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LPI
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Physics and Detectors at International Linear Collider (ILC)

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New era starts in 2009 – the LHC era.
The HEP community is eager to see exciting discoveries at LHC

However already now a large group works hard to develop the next world project–
The International Linear Collider

Accelerator design is done within GDE (director B.Barish)
with a goal to be ready to start construction in 2012-2013 when LHC results come

Physics and detector studies were initially organized within the
World Wide Study on Physics and Detectors for ILC
which combines 3 regional activities in America, Asia, and Europe.
WWS is to a large extent a self-organized activity
Coordination is performed by WWS OC (representatives from each region)
WWS OC organizes working groups and promotes joint R&D efforts
Results are annually discussed at LCWS organized by WWS OC and regional WSs

Last year the director (S.Yamada) was appointed to coordinate this effort.
Three detector collaborations presented LoI's on April.
The LoI's are beeing evaluated by IDAG. Results will be announced in September.
Validated Collaborations will prepare TDRs by 2012

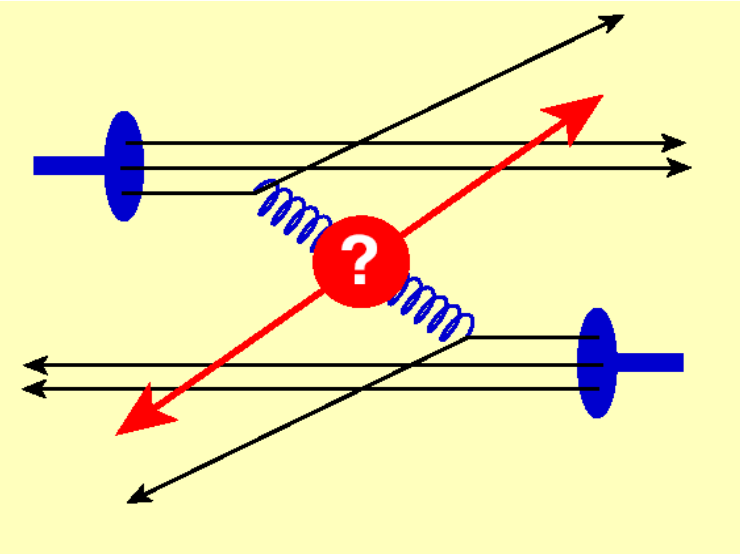
I'll give a short review of the work done by several hundred physicists
Many figures (and even slides) are borrowed from the LCWS talks =>
many thanks to many people in particular to Y.Okada

Why do we need both LHC & ILC?

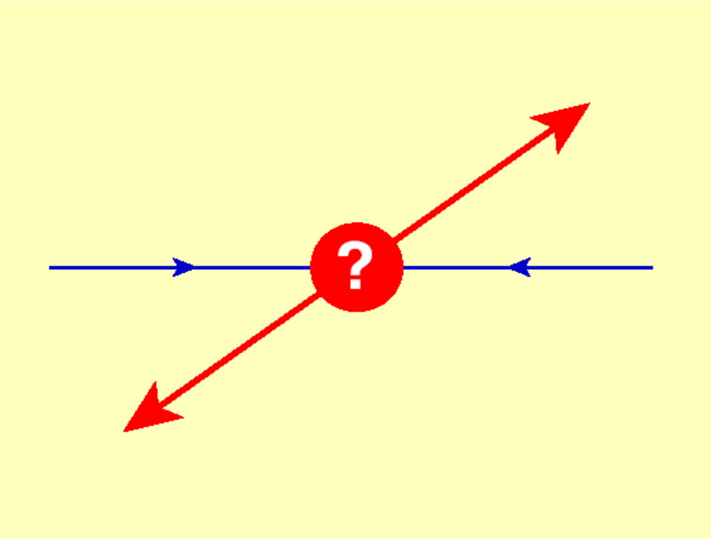
- **Two machines have different characters.**
- **Advantages of lepton colliders:**

e+ and e- are elementary particles (well-defined kinematics).
Less background than in LHC experiments.
Whole energy is available for new phenomena
(only ~1/6Etot in LHC, but still more than in ILC)
Beam polarization, energy scan.
γ - γ, e- γ, e- e- options, Z pole option.

LHC



ILC

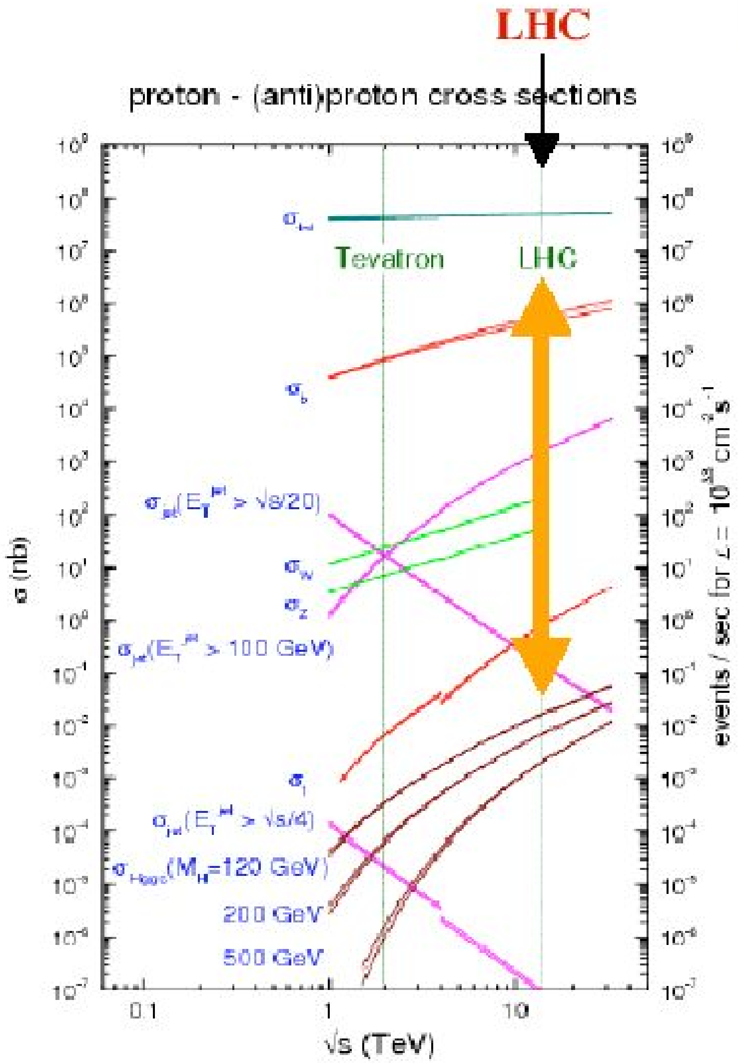


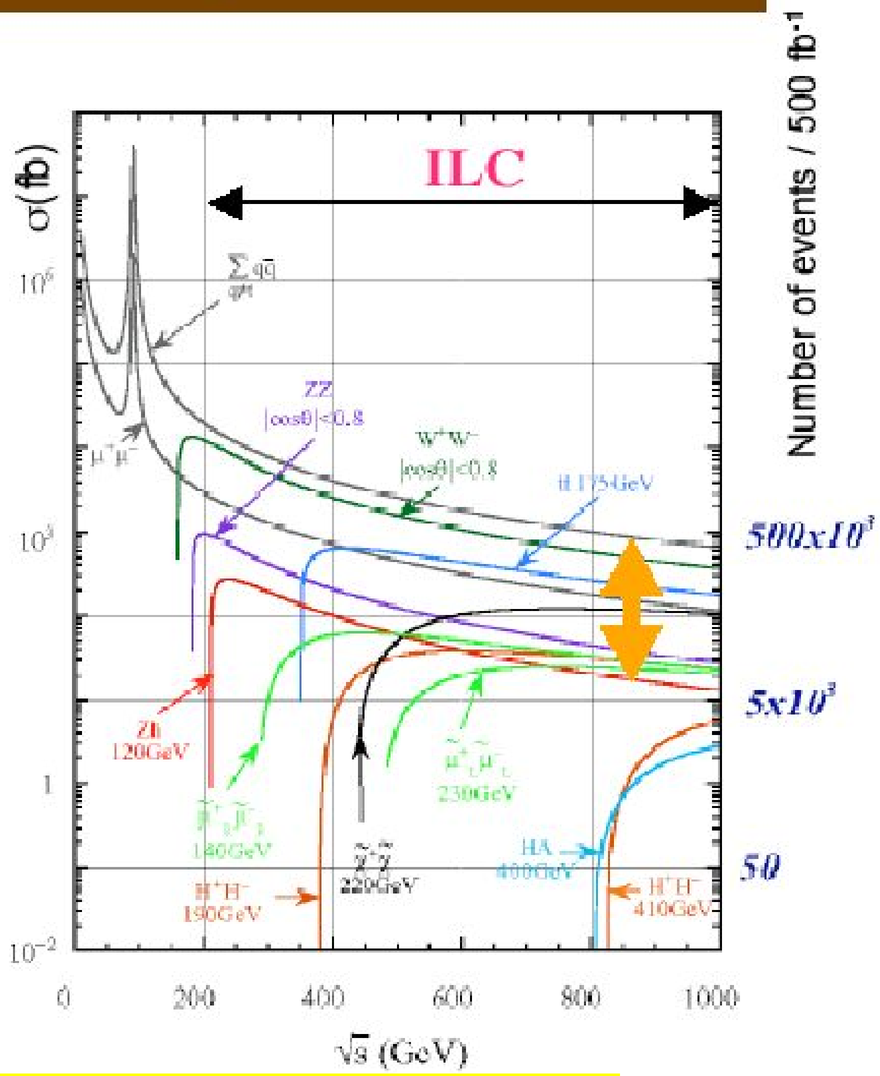
Hadron and electron colliders provided complementary information in the past

Hadron accelerators	e+e- colliders
J particle	Ψ particle
Beauty	Tau lepton
W,Z	Gluon

We hope this will continue in the future

Signal and background Cross-section



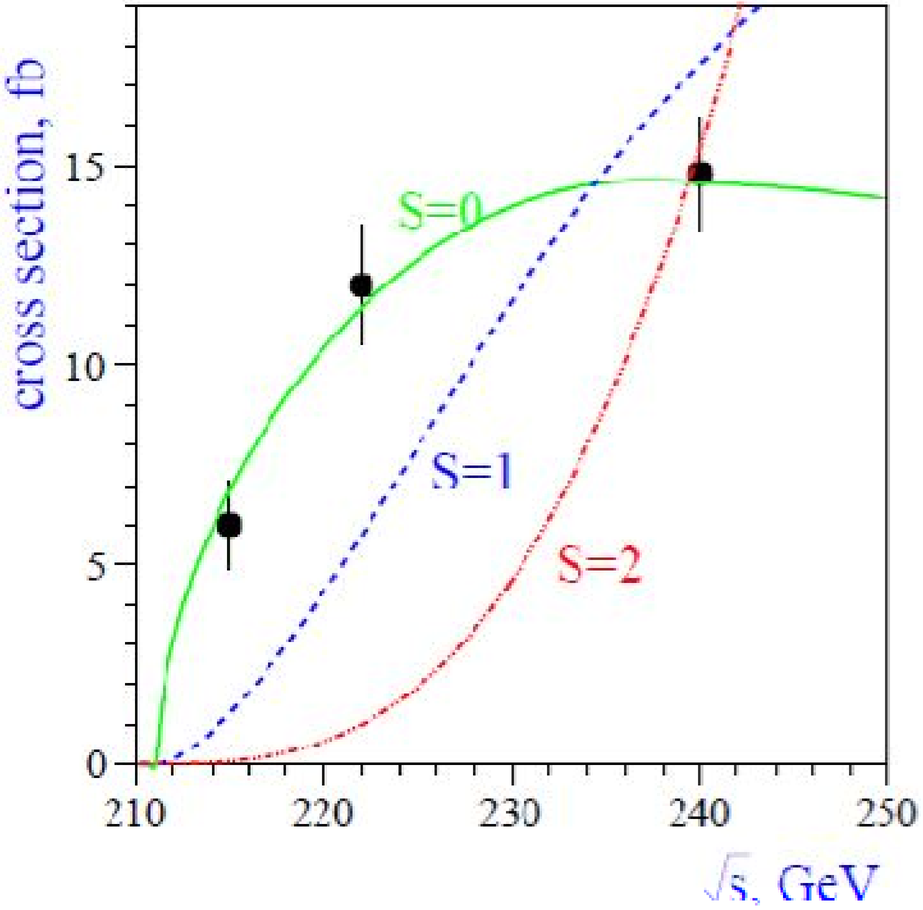


Signal/ background ratio is much better at ILC

Measurement of the H quantum numbers

After the H has been discovered it has to be proven that its quantum numbers are really 0^+

At the LC this can be done with a threshold scan of $e^+e^- \to ZH$:

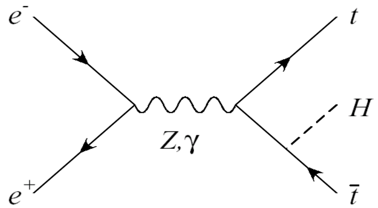


- Large sensitivity to the different states
- The few remaining ambiguities can be resolved from angular dependences and the observation of $H \to \gamma\gamma$

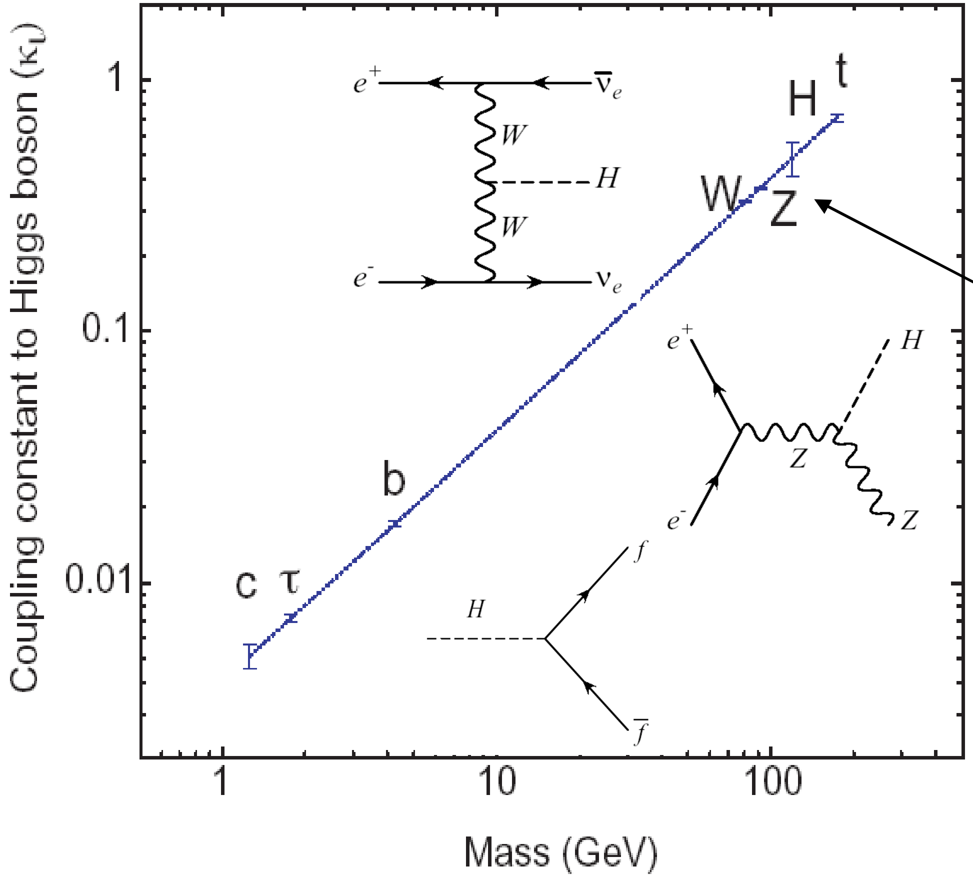
Coupling measurements at ILC

$$m_i = v \times \kappa_i$$

Coupling-Mass Relation

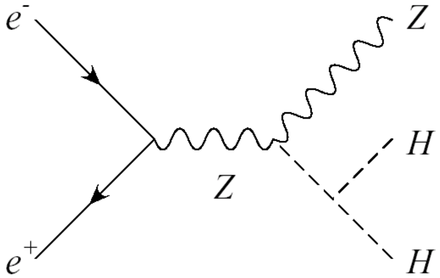


(Ecm>700 GeV)



