Early Days of CDF

Japanese Contribution

Masa Mishina
(KEK, Fermilab Retired)

Tribute

to

Kunitaka Kondo

(Tsukuba/Waseda University)

(1934-2011)

Played a central role in entire process.

Prehistoric Tales

before this large scale International collaboration

Japanese International Collaboration

- INS Tokyo U.- Brazil   Mt. Chacaltaya (Bolivia))

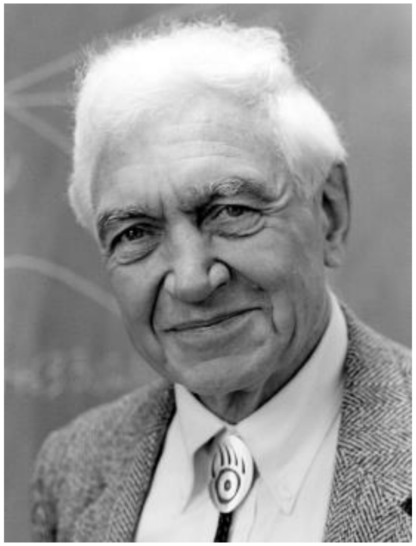
  : Cosmic ray (nuclear emulsion) experiment   1962~
- Osaka City U.(Miyake) - India,   Kolar Gold Mine (India)

  : Cosmic ray experiment. Scintillation counter and Neon flash Tubes   1961~
- Tokyo U. (M. Koshiba),

  DASP (DORIS), JADE (PETRA, DESY) (1977~1979)

  OPAL(LEP)   (1998~2000)
- KEK & Other Universities (K. Takahashi)

  15-ft bubble chamber (Fermilab, L. Voivodich)
- Tsukuba U. (K. Kondo) – Yale U. (V. W. Hughes)   (1973-1980)



Vernon Willard Hughes (Yale University)

(1921-2003)

From “A Biographical Memoir” by Robert K. Adair
National Academy of Science Vol 84 (2003)
National Academies Press

Kuni Kondo stayed at Yale in 1971-1972(?)

Since they had a lifelong friendship.

Yale-Tsukuba collaboration (1973-1980)

SLAC : Polarized electron beam on polarized proton target

BNL (M. Zeller, Yale) : Hadron beams on polarized proton target

Collaboration in CDF (Colliding Detector Facility Department) started in 1979 before a formal agreement between DOE and Mombusho.

US-JAPAN COLLABORATION
IN
HIGH ENERGY PHSYCS

Implementation signing
November 1979
at
SLAC

Kondo organized the 30th anniversary symposium .

(Proceedings edited by Satoshi Ozaki, BNL)

Organizing Committee

M. Nozaki (KEK), K. Kondo (Waseda), T. Yamanaka (Osaka), S. Kim (Tsukuba)

G. Loew, (SLAC), S. Ozaki(BNL), R. Rubinstein(FNAL)

Satoshi Ozaki passed away on July 22.

Bernard Hildebrand (DOE, Retired)

and

William Wallenmeyer (Head DOE Office of HEP, Retired)

Gave a detailed account of the events leading to the final agreement.

William Wallenmeyer

"President Carter considered the energy crisis the Nation's greatest challenge, except for preventing war.

On the day after his inauguration in January 1977, he named James Schlesinger as his personal representative to work on an immediate energy problem.

On February 2, Carter proclaimed a national emergency on energy.

In the first 90 days of Carter's presidency, Schlesinger developed the administration's basic energy-reorganization plans, including a new Cabinet Level Department of Energy, and new energy policy strategies.

Legislative action creating the Department of Energy was completed by August 3, 1977, Carter signed the Bill into law on August 4, and the next day named Schlesinger as the first Secretary of Energy.

The Department was officially activated on October 1, 1977."

Umbrella agreement

Japan/US Collaboration
in
R & D
on
New Energy Sources and Related Fields

(Nuclear Fusion, Coal Liquification, Solar Photo synthesis, Geo Thermal Energy, Wind Mill, Superconducting Power Transmission Cable,….)

Carter – Fukuda Agreement
(Schlesinger - Saito)
May 1978

1978 in High Energy Physics

- Leon Lederman designated as the next director
- Alvin Tollestrup took over the head of CDF Department
- ISABELLE workshop. Tunnel ground breaking.
  - *Kuni Kondo, Fumihiko Taksaki, and M.M. attended the workshop,*
  - *Kondo had a discussion with Alvin about a possible collaboration.*
- Rochester Conference in Tokyo

  Idea of US-Japan collaboration I high energy physics was intensely discussed.

Testuji Nishikawa (KEK) (1926-2010)

started talking with :

Leon Lederman (Fermilab)
Satoshi Ozaki (BNL)
Ryuji Yamada (Fermilab)
Bernard Hildebrand (DOE)
William Wallenmeyer(DOE,Office of HE)
……

a possibility of including *High Energy Physics in the energy-related agreement*.

with Panofsky too

Wolfgang (Pief) K. H. Panofsky
(1919-2007)

TRISTAN ground breaking (1981)

Nishikawa was an expert on linac.
Panofsky and Nishikawa were good friends

Vernon Highes and Panofsky were classmates at CALTECH.
Kuni Kondo was working with Hghes on polarized electron-polarized target experiment at SLAC and Hughes introduced Kondo to Panofsky.

Nov 6, 1978

Secretary of Energy Schlesinger met Prime Minister Fukuda in Japan on Nov.6, 1978.

One subject they discussed was the proposed

Japan/US Collaboration in R & D on New Energy Sources and Related Fields

including High Energy Physics.

Joint Working Group set up.

HEP Subgroup

T. Saito (MOE)	J. Sandweiss (Yale)
T. Nishikawa (KEK)	B. Hildebrand (DOE)
L. Lederman (FNAL)	W. Wallenmeyer (DOE)
S. Ozaki (BNL)	

May 2, 1979

Ohira (New Prime Minister) visited Washington DC.

AGREEMENT
between
US and JAPAN
on
COOPERATION
in
R & D in ENERGY and RELATED FIELDS
(High-Energy Physics included)

was signed by

J. Schlesinger : Secretary of Energy,
S. Sonoda : Foreign Minister

Nov 11, 1979

signing

"IMPLEMENTING ARRANGEMENT
between
US DOE and Japanese MOE
on
COOPERATION
in
the FIELD
of
HIGH ENERGY PHYSICS".

1978 November

MOMBU SHO instructed Kikuchi to make 10-year plan for US-Japan Collaboration

Kikuchi and Kondo made a draft proposal in a hurry.

Nov 11: Armistice Day Shoot Out at Fermilab

Plan A: $\bar{p}$-p (1 TeV x 1 TeV Tevatron)

Plan B: p (400 GeV Main Ring)-p (1-TeV Doubller/Saver)

1979

April : First year budget from Japanese government allocated.

August : M. M. settled in Fermilab

Events around the time

1978 Stochastic Cooling was tested at ICE (CERN).

Test on electron cooling ring at Fermilab in progress

1981 Technology transfer for the ISABELLE superconducting magnet to Grumman failed.

1981-1984 CERN S$p\bar{p}$S

1982 December Energy Saver/Doubler commissioned

1983 W, Z discovered

ISABELLE/CBA cancelled in favor of SSC (cancelled 1993)

512 GeV reached by Energy Saver/Doubler

May 1979 (From Ken Kikuchi's memoir)

Proposed Experment (Approved)

1) Neutrino Scattering	Nagashima (Osaka)	- BNL
2) Bubble Chamber	Kitagaki (Tohoku)	- BNL, FNAL,SLAC
3) p-p Colliding Beam	Kondo (Tsukuba)	- FNAL
E 605	Miyake (Kyoto)	- FNAL
4) Neutrino Interaction E 594	Osugi (Hiroshima)	- FNAL
5) Bubble Chamber	Kitagaki (Tohoku)	- FNAL
6) Neutrino (Emulsion) E531 (E872 DONUT later)	Fujioka (Kobe), Nyu (Nagoya)	- FNAL
7) Charm Production	Ozaki (Osaka)	- FNAL
8) Electromagnetic Shower	Dake (Konan)	- FNAL
9) PEP-4 (TPC) experiment	Kamae (Tokyo)	- SLAC
10) LASS	Kajikawa (Nagoya)	- SLAC
11) Hybrid Bubble Chamber	Takahashi (KEK)	- SLAC

** K-TeV was proposed and approved much later.*

The Tevatron Collider: A Thirty Year Campaign

Fermilab Colloquium March 10, 2010

John Peoples

The Tevatron I Project

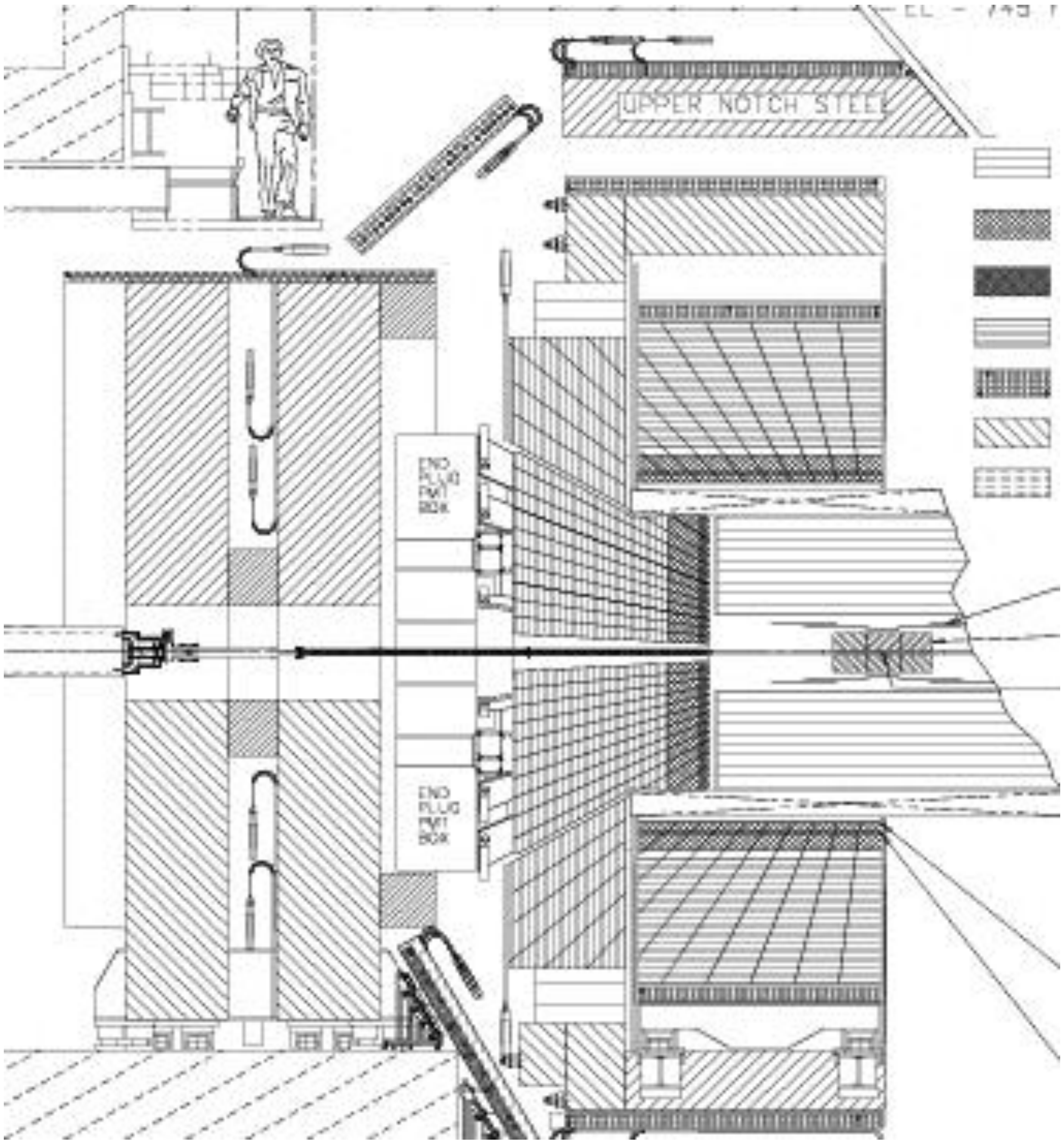
- In mid 1979 Leon gets a phone call from Washington. “If Fermilab submits a proposal for colliding beams it is likely that it will be approved.”
- Fermilab submits a proposal for Tevatron I. Cost $41.5 million without R&D. It appears in the FY81 budget.

Consensus on the CDF detector was reached quickly.

Axially symmetric :

Tracking
Calorimeter (EM + HAD)
Muon

- *4π coverage*
- *Hermeticity*
- *Projective towers*



THIN WALL SUPERCONDUCTING SOLENOID

Possibity:

*ANL group : Just finished large solenoid for MHD generator and

shipped to Moscow.

The director petitioned for the task in a letter to Leon

*Fermilab : a)Active on Tevatron magnet

b) Bob Kephart just finished converting Chicago Cyclotron

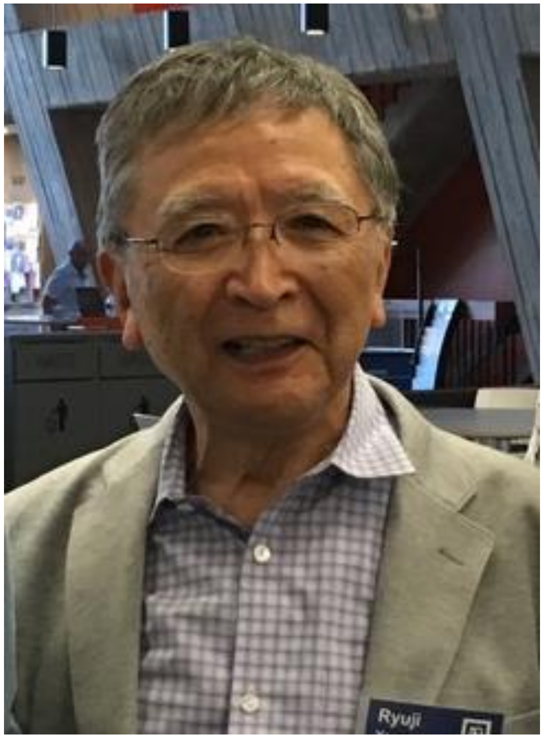
magnet into a superconducting analyzing magnet.

