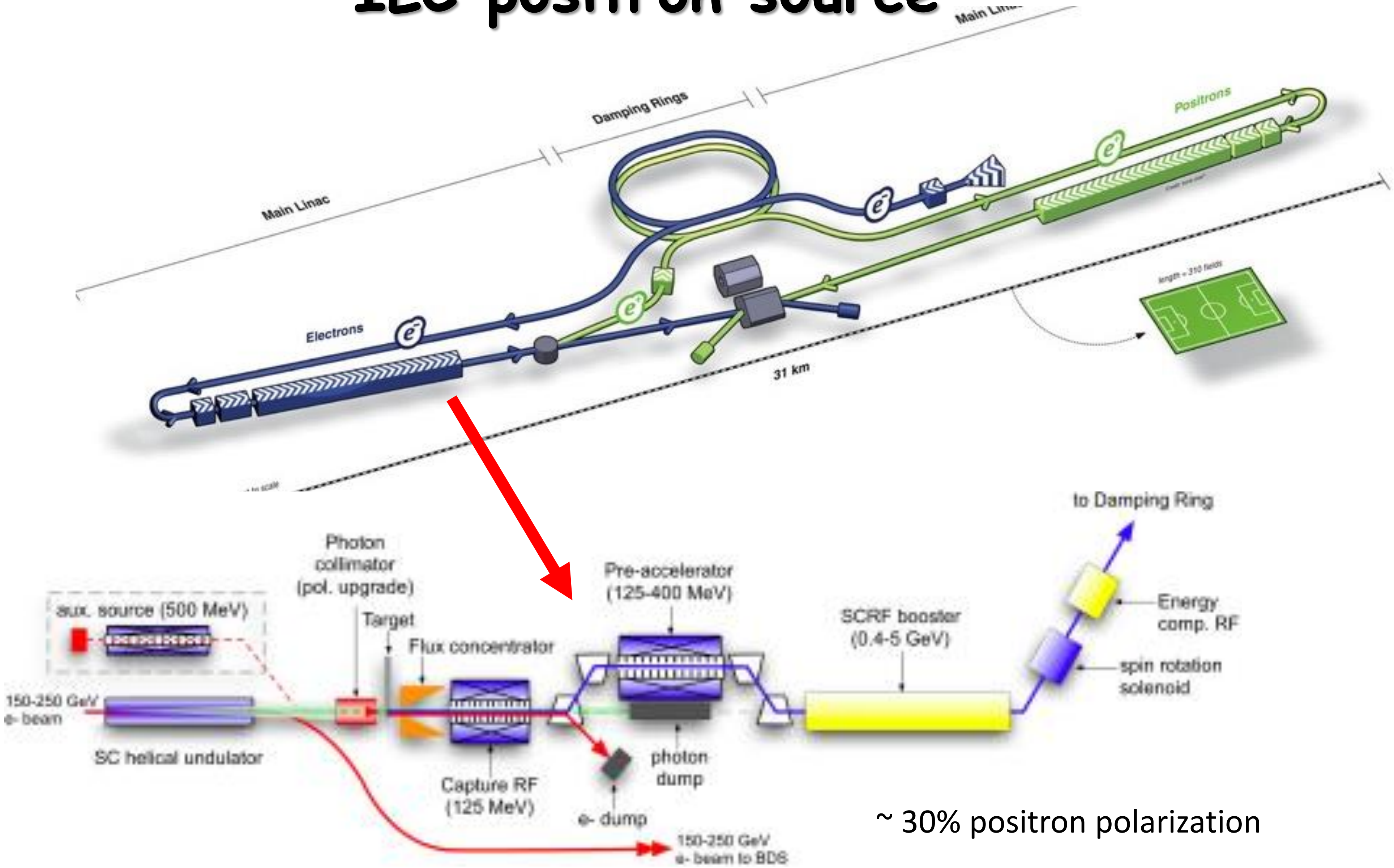
Positron Sources for future colliders

- Positron sources for Linear Colliders (CLIC and ILC) and for the circular collider FCC-ee
- Comparison of requirements and performances
- Lemma scheme
- Comments and conclusions

