Adaptations on Laser Compton e^+ source

KURIKI Masao (KEK)

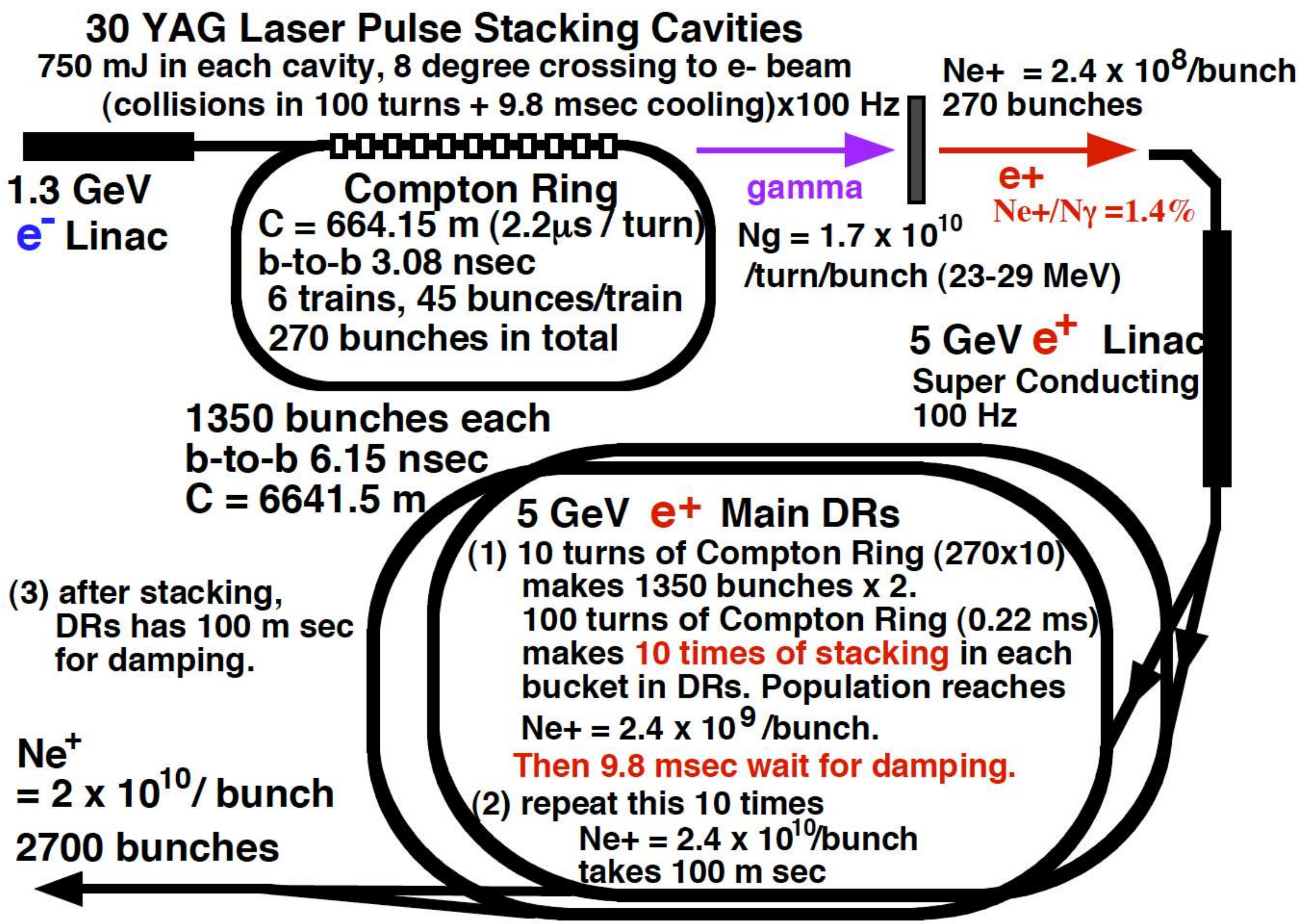
A. Laser-Compton Scheme Masao Kuriki

- Develop full design which is compatible with current ILC design:
  - full source accelerator design: OMD, rf, yield calcs
  - Simulation of compton ring dynamics, incl nonlinear beam dynamics
  - Simulation of e+ stacking in the ILC DR.
- Optical cavity and laser experiments
- „Schedule“ for compton scheme development, now thru completion: how to we get from here to there

LC ILC e^+ Source Status

- RLC (Ring based Laser Compton): Electron Storage Ring + Mode-lock medium power laser
  - Laser and electron beam are effectively recycled.
  - Beam in CR is hard to control.
  - Yield at one collision is limited.
- LLC (Linac based Laser Compton): Linac + CO_2 high power laser
  - Yield at one collision is relatively large.
  - Need a high brightness electron injector.
  - Laser repetition is limited.

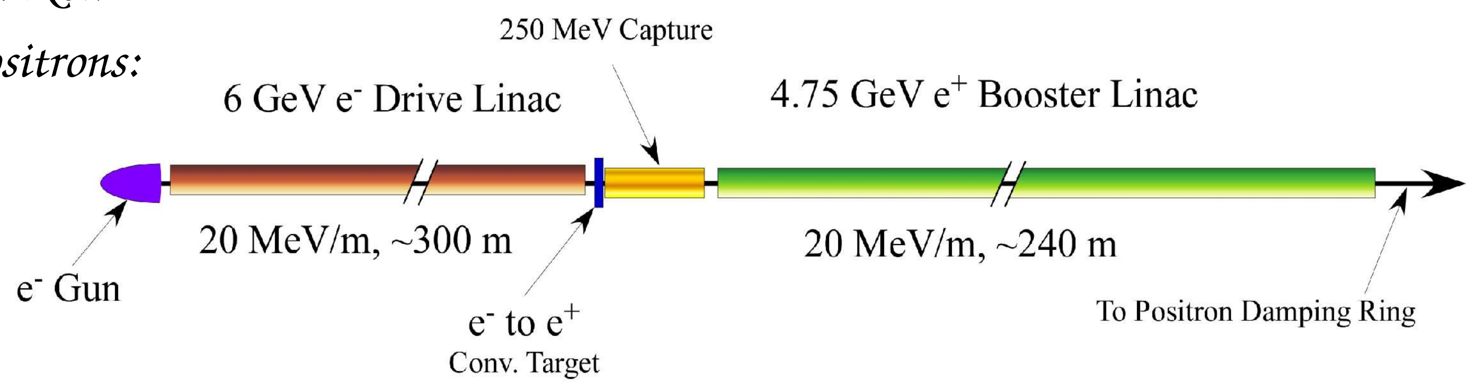
RLC by Omori



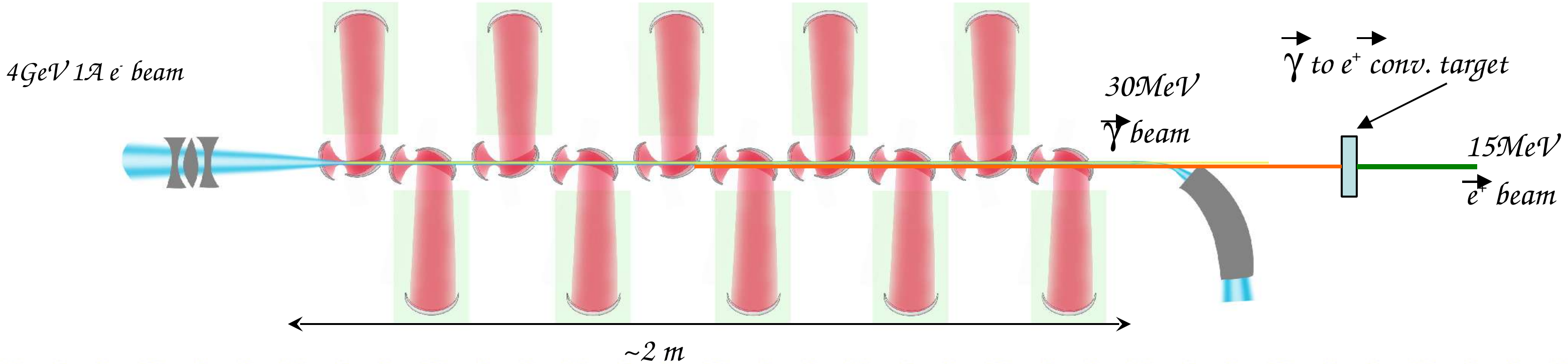
30 YAG Laser Pulse Stacking Cavities
750 mJ in each cavity, 8 degree crossing to e- beam
(collisions in 100 turns + 9.8 msec cooling)x100 Hz
Ne+ = 2.4 x 10^8/bunch
270 bunches
1.3 GeV
e- Linac
Compton Ring
C = 664.15 m (2.2μs / turn)
b-to-b 3.08 nsec
6 trains, 45 bunces/train
270 bunches in total
gamma
Ng = 1.7 x 10^10
/turn/bunch (23-29 MeV)
e+
Ne+/Nγ =1.4%
5 GeV e+ Linac
Super Conducting
100 Hz
1350 bunches each
b-to-b 6.15 nsec
C = 6641.5 m
5 GeV e+ Main DRs
(1) 10 turns of Compton Ring (270x10)
makes 1350 bunches x 2.
100 turns of Compton Ring (0.22 ms)
makes 10 times of stacking in each
bucket in DRs. Population reaches
Ne+ = 2.4 x 10^9 /bunch.
Then 9.8 msec wait for damping.
(2) repeat this 10 times
Ne+ = 2.4 x 10^10/bunch
takes 100 m sec
(3) after stacking,
DRs has 100 m sec
for damping.
Ne+
= 2 x 10^10/ bunch
2700 bunches

