Positron Production Experiment with Single Crystal

(Preliminary Results)
[1st. Part: for KEK Exp.]
[2nd. Part: for CERN Exp. (in Separate Presentation)]

Kazuro Furukawa, KEK
<kazuro.furukawa@kek.jp>
for
Collaboration group of
S.Anami, A.Enomoto, K.Furukawa, K.Kakihara, T.Kamitani,
H.Okuno, Y.Ogawa, A.Ohsawa, T.Oogoe, T.Suwada [KEK],
R.Chehab [LAL, Orsay],
R.Hamatsu, K.Sasahara [Tokyo Metro. Univ.],
T.Fujita, K.Umemori, K.Yoshida [Hiroshima Univ.],
V.Ababiy, A.P.Potylitsin, I.E.Vnukov [Tomsk Polytech.]

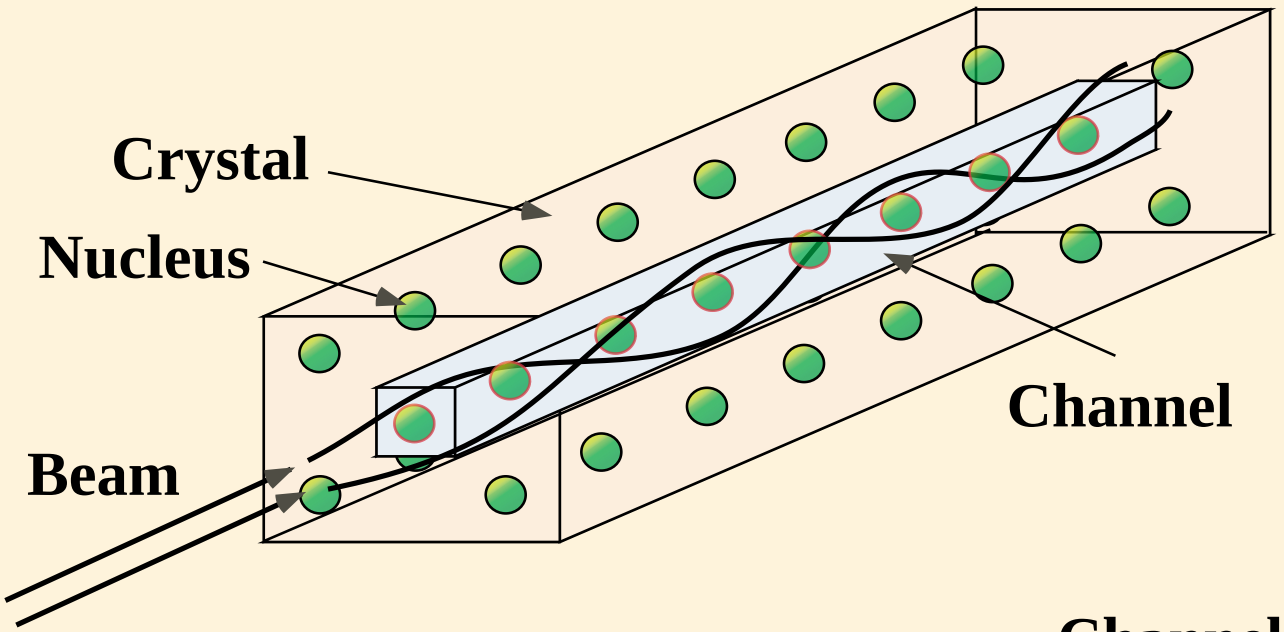
<URL:http://www-linac.kek.jp/chan-pos/>

Positron Generation Enhancement by Channeling Radiation and Coherent Bremsstrahlung Using Single Crystal (Tungsten or Diamond)

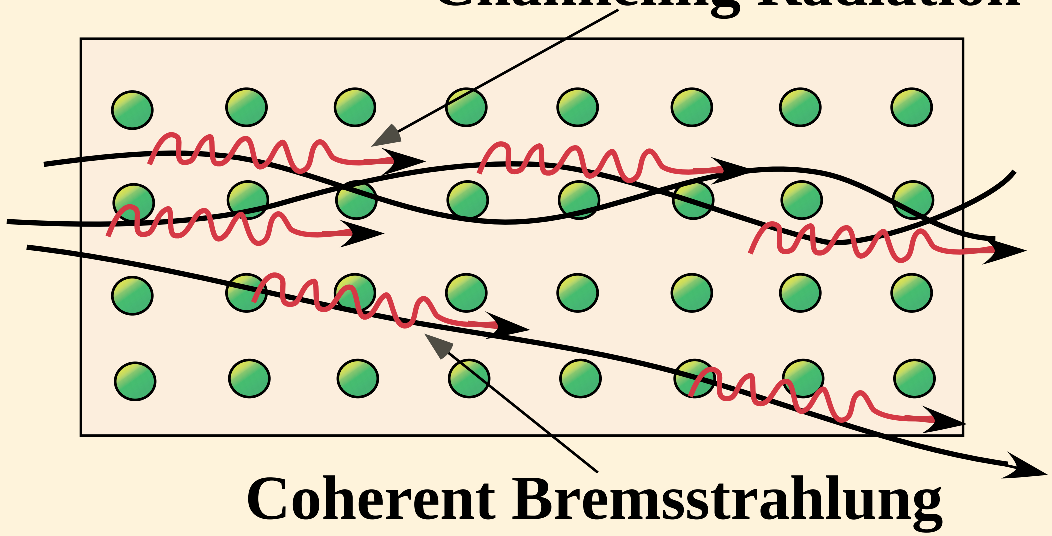
- Suggested by R. Chehab (LAL) et al, 1989
  - Technical Issues -- Vacuum, Cooling (because of Goniometer)
  - Thick Crystal Production
- Thickness Dependence
- Incident and Outgoing Energy Dependence
  - Mosaicity
  - Instant and Integrated Radiation Hardness of Crystal
- Composite Target (Crystal / Amorphous, Diamond+Tungsten)
- Simulation Code Development for Positron Generator Design

  (GEANT+Channeling, Fast Code, Heating, e+ Capturing)

Channeling and Coherent Bremsstrahlung



- In single crystal these two phenomena enhance e.m. shower (photon) and positron yields



Beam Experiment in Japan

- INS ES 1GeV (-1999)
- KEK Linac 3-GeV Experiment (1998)
  - Enhancement Confirmation
- KEK Linac 8-GeV / 4-GeV Experiment (2000-)
  - More Quantitative Considerations

