ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

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ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

- **OUTLINE**
- **1- Introduction**
- **2- Use of channeling radiation for providing photons for e+e- pair conversion**
- **3- Hybrid schemes instead of thick crystal converters**
- **4- Granular instead of bulk converters**
- **5- Other possible converters using several targets of reduced dimensions**
- **6- Summary and conclusion**

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

1- Introduction

* Luminosity is the key parameter in e+e- colliders to get large number of events

* High luminosity ➔ high intensities for e+ and e- and low emittances

* High intensities in e+ ➔ large number of photons to get large number of e+e- pairs

* Photon generation:

- Bremsstrahlung in amorphous targets
- Undulator radiation {polarized}
- Compton backscattering {polarized}
- Radiation in oriented crystals (Channeling and Coherent Bremsstrahlung in addition to Bremsstrahlung)

* Unpolarized positrons obtained with conventional converters: high energy incident electrons on thick targets

Inconvenients:➔ large energy density deposition, important heating and high PEDD (Peak Energy Deposition Density)➔ thermal and mechanical stresses, large emittance due to multiple scattering in thick targets

* For positron sources ➔ interest in providing larger number of photons for pair conversion to go towards thinner targets

➔ generation of photons in periodic structures/fields (undulator, laser, crystals) before conversion in e+e-

Channeling radiation in crystals is chosen as the source of photons for positron generation.

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- **2- USE OF CHANNELING RADIATION FOR PHOTON CONVERSION**
- **2-1 CHOICE OF THE CRYSTAL-RADIATOR: AVAILABLE POTENTIALS**
- **The radiated energy as the photon yield is depending, for all crystals, on their thickness. It is depending also on the depth of the potential well and so, on the available fields. Materials with high Z, like tungsten, are providing high potentials (about 1 kV at normal temperature for <111> axis). Si , Ge and C(d) diamond have weaker potentials (140 V for <110> Si, 191 V for <111>Ge)**
- **The <111> diamond crystal has a little more than 100 V potential at normal temperature.**
- **(see V.N.Baier, V.M. Katkov, V.M.Strakhovenko in: Phys.Stat.Solidi vol.133 (1986) 583-592)**
- **➔ For our application we used W crystals oriented on <111> axis; mosaicity measured at MPI-Stuttgart with γ rays ➔ 0.5 mrad FWHM**
- *** Thicknesses: 1, 4, 8 mm**
- *** Transverse dimensions: < 10 mm**

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- PHOTON CONVERSION
- * A CRYSTAL FOR RADIATION AND CONVERSION:
- In order to get a large number of photons and e+e- pairs➔ thick crystals. With the incident energies considered $E^- \leq 10$ GeV pair creation is described by Bethe Heitler formalism.
- ➔ Experiments at CERN (WA 103) brought good results: for accepted e+ η^+ ~2.5 e+/e- with 8 mm thick W crystal and incident E^- =10 GeV
- Drawback: heating of the crystal ➔ decrease of the available atomic potential due to thermal vibrations of the rows [for instance for ΔT=500 degrees, the potential is half of that at normal temperature, for W) Ref. X.Artru et al, Particle accelerators vol. 59 (1998)19-41

  ➔ better to use a thin crystal followed by an amorphous converter ➔ hybrid source
- * HYBRID SOURCE
- # Photons are created in a thin crystal axially oriented on one main axis
- # Positrons are generated by these photon conversion in thick amorphous converters .
- ➔ For intense beams (linear colliders) a sweeping magnet is put between the radiator and the converter to reduce
- the heat load .
- ➔ For moderate beam intensities (circular colliders) a collimator or a free space between the two targets is
- considered.

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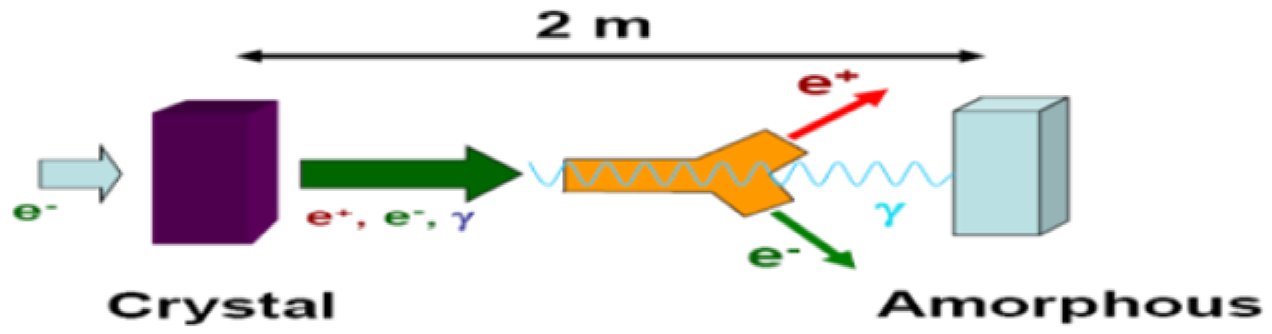
3- HYBRID POSITRON SOURCE

3-1 The scheme

- Assuming thin crystal target and, hence, moderate heating, in it and in order to lower the amount of energy deposited in the amorphous target and also the PEDD, the following scheme has been proposed
- [R.Chehab, V.M.Strakhovenko, A.Variola]

See X.Artru et al: NIMB 266(2008)3868



Putting a drift between the 2 targets allows sweeping off the charged particles coming from the crystal; only the γ impinge on the amorphous target

In the KEK lay-out the distance crystal-amorphous converter was about 3m.

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3-2 HEATING OF THE HYBRID SOURCE CONVERTER

The deposited power density of the shower developed in the amorphous converter is far from being homogeneous leading to thermal stresses and henceforth to mechanical stresses. These stresses are expected to be the largest at the maximum of the transition curve, on the axis of the converter. There, it is possible to observe a Peak of the Energy Deposited Density (PEDD). When the PEDD is exceeding a certain amount, which depends on the tensile strenght of the material, breakdown of the target is occuring. That was observed on the SLC tungsten converter; analyses led to a maximum tolerated of 35 J/g for this kind of material. The breakdown is more probable for very short beam pulses duration [redacted] shorter than the time put by the stress (sound wave) to cross the target.

In the simulations, for instance using GEANT4 code, it is possible to determine the value of the PEDD in the converter. Calculation of the deposited energy in the smallest volume leads to its determination. The incident beam spot size on the converter directly influences the dimensions chosen for this volume.

Moreover experimental studies to measure the temperature distribution on the converter, allowing the determination of the PEDD, are going on.

➔ To ensure a good reliability of the converter: ➔ Improve heat dissipation and limit the PEDD

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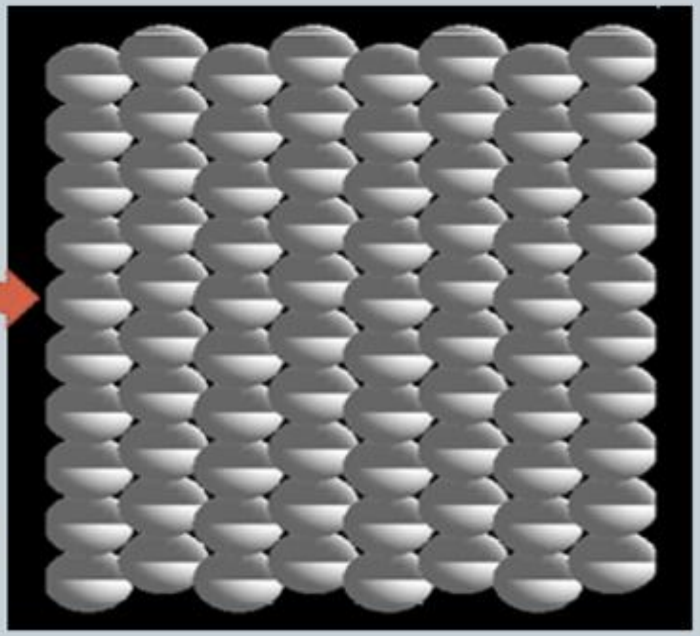
4- CONVERTER: BULK OR GRANULAR?