LHC: (10)% for ratios of coupling constants
ILC: a few % determination

Higgs self-coupling

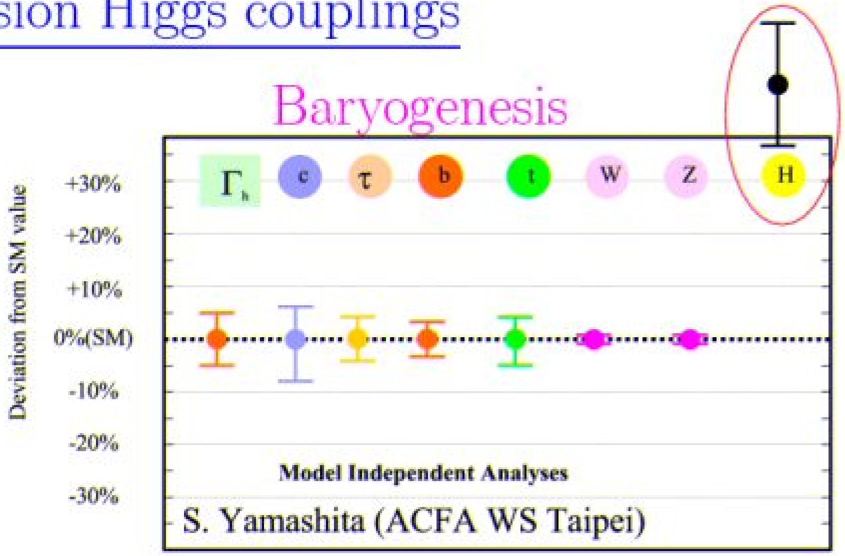


m_H=120 GeV, Ecm=300-500 GeV.L=500fb^{-1}

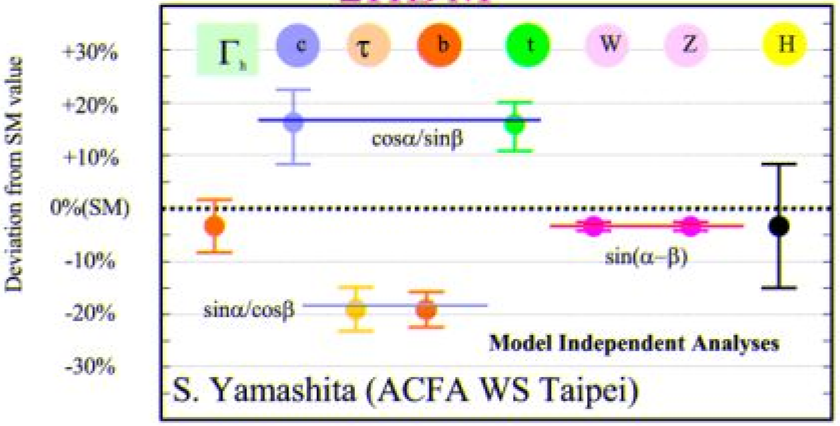
Applications of precision Higgs couplings

The Higgs-coupling measurements allow for a powerful distinction between models

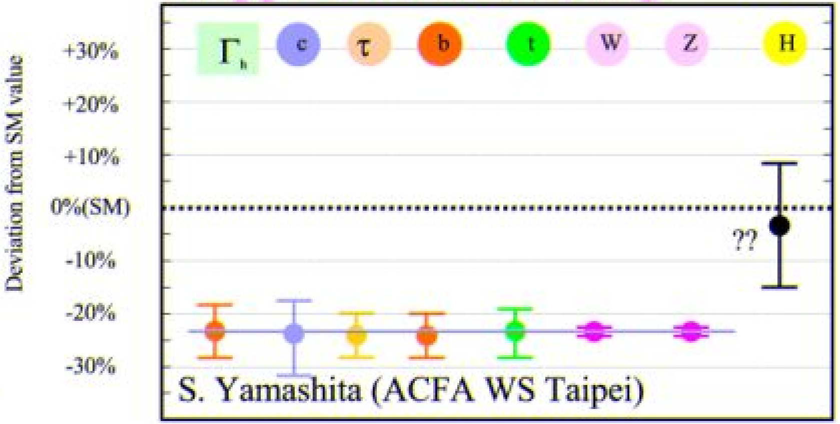
Baryogenesis



2HDM



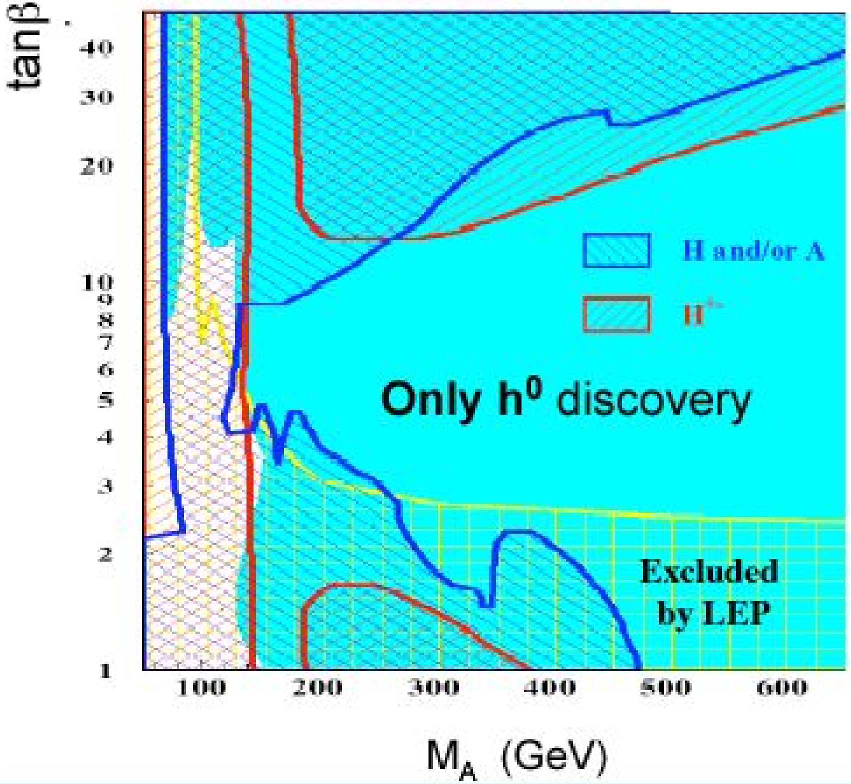
Higgs-Radion mixing



Heavy Higgs (A^0, H^0, H^{+-}) Discovery Reach

LHC

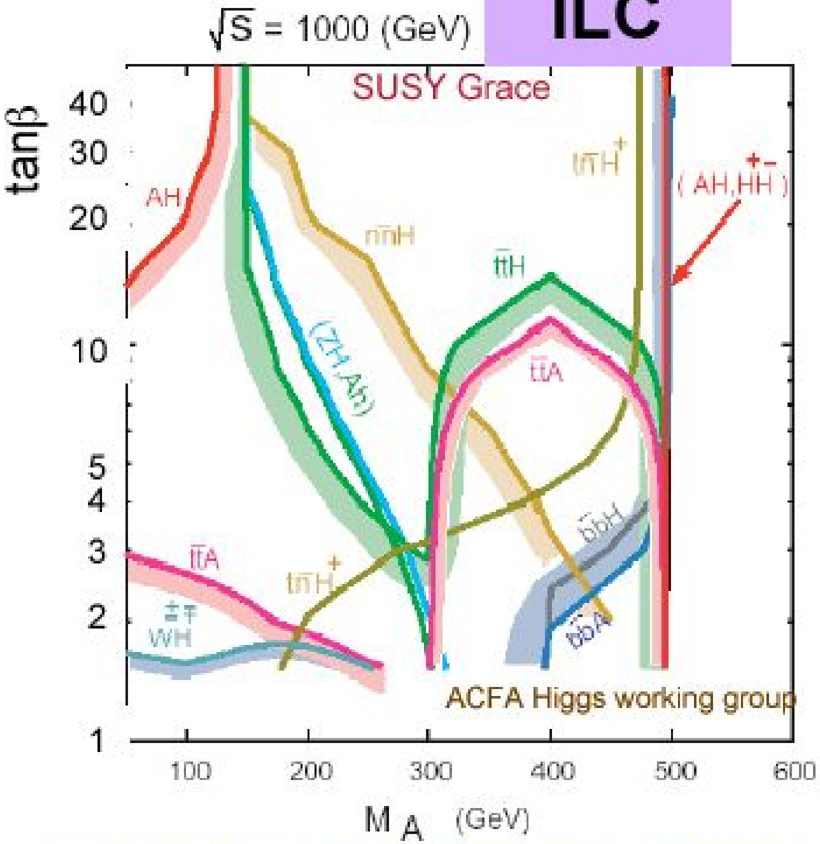
Mhmax **scenario**



Discovery reach depends on tanβ and model

Good at large tanβ case

ILC

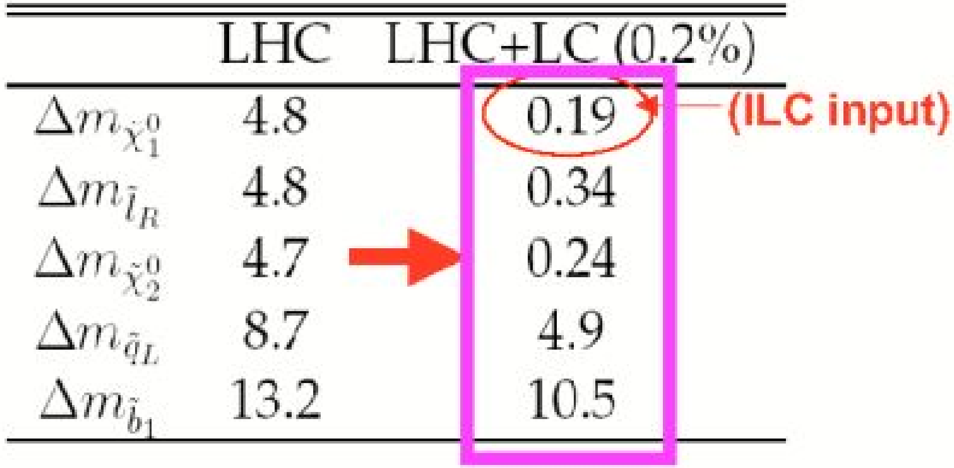


Full discovery in many channels independent of tanβ

Reach up to ~ beam energy

SUSY particle masses, quantum numbers, couplings, mixing angles can be determined with high accuracy at ILC

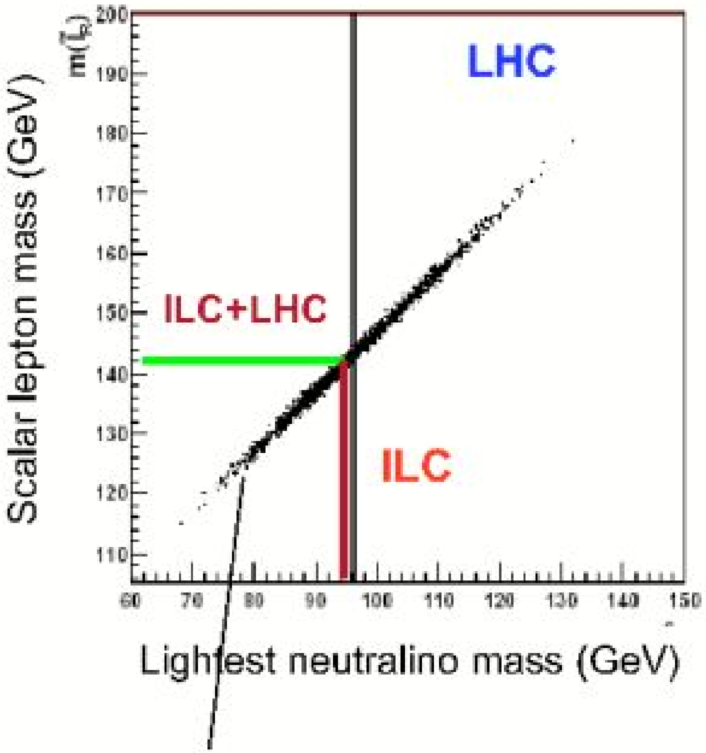
300 fb^{-1}@LHC
ΔM values in GeV



	LHC	LHC+LC (0.2%)
$\Delta m_{\tilde{\chi}_1^0}$	4.8	0.19
$\Delta m_{\tilde{l}_R}$	4.8	0.34
$\Delta m_{\tilde{\chi}_2^0}$	4.7	0.24
$\Delta m_{\tilde{q}_L}$	8.7	4.9
$\Delta m_{\tilde{b}_1}$	13.2	10.5

(ILC input)

Significant improvements even if only m(χ^0) is measured at ILC



Strong correlation at LHC

An input from ILC resolve this correlation

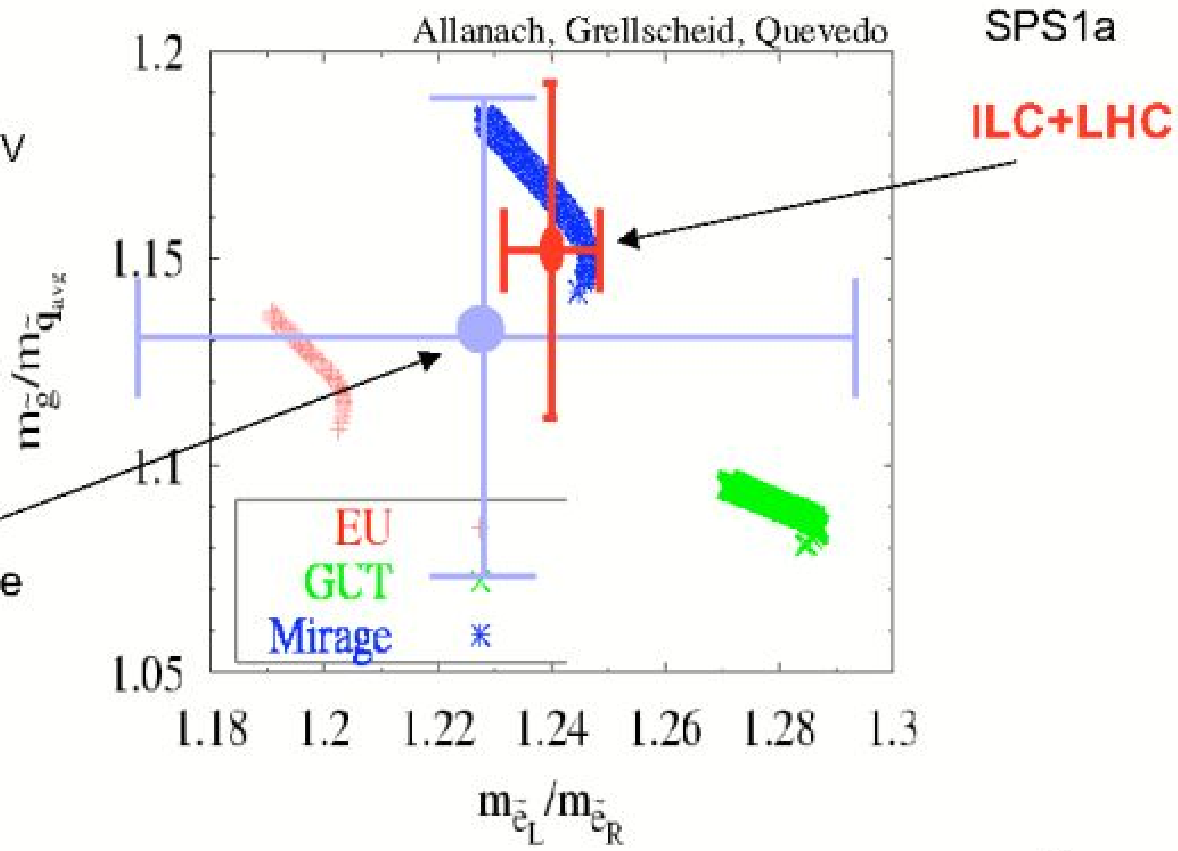
Discrimination between different SUSY-breaking scenarios

