“Practical” Challenges with Positron Sources

- Positron sources for Linear Colliders (CLIC and ILC)
- Requirements for even more advanced colliders
- Alternative positron sources
- Conclusions

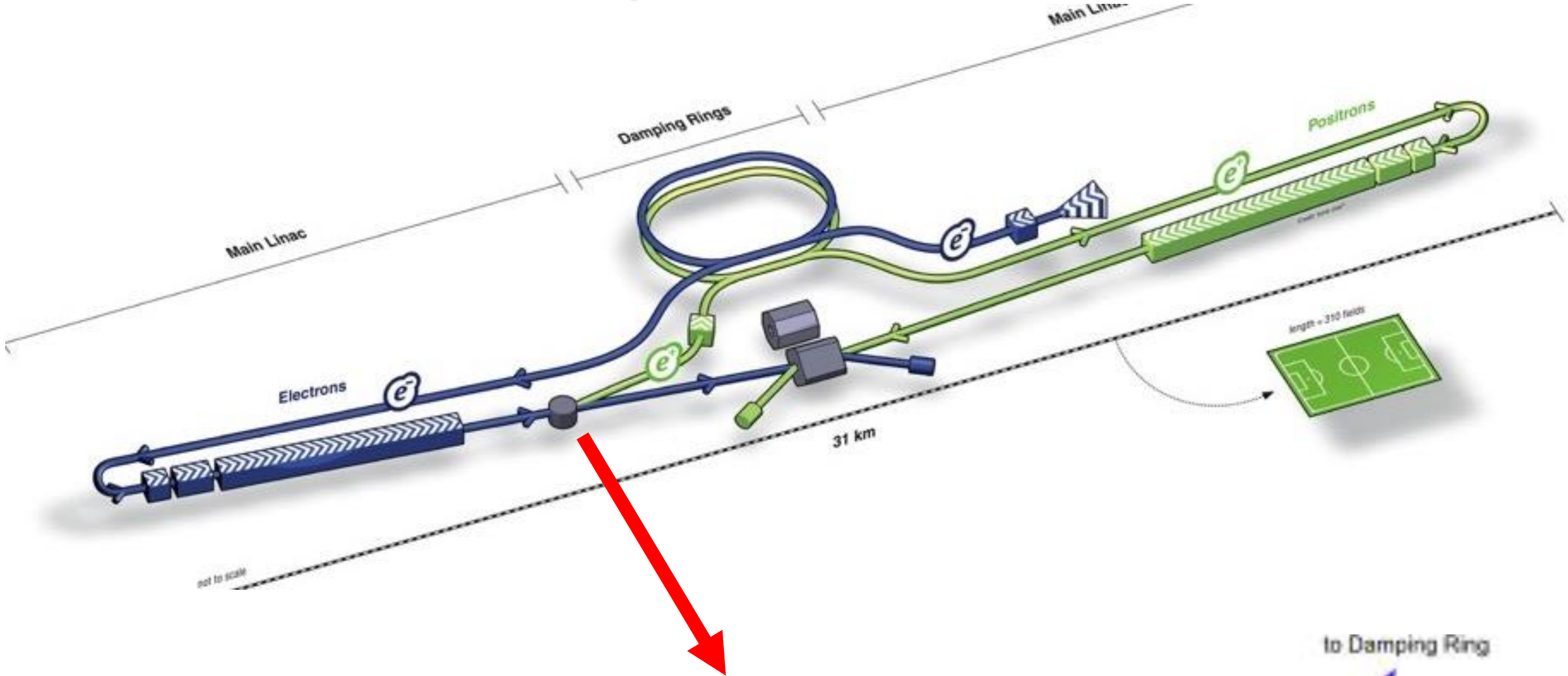
Typical requirements for a Positron Source for a collider for high energy physics

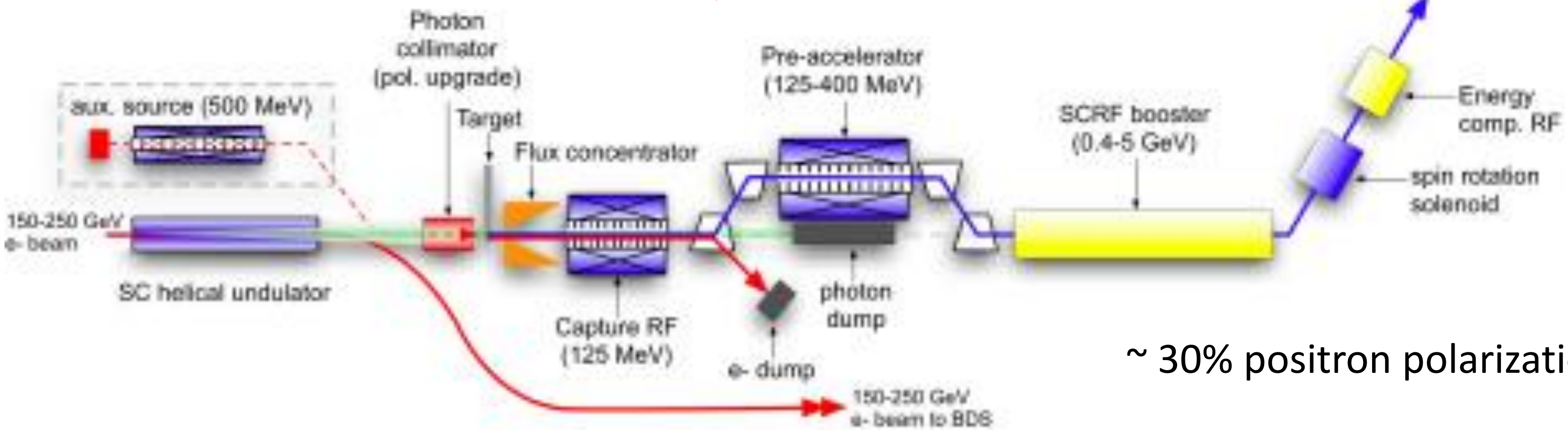
- Delivers required intensity ~ 10^{9}-10^{10} per bunch
- Requires typically a yield of ~ > 1 if produced with primary electron beam
- Extremely reliable and stable because the "complicated part" comes afterwards
- Small energy spread before injection into damping ring $\Delta E/E$ ~ 1%
- Extremely small emittance, needed for luminosity goals; implies flat beams

  Requires in general one or two damping rings !
- Synchronised with electron beam
- Polarized beams preferred by physics
- Low cost compared to collider total (in reality a significant fraction)

