Positron source

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Outline

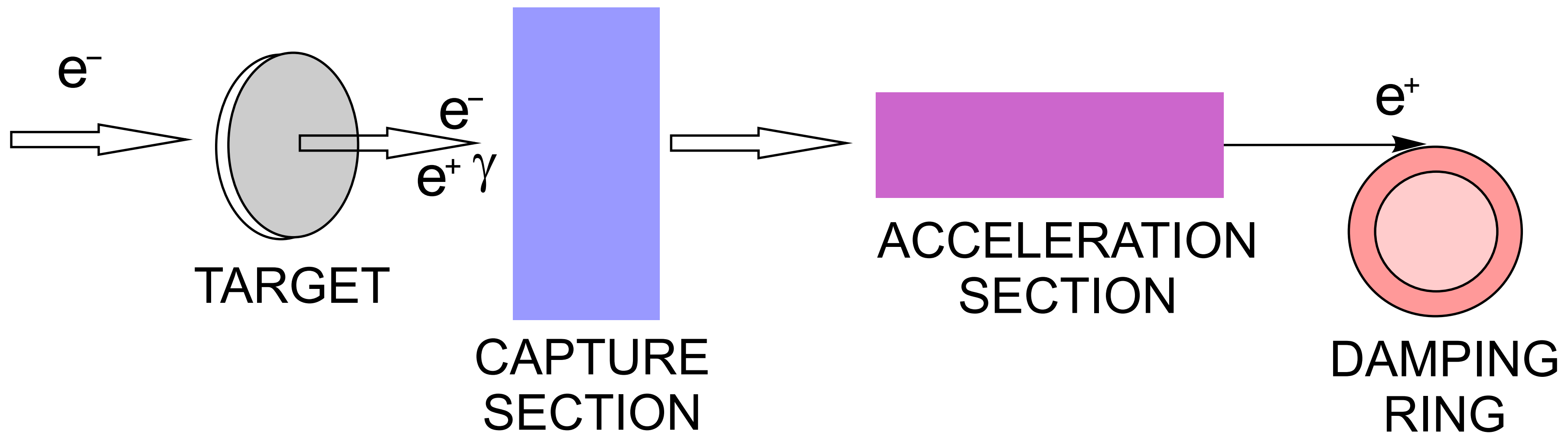
- Introduction: positron sources are critical components of the future Linear and Circular Colliders
- Hybrid positron source
- Positron sources for the ILC and CLIC
- Experimental test of hybrid positron source at KEK
- FCC-ee positron source
- Positrons for muons: LEMMA (Low EMittance Muon Accelerator) positron source

Background

- High intensity low emittance positron beams are required in HEP, especially by the future Linear and Circular Collider projects (ILC, CLIC, FCC…).
- It has been comprehensively analysed that having both beams polarized will increase precision of the measurements and provides versatile methods to search for New Physics.
- Polarized electron beams are more easily to obtain with e.g. AsGa photocathodes (~90% of polarization).
- Production of **polarized positron** beams **remains a challenge**.
- Strong efforts are put on the development of the high intensity unpolarized/polarized positron source for the future colliders.

Introduction

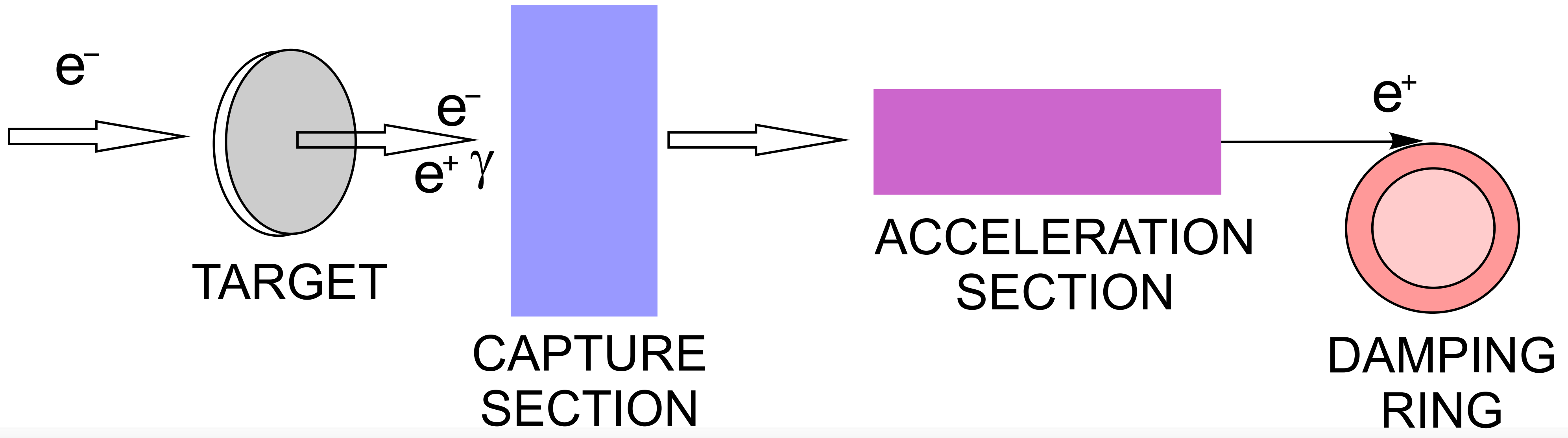
☞ Why e+ sources are critical components of the future linear/circular colliders?



- e+ are produced within large 6D phase space (e+/e- pairs produced in a target-converter).
- Thermo-mechanical effects in the target limit the e+ source intensity (sophisticated targets and cooling systems).
- e+ produced are transported and transferred to the DR with their phase space characteristics (transport and injection at high 6D emittance).
- High luminosity at the future machines => needs high average and peak e- and e+ flux.

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 (3 TeV) e+ source: ~ 4e9 e+/bunch & 312 bunch/train & 50 Hz => 0.6e14 e+/s
- ILC (500 GeV) e+ source: ~ 2e10 e+/bunch & 1312 bunch/train & 5 Hz => 1.3e14 e+/s
- LHeC (ERL) e+ source: ~ 2e9 e+/bunch & 2e7 bunches/s (CW operation) => 440e14 e+/s
- FCC-ee e+ source: ~4e10 e+/bunch in the collider & 3 kHz => 1.2e14 e+/s (only ~0.05e14 e+/s @ Injector)

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.

Positron Sources using channeling

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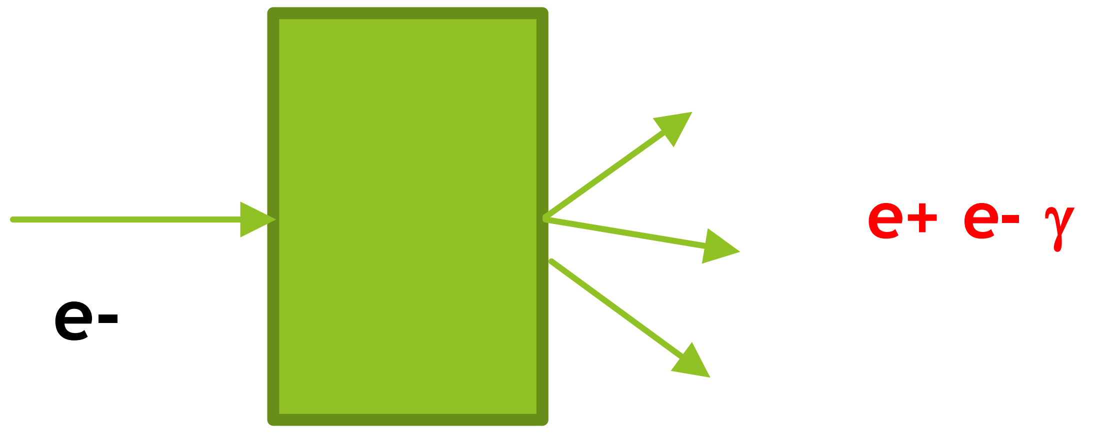
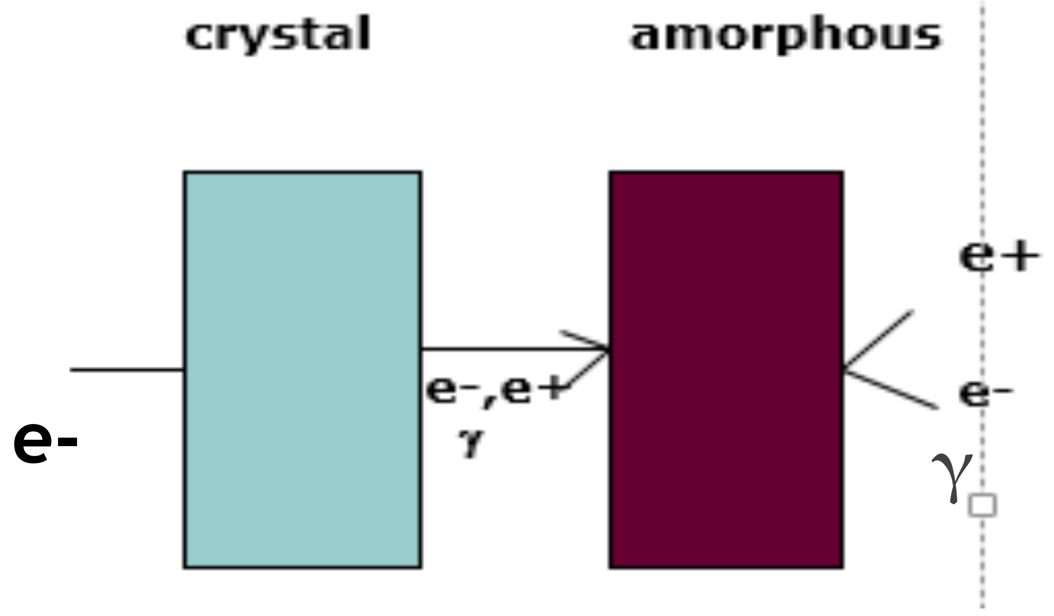
☞ Use the intense radiation emitted by high energy (some GeV) electrons channeled along a crystal axis => *channeling radiation*.

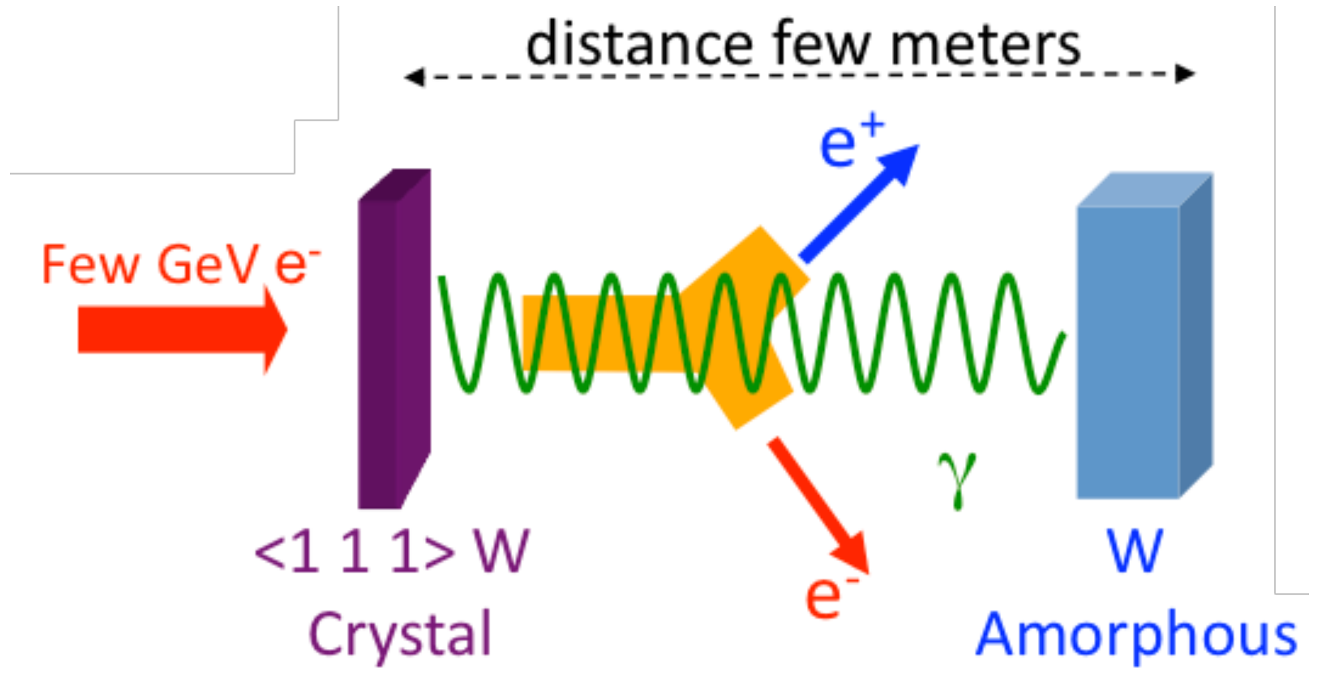
- Thick crystals: radiation and conversion in the same target



- Hybrid scheme: thin crystal-radiator & thick amorphous-converter



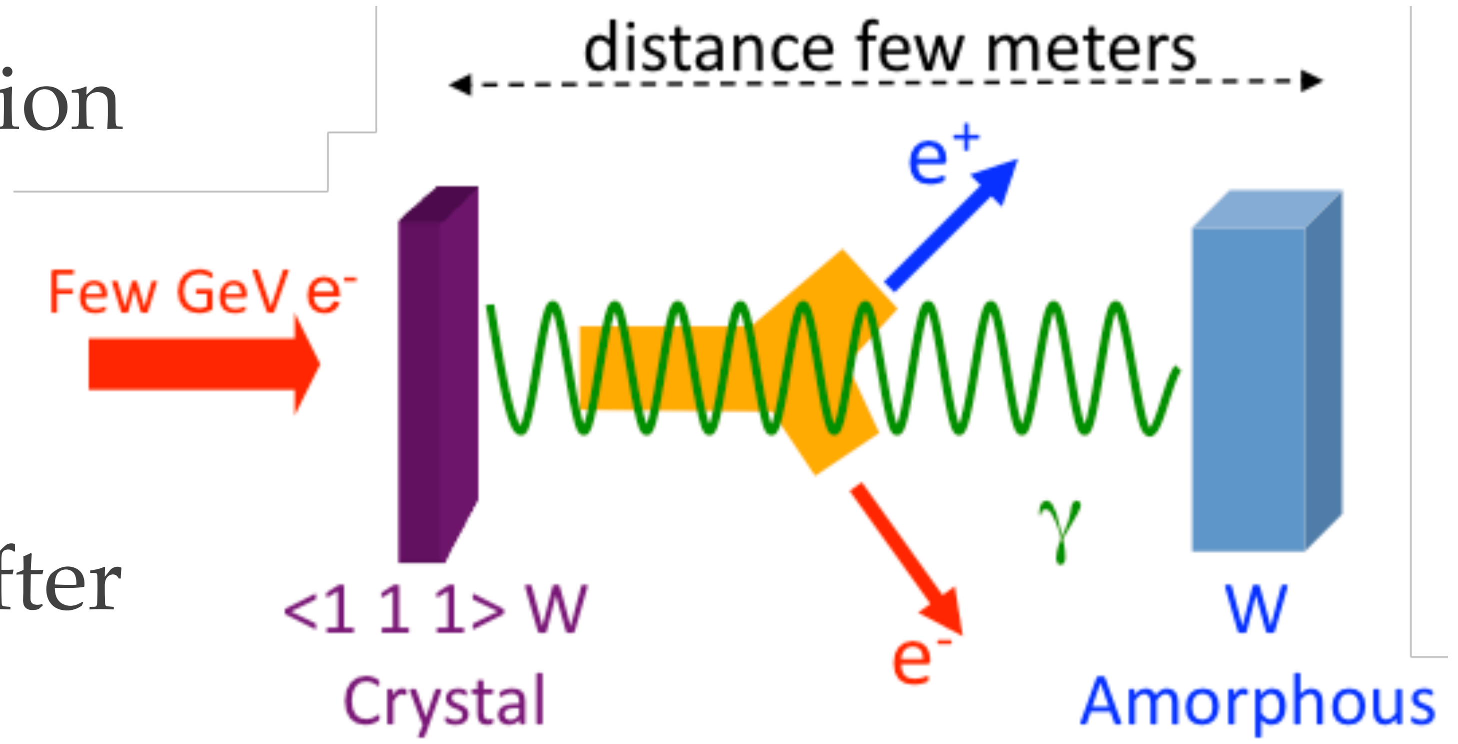
- Optimized hybrid scheme: decrease of the deposited energy by sweeping off the e+/e- (from crystal)



Three approaches have been studied experimentally

Positron Sources using channeling

Advantages of optimized hybrid scheme:

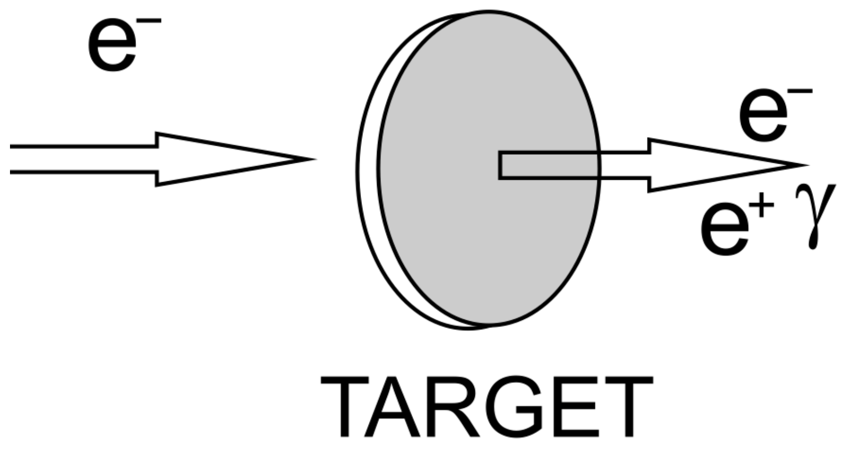


- Thin crystal => higher enhancement, more γ produced per e- => less energy deposition => less heating => higher potentials
- Thick amorphous converter: high conversion $\gamma \rightarrow$ -e-/e+
- Distance between radiator and converter: use sweeping magnet to sweep off e+/e- after the crystal => less energy deposition, weaker density: avoids high values of PEDD

