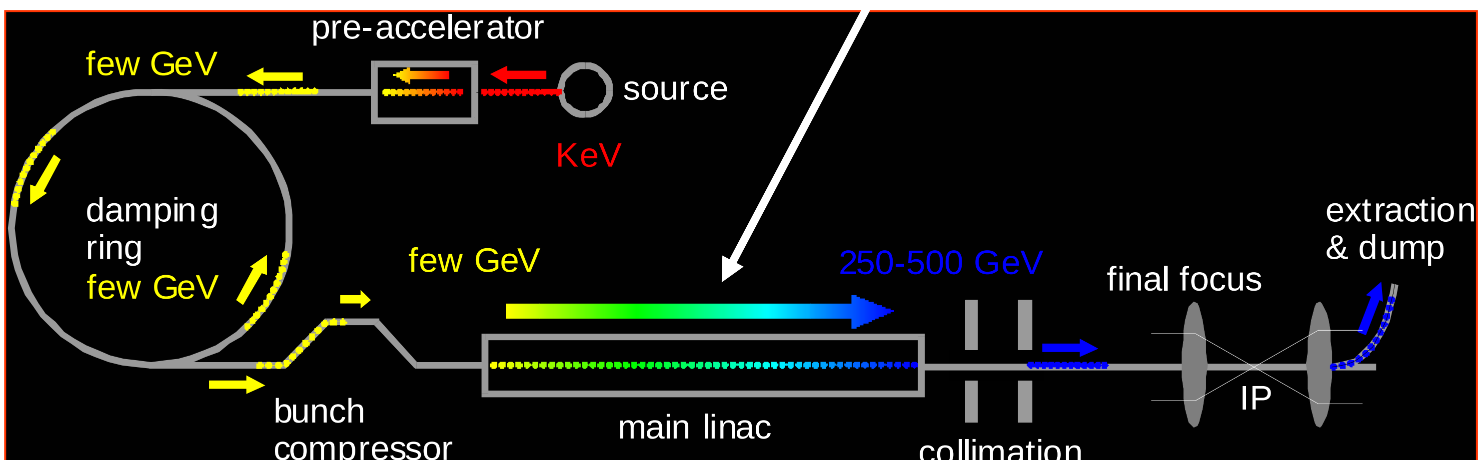
- **Summary:**
  - **ILC ready to go ahead, but limited in energy reach (≤ 1 TeV)**
  - **CLIC in very early state, but may pave the way for higher energy**

The International Linear Collider

- Electron-positron collider
  - centre-of-mass energy up to 1 TeV centre-of-mass energy
  - luminosities $> 10^{34}/cm^2/s$
- Designed in a global effort
- Accelerator technology: supra-conducting RF cavities



- Elements of a linear collider:

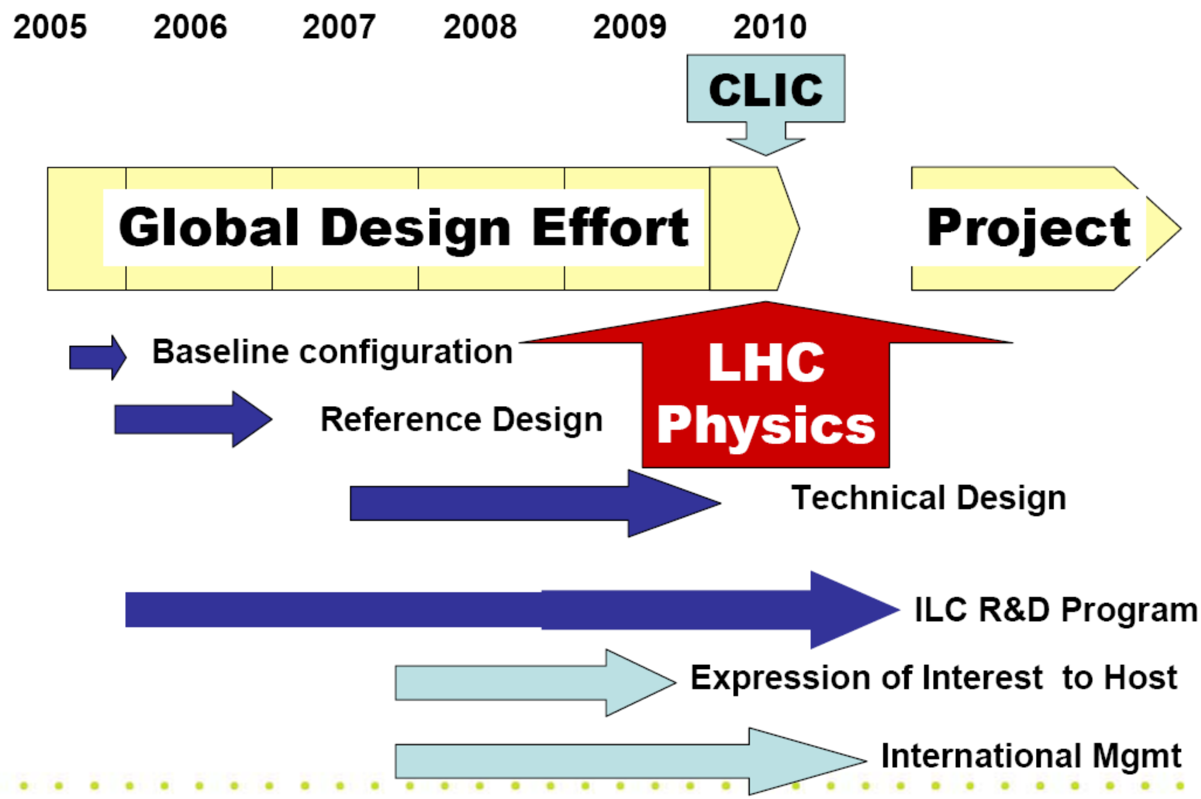


The International Linear Collider

- **International organisation:**
  - **Global Design Effort (GDE), started in 2005**
  - **Chair: Barry Barish**

    representatives from Americas, Asia and Europe

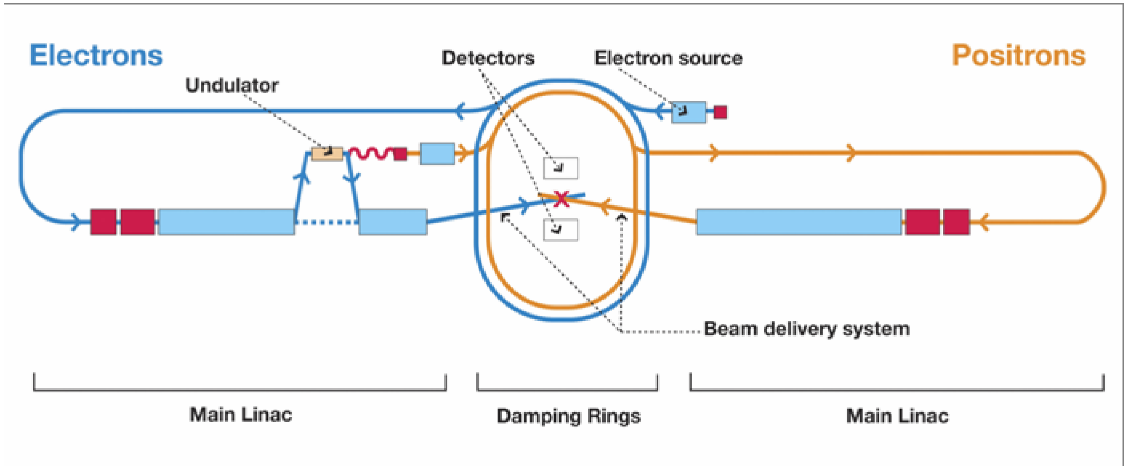
    all major laboratories and many people contributing



The International Linear Collider

- 2006: Baseline Configuration Document
- 2007: Reference Design Report

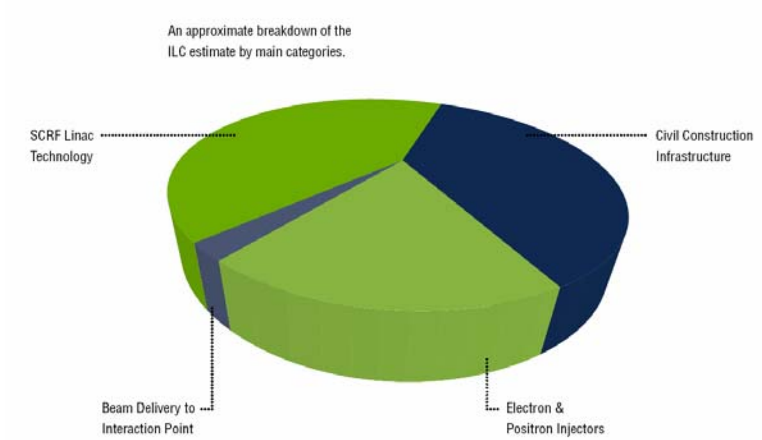
- Layout of the machine:



- 2 × 250 GeV
  upgradable to 2 × 500 GeV
- 1 interaction region
- 2 detectors (push-pull)
- 14 mrad crossing angle

- Cost estimate:
  4.87 G$ shared components
  + 1.78 G$ site-dependent
  = 6.65 G$

  + 13000 person years



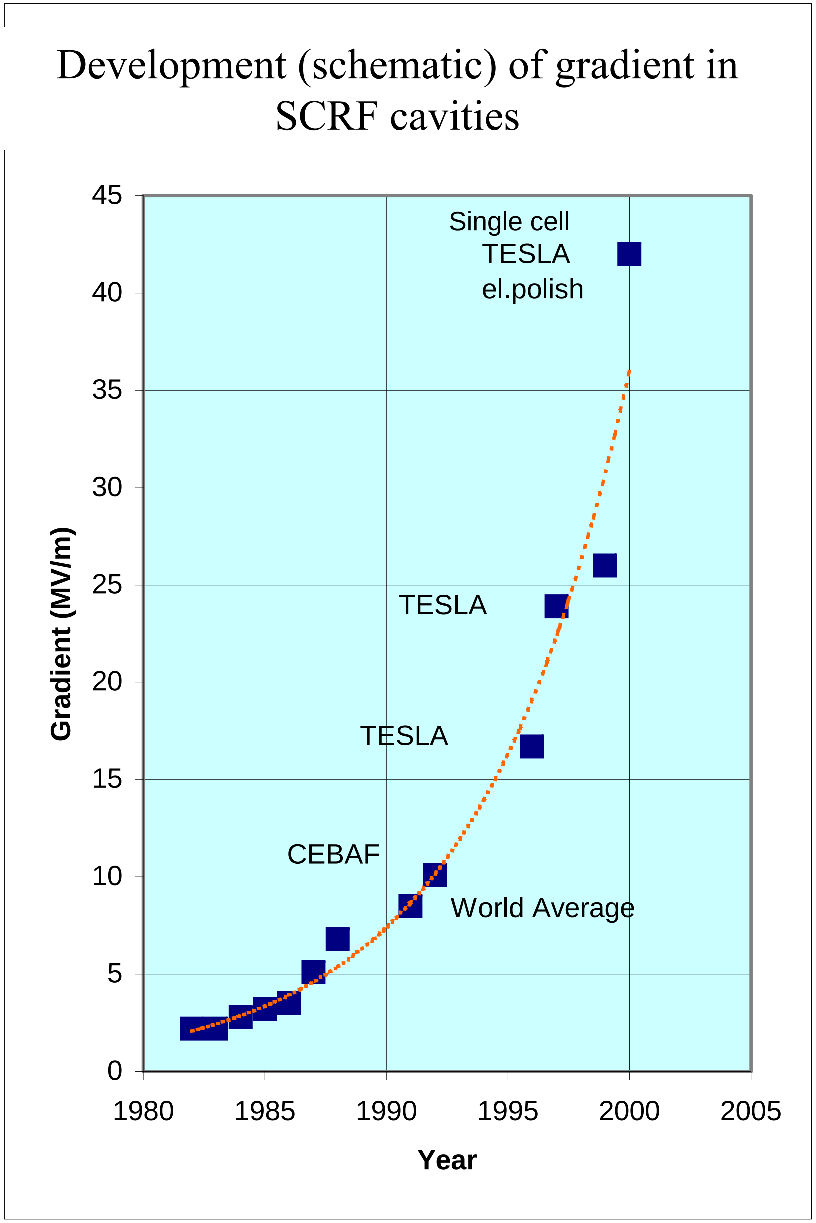
Challenges

- Quest for the highest possible accelerator gradient
- ILC goal: 35 MV/m

- Huge progress over the last 15 years
- 25-fold improvement in perfomance/cost

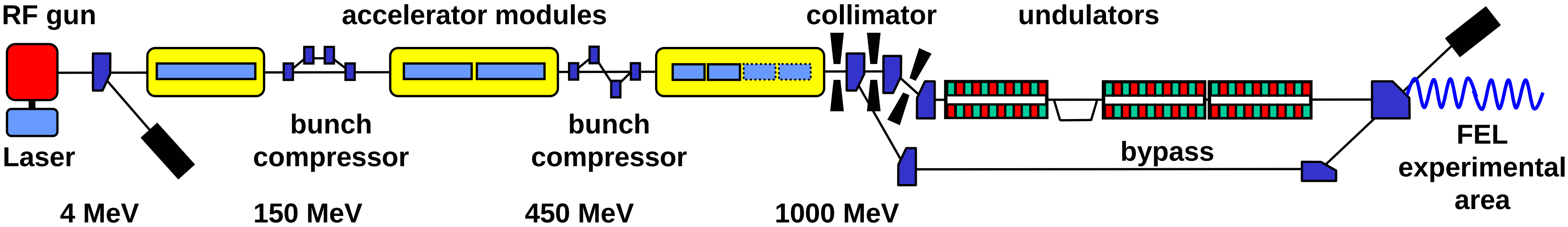
- Major impact on next generation light sources:
  - XFEL designed for ≥ 25 MV/m 10% prototype for ILC

- Recall: LEP II used 7 MV/m



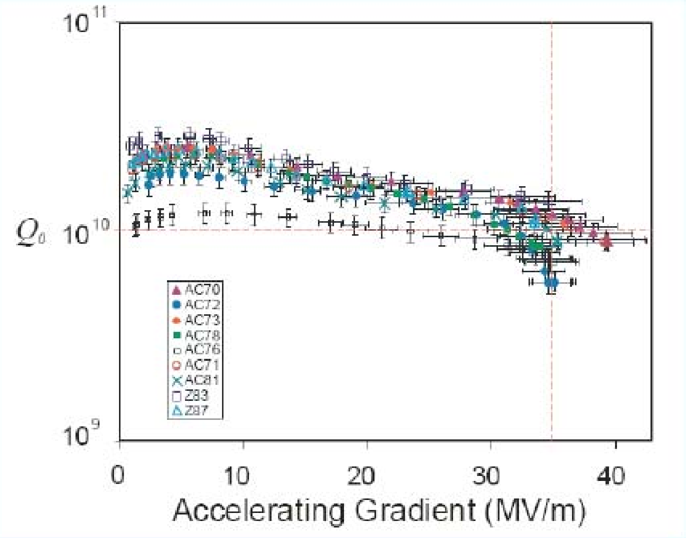
FLASH: Prototype for XFEL and ILC

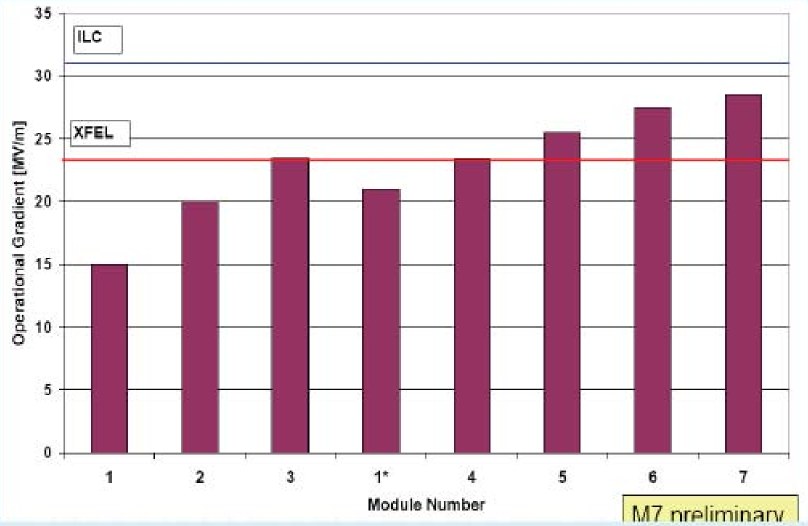
- 1 GeV electron LINAC based on SCRF
- used for ILC studies and as light source (free electron laser)




- **Getting to 35 MV/m:**

- Acceleration gradient goal:
  - 35 MV/m in 9-cell cavities with production yield >80%
  - 50 MV/m have been reached with single cavities
  - Mass production reliability is the key problem





Challenges

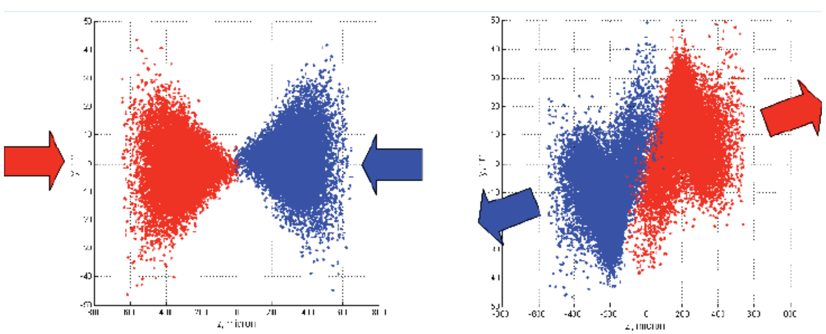
- **Luminostity:**

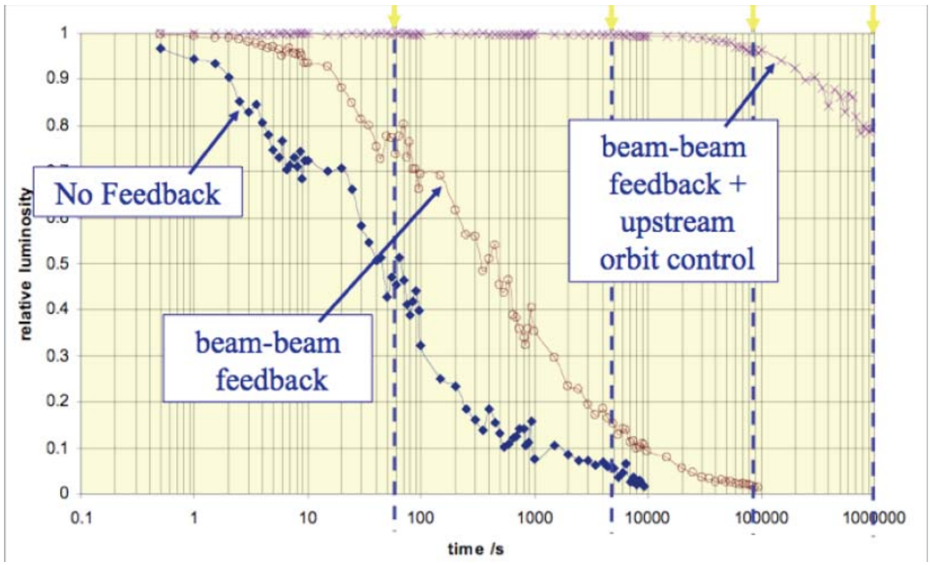
$$L = \frac{n_b N_e^2 f_{rep}}{4\pi \sigma_x^* \sigma_y^*} \times H_D$$

n_b	number of bunches per pulse
N_e	number of electrons (positrons) per bunch
f_{rep}	pulse repetition frequency
H_D	disruption enhancement factor (≈ 2)
$\sigma^*_{x(y)}$	beam dimensions at interaction point

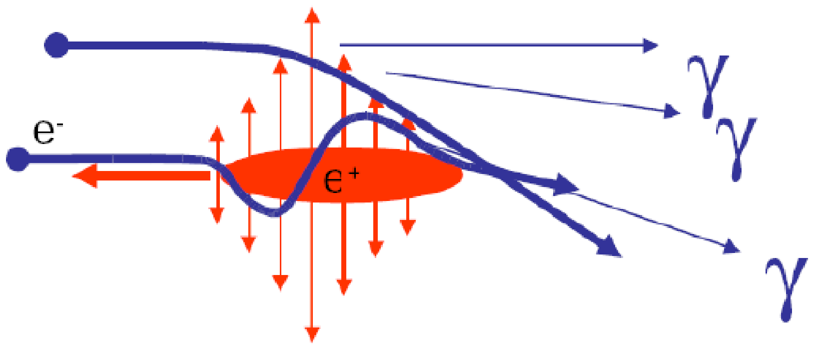
- **make beams as small as possible at IP**
  6 nm × 600 nm

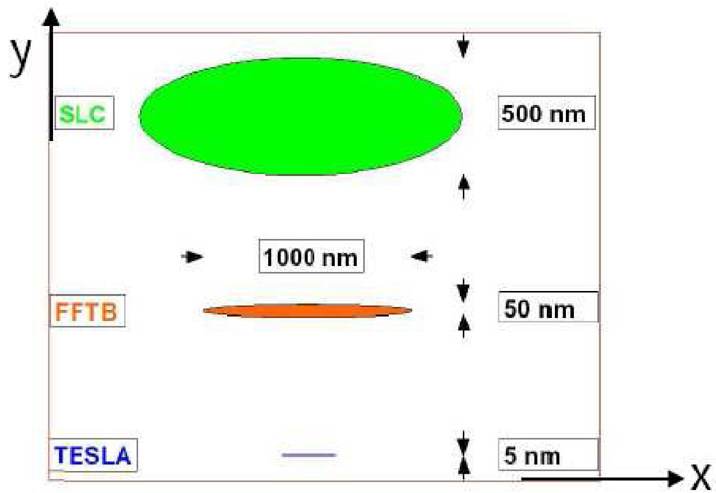
- **and make them collide!!!**





Beamstrahlung





- Energy loss in collision due to Beamstrahlung:

$$\delta_{BS} = \frac{\Delta E}{E} = \frac{E_{CM}}{\sigma_Z}\left(\frac{N}{\sigma_x + \sigma_y}\right)^2$$