Collaboration

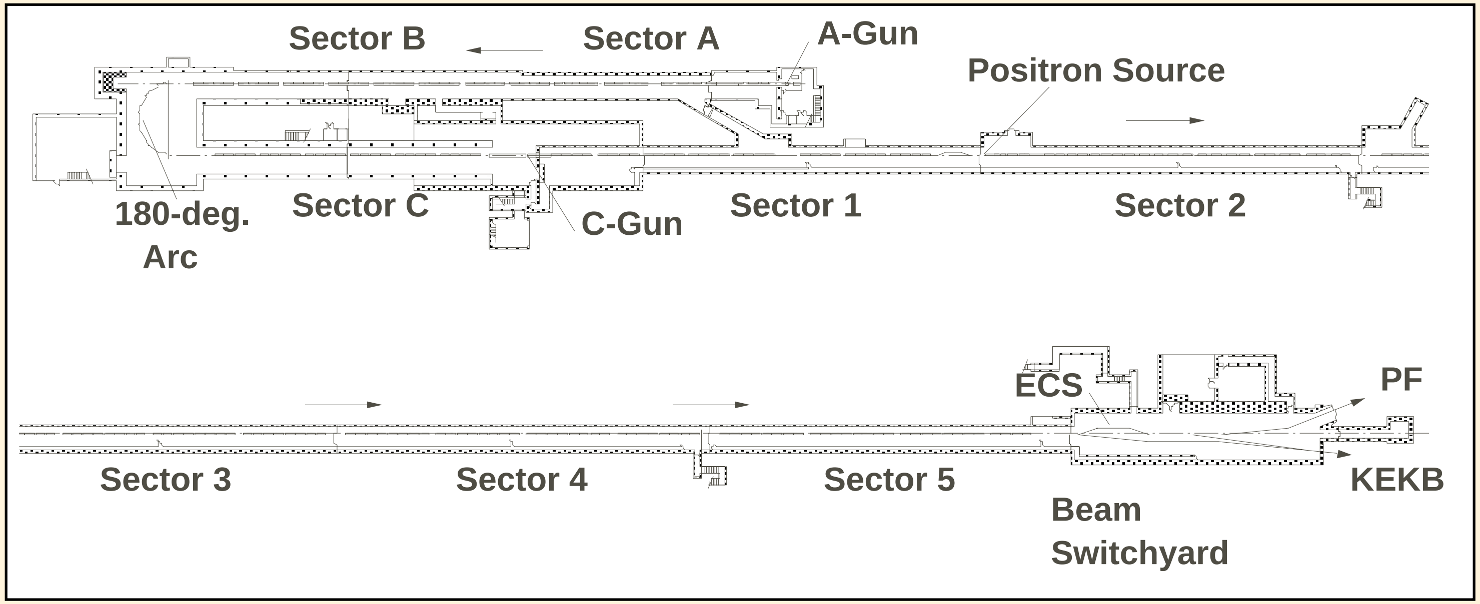
Tomsk Polytech. --- Crystal Production, Simulation Code

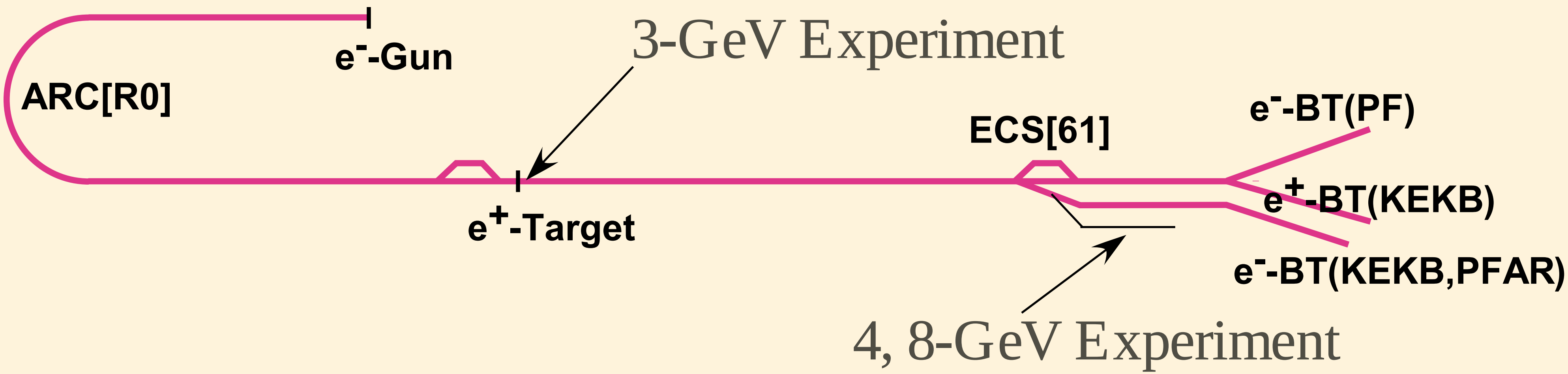
Tokyo Metro. Univ., Hiroshima Univ., KEK

Beam Line Construction, Detector Design, Simulation

R. Chehab --- Ideas, etc.

Experiment Stations





8 and 4 -GeV Experiment at KEK Linac

- Analyzer Line at the End of Linac

  No Direct Interference against KEKB, PF, PFAR Operation

- 8-GeV 0.2nC (~$1x10^9$) 10ps
- 2.2mm (=0.63 Radiation Length (r.l.)) Crystal

  (r.l. = 3.4mm for Tungsten)

