High Intensity ν Source R&D Overview

or

Multi MW Proton Sources

G.A. – FNAL Steering Group – April 30th '07

- **What**
- **R&D Status**
- **PS vs. "6 GeV ILC Test Line"**
  - **Charge to the Steering Group: a strategic roadmap that**
    1. **supports the international R&D and engineering design for as early a start of the ILC as possible and supports the development of Fermilab as a potential host site for the ILC;**
    2. **develops options for an accelerator-based high energy physics program in the event the start of the ILC construction is slower than the technically-limited schedule**
  - **Technical issues to convert from 6 GeV ILC Test Line to PS**

Role of Multi-GeV Proton Sources (FNAL)

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- **Multi-MW proton source necessary for full exploration ν sector**
  - NoVA will operate at 700 kW
  - SuperNuMI could operate in the 1 MW range
- **Multi-MW proton source is necessary as FE for μ source**
- **Multi-MW proton source in EA applications**

} ~1 GeV'sh

- **…**

- **An 8 GeV Linac coupled with an upgraded Main Injector is required to get above 2 MW at 120 GeV**
- **The 8 GeV Linac β=1 section could be used to ri-circulate and accelerate cooled μ's**
- **The 8 GeV Linac idea* incorporates concepts from the ILC, the Spallation Neutron Source, RIA and APT.**
  - Copy SNS, RIA, and JPARC Linac design up to 1.3 GeV
  - Use ILC Cryomodules from 1.3 - 8 GeV
  - H^- Injection at 8 GeV in Main Injector

* *The 8 GeV Linac concept actually originated with Vinod Bharadwaj and Bob Noble in 1994,when it was realized that the MI would benefit from a Linac injector. Gradients of 4-5 Mev/m did not make the proposal cost effective at the time. Idea revived and expanded by GWF in 2004 with the advent of 20-25 MeV/m gradients.*

Intense Proton Source & FE under consideration around the World

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…excluding SNS and JPARC

Pulsed

- **CERN SPL II – (ν,EURISOL)**
  - **3.5 GeV H- Linac at 4 MW**
- **Rutherford Accelerator Lab – ESS (Neutron, ν)**
  - **Synchrotron-based PD, 5-15 GeV, 4 MW, 180 MeV Linac FE**

CW

- **CEA Saclay – IPHI Injector (Neutron, Transmutation)**
- **LNL TRASCO – (Transmutation)**

Table 1: Summary of the typical parameters for different applications.

Application	Beam Power	Energy	Average Current
Condensed matter	5 MW	1.3 GeV	3.75 mA
Radioactive Ions from Protons from Neutron	- 200 kW > 10 MW	> 200 MeV ~ 1 GeV	~ 1 mA ~ 10 mA
Hybrid System 100 MWth demo Industrial System	~ 6 MW ~ 50 MW	~ 600 MeV ~ 1 GeV	~10 mA ~ 50 mA
Irradiation tool	10-40 MW	~ 1 GeV	10-40 mA
Tritium production	10-100 MW	~ 1 GeV	…100 mA
Muons - Neutrinos	4 MW	2 GeV	2 mA

Multi-GeV Linac as ILC Test Facility

- **Test Facility for the ILC**
  - **1.5% ILC Demonstration**
  - **Seed for SCRF Industrialization in the US and International Collaborations (KEK, DESY, India/China, etc.)**

- **In the event the start of the ILC construction is slower than the technically-limited schedule, this is beneficial to:**
  - **ν and "high-intensity" proton-beam physics programs**

8 GeV Superconducting Linac

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Two Design Points for 8 GeV Linac

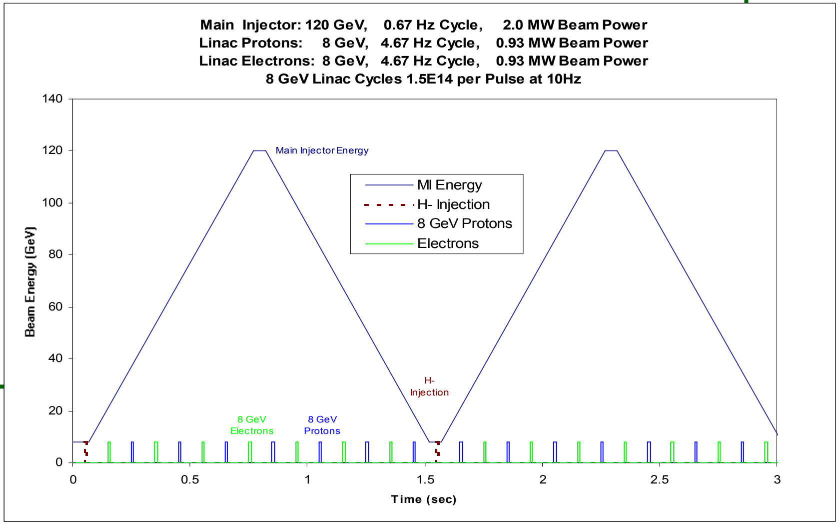
- **Initial: 0.5 MW Linac Beam Power**
  - **8.3 mA x 3 msec x 2.5 Hz x 8 GeV = 0.5 MW** ***(11 Klys)***
- **Ultimate: 2 MW Linac Beam Power**
  - **25 mA x 1 msec x 10 Hz x 8 GeV = 2.0 MW** ***(33 Klys)***

<u>Either Option Supports:</u>

1.5E14 x 0.7 Hz x 120 GeV = 2 MW from MI

- ***Name of the Game in Linac Intensity:***

  RF POWER
  - ***Production (Klystrons)***
  - ***Delivery to Cavity (PC)***



HINS Program Goals (pre-ILC RDR Feb '07)

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- **HINS R&D Phase: Proof of innovative approach to high intensity beam acceleration !**
  - 2007-2010 R&D period
  - Prove, Develop & Build Front-End in Meson Bldg. at 325 MHz (0-60 MeV) since much of the technical complexity is in the FE Mechanical/RF Systems
    - Demonstrate for the first time Amplitude/Phase Modulator (FVM) Technology and RF Power Scheme with H^-
    - Demonstrate for the first time RT-SC Transition at 10 MeV
    - Acquire capability to test/operate SC Spoke Cavities at FNAL
    - Demonstrate for the first time beam loading and pulsed operation of Spoke Cavities
    - Demonstrate Axis-Symmetric focusing and Beam Chopping
    - Demonstrate for the first time the ability to drive RT and SC Sections with a single klystron
  - Retain conceptual design compatibility between HINS and ILC
    - β=1 R&D is necessary in the event of an 8 GeV Linac phase
- **8 GeV Linac Phase**
  - "Post-2010"period
  - Construction of ~400 *ILC* cavities and ~50 *ILC* cryomodules at 1.3 GHz

