Brief history of the CLIC and other brilliant positron sources

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CERN - Geneva

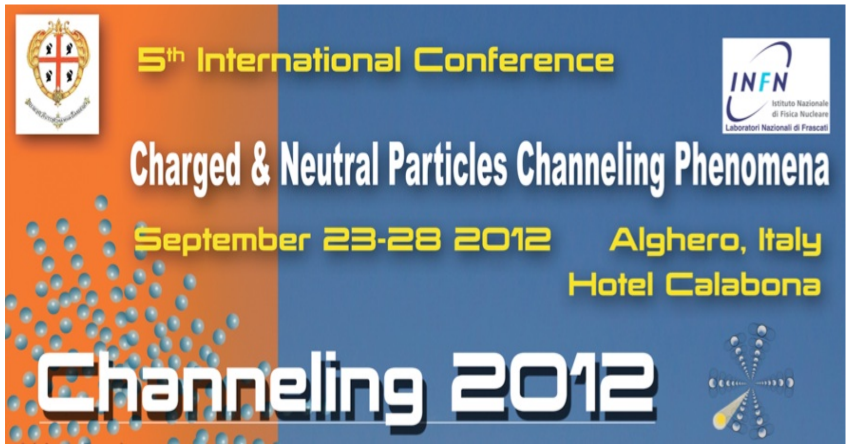
Thanks to:

R. Chehab / IPNL - Lyon

O. Dadoun, A. Variola / LAL - Orsay

T. Kamitani / KEK - Tsukuba

V. Strakhovenko / BINP - Novosibirsk



Acknowledgments

Alphabetic order for countries

for the CLIC Main Beam Generation studies

Countries	Institutes	Collaborators	Subject
France	LAL	I. Chaikovska, O. Dadoun, F. Poirier, A. Variola, C. Xu	e^+ studies
France	IPNL	X. Artru, R. Chehab, M. Chevallier	Channeling studies
Italy	Trieste	G. D'Auria	Linacs
Japan	Hiroshima Uni.	M. Kuriki, T. Takahashi	Experiments at KEKB
Japan	KEK	T. Kamitani, T. Omori, J. Urakawa	e^+ studies
Russia	BINP	V. Strakhovenko	Channeling studies
Sweden	Uppsala Uni.	A. Ferrari	Linacs optics
Switzerland	CERN	F. Antoniou, A. Latina, Y. Papaphilippou, P. Sievers, F. Tecker, A. Vivoli, F. Zimmermann	Targets, Linacs & Damping rings
Turkey	Uludag Uni.	E. Eroglu, A. Kenan Çiftçi, E. Pilicer, I.Tapan	FLUKA simulations
Ukraine	Kharkov Inst.	E. Bulyak, P. Gladkikh	Compton Rings
UK	Cockcroft Inst.	I. Bailey, J. Clarke, L. Zang	Undulator e^+ studies
USA	ANL	W. Gai, W. Liu	Undulator e^+ studies
USA	BNL	I. Pogorelski, V. Yakimenko	Compton Linac
USA	JLAB	M.Poelker, J. Grames	DC gun for polarized e-
USA	SLAC	A. Brachmann, J. Sheppard, F. Zhou	Polarized e- sources

A very brief history

CLIC

1985: **CLIC = CERN Linear Collider**

CLIC Note 1: "Some implications for future accelerators" by J.D. Lawson => first CLIC Note

1995: **CLIC = Compact Linear Collider**

=> 6 Linear colliders studies (TESLA, SBLC, JLC, NLC, VLEPP, CLIC)

2004: International Technology Recommendation Panel selects the Superconducting RF technology (TESLA based) versus room temperature technology (JLC/NLC based)

=> ILC at 1.3 GHz for the TeV scale and CLIC study at 30 GHz continues for the multi-TeV scale

2006: CERN Council Strategy group (Lisbon July 2006) => "… a coordinated programme should be intensified to develop the CLIC technology … for future accelerators…."

2007: **Major parameters changes:** 30 GHz => **12 GHz** and 150 MV/m => **100 MV/m**

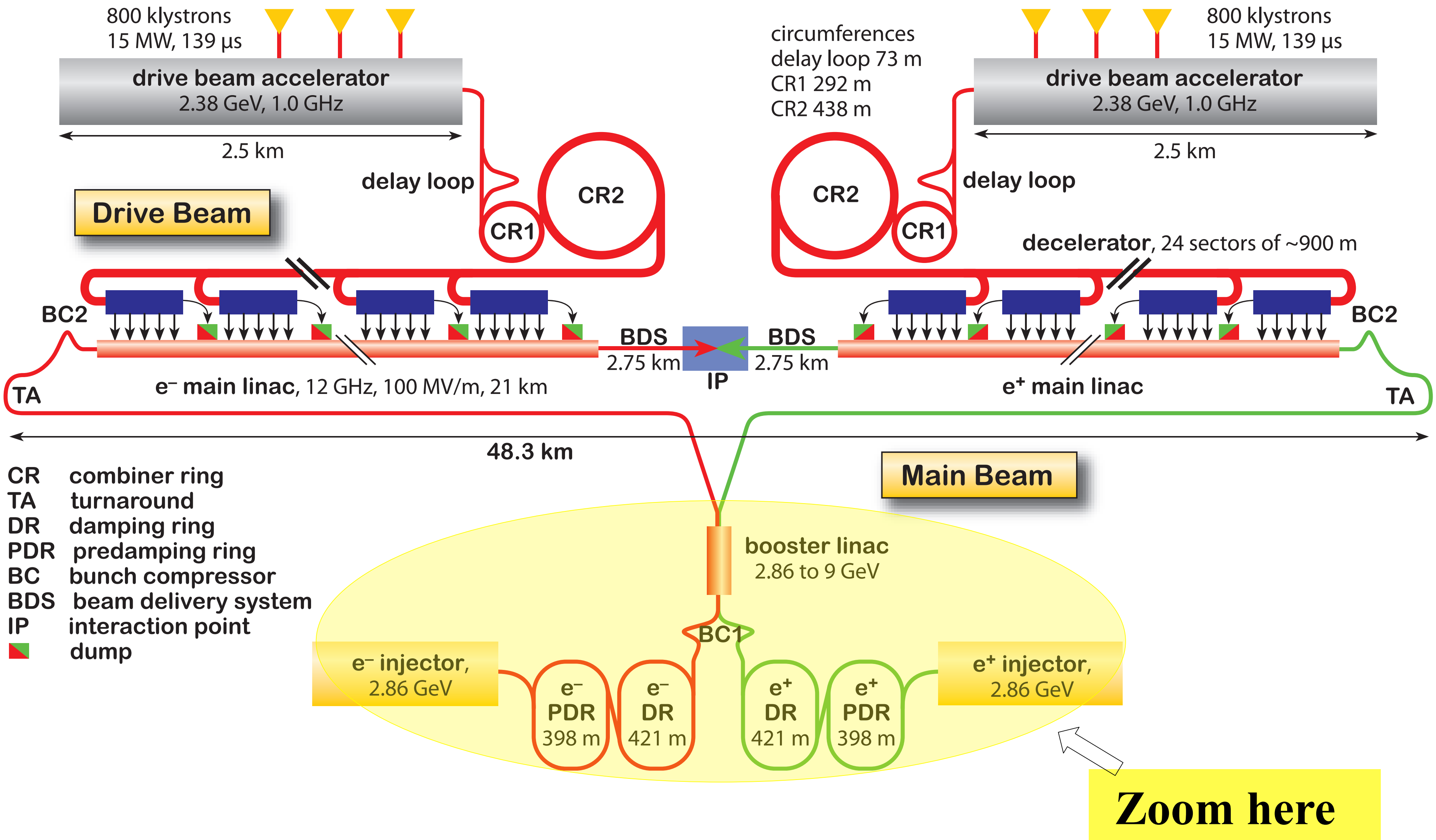
2008: New ILC/CLIC common working groups called "e^+ generation"

2012 : July: Announce observation at LHC of particle consistent with long-sought Higgs boson
CERN Council Strategy group for Particle Physics (Krakow September 2012)

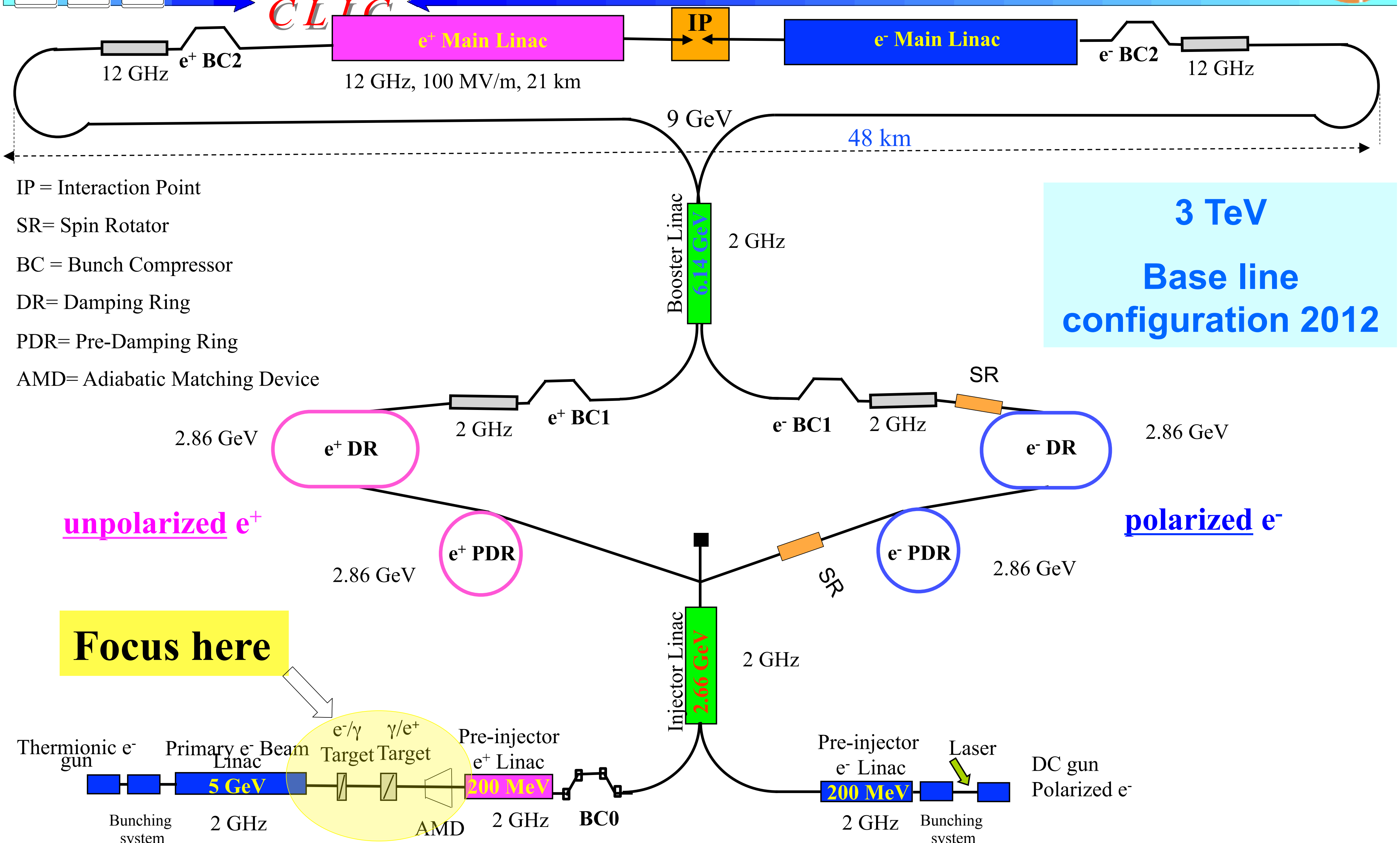
Publication of CLIC - CDR (Conceptual Design Report)

27 years !!!

