Summary on Accelerator Infrastructures and commissioning

Y. Funakoshi

Accelerator Laboratory, KEK

2018.09.27@eeFACT2018

Talks

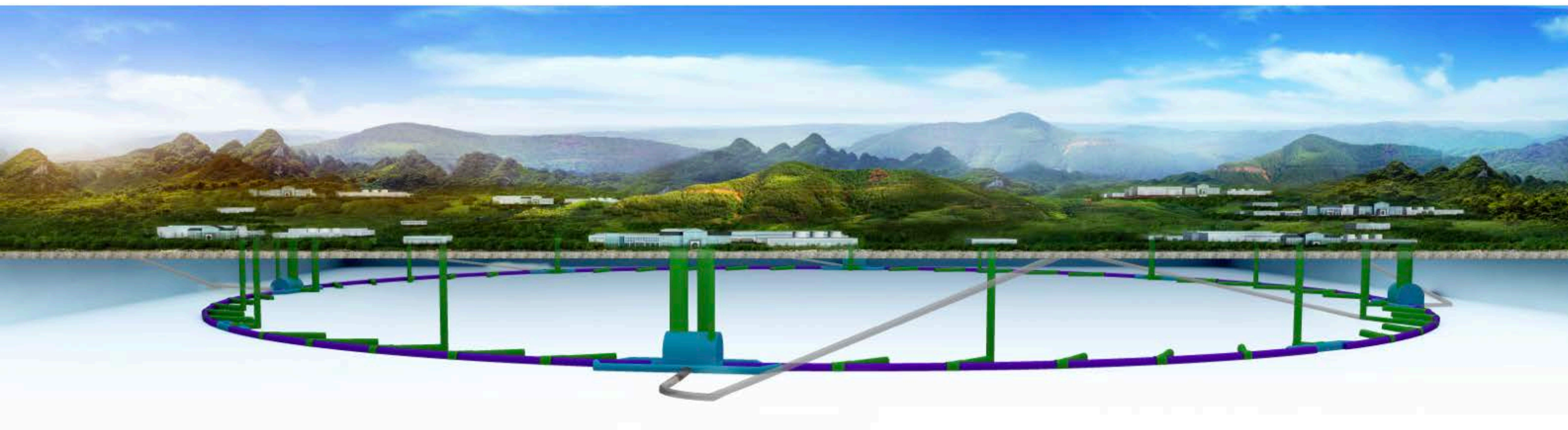
14:00 - 14:20	"**BEPCII Status**" Qing Qin (Institute of High Energy Physics (IHEP), Chinese Academy of Sciences)
14:20 - 14:40	"**CEPC Civil Engineering Design and Infrastructure**" Yu Xiao (Yellow River Engineering Consulting Co., Ltd)
14:40 - 15:00	"**Operation Model, Availability and Performance**" Frank Zimmermann (CERN)
15:00 - 15:20	"**CEPC Cryogenic System**" Jianqin Zhang (Institute of High Energy Physics (IHEP), Chinese Academy of Sciences)
15:20 - 15:40	"**LHC Commissioning : The Good, the Bad and the Ugly**" Frank Zimmermann (CERN)
15:40 - 16:00	"**Cryogenics Operation for the Super KEKB**" KEKB/SuperKEKB Cryogenics Operation
16:30 - 16:50	"**Operation of SuperKEKB in Phase 2**" Yoshihiro Funakoshi (High Energy Accelerator Research Organization (KEK))
16:50 - 17:10	"**A Site-specific ILC-CFS Design and the Green ILC**" Masakazu Yoshioka (Iwate University)
17:10 - 17:30	"**DAFNE as Open Accelerator Test Facility**" Catia Milardi (National Institute for Nuclear Physics (INFN), Italy)

Civil engineering and infrastructure

- 2 talks
  - CEPC (Yu Xiao)
  - ILC(M. Yoshioka)
- Theme
  - Site investigation
  - Project layout
  - Electric engineering (Energy saving)
  - Cooling water
  - Ventilation
  - Fire protection
  - Transportation and Lifting

CEPC Civil Engineering design and Infrastructure

Yu Xiao



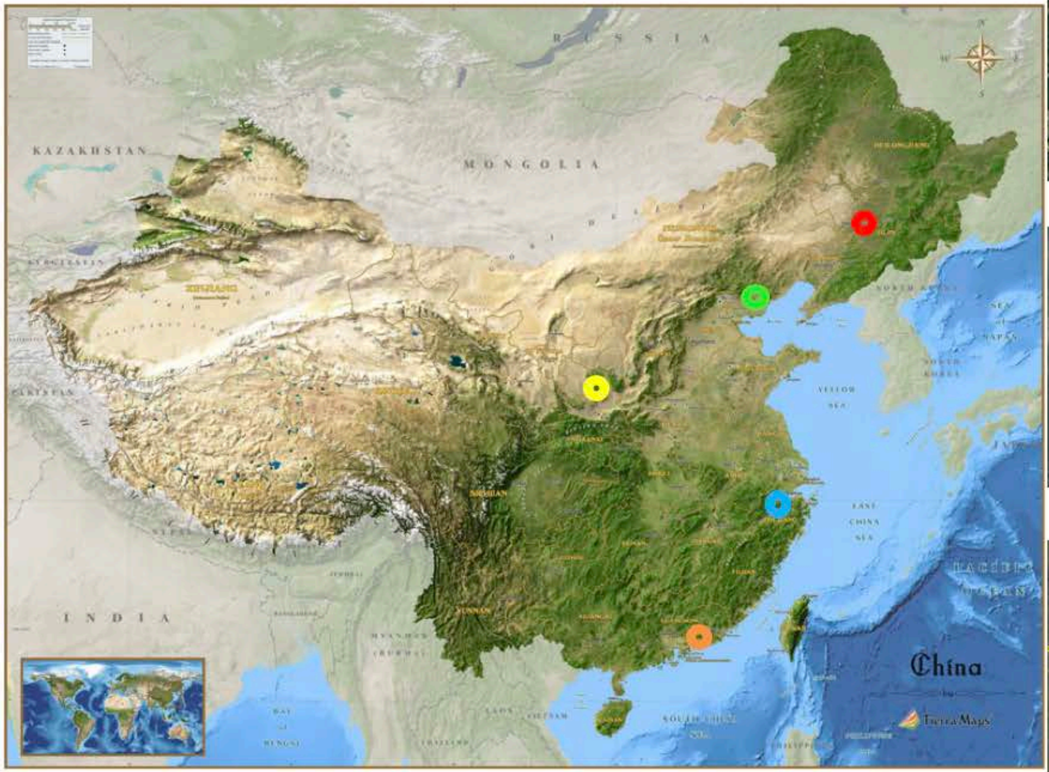
26 Sep 2018

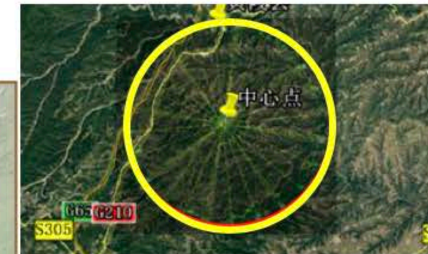
Site Investigation

Changchun, Jilin

Shenshan,

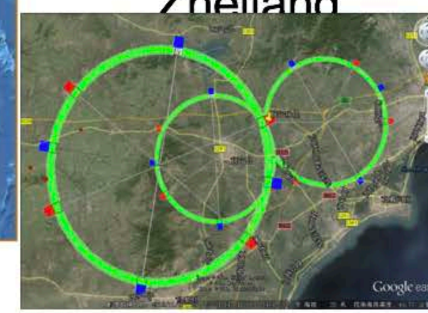
Guangdong





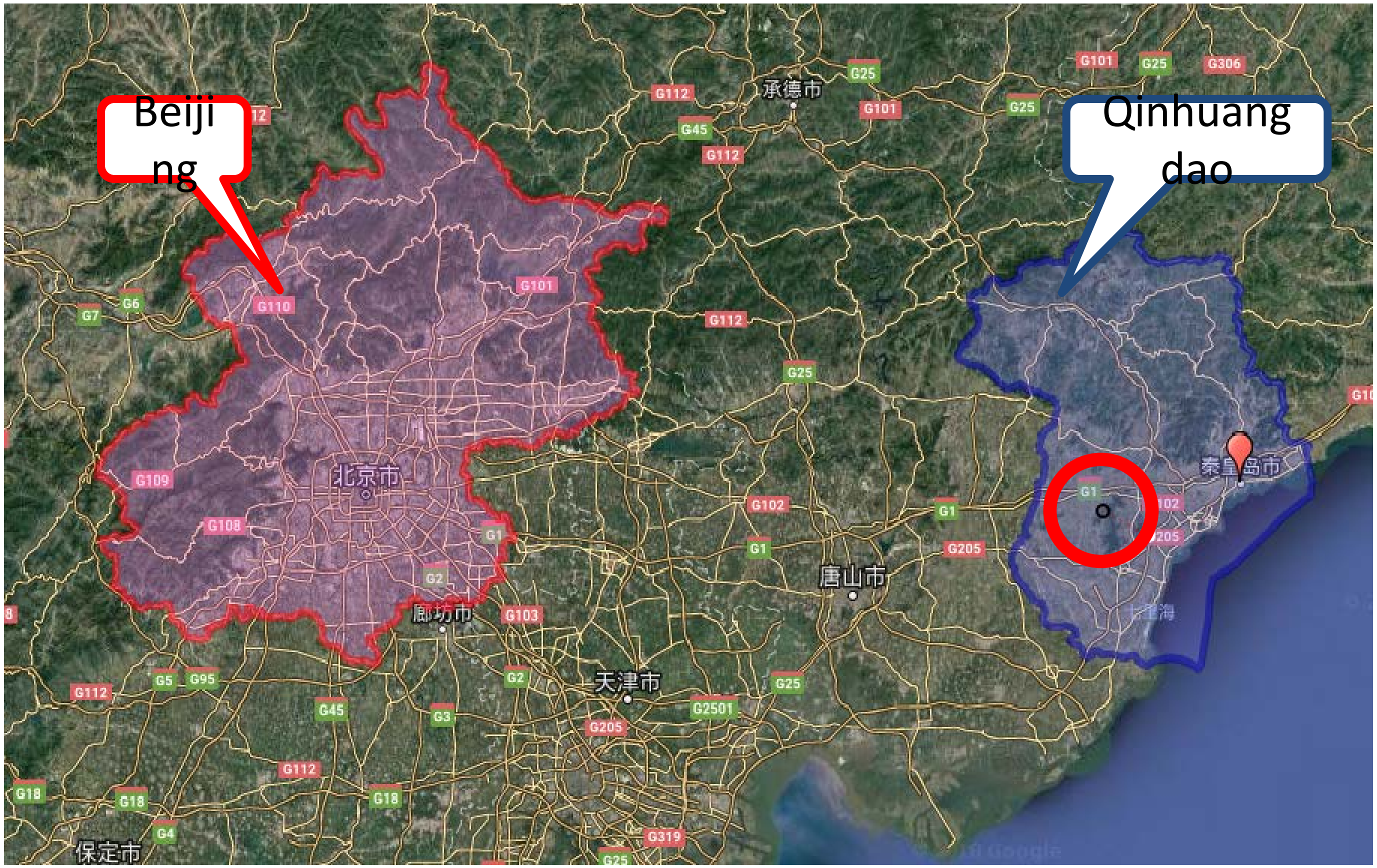
Huangling

Zhejiang



Qinhuangdao,

Hebei


Beiji
ng
Qinhuang
dao
承德市
北京市
秦皇岛市
唐山市
廊坊市
天津市
保定市
G112
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G101
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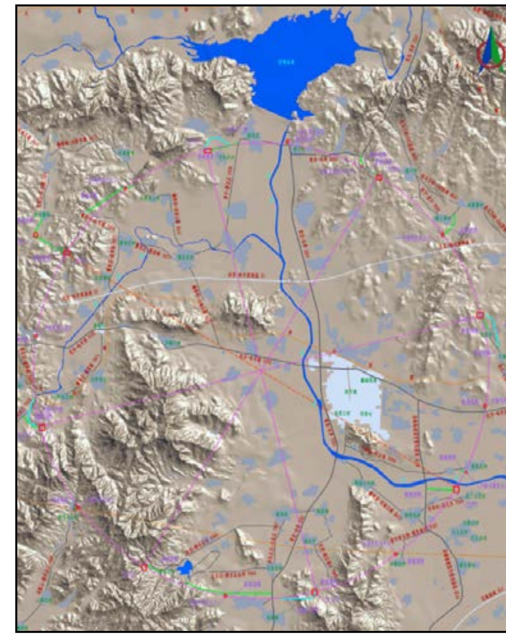
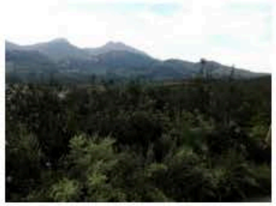
G319

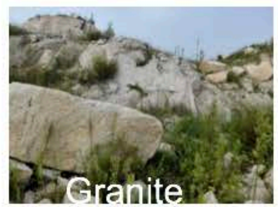


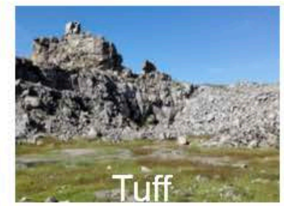
Qinhuangdao, Hebei Province

Topography and landforms

Stratum Lithology

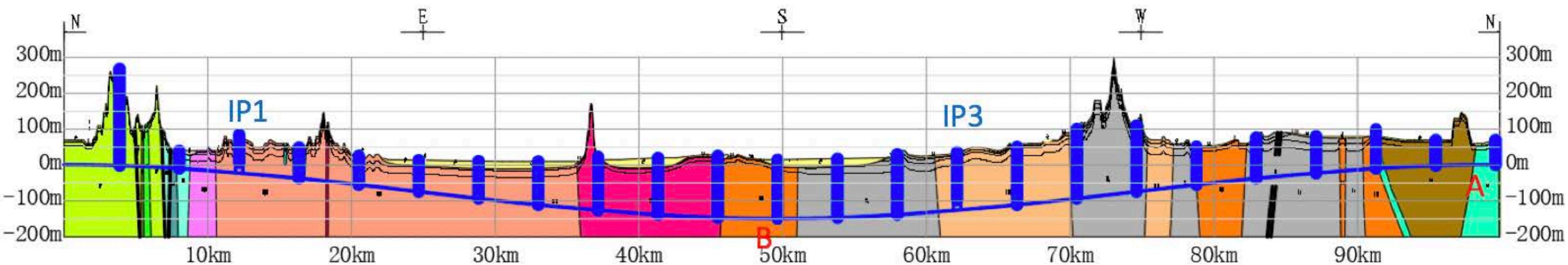








Drill Holes



Summary

Based on the terrain and geological conditions, Qinhuangdao site is the best among current sites. But in general, all the sites are suitable for the underground construction of such a large extent. The main geological problems encountered can be solved by engineering measures.

There are no limitation factors for engineering construction and project operation from all the sites considering the conditions of external access, water and electricity supply, social service, hydrology and meteorology, etc.

The engineering design and construction of CEPC will adopt the mature technology widely used in hydraulic engineering, road, railway or mining sectors. The site conditions are good enough to meet the requirements for construction arrangement.

With comprehensive comparison from construction technology, construction period and project cost, the drill and blast method is recommended at present.

CEPC-SppC is the national major scientific infrastructure facilities, and the site selection shall be compared and determined comprehensively considering the factors of social environment, ecological environment, engineering design and project cost, etc.

