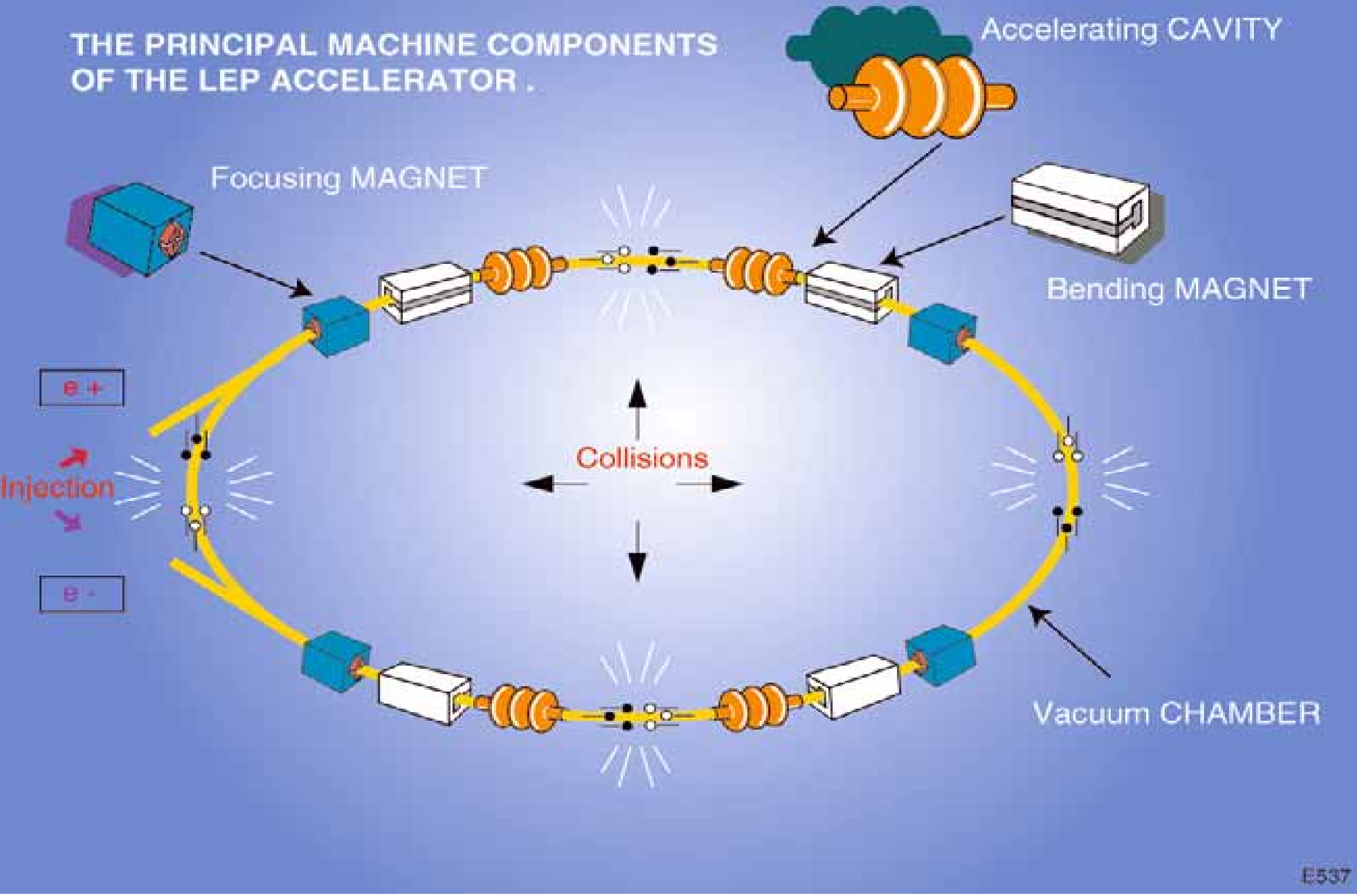
Trends in Magnet Technologies

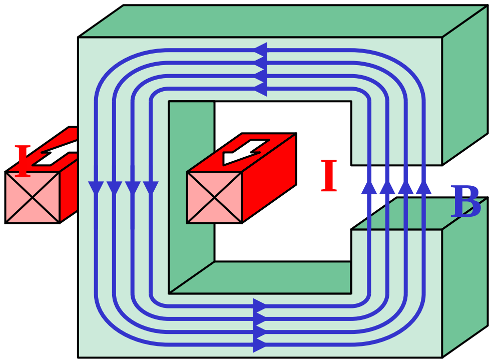
Davide Tommasini

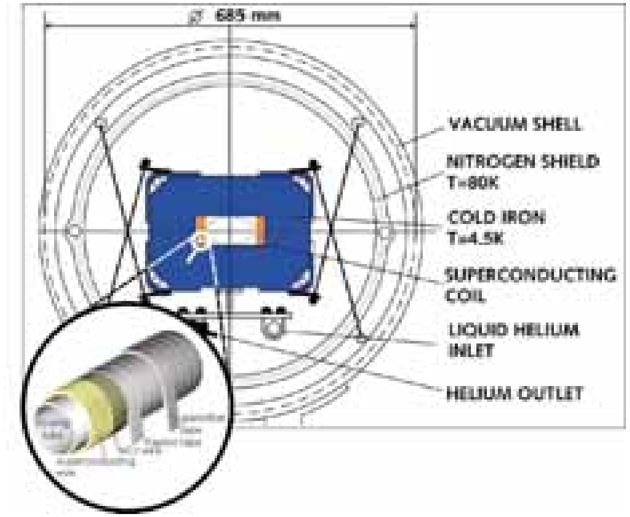
- **State of the art**
- **Motivation for new developments in Magnet Technology**
- **Fast cycled superconducting magnets**
- **Higher Magnetic Fields**
- **Conclusions**

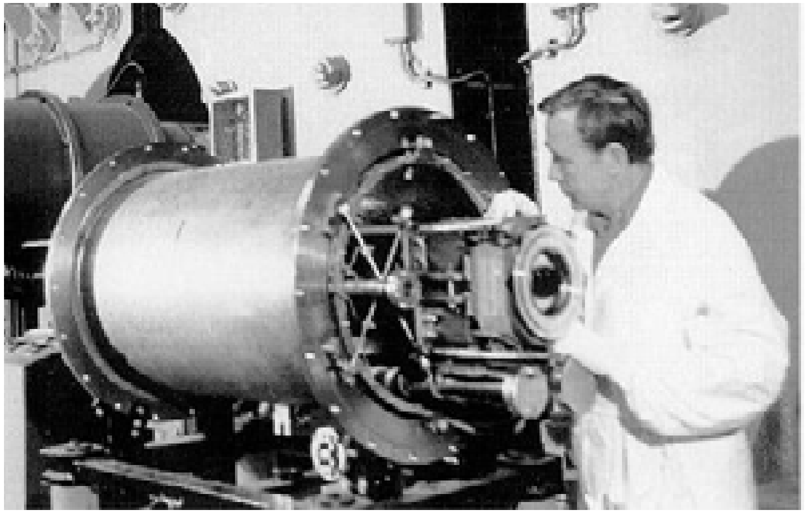
THE PRINCIPAL MACHINE COMPONENTS OF THE LEP ACCELERATOR .