CLIC layout for 3 TeV



CLIC Main Beam Injector Complex



Linear colliders in 1996

Technology			TESL	SBLC	JLC_C	JLC_X	NLC	VLEPP	CLIC
			S.C.	⇐	KLYSTRONS			⇒	TBA
Beam parameters at I.P.									
Centre of mass energy	[TeV]	$2U_b$	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Luminosity	$10^{33}cm^{-2}s^{-1}$	L	6.0	5.0	6.6	5.2	5.5	9.3	6.7
Beamstrahlung mom. spread	[%]	δ_B	2.9	3.1	3.9	3.5	3.2	13.3	3.5
Linac repetition rate	[Hz]	f_{rep}	5	50	100	150	180	300	700
Number of particles/bunch	$[10^{10}e^{\pm}]$	N_e	3.63	1.1	1.0	0.63	0.75	20	0.8
Number of bunches/pulse	[-]	N_b	1130	333	72	85	90	1	20
Bunch spacing	[nsec]	Δ_b	708	6	2.8	1.4	1.4	-	1.0
Transverse emittances .	10^{-8} radm	$\gamma\varepsilon_{x,y}$	1400/25	500/25	330/4.5	330/4.8	400/9	2000/7.5	487/10
RMS beam width .	[nm]	$\sigma_{x,y}$	845/19	335/15	318/4.3	260/3.0	294/6.3	2000/4	315/4.2
Bunch length	[µm]	σ_z	700	300	200	90	125	750	160
Enhancement factor	[-]	H_D	2.3	1.8	1.82	1.4	1.4	2.0	1.24
Beam power per beam	[MW]	P_b	16.5	7.25	3.2	3.2	4.8	2.4	4.49
Main Linac									
RF frequency of main linac	[GHz]	$\omega/2\pi$	1.3	3	5.7	11.4	11.4	14	30
Accelerating field (loaded)	[MV/m]	G	25	17	31.9	58	29.4	91	100
Total two linacs length	[km]	l_T	32	36	18.8	10.4	17.6	7	7.5
Length of sections	[m]	l_s	1.04	6	1.8	1.31	1.8	1.0	0.32
Klystron peak power	[MWatts]	P_k	8	150	50.3	135	50	150	159000
Klystron pulse length	[µsec]	Δ_k	1315	2.8	2.44	0.5	1.2	0.5	0.041
RF pulse compression ratio	[-]	-	-	-	5	2	3.6	3.2	-
Number of klystrons	[-]	N_k	604	2517	4184	3320	4528	140	10
AC to RF efficiency	[%]	η_{RF}^{AC}	35	37	22.6	30	28	39	35
AC to beam efficiency	[%]	η_b^{AC}	19	10.7	4.2	5.6	7.9	8.4	9.4
AC power for RF generation	[MW]	P_{AC}	88	136	153	114	121	57	96

Table 1: Main parameters of TLC designs in a first stage at 500 GeV c.m., updated from [2]

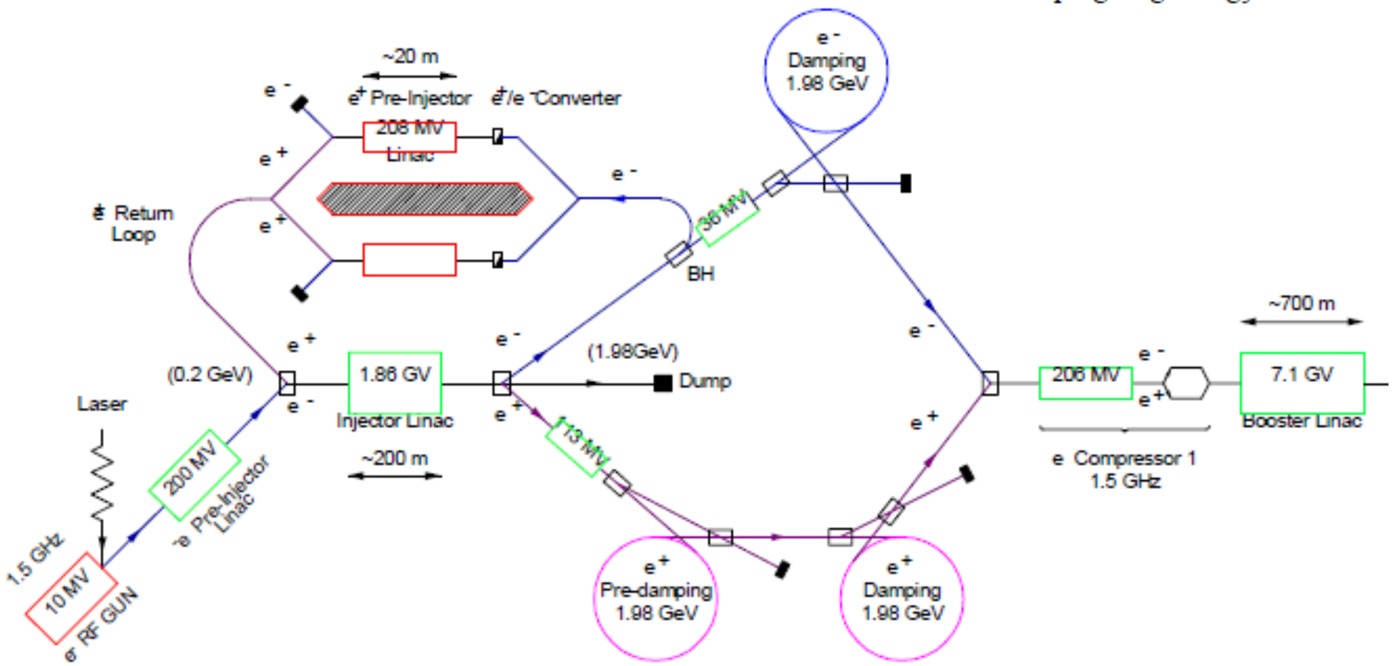
CLIC Main beam parameters in 1997

CLIC Note 354

Parameters	Unit	1994	1997 (1 TeV)
Number of bunches in the train	k	1 to 4	60
Number of particles per bunch	10^9 $e^{\pm}$	8.3	4
Normalised vertical emittance	rad-m	0.05×10^{-6}	0.04×10^{-6}
Normalised horizontal emittance	rad-m	1.50×10^{-6}	1×10^{-6}
RMS bunch length	µm	170	50
RMS bunch length	ps	56	16
Train repetition frequency	Hz	1700	444
Bunch spacing	ps	800	666
Beam power	MW	4.51	8.53
Damping ring energy	GeV	2.15	1.98

All linacs are L-band (1.5 GHz) and have super-conducting structures except the e pre-injector linac and the main linacs

