

ILC : 設計から実現へ 超伝導技術

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@ 富山・2013-7-21

はじめに

- 合宿での超伝導加速空洞技術に関する発表
 - 7/20: LINAC, 超伝導試験施設 : STF (早野)
 - 7/21: 『超伝導技術』 : 概論 (山本 明)
 - 7/21: 超伝導加速空洞開発施設 : CFF (山中)
 - 7/16: 超伝導空洞空洞製造・工業化 (佐伯学行)
- 本発表 (山本) での力点
 - 『 ILC実現にむけた超伝導技術開発』 の状況、展望。

アウトライン

- インTRODクシヨN
 - 超伝導の基礎： 超伝導磁石、超伝導加速空洞
- LHCの基盤技術：
 - 加速器、測定器における超伝導磁石
- ILC の基盤技術：
 - 超伝導加速空洞技術の開発
- 展望、まとめ

粒子加速器における”加速”

■ 粒子を加速する

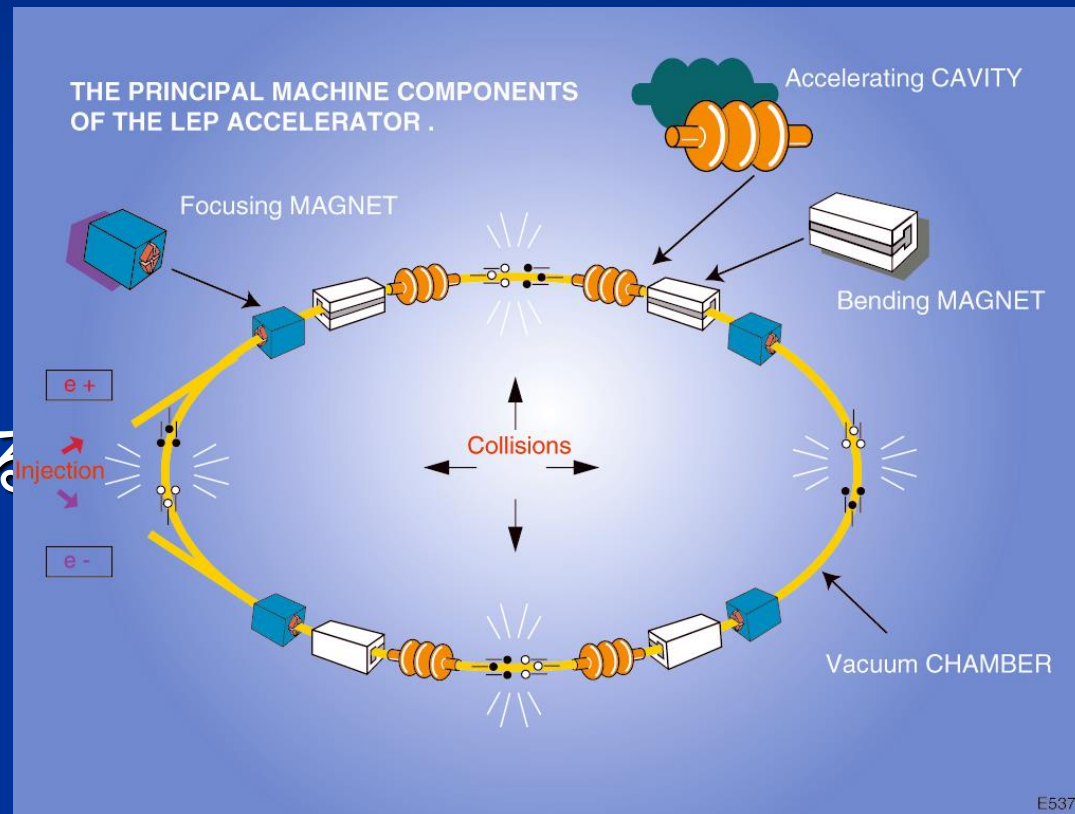
■ 電界: E

- 静電界
- 高周波空洞 (cavity)
 - > 超伝導技術

■ 粒子の軌道を制御する

■ 磁界: B

- 偏向磁石
(Bending Magnet)
- ビーム収束
(Focusing Magnet)
 - > 超伝導技術

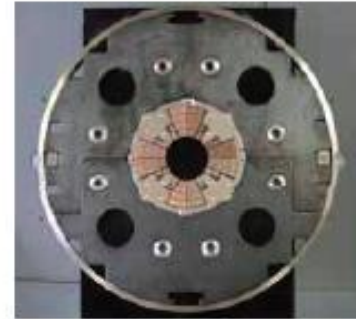


粒子加速器のエネルギーフロンティアを担う 超伝導技術

加速器に使われる超伝導技術

超伝導磁石:

強いDC磁場: 加速粒子の軌道を曲げる
偏向磁石、収束磁石、測定器ソレノイドなど



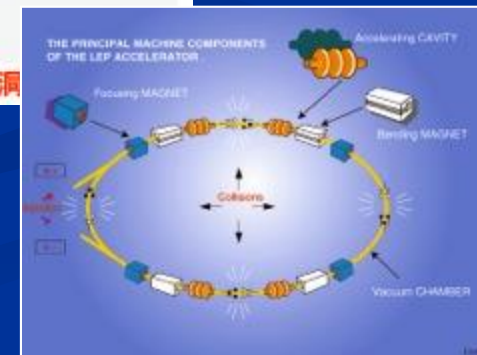
超伝導高周波空洞:

空洞共振器が作る高周波電磁場:
粒子に電圧を与える唯一の装置
加速空洞、クラブ空洞、
高周波セパレーターなど



KEK-ERL 9連空洞

■ 先端加速器の鍵を握る基盤技術



加速器の技術革新 (75年の歴史)



1932年 ローレンス
世界初のサイクロトロン

直径13 cm, エネルギー80 keV
A. Yamamoto, 130721



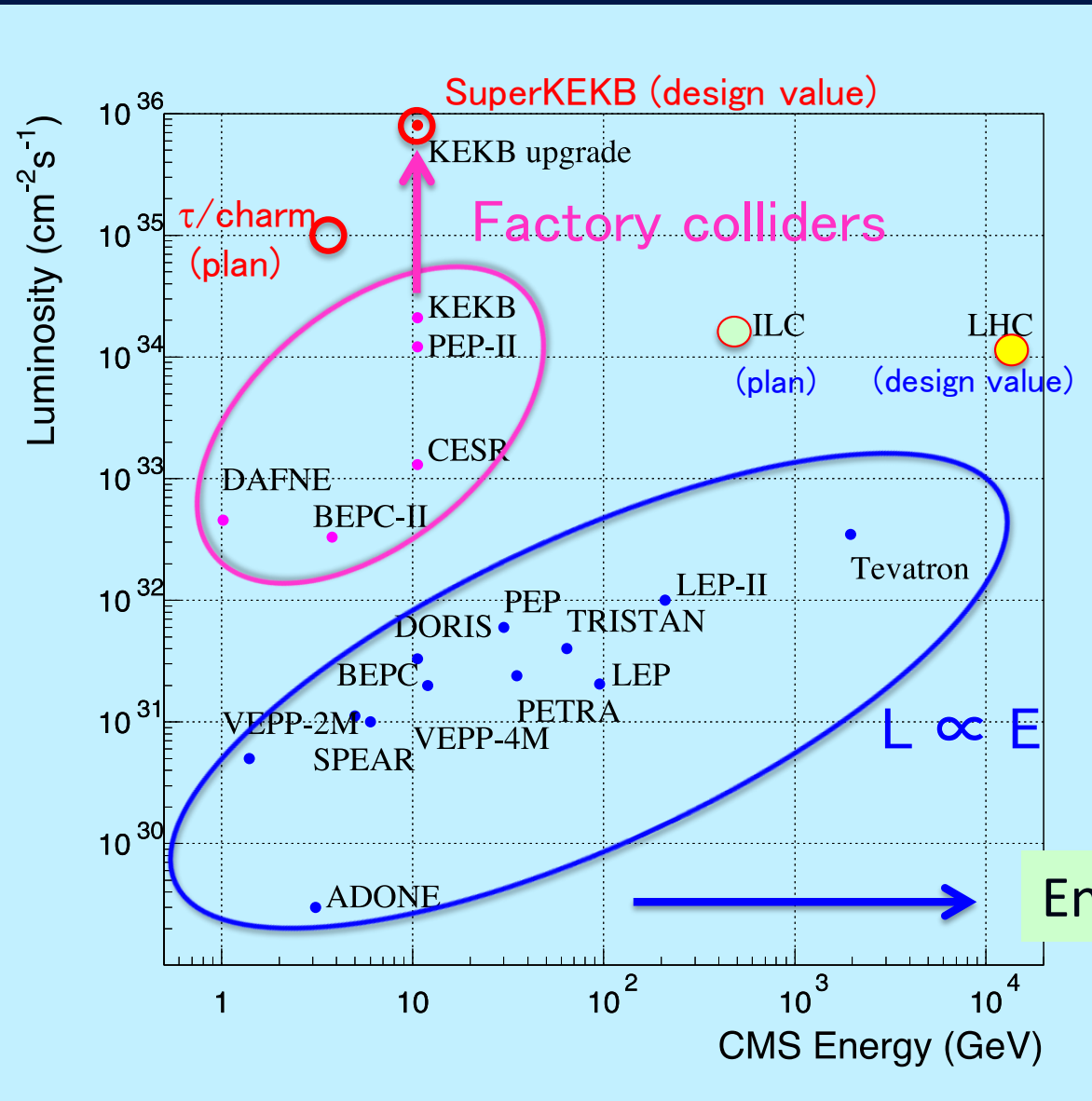
LHC 2008年完成 2009年稼動
直径9 km, エネルギー: 7 → 14 TeV

$$9\text{km}/13\text{cm} = 69,231$$

$$14\text{TeV}/80\text{keV} = 175,000,000$$

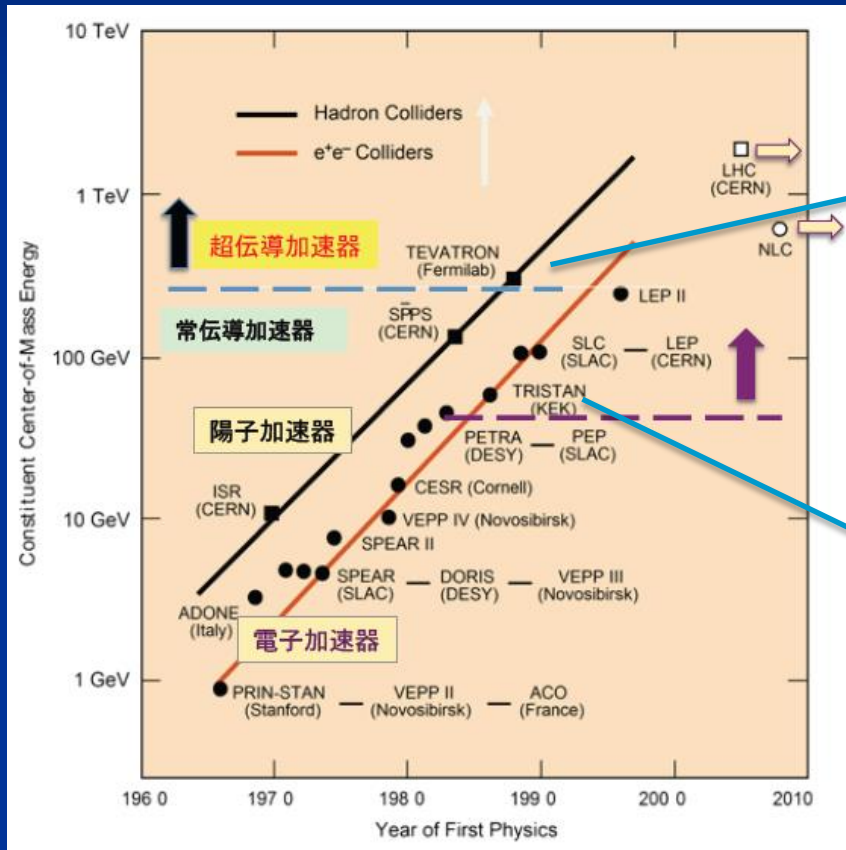
Frontier of colliders

Luminosity frontier

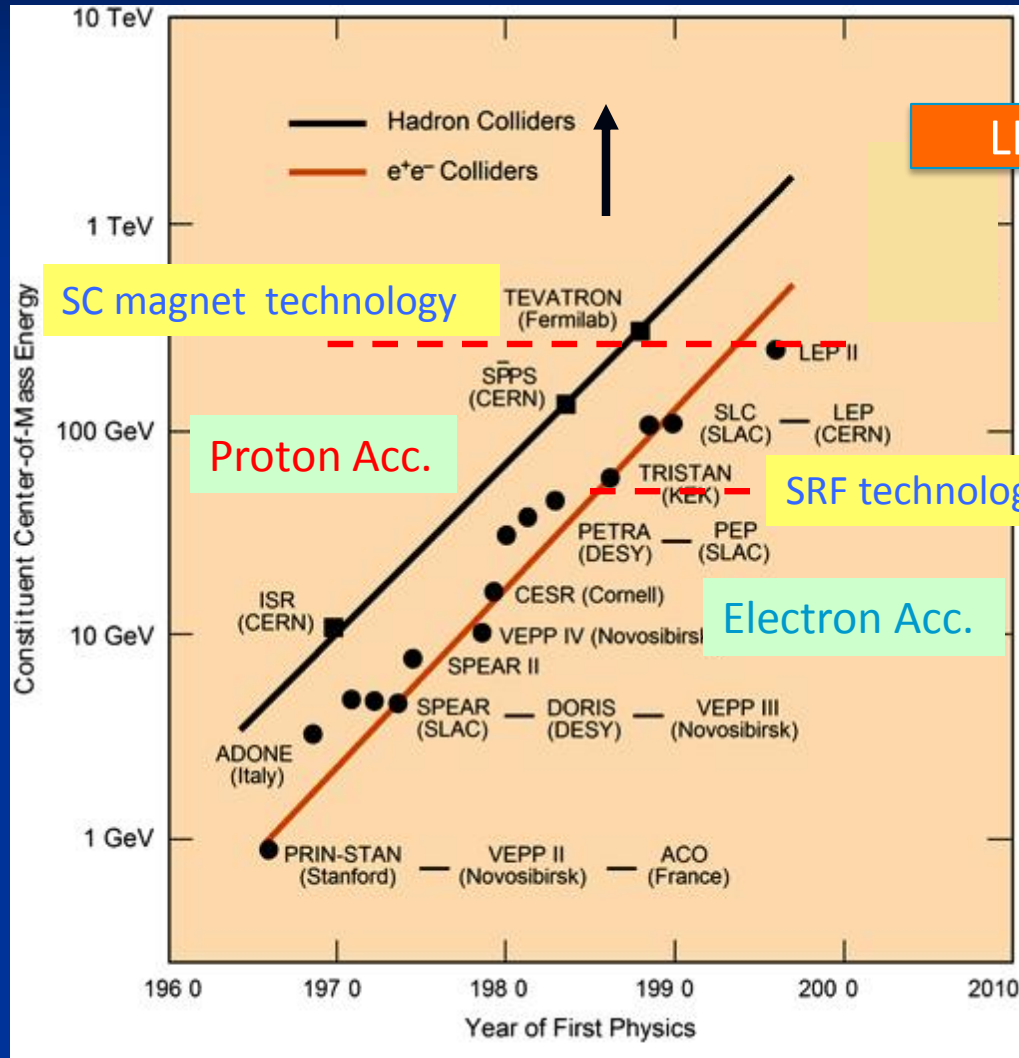


Energy frontier

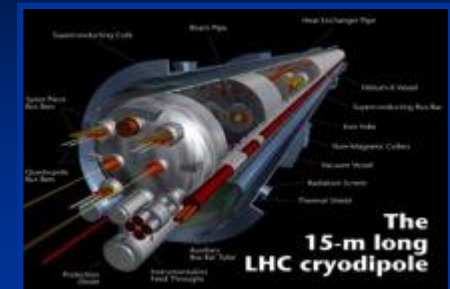
加速器の進展と超伝導技術



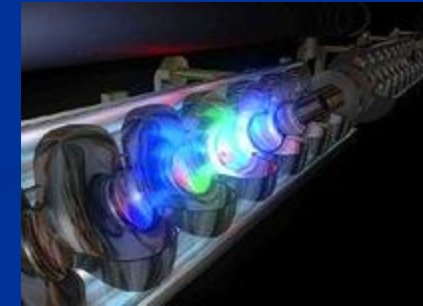
Progress in Particle Accelerator in energy frontiers



LHC



ILC



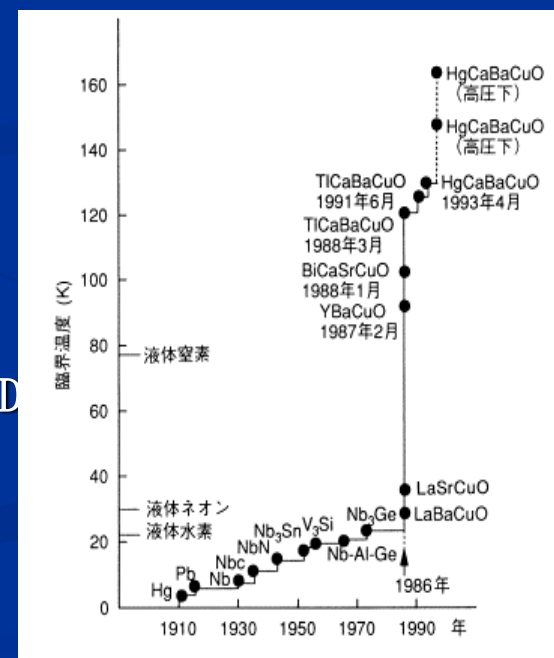
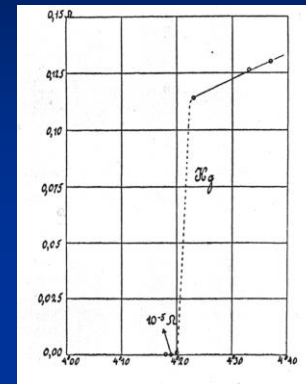
- Superconducting technology getting inevitable

Progress in SC “Big” Acc. Projects

Location	Accelerator (proton)	Energy [GeV]	B Field [T]	Operation	Key Technology
Fermilab	Tevatron	2 x 900	4.0	1983-2011	SC Magnet
DESY	HERA	820	4.68	1990-2007	SC Magnet
BNL	RHIC	2 x 100	3.46	2000 -	SC Magnet
CERN	LHC	2 x 7,000	8.36	2009 -	SCM / SCRF
Location	Accelerator (electron)	Energy	E / (Freq.) MV/m / (GHz)	Operation	Key Technology
KEK	TRISTAN	2 x 30	5 (0.5)	1986-1995	SCRF
CERN	LEP	2 x 105	5 (0.5)	1989-2000	SCRF
JLab	CEBAF	6	7 (1.3)	1995~	SCRF
KEK	KEKB	8	5 (0.5)	1999~2007	SCRF
DESY	EXFEL*	14	24 (1.3)	construction	SCRF
Fermilab	Project-X*	8	~20 (1.3)	Plan	SCRF
---	ILC*	2 x 250	31.5 (1.3)	Plan	SCRF

超伝導・低温技術の発展

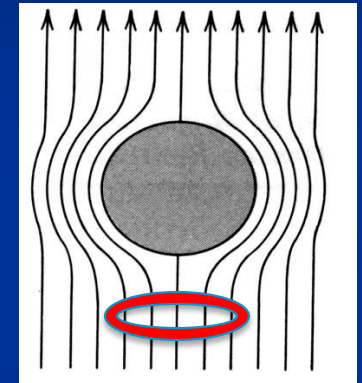
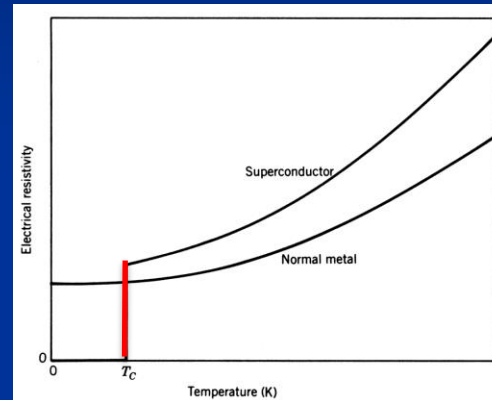
- 1908 ヘリウムの液化
- 1911 超伝導の発見
- 1924 超流動ヘリウムの発見
- 1933 マイスナー効果の発見
- 1957 BCS理論の完成
- 1970 NbTi伝導線の工業化
- 1979 医療用MRI超伝導マグネットの実用化
- 1983 米：超伝導加速器（米：FNAL）の完成
- 1986 高温超伝導の発見
- 1995 欧：CERN/LHC建設開始
- 1996 日：超伝導・核融合実験装置・LHD
- 1998 米：超伝導加速器（BNL/RHIC）完成
- 2001 新超伝導体・MgB₂発見（日：青学大）
- 2008 欧：CERN/LHC完成



超伝導の基本的な性質

■ 完全導電性 ($E = 0$)

- 電気抵抗がゼロ ($R = 0$)
- 発熱なく多くの電流が流せる
 - $I^2 \times R = 0$
 - 大電流で、高磁場が発生できる



Superconductor

超伝導体

■ 完全反磁性 ($B = 0$)

- マイスナー効果
- 内部の磁場を打ち消す表面電流
 - 誘導電流による磁気浮上可以实现できる



■ 量子性

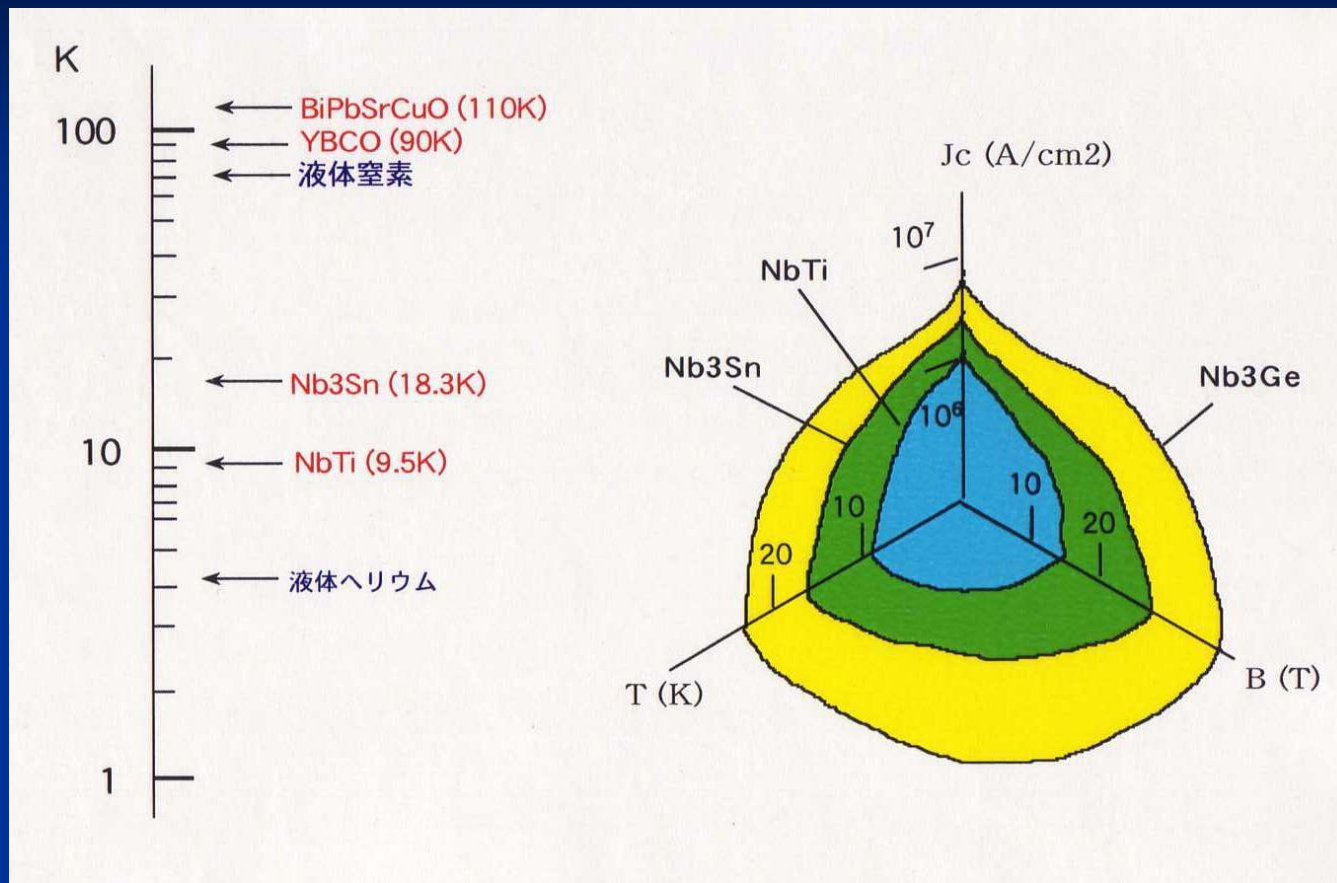
- 不連続な量子束 (フラクソイド)

