Advances in Applied Superconductivity leading Frontiers of particle accelerators and physics

Akira Yamamoto (KEK/CERN)

A Seminar at LAL, 21 Oct., 2016

Acknowledgments

- I would thank
  - M. Benedikt, L. Bottura and H. ten Kate of CERN, for their presentations at ASC2016 (Denver) referred here.

  - N. Ohuchi, K. Sasaki, M. Yoshida, T. Tomaru of KEK for their personal information,

- to prepare for this presentation.

Outline

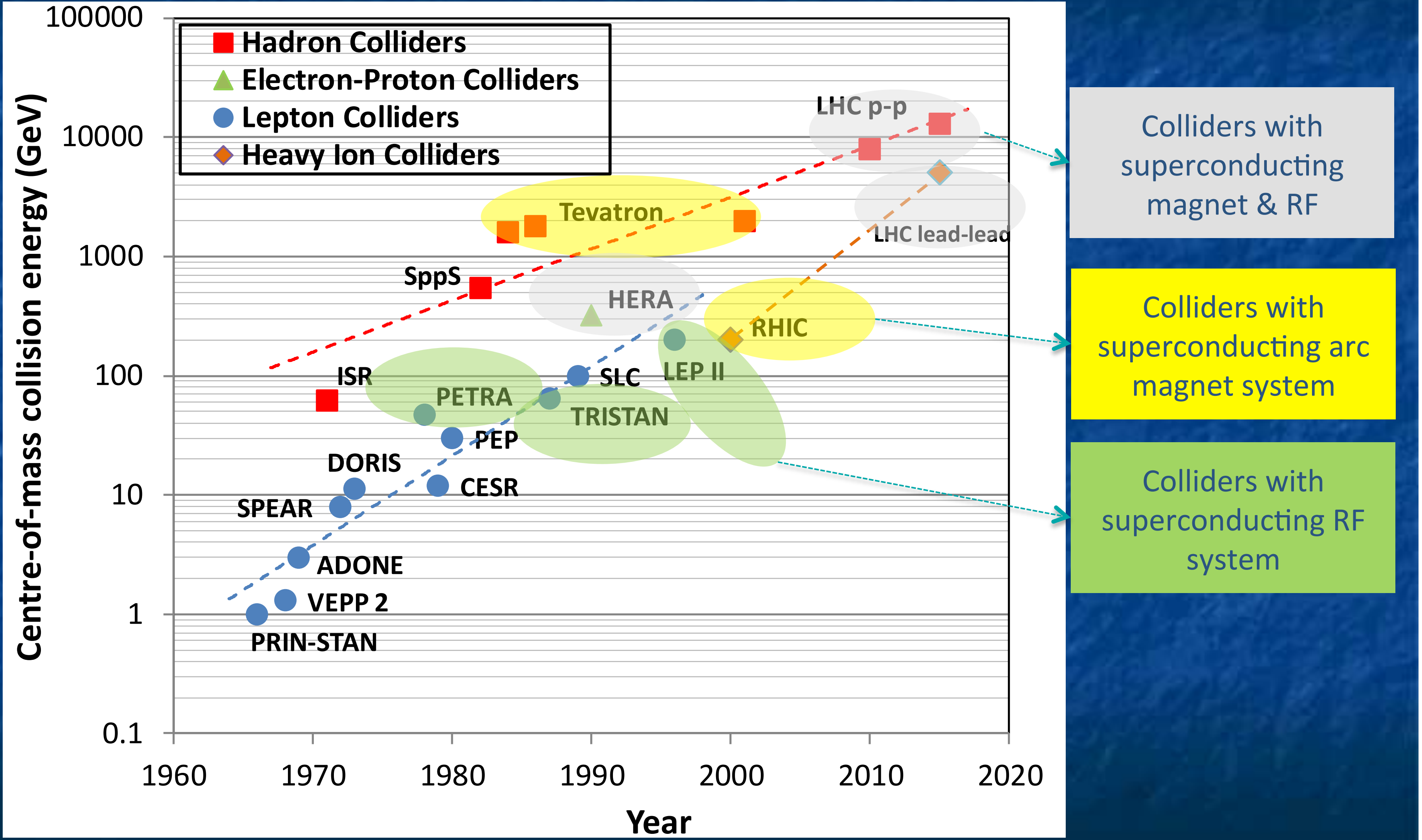
- Introduction
- Advances in particle accelerators
  - Superconducting magnets and SRF

- Advances in particle detectors
  - Solenoid magnets in collider detectors
  - A unique application for scientific ballooning

- Recent advances in Japan

Progress in Collider Accelerators Constructed and Operated

M. Benedikt



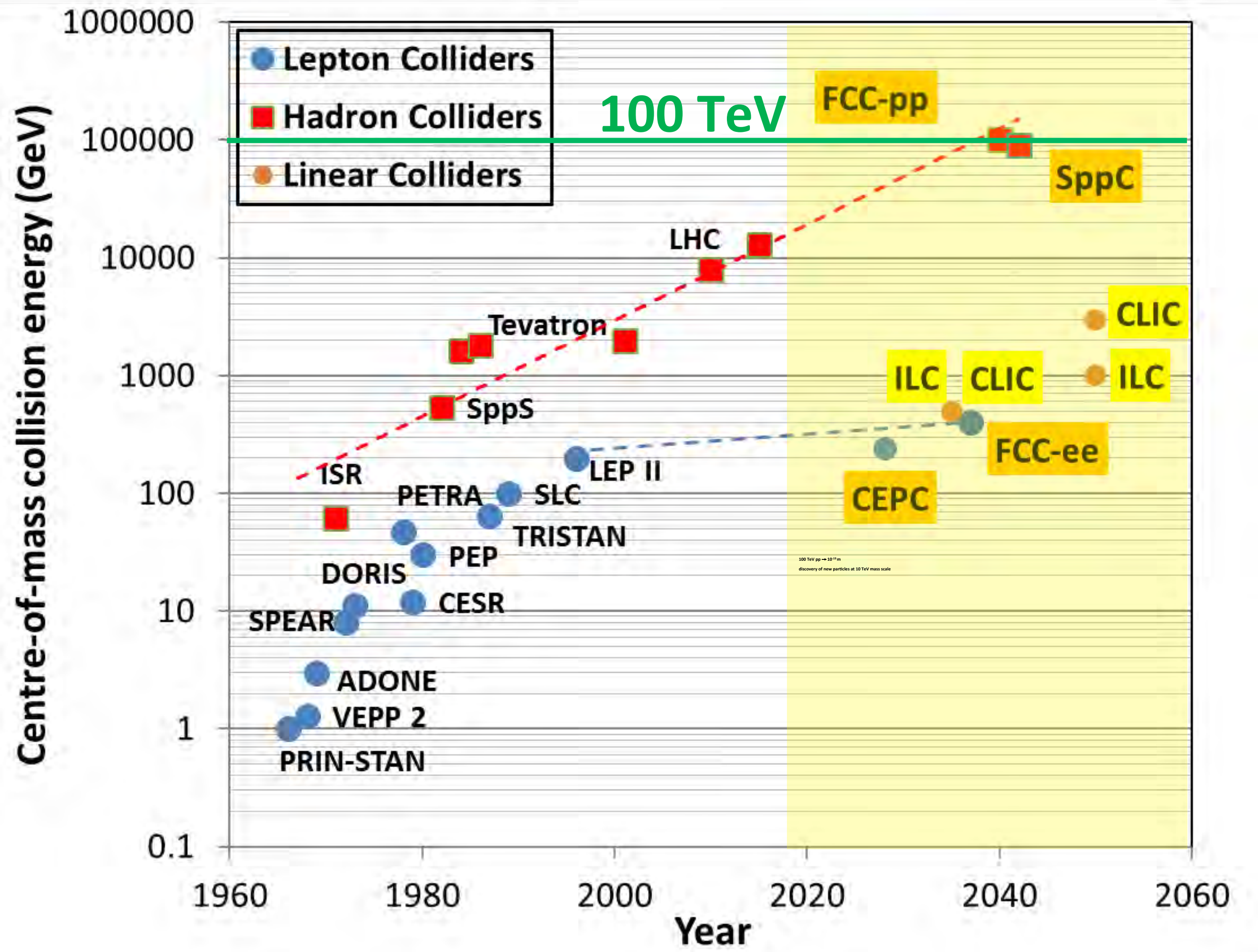
Colliders with superconducting magnet & RF

Colliders with superconducting arc magnet system

Colliders with superconducting RF system

M. Benedikt

High Energy Colliders under study



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    - Superconducting magnets and SRF
- Advances in particle detectors
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    - A unique application for scientific ballooning
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Progress in Particle (Hadron) Accelerators based on Superconducting Magnet Technology

Location	Accelerator (proton)	Energy [TeV]	B Field [T]	Operation
Fermilab	Tevatron	2 x 0.9	4.0	1983-2011
DESY	HERA	0.82	4.68	1990-2007
BNL	RHIC	2 x 0.1	3.46	2000 -
CERN	LHC	2 x 7	8.36	2009 -
CERN	HL/HE-LHC, FCC	2 x 14 2 x 50	16 16	Study

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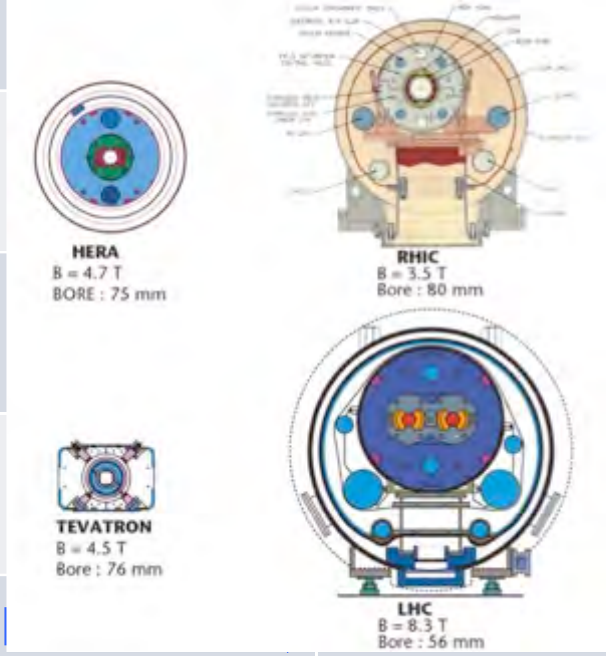
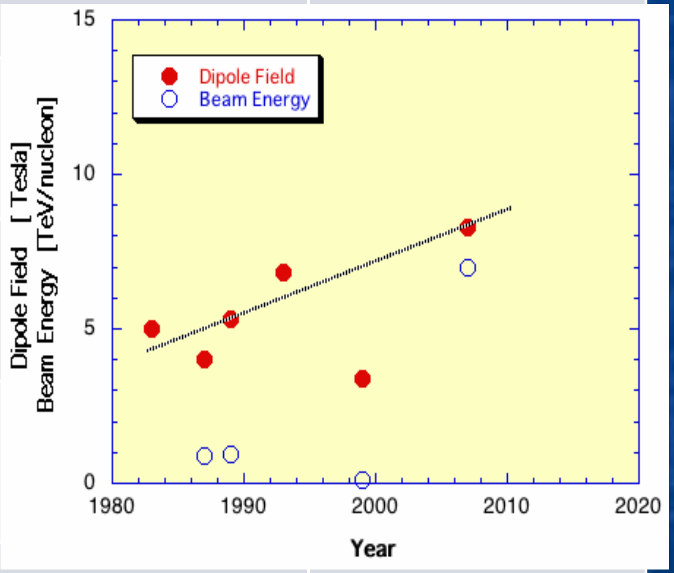
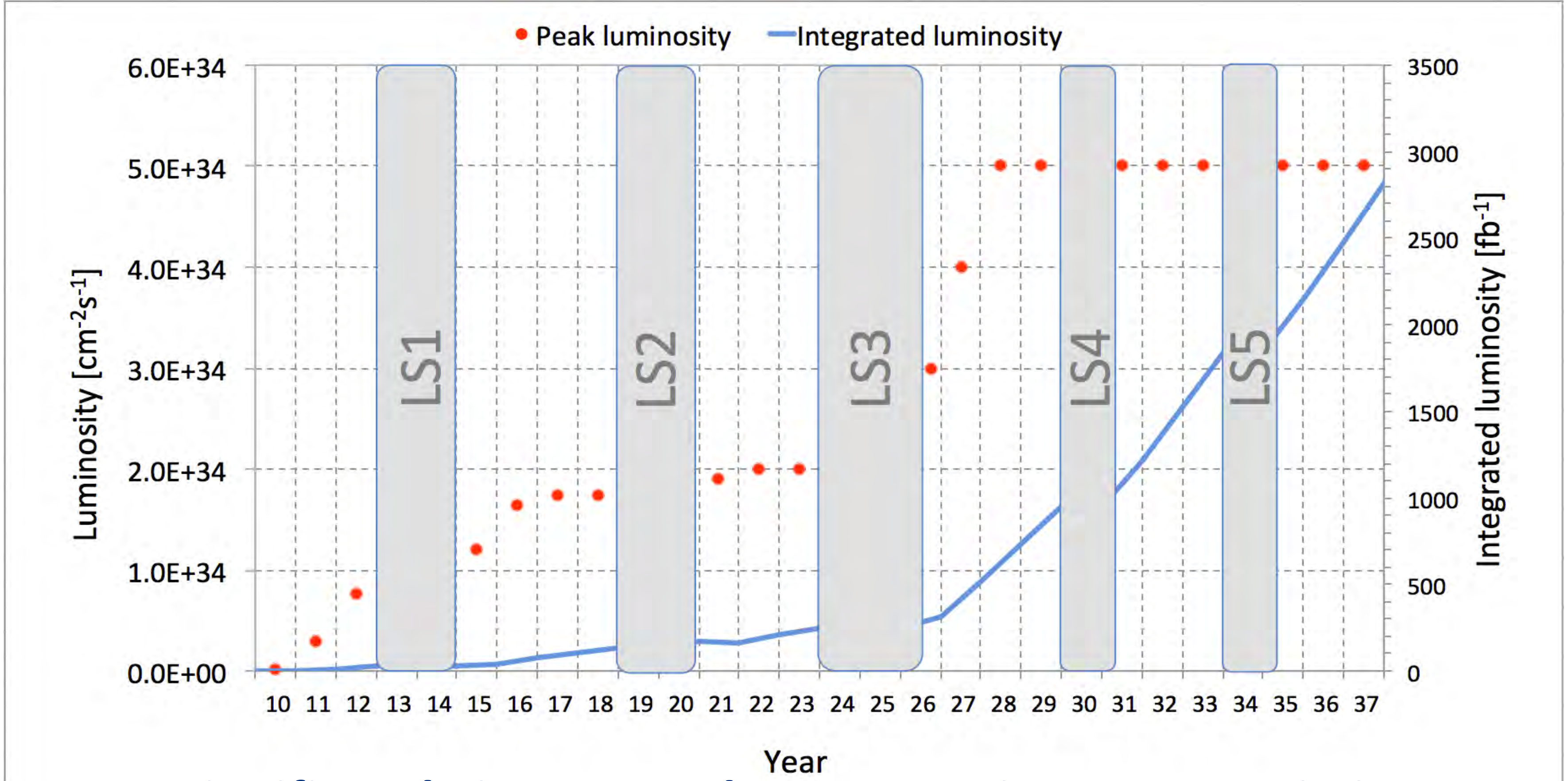
CERN				
CERN	FCC	2 x 50	16 16	Study





L. Rossi

Step 1: HL-LHC upgrade – ongoing

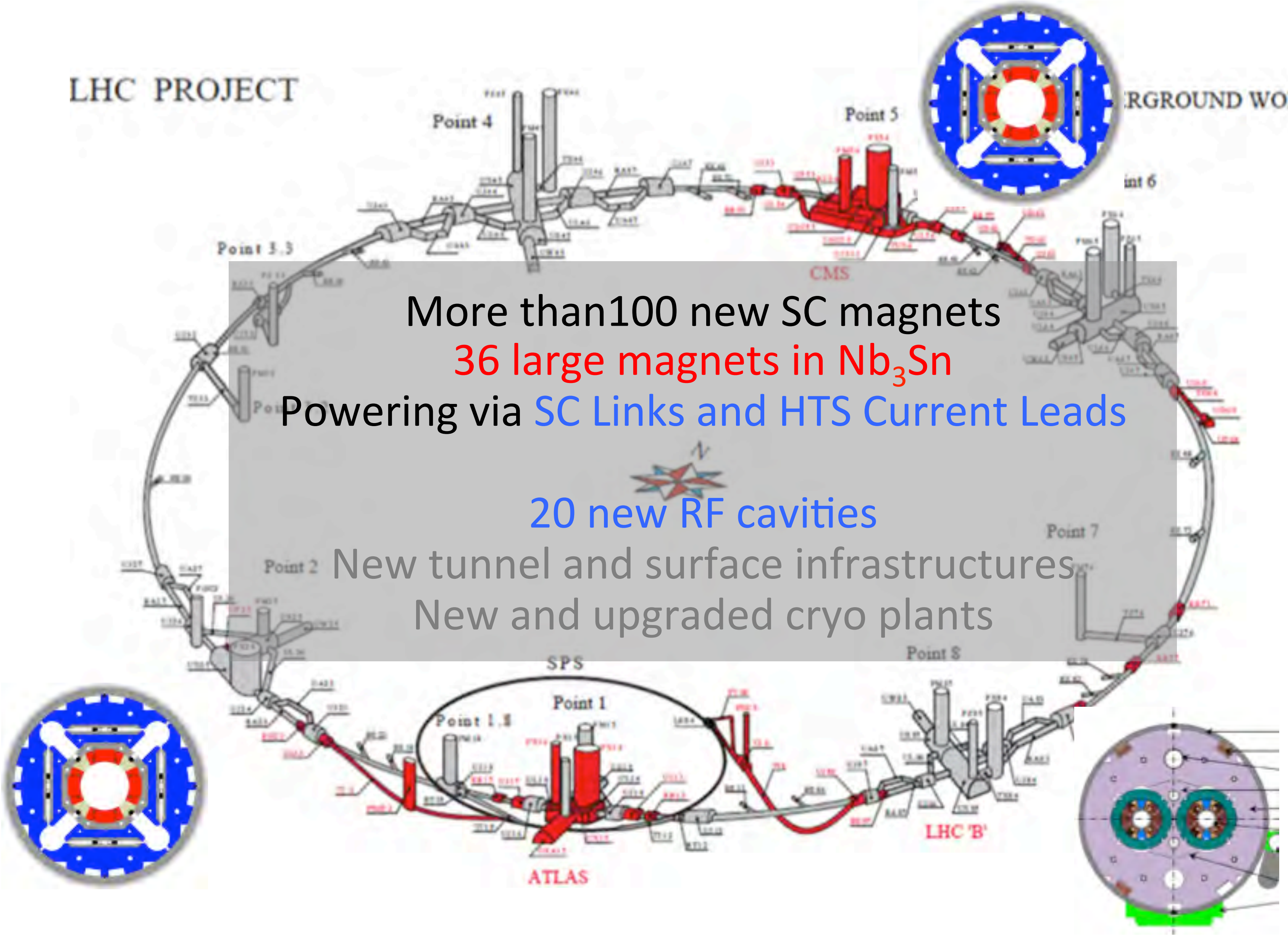


HL-LHC significantly increases data rate to improve statistics, measurement precision, and energy reach in search of new physics

Gain of a factor 5 in rate, factor 10 in integral data wrt initial design

L. Rossi

High Luminosity LHC project scope



More than100 new SC magnets

36 large magnets in Nb_3Sn

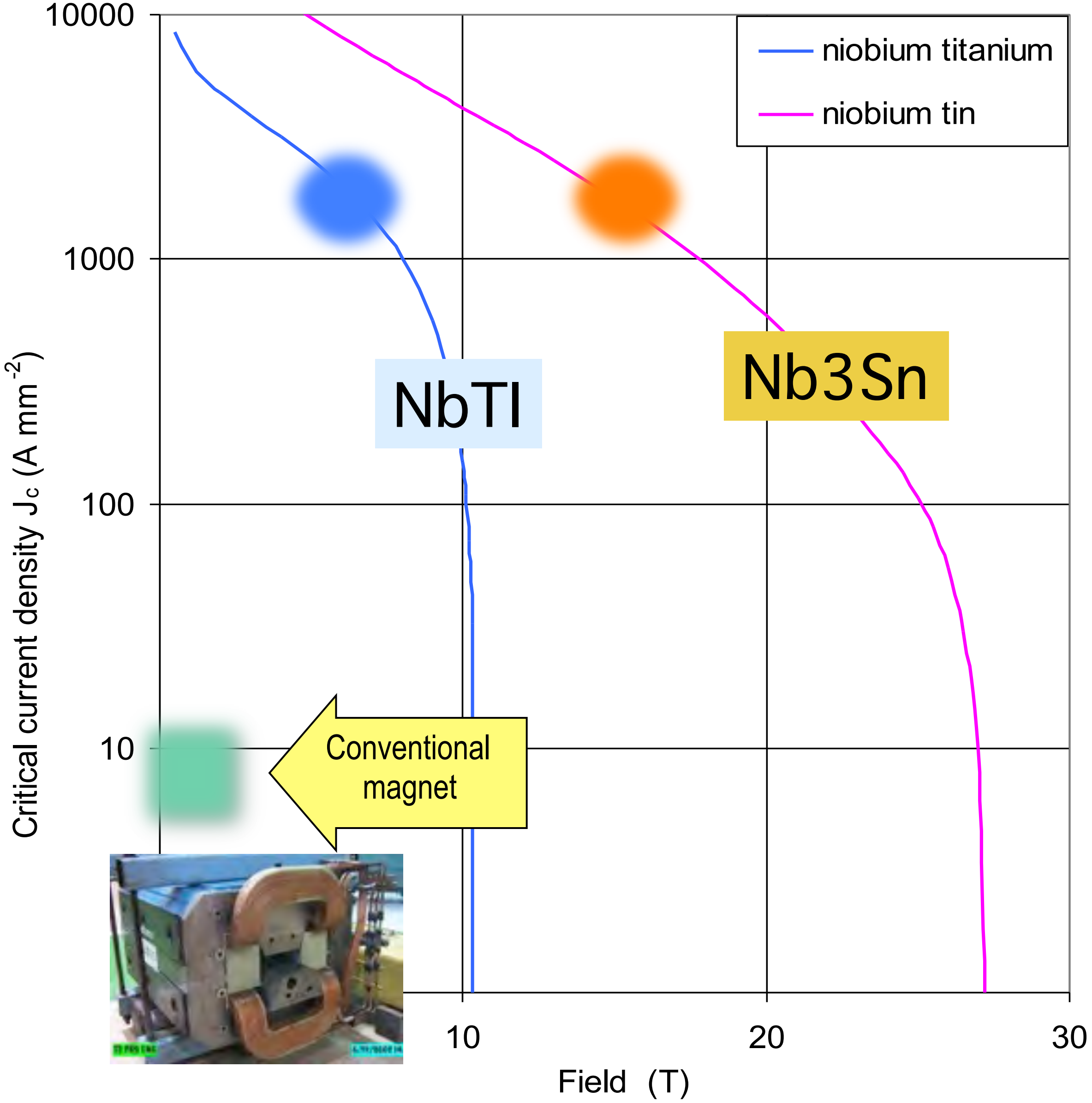
Powering via SC Links and HTS Current Leads

20 new RF cavities

New tunnel and surface infrastructures

New and upgraded cryo plants

Superconductor performance at 4.2 K



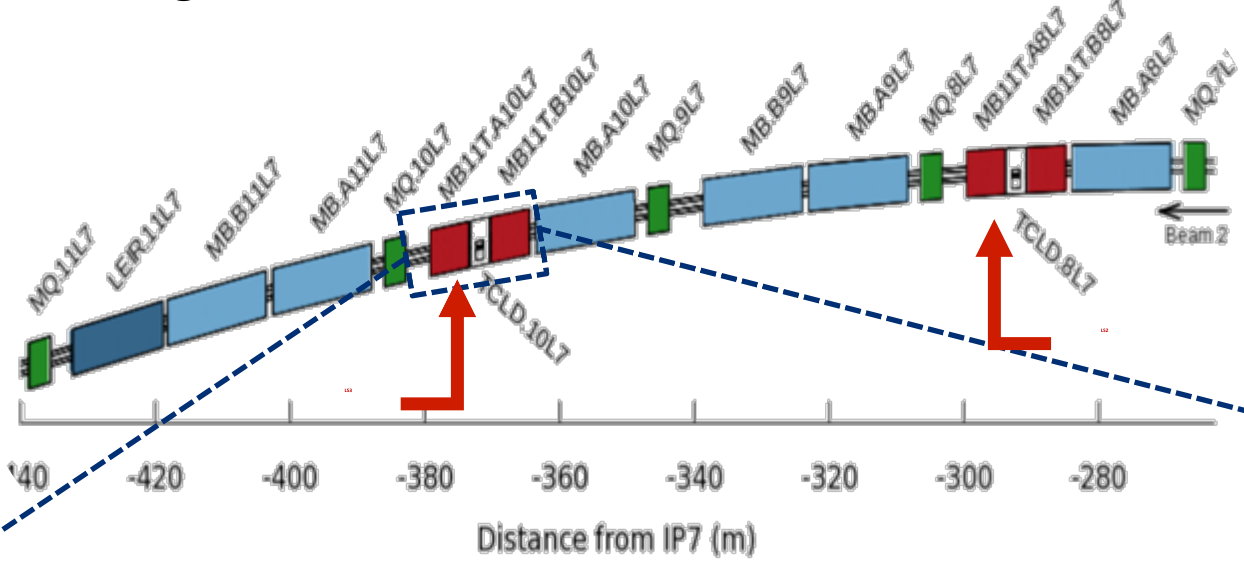
- magnets usually work in boiling liquid helium, so the critical surface is often represented by a curve of current versus field at 4.2K
- niobium tin Nb$_3$Sn has a much higher performance than NbTi
- **but** Nb$_3$Sn is a brittle intermetallic compound with poor mechanical properties

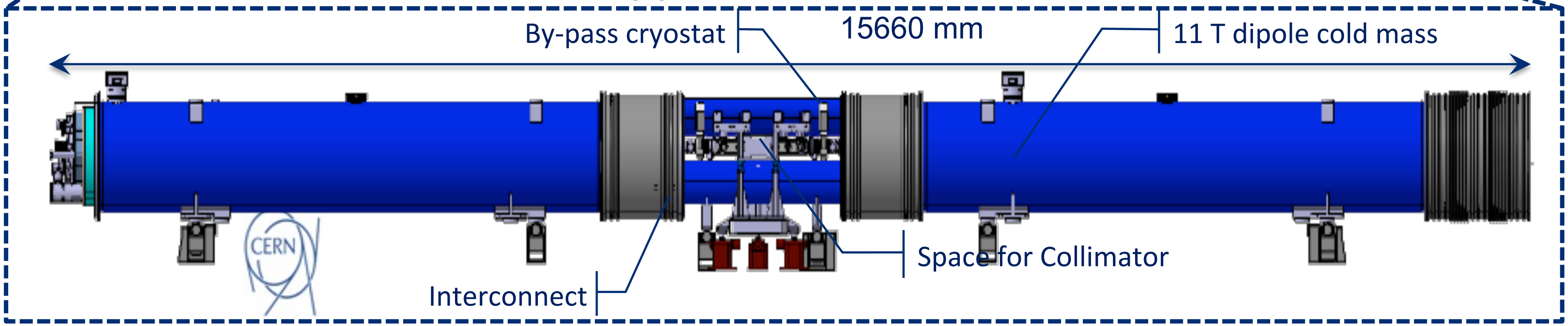
- both the field and current density of both superconductors are way above the capability of conventional electromagnets