Flux = 2.2 x 10^{14} e^+ /s



G. Lemeur / LAL

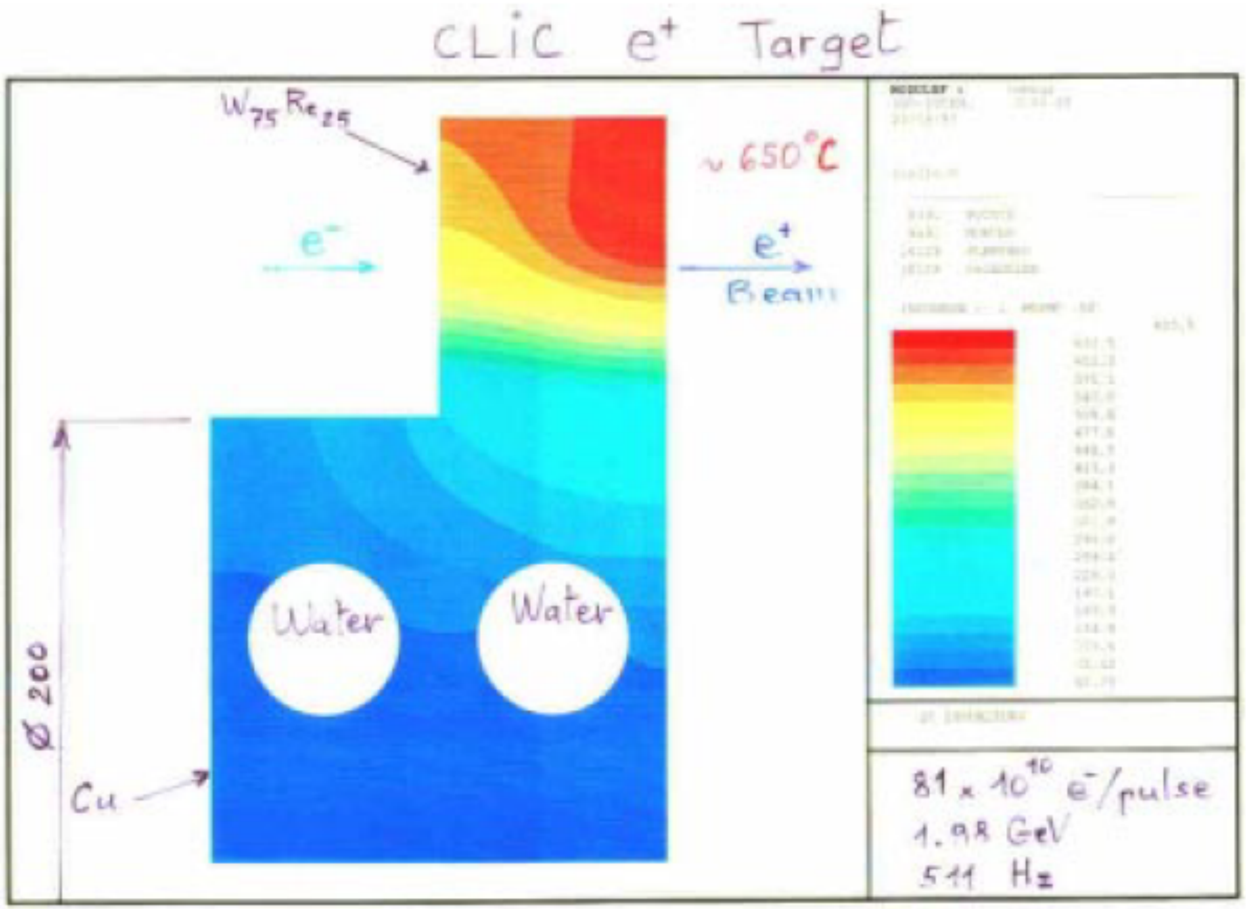


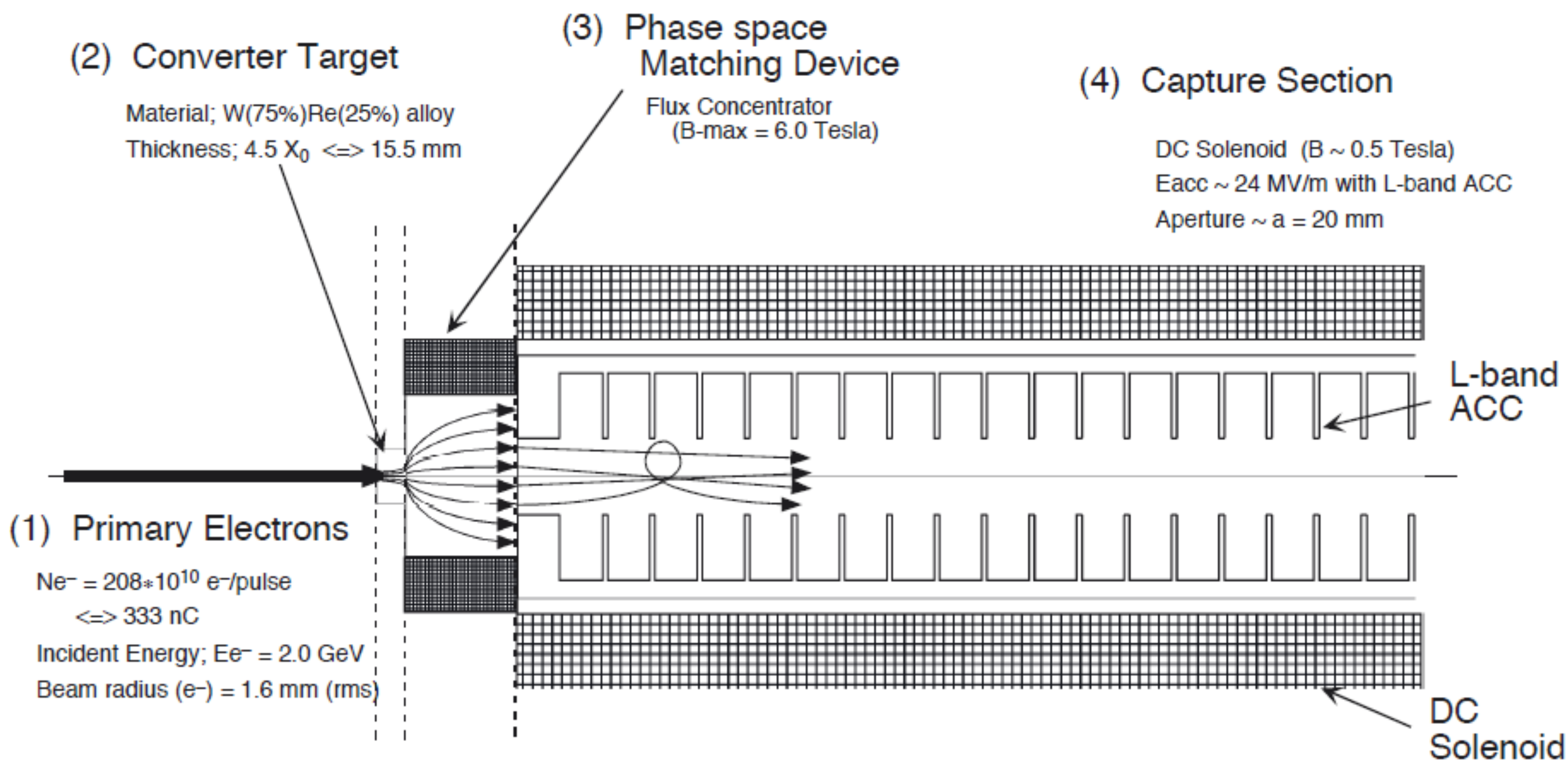
Figure 5: CLIC e^+ target. The target $W_{75}Re_{25}$ (red and green regions) is installed on a copper block (blue) where the 2 holes are foreseen for the water cooling. The temperature rise is calculated for 81×10^{10} e^- /pulse at 1.98 GeV and with a repetition rate of 511 Hz. It is 630 °C above the water temperature

CLIC e⁺ source in 2001

CLIC Note 465

Positron Conversion Efficiency

$$\frac{Ne^{+}}{Ne^{-} \times Ee^{-}} = 0.30\ [GeV^{-1}]$$



SLAC – CLIC targets comparison

Parameters	Units	SLAC Exp. (sample B1)	CLIC
Beam energy	[GeV]	24.4	2.0
Ne^- per pulse	[10^{10} e^-]	8.0	208.0
Beam size	[mm]	0.91 (x), 0.35 (y)	1.6 (r)
Target thickness	[χ_0]	5.4	4.5
Target material		$W_{75}Re_{25}$	$W_{75}Re_{25}$
Density per area	[10^{12} GeV/mm^2]	1.95	0.52
Peak density per vol.	[10^{10} GeV/mm^3]	0.93	0.64
Incident beam energy	[10^{10} GeV/mm^2 χ_0]	7.2	3.3
Beam density	[kJ/kg]	76	53

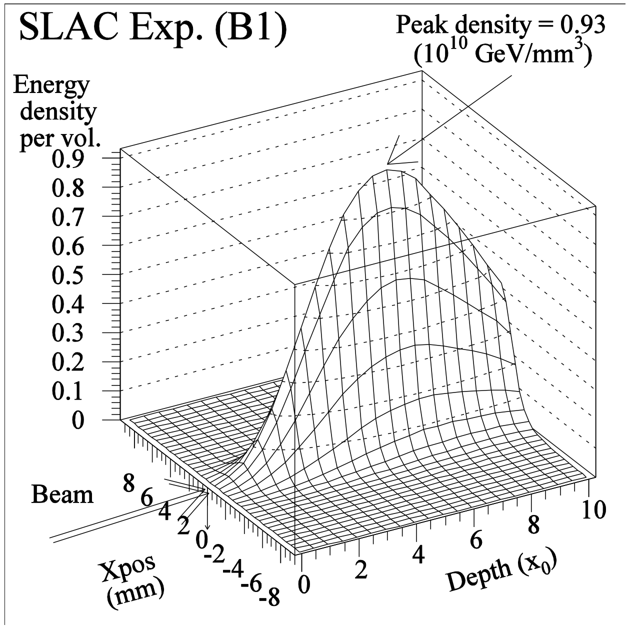
Peak volume density calculation from EGS4:

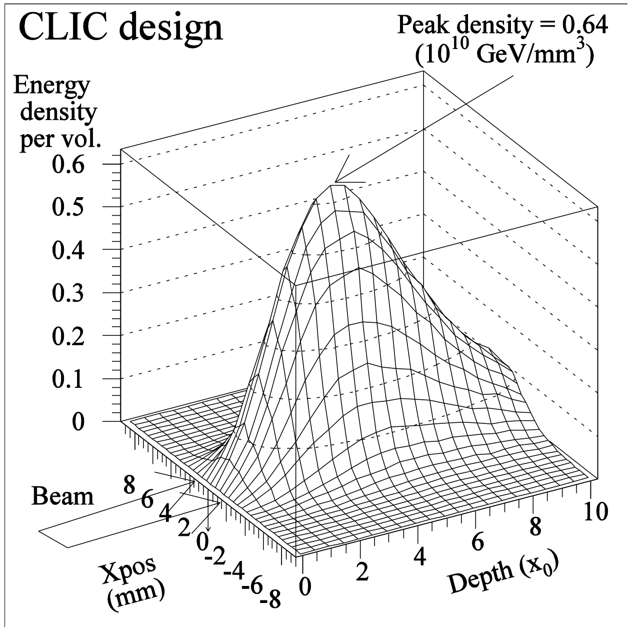
Mesh volume = dx*dy*dz = 0.425 mm^2

dx = dy = 0.5 mm

dz = 1.7 mm = 0.5 χ_0

For CLIC => E_{max} = 1.3 MeV/e-





Shower distribution around the Peak Energy Distribution Density (PEDD)

Peak at 6 χ_0 for SLAC

Peak at 4 χ_0 for CLIC

Flux of e^+ in 2012

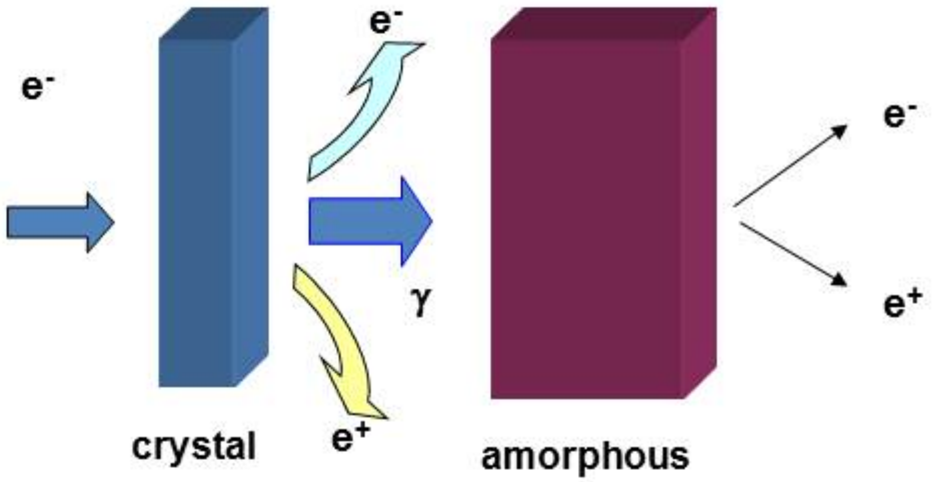
	SLC	CLIC (3 TeV)	CLIC (0.5 TeV)	ILC (RDR)	LHeC (pulsed)	LHeC ERL
Energy	1.19 GeV	2.86 GeV	2.86 GeV	5 GeV	140 GeV	60 GeV
e^+/ bunch (at IP)	40×10^9	3.7×10^9	7.4×10^9	20×10^9	1.6×10^9	2×10^9
e^+/ bunch (aft. capture)	50×10^9	7×10^9	14×10^9	30×10^9	1.8×10^9	2.2×10^9
Bunches / macropulse	1	312	354	2625	100 000	NA
Rep. Rate (Hz)	120	50	50	5	10	CW
Bunches / s	120	15600	17700	13125	10^6	20×10^6
e^+ / second $\times 10^{14}$	0.06	1.1	2.5	3.9	18	440

x 20 x 70 x 7000

Hybrid targets for CLIC

Based on the SLAC experiment and our simulations, a conventional fixed target would have difficulty to survive to the beam power deposition and to the shock waves

