Radiation spectra in LHC phase II

Effect on superconducting materials

R. Flükiger

Outlinie

Circulation for Phase I

New results for Phase II

Effect of irradition on superconductors

* neutrons
* protons

Conclusion

Introduction

Compound	T_c	$B_{c2}(0)$	x
	(K)	(T)	(nm)
NbTi	10	14	6.3
Nb_3Sn	18	28	4.2
Nb_3Al	19	33	
MgB_2	39	35 - 65	5
Bi-2212	92	anisotropy	<2nm (//>p)
Y-123	95	anisotropy	< 2 nm (//>p)

Expected Radiation Load on the LHC Quadrupoles

LHC Upgrade Phase I

Calculated 2008 for the Quadrupole Q2a Inner Winding by:

Francesco Cerutti , CERN
Alessio Mereghetti, CERN
Marco Mauri, CERN
Elena Widmer, CERN

Peak Fluence during Phase 1 Upgrade (2.5 x of 10^{34} cm^{-2} s^{-1})

Quadrupoles Q1, Q2a, Q2b, Q3

Radiation spectrum at Q2a: 35m from Collision Point

Photons	87 %	
Neutrons	6 %	100.0 %
Protons	0.15 %	2.5 %
Electrons	3.5 %	
Positrons	2.5 %	
Pions (+/-)	0.4 %	

Neutrons : main source of damage to the superconductors.
Protons: smaller, but not negligible effect
Photons: effect on insulators
small effect on s.c. expected, more data necessary

Peak Fluence, LHC Upgrade Phase II (10^{35} cm^{-2} s^{-1})

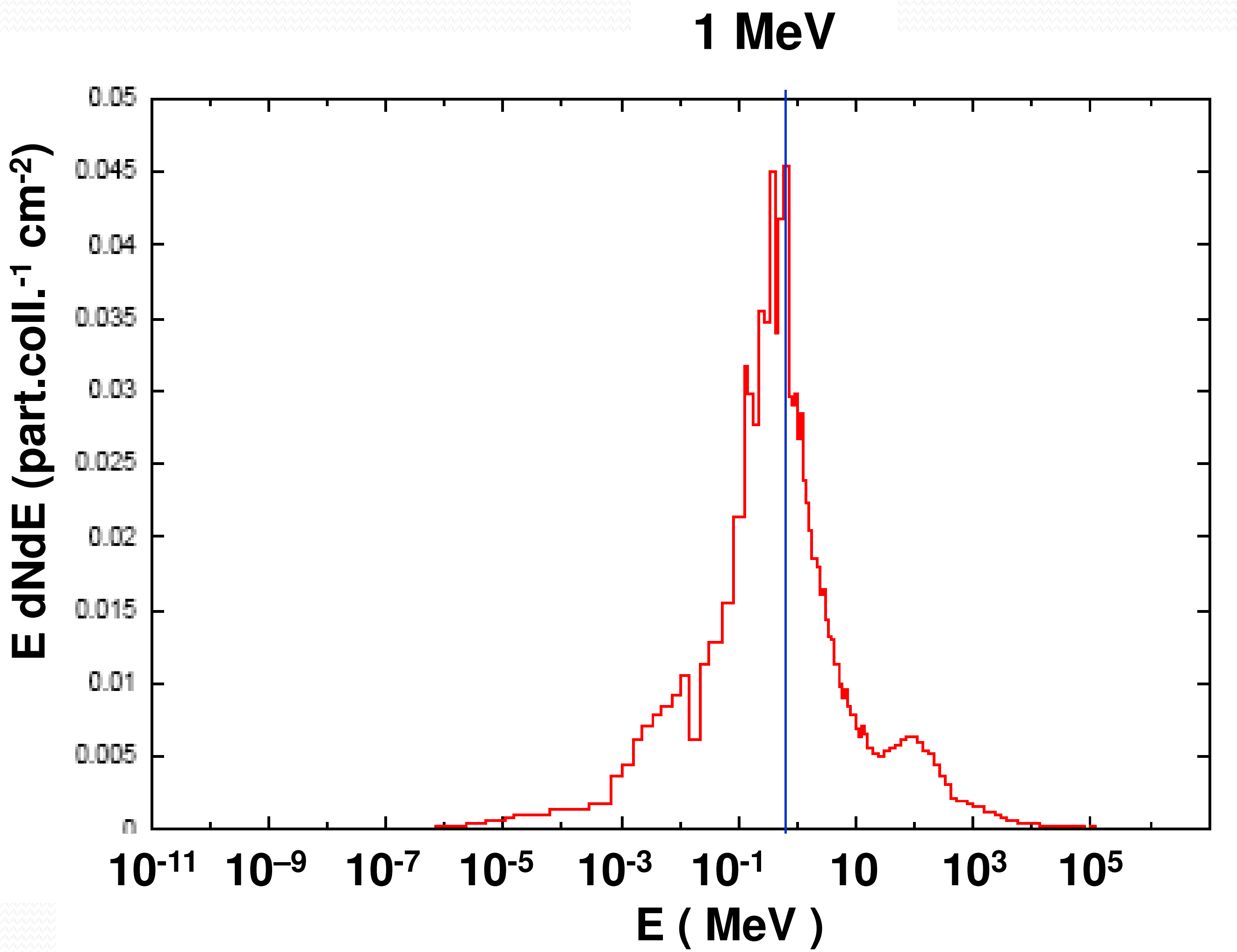
Radiation spectrum at Q2a: 35m from Collision Point

Aperture	200mm	130mm
Neutrons	4.82	4.04
Protons	0.14	0.13
Photons	88.93	89.00
Pions+	0.19	0.19
Pions-	0.26	0.25
Electrons	4.31	4.63
Positrons	2.23	2.45

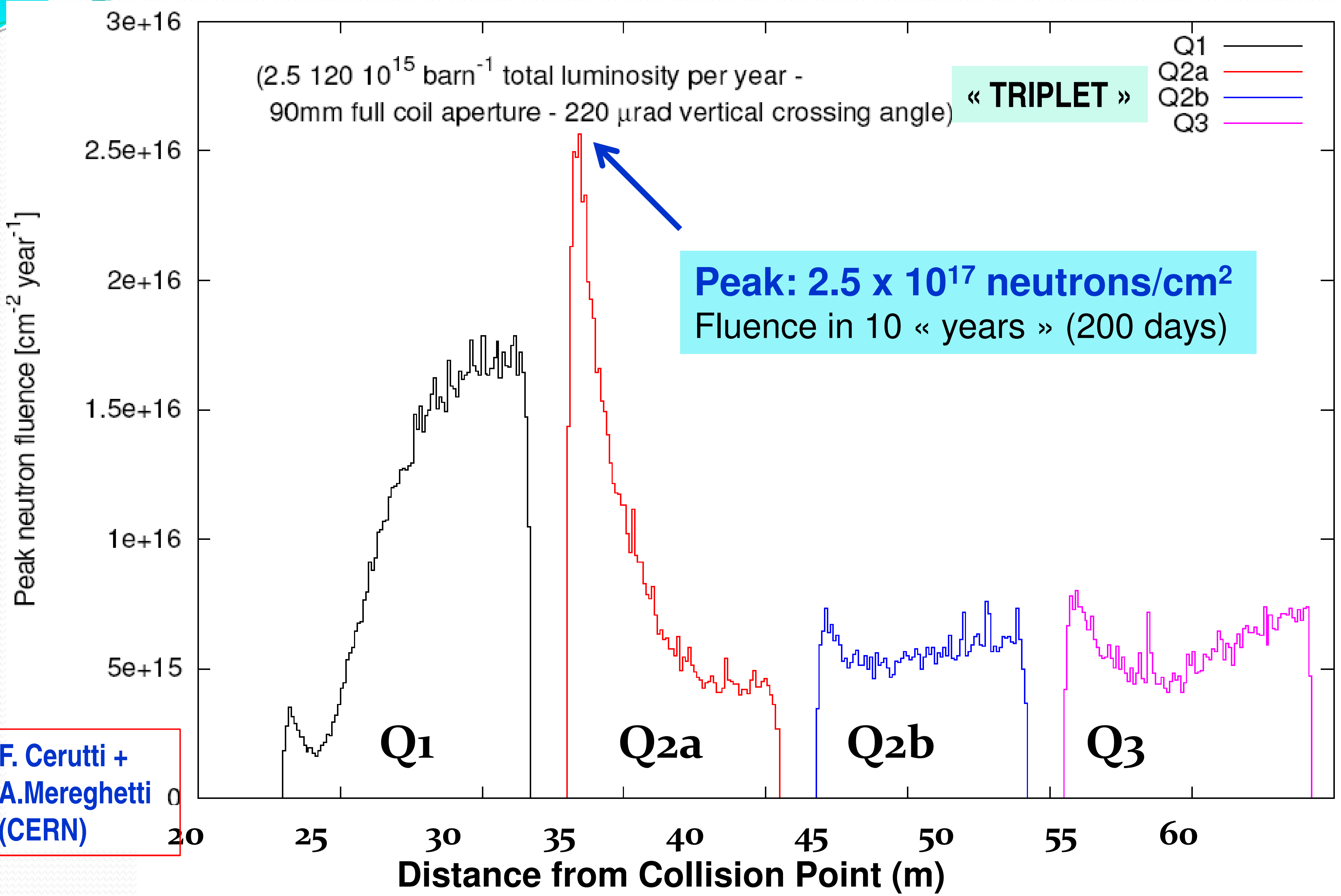
200mm	130 mm
100.0%	100.0%
2.8%	3.1%

Neutron spectrum in the inner winding of Quadrupole Q1

The neutron energy fully covers the possible interval, down to thermal energies



Neutron fluence in the inner winding of Quadrupoles (Phase 1 Upgrade)



F. Cerutti + A.Mereghetti (CERN)

Peak Fluence at Quadrupole Q2a: 2.5×10^{17} n/cm^2 after 10 years (Phase I upgrade)

For NbTi: no effect

Later, for Nb_3Sn wires:
Even after 10 years of operation, peak fluence remains below
> 1×10^{18} n/cm^2.

Different fluences for Q1 – Q3: the operation conditions of these quadrupoles may have to be individually modified with time, for maintaining a constant field.

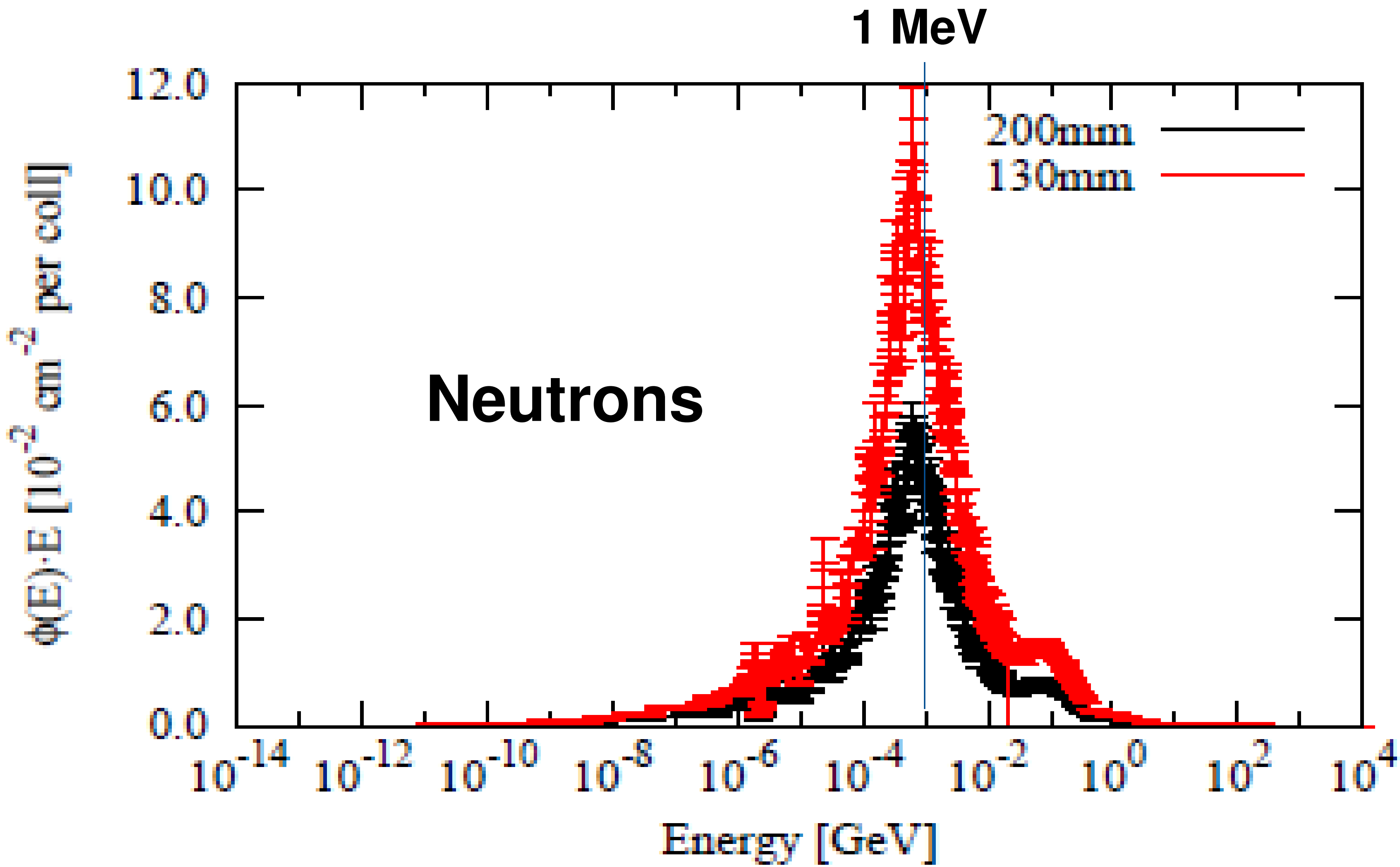
Expected Radiation Load on the LHC Quadrupoles

