Summary of the Accelerator Sessions

International Workshop on Future Linear Collider 2019

2019/11/01

Mathieu Omet (KEK)

Disclaimer

- The summary is (by nature) incomplete and is a personal view
  - Several excellent and interesting results, which were presented during the sessions are not mentioned
- I invite everyone to take a look at the contributions uploaded

Accelerator Session Overview

Session name	Session count	Talk count	Discussion count
CFS	3	9	2
Green Accelerator	1	5	-
Sources	3	14	-
Warm RF	2	9	2
SCRF	4	20	-
ATF/DR/BDS	2	8	-
Total	**15**	**65**	**4**

Accelerator Session Conveners

- CFS
  - John Osborne (CERN), Nobuhiro Terunuma (KEK)
- Green Accelerator
  - Takayuki Saeki (KEK), Steinar Stapnes (CERN)
- Sources
  - Steffen Doebert (CERN), Joe Grames (JLab), Masao Kuriki (U. Hiroshima)
- Warm RF
  - Toshi Higo (KEK), Emilio Nanni (SLAC), Walter Wuensch (CERN)
- SCRF
  - Matthia Checchin (FNAL), Marc Wenskat (DESY), Yasuchika Yamamoto (KEK)
- ATF/DR/BDS
  - Philip Burrows (Oxford), Toshiyuki Okugi (KEK), Rogelio Tomas (CERN), Renjun Yang (CERN)

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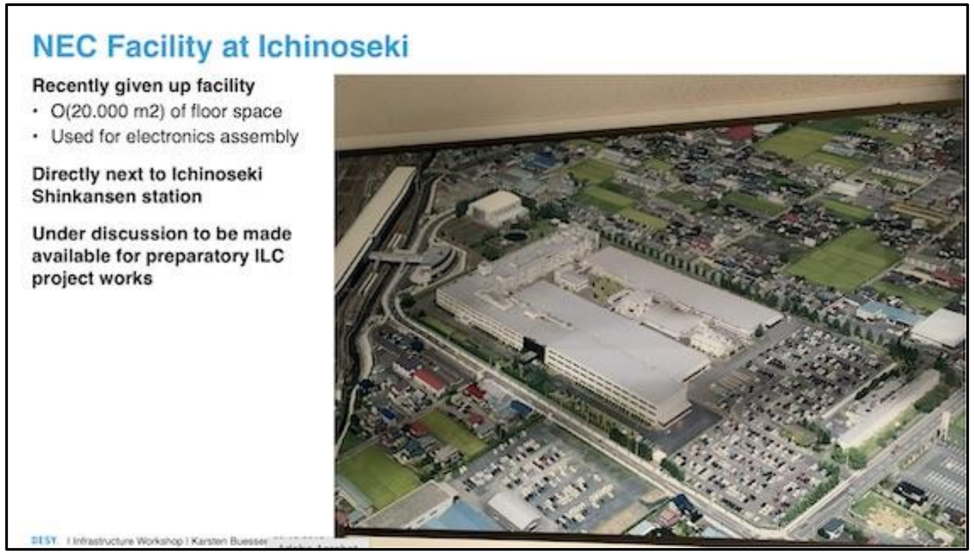
A big thank you to all accelerator session conveners!

CFS

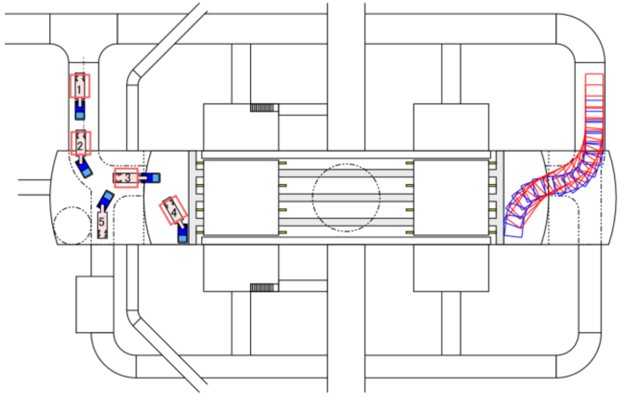
Siting and facility layout considertaions

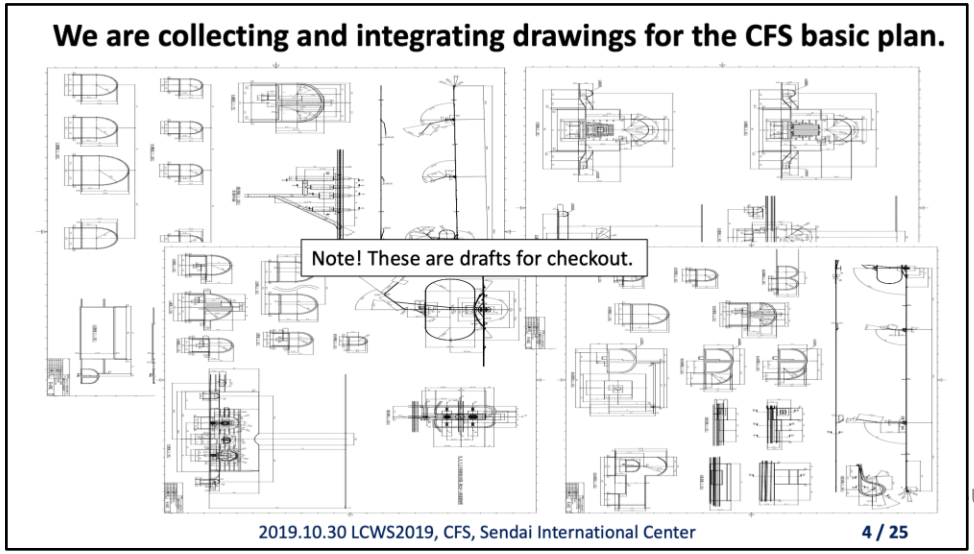


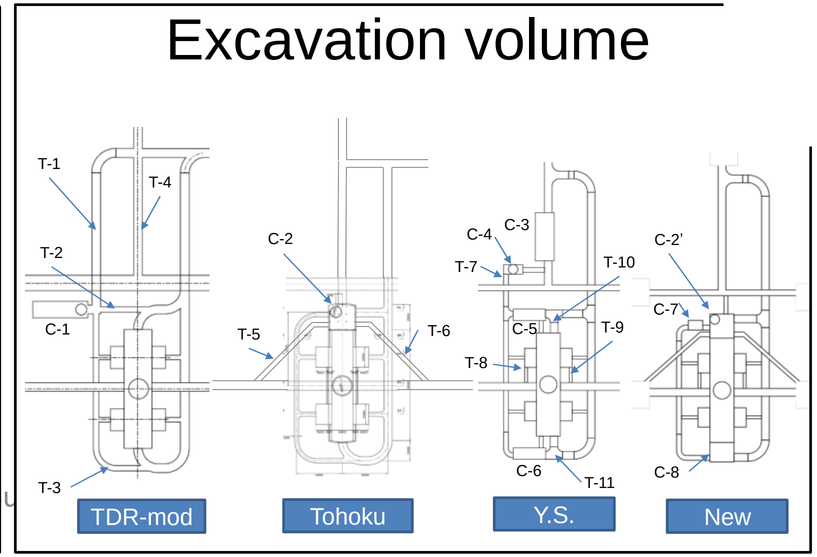
- 2 campus model
- Collection of CFS basic plan
- Volume optimization
- Layout considerations

Carry in to DH

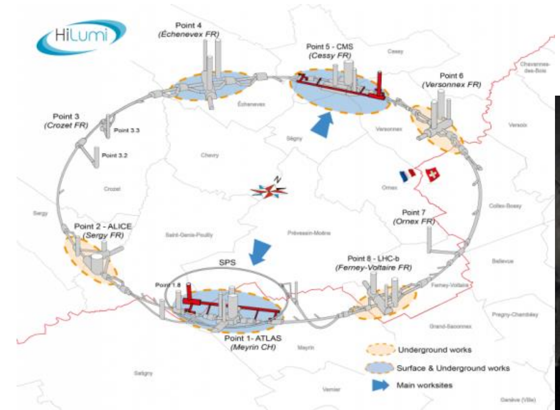
- Go forward to DH (position 4)
- After unloading, go back to 6m passage (position 5), then go forward to surface

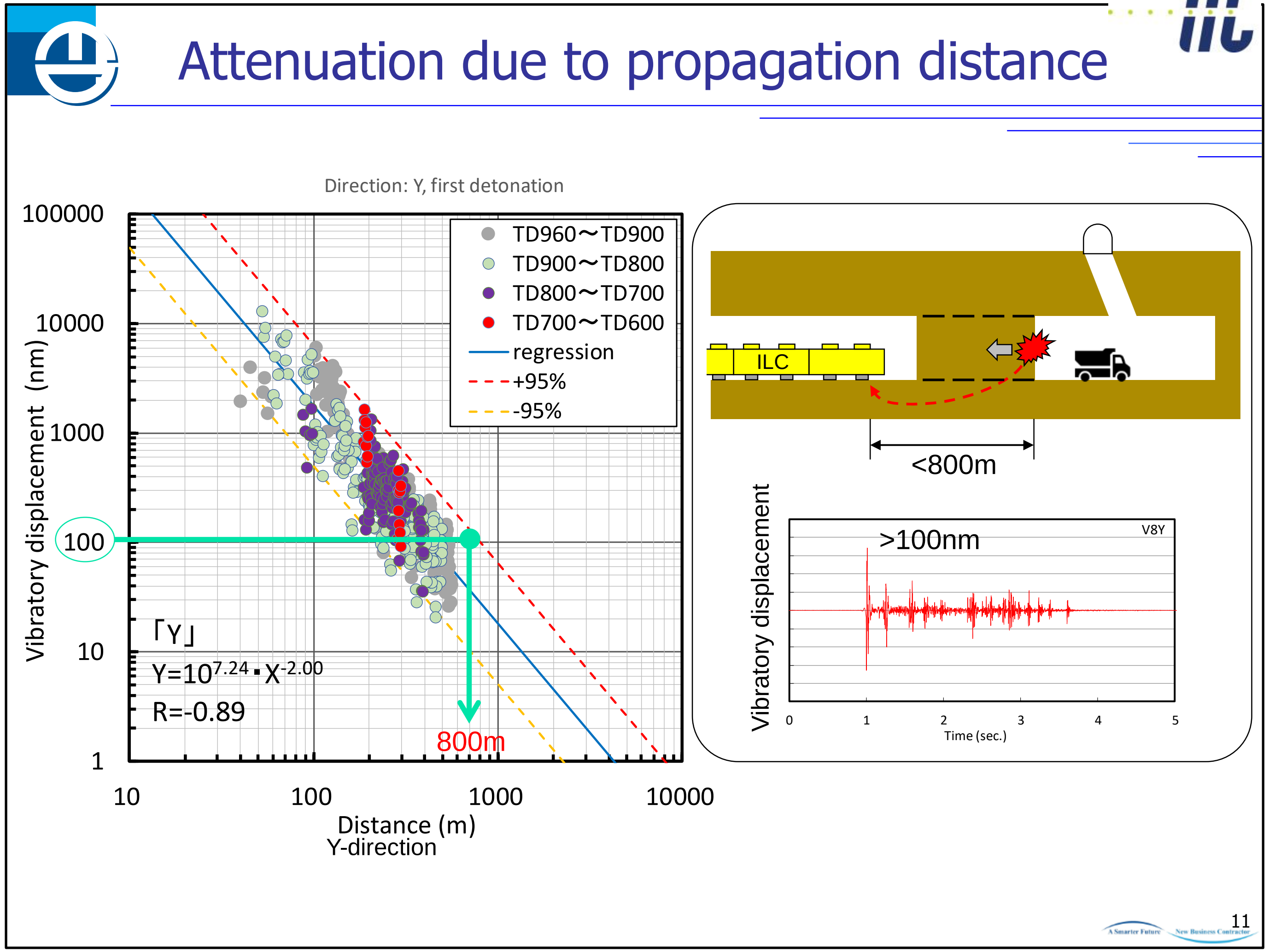




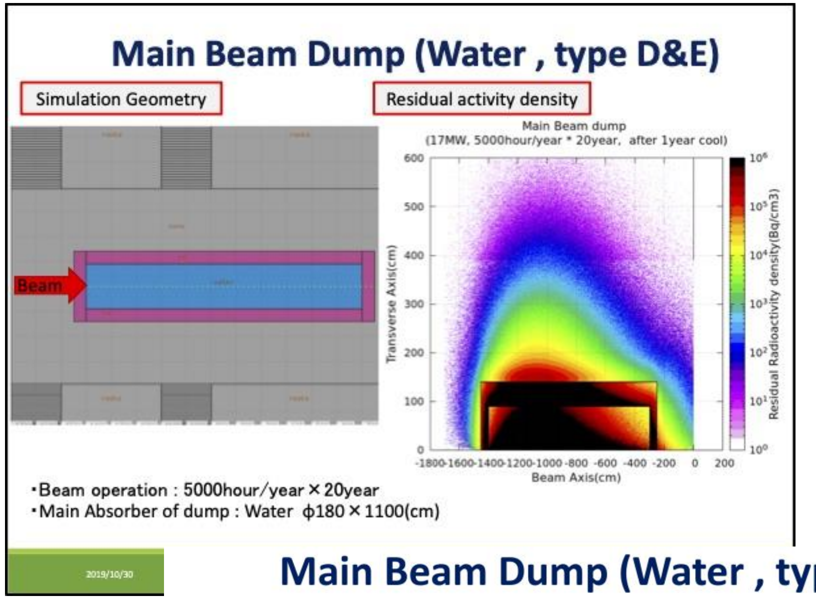


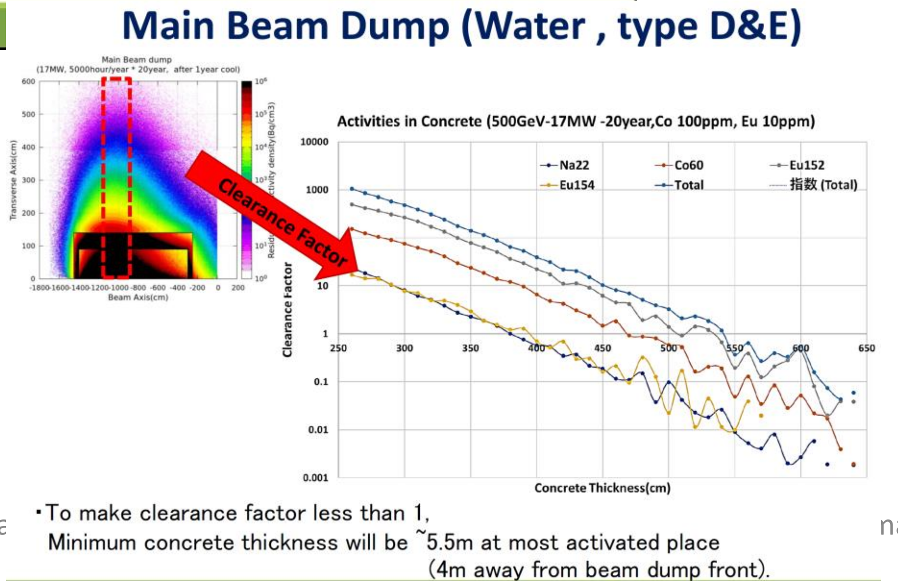
HL-LHC civil works & ILC upgrade studies



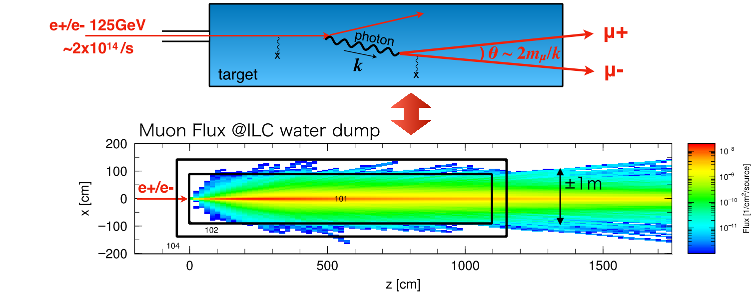


Dump shielding & Muon radiation



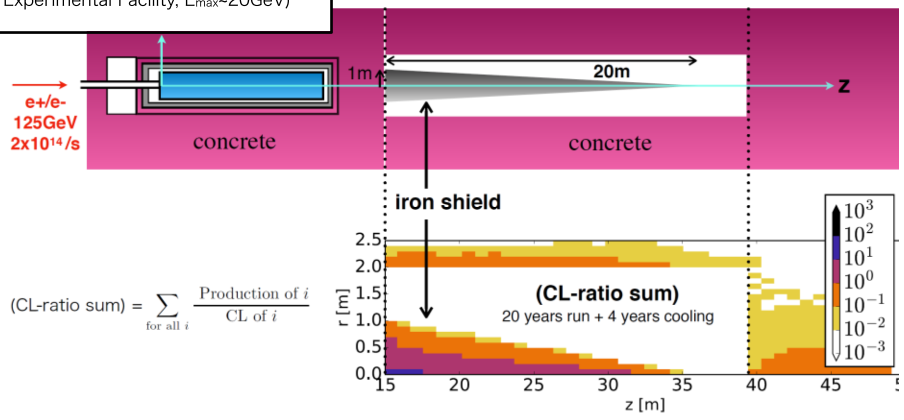


Muon production at electron accelerators



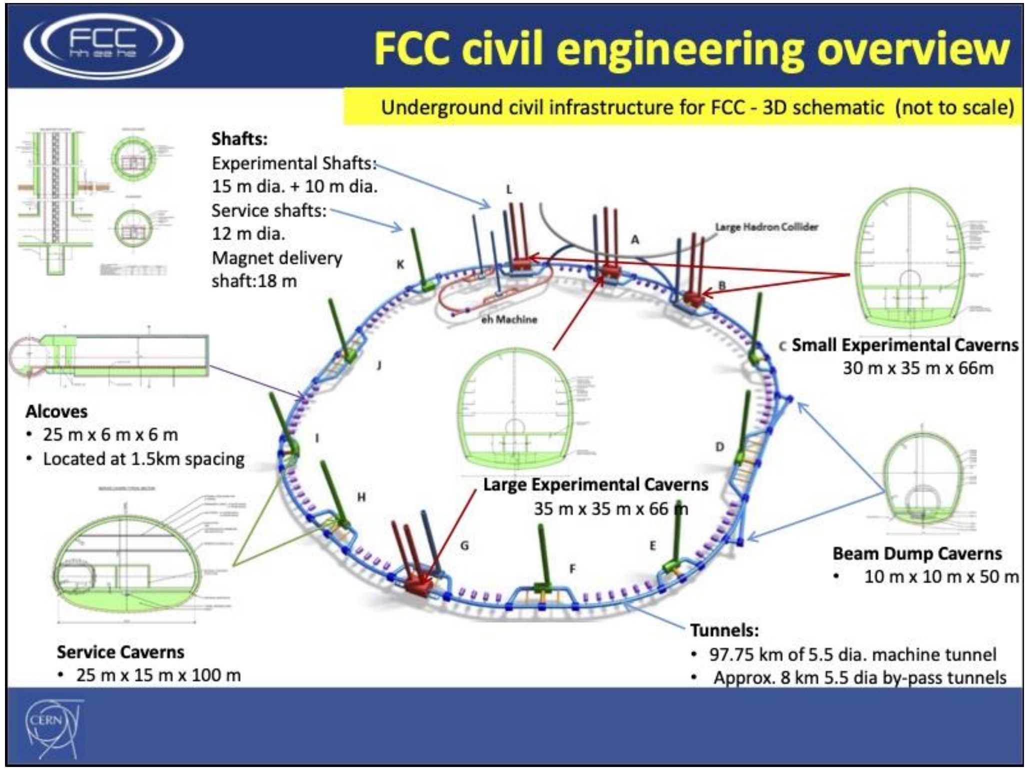
- Muons are mainly produced by pair production via bremsstrahlung in target
- extremely forward direction: $\theta \sim m_\mu/k$
- smaller cross section: $\sigma(\mu\mu) \sim \sigma(ee)/40000 \sim 0.1\ Z^2\ \mu b$
  - 10^(10-11) muons/s (ILC, E_{max}~100GeV)
  - 10^(6-7) muons/s (J-PARC. MLF)
  - 10^(10-11) muons/s (J-PARC. Neutrino Experimental Facility, E_{max}~20GeV)

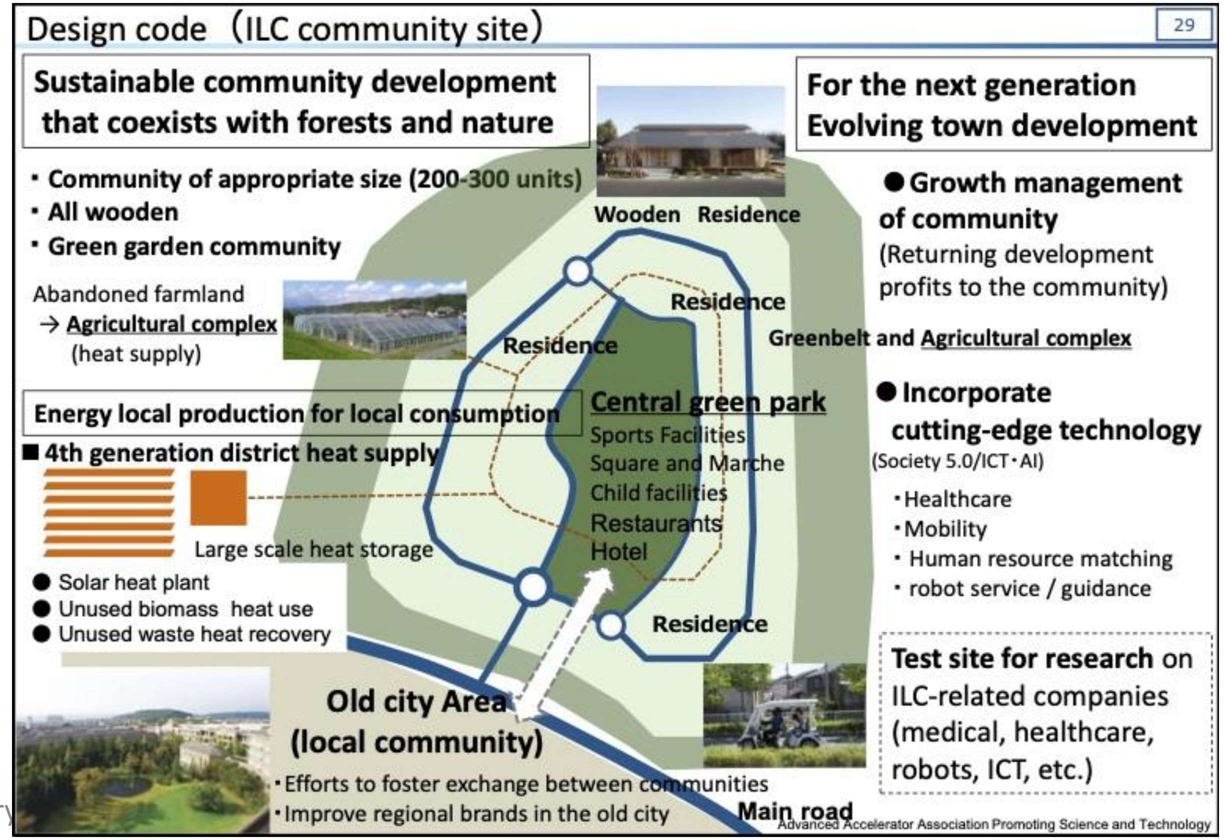
A case of muon shield



- "CL-ratio sum" becomes less than 1 except for the iron shield
- If we reduce radioactivity down to this level, radiation problems behind the beam dump at a decommissioning stage will be easier.