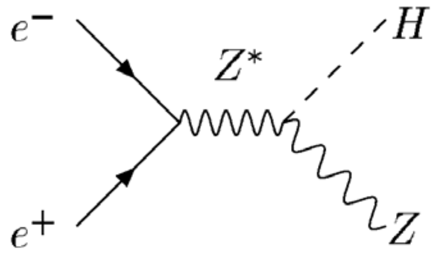
- But: $\mathcal{L} \sim 1/\sigma_x \sigma_y \Rightarrow$ choose flat beams
- 1.5 % energy loss on average
- $\approx 100\,000\ \gamma\gamma$ pairs per BX!
- Intense backgrouns in the forward direction, need high B field to control e^+e^- pairs

ILC Physics Motivation

- ILC will complement LHC discoveries by precision measurements

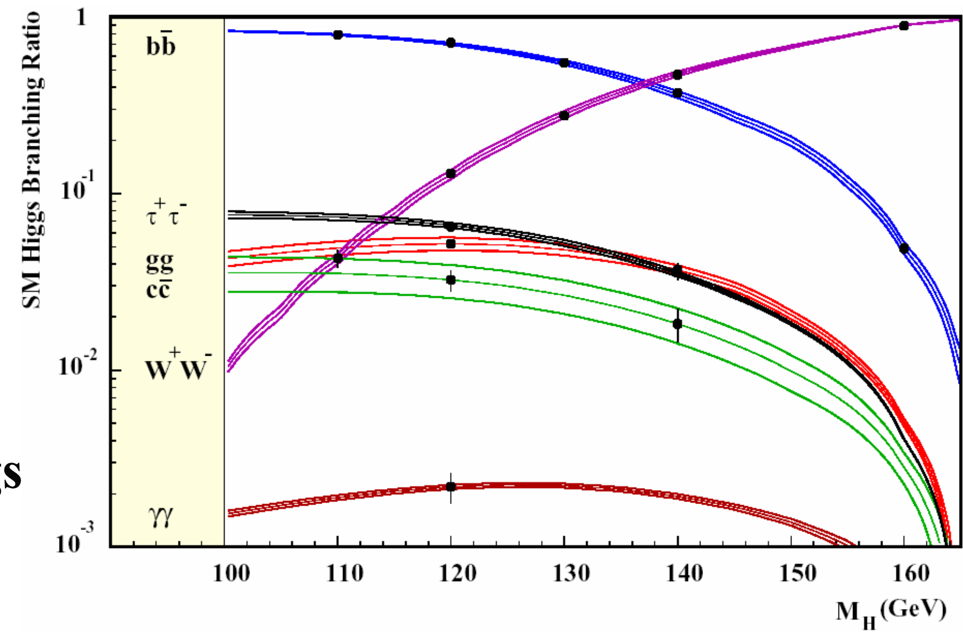
- Here just two examples:

1) There is a Higgs, observed at the LHC
   - e^+e^- experiments can detect Higgs bosons without assumption on decay properties Higgs-Strahlungs process (à la LEP)



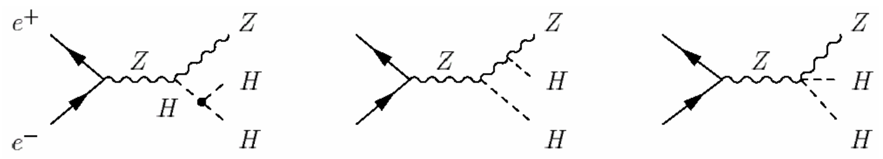
   - identify Higgs events in $e^+e^- \rightarrow ZH$ from $Z \rightarrow \mu\mu$ decay

   - count Higgs decay products to measure Higgs BRs
   - and hence (Yukawa)-couplings

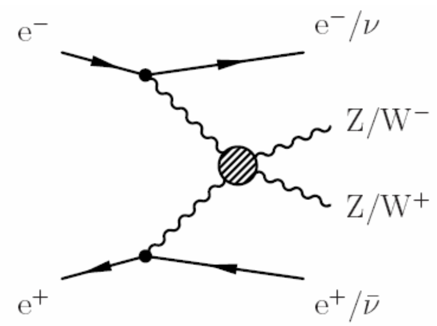


ILC Physics Motivation

- **Measure Higgs self-couplings $e^+e^- \rightarrow ZHH$ to establish Higgs potential**
  Note: small signal above large QCD background



2) There is NO Higgs (definite answer from LHC!)



  - **something else must prevent e.g. WW scattering from violating unitarity at O(1 TeV)**
  - **strong electroweak symmetry breaking?**
    → study $e^+ e^- \rightarrow WW\nu\nu$, $Wze\nu$ and $ZZee$ events

  - **need to select and distinguish W and Z bosons in their hadronic decays!**
    BR (W/Z → hadrons) = 68% / 70%

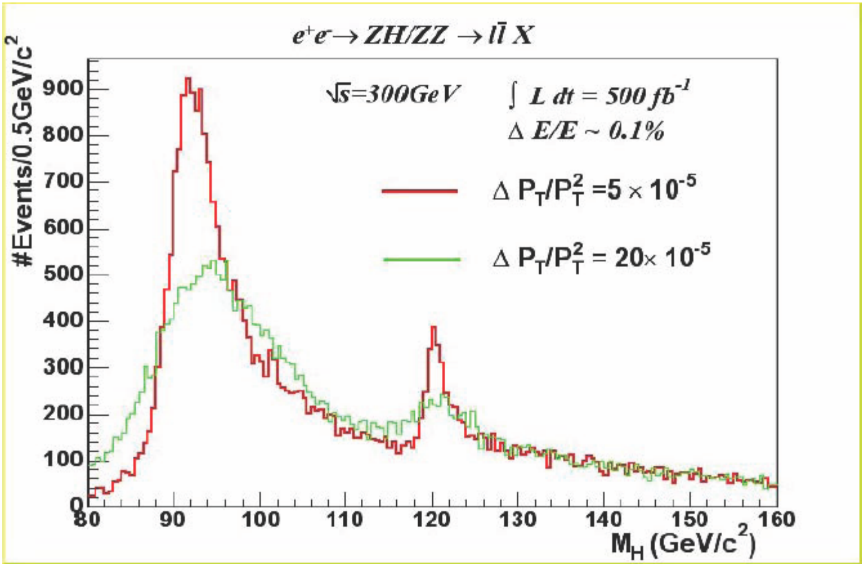
- **Many other physics cases: SM, SUSY, new phenomena, …**

Need ultimate detector performance to meet the ILC physics case

Impact on Detector Design

- Vertex detector:
  e.g. distinguish c- from b-quarks
  - goal impact parameter resolution
    $\sigma_{r\varphi} \approx \sigma_z \approx 5 \oplus 10/(p \sin \Theta^{3/2})$ µm   3 times better than SLD
  - small, low mass pixel detectors, various technologies under study
    $O(20\times20\ \mu m^2)$
- Tracking:
  - superb momentum resolution to select clean Higgs samples
  - ideally limited only by Γ_Z

  $\rightarrow \Delta(1/p_T) = 5\cdot10^{-5}$ /GeV
  (whole tracking system)
  3 times better than CMS

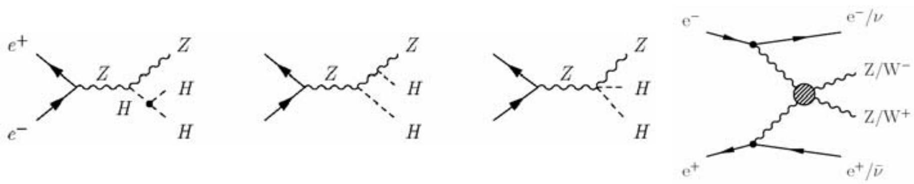


Options considered:
- Large silicon trackers (à la ATLAS/CMS)
- Time Projection Chamber with ≈ 100 µm point resolution (complemented by Si–strip devices)

Impact on Detector Design

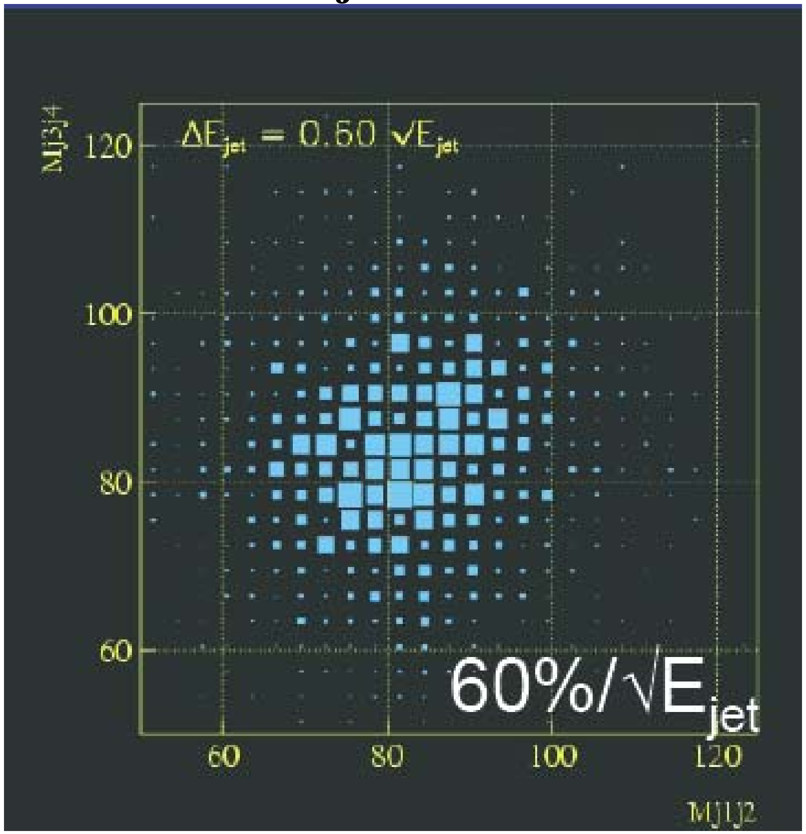
- **Calorimeter:**
  distinguish W- and Z-bosons in their hadronic decays

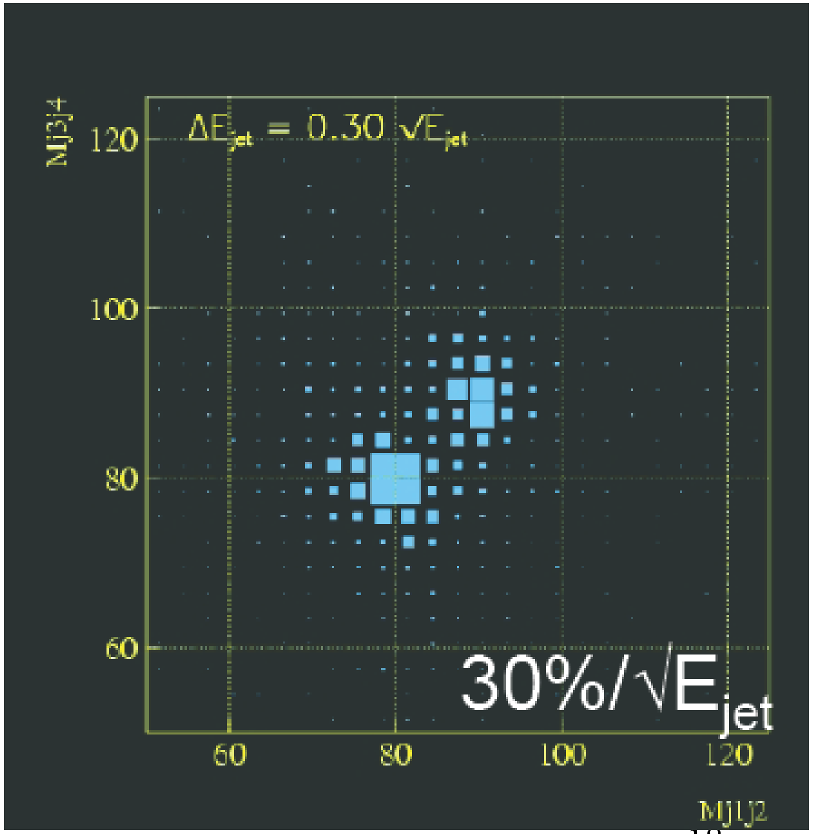
→ 30%/√E jet resolution!



2 times better than ZEUS

- **WW/ZZ → 4 jets:**

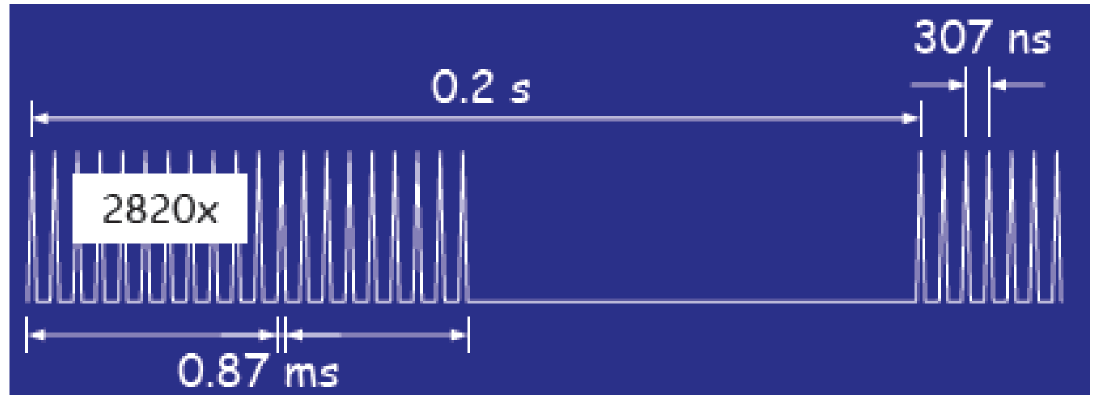




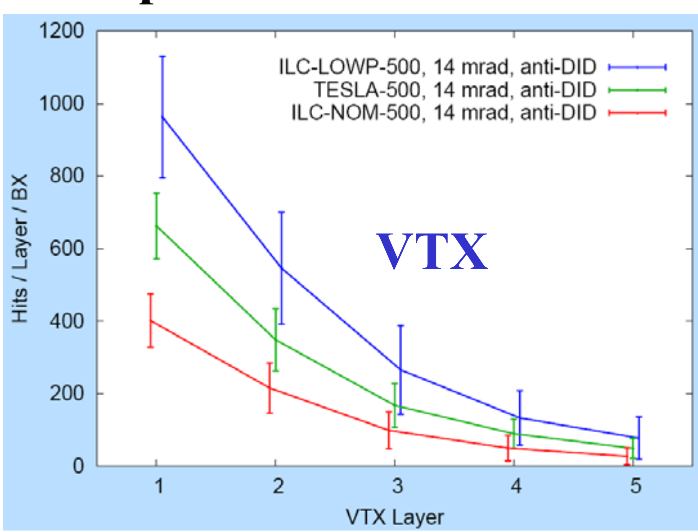
→ Particle Flow or Dual Readout calorimeter

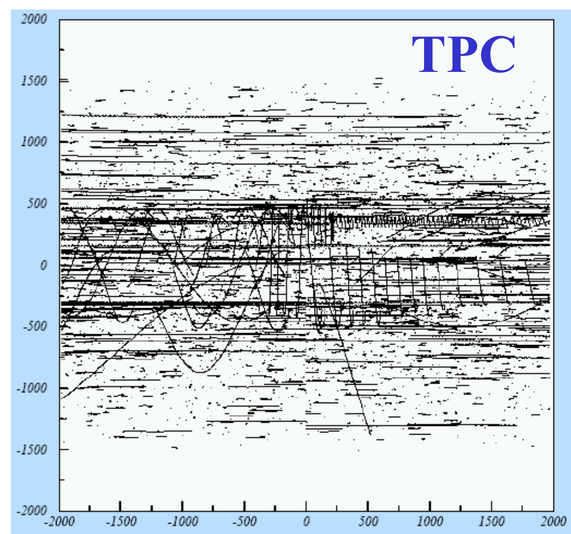
Detector Challenges at the ILC

- **Bunch timing:**
  - 5 trains per second
  - 2820 bunches per train separated by 307 ns
    - no trigger
    - power pulsing
    - readout speed
- **14 mrad crossing angle**
- **Background:**
  - small bunches
  - create beamstrahlung → pairs



backgound not as severe as at LHC but much more relevant than at LEP





Detector Concepts

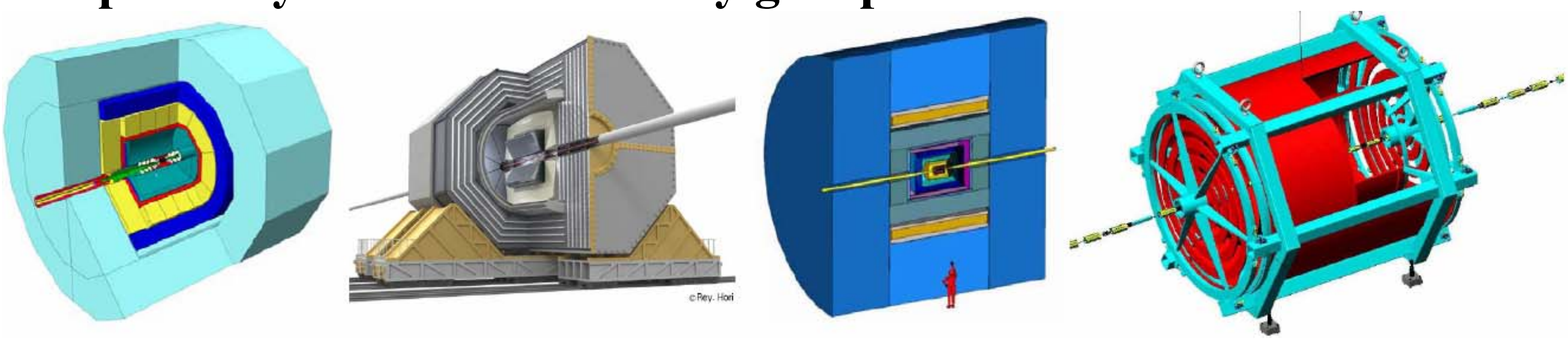
- Four detector concepts are being investigated
  - GLD (Global Large Detector)
  - LDC (Large Detector Concept)
  - SiD (Silicon Detector)
  - 4th concept

GLD and LDC: Merging into one concept: (ILD) International Large Detector

- Summer 2006: Detector Outline Documents (DOD) evolving documents, detailed description

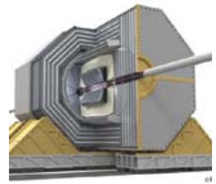
- Summer 2007: Reference Design Reports (RDR) comprehensive detector descriptions, along with machine RDR

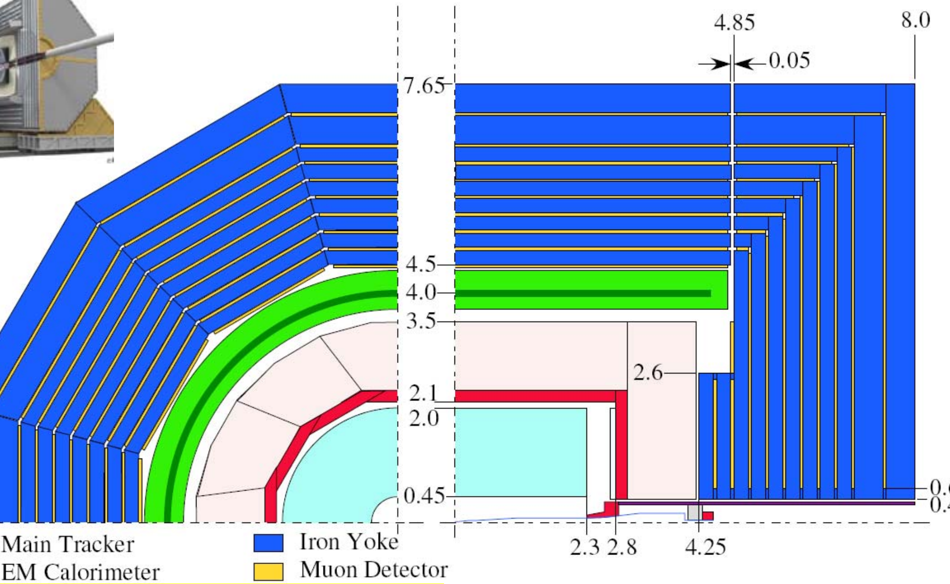
- Prepared by international study groups



Detector Concepts

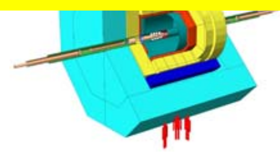
- GLD
  - TPC tracking
    large radius
  - particle flow calorimeter
  - 3 Tesla solenoid
  - scint. fibre μ detector