A site-specific ILC-CFS design and the Green ILC September 26, 2018

Masakazu Yoshioka

Iwate University

"Kitakami highland" is the unique ILC candidate site since summer in 2013: Characteristics are summarized below;

- Geology ➔ Large and uniform granite area without fault
  - Low risk for underground construction
  - Very small ground motion/vibration
- Topography ➔ rolling hills
  - Easy to access from ground surface to the main tunnel
  - Tunnel elevation is 110m high ➔ ground water drainage can be due to gravity (no risk of flood)
- Important social infrastructures
  - Electricity
  - Industry water
  - Transportation & mobility
- Small impact on the natural environment
  - Preliminary studies were carried out for two years

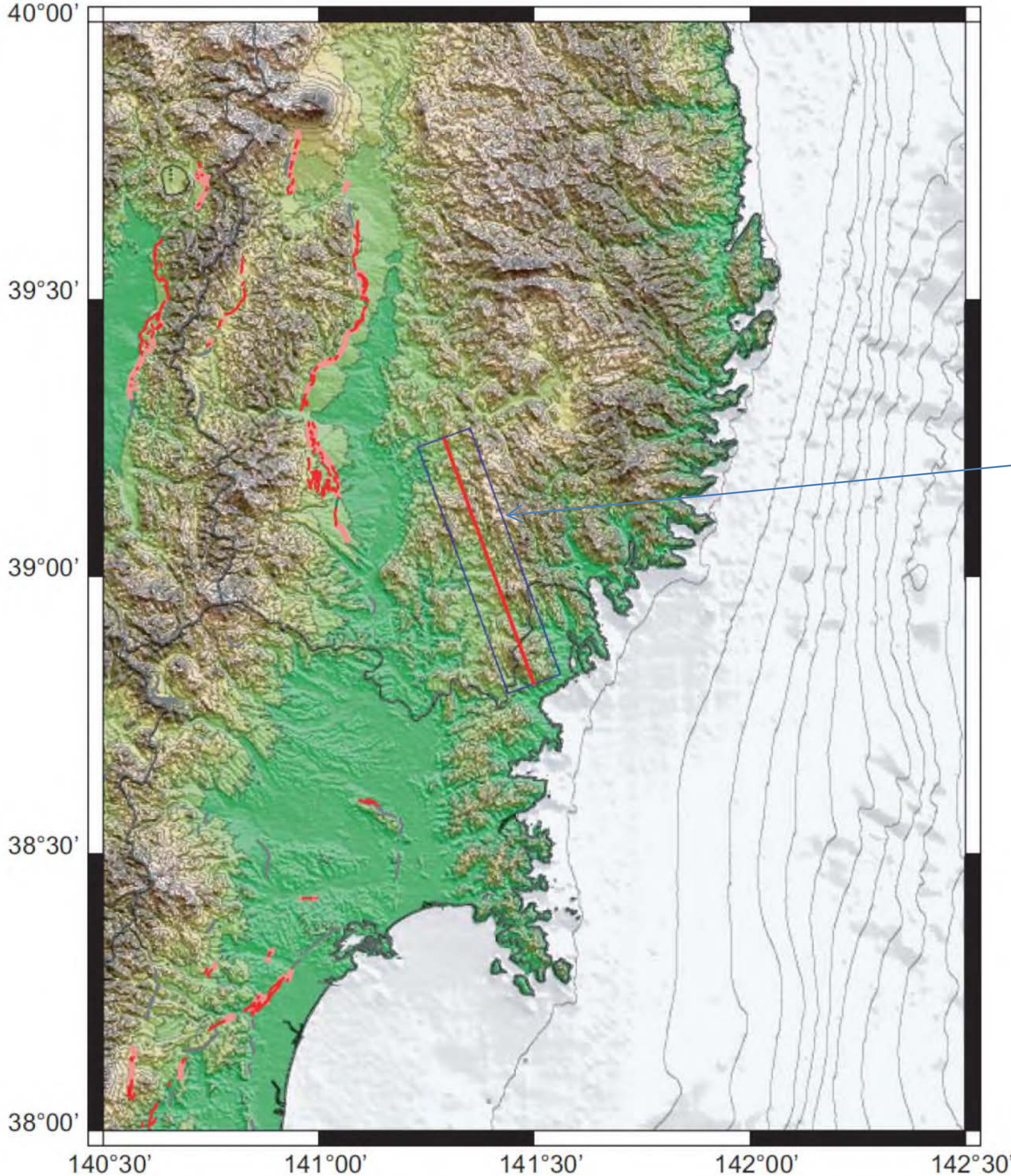
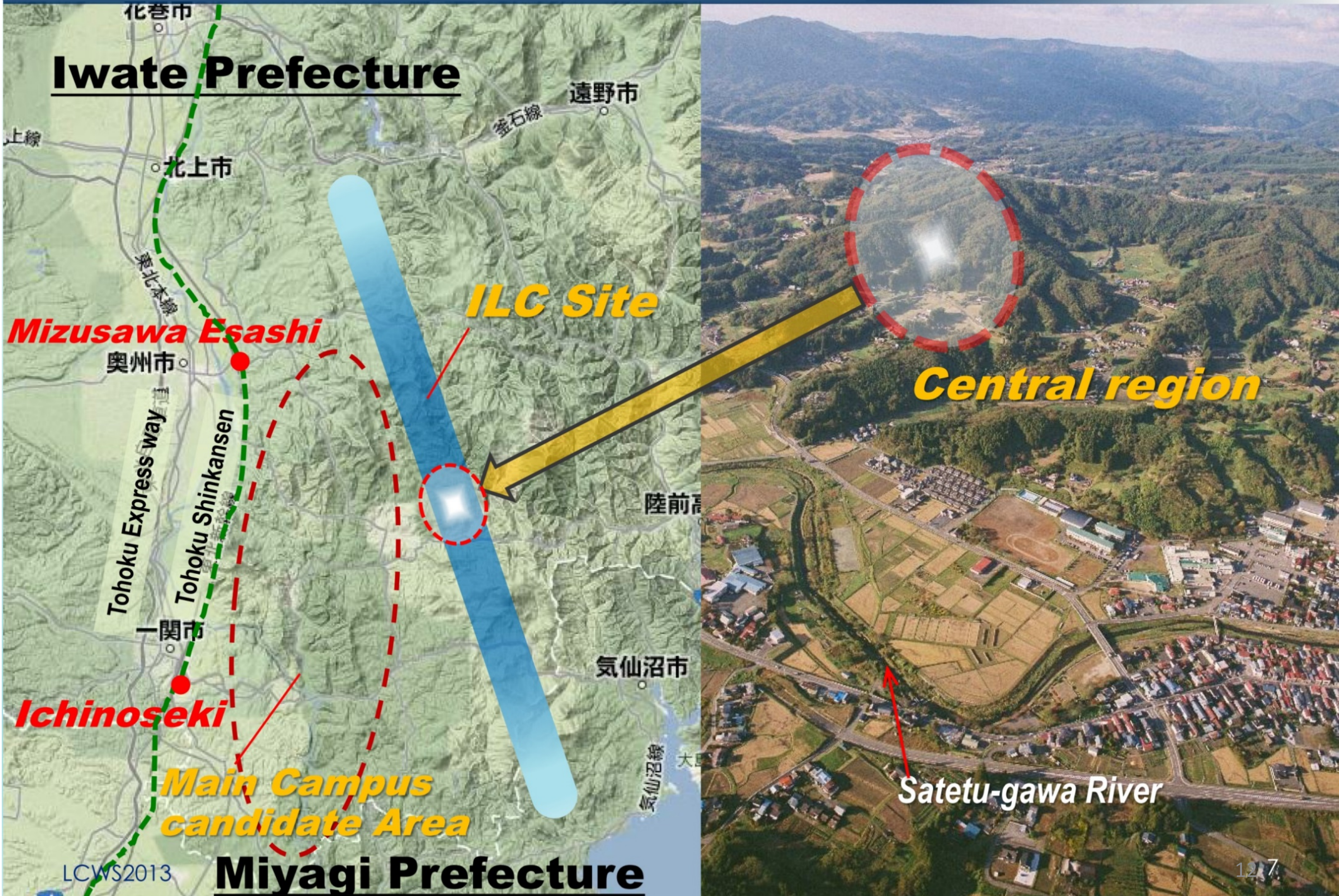


図 2.3　地形と活断層分布図

Kitakami site is free from the fault type earthquake

Location

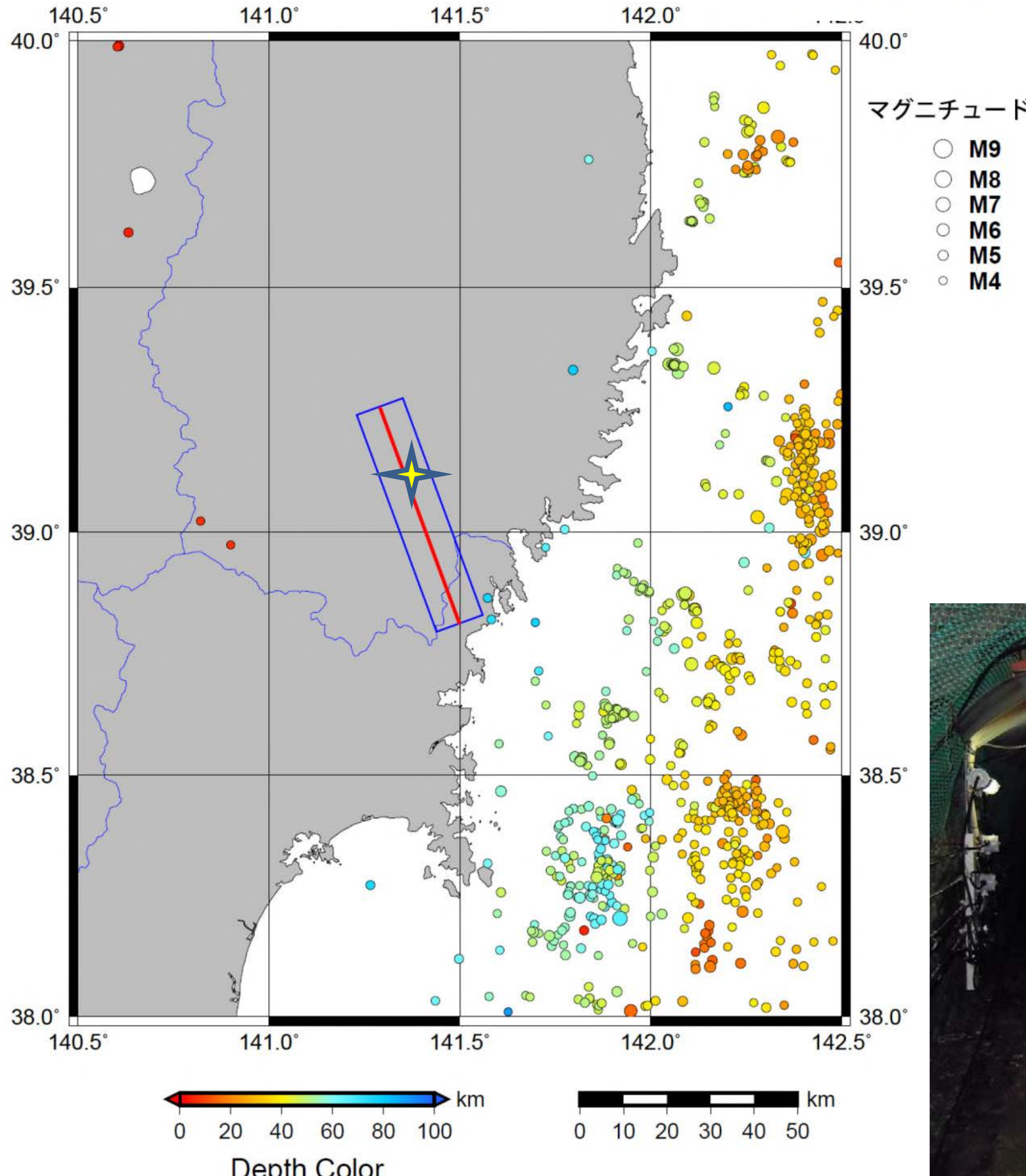


花巻市
Iwate Prefecture
遠野市
釜石線
北上市
東北本線
ILC Site
Mizusawa Esashi
奥州市
Central region
Tohoku Express way
Tohoku Shinkansen
陸前高
一関市
気仙沼市
Ichinoseki
気仙沼線
Main Campus candidate Area
Satetu-gawa River
Miyagi Prefecture

List of necessary survey and study items, which Tohoku team has carried out so far.

- 地表探査 Survey from ground surface
  - 断層調査 Fault survey
  - 地表地質調査 Ground surface geological survey
  - 放射能探査 Radioactivity survey
  - 屈折法地震探査 Seismic refraction
  - 反射法地震探査 Seismic reflection
  - 電磁探査（CSAMT法） Electromagnetic survey
  - 重力探査 Gravity Survey
- 穿孔探査 Boring survey
  - 試験片調査 Sample survey
  - 穿孔孔電気検層 Boreholes Electrical logging
  - 同・速度検層 Boreholes velocity logging
  - 湧水圧試験（JFT法） Ground water pressure test
  - 岩石試験 Laboratory test of rock samples
  - 穿孔内面撮影/内壁面構造調査 Borehole inner face test
  - 屈折法地震探査（垂直） Seismic refraction (Vertical test)
  - 孔内水平載荷試験 Borehole lateral loading test
- 地盤振動調査 Ground vibration survey
  - 地表 Surface: GPS network 1250 stations in Japan
  - 地下 (KIK-net, national earthquake measuring network, by National Research Institute for Earth Science and Disaster Resilience) 100m deep underground stations (700 stations in Japan)
- 広域変動調査 Wide ground variation survey
  - 三角点測量 Triangulation point measurement (974 1st level point, and many 2nd ~4th level points are maintained in Japan)
  - GPS network
- 水文調査 Hydrological survey

Hypocenter Distribution 2011/3/11 - 2013/2/28 M: 4.0-9.0 D: 0.0-100.0km



Coincidentally, “Esashi earth tide observatory underground facility” locates in the same granite zone as ILC. All fragile equipment and long glass tubes are not damaged at all.

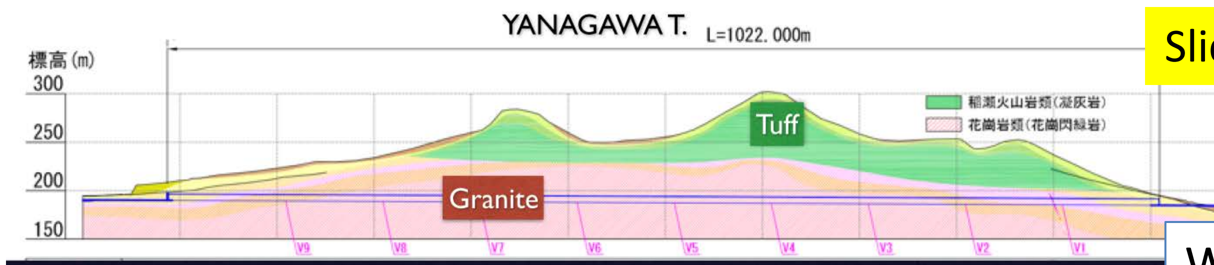
① Earthquake ground motion in the granite zone is coherent .

② Earthquake ground motion in the deep underground is ~20% of the ground surface.

震源データは「気象庁一元化処理」

Geological survey

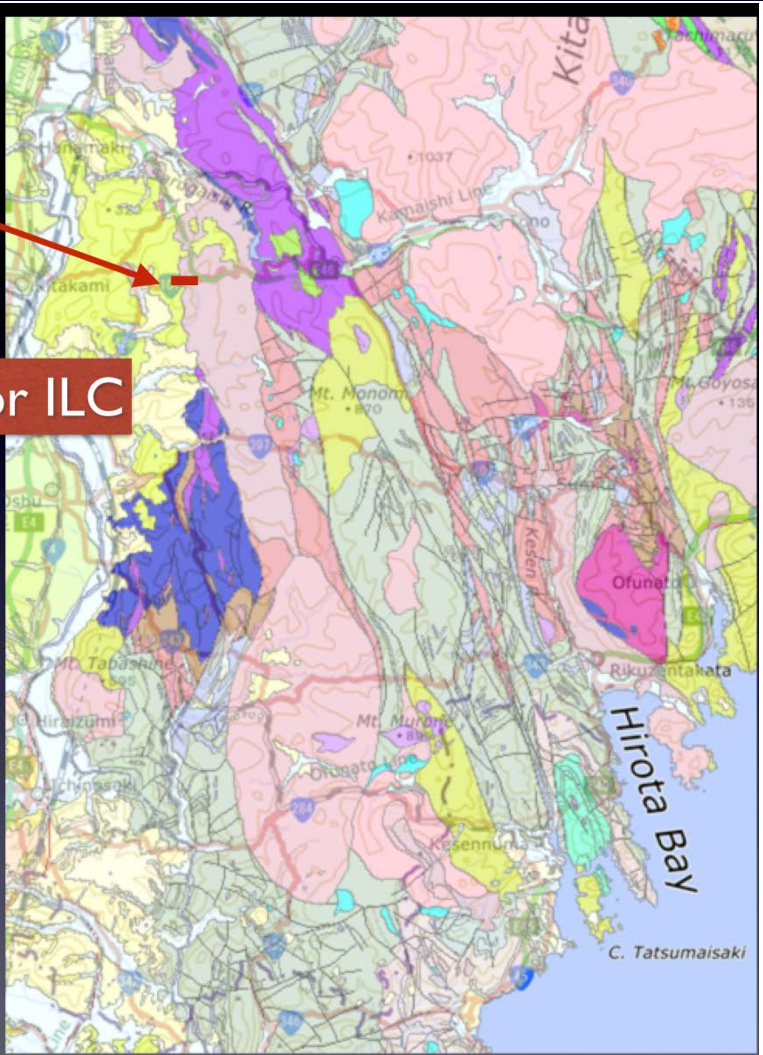
Slide by Tomo Sanuki (Tohoku Univ.)



