(Electroweak) Precision physics at a future Linear Collider at the TeV Scale

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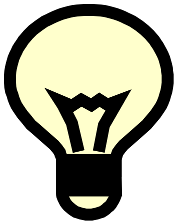
Directeur de la Recherche of CNRS

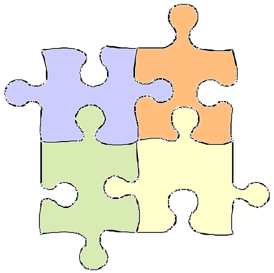
ICTP-NCP School – NCP Islamabad November 2014

An enigmatic couple ...

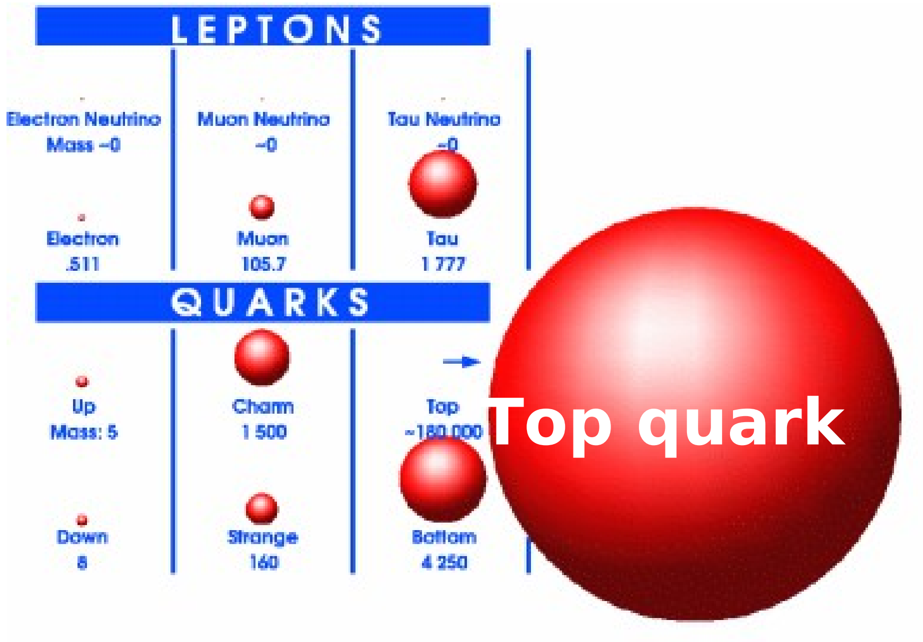
Higgs Boson



Elementary Scalar?



Composite object?

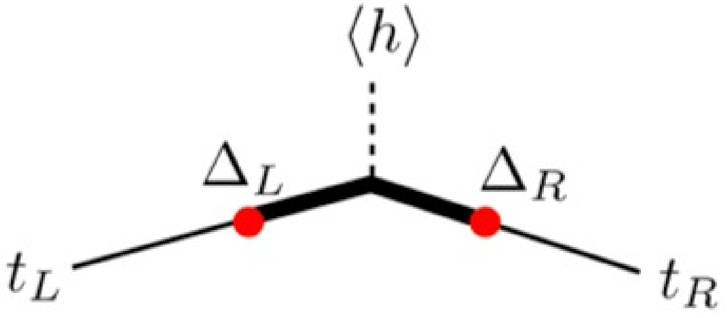


More on top quark
Lecture by Thomas Müller

- Higgs and top quark are intimately coupled!
  Top Yukawa coupling O(1) !
  => Top mass important SM Parameter

- New physics by compositeness?
  Higgs and top composite objects?

- **LC perfectly suited to decipher both particles**

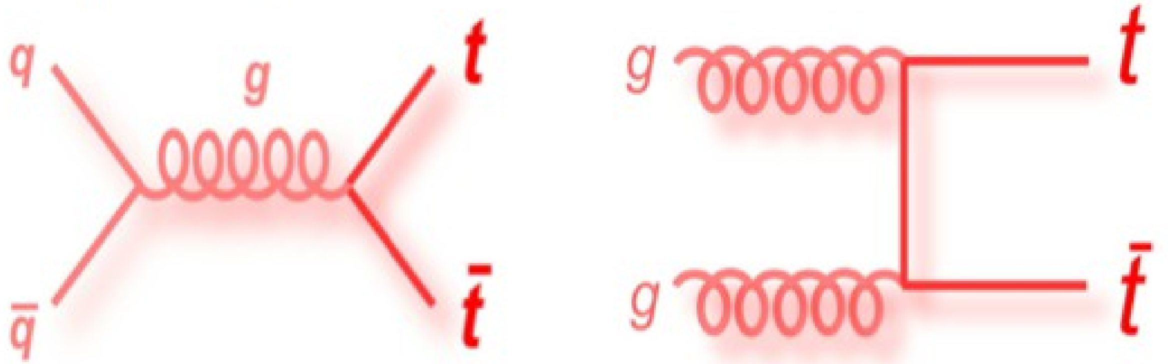


Courtesy of S. Rychkov

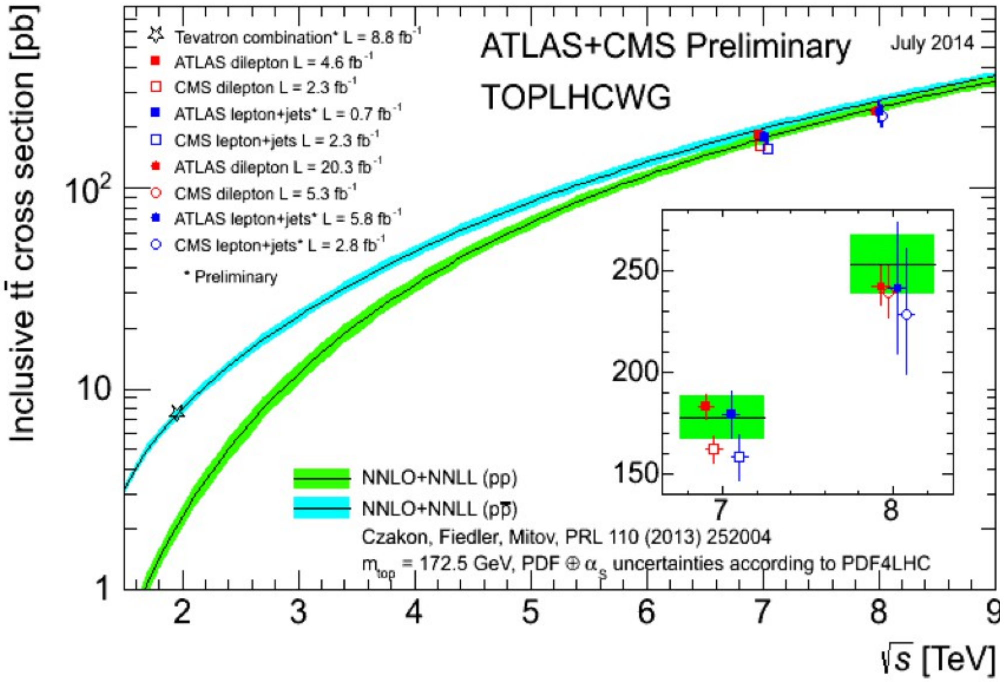
Top quark pair production at hadron colliders

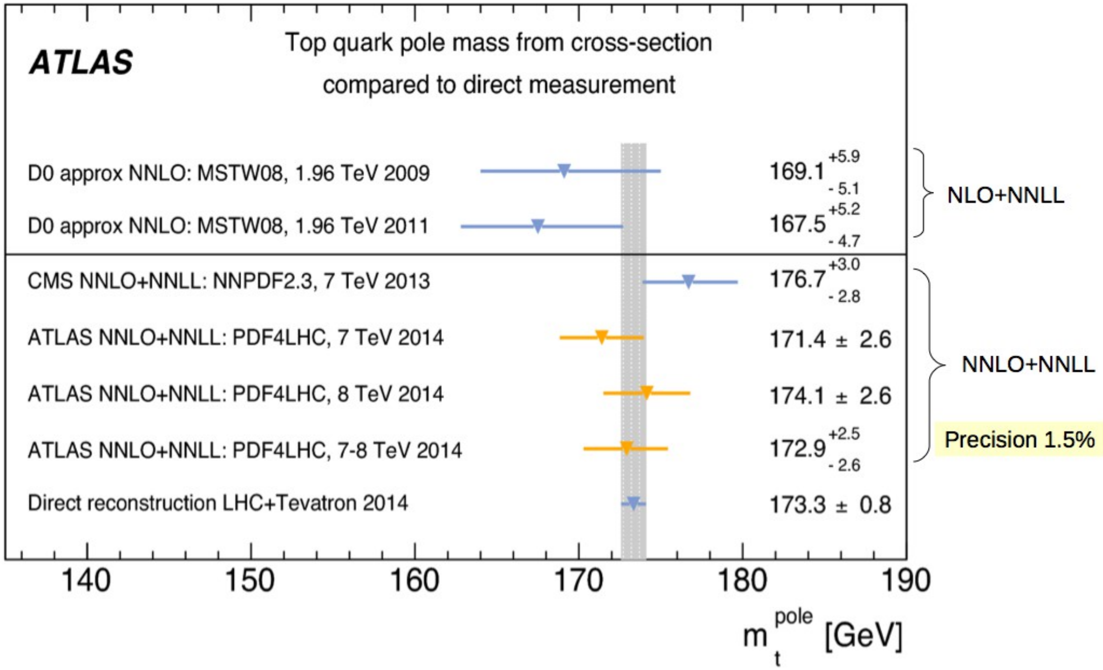
So, far top quarks have only been observed at hadron colliders ...

Example diagrams:



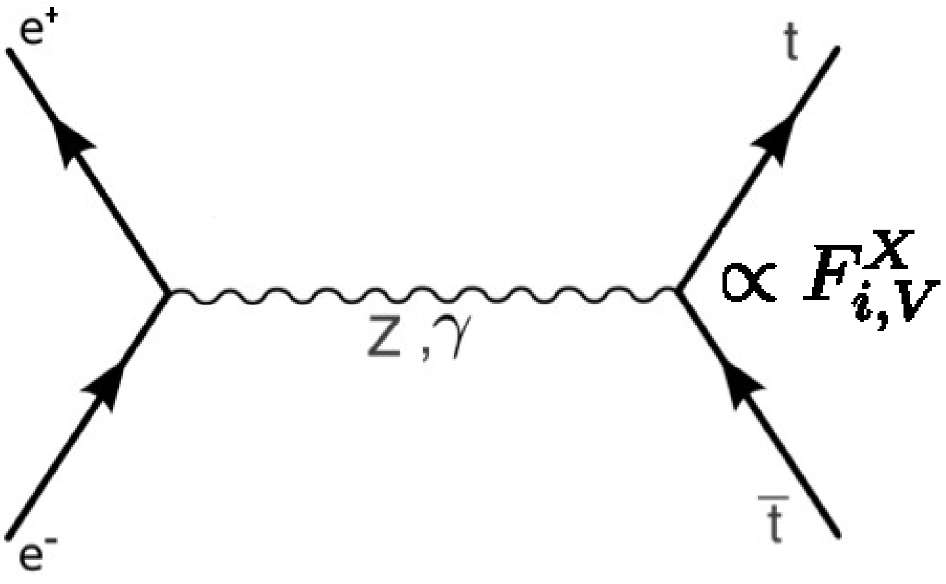
	$\sigma_{gg}/\sigma_{\text{tot}}$
Tevatron	$\approx 15\%$
LHC 7 TeV	$\approx 85\%$
LHC 14 TeV	$\approx 90\%$

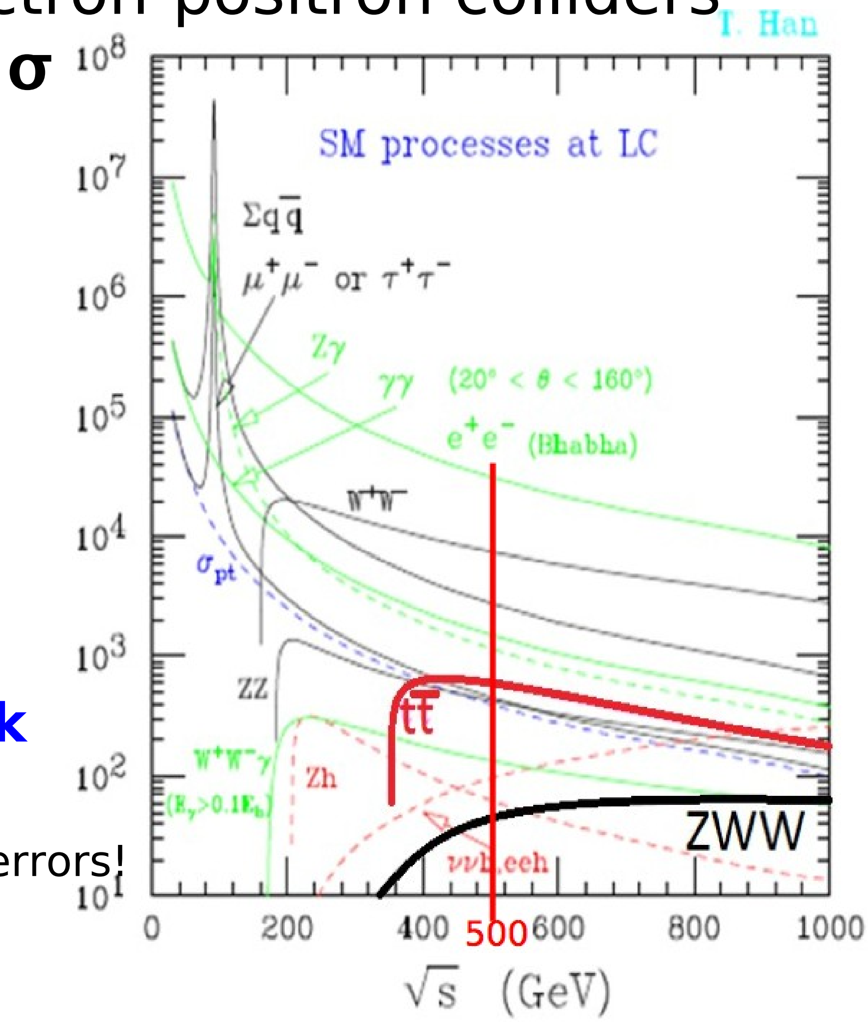




=> High time to see them at lepton colliders!

Top quark physics at electron-positron colliders





- Top quark production through **electroweak** processes,

  no competing QCD production => Small theoretical errors!

- High precision measurements

  Top quark mass at ~ 350 GeV through threshold scan

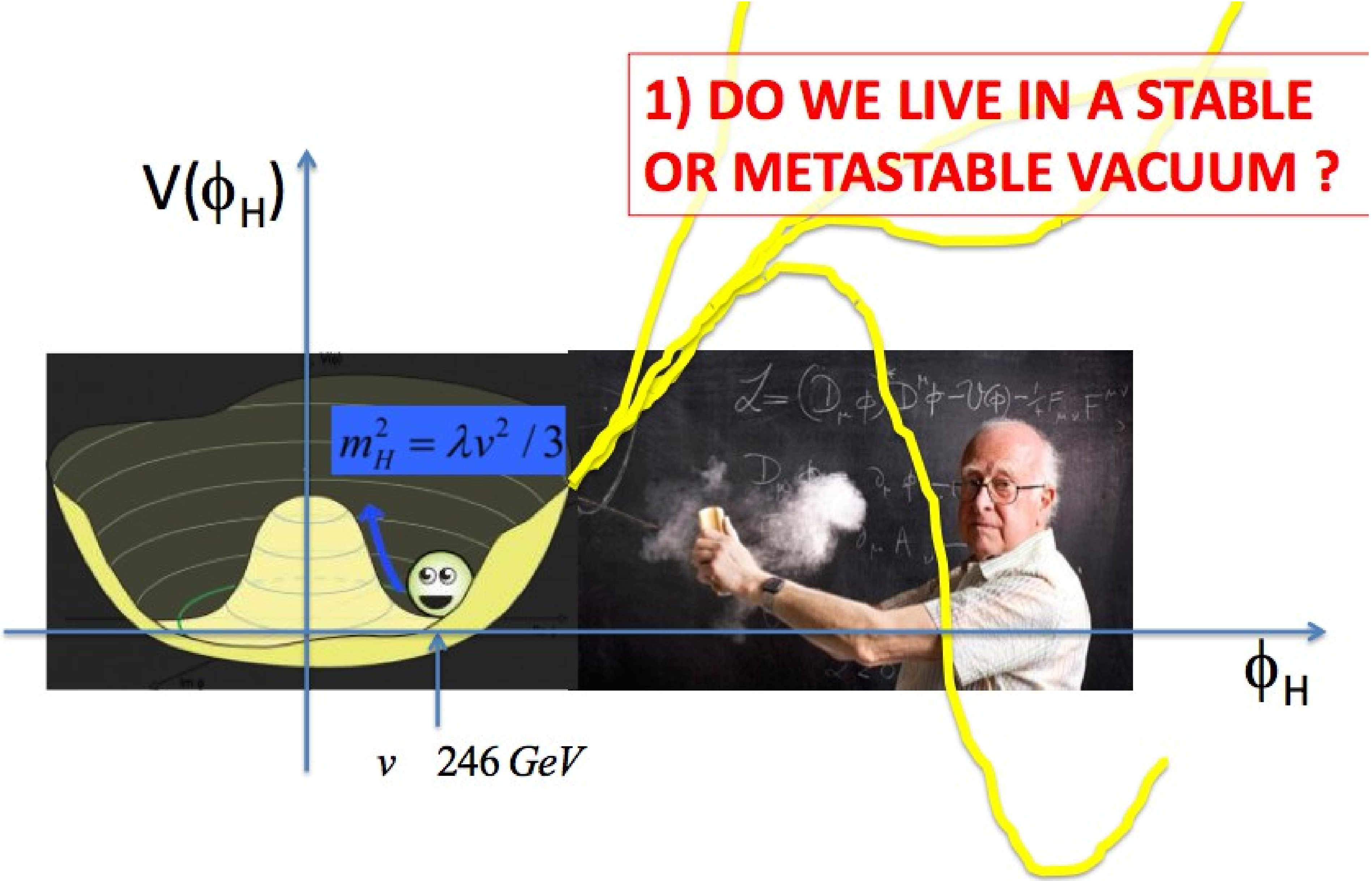
  Polarised beams allow testing chiral structure at ttX vertex
  => Precision on form factors F

- Studies presented here deal with no or only mildly boosted tops, beta~0.7

  - A major difference between LC and LHC is that an LC will run triggerless

  -> Unbiased event samples, all event selection happens off-line!

The fate of the universe

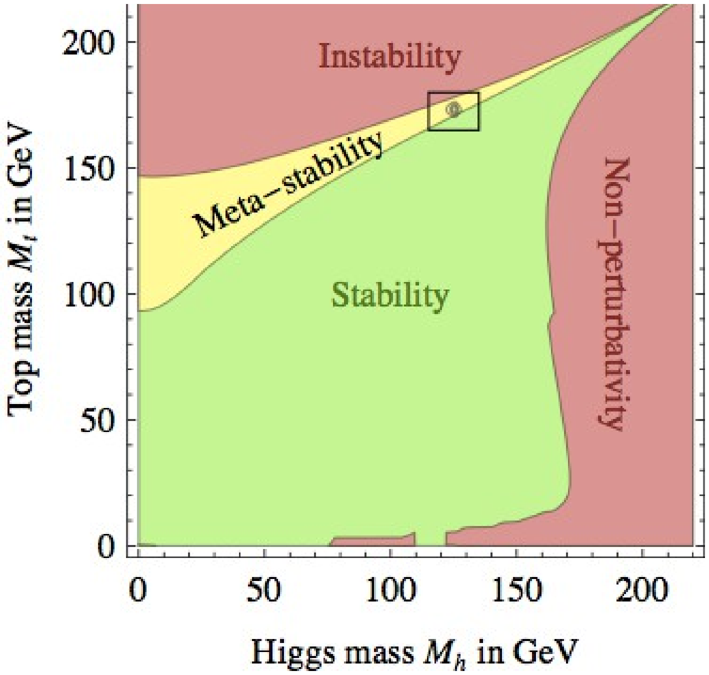


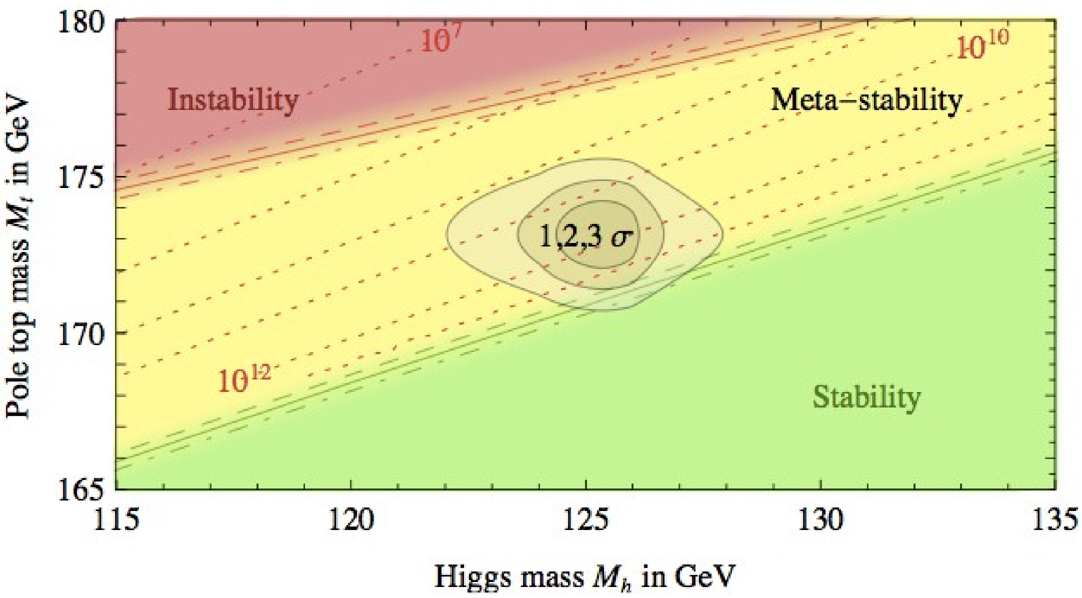
1) DO WE LIVE IN A STABLE OR METASTABLE VACUUM ?

Vacuum stability and top quark mass

Degrassi et al.
arXiv:1205.6497

$$M_h\ [\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\mathrm{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\mathrm{th}}\ .$$



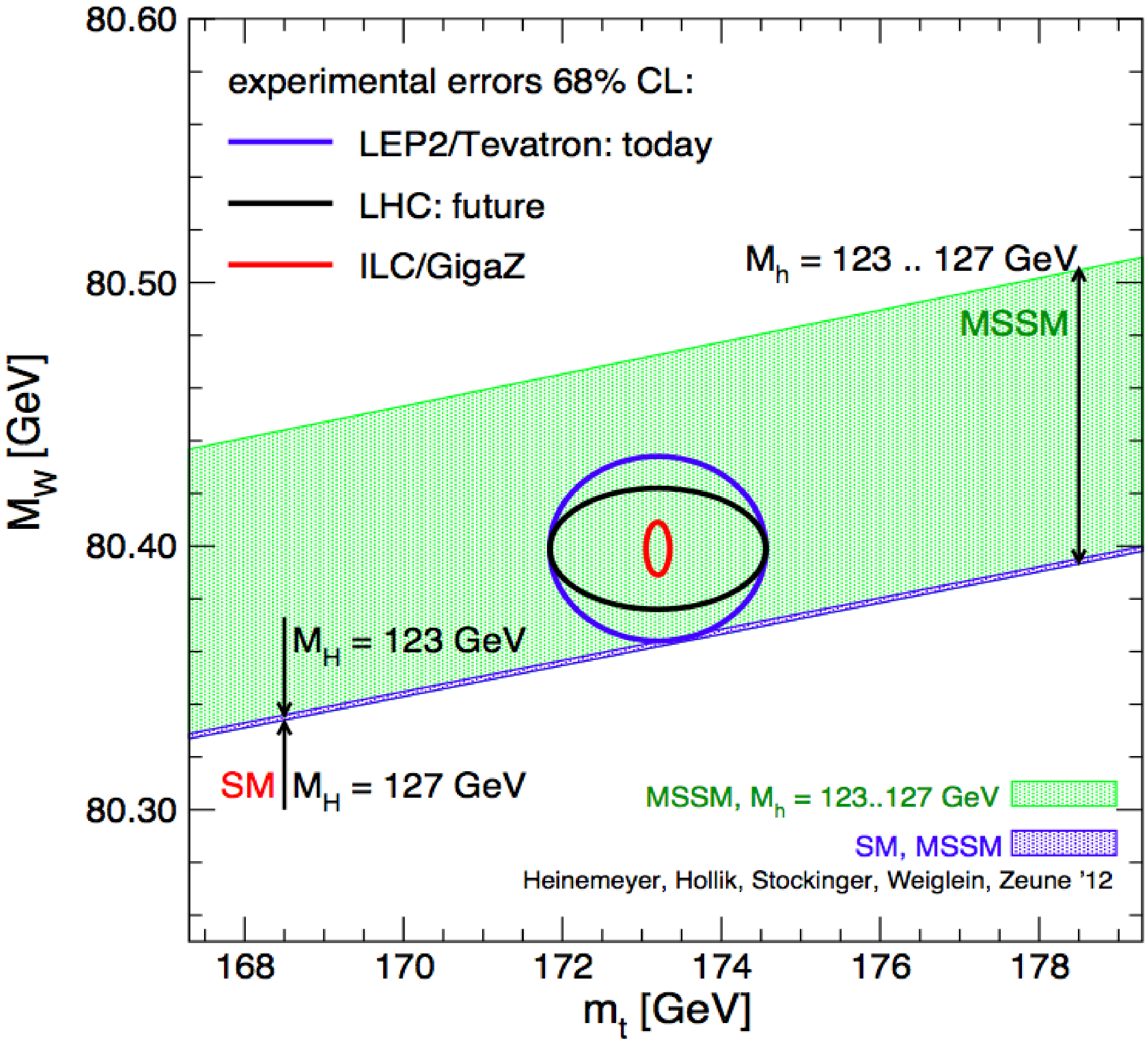


Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	±1.4 GeV
α_s	experimental uncertainty in α_s	±0.5 GeV
Experiment	**Total combined in quadrature**	**±1.5 GeV**
λ	scale variation in λ	±0.7 GeV
y_t	$\mathcal{O}(\Lambda_{\mathrm{QCD}})$ correction to M_t	±0.6 GeV
y_t	QCD threshold at 4 loops	±0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	±0.2 GeV
Theory	**Total combined in quadrature**	**±1.0 GeV**

Uncertainty on **(pole)** top quark mass dominates uncertainty on stability conditions

(argument is repeated In literature!)