F. Savary

11T dipole in HL-LHC

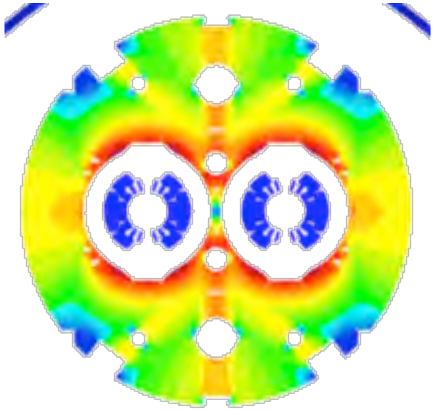
- **Create space in the dispersion suppressor regions of LHC, to install additional collimators** needed to cope with beam intensities larger than nominal
- Replace a standard Main Dipole by a **pair of 11T Dipoles producing the same integrated field of 119 T·m at 11.85 kA**

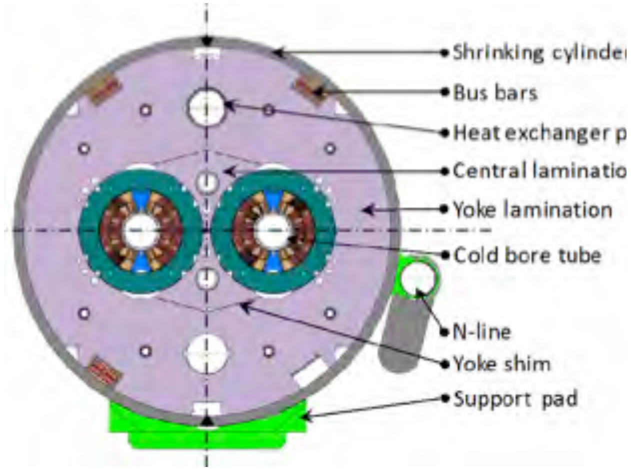


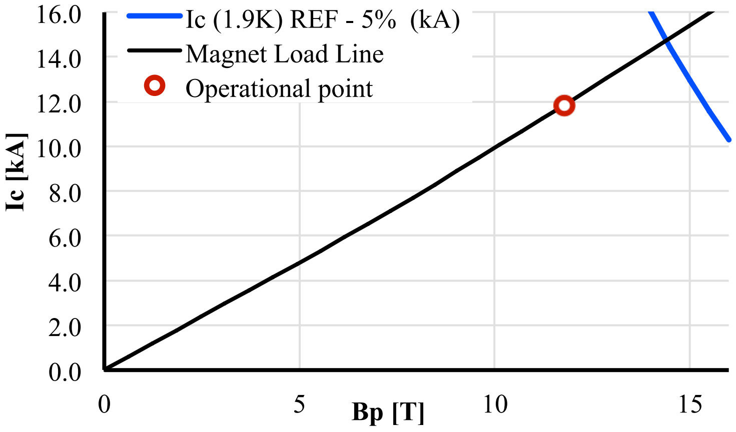


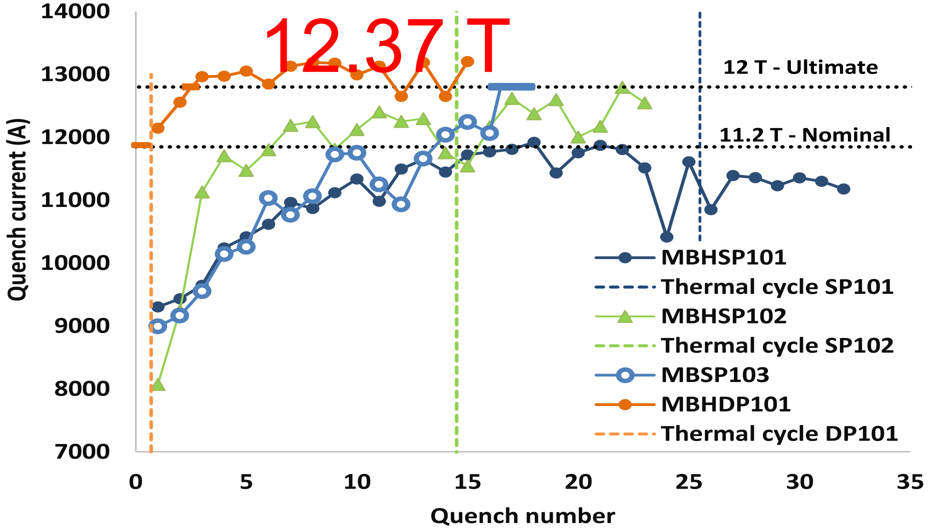
F. Savary

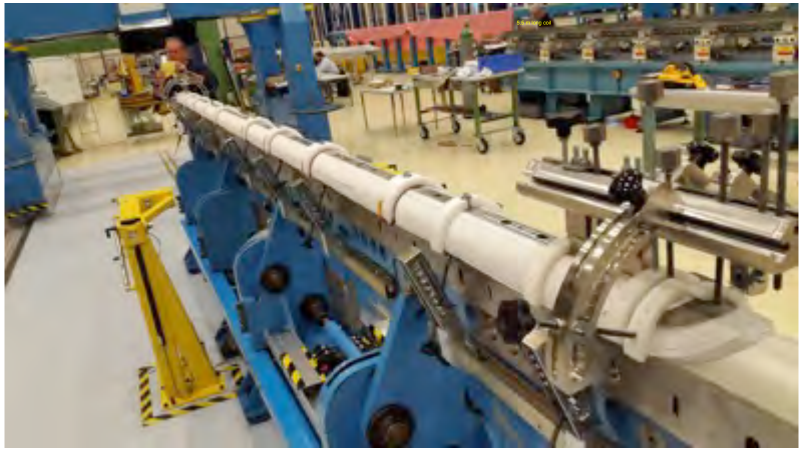
MBH (11T) dipole





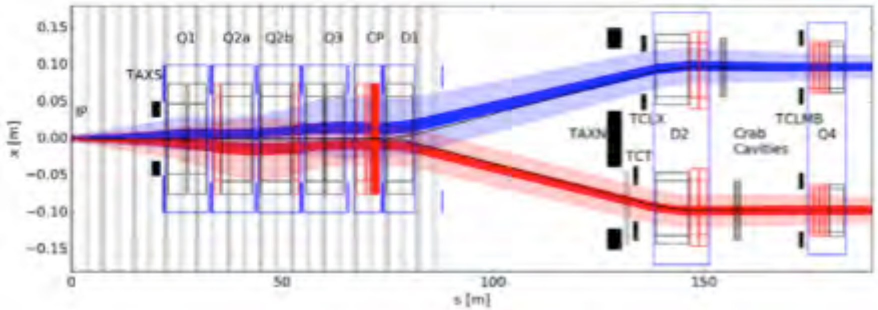


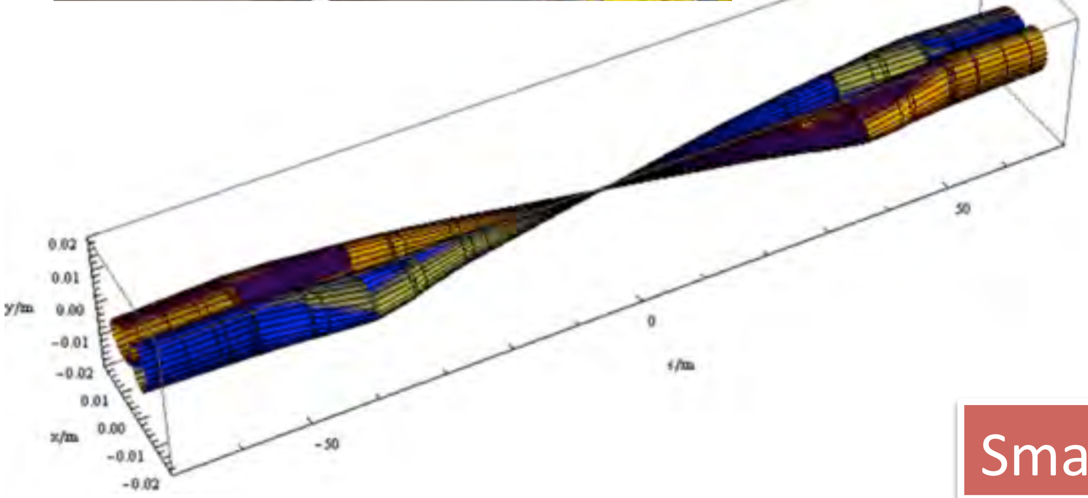


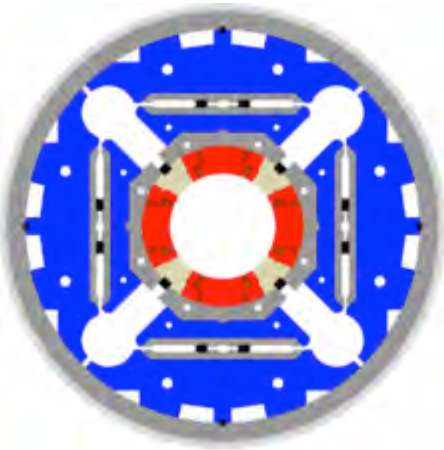


By courtesy of F. Savary (CERN)

Reducing beam-size at IP with Large Aperture Quadrupoles

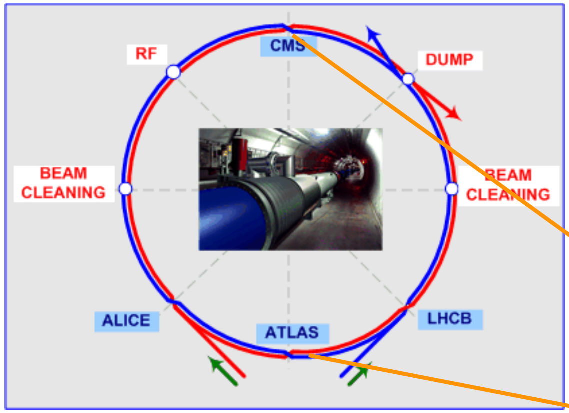


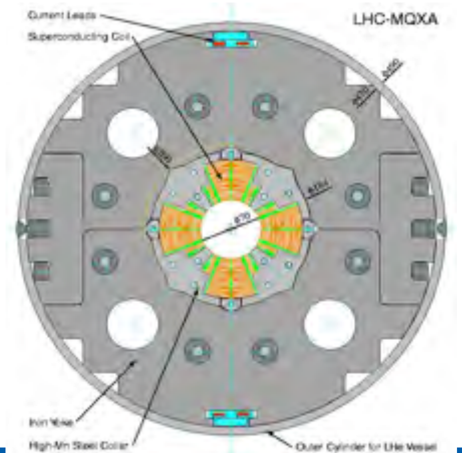




Smaller β^* $\Rightarrow$ larger IT aperture

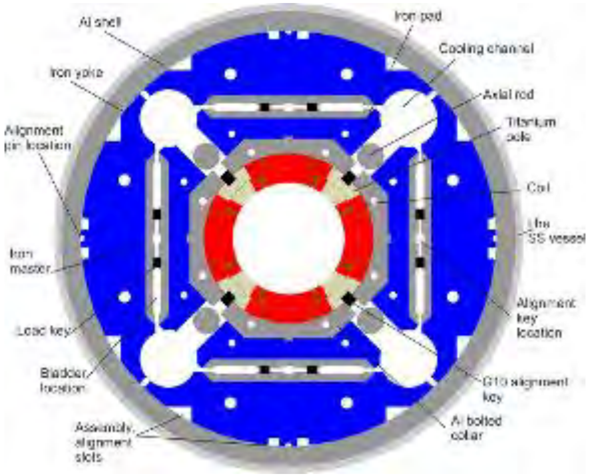
LHC IR Quadruple with KEK-Fermilab Collaboration to be replaced

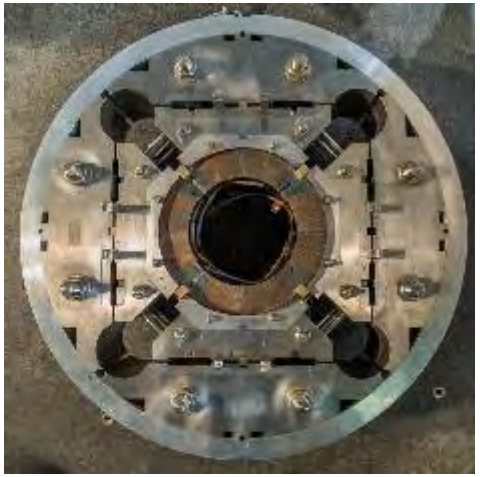


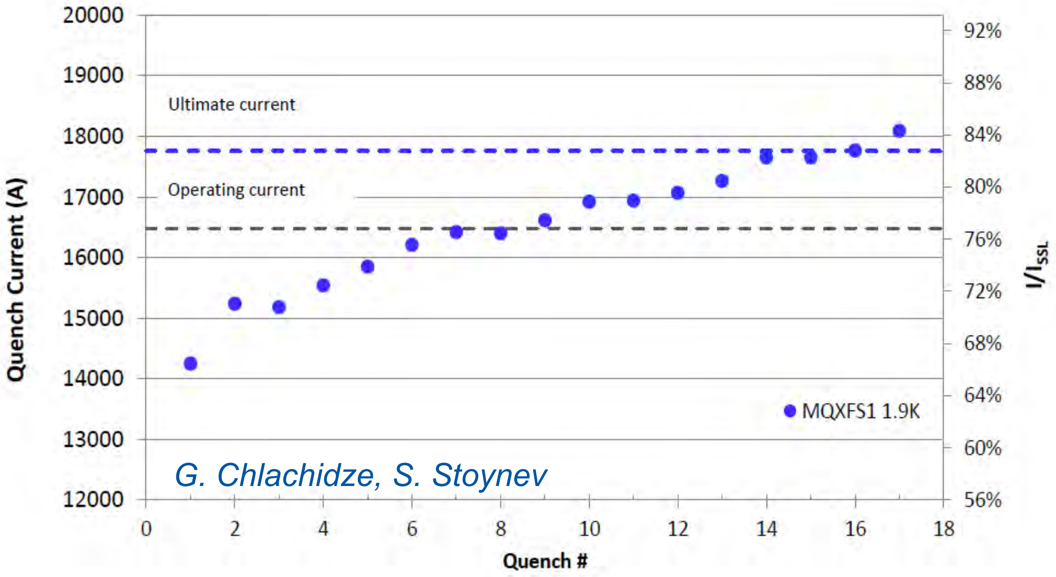


MQXF quadrupole

G. Ambrosio (FNAL),
P. Ferracin (CERN)

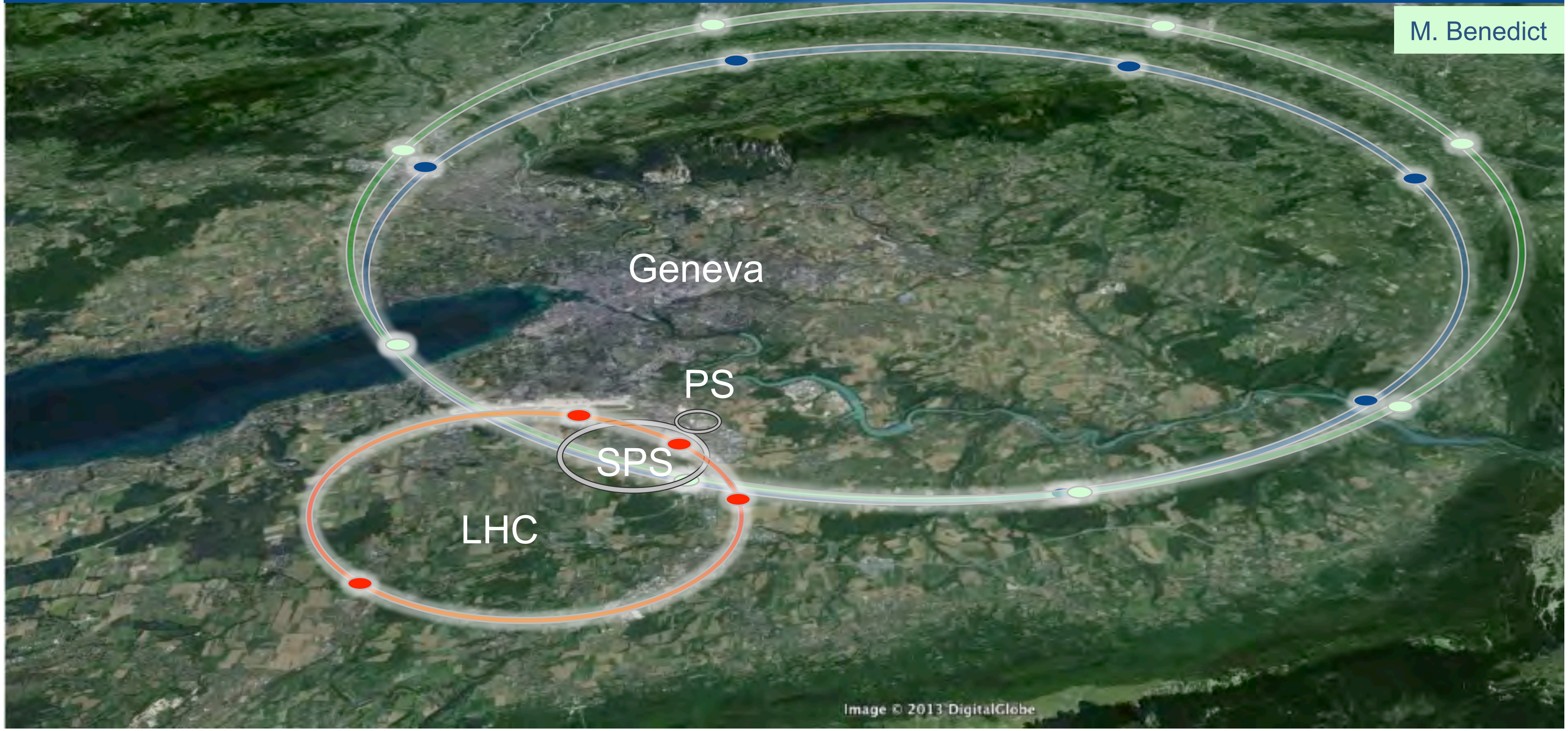






G. Chlachidze, S. Stoynev

FCC SC main magnet options and requirements



LHC	**HE-LHC baseline**	**FCC-hh baseline**	FCC-hh
27 km, 8.33 T	**27 km, 16 T**	**100 km, 16 T**	80 km, **20 T**
14 TeV (c.o.m.)	26 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)
1300 tons NbTi	**2500 tons Nb$_3$Sn**	**10000 tons Nb$_3$Sn**	2000 tons HTS 8000 tons LTS

M. Benedikt

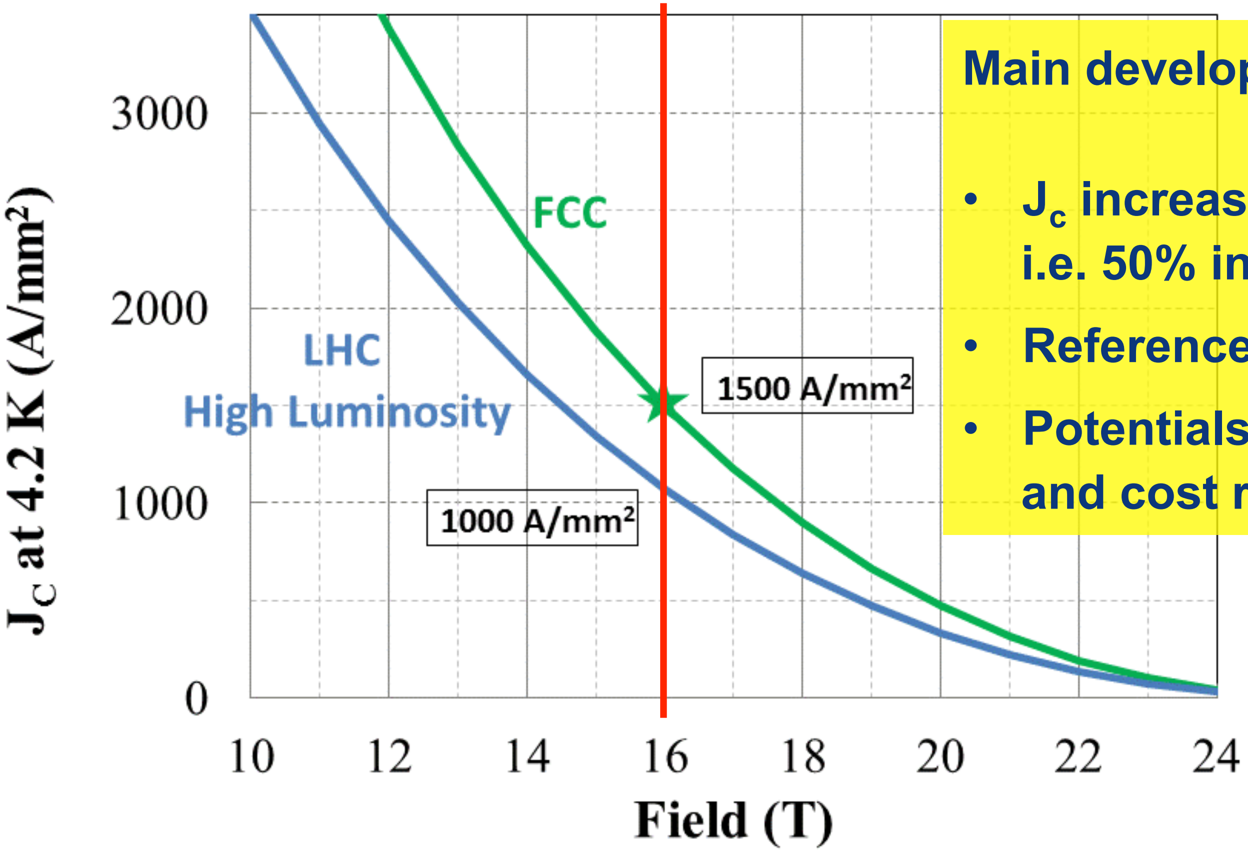
Hadron collider parameters

parameter	FCC-hh		HE-LHC*	(HL) LHC
collision energy cms [TeV]	100		>25	14
dipole field [T]	16		16	8.3
circumference [km]	100		27	27
# IP	2 main & 2		2 & 2	2 & 2
beam current [A]	0.5		1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25
beta* [m]	1.1	0.3	0.25	(0.15) 0.55
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	>25	(5) 1
events/bunch crossing	170	<1020 (204)	850	(135) 27
stored energy/beam [GJ]	8.4		1.2	(0.7) 0.36
synchrotron rad. [W/m/beam]	30		3.6	(0.35) 0.18

*tentative

Nb_3Sn conductor program

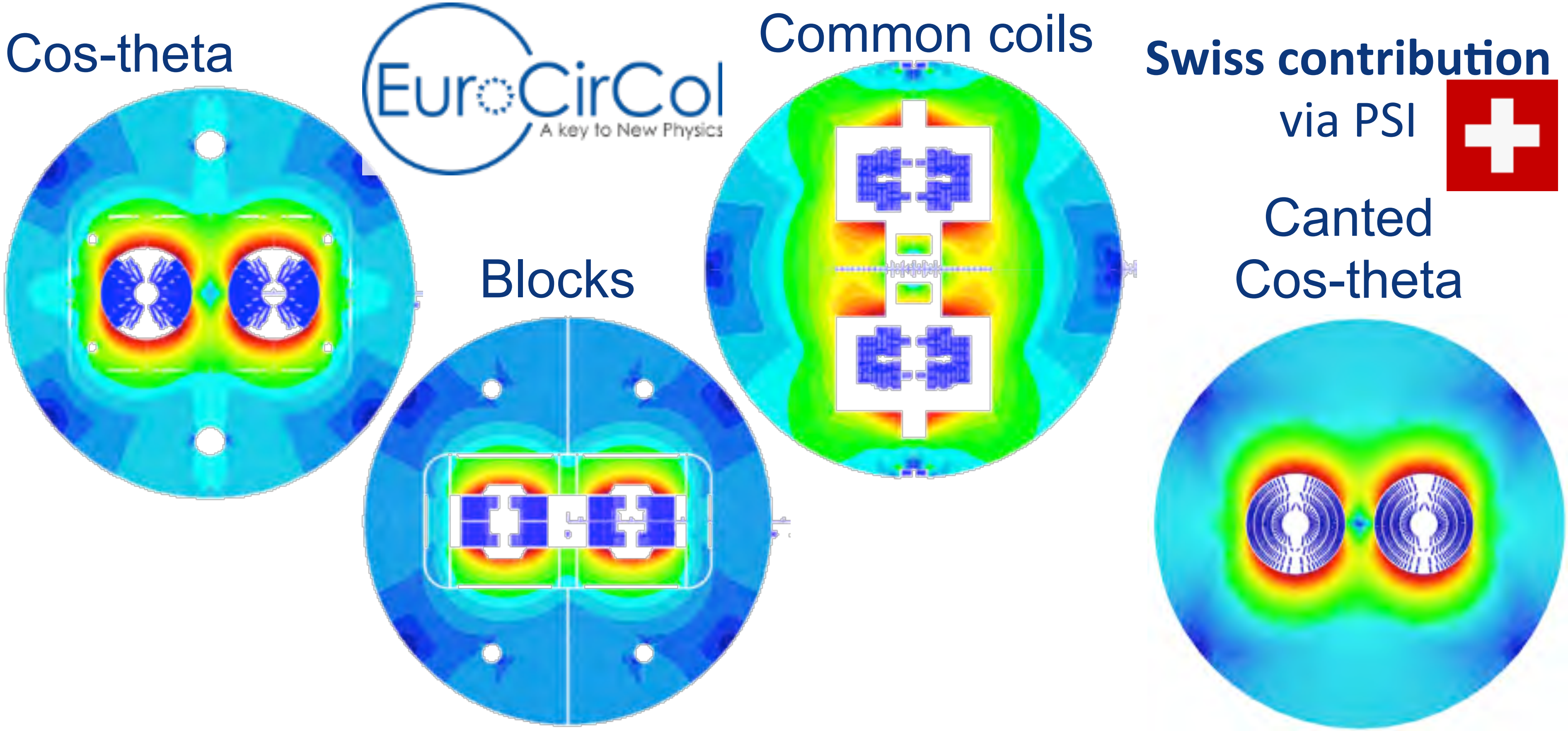
Nb_3Sn is one of the major cost & performance factors for FCC-hh and must be given highest attention



