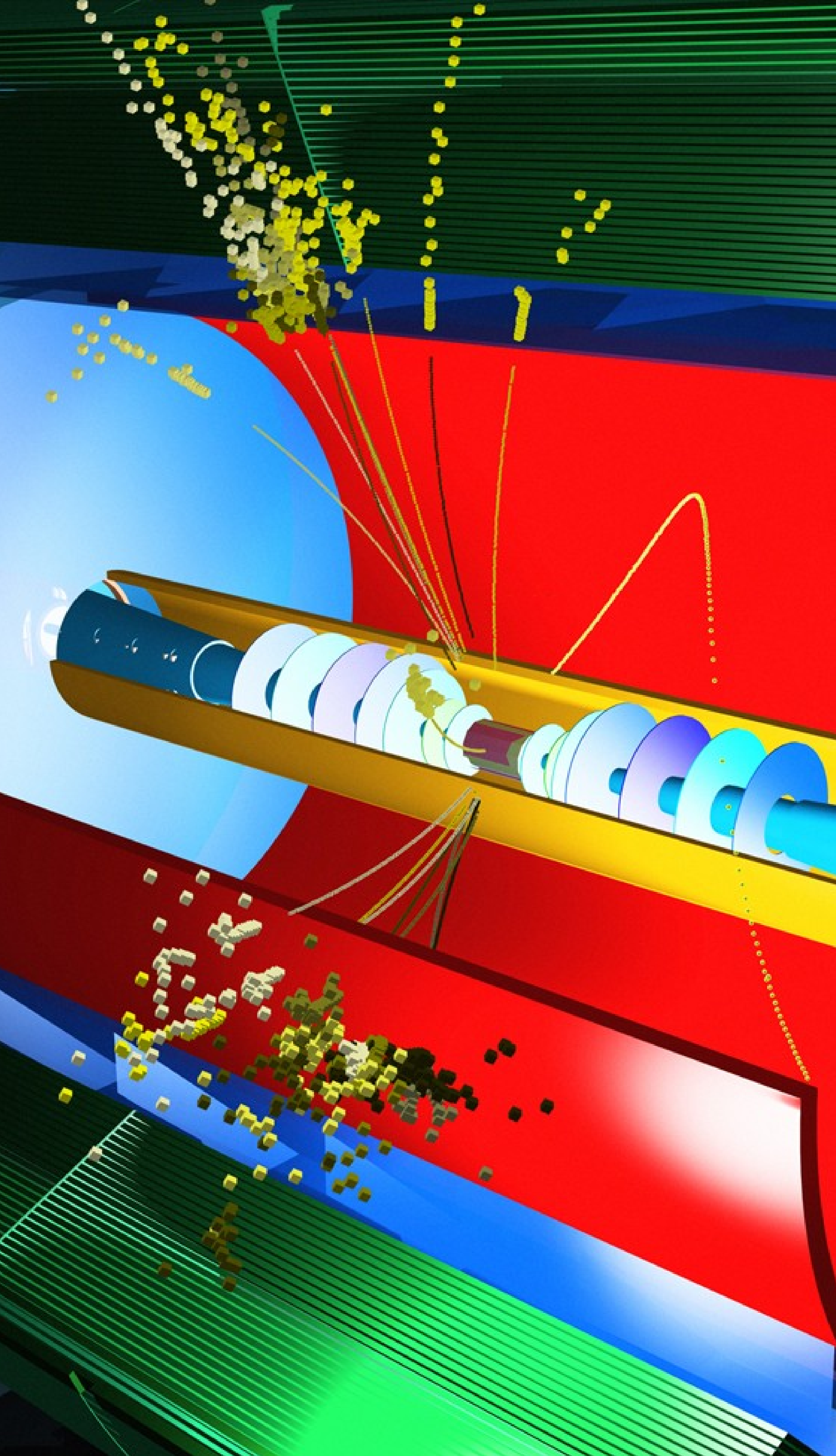


DEPFET

Active Pixel Detector

DEPFET for energy-frontier electron-positron colliders;

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

20th International workshop on DEPFET detectors and applications

Kloster Seeon, May 2016

Marcel Vos

IFIC (U. Valencia/CSIC), Spain

DEPFET

Active Pixel Detector

Challenges for colliders in 2020-2030

- precision measurements on Higgs production

- Model-independent couplings to SM particles
- Higgs → invisible rate
- Higgs self-coupling

- precision measurements on top quarks

- Properties
- Top + EW gauge bosons

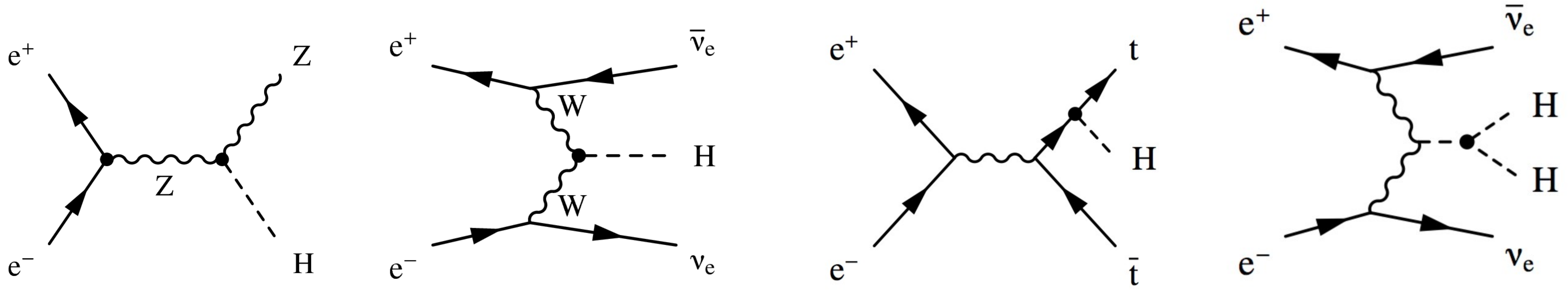
- new physics

- **??**

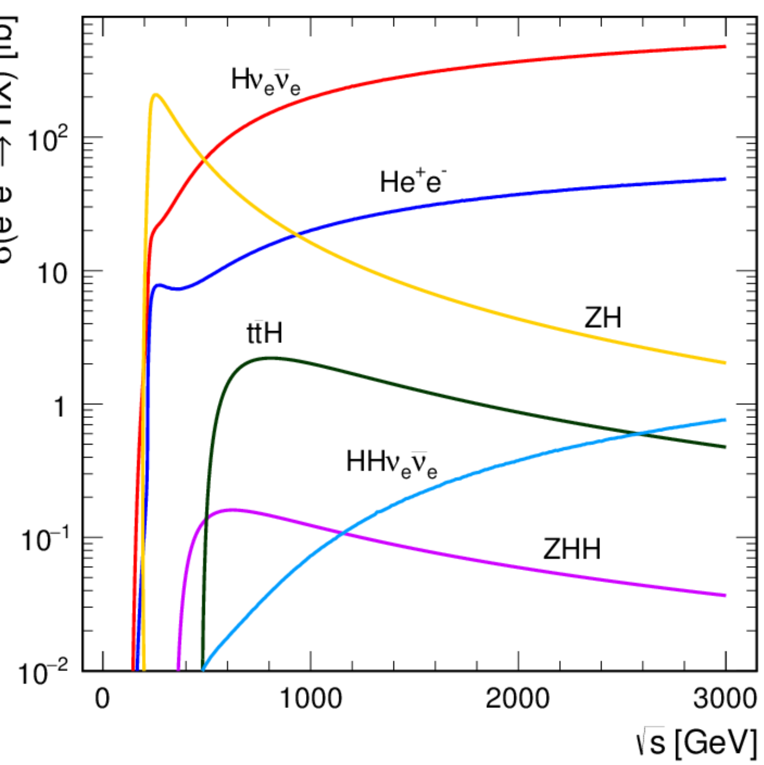
Marcel.Vos@ific.uv.es

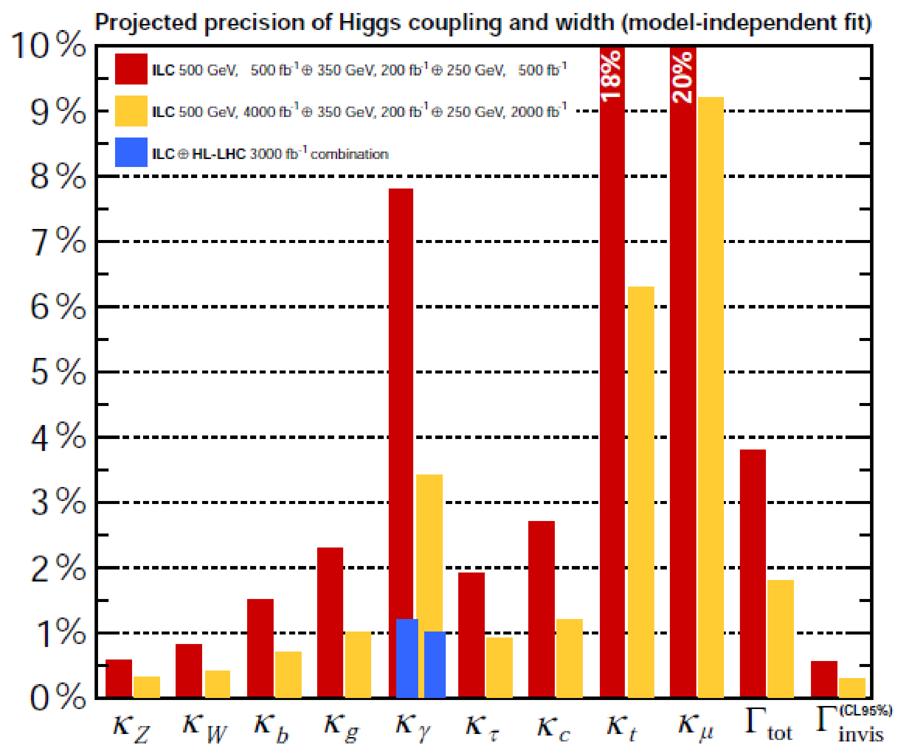
Higgs physics

Higgs boson production mechanisms:

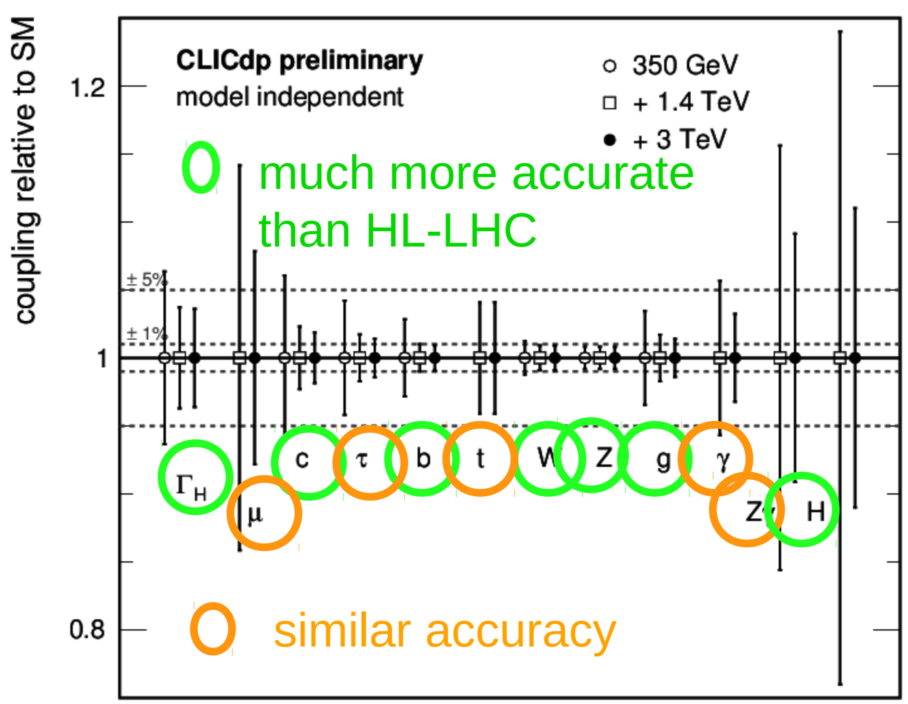


- Higgstrahlung
- vector-boson fusion
- associated $t\bar{t}H$ production
- di-Higgs production