Field range up to 2 T

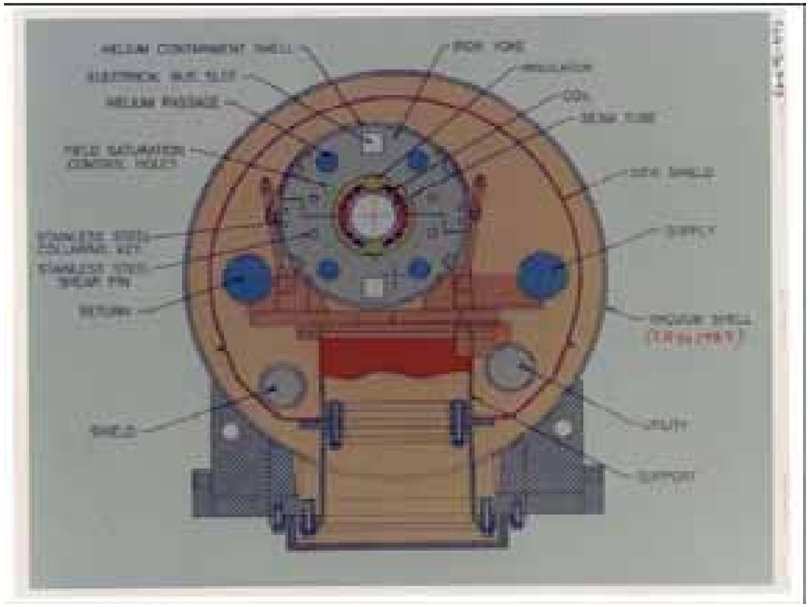


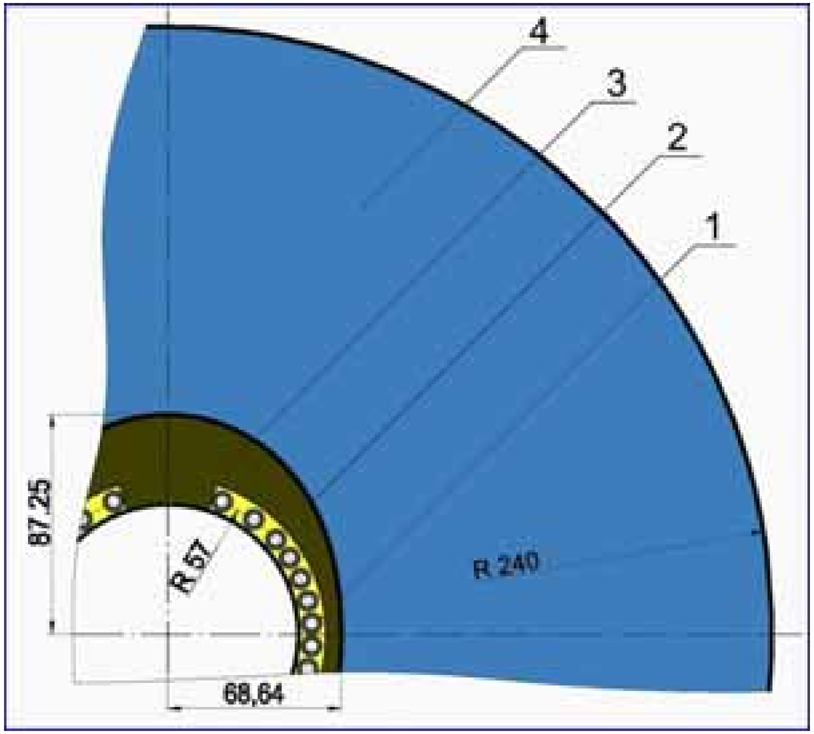




Field range up to 4 T

Above 2 T the magnet is no longer iron dominated, but can be “iron helped”



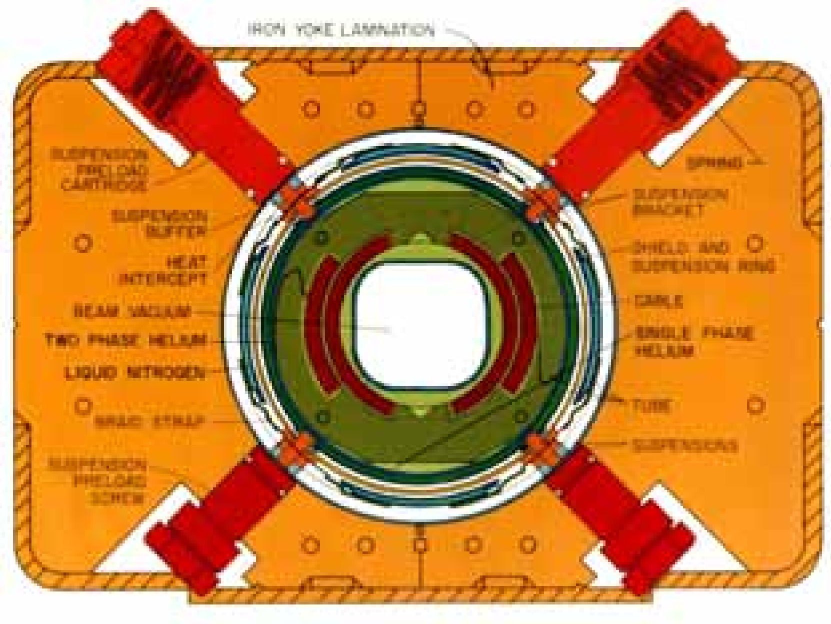


and … do not forget other arrangements with block/split coils – window frame type*

*notice a cos teta still may be considered as belonging to window-frame type

Field range from 4 to 7 T

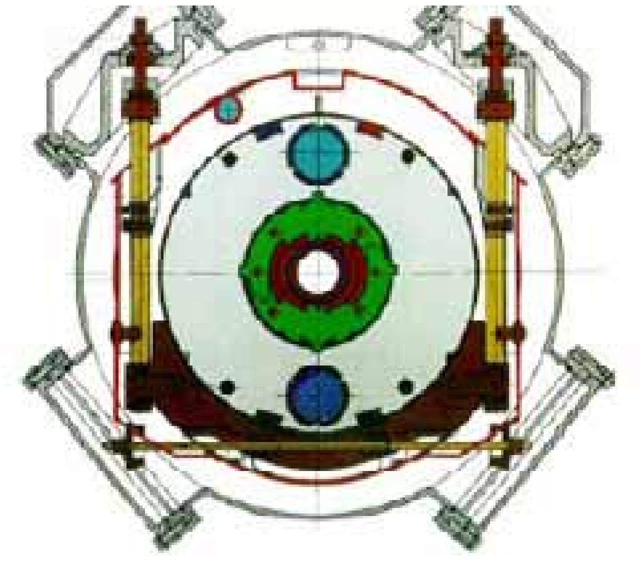
76.2 mm aperture, 4 T



TEVATRON

The first successful use of sc magnets in a machine
Commissioned in 1983, running today at 980 GeV

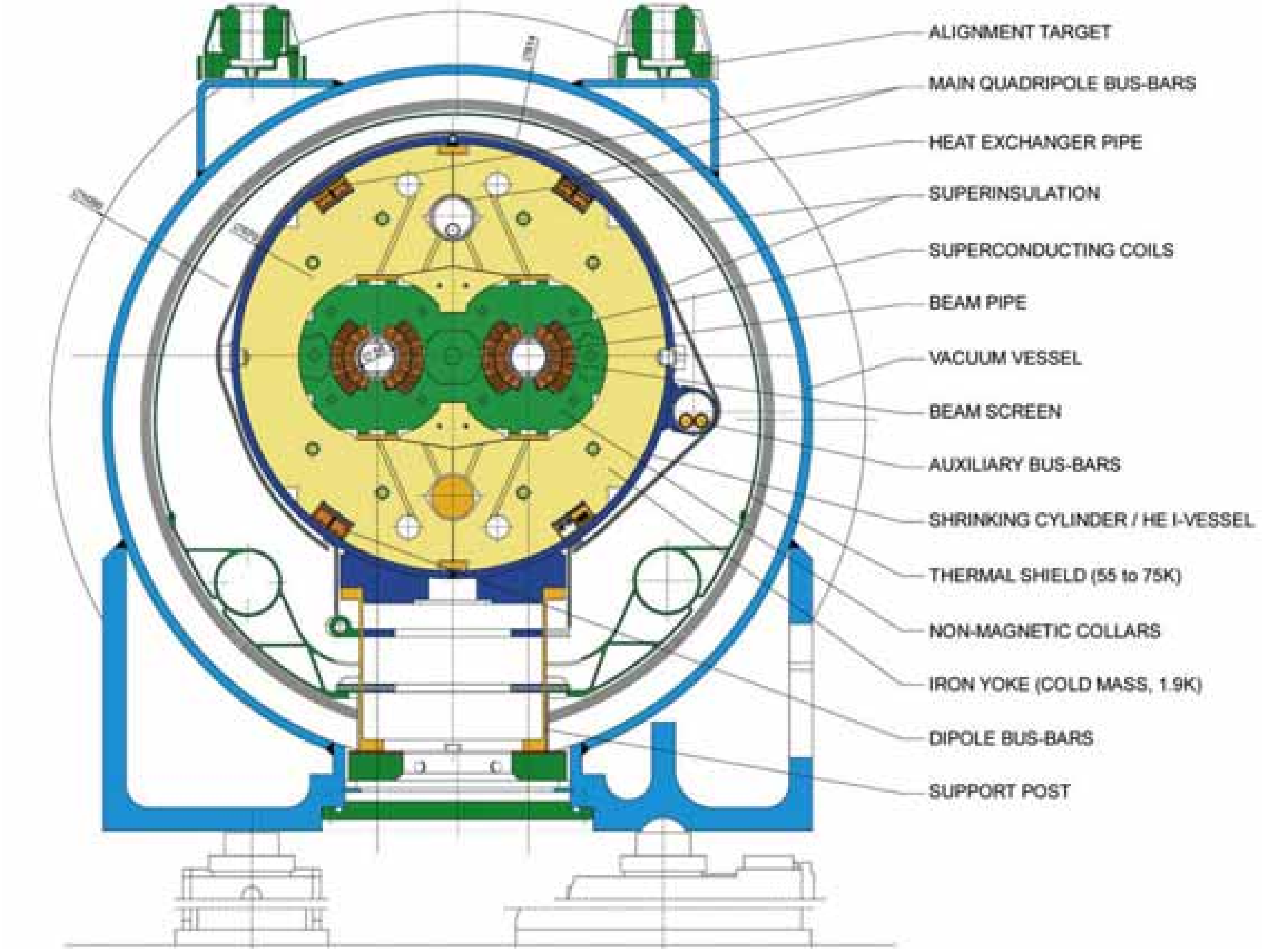
75 mm aperture, 4.7 – 5.5 T



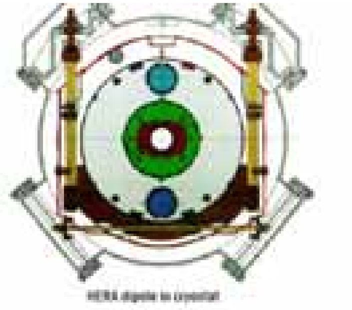
HERA

The first massive industrialization.
Commissioned in 1989 at 800 GeV, 920 GeV today