Type-I string inspired models

EU: early unification at 10^{11} GeV

GUT: string scale at GUT scale ~10^{16} GeV

Mirage: Intermediate string scale
at 10^{11} GeV + Mirage unification



Allanach, Grellscheid, Quevedo

SPS1a

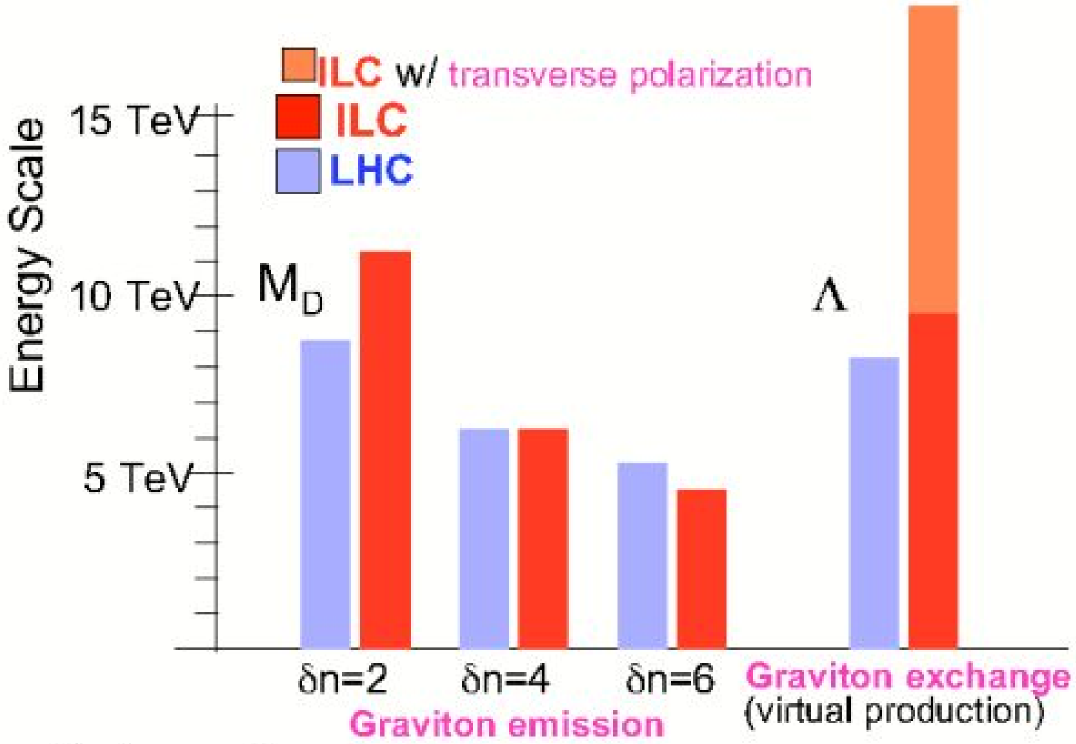
ILC+LHC

LHC alone

Precise determination of SUSY parameters at ILC and LHC allows to achieve accuracy in SUSY Dark Matter density comparable to the accuracy of Planck measurements

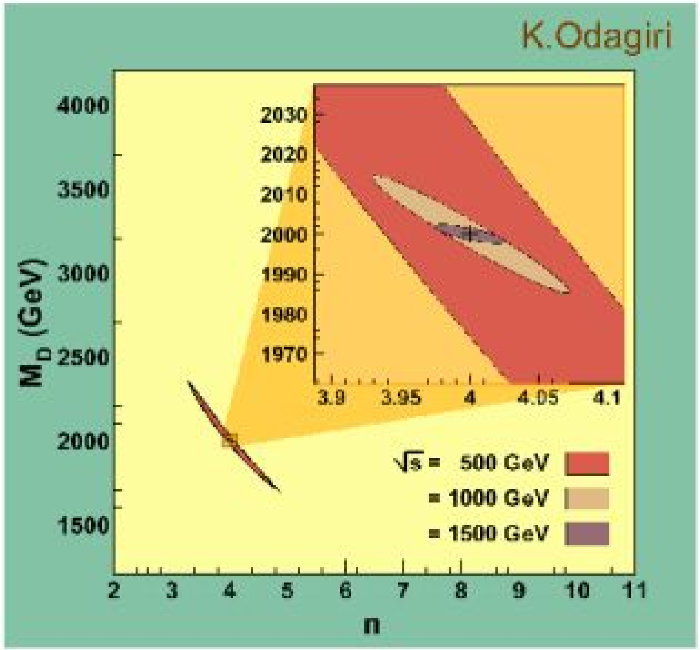
Examples: Reach and beyond

Large Extra Dimension Reach



Numbers are taken
From J.Hewett et al

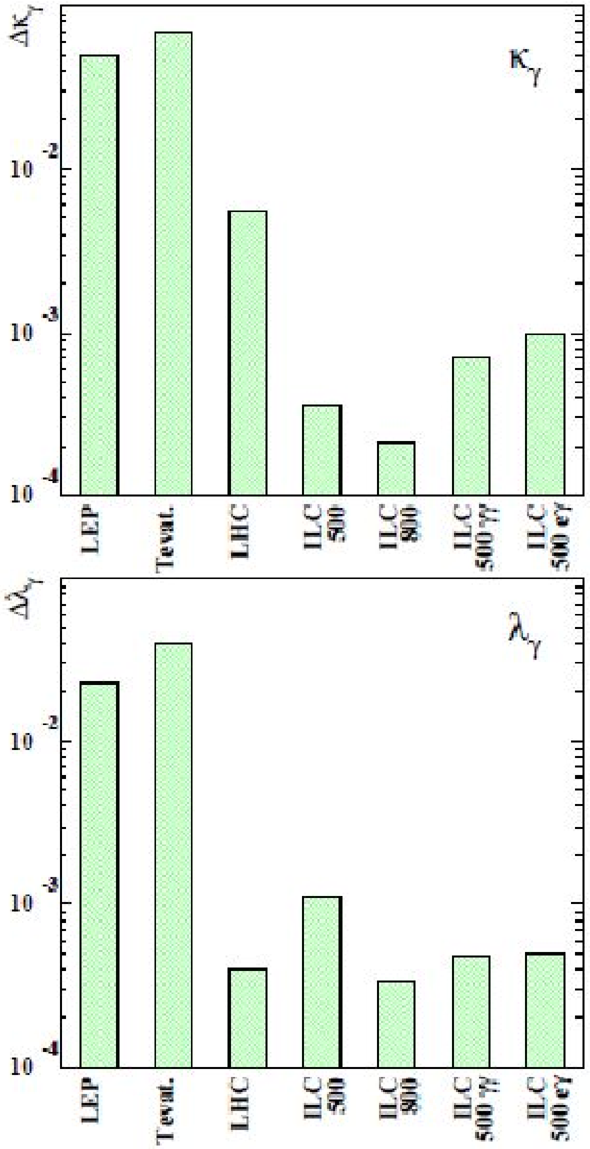
Not only the reach !



# of extra-dimensional space

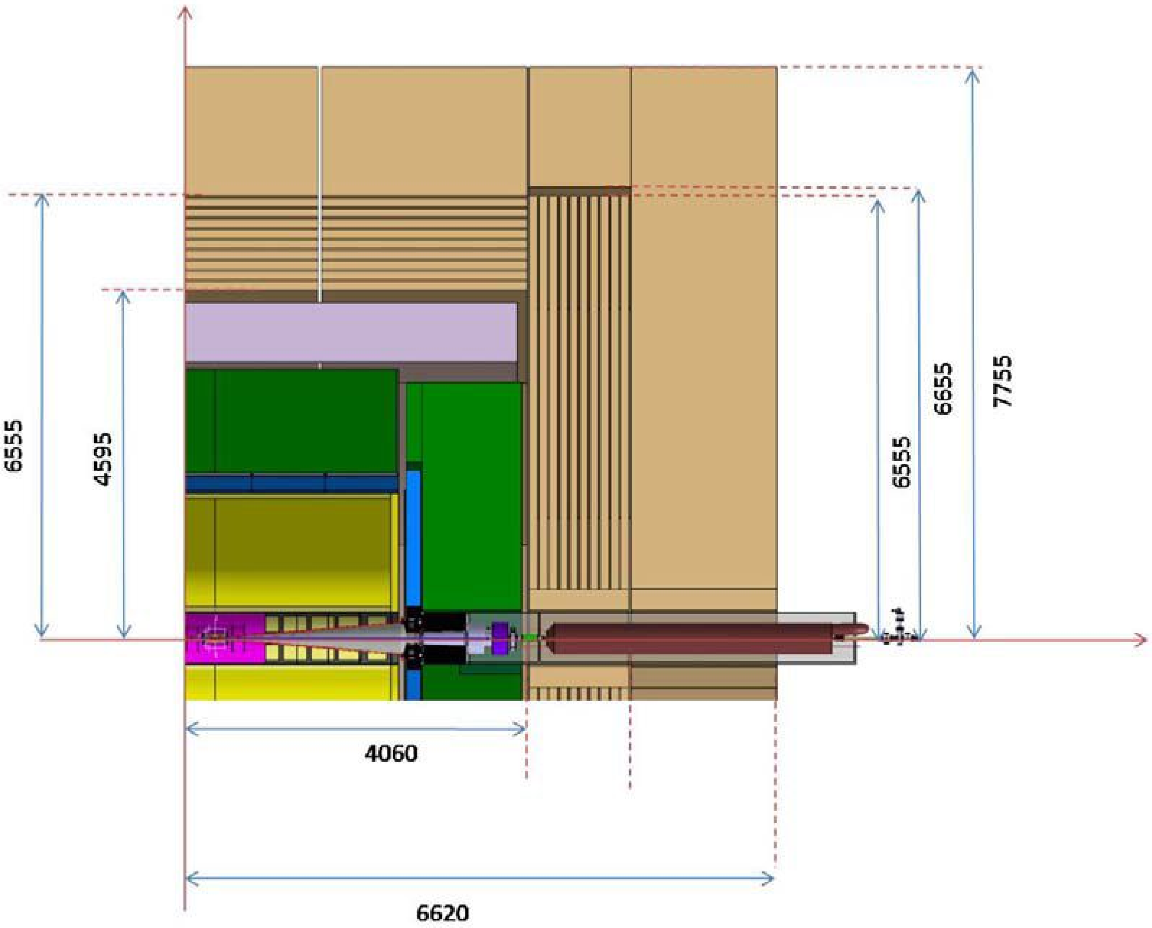
The **size and number of the extra-space** to be determined at ILC.

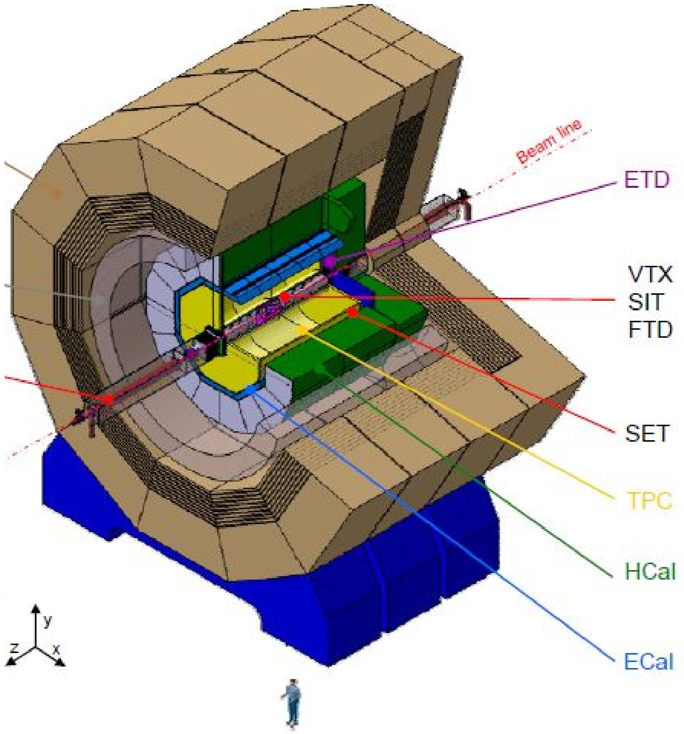
Gauge boson anomalous couplings



- LC much better than LHC for κ, somewhat better for λ
- If new physics scale is high, effects are expected in κ because of lower dimension
  ➠ big advantage for LC
- If new physics scale is low, both couplings can show effects and LHC probes at higher scales where new physics might be visible directly
  ➠ advantage for LHC
- If some effect is found somewhere it is definitely invaluable to have complementary information

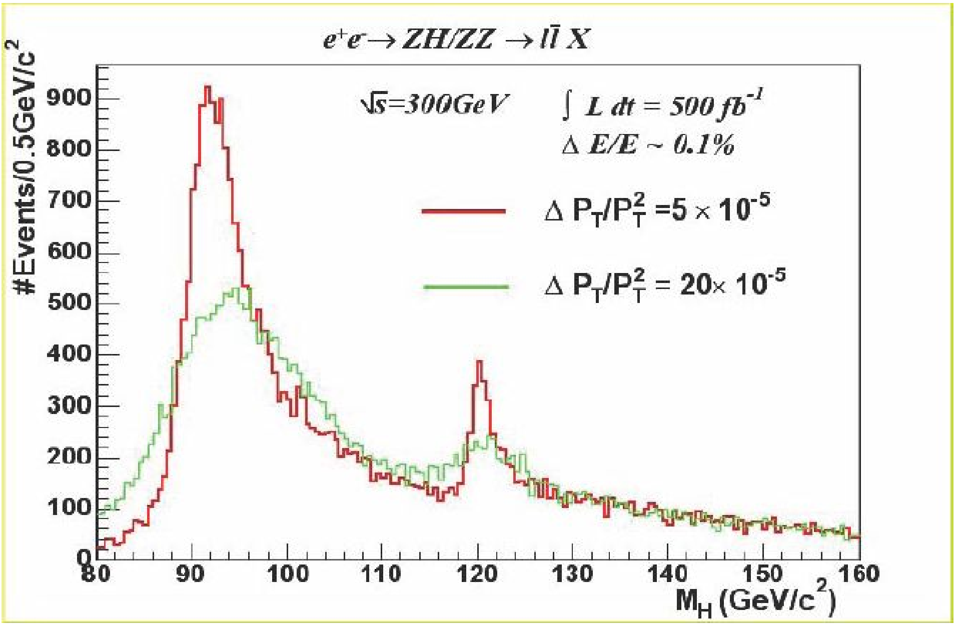
The ILD Detector





Requirements for Vertex and Track reconstruction

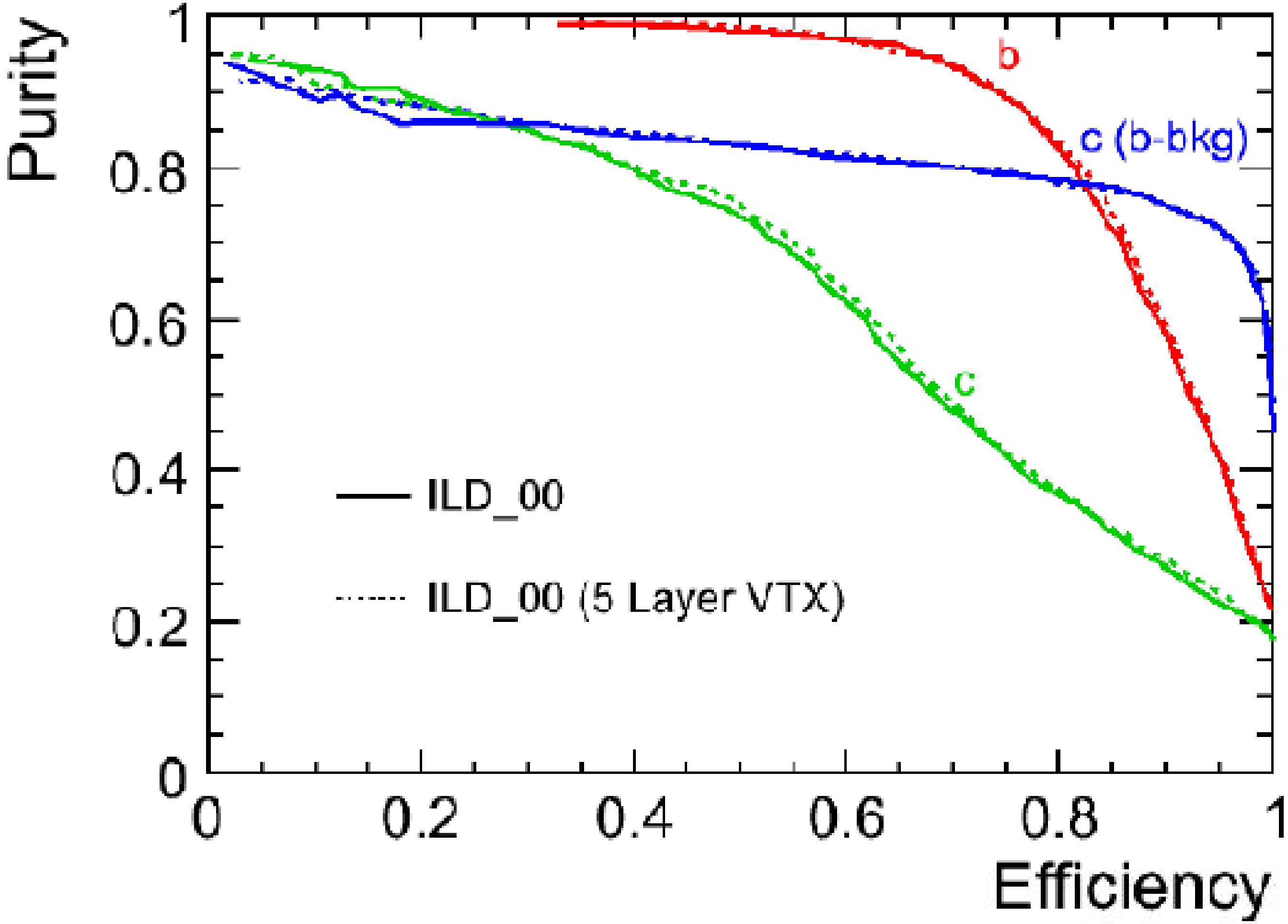
- Vertex detector – best flavour tagging
  - goal impact parameter resolution
    $\sigma_{r\varphi} \approx \sigma_z \approx 5 \oplus 10/(p \sin\Theta^{3/2})$ µm 3 times better than SLD
  - small (R~1.5cm), low mass (~$0.1X_0$) pixel detectors,
  - various technologies under study with pixels ~20×20 μm^2 (~10^9 pixels)
- Tracking:
  - superb momentum resolution to select clean Higgs samples
  - ideally limited only by Γ_Z