Infrastructure planning for FCC and CLIC / Planning of green ILC community

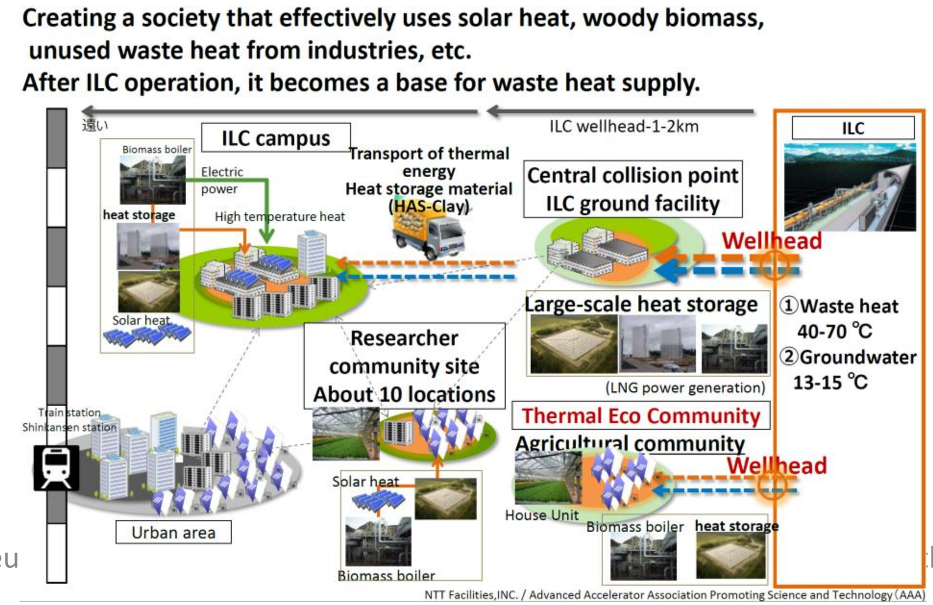


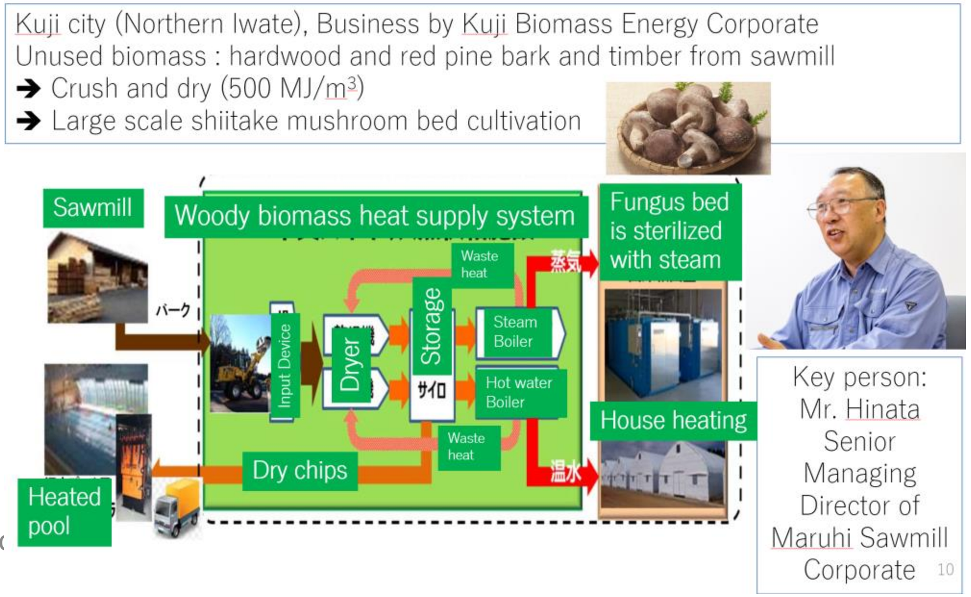


Green Accelerator

Renewable energy and waste heat usage

- Solar heat utilization project in Iwate Prefectural University based on existing technology in Denmark
- Waste heat recovery and offline transport is part of the concept (HAS-Clay)
- Unused biomass will be used in surrounding industry (e.g. wood and wood chip drying, etc.)





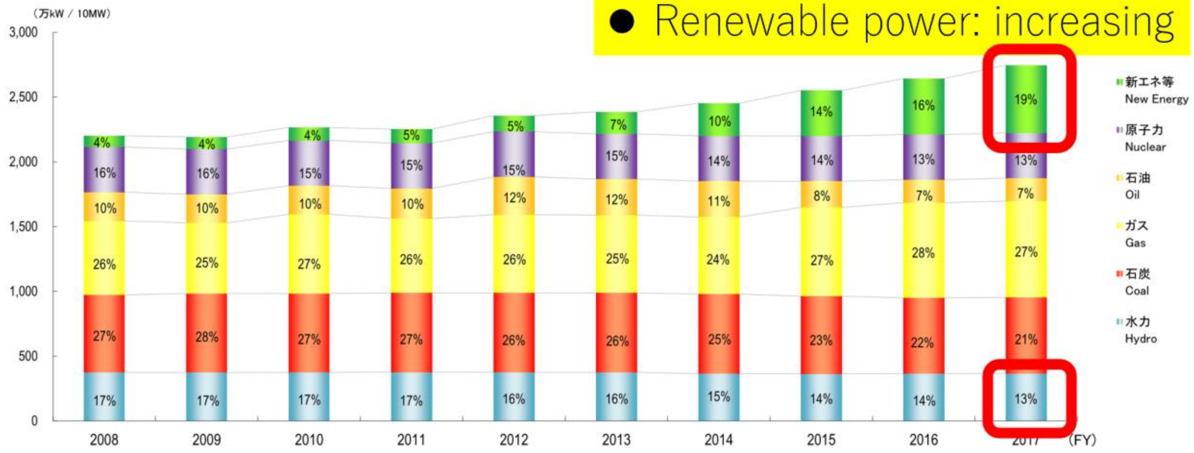
Electrical power situation in Tohoku

Annual report by Tohoku Electric Power Co., Inc.

1. 電力供給 Electric Power Supply capacity

（1）発電設備容量構成比（含他社受電） Generating Capacity by Energy Source (includin

- Total : 27.5 GW
- Hydro power: constant
- Renewable power: increasing



（万kW / 10MW）

	2008年度 [FY2008]	2009年度 [FY2009]	2010年度 [FY2010]	2011年度 [FY2011]	2012年度 [FY2012]	2013年度 [FY2013]	2014年度 [FY2014]	2015年度 [FY2015]	2016年度 [FY2016]	2017年度 [FY2017]
水力 Hydro	374	374	375	376	375	375	364	363	364	366
火力 Thermal	1,391	1,376	1,441	1,419	1,509	1,492	1,487	1,488	1,498	1,508
石炭 Coal	599	609	609	612	613	613	615	599	586	587
ガス Gas	571	546	611	575	604	601	595	686	735	744
石油 Oil	221	221	221	232	292	278	277	202	177	177
原子力 Nuclear	349	349	349	349	349	349	349	349	349	349
新エネ等 New Energy※	87	93	100	108	124	170	252	352	432	[illegible]
計 Total	2,202	2,192	2,265	2,252	2,357	2,386	2,452	2,552	2,643	27.5 GW

※ 新エネ等は，風力発電，太陽光発電，バイオマス発電，廃棄物発電，地熱発電を含む既連系の発受電設備容量
Genereting capacity by New Energy means the capacity of plants of Wind, Solar, Biomass, Waste and Geothermal, which are already connected.

Summary of electric power situation in Tohoku

- Power generation facility capacity: Total 27.5GW
  - Total renewable power: 32 %
  - ILC peak power: 0.5 % of total capacity
- Electricity sales volume in 2017: 72 TWh/year
  - Total sustainable power: 22 %
  - Nuclear power: 0 %
  - ILC power demand: 1 % of total sales

We can contract with sustainable electric power company

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Further possibilities of energy saving

- Proposal of solid-state amplifier for ILC in terms of Green Accelerator by R&K Company Limited
  - Cost per watt constantly decreasing, performance constantly increasing
  - Maybe worth to reevaluate SSAs for ILC
- Would have impact on e.g. waveguide design, LLRF systems, tunnel layout, etc.

Increase klystron and modulator efficiency

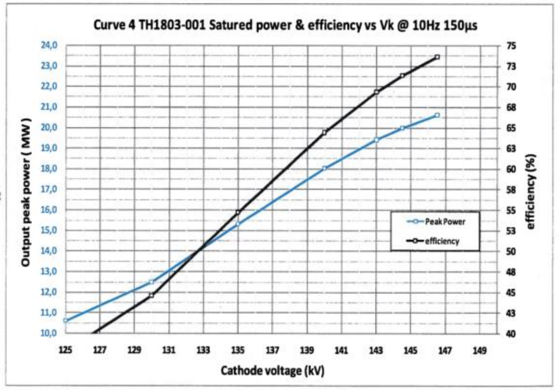
- Efforts at CERN in scope of CLIC
- Klystron prototypes tested together with Thales and Toshiba (Canon)

Thales Electron Devices TH1803

Efficiency > 73% measured during test

Test results:

f= 999,5 MHz
P_{max} = 21 MW
P_L = 150 μs
V= 146.5 kV
I= 191 A
η= 73.5 %
G= 3.41 μA/V$^{3/2}$
Gain = 51.5 dB

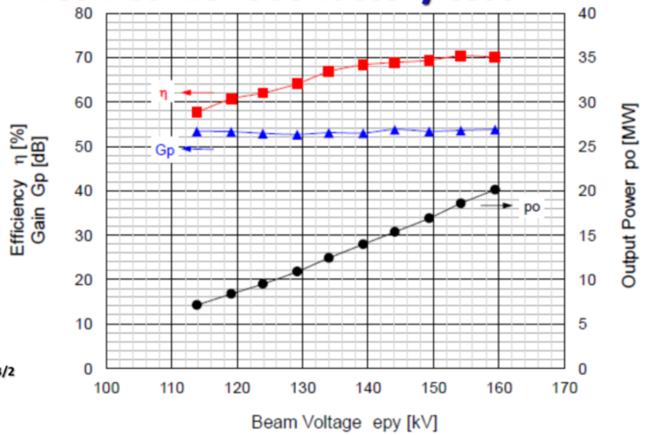


Problems:
Only useable up to 10Hz for time being
Beam loss to high close to output cavity
Large power output asymmetry, 30 %
Instable regions for operation

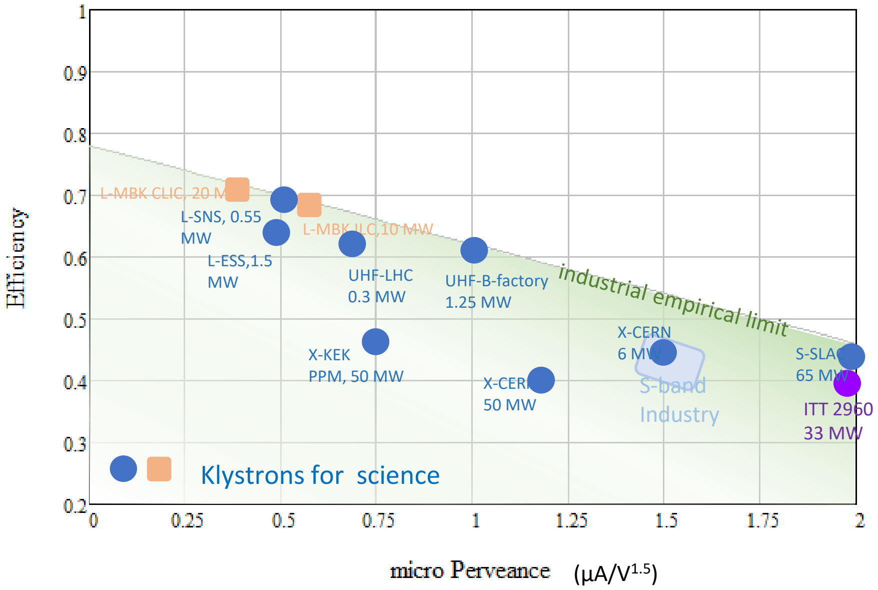
Toshiba E37503 factory test

Test results:

f= 999,5 MHz
P_{max} = 21 MW
P_L = 150 μs
V= 159.4 kV
I= 180 A
η= 71.5 %
G= 2.83 μA/V$^{3/2}$
Gain = 53.9 dB

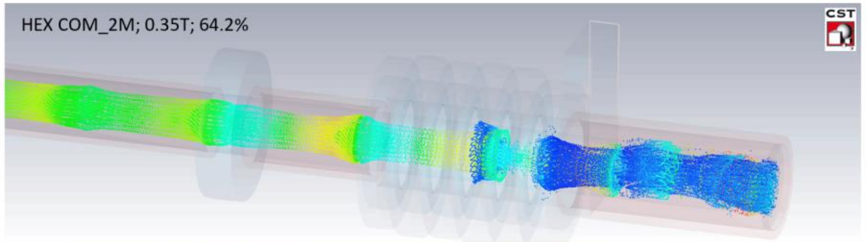


Tests done at 25 Hz and double HV pulse length, nominal 50 Hz
Stable operation over a wide range of parameters



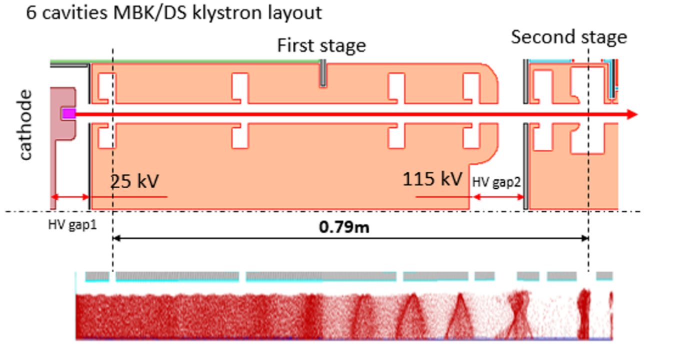
Development of new klystrons at CERN

- New bunching methods and simulation tools



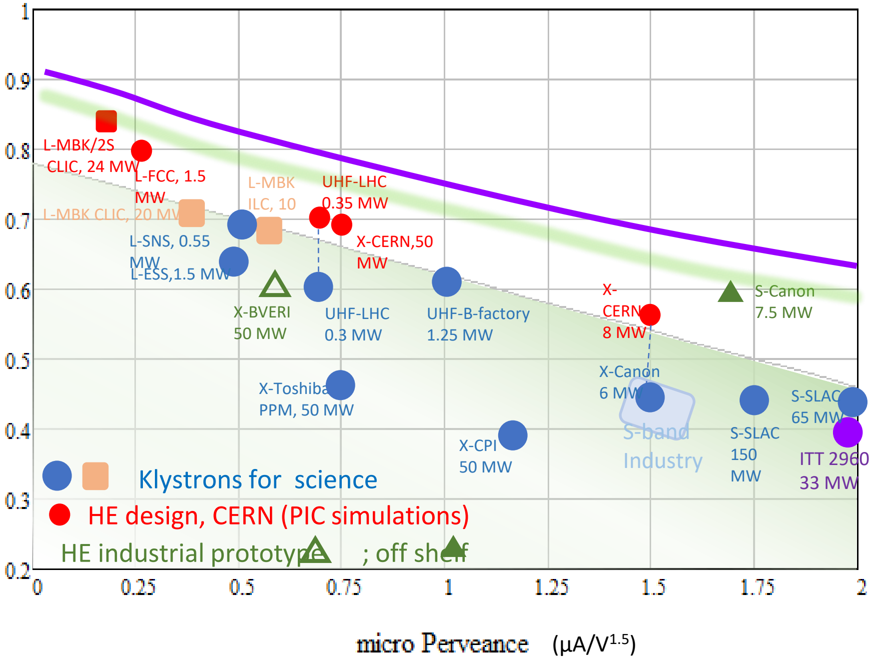
	VKX-8311A	HEX COM_M (CERN/CPI)
Voltage, kV	420	420
Current, A	322	204
Frequency, GHz	11.994	11.994
Peak power, MW	49	59
Sat. gain, dB	48	58
Efficiency, %	36.2	68.8/ MAGIC.2D
Life time, hours	30 000	85 000
Solenoidal magnetic field, T	0.6	0.35
RF circuit length, m	0.32	0.39

The CLIC MBK with **two high voltage stages**.
Electron efficiency measured in PIC simulations is **84%**.



Conceptual features:

1. Bunching at a low voltage (high perveance). Very **compact RF bunching circuit.**
2. Bunched beam acceleration and cooling (reducing Δp/p) along the short DC voltage gap.
3. Final power extraction from high voltage (low perveance) beam. **High efficiency.**



Increase klystron efficiency

A Prototype of Superconducting Solenoid for 50 MW X –band Klystron

A. Yamamoto（KEK and CERN) and S. Michizono (KEK)
W. Wuench, I. Syratchev, G. Mcmonagle, N. Catalan-Lasheras, S. Calatroni, and S. Stapnes (CERN)
H. Watanabe, H. Tanaka, Y. Koga, S. Kido, T. Koga, and K. Takeuchi et al., (Hitachi)
in cooperation with SLAC and CPI

High-efficiency RF Workshop, Uppsala Univ., 18 June., 2019

Background and Objectives

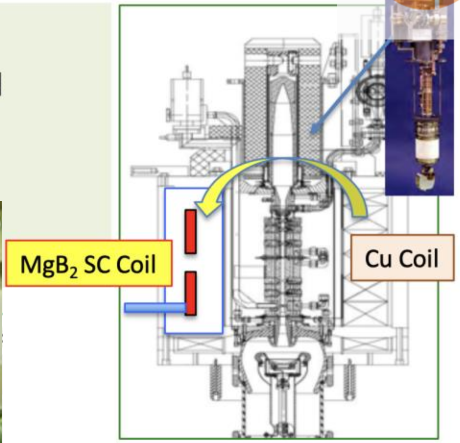
- The CLIC-380 staging scenario being studied at CERN,
- X-band (12 GHz) klystron-based accelerating scheme as a quick option.
- The X-band klystron requiring a beam-focusing solenoid and magnet field:
  - Bc = ~ 0.6 T in a warm bore-diameter of 0.24 m
- A Cu-based solenoid magnet, currently consuming
  - Power of ~20 kW/**Klystron**, corresponding to ~ 100 MW for ~ 5,000 Klystrons for CLIC-380.
- The superconducting magnet option may realize:
  - Power saving down to < 2 kW/Klystron (for , corresponding to ~ 10 MW, for Cryogenics. --> 90 % power saving

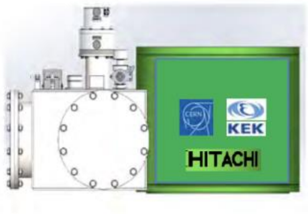
Summary: Development of a Superconducting Solenoid for X-band Klystron beam-focusing

Objective

- SC-mag technology to be demonstrated for high-efficiency X-band Klystron for future applications

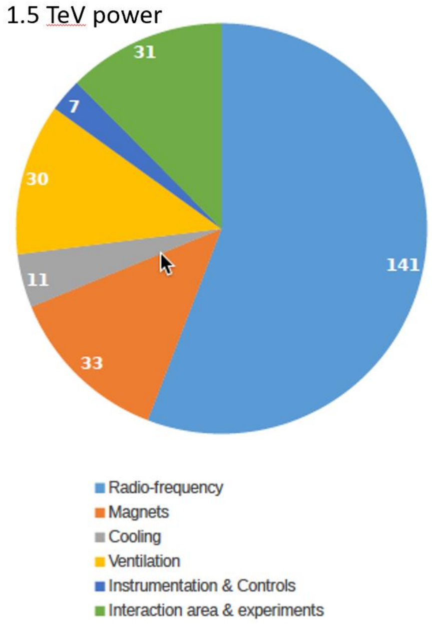
Prototype SC Magnet Design:





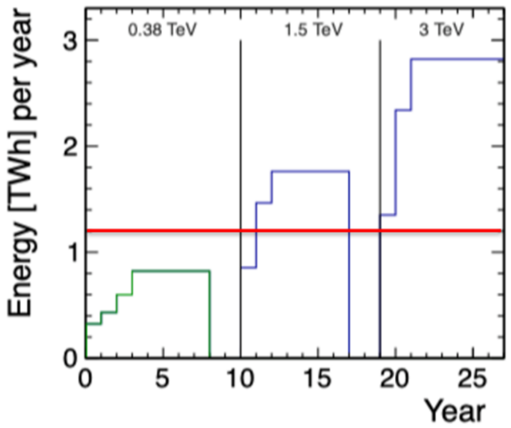
Reduction of operation cost studies for CLIC

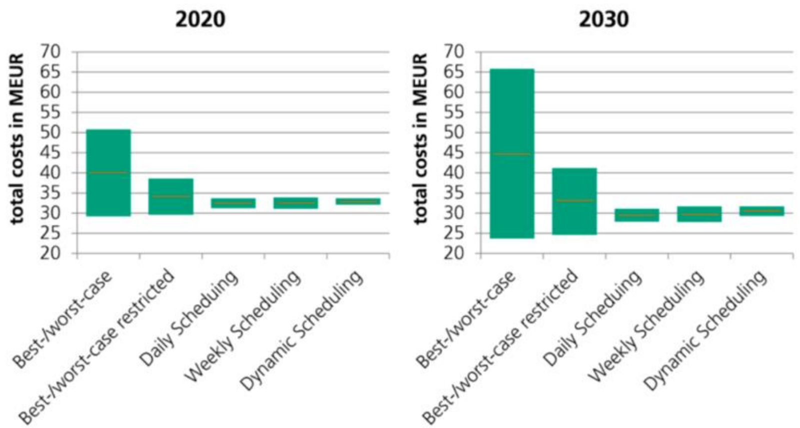
- Usage of permanent magnets (also being considered for ILC)
- Operations schedule following energy prices



ZEPTO (Zero Power Tuneable Optics) project is a collaboration between CERN and STFC Daresbury Laboratory to save power and costs by switching from resistive electromagnets to permanent magnets.