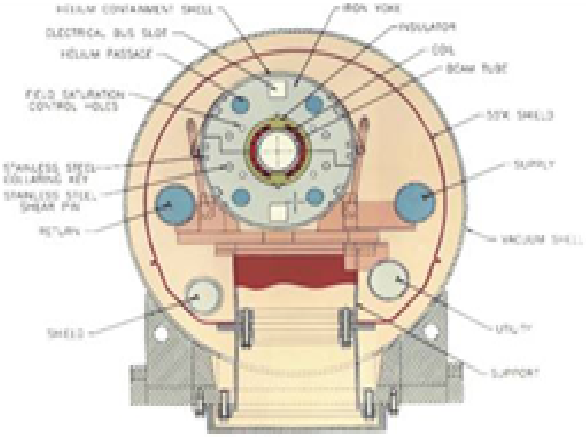
Up to 9T


ALIGNMENT TARGET
MAIN QUADRIPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
VACUUM VESSEL
BEAM SCREEN
AUXILIARY BUS-BARS
SHRINKING CYLINDER / HE I-VESSEL
THERMAL SHIELD (55 to 75K)
NON-MAGNETIC COLLARS
IRON YOKE (COLD MASS, 1.9K)
DIPOLE BUS-BARS
SUPPORT POST

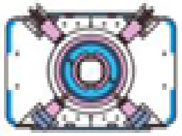
Size overview



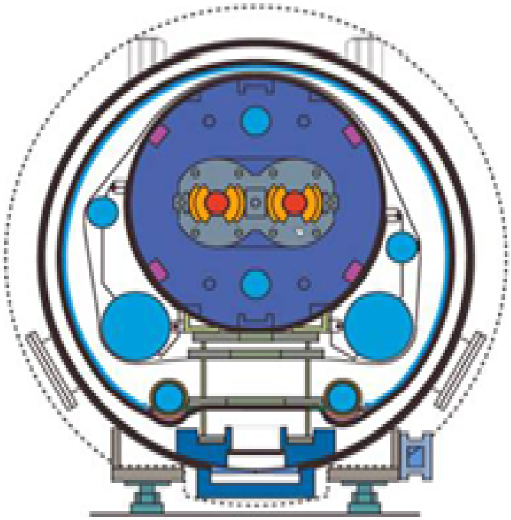
HERA
B = 4.7 T
BORE : 75 mm



RHIC
B = 3.5 T
Bore : 80 mm

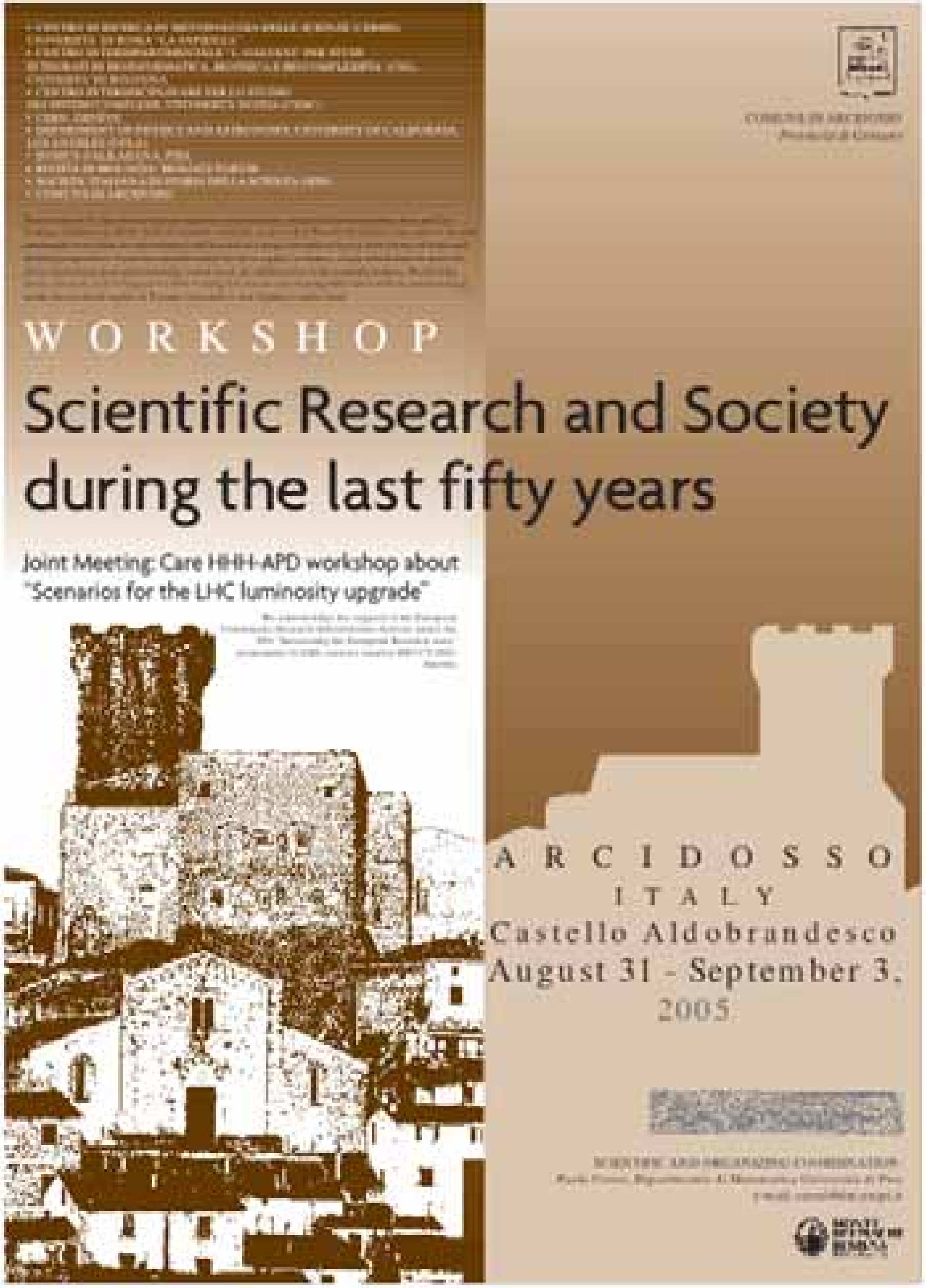


TEVATRON
B = 4.5 T
Bore : 76 mm



LHC
B = 8.3 T
Bore : 56 mm

Future upgrade



WORKSHOP

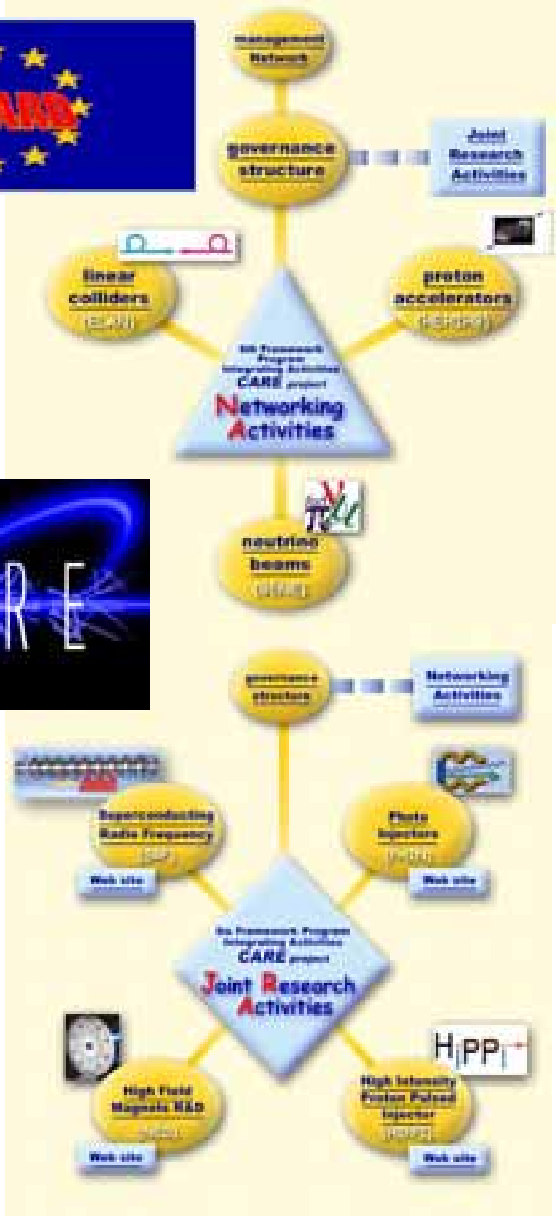
Scientific Research and Society during the last fifty years

Joint Meeting: Care HHH-APD workshop about "Scenarios for the LHC luminosity upgrade"