Main development goals until 2020:

- J_c increase (16T, 4.2K) > 1500 A/mm^2 i.e. 50% increase wrt HL-LHC wire
- Reference wire diameter 1 mm
- Potentials for large scale production and cost reduction

16 T dipole options under consideration



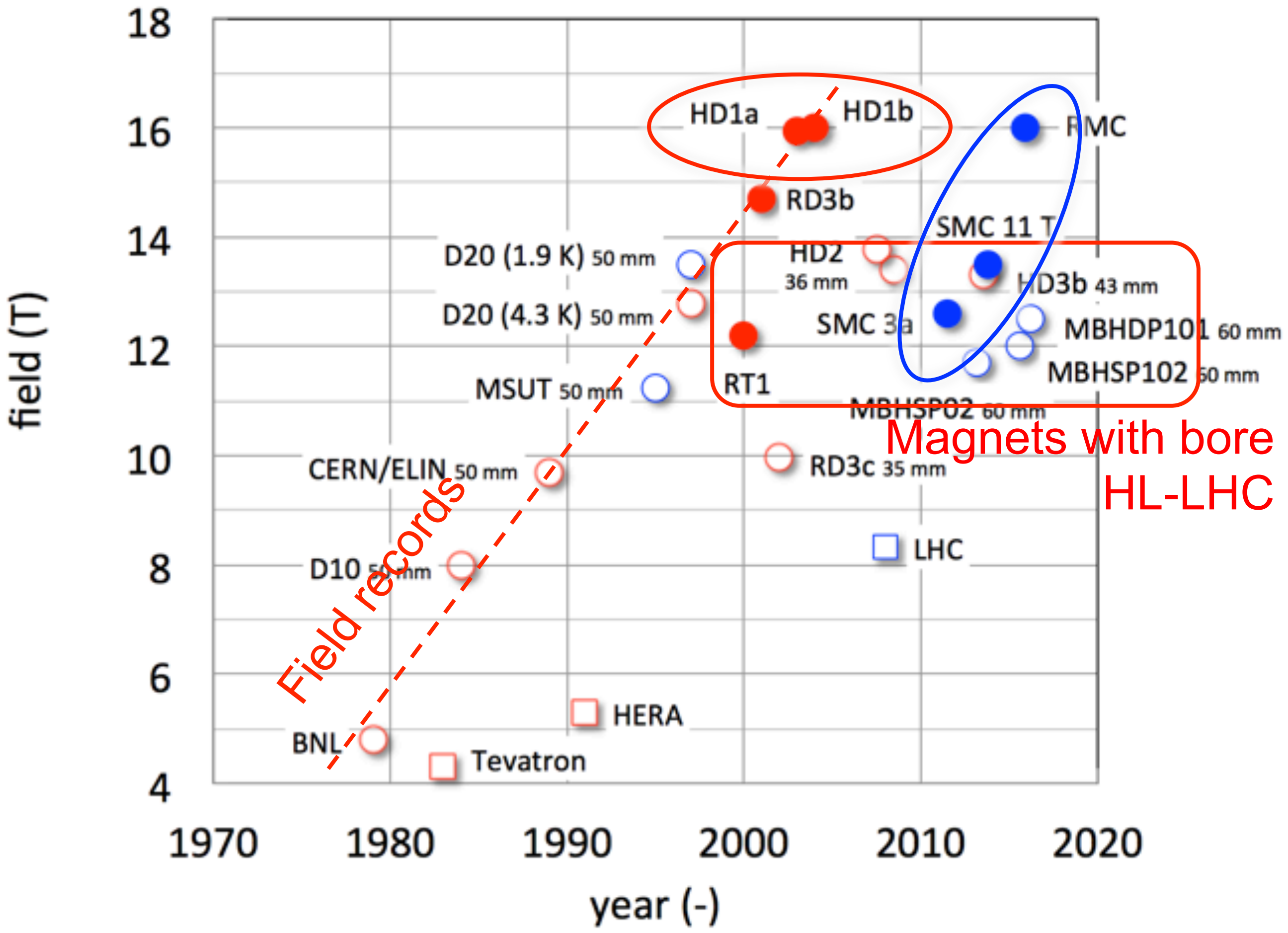
Swiss contribution
via PSI

1LOr3C-02, 2PL-01, 2LPo1A-10, 2LPo1D-02, 2LPo1D-03, 2LPo1D-05, 2LPo1D-07, 2LPo1D-08

Down-selection of options end 2016 for more detailed design work

L. Bottura

High field magnets – Neolithic

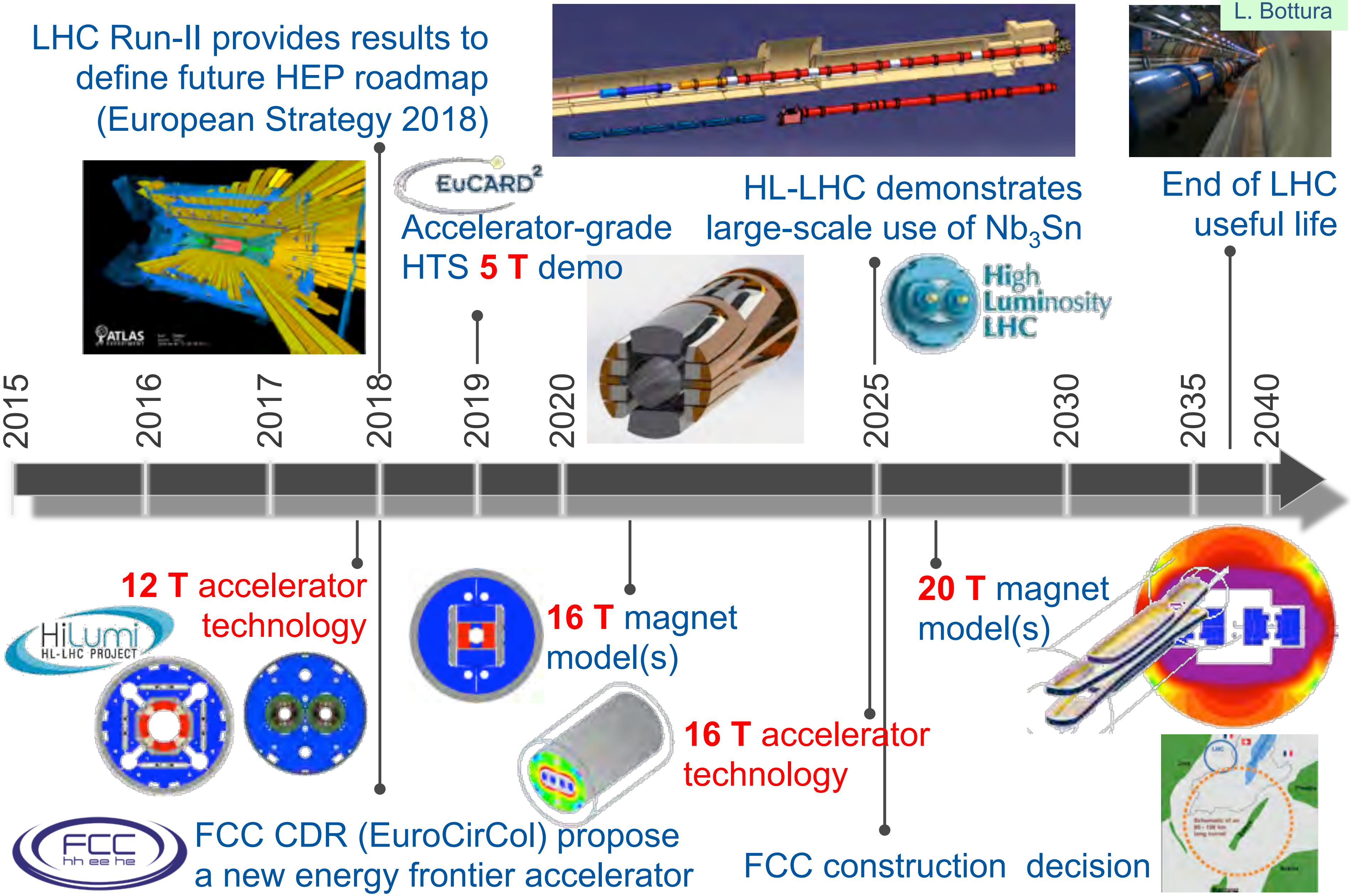


LBNL HD1
(16 T at 4.2 K)

CERN RMC
(16.2 T at 1.9 K)

Record fields for SC magnets in “dipole” configuration

L. Bottura



LHC Run-II provides results to define future HEP roadmap (European Strategy 2018)

Accelerator-grade HTS **5 T** demo

HL-LHC demonstrates large-scale use of Nb_3Sn

End of LHC useful life

12 T accelerator technology

16 T magnet model(s)

16 T accelerator technology

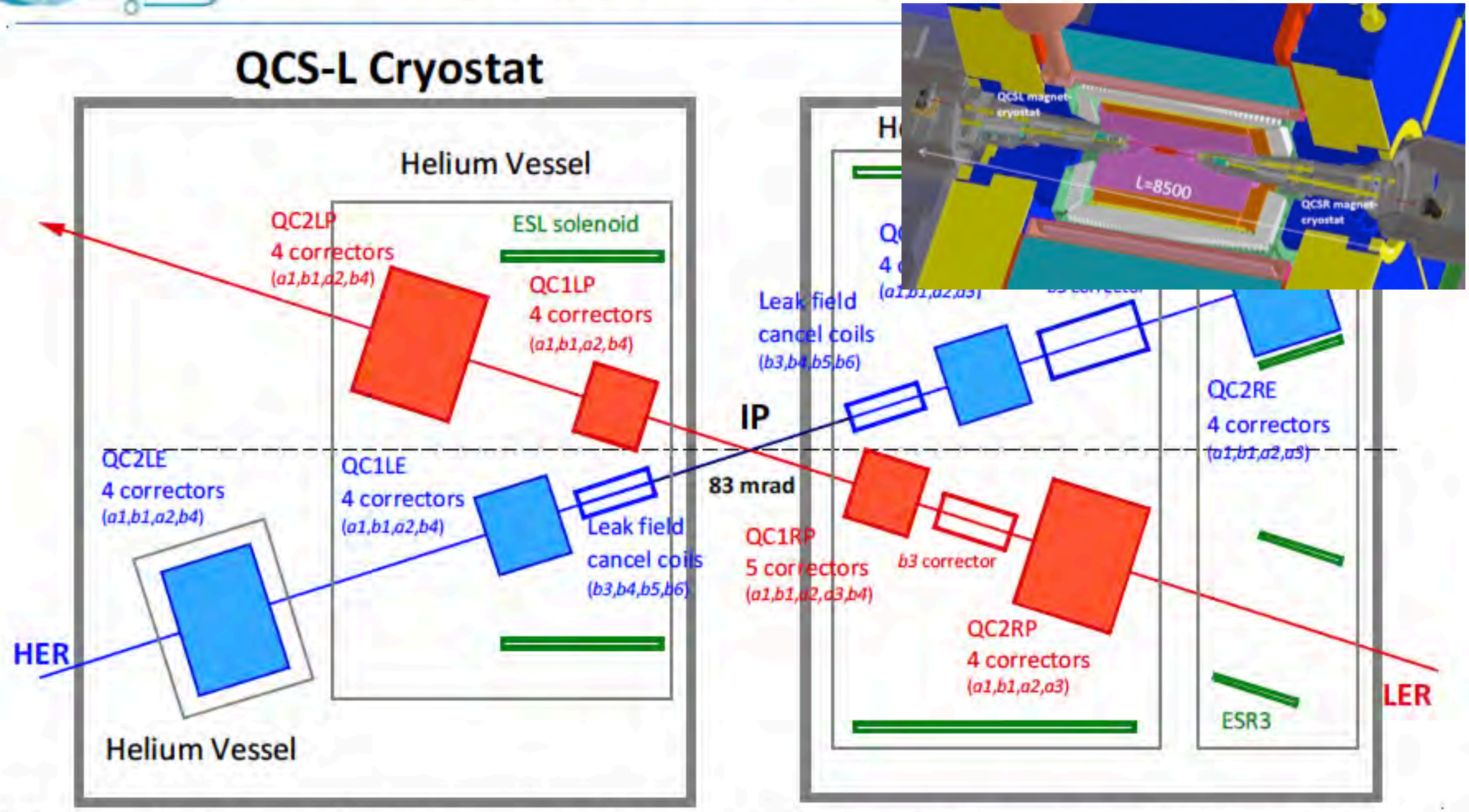
20 T magnet model(s)

FCC CDR (EuroCirCol) propose a new energy frontier accelerator

FCC construction decision

N. Ohuchi

Overview of IR magnets

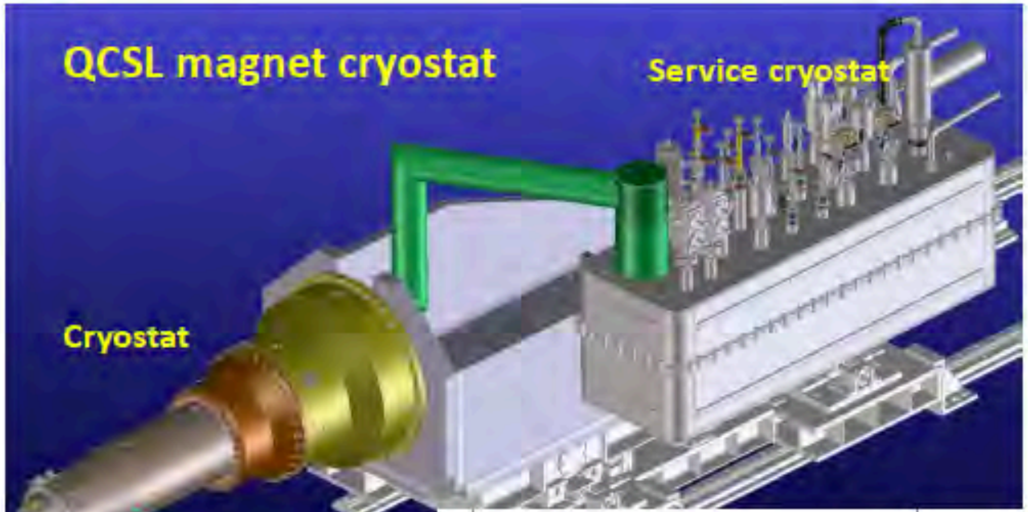


4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
16 SC correctors: a1, b1, a2, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
1 compensation solenoid

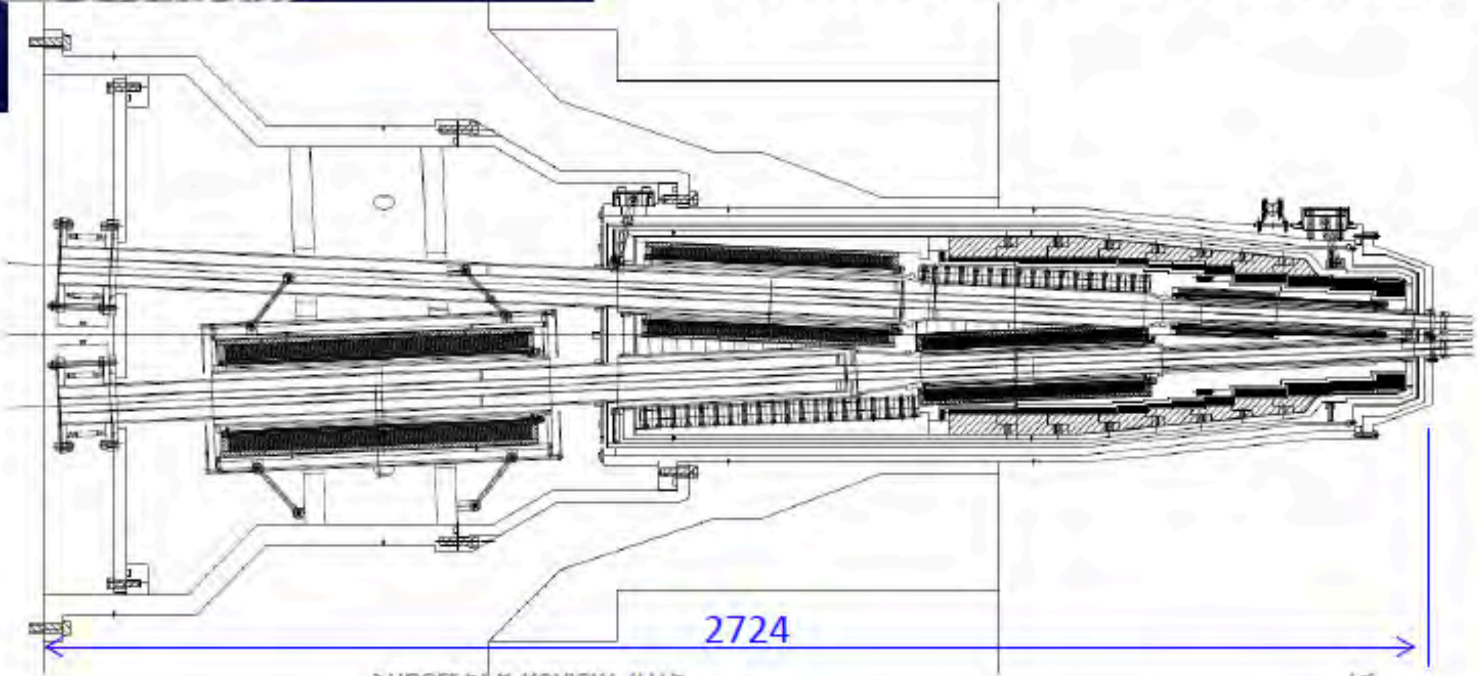
4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
19 SC correctors: a1, b1, a2, a3, b3, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
3 compensation solenoid

N. Ohuchi

Production of magnets and cryostats



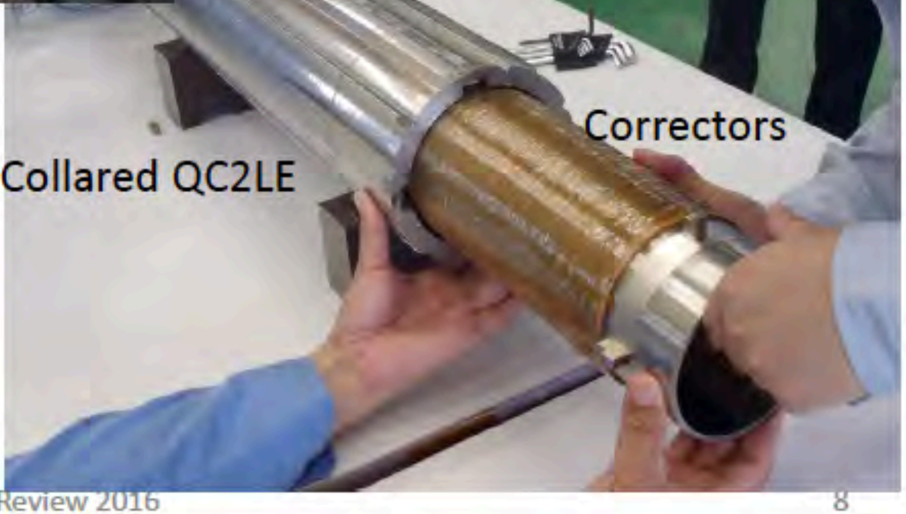
Cross section of QCSL magnet cryostat



Overview of IR magnets

- Direct winding SC Corrector by BNL

a_1 corrector winding for QC1LP @BNL

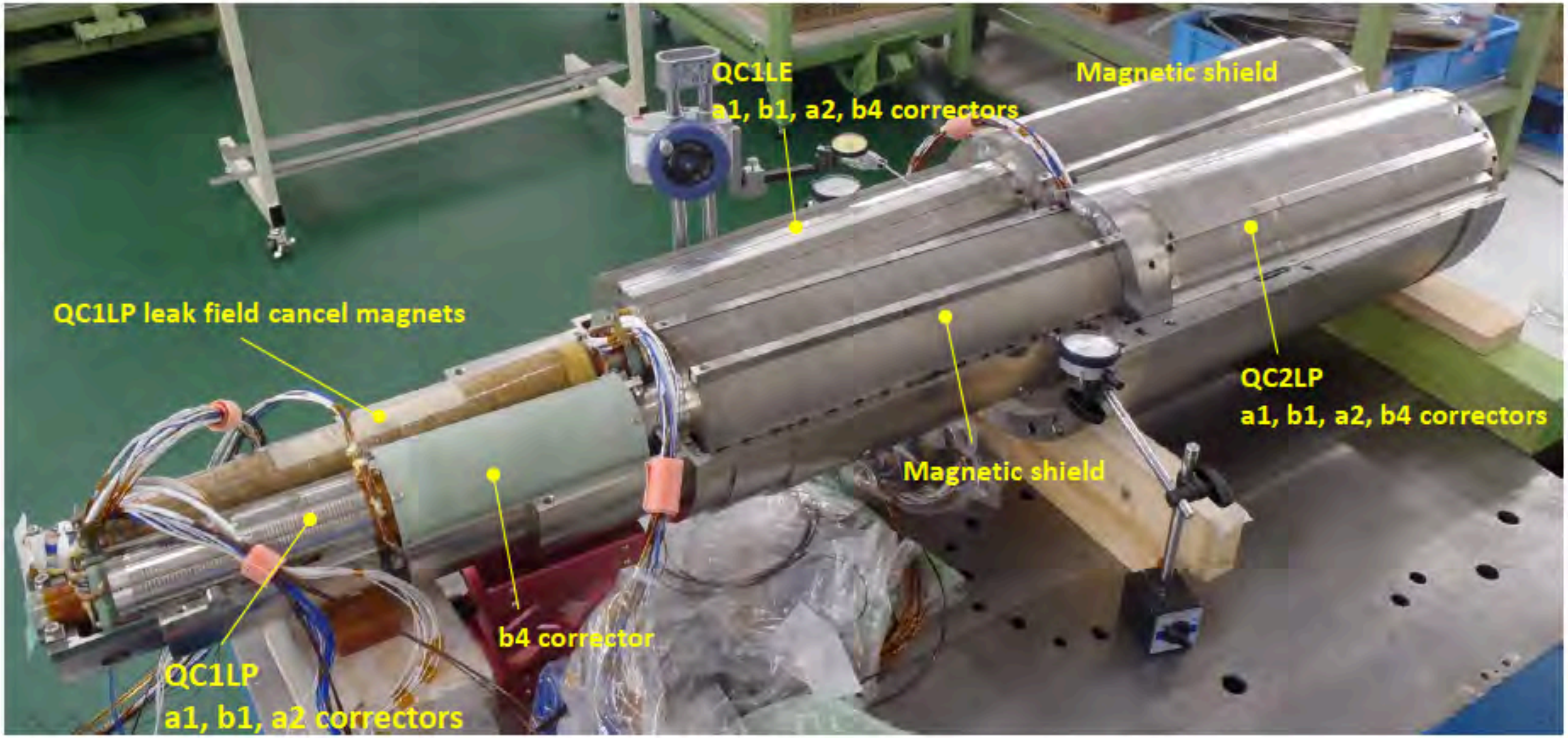


Assembly of QC2LE and correctors

N. Ohuchi

Production of magnets and cryostats

Assembly of the QC1LP, QC2LP, QC1LE, correctors and QC1LP leak field cancel magnets (Front cold mass of QCSL)



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- Advances in particle accelerators
  - Superconducting magnets and SRF
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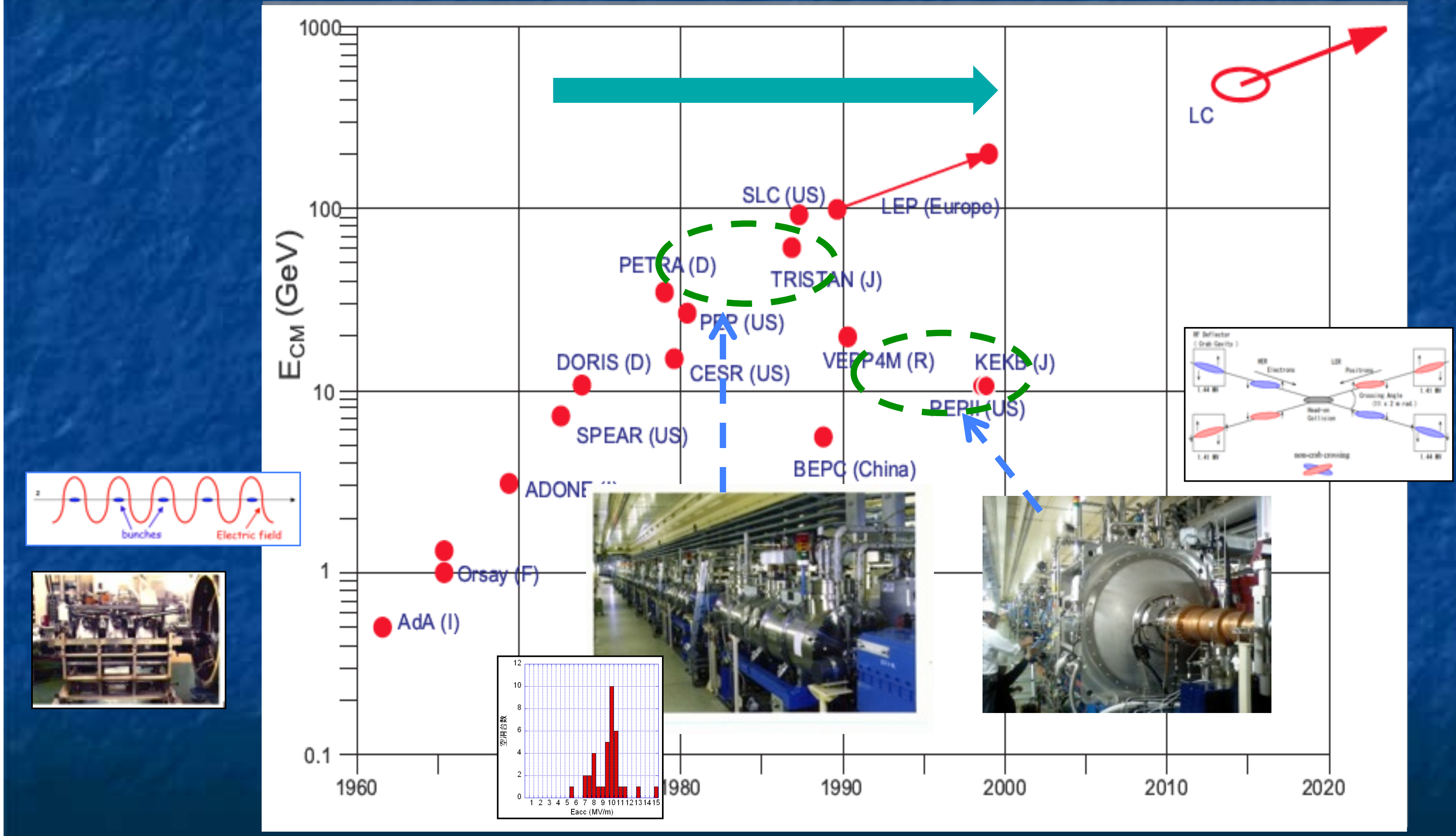
Progress in lepton Colliders