■ ジョセフソン効果 (トンネル効果)

- 量子トンネル効果



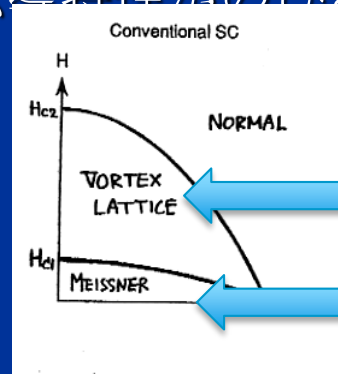
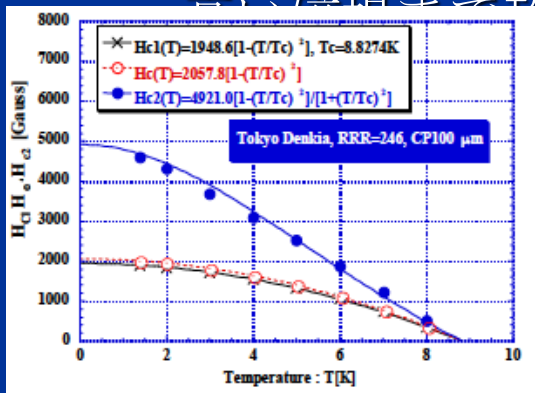
● 超伝導体の動作温度



超伝導状態を得るには低温が必要→臨界温度は高いほど利用価値が大きい

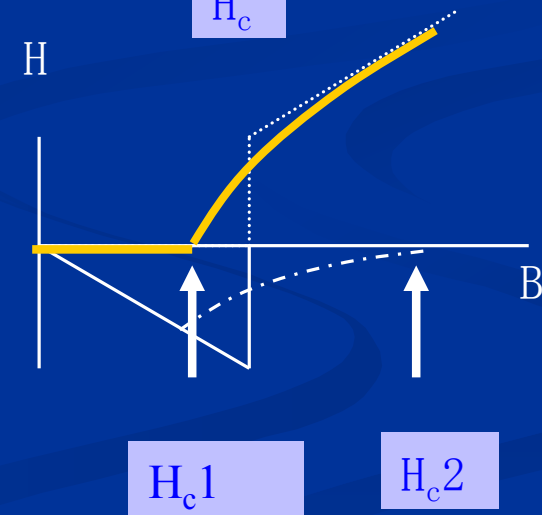
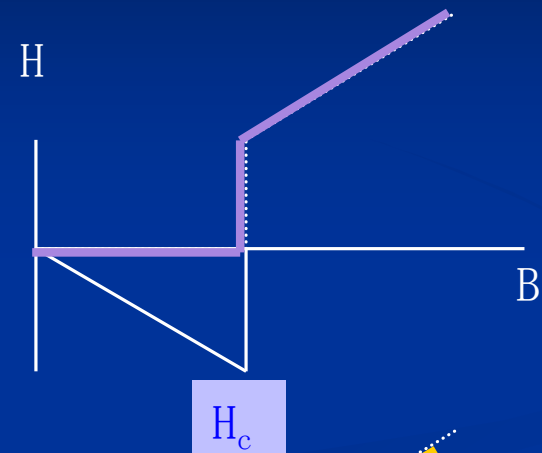
超伝導体の分類

- 第一種 (Hg, Pb, Sn 等)
 - マイスナー領域から直接、
 - ノーマル領域に変化
- 第二種 (Nb, Nb-Ti, Nb₃Sn 等)
 - 混合領域の存在



磁石

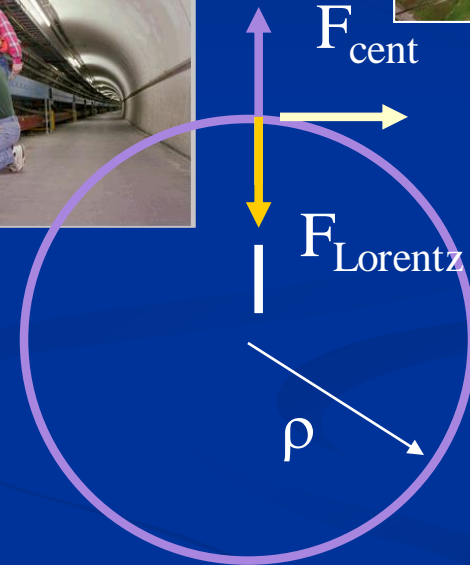
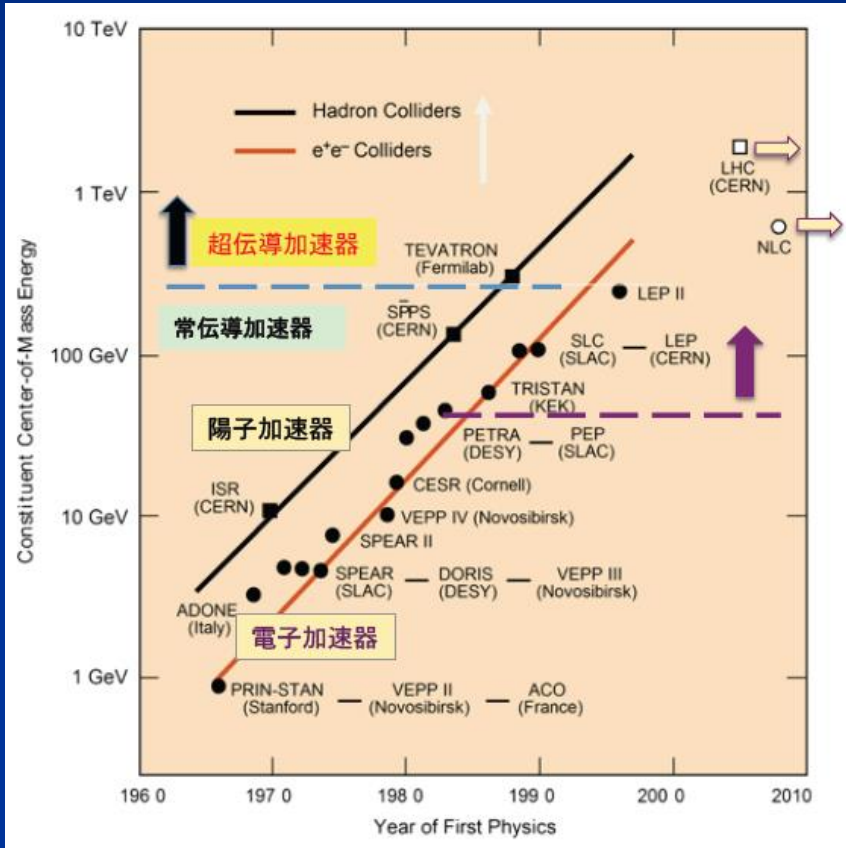
空洞



各種超伝導体の特徴

Material	Tc	Bc1	Bc2
	[K]	[T]	[T]
Type-1			
Hg	4.15	0.041	
Pb	7.20	0.080	
Ta	4.47	0.083	
Type-2			
Nb	9.25	0.190	0.404
NbTi	9.5		15
Nb3Sn	18.2	0.535	29
MgB2	39	0.429	
Ba ₂ YCu ₃ O ₇	93	0.06	35

加速器の進展と超伝導技術

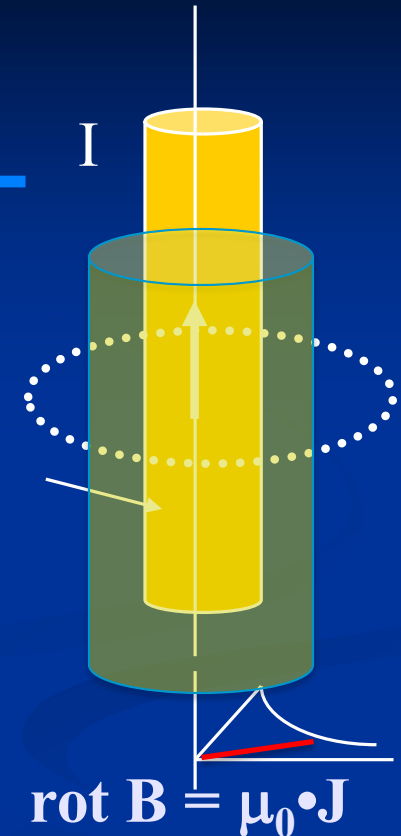
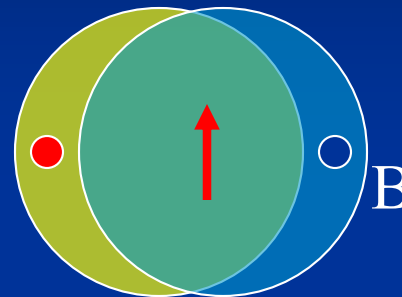
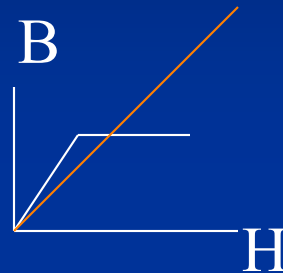
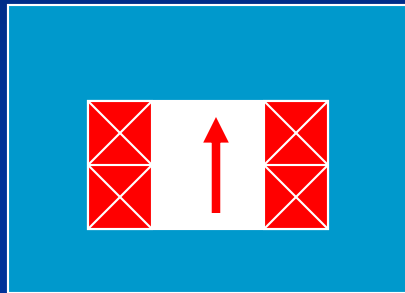


$$p = q \cdot \rho \cdot B$$

$$P [\text{TeV}/c] = 0.3 \cdot \rho [\text{km}] \cdot B [\text{Tesla}]$$

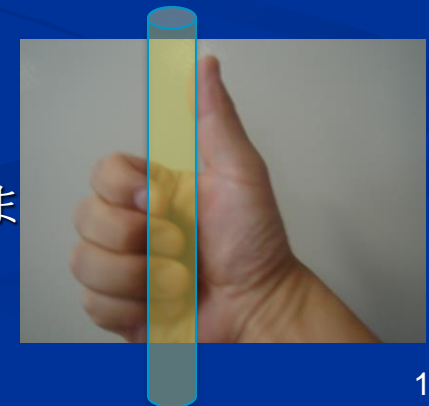
- High Magnetic Field required

超伝導電磁石



$$B = \sim \mu_0 NI / (g + l/\mu_s)$$

- 鉄芯を用いた常伝導磁石：
 - 鉄芯の形状で磁場を形成
 - 鉄の透磁率飽和で磁場が 2T で限界
- 超伝導磁石：電流の分布で磁場：
 - 超伝導体に流す事ができる電流密度で磁場が決ま
 - 現状では～10Tまで到達



大電流密度 >> 高磁場の発生

高電流密度が本質的に重要

•電流密度

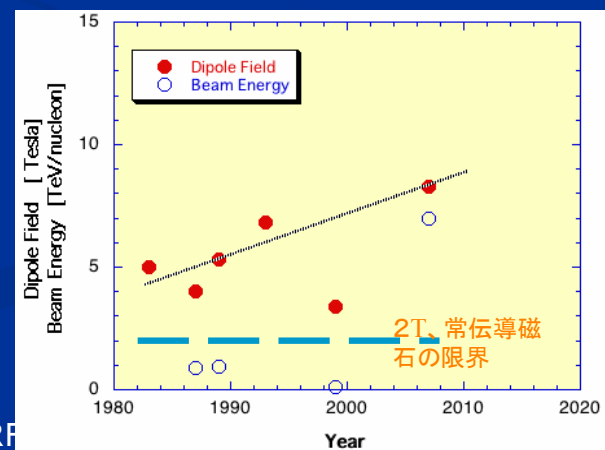
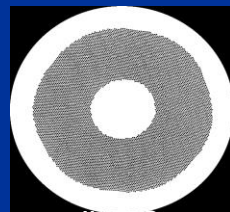
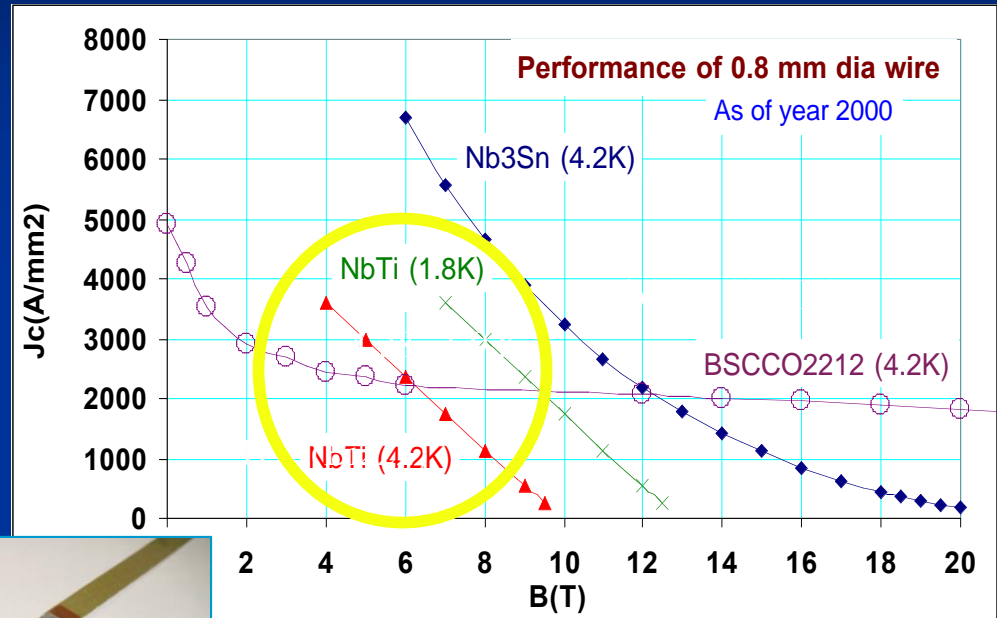
超伝導素線: $\sim 2000 \text{ A/mm}^2$

超伝導磁石: $\sim 500 \text{ A/mm}^2$

(安定化材、電気絶縁などで一桁下がる)

•常伝導磁石: $\sim 10 \text{ A/mm}^2$

超伝導: 1~2桁高い電流密度。

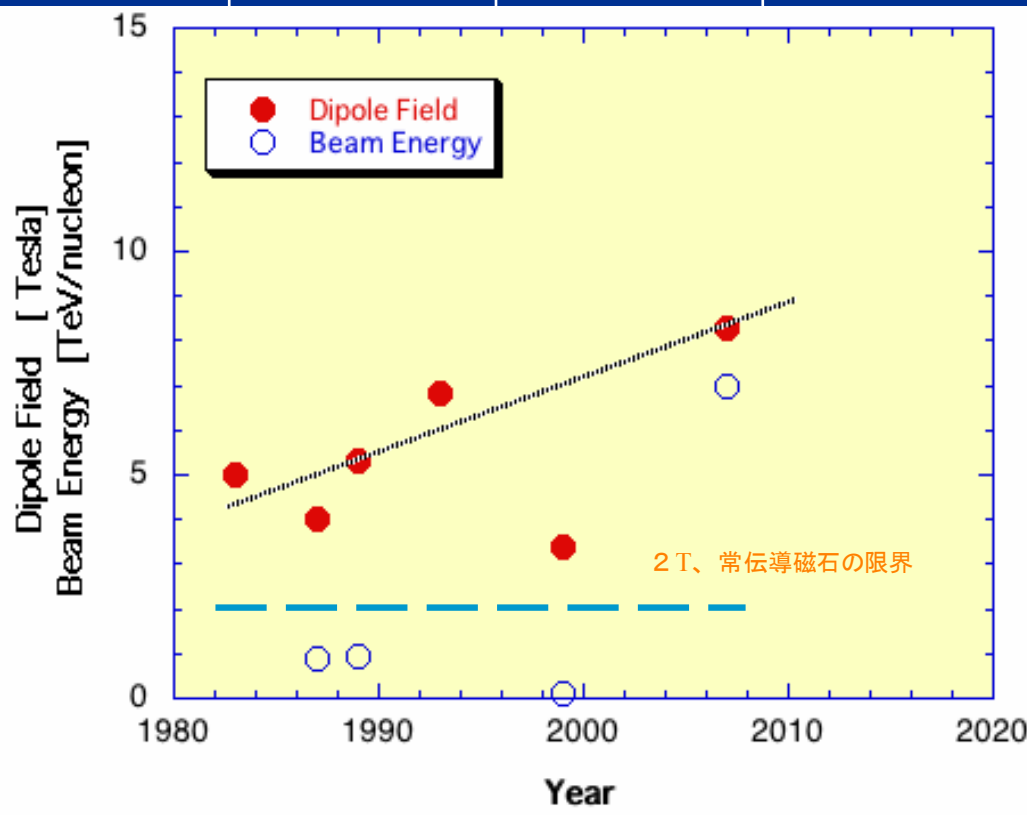


高エネルギー超伝導加速器の発展

Accelerator	Tevatron	SSC	HERA	RHIC	LHC
Lab.	FNAL	SSC	DESY	US	CERN
Energy [TeV]	0.9	20	0.82	0.1/anm	7
Radius [km]	1	14	1	0.5	4.5
Ring	1 (p+p-)	2 (p+p)	1 (e+p)	2 (p+p) &	p+p-
B-dipole [T]	4.4	6.6	4.7	3.5	8.36
G-quad [T/m]	76	205	91	72	220
R-coil [mm]	38	25	37.5	40	28
#Dipoles	774	7986 (676)	422	288	2x1232
Temperature [K]	4.5	4.4	4.5	4.5	1.9
Complete year	1985	Canceled	1990	2000	(2007)
Note	First SC large Accelerator	Few training quench	First industrial contribution	Economical	Highest field SF-He

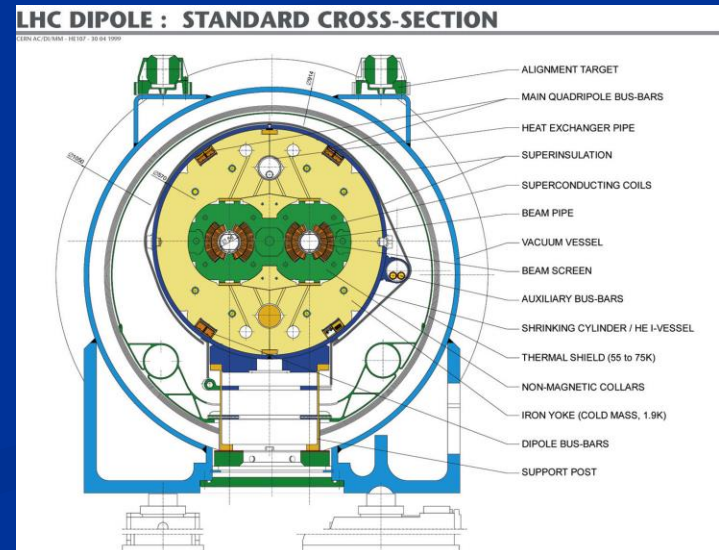
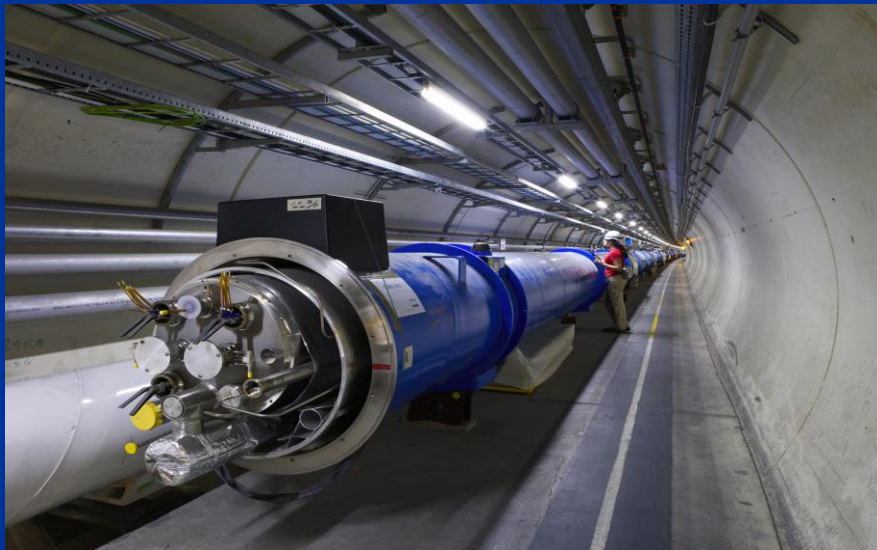
高エネルギー超伝導加速器の発展

Accelerator	Tevatron	SSC	HERA	RHIC	LHC
Lab.	FNAL	SSC	DESY	US	CERN
Energy [TeV]	0				7
Radius [km]	1				4.5
Ring	1				p+p-
B-dipole [T]	4				8.36
G-quad [T/m]	7				220
R-coil [mm]	3				28
#Dipoles	7				2x1232
Temperature [K]	4				1.9
Complete year	1				(2007)
Note	First charge Accelerator	Few training quench	First industrial contribution	Economical	Highest field SF-He



LHC Superconducting Magnets

- 加速器 直径27 km
- エネルギー 7 TeV
- 主・二極超伝導磁石 8.3 T, 約1,200 台



CERN/LHC衝突点用四極磁石

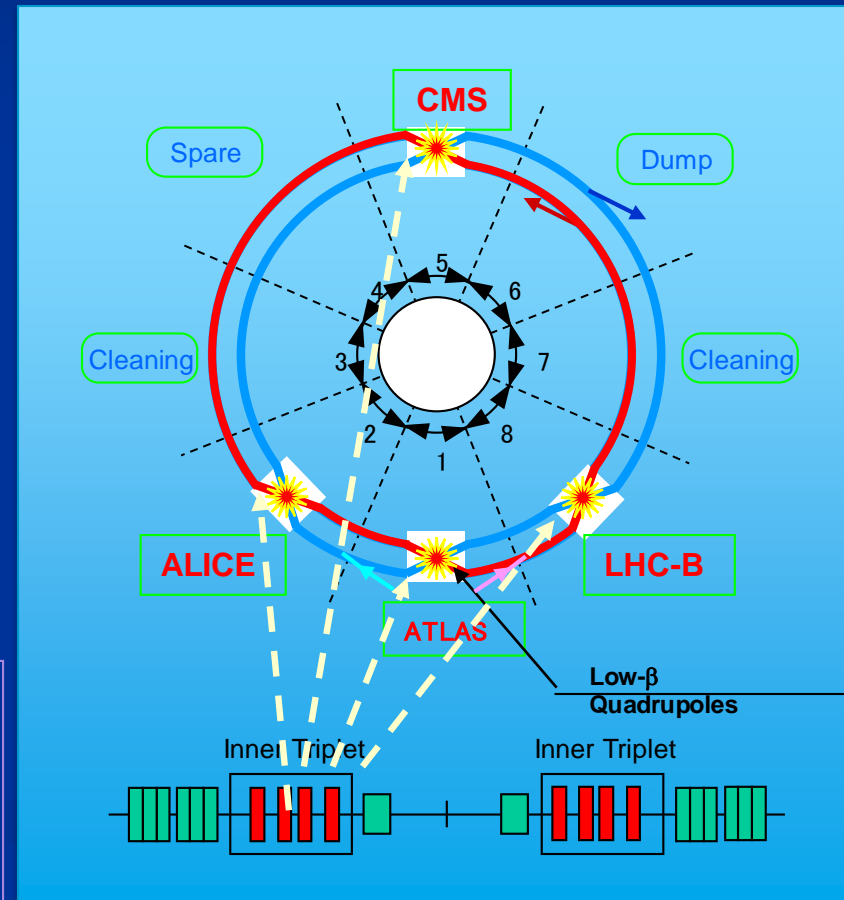
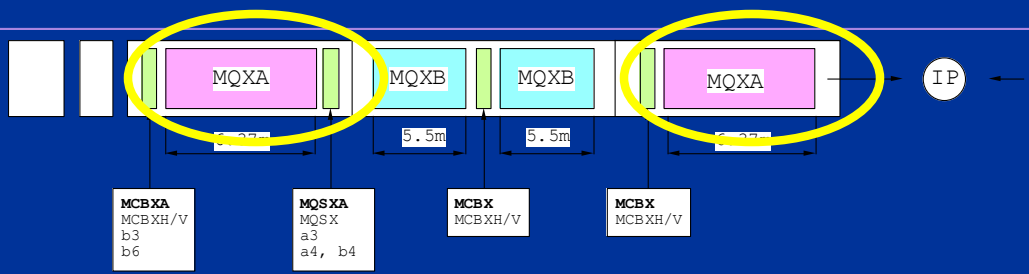
$G = 215 \text{ T/m}$, $L = 6.37 \text{ m}$