Collision Energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	168	25	9
1500	364	38	13
3000	589	46	17



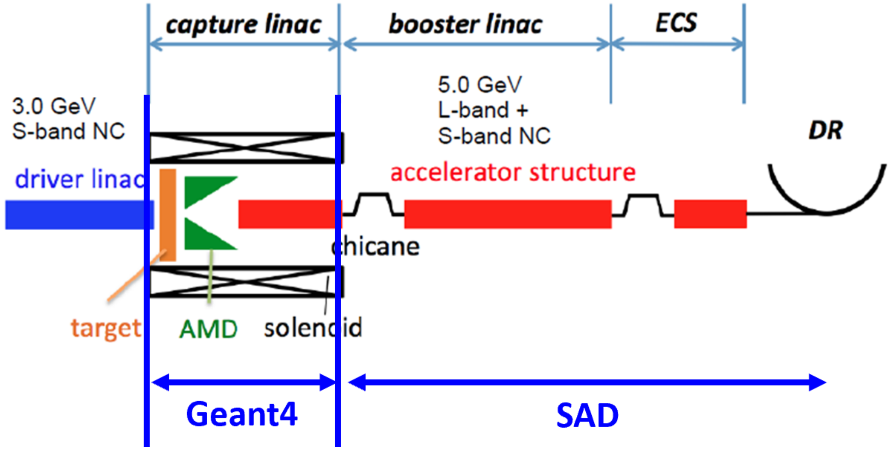


Study by Fraunhofer

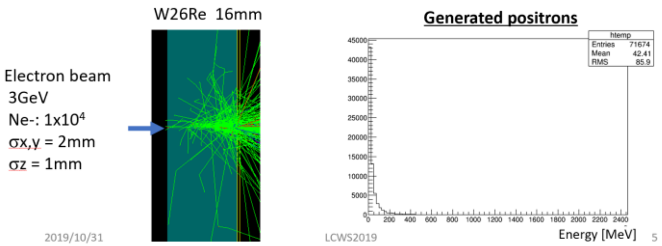
Sources

Simulation of e- driven scheme

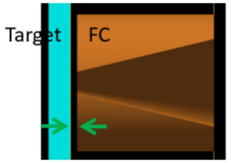
- Results from previous simulations confirmed
- Parameter scan (L-band Vacc, z offset, chicane angle, etc.)



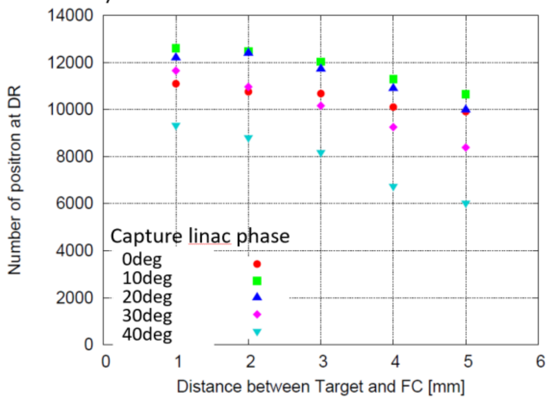
Primary e- beam
Energy: 3GeV
Number of electron: 1x10^4
Beam size on the target: 2mm (1σ)
Bunch length: 1mm (1σ)
Target: W26Re, thickness 16mm
Number of generated positrons: 7.17x10^4



Scan of distance between Target and FC



Yield increase from 1.06 to 1.26 when the distance is changed from 5mm to 1mm.
The yield saturates less than the distance of 2mm.



Distance between Target and FC [mm]	Ne+(DR)	Yield(DR)
1.0	12601	1.26
2.0	12472	1.25
3.0	12042	1.20
4.0	11292	1.13
5.0	10646	1.06

Primary e-: 10000

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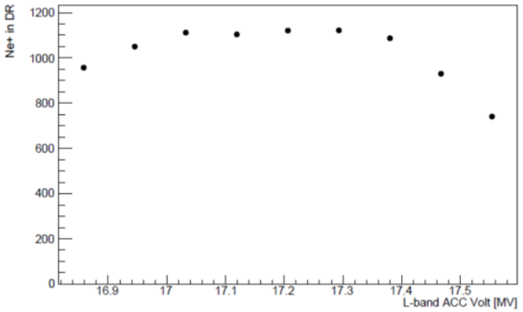
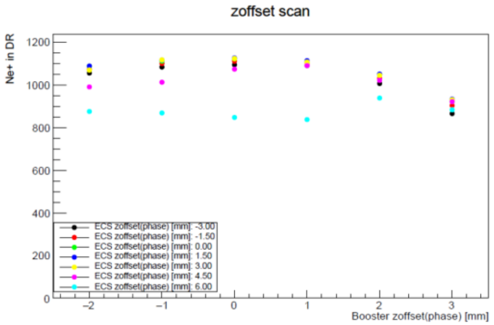
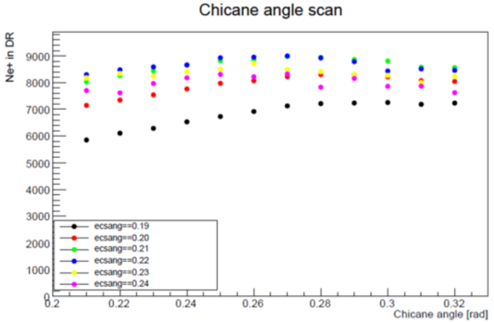
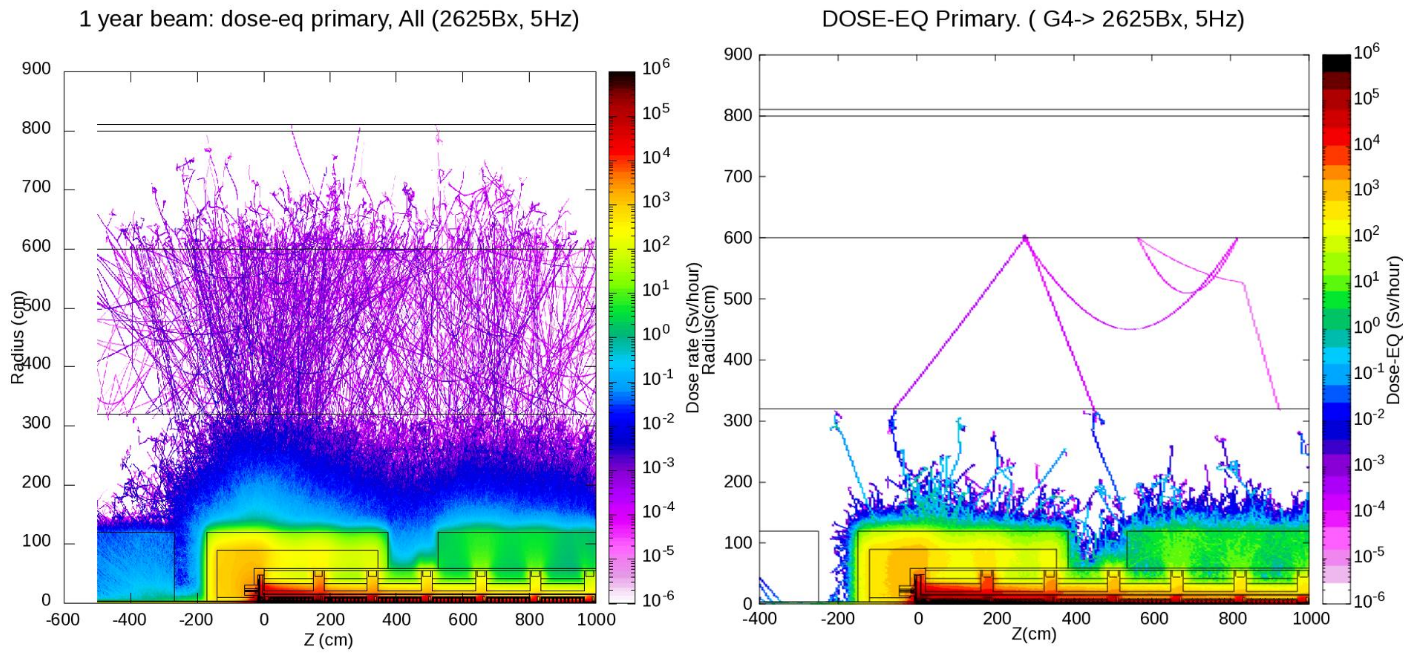






Simulation of radiation environment of e-driven positron source

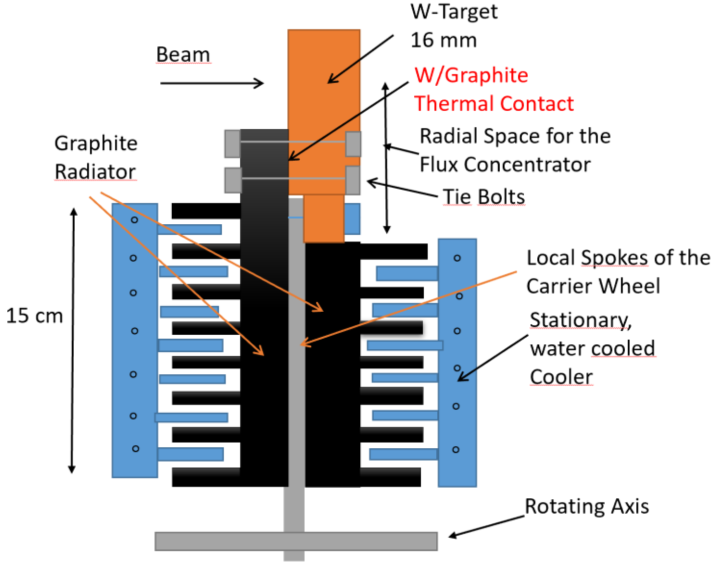
- Realistic geometries, but not actual ones yet
  - Gives an idea for following engineering design
- Developed tools can be used for final design



Fluka alone and Fluka with G4 data are consistent, though limited statistics.

Thermal radiation cooled conventional target

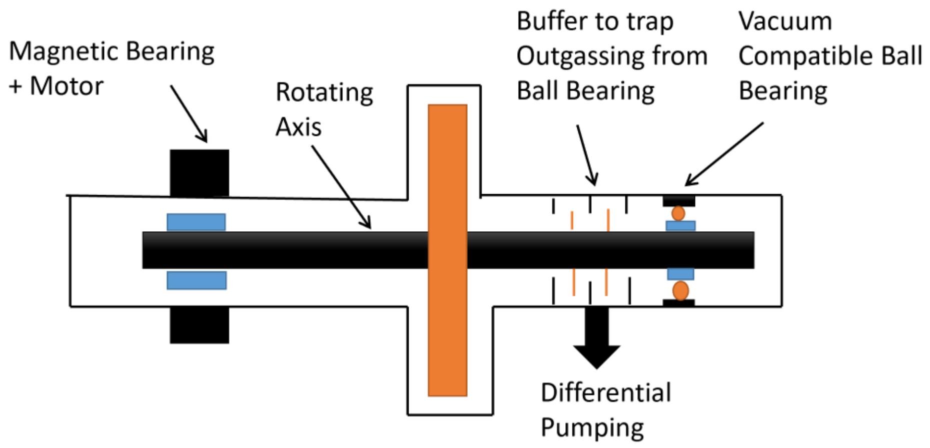
Conventional Target:
Radiation Cooled Rotating Wheel



Design Parameters:

- For a radiating surface of 2 m^2, the wheel should have a diameter of of 1.0 m! , rotating at 100 rpm, velocity at rim 5,2 m/s (plenty to separate beam pulses).
- Weight: W$-$Target $\sim$50 kg + C-Radiator 30 kg + Axis = $\sim$100 kg.
- Such a weight must be carried by two Rotating Magnetic Bearings or by Vacuum Compatible Ball Bearings, at low 100 rpm.

Options for Rotating Bearings.



- Cooling of the rotating W-target wheel by heat radiation avoids the use of a vacuum tight rotating seal.
- Operating the W-target at temperatures of 500-600 deg C with Graphite radiators, average powers of around 26-29 kW can be evacuated.
- Such a wheel needs a diameter of about 1 m and a weight of 100 kg.
- This enlarged wheel will have a longer lifetime.
- Vacuum compatible Rotating Ball- or Magnetic Bearings must be validated.
- The efficiency of the radiation cooling can readily be checked in simple laboratory tests.

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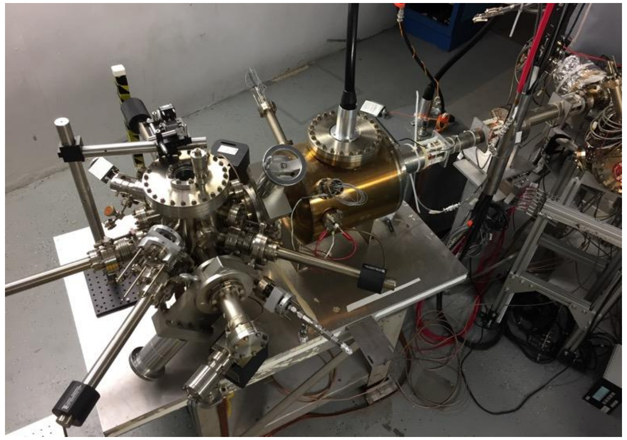
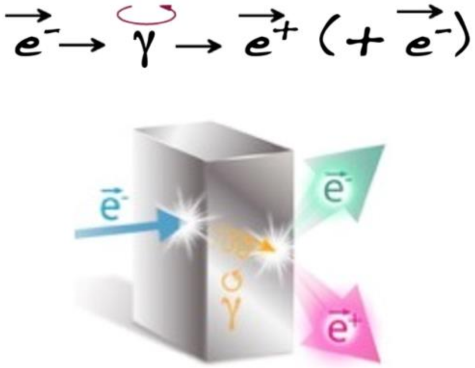
Polarized Electron Source R&D at JLab

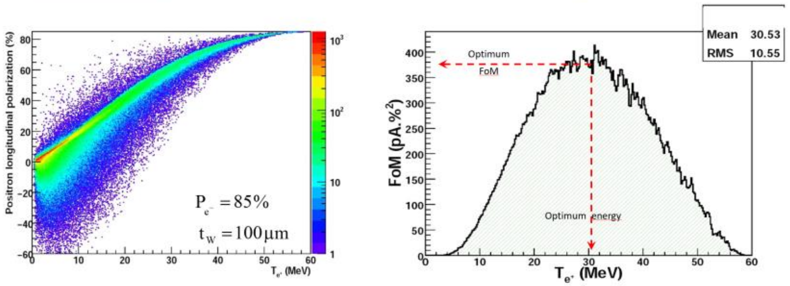




PEPPo : Polarization & Intensity Tunability

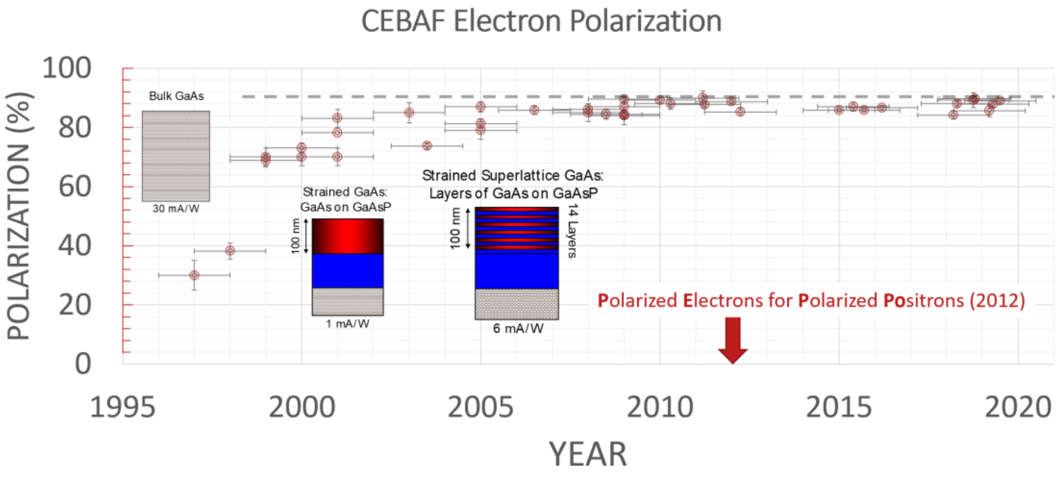
The polarization transfer can be high but the distribution is dominated by **low-energy events**.

A general feature is the positron energy at the optimum FoM (P^2I) is **about half** of the electron beam energy.



J. Dumas, J. Grames, E. Voutier, JPos09, AIP **1160** (2009) 120

Electron beam polarization from GaAs (1997 – 2019)



PEPPo for e-driven ILC

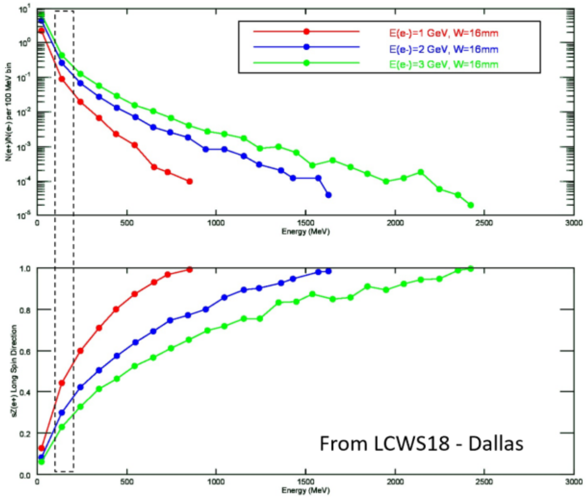
If the **e-driven source were polarized**, then some degree of spin polarization should be transferred to the collected positrons.