Top mass Higgs Mass and BSM – SM vs. MSSM



Heinemeyer, Hollik, Stockinger, Weiglein, Zeune '12

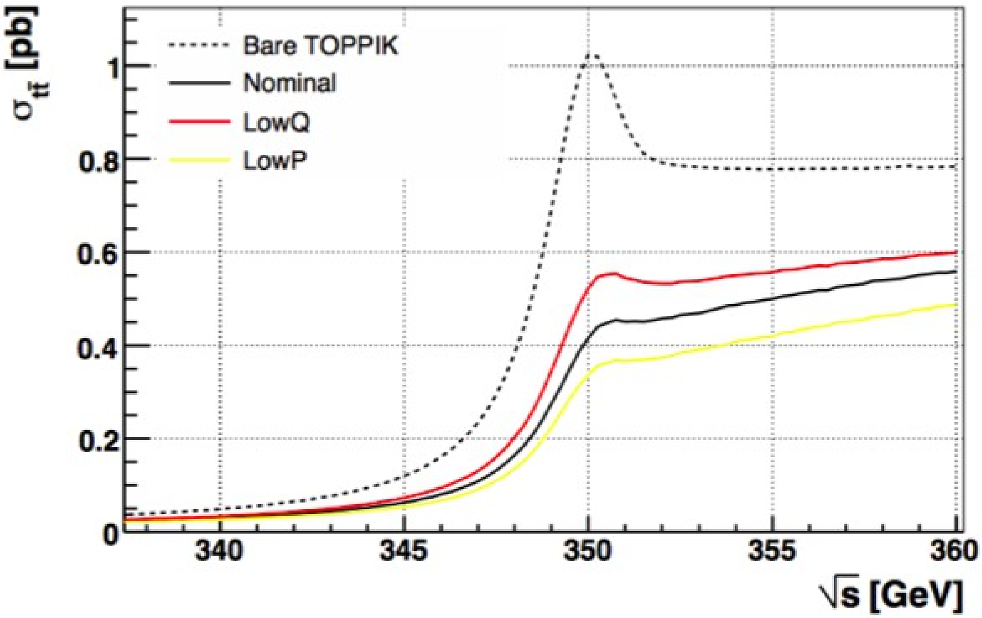
Precise Top (and W) mass crucial to test compatibility of measured Higgs mass

MS might not be sufficient to explain Higgs mass

LHC may not reach sufficient discriminative power

A lepton collider will

Total tt cross section in e+e- collisions



Principle: m_t from $\sigma_{tt}(m_t)$

Advantages:

- ▹ count number of $t\bar{t}$ events
- ▹ color singlet state
- ▹ background is non-resonant
- ▹ physics well understood (renormalons, summations)
- ➢ Top decay protects from non-pert effects

Much of the discriminating power of the approach related to the strong mass-dependence (ttbar resonance).

Peak position very stable in theory predictions (threshold mass scheme).

Typical results:

$\rightarrow \delta m_t^{\mathrm{exp}} \simeq 50$ MeV

$\rightarrow \delta m_t^{\mathrm{th}} \simeq 100$ MeV

What mass?

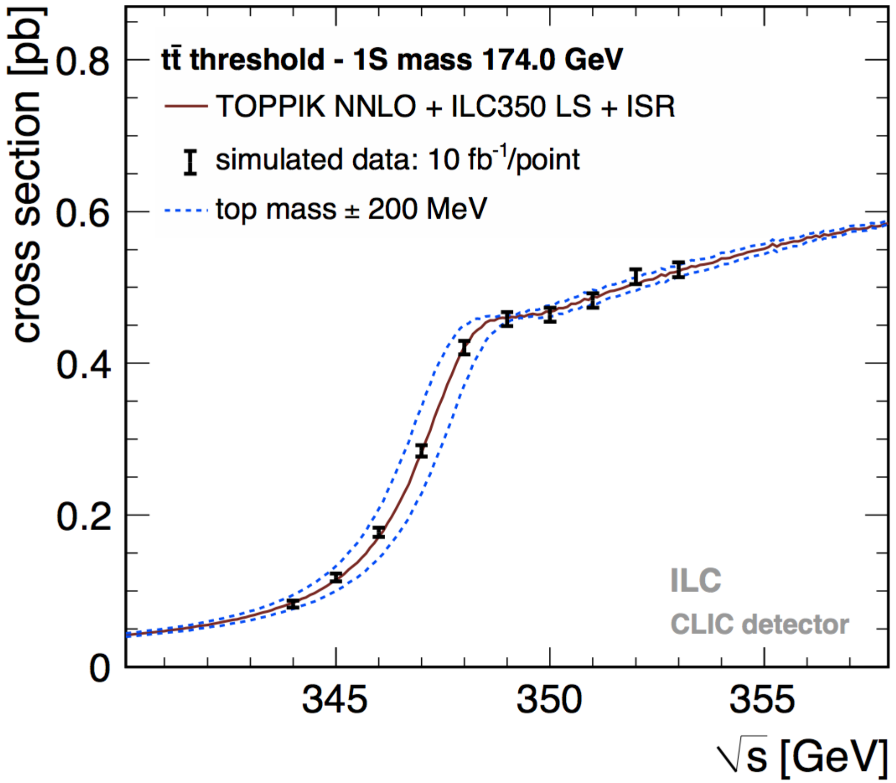
$\sqrt{s}_{\mathrm{rise}} \sim 2m_t^{\mathrm{thr}} +$ pert.series

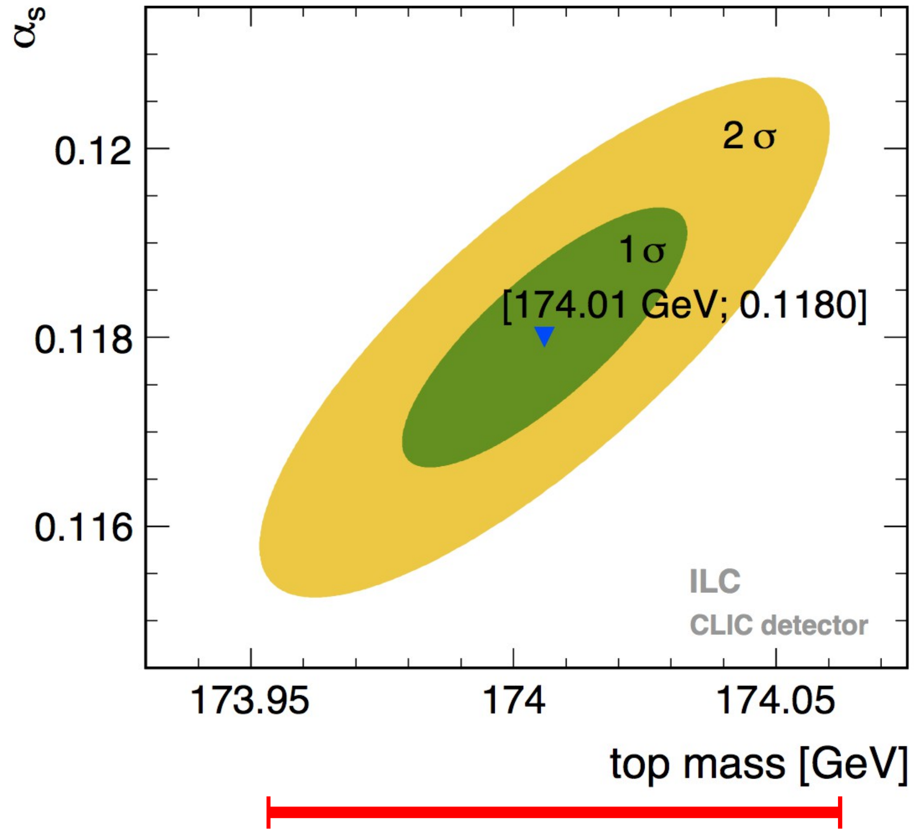
(short distance mass: 1S $\leftrightarrow \overline{\mathrm{MS}}$)

A. Hoang

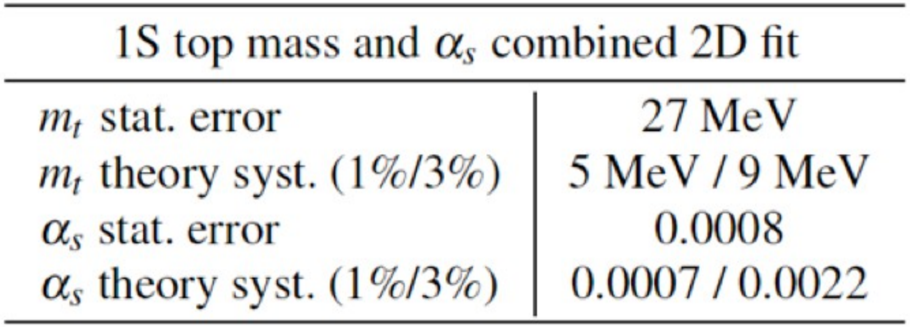
Top quark mass – Results of full simulation studies

Mass and α_s



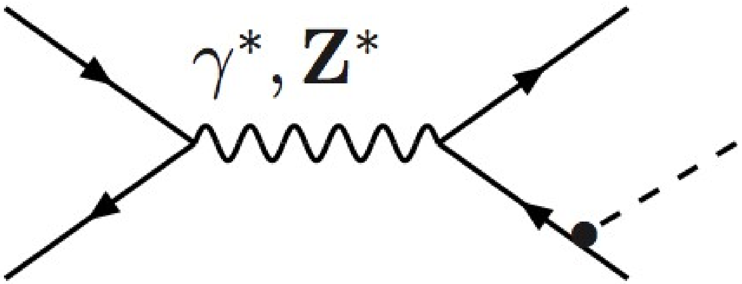


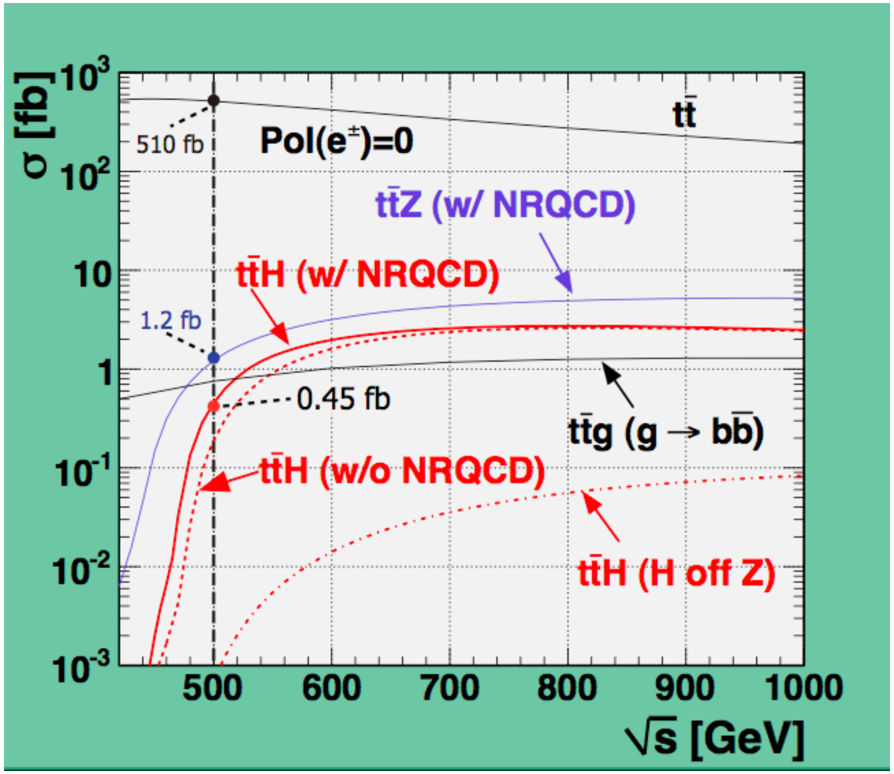
~100 MeV

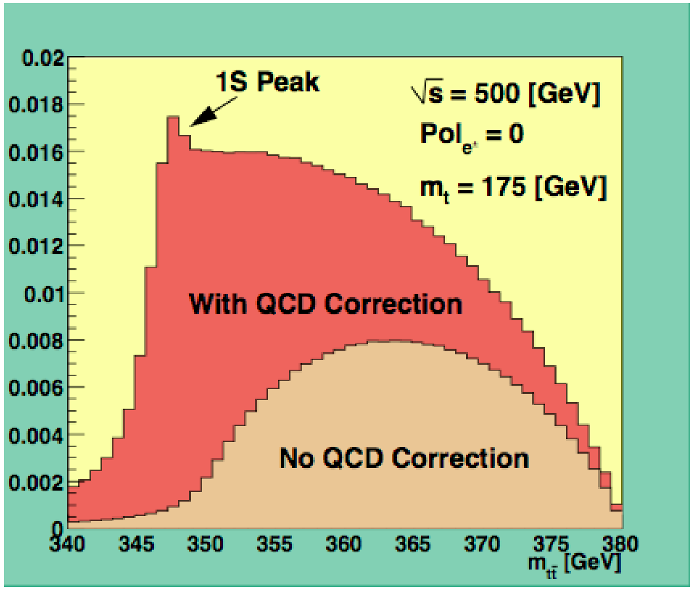


1S top mass and α_s combined 2D fit	
m_t stat. error	27 MeV
m_t theory syst. (1%/3%)	5 MeV / 9 MeV
α_s stat. error	0.0008
α_s theory syst. (1%/3%)	0.0007 / 0.0022

Top Yukawa coupling above threshold

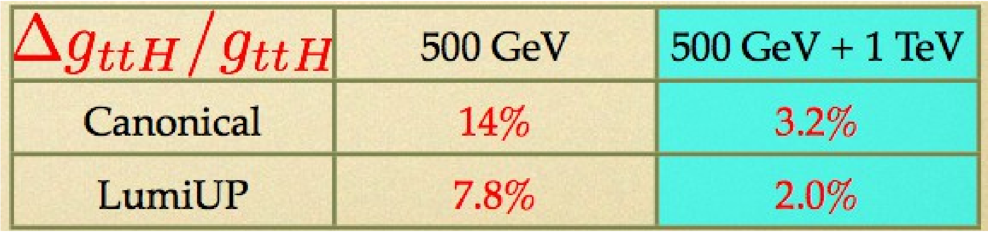






~ Factor 2 enhancement
From QCD bound states

R. Horiguchi et al.
T. Tanabe, T. Price



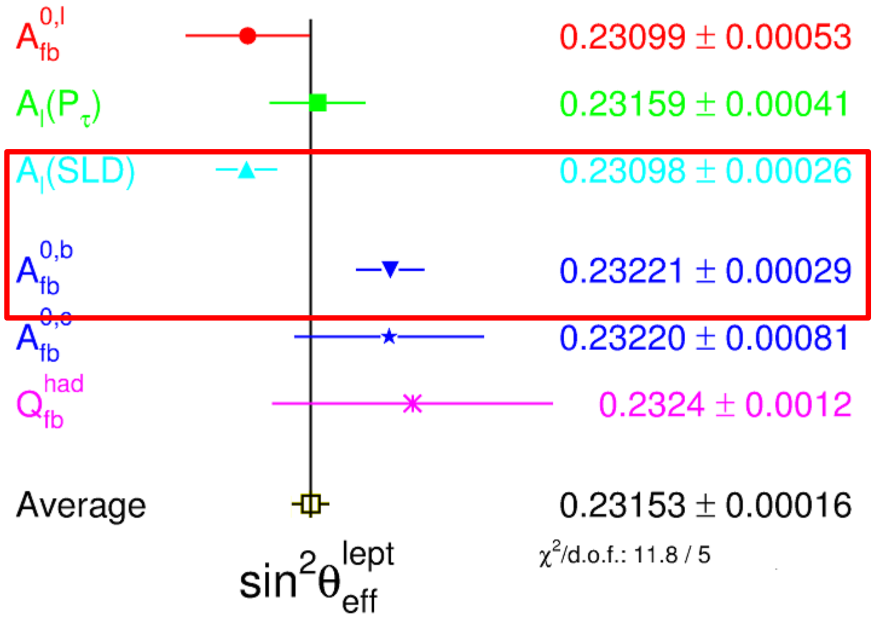
$\Delta g_{ttH} / g_{ttH}$	500 GeV	500 GeV + 1 TeV
Canonical	14%	3.2%
LumiUP	7.8%	2.0%

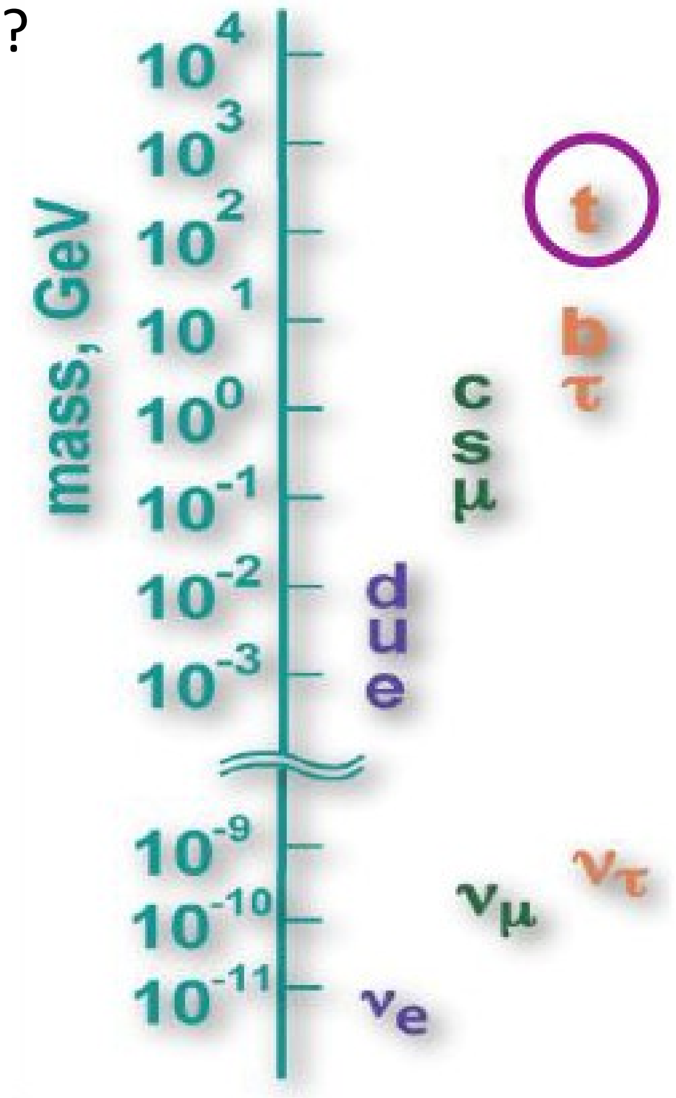
ILC TDR

Technically possible

The top quark and flavor hierarchy

- Flavor hierarchy ? Role of 3rd generation ?





- A_{FB} anomaly at LEP for b quark

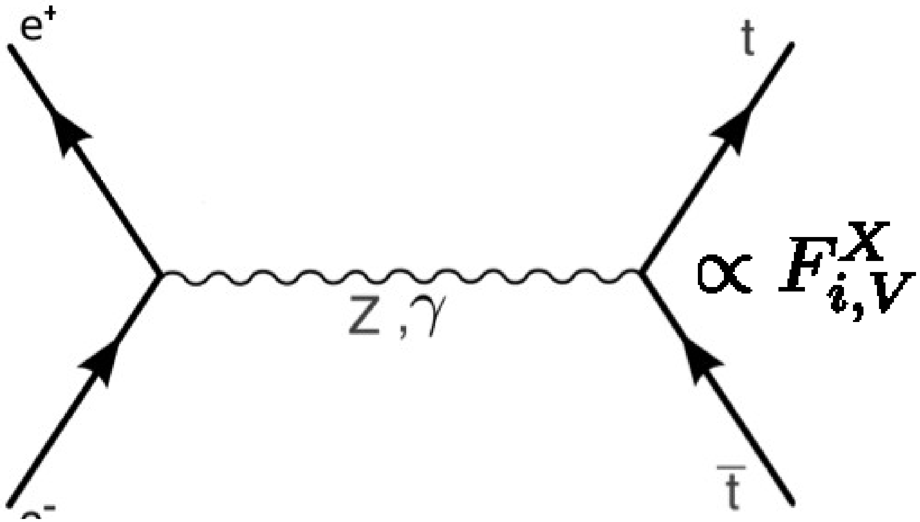
  Tensions at Tevatron?

- Heavy fermion effect

Strong motivation to study chiral structure
of top vertex in high energy e+e- collisions

Why is it sooo heavy?

Testing the chiral structure of the Standard Model



$$\propto F^{X}_{i,V}$$

$$\Gamma^{ttX}_{\mu}(k^2,q,\overline{q}) = -ie\left\{\gamma_\mu\left(F^X_{1V}(k^2)+\gamma_5 F^X_{1A}(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\overline{q})^\mu\left(iF^X_{2V}(k^2)+\gamma_5 F^X_{2A}(k^2)\right)\right\}, \tag{2}$$

$$\begin{aligned}\mathcal{F}^L_{ij} &= -F^\gamma_{ij}+\left(\frac{-\frac{1}{2}+s^2_w}{s_w c_w}\right)\left(\frac{s}{s-m^2_Z}\right)F^Z_{ij}\\ \mathcal{F}^R_{ij} &= -F^\gamma_{ij}+\left(\frac{s^2_w}{s_w c_w}\right)\left(\frac{s}{s-m^2_Z}\right)F^Z_{ij}\ ,\end{aligned}$$

Pure γ or pure Z^0 : $\sigma \backsim (F_i)^2 \Rightarrow$ No sensitivity to sign of Form Factors

Z^0/γ interference : $\sigma \backsim (F_i) \Rightarrow$ Sensitivity to sign of Form Factors

Disentangling

At ILC **no** separate access to ttZ or ttγ vertex, but ...

ILC 'provides' two beam polarisations

$P(e^-) = \pm 80\%$ $P(e^+) = \mp 30\%$

There exist a number of observables sensitive to chiral structure, e.g.

$$\sigma_I \qquad A^t_{FB,I} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)} \qquad (F_R)_I = \frac{(\sigma_{t_R})_I}{\sigma_I}$$

x-section Forward backward asymmetry Fraction of right handed top quarks

⇩

Extraction of six (five) unknowns

$$F^\gamma_{1V},\ F^Z_{1V},\ F^\gamma_{1A} = 0,\ F^Z_{1A}$$

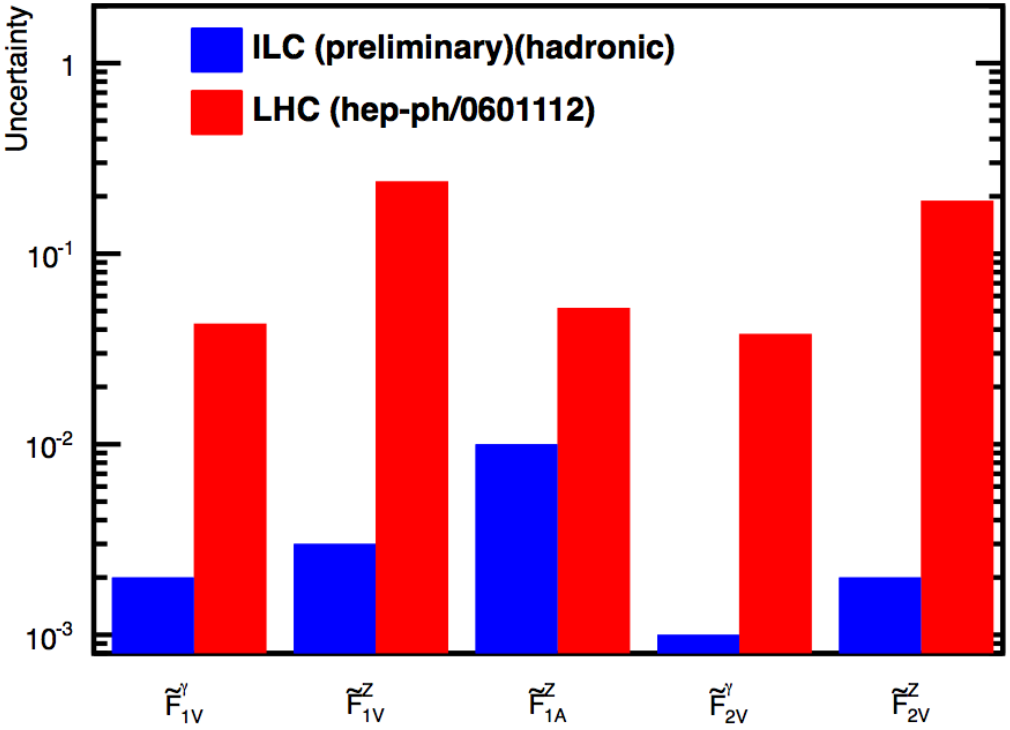
$$F^\gamma_{2V},\ F^Z_{2V}$$

Results of full simulation study for DBD at $\sqrt{s}$ = 500 GeV

ArXiv: 1307.8102

Precision: cross section ~ 0.5%, Precision A_{FB} ~ 2%, Precision λ_t ~ 3-4%

Accuracy on CP conserving couplings



PhD of Pakistanian student
Mohammed Sohail Amjad

- ILC might be up to two orders of magnitude more precise than LHC ($\sqrt{s}$ = 14 TeV, 300 fb^{-1})
  Disentangling of couplings for ILC
  One variable at a time For LHC
  However LHC projections from 8 years old study

-Need to control experimental (e.g. Top angle) and theoretical uncertainties (e.g. Electroweak corrections)
  -> Dedicated work has started

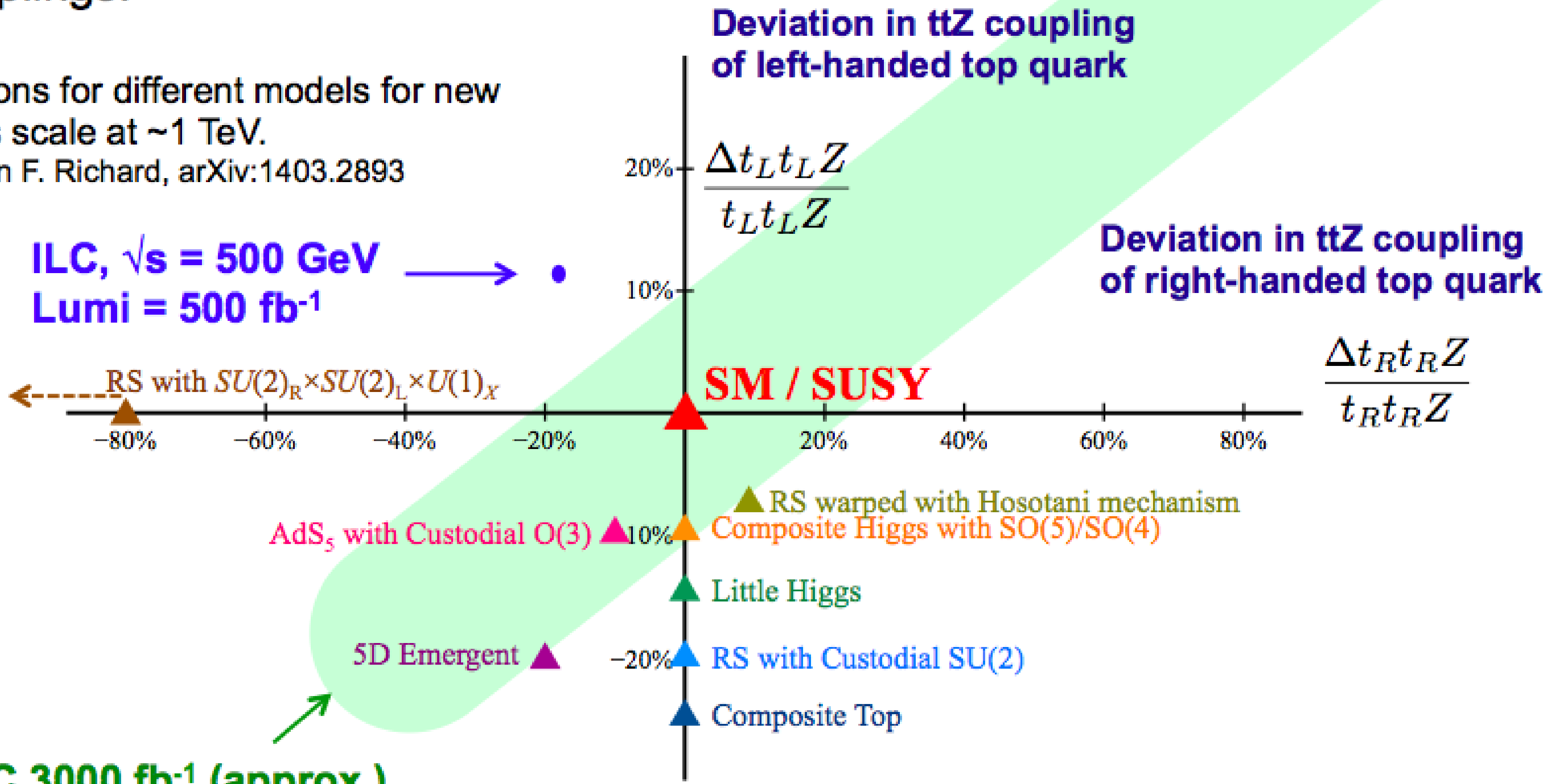
- Potential for CP violating couplings at ILC under study

ILC promises to be high precision machine for electroweak top couplings

Sensitivity to New Physics

Composite Higgs theories have an impact on the top sector. Composite Higgs models can be tested at the ILC through precise measurements of the top couplings. Beam polarization (both e- and e+) is essential to distinguish the ttZ and ttγ couplings.