LHC Upgrade Phase II

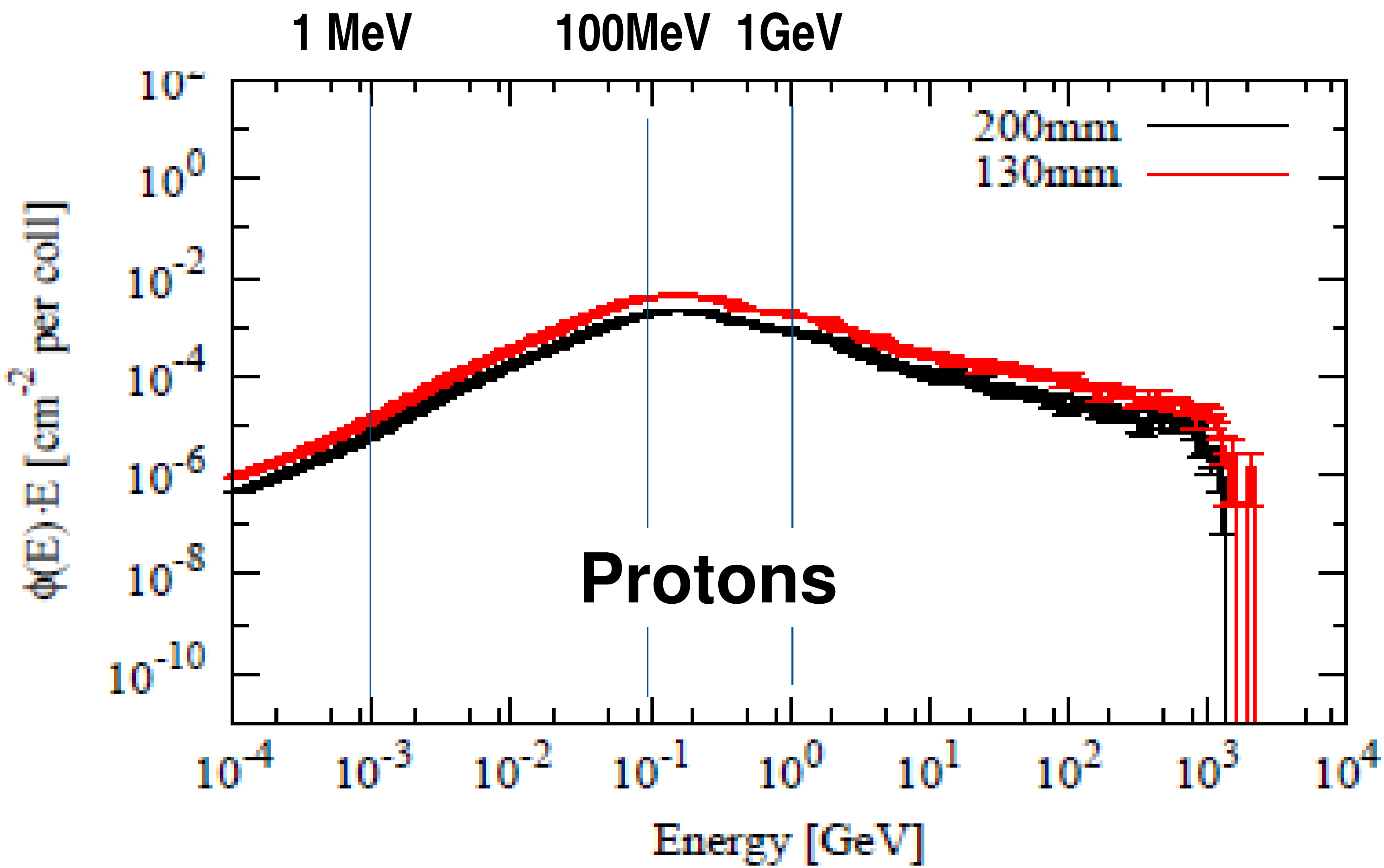
Calculated 2009 for the Quadrupole Q2a Inner Winding by:

Francesco Cerutti , CERN
Alessio Mereghetti, CERN

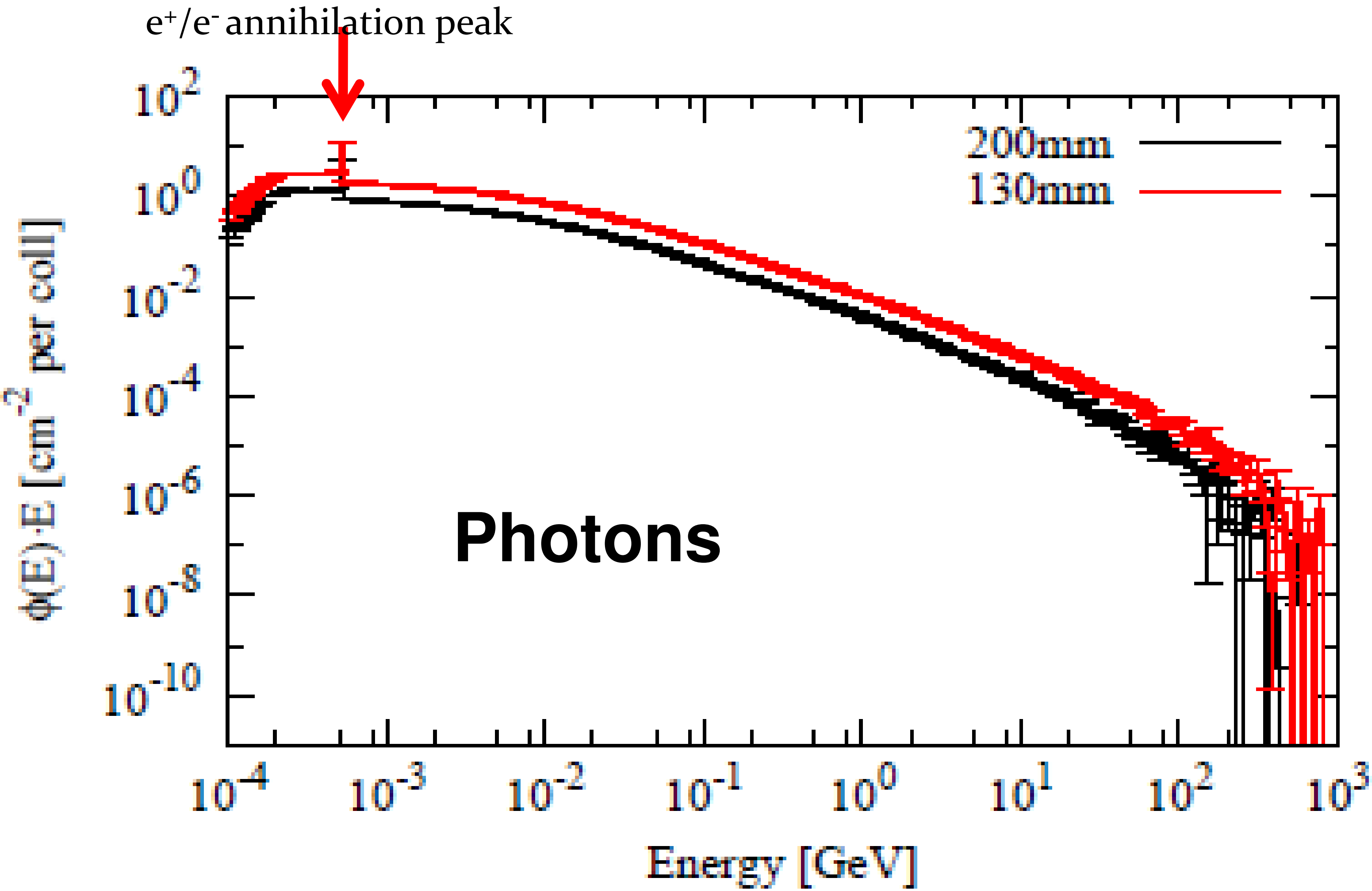
Neutron spectrum in the inner coil of Q2a at peak location



Proton spectrum in the inner coil of Q2a at peak location



Photon spectrum in the inner coil of Q2a at peak location



Phase II Aperture 130 / 200 mm

	Maximum number of particles per collision	Particle Energy
	$\phi(E) \cdot E$ [cm^{-2}]	E [MeV]
Neutrons	~10 / ~6	~ 1/ ~1
Protons	~ 0.01 / < 0.01	~ 100 / ~100

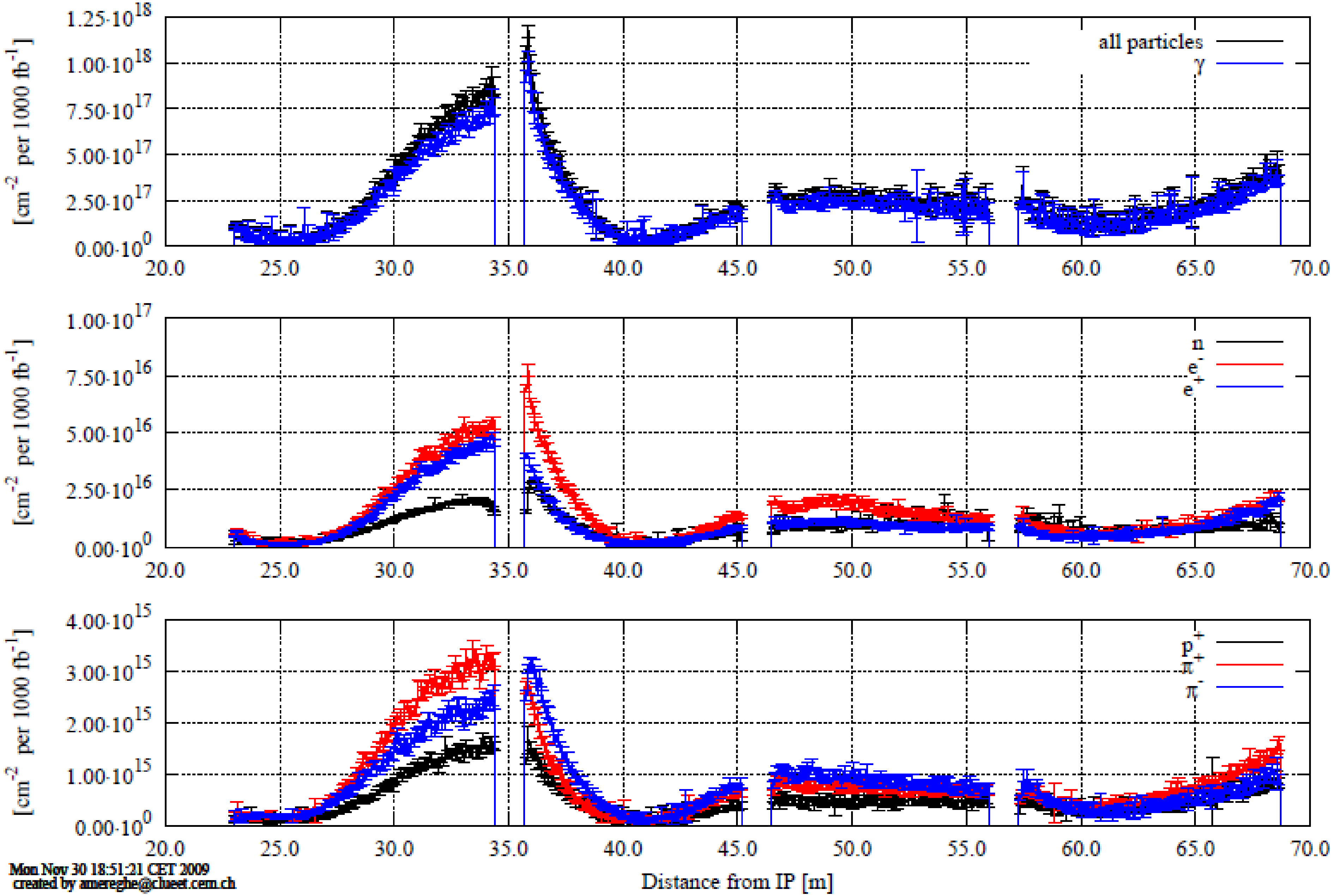
Peak Fluence, LHC Upgrade Phase II (10^{35} cm^{-2} s^{-1})

Radiation spectrum at Q2a: 35m from Collision Point

Aperture	200mm	130mm
Neutrons	4.82	4.04
Protons	0.14	0.13
Photons	88.93	89.00
Pions+	0.19	0.19
Pions-	0.26	0.25
Electrons	4.31	4.63
Positrons	2.23	2.45

