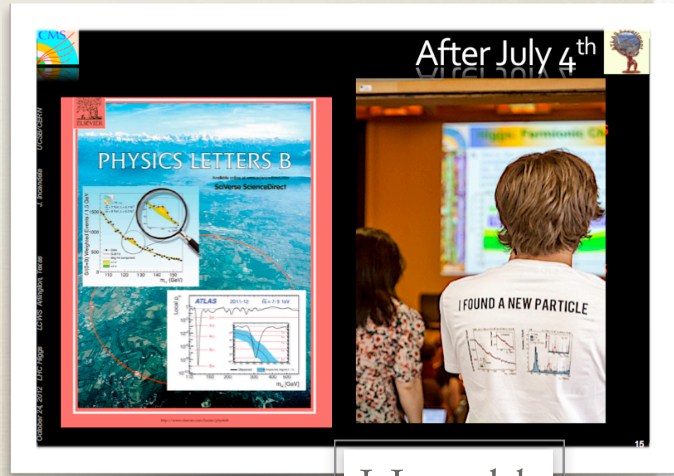
PHYSICS AND DETECTORS FOR THE LINEAR COLLIDER

LCWS 2012

Jim Brau

Linear Collider in 2012

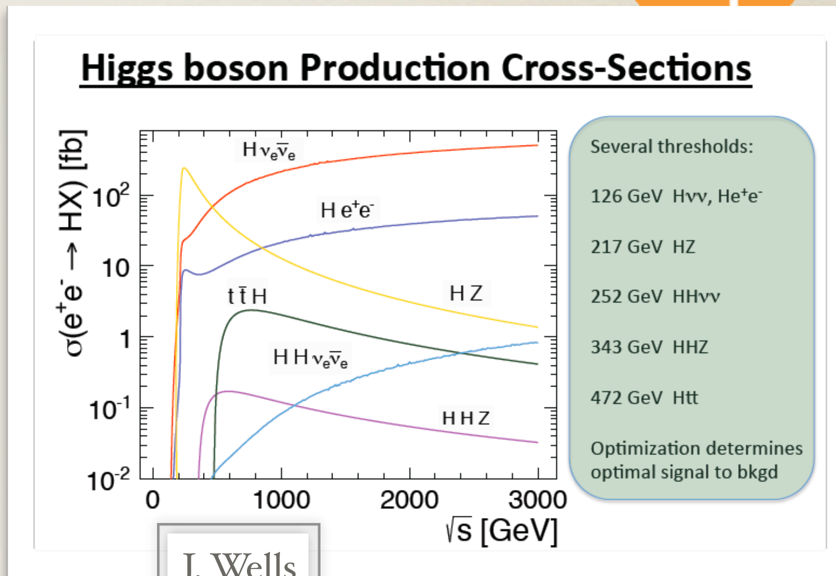
- We now have an excellent physics case for the LC
  - New particle (scalar? SM Higgs? What is "it" precisely?)
    - Golden opportunity for the LC
  - Follow up on any additional LHC discoveries
  - Unique sensitivity to other New Physics
    - Color neutral states
    - extended Higgs sector



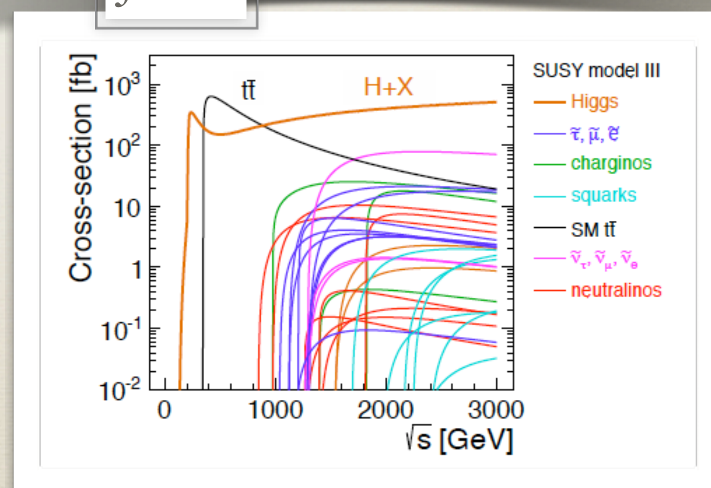
J. Incandela

Higher Energy w/CLIC

- Physics case for ILC and CLIC are similar
  - Higgs, LHC discoveries, weakly interacting particles
  - Higher energy reach
- Technical readiness of collider is critical issue

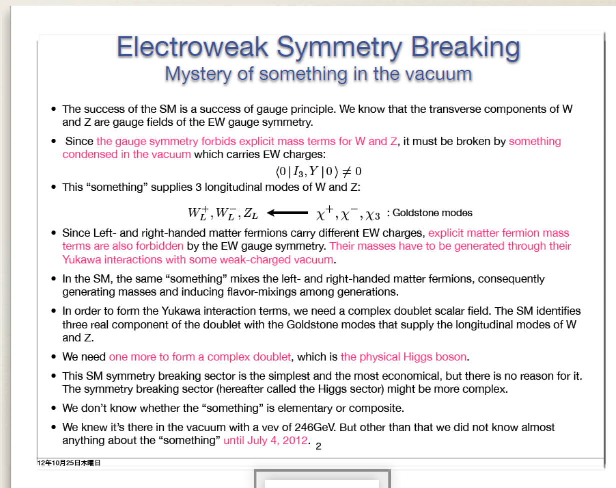


J. Wells



Higgs Boson

- Role of scalar bosons has been central question in HEP for decades
  - mediate symmetry breaking?
  - moderate cross section?
  - give mass to particles?
- With the discovery of the Higgs Boson we will begin to answer these questions - and more



Electroweak Symmetry Breaking

Mystery of something in the vacuum

- The success of the SM is a success of gauge principle. We know that the transverse components of W and Z are gauge fields of the EW gauge symmetry.
- Since the gauge symmetry forbids explicit mass terms for W and Z, it must be broken by something condensed in the vacuum which carries EW charges:

$$\langle 0 \,|\, I_3, Y \,|\, 0 \rangle \neq 0$$

- This “something” supplies 3 longitudinal modes of W and Z:

$$W_L^+, W_L^-, Z_L \longleftarrow \chi^+, \chi^-, \chi_3 \quad \text{: Goldstone modes}$$

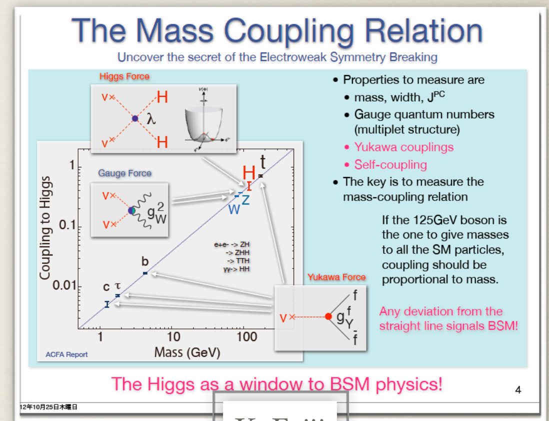
- Since Left- and right-handed matter fermions carry different EW charges, explicit matter fermion mass terms are also forbidden by the EW gauge symmetry. Their masses have to be generated through their Yukawa interactions with some weak-charged vacuum.
- In the SM, the same “something” mixes the left- and right-handed matter fermions, consequently generating masses and inducing flavor-mixings among generations.
- In order to form the Yukawa interaction terms, we need a complex doublet scalar field. The SM identifies three real component of the doublet with the Goldstone modes that supply the longitudinal modes of W and Z.
- We need one more to form a complex doublet, which is the physical Higgs boson.
- This SM symmetry breaking sector is the simplest and the most economical, but there is no reason for it. The symmetry breaking sector (hereafter called the Higgs sector) might be more complex.
- We don’t know whether the “something” is elementary or composite.
- We knew it’s there in the vacuum with a vev of 246GeV. But other than that we did not know almost anything about the “something” until July 4, 2012. 2