- Polarised electron beam (~80%) is "standard" for linear colliders

ILC positron source

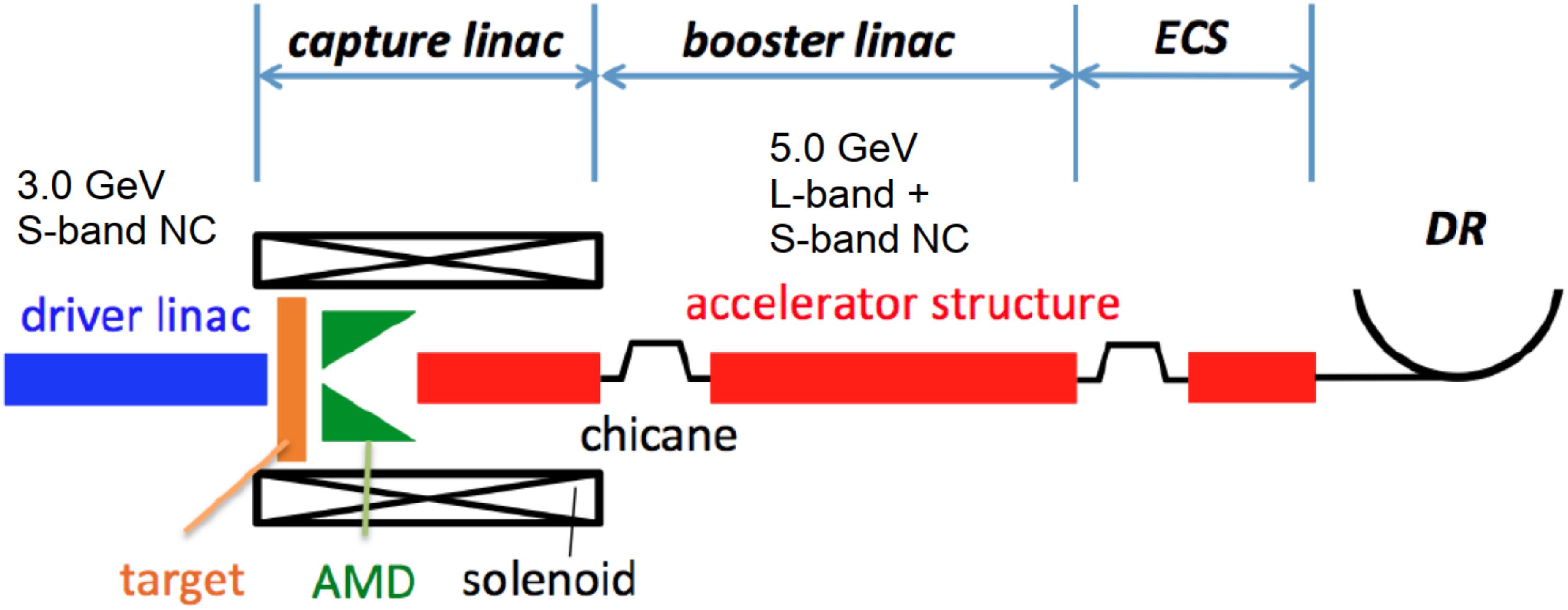




~ 30% positron polarization

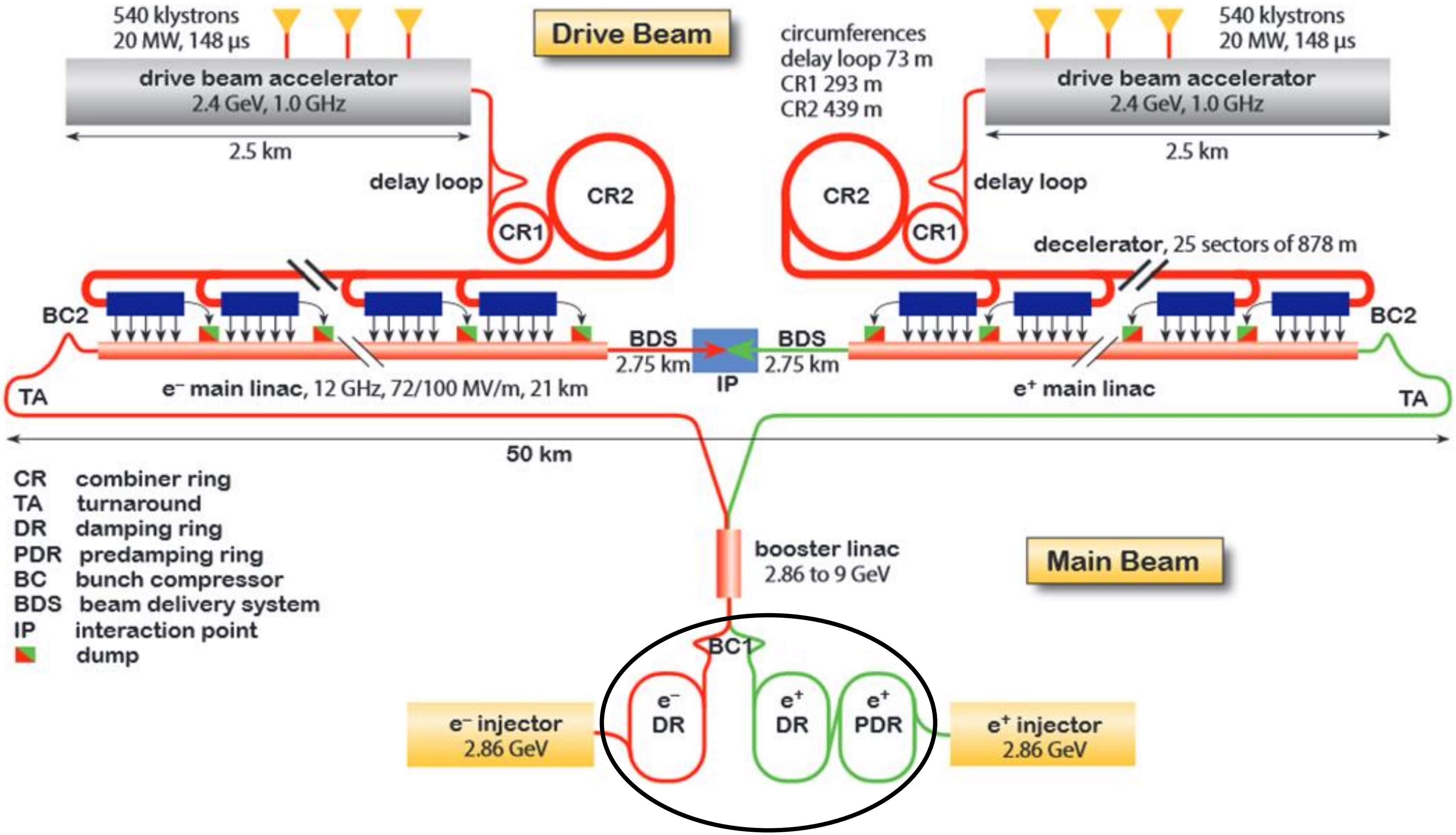
ILC positron source

E-driven ILC Positron Source

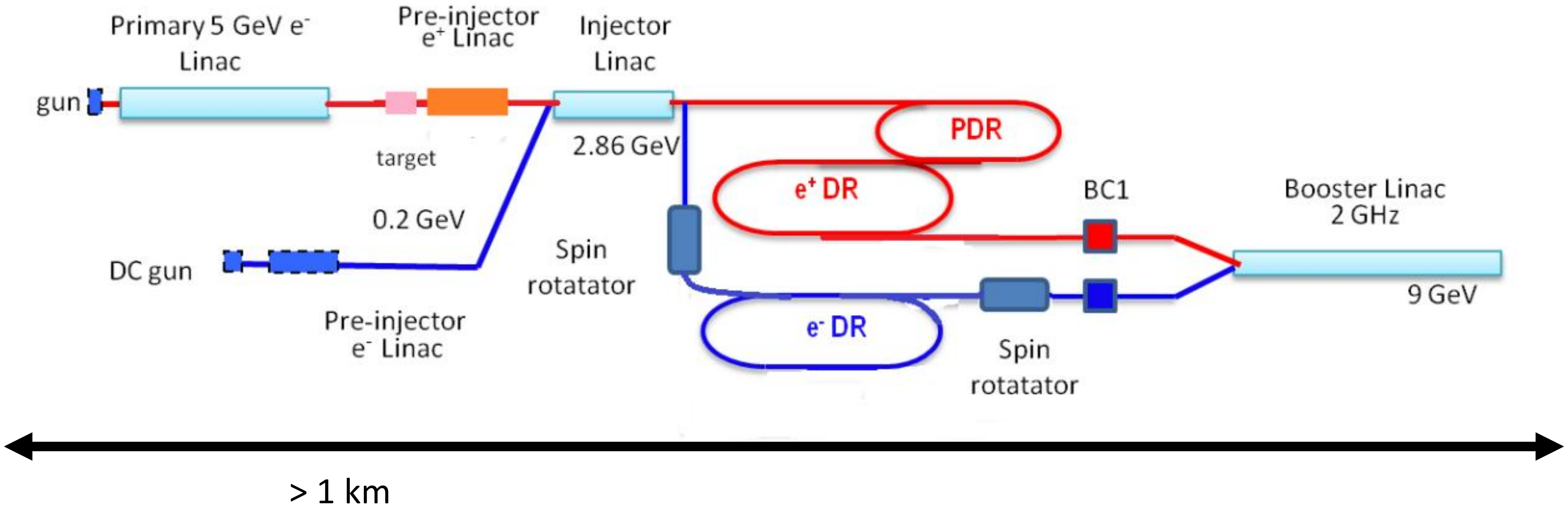


- 20 of 0.48us pulses are handled with NC linacs operated in 300Hz.
- 100 of 300 pulses are actually fired.

CLIC complex

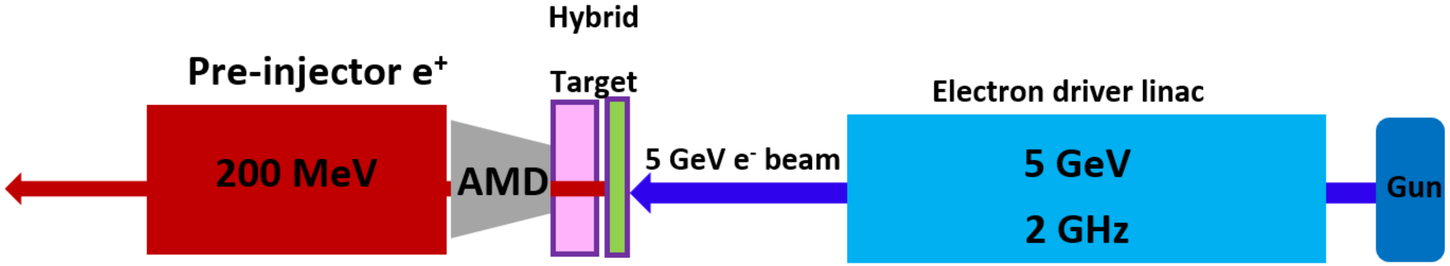