Aperture = 70 mm

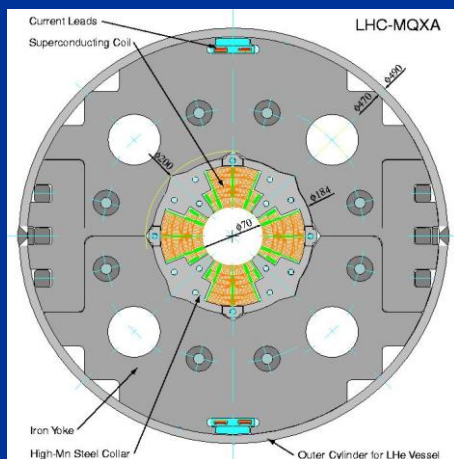
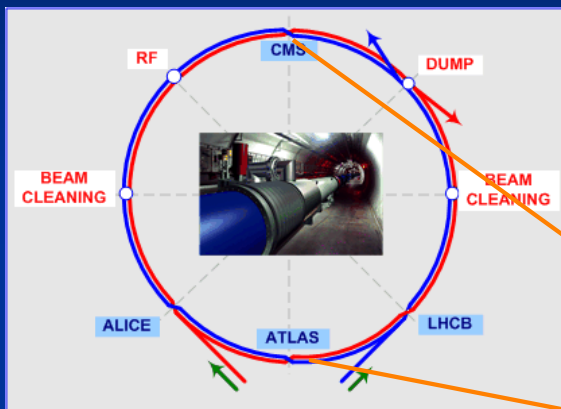
Higher Order Multipoles $< 1 \text{ unit } (10^{-4})$

Beam Heating: 5 ~ 10 W/m

KEK が貢献: MQXA (16 + spare)



CERN-LHC ビーム衝突点収束磁石 KEK-Fermilab Collaboration



衝突点ビーム収束磁石: 日本のLHC建設貢献
日(KEK)、米(Fermilab)間の国際協力
ILC Summer School - SCRF

無限長電流のつくる磁場

- マクスウェルの方程式より

- $\text{rot } B = \mu_0 \cdot J$

- 円筒内部 ($r < a$) において

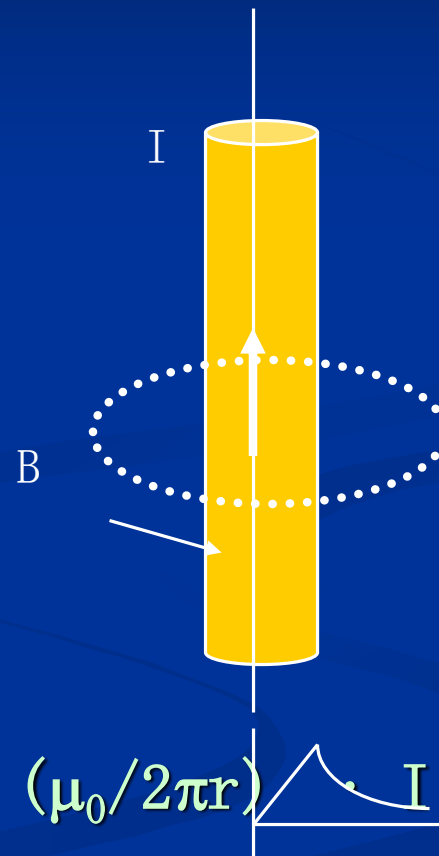
- $2 \pi r B = \mu_0 \pi r^2 J$

- $B_r = (1/2) \cdot \mu_0 \cdot r \cdot J$

- 円筒外部 ($r > a$) において

- $2 \pi r B_r = \mu_0 \pi a^2 J$

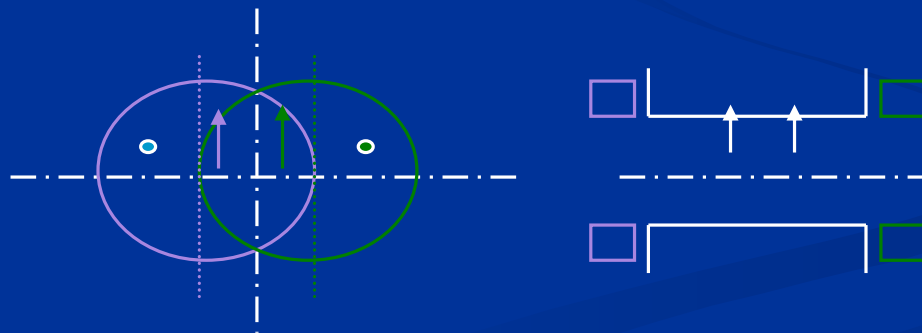
- $B_r = (1/2) \cdot \mu_0 \cdot a^2 \cdot J \cdot 1/r = (\mu_0/2\pi r) J a^2$



電流のつくる磁場 (続)

- 一対の円筒電流が $\pm 1/2 dx$ ずれ、反対向き：
磁場 (@ $Y = 0$) は

$$\begin{aligned} B_y &= B_{y_1} + B_{y_2} \\ &= (1/2) \cdot \mu_0 \cdot (x + 1/2 dx) \cdot J + (1/2) \cdot \mu_0 \cdot (x - 1/2 dx) \cdot (-J) \\ &= (1/2) \cdot \mu_0 \cdot dx \cdot J \quad \Rightarrow \text{constant} \end{aligned}$$



電流のつくる磁場 (続)

- 線電流が円筒の周方向に分布:

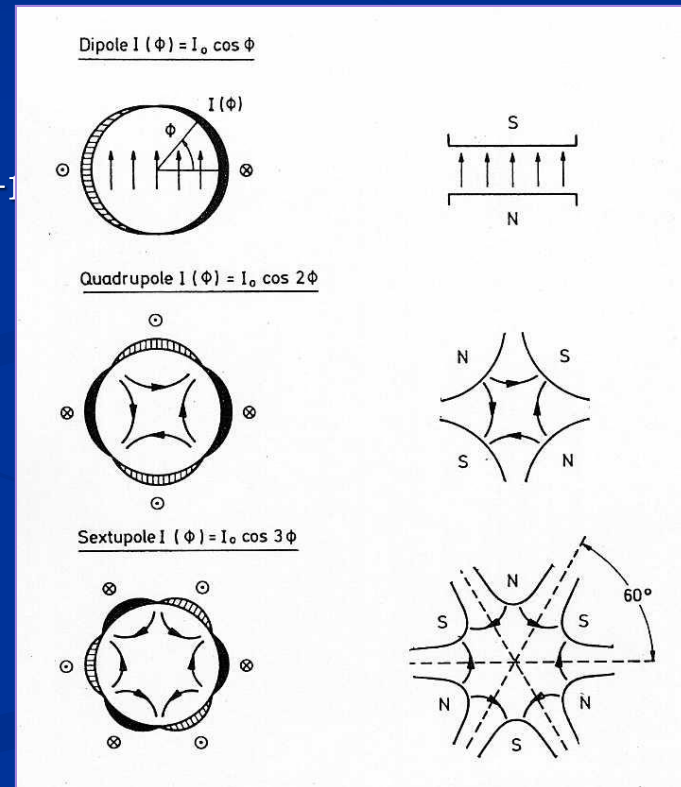
$$I(\phi) = I_0 \cos(n\phi)$$

$$B_\theta(r, \theta) = -(\mu_0/2a) \cdot I_0 \cdot (r/a)^{n-1}$$

$n = 1$: dipole


$n = 2$: quadrupole

$n = 3$: sextupole

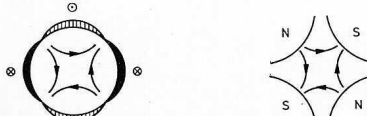


電流のつくる磁場 (続)


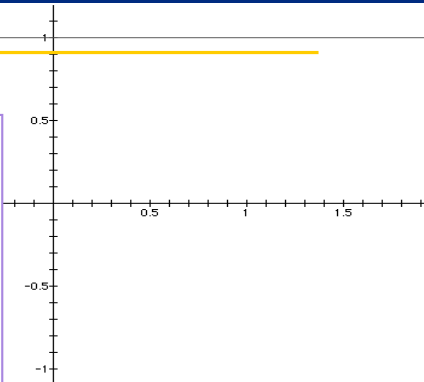
Dipole $I(\Phi) = I_0 \cos \Phi$



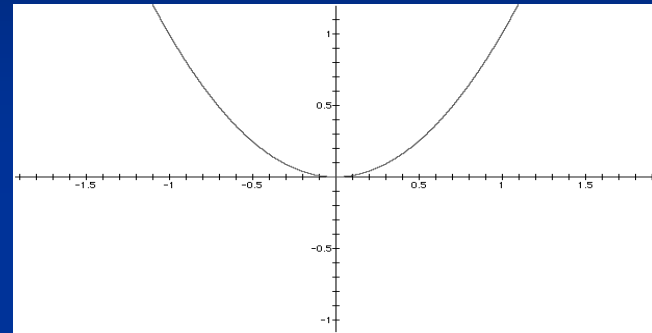
Quadrupole $I(\Phi) = I_0 \cos 2\Phi$



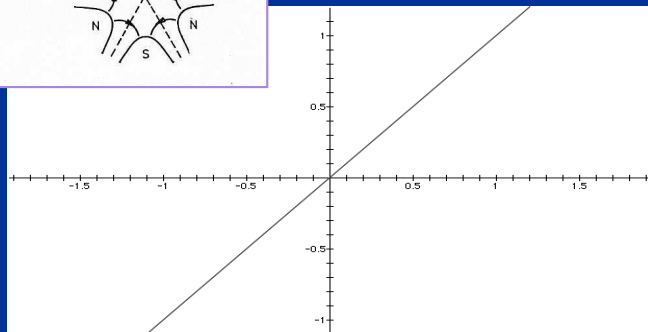
Sextupole $I(\Phi) = I_0 \cos 3\Phi$

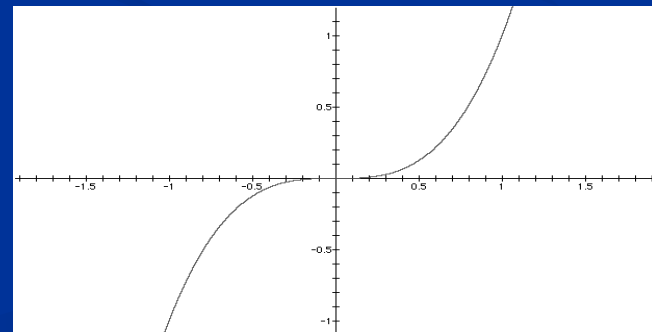
$n = 1$
Dipole



$n = 3$
Sextupole



$n = 2$
Quad.



$n = 6$
12th pole

磁場： 2 極磁石

最も単純化されたDipole 磁場を作る電流分布

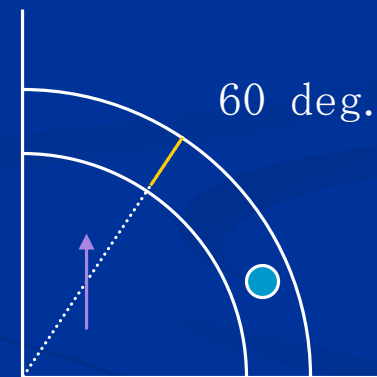
$$I = I_0 \cos \theta \quad \rightarrow \quad \theta = 60 \text{ degrees}$$

$I = \cos 3\theta$ Sextupole) の現れ方

$b_3 = \text{positive} \quad @ \quad 0 \sim 30 \text{ deg}$

$= \text{negative} \quad @ \quad 30 \sim 60 \text{ deg}$

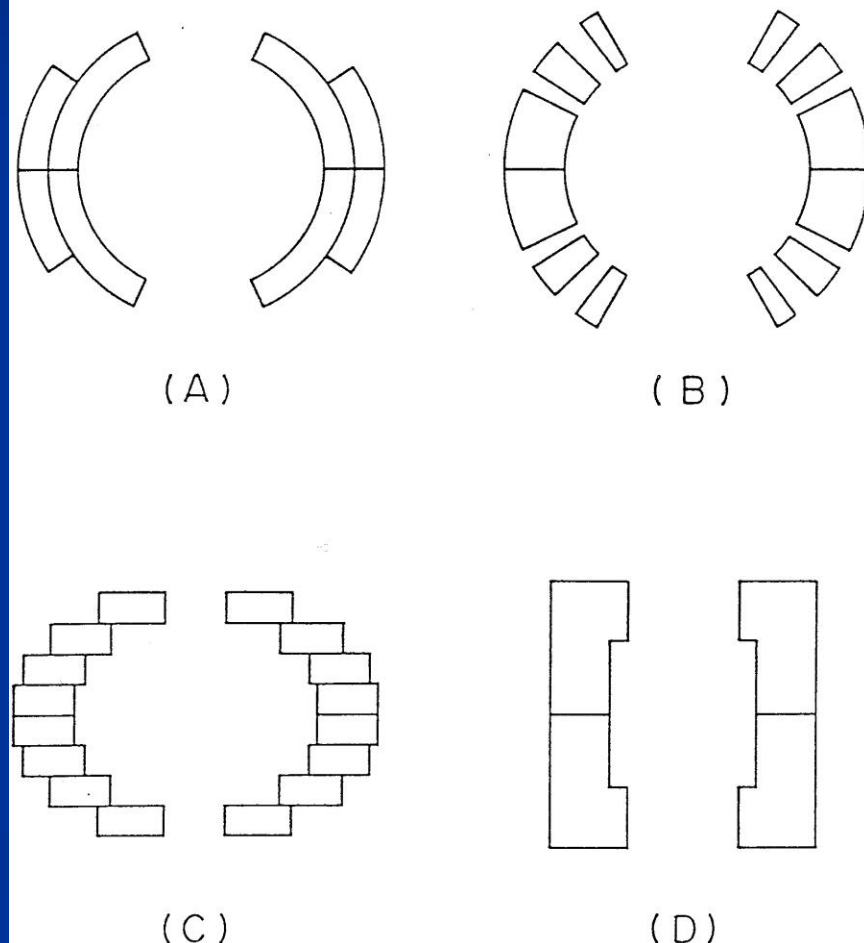
- $\{\theta = 60 \text{ deg}\}$ でちょうどキャンセルする。
- 角度がずれたとすると高調波 (b_3) が発生する。



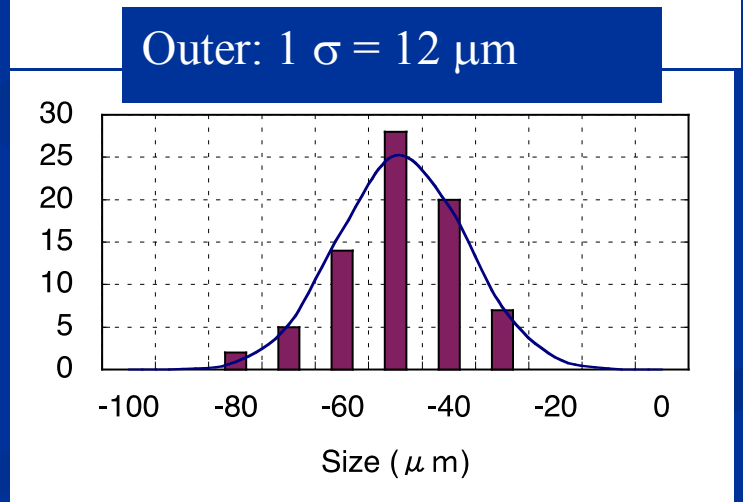
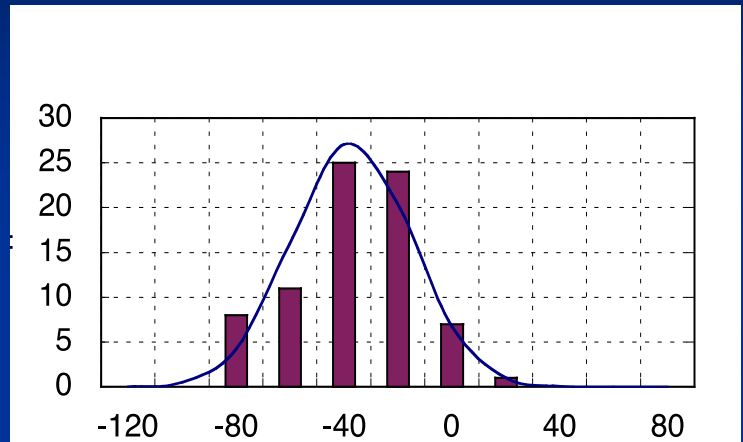
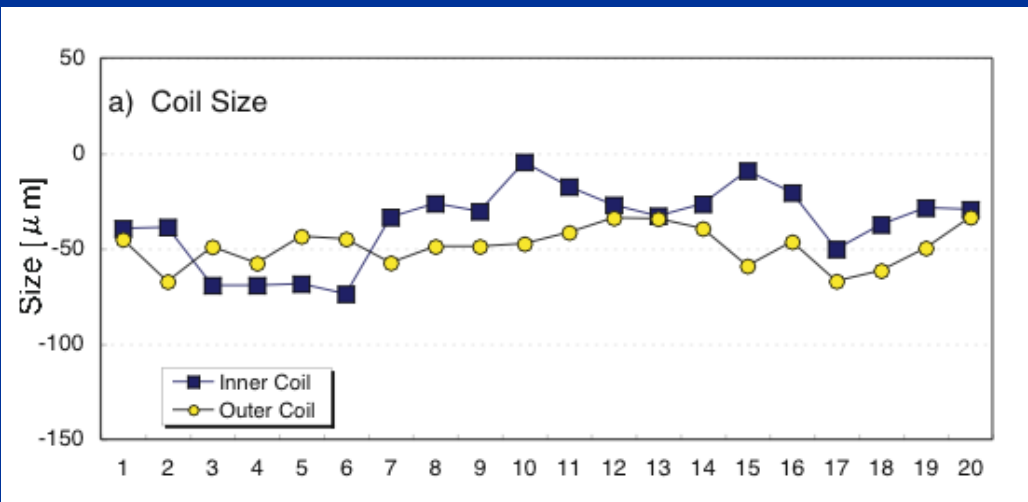
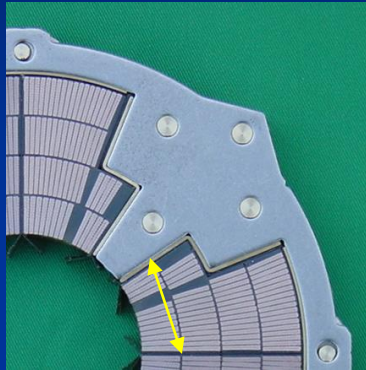
磁場を作るー2極磁石

■ 実際の磁石

- 6極以外の高調波も消す必要
- $\cos(\theta)$ を模擬した電流分布
- 現状実用化されているものはA, Bが多い
 - 機械的に安定
 - ラザフォードケーブル
 - 鞍形コイル
 - ローマンアーチ



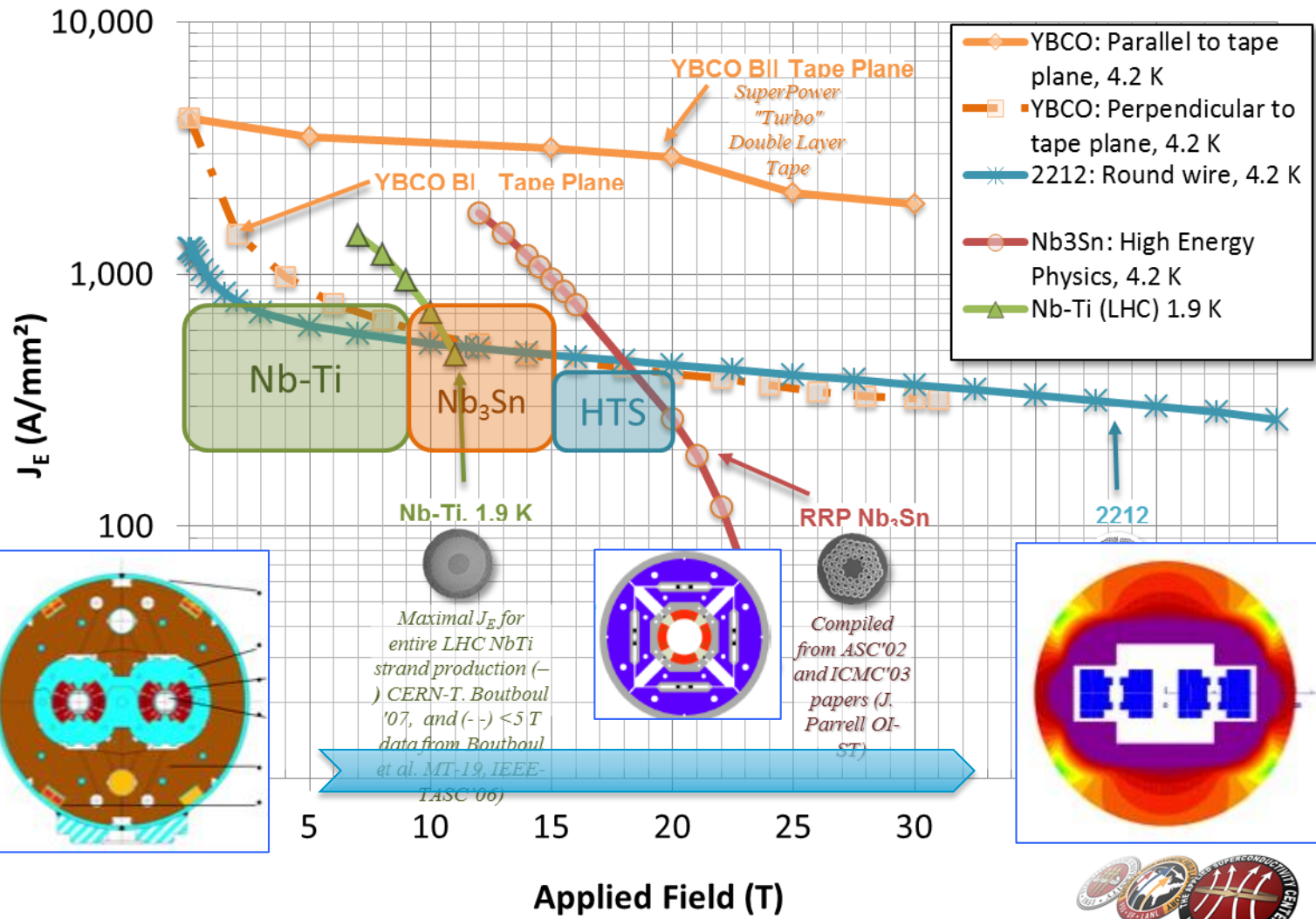
Coil Size and Deviation



Relative coil size controlled: in a level of $20\mu\text{m}$

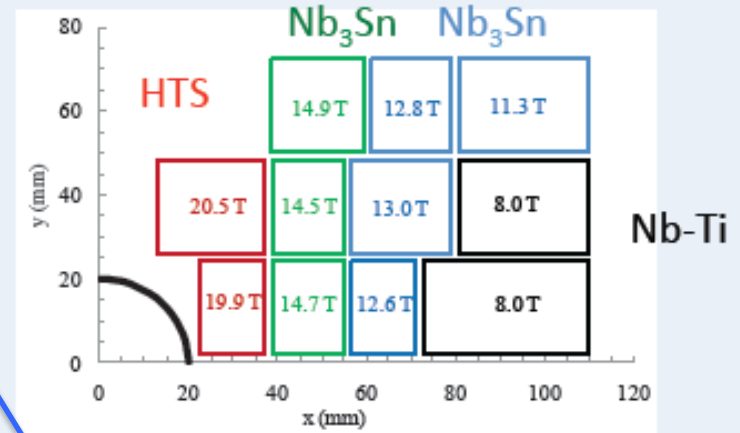
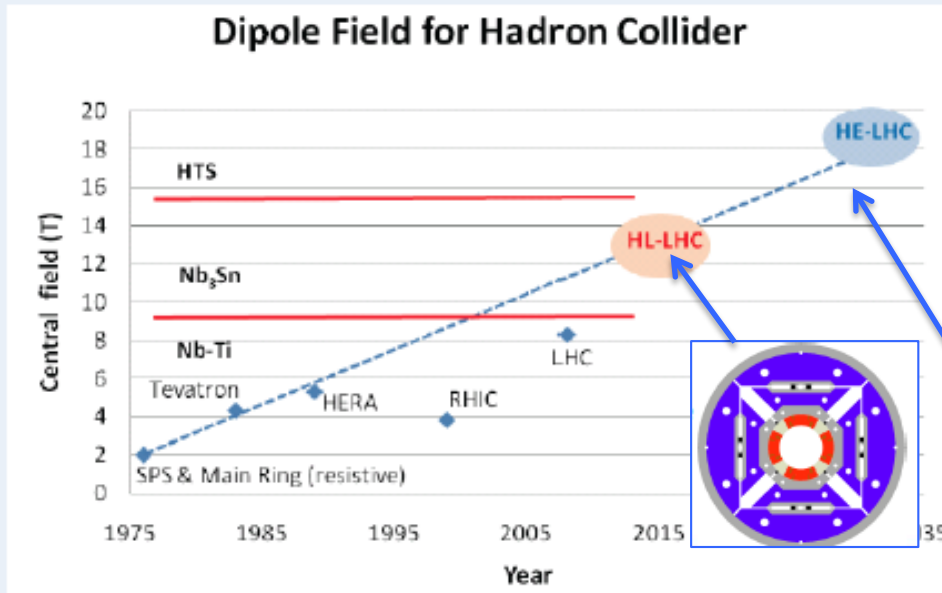
Superconductor Advanced toward High Field Magnets

