Development of Positron Source

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on behalf of the Positron Source collaboration
LAL / IPNL / CERN / KEK / IHEP

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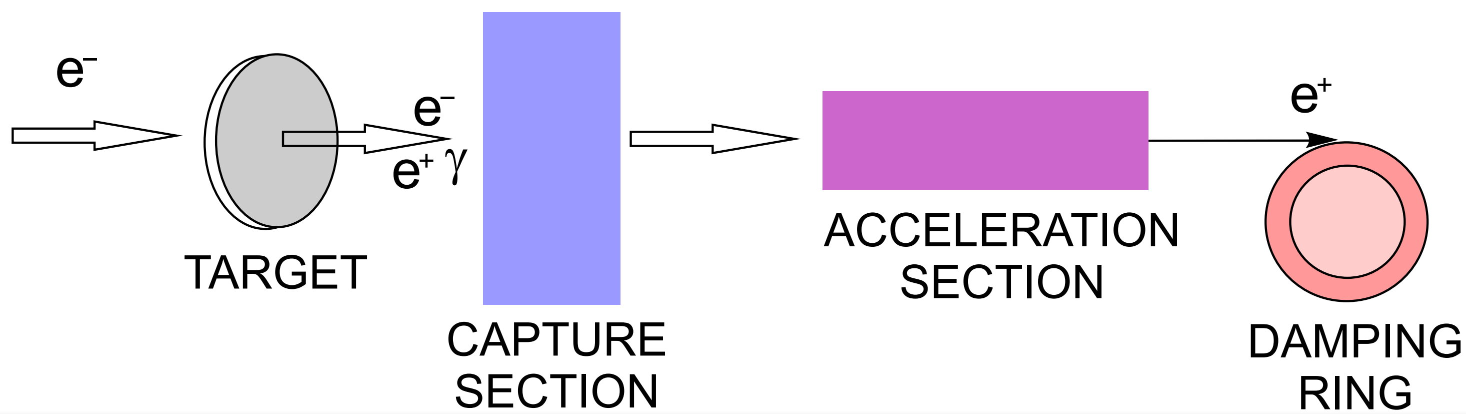
Outline

- Introduction
- e+ source using channeling / hybrid e+ source
- The hybrid e+ source with a granular converter
- Hybrid e+ source for the ILC and CLIC
- Experimental studies / test at KEK
- Summary and perspectives

Positron Sources

Conventional positron source: bremsstrahlung and pair conversion



Energy deposition in target => Heating
Inhomogeneous energy deposition =>
Peak Energy Deposition Density (PEDD)
=> mechanical stresses => target failure!

☞ Very difficult to realize for the future linear colliders due to the target thermal and mechanical stresses issues.

- SLC e+ source: ~ 3.5e10 e+/bunch & 1 bunch/train & 120 Hz => 0.042e14 e+/s
- CLIC e+ source: ~ 4e9 e+/bunch & 312 bunch/train & 50 Hz => 0.6e14 e+/s
- ILC e+ source: ~ 2e10 e+/bunch & 1312 bunch/train & 5 Hz => 1.3e14 e+/s

Positron sources

Better solution: Two-stage process to generate the positron beam.

First stage: γ-ray generation.
Second stage: e-/e+ and γ-ray beams are separated and the latter is sent to the target-converter.

Charged particles are swept off => the deposited power and PEDD are strongly reduced.

The γ-rays can be generated by the following methods:

- **Radiation from helical undulator**
- **Channeling radiation**
- **Compton scattering**

- **γ-rays produced by channeling effect in the oriented crystals can be used for the unpolarised positron source**.

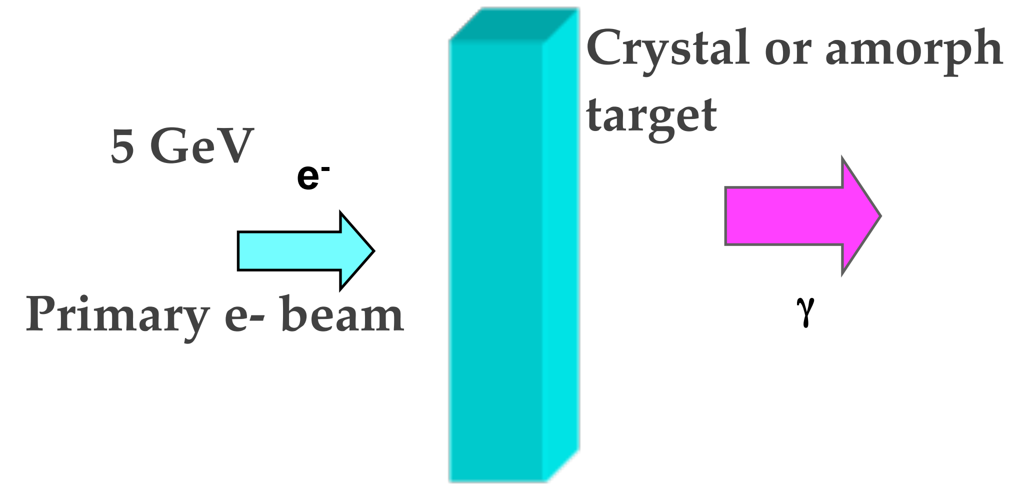
- **Polarized positrons** can be obtained by using polarized γ rays produced in helical undulator or in Compton scattering.

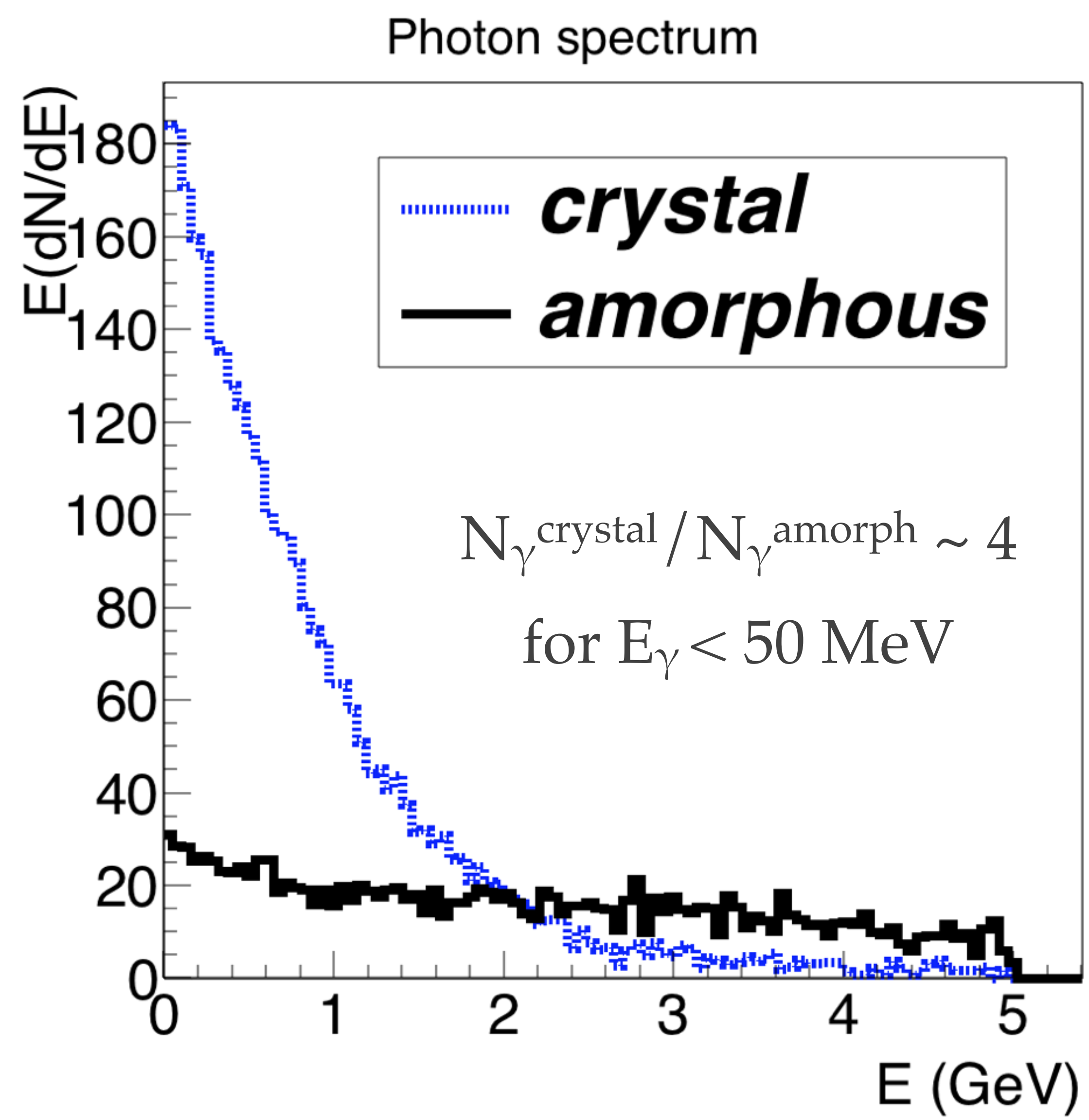
Background

- e+ sources are critical components of the future LC projects.
- The main concern for all e+ sources is not only the yield but also the target **energy deposition** and the associated **PEDD (Peak Energy Deposition Density)**.
- Recent investigations led to the concept of a **hybrid source** using channeling radiation => **the deposited power and PEDD are strongly reduced.**

e+ source using channeling

- For targets of the same thickness there is an enhancement of the soft photons production in the crystal compared to the amorphous.
- Such effect is mainly due to channeling.
- The vertical scale is E.dN/dE. As bremsstrahlung spectrum has a 1/E behaviour it exhibits an almost constant dependence.
- The soft photons create the soft positrons => easier capture by matching devices.