Ryuji Yamada

proposed to Kondo that Japanese group carry the task.

Made a prototype together with M. Wake at KEK.

*Japanese group (Tsukuba, KEK, Shigeki Mori)



References:

"Characteristics of Thin Wall Superconducting Solenoid Magnets and Its Model Magnet Results",
R.Yamada, et al.,
Proc. International Cryogenic Engineering Conference, vol9 (Kobe) p221 (1980)

"Quench Simulation in the Thin Superconducting Solenoid", T.Tominaka, M.Takasaki, M.Wake and R.Yamada
KEK 83-11 (1980)

"Cooling and Tests of a Thin 1mØ X 1m Superconducting Solenoid Magnet",H. Hirabayashi et al.,
Japan J. Appl. Phys. [21] 1149 (1982)

Funding in Japan secured through Tsukuba University.

Leon decided to assign the task to Tsukuba University under the overall charge of Bob Kephart.

Responsibility

Bob Kephart	: In charge of the solenoid project
Japanese group	: Solenoid fabrication
Ferlmilab	: Return yoke
	Cryogenic system
	Operation
	Mapping

US side

R. Kephart :   Project Leader
D. Theriot
R. Yamada
R. Fast
R. Wands

Japan side

Shigeki Mori : In charge
H. Hirabayashi
A. Yamamoto
K. Morimoto
R. Saito (Engineer from Hitachi)

FERMILAB-TM-1135

DESIGN REPORT FOR AN
INDIRECTLY COOLED 3-m DIAMETER
SUPERCONDUCTING SOLENOID FOR THE
FERMILAB COLLIDER DETECTOR FACILITY

FERMILAB
OCTOBER, 1982

Design Report (254 pages)

- Parameters
- Superconducting cables
- Structure
- Field distribution
- Cryogenics
- Finite element analysis

Troubled Predecessors

Thin wall solenoid was regarded as a risky gadget.

		CELLO	CLEO	TPC	CDF
		PETRA DESY	CESR Cornell	PEP SLAC	TEVATRON
Bore					
Diameter	m	1.656	2	2.18	2.858
Length	m	3.4	3.25	3.3	5.067
Radial Thickness	Rad L	0.5	0.75	0.75	0.84
Central Field	Tesla	1.3	1	1.5	1.5
Current	kAmp	3.2	1.6	2.23	5
Stored Energy	MJ	5.4	9.4	10.9	30
Conductor					
Superconductor		NbTi/Cu	NbTi/Cu	NbTi/Cu	NbTi/Cu
Stabilizer			Al(2ndary)	Al/Cu(2ndary)	Al
NbTi-CuAl ratio					1:01:21
Cross Section	$(mm)^2$	2.24 x 10.6	1.83 x 3.43	1 x 3.7	3.89 x 20
Fabrication Process		NbTi soldered	NbTi/Cu	NbTi/Cu	NbTi/Cu-Al
		on Cu			Co-extruded
Frame		Al Bobbin	Al Bobbin	Al Bobbin	Outer Frame
Completion		1979	1981	1983	1984

<u>Three major innovations</u>

- Pure Aluminum Stabilizer*
- **In case of a quench, a nearby stabilizer bypasse the huge current to avoid heat - voltage surge.*
-

A) At low temperature, better conductivity than Copper

NBS Note 1053

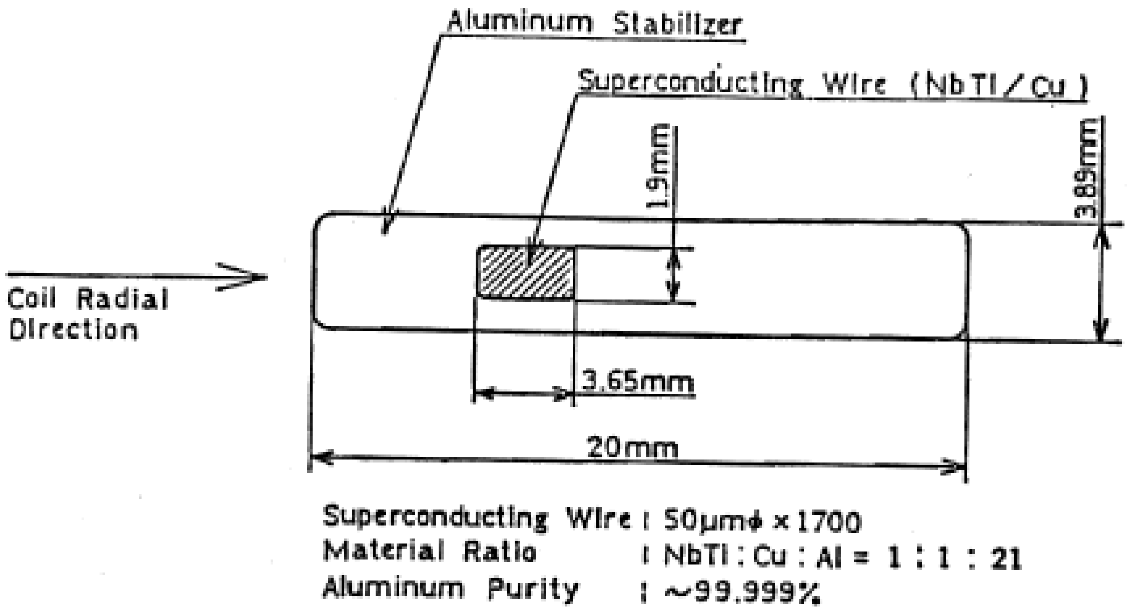
	273 K	ρ (273 K)/ρ (4 K)	=> 4 K
Al:	2.43 μΩ· cm	$4x10^4$	=> 0.06 nΩ· cm
Cu:	1.55 μΩ· cm	$1.2x10^4$	=> 0.13 nΩ·cm

B) Thinner material

	Z	A	d g/cm^3	dE/dx MeV / (g/cm^2)	MeV / cm	Rad L cm	Nuc_Int L g/cm^2)
Al:	13	26.98	2.70	1.615	4.37	8.9	106.4
Cu:	29	63.55	8.96	1.403	12.58	1.43	134.9

- Co-extrued with superconducting cable
    - *Invention by Hitachi Densen*

Greater mechanical bonding with superconductor cable



- Outer bobbin/frame

: When energized, coil expands (=radial tension) and

rather flimsy outer frame provides superior grip.

Shrink Fitting

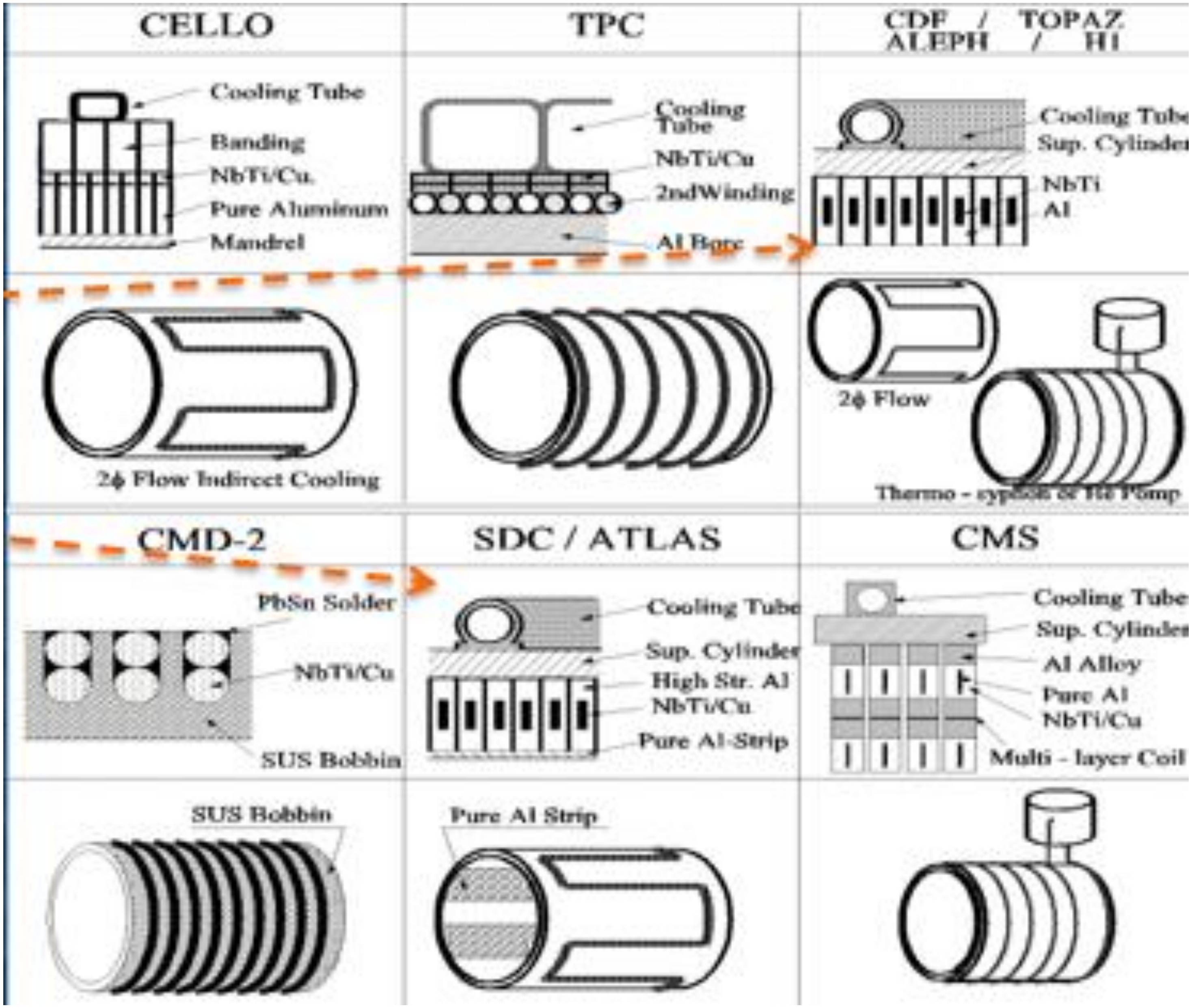
Heating the outer hoop to ~100℃)

Aluminum

Thermal Expansion Coeff		25×10^{-6} /℃ (0-100℃)
Temperature difference	X	~ 80 ℃
Diameter	X	3 meter
Clearance in diameter	=	~ 6 mm

Yamamoto devised coil winding inside an outer frame for TOPAZ solenoid.

A.Yamamoto et al.,
“A Thin Superconducting Solenoid Would with the Internal Winding Method for Colliding Beam Experiments”,
J. de Phys/ 45 (1984) C1-337


CELLO
TPC
CDF / TOPAZ
ALEPH / H1
Cooling Tube
Banding
NbTi/Cu.
Pure Aluminum
Mandrel
Cooling Tube
NbTi/Cu
2ndWinding
Al Bore
Cooling Tube
Sup. Cylinder
NbTi
Al
2ϕ Flow Indirect Cooling
2ϕ Flow
CMD-2
SDC / ATLAS
CMS
PbSn Solder
NbTi/Cu
SUS Bobbin
Cooling Tube
Sup. Cylinder
High Str. Al
NbTi/Cu
Pure Al-Strip
Cooling Tube
Sup. Cylinder
Al Alloy
Pure Al
NbTi/Cu
Multi - layer Coil
SUS Bobbin
Pure Al Strip

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 78 (1999) 565–570

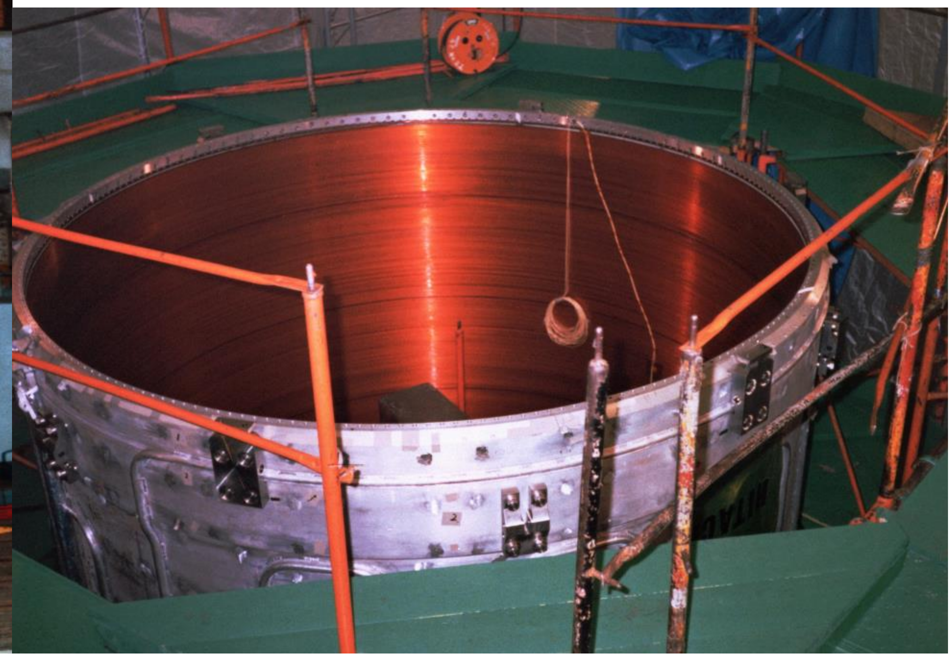
SUPPLEMENTS

www.elsevier.nl/locate/npe

Development towards Ultra-thin Superconducting Solenoid Magnets for High Energy Particle Detectors

Akira Yamamoto[a], Yasuhiro Makida[a], Ken-ichi Tanaka[a], Yoshikuni Doi[a], Takahiko Kondo[a]
Katsunori Wada[b], and Shin-ichiro. Meguro[b]

CDF Solenoid coil winding at Hitachi



Bob Kephart prefered <u>air-lifting</u> for less chance of damaging the large but fragile object by minimizing the number of loading-unloading operations.

