THE HYBRID POSITRON SOURCE USING CHANNELING: A PROMISING DEVICE FOR FUTURE COLLIDERS

R.Chehab, I.Chaikovska
Y.Enomoto ,K.Furukawa, H.Guler, T.Kamitani, F.Miyahara, M.Satoh, P.Sievers, T.Suwada, L.Bandiera,V. Guidi , A.Mazzolari , P.Martyshkin , X.Artru, M.Chevallier, V.Tikhomirov

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OUTLINE

* Introduction
* Enhancement in photon and positron production with oriented crystals
* Thick and thin crystals ➔ optimization
* The hybrid sources (Crystal =>Sweeping magnet =>Converter)
* Reliability of the source: crystal and converter: PEDD and shock waves, target activation
* The particular choice of the granular converter : advantages
* Applications to positron sources for linear and circular colliders
* R&D
* Summary and conclusions

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INTRODUCTION

* Needs for positron sources with high intensities, low emittances and reliable targets

* Hybrid positron source associating a high photon flux generated in crystals in axial channeling conditions with an amorphous W converter ➔ very promising [simulations, experiments @ CERN & KEK]

* After a short recall of the main features of such sources, development of the different ways of optimization [yield, heating, reliability]

* Some applications for linear and circular colliders will be described

* Summary & Conclusions

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ENHANCEMENT IN PHOTON AND POSITRON PRODUCTION WITH ORIENTED CRYSTALS

* Enhancement of photon generation in crystals in channeling conditions ➔ radiation length shorter than in amorphous and decreasing with increasing energy.

* High rate of soft photons ➔ creation of soft positrons easily captured in matching systems.

* Number of Photons and Positrons increase with incident energy

(ex. WA103 @ CERN) ➔ see figure

* The energy radiated is increasing with crystal

thickness but getting saturation (see V.Baier et al., in Phys.Stat.Solid)

➔ interest to use thin crystals: mitigation of heating effects

on available potential.

Baier's expression for potential: ➔

$U(x)= Vo[\ln(1+1/(x+b) - \ln(1+1/(x_0 +b)]$

With $b = 2u_1^2 / a_s^2$; u_1 being thermal vibration amplitude

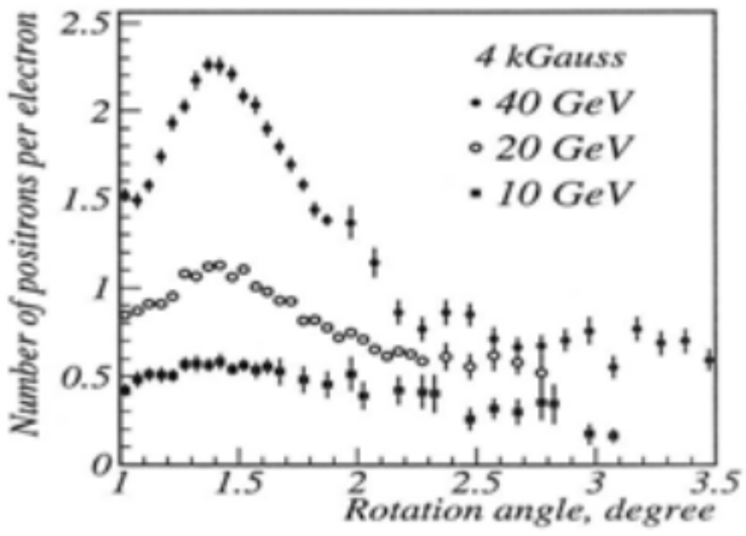

Figure 116: Rocking curves.

WA 103 @ CERN

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THICK AND THIN CRYSTALS ➔ OPTIMIZATION

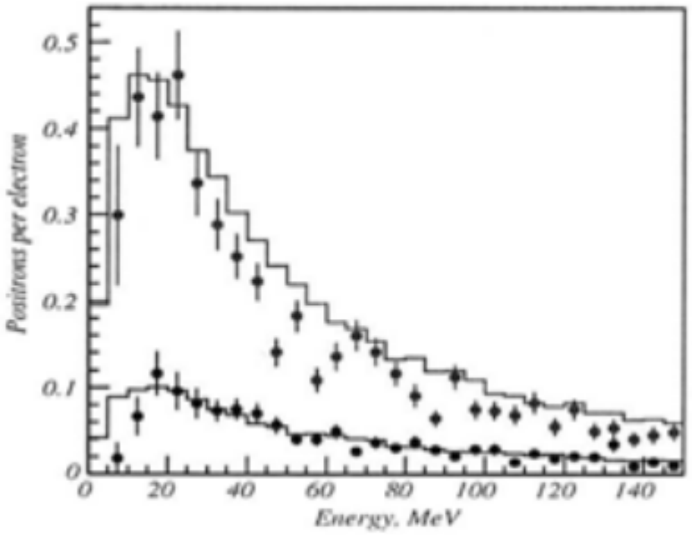
* First choice: generation of photons and e+e- pairs in rather thick crystals (4-8 mm): ex WA103 @ CERN

W crystals 4 and 8 mm thick, oriented on <111> axis have been tested at CERN ➔ high e+ yields were obtained, satisfying linear colliders requirements.

* With a 4 mm W crystal and 10 GeV e- beam, the enhancement oriented/random is of more than 4.