0.5 MW Initial 8 GeV Linac

11 Klystrons (2 types)
449 Cavities
51 Cryomodules

"PULSED RIA" Front End Linac

325 MHz
0-110 MeV

Modulator
Single 3 MW JPARC Klystron

Multi-Cavity Fanout at 10 - 50 kW/cavity
Phase and Amplitude Control w/ Ferrite Tuners

H- | RFQ | MEBT | RTSR | SSR | DSR | DSR

β<1 ILC LINAC

Modulator

β=.81

ILC LINAC

β=1 β=1 β=1

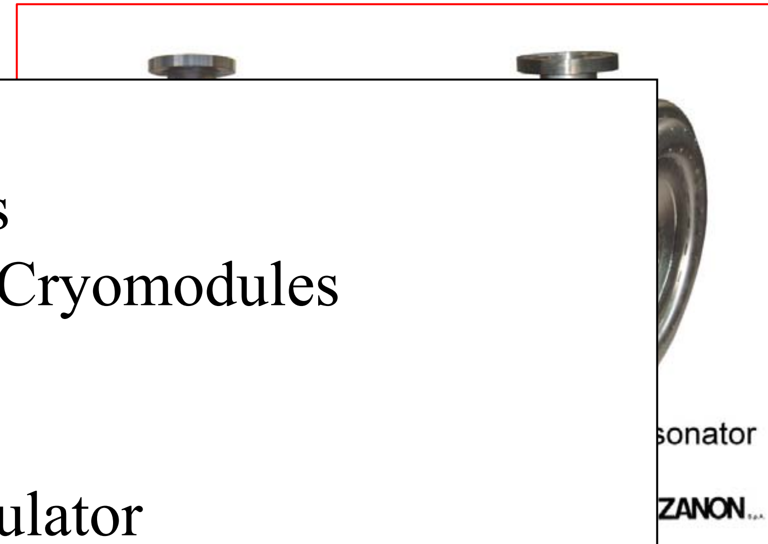
~80 % of the Engineering & Technical System Complexity

R&D HINS Program (2007-2010)

~1 Gev'sh SC Linac has very little "ILC" in it

- no frequency transition (?)

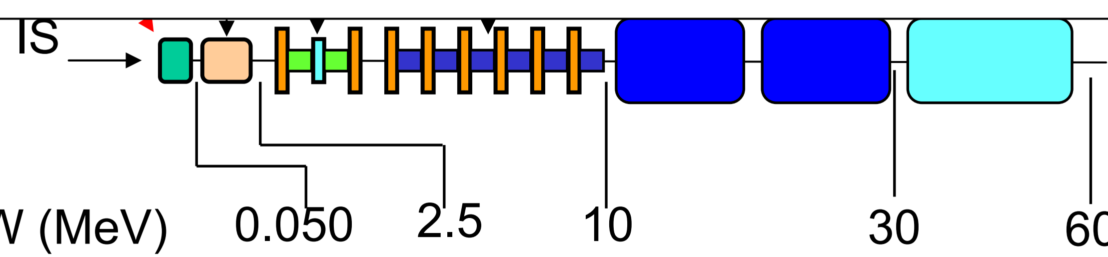
Front End - Beam Line Layout



Beam Line Elements:
- 19 Conventional RT Cavities
- 29 SC Spoke Cavities and 3 Cryomodules
- 42 SC Focusing Solenoids

RF Power Elements:
- one 325 MHz Klystron/Modulator
- one 400 kW RFQ FVM
- 19 ~20 kW FVM/Fast Tuning for RT Section
- 29 ~20-120 kW FVM/Fast Tuning for SC Section

Joint AD/TD Effort



Frequency 325 MHz
Total length ~ 55 m

Success – Working 325 MHz Klystron!!!

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From HINS logbook, Wednesday, April 4
Full peak klystron output power achieved at short pulse

Date Created: Wednesday, April 4, 2007 4:22:20 PM CDT
Date Saved: Wednesday, April 4, 2007 4:22:20 PM CDT
Category - Topic - sequence number: 325_MHz_RF/Klystron - Log - 69
Operator(s): Peter Prieto
Keyword(s): :
Click here to download a copy of file

Klystron average RF power reached 2.6 MW with 17.7 Watt input power.
The RF pulse length was 100 usec at 1 pps.

Attached File: klypower.xls

Klystron, Modulator and Waveguide

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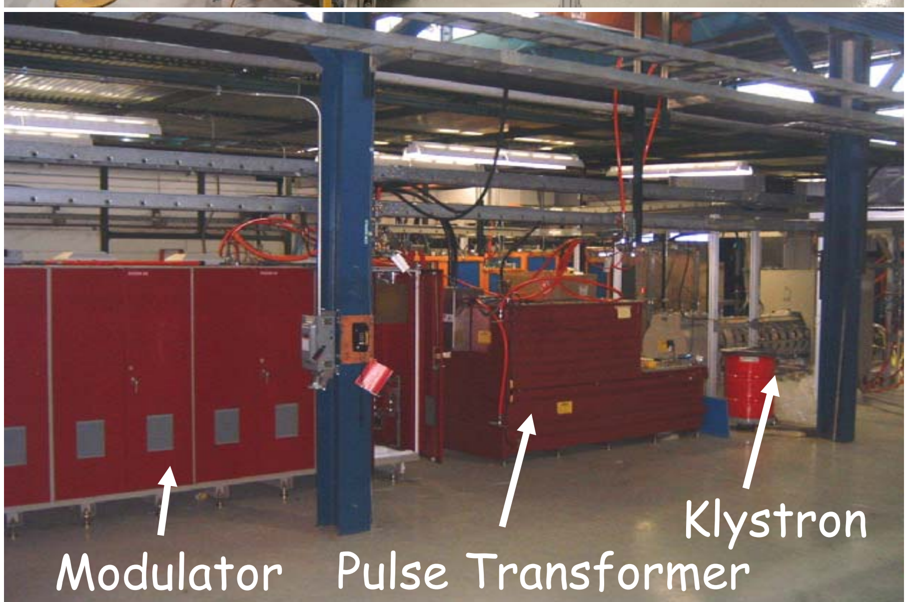