<u>Possible Choices for</u>

1) Solenoid : 550 cm x 339 cm x 356 cm, 11 Met T
(18’ x 11’1” x 11’8”)
2) Control Dewer : 304 cm x 220 cm x 347 cm, 1.1 Met T

-AT 125 (Antonov, Russian Military plane) ……………………………. $ 500k

-C5A (Galaxy) (US Airforce…………………………………………….. $ 0 or $ 700K

-Belfast (Former British military plane) (Company: Heavy Lift) …….. $ 200 K

KEK NATIONAL LABORATORY FOR HIGH ENERGY PHYSICS
OHO-MACHI, TSUKUBA-GUN, IBARAKI-KEN, 305, JAPAN

TELEPHONE: 0298 (64) 1171
TELEX: 3652-534
CABLE: KEK OHO

Date : Jul. 7, 1984

I N V O I C E
****

Messrs : Dr. Masanori Mishina
C/O Fermi National Accelerator Laboratory
P.O. Box 244 Batavia, Illinois 60510, U.S.A.

Shipped per : Aircraft
From : Narita, Japan
To : Chicago, U.S.A.

Shipping Mark	Description	Qnantity	Amount
			FOB Narita
FERMI CHICAGO, U.S.A.	CDF Superconducting Solenoid with ACC.	1 set	¥654,000,000.-
		=====	==============

NATIONAL LABORATORY FOR
HIGH ENERGY PHYSICS

Ken Kikuchi

INVOICE

¥654 M

/ ¥230/$

= $ 2.8 M


HeavyLift
HeavyLift


HeavyLift
G-BEPS

Transporting from O'Hare to Fermilab

Andy Muravka (Head,DOE Fermilab Site Office) pre-arraged :

- Waiver of Custom Inspection
- Waiver of Custom Duty : *Based on the AGREEMENT*

Air-ride truck

1) Solenoid : 550 cm x 339 cm x 356 cm,
(18' x 11'1" x 11'8")
11 Met T

2) Control Dewer : 304 cm x 220 cm x 347 cm
1.1 Met T


HeavyLift
米国FNAL納超電導ソレノイド
成田—シカゴ間 チャーター輸送
(株)日立製作所・日立運輸(株)・日通航空(株)

July 16, 1984 John Rob, Bob Kephart, Shigeki Mori, Bob Wands


RSIZE LOAD

Dean Beckner

Tom Kirk

Hans Kautzky

Prototype design	:	1980
Final solenoid design	:	1981
Fabrication	:	1981 – 1984

Successfully commissioned up to 1.5 Tesla without any quenches

Later developed a minor leak in transition piece => Repaired
Since: kept at 1.4 Tesla to preserve detailed field map
No problem

flipping coil
particle tracks

Mystery

When magnetic field polarity was flipped, it quenched.

Since there is no need for flipping, the polarity was kept in one direction.

		TOPAZ	VENUS	AMY	CDF
		TRISTAN KEK	TRISTAN KEK	TRISTAN KEK	TEVATRON FNAL
Bore					
Diameter	m	2.72	3.5	2.22	2.858
Length	m	5.08	5.27	1.54	5.067
Radial Thicknes	Rad L	0.7	0.52	10	0.84
Central Field	Tesla	1.21	0.75	3	1.5
Current	kAmp	3.65	5	5	5
Stored Energy	MJ	19.5	12	40	30
Conductor					
Superconductor		NbTi/cu	NbTi/Cu	NbTi/Cu	NbTi/Cu
Stabilizer		Al	Al	Al	Al
NiTi-Cu-Al Ratio		1:01:20	1 : 1.27 : 20.9	1 : 15.6 : 1.85	1:01:21
Cross Section $(mm)^2$		2.6 x 18	8 x 10	9.8 x 12	3.89 x 20
Fabrication Process		NbTi/Cu - Al	NbTi/Cu - Al	NbTi/Cu - Al	NbTi/Cu - Al
		Co-extruded	Co-extruded	Co-extruded	Co-extruded
Frame		Outer frame	Outer frame	Outer frame	Outer frame
Cooling		Indirect	Indirect	Bath cooled	Indirect
		Forced flow	Forced flow		Forced flow
		2 phase He	2 phase He		2 phase He
Completion		1984	1984	1986	1984

Compiled by Hrabayashi

After CDF (*Compiled by Yamamoto)*

Progress of thin and some other Al-stabilized superconducting solenoid magnets for particle physics detectors

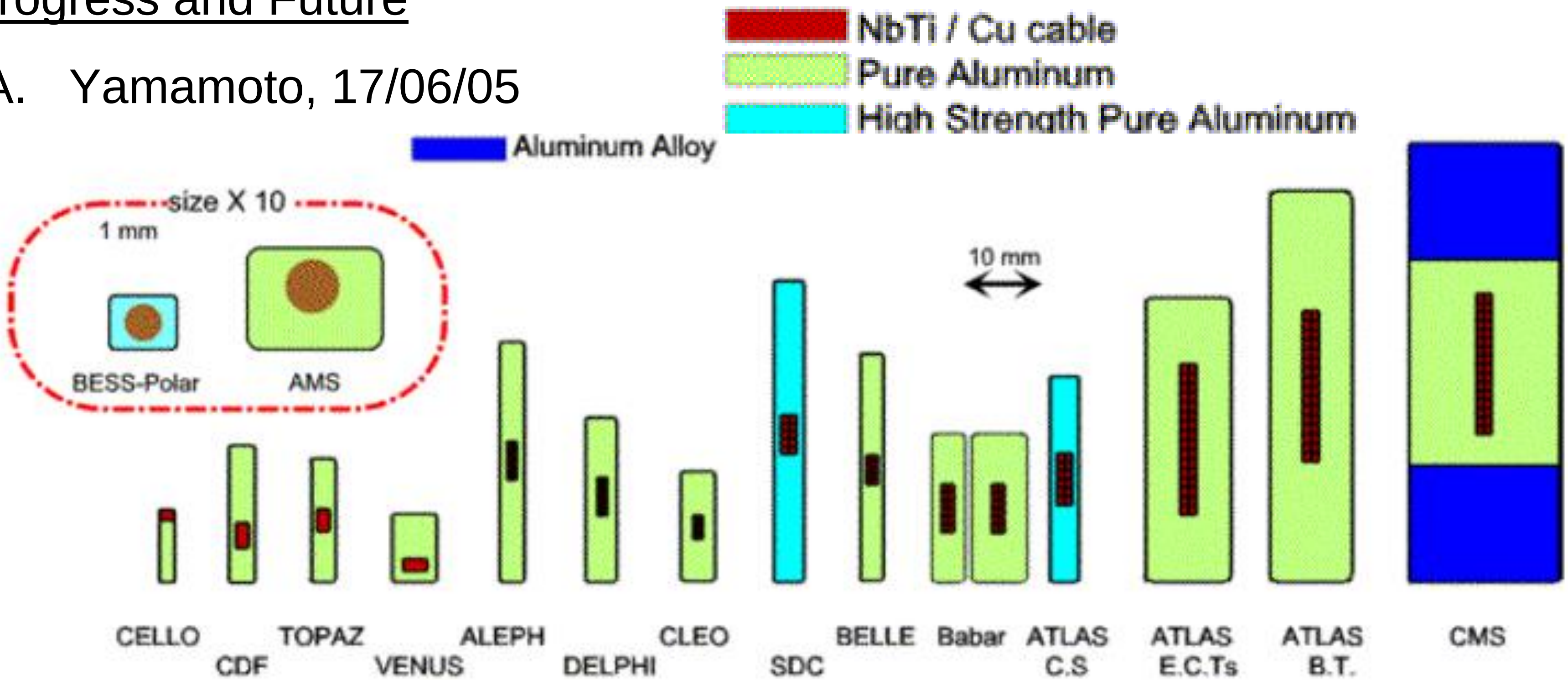
Experiment	--Lab.	B	R-coil	X	E/M	Technical Remark	(Year)	[Ref]
CELLO	Saclay/DESY	1.5 T	0.85 m	$0.6X_0$	[kJ/kg]	Al soldered to S/C	(1978)	[4]
PEP-4	LBL	1.5	1.1	0.83		Cu stabilized coil	(1983)	[5]
CDF	Tsukuba/Fermi	1.5	1.5	0.84	5.4	Al co-extruded with S/C	(1984)	[6]
TOPAZ	KEK	1.2	1.45	0.70	4.3	Inner coil winding,	(1984)	[7]
VENUS	KEK	0.75	1.75	0.52	2.8	CFRP vacuum shell,	(1985)	[8]
CLEO-II	Cornell	1.5	1.55	2.5	3.7	Double layer	(1988)	[9]
ALEPH	Saclay/CERN	1.5	2.75	2.0	5.5	Thermo-siphon cooling.	(1987)	[10]
DELPHI	RAL/CERN	1.2	2.8	1.7	4.2	LHe-pump cooling	(1988)	[11]
H1	RAL/DESY	1.2	2.8	1.8	4.8		(1990)	[11]
ZEUS	INFN/DESY	1.8	1.5	0.9	5.5	Current grading	(1988)	[12]
BESS	KEK	1.2	0.5	0.2	7.0	Pure-Al strip quench propagator	(1990)	[13]
SDC-proto	KEK/Fermi/SSC	2-1.5	1.85	1.2	9.6	High-st. Al, Isogrid/honeycomb	(1993)	[14]
WASA	KEK/Uppsala	1.3	0.25	0.18	7	Compact and thinnest	(1996)	[15]
BARBAR	INFN/SLAC	1.5	1.5				(1997)	[16]
D0	Fermilab	2.0	0.6	0.9	3.7	Two layer coil	(1998)	[17]
BELLE	KEK	1.5	1.8		4.6	Al-co-extrusion by conforming	(1998)	[18]
ATLAS	KEK/CERN	2.0	1.25	0.66*	7.1	High-st. Al. (Ni-microalloyed)	(in progress)	[19]
CMS	CERN/CEA/ETH/INFN	4.0	3.2			Hybrid high-st. Al, EB-welded	(in progress)	[20]

* no own cryostat and to be installed into the LAr calorimeter cryostat to save wall material.

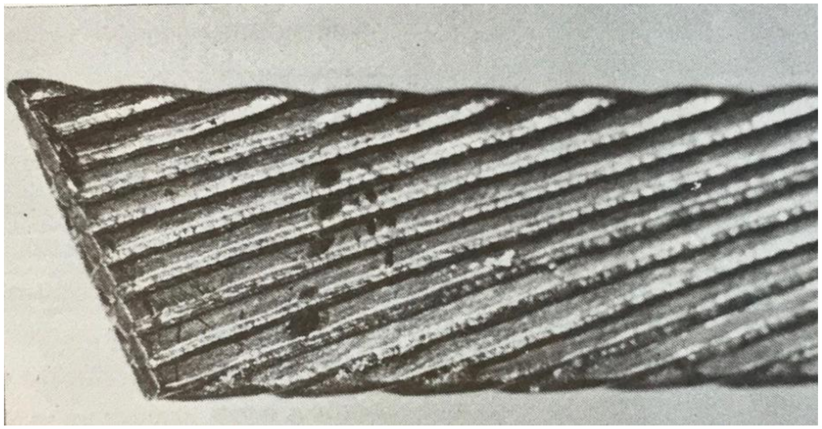
Al-Stabilized Superconductor developed for Detector Magnets: E/M :

Progress and Future

A. Yamamoto, 17/06/05



After ALEPH, Rutherford cable (multi-strand, twisted, flat) are also co-extruded with Al stabilizer.



Tevatron magnet Rutherford cable

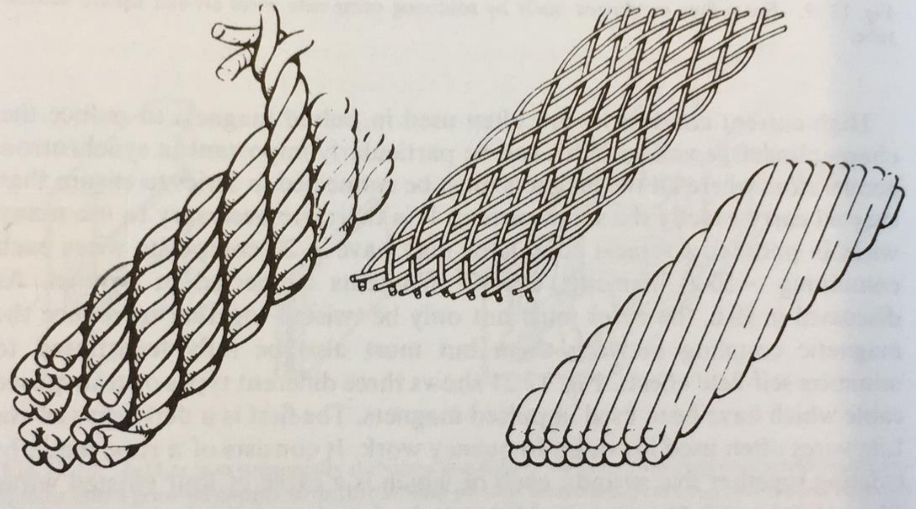


Fig. 12.21. (a) Transposed cable for a.c. use, made in form of a twisted rope; (b) transposed braid for a.c. use, made by a weaving process; (c) transposed cable for a.c. use, made by roll flattening a hollow twisted tubular cable.