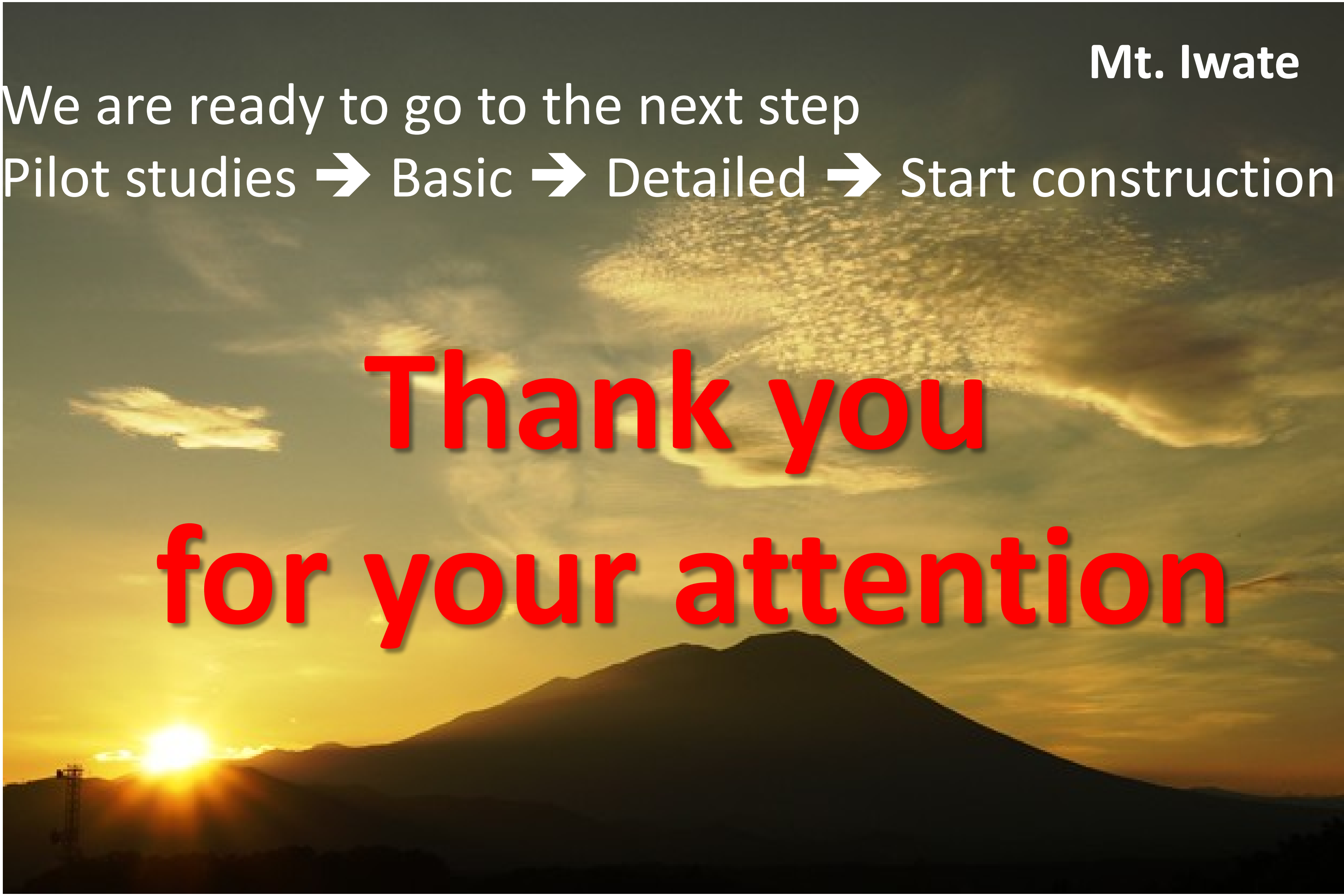
We have a real road tunnel excavation example, coincidentally, in the same rock as ILC with same NATM (blasting method), similar to ILC access and main tunnel excavation.

YANAGAWA Tunnel
L=1,022m

"Pilot tunnel" for ILC



fresh granite
2017.9


Mt. Iwate
We are ready to go to the next step
Pilot studies → Basic → Detailed → Start construction
Thank you
for your attention

Cryogenics system

- 2 talks
  - KEK(K. Nakanishi)
    - Experience more than 30 years
  - CEPC(Jianqin Zhang)
    - Future machine
    - Larger scale
    - Aggressive R&D

KEKB/SuperKEKB Cryogenics Operation

eeFACT2018@HKUST

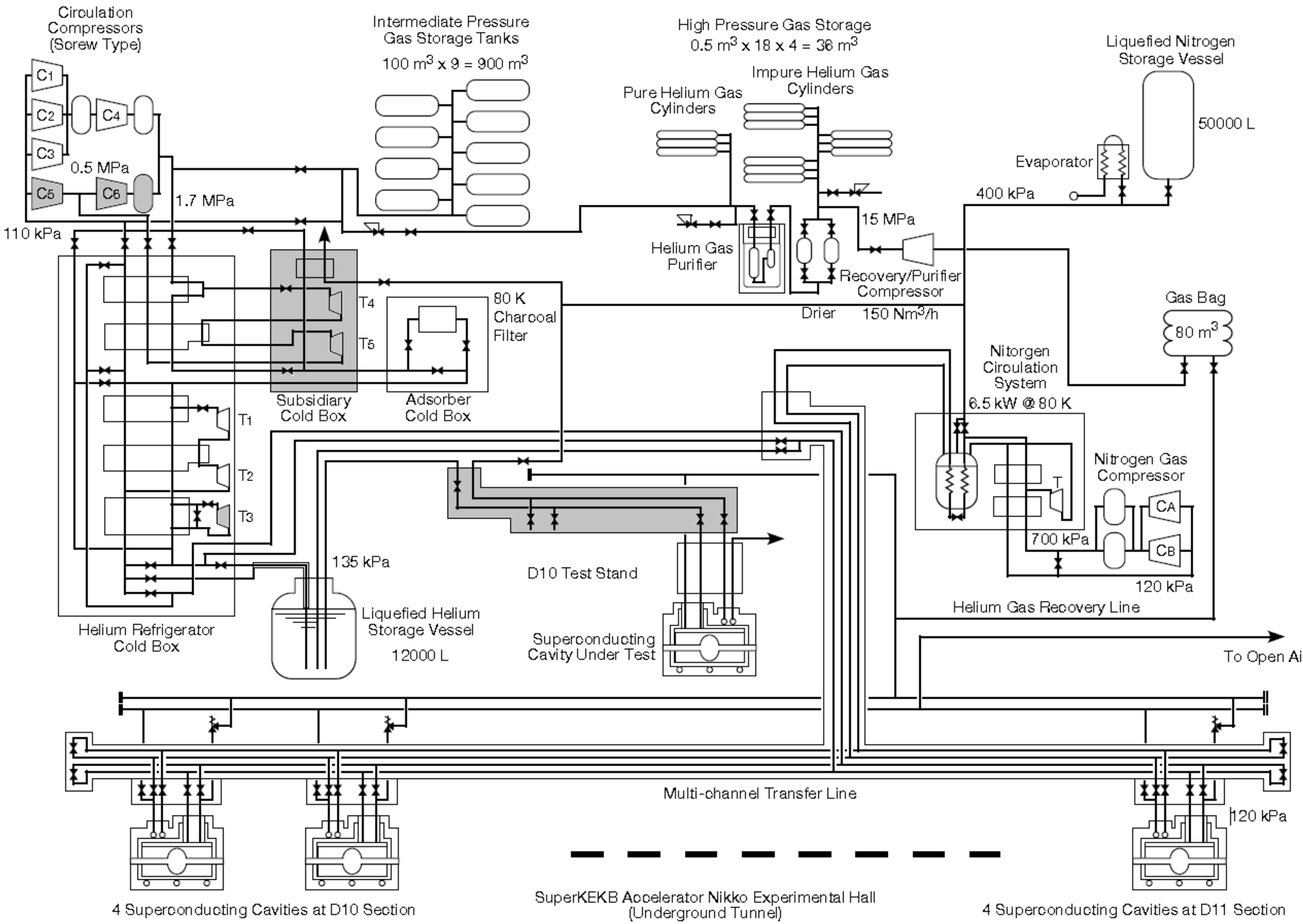
K.Nakanishi, K.Hara, T.Honma, K.Hosoyama, M.Kawai,
Y.Kojima, Y.Morita, H.Nakai, N.Ohuchi, H.Shimizu (KEK)
T.Endo. T,Kanekiyo (Hitachi Plant Mechanics Co,.Ltd.)

History of refrigerator for superconducting cavity.

TRISTAN without Superconducting cavities (SCC)	1986~
TRISTAN with SCC	1988~1995
KEKB with SCC	1998~
KEKB with SCC and Crab cavities	2007~2010
SuperKEKB with SCC	2016~

> 30 years!

Cryogenic system for Superconducting Cavities.



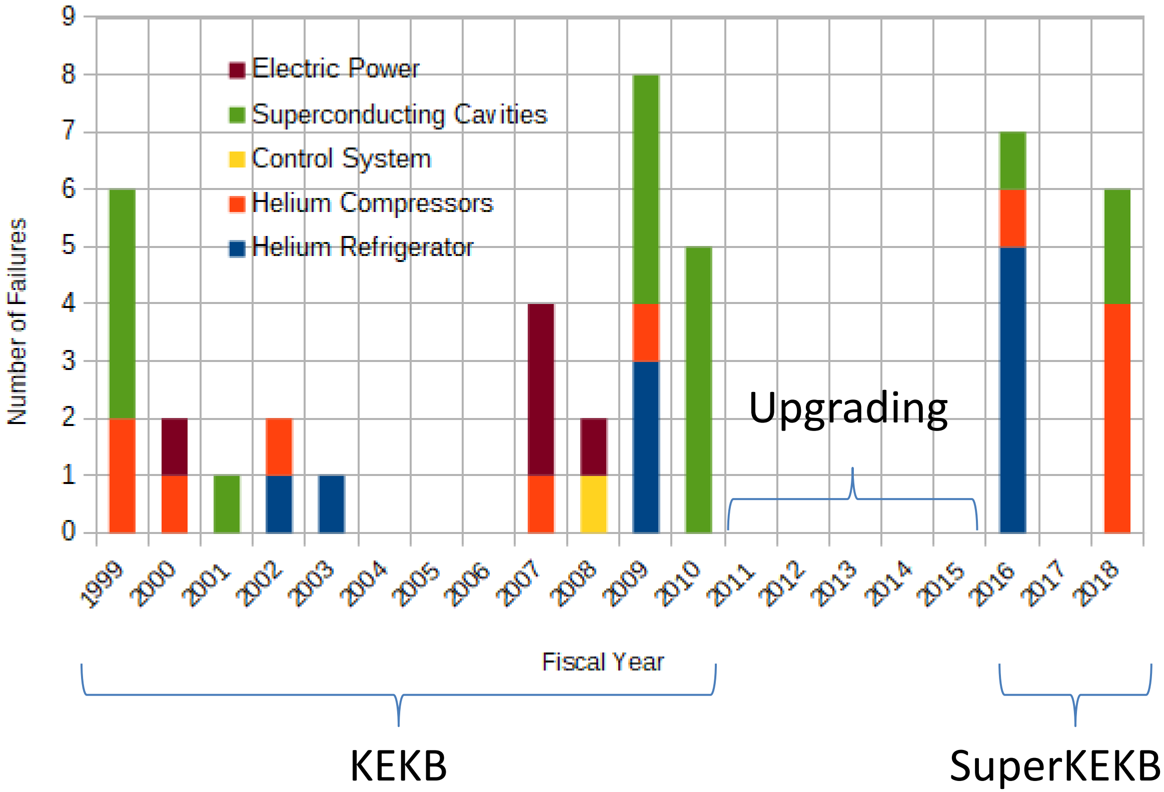
1988
4kW @ 4.4K
(Design)

Compressor (C5,C6) were added.

Supercritical turbine expander (T3) was added.

1989
6.5kW @ 4.4K
(Design)
8.1kW @ 4.4K
(Achieved)

Trouble



The total operation time

TRISTAN	: 38000 hours
KEKB	: 62000 hours
SuperKEKB	: 7700~ hours

Initially there were many stops due to expansion turbo tripping, interlock due to superconducting cavities and power outage.
Malfunction due to aging of electronic equipment is increasing.

Maintenance and Updating

- Maintenance are carried out in accordance with the High Pressure Gas Safety Act.

Required inspection period

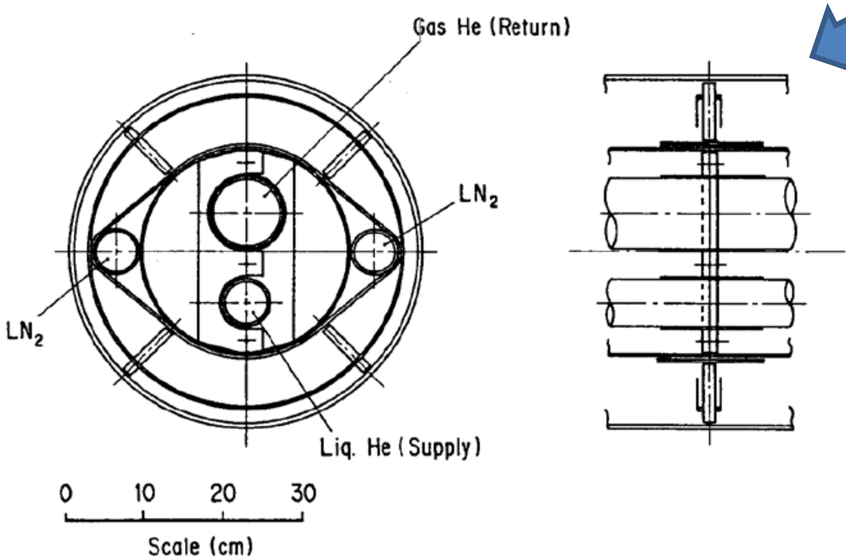
Item	Maintenance cycle
Whole system	1 year
Compressor	2 year
Pressure gauge	2 year
Thermometer	2 year
Cold evaporator	3 year
others	1 year

item	Open inspection cycle
Recovery compressor	10 years or 3000 hours operation
Circulating compressor	10 years or 30000 hours operation
others	exemption

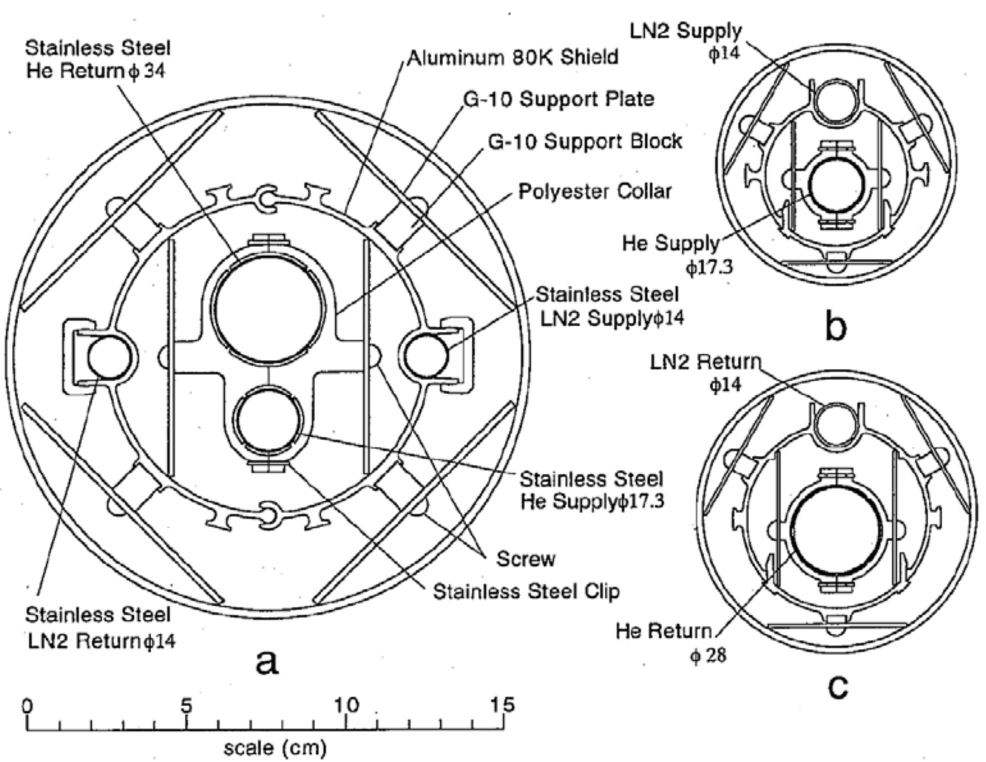
Maintenance and Updating

- The cryogenic systems were inspected every year by the prefectural government. The legal inspection is a good guideline for maintenance.
- Filter replacement of control rack is done every year.
- Check the actuators of the controlled valves, pressure gauges and thermometers in the inspection cycle and replace those that can not be adjusted.
- It is recommended to replace the input / output module of the control system every 5 ~ 7 years. (However, the update cycle is often extended.)
- Compressors are open checked at the manufacturer's recommended operation time. Replacement of parts such as the oil separator is also carried out at this time.
- If needed, painting of tanks is done. Just before legal inspection.