LLC by V. Yakimenko

Conventional Non-Polarized Positrons:

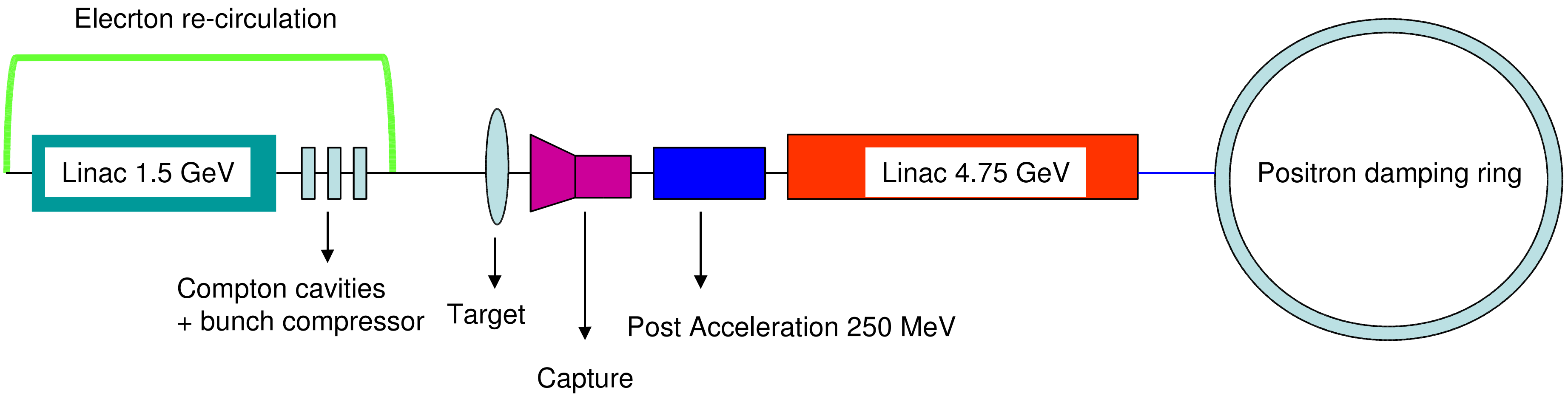


- Optical cavity of CO_2 laser beam + 4 GeV e-beam.
- For required e+ : 5x3nC e-beam + 5 to 10 optical cavities.



ELC by A. Variola

- Because high intensity e^- beam is "circulated" only in energy, difficulties in CR beam dynamics are solved.
- The gamma yield can be increased up to the non-linear limit by employing a high power laser without difficulty on the geometrical factor (crossing angle) because short bunch is possible.



LLC + RLC

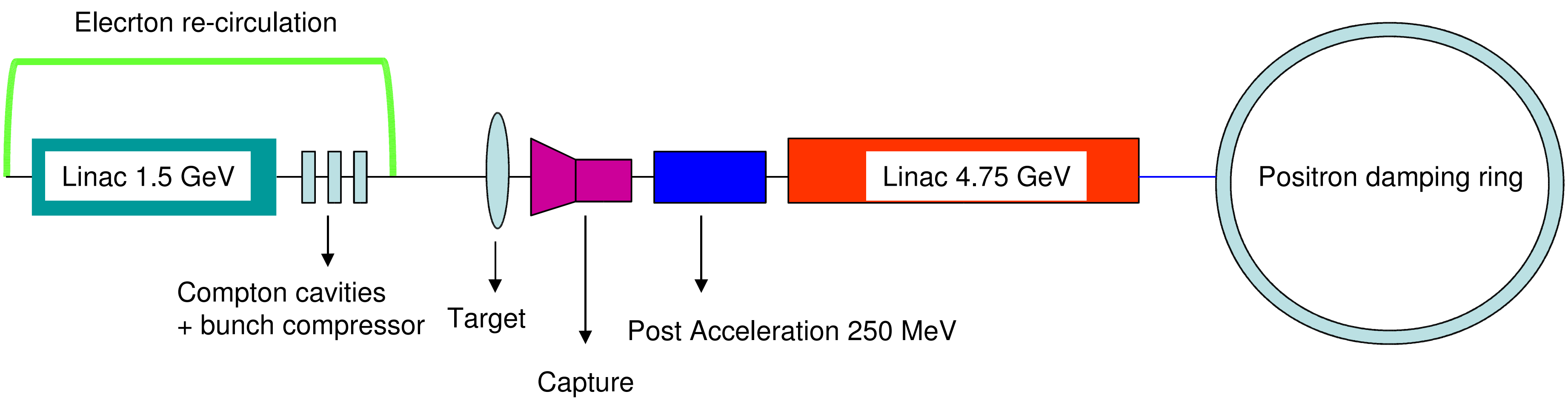
- Upgradability from Conventional to LLC is one way to minimize the unexpected risk, but LLC has still some difficulties.
- This is a straightforward way to develop components, which meet the requirements as presented by V. Yakimenko.
- Another way to solve this problem is a hybrid system of LLC and RLC.
  - **LLC has advantages on high yield,**
  - **RLC has advantages on high reputation.**

LLC + RLC = ELC

- ERL solution is a variant, which is a mixture of LLC and RLC. Both advantages of LLC and RLC can be skimmed.
- Short bunch operation down to few ps is even possible; The crossing angle between the e-beam and laser is not an issue anymore.
- Optical cavity + mode lock medium power laser can be employed; High repetition is possible.

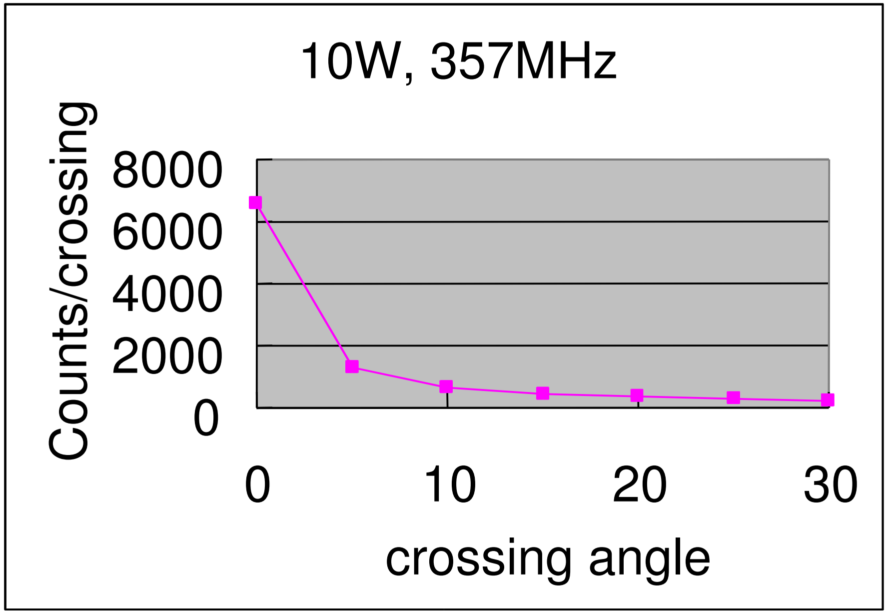
ERL Laser Compton

- 6nC/bunch with 300 ns spacing (20mA) is "circulated" in ERL mode, which decreases the yield to be 60%.
- Gamma yield by one collision is enhanced by the short bunch length by a factor of 5.
- The capture efficiency is improved by introducing AMD by a factor of 2.
- Extremely high finesse cavity by LAL, x5000 enhancement.



