The Cockcroft Institute
of Accelerator Science and Technology

Lancaster University

Overview of Positron Sources

PAEPA, Oct 2016
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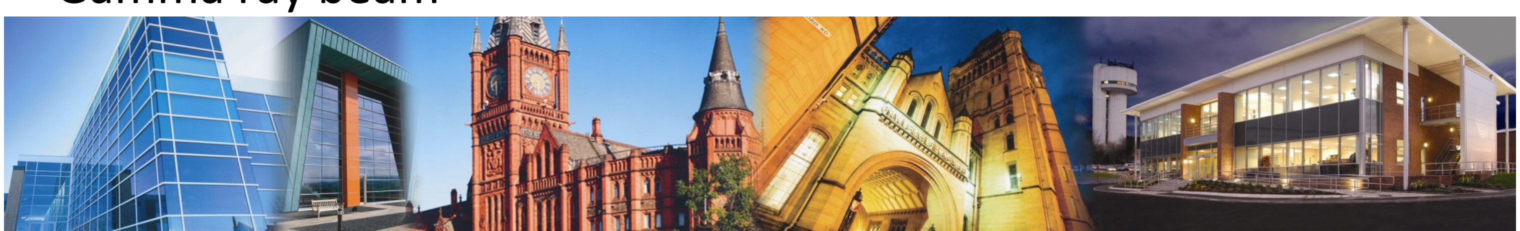
Positron Sources

- Communities
  - Slow positrons (eV for e.g. positron annihilation spectroscopy in materials studies)
  - Fast positrons (MeV for e.g. particle accelerator sources)
- Technologies
  - Radio-isotope source
    - long-lived e.g. ^{22}Na (~10^6 e^+/s)
    - or beam-induced e.g. ^{13}N (~10^9 e^+/s)
  - MeV electron beam
  - GeV electron beam
  - Gamma ray beam



Fast Positrons

- Conventional Sources
- Advanced Sources
    - Hybrid target
    - Undulator gamma-ray
    - Compton gamma-ray

Bremmstrahlung and pair-production take place when an incident electron beam enters a (usually solid) conversion target.

In all cases the major technological limitation is usually the heat-load or shockwaves in the conversion target.

Fast Positron Source Parameters

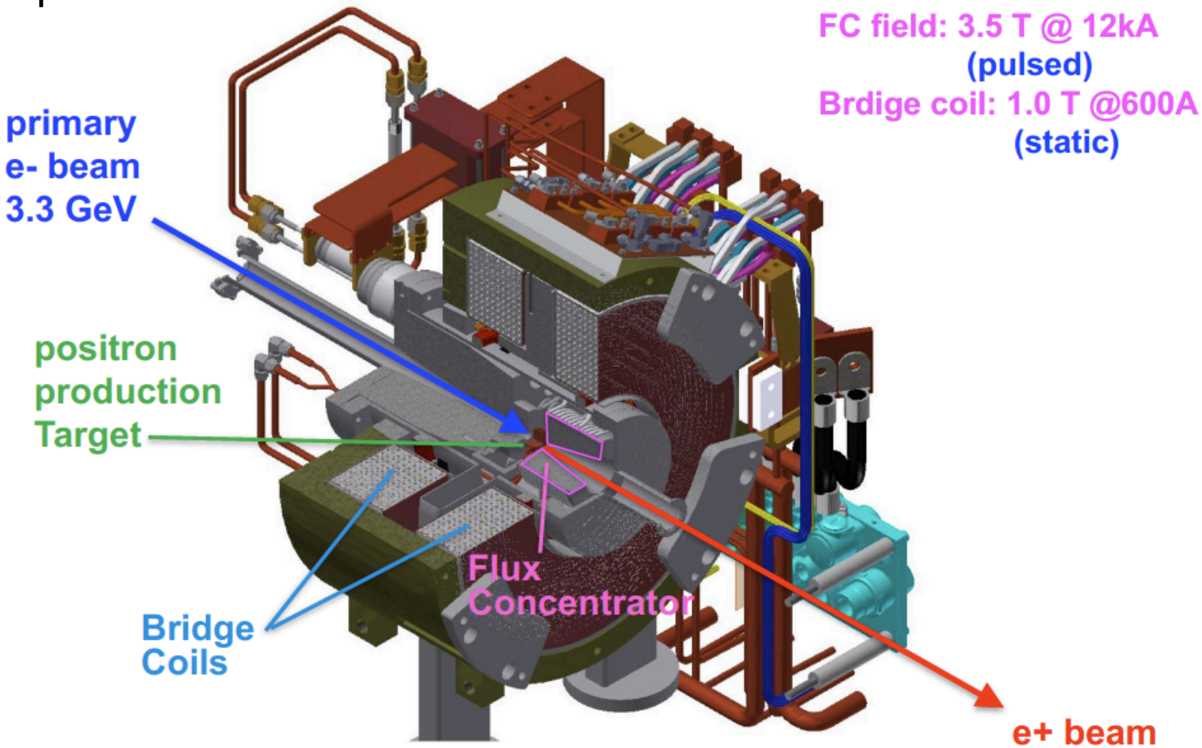
	SLC	CLIC (3 TeV)	CLIC (0.5 TeV)	ILC (RDR)	FCChe (pulsed)	FCCee (Z^0)
Energy [GeV]	1.19	2.86	2.86	5	140	45.6
e^+/ bunch (at IP) [10^9]	40	3.7	7.4	20	1.6	33
e^+/ bunch (aft. capture) [10^9]	50	7	14	30	1.8	3.3
Bunches / macropulse	1	312	354	2625	100 000	915
Rep. Rate (Hz)	120	50	50	5	10	50
Bunches / s	120	15600	17700	13125	10^6	45750
e^+ flux [10^{14}p/s]	0.06	1.1	2.5	3.9	18	1.5(fill)