Two simulation exercises could be interesting:

- ✓ Compute spin polarization for baseline parameters of e-driven source.
- ✓ Explore if there is an optimum by adjusting the drive beam or collection energy

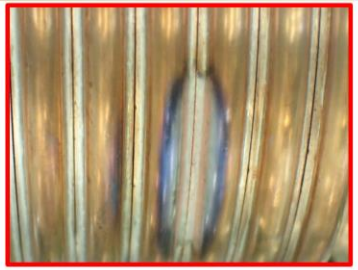
E(e+)=150 MeV, W=16mm

E (e-)	N(e+)/N(e-)	<Sz>	P (%)
3 GeV	0.436	0.23	21
1 GeV	0.091	0.44	40



SuperKEKB positron source

- Old material

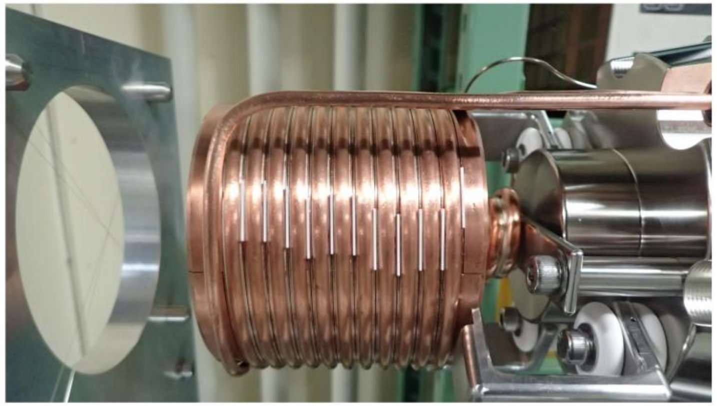


Avoid discharge
→Reduce electric field between gap
→manage slit distance
→avoid deformation

- New material for FC (flux concentrator) head

  - Be care about yield strength after brazing
  - New Cu alloy NC 50 has promising properties
  - Preliminary test shows very good result
  - Insertion of ceramic plate works well
    - Further investigation is needed

Insertion of insulator plates in the slits



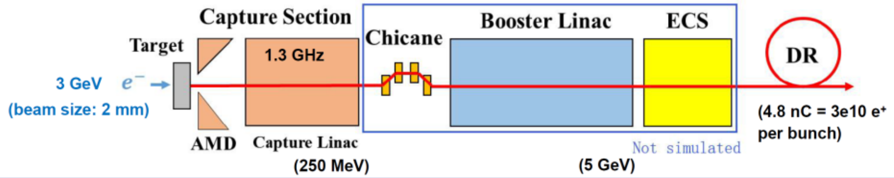
20mm x 25mm x 0.2mm or 0.3 mm Zirconia (ZrO_2) plates are inserted from 3 direction

It works well but not perfect
→discharge decreased but happened
→further investigation is needed

Positron source optimization studies at CERN and Shandong University

Cross-check with ILC

- ILC positron source (**e-driven**) quite similar as CLIC, which can be used to **cross-check** and **validate our code**
- Cross-check based on talks from **Nagoshi-san** and **Fukuda-san** on **LCWS2018**, and discussions with the team (Fukuda-san, Takahashi-san, Kuriki-san, Wanming, etc. To whom I give all my thanks!)
- Main **difference** from CLIC: rotating single target; standing wave (SW) structures used after AMD instead of TW; injector linac replaced by a booster linac in ILC.
- But booster linac is not simulated, a **time window** $\pm$**7 mm/c** used for damping ring (DR) acceptance instead



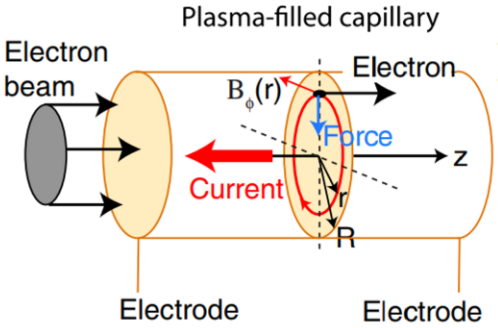
A new simple optimisation method

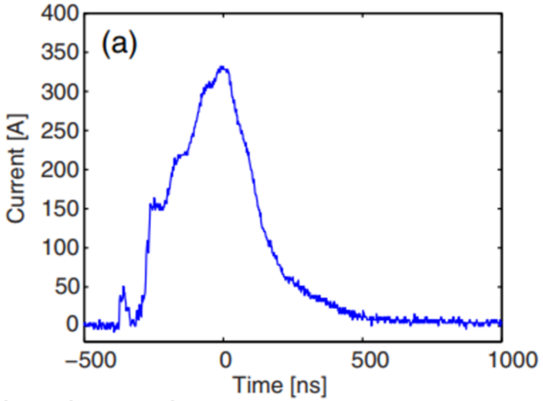
- The new method is a **global** optimisation (parameters optimised **simultaneously**), based on the '**start-to-end**' optimisation used by previous studies
- But instead of using **Nelder-Mead** algorithm (used by Yanliang), we propose a **new strategy** based on a simultaneous scan:
  ① Provide initial values as a **starting point**, and **Scan** parameters **separately but simultaneously**, and find optimised parameters (during a scan of one parameter, the other parameters are fixed)
  ② Use **all optimised parameters** (or **best one from scan** if it's better) as a **new starting point** for the next scan
  ③ Continue the **iterations** of scan until we find **final** optimal parameters (parameters are **stable** and results can not be improved)
- **Advantages** of the new strategy:
  - ✓ **Much faster** (**weeks → hours !**) and **simpler**
  - ✓ More **reliable and convincing** results (**visual** scan plots, not like Nelder-Mead algorithm which is a black box)
  - ✓ Allow us to see **individual effects** from parameters

- Latest **preliminary results** using the new method **presented** and **compared with previous CLIC results** for the **380 GeV** stage, with final e^+ **yield** and **PEDD** improved to about **1.7** and **25 J/g**. And final yield found to be **linearly increased** with primary e^- energy (**~0.35·E**, PEDD not changed much)

Plasma Lens as possible alternative Optical Matching Device (OMD)

- OMD alternative to flux concentrator (FC) & quarter wave transformer (QWT) at ILC by M. Fukuda (today's talk at 10.30 am!)
- High potential for positron yield improvement due to azimuthal magnetic field
  (→ radially symmetric, decreased chromatic aberration & focal length)
- Lots of on-site expertise at DESY and Uni HH (Dr. Floettmann, Dr. Osterhoff, Prof. Gruener)
- If simulations are promising:
  → prototype at DESY-site possible

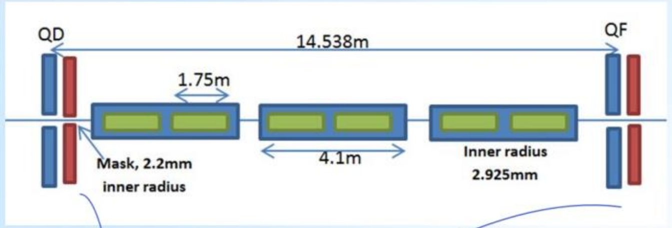




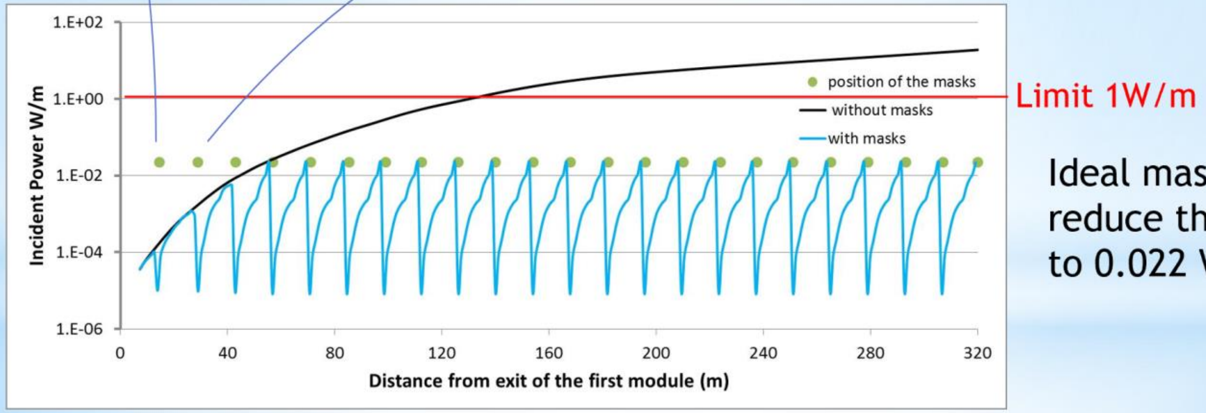
Gas filled capillary (e.g. with H_2)
Applying voltage pulse (some kV) by electrodes
→ Ionization: gas ions + e^- = plasma
→ Axial electric discharge current pulse (some 100 A)
→ Azimuthal B-field (similar to an ordinary wire)
→ Radially symmetric focussing of particle beam (little interaction with plasma)

Energy and temperature simulations in photon masks at ILC undulators

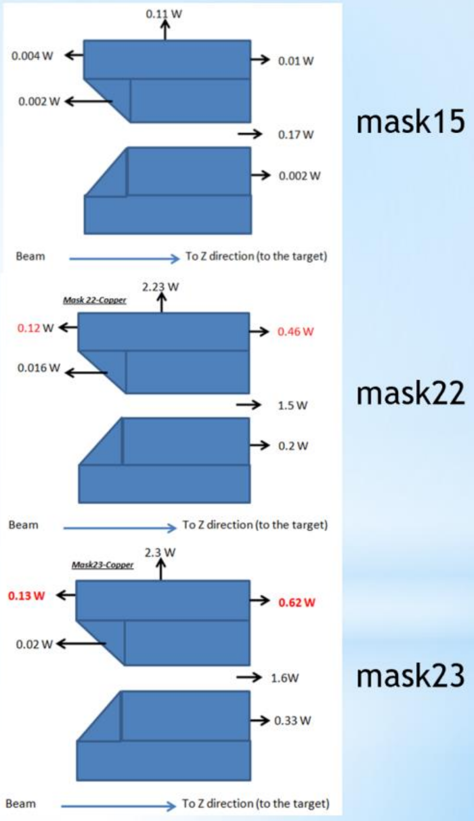
Power Deposition without and with Photon Masks

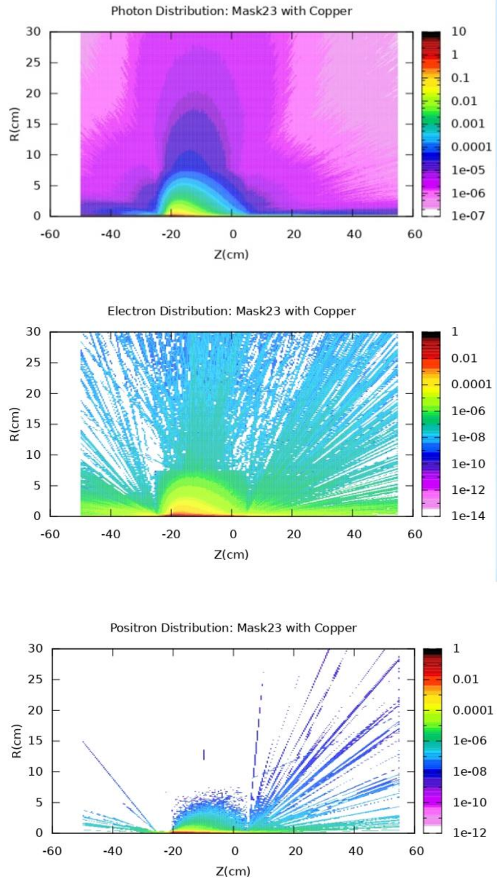


- ILC TDR: mask with 2.2mm radius was chosen.
- Masks placed behind Quadrupoles.



Ideal masks can reduce the peak to 0.022 W/m.



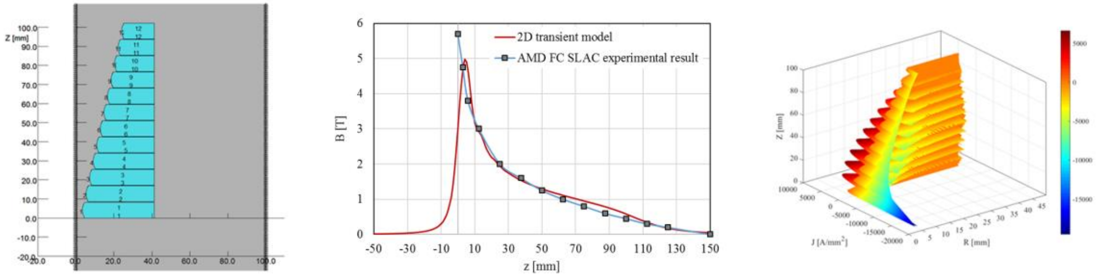


Flux Concentrator Opera Model

- To understand the **working principle** of an Adiabatic Matching Device Flux Concentrator (AMD FC) by the mean of **electromagnetic models** using Opera® software

Comparison with experimental result

- SLAC design is modelled. It includes:
  - 200 microns gap between the turns
  - Round conductor tip (for numerical singularity removal)
  - Excellent agreement between numerical and experimental curves



- Development of a **parametric numerical model** of Flux Concentrator using Opera software.
- Understanding of the field boost as the creation of **Eddy current loops circulating in opposite directions** in each turn. Phenomenon that only occurs in the case of tapered solenoid in transient mode. The **current flows only within the skin depth** of the conductor.
- **Validation of the model** and measurement by direct comparison of the field profile.
- Possible optimisation of the design thanks to **sensitivity analysis** for future FC.

Warm RF

Different production approaches

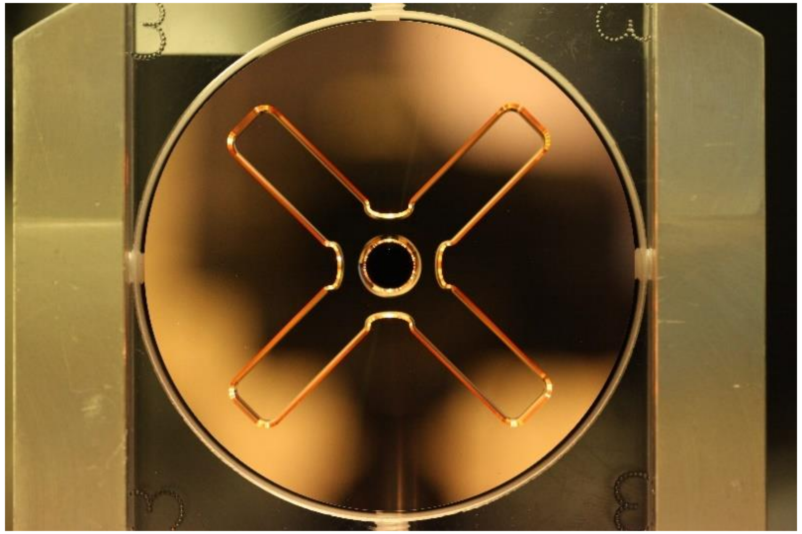
- Round disk*
- Square disk
- Half structure
- Quarter structure**

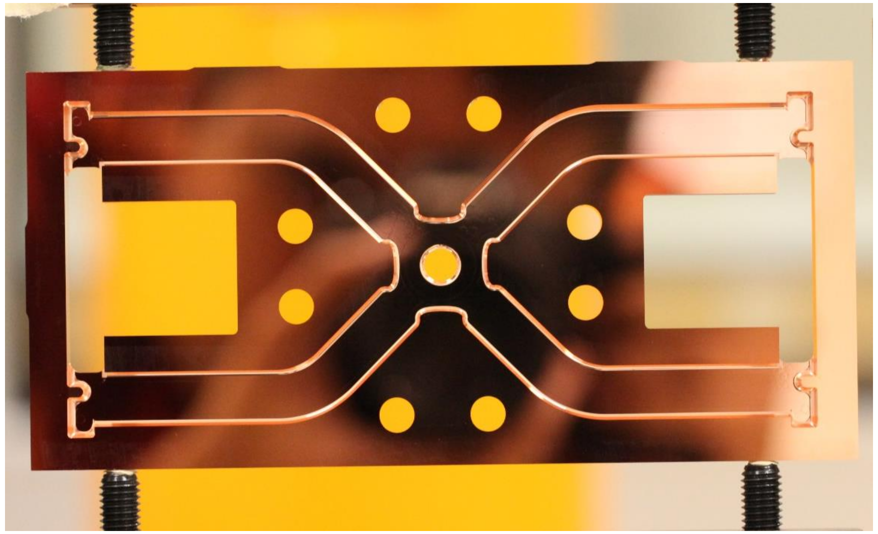
* ■ Advantages
- ✓ Machining by turning for main parts
- ✓ Very smooth surface (Ra = ~30 nm)
- ✓ Shallow machining damage (depth < 1 μm)

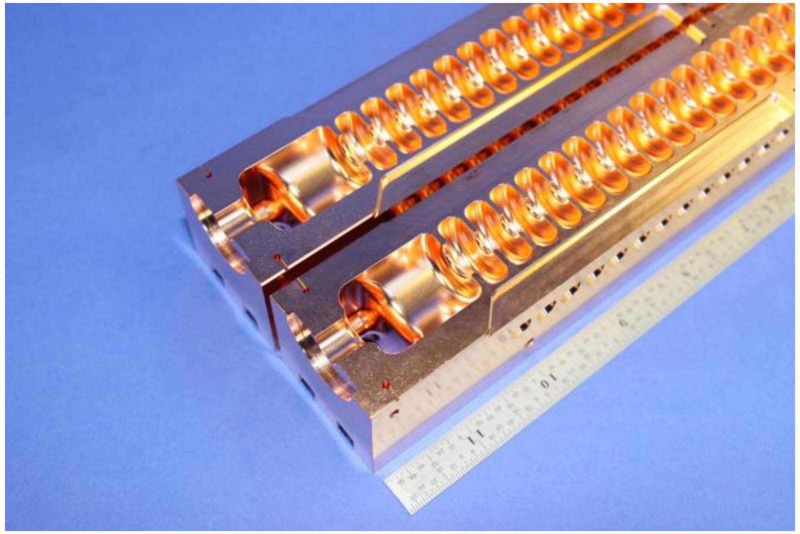
■ Disadvantages
- ✓ Ultraprecision machining of dozen of disks
  → Delicate stack and bonding
- ✓ Great care needed to be taken
- ✓ **Surface currents flow across disk-to-disk junctions.**

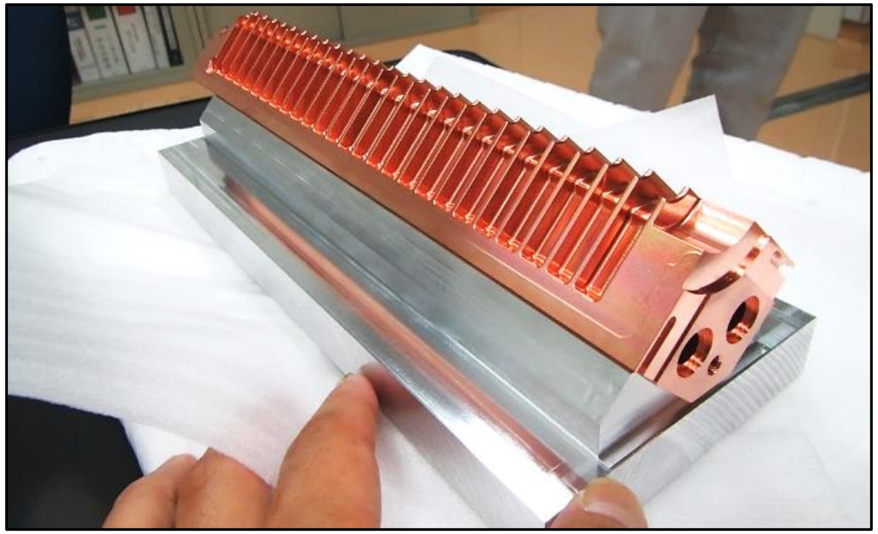
** ■ Advantages
- ✓ **Surface currents do not flow across any bonding junction.**
- ✓ Simple machining by five-axes milling machines
- ✓ Simple assembly process with FOUR parts only
  → Possibility of significant cost reduction

■ Disadvantages
- ✓ Not very smooth surface (Ra = ~ 0.3 μm)
- ✓ Deep machining damage (~10 μm?)
- ✓ **Possible virtual leak from quadrant-to-quadrant junctions**
- ✓ **Field enhancements at the edges of quadrants**