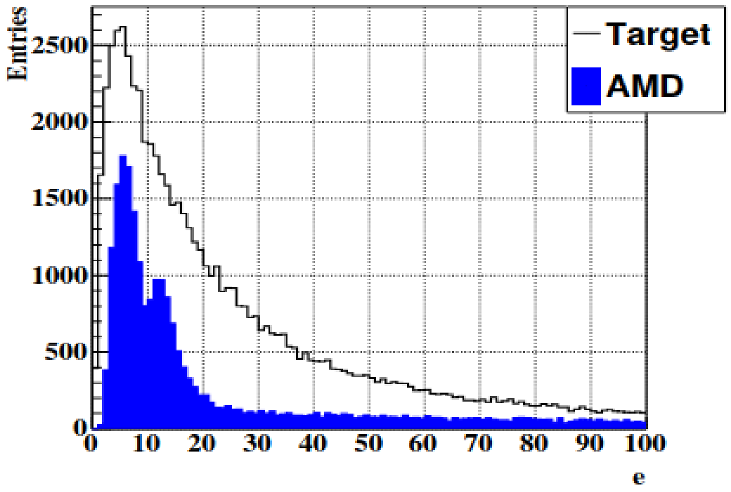
The CLIC Injector Complex



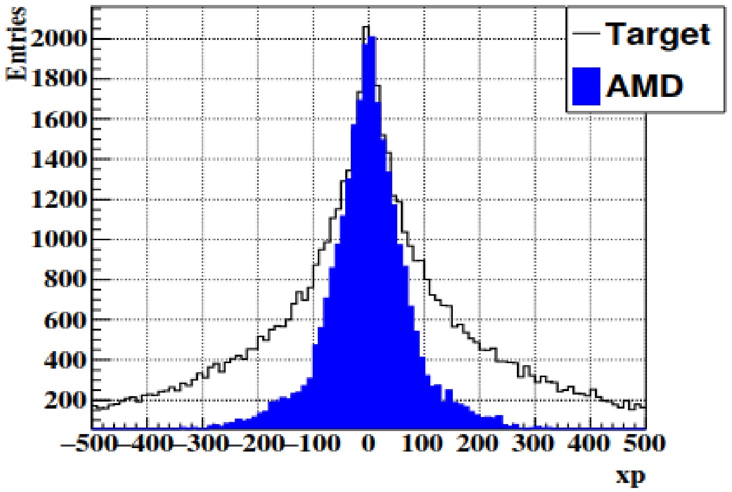
- **Pre-damping ring can be avoided if the beam emittance is ~ < 25 μm (norm)**
- **Main damping ring; in: $\varepsilon_{xn}/\varepsilon_{yn}$ = 65/10 μm**
  out: $\varepsilon_{xn}/\varepsilon_{yn}$ = 472/5 nm
- **Bunch compressors needed after the rings for further acceleration**

CLIC Positron Source





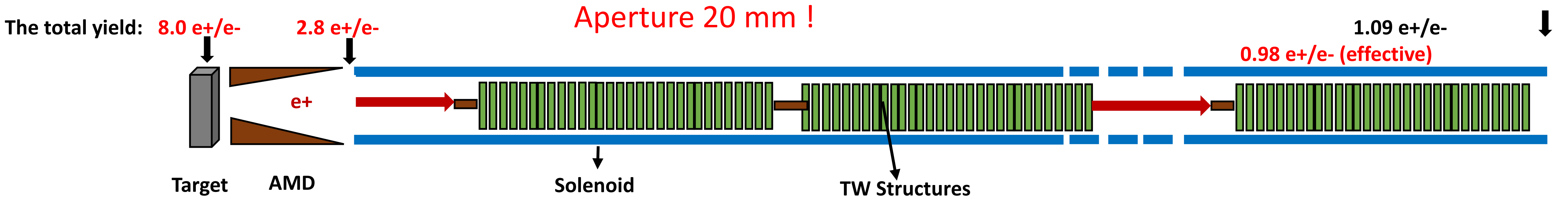
Energy (MeV)