- Instead of a compact amorphous converter,
- a granular target made of small tungsten spheres
- 1-2 mm diameter arranged in staggered rows has
- a lot of advantages:
- - better heat dissipation ~ surface/volume of
- the ball ; improves with decrease of radius
- - lower energy deposition density
- Such a system was previously proposed for
- neutrino factories (Targets submitted to
- high power proton beams) by P.Sievers et al.
- A systematic study started with the PhD work
- of Chenghai XU at LAL-Orsay
- Example: we got for W targets giving almost he same yield
- For E-= 10 GeV; 6 layers ; W crystal (1 mm)
- Deposited energy: compact; 520 MeV/e-
- Granular (1 mm radius spheres): 400 MeV/e- (For a little less total yield)
- PEDD: compact: 2.20 GeV/cm3/e-
- Granular (1 mm radius) : 1.4 GeV/cm3/e-

photons



Simulations on granular targets in the article :Chenghai Xu et al; Chinese Physics C 36(9) (2012)871

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-1 STRESSES IN THE TARGET**

- *** The stresses are resulting from the inhomogeneous distribution of the temperature in the target. Very often, as in present e+e- collider projects the impinging electron bunch on the conversion target has a short duration which involves a negligible heat conduction. Thermal dilatation of the target does not proceed due to mass inertia ➔ stresses. As an example: the SLC target (6 Xo of W-Re) with ps bunch duration and 50 Hz.**

*** Stresses in targets due to thermal load have been studied at CERN (see P.Sievers, « Elastic stress waves in matter due to rapid heating by an intense high energy particle beam » in LAB.II/BT/74-2 (1974) and P. Pugnat, and P. Sievers, Journal of Physics G: Nuclear and Particle Physics 29.8 (2003): 1797)**

➔ Stresses in small spheres

At t=0 , with an instantaneous and uniform heating of a sphere, a uniform pressure is standing:

- $$\sigma \sim 3E\,\alpha\,\Delta T$$

- **where E is the Young modulus (psi or Mpa); α the expansion coefficient ($°K^{-1}$) , ΔT, the temperature rise (°K).**

- *** It is important to have a knowledge of the energy deposition density in the target in order to determine its maximum: PEDD. In the case of the W-SLC target a limit for the PEDD led to 35 J/g to avoid the target breakdown.**

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-1 STRESSES IN THE TARGET**
- **Following P.Sievers studies on granular targets for a υ-factory [CERN NUFACT Note 094/2001] the stress in the target is traversing it with the sound velocity (5 km/sec for W). Two cases must be considered:**
- **a) The time τ needed to traverse the target (from the periphery to the center) is greater than the duration t_0 of the pulse impinging on the target ➔ the maximum stress is to be considered.**
- **b) The time τ needed to traverse the target is smaller than the duration t_0 of the pulse impinging on the target ➔ the maximum stress to be considered is reduced by the factor τ/t_0.**
- **So, granular targets made of small spheres with diameters of the order of mm can ensure small τ values .**

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- **4-2 THE PEDD**
- *** The PEDD represents the highest deposited energy density in the target: this high density is usually on the axis at the exit face of the target, corresponding, generally, to the maximum of the Transition Curve. It is associated with the smallest volume of the target where the energy density is high. It is usually related to the transverse dimensions of the impinging beam spot size.**
- *** The experimental determination of the PEDD need the knowledge of the deposited energy ΔE which can be determined through the associated temperature rise ΔT which can be given by thermocouples put on the exit face of the target . The relation:**
- $$\Delta T = \Delta E / v\rho C_p$$
- **where v is the small volume associated to the high density energy deposition ; ρ, the density and C_p the heat capacity (J/g °K)**
- *** In the particular case of a sphere of radius r , considered with some approximation as the « smallest volume » with highest energy density, vρ is the corresponding mass of the sphere , so the quantity ΔE/ (vρ) expressed in J/g represents *approximatively* the PEDD. In the case of W, this quantity is directly related to the temperature by:**
- $$\Delta E / v\rho = C_p \, \Delta T$$
- **with ΔE/vρ expressed in J/g; C_p =0,134 J/g °K.**
- **The condition (ΔE/vρ) < $(PEDD)_{max}$ as the condition $\sigma < \sigma_{max}$ put a limitation on ΔT; the knowledge of the temperature rise is essential ➔ measurements foreseen (KEK, MAMI,..)**

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

◦ 4-3 – SIMULATIONS ON GRANULAR TARGETS

◦ 4-3-1 Simulations by Xu Chenghai ,LAL/IHEP)

- **Simulations on an hybrid source: (Chenghai Xu PhD; see Chenghai Xu et al, Chinese Physics C 36(9) (2012)871**
- **Simulations: VMS (V.Strakhovenko, for crystal) and GEANT4, for converter**
- **- W crystal <111> orientation, 1 mm thick**
- **- E^- incident = 10 GeV**
- **- distance crystal-converter: 2 m**
- **Comparisons have been done between a bulk and granular converters**

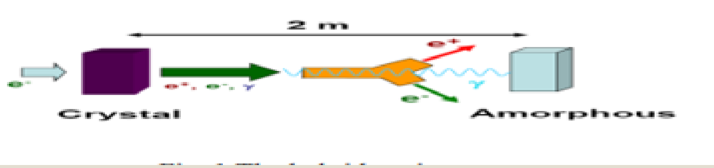

Table 1. Comparison of compact and granular targets

	Thickness (mm)	Yield (e+/e-)	PEDD (GeV/cm^3/e-)	ΔE dep. (MeV/e-)	N-layer	Sphere number	Effective density (g/cm^3)
Compact	8	13.3	2.24	523			19.3
Granular r = 1mm	10.16	12.5	1.81	446	3	864	13.9
Granular r =0.5mm	11.60	13.45	2.33	613	7	8064	13.9

The N-layer corresponds to N pairs of layers put in staggered position; the 3-layer has almost 6% less e+ yield but 20% lower PEDD

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4-3-1 ◦ **HYBRID SOURCE WITH GRANULAR CONVERTER: SIMULATIONS** (C. Xu)

◦ **Some results are summarized on the figure below:**

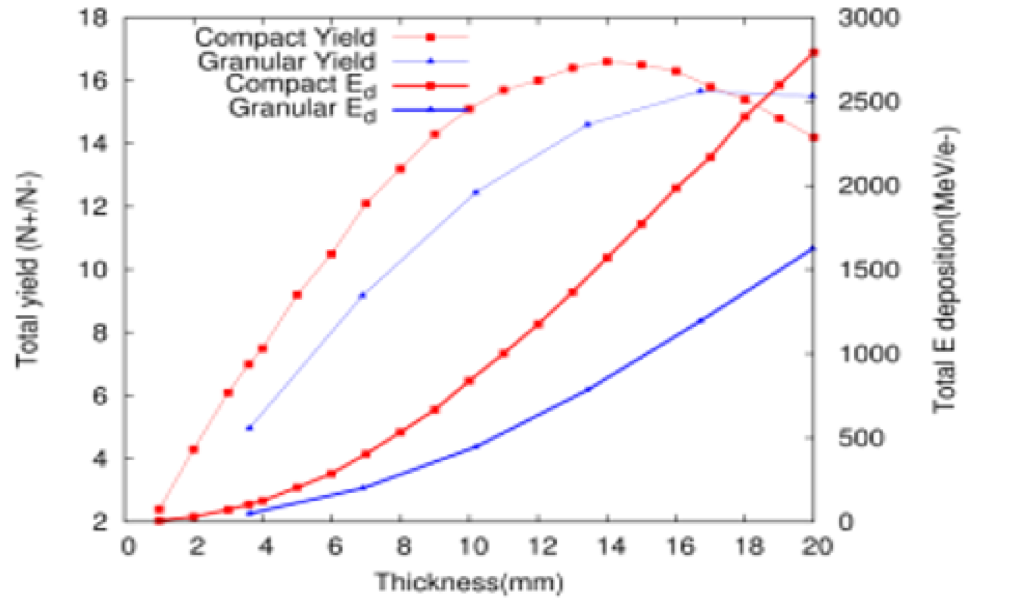

Fig.3 Comparison of compact and granular targets

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4-3-1 ◦ **PEDD**

- **For the « 3-layer » case the Energy Deposition Density has been determined** (C.XU)