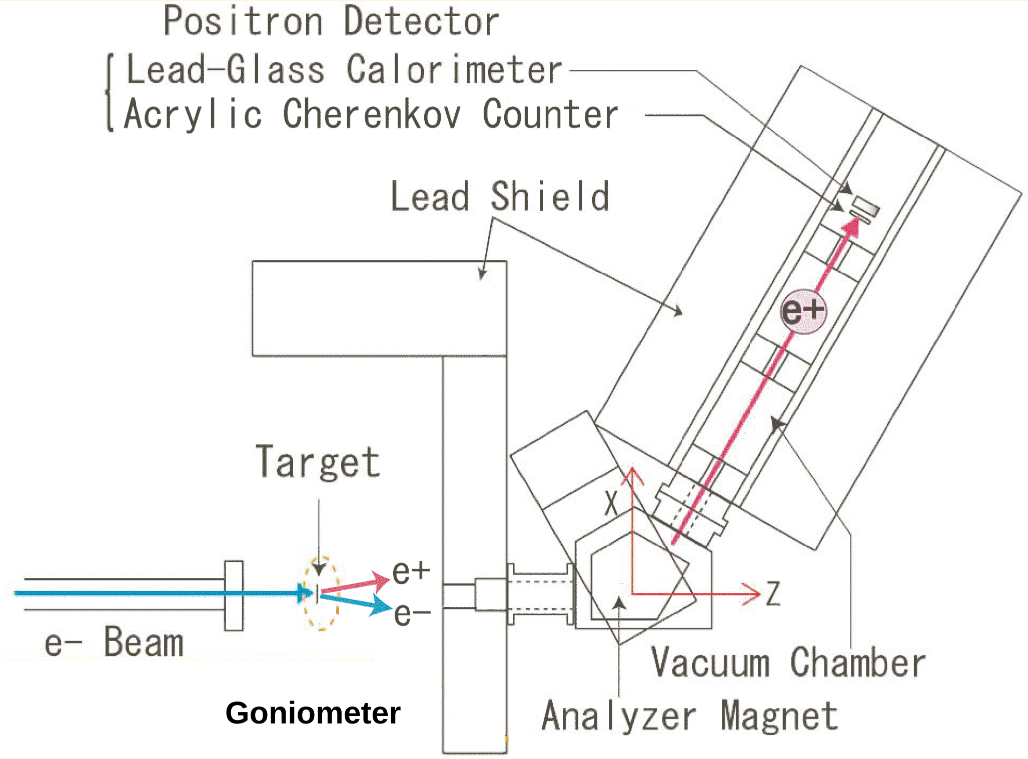
  Then 5.3mm, 9.0mm Thick Crystal

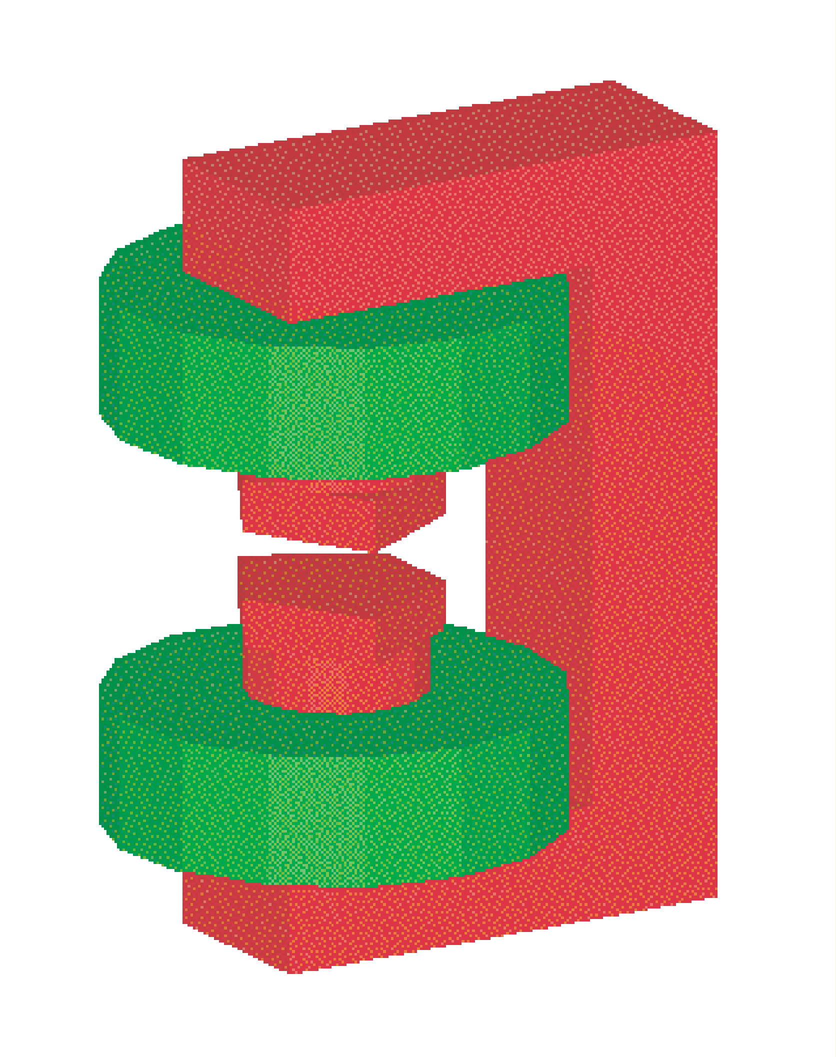
  Measured Enhancement

- 4-GeV - 2.2mm, 5.3mm, 9.0mm Crystals

  Also 1.1mm Diamond

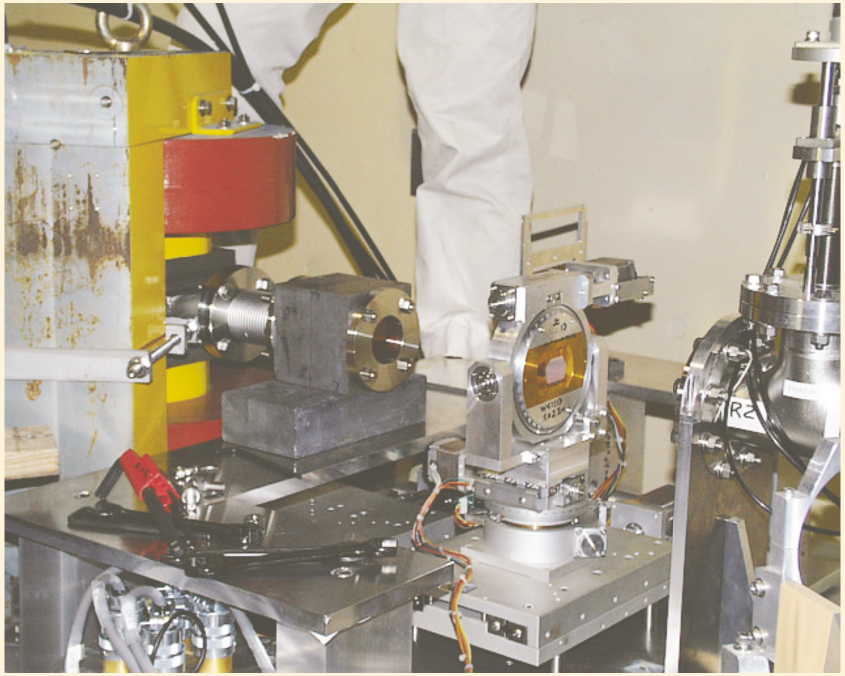