Transfer Line



Transfer Line developed for TRISTAN
This transfer line adopted for connection between the liquid helium dewar and the accelerator tunnel.
The heat load is about 1W/m.



Transfer Line developed for KEKB
This transfer line adopted for connection between the liquid helium dewar and the D10 test stand.
The heat load is about 0.05W/m.

Summary

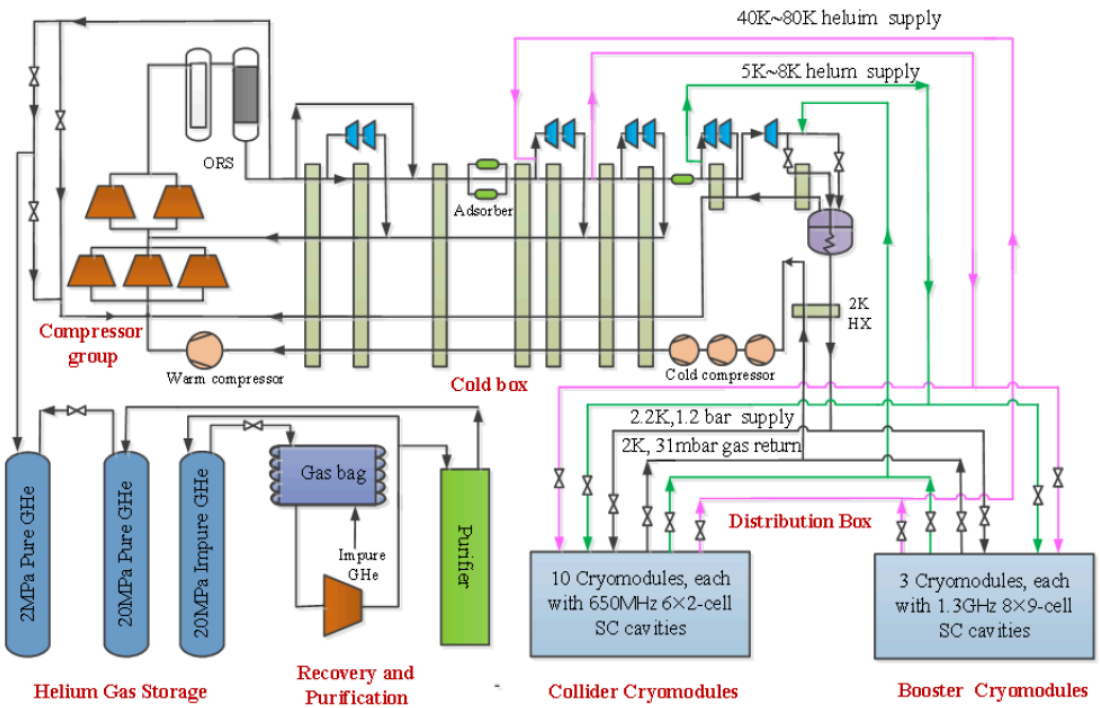
- In SuperKEKB, superconducting cavities are operated using a cryogenic system constructed for TRISTAN in 1988.
- The demand for SuperKEKB's cryogenic system is not higher than TRISTAN’s. (Low and static heat load)
- Periodic maintenance is required.
- The cryogenic systems for magnet are also diverted from TRISTAN.
- All of cryogenic system are very old, however they are working very well.

CEPC Cryogenic System

Jianqin Zhang, Shaopeng Li
Accelerator Divison, IHEP

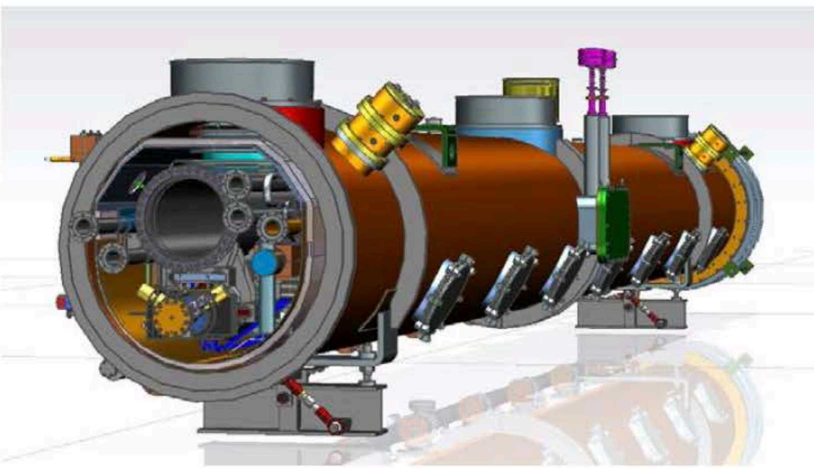
2018.09.26

Flowchart of one Cryo-station



- Each Cryo-station mainly includes Compressor, Cold box, helium gas storage tanks, cryomodules and purification system.
- The cryomodules have two shields, a 40K~80K shield and a 5K~8K shield.
- A 2.2K, 1.2bar helium is supplied for the cryomodules and the 2K, 31mbar helium gas return to the cold box with the cold compressors.

Cryomodule for 1.3GHz 9-cell cavities



Design Goals:
- **Low heat loss**
- **Fast cool down**

XFEL / LCLS-II type Cryomodule for High Q Cavity

- Cryogenic Group in IHEP has manufactured 58 1.3GHz 9-cell Cryomodules for EXFEL cooperated with domestic companies.
- It's a good foundation for the optimization design for the CEPC cryomodules.

Summary

- The heat load is evaluated, the required total 4.5K equiv. heat load is 47.53kW and total installed power is 10.4MW.
- There are four cryo-stations and each station has an individual 18kW@4.5K refrigerator.
- The R&D of 2K JT heat exchanger and cold compressor is under way.

Operation Model, Availability and Performance

A. Apollonio, M. Benedikt, O. Brunner, A. Niemi, J. Wenninger, F. Zimmermann, CERN, Switzerland

S. Myers, ADAM S.A.., Meyrin, Switzerland

J. Seeman, SLAC, U.S.A.

Y. Funakoshi and K. Oide, KEK, Japan

C. Milardi, INFN Frascati, Italy

Q. Qin, IHEP Beijing, P.R. China

luminosity estimate based on

$$\boxed{L_{\mathrm{int}}/\mathrm{year} \approx T\ E\ L_{\mathrm{nominal}}}$$

efficiency

number of days scheduled for physics per year

nominal (design) luminosity

FCC-ee assumptions:
T=185 days,
E= 75% (with top-up injection)

minimum lengths of FCC-ee winter shutdowns; shutdown no. 1 refers to the first shutdown after one year running on the Z pole.

shutdown	no. cryomodules	length of shutdown
shutdown 1	–	12 weeks
shutdown 2	–	12 weeks
shutdown 3	10 CM	12 weeks
shutdown 4	26 CM	20 weeks
shutdown 5	21 CM	14 weeks
shutdown 6	42 CM	18 weeks
shutdown 7	30 CM	15 weeks
shutdown 8	30 CM	15 weeks
long shutdown	104 CM	1 year
shutdown 11	39 CM	17 weeks
shutdown 12	–	–
shutdown 13	–	–
shutdown 14	–	–

O. Brunner

average value: 11.25 weeks (assumption is 17 weeks!)

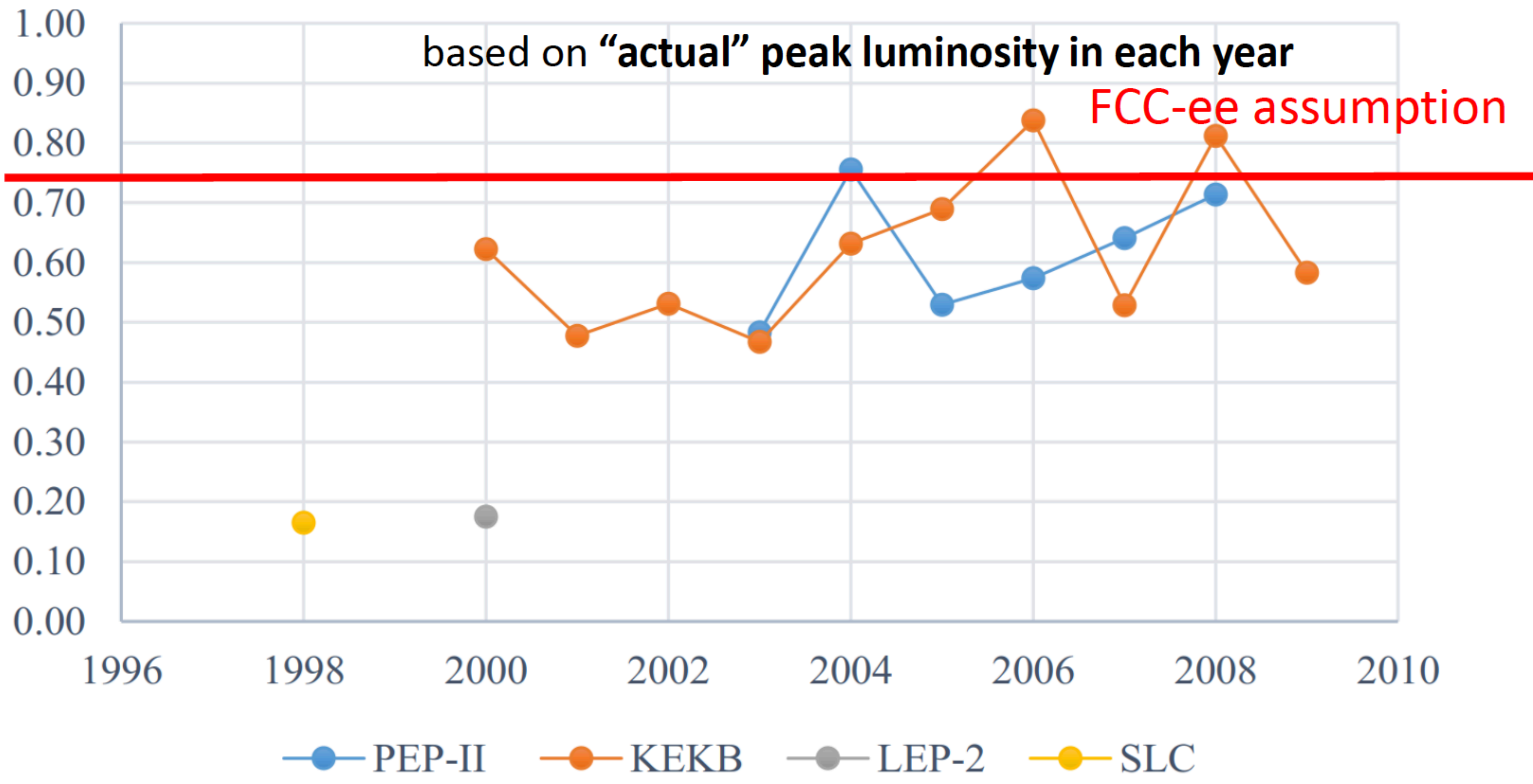
$$E < A \text{ (machine availability)}$$

FCC-ee assumption:

$A \geq 80\%$ to obtain $E \geq 80\% - 5\% \sim 75\%$

recovery from 3 failures/day ~5% at the Z [filling time: 18 min (Z), 2 min (H)]

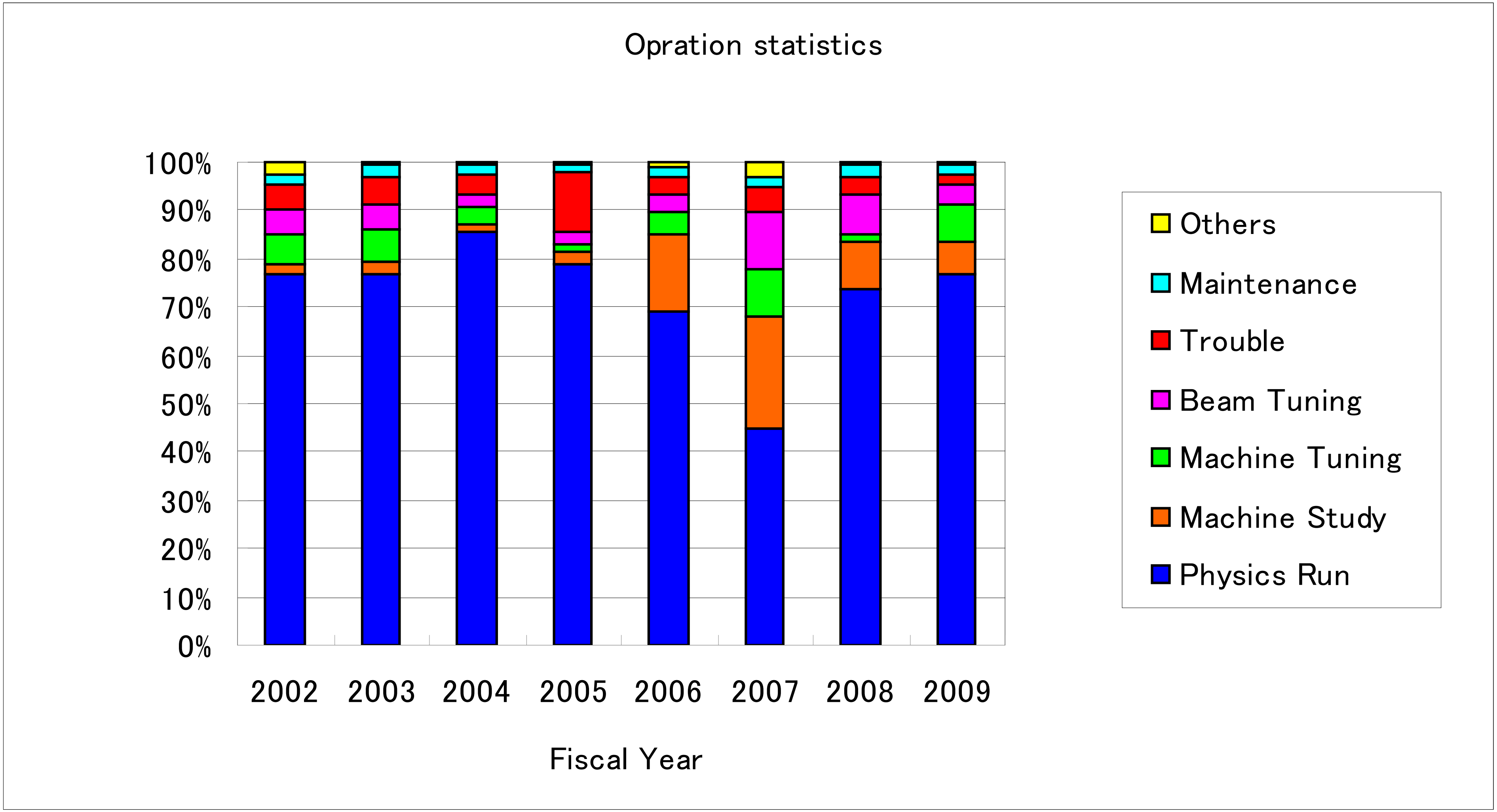
efficiency of lepton colliders – one definition