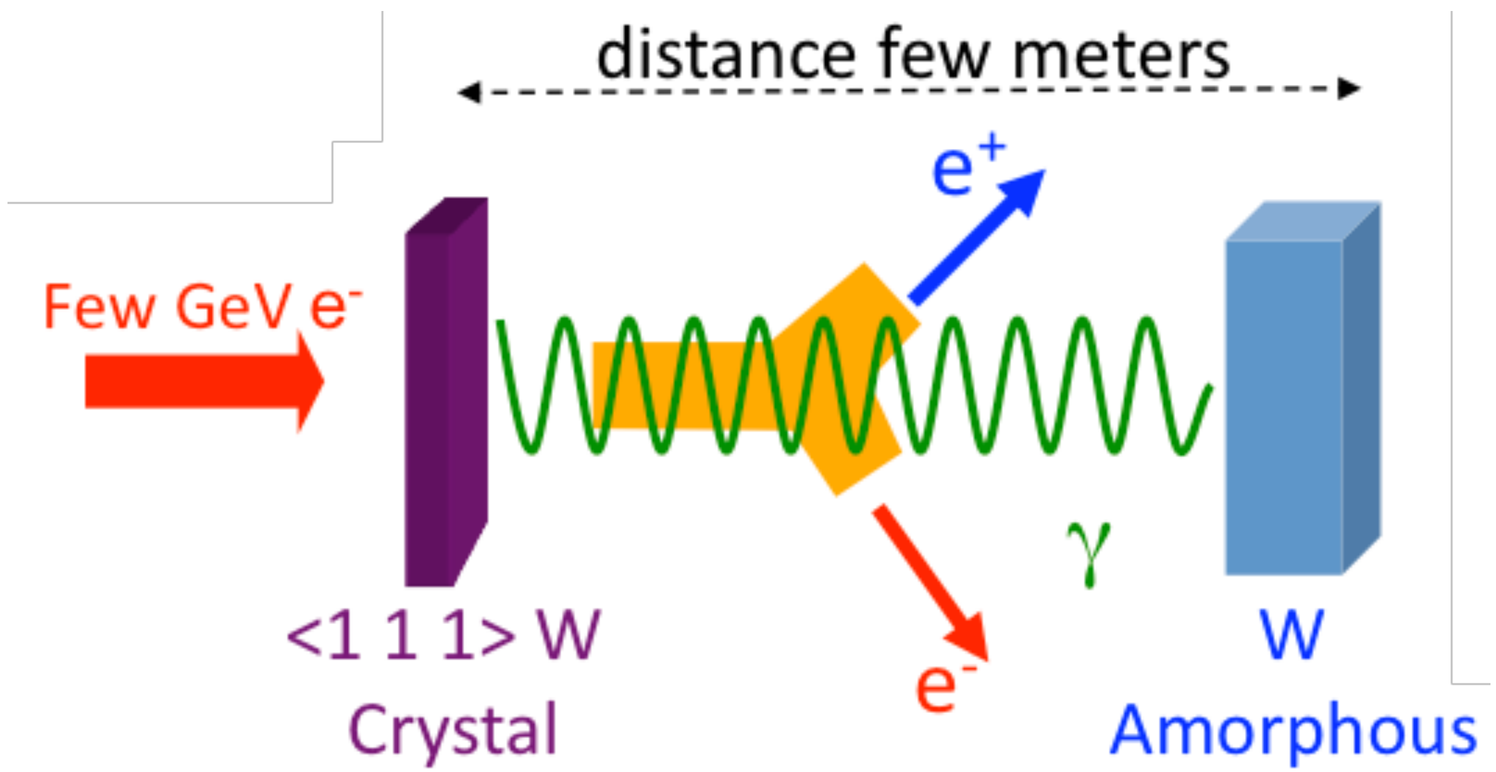




Hybrid e+ Source

Originally proposed by R. Chehab V. Strakhovenko and A. Variola. **A baseline design for the CLIC positron source.**

- Hybrid scheme is based on a relatively new kind of e+ source using the intense radiation emitted by high energy (some GeV) electrons channeled along a crystal axis => **channeling radiation**.
- Channeling radiation in axially oriented crystals is a powerful source of photons => useful to produce the high intensity e+ beams.



There were several experiments to study the hybrid e+ source (proof-of-principle experiment in Orsay, experiment WA 103 @ CERN and experiment @ KEK).