ILC physics case: arXiv:1506.05992



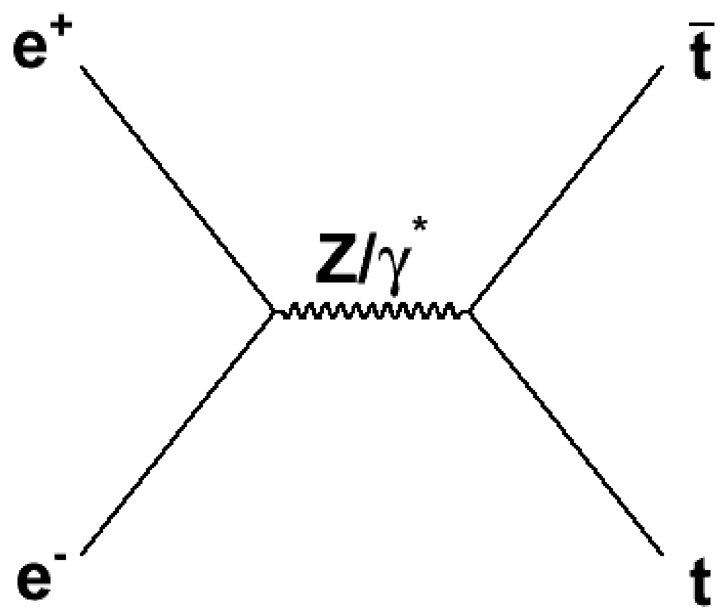
Expected soon: CLIC Higgs paper

Top quark physics

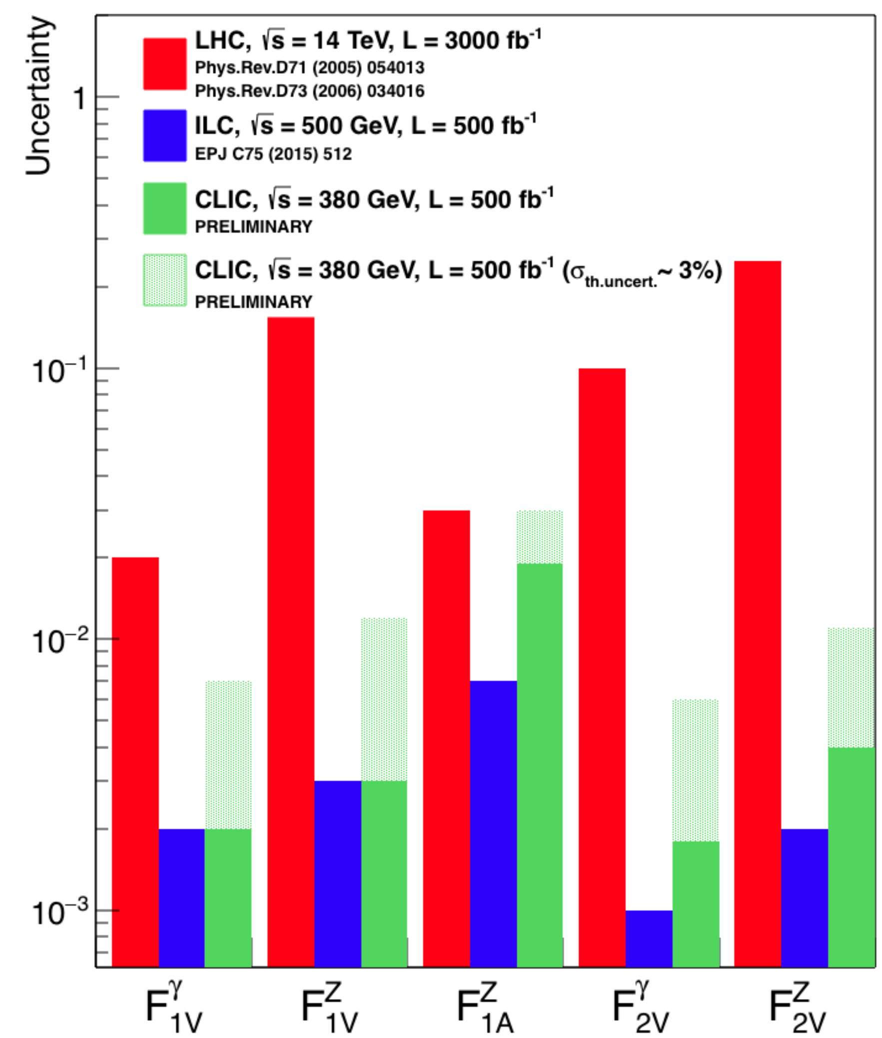
Top quark pair production

- $t\bar{t}Z$ coupling is a sensitive probe that may

present sizeable deviations for BSM at 10-30 TeV



+top mass to 50 MeV, $t \rightarrow cH$ to 10^{-5}
Coordinated effort towards a top paper



LC prospects are an order of magnitude better than LHC
500 GeV: larger boost and smaller theory uncertainty

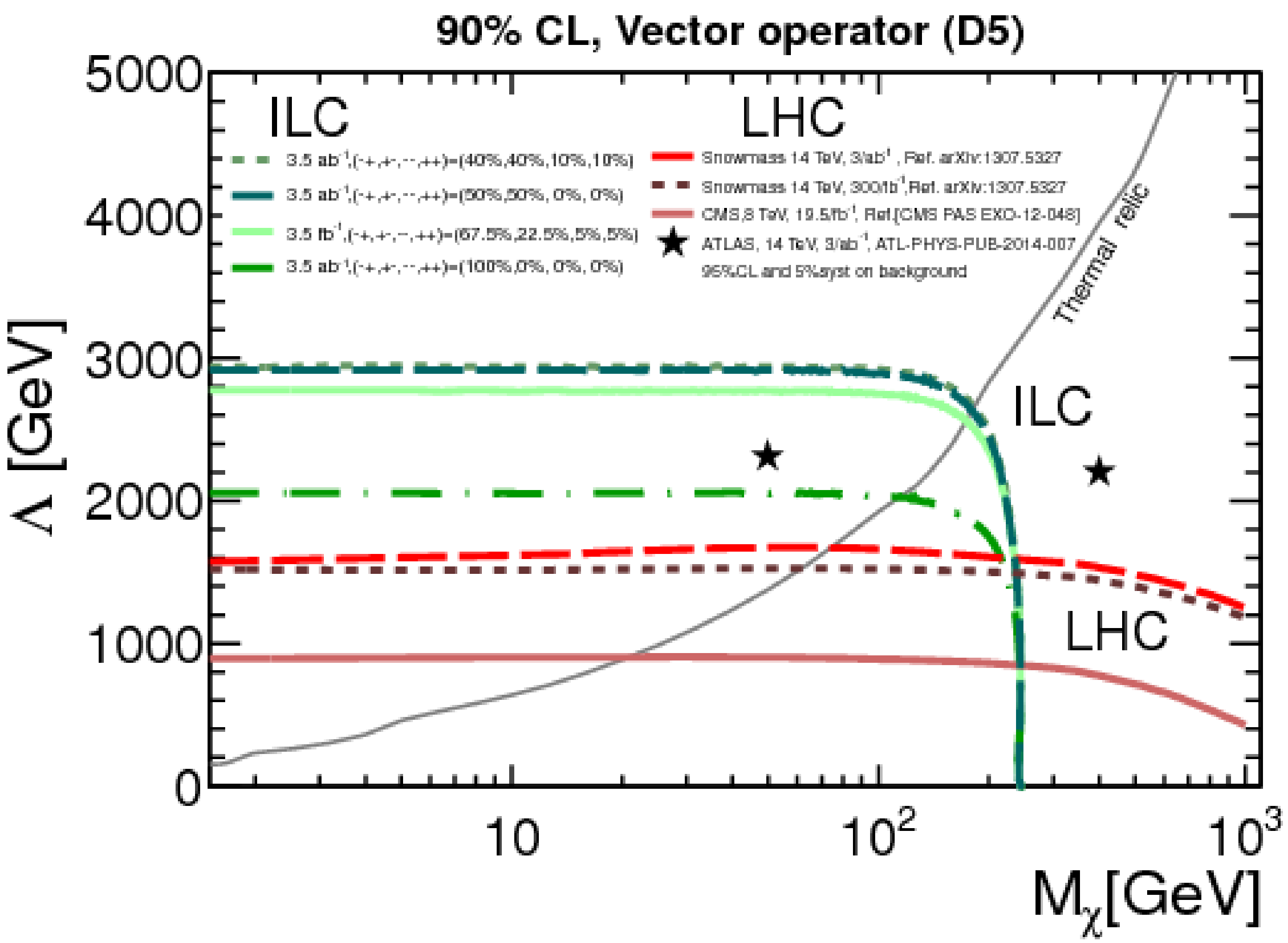
New physics

SUSY, sleptons & electroweakinos

Loophole-free searches for heavy Higgs bosons

Dark matter through mono-photons

Complementary to LHC programme

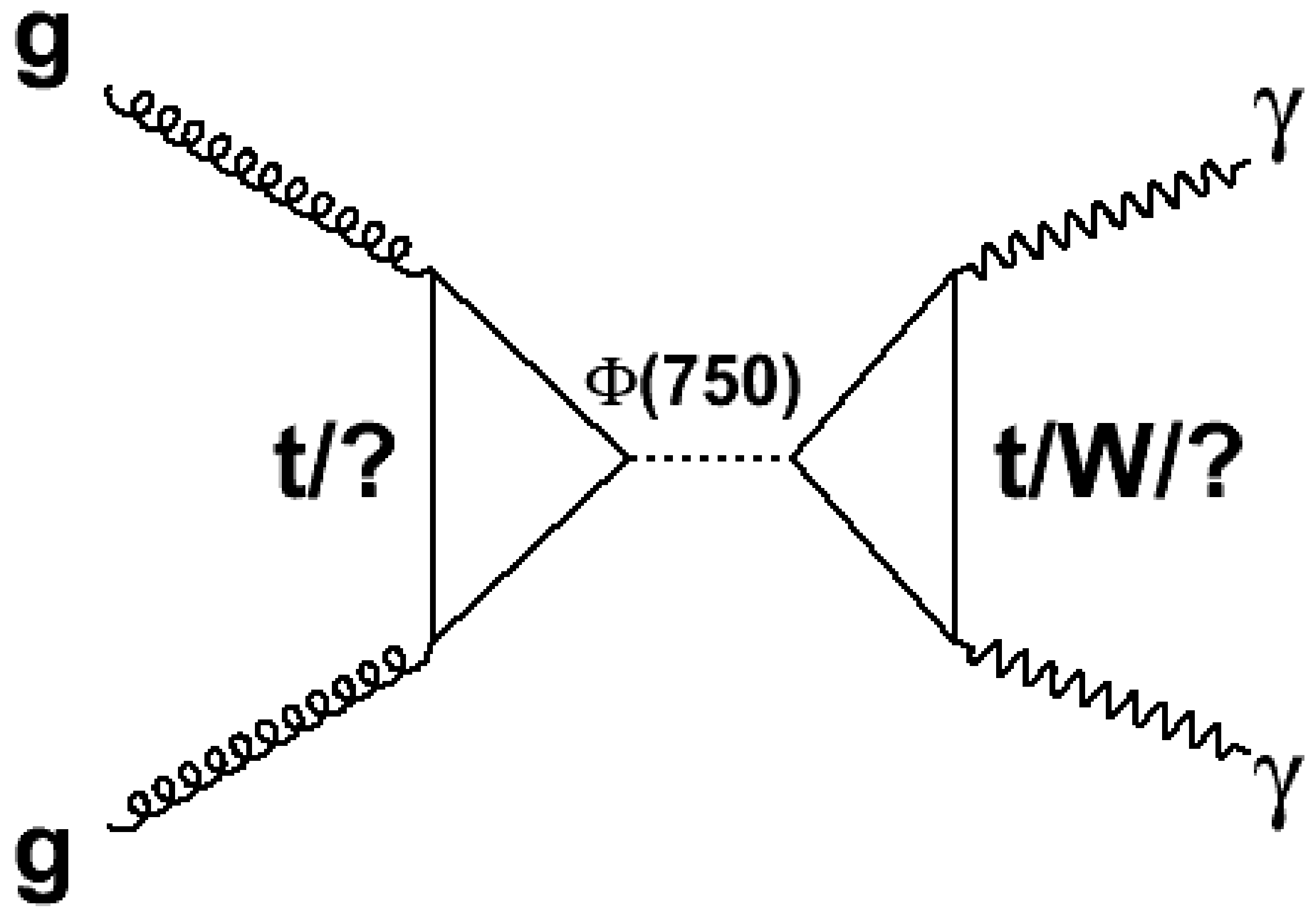


New physics: be prepared for surprises

From the LHC, with love: a new scalar with m=750 GeV

The new state – if it exists - couples to photons, presumably through loops

So we might be seeing something like this:

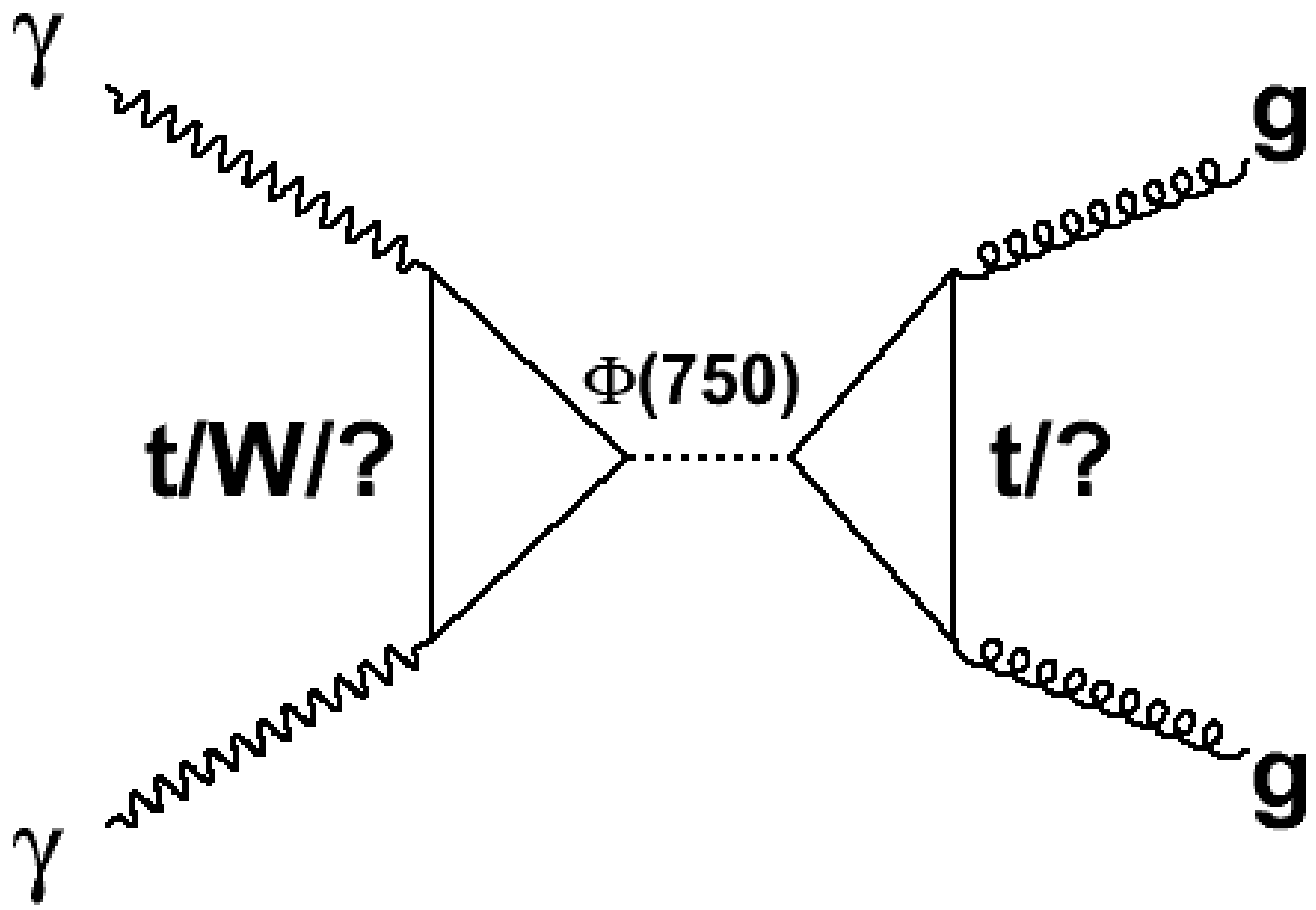


New physics: be prepared for surprises

From the LHC, with love: a new scalar with m=750 GeV

The new state – if it exists - couples to photons, presumably through loops

Then this other process should also have a sizeable rate:



New physics: photon collider?

A 1 TeV $e^+ e^-$ collider + couple of lasers

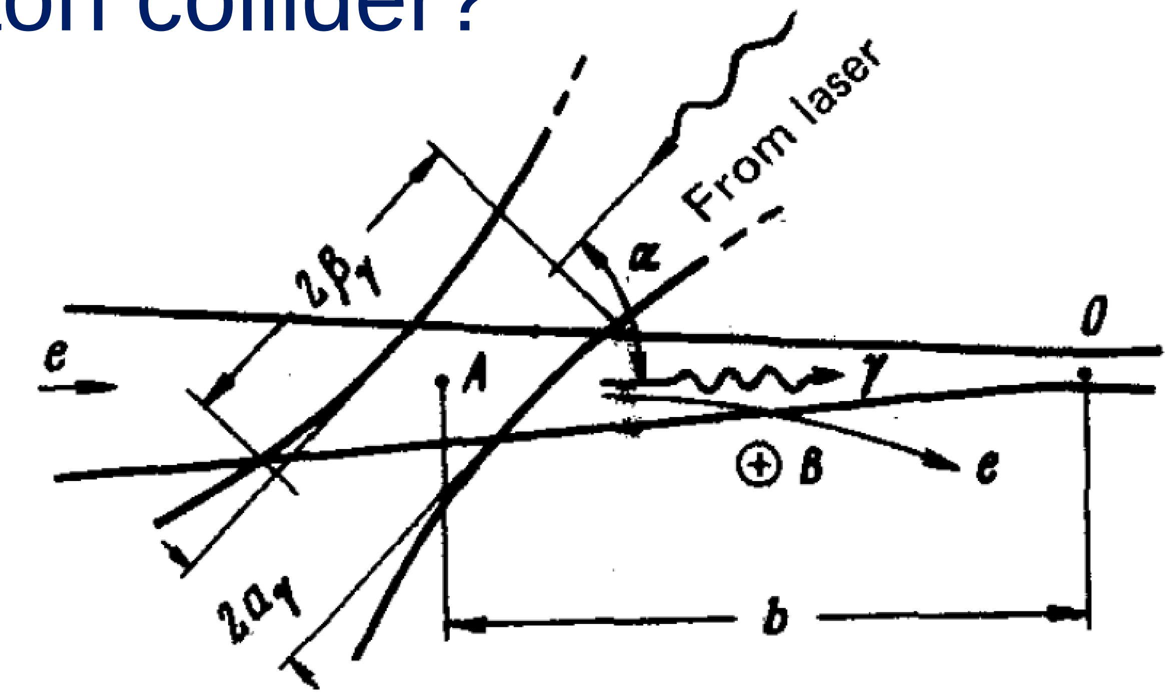
= 750 GeV photon collider

Production rate expected to be O(100) fb

F. Richard, private comm.

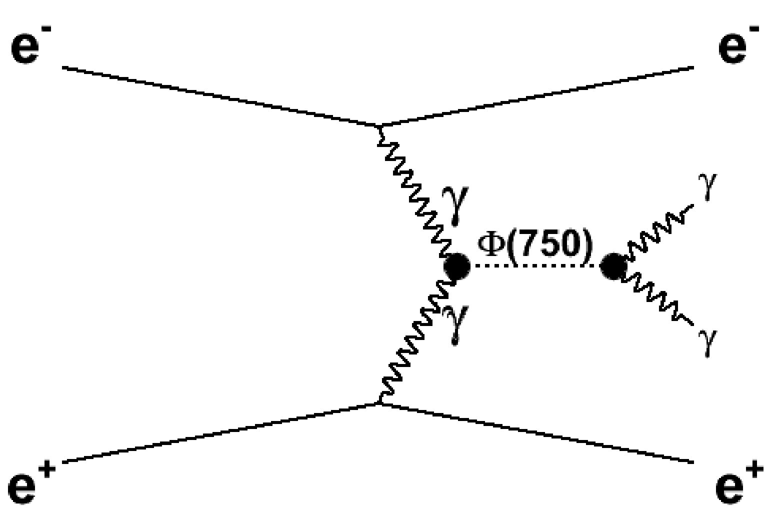
Ito, Moroi, Takaesu, arXiv:1601.01144

Djouadi el a., arXiv:1601.03696



Ginzburg et al., NIM 205, NIM 219, JETP Lett. (early 80s)
TESLA TDR, V. Telnov, JINST 9 (2014) 09 C0909

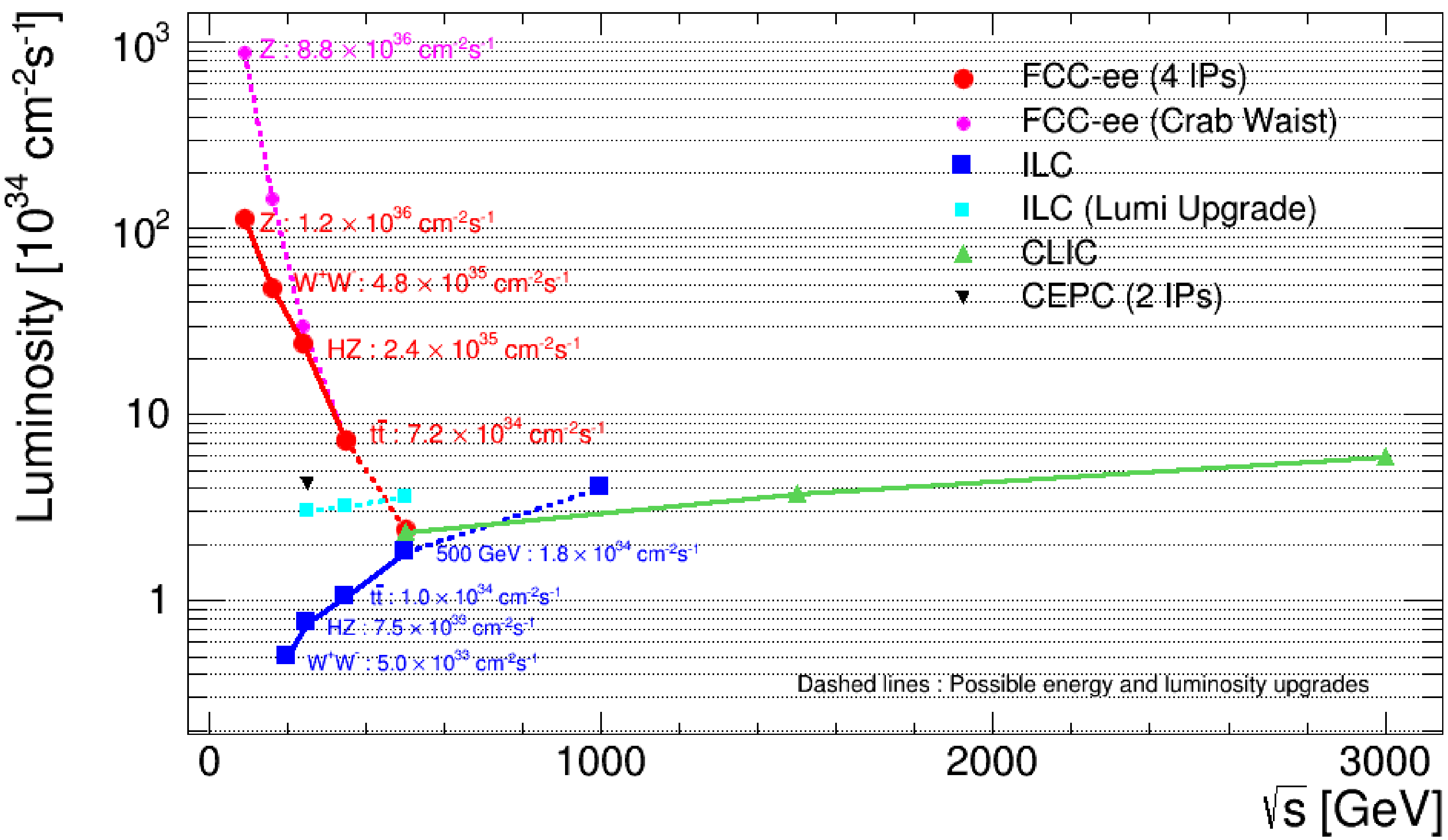
Fusion production at high energy collider



Sizeable cross-sections possible if photon dominates the Φ(750) width
Sizeable W,Z couplings not excluded

Best at rather high energy (2 TeV)

Lepton collider complementarity



Trust the slopes as indicative of "typical" machines, don't trust the normalization

The designs have very different degrees of maturity/realism.

Projects live on different time lines.

Circular vs. Linear – a matter of taste?

- Circular colliders: high luminosity at 1-2X LEP, great for Higgs-strahlung production (~250 GeV) synchrotron radiation limits energy reach (365 GeV for FCC-ee, ~250 GeV for CEPC)

- Linear colliders: running at 350 GeV – 1 TeV allows to access VBF Higgs, ttH and di-Higgs production. Yukawa and Higgs self-couplings. Multi-TeV operation in case of new discoveries.

Physics should tell us at which energy to invest

The energy-frontier landscape

Projects for high-energy electron-positron colliders

ILC – Japan
31 km – 500 GeV – 1 TeV
TDR 2012: shovel-ready
Physics by 2027

CLIC – CERN
31 km – 2-3 TeV
CDR 2014

CEPC – China

50 km – 250 GeV

Pre-CDR 2015

Physics by 2027?