12年10月25日木曜日

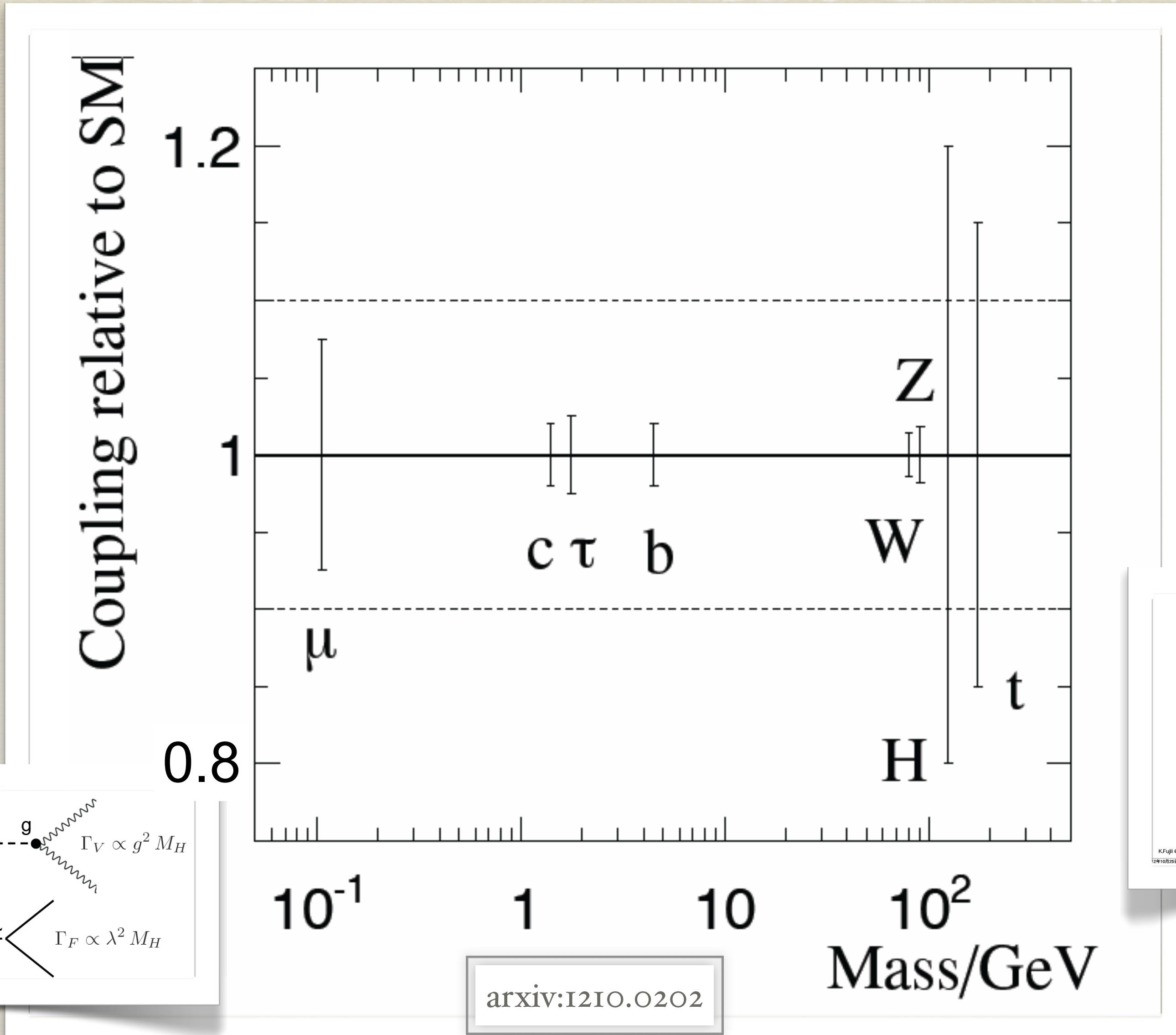
K. Fujii

Higgs Boson

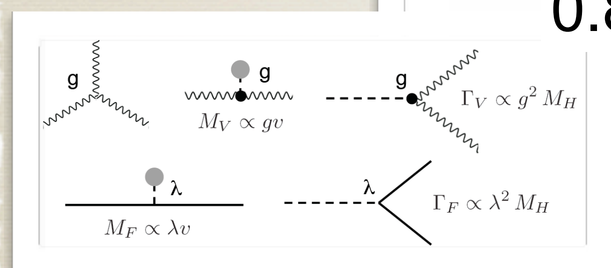
- The Higgs, a fundamental spin-zero (scalar) particle is a NEW TYPE OF MATTER and VERY DIFFERENT
  - Standard Model specifies relationships
    - couplings, cross sections, etc.
  - BSM varieties suggest alternative behaviors and multiple states
  - What is "it"? It is essential to know to advance high energy physics

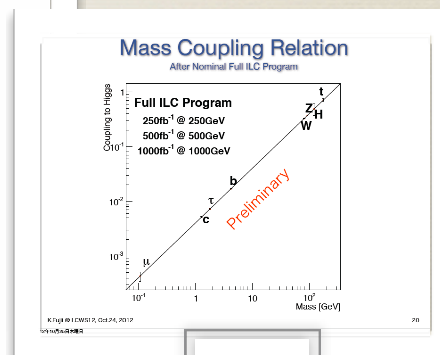


K. Fujii



arxiv:1210.0202





K. Fujii

* Linear Collider precision is excellent, but what level is needed?

Few percent Needed

- Decoupling limit - deviations from SM could be quite small - Haber arxiv:9501320

- SUSY

$$g(\tau)/SM = 1 + 10\% \left(\frac{400 \text{ GeV}}{m_A}\right)^2$$

$$g(b)/SM = g(\tau)/SM + (1-3)\%$$

- Little Higgs

$$g(g)/SM = 1 + (5-9)\%$$
$$g(\gamma)/SM = 1 + (5-6)\%$$

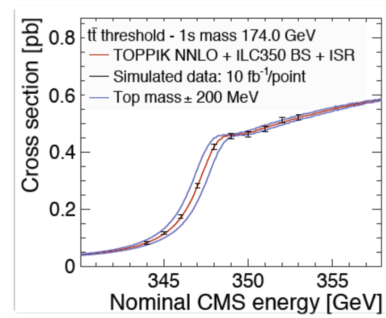
- Composite Higgs

$$g(f)/SM = 1 + (3-9)\% \cdot \left(\frac{1 \text{ TeV}}{f}\right)^2$$

Peskin arxiv:1208.5152

LC does more than Higgs couplings!

- HIGGS - beyond precision coupling measurements
  - Higgs mass – < 50 MeV; Higgs width – 4-5%
  - Sensitive to mixing of CP-even and CP-odd to 3-4%
- TOP
  - Top quark mass <100 MeV (statistical precision of 20 MeV)
    - stability of the vacuum
  - Top quark width ~30 MeV
  - Asymmetries ~5%
  - Precise tests of Top couplings to Gauge bosons
- LOW MASS DARK MATTER SEARCH



Preliminary: Baer et al., Physics at ILC, DBD Report.

