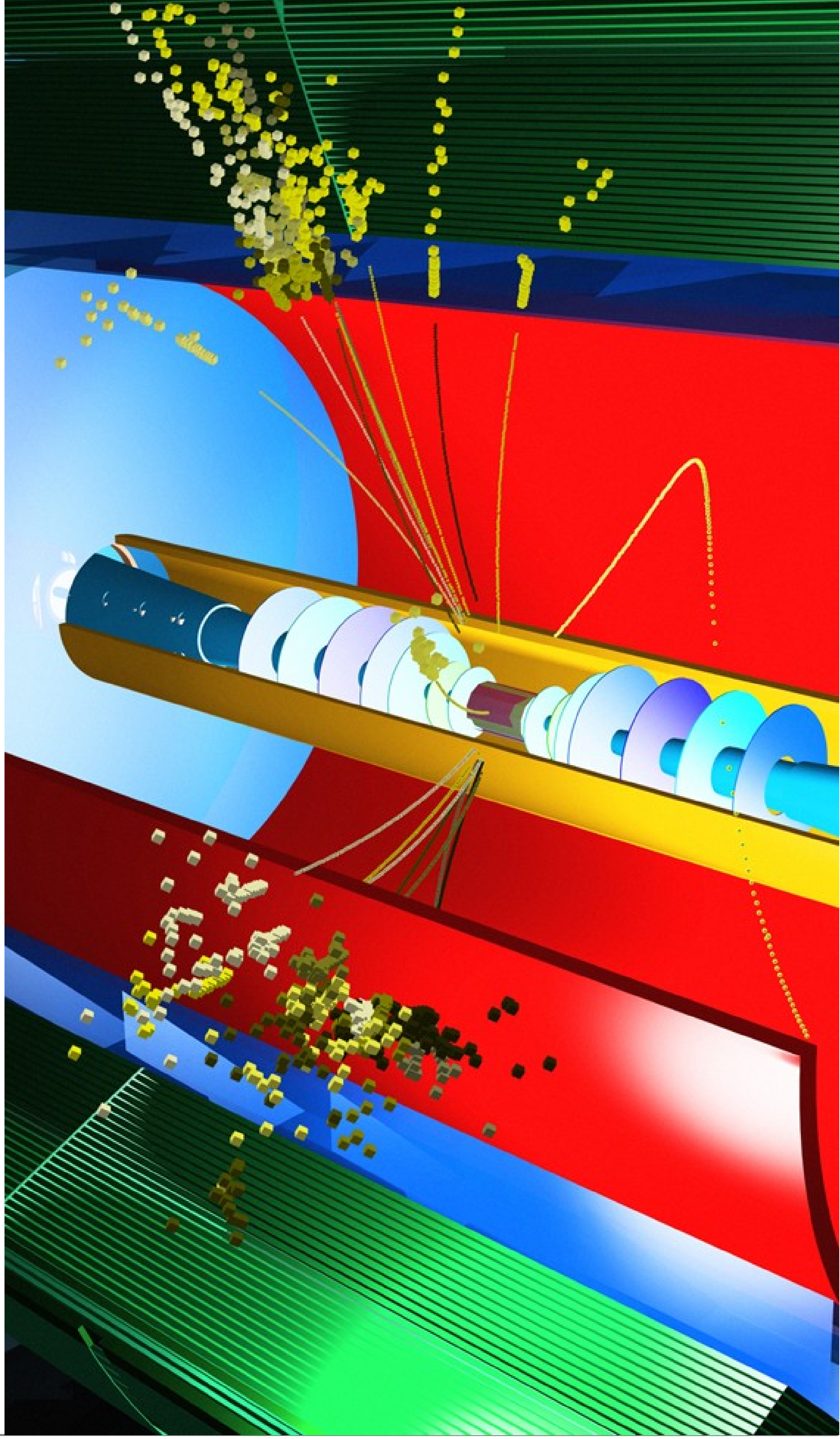
DEPFET for the linear collider;

status of the e^+e^- projects, specific DEPFET LC activities

13th International workshop on DEPFET detectors and applications

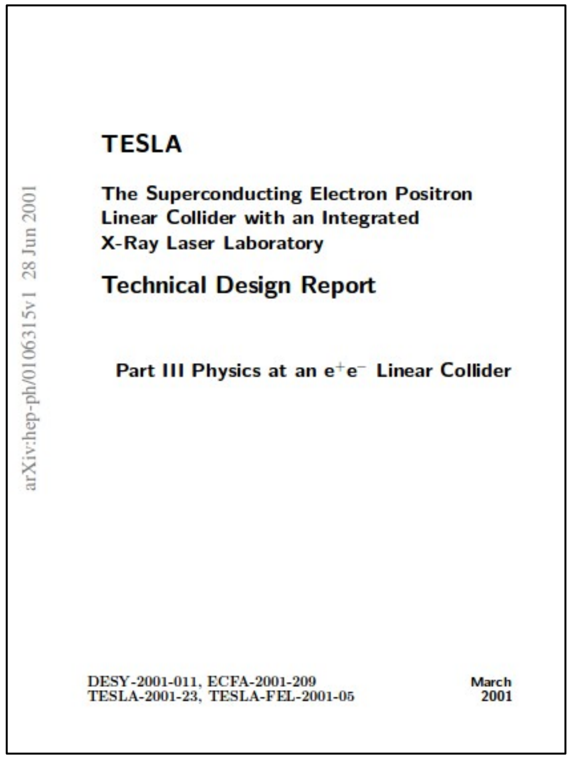
Marcel Vos
IFIC (U. Valencia/CSIC), Spain



Linear Collider history

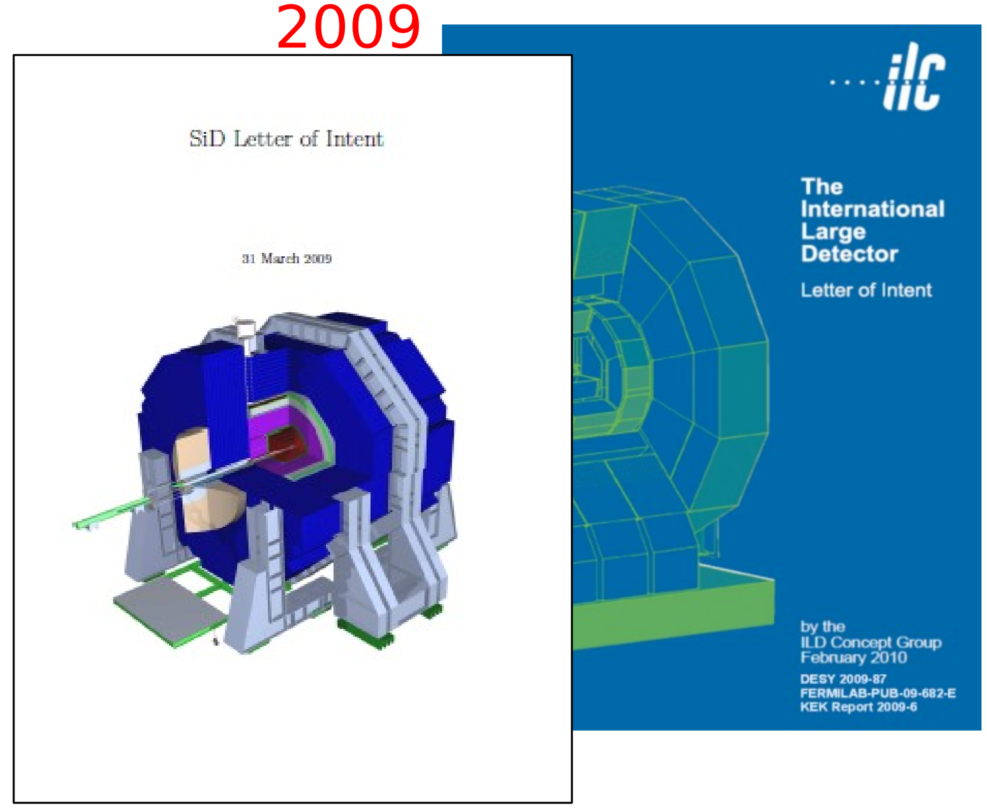
2012

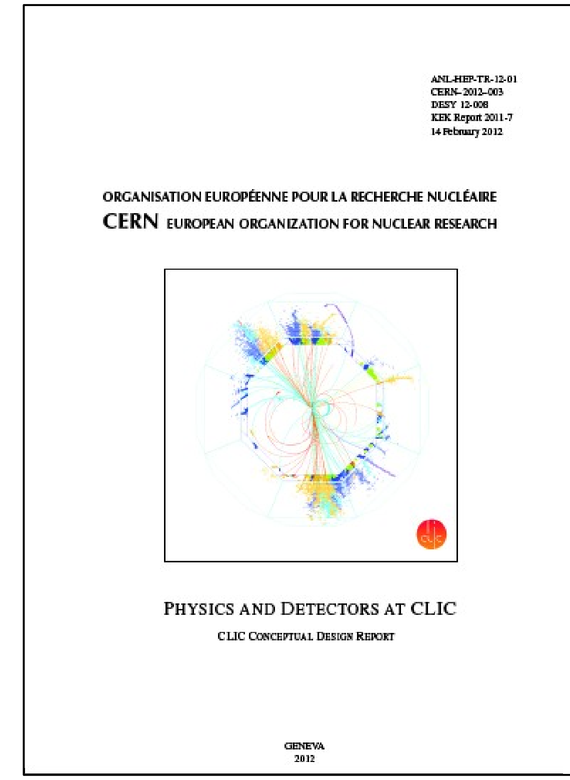
2001



...

2009





Reference documents prepared by the LC community:

- Tesla TDR (2001) part III on physics
- 2004 Report on the complementarity of LC and LHC
- CLIC physics report
- ILC Reference Design Report (2007): physics and detectors
- Letter Of Intent of the ILC experiments (2009) SiD and ILD
- Conceptual Design Report (2012) of the CLIC detectors
- Yesterday (june 2013): ILC TDR
- Includes: Detailed Baseline Design for the ILC experiments

http://www.linearcollider.org

Japanese bid

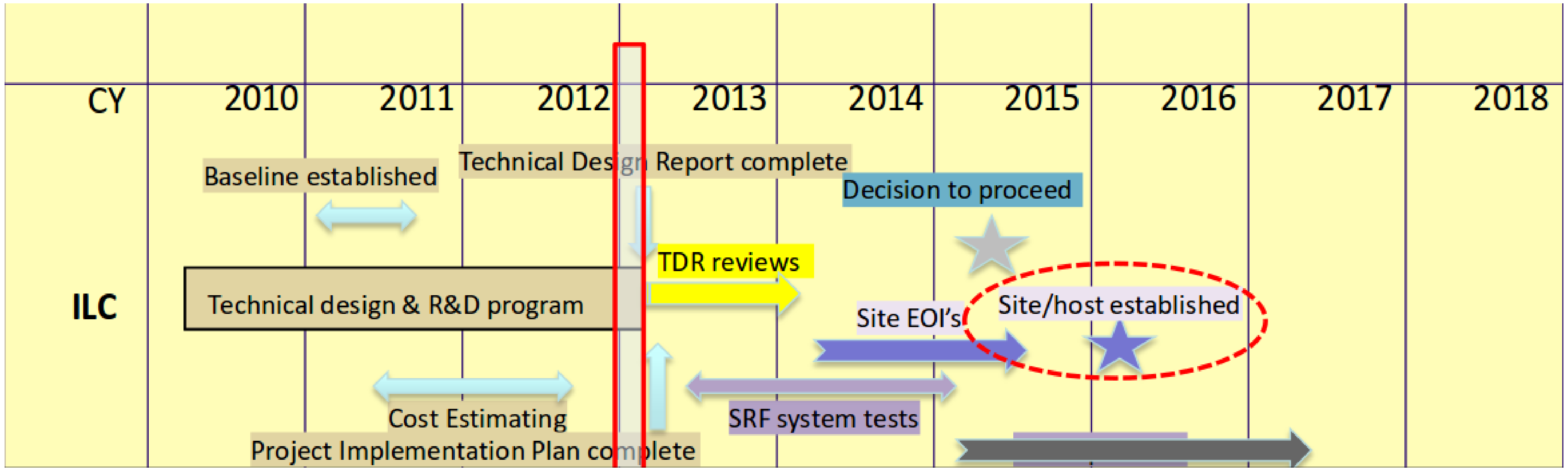
LDP won the elections with a programme that included:

...our country should be able to play a leading role in creation of international centers for scientific innovations such as the ILC project which is a grand project in the field of particle physics.

...playing a leading role in creation of international centers for scientific innovations such as the ILC (the international linear collider construction) project which is a grand project in the field of particle physics.

MEXT minister Hakubun Shimomura (Jan 2013): *'We will call for inter-governmental negotiations with European and American governments in the first half of 2013'*

Two candidate sites: Kitakami (Tohoku area) and Sefuri (Kyushu area)



International support required: Nature editorial, Facebook, YouTube

European strategy - summary

CERN council approved European Strategy update (May 2013)

Extracting some key phrases:

The LHC is in a unique position to [measure the Higgs boson properties]. Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors.