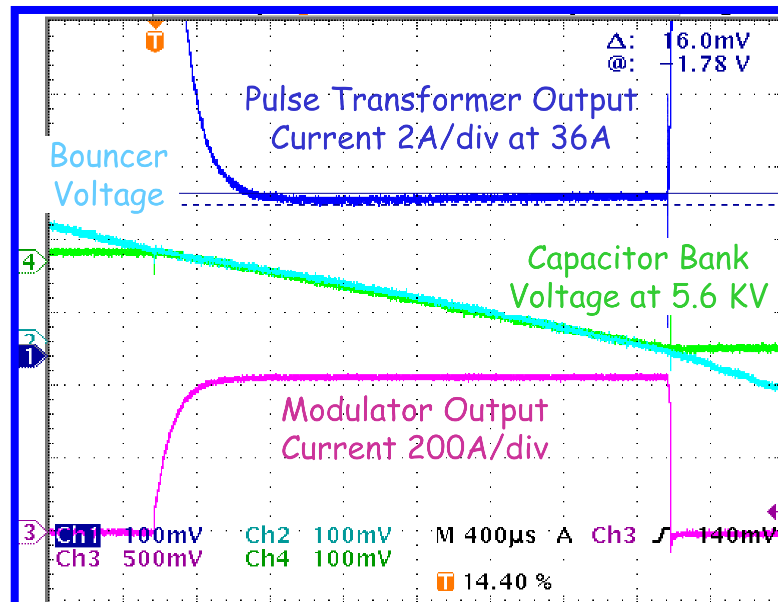

Modulator Signals at 5.6 KV into Resistive Load February 2, 2007

Collaborative Efforts

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- **Collaborations**
  - **ANL**
    - **Beam Dynamics**
    - **Spoke Cavities Processing (EP & HPR - Prototypes and Production)**
  - **LBL**
    - **Buncher Cavities and Electron Cloud Effects in MI**
  - **BNL**
    - **Laser Beam Profiler**
  - **MSU**
    - **β=0.81 Elliptical Cavities development**
  - **IUAC, Delhi (India)**
    - **Spoke Cavities Prototypes (& Production)**
- **Budget**
  - **ILC R&D has been the first priority at Fermilab**
  - **Thus, small R&D budget for HINS**
    - **FY06 SOW: ~2.2 M$ (~4.9 M$ HINS budget)**
    - ***FY07 SOW: ~0.4 M$ (~2.5 M$ HINS budget)***

"Post-2010" 8 GeV Linac (…in the pre-ILC RDR era…)

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- **~50 Cryomodules, ~400 cavities**
  - **5 different types: SSR1 (completed in FE), SSR2, TSR, β0.81 and β1.0(ILC)**
  - **Too much diversity for full Industrialization of all elements -> Rely heavily on "SRF Infrastructure at FNAL"**
  - **Production: Cavities and Cryomodules**
    - **ILC SRF Infrastructure rate: ~1 cryo/month on single shift/single production line**
    - **8 GeV Linac: 1.5-2 cryo/month (AAC-2005 & 2005 Director Review)**
      - **~double Shift + double production line – "SRF Infrastructure" worth at least ~60-70% of 8 GeV Linac Tooling & Facilities needs**
- **Scale of SRF Infrastructure and Scope of facilities built for the ILC are well matched to the needs of an 8 GeV Linac production.**
  - **Detailed analysis may be needed for a complete match of the SRF Infrastructure to the needs of a possible 8 GeV Linac project.**

HINS/6 GeV ILC Alignment

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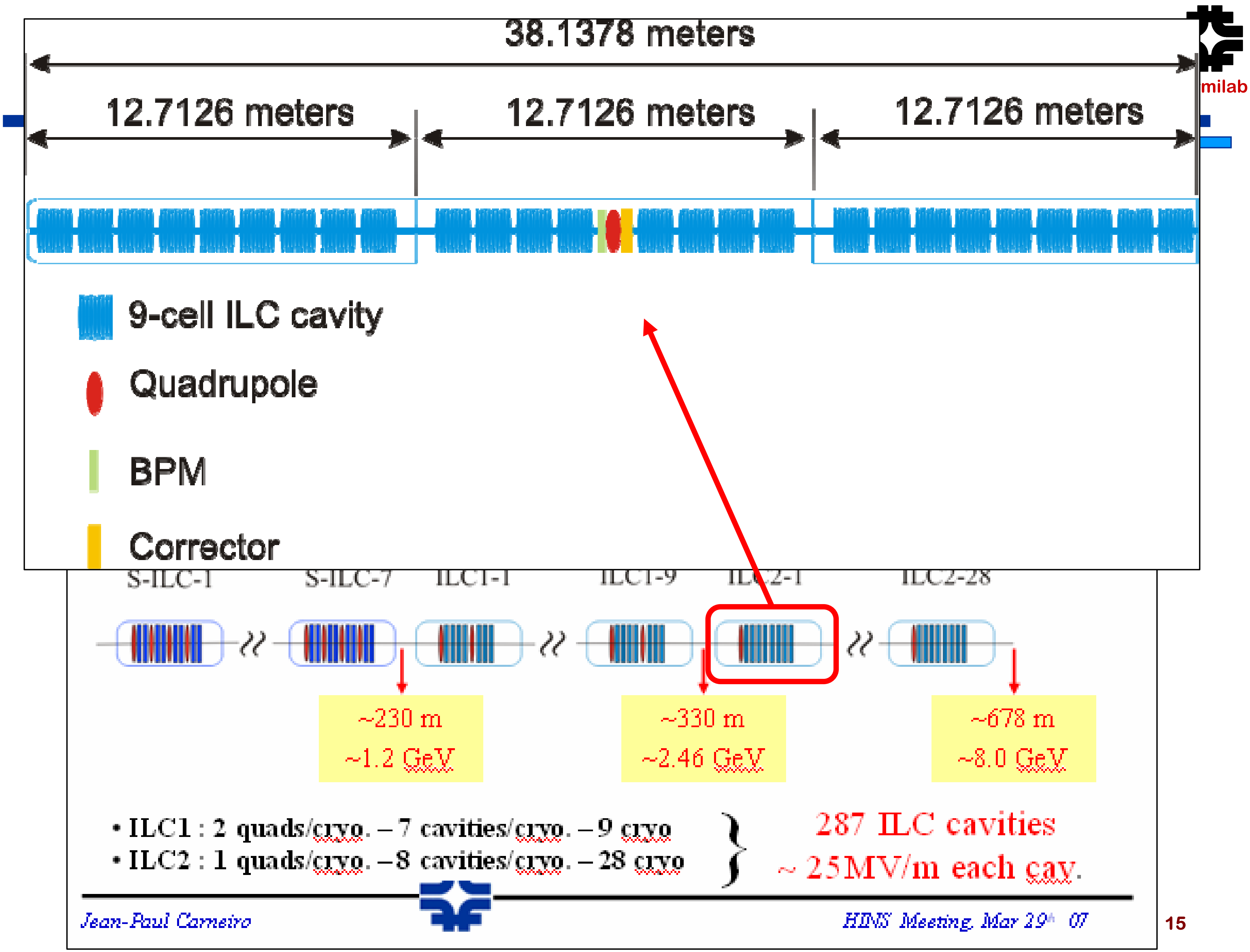
- **Idea:**
  - **Develop and build several ILC RF-units (5 or 6) for system integration studies,** *….ILC justifications….*
  - **If ILC (delayed beyond 20##, not technically feasible, not right energy, etc.) then use facility as last accelerating stage of high intensity proton machine**
- **Items presently being considered (in order of "seriousness" of effort applied):**
  - **Beam dynamics** — **Ostroumov, Carniero actively simulating**
  - **Power input to cavities** — **Khabibouline providing "expertise"**
  - **Civil Engineering** — **…need FESS involvement …**