e+ Source: CLIC Baseline

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

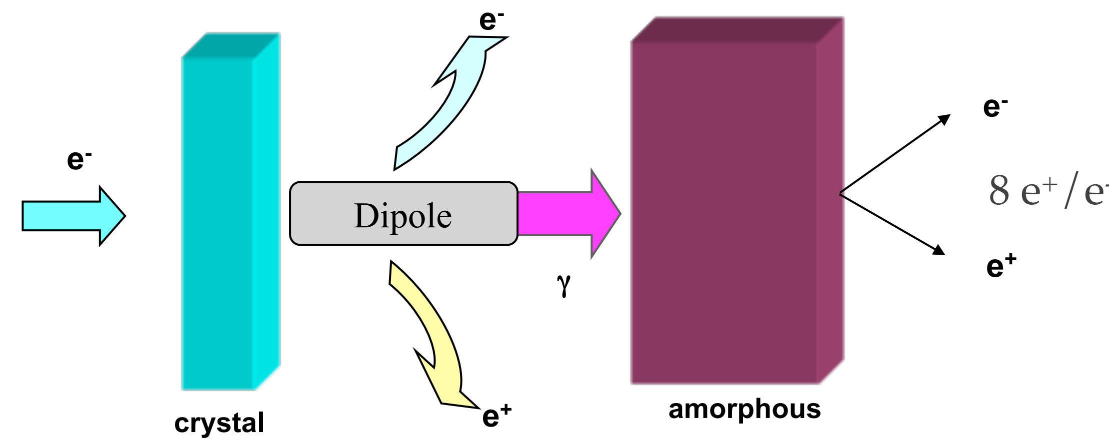
< 35 J/g

Distance (crystal-amorphous) d = 2 m

Primary e- beam

5 GeV

1.1×10^{10} e-/bunch



Crystal thickness: 1.4 mm

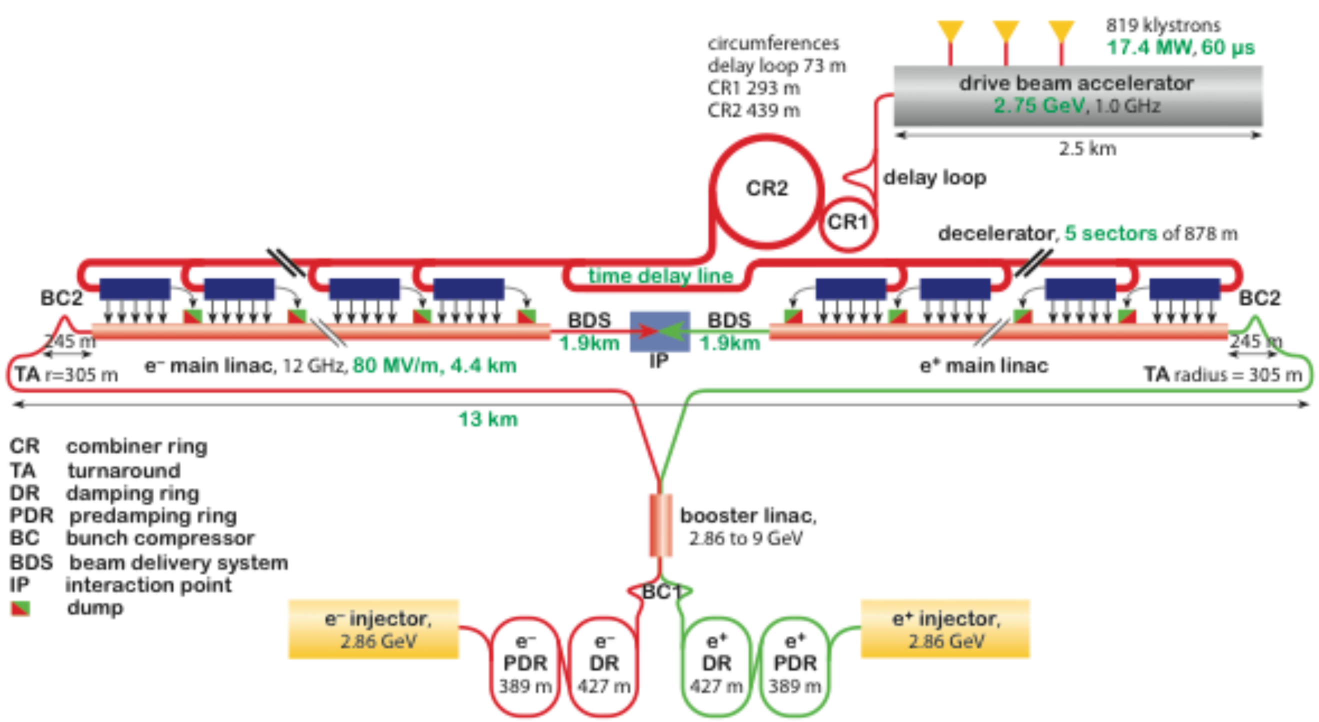
Oriented along the <111> axis

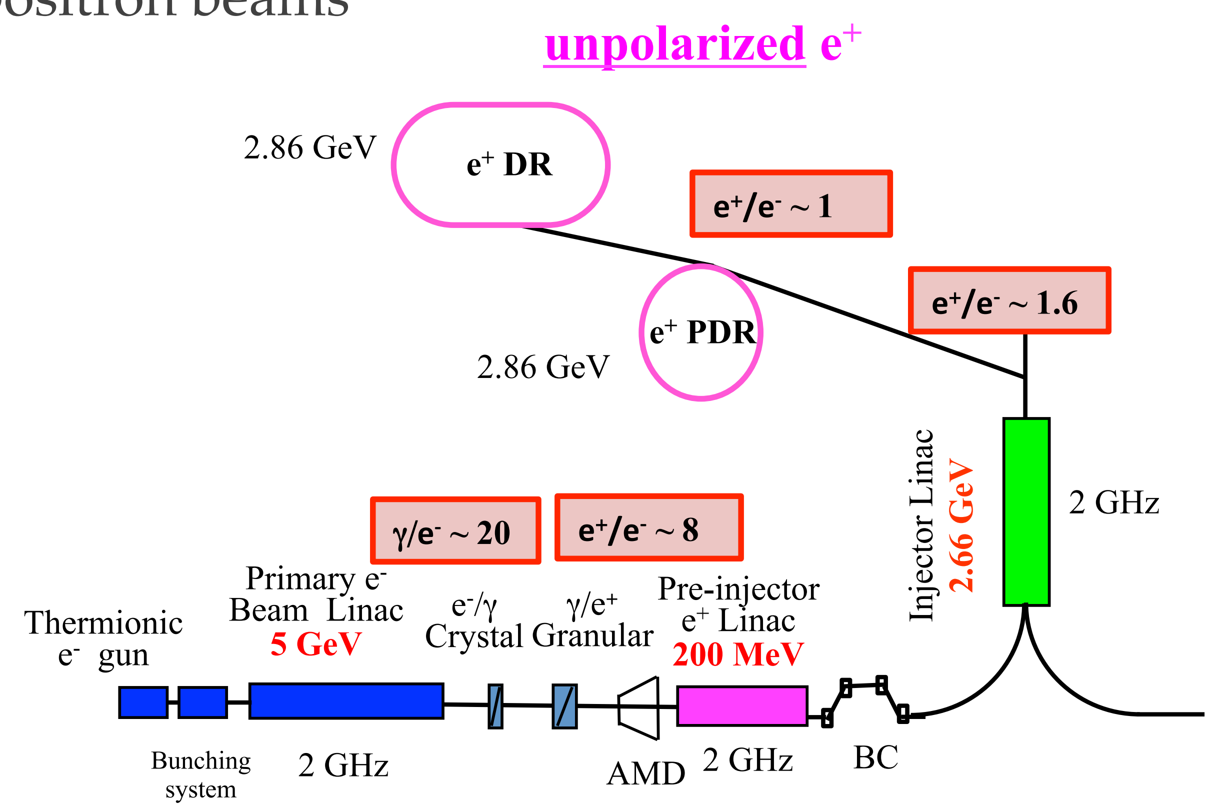
Amorphous thickness: 10 mm

Target-converter: easier to cool (under study at CERN), PEDD is well below the critical limit imposed by SLC target.

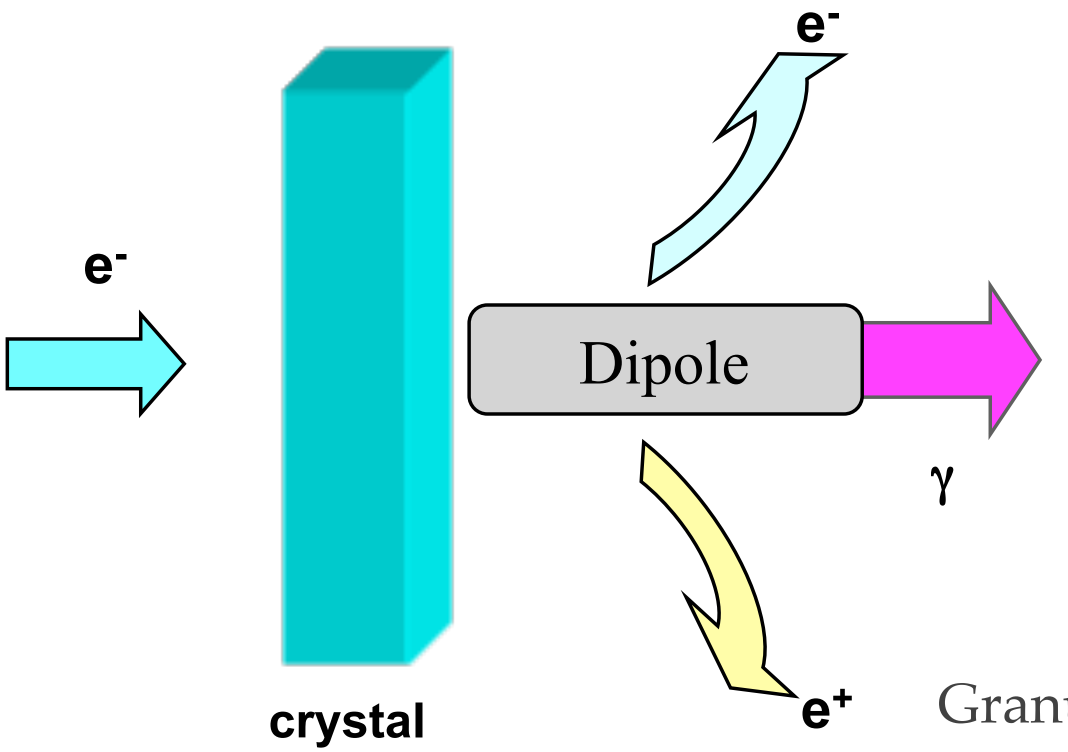
Yield: 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled!!!

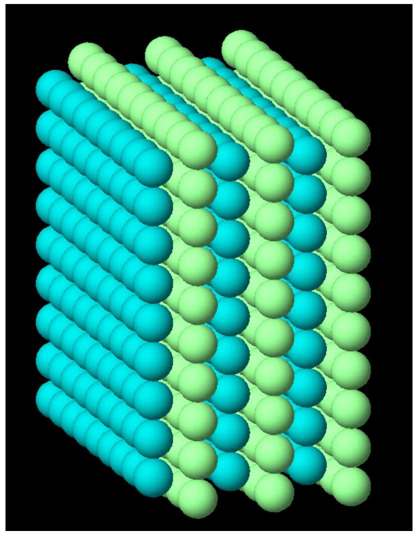
Separate injector complexes to produce electron and positron beams





Hybrid e+ source (granular converter)