Europe should be in a position to propose a post-LHC machine [with emphasis on proton-proton and electron-positron high-energy frontier machines (VLHC/CLIC)] → high-field magnets and high-gradient accelerating structures.

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded → ILC. Europe looks forward to a proposal from Japan to discuss a possible participation.

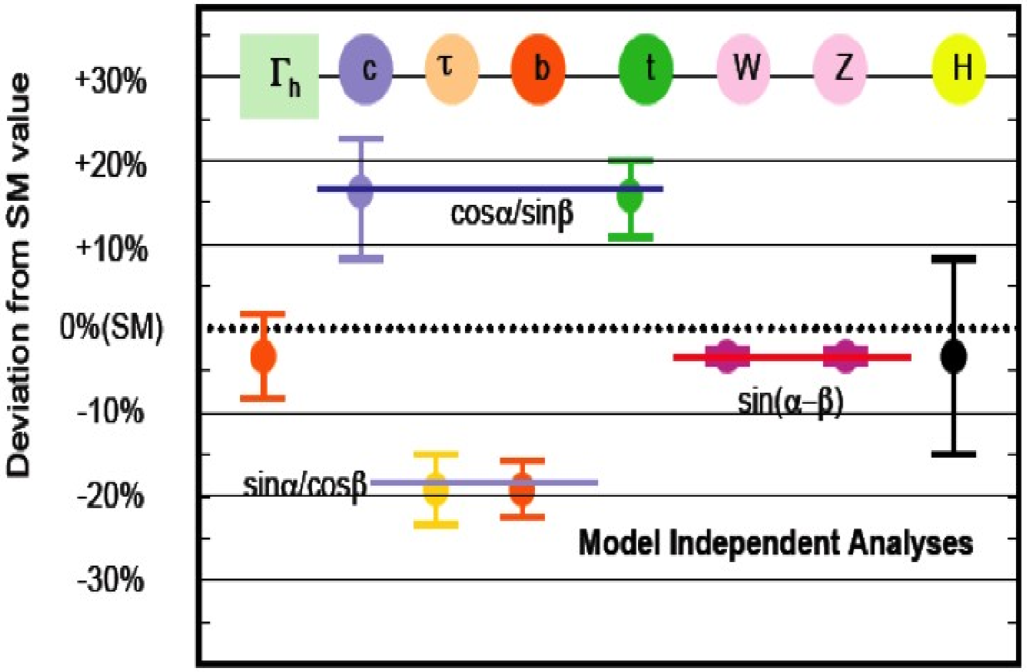
US to define its strategy (Snowmass, August 2013)

The complete European strategy document

An interesting view on how this fits in the global picture

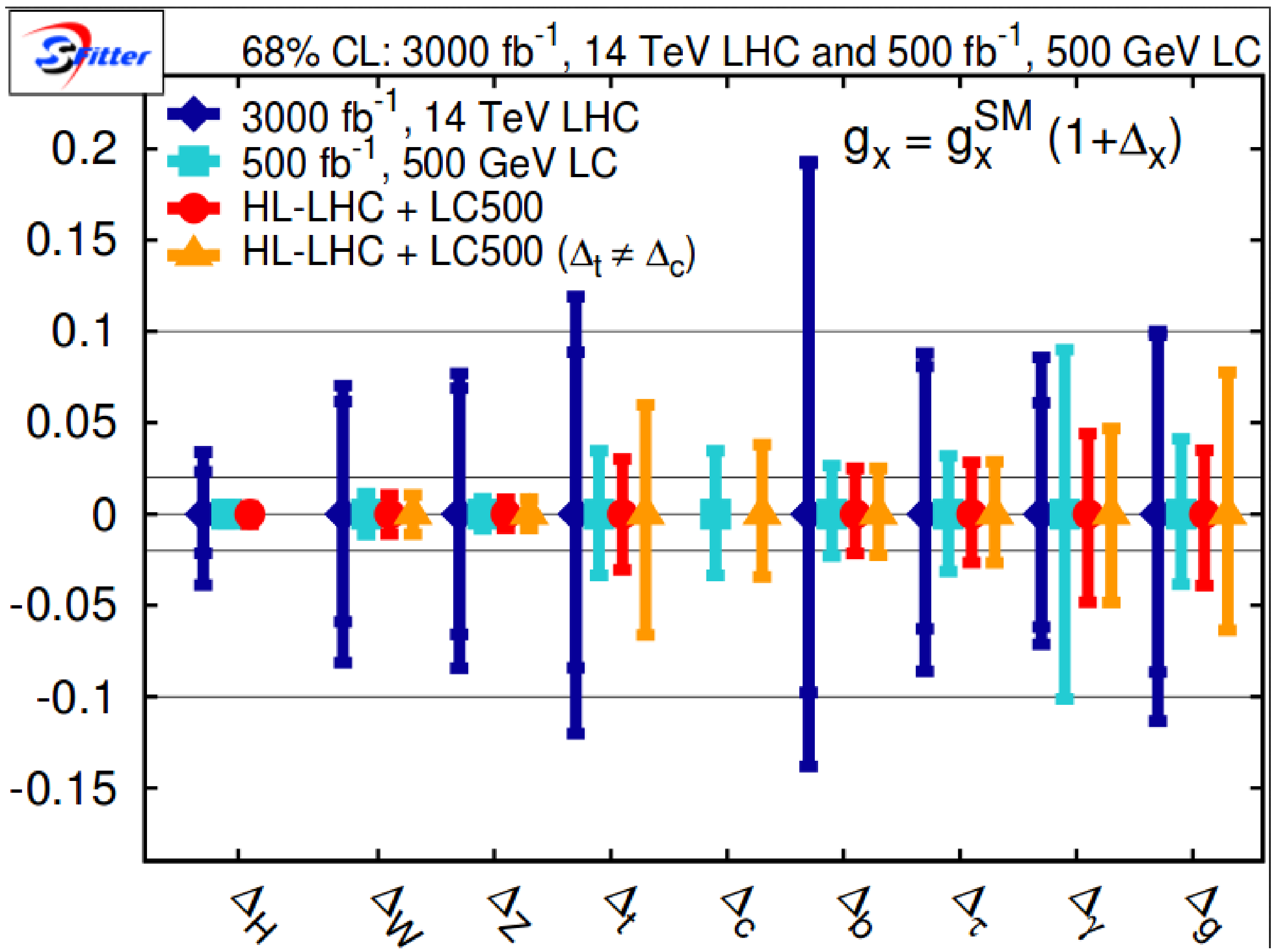
Precision Higgs physics

The Higgs boson? A Higgs boson? An impostor? Even if it's the SM Higgs boson, its couplings are likely a sensitive probe of BSM physics...



How well should we measure these?

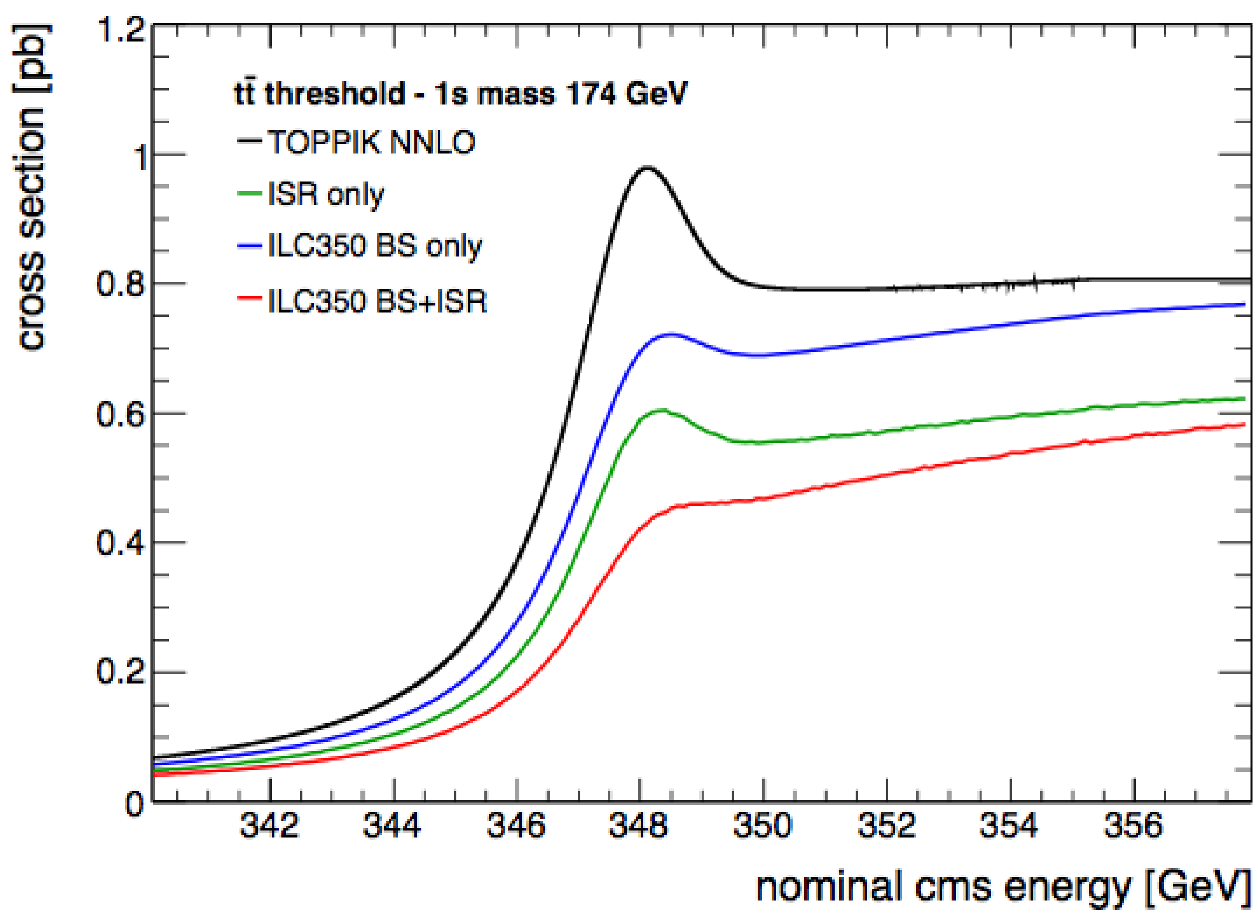
And how well can we measure them?