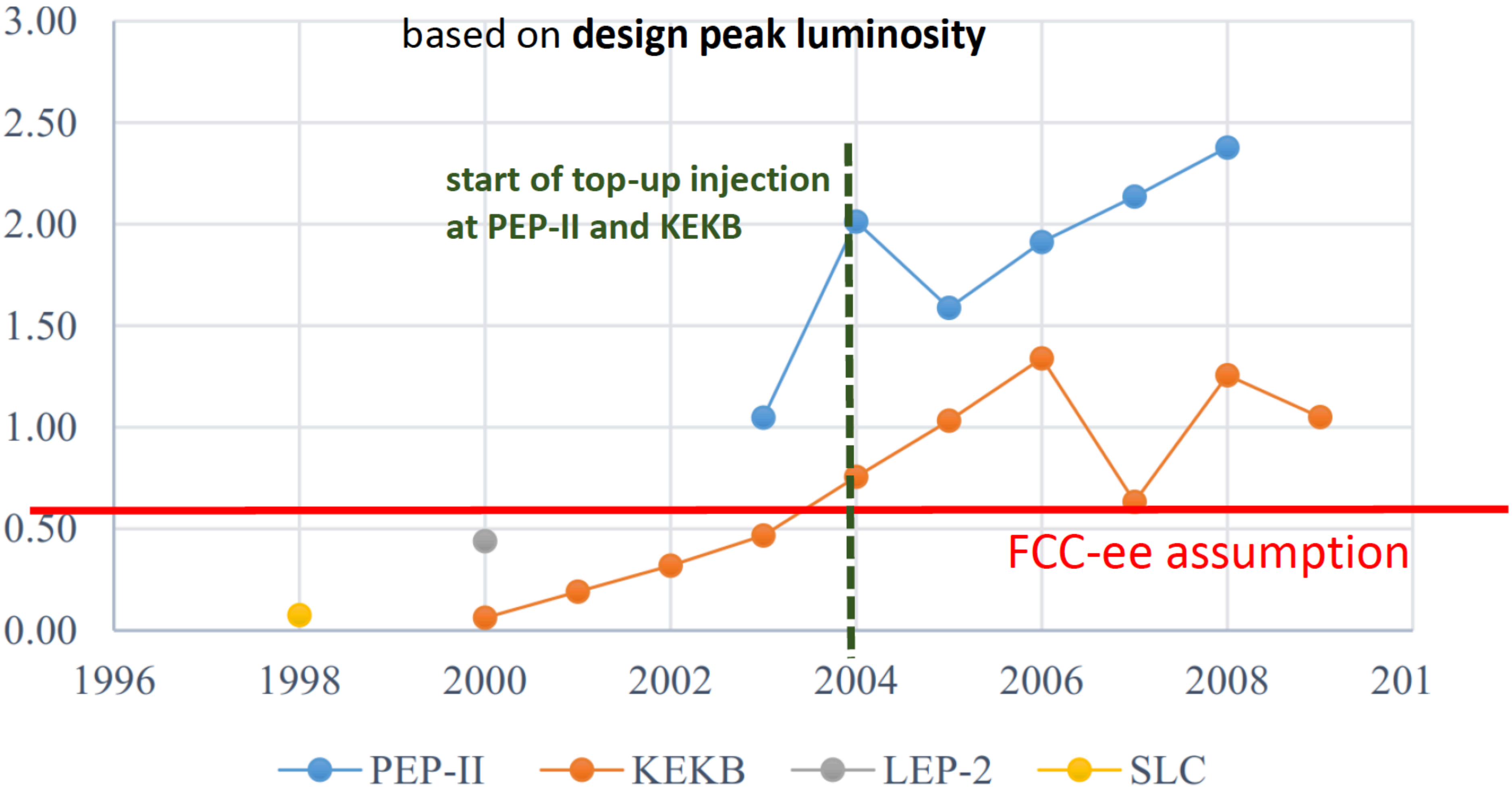
the question is which peak luminosity to take for each year -

peak in that year (LEP), peak reduced by ~15% (above SLC, PEP-II above), average peak over the year after removing values <10% (KEKB), design value (easiest, well defined – FCC-ee)

KEKB operation statistics (2)



efficiency of lepton colliders – a second definition



more than 100% !?!

a few conclusions

assumed annual physics run time of 185 days, hardware availability of at least 80%, corresponding physics efficiency of 75%, and projected annual luminosities of FCC-ee look solid, in view of the experience at several circular lepton colliders over the past 30 years

surpassing FCC-ee baseline values for both peak and integrated luminosity appears a possibility

Summary of talks on operation

	Excellent	Good	Bad	Ugly	Future
DAFNE	-Crab waist	-Collision with negative α -low impedance -long. kicker			DAFNE-TF
BEPC-II	-Achieve design luminosity	-Improved optics, beam-beam parameter	-Hardware failures		BEPC-III
LHC	-Peak luminosity -Integrated luminosity	-Optics -Collimation -Machine protection	-UFOs -16L2	-Quench incident (2008) -Dipole de-training	Run 3
SuperKEKB				QCS quench	Phase 3

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

DAΦNE as Open Accelerator Test Facility

aimed at studying physics and innovative technology for particle accelerators

Catia Milardi

on behalf of the DAΦNE-TF Workshop Scientific Committee

eeFACT18 – 24÷27 Spt 2018 – Hong Kong

DAΦNE achievements

- luminosity achieved at DAΦNE is almost an order of magnitude higher than the one obtained at other colliders operating in the same energy range
- Impedance budget is a factor 80 lower than in similar storage ring (EPA)
- Collisions with negative momentum compaction gave a 25% gain in terms of specific luminosity at low current without sextupoles
- Longitudinal feedback kicker designed for DAFNE has been adopted at: KEKB, BESSYII, PLS, SLS, HLS, ELETTRA, KEK Photon Factory, PEP II …
- Maximum current stored in the DAFNE electron ring, 2.45 A, is the higher ever stored in particle factories and modern synchrotron radiation sources.
- DAΦNE is the only collider operating routinely with, and thanks to the electrodes for e-Cloud mitigation
- *Crab-Waist collision scheme proved to be an effective approach to increase luminosity in circular colliders even in presence of an experimental apparatus strongly perturbing beam dynamics.*

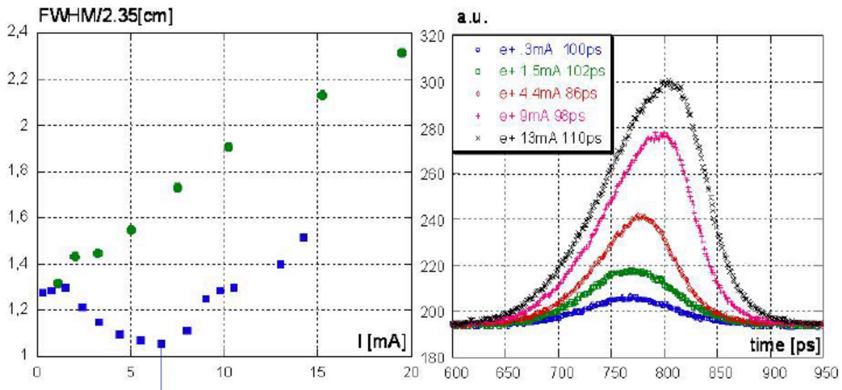
DAΦNE is a collider operating with high currents

Lepton Beam Currents achieved so far

	beam current I [A]	bunch population N_b [10^{11}]	rms bunch length [mm]	bunch spacing [ns]	comment
PEP-II	2.1 (e^-), 3.2 (e^+)	0.5, 0.9	12	4.2	closed
superKEKB	2.62 (e^-), 3.6 (e^+)	0.7, 0.5	7	6	commissioning
DAFNE	**2.4 (e^-), 1.4 (e^+)**	**0.4, 0.3**	**16**	**2.7**	
BEPC-II	0.8	0.4	<15?	8	
CesrTA	0.2	0.2	6.8	4	
VEPP-2000	0.2	1	33	80 (1 b)	
LHC (des)	0.58	1.15	75.5	25	
ESRF	0.2	0.04	6.0	2.8	
APS	0.1	0.02	6.0	2.8	
Spring8	0.1	0.01	4.0	2.0	
SLS	0.4	0.05	9.0	2.0	

$\alpha_c < 0$ at DAΦNE

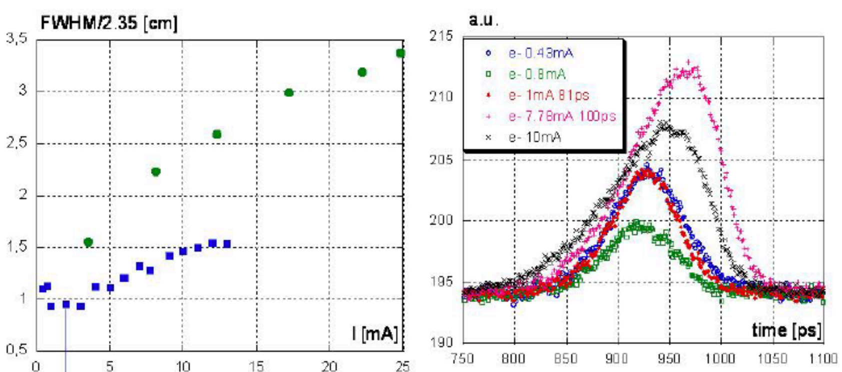
Bunch Shortening in the Positron Ring



I_{th} = 7 mA at $\alpha_c < 0$

I_{th} = 9 mA at $\alpha_c > 0$

Bunch Shortening in the Electron Ring



Low microwave instability threshold

Experimental Results

- DAΦNE flexible optics

$$-0.036 \leq \alpha_c \leq +0.034$$

- Bunches shorten as predicted by numerical simulations.
- It was possible to store high bunch current with large negative chromaticity

I_b ~40 mA

- Stable multibunch beams with ***I > 1 A***
- **Specific luminosity gain of about 25%** till 300 mA per beam without SXTs
- Higher current beam-beam collisions failed due to σ_y^- above the microwave instability threshold

Crab-Waist Colliders

Colliders	Location	Status
DAΦNE	Φ-Factory Frascati, Italy	In operation
SuperKEKB	B-Factory Tsukuba, Japan	~~Under commissioning~~ Under consideration
SuperC-Tau	C-Tau-Factory Novosibirsk, Russia	Russian mega-science project
FCC-ee	Higgs-Factory CERN,Switzerland	100 km, CW baseline design option
CEPC	Higgs-Factory China	54 km, local double ring option with CW
LHC Upgrade	LHC CW Option CERN,Switzerland	LHC with very flat beams (low priority)

Proposed DAFNE-TF

Then ....

The aforementioned considerations, and not only, led to conclude that DAFNE a unique facility to realize tests and measurements finalized to:

- study physics problems and innovative technologies which are of interest for the particle accelerator community
- test innovative concepts
- implement short term experiment about fundamental and applied physics
- train young generations of particle accelerator physicists

DAΦNE-TF Workshop
(December 17th 2018 in Frascati)

Organized under the auspices of the LNF Director Dr. Pierluigi Campana

Scientific Committee:

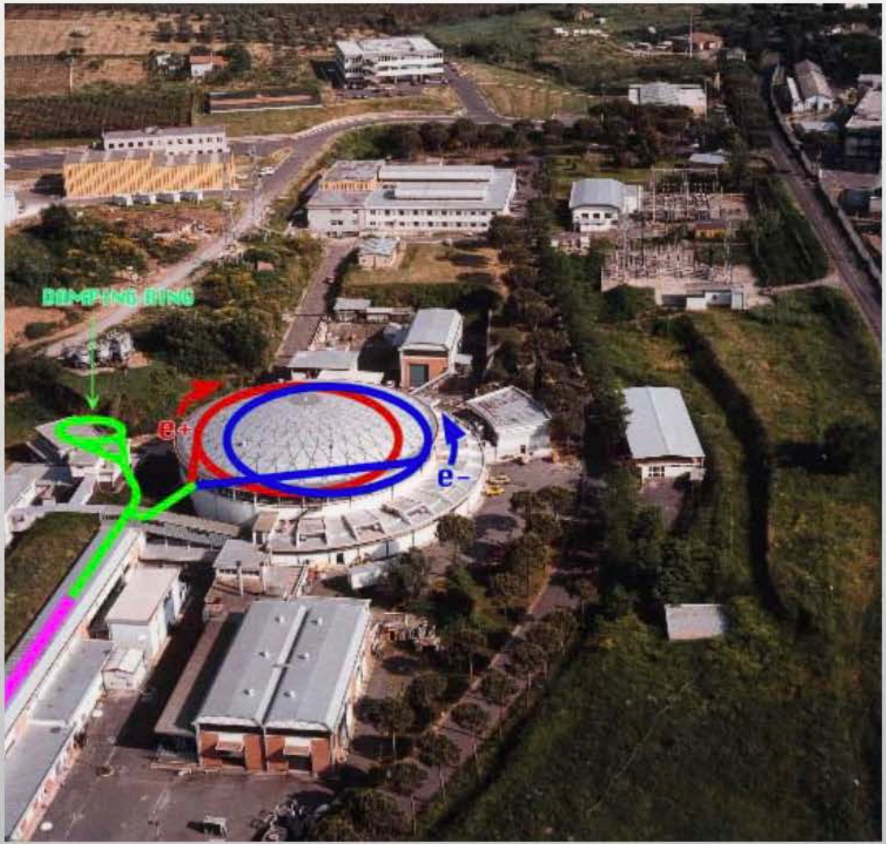
L. Rivkin (EPFL and PSI, chair)
C. Bloise (INFN-LNF)
A. Ghigo (INFN-LNF)
M. Giovannozzi (CERN)
C. Milardi (INFN-LNF),
N. Pastrone (INFN-Torino)
A. Variola (INFN-LNF)

Local Organizing Committee

A. Drago (INFN-LNF, chair)
A. De Santis (INFN-LNF)
O. R. Blanco Garcia (INFN-LNF)

Conclusions

DAΦNE is a valuable and unique infrastructure that can still play a role in the particle accelerator community.