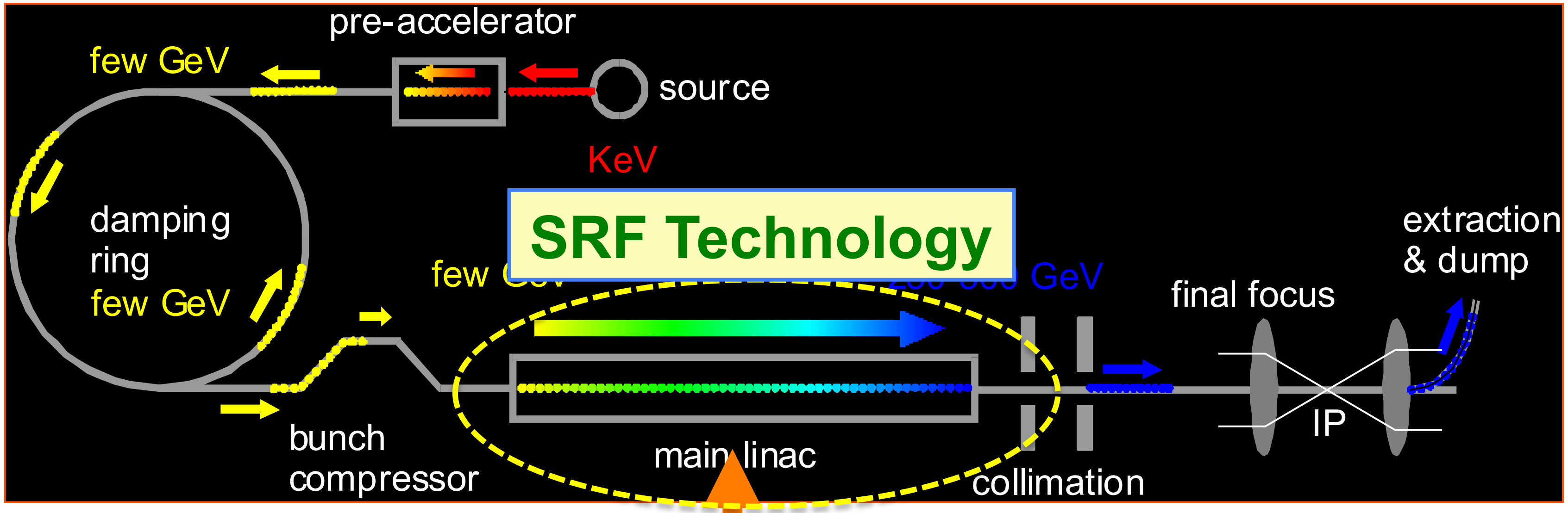
Great Steps with TRISTAN and LEP



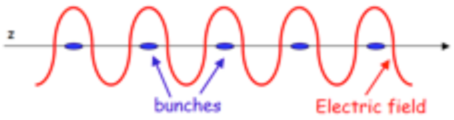
Progress in Particle (Lepton) Accelerators based on SRF Technology

Location	Acc.	Energy	E [MV/m]	Freq. [GHz]	Operation
KEK	TRISTAN	2 x 30	5	0.5	1986-1995
CERN	LEP	2 x 105	5	0.5	1989-2000
JLab	CEBAF	6	7	1.3	1995~
KEK	KEKB	8	5	0.5	1999~2007
DESY	EXFEL*	14	24	1.3	construction
Fermilab	PIP*	8	~20	1.3	Plan
---	ILC*	2 x 250	31.5	1.3	Plan

SRF Technology



- Electron and Positron Sources (e-, e+) :
- Damping Ring (DR):
- Ring to ML beam transport (RTML)
- **Main Linac (ML）: SCRF Technology**
- Beam Delivery System （BDS）



Media.xfel.au, Dec. 2015

European XFEL SRF being Completed

Progress:

2013: Construction started

2015: SRF cav. (100%) completed

CM (70%) progressed

Further Plan:

2016: E- XFEL acc. completion

2016/E: E-XFEL beam to start

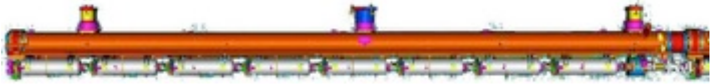
Acc. : ~ 1/10 scale to ILC-ML

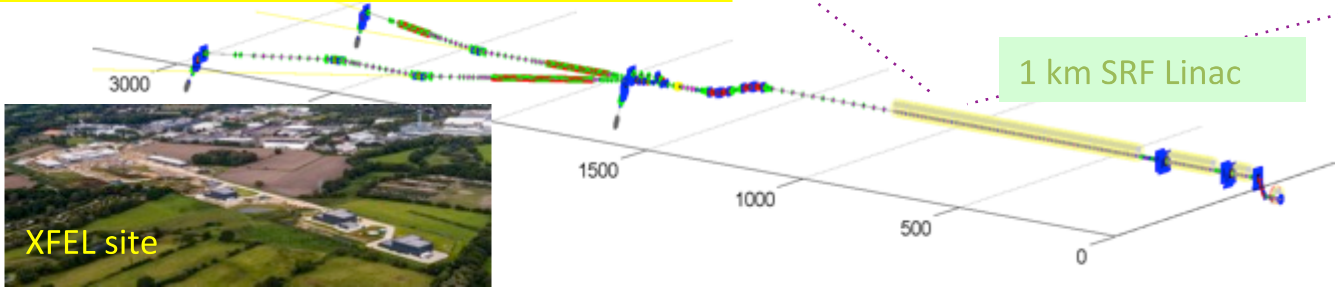
SRF system: ~ 1/20 scale to ILC-SRF

1.3 GHz / 23.6 MV/m

800+4 SRF acc. Cavities

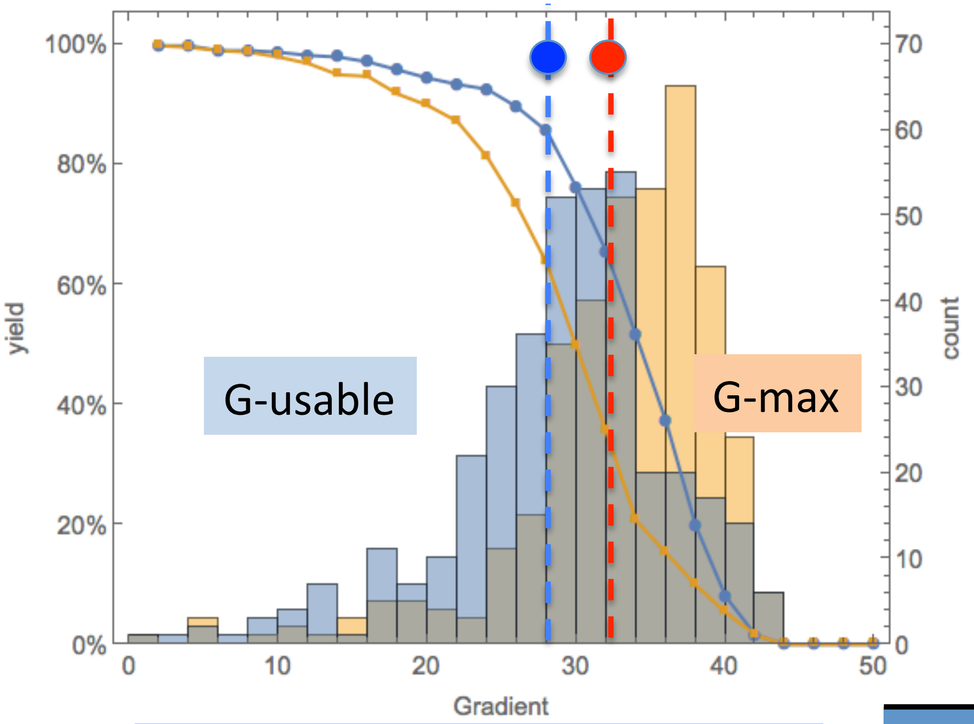
100+3 Cryo-Modules (CM)





N. Walker, D. Reschke, SRF’15

E-XFEL: SRF Cavity Performance (as received)



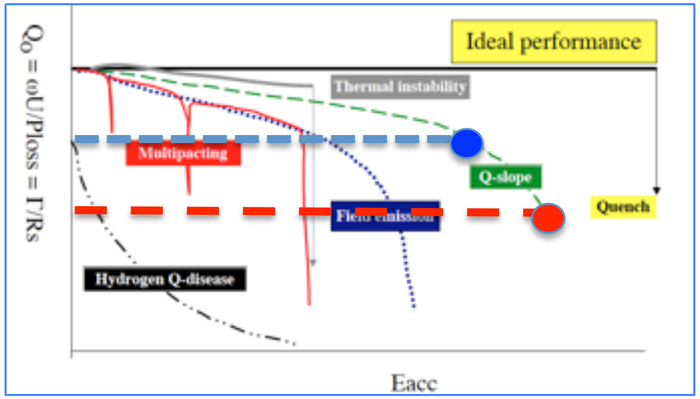
SRF cavity production/test ;

 # RI Cavities, 373 (as of Sept. 2015)

- Final process: 40 μm EP.
  - w/ same recipe to ILC-SRF’s
- Tested at DESY-AMTF

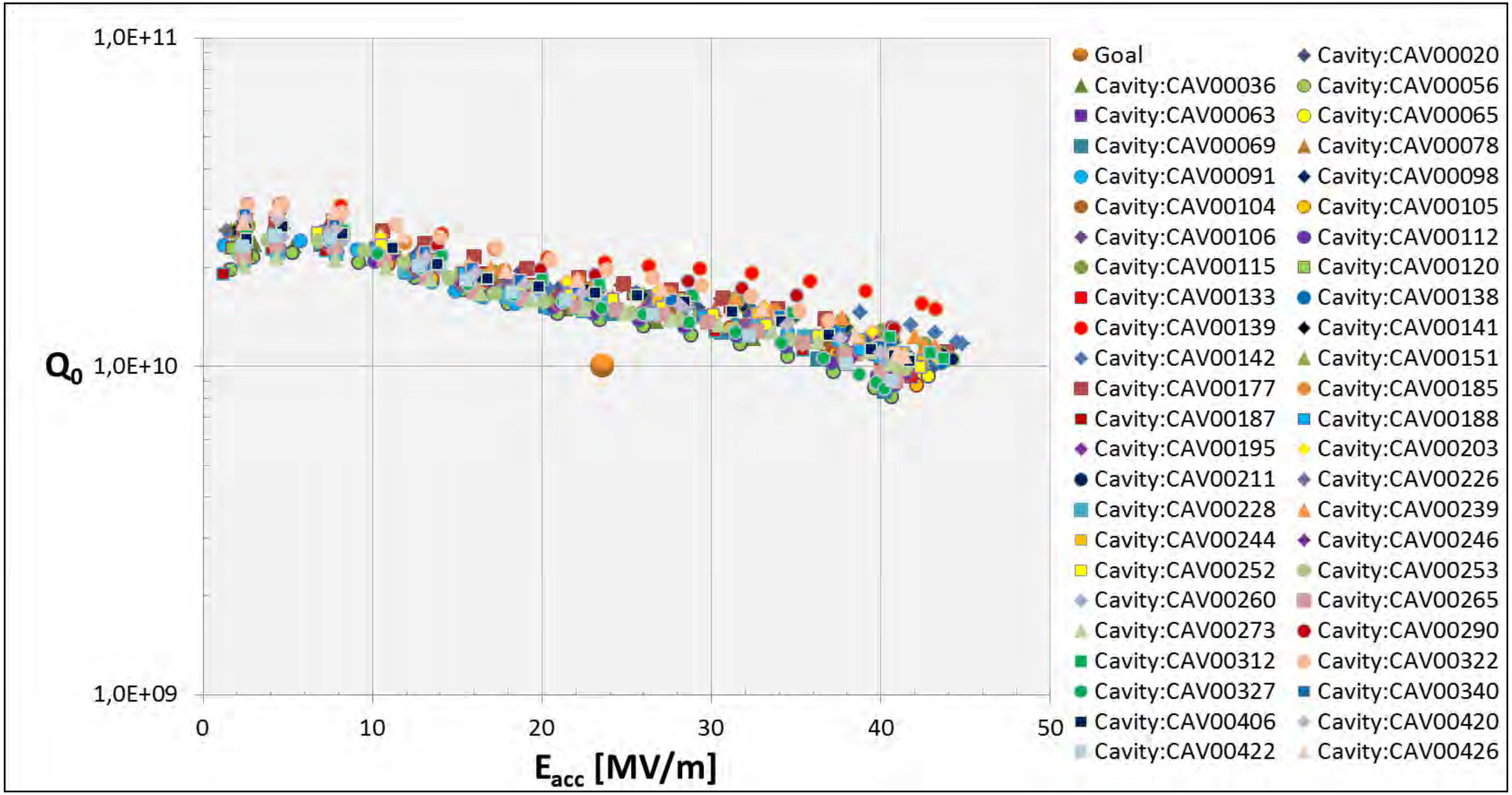
Notes::

- “Ultra-pure water rinsing as the 2nd process improving the gradient performance (> ~10%) for lower-performed cavities (not shown here).



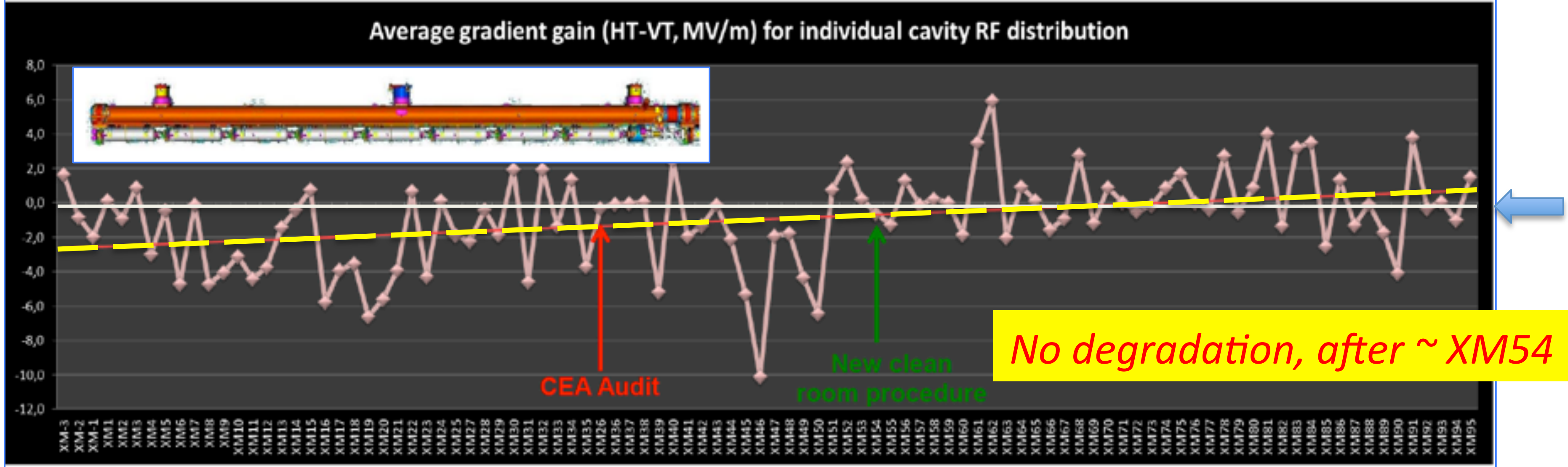
	G-usable ($Q_0 > 10^{10}$)	G-max	(ILC)
<G> MV/m	29.4	33	(35)
Yield at 28MV/m	66%	86%	(90%)

47 of 420 cavities of RI cavity production exceed 40 MV/m



O. Napoly, TTC2016

Cryomodule Performance: VT vs. MT



CEA Audit

New clean room procedure

No degradation, after ~ XM54

1st sample of 34 series CM
ΔE_{op} = -2.1 MV/m

2nd sample of 19 series CM
ΔE_{op} = -1.7 (-0.9) MV/m

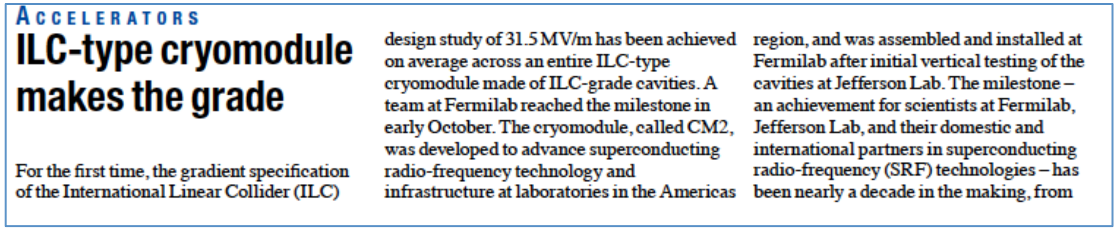
last 42 series CM
ΔE_{op} =+0.4 MV/m

- Significant gradient degradation from XM6 to XM23, while CEA and Alsyom put all their effort in achieving production goal of 1 CM/week: an audit of string and module assembly was conducted by CEA on XM26
- A simplification of the clean room procedures was introduced at XM54: **no degradation after**

E. Harms, TTC2014

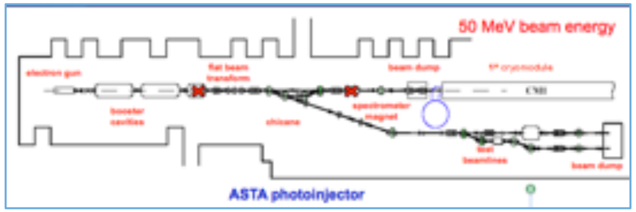
Fermilab : CM2 reached <31.5 MV/m >

CERN Courier December 2014

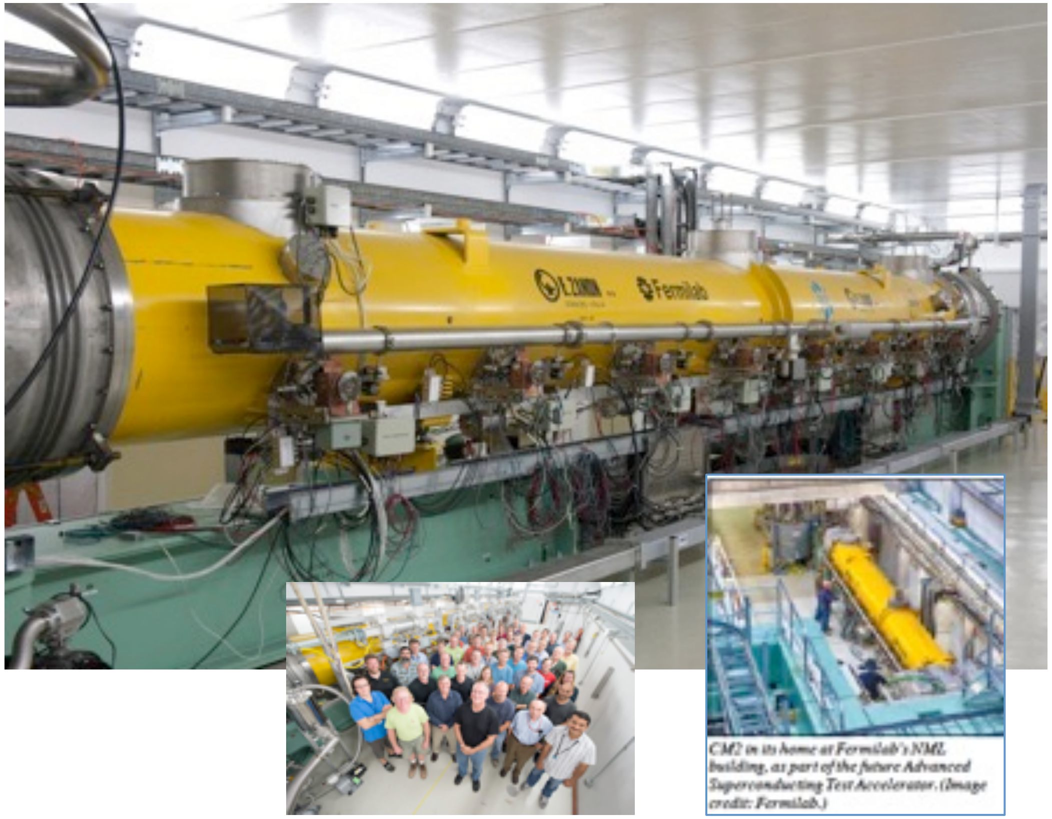

ACCELERATORS

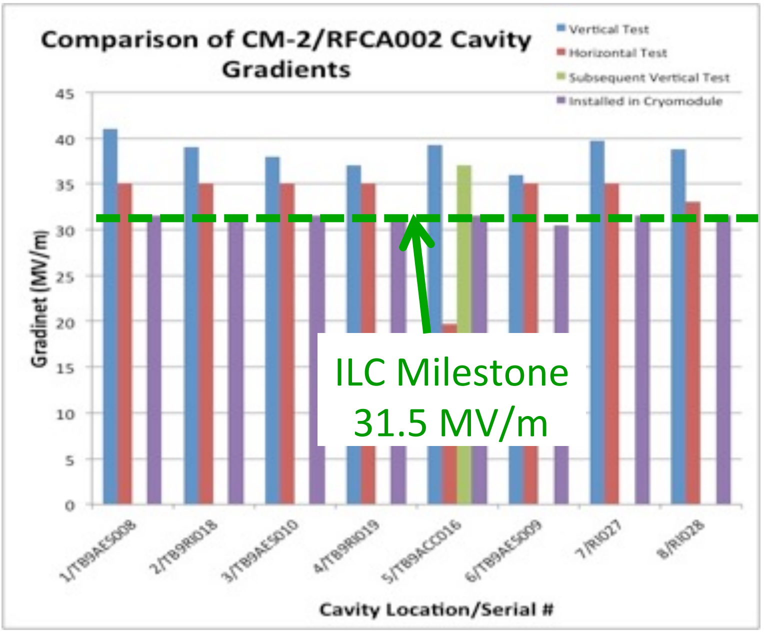
ILC-type cryomodule makes the grade

For the first time, the gradient specification of the International Linear Collider (ILC) design study of 31.5 MV/m has been achieved on average across an entire ILC-type cryomodule made of ILC-grade cavities. A team at Fermilab reached the milestone in early October. The cryomodule, called CM2, was developed to advance superconducting radio-frequency technology and infrastructure at laboratories in the Americas region, and was assembled and installed at Fermilab after initial vertical testing of the cavities at Jefferson Lab. The milestone – an achievement for scientists at Fermilab, Jefferson Lab, and their domestic and international partners in superconducting radio-frequency (SRF) technologies – has been nearly a decade in the making, from



Cryomodule test at Fermilab reached < **31。5** > MV/m, exceeding ILC specification


CM2 in its home at Fermilab's NML building, as part of the future Advanced Superconducting Test Accelerator. (Image credit: Fermilab.)



Y. Yamamoto, E. Kako, H. Hayano

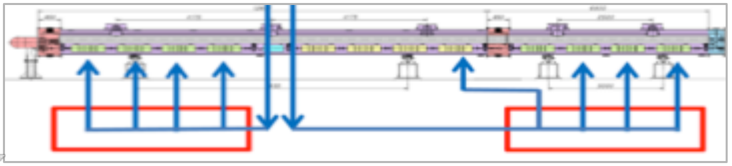
KEK-STF: Cavity/CM Performance, and RF and Beam Test Preparation

SRF cavity Gradient (MV/m) before/after CM Assembly

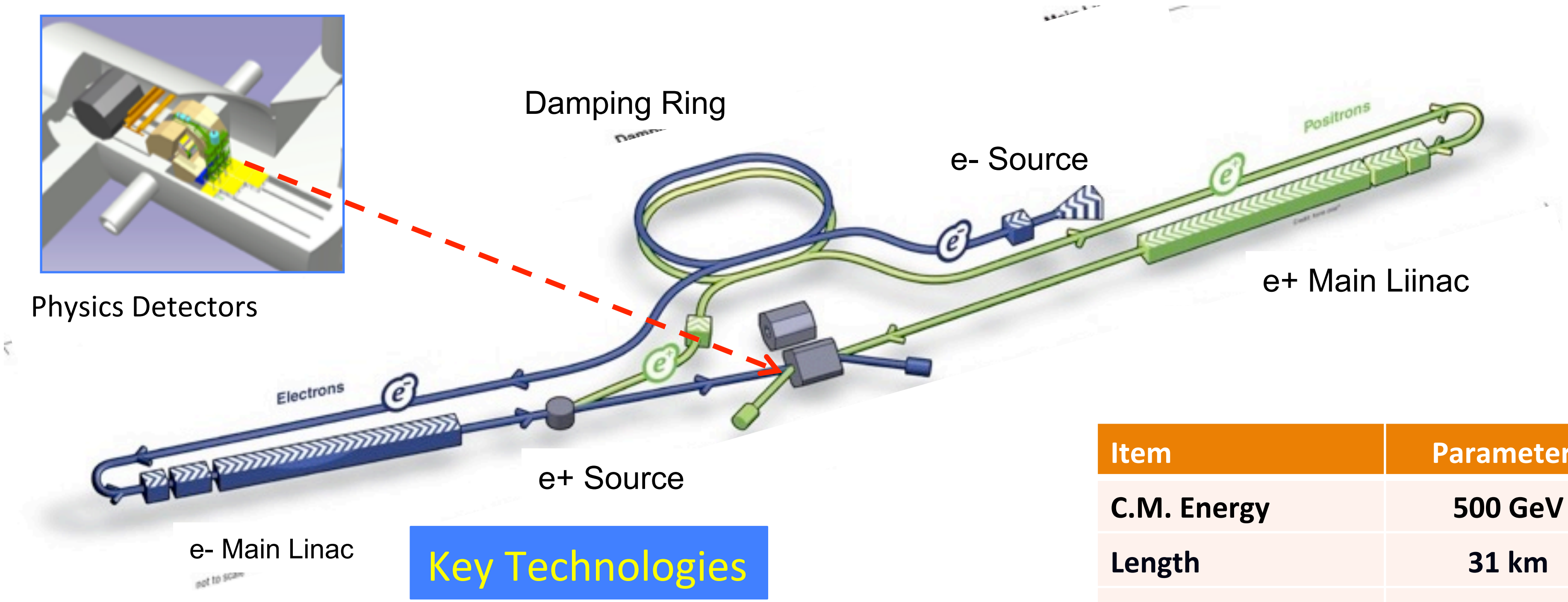
Module	CM1a				CM1b				CM2a			
Cav. #	1	2	3	4	5	6	7	8	9	10	11	12
V. Test (CW)	37	36	38	36	37	35	39	36	12	36	32	32
in CM (pulse)	**39**	**37**	**35**	**36**	26	16	26	**32**	18	**34**	**33**	**32**
	Gradient stable				Degraded				Gradient stable			

*<G> : 30 MV /m (12 Cav.) , 35 MV/m (best 8)

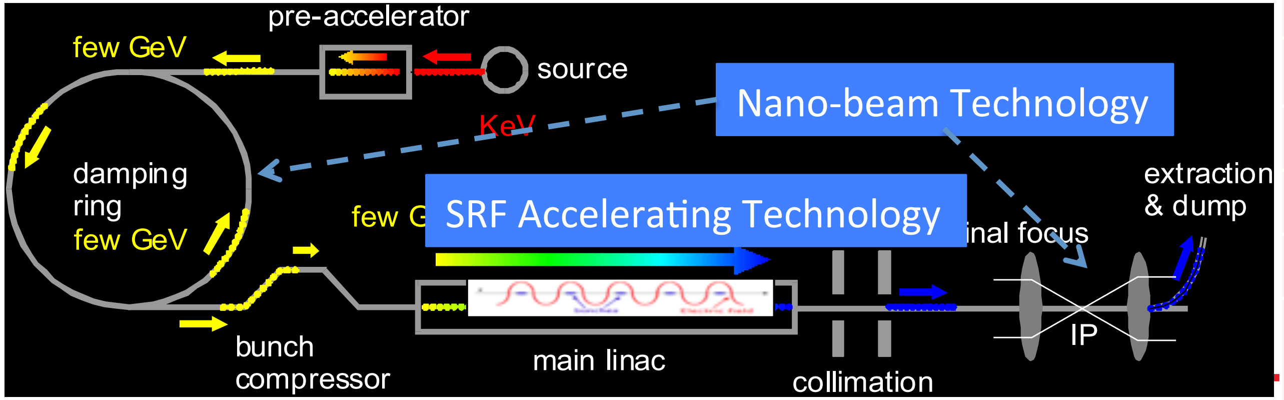
- FY14: CM1+CM2a (8+4) assembly
- FY15: Cavity individually tested in CM
  RF power system in preparation
- FY16: **8-cavity** string to be RF tested
- FY17: Beam Acceleration expected
  （to reach ＞250 MeV)



ILC Acc. Design Overview (TDR)



Key Technologies



Nano-beam Technology

SRF Accelerating Technology

Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

Progress in Acc. Key Technologies for the ILC

- **Nano-beam Technology:**

KEK-ATF2: FF **beam size (v)** of 41 nm at 1.3 GeV (to go 37nm as a primary goal)

FF beam position stability of 67 nm (limited by monitor resolution)

- **SRF Technology :**

SRF cavity grad. in TDR: reached G-max = 37 MV/m and an Yield of 94 % at > 28 MV/m

Beam acceleration: DESY-FLASH and KEK-STF realized 9 mA, and 1 ms

European XFEL: Cavity production at RI/EZ, 100% (800+4) completed, <G> = ~ 30 MV/m.