$\rightarrow \Delta(1/p_T) = 5{\cdot}10^{-5}$ /GeV
(whole tracking system)
3 times better than CMS

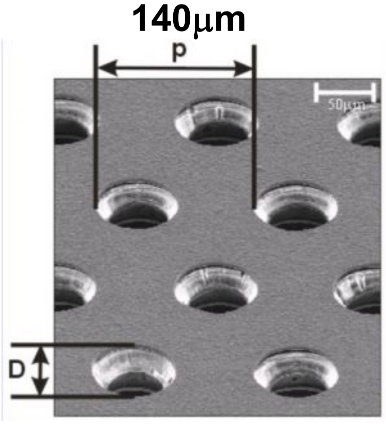
  - Time Projection Chamber with ≈ 100 µm point resolution (complemented by Si–strip devices)

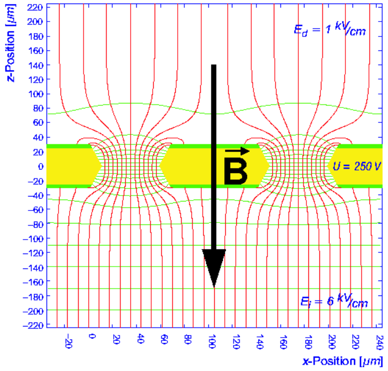
ILD Flavour Tagging Efficiency



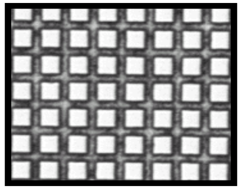
TPC Tracker for LC Detector (Worldwide collaboration)

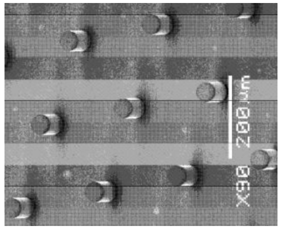
Established technique but with novel Micropattern Readout

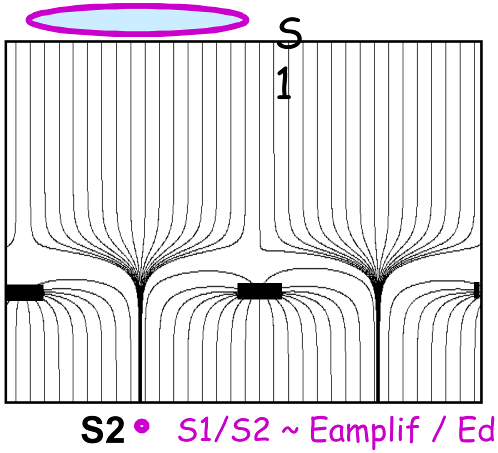




GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages



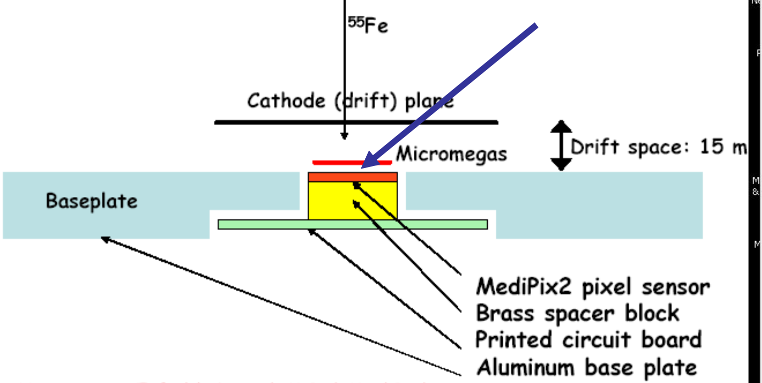




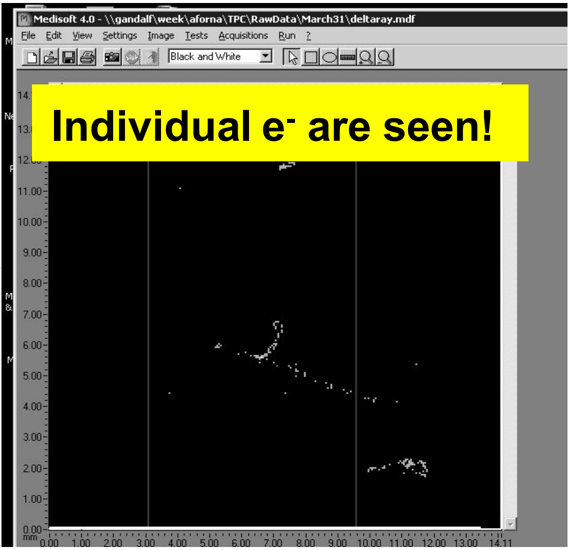
S1/S2 ~ Eamplif / Edrift

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

256x256 pixel chip with Preamp, Discriminator, DAC, 14-bit counter,…



Very strong E-field above (CMOS) MediPix!



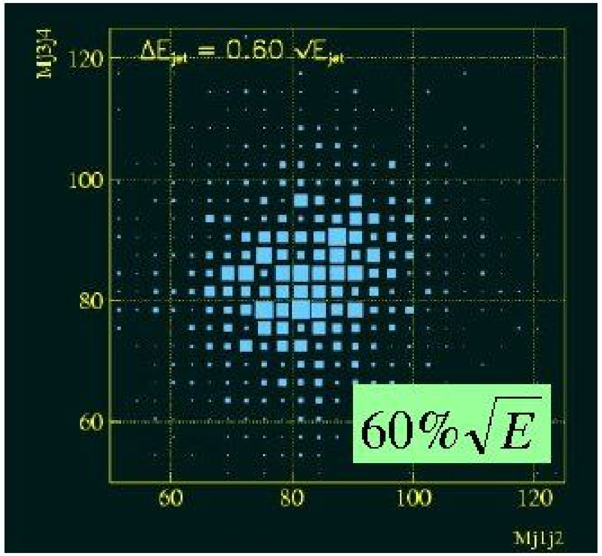
Individual e⁻ are seen!

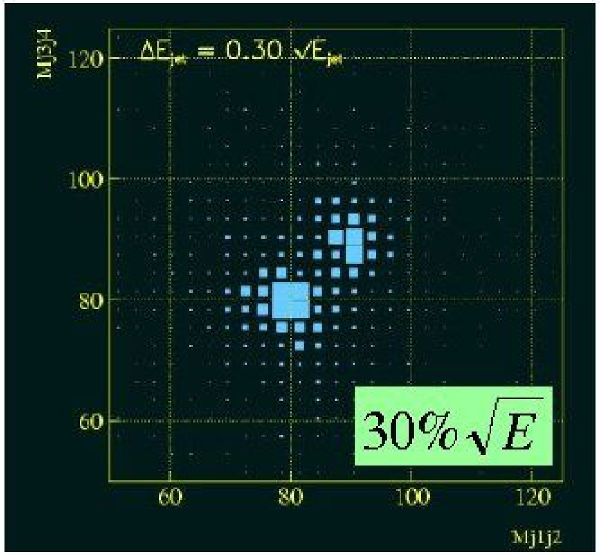
Micromegas can be produced directly on chip

GEM can be also used

TimePix chip gives 3d results

LC Physics goals require $\Delta E_J/\sqrt{E_J} \sim 30\%$





This can be achieved with Particle Flow Method (PFM):

⇨ Use calorimeter only for measurement of K,n, and γ

Substitute charged track showers with measurements in tracker

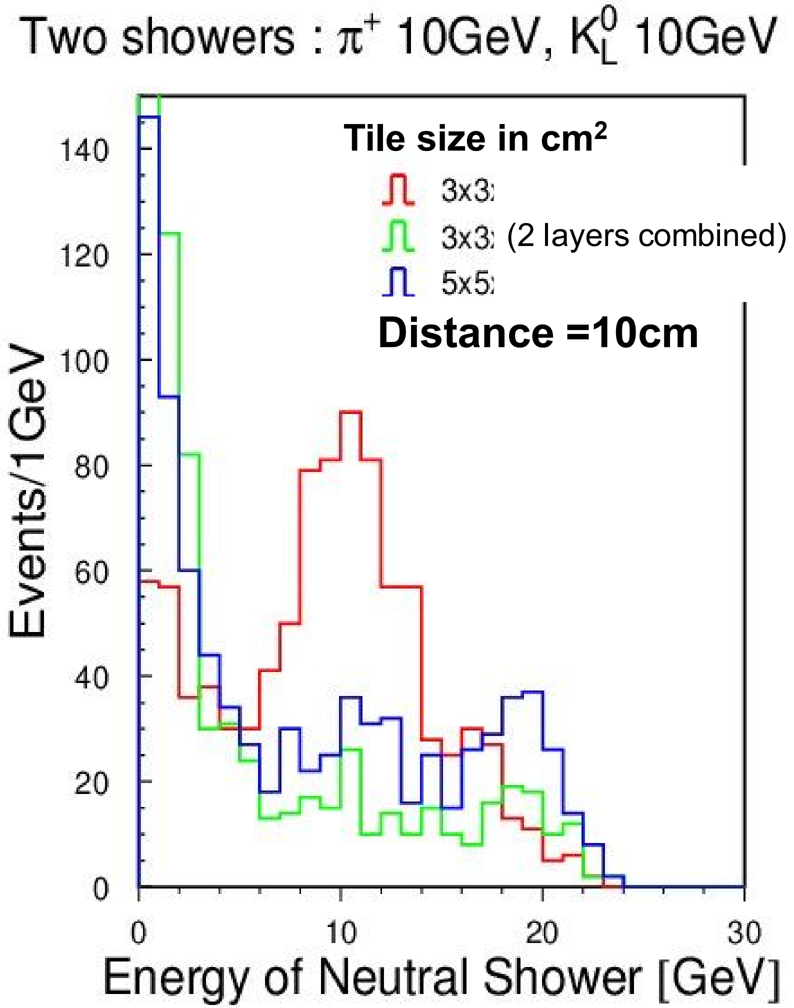
LC detector architecture is based on PFM,
which is tested mainly with MC

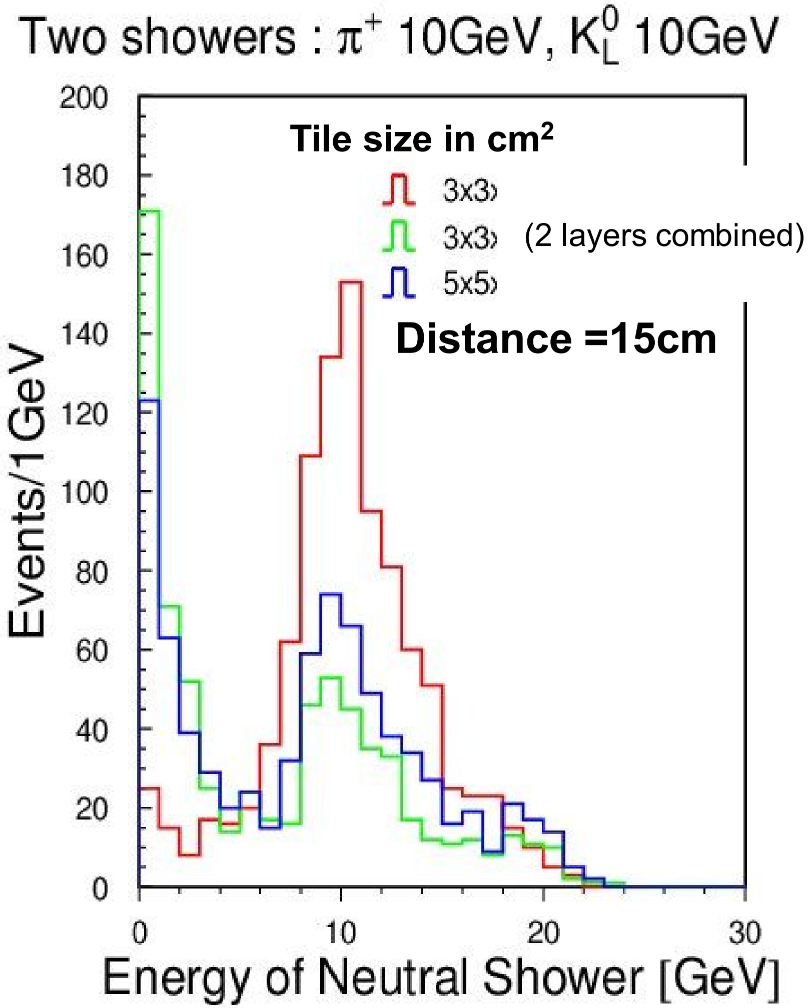
⇩

Experimental tests of PFM are extremely important

We constructed a 8000 chan. prototype of scintillator tile calorimeter to test PFM

Shower Reconstruction/Separation

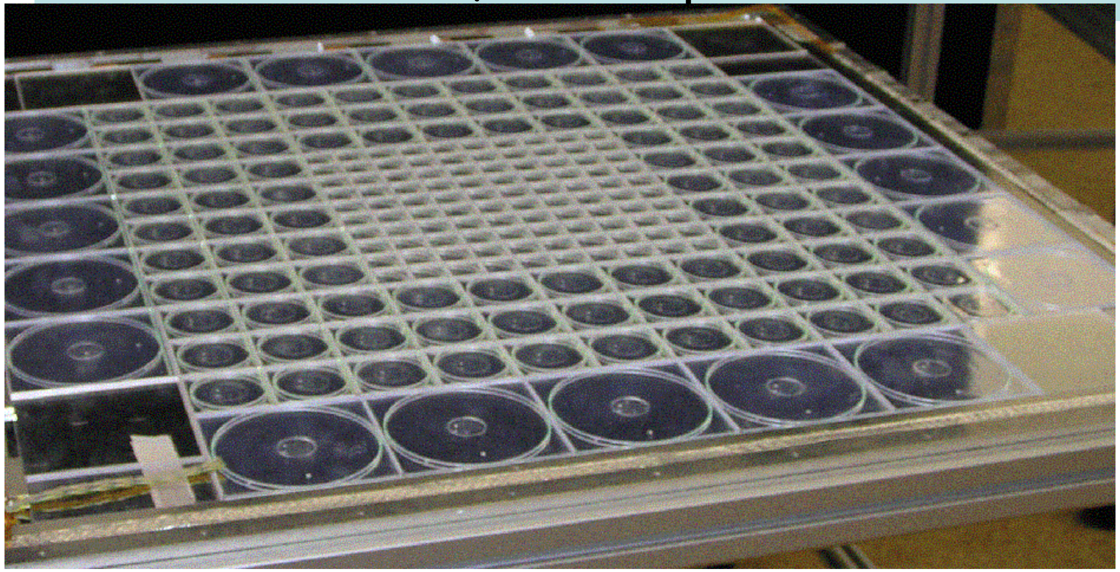


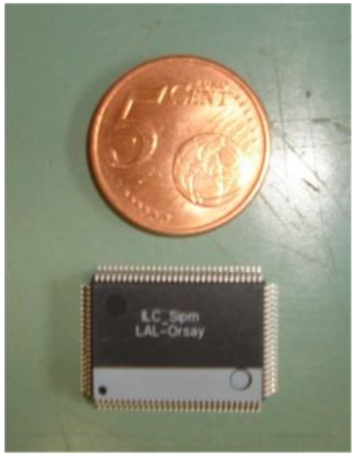


Very high granularity is required for Particle Flow Method

It can be achieved with novel photo-detectors - Silicon Photo Multipliers (SiPM)

The HCAL prototype comprises 38 planes of scintillating detectors with 216 tiles in first 30 planes and 145 tiles in 8 last ones.