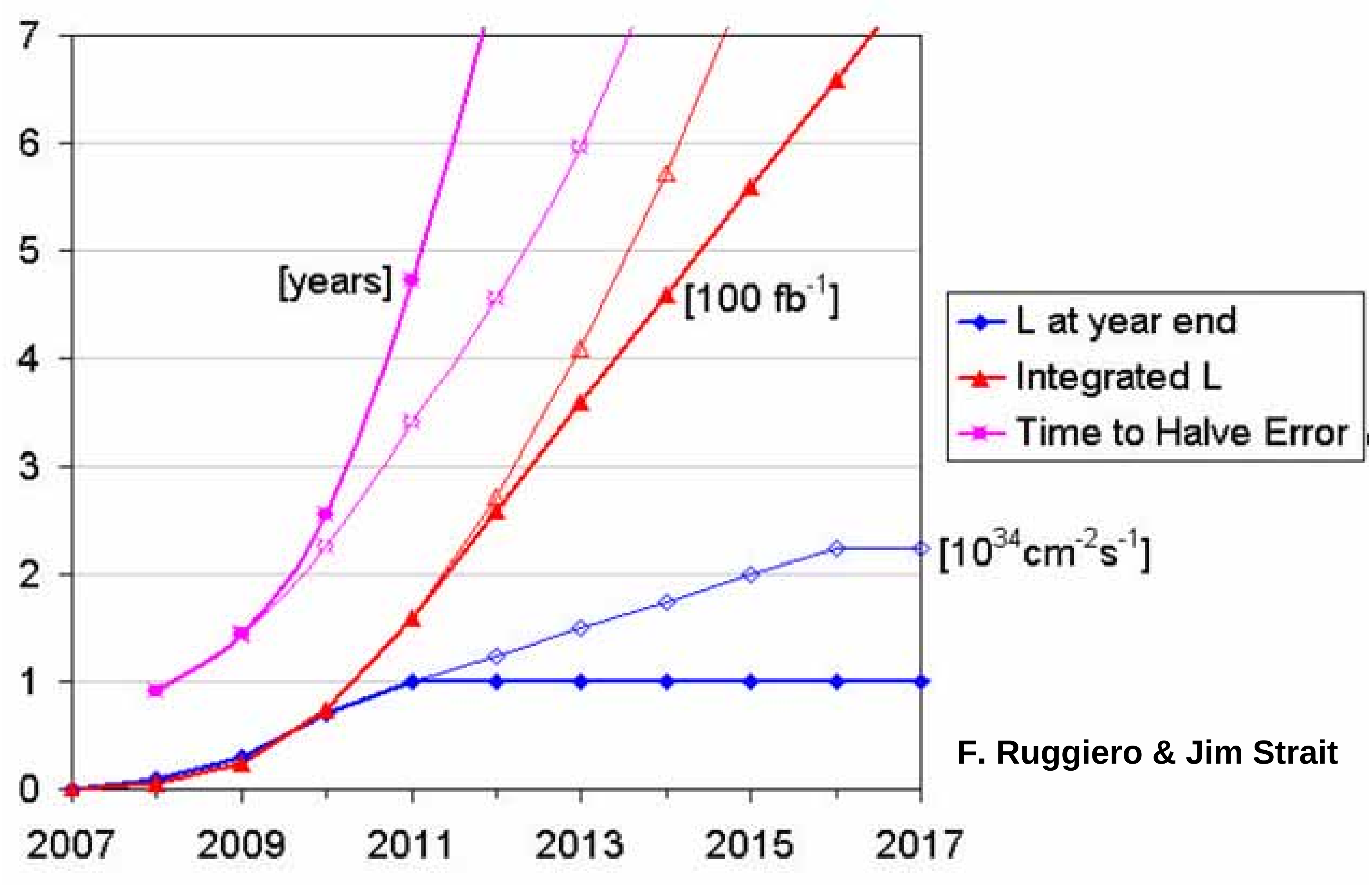
ARCIDOSSO
ITALY
Castello Aldobrandesco
August 31 - September 3, 2005

ESGARD

CARE



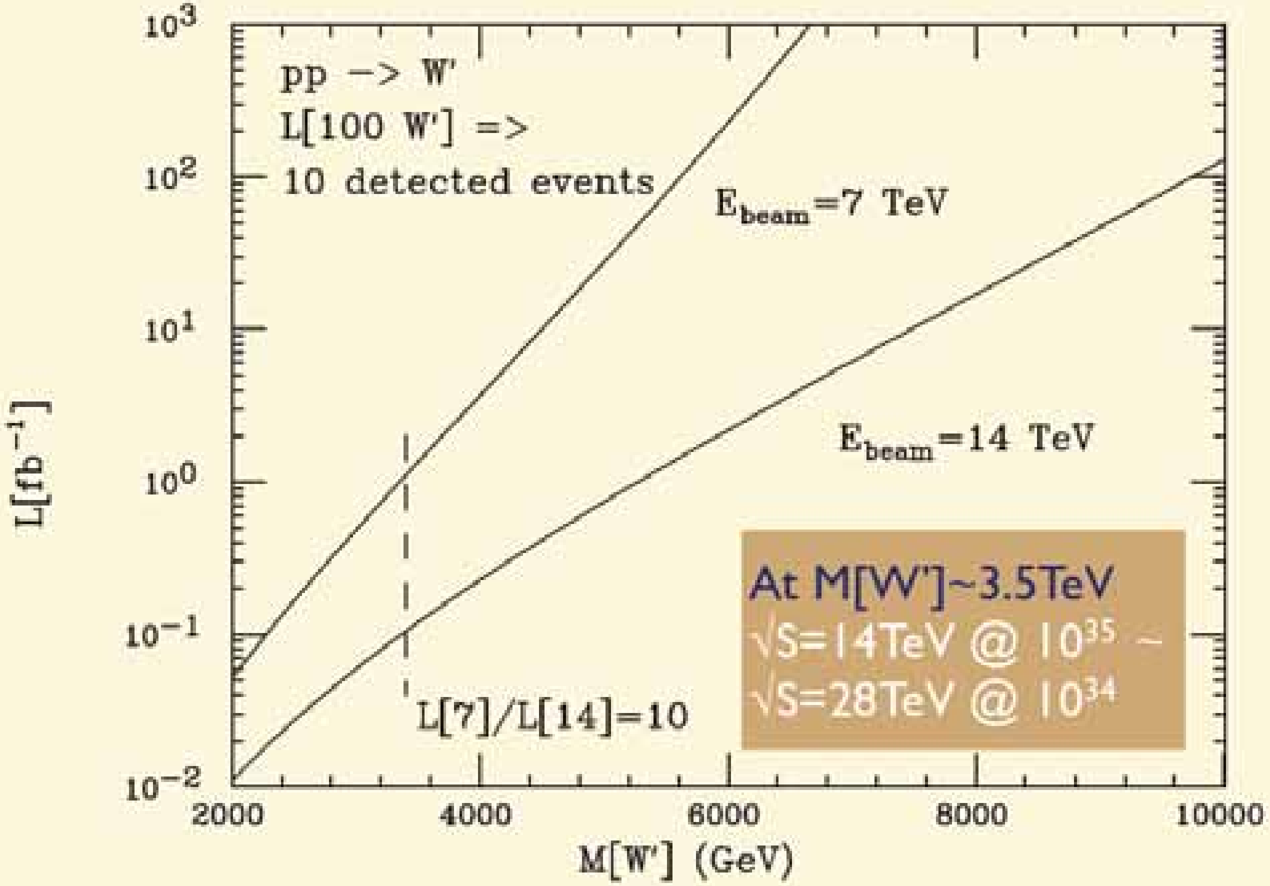
Why upgrading the LHC : Luminosity



F. Ruggiero & Jim Strait

Why upgrading the LHC : Energy

At low mass, the energy-dependence of the cross section is weaker, and a factor x10 in Lum is better than a factor of x2 in Ebeam



At M[W']~3.5TeV
√S=14TeV @ 10^{35} ~
√S=28TeV @ 10^{34}

M.Mangano

At high masses, the E upgrade is essential

LHC Upgrades

Interaction regions upgrade : xx MEuros

Luminosity Upgrade

New quadrupoles and possibly new dipoles in the interaction regions : needed in 2015

Injectors upgrade : xxx MEuros

Luminosity and Energy Upgrade

Fast cycled, low losses superconducting magnets : 5-10 years program

Energy doubler 7 TeV to 14 TeV : xxxx MEuros

Energy upgrade

New dipoles and quadrupoles in the arcs : 15-20 years program


Fermilab

Limits of the present LHC triplets

- Aperture
  - 70 mm coil
  - 63 mm beam tube
  - 60 mm beam screen → $\beta^* = 0.55$ m
- Gradient
  - 215 T/m → operational 205 T/m
- Peak power density
  - 12 mW/cm^3 → **L** = 3 10^{34}
- Total cooling power
  - 420 W at 1.9 K → **L** = 3 10^{34}

Focus on

- **capacity of removing heat (shield + transparency)**
- **making the quadrupoles stronger and shorter**

Fast cycled magnets for injectors

Requirements

Bore diametre 80-100 mm

Peak field 3.5 T up to 5 T/s or 5 T up to 1.5 T/s

Capable to perform several millions cycles in a radiative environment

Capable to draw beam deposited energy of the order of 5-10 W/m and possibly higher

State of the art

Superferric magnets with internally cooled cables, 2 T peak, 4T/s, 1 Hz, based on JINR Nuclotron.

GSO001 model, based on a modified RHIC type dipole, built by BNL for the FAIR Project.

