International Linear Collider: Status and Plans

Benno List
DESY

15.6.2012

1st International Conference on New Frontiers in Physics (ICFP 2012)
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The International Linear Collider

- A linear e^+e^- collider with 500GeV CM energy, upgradeable to 1TeV
- Acceleration with superconducting RF cavities
- Polarized beams
- Designed by a worldwide collaboration
- About 31km long

For more information:
www.linearcollider.org

Three Questions

Why?

How?

When?

WHY

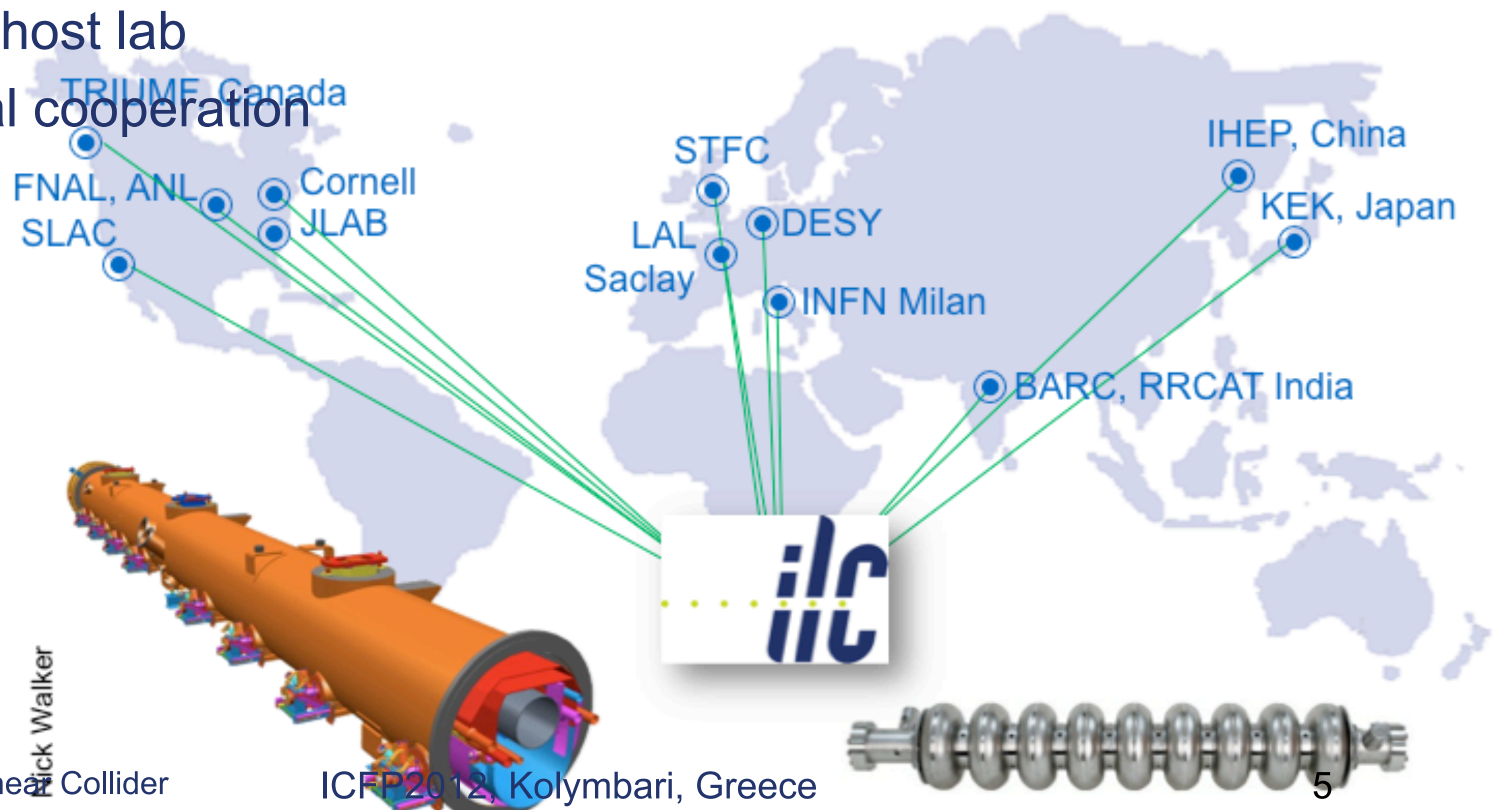
- … international?
- … linear?
- … e^+e^- collider?
  → physics case
- … superconducting?
  → how?

Why International?

- 1990s: Several projects in America, Asia (warm) and Europe (superconducting) for a linear collider
- 2004: International accord: go **Superconducting**!
- 2005: GDE (Global Design Effort) founded

New paradigm:

- No central host lab
- Truly global cooperation



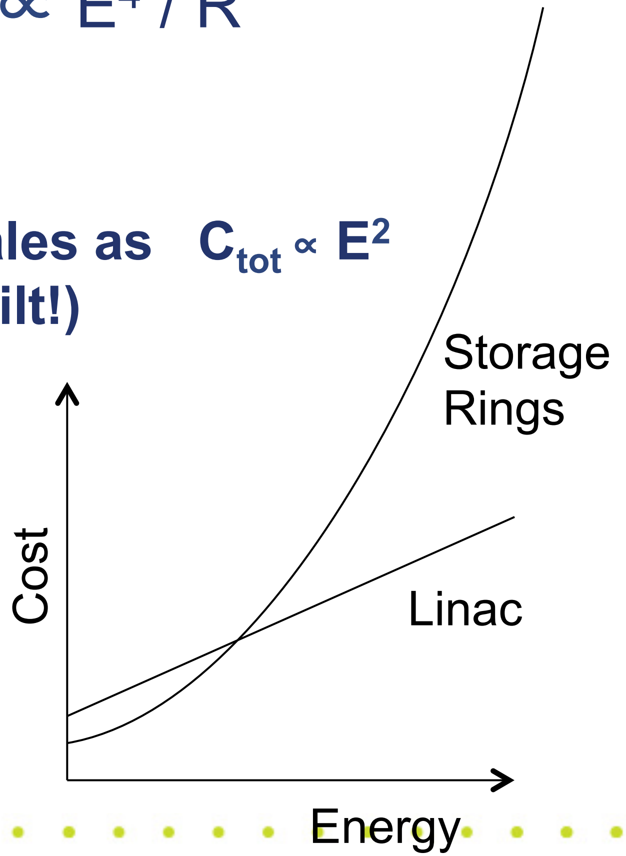
Why Linear?

- Circular e^+/e^- accelerator:
  Limiting factor is energy loss by synchrotron radiation

- Synchrotron radiation power: $P \propto E^4 / R$
  - **Tunnel cost scales as $C_T \propto R$**
  - **RF costs scales as $C_{RF} \propto P$**

  → make $R \propto E^2$, then total cost scales as $C_{tot} \propto E^2$
  (note: needs a new tunnel to be built!)

- **For a linear accelerator: $C_{tot} \propto E$**
- **Increasing the energy:**
  Just make tunnel longer!



Why an e^+e^- Collider?

- pp and e^+e^- colliders are **complementary**, we need **both**:
  - **Energy reach and precision**
  - **Strong and electroweak interactions**
- e^+e^- strong points:
  - **Pointlike interaction**
  - **No debris from witness quarks**
  - **Known energy and polarization of initial state**
  - **Flavour democracy: no bias towards up/down, i.e. proton consituent flavours**

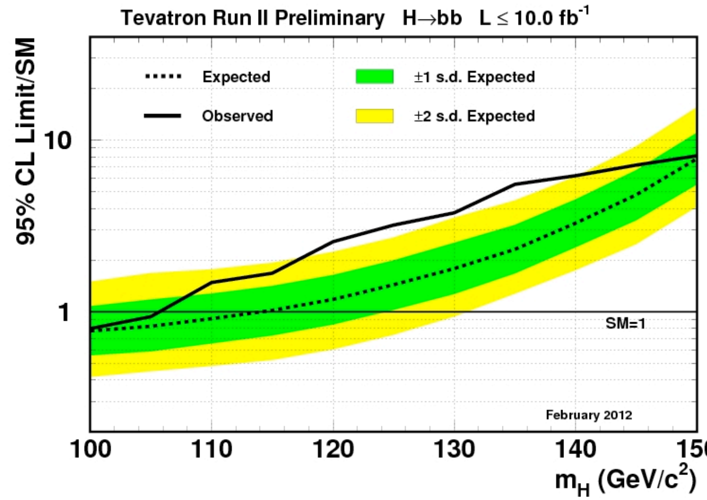
Why an e^+e^- Collider?

- To measure the Higgs properties
- To measure the Top properties
- To constrain SUSY / BSM by precision measurements
- To look for new particles:
  Discovery potential is complementary to LHC, not inferior

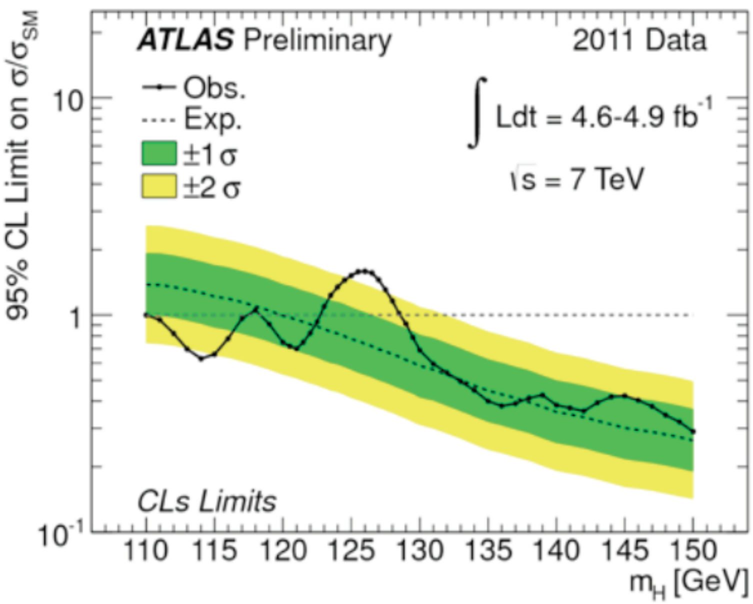
The Higgs Discovery

… may be nigh!