BEPCII Status

Qing Qin, Yuan Zhang, Chenghui Yu, Jianshe Cao, Jun Xing, Lei Qian

IHEP, CAS

Sept. 26, 2018

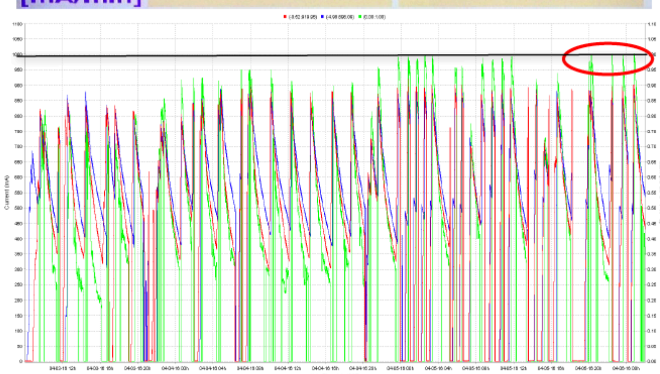
中国科学院高能物理研究所
Institute of High Energy Physics

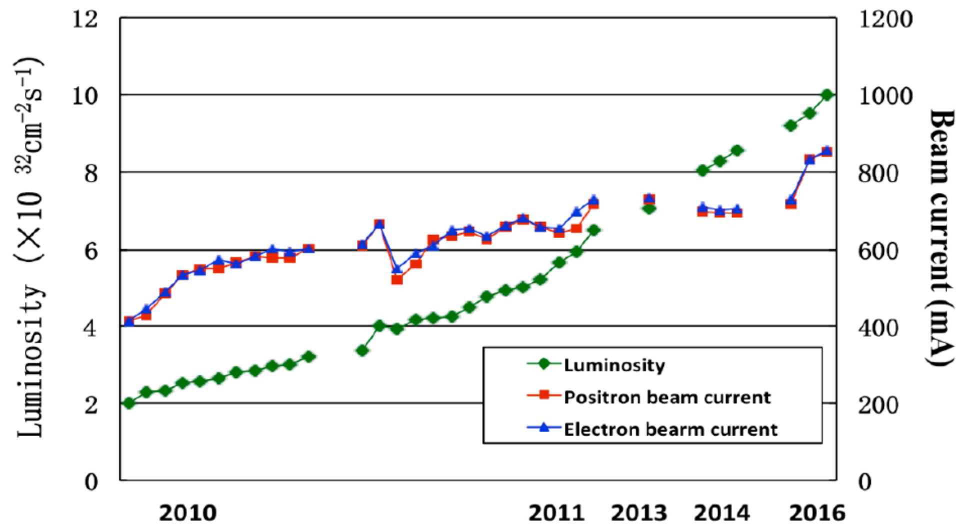
Summary of talks on operation

	Excellent	Good	Bad	Ugly	Future
DAFNE	-Crab waist	-Collision with negative α -low impedance -long. kicker			DAFNE-TF
BEPC-II	-Achieve design luminosity	-Improved optics, beam-beam parameter	-Hardware failures		BEPC-III
LHC	-Peak luminosity -Integrated luminosity	-Optics -Collimation -Machine protection	-UFOs -16L2	-Quench incident (2008) -Dipole de-training	Run 3
SuperKEKB				QCS quench	Phase 3

Designed luminosity achieved

- The designed luminosity 10.0×10^{32} $cm^{-2}s^{-1}$ achieved on April 5, 2016, with the beam current of 849mA*852mA, 119 b. The beam-beam parameter reached 0.0384.





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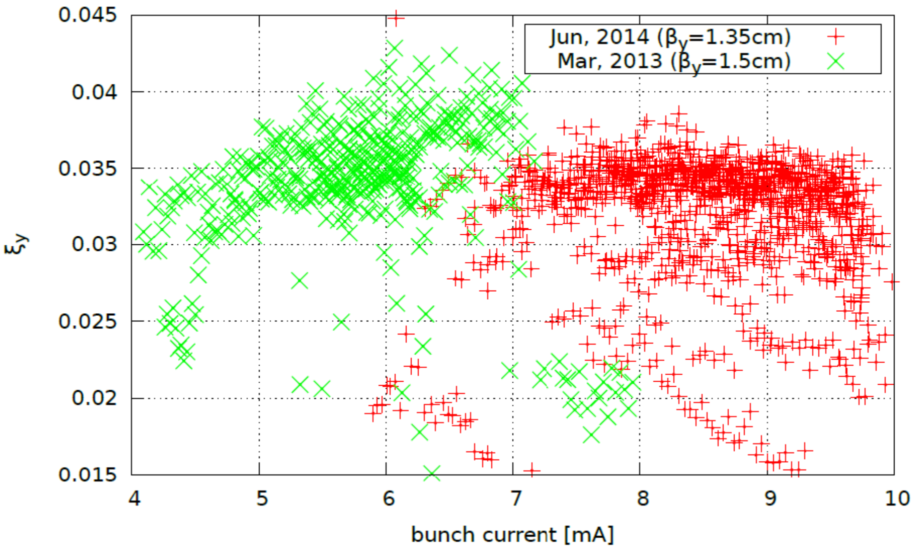
- **Lattice evolution**
  - The bunch number should be controlled as less as possible to keep beam stable with a high beam current. The lattice with low momentum compaction was improved. The emittance was increased from 100 nm to 122 nm to increase the collision bunch current.

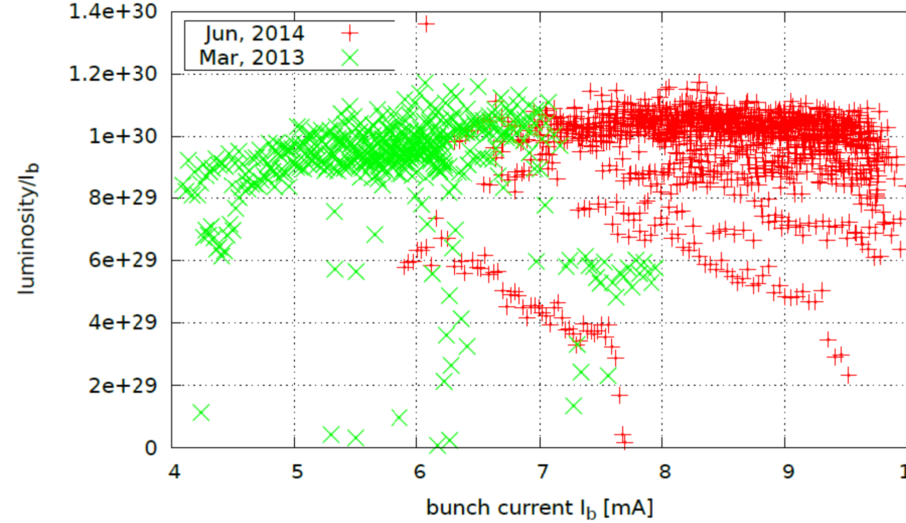
Parameters	Values
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	9.8 mA
β function at IP	1.0 m/1.5 cm
Horizontal emittance	144 nm·rad
Working point	6.53/5.58
Harmonic number	396
Bunch number	93
Bunch spacing	2.4 m
RF voltage	1.5 MV
Momentum compaction	0.0235
Natural bunch length	1.35 cm
Beam-beam parameter	0.04
Luminosity	$1.0\times10^{33}cm^{-2}s^{-1}$

Parameters	Values
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	7.0 mA
β function at IP	1.0 m/1.5 cm
Horizontal emittance	100 nm·rad
Working point	7.505/5.580
Harmonic number	396
Bunch number	130
Bunch spacing	1.8 m
RF voltage	1.5 MV
Momentum compaction	0.0170
Natural bunch length	1.15 cm
Beam-beam parameter	0.04
Luminosity	$1.0\times10^{33}cm^{-2}s^{-1}$

Parameters	Values
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	8.3 mA
β function at IP	1.0 m/1.35 cm
Horizontal emittance	122 nm·rad
Working point	7.505/5.580
Harmonic number	396
Bunch number	110
Bunch spacing	1.8 m
RF voltage	1.5 MV
Momentum compaction	0.0181
Natural bunch length	1.15 cm
Beam-beam parameter	0.04
Luminosity	$1.1\times10^{33}cm^{-2}s^{-1}$

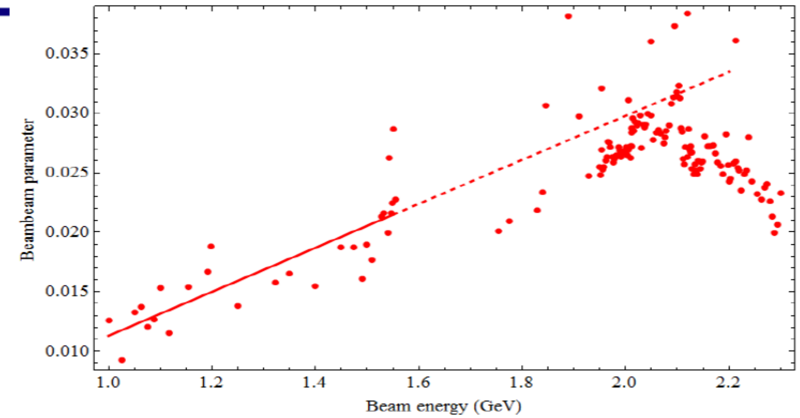
Different β_y@ IP for high luminosity

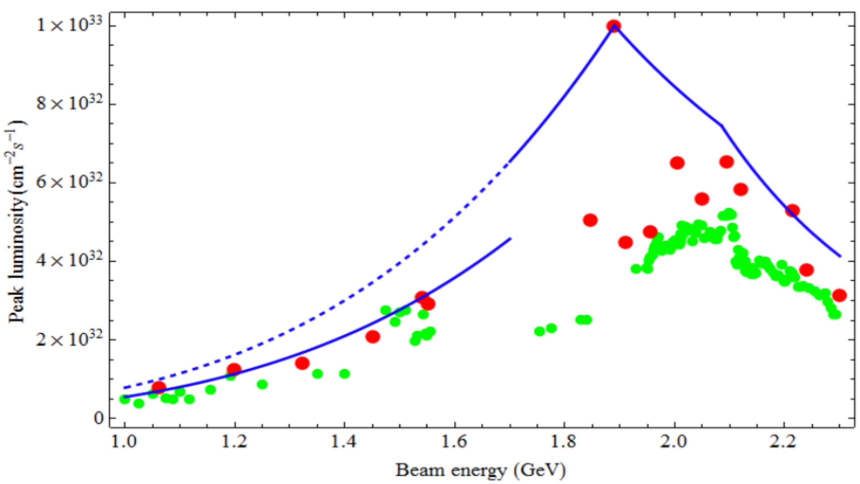


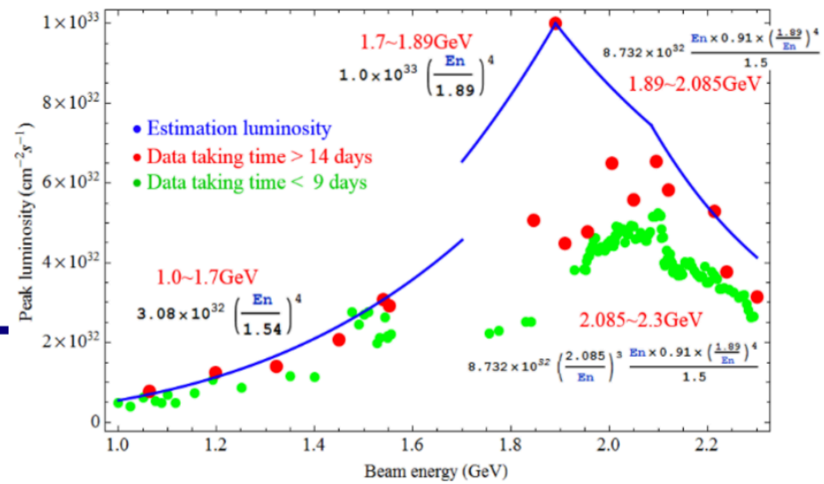


Peak luminosity and scaling law wrt beam energy

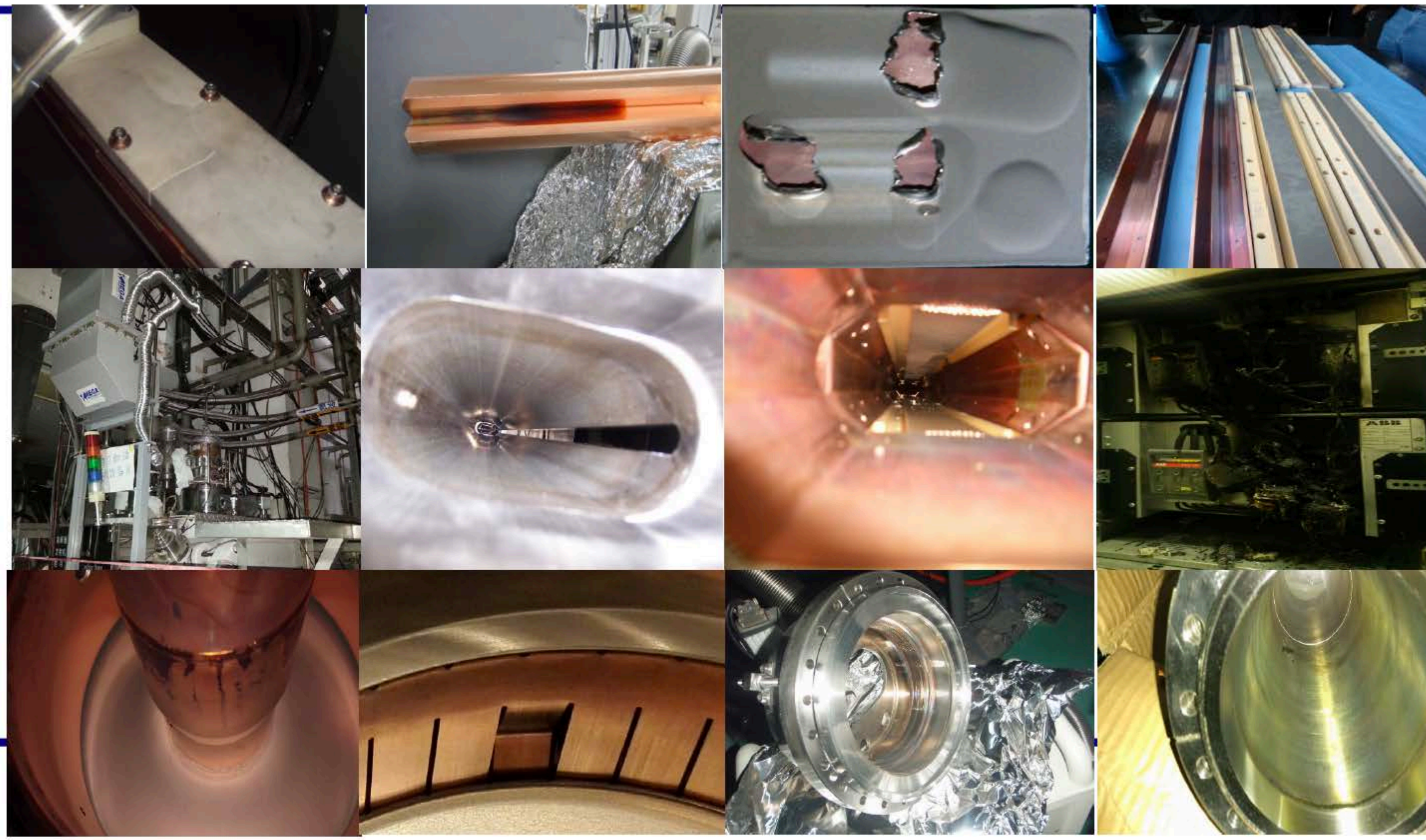
- Lower energy – multi-bunch instability ↗
  damping time ↗, injection efficiency ↘
- Higher energy – beam current ↘
  bunch length & emittance optimized







Hardware failures limited increasing beam current



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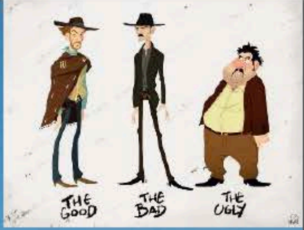
Conclusion

- From late 2008, BEPCII runs for HEP and SR for more than 9 years with an increasing luminosity, and a big energy span for various HEP exp.;
- A lot of work on AP and hardware improvements done in recent years help to enhance luminosity greatly;
- The design luminosity @ ψ(2S) energy was achieved, although most of the time accelerator was not run at that energy;
- A fruitful HEP results has been obtained and will be got in the near future with the high efficient operation and beam performance;
- High luminosity and high energy operations are foreseen in the near future.