- Cryomodule (CM) assembly, 100% (100+3) completed, <G> =~28 MV/m.
    - {last CM, delivered from CEA-Saclay to DESY on 29 July, 2016}

Fermilab: CM reached the ILC gradient specification: G ≥ 31.5MV/m

KEK-STF2: The best 8-cavity string for beam acceleration: G ≥ 31.5 MV/m.

- **ADI: Accelerator Design and Integration**

LCC-ILC: working for further robust and cost-effective design and R&D

KEK-ILC Action Plan Issued, Jan. 2016

https://www.kek.jp/en/NewsRoom/Release/20160106140000/

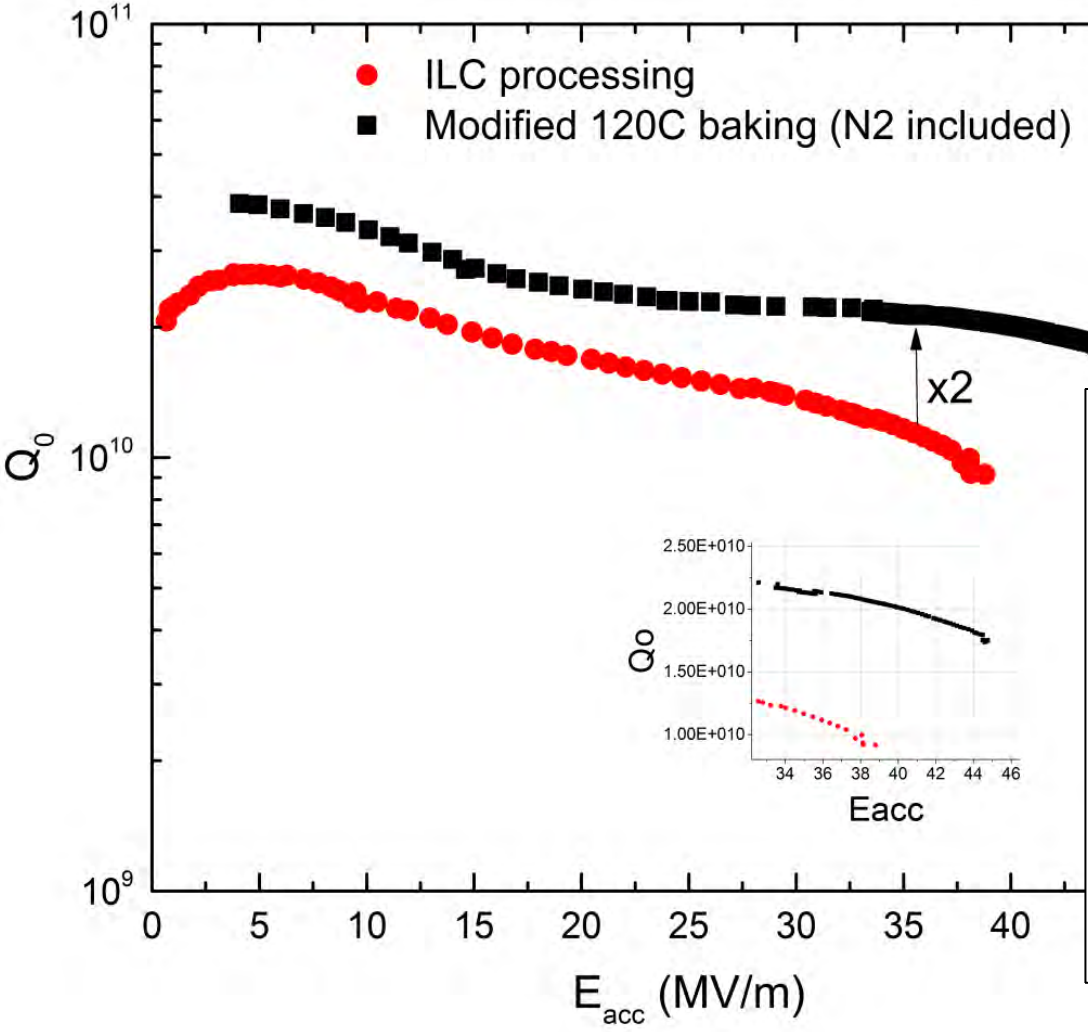
Topics

KEK issues action plan for the International Linear Collider

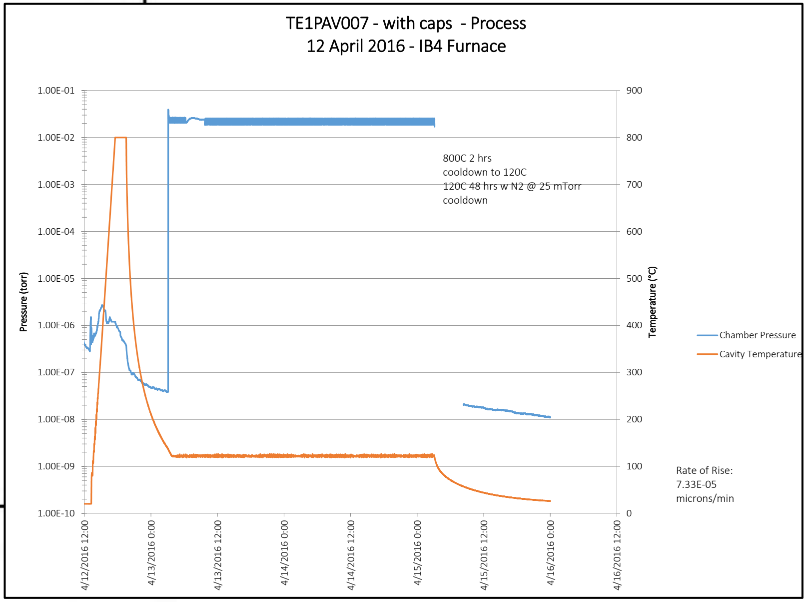
	Pre-Preparation Stage	Main Preparation Stage			
	present (we are here)	P1	P2	P3	P4
ADI	Establish main parameters	Verify parameters w/ simulations			
SRF	Beam acc. with SRF cavity string, Cost Reduction R&D (proposed)	Demonstrate mass-production technology, stability, hub-lab functioning, and global sharing			
Nano-beam	Achieve the ILC beam-size goal	Demonstrate the nanobeam size and stabilize the beam position			
e+	Demonstrate technological feasibility	Demonstrate both the undulator and e-driven e+ sources			
CFS	Pre-survey and basic design	Geology survey, engineering design, specification, and drawings			

A. Grassellino, S. Aderhold, TTC-2016

New Low T Nitrogen Treatment for High-Q and –G studied and demonstrated at Fermilab



- Same cavity, sequentially processed, no EP in b/w
- Achieved: 45.6 MV/m
  Q at ~ 35 MV/m : ~ 2.3e10

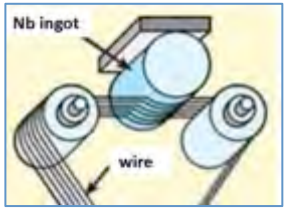


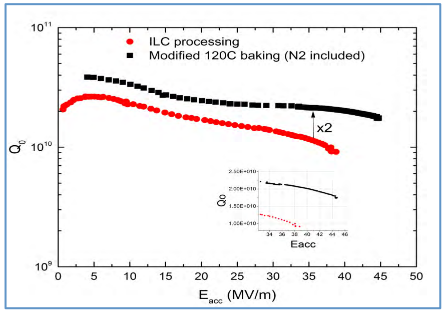
S. Michizono, S. Belomestnykh

A plan for ILC Cost-Reduction R&D in Japan and US focusing on SRF Technology, in 2~3 years

Based on recent advances in technologies;

- Nb material preparation
  - w/ optimum RRR and clean surface
- SRF cavity fabrication for high-Q and high-G
  -w/ a new baking recipe provided by Fermilab
- Power input coupler fabrication
  - w/ new (low SEE) ceramic without coating
- Cavity chemical process
  - w/ vertical EP and new chemical (non HF) solution
- Others





Outline

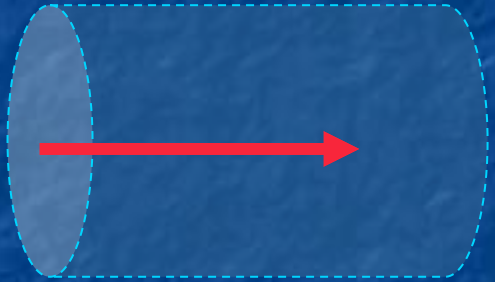
- Introduction
- Advances in particle accelerators
  - Superconducting magnets and SRF
- Advances in particle detectors
  - Solenoid magnets in collider detectors
  - A unique application for scientific ballooning
- Recent advances in Japan

Solenoidal Magnetic Field expected in Particle Detectors

- **Dream**
  - Only magnetic field

Momentum Resolution

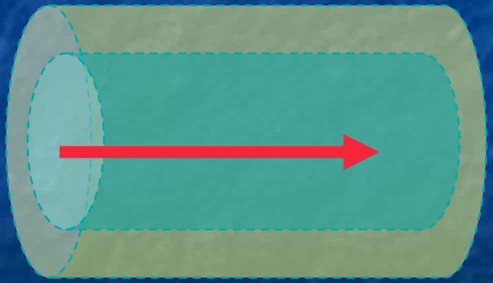
$dp/p \sim \{B \bullet R^2\}^{-1}$

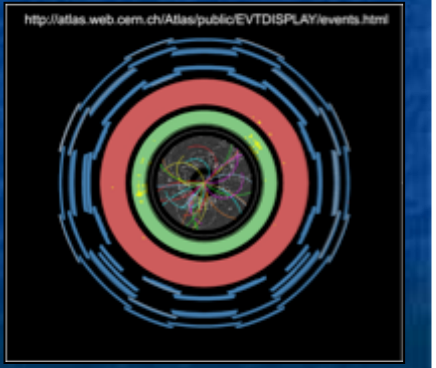


- **Reality**
  - Coil and structure

Wall thickness (material):

$t \sim (R/\sigma_h) \bullet B^2/2\mu_0$

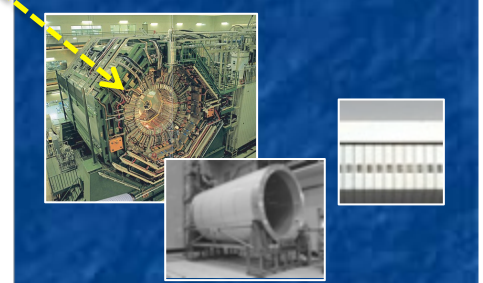




http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

History of Detector Solenoids

Experiment	Laboratory	R (m)	B (T)	I (kA)	X (X_0)	E/M (kJ/kg)	E (MJ)	Year
PLUTO	DESY	0.75	2.2	1.3	4.0	2.3	4.1	1972
ISR point 1	CERN	0.85	1.5	2	1.1	1.8	3.0	1977
CELLO	Saclay/DESY	0.85	1.5	3	0.6	5.0	7.0	1978
PEP4/TPC	LBL/SLAC	1.1	1.5	2.27	0.83	7.6	11	1983
CDF	KEK/FNAL	1.5	1.6	5	0.84	5.4	30	1984
TOPAZ	KEK	1.45	1.2	3.65	0.70	4.3	19	1984
VENUS	KEK	1.75	0.75	4	0.52	2.8	11.7	1985
AMY	KEK	1.2	3	5	N/A	N/A	40	1985
CLEO-II	Cornell	1.55	1.5	3.3	2.5	3.7	25	1988
ALEPH	Saclay/CERN	2.75	1.5	5	2.0	5.5	136	1987
DELPHI	RAL/CERN	2.8	1.2	5	1.7	4.2	110	1988
ZEUS	INFN/DESY	1.5	1.8	5	0.9	5.2	10.5	1988
H1	RAL/DESY	2.8	1.2	5	1.8	4.8	120	1990
BESS	KEK	0.5	1.2	0.38	0.2	6.6	0.25	1990
WASA	KEK/Uppsala	0.25	1.3	0.9	0.18	6	0.12	1996
BABAR	INFN/SLAC	1.5	1.5	6.83	0.5	N/A	27	1997
D0	FNAL	0.6	2.0	4.85	0.9	3.7	5.6	1998
BELLE	KEK	1.8	1.5	4.16	N/A	5.3	37	1998
ATLAS-CS	KEK/CERN	1.25	2.0	7.8	0.66	7.1	38	2001
BESS-polar	KEK	0.45	1.0	0.48	0.156	9.2	0.34	2005
CMS	CMS/CERN	3.0	4.0	19.5	N/A	12	2600	2007
BESIII	IHEP (China)	1.45	1.0	5	N/A	2.6	9.5	2008
CMD-3	BINP	0.35	1.5	1	0.085	8.2	0.31	2009

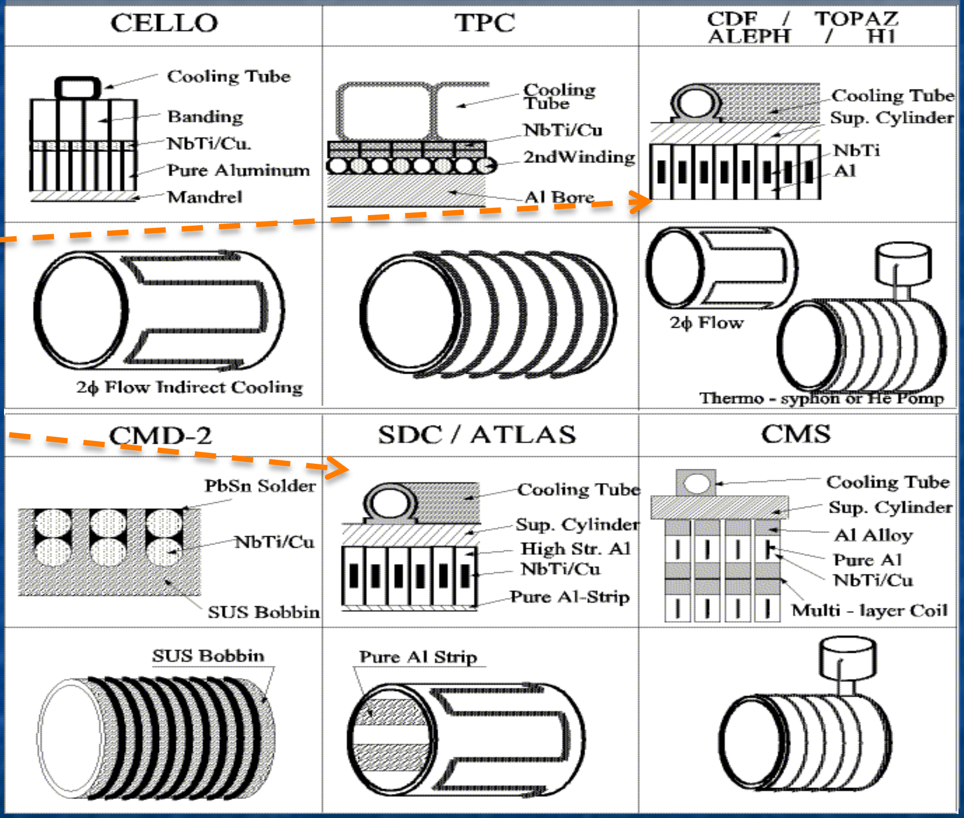


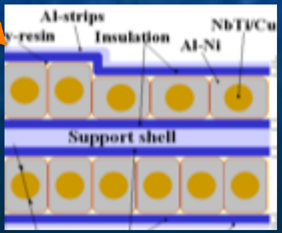
Technical Progress in Particle Detector Solenoid

Technical Progress, since 1970~ :

Al-soldered to NbTi/Cu	ISR, Cello
Secondary winding	TPC
Al co-extrusion w/ NbTi/Cu	CDF
Inner winding	Topaz,
Thermo-siphon	Aleph, Delphi
2-layer-coil w/ grading	Zeus, Cleo
High-str. Al. stab.	ATLAS, BESS
Pure-Al strip Q. propagator	
Hybrid conductor	CMS
Shunted w/ SUS mandrel	CMD-2

Radially self-supporting	BESS-Polar
No outer support cylinder	(for ballooning)

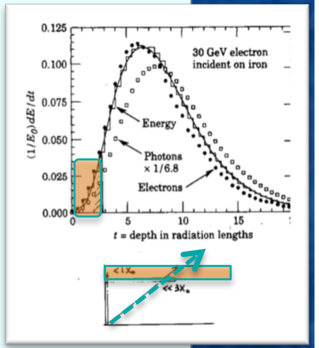




Focusing on ATLAS-CS and BESS, in this talk

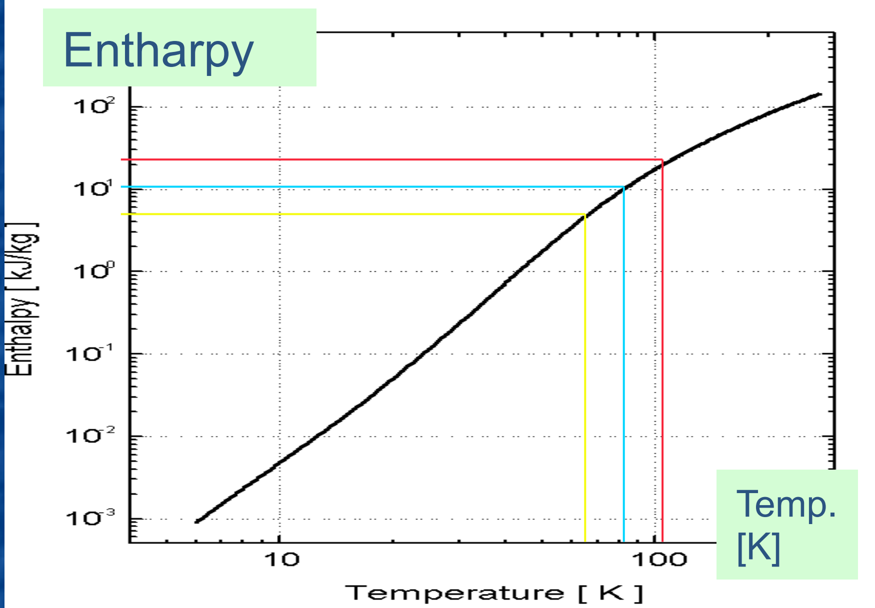
Issues and technical development in Thin Solenoid Magnets

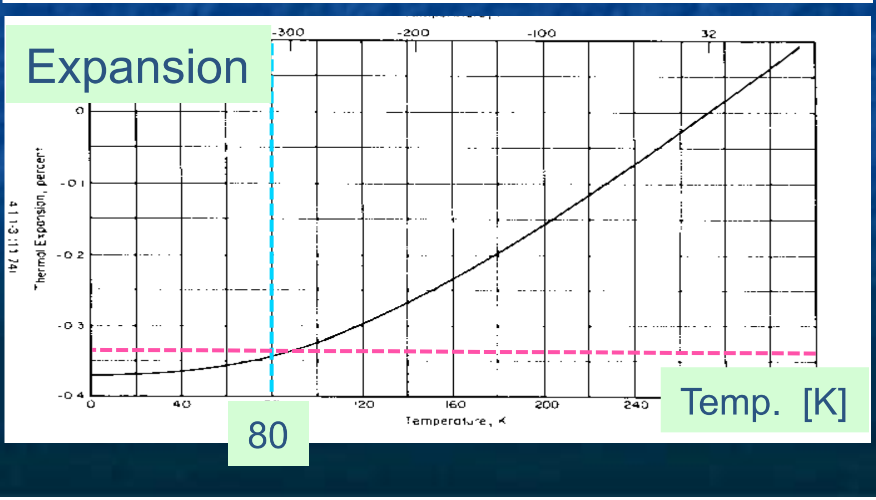
- **Thickness:** $t \propto RB^2/(E/M) \propto RB^2(\gamma/\sigma)$
  - High E/M (stored energy / coil-mass)
  - Light (low Z, γ) stabilizer (Cu → Al)
    - Al provide long radiation length (Xo): (Cu) = 14 mm → (Al) = 89 mm
    - Al provide high stability → high MQE (to be discussed in the next talk)
  - High mechanical strength to be improved
    - High-strength Al stabilizer or reinforcement required
    - → Micro-alloying (Al + Si, Zn, Mg, Ni, …) + Cold-work hardening
    - → Reinforcement using hybrid configuration
- Quench safety: thermo-mechanical stability
  - Fast quench propagation and uniform energy absorption
    - Pure-Al strip contributing fast thermal propagation
    - → Minimizing thermal stress/strain, above 80 K



E/M Ratio: Stored Energy to Coil Mass

→ Temperature Rise after Quench (all energy dump)





Enthalpy

$H = E/M = \text{Integral } \{C_p\}\ dT$

---

20 kJ/kg → ~100 K

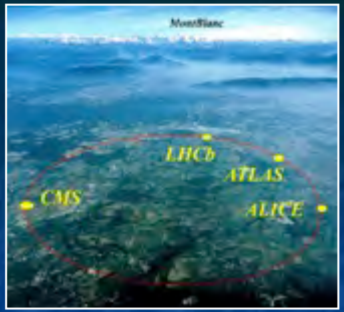
10 kJ/kg → ~ 80 K

5 kJ/kg → ~ 65 K

Corresponding to:
Temperature rise after homogeneous stored energy absorption

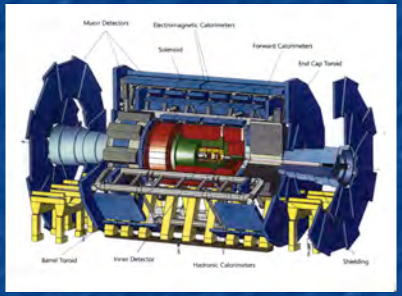
Al-stabilized Conductor Technology reached with

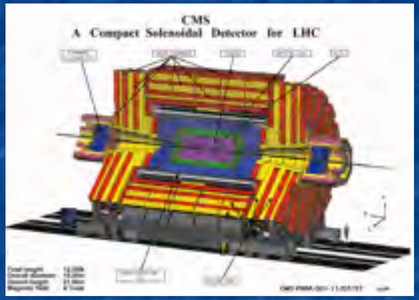
LHC-ATLAS and – CMS

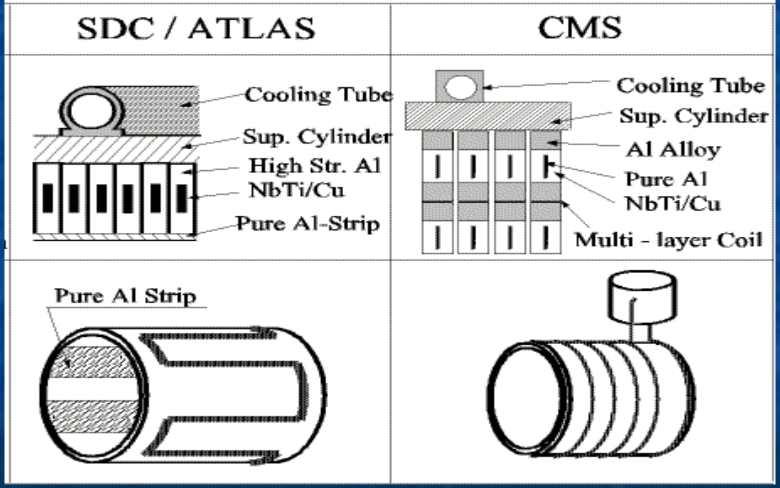


- **Reinforcement of Al**
  - with keeping low resistivity
- **Uniform reinforcement**
  - Micro-alloying and cold work
  - ATLAS-CS

- **Hybrid reinforcement**
  - Welding Al-Alloy with pure-Al
  - CMS







Micro-alloying with pure-Al

with ATLAS-CS and BESS

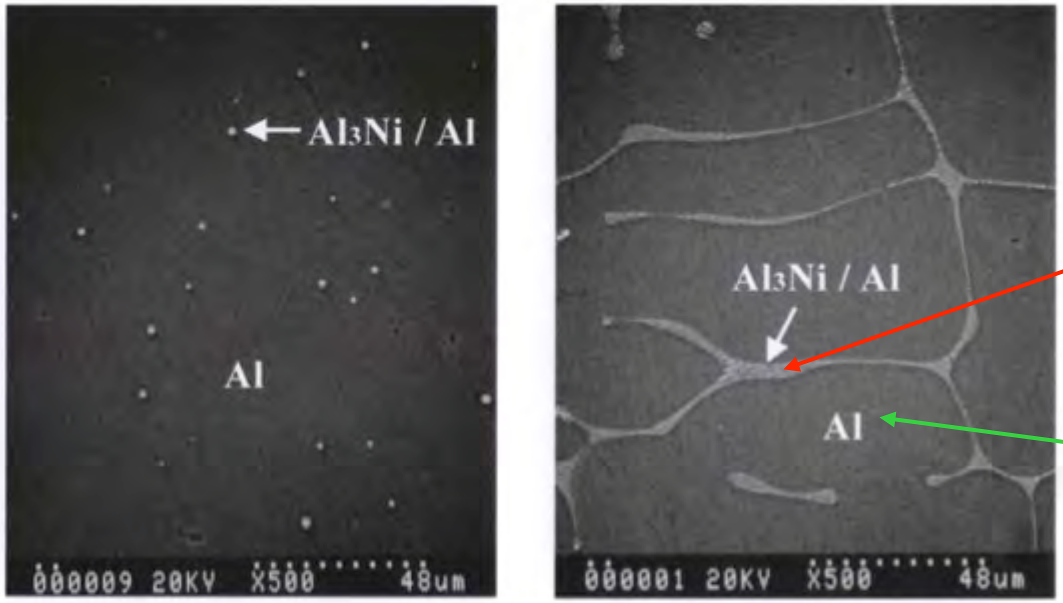
Additve metal	A	Dens. [g/cm^3]	Solubility [w-%]	resistivity contribution (in solution / crystal.) [10^{-12} Ωm/wppm]	
Solid solution:					
Si	28	2.6	1.65	0.7	0.088
Zn	65	7.1	83 @ 400C	0.10	0.023
Crystallization / Precipitation:					
Ni	59	8.8	0.05 @640C <0.006 @<500C	0.81	0.061

Ni: Best reinforcement with keeping Low resistivity.