Apply the concept of hybrid targets proposed by R. Chehab, V. Strakhovenko and A. Variola



Channeling process in the thin crystal

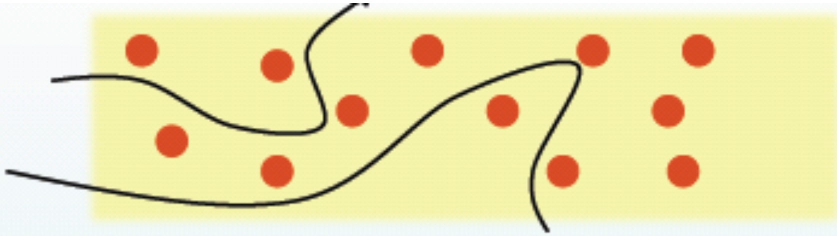
Only photons are impinging on the amorphous converter

Presented at POSIPOL workshop 2008 for CLIC

Channeling of charged particles

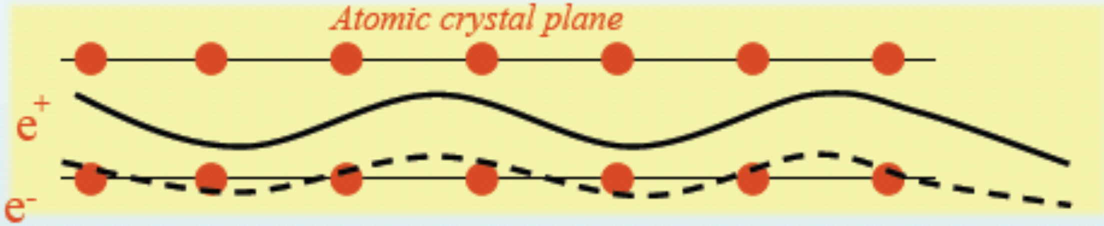
S. Dabagov

@ Amorphous:

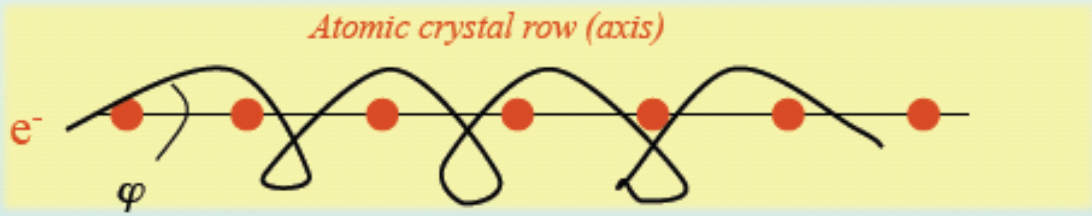


@ Channeling:

planar channeling



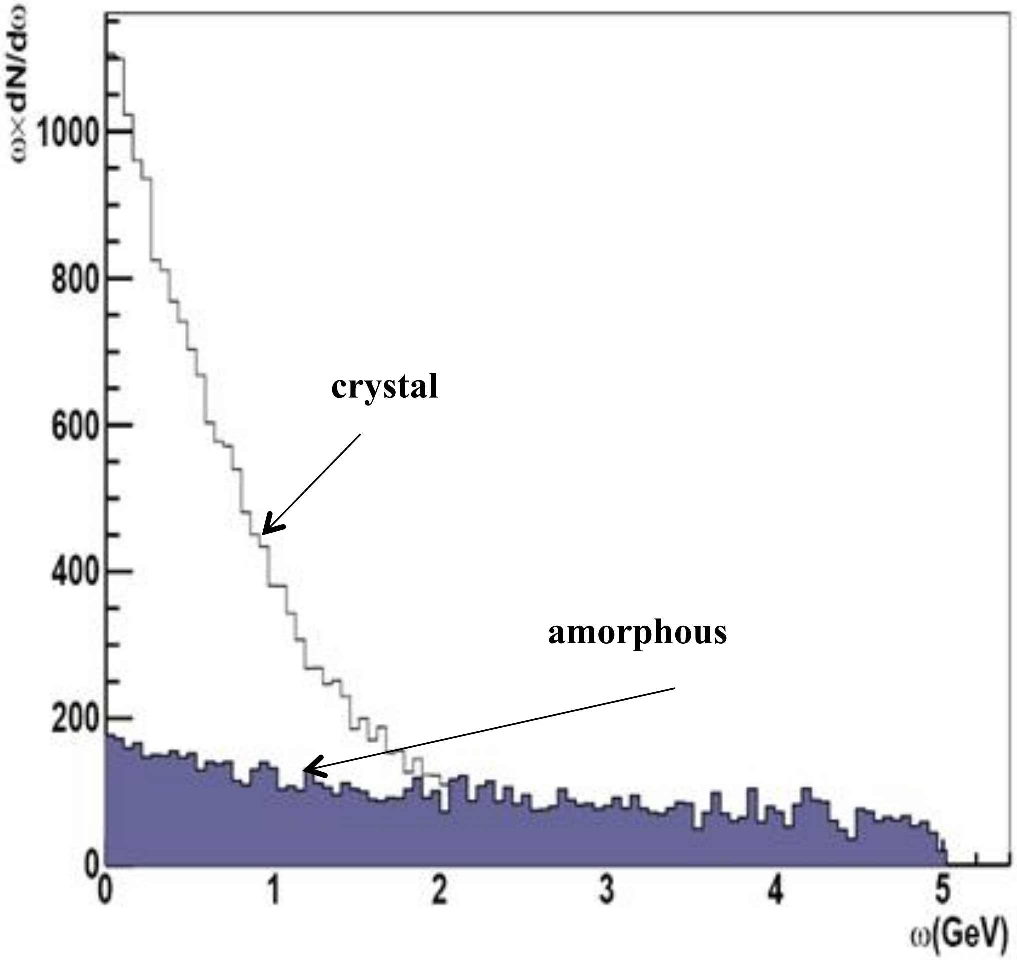
axial channeling



$\varphi << 1$ $\quad (\varphi < \varphi_L \sim \sqrt{U/E})$ - *the Lindhard angle is the critical angle for the channeling*

GEANT 4 simulations for channeling

O. Dadoun



Normalized photon spectrum:

With vertical scale in ω. dN/dE => plot bremsstrahlung ~ constant

GEANT4 cannot handle interaction between e- and crystal => a package, based on simulations developed by *X. Artru*, has been implemented.

U = potential (on axis)

φ = normal incidence angle

$\varphi < \sqrt{2U/E}$ for channeling

E ~ 0.7 GeV
"threshold" for channeling inside W
➔ the radiated energy by channeling process ≥ radiated energy by bremsstrahlung