Deviations for different models for new physics scale at ~1 TeV.
Based on F. Richard, arXiv:1403.2893



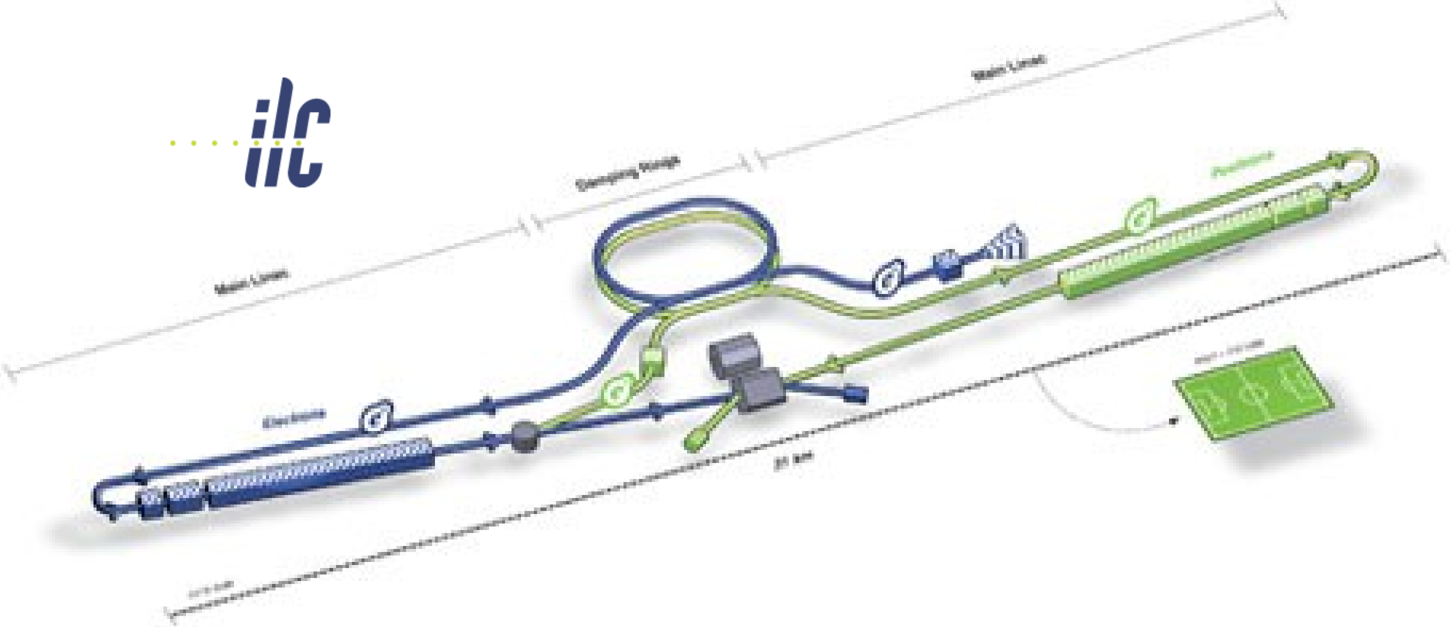
ILC, √s = 500 GeV
Lumi = 500 fb^{-1}

HL-LHC 3000 fb^{-1} (approx.)
Based on Baur, Juste, Orr, Rainwater, PRD71, 054013 (2005)

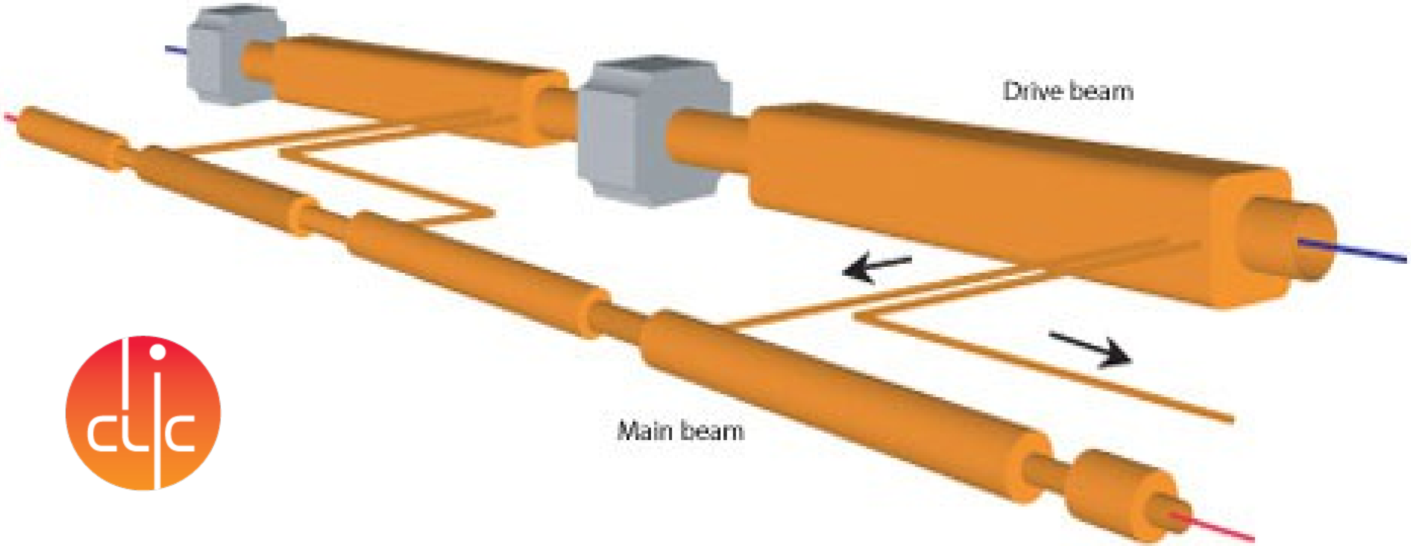
Chapter IV: Linear Collider - Machine aspects

Material from Nick Walker, Steinar Stapness and Olivier Napoly

(Future) Linear electron-positron colliders



Energy: 0.1 - 1 TeV
Electron (and positron) polarisation
TDR in 2013
+ DBD for detectors
Possible timeline for project see later



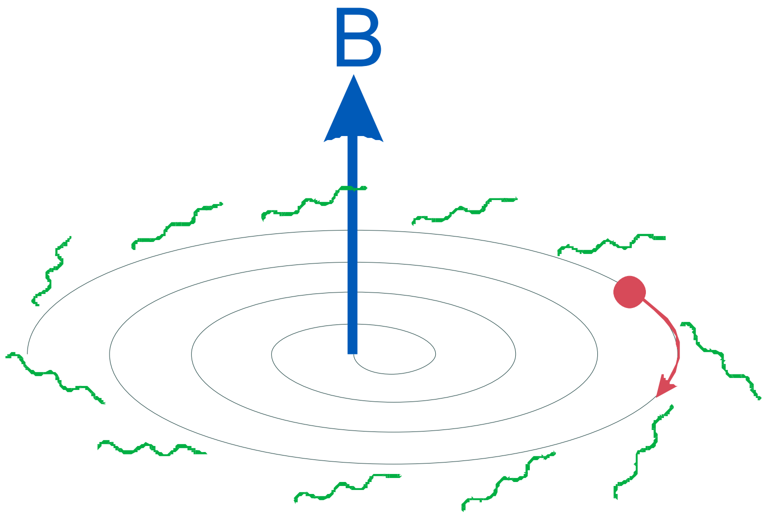
Energy: 0.5 - 3 TeV

CDR in 2012

Why Linear ?

Synchrotron Radiation from an electron in a magnetic field:

$$P_\gamma = \frac{e^2c^2}{2\pi} C_\gamma E^2 B^2$$

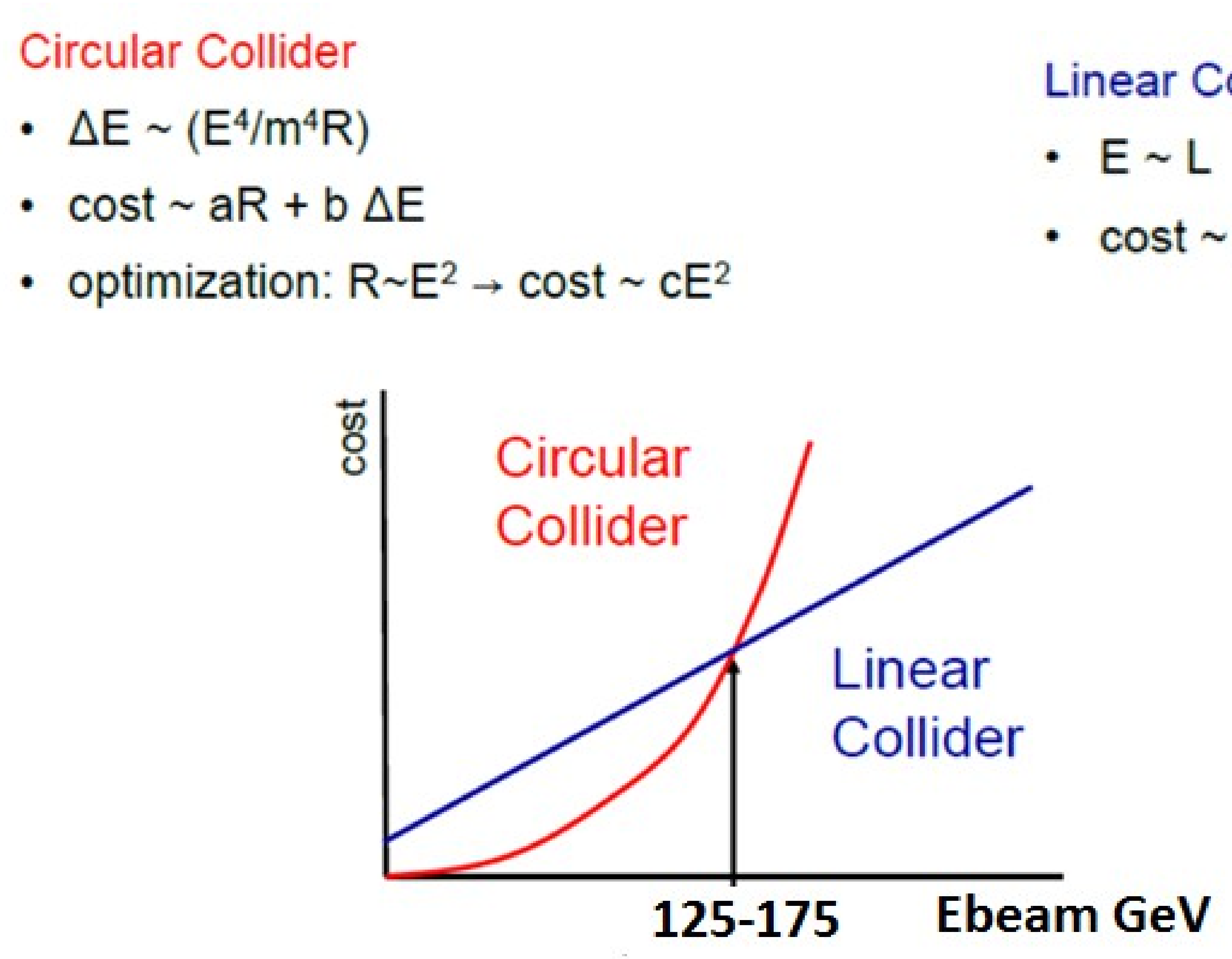


Energy loss per turn of a machine with an average bending radius Ξ

$$\Delta E/rev = \frac{\gamma^4}{r} = \frac{E^4}{m^4 r}$$

- Energy loss must be replaced by RF system → cost

Circular vs. Linear e+e-



Circular Collider

- $\Delta E \sim (E^4/m^4 R)$
- cost ~ $aR + b\,\Delta E$
- optimization: $R \sim E^2 \rightarrow$ cost ~ cE^2

Linear Collider

- $E \sim L$
- cost ~ aL

F. Richard
ILC School 2014

25 year – long effort towards a very high performance e+ / e- collider

Year	**1987**	**1992**	**1998**	**2004**	**2006**	**2012**
Phase	**SLC @ SLAC**		LC Design	<u>Global Design Effort - ILC</u>		
500 GeV Linear Collider R & D	**8 schemes**		**4**	**2**		→
Comparative Reviews		**Technology Review 1995**	**Technology Review 2002**	**International Technology Review Panel 2004**	**'General issues' ILC/CLIC**	
Beam Test Facilities - Linac (cost-driver)	**(SLAC)**	**NLCTA, TTF / FLASH**			**NML, STF, CTF**	
Beam Test Facilities - Emittance		**FFTB**	**ATF** **ATF2**		**CesrTA**	

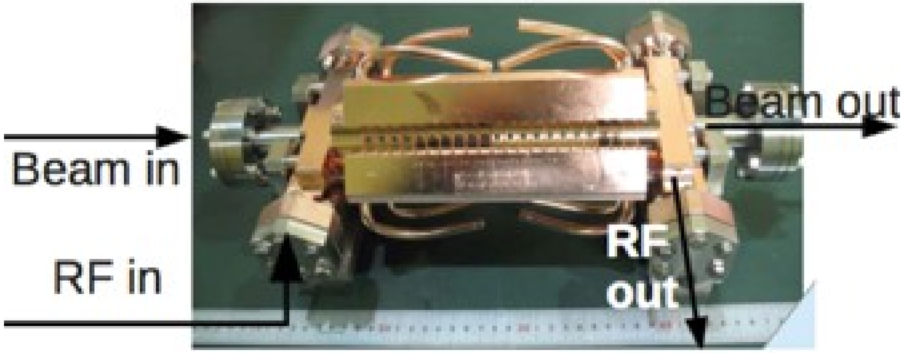
Two Technologies

ILC 'cold' technology - Superconducting 1.3 GHz RF

- Solid niobium
- Standing wave
- 9 cells operated at 2K

- 35 MV/m
- $Q_0 > 10^{10}$

CLIC 'warm' technology - 12 GHz Normal conducting cavity



- Copper
- Traveling wave

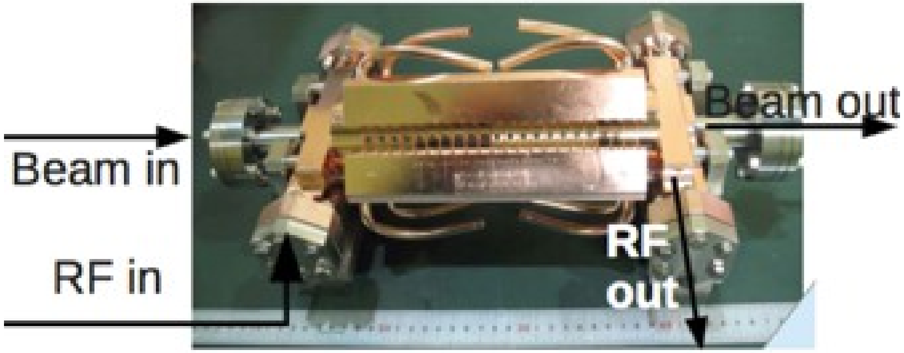
- 100 MV/m
- Rf pulse length 240 ns

Two Time Scales

ILC Technical Design published in 2013

- Ready to go
- Strong physics case now
- Preparation of construction

CLIC Conceptual design published in 2012

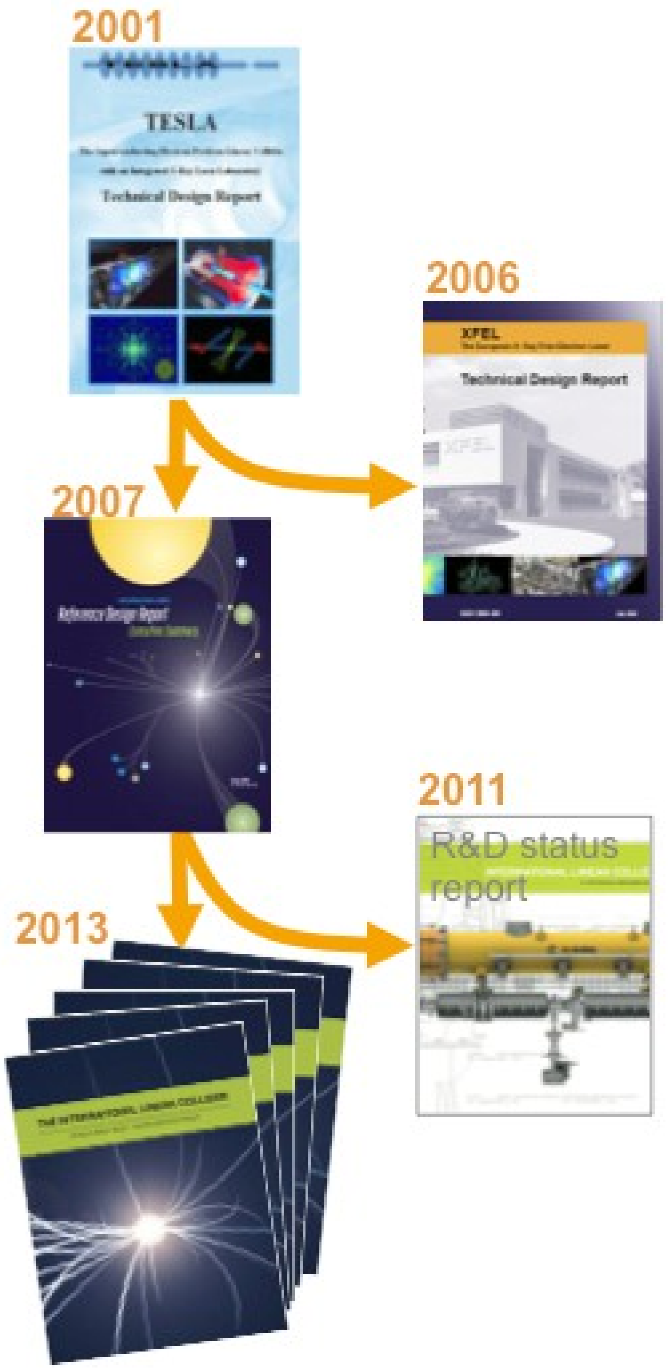


Goal for the next European Strategy update (2018):
Present a CLIC project that is a “credible” option for CERN beyond 2030
S. Stapness: LC Physics school Oct. 2013

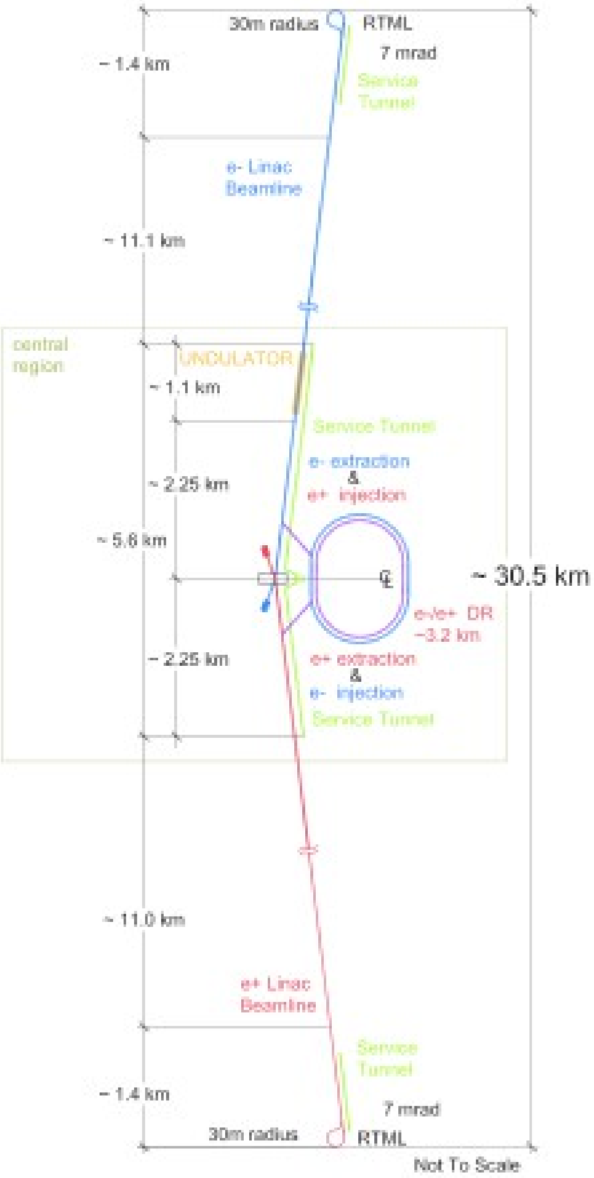
ILC 'just' around the corner

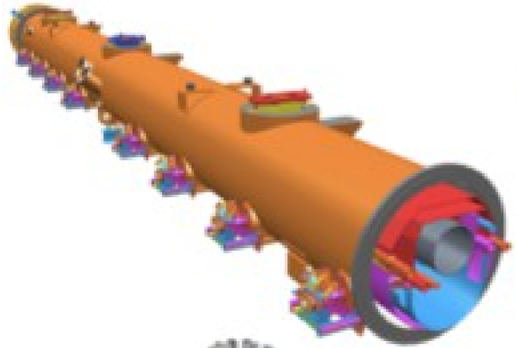
ILC History

- Pre Global Design Effort
  - 1992 TESLA starts (TTF)
  - 2002 BMBF XFEL decision
  - 2004 ITRP decision
  - 2009 XFEL construction begins
- Since 2005: GDE
  - 2005-2007 Reference Design Report and cost estimate
  - 2008-2012 Technical Design Phase
  - 2012 Technical Design Report and updated cost estimate
- **2013…**
  Linear Collider Collaboration (LCC) and towards Project Realisation (in Japan)



ILC in a nutshell





- **SCRF Technology**
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs

Luminosity

$$L \propto \frac{\boxed{\eta_{RF}} P_{RF}}{E_{cm}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

η_{RF} ~ 40% for cold technology

-> efficient technology

ILC 500 GeV parameters

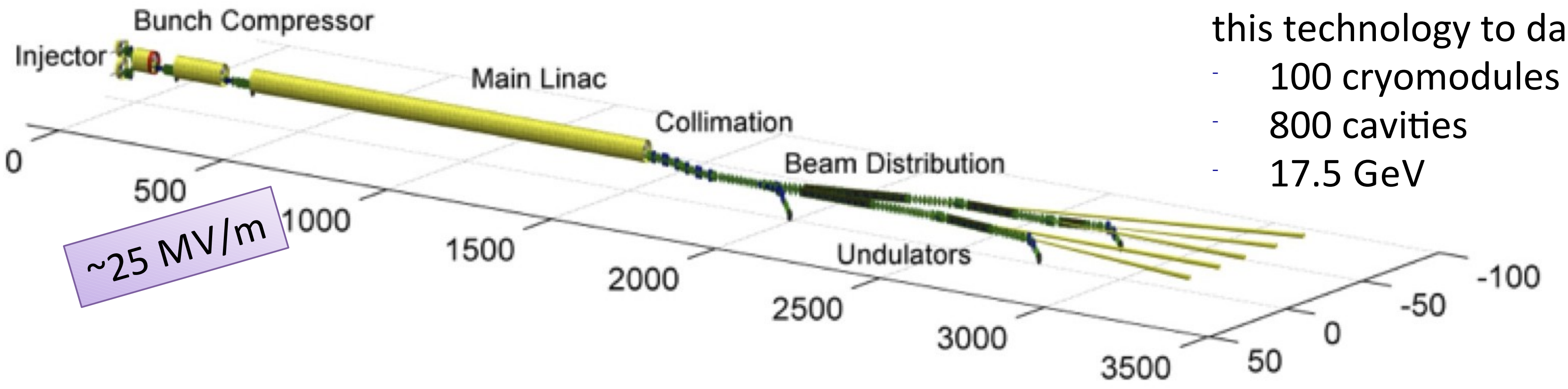
Physics	Max. Ecm	500 GeV
	Luminosity	1.8×10^{34} cm-2s-1
	Polarisation (e-/e+)	80% / 30%
	∫BS	4.5%
Beam (interaction point)	Ox / Oy	574 nm / 6 nm
	Oz	300 I m
	BJx / BJy	10 I m / 35 nm
	∩x / ∩y	11 mm / 0.48 mm
	bunch charge	2×1010
structure)	Number of bunches / pulse	1312
	Bunch spacing	554 ns
	Pulse current	5.8 mA
	Beam pulse length	727 I s
	Pulse repetition rate	5 Hz
Accelerator (general)	Average beam power	10.5 MW (total)
	Total AC power	163 MW
	(linacs AC power	107 MW)

tiny emittances
nano-beams at IP
strong beam-beam

High-power high-current
beams. Long bunch trains.
→ SCRF

Please note that #bunches and pulse repetition rate can be both increased by a factor of 2 w/o a problem

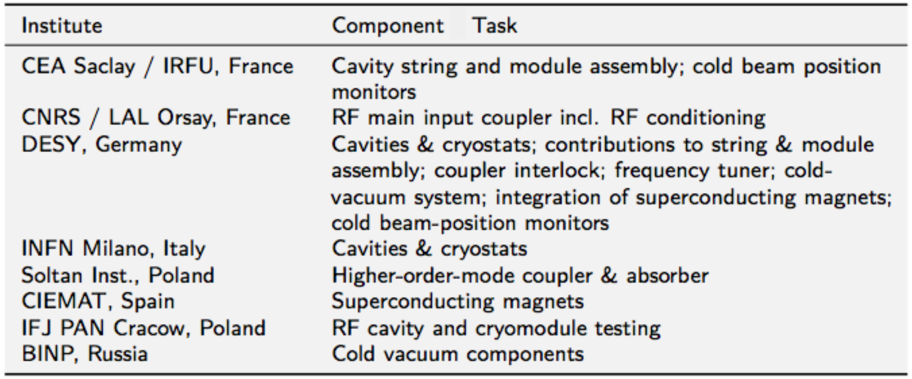
European XFEL @ DESY



~25 MV/m

Largest deployment of this technology to date

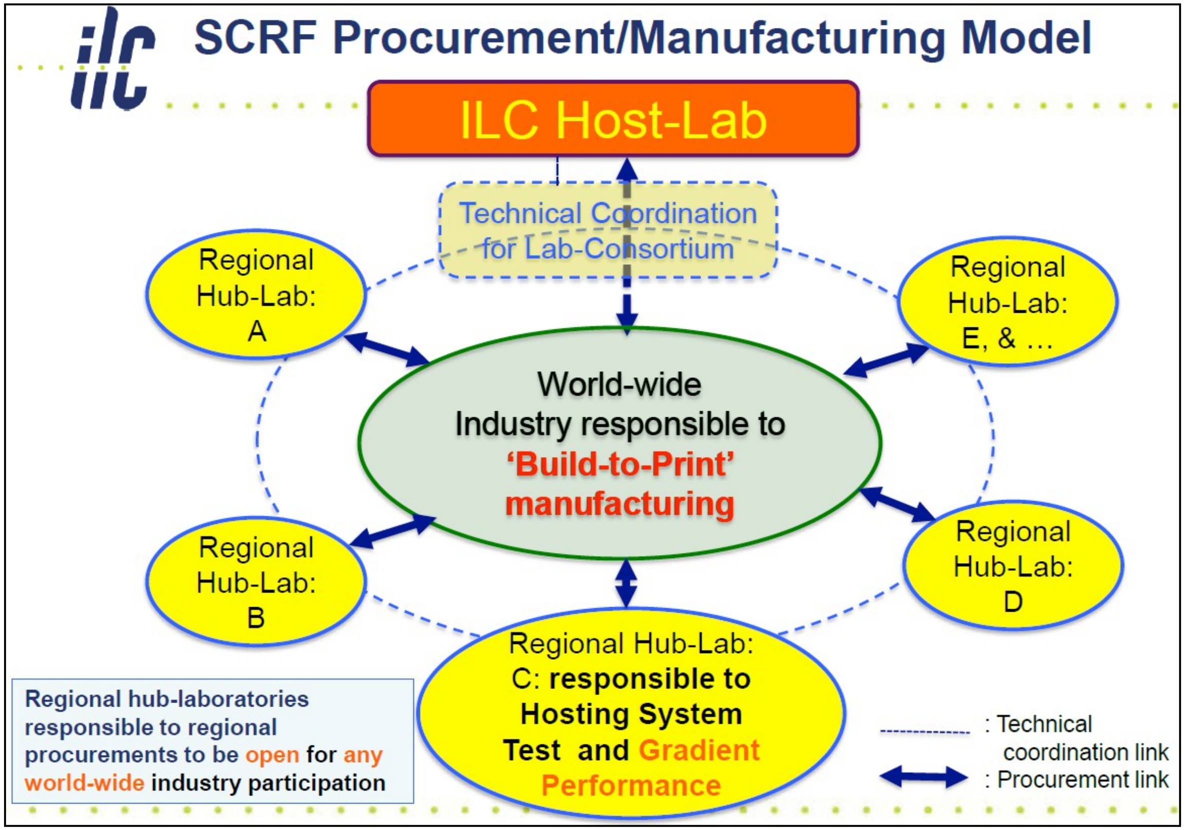
- 100 cryomodules
- 800 cavities
- 17.5 GeV



Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

The ultimate ‘integrated systems test’ for ILC.
Commissioning with beam 2nd half 2015

Organisation of ILC construction (A rough view)



Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

For ILC 500 GeV
with ~2000 cryomodules:
The goal is to achieve a
production rhythm of
2 cryomodules/week * 5 (3) hubs
→ 4 (7) years of construction

For XFEL with 100 cryomodules :
1 cryomodule / week
The infrastructures
(e.g. at Saclay and LAL)
are compatible with a production rhythm of
2 cryomodules / week

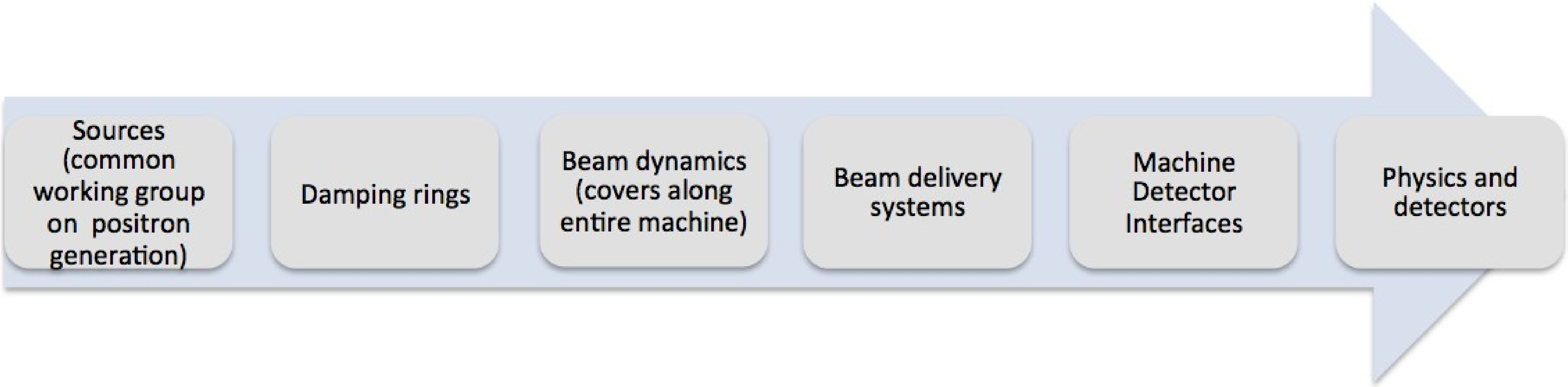
The majority of the linac fabrication will happen
in regional hubs in collaboration with regional vendors

“In kind contribution”

Money will be invested in regional industry

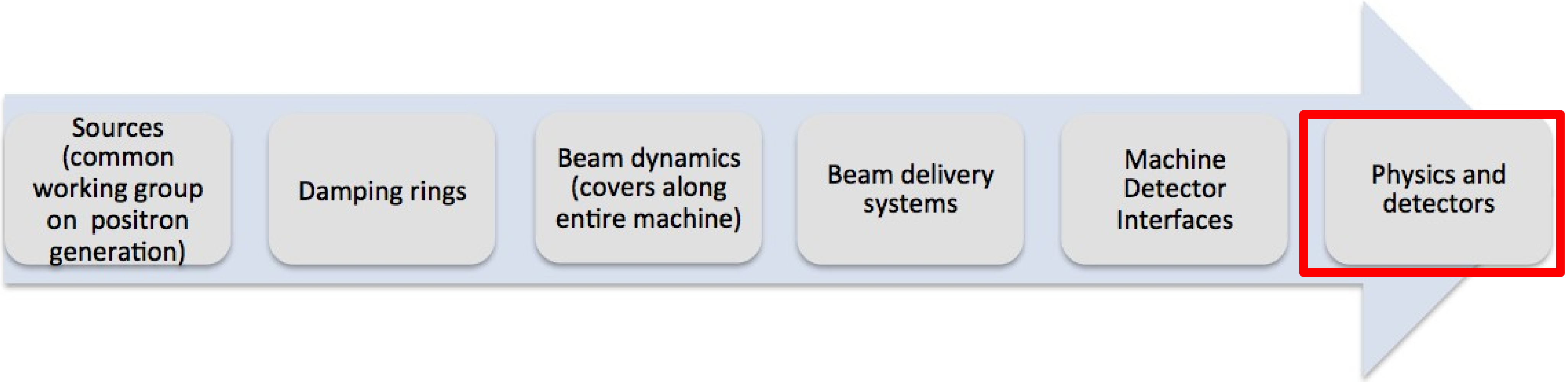
CLIC - ILC cooperation

Although quite different in technology there exists a lot of fields where CLIC and ILC can search for common solutions



- Sources (common working group on positron generation)
- Damping rings
- Beam dynamics (covers along entire machine)
- Beam delivery systems
- Machine Detector Interfaces
- Physics and detectors

Chapter V:


Sources (common working group on positron generation)

Damping rings

Beam dynamics (covers along entire machine)

Beam delivery systems

Machine Detector Interfaces

Physics and detectors

... with focus on European activities

Material from M. Winter, N. Garcia, R. Diener

Detector requirements

Track momentum: $\sigma_{1/p} < 5 \times 10^{-5}$/GeV (1/10 x LEP)

(e.g. Measurement of Z boson mass in Higgs Recoil)

Impact parameter: $\sigma_{d0} < [5 \oplus 10/(p[\mathrm{GeV}]\sin^{3/2}\theta)]$ μm(1/3 x SLD)

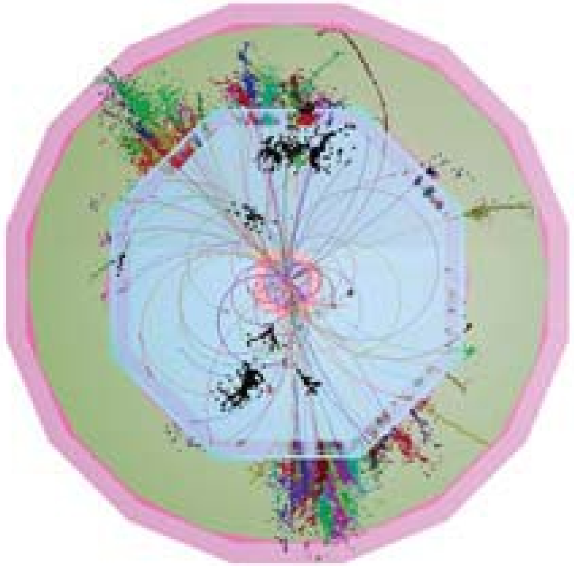
(Quark tagging c/b)

Jet energy resolution : $dE/E = 0.3/(E(\mathrm{GeV}))^{1/2}$ (1/2 x LEP)

(W/Z masses with jets)

Hermeticity : $\theta_{min} = 5$ mrad

(for events with missing energy e.g. SUSY)



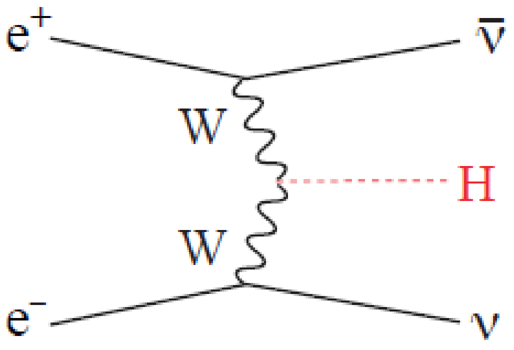
Final state will comprise events with a large number of charged tracks and jets(6+)

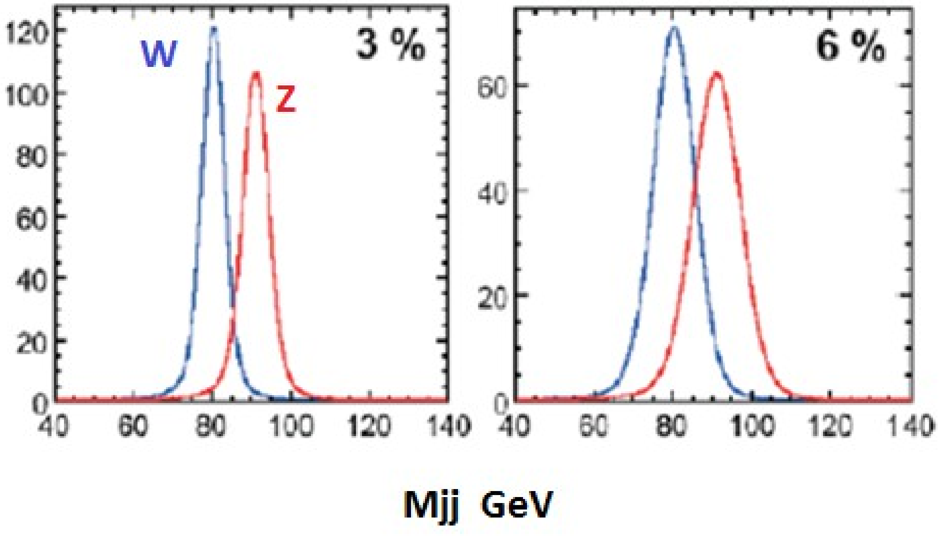
- High granularity
- Excellent momentum measurement
- High separation power for particles

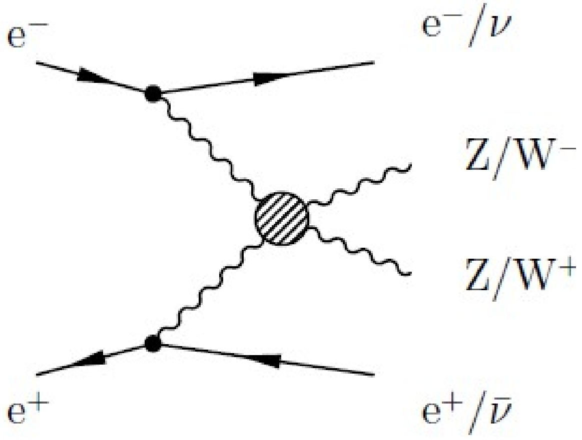
Particle Flow Detectors

Examples

- W Fusion with final state neutrinos requires reconstruction of H decays into jets
- Jet energy resolution of ~3% for a clean W/Z separation

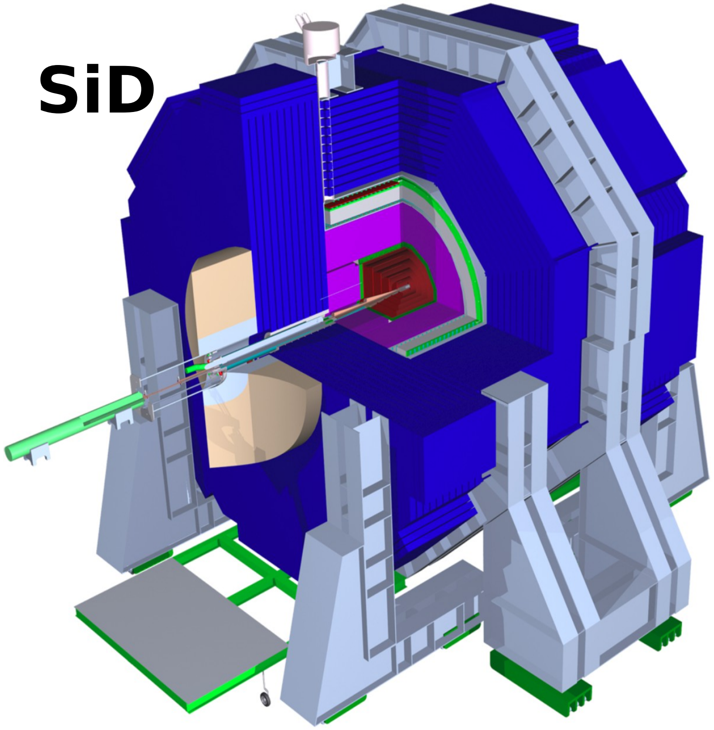




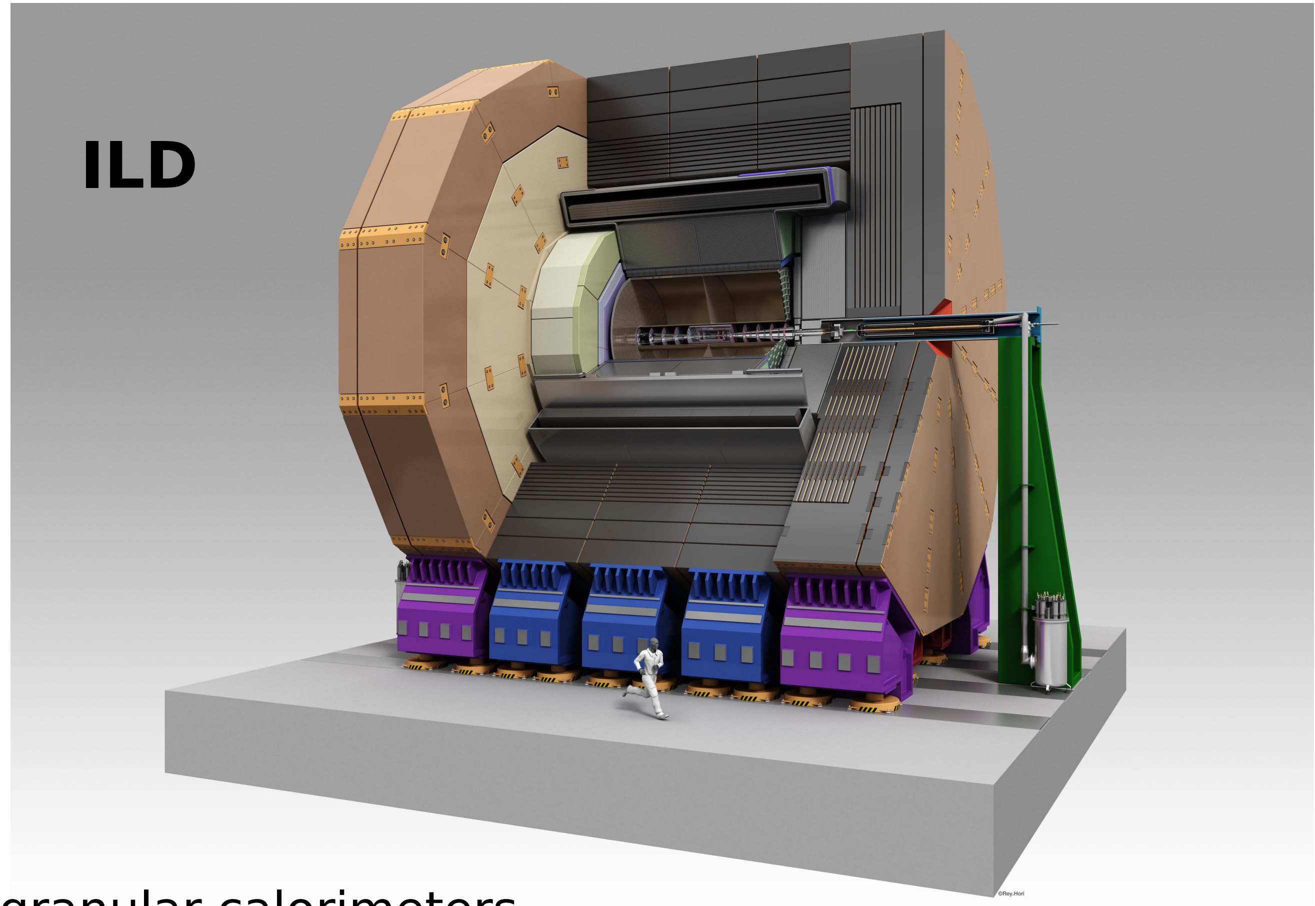


F. Richard at International Linear Collider – A worldwide event

Detector concepts



SiD



ILD

Highly granular calorimeters

Central tracking
with silicon

Central tracking
with TPC

Inner tracking with silicon

- LOI's Validated by IDAG in 2009
- Publication of **D**etector **B**aseline **D**esign in 2013, together with TDR
- Concepts based on input from physics studies and detector R&D organised in R&D collaborations

Examples for detector R&D collaborations

LC TPC

Time Projection Chamber
for Linear Collider

CALICE
Calorimeter for ILC

Highly granular calorimeters
for Linear Collider

FCAL
Collaboration
High precision design

Forward calorimeters
for Linear Collider

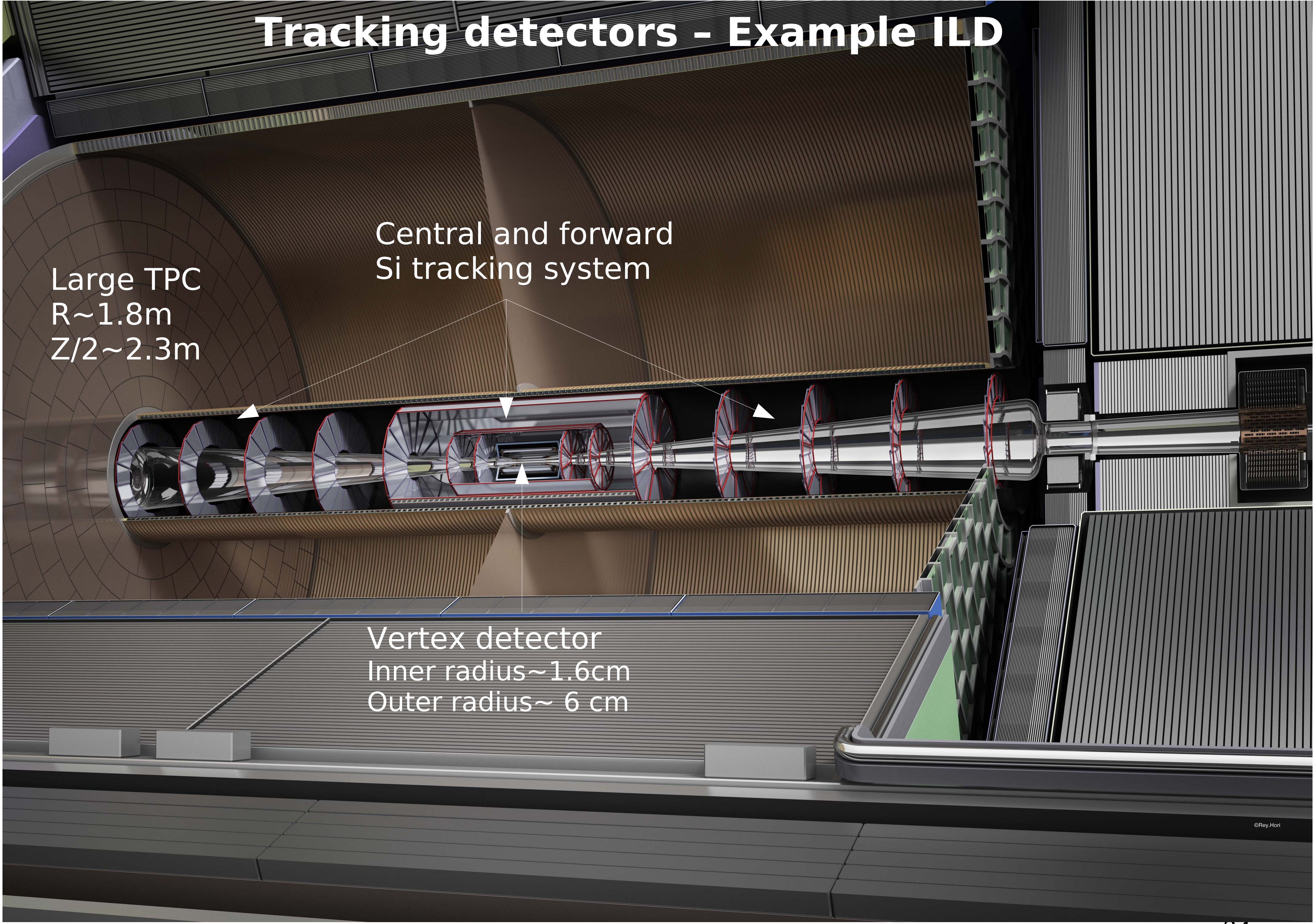
Silicon tracking for the
International
Linear
Collider

PLUME

- Oriented towards LC but very generic R&D

R&D RPCs, Micromegas, SiPMs, ultrathin vertex layers, diamond sensors
Large scale integration of electronics, small power consumption

Tracking detectors – Example ILD



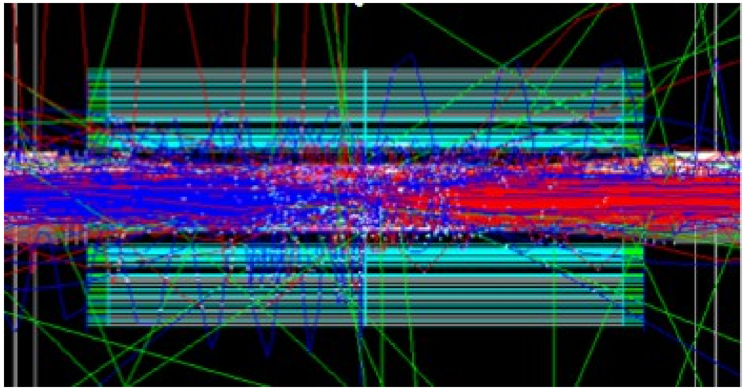
Large TPC
R~1.8m
Z/2~2.3m

Central and forward
Si tracking system

Vertex detector
Inner radius~1.6cm
Outer radius~ 6 cm

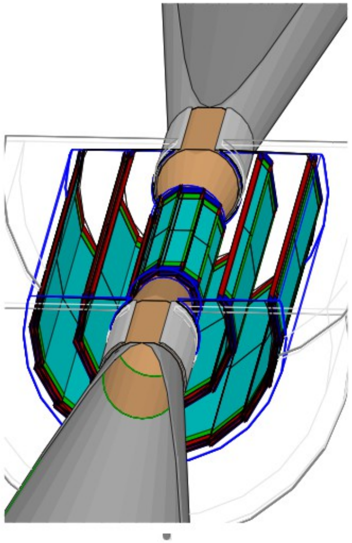
©Rey.Hori

Vertex detector systems



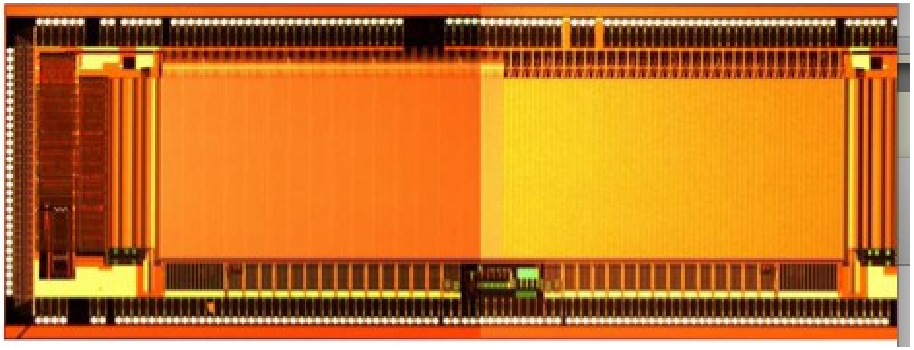
Motivation:
b/c separation for Higgs decays
B charge measurement

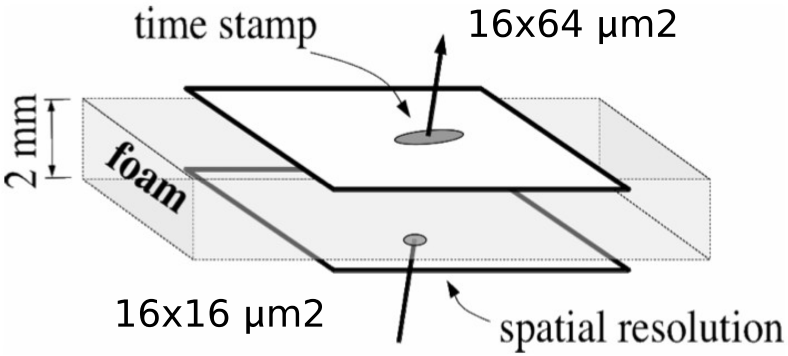
Approach:
Double sided ladders
Large bandwidth (no trigger)
Ulthathin ~ 50μm



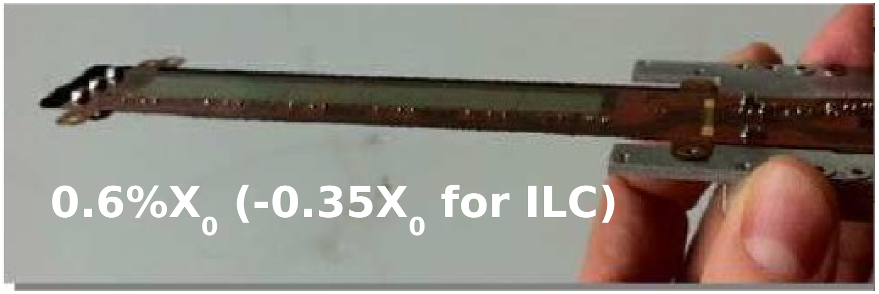
Example MIMOSA Chip:

0.35μm CMOS

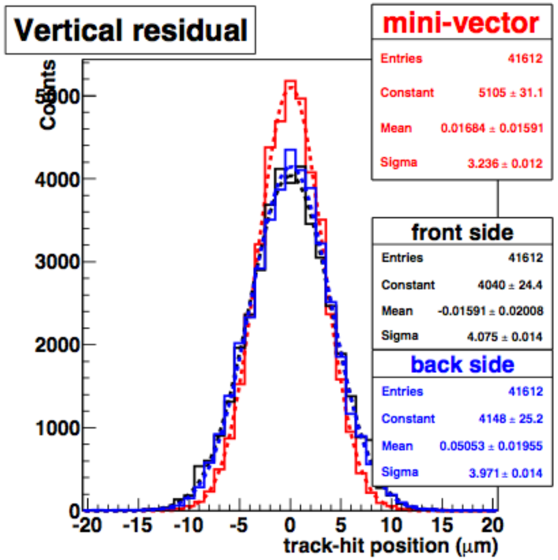




Ultrathin ladder - PLUME



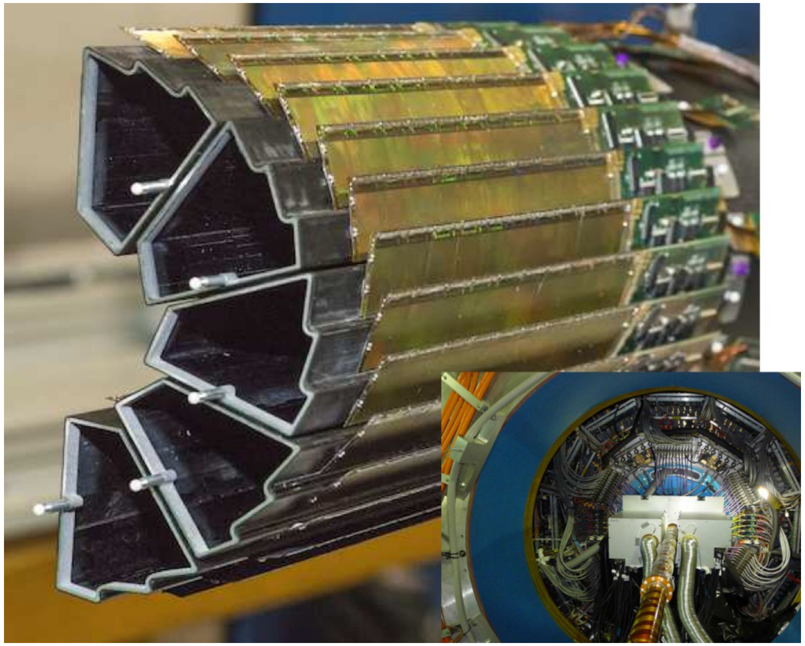
$0.6\%X_0$ ($-0.35X_0$ for ILC)

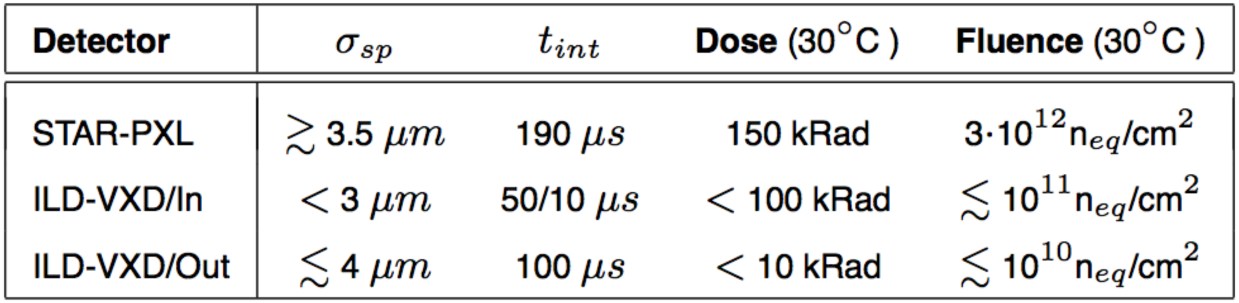


~3μm
Track
resolution

Applications beyond/before ILC

CMOS



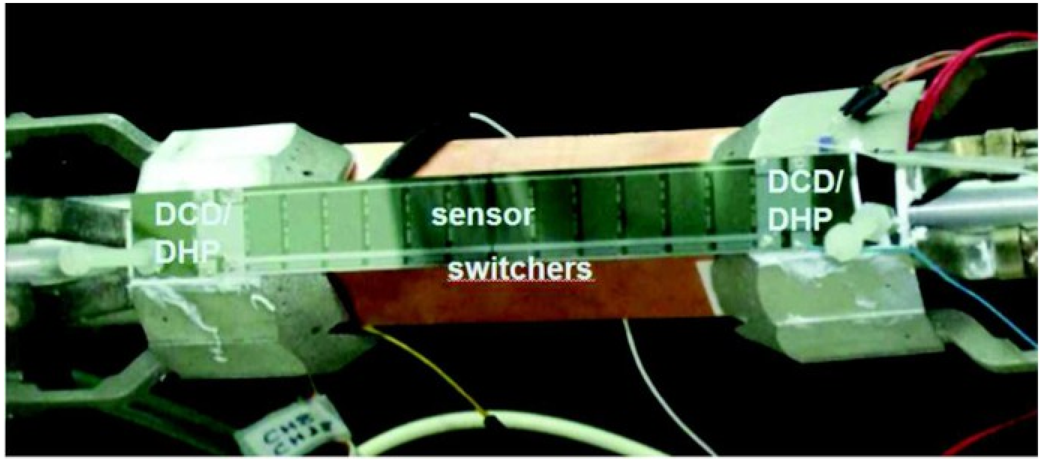


Detector	σ_{sp}	t_{int}	**Dose** (30°C)	**Fluence** (30°C)
STAR-PXL	$\gtrsim 3.5\ \mu m$	$190\ \mu s$	150 kRad	$3\cdot10^{12}\,\mathrm{n}_{eq}/\mathrm{cm}^2$
ILD-VXD/In	$< 3\ \mu m$	$50/10\ \mu s$	$<$ 100 kRad	$\lesssim 10^{11}\,\mathrm{n}_{eq}/\mathrm{cm}^2$
ILD-VXD/Out	$\lesssim 4\ \mu m$	$100\ \mu s$	$<$ 10 kRad	$\lesssim 10^{10}\,\mathrm{n}_{eq}/\mathrm{cm}^2$

ILC requires ten times better time stamping

NB.: CLIC would require ns time stamping

DEPFET

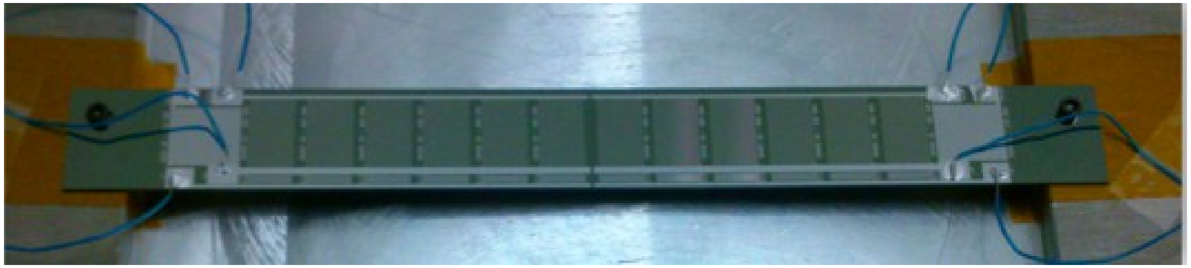


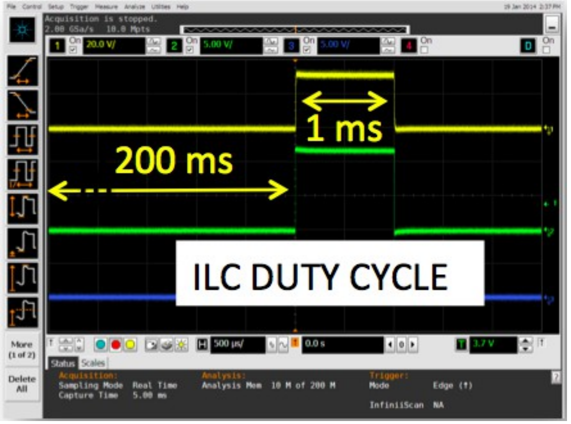
Proposal for ILC
and
choice of Belle II

Forward (and central) silicon tracking

75 µm Si petals carried by 1mm support disks

DEPFET mecanical ladder .... tested for power pulsing

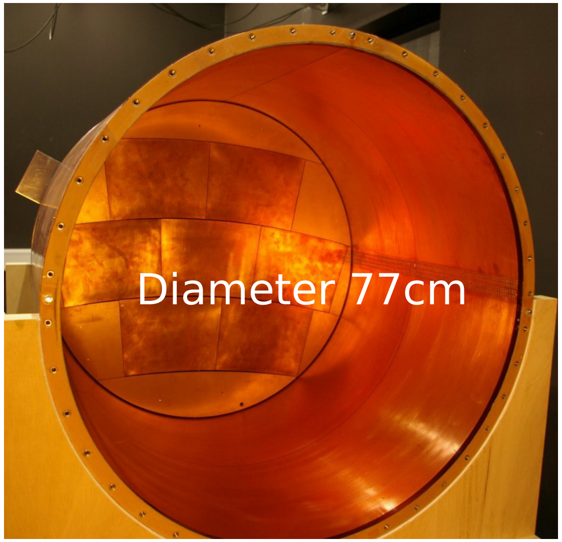


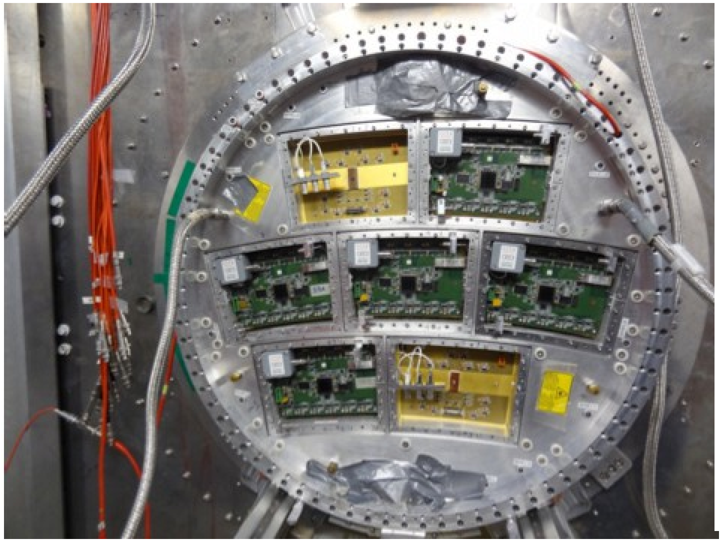


Central tracking - TPC

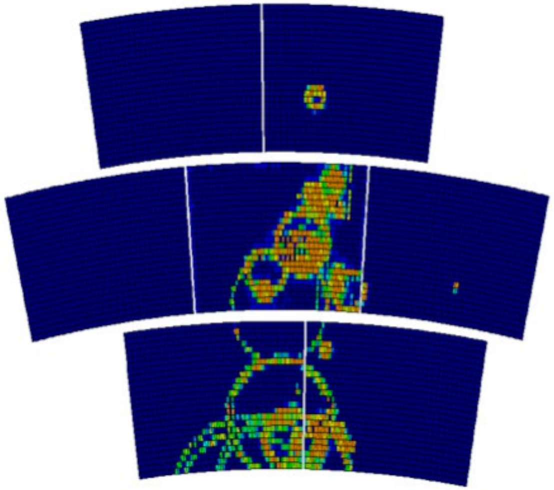
Motivation: Sweep out particles for Particle Flow
Precise momentum for e.g. ee->HZ->Zμμ

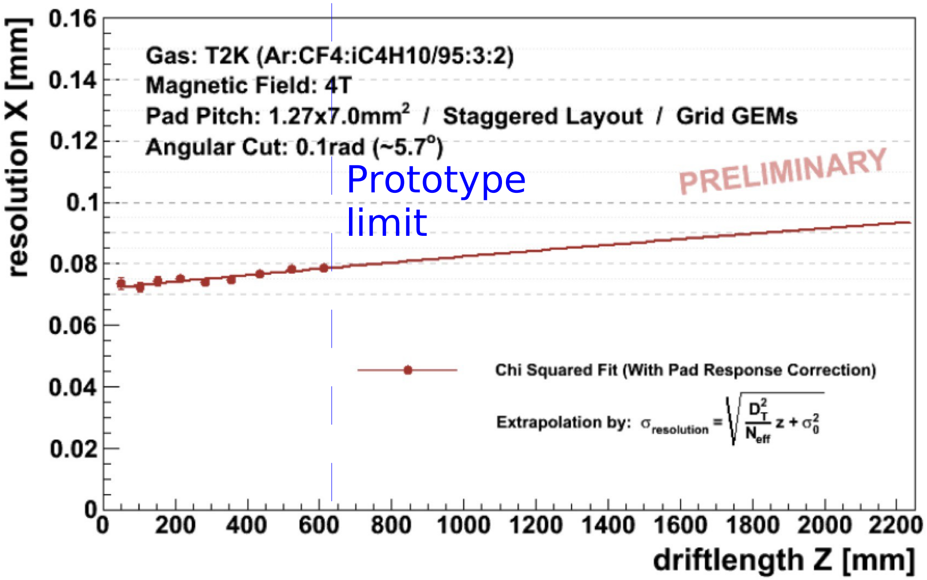
TPC prototype with versatile endplate





Testbeam inside PCMAG@DESY



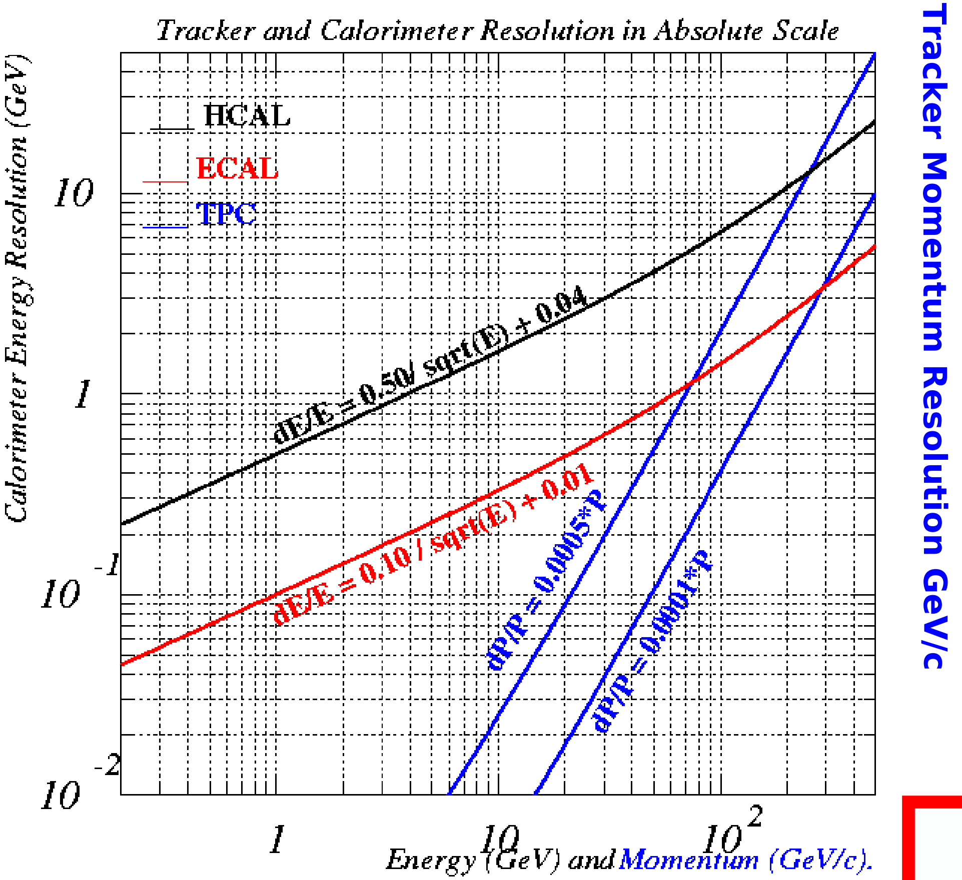


TPC prototype reaches ~0.1mm position resolution

-> Goal for final TPC can be reached

Jet energy resolution and Calorimeters

Final state contains high energetic jets from e.g. Z,W decays
Need to reconstruct the jet energy to the utmost precision !
Goal is around dE_{jet}/E_{jet} - 3-4% (e.g. 2x better than ALEPH)



Jet energy carried by …

- Charged particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$65% :((
  Most precise measurement by Tracker
  Up to 100 GeV

- Photons: 25%
  Measurement by Electromagnetic
  Calorimeter (ECAL)

- Neutral Hadrons: 10%
  Measurement by Hadronic
  Calorimeter (HCAL) and ECAL

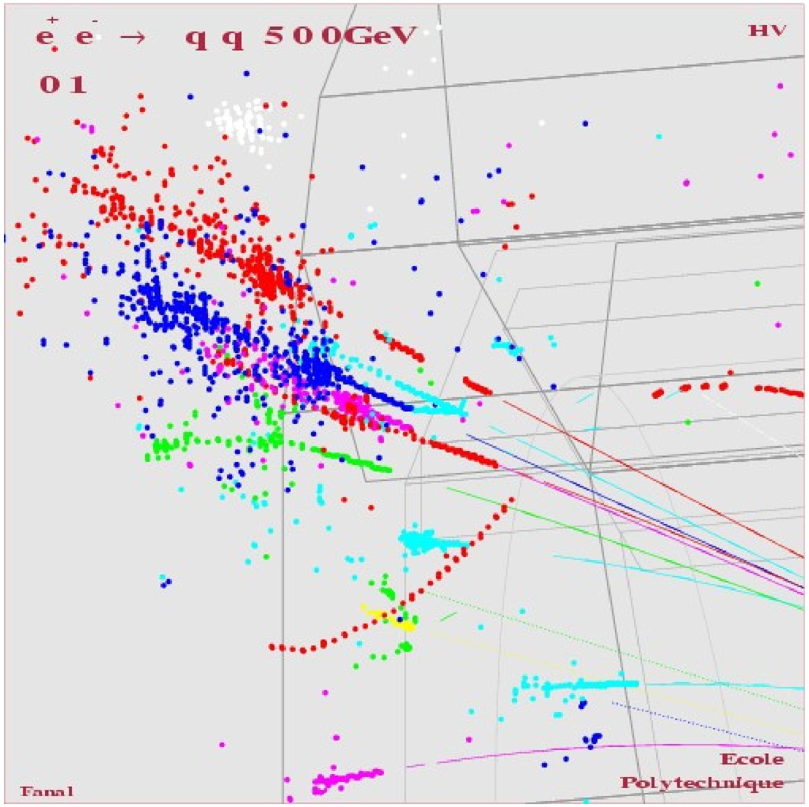
$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{Had.} + \sigma^2_{elm.} + \sigma^2_{Confusion}}$$

Confusion term

- Reconstruct jet energy on the basis of the measurement of individual particles

Particle Flow

- Base measurement as much as possible on measurement of charged particles in tracking devices
- Separate of signals by charged and neutral particles in calorimeter



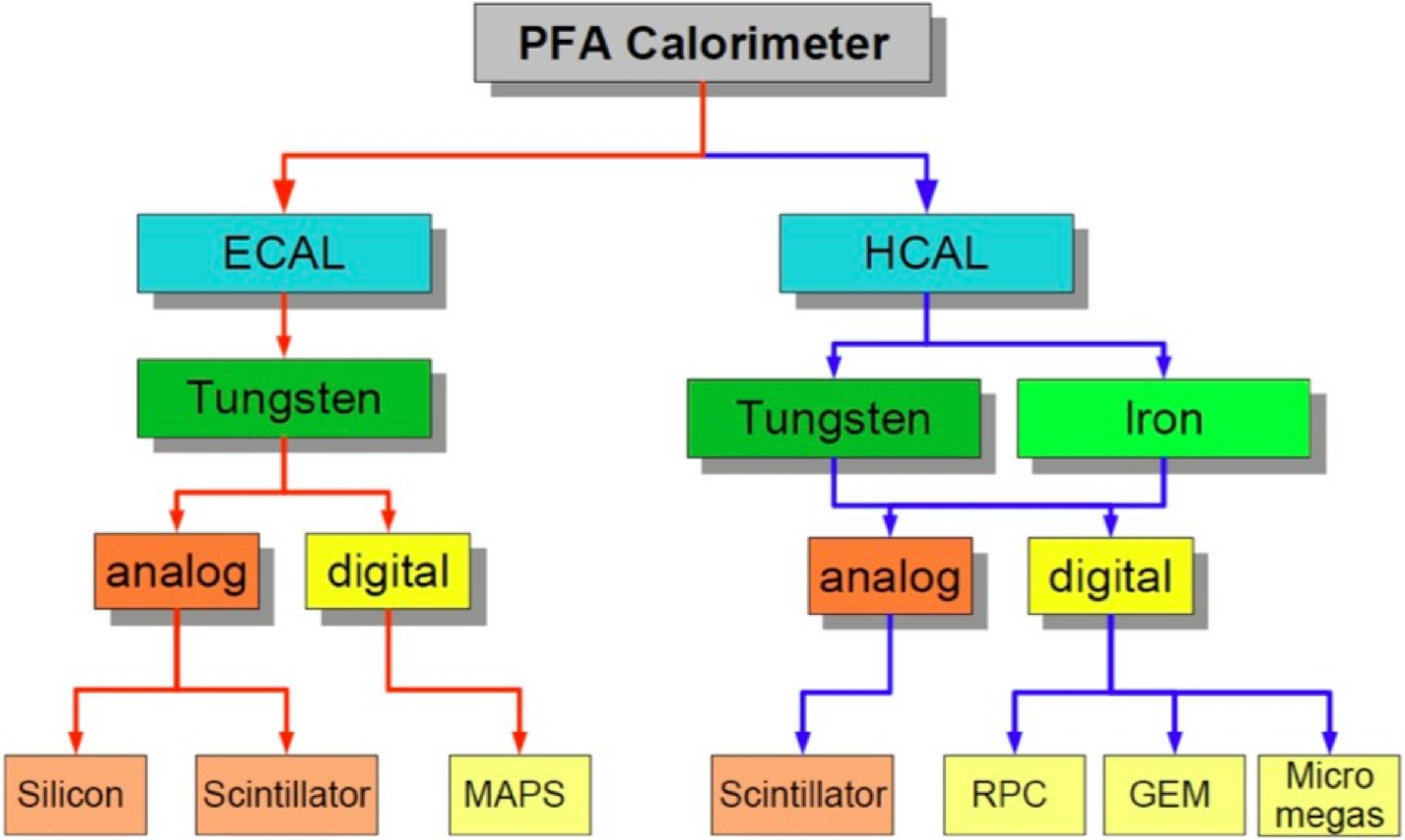
- Complicated topology by (hadronic) showers

- Overlap between showers compromises correct assignment of calo hits

☐ Confusion Term

Control of confusion term by highly pixelised calorimeters

Calorimeter technologies for LC Detectors



PFA Calorimeter

ECAL

Tungsten

analog

digital

Silicon

Scintillator

MAPS

HCAL

Tungsten

Iron

analog

digital

Scintillator

RPC

GEM

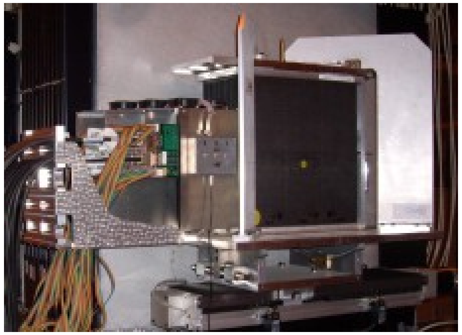
Micro megas

Example for R&D cycle – CALICE SiW Ecal

Physics Prototype

Proof of principle

2003 - 2011



Number of channels : 9720

Pixel size: 1x1 cm2

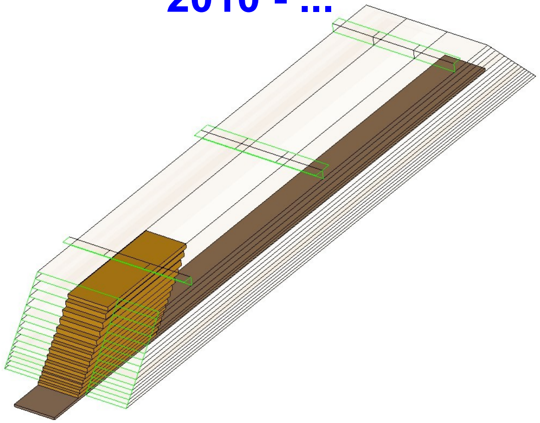
$R_{M,eff}$: ~ 1.5cm

Weight : ~ 200 Kg

Technological Prototype

Engineering challenges

2010 - ...



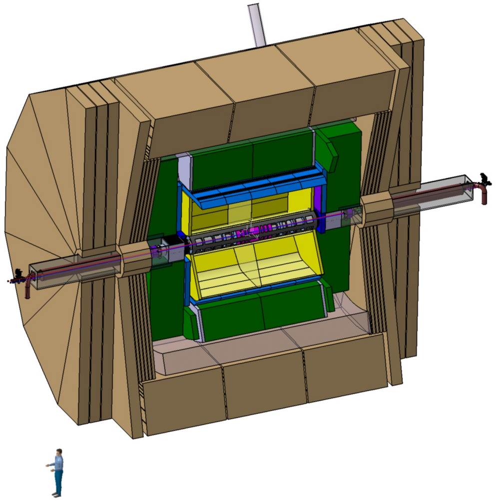
Number of channels : 45360

Pixel size: 0.55x0.55 cm2

$R_{M,eff}$: ~ 1.5cm

Weight : ~ 700 Kg

LC detector



ECAL :

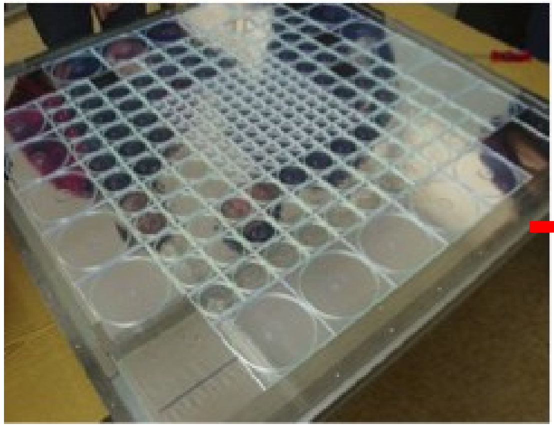
Channels : ~100 10^6

Total Weight : ~130 t

SiW Ecal is maybe most ambitious sub-detector project
Nice French-Japanese collaboration but clearly understaffed
Mutual benefit with CMS upgrade !?