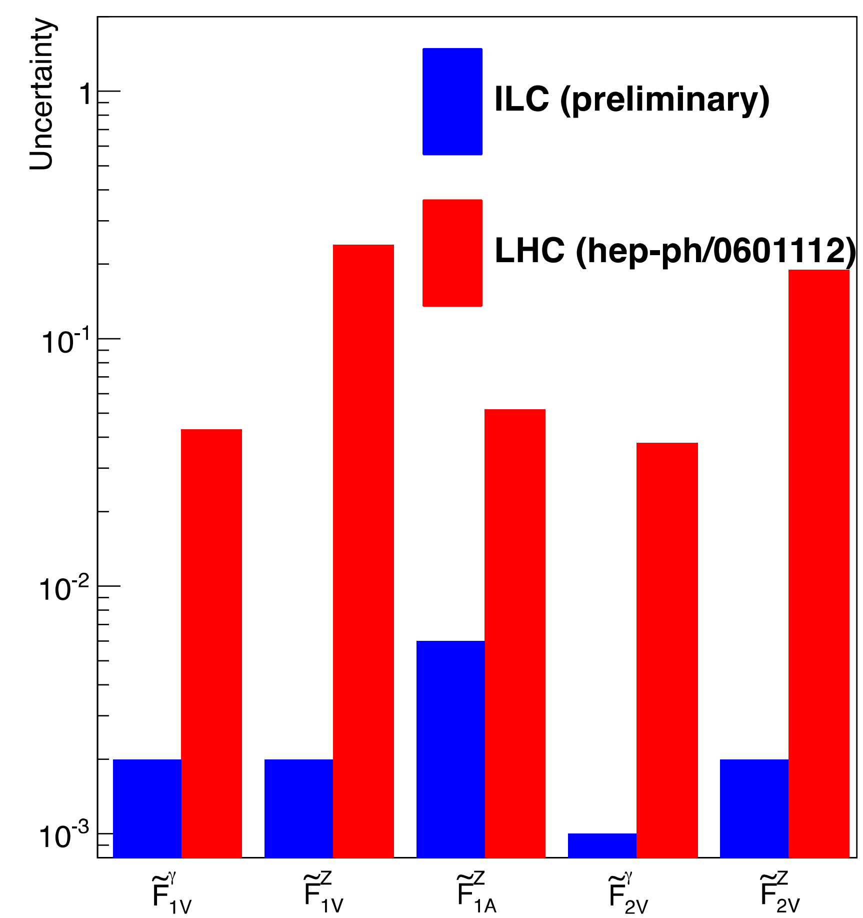


Precision top physics

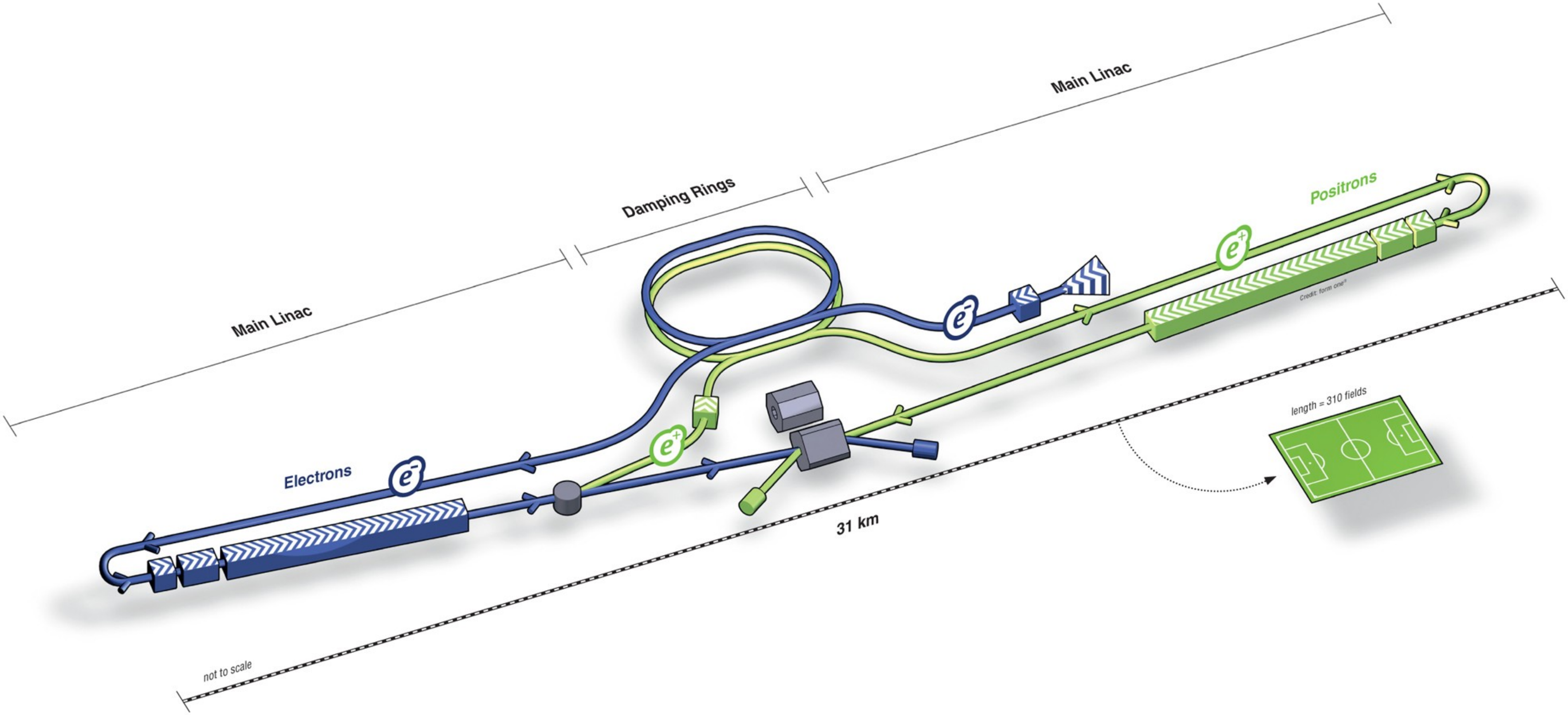
Top quark mass: threshold scan yields 100 MeV uncertainty
(and a rigorous interpretation in a well-defined mass scheme)

Top quark electroweak couplings: order of magnitude (or more)





Future linear e^+e^- colliders



Accelerator R&D around the globe. Non-exhaustive list of test facilities:

ATF@KEK, nm size, low emittance beams

CESR/IT@Cornell (electron cloud)

CTF3@CERN, drive beam

XFEL@DESY

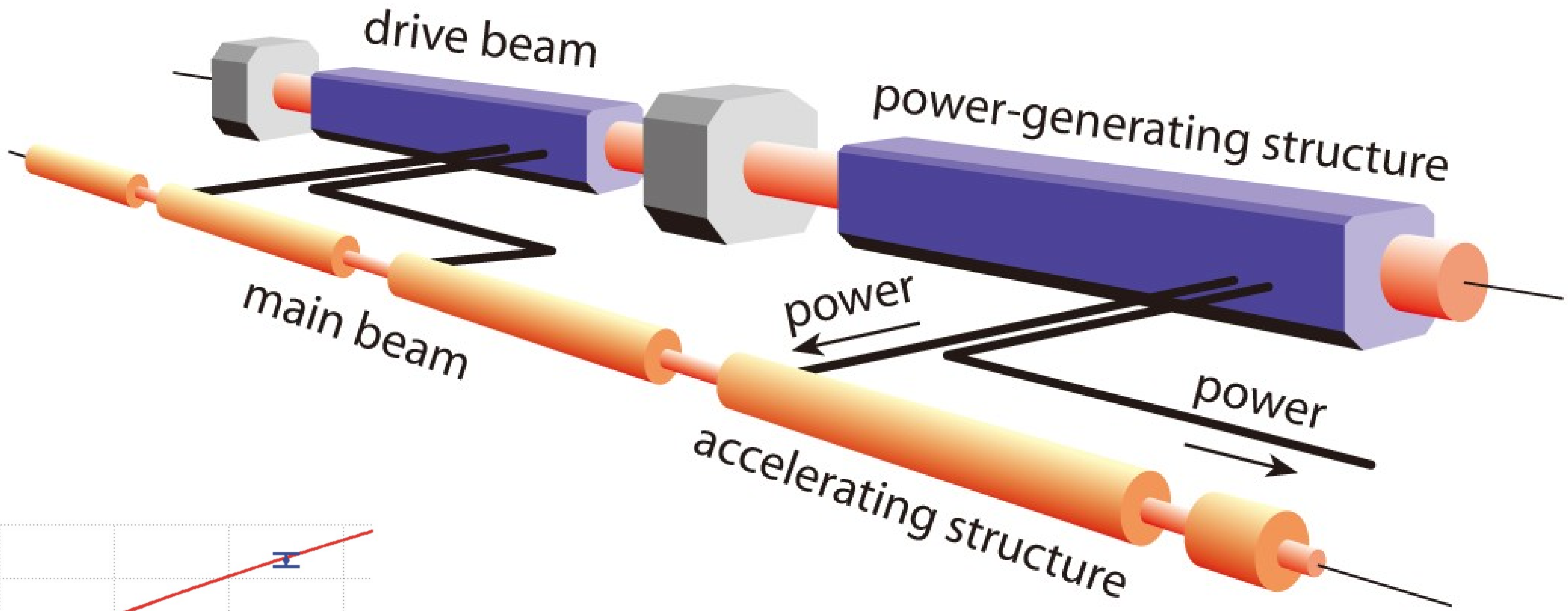
Future linear e^+e^- colliders

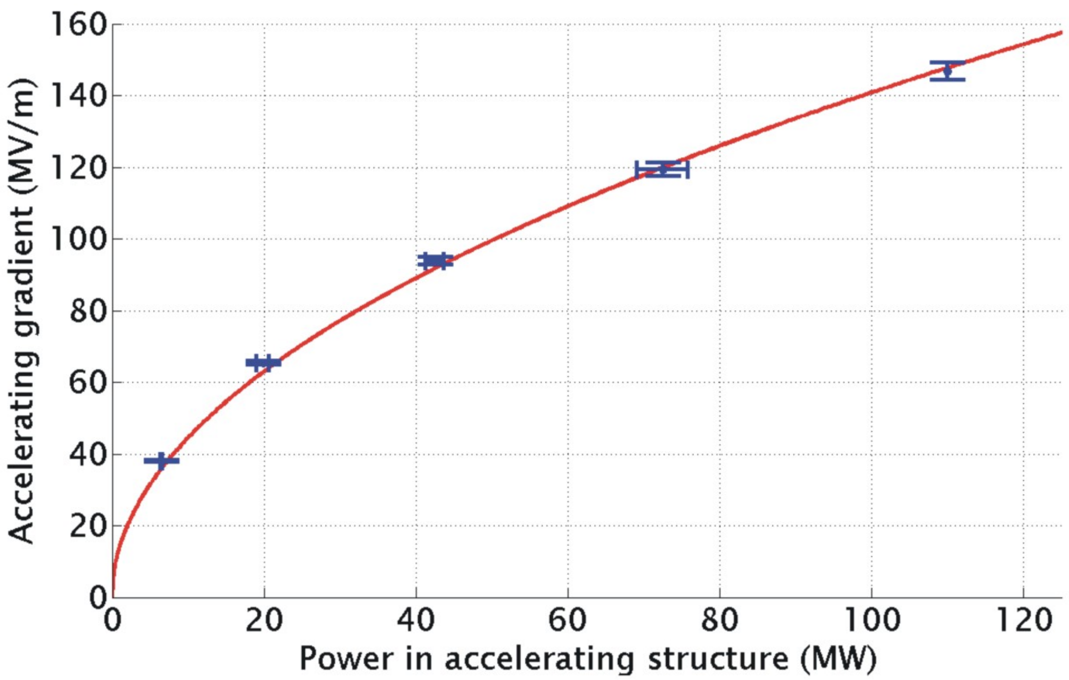
Superconducting RF cavities are in the industrialization phase and routinely reach gradients well over 30 MV/m.

RF technology exists for a low-energy machine ($\sqrt{s}$ ~ 250-500 GeV)

ILC is shovel-ready!

Future linear e^+e^- colliders





Higher gradient (~100 MV/m) can be achieved using drive beam concept.

R&D for $\sqrt{s}$ ~ 1-3 TeV → CLIC to open up the multi-TeV regime.

The e^+e^- precision physics programme

The physics programme of the LC (ILC and/or CLIC) envisages runs at several center-of-mass energies:

91 GeV *GigaZ* (*optional*) high-lumi run at the Z-pole

– ultra-precise measurements of electroweak observables

250/350 GeV *Higgs factory* study of $e^+e^- \rightarrow ZH$ process using recoil method

– Higgs couplings to Z and W, g, c, b, τ

345-355 GeV *top threshold scan*

– Precise top quark mass (width, α_s and top Yukawa coupling)

500 GeV *(nominal ILC energy)*

– Precise electroweak top couplings

1 TeV *(ILC energy upgrade)*

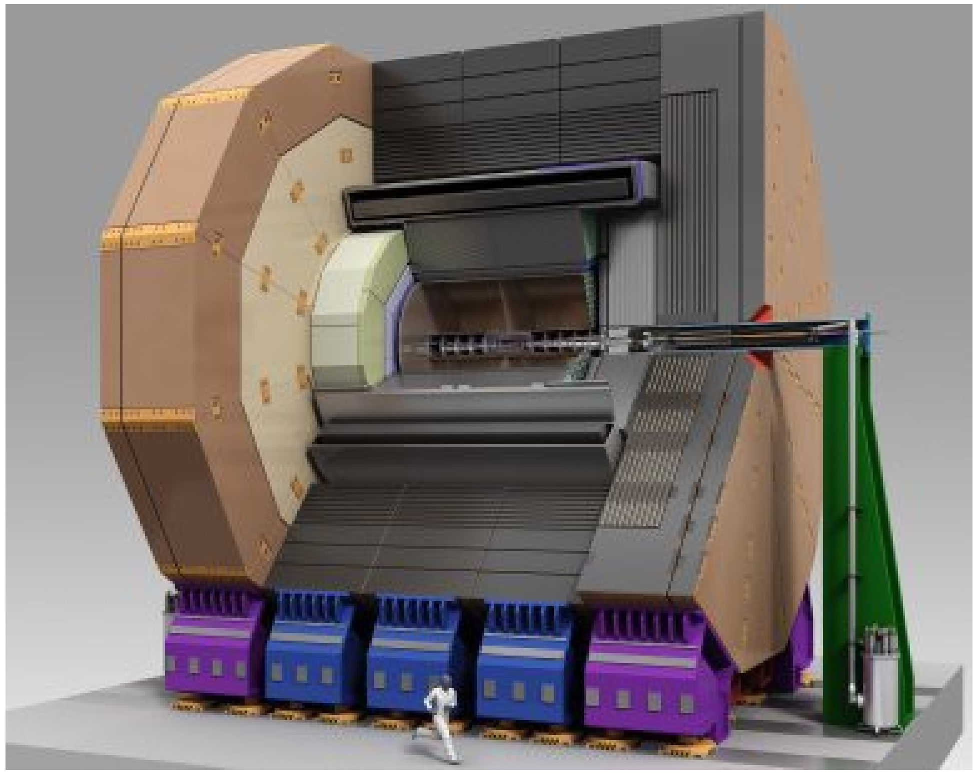
– *Higgs self-coupling*

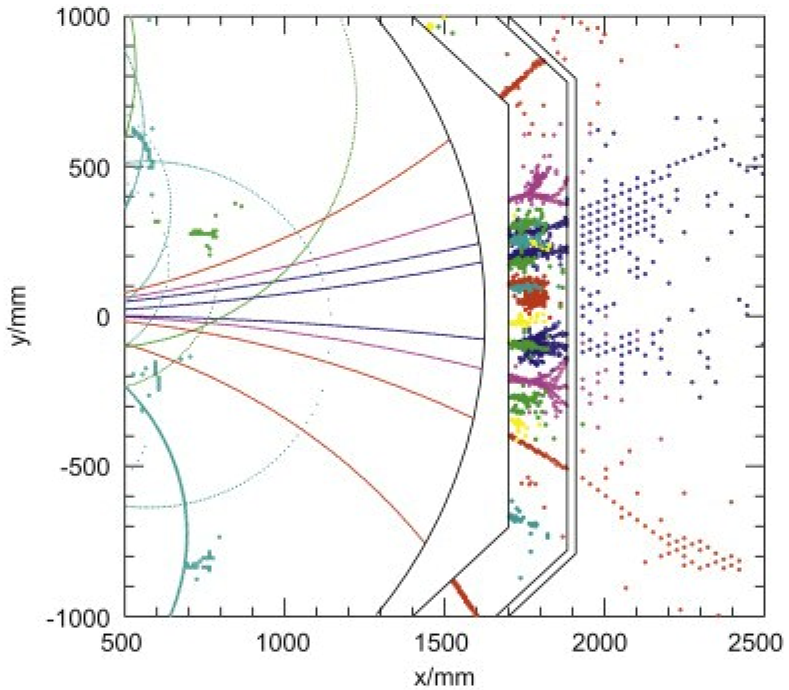
1.5 - 3 TeV *(CLIC high-energy programme)*