200mm	130 mm
100.0%	100.0%
2.8%	3.1%

Peak fluence in the inner Q2a for 200 mm aperture



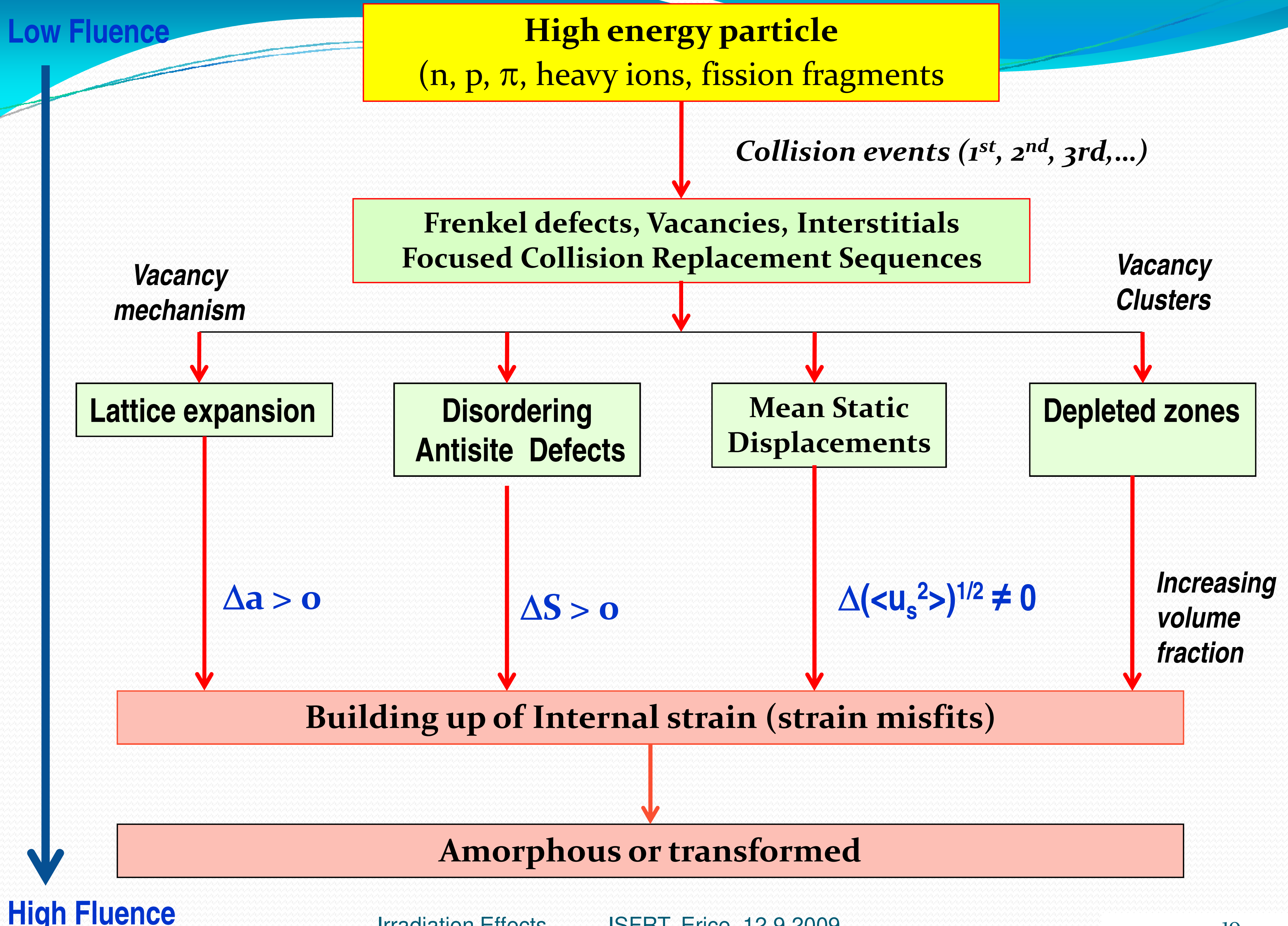
Phase II: Integrated luminosity: 20’000 fb^{-1}

Fluence expected for phase II

130 mm aperture: 1×10^{18} n/cm^2

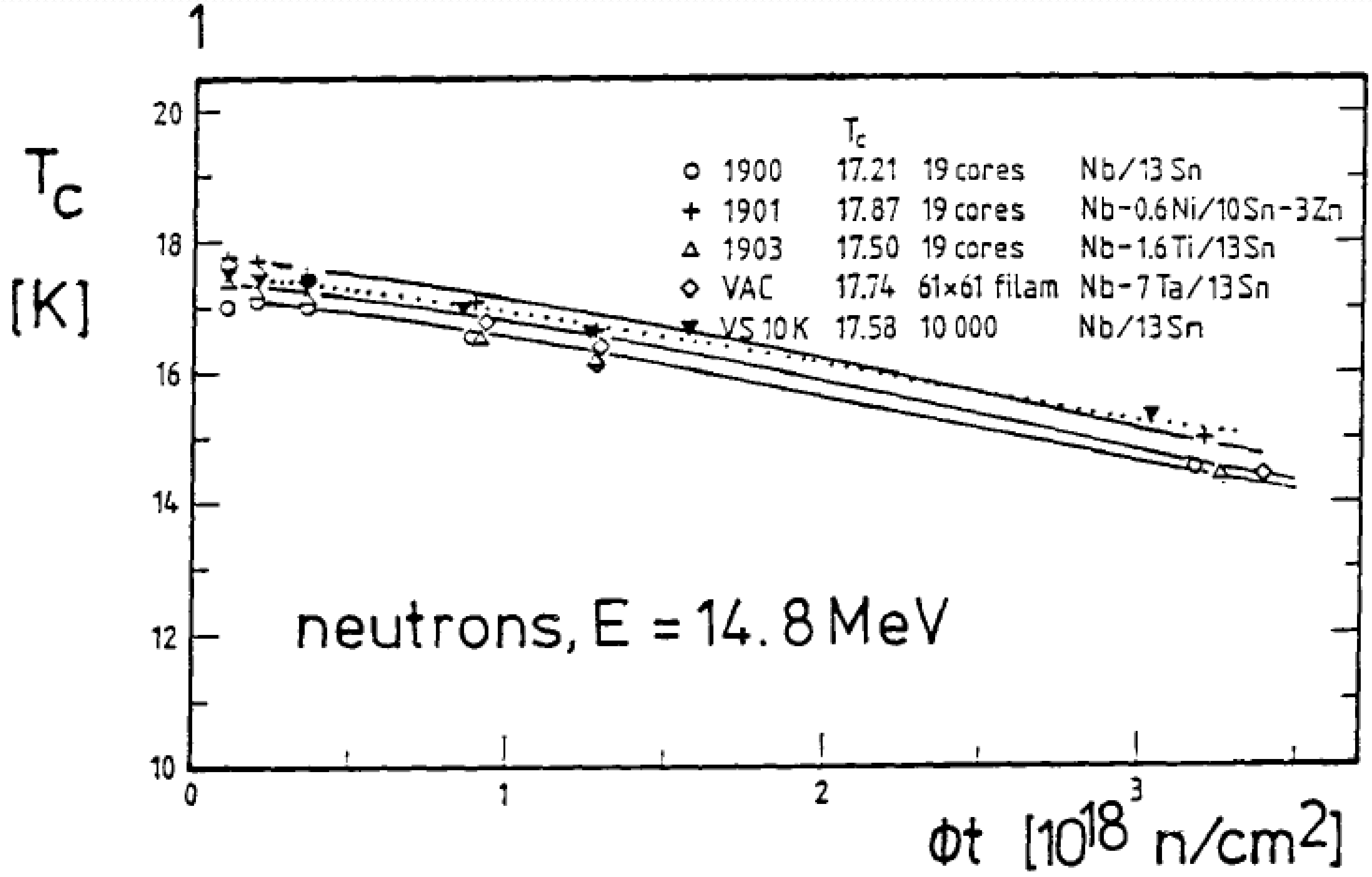
200 mm aperture: 5×10^{17} n/cm^2

Effect of irradiation on superconductors



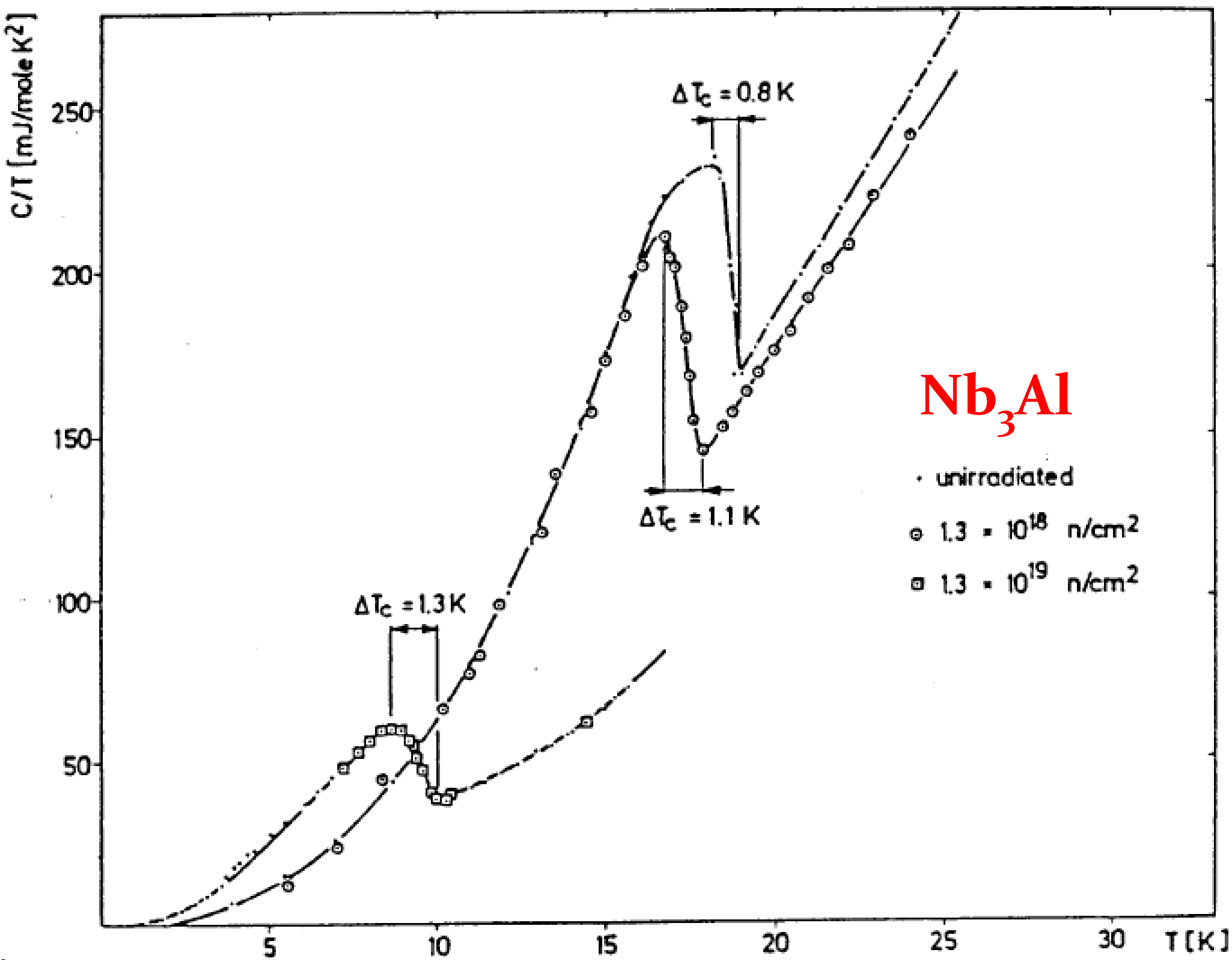
R. Flükiger, 1989

Decrease of T_c with neutron irradiation



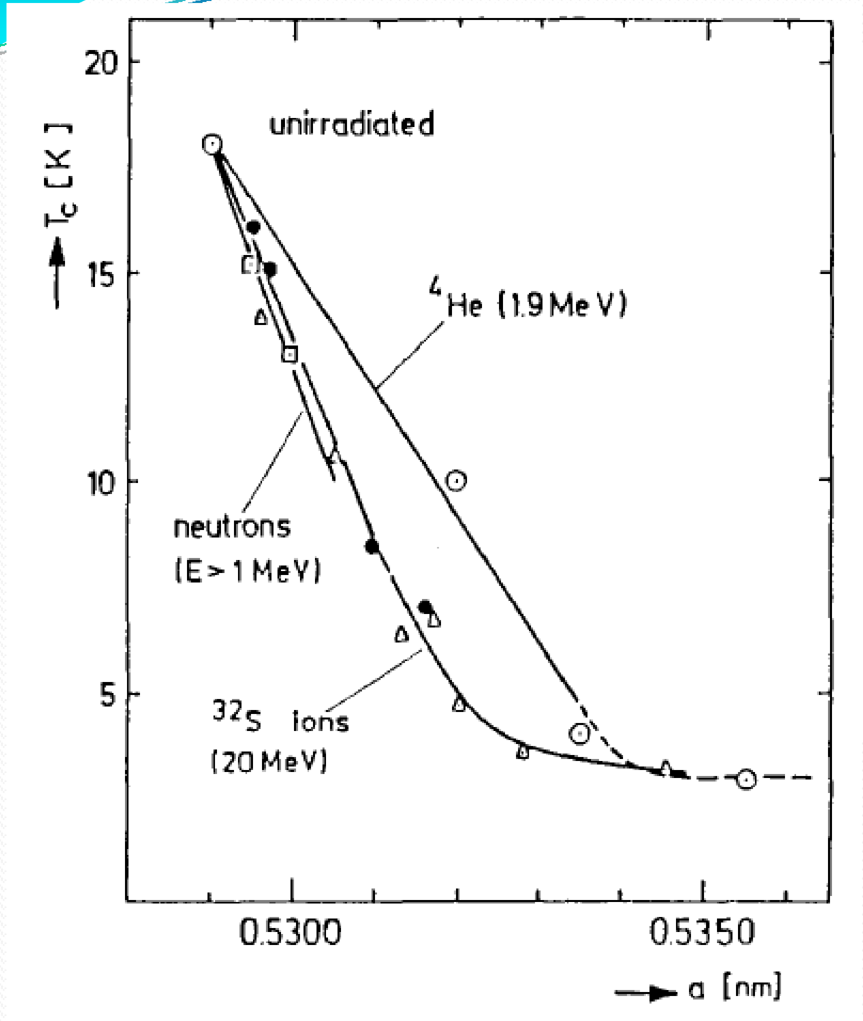
F. Weiss, R. Flükiger, W. Maurer, IEEE Trans. Magn., MAG-23(1987)976