Typical parameters of the hybrid e+ sources:

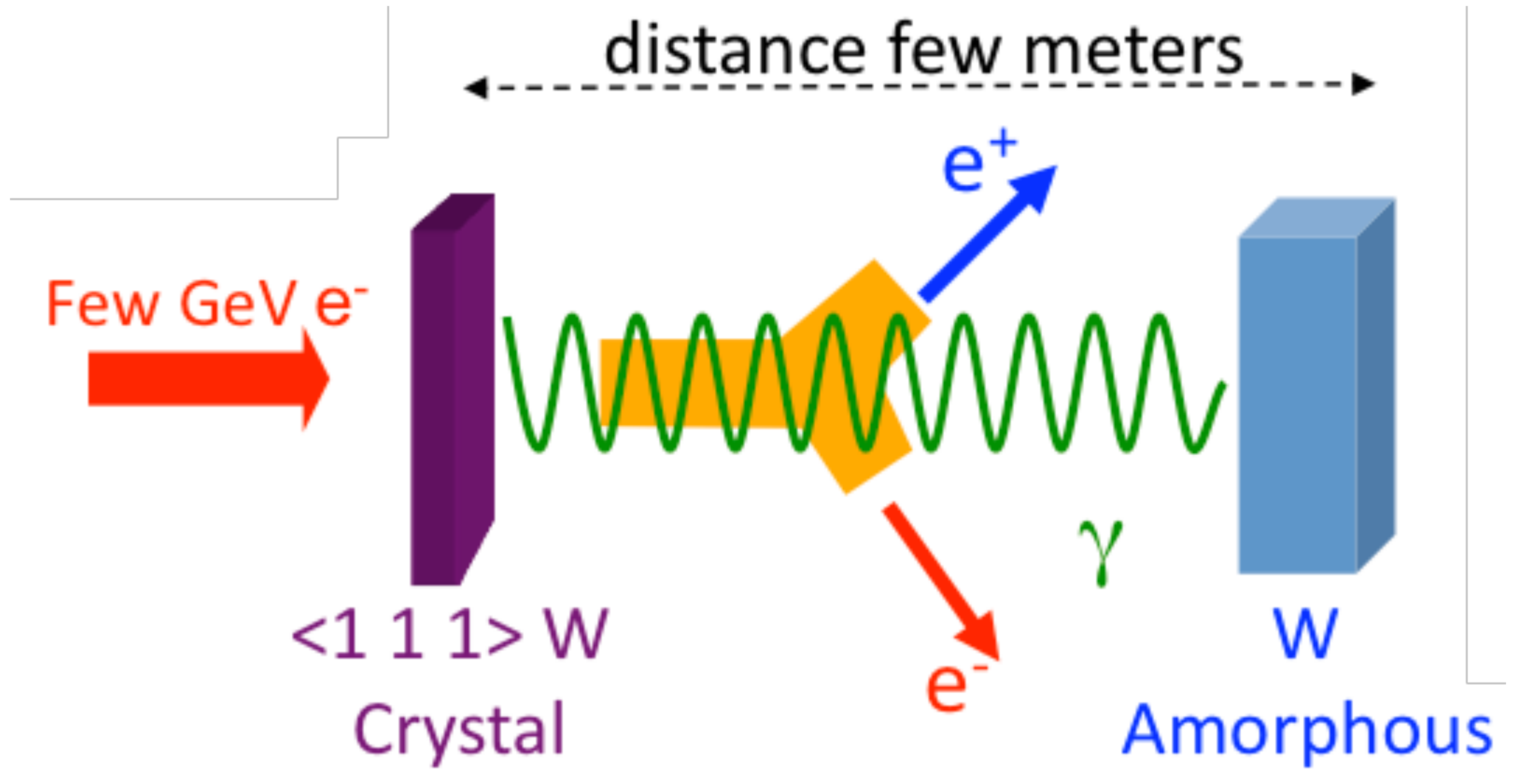
- **Thickness of the crystal:** optimum thickness is between 1-2 mm for E ≤ 10 GeV (higher values saturation)
- **Thickness of the amorphous target (high Z material):** compromise between the requested yield and the amount of deposited energy => what is essential is **the accepted yield**
- **Distance between the radiator and converter:** 1) installation of a sweeping magnet 2) increase the size of the photon beam => contribute to lower the deposited energy and its density
- **Incident e- energy:** some GeV (to get $U_{ch} >> U_{bremss}$), U is the energy radiated
- **Crystal kind and orientation:** Tungsten W => high atomic potential (1 keV) at <111> orientation

Positron Sources recap



1) **Conventional positron target:** bremsstrahlung and pair conversion

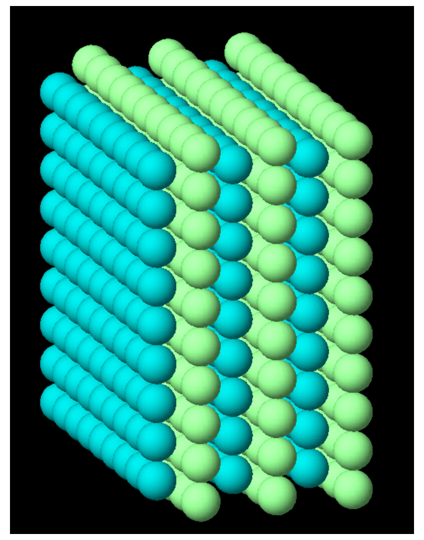
- Classical e+ source
- It was employed to produce e+ beam at the existing machines (ACO, DCI, SLC, LEP, KEKB…)



2) **Hybrid positron target:** two-stage process to generate positron beam. Channeling (crystal target) and pair conversion (amorphous target)

- Charged particles are swept off after the crystal target => the deposited power and PEDD (Peak Energy Deposition Density) are strongly reduced
- *Granular target* can provide better heat dissipation associated with the ratio Surface/Volume of the spheres and the better resistance to the shocks

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

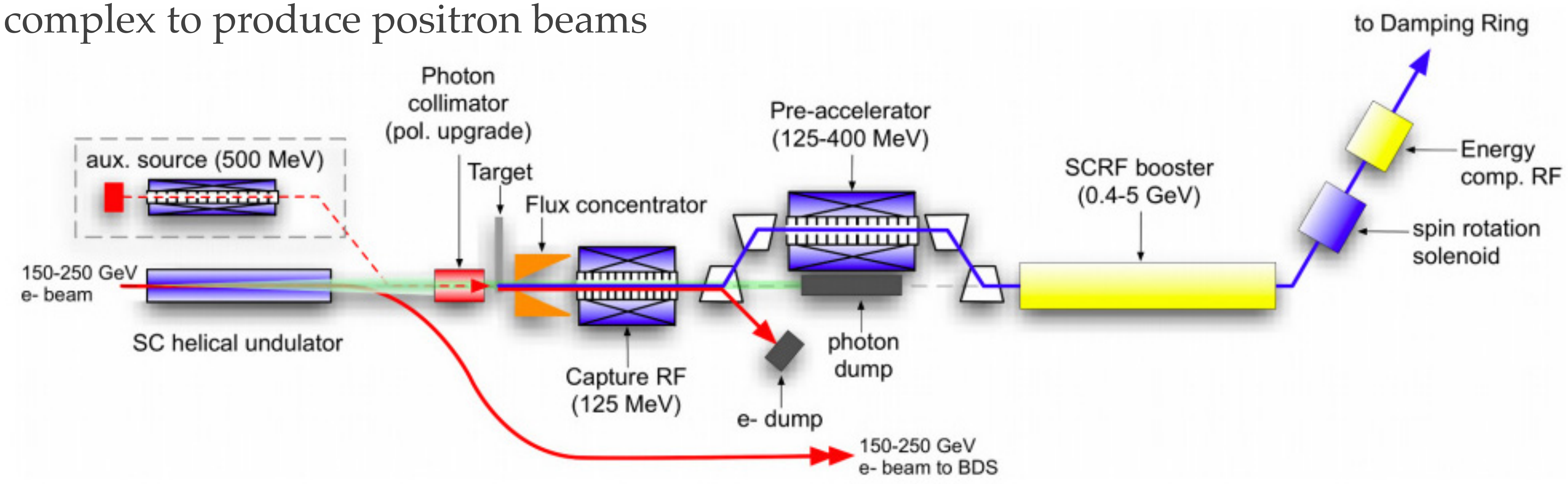


Several experiments had been conducted to study the hybrid e+ source (proof-of-principle experiment in Orsay, experiment @ SLAC, experiment WA 103 @ CERN and experiments @ KEK).

Positron Sources : ILC baseline

Efforts are shared between USA, UK, CERN, Germany and Japan. A proof-of-principle experiment E-166 in FFTB at SLAC.

Combined injector complex to produce positron beams



- **SC helical undulator:** 147m active length (max 231 m), 11.5 mm period, K ~0.92 (B ~0.86 T) with beam aperture 5.85 mm
- **e+ target:** 400 m downstream the undulator, 0.4X0 (1.4 cm) thickness, Ti6Al4V rim rotated with 100 m/s tangential speed
- **Flux concentrator:** 12 cm length, B_{max} = 3-5 T, B_{end} = 0.5 T
- **NC capture RF:** 1.3 GHz, ~10 m length up to 125 MeV
- **e+ polarization:** default ~30%, polarization upgrade up to 60% with photon collimators

ILC baseline: e+ target issue

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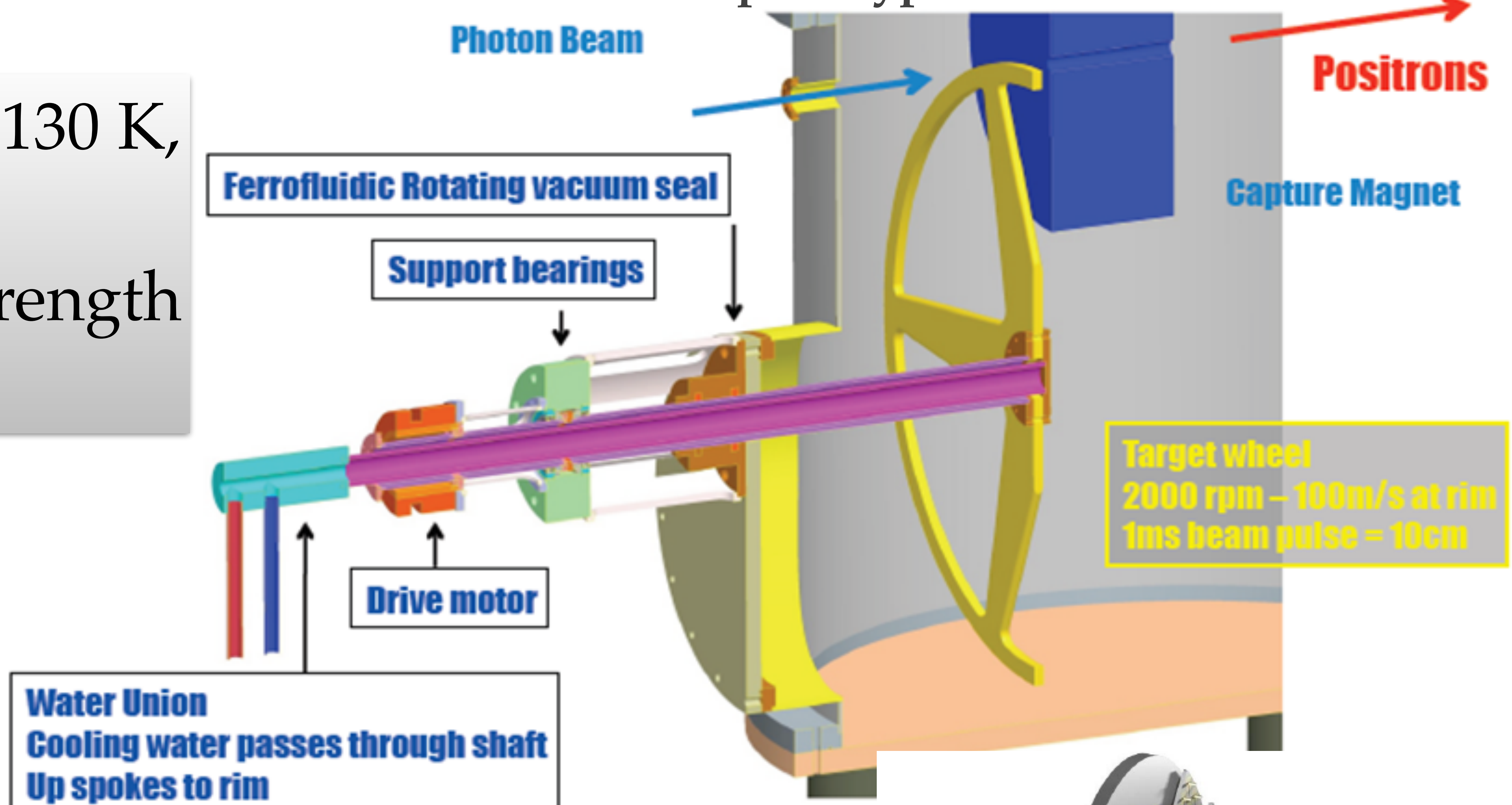
Energy deposition @ 500 GeV (nom. lumi): 2 kW <=> ΔT_{max}/pulse~130 K, photon beam spot size on target ~1mm => PEDD 67.5 J/g.
Max. thermal stress in target => fatigue limit and ultimate tensile strength in Ti material.

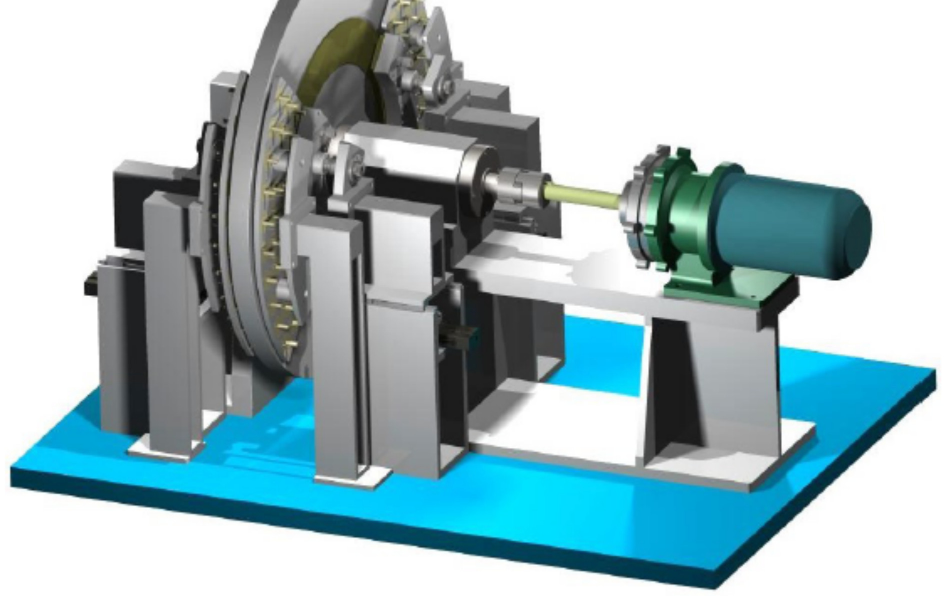
e+ target: wheel made of Ti6Al4V (1m diameter and 0.4X0 (1.4 cm) thick. During operation the outer edge of the rim moves at 100 m/s (2000 rpm) to smear out long ms pulses.
Design and prototyping of the Rotating Target FerroFluidic Seal and the capture magnet are ongoing.