FCC-ee – CERN
80-100 km – 365 GeV
No estimate for a date

Both circular tunnels to be used also for a hadron collider machine
China and CERN both start with electron-positron collisions

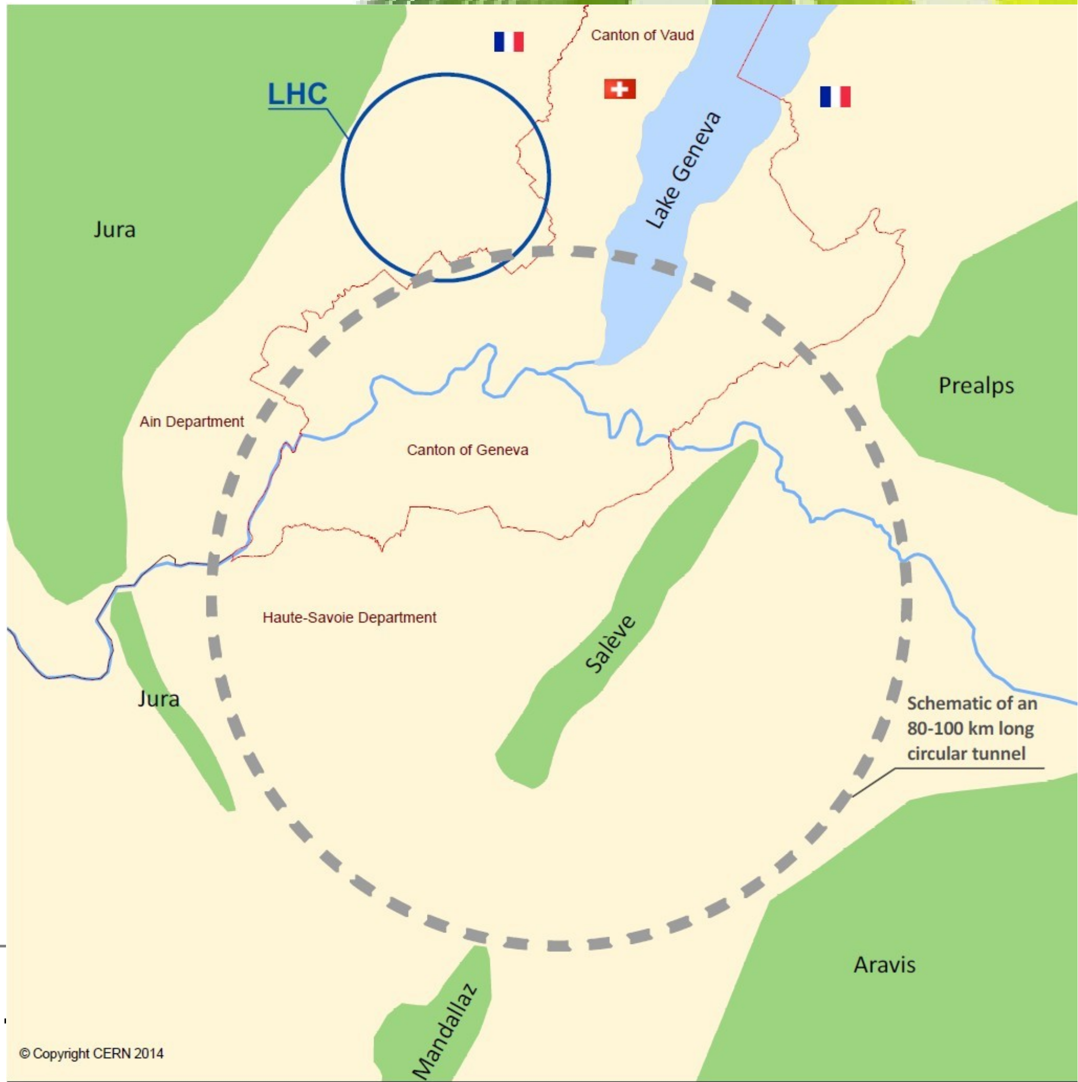
Circular lepton colliders

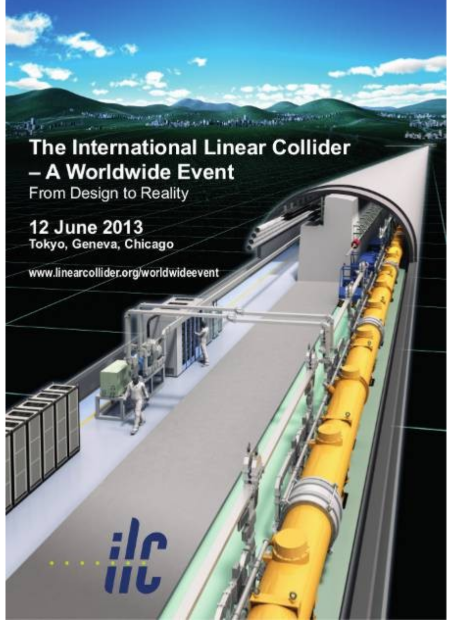
100 TeV p-p collisions as the ultimate goal
e^+e^- as an intermediate step

The European installation after the LHC?
Decision CLIC vs. FCC at CERN by 2019-20
Data in China by 2025?

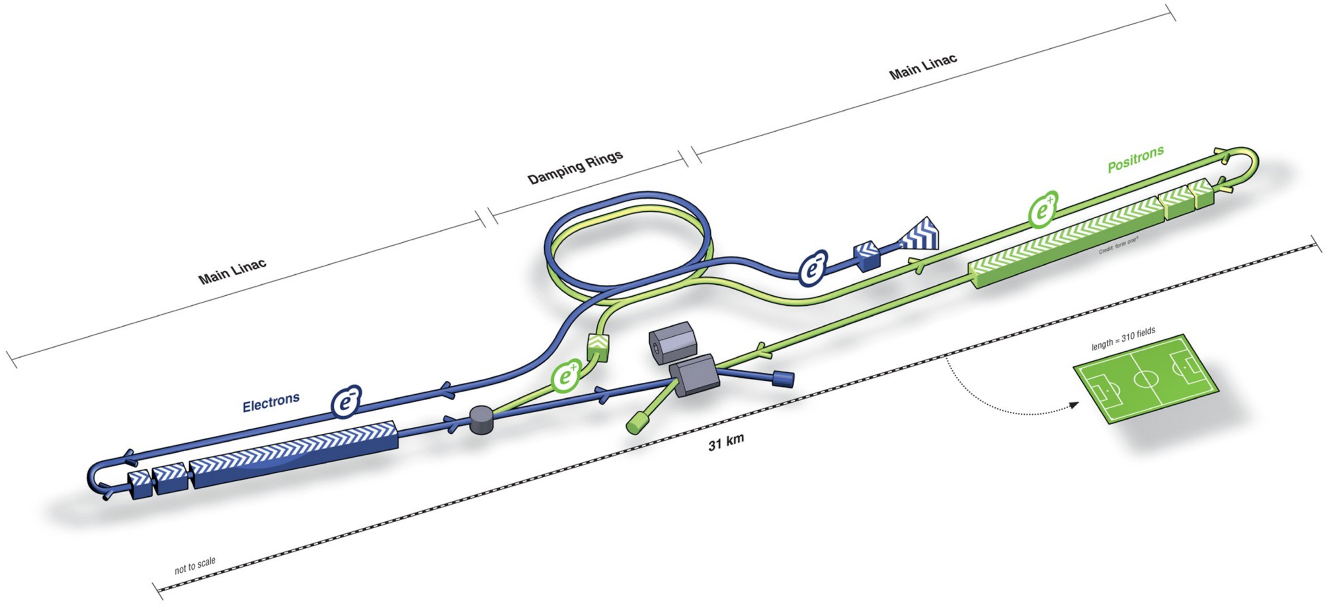
Circular energy-frontier machines:

CEPC	→ **pre-CDR**
TLEP/FCC-ee	→ **Starting coordinated effort**
FCC-hh	→ Magnet R&D
Muon Collider	→ Principle to be proven
	→ Very little actual effort





Linear lepton colliders



ILC Scheme | © www.form-one.de

Linear energy-frontier machines:

ILC → **TDR 2013;**

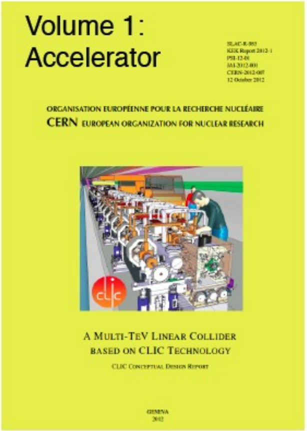
CLIC → CDR 2012

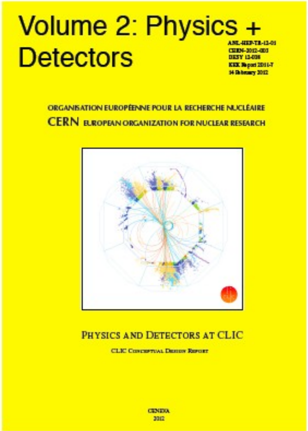
Wakefield e^+e^- → R&D

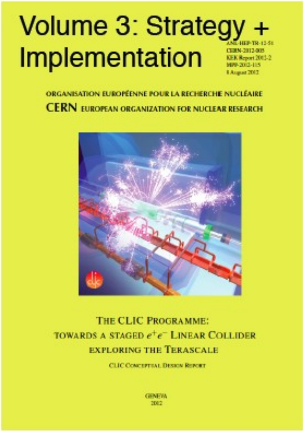
Shovel-ready Super Conducting RF at 30 MV/m
Programme: 550 GeV, 350 GeV, 250 GeV, LumiUp, 1 TeV
Political decision from Japan + US + Europe in next years

"The ILC design is much more mature than the LHC was when it was approved", Lyn Evans
XFEL at DESY is 10% prototype

Linear lepton colliders





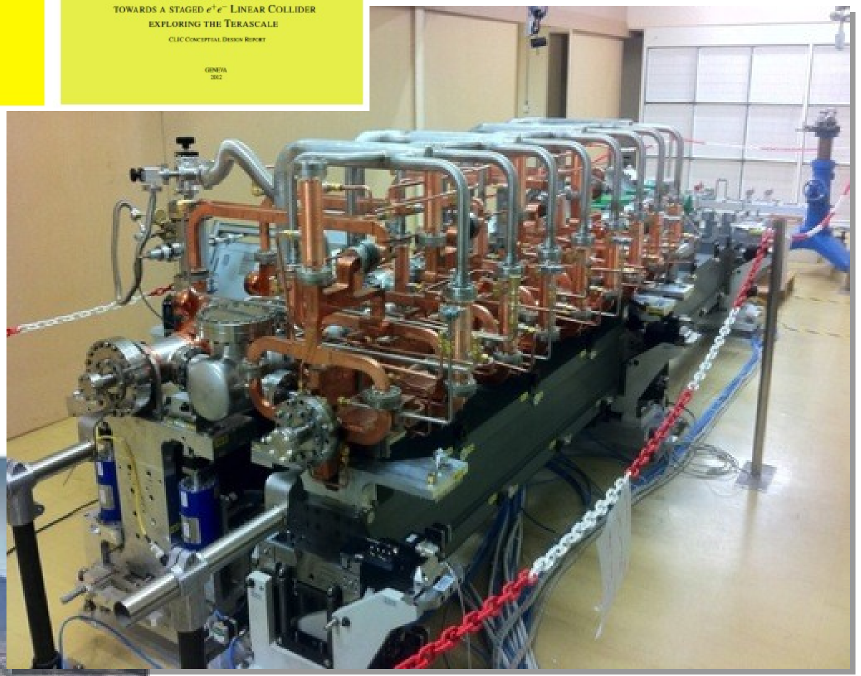


Linear energy-frontier machines:

ILC → TDR 2013

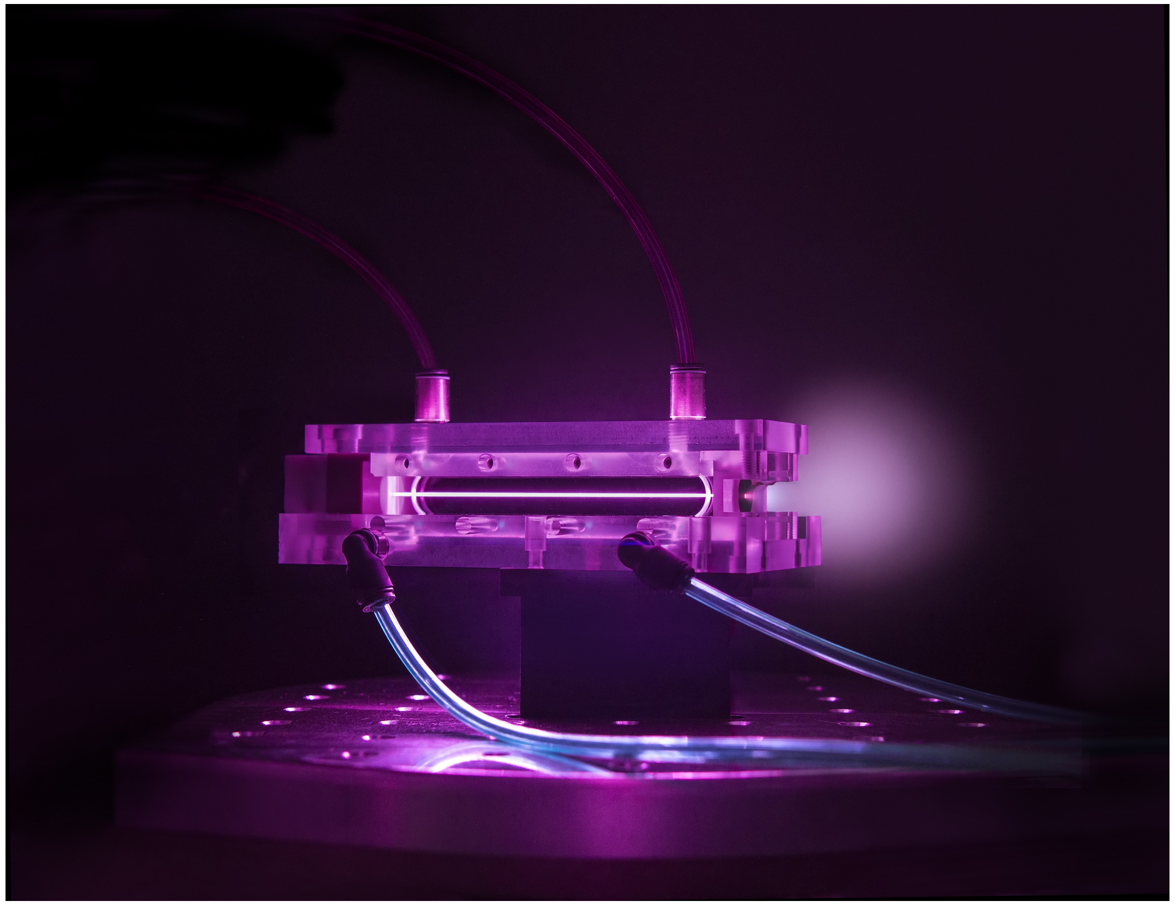
CLIC → CDR 2012

Wakefield e^+e^- → R&D



Proof-of-principle for acceration at 100 MV/m
Programme: 380 GeV (klystron-based?), 1.4 TeV, 3 TeV
Physics case high energy stage = new physics/exploration?
Decision by CERN by next European strategy