38.1378 meters
12.7126 meters
12.7126 meters
12.7126 meters
9-cell ILC cavity
Quadrupole
BPM
Corrector
S-ILC-1
S-ILC-7
ILC1-1
ILC1-9
ILC2-1
ILC2-28
~230 m
~1.2 GeV
~330 m
~2.46 GeV
~678 m
~8.0 GeV
• ILC1 : 2 quads/cryo. – 7 cavities/cryo. – 9 cryo
• ILC2 : 1 quads/cryo. – 8 cavities/cryo. – 28 cryo
287 ILC cavities
~ 25MV/m each cav.
Jean-Paul Carneiro
HINS Meeting, Mar 29th 07
milab

Beam Dynamics

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8 ILC Unit after ILC1 (to replace ILC2)

- **ILC2 : 1 quads/cryo. – 8 cavities/cryo. – 28 cryo – 224 cavities – 28 quads**
- **8 ILC-units : (9+8+9)×8 = 208 cavities – 8 quads**

idea

ILC1 – 31.5 MV/m

4 ILC Units – 18.25 MV/m

4 ILC Units – 31.5 MV/m

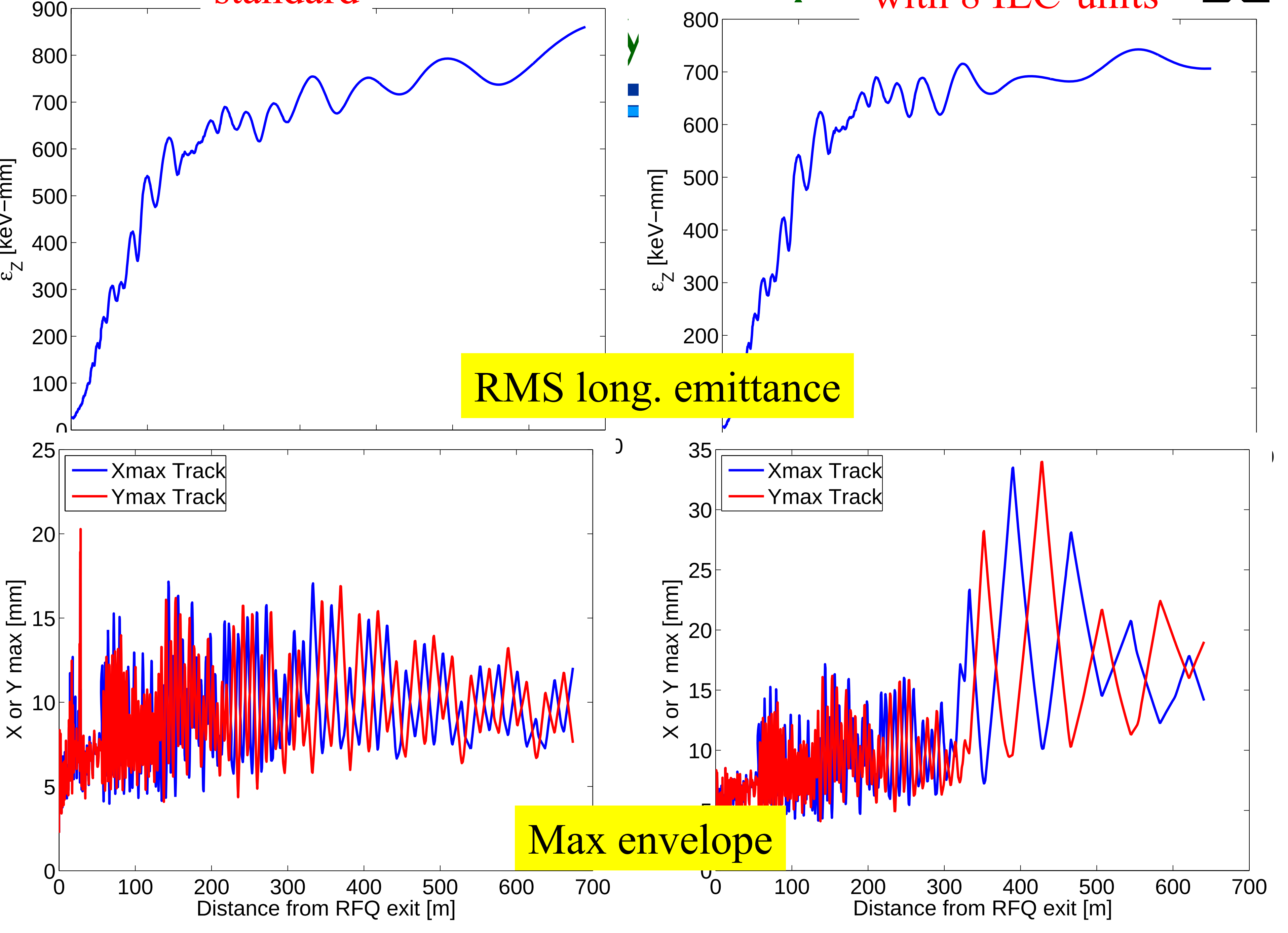
~330 m
~~~2.46 GeV~~
~2.8 GeV

Lower fields helps RF defoc.