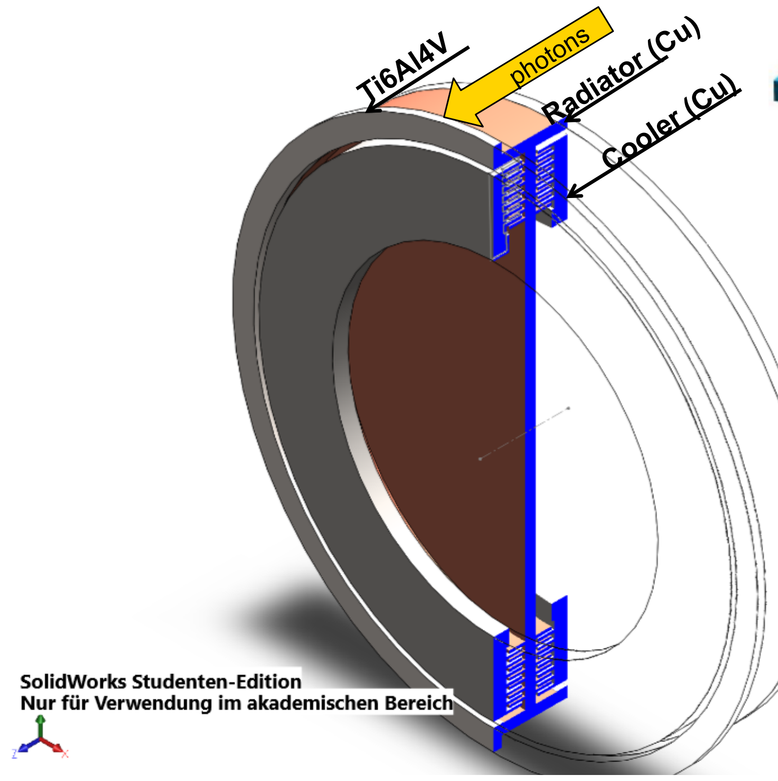
Polarization upgrade to 50-60% => increase in energy deposition and PEDD due to beam collimation.

prototype @LLNL



Active Sliding Contact Cooling of e+ target (IHEP/ANL)





Radiative thermal cooling of e+ target (DESY/CERN)

ILC baseline: critical points

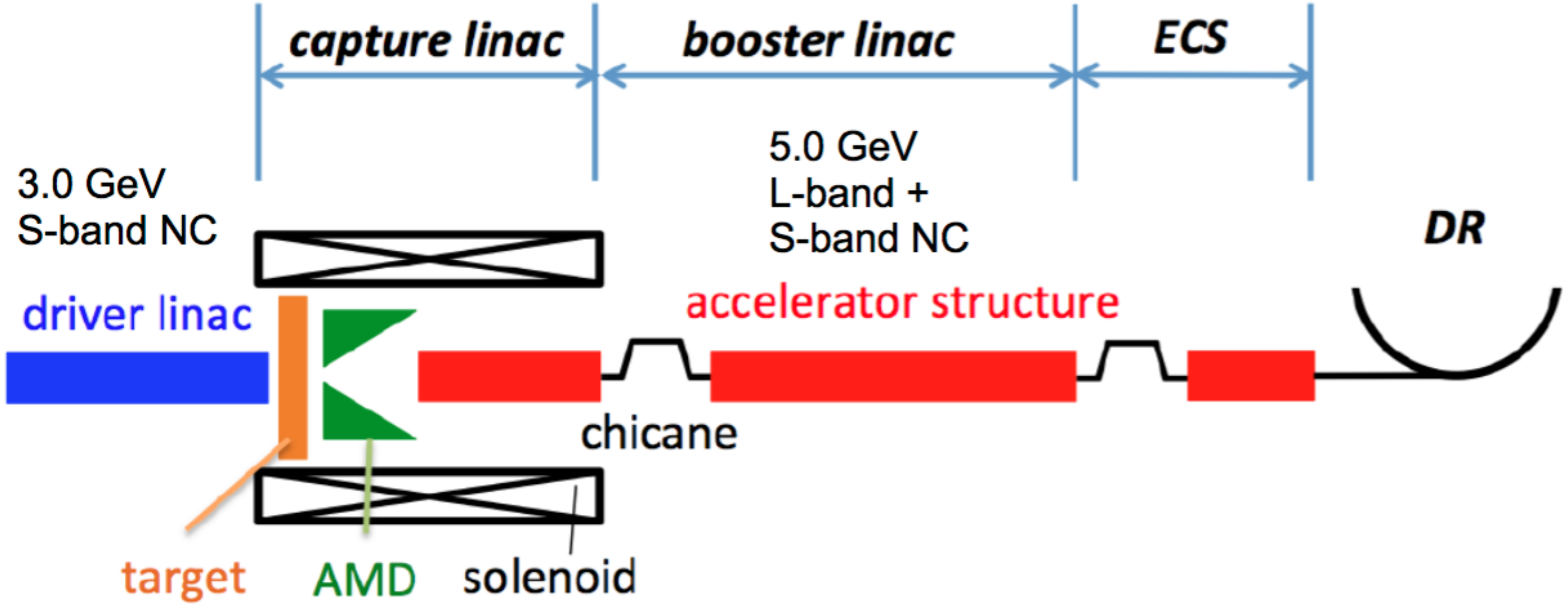
- **Undulator:** 150 m long SC helical undulator with a ~6 mm inner diameter vacuum chamber (prototyping STFC/RAL/Daresbury)
- **Photon collimator:** absorbs ~ 50% of photon beam power (DESY)
- **Target-converter:** target wheel (Lancaster/Cockcroft/STFC/LLNL), rotating vacuum seal (LLNL), target cooling system (radiative thermal cooling DESY/CERN and active sliding contact cooling IHEP/ANL), remote handling/target removal engineering design (IHEP).
- **Thermal shock problem:** energy deposition causes shockwaves in the material => target can be broken if induced thermal stress exceeds the ultimate tensile strength of the target material (SLC e+ target failure)
- **e+ capture system:** flux concentrator (LLNL)

ILC unpolarised positron source

Efforts are shared between ANL, IHEP, Hiroshima U, U of Tokyo, KEK, DESY, U of Hamburg, CERN. **Following design is the backup for proposed ILC e+ source.**

- The proposed ILC e+ source contains risks => backup solution
- So-called 300 Hz conventional source: e+ generation in 63 ms (cf. undulator : in 1 ms)

Conventional e+ source but still needs some more R&D



High current, high rep rate driver linac ~6 GeV and booster linac ~5 GeV.

Moving target (slow rotation ~5 m/s required vs. 1/20 of undulator scheme)

Flux concentrator (pulse length ~1 μs (cf. ~1 ms in undulator scheme) => almost existing FC technology.

Shock waves and thermal dynamics: in principle OK because triplet to triplet separation 3.3 ms in time but studies are ongoing.

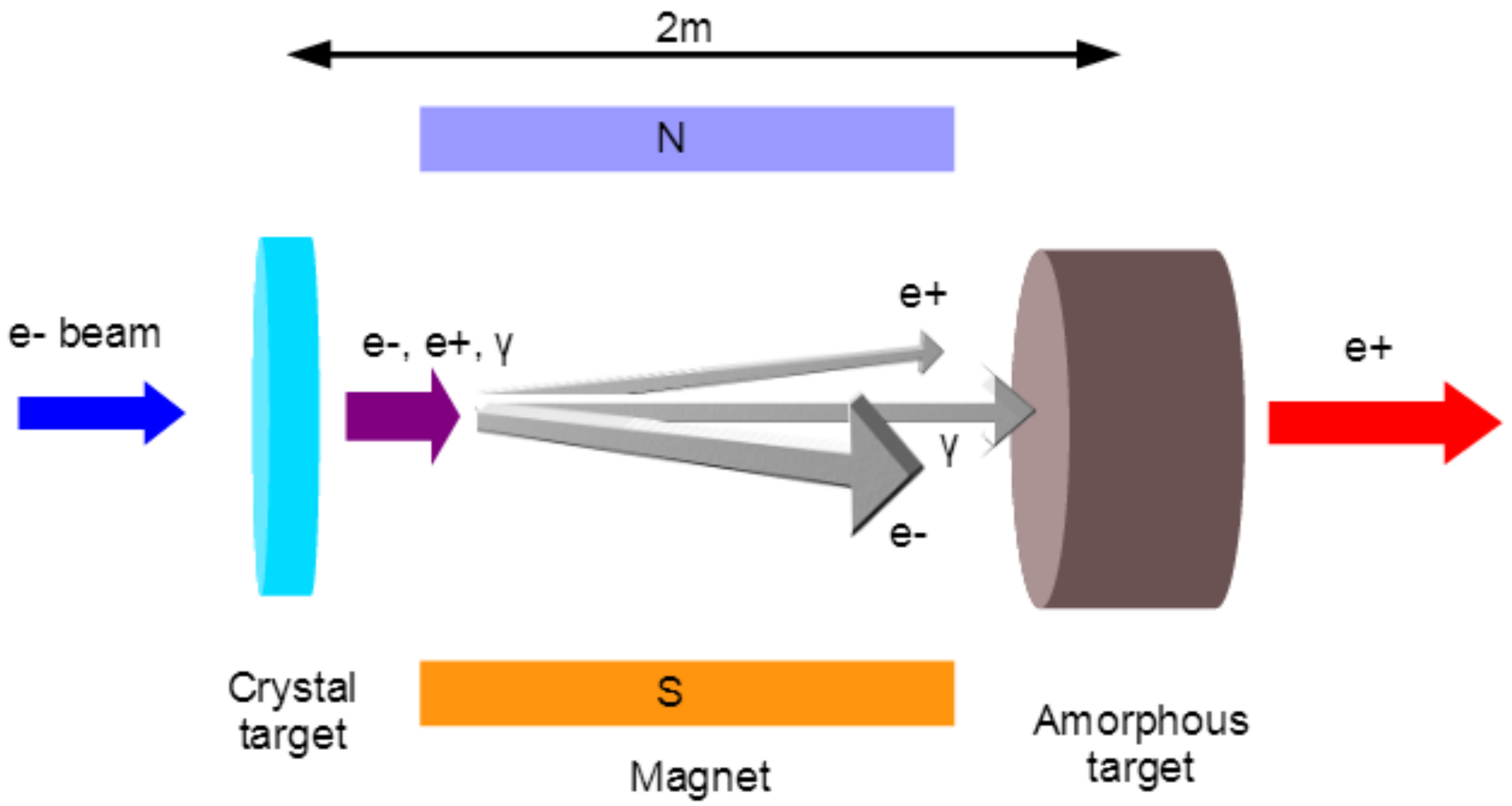
Target-converter: a full target prototype d = 500 mm (no water channels and not W material) in two years for continuous running test.

ILC unpolarised positron source

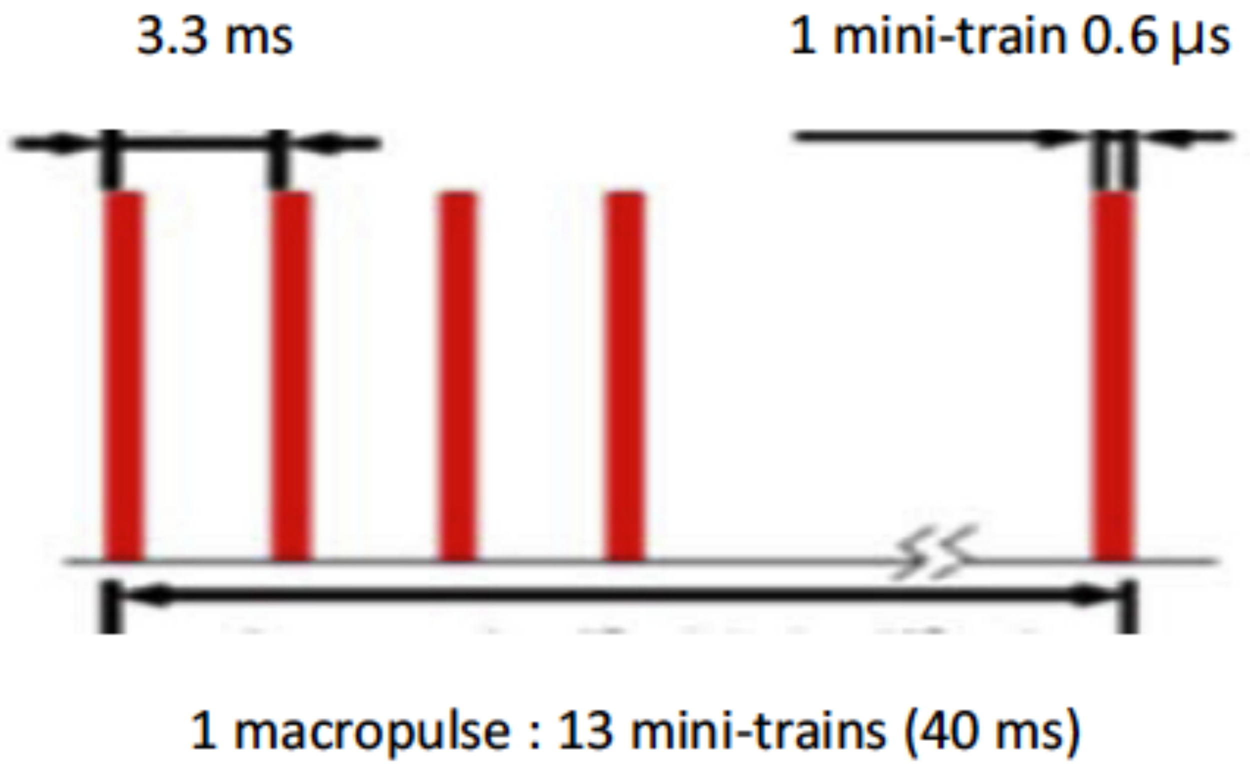
Alternative solution: hybrid target. Efforts are shared between France (LAL, IPNL), KEK and CERN

Hybrid target parameters:

- 1 mm thick W crystal <111>, incident e- energy: 10 GeV
- 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-



☞ In the same way as for the conventional scheme, we are proposing after T. Omori to modify the beam time structure before the target recuperating the nominal one after the DR.



Positron Sources : CLIC baseline

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Efforts are shared between LAL, IPNL and CERN. **Hybrid target: baseline design for the CLIC positron source**

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

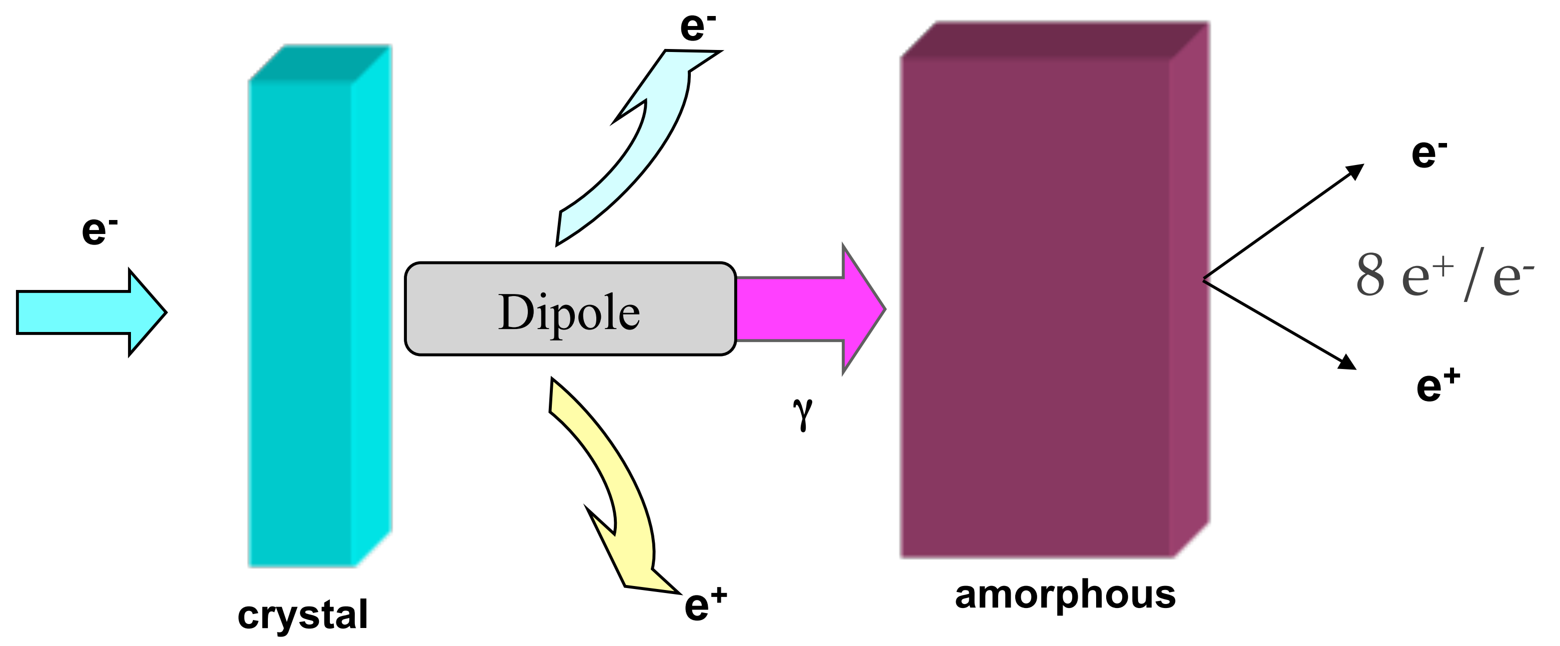
Target Parameters Amorphous		
Material	**Tungsten**	**W**
Thickness (Radiation length)	**3**	**χ_0**
Thickness (length)	**10**	**mm**
PEDD	**30**	**J/g**
Distance to the crystal	**2**	**m**