* With a 8 mm thick W crystal, the positron yield in momentum domain: $5 < p_L < 25$ MeV/c and $p_T < 8$ MeV/c ➔ yield e+/e- is > 2

This energy domain corresponds to transverse capture systems and DR acceptance. A thick W crystal could be a solution for LC, concerning the yield



10 GeV e- on 4 mm W crystal

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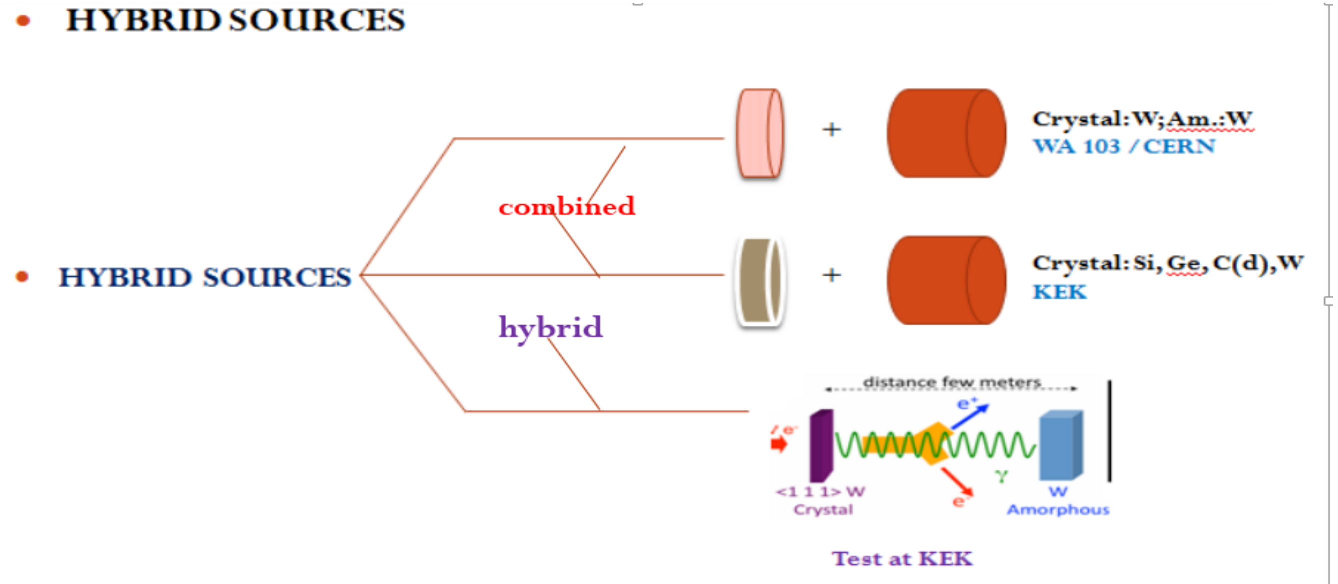
THIN AND THICK CRYSTALS: ➔ OPTIMIZATION

* If thick crystals are fulfilling yield requirements, energy deposition leading to heating must be taken into account. Moreover some saturation, with thickness increase-in the energy radiated- led to the choice of thin crystals associated to thicker converters. In the incident energy domain up to 10 GeV, an optimized thickness of 1 to 2 mm has been determined. Such association : ➔ hybrid source



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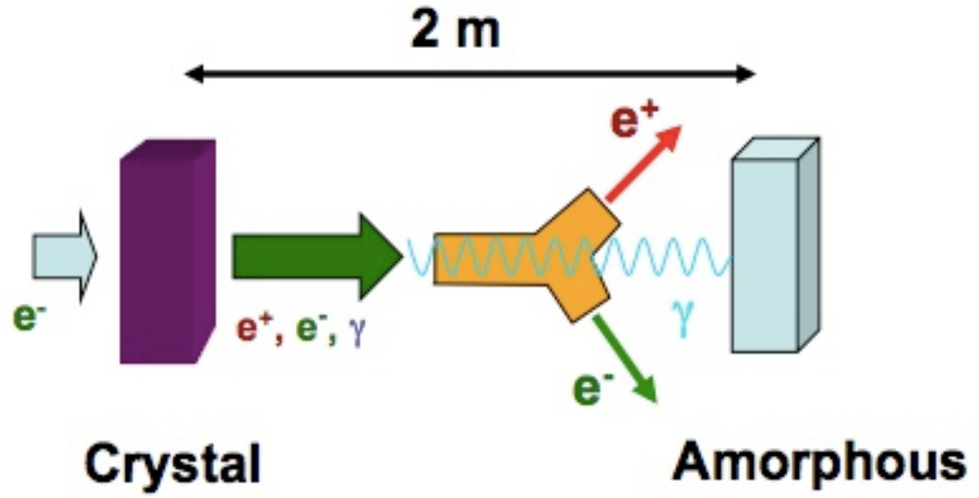
THE HYBRID SOURCE

A multi-GeV electron beam is impinging on a (W) thin crystal oriented on its main axis (here <111>).
The charged particles e+ and e- are swept off and only the photons are hitting the amorphous converter. The distance between the two targets is about 2-3 m to allow the installation of a bending magnet.



The amorphous target can be a bulk or a granular material (made of layers of small spheres).

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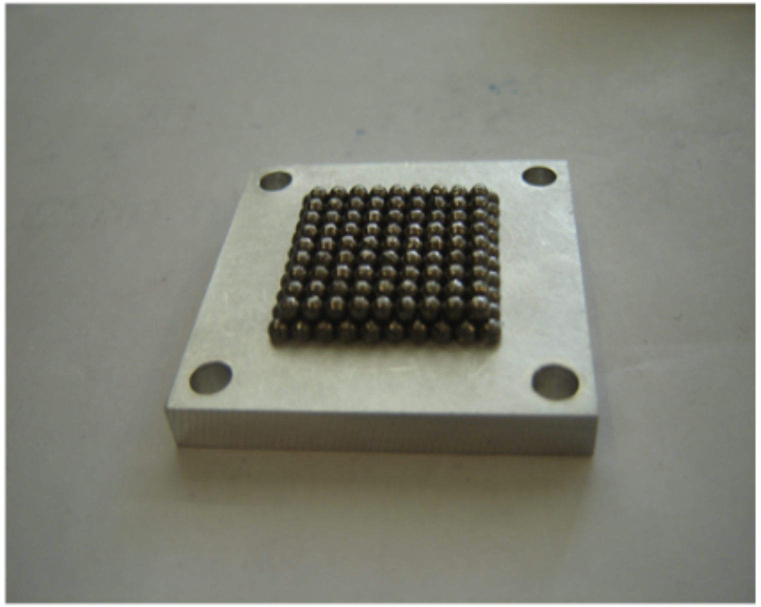
THE CHOICE OF THE CONVERTER ➔ GRANULAR

