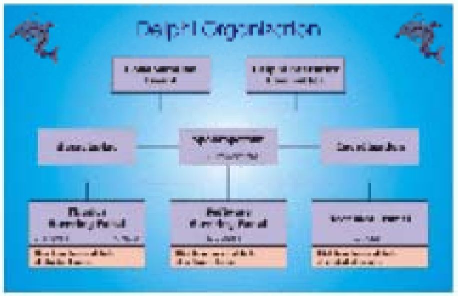
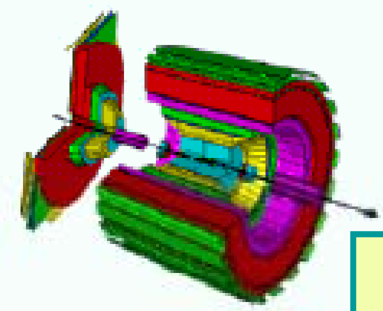
## DELPHI Experiment

DEtector with Lepton, Photon and Hadron Identification

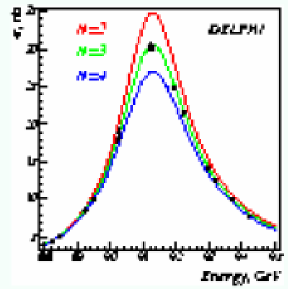
## The DELPHI Organization



### The DELPHI Detector



### Physics Results




**DELPHI final meeting 29 May 2008**

# Remembrances of data analysis at LEP1

*Hum!*

*and a look at ILC e+e- collider*

*Ah!*

Jean-Eudes Augustin

# LEP1 era

- Back to 1989-1995: 12 to 19 years ago, this is a lot!

  *…In those days, very few of us were white haired*

- My memory is not good, I know it is biased, and worse, I have dumped many old papers.
- I am no historian, DELPHI published results speak for ourself.

**«Memory is the past, History opens the future»**

So my plan is

- 1) to gather my memories and may be entertain you.
- 2) to try and speak about things of interest now

# "How an active data taking experiment should best be organised ?"

DELPHI did set-up at various times
whatever organ was needed for its smooth and effective operation:

CB, DEC, Delphi Weeks, TCP, SCOOP, Running Panel, pit meetings, Software panel, Analysis teams and panel, Production Steering panel, Software weeks, tasks forces, Speaker's Bureau, etc.

My notes of DEC, 24 oct 1989: UA,PB,DT,JD,POH,FR,JL,LV,HJH,EL,(JVA,GK)

*(Ugo, Paul, Daniel, Jürgen, Per-Olof, François, Jacques, Luigi , Hans-Jürgen, Egil ,Jim, George)*

*« U.A. very unhappy about Delphi.*

*Data taking and data analysis are bound to fail … disaster…*

*We have to get organized… people are desperate down in the pit… »*

So it was sometimes painful,
but it is more or less what a collaboration is undergoing during its lifetime:

1: It should have the best (Ugo) as Spokesperson!

Was this the result?

## DELPHI TEAM CONVENERS:

| | | |
|---|---|---|
| T 1: | Scan and asymmetry with e+e-. | Convenors: P.Siegrist & G.Zumerle. |
| T 2: | Scan and asymmetry with mu+mu-. | Convenors: G.Mitselmacher & P.Renton. |
| T 3: | Asymmetry and polarization with tau+ tau-. | Convenors: A.Ruiz & D.Treille. |
| T 4: | Scanning with hadrons. | Convenors: H.Wahlen & M.Winter. |
| T 5: | Neutral higgsons. | Convenors: G.Crosetti & V.Obraztsov. |
| T 6: | New particles in simple topology. | Convenors: M.Pimenta & F.Richard. |
| T 7: | New heavy particles. | Convenors: S.Katsanevas & R.Moller. |
| T 8: | Neutrino counting. | Convenor: A.Firestone. |
| T 9: | Anomalous ionization. | Convenors: P.Baillon & I.Herbst. |
| T 10: | Hadronic final states. | Convenors: W.De Boer & J.Drees. |
| T 11: | Heavy Flavour Physics. | Temporary Convenor: M.Mazzucato & P.Roudeau. |
| T 12: | Second-family Quarks. | Convenors: A.de Angelis & T.Ekelof |
| T 13: | Photon-Photon Physics. | Convenor: F.Kapusta. |

P.Ratoff will coordinate common papers of teams 1 to 3.
F.Richard will coordinate common papers of teams 5 to 7.

The following People are part of this group:

| | |
|---|---|
| L.Pape | Software Project |
| R.Gokieli | Production Project |
| J.Wickens | Physics Analysis |
| G.Grosdidier | VM |
| W.Venus | Alignment |
| A.Read | Luminosity |

12th November, 1990

2: and it should have the best people, physicists and esp. **doctoral students**

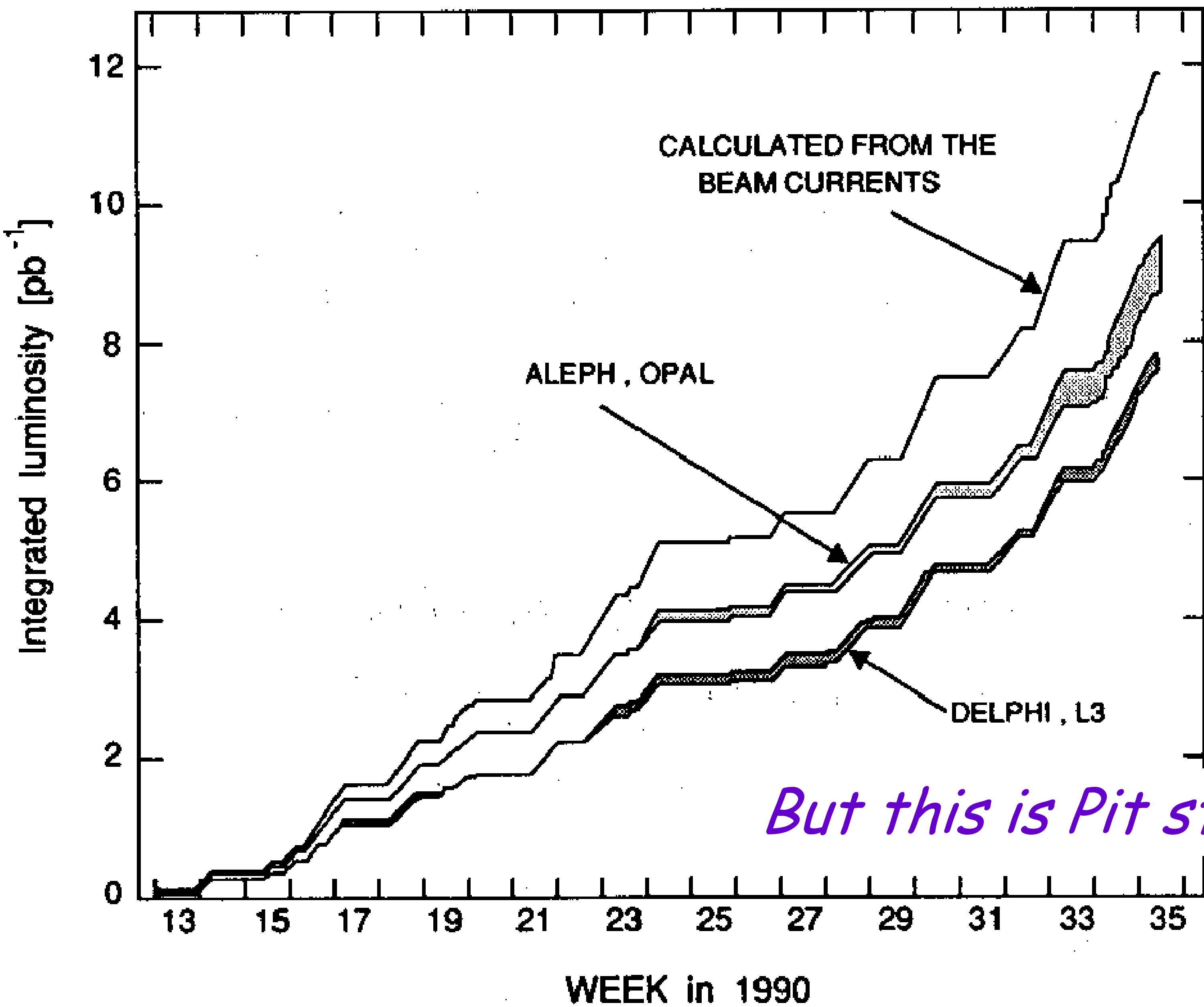
*Summary of my memories*

For number crunching and computing power,
VM was our original support,
but was not able to cope with the charge
The advent of 'microVAX' farms progressively saved us
DELFARM with DSTANA
**Luc**, Nick, Gilbert, Ryszard, Antonio,
Jean-Claude, Mirco, Gianni, and farm shifters,
John, Maria-Elena, Pedro,
and Wilbur, Hans-Jörg, Yura, Gian, Alan, Anita
plus outside centers
…and all those I have missed

In fact, the incredible dedication of DELPHI'sts,
…and Moore's law *(Workstations, Exabytes…)*
(plus money from Italy and a few others)
allowed data analysis to proceed.