Adapted from Y. Papaphilippou (CERN) and L.Rinolfi (JUAS)

Conventional Source

Super KEKB Positron Source

Takuya Kamitani (KEK), POSIPOL 2016



$0.4\ e^+/\ e^-$

Target 14mm of amorphous tungsten.

Note that a beam spoiler is used to keep the peak energy deposition density below 35J/g.

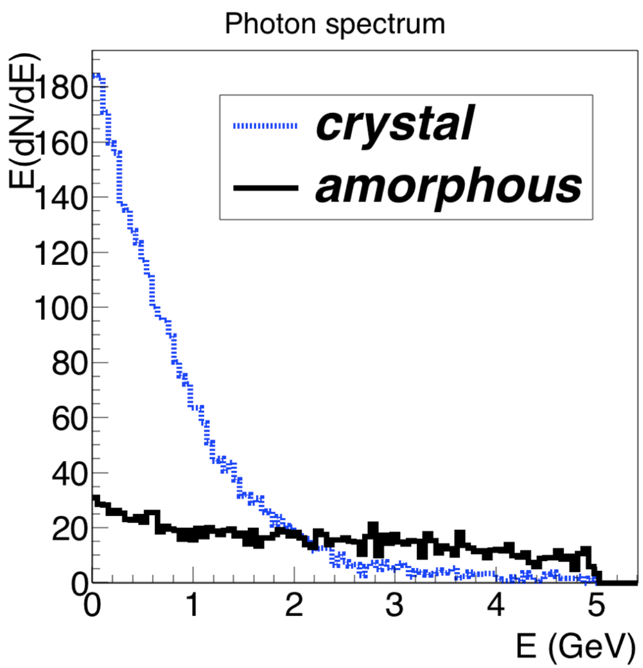
Normalised emittance 2100 mm.mrad before damping ring. Energy spread 0.1% at 4 GeV.

Injector aims to produce 2 bunches per pulse at 50Hz rep rate with a bunch charge of $2.5\times10^{10} = 2.5\times10^{12}\ e^+/s$

Hybrid Target Source

One strategy to avoid damaging the conversion target is to separate the bremmsrahlung and pair-conversion processes into two separate targets.