~~~678 m~~
~640 m
~8.0 GeV

Higher energy helps Space Charge

standard   with 8 ILC-units



Power to Cavities

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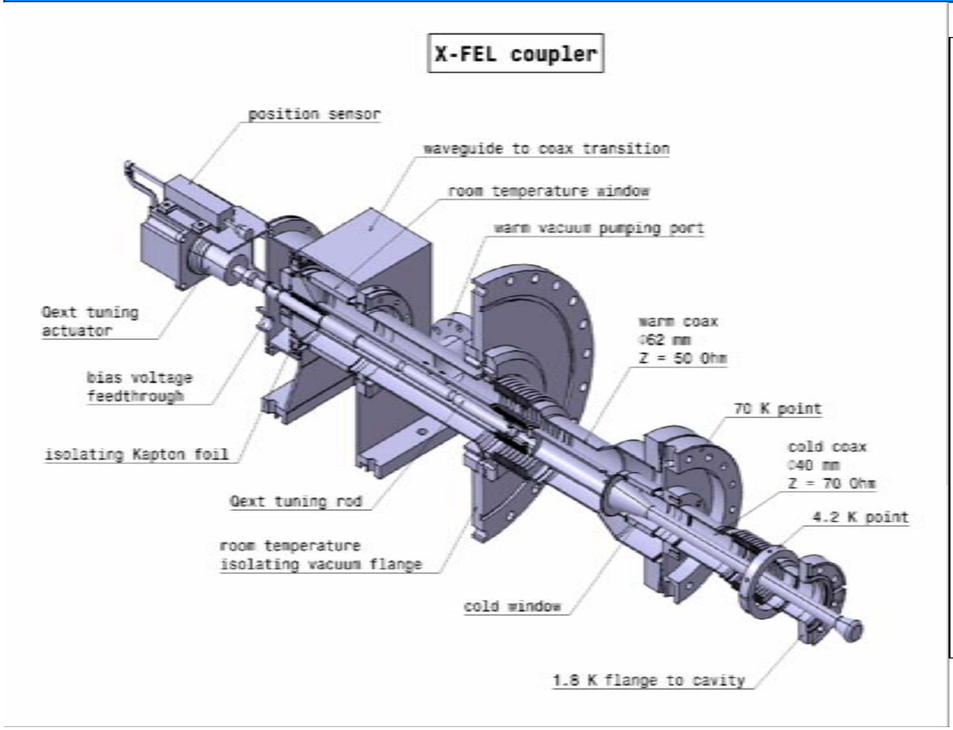
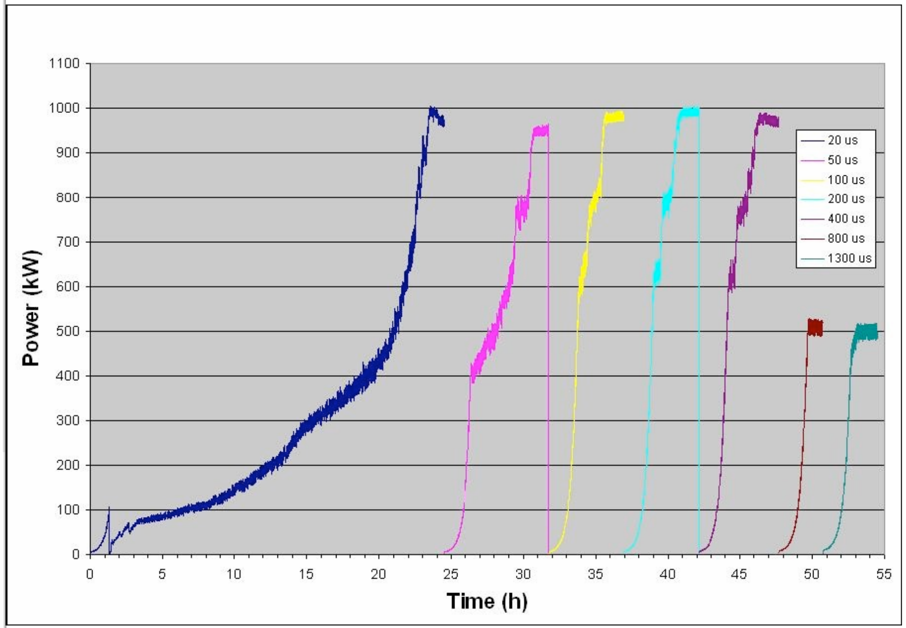
	ILC	HINS/ILC	HINS
I, mA	9	26	26
Eacc, MV/m	31.5	31.5	26
U, MV	32.7	31.4	25.9
Tbeam	969	1000	1000
Tfill	596	215	223
Rep. rate	5	10	10
Phase, deg	1	16	16
P pulse, kW	294	817	674
P average, kW	2.30	9.92	8.25
Qext, coupler	3.7E+06	1.3E+06	1.1E+06

The TTF3 coupler goes only up to average power of 4.5kW traveling wave. The limiting effect is the temperature of the warm inner conductor. Bessy did some tests with air cooling of the inner conductor and was able to go to 10kW average at the cavity.

Sergey Belomestnykh
sab@lepp.cornell.edu
has a TTF3 like design with cooling of the inner conductor and increased cold coax diameter. It is under test right now and should go up to 80kW cw.

Tesla Power Coupler





- ILC Power Coupler as presently conceived will not work, but:
  - Lot of work on improving performance
  - Adjustable coupling to become available in TTFIII
  - If not adjustable, design needs to be optimized for 26 mA
- ..or, PC replacement (see next)

INPUT COUPLER FOR ERL INJECTOR CAVITIES *

V. Veshcherevich., I. Bazarov, S. Belomestnykh, M. Liepe, H. Padamsee, and V. Shemelin. Laboratory for Elementary-Particle Physics, Cornell University, Ithaca, NY 14853, USA

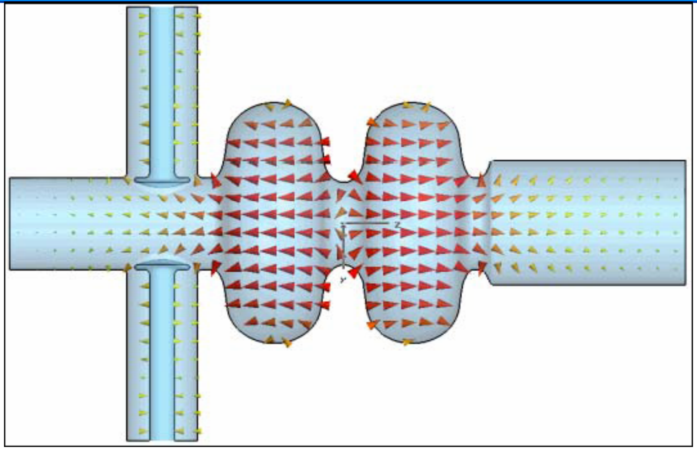


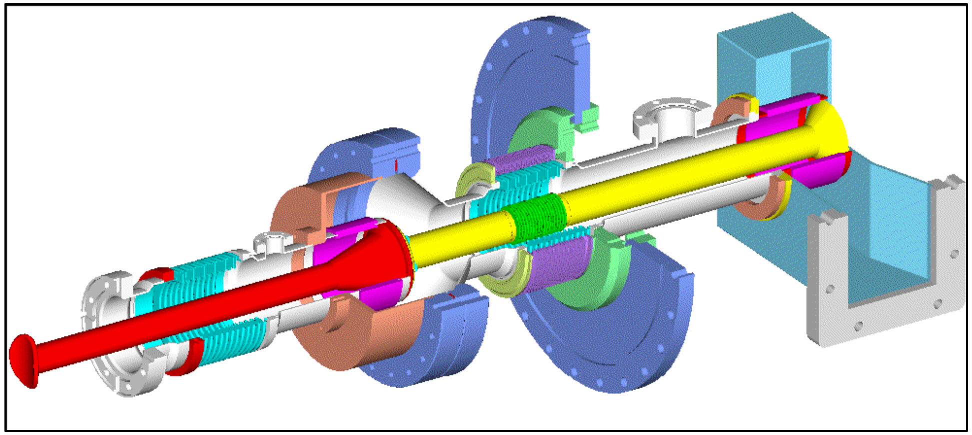
Table 1: Parameters of the injector cavities