*I hope this is reasonably true*

Some problems came from outside: luminosity in DELPHI…!




*But this is Pit story!*

*The result:*

CERN–PPE/91–95

17 June 1991

# Determination of $Z^0$ resonance parameters and couplings from its hadronic and leptonic decays

**Abstract**

From measurements of the cross-sections for $e^+e^- \rightarrow$ hadrons and the cross-sections and forward-backward charge asymmetries for $e^+e^- \rightarrow e^+e^-$, $\mu^+\mu^-$ and $\tau^+\tau^-$ at several centre of mass energies around the $Z^0$ pole with the DELPHI apparatus, using approximately 150,000 hadronic and leptonic events from 1989 and 1990, one determines the following $Z^0$ parameters: the mass and total width $M_Z = 91.177 \pm 0.022$ GeV, $\Gamma_Z = 2.465 \pm 0.020$ GeV, the hadronic and leptonic partial widths $\Gamma_h = 1.726 \pm 0.019$ GeV, $\Gamma_l = 83.4 \pm 0.8$ MeV, the invisible width $\Gamma_{inv} = 488 \pm 17$ MeV, the ratio of hadronic over leptonic partial widths $R_Z = 20.70 \pm 0.29$ and the Born level hadronic peak cross-section $\sigma_0 = 41.84 \pm 0.45$nb. A flavour-independent measurement of the leptonic cross-section gives very consistent results to those presented above ($\Gamma_l = 83.7 \pm 0.8$ MeV). From these results the number of light neutrino species is determined to be $N_\nu = 2.94 \pm 0.10$. The individual leptonic widths obtained are: $\Gamma_e = 82.4 \pm 1.2$ MeV, $\Gamma_\mu = 86.9 \pm 2.1$ MeV and $\Gamma_\tau = 82.7 \pm 2.4$ MeV. Assuming universality, the squared vector and axial-vector couplings of the $Z^0$ to charged leptons are: $\bar{V}_l^2 = 0.0003 \pm 0.0010$ and $\bar{A}_l^2 = 0.2508 \pm 0.0027$. These values correspond to the electroweak parameters: $\rho_{eff} = 1.003 \pm 0.011$ and $\sin^2\theta_W^{eff} = 0.241 \pm 0.009$. Within the Minimal Standard Model (MSM), the results can be expressed in terms of a single parameter: $\sin^2\theta_W^{\overline{MS}} = 0.2338 \pm 0.0027$. All these values are in good agreement with the predictions of the MSM. A fit yields $43 < m_{top} < 215$ GeV at the 95% level. Finally, the measured values of $\Gamma_Z$ and $\Gamma_{inv}$ are used to derive lower mass bounds for possible new particles.

A fit yields $43 < m_{top} < 215$ GeV at the 95% level.

$$43 < m_{top} < 215 \text{ GeV at the 95\% level}$$

Other LEP expts in 1991:

Aleph $M_{top} = 120 \pm 40 \pm 3_{M_Z} \pm 1_{\alpha_s} \pm 20_{M_{Higgs}}$ GeV

L3 $m_t = 193^{+52}_{-69} \pm 16$ (Higgs) GeV.

Opal $M_t < 218$ GeV at 95% confidence level.

long before the Tevatron direct detection :

| | | | | | |
|---|---|---|---|---|---|
| 174 | $\pm 10$ | $^{+13}_{-12}$ | ABE | 94E | CDF |
| 199 | $^{+19}_{-21}$ | $\pm 22$ | ABACHI | 95 | D0 |

# Comparison of Grand Unified Theories with electroweak and strong Coupling Constants measured at LEP

Published in **Phys.Lett.B260:447-455,1991**

TOPCITE = 1000+

Ugo Amaldi*
CERN, Geneva, Switzerland

Wim de Boer and Hermann Fürstenau†
Institut für Experimentelle Kernphysik,
Universität Karlsruhe, D-7500 Karlsruhe

*The most cited paper coming out of DELPHI was* ***not*** *a DELPHI collaboration paper (and in my opinion rightly so)*

## Abstract

Using the renormalization group equations one can evolve the electroweak and strong coupling constants, as measured at LEP, to higher energies in order to test the ideas of Grand Unified Theories, which predict that the three coupling constants become equal at a single unification point. With data from the DELPHI Collaboration we find that in the minimal *non-supersymmetric* Standard Model with one Higgs doublet a single unification point is excluded by more than 7 standard deviations. In contrast, the minimal *supersymmetric* Standard Model leads to good agreement with a single unification scale of $10^{16.0\pm0.3}$GeV. Such a large scale is compatible with the present lower limits on the proton lifetime. The best fit is obtained for a SUSY scale around 1000 GeV and limits are derived as function of the strong coupling constant. The unification point is sensitive to the number of Higgs doublets and only the minimal SUSY model with two Higgs doublets is compatible with GUT unification, if one takes the present limits on the proton lifetime into account.

# CONFERENCES 1990

| | |
|---|---|
| **January** | |
| *Rice APS* | A. Firestone (Ames), I. Herbst (Wuppertal) |
| *Spating* | G. Jarlskog (Lund) |
| *Aspen* | A. Read (Oslo) |
| *Moriond* | K. Moenig (Wuppertal) |
| **March 4-10** | M. Winter (Strasbourg), P. Vaz (Lisboa), G. Wormser (Orsay) |
| *Moriond* | |
| **March 11-23** | H. Wahlen (Wuppertal), A. De Angelis (Udine) |
| *Moriond* | |
| **March 18-23** | |
| *LaThuile* | T. Camporesi (CERN/Bologna), M. Dam (Oslo) |
| **March 27-31** | |
| *PASCOS '90* | P. Kluit (Brussels) |
| *XVIII IMFP Santander* | J. Marcos |
| **April** | |
| *Washington APS* | E. Rosenberg (Ames) |
| *Poland-Kasimiercz* | Y. Sacquin (Saclay) |
| *Japan-Osaka* | B. King (Liverpool) |
| **June 21-23** | |
| *Physics in collision* | F. Richard (Orsay) |
| *Neutrino '90* | J. Drees |
| *Quark '90 Tbilissi* | R. Moeller |
| **July 4-7** | |
| *SLAC summer school* | W. DeBoer (Karlsruhe) |
| **July 17** | |
| *QCD Montpellier* | R. Pain, D. Bloch, M. Hahn |
| *Singapour* | U. Amaldi, P. Renton, B. Koene, R. Zitoun, W. Adams H. Mueller |

# But nothing would have happened without «the pit»

D. Spokesman (RP) : *P.S.L. Booth*

**COP Coordination Panel**

Chairman : U. Amaldi

*Members of DEC*

\+

*C. Bricman*
*Ph. Gavillet*
*J.J. Hernandez*
*H. Herr*
*L. Pape*
*W. Trischuk*
*G. Valenti*