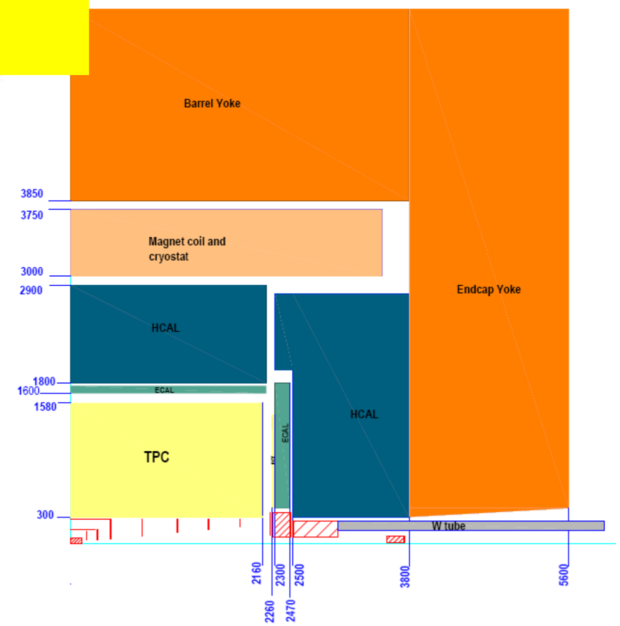


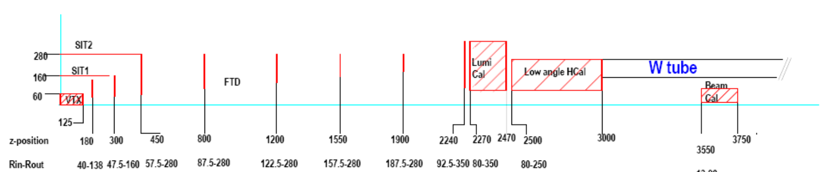


Both concepts are rather similar now merging into one (ILD)

- LDC
  - TPC tracking
    smaller radius
  - particle flow calorimeter
  - 4 Tesla solenoid
  - μ detection: RPC or others

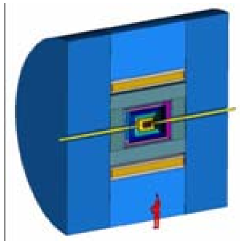


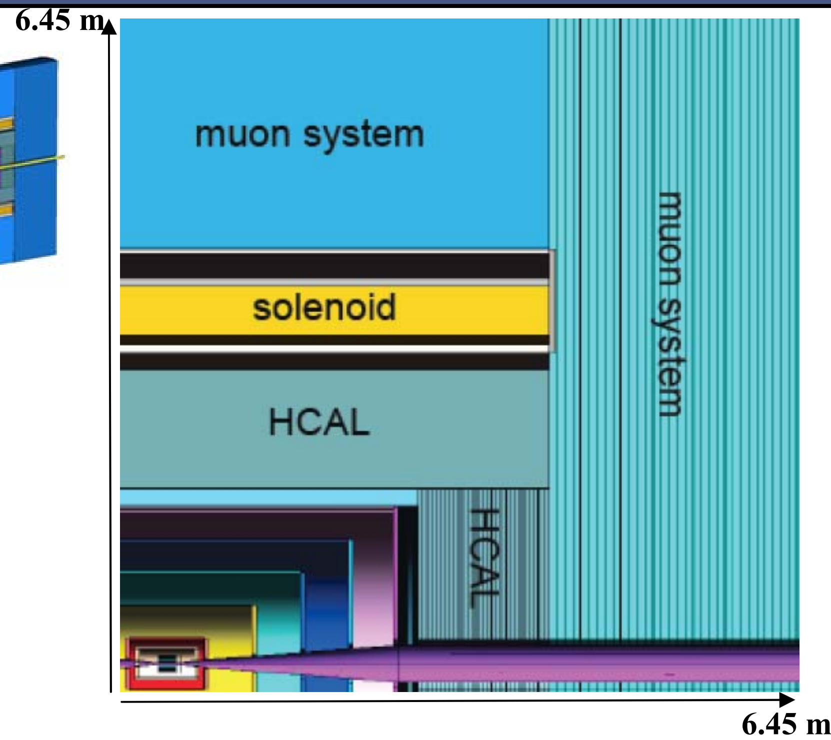




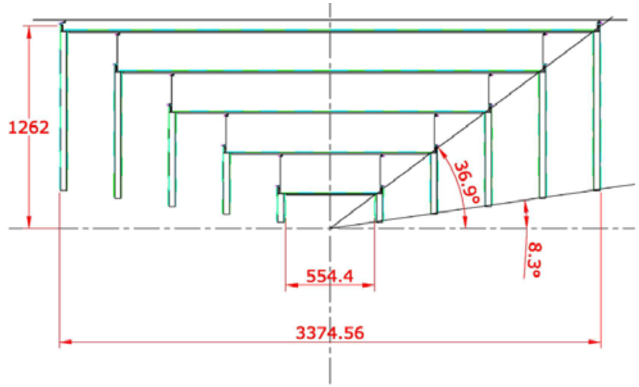
Detector Concepts

- **SiD**
  - silicon tracking
  - smaller radius
  - high field solenoid (5 Tesla)
  - scint. fibre / RPC μ detector

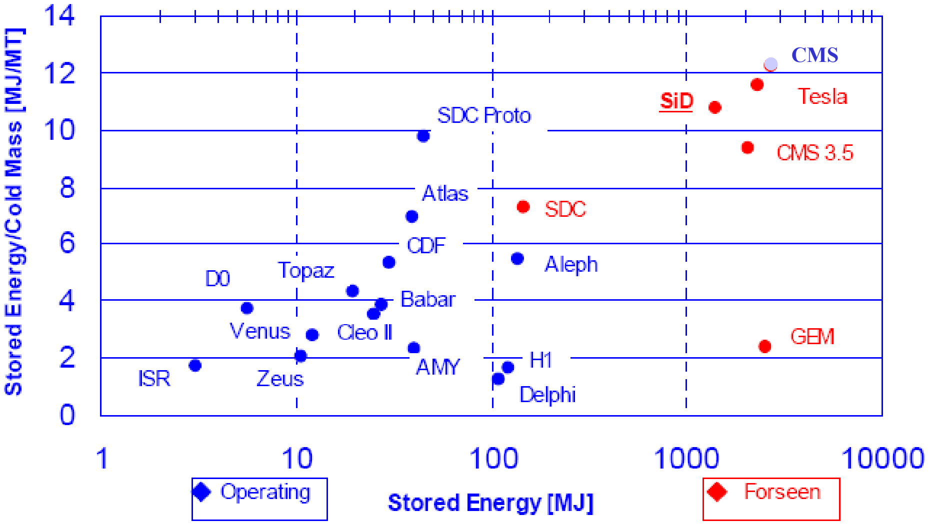




- **Silicon tracker**

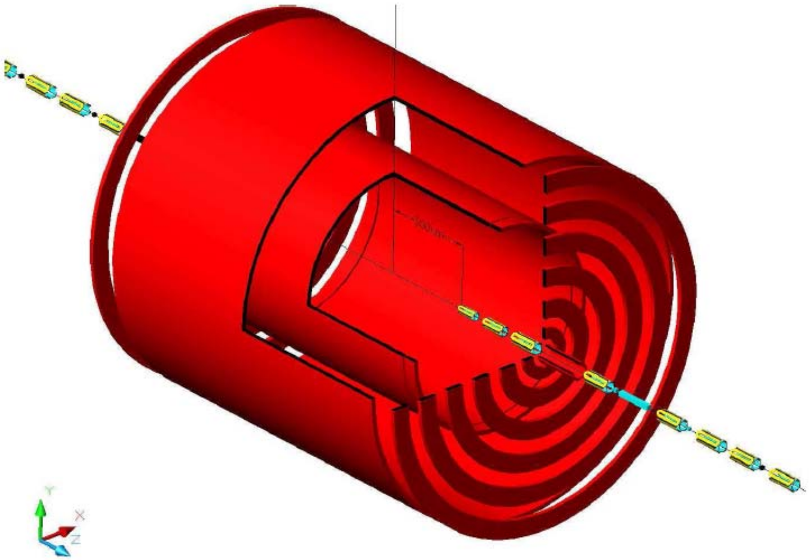


- **Magnet**
  - high field
  - but smaller volume

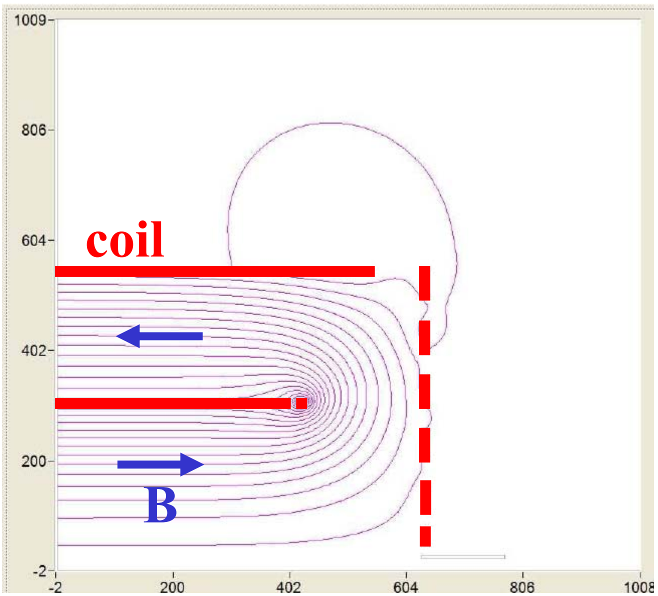


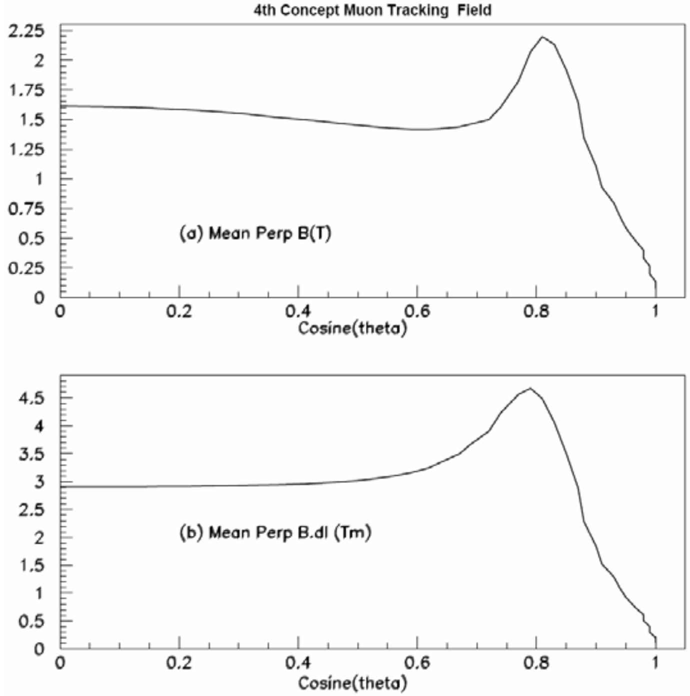
Detector Concepts

- **4th concept**
  - TPC
  - multiple readout calorimeter
  - iron-free magnet, dual solenoid
  - muon spectrometer (drift tubes)



- **Dual solenoid**
  - iron return yoke replaced by second barrel coil and endcap coils





Average field seen by μ:

<B> ≈ 1.5 T
<Bl> ≈ 3 Tm

Detector Concept and R&D efforts

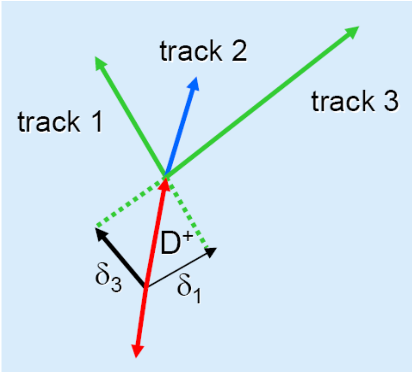
- R&D efforts for key detector elements
- Overlap with detector concepts:

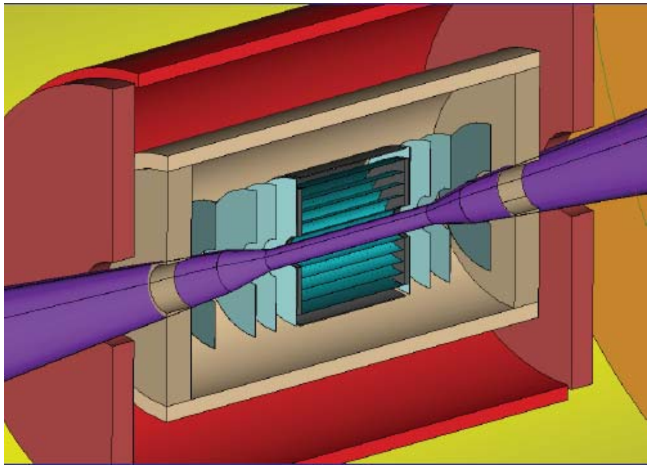
	GLD	LDC	SID	4th concept	Detector R&D collaborations
Vertex	X	X	X	X	LCFI
Tracking					
- TPC	X	X		X	LCTPC
- Silicon	*	*	X	*	SILC
Calorimetry:					
- Particle Flow	X	X	X		CALICE
- Multiple Readout				X	
- Forward region	X	X	X	X	FCAL

* silicon forward and auxiliary tracking also relevant for other concepts

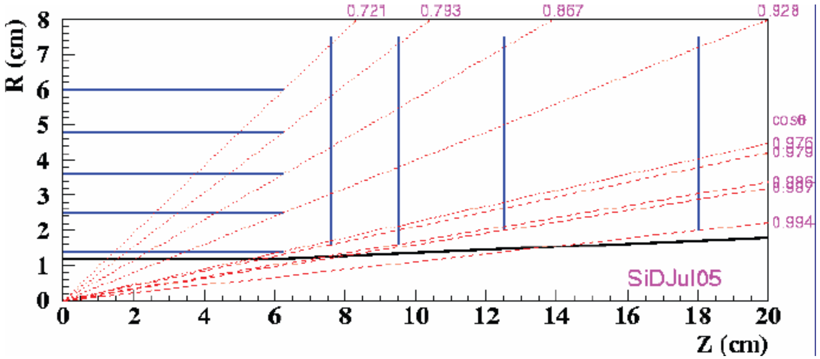
Vertex Detector

- Key issuses:
  - measure impact parameter for each track
  - space point resolution < 5 µm
  - smallest possible inner radius $r_i \approx 15$ mm
  - transparency: ≈ 0.1% X_0 per layer
    = 100 µm of silicon
  - stand alone tracking capability
  - full coverage |cos Θ| < 0.98
  - modest power consumption < 100 W





- Five layers of pixel detectors plus forward disks
  - pixel size O(20×20 µm²)
  - 10^9 channels



- Note: wrt. LHC pixel detectors
  - 1/5 r_i
  - 1/30 pixel size
  - 1/30 thickness

Vertex Detector

- **Critical issue is readout speed:**
- **Inner layer can afford O(1) hit per mm^2 (pattern recognition)**
  - **once per bunch = 300 ns per frame too fast**
  - **once per train ≈ 100 hits/mm^2 too slow**
  - **20 times per train ≈ 5 hits/mm^2 might work**

    50 µs per frame of 10^9 pixels!

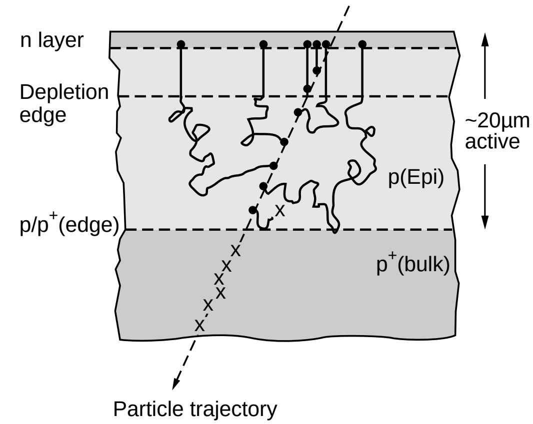
→ readout during bunch train (20 times)
or store data on chip and readout in between trains
e.g. ISIS: In-situ Storage Image Sensor

- **Many different (sensor)-technologies under study**
  CPCCD, MAPS, DEPFET, CAPS/FAPS, SOI/3-D, SCCD, FPCCD, Chronopixel, ISIS, …
  → Linear Collider Flavour Identification (LCFI) R&D collaboration
- **Below a few examples**

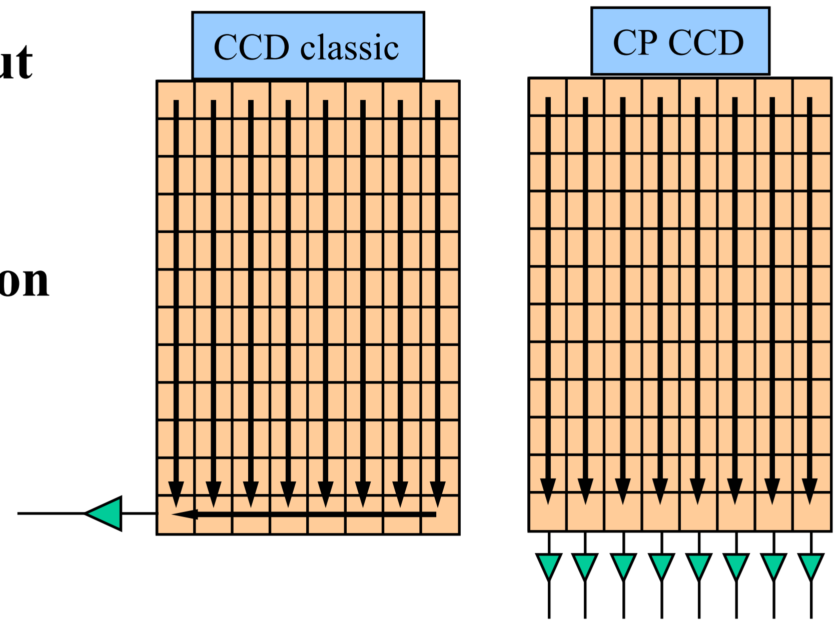
- **Note: many R&D issues independent of Si-technology (mechanics, cooling, …)**

CP CCD

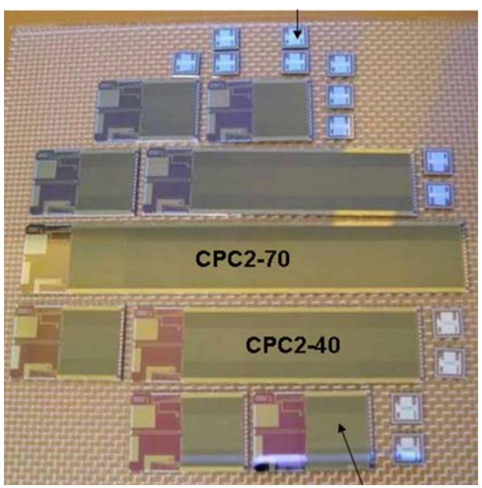
- CCD
  - create signal in 20 µm active layer
  - etching of bulk material to keep total thickness ≤ 60 µm
  - low power consumption
  - but very slow



→ apply column parallel (CP) readout

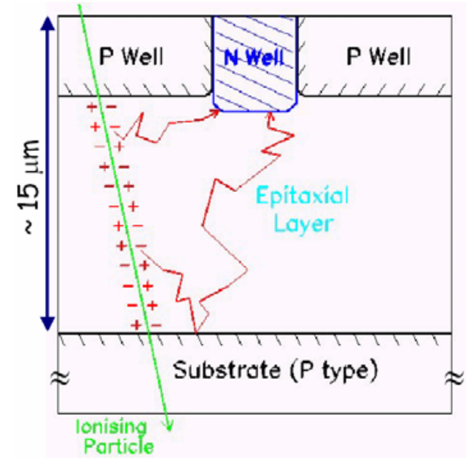


- Second generation CP CCD designed to reach 50 MHz operation

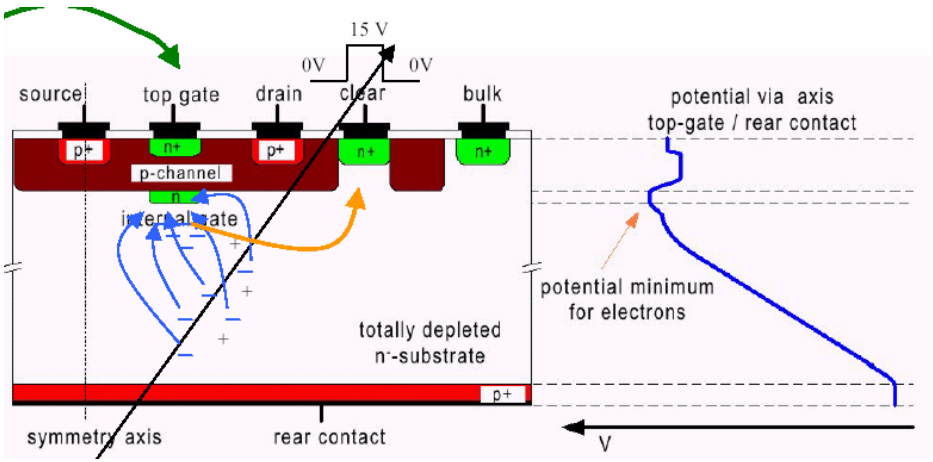


MAPS and DEPFET

- **CMOS Monolithic Active Pixel detectors**
  - **standard CMOS wafer integrating all functions**
  - **no bonding between sensor and electronics**
  - **e.g. Mimosa chip**



- **DEPFET: DEPleted Field Effect Transistor**
  - **fully depleted sensor with integrated pre-amplifier**
  - **low power and low noise**