8 and 4 -GeV Experiment Apparatus

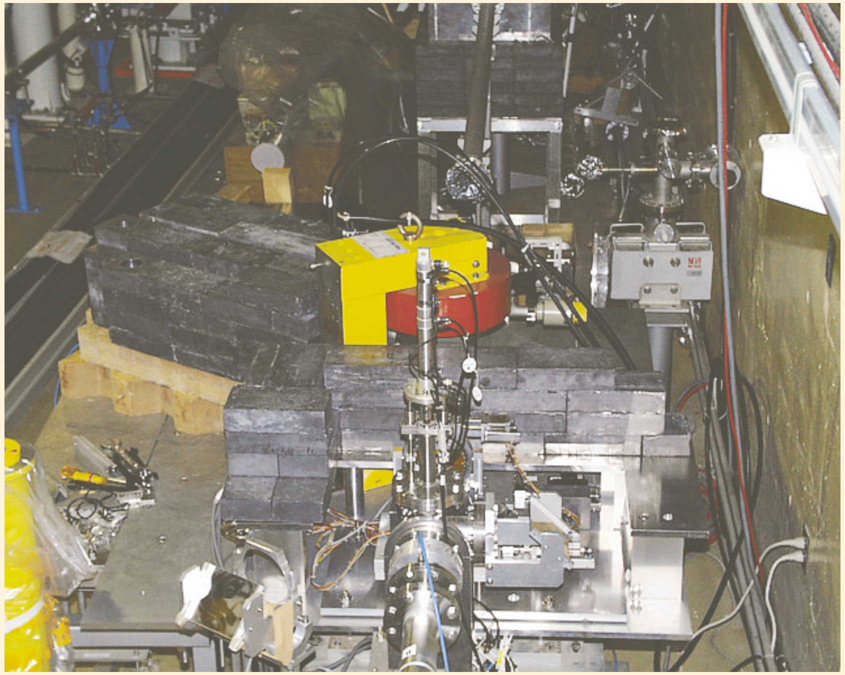


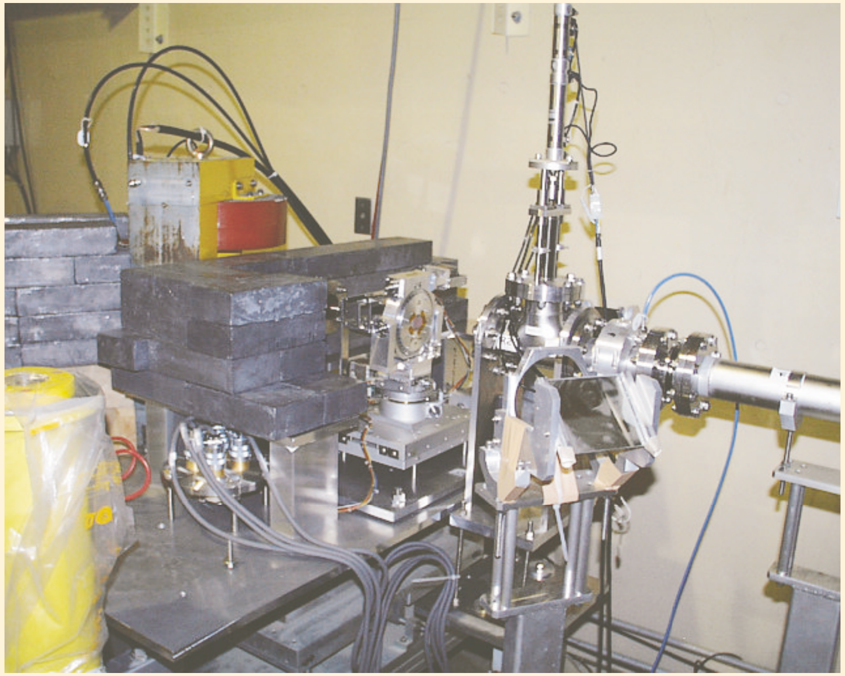


$\Delta p/p \sim 3.0\%$, $\Delta\theta \sim 20$mrad

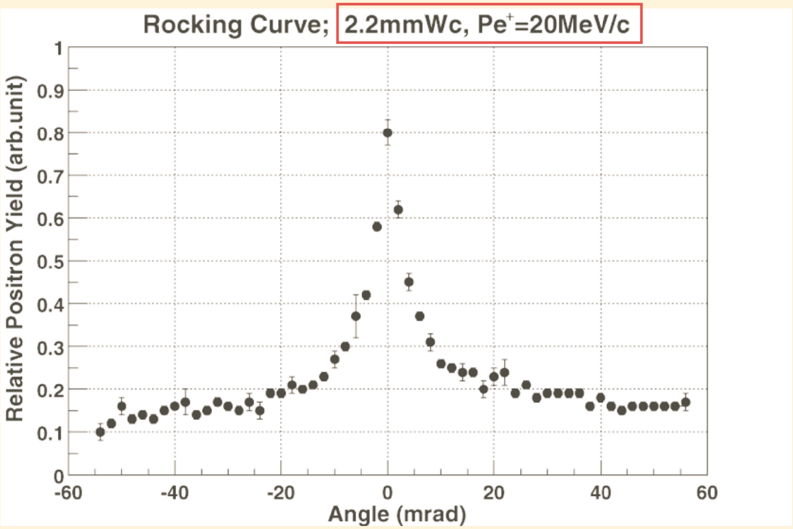
Goniometer
Lucite Cerenkov Counter
Lead Glass Cerenkov Counter