R&D for hadronic calorimeters – Large scale prototypes

Scintillating tiles



... with SiPM r/o

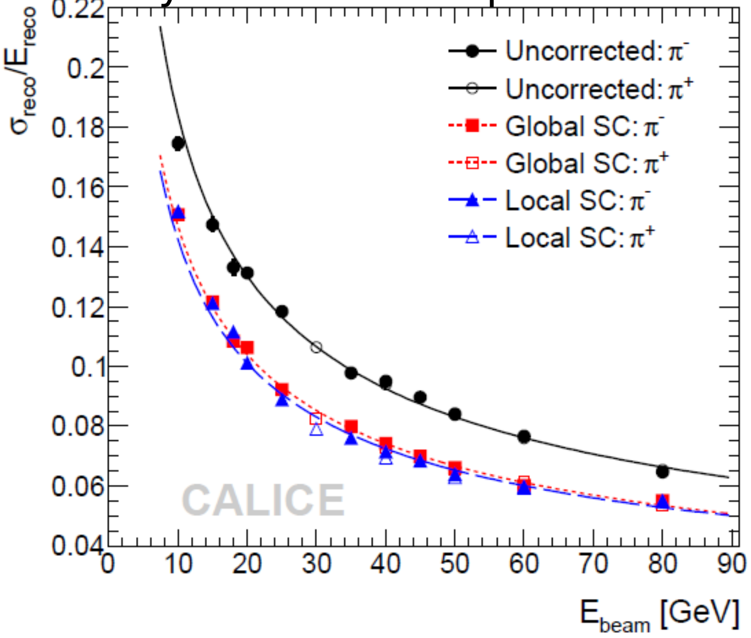
~1m^3 absorber structure

Steel or Tungsten

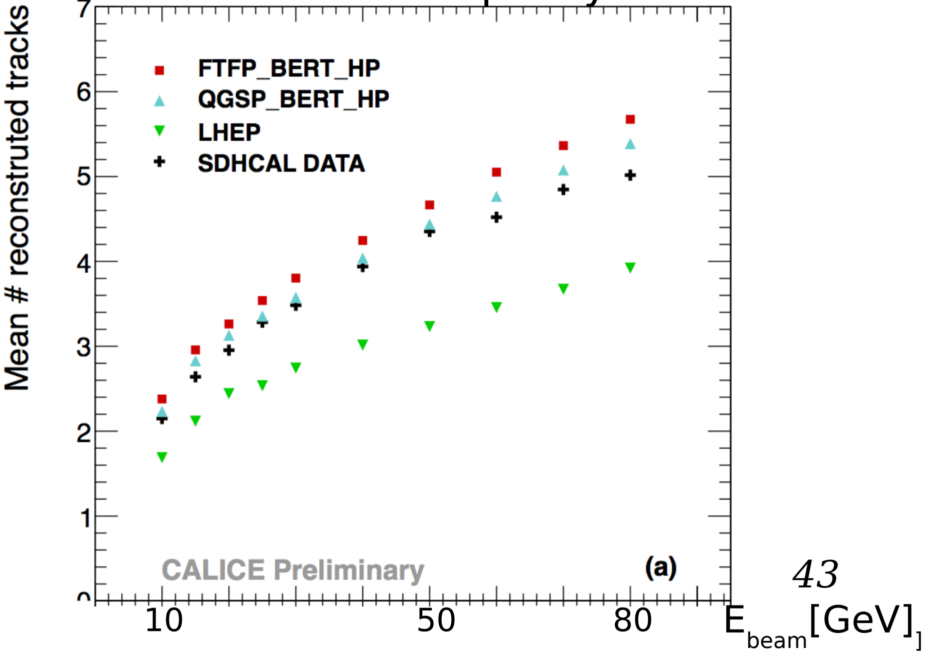
Glass RPCs

... with semi-digital r/o

Excellent hadronic energy resolution by software compensation

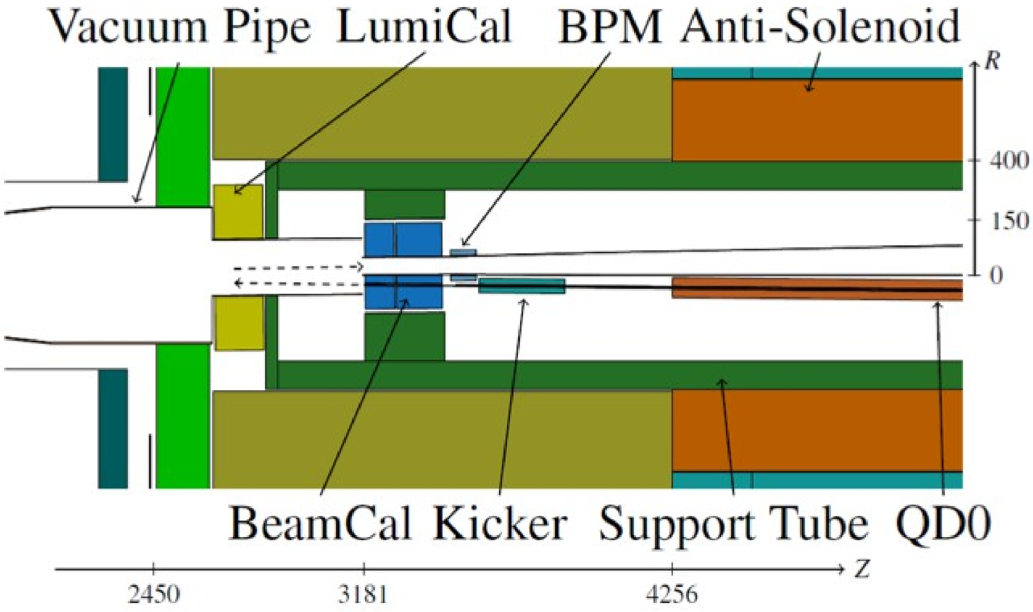


Shower substructure
Track multiplicity

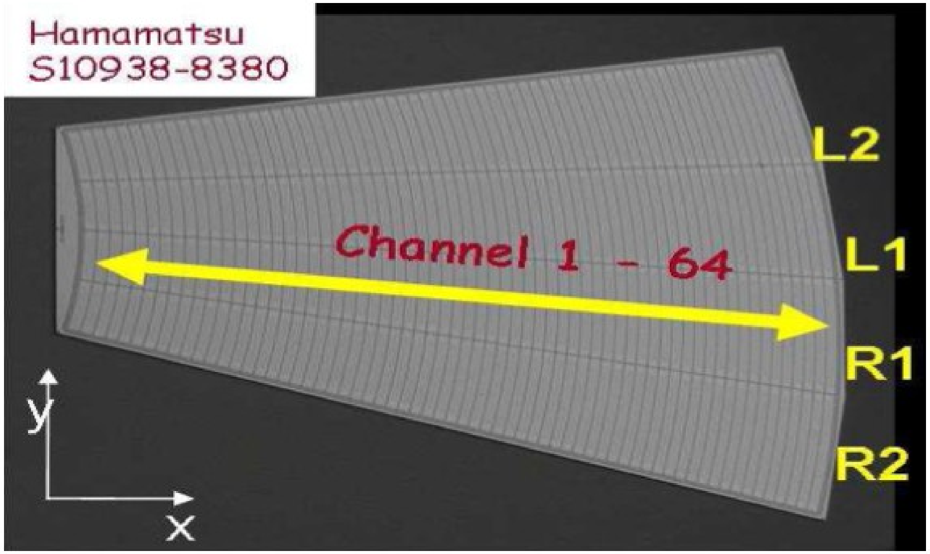


Forward calorimetry

- LumiCal provides integrated luminosity measurements:
  - 30 interspersed layers of tungsten absorber and silicon sensors.
  - 3.5 mm tungsten plates ($1X_0$)
  - 320 μm Si sensor with radial and azimuthal segmentation.



- BeamCal provides instant luminosity measurement and assists beam tuning:
  - Estimated dose 1 MGy/year;
  - GaAs sensor;
  - CVD diamond sensors for innermost part;
  - 3.5 mm thick tungsten absorber.



Chapter VI: “Political” issues

General status of LC project

There is no doubt on the utmost relevance of LC project

Linear Collider Collaboration established

ILC:

- TDR and DBD prove mature technology
- Serious interest of Japan to host the machine (-> see next slides)
- Positive reactions from other regions
  -> European strategy published in spring 2013
  -> P5 report underlined outstanding scientific potential
  -> ACFA expressed unanimous support of project
    However, somewhat heterogenous community
  -> Positioning of China?
    Repetitive positive statements on ILC, however national program

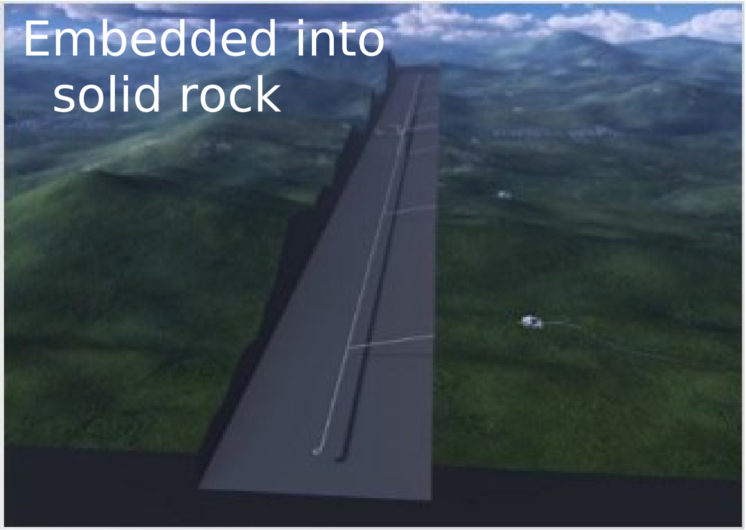
Hour of politics did come

CLIC:

- Not yet ready for a proposal
- R&D will continue to assure readiness for e.g. Next European Strategy

23 August 2013 – Selection of Japanese Site for ILC

Prefectures
Iwate and Miyage


Embedded into solid rock

Japan strives for truly international project

(See also in-kind policy above)

Concrete site allows to tailor accelerator and detector design

Very Recent Activities

2013 June: ILC Event TDR Review is completed
(Tokyo ⇒Geneva ⇒Chicago)

2013 June-August: ILC Review Committee was formed in Science Council of Japan

2013 April: ILC Taskforce started in MEXT Japan

2013 August: A site in Japan has been chosen by scientists (MEXT, Politicians have agreed to the process)

2013 November: Address of Chair of Japanese Diet members for the promotion of the ILC

2013 Xmass: **First allocation of ILC budget by Japanese government**
Small but real, in Japan all projects start like this, doubled in 2015!

2014 March: Formation of an international committee to revise the Project Implementation Plan

2014 May: Review of ILC Project by MEXT Task Force - Results in ~Spring 2016

ILC in a staged approach

- Looks intuitive to run the machine initially @ 250 GeV as a Higgs Factory

  At initially lower cost

- ILC @ 500 GeV could then be considered as a first upgrade (Crossing the) tt-threshold, ZHH final states

  Note however that this upgrade would only concern the linac

  All other components need to be in place already at 250 GeV

- ILC @ 1 TeV would be then the second upgrade phase

  ttH, unitarity bounds,
  new particles (?), e.g. colorless supersymmetric particles
  Sensitivity versus extra dimensions up to several 10 TeV

- Options

  Luminosity x4, technically possible but increase of running costs
  Higher energy (First SCRF cells with 60 MV/m have been produced)
  The last remark is the poor-mans view of R.P.

Time line ?

Very touchy subject!

- TDR in 2013 has been kick-off for project preparation phase

  Japanese interest is serious and the country has to take the lead

- Negotiations between Japan and other countries region have started

  Regular visits of Japanese representatives to Europe/US

  MEXT Members

  Parliamentary delegations

  Repetitive positive statements on ILC, however national program

- Construction start depends on a lot of parameters

  It is not serious to speculate, Facility planning has to start at ~ t_0-4 years

- Data taking 7-9 years after t_0

Summary

- The ILC is versatile machine for precision physics in the range m_z – 1 TeV

  Polarised beams to test chiral theory!

- Higgs and top quark are physics guaranteed

  (My conviction) both are messengers to New Physics

- Discovery potential in supersymmetric and dark matter sector

- Technologies are getting mature

  ILC is ready to be constructed
  CLIC made remarkable progress
  Sharing well advanced detector technologies

- It's time to make the step towards the project

  Window of opportunity to build the ILC is open
  We must not miss this (maybe unique) chance

- Pakistanian group (COMSATS) is considering to join

For learning more: www.linearcollider.org

LC workshops 2015

- **CLIC workshop 2015, CERN, 26-30 Jan.**
  https://indico.cern.ch/event/336335/

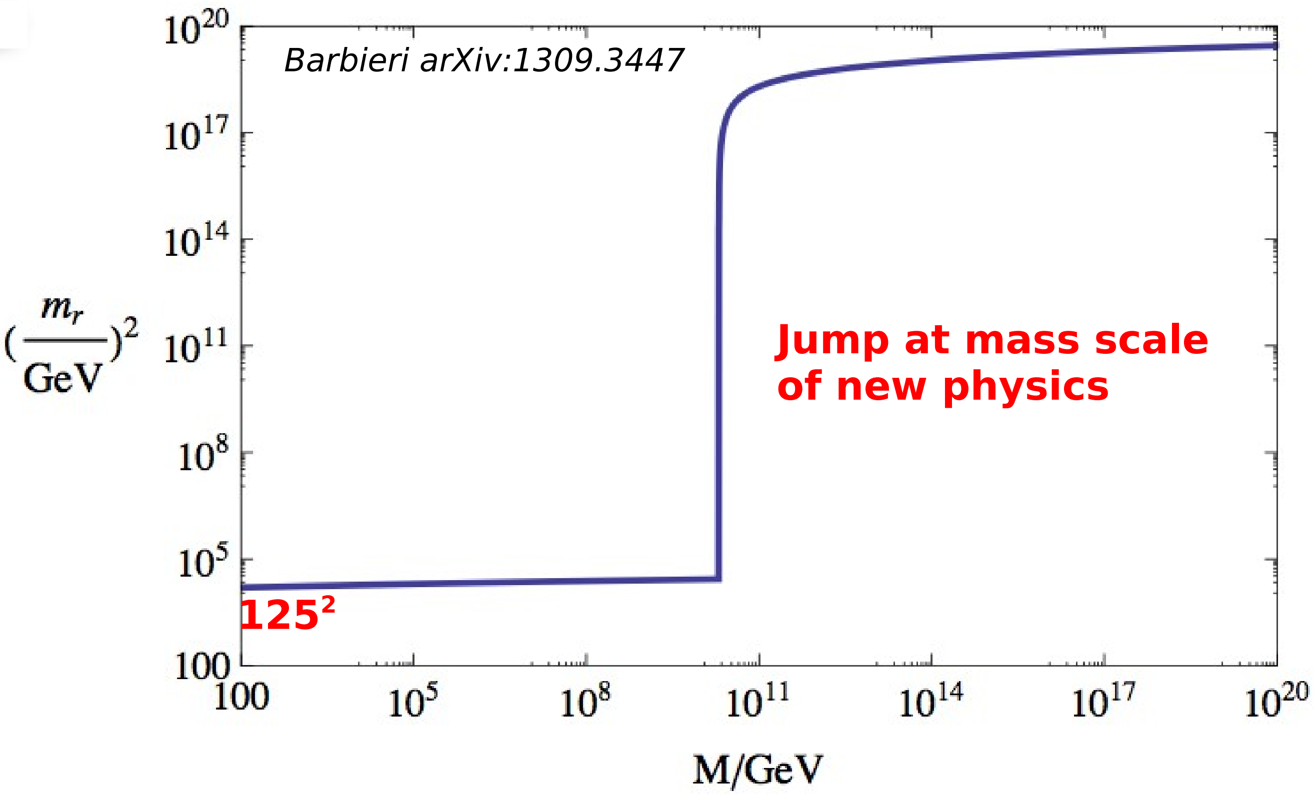
- **Asian Linear Collider Workshop 2015, 20-24 April**
  KEK
  Local Chair: Y. Okada, A. Yamamoto
  Special separated event with Japanese authorities is planned during the workshop at Tokio

- **LCWS15, Americas, 2015, Vancouver & date to be decided**

Backup slides

Effect on New Scale of Higgs Mass

Renormalised running Higgs mass
(in dimensional regularisation)



The higher the new physics is the more drastic is the Jump or the more carefully one has to tune the initial conditions at some high scale

Intuitive argument that New Physics cannot be that far out there!

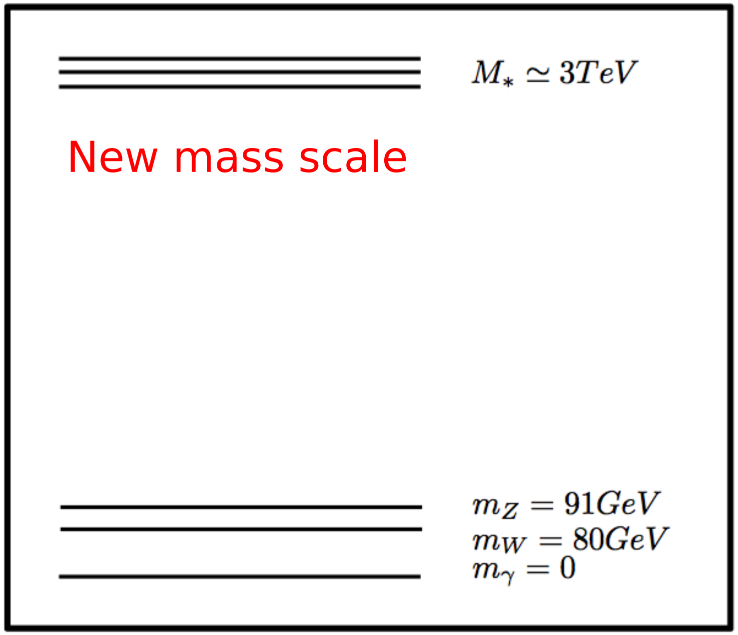
The quest for a new scale – Compositeness

à la G.M. Pruna, LC 13, Trento

Compositeness:

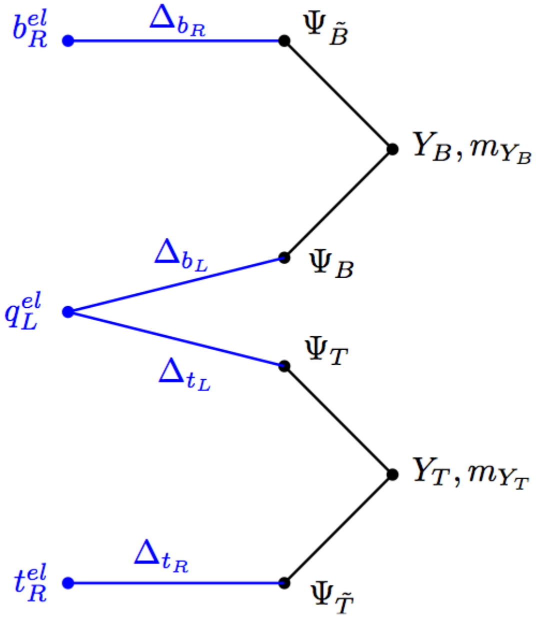
- ... provides elegant solution for naturalness
- ... few tensions with SM predictions
- ... composite Higgs hypothesis has only been marginally studied in comparison with other “fundamental” scenarios
- ... **all** scalar objects observed in nature turned out to be bound states of fermions

Bosonic sector mass spectrum



Fermionic resonances

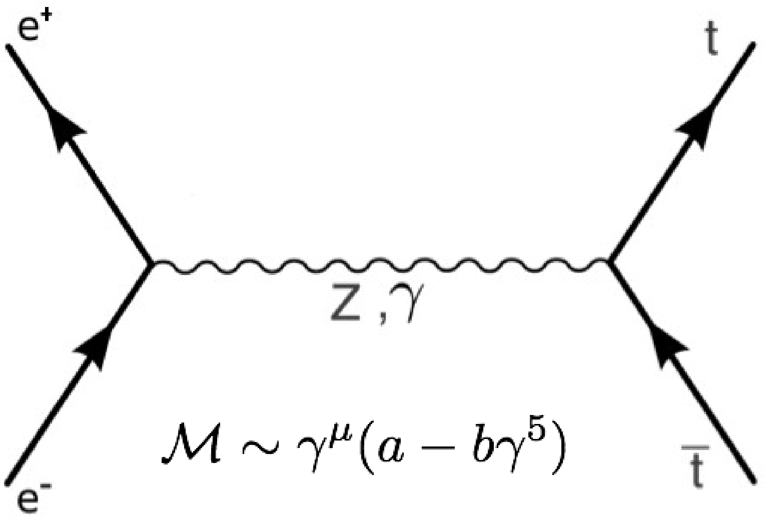
From heavy left handed SM doublet
and heavy right handed SM singlet

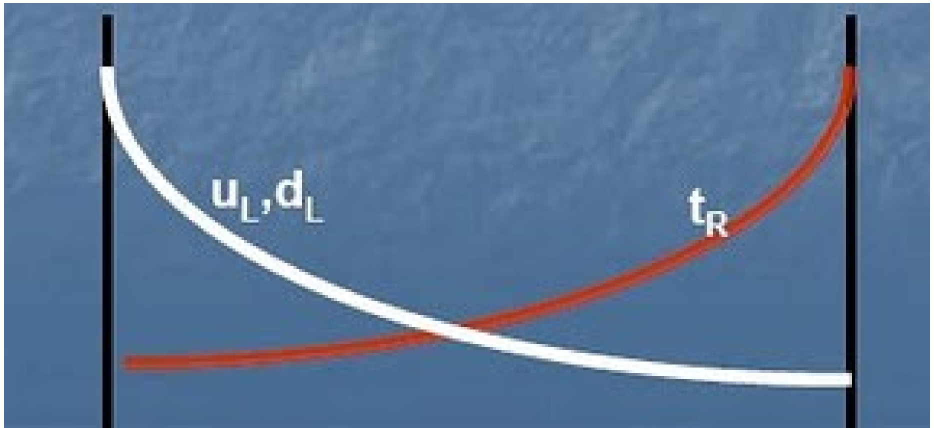


Physics modify Yukawa couplings and Ztt, Zbb

Heavy fermion effect!

Closer look to helicity states ...

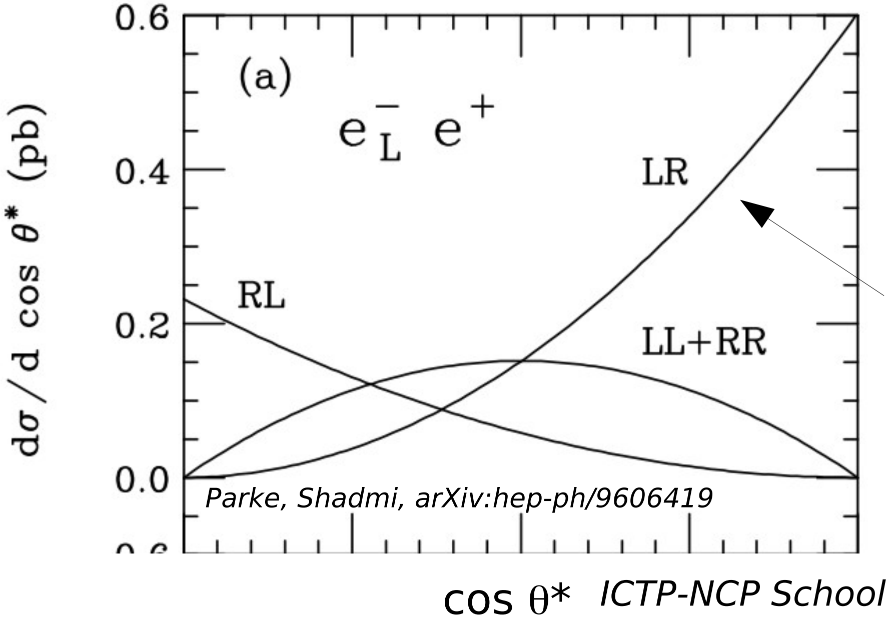




Standard model 'prefers' left handed particles

New physics may alter this 'preference'

Beam polarisation allows to study left and right handed particles seperately



Parke, Shadmi, arXiv:hep-ph/9606419

(Generic) example

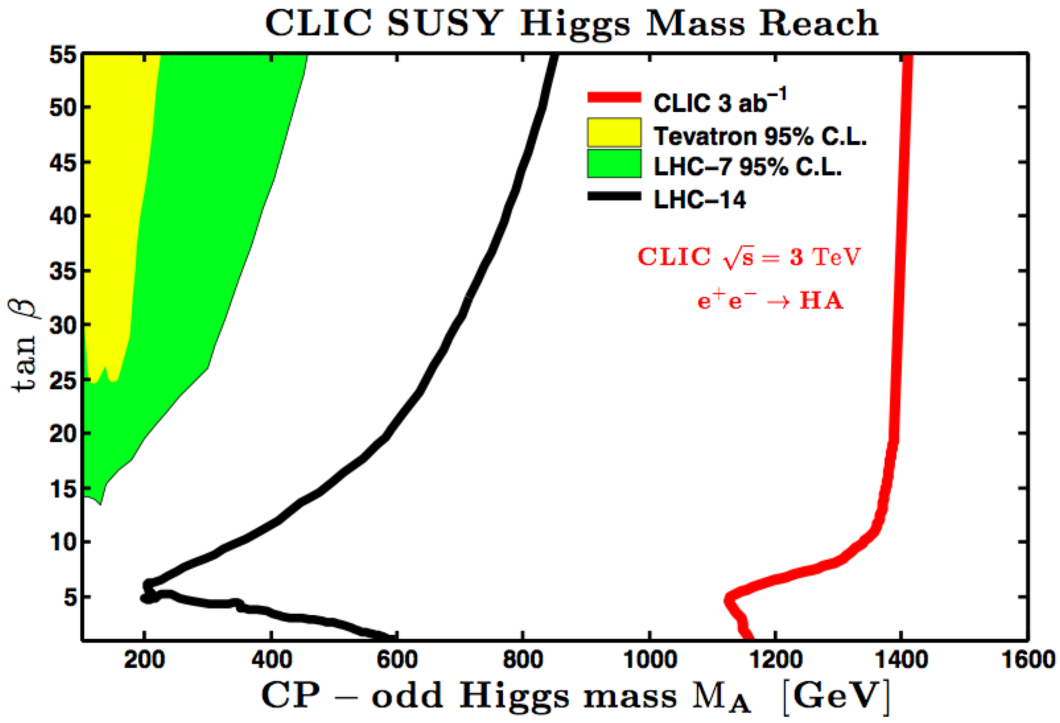
Top quark production in e+e- at 400 GeV

Enrichment of let handed top quarks
in forward region

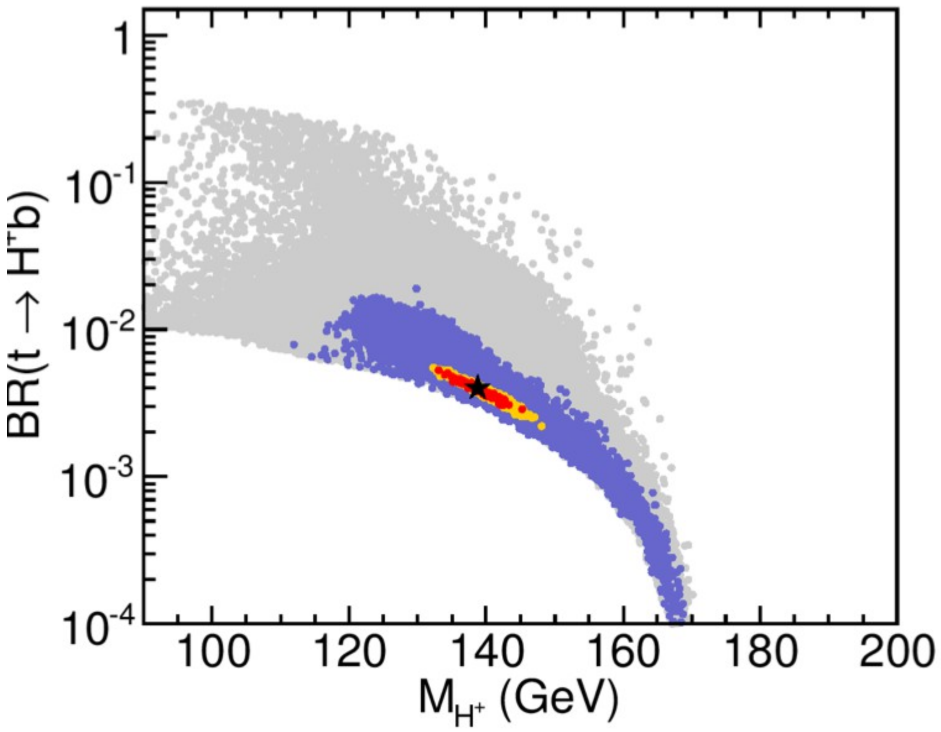
New physics through direct observation

Discovered state is ....