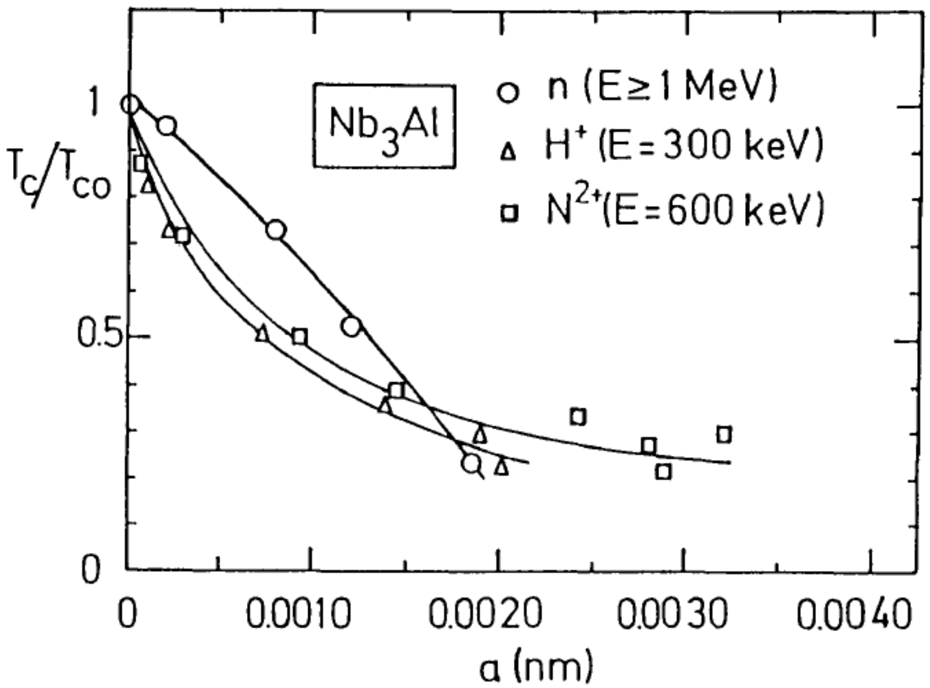
Homogenenity of T_c distribution (Specific Heat Measurements)



B. Cort, G.R. Stewart, C.L. Snead, A.R. Sweedler, Phys. Rev. B24(1981)379

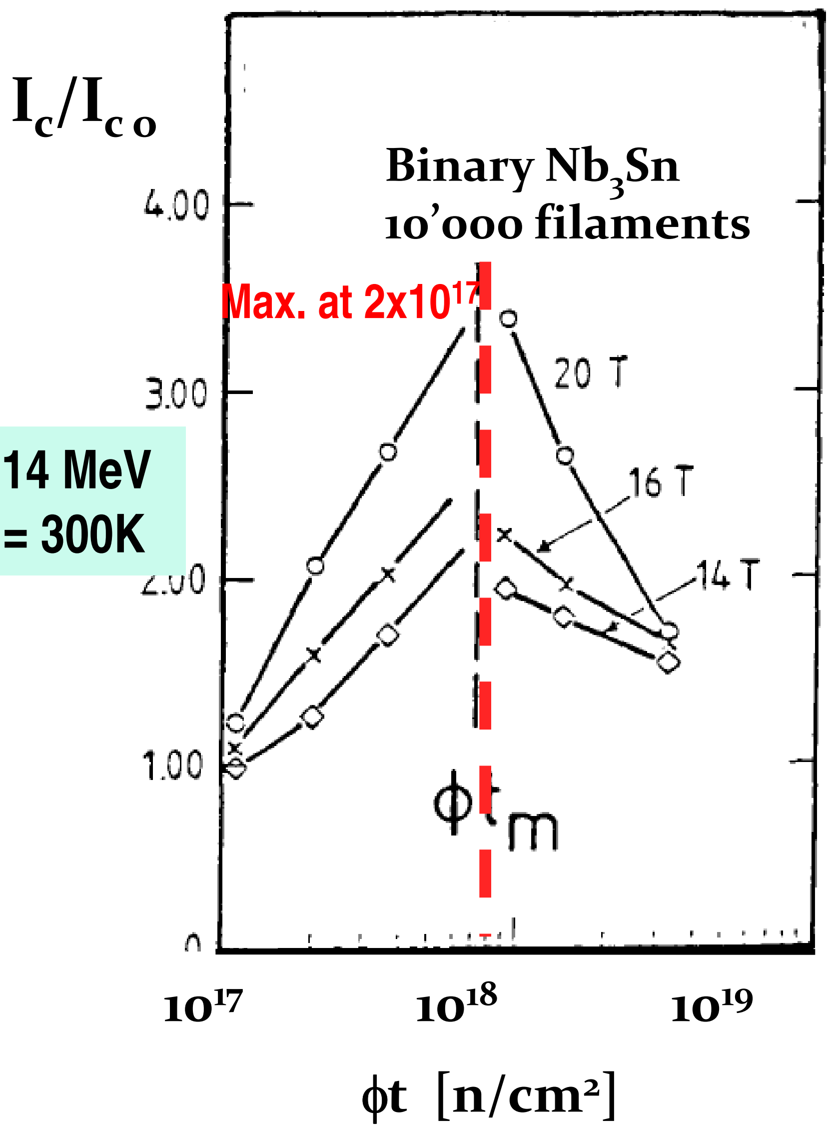
Decrease of T_c and lattice expansion after irradiation with various particles



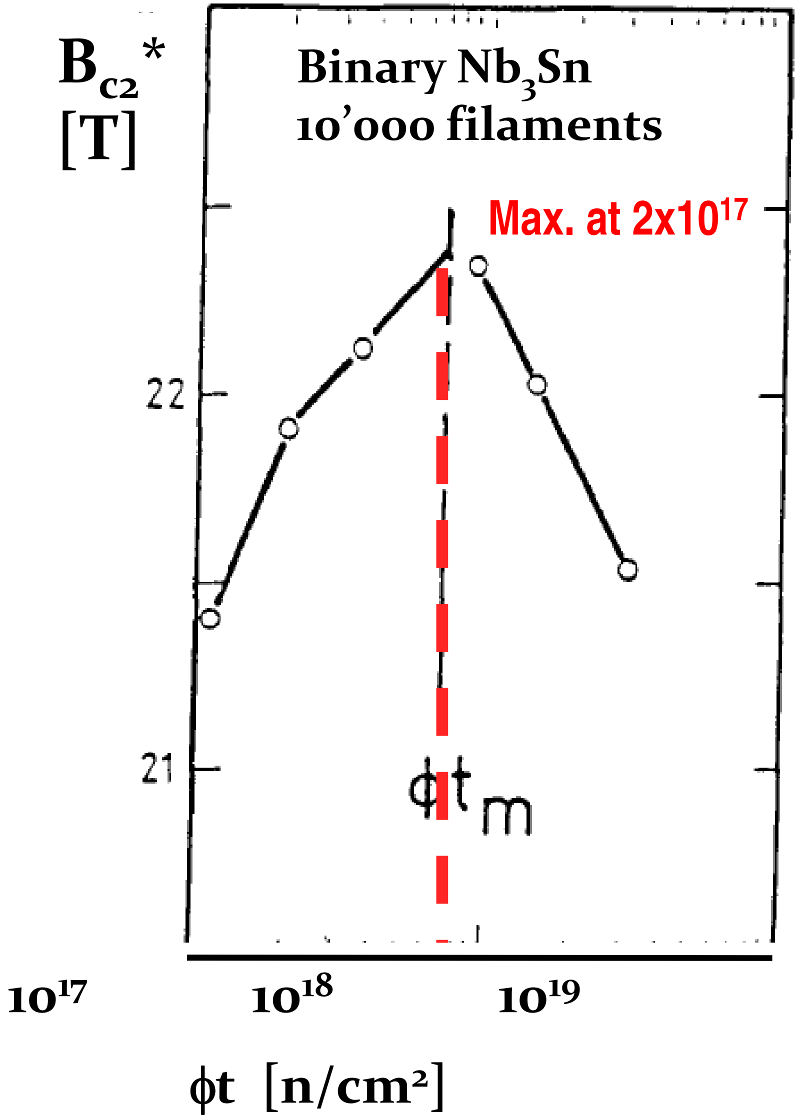


Neutrons: Sweedler, 1978, H^+, N^{2+}: Schneider, 1982, ^{4}He: Burbank, 1979, ^{32}S: Nölscher, 1985.

Binary Nb_3Sn wire (10'000 filaments)