Yield and Crossing Angle

- γ-ray yield strongly depends on crossing angle when the e- bunch length is longer than the laser length.
- This is not an issue when both length are comparable.
- By shortening the e- bunch length with a finite crossing angle, more than a factor of 5 is obtained.



ATF

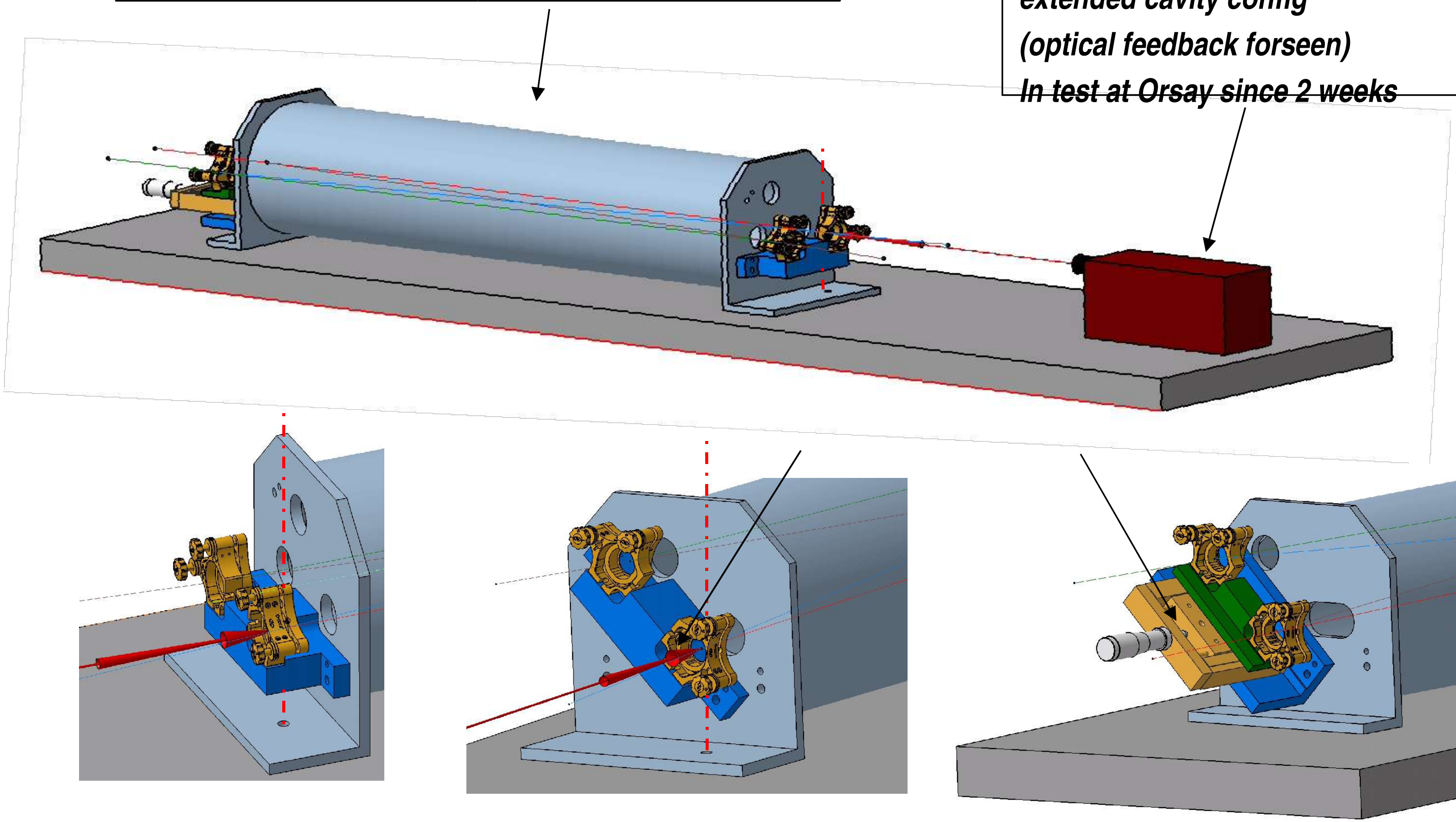
e^- bunch length = 9 mm (rms)

Ne = $1x10^{10}$/bunch

4 mirrors non-plannar cavity

Cavity vessel under construction in the LAL workshop

Cw laser diode in extended cavity config (optical feedback forseen) In test at Orsay since 2 weeks



Manpower: 1PhD. & 1 technician full time

Rough Valuation

- Total enhancement compare to RLC can be 0.6 (Bunch charge) x 5(Bunch length) x2(AMD) x5(Finesse) = 30.
- 12.7E+10 γ yield corresponding to 3.2 γ/e-.
- The yield is 0.18 e+/e- and 0.36 E+10 e^{+} for one bunch, which is 1/6 of the requirement. Need 6 bunches stacking, which is much easier than 100 stacking.
- The generated pulse structure is identical to that of Conventional and Undulator with 1/3 bunch charge, so the capture section and the booster can be nearly identical.
- The heat load to the target is much less than that of Conventional and Undulator.

Rough Valuation Summary

	RLC	ELC	ELC/RLC
e- bunch	10nC	6nC	0.6
Bunch length	3mm	0.6mm	5
Finesse	1000	5000	5
γ/e- yield	0.30	4.5	15
Total γ yield	1.70E+10	2.55E+11	15
e+ capture	1.40%	2.80%	2
e+/e- yield	3.97E-03	0.18	45
Total e+ yield	2.38E+08	7.14E+09	30
# of stacking	84.03	2.8	0.03

New Optimization

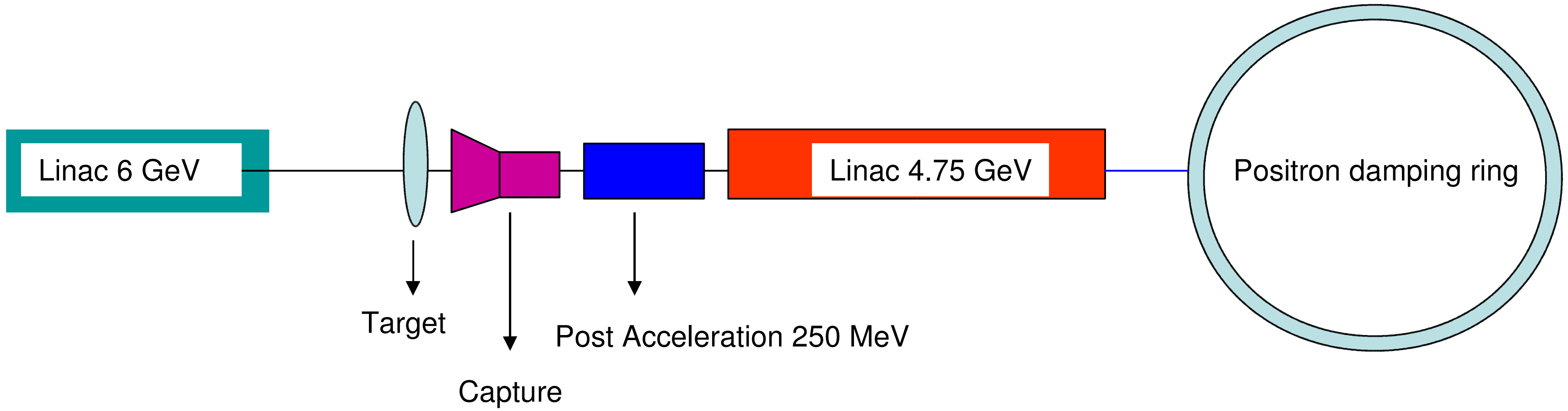
- A new layout, where both DRs are placed in a same tunnel, has been approved.
- Under the new boundary condition, many adaptations and optimizations in a context of the system performance and cost, have to be made for the baseline configuration.
- That is also true for the alternative. A. Variola has initiated this discussion in RAL meeting, by giving many concepts.