~ 10 kW

< 35 J/g

Distance (crystal-amorphous) d = 2 m

Primary e- beam
5 GeV
1.1× 10^{10} e^-/bunch

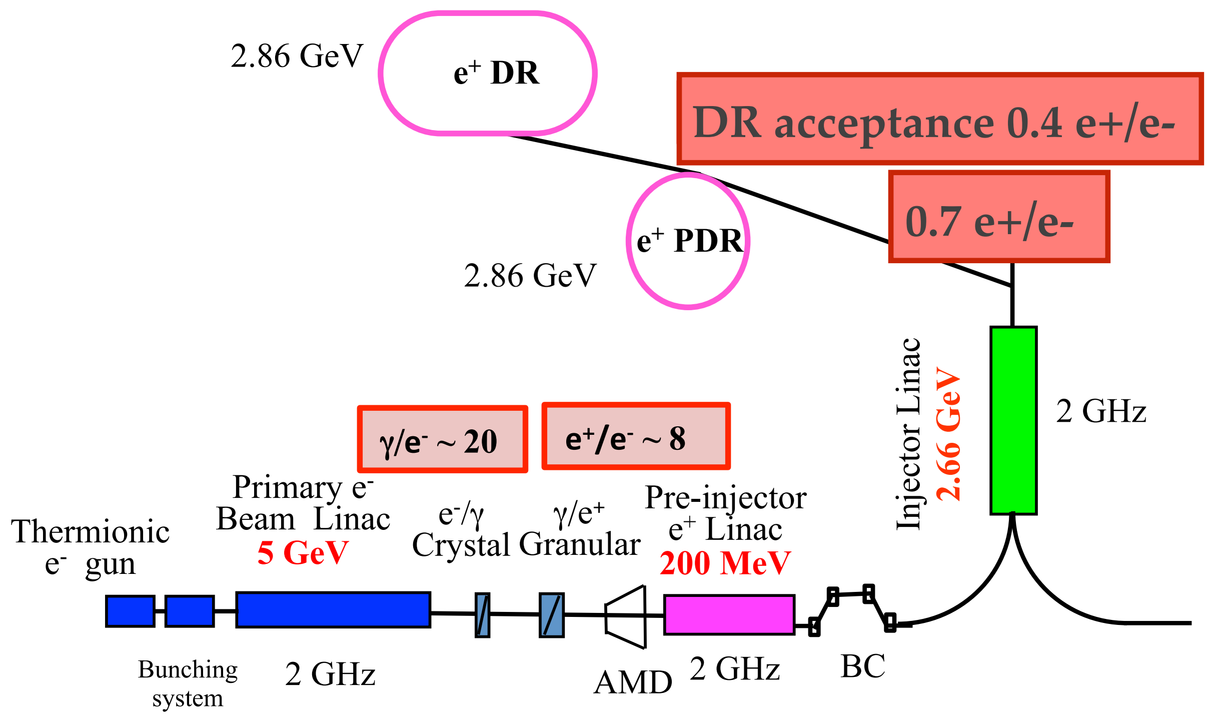


Crystal thickness: 1.4 mm
Oriented along the <111> axis

Amorphous thickness: 10 mm

Required: 4.3 × 10^9 e^+/bunch

unpolarized e^+



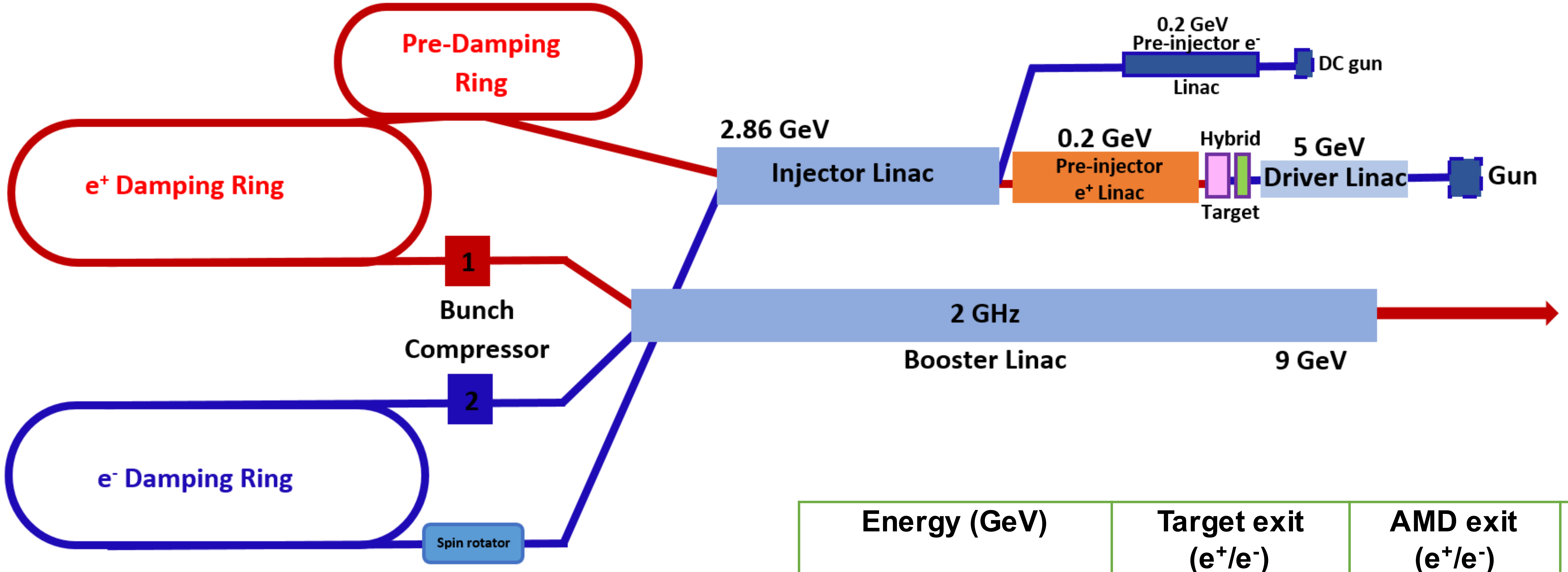
Yield: 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled.

- **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

Positron Sources : CLIC baseline

☞ CLIC e+ source design update (compared to CDR): new beam transport and acceleration design from the target to the pre-damping ring



C. Bayar, S. Doebert

Energy (GeV)	Target exit (e$^+$/e$^-$)	AMD exit (e$^+$/e$^-$)	Total yield (e$^+$/e$^-$)	Effective yield (e$^+$/e$^-$)
3 (new)	**4.18**	**1.38**	**0.50**	**0.44**
5 (new)	7.14	3.06	1.36	1.21
5 (previous)	8.00	2.80	1.09	0.98
5 (CDR)	8.00	2.10	0.95	0.39

e+ yield at the entrance of the pre-damping ring is increased by a factor ~3 compared to the CLIC CDR.

This result allows to reduce the beam current or energy of the electron driver linac => significant cost savings for electron driver linac.

Experimental activity on hybrid source

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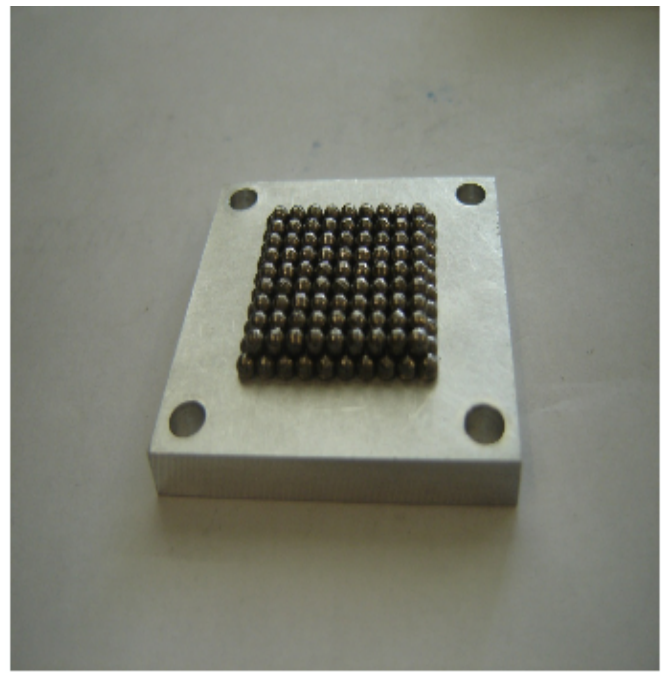
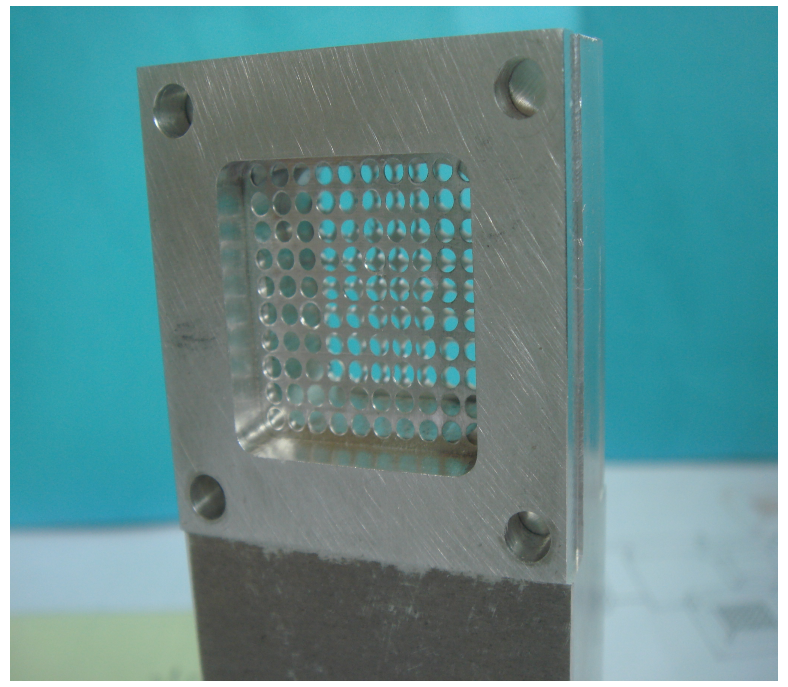
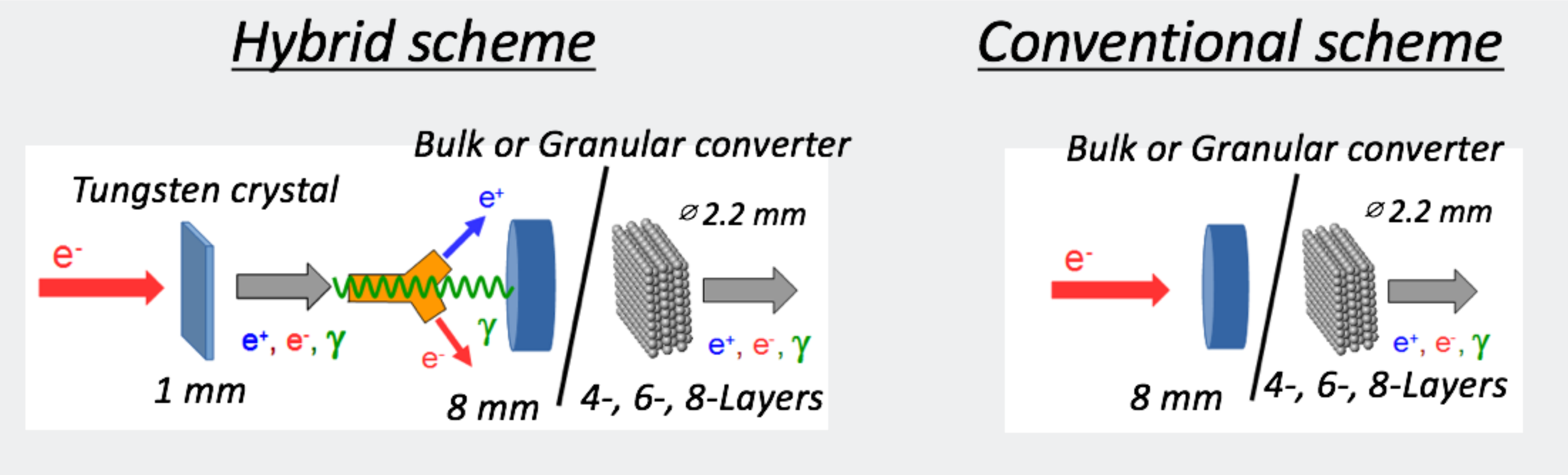
The experimental activities have restarted in KEK (KEKB injector linac) in 2015/2016. **Goals**: *e+ yield and target temperature measurements* to compare different targets (Bulk & Granular) => e+ source performances.

Experimental conditions:

- Energy = 7-8 GeV, single bunch (Frep =1 to 50 Hz), Charge = 1-2 nC
- Emittance (norm)~ 150(H)/63(V) mm mrad, beam divergence < 0.1 mrad
- Crystal W: 1mm thick, <111> orientation
- Granular targets: 4, 6 and 8 layers. Bulk target (reference): 8 mm thick
- Temperature rise on the converter : thermocouples





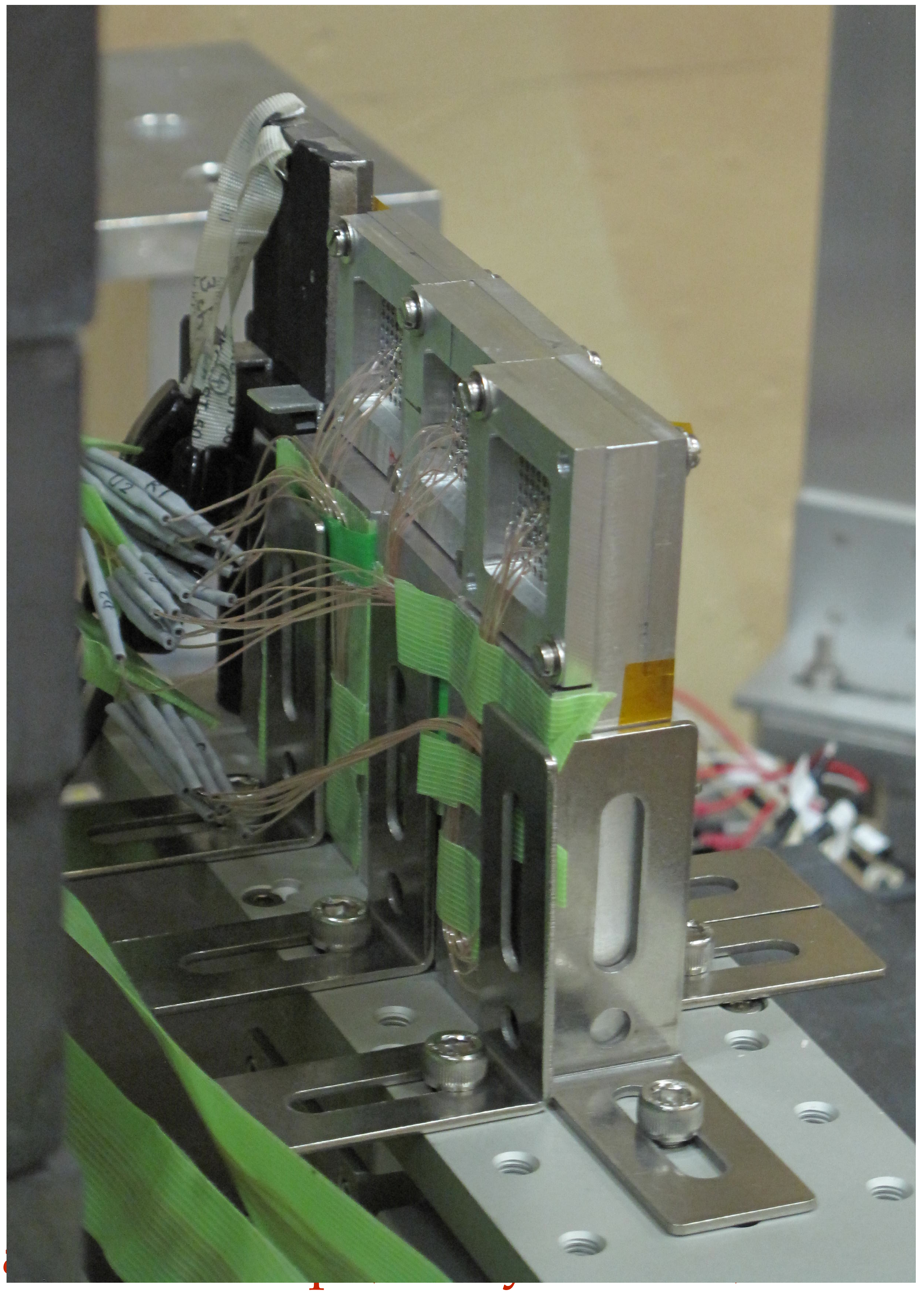


Experimental activity on hybrid source

Photons and e+ detection:

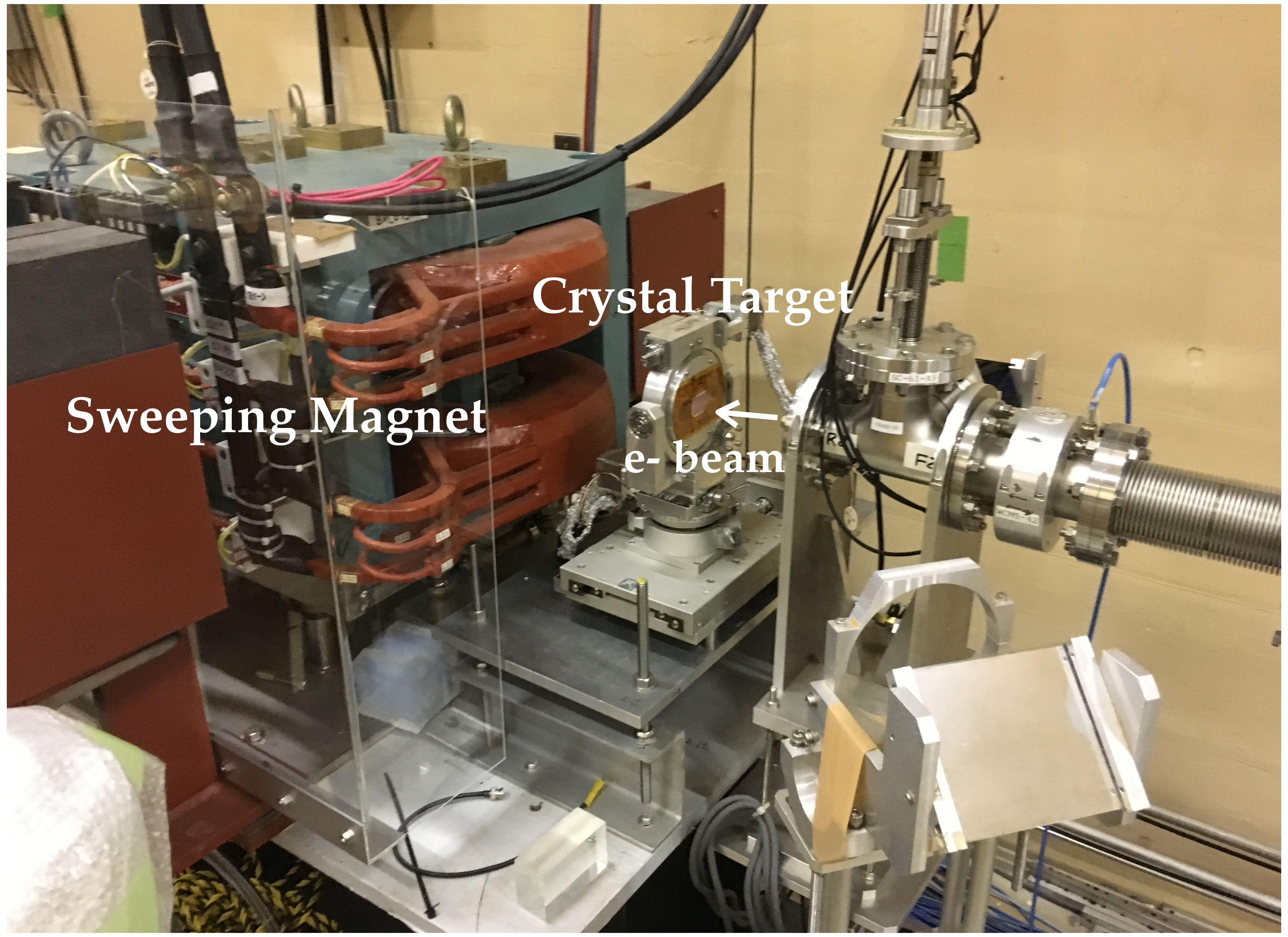
- **Photon detection:** CVD diamond detector 500 µm thick, 4x4 mm^2. Weak interaction efficiency (~0.3 %) but enough γ rays (>10^{11} per shot)
- **Positron detection:** produced e+ are analysed by a spectrometer (60^o bending magnet) at 5-20 MeV/c and then detected by 5 mm lucite Cherenkov detector

The e+ detection system is simulated by using the GEANT4. Typical momentum acceptance is 2.6% (FWHM) at the positron momentum 20 MeV/c. ***Collaboration with V. Rodin (KNU-Ukraine, Cockcroft Institute-UK).***