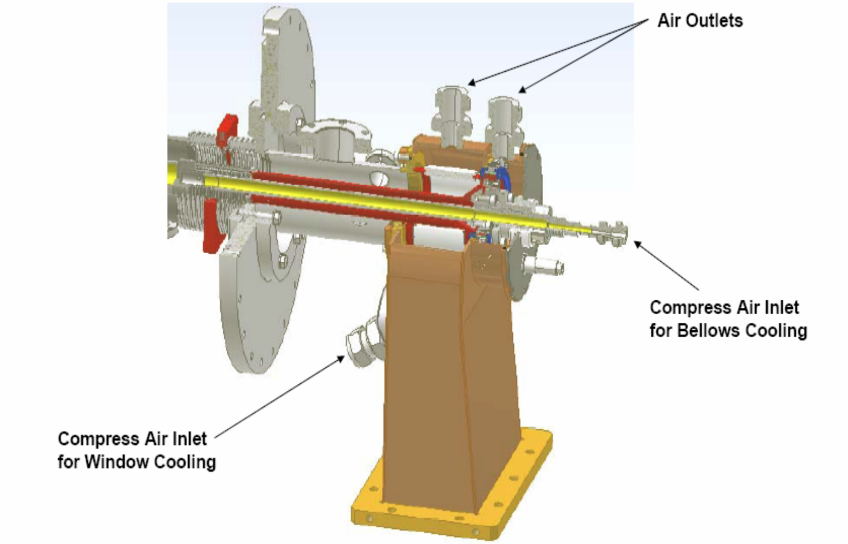
Energy of electrons, *E*	0.5 to 5.5 (15.5) MeV
Beam current, *I*0	100 (33) mA
Frequency, *f*	1300 MHz
Number of cells per cavity, *N*c	2
*Q*0	≥ 5×109
*Q*ext, nominal	4.6×104
*Q*ext, range	4.6×104 to 4.1×105
R/Q	218 Ohm
Cavity voltage, *V*	1 (3) MV
RF power per cavity, *P*	150 kW

Table 2: Injector cavity coupler heat loads.

	Static	At 50 kW (CW, TW)
1.8 K	0.05W	0.2W
4.2 K	0.30W	2.0W
70 K	6.80W	31W

Cornell ERL – Modified TTFIII for CW mode

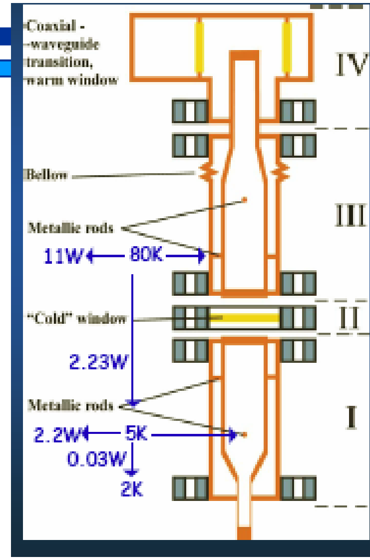


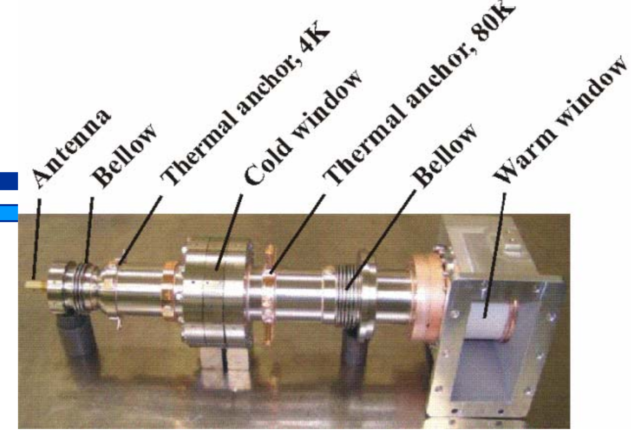


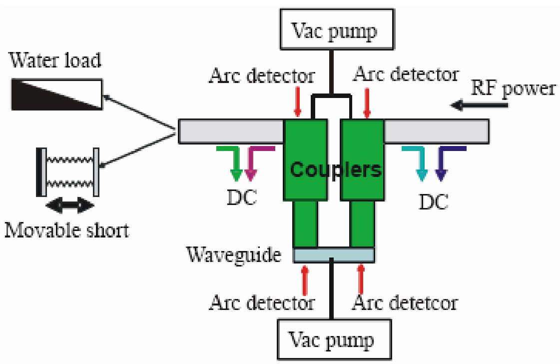
HIGH POWER TEST OF COUPLER WITH CAPACITIVE WINDOW. S. Kazakov1, H. Matsumoto1, K.Saito1, T.Higo1, T.Saeki1, M.Sato1, F.Furuta1, R.Orr2, J.Hong1, A.Yano3, H.Urakata3, O.Yushiro3

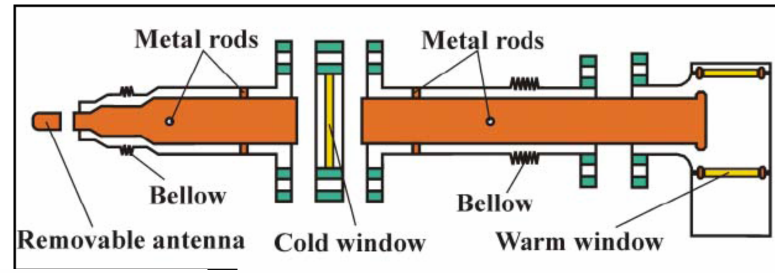
KEK – Capacitive coupling

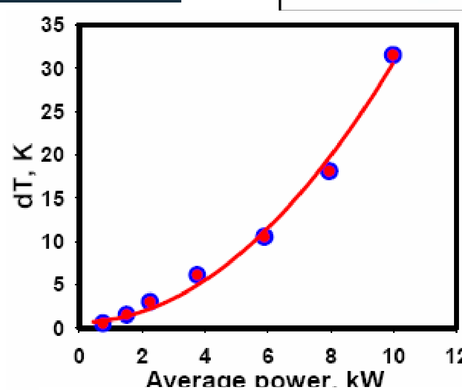
1 cylindrical – 1 planar

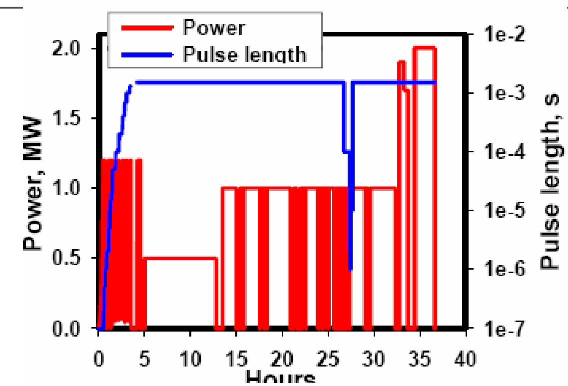












CONCLUSION

The L-band high-power couplers with capacitive coupling mechanism at the cold window were made for superconductive accelerator cavity. Couplers were tested at high power level. Test demonstrated that couplers can successfully operate with pulse 1MW x 1.5ms x 5pps and 2MW x 1.5ms x 3pps with matching load and with pulse 500kW x 1.5ms x 5pps with short. Effect of multipactor is weak. Upper limit of multipactor is about 200 kW. These couplers will be used for STF in KEK.

