# International Linear Collider – Technical Design Phase (TDP)

Marc Ross, (Fermilab)
Nick Walker, (DESY)
and Akira Yamamoto (KEK)

*A straightforward path to the Energy Frontier*

ILC Reference Design Talk - *2007* → →

# The Reference Design Report and cost estimate for the International Linear Collider

**Marc Ross, Fermilab**

**Jan 31, 2007**

**Reference Design:**
***'RDR'***

**First slide – 2007…**

# Role of Fermilab

- Research and Development of SRF across a broad front:
  - Fundamentals
  - Mass production technology
  - Accelerator operation
  - Cost reduction
- There are no entitlements in the accelerator building business
  - We have to demonstrate competence
  - Our partners are more advanced
  - Timing is critical → 50 KW electron beam
- Your participation is important

Last slide – 2007…

# Technical Design Phase:

- ***R & D*** to demonstrate and support key design parameters
- Updated ***technical design***
- Practical scenarios for ***global distribution of*** mass production of ***high-technology***
- Updated ***cost estimate***

- Documented (2012) in the

***TECHNICAL DESIGN REPORT***

# ILC TDP: Outline

- **SRF R & D**
    - Cavity
    - Cryomodule
    - Linac w/ beam
- **SRF Mass Production and Cost**
- **Beam Test Facilities**
- **Siting the ILC**
- **Path to the Energy Frontier**

# **SRF** R & D Goals:

**Validate RDR Parameter choices**

→ ***demonstrations at: DESY, US labs, KEK***

**Fabrication quality and diagnostics**

→ ***Electron Beam Welding & hi-res camera***

**Surface treatment Recipe**

→ ***Electro-polish chemical rinse***

**System assembly and test**

→ ***cavity string***

**Power/gradient overhead w/beam**

→ ***1.2 GeV, 7 cryomodule string - DESY (FLASH)***

→ ***NML, STF at KEK***

# Global Plan for ILC Gradient R&D

| Year | 07 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Phase | TDP-1 | | | TDP-2 | | |
| Cavity Gradient in v. test to reach 35 MV/m | → Yield 50% | | | → Yield 90% | | |
| Cavity-string to reach 31.5 MV/m, with one-cryomodule | | **Global effort for string assembly and test**<br>(DESY, FNAL, INFN, KEK) | | | **NML CM1 and CM2** | |
| System Test with beam acceleration | | **FLASH (DESY) , NML (FNAL)**<br>**STF2 (KEK, test start in 2013)** | | | | |
| Preparation for Industrialization | | | **Production Technology R&D** | | | |

New baseline gradient:

Vertical acceptance: 35 MV/m average, allowing ±20% spread (28-42 MV/m)

Operational: 31.5 MV/m average, allowing ±20% spread (25-38 MV/m)

# ILC TDP: (1.1)

- **SRF R & D:**
  - **Cavity** production *yield* @ nominal avg. gradient:
  - Combining / Unifying results:
    - 31 cavities 2nd pass (50:40:10% / US:DESY:KEK)
  - Challenge: Taming Field Emission
  - 45 MV/m
- **SRF Mass Production and Cost**
- **Beam Test Facilities**
- **Siting the ILC**
- **Path to the Energy Frontier**

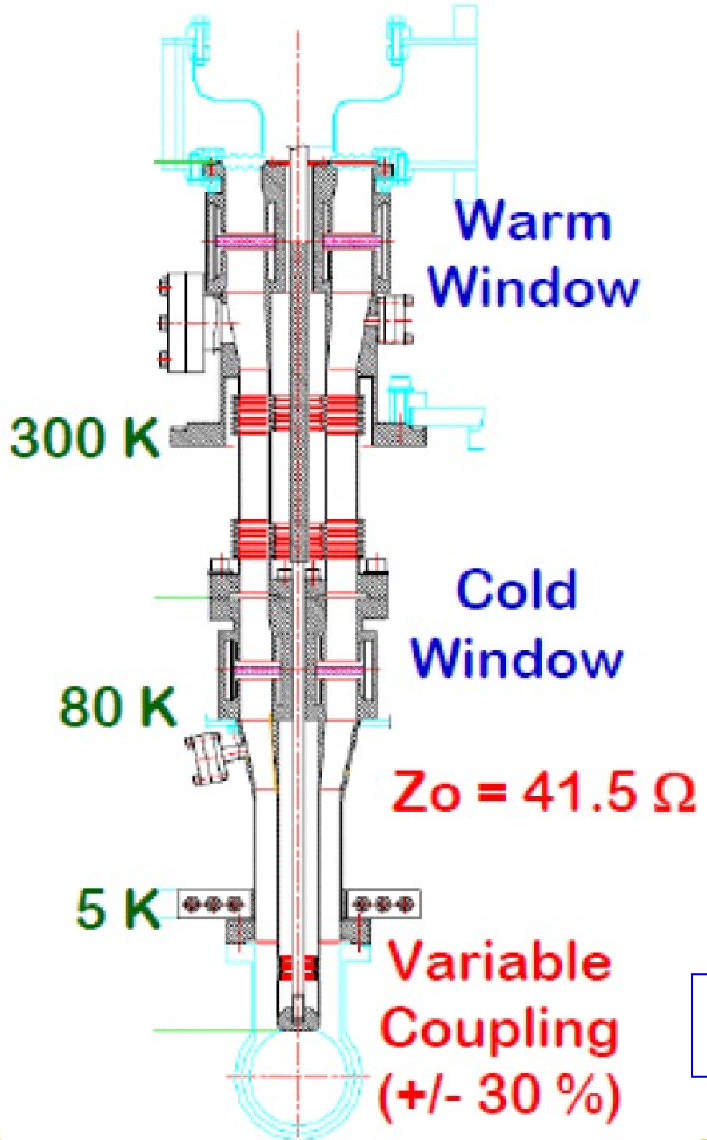
# SCRF linac – basic building block

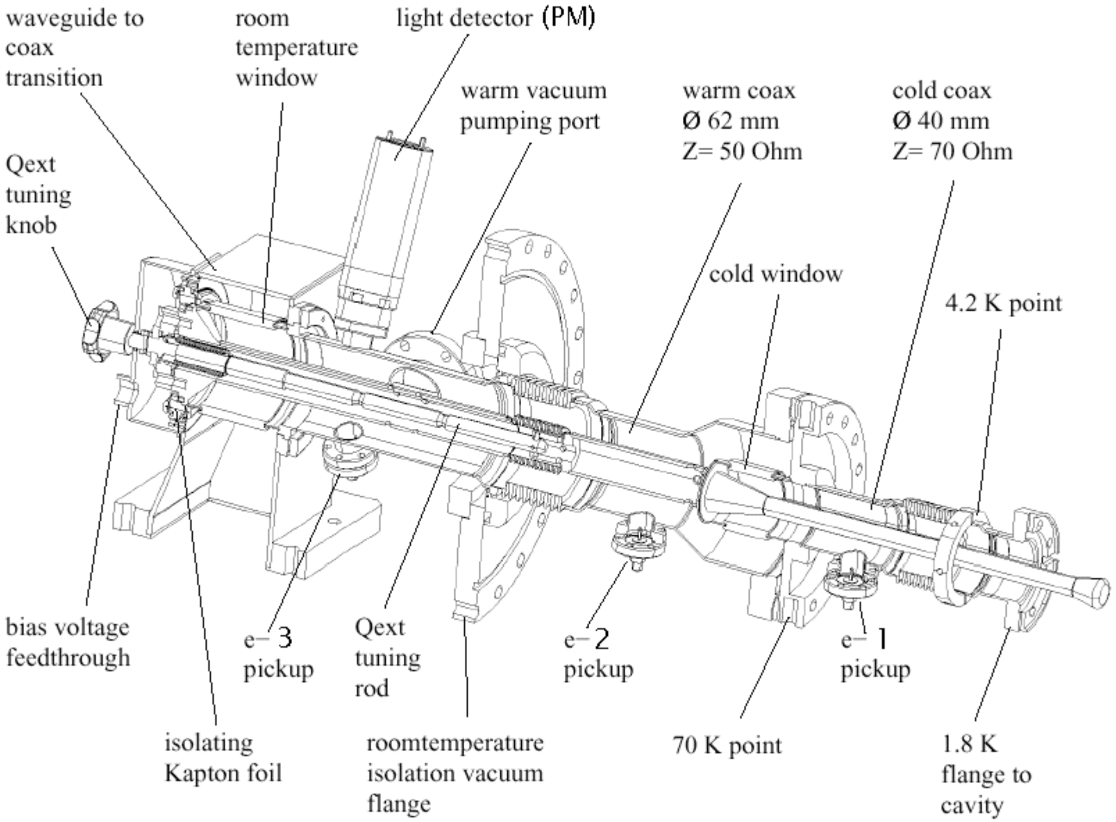
Figure 1.2-1: A TESLA nine-cell 1.3 GHz superconducting niobium cavity.

- ~ 70 parts electron-beam welded at high vacuum
  - **~ 1.25 m$^2$ x 3mm thick sheet metal**
- pure niobium and niobium/titanium alloy
  - **niobium cost similar to silver**
- weight ~ 70 lbs
- 6 flanges

# Cavity production

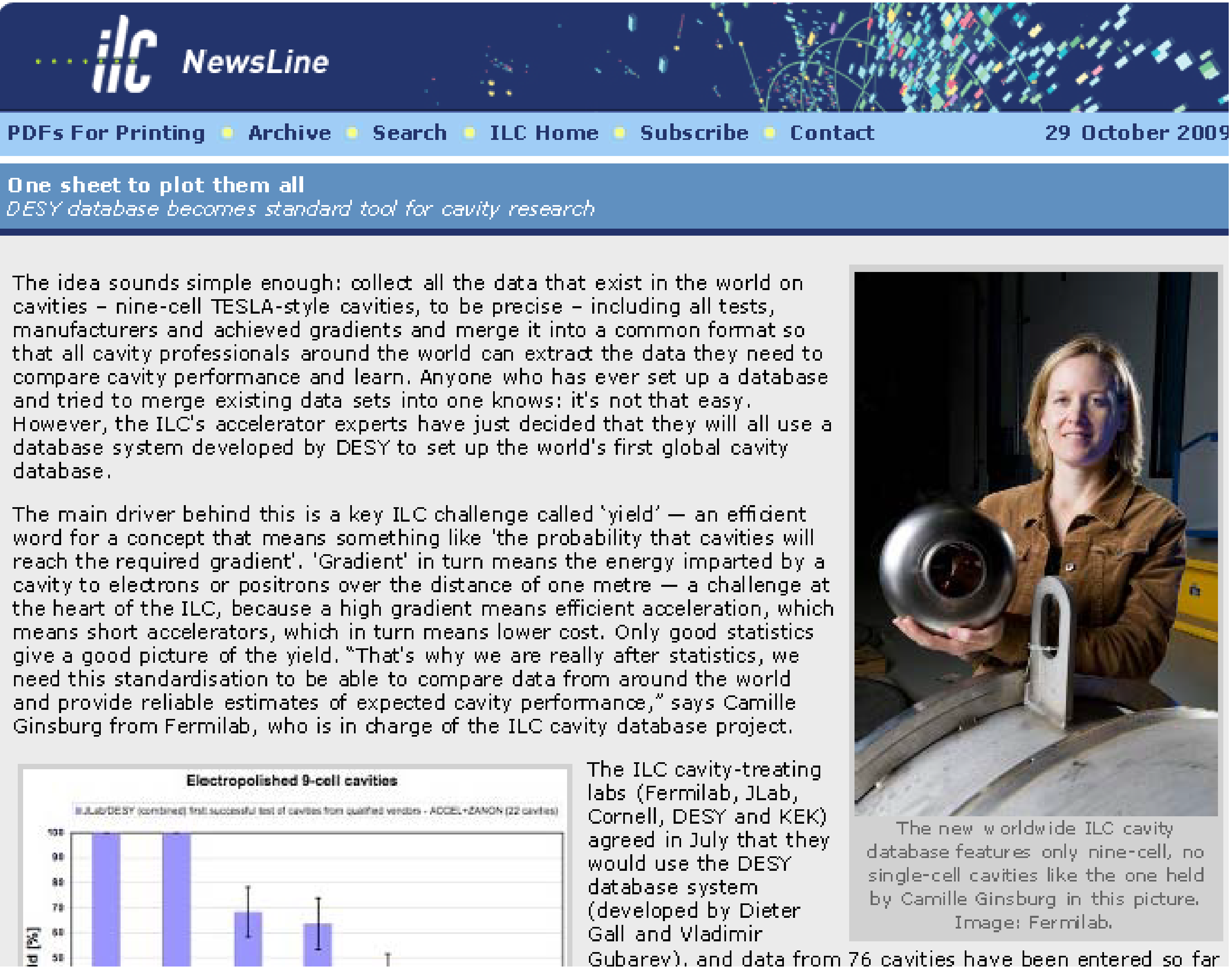
# Two Power Coupler Designs





Adjustable; Both tested / compared

# Creation of a Global Database to understand cavity *Production Yield*



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29 October 2009

**One sheet to plot them all**

*DESY database becomes standard tool for cavity research*

The idea sounds simple enough: collect all the data that exist in the world on cavities – nine-cell TESLA-style cavities, to be precise – including all tests, manufacturers and achieved gradients and merge it into a common format so that all cavity professionals around the world can extract the data they need to compare cavity performance and learn. Anyone who has ever set up a database and tried to merge existing data sets into one knows: it's not that easy. However, the ILC's accelerator experts have just decided that they will all use a database system developed by DESY to set up the world's first global cavity database.

The main driver behind this is a key ILC challenge called 'yield' — an efficient word for a concept that means something like 'the probability that cavities will reach the required gradient'. 'Gradient' in turn means the energy imparted by a cavity to electrons or positrons over the distance of one metre — a challenge at the heart of the ILC, because a high gradient means efficient acceleration, which means short accelerators, which in turn means lower cost. Only good statistics give a good picture of the yield. "That's why we are really after statistics, we need this standardisation to be able to compare data from around the world and provide reliable estimates of expected cavity performance," says Camille Ginsburg from Fermilab, who is in charge of the ILC cavity database project.

The ILC cavity-treating labs (Fermilab, JLab, Cornell, DESY and KEK) agreed in July that they would use the DESY database system (developed by Dieter Gall and Vladimir Gubarev), and data from 76 cavities have been entered so far

The new worldwide ILC cavity database features only nine-cell, no single-cell cavities like the one held by Camille Ginsburg in this picture. Image: Fermilab.

Global Data Base Team formed by:

Camille Ginsburg (Fermilab)

Rongli Geng (JLab)

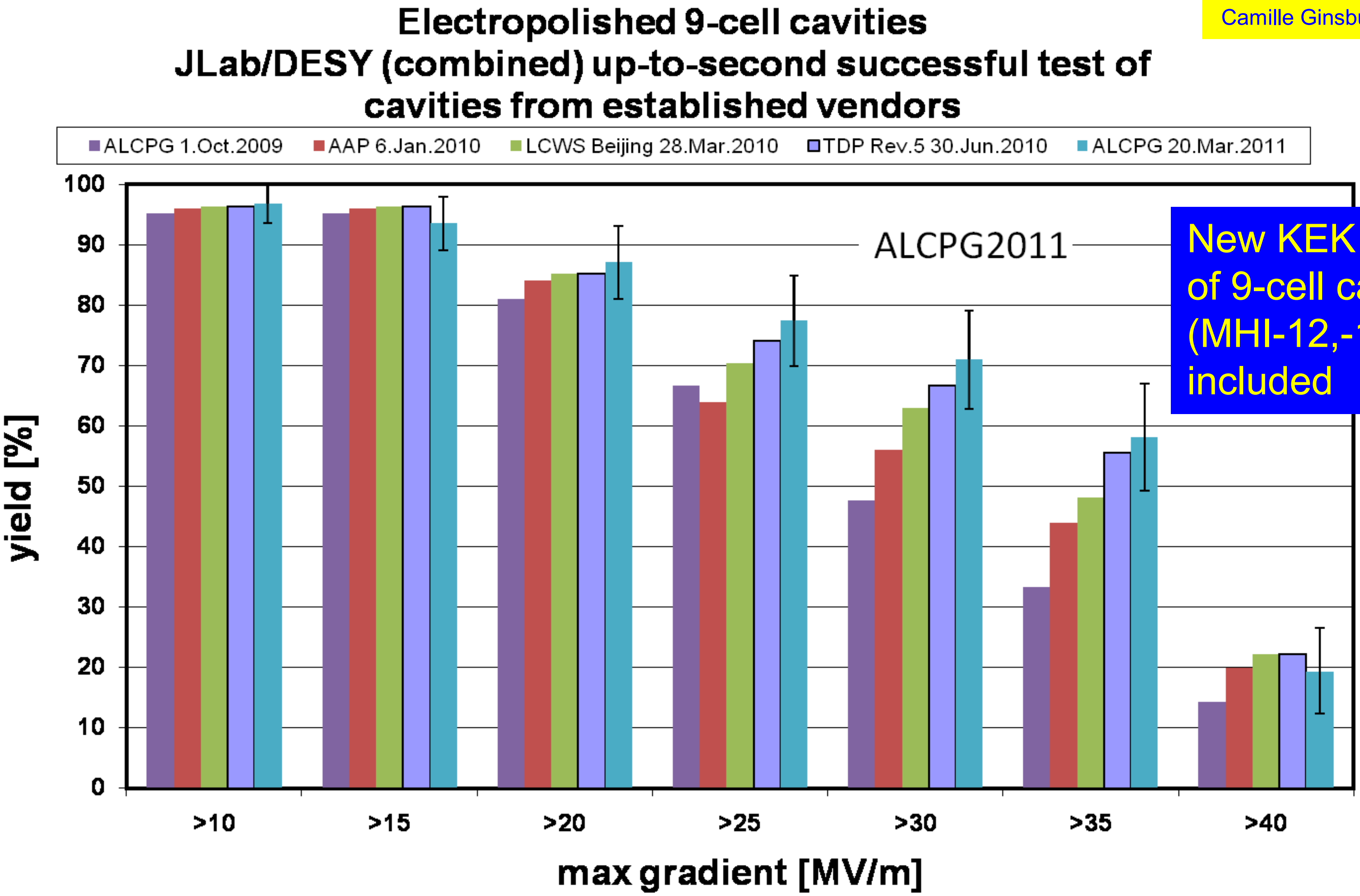
Zack Conway (Cornell University)

Sebastian Aderhold (DESY)

Yasuchika Yamamoto (KEK)

# Global ILC Cavity Gradient Yield Updated at ALCPG2011

Plot courtesy
Camille Ginsburg of FNAL



Electropolished 9-cell cavities
JLab/DESY (combined) up-to-second successful test of cavities from established vendors

New KEK results of 9-cell cavities (MHI-12,-13,-14) included

# Impact of Mechanical Polishing Today at 6th PAC Meeting in Taipei

88% Yield at 35 MV/m achieved at JLAB + FNAL

Average gradient 39 MV/m

94% yield at ≥31 MV/m

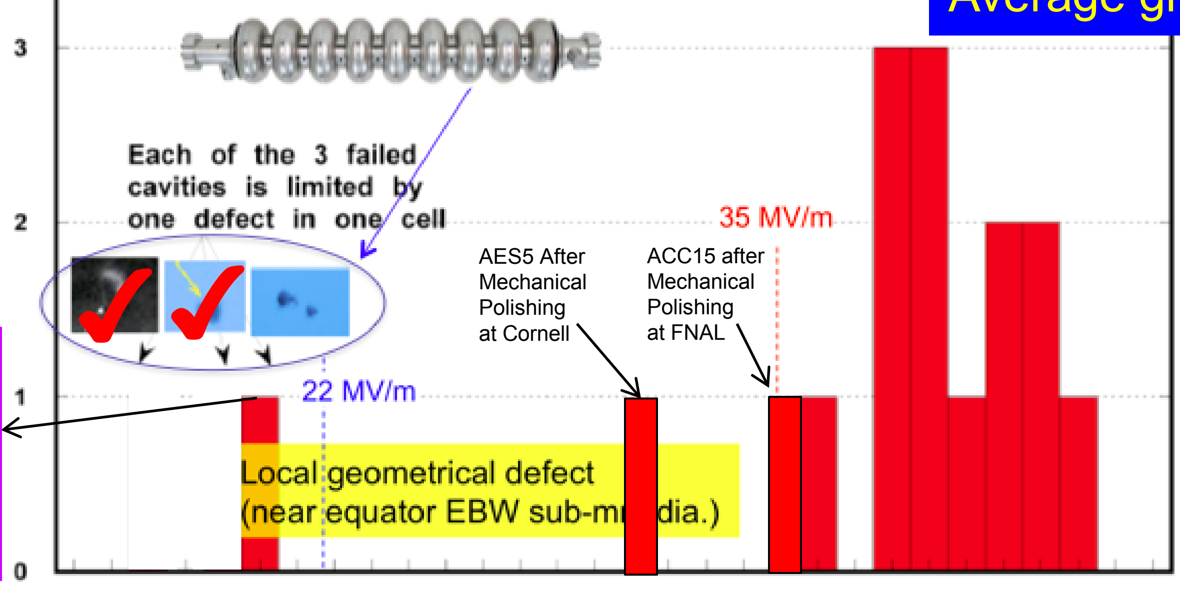
Jefferson Lab + Fermilab + Cornell University