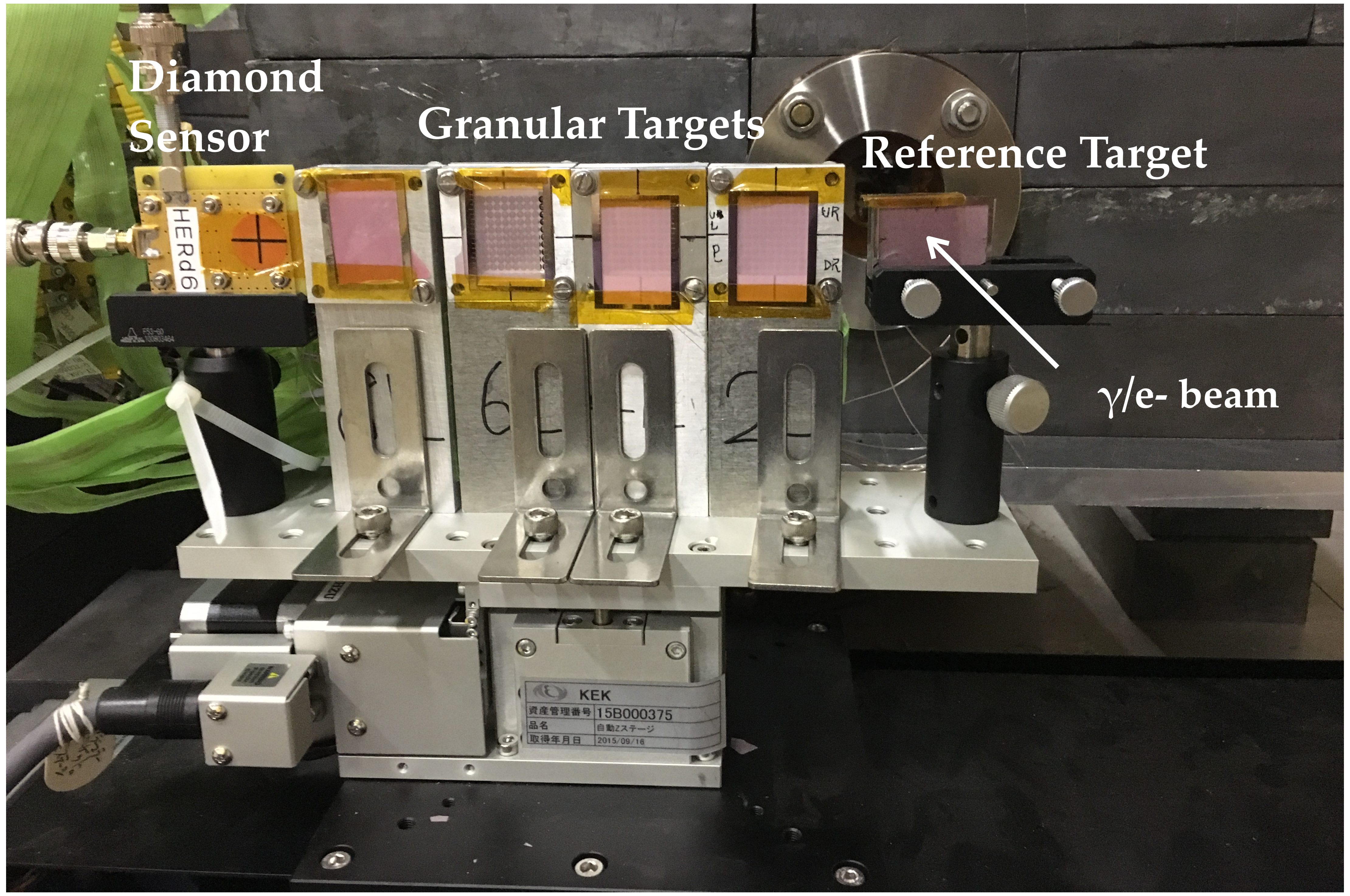


Temperature measurements:

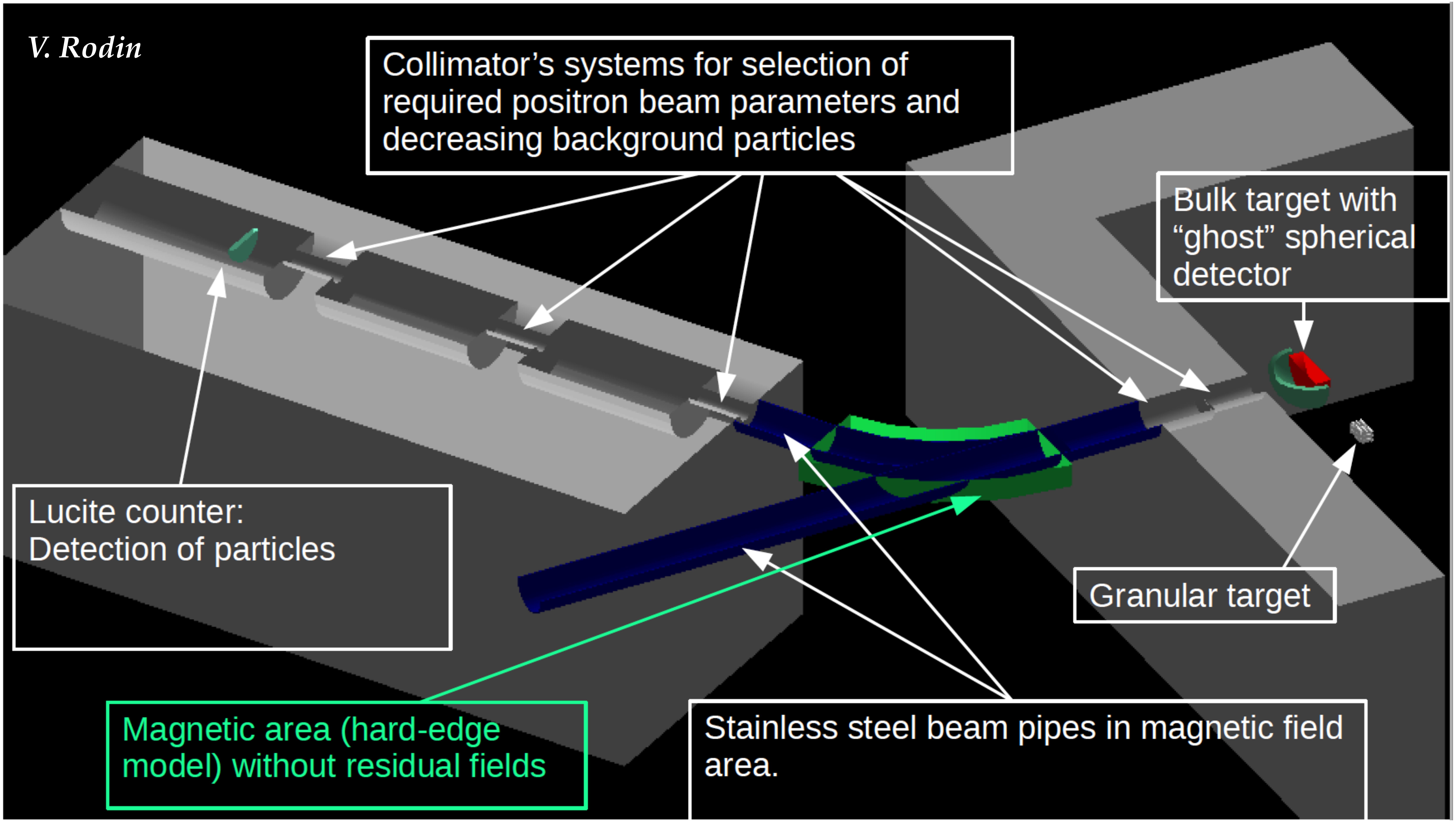
- Standard K-type thermocouples (with area < 1 mm^2) attached to the backside of the targets (glued by an epoxy thermal conductive paste)
- The output has been calibrated (0 -100^oC) and sent by a 40 m long extension cables to the experimental room


Crystal Target
Sweeping Magnet
e- beam


γ/e- beam
Targets
Sweeping Magnet
1.1 T


Diamond
Sensor
Granular Targets
Reference Target
γ/e- beam
HERd6
KEK

V. Rodin



Collimator's systems for selection of required positron beam parameters and decreasing background particles

Bulk target with "ghost" spherical detector

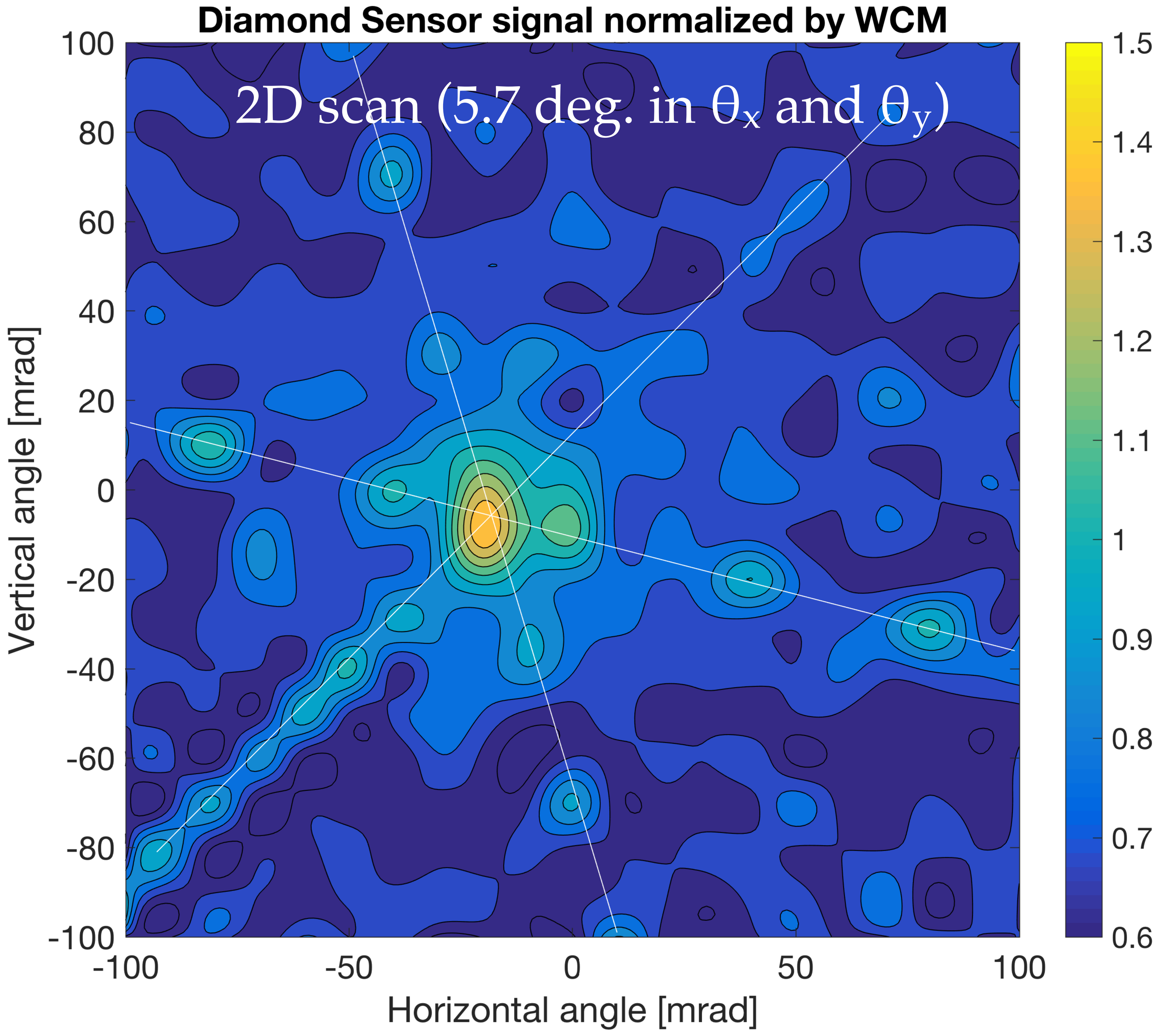
Lucite counter:
Detection of particles

Granular target

Magnetic area (hard-edge model) without residual fields

Stainless steel beam pipes in magnetic field area.

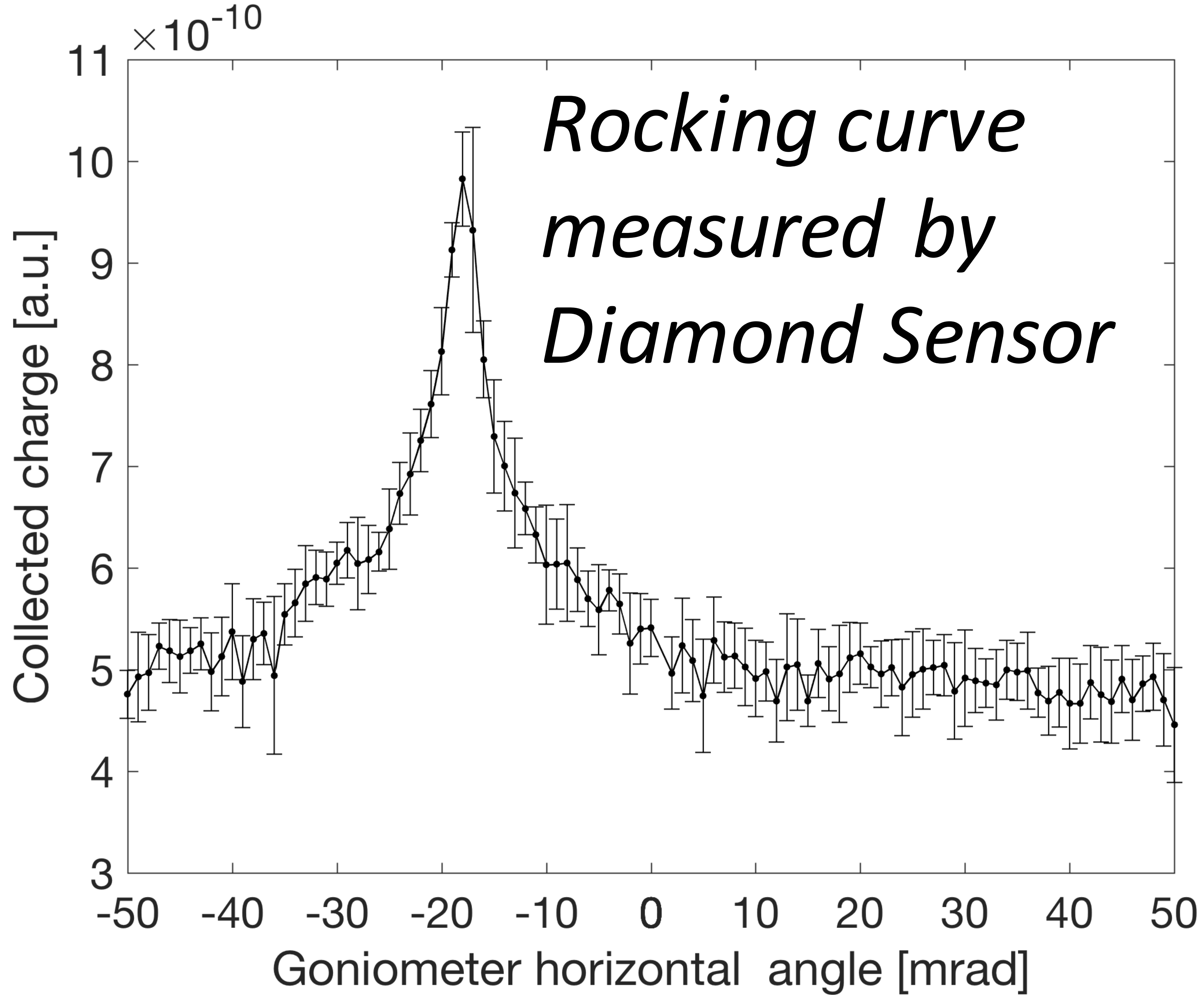
Experimental activity on hybrid source



STEREOGRAPHIC PROJECTION

<110> axis is at 35.2 degrees from <111> and <100> axis is at 54.7 degrees from <111>

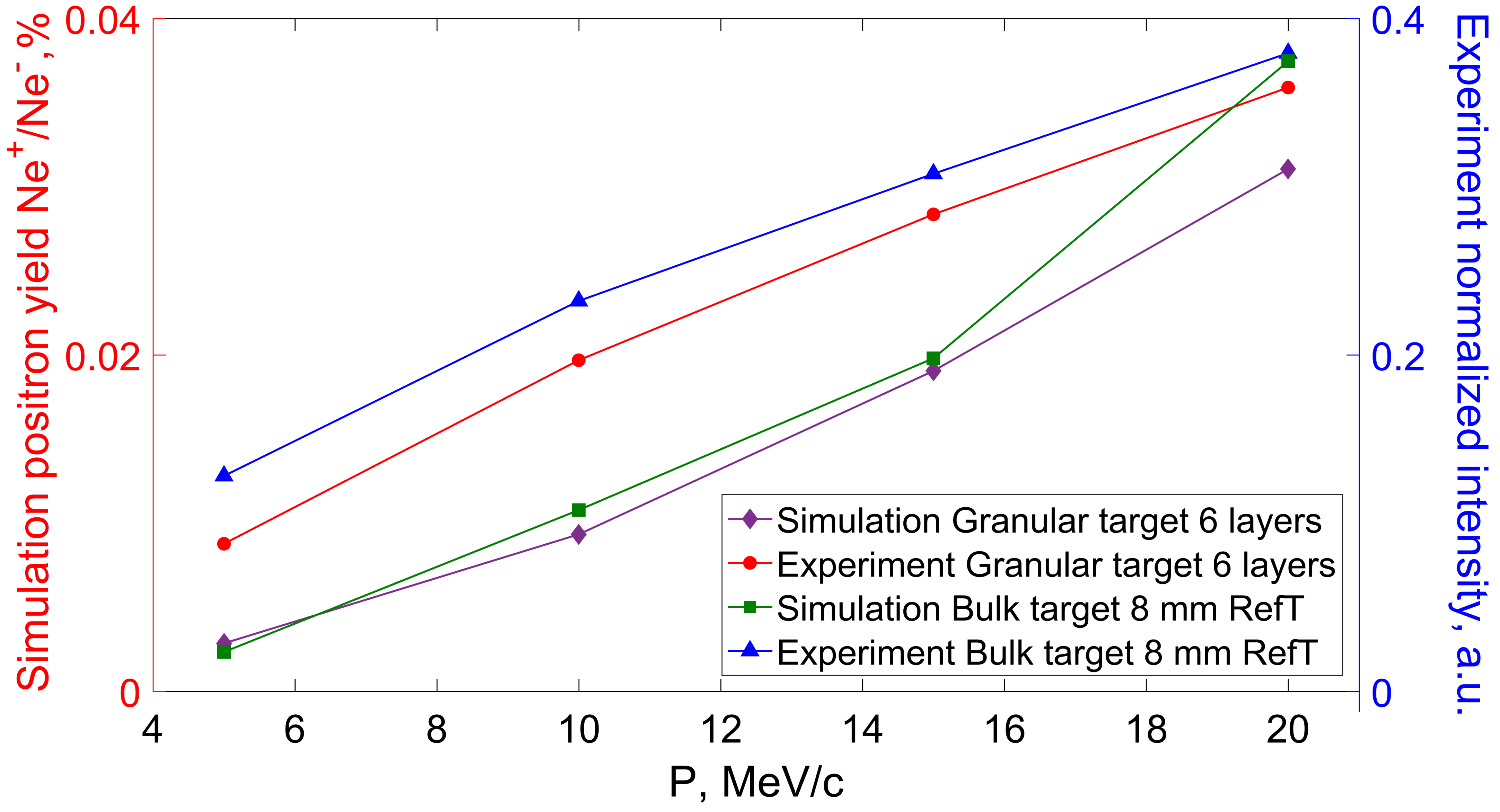
On the border of the scanned area => the axis <455>



To align <111> crystal axis with respect to the electron beam, a 2D angular scan has been performed.