\+

Run Coordinator of the month

**DELPHI CHART**

17/09/92

*and many others…*

**Project Leaders**

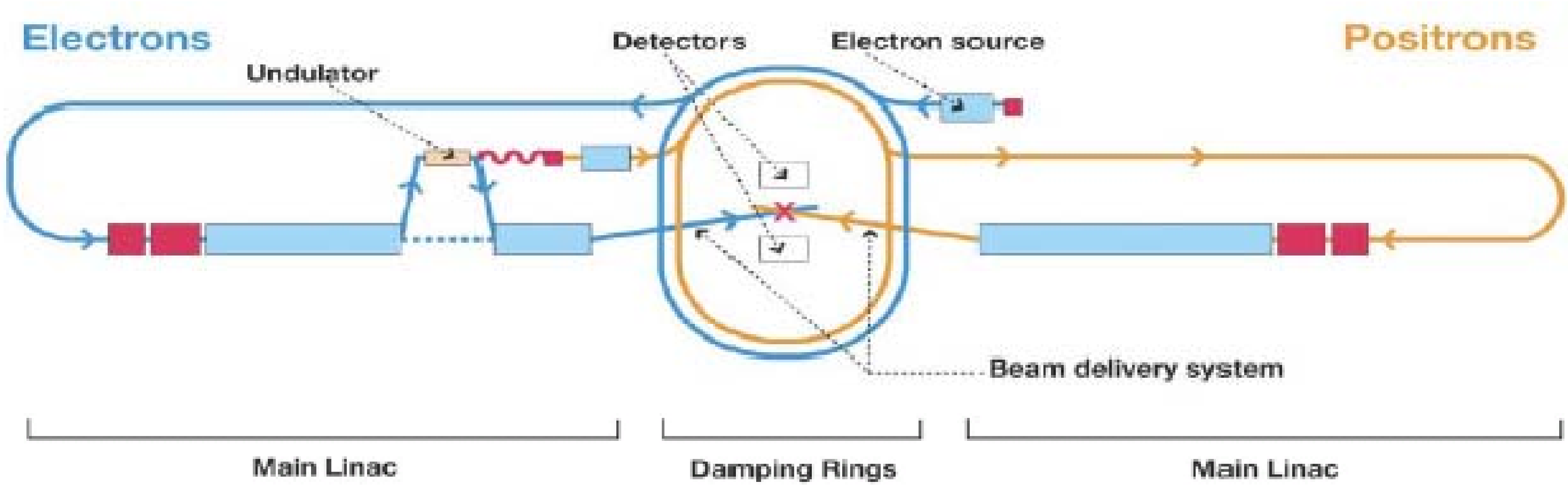
Barrel RICH : *B. D'Almagne*
DAS Hardware Project : *Ph. Gavillet*
DAS Software Project : *F. Harris*
FEMC : *I. Lippi*
Forward Chambers : *G. Leder/J. Drees*
Forward RICH : *O. Ullaland*
Gas System : *RC. Brown*
Hadron Calorimeter : *AM. Wetherell*
HPC : *S. Ragazzi*
Inner Detector : *J. Timmermans*
Microvertex Detector : *H. Dijkstra*
Microvertex Upgrade : *M. Tyndel*
Muon Chambers : *A. Segar*
Off-Line Software : *L. Pape*
Outer Detector : *R. Pain*
Production Project : *JJ. Hernandez*
SAT : *A. Read*
Scintillators : *A. Ferrer*
STIC : *T. Camporesi*
TPC : *P. Siegrist*
Trigger Project : *G. Valenti*
VSAT : *G. Rinaudo*

So much for the past,

let's look into the future!

# International Linear Collider

## electron-positron collider, 200 to 500 GeV  in e+e- c.m



Since Saariselka in 1991,

# Numerous international workshops on the future of particle physics

*A common view has emerged:*

- The **Terascale** energy should provide answers on the fundamental mechanisms governing our universe.
- From Colliders (LEP/SLC and Tevatron) results, one expects at least a light Higgs detectable at LHC.
- Discovering Higgs at LHC is very important !
- The next step is understanding the origin of the Electro-Weak Symmetry Breaking mechanism and this calls for precise and complete mass, spin and coupling (ttH,ZHH) determinations, ideal with the clean environment of an e+e- collider as ILC.

# Beyond Standard Model physics

- More speculative are the new physics scales which will be revealed by LHC but ILC with high *Luminosity* and with Polarized $e^-$ (>80%) can explore indirectly physics well beyond LHC (Z', KK excitations)
- This is only true if errors from *Luminosity*, Polarization and Energy, and from theory are kept under control

$\Rightarrow$**Very challenging goals**

Future ILC Options will be determined by findings:

- An upgrade to 1 TeV / Polarized positrons P~60%
- GigaZ ($10^9$ Z ) / e-e- *(easy)* /$\gamma\gamma$ and $\gamma$e (not *easy*)
- The energy scale, 500 GeV in the first phase, is set by the most difficult ZHH and ttH channels

# ILC Progress

international linear collider

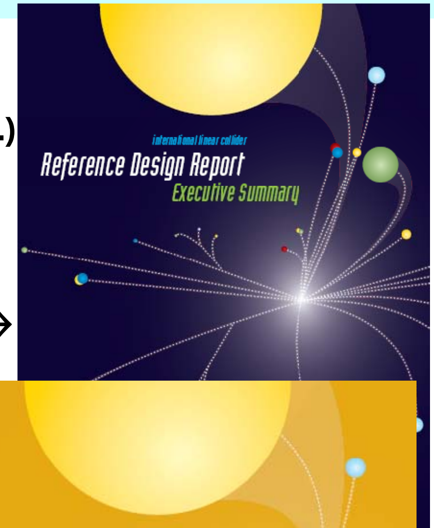
**Authority:** ICFA Comittee **ILCSC**, **chairman E. Iarocci**

The GDE (***Global Design Effort)*** Executive Committee (**Barry Barish** **et al.)** is coordonnating the world effort towards the ILC

⇒**Reference Design Report** issued April 2007 (4 vols.)

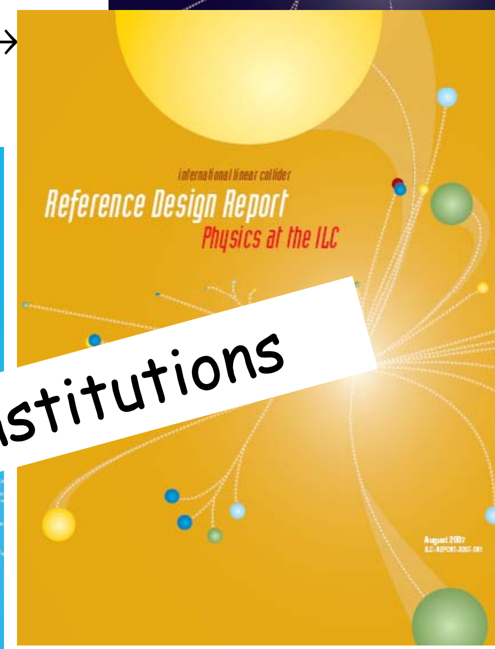
allowed a **cost** Evaluation

**Ex. Summary** →



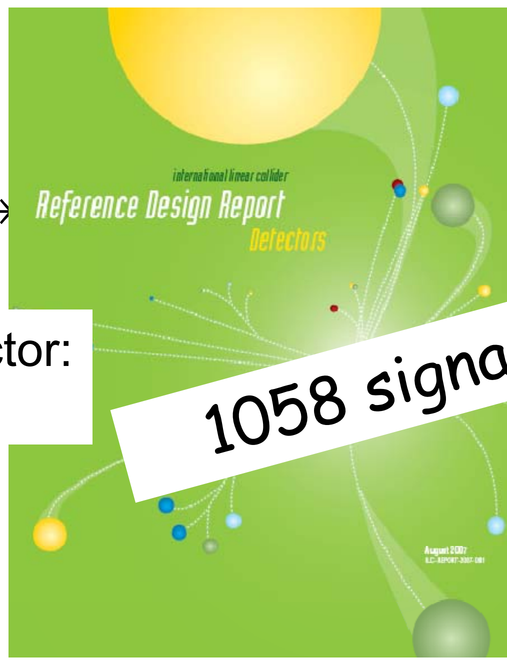

**Physics with ILC** →

(editors **K. Mönig** et al.)




**Accelerators** →


**Detectors**→




1058 signatories from 296 institutions

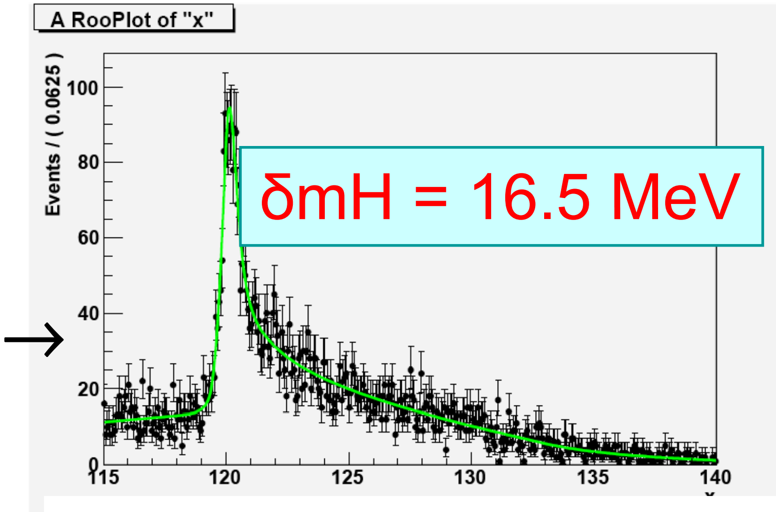
Research Director:
**Sakue Yamada**

**Next: Technical Design Phase**
**TDP – 2010 / 2012**

Physics at ILC:

**Precision measurements**

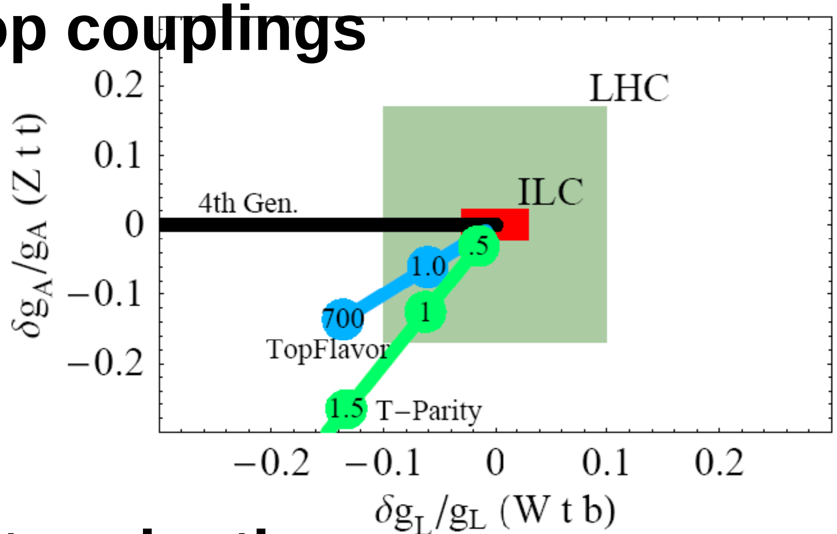
for **discovery physics**



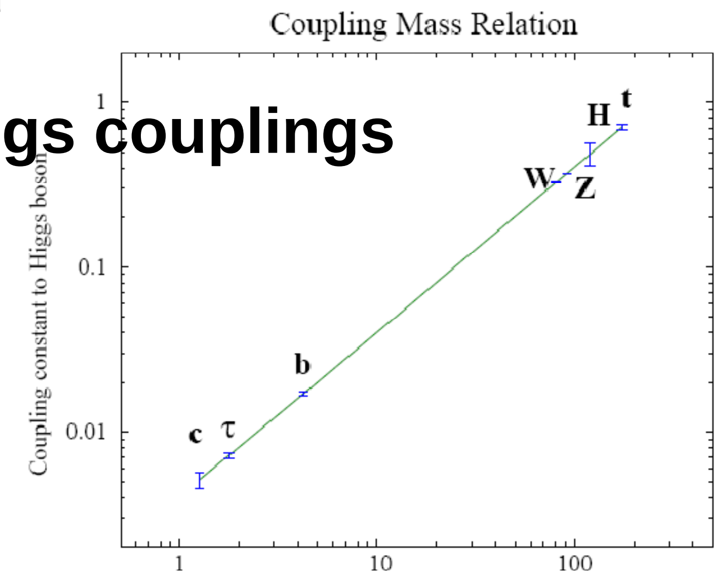

Exemples: **Higgs (Invisible) decay** →

(e+e-→HZ→μμH) missing mass plot

## Top couplings




## Higgs couplings




## Determination of SUSY parameters

Example of mSUGRA, using all previous measurements at LHC/ILC

| | SPS1a | LHC | ILC | LHC+ILC |
|---|---|---|---|---|
| $m_0$ | 100 | $100.03 \pm 4.0$ | $100.03 \pm 0.09$ | $100.04 \pm 0.08$ |
| $m_{1/2}$ | 250 | $249.95 \pm 1.8$ | $250.02 \pm 0.13$ | $250.01 \pm 0.11$ |
| $\tan\beta$ | 10 | $9.87 \pm 1.3$ | $9.98 \pm 0.14$ | $9.98 \pm 0.14$ |
| $A_0$ | $-100$ | $-99.29 \pm 31.8$ | $-98.26 \pm 4.43$ | $-98.25 \pm 4.13$ |

***See Klaus Mönig*** *lectures: http://delphiwww.cern.ch/offline/physics_links/reviews.html*

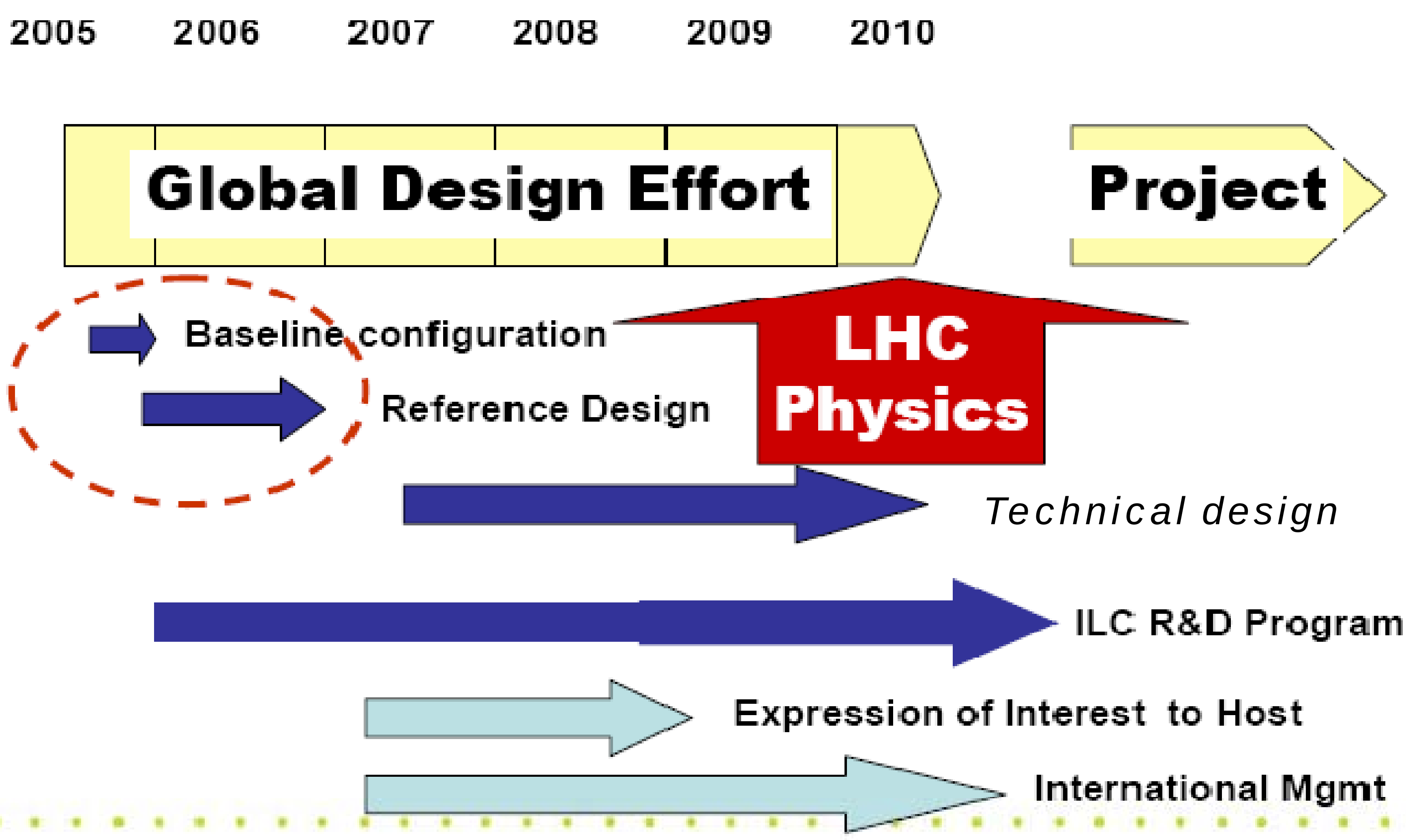
# The accelerator: International Linear Collider ILC

**electron-positron collider, 200 à 500 GeV in e+e- c.m,**
**$L = 2.10^{34}\ cm^{-2}sec^{-1}$, 500 $fb^{-1}$ in 4 yrs, Polarization e- 80% (e+ 50%)**

- **Two 11km supra-conducting Linacs, 31.5 MV/m at 500 GeV**
- **Central Injection**
  - **Damping rings for electrons and for positrons**
  - **Positron source form undulator**
- **One interaction region, 14 mrad crossing angle**
- **Two Tunnels, total site length 31km**
- **6,6 G$ + 14000 person•year: *"cost similar to LHC one"***
- **Extension to 1 TeV foreseen from start**