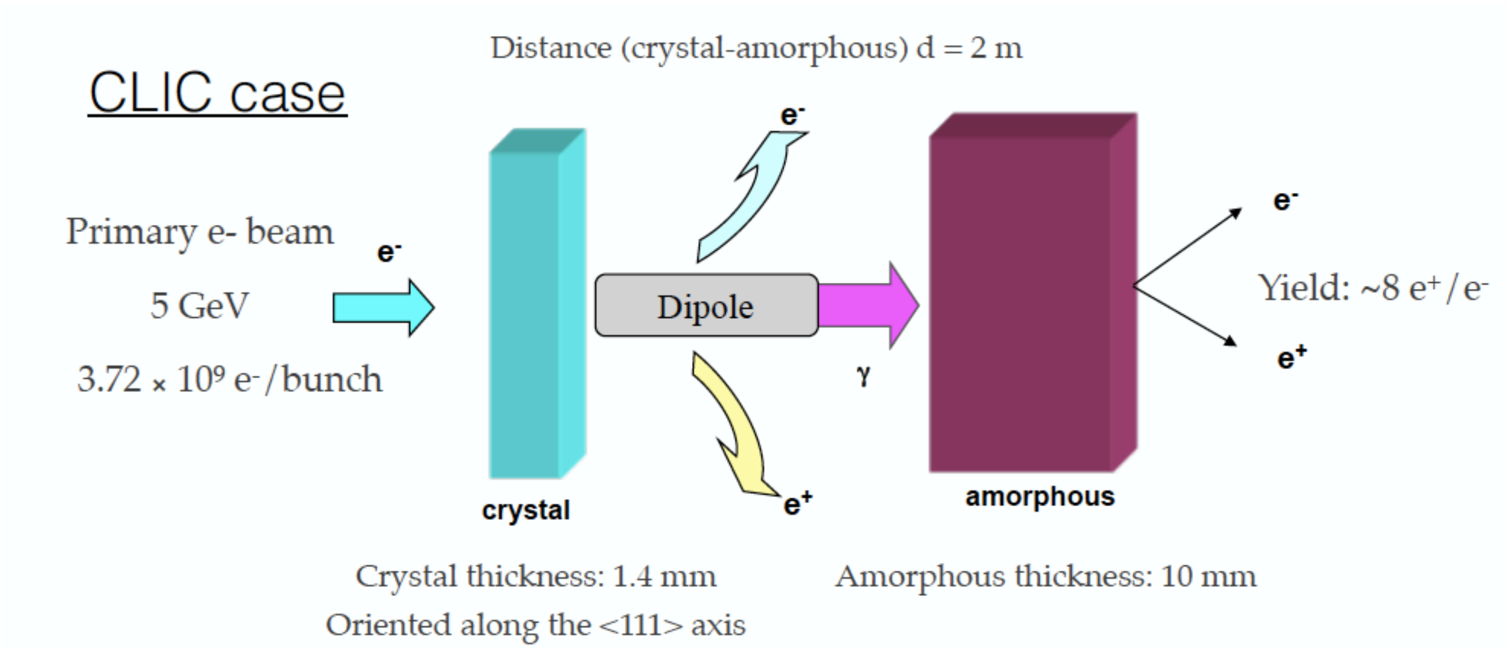
Enhanced photon production is possible in a crystalline target due to channeling radiation.



Difference in photon yield for a 5 GeV electron beam incident on a 1.4mm thick amorphous W target compared with a crystalline target of the same thickness.
(I. Chaikovska, LAL, POSIPOL 2015)

Hybrid Target Source (2)

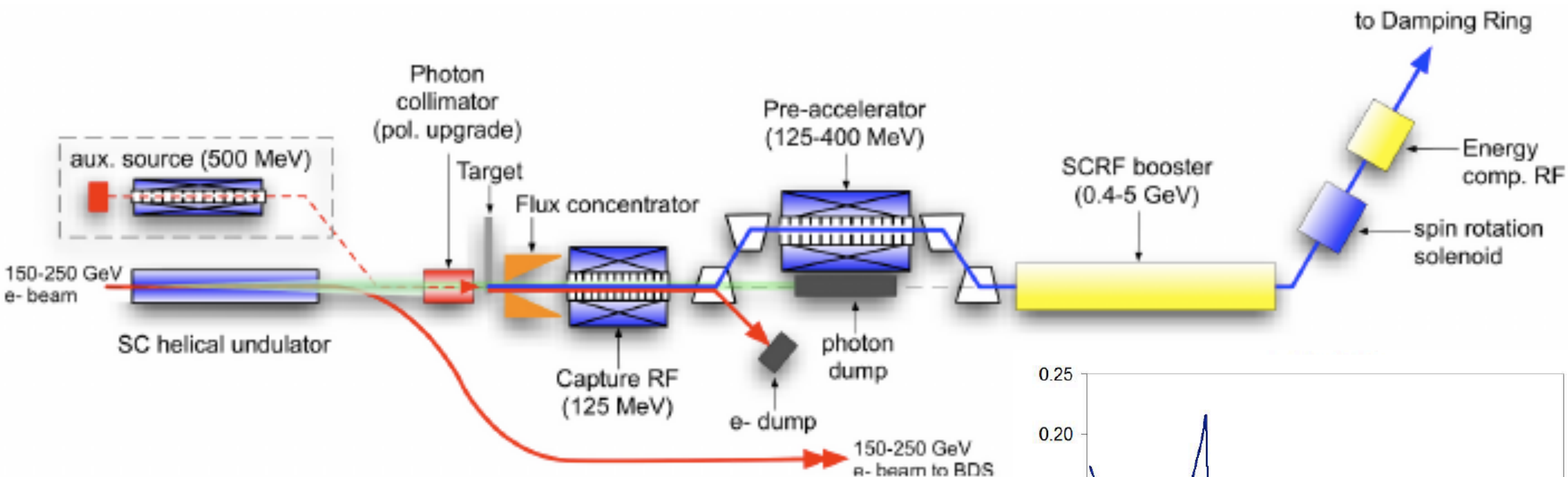
Sources of this kind are considered for SuperKEKB and for CLiC.