Average gradient 38.8 MV/m

Gradient Scatter (up to 2nd-pass

16 recent data from cavities built by ACCEL/RI and AES

16 9-cell cavities (10 built by ACCEL/RI and 6 by AES) processed and tested at JLab since July 2008



Each of the 3 failed cavities is limited by one defect in one cell

AES5 After Mechanical Polishing at Cornell

ACC15 after Mechanical Polishing at FNAL

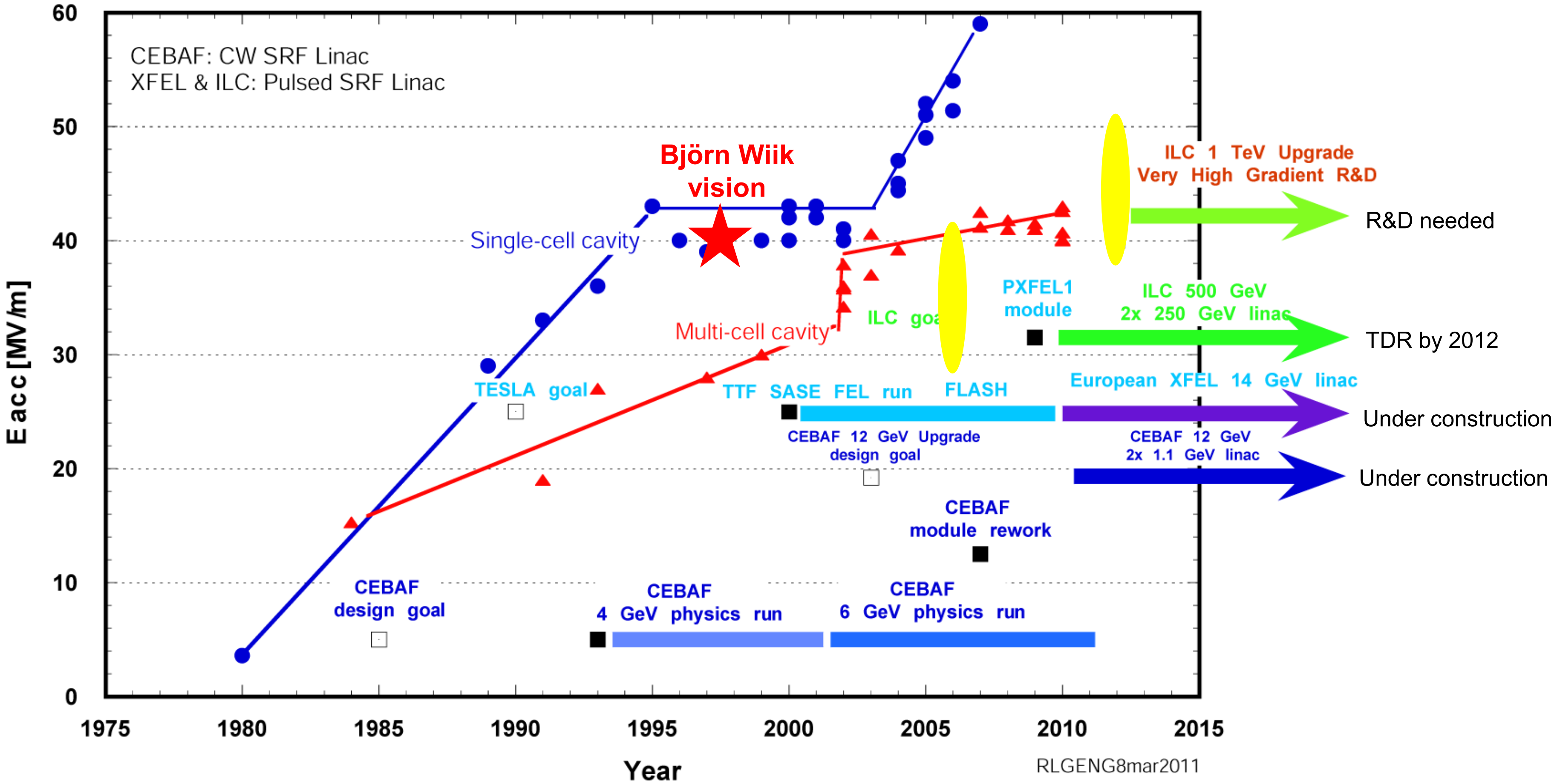
Local geometrical defect (near equator EBW sub-m dia.)

This cavity AES6 is being treated with mechanical polishing at FNAL and will be then EP processed and tested at JLAB

A, Yamamoto, 10-11-11 ILC-PAC: SCRF 17

# SRF Cavity Gradient Progress

## L-Band SRF Niobium Cavity Gradient Envelope and Gradient R&D Impact to SRF Linacs



Steady progress in SRF cavity gradient makes SRF an enabling technology
SRF based electron linacs (CW & pulsed) have track record of successful operations

# Main Issues at Very High Gradients (1)

## Field Emission / Dark Current

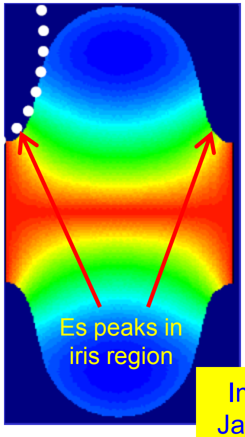


Image courtesy Jacek Sekutowicz

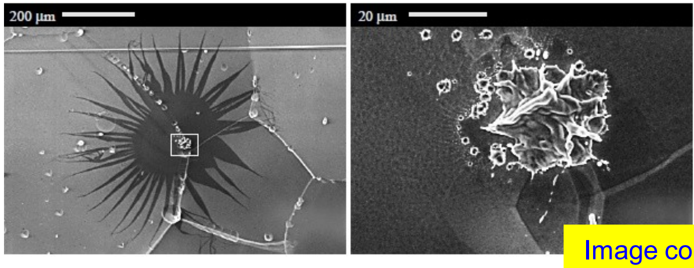
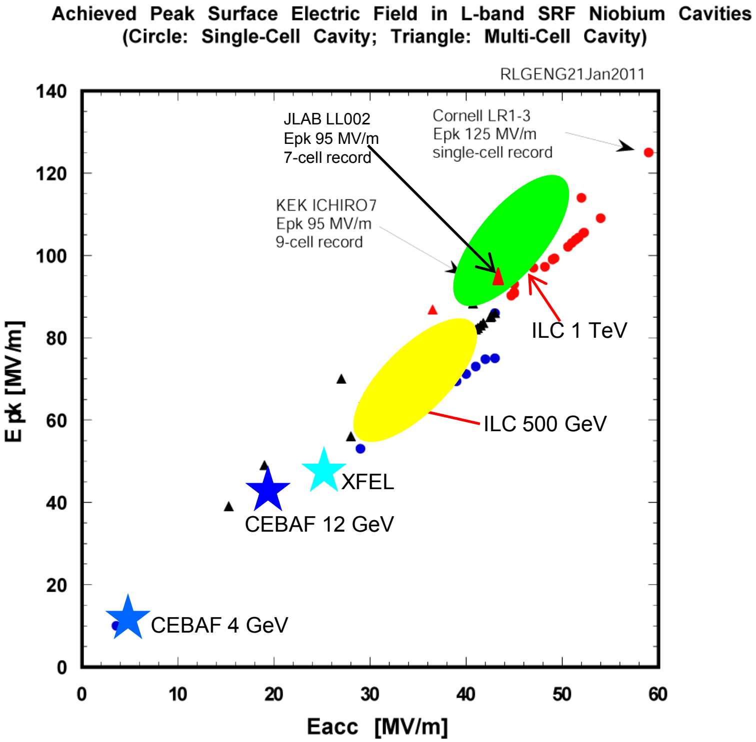
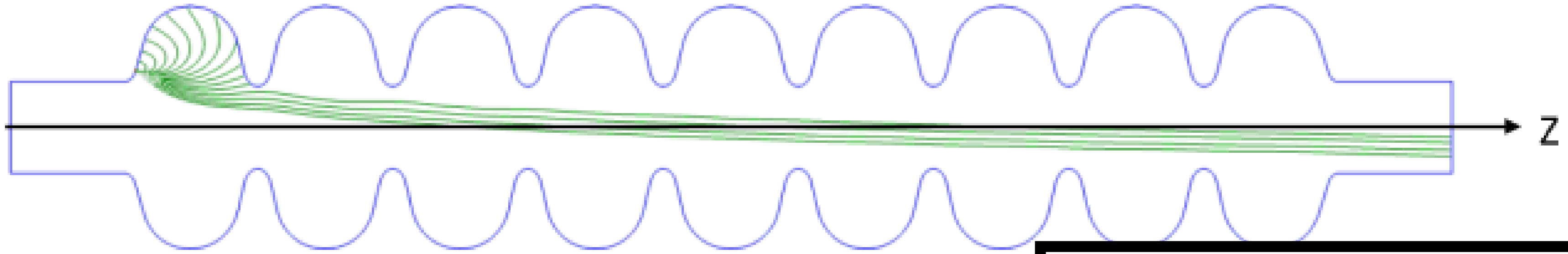


Image courtesy Jens Knobloch



- Peak surface electric field (Epk) a governing parameter
- Physics fairly understood and no known fundamental limit
- Microscopic particles an important family of field emitters
- Epk 100-120 MV/m demonstrated in 1-cell Nb cavities
- Epk100-120 MV/m needed in multi-cell for ILC 1 TeV
  - Record Epk reached in 9-cell cavity 95 MV/m (KEK ICHIRO7)
  - Improved HOM coupler cleaning is necessary

Field emission is a known problem and has not been completely resolved, despite recent progress in post-EP cleaning advancement. Sudden field emitter turn-on in 9-cell cavities has been reported by almost all labs. Pushing Epk into 100-120 MV/m regime is necessary for reaching Eacc 40-45 MV/m. It is most likely new processing technology needs to be applied besides HPR. Promising work has started in this direction such as snow cleaning, plasma cleaning and HOM horn cleaning.

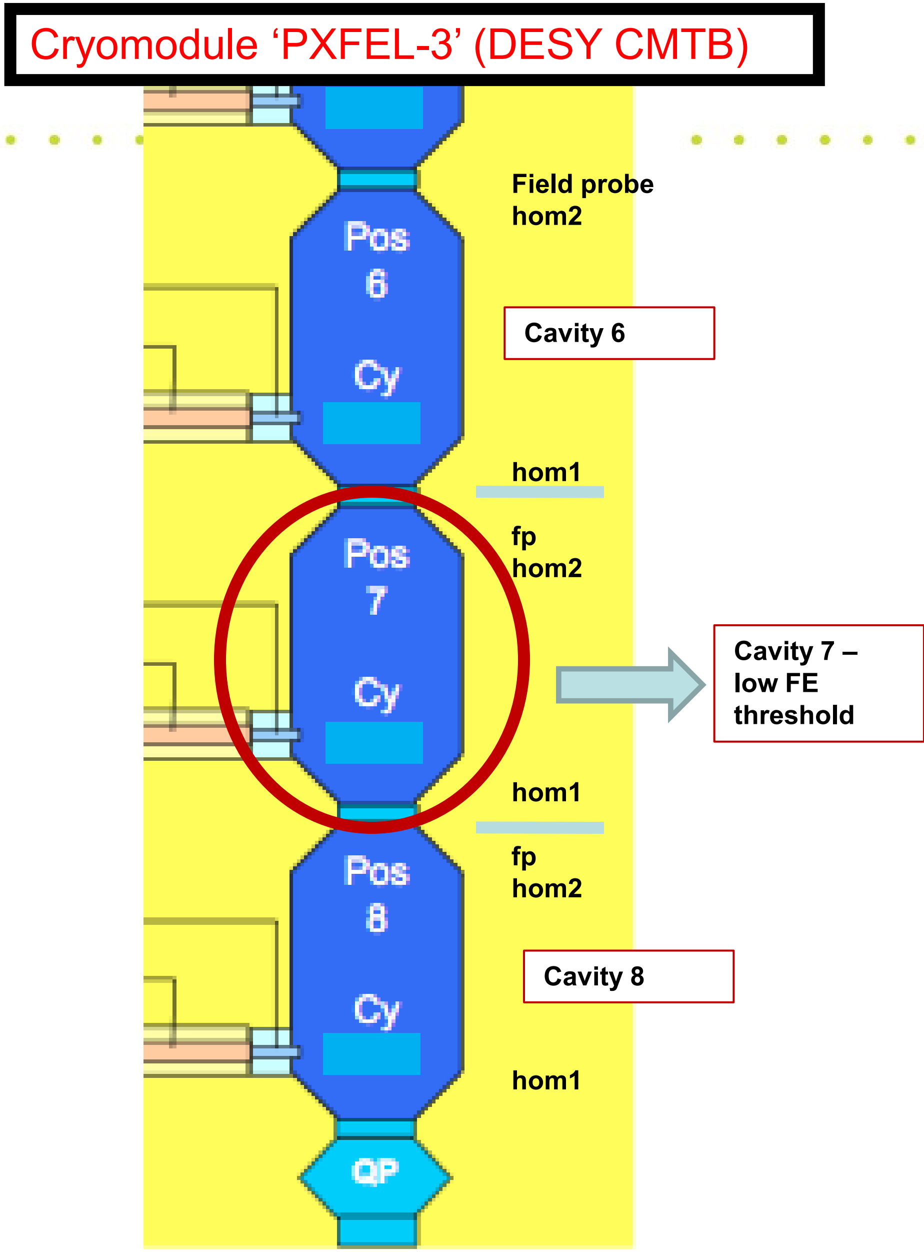


## Field Emission / Dark Current

- 9 cell dark current simulation
  - (Ginsburg – IPAC2010)
- Field emitted current shows non-linear increase as gradient is raised – roughly following ‘Fowler-Nordheim’ scheme.
  - **Clear, repeatable field emission *threshold***
- A field emission point is a ‘diode’ →
  - **dark current is ‘bunched’ w/characteristic time structure**
- Will radiate harmonics of the fundamental 1.3GHz (up to ω ~ 1/bunch length)

# Experiment:

- Look for 2nd / 3rd harmonics (DESY)
  - **cavity 7, PXFEL 3 contaminated**
  - **15MV/m threshold**
- Check both HOM pickups and field probe
  - **→ signal easily seen**
- compare amplitude of harmonics above & below the threshold


Cryomodule ‘PXFEL-3’ (DESY CMTB)

Cavity 7 – low FE threshold

# 2nd/3rd harmonic change:

- above – below FE threshold:
  - **changing klystron output by 20%**

| Voltage increase | Cav6 HOM1 | Cav7 – FP | Cav7 – HOM2 | Cav7 – HOM1 | Cav8 FP |
|---|---|---|---|---|---|
| 2.6 GHz | 8db (x2.5) | 8dB (x2.5) | 0dB | 3dB (x1.5) | -4dB |
| 3.9GHz | -2dB | 2dB | 18 dB (x7.5) | -7.5dB | 3dB |

- Conclusion:
  - **a strong signal; seems to respond above/below FE**
  - **but many questions; esp. klystron harmonics…**

# ILC TDP: (1.2)

- SRF R & D:
  - Cryomodule **string assembly / design**
  - **Compare distinct designs/interfaces: S1** ***Global***
  - ***Fermilab CM1 @ NML***
  - **Lorentz-Force Detuning Compensation**
  - **Industrial High-Technology:** ***Tuning Machine***
  - **FLASH: 1.2 GeV / 56 cavities → Field emission**
- SRF Mass Production and Cost
- Beam Test Facilities
- Siting the ILC
- Path to the Energy Frontier

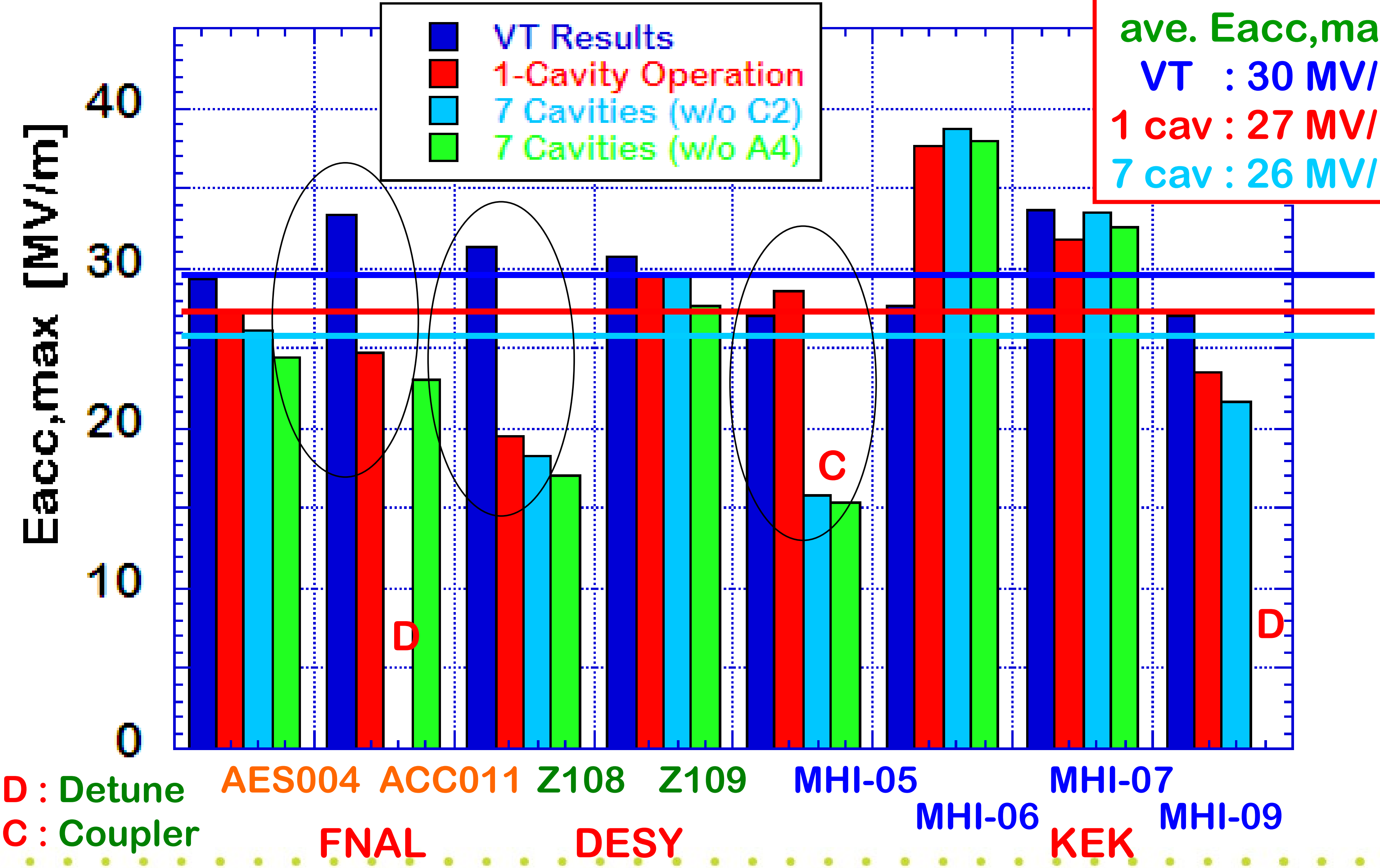
# S1 Global Cryomodule - KEK

**Goal:**

1. **Integrate cavity efforts**
   - to understand and / or highlight differences
   - 1) Mechanical Stiffness, 2) Tuner, 3) Power Coupler
2. **Help define plug-compatibility interfaces**

- **RDR 6.1.4:**
  - “The European estimate for the cavities and cryomodules is used for the ILC value as it is the most mature, in terms of R&D and industrial studies. Estimates from the other regions provide a crosscheck.”
- **TDR cost estimate will have a global basis**