Rutherford Cable

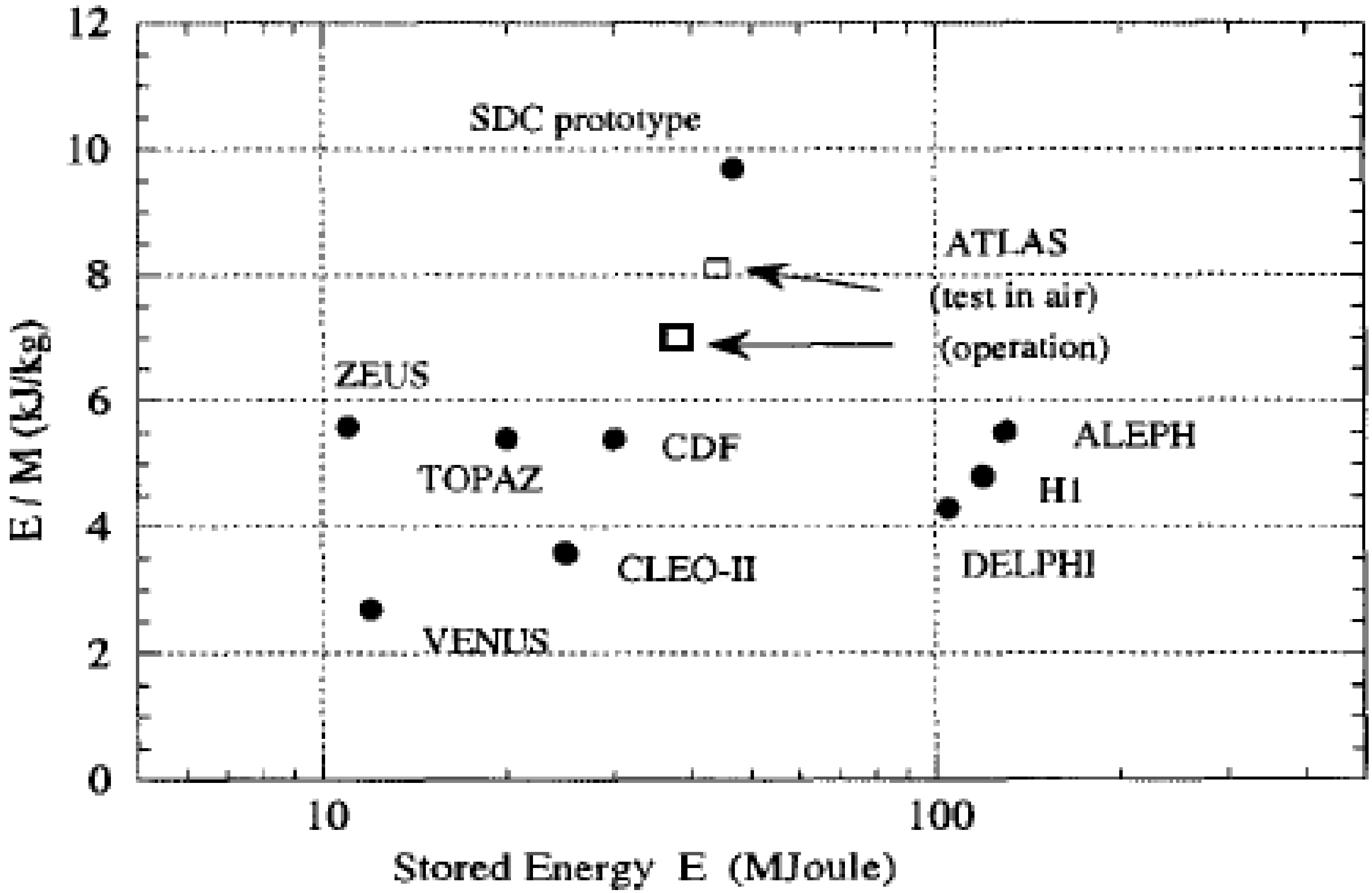
-Finer and longer filament/strand

-Multi-strand

-Twisted

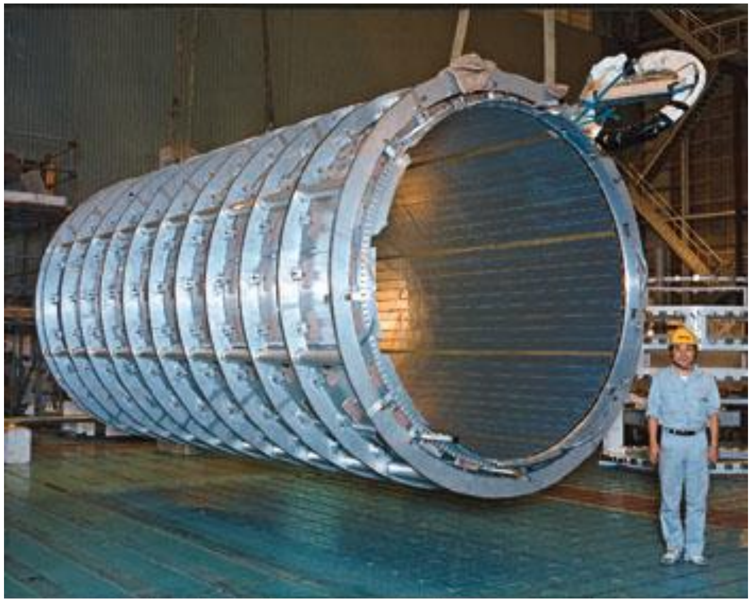
-flattened

=> higher current, flexibility



(A. Yamamoto, 17/06/05)

ATLAS Central Solenoid



Inner Bore : 2.3 m D x 5.3 m L

Field : 2 Tesla

Current : 7.6 kAmp

(Photo: CERN Courier)

Rutherford type NbTi/Cu superconducting cable with aluminum stabilizer (Furukawa Electric and Hitachi)

"Design and Development of the ATLS Central Solenoid Magnet"

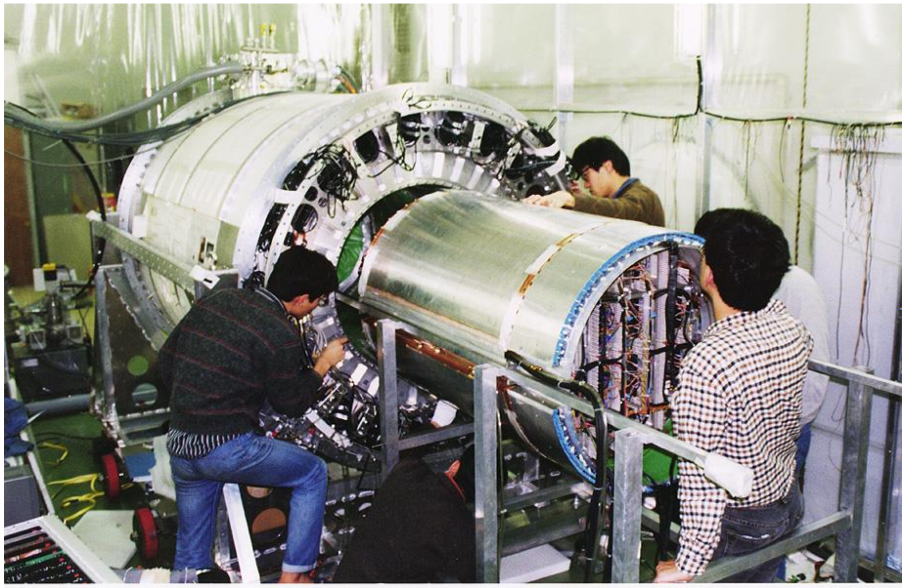
A. Yamamoto, T. Kondo, Y. Doi, Y. Makida, K. Tanaka, T. Haruyama, H. Yamaoka (KEK) ; H. ten Kate, L. Bjrset, (CERN) ; K. Wada, S. Meguro (Furukawa Electric CO.) ; J. S. H. Ross, K. D. Smith, (Oxford Instruments)

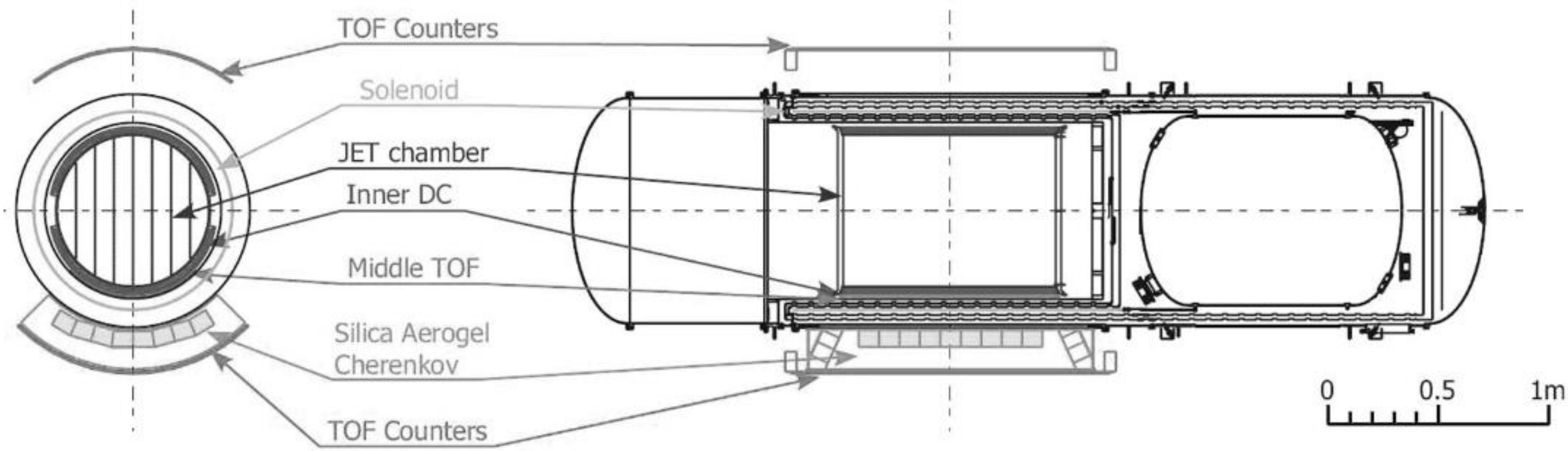
Micro-alloying with pure-Al
with ATLAS-CS and BESS

Additve metal	A	Dens.	Solubility	resistivity contribution (in solution / crystal.)	
		[g/cm³]	[w-%]	[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.

BESS-Polar Experiment
(Balloon-borne Experiment with Superconducting Spectrometer)



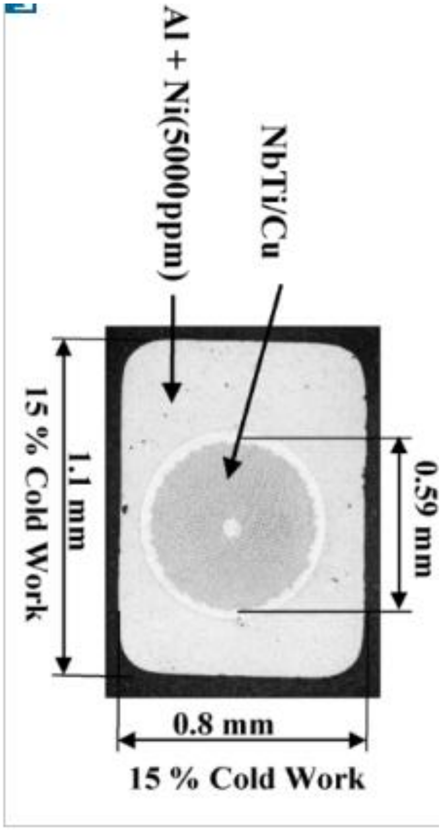


BESS II

Conductor	0.8 mmx 1.1 mm
Ni micro-alloying, cold-work	
Coil thickness	3.4 mm
With cryostat	0.1 X0)
Current	570 A
Field	0.8 T (test 1.2 T)
Dimension	0.9 m D x 1.4 m L
Stored energy	550 kJ
Total	380 kg

Superconductor

1.1 mm x 0. 8 mm

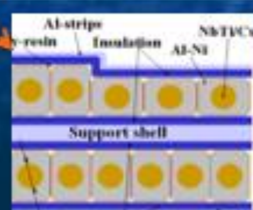


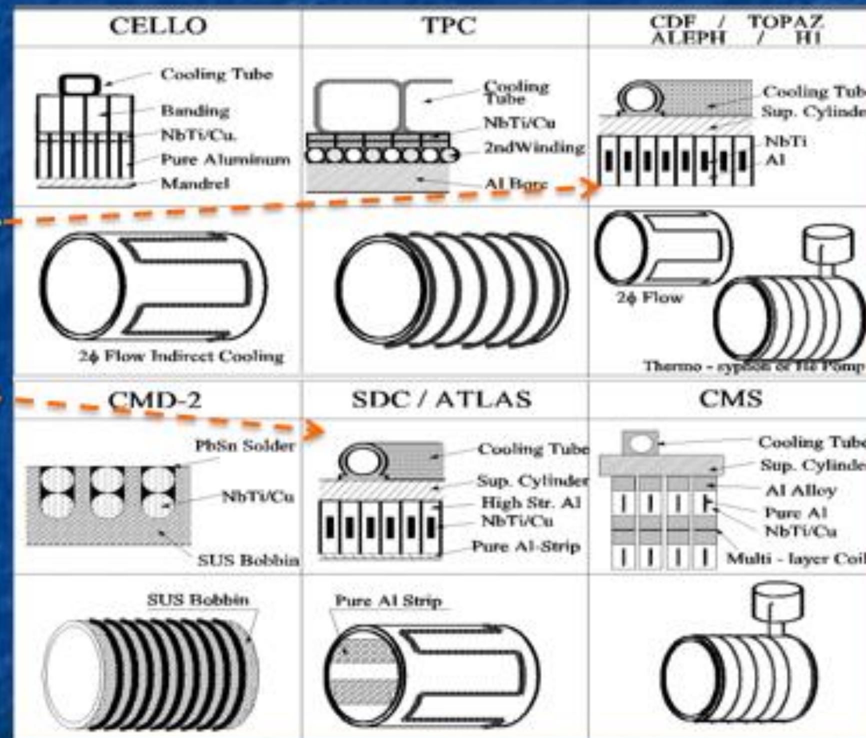
In flight : *24.5 days* (2007-2008)

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

μ g-2 BNL E-821

Vernon Hughes conceived of a new experiment on muon g-2 after CERNs 3rd experiment.

Kondo introduced Hughes to Nishikawa.
Nishikawa suggested to recruit KEK's superconducting magnet group (Hirabayashi, Yamamoto)

KEK	*Superconducting coil design/fabrication,* *Iron yoke,* *Muon Inflector*
Tokyo Inst Tech	*Beam monitor*

E821 was tucked into the US-Japan Collaboration umbrella.