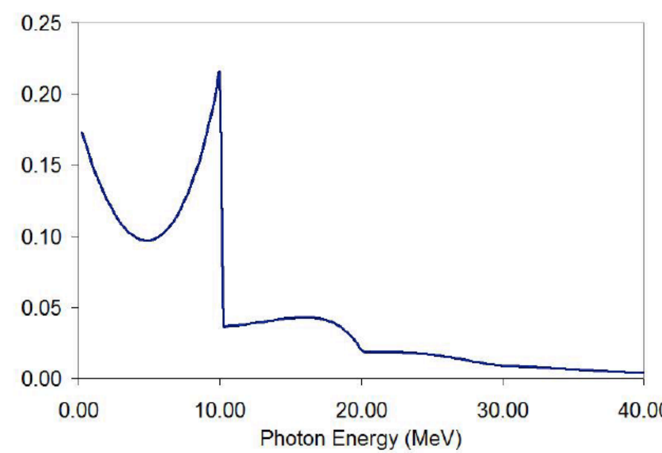
Heat dissipation in the amorphous target may be improved by replacing it with a granular target (experiment underway at KEK).

Undulator Source

Considered primarily for the ILC



The undulator produces a gamma-ray spectrum with a series of harmonic peaks.



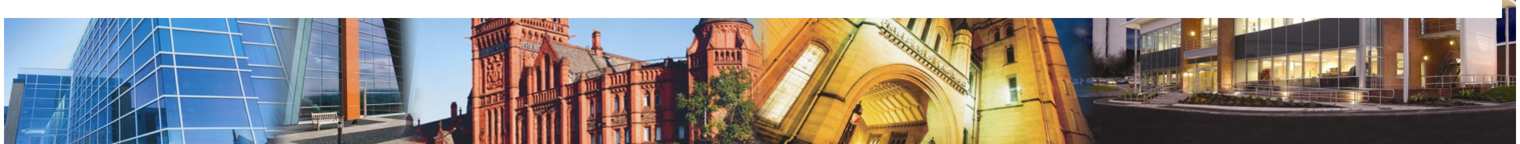
Undulator Source (2)

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	%

[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.

Normalised emittance after target 0.13m rad



Compton Source

Compton backscattering of a laser beam using an electron beam as used in most intense gamma-ray sources such as ELI-NP.

The laser is typically a YAG laser using one or more high finesse optical cavities.