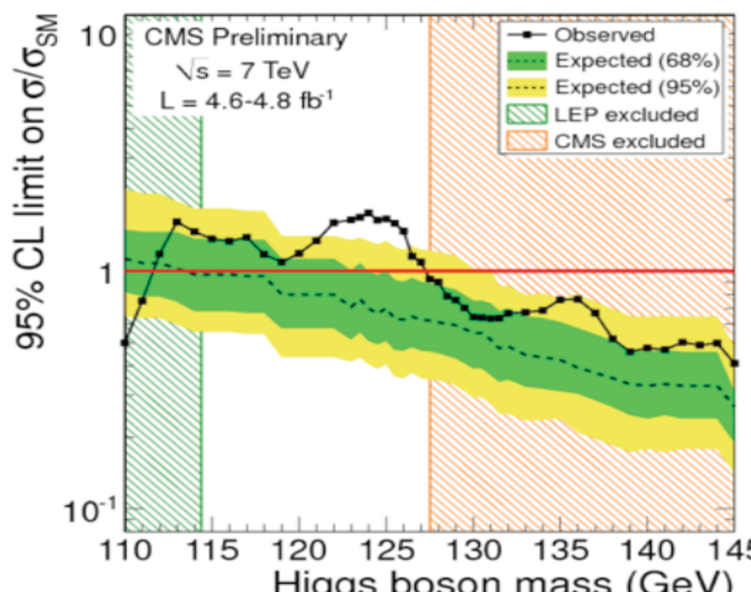
Allowed region is now quite narrow



arXiv:1203:3774



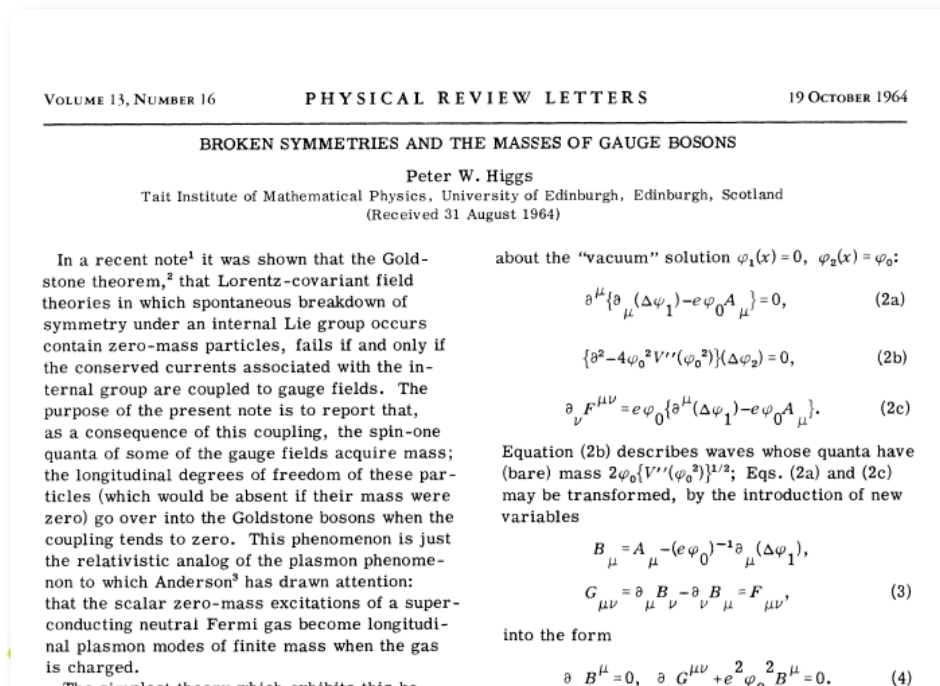
ATLAS-CONF-2012-019



CMS-PAS-HIG-12-008

Why Investigate the Higgs?

- Discovering the Higgs after almost 50 years will be an enormous achievement
- A fundamental scalar is something fundamentally new!
- It will be the key stone of the Standard Model, and the foundation stone for the next storey



VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this be-

about the "vacuum" solution $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}=0, \quad (2a)$$

$$\{\partial^2-4\varphi_0^2V''(\varphi_0^2)\}(\Delta\varphi_2)=0, \quad (2b)$$

$$\partial_\nu F^{\mu\nu}=e\varphi_0\{\partial^\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}. \quad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu=A_\mu-(e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

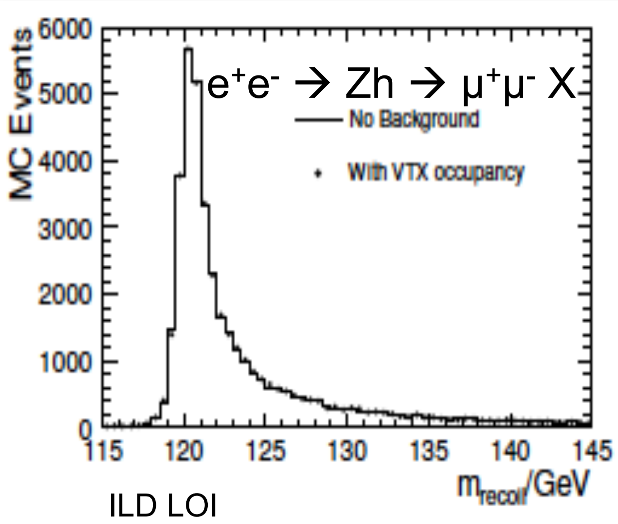
$$G_{\mu\nu}=\partial_\mu B_\nu-\partial_\nu B_\mu=F_{\mu\nu}, \quad (3)$$

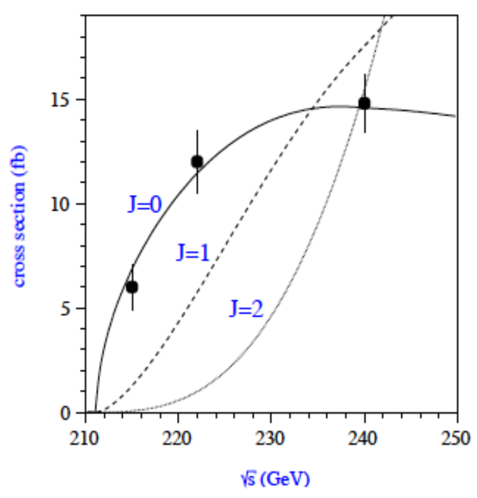
into the form

$$\partial_\mu B^\mu=0, \quad \partial_\nu G^{\mu\nu}+e^2\varphi_0^2B^\mu=0. \quad (4)$$

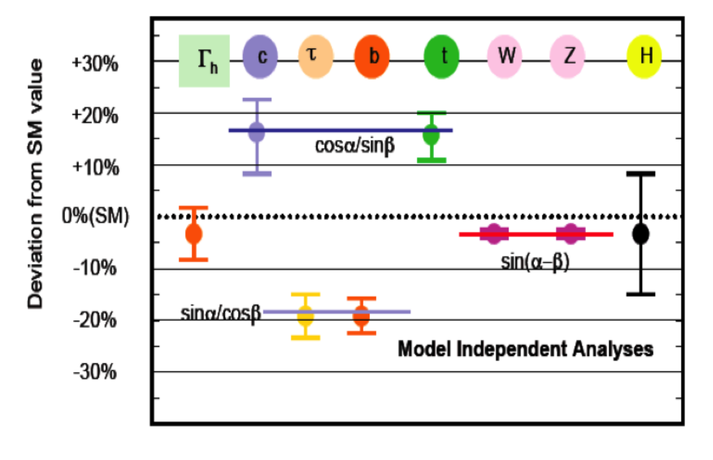
Why a Higgs Factory?

- Establish that it is really the Higgs:
  - **Measure the spin → threshold scan**
  - **Measure the branching ratios and absolute width model independently → recoil mass method: $e^+e^- \to Zh \to \ell^+\ell^- X$ → Includes invisible decays!**
  - **Measure Top-Higgs coupling in $e^+e^- \to tth$**
  - **Measure Higgs self-coupling: $e^+e^- \to Zhh$**
- Is it a SM Higgs, SUSY Higgs, mixed with Radions…?





TESLA TDR vol 3, Fig. 2.2.7



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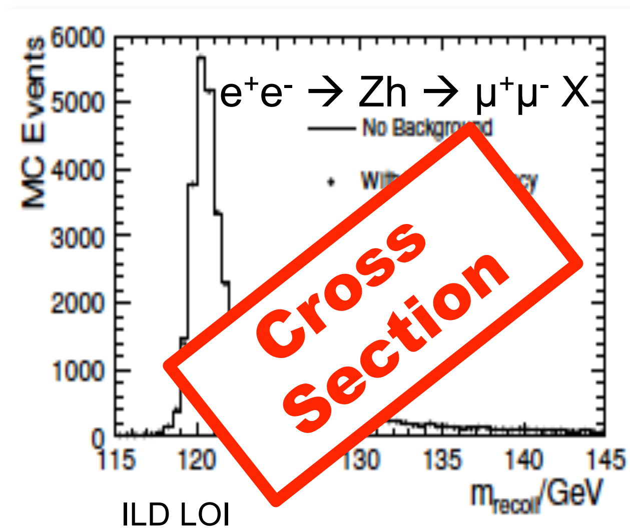
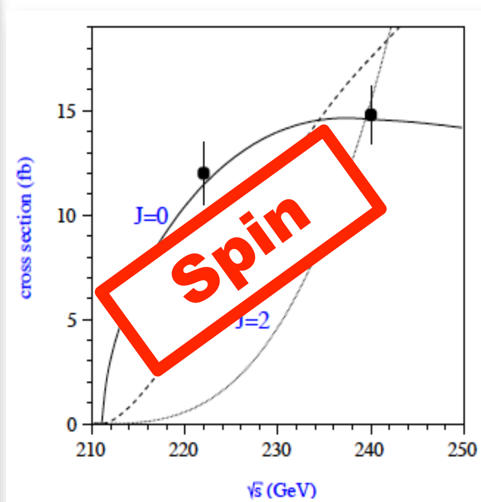
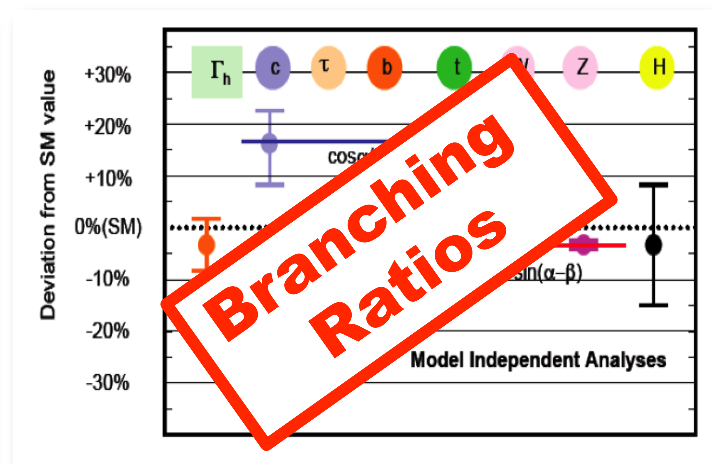