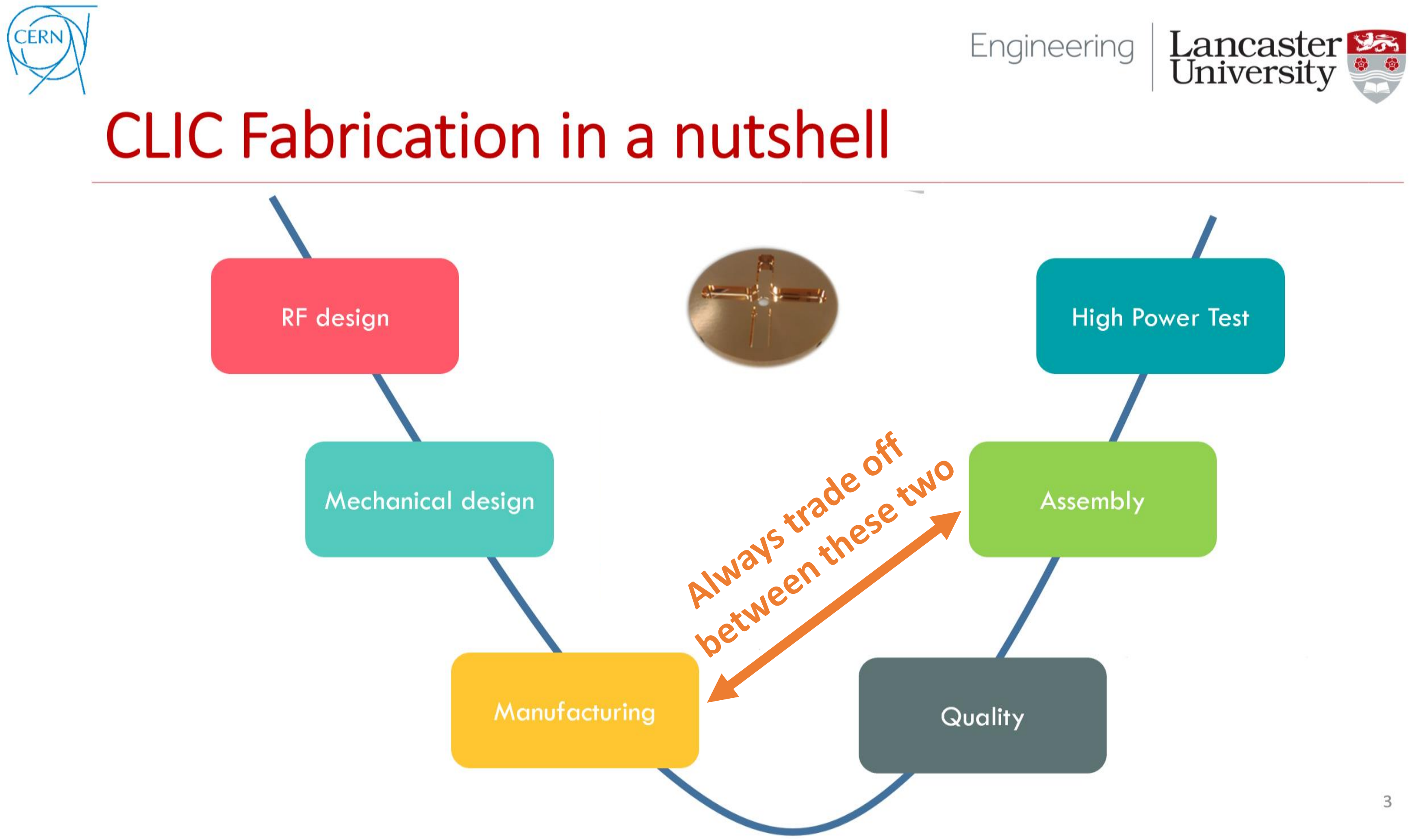






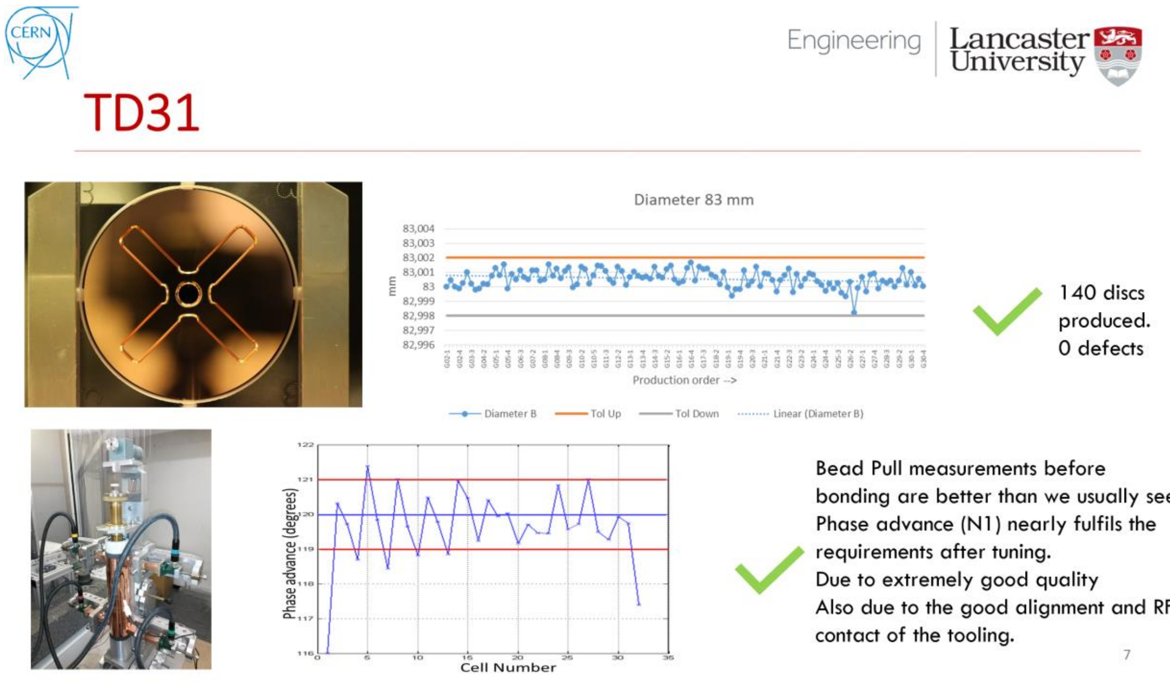


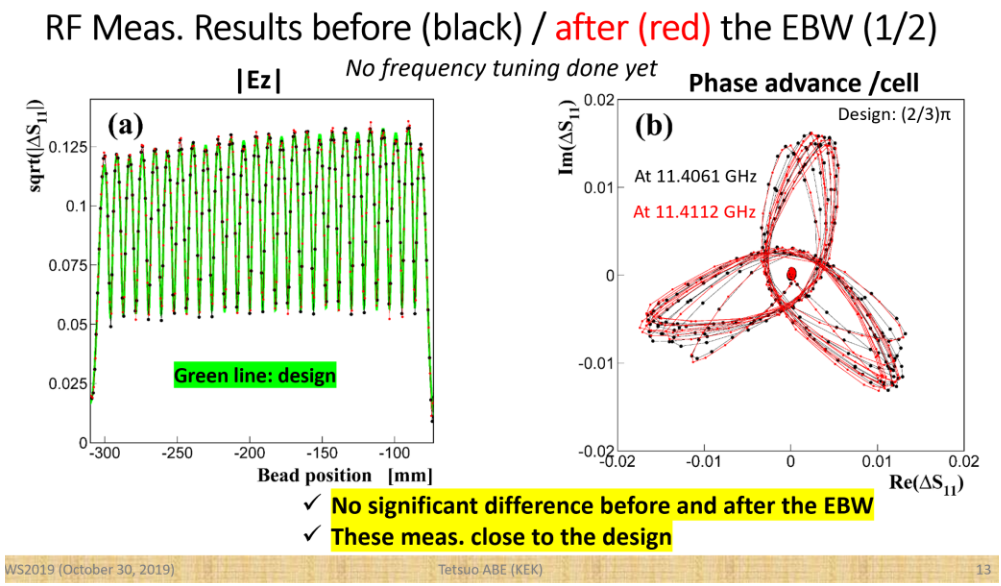
Fabrication

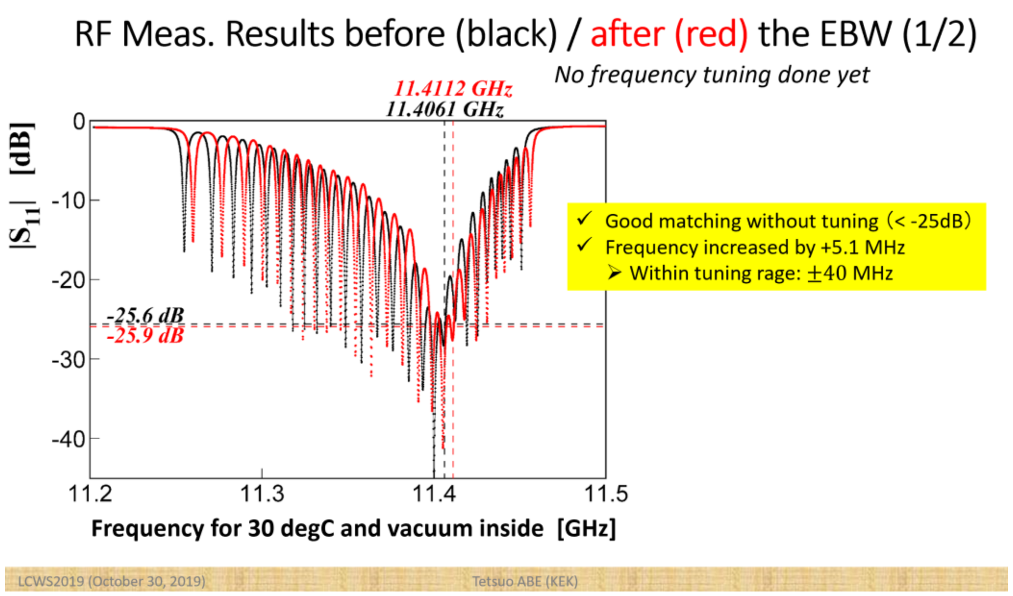


High precision manufacturing

- Excellent performance even before tuning

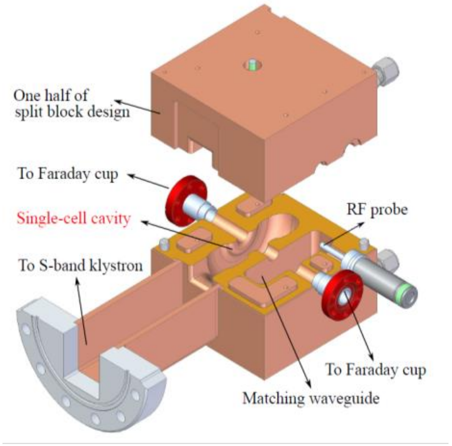




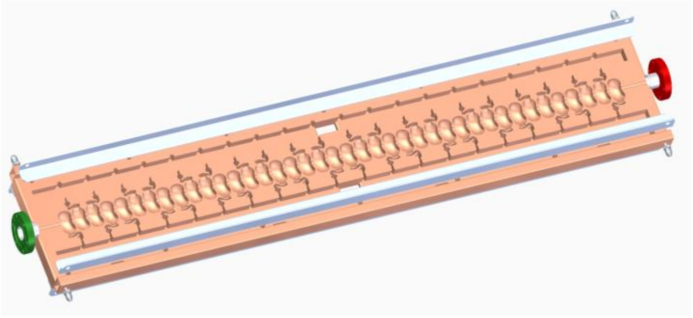


R&D for large frequency range at SLAC

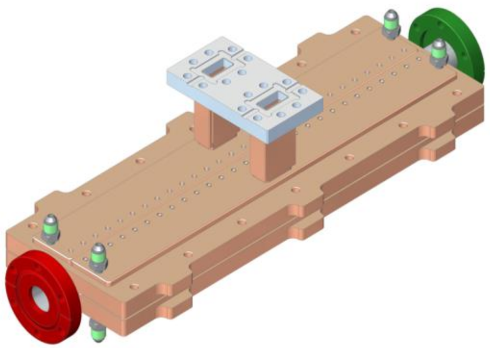
S-band



C-band

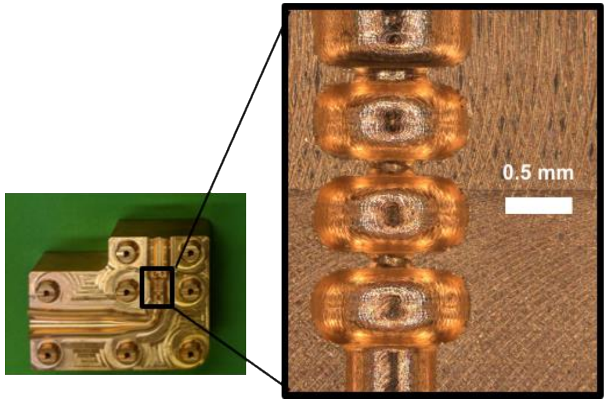


X-band



108 GHz

300 GHz

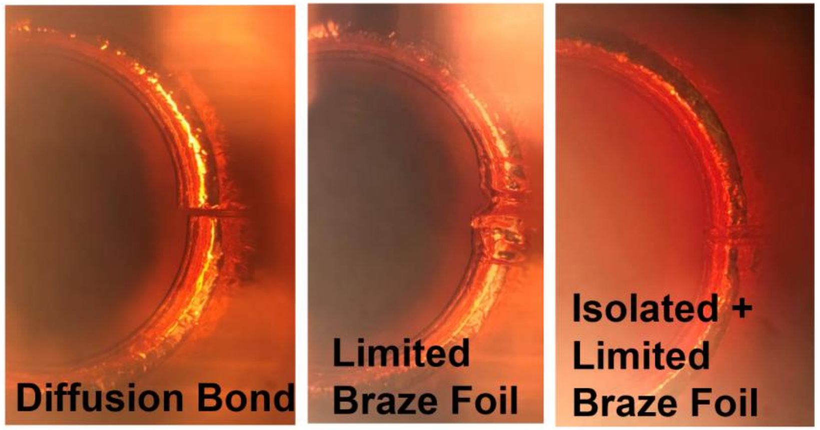


Assembly R&D at SLAC

Comparison of Assembly Techniques

SLAC

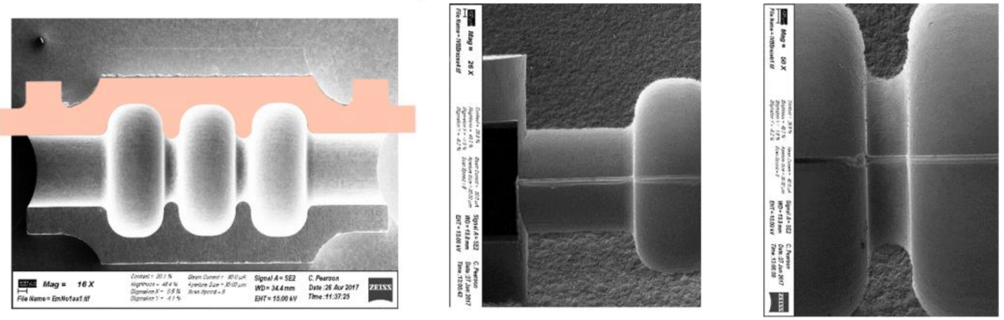
- Assembly from halves makes RF performance insensitive
- Local features significantly different



Details of Brazed Assembly

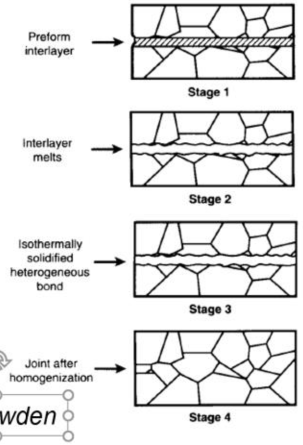
SLAC

- New techniques and approaches needed for fabrication
- Successfully adapted split-cell approach to mm-Wave/THz range
- Braze foil tailored to cavity shape to control volume

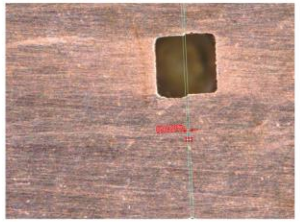


Tin Diffusion-Brazing – Low-Temp High-Pressure

SLAC

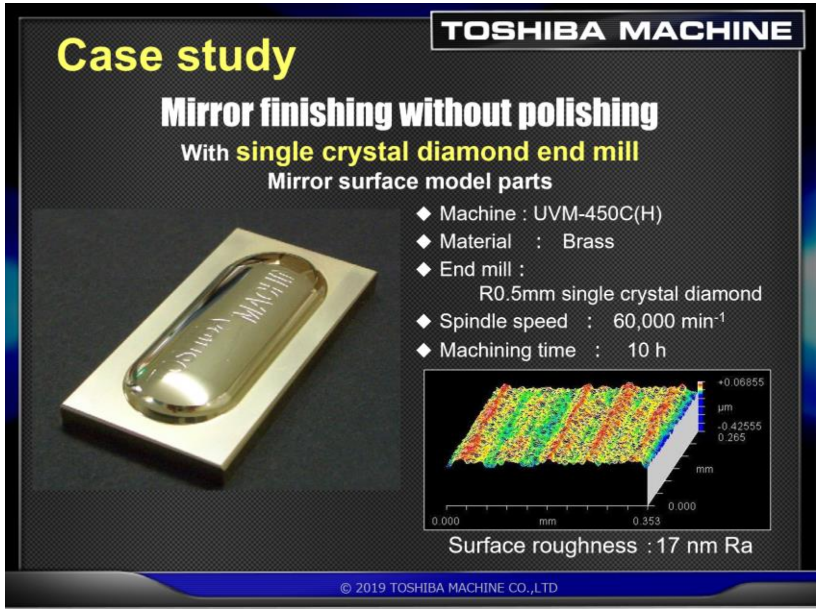


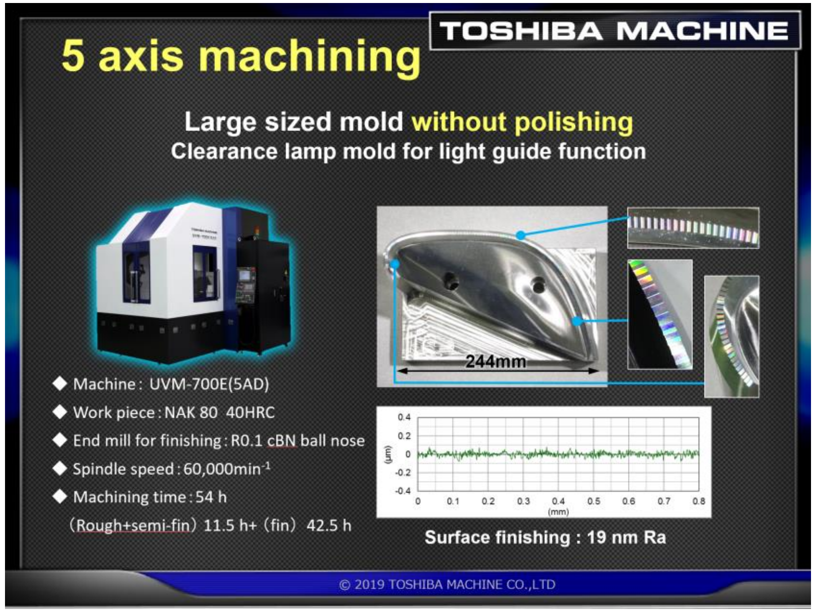
- Coated full structure on one half with tin
- Good bond achieved – proceeding with further tests
- Future work will include coat and then machine cavities



G. Bowden

State of the art milling





- Further discussions
  - Milling technique
    - Time consumption has to be reduced (quarter CLIC multicell structure at KEK took one week to be manufactured)
  - Turning vs milling

High power RF tests at CERN

High Power Test Stands at CERN

To test the novel structures and high power RF components for CLIC, CERN has developed a high gradient test programme.

Today, said programme is comprised of three test stands:

- **Xbox 1**: 50 MW klystron, 50 Hz, connection with CLEAR (e- LINAC)
- **Xbox 2**: 50 MW klystron, 50 Hz
- **Xbox 3**: 4x6 MW klystrons, 400 Hz (4 structure test slots)
- ***Sbox**: 45 MW klystron, 50Hz, S-band (3 GHz)*

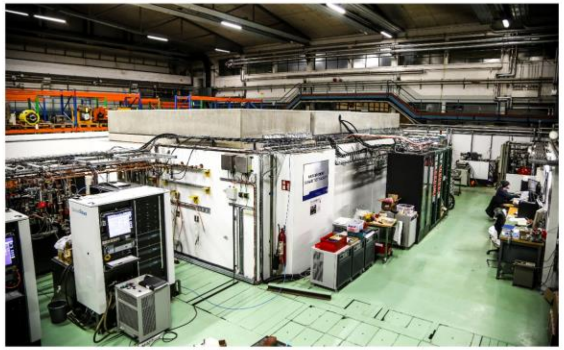


Figure: X-band high gradient test facility at CERN.

The Conditioning Process

It has also become apparent that:

- Structures condition on the **number of pulses not the number of breakdowns [1]**.
- Cleanliness of preparation shown to affect number of breakdowns during conditioning, **not ultimate performance. [2]**

Conditioning is now **automated and accomplished algorithmically**[3,4], however occasionally we must deviate from the aforementioned “ideal” case…

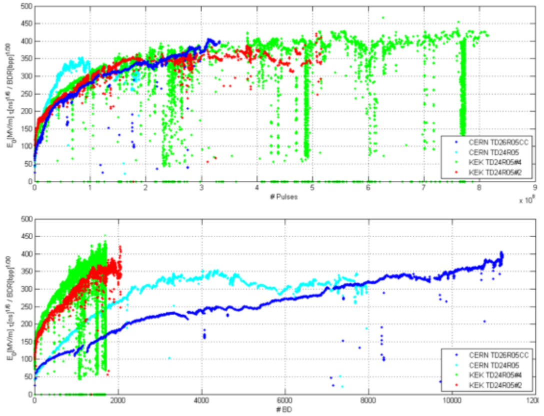


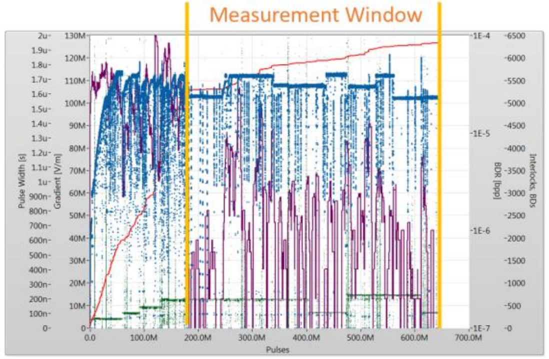
Figure: Scaled gradient vs. cumulative no. pulses (top) and scaled gradient vs. cumulative no. breakdowns (bottom) for four different structures.

7

Statistics of Breakdown at High Gradient

In 2018, we ran a PSI2 T24 structure for several months at fixed gradients.

- **~75% BDs** during this time did not occur as isolated events (isolated defined as occurring more than 1000 pulses apart i.e. 20s at 50Hz).
- Suggests that at high fields BDs are **more likely to occur in groups** (higher probability of follow-ups).
- Additionally they tend to occur spatially close to one another, although breakdowns do tend to occur in the first cell in the later stages of testing so it is difficult to draw conclusions.
- For more details see[2,6]



Figures: Conditioning history of the PSI2 structure showing the flat gradient runs from 200M pulses on.