... light Higgs


CLIC SUSY Higgs Mass Reach

... heavy Higgs



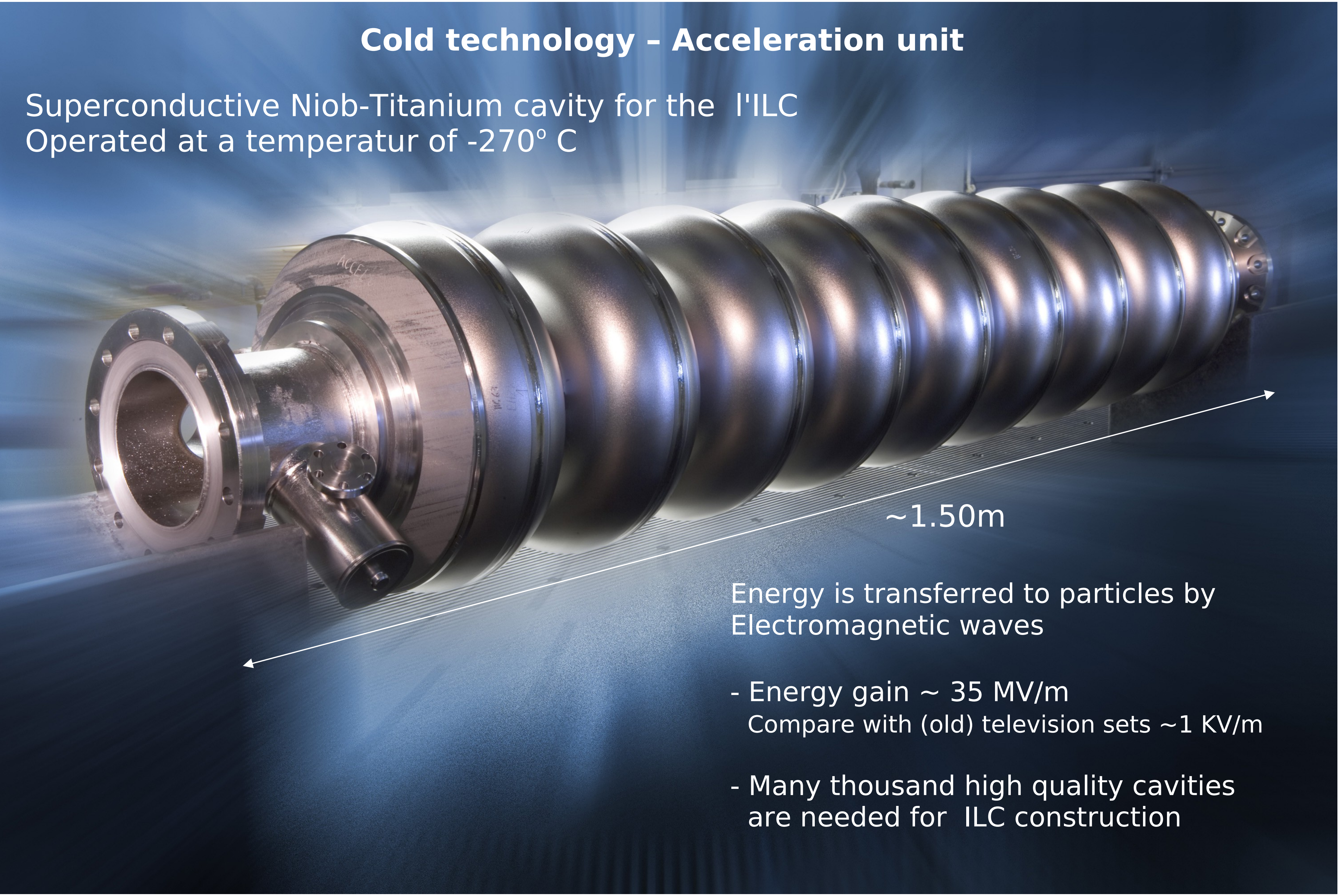
Multi-TeV e+e- collider extends mass reach and discovers further Higgs particles

Sub-TeV e+e- collider discovers new particles

N.B.: LHC may miss light color neutral SUSY particles

Cold technology – Acceleration unit

Superconductive Niob-Titanium cavity for the l'ILC
Operated at a temperatur of -270° C

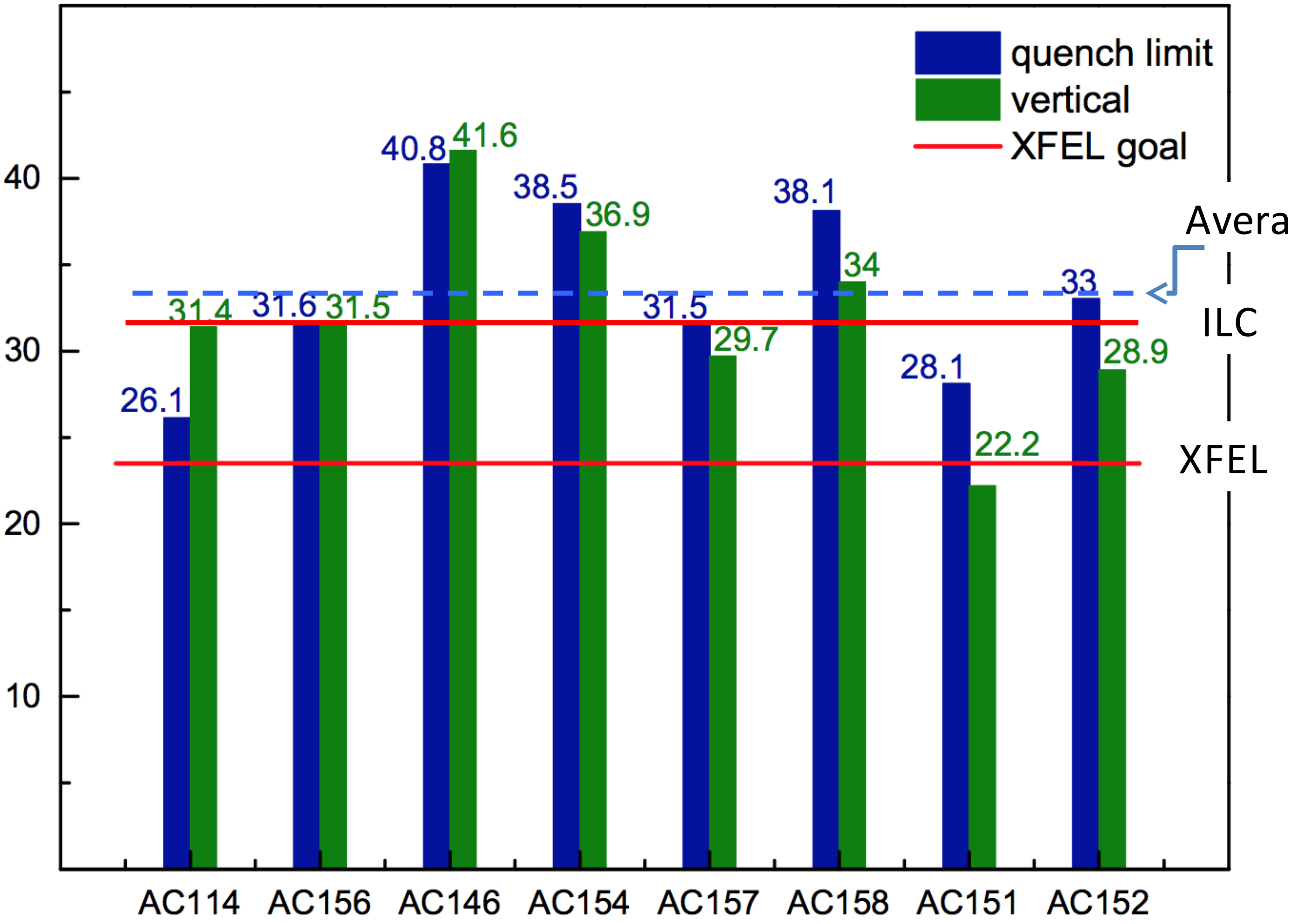


Energy is transferred to particles by Electromagnetic waves

- Energy gain ~ 35 MV/m
  Compare with (old) television sets ~1 KV/m
- Many thousand high quality cavities are needed for ILC construction

XFEL XM3 result

XM3 is the assembly demonstration cryo module



Average quench: 33.4 MV/m

An ILC spec cryomodule!

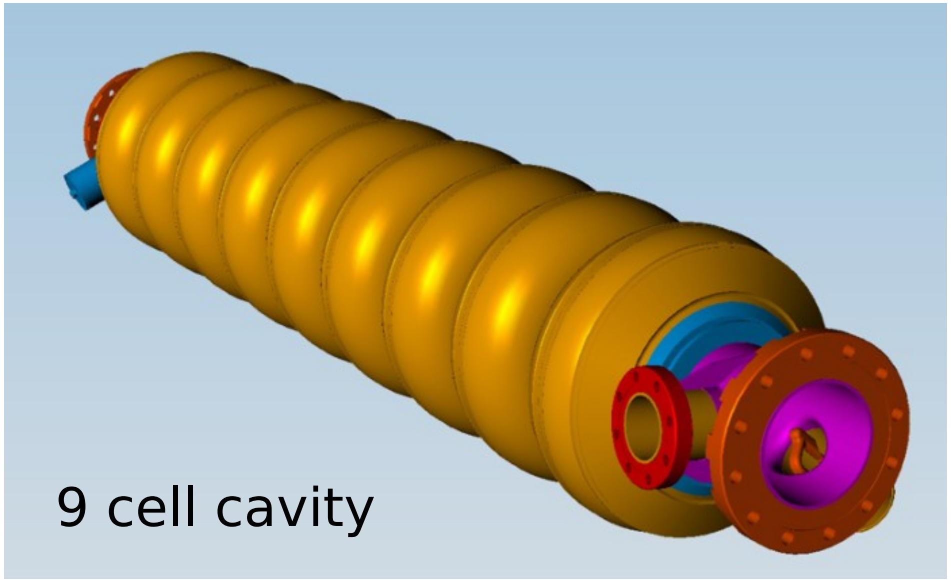
Heat loads < expected

7 **Large Grain** cavities

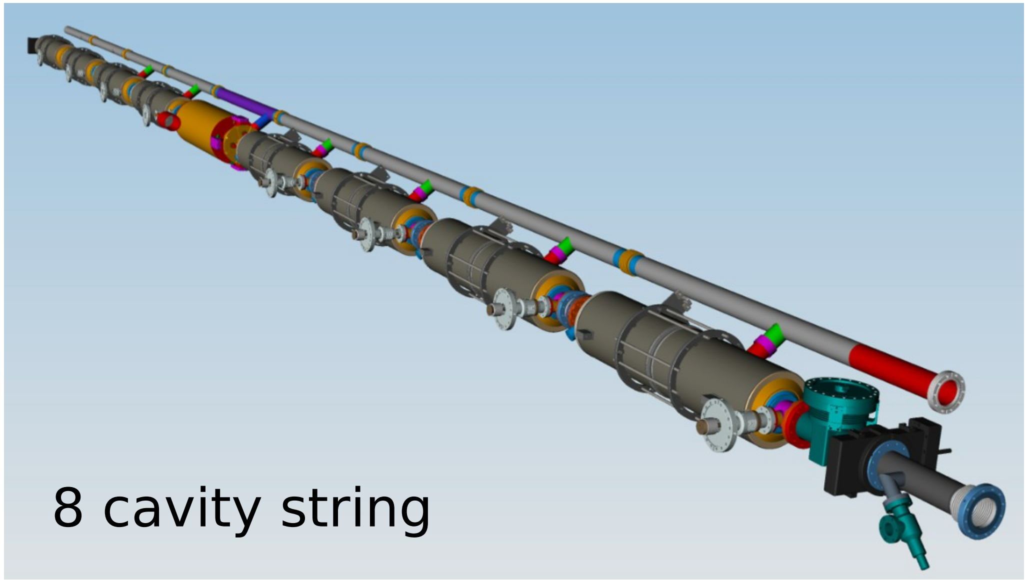
Qualification of Saclay assembly facility

- Success for SCRF Technology
- Success for industrialisation process

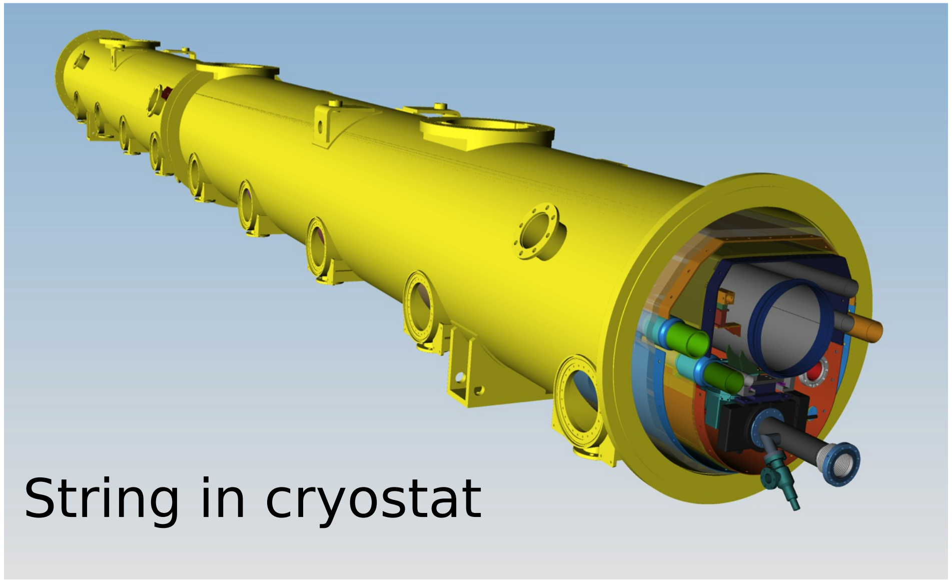
From cavities to cryo modules (Shortcut)



9 cell cavity



8 cavity string



String in cryostat

- Cavities are assembled a string
- Strings are integrated into a cryostat

Example for an assembly infrastructure – CEA Saclay

28 Novembre 2013 O. Napoly, Journées ILC, Saclay 14

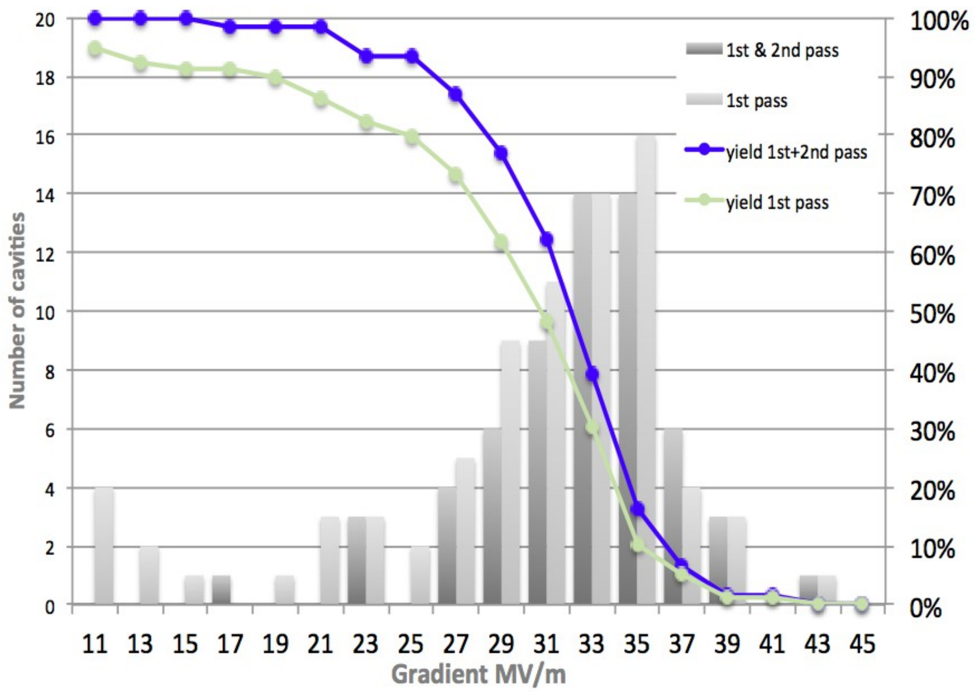
XFEL cavity production status

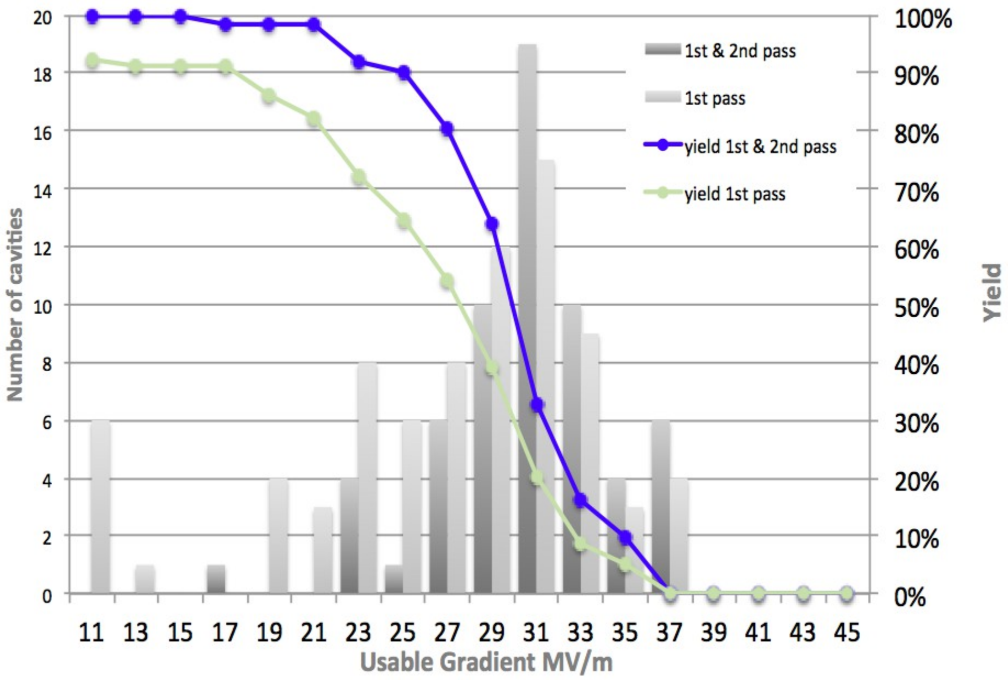
As of 11.09.2013

Num. of cavities:	
vendor 1	23
vendor 2	56

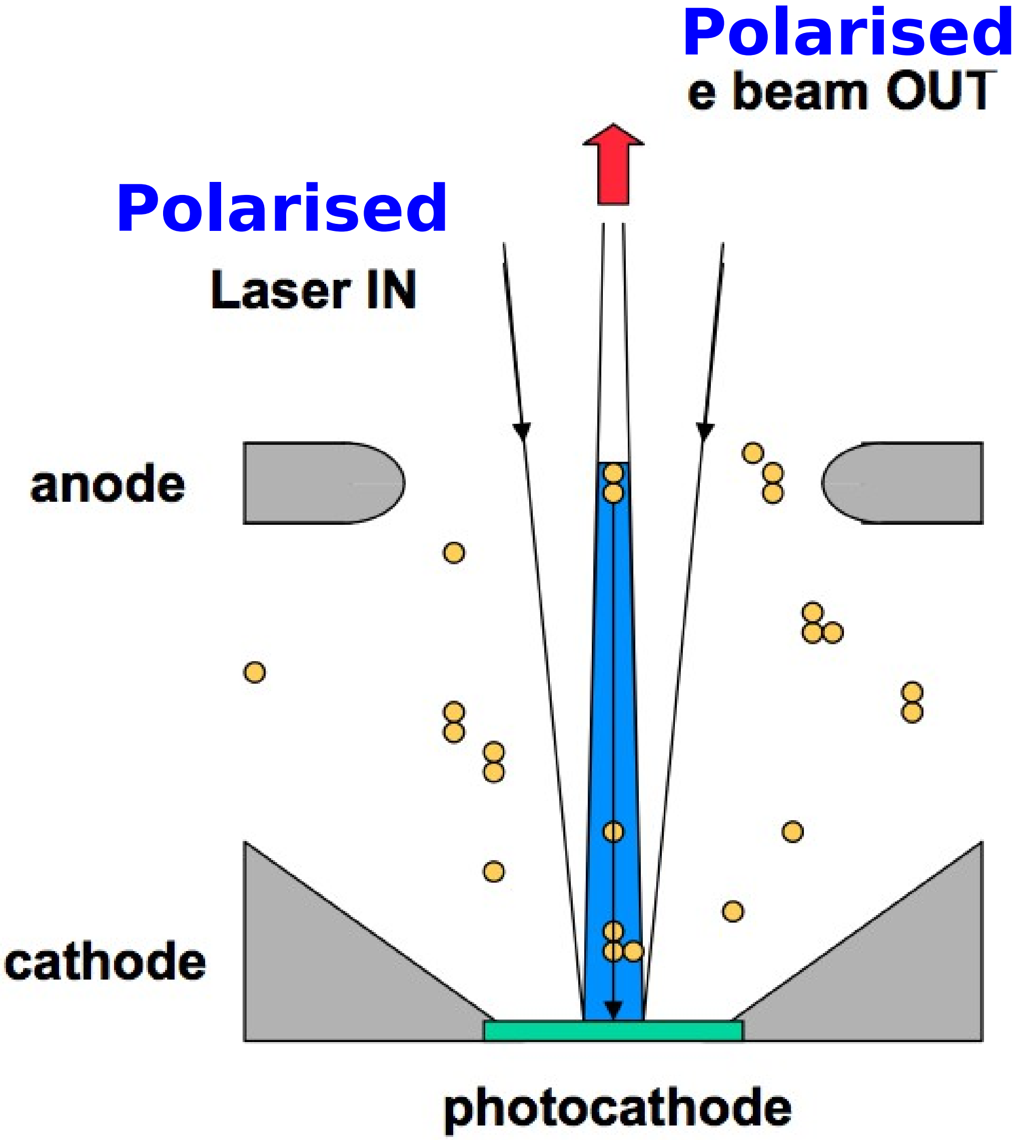
2nd pass: additional high-pressure rinse

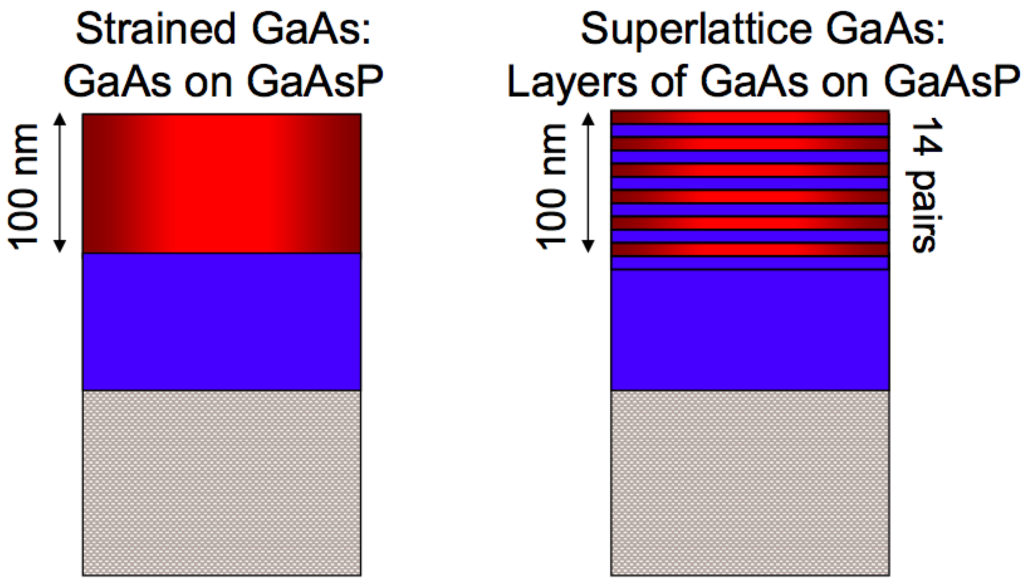
		Vendor 1	Vendor 2	Total stats
max. gradient	1st pass	30.5 ±7.5	28.8 ±6.9	29.3 ±7.1
	1st+2nd pass	33.4 ±3.8	31.4 ±4.5	32.0 ±4.4
usable gradient	1st pass	27.6 ±6.8	26.0 ±6.5	26.5 ±6.6
	1st+2nd pass	31.8 ±2.9	29.5 ±4.1	30.1 ±3.9





Polarised Electron Production – Very simplified!