Courtesy:
G. Sabbi,
L. Rossi

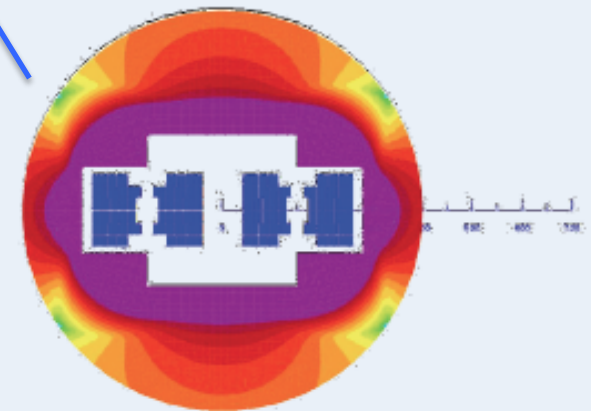


For Higher Energy

Eucard 2 (Lucio Rossi, CERN Edms No. 1152224)



$$J_{\text{overall_HTS}} = 400 \text{ A/mm}^2 @ 20 \text{ T}$$



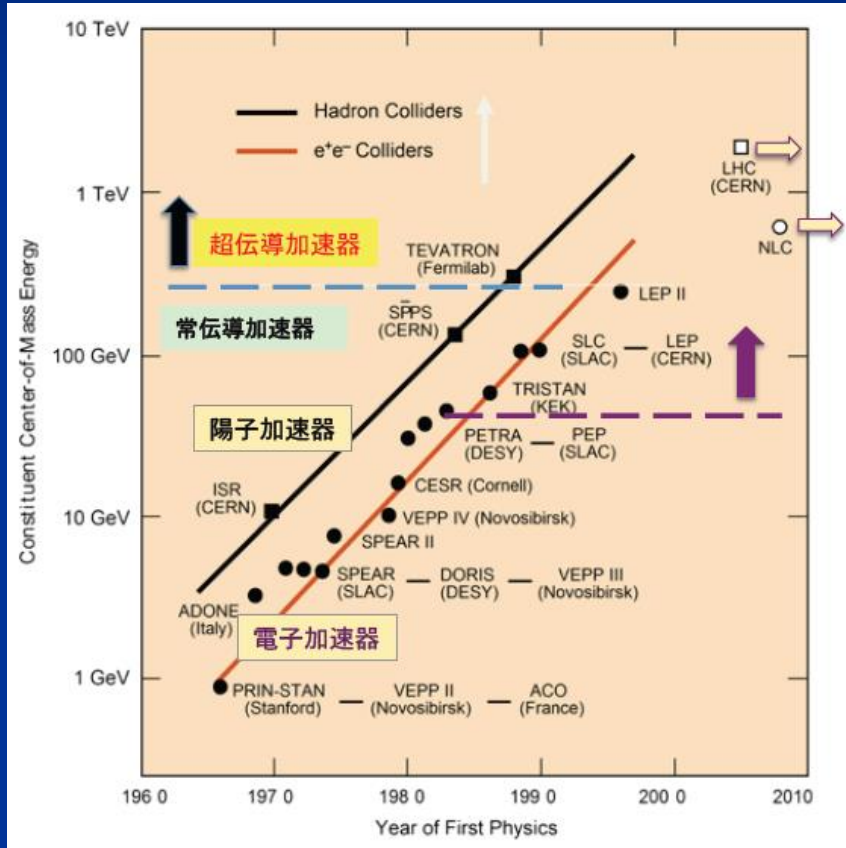
High Energy LHC: 2×16.5 TeV beams

Twin aperture dipole, 20 T, 15 m long, bore spacing 300 mm, iron diameter 800 mm

アウトライン

- インTRODクシヨン
- LHCでの経験に学ぶ超伝導技術開発
 - 加速器、測定器における超伝導磁石
- ILC 実現を目指す超伝導技術
 - 超伝導加速空洞技術の開発
 - 将来への展望
- まとめ

加速器の進展と超伝導技術

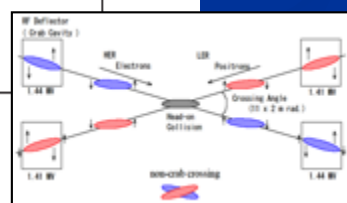
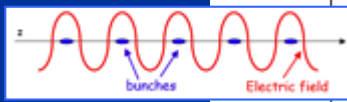
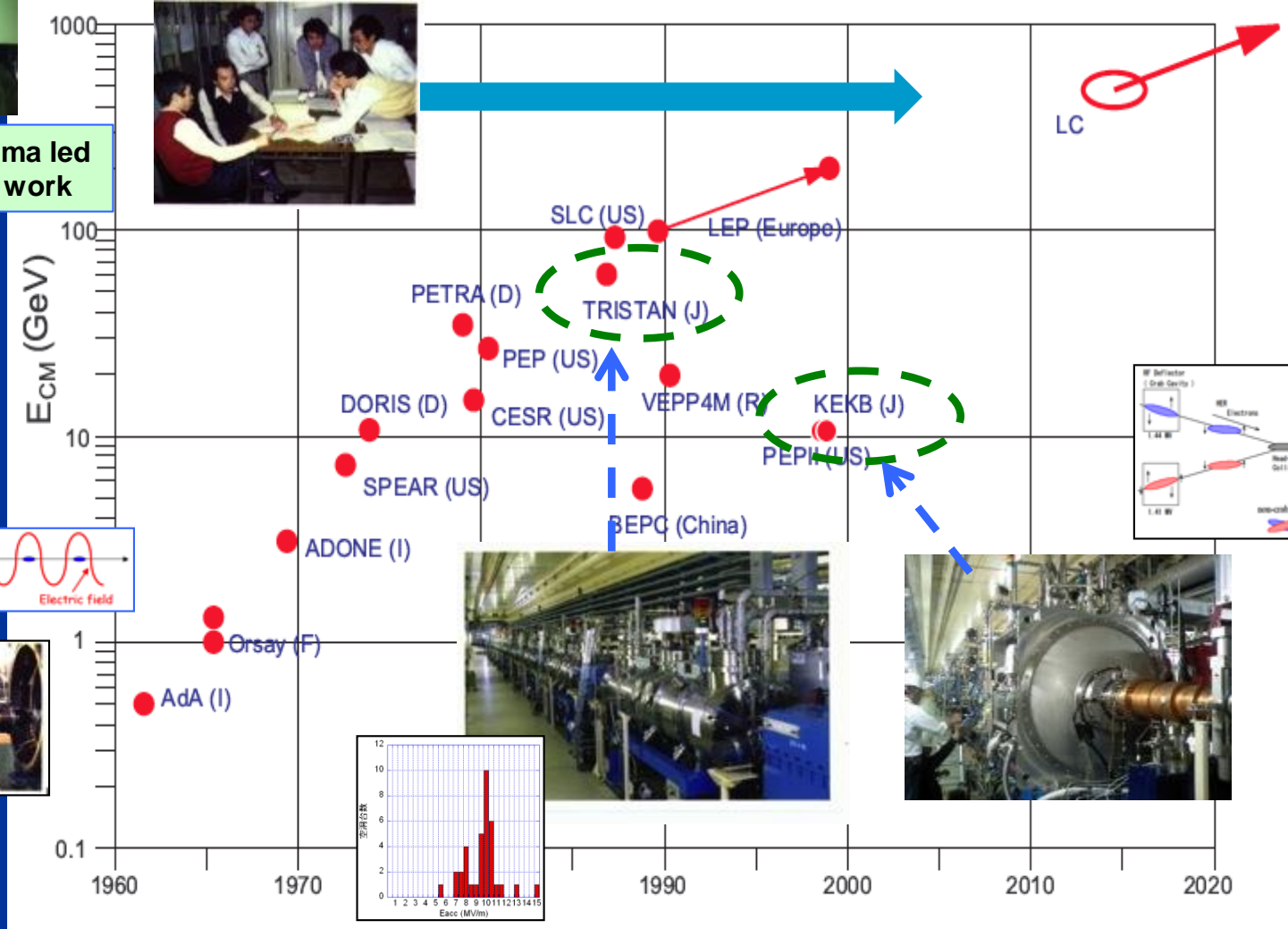


Development of e⁻/e⁺ Colliders

KEK' pioneering for SCRF beam acceleration TRISTAN → KEKB



Prof. Y. Kojima led the pioneer work



超伝導加速空洞を基盤とした 高エネルギー粒子加速器

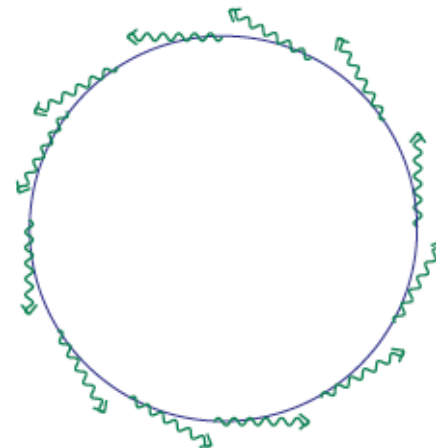
所在	加速器名	エネルギー [GeV]	加速電場、周波数 [MV/m, (GHz)]	運転期間
KEK	TRISTAN	2 x 30	5 (0.5)	1986-1995
CERN	LEP	2 x 105	5 (0.5)	1989-2000
JLab	CEBAF	6 → 12	5 ~12 (1.3)	1995~ (建設中)
DESY	EXFEL	14	24 (1.3)	建設中
---	ILC	2 x 250	31.5 (1.3)	計画中

円形コライダーの限界、 リニアコライダーへの展開

- エネルギー増加は年代に対して指数関数的
- しかし、1980年頃を境にしてエネルギー増加がゆるやかになる
- 高エネルギー電子は円軌道上でシンクロトロン輻射を出してエネルギーを失う
- 一周のエネルギー損失

$$\frac{(\text{エネルギー})^4}{(\text{軌道半径})}$$

- 最大の e^+e^- Collider **LEP** (CERN) は約200GeVを達成
- しかし、LEPはすでに一周27km、より高いエネルギーは不可能



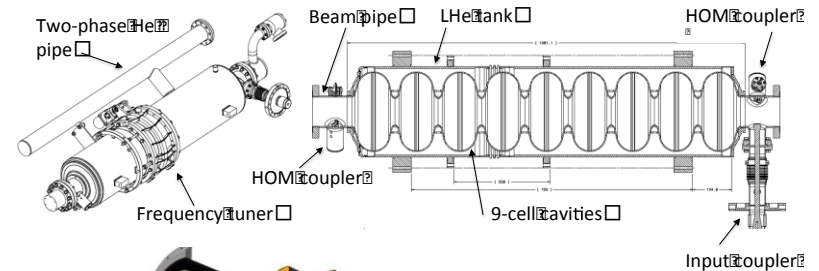
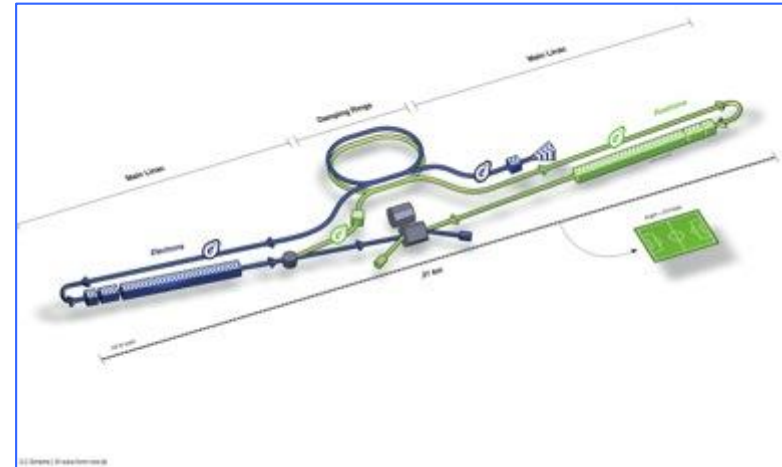
⇒ 直線的 Collider





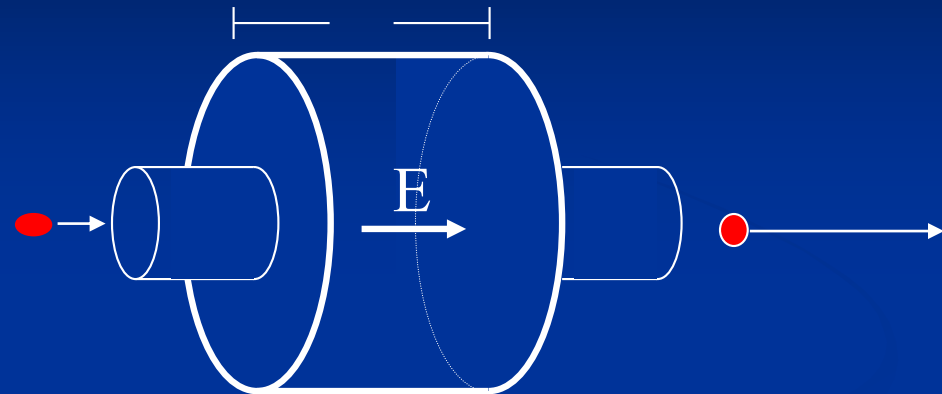
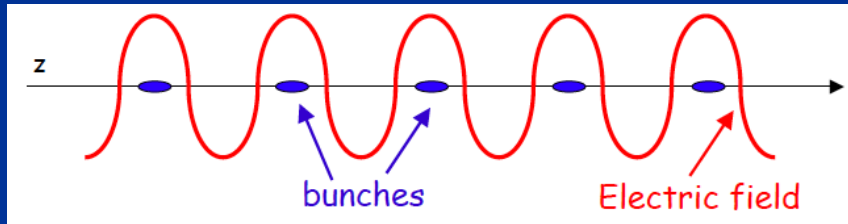
SCRF Industrialization required

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	$1.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% $Q_0 = 1E10$
# 9-cell cavity	16024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

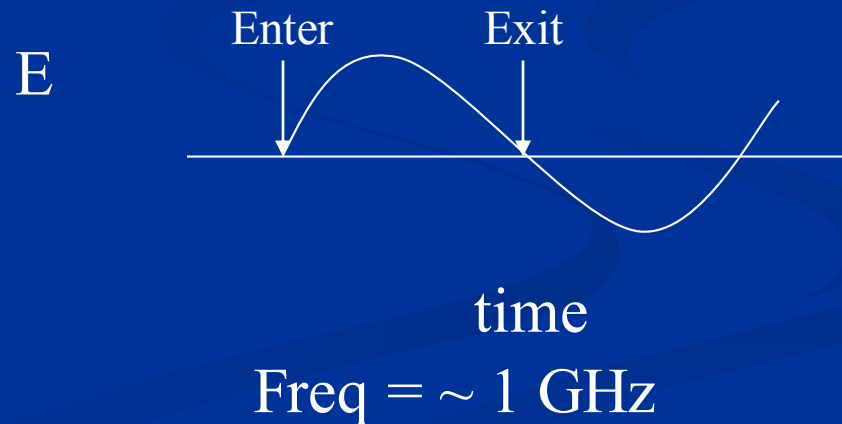


加速器における加速電場と超伝導応用（加速空洞）

$$\vec{F}_{\text{Lorentz}} = \frac{d\vec{p}}{dt} = q \cdot (\vec{E} + \vec{v} \times \vec{B}) = \vec{F}_{\text{el}} + \vec{F}_{\text{mag}}$$



$$\Delta E = \Delta T = \int \vec{F}_{\text{Lor}} \cdot d\vec{s} = q \cdot \int \vec{E} \cdot \vec{v} \cdot dt$$



加速空洞を超伝導化すると

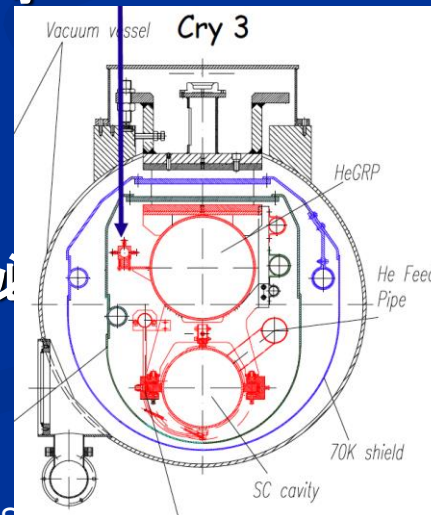
■ 超伝導化により

- 高周波（表面）抵抗が小さい
- パワーロスが小さい
- Q値(蓄積エネルギー／エネルギー損失)が大きい
- 周波数を低く、口径を大きく
- ビームロスが少ない（スクレーパー等が少ない）



■ 低温化の為に

- クライオスタット（断熱真空容器が必要）
- 冷却、冷凍機の電力



Comparison of ILC w/ CLIC

	ILC	CLIC
Centre-of-mass energy	500 GeV (to 1 TeV)	3 TeV (first, at 500
Total luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	$2.0(1.5) \cdot 10^{34}$	$5.9(2.0) \cdot 10^{34}$
Total site length (km)	31	48.3
Loaded accel. gradient (MV/m)	31.5 (33)	100 (80)
Main linac techno. & RF frequency	Super-Conduct @ 1.3 GHz	Normal-Conduct @12GHz
Beam power/beam (MW)	10	14
Bunch charge ($10^9\text{e}^{+/-}$)	20	3.72
Bunch separation (ns)	396	0.5
Beam pulse duration (ms)	960	0.156
Repetition rate (Hz)	5 (4)	50
Hor./vert. norm. emitt ($10^{-6}/10^{-}$)	10/40	0.66/20
Hor./vert. IP beam size (nm)	639/5.3	40 / 1
Beamstrahlung photon/electron	1.3	2.2
Wall plug to beam transfer eff	13.7	6.8%
Total power consumption (MW)	230	415



Global Plan for SCRF R&D

Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule	Global effort for string assembly and test (DESY, FNAL, INFN, KEK)			We are here		
System Test with beam acceleration				FLASH (DESY) , NML/ASTA (FNAL) QB, STF2 (KEK)		
Preparation for Industrialization				Production Technology R&D		
Communication with industry:	1 st Visit Vendors (2009), Organize Workshop (2010) 2 nd visit and communication, Organize 2 nd workshop (2011) 3 rd communication and study contracted with selected vendors (2011-2012)					

R&D Efforts Required

■ Fabrication:

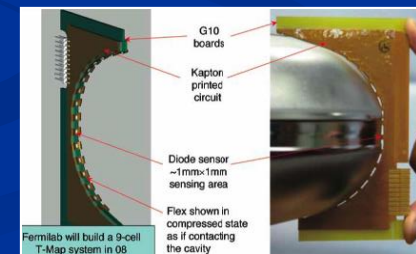
- Forming and welding (EBW)

■ Surface Process:

- Chemical etching
 - Electro-polishing
- Cleaning
 - Ethanol, Detergent, Micro-EP
 - High pressure water rinsing

■ Inspection/Tests/Repair

- Optical Inspection (warm)
- Thermometry (cold)



Why Field Gradient Limited in SC Cavity ?

Current major reasons

■ Field Emission

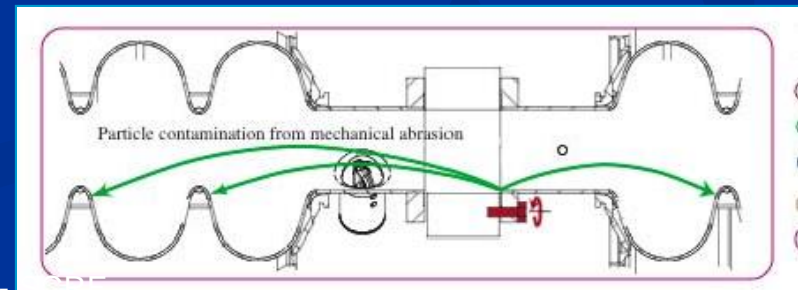
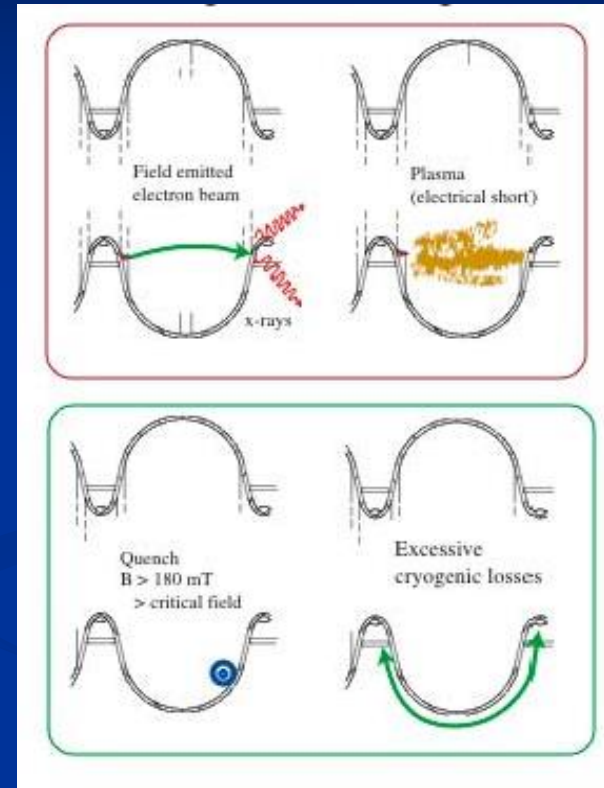
- due to high electric field
 - around “Iris”

■ Quench

- caused by surface heating from dark current, or
- magnetic field penetration.
 - around “Equator”

■ Contamination

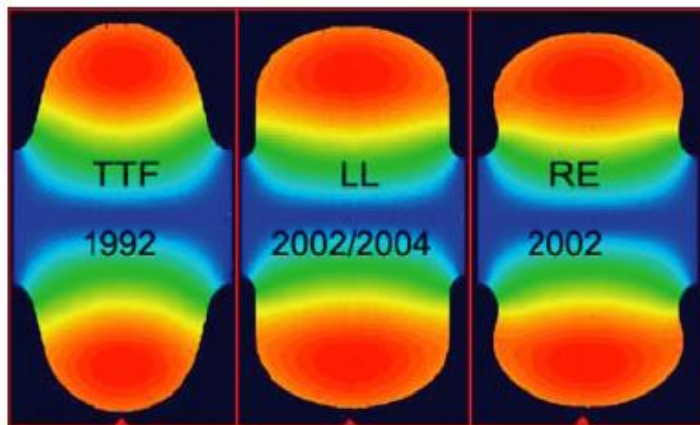
- during assembly



Cavity Shape Design Investigated

TABLE II. CAVITY SHAPES STUDIED FOR THE ILC.