Linear lepton colliders



Linear energy-frontier machines:

ILC → TDR 2013

CLIC → CDR 2012

Wakefield e^+e^- → R&D

R&D at LBL, SLAC, CERN, DESY
Concept designs for 1 TeV machine
Recent progress: 6 GV/m, 20% efficiency, good emittance

World-wide strategy

The roadmap of particle physics envisages some support for ILC (after ensuring LHC + Lumi upgrade

Japan: *"We will call for inter-governmental negotiations with European and American governments in the first half of 2013"*, Minister Shimomura (MEXT) *Kitakami site in Tohoku, North Japan selected in August 2013*

AsiaHEP/ACFA (September 2013): *"...believes that the ILC is the most promising electron positron collider to achieve next generation physics objectives […], ... welcomes the proposal by the Japanese HEP community [...and] looks forward to a proposal from the Japanese Government to initiate the ILC project [...]"*

European Strategy (Cracow 2012, approved by CERN council): *"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 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."*

American Strategy: (Snowmass 2013, particle physics project priorization panel): *"The interest expressed in Japan in hosting the International Linear Collider (ILC) is an exciting development. Participation by the U.S. in project construction depends on a number of important factors, some of which are beyond the scope of P5 and some of which depend on budget Scenarios. As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years."*

Scientists have defined our roadmap. Now move over to political level:

- Japanese science ministry (MEXT) has created a committee to evaluate impact (social, economic and scientific) on Japan – interim report insists on ILC as a truly international project
- High-level negotiations with US are ongoing
- Less advanced discussions with Europe (CERN, EU)
- China has promised a contribution

Next European strategy delayed until 2019-2020...
Germany one of the first countries to express solid support for ILC
CERN will continue with one future project in Europe (i.e. CLIC OR FCC)

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LC 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)

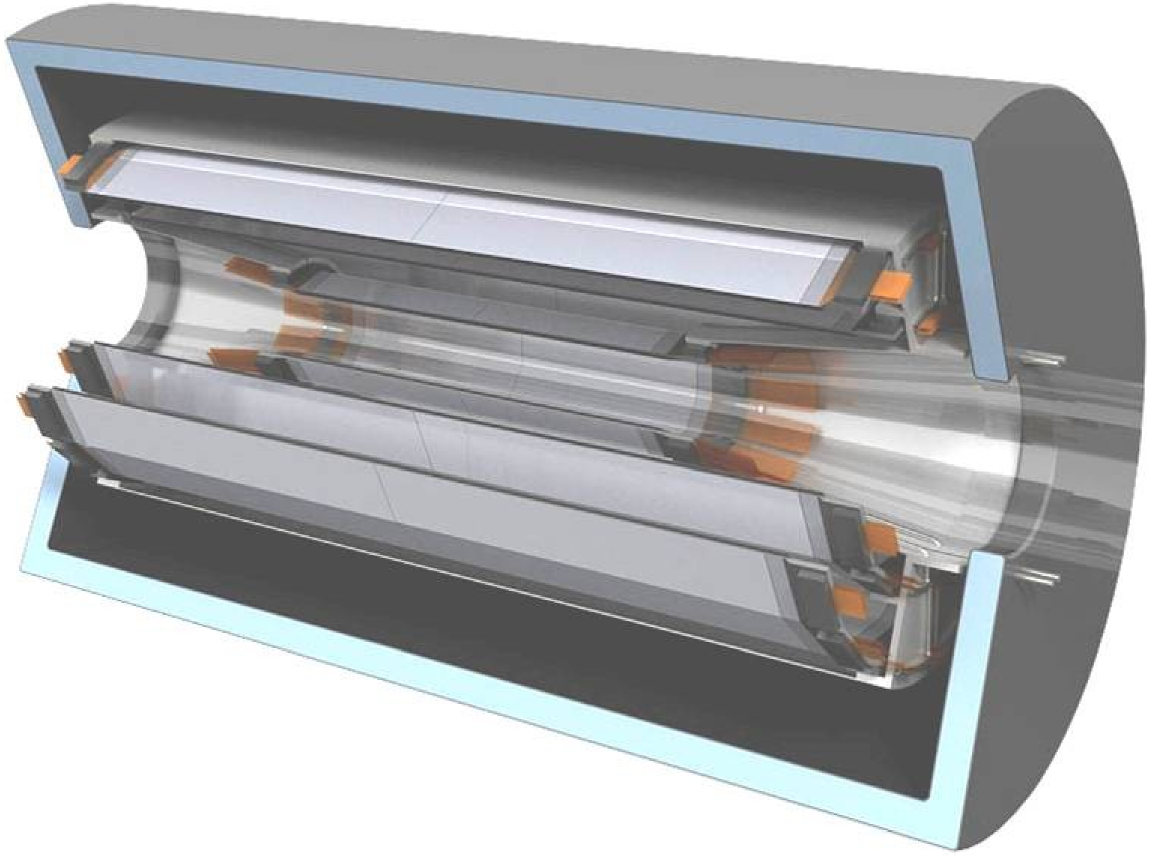
Stringent requirements

Resolution: 20 x 20 μm^2

Read-out speed: < 25/100 μs

(down to 500 or even 0.5 ns)

Material: 0.1...% / layer



DEPFET@ILC publications

Document by LCC detector R&D liaisons contains two pages on DEPFET

DEPFET active pixel detectors for a future linear e^+e^- collider - Report for the ECFA Detector R&D review, DESY, June 2014

The DEPFET collaboration (www.depfet.org)
E-mail: marcel.vos@ific.uv.es, cmarinas@uni-bonn.de, chk@hll.mpg.de, lca@hll.mpg.de

ABSTRACT: The DEPFET collaboration develops highly granular, ultra-transparent active pixel detectors for high-performance vertex reconstruction at e^+e^- collider experiments, such as Belle II and a future e^+e^- collider at the energy frontier. In this report, we review measurements on prototypes that prove the potential of the DEPFET operation principle and provide a status report for the development of a complete detector concept, including solutions for mechanical support, cooling, and services. An overview is also given of LC-specific R&D. Based on this experience we revisit the expected performance of a DEPFET-based vertex detector and show that DEPFET can meet the stringent requirements of the detector concepts for a future linear e^+e^- collider.

ECFA detector R&D panel
June 2014

MCC paper
http://arxiv.org/abs/arXiv:1604.08776

arXiv:1604.08776v1 [physics.ins-det] 29 Apr 2016

Integrated cooling channels in position-sensitive silicon detectors

L. Andricek[a] M. Boronat[b] I. Garcia[b,1] P. Gomis[b] C. Marinas[c] J. Ninkovic[a] M. Perelló[b] M.A. Villarejo[b] M. Vos[b]
[a] HalbLeiterLabor, Max Planck Gesellschaft, Munich, Germany
[b] IFIC (UV-CSIC) Valencia, Spain
[c] University of Bonn, Germany
E-mail: ignacio.garcia@ific.uv.es

ABSTRACT: We present an approach to construct position-sensitive silicon detectors with an integrated cooling circuit. Tests on samples demonstrate that a very modest liquid flow very effectively cool the devices up to a power dissipation of over 10 W/cm². The liquid flow is found to have a negligible impact on the mechanical performance. A finite-element simulation predicts the cooling performance to an accuracy of approximately 10 %.

KEYWORDS: Only keywords from JINST's keywords list please

ILC newsline

December 2012

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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
Download the current issue as a full .pdf

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

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

for ILC TDR

in IEEE TNS 60, 2 (2012),

still the official source

+ Regular assistance to LCWS and detector concept meetings
ECFA LC Santander → abstracts by L. Andricek, C. Marinas, M.A. Villarejo

DEPFET
Active Pixel Detector

DEPFET and detector concepts

ILD (see DBD)

Candidate technologies:

(mature & pursued in ILD)

- CMOS MAPs (Strasbourg, Besson)
- FPCCD (KEK/Sendai, Akimasa)
- **DEPFET** (collab, M.V. VXD convener)

Several alternatives

high-resistivity substrate CMOS sensors

multi-tier 3D pixel sensors.

SiD (see DBD)

Pushes for 3D integration

single BX (~500 ns) time stamping

Fall-back scenario:
DEPFET, MAPs, FPCCD

CLIC (see CDR)

Pushes hybrid pixel solution (TimePix)

HVCMOS, HRCMOS?

10 ns time stamping

CEPC (see pre-CDR)

fine pitch, low power consumption and fast readout

DC machine, no power-pulsing!!!

DEPFET is mentioned prominently

TLEP (no document)

Similar to CEPC, study impact of synchrotron radiation

Current effort

Adequate presence in ILD

Essentially no effort in SiD

Some synergy with CLIC on thermo-mechanical issues

Some interest from CEPC

DEPFET for LC detectors

Recommendations from ECFA detector R&D review:

Not all issues for ILC will be addressed in the Belle II development hence additional support will be needed for developing the DEPFET technology for use in an ILC tracker.

Many of these issues are progressing slowly as priority of the collaboration clearly lies elsewhere. Launch renewed effort as resources/manpower become available (and as the urgency of the LC requires)

Compared to pre-Belle II times we can produce a very good **ILC prototype:**

- thinned LC-design sensors
- read out by DCD
- beam test as “parasitic” user.

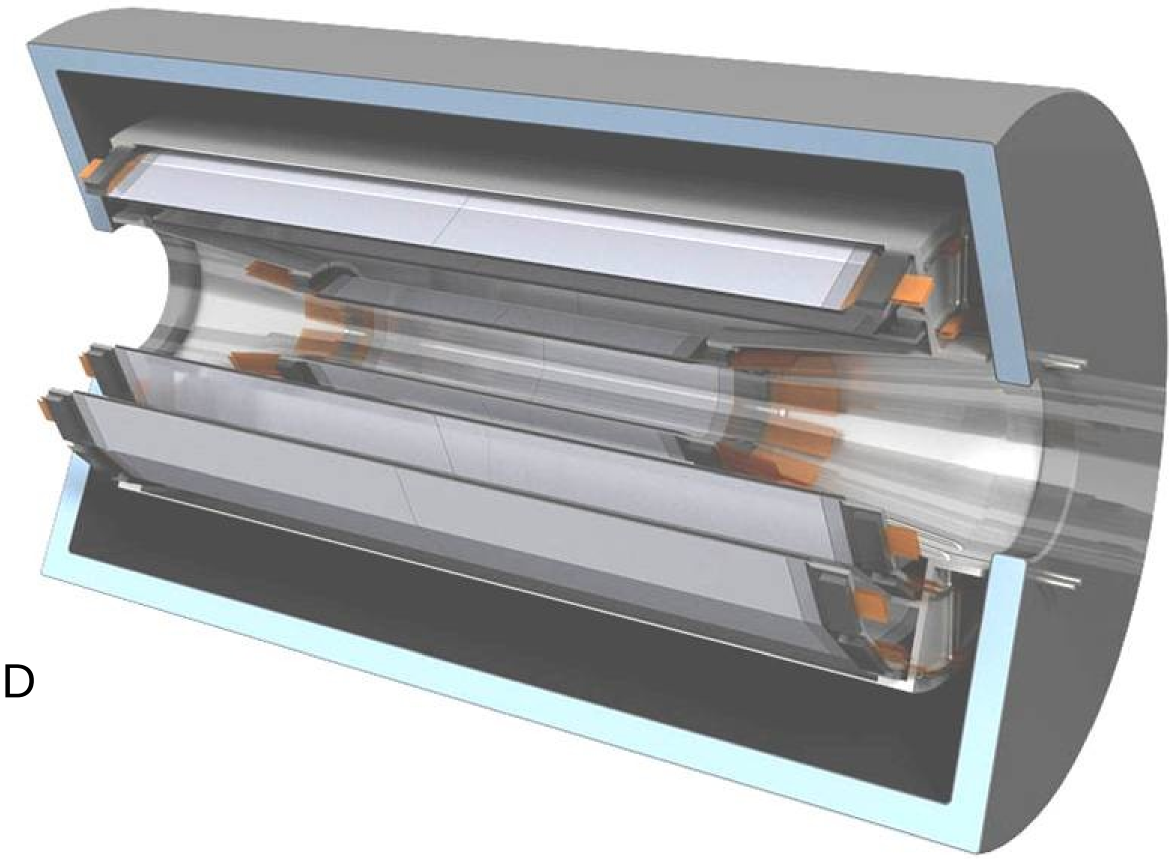
Detailed, realistic design

ECFA review panel: “The DEPFET collaboration has developed a detector ladder that already now meets many ILC requirements.”