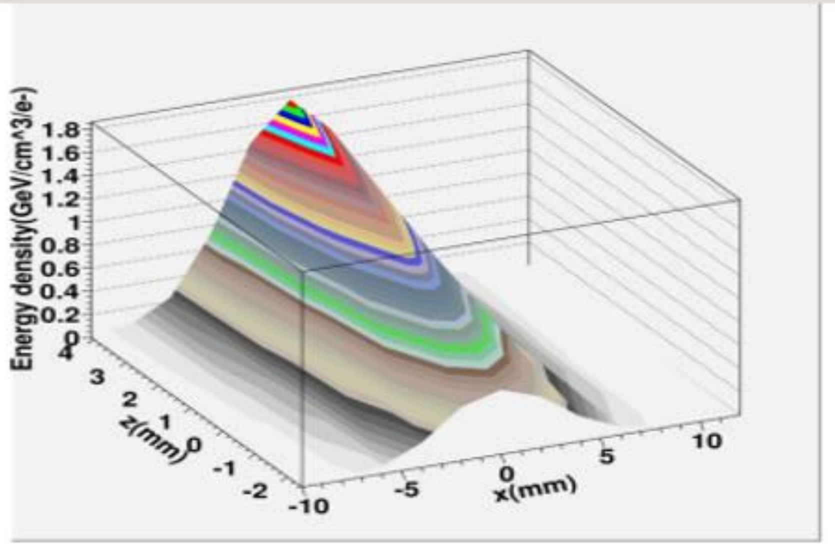

Fig. 10 Energy deposition density in the 3 layers granular converter. Beam direction is indicated (z axis). Maximum density is at target exit.

The « 3 layers » is made of 3 double planes of spheres: one of 10x10 spheres and the other of 9x9 spheres in a staggered arrangement.

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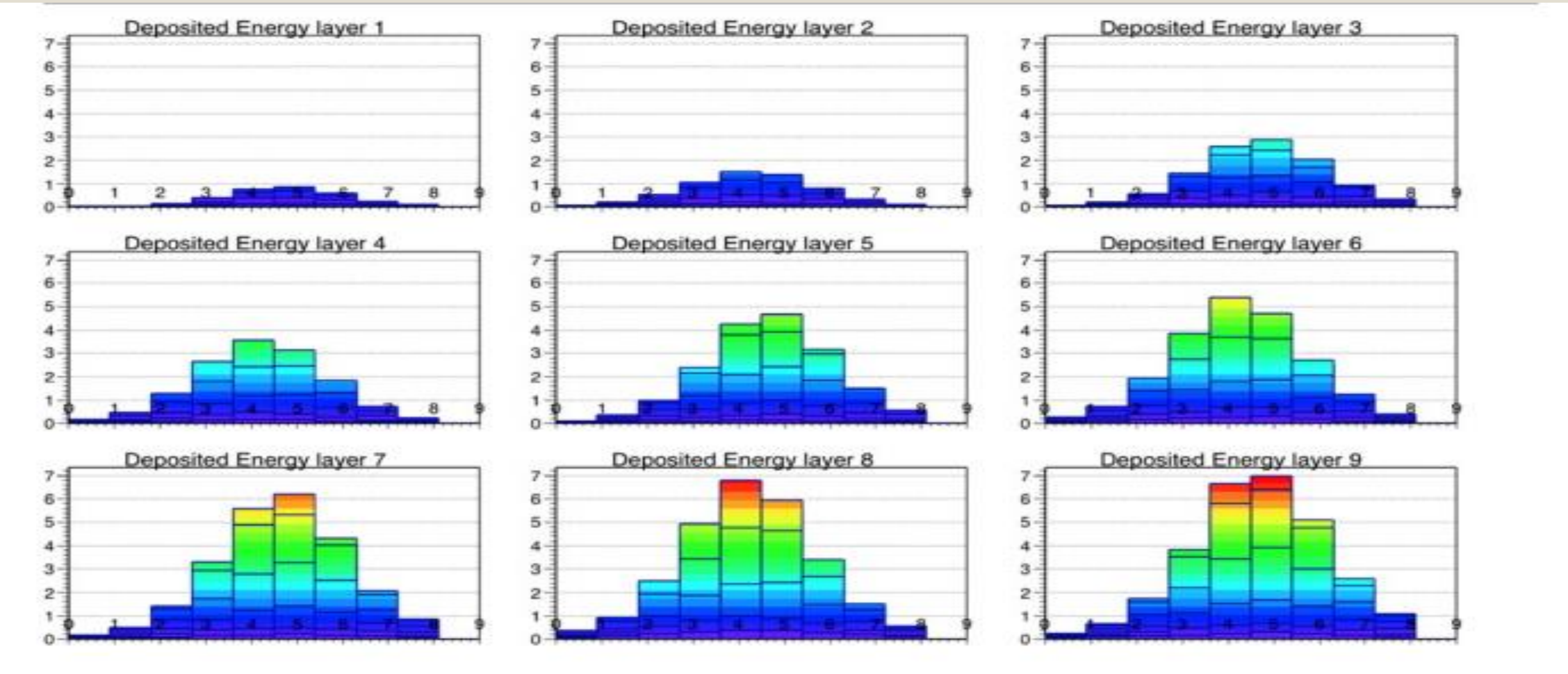
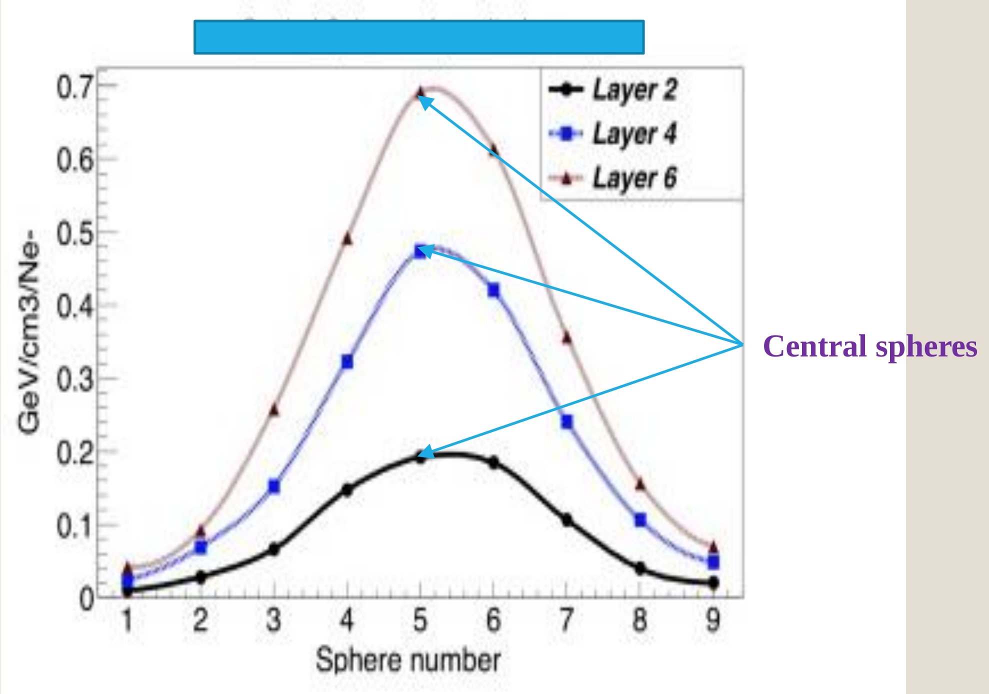
- **4-3-2 SIMULATIONS MADE BY H.Guler see X.Artru et al. NIM B 355(2015)60**
- **The energy deposited in the converter is calculated in each W sphere and so on its distribution on the successive transverse planes of the converter. {E=8 GeV; σ^{-} = 2.5 mm; r_{sphere} = 1.1 mm}; such distribution in the successive layers is shown.**



ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

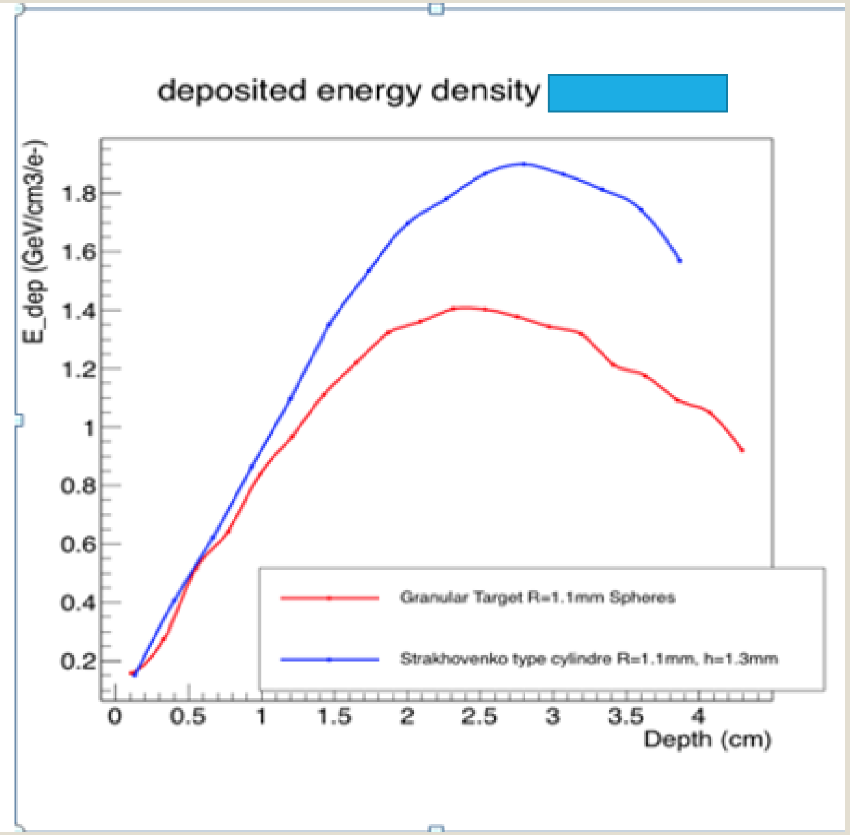
- **4-3-2 SIMULATIONS MADE BY H.GULER**
- **The energy deposition density has been calculated (GeV/cm^3 Ne$^-$). More specifically, this energy density has been calculated in the central sphere of the exit face of the converter which could give some approached value of PEDD; We have considered:**
- **a narrow e- beam (1mm radius) ;**
- **Electron energy: 8 GeV; sphere radius: 1.1 mm**
- **We represent the case of a 6-layer converter**
- **If thermocouples are put at determined positions**
- **represented on the figure , for instance on the last**
- **layer (6) it would possible to have access to ΔT and**
- **then to ΔE.**
- **Note that the energy density depends on the incident**
- **electron beam size: here σ^- = 2.5 mm. At smaller σ values**
- **this density is increasing.**

The lateral density distribution has been calculated.!
• The deposited energy density is calculated on adjacent spheres at the exit of the converter (maximum deposited energy density).



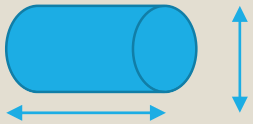
ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-3-2 COMPARISON: BULK/GRANULAR TARGETS (H.G.)**
- **The energy deposition density (EDD) is compared for the 2 cases:**
- **granular (red) and compact (blue). The elementary volumes are**
- **approximately of the same values: spheres with r= 1.1 mm;**
- **cylinders with r= 1;1 mm and h= 1.3 mm;**
- **It is seen that for moderate thicknessses (up to 1.5 cm) the**
- **energy deposition density is slightly lower for the granular**
- **converter. At larger thicknesses, the advantage of the granular**
- **target is obvious.**

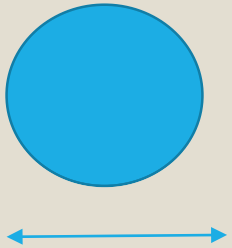


ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-3-3 SIMULATIONS OF THE STRESSES (see S.Jin et al. « Numerical analysis of the stresses for the target of the ILC 300 Hz conventional positron source » in Proceedings of IPAC2016, Busan, Korea)**
- **Two converters were considered:**
- **- a W cylinder: with L= 20 mm**
- **r = 5 mm**



-granular converter with small spheres d= 2mm



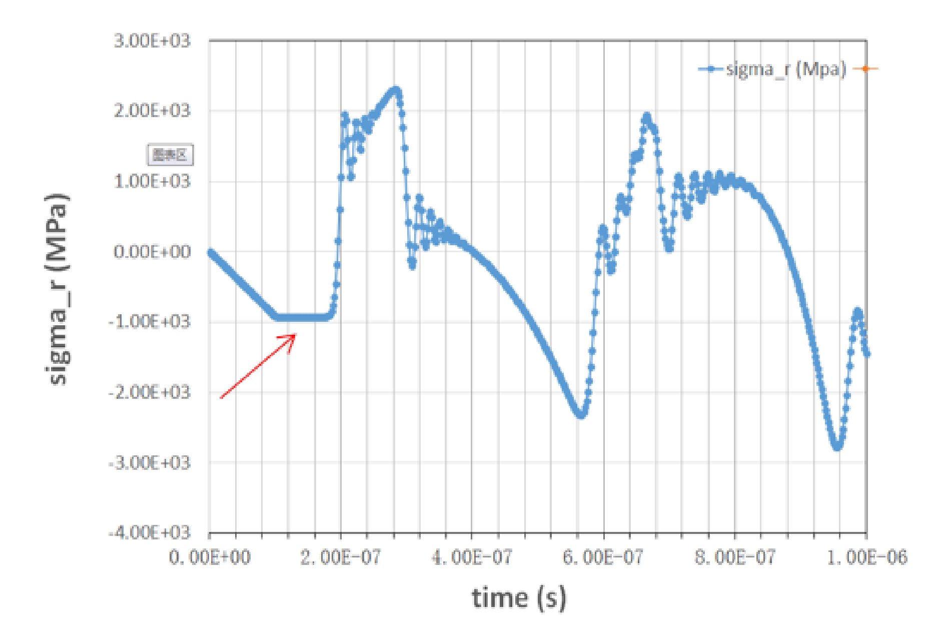
S.Jin made two kinds of comparisons:
- compared stresses for a cylinder and a sphere in the same beam conditions
- compared stresses in a sphere for two different beam pulse durations: 100 ns and 1 µs

➔ **The stresses in a sphere were about 40 Mpa, whereas it was 400 Mpa for the cylinder.**