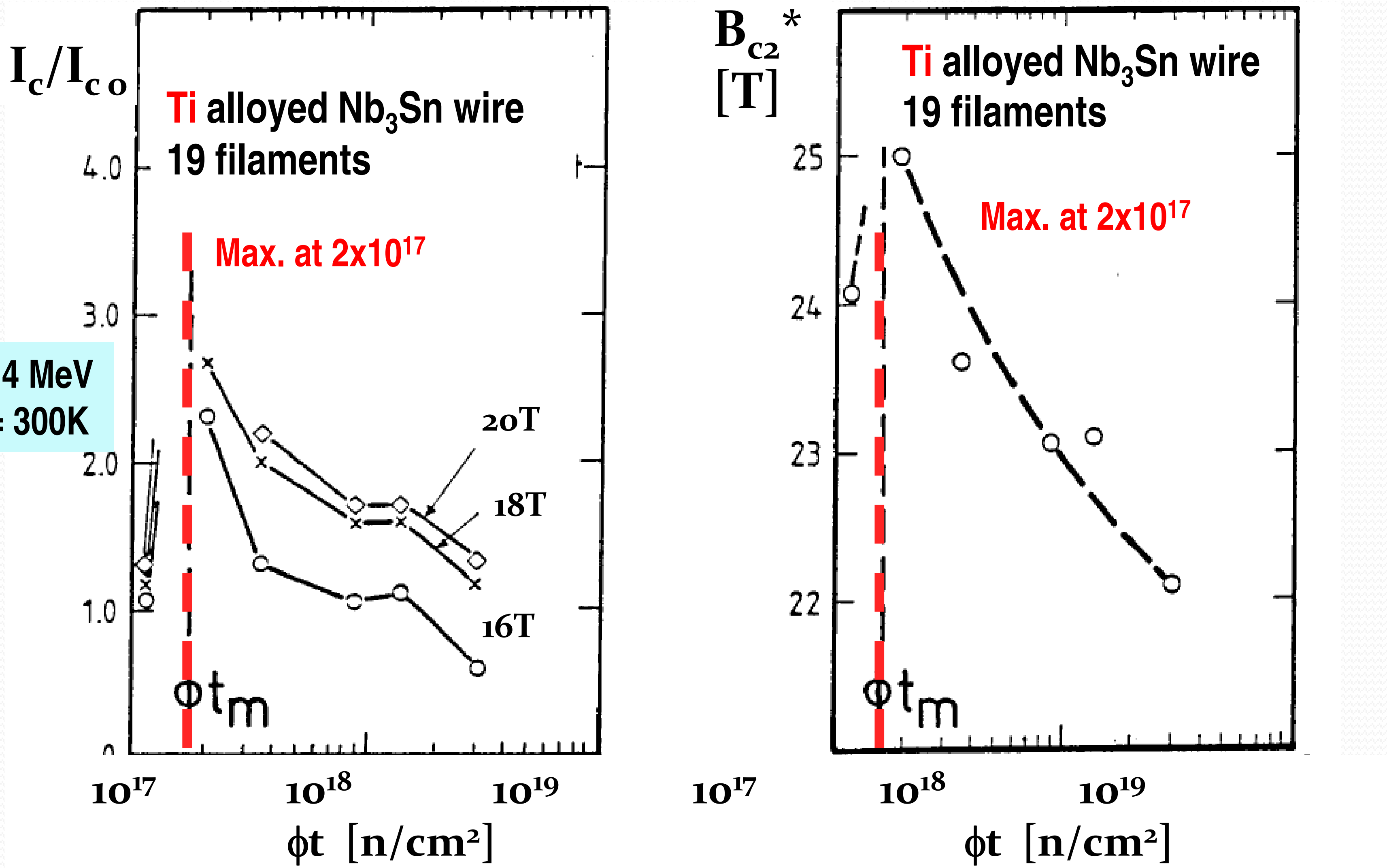
E =14 MeV
T_{irr} = 300K



F. Weiss et al. IEEE Trans. Magn., MAG-23(1987)976

Ti alloyed Nb_3Sn wires

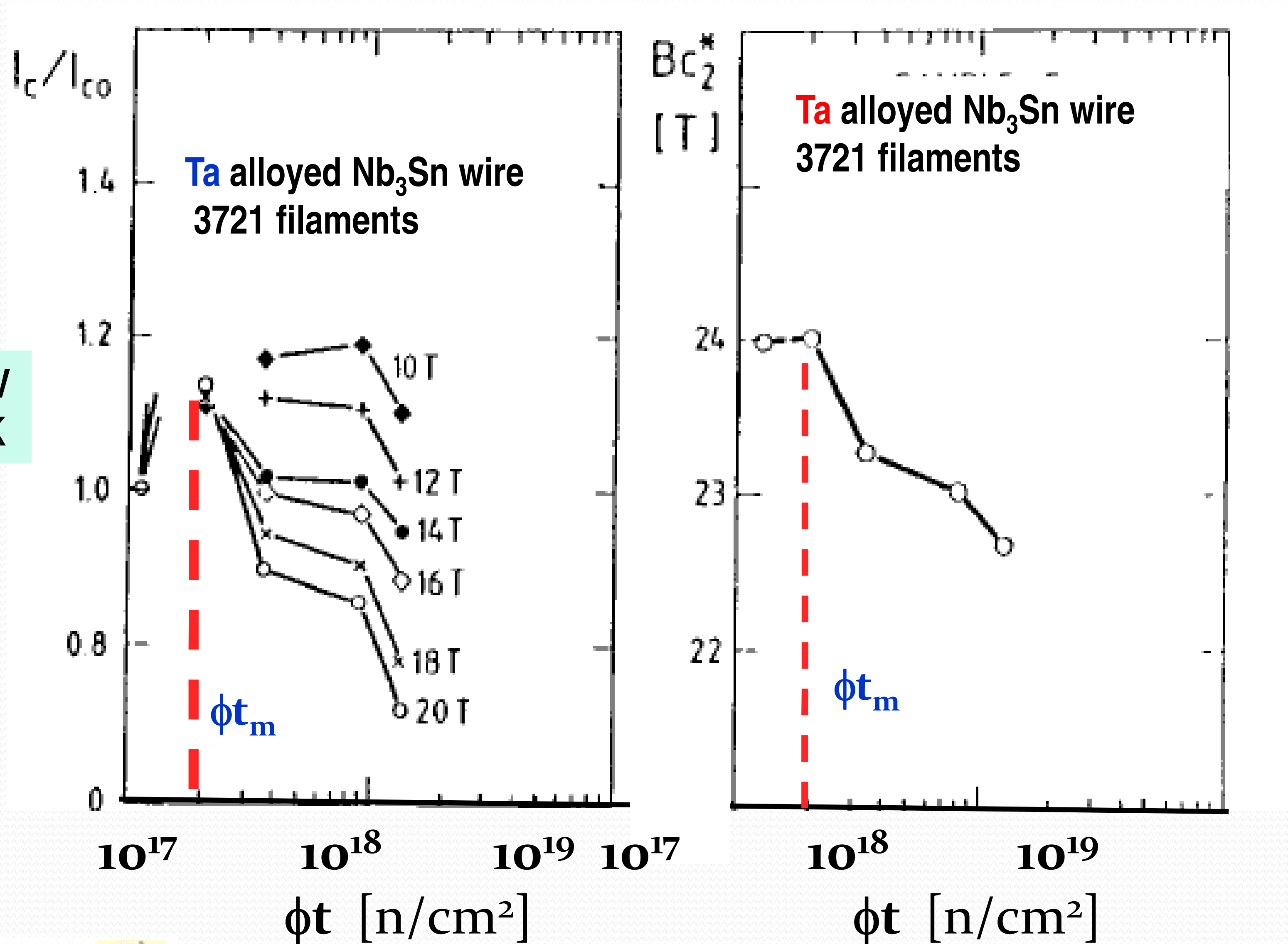
E =14 MeV
T_{irr} = 300K



F. Weiss et al. IEEE Trans. Magn., MAG-23(1987)976

Ta alloyed multifilamentary Nb_3Sn wires

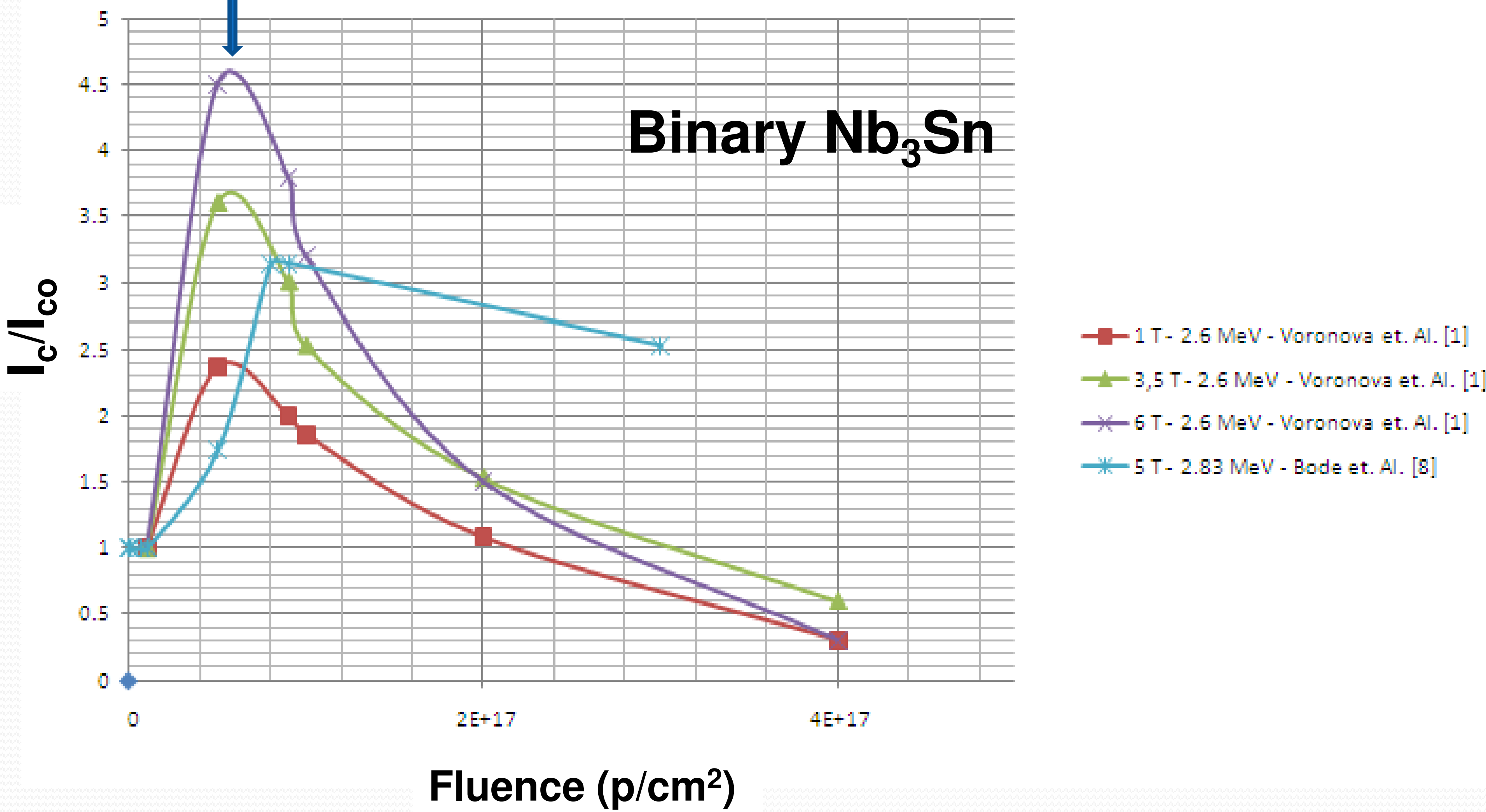
E =14 MeV
T_{irr} = 300K



F. Weiss et al. IEEE Trans. Magn., MAG-23(1987)976

Low maximum of I_c after proton irradiation

0.6 x 10^{17} p/cm^2



Binary Nb_3Sn wires:

Maximum of I_c: neutrons: 8×10^{17} n/cm^2

protons: 6×10^{16} p/cm ^{2}

Ternary Nb_3Sn wires:

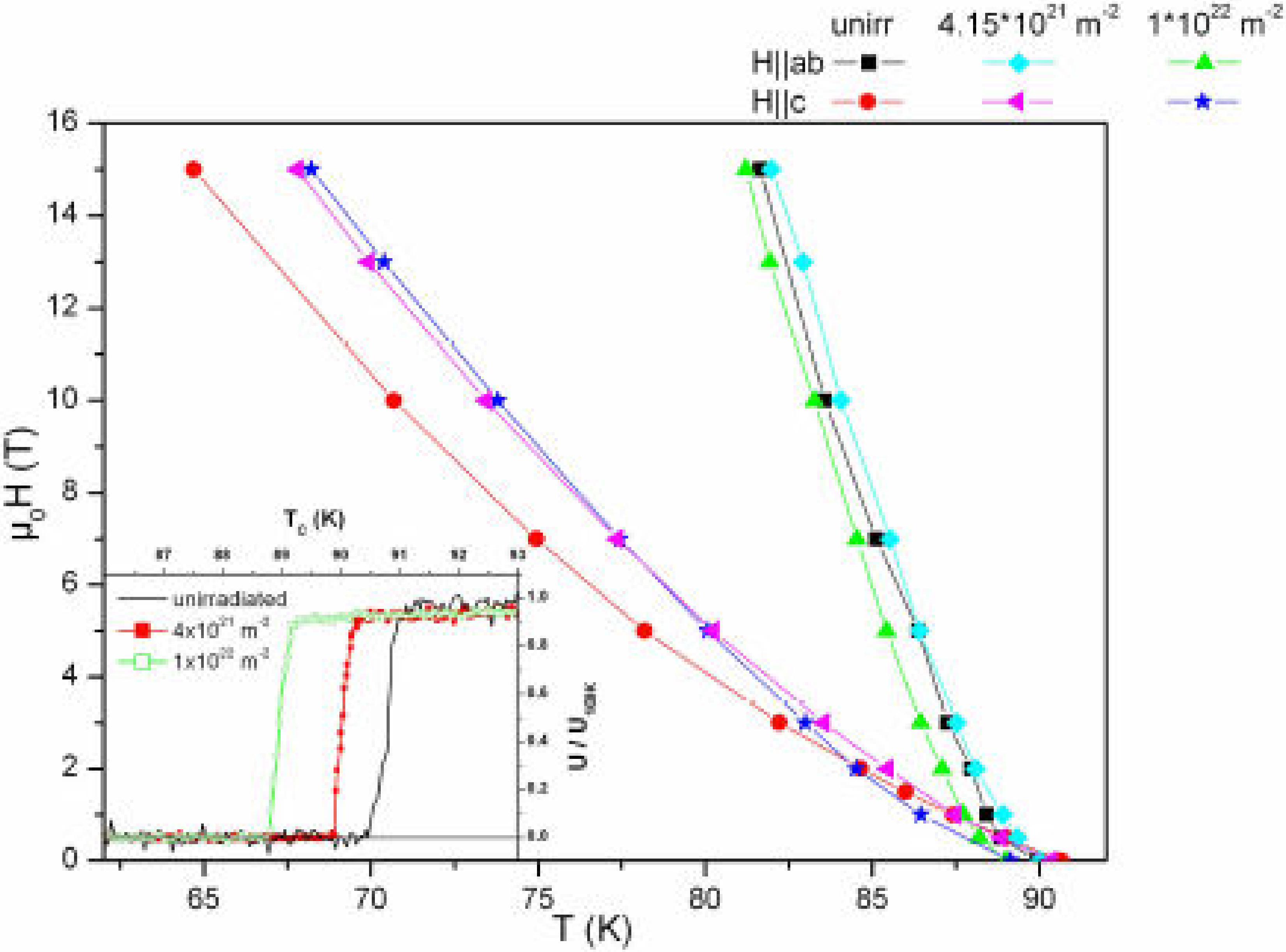
Maximum of I_c: neutrons: 2×10^{17} n/cm^2

protons: ?