A System Approach

- It can be considered from a point of view of minimizing the system risk, which can not be avoided because the polarized positron is the first technical challenge in the world.
- On the other hand, constructing both Conventional and Undulator are disfavor from a point of view of the cost.
- Since LC is more compact than Undulator, constructing both or upgrade scenario from Conventional to LC is possible without large cost pressure.

Upgrade Scenario (1)

- SC Linac is operated in a pulse mode (not in ERL mode) same as in ML.
- e+ is generated in the conventional way.
- The crystalline production target is employed to suppress the heat load on target compare with amorphous target to be 50% with an equivalent e+ yield.
- 2 target stations are sufficient.

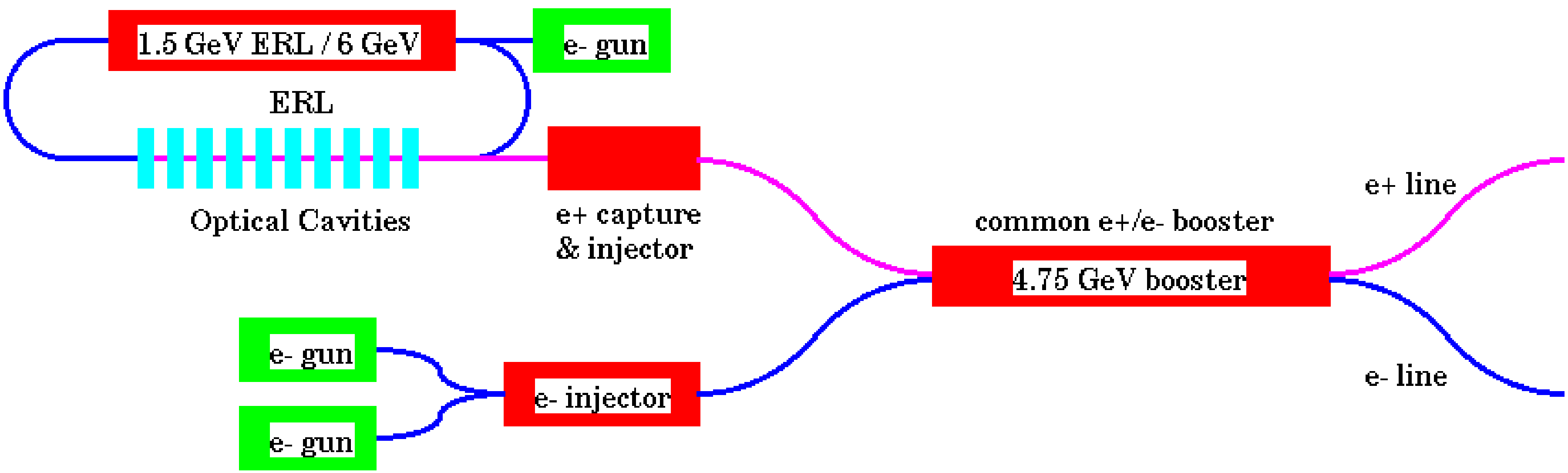


Upgrade Scenario (2)

- Conventional can be upgraded to ELC by
  - putting the return path for ER,
  - changing the operation mode to ERL,
  - installing lasers and optical cavities,
  - changing the conversion target.
- An intermediate step, unpolarized e+ with ELC with lower average current, less laser power, less finesse, and/or less number of optical cavities, is possible to reduce the risk further.

Further Adaptations

- The e+ and e- system can share a common booster linac by increasing the RF power.
- In ELC case, the layout is fully compatible with that for the upgrade scenario from the initial Conventional to the polarized ELC.



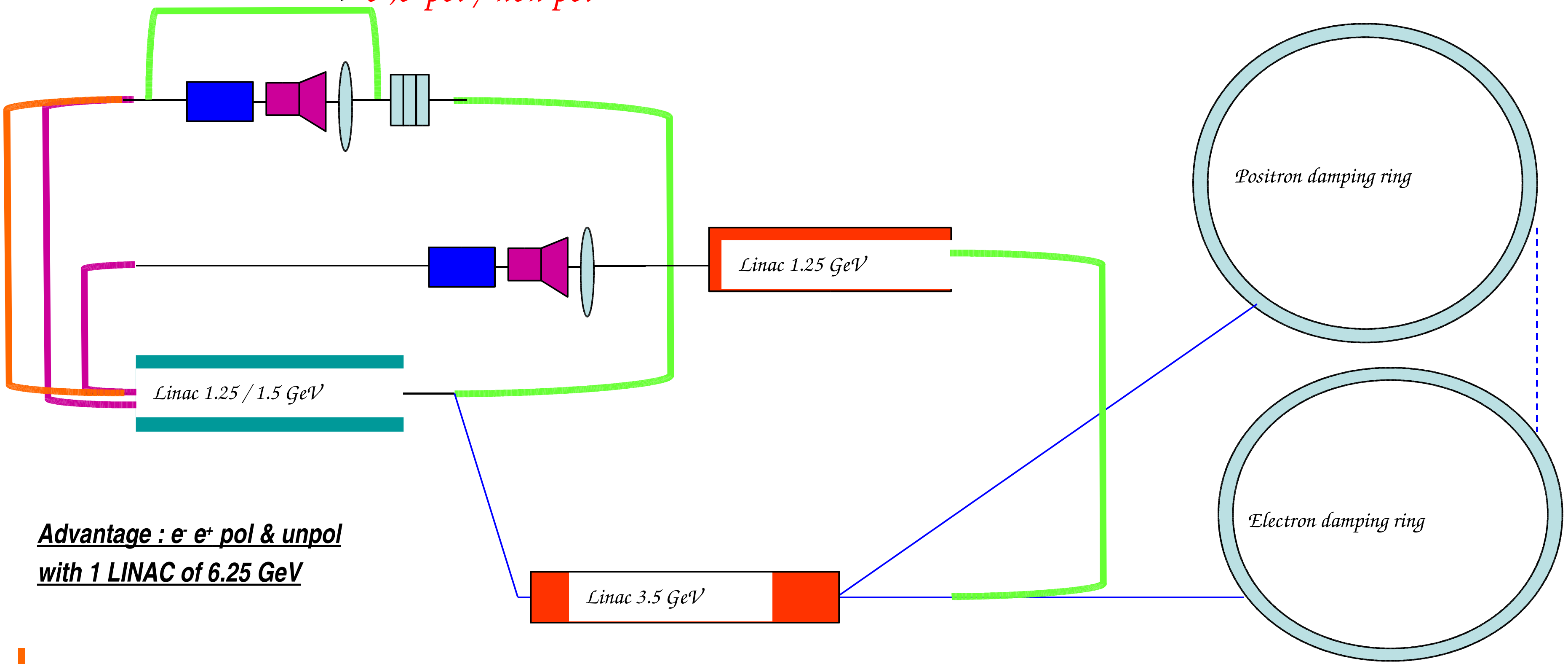
Tightly Coupled Concept by A. Variola

Electron polarised (unpolarised) source

Conventional & Polarised source – Compton cavities + ERL.

Damping rings in the same location (splitting)

=> *e^+, e^- pol / non pol*



Advantage : e^- e^+ pol & unpol with 1 LINAC of 6.25 GeV

Electron re-circulation

Positron re-circulation

Disrupted electrons and polarised positrons are re-circulated in the same train (deceleration for electrons and acceleration for positrons)

All this complex can be accommodated inside the damping rings

Summary

- Several variants of LC ILC e+ source have been proposed.
- ELC is a solution, which skims advantages from RLC and LLC.
- A risk minimized scenario, in which it starts with Conventional and arrives finally to ELC, is a natural thought.
- Sharing a common booster linac between e- and e+ is possible for more cost reduction.
- Further optimization is possible as proposed by A. Variola, but need more considerations.

ILC e+ R&D meeting

- Next Meeting will be held in Asian.
- The place is Beijing, dates are from Jan 31 – Feb. 2 (GDE meeting is from Feb 4 – 7).
- Pei Guoxi of IHEP will be local organizer.