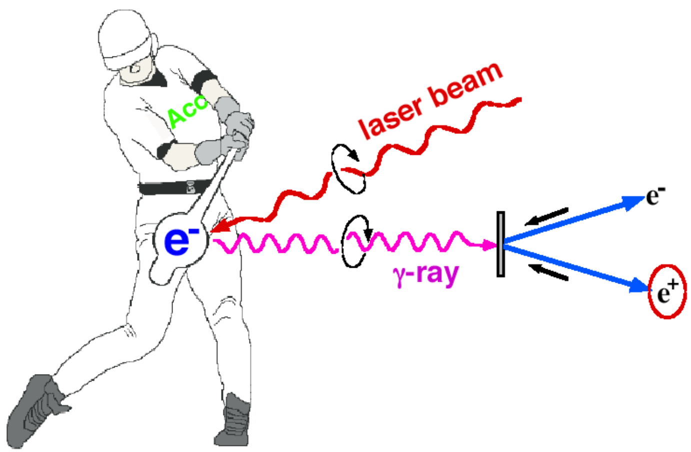


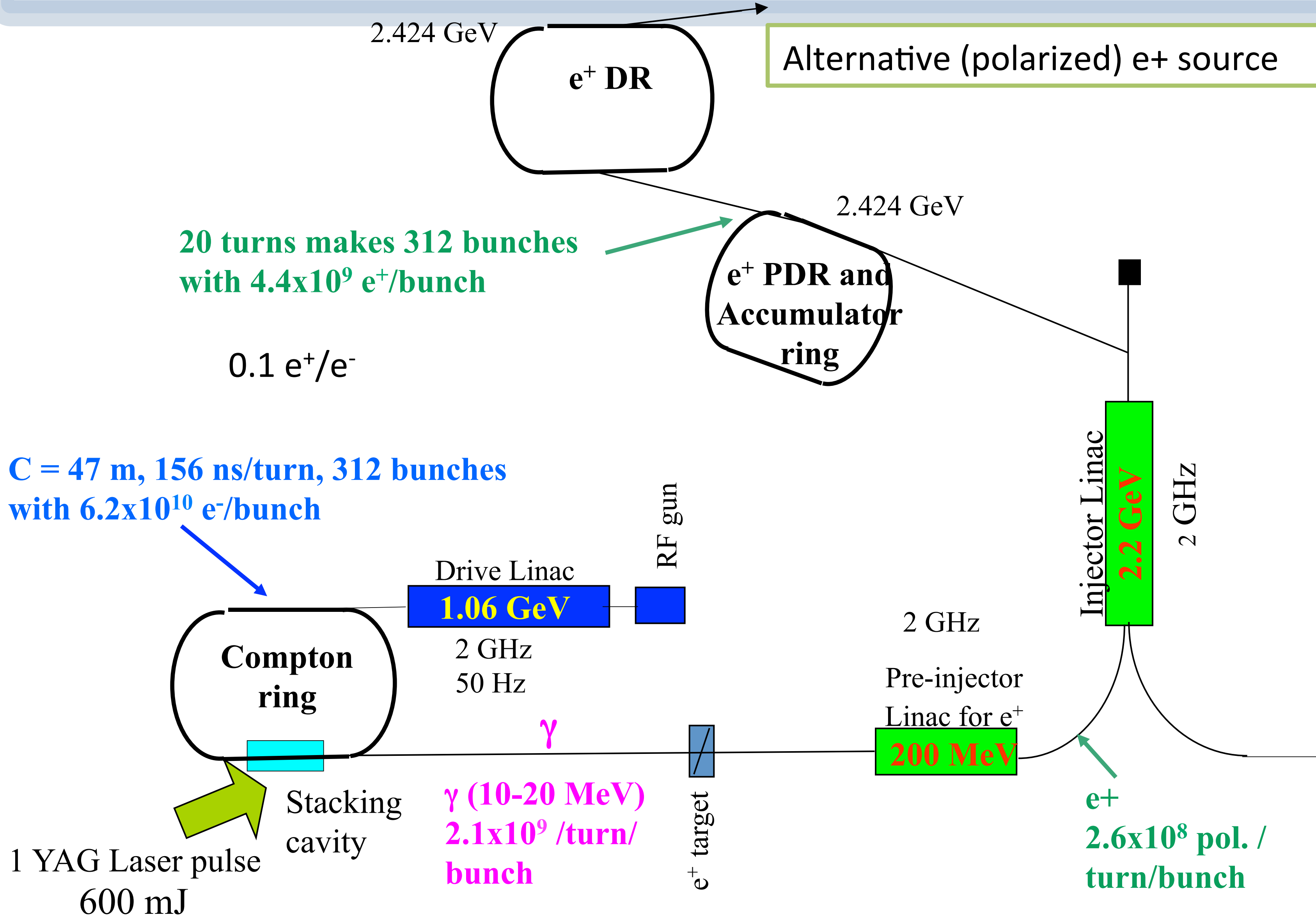
Table 1: CLIC parameters for e+ beam

Parameters	Units	CLIC 3 TeV
Energy	MeV	200
N e^+ / bunch	10^9	6.7
N bunches/pulse	-	312
Bunch spacing	ns	0.5
Pulse length	ns	156
Emittance (x,y)	mm.mrad	< 10 000
Bunch length	mm	< 10
Energy spread	%	< 8
Repetition rate	Hz	50

(pre-damping ring)