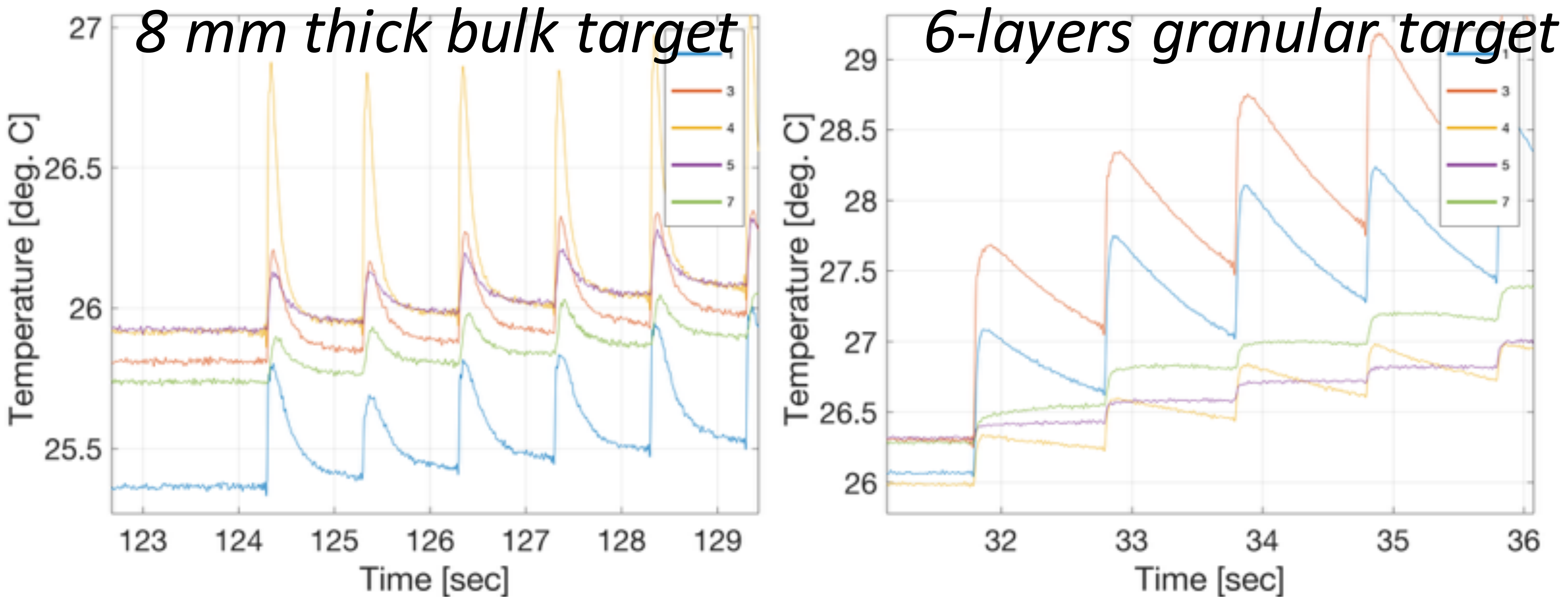
Data suggest an increase by a factor of two in the photon production => the simulations and further analysis of the background are under way to describe the experimental data.

Experimental activity on hybrid source



Positron yield: once the crystal axis was aligned with the e- beam, e+ yield was measured systematically for various conditions in hybrid and conventional schemes.

Bunch-by-bunch temperature rise



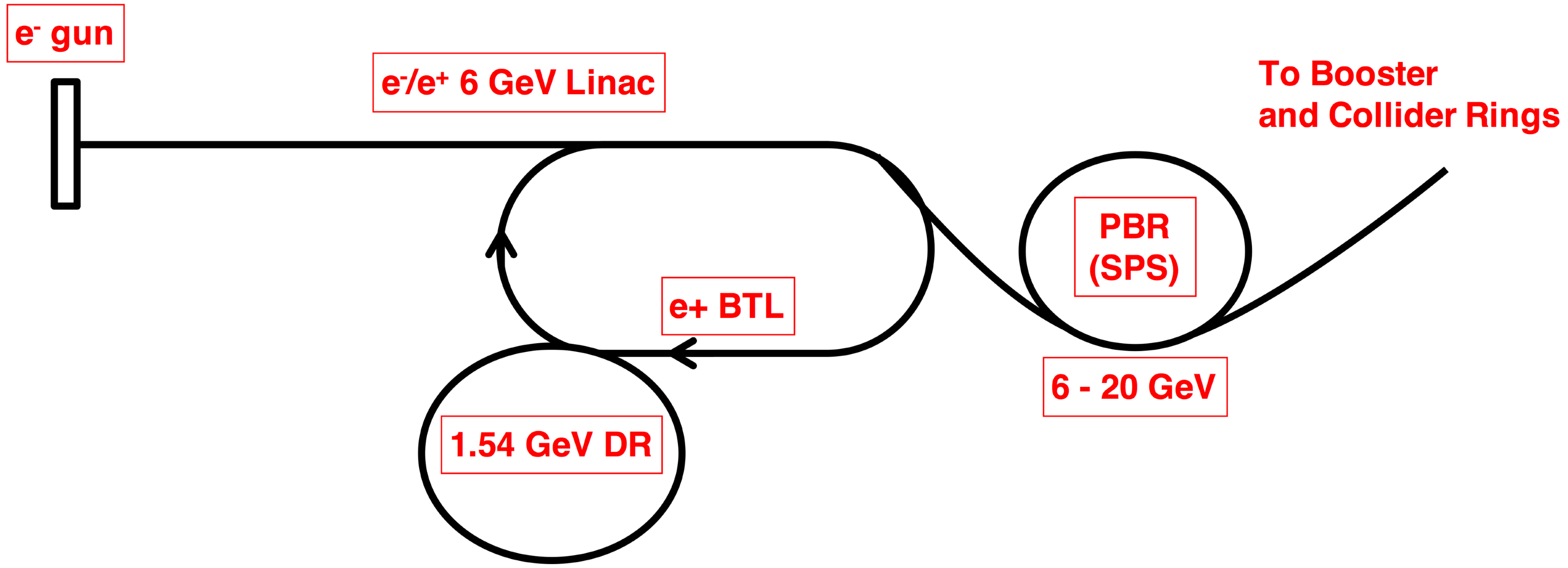
Temperature measurements: it was performed in order to estimate the heat load in the bulk and granular converters.

Bunch-by-bunch temperature rise => PEDD information.

Temperature at equilibrium => total energy deposition.

FCC-ee Positron Source

☞ FCC-ee would be the first step towards the long-term goal of a 100 TeV proton-proton collider. FCC-ee operation is foreseen at 91 GeV (Z-pole), 160 GeV (W pair production threshold), 240 GeV (Higgs resonance) and 350 GeV (t-tbar threshold).



The main 6 GeV linac hosts the e+ source. The positrons are produced with 4.46 GeV e- beam.

- RF-gun
- e-/e+ linac up to 6 GeV
- 1.54 GeV Damping Ring
- SPS as a Pre-Booster Damping Ring (6 - 20GeV)
- Booster Ring (20 - 45.6 GeV)

The FCC-ee positron injector has to be designed to produce the positron beam with the requested parameters accepted by the DR (**participation of the LAL group**)

FCC-ee Positron Source

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Injector parameters: summer 2017

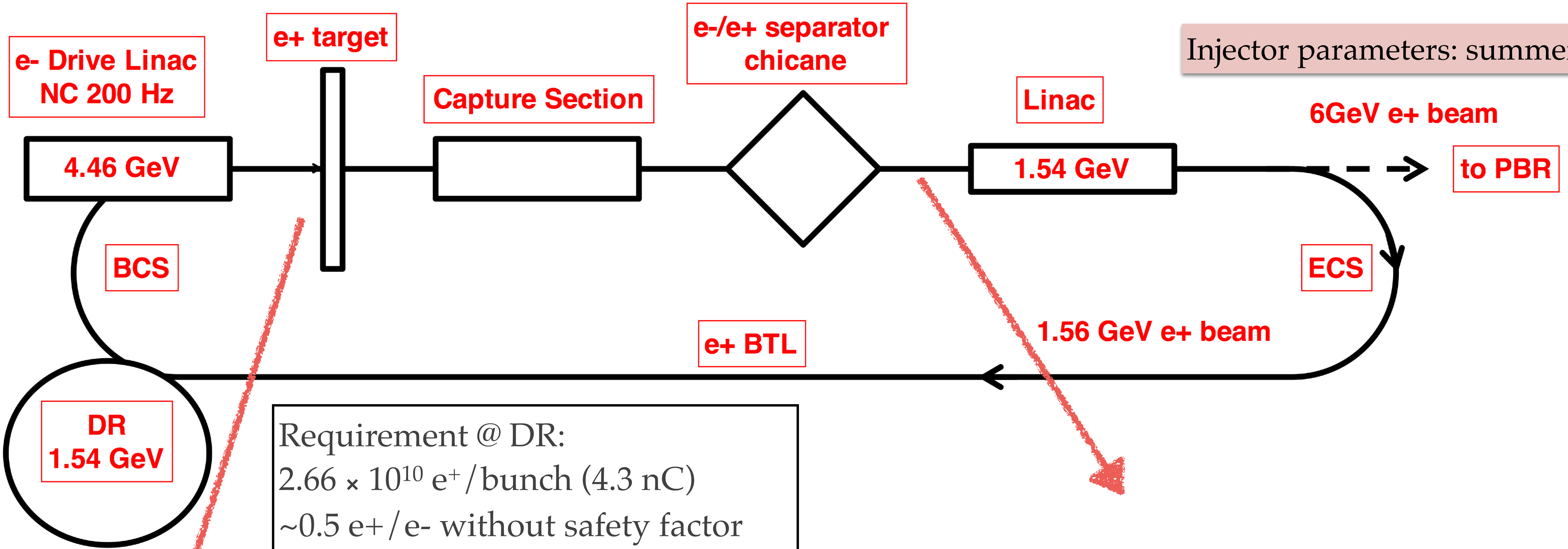
Primary e- beam

4.46 GeV

2.66×10^{10} e^-/bunch ~ 4.3 nC
(main e- beam)

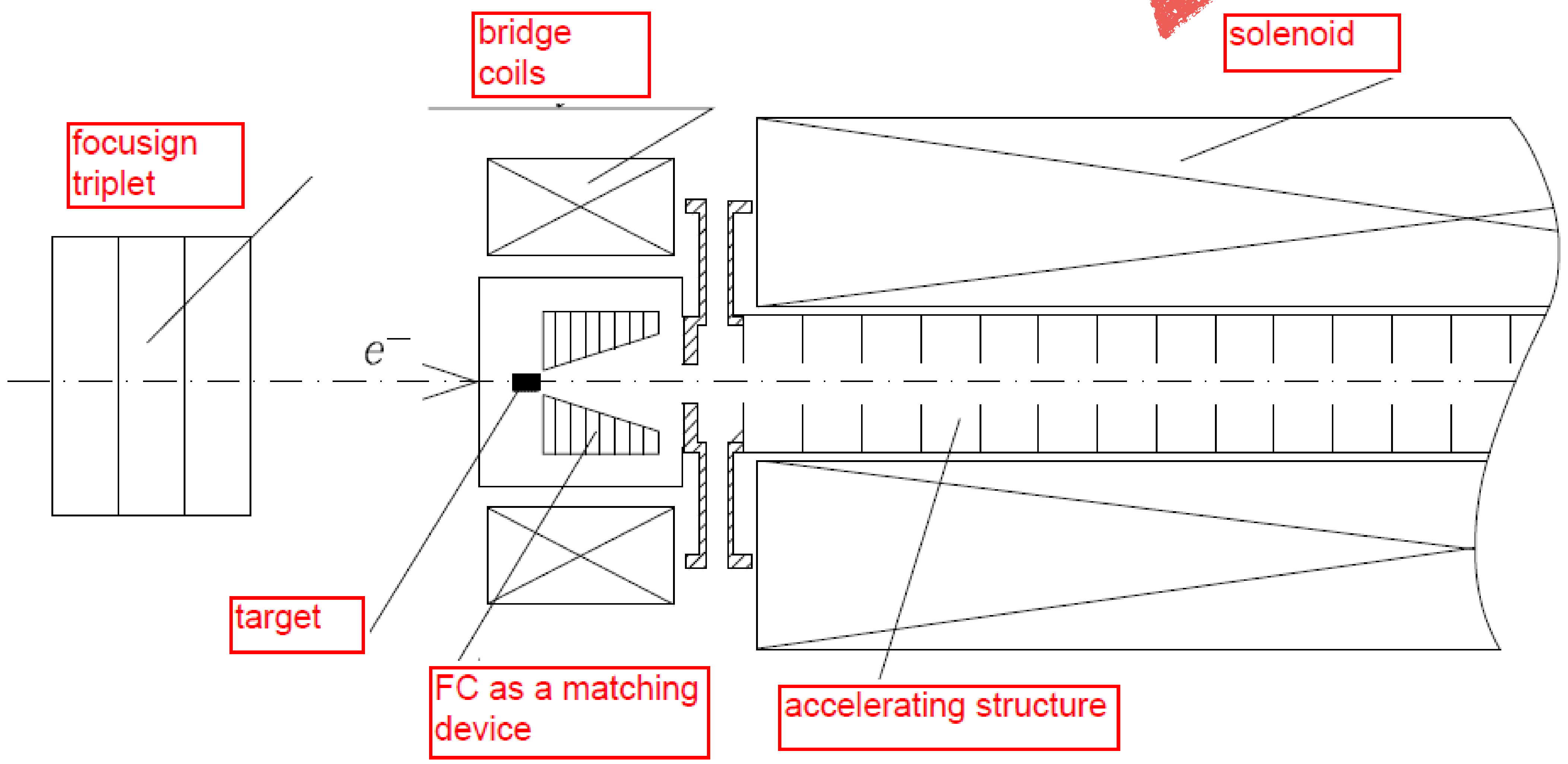
5.3×10^{10} e^-/bunch ~ 8.5 nC
(for e+ production)

2 bunches/pulse spaced by 60 ns

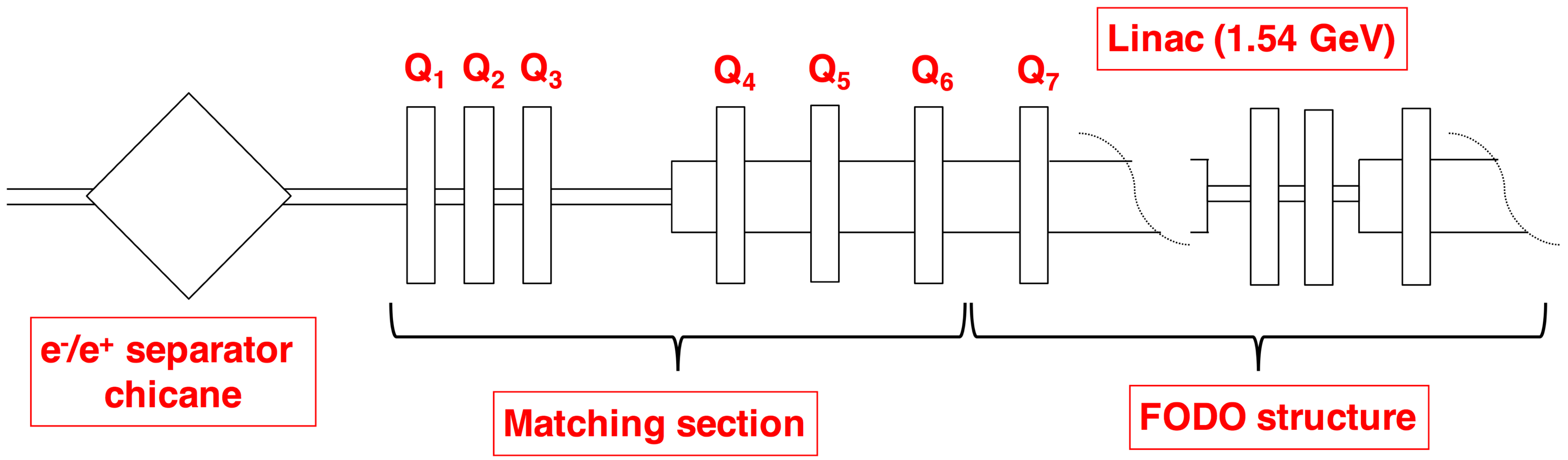


Requirement @ DR:
2.66×10^{10} e^+/bunch (4.3 nC)
~0.5 e+/e- without safety factor

e+ production and capture section



e+ acceleration up to 1.54 GeV



FCC-ee Positron Source (Target)