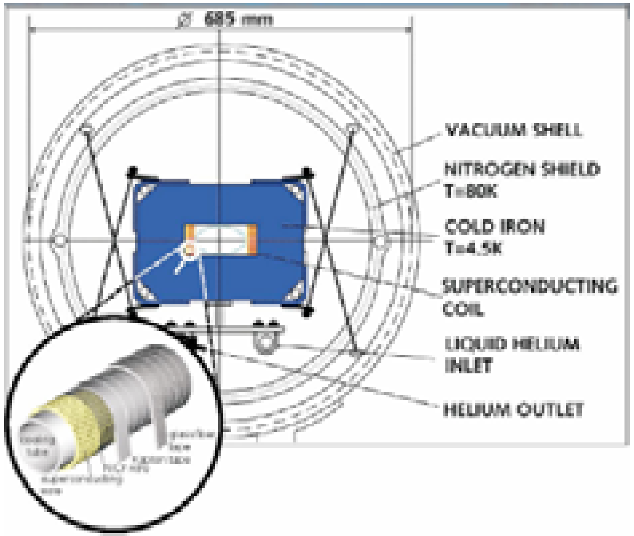
State of the art : superferric dipoles

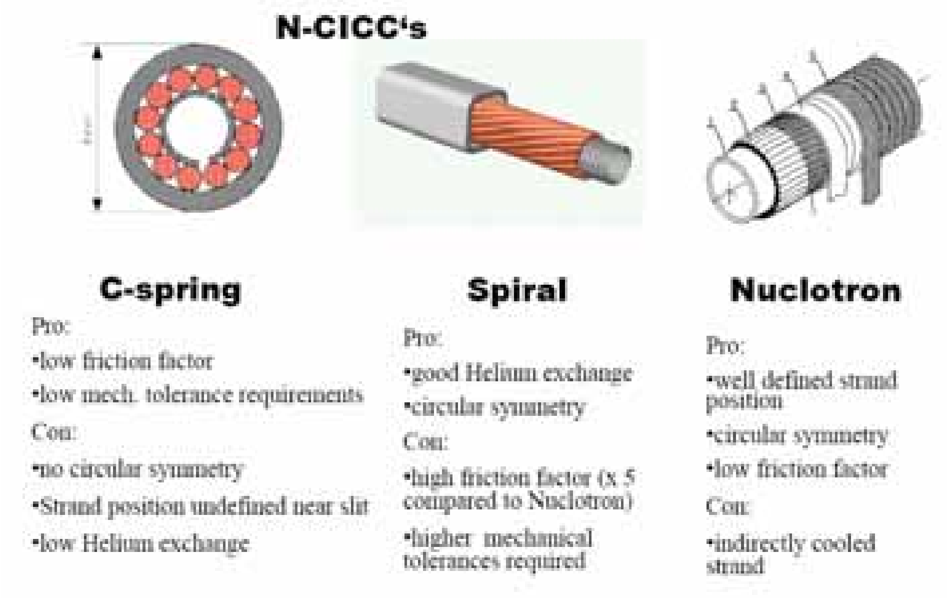
SIS 100

- Triangular cycle, 0-2 T, 1 Hz ⇒ 4T/s
- Superferric, window frame
- 2T central field, 4 T/sec ramp
- 18 W/m with Nuclotron design, smaller filaments

Activity

- Design alternatives : warm/cold iron, resistive magnets
- Cable developments (smaller filament size 3.5 microns)





C-spring

Pro:
- low friction factor
- low mech. tolerance requirements

Con:
- no circular symmetry
- Strand position undefined near slit
- low Helium exchange

Spiral

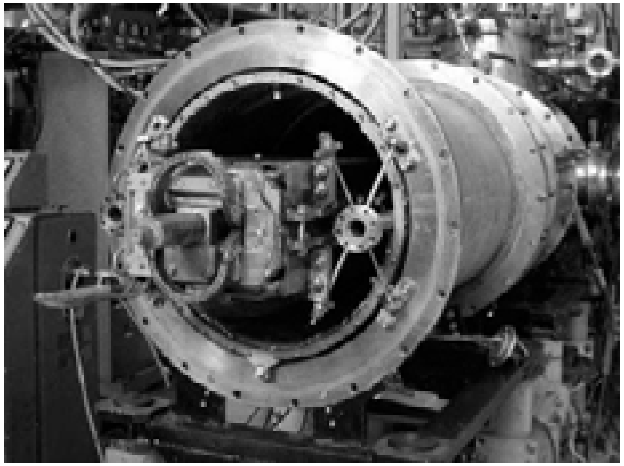
Pro:
- good Helium exchange
- circular symmetry

Con:
- high friction factor (x 5 compared to Nuclotron)
- higher mechanical tolerances required

Nuclotron

Pro:
- well defined strand position
- circular symmetry
- low friction factor

Con:
- indirectly cooled strand

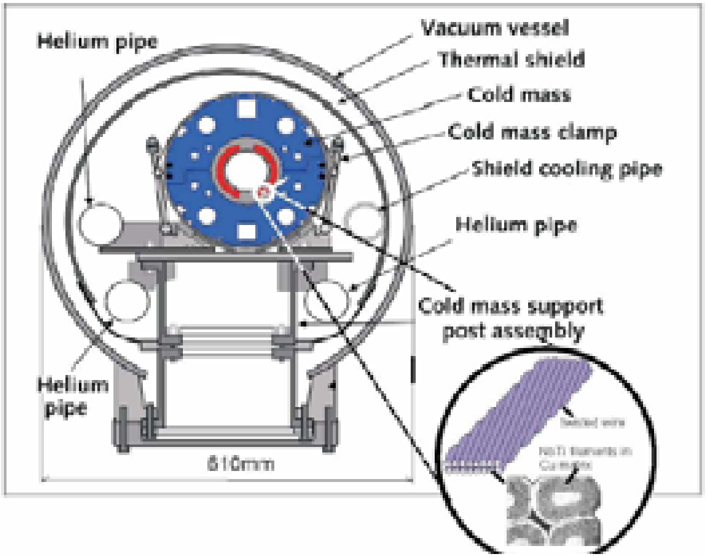


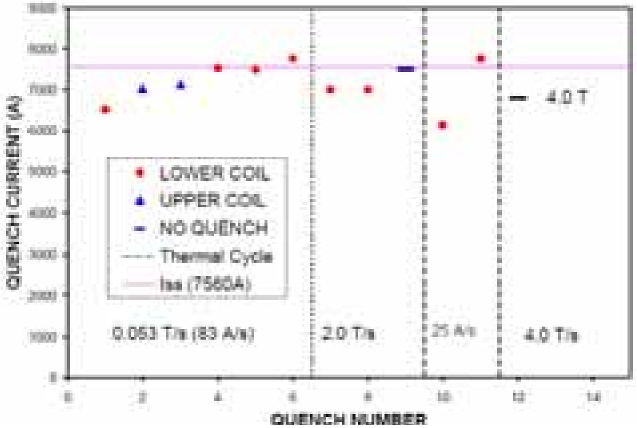
Courtesy AD.Kovalenko

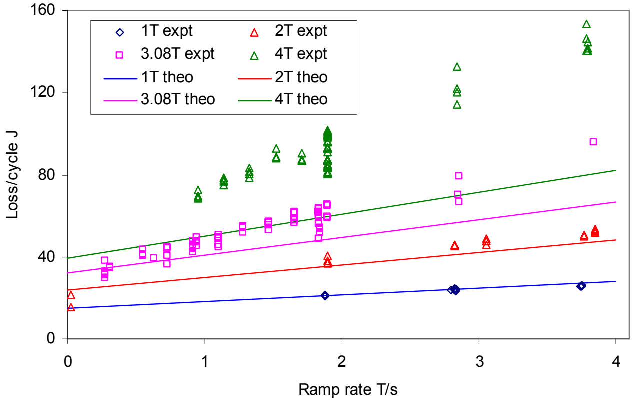
State of the art : 4T dipoles

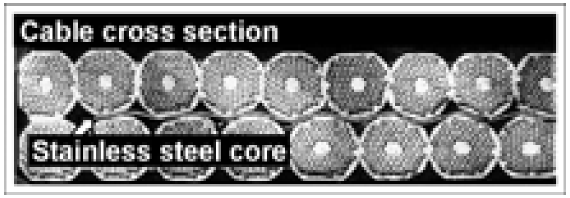
BNL model : optimize to higher ramp-rate

- Wire twist pitch 4 mm instead of 13 mm
- Stabrite coating instead of no coating
- Stainless steel core (2x25 microns)
- G-11 wedges instead of copper wedges
- Thinner yoke laminations, 3.5 % silicon, glued with epoxy.









y A.Ghosh, P.Wanderer, M.Wilson

Fast cycled magnets

A considerable advancement of the state of the art is needed.

- development of low AC losses cables with fine filament (1 μm diameter) in resistive matrix
- thermal models and different cooling schemes, with optimization of the whole cryogenic chain;
- magnet design with wide bore and cable insulation configurations for improved heat removal;
- loss computations models as well quench propagation models;
- powering and protection schemes with development of novel techniques for quench detection
- characterization of mechanical/fatigue behavior of materials and structures to guarantee 10 Mcycles;
- radiation resistance of material to be employed;
- design and set-up of fast magnetic measurements systems in the 20-100 Hz range;

The use of internally cooled cables, at least for fields up to 4 T, may also be envisaged. This option makes however magnet manufacture (in particular the interface with connections and interconnections) and operation much more difficult and less reliable than with Rutherford cables, and shall be reserved where heat deposition from beam losses becomes much higher than the order of 10 W/m of magnet length.