Vertex detector design in MC still very “generic”

Estimate technology-dependent performance

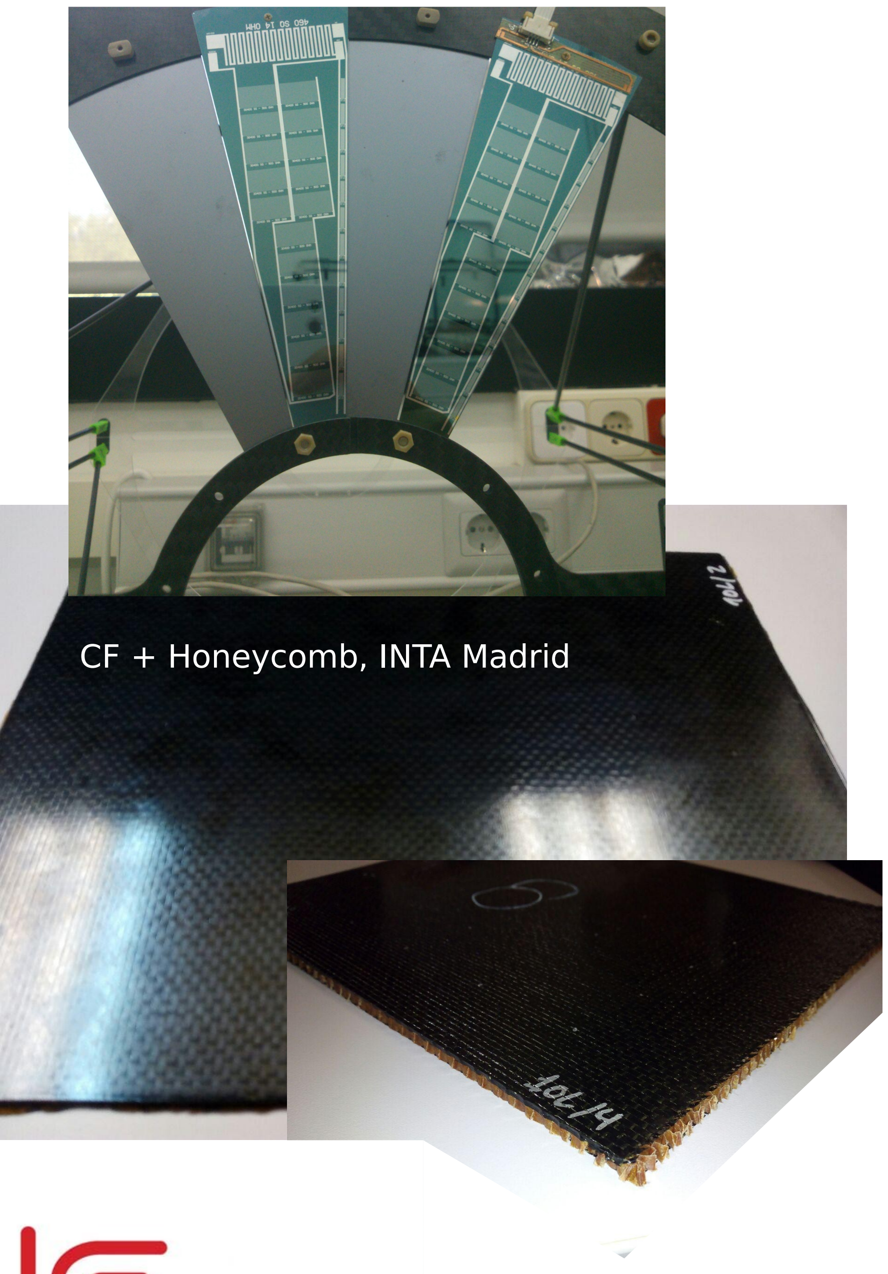
- detailed DEPFET digitizer
  - Software exists, needs some effort
- realistic support structures
  - To be shared with other group
- realistic end-of-ladder material and services
  - M.A. Villarejo (IFIC)



The ILD concept has seen some activity from MAPS and FPCCD
Need to step up our effort!!

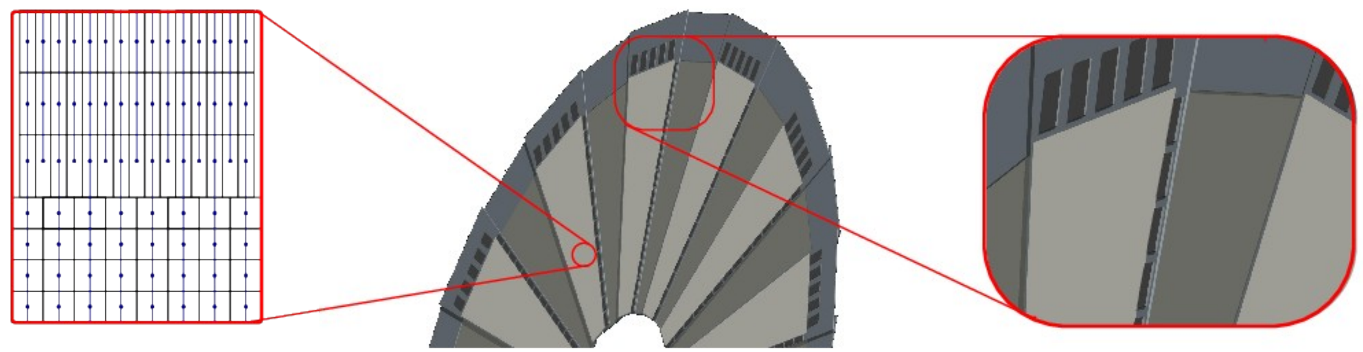
Disk design and mock-up

ECFA review panel: “For the ILC the main challenge is to engineer the forward tracking disk region. We recommend that the work on forward petal continues to demonstrate that petals that meet ILC requirements can be made... that more effort is made on the transition and forward regions to find a credible engineering solution , cooling and services.”



ILC detectors extend coverage to 6 degrees

- need end-cap for vertex detector



Subject thin DEPFET petals to ILC environment:

- ILD/FTD geometry
- low-mass CF support structure
- pulsed power in heater circuits
- forced air flow for cooling (no liquid!)

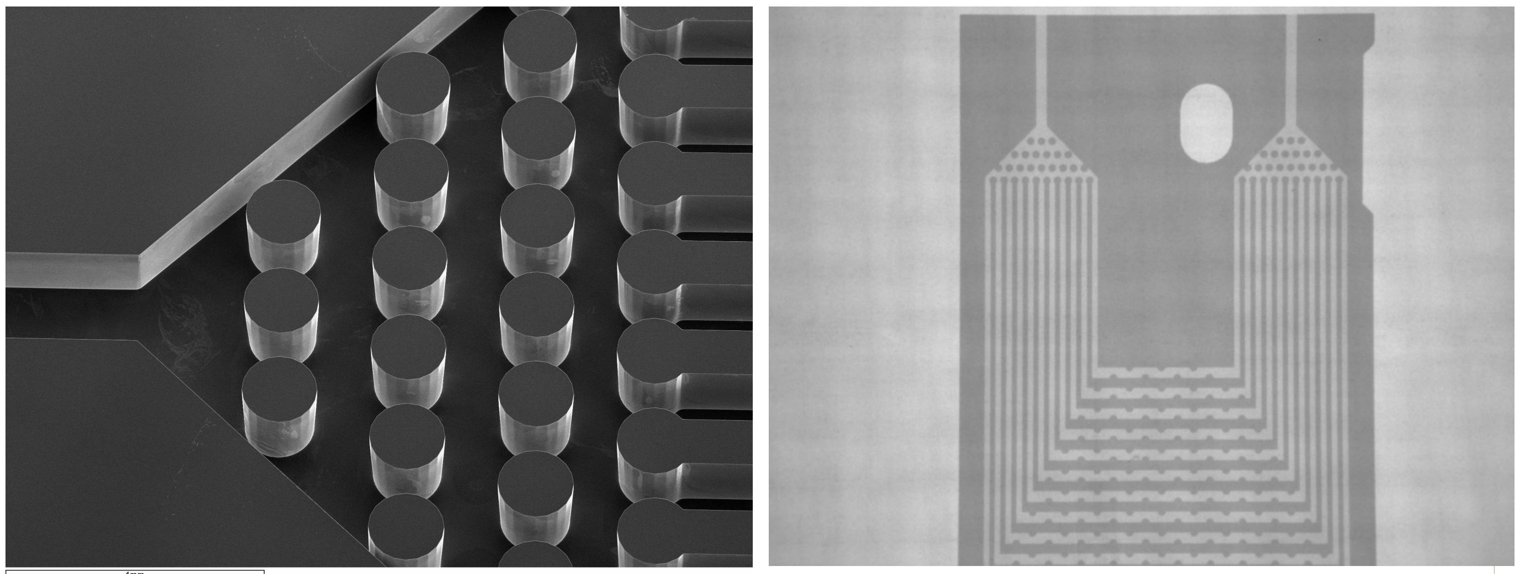
And monitor thermo-mechanical properties:

- power pulsing + air flow yield adequate cooling
- deformations and vibrations under control

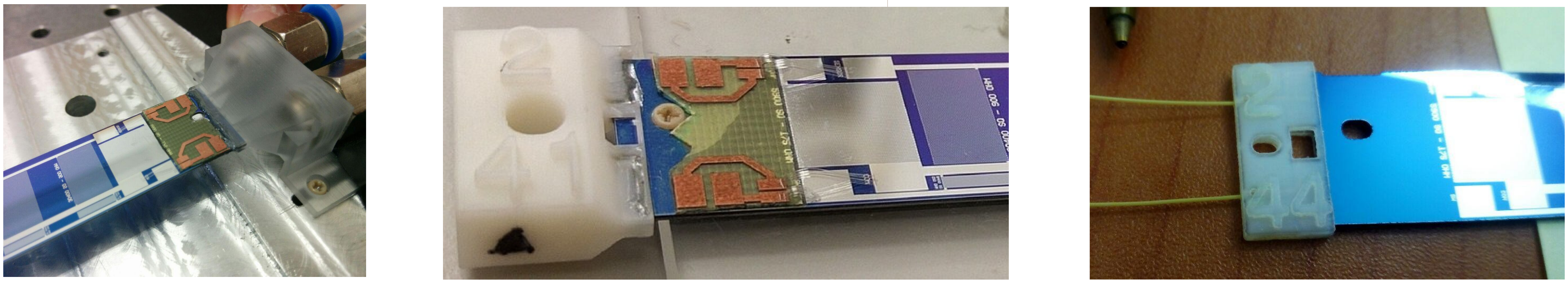
Micro-channel cooling

ECFA review: “The work on micro-channel cooling can profit from collaboration with other groups doing the same development.” → funding in AIDA2020

Generic R&D to add a technology to our portfolio: not ILC-specific, probably best at CEPC/TLEP