Granular target-converter

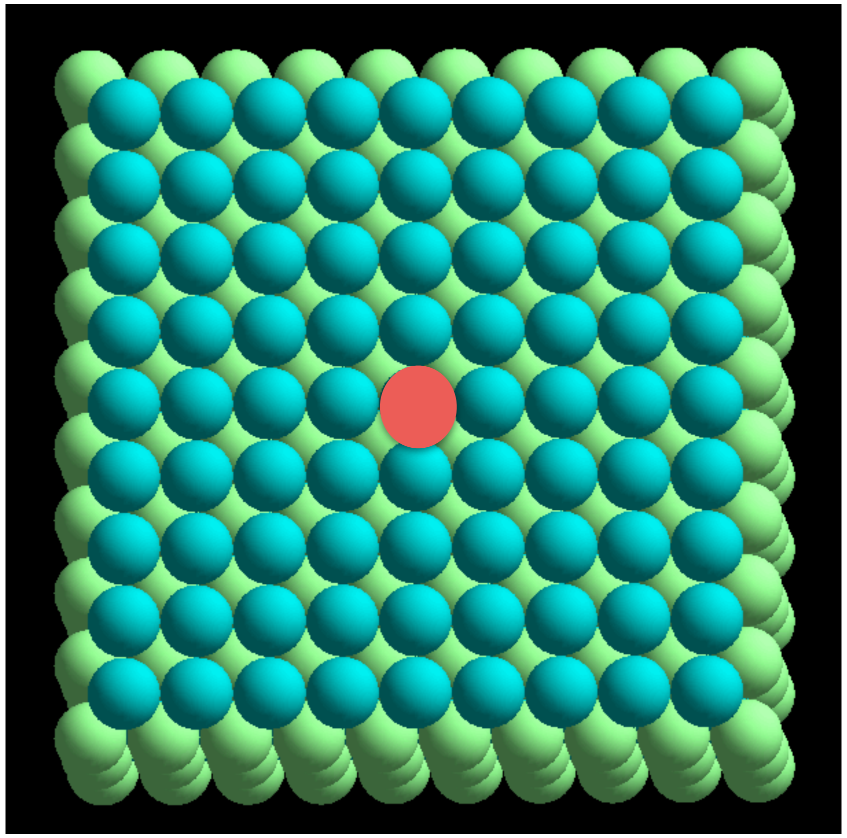
Recent idea: to replace the compact target-converter by a **granular** one made of **small spheres**.

Granular target can provide **better heat dissipation** associated with the ratio Surface / Volume of the spheres and the **better resistance to the shocks**.

P. Pugnat, and P. Sievers, Journal of Physics G: Nuclear and Particle Physics 29.8 (2003): 1797.

- The spheres are made of Tungsten material.
- Spheres R ~ a few mm.
- The spheres are arranged in staggered layers with alternation of the layers having even and odd number of spheres => more compact packaging with a central sphere at the converter exit.

Hybrid e+ source (granular converter)

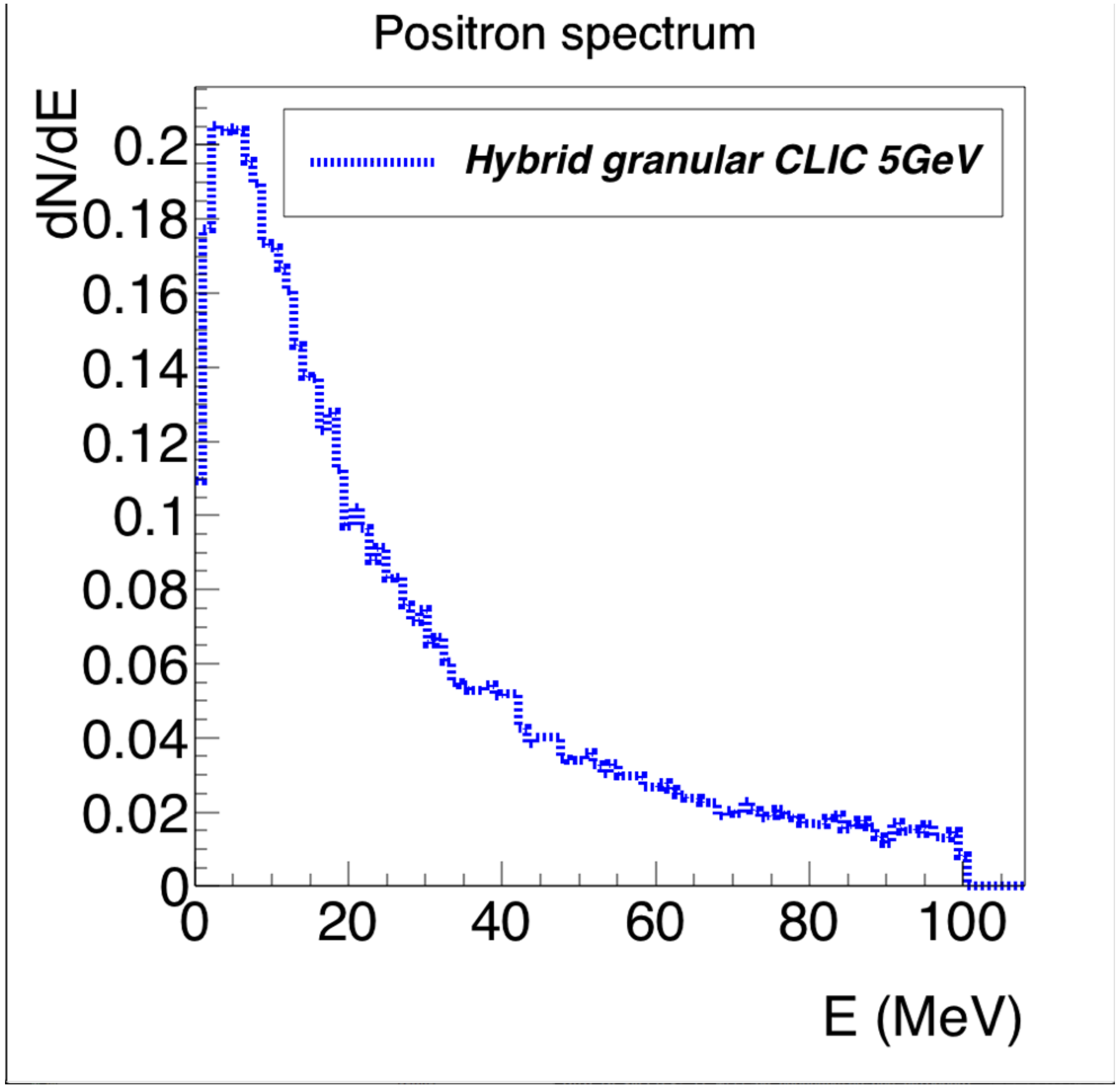


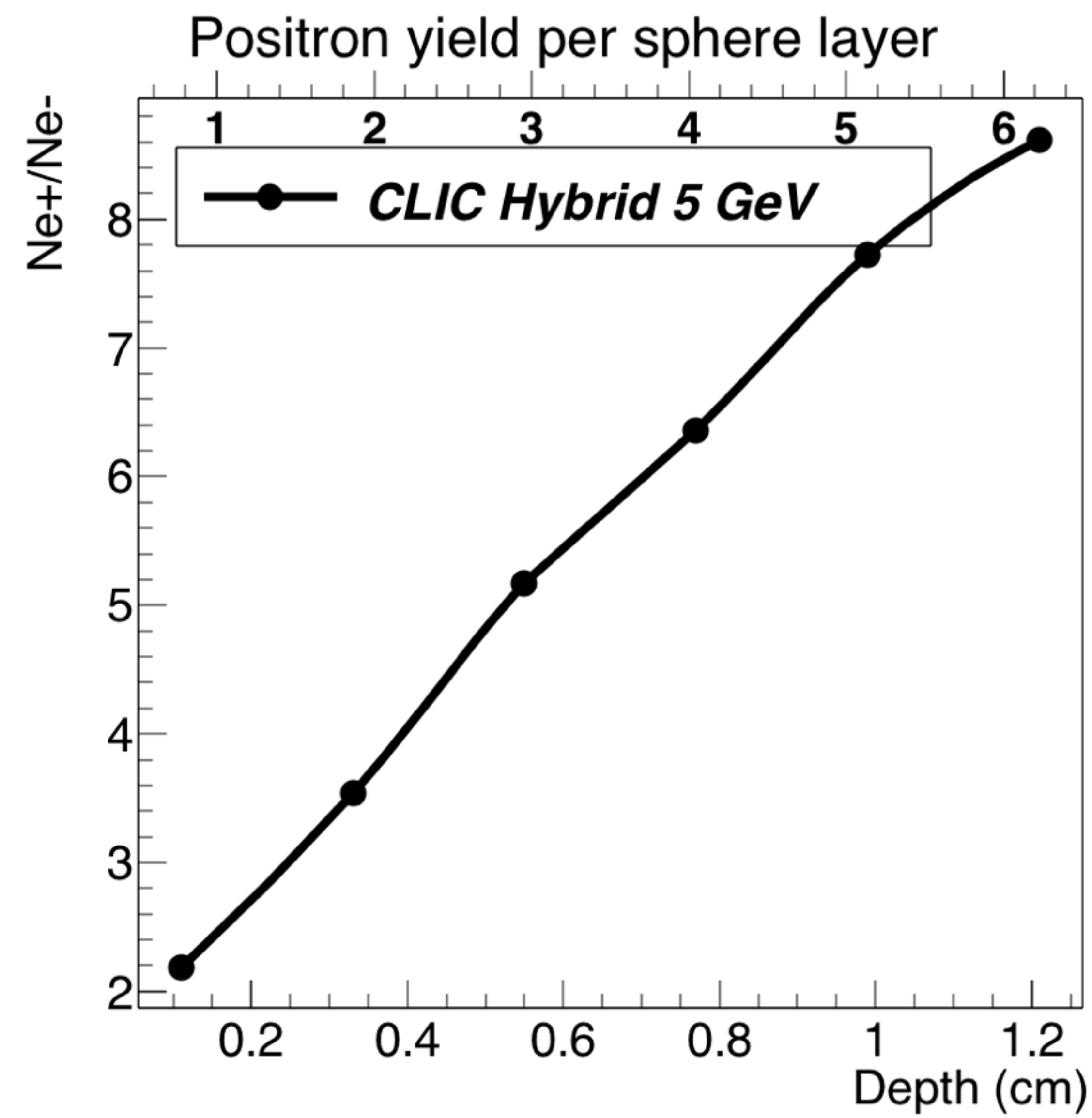
Simulations are carried out under the following conditions:

- Incident electron energy on the crystal is 5 GeV (CLIC) or 10 GeV (ILC) with the beam size of 2.5 mm rms.
- Granular target sphere radii are 1.1 mm.
- Distance crystal-converter is 2 m.