Strand & Cable R&D for pulsed magnets

2 types of dipoles aperture in the range of 80-120 mm:

	Peak field	Ramp-rate	Cycle	Length	Salient aspects
PS+	3.5 T	5 T/s	2 s	4 m	High ramp-rate, large aperture
SPS+	4.5-5.5 T	1.5	12 s	6 m	Moderate ramp-rate, higher field

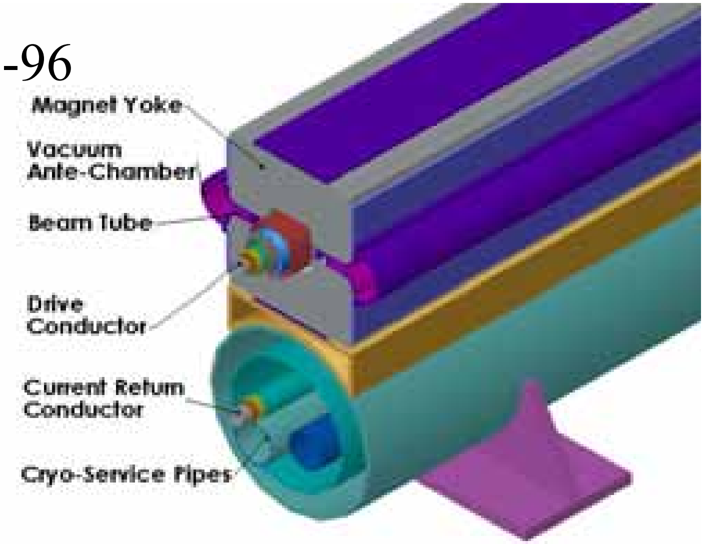
2 types of superconducting wires/cable :

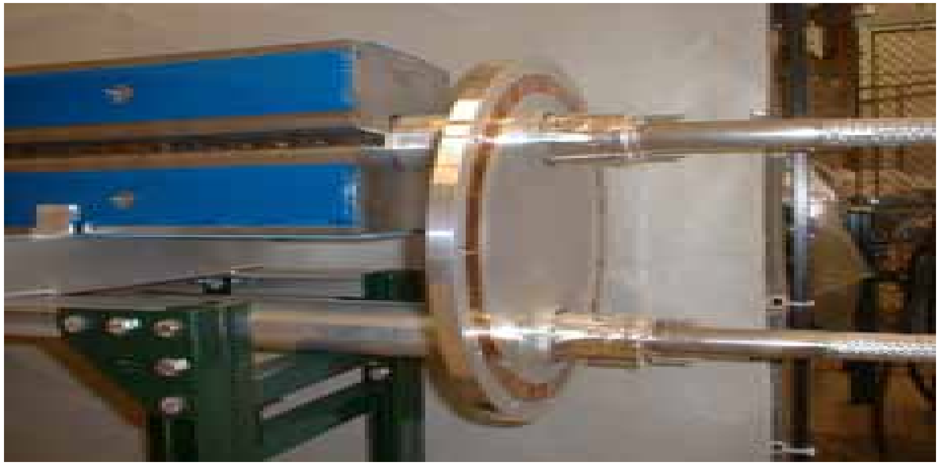
	Filament Φ	Matrix	Cable Ra	Cable Rc	Status of wire
PS+	~ 1 μm	Cu-Mn or Cu-Ni	>0.8 mΩ	>40 mΩ	Feasible, but needs massive R&D
SPS+	< 3 μm	Cu-Mn or Cu-Ni	>0.3 mΩ	>10 mΩ	Needs industrialization

- industrialize 3 μm filaments in resistive matrix : moderate R&D, billets, measurements
- develop 1 μm filaments in resistive matrix : massive R&D, billets, filaments
- optimize wire coating techniques to achieve the required electrical and thermal properties
- study stability of cables as a function of adjacent and cross inter-strand resistance
- establish, and validate with experimental results, loss computations models
- instrumented model magnets have to be built and tested to provide feedback to wires/cables

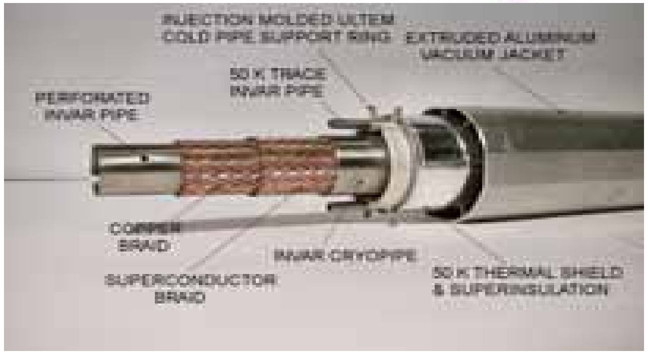
Pipetron - VLHC magnets FNAL

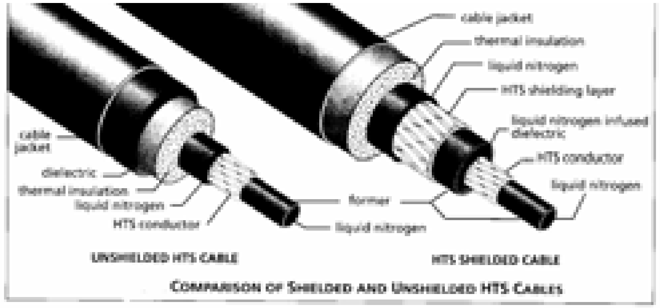
- Invented in Fermilab by W. Foster around 1995-96
- 0.45 TeV injection at 0.48 T
- 1.5 TeV top at 1.595 T (55KA)
- 1 m prototype tested at FNAL
- Reported at MT19



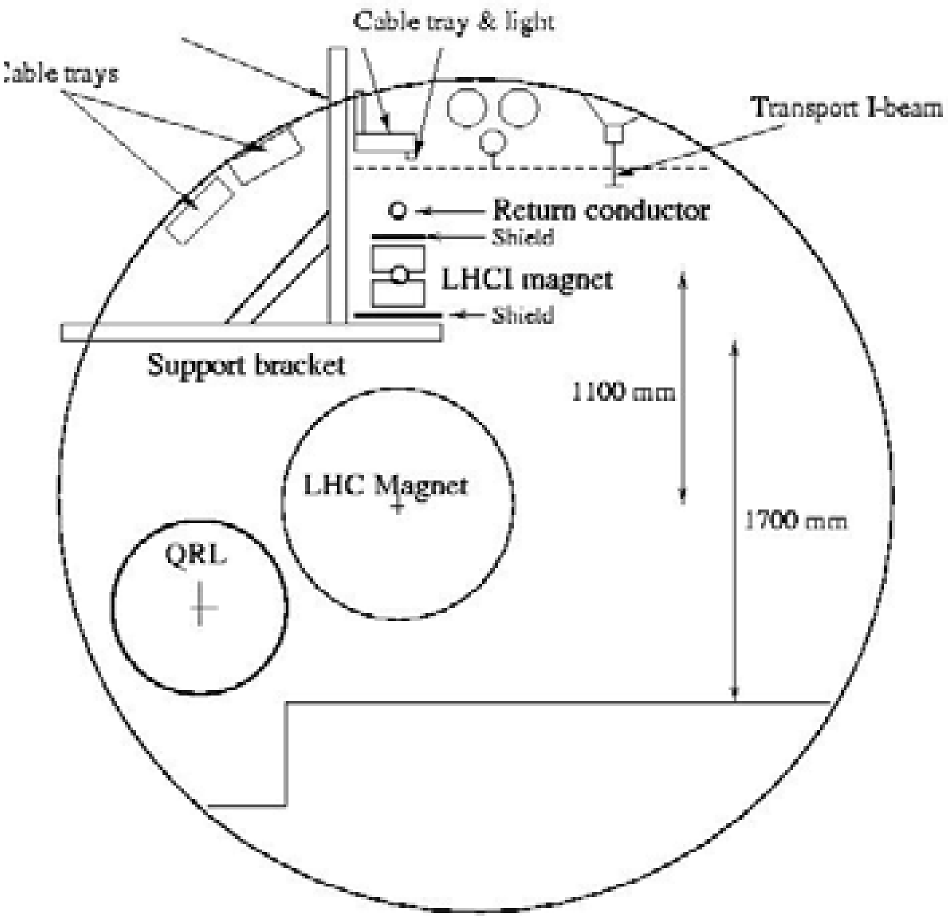


Courtesy of H. Piekarz (Fermilab)