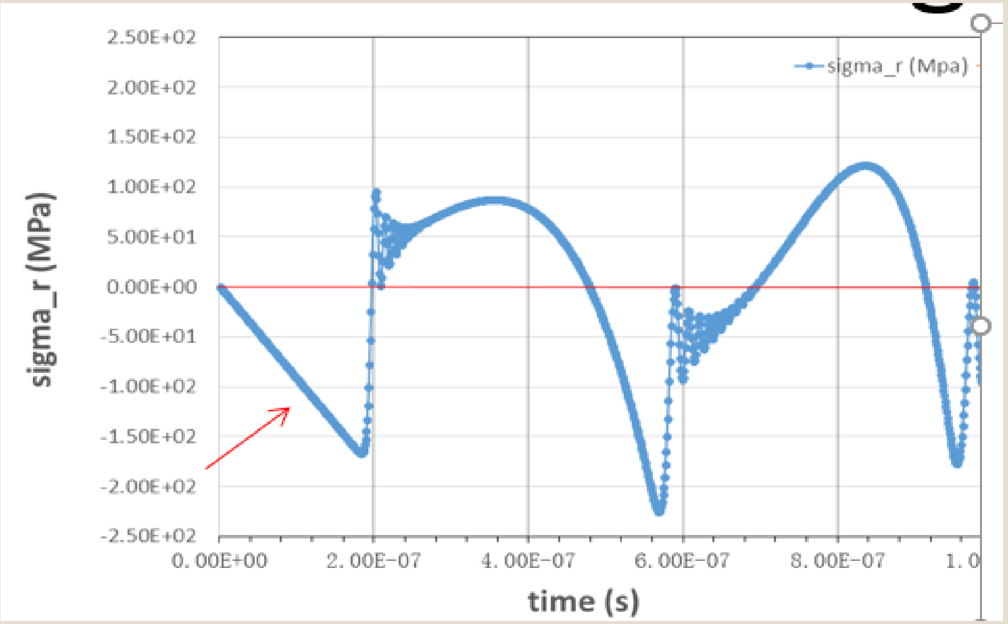
➔ **The stresses, in a sphere, were almost 10 times less in the case of 1 µs than for 100 ns.**

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-3-3 SIMULATIONS ON GRANULAR TARGETS (S.Jin)➔ comparison of stresses for 1µs and 100 ns beam pulses.**



100 ns beam pulse



1 µs beam pulse

The radial stresses are showing a reduction of about an order of magnitude when starting from 100 ns to 1µs (see « Sphere simulations by ANSYS » by Song Jin (IHEP)

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

4-4 ◦ **EXPERIMENTS WITH GRANULAR TARGETS AT KEK**

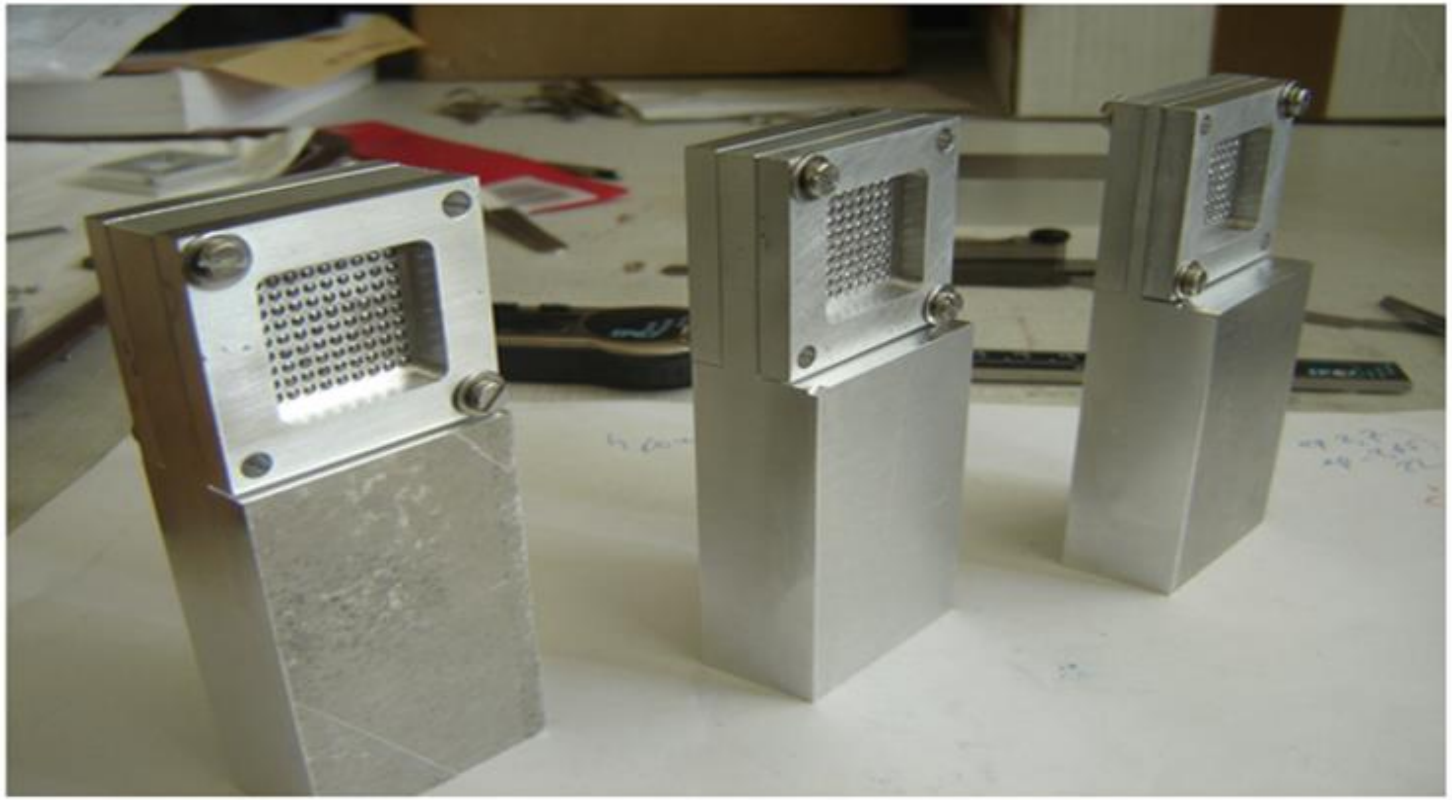
TEST AT KEK OF AN HYBRID SOURCE WITH A GRANULAR CONVERTER

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.

R.Chehab/Channeling2023/Riccione

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

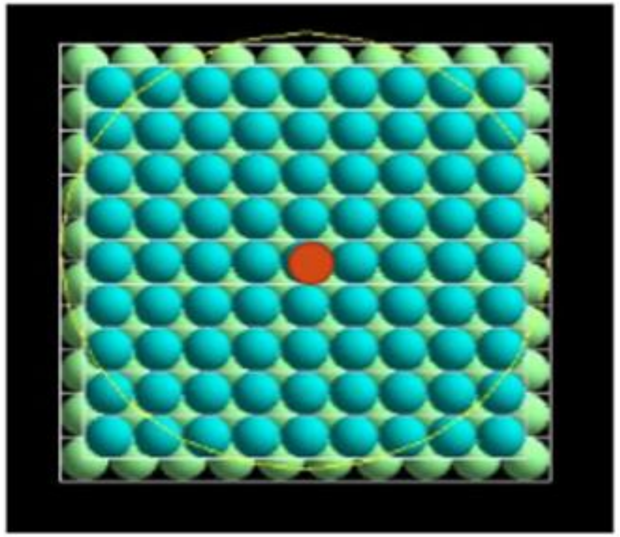
4-4-1 THE GRANULAR TARGETS: CONVERTERS USED AT KEK



ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

4-4-1 **GRANULAR CONVERTERS:** 4 converters have been built (LAL) and some tested at KEK