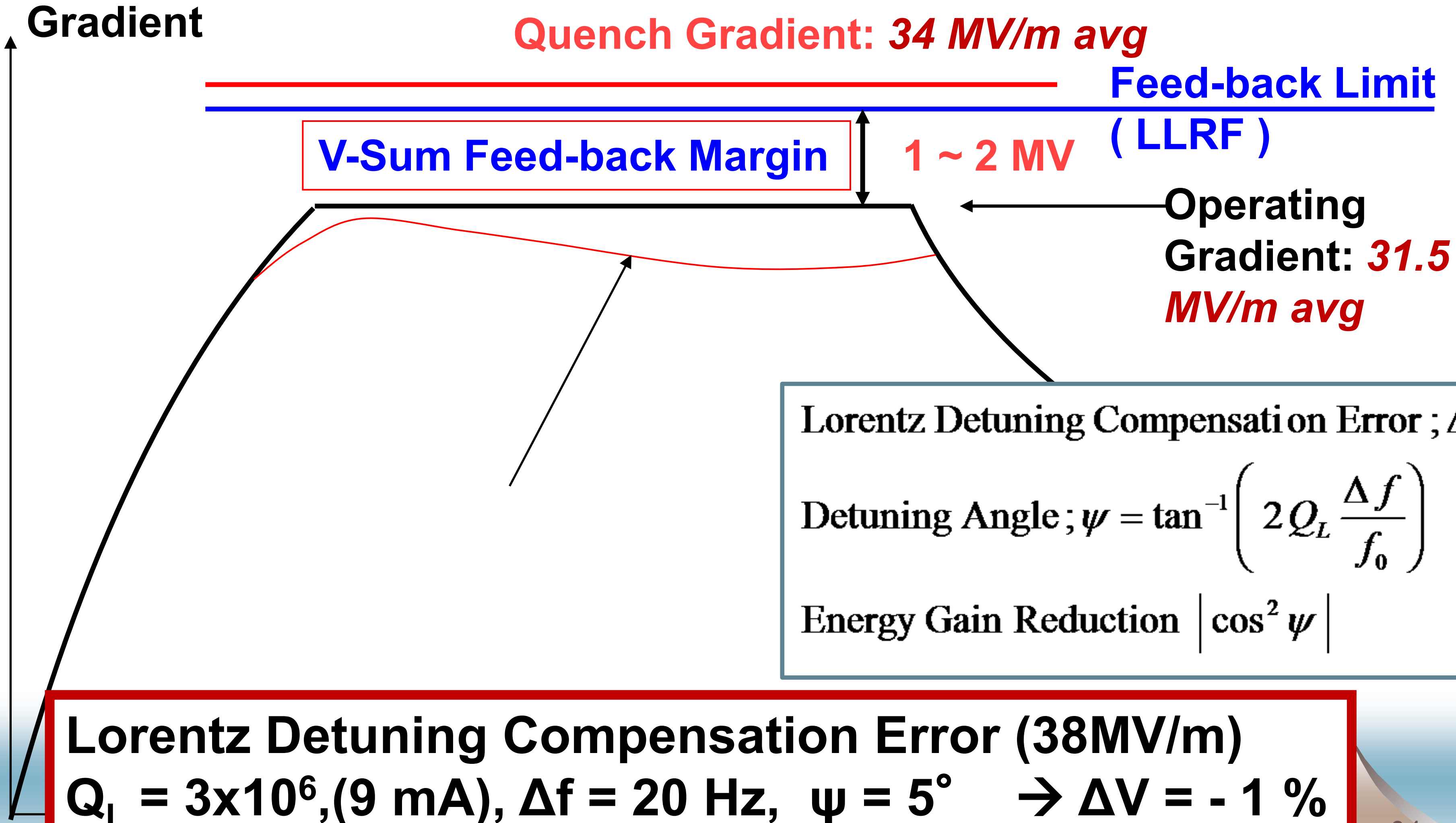
# Comparison of cavity performance



ave. Eacc,max
VT : 30 MV/m
1 cav : 27 MV/m
7 cav : 26 MV/m

D : Detune
C : Coupler

# Highest Gradient Operation



**Gradient**

Quench Gradient: ***34 MV/m avg***

**Feed-back Limit ( LLRF )**

**V-Sum Feed-back Margin**

**1 ~ 2 MV**

**Operating Gradient: *31.5 MV/m avg***

Lorentz Detuning Compensation Error ; $\Delta f$

Detuning Angle ; $\psi = \tan^{-1}\left( 2 Q_L \dfrac{\Delta f}{f_0} \right)$

Energy Gain Reduction $\left| \cos^2 \psi \right|$

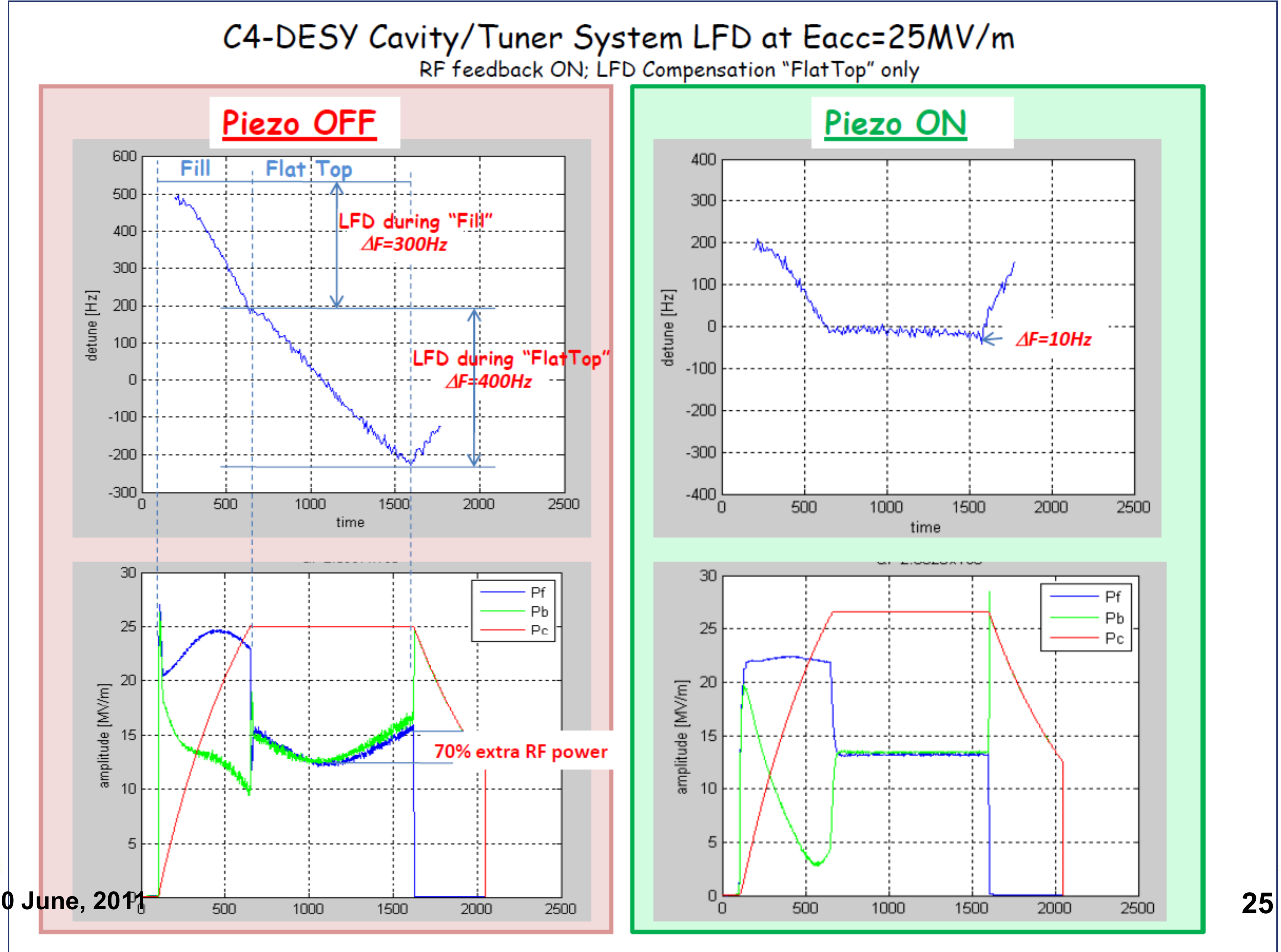
**Lorentz Detuning Compensation Error (38MV/m)**

**$Q_L$ = 3x$10^6$,(9 mA), Δf = 20 Hz, ψ = 5° → ΔV = - 1 %**

**$Q_L$ = 7x$10^6$,(5 mA), Δf = 20 Hz, ψ = 12° → ΔV = - 4 %**

# FNAL Piezo Control System

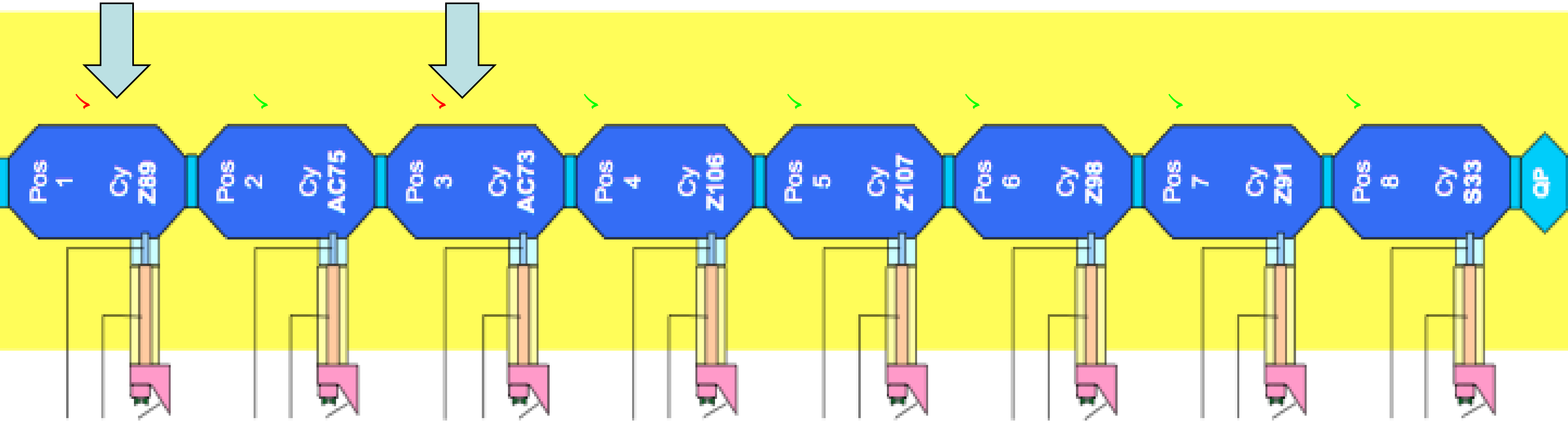
*Warren Schappert and Yuriy Pischalnikov (FNAL)*



C4-DESY Cavity/Tuner System LFD at Eacc=25MV/m

RF feedback ON; LFD Compensation "FlatTop" only

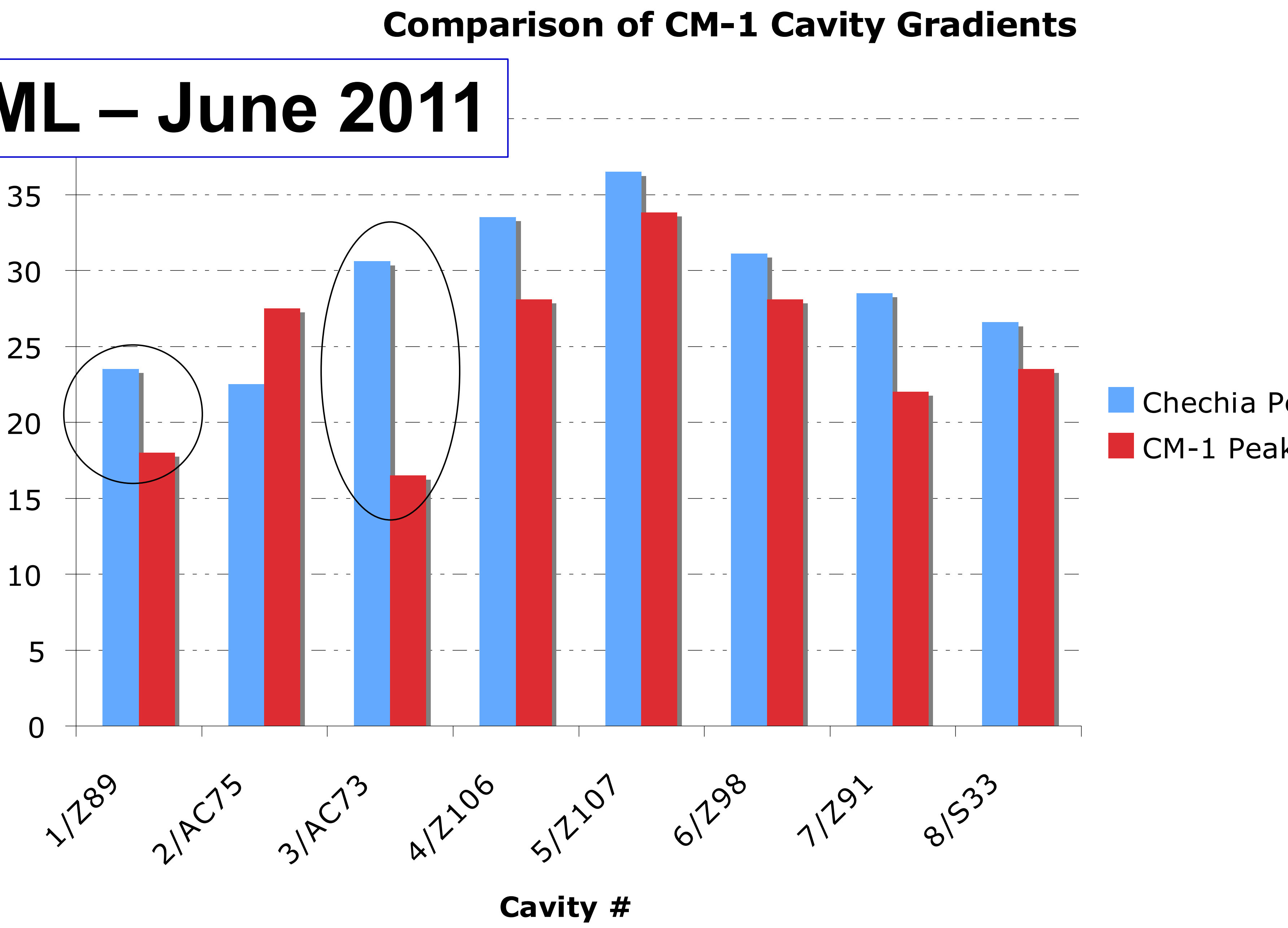
# NML – CM1



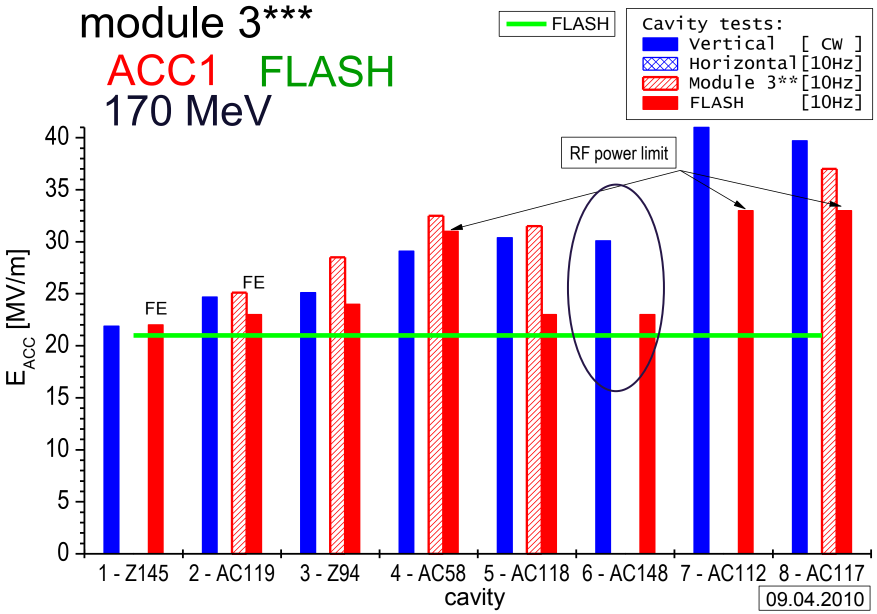
- ***All cavities individually evaluated (June 2011)***
- ***Elvin Harms, AD***

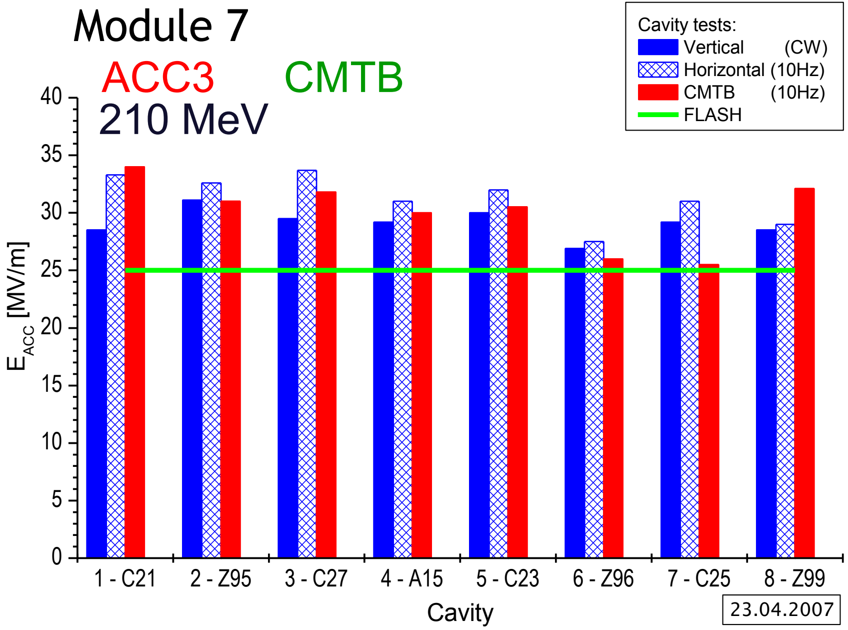
- **Cavity 1 and 3 operation may be limited by field emission**
- **But → expected strong radiation is *not* observed …**
- **May be below ~100 KV or well collimated**

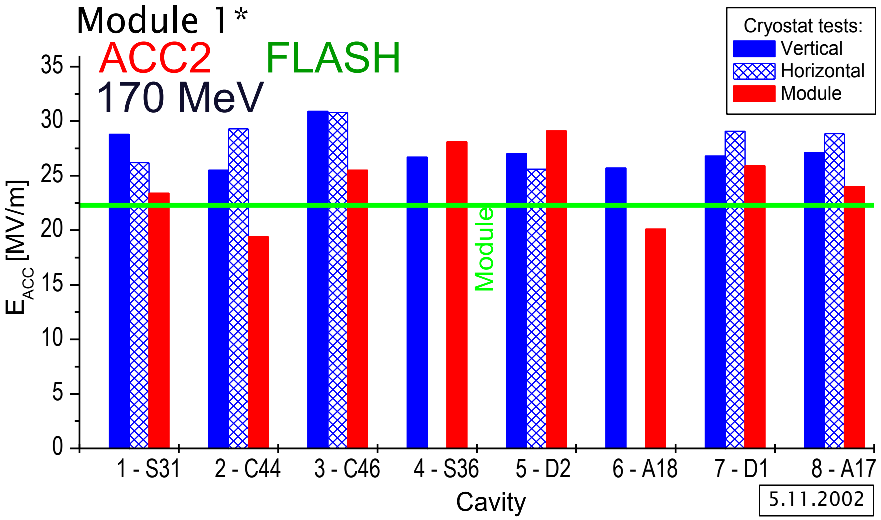
# NML – June 2011



# Modules @ FLASH LINAC (1)



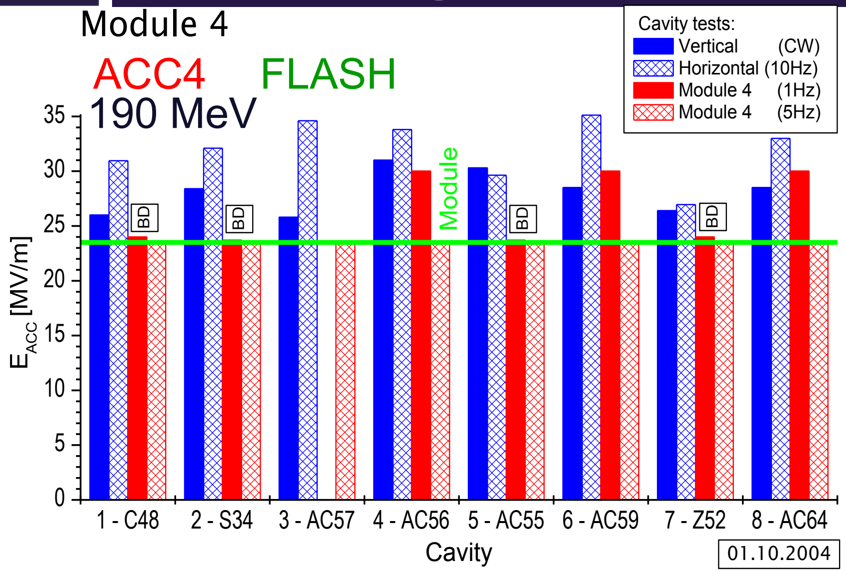


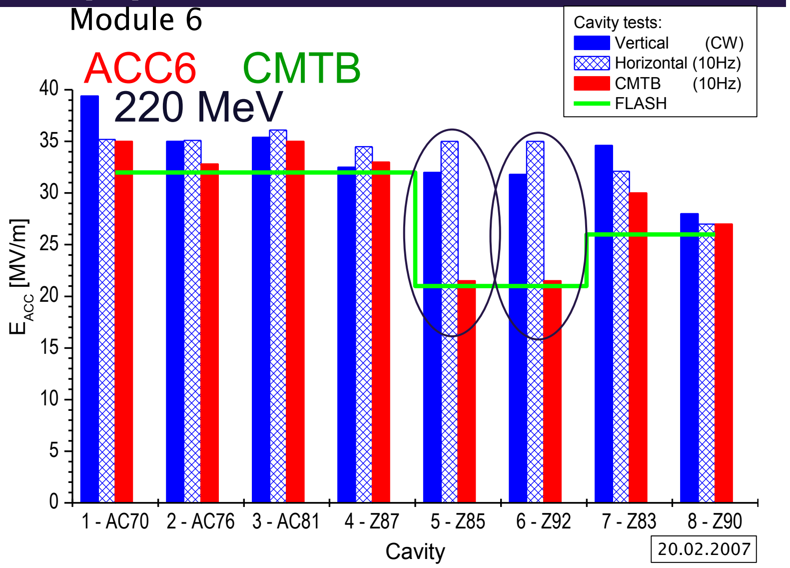


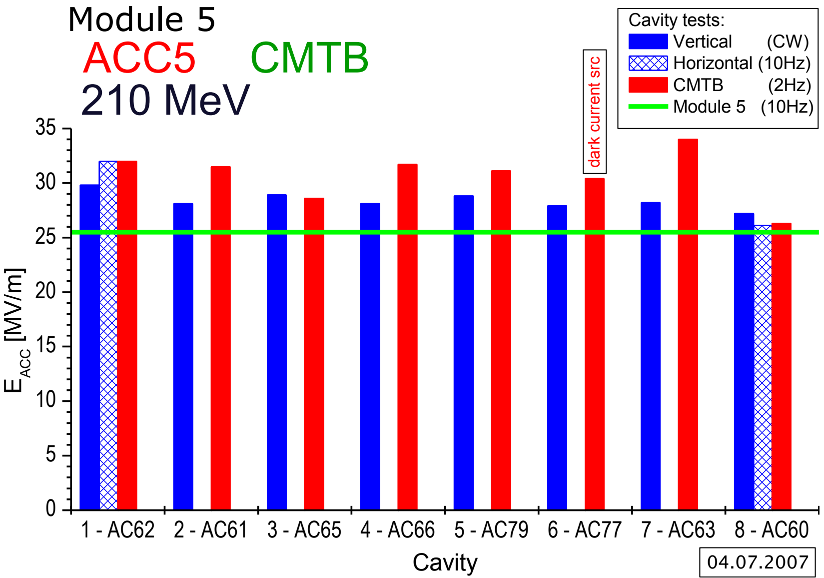
7 Modules are used now at FLASH LINAC at DESY. 3 modules were tested at FLASH and 4 modules were tested at CMTB facility.