Brookhaven μ g-2 Experiment E821

(Presented by M. Iwasaki, A. Yamamoto, For E821 g-2 Collaboration)

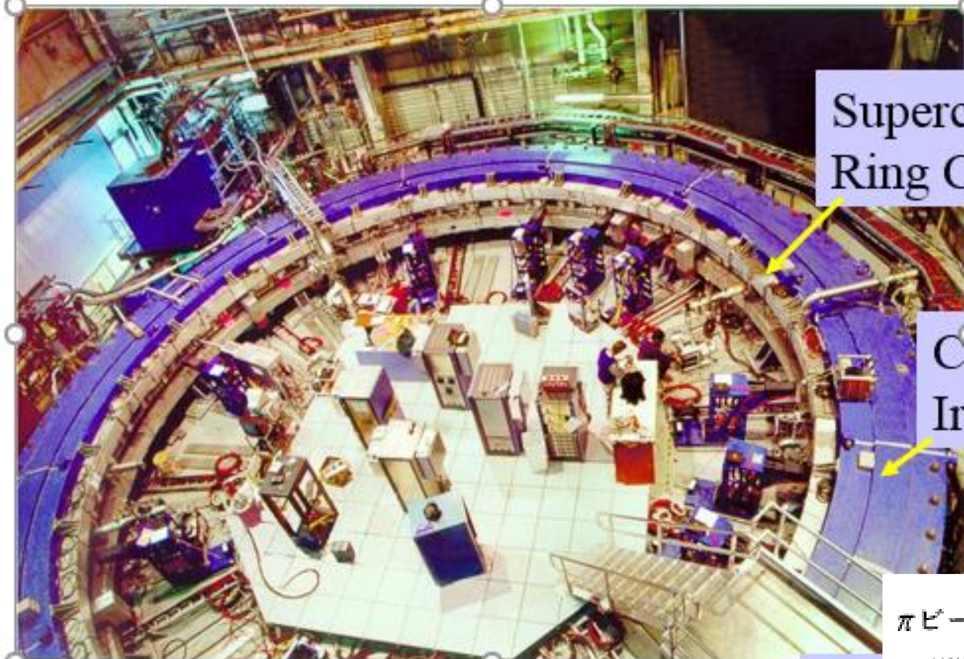
Keep CERN's 3rd generation experiment parameters:

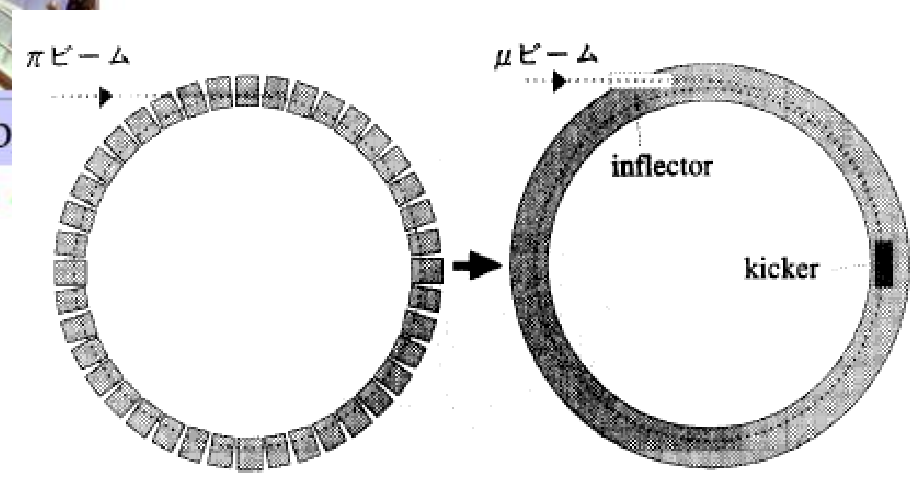
Magic number : $\gamma = 29.3$ **=>** p_μ **= 3.094 GeV**

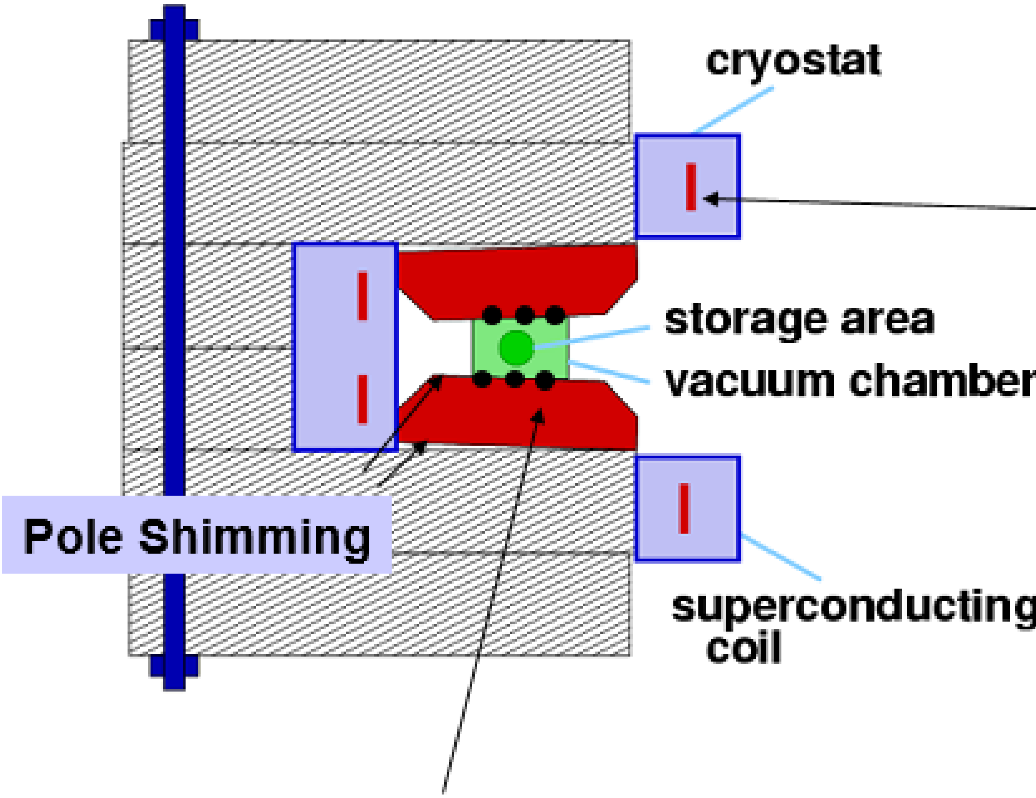
	CERN	BNL E821
Radius	7.112 m	7.112 m
Magnetic field	1.45 T	1.45 T
Magnet	40 separate dipoles Common coil	Single continuous ring of superconducting dipole
Current		5.2 kA
Storage aperture		90 mm D
Injection	π Pulsed	μ DC superconducting inflector
Kicker		**Pulsed kicker magnet**
Focusing		Electrostatic quadrupole lens

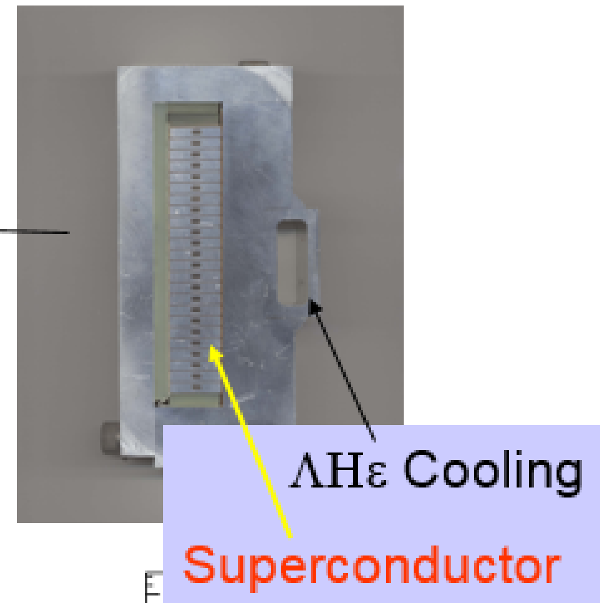
Muon Storage Ring Installed

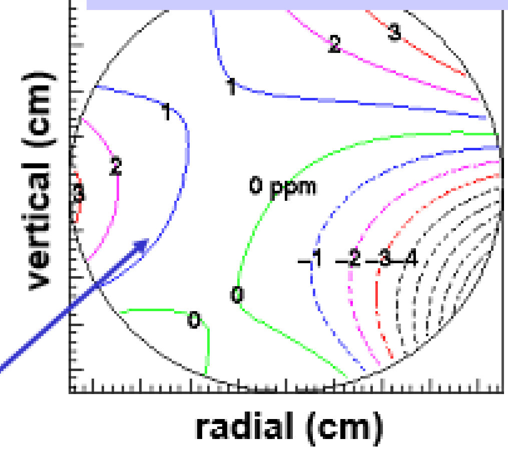
BNL E821





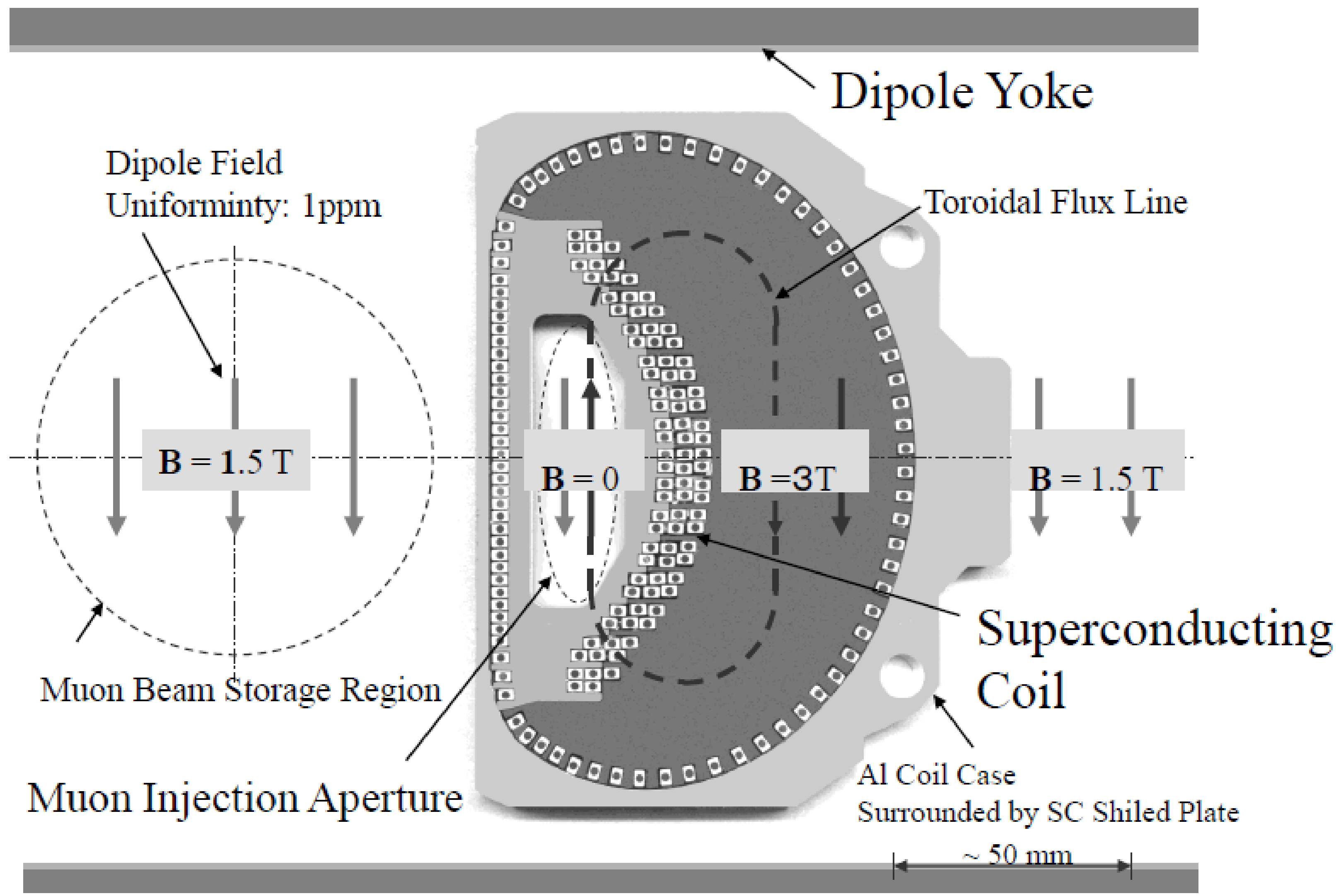


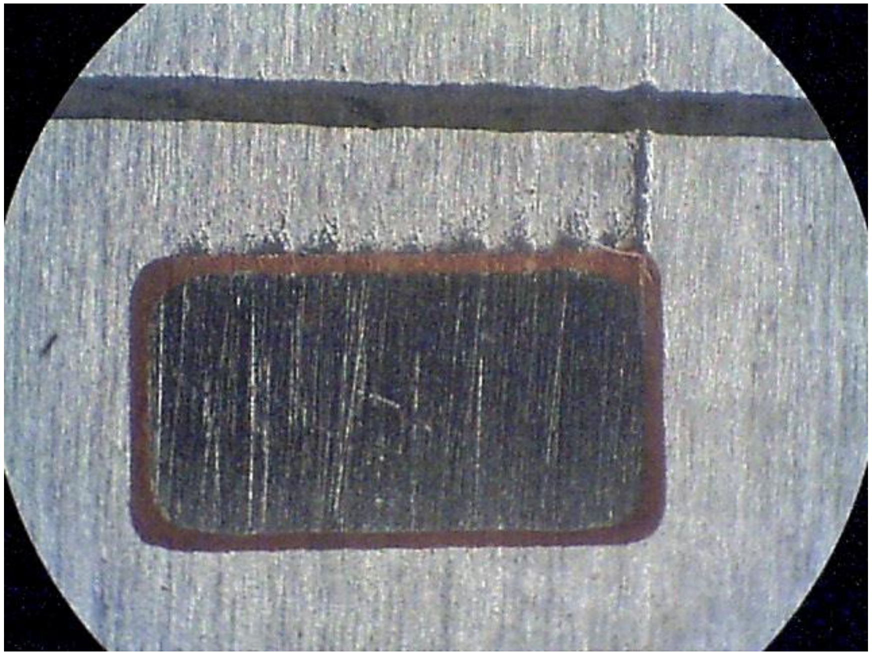


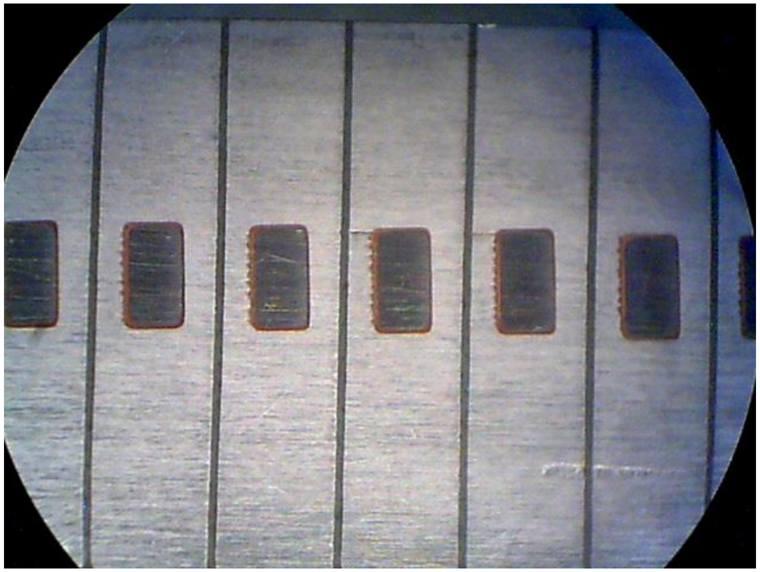


Continuously monitored with 378 fixed probes mounted above and below the storage region