Steffen Doebert, BE-RF

Muon Collider Workshop,
CERN 9-11 October 2019

ILC positron source

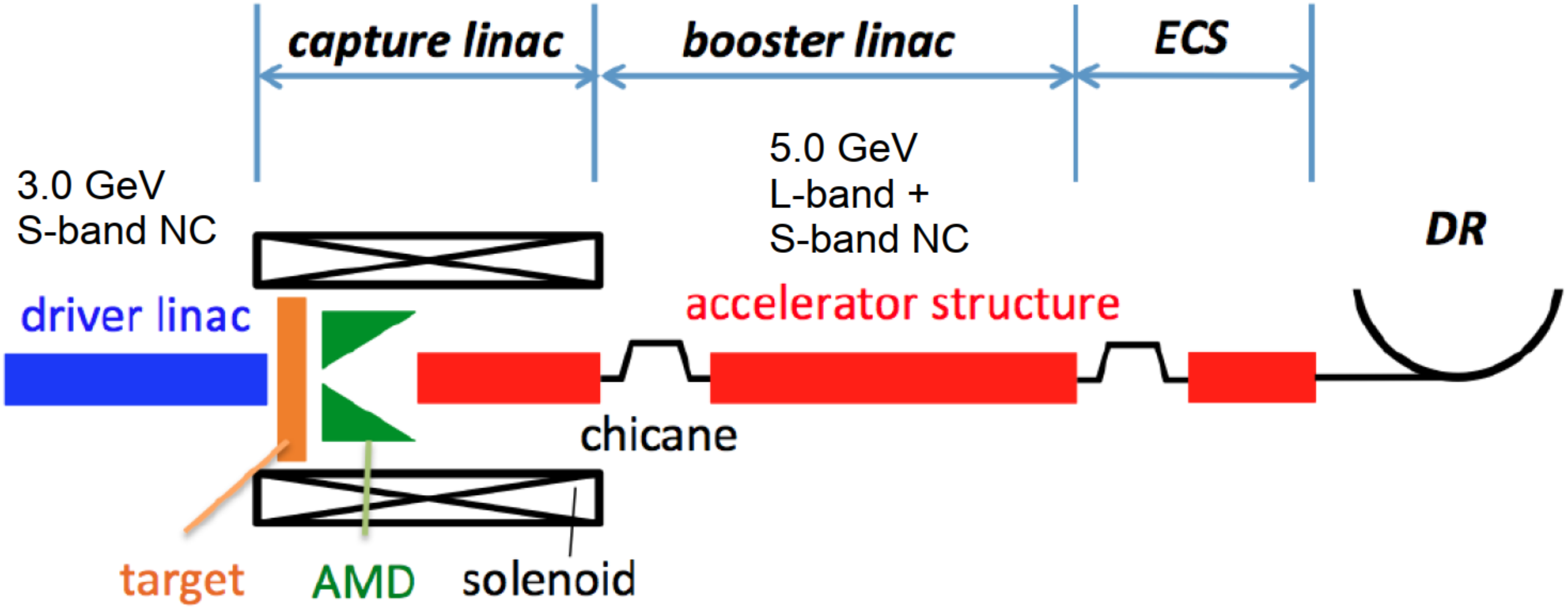


~ 30% positron polarization

Undulator driven with 125 GeV electrons produces gamma's for positron production

ILC positron source, alternative

E-driven ILC Positron Source

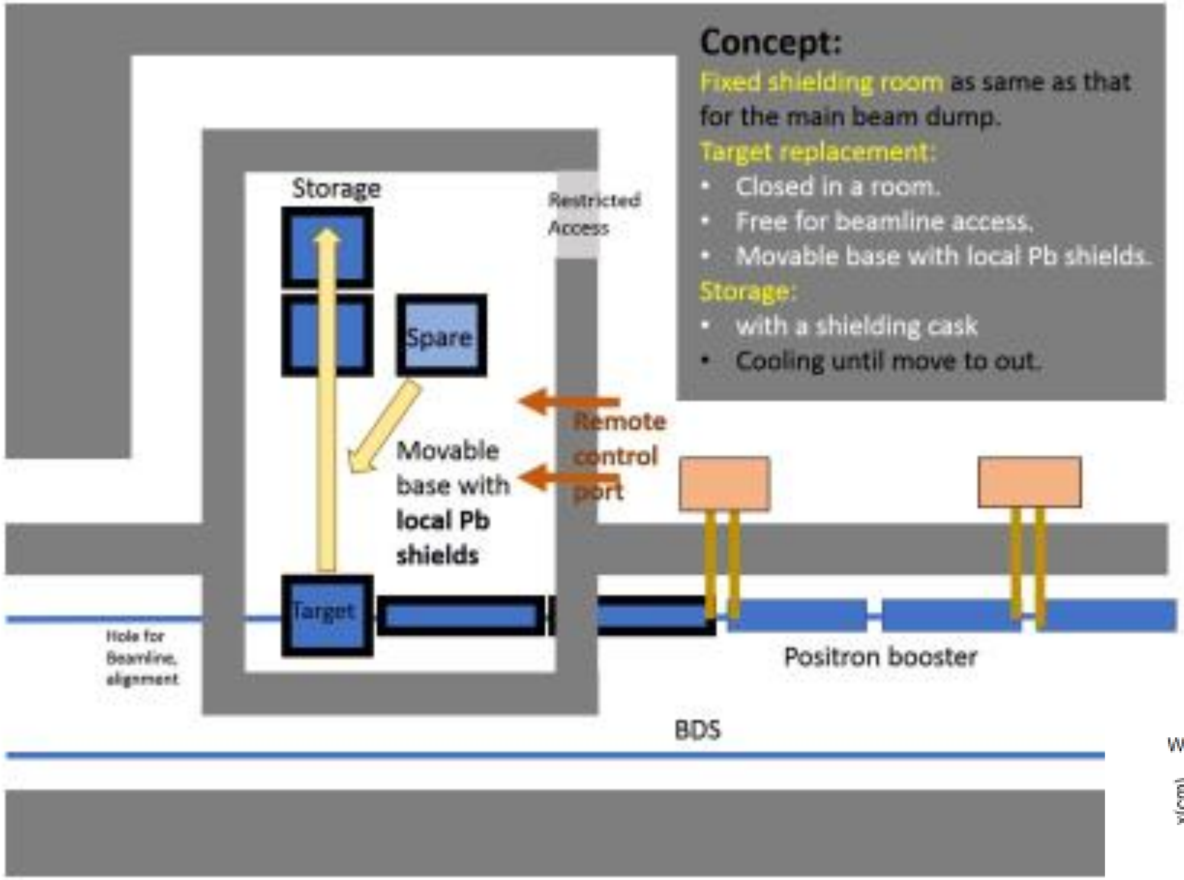


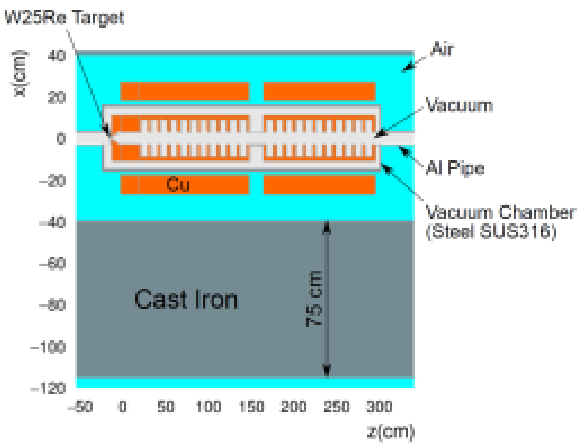
- 20 of 0.48us pulses are handled with NC linacs operated in 300Hz.
- 100 of 300 pulses are actually fired.