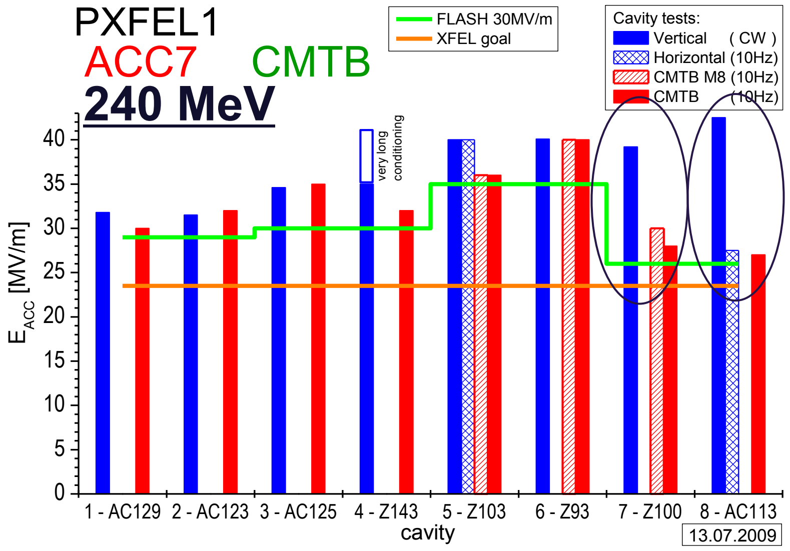
# ILC – 261.5 MeV / CM

# Modules @ FLASH LINAC (2)

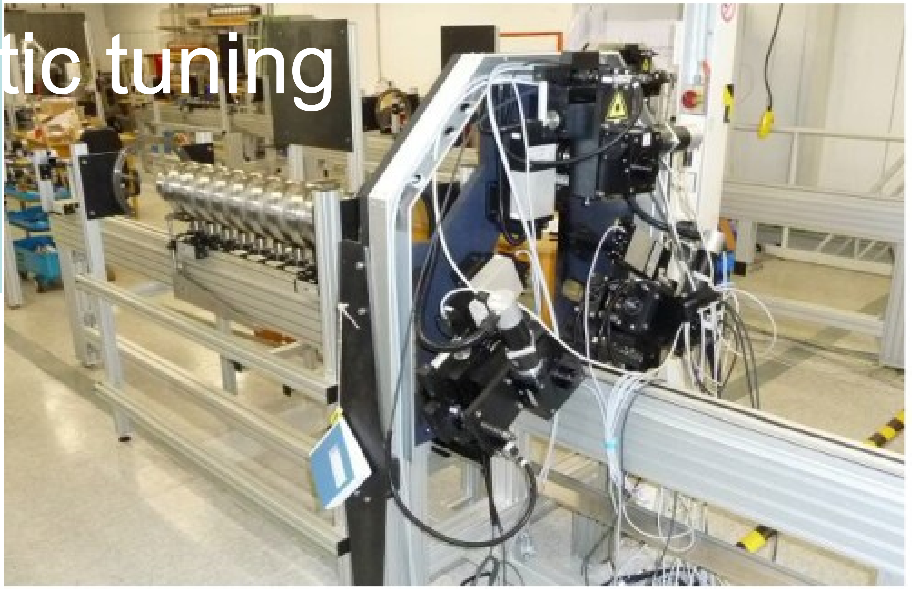


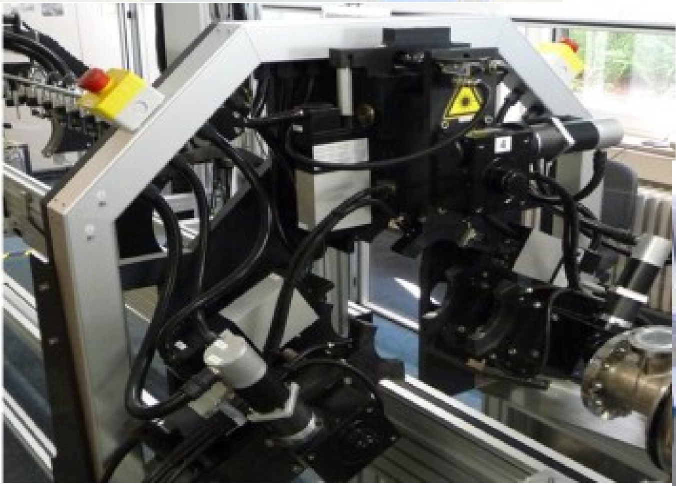






# Fermilab/DESY Automatic tuning machine





# ILC TDP: (1.3)

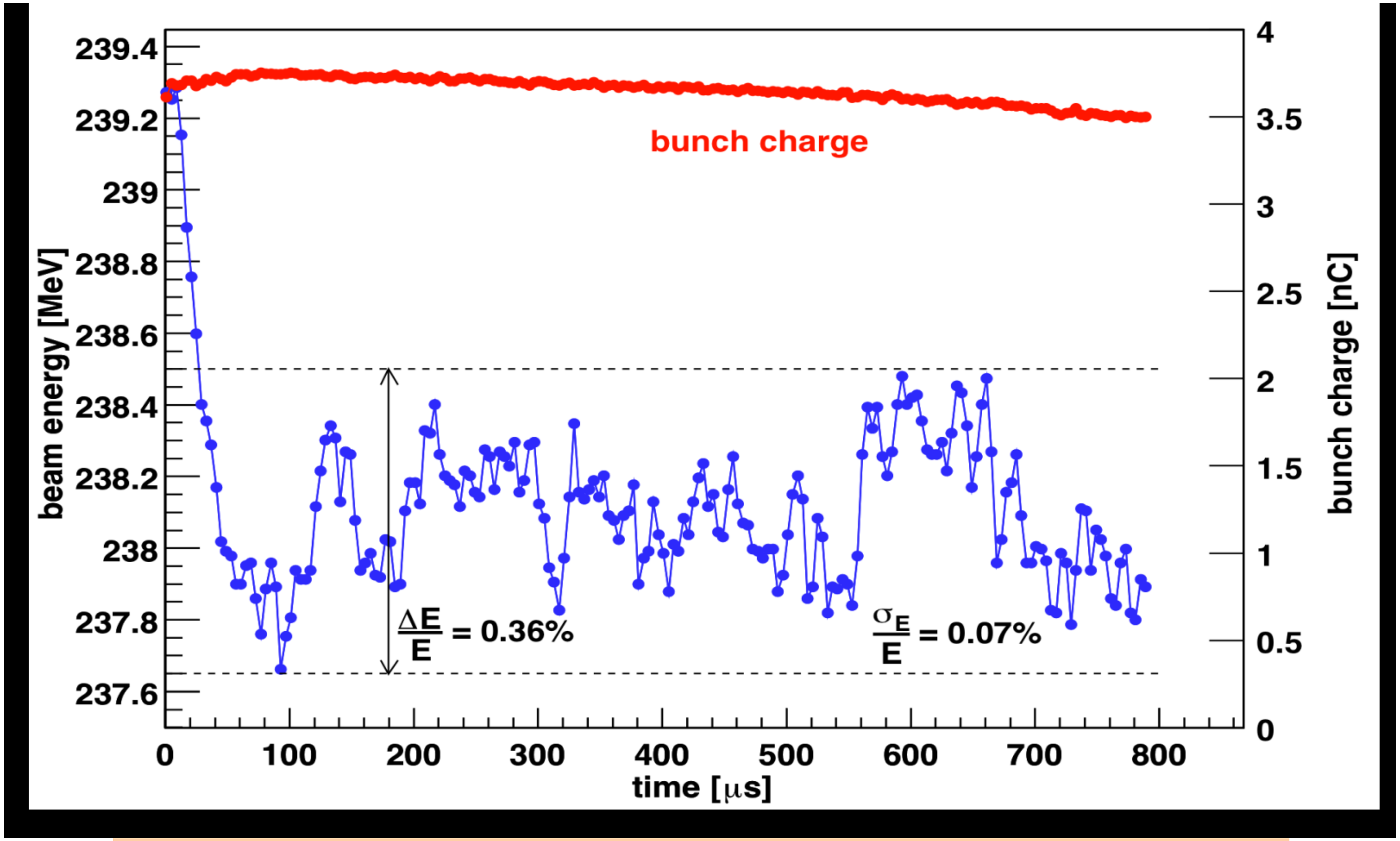
- **SRF R & D:**
  - SC Linac w/Beam: FLASH (DESY)
  - Feedback and Overhead:
    - mid-2010 performance jump (3.9 / beam-based feedback)
  - High current modeling and optimization
  - Post 2012
- **SRF Mass Production and Cost**
- **Beam Test Facilities**
- **Siting the ILC**
- **Path to the Energy Frontier**

# SRF test linac objectives

- ***Demonstration of:***
  - *accelerating gradient*
- ***With specified:***
  - *Beam phase and energy stability at full current; with gradient spread*
  - *Gradient and RF power overhead*
- **to establish technology for:**
  - controlling beam loading effects
  - Lorentz – Force detuning compensation
  - *in both static and dynamic conditions*

# Feasibility demonstation at TTF (8mA, 800us)

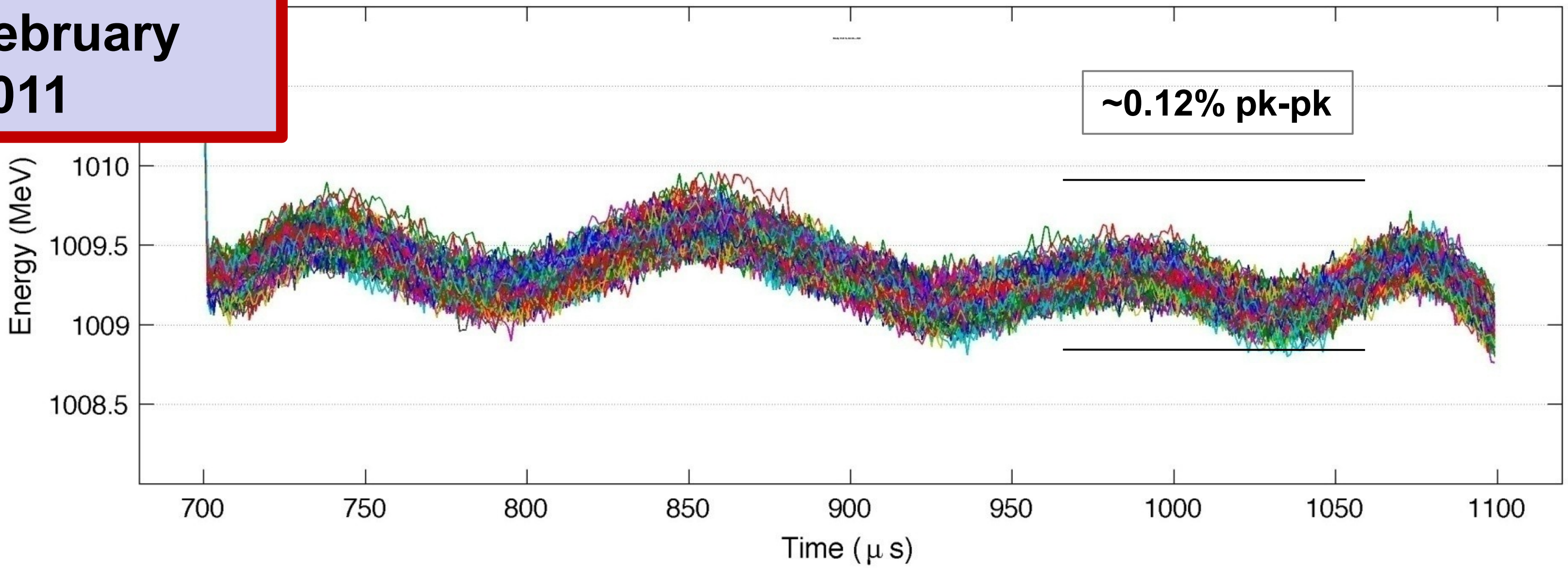
***From ICFA Beam Dynamics Newsletter #24, April 2001***



- 2 cryomodules, 8+8 cavities, single klystron
- 238MeV final beam energy
- 3.5nC/bunch 1800 bunches @ 2.25MHz

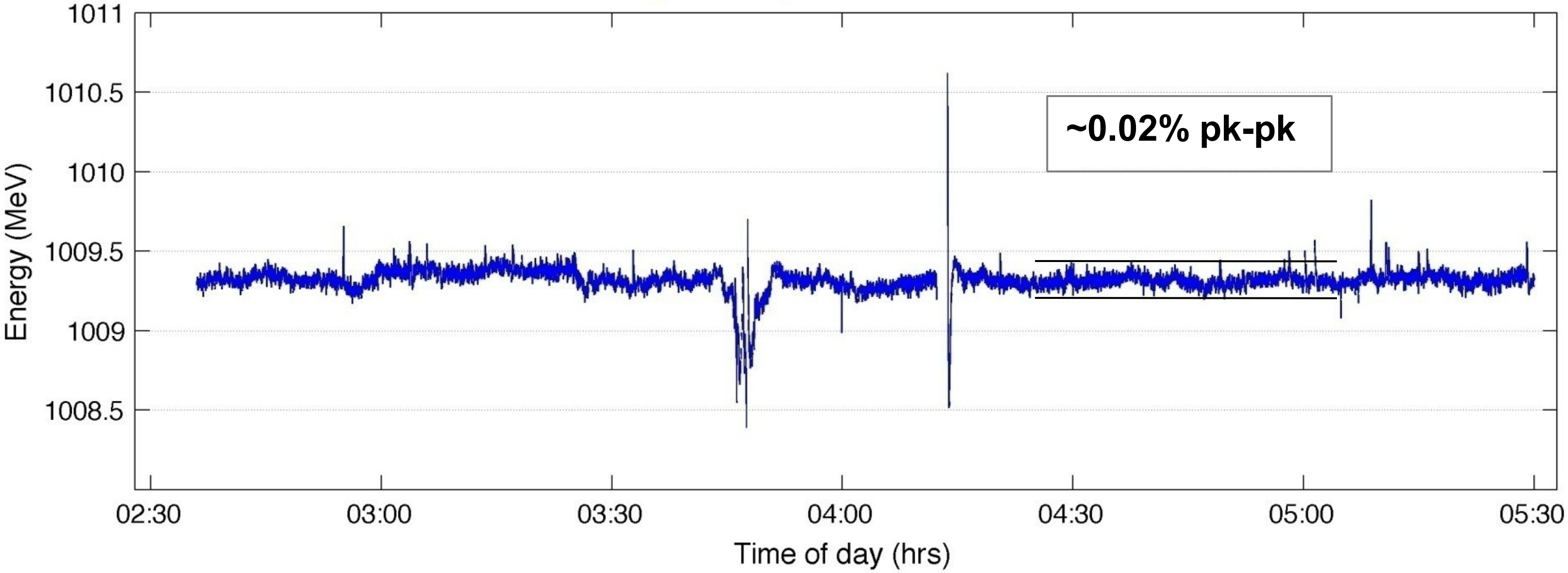
**FLASH: February 2011**

Energy stability over a 400µ s bunch-train with 4.5mA



~0.12% pk-pk

Energy stability over 3hrs with 4.5mA

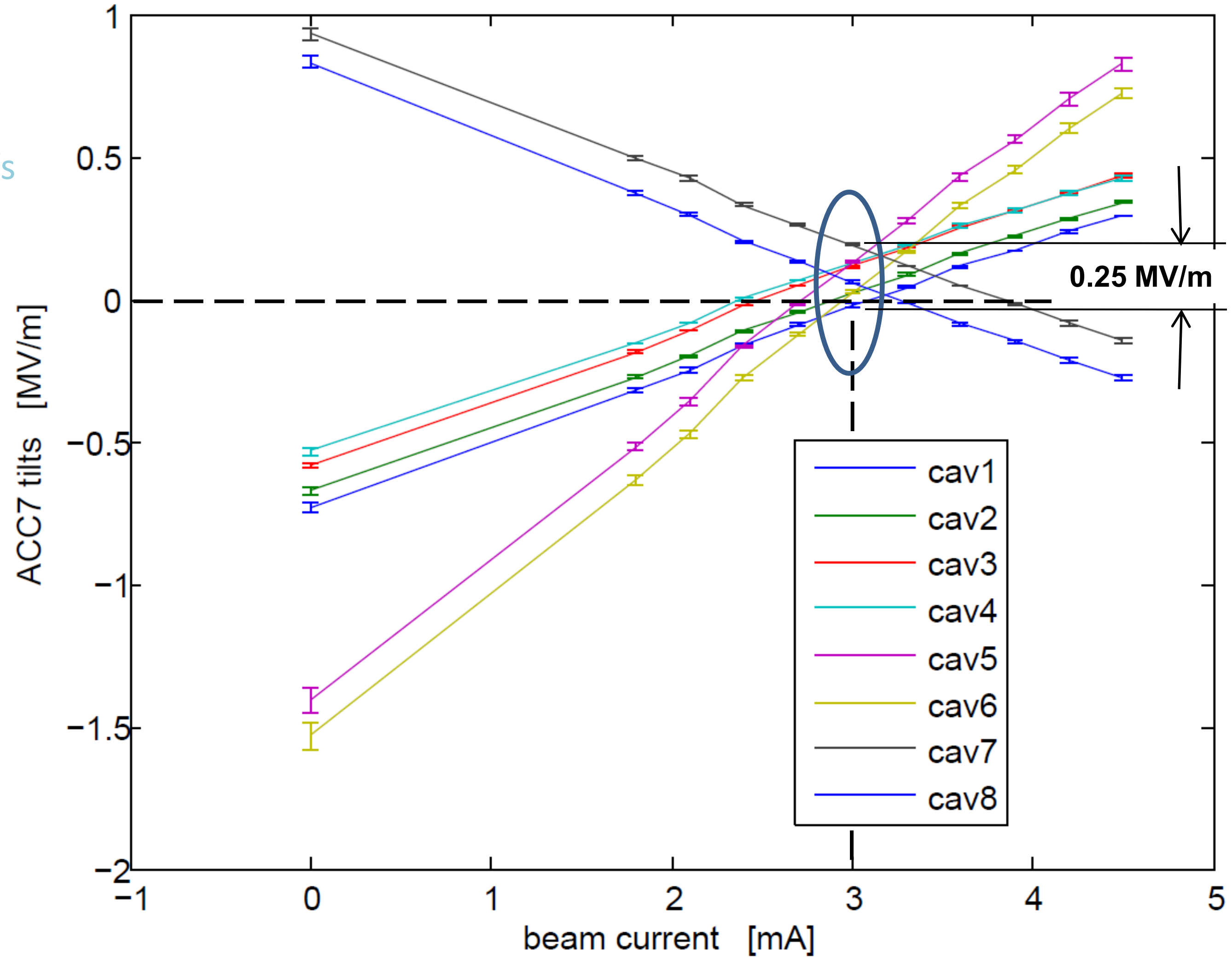


~0.02% pk-pk

# Assessing the accuracy of the model

- $Q_L$ scan
  → Keep beam current constant but walk $Q_L$'s around optimized value