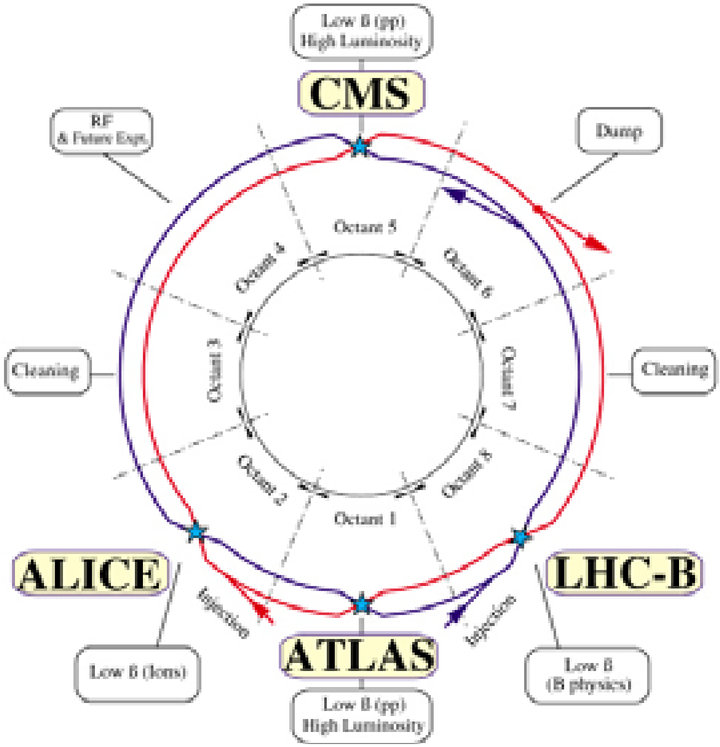




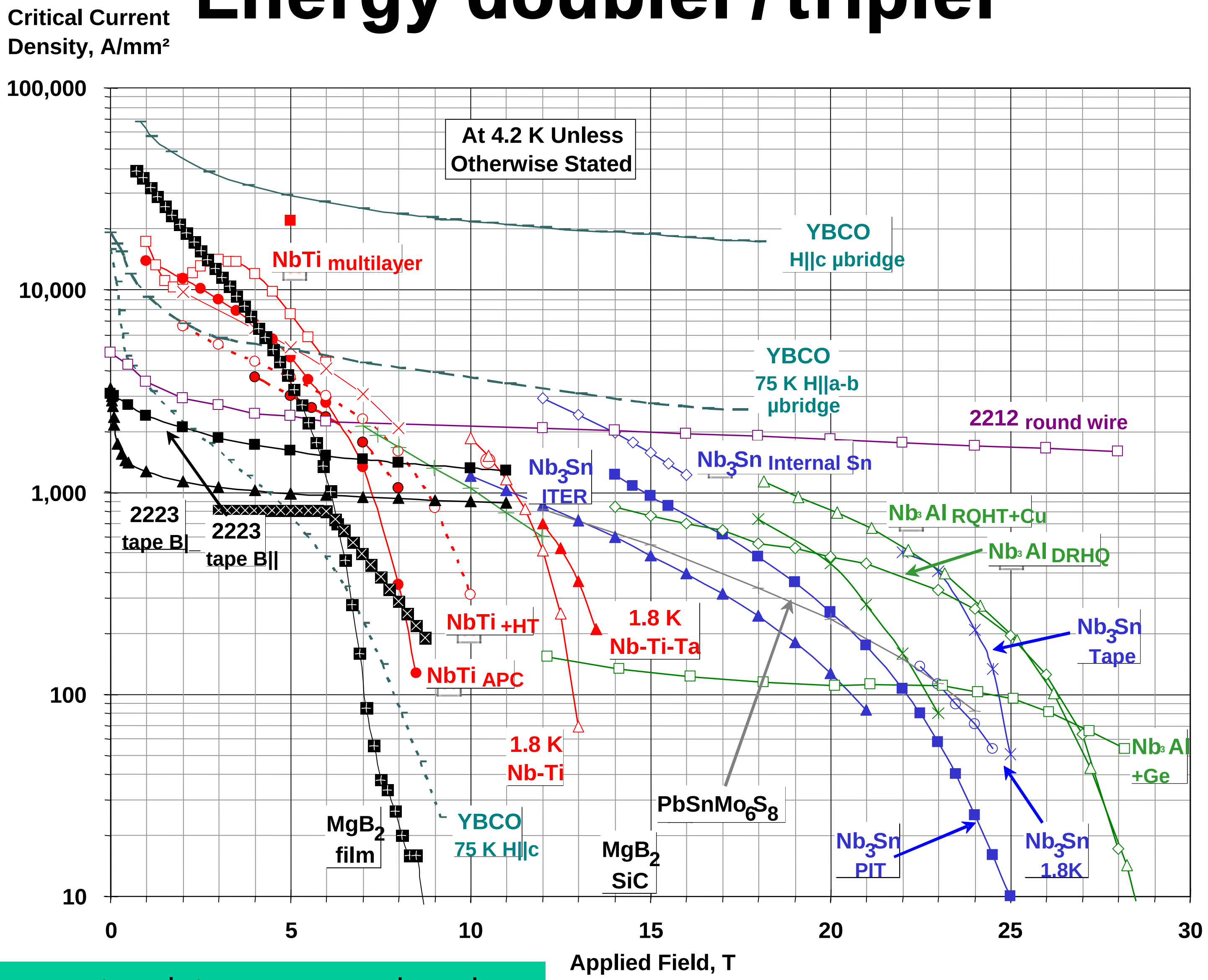
Tunnel space



Courtesy G. de Rijk



Energy doubler / tripler



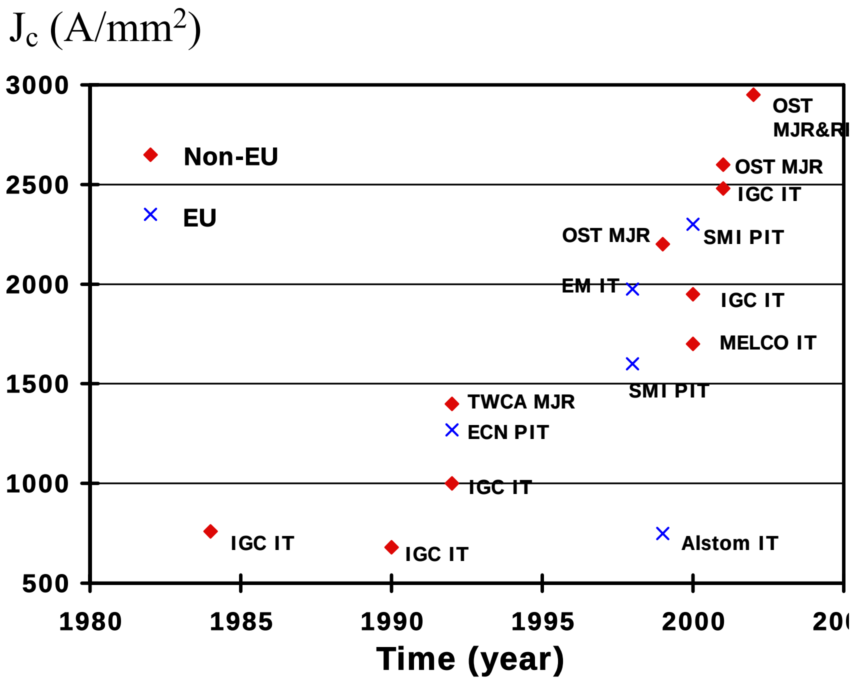
Peter Lee master plot – www.asc.wisc.edu