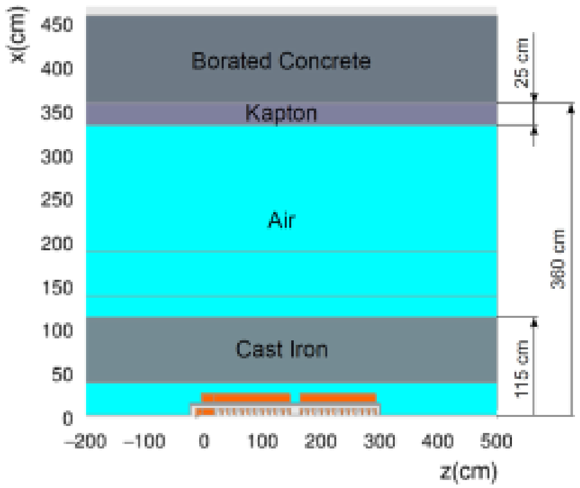
ILC positron source, target area

Meter’s of shielding and a sophisticated target exchange concept

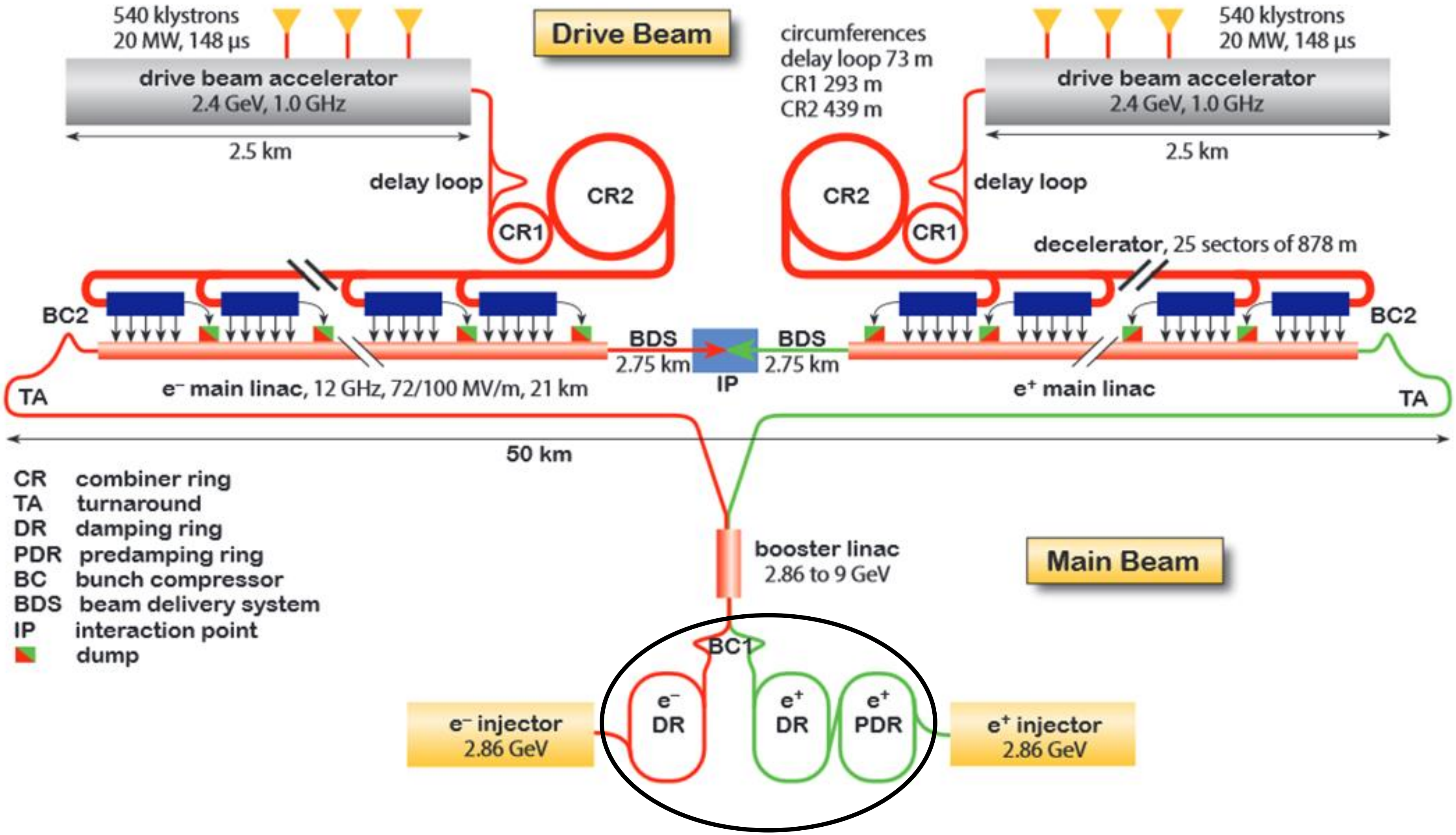
→ Positron sources need space



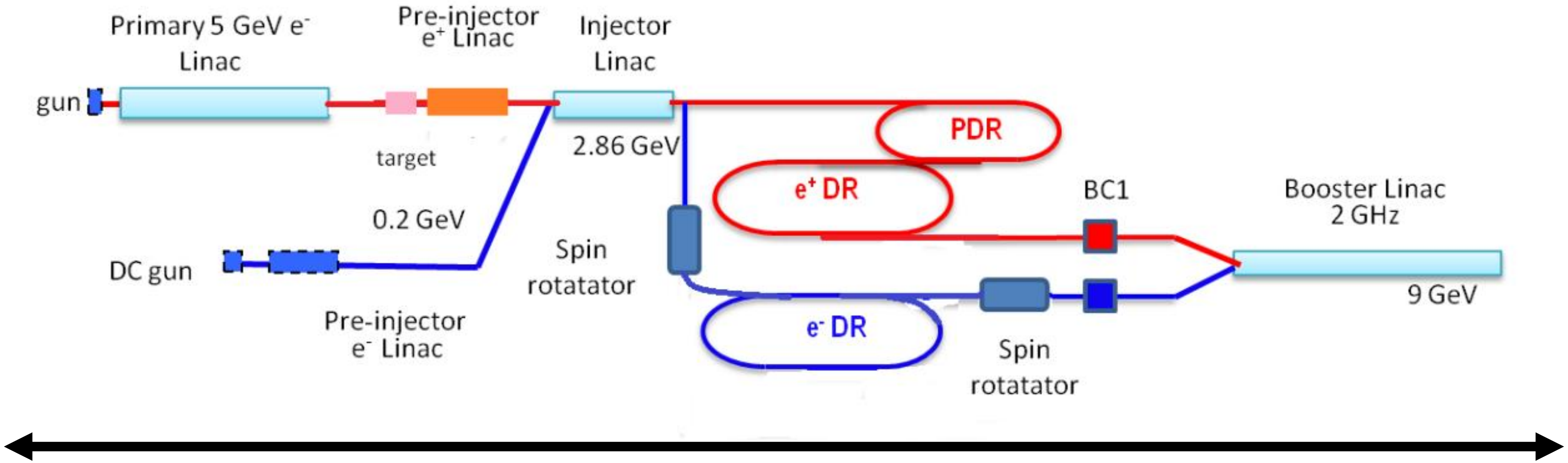




CLIC complex, 3 TeV



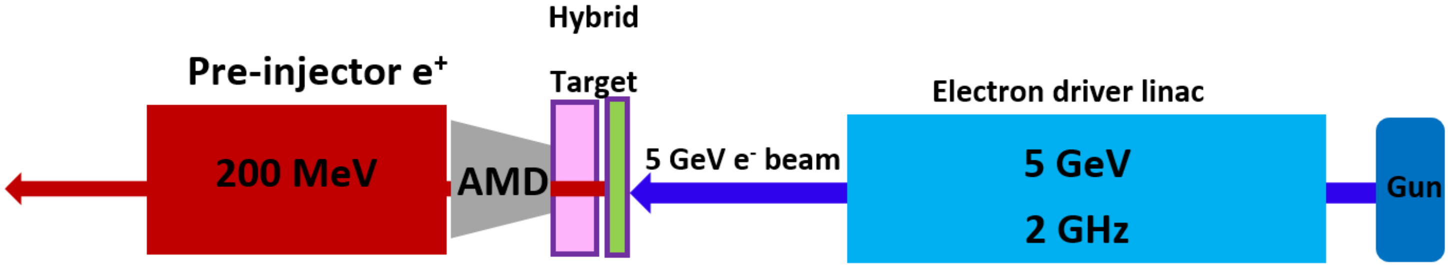
The CLIC Injector Complex

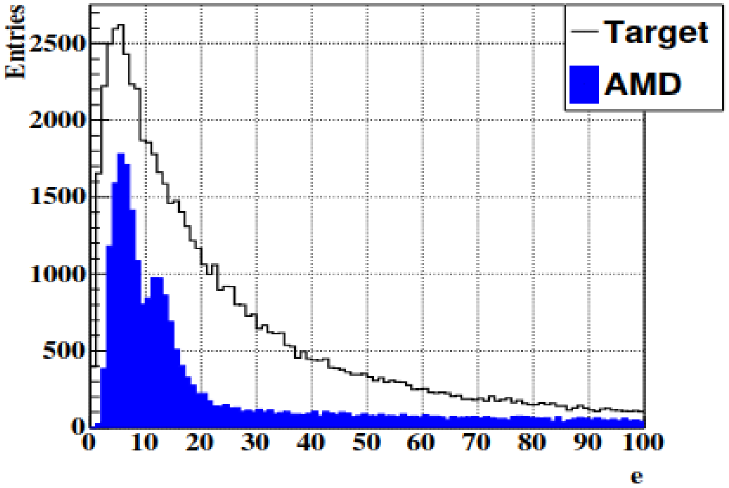


> 1 km

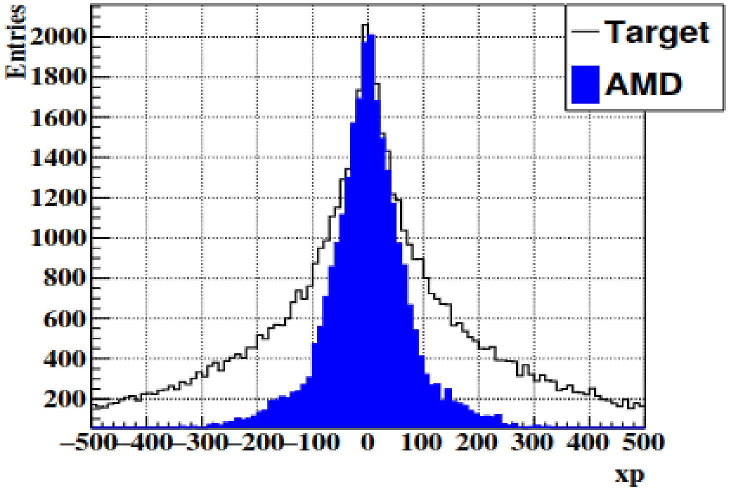
- Pre-damping ring can be avoided if the beam emittance is ~ < 25 mm (norm)
- Positron emittance before pre-damping ring: 7 mm
- Main damping ring; in: e_{xn}/e_{yn} = 65/10 μm
  out: e_{xn}/e_{yn} = 472/5 nm