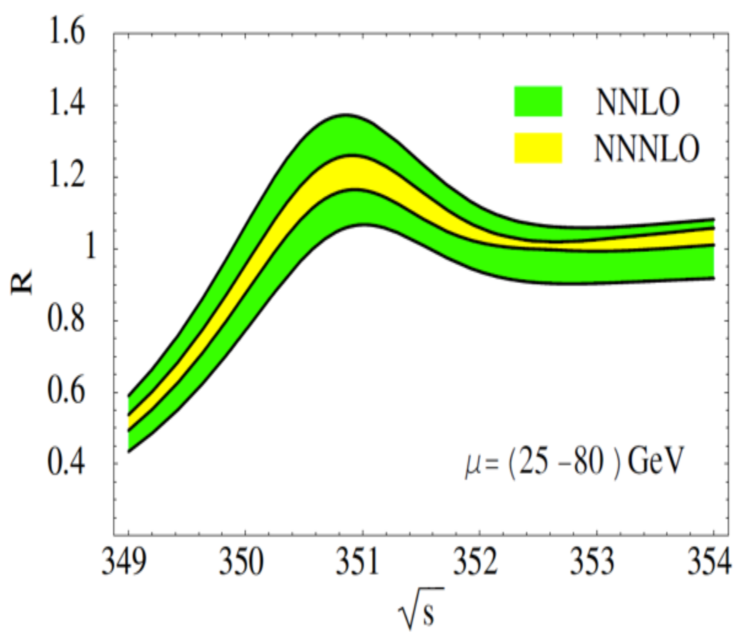


TESLA TDR vol 3, Fig. 2.2.7

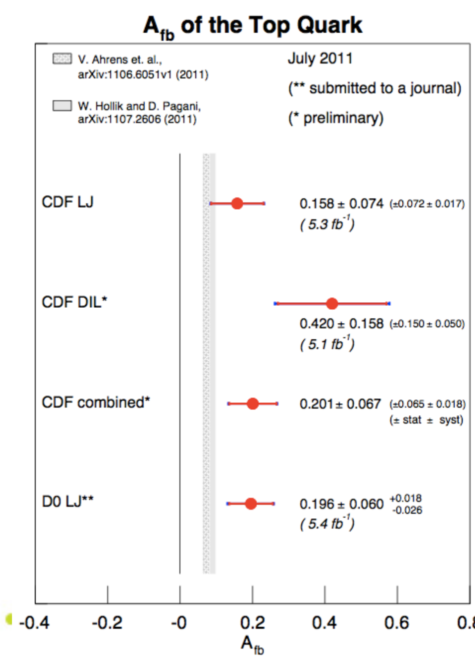


Why the Top again?

- Top mass: Fundamental SM parameter, leading contribution to radiative corrections
- Threshold scan measures mass in a theoretically very clean way → gets rid of QCD uncertainties (~1 GeV)
- Important input for radiative correction measurements!
- Remember: 2σ discrepance for A_{FB} at Tevatron…



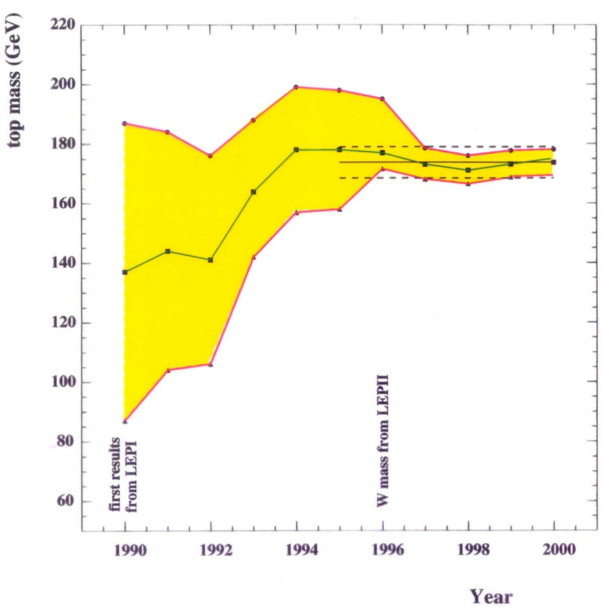
Top performance:
Mass: 100MeV (0.06%)
Width: 22MeV (1.7%)

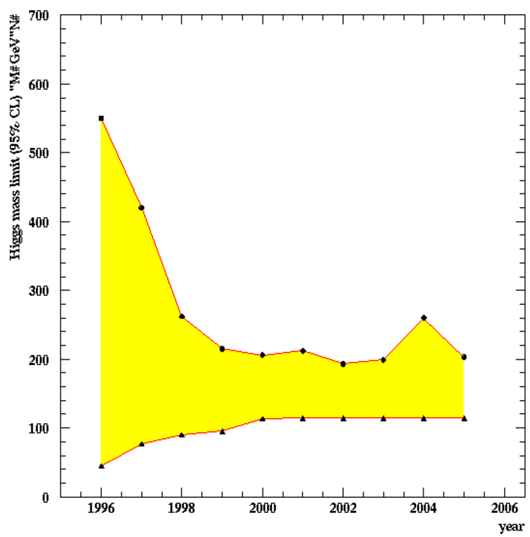


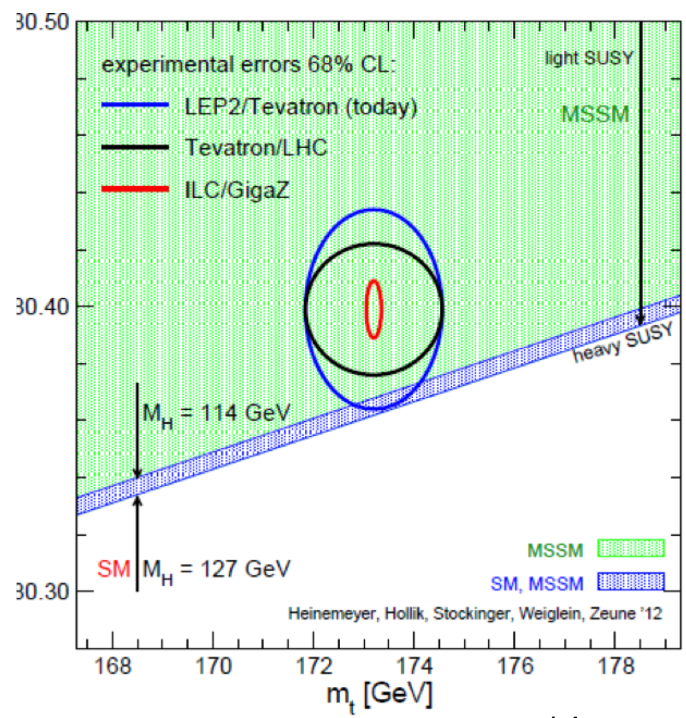
http://www-cdf.fnal.gov/physics/new/top/public_tprop.html

Why continue precision physics?

- Radiative corrections gave us
  - **the Top mass before the Top discovery**
  - **bounds for the Higgs mass before the Higgs discovery**
- With known Top and Higgs masses, we constrain whatever lies beyond the SM!





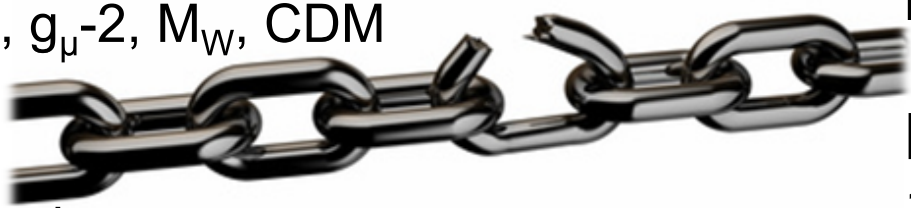


WHAT ABOUT DISCOVERIES?

Why ILC May Still See SUSY

Mounting Tension:

Naturalness, g_μ-2, M_W, CDM



LHC Results

Light

3^{rd} gen. Squarks,
Sleptons,
Elektroweakinos

Mass Unification:
m_0,
$m_{1/2}$

Heavy

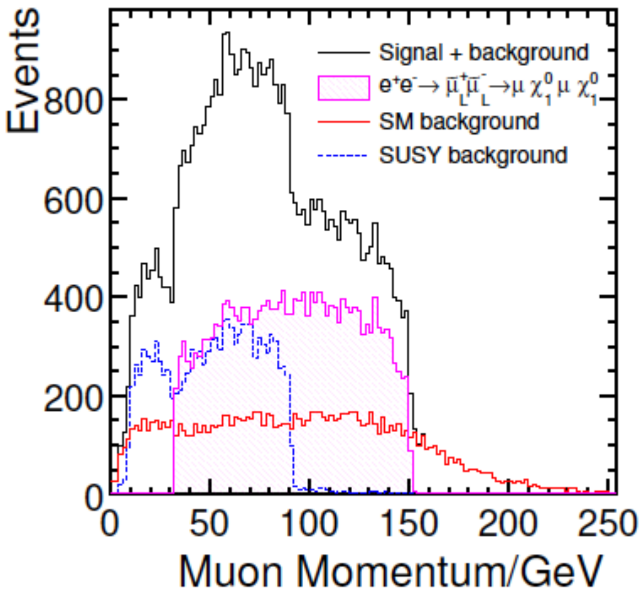
1^{st}, 2^{nd} gen. Squarks
Gluinos

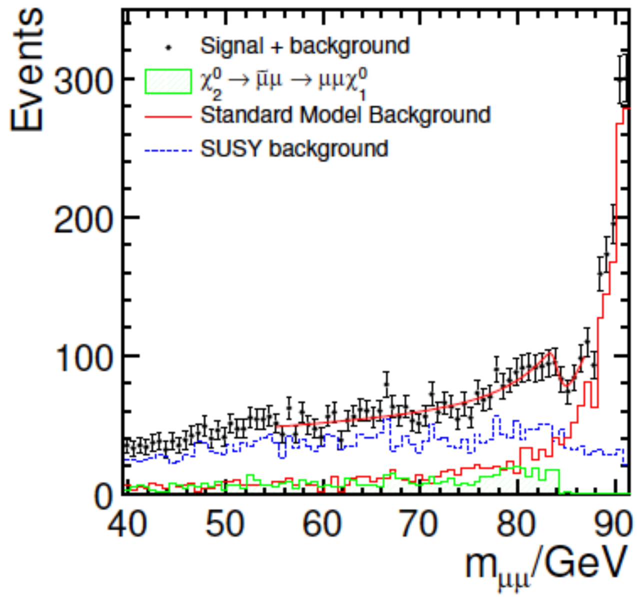
- Mass unification may not be such a good approximation
- Particles best accessible in pp are least constrained by SUSY raisons d'être (naturalness…)

- Naturalness still predicts light SUSY particles
- LHC results do not exclude them

… and then

New (SUSY or whatever) particles within ILC's reach might be hard or impossible to investigate at a hadron machine

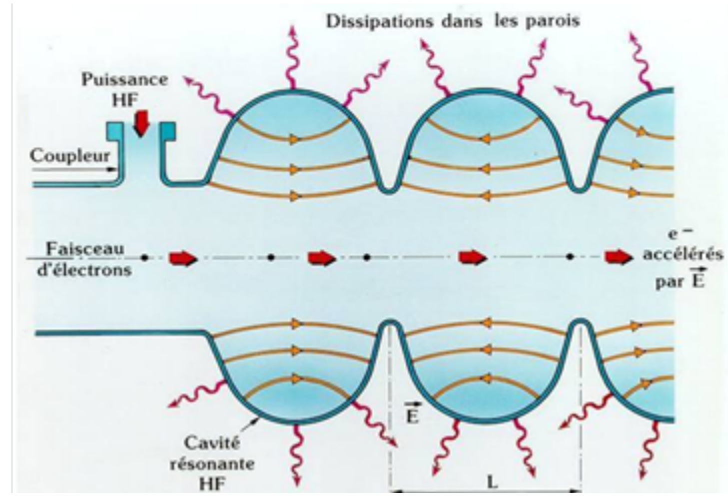




ILD LOI fig. 3.3-23

Why Superconducting?