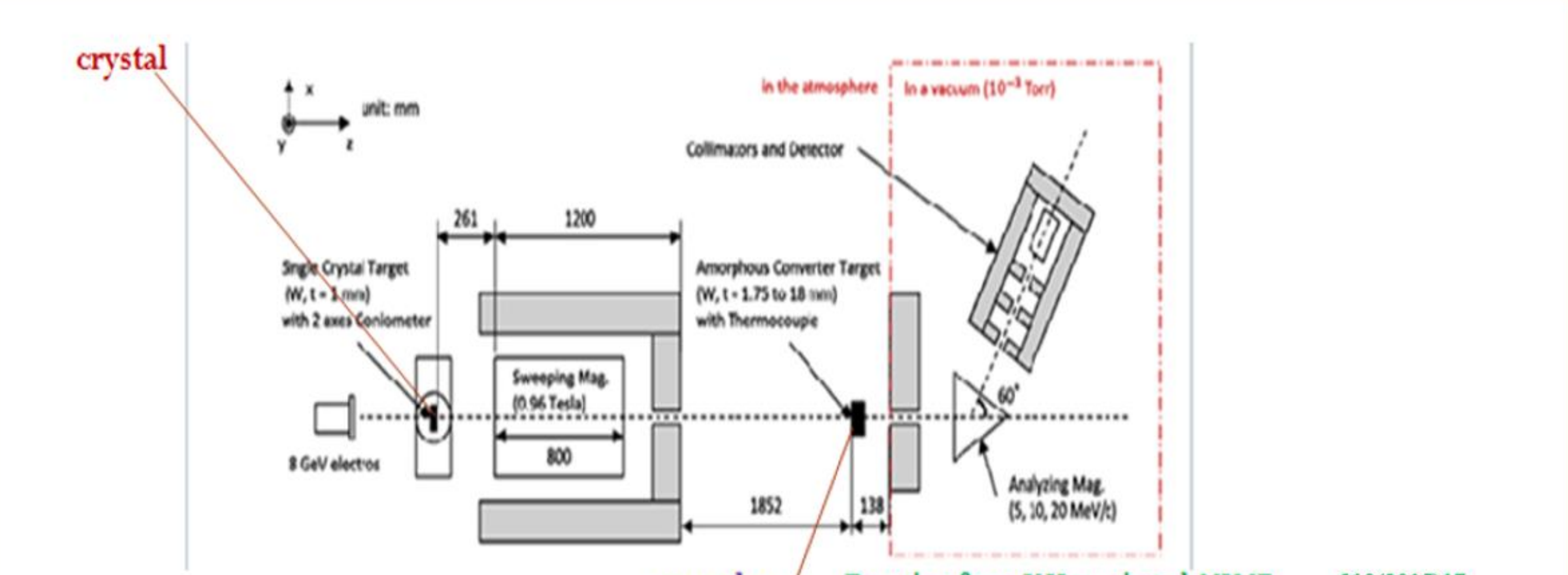
- * One with 2 staggered layers (10x10
- and 9x9 spheres),
- * One with 4 staggered layers,
- * one with 6 staggered layers
- * one with 8 staggered layers
- The energy deposition is calculated in
- each sphere. The entrance face w.r.t.
- the photon beam has 10x10 spheres;
- the exit face has 9x9 spheres, presenting
- a central sphere on the axis (probable maximum heating). From the energy deposited in this central sphere we could derive the PEDD (approximation)



ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

4-4-2- ◦ EXPERIMENTS AT KEK WITH A CRYSTAL CONVERTER

THE EXPERIMENTAL LAY-OUT



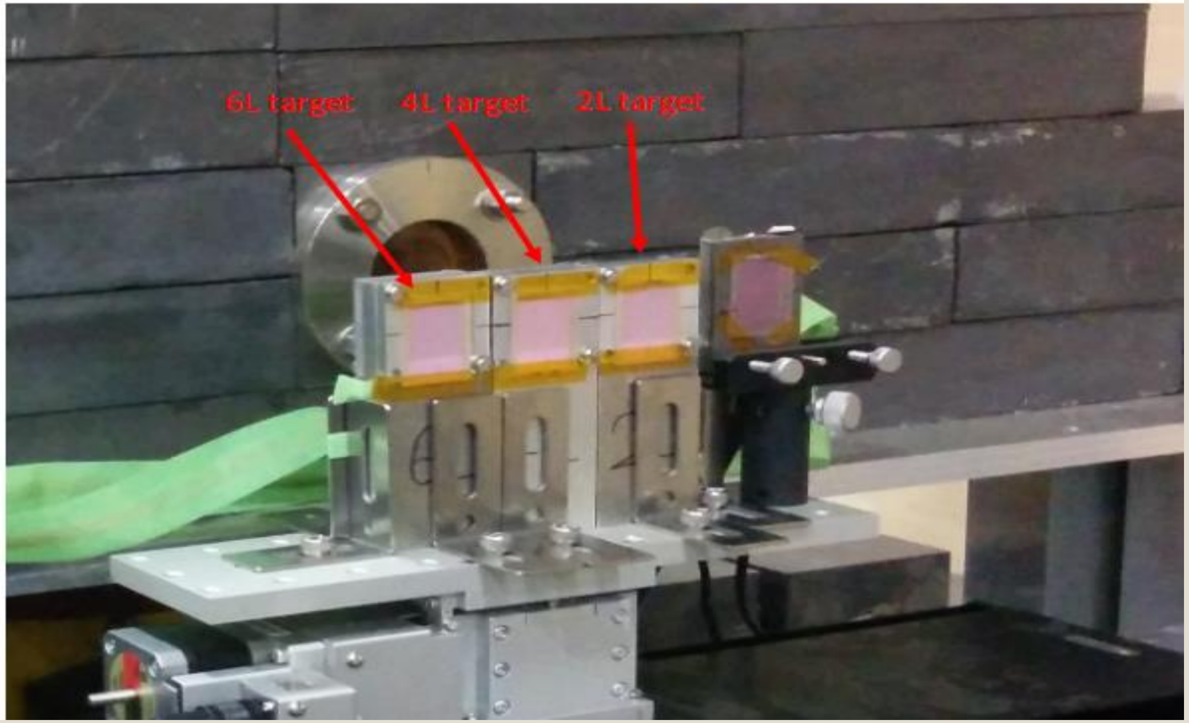
Drawing from Y.Uesugi et al.NIMB 319(2015)17

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

4-4-2 KEK EXPERIMENT

INSTALLATION OF THREE GRANULAR TARGETS AT KEK

- Automatically switch between different targets
  - Without stopping the beam and have an access
  - Different thickness (2,4,6 or 8) Layers



Courtesy of Hayg Guler

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

4-4-2

- TEST OF THE HYBRID/GRANULAR SOURCE AT KEK: EXPERIMENTAL CONDITIONS
- * EXPERIMENTAL CONDITIONS:
- E^-=7 GeV; single bunch (f=1 to 50 Hz); q(bunch) = 1-2 nC;
- Emittance (norm)~ 150(H)/63(V) π mm mrad; beam divergence< 0.1 mrad
- Crystal W: 1mm thick, <111> orientation
- Granular targets: 4, 6 and 8 layers; Compact target: 8 mm thick
- All amorphous targets on a translation stage; also for the γ detector
- Temperature rise on the converter :➔ thermocouples

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- DETECTION OF PHOTONS AND POSITRONS
- * PHOTON DETECTION
- ➔ Crystal alignement using a photon detector [CVD diamond 500 µm thick, 4x4 mm^2] with a potential of 400 V on electrode for charge collection.; the other electrode connected to Lecroy scope.. Weak interaction efficiency but enough γ rays (> 10^{11}).

  * POSITRON DETECTION

  ➔ After the bending magnet analyzer, a Cherenkov counter (Lucite, 5 m thick)

  Four values of E^+ chosen for data taking : 5, 10, 15 and 20 MeV.