- The entrance face (for the photon beam) has an even number of spheres 10x10 spheres and the exit face has 9x9 spheres => a central sphere lies at the converter exit (maximum heating).
- From the energy deposited in the last central sphere we could derive the PEDD.

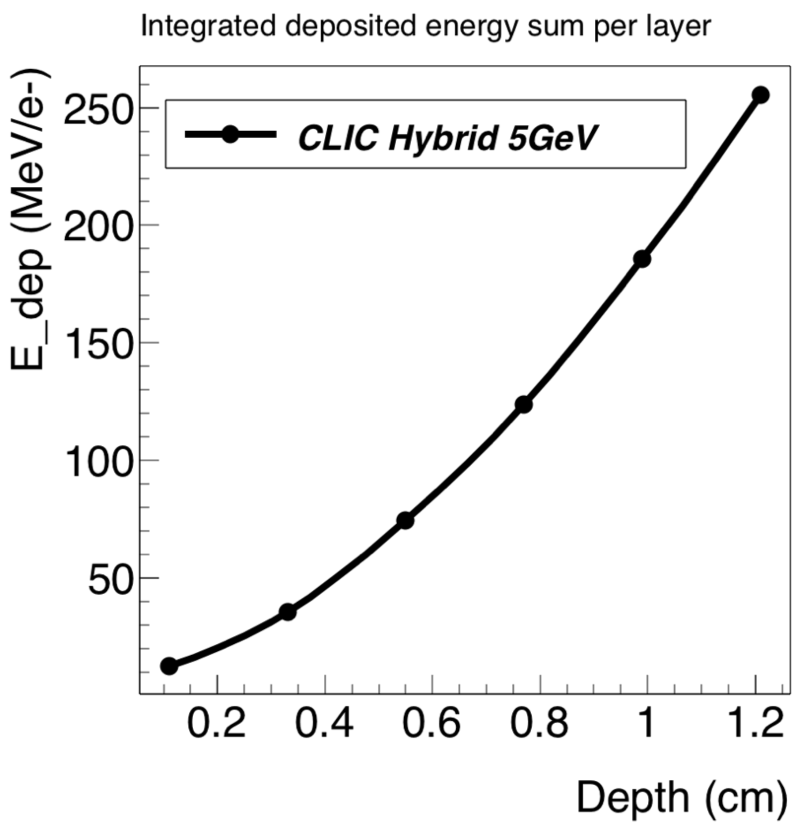
Simulation results (CLIC)

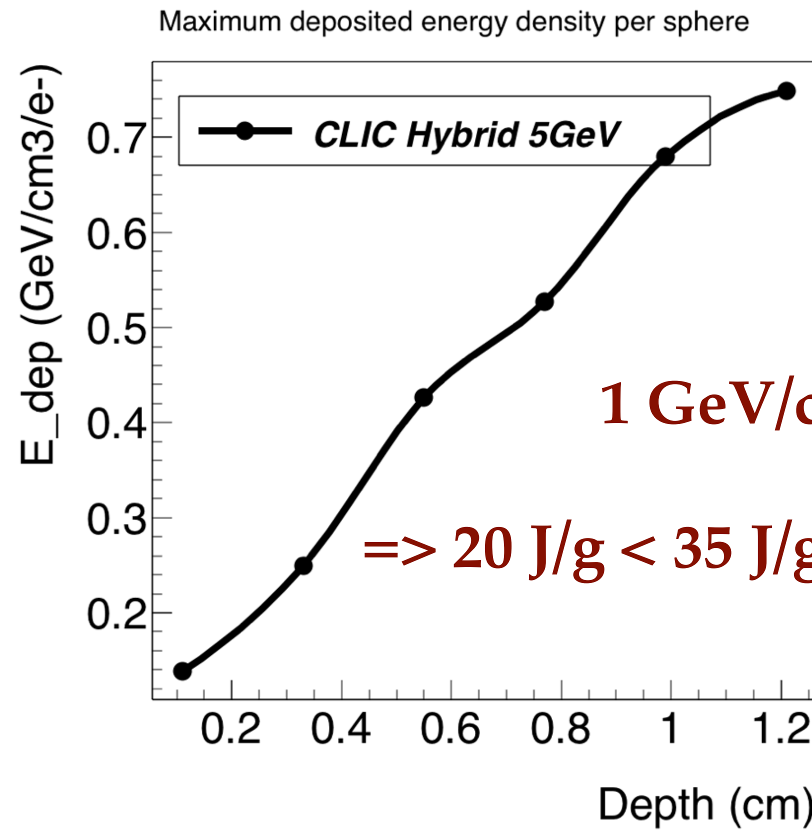




The positron spectrum for the granular target made of 6 layers and the yield integrated per layer are presented.

Simulation results (CLIC)