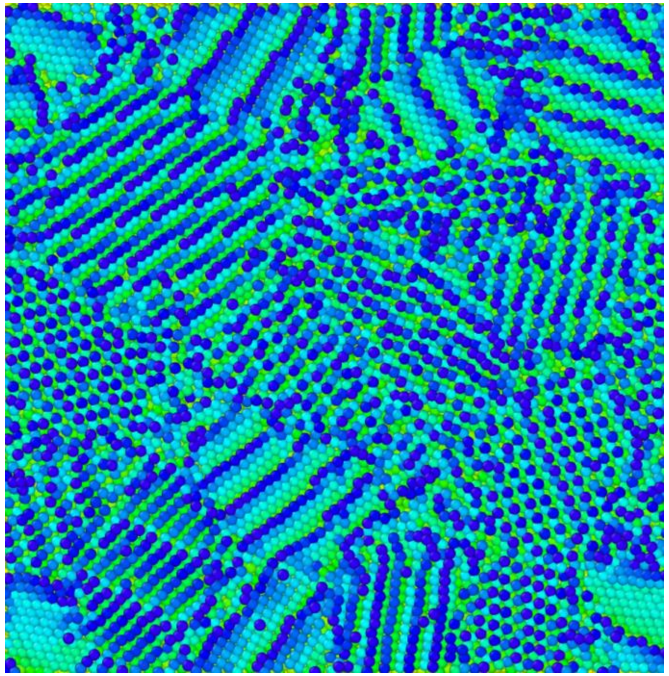
celerat

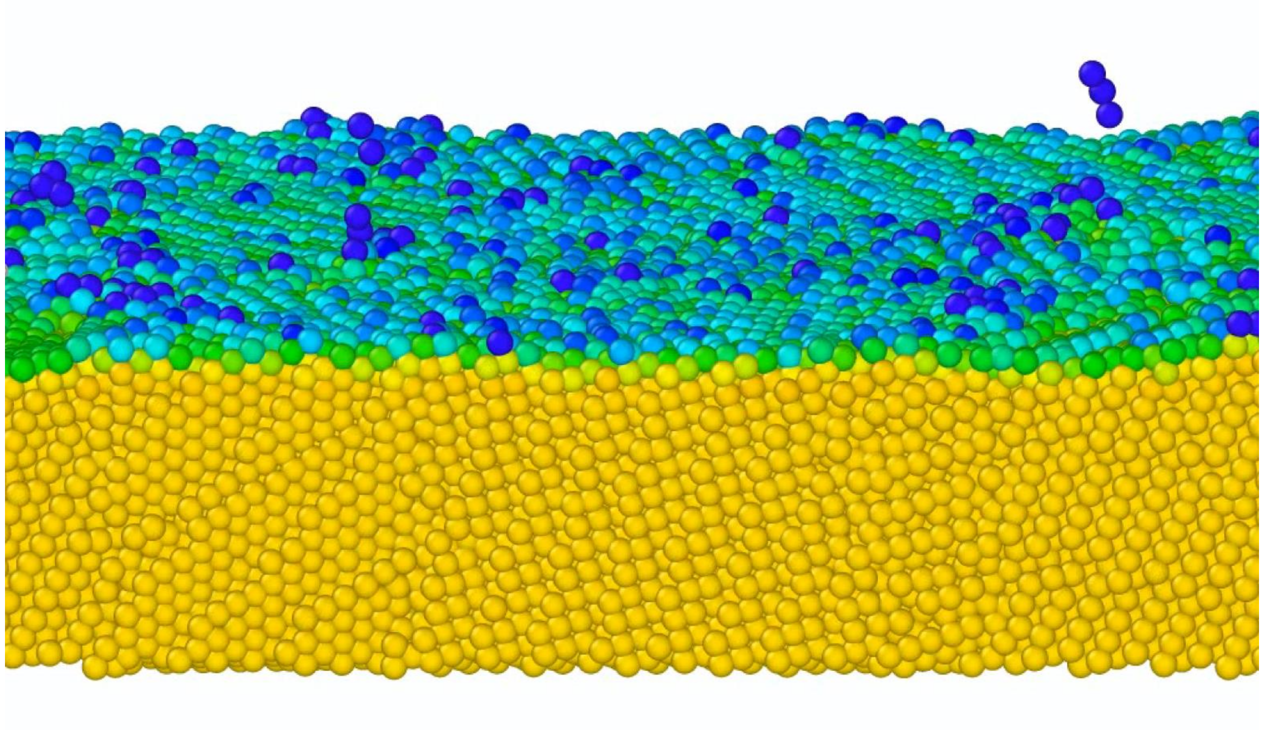
We have three test stands which run at high gradient (>100MV/m) for long periods of time:

- By approaching the limit we necessarily push systems towards instability and as a product of this we learn of the limiting factors/weak points as they emerge.
- We are now in the process of quantifying such issues and their implications for a large machine.

Simulations at Los Alamos

- Atomistic modeling of surface evolution under strong electric fields
- Simulations to understand breakdown mechanisms on atomic scale on clean flat Cu surface





SCRF

ILC cost reduction

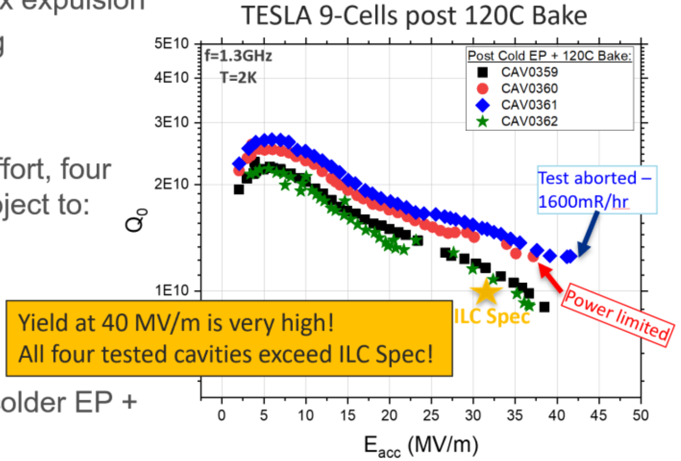
- Average accelerating gradient of main SRF LINAC is the largest cost driver
- Higher gradients = fewer cryomodules ➔ less $$
- Higher Q_0 = lower cryogenic costs

High Gradient 9-Cell TESLA-shaped Nb cavities

Recent lessons learned:

1) High temperature annealing – flux expulsion
2) Low temperature electropolishing
3) 75/120C low temperature bake

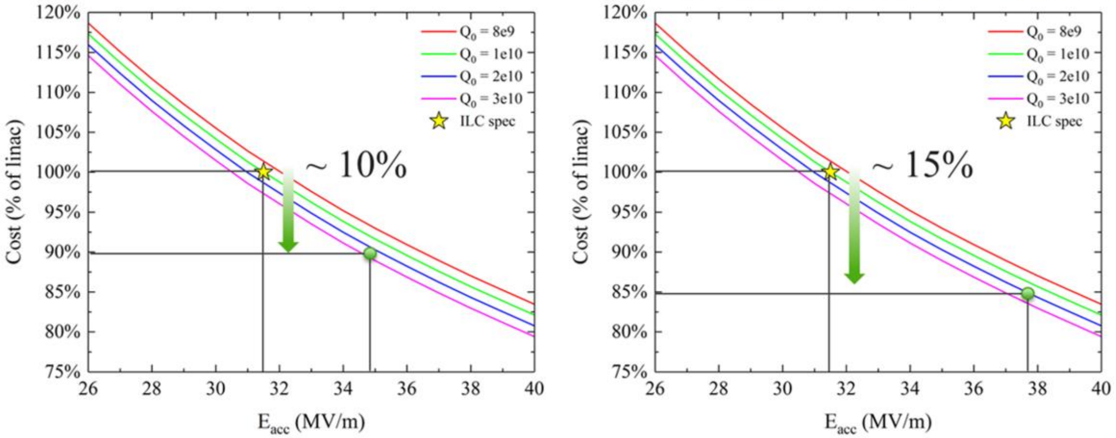
- As part of the LCLS II-HE R&D effort, four TESLA shaped 9-cell cavities subject to:
  - High temp annealing
  - Electropolishing
  - In-situ 120C x 48hr bake
- Next steps: repeat process with colder EP + 75/120C bake



LCLS-II-HE Fermilab ILLINOIS INSTITUTE OF TECHNOLOGY

Cost Estimation of a 250 GeV ILC LINAC

Courtesy of M. Checchin, US-Japan Coll. Worksh., 2017



Increasing cavity specs to Q_0=2e10 and 34.8 MV/m (37.7 MV/m) allows for a ~10% (~15%) decrease in LINAC cost

Fermilab ILLINOIS INSTITUTE OF TECHNOLOGY

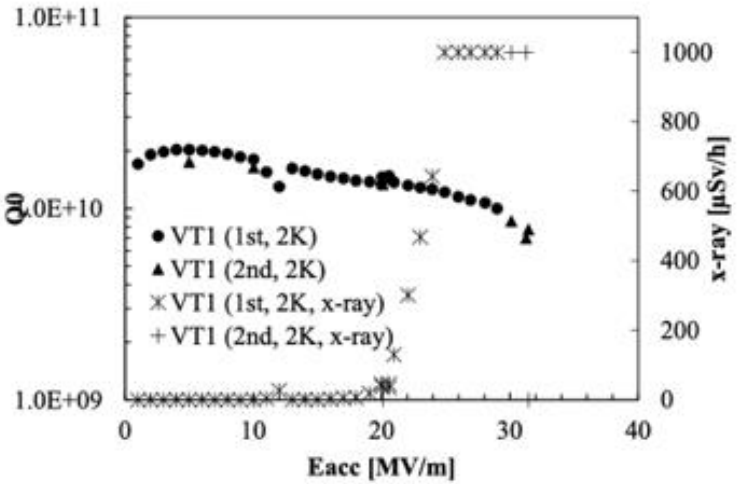
Current status of Cavity Fabrication Facility (CFF)

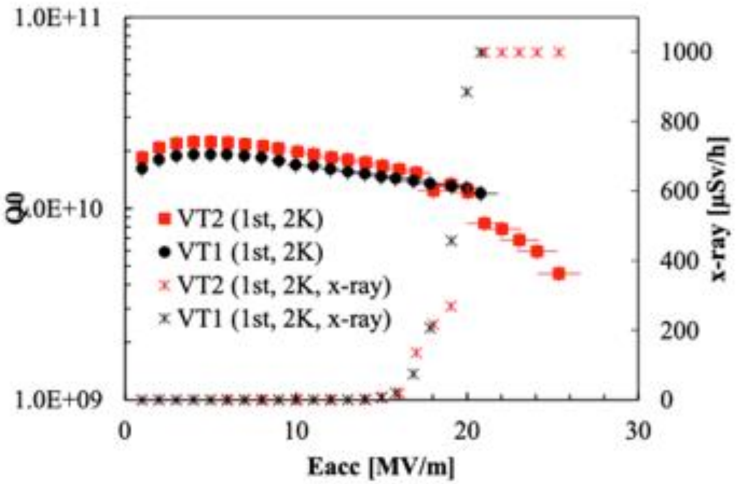
Cavity Fabrication Facility (CFF) is working for ILC;

- Study for cost reduction in cavity fabrication
  - ✓Try new materials (large grain Nb)
  - ✓Mass production techniques
- Pass the Japanese helium vessel code (high pressure gas safety act.)
  - ✓Tensile test in cryogenic temperature
  - ✓Buckling simulation
  - ✓Welding Procedure Specification
- Investigation on tuner
- Cooperation with companies
- Hydroforming cavity

Large grain

CBMM LG: 9-cell cavity





Maximum gradients

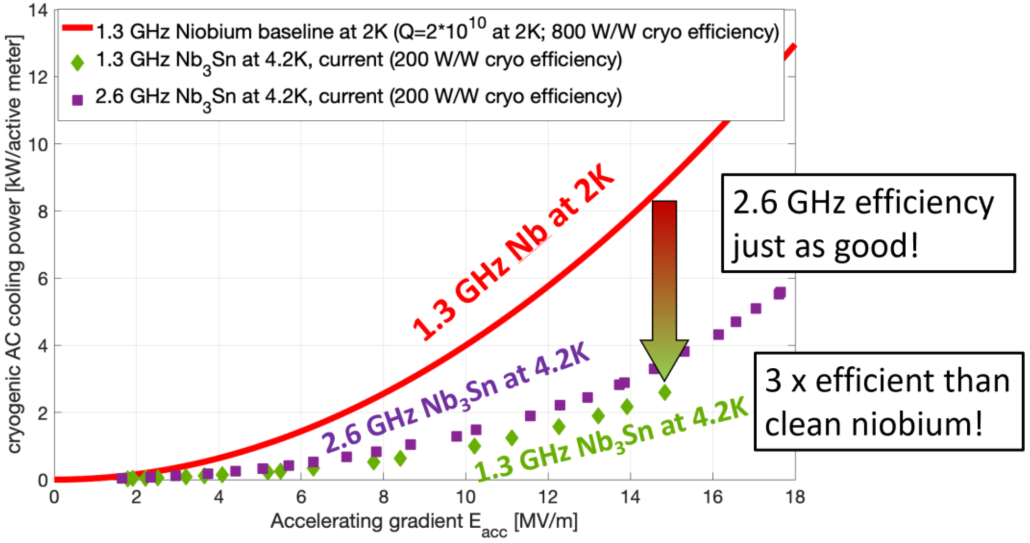
	Cell1	Cell2	Cell3	Cell4	Cell5	Cell6	Cell7	Cell8	Cell9
KEK-4	40.0	40.9	>31.5	>31.5	>40.9	31.5	31.5	>40.9	>40.0
KEK-5	>34.4	32.9	30.3	33.4	35.9	>33.4	>30.3	>32.9	>34.4

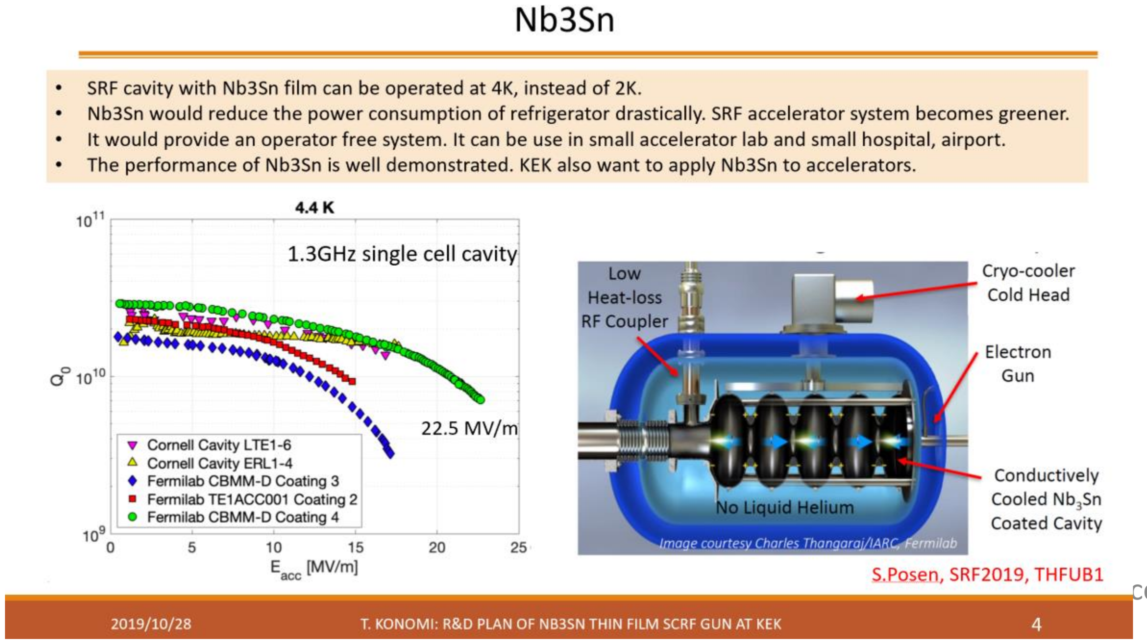
8

→To be measured again

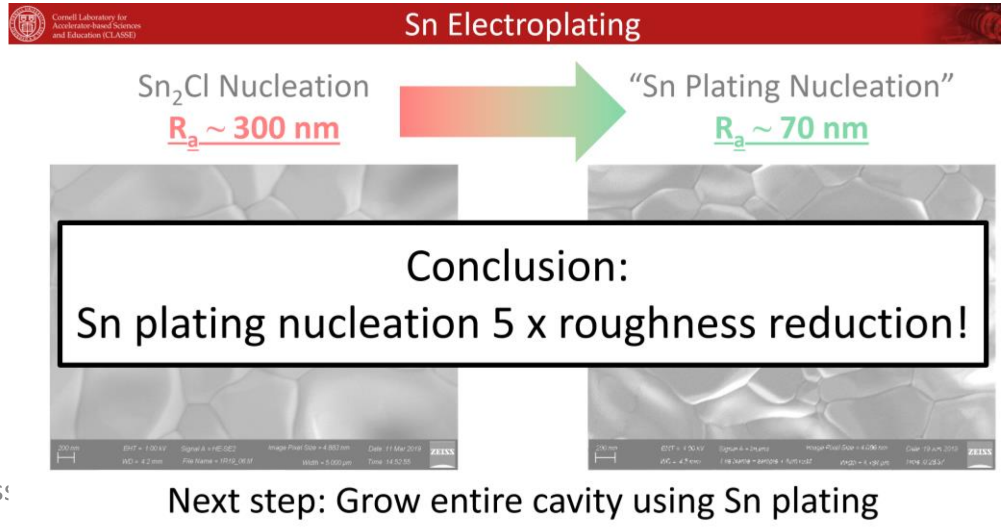
SRF cavities with Nb3Sn film

- Efforts at Cornell, Fermilab and KEK
- Nb3Sn more efficient at 4 K instead of pure Nb at 2 K
  - Lower dynamic load, lower static load, simpler cryo system
  - 2.6 GHz cavities smaller, thus cheaper
- Technology maybe ready for ILC upgrade





ccelerator Sess

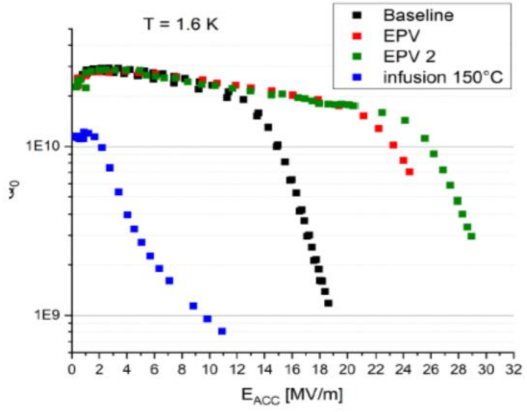


Nitrogen infusion

- First N infusion at IPN Orsay, France on single cell cavity
- They think they suffer from N contamination from the N vessel to the injector valve

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Saclay cavity 1AC03 results



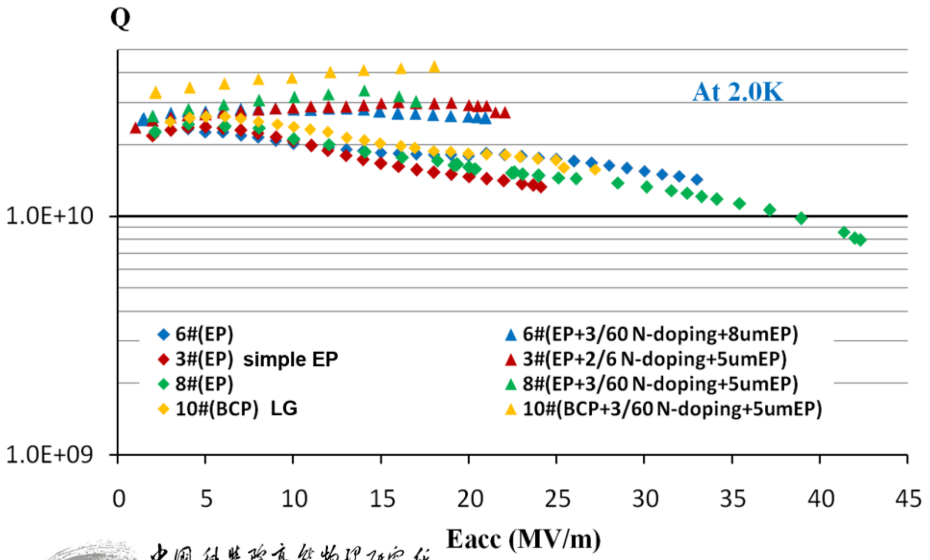
- Baseline: BCP
- EPV=Electro-polissage vertical 50 µm
- EPV2=Electro-polissage vertical 50 µm
- Infusion: T_{sp} = 120°C, $T_{réelle\ cavité}$ = 147°C

P_{N2} = 2.10^{-2} mbar ; N_2 alphagaz 2

- Capots Nb: BCP ~ 100 µm + rinçage UHP

- Production and development of N infused cavities has started in at IHEP China

Need to improve N-doping and light EP process to increase gradient and Q.



中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

- Evidence for correlation between carbides and cavity performance degradation
- Carbide formation is in connection with
  - Cleanliness and vacuum conductance of line of sight protection
  - Furnace conditions
- Our cavity furnace will undergo an upgrade till Q3 2020 (oil free pre-pumps and software upgrade)
- Magnetic hygiene will be studied and Helmholtz-Coils for active field cancellation will be prepared for future tests.
  - Origin for difference in Rres for FNAL and DESY tests of 1DE20 is unclear

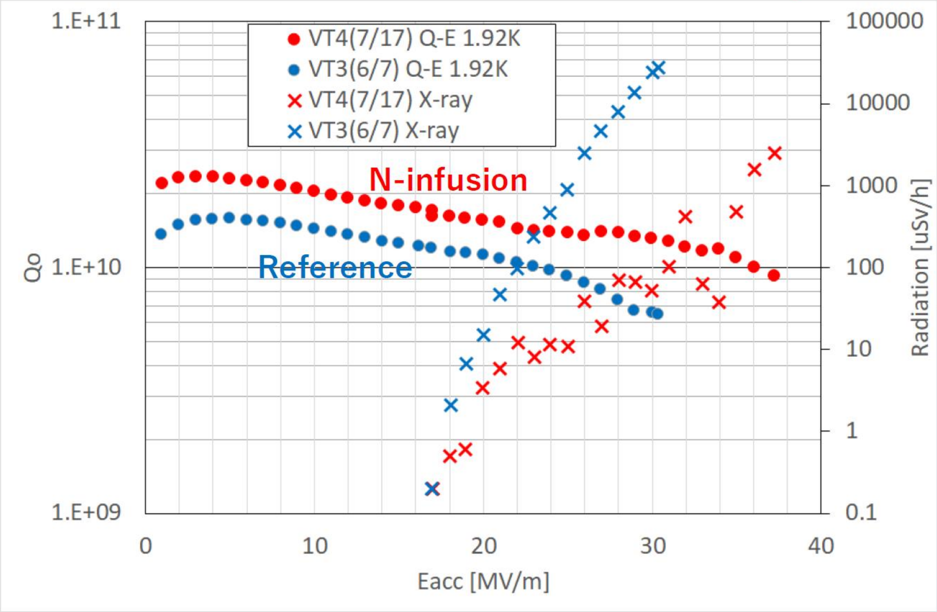
DESY. | DESY Infusion R&D | Bate Christopher, 31.10.2019

Nitrogen infusion

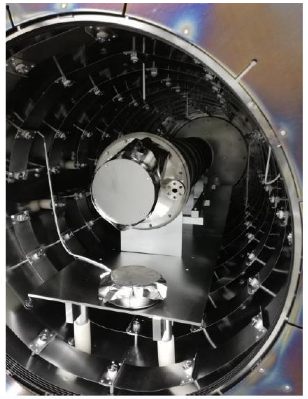
KEK furnace(located at COI)

- Completed at the end of FY2017
- Cryopump for main pump, oil-free pumping system.
- Molybdenum is used for heater, reflector, table etc.
- TMP is used during N-injection, can reach ~2e-5Pa.
- Clean-booth surround entrance door.