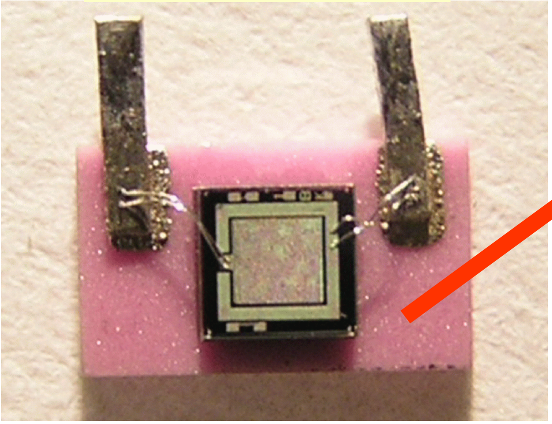




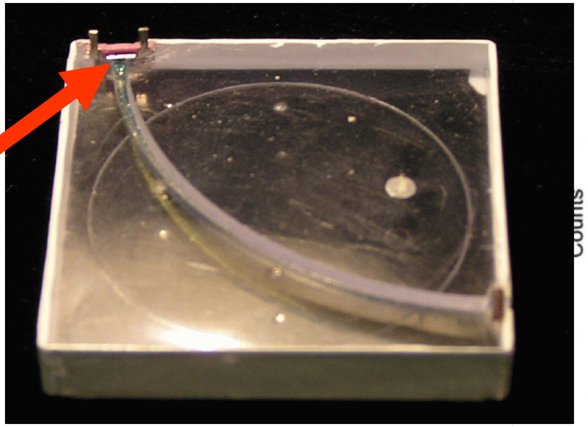
LAL 18 ch. SiPM FE chip

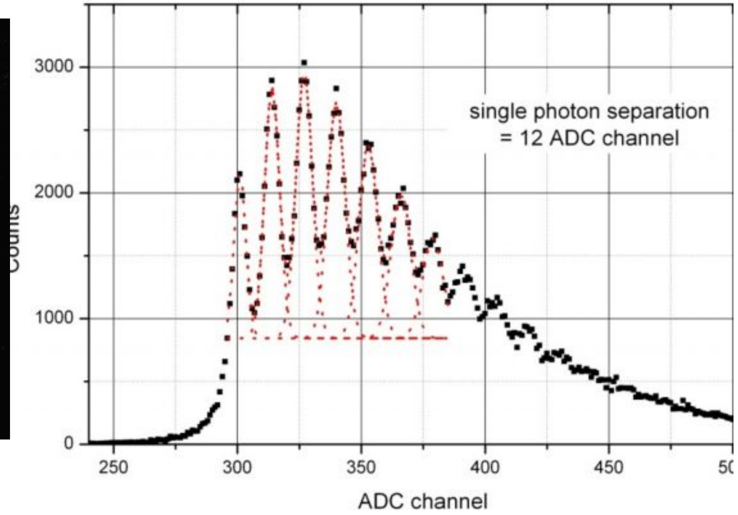
Light from a tile is read out via WLS fiber and SiPM

SiPM

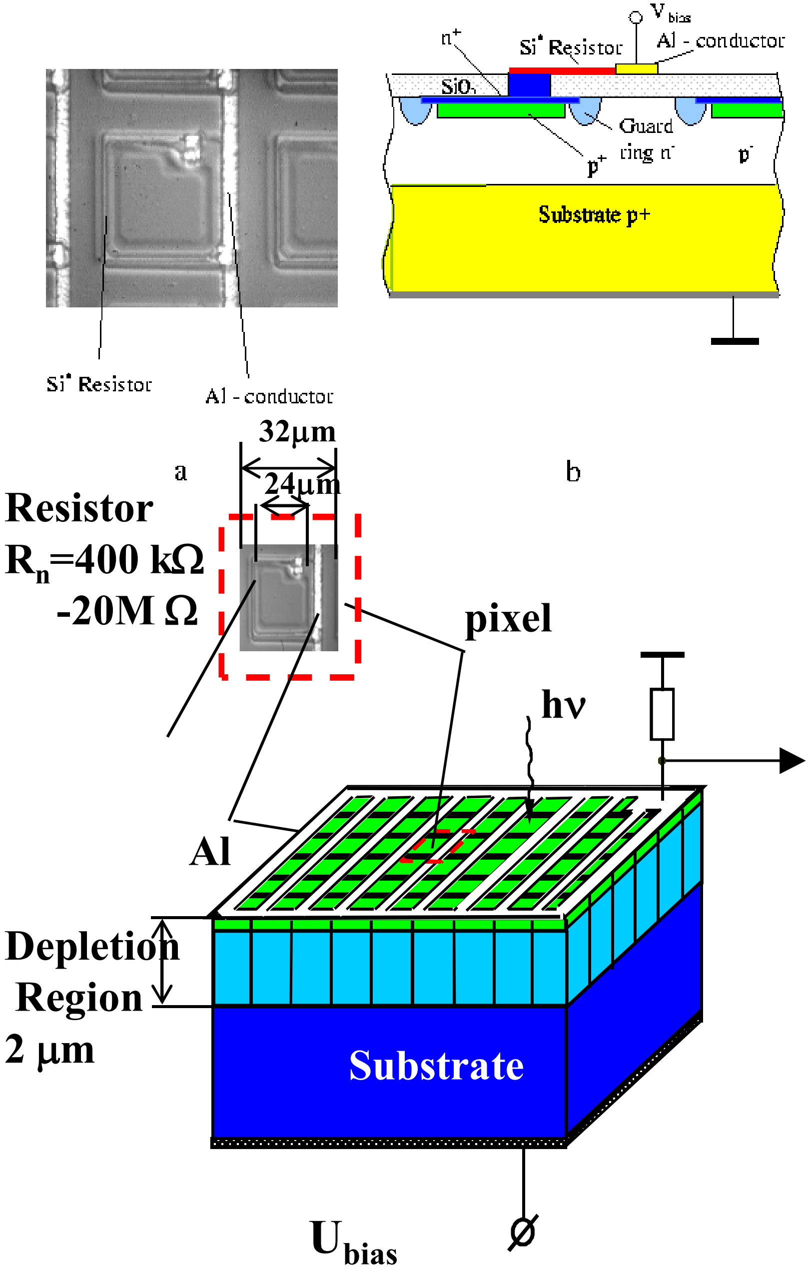


3x3 cm^2 tile with SiPM





SiPM (MEPhI-Pulsar) main characteristics



- ➢ 1156 pixels of 32x32μm^2 (actvive area 24x24)
- ➢ Working point: $V_{Bias} = V_{breakdown} + \Delta V$ ~ 50-60 V
  ΔV ~ 3V above breakdown voltage
- ➢Each pixel behaves as a Geiger counter with
  $Q_{pixel} = \Delta V\, C_{pixel}$ with C_{pixel}~50fF ➔
  Q_{pixel}~150fC=10^6e

- Noise at 0.5 p.e. ~ 2MHz

- Optical inter-pixel cross -talk:
-due to photons from Geiger discharge initiated by one electron and collected on adjacent pixels
-Xtalk grows with ΔV. Typical value ~20%.

-PDE ~15% for Y11 spectrum

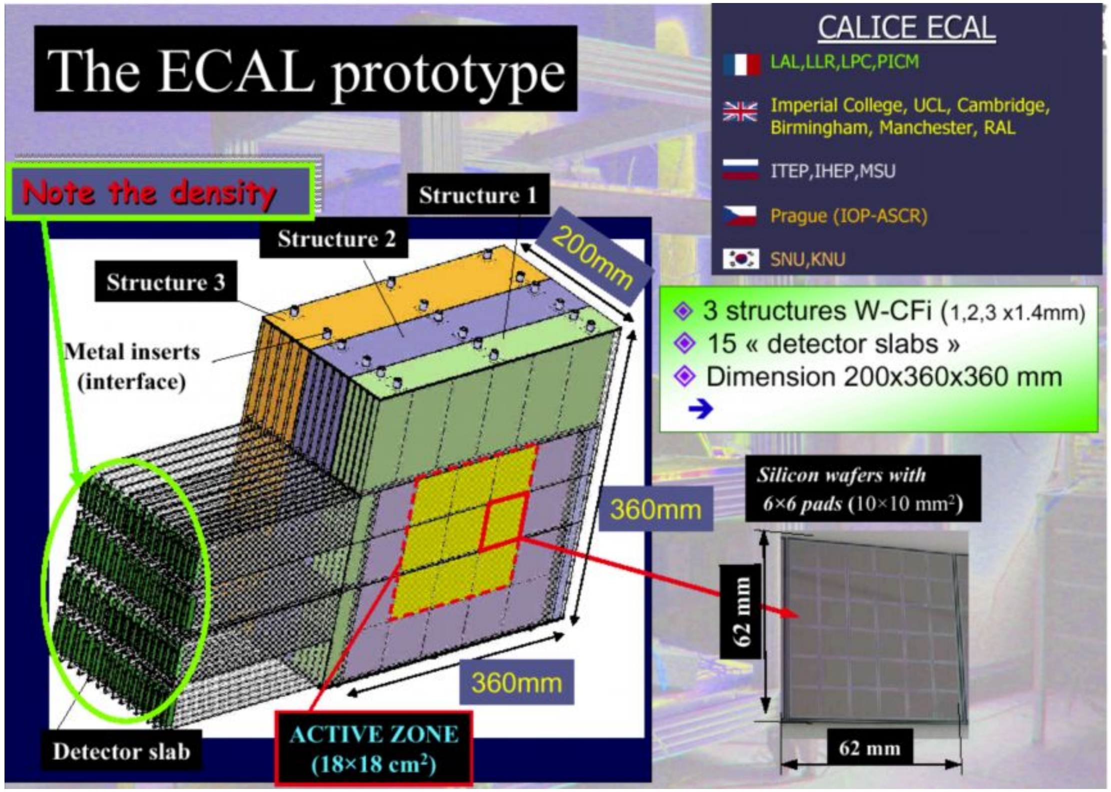
Insensitive to magnetic field (tested up to 4Tesla)

Very short Geiger discharge development < 500 ps

Pixel recovery time = (C_{pixel} R_{pixel}) ~ 20 ns (for small R)

Dynamic range ~ number of pixels (1156)➔ saturation

CALICE – Si/W Electromagnetic Calorimeter



The ECAL prototype

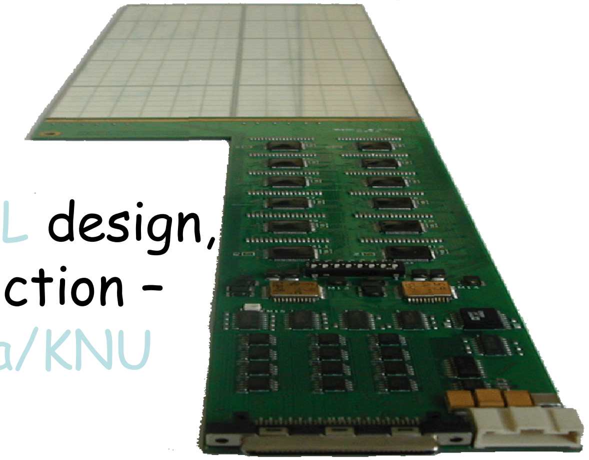
CALICE ECAL

- LAL,LLR,LPC,PICM
- Imperial College, UCL, Cambridge, Birmingham, Manchester, RAL
- ITEP,IHEP,MSU
- Prague (IOP-ASCR)
- SNU,KNU

- 3 structures W-CFi (1,2,3 x1.4mm)
- 15 « detector slabs »
- Dimension 200x360x360 mm
- ➔

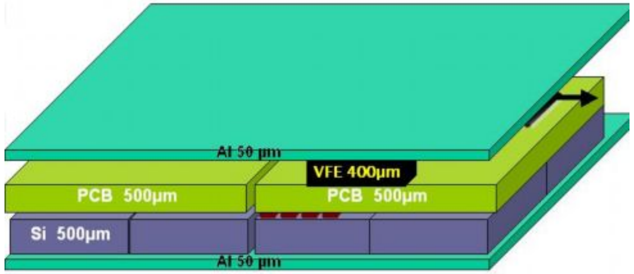
Tungsten:
ITEP

Wafers:
Russia/MSU
and Prague



PCB: LAL design,
production –
Korea/KNU

New design for ECal active gap. Reduction from 3.4mm to 1.75mm, R_m = 1.4cm

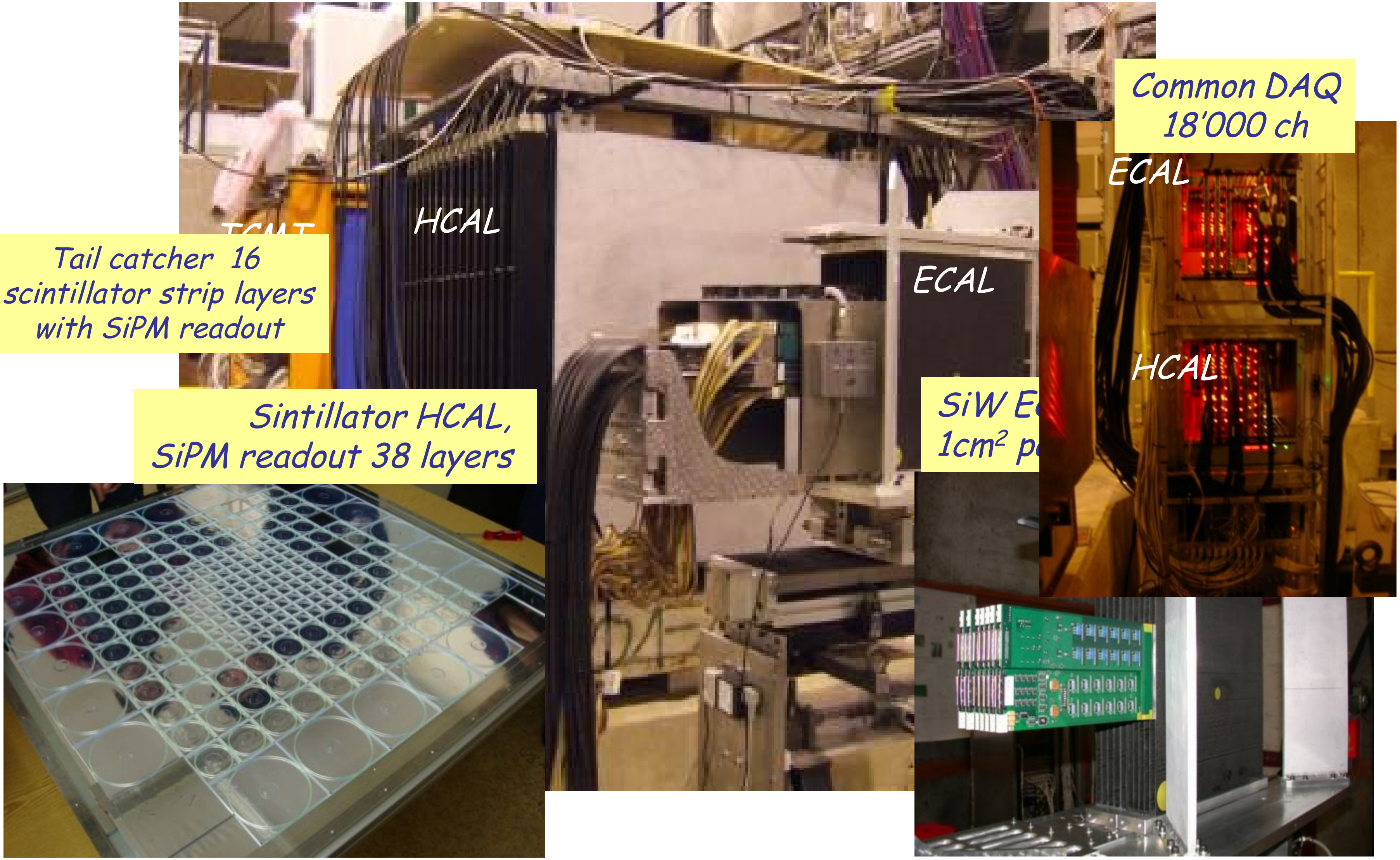


Real 640 μm PCB exists

High resolution plane at about $3X_0$

HCAL, ECAL and TC have been tested in 2007 at CERN, in 2008-09 at FNAL

Set-up at SPS H6b



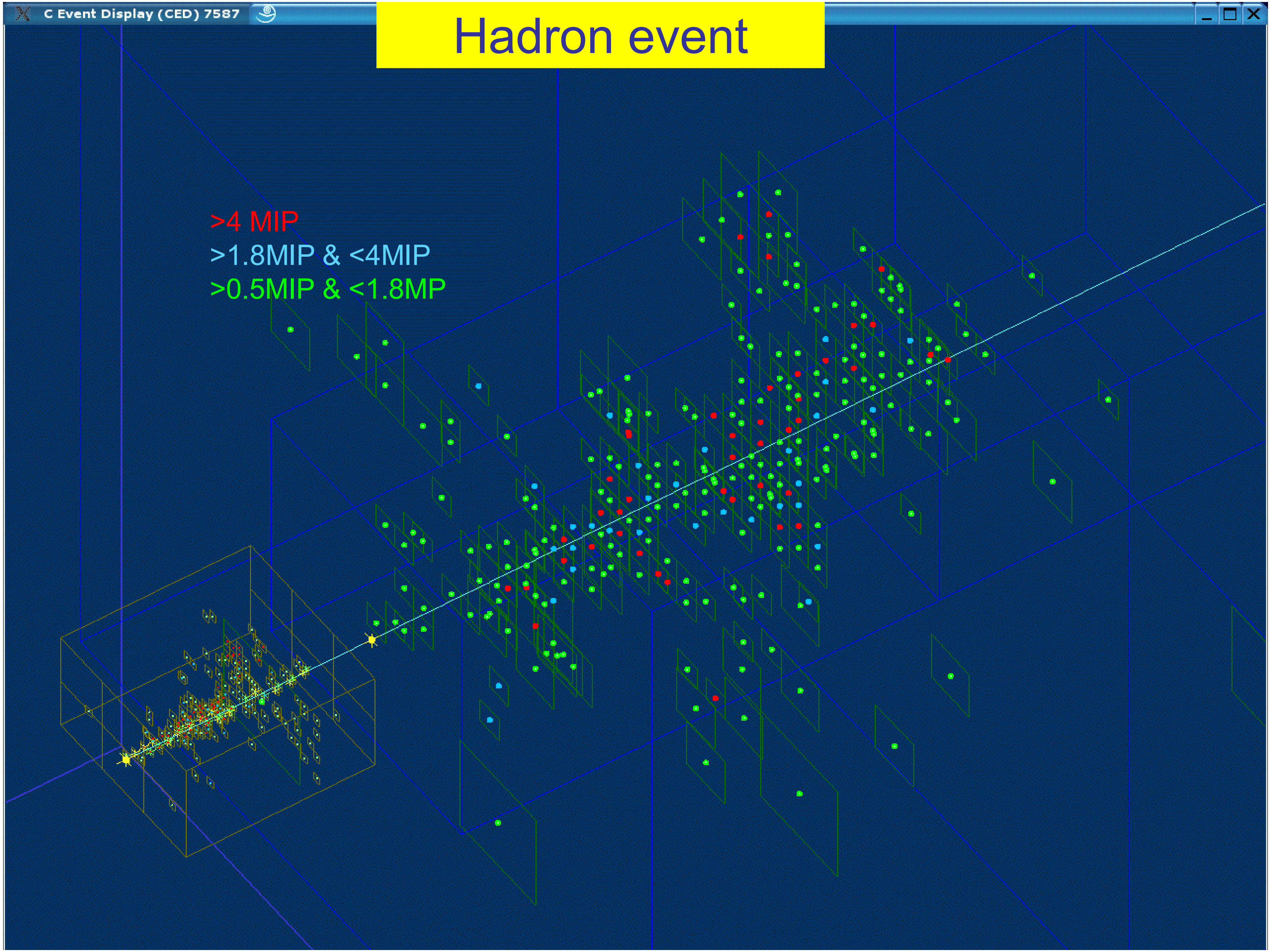
Tail catcher 16 scintillator strip layers with SiPM readout