Parameter	TESLA	LL/IS	RE
Iris aperture (mm)	70	60/61	66
$E_{\text{peak}}/E_{\text{acc}}$	1.98	2.36/2.02	2.21
$B_{\text{peak}}/E_{\text{acc}}$ (mT/(MV/m))	4.15	3.61/3.56	3.76
Char. shunt impedance: R/Q (Ω)	114	134/138	127
Geometric factor: G (Ω)	271	284/285	277
$G \times R/Q$ ($\Omega \times \Omega \times 10^5$)	3.08	3.80/3.93	3.51

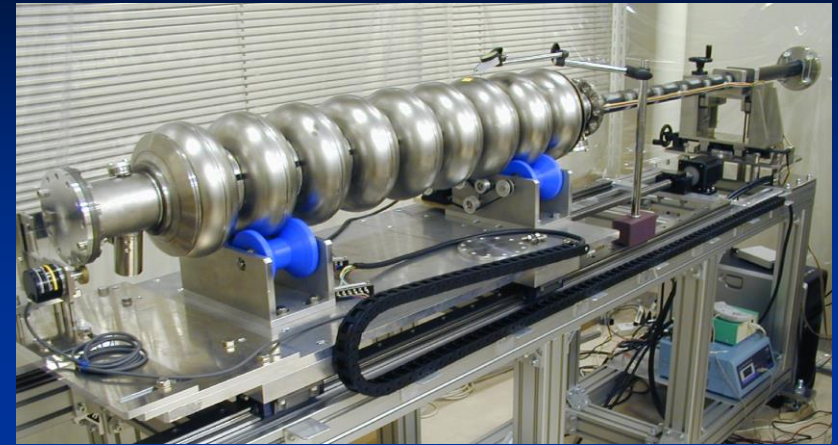


- TESLA
 - Lower E-peak
 - Lower risk of field emission
- LL/IS, RE
 - Lower B-peak
 - Potential to reach higher gradient

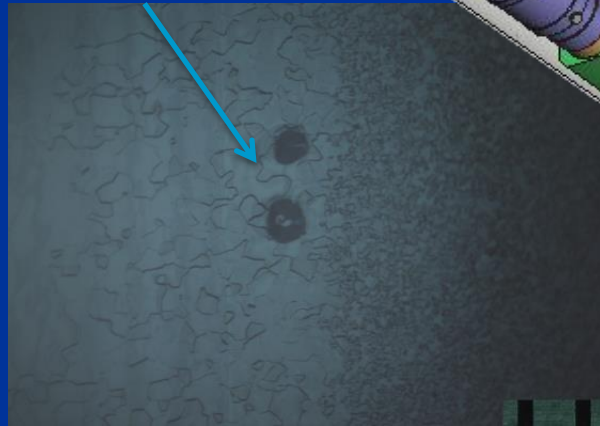
A New High Resolution, Optical Inspection System

For visual inspection of cavity inner surface.

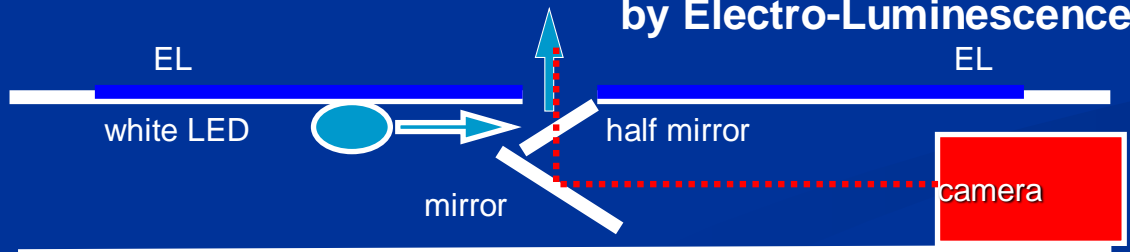
motor & gear for mirror
camera & lens
~600 μ m beads on Nb cavity



Camera system (7 μ m/pix)
in 50mm diameter pipe.



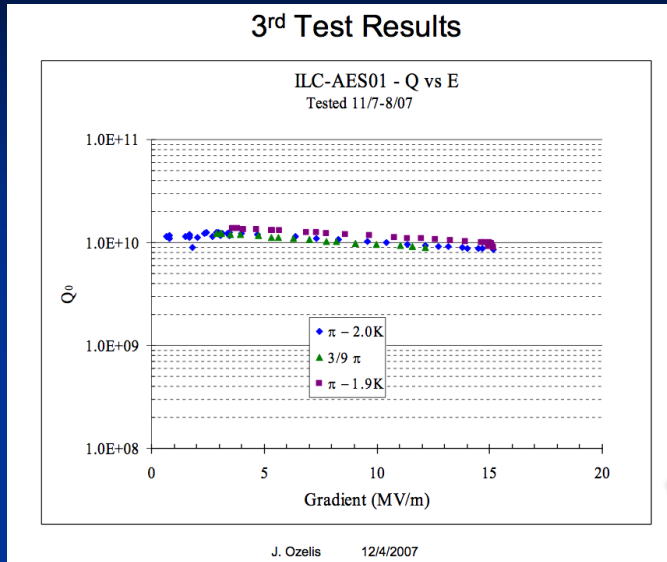
perpendicular illumination
by LED & half mirror



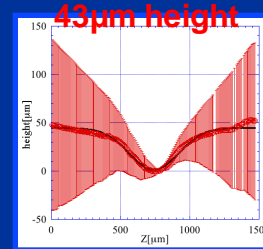
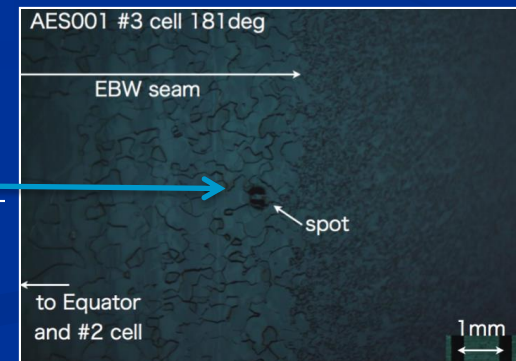
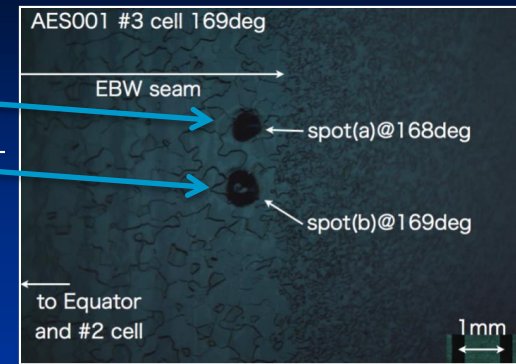
tilted sheet illumination
by Electro-Luminescence

sliding mechanism of camera

Consistent with Thermal Measurement at FNAL



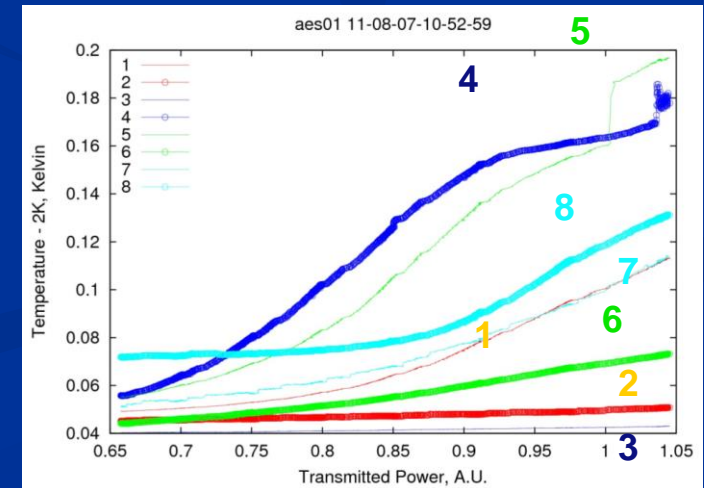
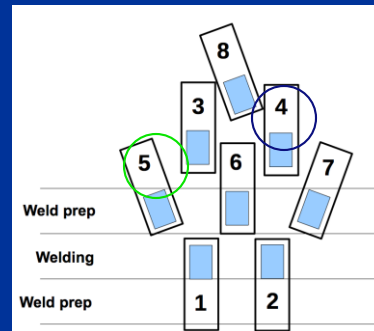
AES01 has hard quench at 15MV/m, its location was identified by Cernox at FNAL, (M. Champion et al., This conference)



84µm height

60µm height

~21mm

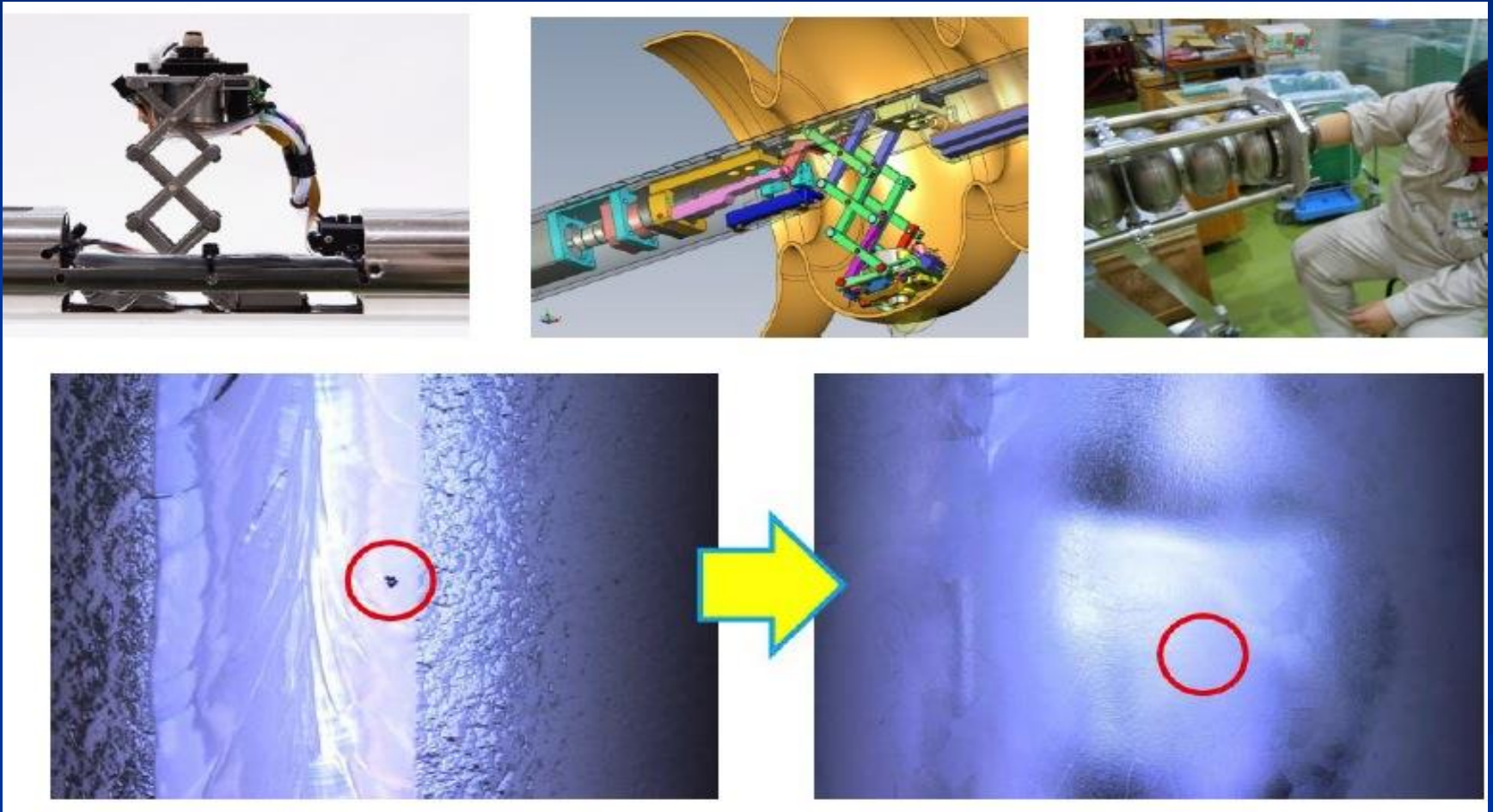


Kyoto-camera found 3 spots in their exact location

A. Yamamoto, 130721

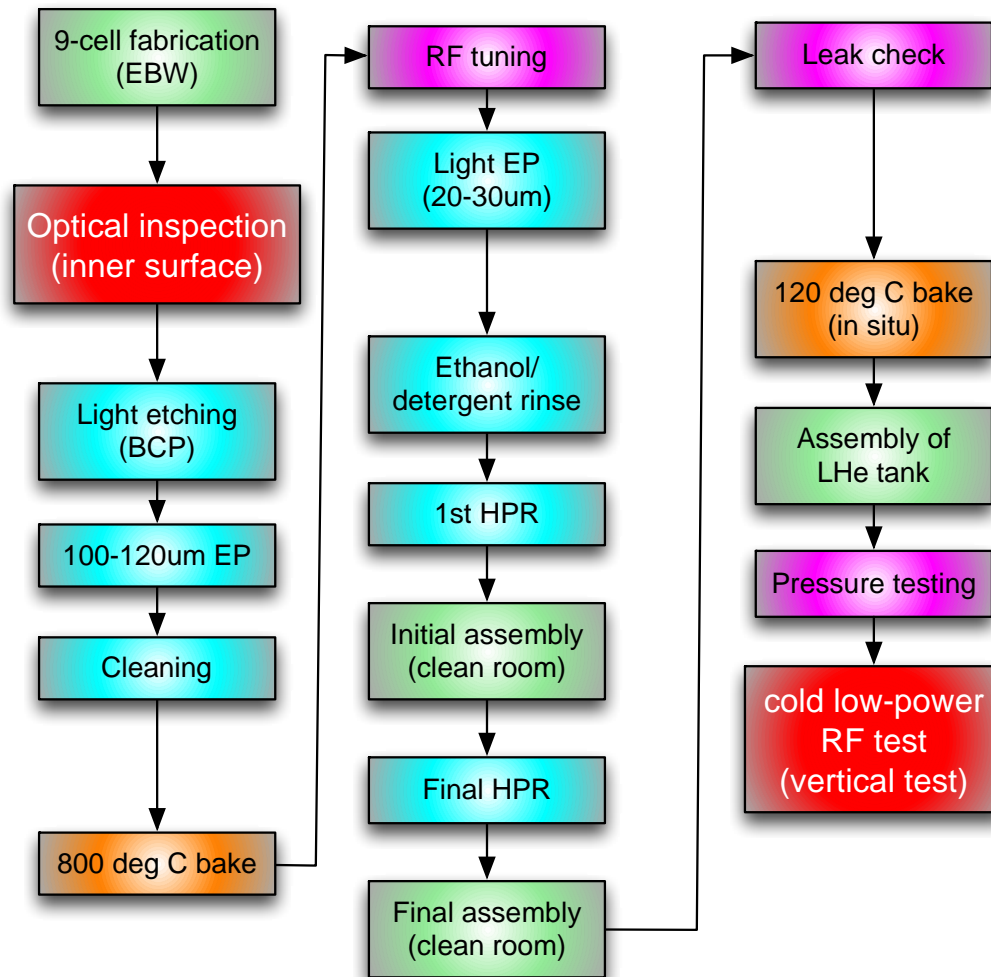
ILC Summer School - SCRF

Local Grinding Technology





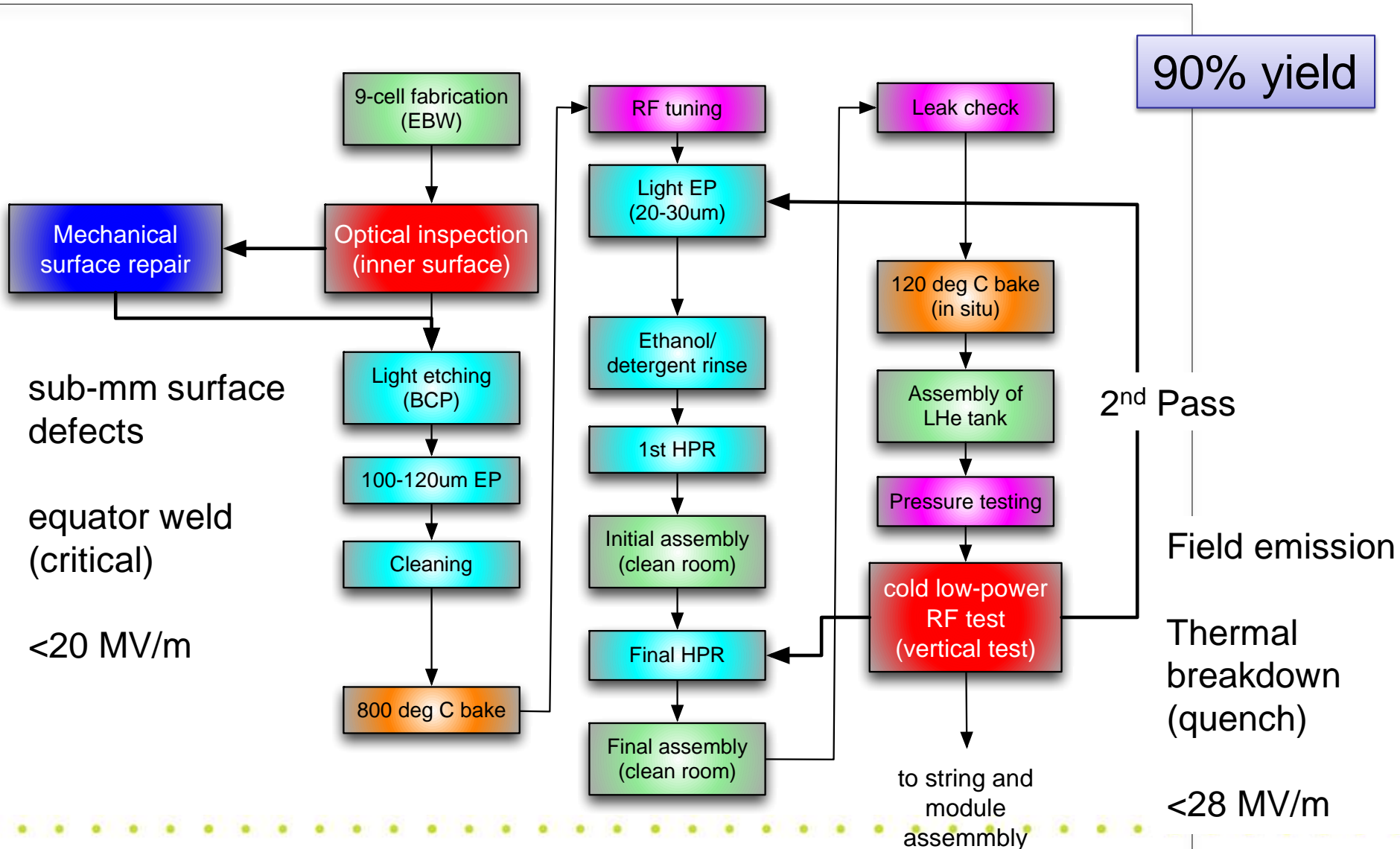
The Path to High Performance



70% yield



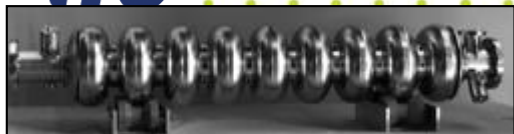
The Path to High Performance





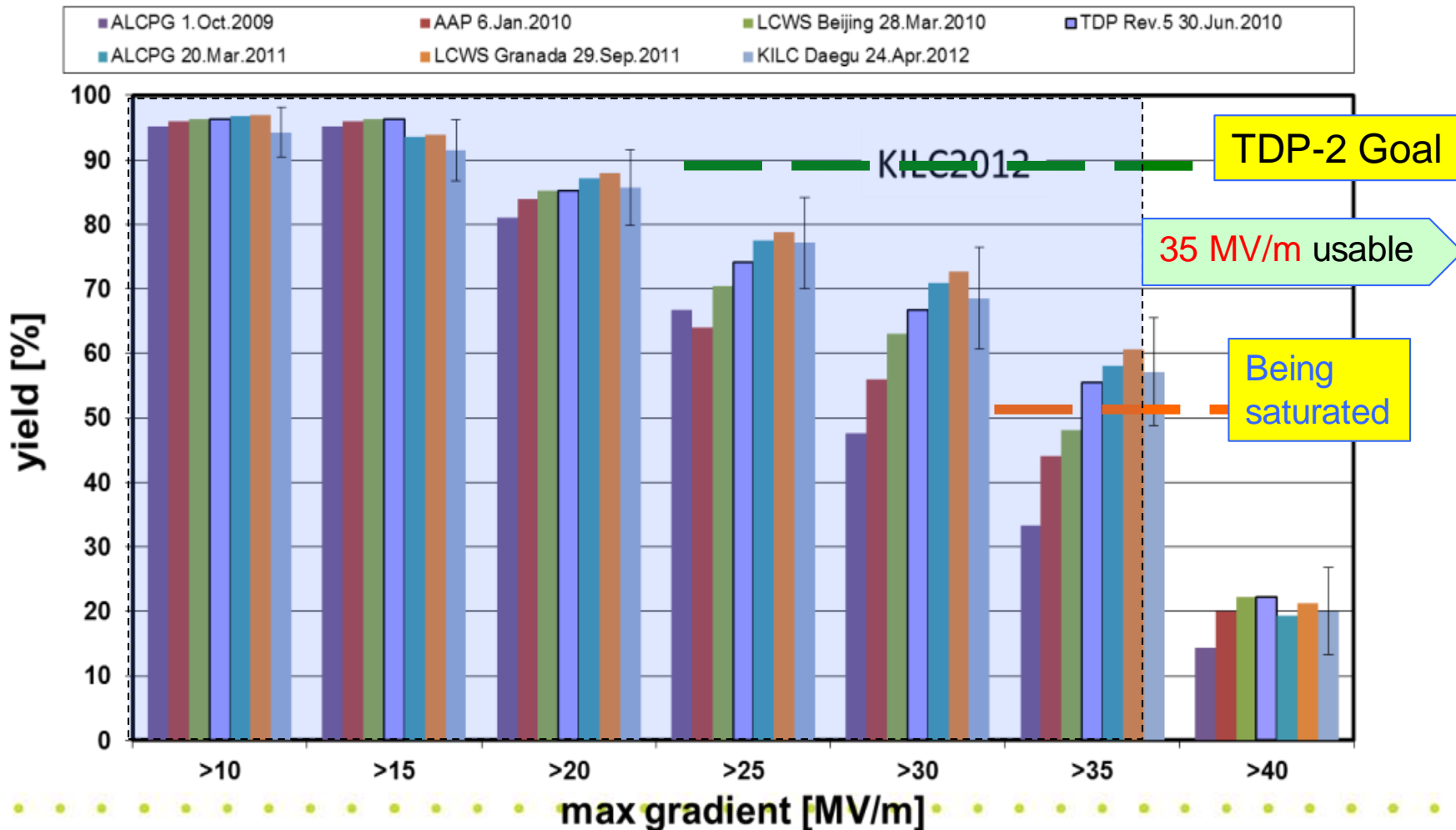
Progress Integrated in Cavity Gradient Yield