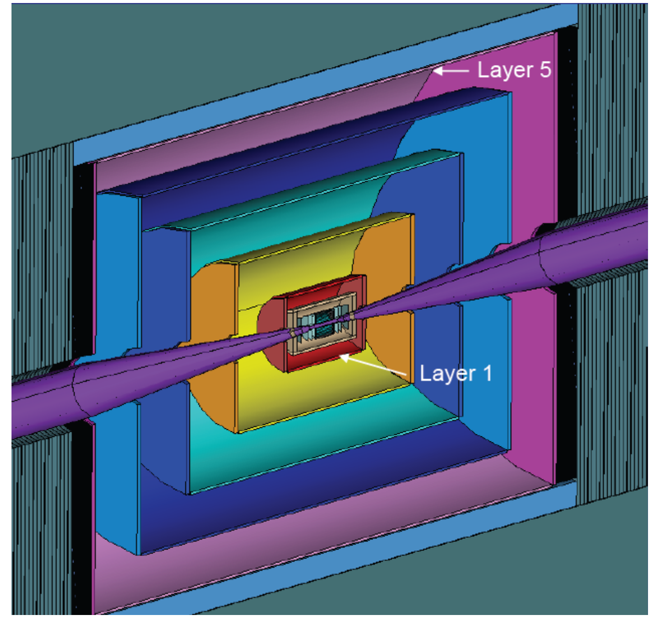


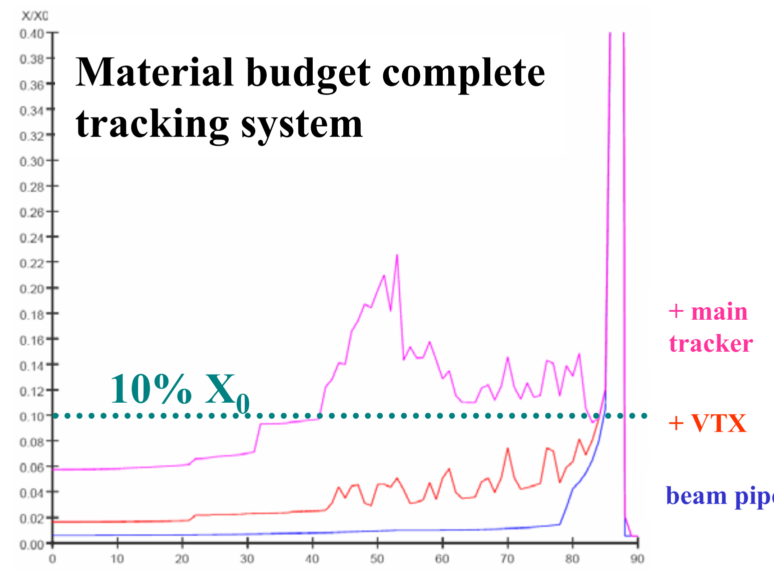
Silicon Tracking

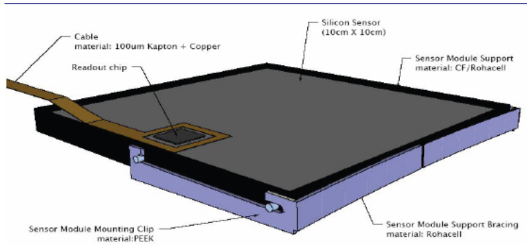
- The SiD tracker:
  - 5 barrel layers
    r_i = 20 cm
    r_o = 125 cm
  - 10 cm segmentation in z
    short sensors
  - measure phi only

- endcap disks
  - 5 double disk per side
  - measure r and phi

- critical issue:
  - material budget
    (support, cooling, readout)
  - goal: 0.8% X_0 per layer

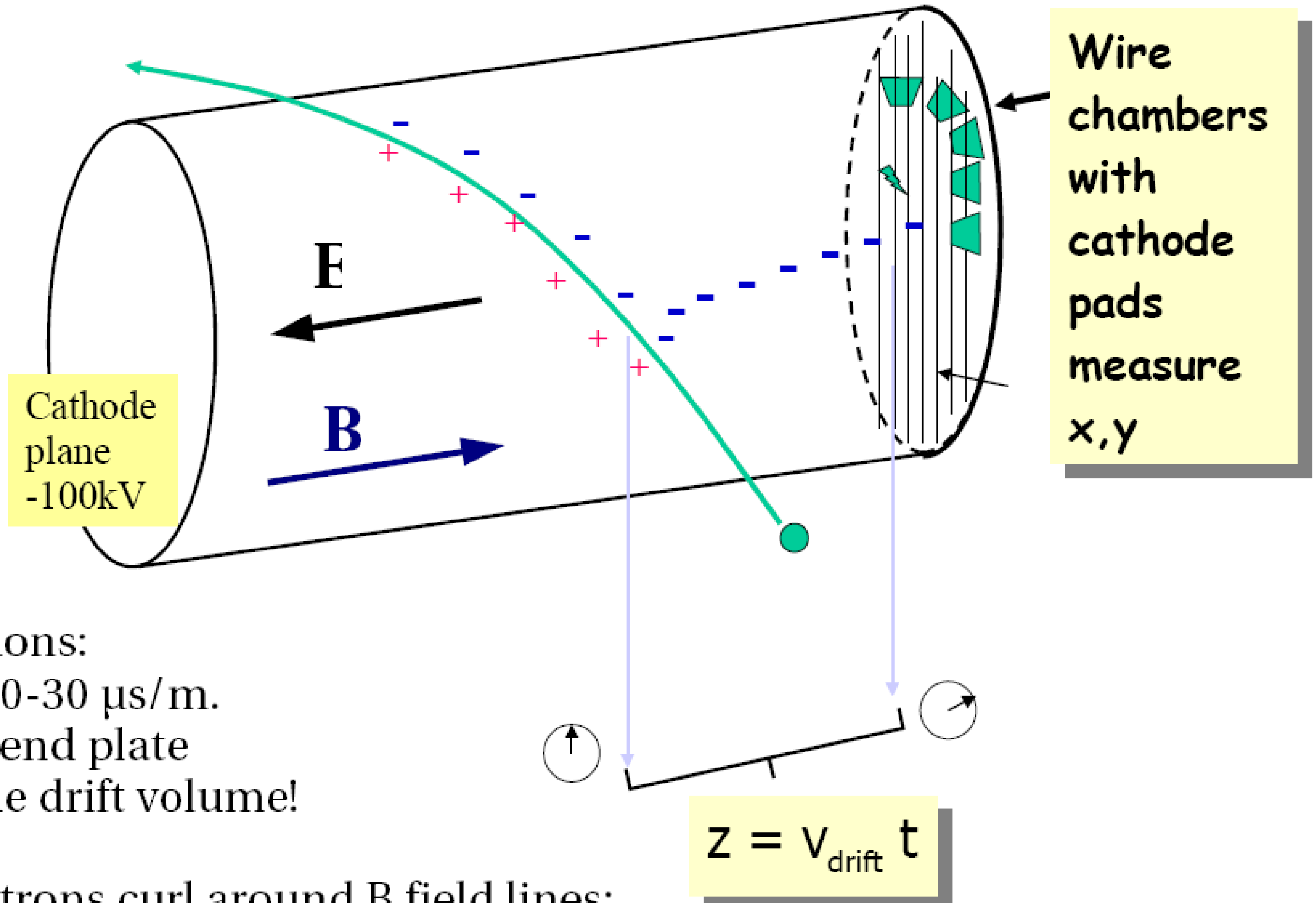






TPC Tracking

Time Projection Chamber in a solenoid field



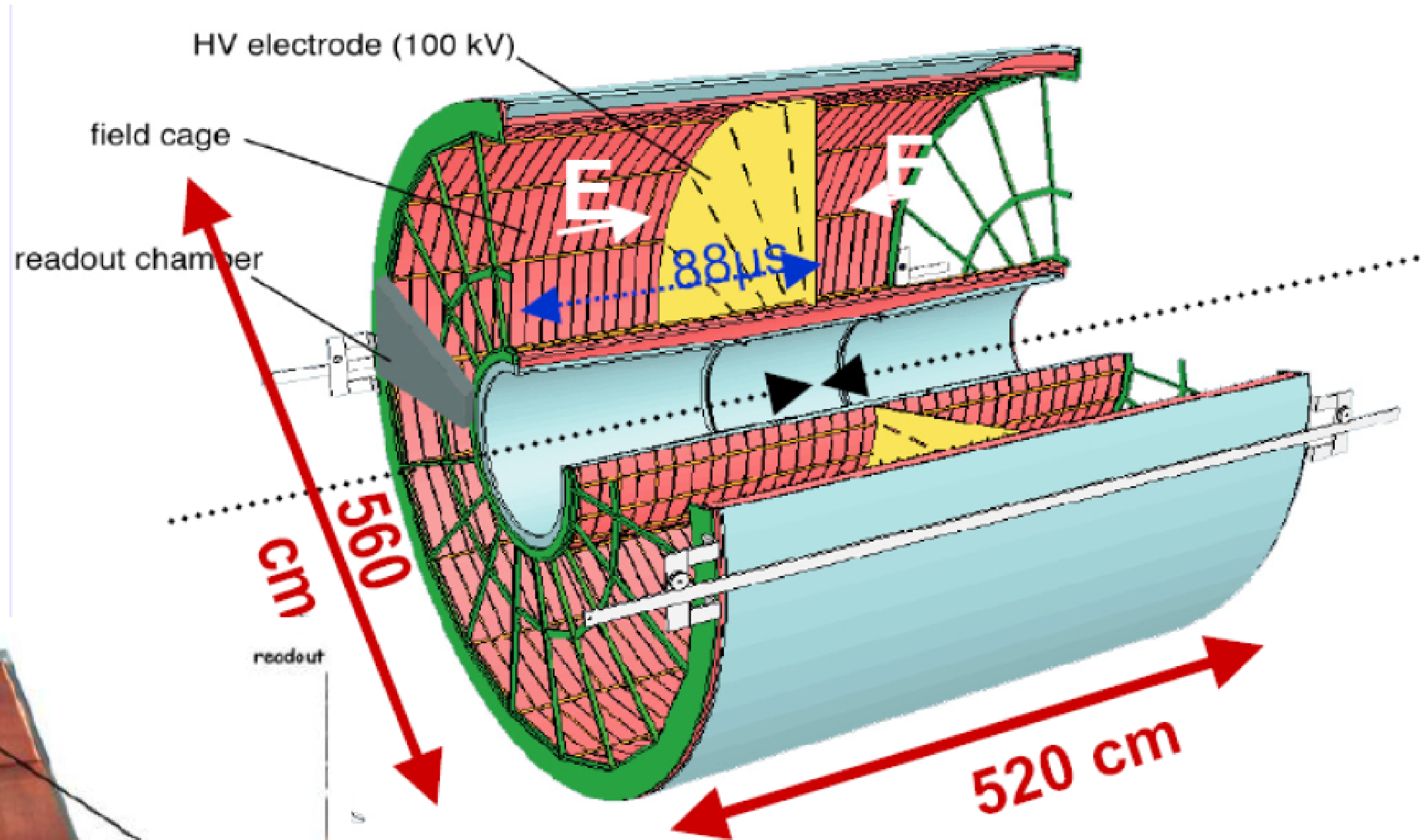
Separate two regions:
- Drift along z: 20-30 μs/m.
- Amplify at the end plate

No material inside drift volume!

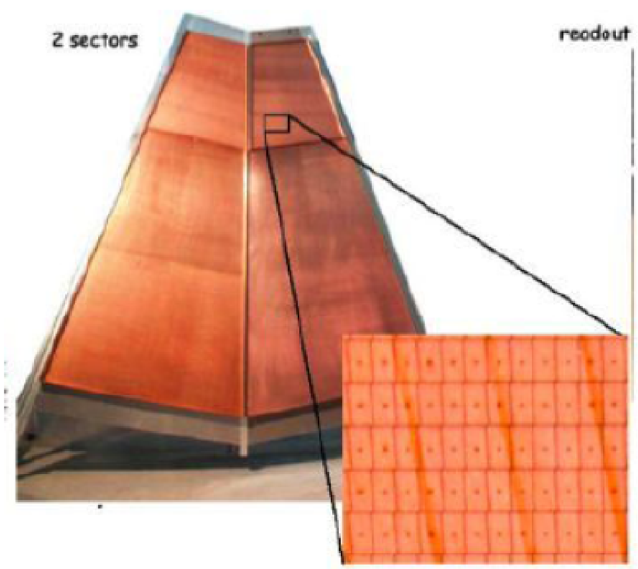
E||B: drifting electrons curl around B field lines: limited spread.

TPC Tracking

ALICE TPC



readout:



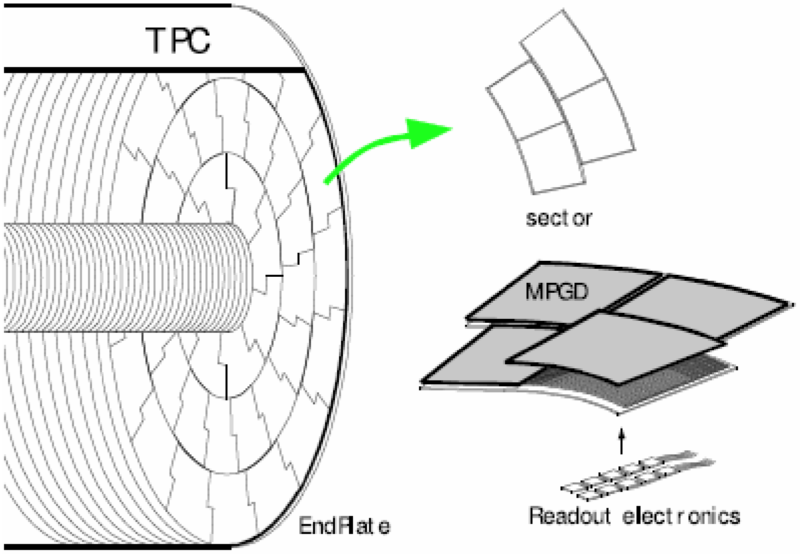
max. drift time 88 µs.
LHC operates with low luminosity at ALICE (pp and PbPb).

Time Projection Chamber

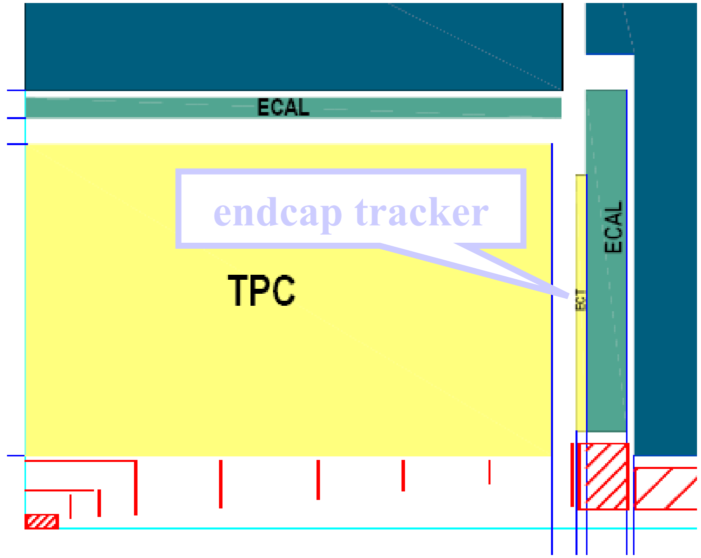
- GLD, LDC and 4th:
  high resolution TPC as main tracker
  - 3 – 4 m diameter
  - ≈ 4.5 m length
  - low mass field cage
    - 3%X_0 barrel
    - < 30% X_0 endcap
  - ≈ 200 points/track
  - ≈ 100 µm single point res.

  → $\Delta(1/p_T) = 10^{-4}$ /GeV

  (10 times better than LEP!)



- Complemented by Forward Tracking
  - endcap between TPC and ECAL
  - Si strip, straw tube, GEM-based, … are considered

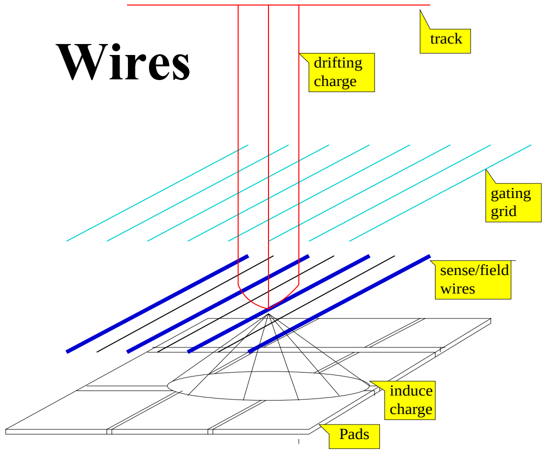


- TPC development performed in LCTPC collaboration

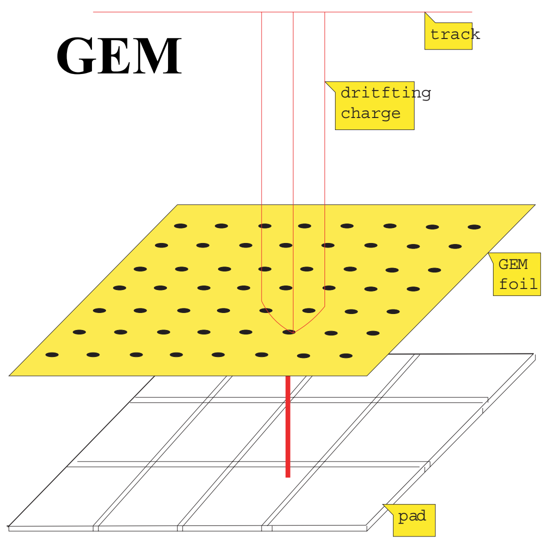
- New concept for gas amplication at end flanges: Replace proportional wires by Micro Pattern Gas Detectors (MPGD)

- GEM or MicroMegas
  - finer dimensions
  - two-dimensional symmetry → no E×B effects
  - only fast electron signal
  - intrinsic suppression of ion backdrift

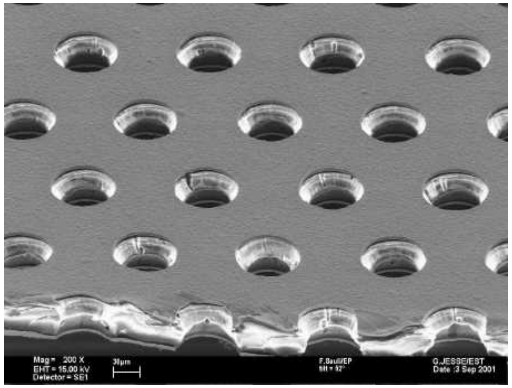
Wires



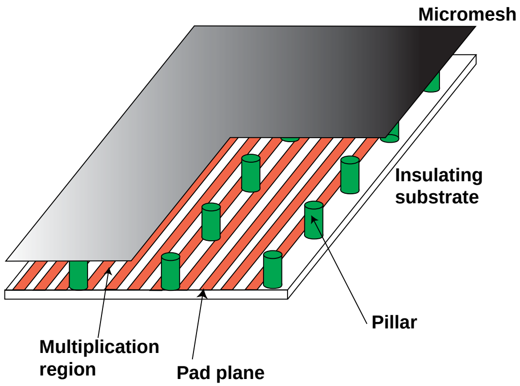
GEM



GEM

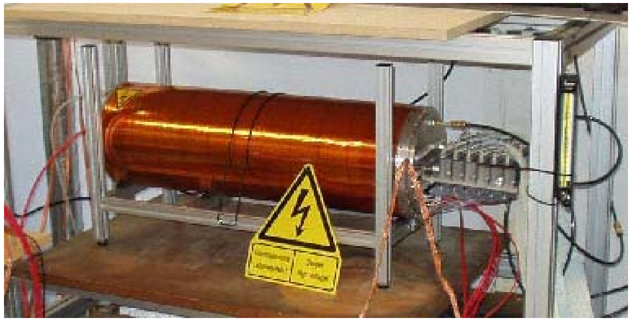


µMegas

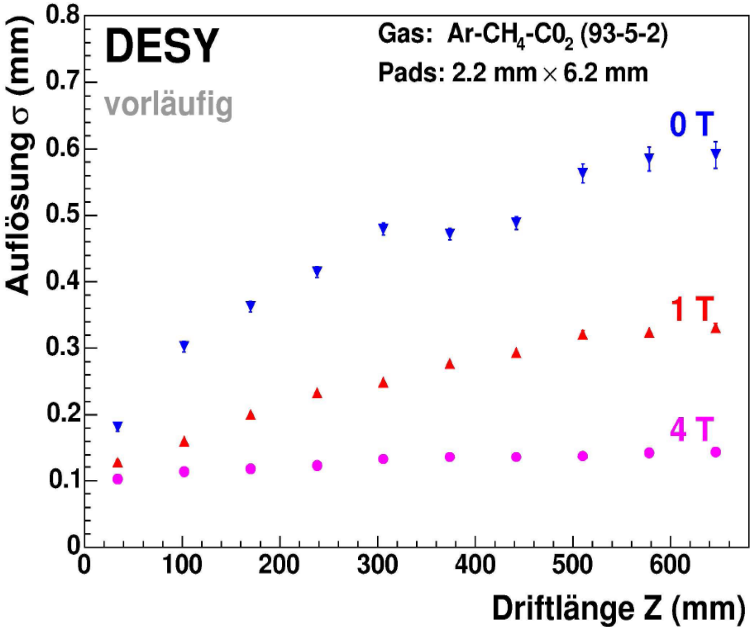


Time Projection Chamber

- **Principle of MPGD based TPC established**
  many small scale prototype experiments over the last ≈ 5 years



Example:



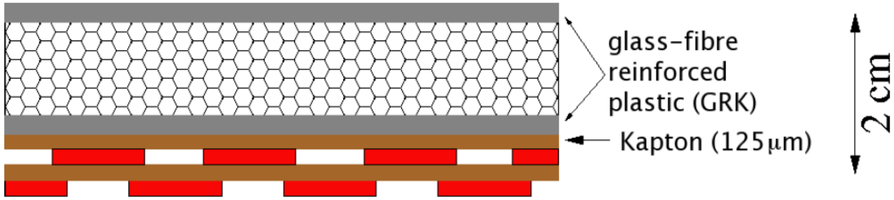
- **cosmics, testbeam**
- **magnetic field**