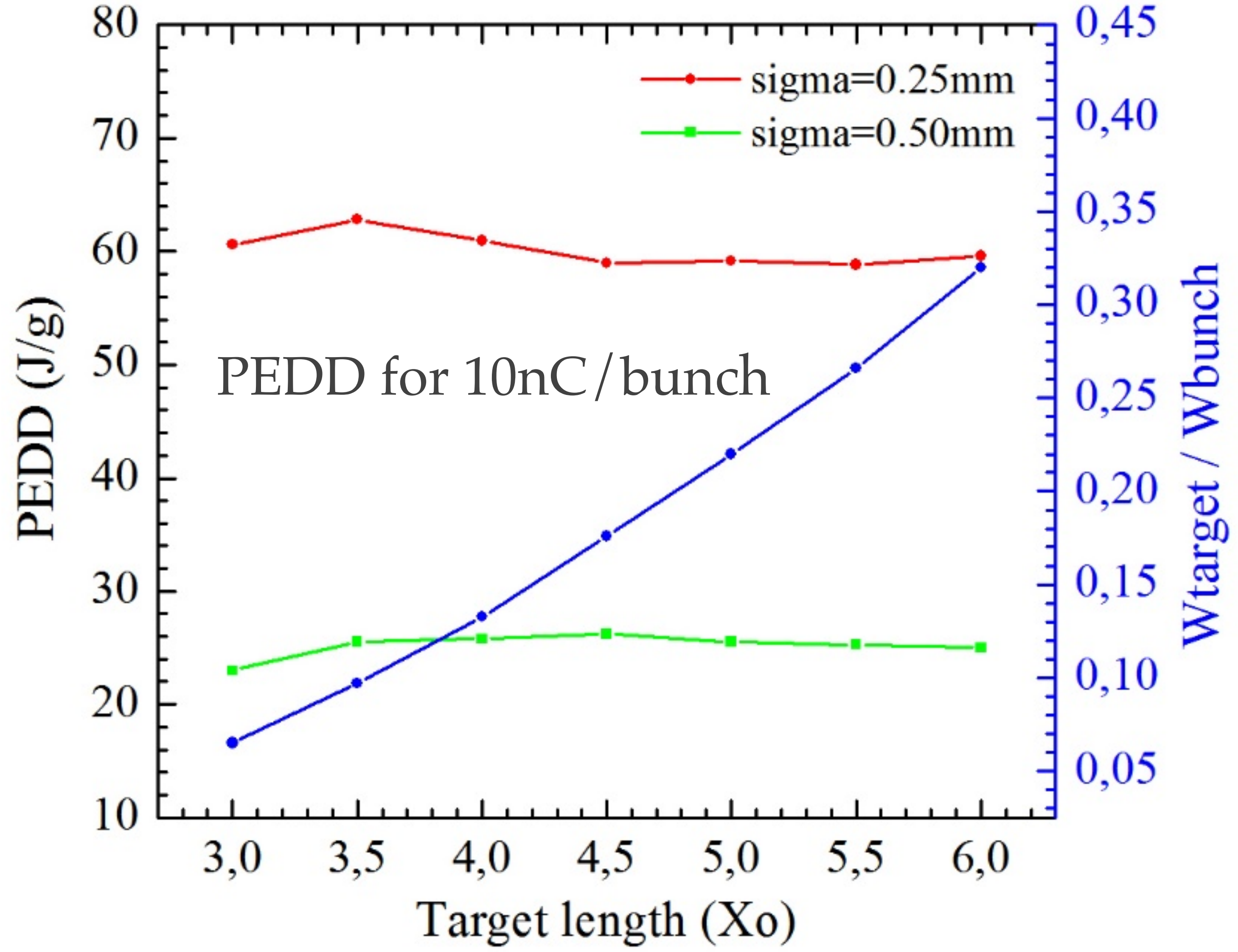
FCC-ee can employ the conventional/hybrid positron source. Studies are ongoing.

Comparison between the two options: conventional/hybrid (preliminary)

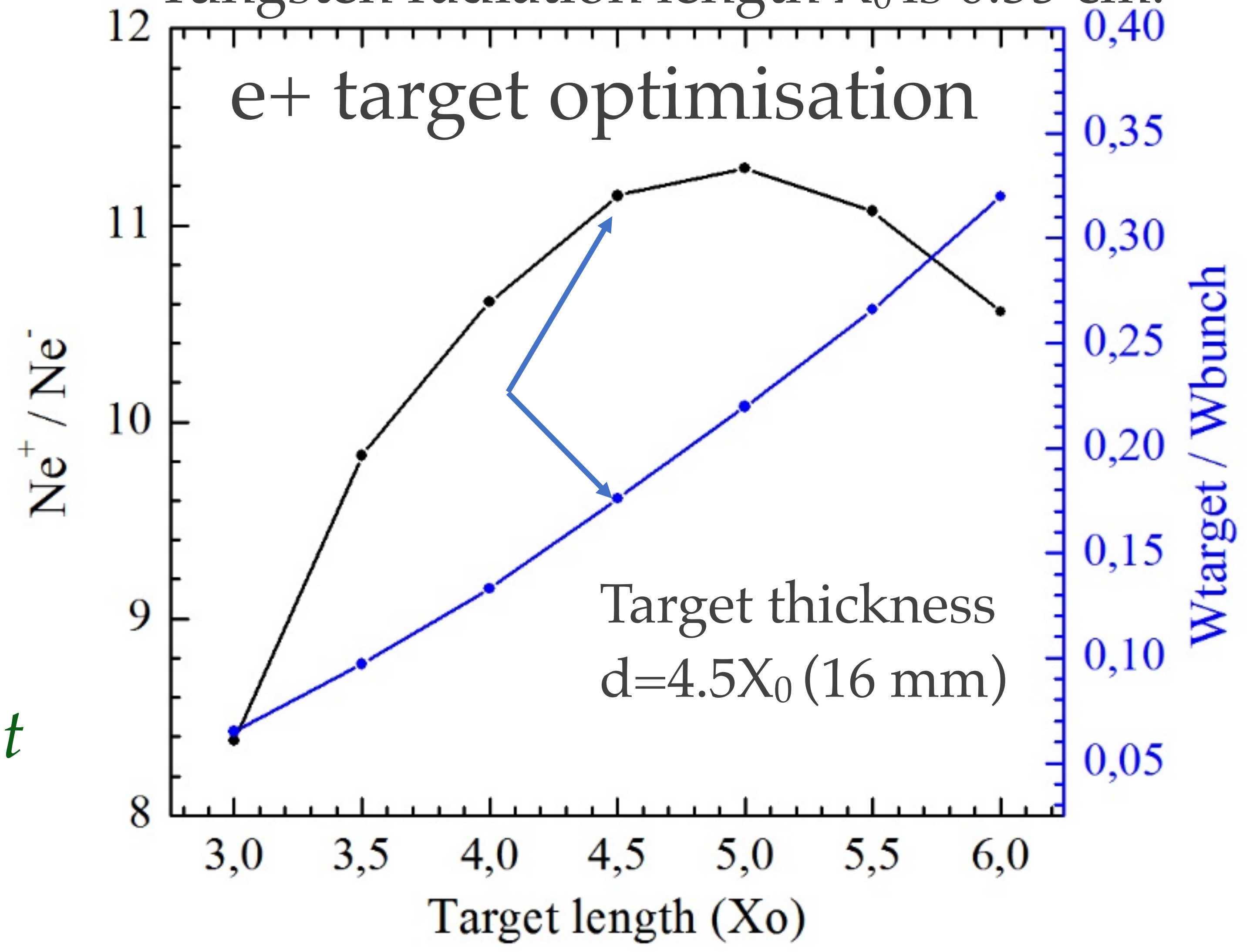
General conditions: E = 5 GeV, $\sigma_{x,y}$ = 2.5 mm, C = 8.5 nC, 2 bunches @ 200 Hz. Incident beam power is 15 kW.

Kind of e+ source	**Deposited energy**	**PEDD**
Conventional scheme (4.5 X0):	2.7 kW	2.1 J/g
Hybrid scheme (1.4 mm/10 mm)	1.2 kW	1 J/g
Hybrid scheme with granular converter (6 layers)	0.85 kW	0.6 J/g

According to SLC experience, W74Re26 material has a PEDD limit of 35 J/g (safe value to avoid target failure).



Tungsten radiation length X_0 is 0.35 cm.



Positrons for muons

LABORATOIRE
DE L'ACCÉLÉRATEUR
LINÉAIRE

Motivation: muon collider (get good muon beam emittance at the production). A μ+μ- collider offers an ideal technology to extend lepton high energy frontier in the multi-TeV range.

- **Conventional muon production:** from proton on target. π decays from proton on target have typical P_μ ~ 100 MeV/c. *Problem:* **large transverse momentum** of muons => **need to cool the emittance**.
- **Novel proposal:** direct μ pair production: e+e- → μ+μ- just above the μ+μ- production threshold (√s ≈ 0.212 GeV) with minimal muon energy spread. Direct annihilation of ~45 GeV e+ with atomic e- in a thin target (~0.01 radiation length). **Very small emittance** at μ production point => **no cooling needed!** *Disadvantage:* production rate. Much smaller cross section compared to protons (~mb) => σ(e+e- → μ+μ-) ≈ 1 μb at most.
- *Solution:* high intensity positron beam should hit the target with a large frequency => target in a positron ring!

LEMMA Positron Source

☞ Low EMittance Muon Accelerator (LEMMA). Collaboration with LNF.

Goal: produce ~ 10^{11} μ/s @Target. Efficiency ~10^{-7} (with 3mm Be target).

Flux of 10^{18} e+/s is needed @Target (LHeC like e+ source).

Stored e+ beam with μ target needs the largest possible lifetime to minimize positron source rate.

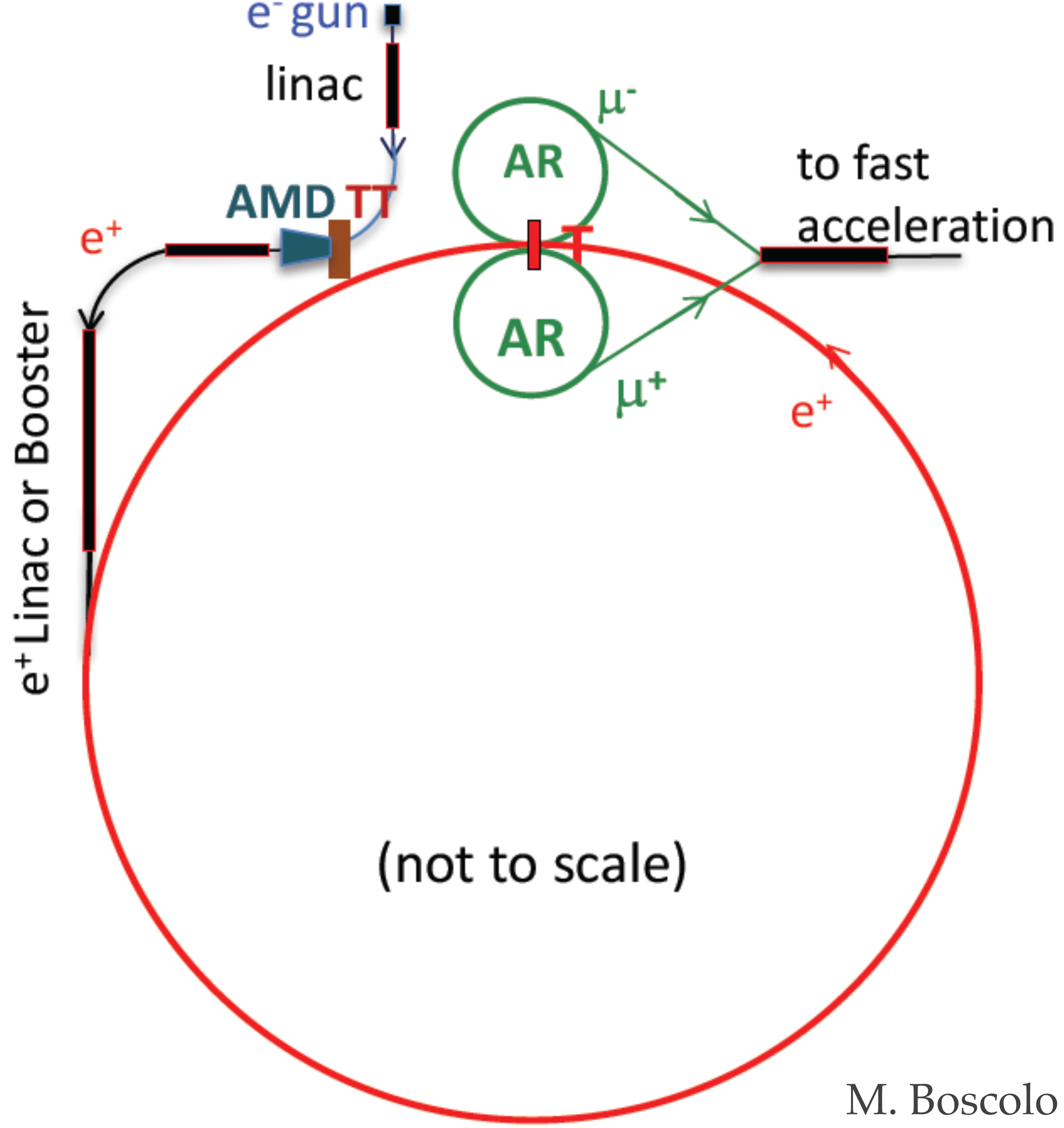
1) e+ source. Transport of the e+ beam to the ring.

2) e+ ring: 6.3 km 45 GeV storage ring with target for muon production.

3) μ+μ- production and their transport to the collider. Muons produced by the e+ beam on target with $E(\mu) \approx 22$ GeV, $\gamma(\mu) \approx 200 \Rightarrow \tau_{lab}(\mu) = 500$ μs go to the μ rings: 60 m isochronous and high mom. acceptance rings will recombine μ bunches for ~ 1 $\tau_\mu^{lab} \approx 2500$ turns.

4) Fast μ acceleration and transport to muon collider.

Preliminary scheme for low emittance μ production



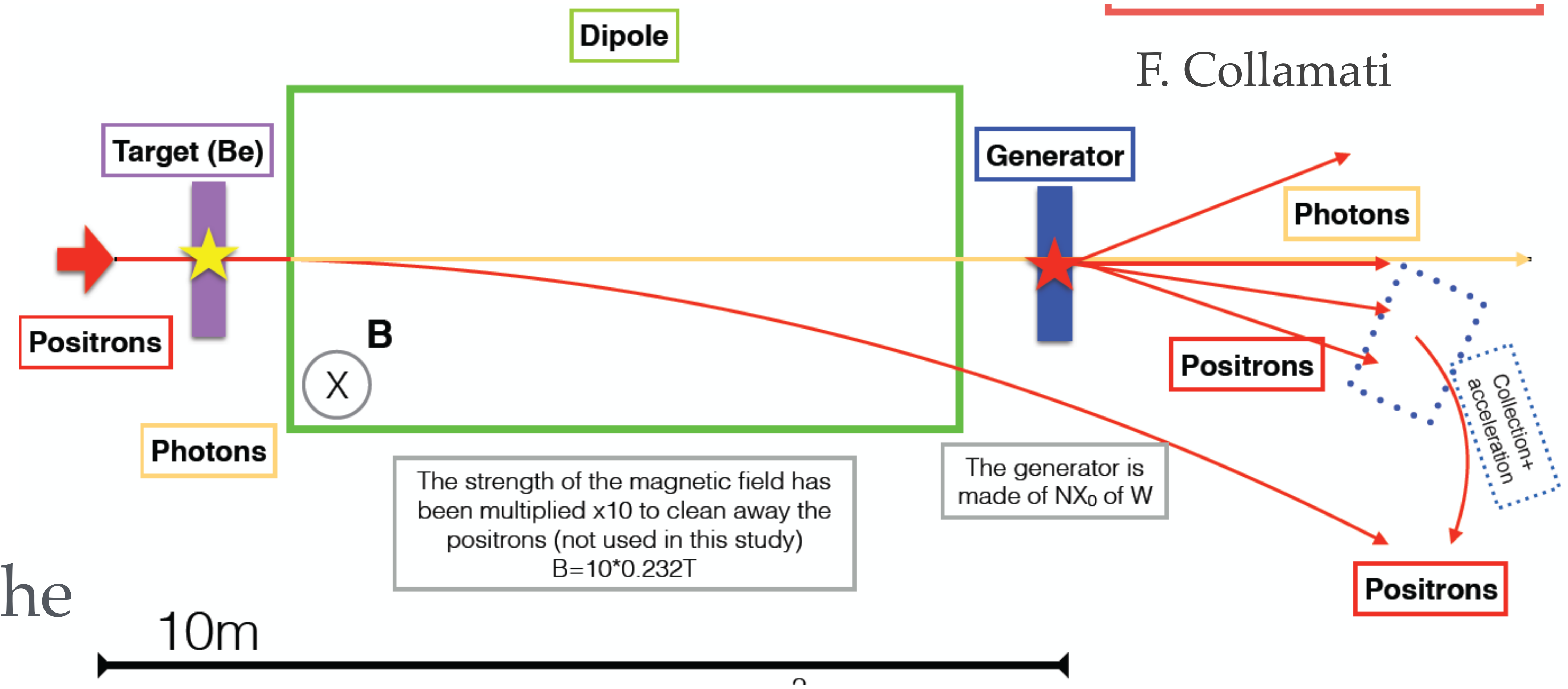
M. Boscolo

LEMMA Positron Source challenges

- To overcome low muon production efficiency (< 10^{-5}), the e+ rate ~ 10^{18} e+/s (or ~3 × 10^{11} e+/bunch inside the main ring) is needed. **Extremely high e+ flux is needed!**
- Preliminary simulations of the 45 GeV positron ring with a target show a e+ lifetime of about 40 turns for a 3 mm Be target. **The time structure of the beam on the positron target** (or CW operation) **may impose a true technological challenge** for the e+ source design.
- Positron source is a major R&D issue.