Linear Collider Physics

- REFINING LHC DISCOVERIES
  - Precision probe in clean, low background environment reveals underlying physics
- DIRECT DISCOVERIES
  - Color neutral states
  - Higgs sector
- DISCOVERIES THROUGH PRECISION
  - Precision tests of SM particles highly sensitive to new physics

Unprecedented Detectors Needed

- Clean events with low backgrounds allow unprecedented detectors
- Detector R&D critical to develop technology
- Many advances by LC community - especially,
  - calorimetry
  - tracking
  - vertex detector
  - forward detectors
- Significant progress has been achieved, BUT important detailed R&D work remains - the experts know this

Detector Challenges

Physics Process	Measured Quantity	Critical System	Critical Detector Characteristic	Required Performance
$H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impact parameter ⇒ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$ Precise
ZH→$\ell^+\ell^-$X $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu}$ $\to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR (H →μμ)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ ⇒ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV$ Superb
ZHH $ZH \to q\bar{q}b\bar{b}$ ZH→ZWW* $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass BR (H → WW*) σ(e+e- → νν W+W-)	Tracker & Calorimeter	Jet Energy Resolution, σ_E/E ⇒ Di-jet Mass Res.	~3% for E_{jet} > 100 GeV $30\%/\sqrt{E_{jet}}$ for E_{jet} < 100 GeV Excellent
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum resolution, Hermiticity ⇒ Event Reconstruction	Maximal solid angle coverage Full

Recent advances in LC detector R&D

Disclaimer:

Impossible to pay justice to the ongoing detector R&D in 25 minutes !

This talk concentrates on **recent 2011-2012** advances in <u>detector technology</u>

Collection of snapshots

Challenges in LC detector R&D

These requirements lead to the following challenges:

Vertex and tracker

- Very high granularity
- Dense integration of functionalities
- Super-light materials
- Low-power design + power pulsing
- Air cooling

ultra – light

Calorimetry

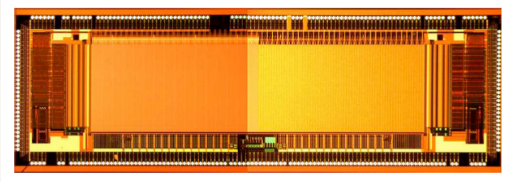
- Fine segmentation in R, phi, Z
- Ultra – compact active layers
- Pushing integration to limits
- Power pulsing

ultra – heavy and compact

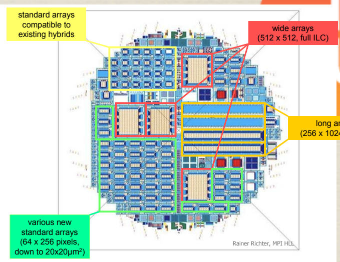
Detector R&D

Vertex Detectors

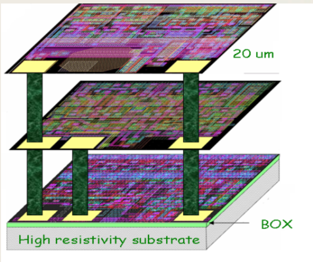
- Candidate VXD sensors have been produced
- Integration issues are being addressed (mechanics, power, heat,…)
- Tough requirements
  High resolution, fast readout, low mass, low heat
- Technical demonstration needed



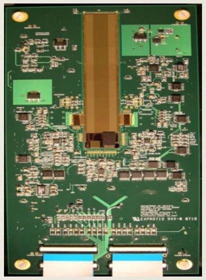
MIMOSA



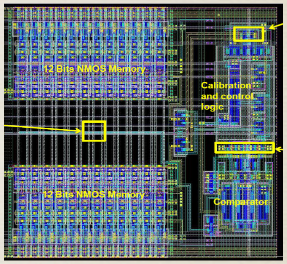
DEPFET



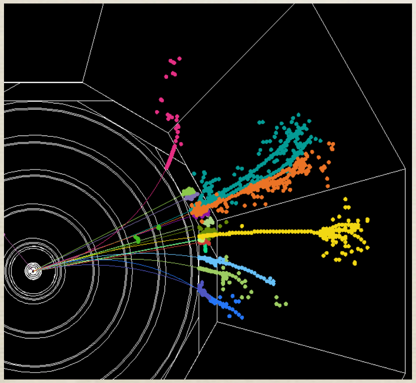
3D-SOI



CCD



CHRONOPIXEL

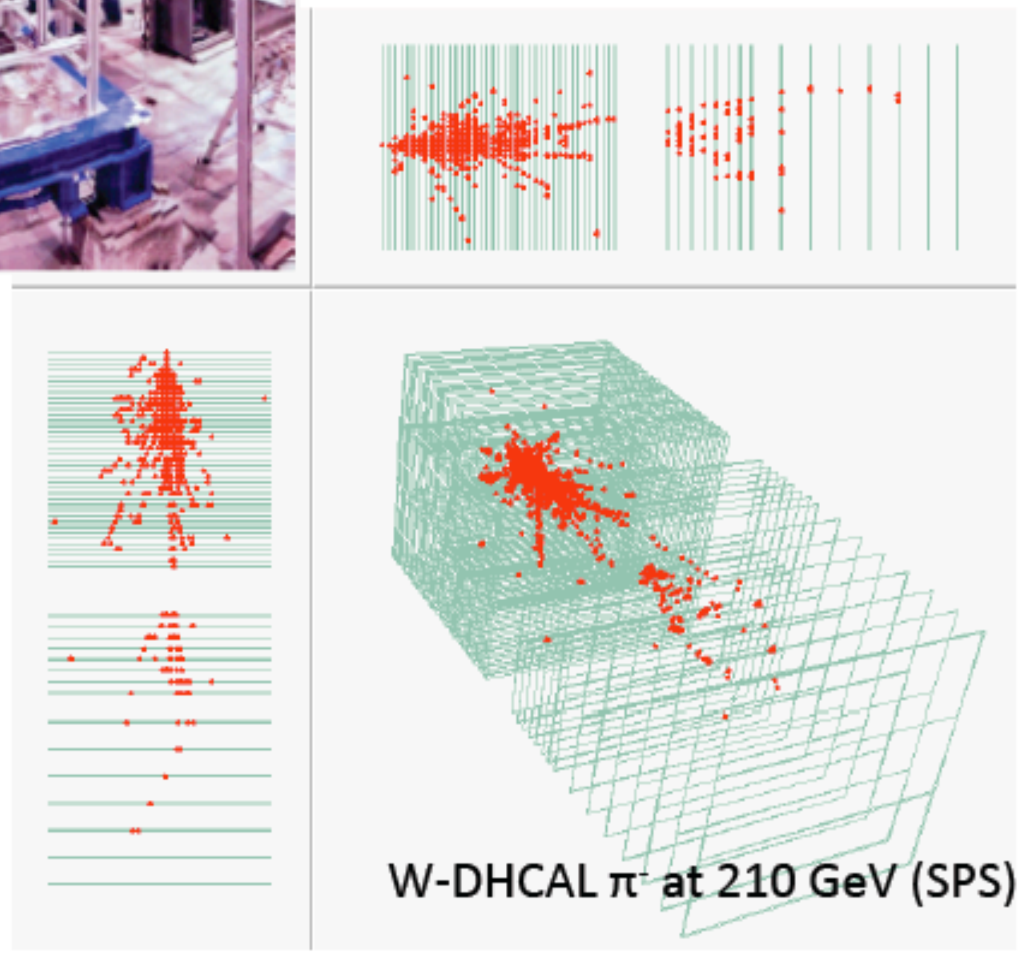


Particle Flow Calorimetry

- Pandora PFA gives $\Delta E/E$ = 3-4% in full simulation
- Experimental confirmation from CALICE
- PFAs have become a design tool, useful for detector optimization.