- **under construction for experiments (MICE, T2K)**

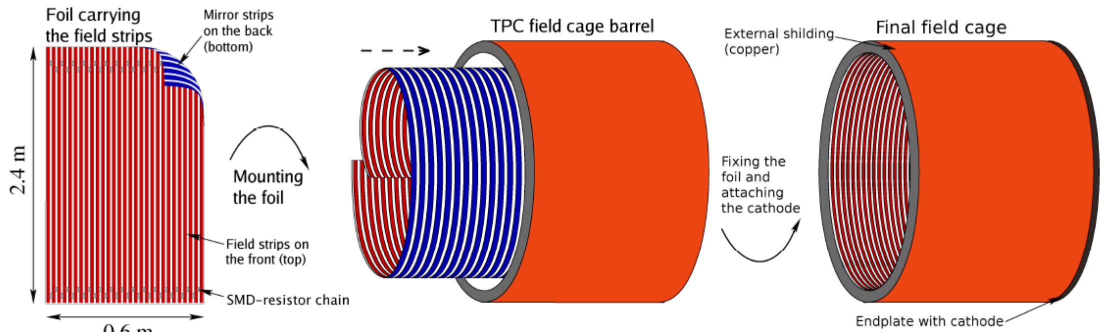
Single point resolution O(100 µm) established in
- small scale prototypes
- high magnetic fields

Time Projection Chamber

- **Low mass fieldcage**
  - **large prototype under construction**
  - **using composite material**



≈ 1% X_0



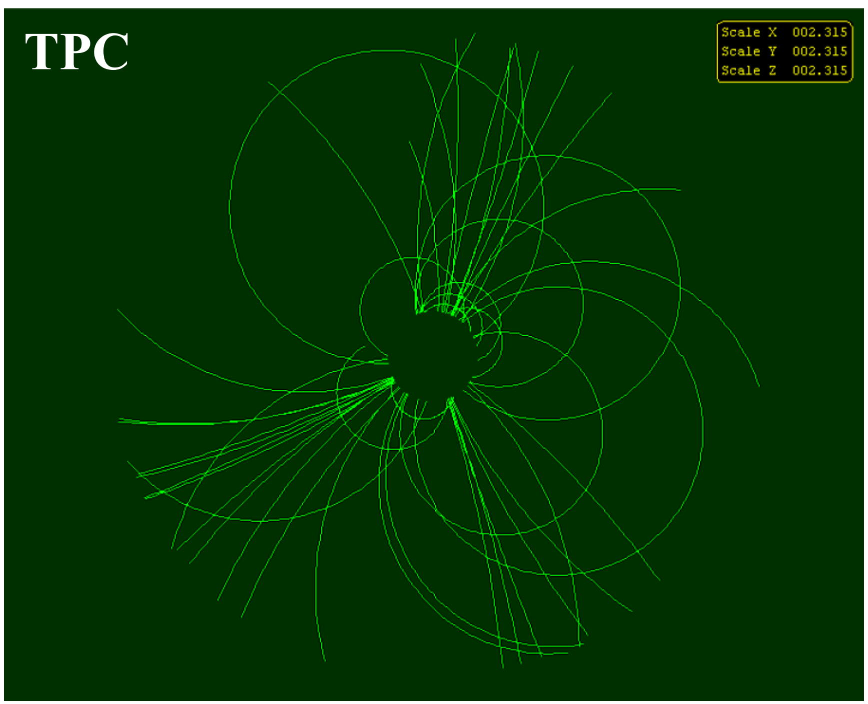
- **Electronics**
  - **few 10^6 channels on endplate (ILD)**
  - **low power to avoid cooling**

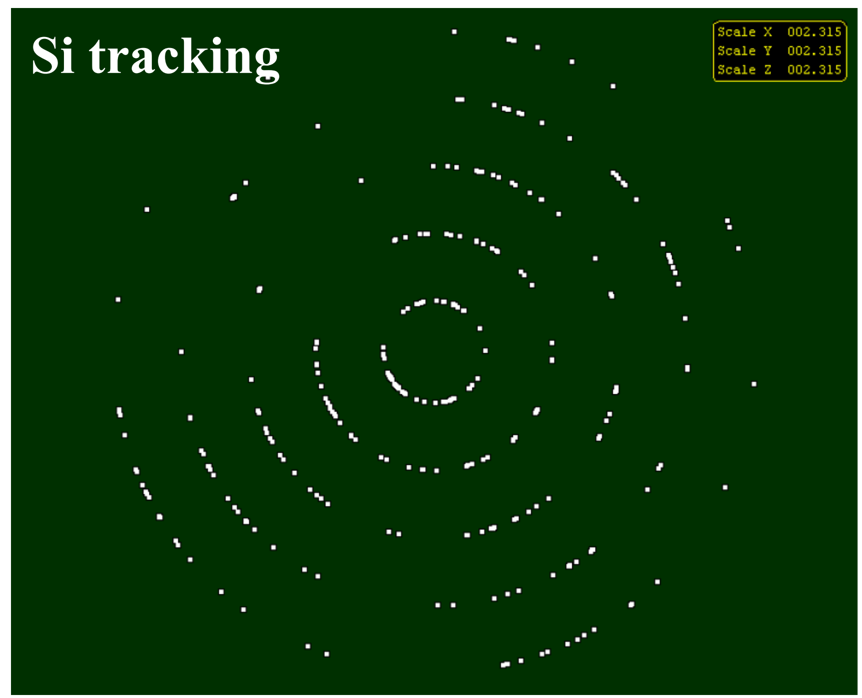
  - **two development paths:**
    - FADC based on ALICE ALTRO chip
    - and TDC chips

TPC versus Silicon Tracking

- **TPC**
  - **200 space points (3-dim) → continuous tracking, pattern recognition**
  - **low mass easy to achieve (barrel)**

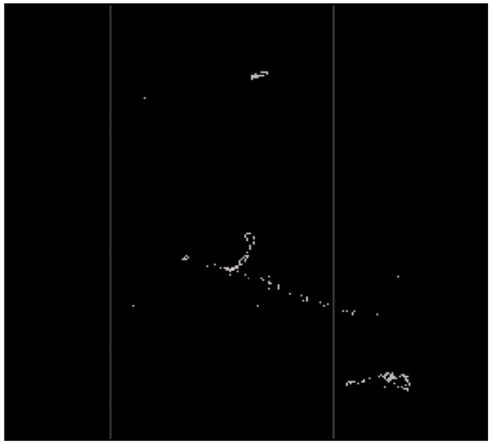
- **Silicon tracking**
  - **better single point resolution**
  - **fast detector (bunch identification)**



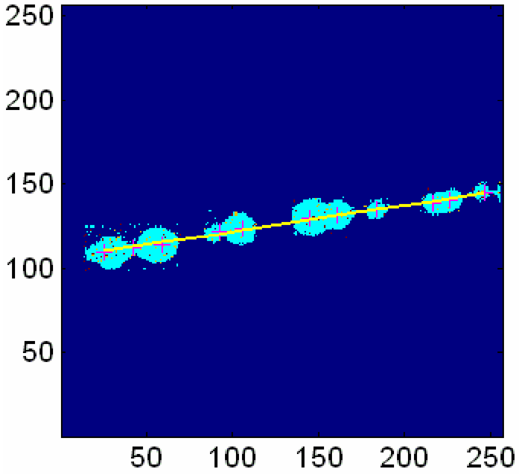


Silicon TPC Readout

- Combine MPGD with pixel readout chips
- 2-d readout with
  - Medipix2 0.25 μm CMOS
  - 256×256 pixel
  - 55 ×55 μm²



(Micromegas)

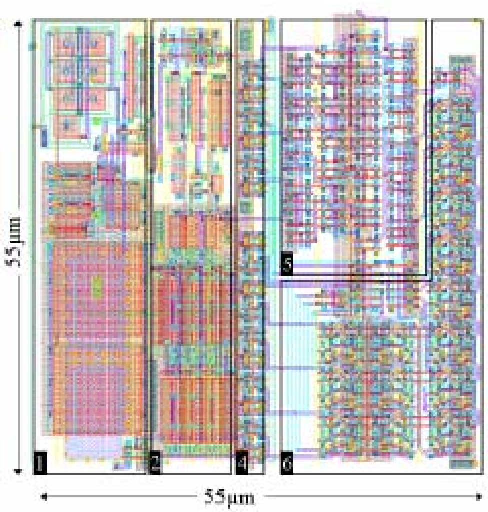


(GEM)

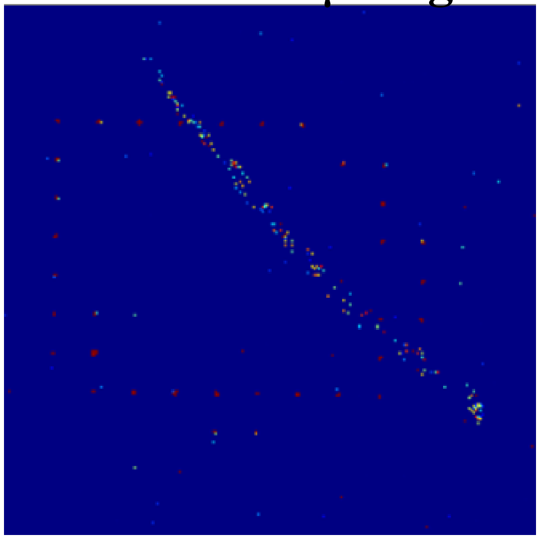
- Medipix (2-d) → TimePix (3- d)
- 50 - 150 MHz clock to all pixel
- 1st version under test

- Will eventually lead to
  - TPC diagnostic module
  - cluster counting to improve dE/dx

TimePix layout



TimePix + μMegas



Calorimetry

- **The paradigm of Particle Flow Algortihm (PFA) for optimum jet energy resolution:**
  - **try to reconstruct every particle**
  - **measure charged particles in tracker**
  - **measure photons in ECAL**
  - **measure neutral hadrons in ECAL+HCAL**
  - **use tracker + calorimeters to tell charged from neutral**

- **average visible energy in a jet**
  ≈ 60% charged particles
  ≈ 30% photons
  ≈ 10% neutral hadrons

particles in jet	fraction of energy in jet	detector	single particle resolution	jet energy resolution
charged particles	60 %	tracker	$\frac{\sigma_{p_t}}{p_t} \sim 0.01\% \cdot p_t$	negligible
photons	30 %	ECAL	$\frac{\sigma_E}{E} \sim 15\%/\sqrt{E}$	$\sim 5\%/\sqrt{E_{jet}}$
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

- **Jet resolution**

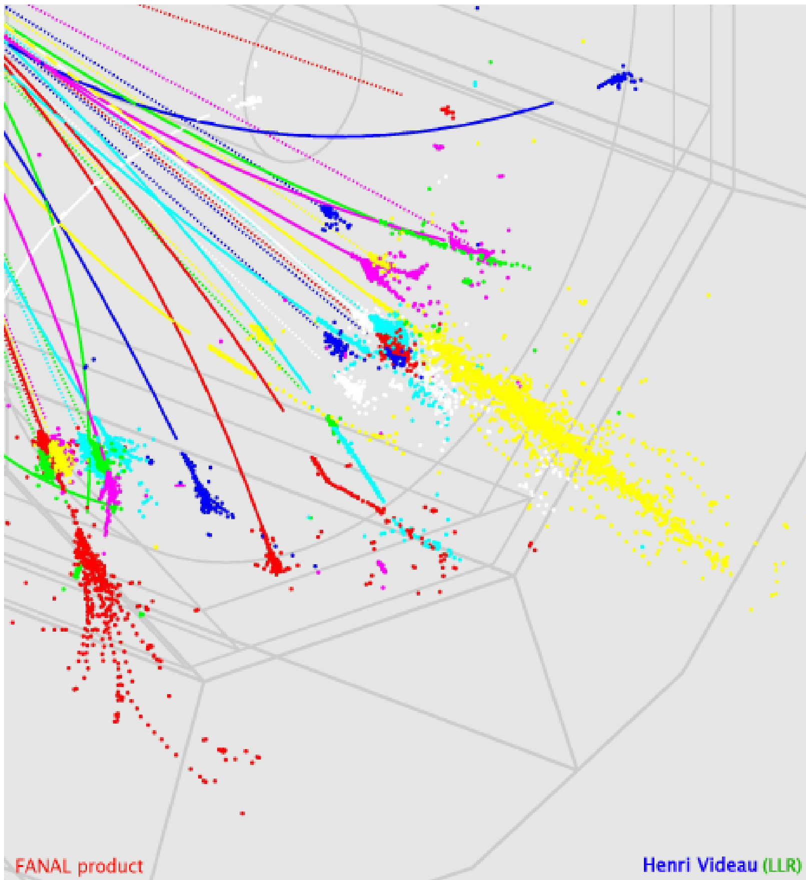
  $\sigma = \sigma_{charged} \oplus \sigma_{photons} \oplus \sigma_{neutral} \oplus \sigma_{confusion}$

- **confusion term arises from misassignment, double counting, overlapping clusters, …**

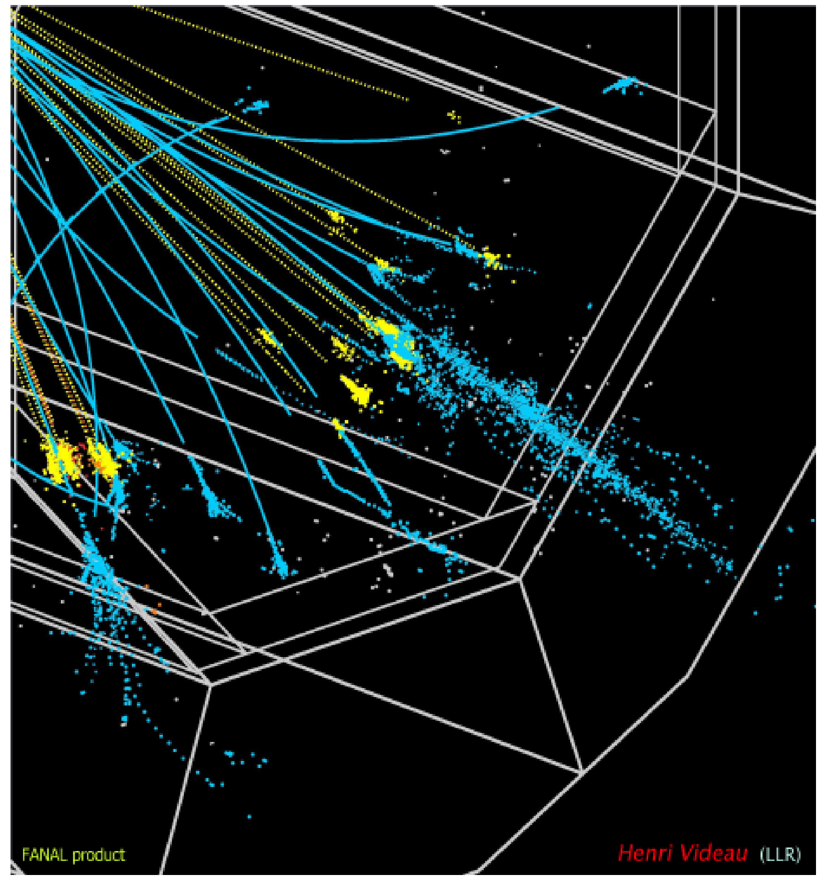
- **minimizing confusion term requires highly granular calorimeter both ECAL and HCAL**

Particle flow simulation

idea: reconstruct each particle separately: tracks, γ, n, K^0_L, μ



generated

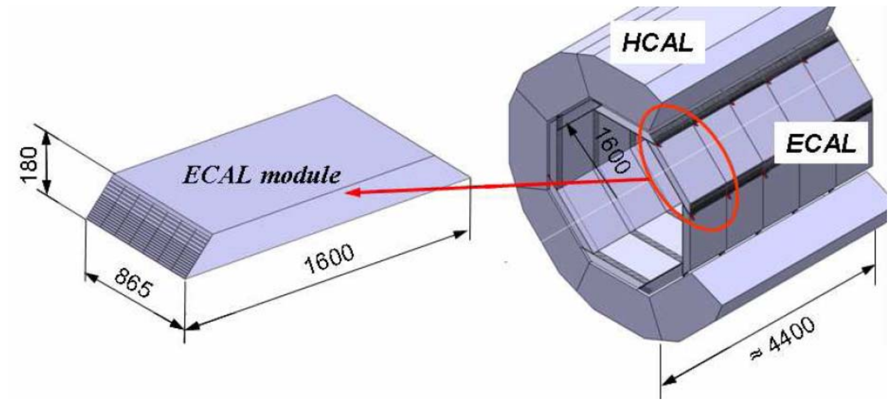


reconstructed

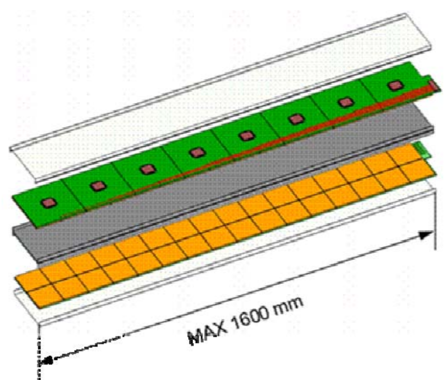
Calorimetry

- CALICE collaboration (Calorimeter for the Linear Collider Experiment) > 30 institutes from > 10 countries
  - performs R&D effort to validate the concept and design calorimeters for ILC experiments

- GLD, LDC, SID concepts based on PFA calorimeters



- ECAL:
  - SiW calorimeter
  - 23 X_0 depth
  - 0.6 X_0 – 1.2 X_0 long. segmentation
  - 5×5 mm^2 cells
  - electronics integrated in detector



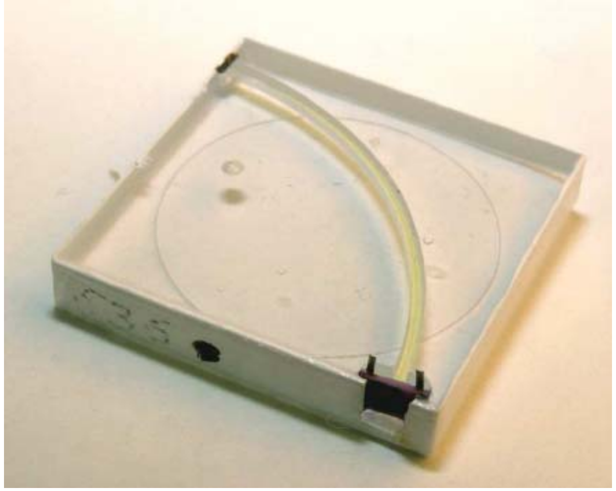
ECAL slab
- FE ASIC
- PCB board
- Si pads

- Alternative: W + Scintillating strips (GLD)

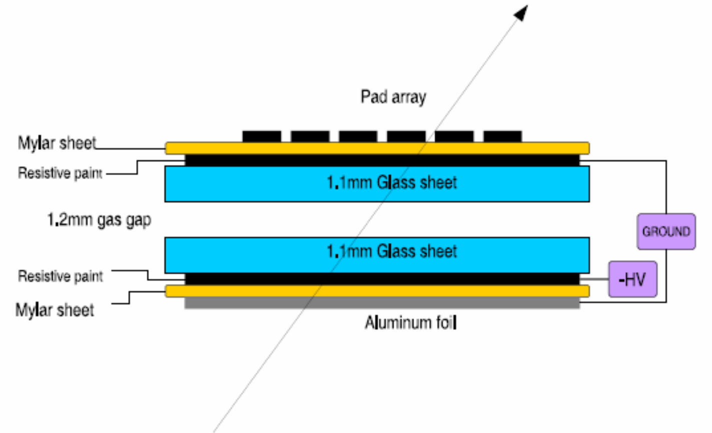
Calorimetry

- **HCAL:**
  2 options under consideration

- **Analogue Scintillator Tile calorimeter**
  - **moderately segmented 3×3 cm^2**
  - **use SiPM for photo detection**



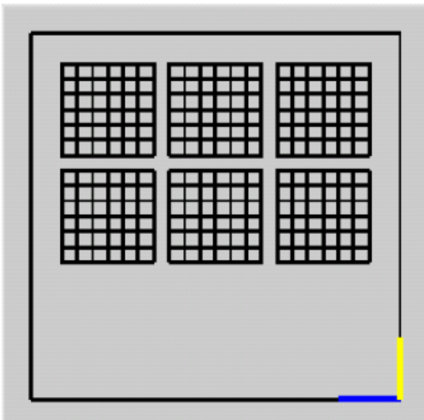
- **Gaseous Digital HCAL**
  - **finer segmentation 1×1 cm^2**
  - **binary cell readout**
  - **based on RPC, GEM or µMegas detectors**



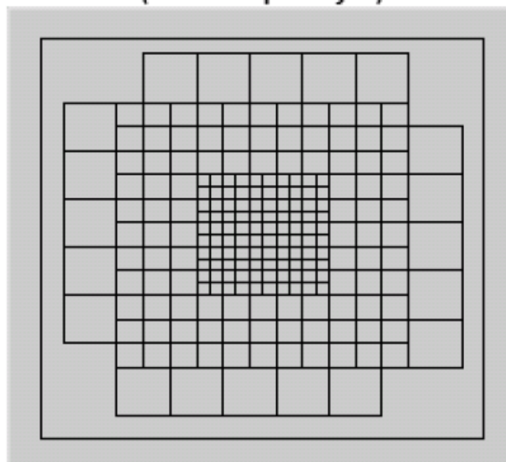
Calorimeter

- **CALICE Testbeam at CERN (2006/07)**

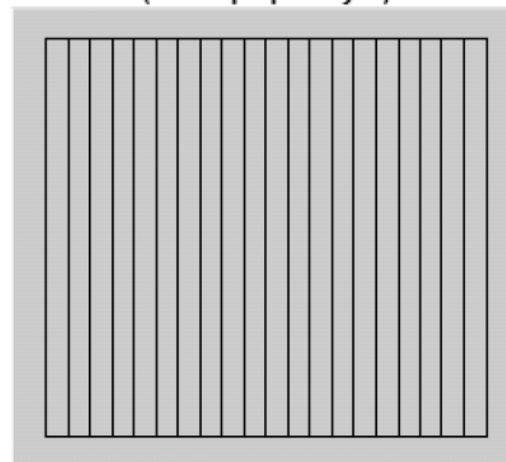
ECAL 18×18 cm^2
Si cells of 1×1 cm^2
(216 cells per layer)