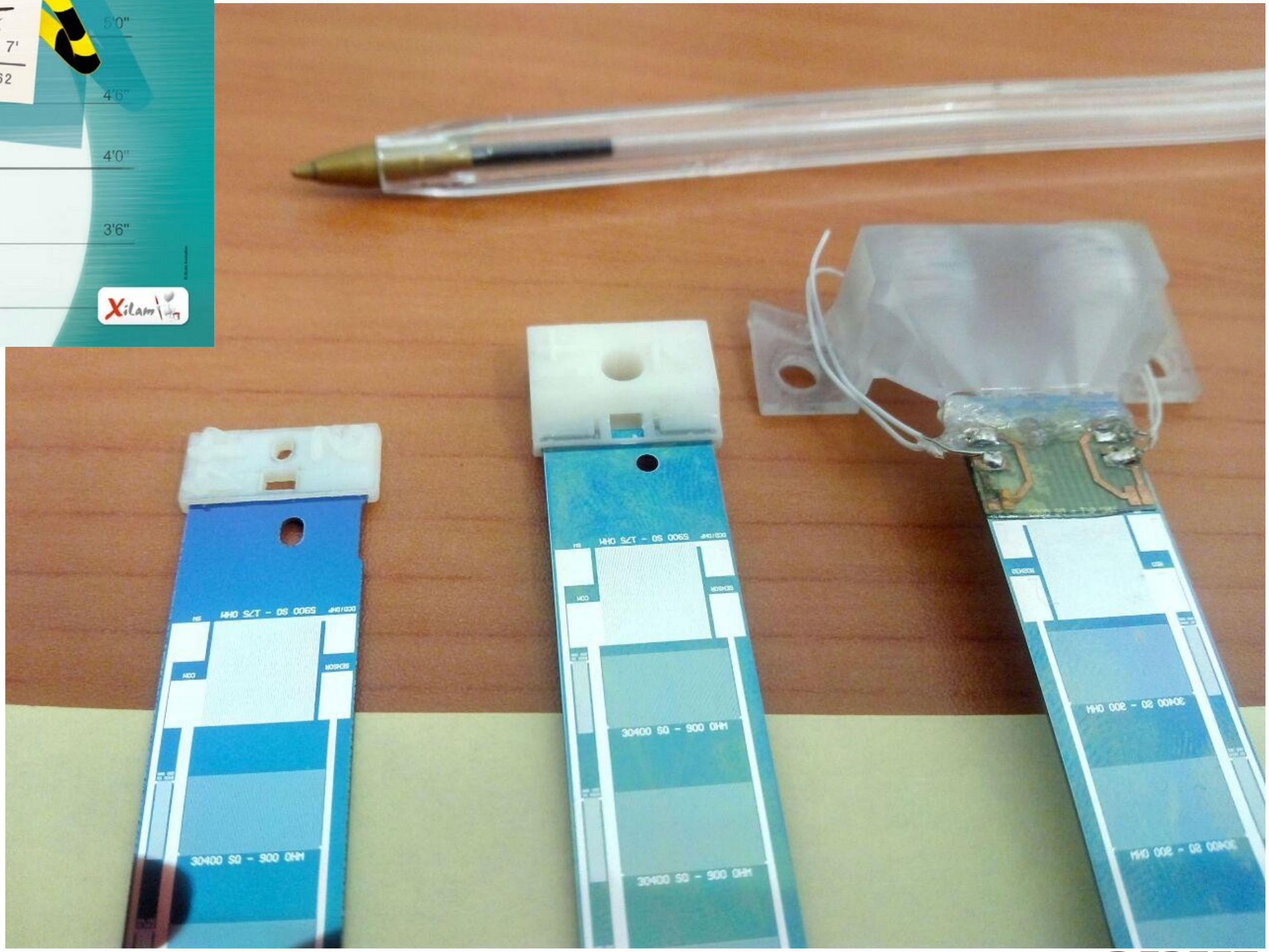
Micro-manifold before (photograph) and After wafer bonding (X-ray image) Samples produced at HLL.



High-tech plumbing: custom, 3D-printed interfaces to commercial piping

First encouraging results: “cool 40 W with 3 l/h and ΔT = 10 K”
Paper sent to JINST (arXiv:1604.08776), MCCv2 in production

Towards a low-X_0 connector



Conclusions

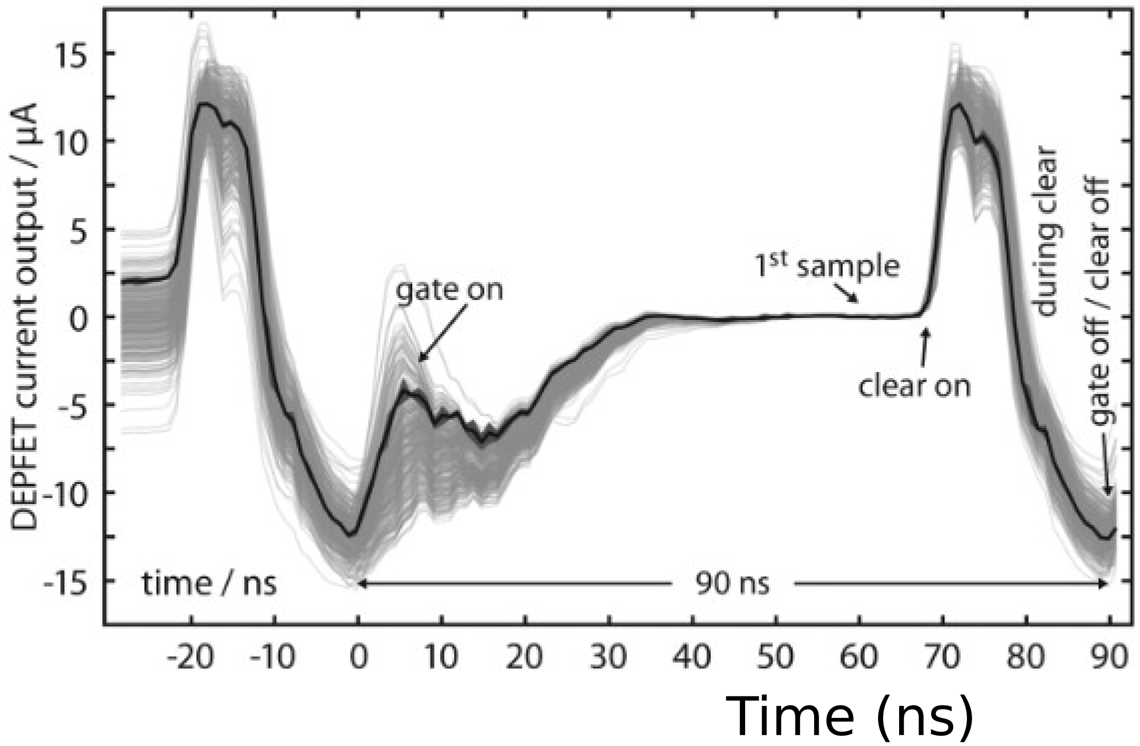
A global LC hosted in Japan... might just happen! React if it does.
DEPFET is a good candidate for the circular machines.

Small, but adequate, DEPFET presence in LC:
- contributions to ILC TDR & liaison report
- Regular reports in LC workshops (ALCW15, LCWS14, ….)

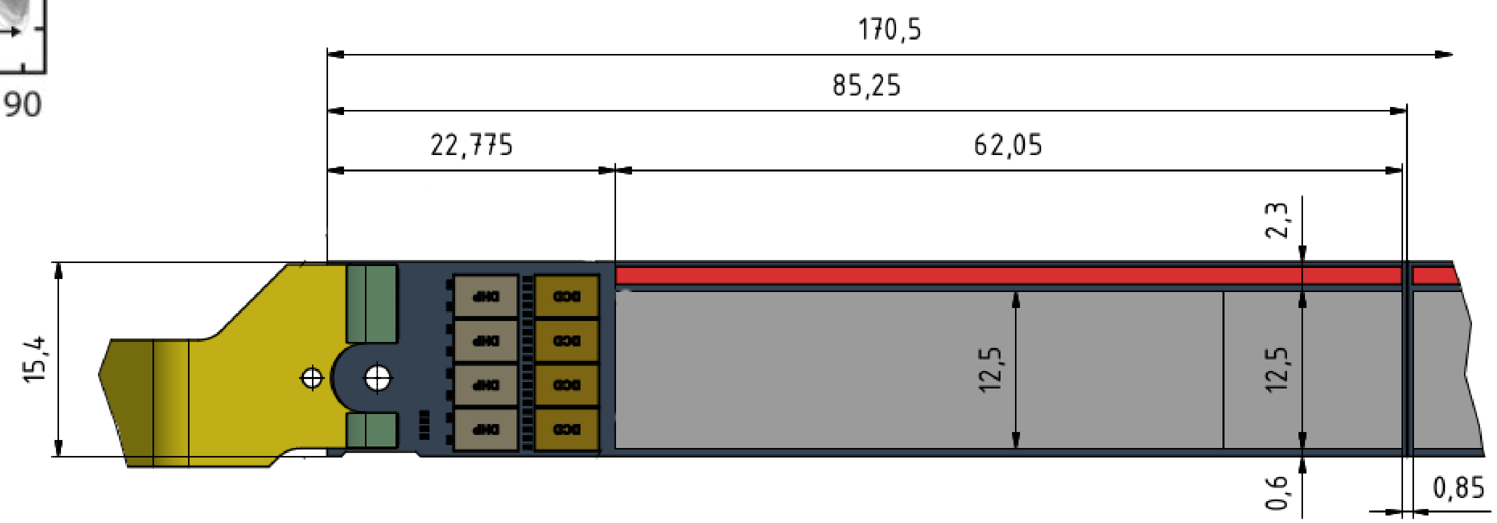
DEPFET remains a solid candidate for the ILC VXD:
The best argument for DEPFET is: **success of the Belle II PXD**

Step up LC-specific developments:
- R&D → improve read-out speed, cooling concept
- Take advantage of Belle-II developments
  → bring thin ILC design to TB
  → provide DEPFET-digitizer to LC concepts
  → translate lessons learnt to realistic design

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 //*

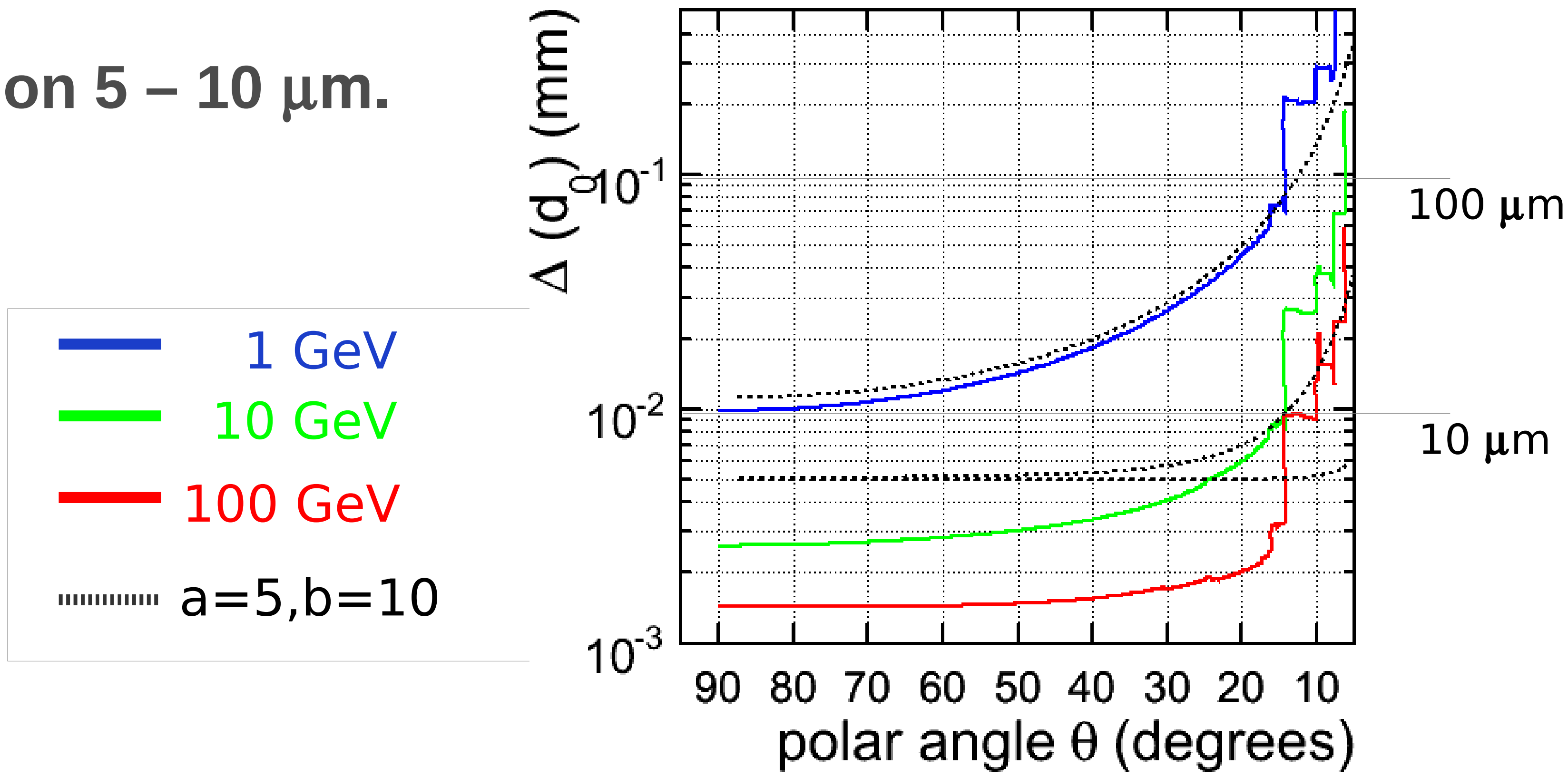
Row rate: *1/80 ns*

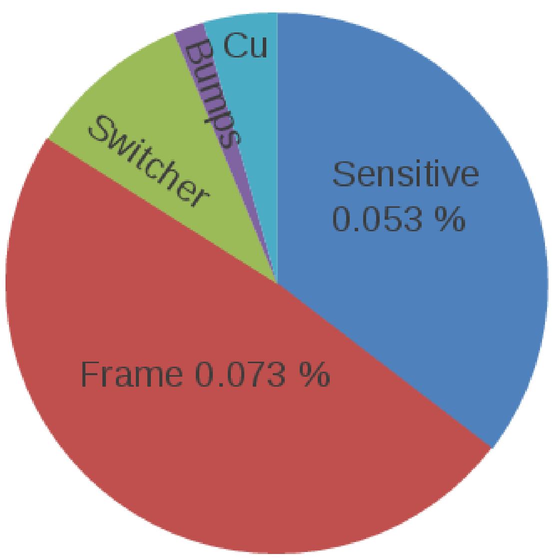
Frame time: *40 μs (20 μs)*

Impact parameter resolution

VXD: impact parameter resolution 5 – 10 µm.