Following an idea of P.Sievers for the target of a neutrino factory (protons on target ➔ $\pi+\pi-$ ➔ $\mu+\mu-$ ➔ ν), we considered a granular target made of small W spheres (2 mm diameter) instead of the compact W target. Four granular targets were built at LAL (2, 4. 6 and 8 staggered layers) and sent to KEK. Simulations have shown the ability of such targets to serve as converters providing equivalent yields and better performances for the deposited powers and Peak Energy Deposition Density (PEDD). For example the yield for a 8 mm compact converter is close to that of a 8 layers granular.



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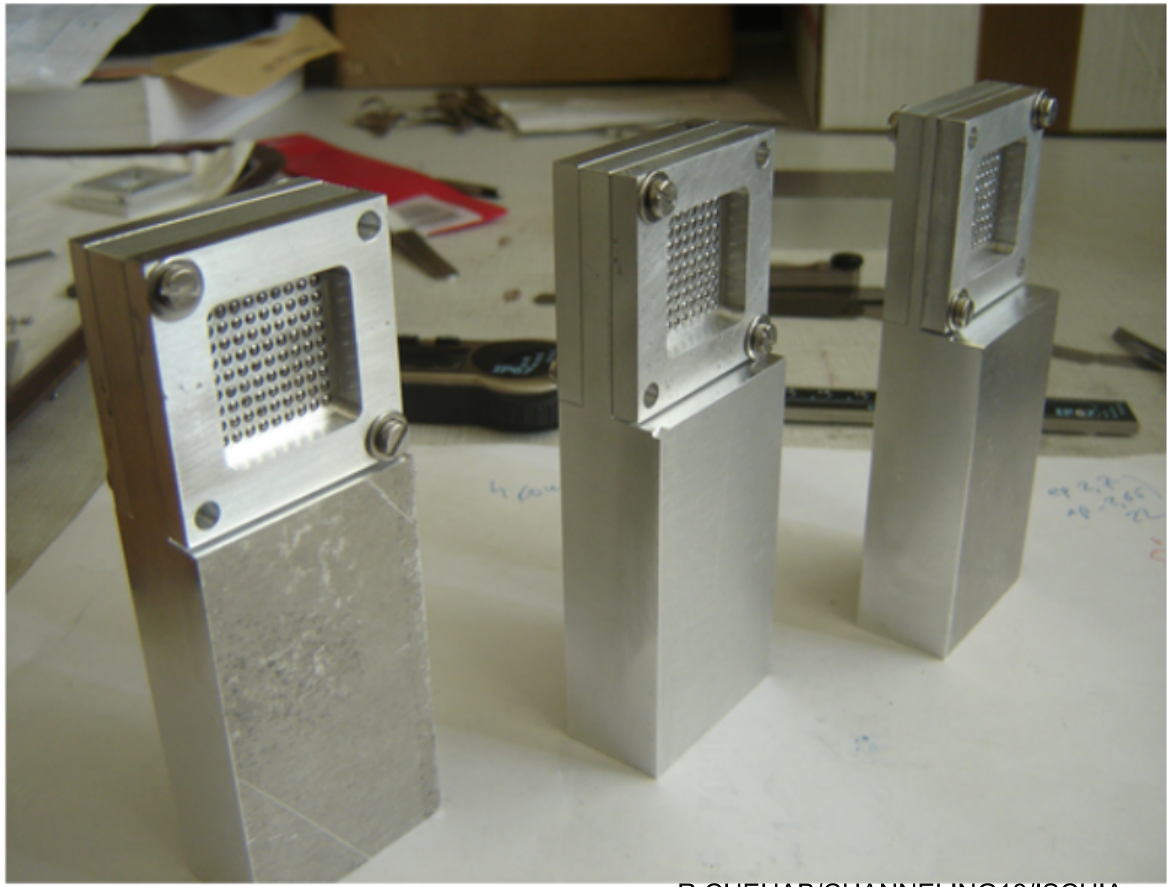
GRANULAR CONVERTERS

4 Granular targets with 2, 4, 6 and 8 layers have been built at LAL-Orsay and sent to KEK for beam tests. The entrance face had 10x10 W spheres and the exit face 9x9 spheres having, then a central sphere. That allowed use of thermocouples on the exit faces to measure the temperature rise. The “hottest point” being on the central sphere on the beam axis.



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RELIABILITY OF THE HYBRID SOURCE; That is concerning:

 # Radiation resistance of the crystal

 # Heating effects on crystal and converter

 # The PEDD

 # Activation of the targets

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RADIATION RESISTANCE OF THE CRYSTAL

The main source of damage being the Coulomb scattering of the incident electrons on the nuclei of the crystal string. When the recoil energy of the nucleus is above some threshold ($E_d \sim 50$ eV for W) the nucleus can be displaced from its site. If the recoil energy is > 2 E_d the nucleus can provoke a cascade of displacements. ➔ An experimental test has been done at SLAC.

A 0.3 mm W crystal has been installed upstream of the SLC positron converter. It was irradiated during a period of 6 months. Incident electron intensity as beam position and dimensions on the crystal were continuously controlled.