=> Higher E, higher channeling effects

Hybrid targets

CLIC Note 808

Optimized for the present CLIC parameters as e^+ source

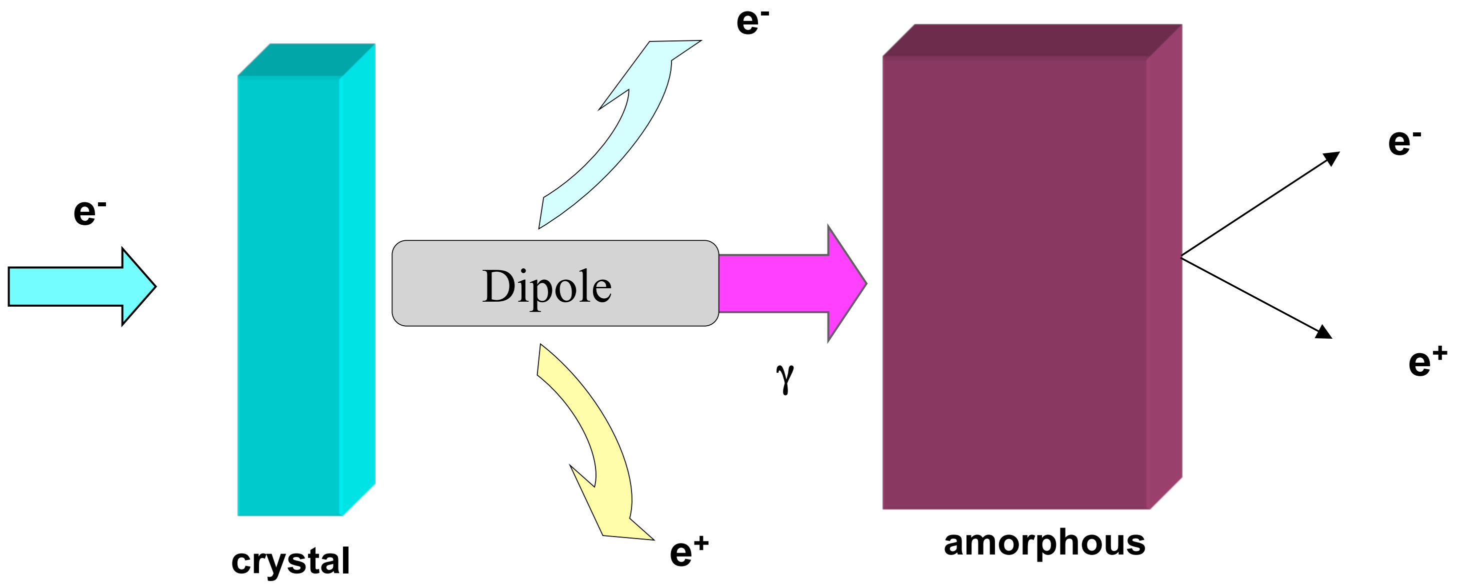
Yield (after AMD) = 1.8 e^+/e^-

$P_{deposited}$ = 9.2 kW

PEDD = 17.3 J/g

Primary electron beam Linac

5 GeV



Crystal thickness: 1.4 mm

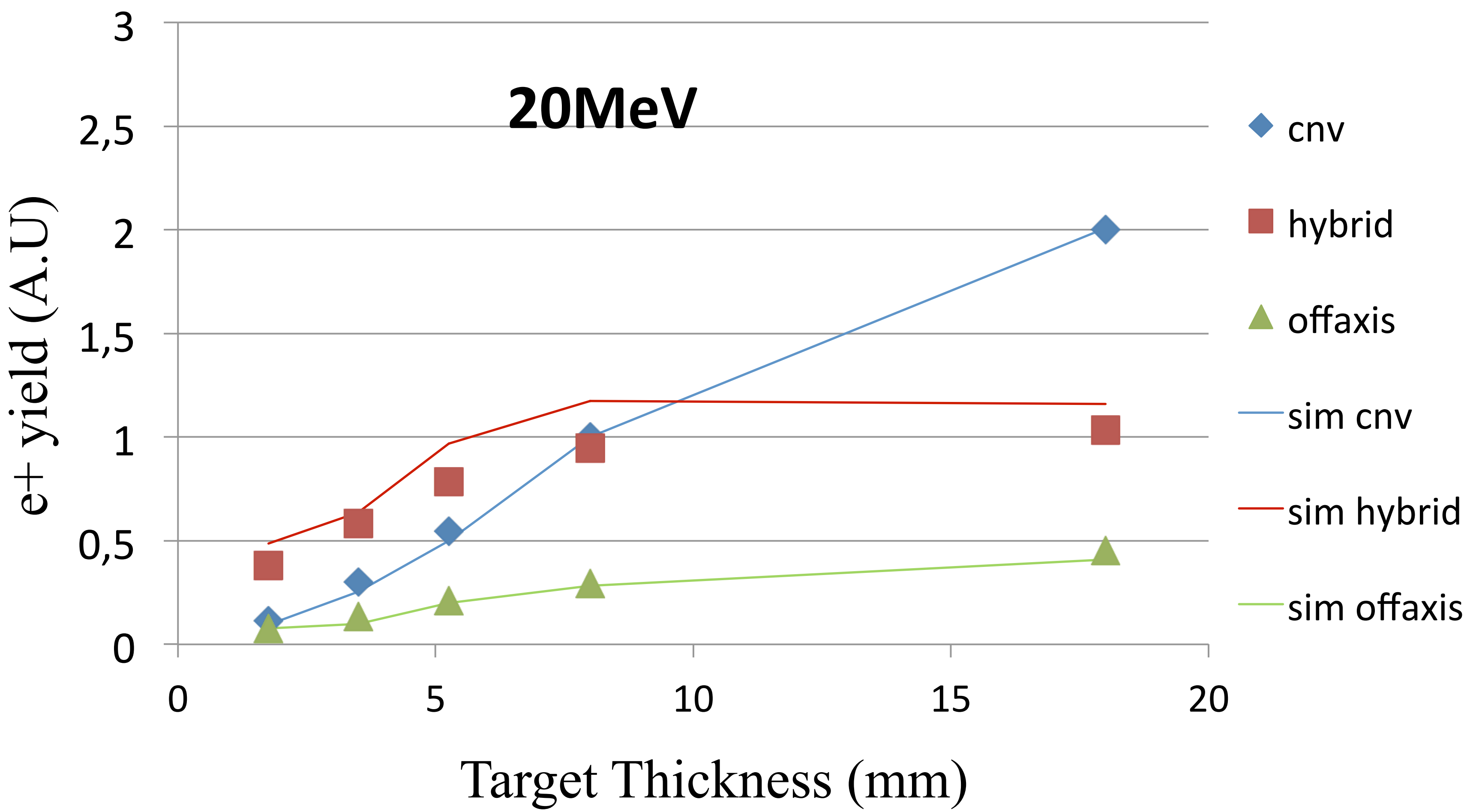
Oriented along the <111> axis

Distance (crystal-amorphous): 3 m

Amorphous thickness: 10 mm

Experimental results at KEK

For hybrid targets



Recent results presented at POSIPOL 2012 DESY Zeuthen by *T. Takahashi / Hiroshima University*

Many studies have been done for CLIC polarized e^+ sources:

- Compton rings
- Compton ring + stacking rings
- Compton Linacs
- Undulators

The CLIC positron source based on Compton schemes
L. Rinolfi et al.
Presented at PAC 2009 – Vancouver - Canada

The CLIC electron and positron polarized sources
L. Rinolfi et al.
Presented at XIIIth International workshop on polarized sources, targets & polarimetry (PST 2009) Ferrara, Italy

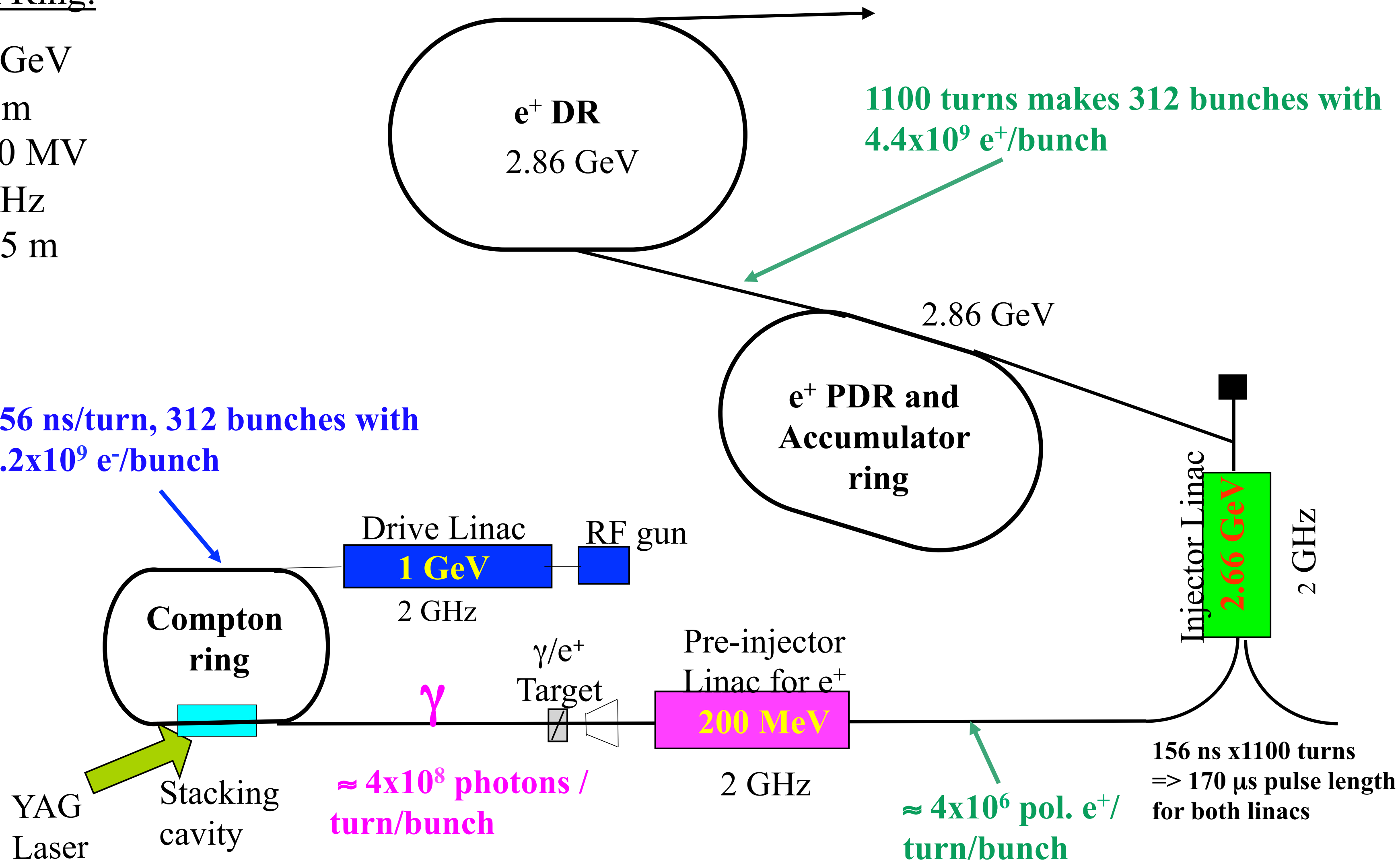
An undulator based polarized positron source for CLIC
W. Liu, W. Gai. L. Rinolfi, J. Sheppard
Presented at IPAC 2010 – Kyoto –Japan - CLIC Note 856

CLIC based Compton Ring

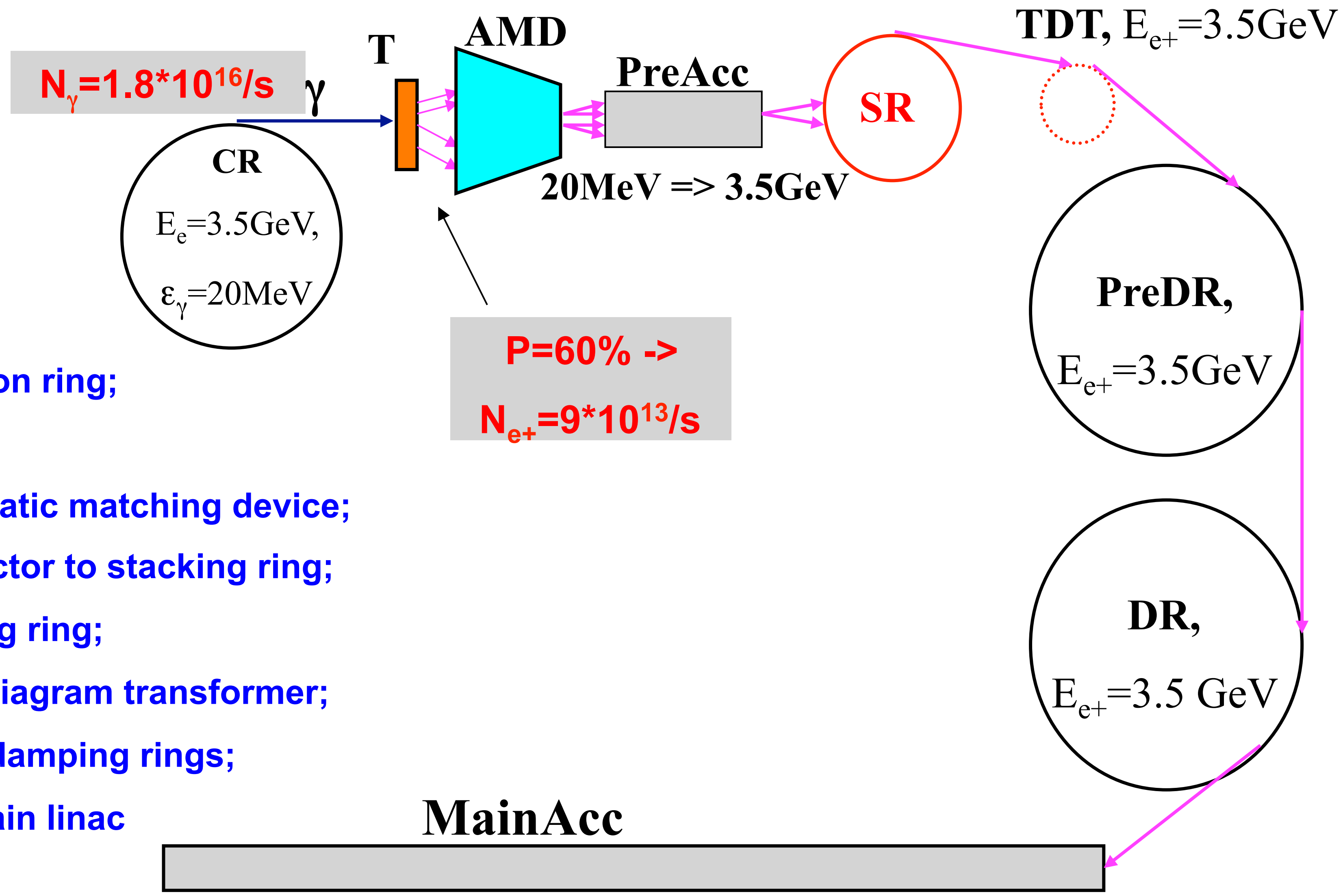
Compton Ring:

$E = 1.06$ GeV
$C = 46.8$ m
$V_{RF} = 200$ MV
$f_{RF} = 2$ GHz
$\beta_{CP} = 0.05$ m

Laser pulse:
$E = 1.164$ eV
$r = 0.005$ mm
$l = 0.9$ mm



CLIC e+ source



CR, Compton ring;

T, target;

AMD, adiabatic matching device;

PreAcc, injector to stacking ring;

SR, stacking ring;

TDT, time diagram transformer;

PreDR, DR, damping rings;

MainAcc, main linac

Presented at POSIPOL 2012 DESY Zeuthen by *P. Gladkikh / NSC KIPT*

Other brilliant e^+ sources

ILC

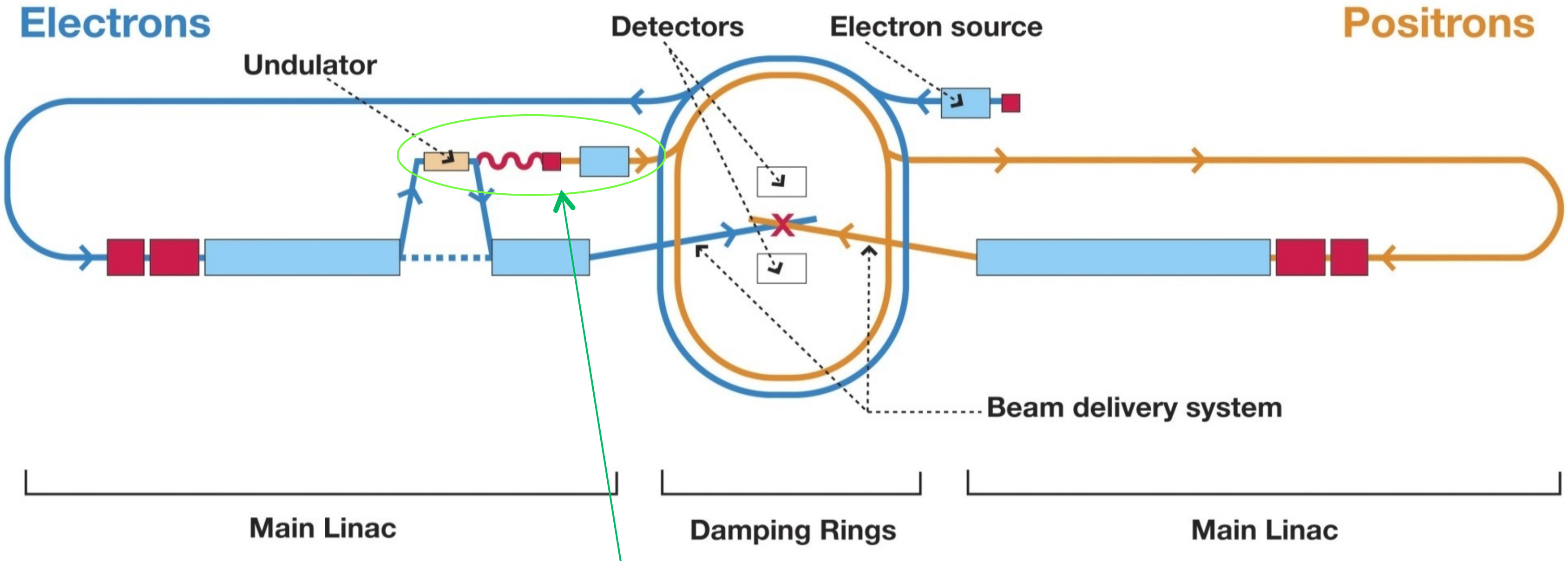
LHeC at CERN

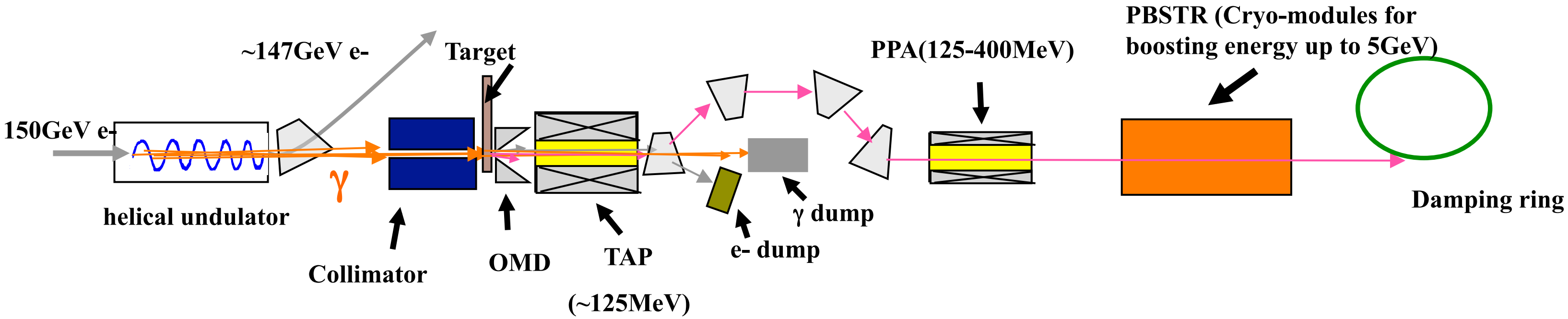
Super KEKB in Japan

Super B in Italy

…….

ILC RDR baseline schematic





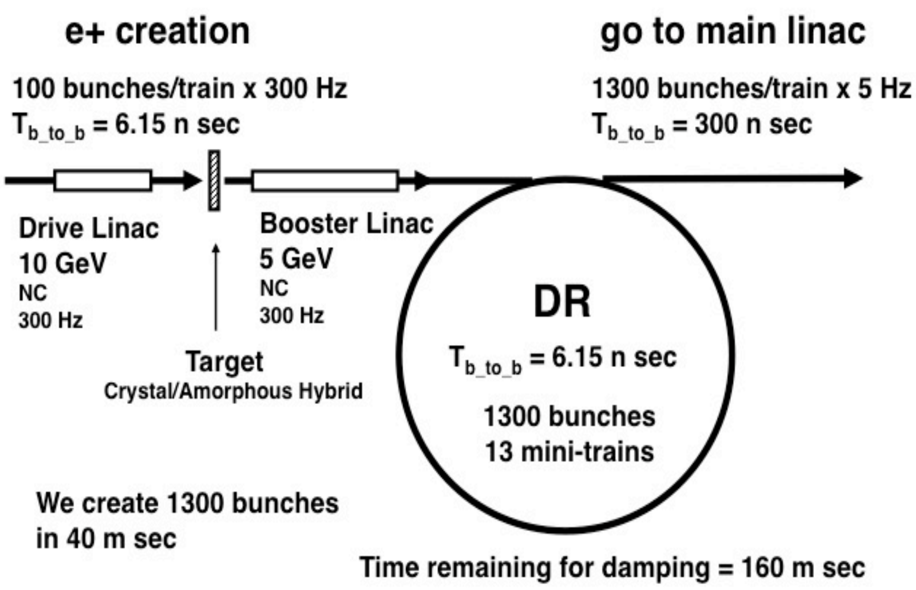
Alternative option for ILC e^+ source

T. Omori / KEK
R. Chehab

300 Hz Advanced Conventional e^+ Source for MM

Crystal/Amorphous Hybrid Target

Normal Conducting Drive and Booster Linacs in 300 Hz operation



PEDD ~ 2 GeV/cm³/e-.

The PEDD associated to a minitrain of 100 bunches is ~ 33 J/g (just below the 35J/g limit).

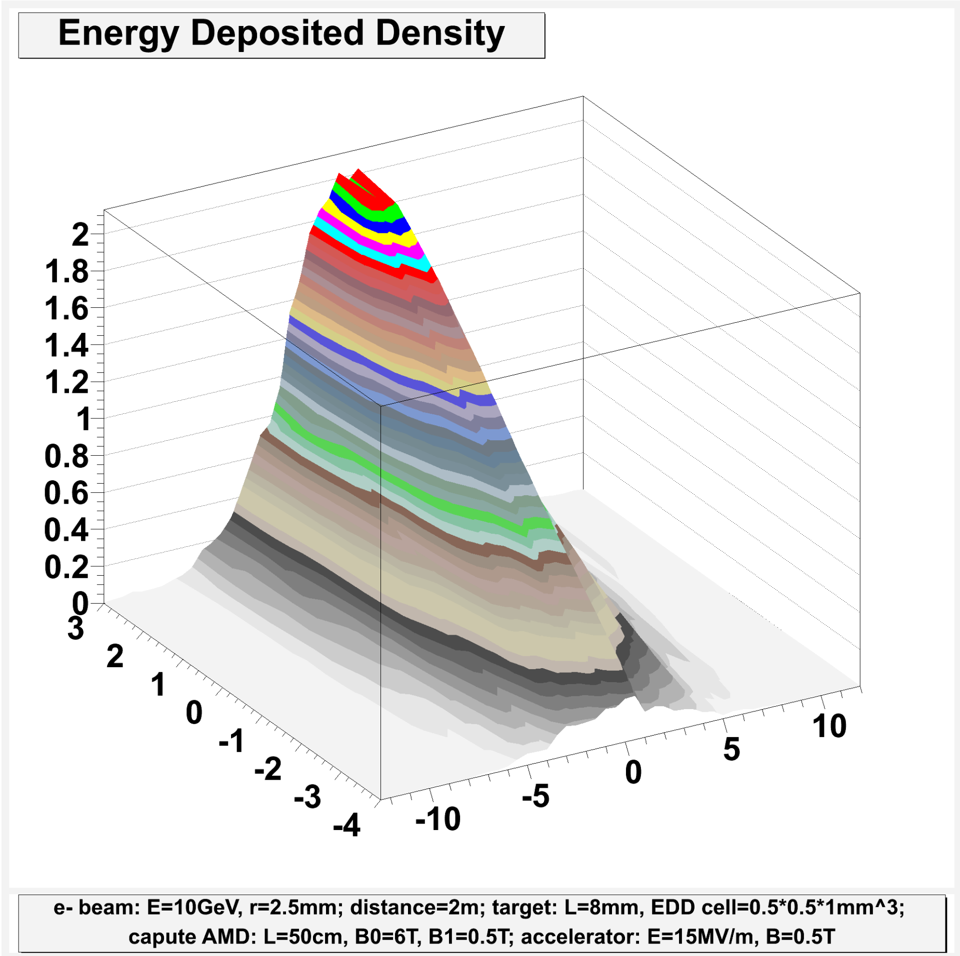
A moving converter avoiding the superposition of the micropulses on the same location is a solution for adopting the hybrid positron source