- Bunch compressors needed after the rings for further acceleration

CLIC Positron Source





Energy (MeV)

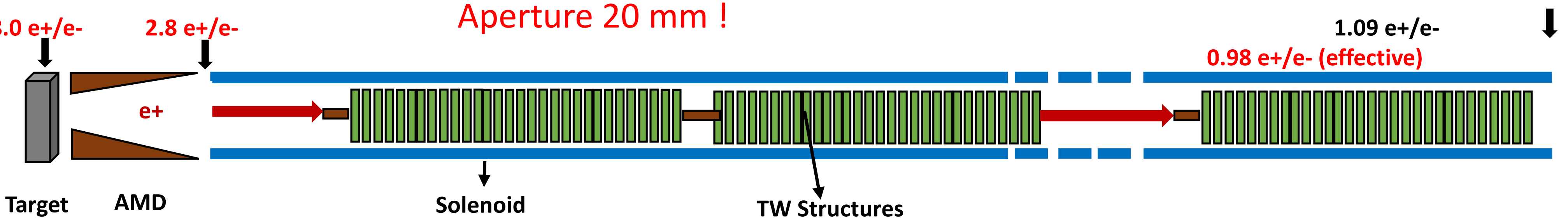


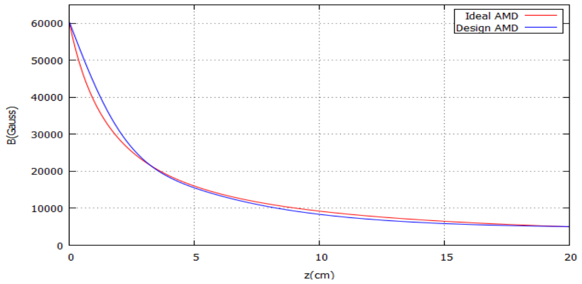
$x'(mrad)$

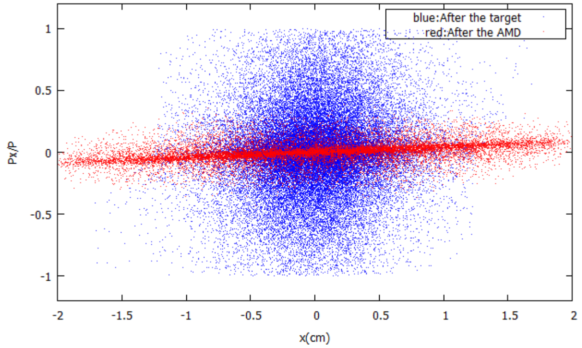
- ❑ Generation of adequate photons (0-20 MeV) for pair production
- ❑ Complex and lossy positron collection and capture system
- ❑ Performance limited often by peak energy deposit density (PEDD < 35 J/g pulse)
- ❑ Very high radiation area, constraints for operation and maintenance, engineering challenge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

Previous studies: The Pre-Injector Linac

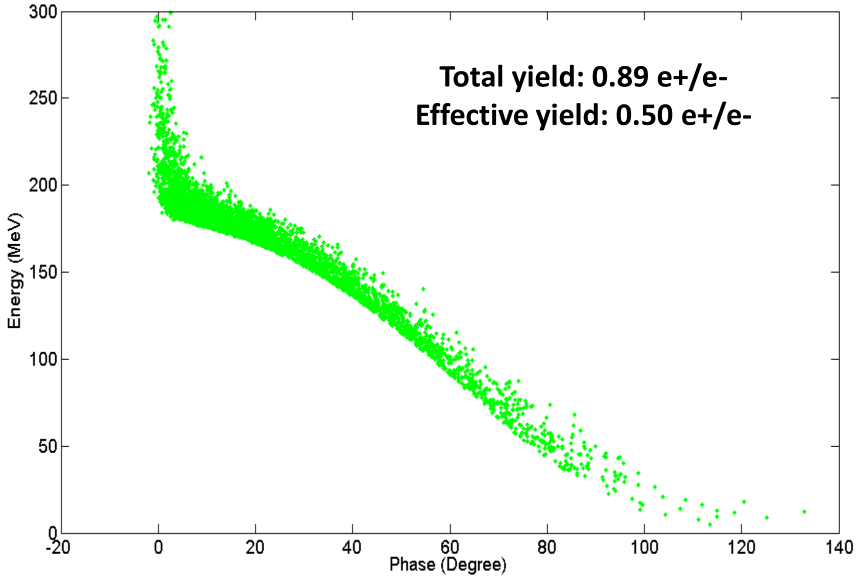
The total yield:



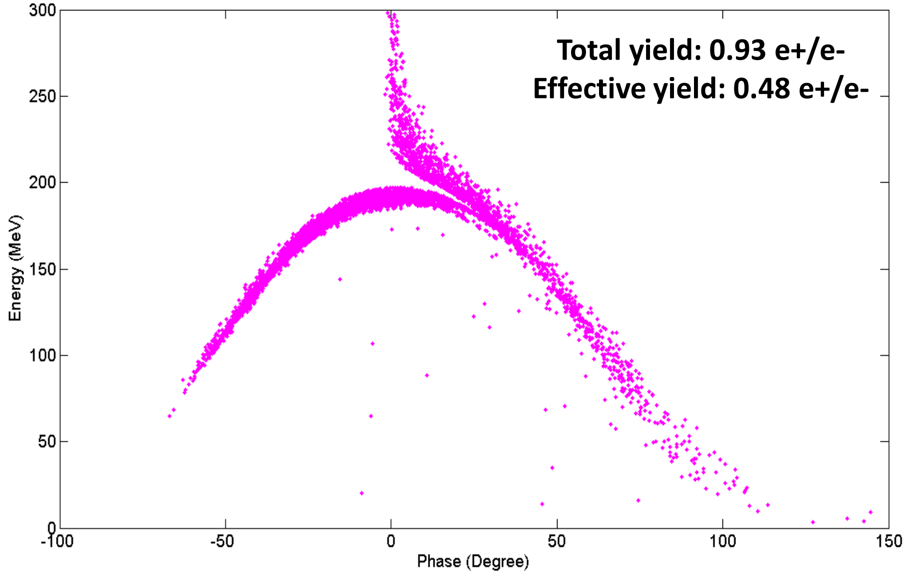




The effective yield : (-20,20) degrees in phase and (150,250) MeV in energy



Acceleration



Deceleration

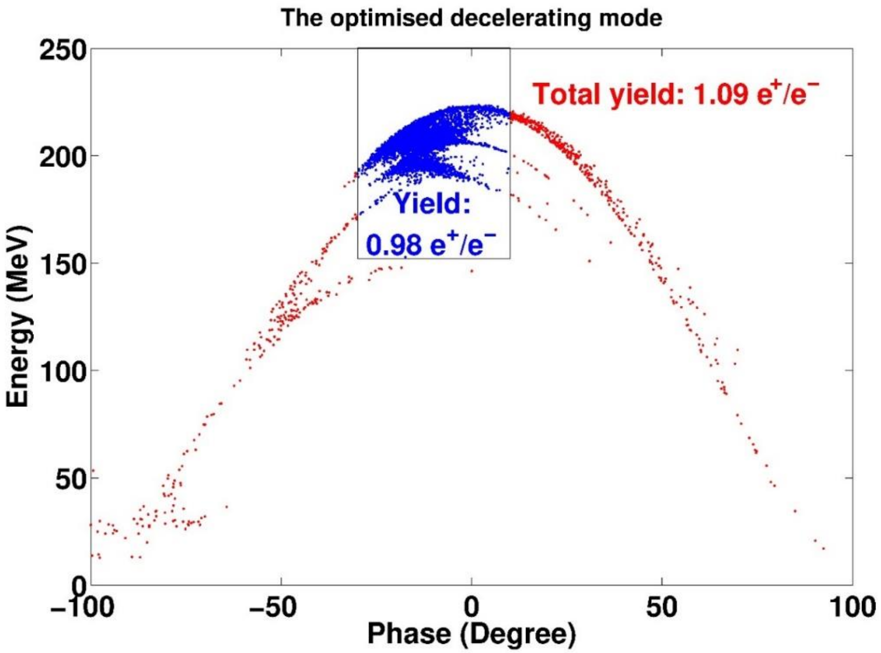
Parameters of the accelerating structures in the Pre-Injector linac

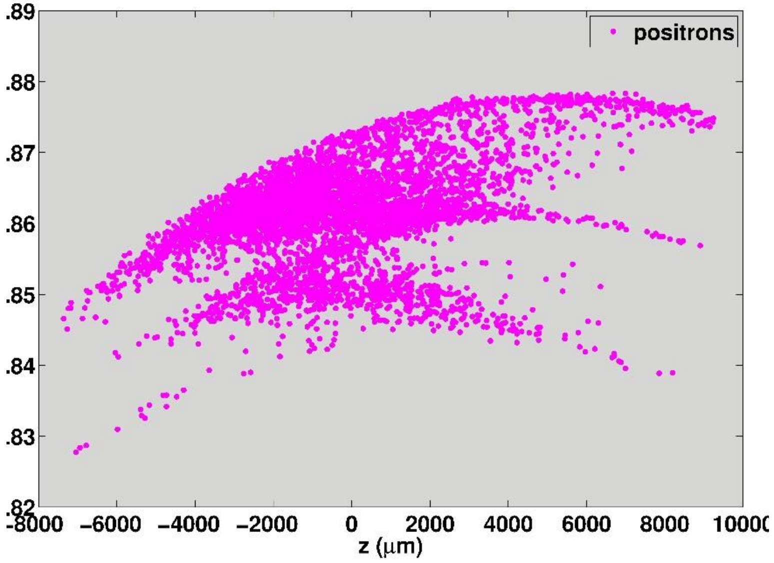
Parameters	Unit	Value
Cell length	cm	5
Frequency	GHz	2
Phase advance per cell	π	2/3
Average axial electric field	MV/m	15