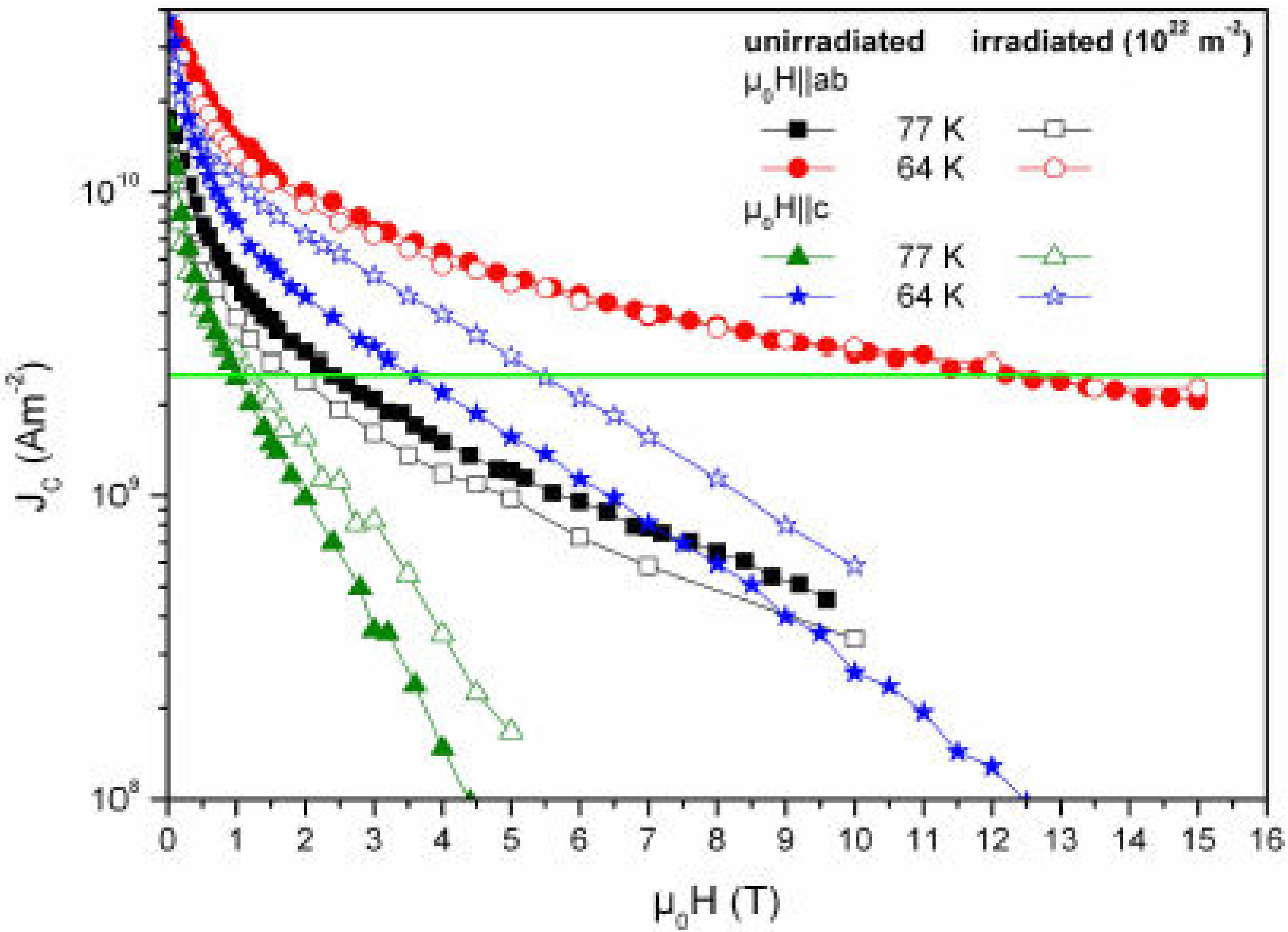
Still necessary to know behavior after proton irradiation, in spite of 3% fluence with respect to neutrons !

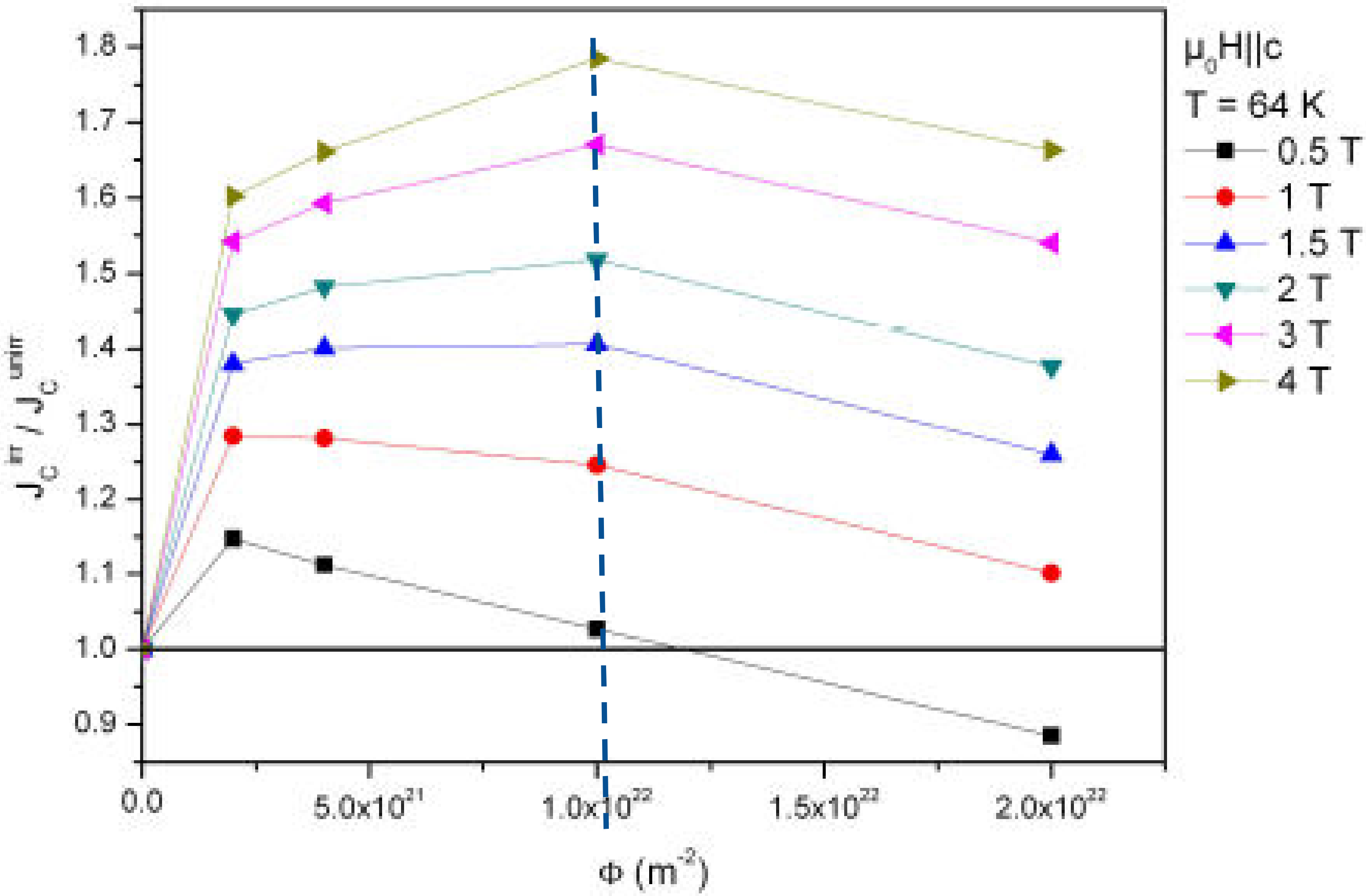
YBCO coated conductors

R. Fuger, M. Eisterer, H. Weber, Physica C, 468 (2008)

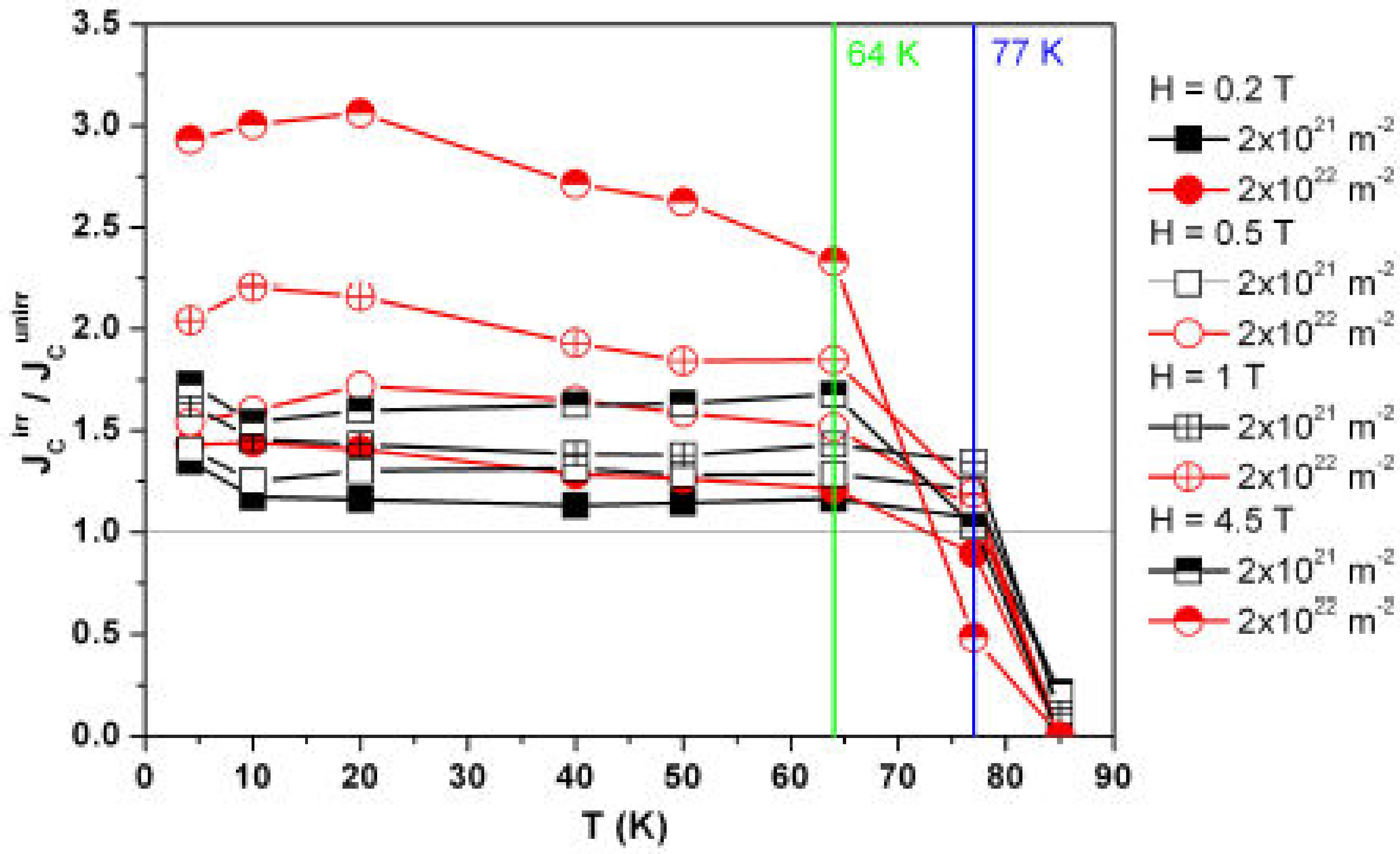


unirr
4.15*10^21 m^-2
1*10^22 m^-2
H||ab
H||c
μ0H (T)
T (K)
Tc (K)
unirradiated
4x10^21 m^-2
1x10^22 m^-2
U / Umax
16
14
12
10
8
6
4
2
0
65
70
75
80
85
90

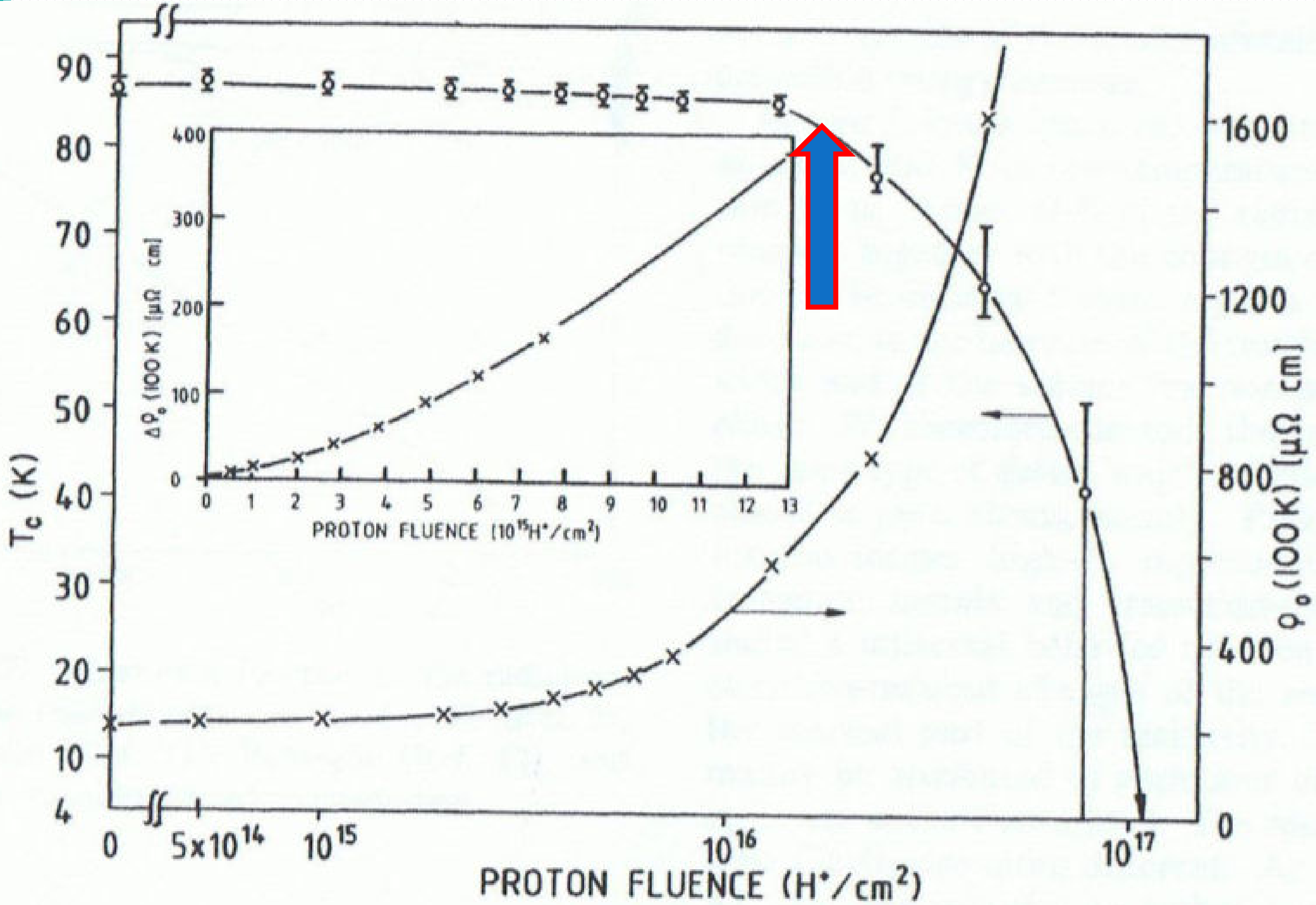

unirradiated
irradiated (10^{22} m^{-2})
μ_0H||ab
77 K
64 K
μ_0H||c
77 K
64 K
J_c (Am^{-2})
10^{10}
10^{9}
10^{8}
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
μ_0H (T)



Neutron irradiation provides a clear distinction between the **low field region**, where Jc is limited by the grain boundaries, and the **high field region**, where depinning leads to dissipation.