HCAL: DHCAL (CALICE)

Steel DHCAL
Tungsten DHCAL
500’000 readout channels



54 glass RPC chambers, 1m² each
PAD size 1×1 cm²
Digital readout (1 threshold)
100 ns time-slicing
Fully integrated electronics
Main DHCAL stack (39) + tail catcher (15)
Total 500’000 readout channels

Successfully tested:
2010+2011 **Fermilab**
Steel absorber
2012 **CERN** PS + SPS
Tungsten absorber

CERN test setup includes **fast readout RPC after** (T3B)

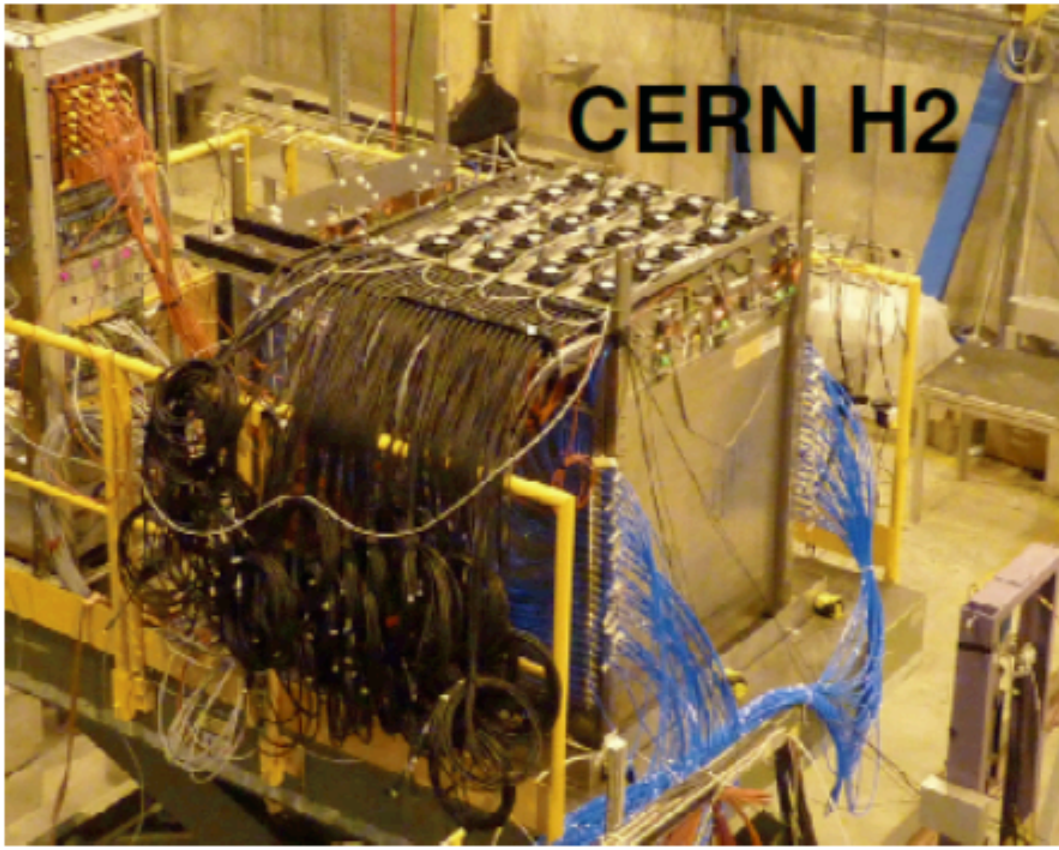
HCAL: SDHCAL (CALICE)

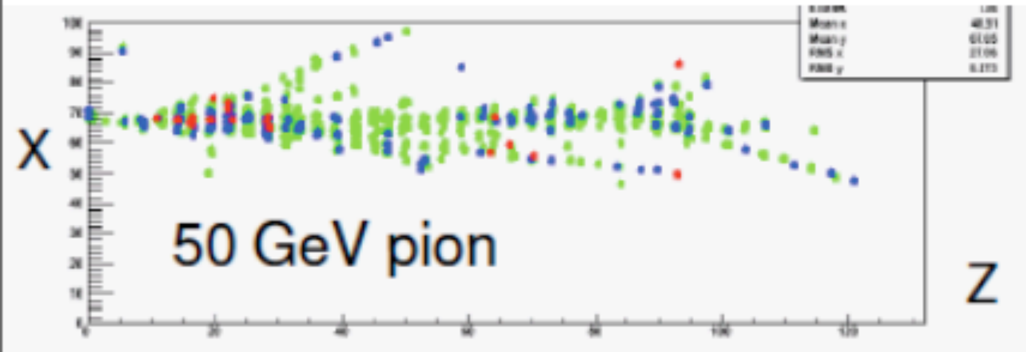
Steel SDHCAL
500'000 readout channels

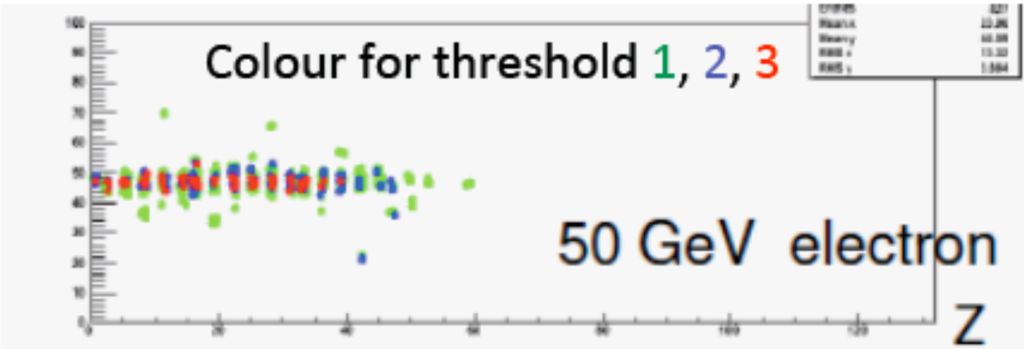
~50 glass RPC chambers, 1m^2 each
PAD size 1×1 cm^2
Semi-digital readout (3 thresholds)
200 ns time-slicing
Fully integrated electronics

With power-pulsing !
Separate power-pulsing tests in 3T magnet
=> Stable signal response

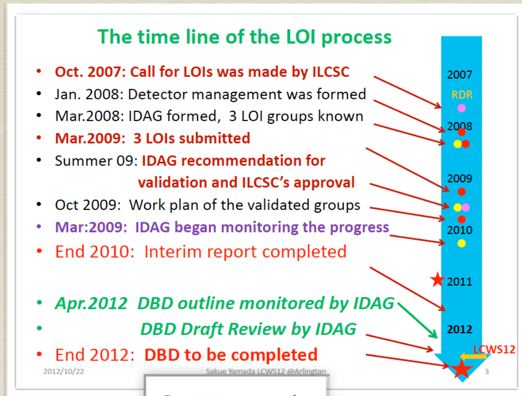
Full SDHCAL stack **successfully tested**:
2012 (2011) CERN - ongoing
Steel absorber