LC detectors

LC environment and detector R&D allow for a big leap in performance

- Signal and bkg x-sections of similar magnitude
- Well-defined initial state (CM energy, polarization)
- Triggerless read-out
- Background confined to innermost detectors





Particle Flow: highly granular calorimetry inside a large 3.5-5 Tesla solenoid allows to follow every single visible particle produced in the collisions from the cradle to the grave → best possible estimate of the jet energy: $\Delta E/E \sim 3\text{-}5\%$

Transparent and precise tracking/vertexing:

$\Delta(1/p_T) \sim 10^{-5}\ \mathrm{GeV}^{-1}$

$\Delta(d_0) \sim 5 \oplus 10\text{-}20 / (p \sin^{3/2}\theta)$

Detailed Geant4 model and sophisticated reconstruction software allow realistic estimates of performance

Vertex detector

	a (μm)	b (μm GeV)
LEP	25	70
SLD	8	33
LHC	12	70
ILC	5	10

Vertex detector

Reconstruct primary and secondary vertices,

flavour tagging, bottom/charm separation

Large polar angle coverage

Unprecedented performance:

$\sigma(d_0) < 5 \oplus 10/(p \sin^{3/2}\theta)$

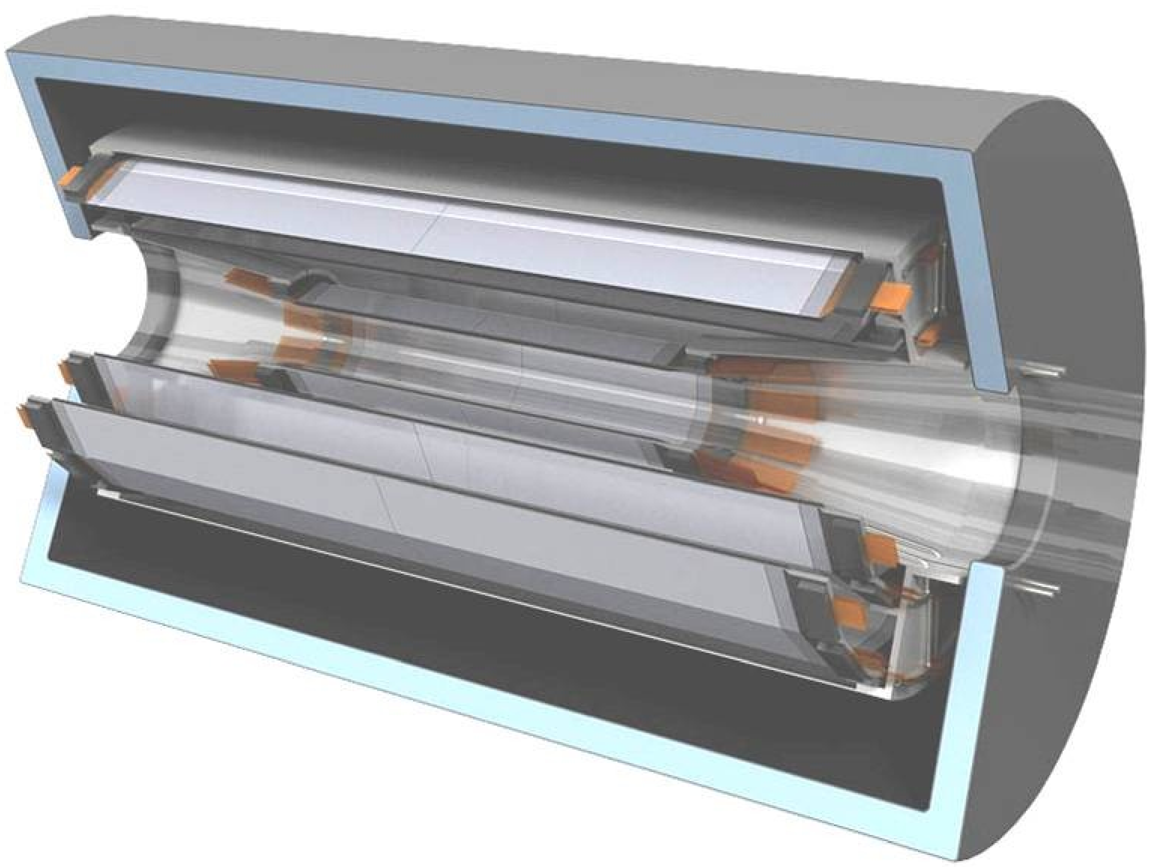
Strongly reduce the multiple Coulomb scattering term
(0.1 % X_0 / layer ~ 100 μm Si)

Stringent requirements

Precision (20 x 20 μm^2)

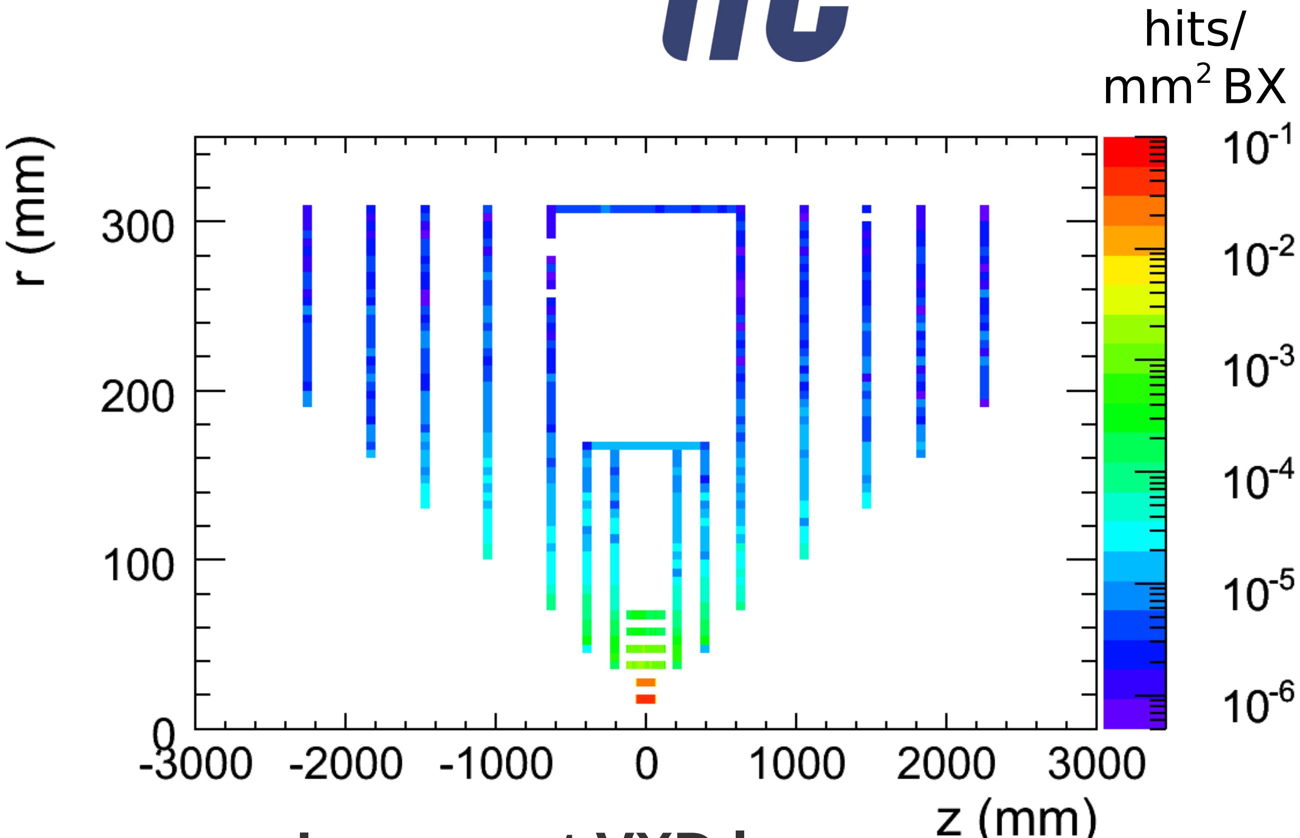
Read-out speed (25/100 μs)

Material: 0.1...% / layer

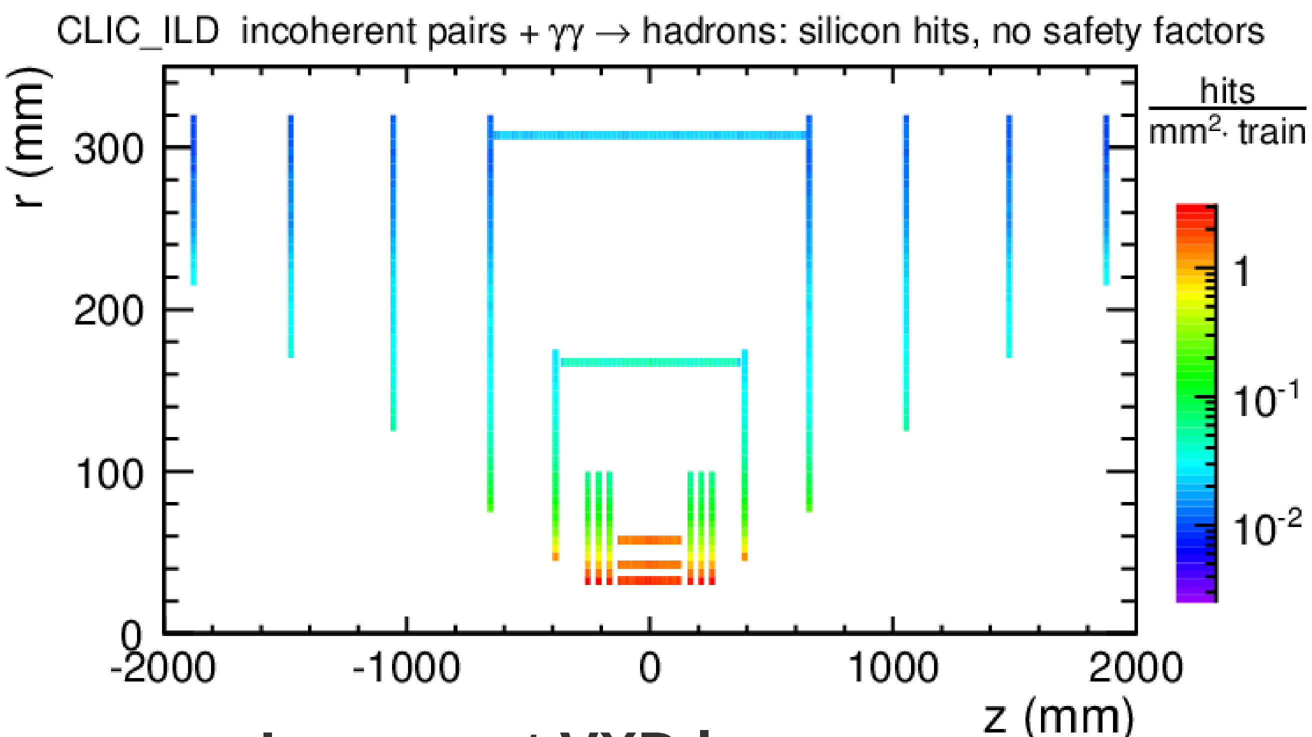


Environment

Background levels in innermost detectors drives read-out speed requirement.
→ large uncertainties and strong dependence on the machine design
Rates are much reduced during initial low-energy phase
CLIC has ultra-fast bunch train structure: 312 BX in 150 ns
→ requires 10 ns time stamping for all sub-systems



Innermost VXD layer
R = 1.5 cm



Innermost VXD layer
R = 3 cm

Technology options

ILD (see DBD)

Candidate technologies:

(mature & pursued in ILD)

- CMOS MAPs (Strasbourg)
- FPCCD (KEK)
- DEPFET

One-page description in DBD

Several alternatives

A number of alternative technologies are under study which could feature the required high granularity and low material budget. Developments undertaken for the high energy run of the ILC, in particular high-resistivity substrate CMOS sensors and to multi-tier 3D pixel sensors.