Backup Slides

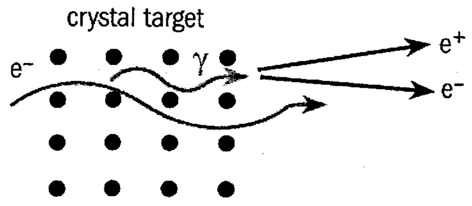
Conventional with Crystalline Target

- Channeling radiation and coherent bremsstrahlung enhances the gamma radiation by electron beam in target and positron yield with 25%.
- Due to the high radiation yield, the shower max is shorter than that in amorphous target in radiation length; Thermal heat load is 40% less compared with amorphous target .
-

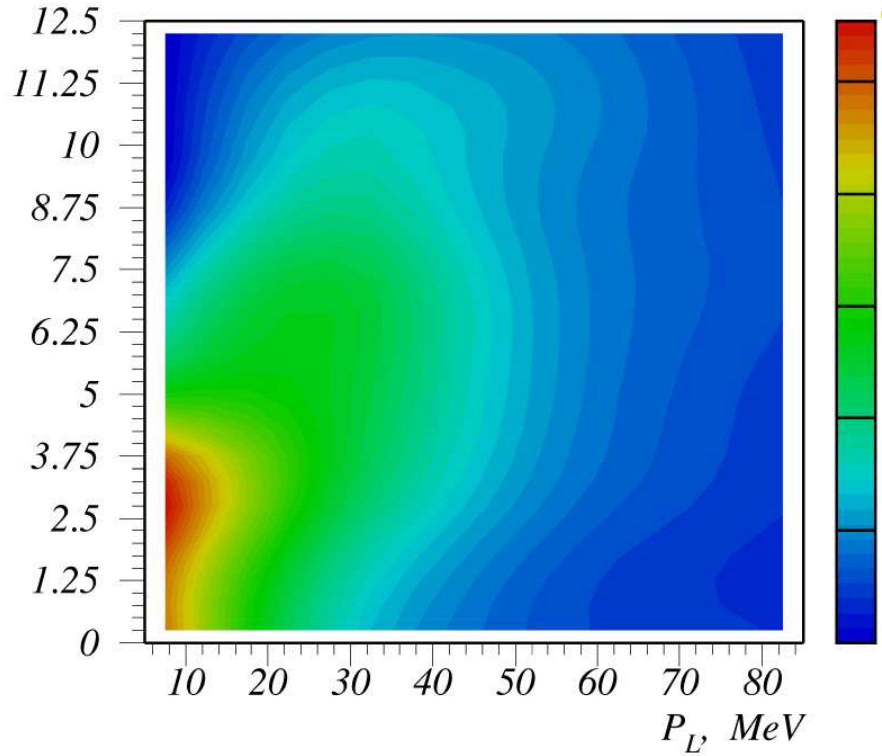
- *UNPOLARIZED SOURCES*
- *- an amorphous target with high Z submitted to an unpolarized e- beam of high energy [conventional]*
- *- a crystal source made of a crystal aligned on one of its axes (radiator) and of an amorphous W disk (converter) placed after it. = Hybrid*

- *THE Hybrid SOURCE*

- *Pair production in the same crystal or in an amorphous disk put after the crystal (preferably)*
- *The beam aligned on one of the crystal axes (where the potential is strong).*
- *Experiments made at CERN, KEK*
- *Simulations showed less deposited energy than in equivalent (e+ yield) amorphous target*



- *RESULTS OF WA 103 (10 GeV)*
- *e+ yield in large momentum (150 MeV/c) and angular (30°) domains.*
- *measured e+ yield in a (p_L,p_T) diagram; the case corresponds to a 8 mm crystal and a 10 GeV incident energy.*



Example of absolute rate : W crystal [<111> orientation], 8mm thick, the yields have been measured in (p_L,p_T) domains..

	$5 < p_l < 25$	$5 < p_l < 30$	$5 < p_l < 40$
$p_t < 4$	1.16 ± 0.04	1.28 ± 0.04	1.43 ± 0.04
$p_t < 6$	1.66 ± 0.05	1.85 ± 0.05	2.13 ± 0.05
$p_t < 8$	2.11 ± 0.07	2.46 ± 0.08	2.90 ± 0.08
$p_t < 10$	2.31 ± 0.08	2.75 ± 0.08	3.32 ± 0.08
$p_t < 12$	2.40 ± 0.08	2.94 ± 0.09	3.67 ± 0.10

For 6GeV : Yield plus ~ 15%

Energy loss (heating) minus ~40 %

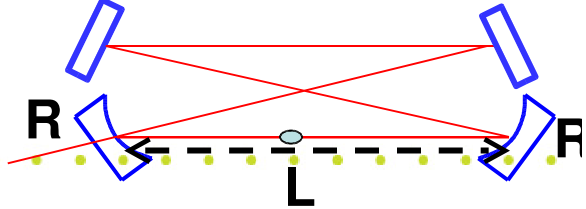
ILC positron Source meeting

Wednesday 27 - Friday 29 September 2006   Rutherford Appleton Laboratory

Alessandro Variola

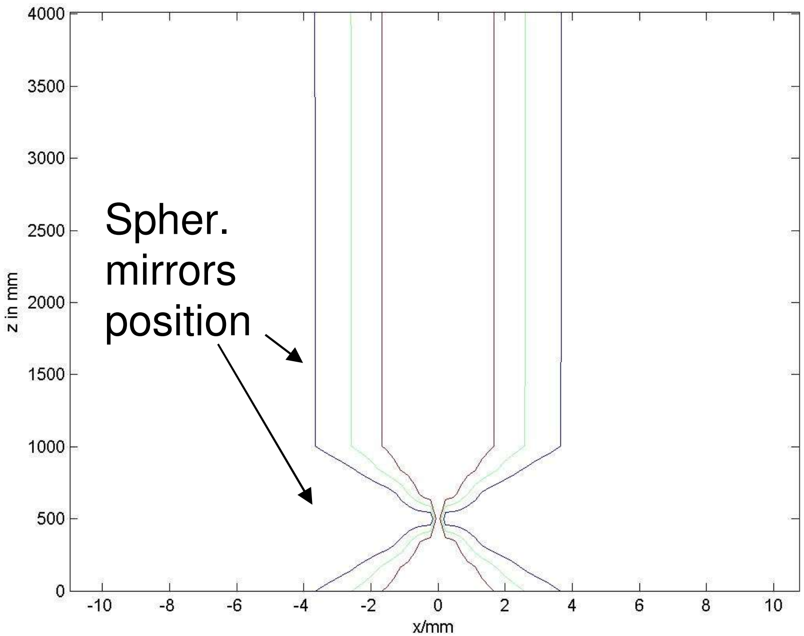
For the L.A.L. Orsay group

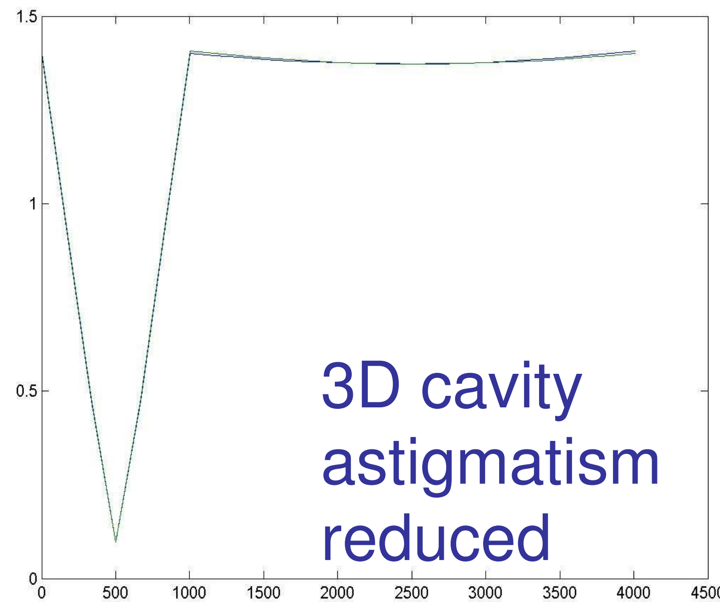
Brisson V., Chehab R., Chiche R., Cizeron R., Fedala Y., Jacquet-Lemire M., Jehanno D., Soskov V., Variola A., Vivoli A., Zomer F.,



Astigmatism

)-2)