Target:

Crystal W <111>, 1 mm thick

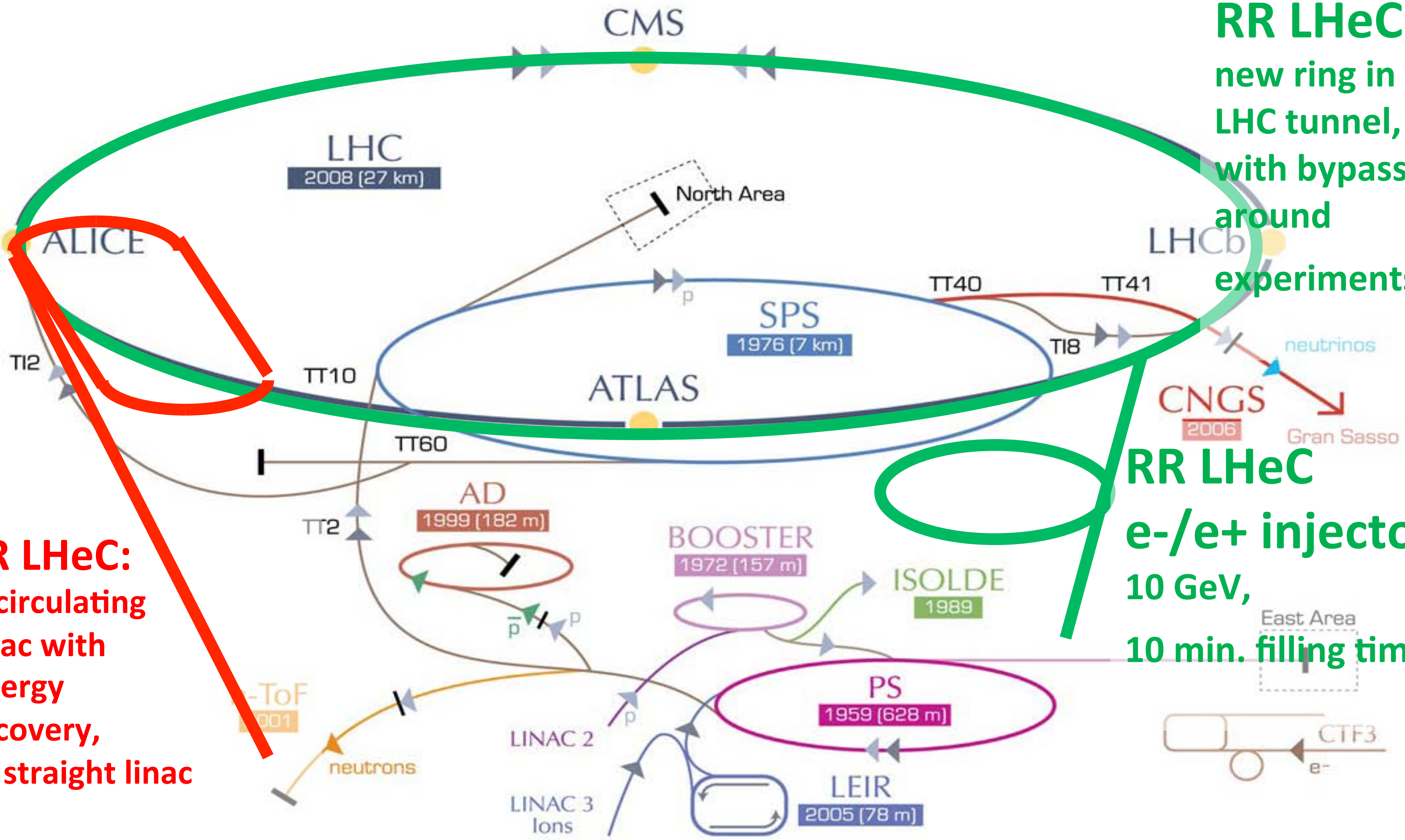
Converter W: 8 mm thick

Distance Cryst.-Conv. 2 m,



LHeC – the two options

LR= Linac-Ring   RR= Ring-Ring

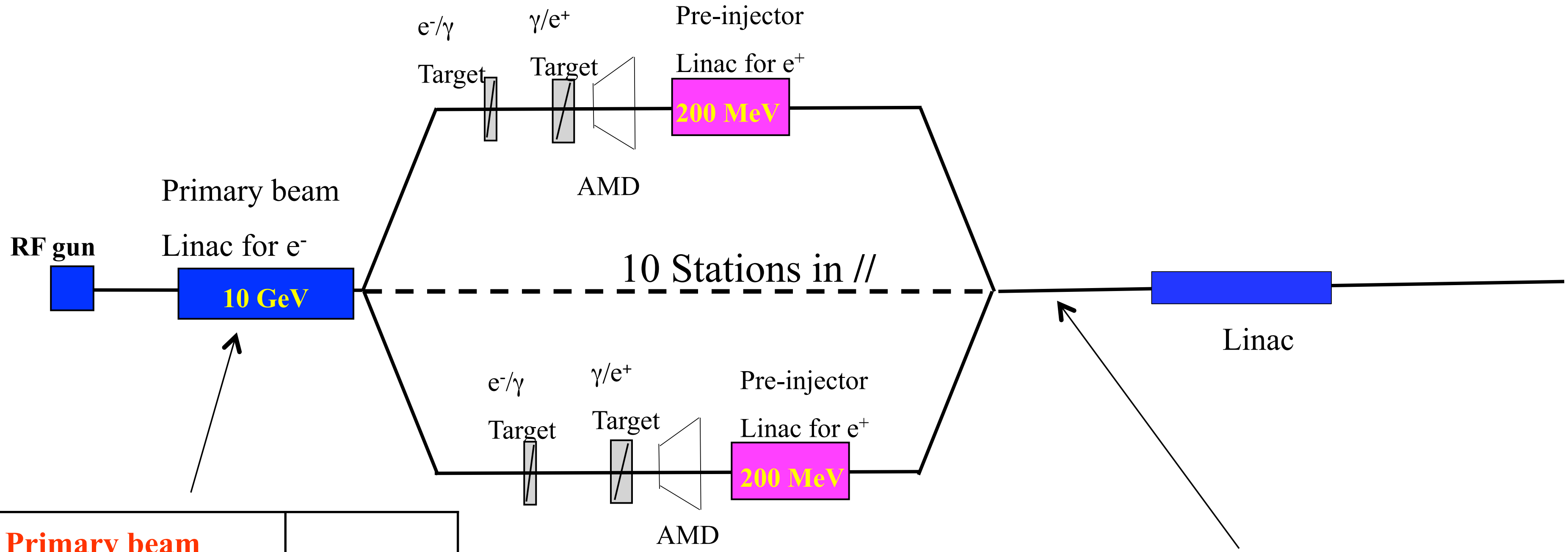


RR LHeC:
new ring in LHC tunnel, with bypasses around experiments

RR LHeC
e-/e+ injector
10 GeV,
10 min. filling time

LR LHeC:
recirculating linac with energy recovery,
or straight linac

A possibility for unpolarized e^+ at LHeC

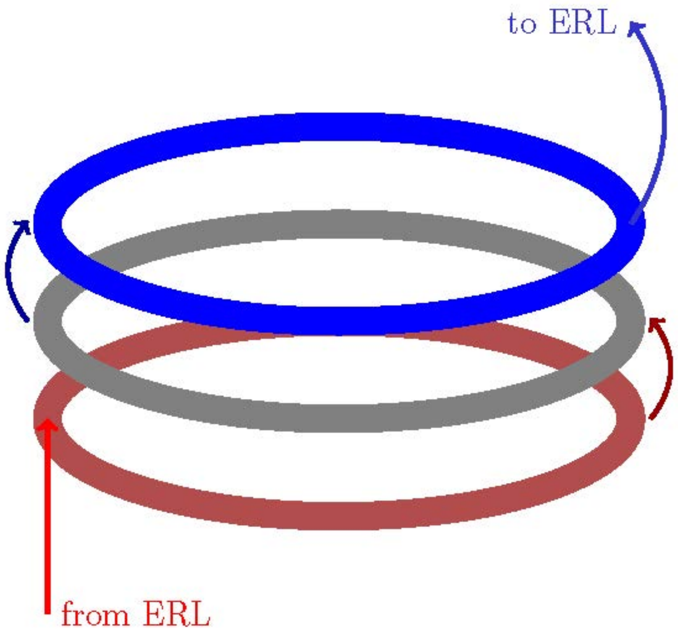


Primary beam	
Primary beam energy	10 GeV
Nb e^- / bunch	1.2×10^9
Nb bunches / pulse	100 000
Nb e^- / pulse	1.2×10^{14}
Pulse length	5 ms
Beam power	1900 kW
Bunch length	1 ps

Target @ 1 station	
Yield (e^+ / e^-)	1.5
Beam power	190 kW
Deposited power / target	5.6 kW
PEDD	30 J/g
Nb e^+ / bunch	1.8×10^9
Nb bunches / pulse	10 000
Nb e^+ / pulse	1.8×10^{13}

e^+ @ 10 stations	
Beam energy	200 MeV
Nb e^+ / bunch	1.8×10^9
Nb bunches / pulse	100 000
Nb e^+ / pulse	1.8×10^{14}
Bunch spacing	50 ns
Rep. rate	10 Hz

Concept of three rings transformer



extraction ring (N turns)

fast cooling ring (N turns)

accumulator ring (N turns)