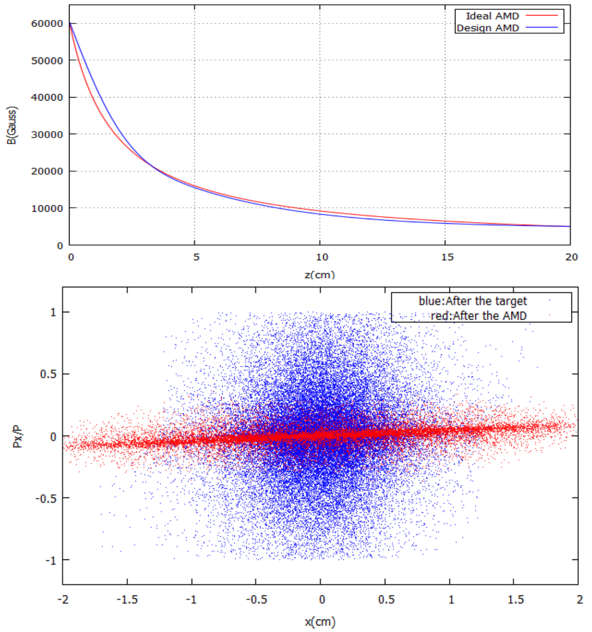


$x'(mrad)$

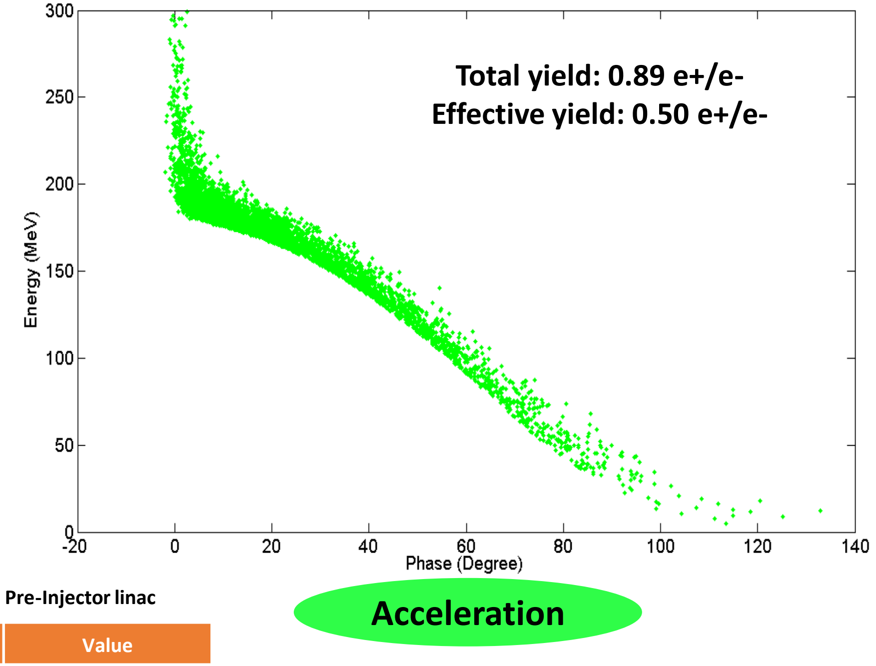
- ❑ Generation of adequate photons (0-20 MeV) for pair production
- ❑ Complex and lossy positron collection and capture system
- ❑ Performance limited often by peak energy deposit density (PEDD < 35 J/g pulse)
- ❑ Very high radiation area, constraints for operation and maintenance, engineering challenge
- ❑ Long solenoidal field for guidance

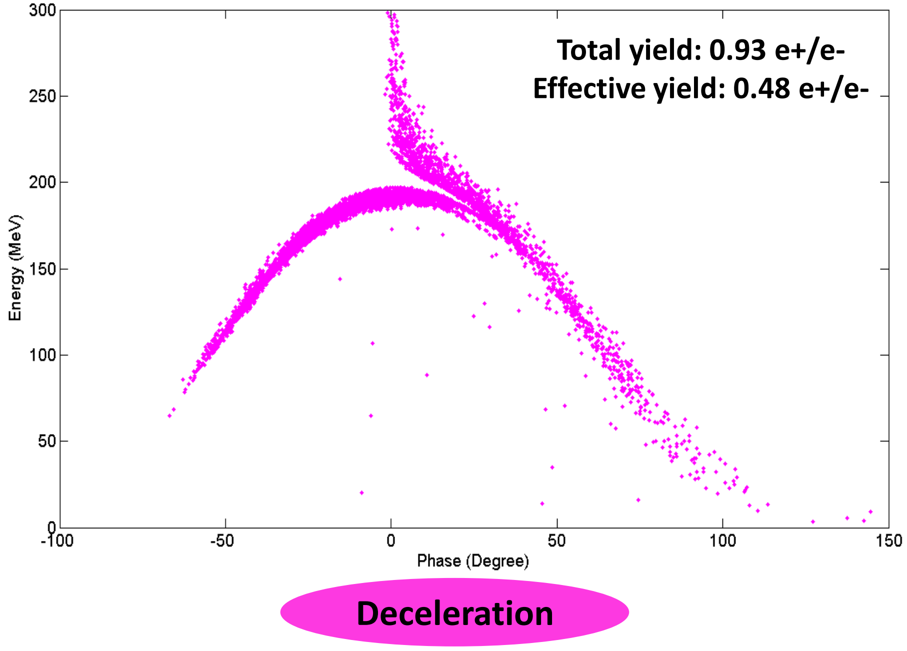
Previous studies: The Pre-Injector Linac





The effective yield : (-20,20) degrees in phase and (150,250) MeV in energy





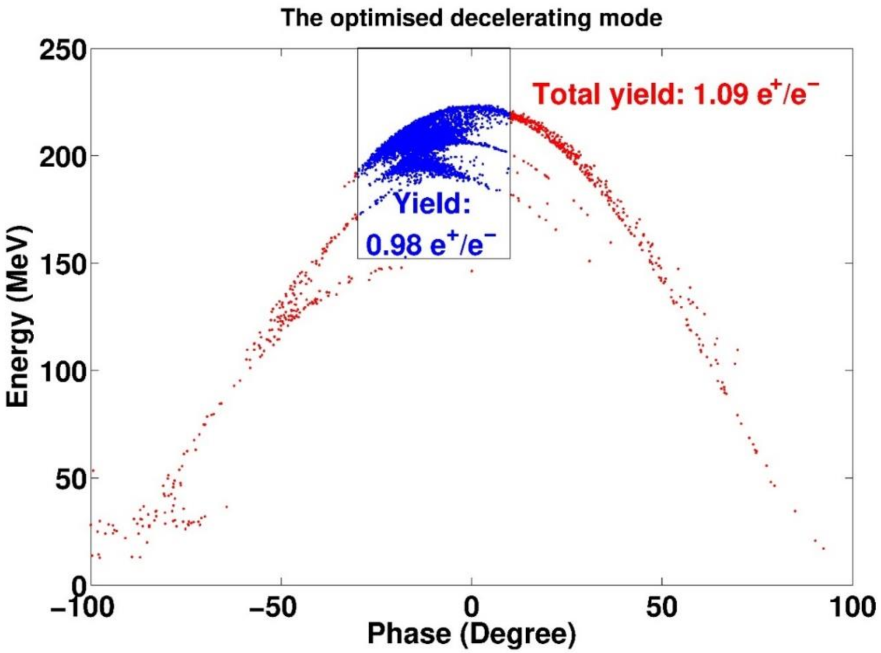
Parameters of the accelerating structures in the Pre-Injector linac