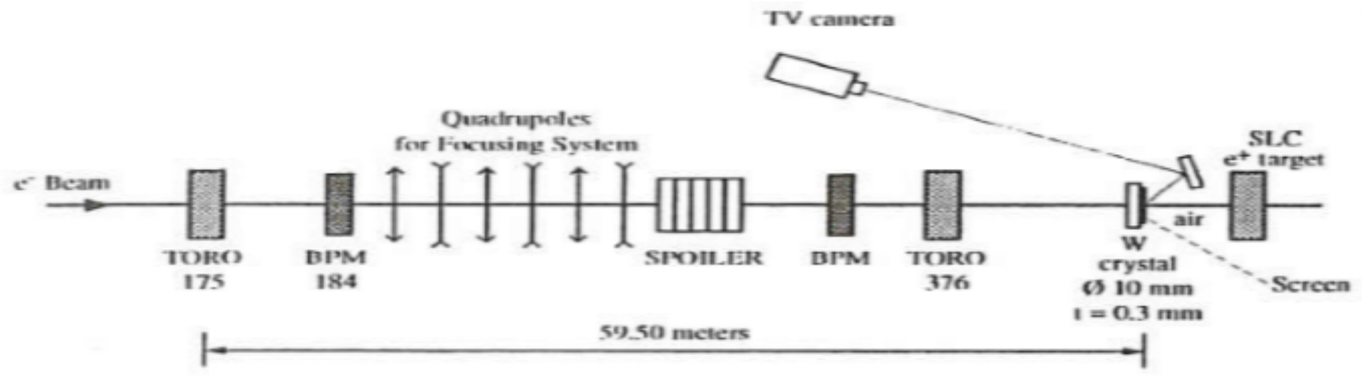

Figure 3: The SLC experimental set-up

Ref: R.Chehab et al. Proceedings of EPAC 1998 Conference , Stockholm, june 1998

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RADIATION DAMAGE TEST AT SLAC

The SLC beam: E-= 29.5 GeV
average intensity: 2.5×10^{10} /pulse
Frequency: 10 and 30 Hz
Integrated intensity (6 months): 1.2×10^{19} e-
Spot area on the crystal: 6.2 mm^2
Total fluence: 2×10^{20} e-/cm^2

Analysis:
X-ray and γ analysis have been operated by diffractometry methods at the Max-Planck Institue of Stuttgart, before and after irradiation. No modification in the mosaic spread of the crystal was observed. The result of the measurement done after irradiation ids shown. The damage threshold should be higher (for e-).
That fluence corresponded to the level of appearance of damages on a Si crystal hitted by 28 GeV and 450 GeV protons (BNL & Fermilab)

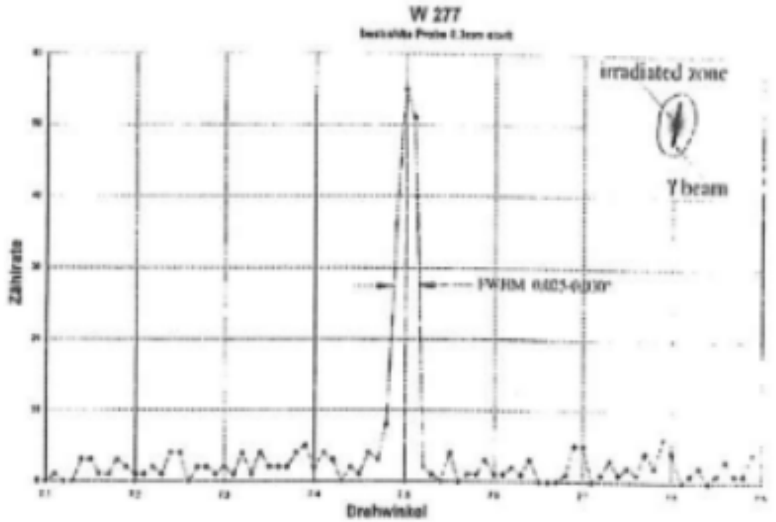

Figure 4: Mosaic distribution function of sample C2 obtained by γ-diffractometry. The γ beam is on the irradiated zone.

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CRYSTAL HEATING

Taking into account the variation of the potential with the temperature, simulations were undertaken with a 8 mm thick W crystal (<111> axis) . It resulted that a variation of ?T = 600?K decreased the e+ yield by ~ 15 %. The incident beam ➔ 10 GeV; 5.10^{11} e-/pulse; 150 Hz. In order to keep a moderate temperature ➔ crystal cooling

Moreover: better to use thin crystal

Cooling may be realized using water cooling (left fig.)

Or using gas jet (right fig.)

HEATING AND COOLING: THE CRYSTAL

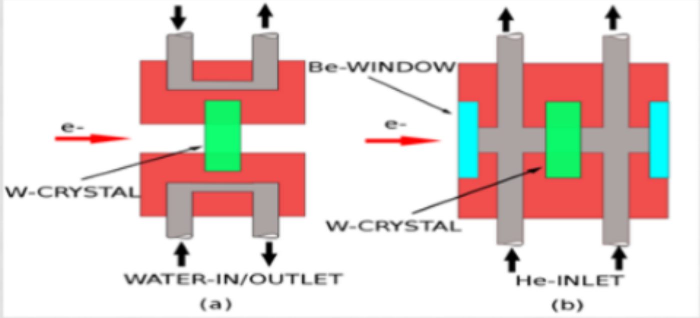
With an incident e- beam of 10 GeV and a transverse size of 2.5 mm rms, the energy deposited and PEDD/μpulse are:

E_{dep}= 2.6 Joule

PEDD➔ 5.8J/g

The crystal needs cooling:➔ solution: a 5-crystal holder in a goniometer. Cooling is realized with water or He jet.