- $I_B$ scan
  → Keep optimized $Q_L$'s but ramp beam up/down



**(Tilt: gradient change during 400 us beam pulse )**

# Achievements: SRF Linac – FLASH (DESY)

***High beam power and long bunch-trains*** *(Sept 2009)*

| Metric | ILC Goal | Achieved |
|---|---|---|
| • **Macro-pulse current** | 9mA | 9mA |
| • **Bunches per pulse** | 2400 x 3nC (3MHz) | 1800 x 3nC<br>2400 x 2nC |
| • **Cavities operating at high gradients, close to quench** | 31.5MV/m +/-20% | 4 cavities > 30MV/m |

***Gradient operating margins*** *(Feb 2011)*

| Metric | ILC Goal | Achieved |
|---|---|---|
| • **Cavity gradient flatness (all cavities in vector sum)** | 2% ΔV/V (800μs, 9mA) | 2.5% ΔV/V (400μs, 4.5mA)<br>*“Methodology established”* |
| • **Gradient operating margin** | All cavities operating within 3% of quench limits | *(Focus of early 2012 run)* |
| • **Energy Stability** | 0.1% at 250GeV | <0.15% p-p (0.4ms)<br><0.02% rms (5Hz) |

# ILC TDP: (2.1)

- SRF R & D
- **SRF Mass Production and Cost**
  - **Global cavity fabrication** model
    - Tie to ILC Project Governance
  - TESLA industrial studies (~10 years old)
  - Breakthrough welding costs → ‘*Pilot Plant*’
  - *Commercializing SRF*
- **Beam Test Facilities**
- **Siting the ILC**
- **Path to the Energy Frontier**

# Mass Production of SRF

**2005:**

- **RDR cost based on central control**
  - DESY-led industrial studies
  - Modeled after LHC
- **Large process improvements assumed**
  - But - only 1 ½ qualified cavity vendors in 2005

**2011:**

- **Independent markets developing**
  - Expect ~10 qualified cavity vendors ←
- **Joint workshops: 2010, 2011**

# European cost / mass production evaluation by Industrial Studies, cont.

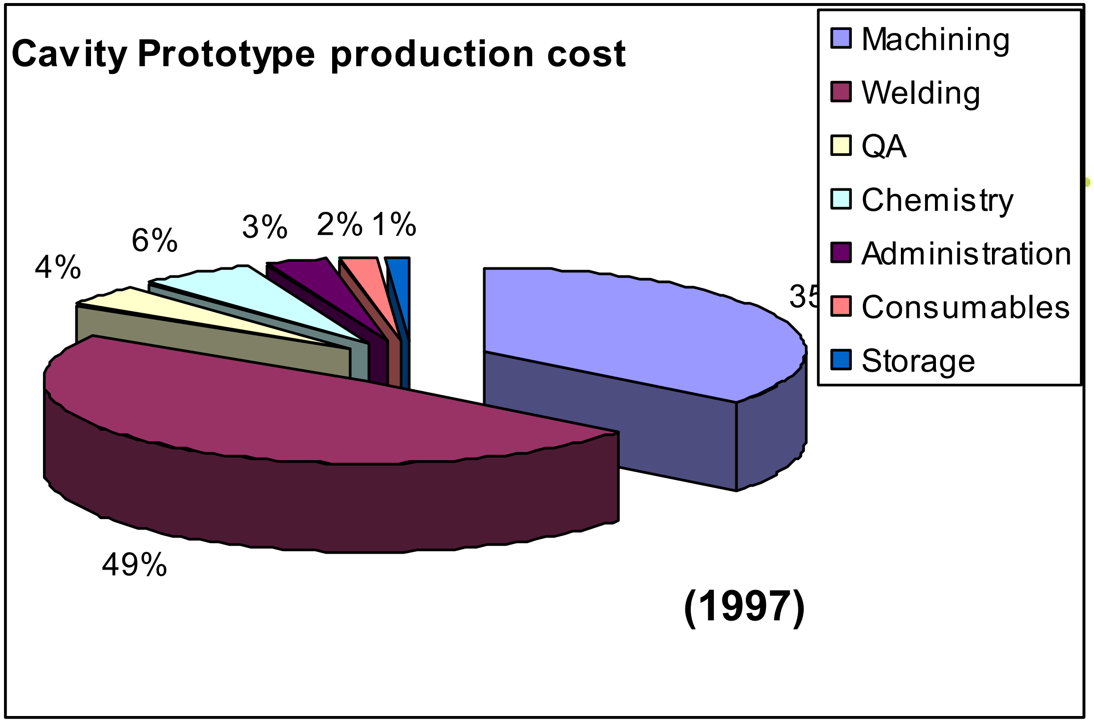
- **Complete planning of new "core tech" factory**
  - Determine costs for buildings, investment, man power, ramp up & production & ramp down, overhead, consumables, QC,…
  - Get bits for outsourced parts
  - Sum up total cost of component fabrication

- **NO** learning curve assumed (e.g. -10% for doubling the production)
- But assumption: stable production after about 50 cavities, couplers,…
  - **Is verified e.g. by LHC magnet production: assembly time reached stable (and predicted) level after about 40 magnets**

- **This cost model is valid because it was developed by experienced companies. Additional studies would require time, money and competent industry.**

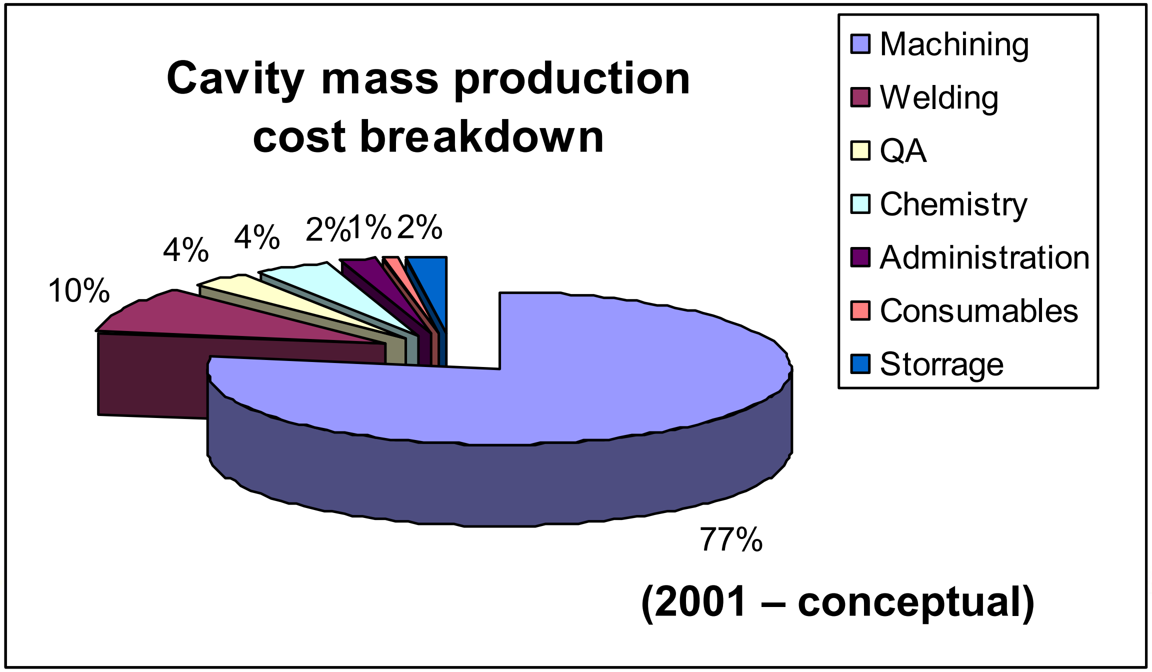
**D.Proch, LCWS 2007**

# Cavity fab cost breakdown


Cavity Prototype production cost

(1997)

**EBW process development: tooling, multi-chamber machines**

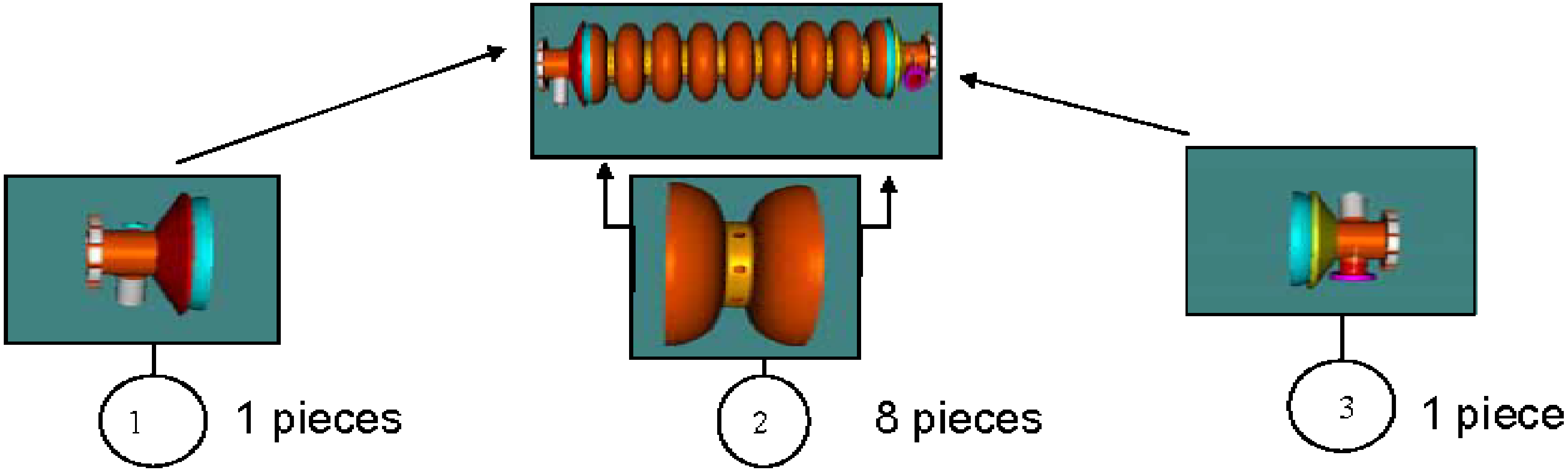

Cavity mass production cost breakdown

(2001 – conceptual)

***Machining to be outsourced*** →

D.Proch, LCWS 2007

# Cavity welding: the general way
# There are differences of welding processes in industry



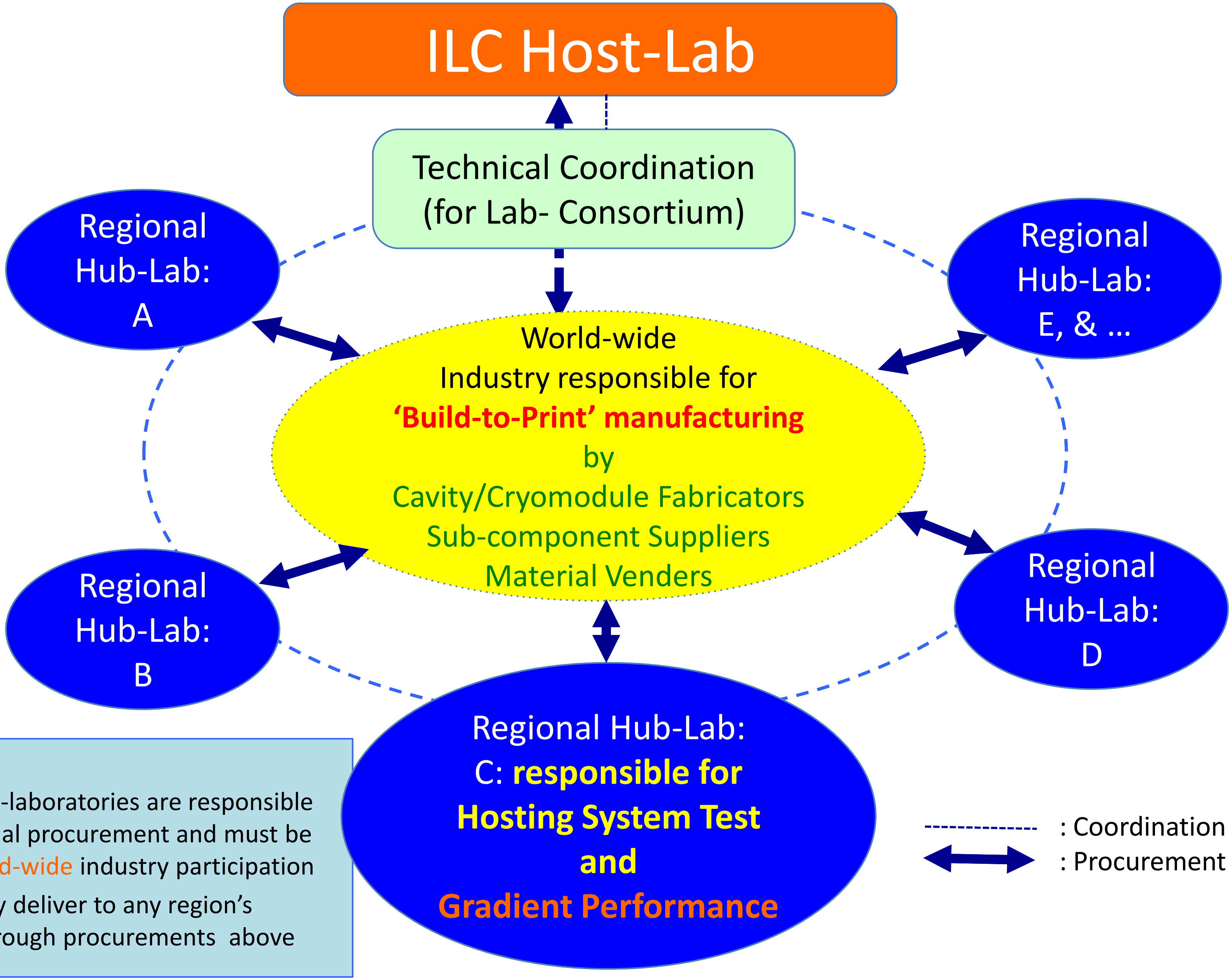
1. Degreasing and rinsing of parts
2. Drying under clean condition
3. Chemical etching at the welding area ( Equator)
4. Careful and intensive rinsing with ultra pure water
5. Dry under clean conditions
6. Install parts to fixture under clean conditions
7. Install parts into electron beam (eb) welding chamber ( no contamination on the weld area allowed)
8. Pump down to vacuum in the EBW chamber E$^{-5}$ mbar
9. Welding and cool down of Nb to T< 150° C, venting
10. Leak check of weld

# Conclusion: What can we learn from LHC magnet production for XFEL / ILC planning

- SC magnet and cavity fabrication is not (yet) of the shelf technology
  - Very tight supervision of companies is recommended
  - XFEL production will improve the situation, but can companies preserve this expertise until ILC construction?
- Cryostat assembly time (=cost) levels around 50 units
- QA on some components for ILC (e.g. Nb sheet scanning) might require automatic chains
- A pre-series production (after proto-typing) will establish the required expertise at companies for realistic bidding without too high risk margin.
  - A cooperative spirit should be established between scientific laboratories and production companies in early time

e-beam welder at KEK → 'Pilot Plant'

# A Possible ILC-SCRF Industrialization Model



ILC Host-Lab

Technical Coordination
(for Lab- Consortium)

Regional
Hub-Lab:
A

Regional
Hub-Lab:
E, & …

World-wide
Industry responsible for
**'Build-to-Print' manufacturing**
by
Cavity/Cryomodule Fabricators
Sub-component Suppliers
Material Venders

Regional
Hub-Lab:
B

Regional
Hub-Lab:
D

Regional Hub-Lab:
C: **responsible for**
**Hosting System Test**
**and**
**Gradient Performance**

Note 1:

-Regional hub-laboratories are responsible for any regional procurement and must be open for world-wide industry participation

- Industry may deliver to any region's laboratory through procurements above

------------ : Coordination link
⟷ : Procurement link

# SRF Technology Cost – 2011:

- **semi-finished material : fabrication : surface etch & rinse**
  - Roughly equal contribution → **1/3**:1/3:1/3
- **ITRP (2004): S**uperconducting technology:
  - “The construction of the superconducting *XFEL free electron laser* will provide prototypes and test many aspects of the linac.
  - The *industrialization* of most major components of the linac is underway.
  - …. “

# ILC TDP: (2.2)

- SRF R & D
- **SRF Mass Production and Cost**
  - **Pure Niobium** semi-finished material
  - $ and chemistry
  - Capacity and Constraints
  - Vendor seminar
- **Beam Test Facilities**
- **Siting the ILC**
- **Path to the Energy Frontier**

# Material – ATR Nb from mine (BR)

- **Is raw niobium a cost driver?**

1

  - mixed oxides tantalum $Ta_2O_5$ and niobium $Nb_2O_5$
  - $Ta_2O_5 + 14\ HF \rightarrow 2\ H_2[TaF_7] + 5\ H_2O$
  - $Nb_2O_5 + 10\ HF \rightarrow 2\ H_2[NbOF_5] + 3\ H_2O$

2

  - liquid extraction of the fluorides from aqueous solution by organic solvents like cyclohexanone
  - or precipitated with ammonia as the pentoxide

3

  - process involving the AluminoThermic Reaction (ATR) a mixture of iron oxide and niobium oxide is reacted with aluminium:
  - $3\ Nb_2O_5 + Fe_2O_3 + 12\ Al \rightarrow 6\ Nb + 2\ Fe + 6\ Al_2O_3$

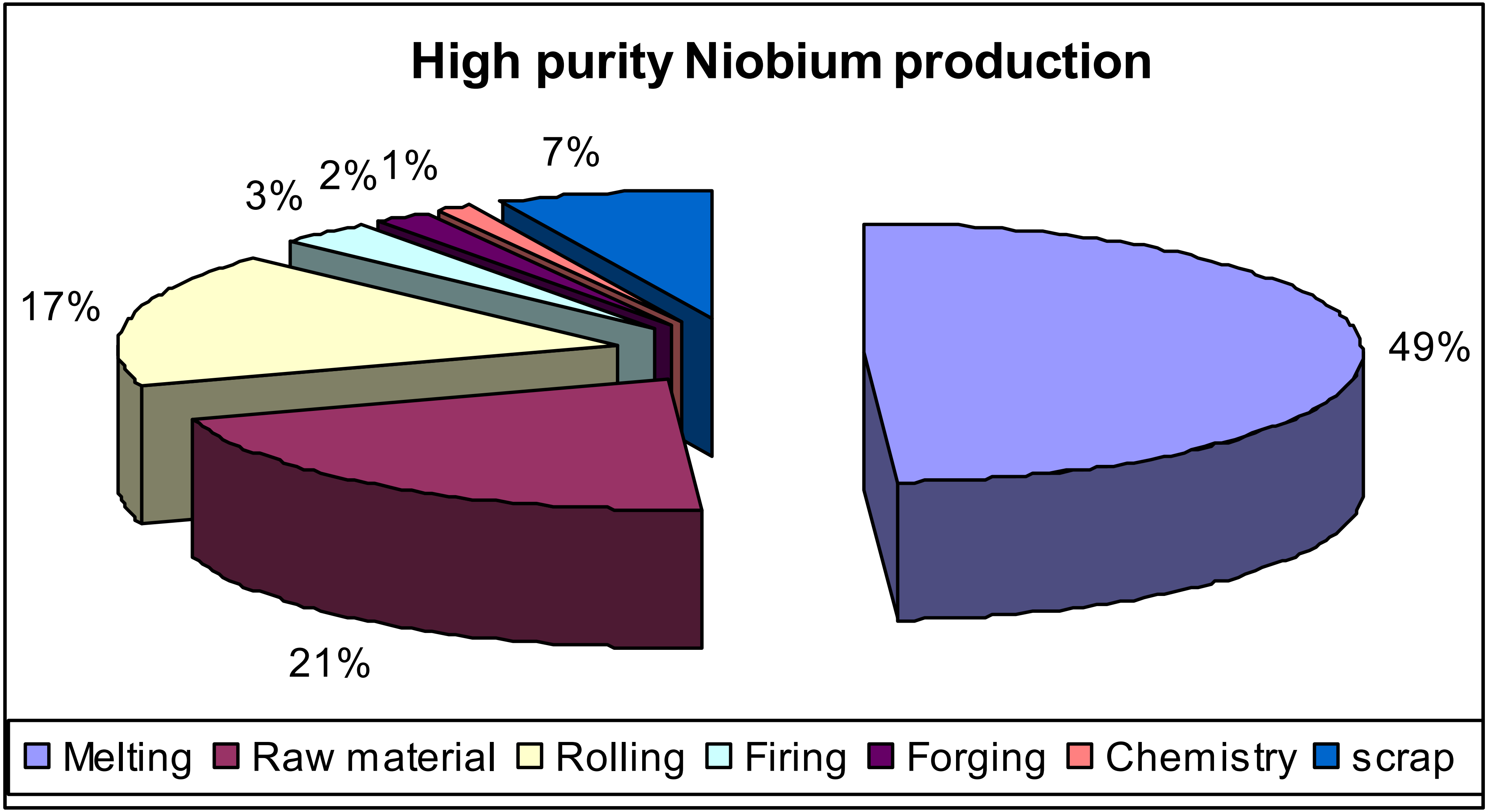
- **(Wikipedia)**

# Comments to mass production / cost evaluation of high purity Niobium

- **Nb Material (high purity, RRR 300)**
  - No shortage of raw Nb material (40.000 tons annual production, ILC needs around 500 tons)
  - But limited number of high purity melting facilities
    - Today (2007) there are 4 qualified companies, but only one is capable of producing full yield for ILC
  - Marginal savings in mass production (from industrial study)
    - Size of melting furnace is limited
    - But some saving can be realized by
      - Disc rather than rectangular sheet (scrap can be recovered)
      - Other material produced ready for fabrication, e.g. flange material
    - **Latest developments in large/single crystal cavities promise cost reductions, needs more experience / studies**