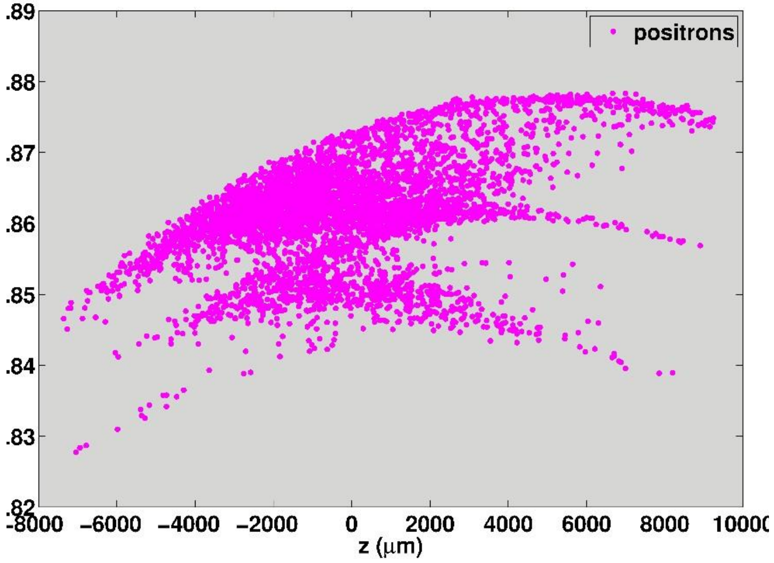
Parameters	Unit	Value
Cell length	cm	5
Frequency	GHz	2
Phase advance per cell	π	2/3
Average axial electric field	MV/m	15

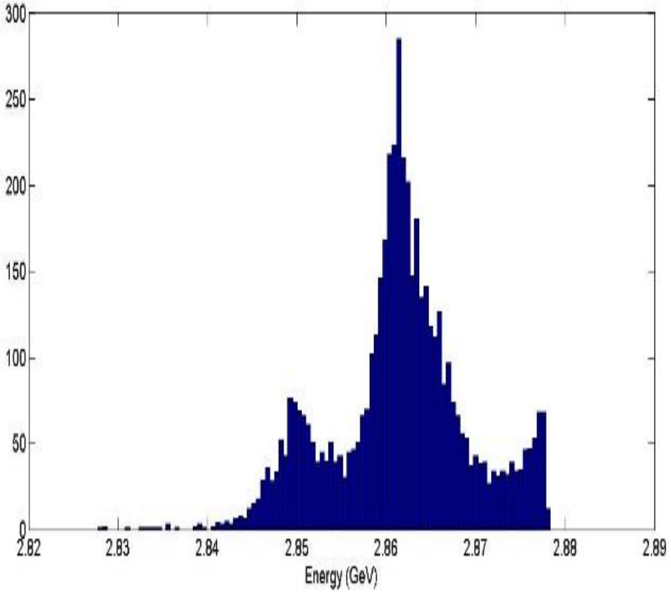
C. Bayar

Injector Linac

Positron yield, 0.97 e^+/e^-







- **All positrons are within 1% acceptance window of the pre-damping ring.**

The effective yield : (-20,20) degrees in phase and (150,250) MeV in energy

Energy (GeV)	Target exit (e^+/e^-)	AMD exit (e^+/e^-)	Total yield (e^+/e^-)	Effective yield (e^+/e^-)
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	0.38

C. Bayar

Positron requirements / beam parameters

D. Schulte, “Application of Advanced Accelerator Concepts for Colliders”, RAST, Vol 9, 2016

Parameter	Unit []	ILC	CLIC	LPA	PWFA	DLA
CMS energy / Luminosity	[TeV] / 10^{34} $cm^{-2}s^{-1}$	0.25 1.8	3 6	3 10	3 6.3	3 3.2
Bunch charge	N [10^9]	20	3.72	1.2	10	0.0047
Bunch length	[μm]	300	44	8	20	0.0028
Emittance norm	$\varepsilon_x/\varepsilon_y$ [nm]	10^4/35	660/20	50/5	10^4/35	0.1/0.1
Bunches per train	n	1312	312	1	1	1
Repetition rate	[Hz]	5	50	84 k	10-15 k	20 M
Particles /s	N [10^{14}]/[s]	1.3	0.58	1.0	1.5	0.94

- Intensity probably OK with conventional technologies
- Emittance and bunch length for DLA beyond todays reach
- Emittance for LPA on the edge
- Repetition rates > 1 kHz needs study

Example: Laser-driven Plasma Accelerator (LPA)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 051301 (2012)

Parameters from

Beamstrahlung considerations in laser-plasma-accelerator-based linear colliders

C. B. Schroeder, E. Esarey, and W. P. Leemans

Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

(Received 23 November 2011; published 4 May 2012)

plasma density, n (10^{17} cm^{-3})

ıgle-linac length versus plasma density n for
oupling distances L_c, for $E_b = 0.5$ TeV and

44 March 2009 Physics Today

feature article

Laser-driven plasma-wave electron accelerators

Wim Leemans and Eric Esarey

Surfing a plasma wave, a bunch of electrons or positrons can experience much higher accelerating gradients than a conventional RF linac could provide.