Max. Temperature rise is:
275°K =>>Water
406°K=>> He



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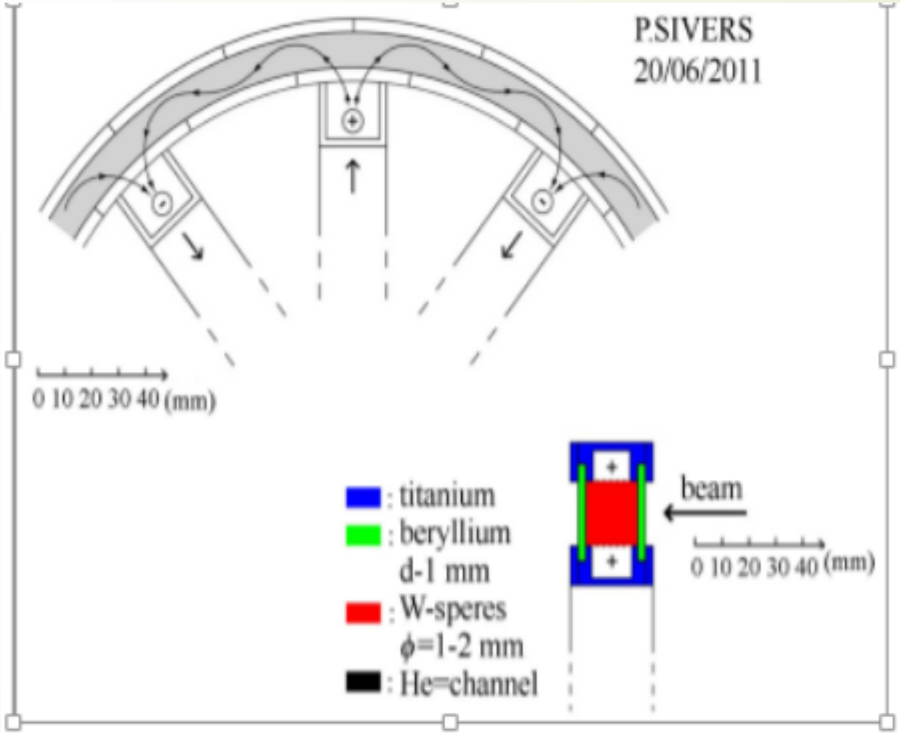
HEATING OF THE CONVERTER

- The large amount of deposited energy due to the high
- positron beam intensity required for the future linear
- colliders is leading to important heating and thermal
- shocks. The average heating as the energy deposition
- density can be mitigated using rotating converters as
- wheel (see figure) or pendulum. The Peak Energy
- Deposition Density (PEDD) may provoke thermal shocks
- leading to breaking ➔ SLC
- As an example, the converter foreseen for the hybrid
- source of ILC is receiving a deposited power of 10 kW: this is
- two times less than for a conventional source using 4.8 GeV e- and
- a 16 mm W target or 60% less with a 3 GeV e- beam
- (see former project of purely conventional source @ POSIPOL 17)



C.Xu et al. Chinese Physics C Vol.36, No 9 (2012) 871-878

R.Chehab/Hybrid/POSIPOL-18

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Peak Energy Deposition Density (PEDD)

The deposited energy by the beam pulses is distributed in the target volume in non-uniform way; it is maximum on the beam axis and increases with the depth. At each pulse, a mechanical stress could appear due to the thermal gradient. At the exit face of the converter and on the axis, the Peak Energy Deposition Density is present. ➔ Breaking may appear. That happened for the SLC target. After analysis: a maximum PED for W was stated at 35 J/g. Simulations are systematically operated to verify that this limit is not reached.

➔ determination of the energy deposited in the smallest volume on the exit face of the target and on the axis ➔ PEDD

➔ choice of the source parameters (Incident beam dimensions, distance crystal-converter,…) to keep the PEDD under the limit

➔ the mechanical stresses giving rise to shock waves propagating at sound velocity in the material, simulate the internal tensile efforts.

➔ granular converter offers the best solution: simulations made with a granular converter (2 mm diameter spheres) and a bulk converter have shown a maximum shock pressure ten times less than for a bulk converter with the same working conditions. : ILC case (40MPa vs 400 Mpa)

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ACTIVATION OF THE TARGETS

- The activation is related to photon/electron interaction with the nuclei causing emission of nucleons (protons, neutrons,etc..) when the impinging particle has an energy over the nucleus binding energy. The threshold is of some MeV for heavy materials as W. In such materials the main interaction is of (γ, n) type. The photon absorption by the nucleus leads to its excitation followed by a de-excitation leading to emission of secondaries as neutrons. The main process is related to the GDR (Giant Dipole resonance) which exhibits a maximum E(γ) around 14 MeV for W. The neutrons may be a radiation hazard themselves or provoking induced activity. Their number N_n is rising with the nuclear size [~ NZ/A, where N=A-Z]. The activation is increasing with the target thickness.

- The description of this process can be quantitatively operated with codes as FLUKA or GEANT. As underlined by Frascati physicists after tests on the Beam Test Facility, the experimental results are in better agreement with FLUKA (L.Quintieri et al. *Quantification of the validity of simulations based on GEANT4 and FLUKA for photo-nuclear interactions in the high energy range*, in The European Physical Journal Conferences 153, 06023, (2017).