Linac Proton Driver Site Plan

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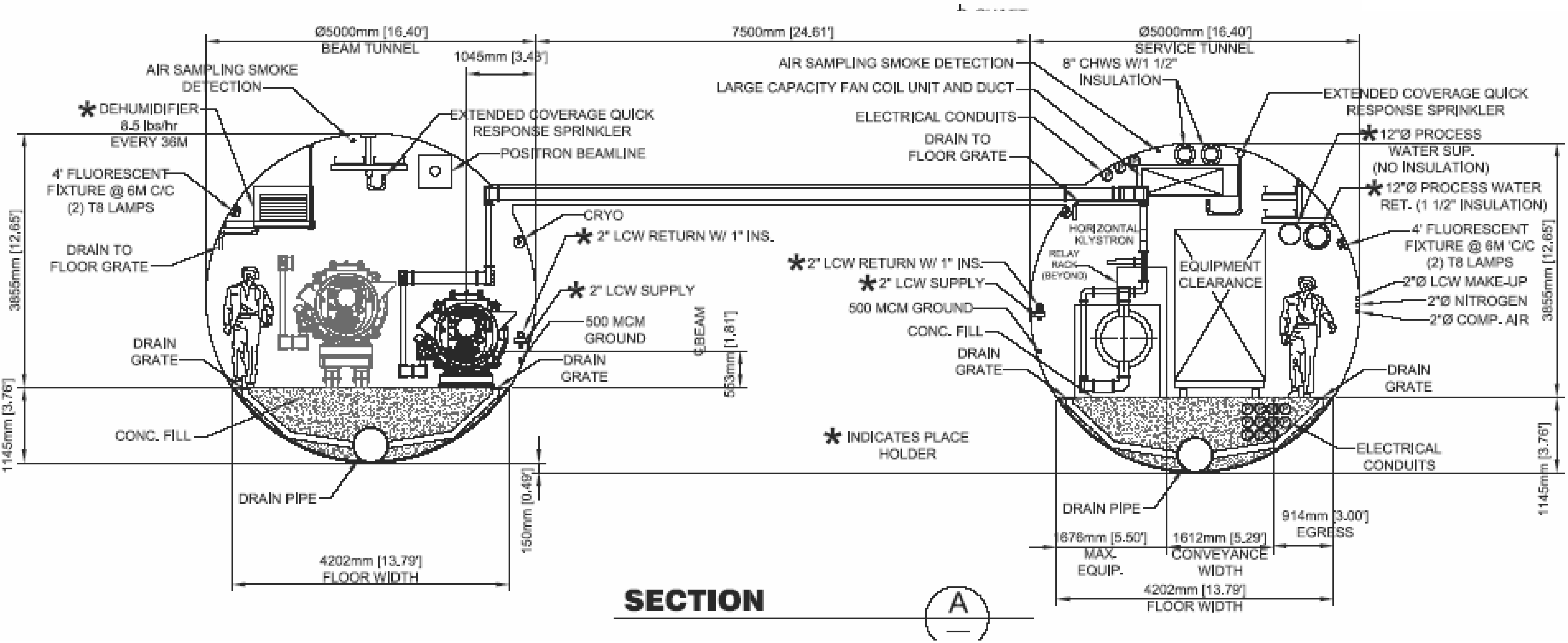

Ø5000mm [16.40']
BEAM TUNNEL
7500mm [24.61']
Ø5000mm [16.40']
SERVICE TUNNEL
1045mm [3.43']
AIR SAMPLING SMOKE DETECTION
DEHUMIDIFIER 8.5 lbs/hr EVERY 36M
EXTENDED COVERAGE QUICK RESPONSE SPRINKLER
POSITRON BEAMLINE
4' FLUORESCENT FIXTURE @ 6M C/C (2) T8 LAMPS
DRAIN TO FLOOR GRATE
CRYO
2" LCW RETURN W/ 1" INS.
2" LCW SUPPLY
500 MCM GROUND
DRAIN GRATE
CONC. FILL
DRAIN PIPE
BEAM
553mm [1.81']
150mm [0.49']
3855mm [12.65']
1145mm [3.76']
4202mm [13.79']
FLOOR WIDTH
AIR SAMPLING SMOKE DETECTION
LARGE CAPACITY FAN COIL UNIT AND DUCT
ELECTRICAL CONDUITS
DRAIN TO FLOOR GRATE
8" CHWS W/1 1/2" INSULATION
EXTENDED COVERAGE QUICK RESPONSE SPRINKLER
12"Ø PROCESS WATER SUP. (NO INSULATION)
12"Ø PROCESS WATER RET. (1 1/2" INSULATION)
4' FLUORESCENT FIXTURE @ 6M 'C/C (2) T8 LAMPS
2"Ø LCW MAKE-UP
2"Ø NITROGEN
2"Ø COMP. AIR
HORIZONTAL KLYSTRON
RELAY RACK (BEYOND)
EQUIPMENT CLEARANCE
2" LCW RETURN W/ 1" INS.
2" LCW SUPPLY
500 MCM GROUND
CONC. FILL
DRAIN GRATE
DRAIN GRATE
ELECTRICAL CONDUITS
DRAIN PIPE
* INDICATES PLACE HOLDER
1678mm [5.50'] MAX. EQUIP.
1612mm [5.29'] CONVEYANCE WIDTH
914mm [3.00'] EGRESS
4202mm [13.79'] FLOOR WIDTH
3855mm [12.65']
1145mm [3.76']
SECTION
A

Klystron Gallery (HINS)/Tunnel (ILC)