Strained GaAs:
GaAs on GaAsP

"conventional" material
QE ~ 0.15%
Pol ~ 75%
@ 850 nm

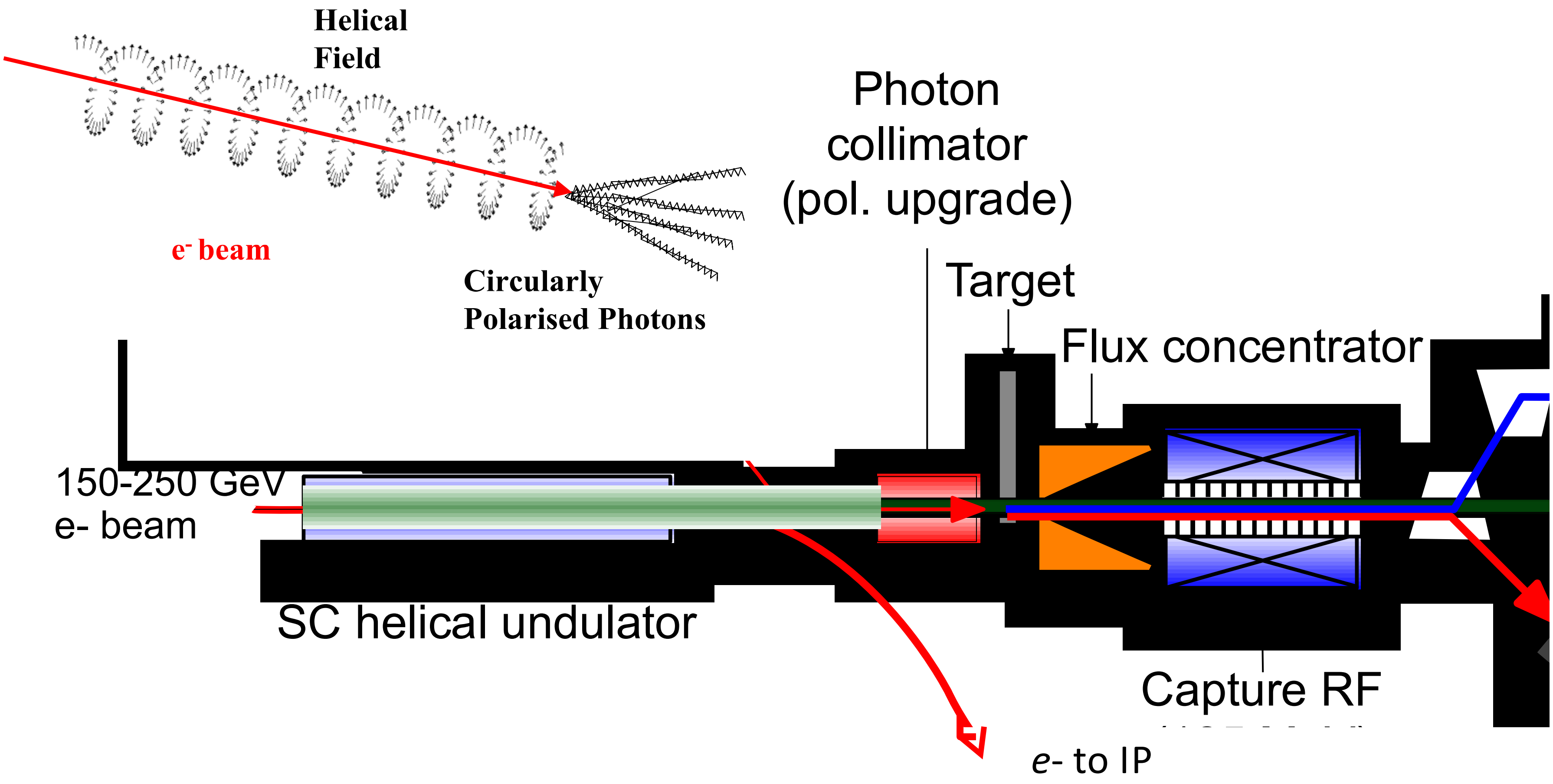
Superlattice GaAs:
Layers of GaAs on GaAsP

No strain relaxation
QE ~ 1%
Pol ~ 85%
@ 780 nm

Commercial Products

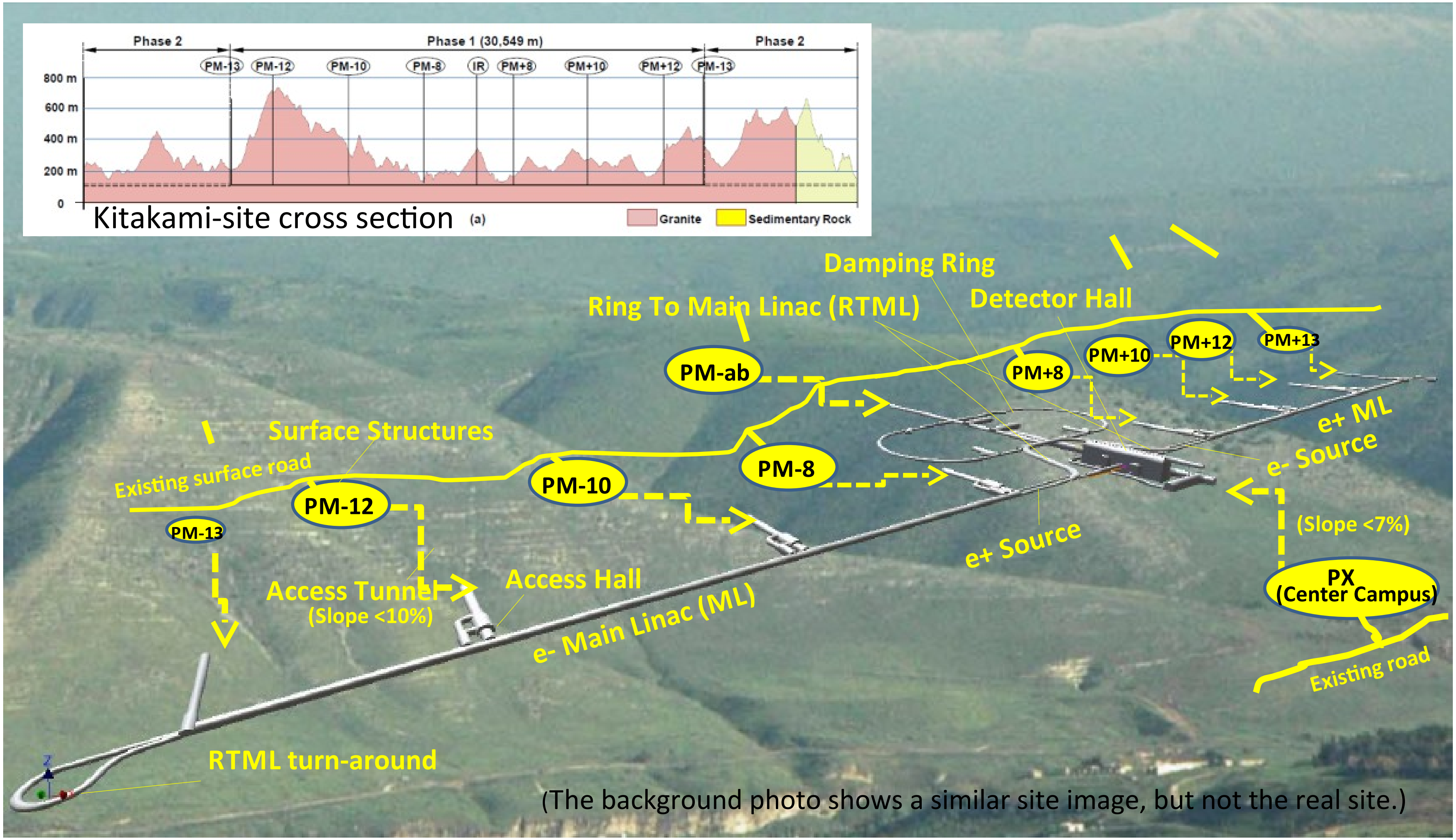
M. Poelker
JLAB Seminar 2007

Polarised Positron Production



circ. pol. photons → long. pol. *e*±

Site Specific Design

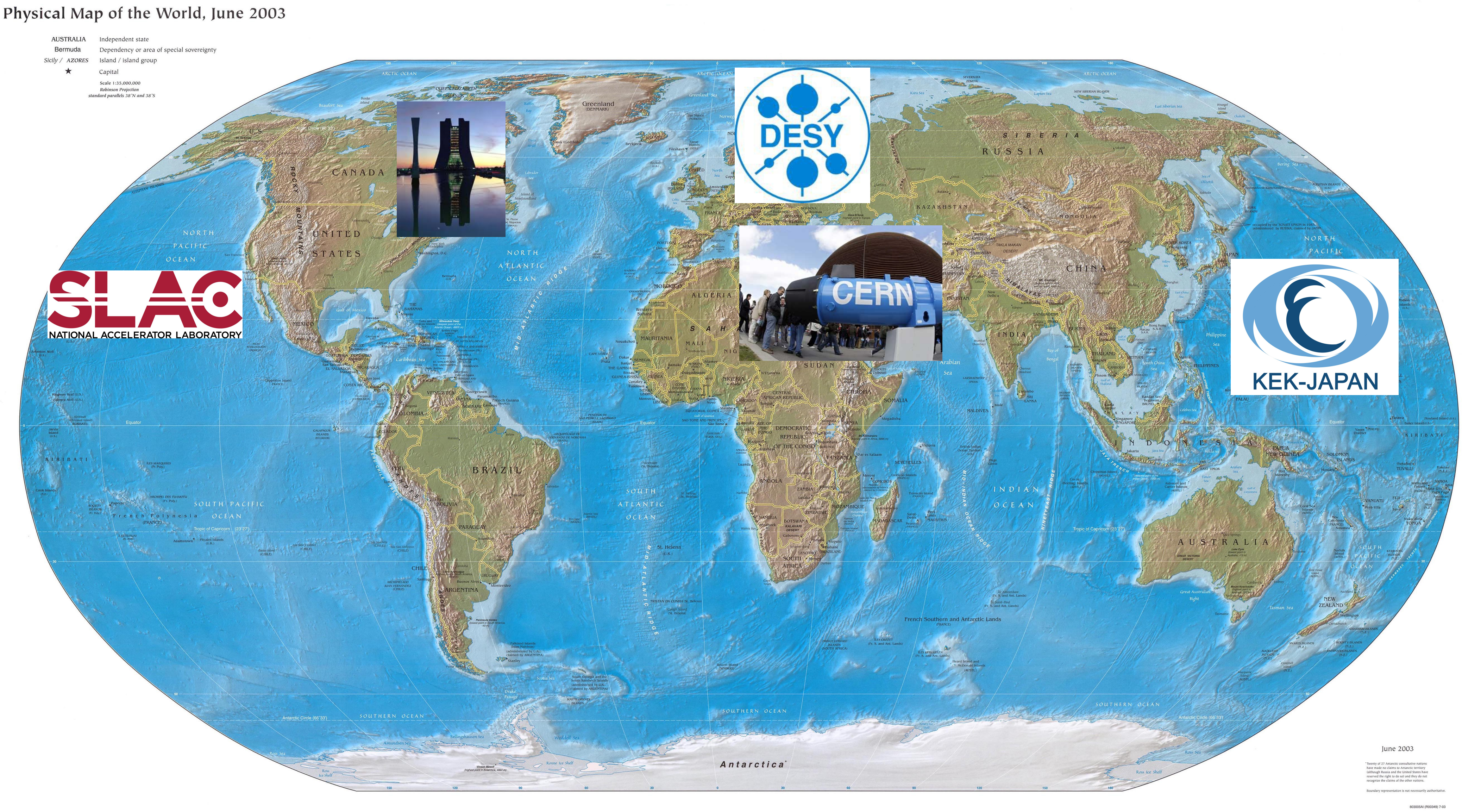


(The background photo shows a similar site image, but not the real site.)

Need to establish the IP and linac orientation
Then the access points and IR infrastructure
Then linac length and timing

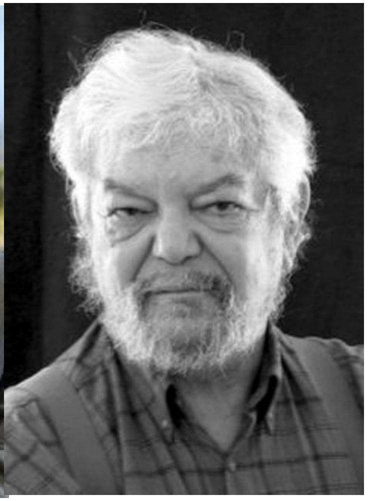
M. Harrison, LCWS13

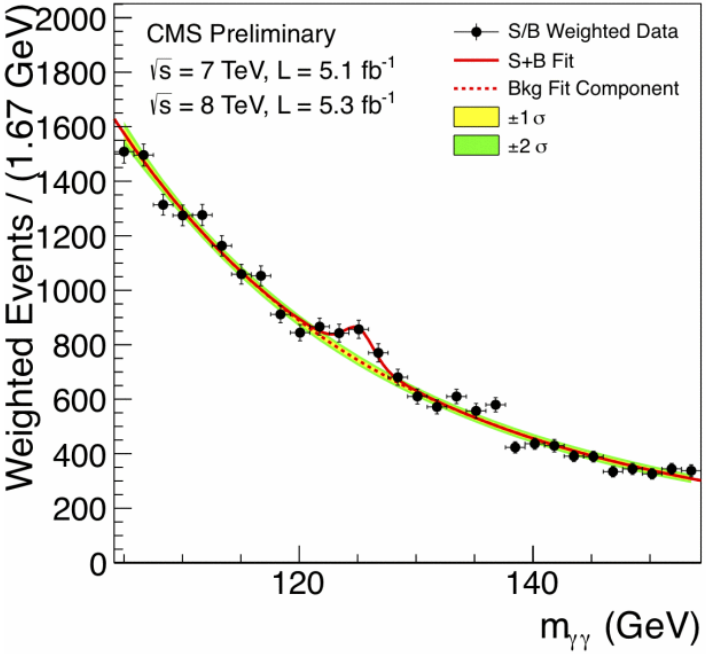
Worldwide network for LC

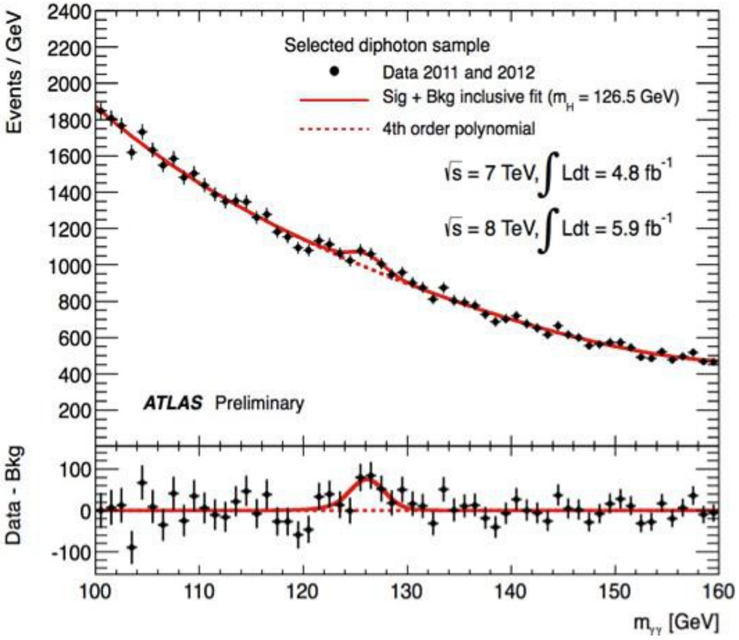


- **Network of big research centers and strong national institutes**
- **(Maybe) the first real worldwide project**

4th of July 2012







Mass hierarchy and extra dimensions

The introduction of one (or more) extra dimensions allow for arranging the wave functions along this new dimension

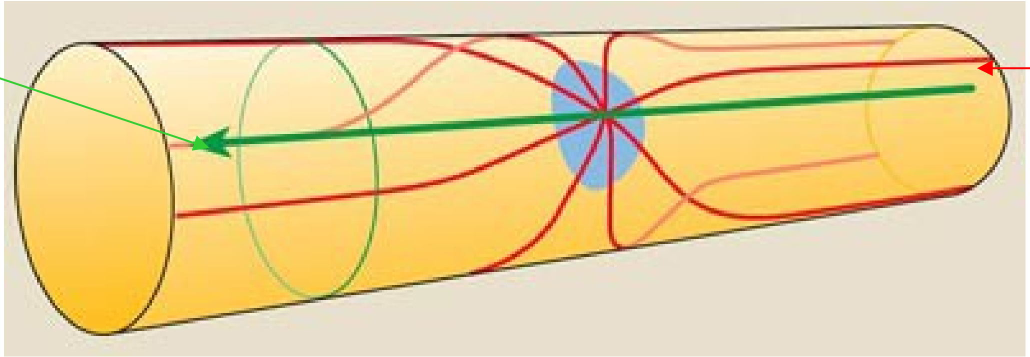
Extra dimension

'Our' 3+1 dimensions

The particle mass oberved in 'our' world depends of the position of a particle in the extra dimension

Most likely extra dimensions are curved

Our world



Gravitation

Remark: Extra dimension models are dual to compositeness models

Measurement of top quark polarisation

Measure angle of decay lepton in <u>top quark rest frame</u>

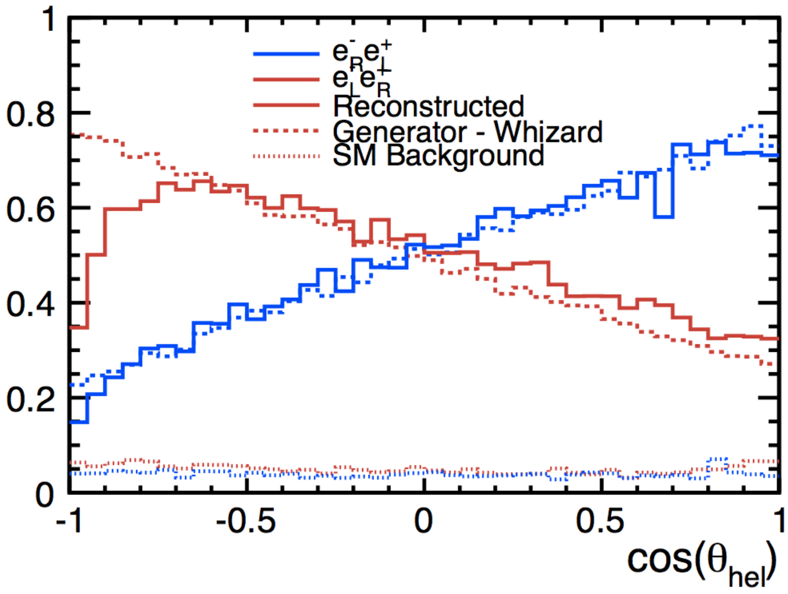
Lorentz transformation benefits from well known initial state

(N.B. : Proposal for hadron colliders applied to lepton colliders)

Differential decay rate

$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_\ell} = \frac{1+\lambda_t cos\theta_\ell}{2} \quad \mathrm{with}\ \lambda_\mathrm{t} = 1\ \mathrm{for}\ \mathrm{t_R}\ \mathrm{and}\ \lambda_\mathrm{t} = 1\ \mathrm{for}\ \mathrm{t_L}$$

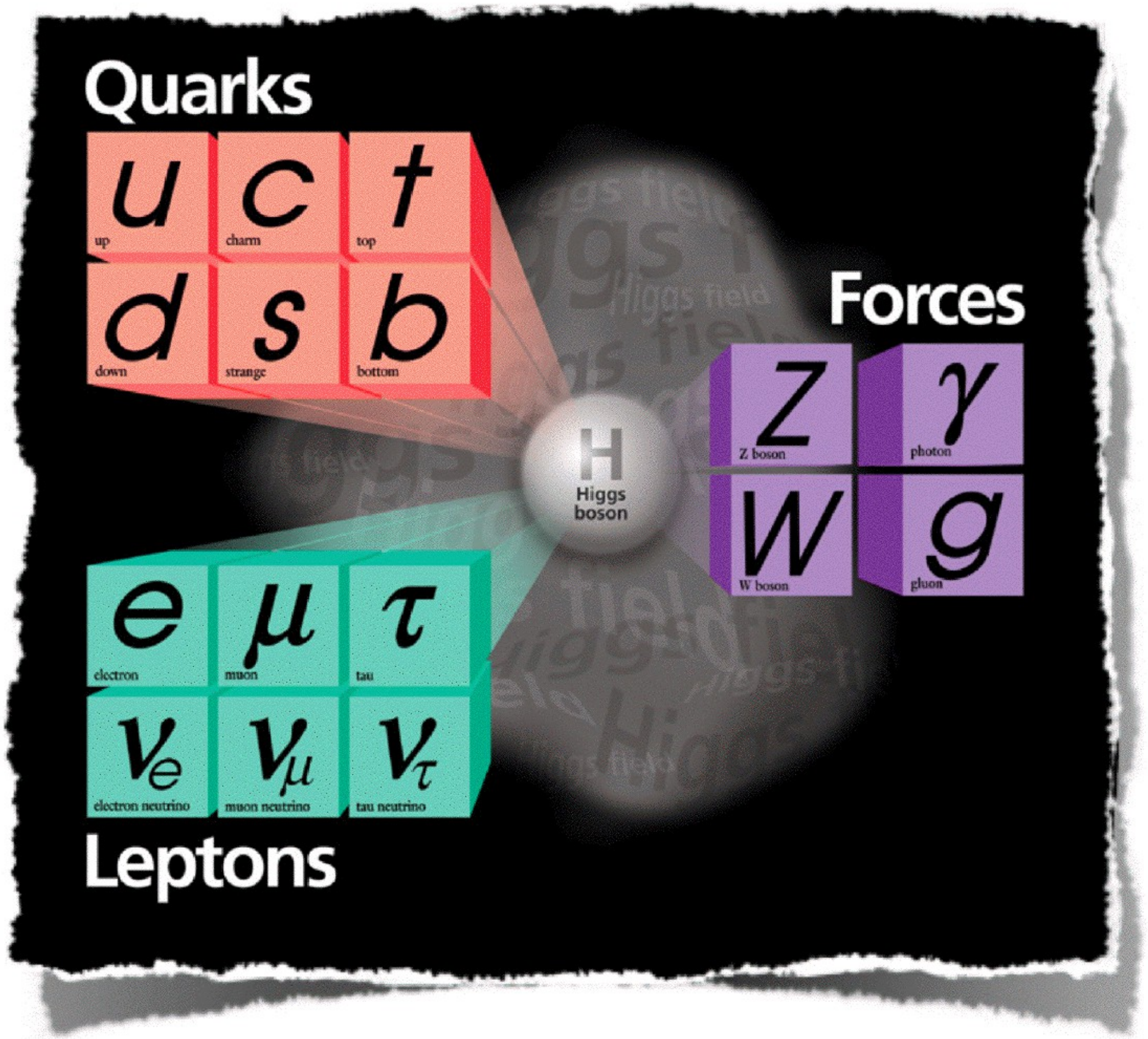
Slope measures fraction of $t_{R,L}$ in sample

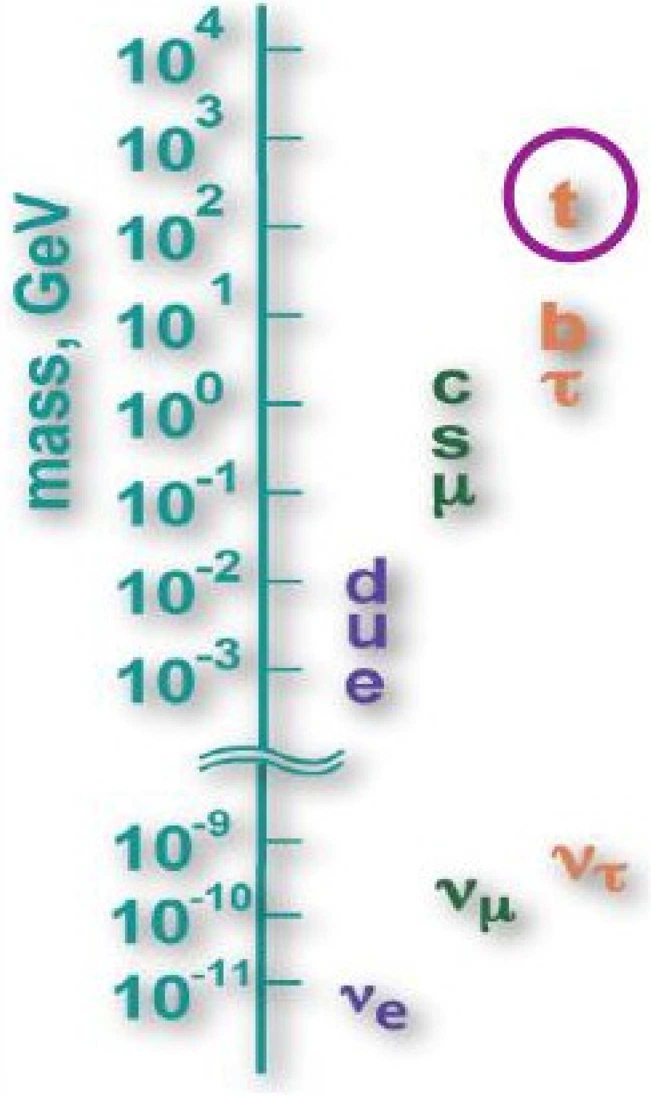


- Measurement of decay lepton almost 'trivial' at LC
  High reconstruction efficiency for leptons
- Reconstructed slope coincides with generated slope

Slope λ_t can be measured to an accuracy of about 3-4%

Striking hierarchy



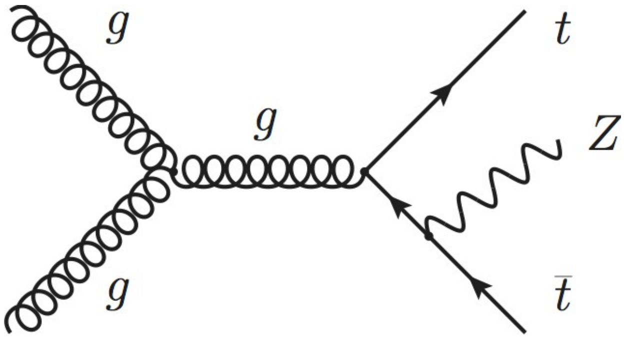


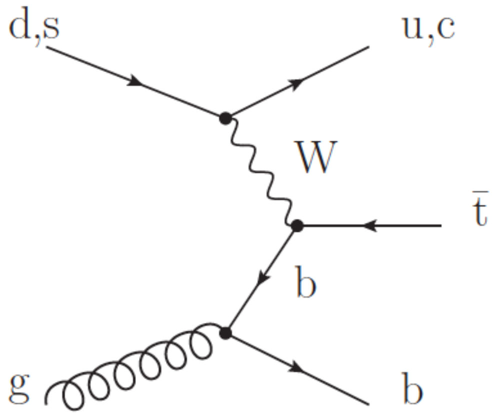
Heavier than a gold atom

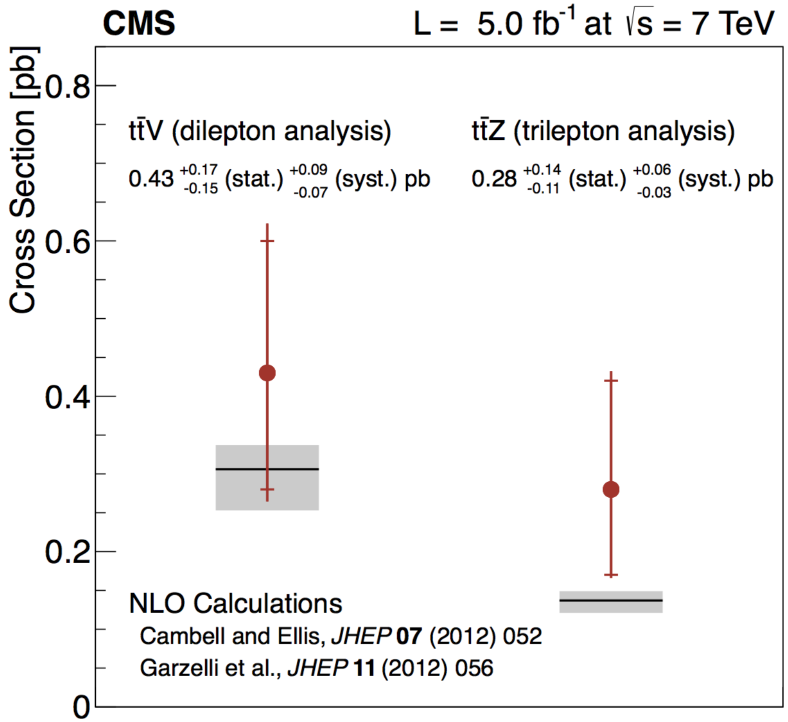
Barbieri: "... there is no reason to be proud of the λ_{ij} parameters"

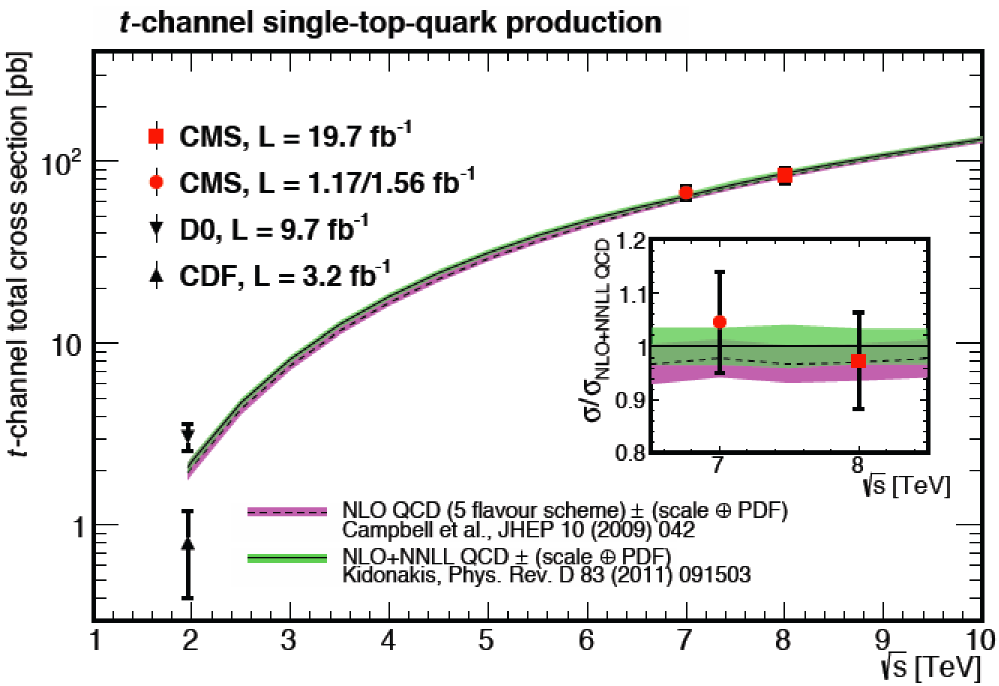
Jaegerlehner: "... issues like the unknown origin of the hierarchy of the Yukawa couplings"

Electroweak couplings – LHC contributions









$$\sigma(t\bar{t}Z) = 0.28^{+0.14}_{-0.11}\,(\mathrm{stat.})\,^{+0.06}_{-0.03}\,(\mathrm{syst.})\,\mathrm{pb}$$

=> δV_{tb} ~ 5%

May expect: $\frac{\delta\sigma_{t\bar{t}Z}}{\sigma_{t\bar{t}Z}} \backsim 10\%$?

=> Constraints on left handed top couplings