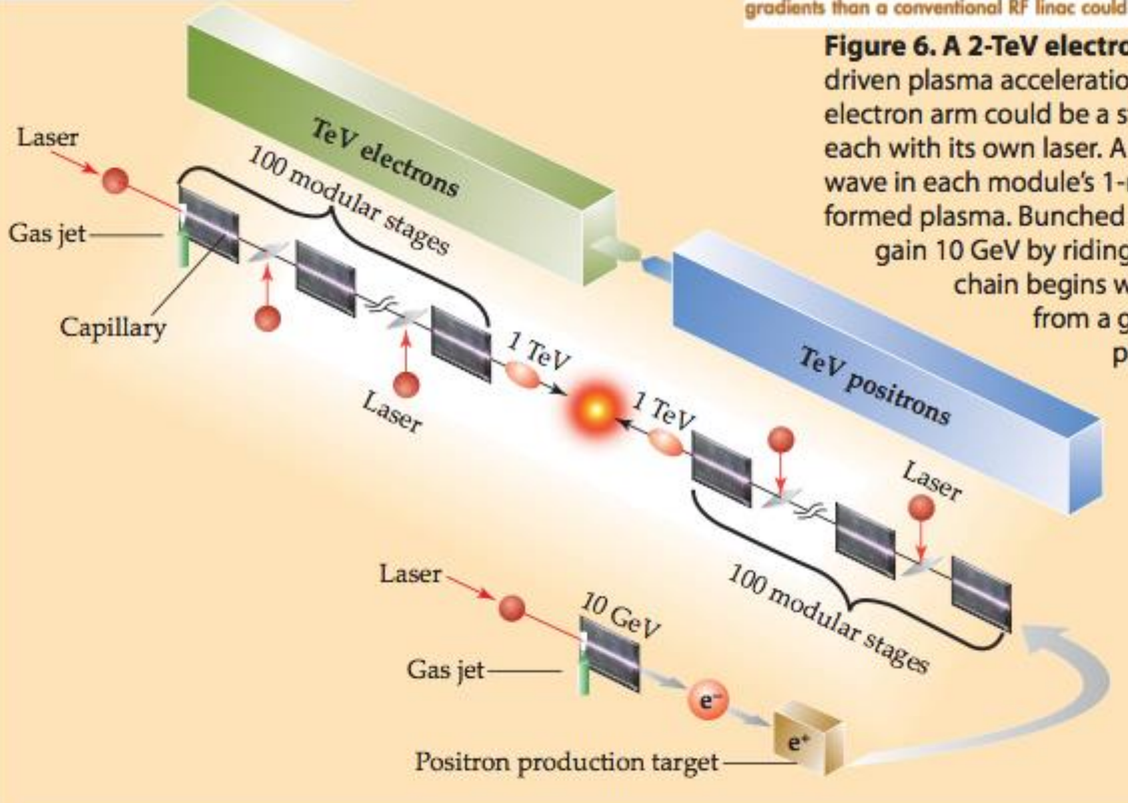
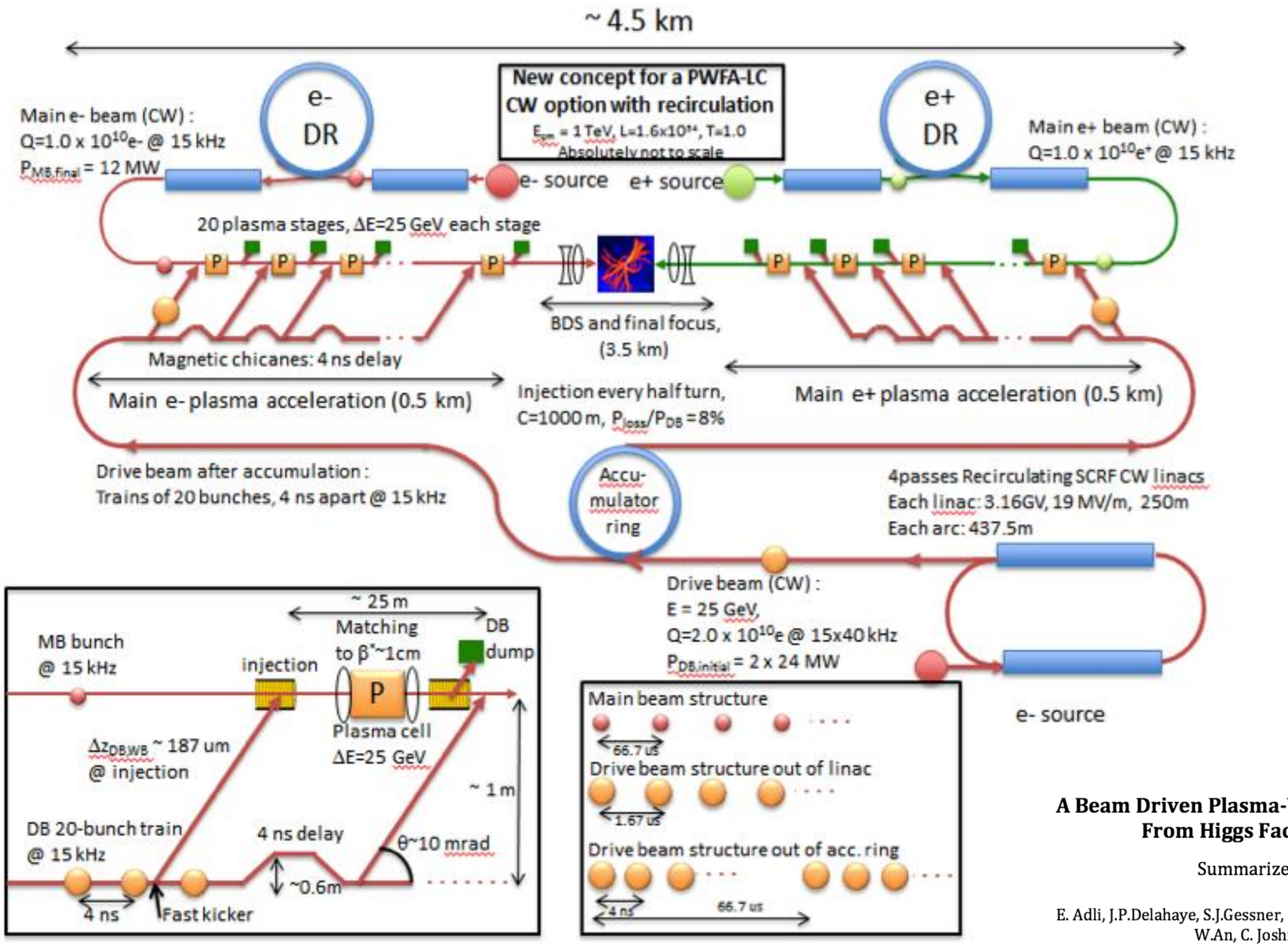


Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first module's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.

Conventional positron source might be as well 1 km long !

Here is the tricky part

Example: Beam-driven Plasma Accelerator (PWFA)



Assumes already LC-type sources

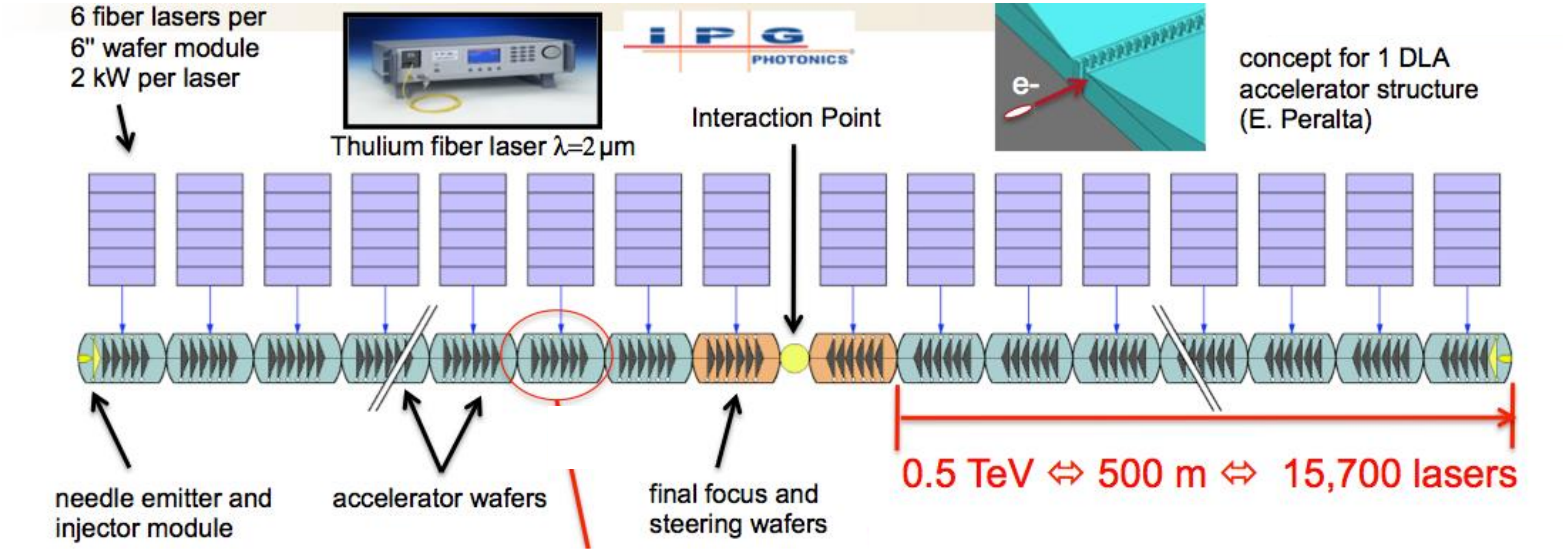
SLAC-PUB-15426
arXiv:1308.1145

A Beam Driven Plasma-Wakefield Linear Collider: From Higgs Factory to Multi-TeV

Summarized for CSS2013

E. Adli, J.P.Delahaye, S.J.Gessner, M.J. Hogan, T. Raubenheimer (SLAC)
W.An, C. Joshi, W.Mori (UCLA)

Example: Dielectric Laser Collider (DLA)