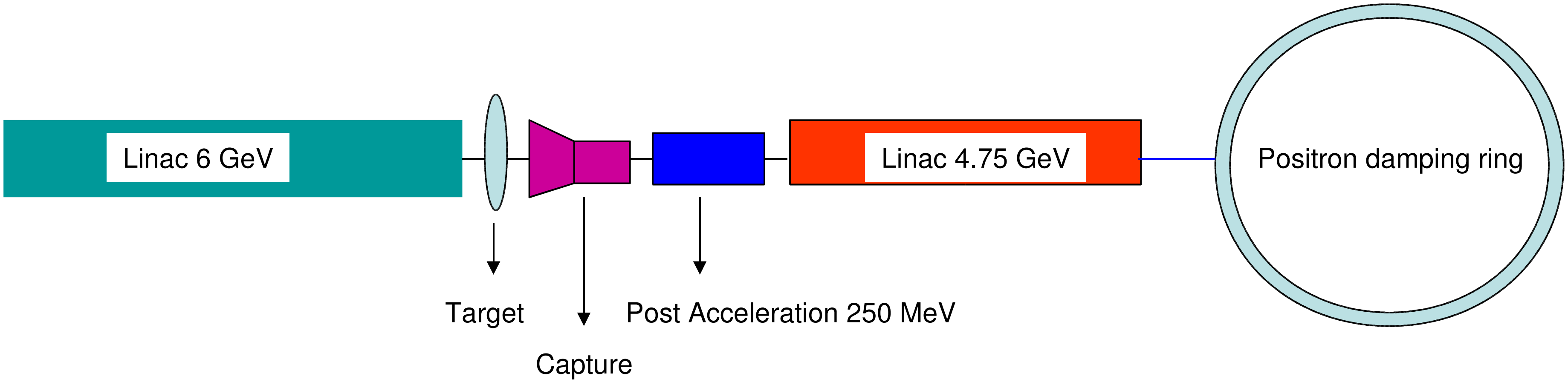




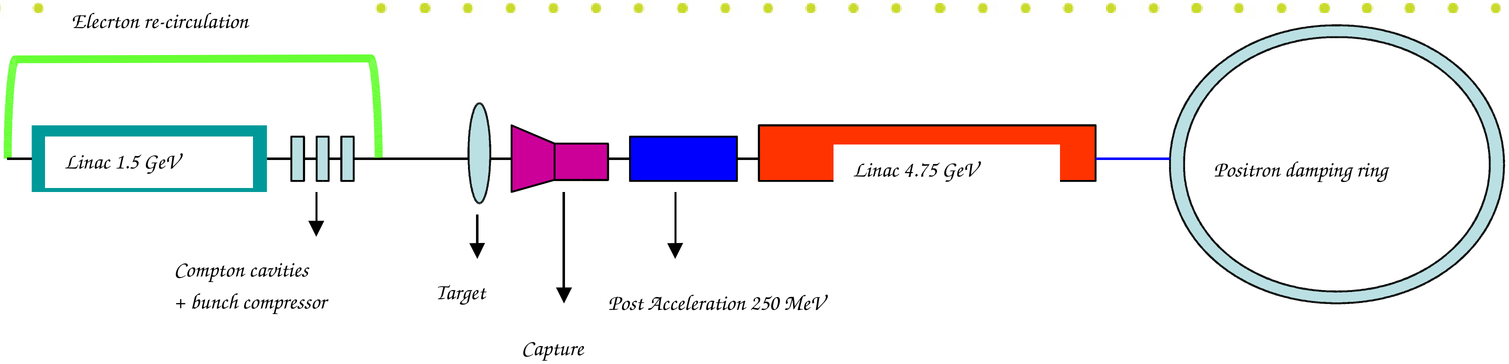
Posipol scheme: we are working on a proposal for a unique "lepton source" ERL based

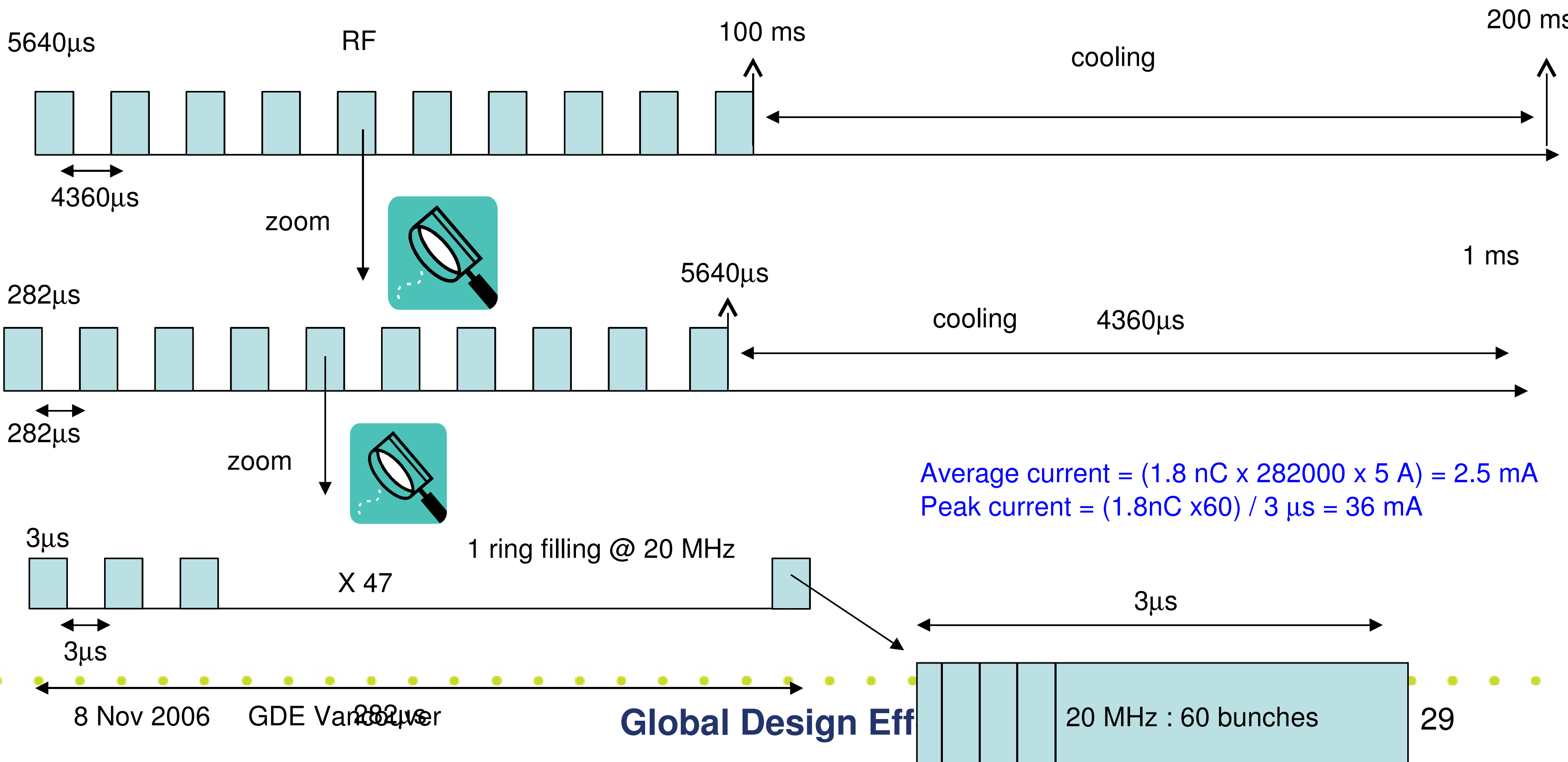
1) We have a Post Doc !!!!!!

Conventional positron source



a possible example ERL : 100 re injection if 1 damping ring scheme. 50 if double damping ring scheme