64 K
77 K
H = 0.2 T
2x10^21 m^-2
2x10^22 m^-2
H = 0.5 T
2x10^21 m^-2
2x10^22 m^-2
H = 1 T
2x10^21 m^-2
2x10^22 m^-2
H = 4.5 T
2x10^21 m^-2
2x10^22 m^-2
J_c^irr / J_c^unirr
T (K)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
10
20
30
40
50
60
70
80
90

Variation of T_c, ΔT_c and ρ_o of Y-123 films vs. proton fluence



Decrease of T_c : at lower fluences than for neutron irradiation

G.C. Xiong, H.C. Li, G. Linker. O. Meyer, Phys.Rev. B, 38(1988)240

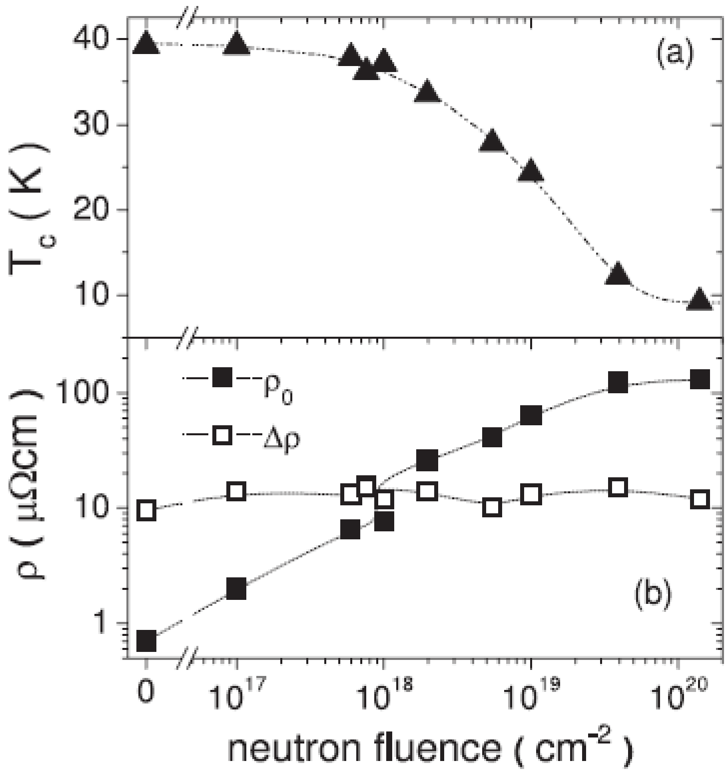
Irradiation effects on MgB_2:

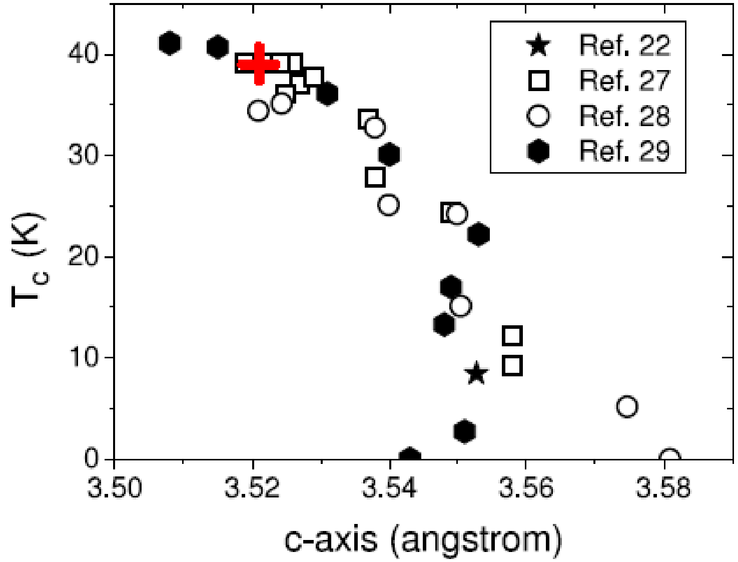
Bulk samples and thin films

M. Putti, R.Vaglio, J.M. Rowell, Supercond. Sci. Technol. 21(2008)043001

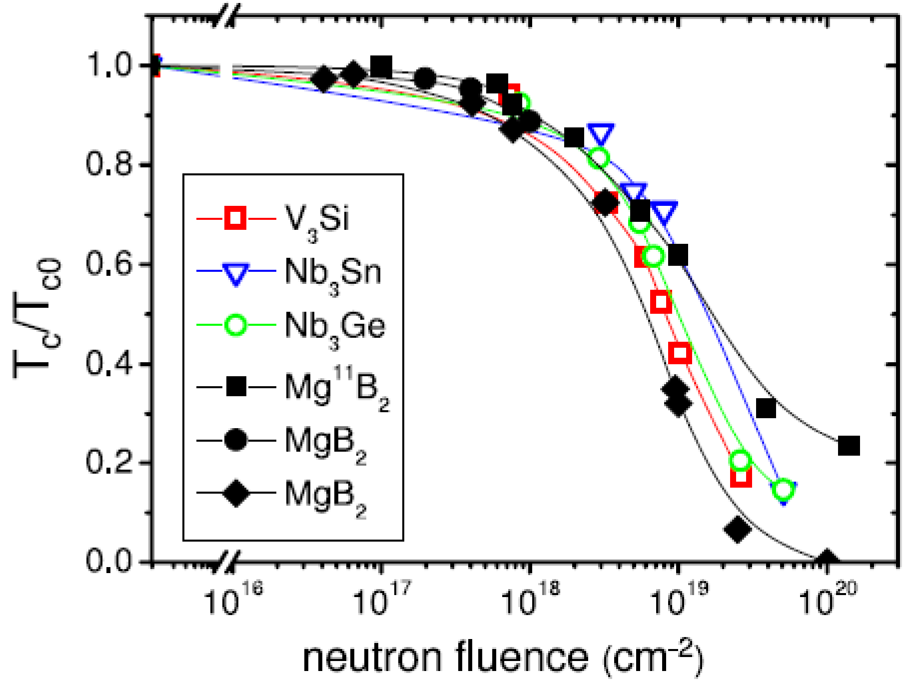
Neutron irradiation of MgB2 (bulk and thin films) leads to:

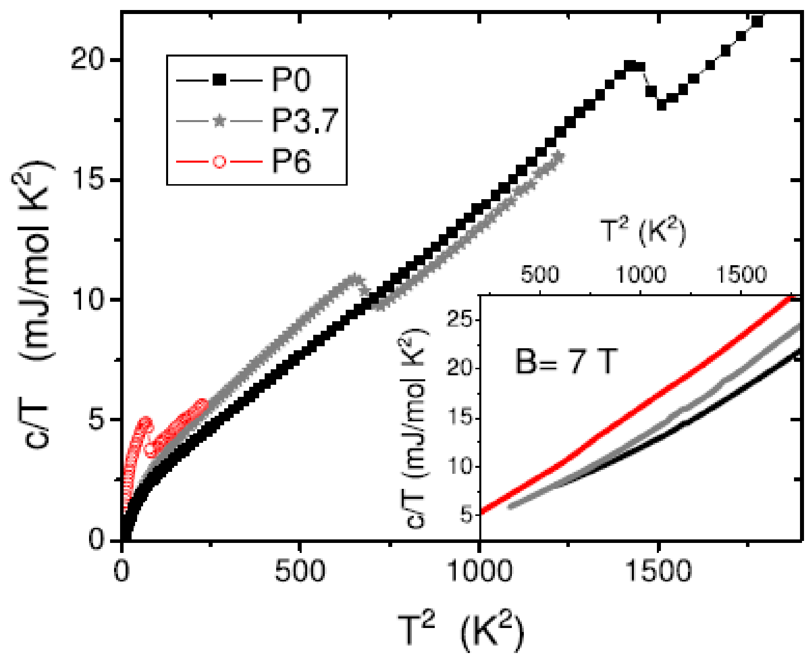
- **decrease of T_c**
- **enhancement of ρ**
- **Enhancement of axis *c***





Similarities between MgB2 and A15 type compounds

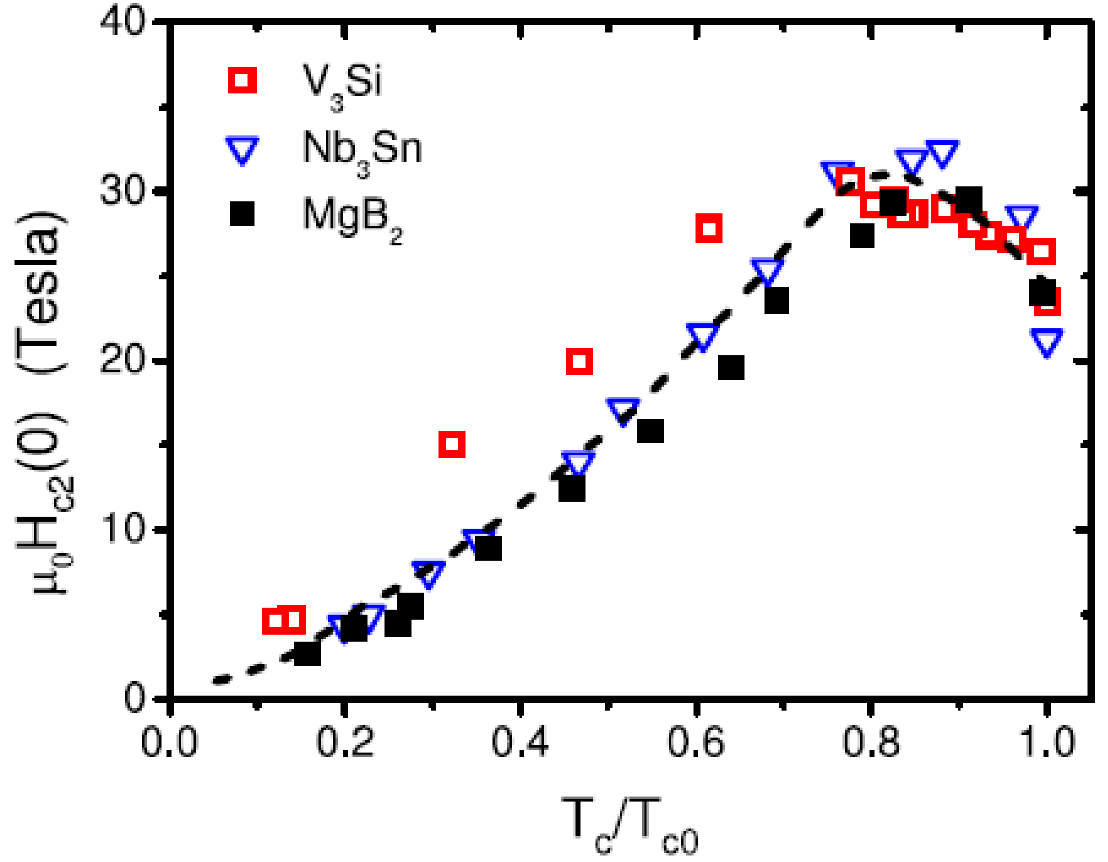




Response of T_c of MgB_2 and A15 type compounds to neutron fluence

Calorimetric detection of neutron irradiation on MgB2: volume effect

No data available about the effect of neutron irradiation on J_c: only the variation of B_{c2} was measured