Al-stabilizer strengthened with

Micro-alloying and precipitation

Ni → high

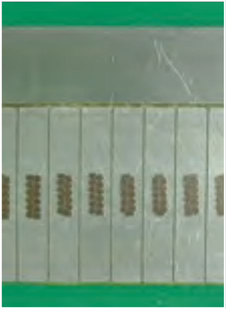


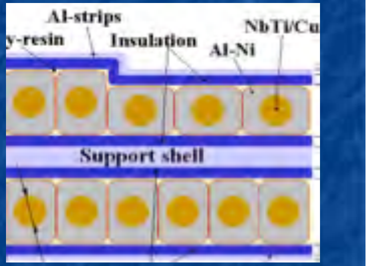
a) Al-0.1wt%Ni Alloy

b) Al-0.5wt%Ni Alloy

0.1%

0.5%

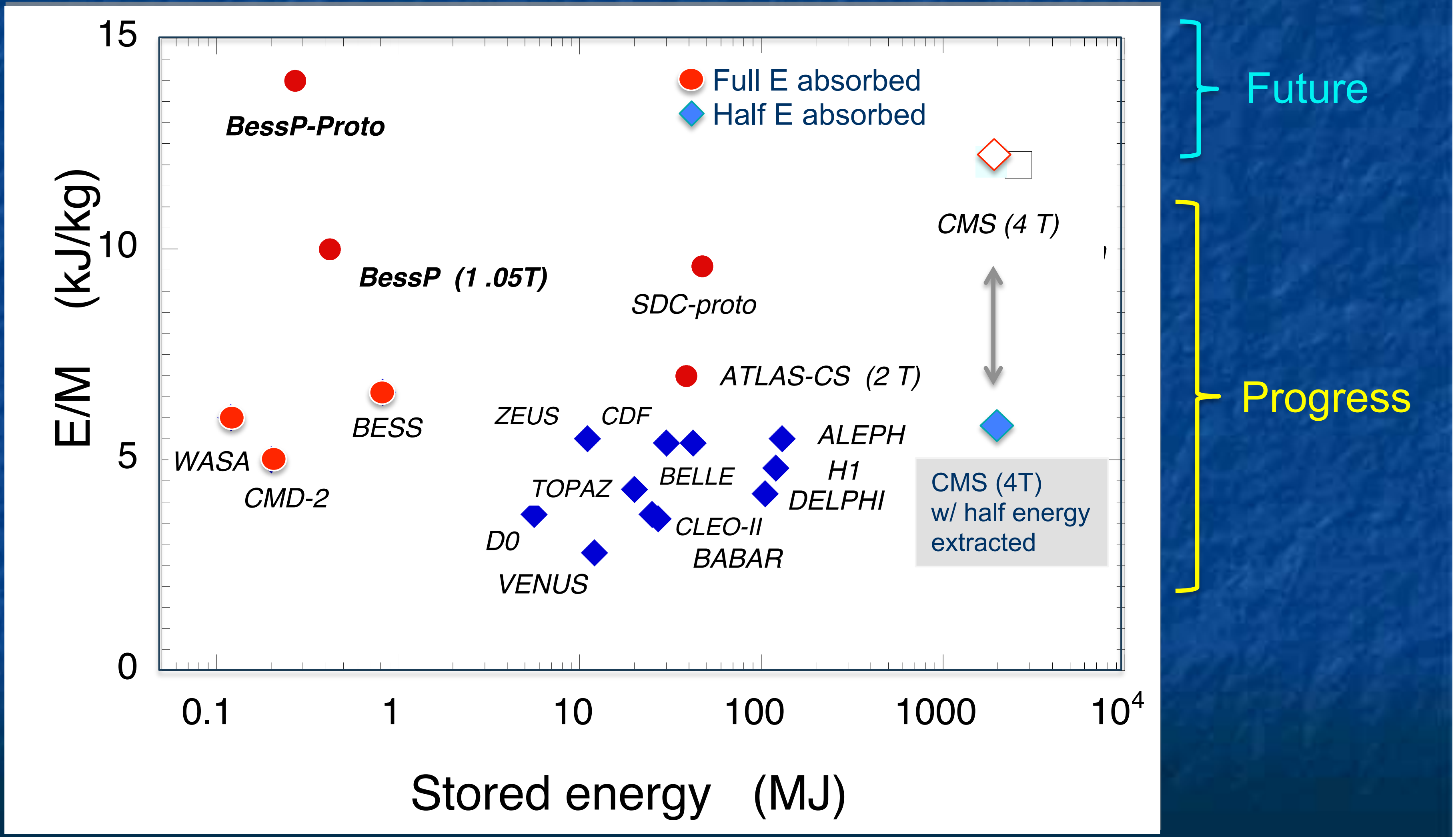




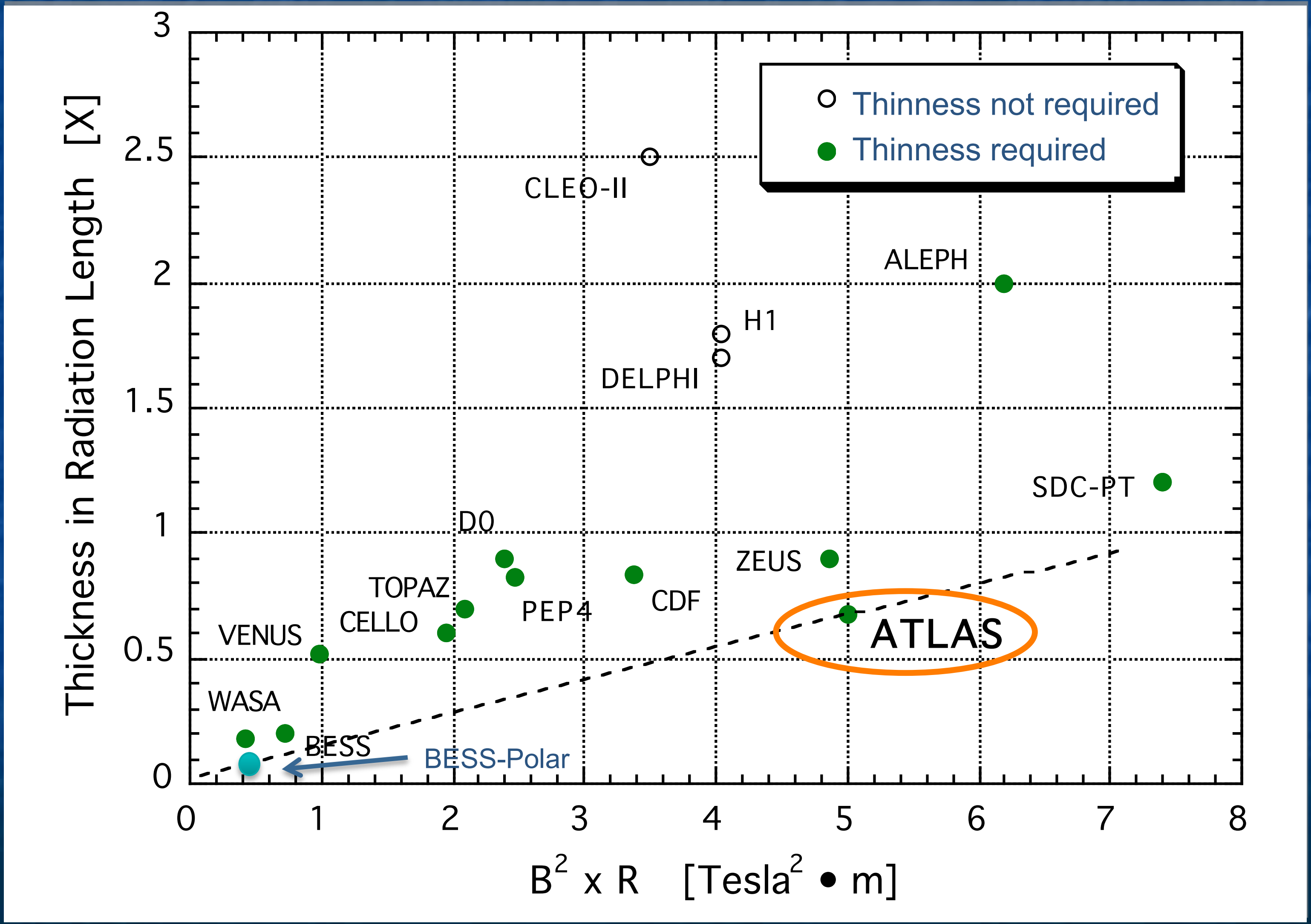
Al_3Ni precipitated
Contributes as
structural component

Pure-Al region
Keep low resistivity

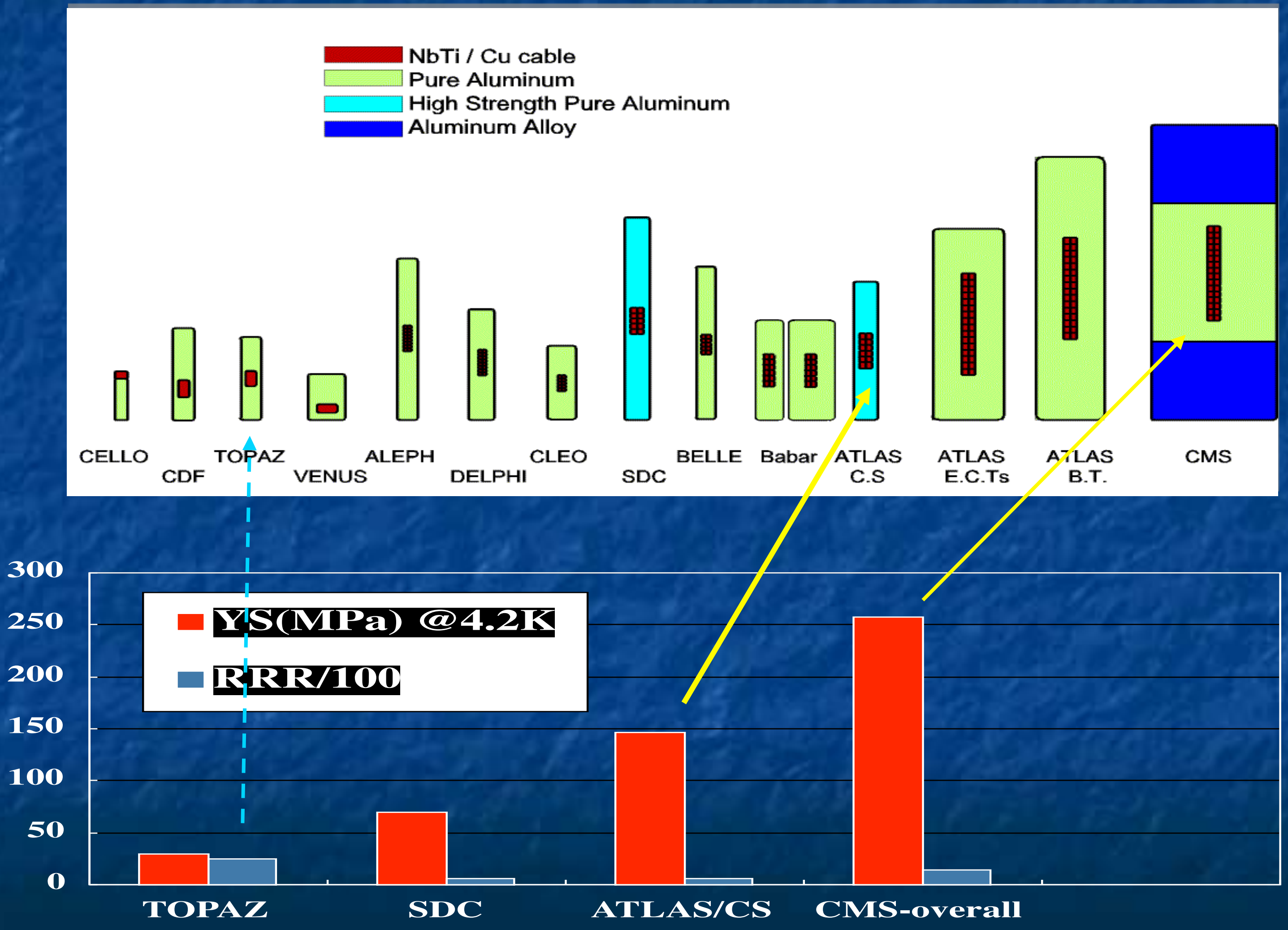
E/M: Progress and Future



Progress in Thickness of Solenoid Coil Wall in terms of Radiation Length [X]

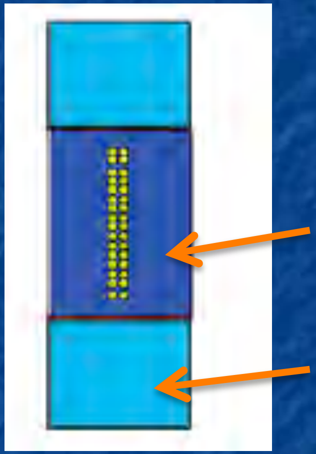


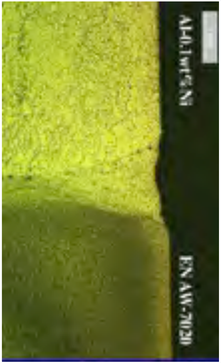
Progress of Al-Stabilizer Superconductor in Colliding-Detector Magnets



Development to further optimize "Strength" and "RRR" for future Detectors

CMS structure and ATLAS-CS alloy may be combined

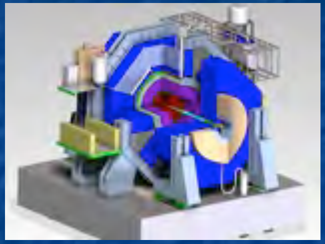




	Rein-force	Feature	Al Y. S. (MPa)	Full cond. Y.S.	Full cond. RRR
ATLAS-CS	Uniform	Ni-0.1% Al	110 MPa	146 MPa	590
CMS	Hybrid	Pure-Al & A6082-T6	26 / 428	258	(1400)
Future	**Hybrid**	**Ni-Al & A6082-T6**	**110 / 428**	**300**	**400**
Future	**Hybrid**	**Ni-Al & A7020-T6**	**110 / 677**	**400**	**400**

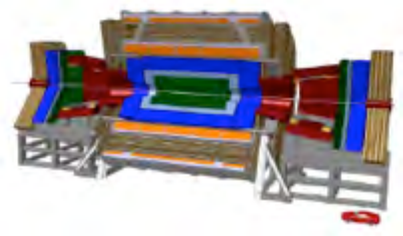
Future Prospects for Collider Detector Solenoids

- Magnet Parameters
  - Field : 4 ~ 6 Tesla
  - Diameter: 4 ~ 8 m
  - E/M: 10 ~ 12 (< 15) kJ/kg



ILC: SiD

ILD

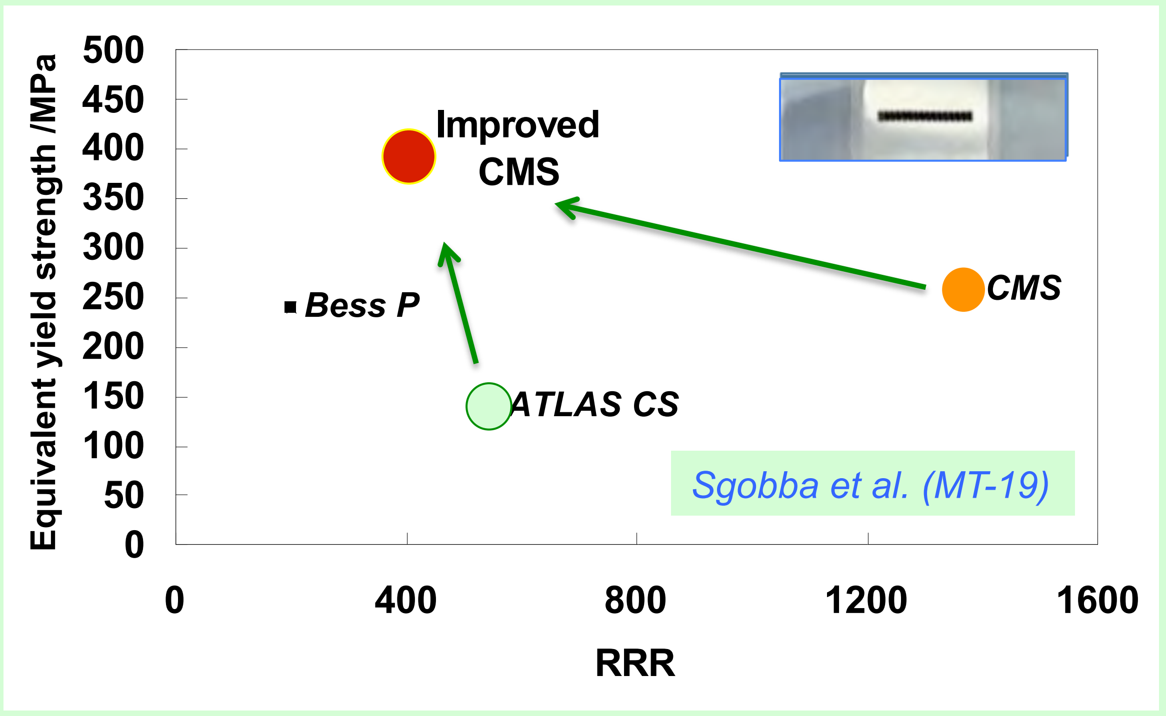


FCC (Courtesy, H. ten Kate)

- Reinforcement
  - Target:

    Y.S.(0.2%) = 400 MPa

    RRR = 400
- Issue: quench safety
  - Energy Extraction
  - Uniform E. Absorption
    - Fast Q. propagation,
    - Quench back



Sgobba et al. (MT-19)

Outline

- Introduction
- Advances in particle accelerators
  - Superconducting magnets and SRF
- Advances in particle detectors
  - Solenoid magnets in collider detectors
  - A unique application for scientific ballooning
- Recent advances in Japan

Scientific Objectives

Cosmic-ray Antiparticles provide important information on …

Elementary particle phenomena in the early universe

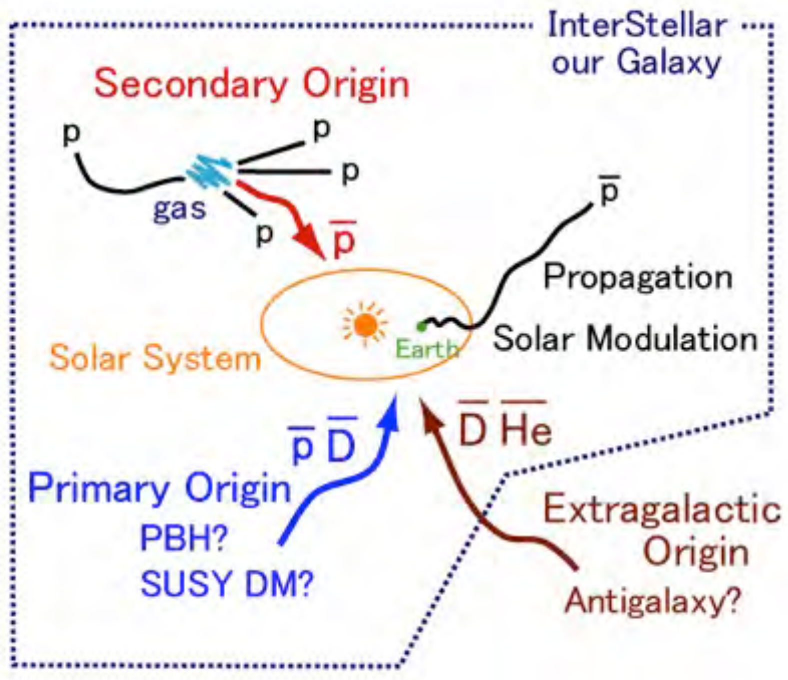
Matter/Antimatter symmetry,
SUSY darkmatter,
Primordial Black hole, etc.

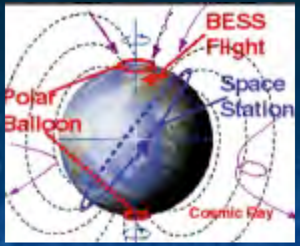
Fundamental data of Cosmic-ray

Production, propagation
Solar modulation
Interaction in the atmosphere

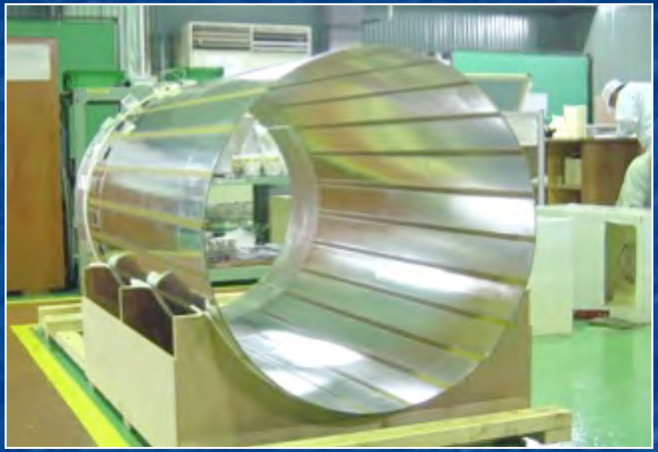
Fluxes are extremely small

No positive signals before late 1970’s.



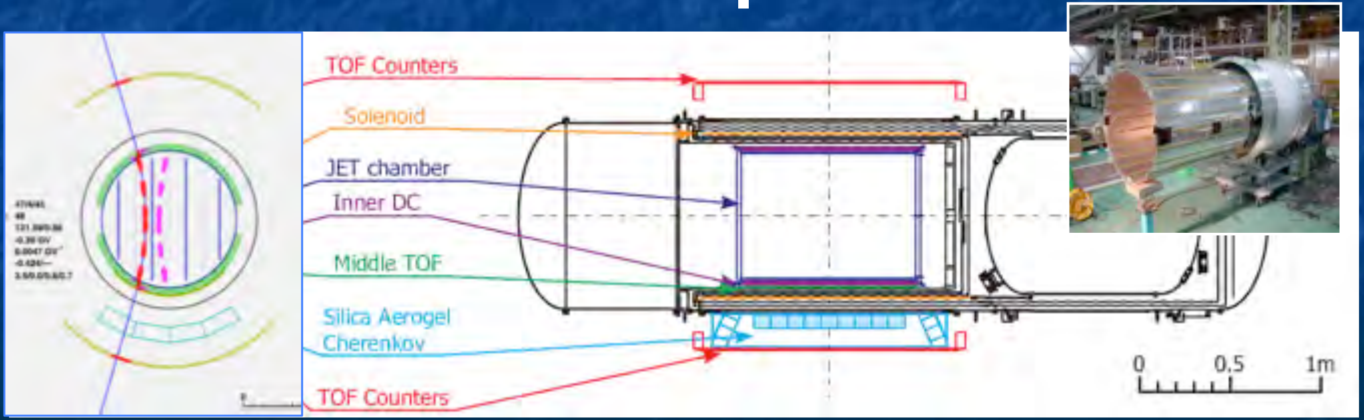


A Thin Solenoid for Cosmic-ray Observation in Antarctica



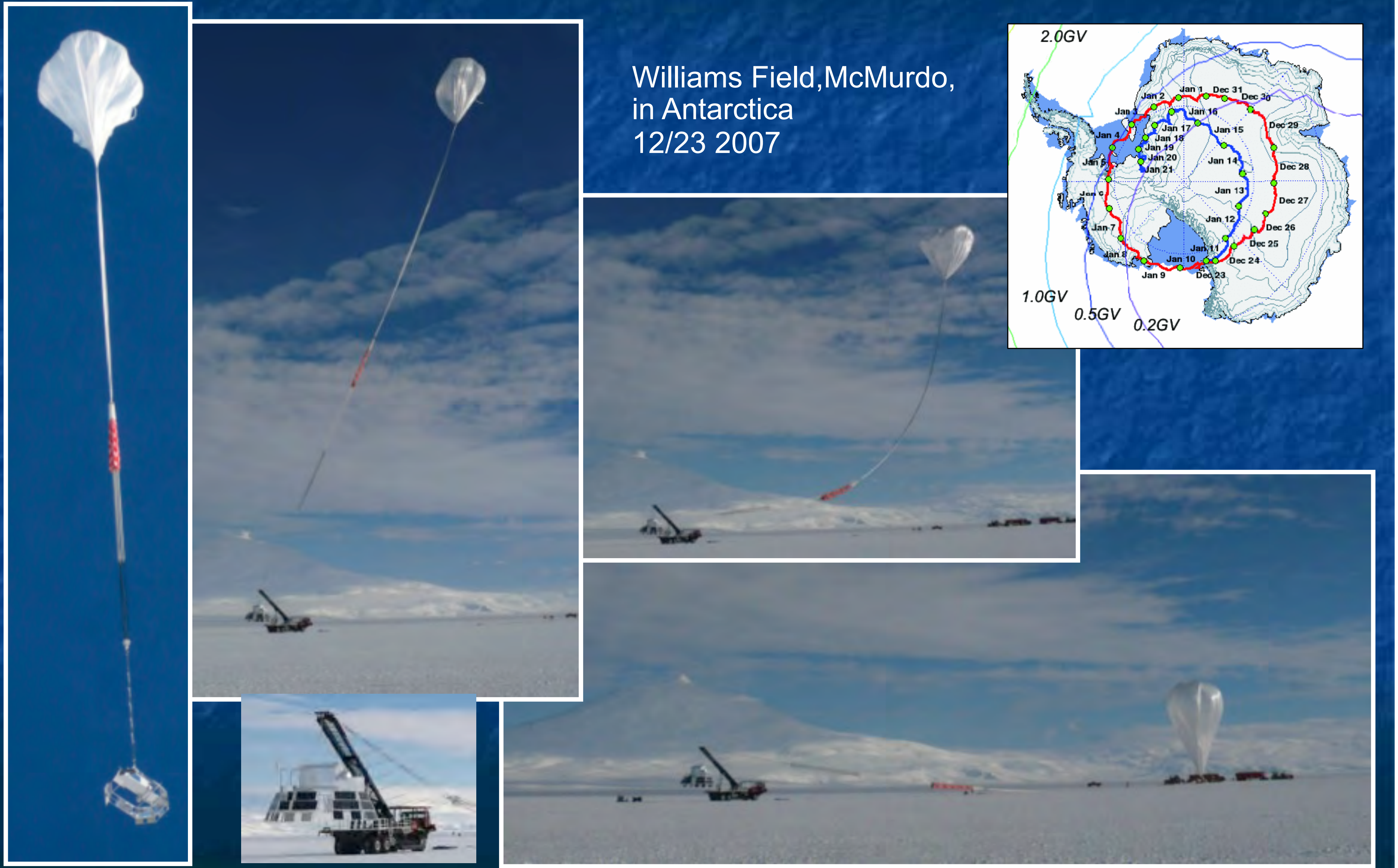
BESS-Polar Thin Solenoid

B: 0.8 (~ 1.05) T
D: 0.9 m
L : 1.3 m
t: 3.4 mm
X-coil: 0.06 Xo
X-total: 0.1 Xo
E/M : 7 (10) kJ/kg
LHe life: 25 days (~ 550 l)



Scientific Ballooning of BESS Detector at Antarctica

- for Cosmic-Ray Observation -



Williams Field,McMurdo,
in Antarctica
12/23 2007

End of BESS-Polar II Flight

- Flight termination January 20, 2008 ~30 days
- Location 83 ° 51.23' S, 73° 5.47' W
- On West Antarctic ice sheet - 225 nm from Patriot Hills Camp, 185 nm from AGO-2, 357 nm from South Pole
- Data successfully recovered February 3, 2008!