Updated, April., 24, 2012



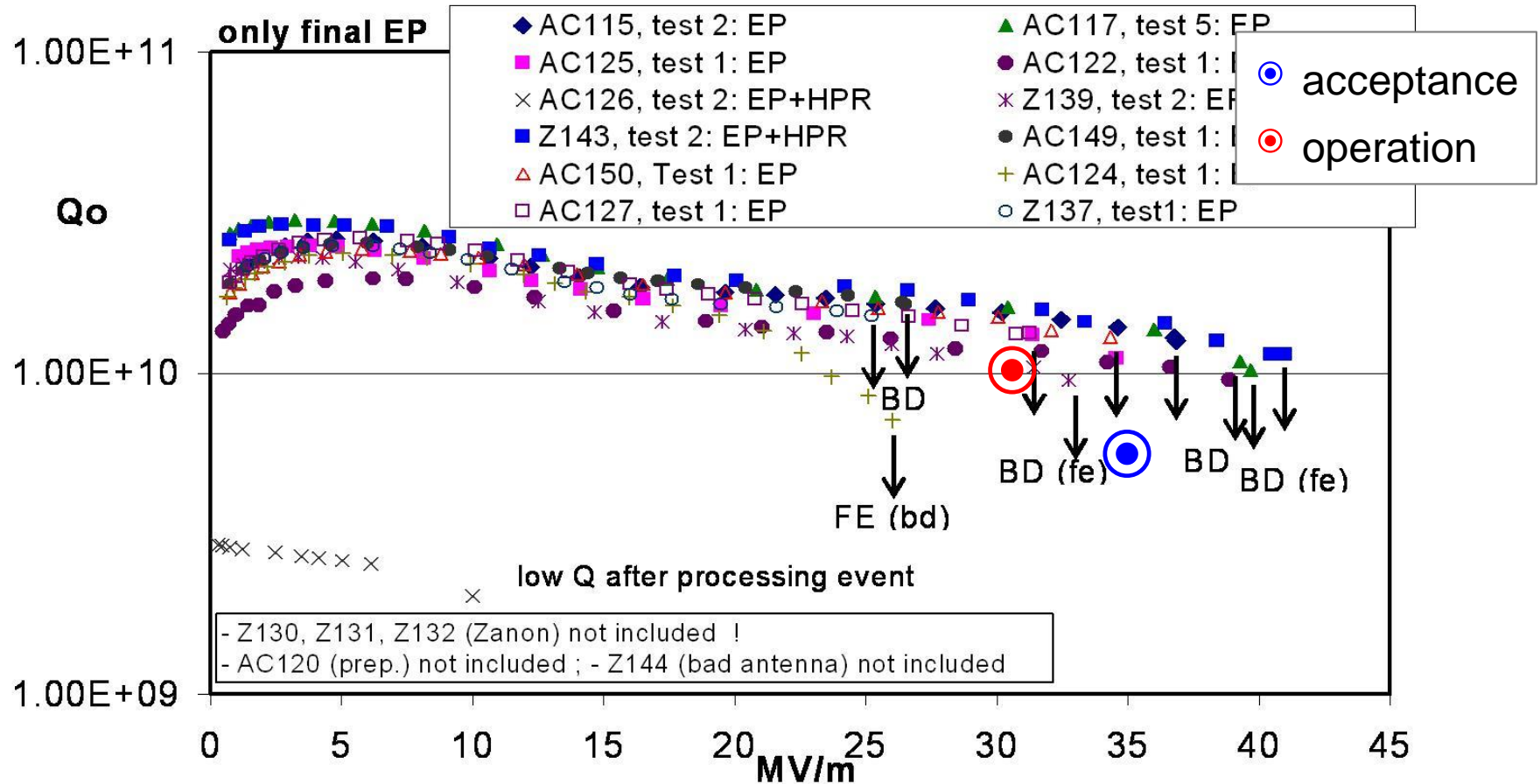
Electropolished 9-cell cavities /KEK (combined) up-to-second successful test of cavities from established vendors

Plot courtesy
Camille Ginsburg of FNAL





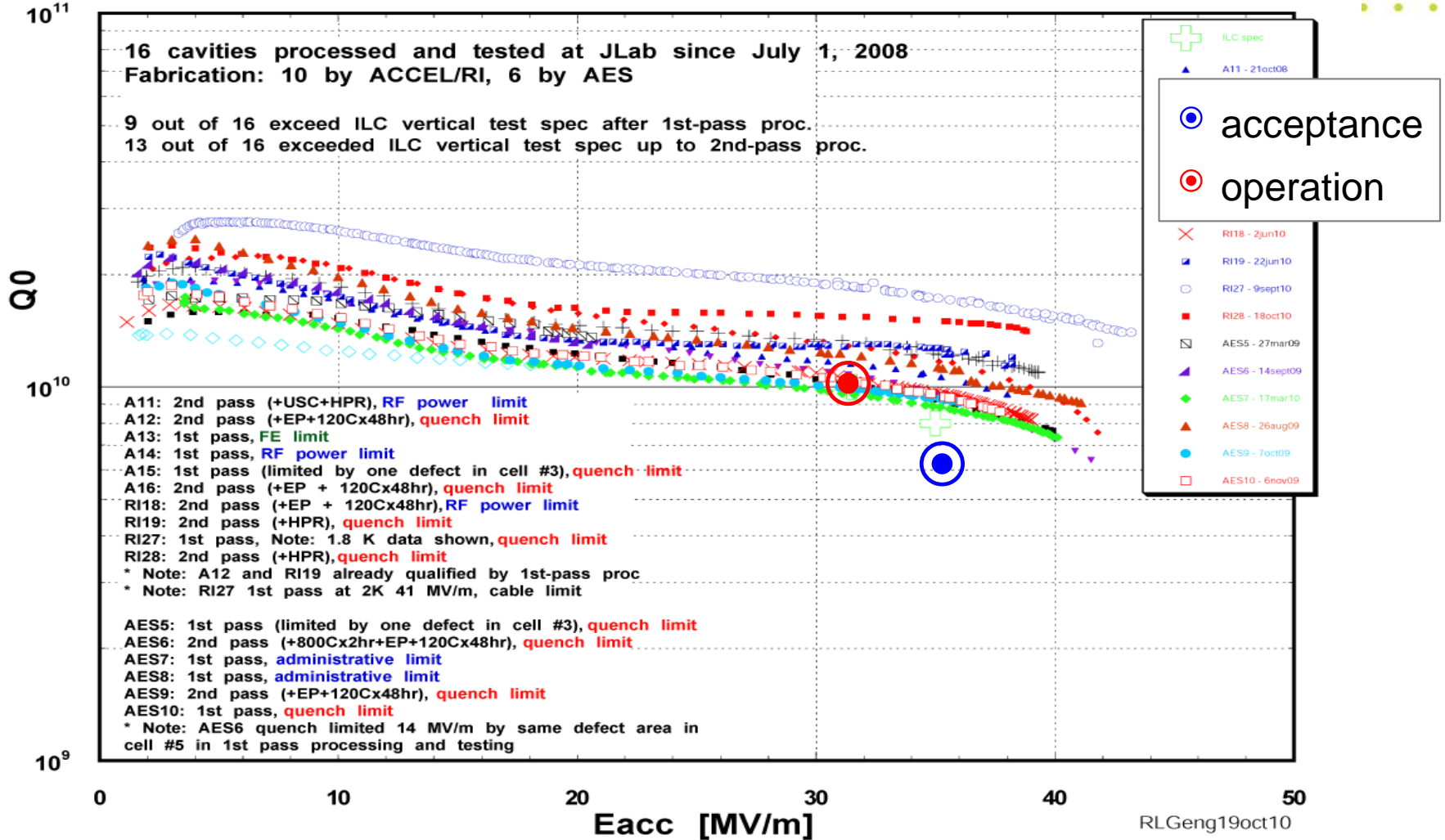
Global Cavity Gradient Results - EU



DESY data, D. Reschke et al., SRF2009, TUPPO051.



Global Cavity Gradient Results - Americas

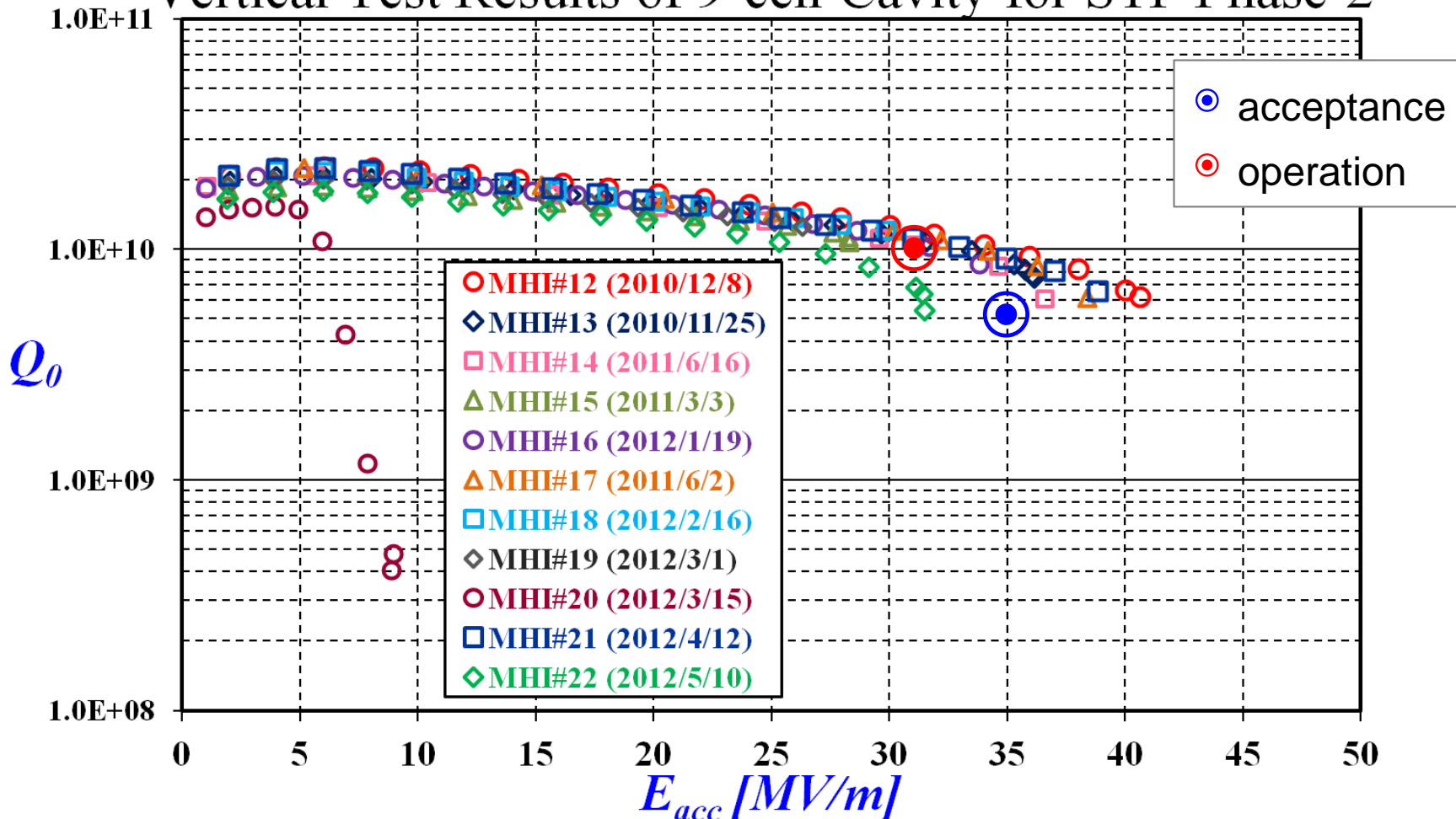


JLAB data, R.L. Geng et al., IPAC2011, MOPC111.



Global Cavity Gradient Results - Asia

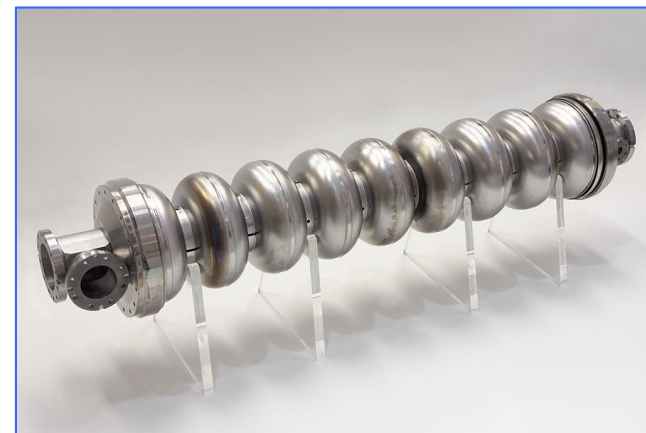
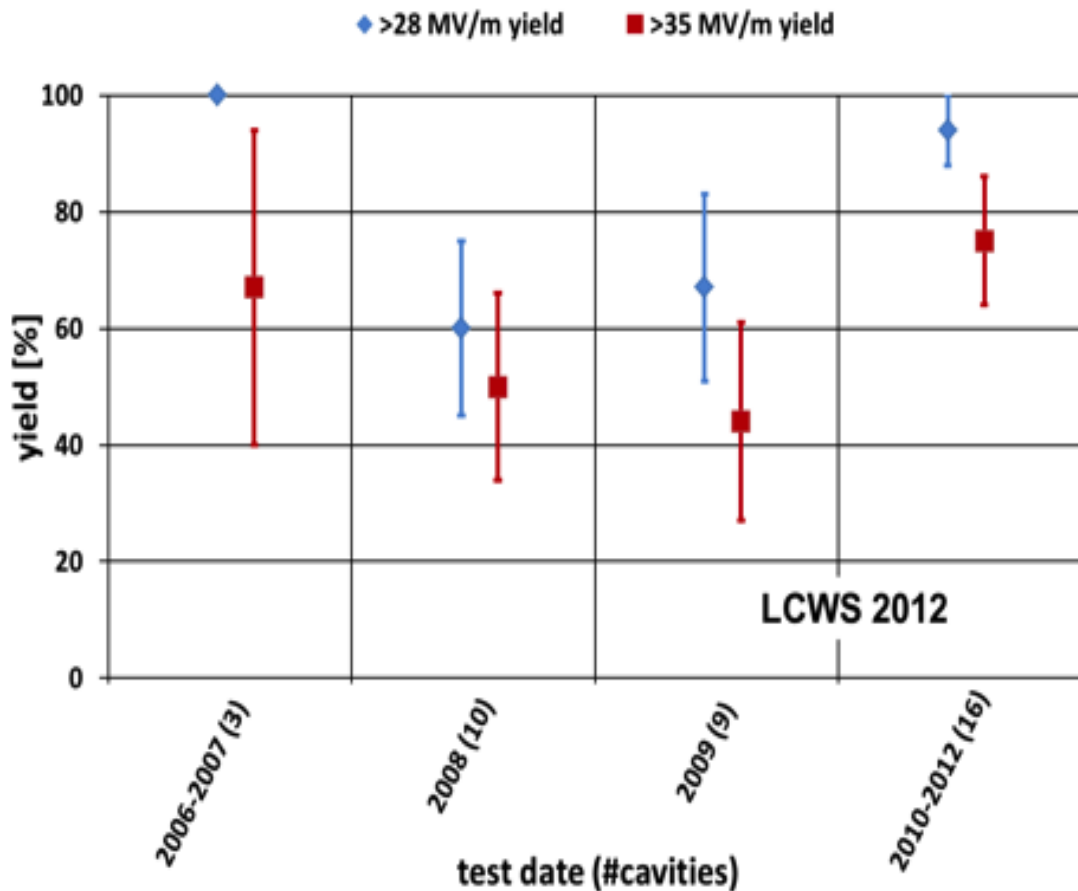
Vertical Test Results of 9-cell Cavity for STF Phase-2



KEK data, Y. Yamamoto et al., IPAC2012, WEPPC013.

Progress in SCRF Cavity Gradient

2nd pass yield - established vendors, standard process



Production yield:
94 % at > 28 MV/m,
 Average gradient:
37.1 MV/m
 reached (2012)



Progress in cooperation of Laboratories and Industry

year	# 9-cell cavities qualified	Capable Lab.	Capable Industry
2006	10	1 DESY	2 ACCEL, ZANON
2011	41	4 DESY, JLAB, FNAL, KEK	4 RI, ZANON, AES, MHI,
2012	(45)	5 DESY, JLAB, FNAL, KEK, Cornell	5 RI, ZANON, AES, MHI, <u>Hitachi</u>

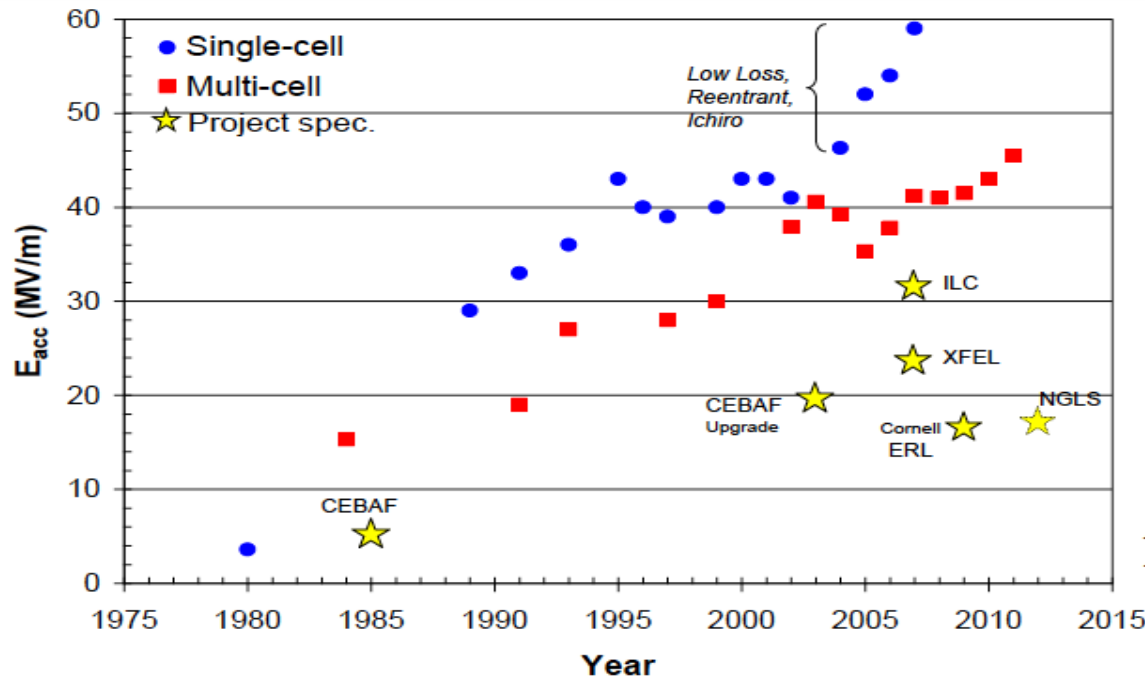
- **Progress in EXFEL (800 cavity construction as of 2012/10):**

(courtesy by D. Reschke: the 2nd EP at DESY)

- **RI:** 4 reference cavities with $E_{acc} > 28$ MV/m, (~ 39 MV/m max.)
- **Zanon:** 3 reference cavities with $E_{acc} > 30$ MV/m (~ 35 MV/m max.)

Progress in Accelerating Gradient, L-band, $\beta = 1$ Cavities

Accelerating gradient, L-Band $\beta=1$ cavities

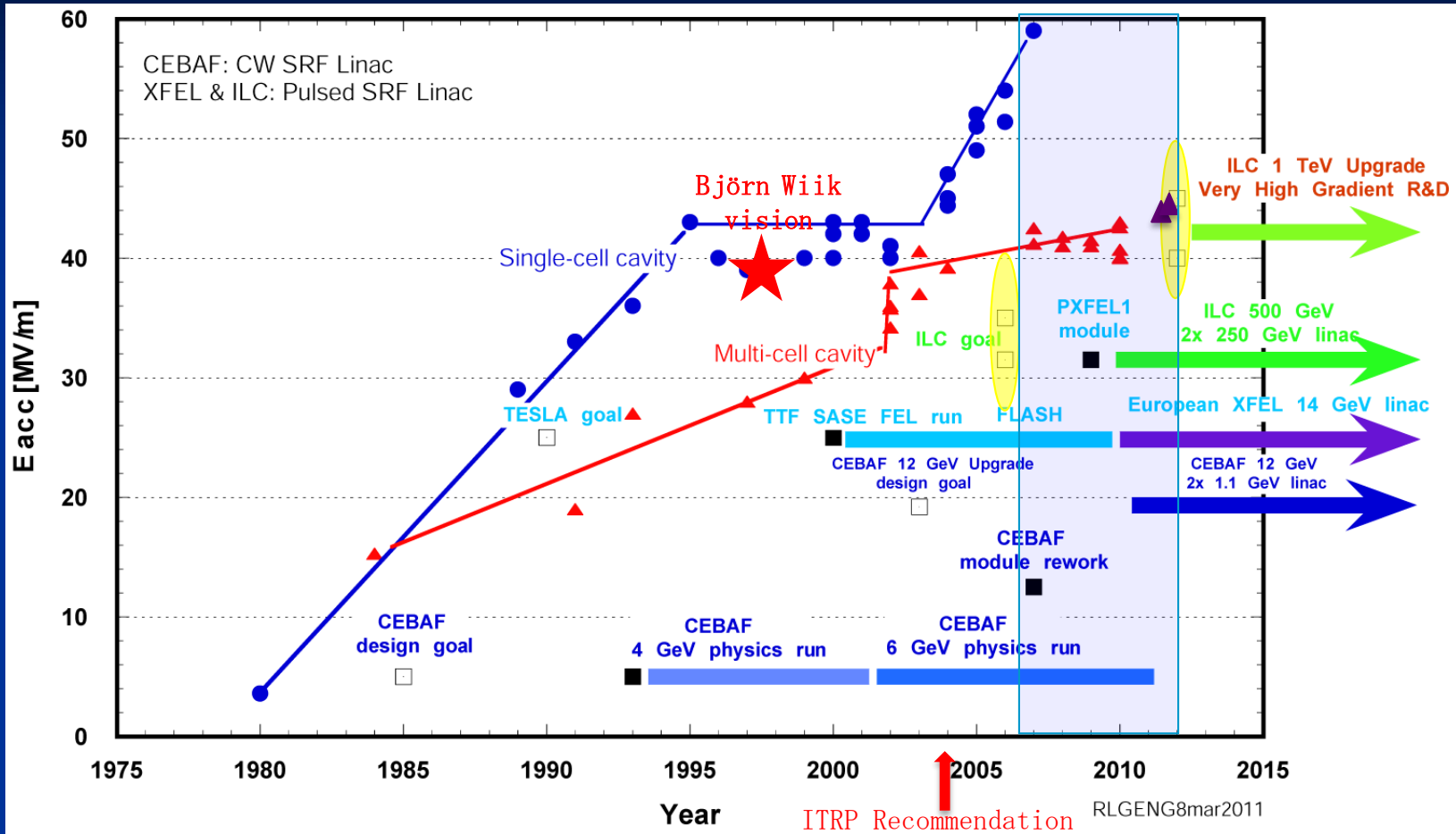


G. Ciovati
IPAC'13
THYB201

Data is courtesy of
R. Geng, JLab

- $E_{acc} > 50$ MV/m is yet to be achieved in “low B_p ” multi-cell cavities
- Average gradient specification of current and future projects is ~ 20 MV/m