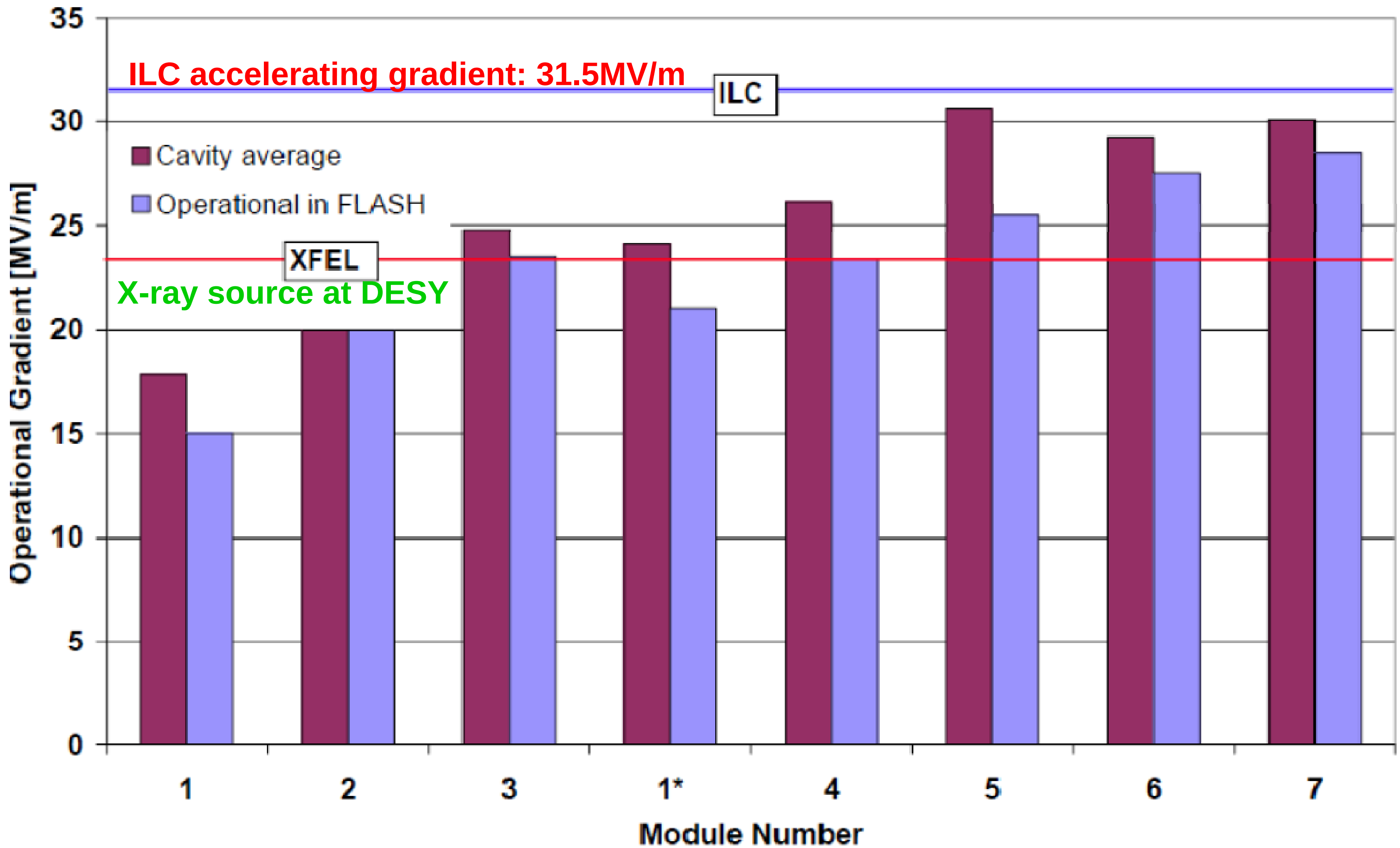

Schematic Layout of the 500 GeV Machine

# The GDE Plan and Schedule



**RF cavities and cryomodules** development in DESY, KEK, Fermilab, Saclay,etc.

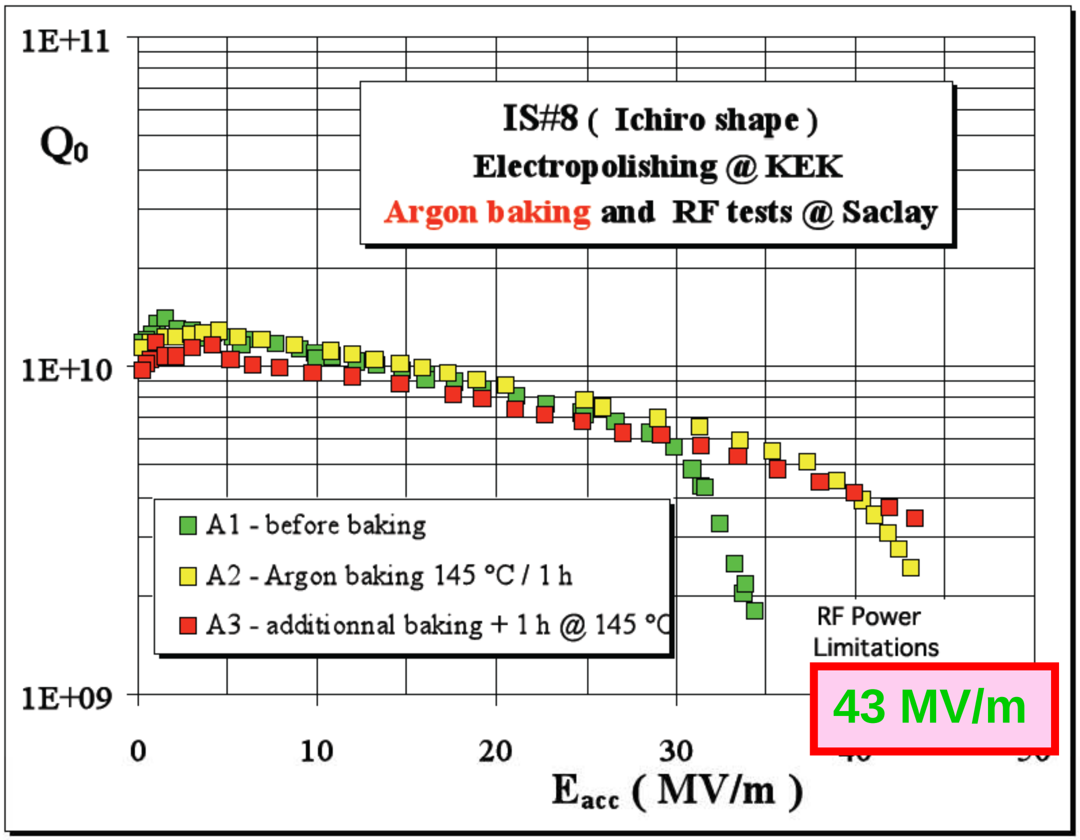
# DESY Cryomodule Performance

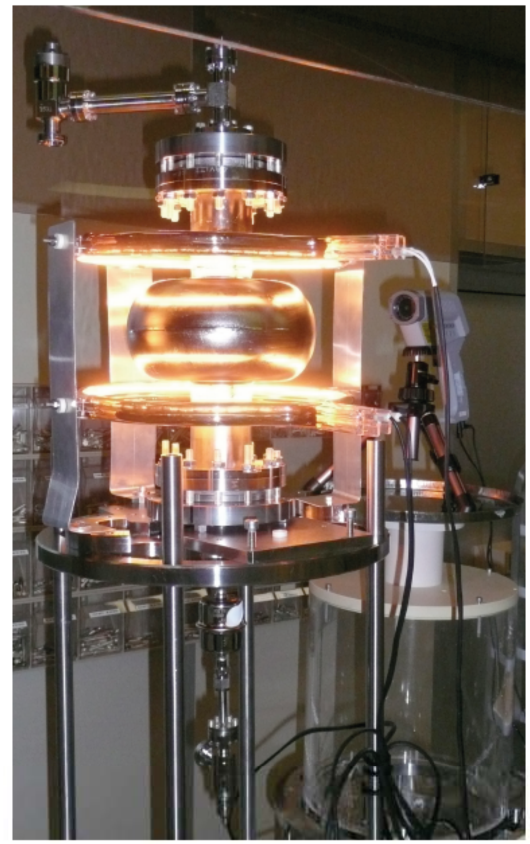


# Understanding the ultimate accelerating gradient limit: a truly international effort!

Electropolishing at KEK

Argon baking and RF tests at Saclay



*ICHIRO IS#8*

# ATF
## KEK Accelerator Test Facility

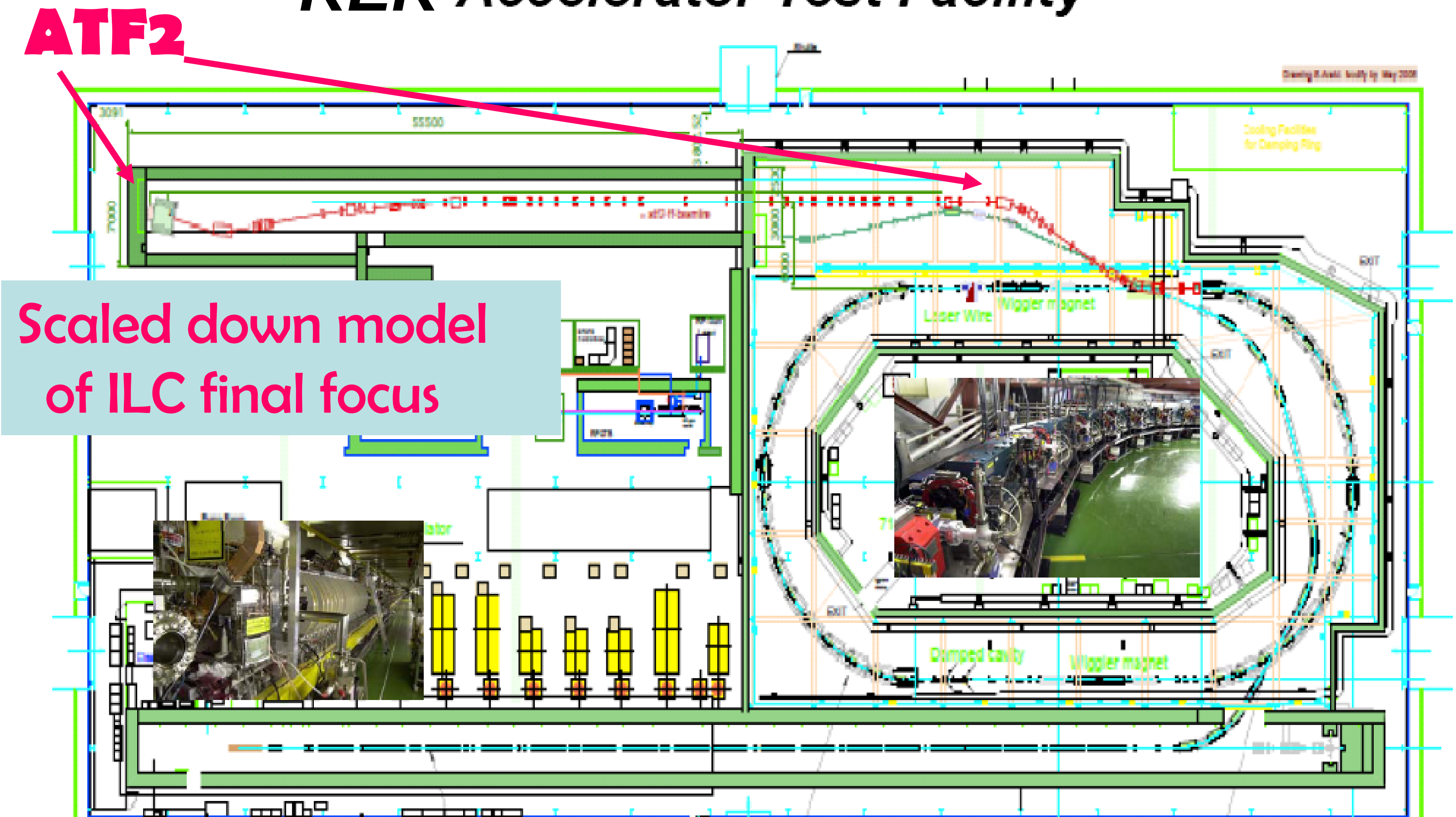
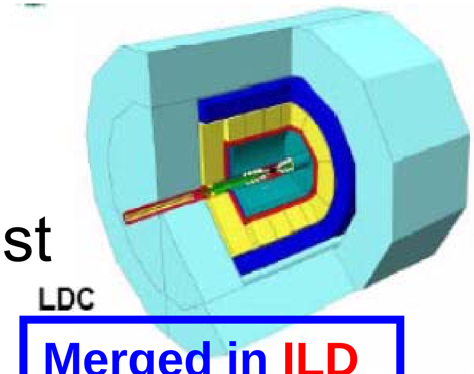


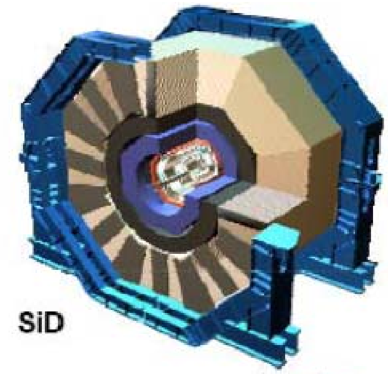

Photo-cathode RF Gun which can generate 20 bunches/pulse.

**Commissionning of ATF2: Autumn 2008**

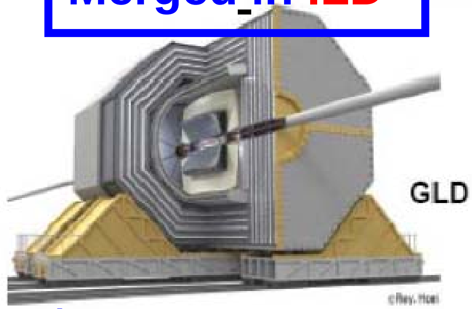
# Detectors

**3** expressions of interest to submit a LOI by 31rst march 2009 received by ILCSC & Research Director:




**Merged in ILD**





⇒*about 300 University/laboratory teams involved*