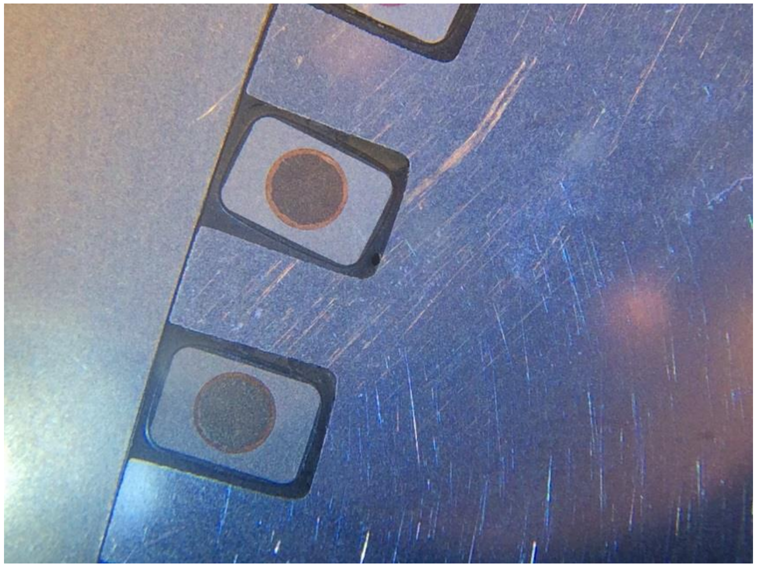
Superconducting Beam Inflector



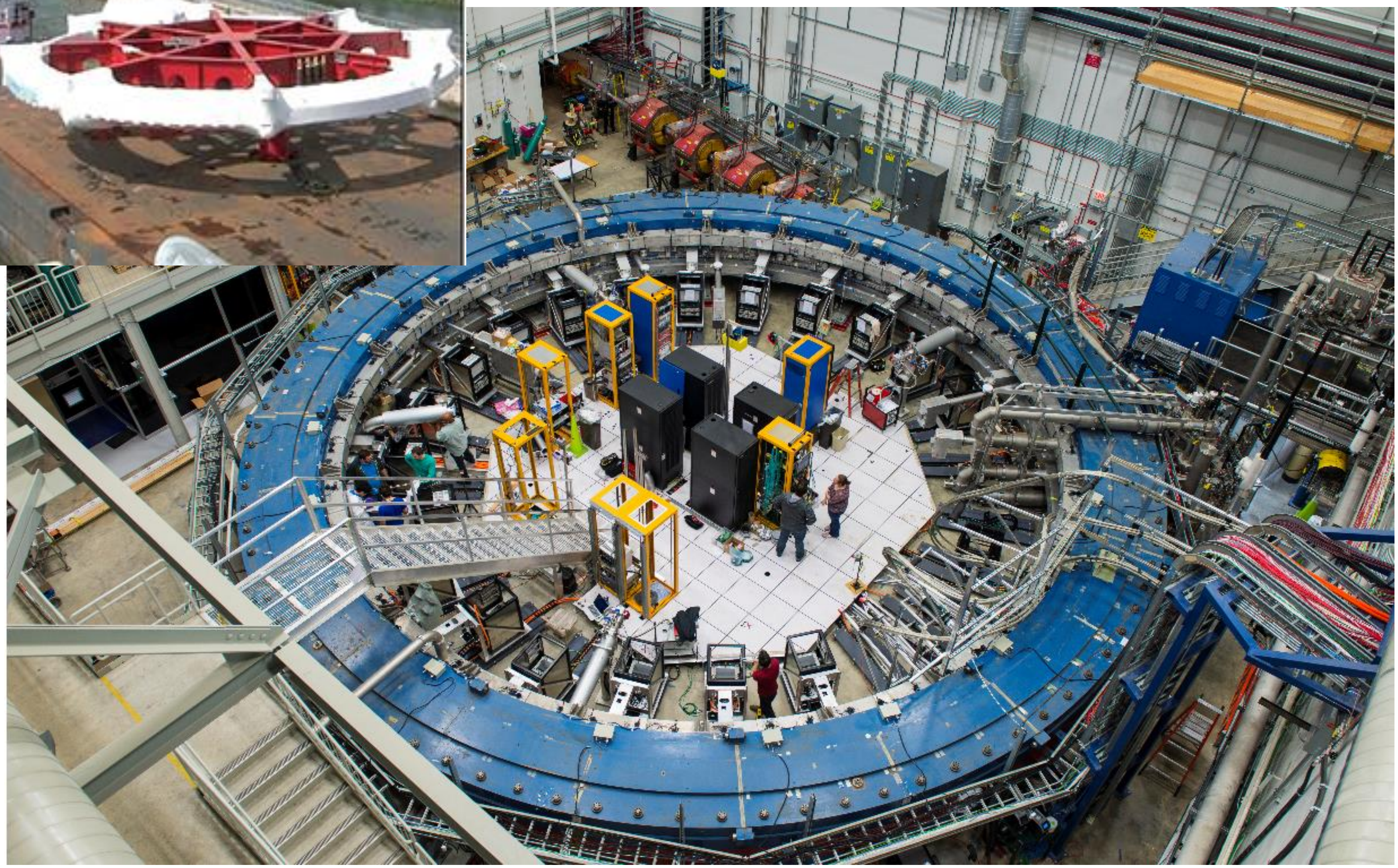




Inflector



May 31, 2017 Fermilab News



New era of Parton Fragmentation

Series of papers in '77-'78: Feynman, Field, Fox (CALTECH)

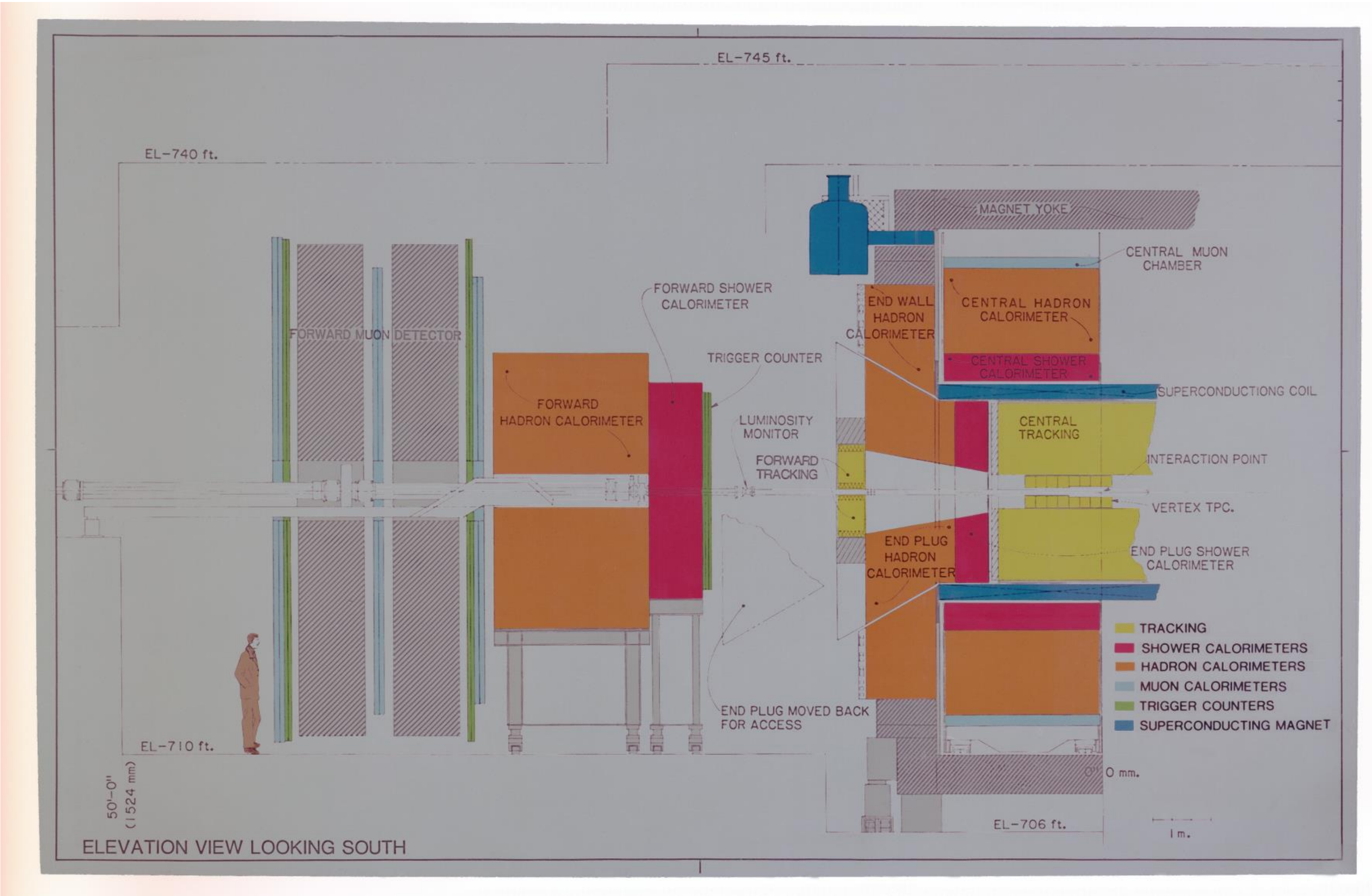
(Field-Wolfram 1983)

Rick Field later joined CDF from U. Florida

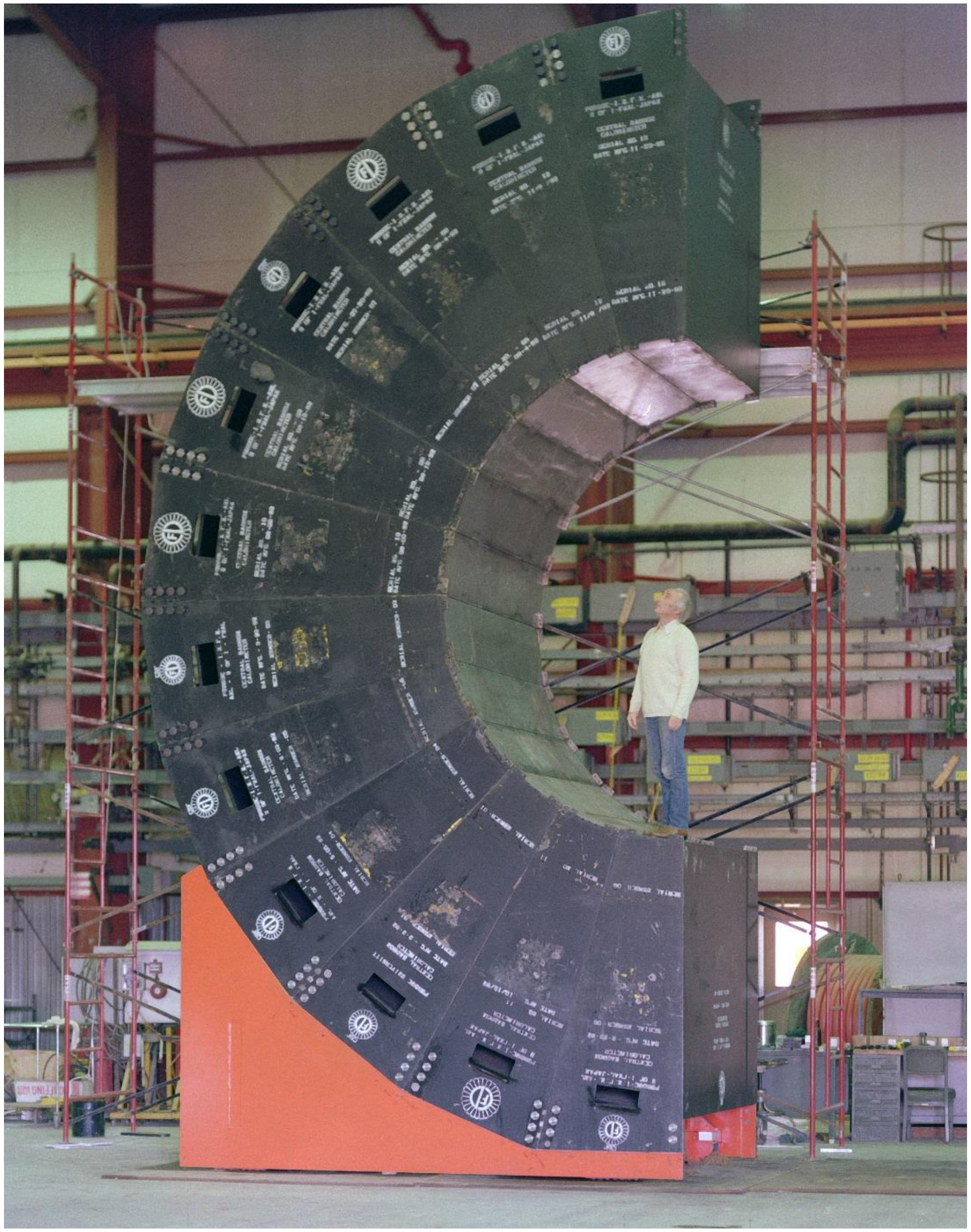
Jeff Fox gave a talk at CDF meeting:

- How messy the outcome of the parton fragmentation will be.
- Needs to measure energy flow in additon to individual particles
- Calorimeter has to have projective tower geometry.
- Lateral segmentation of ~1,000 in 4π, necessary/adequate

~ 1,000 projective towers were actually formed in 4π.