Outline

- Introduction
- Advances in particle accelerators
  - Superconducting magnets and SRF
- Advances in particle detectors
  - Solenoid magnets in collider detectors
  - A unique application for scientific ballooning
- Recent advances in Japan

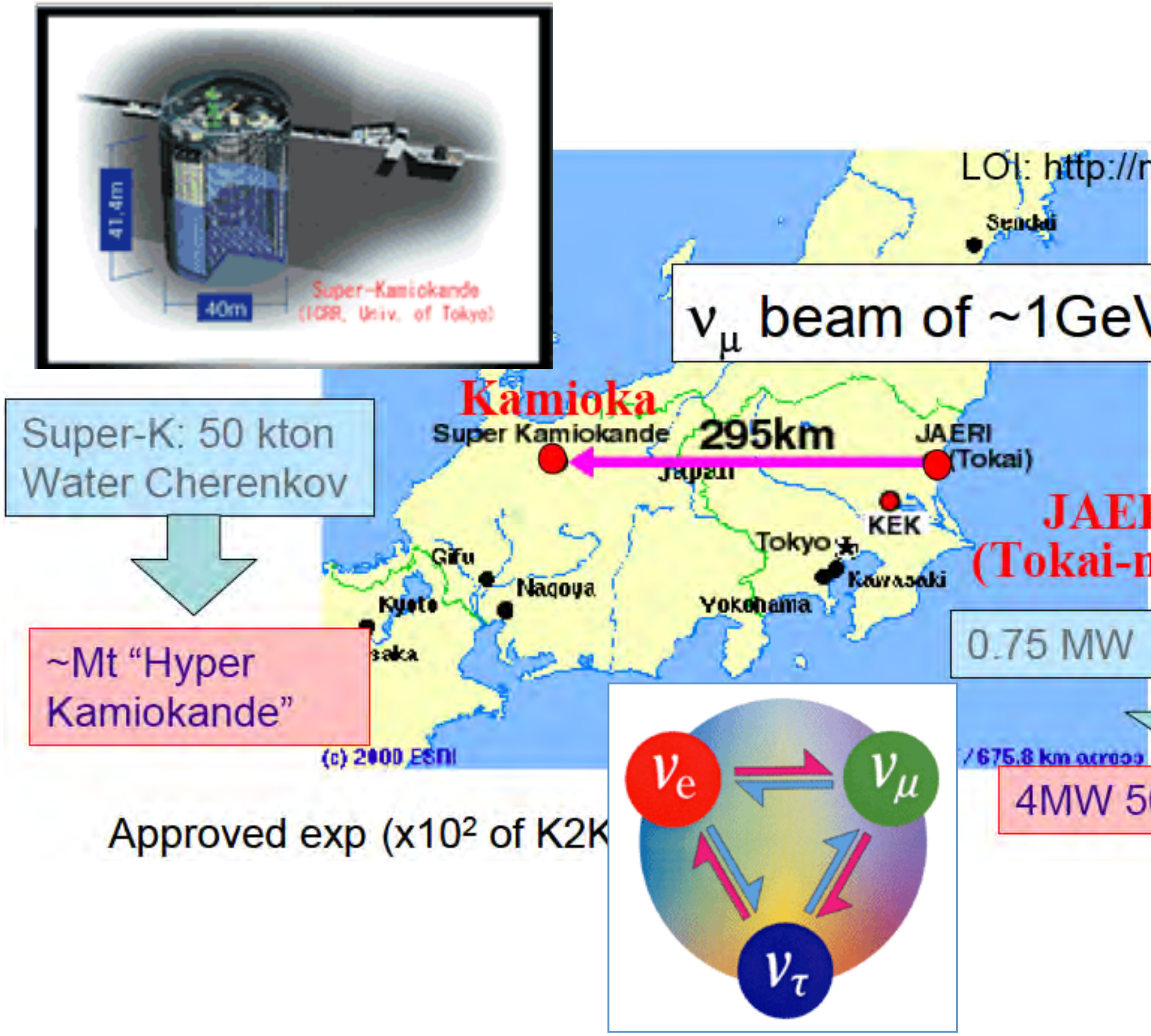
J-PARC Facility (KEK/JAEA)

LINAC
400 MeV

Rapid Cycle Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Design Power : 1 MW

Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1 MW

Primary Proton Beam Line for JPARC Neutrino Experiments



LOI: http://neutrino.kek.jp/jhfnu

ν_μ beam of ~1GeV

Super-K: 50 kton Water Cherenkov

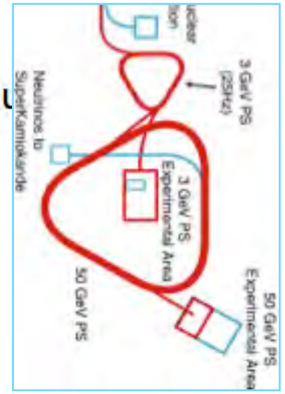
~Mt "Hyper Kamiokande"

JAERI (Tokai-mura)

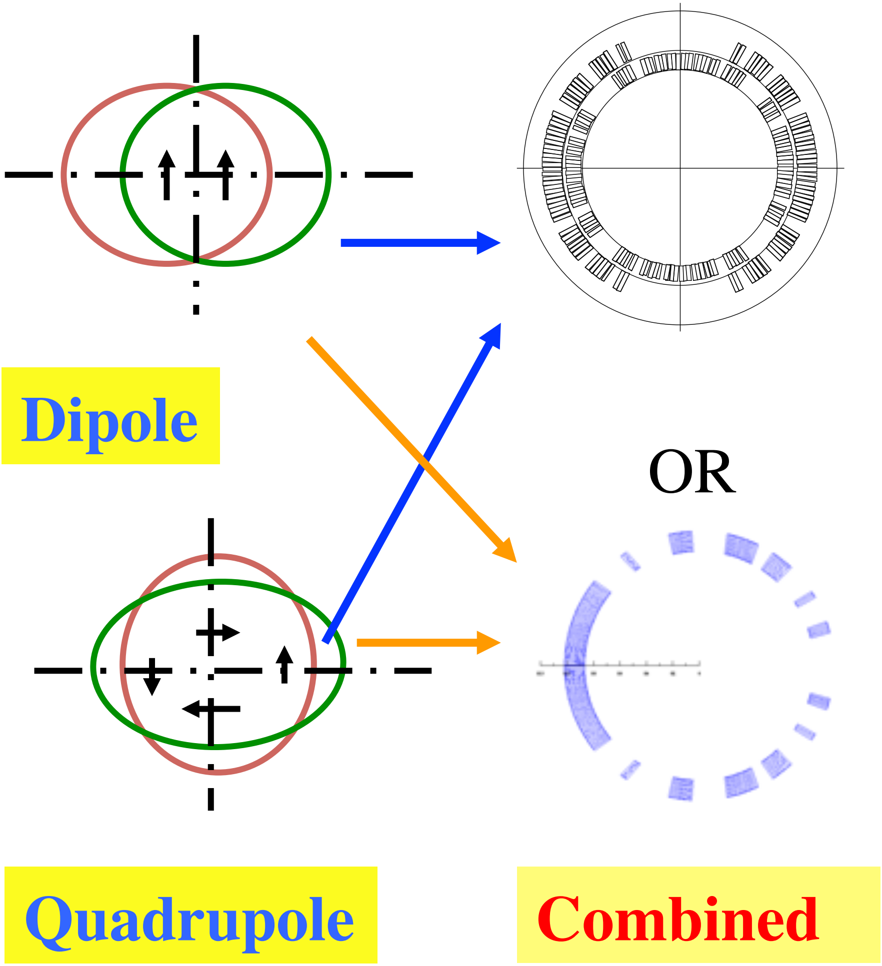
0.75 MW 50 GeV PS

4MW 50GeV PS

Approved exp (x10^2 of K2K



Superconducting
Combined Function Magnets



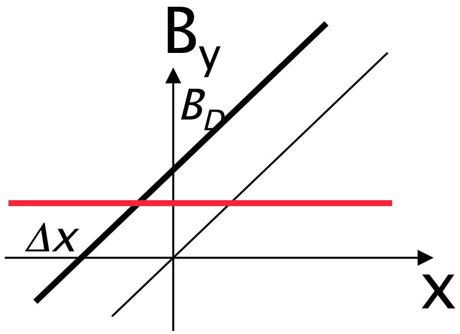
Dipole

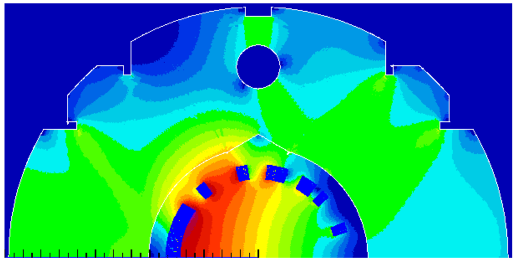
OR

Quadrupole

Combined

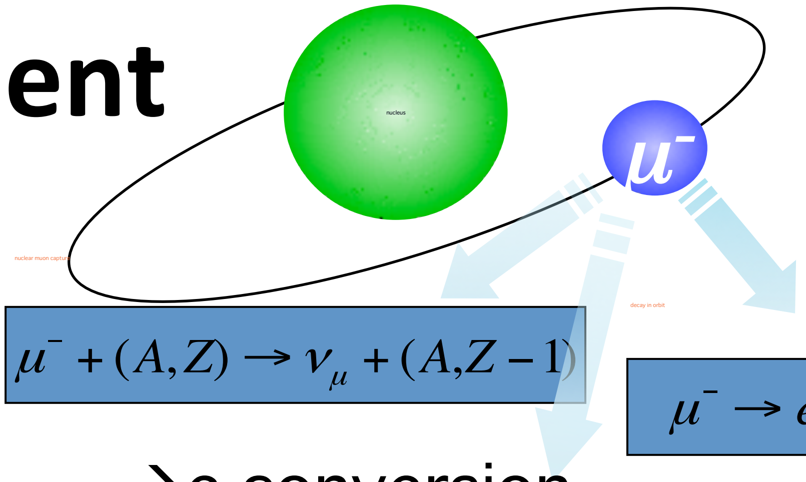
$$B_y = B_D + Q_{\mathrm{grad}} \times x$$
$$= Q_{\mathrm{grad}}(x - \Delta x)$$
$$\Delta x = -\frac{B_D}{Q_{\mathrm{grad}}}$$





Dipole: 2.6 T
Quadrupole: 19 T/m
Peak Field: 4.2 T

COMET Experiment



$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

μ→e conversion

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

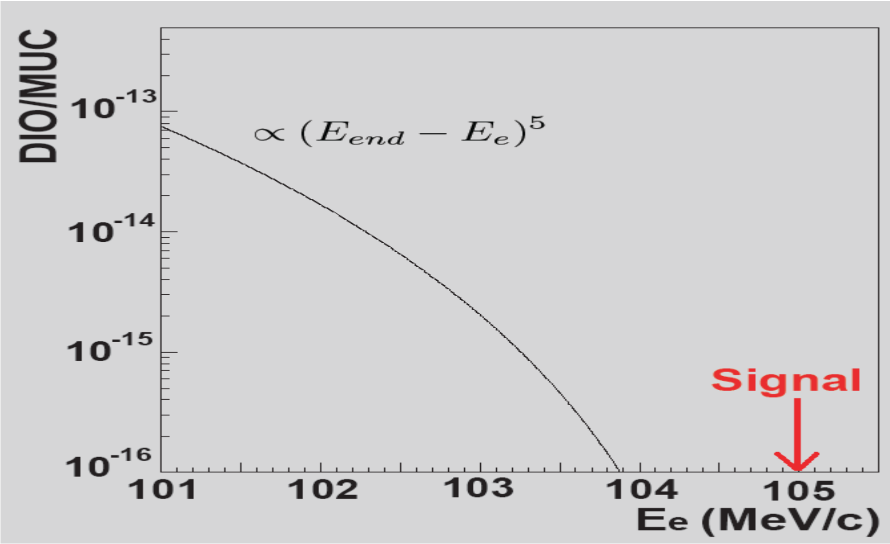
- J-PARC E21
- 8GeVx7μA
- stopping μ⁻ → Muonic atom

$$B\left(\mu^- N \rightarrow e^- N\right) = \frac{\Gamma\left(\mu N \rightarrow eN\right)}{\Gamma\left(\mu N \rightarrow \nu N'\right)}$$

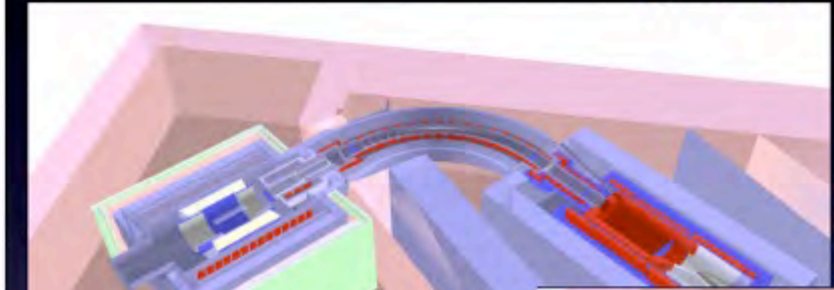
Detect monoenergetic electrons from μ-e conversion

Physics Reach: Br<10^{-16}
→ $2\text{x}10^{18}$ muon stops

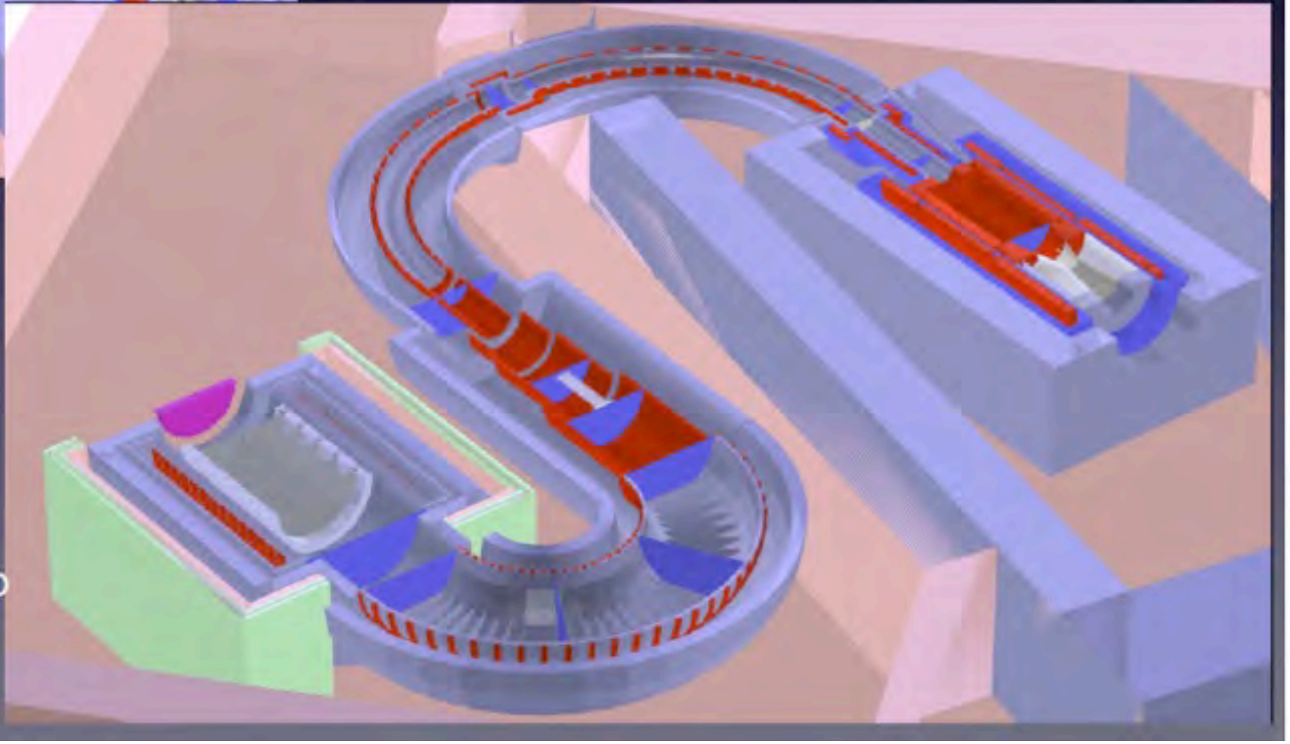
→ 10^{11} μ^-/sec



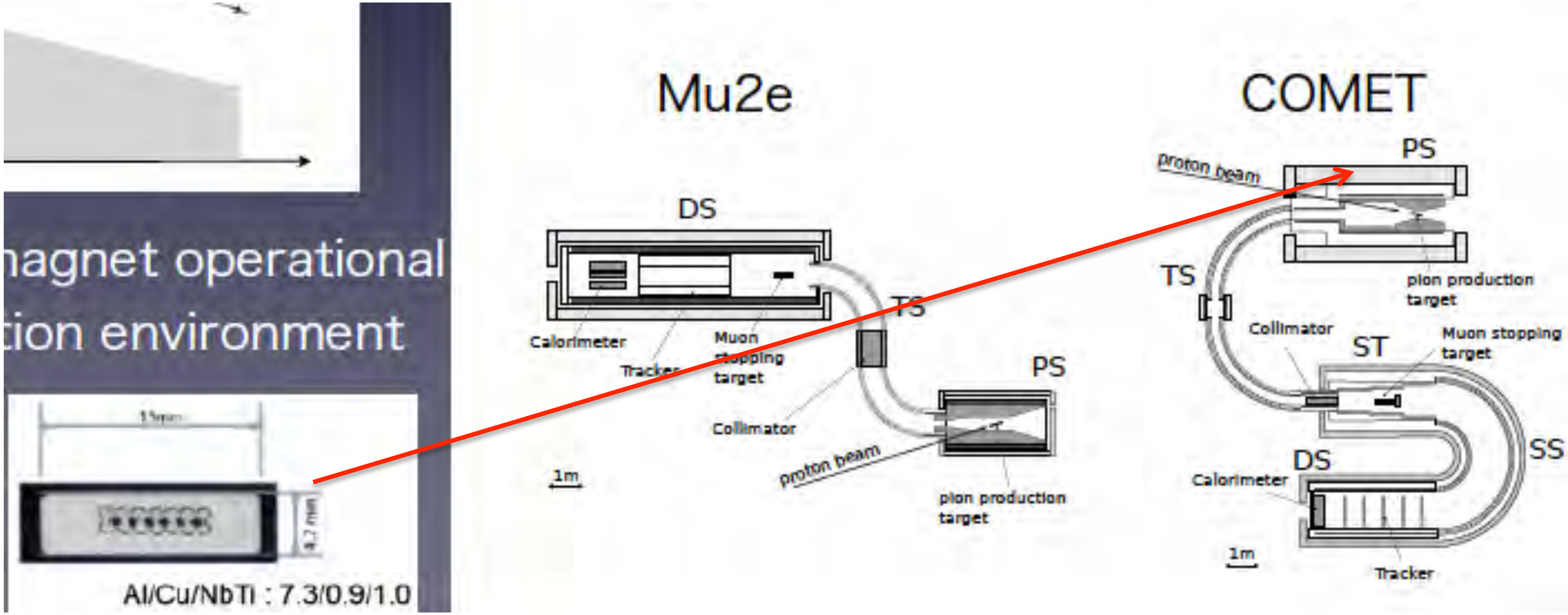
Solenoid Magnet Extension in Phase II



Phase I Setup (Proton Beam 3.2 kW)
Muon Transport by a 90 degree bend Solenoid
CDC detector in a spectrometer solenoid



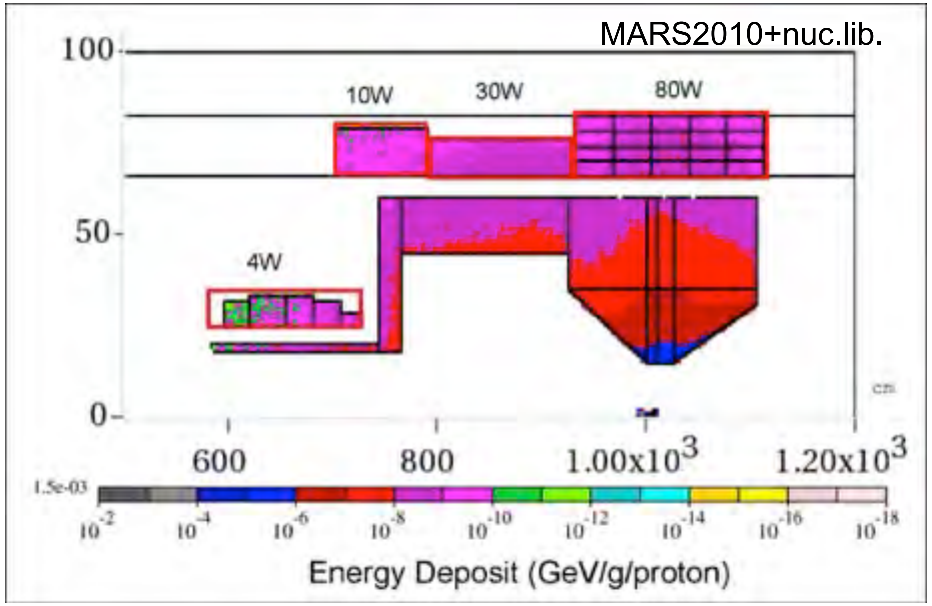
Phase II Setup (Proton Beam 56 kW)
Muon Transport by a 180 degree bending solenoid and a 180 degree bending spectrometer magnet to detect the signal
Straw Tracker & Ecal

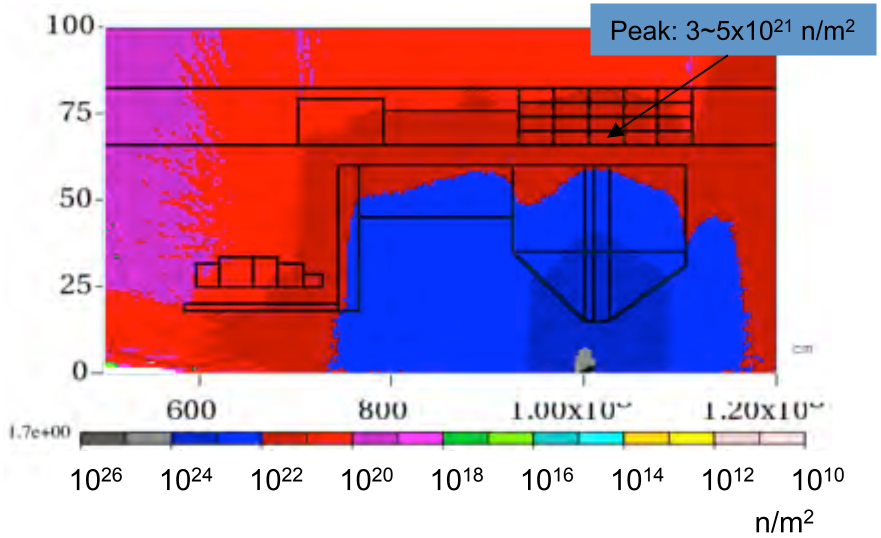

agnet operational
ion environment
15mm
4.2 mm
Al/Cu/NbTi : 7.3/0.9/1.0
Mu2e
DS
TS
PS
Calorimeter
Tracker
Muon stopping target
Collimator
proton beam
pion production target
1m
COMET
PS
proton beam
pion production target
TS
Collimator
ST
Muon stopping target
SS
DS
Calorimeter
Tracker
1m

Key Issue

Nuclear Heating : >100W
Peak dose rate in Al : ~1MGy
Neutron fluence : >10^{21} n/m^2

- Radiation tolerance of magnet materials
- Organic material
  - Strength
  - Out gas
- Metal
  - Electrical conduction
  - Thermal conduction
- Radioactivation of He





Muon g-2

- Muon g-2, the experiment and the Standard Model prediction, directly test and challenge our understanding of 3 of the 4 known forces.
- The muon g-2 is a fundamental constant of nature, and should be measured as precisely as possible.