They will be referred by the international committee ''IDAG''

(Int. Advisory Detector Group), named by ILCSC *(chair: M.Davier).*

- IDAG to select proto-collaborations preparing Technical Designs.

*Advanced prototypes will be mandatory for the TDP*

- LOIs will allow detailed simulation studies of reference physics channels

there is a
very active R&D on calorimetry, vertexing and tracking

# Physics with jets: PFA

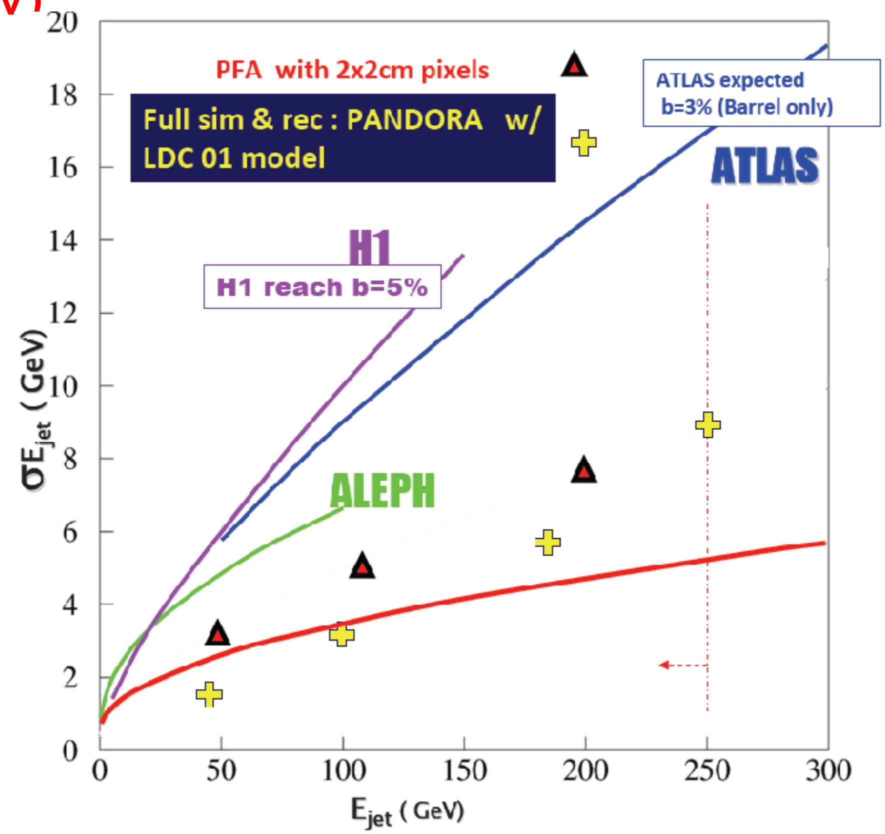
## Particle Flow Analysis:

- Measure charged particle by trackers and neutral particles by calorimeter.
- High grain calorimeter both Ecal and Hcal, and sophisticated algorithm is crucial to achieve a good jet energy resolution
- Performance goal set at $30\%/\sqrt{E_{jet}}$ (GeV)

- Pandora PFA has achieved the goal: For E<100 GeV jets

| $E_{JET}$ | $\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$ | $\sigma_E/E_j$ |
|---|---|---|
| 45 GeV | 0.235 | 3.5 % |
| 100 GeV | 0.306 | 3.1 % |
| 180 GeV | 0.427 | 3.2 % |
| 250 GeV | 0.565 | 3.6 % |