R. J. England et al.

Not many details on sources yet
Positron source might be larger then the rest of the collider
Very challenging emittance and repetition rates

Key element damping ring, CLIC example

Injected Parameters	e^-	e^+
Bunch population [10^9]	**4.7**	**4.7**
Repetition frequenzy [Hz]	**50**	**50**
Bunch length [mm]	1	9
Energy Spread [%]	**0.1**	**1**
Long. emittance [eV.m]	2000	257000
H/V norm. emittance [nm-rad]	**100 x 10^3**	**7 x 10^6**

Extracted Parameters	PDR e^-/e^+	DR e^-/e^+
Bunch population [10^9]	**4.1-4.4**	**4.1**
Bunch length [mm]	10	1.4
Energy Spread [%]	**0.5**	**0.1**
Long. emittance [eV.m]	143000	5000
Hor. Norm. emittance [nm-rad]	**63000**	**500**
Ver. Norm. emittance [nm-rad]	**1500**	**5**

DR complex challenges

- Large injected emittances and energy spread → Requirement of large DA and MA
- **Ultra low emittance at extraction**

  Repetition time of 20 ms → Fast damping requirement
- **PDR** → efficient injection of the large incoming beams
- **Main DR** → ultra-low emittance generation

The positron beam needs at least 8 damping times to reach equilibrium (w/o taking into account injection, IBS, etc)

→ **The positron PDR is necessary!**

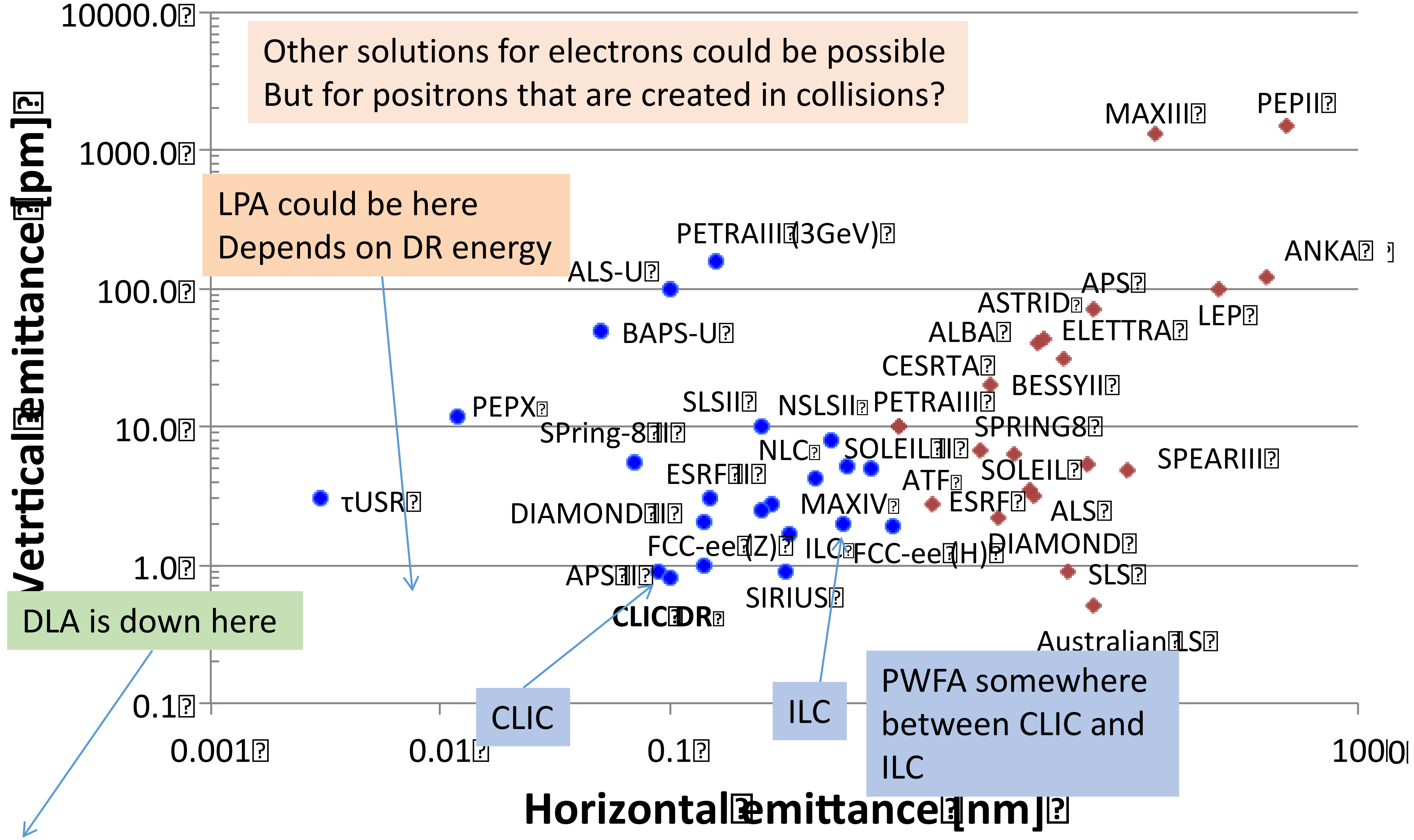
See for example: Y. Papaphilippou, “Reaching ultra-low emittance in the CLIC damping rings”

Damping Ring and Transverse Emittances

Can deliver O(10^4) bunches/s

E.g. CLIC with 5ns kickers could cool 200 bunches at any time

Some beam dynamics issues but probably manageable



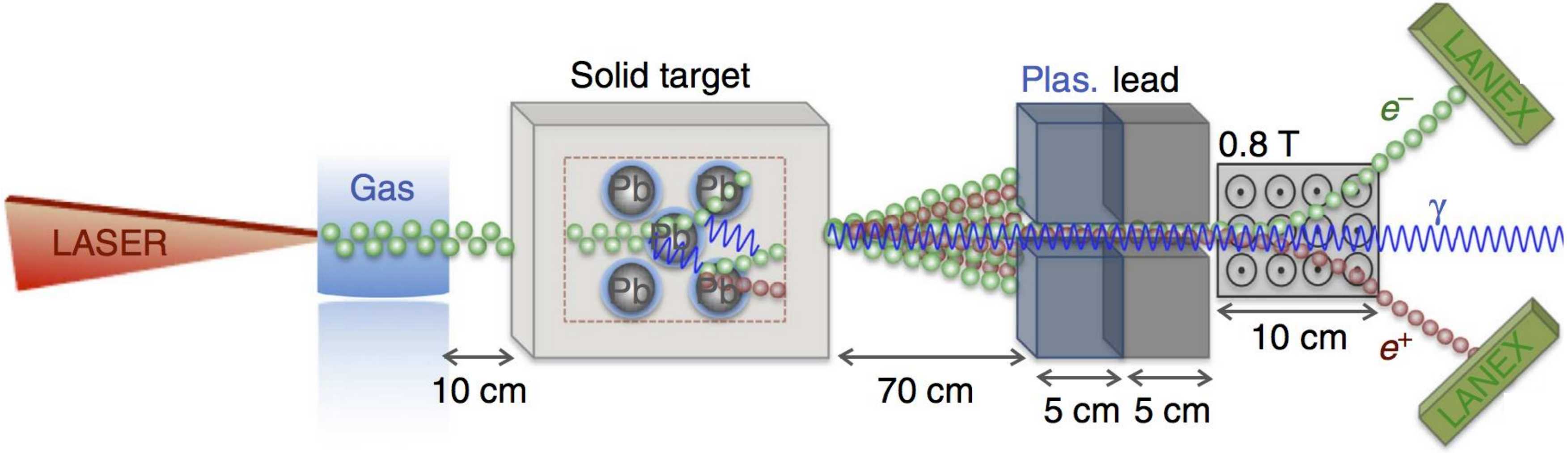
D. Schulte

“Exotic” / Advanced schemes for positron production

- Positrons from Laser acceleration
- Positrons from ultra high field laser interaction
- Positrons from electro-static traps