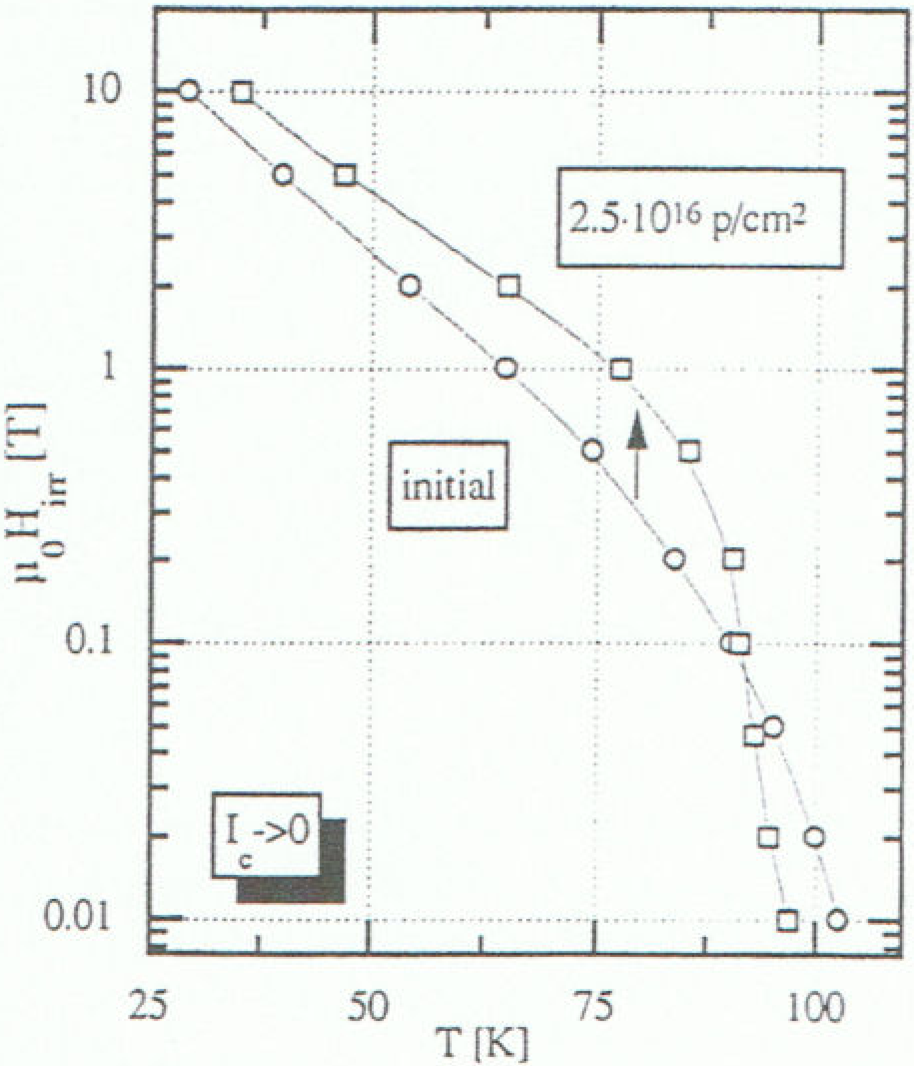


A similar variation of J_c to A15 compounds is expected in MgB2 tapes and wires.

Proton irradiation of Bi-2223 tapes

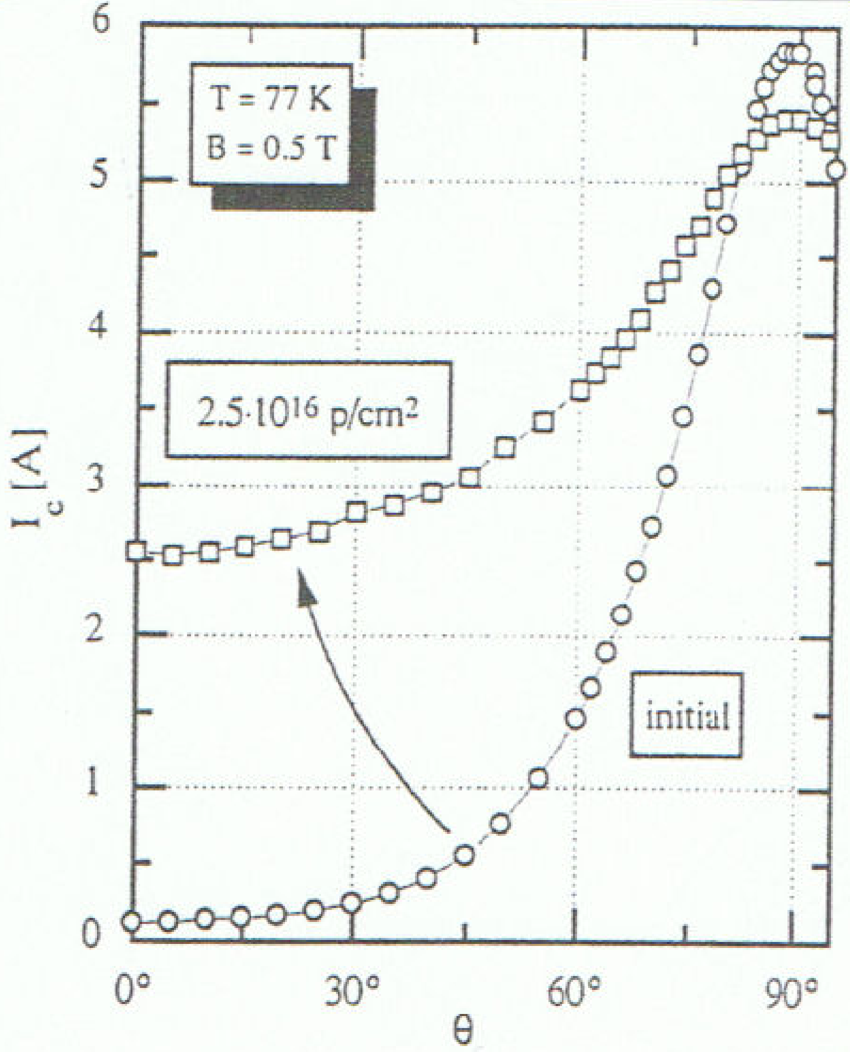
B. Hensel, F.Marti, G. Grasso, R. Flükiger
Trans. Appl. Supercond. 1996

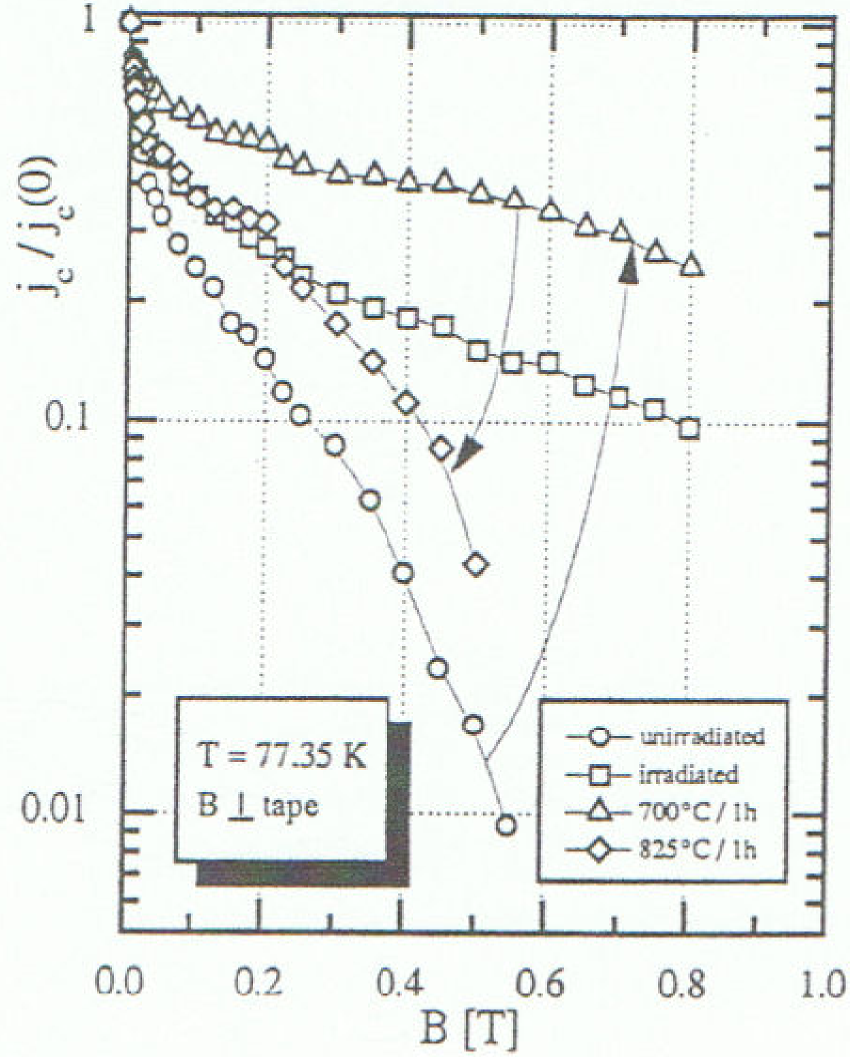
Proton irradiation of Bi-2223 tapes



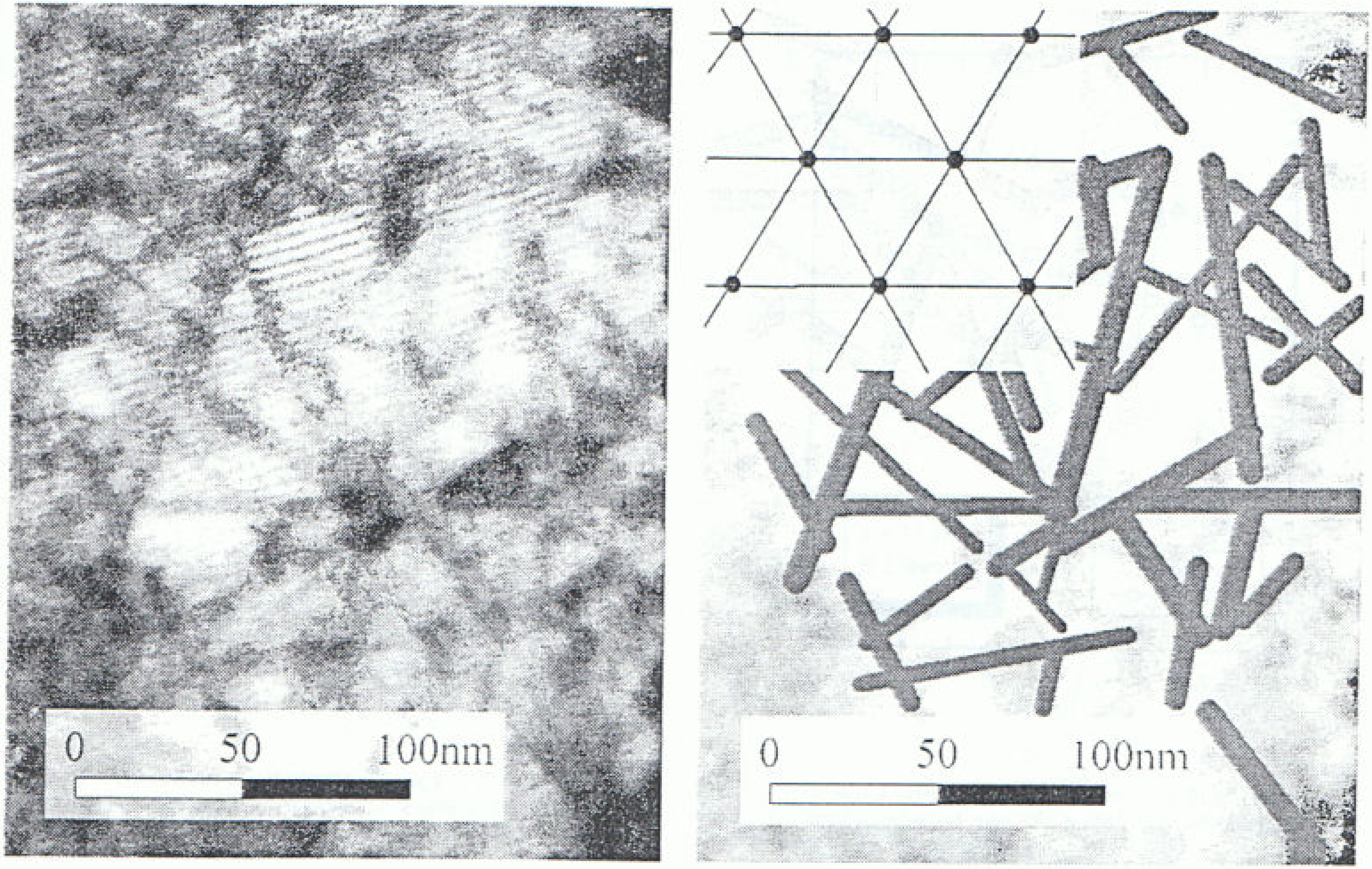
B. Hensel, F.Marti, G. Grasso, R. Flükiger. Trans. Appl. Supercond. 1996

Proton irradiation of Bi-2223 tapes





TEM micrograph of proton irradiated Bi-2223 tape



Conclusions

Neutron irradiation effects have been reviewed for various superconductors, and the their effects on the transport properties were presented for

- Nb_3Sn wires, with and without additions
- Nb_3Al wires
- YBCO coated conductors
- MgB_2 bulk samples and thin films

Strong similarities have been observed for A15 compounds and MgB_2 caused by disorder (for A15 antisite effects, for MgB_2 not yet defined), leading to higher r_o and B_{c2} (or B_{irr})

YBCO : low fields: J_c is limited by the grain boundaries

high fields: depinning leads to dissipation

The peak of Ic for proton irradiation occurs at lower fluences than for neutron irradiation

There is always a maximum of J_c and B_{c2} with increasing fluence , between $2x10^{21}$ n/m^2 (alloyed Nb_3Sn) and 0.9-1.15 x 10^{22} n/m^2

General, for all analyzed systems, for irradiations at 300K: no or little decrease up to 1 x 10^{22} n/m^2 .
Data at 4.2K are expected to be similar, but no systematical data exist.