SiD (see DBD)

Pushes for 3D integration

single BX time stamping

Fall-back scenario:

DEPFET, MAPs, FPCCDs

CLIC (see CDR)

Pushes hybrid solution (TimePix)

10 ns time stamping
Prohibitive for most

(alternative with timing fast timing layers interleaved with precise layers that integrate 150 ns bunch train – 20 ms to process frame)

Current effort

Adequate presence in ILD
Essentially no effort in SiD
Some involvement in CLIC

What about the end-caps?
Will we really have two detectors?

DEPFET@ILC publications

TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 6, NO. 1, SEPTEMBER 2010 1

DEPFET active pixel detectors for a future linear e^+e^- collider

The DEPFET collaboration
(www.depfet.org)
O. Alonso, R. Casanova, A. Dieguez, J. Dingfelder, T. Hemperek, T. Kishishita, T. Kleinohl, M. Koch, H. Krüger, M. Lemarenko, F. Lütticke, C. Marinas, M. Schnell, N. Wermes, A. Campbell, T. Ferber, C. Kleinwort, C. Niebuhr, Y. Soloviev, M. Steder, R. Volkenborn, S. Yaschenko, P. Fischer, C. Kreidl, I. Peric, J. Knopf, M. Ritzert, E. Curras, A. Lopez-Virto, D. Moya, I. Vila, M. Boronat, D. Esperante, J. Fuster, I. Garcia Garcia, C. Lacasta, A. Oyanguren, P. Ruiz, G. Timon, M. Vos*, T. Gessler, W. Kühn, S. Lange, D. Münchow, B. Spruck, A. Frey, C. Geisler, B. Schwenker, F. Wilk, T. Barvich, M. Heck, S. Heindl, O. Lutz, Th. Müller, C. Pulvermacher, H.J. Simonis, T. Weiler, T. Krausser, O. Lipsky, S. Rummel, J. Schieck, T. Schlüter, K. Ackermann, L. Andricek, V. Chekelian, V. Chobanova, J. Dalseno, C. Kiesling, C. Koffmane, L. Li Gioi, A. Moll, H. G. Moser, F. Müller, E. Nedelkovska, J. Ninkovic, S. Petrovics, K. Prothmann, R. Richter, A. Ritter, M. Ritter, F. Simon, P. Vanhoefer, A. Wassatsch, Z. Dolezal, Z. Drasal, P. Kodys, P. Kvasnicka, J. Scheirich

supporting paper

in IEEE TNS

ILC newsline

December 2012

(M. Vos, B. Warmbein)

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LC NEWSLINE
THE NEWSLETTER OF THE LINEAR COLLIDER COMMUNITY

CURRENT ISSUE
30 MAY 2013

The ECFA LC2013 workshop
Setting the course for European particle physics
Hiking like an electron
Impressions from Hamburg
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CALENDAR

AROUND THE WORLD

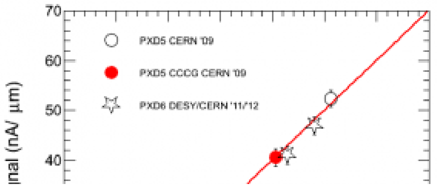
DEPFET active pixel detectors for the linear collider

Marcel Vos reports on behalf of the collaboration

Share |

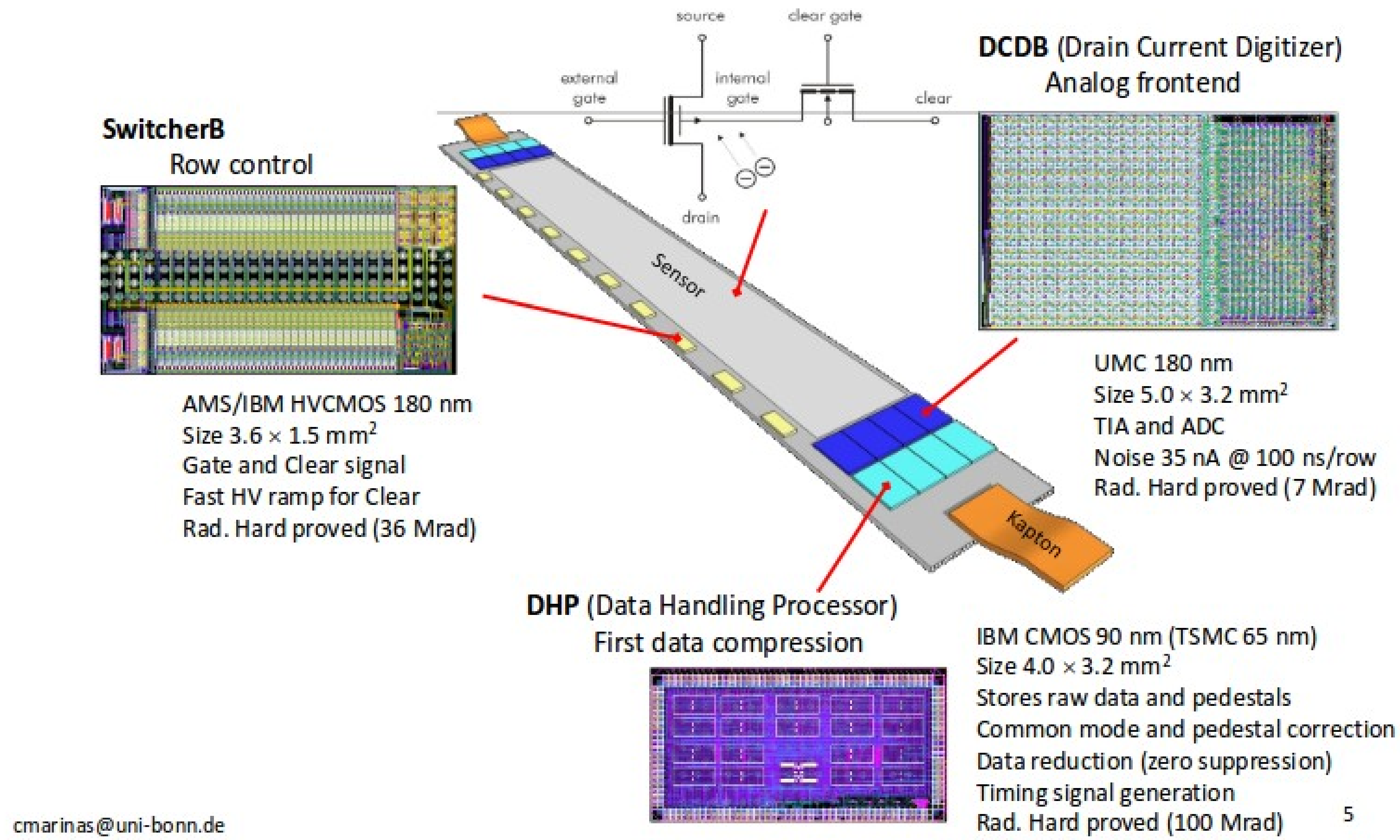
24 January 2013

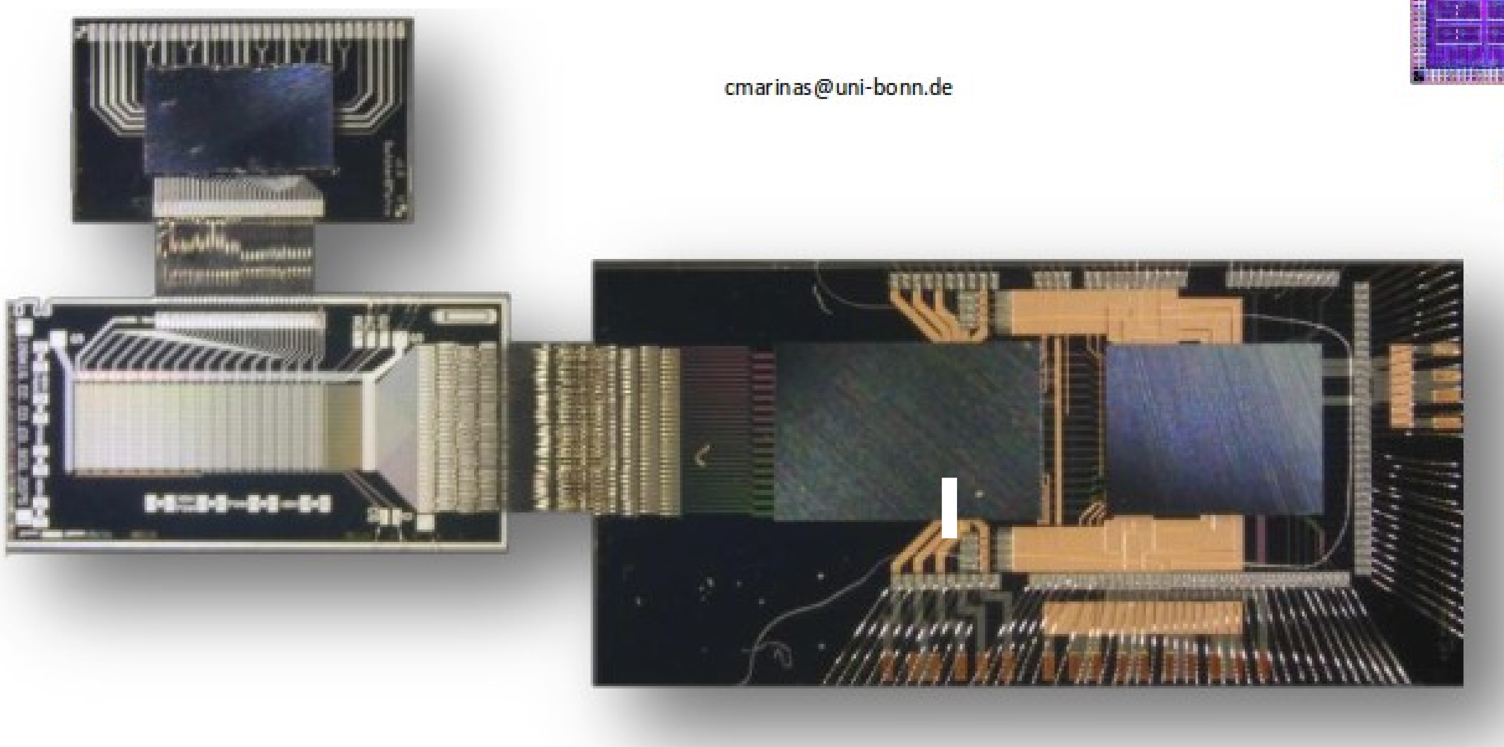
Solid-state devices for charged particle tracking proved their value in high energy physics in the most internal layers of the experiments of the Large Electron Positron Collider LEP at CERN, where they provided precise information on the production vertex of charged particles. These silicon micro-strip detectors consisted of a thin reverse-biased *pn*-junction segmented in narrow strips, each of which was read-out by an amplifier and analog-to-digital converter on a read-out ASIC. After a rapid evolution fueled