EL-745 ft.
EL-740 ft.
MAGNET YOKE
CENTRAL MUON CHAMBER
FORWARD SHOWER CALORIMETER
END WALL HADRON CALORIMETER
CENTRAL HADRON CALORIMETER
FORWARD MUON DETECTOR
TRIGGER COUNTER
CENTRAL SHOWER CALORIMETER
SUPERCONDUCTIONG COIL
FORWARD HADRON CALORIMETER
LUMINOSITY MONITOR
CENTRAL TRACKING
FORWARD TRACKING
INTERACTION POINT
VERTEX TPC.
END PLUG HADRON CALORIMETER
END PLUG SHOWER CALORIMETER
TRACKING
SHOWER CALORIMETERS
HADRON CALORIMETERS
MUON CALORIMETERS
TRIGGER COUNTERS
SUPERCONDUCTING MAGNET
END PLUG MOVED BACK FOR ACCESS
EL-710 ft.
0" 0 mm.
50'-0" (1524 mm)
EL-706 ft.
1 m.
ELEVATION VIEW LOOKING SOUTH

Kautzky mockup



Endplug Calorimeter

Tevatron Run I

1 x 1 bunches / cycle

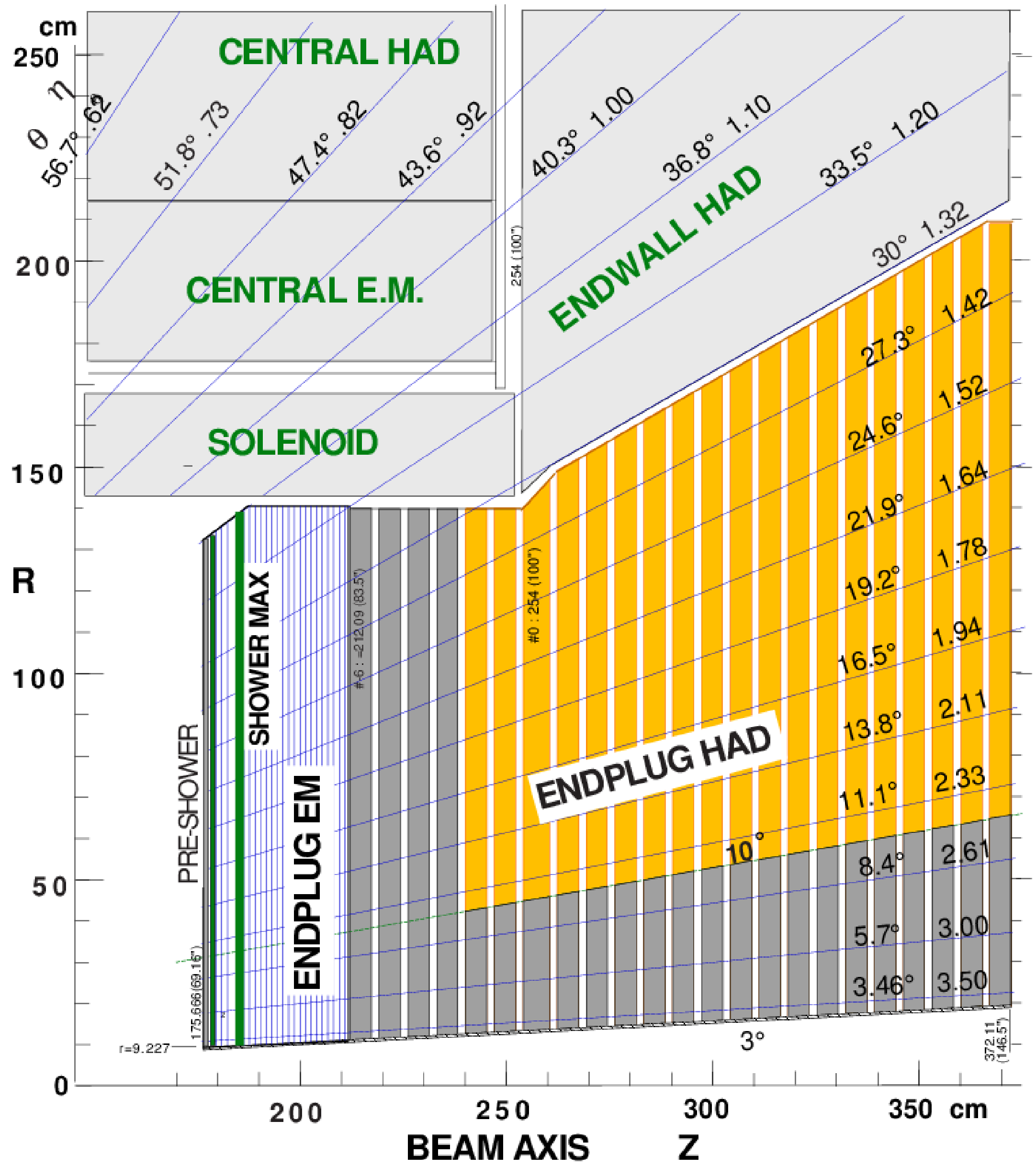
6 x 6 bunches / cycle later

Constraint

:

- 1.5 T magnetic field

- Small physical size of projective towers

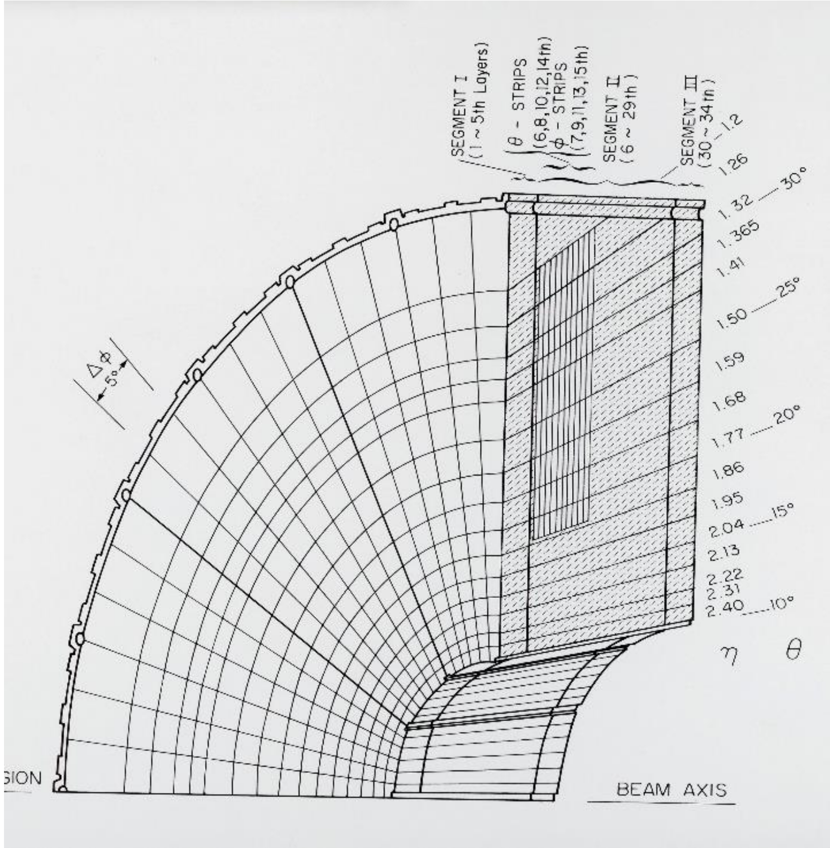


⇨ *Proportional tube wire chamber - Absorber Sandwitch*

Resistive wall with pick-up electrode plane behind

Fine lateral ($\Delta\theta x \Delta\varphi$) segementation was achieved by patterning "pickup" plane.

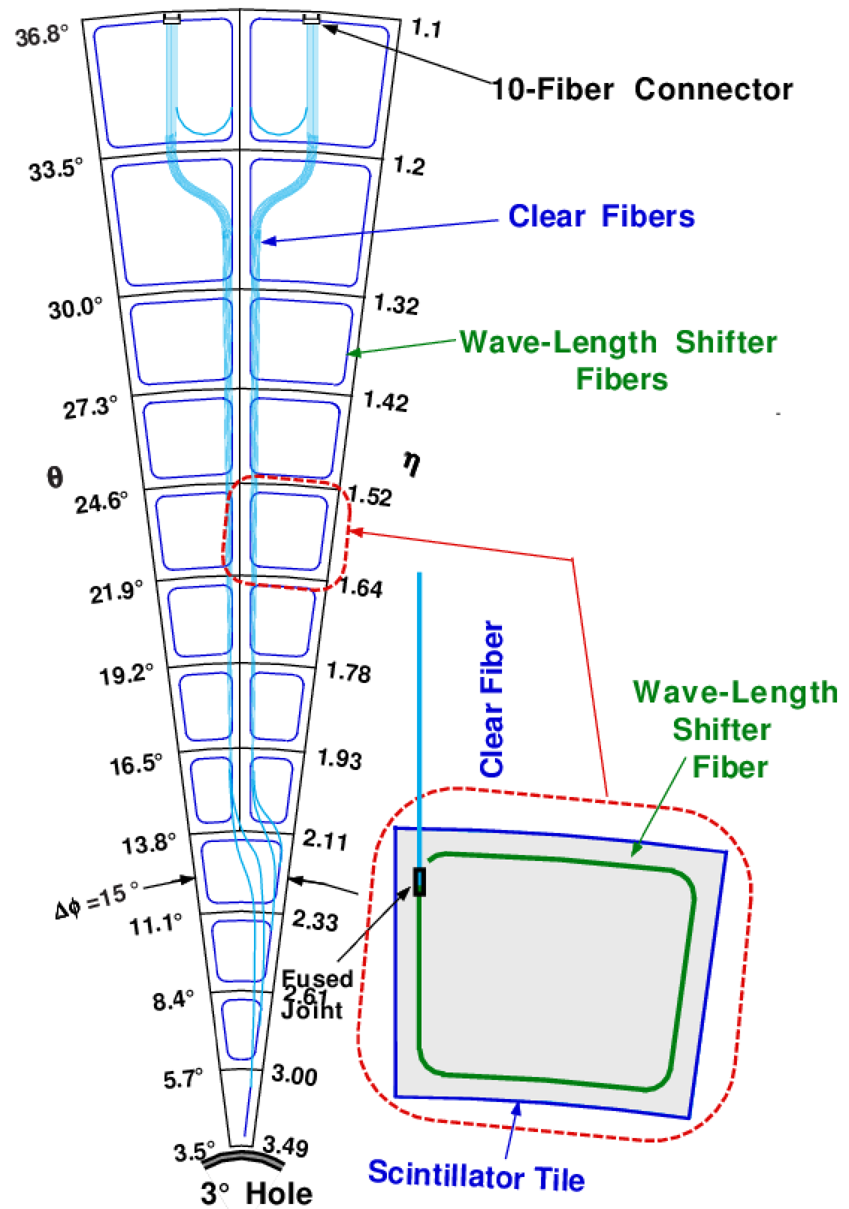
Worked well for 1x1 bunch ~ 6 x 6 bunches/cycle



TEVATRON Run II

36x36 bunces /cycle

. => faster sytem.



Scitillator tile – WLS fiber Readout

Jim Freeman came up with an idea of refurbishing UA1's effort of

Scintillator tile-WLS fiber readout

"A uranium scintillator calorimeter
With plastic-fiber readout"
M.G. Albrow et al., NIM A 256(1987)23

After the decision, Japanese group, Tsukuba-KEK-Saga-Osaka City, with Fermilab team (including Freeman), worked on the refinement of the technology making it a viable option for a sampling calorimeter.

In the course all the necessary details were worked out.

-Choice of fiber (attenuation length, fluor, flexibility, ..)