LHC Commissioning
The good, the bad the ugly

eeFact2018

Hong-Kong, 25-28 September 2018

J. Wenninger / R. Giachino
CERN Beams Department
Operation Group / LHC

On behalf of the LHC operation & commissioning teams

Summary of talks on operation

	Excellent	Good	Bad	Ugly	Future
DAFNE	-Crab waist	-Collision with negative α -low impedance -long. kicker			DAFNE-TF
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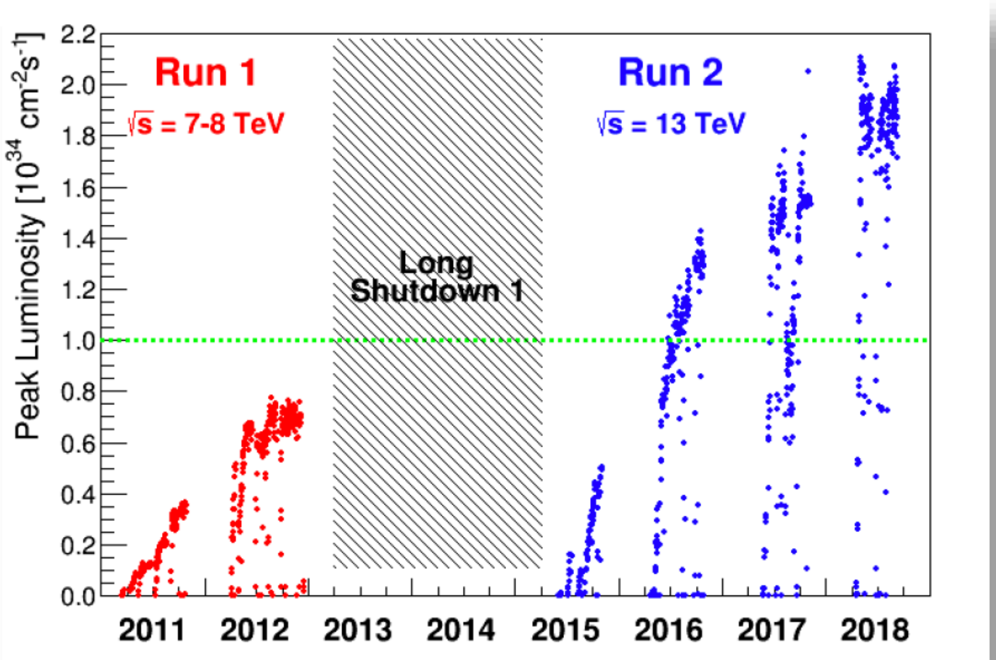
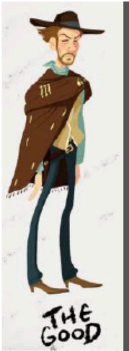
SuperKEKB				QCS quench	Phase 3

Peak performance 2011-2018

Progressively more bunches, lower β^*, smaller crossing angles etc





Peak luminosity limited to ***≈2.2×10^{34} cm^{-2}s^{-1}*** *by the cryogenic cooling capacity of the low-beta quadrupoles*

Peak luminosity:

Run 1: 7.6×10^{33} $cm^{-2}s^{-1}$

Run 2: 1.4×10^{34} $cm^{-2}s^{-1}$

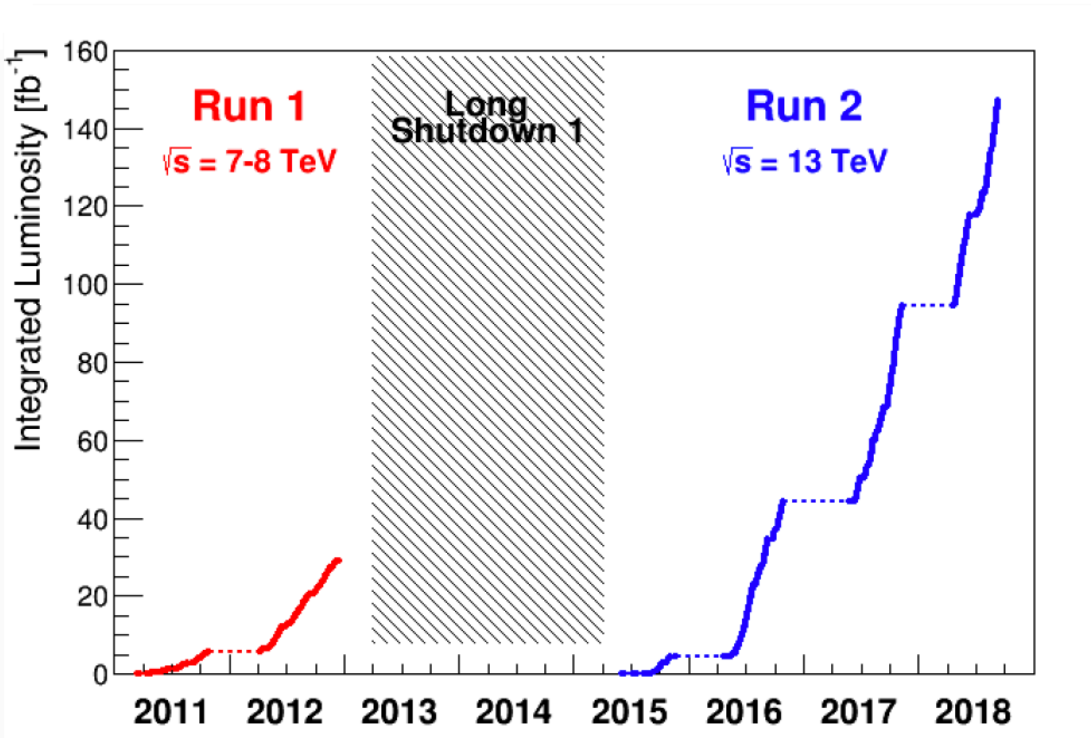
Design luminosity:

1×10^{34} $cm^{-2}s^{-1}$

Integrated performance 2011 - 2018

Integrated luminosity:

- ✓ ***30 fb^{-1}*** *at 3.5 TeV & 4 TeV – Run 1,*
- ✓ ***147 fb^{-1}*** *at 6.5 TeV – Run 2.*



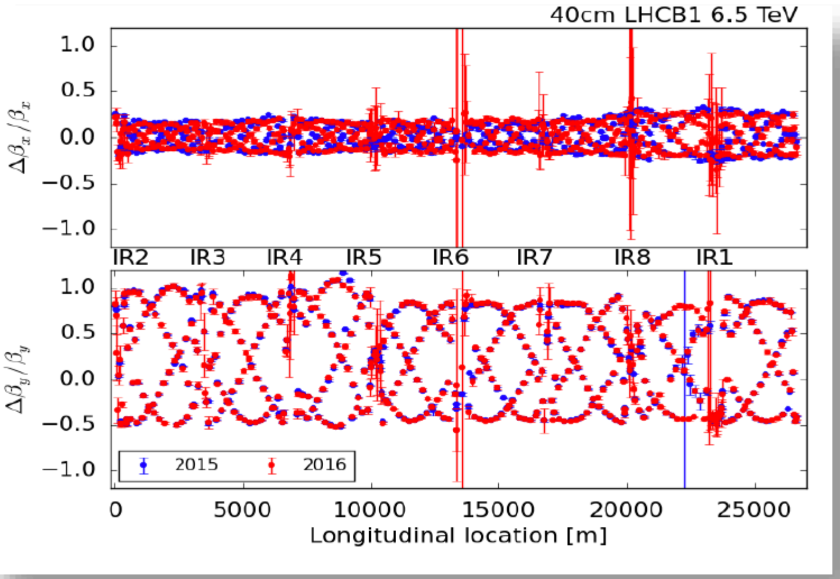
Initial target of 100 fb^{-1} in Run 2 will be exceeded by ~50%

LHC optics

- The machine optics is **reproducible from one year to the next** and the beta-beating is corrected down to the % level at 6.5 TeV.
- Improving optics control including NL correction in low beta sections allowed a progressive reduction of **β* to 30 cm** (design 55 cm).

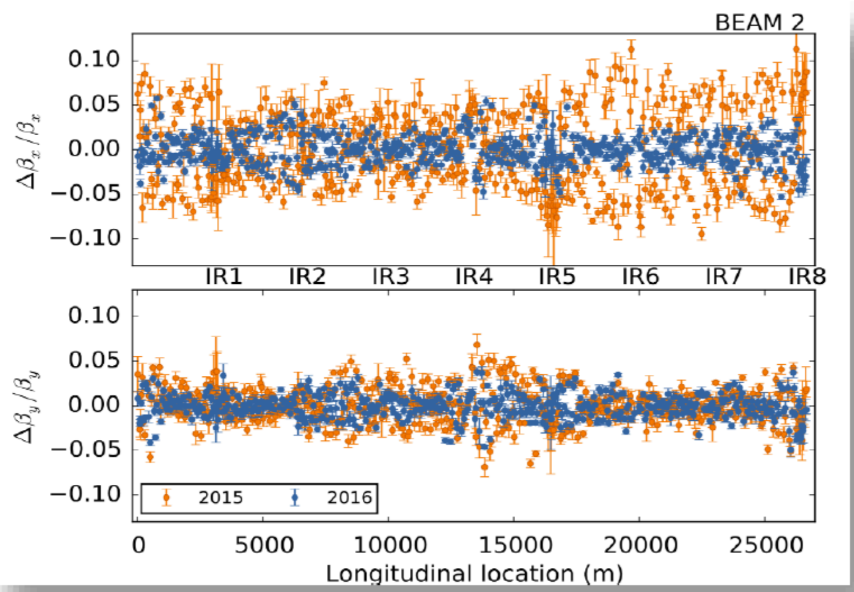
Virgin machine, β* = 40 cm

Beta-beating 50-100%

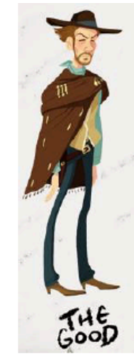


Corrected machine, β* = 40 cm

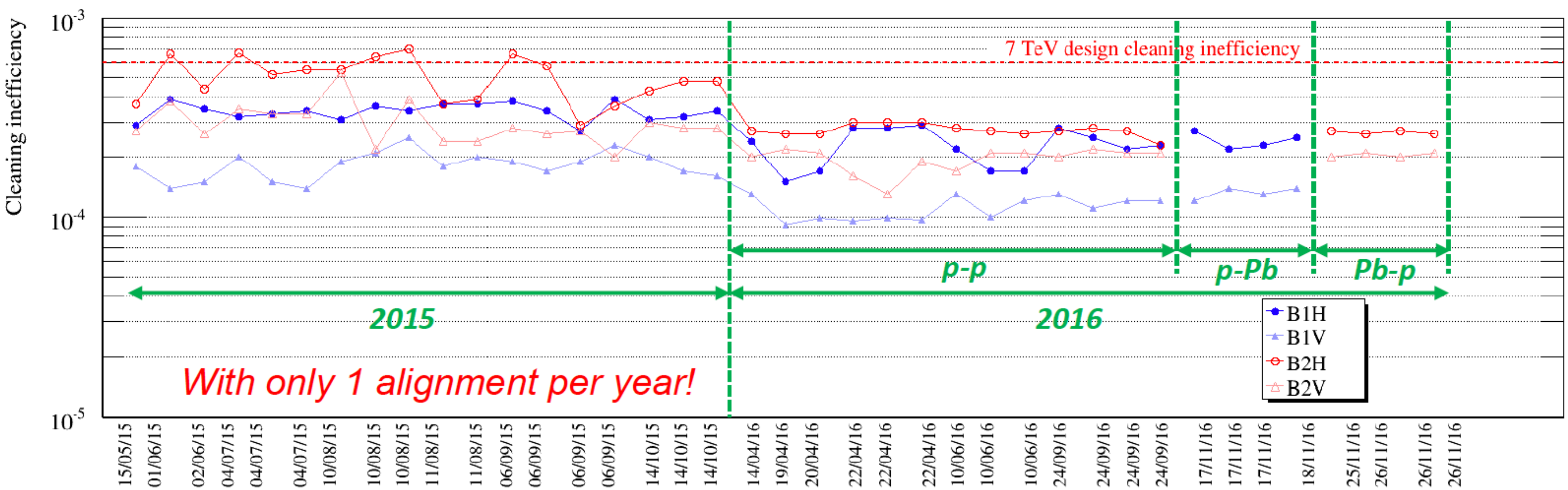
Beta-beating 2%



Collimation

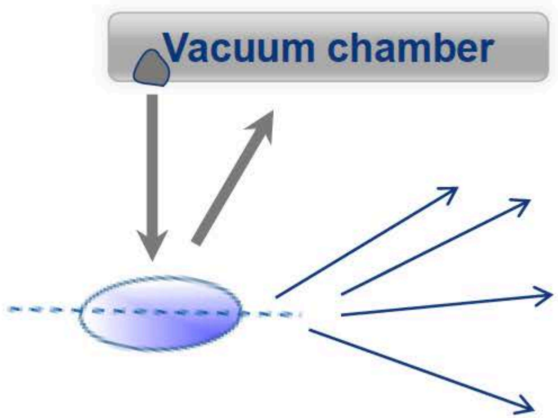


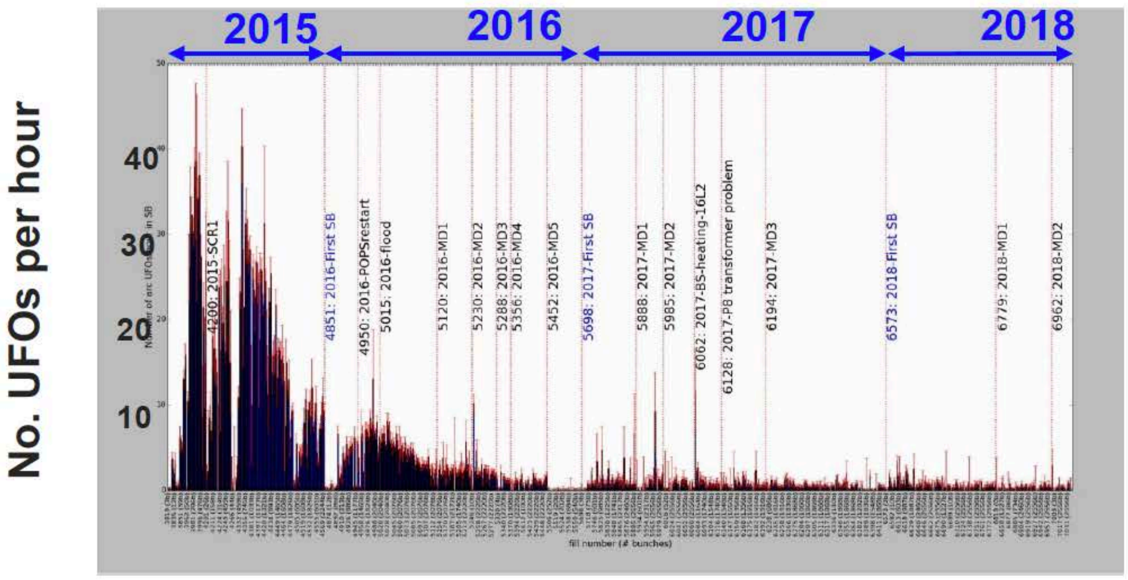
- The performance of over 100 collimators is excellent and very stable, with inefficiencies of $\leq$ 0.03% for a **stored energy of 320 MJ/beam**.
  - ***No beam induced quench from collimation losses in operation***.
  - *A single setup per year is sufficient ⇔ machine reproducibility.*
- **Tightening the collimation hierarchy** (reduced retractions between collimators) coupled to good understanding of the machine aperture allowed to **lower β*** over time.



Unidentified Falling Objects - UFOs

- The most credible theory for the **Unidentified Falling Objects** observed at the LHC are dust particles that fall into the beam and generate beam losses due to inelastic collisions with the beam. These losses can quench a superconducting magnet.





- UFOs cause 10-20 dumps per year, mostly intercepted by beam loss monitors.
  - *Loss monitor thresholds were adjusted to* ***balance the risk of spurious dumps and the need for quench prevention & recovery (~5-8 hours)****.*
  - *A clear* ***conditioning*** *has been observed along the years*

Outlook

- After a two year long shutdown in 2019-2020, the LHC will be back for Run 3 with upgraded injectors that should be able to provide roughly twice higher bunch currents (~ constant brightness) by ~2023.
- The projected peak luminosity of Run 3 is more than a factor 2 above the cryogenic limit, opening an area of luminosity levelled operation at the LHC !