From concept to system

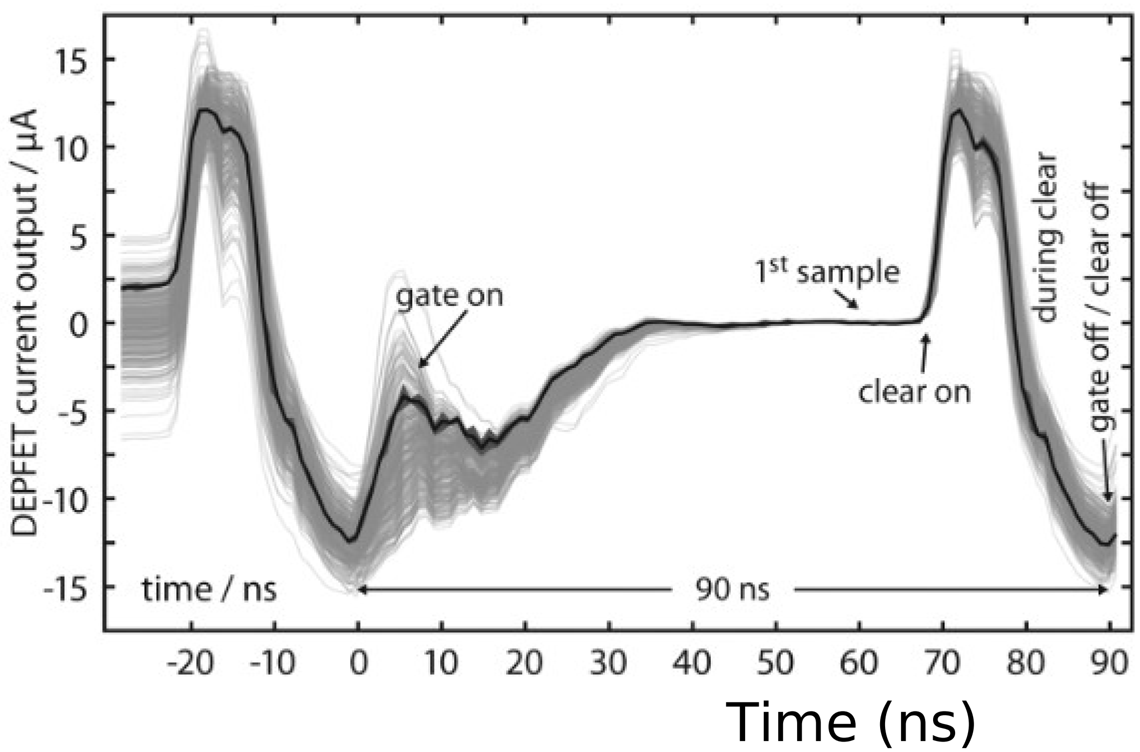
Status of read-out and steering ASICs





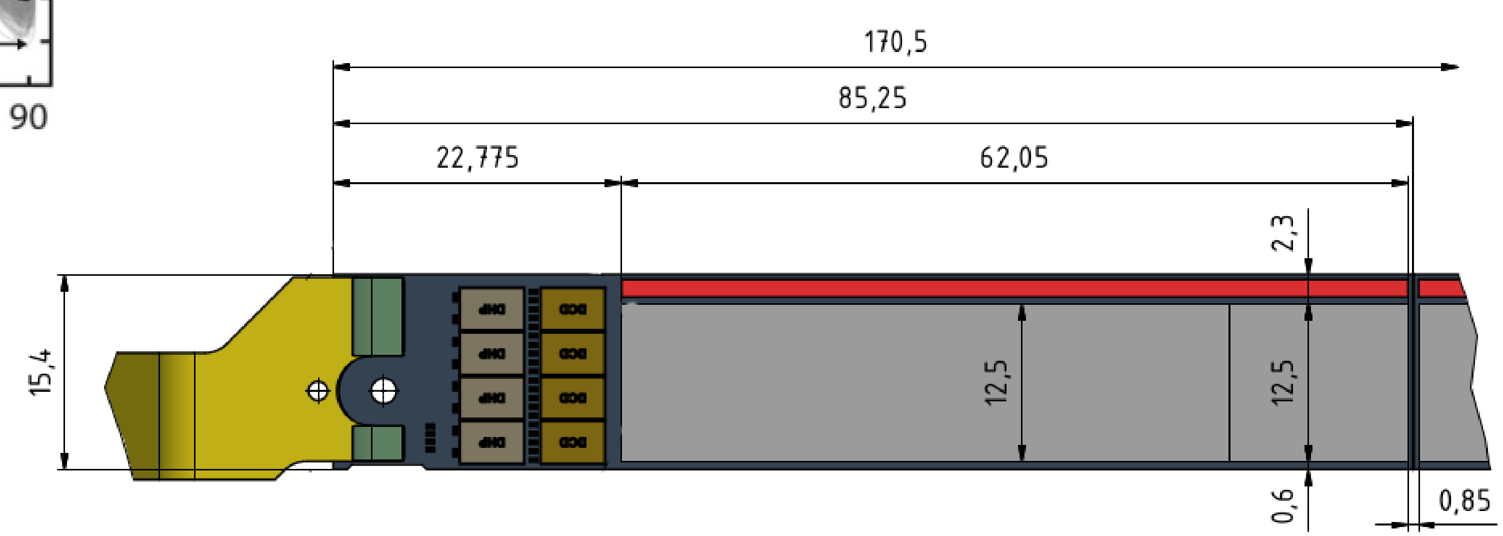
All in one chain

DEPFET @ LC - barrel



Read-out speed: current state-of-the-art allows for a row rate of 1/100 ns. Room for improvement.

VXD0 → 12.5cm long barrel layer with read-out ASICs on both ends.



Pixel size:

Center (|z|<1) → 25 x 25 µm^2

1 <|z|< 2 cm → 25 x 50 µm^2

|z| > 2 cm → 25 x 100 µm^2

Column depth: *1025 pixels/half-ladder*

Multiplexing: *2 (4) rows sampled in //*

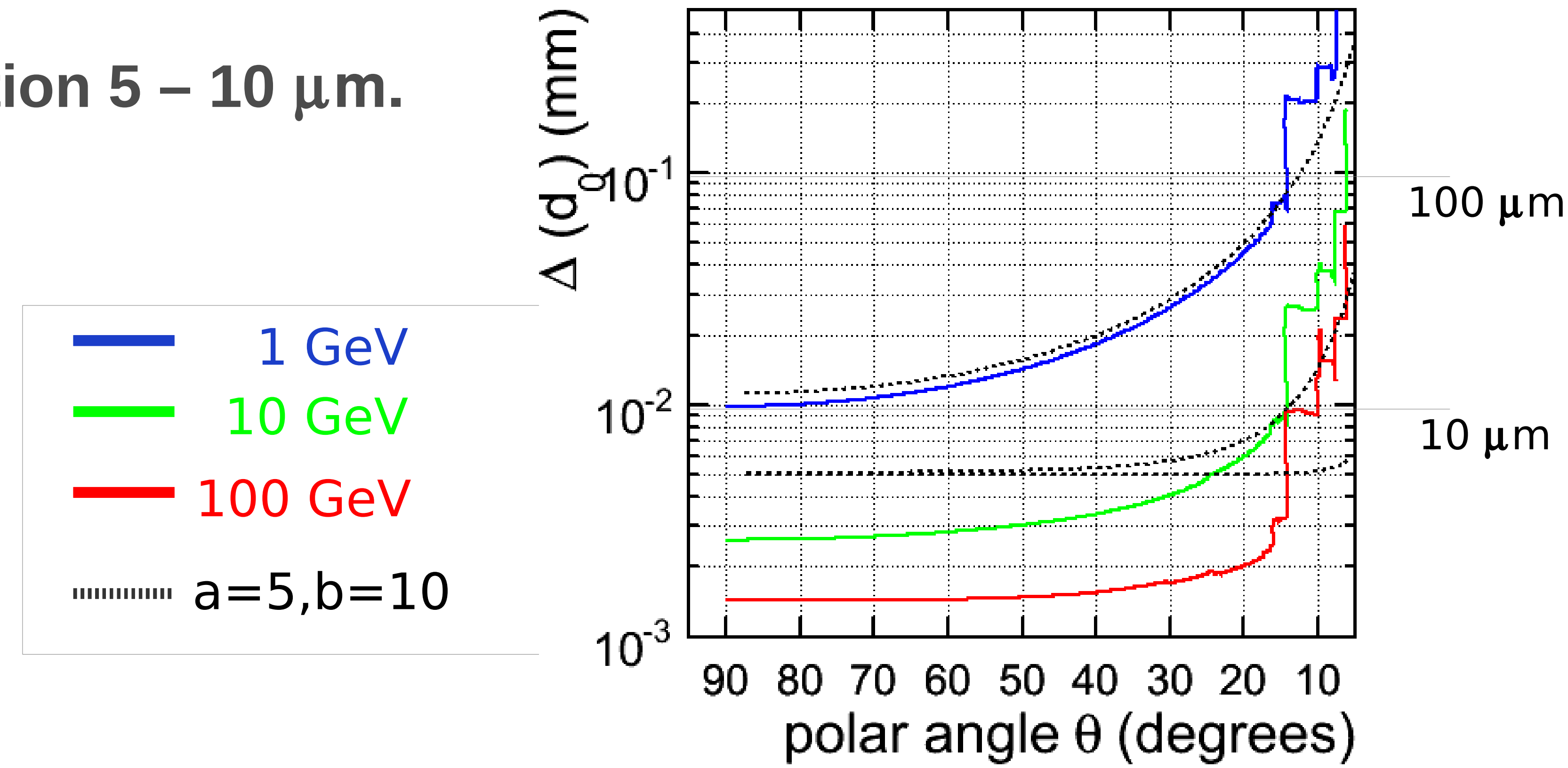
Row rate: *1/80 ns*

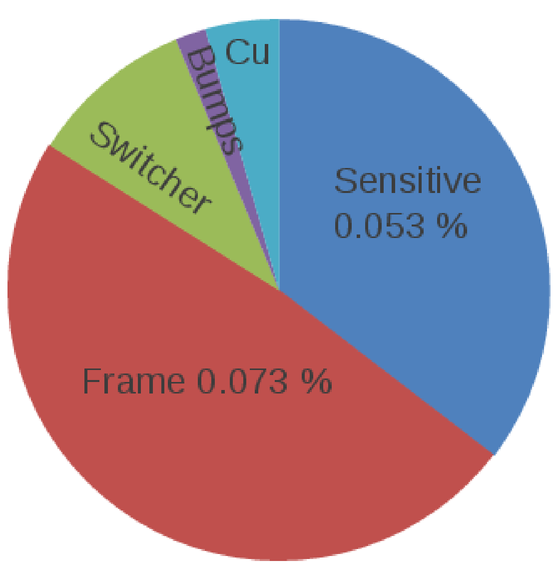
Frame time: *40 µs (20 µs)*

Impact parameter resolution

VXD: impact parameter resolution 5 – 10 μm.

Forward vertexing in ILD:
http://arxiv.org/pdf/1303.3187.pdf

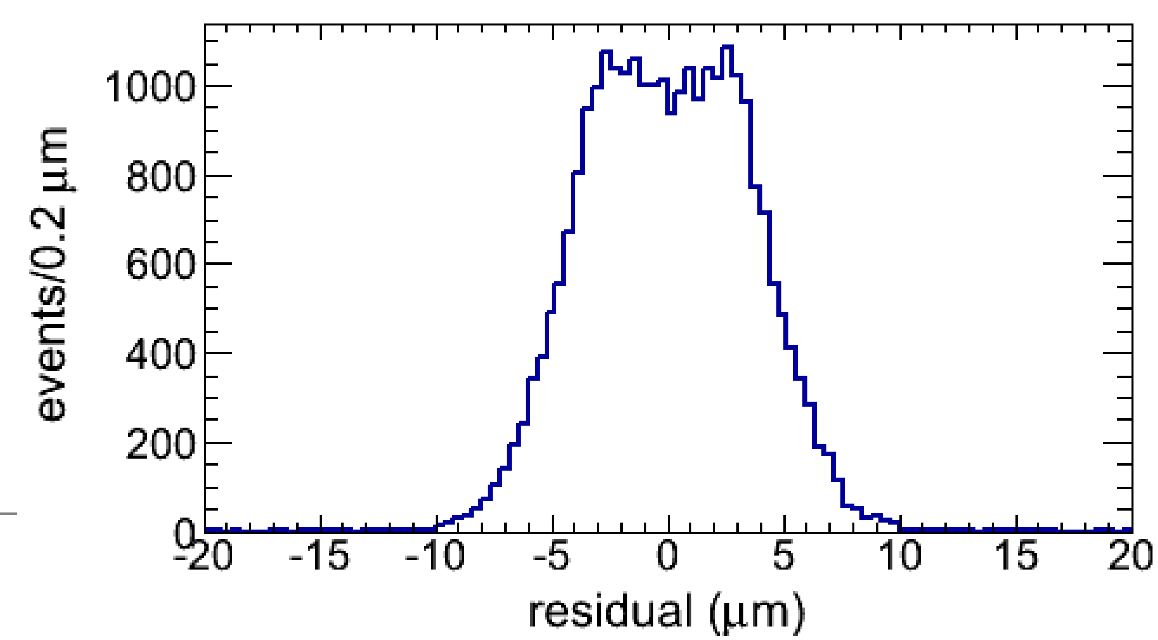




Sensitive	0.053 % X_0
Frame	0.073 % X_0
Switcher	0.015 % X_0
Cu layer	0.007 % X_0
Bumps	0.003 % X_0
Total ladder	0.15 % X_0

← **Material budget**
(averaging over ladder area)

Spatial resolution →
(simulation, perp. Incidence)