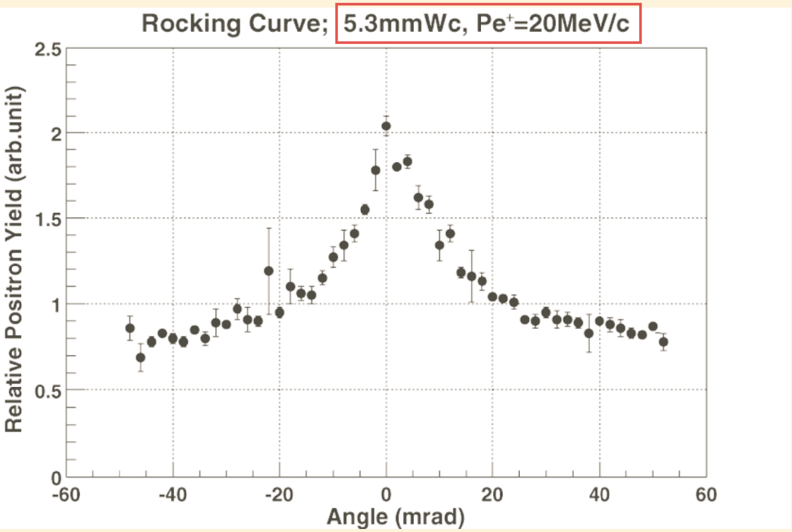


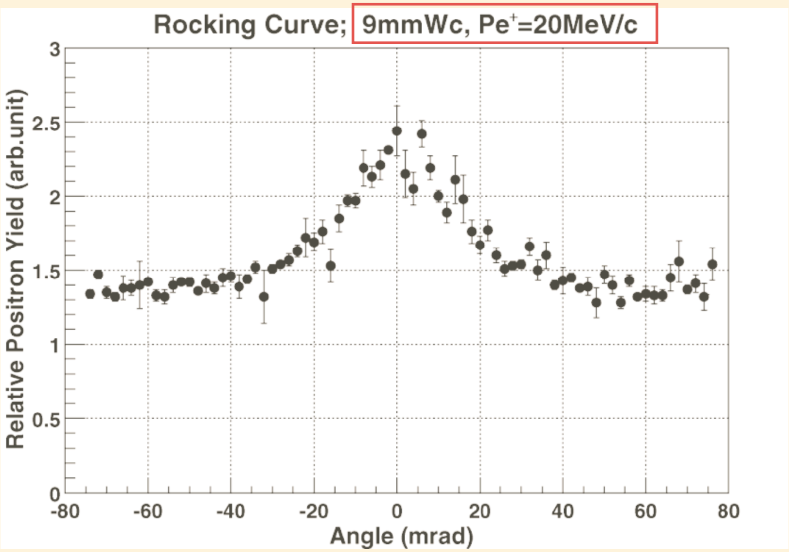




Rocking Curves (8GeV)



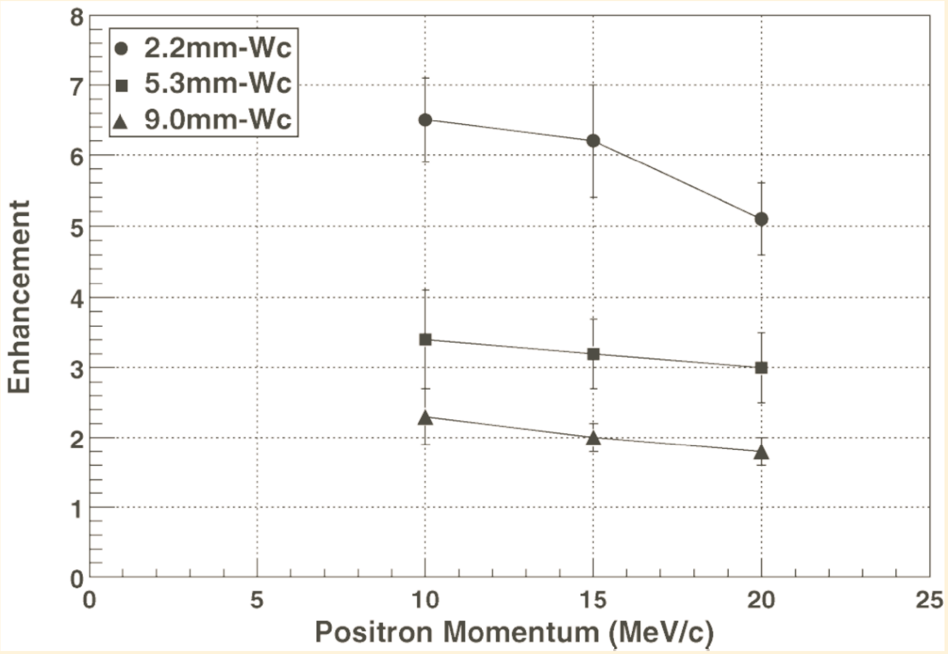




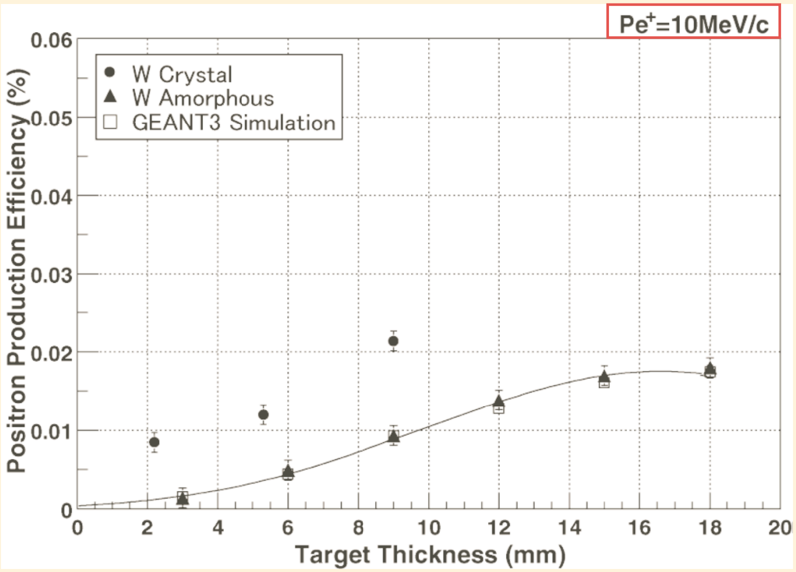
2.2mm, 5.3mm, 9mm W Crystal
FWHM
~9mrad, ~20mrad, ~39mrad

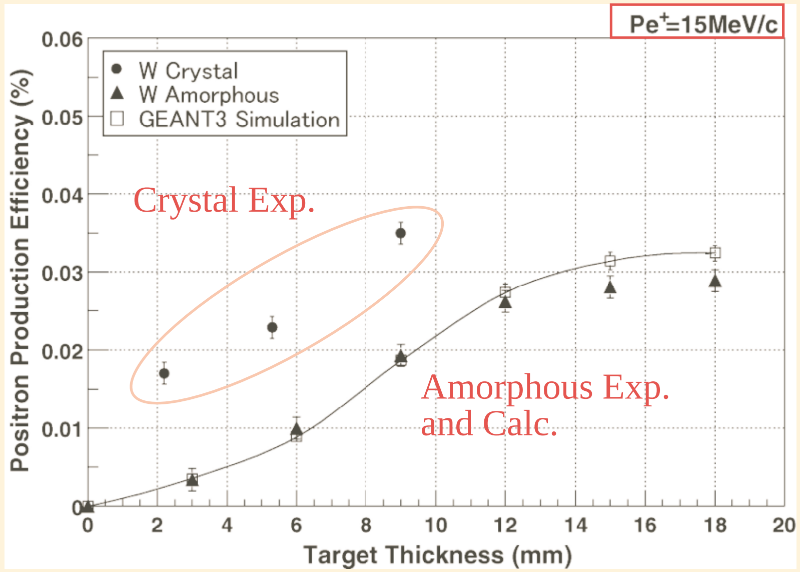
Enhancement Factors (8GeV)