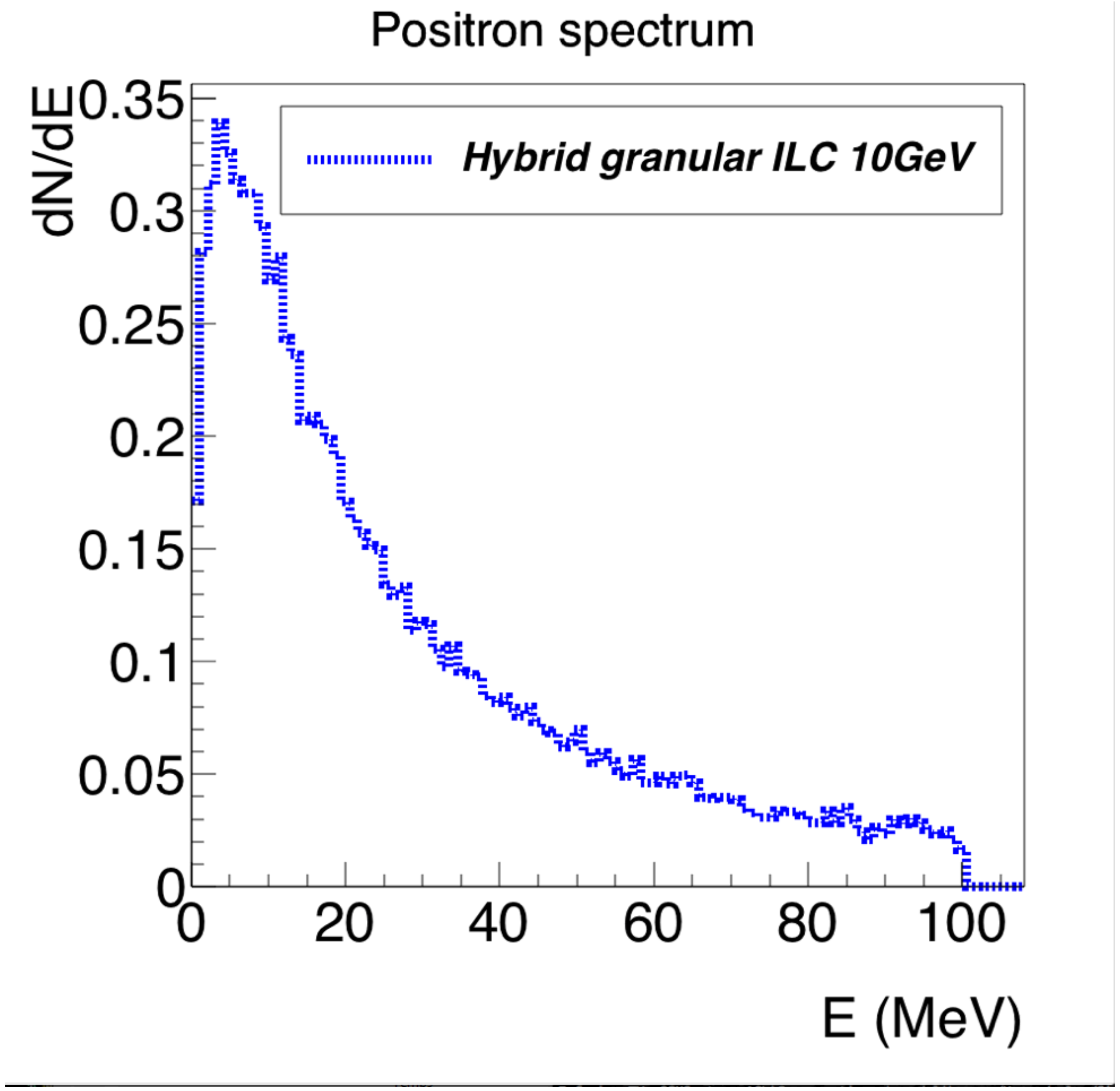


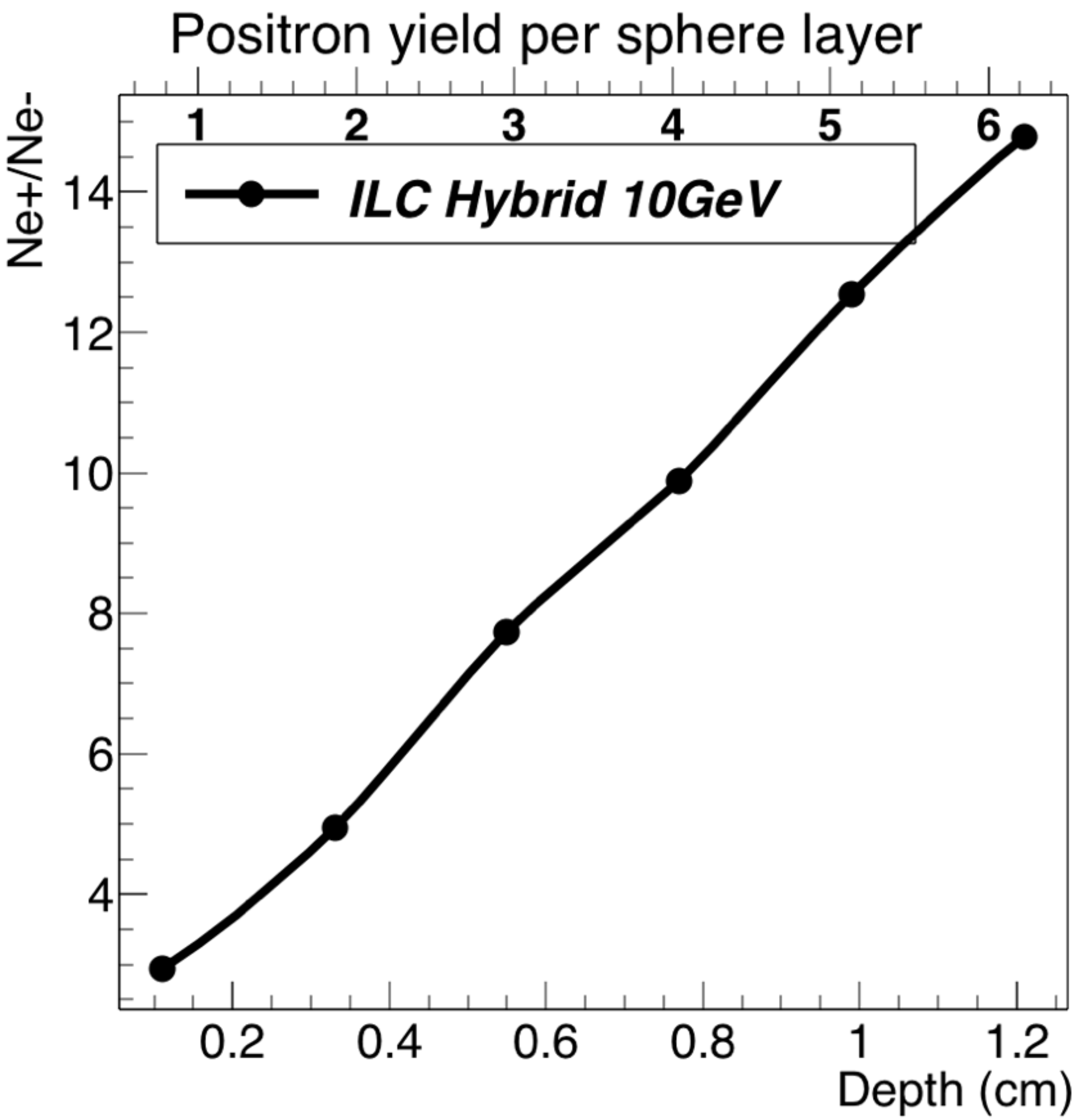
1 GeV/cm^3 = 8.3x10^{-12} J/g for W

=> 20 J/g < 35 J/g after 1 pulse of 312 bunches

- Deposited energy for the granular target integrated on the number of layers are presented.
- High inhomogeneous energy deposition => **Peak Energy Deposition Density (PEDD)** => mechanical stresses => target failure!!!
- To calculate the PEDD => energy deposited in the last central sphere.
- The deposited energy density calculated with the spheres of 1.1 mm radius represents a rather good approximation for the PEDD given the elementary volume issue (cf. X. Artru, et al., NIM in Physics Research Section B, 355 (2015): 60–64).

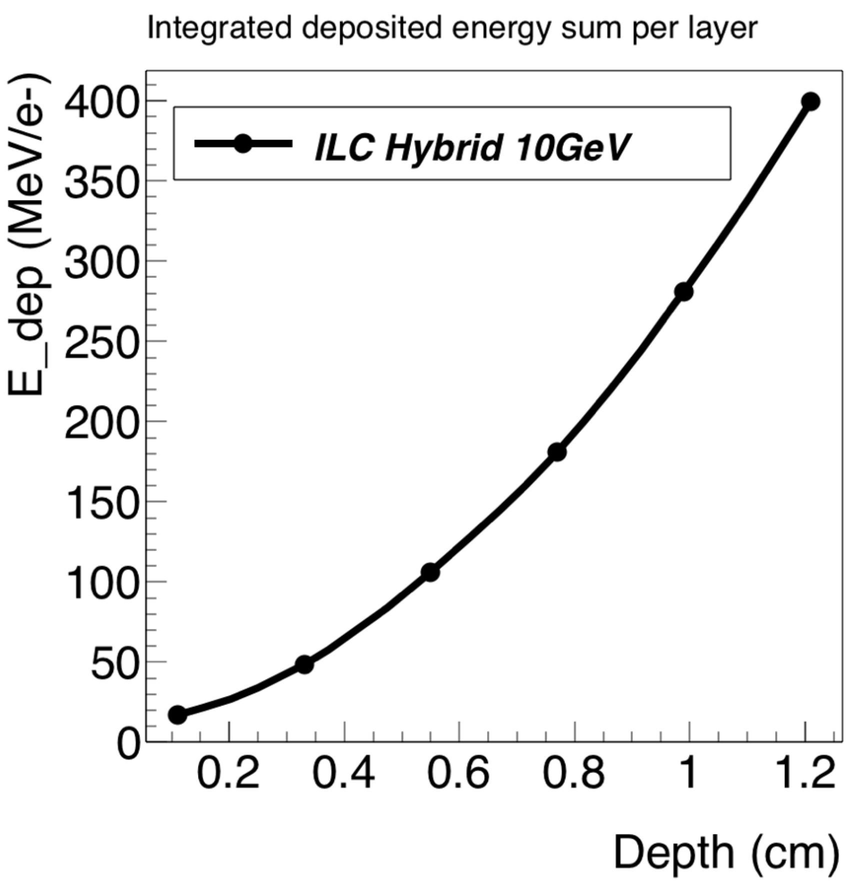
Simulation results (ILC)

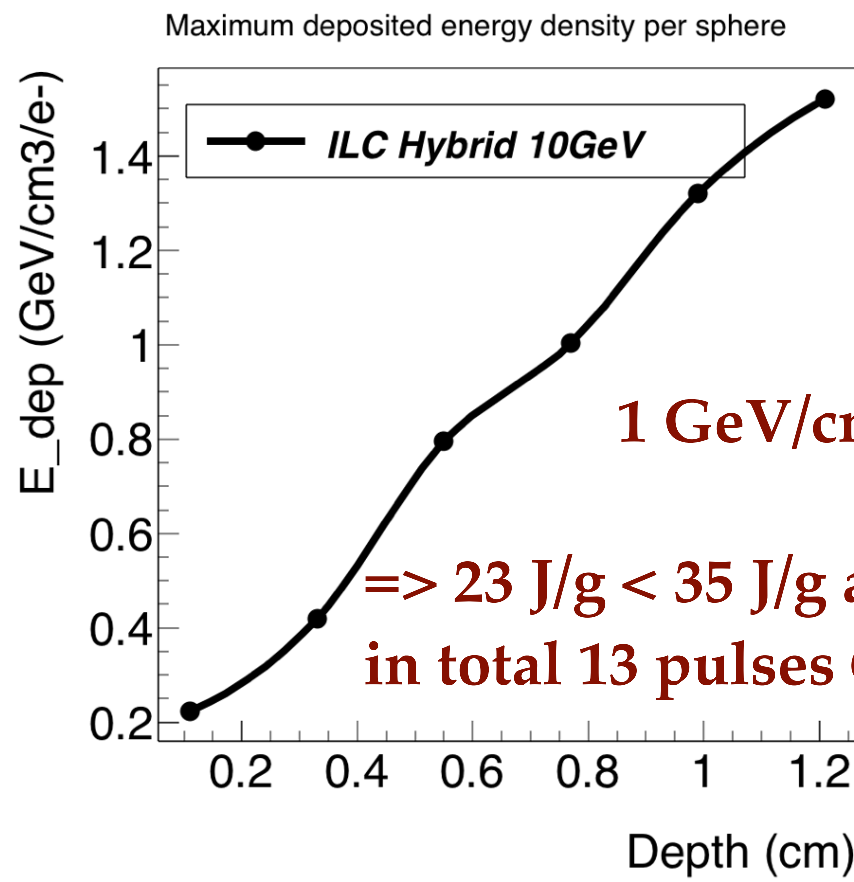




The positron spectrum for the granular target made of 6 layers and the yield integrated per layer are presented.