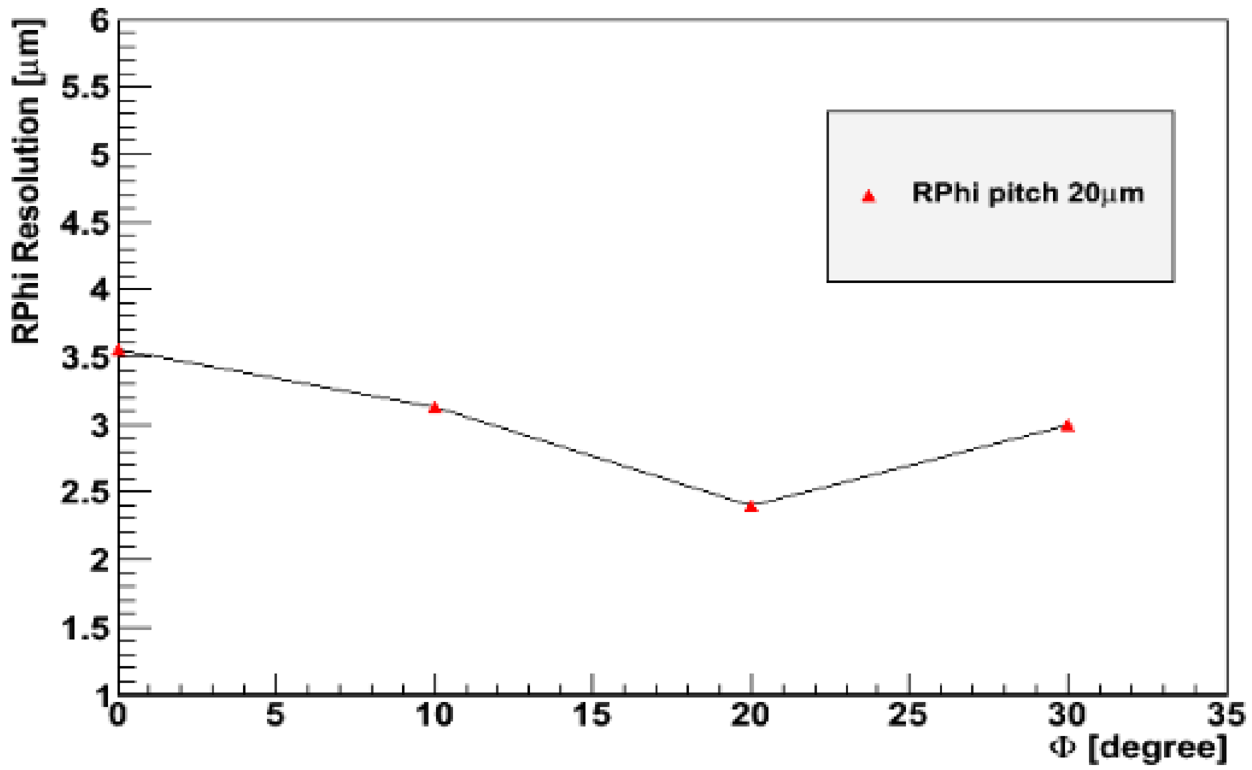
Summary: LC vs Belle-II

	ILC	***Belle-II***
occupancy	0.13 hits/μm^2/s	0.4 hits/μm^2/s
radiation	< 100 krad/year	> 1Mrad/year
	10^{11} 1 MeV n_{eq}/year	2 10^{12} 1 MeV n_{eq}/year
Duty cycle	1/200	1
Frame time	25-100 μs (10 ns @ CLIC)	20 μs
Momentum range	All momenta	Low momentum (< 1 GeV)
Acceptance	6°-174°	17°-150°
Resolution	Excellent 3-5 μm (pixel size = 20 x 20 μm^2)	Moderate (pixel size = 50 x 75 μm^2)
Material budget	0.12 % X_0/layer	0.15 % X_0/layer

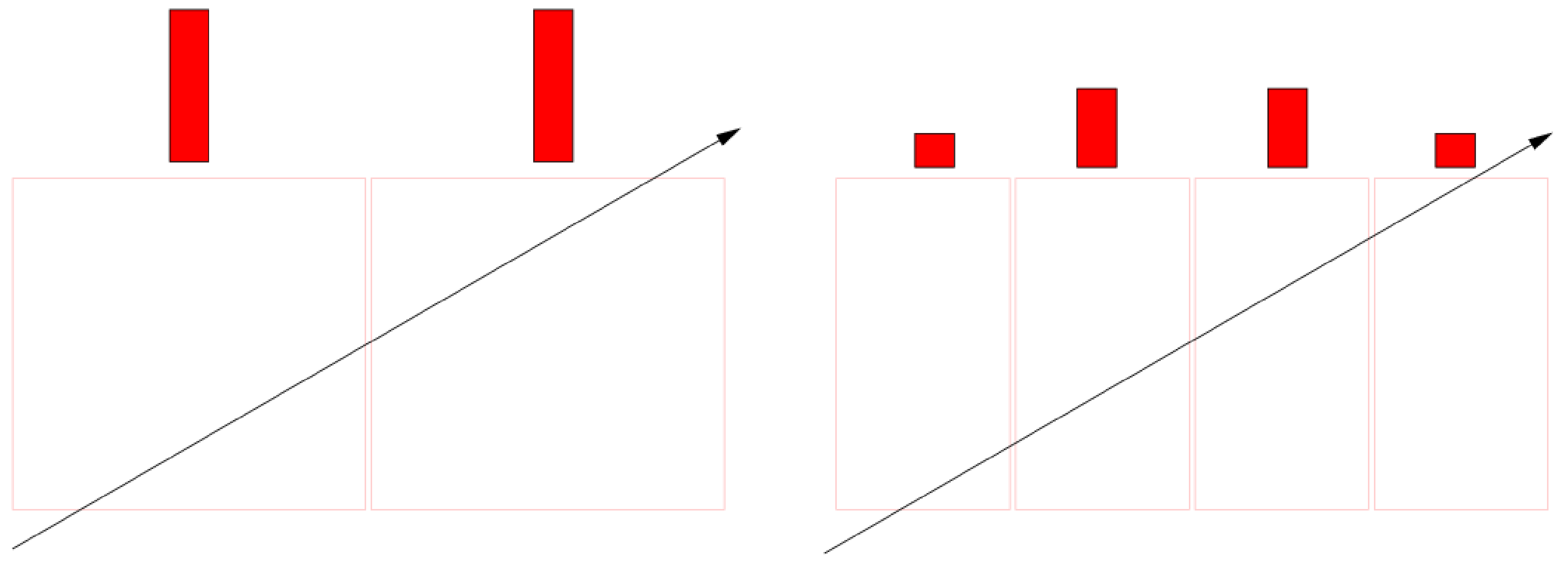
Belle-II presents a more severe challenge than the ILC in several aspects!

Resolution vs. incidence angle

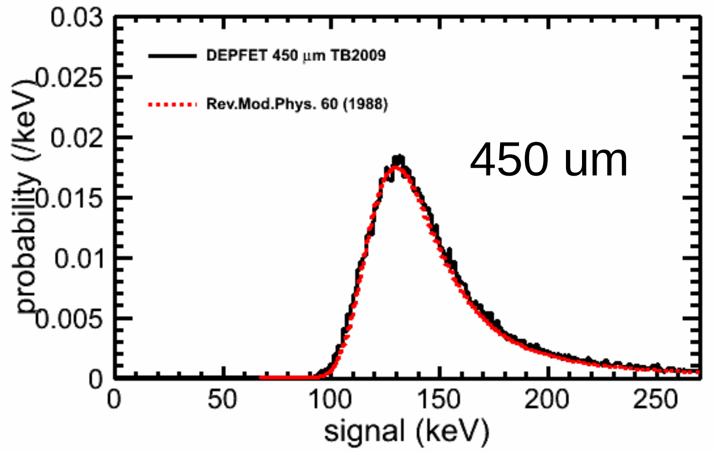
Spatial resolution of an ILC design DEFPET vertex detector predicted by digitizer

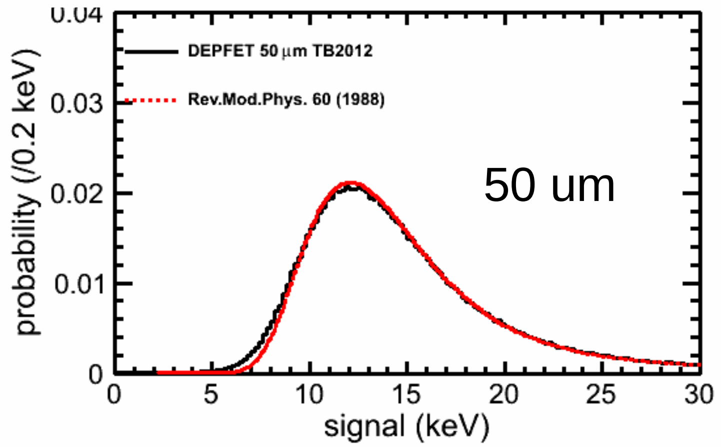


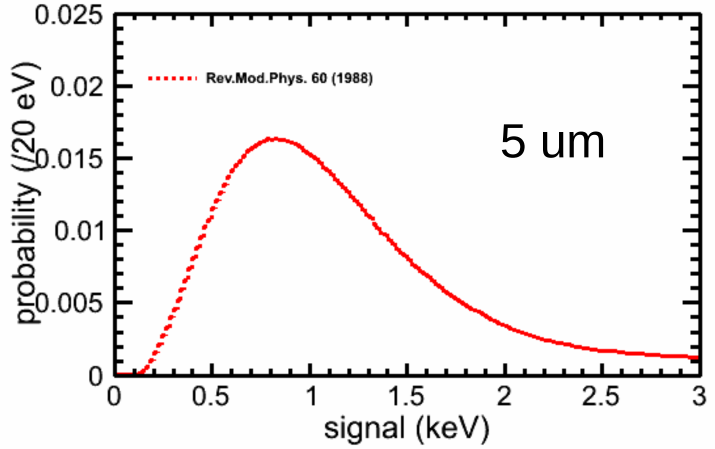
Charge sharing helps improve the resolution (up to a point)

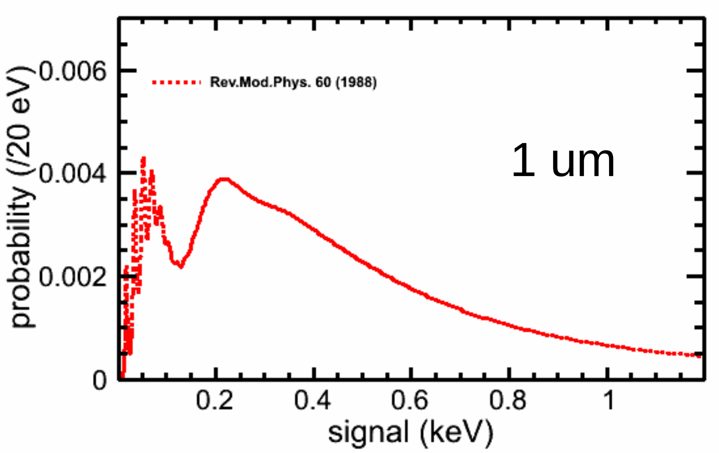


Landau fluctuations





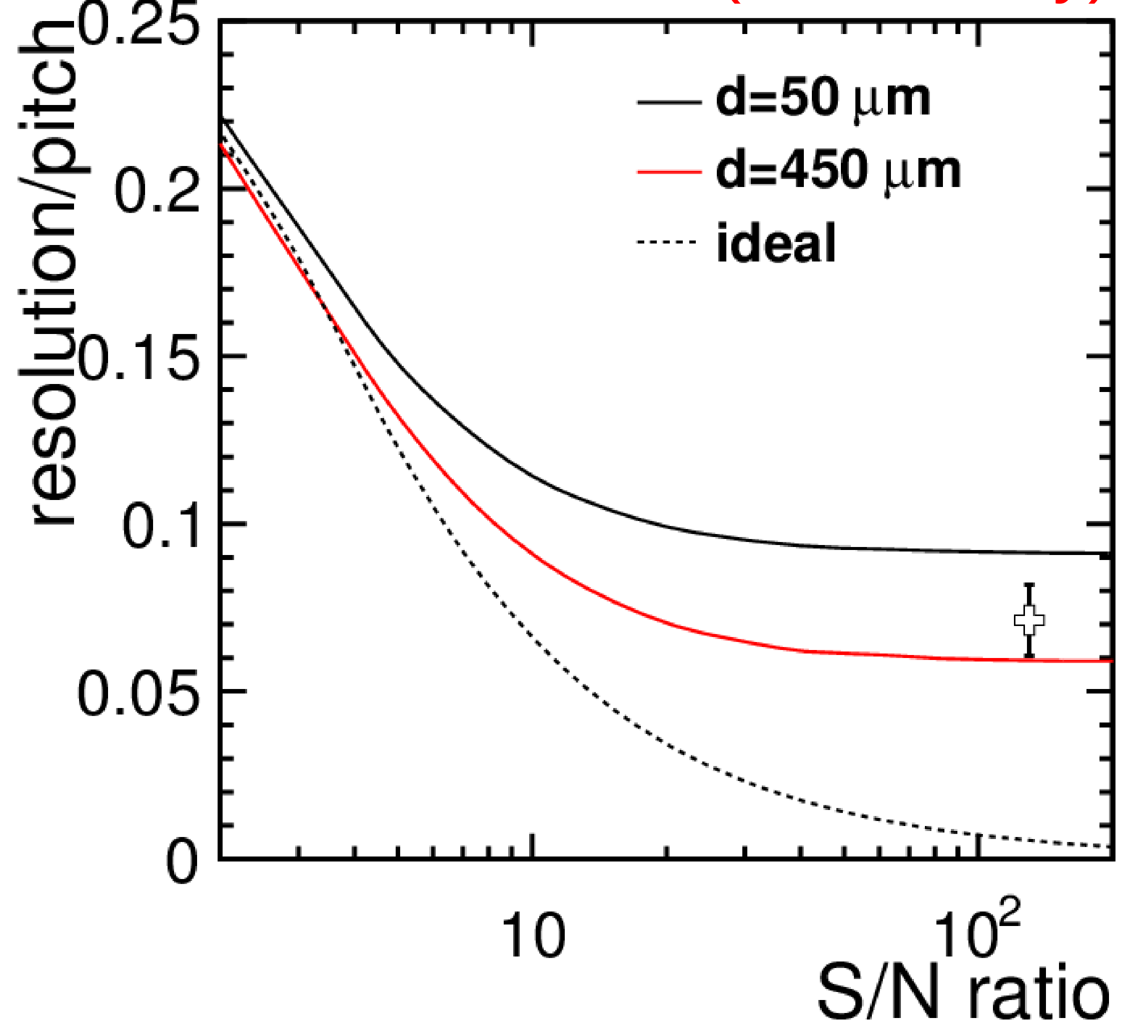




σ/p ~ 7%
thick sensors
(d=300-500 um)