  * TEMPERATURE MEASUREMENT

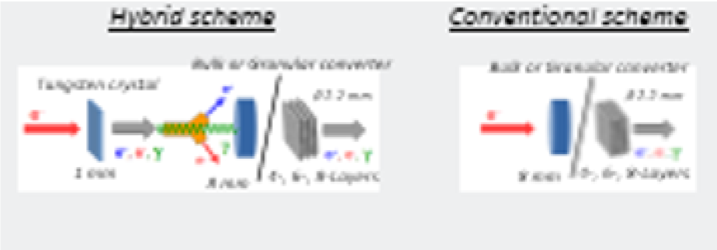
  ➔ Thermocouples with an area < 1 mm^2 glued on the spheres of the last layer (or bulk converter exit face); epoxy thermal conductive paste, used. The dynamical range for thermocouples: [0 to 100 °C]

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTERS

- **4-4-2 RESULTS ON GRANULAR CONVERTER AT KEK**

RESULTS ON POSITRONS: POSITRON YIELD

The positron yield has been measured for 4 values of the positron energy (5, 10, 15 and 20 MeV). Comparisons with simulations have been carried out. On the figure, we show results for a 6-layer granular and a 8 mm bulk converters.



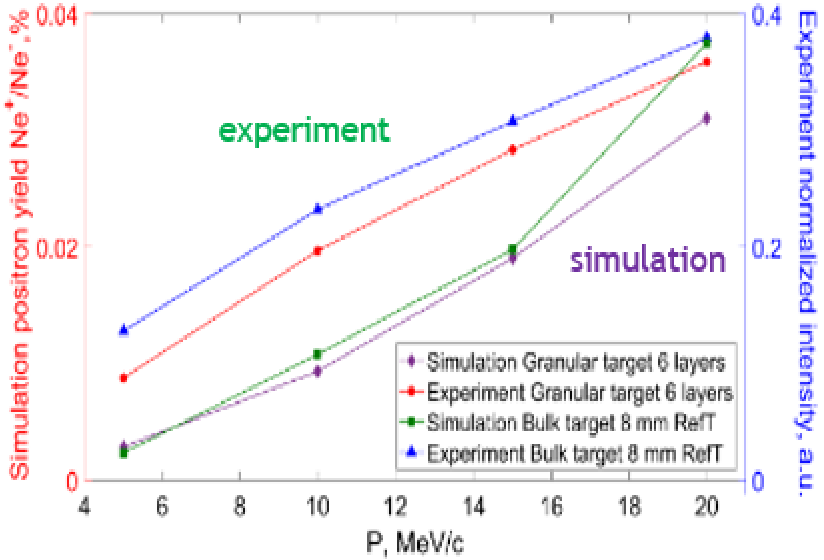


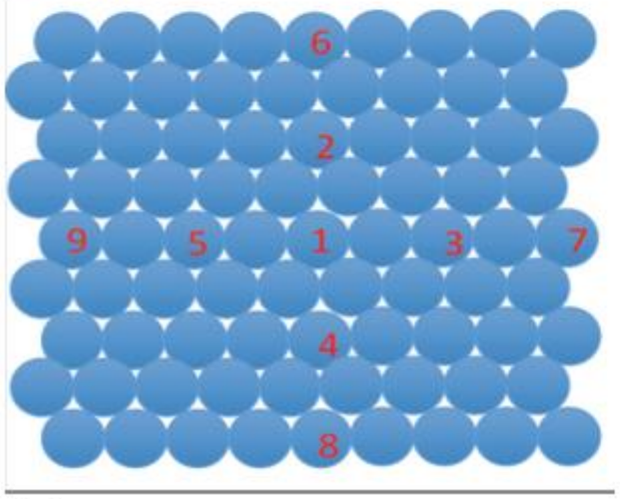
Figure 5: Momentum dependence of the positron yield in the conventional positron production scheme for the 8 mm thick bulk and 6-layers granular targets.

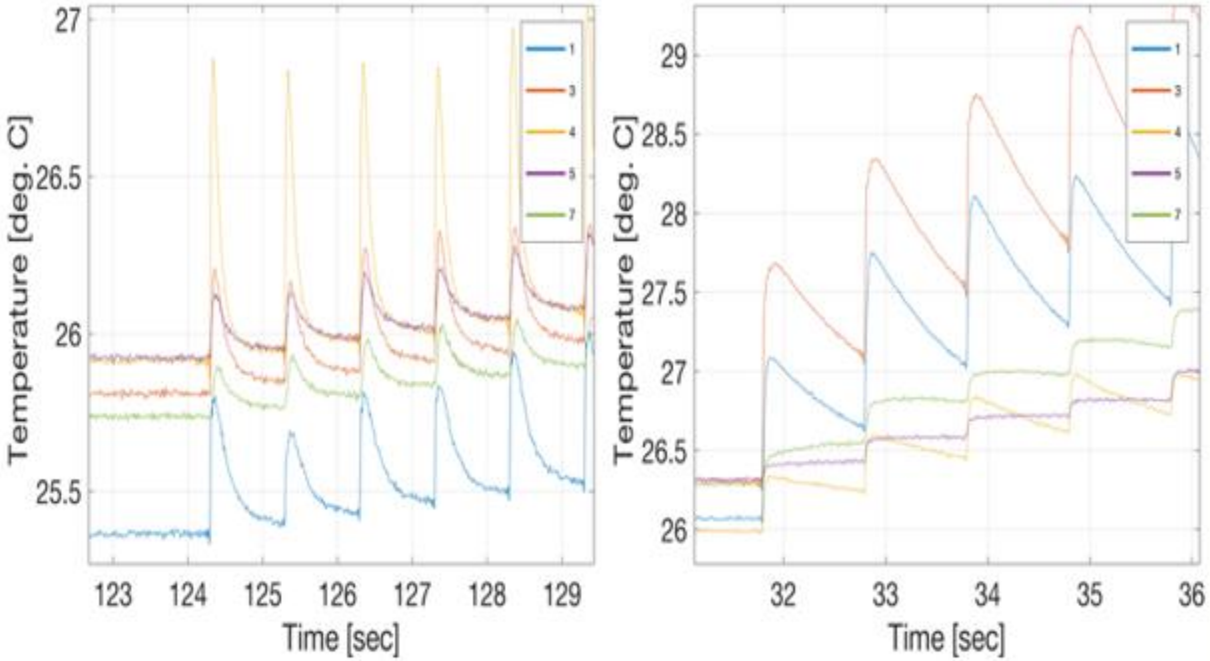
R.Chehab/POSIPOL2017/BINP

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

4-4-2 ▶ **TEST AT KEK: TEMPERATURE MEASUREMENTS**

- Temperature rise bunch per bunch(1Hz)
- on some W spheres and on bulk converter.
- Different colours→Diff. thermocouples.
- PEDD derived from the temperature rise
- on the central sphere of
- the exit face.