Sintillator HCAL, SiPM readout 38 layers

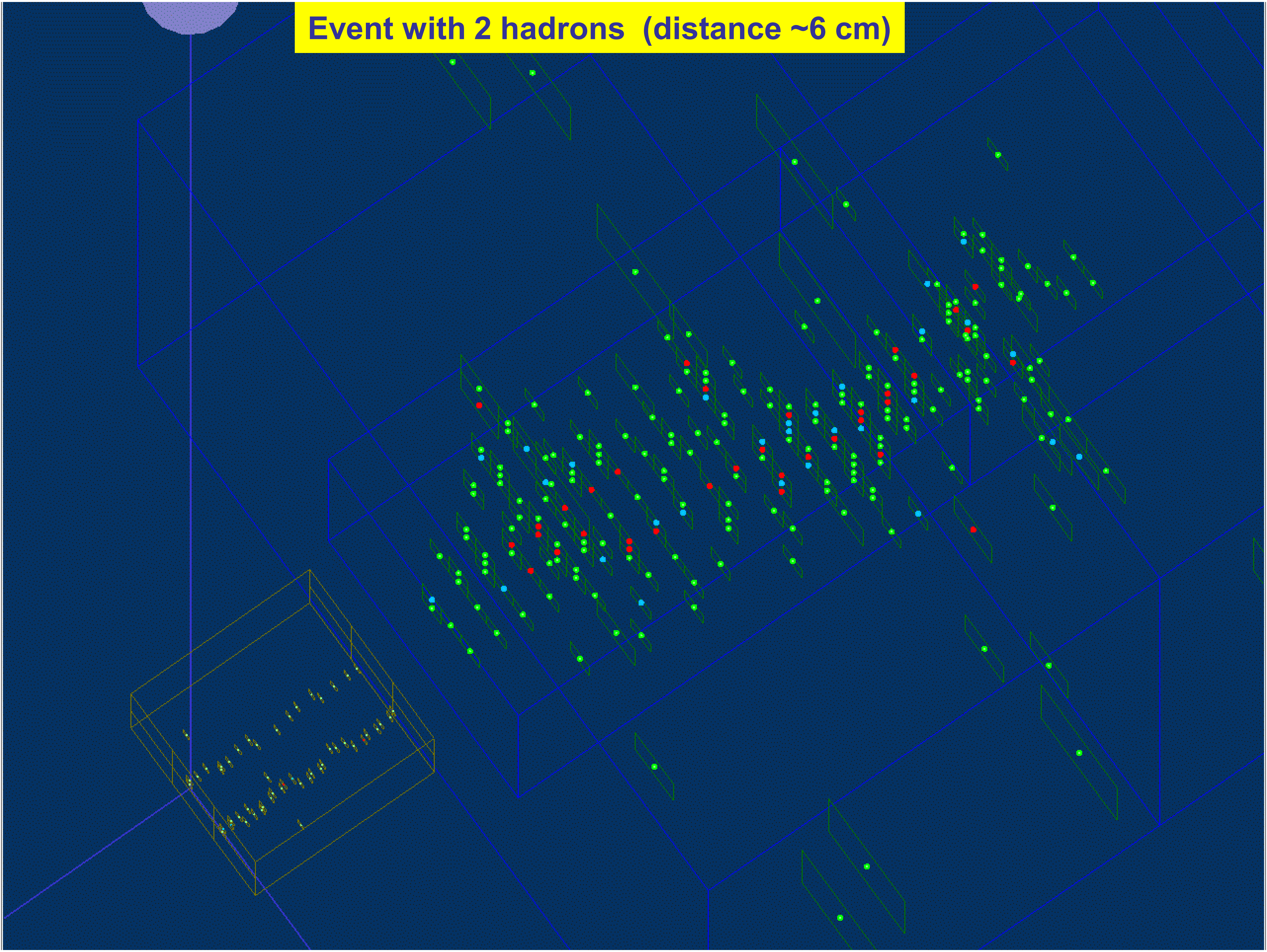
SiW E
$1cm^2$ p

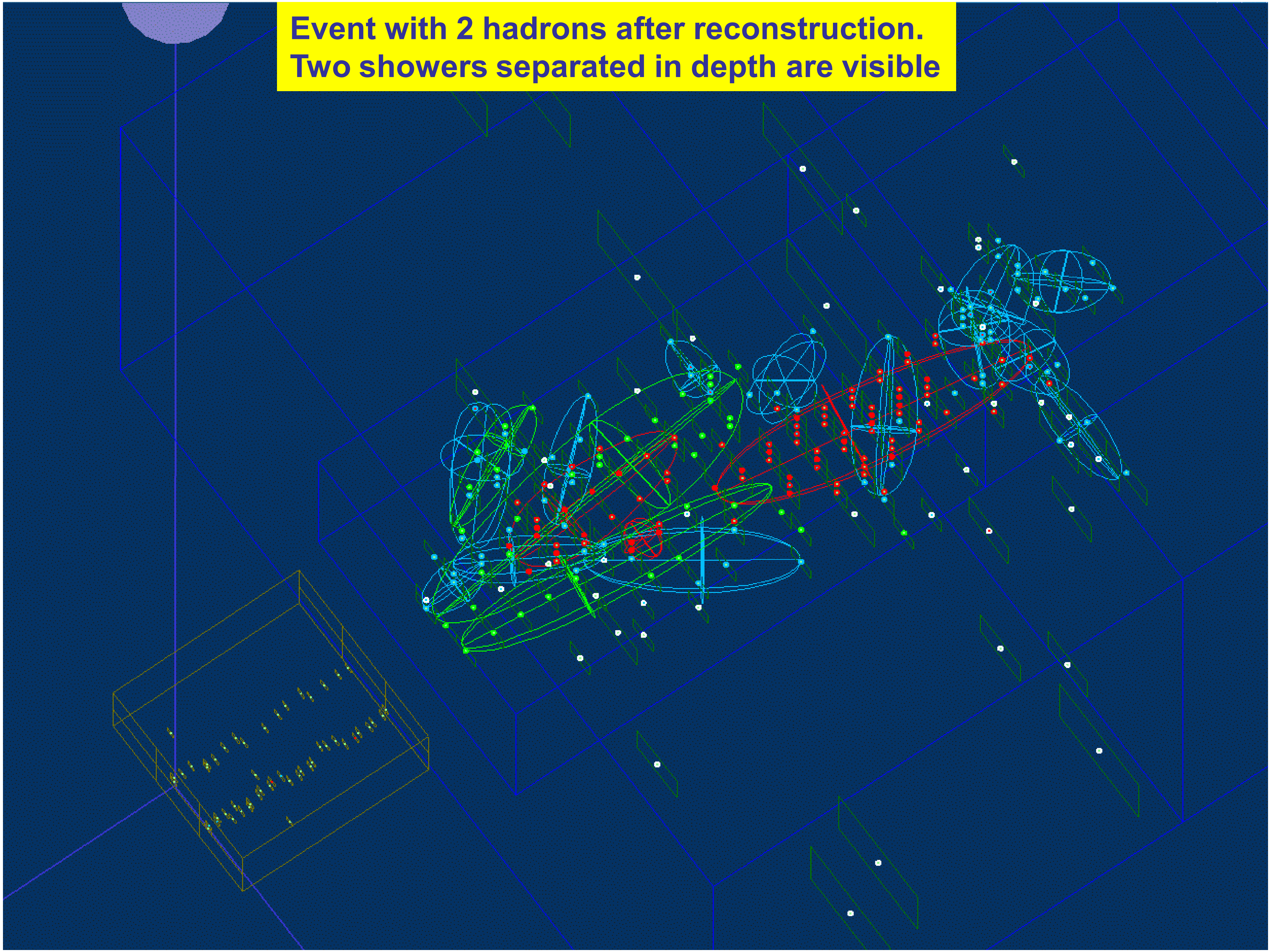
Common DAQ
18'000 ch

Hadron event



Event with 2 hadrons (distance ~6 cm)





Event with 2 hadrons after reconstruction.
Two showers separated in depth are visible

Scintillator tile calorimeter with WLSF and SiPM readout is a viable option for ILC HCAL but industrialization is needed for several hundred times larger system

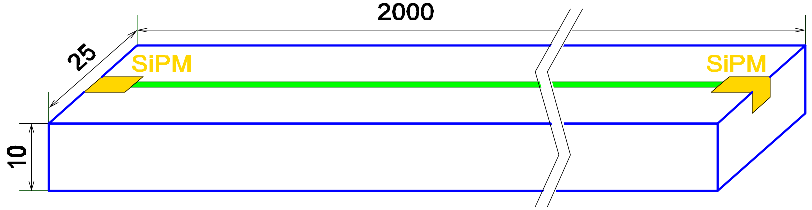
New types of SiPMs are being developed by many firms.

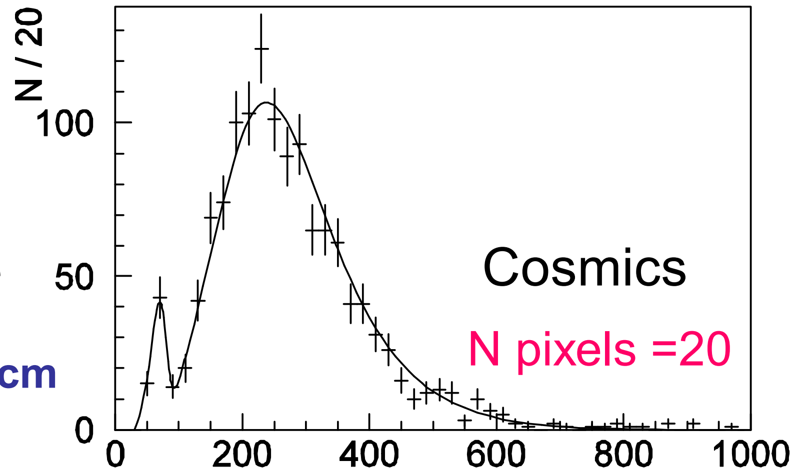
Final choice of the photodetector depends on overall optimization

Comparison with Digital Calorimeter will be made using beam test data

Scintillator strips with WLSF and SiPM readout can be used for ILC muon system

Tests of 2 m long strip at ITEP





Position along strip can be determined from time measurements:

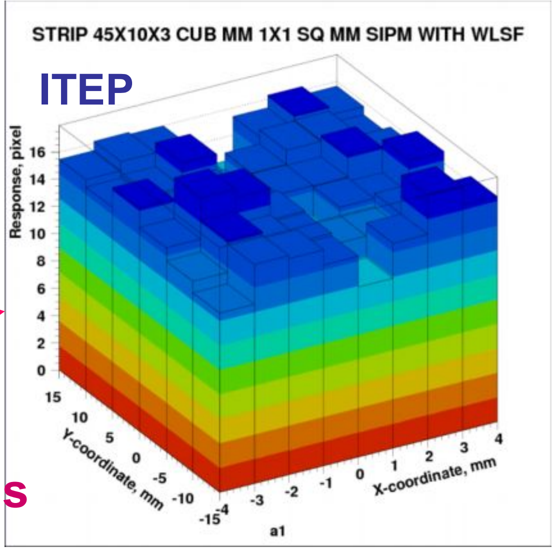
Achieved time resolution ΔT~2ns leads to ΔX~25cm

More experience will be gained from TCMT tests

Thin scint. strips with WLSF+SiPM readout provide sufficient light and uniformity (~6%) for last layers of EM calorimeter

(approach is extensively tested by Japanese groups)

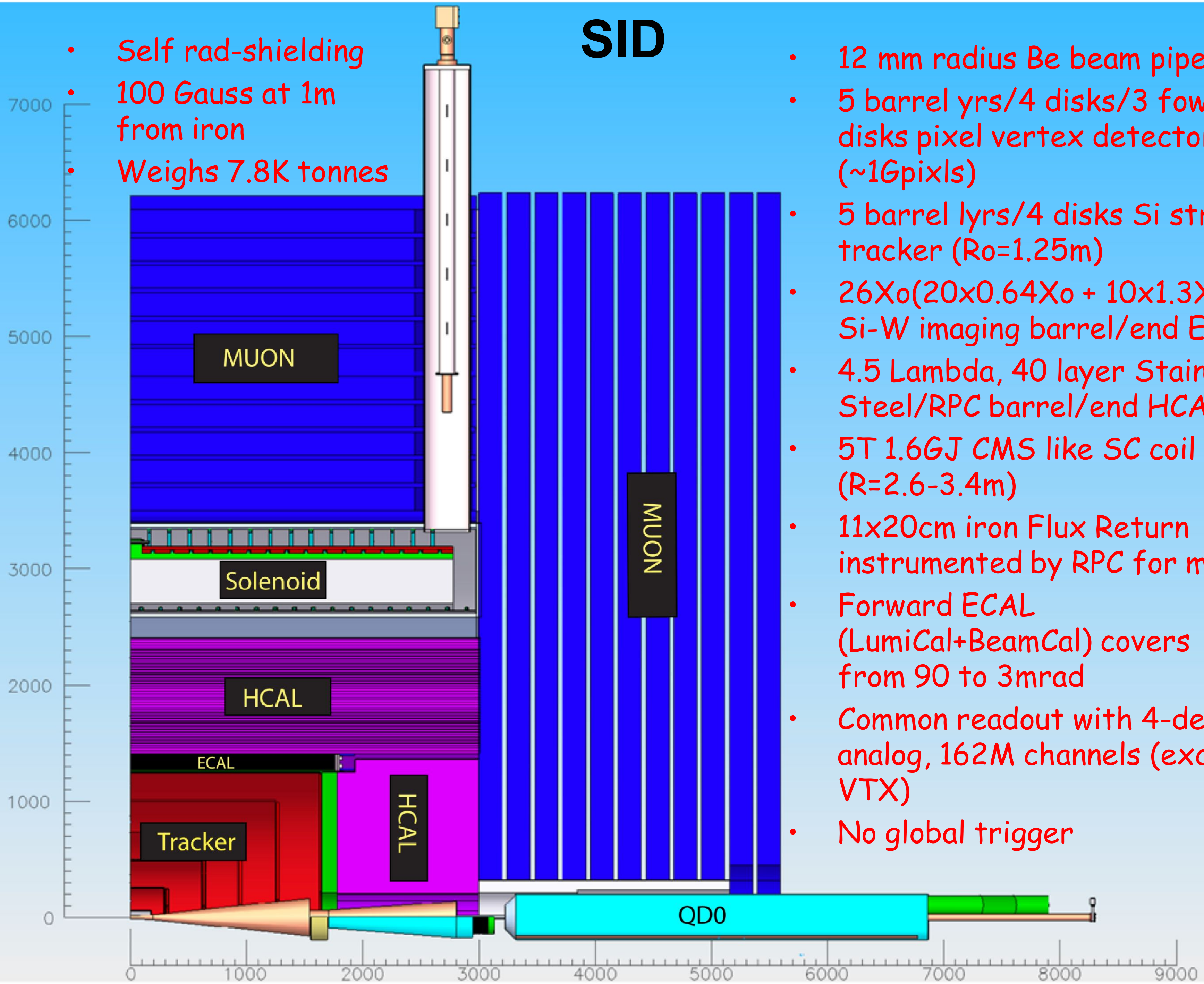
Uniformity measurements for 3x10x45 mm^3 strip with WLSF and SiPM readout