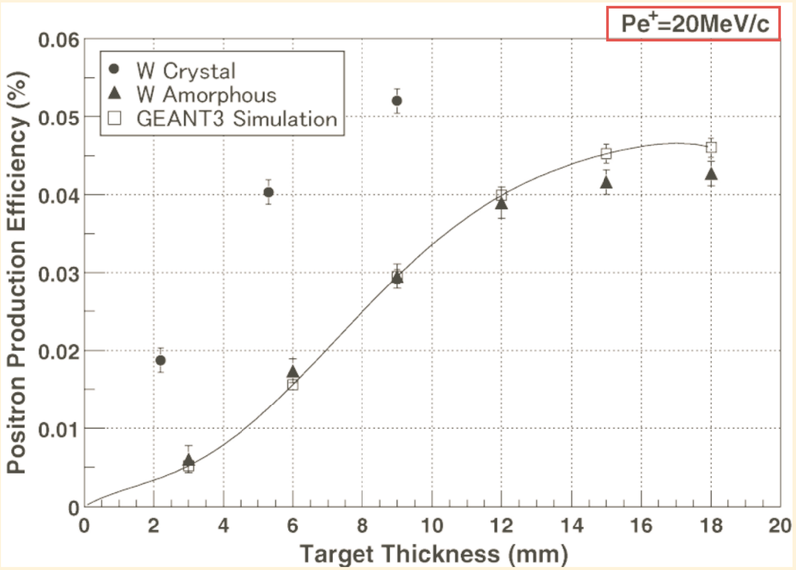
Outgoing e+ Momentum [MeV/c]	Enhancement (2.2-mm-thick)	Enhancement (5.3-mm-thick)	Enhancement (9.0-mm-thick)
10	6.5 ± 0.6	3.4 ± 0.7	2.3 ± 0.4
15	6.2 ± 0.8	3.2 ± 0.5	2.0 ± 0.2
20	5.1 ± 0.5	3.0 ± 0.5	1.8 ± 0.2



Positron Yields Enhancement (8GeV)