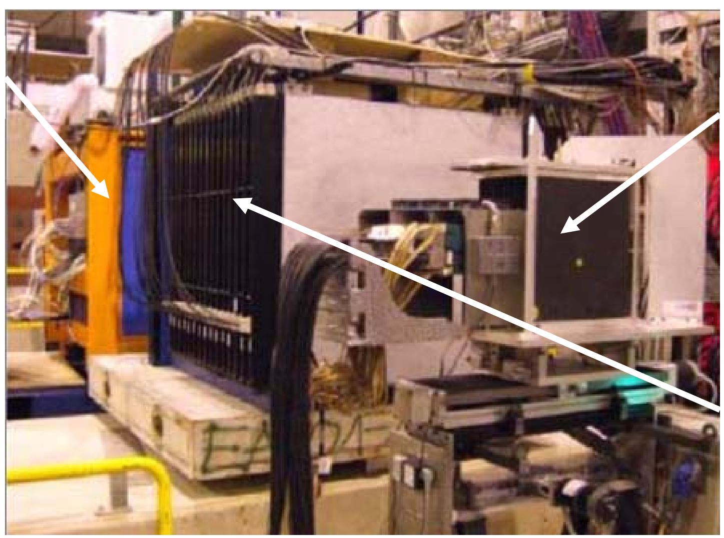
HCAL 100×100 cm^2
scint.tiles of 3×3, 6×6, 12×12 cm^2
(216 tiles per layer)



TCMT 100×100 cm^2
scint.strips X or Y of 5×100 cm^2
(20 strips per layer)



Tail Catcher - Muon Tracker



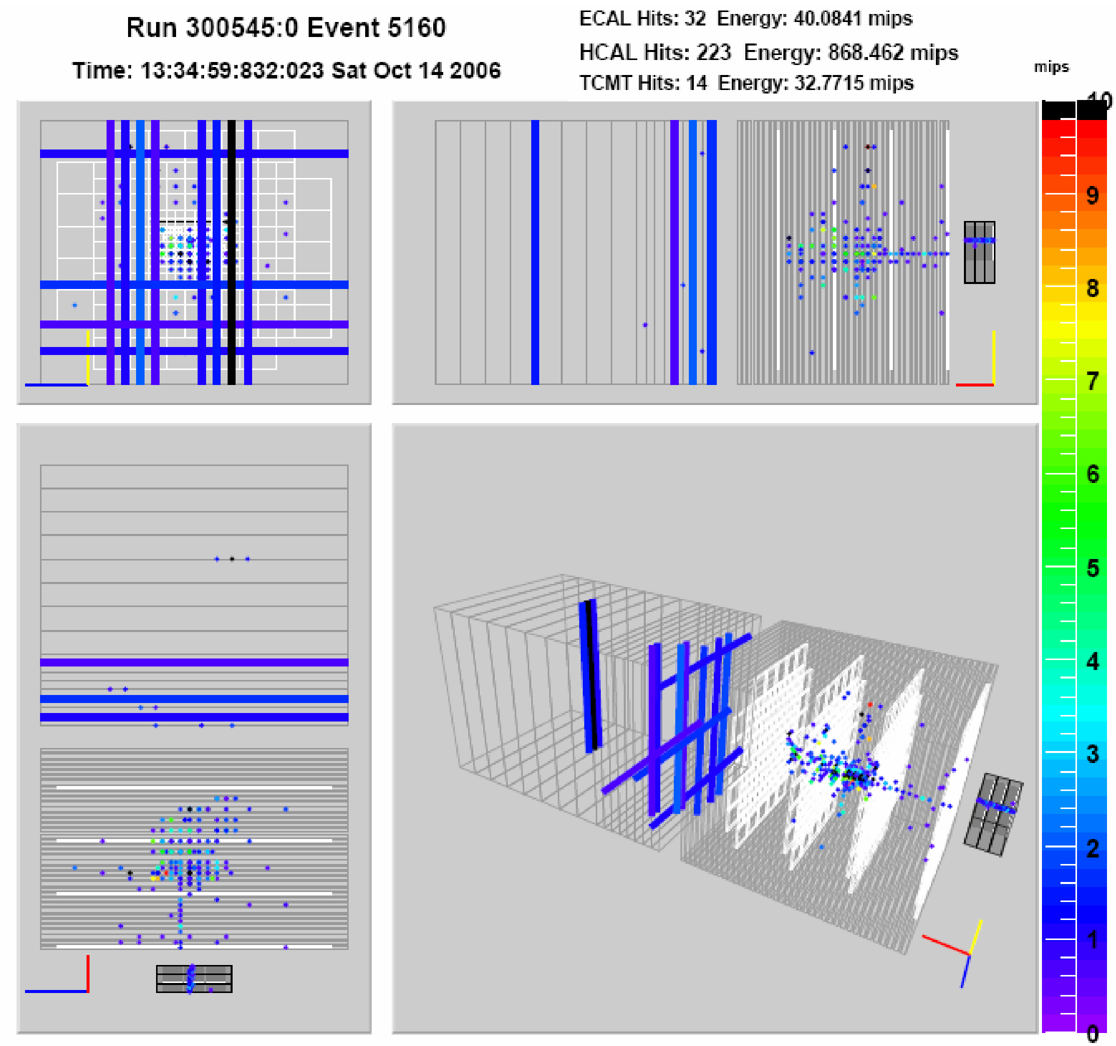
TCMT

ECAL

HCAL

Calorimeter

- **CALICE Testbeam at CERN (2006/07)**



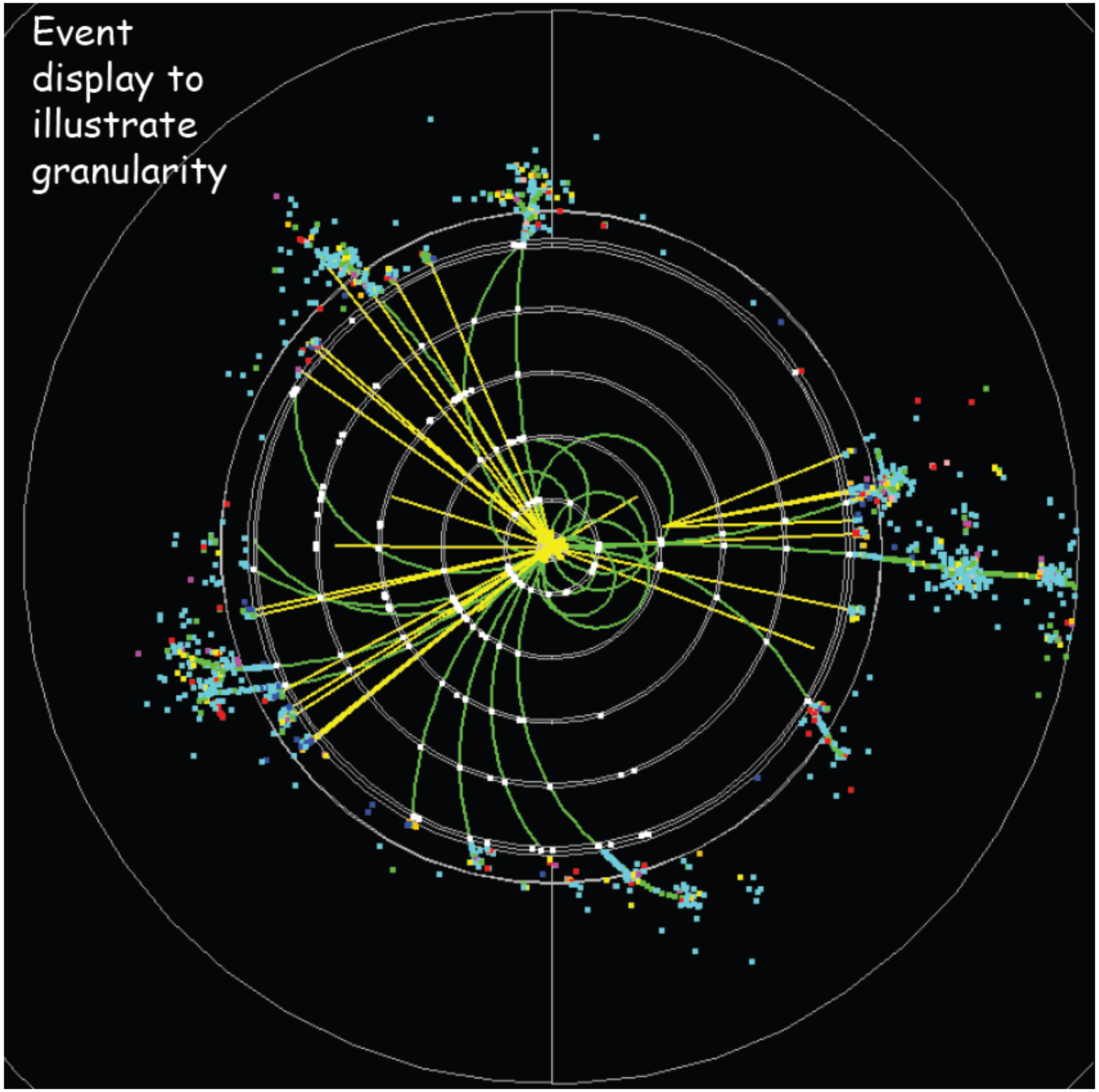
π^- 30 GeV

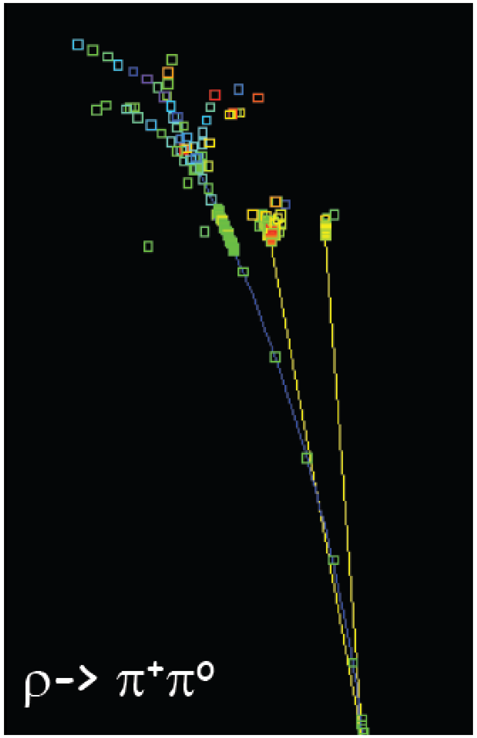
ECAL threshold = 0.5 mip
HCAL threshold = 0.5 mip
TCMT threshold = 0.7 mip

- **CALICE prototype now at FNAL**

Calorimeter

- **Simulation of an ILC event**



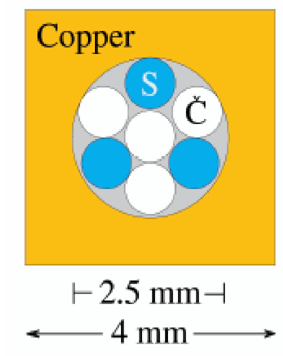


Dual Readout Calorimeter

- 4th concept
  - calorimetry based on dual/triple readout approach
  - complementary measurements of showers reduce fluctuations

- Fluctuations of local energy deposits
- Fine spatial sampling with SciFi every 2 mm
- like SPACAL (H1)

- Fluctuations in electromagnetic fraction of shower energy
- clear fibres measure only EM component by Cerenkov light of electrons (E_{th} = 0.25 MeV)
- like HF (CMS)



Dual Readout Module (DREAM) in testbeam at CERN

- Binding energy losses from nuclear break-up
- try to measure MeV neutron component of shower (history or Li/B loaded fibres)
- triple readout

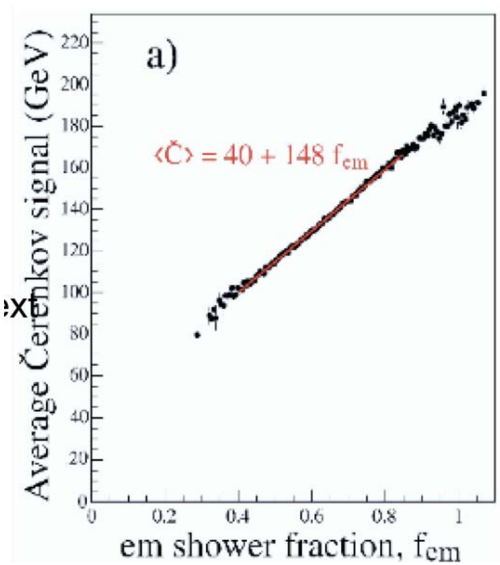
Dual Readout Calorimeter

- **DREAM testbeam:**
  - **measure each shower twice**

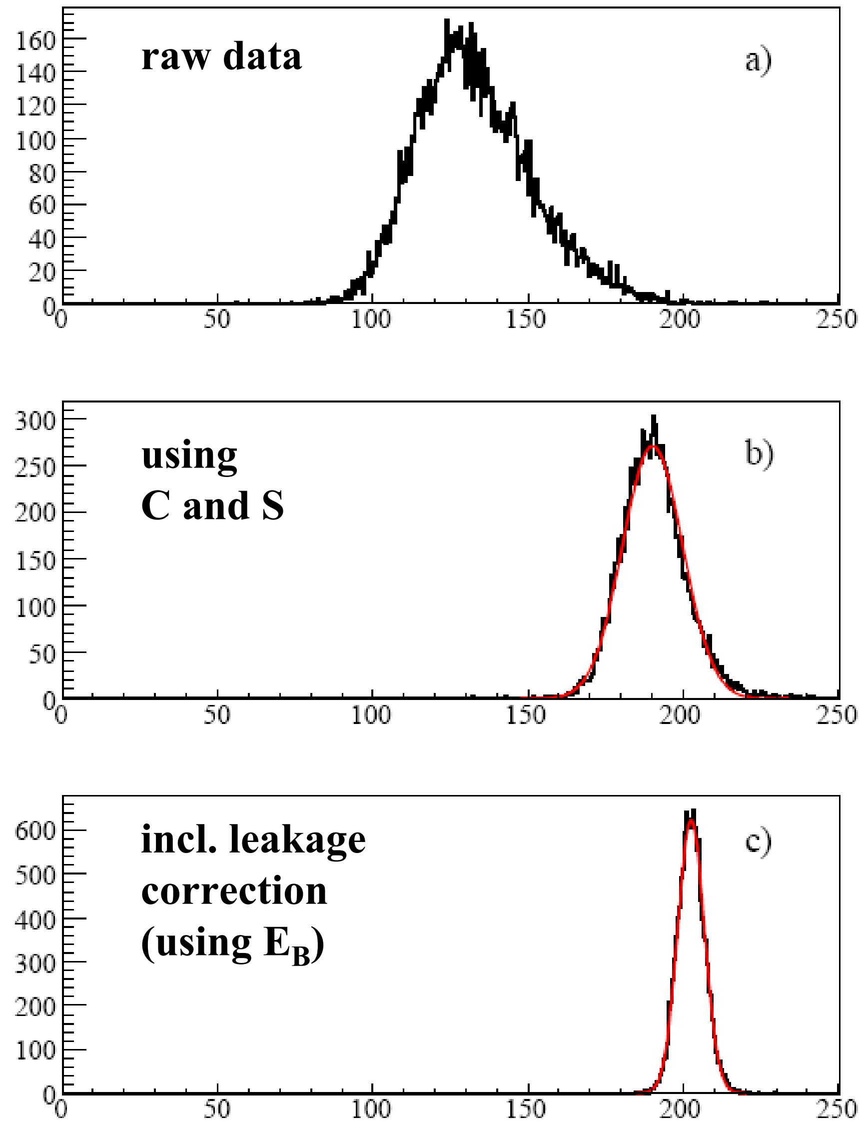
$$(e/h)_C = \eta_C \approx 5$$
$$(e/h)_S = \eta_S \approx 1.4$$

$$C = [f_{em} + (1 - f_{em})/\eta_C]E$$
$$S = [f_{em} + (1 - f_{em})/\eta_S]E$$

$$\rightarrow C/E = 1/\eta_C + f_{em}(1 - 1/\eta_C)$$



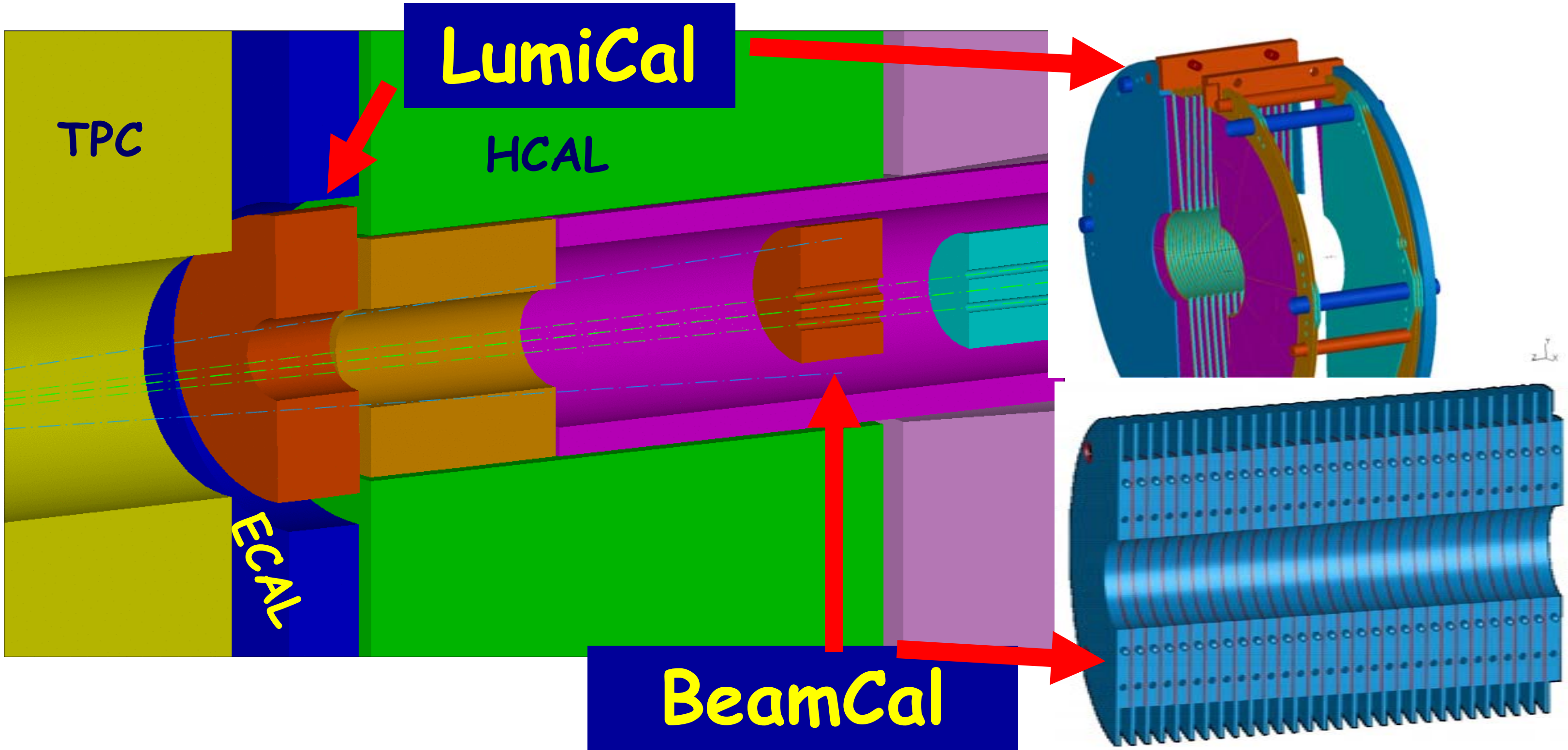
200 GeV π^- beam at CERN



Forward Calorimetry

- Forward calorimeters needed
  - LumCal: precise luminosity measurement
    precision < 10^{-3}, i.e. comparable to LEP or better
  - BeamCal: beam diagnostics & luminosity optimisation

- Detector technology: tungsten/sensor sandwich
- Example: LDC design for zero cross angle
  to be adapted for 14 mrad ILC design



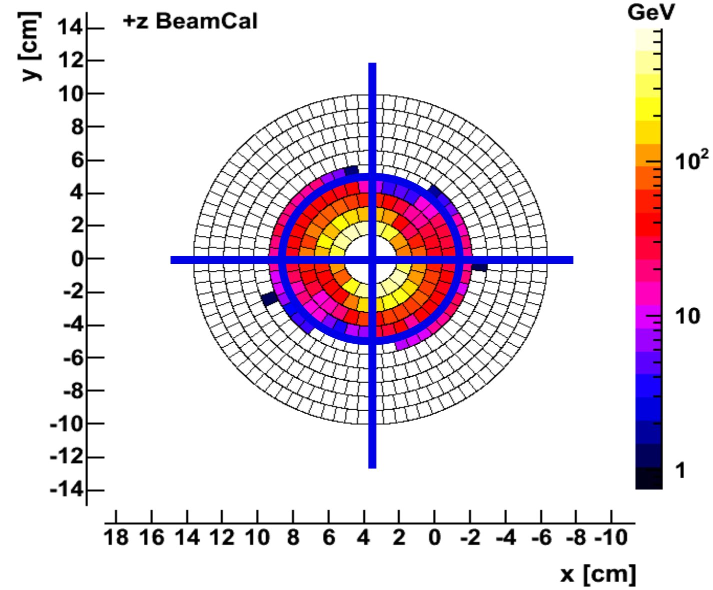
BeamCal

- Challenges:
  - ≈ 15000 e^+e^- pairs per BX in MeV range, extending to GeV
  - total deposit O(10 TeV)/BX
  - ≈ 10 MGy yearly rad. dose

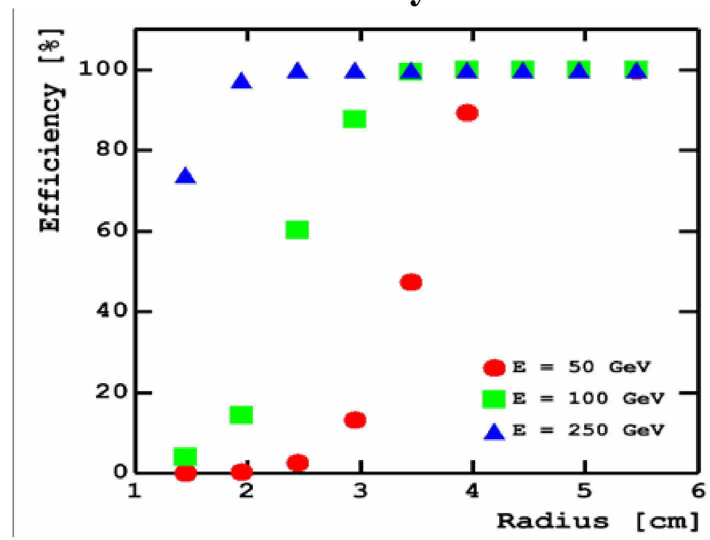
  - identification of single high energy electrons to veto two-photon bkgd.