Parameter	Design	2018	Run 3
Bunch population N_b (10^{11} p)	1.15	~1.1-1.2	1.7
No. bunches k	2780	~2556	2700
Emittance ε (mm mrad)	3.5	~2.0	1.5-2
β^* (cm)	55	30 - 25	~30
Full crossing angle (μrad)	285	320 - 260	340-250
Peak luminosity (10^{34} cm^{-2}s^{-1})	1.0	~2.1	~4-5

Operation of SuperKEKB in Phase 2

Y. Funakoshi for the SuperKEKB commissioning team

Accelerator Laboratory, KEK

2018.09.26@eeFACT 2018

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SuperKEKB				QCS quench	Phase 3

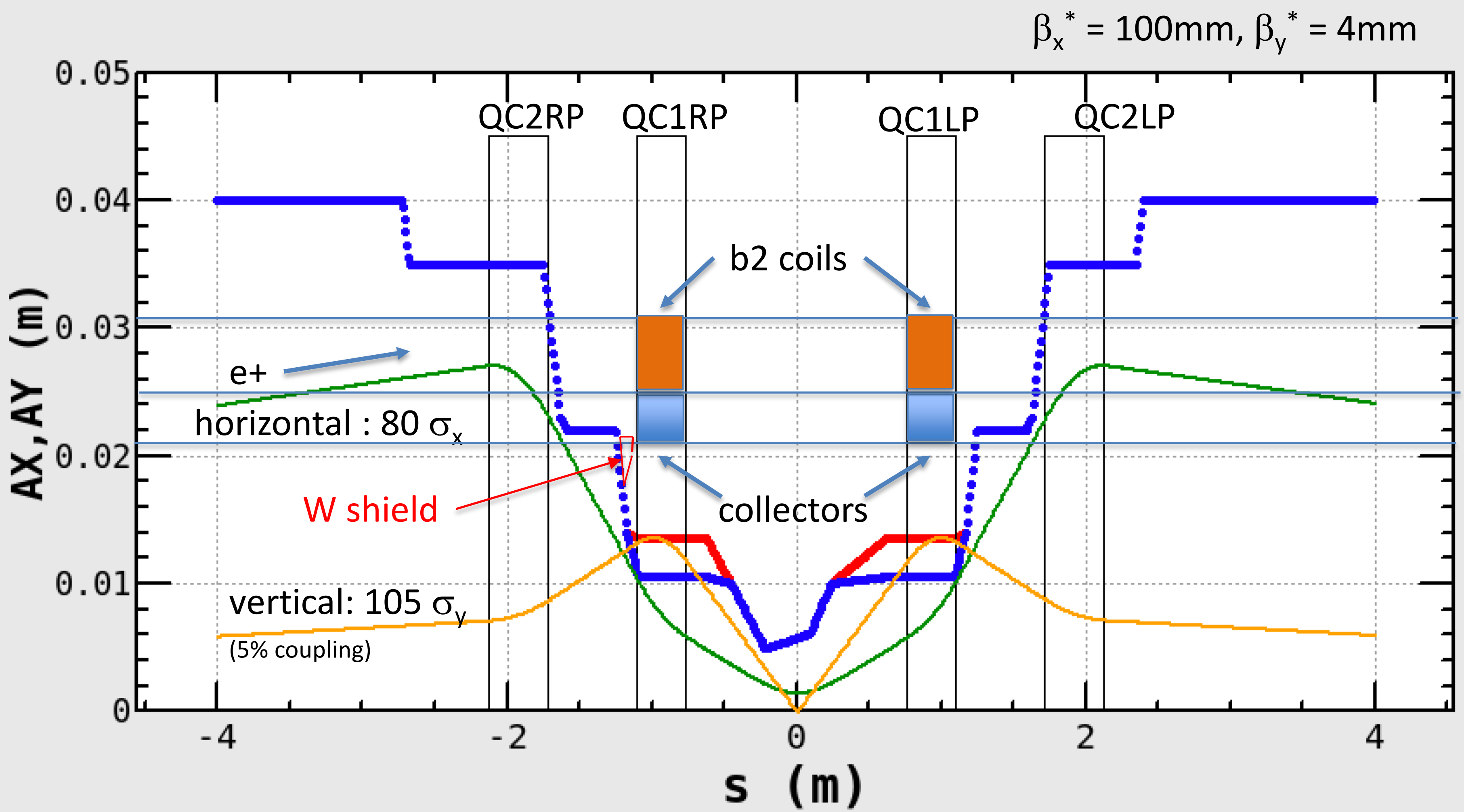
Summary of QCS quench in Phase 2

- During Phase 2, QCS quenches happened 26 times. Once QCS quench happens, it takes about 1.5~2 hours for recovery.
- Initial quenches in Phase 2 were mainly induced by injecting beams.
  - The quenches were almost prevented by setting movable collimators properly and introducing the Belle 2 abort using diamond sensors.
  - We felt that we had overcome the quenches, since we had no quenches for about a month after the quench on May 24th.
- However, on June 25th, the quench happened again by a stored LER beam and 4 quenches followed in July.
  - The reasons for the QCS quenches have not been understood well. I suspect the dust events may have something to do with the quenches.

To do list for QCS quench

- Install more collimators before Phase 3
  - 1 vertical collimator (LER)
  - 3 horizontal collimators (LER), 1 horizontal collimator (HER)
- Understanding of mechanism of QCS quench
  - Ohuchi-san's simple calculation: If ~8000 electrons (7GeV) lose their entire energy at a small part of a coil, QCS quench can happen.
  - Simulation on the more precise locations of particle loss near QCS.
    - Collimator chip scattering, dust trapping…
  - Simulation on the effect of continuous particle loss due to some processes (ex. Radiative Bhabha process).
  - More experiences in early stage of Phase 3
- W shields near QCS? (2019?)
  - Simulation works are in progress.
- Modification of QCS magnet system?

LER beam envelop



As a test machine for FCC-ee/CEPC

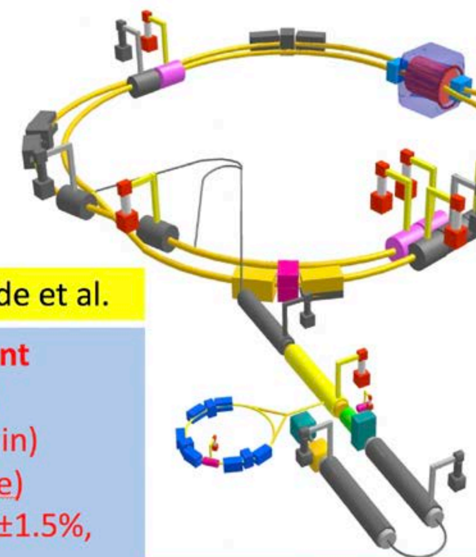
SuperKEKB: extremely low β*

I_{e+}=3.6 A, I_{e-}=2.6 A

P_{SR} ~ 13 MW

C = 3 km

beam commissioning started this year



K. Oide et al.

top up injection at high current

β_y* =300 μm (FCC-ee: 1 mm)

lifetime 5 min (FCC-ee: ≥20 min)

$\varepsilon_y/\varepsilon_x$ =0.25% (similar to FCC-ee)

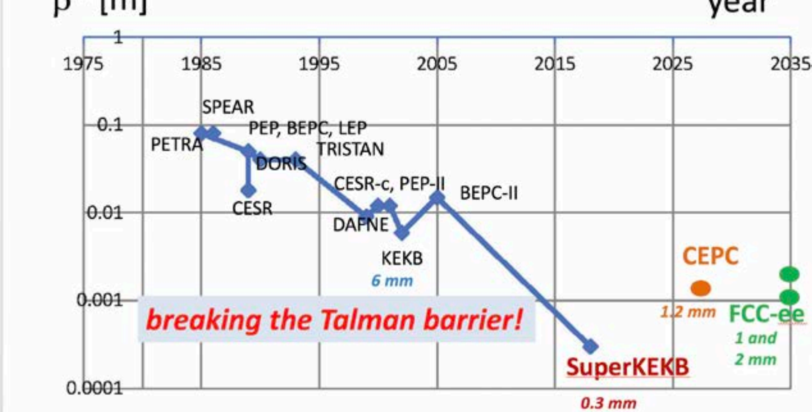
off momentum acceptance (±1.5%, similar to FCC-ee)

e⁺ production rate (2.5x10¹²/s, FCC-ee: <1.5x10¹²/s (*Z* cr.waist)

SuperKEKB goes beyond *FCC-ee/CEPC*, testing all concept

Frank Zimmermann eeFACT2016, Daresbury, 24 October2016

β_y* evolution over 40 years



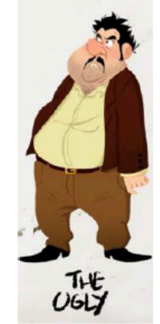
entering a new regime for ring colliders – SuperKEKB will pave the way towards β*≤2 mm

Remarks

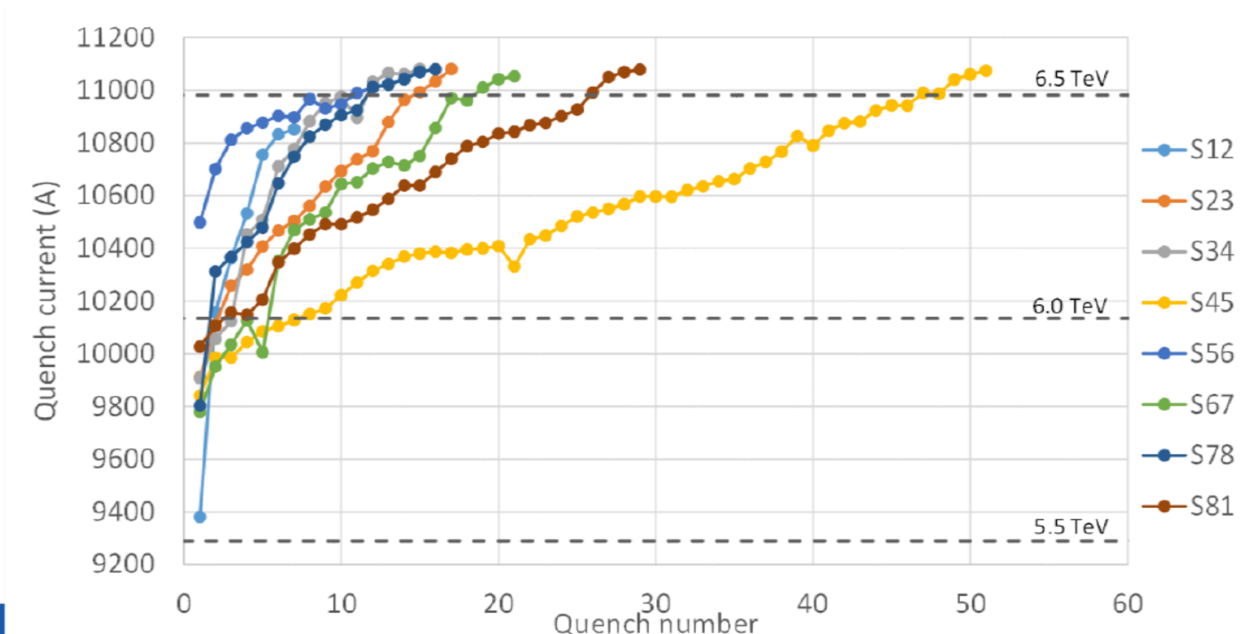
- From old machine to future machine
  - In the sessions, both old and future machines were reported. Useful lessons from old (or present) machines should be made use of in the future machines. Experiences in SuperKEKB may be useful in future machines.
- Experiences of other fields
  - Study on the ILC civil engineering investigation is very impressive. Like this, we should learn from machines in other fields such as SR machines.
- In next meeting in 2020 (in Frascati)
  - I expect to hear excellent progress in future machines such as CEPC, FCC-ee, Super τ-c factories, DANFE-TF, BEPC-III, SuperKEKB….

Spare slides

Dipole training and energy

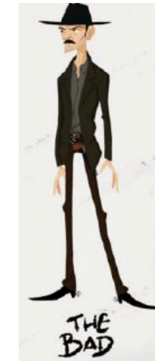


- Significant **de-training** was observed on the 1232 LHC dipole magnets.
- The dipole magnets were finally trained for 6.5 TeV operation in 2015.
- Over **150 training quenches** were required to reach **6.5 + ε TeV**.
  - *The spread in number of quenches between the sectors is due to the mixture of magnets from the 3 producers – the magnets of one producer are particularly affected.*
- After the next shutdown (2019-202) it is planned to push the magnets to **7 TeV**, expect **~ 500 training quenches** !

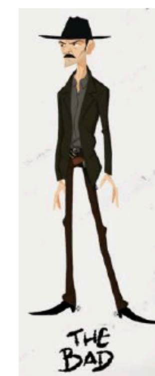


8 LHC sectors (~ arcs)

'16L2'

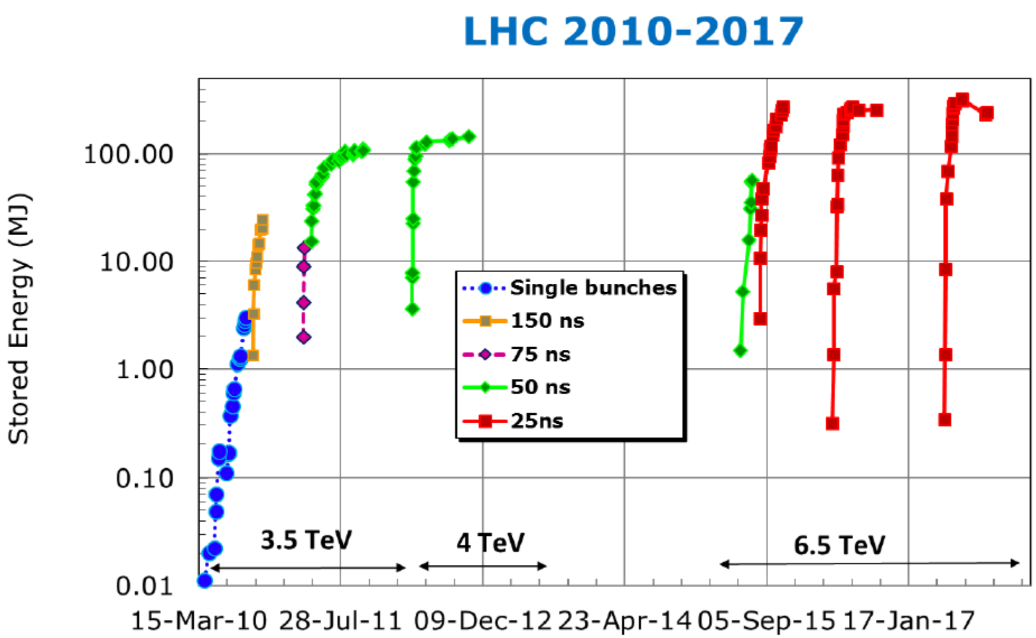


- During the extended winter shutdown 2016-2017, one LHC sector (S12) was brought to room temperature to exchange a dipole with a suspected inter-turn short (which was confirmed on the test bench).
- During the cool down an issue during the disconnection of vacuum pumps led to **an air inlet** (~few liters) **into the cold vacuum chamber**. The event and its consequences became only clear a few months later.
  - The air condensed as ice on the vacuum chamber.
- In June 2017 **very strange beam loss events** were observed in conjunction with small UFO-like losses in one cell (16L2), eventually operation could only be sustained with a low e-cloud beam and limited beam intensity.
  - Side effect: fewer bunches and higher pile-up, requiring levelling of the luminosity.
- **Partial warm up of the sector to 80K** in the winter stop 2017-2018, pumping of the N2 gas present in the cell.
- **In 2018 the loss events are back**, partial warm up was **insufficient**, but operation with 25 ns beams was possible – better, but something left over…



Machine Protection

- With over 300 MJ of stored energy (> 100 times Tevatron) each LHC beam has a tremendous destruction power.
- **Rigorous design, implementation, testing and operation of the MP system** ensured that so far no beam incident was recorded.
  - *An occasional quench is of course part of the life of a super-conducting machine.*



- After any stop or intervention with important impact, MP tests and intensity ramp-ups are scheduled by the MP team.
- Excellent **MP culture** shared by all teams !