First N-infusion for 9-cell cavity



※ Eacc for reference measurement was limited by F.E.

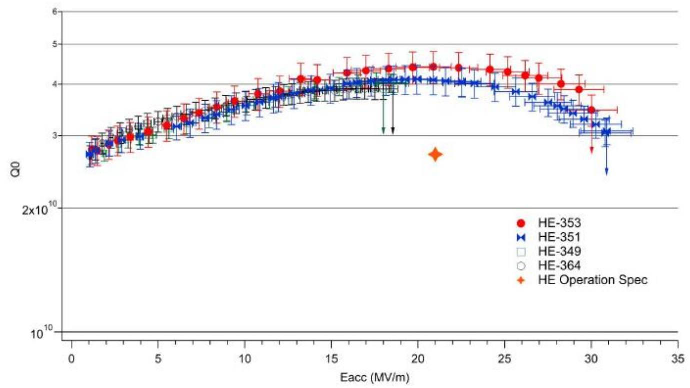


- Max Eacc = 37MV/m
- Quench : 1-cell, 120deg.
- Final field emission onset Eacc = 20-21MV/m

- Improvement of Qo ?
- Magnetic field inside VT dewar was not controlled for 9-cell cavities.

Nitrogen doping for LCLS-II HE cavities

9 cell results – All 3/60



- 2 of 4 cavities easily pass the HE spec with Q0>4e10 and gradients
- One appears to have questionable material
- One in under investigation
- 3/60 Development continues under LCLS-II HE
- **See Gonnella slides next for 2/0 complied results from FNAL**

Jefferson Lab 22

Cold EP

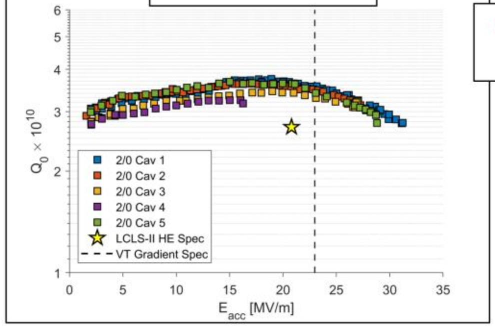
SLAC

- The key to achieving good performance in 9-cells is now understood to be related to performing very cold EP's
  - This is necessary for the last part of the bulk and the final EP after nitrogen-doping

9-Cell Results

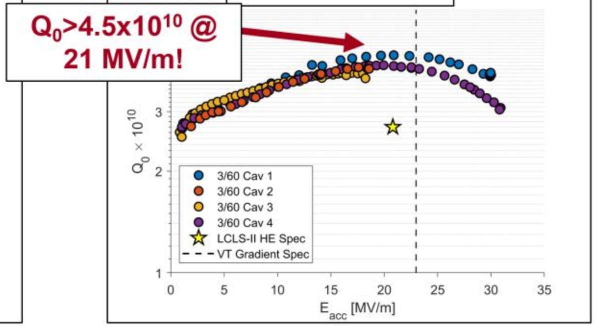
SLAC

2/0 Cavities



4 out of 5 2/0 9-cells exceed HE requirements by a large margin!

3/60 Cavities



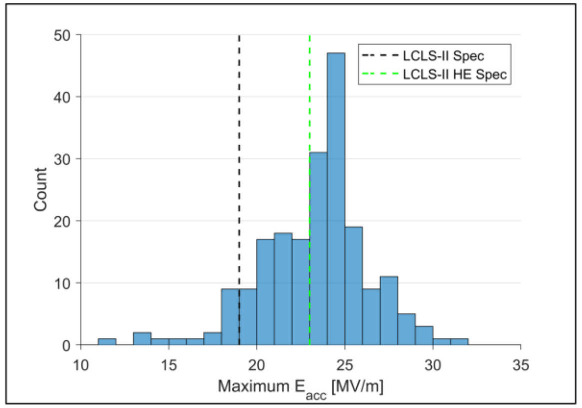
2 out of 4 3/60 9-cells exceed HE requirements with unprecedented Q_0 and gradient

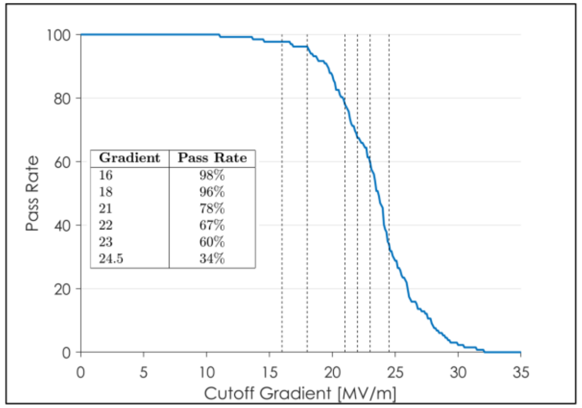
18

of th

LCLS-II Results: Gradient

SLAC



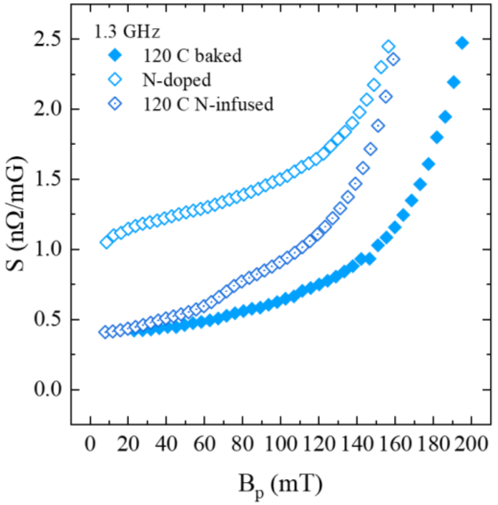


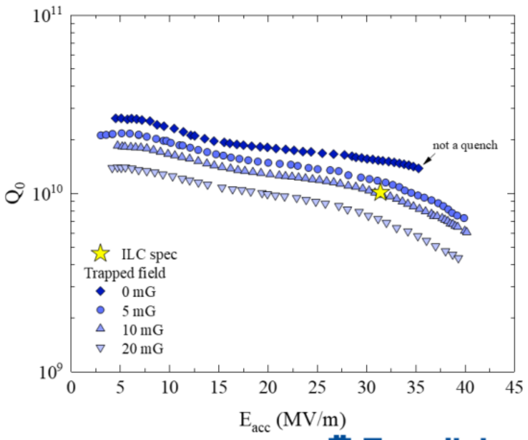
Only 60% of LCLS-II cavities exceed the HE VT Gradient Specification

While the average LCLS-II cavity meets HE requirements, the distribution needs to be shifted

Trapped-flux Surface Resistance at High Gradients

- **High-gradient sensitivity is very large** and jeopardizes the performance of high-Q/high-E_{acc} SRF cavities
- To mitigate this issue, it is of primary importance to:
  - utilize materials with low occurrence of high local misorientation (good expulsion)
  - allow for fast cool-down in CMs
  - implement strict magnetic field hygiene
  - improve magnetic shielding (compensation coils?)
- **LCLS-II** is a **successful example ILC should follow** to mitigate this issue

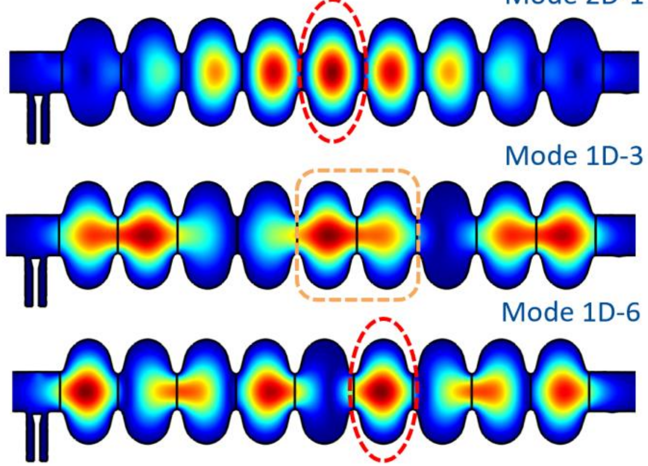




Plasma processing R&D

- Reducing FE by **increasing work function** of cavity RF surface
  - Hydrocarbons and adsorbates lower work function of Nb
- Enabling operation at higher accelerating gradient

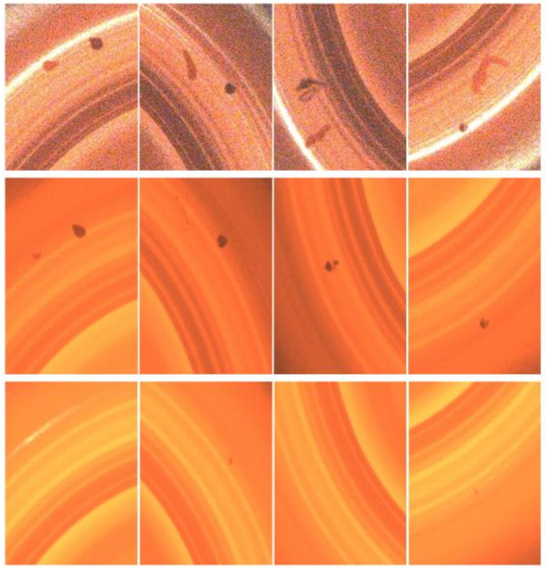
- Plasma is ignited cell by cell, not in the entire cavity
- **Dual tone excitation to transfer the plasma:** using a superposition of HOMs it is possible to transfer the plasma through adjacent cells



Initial state

After 5h of plasma cleaning

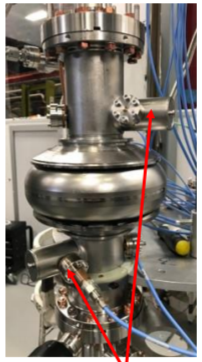
After 19h of plasma cleaning



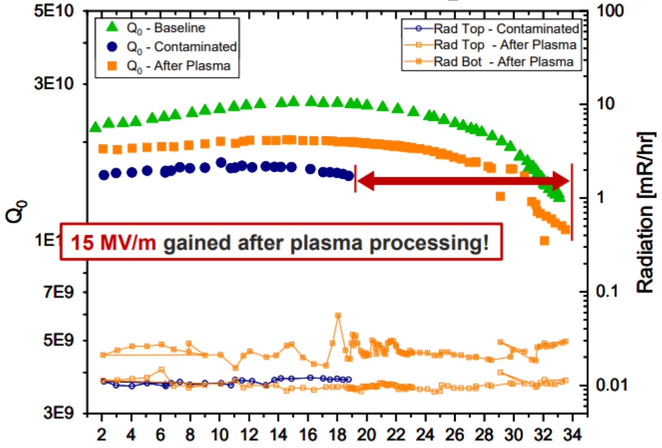
Carbon contamination: RF results before and after plasma processing

Scope: study the removal of Carbon contamination

- Single cell cavity processed for 17h with Ne-O_2 plasma.



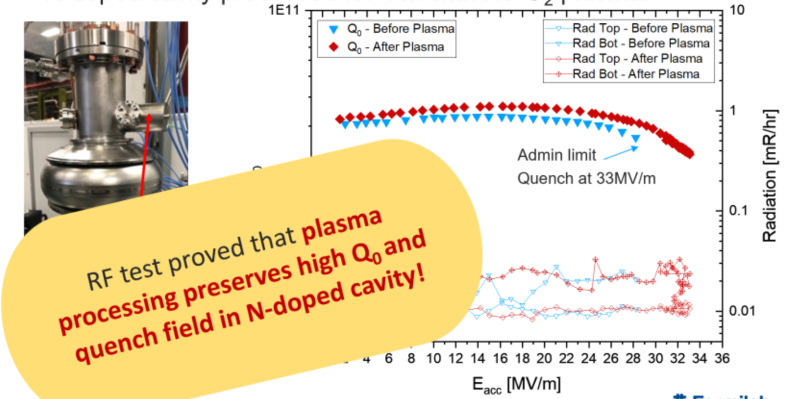
HOM couplers



N-doped single cell: RF results before and after plasma processing

Scope: study effect of plasma processing on Q-factors on N-doped cavities

- N-doped cavity processed for 16h with Ne-O_2 plasma.



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Alternative Cavity Shapes for High Gradient Low-Surface-Field (LSF) Shape Cavity R&D

- Jlab, KEK & SLAC

EP
Cavity surface chemistry

Achievable gradient

Nb: > 2000 Oe (exp.)
2400 Oe (the.)
Nb_3Sn: > 4000 Oe (the.)

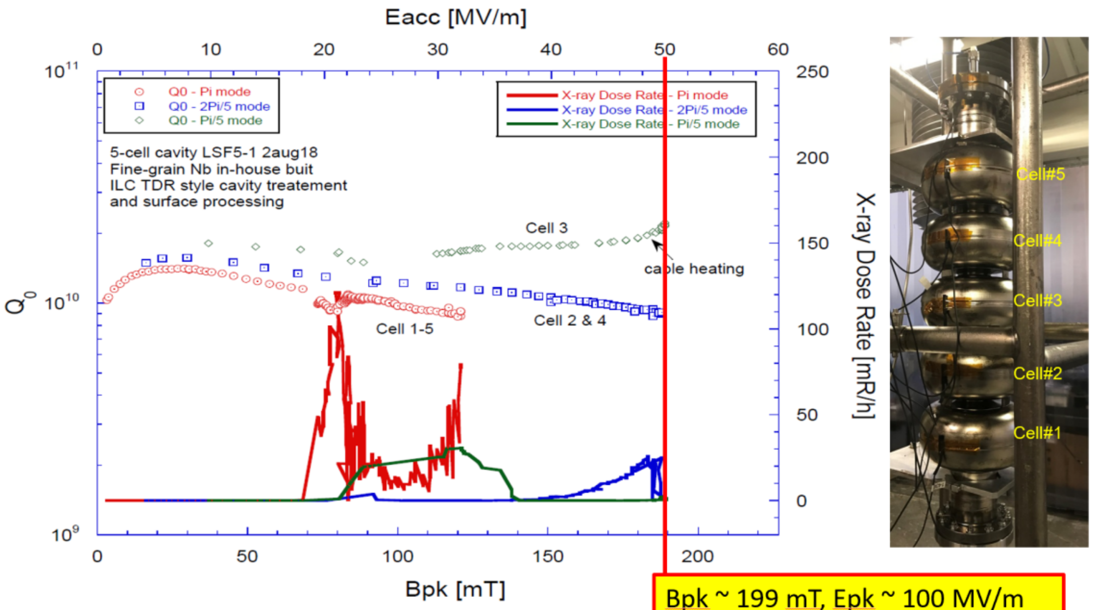
$$E_{acc}^{max} = d \cdot \frac{r \cdot H_{crit,RF}}{\beta_{MAG} \cdot (H_{pk}/E_{acc})}$$

Cavity wall thermal conductance
High purity (RRR) Nb

Cavity surface smoothness
EBW, EP

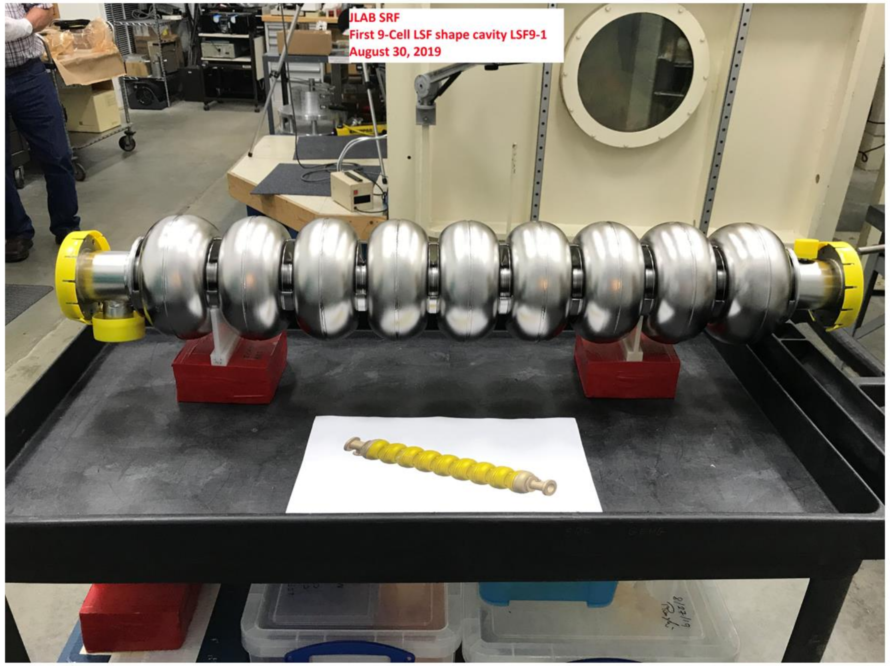
Cavity shape

LSF5-1 Current Performance



Bpk ~ 199 mT, Epk ~ 100 MV/m
Pi mode equivalent 50 MV/m

Birth of First 9-cell LSF Shape Cavity



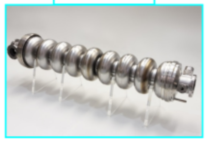
- The first LSF 9-cell (FG Nb) cavity LSF9-1 is completed in-house fabrication at JLAB. It is being shipped to KEK for surface processing and field flatness tuning.
- Plan is to build two more 9-cell LSF shape cavities including one from FG Nb (material in hand) one from LG Nb (material to be acquired).
- We anticipate this work would allow us to make new contributions in several fronts relevant to ILC: shifting the gradient performance frontier in full scale 9-cell cavity; increase gradient margin; save cavity fabrication cost; save accelerator operation cost.