- Requires:
  - rad. hard sensors (diamond)
  - high linearity & dynamic range
  - fast readout (307 ns BX interval)
  - compactness and granularity

Energy deposit per BX:



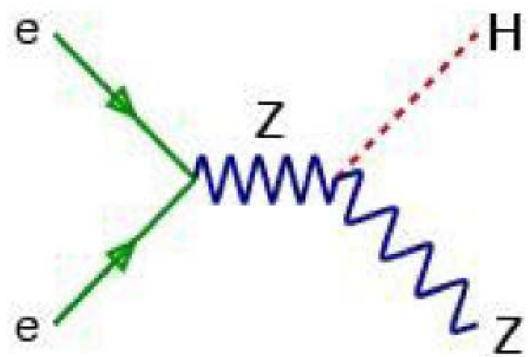
Electron ID efficiency:

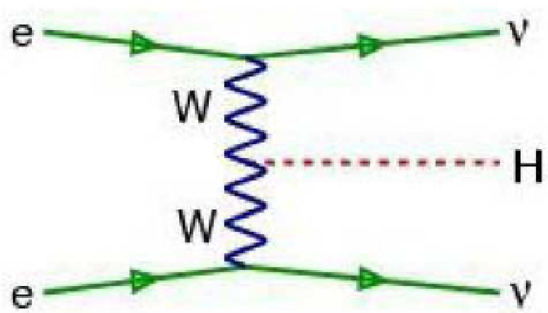


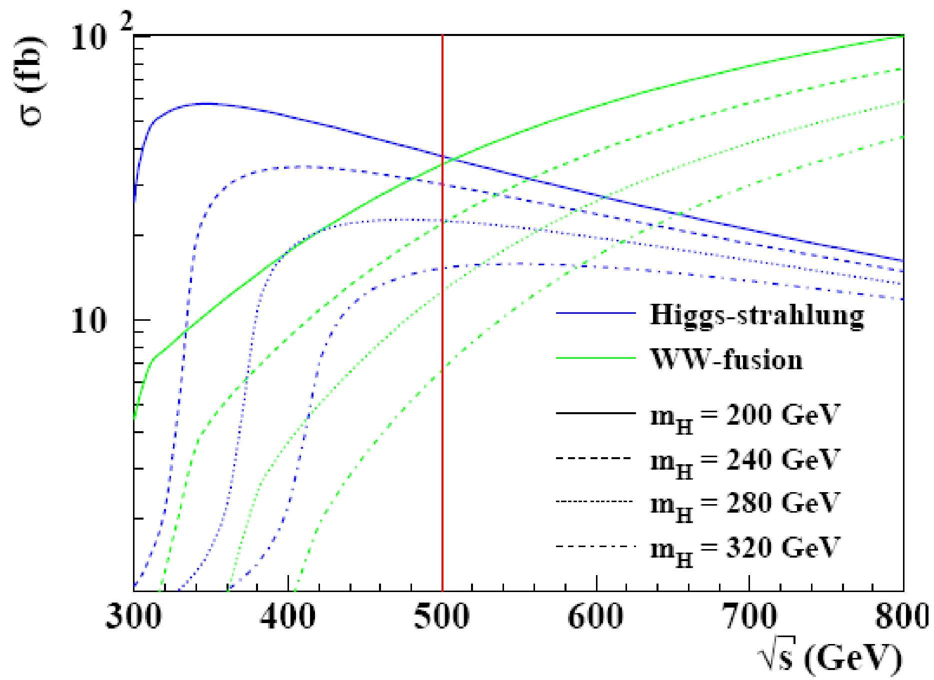
The ILC Physics Case

Higgs

SM Higgs Production at the ILC



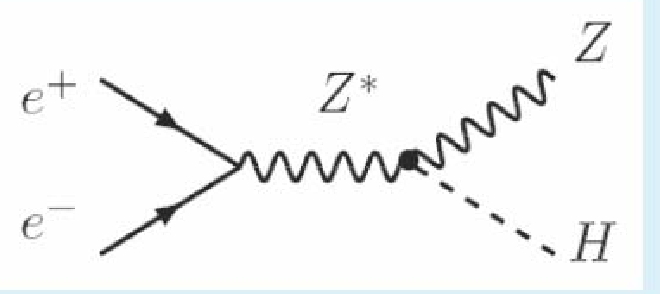


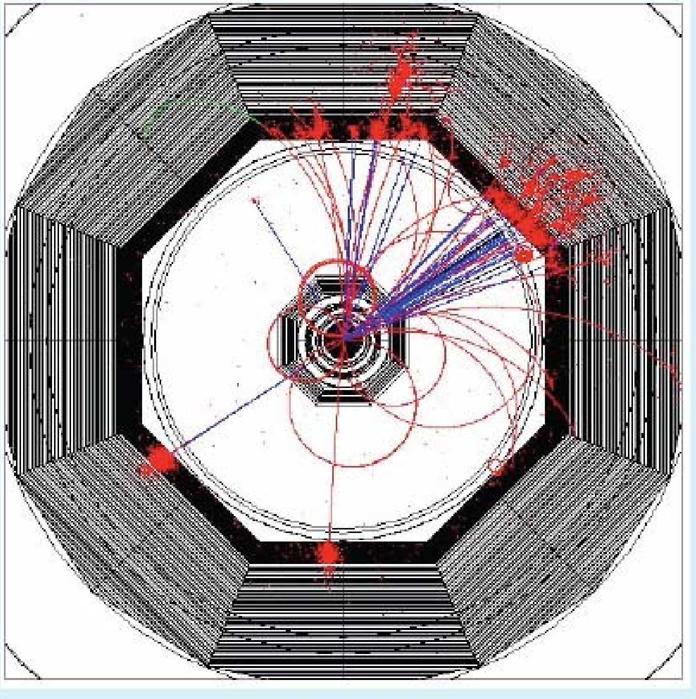


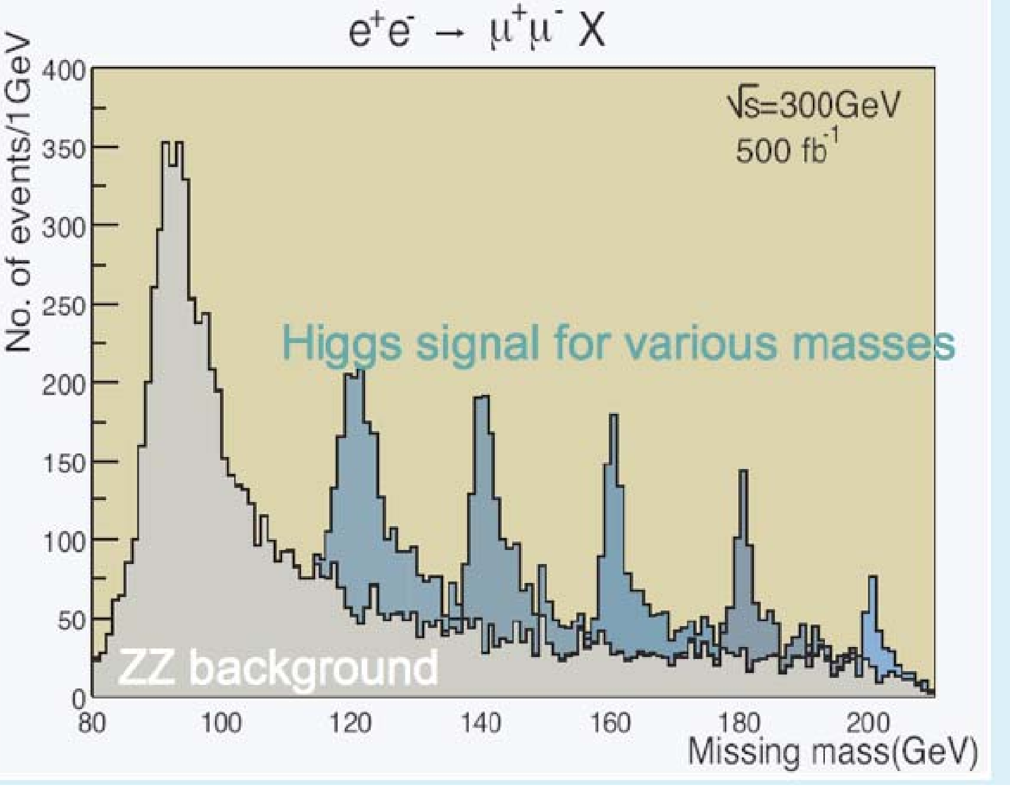
- Dominant production mechanisms: Higgsstrahlung and WW-fusion

Higgs

- Model independent Higgs measurement

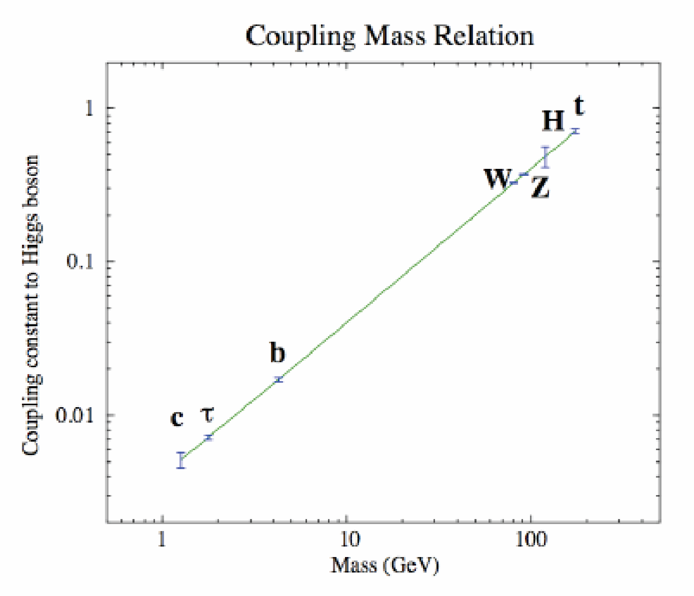


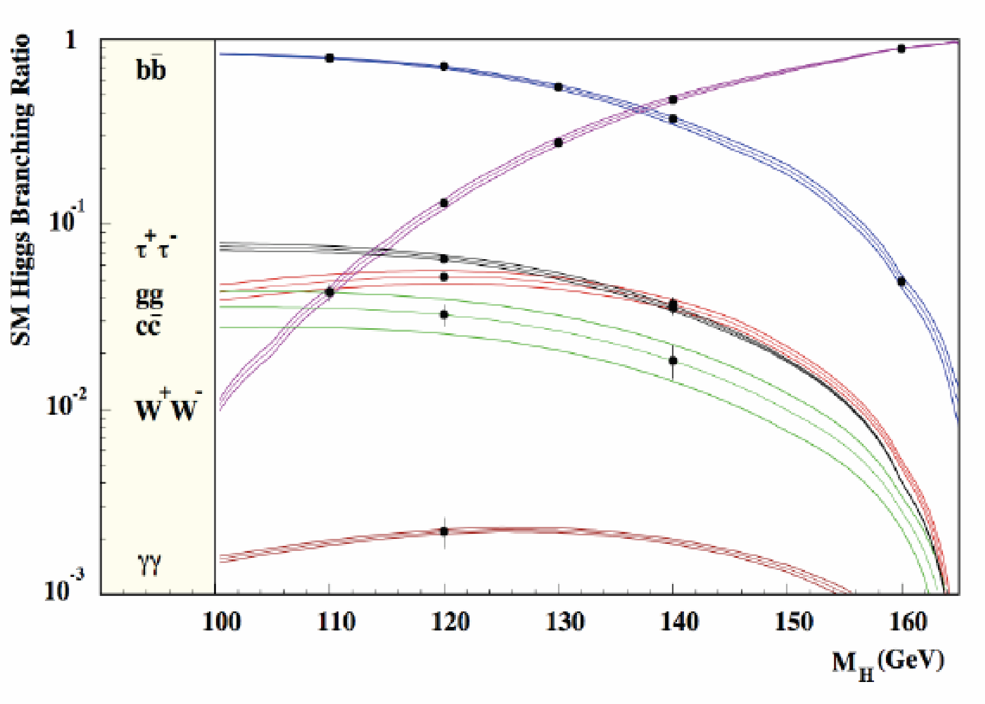




Higgs Couplings

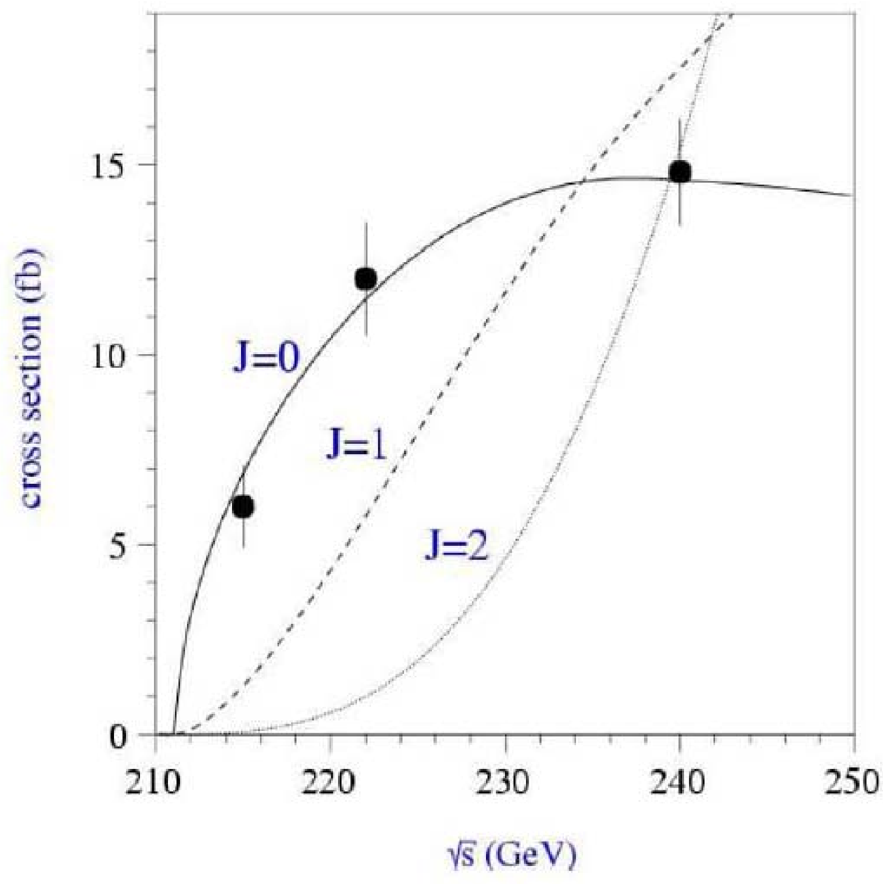
- Measuring the couplings of the Higgs to massive particle
- Check coupling-mass relation
  - The smoking gun!





Higgs Spin

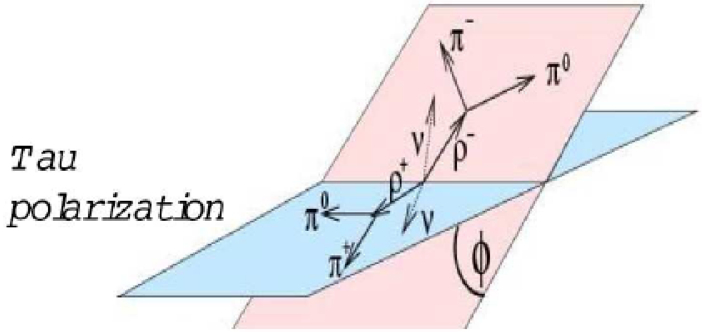
- Higgs would be the first fundamental scalar
- Need to confirm its spin
  - Threshold scan
- Softer turn-on for non-zero spin

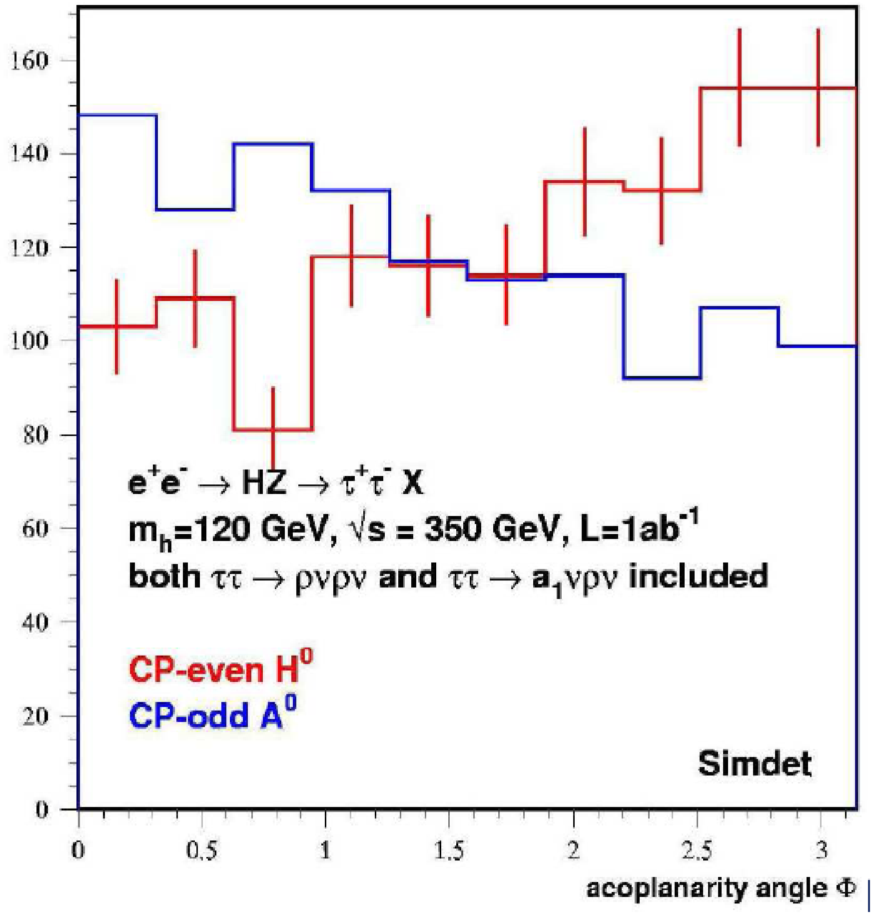


Other Higgs Quantum Numbers

Higgs *CP*

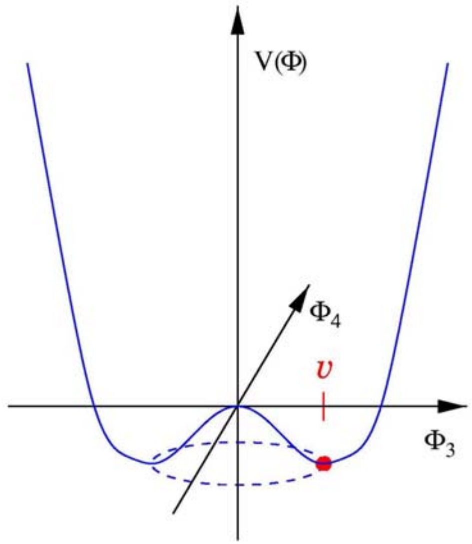
- SM Higgs is CP even
- Confirm that, using spin correlations in $h \to \tau\tau$ decays





Verification of the Higgs Potential

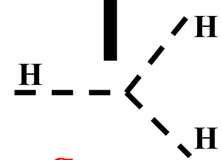
$$V(\Phi) = \mu^2|\Phi|^2 + \lambda|\Phi|^4 \qquad \mu^2 < 0 \quad \lambda > 0$$