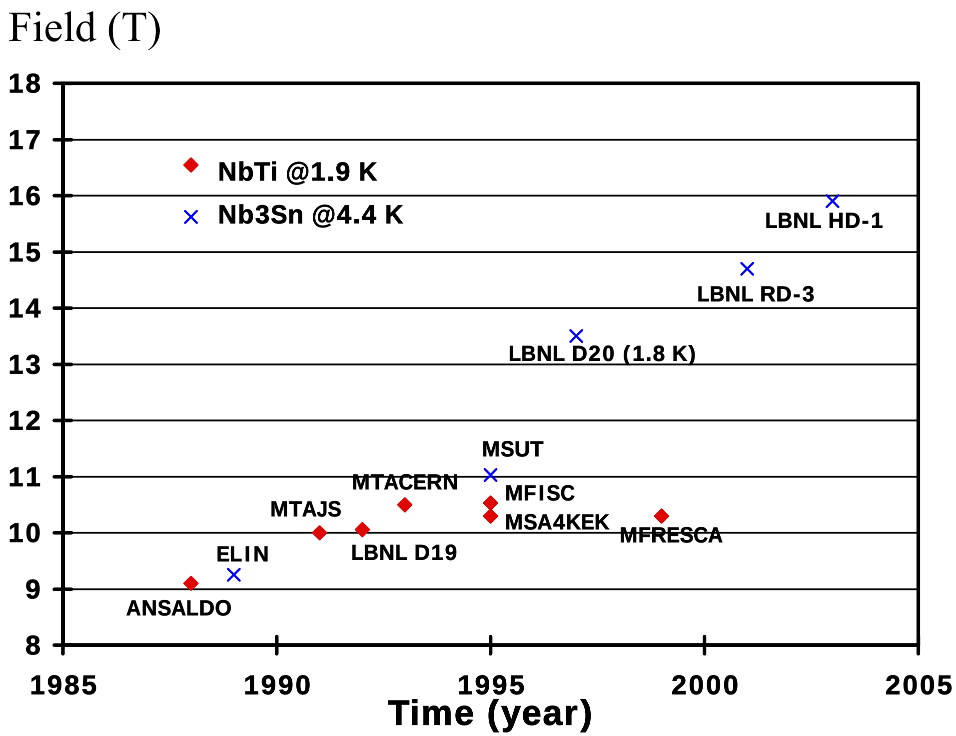
Progress on Nb_3Sn

Manufacturing and test of ITER model coils ~30 t of Nb_3Sn wires

US National Program for high-current density Nb3Sn wires

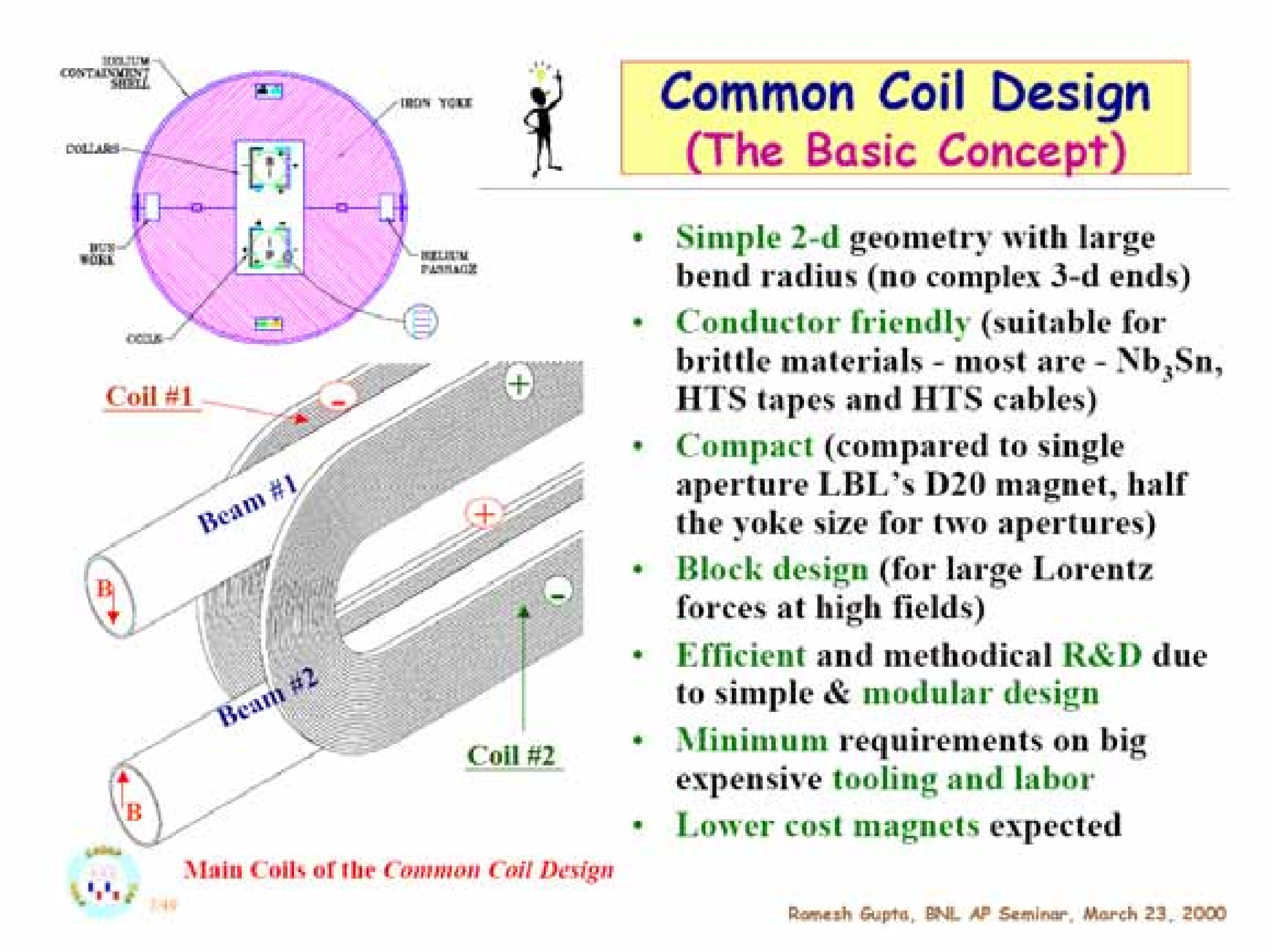
Dipole models opening the 10-to-15 T field range.





Courtesy of A. Devred

Magnet Design



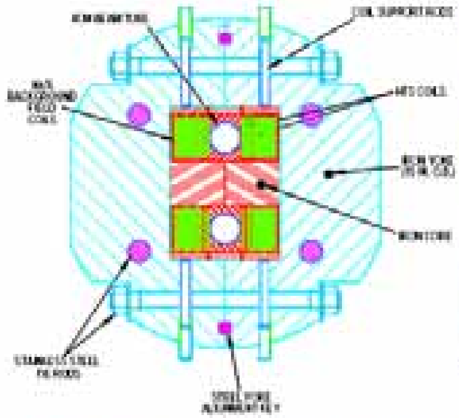
Common Coil Design (The Basic Concept)

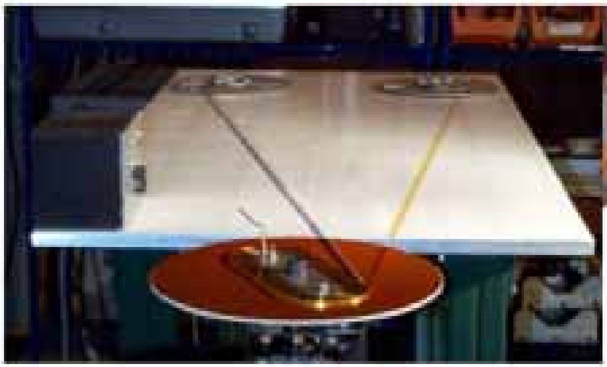
- Simple 2-d geometry with large bend radius (no complex 3-d ends)
- Conductor friendly (suitable for brittle materials - most are - Nb_3Sn, HTS tapes and HTS cables)
- Compact (compared to single aperture LBL's D20 magnet, half the yoke size for two apertures)
- Block design (for large Lorentz forces at high fields)
- Efficient and methodical R&D due to simple & modular design
- Minimum requirements on big expensive tooling and labor
- Lower cost magnets expected

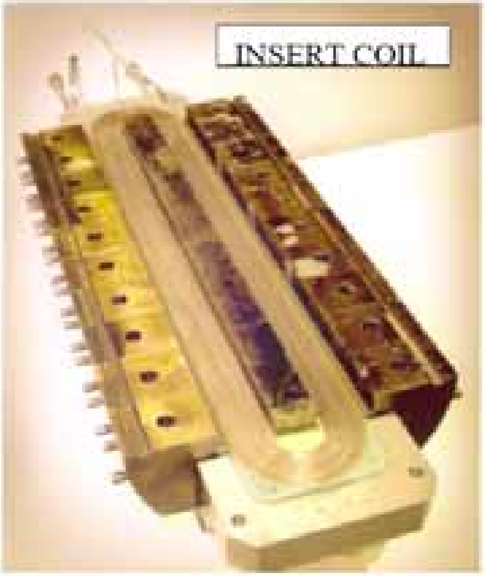
Main Coils of the *Common Coil Design*

Ramesh Gupta, BNL AP Seminar, March 23, 2000

Hybrid Common Coil Magnet at BNL







Ramesh Gupta, BNL AP Seminar, March 23, 2000

High Field Magnet Road Map

Technology	Machine	Field	Year
Cu (resistive)	LEP, ESRF Soleil, Diamond	< 2 T	1970’s
NbTi, 4,2 K	Tevatron	4 T	1983
NbTi, 1,9 K	Tore Supra	7 T (conductor peakfield)	1988
NbTi, 1,9 K	LHC	8.33 T	2007
NbTi, 1,9 K	*NEUROSPIN*	*11.7 T (conductor peakfield)*	*2008-2009 ?*
Nb_3Sn, 4,2 K	ITER/EDA *ITER*	12 T (conductor peakfield)	1995-2000 *> 2010 ?*
Nb_3Sn	CARE/NED *LHC IR upgrade* *LHC doubler*	14-15 T	2004-2008 *2015 ?* *> 2020 ?*
BSCCO	*LHC tripler*	*24-25 T*	*> 2030 ?*

Courtesy of L.Rossi

Magnet Programs worldwide

- EU
  - CARE/NED : 8 institutes, CCLRC, CEA, CERN, CIEMAT, INFN/Milan and Genova, Twente University and Wroclaw University of Technology
  - Two very small programs: CERN/Twente and CEA/Saclay
- US
  - Four independent base programs (BNL, FNAL, LBNL and TAMU)
  - Three labs collaborate under LARP
- Japan/KEK
  - Nb_3Sn and Nb_3Al conductor development and Al stabilized conductors
  - Cost-effective magnets for accelerators and beamlines

Conclusions

Superconducting magnets for accelerators : three trends

- fast cycled (common interest with FAIR and possibly medical applications)
- high field (any cost)
- high field low cost

Desirable initiatives in Europe

More participation and efforts into base Sc materials research

Development of wire/cable processing & industrialization

Consolidate practical experience with materials and magnets

Development of concepts for low cost HF magnets : design and manufacture