- Linear accelerator: Accelerate electrons in a long string of Rfcavities
- Gradient: 31.5MV/m
  → need 15.8km for 500GeV!



http://www.supraconductivite.fr/media/images/Applications/image037.png

- For given total power (electricity bill!), luminosity proportional to efficiency
- ILC: ~170MW @ 500GeV

RF efficiency RF power

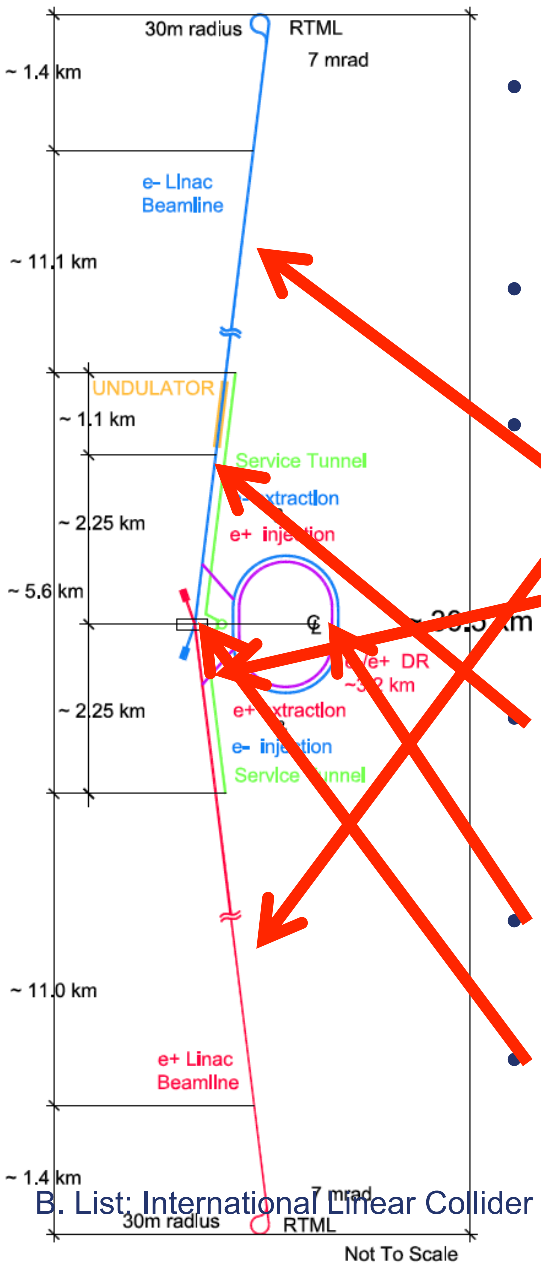
$$L \propto \frac{\eta P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

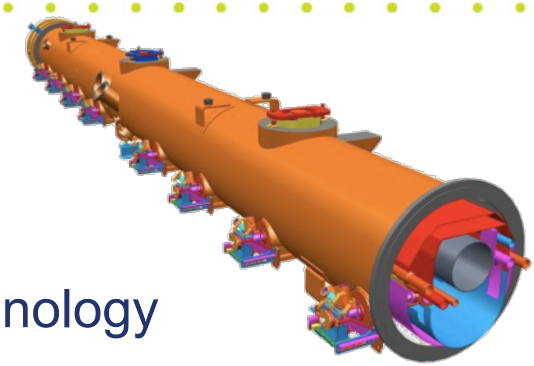
- Superconducting cavities maximise RF-to-beam efficiency

HOW

- … will it look like?
- … can one get the energy?
  → Superconducting RF technology
- … can one get the luminosity?
  → low emittance beams, final focus
- … can one do measurements?
  → the experiments
- … much will it cost?

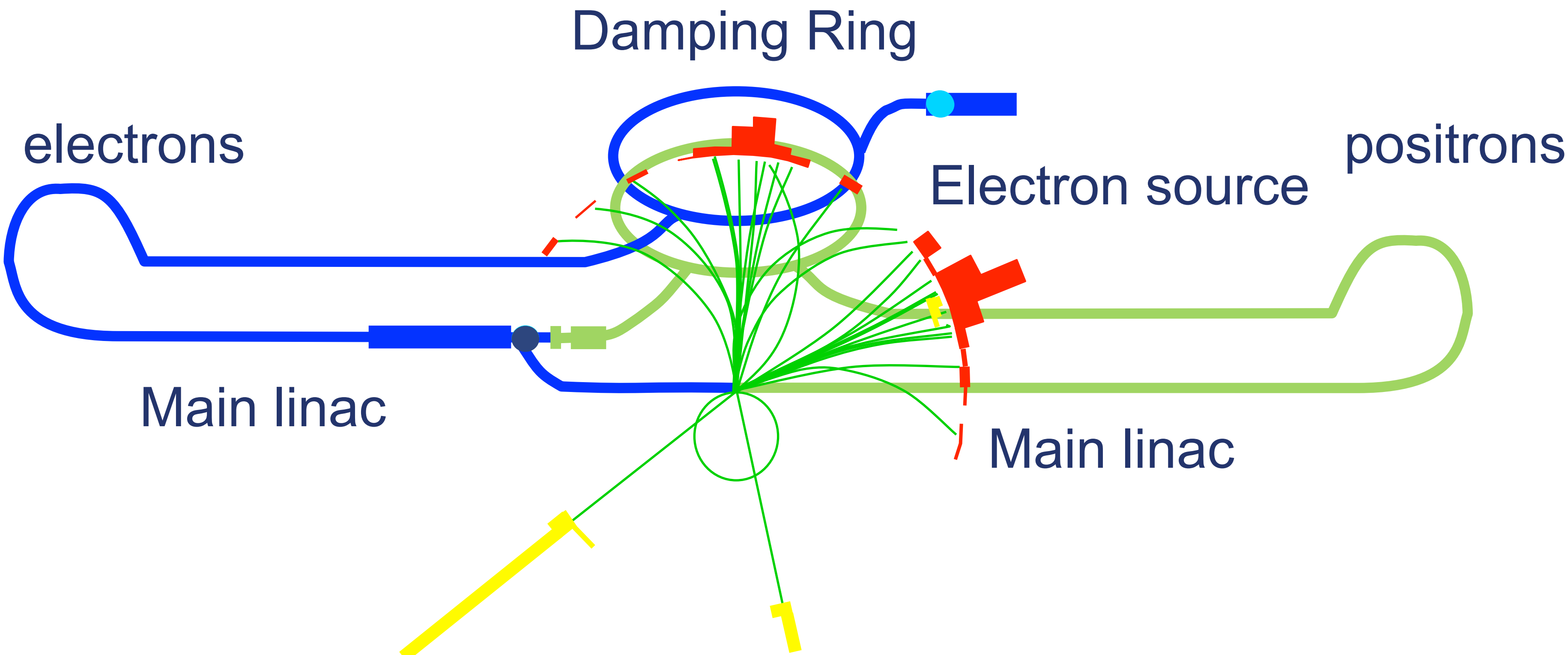
How will the ILC look like?





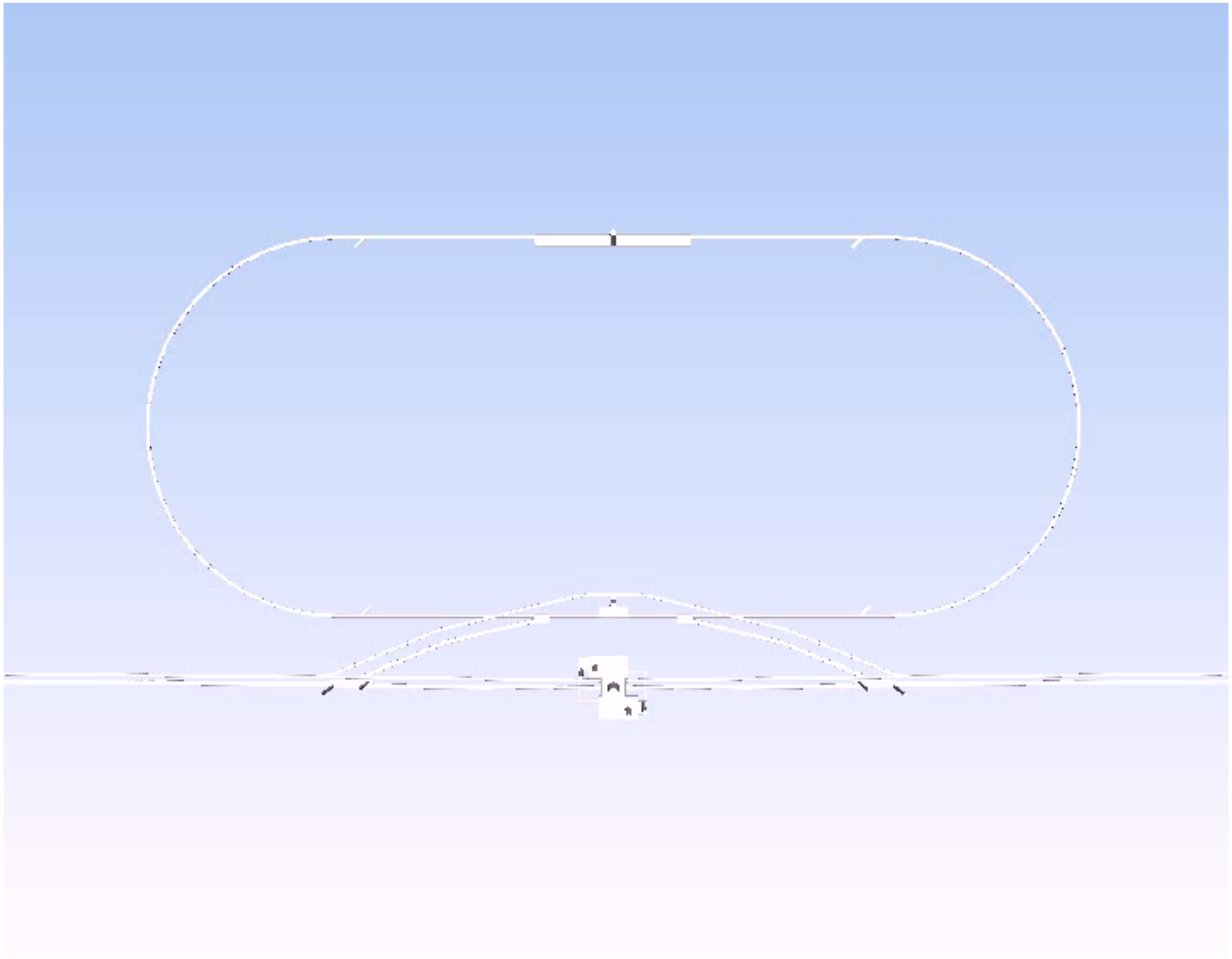
- 200-500 GeV E_{cm} $e^{+}e^{-}$ collider
  $L \sim 2\times10^{34}\ cm^{-2}s^{-1}$
- Superconducting “TESLA” Technology
- 30km long main tunnel
  - 21km Main Linac
  - 4.5km interaction region
- Positron production from undulator radiation (polarized source!)
- 3.2km central damping ring
- 14mrad crossing angle

How Does it Work?