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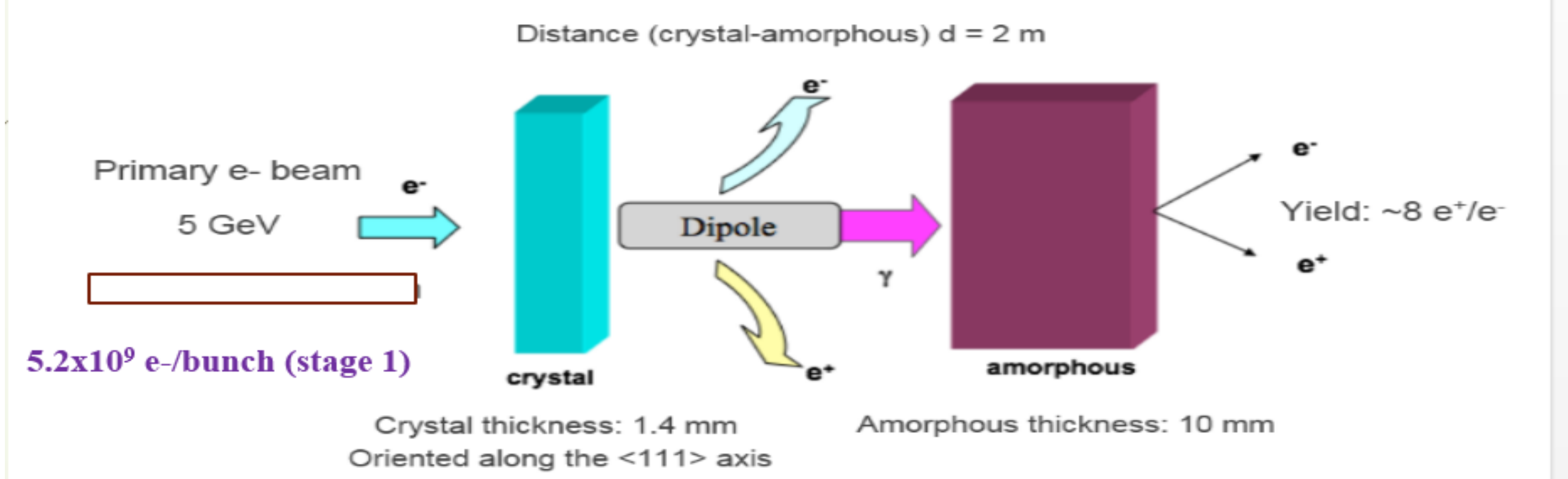
APPLICATIONS OF HYBRID SOURCES FOR FUTURE COLLIDERS

A- CLIC BASELINE POSITRON SOURCE



This kind of source has been already profoundly studied and adopted by the CLIC (many publications available).

__Yield:__ 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled!!!

PEDD➔ ~ 1 GeV/cm3/e- ➔ with 5.2x10^{9}e-/bunch and 312 bunches/pulse ➔ PEDD ~ 14 J/g

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- ILC Linear collider: results of simulations
- Granular target: 6 layers
- Total positron yield of
- about ~14 e+/e-
- Deposited energy of ~400 MeV/e-
- Energy deposition density
- of about ~1.4 GeV/cm^3 /e-

With ILC pulse (2.10^{12} e-) ➔ 23 J/g

W crystal <111>, 1 mm thick
Incident energy: 10 GeV

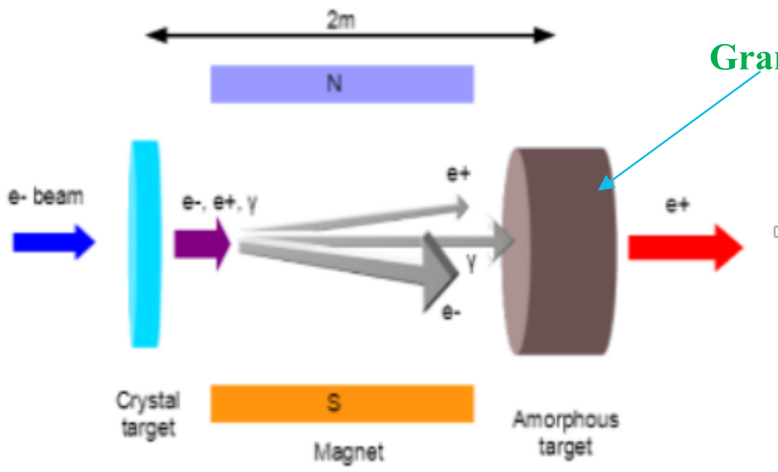

Figure 5.1: Hybrid scheme using crystal and granular target for ILC.

R.Chehab/Hybrid/POSIPOL-18

The pulse time structure of ILC has been modified before the target in order to decrease the power deposited by pulse. ➔ 1ms ➔ 13 macropulses @ 300 Hz

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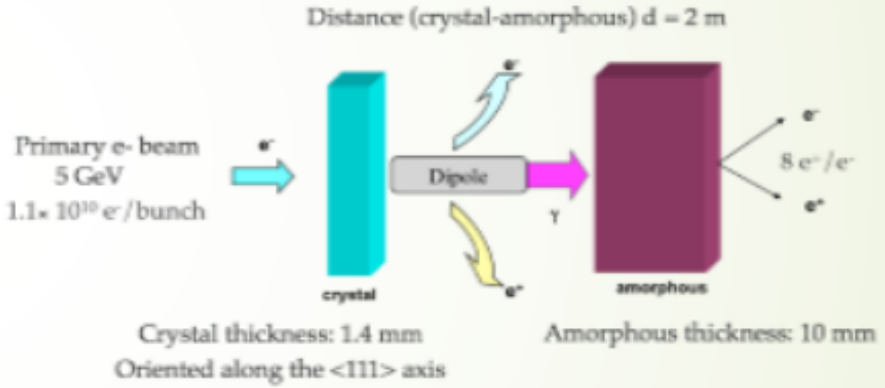
FCC-ee Positron Source (CLIC design)

Hybrid scheme

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	χ_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	χ_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

~ 10 kW
< 35 J/g



- Flux Concentrator (FC): peak field is 6 T, DC solenoid field is 0.5 T, length = 20 cm, aperture 40 mm.
- Accelerating structures: L-band 2GHz, 25 MV/m, aperture 30 mm.