- Primary electron accelerator could be based on advanced accelerator technologies and used in a classical positron production scheme
- Plasma lenses for matching, plasma based capturing section could be attractive

Positrons from laser wakefield acceleration



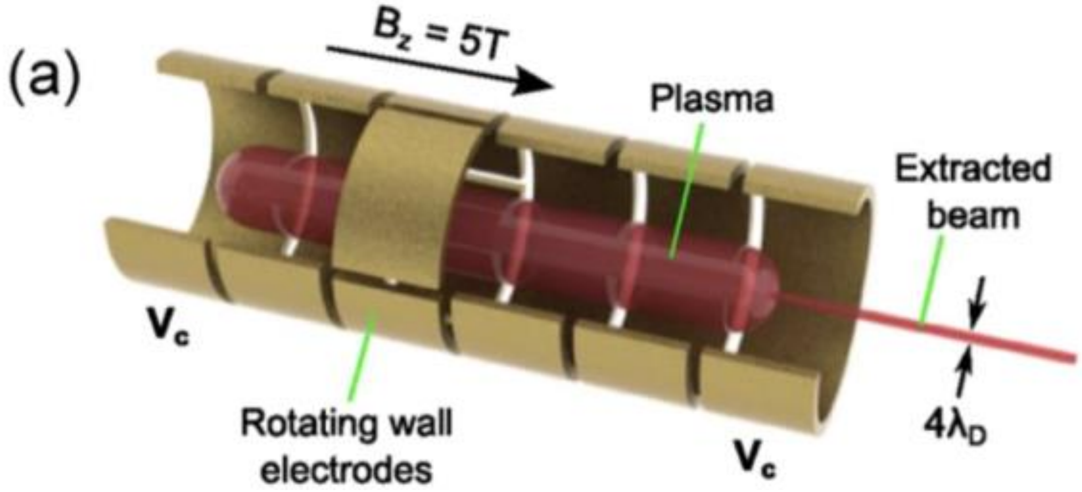
G. Sarri et al

- High energy (600 MeV) from the source
- High energy spread (50%)
- Emittance (~ um), likely damping ring still needed
- Possibly very short beams fs
- Charge ~ 10^8 total but small in reasonable bandwidth
- Future example EuPRAXIA: 5 x10^6 positrons at 1 GeV, 5% bandwidth, 190 μm emittance

Positrons from electro-static traps

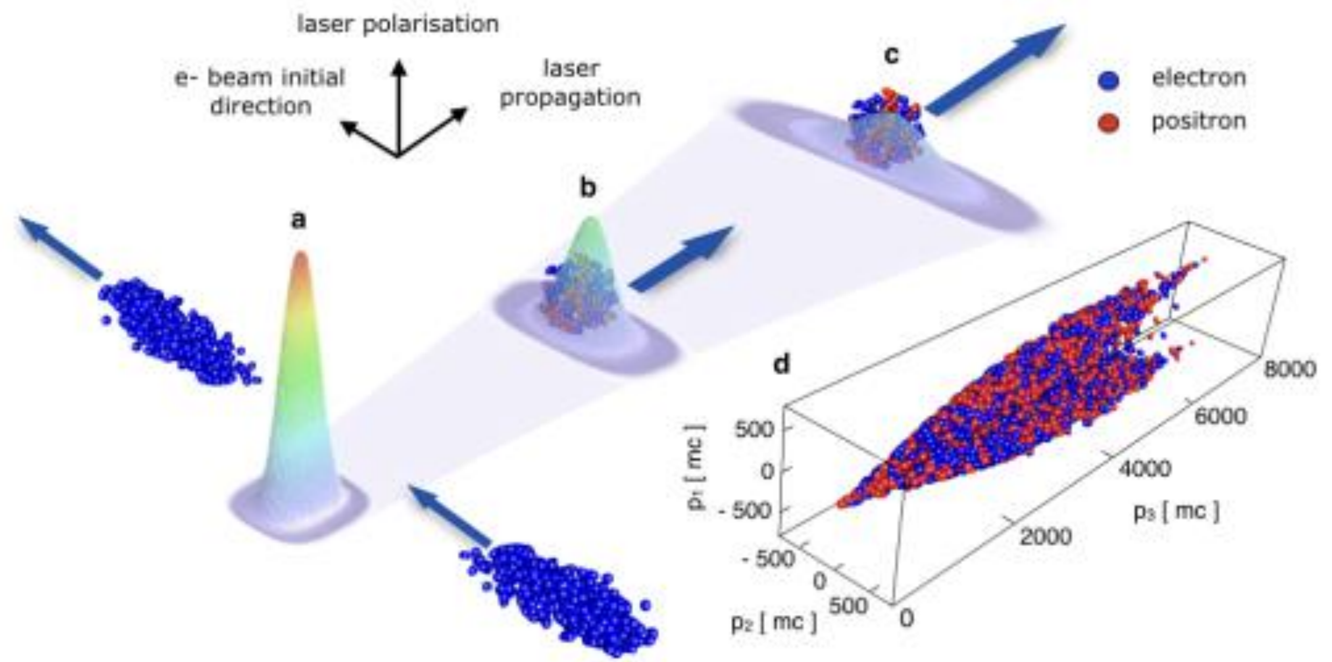
Positron Beams from Electro-static Traps

J. Danielson, Rev. Mod. Phys., Vol. 87, 2015



- Excellent emittance, no need of damping ring ?
- Very low energy (keV) but low energy spread as well
- Long bunch length (ns)
- Low intensity and repetition rate (10^7 and 0.1 Hz)

Positrons from very high field laser interaction



M. Vranic et al.
(see next talk)

- High energy (>1 GeV) from the source
- High energy spread (50%)
- Emittance ?, likely damping ring still needed
- Possibly short beams ?
- Low intensity in useable bandwidth
- High energy electron LINAC needed and high power laser needed

Conclusions

- Positron sources are by no means trivial
- Already very challenging for conventional linear colliders, may be considered as state of the art
- For advanced colliders main limitation comes from beam quality requirements for further transport and acceleration; emittance, energy spread and bunch length
- Very high repetition rate likely very costly and challenging
- Alternative positron sources need to be considered.
  Can we find a scheme which gets rite of the damping rings and provides equivalent or better beam quality

- Without extremely stable and reliable source → no luminosity !!!