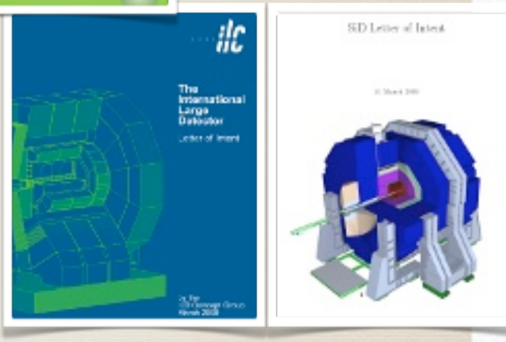


ILC Detector Roadmap



S. Yamada

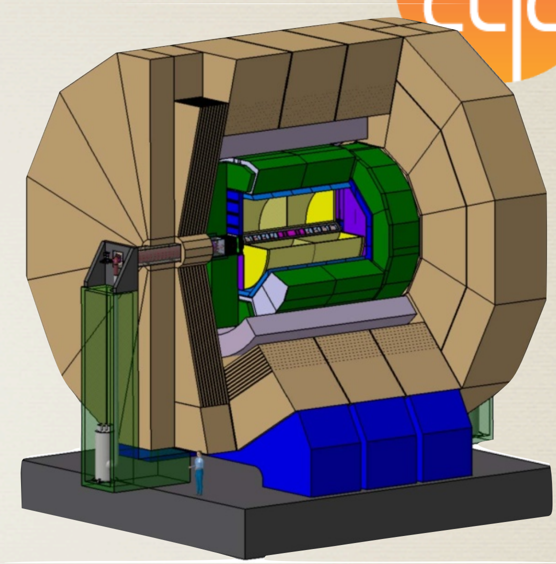
- Aug 2007 Detector Concept Report (RDR)
  - Four (4) detector concepts
  - LDC, GLD, SiD, 4th
- Oct 2007 ILCSC calls for LOIs / appoints Research Director
- Jan 2008 RD forms detector management
- Mar 2008 IDAG formed, Three (3) LOI groups identified
- Mar 2009 Three (3) LOIs submitted
  - detailed detector description, status of critical R&D, full GEANT4 simulation, benchmark analysis, costs
- Aug 2009 IDAG recommends validation of 2 / ILCSC approves
- Oct 2009 Work plan of the validated groups
- Mar 2009 IDAG began monitoring the progress
- 2011 Interim Report
  - http://www.linearcollider.org/about/Publications/interim-report
- End 2012 Detailed Baseline Design Report (w/TDR)
  - including physics case for ILC

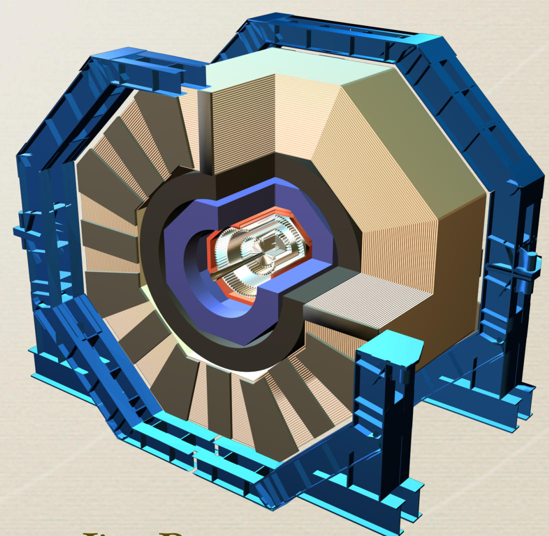


Validated LOIs

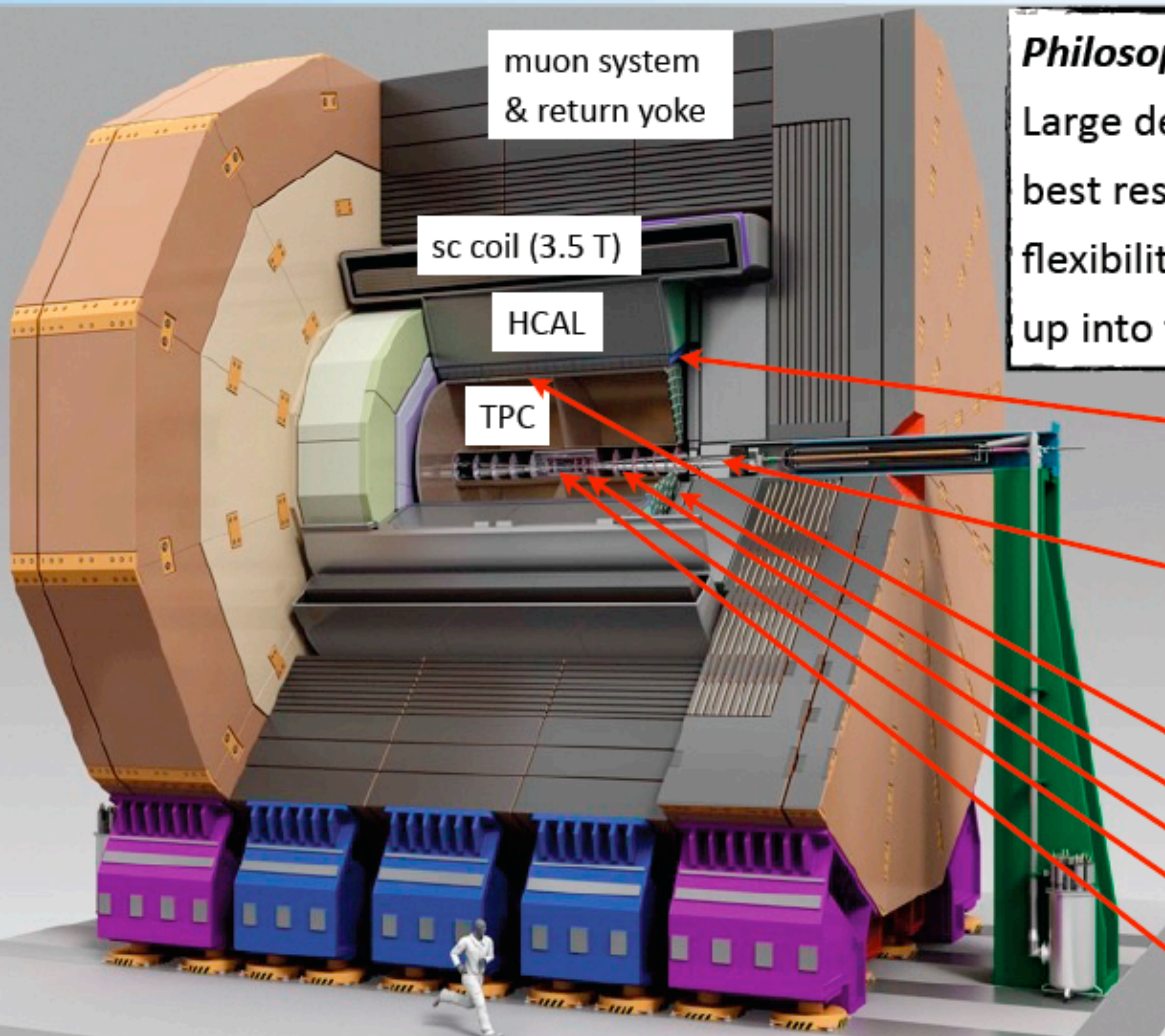
Validated Detectors ILD and SiD

- ✴ Both 4π detectors - complementary designs
  - ✴ common sys. - thin pixel vxd, Si-W Ecal
- ✴ ILD
  - ✴ TPC tracking aided by silicon
  - ✴ Scintillator-steel hadron calorimeter
  - ✴ Excellent tracking and calorimetry for best possible event reconstruction
- ✴ SiD
  - ✴ Silicon tracking
  - ✴ Gaseous (RPC) digital hadron calorimeter
  - ✴ Fast tracking and calorimeter for robustness