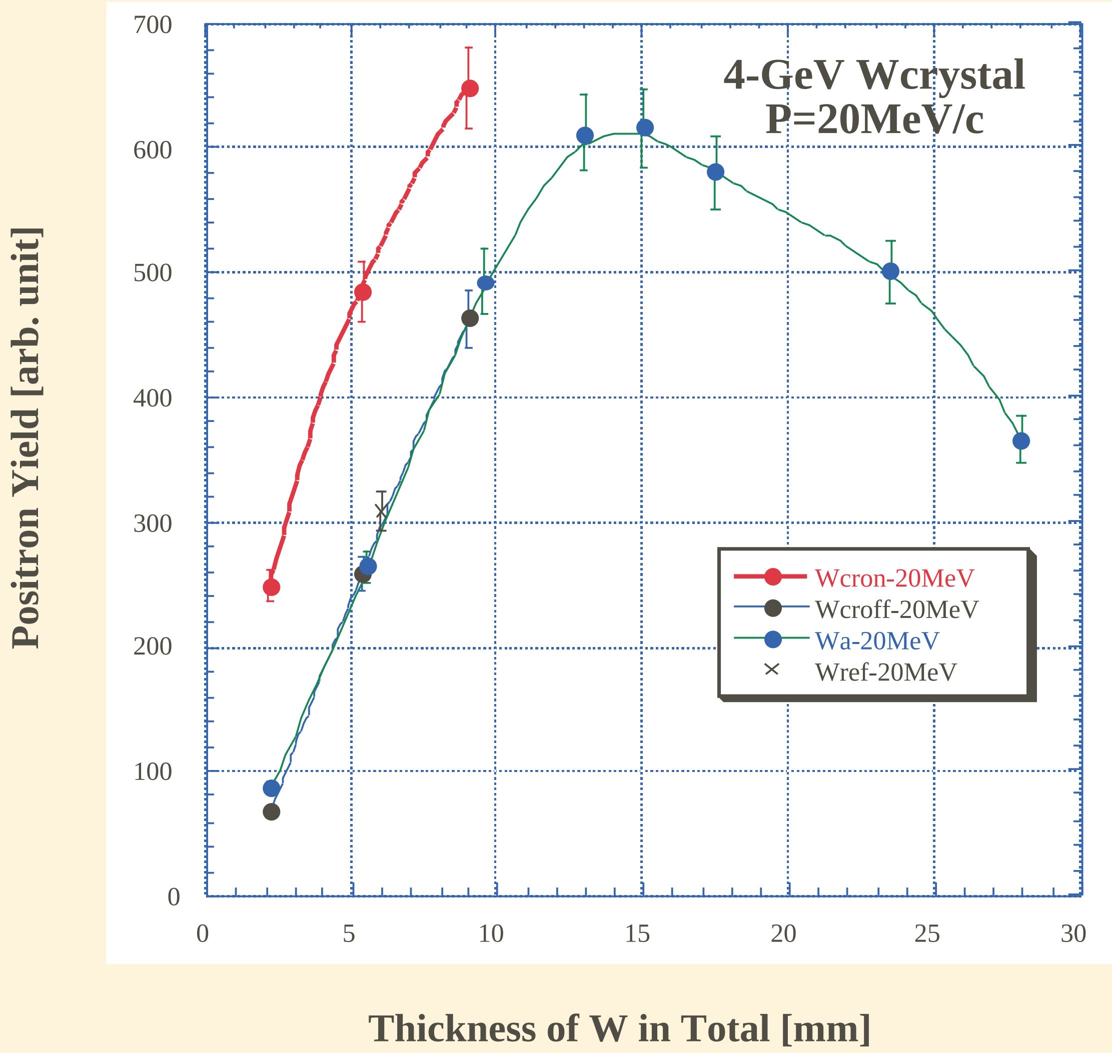
Positron Production
vs. Thickness

Out-going Positron Momentum
10, 15, 20 MeV/c

9mm Crystal Generates More e+
than Thick Amorphous

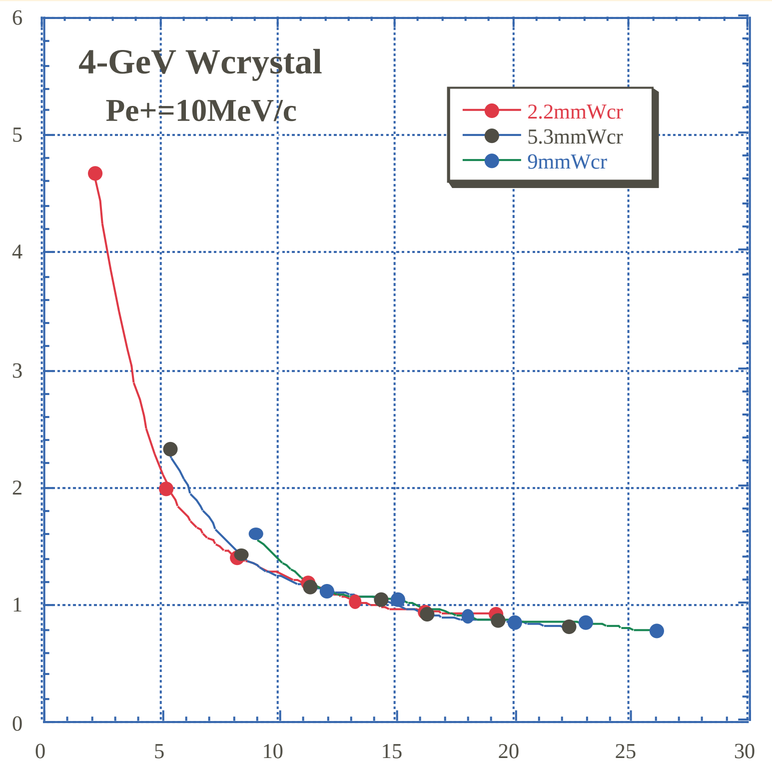
Positron Enhancement with 4GeV Incident Beam

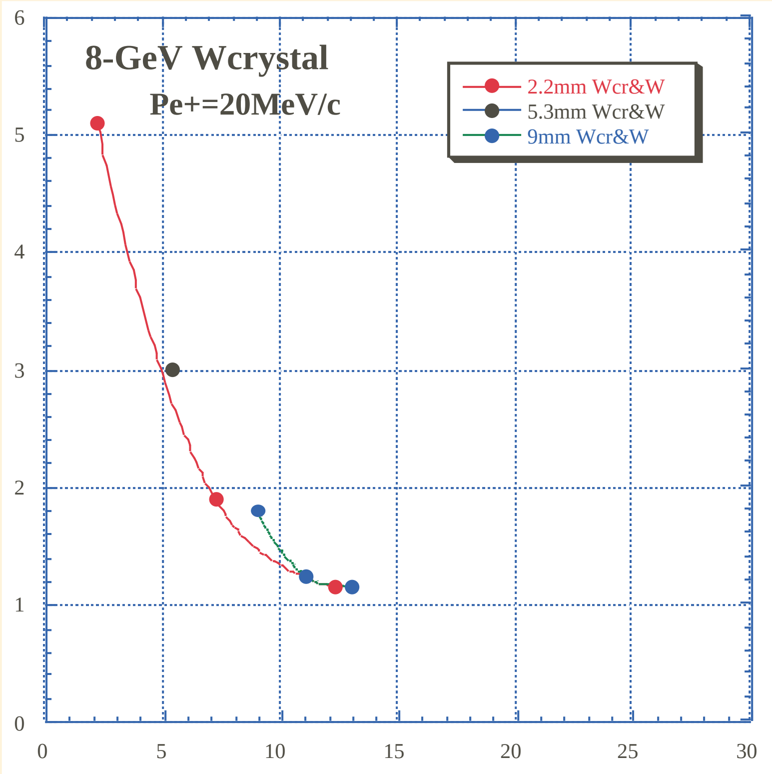
- 2.2, 5.3, 9 mm-thick Tungsten Crystal and Amorphous
  (Preliminary Analysis)



Positron Enhancement with 4GeV and 8GeV

- 2.2, 5.3, 9 mm-thick Tungsten Crystal and Amorphous (Preliminary Analysis)





- Most Enhancement Occurs in the First millimeter

Optimal Thickness and Brightness

Theoretical Work
by V.N.Baier, V.M.Katkov,
and V.M.Strakhovenko
Phys. Stat. Sol. 133(1986)583

Table 1

Parameters of the potential for the ⟨111⟩ axis and some characteristics of the radiation

crystal	u_1 (10^{-10} m) $T = 293$ K	V_0 (eV)	U_0 (eV)	β	a_s (10^{-10} m)	$c = \frac{L_{rad}}{L_{ph}}$	R	ω_{ch} (MeV)	L_0 (mm)
C(d)	0.040	29	103	0.025	0.326	0.61	1.87	21.1	15.6
Si	0.075	54	106	0.150	0.30	0.57	0.80	23.3	15.3
V	0.082	135	280	0.135	0.306	0.49	1.16	37.0	4.8
Cr	0.061	165	358	0.122	0.272	0.48	1.64	47.0	3.6
Fe	0.068	180	363	0.145	0.276	0.48	1.46	46.6	3.15
Ge	0.085	91	191	0.13	0.30	0.51	0.53	31.1	4.3
W(293K)	0.050	417	937	0.115	0.215	0.50	1.48	96.2	0.65
W (77 K)	0.030	348	1255	0.027	0.228	0.50	2.38	105.0	0.61

u_1 amplitude of thermal vibrations. V_0, β, a_s parameters of the potential (6). U_0 depth of the potential well, c ratio of the radiation length to the effective length of photon absorption, R: I_{as}/I_{fr} ratio at $\varepsilon_0 = 1$ GeV, ω_{ch} frequency calculated by means of (16) at $\varepsilon_0 = 1$ GeV, L_0 optimal thickness of the crystal at $\varepsilon_0 = 1$ GeV.

◆ Optimal Thickness
Thickness of satulated
radiation brightness

(at 1GeV, Energy dependence is small)