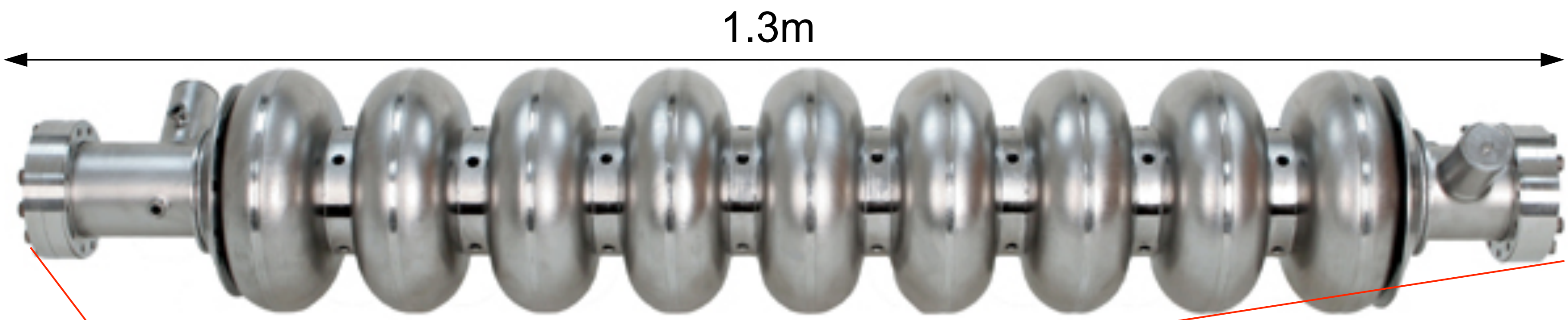


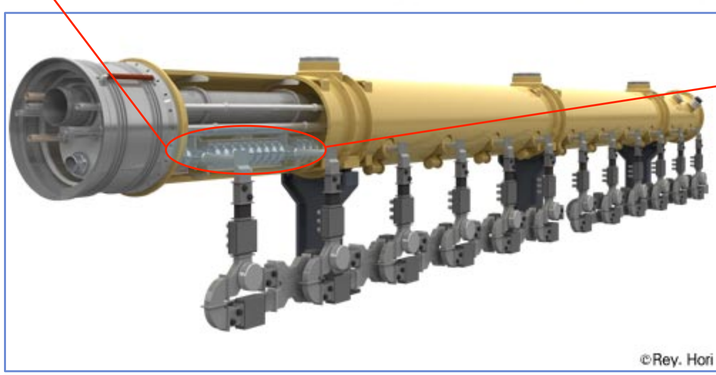
Animation by T. Takahashi (Hiroshima)

Flight through the ILC



How to get the energy



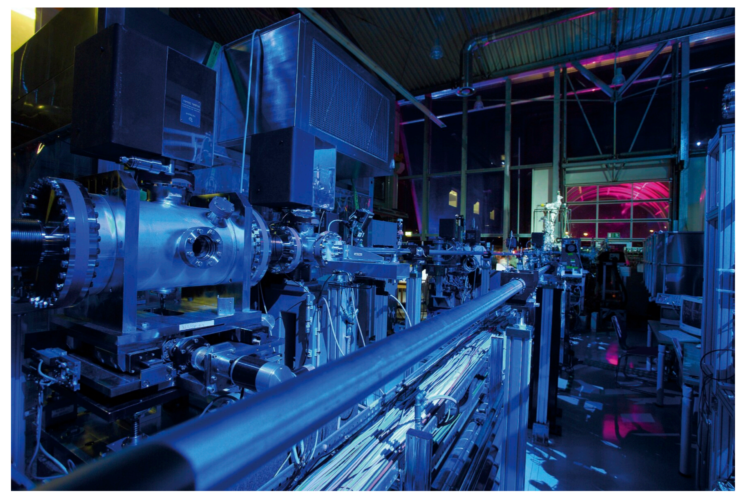


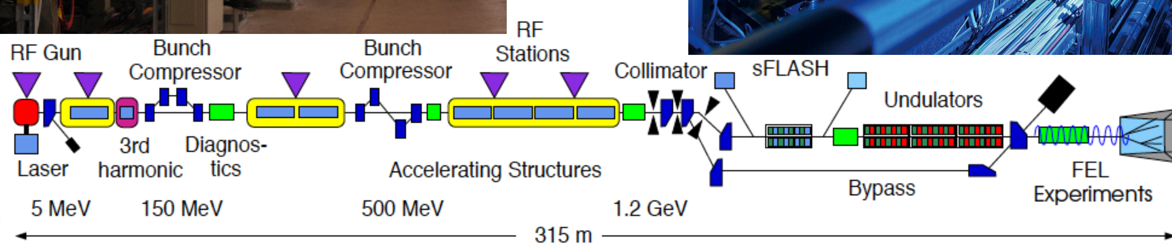
Superconducting "TESLA" Cavities

Parameter	Value
Av. field gradient	31.5 MV/m
Length	1.3026 m
Frequency	1.3 GHz
Quality factor Q_0	$> 10^{10}$
# 9-cell cavities	16024
# cryomodules	1855

How mature is SCRF technology?

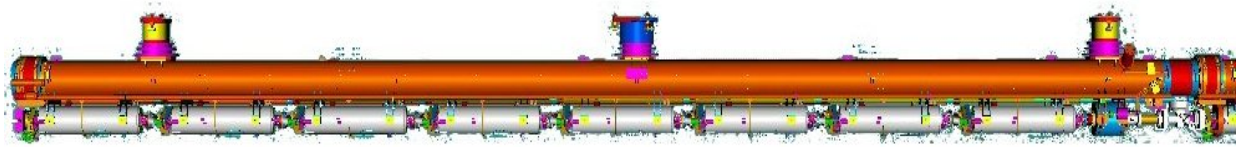
- Since 1997: **TESLA Test Facility at DESY** operational with ILC-style cryomodules
- 2004: Renamed FLASH, now a Free Electron Laser user facility
- 2004: Reached ILC design gradient in one cavity, with beam!
- 2009: Module PXFEL1 reaches 32MV/m -→ world record!
- Regular studies ("9mA studies") with ILC beam parameters





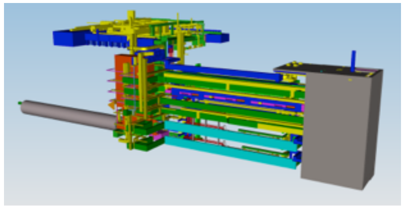
The European XFEL

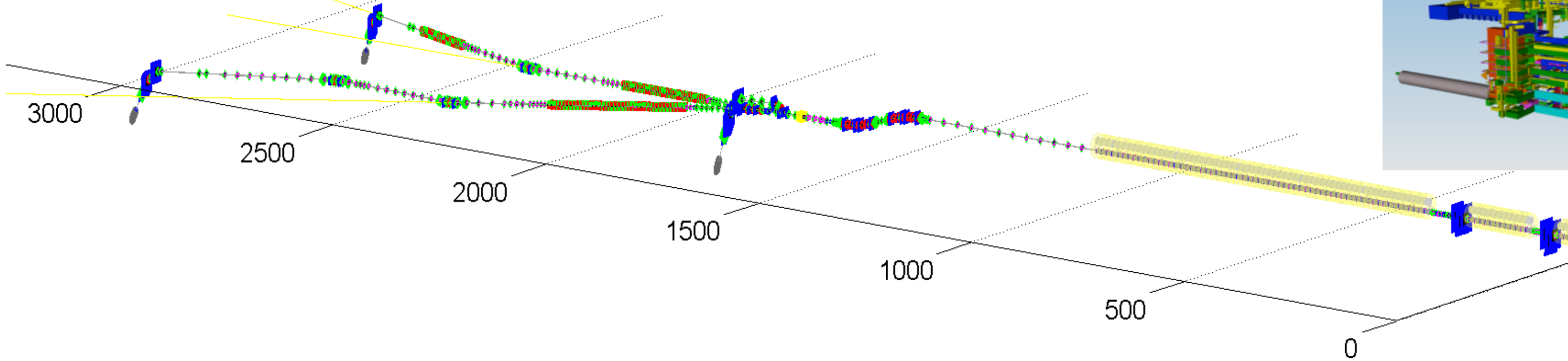
100 accelerator modules



800 accelerating cavities
1.3 GHz / 23.6 MV/m

25 RF stations
5.2 MW each





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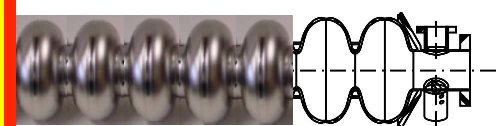
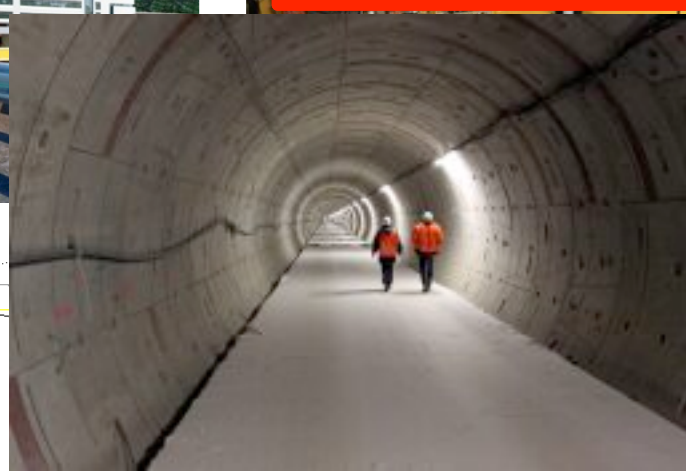
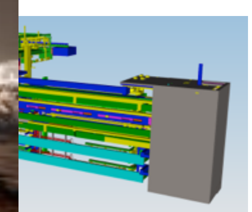
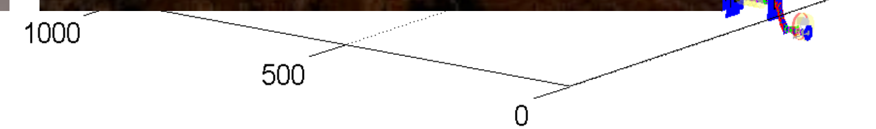


A “5% prototype”
for the ILC,
being built today!