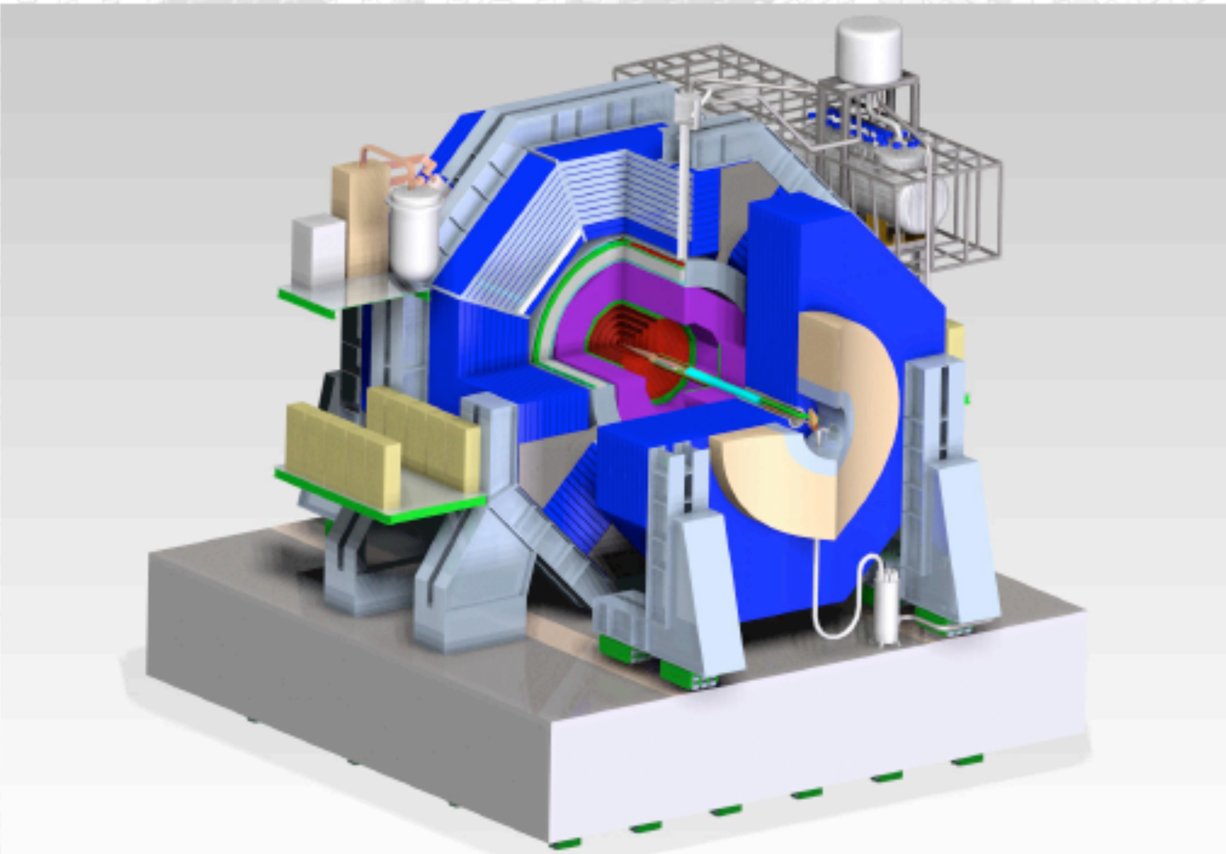
ILD - Overall Design

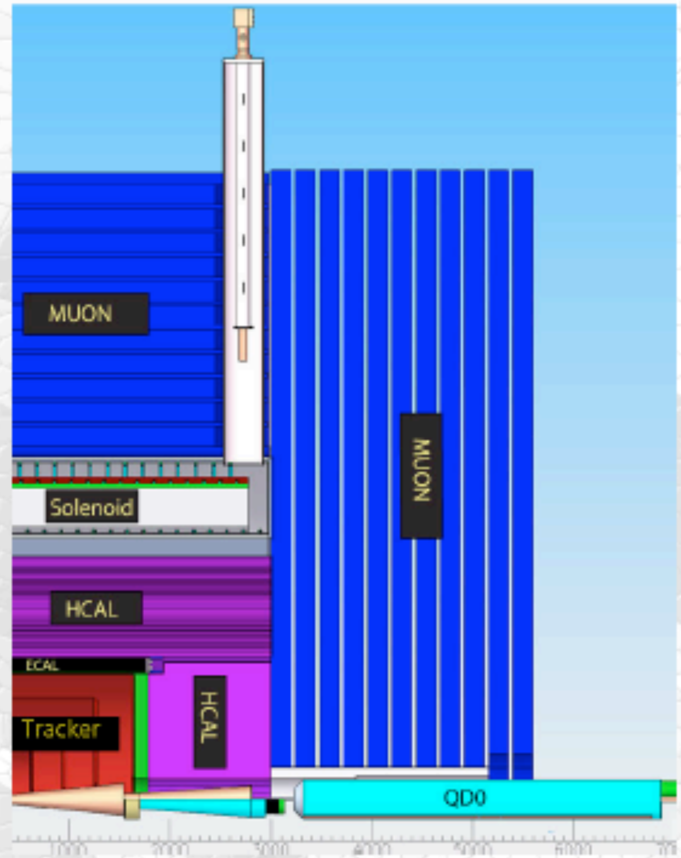


Philosophy:

Large detector optimized for best resolution, providing flexibility for higher energies up into the TeV range

The DBD detector





- SiD is fully designed for push-pull (using a platform)
- PFA paradigm has driven design choices

Marcel Stanitzki

IDAG

- International Detector Advisory Group (IDAG)
  - monitors the ILC detector research and development
  - advises the Research Director
  - reviewed 2009 Letters of Intent / recommended validation
  - reviewed recent DBD drafts

  - IDAG membership includes
    - experienced experimentalists
      - Michael Danilov (ITEP), Michel Davier (Chair, Orsay), Paul Grannis (Stony Brook), Dan Green (FNAL), Dean Karlen (Victoria), Sun-Kee Kim (SNU), Tomio Kobayashi (Tokyo), Weiguo Li (IHEP), Richard Nickerson (Oxford), Sandro Palestini (CERN)
    - active phenomenology theorists
      - Christophe Grojean (CERN & CEA-Saclay), Rohini Godbole (IIS), JoAnne Hewett (SLAC)
    - ILC accelerator experts
      - Thomas Himel (SLAC), Nobukazu Toge (KEK), Eckhard Elsen (DESY)