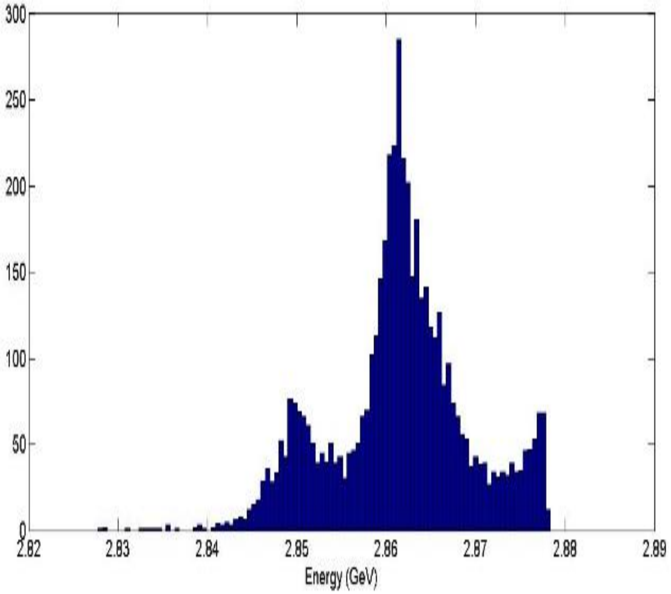
C. Bayar

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

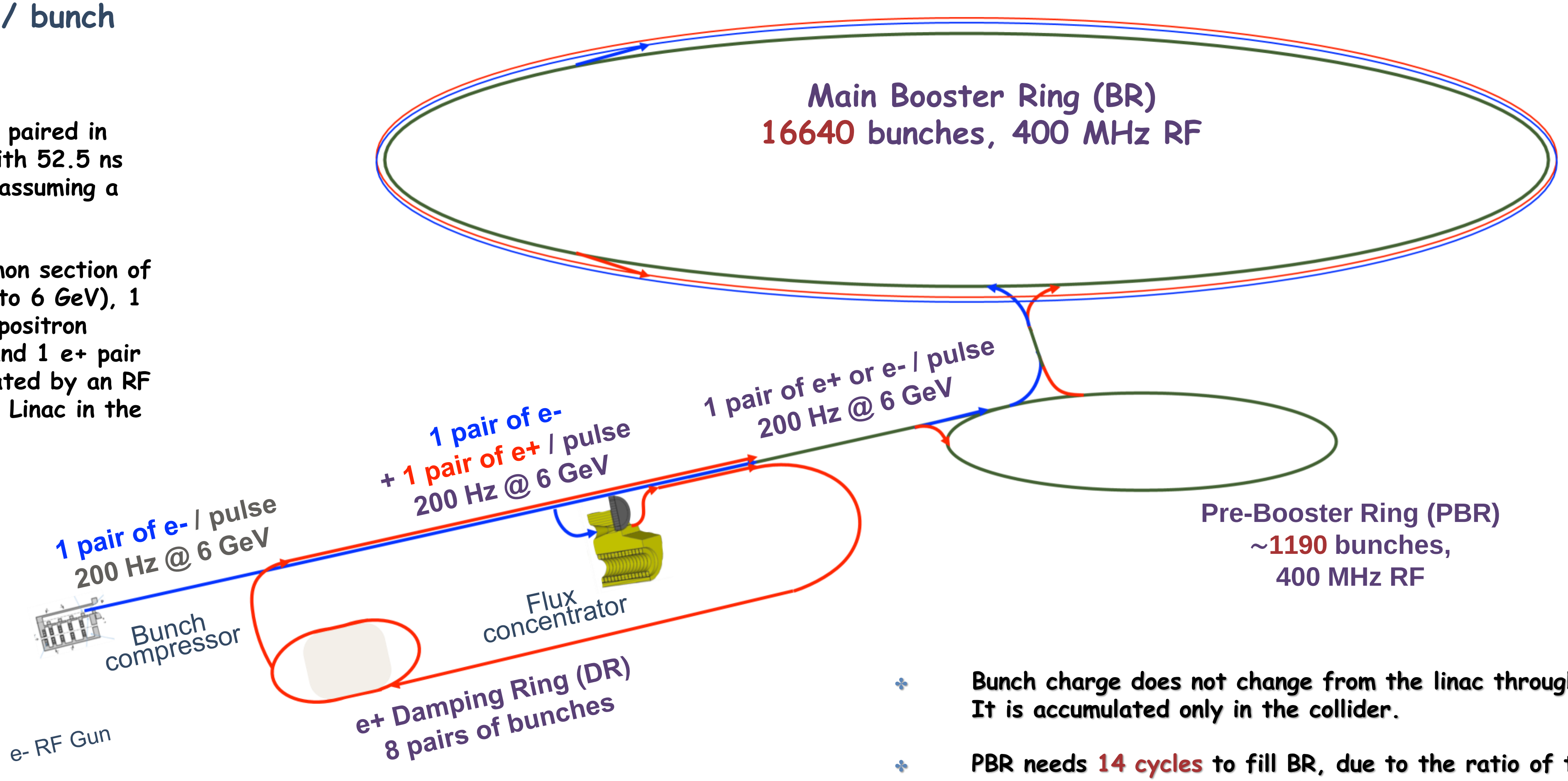
Energy (GeV)	Target exit (e^+/e^-)	AMD exit (e^+/e^-)	Total yield (e^+/e^-)	Effective yield (e^+/e^-)
5 (new)	7.14	3.06	1.36	**1.21**
5 (previous)	8.00	2.80	1.09	0.98
5 (CDR)	8.00	2.10	0.95	0.38

C. Bayar

FCC-ee positron source
injection scheme for Z

Collider rings
16640 bunches
1.7 x 10^{11} / bunch

- Bunches are paired in the linac, with 52.5 ns separation, assuming a usual SLED.
- In the common section of e+e- (1.54 to 6 GeV), 1 e- pair for positron production and 1 e+ pair are accelerated by an RF pulse of the Linac in the e+ mode.

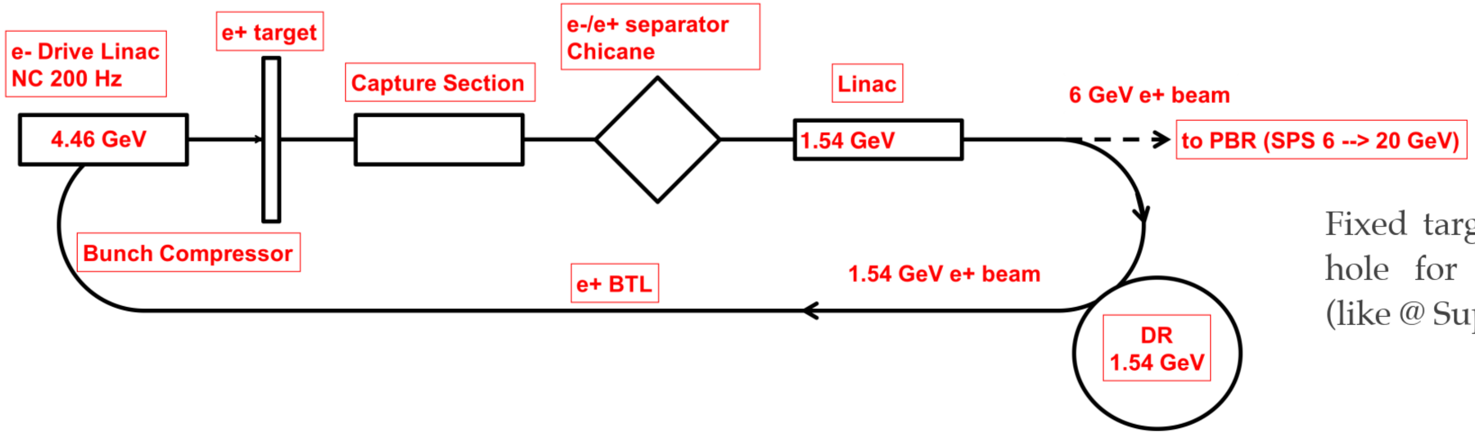


- Bunch charge does not change from the linac through BR. It is accumulated only in the collider.
- PBR needs 14 cycles to fill BR, due to the ratio of the circumferences (M. Benedikt).