RF stations





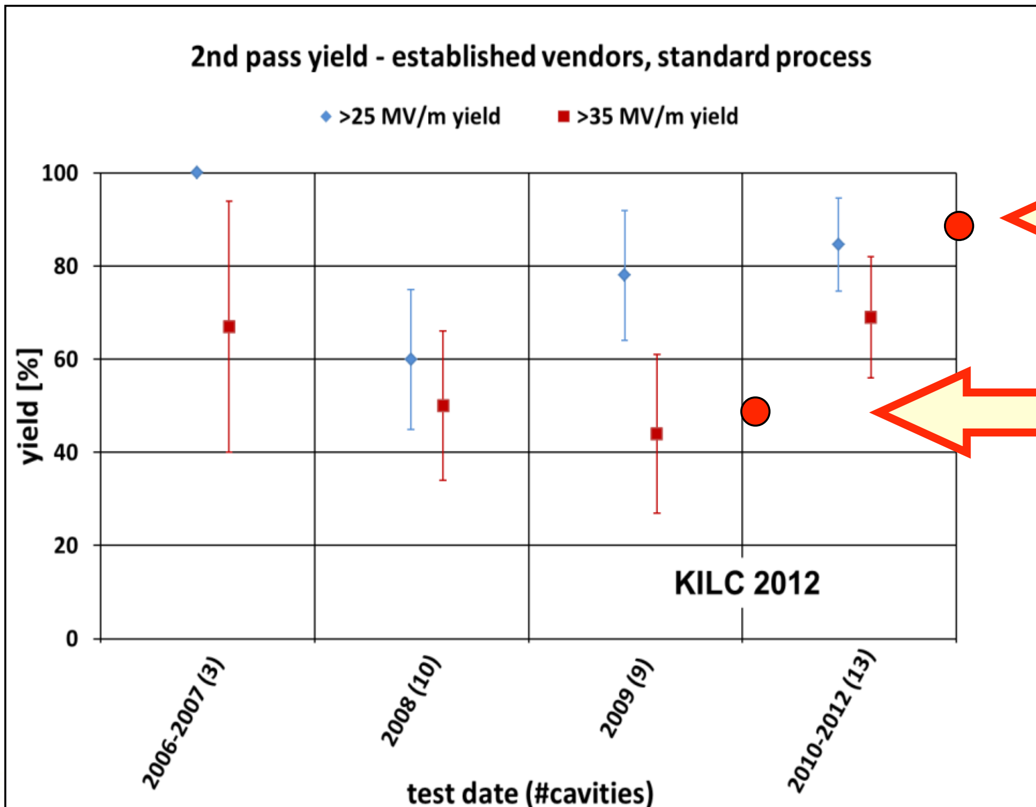


SCRF Cavities: Almost a Stock Item

Qualified vendors in all regions: America, Asia, and Europe

How can we reduce Cost?

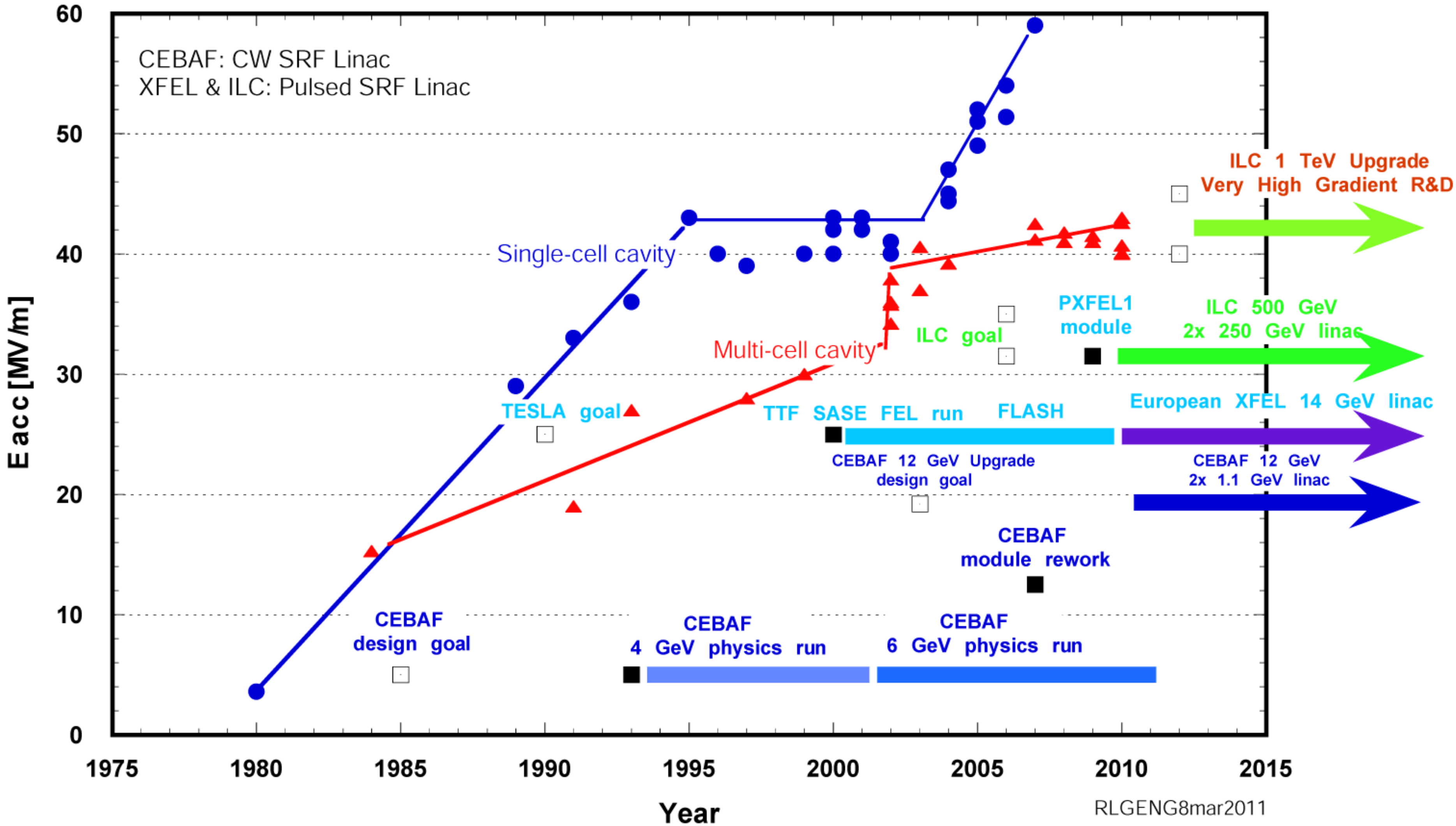
- We know we can build the ILC
- Now: Work on perfection of fabrication in industry
- Aim: further cost reduction by increasing the yield



TDR Goal

2010 Milestone

How Much Gradient is Possible?



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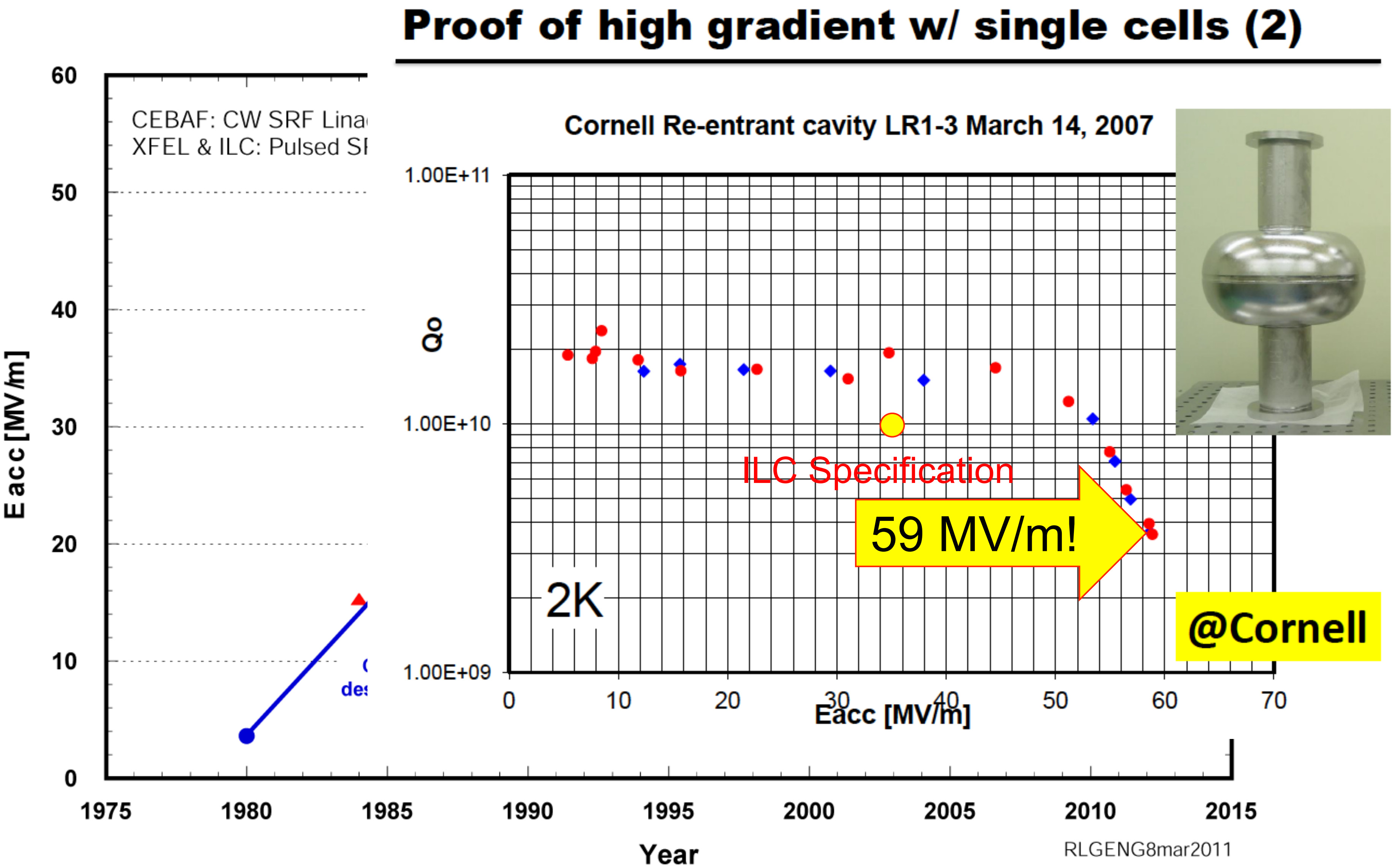
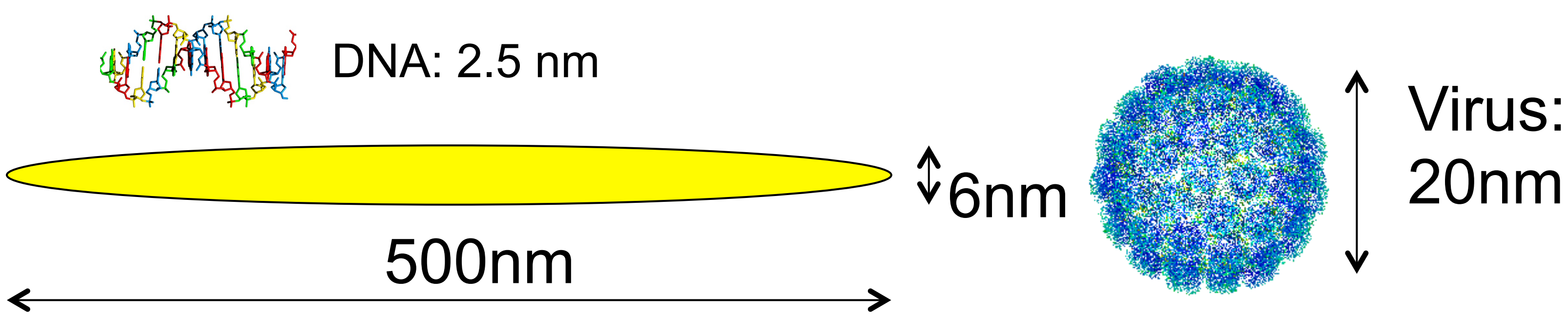