ILC Prototypes (actual & planned)

STF-2 project and STF-2 accelerator

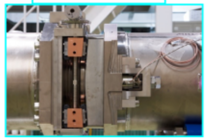
Purpose: Beam operation fulfilling ILC specification

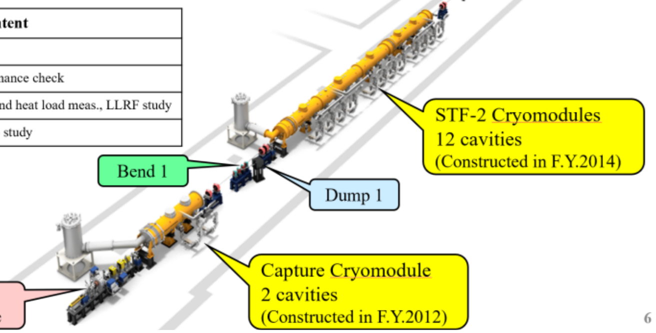
STF Cavity



STF-II power coupler

Slide-jack tuner



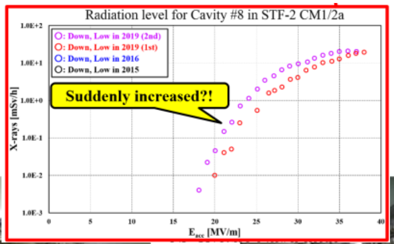


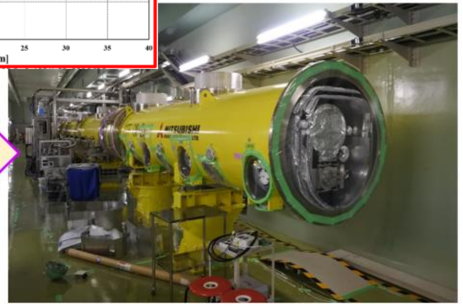
Cooldown	Date	Content
1	Oct/2014 ~ Dec/2014	Low power test
2	Oct/2015 ~ Dec/2015	Single cavity operation, performance check
3	Sep/2016 ~ Nov/2016	Eight cavities operation, LFD and heat load meas., LLRF study
4	Jan/2019 ~ Mar/2019	Beam commissioning, Machine study

Operational condition
- RF: 1.65 msec/5 Hz (ILC/TDR)
- Temperature: 2K in liq. Helium
- As max. E_{acc} as possible for STF-2 CM

31/Oct/2019 6

33.1 MV/m (averaging for 7 cavities)





Plans for 2020-2021: High G/High Q_0 ILC Style Cryomodule

- With ILC Cost Reduction R&D funds from DOE, FNAL plans to assemble a High G/High Q_0 CM
- Goal: demonstrate an $E_{acc,avg}$ **= 38MV/m @ Q_0= 1E10** in a CM test with a stretch goal of **40MV/m**
- Refurbish CM1, the first SRF cryomodule assembled at Fermilab in 2007, as a part of a collaboration between Fermilab, DESY, and LASA
- Reuse structural elements (vacuum vessel, support posts, cryogenic piping)
- Improved magnetic shielding will be implemented
- Encapsulated piezo tuner designs
- Cavities will be replaced by cavities that had achieved ILC spec and were set aside ~10 years ago for future modules
- Baseline treatment plan:
  - High temperature furnace treatment - flux expulsion
  - New low temperature EP
  - New 2-step low temperature baking treatment

Assembly will be carried out in FY20
Testing will take place in FY21 using existing facilities at FAST

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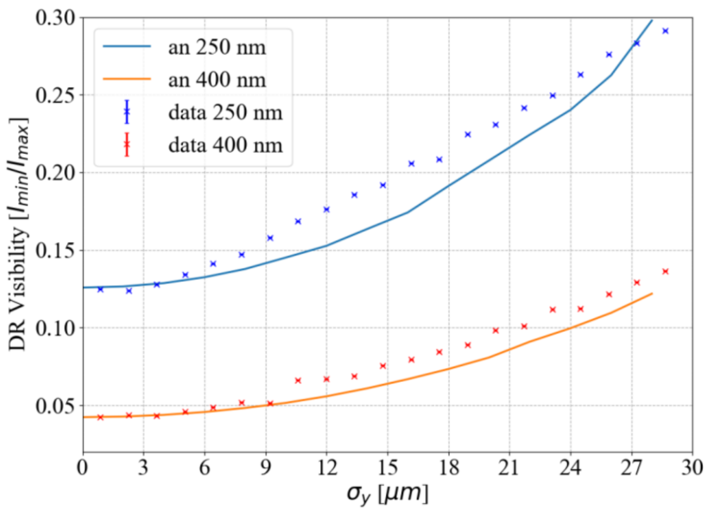
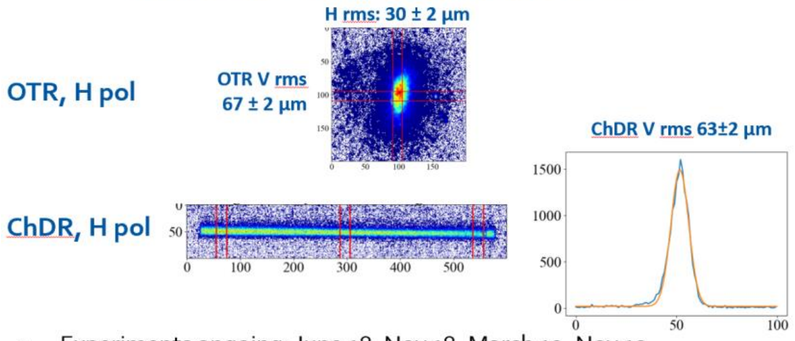
ATF/DR/BDS

Beam instrumentation studies for future LCs

- Goal: non-invasive way to measure beam size
- Tests ongoing at ATF, CLEAR and Diamond light source
- ODR: Sensitivity to 4 µm achieved at 250 nm @ATF2
- ChDR: measured 63 ± 2 µm, 30 µm not verified yet
  - If requirements are all met, it would be a nicely simple and this easy scalable beam instrumentation tool for linear colliders

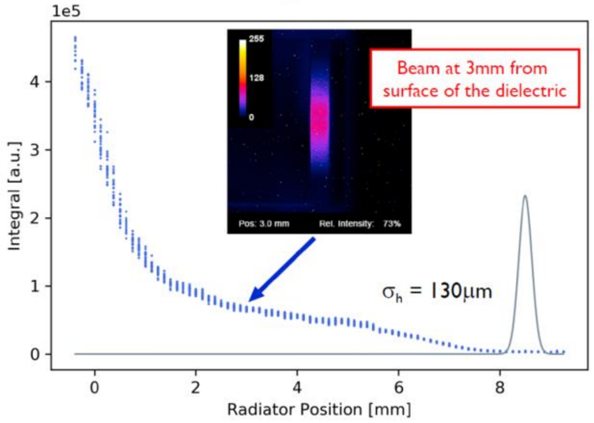


ChDR @ KEK: results…so far



- Experiments ongoing: June 18, Nov 18, March 19, Nov 19,…
- 60 um beam correctly measured at 700 nm (40 nm BW).
- Smaller beams down to 30 um also observed. LSF still to be assessed
- Ongoing tests also at Diamond light source (UK)

ChDR @ CLEAR

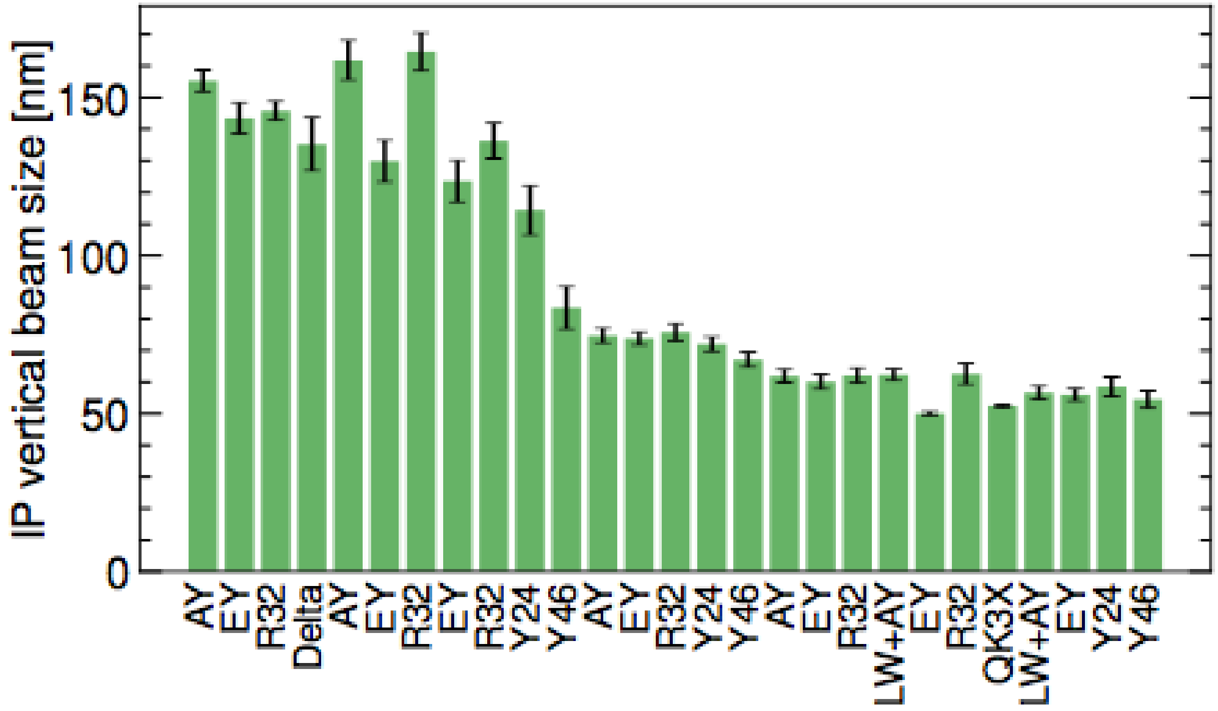


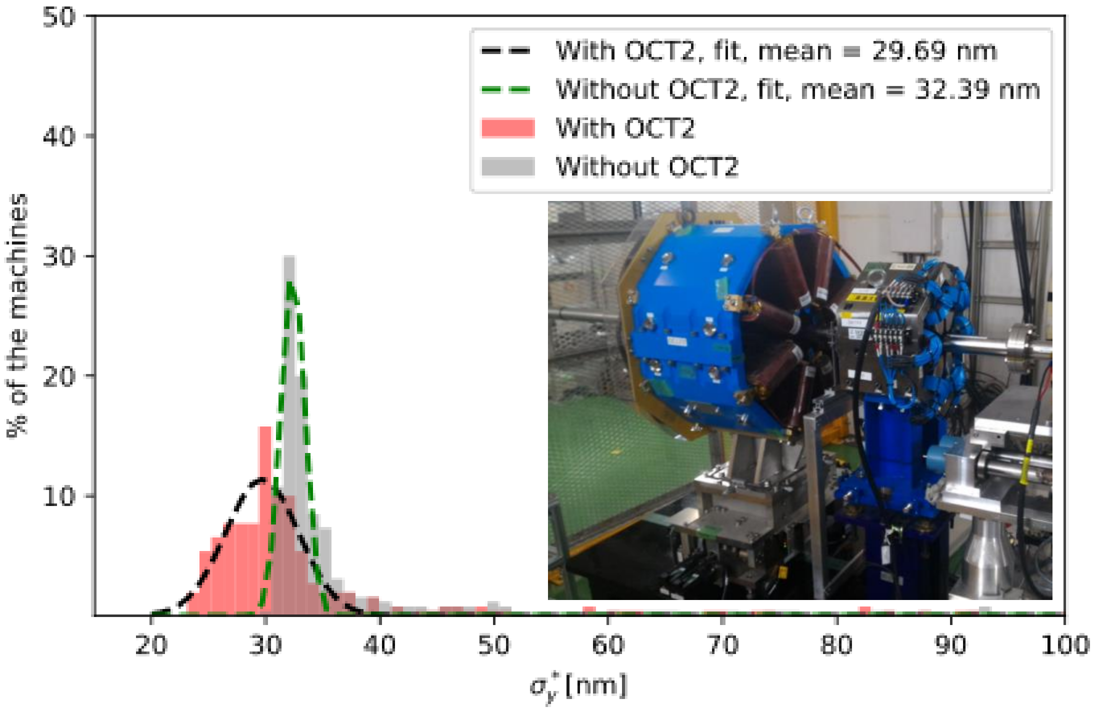
Impact parameter scan with 200 MeV, 500 pC bunch

Measuring at 600 +/- 10 nm: **signal present at h> 7 mm**

Status of ultra-low βy* optics tuning at ATF / Nonlinear optimization of the Ultra-low (25β∗x × 0.25β∗Y) optics

- 50 nm IP beam size achieved with ultra-low betay* optics @ATF2
- Swapping octupoles for further beam size reduction at ATF2

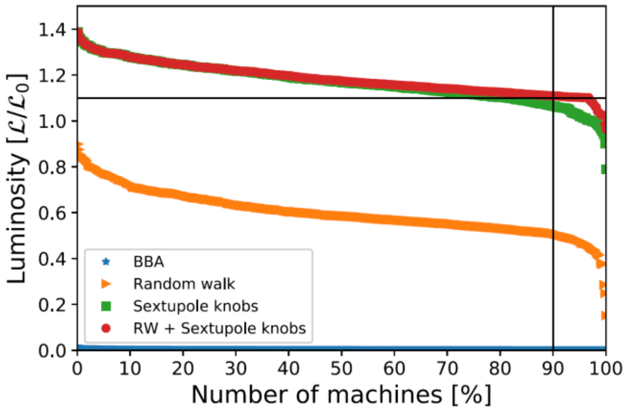




Completion of two-beam lumi tuning for CLIC

- Simulation with realistic signal for CLIC BDS

Results



- 500 machines
- After sextupole knobs: 406 machines reached target
- Untuned machines. Repeated scans of sextupole knobs unsuccessful
- Solution: Quadrupole and sextupole random walk tuning followed by sextupole knobs

Final results: 484 machines successfully tuned

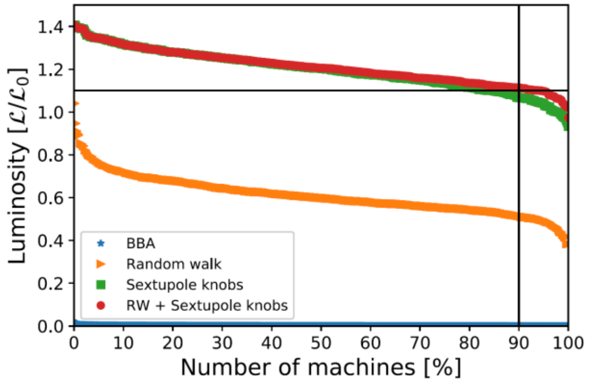
484/500 = **96.8% success rate**

Low β_y lattice

Updated lattice for the CLIC 380 GeV

- Vertical beta function at IP was reduced from 100 μm to 70 μm
- See: A. Pastushenko: "A New FFS at CLIC 380 GeV," *this workshop.*

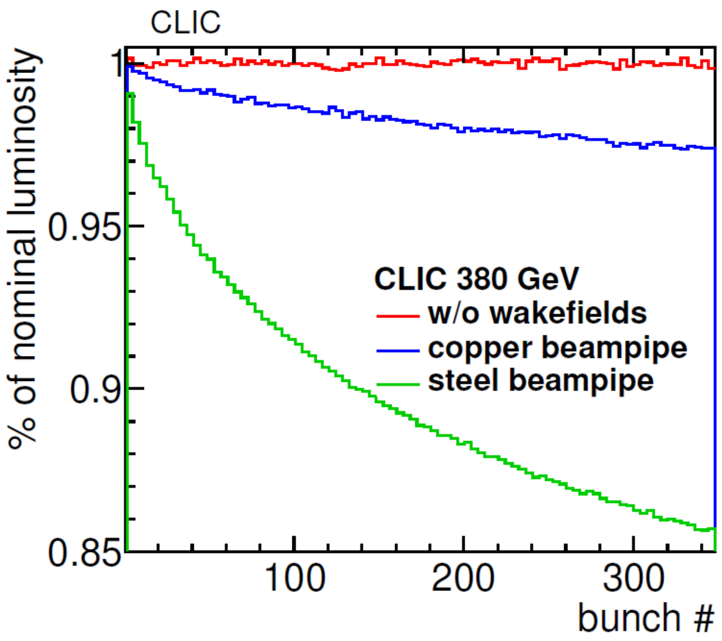
Tested same tuning procedure on new lattice

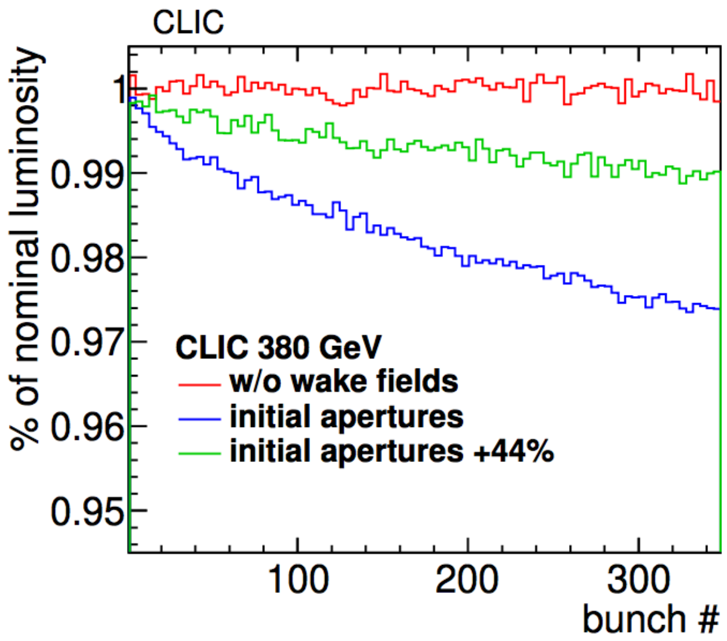


- Results very similar to nominal lattice
- Final result: **94.6 % successfully tuned**
- But tuning time was slightly lower

Wakefield effects in the CLIC BDS

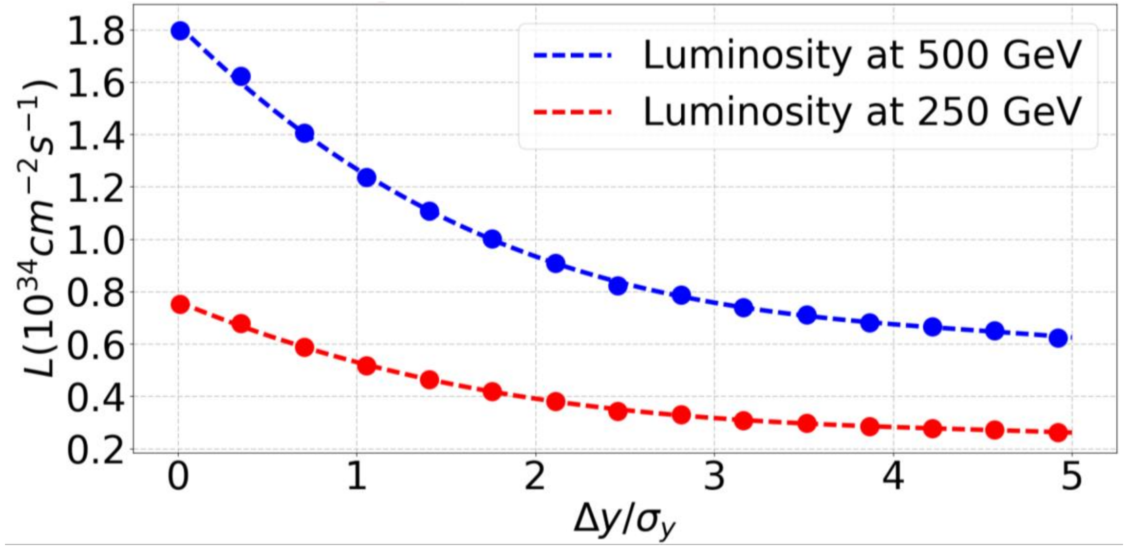
- Copper coated pipe is favorable for CLIC BDS
- 44% increase of aperture can mitigate the wakefield impact





Intensity-dependent effects in ATF2 and ILC

- ILC BDS long-range wakefields induce mainly IP position
- 3.6% luminosity loss at $2\text{x}10^{10}$ e- with an incoming position offset of 1 σ_y



Incoming Y	Intensity	Δ_y at IP	L / L_0
$0.1\sigma_y$	$2.0 \times 10^9 e^-$	0.008 nm	~ 1.0
$0.1\sigma_y$	$2.0 \times 10^{10} e^-$	0.076 nm	0.998
$1.0\sigma_y$	$2.0 \times 10^9 e^-$	0.075 nm	0.998
$1.0\sigma_y$	$2.0 \times 10^{10} e^-$	0.755 nm	0.964
Incoming Y'	**Intensity**	**Δ_y at IP**	**L / L_0**
$0.1\sigma_{y'}$	$2.0 \times 10^9 e^-$	0.019 nm	~ 1.0
$0.1\sigma_{y'}$	$2.0 \times 10^{10} e^-$	0.20 nm	0.992
$1.0\sigma_{y'}$	$2.0 \times 10^9 e^-$	0.19 nm	0.996
$1.0\sigma_{y'}$	$2.0 \times 10^{10} e^-$	2.03 nm	0.901

Luminosity loss at 500 GeV:

3.6% at $2\text{x}10^{10}$ e^- with an incoming position offset of $1.0\sigma_y$

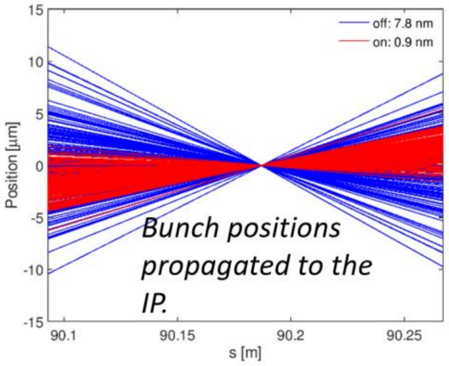
9.9% at $2\text{x}10^{10}$ e^- with an incoming angle offset of $1.0\sigma_{y'}$

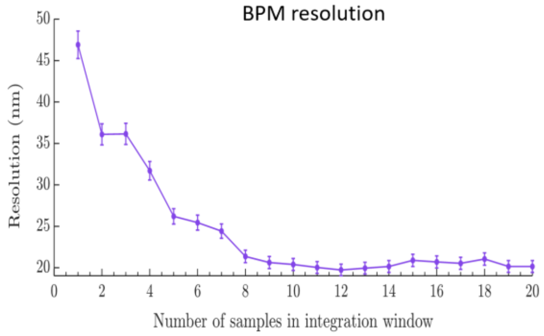
FONT beam stabilization results at ATF

- Feedback On Nanosecond Timescale (FONT)
- Study for ILC and CLIC at the ATF extraction line and the IP
- BPM resolution improvement by integration -> better FB performance
  - Jitter reduction from 96 nm to 41 nm with 2-BPM IP FONT feedback

- Feedback achieved **position** stabilisation from:
  - 1.69 ± 0.09 μm to **165 ± 8 nm** at P2.
  - 1.68 ± 0.08 μm to **200 ± 10 nm** at P3.
- Using a model of the ATF2 beamline, transfer matrices can be calculated in order to infer the stabilisation at the IP of:
  - 7.8 ± 0.4 nm to **0.86 ± 0.04 nm**
  - Factor of 3 reduction in the angle jitter when propagated to the IP.

29/10/2019





	Single-sample	11-sample
Resolution	46.9 ± 1.7 nm	19.0 ± 0.4 nm

Best results demonstrated for 1-BPM feedback mode with stabilisation at IPC.

	Position jitter (nm)	
Bunch	Feedback off	Feedback on
1	109 ± 11	118 ± 8
2	119 ± 12	50 ± 4

Best results demonstrated for 2-BPM feedback mode, with stabilisation at IPB.

	Position jitter (nm)	
Bunch	Feedback off	Feedback on
1	106 ± 16	106 ± 16
2	96 ± 10	41 ± 4

A big thank you to all the speakers for the excellent talks!

Takeaways

Takeaways

- We have an excellent and strong world-wide accelerator community
- We keep optimizing and advancing already mature technologies
- We are well prepared and ready for all upcoming large-scale LC projects

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- Thank you very much for your attention!