Participation of the LAL group:

- Study of the e+ source for the 45 GeV ring
- Studies on the positron/muon targets
- Study of an auxiliary e+ source using photons from the muon target (to compensate the e+ losses in the main ring).

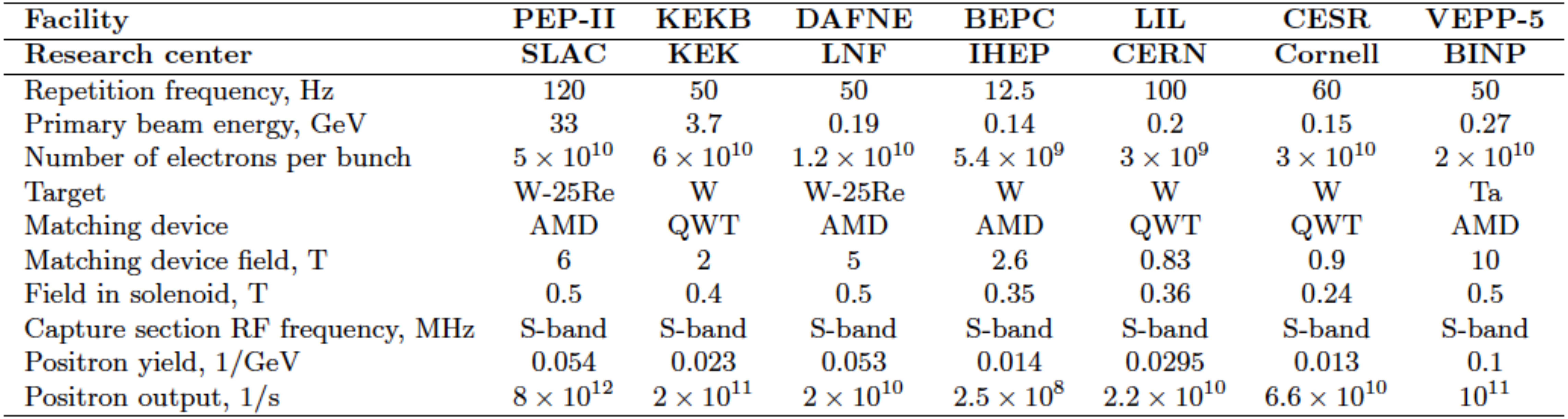


The strength of the magnetic field has been multiplied x10 to clean away the positrons (not used in this study) B=10*0.232T

The generator is made of NX_0 of W

F. Collamati

Positron source performances



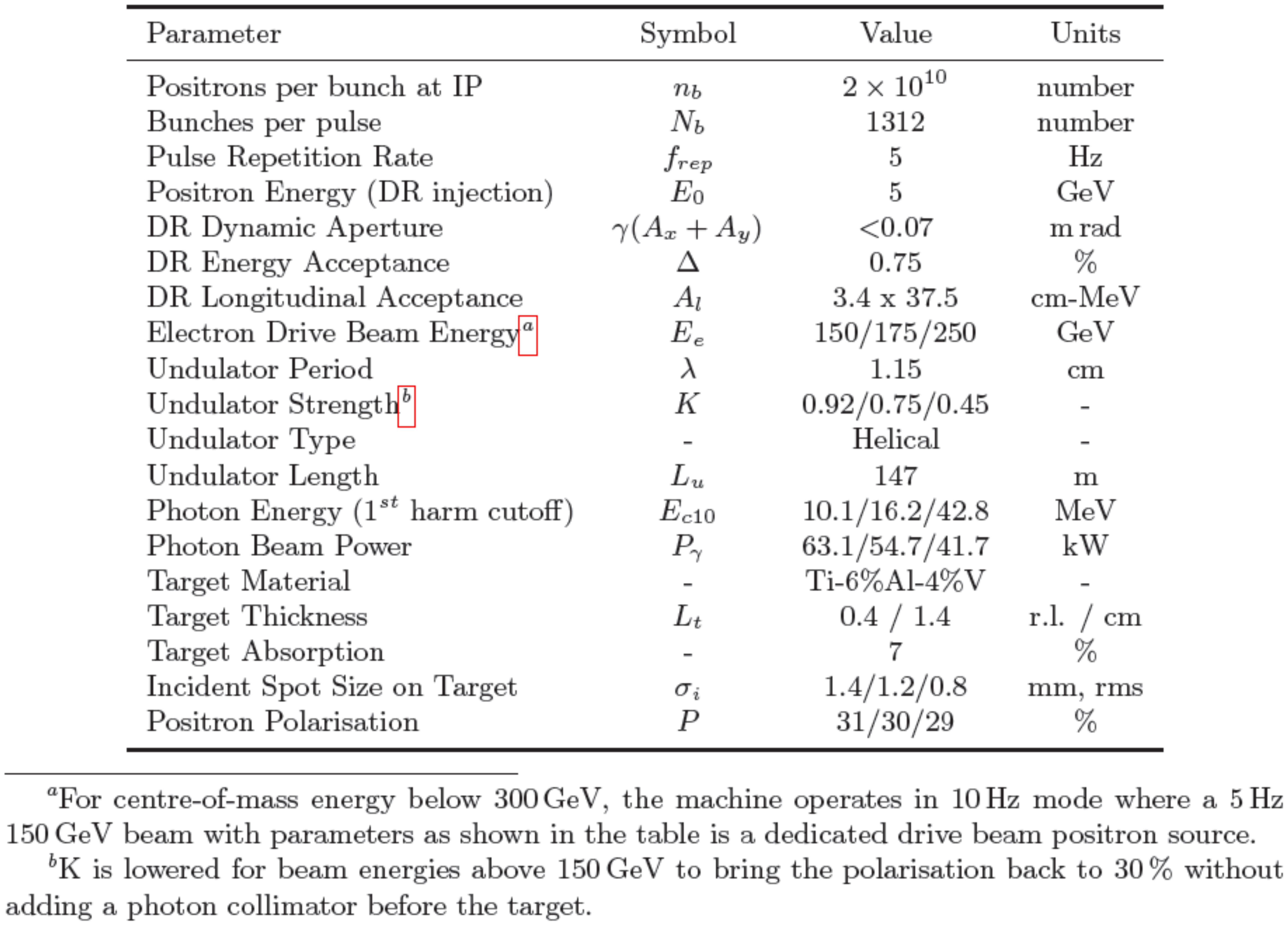
Facility	PEP-II	KEKB	DAFNE	BEPC	LIL	CESR	VEPP-5
Research center	SLAC	KEK	LNF	IHEP	CERN	Cornell	BINP
Repetition frequency, Hz	120	50	50	12.5	100	60	50
Primary beam energy, GeV	33	3.7	0.19	0.14	0.2	0.15	0.27
Number of electrons per bunch	5×10^{10}	6×10^{10}	1.2×10^{10}	5.4×10^{9}	3×10^{9}	3×10^{10}	2×10^{10}
Target	W-25Re	W	W-25Re	W	W	W	Ta
Matching device	AMD	QWT	AMD	AMD	QWT	QWT	AMD
Matching device field, T	6	2	5	2.6	0.83	0.9	10
Field in solenoid, T	0.5	0.4	0.5	0.35	0.36	0.24	0.5
Capture section RF frequency, MHz	S-band	S-band	S-band	S-band	S-band	S-band	S-band
Positron yield, 1/GeV	0.054	0.023	0.053	0.014	0.0295	0.013	0.1
Positron output, 1/s	8×10^{12}	2×10^{11}	2×10^{10}	2.5×10^{8}	2.2×10^{10}	6.6×10^{10}	10^{11}

Positron source performances

	SLC	LEP (LIL)	KEKB/SUPER KEKB	FCC-ee (conv.)*
Incident e- beam energy	33 GeV	200 MeV	3.3/3.3 GeV	4.46 GeV
e-/bunch [10^{10}]	3-5	0.5 - 30 (20 ns pulse)	6.25/6.25	5.53
Bunch/pulse	1	1	2/2	2
Rep. rate	120 Hz	100 Hz	50 Hz/50 Hz	200 Hz
Incident Beam power	~20 kW	1 kW (max)	3.3 kW	15 kW
Beam size @ target	0.6 - 0.8 mm	< 2 mm	/>0.7 mm	0.5 mm
Target thickness	$6X_0$	$2X_0$	$/4X_0$	$4.5X_0$
Target size	70 mm	5 mm	14 mm	
Target	Moving	Fixed	Fixed/Fixed	
Deposited power	4.4 kW		/0.6 kW	2.7 kW
Capture system	AMD	λ/4 transformer	/AMD	AMD
Magnetic field	6.8T->0.5T	1 T->0.3T	/4.5T->0.4T	7.5T->0.5T
Aperture of 1st cavity	18 mm	25mm/18 mm	/30 mm	20 mm
Gradient of 1st cavity	30-40 MV/m	~10 MV/m	/10 MV/m	30 MV/m
Linac frequency	2855.98 MHz	2998.55 MHz	2855.98 MHz	2855.98 MHz
e+ yield @ CS exit	~1.6 e+/e-	~3 $\times 10^{-3}$ e+/e- (linac exit)	/~0.5 e+/e-	~0.7 e+/e-
Positron yield @ DR	~1.1 e+/e-		0.4 e+/e-	
DR energy acceptance	+/- 2.5 %	+/- 1 % (EPA)	+/- 1.5 % (1 σ)	+/- 8 %
Energy of the DR	1.15 GeV	500 MeV	NO/1.1 GeV	1.54 GeV

*FCC-ee under study

Nominal parameters of ILC e+ source



Parameter	Symbol	Value	Units
Positrons per bunch at IP	n_b	2×10^{10}	number
Bunches per pulse	N_b	1312	number
Pulse Repetition Rate	f_{rep}	5	Hz
Positron Energy (DR injection)	E_0	5	GeV
DR Dynamic Aperture	$\gamma(A_x + A_y)$	<0.07	m rad
DR Energy Acceptance	Δ	0.75	%
DR Longitudinal Acceptance	A_l	3.4 x 37.5	cm-MeV
Electron Drive Beam Energy[a]	E_e	150/175/250	GeV
Undulator Period	λ	1.15	cm
Undulator Strength[b]	K	0.92/0.75/0.45	-
Undulator Type	-	Helical	-
Undulator Length	L_u	147	m
Photon Energy (1^{st} harm cutoff)	E_{c10}	10.1/16.2/42.8	MeV
Photon Beam Power	P_γ	63.1/54.7/41.7	kW
Target Material	-	Ti-6%Al-4%V	-
Target Thickness	L_t	0.4 / 1.4	r.l. / cm
Target Absorption	-	7	%
Incident Spot Size on Target	σ_i	1.4/1.2/0.8	mm, rms
Positron Polarisation	P	31/30/29	%

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[a] For centre-of-mass energy below 300 GeV, the machine operates in 10 Hz mode where a 5 Hz 150 GeV beam with parameters as shown in the table is a dedicated drive beam positron source.

[b] K is lowered for beam energies above 150 GeV to bring the polarisation back to 30 % without adding a photon collimator before the target.

Nominal parameters of ILC e- source

Parameter	Symbol	Value	Units
Electrons per bunch (at gun exit)	N	$3\text{x}10^{10}$	Number
Electrons per bunch (at DR injection)	N	$2\text{x}10^{10}$	Number
Number of bunches	n_b	1312	Number
Bunch repetition rate	f_b	1.8	MHz
Bunch train repetition rate	f_{rep}	5	Hz
FW Bunch length at source	Δt	1	ns
Peak current in bunch at source	I_{avg}	3.2	A
Energy stability	σ_E/E	<5	% rms
Polarization	P_e	80 (min)	%
Photocathode Quantum Efficiency	QE	0.5	%
Drive laser wavelength	λ	790±20 (tunable)	nm
Single bunch laser energy	u_b	5	μJ

Energy deposition/accumulation on Target

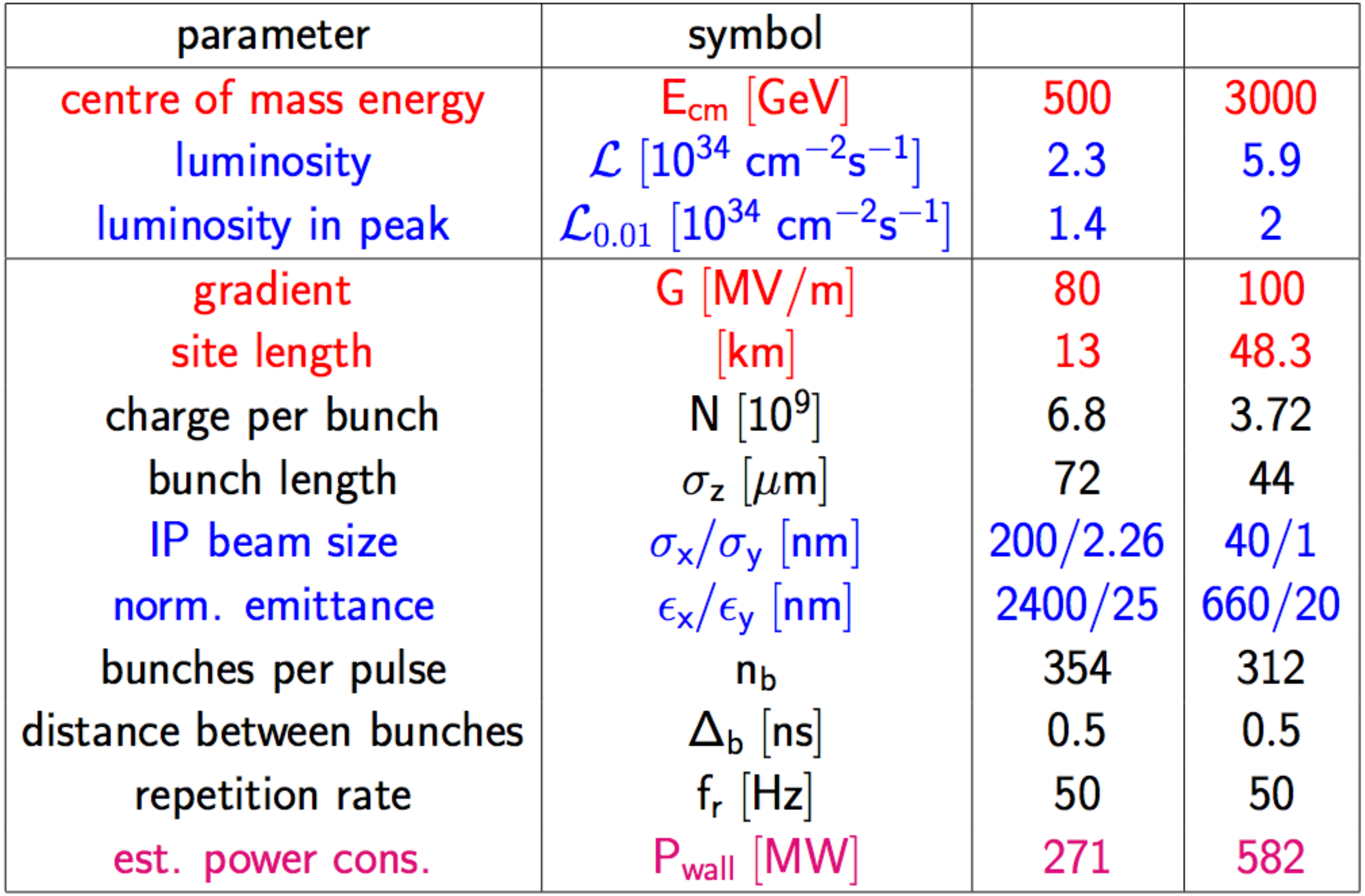
Parameter			Centre-of-mass energy E_{cm} (GeV)				
			200	230	250	350	500
Positron pulse production rate		Hz	5	5	5	5	5
Electron beam energy (e+ prod.)		GeV	150	150	150	178	252
Number of electron bunches	n_b		1312	1312	1312	1312	1312
Electron bunch population	N_+	$\times 10^{10}$	2	2	2	2	2
Required undulator field	B	T	0.86	0.86	0.86	0.698	0.42
undulator period length	λu	cm	1.15	1.15	1.15	1.15	1.15
undulator *K*	K		0.92	0.92	0.92	0.75	0.45
Average photon power on target		kW	91	100	107	55	42
Incident photon energy per bunch		J	9.6	9.6	9.6	8.1	6.0
Energy deposition per bunch (e+ prod.)		J	0.72	0.72	0.72	0.59	0.31
Relative energy deposition		%	7%	7%	7%	7.20%	5%
Photon rms spot size on target		mm	1.4	1.4	1.4	1.2	0.8
Peak energy density in target		J/cm^3	232.5	232.5	232.5	295.3	304.3
		J/g	51.7	51.7	51.7	65.6	67.5

CLIC injector beam parameters

500 GeV

Parameter	Unit	CLIC polarized electrons	CLIC positrons	CLIC booster
E	GeV	2.86	2.86	9
N	10^9	4.3/7.8	4.3/7.8	3.75/6.8
n_b	-	312/354	312/354	312/354
Δt_b	ns	1	1	0.5
t_{pulse}	ns	312/354	312/354	156/354
$\varepsilon_{x,y}$	μm	< 100	7071, 7577	$600,10 \cdot 10^{-3}$
σ_z	mm	< 4	3.3	$44 \cdot 10^{-3}$
σ_E	%	< 1	1.63	1.7
Charge stability shot-to-shot	%	0.1	0.1	0.1
Charge stability flatness on flat top	%	0.1	0.1	0.1
f_{rep}	Hz	50	50	50
P	kW	29	29	85

CLIC main parameters



parameter	symbol		
centre of mass energy	E_{cm} [GeV]	500	3000
luminosity	$\mathcal{L}$ [10^{34} cm^{-2}s^{-1}]	2.3	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ [10^{34} cm^{-2}s^{-1}]	1.4	2
gradient	G [MV/m]	80	100
site length	[km]	13	48.3
charge per bunch	N [10^9]	6.8	3.72
bunch length	σ_z [μm]	72	44
IP beam size	σ_x/σ_y [nm]	200/2.26	40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20
bunches per pulse	n_b	354	312
distance between bunches	Δ_b [ns]	0.5	0.5
repetition rate	f_r [Hz]	50	50
est. power cons.	P_{wall} [MW]	271	582