Compton Source CLIC layout

Alternative (polarized) e+ source

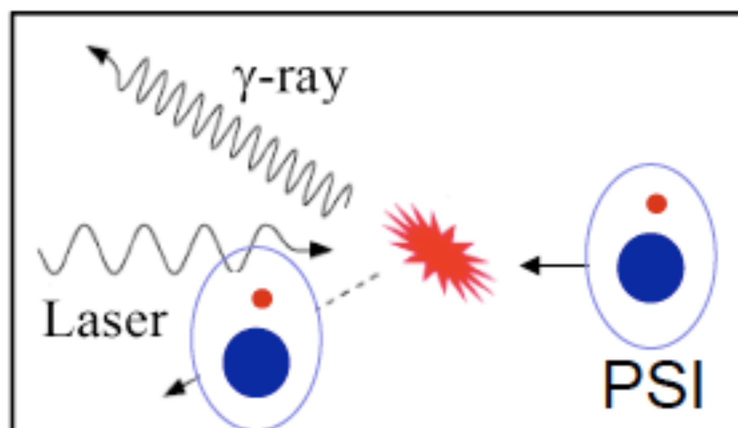


L. Rinolfi (JUAS)

Gamma Factory Proposal

Project name	LADON[a]	LEGS	ROKK-1M[b]	GRAAL	LEPS	HIγS[c]
Location	Frascati Italy	Brookhaven US	Novosibirsk Russia	Grenoble France	Harima Japan	Durham US
Storage ring	Adone	NSLS	VEPP-4M	ESRF	SPring-8	Duke-SR
Electron energy (GeV)	1.5	2.5–2.8	1.4–6.0	6	8	0.24–1.2
Laser energy (eV)	2.45	2.41–4.68	1.17–4.68	2.41–3.53	2.41–4.68	1.17–6.53
γ-beam energy (MeV)	5–80	110–450	100–1600	550–1500	1500–2400	1–100 (158)[d]
Energy selection	Internal tagging	External tagging	(Int or Ext?) tagging	Internal tagging	Internal tagging	Collimation
γ-energy resolution (FWHM)						
ΔE (MeV)	2–4	5	10–20	16	30	0.008–8.5
$\frac{\Delta E}{E}$ (%)	5	1.1	1–3	1.1	1.25	0.8–10
E-beam current (A)	0.1	0.2	0.1	0.2	0.1–0.2	0.01–0.1
Max on-target flux (γ/s)	5×10^5	5×10^6	10^6	3×10^6	5×10^6	10^4–5×10^8
Max total flux (γ/s)						10^6–3×10^9[e]
Years of operation	1978–1993	1987–2006	1993–	1995–	1998–	1996–

The idea is to use a partially-stripped ion beam, which has a far larger cross-section (approx 9 orders of magnitude) for absorbing and re-emitting the laser photons than an electron beam.



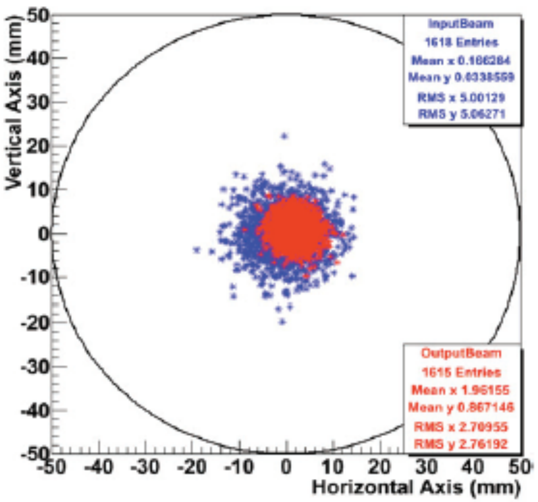
M. Krasny, LPNHE, Sep 2016

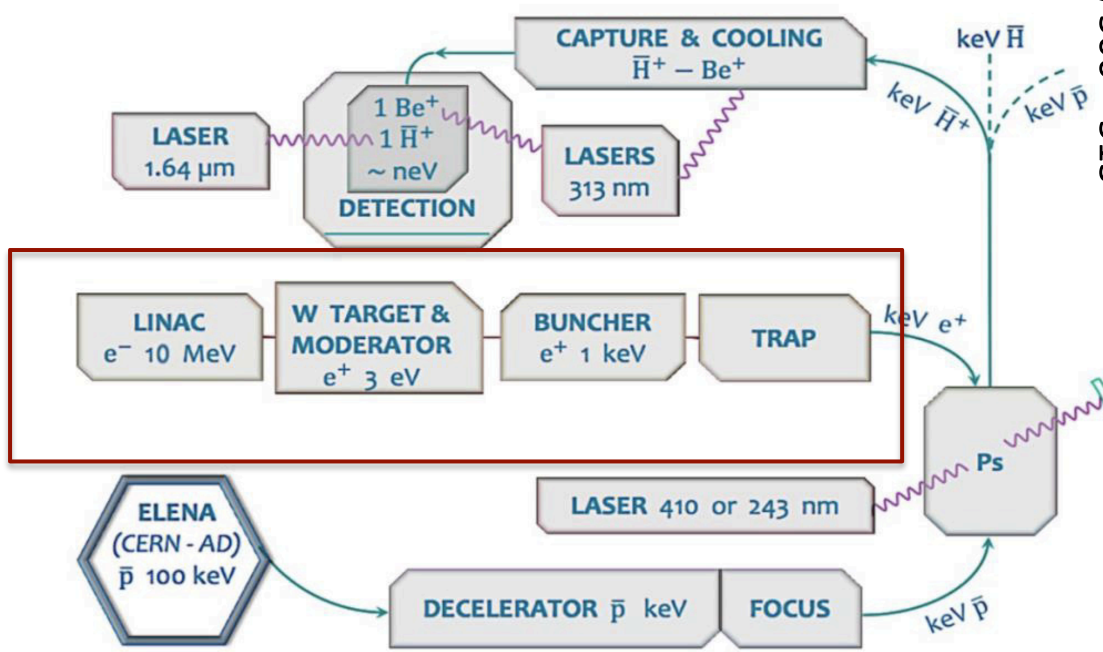
Positrons for GBAR

Physics Procedia 66 (2015) 506 – 513

GBAR (Gravitational behaviour of anti-matter at rest) under construction at CERN requires approximately 10^8 slow e^+/s to form anti-hydrogen.