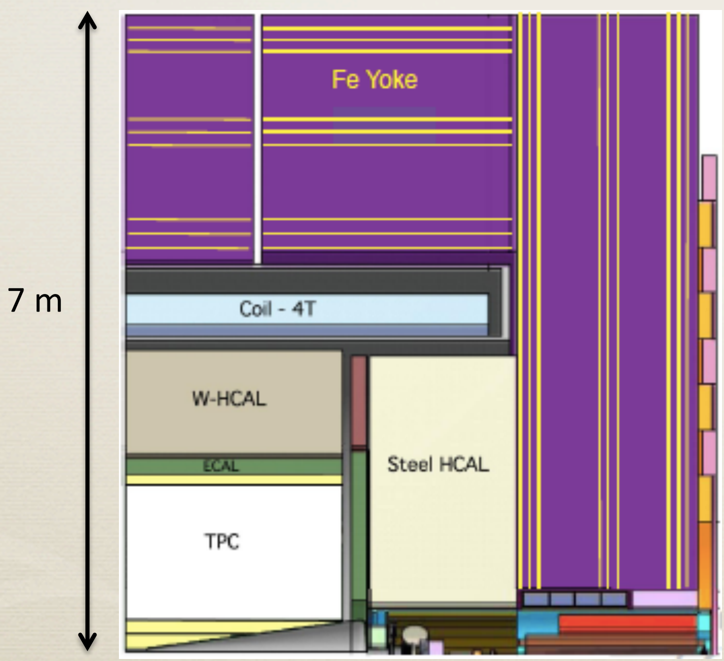
ILC Physics Volume & Detailed Baseline Design

- Physics volume &
- DBD chapters have been drafted and are in final phase of revision
  - Introduction (physics, organization, common detector aspects)
  - SiD & ILD
  - Chapter discussing future
- DBD drafts have been reviewed by IDAG
- Review by ILCSC's Project Advisory Committee (PAC), augmented by a few IDAG members, KEK, 13-14 December
  - Revised Introduction to be submitted Nov 16
  - Final drafts of SiD & ILD to be submitted Nov 30
- Presented to ILCSC, February 21-22, 2013
- Published along with ILC TDR

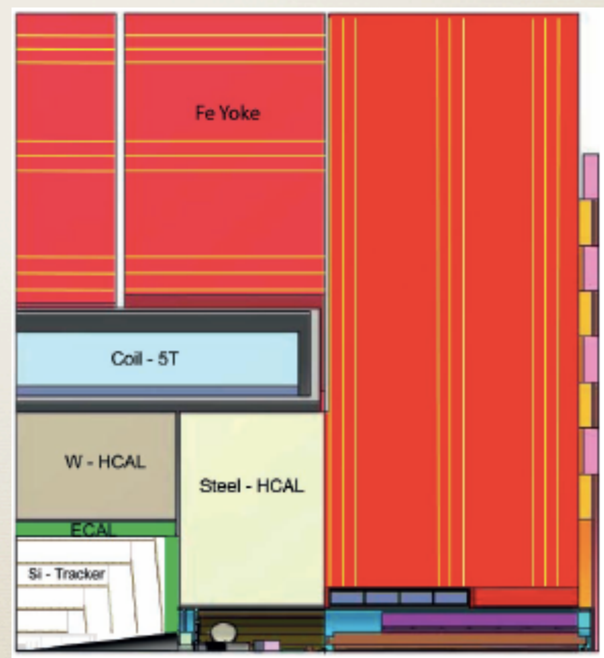
CLIC Detectors

- Two general-purpose CLIC detector concepts
  - Based in initial ILC concepts (ILD and SiD)
  - Optimized and adapted to CLIC conditions

CLIC_ILD

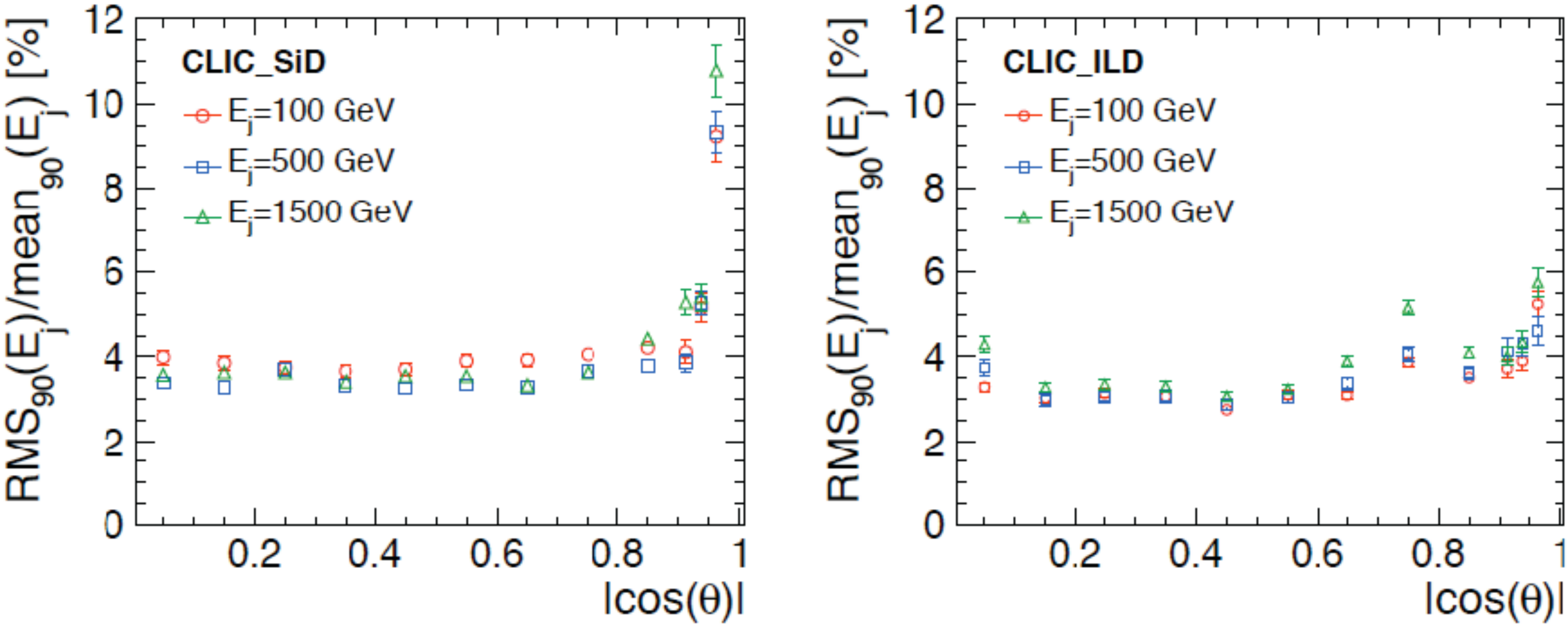


CLIC_SiD



calorimetry and PFA

jet energy resolution
(no jet clustering, no background overlay)



CLIC CDR Studies

Table 12.19: Summary table of the CLIC benchmark analyses results. All studies at a centre-of-mass energy of 3 TeV are performed for an integrated luminosity of 2 ab^{-1}. The study at 500 GeV assumes an integrated luminosity of 100 fb^{-1}.