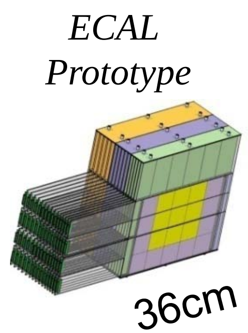
Summary of Pandora PFA performance
w. LDC01 model – SiD meeting, RAL april08

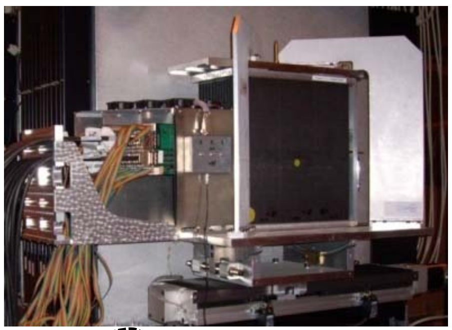


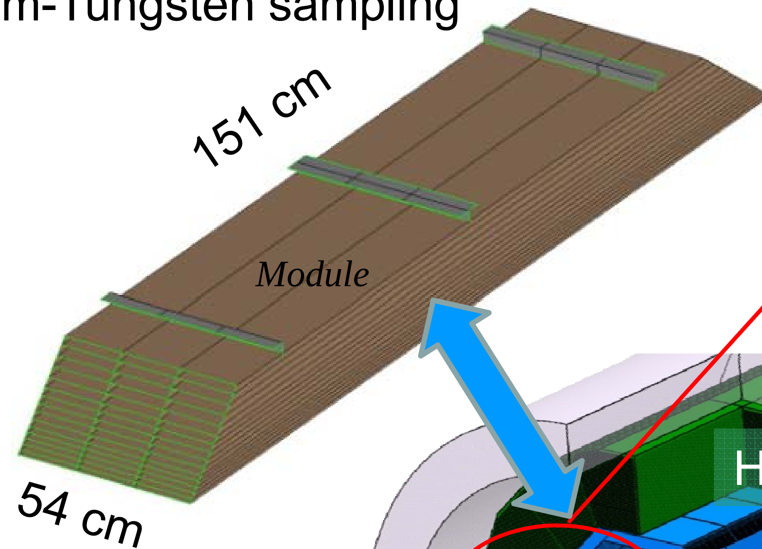
2) EUDET Detector R&D towards the International Linear Collider

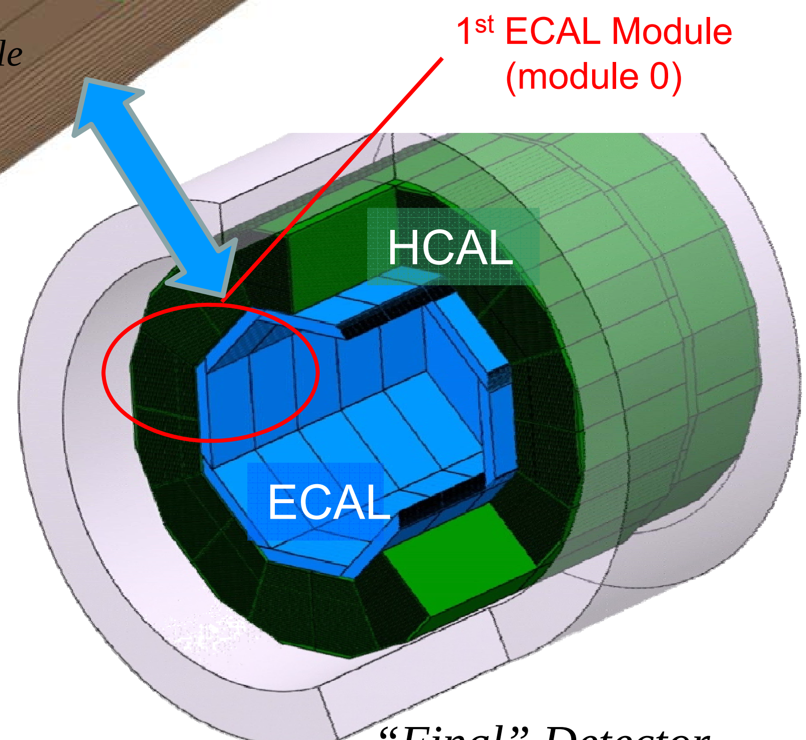
# Advanced Ecal engineering prototype 1/48th of final barrel calorimeter

Silicium-Tungsten sampling






"Final" Detector

5/8 of CMS ECAL

| ECAL | | |
|---|---|---|
| | 1rst proto. | EUDET |
| number of channels | 9720 | 45 360 |
| Size (cm) | 36 x 36 | 154 x 54 |
| Tungsten (kg) | 200 | 700 |
| electronics VFE | external | internal |

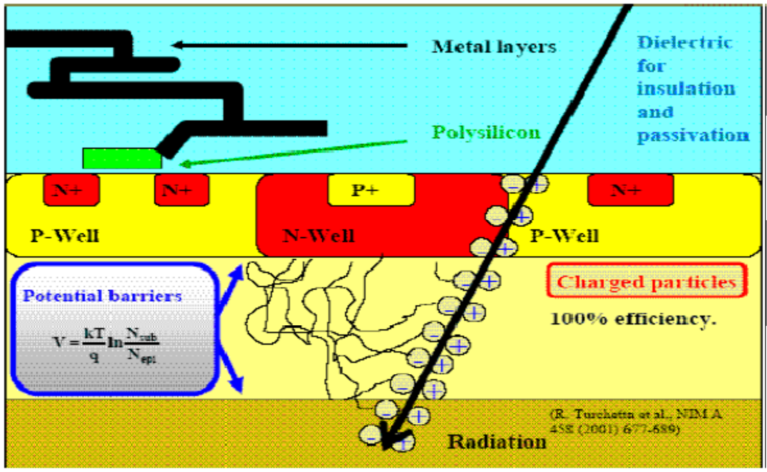
# CMOS detectors optimized for ILC vertex detector

**Marc Winter IPHC Strasbourg**

LPSC/Grenoble, IPHC/Strasbourg

IRFU / Saclay, DESY, Uni. Hamburg, JINR-Dubna

Uni. Frankfurt, GSI-Darmstadt, STAR coll.(LBNL, BNL)

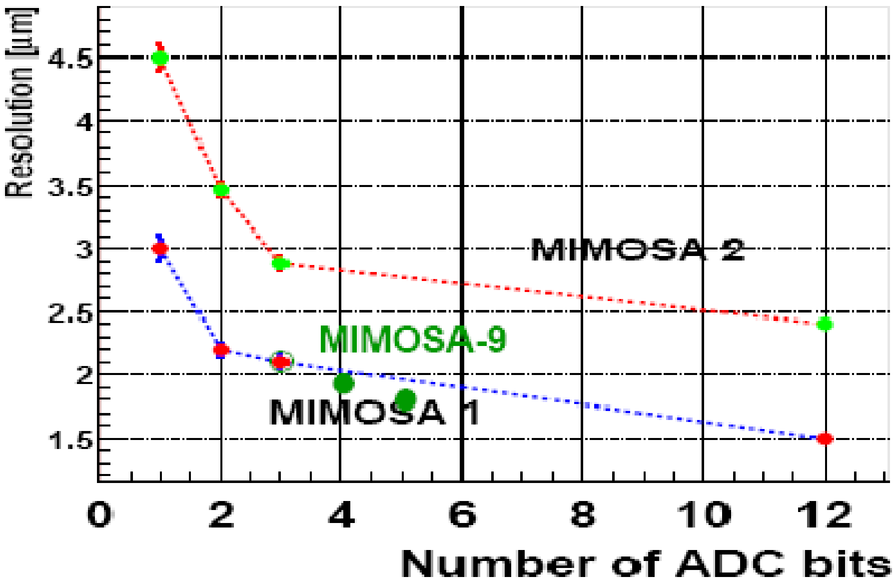



Pixel detectors very accurate, **very thin,** very close to the beams & radiation resistant (pairs)
→CMOS technology, epitaxial detection layer

## Present Results

Efficiency > 99.5 – 99.9% @ $10^{-5}$ ghosts

Resolution ~<1. µm,*(MIMOSA-18 : 512×512 pixels, 10 µmpitch, analog output, S/N 30* )
<2 µm avec ADC 4 bits→




Chosen for STAR (RHIC) upgrade

Radiation Tolerance (AMS-0.35 opto)
- ionizing:1 MRad –$10^{13}$ $e^-$ 10 MeV /$cm^2$ OK
- non-ionizing (été-automne 2007):