The same technique can be used for 3 detector systems

SID

- Self rad-shielding
- 100 Gauss at 1m from iron
- Weighs 7.8K tonnes

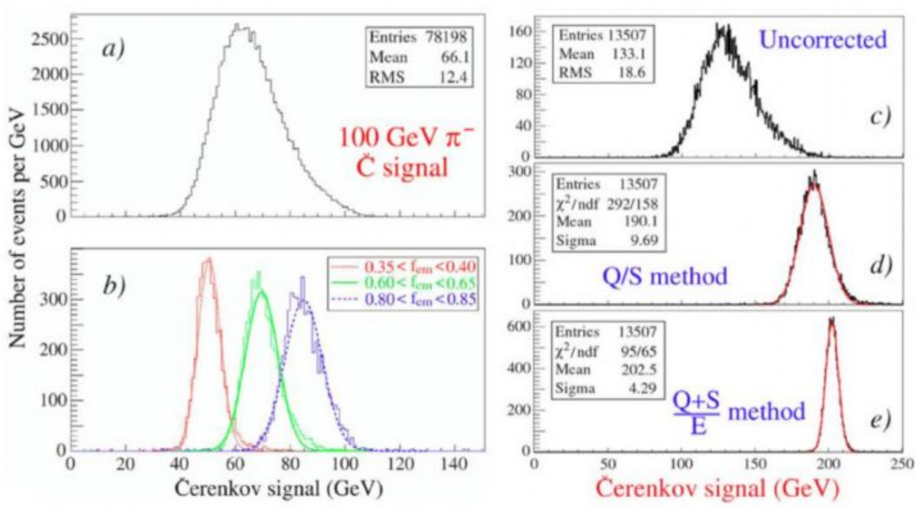


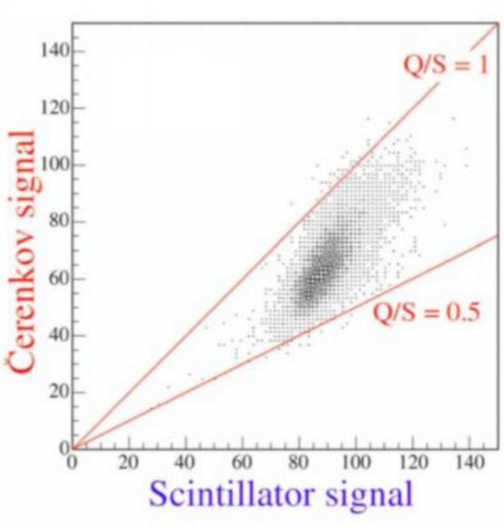
- 12 mm radius Be beam pipe
- 5 barrel yrs/4 disks/3 foward disks pixel vertex detector (~1Gpixls)
- 5 barrel lyrs/4 disks Si strip tracker (Ro=1.25m)
- 26Xo(20x0.64Xo + 10x1.3Xo) Si-W imaging barrel/end ECAL
- 4.5 Lambda, 40 layer Stainless Steel/RPC barrel/end HCAL
- 5T 1.6GJ CMS like SC coil (R=2.6-3.4m)
- 11x20cm iron Flux Return instrumented by RPC for muons
- Forward ECAL (LumiCal+BeamCal) covers from 90 to 3mrad
- Common readout with 4-deep analog, 162M channels (excl. VTX)
- No global trigger

4^{th} Detector

Fiber Calorimeter

Based on the well established and copiously documented technique of **dual readout in fibers**. Deep understanding of the under laying physics processes proven by the detailed reproducibility of the beam test data in ILCroot.





$$Q = E\left[f_{\rm em} + \frac{1}{(e/h)_Q}(1-f_{\rm em})\right]$$

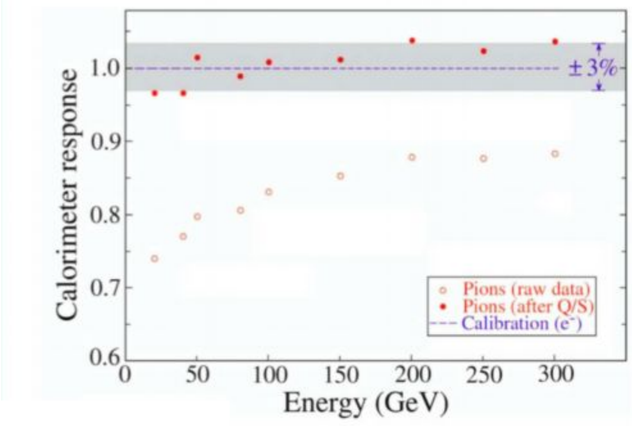
$$S = E\left[f_{\rm em} + \frac{1}{(e/h)_S}(1-f_{\rm em})\right]$$

e.g. If $e/h = 1.3\ (S),\ 4.7\ (Q)$

$$\boxed{\frac{Q}{S} = \frac{f_{\rm em}+0.21\,(1-f_{\rm em})}{f_{\rm em}+0.77\,(1-f_{\rm em})}}$$

$$\boxed{E = \frac{S-\chi Q}{1-\chi}}$$

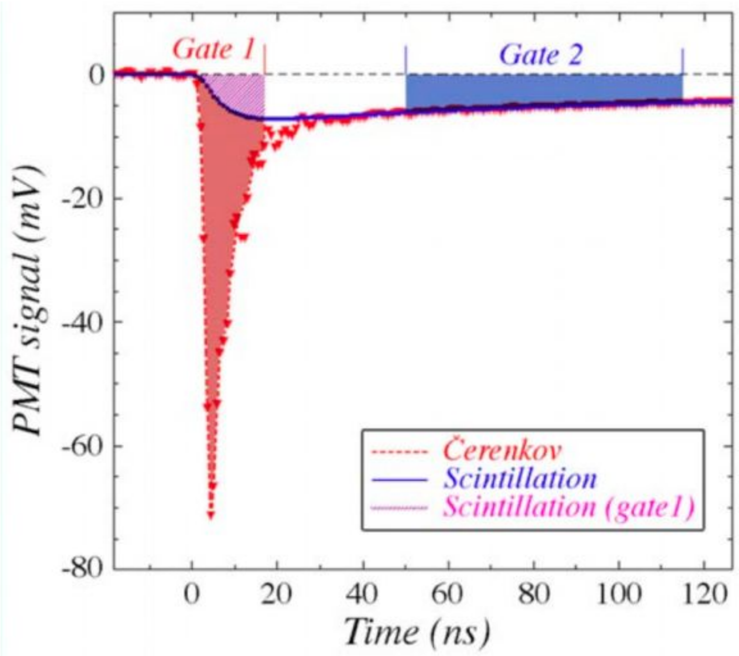
with $\chi = \frac{1-(h/e)_S}{1-(h/e)_Q} \sim 0.3$



Crystal Calorimeter

The physics motivation for placing **crystals** (we have chosen **BGO** for the beam tests and for their detailed simulations) upstream of the fiber calorimeter is to achieve optimum **electro-magnetic four-vector resolutions** on γ and *e* while maintaining, at the same time, the unprecedented **hadronic energy resolution** granted by the **fiber calorimeter**.
See next talk by Corrado Gatto on the very good reproducibility of the DREAM beam test data by the ILCroot simulations and the resulting excellent combined performances of the two calorimetric systems.

Cerenkov (black filter) and scintillation (yellow filter) oscilloscope signals from beam DREAM data in BGO.

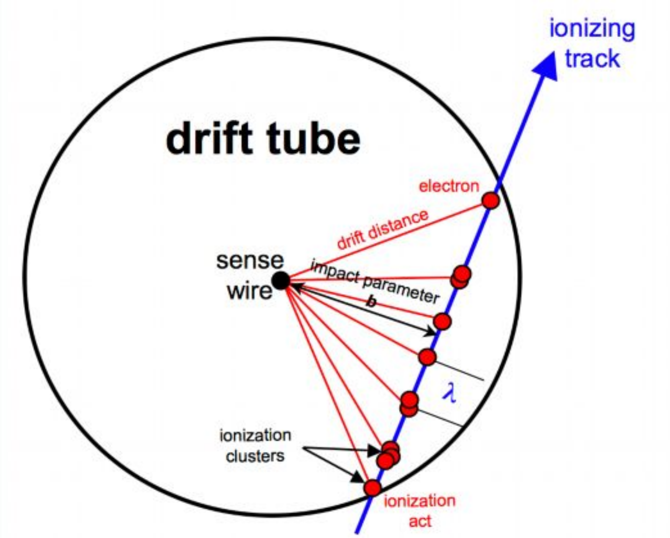


Two separate readouts are not required. A single readout will accomplish dual-readout of BGO:

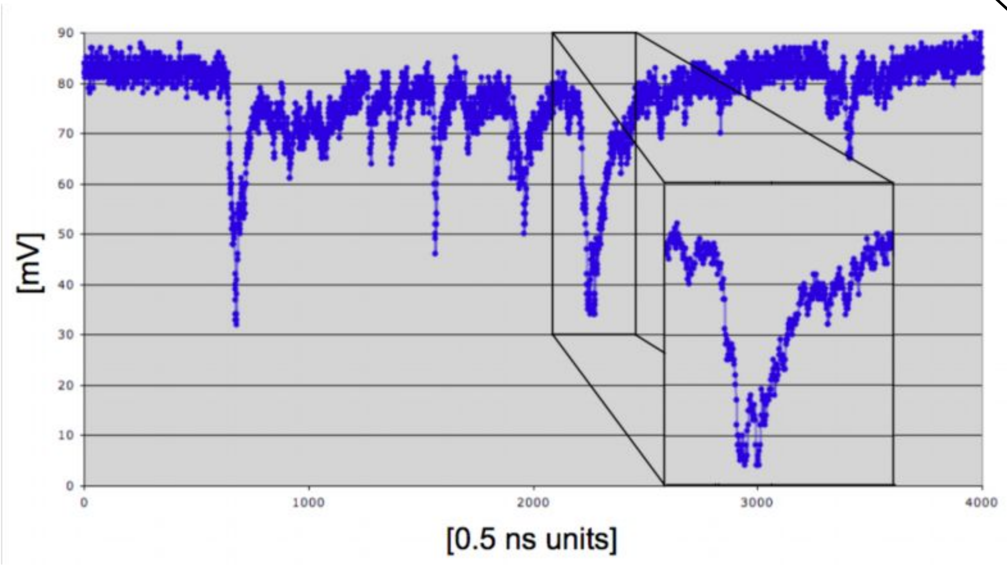
$$S = \int_{50ns}^{115ns} p.h.(t) \cdot dt$$

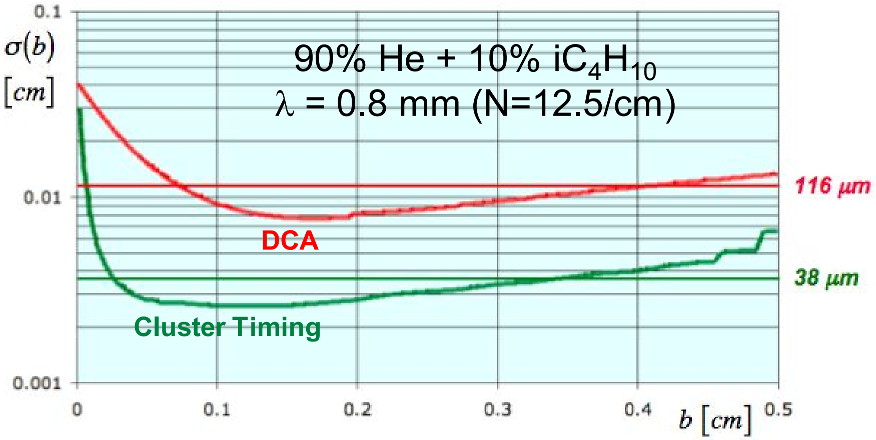
$$C = \int_{0}^{15ns} p.h.(t) \cdot dt - 0.2S$$

Central Tracker

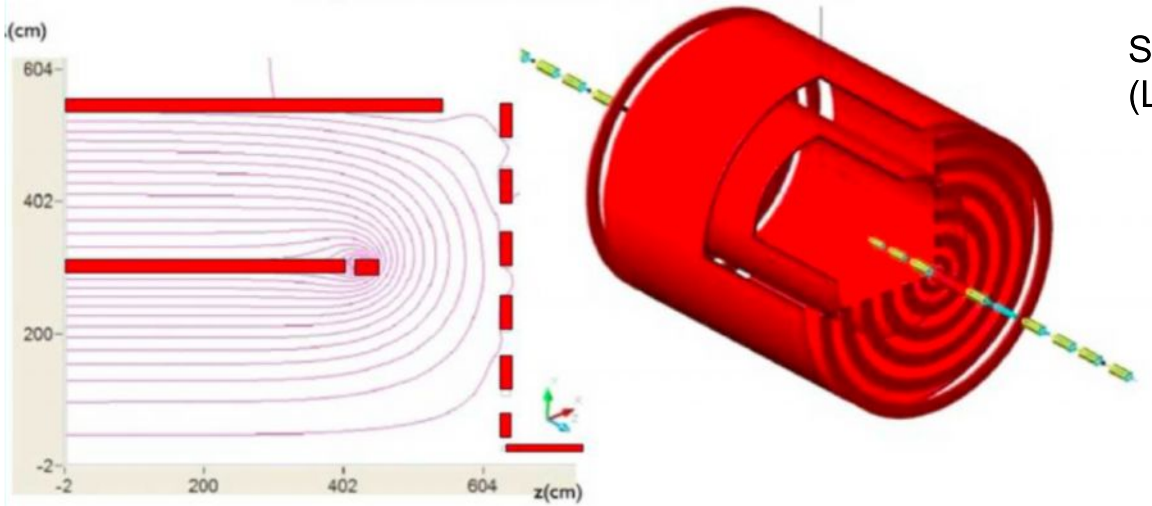


Cluster timing in drift chambers consists in recording the drift times of all individual ionization electrons collected on a sense wire and due to the passage of an ionizing track in the active gaseous medium.
This leads to spatial resolutions like



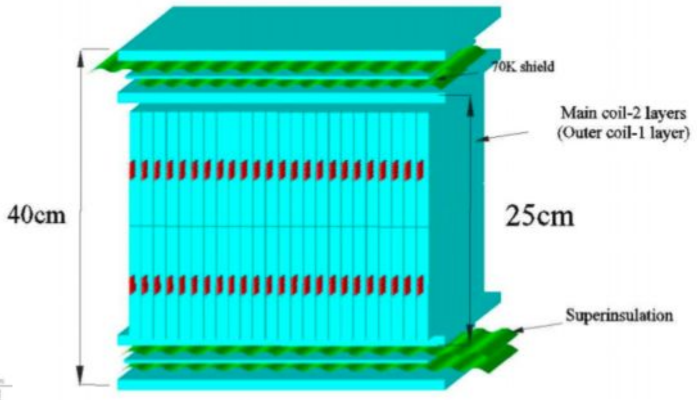


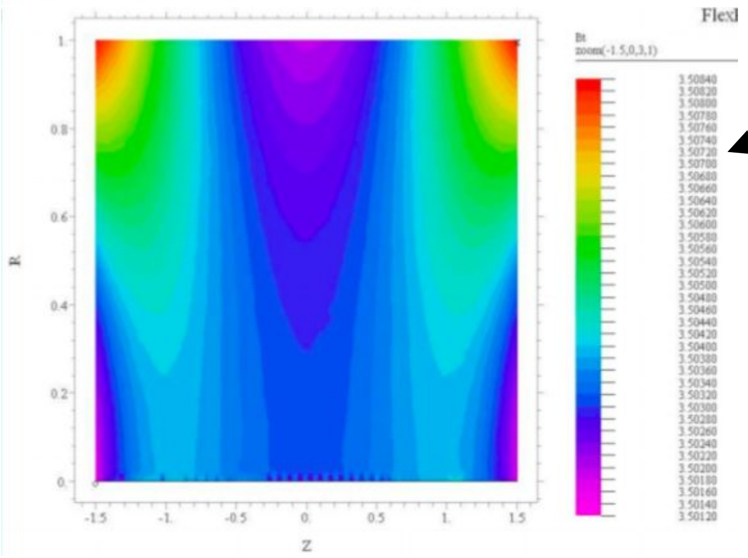
Magnet System



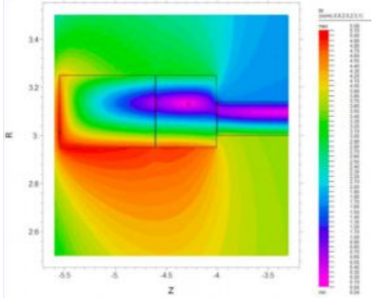
See “Solenoid Design” by A. Mikhailichenko (LOI - Appendix A)

We think we can use the CMS-type conductor with a safety margin of 2 for the inner and outer solenoids.