◆ Brightness
at Optimal Thickness

Diamond Produces
3-Times Larger
Radiation than
Tungsten

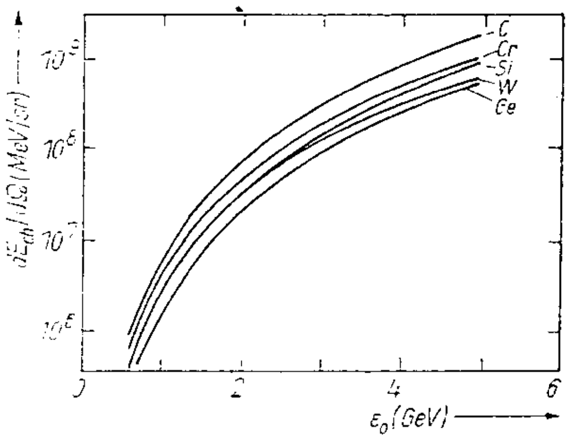
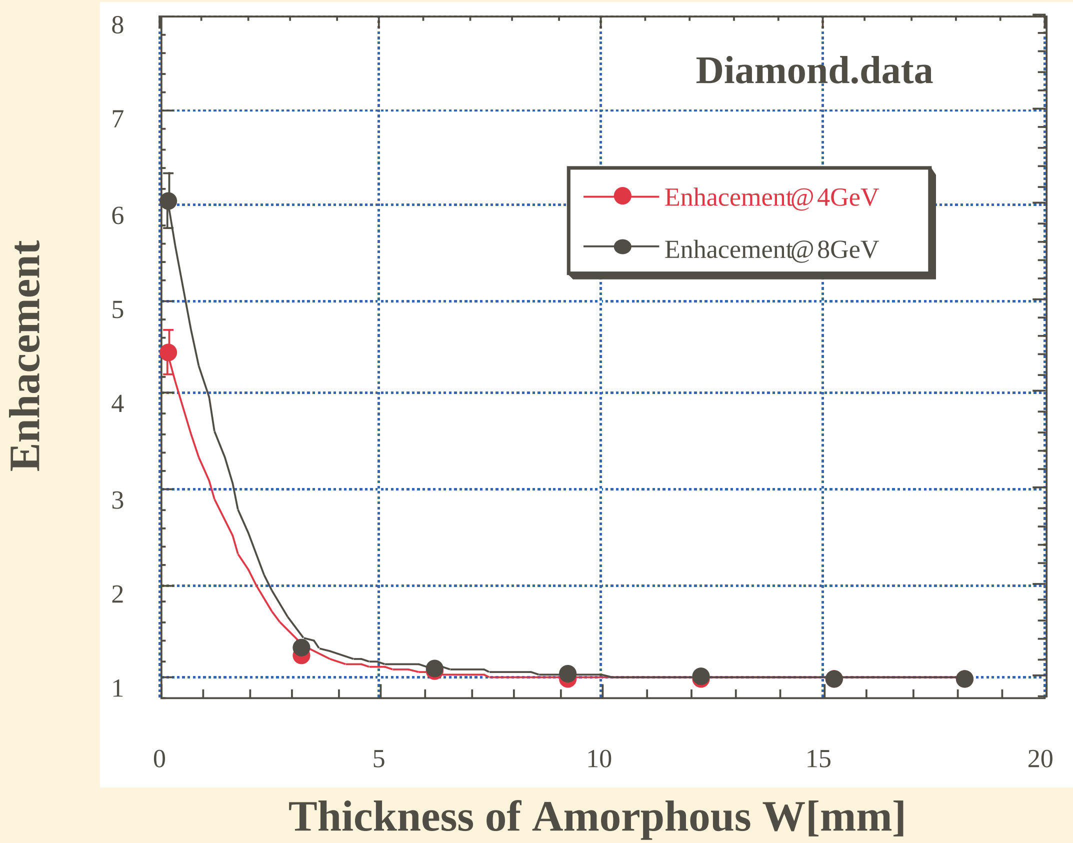


Fig. 5. The brightness at optimal thickness in Ge, W, Si, Cr, and diamond as a function of the initial electron energy

Diamond Target and Positron Enhancement

- 1.1mm-thick Diamond + Tungsten
  Diamond as Photon Emitter, Tungsten as Pair Producer
- at 4 GeV and 8 GeV (Preliminary Analysis)
- Far from Optimal Thickness (We need 10mm Diamond)

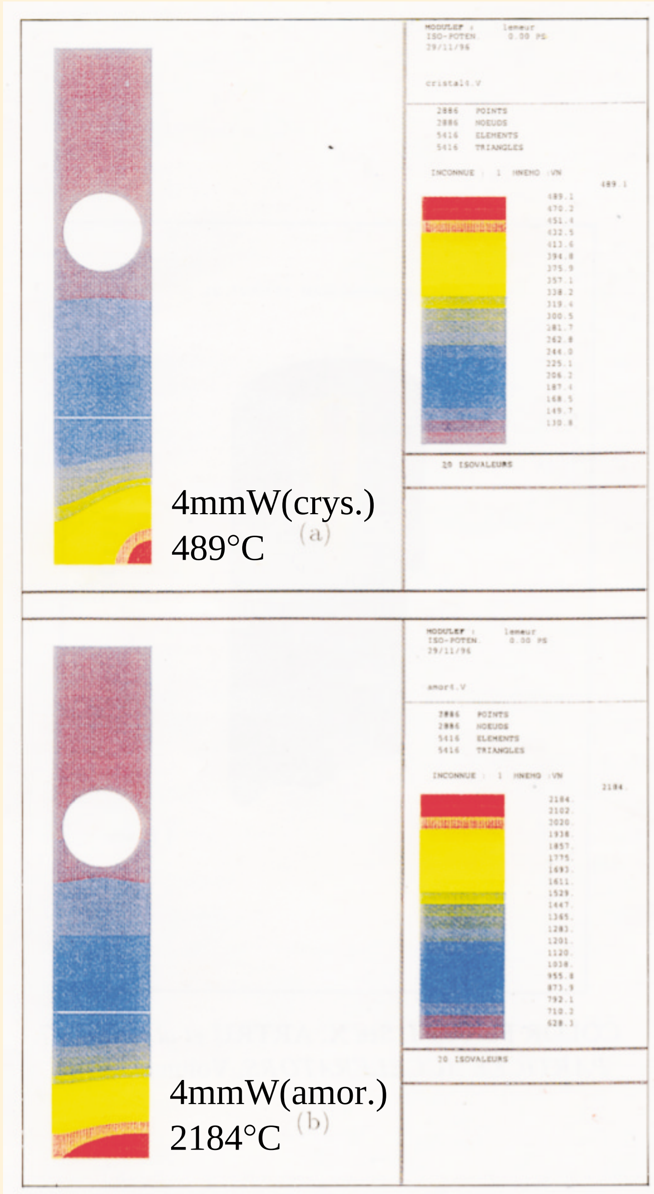


Heating

- Simulation by R.Chehab, et.al
  Particle Accelerators 59(1998)19
- 21mm Amorphous, 8mm Crystal,
  4mm Crystal + 4mm Amorphous

	e^- for $5x10^{11}$ e^+ at IP	BeamPower (kW)	Target Power (kW)	Target Peak Temp. (°C)
8mm W(crys.)	$5x10^{11}$	120	6.6	1400
4mm W(crys.) + 4mm W(amor.)	$5x10^{11}$	120	6.7	489(crys.) 2184(amor.)
21mm W(amor.)	$3.3x10^{11}$	79	27.0	2102

10GeV 150Hz, JLC(1995)-like System Assumed



Summary

- Positron Production Enhancement with W Crystal was Measured
  - Dependencies on
    - Incident Energy (4, 8 GeV),
    - Target Thickness (2.2, 5.3, 9, etc mm)
    - Out-going Positron Energy (5,10,15,20 MeV)
- With Thin (2.2 mm) Crystal 5-Times Enhancement was Observed
- Yield from 9mm Crystal was Larger than 15-28mm Amorphous
- The Results will Help Refining Simulation Codes
- Diamond Compound (Thick Diamond+Tungsten) Target
  May be promising
- Need More Heating Simulation