Simulation results (ILC)





1 GeV/cm^3 = 8.3x10^{-12} J/g for W

=> 23 J/g < 35 J/g after 0.6 μs pulse of 100 bunches in total 13 pulses @ 300 Hz

- Deposited energy for the granular target integrated on the number of layers are presented.
- To calculate the PEDD => energy deposited in the last central sphere.

Scheme for the ILC and CLIC

The simulation results for a hybrid positron source with a granular converter show (σ_{e-} = 2.5 mm):

CLIC case:

- Granular target: 6 layers
- Total positron yield of about ~8 e+/e-
- Deposited energy of ~250 MeV/e-
- Energy deposition density of about ~0.7 GeV/cm^3/e-

ILC case :

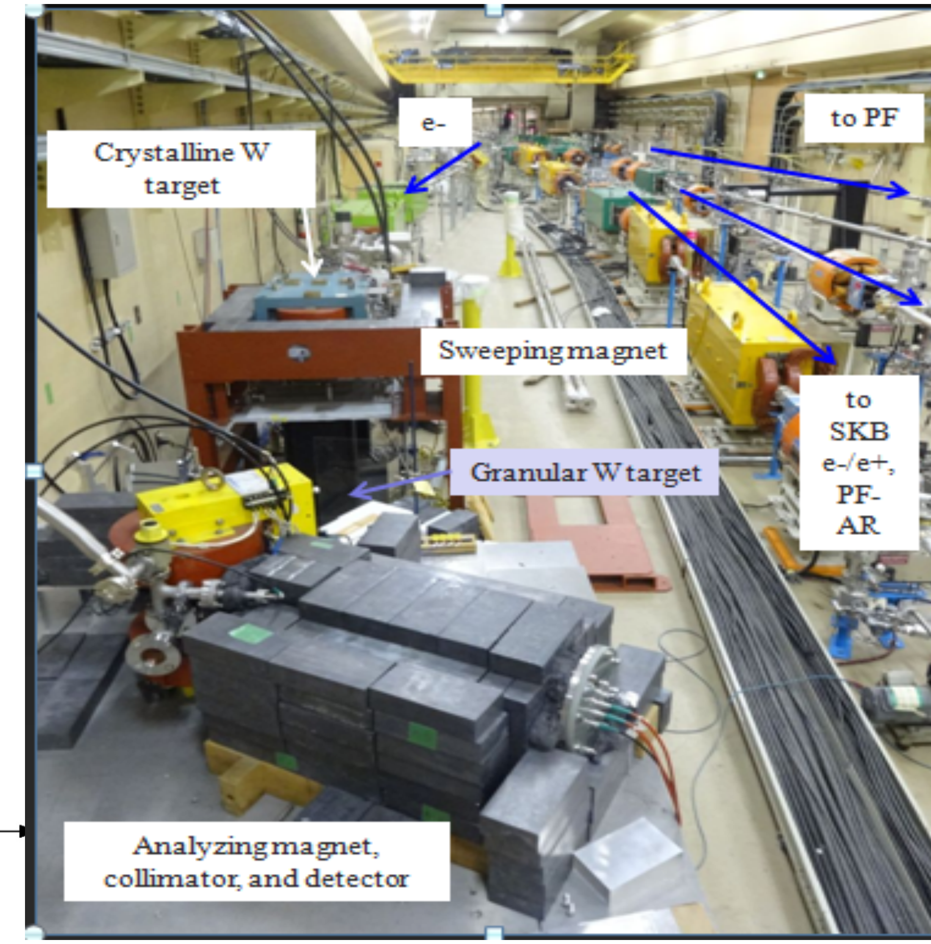
- Granular target: 6 layers
- Total positron yield of about ~14 e+/e-
- Deposited energy of ~400 MeV/e-
- Energy deposition density of about ~1.4 GeV/cm^3/e-