8 kWh/kg/melt (mcr)

D.Proch, LCWS 2007



**TESLA 2001-27 Kouptsidis (German)**

# Niobium Production at CBMM

- Niobium Ore in Araxa mine (open air pit) is pyrochlor with 2.5% $Nb_2O_5$
- The ore is crushed and magnetite is magnetically separated from the pyrochlor.
- By chemical processes the ore is concentrated in Nb contents (50 –60 % of $Nb_2O_5$)
- A mixture of $Nb_2O_5$ and aluminum powder is being reacted to reduce the oxide to Nb
- This Nb is the feedstock for the EBM processes

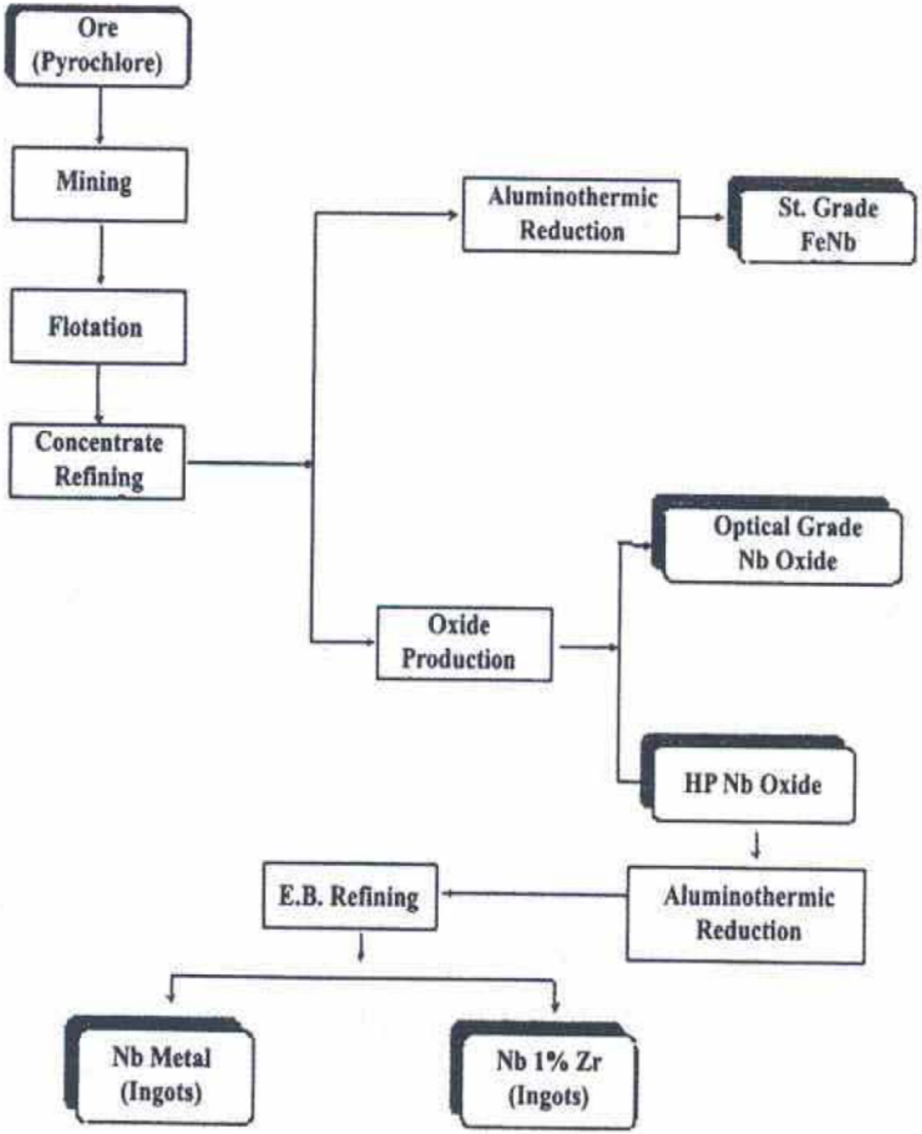
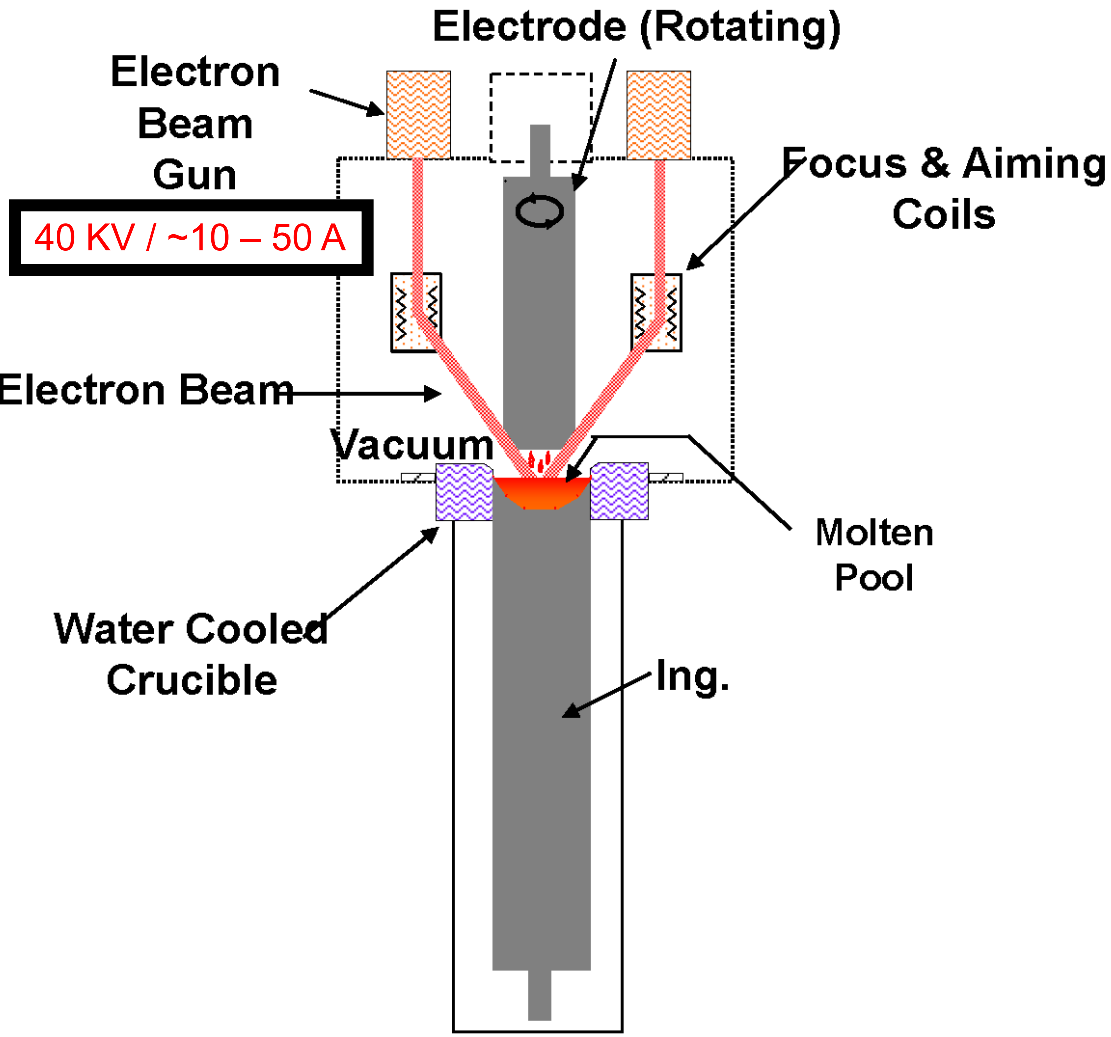


Fig. 3: Production flow chart at CBMM.

500KW electron beam cold hearth furnace

# Electron Beam Melting



Electron beam melting of Nb

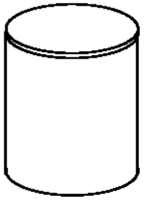
During of the ingot melts, molten metal globules fall into a pool on the ingot which is contained in a water cooled copper cylinder (sleeve). Impurities are evaporated and pumped away. Power impact is maintained to keep the pool molten out to within a few mm of the crucible wall. During melting the ingot formed is continuously withdrawn through the sleeve. The rate of withdrawal has to be carefully coordinated with the rate of the material to insure complete melting of the feed material and proper outgassing.

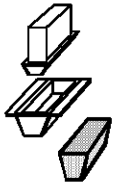
# Electron Beam Melting

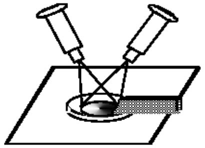
As a result of the increasing demand for refractory metals in the last few decades, the electron-beam furnace has been developed to a reliable, efficient apparatus for melting and purification.

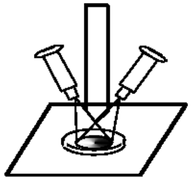
# Fabrication of Nb sheets at Tokyo Denkai

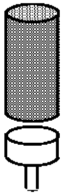
**60% yield?**

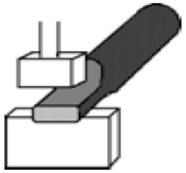

Mother material

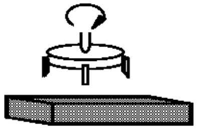

Pressing

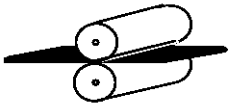

1st EB melting

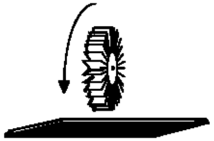

2nd, 3rd etc EB melting

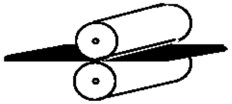

Separate from base plate

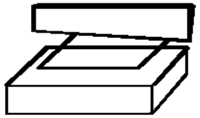

Forging

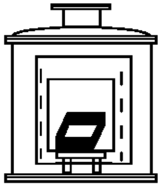

Milling


Rolling


Polishing

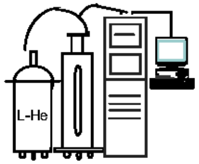

Rolling


Cutting


Annealing


Levering


Chemical polishing

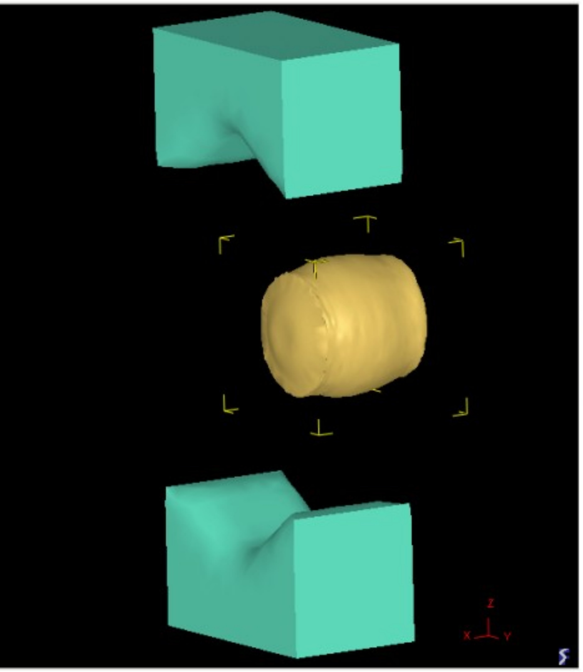


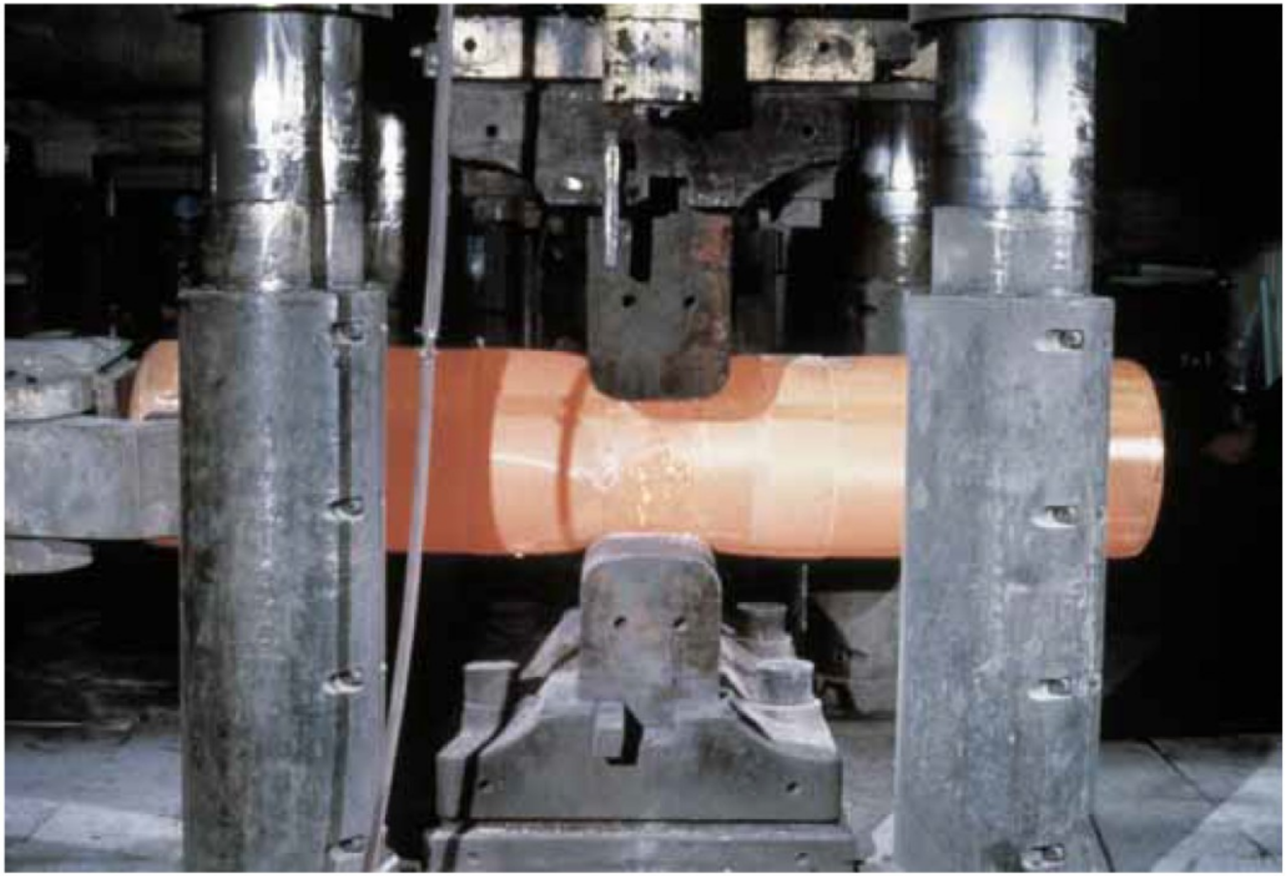
Inspection

ICP-AES
Gas Analysis
RRR
Grain size
Hardness
Tensile tests

In the final sheet the purity of niobium should be not inferior as in the ingot

# Forging





2000 ton open die forge
(Wah Chang )

# Rolling

700 mm wide cold rolling mill (Wah Chang)

800 mm wide
hot rolling mill
(Wah Chang)

Hot rolling, used mainly to produce sheet metal is when industrial metal is passed or deformed between a set of work rolls and the temperature of the metal is generally above its recrystallization temperature.

Cold rolling takes place below recrystallization temperature.

# Updated Plan for Visiting Vendor

| | Date | Company | Place | Technical sbject |
|---|---|---|---|---|
| 1 | 2/8 | Hitachi | Tokyo (JP) | Cavity & Cryomodule |
| 2 | 2/8 | Toshiba | Yokohana (JP) | Cavity & Cryomodule |
| 3 | 2/9 | MHI | Kobe (JP) | Cavity & Cryomodule |
| 4 | 2/9 | Tokyo Denkai | Tokyo (JP) | Nb, NbTi Material |
| 5 | 2/18 | OTIC | NingXia (CN) | Nb, NbTi, Ti Material |
| 6 | 3/3 | Zanon | INFN, Milano (IT) | Cavity & Cryomodule |
| 7 | 3/4 | RI | Koeln (DE) | Cavity & Cryomodule |
| 12 | 4/27 | Plansee | Ruette (AS) | Nb, NB-Ti Material |
| 8 | 3/14, (4/8) | AES | LI, NY (US) | Cavitu & Cryomodule |
| 9 | 3/15, (4/7) | Niowave | Lansing, MI (US) | Cavity & Cryomodule |
| 10 | 4/6 | PAVAC | Vancouver (CA) | Cavity & Cryomodule |
| 11 | 4/25 | ATI Wah-Chang | Albany, OR (US) | Nb, Nb-Ti material |

GDE members: PMs, and RDs / Cost-experts / Experts from Lab (shared regionally)

# Material

- **Niobium:**
  - Has high melting point – 2500 degC
  - Has strong acid resistance → ‘refractory’
  - Is difficult to machine
  - (pure RRR Nb) is ductile and very difficult to grind
  - Has affinity for oxygen
  - Is a daughter metal to Tantalum

- **R & D post 2012**
  - Ta content?

# ILC TDP: (3)

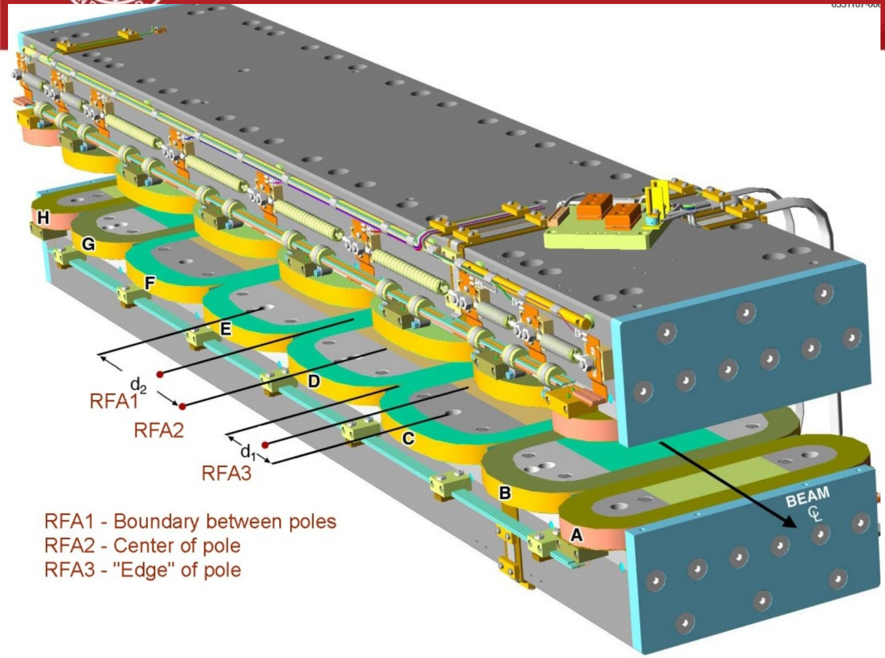
- SRF R & D
- SRF Mass Production and Cost
- **Beam Test Facilities**
  - **CesrTA**: Recommendation delivered 2011
  - ATF2: *Recovery*
    - Nominal intensity / reasonable starting emittance
    - Alignment ongoing
- **Siting the ILC**
- **Path to the Energy Frontier**