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

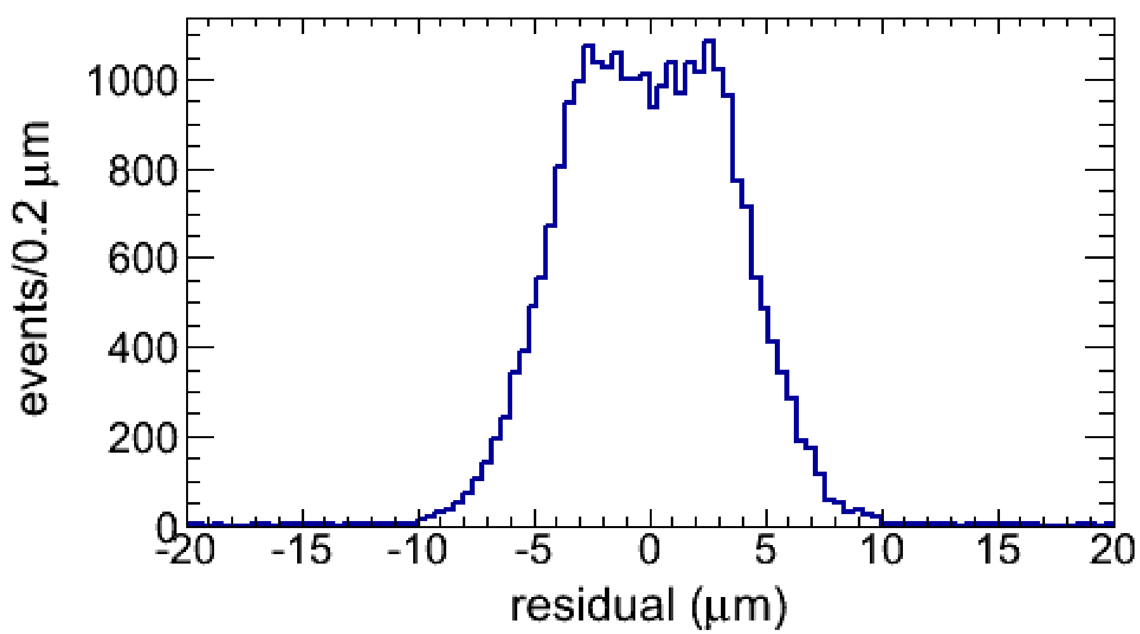




Sensitive	0.053 % X_0
Frame	0.073 % X_0
Switcher	0.015 % X_0
Cu layer	0.007 % X_0
Bumps	0.003 % X_0
Total ladder	0.15 % X_0

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

Spatial resolution →
(simulation, perp. Incidence)



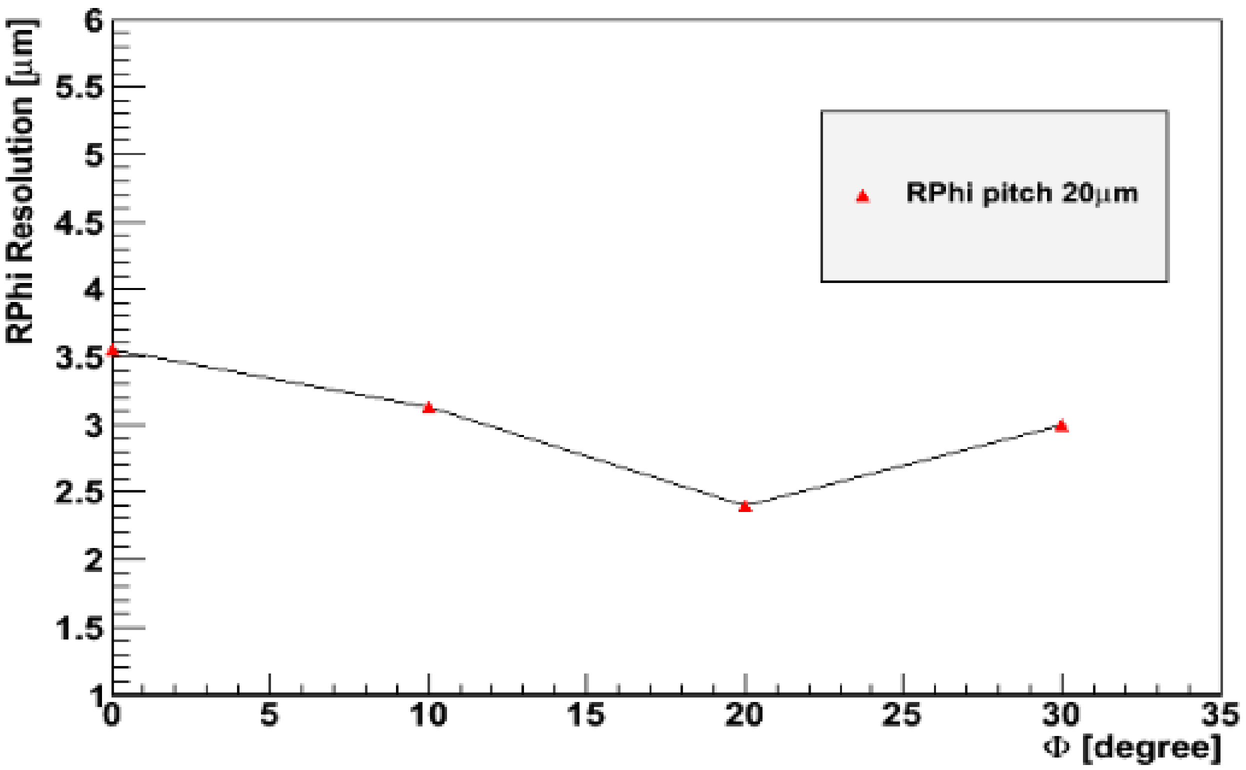
Summary: LC vs Belle-II

	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

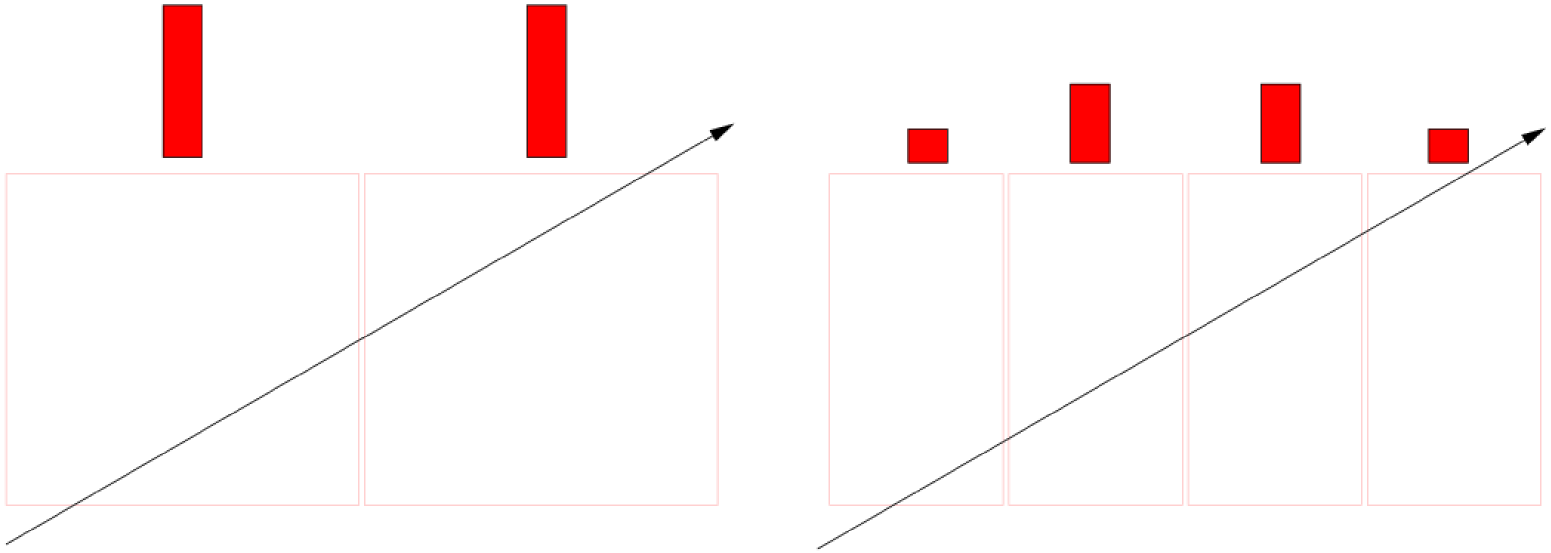
Belle-II presents a more severe challenge than the ILC in several aspects!

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)

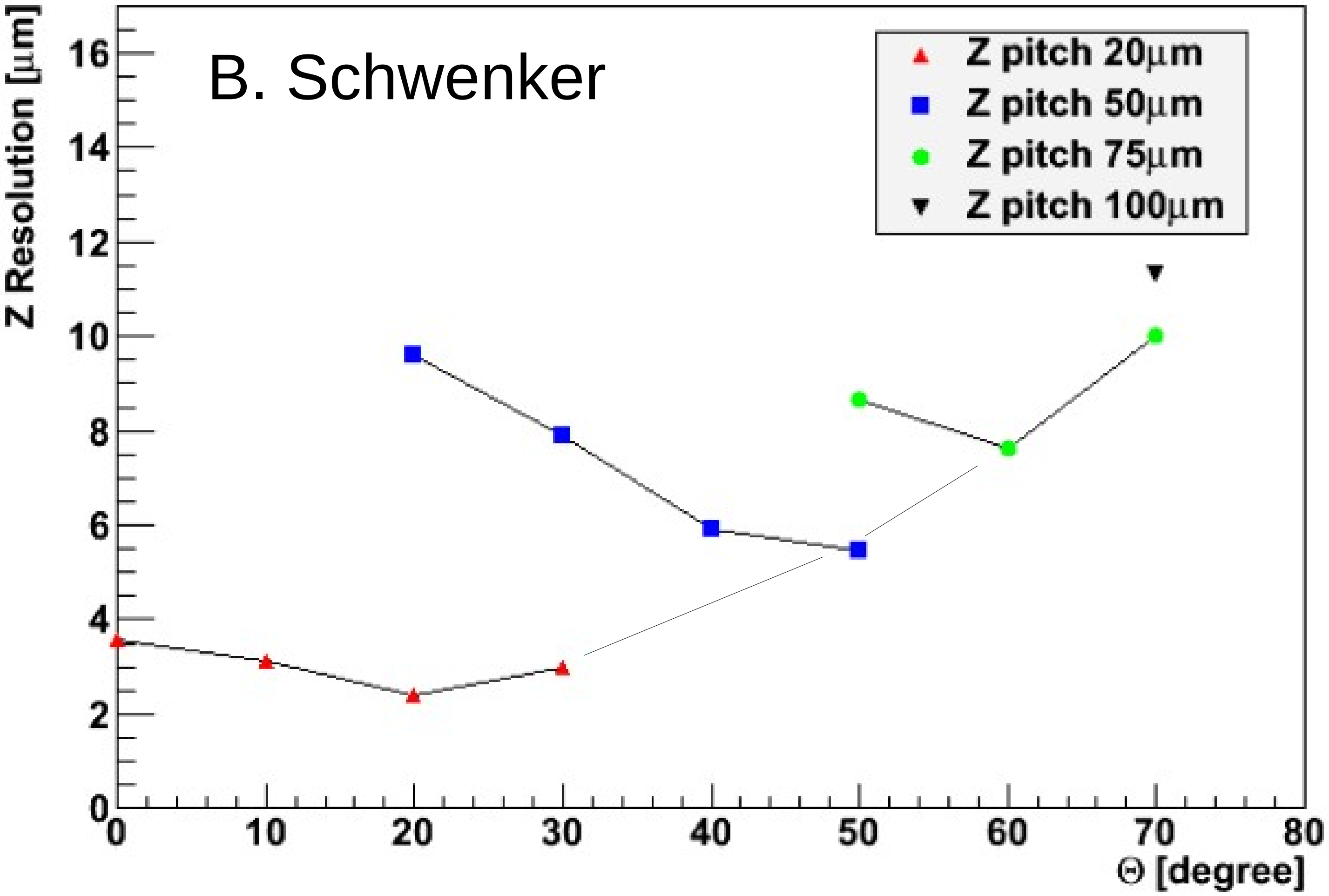


Spatial resolution for shallow tracks

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



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.