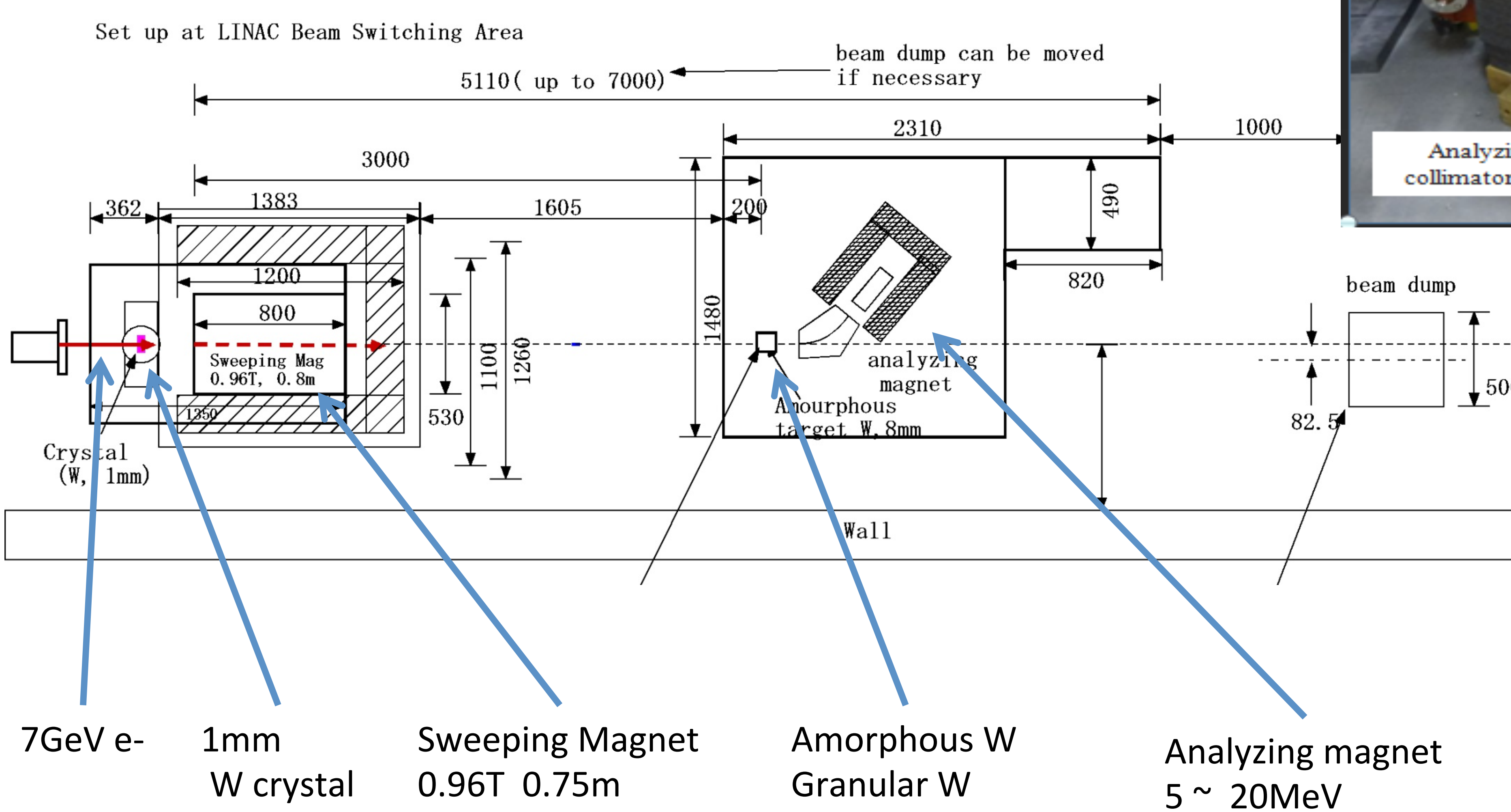
Hybrid Scheme: Recent Investigations

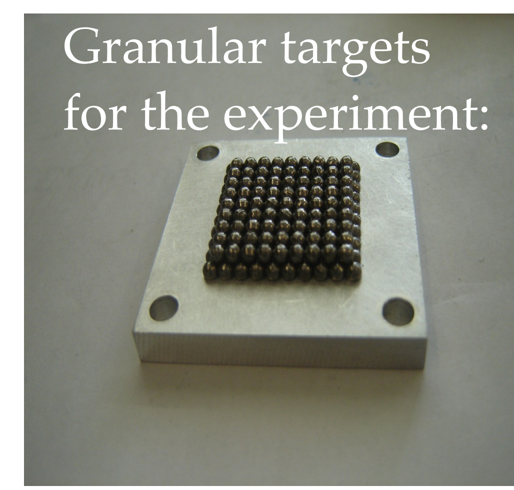
- Experimental verification and benchmarking of the granular target are necessary.
- The PEDD can be derived by measuring the temperature rise using thermocouples at the exit of the granular target. Can be made at lower than nominal beam intensities.
- Thermal shock: one would require tests with a nominal gamma beam and with the proper pulse duration of ~µs. Tests with equivalent electron or proton beams may also be possible.
- To ensure the target reliability and its ability to sustain the heat load and mechanical stresses => a dedicated model to evaluate the **static (effect due to accumulated pulses)** and **transient (one pulse)** regimes of the heat load (LAL/CERN/IHEP collaboration).

Beam Test at the KEKB linac

- Beam test took place last autumn at the KEKB injector linac to study the granular converter. Next one => this autumn (systematic studies).
- KEKB e- beam: E = 7 GeV, 1 mm rms, 1nC, 25 Hz.
- **<u>Goals:</u> e+ yield and temperature measurements to compare different target-converters => e+ source performances.**



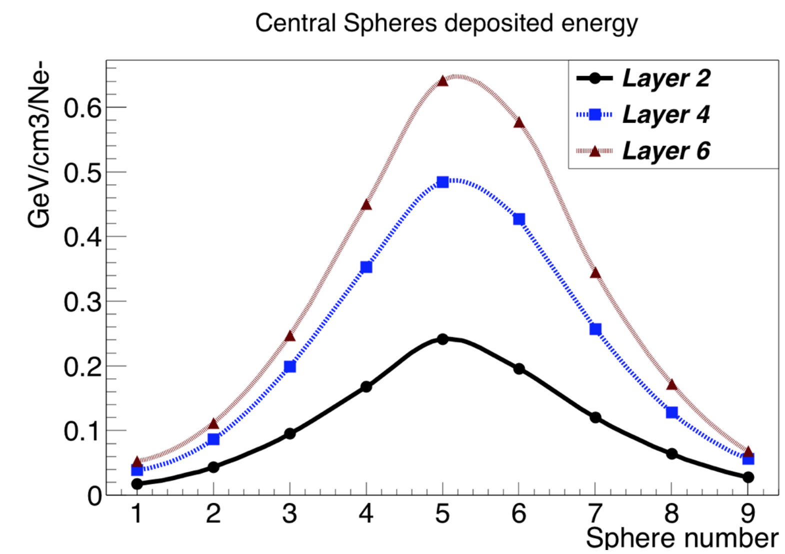


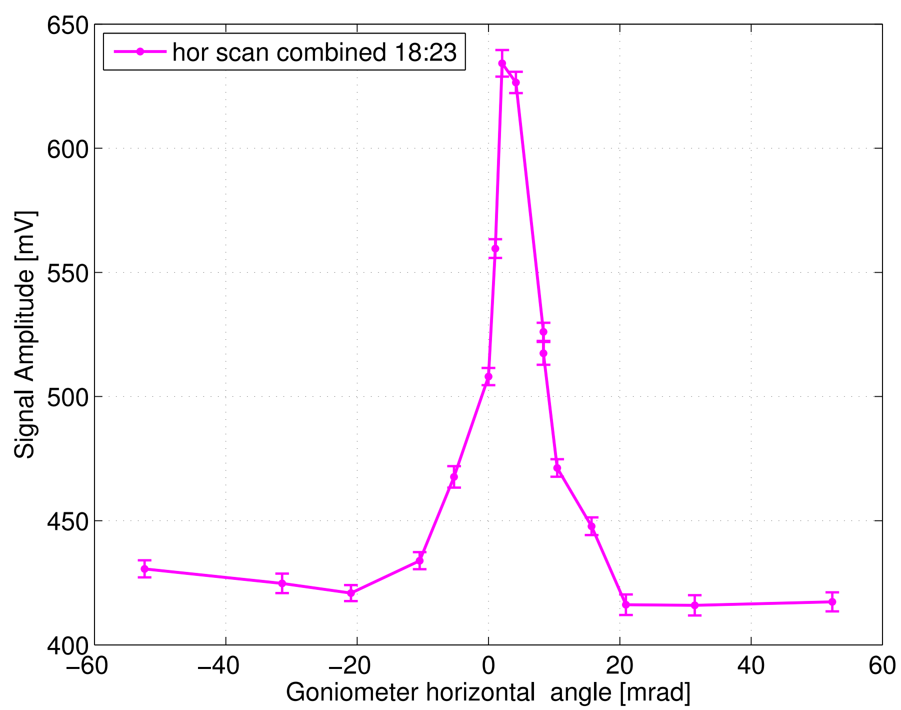


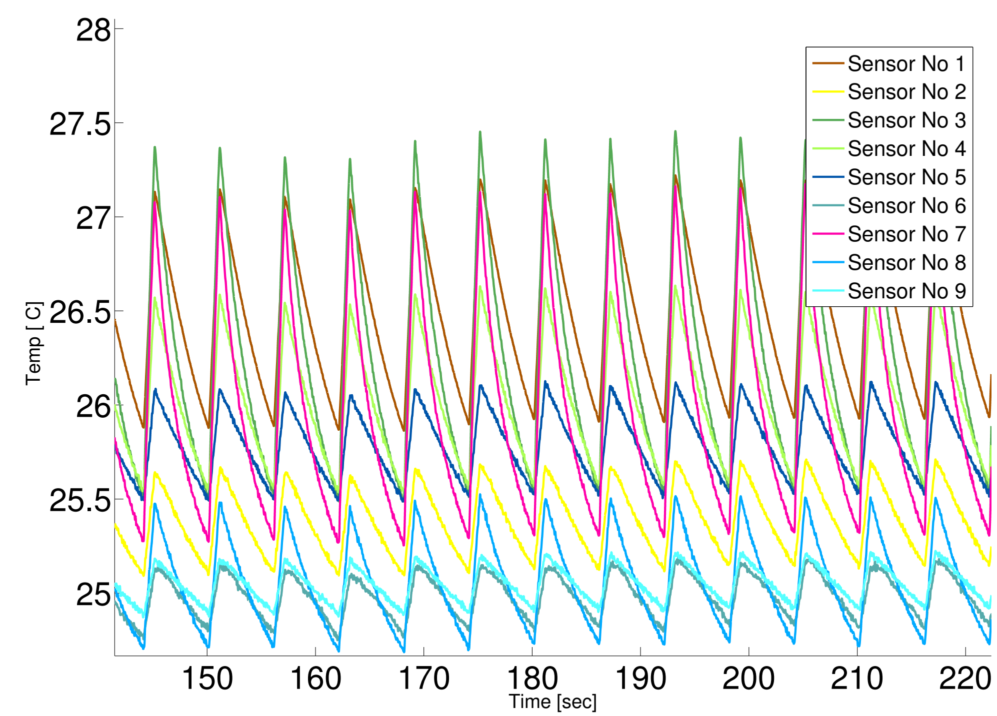
4 granular targets have been built (2, 4 ,6, 8 layers), spheres r=1.1 mm.

Preliminary Results

- Channeling axis is found using goniometer.
- Positron yield is measured by the lucite Cherenkov detector.
- Temperature measurement: 9 thermocouples on exit face of the granular target to measure lateral energy deposition density distribution along a central axis.







Simulations of the temperature distribution of the granular converter and thermal shocks are ongoing.

Data taken should improve our understanding on thermal load and heat dissipation in the target.

Summary and Perspectives

- Choosing a hybrid e+ source using channeling already meets the requirements of the ILC and CLIC.
- Replacing the compact converter with a granular one made of small spheres improves the heat dissipation, decreases the PEDD and provides better resistance to the shocks.
- Simulations of the temperature distribution of the W spheres and evaluations of the granular converter thermal shocks are ongoing in collaboration with IHEP.
- New design with a granular converter. Experimental tests are mandatory. The KEKB results are a major step towards understanding of the thermal load in the targets.

The 11th International workshop **POSIPOL** will be held in **Orsay** and hosted by **LAL**.

This workshop is mainly focused on the e+ sources and is addressed to the community working on the e+e- collider projects and on development of sources for industrial and medical applications.