# EC Mitigations

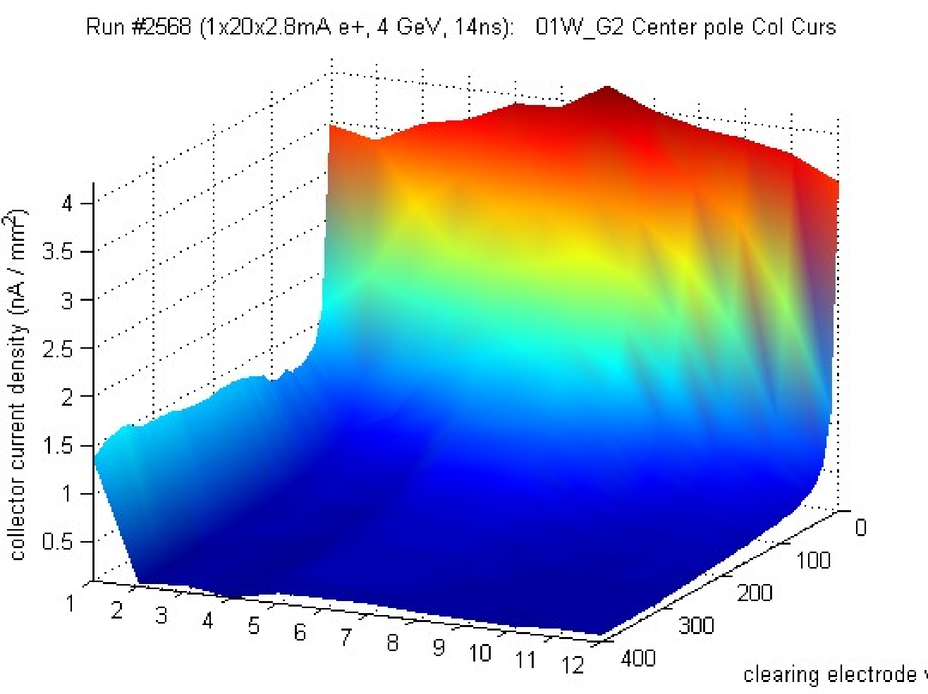
| | Drift | Quad | Dipole | Wiggler | VC Fab |
|---|---|---|---|---|---|
| Al | ✓ | ✓ | ✓ | | CU, SLAC |
| Cu | ✓ | | | ✓ | CU, KEK, LBNL, SLAC |
| TiN on Al | ✓ | ✓ | ✓ | | CU, SLAC |
| TiN on Cu | ✓ | | | ✓, ✗ | CU, KEK, LBNL, SLAC |
| Amorphous C on Al | ✓ | | | | CERN, CU |
| NEG on SS | ✓ | | | | CU |
| Diamond-like C on Al | ✓ | | | | CU, KEK |
| Solenoid Windings | ✓ | | | | CU |
| Fins w/TiN on Al | ✓ | | | | SLAC |
| Triangular Grooves on Cu | | | | ✓ | CU, KEK, LBNL, SLAC |
| Triangular Grooves w/TiN on Al | | | ✓ | | CU, SLAC |
| Triangular Grooves w/TiN on Cu | | | | ✓ | CU, KEK, LBNL, SLAC |
| Clearing Electrode | | | | ✓ | CU, KEK, LBNL, SLAC |

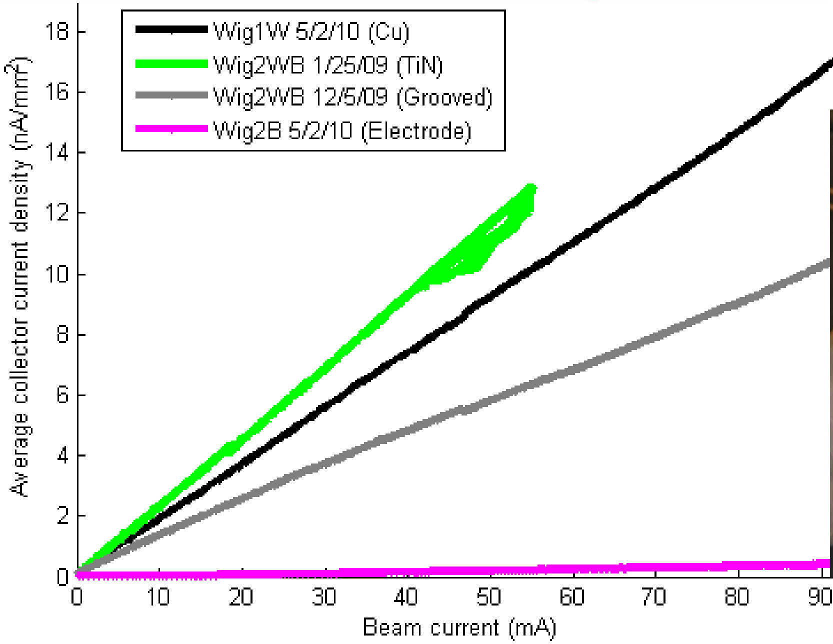
**✓ = chamber(s) deployed ✗ = deployed in CESR Arc, Jan 2011 ✓= installed Jan 2011**

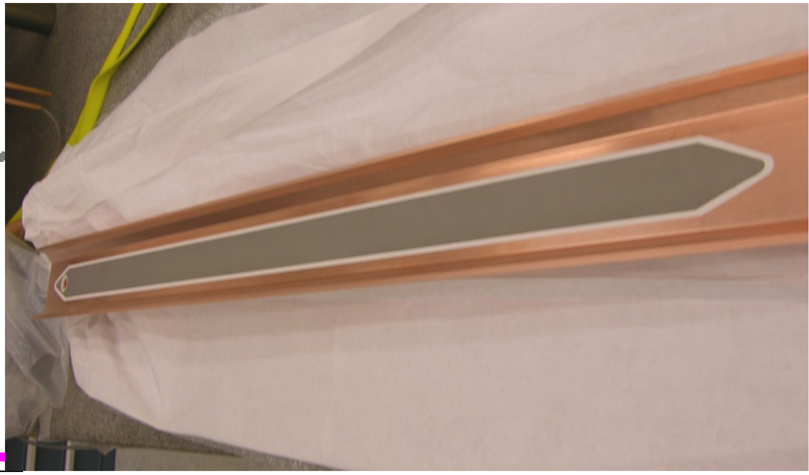
# Wiggler Observations

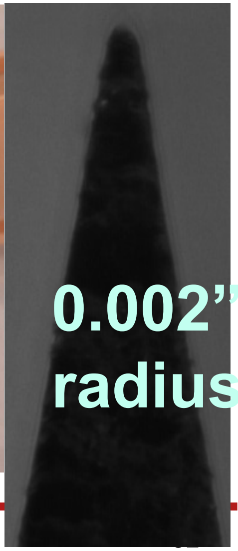


RFA1 - Boundary between poles
RFA2 - Center of pole
RFA3 - "Edge" of pole









# EC Working Group Baseline Mitigation Plan

**Mitigation Evaluation conducted at satellite meeting of ECLOUD`10 (October 13, 2010, Cornell University)**

## *EC Working Group Baseline Mitigation Recommendation*

| | Drift* | Dipole | Wiggler | Quadrupole* |
|---|---|---|---|---|
| **Baseline Mitigation I** | TiN Coating | Grooves with TiN coating | Clearing Electrodes | TiN Coating |
| **Baseline Mitigation II** | Solenoid Windings | Antechamber | Antechamber | |
| **Alternate Mitigation** | NEG Coating | TiN Coating | Grooves with TiN Coating | Clearing Electrodes or Grooves |

***Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers**

- **Preliminary CesrTA results and simulations suggest the presence of *sub-threshold emittance growth***
  - **Further investigation required**
  - **May require reduction in acceptable cloud density ⇨ reduction in safety margin**
- **An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option**

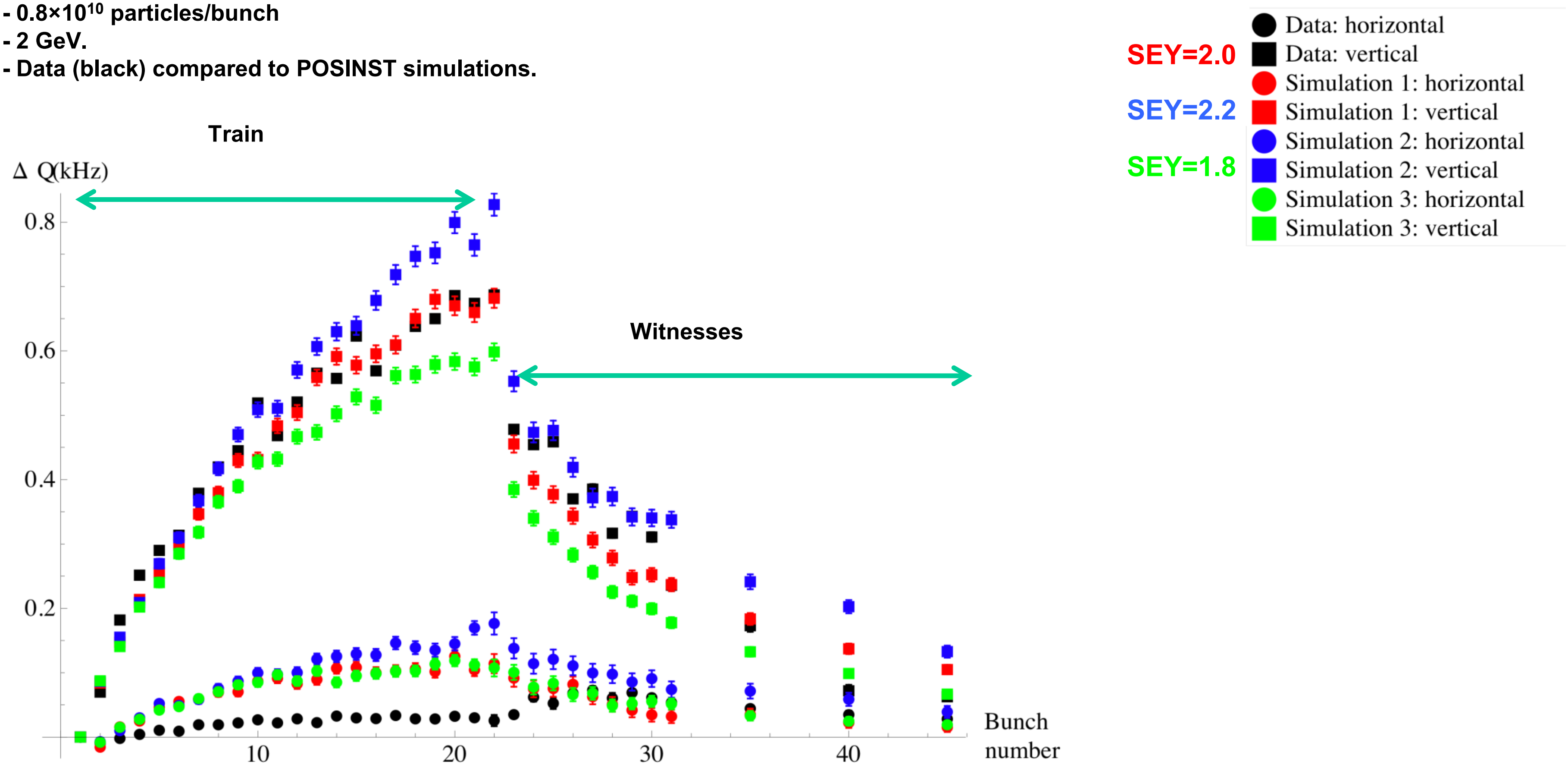
**S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group**

# Example: Positron Witness Bunch Study at 2GeV

## Peak SEY Scan

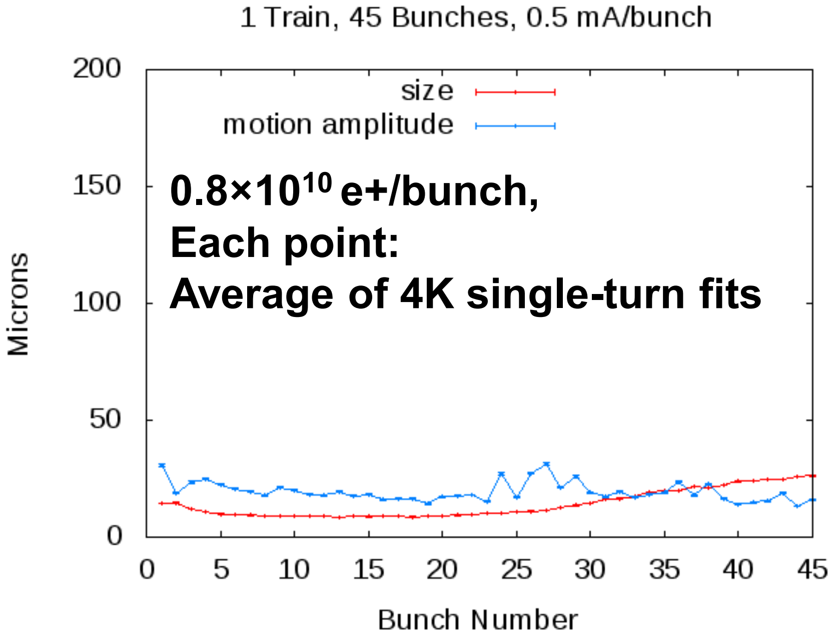
## Coherent Tune Shifts (1 kHz ~ 0.0025), vs. Bunch Number

- 21 bunch train, followed by 12 witness bunches
- $0.8\times10^{10}$ particles/bunch
- 2 GeV.
- Data (black) compared to POSINST simulations.

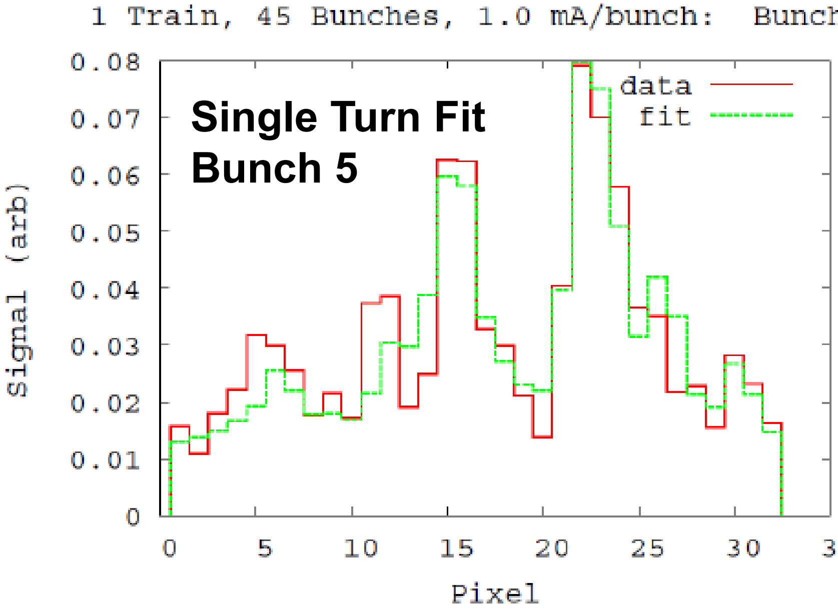


# EC-Induced Emittance Growth

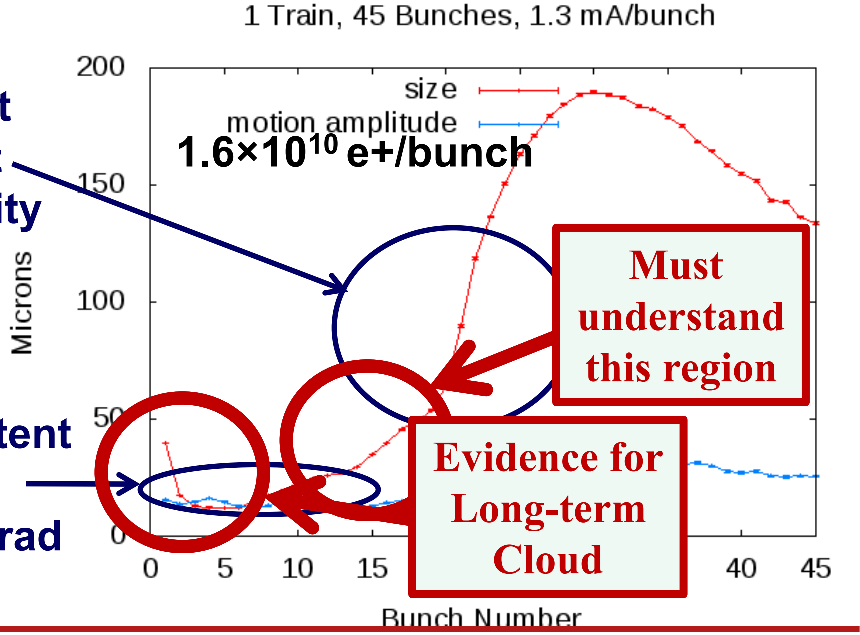
- Measure Bunch-by-Bunch Beam Size
  - Beam size enhanced at head and tail of train
    *Source of blow-up at head appears to be due to a long lifetime component of the cloud.*
    *Bunch lifetime of smallest bunches consistent with observed single bunch lifetimes during LET (Touschek-limited) and with relative bunch sizes.*
  - Beam size measured around bunch 5 corresponds to $\varepsilon_y \sim 20$pm-rad [$\sigma_y = 11.0 \pm 0.2\ \mu$m, $\beta_{source} = 5.8$m]



**$0.8 \times 10^{10}$ e+/bunch,**
**Each point:**
**Average of 4K single-turn fits**



**Single Turn Fit**
**Bunch 5**



**$1.6 \times 10^{10}$ e+/bunch**

**Consistent with onset of instability**

**Consistent with 20 pm-rad**

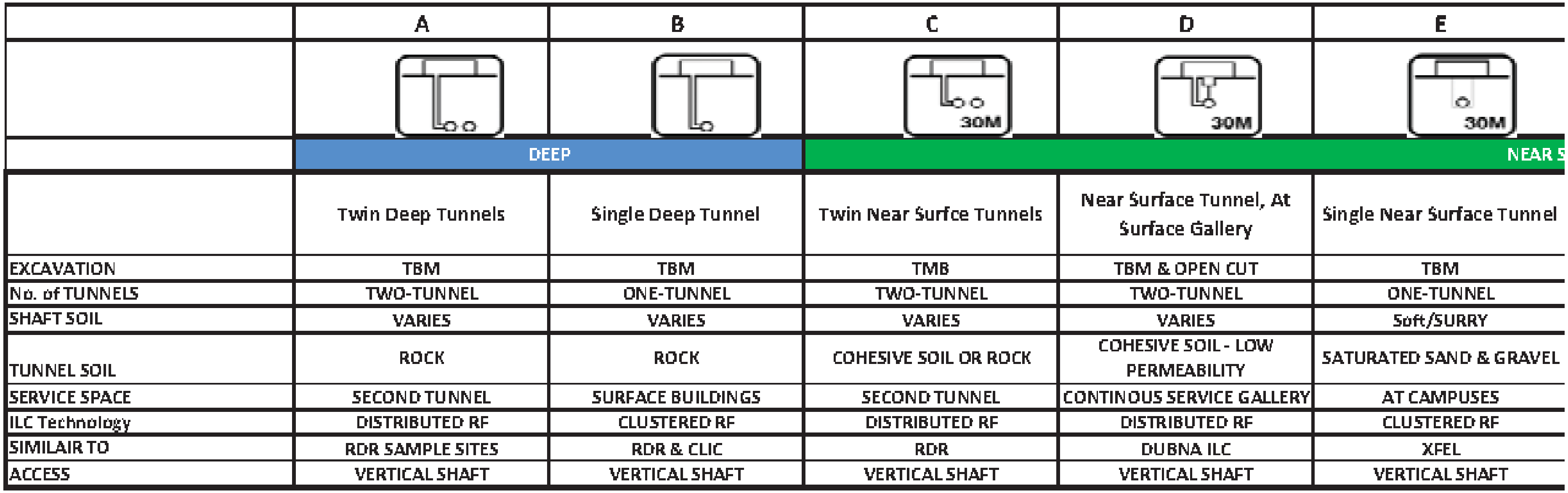
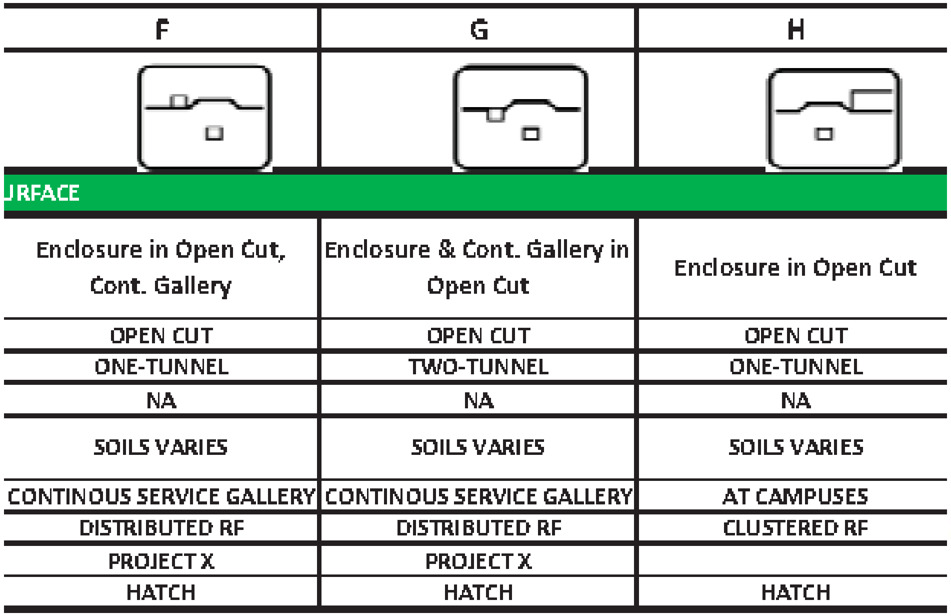
**Must understand this region**

**Evidence for Long-term Cloud**

# ILC TDP (4)

- SRF R & D
- SRF Mass Production and Cost
- Beam Test Facilities
- **Siting the ILC**
  - Jump starting a multi-dimensional process
    - SSC 'Site-Specific' Conceptual Design: 1000 pgs/18 months
  - Technology ←→ geology/topography
  - US / Japan studies
    - Tunnel configuration studies →
- **Path to the Energy Frontier**