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Generator value	Stat. uncertainty
3.0	Light Higgs production	$h \to b\bar{b}$		$\sigma \times$ Branching ratio	fb	285	0.22%
		$h \to c\bar{c}$				13	3.2%
		$h \to \mu^+\mu^-$				0.12	15.7%
3.0	Heavy Higgs production	$HA \to b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
			II	Mass	GeV	742.0	0.2%
				Width	GeV		17%
		$H^+H^- \to t\bar{b}b\bar{t}$	I	Mass	GeV	906.3	0.3%
				Width	GeV		27%
			II	Mass	GeV	747.6	0.3%
				Width	GeV		23%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%

CLIC CDR Studies

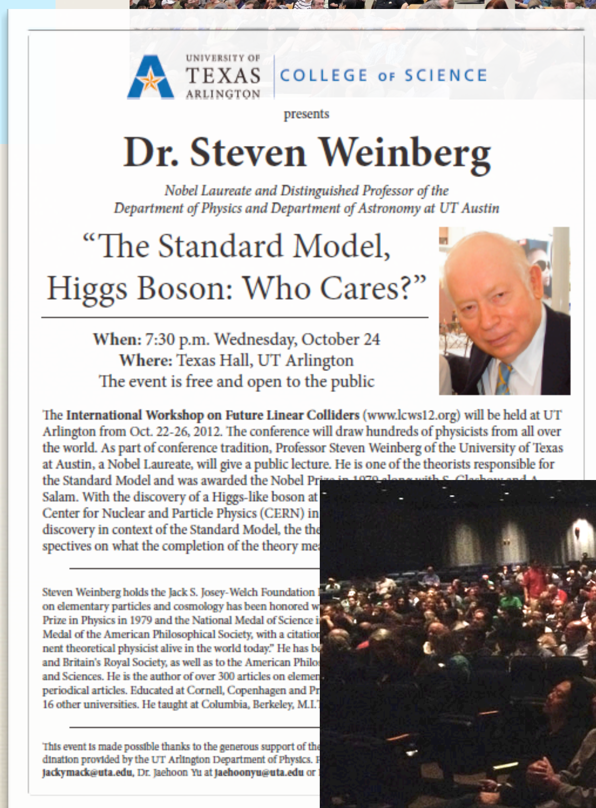
3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino and neutralino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h^0/Z^0 h^0/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
0.5	$t\bar{t}$ production	$t\bar{t} \to (q\bar{q}b)(q\bar{q}b)$		Mass	GeV	174	0.046%
				Width	GeV	1.37	16%
		$t\bar{t} \to (q\bar{q}b)(\ell\nu b)$, $\ell = e, \mu$		Mass	GeV	174	0.052%
				Width	GeV	1.37	18%

Outreach

- Public
  - science AND technology
- Scientific Community
- Policy makers
- Funding agencies

Particle Physics Slam - ALCPG11 - Eugene - March 22, 2011

Particle detectors: they're nearer than you think, **Marcel Demarteau**
Seeking hidden dimensions, **Brian Foster**
Neutrinos from outer space! **Garabed Halladjian**
An illumination of dark matter, **JoAnne Hewett**
Why physics, dude? **Marc Wenskat**



Outreach - IEEE NSS

Organized by Maxim Titov (IRFU/CEA Saclay) & Ingrid-Maria Gregor (DESY)

LC https://indico.desy.de/conferenceDisplay.py?confId=6537

Outreach - Spinoffs

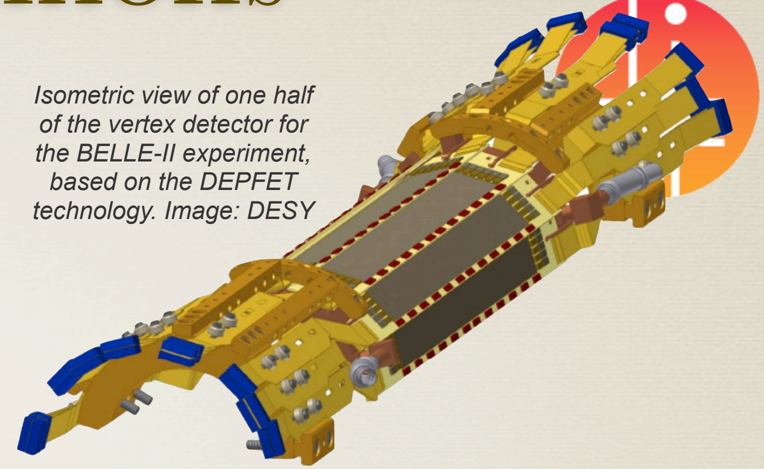
ilc newsline

RESEARCH DIRECTOR'S REPORT

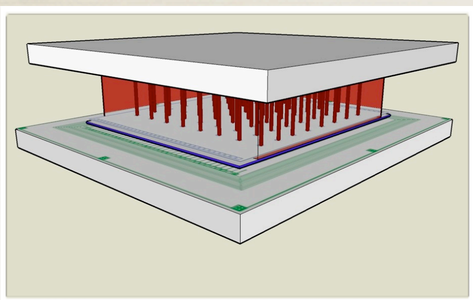
The impact of ILC detector R&D

This month's Research Director's Report was written by Marcel Demarteau, chair and convener of the ILC Detector Common Task Group

Marcel Demarteau | 18 August 2011

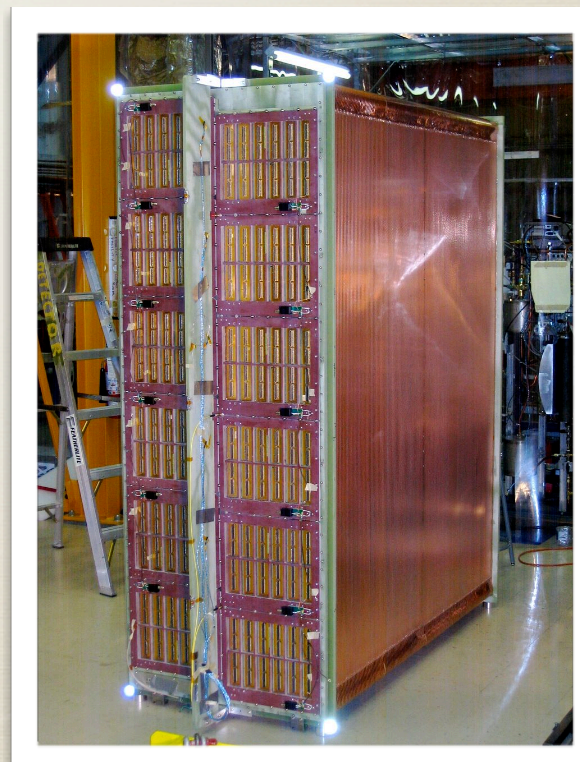


Isometric view of one half of the vertex detector for the BELLE-II experiment, based on the DEPFET technology. Image: DESY



Conceptual view of a 3-D silicon assembly for a track trigger for an LHC upgrade showing a silicon sensor at the top and bottom interconnected through an interposer. Image: Ron Lipton

Beam telescope in the CERN and DESY test beam lines based on the MIMOSA-26 pixel sensors. Image: DESY



MicoMegas-based time projection chamber for the T2K experiment in Japan, based on ILC detector R&D. Image: T2K

Outreach - TDR/DBD

- Global event being planned
  - Celebrate completion of TDR/DBD and look forward to next steps
  - mid-June - sequence of events in three regions
    - KEK ⇒ CERN ⇒ Fermilab (& webcast)
  - symposium of overview talks ending with a keynote speaker

Future Workshops

- European Linear Collider Workshop, ECFA LC 2013
  - DESY, Hamburg
    - local chair: Karsten Buesser
  - 27-31 May 2013
- next LCWS
  - Tokyo
    - local chair: Sachio Komamiya
  - late Oct/early Nov 2013

ECFA LC 2013

European Linear Collider Workshop

27-31 May 2013

DESY, Hamburg

May 27-31 2013

lc2013.desy.de

Registration will open soon

Thank YOU!


- Jae Yu & Andy White


- Margie Jackymack & Alexia Augier
- UTA Students and Staff
  - 60 student volunteers
  - Chris Jackson, organized student volunteers
  - Victor Reece, web master and online payment
  - Mark Sosebee, tech support/ computers, video conferencing, power strips
  - Fred Olness, fund raising
  - UTA Physics, College of Science Dean's office, Provost's & President's offices
  - UTA University Center
- Bailey Tool and Manufacturing
- Program Committees, Conveners, & All of you