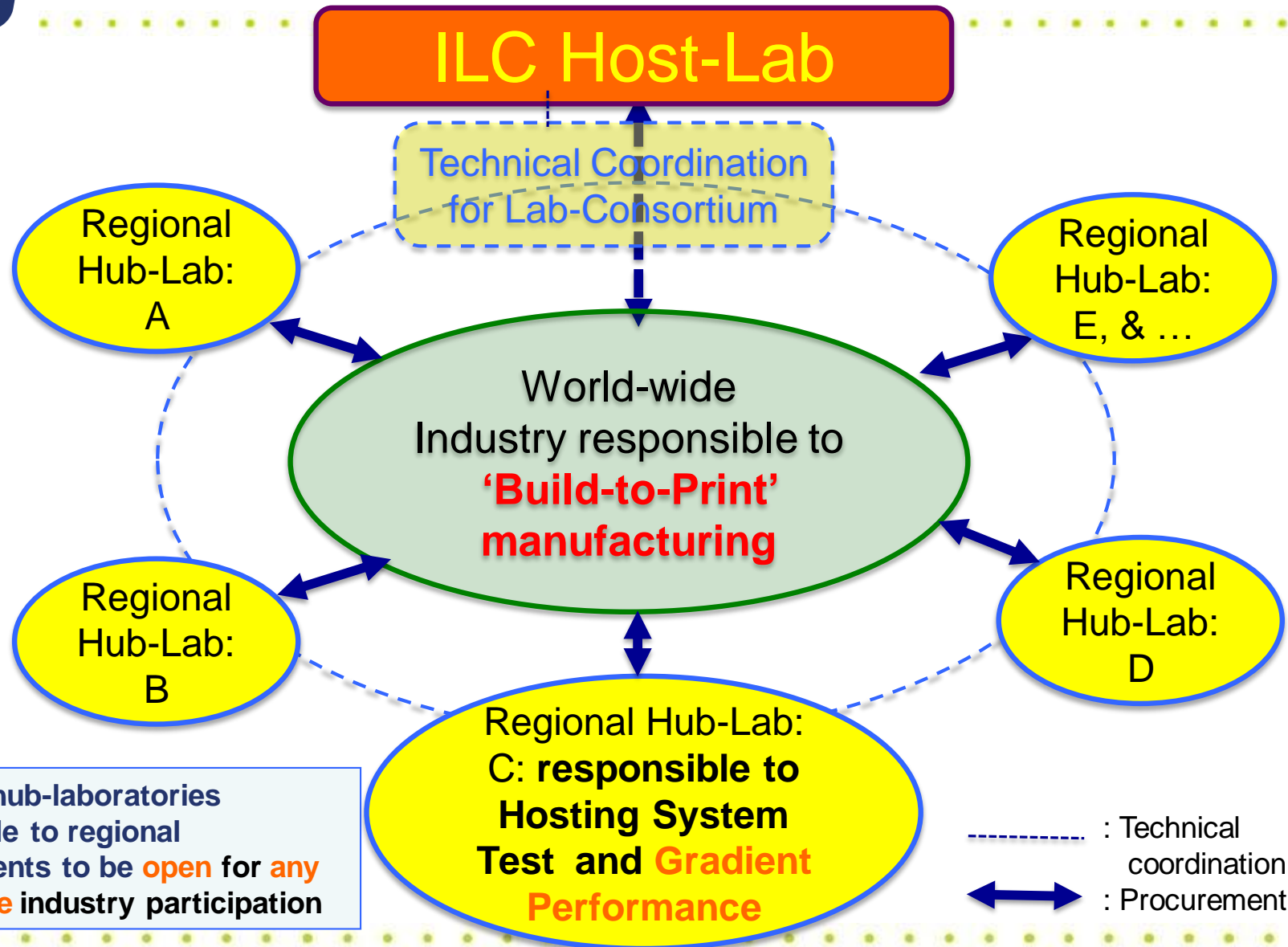
超伝導加速空洞性能、プロジェクトの進展



- Continued progress in SRF gradient : breakthrough of 45 MV/m in 1-cell, ~60 MV/m record; 45 MV/m in 9-cell
- GDE began in 2005: produce a design for ILC and coordinate worldwide R&D efforts
- New SRF Test Facilities in operation: STF at KEK and NML at Fermilab
- Upgrade of CEBAF to 12 GeV underway at Jefferson Lab (80 cavities)



Cooperation of ILC host- and hub-laboratories with worldwide industry (proposed)

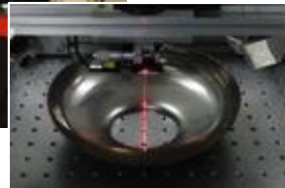




→山中さん,佐伯さんの講演

KEK' Own Effort for Industrialization

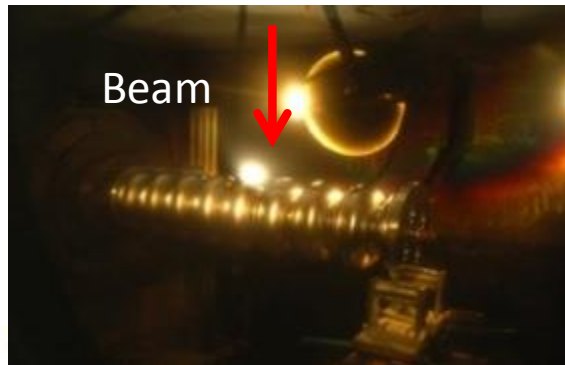
best cost-effective fabrication technology



KEK is preparing for SCRF
Industrial technology R&Ds
to provide the facility and to cooperate
with industry in coming years.



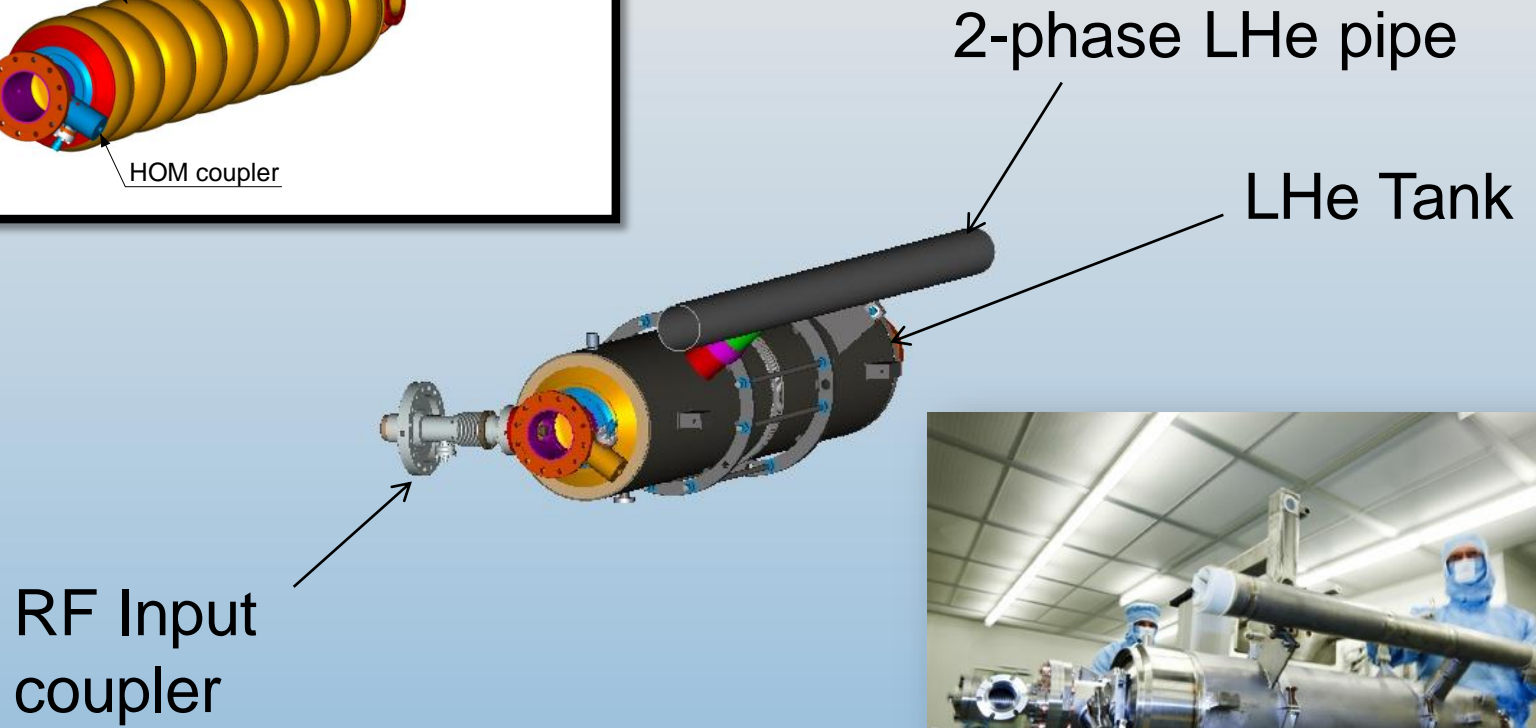
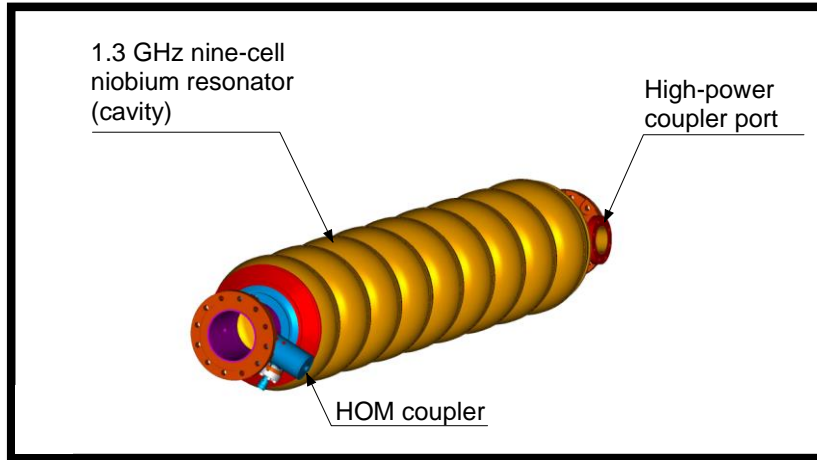
A. Yamamoto, 130721

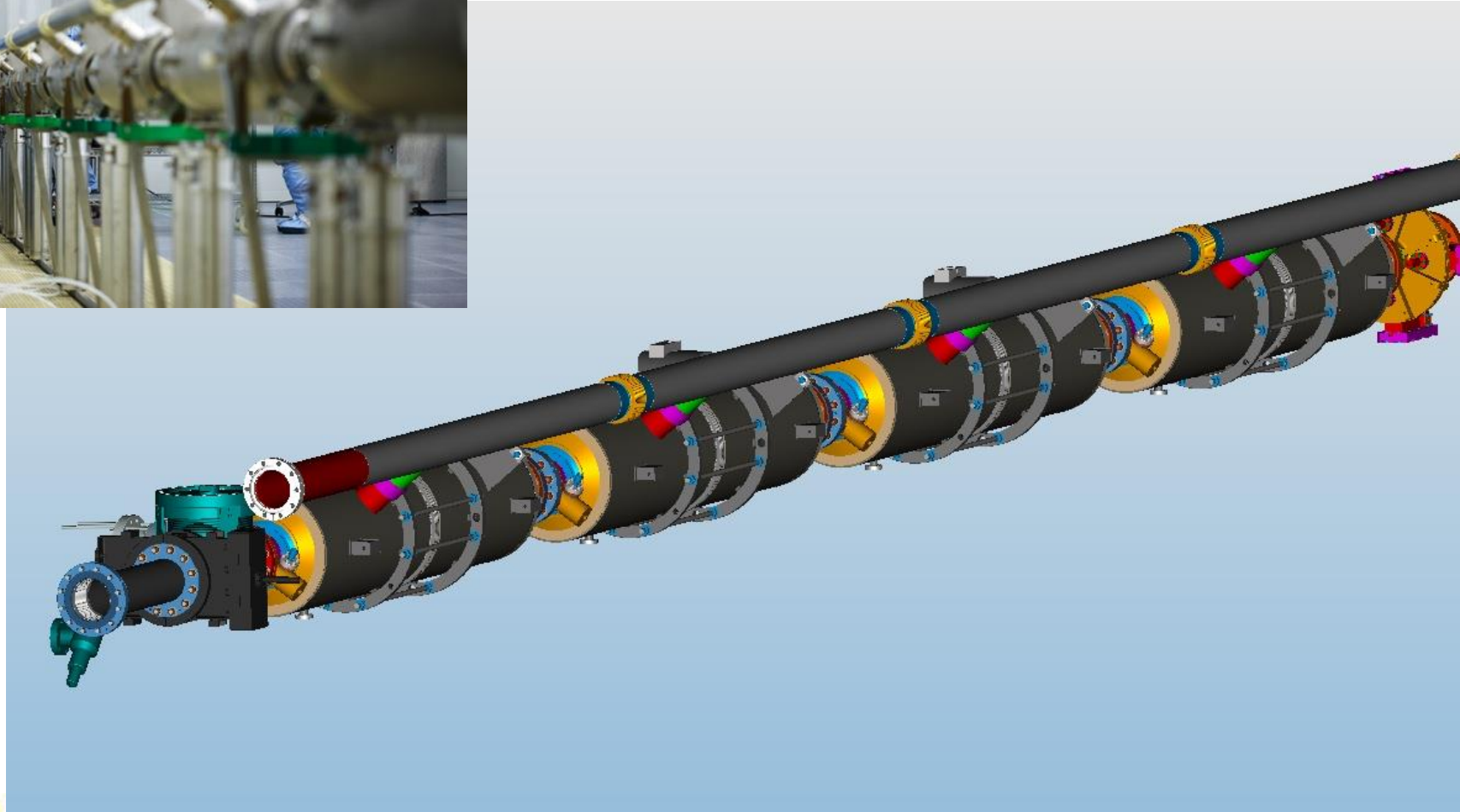


ILC Summer School - SC



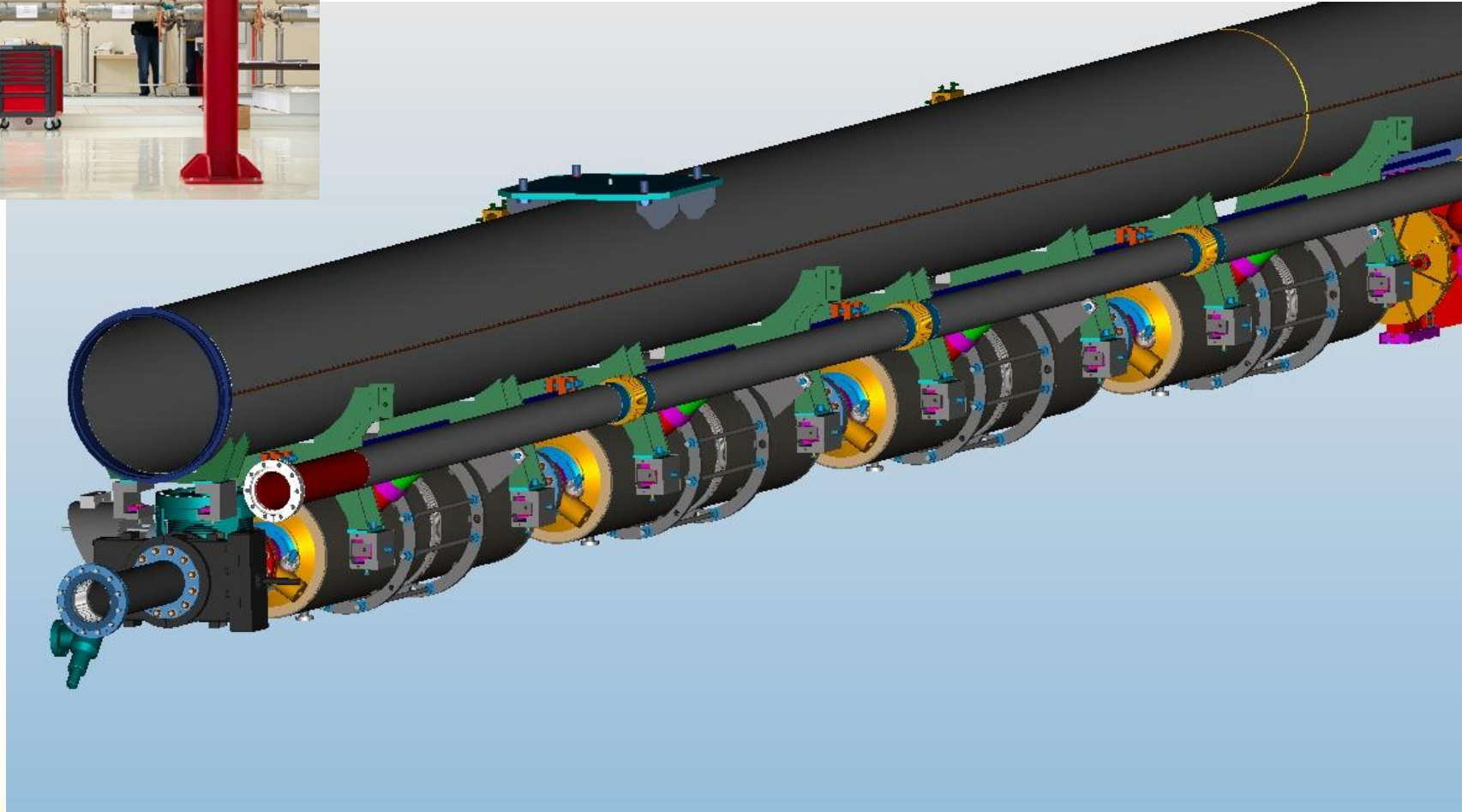
Cavity Package

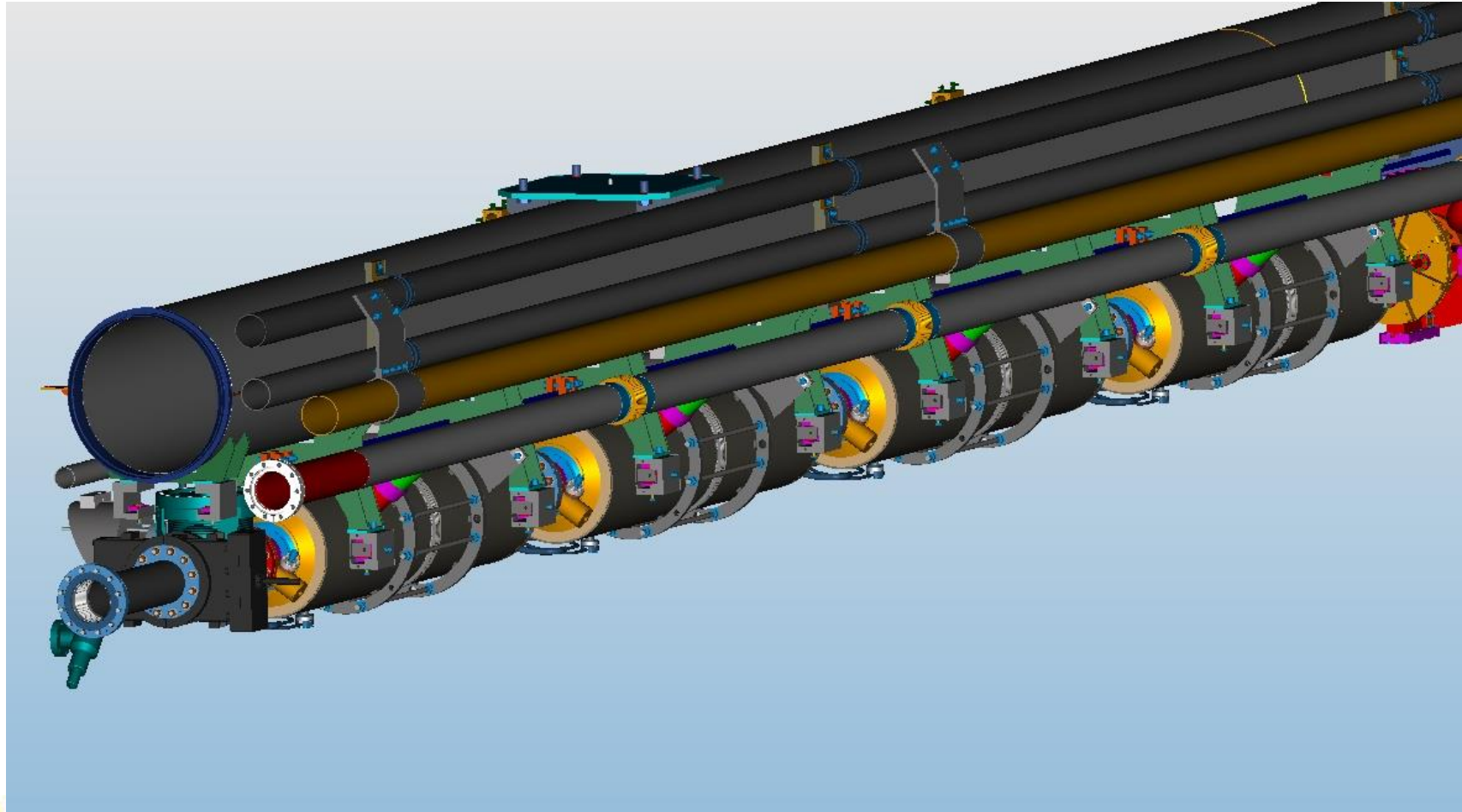






Mounted to Gas Return Pipe







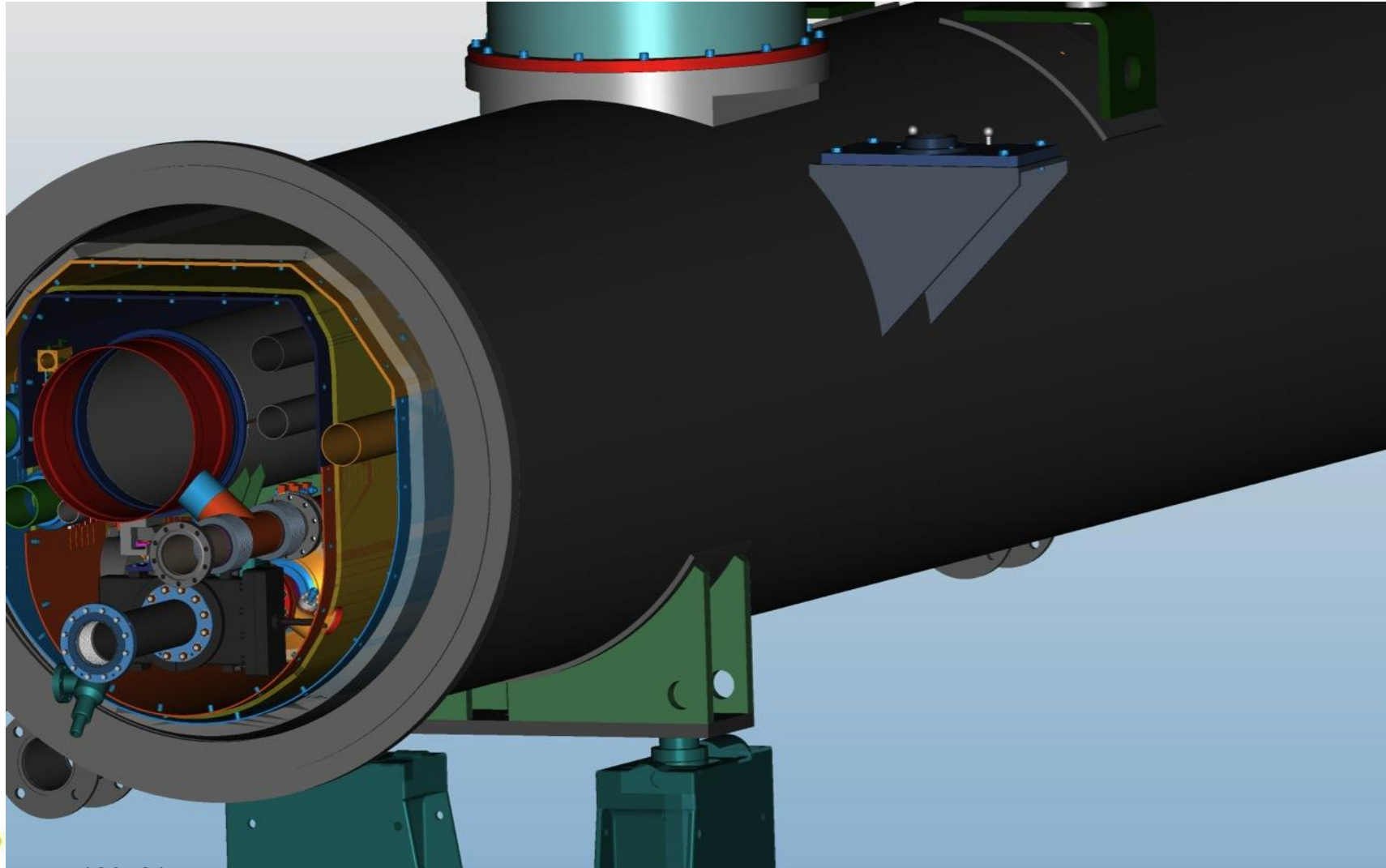
5K and 70K Thermal Shields

and insulation





Insertion into outer vacuum vessel





Complete Cryomodule



FNAL CM1 in NML



Global Cooperation for ILC Accelerator Beam Demonstration

TTF/FLASH (DESY) ~1 GeV
ILC-like beam ILC RF unit
(* lower gradient)



DESY



INFN Frascati



DAFNE (INFN Frascati)
kicker development
electron cloud

A. Yamamoto, 130721

STF (KEK) operation/construction
ILC Cryomodule test: S1-Global
Quantum Beam experiment