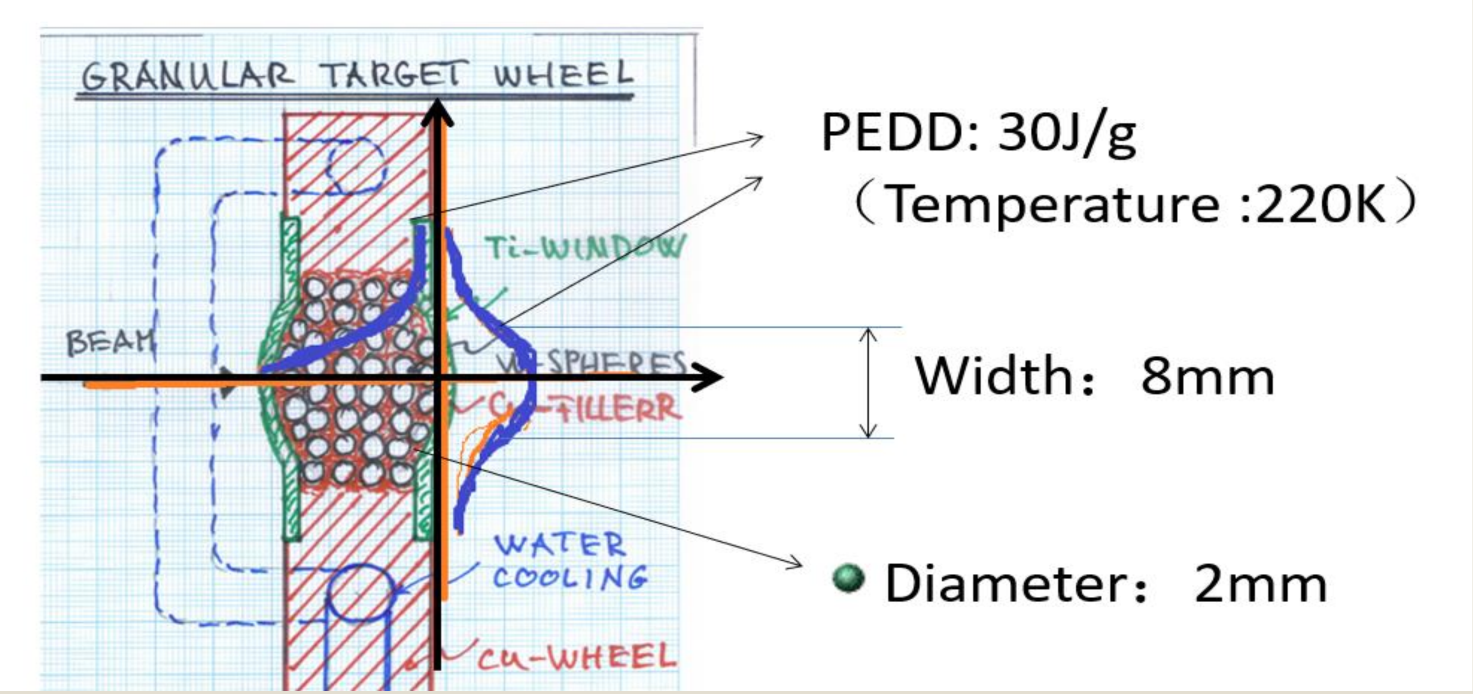




Bulk converter/8mm Granular 6-layers

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

- 4-4-3 HEATING/COOLING OF THE CONVERTER
- In order to move off the heat from the granular converter a cooling system must be considered:
- - He gas circulation between the spheres (see next slide)
- - Water cooling:



- In any case the windows
- Be or Ti must be checked
- concerning the PEDD

Scheme from Peter Sievers (CERN)

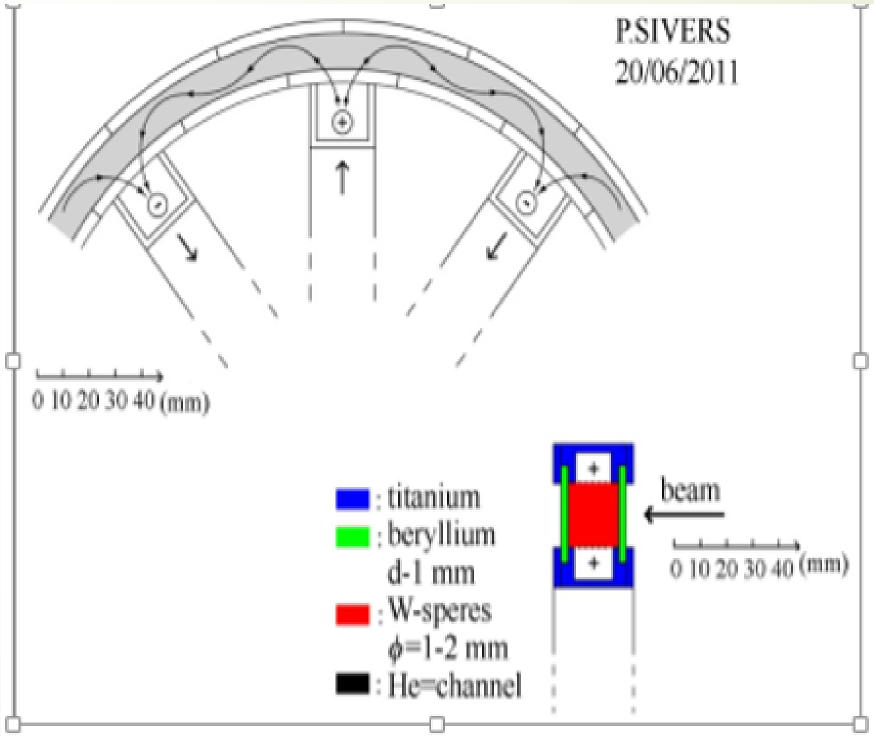
ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

4-4-3

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)

R.Chehab/Hybrid/POSIPOL-18



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

The wheel is containing W spheres with Be windows; a He gas is circulating between the spheres for cooling

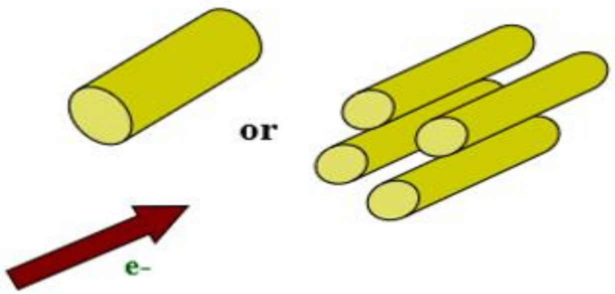
ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

- OTHER POSSIBLE CONVERTERS

5--

(b) The wire target; in order to limit the important multiple scattering in large transverse size and thick targets and to allow low energy positrons to leave the target without being absorbed before the downstream edge of the target, wire targets have been proposed (R.Miller et al, 1990). In these targets, positrons are allowed to emerge from the sides. For SLC beam (33 Gev incident) one mm diameter and 10 Xo long W wires showed promising results (3xyield) [calculations by R.Miller et al]

Similar conclusions were derived from a recent study (N.Shul'ga, 2006)



Appropriate focusing device is foreseen. The better collection is due to lower transverse momenta.

Such converter can be used, associated to a crystal-radiator, in an hybrid system :problem➔ needs large aperture Matching system

Thin rod converters are considered as a solution for FCC positron source (see N.Vallis, injector workshop, Frascati, april 2023)

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

- 6- SUMMARY AND CONCLUSIONS
- * Channeling radiation is a promising intense source of photons for electron-positron conversion
- * Preservation of crystal qualities leads to thin crystals associated to thick converters ➔ hybrid sources
- * Hybrid sources with granular converters are more interesting, because:
- - heat dissipation with small spheres is better (~1/R)
- - stresses are reduced when the time needed to the stress wave to cross the target is lower than the
- beam pulse heating : easily reached with small sphere radius.
- * Granular targets have been built at LAL/IJClab- Orsay, installed at KEK and tested➔ interesting results
- * With granular targets made of small spheres it is easier to derive the deposited energy ΔE from the temperature rise ΔT and to access, with some approximation, to the PEDD value. (system quasi-isolated)

BACK UP SLIDES

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

RELIABILITY- ACTIVATION OF THE TARGET

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 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).

ADVANTAGES OF HYBRID POSITRON SOURCES WITH GRANULAR CONVERTER

RELIABILITY: ACTIVATION OF THE TARGET (2)

For electron triggered targets, the bremsstrahlung photons initiate the (γ, n) process; Concerning the hybrid targets, the process is generated by the photons created in the crystal. The neutron yield is expressed in $n.s^{-1}.kW^{-1}$ .The power of incident beam being expressed in kW. As an example, in the case of a 6 GeV e- beam incident on a thick heavy target (Pb), the neutrons with $E_n < 25$ MeV are about 3 times more numerous than for $E_n > 25$ MeV

Simulations for the hybrid source as for the source surroundings must be undertaken.

We may notice that tungsten (collimators) and stainless steel (shielding) are highly susceptible of activation w.r.t. copper (cavities)

Simulations on the neutron yields, for the FCC-ee hybrid positron source have been worked out by M.Soldani for his Phd thesis: yields about 0.3 n/e- were found for: E- = 6 GeV; crystal 2 mm; amorphous 11.6 mm; distance between targets 1-2 m). See M.Soldani thesis report