Spectral Matching

scintillator emission ⇔ WLS fiber absorption

WLS emission ⇔ photocathode sensitivity

(extended bi-alkali)

-Bending curvature

-WLS fiber pattern/depth of grooves

-Reflecting end

-Cutting fibers

-Splicing/jointing

-Multi-fiber connector

-Radiation damage

"A scintillating tile / fiber system for the CDF plug upgrade EM calorimeter"

S. Aota et al.,

NIM A 352 (1995) 557-568

Features of Scintillating tile-WLS fiber readout calorimeter

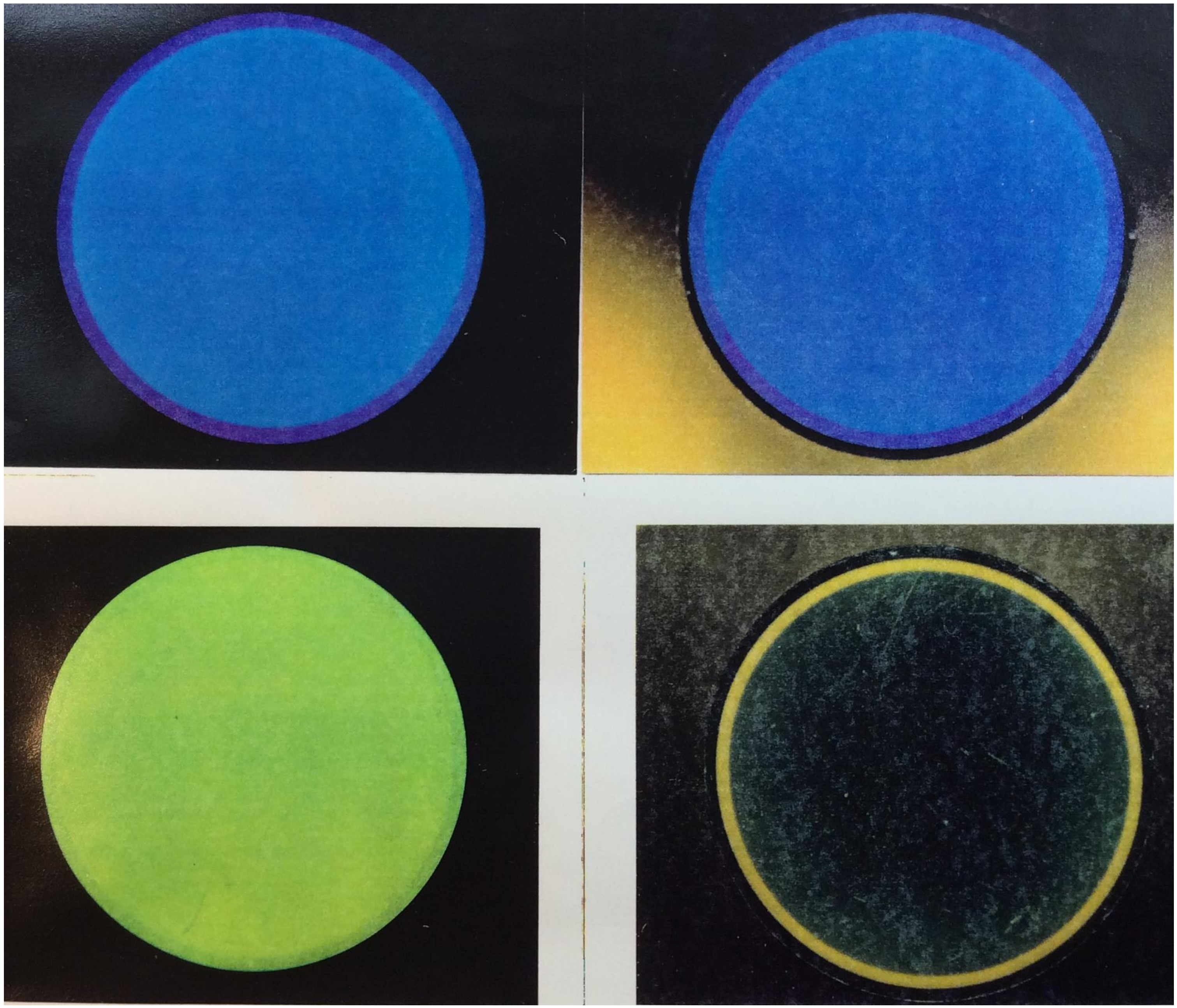
- Fast
- Uniform
- Durable/low maintenance
- Fine segmentation into arbitrary pattern
- Without sacrificing hermeticity
- Easily scalable*(Ex. Spin-off: MINOS, GLAST)

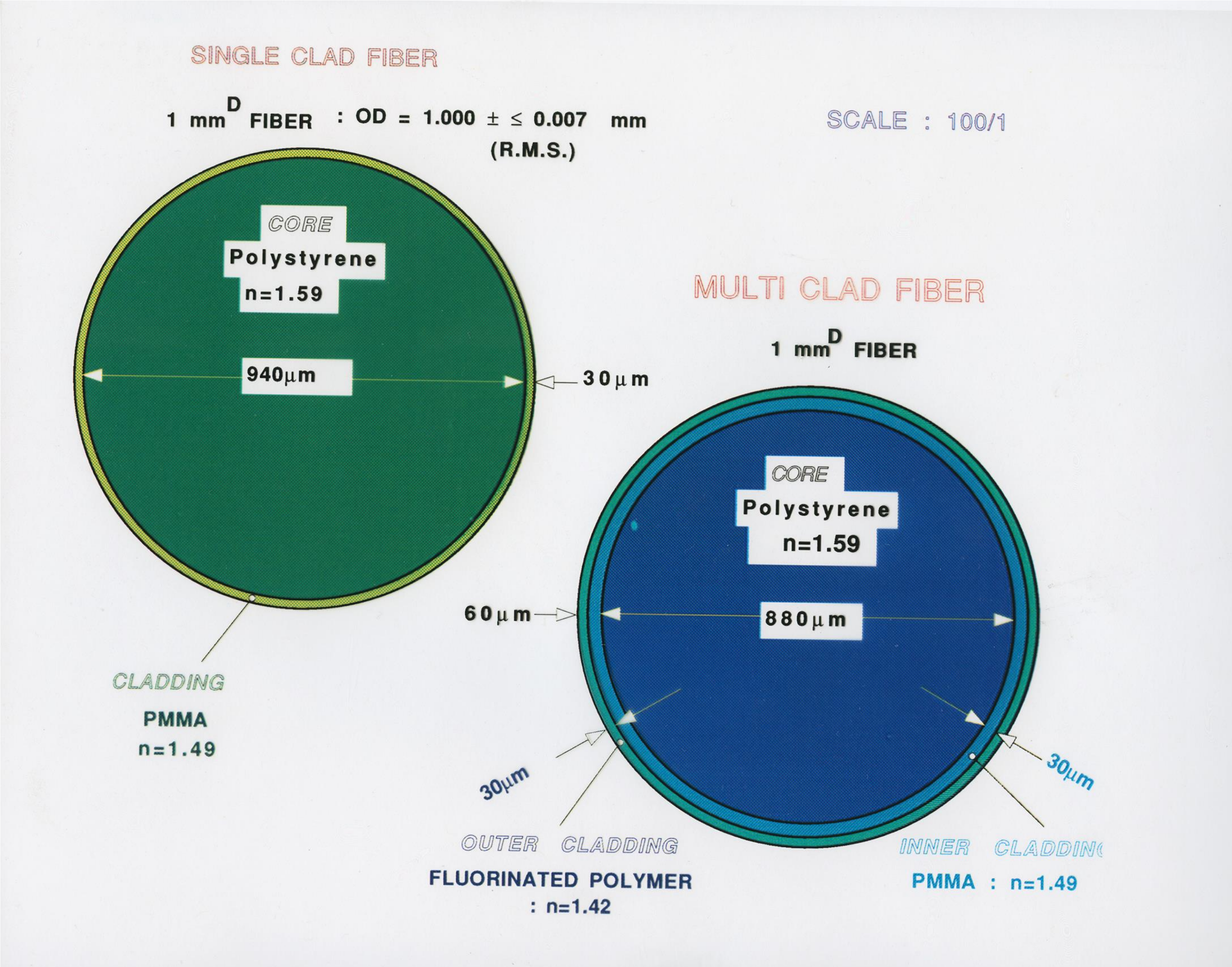
KURARAY invented "Multiclad" fibers.

Core	*: Polysyrene*	*n=1.5*
Inner cladding	*: PMMA*	*n=1.49*
Outer cladding	*: Fluorinated Polymer*	*n=1.42*

solid angle (aperture) 3.14% => 5.34 % ***=> 50% gain***

less sensitive to bending
less brittle

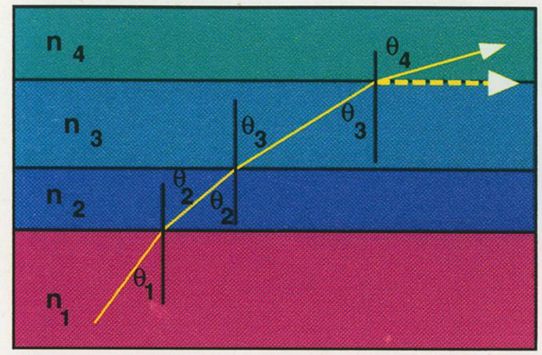




SINGLE CLAD FIBER
1 mm^D FIBER : OD = 1.000 ± ≤ 0.007 mm
(R.M.S.)
SCALE : 100/1
CORE
Polystyrene
n=1.59
940μm
30μm
CLADDING
PMMA
n=1.49
MULTI CLAD FIBER
1 mm^D FIBER
CORE
Polystyrene
n=1.59
60μm
880μm
30μm
30μm
OUTER CLADDING
FLUORINATED POLYMER
: n=1.42
INNER CLADDING
PMMA : n=1.49

SNELL'S LAW OF REFRACTION

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = ... = n_4 \sin\theta_4 = ...$$



TOTAL INTERNAL REFLECTION

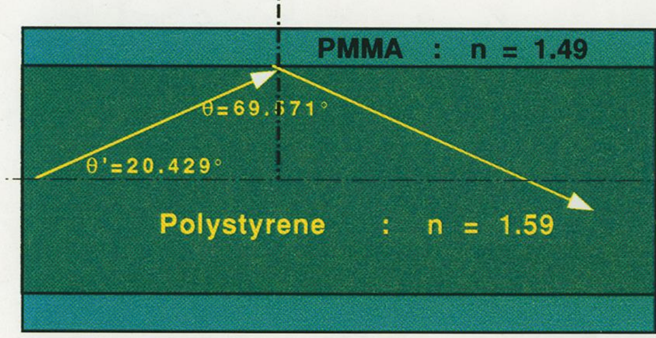
$$\theta_4 = 90° \rightarrow \sin\theta_4 = 1$$

$$\sin\theta_1 = \frac{n_4}{n_1}$$

SINGLE CLAD FIBER

F : n_1 = 1.59 (Poplystyrene)

n_4 = 1.49 (PMMA)

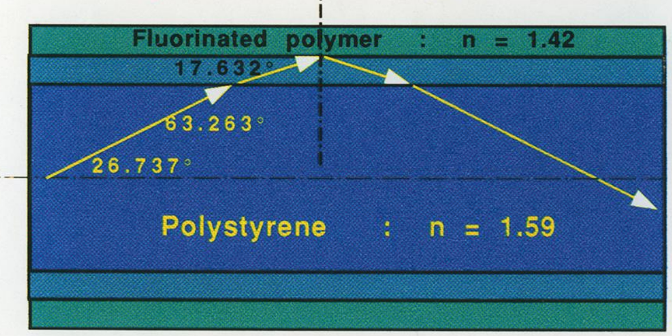


MULTICLAD FIBER

IF : n_1 = 1.59 (Poplystyrene)

(n_2 = 1.49 (PMMA))

n_4 = 1.42 (Fluorinated polymer)



FRACTIONAL SOLID ANGLE : ONE DIRECTION

$$\Omega = 2\pi \, (1 - \cos\theta') \, / \, 4\pi$$
$$= (1 - \sin\theta) \, / \, 2$$
$$= (1 - n_2 / n_1) \, / \, 2$$

Polystyrnene / PMMA

: (1 - 1.49/1.59)/2 = 3.14 %

Polystyrene / Fluorinated polymer

: (1- 1.42/1.59)/2 = 5.34 %

“Thin scintillating tiles with high light yield for the OPAL endcaps”

G. Aguillion, et al.,

NIM A 417 (1998) 266Ð277

CMS Hadron Calorimter

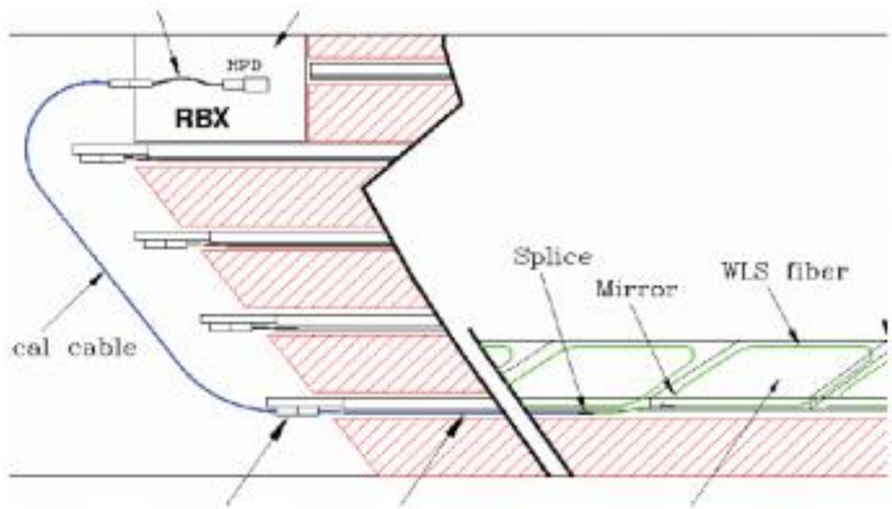


Figure 4, CMS hadronic calorimeter sampling geometry (schematic). Wavelength shifter fibers imbedded in the scintillator tiles couple the scintillation light to the HPD photo-detectors.

J. Proudfoot, 34th SLAC Summer Institute on Particle Physics (SSI) july 17-28, 2006

Spin off

"Development of a Low-Cost Extruded Scintillator with Co-Extruded Reflector for the MINOS Experiment"

D.F. Anderson, .. A. Para, .. A. Pla-Dalmau, et al.,
FERMILAB-Conf-00/261-E October 2
Presented IEEE NS, Lyon France, October 15-20, 2000000

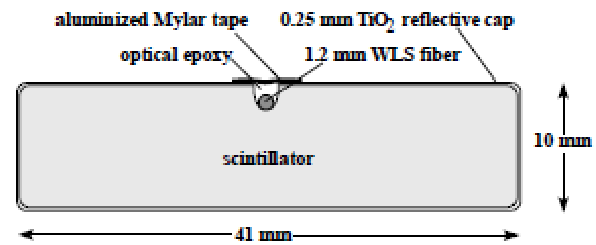


Figure 1: Profile of scintillator strip.

"High efficiency plastic scintillator detector with wavelength-shifting fiber readout for the GLAST Large Area Telescope"

A.A. Moiseeva,_, et al.,
NIM A 583 (2007) 372–381

SPECIAL THANKS

for

warm friendship, kind help, useful advices, and continuous encouragement

to

Ryuji Yamada

Akira Yamamoto

Taiji Yamanouchi

Bruce Chrisman

Roy Rubinstein

Alvin and Janine Tollestrup

John and Nancy Peoples

Leon and Ellen Lederman

THANKS

for

Steady Hands on Collaboration Business

to

Kyoko Kunori