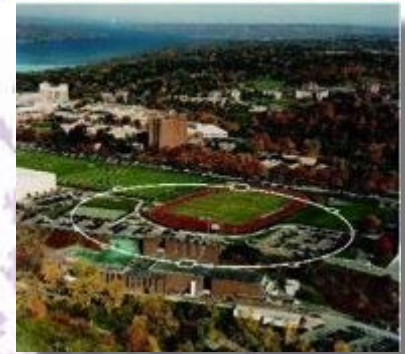
KEK, Japan



ATF & ATF2 (KEK)
ultra-low emittance
Final Focus optics

KEKB electron-cloud

ILC Summer School - SCRF



CesrTA (Cornell)
electron cloud
low emittance

FNAL



Cornell



NML facility ILC RF unit test
Under construction



SCRF Beam Acceleration

ILC requirement: 5.8 mA, 1 ms: realized t DESY, KEK

DESY: FLASH

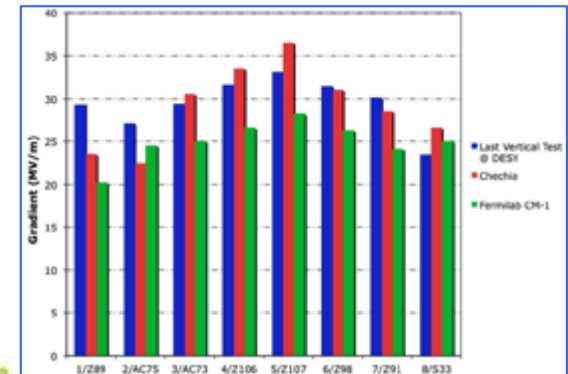
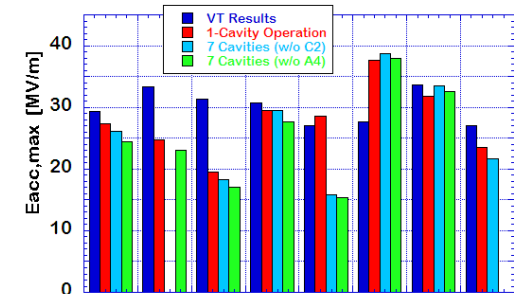
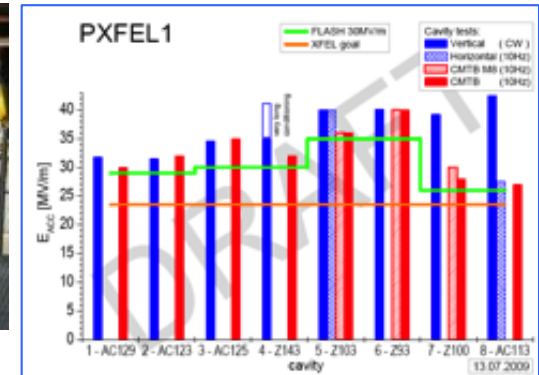
- SRF-CM string + Beam,
 - ACC7/PXFEL1 < 32 MV/m >
- 9 mA beam, 2009
- 800 μ s, 4.5mA beam, 2012

KEK: STF

- S1-Global: complete, 2010
 - Cavity string : < 26 MV/m>
- Quantum Beam : 6.7 mA, 1 ms,
- CM1 & beam, 2014 ~2015

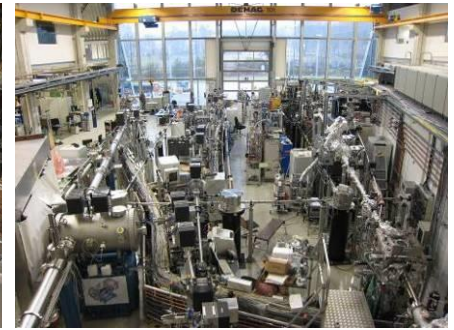
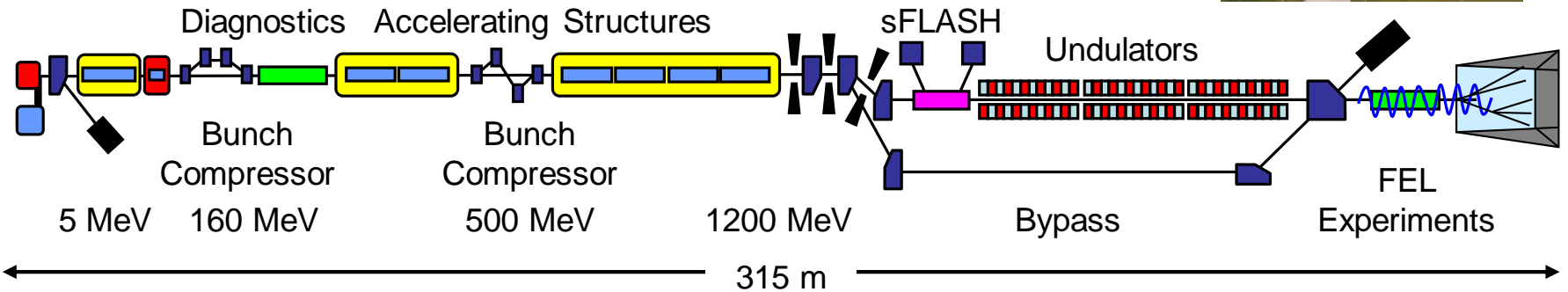
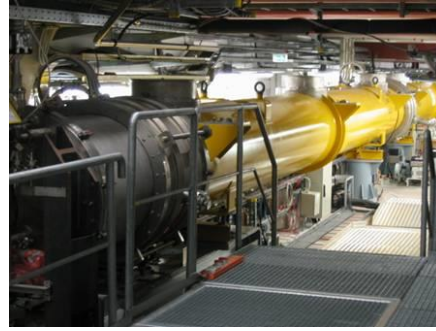
FNAL: NML/ASTA

- CM1 test complete
- CM2 operation, in 2013
- CM2 + Beam, 2013 ~ 2014



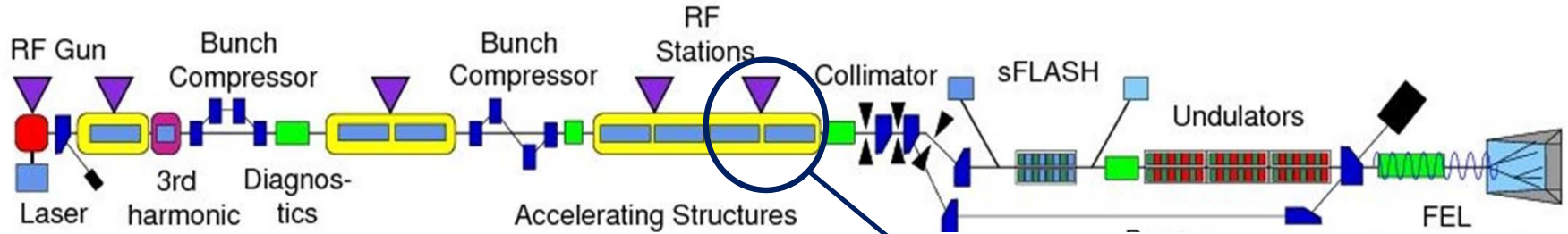


FLASH layout

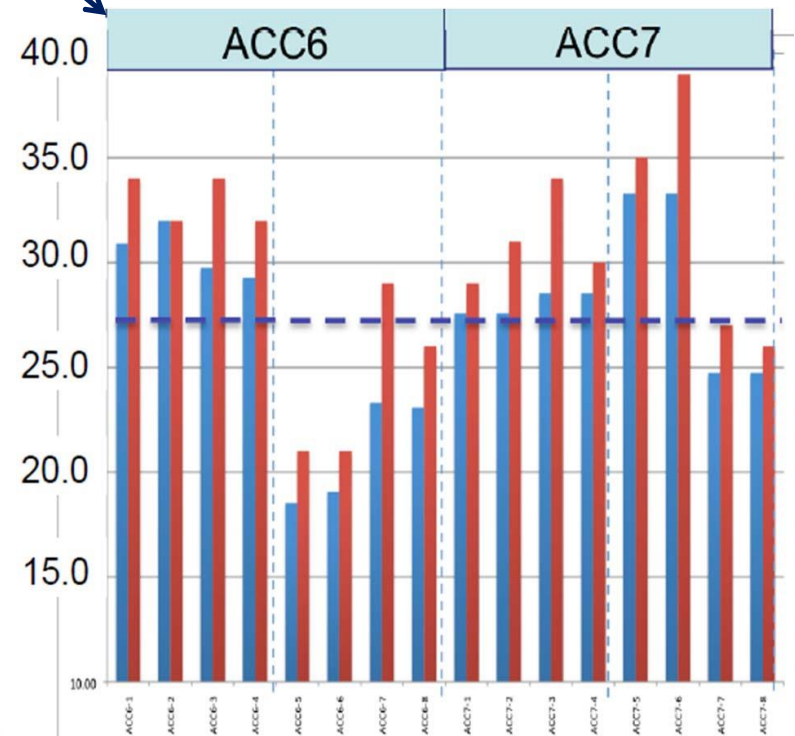




TTF/FLASH layout 9mA Experiment



		XFEL	ILC	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200*	2400
Pulse length	μ s	650	970	800	800
Current	mA	5	9	9	9



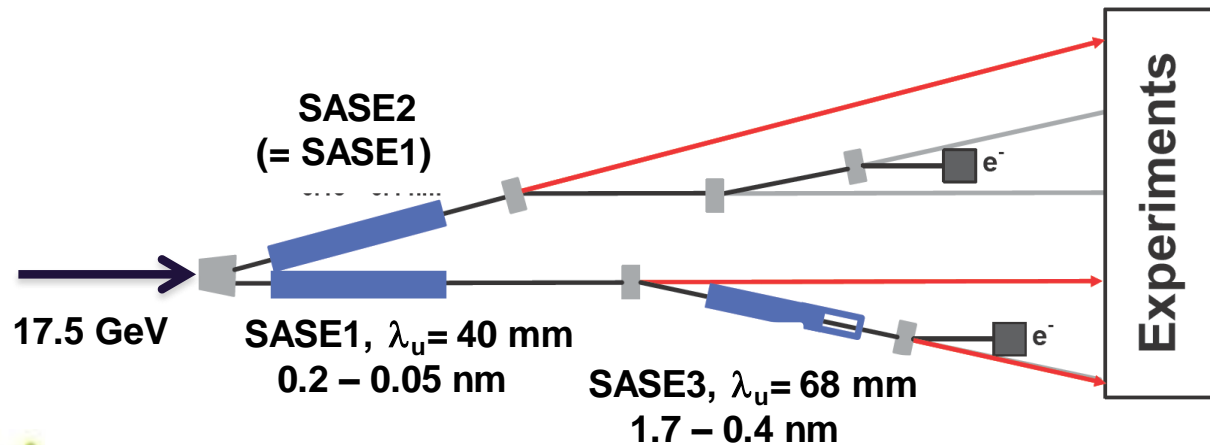
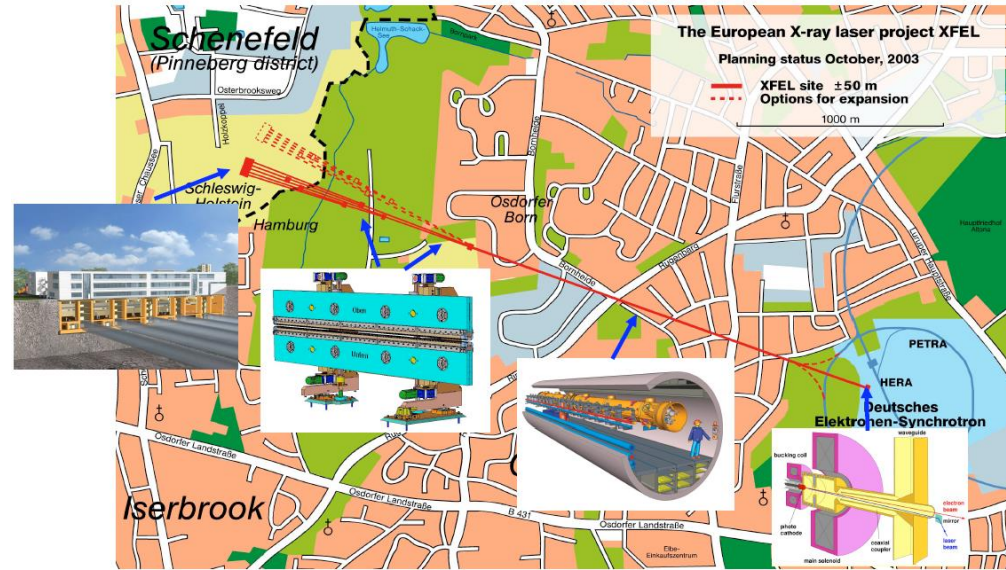
The European XFEL

Some specifications

- Photon energy 0.3-24 keV
- Pulse duration ~ 10-100 fs
- Pulse energy few mJ
- Superconducting linac. 17.5 GeV
- 10 Hz (27 000 b/s)
- 5 beamlines / 10 instruments
 - **Start version with 3 beamlines and 6 instruments**
- Several extensions possible:
 - More undulators
 - More instruments
 -
 - **Variable polarization**
 - **Self-Seeding**
 - **CW operation**

First beam late 2015

← 3.4km →





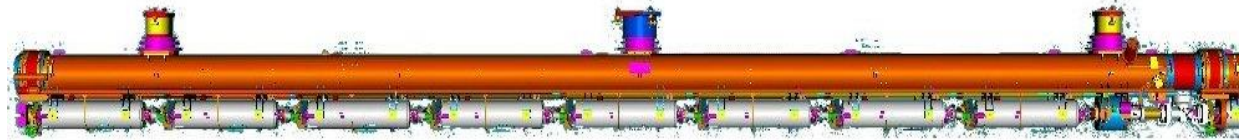
- Three construction sites
- 5.8 km tunnels
- 12000 m² surface are buildings
- 150000 m³ of underground building volume





Accelerator Complex

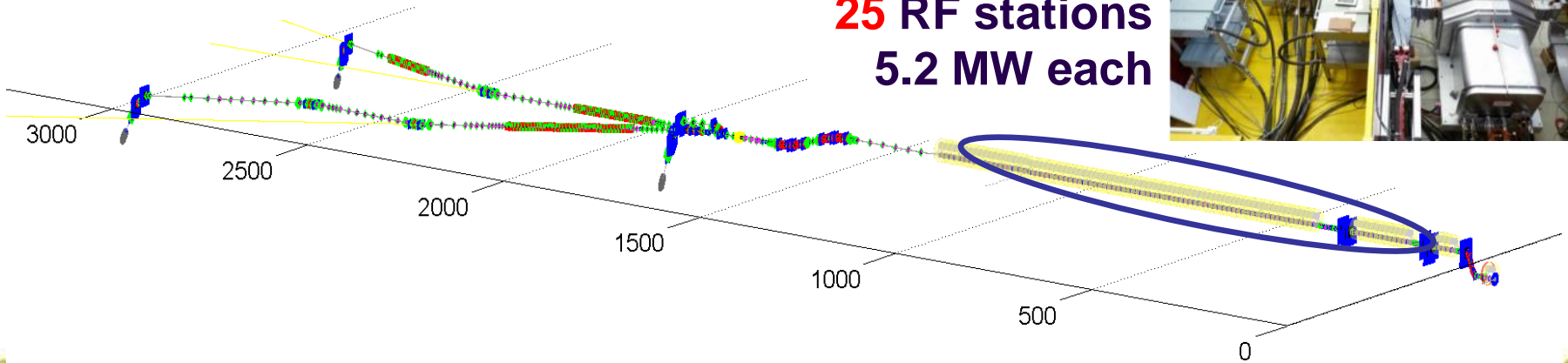
100 accelerator
modules



800 accelerating cavities
1.3 GHz / **23.6** MV/m



25 RF stations
5.2 MW each



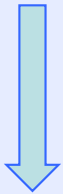


ILC Time Line

1980' ~ Basic Research and Design Study

2005 2006 2007 2008 2009 2010 2011 2012 2013

2004



ILC-GDE

LCC

Ref. Design (RDR)

Tech. Design: TDP1

TDP 2



LHC

Higgs particle discovery

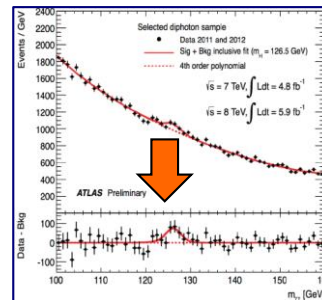
TDR completion



International Technology Recommendation Panel Meeting August 11 ~ 13, 2004, Republic of Korea



Selection of SC Technology

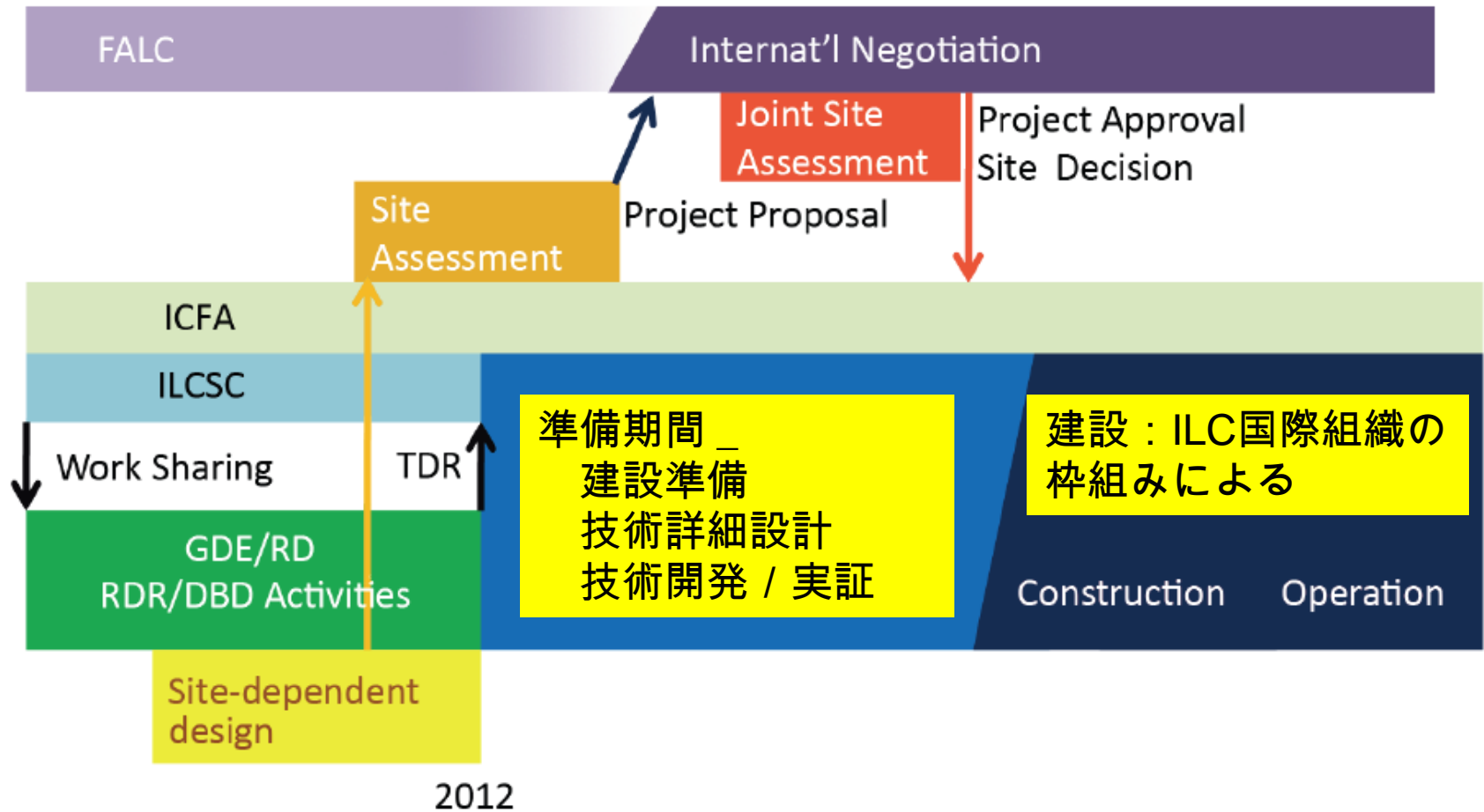


126 GeV



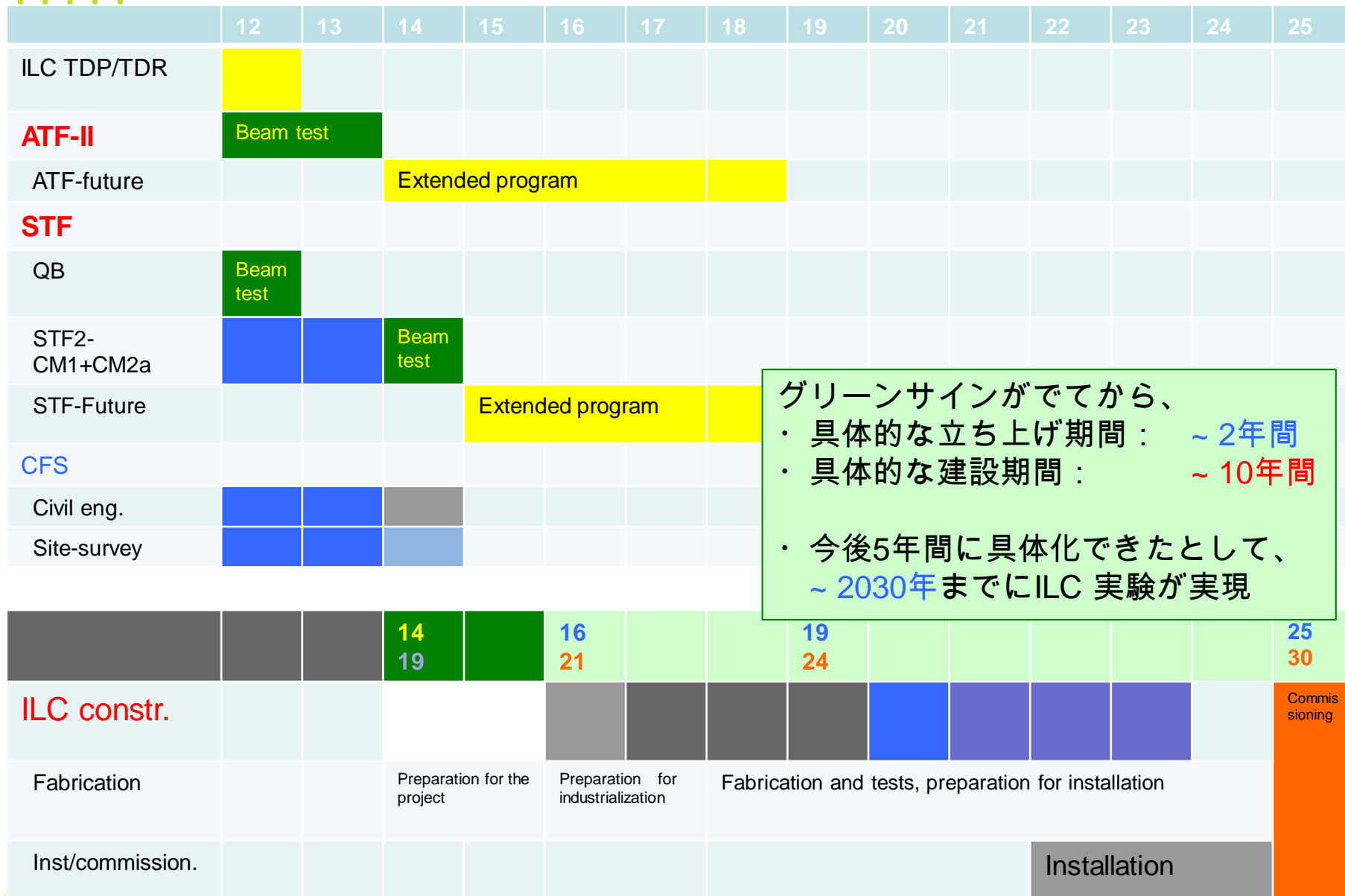


ILC ロードマップ (これから)





ILC 具体化に必要な時間スケール



まとめ

- ILC に求められる超伝導加速器技術は、計画を実現できるレベルに到達
- 工業化技術（性能／コスト）を高めることが不可欠
 - リスクの低減、健全な競争
 - 日本／KEK で（手本となる）製造技術の確立
 - LHC, JPARCへの超伝導磁石への取り組み経験！
 - ーー>超伝導は性能を高め、建設費も運転費も節約できる技術！
- 国際協力による役割分担の構築が急務