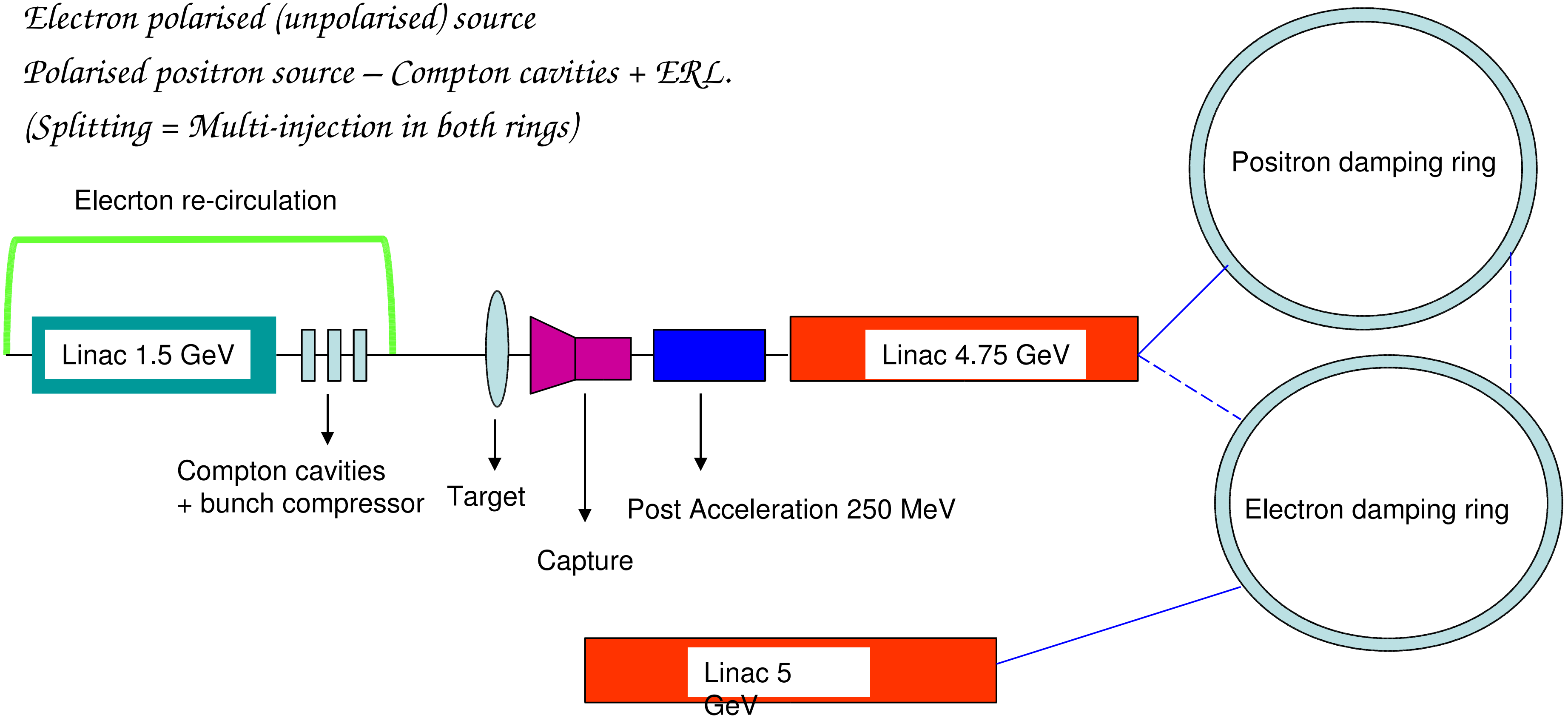
Average current = (1.8 nC x 282000 x 5 A) = 2.5 mA
Peak current = (1.8nC x60) / 3 µs = 36 mA

Two sources. One source every damping ring
If damping rings in the same location …….new scenarios:

Electron polarised (unpolarised) source

Polarised positron source – Compton cavities + ERL.

(Splitting = Multi-injection in both rings)

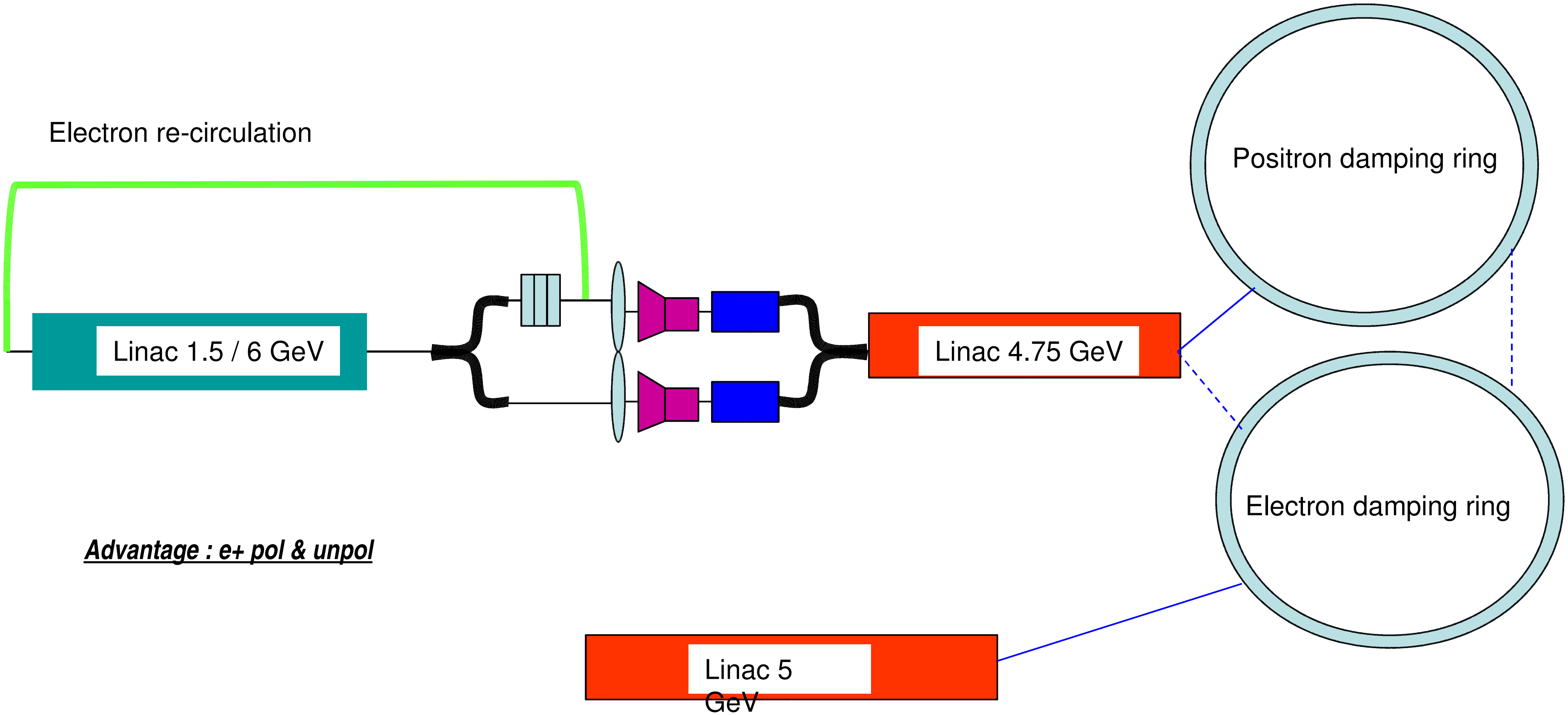


The first 1.5 GeV linac can be substituted with a 6 GeV one to have both sources

Electron polarised (unpolarised) source

Conventional & Polarised source – Compton cavities + ERL.

Damping rings in the same location (splitting)



Advantage : e+ pol & unpol

But positron injection takes not more than 100 msec. The remaining 100 msec are enough for electron cooling, so we can split electron and positron injection in time and unify the electron and positron rings.