	@ 200 MeV	@ 2.86 GeV
e+ yield, Ne+/Ne-	0.9	0.7
Emittance, µm rad	21	1.4

☞ CLIC e+ source design seems compatible with the FCC-ee requirements => optimisation with FCC-ee beam parameters.

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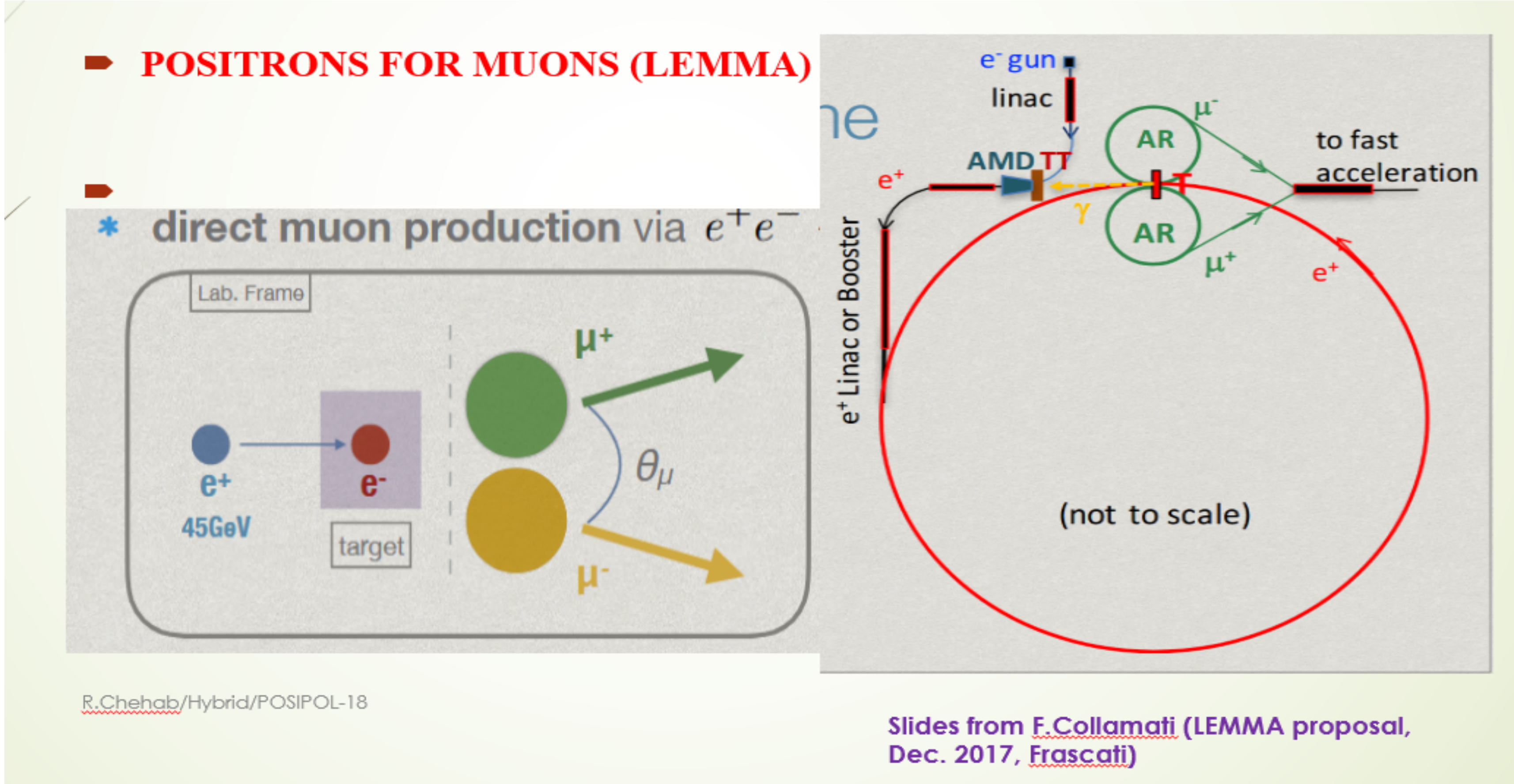

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Positron source requirements

Ring energy acceptance %	Be 3mm			LI 10mm			H2 liquid 35mm		
	e^+ beam lifetime (turns)	ΔN/sec	P e^+ drive beam (MW)	e^+ beam lifetime (turns)	ΔN/sec	P e^+ drive beam (MW)	e^+ beam lifetime (turns)	ΔN/sec	P e^+ drive beam (MW)
5	35	2.69E+16	277	45	2.11E+16	217	78	1.21E+16	125
10	47	2.01E+16	207	62	1.53E+16	157	107	8.86E+15	91

- Drive beam power is given by the number of e^+/sec accelerated up to 45 GeV
- Need to increase ring energy acceptance $\Delta p/p$ in order to reduce requirements on e^+ source!
- **Present:** $\Delta p/p = \pm 6\%$, $\tau = 40$ turns, $e^+/s = 2.4\times10^{16}$, P= 250 MW
- **Goal:** $\Delta p/p = \pm 10\%$, $\tau > 100$ turns, $e^+/s < 10^{16}$, P < 100 MW
- **Ongoing studies on embedded e^+ source from γ coming downstream from target**

e^+ production rates achieved so far (SLC) and needed

	S-KEKB	SLC	CLIC (3 TeV)	ILC (*H*)	FCC-ee (*Z*)	LEMMA
10^{14} e^+ / s	0.025	0.06	1.1	2	0.05	100

State of the art

Synergy with ALL e^+e^- future colliders

From S.Guiducci (see talk M.Biagini; “verso la nuova strategia europea”, Roma, sept.2018)