# Linac Configuration Study - US

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| | | | 30M | 30M | 30M | | | |
| | DEEP | | NEAR SURFACE | | | | | |
| | Twin Deep Tunnels | Single Deep Tunnel | Twin Near Surfce Tunnels | Near Surface Tunnel, At Surface Gallery | Single Near Surface Tunnel | Enclosure in Open Cut, Cont. Gallery | Enclosure & Cont. Gallery in Open Cut | Enclosure in Open Cut |
| EXCAVATION | TBM | TBM | TMB | TBM & OPEN CUT | TBM | OPEN CUT | OPEN CUT | OPEN CUT |
| No. of TUNNELS | TWO-TUNNEL | ONE-TUNNEL | TWO-TUNNEL | TWO-TUNNEL | ONE-TUNNEL | ONE-TUNNEL | TWO-TUNNEL | ONE-TUNNEL |
| SHAFT SOIL | VARIES | VARIES | VARIES | VARIES | Soft/SURRY | NA | NA | NA |
| TUNNEL SOIL | ROCK | ROCK | COHESIVE SOIL OR ROCK | COHESIVE SOIL - LOW PERMEABILITY | SATURATED SAND & GRAVEL | SOILS VARIES | SOILS VARIES | SOILS VARIES |
| SERVICE SPACE | SECOND TUNNEL | SURFACE BUILDINGS | SECOND TUNNEL | CONTINOUS SERVICE GALLERY | AT CAMPUSES | CONTINOUS SERVICE GALLERY | CONTINOUS SERVICE GALLERY | AT CAMPUSES |
| ILC Technology | DISTRIBUTED RF | CLUSTERED RF | DISTRIBUTED RF | DISTRIBUTED RF | CLUSTERED RF | DISTRIBUTED RF | DISTRIBUTED RF | CLUSTERED RF |
| SIMILAIR TO | RDR SAMPLE SITES | RDR & CLIC | RDR | DUBNA ILC | XFEL | PROJECT X | PROJECT X | |
| ACCESS | VERTICAL SHAFT | VERTICAL SHAFT | VERTICAL SHAFT | VERTICAL SHAFT | VERTICAL SHAFT | HATCH | HATCH | HATCH |

T. Lundin /
T. Lackowski

# Tunnel Configuration Study – KEK/J-Power

## 2. Case Variations

- HLRF difference
  - RDR
  - XFEL
  - KCS
  - DRFS

- Tunneling Method
  - TBM (circular section)
  - NATM (horse-shoe section)

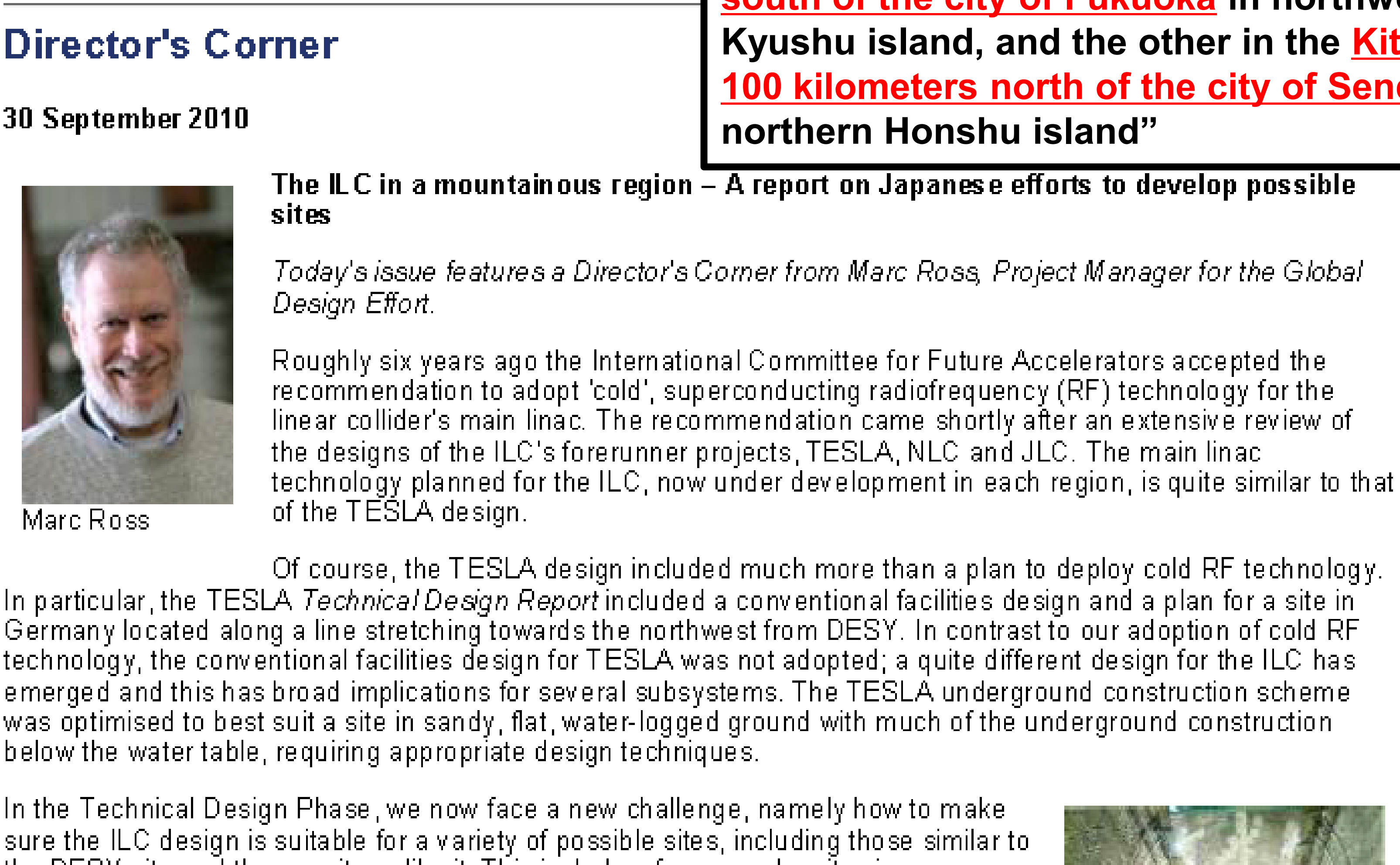
- Tunnel configuration
  - Double tunnel (RDR)
  - Single tunnel (TDR)
  - Japanese-type Single-tunnel Accelerator Configuration

| CASE No. | Name | No. of Tunnel | Tunneling | HLRF | 備考 |
|---|---|---|---|---|---|
| CASE_1 | D-T-R | 2 | TBM | RDR | |
| CASE_2 | S-T-R | 1 | TBM | | |
| CASE_3 | JS-T-X | 2 | TBM | XFEL | Japanese type single-tunnel accelerator configuration |
| CASE_4 | JS-T-K | 2 | TBM | KCS | |
| CASE_5 | JS-T-D | 2 | TBM | DRFS | |
| CASE_6 | JS-N-D | 2 | NATM | | |
| CASE_7 | S-N-DR | 1 | NATM | DRFS/ RDR | Thin wall |
| CASE_8 | S-N-DR | 1 | NATM | | Thick wall |

# Site studies in Japan:

ilc international linear collider

> **"There is an encouraging possibility that Japan will bid to host the ILC. Earlier this month, at the autumn meeting of the Physical Society of Japan held at the Kyushu Institute of Technology, representatives of the Japanese ILC community announced two potential ILC sites. The two locations are at opposite ends of the Japanese archipelago, one in the Seburi-area, 30 kilometers south of the city of Fukuoka in northwestern Kyushu island, and the other in the Kitakami-area, 100 kilometers north of the city of Sendai in northern Honshu island"**



**Director's Corner**

**30 September 2010**

Marc Ross

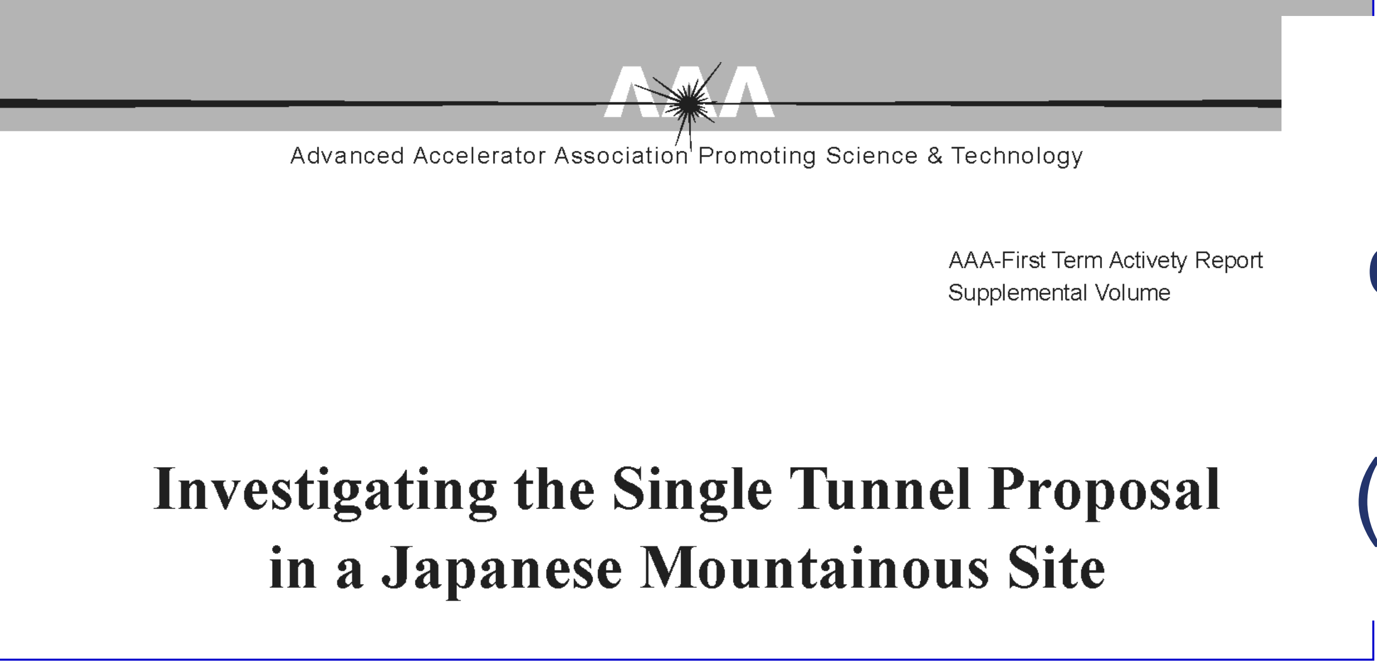
**The ILC in a mountainous region – A report on Japanese efforts to develop possible sites**

*Today's issue features a Director's Corner from Marc Ross, Project Manager for the Global Design Effort.*

Roughly six years ago the International Committee for Future Accelerators accepted the recommendation to adopt 'cold', superconducting radiofrequency (RF) technology for the linear collider's main linac. The recommendation came shortly after an extensive review of the designs of the ILC's forerunner projects, TESLA, NLC and JLC. The main linac technology planned for the ILC, now under development in each region, is quite similar to that of the TESLA design.

Of course, the TESLA design included much more than a plan to deploy cold RF technology. In particular, the TESLA *Technical Design Report* included a conventional facilities design and a plan for a site in Germany located along a line stretching towards the northwest from DESY. In contrast to our adoption of cold RF technology, the conventional facilities design for TESLA was not adopted; a quite different design for the ILC has emerged and this has broad implications for several subsystems. The TESLA underground construction scheme was optimised to best suit a site in sandy, flat, water-logged ground with much of the underground construction below the water table, requiring appropriate design techniques.

In the Technical Design Phase, we now face a new challenge, namely how to make sure the ILC design is suitable for a variety of possible sites, including those similar to



Advanced Accelerator Association Promoting Science & Technology

AAA-First Term Activety Report
Supplemental Volume

**Investigating the Single Tunnel Proposal in a Japanese Mountainous Site**

# Industry consortium site study (AAA 2010)

**ILC Newsline 23. June 2011**

## Tohoku-Oki recovery 11.03.11

*Tohoku recovery logo says: "Let's get together towards Tohoku recovery." Image: Ministry of Land, Infrastructure and Transport*

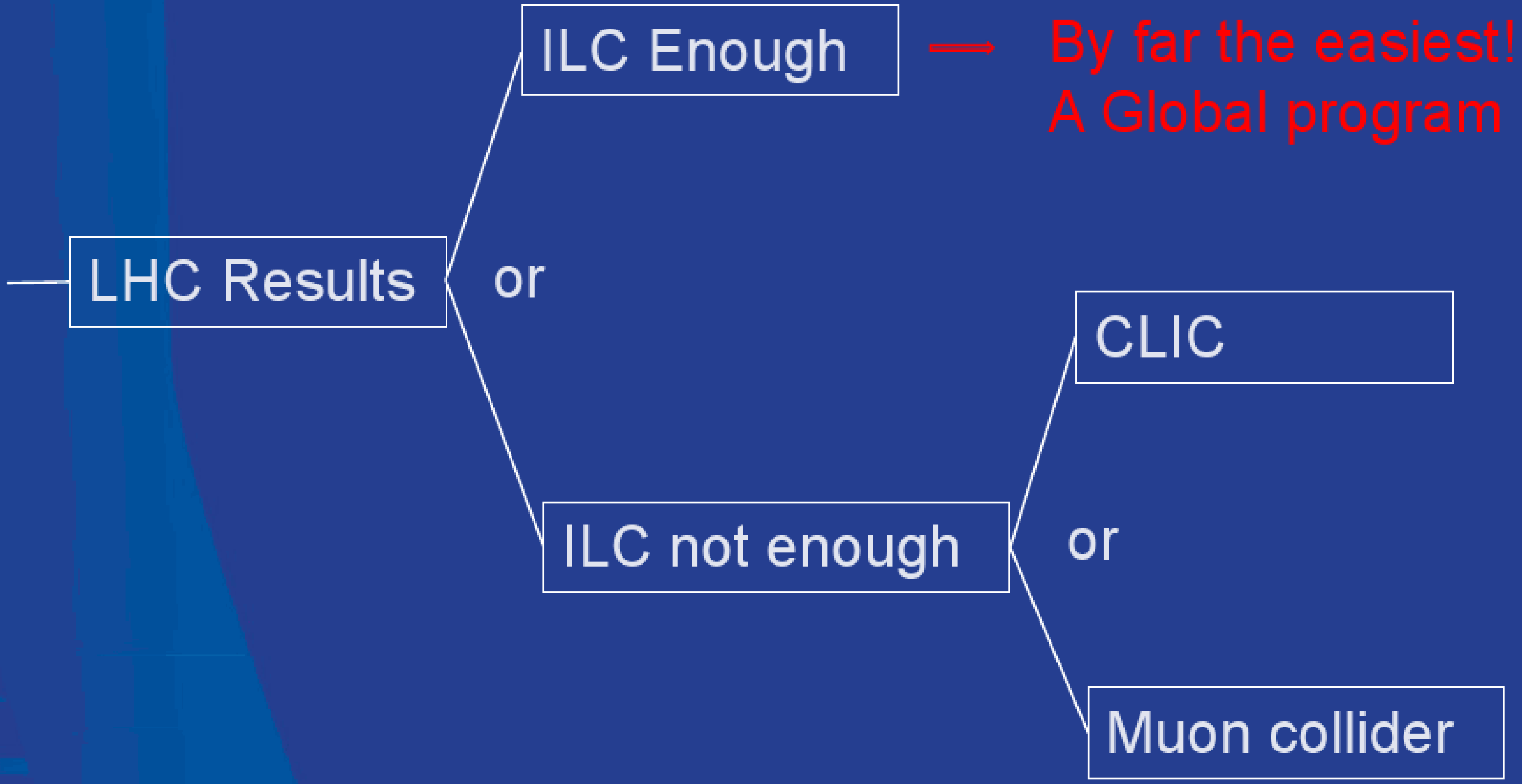
*Iwate Prefectural Governor Takuya Tasso. Image: Iwate Prefecture*

**30 June, 2011**

# ILC TDP (5)

- SRF R & D:
- SRF Mass Production and Cost
- Beam Test Facilities
- Siting the ILC
- **Path to the Energy Frontier**
  - Position US to ***regain the Frontier***…
  - Direction from LHC (2011/2012) – what's next?
  - Normal conducting technology system test
  - Documenting the Technical Design Phase

# Biggest decision of the decade !



LHC Results

or

ILC Enough → By far the easiest! A Global program

ILC not enough

or

CLIC

Muon collider

# 1 TeV: Two Scenarios

- Scenario 1:
  **Consider 1 TeV as upgrade to initial 500 GeV machine**
  - current GDE approach for TDR
  - based on original strategy set-out in 2005

- Scenario 2:
  **Consider >500 GeV (≤1 TeV) as initial machine**
  - consider as gedanken experiment
  - flexibility in light of (emerging) LHC results

# 1 TeV Tentative Parameters

| | | | |
|---|---|---|---|
| Collision rate | $f_{rep}$ | 4 | Hz |
| Number of bunches | $n_b$ | 2625 | |
| Bunch population | $N_-$ | 2 | $\times 10^{10}$ |
| Bunch seperation | $\Delta t_b$ | 356 | ns |
| Pulse current | $I_{beam}$ | 9.0 | mA |
| RMS bunch length | $\sigma_z$ | 0.3 | mm |
| RMS energy spread (e-, e+) | $\Delta p/p$ | 0.105, 0.038 | |
| Polarisation ($e^-$, $e^+$) | $P_-$ | 80, 22 | % |
| Emittance (linac exit) | $\gamma\varepsilon_{x,y}$ | 10, 0.035 | µm |
| IP beta function | $\beta_{x,y}{}^*$ | 30, 0.3 | mm |
| IP RMS beam size | $\sigma_{x,y}{}^*$ | 554, 3.3 | nm |
| Vertical disruption parameter | $D_y$ | 19.2 | |
| **Luminosity** | $\boldsymbol{L}$ | **2.70** | **$\times 10^{34}$ cm$^{-2}$s$^{-1}$** |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | 63.5 | % |
| Average energy loss | $\delta E_{\mathrm{BS}}$ | 4.9 | % |
| Number of pairs per bunch crossing | $N_{pairs}$ | 169 | |
| Total pair energy per bunch crossing | $E_{pairs}$ | 1084 | TeV |

Current "official" parameter set in EDMS*.

Should still be considered tentative, pending review and further study.

Understanding (and updating) these parameters is our job for the next ~6 months.

negotiation!

* EDMS Doc ID: D*925325
http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*925325&fileClass=ExcelShtX

# CLIC main parameters

http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

| Center-of-mass energy | CLIC 500 GeV | | CLIC 3 TeV | |
|---|---|---|---|---|
| Beam parameters | Relaxed | Nominal | Relaxed | Nominal |
| Accelerating structure | 502 | | G | |
| Total (Peak 1%) luminosity | $8.8(5.8)\cdot10^{33}$ | $2.3(1.4)\cdot10^{3}$ | $7.3(3.5)\cdot10^{33}$ | $5.9(2.0)\cdot10^{34}$ |
| Repetition rate (Hz) | 50 | | | |
| Loaded accel. gradient MV/m | 80 | | 100 | |
| Main linac RF frequency GHz | 12 | | | |
| Bunch charge $10^{9}$ | 6.8 | | 3.72 | |
| Bunch separation (ns) | 0.5 | | | |
| Beam pulse duration (ns) | 177 | | 156 | |
| Beam power/beam MWatts | 4.9 | | 14 | |
| Hor./vert. norm. emitt($10^{-6}/10^{-9}$) | 7.5/40 | 4.8/25 | 7.5/40 | 0.66/20 |
| Hor/Vert FF focusing (mm) | 4/0.4 | 4 / 0.1 | 4/0.4 | 4 / 0.1 |
| Hor./vert. IP beam size (nm) | 248 / 5.7 | 202 / 2.3 | 101/3.3 | 40 / 1 |
| Hadronic events/crossing at IP | 0.07 | 0.19 | 0.28 | 2.7 |
| Coherent pairs at IP | 10 | 100 | $2.5\ 10^{7}$ | $3.8\ 10^{8}$ |
| BDS length (km) | 1.87 | | 2.75 | |
| Total site length km | 13.0 | | 48.3 | |
| Wall plug to beam transfert eff | 7.5% | | 6.8% | |
| Total power consumption MW | ~~129.4~~ 241 | | ~~415~~ 568 | |

# GDE - Technically-driven post 2012 program

## THEME for post-2012 program

We are discussing possible major themes to guide this R&D development program. Examples including R&D toward a 1TeV, either directly or as an upgrade, emphasizing achieving higher gradient (energy) economically.

- **SCRF Systems tests; Mass production; Value Engineering, etc.**

- **Design evolution: 1 TeV; Positrons; R&D toward major technical advances**

- **Must preserve GDE-like global decision making and coordination in new pre-project organization**

# TDP Interim Report – ½ way done:

INTERNATIONAL LINEAR COLLIDER

A TECHNICAL PROGRESS REPORT

**Published May 2011**

Fermilab-TM-2491-AD-APC-CD-DI-FESS-PPD-TD

# ILC Technical Design Phase:

- **RDR (2005-2007)**
  - had strong SLAC leadership
- **TDP R & D (2008 – 2012)**
  - Akira Yamamoto,
  - Jim Kerby, Tetsuo Shidara,
  - KEK, INFN, JLab and Fermilab team
- **Accelerator Design (2000 – 2012)**
  - Nick Walker and Accelerator System team
  - CFS: Vic Kuchler, Atsushi Enomoto, John Osborne