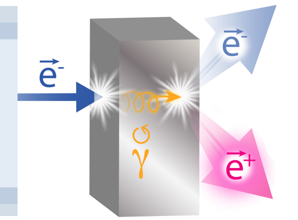
Test facility at CEA Saclay
4.5 to 5.5 MeV e- linac at 0.2mA
Tungsten target and moderator

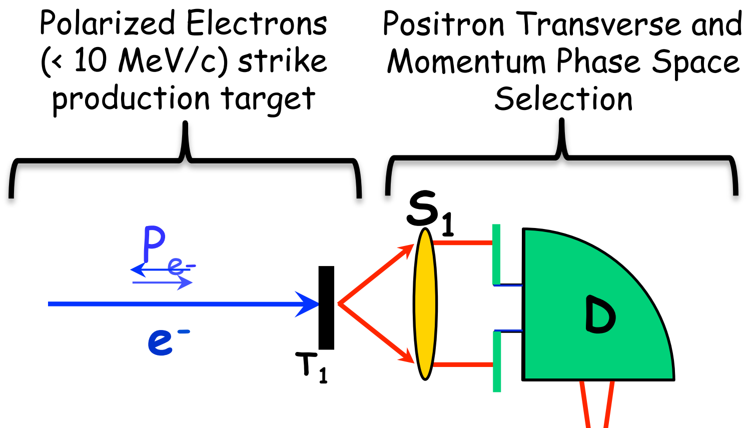


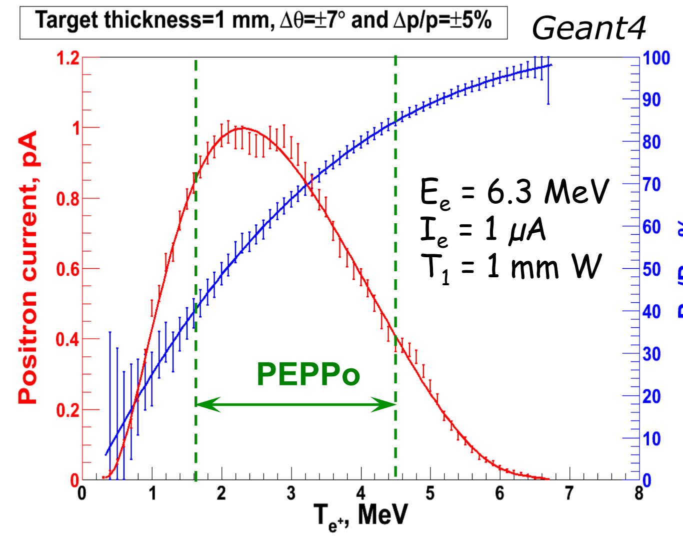


$e^+/e^- = 10^{-8}$

PEPPo @ JLab





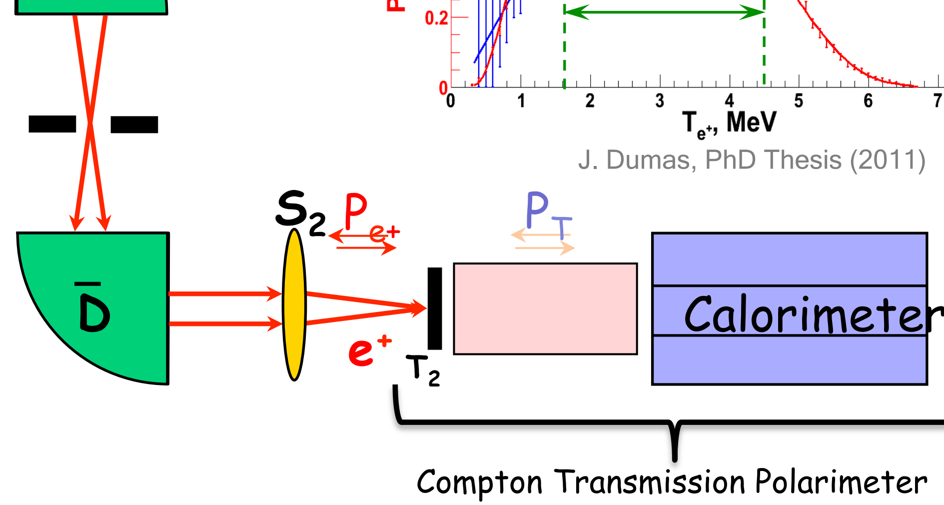


J. Dumas, PhD Thesis (2011)

E. Voutier, IPN Orsay

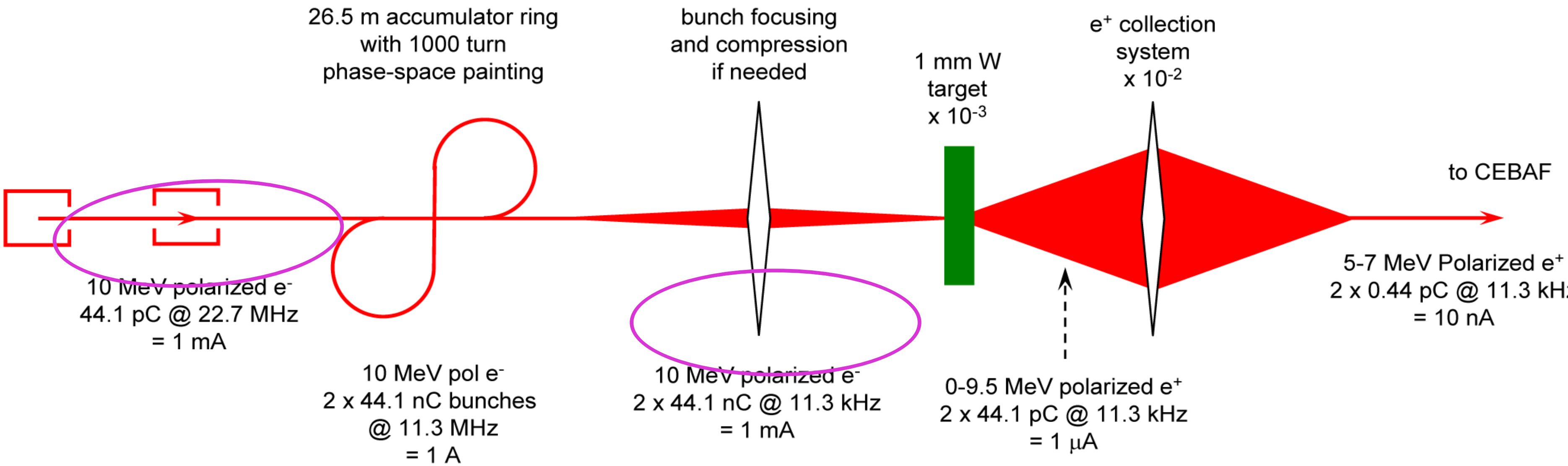
Producing **polarized** positrons using Bremmstrahlung from MeV polarized electrons.

$e^+/e^- = 10^{-5}$



PEPPo (Conceptual Design JLEIC at JLab)

JLEIC is a proposed polarized electron-ion collider



J. Grames, J. Guo, F. Lin, V. Morozov (2016)

50Hz repetition rate

73 bunches/pulse

1.4×10^{7} e^{+}/bunch

Requires 5.0×10^{10} e^{+}/s with 40% polarization

Summary

- All positron injectors for major future particle colliders require 10^{11} to 10^{14} e^+/s
- The injectors are limited by target survivability and/or optical cavity technology
- GeV electron beams give roughly $1e^+/e^-$. MeV e^+ can then be either
  - Moderated…
  - or accelerated.
- MeV electron beams give low conversion rates but avoid activation of the target area.

Backup Slides

ILC Undulator Source polarization

S. Riemann / DESY

Parameter	Unit					L upgrade
Centre-of-mass energy	GeV	200-250	350	500	500	500
Drive-electron-beam energy	GeV	150	175	250	250	250
Undulator K value				0.92		
Undulator period	cm			1.15		
Positron polarisation	%	55	59	50	59	50
Collimator-iris radius	mm	2.0	1.4	1.0	0.7	1.0
Active undulator length	m	231	196	70	144	70
Photon beam power	kW	98.5	113.8	83	173	166
Power absorbed in collimator	kW	48.1	68.7	43.4	121	86.8
Power absorbed in collimator	%	48.8	60.4	52.3	70.1	52.3

Demonstration with E-166 experiment at SLAC

R. Pitthan & J. Sheppard / SLAC

Polarization of 80% was measured for e^+ (and e^-) in the range 4 – 8 MeV