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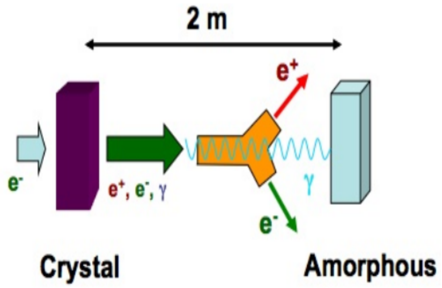
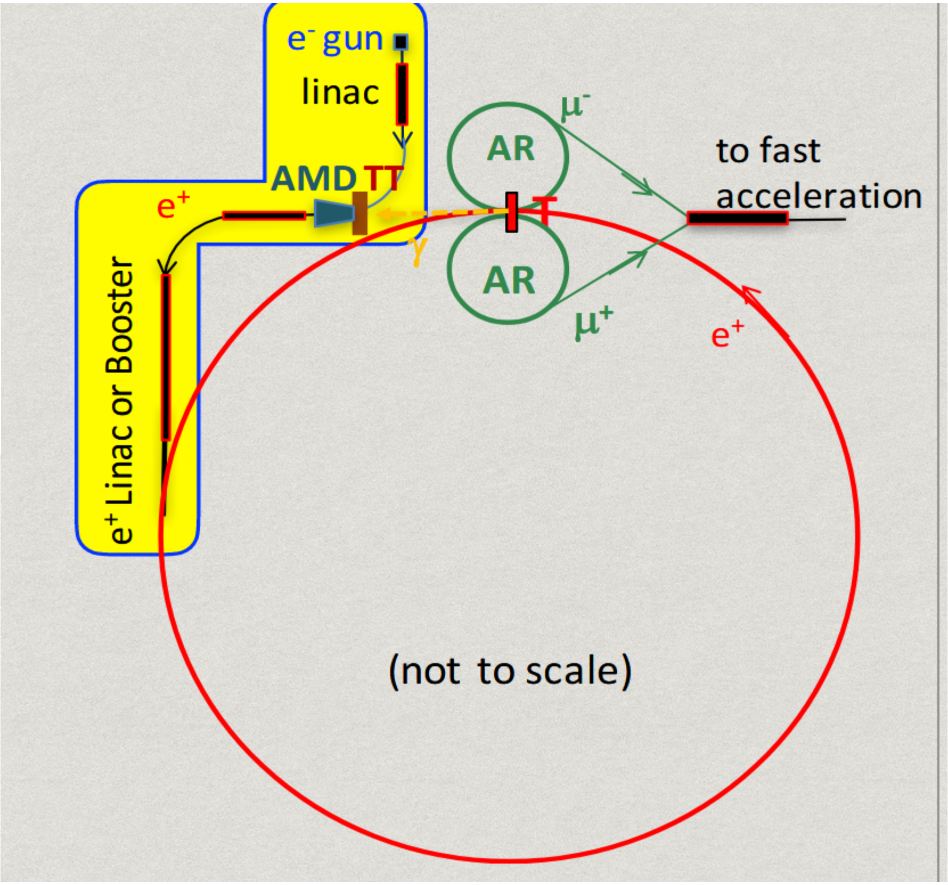
A POSITRON SOURCE FOR LEMMA RING

* The positron source of CLIC type# :



* The hybrid source has the following parameters:
Crystal thickness: 1.4 mm
Amorphous target: granular with 6 layers of 2 mm W spheres.
The number of incident electrons is 1.5×10^{10} /bunch
The number of bunches/pulse is 100. The linac frequency is 50 Hz
The generated positrons are captured by AMD and accelerated up to 45 GeV. With a transmission efficiency slightly close to one, we have 1.5×10^{10} e+/bunch.
The positron bunches are injected in the 100 ring buckets having 200 ns separation. The positron pulse has 1.5×10^{12} e+. The number of injected positrons/sec is 7.5×10^{13} . Reaching the requested number of 2×10^{16} e+/s needs further developments.

CLIC pulse is 1.6×10^{12} e+ similar to LEMMA pulse. PEDD will be also ~ 14 J/g for LEMMA pulses.



From F.Collamati

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R&D FORESEEN FOR HYBRID SOURCES

* OPTIMIZATION OF THE HYBRID SOURCE PARAMETERS

- Simulations ➔ crystal thickness, converter shape and thickness, distance crystal-converter

  ➔ positron beam transport to DR, bunch and energy compression

- Tests with e- beam ➔ at KEK ➔ measurement of temperature rise ➔ derivation of the energy deposited and of its density ➔ comparison with the simulations.

* IMPROVEMENT OF THE ANALYTICAL APPROACH AND OF THE SIMULATION TOOLS

➔ collaboration with Minsk Institute and INFN-Ferrara

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SUMMARY & CONCLUSIONS

* The hybrid positron source is providing solutions for future linear and circular colliders. The great number of photons produced in channeling conditions allows a high yield of positrons in the conversion process leading, henceforth, to thinner converters with alleviated energy deposition and lower PEDD. Moreover, use of granular converters offers better behavior with respect to the thermal shock waves which are responsible of the target breaking, as observed on SLC.

* Additionally , the activation of the converter will be much less than in the case of the conventional thick converter giving the same yield; as an example for ILC conventional option the activation is more than two times stronger than with the hybrid option. This is due to the large number of photons produced in channeling conditions leading to thinner converters- for the same yield- in the case of hybrid sources.