K. Oide

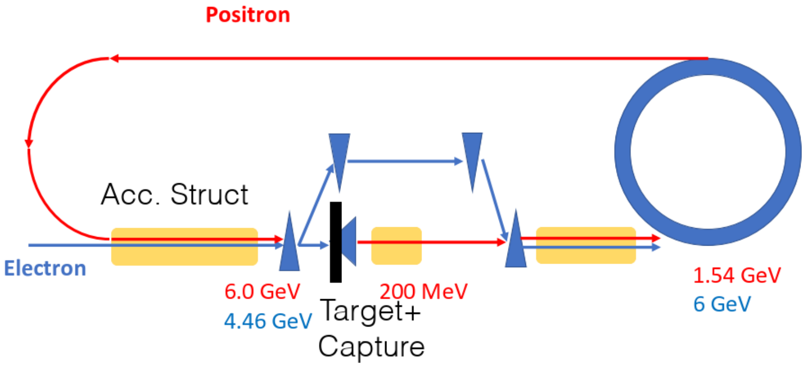
FCC-ee Positron Injector options

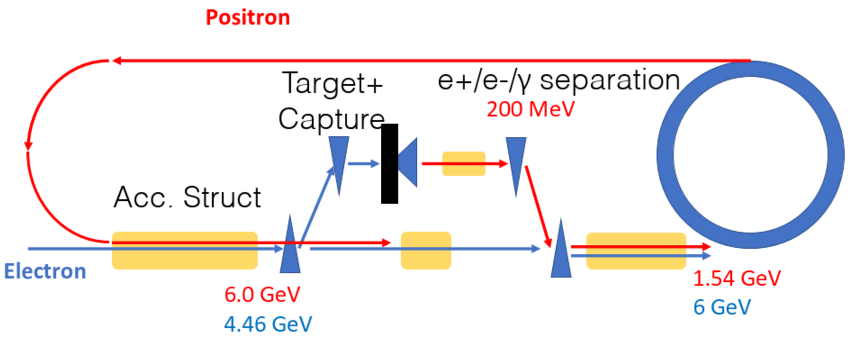
Current scheme



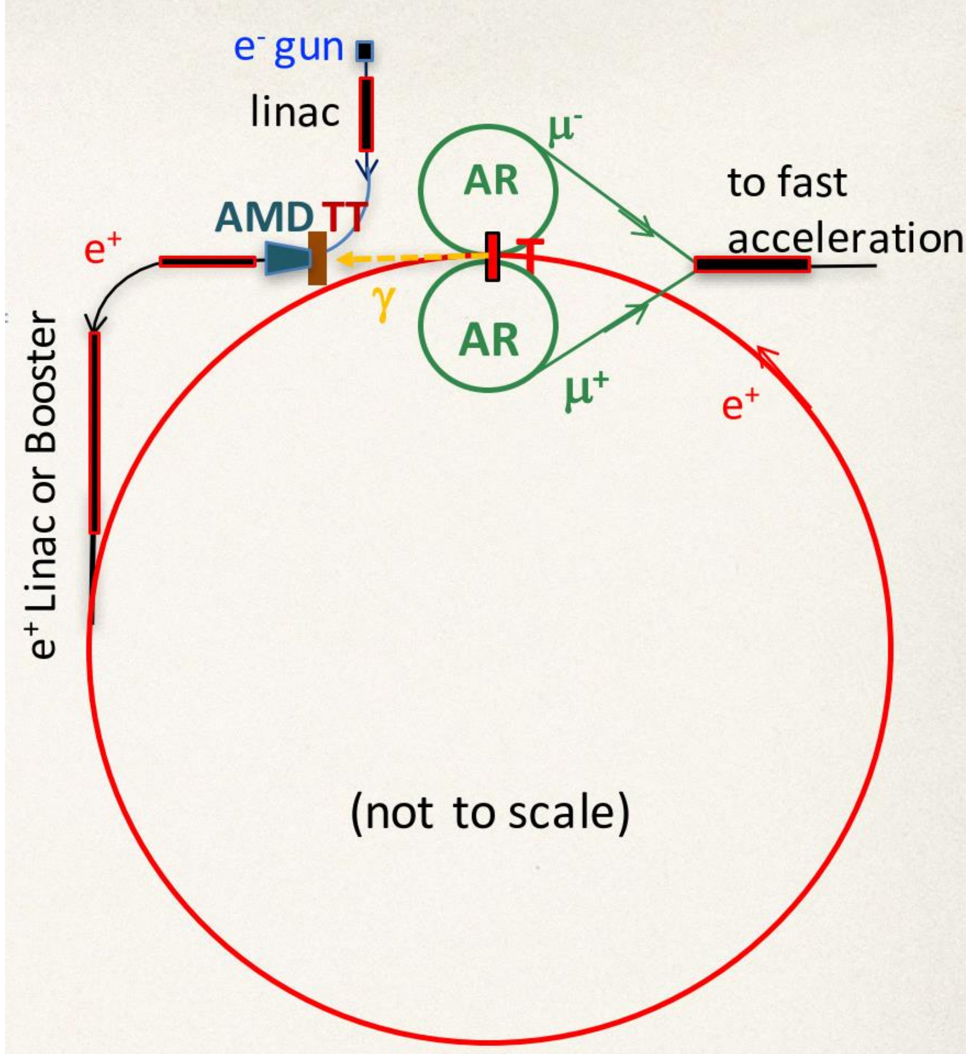
Fixed target-converter has a hole for e- beam passage (like @ SuperKEKB)

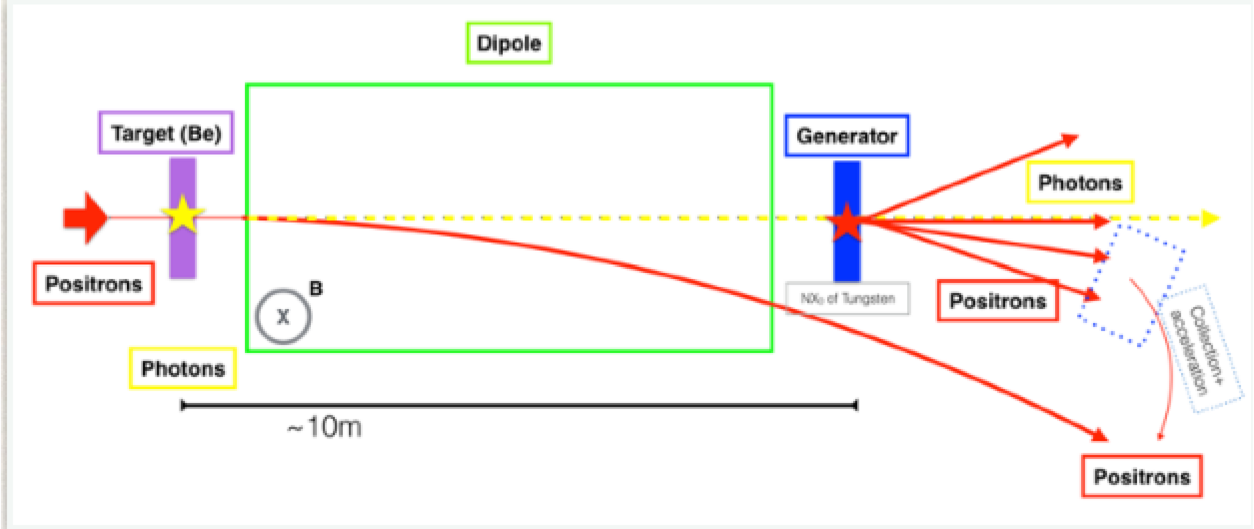
Schemes with the bypass under consideration (very preliminary)





The Lemma0 scheme





YIELDS ($5X_0$ of W)	particle	#
Primary Particles	e^+	100
Primary Particles lost due to target (DE 4%)	e^+	**3**
Exiting Beryllium	γ	10.8
Entering Tungsten	γ	10.6
Exiting Tungsten	e^+	**65**