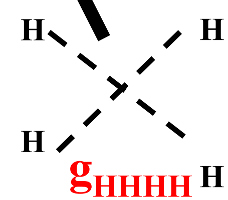
Vacuum expectation value $v = \sqrt{-\mu^2/\lambda}$

$$V(H) = \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4$$

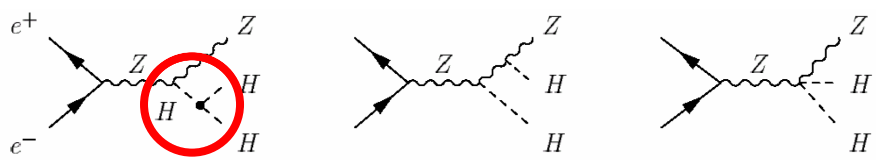
$$m_H = \sqrt{2\lambda v}$$

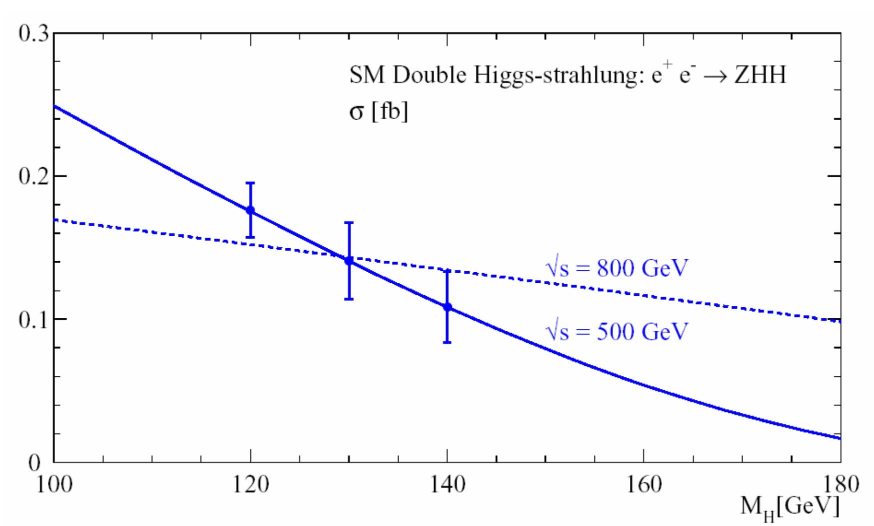


g_{HHH}



g_{HHHH}





- **Measrement of double Higgs strahlung: $e^+ e^- \rightarrow HHZ$**

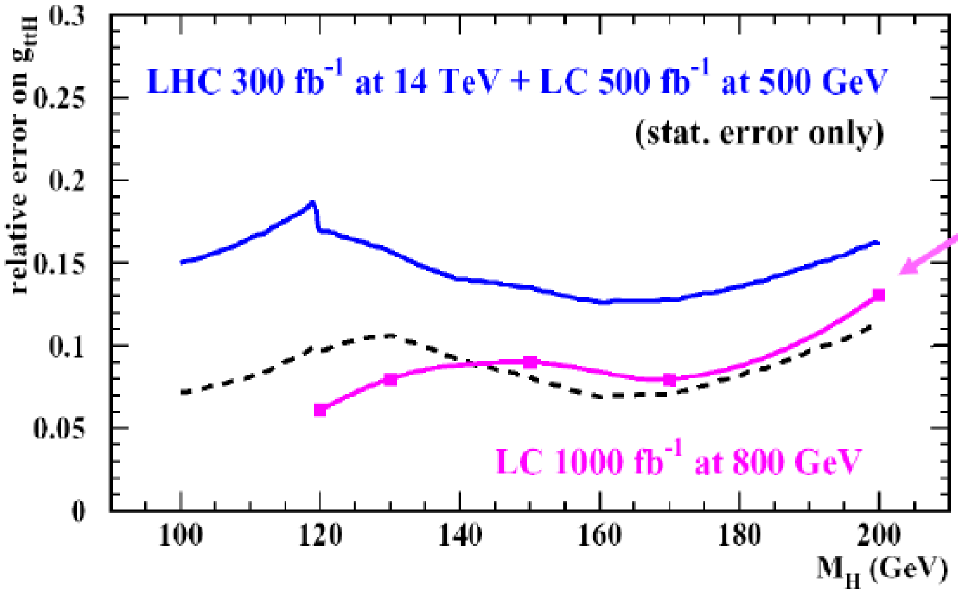
  $$\Delta g_{HHH}/\, g_{HHH} = 0.22$$

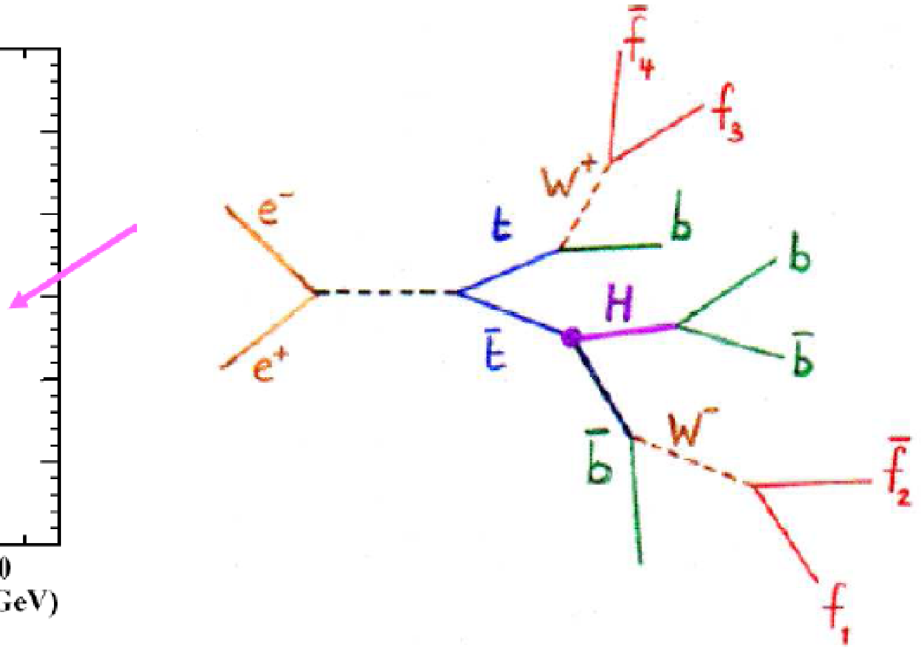
- **Measurement of g_{HHHH} not possible**

Outline

Higgs Top Yukawa Coupling

- Want: absolute top Yukawa coupling
- Use combined information from ILC500 and LHC:
  - From LHC: rate of $gg, qq \to tt\,h$; $(h \to bb, WW)$ is proportional to $g_{tt} \times g_{bb/WW}$
  - From ILC500: $\mathcal{B}(h \to bb, WW)$ absulte measurement of g_{bb}, g_{WW}
- Or simply use ILC1000 . . .



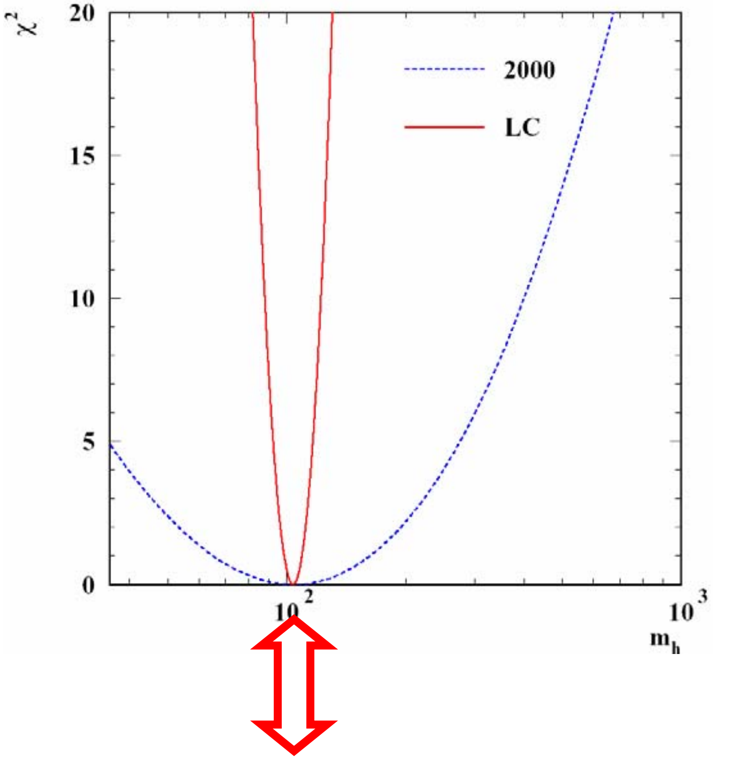


Giga-Z

- Production of 10^9 Z-Bosonen at $\sqrt{s} = 91$ GeV
  - 100-fold LEP I statistics
  - polarisation (as SLC)
  - 30 fb^{-1} = 1/2 year

	LEP/SLC/Tevatron	Giga-Z
m_Z	91 187,5 ± 2,1 MeV	---
$\sin^2\vartheta_W$	0,23153 ± 0,00016	± 0,000013
A_b	0,899 ± 0,013	± 0,001
R_b	0,21629 ± 0,00066	± 0,00014
m_W	80 392 ± 29 MeV	± 6 MeV

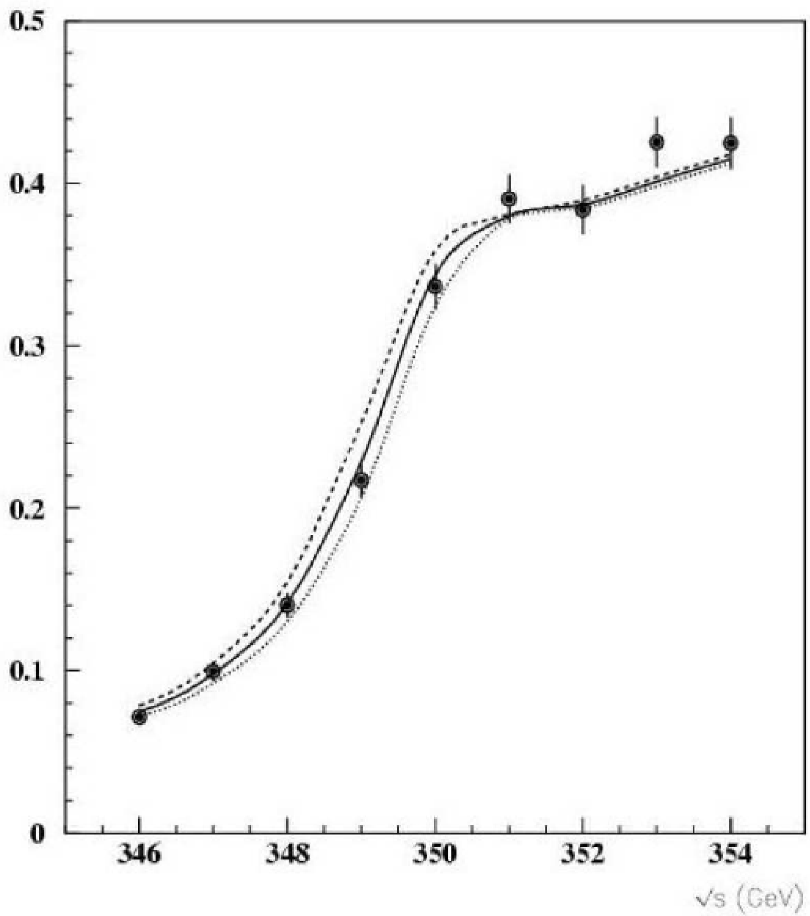
Comparison today's SM-Fits with Giga-Z:



Comparison to direct Higgs mass measurement

Mass of the Top Quark

Cross-checking with Precise top Mass Measurement



- Check g_{htt} vs. SM expectation
- Need: A very precise top quark mass measurement!
- Achieve this via threshold scan (50 MeV uncertainty)
- Width uncertainty $\approx 3\,\%$
- This is very important:
  - Presently the largest source of uncertainty of many SM calculations
  - Top quark might be an interesting window towards new physics, due to its extremely large mass (and $g_{htt} \approx 1$)

Supersymmetry

- **If $m_{SUSY} < 2$ TeV $\Rightarrow$ Discovery at the LHC**

SUSY will be the New Standard Model

- **Scalar partners of fermions**

$$\tilde{e}_R, \tilde{e}_L, \tilde{\mu}_R, \tilde{\mu}_L, \ldots, \tilde{t}_1, \tilde{t}_2$$

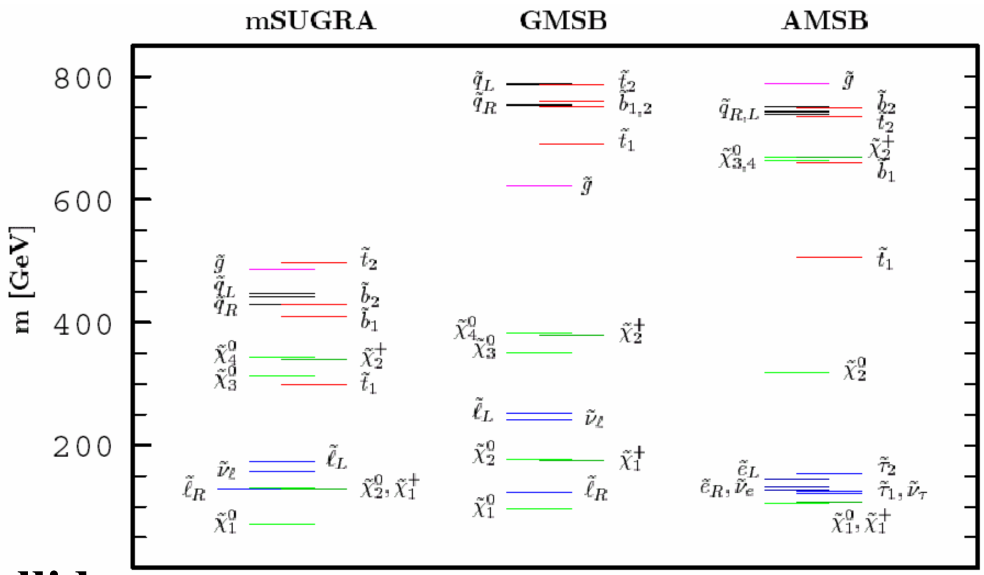
- **Fermionic partners of bosons**

$$\tilde{\chi}^{\pm}, \tilde{\chi}_1^0, \cdots, \tilde{\chi}_4^0, \tilde{g}$$

- **$\geq$ 2 Higgs-doublets**

$$h, H, A, H^{\pm}$$

Template mass spectra:



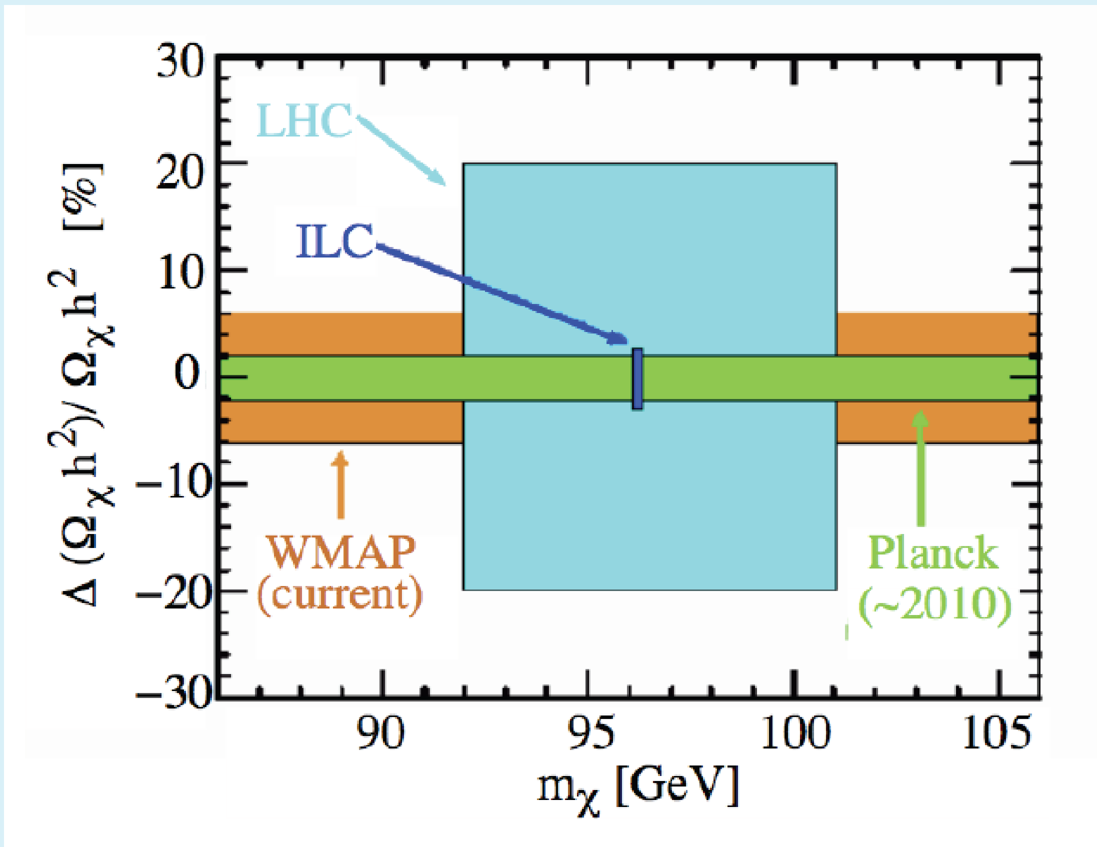
Advantages of an electron positron collider:

- **tune cms energy: turn on SUSY particles one-by one**
- **mass measurement at the kinematic threshold**
- **polarisation of electrons and positrons**

separation of SUSY partners, e.g.: $e_L^+ e_L^- \rightarrow \tilde{e}_L^+ \tilde{e}_L^-$ $\quad e_R^+ e_R^- \rightarrow \tilde{e}_R^+ \tilde{e}_R^-$

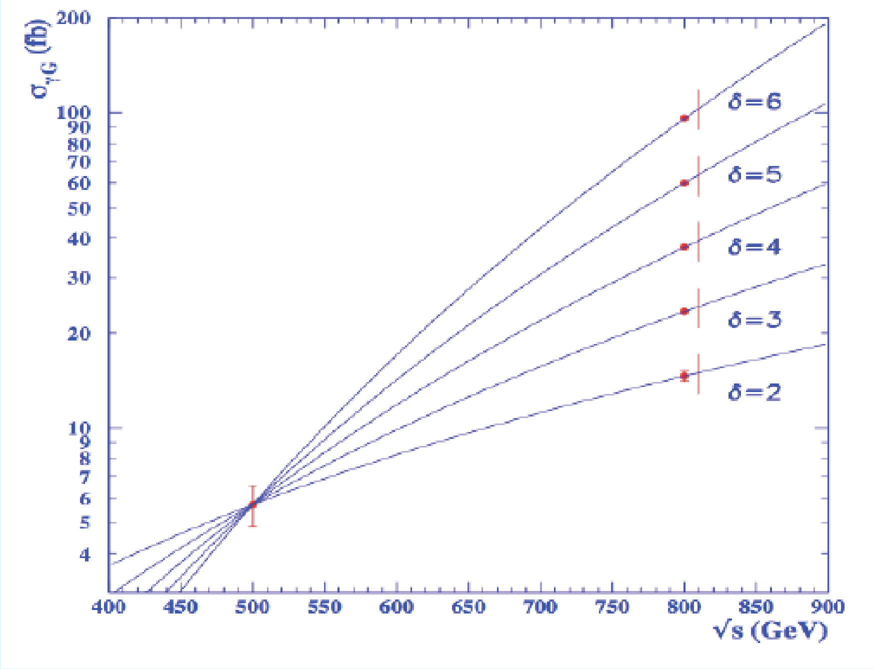
The Cosmological Connection

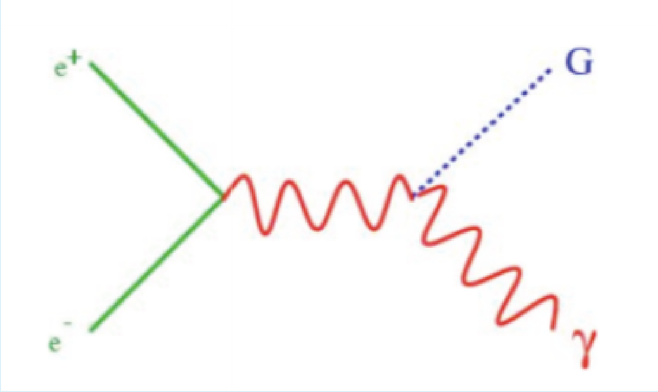
- Could SUSY particles be the Cold Dark Matter?
- Astrophysics experiments measure just densities
- ILC could close the loop



Gravity

- Why is gravity so weak?
- If extra-dimensions would exist, gravitons could vanish there
- Real graviton emission should be measurable
  - single photon plus missing energy in the detector





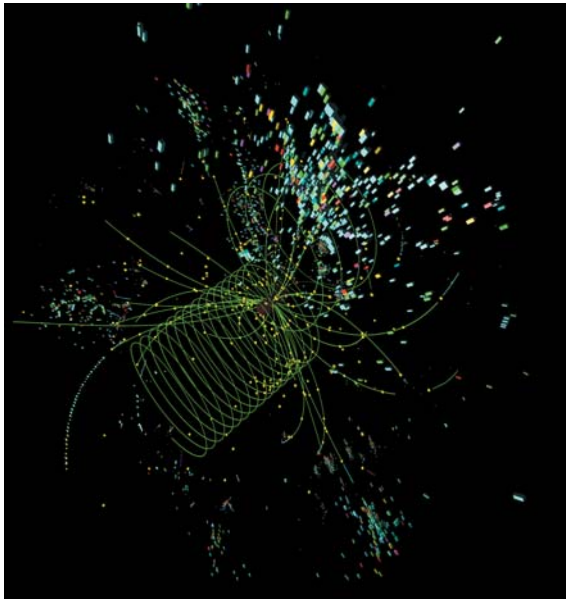
- ILC: 500 → 1000 GeV Linear Collider
  next large collider project

- Ideally complements LHC discoveries by precision measurements

- Requires detectors with unprecedented performances
  - challenges different than at the LHC

- 4 (now 3) detector concepts under development
- R&D on detector technologies
  - candidate technologies
  - identified & verified in small scale experiments
- Many questions still to be answered

- Need to increase efforts to have ILC and
  two detectors ready next decade



Simulated ee → ZZ