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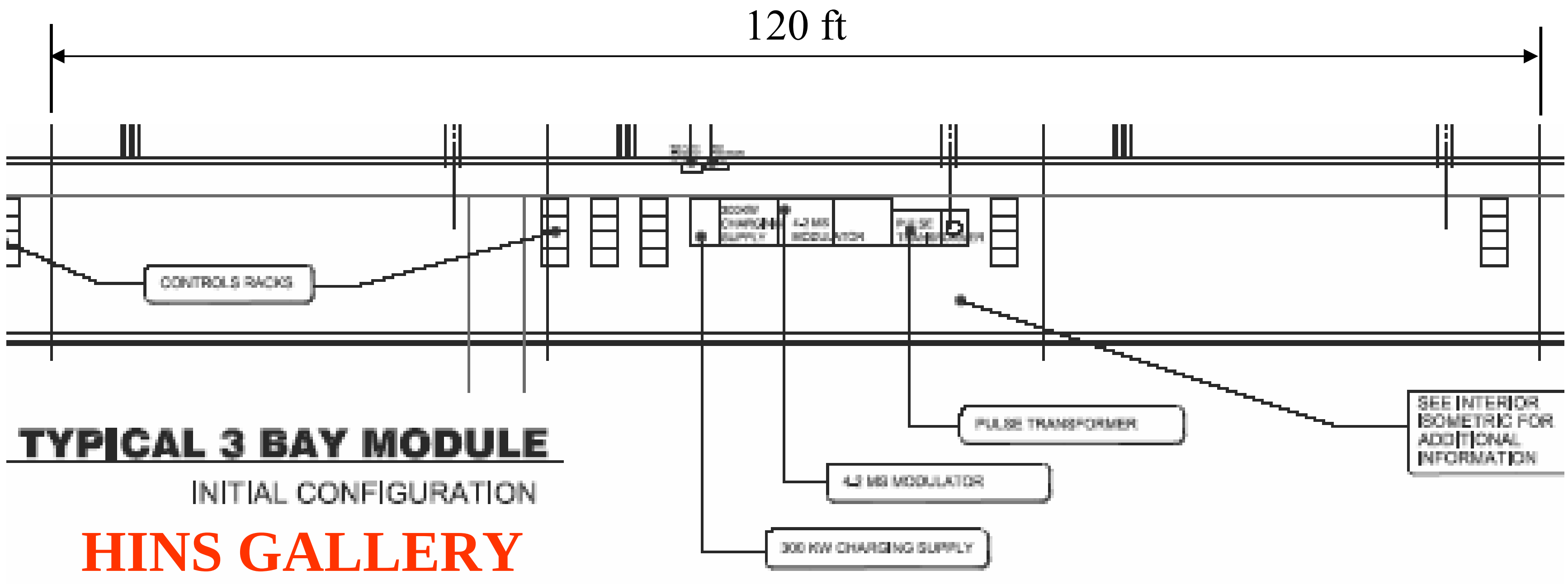

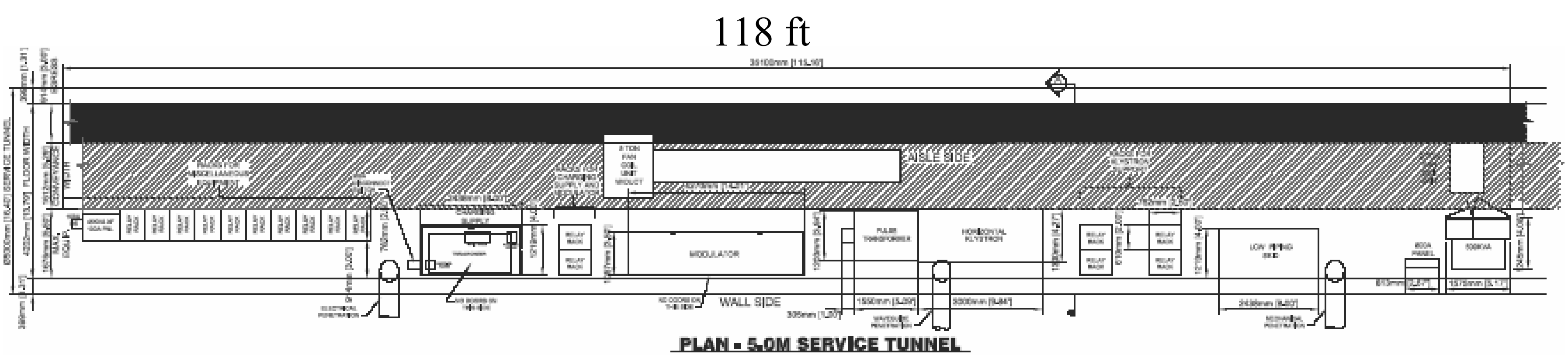

ILC SERVICE TUNNEL

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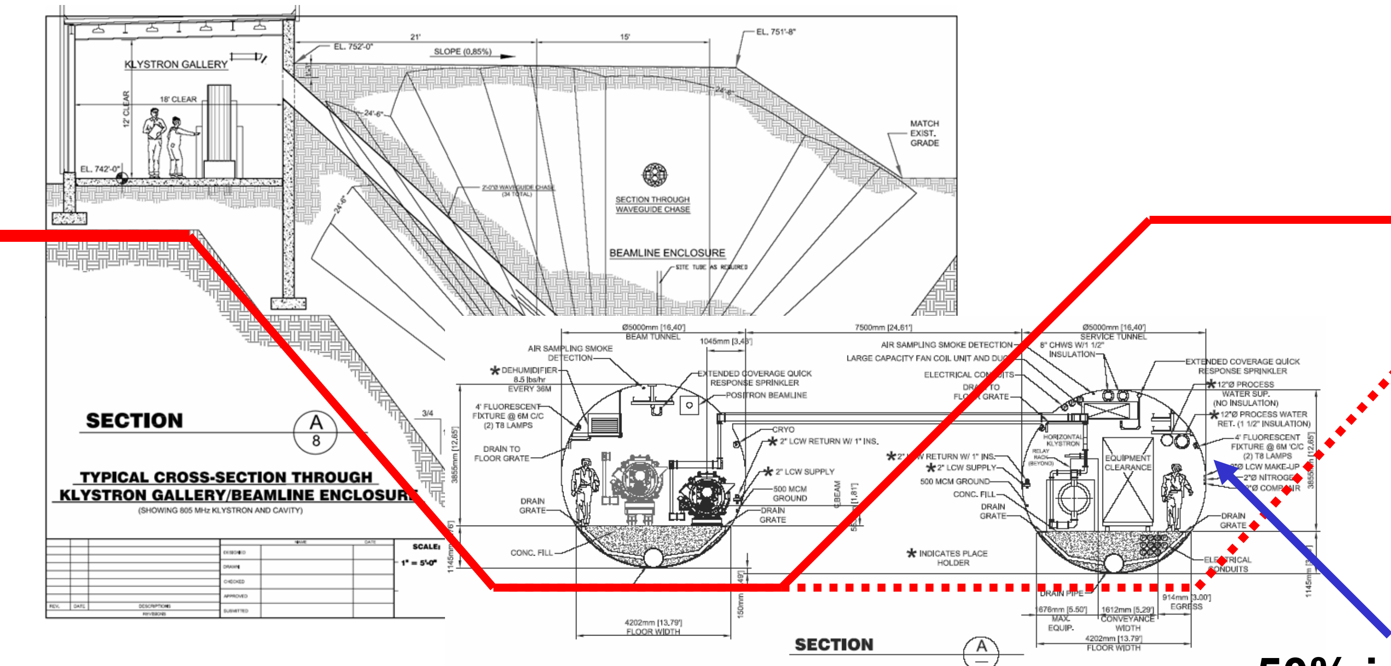

- ~50% increase in excavation
- Excavation is ~15% of civil

Summary

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- Lot of work available from initial preparation for "cancelled" 2005 CD-0 (including civil survey & design)
- Technical Challenges
  - RF Power Distribution/Control to Cavity
  - Mechanical Design of non-ILC Components
  - PS/ILC Convergence
    - Adopt an ILC design for β=1 section (say T4CM) and then disengage from ILC development