MIMOSA-18 irradiated with.$10^{13}$ O(1 MeV) n/cm2 (+ 100–200 kRad gas)
tested with 120 GeV pions at SPS : 1.$10^{13}$ Neq/cm**2→ det.eff. = 99.5 +- 0.1 %

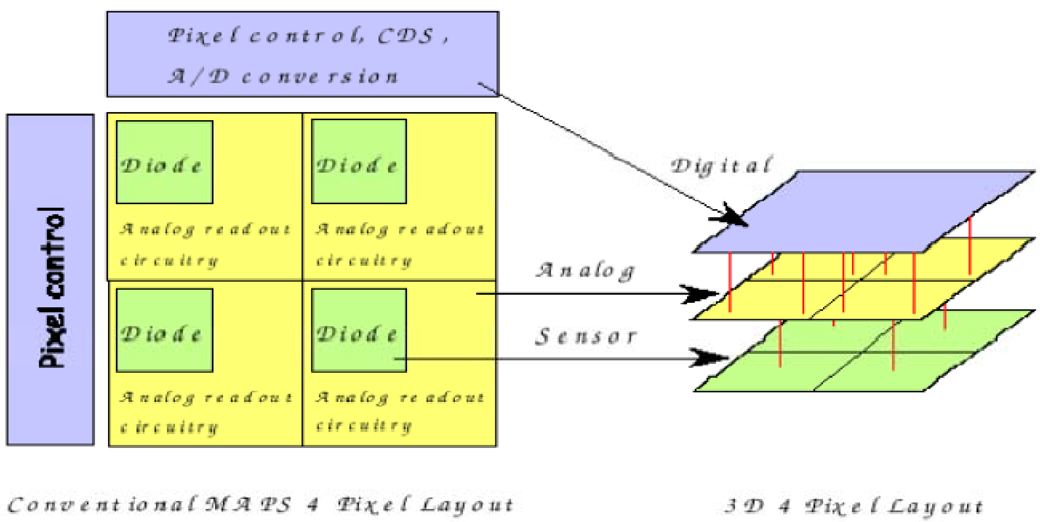
# Use of 3-dimensions Integration Technology (3DIT)

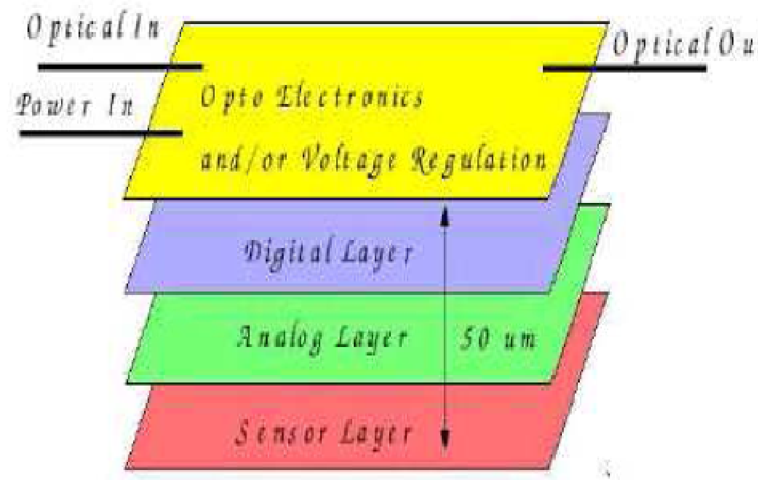
Exploratory work in progress on 130nm IBM-like CMOS
in coll$^{n}$ with Fermilab *(Tezzaron/Chartered)*

- **3DIT are expected to be particularly beneficial for CMOS sensors :**
  - *combine different fab. processes*
  - *alleviate constraints on transistor type inside pixel*

- **Split signal collection and processing functionnalities :**
  - *Tier-1: charge collection system*
  - *Tier-2: analog signal processing*
  - *Tier-3: mixed and digital signal processing*
  - *Tier-4: data formatting (electro-optical conversion ?)*

- **Use best suited technology for each Tier :**
  - *Tier-1: epitaxy, deep N-well ?*
  - *Tier-2: analog, low leakage current, process (nb of metal layers)*
  - *Tier-3 & -4 : digital process (nb of metal layers), feature size ⟶ fast laser (VOCSEL) driver, etc.*



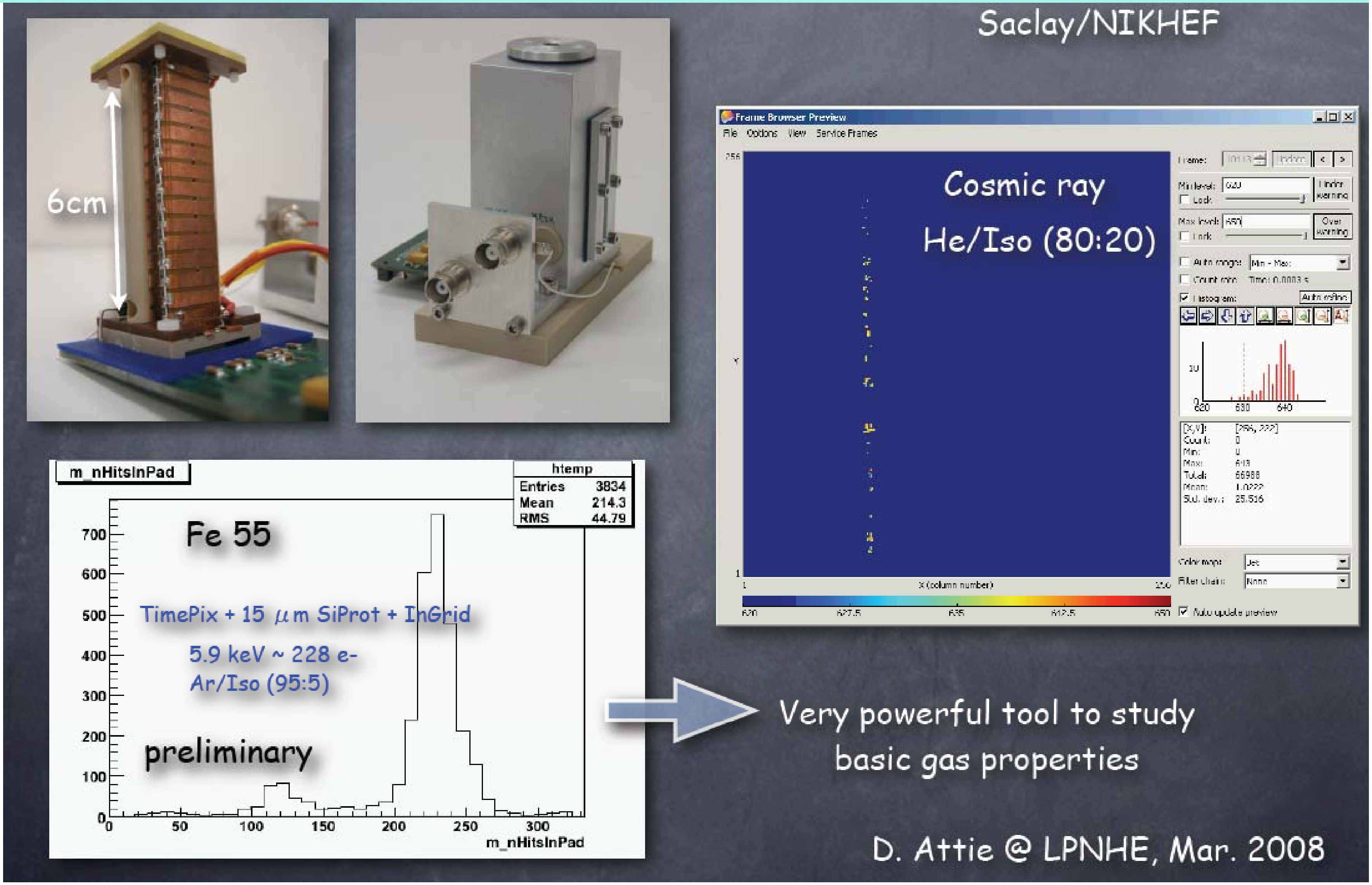



# R&D for a very large and ultra-precise (50µm) TPC

**LC-TPC Collaboration**

## Read-out by Micromegas chambers + timepix silicon chips

Jan Timmermans et al.



# Conclusions

- There is consensus that ILC is after LHC the next Particle Physics frontier machine.
- The R&D ILC on *Accelerator and Detectors*

  is in full swing

  to ensure the precision required by the physics.
- Present results are very positive that this aim can be reached.
- ILC R&D is an excellent training ground for young physicists, especially the work on beam tests data taking and analysis
- ***All this will only be possible***

  ***through the success of LHC !***