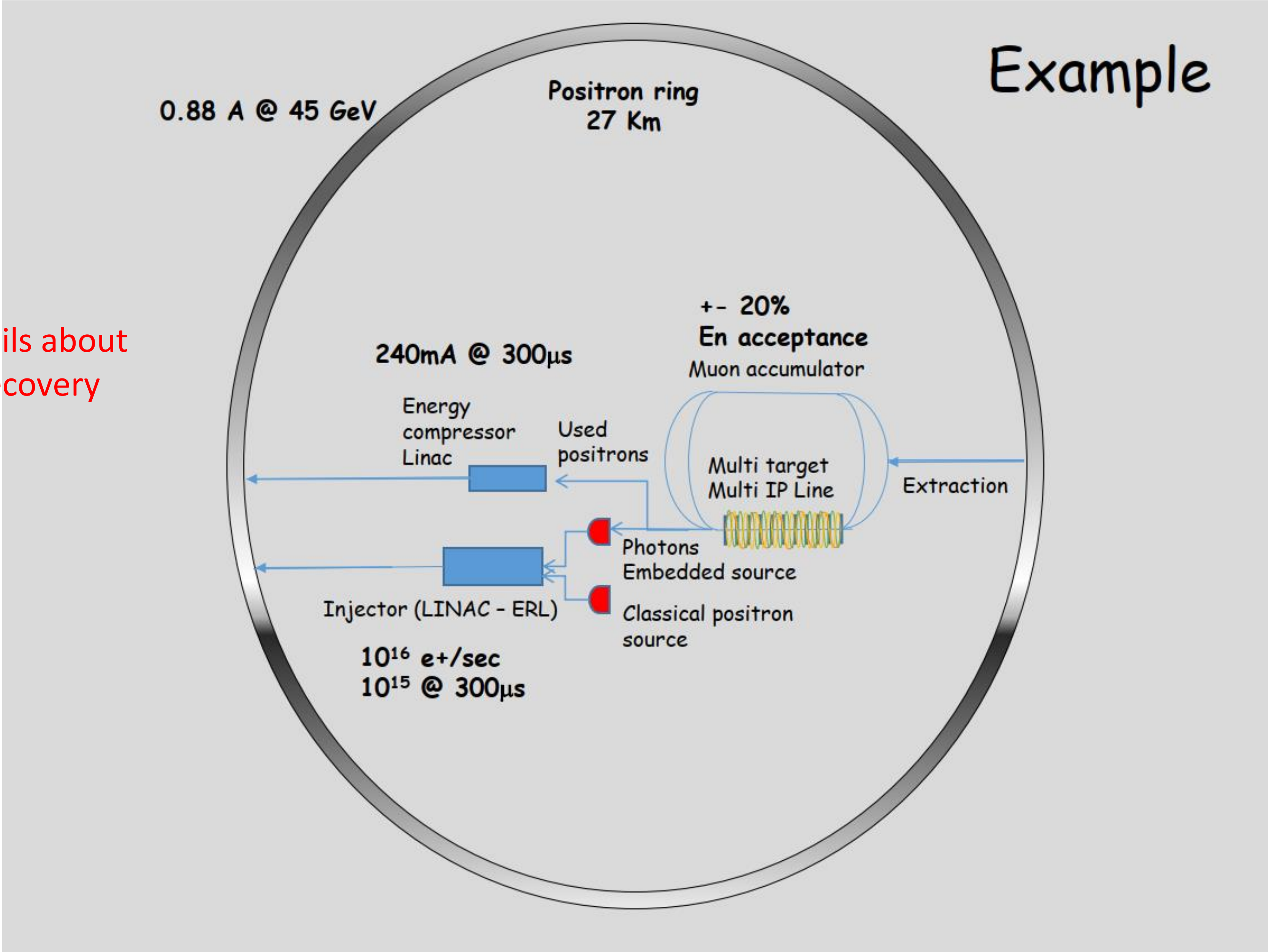
3 new positrons reinjected to replace the lost ones

Cuts:
5-20 MeV
R= 0.5 cm
R'=0.5 rad

Yields about 10

From F. Collamati at Posipol 2018

The Lemma1 scheme



Not many details about the positron recovery schemes yet !

Positron requirements / beam parameters

Parameter	Unit []	ILC	CLIC	SLC	FCC-ee	Lemma-scheme
Bunch charge	N [10^9]	20-30	6	3-5	21 / 170	315
Emittance norm	$\varepsilon_x/\varepsilon_y$ [nm]	10^4/35	660/20		10^4/90	5 10^4
Bunches per train	n	1312	352	1	2	100
Repetition rate	[Hz]	5	50	120	200	5 MHz/100 kHz
Particles /s	N [10^{14}]/[s]	1.3	0.58	0.06	0.0852	10^{18} / 10^{16}
Positron yield	e+/e-	8 /1.28	8/ 1.3	~20 /1.25	11/0.7	80 e+/e+
Collection efficiency	e+/e+ (%)	16	16	~ few %	6	17 % ?
PEDD	J/g	33.6	18	35	17	
Beam power on target / photons	[kW]	48 / 60	64	20	12	MW ?
Deposited power	[kW]	12	11	4.4	2.1	MW ?

Careful, numbers might be not all consistent !

Positron Challenges within the Lemma scheme some comments

- **Full positron source with linear collider intensities needed to fill the ring with numerous injections**
- **Without recovery two orders of magnitude higher positron flux then linear colliders, four orders of magnitude compared to tested systems → recovery needed, still 10^{16} e^+/s**
- **Intensity of photon beam very high, MW on target, existing sources in kW range, neutron source type beam power (ESS: 5 MW), if possible likely not small**
- **Power scaling: Order of 100 MW positron beam power compared to 28 MW in 3 TeV CLIC**

Positron Challenges within the Lemma scheme

- **Innovative but challenging system for recovery to compensate positron loss per turn, collection efficiency to be determined, not clear how the studied cuts compare to full capture system simulations Likely on the optimistic side**
- **Recovered positrons arrive at the bunch distance of the ring (5 MHz cw for example), sc cw linac ?**
- **Top up injection at 45 GeV ?, Emittance ?**
- **Is a damping ring for the positrons needed, timing scheme implications**
- **Huge integration problem in case of recovery, size of the target systems, very close to the ring and the Muon target**

Conclusions

- Positron sources are by no means trivial
- Already very challenging for conventional linear colliders, may be considered as state of the art
- Lemma scheme parameters are clearly beyond the state of the art. Major R&D effort needed to get confidence in feasibility

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

Positron source performances

	SLC	LEP (LIL)	KEKB/SKEKB	FCC-ee*
Incident e- beam energy	33 GeV	200 MeV	4.3/3.5 GeV	4.46 GeV
e-/bunch [10^{10}]	3-5	0.5 - 30 (20 ns)	6.25/6.25	4.2
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)	4.3 kW/3.3 kW	12 kW
Beam size @ target	0.6 - 0.8 mm	< 2 mm	/>0.7 mm	
Target thickness	$6X_0$	$2X_0$	/$4X_0$	
Target size	70 mm	5 mm	14 mm	
Target	Moving	Fixed	Fixed/Fixed	
Deposited power	4.4 kW		/0.6 kW	
Capture system	AMD	λ/4 transformer	/AMD	AMD
Magnetic field	6.8T->0.5T	1 T->0.3T	/4.5T->0.4T	
Aperture of 1st cavity	18 mm	25mm/18 mm	/30 mm	
Gradient of 1st cavity	30-40 MV/m	~10 MV/m	/10 MV/m	
Linac frequency	2855.98 MHz	2998.55 MHz	2855.98 MHz	
e+ yield @ CS exit	~4 e+/e-	~3 $\times 10^{-3}$ e+/e- (linac	~0.1/~0.5 e+/e-	
Positron yield @ DR	~1.2 e+/e-		NO/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

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