- There is presently **a 3 sigma difference** between the Standard Model prediction and the most precise experimental result, from BNL.

$$\delta a_\mu \equiv a_\mu(\mathrm{exp}) - a_\mu(\mathrm{SM}) = \begin{cases} (24.6 \pm 8.0) \times 10^{-10}, & (3.1\ \sigma)^{\text{HLMNT}}_{\text{(2011)}} \\ (27.2 \pm 8.0) \times 10^{-10}, & (3.4\ \sigma)^{\text{DHMZ}}_{\text{(2012)}} \end{cases}$$

- This suggests, particularly if this difference is confirmed by future experiments and further progress on the Standard Model, physics beyond the Standard Model.

$$a_\mu = a_\mu(QED) + a_\mu(had) + a_\mu(weak) + a_\mu(BSM)$$

- There is **one experiment being prepared at Fermilab**, which will use the same 14 meter diameter storage ring, largely the same technique, and with largely the same experimenters, to remeasure g-2.

muon g-2/EDM measurements

Anomalous magnetic moment (g-2)

a_μ= (g-2)/2 = 11 659 208.9 (6.3) x 10^{-10} (BNL E821 exp) **0.5 ppm**

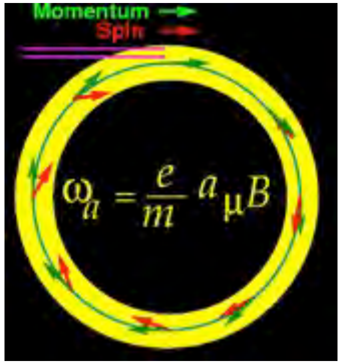
11 659 182.8 (4.9) x 10^{-10} (standard model)

Δa_μ= Exp - SM = 26.1 (8.0) x 10^{-10} **3σ**

In uniform magnetic field, muon spin rotates ahead of momentum due to g-2 = 0

general form of spin precession vector:

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$



BNL E821 approach
γ=30 (P=3 GeV/c)

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

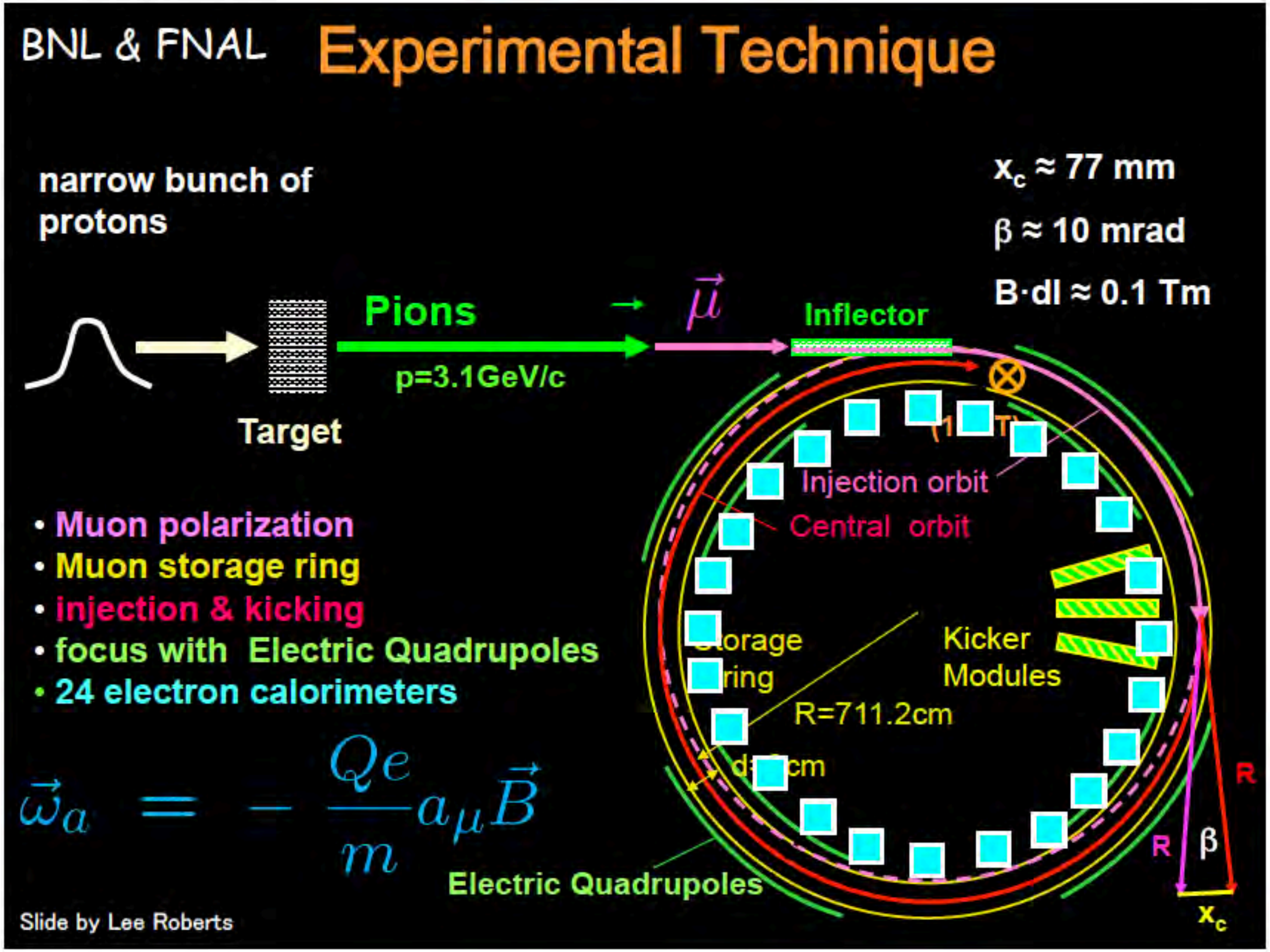
Continuation at FNAL with 0.1ppm precision

J-PARC approach
E = 0 at any γ

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

Proposed at J-PARC with 0.1ppm precision

from T. Mibe



BNL & FNAL

Experimental Technique

$x_c \approx 77$ mm

$\beta \approx 10$ mrad

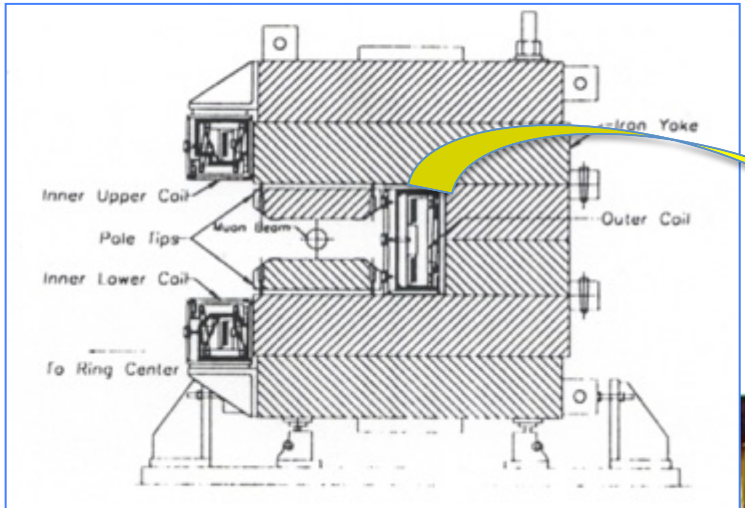
$B \cdot dl \approx 0.1$ Tm

- Muon polarization
- Muon storage ring
- injection & kicking
- focus with Electric Quadrupoles
- 24 electron calorimeters

$$\vec{\omega}_a = -\frac{Qe}{m} a_\mu \vec{B}$$

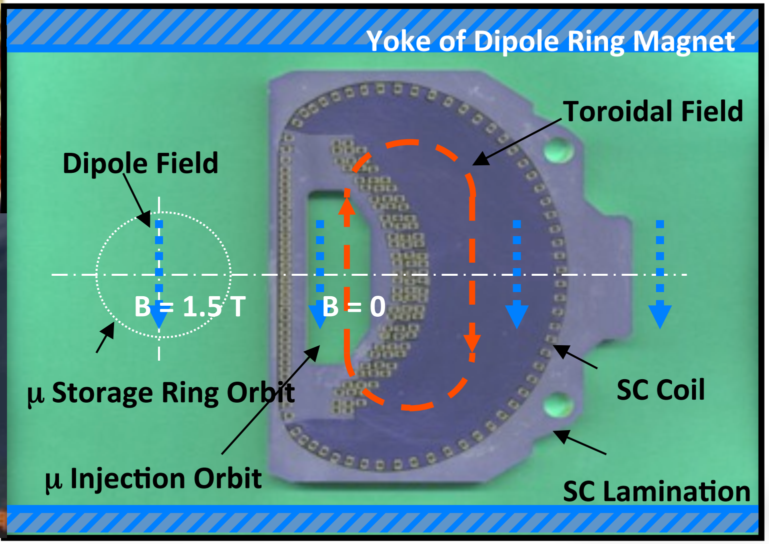
Slide by Lee Roberts

BNL E821 Superconducting Magnet

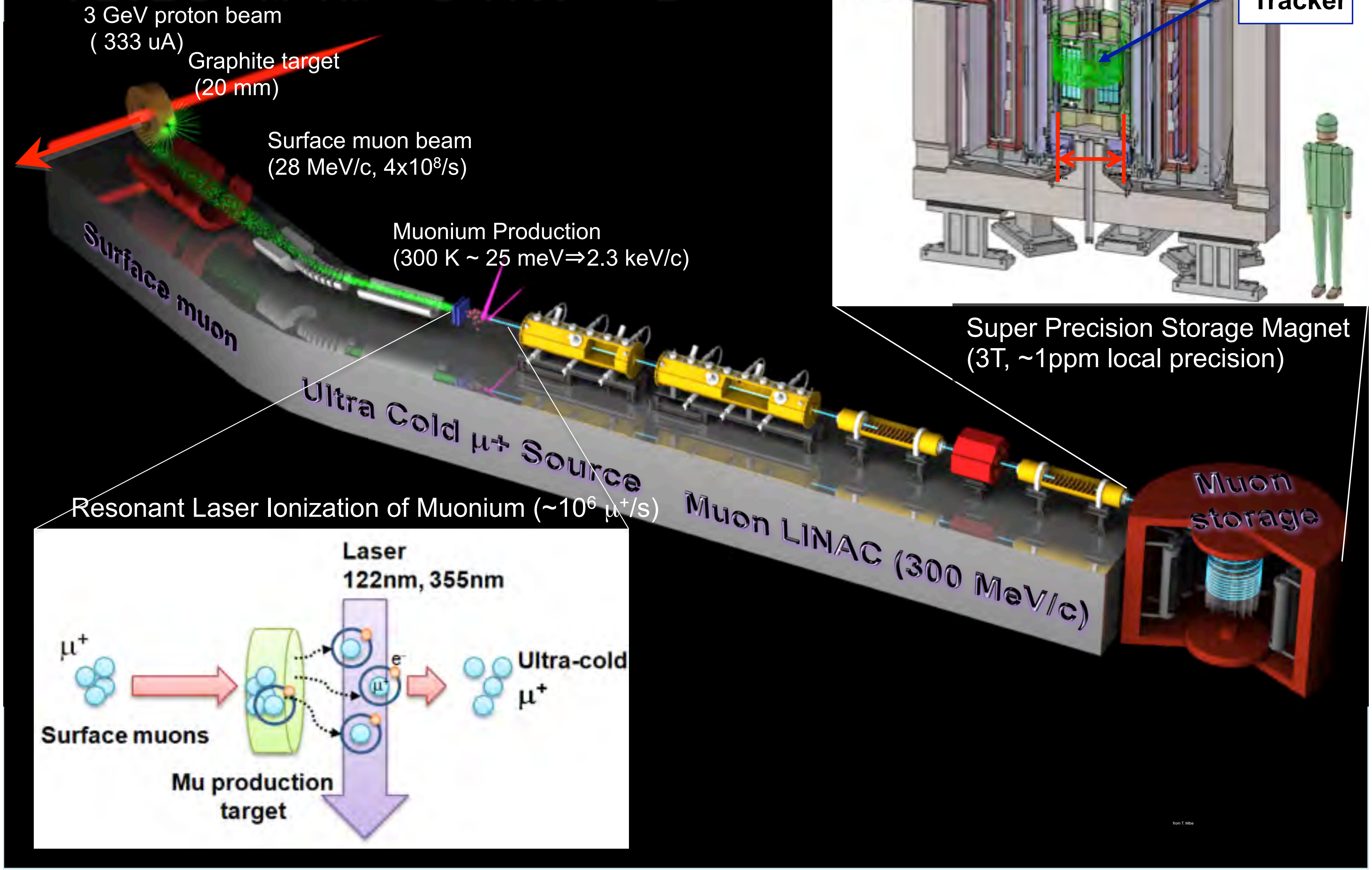


Cross-Section View of Storage Ring

Ring SC Coil



New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam



3 GeV proton beam
(333 uA)

Graphite target
(20 mm)

Surface muon beam
(28 MeV/c, 4x10^8/s)

Muonium Production
(300 K ~ 25 meV⇒2.3 keV/c)

Super Precision Storage Magnet
(3T, ~1ppm local precision)

Resonant Laser Ionization of Muonium (~10^6 μ^+/s)

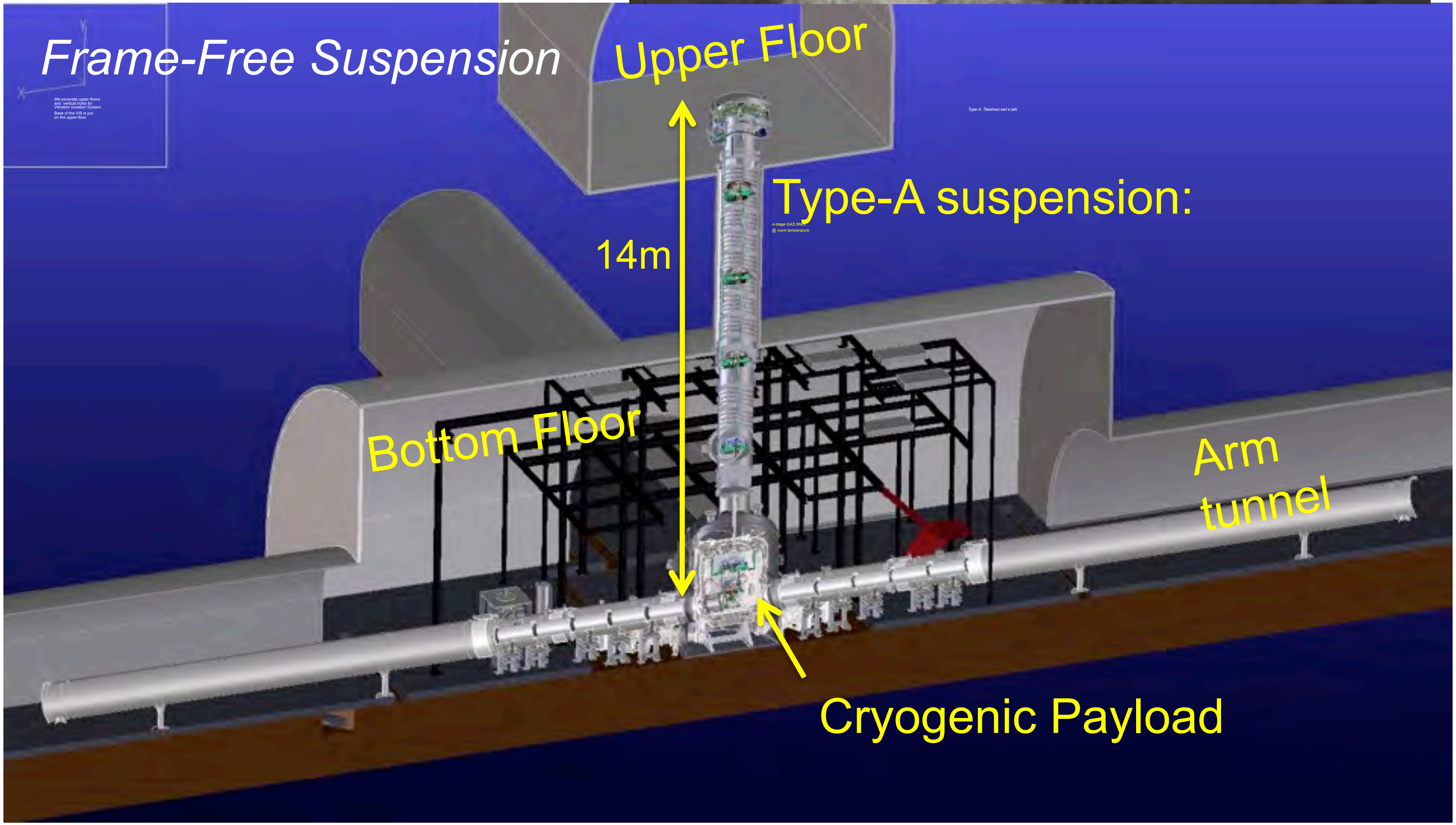
from T. Mibe

Features in KAGRA

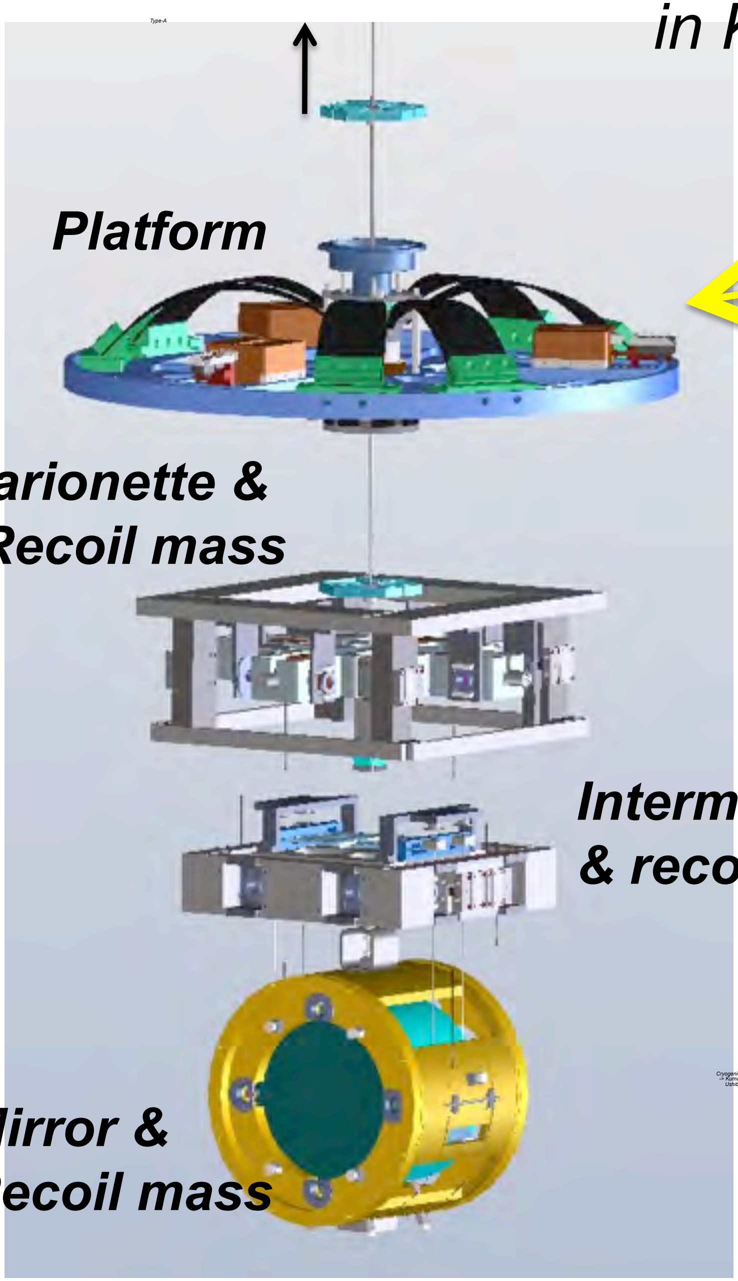
Cryogenic Mirror
S

Underground

Main Mirror Suspension



Cryogenic Payload *under developing in KEK and ICRR*



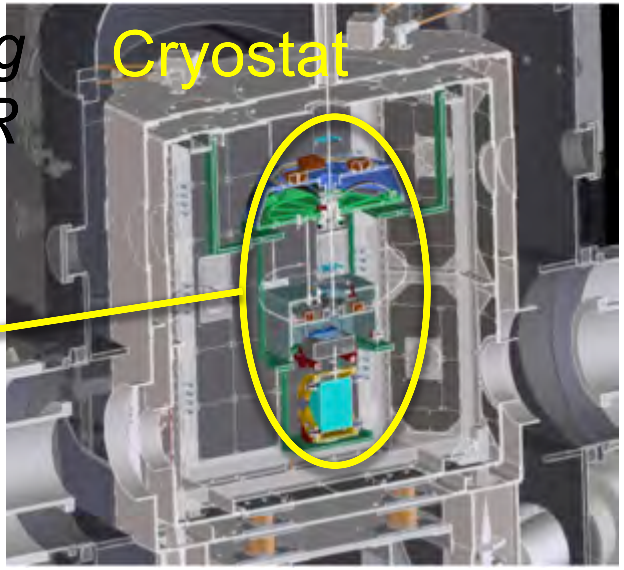
Platform

Marionette & Recoil mass

Intermediate mass & recoil mass

Mirror & Recoil mass

Cryogenics Talks
-> Kumar, Miyamoto, Ushiba and Craig



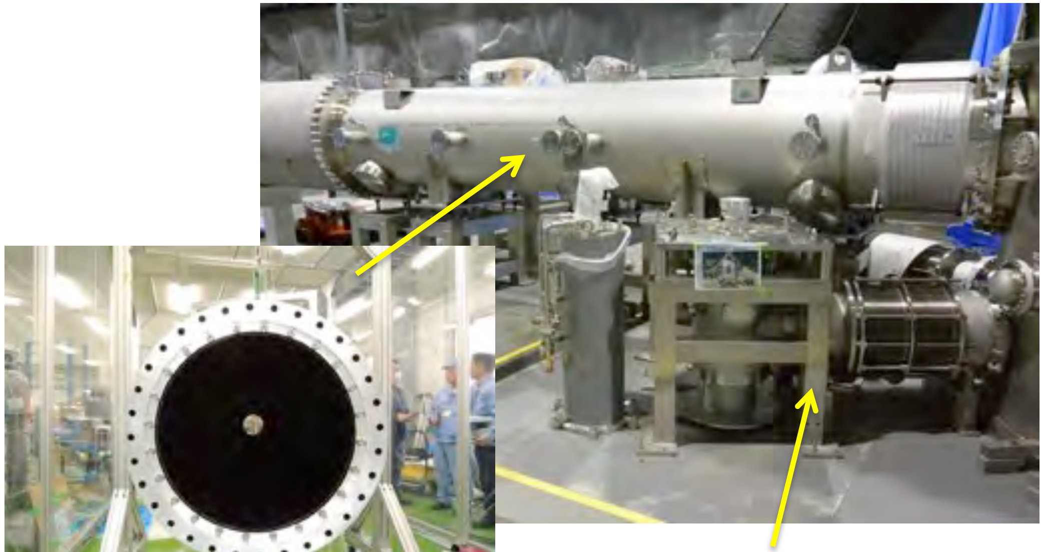
Prototype Cryo-Payload

KAGRA Cryogenics

KAGRA cryostat

6N Al
thermal conductor

Cryostat assembly

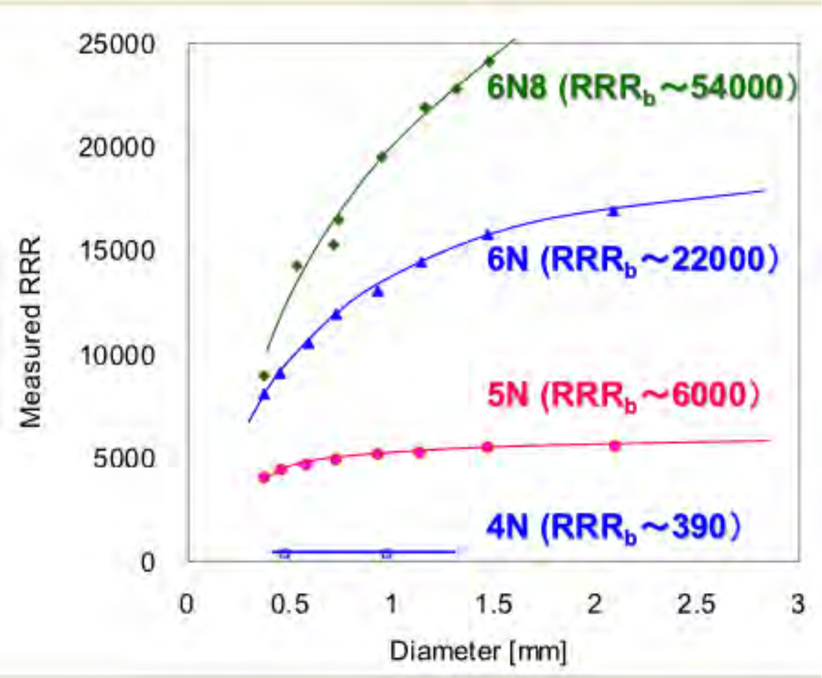


Thermal radiation
reduction by cryogenic “black” pipe

Vibration-Free
cryocooler

Very soft thermal conductor

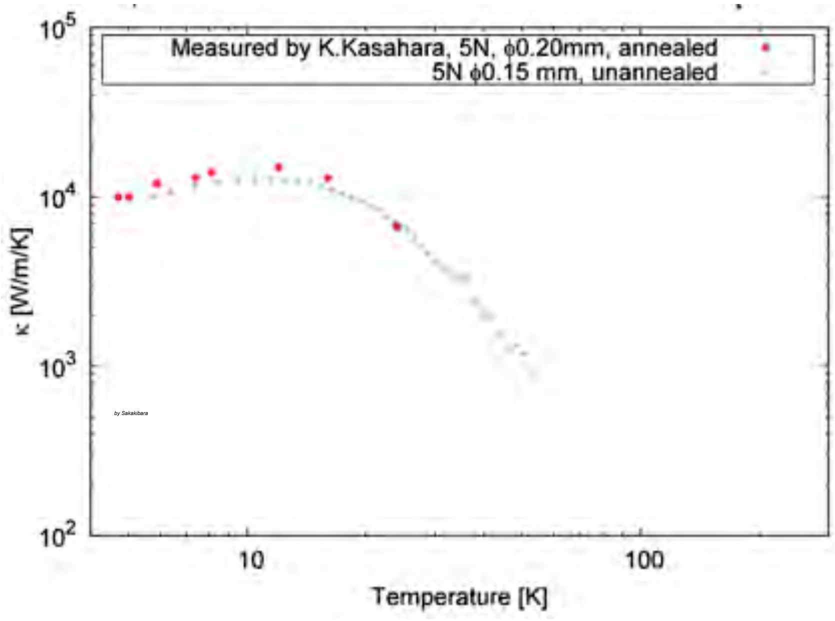
Size effect dominates conductivity o
6N Al thin wire at low temp.



Hoshikawa et al. ICEC-ICMC 2012

Estimated RRR

	Bulk	Φ1.0mm	Φ0.15mm
6N	~22,000	~14,000	~4,000
5N	~6,000	~5,000	~2,700
4N	~390	~390	-



by Sakakibara

Estimated thermal conductivity of 6N Al w/ Φ0.15mm is about 17,000, which is about 1.5 times larger than that of 5N Al.