σ/p ~ 10%
thin sensors
(d=50 um)

M. Boronat (Preliminary)



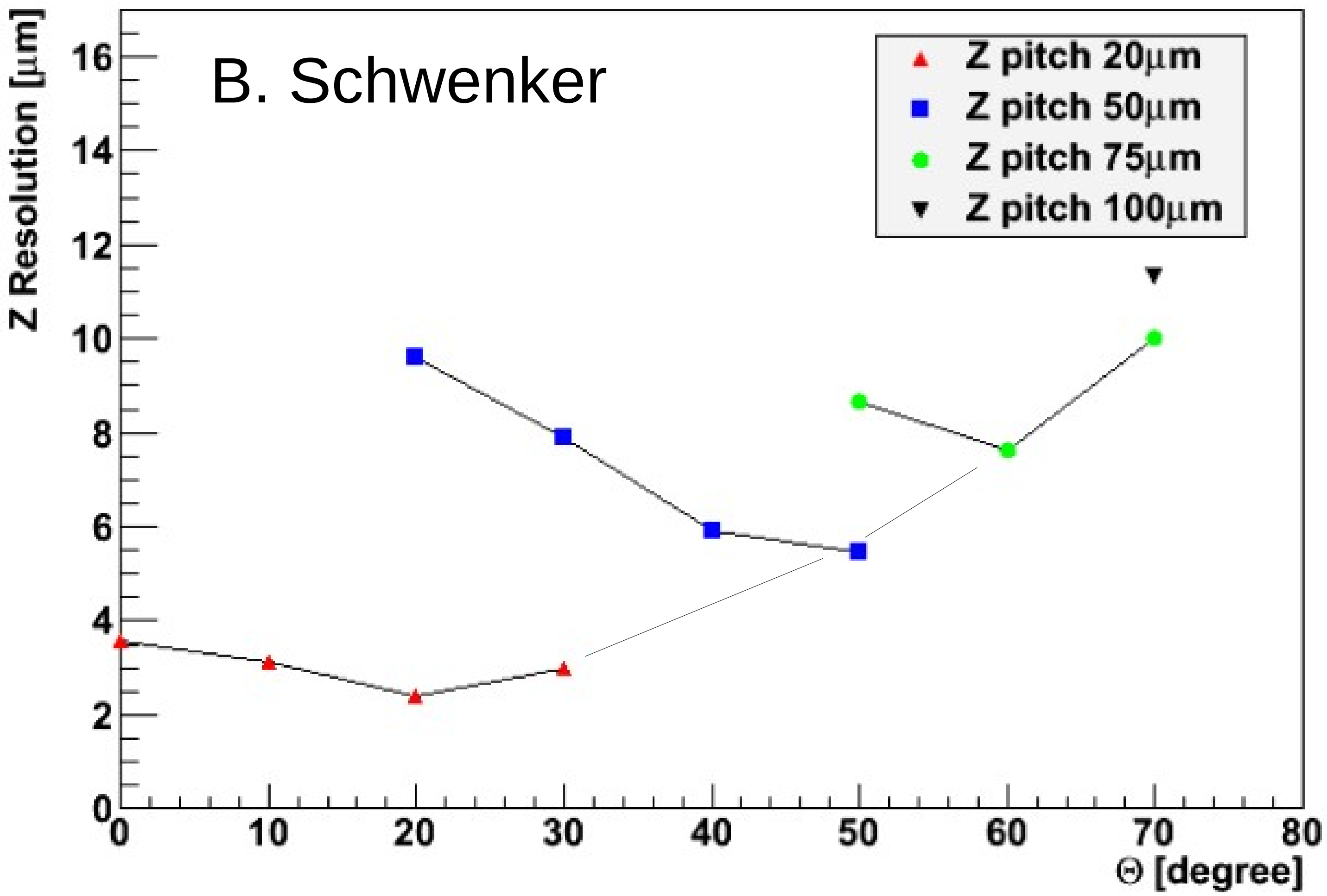
Fluctuations in signal deposition per unit length of the particle trajectory in the silicon (Landau fluctuations) limit the resolution.
Effect should be more pronounced for thin sensors.

Spatial resolution for shallow tracks

Some degradation of the resolution towards the end-of-ladder seems inevitable

S/N is still crucial:
- forces detector thickness
  (and consequently pitch)

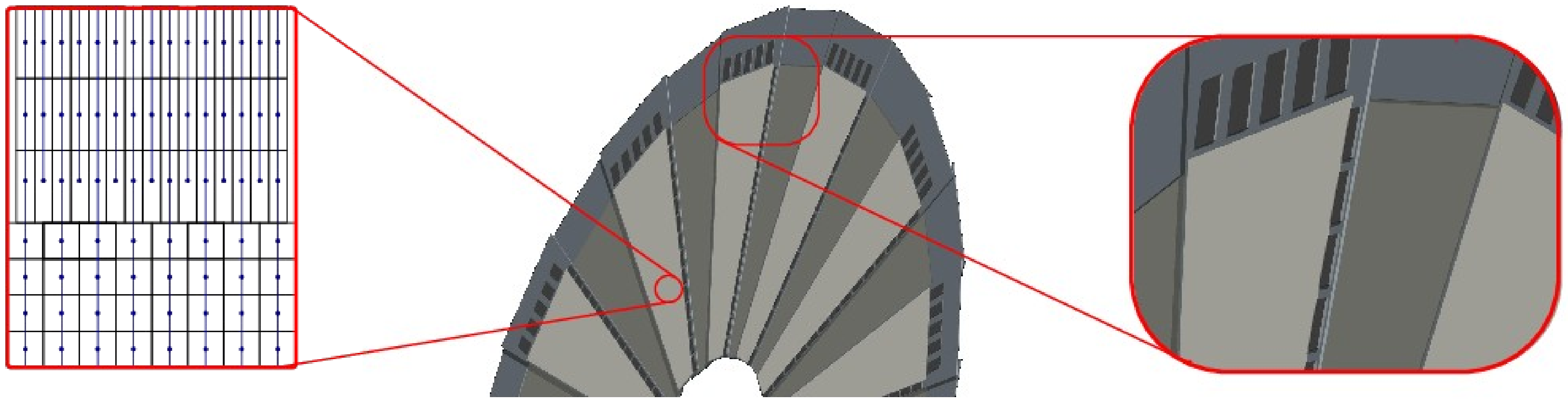
Improve by increasing g_q

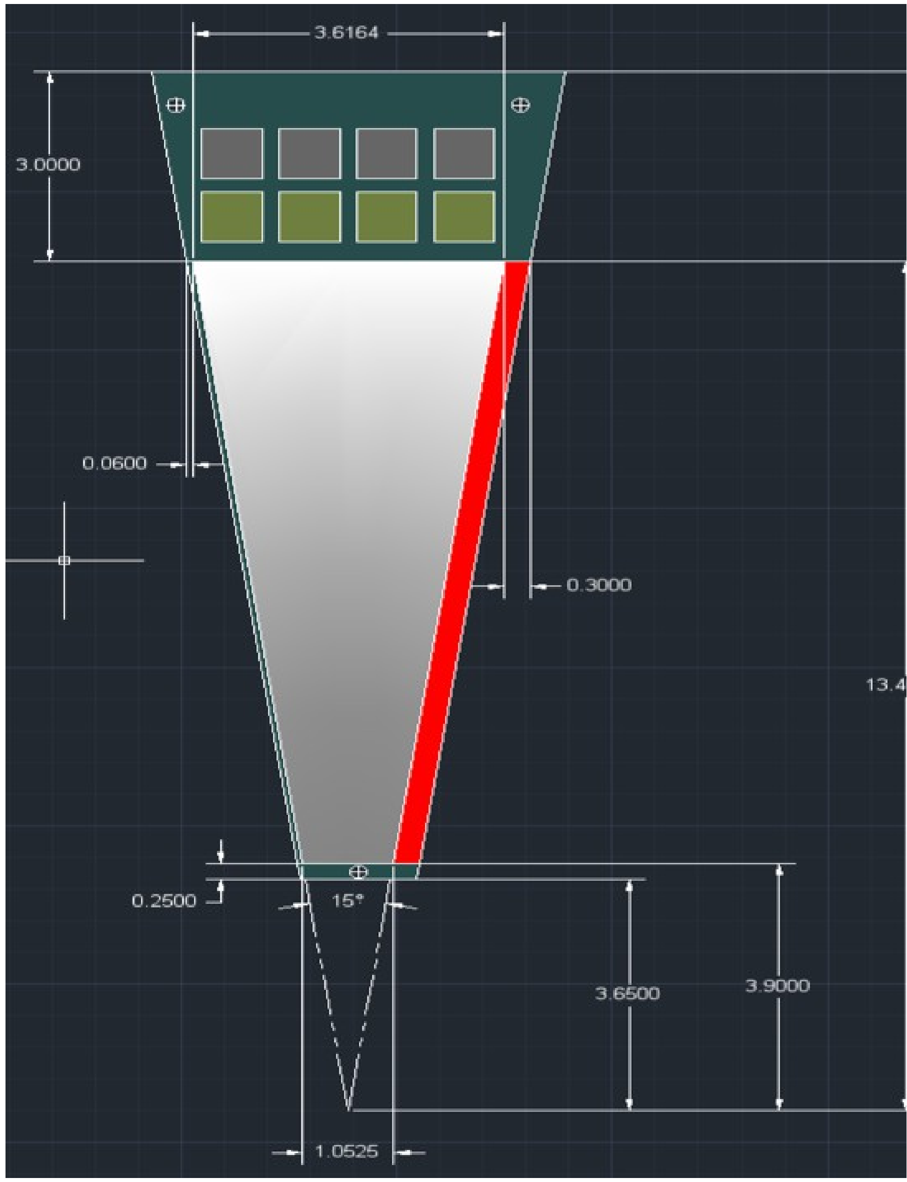


Towards a disk design

One major difference between Belle II and LC is the polar angle coverage

- Implications for support, cooling and services of the barrel detector
  (partially alleviated by pulsed powering)
- Requires also pixelated disks → adapt "ladder" design to "petal" geometry





- Spanish LC community takes care of ILD-FTD design
- DEPFET solution for end-cap being developed
  (from concept to CAD to ...)
- *Questions that need feedback from the experts:*
  Sensor: feasibility of layout with variable pitch & length
  Ancillary: length of switcher lines, load on DCD...
  Mechanics: self-supporting frame
  Cooling: air flow through disks
  Physics: assess performance of this design

DEPFET@LC... conclusions

A global LC hosted in Japan... It might just happen!
Have to be ready to react if it does.

Small, but adequate?, DEPFET presence in LC:

- contributed sections in Detailed Baseline Design (~detector TDR)
- IEEE TNS supporting paper & LC newsline article
- strong presence at ECFA LC2013

(L. Andricek, C. Mariñas, B. Schwenker, M. Vos)

DEPFET remains a solid candidate for the ILC VXD:

The best argument for DEPFET is:

success of the Belle II PXD

LC-specific developments:

- continue to improve system performance (S/N, speed)
- smaller pixels, deeper columns, larger #columns
- pulsed power + air-cooling → IFIC/AIDA mock-up
- disks require 'petal' design

European Strategy - old

The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance. A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.

In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.

It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precisionfr ontier; thereshould be a strong well-coordinated Eur opean activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.

European Strategy - updated

The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide. e.

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.