How to get the Luminosity

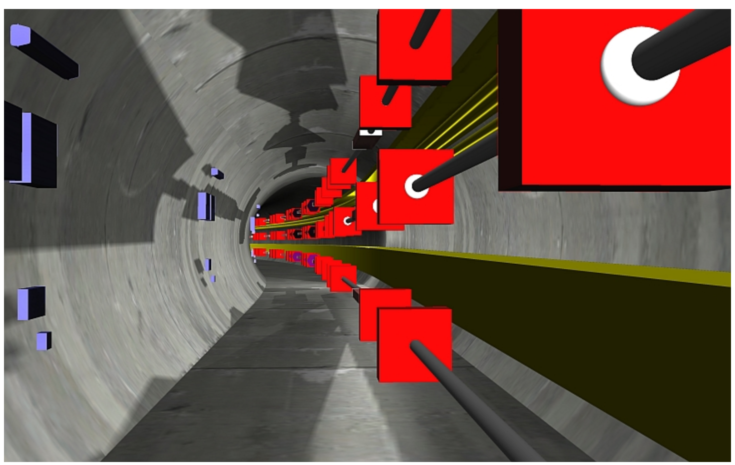
- Design: $\mathcal{L}=1.74\cdot10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ requires:
- Very small beams at interaction point: 500 nm x 6 nm!
- This needs:
  - **Beams with extremely low emittance**
  - **Extremely strong focussing at interaction point**



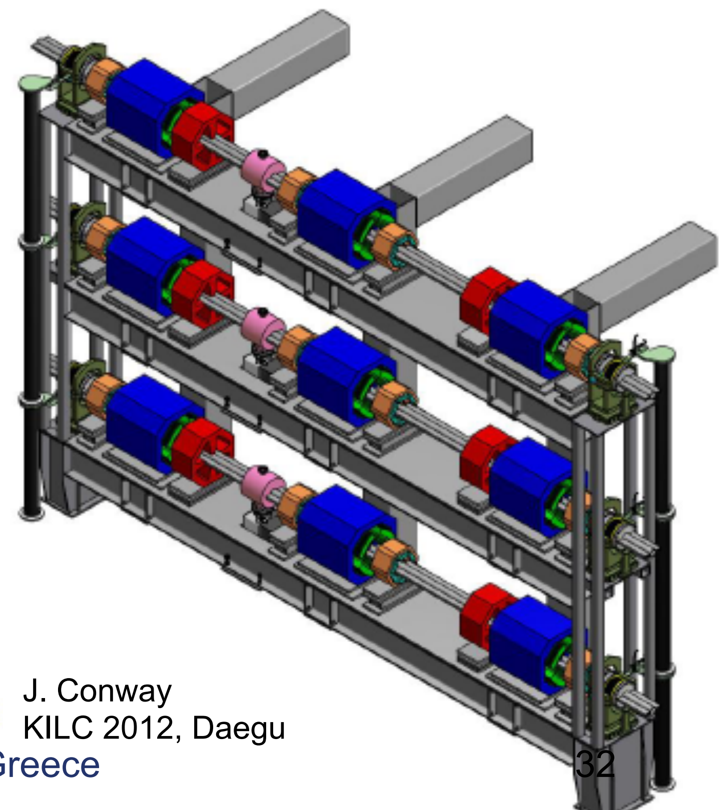
How to get Low-Emittance Beams?

Very advanced Damping Rings!

- Goal: 2pm vertical emittance at 5GeV!
  Similar to a 3rd generation light source
  → Not easy, but doable
- Dedicated test facilities



http://newsline.linearcollider.org/2011/09/22/virtual-tunnel/

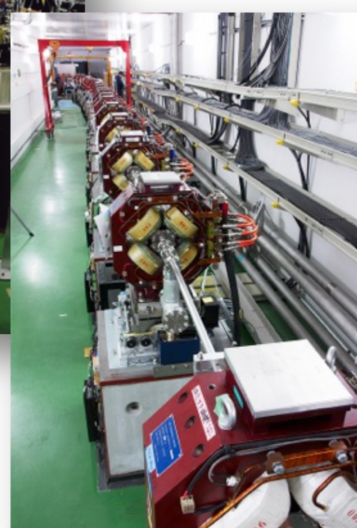


J. Conway
KILC 2012, Daegu

Beam Test Facilities (non SCRF)

- Two Large Scale Test Facilities for R&D:
  - **Damping Ring (ATF, CesrTA for *electron cloud*)**
  - **Beam Delivery System (Final Focus) (ATF2)**

Nick Walker

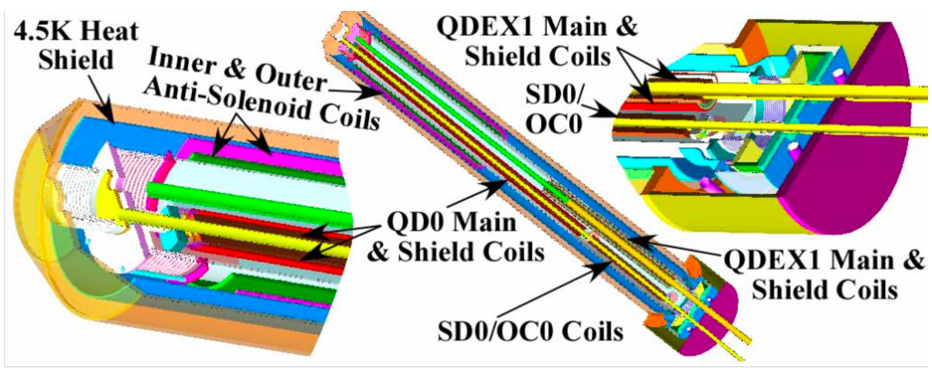



- ATF/ATF-2 (KEK)

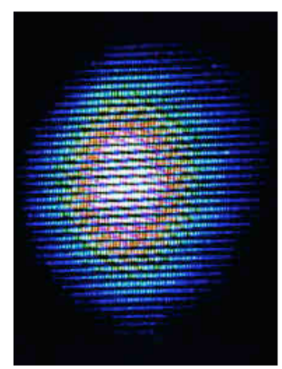
- CesrTA (Cornell)


How to Focus Beams to Nanometers

- Strong magnets reaching into experiments
- Tested at dedicated experiments:
  - **Final focus test facility at SLAC**
  - **ATF in Japan**
- Challenging, but proven to be feasible



B. Parker, PAC07 (THPMS091)



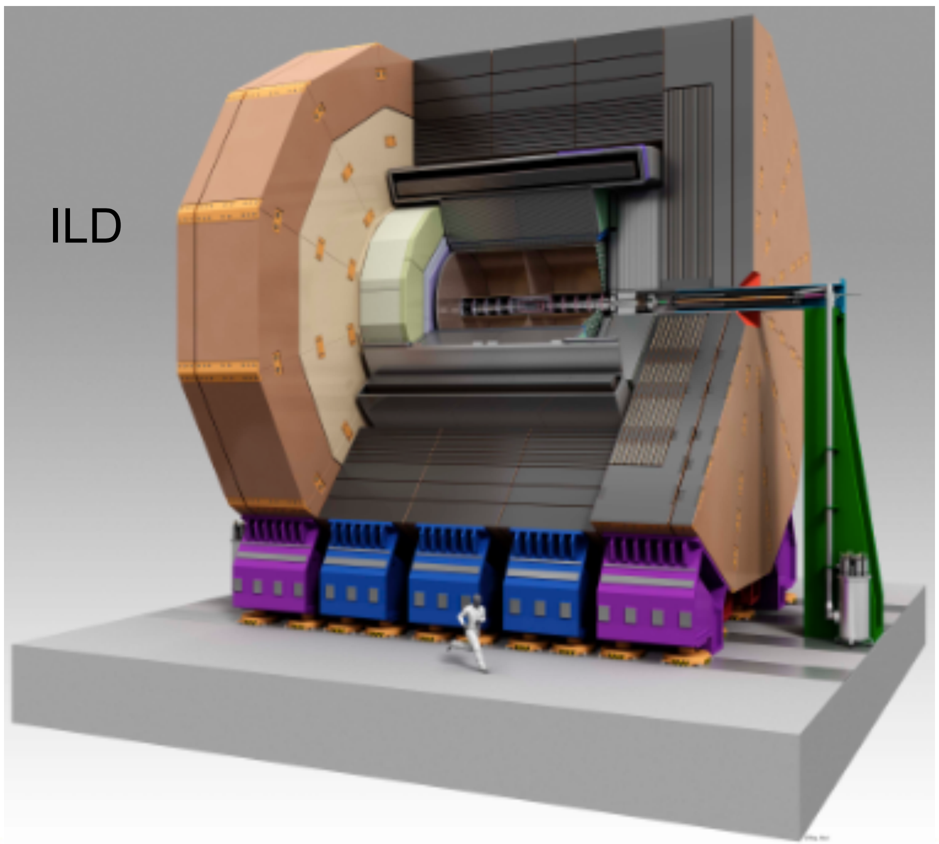
ATF at KEK - world's smallest emittance storage ring

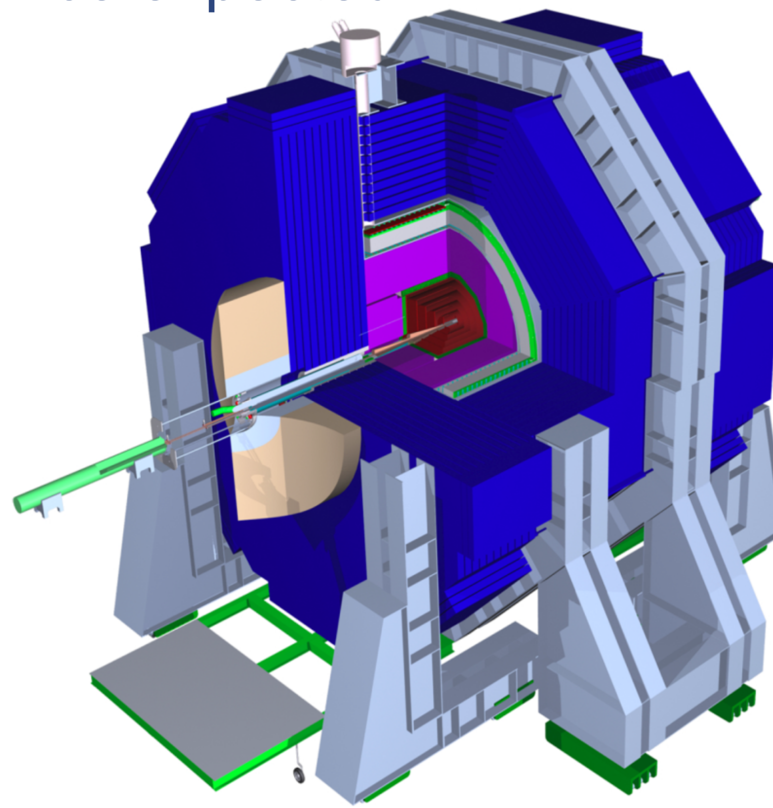
70 nm spot size!