Presented at POSIPOL 2012 DESY Zeuthen by *E. Bulyak / NSC KIPT*

Super KEKB Injector

T. Kamitani

50 Hz (e+ or e-)

pulse-by-pulse

mode switching

e+ for LER

4.0 GeV

4 nC x 2

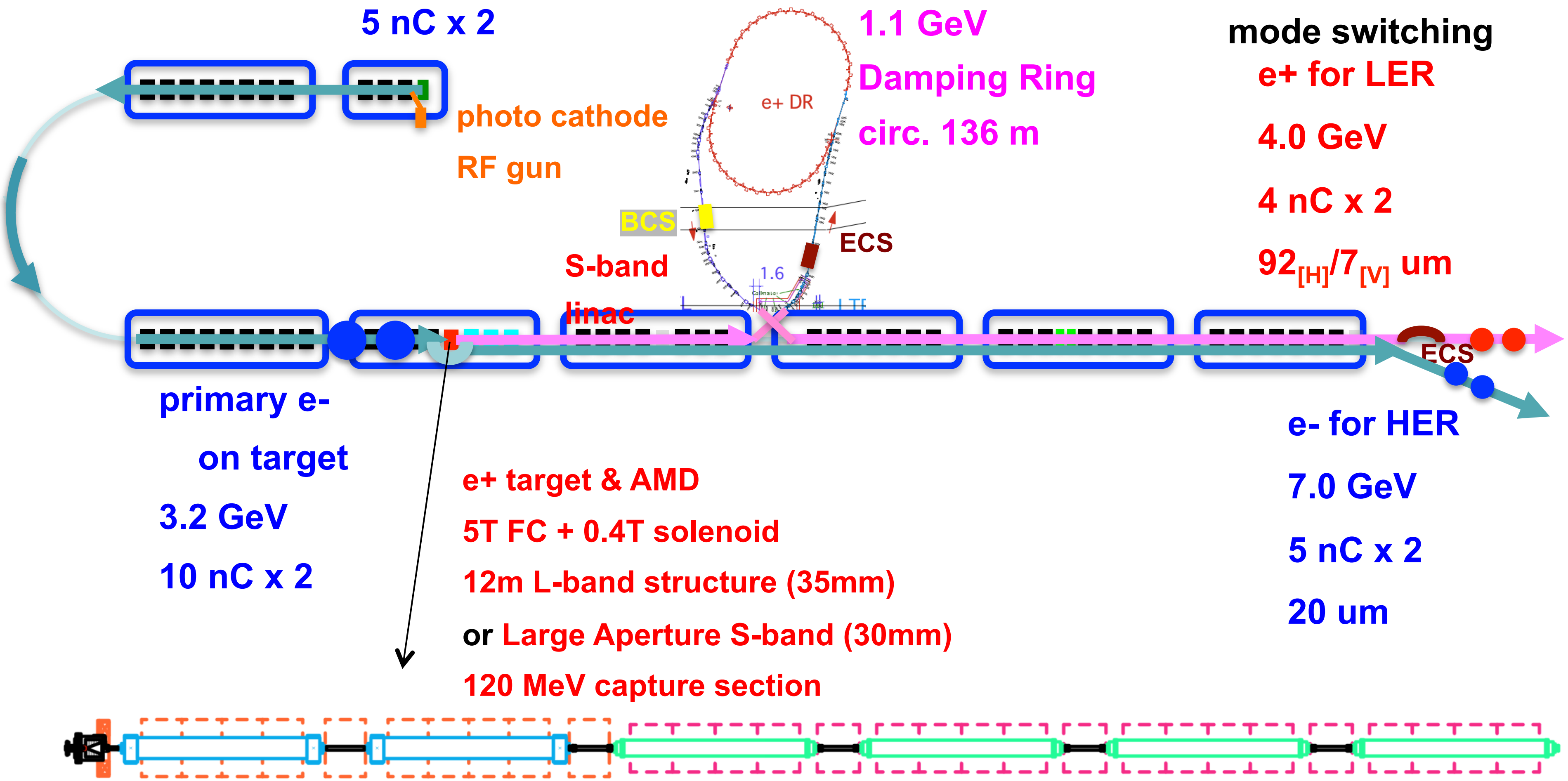
$92_{[H]}/7_{[V]}$ um

primary e- for e+ prod.

10 nC x 2

HER inj. e-

5 nC x 2



primary e-

on target

3.2 GeV

10 nC x 2

e+ target & AMD

5T FC + 0.4T solenoid

12m L-band structure (35mm)

or Large Aperture S-band (30mm)

120 MeV capture section

e- for HER

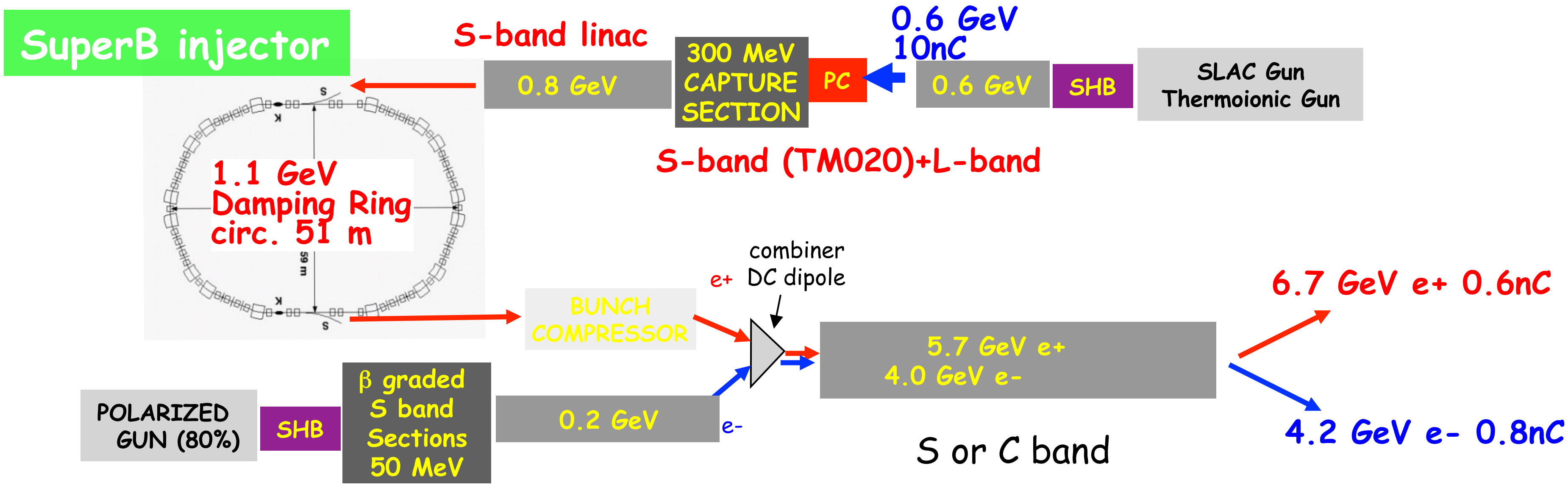
7.0 GeV

5 nC x 2

20 um

Super B Injector

A. Variola



Super-B aims at the construction of a very high luminosity (1x 10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- flavor factory with a possible location on or near the University of Rome at Tor Vergata or the INFN Frascati National Laboratory LNF campus.

<u>ONGOING SIMULATIONS</u>:

1) Target production and optimization
2) AMD vs QWT, Parmela, Geant4 and Astra ok
3) Polarization studies (Geant4) – not needed
4) Capture in 4 different scenarios

See the talk S. Guiducci at this workshop

Summary

1) The CLIC history spans over 27 years with many changes, upgrades, failures and success.

2) The requested CLIC e^+ flux is very challenging (a factor 20 compared to what has been achieved on SLC- a real linear collider).

3) However the requested CLIC unpolarized e^+ source parameters seems reachable based on channeling process for an hybrid targets configuration. BUT it requires experimental demonstrations.

4) For CLIC polarized e^+ source, many studies have been performed and many paths explored.

5) The CDR (Conceptual Design Report) is ready for publication.

6) Other projects involving brilliant positron sources are being studied with a lot of exciting challenges.

Some references

A CLIC injector complex for the main beams
L. Rinolfi CERN-OPEN-98-010 and CLIC Note 354
7th International Workshop on Linear Colliders, Zvenigorod, Russian Federation, Oct 1997

Radiation-Damage Study of a Monocrystalline Tungsten Positron Converter
R. Chehab et al. CERN-PS-98-017-LP ; CLIC-Note-369 ; LAL-RT-98-02

Positron production for CLIC
T. Kamitani, *L. Rinolfi* CLIC Note 465

The CLIC positron production scheme
T. Kamitani, L. Rinolfi, CERN/PS/2002-071 and CLIC Note 537
Presented at the XXIst International Linear Accelerator Conference, August 2002, Gyeongju (Kyongju), Korea

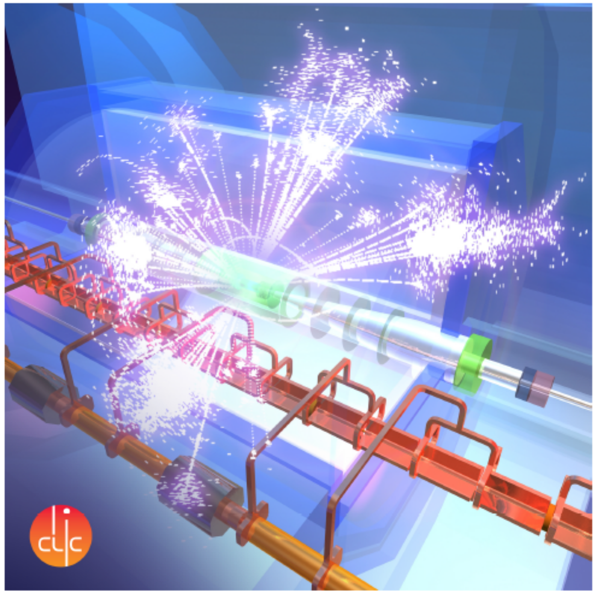
Study of an hybrid positron source using channeling for CLIC
O. Dadoun et al. - CLIC Note 808

Positron options for the linac-ring LHeC
F. Zimmermann et al.
Presented at IPAC 2012 – New Orleans

The 3rd part of the CDR

ANL-HEP-TR-12-51
CERN-2012-005
KEK Report 2012-2
MPP-2012-115
8 August 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



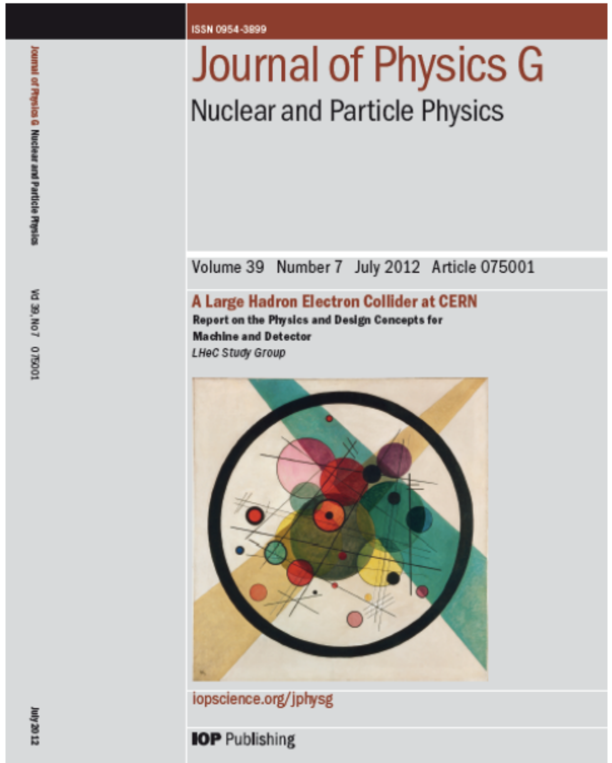
THE CLIC PROGRAMME:
TOWARDS A STAGED e^+e^- LINEAR COLLIDER
EXPLORING THE TERASCALE

CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

ilc newsline **16/08/2012**

The GDE Executive Committee met in a two-day face-to-face meeting in Melbourne just following ICHEP12. The main order of business was to develop a detailed "game plan" for producing the ILC *Technical Design Report*.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