B uniformity < $2X10^{-3}$ in tracking volume

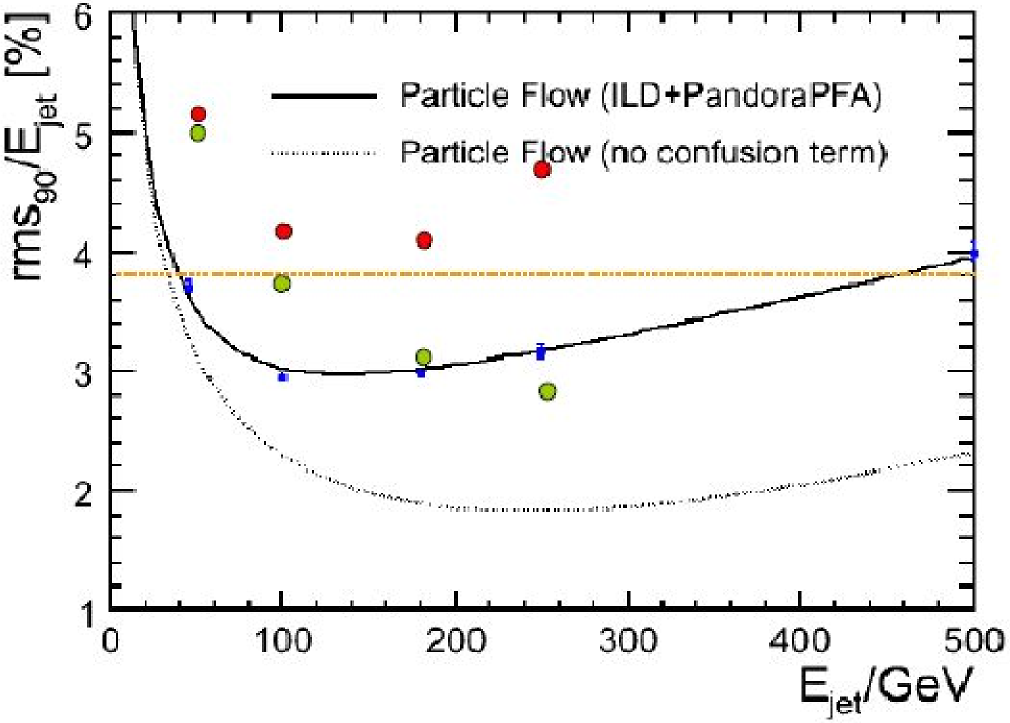


A larger size Helmholtz coil may be needed to reduce the current.

Jet Energy Comparison

● SiD

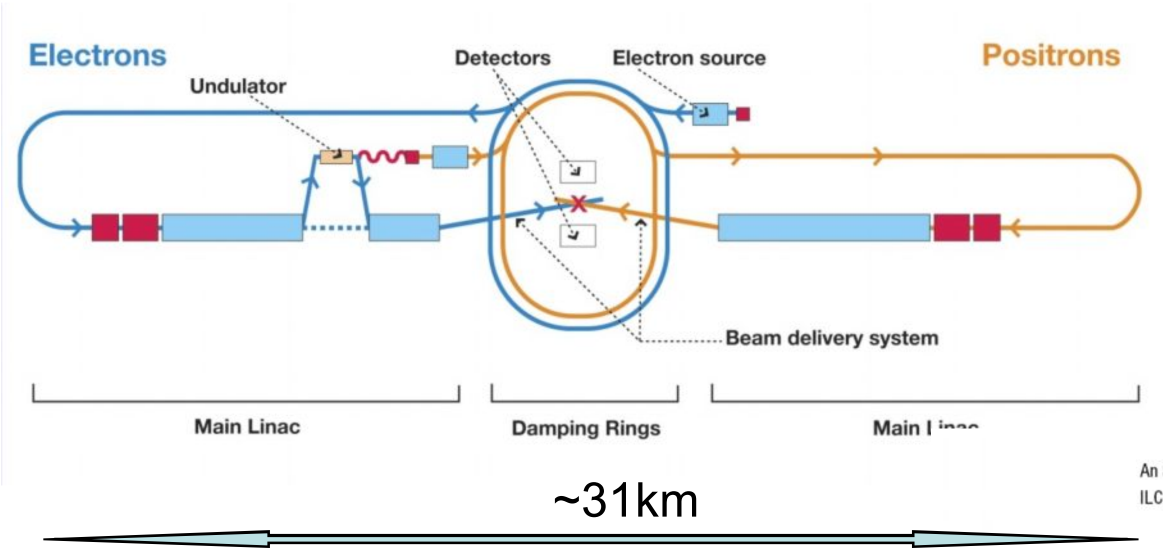
● 4th (Gaussian not rms$_{90}$ – but tails)
(Different simulation)



- SiD/ILD ~ 1.35 - 1.55
- 4th/ILD ~ 1.3 - 0.9

The International Linear Collider

- 2006: Baseline Configuration Document
- February 2007:
    - Reference Design Report presented at Beijing ACFA ILC Meeting
- Layout of the machine:



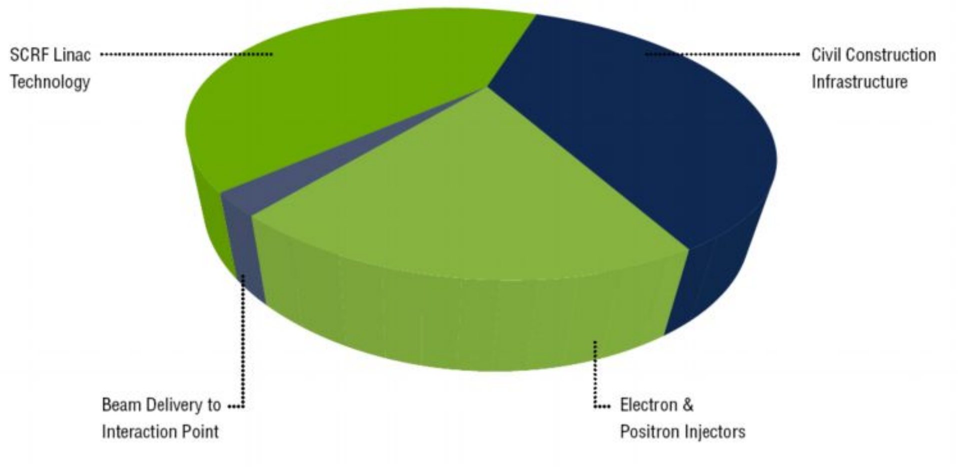
- 2 × 250 GeV
  upgradable to 2 × 500 GeV
- 1 interaction region
- 2 detectors (push-pull)
- 14 mrad crossing angle

- Cost estimate:

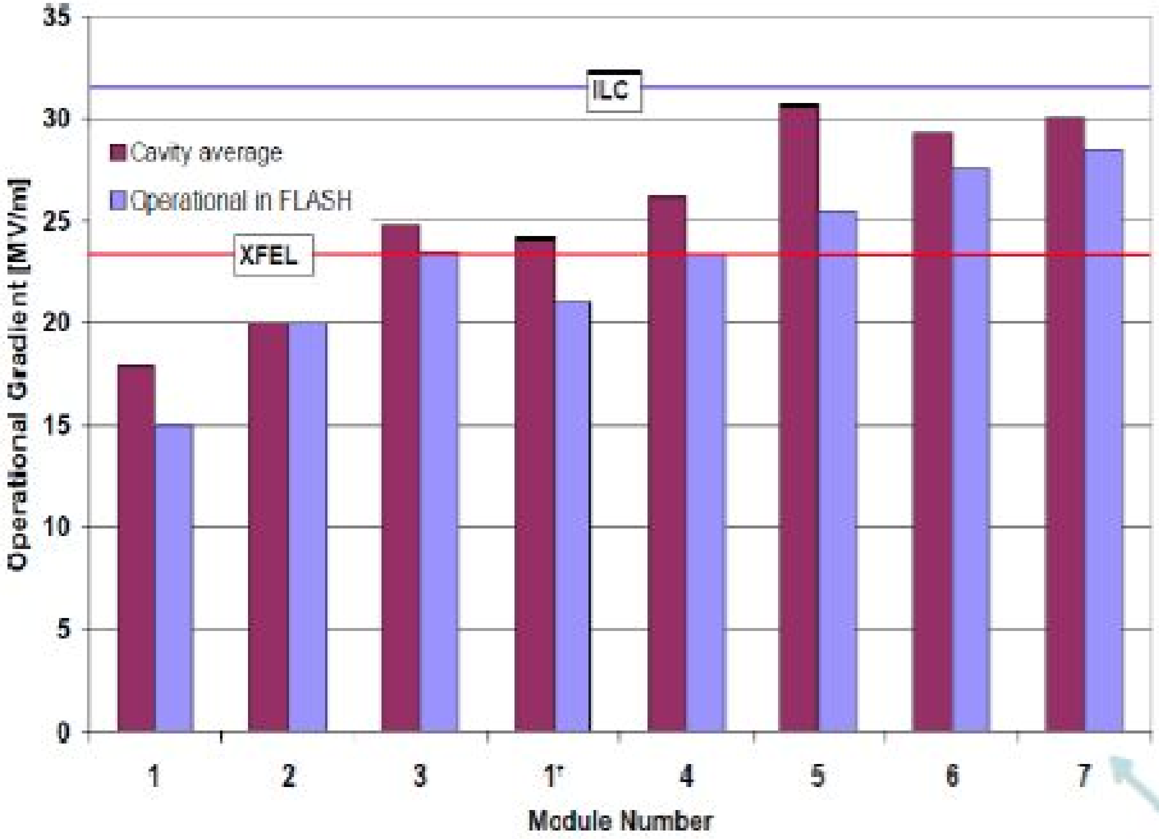
  4.87 G$ shared components
  + 1.78 G$ site-dependent
  = 6.65 G$ (= 5.52 G€)

  + 13000 person years

An approximate breakdown of the ILC estimate by main categories.



Cryomodule Gradient Progress



ILC operation :

- <31.5> MV/m spec
- (27 MV/m achieved at DESY/FLASH)
- (29 MV/m achieved DESY test stand)

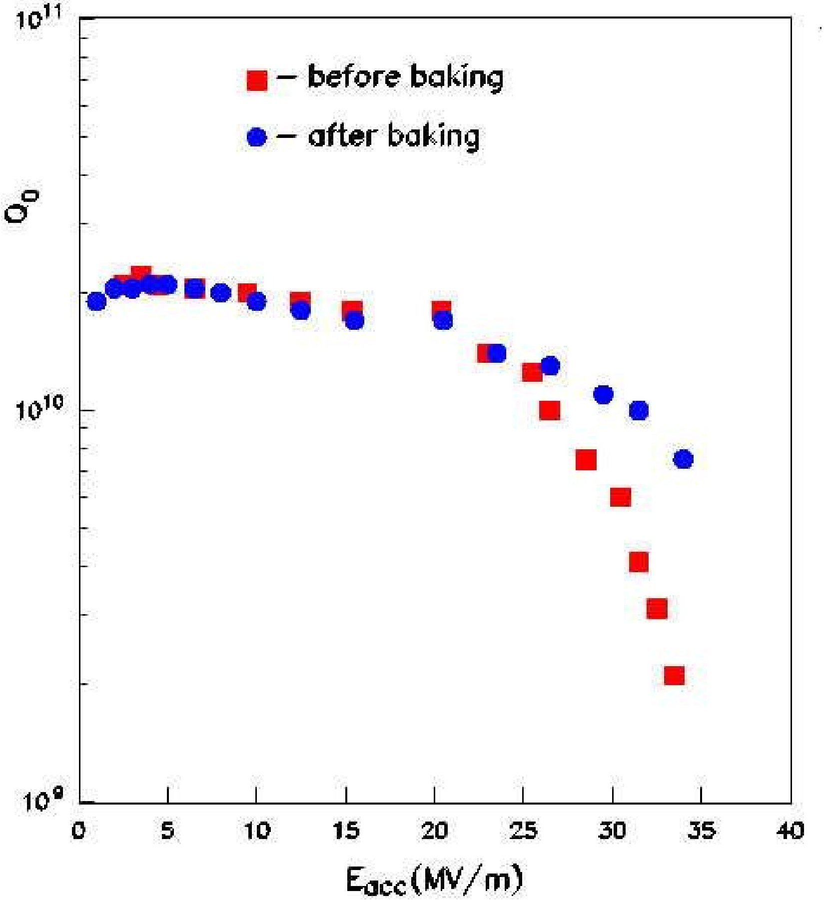
•20 % improvement required for ILC

Russia has technologies useful for SC cavities

Purity of Russian Nb is the best in the world

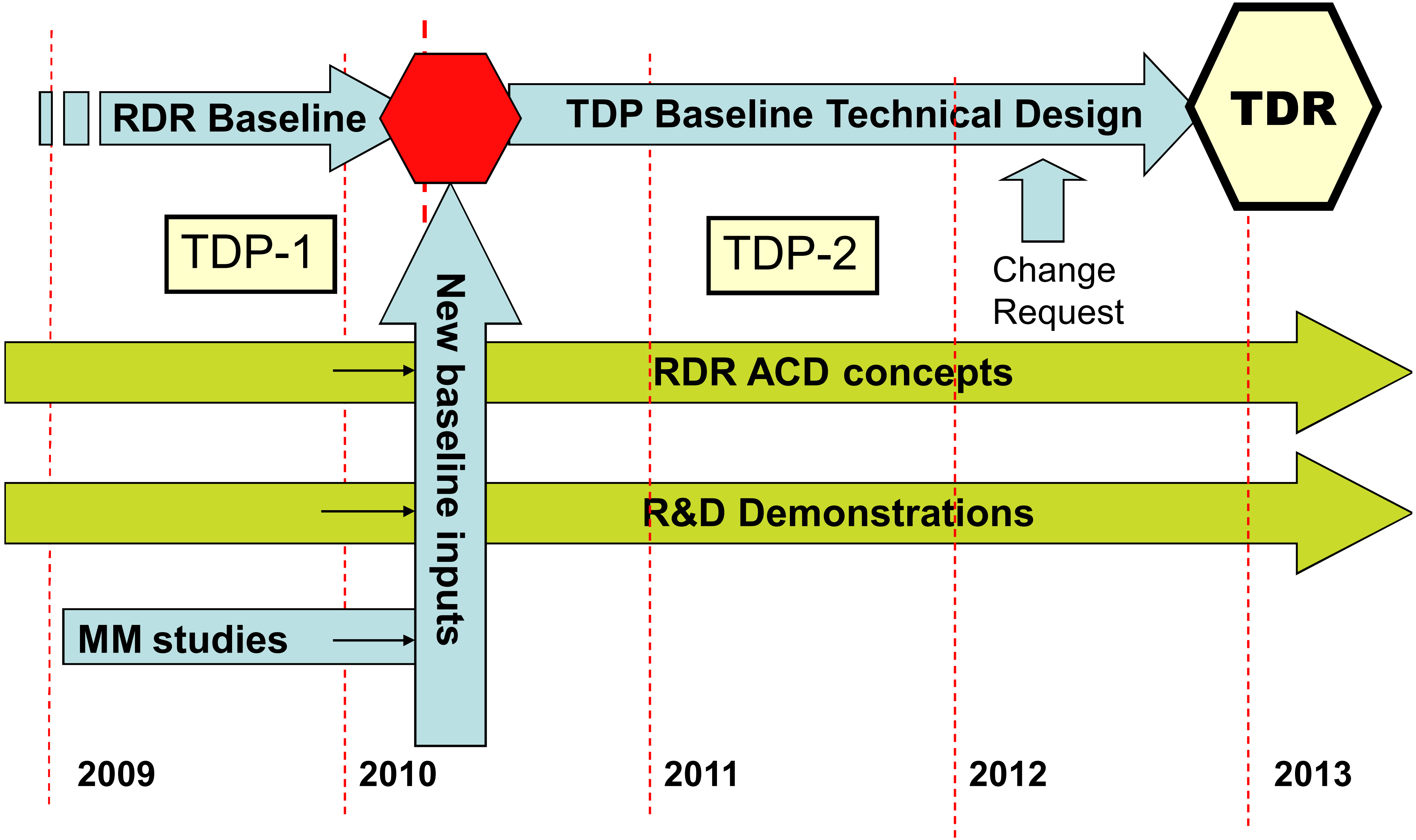
[μg/g]	DESY	ITEP-GIREDMET
Ta	500	2.2
W	70	6
Mo	50	<1
Ti	50	<0.03
N	10	3
C	10	3
RRR	300	~1000

SC Cavity made of Russian Nb



~35 MeV/м

Technical Design Phase and Beyond



RDR Baseline

TDP Baseline Technical Design

TDR

TDP-1

New baseline inputs

TDP-2

Change
Request

RDR ACD concepts

R&D Demonstrations

MM studies

2009

2010

2011

2012

2013

Conclusions

Physics at ILC will be very rich and exciting

Detectors are challenging but feasible

ILC gets a lot of momentum.
Accelerator TDR and two Detector TDR
will be ready in 2012

It is the right time to join the effort!