How to detect the particles?

- Two Detectors: ILD and SiD, sharing one interaction region
- Clean e^+e^- environment permits low-mass, precision trackers → Excellent performance expected

ILD

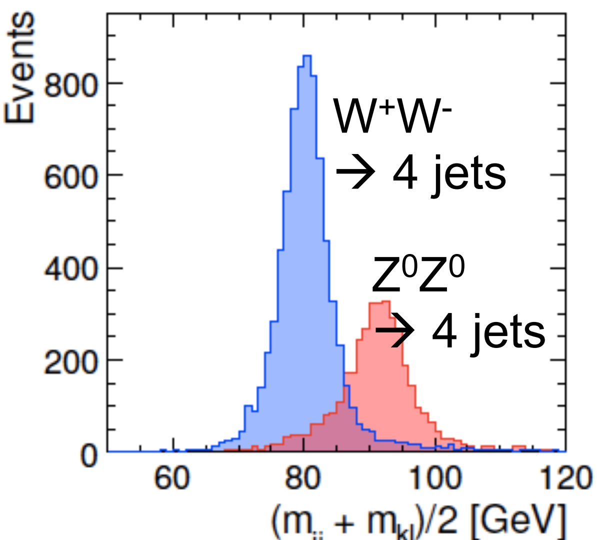




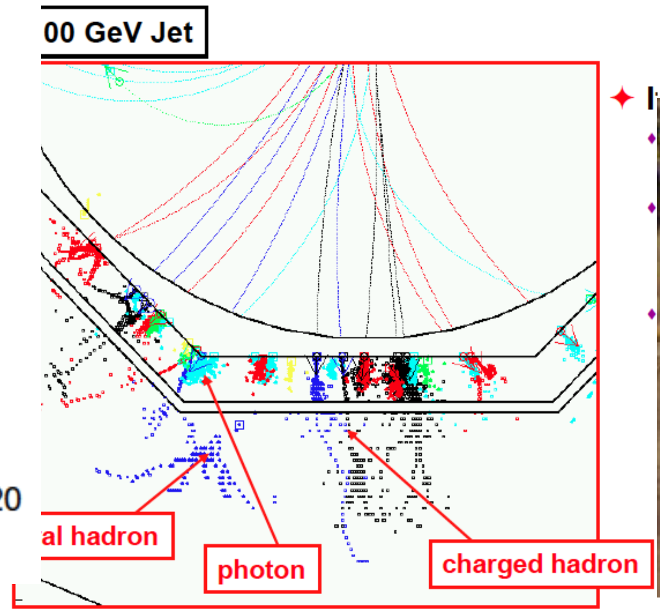
SiD

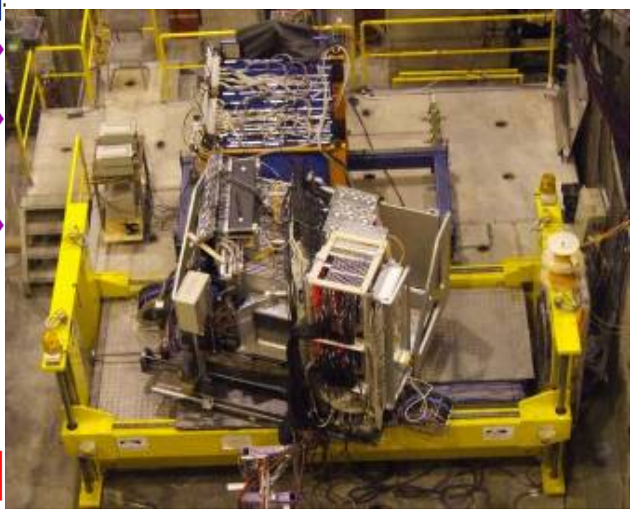
How to measure jet energies

- Need very good jet energy resolution: ~3.5% for Jets > 45GeV
  Example: Separate WW /ZZ → 4 jets
- Approach:
  - **Very fine grained calorimeter**
  - **Particle flow [Thomson, NIM A611(2009)24]**
- Prototypes developed by Calice Collaboration



ILD LOI: www.ilcild.org

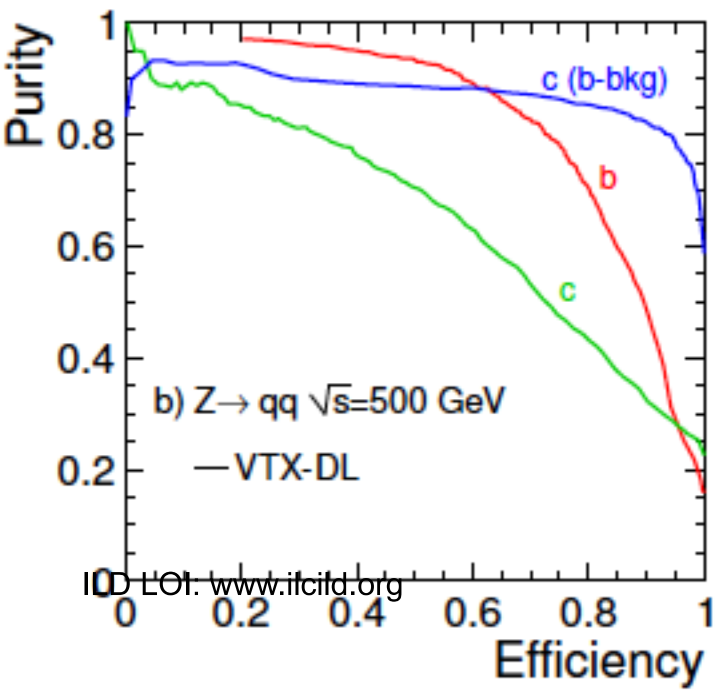




M. Thomson, Calor 2010

How to measure jet flavour

- Goal: unprecedented flavour separation, e.g. for separation H → bb / cc / gg
- Demands: Extremely thin vertex detectors → pushing the limits of silicon pixel detectors!
- Several promising technologies being developed



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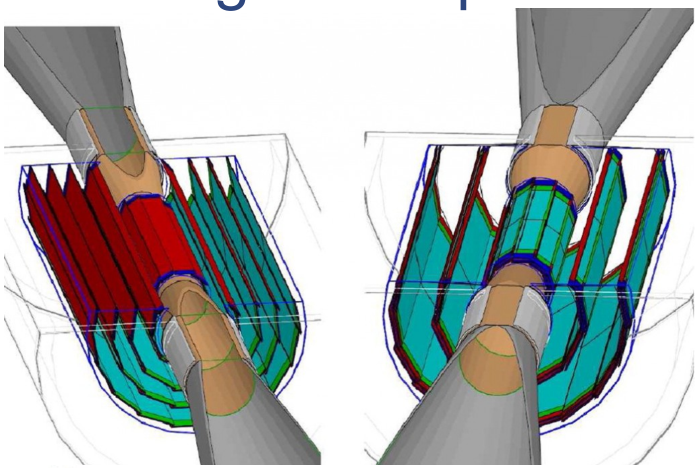
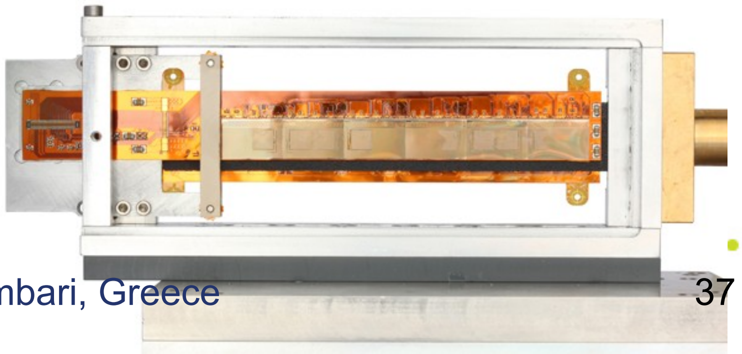
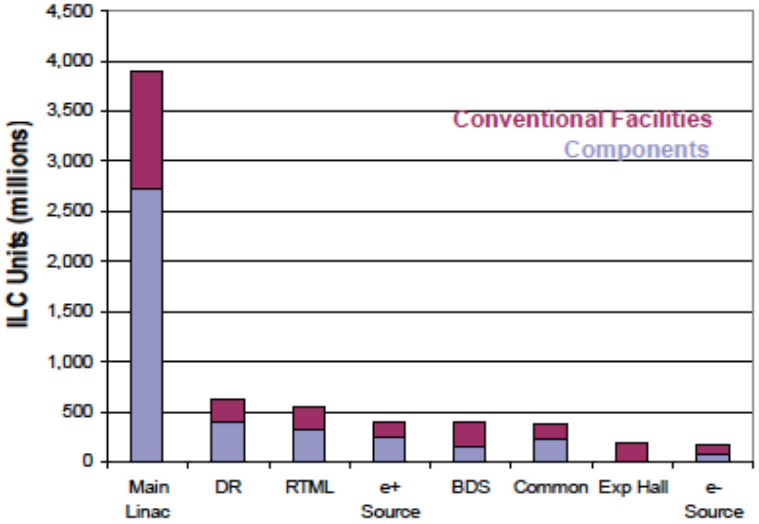




How much does it cost?

- Estimate from 2007 Reference Design Report: $6.62 \cdot 10^9$ ILCU + 14k years labor (1 ILCU = 1US$ 2007)
- New estimate in 2013 Technical Design Report
- Dominated by Main Linac



WHEN

- When does the TDR appear?
- When can ILC be built?
- … and Where?

When do things happen?

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

Reference Design Report (RDR)

Te

iew

g.

LHC p

Presentation of the TDR

We Are here

TDR publication. Ready for Project Submission.

Beyond 2012

- Formation of ILC project
- Funding
- Site selection
- *etc*

Nick Walker

When and Where will the ILC be Built?

- For TDR, sample sites in America, Europe, and Asia are considered to evaluate costs
- Not site decision has been made
- In December, Japanese prime minister Nagoda held highly acclaimed speech at Japanese “Advanced Accelerator Association” meeting about the ILC
- Strong interest in Japan from
  - **Physics community**
  - **Industry**
  - **Politics**
- Need supporting statements from European Strategy!

Two Sites in Japan

Nick Walker

Take Home Message

- ILC has a strong physics case as precision machine:
  - **Complementary to LHC**
  - **Ideal to study light Higgs and Top**
  - **Explores what lies behind the Standard Model, might even discover it!**
- ILC is ready to be built today
- Strong movement in Japan in favour of ILC
  → needs positive statements from Europe!

Acknowledgements

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