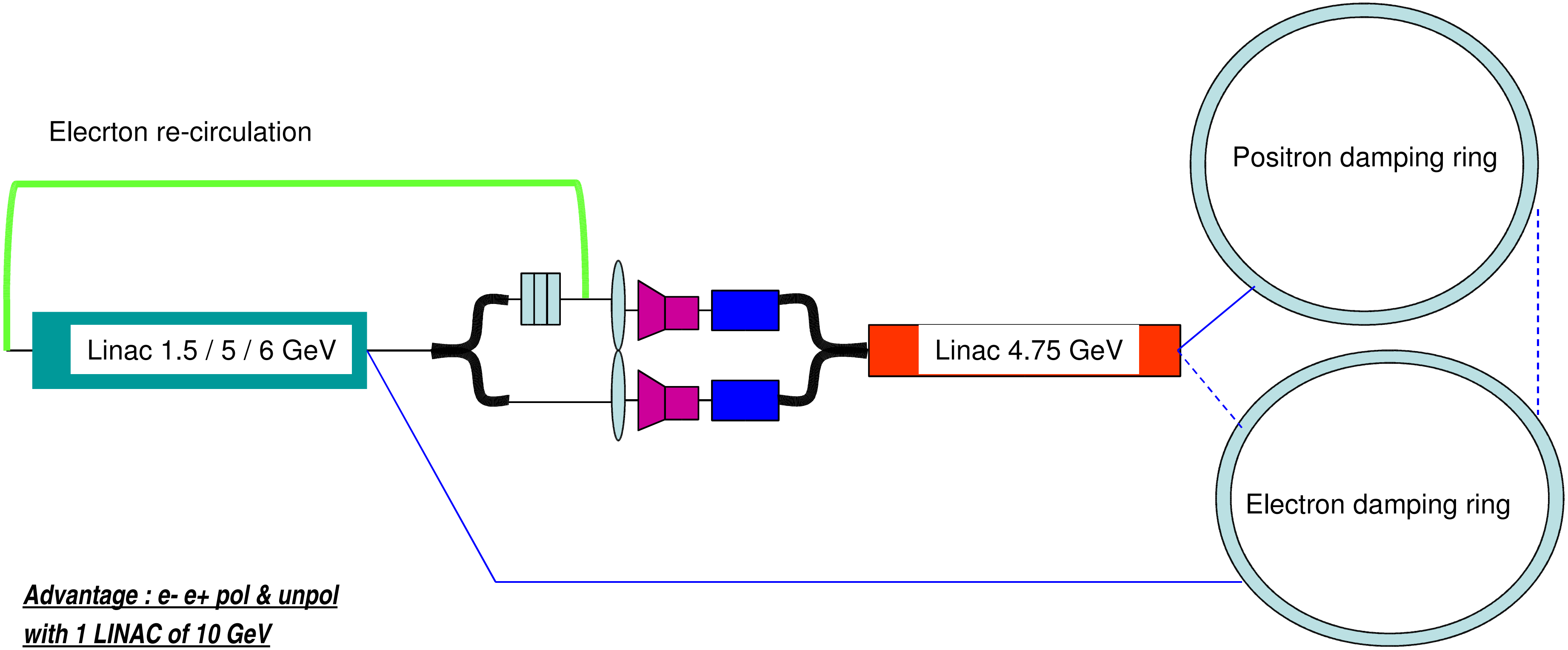
IF DAMPING RINGS @ THE SAME LOCATION

Electron polarised (unpolarised) source

Conventional & Polarised source – Compton cavities + ERL.

Damping rings in the same location

(splitting…why not also for the conventional solution)



Advantage : e- e+ pol & unpol with 1 LINAC of 10 GeV

1 Complex !!!! Moreover, if we can re-circulate and split the first Linac we can avoid the second one

Compton based Polarized Positrons Source for ILC

V. Yakimenko[1], D. Cline[2], Ya. Fukui[2], *V. Litvinenko[1], I. Pogorelsky[1], S. Roychowdhury[3]*

[1]BNL, [2]UCLA, [3]Duke Univ.

POSIPOL 2006
Workshop
CERN 26-27-28 April 2006

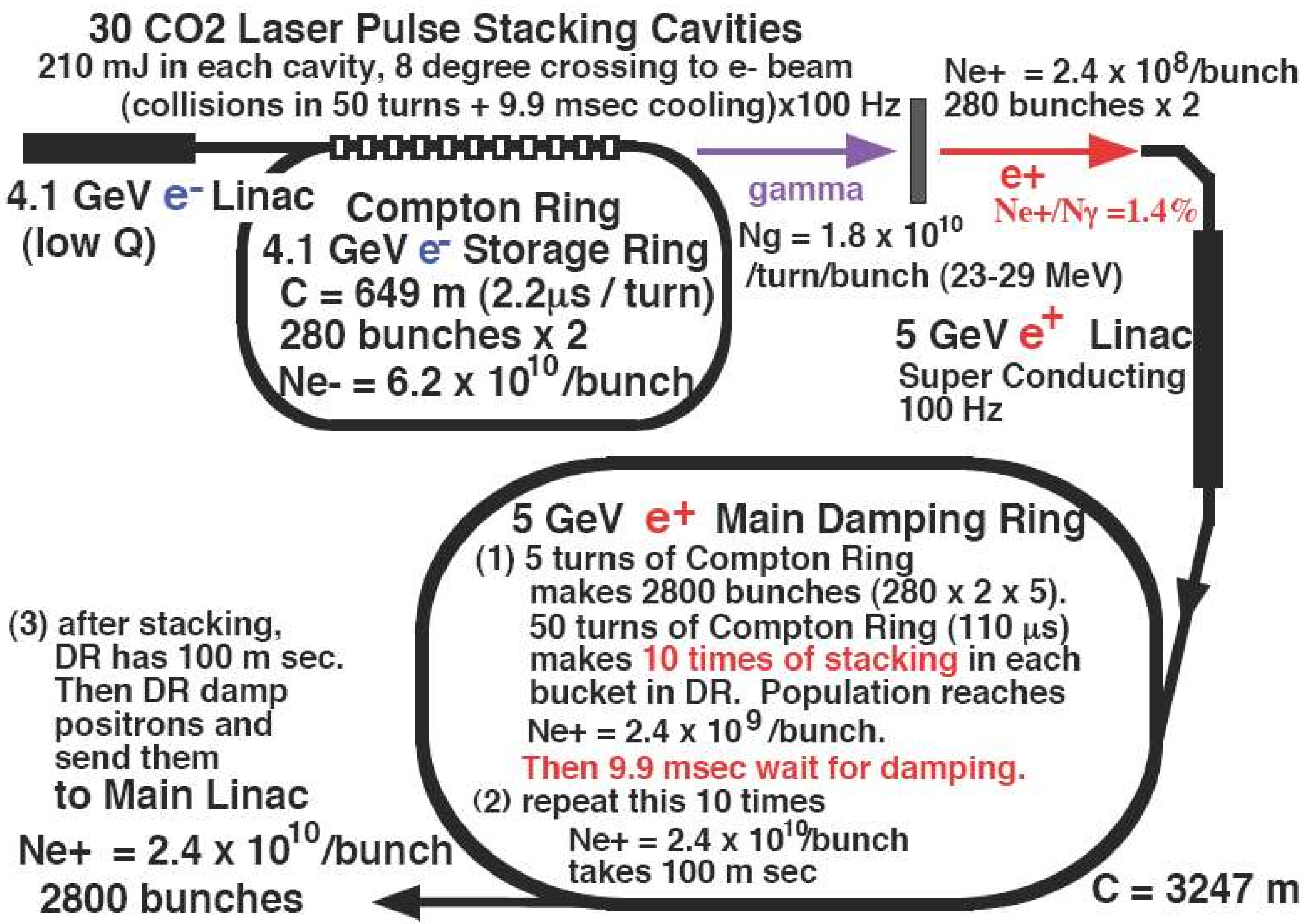
ILC Source requirements

Parameter	Symbol	Value	Unit
Positrons per bunch	n_p	$2x10^{10}$	e^+
Bunches per pulse	N_b	2820	
Bunch Spacing*	τ_b	~300	ns
Pulse rep. rate	f_{rep}	5	Hz
Energy	E_0	5	GeV
Positron Polarization**	P_p	~60	%

* The length of the bunch train in ILC is 2820x300ns = 0.85 ms or 250 km. Bunch spacing has to be reduced in the dumping ring.

** Polarization level defines conversion/capture efficiency of polarized γ rays into polarized positrons. 60% level corresponds to ~1.5% efficiency.

Polarized Positron Production: Compton Ring Scheme: CO_2 Version (Omori, et al.)



Choice of parameters

$$N_{\vec{\gamma}} = \frac{N_e N_\phi}{S} \sigma_C$$

N_γ, N_e and N_ϕ are the numbers of γ-rays, electrons and laser photons, S is the area of the interacting beams and σ_C is the Compton cross sections

- *~40 μm laser focus is set by practical considerations of electron and laser beams focusing and requires ~5 ps long laser pulses*
- *Nonlinear effects in Compton back scattering limit laser energy at ~1J*
- *Pulse train structure of 2820 bunches is set by main linac.*
- *~300ns bunch spacing in the main linac will be changed in the dumping ring in any design. 12 ns bunch spacing is selected to optimize linac acceleration gradient.*
- *Train of ~10 nC electron bunches is required to produce 10^{12} polarized gammas per bunch. (~1 γ-ray per 1 electron per laser IP)*
- *Reduction of charge in the bunches (stacking of the positrons) leads to increase in the average power of the laser and electron beams*
- *Conversion efficiency of polarized gammas into captured polarized positrons is assumed at ~1.5% and is subject of optimization.*
- *The size of the gamma beam on the conversion target is expected to be much smaller when compared to other schemes due to the compact design of the Compton backscattering region.*
- *Laser and drive linac are operated at 150Hz to optimize its performance. Train of 100 bunches is generated with 150Hz. 30 pulses are needed to form ~3000 bunches of ILC beam, stored in the dumping ring.*

Polarized γ beam generation

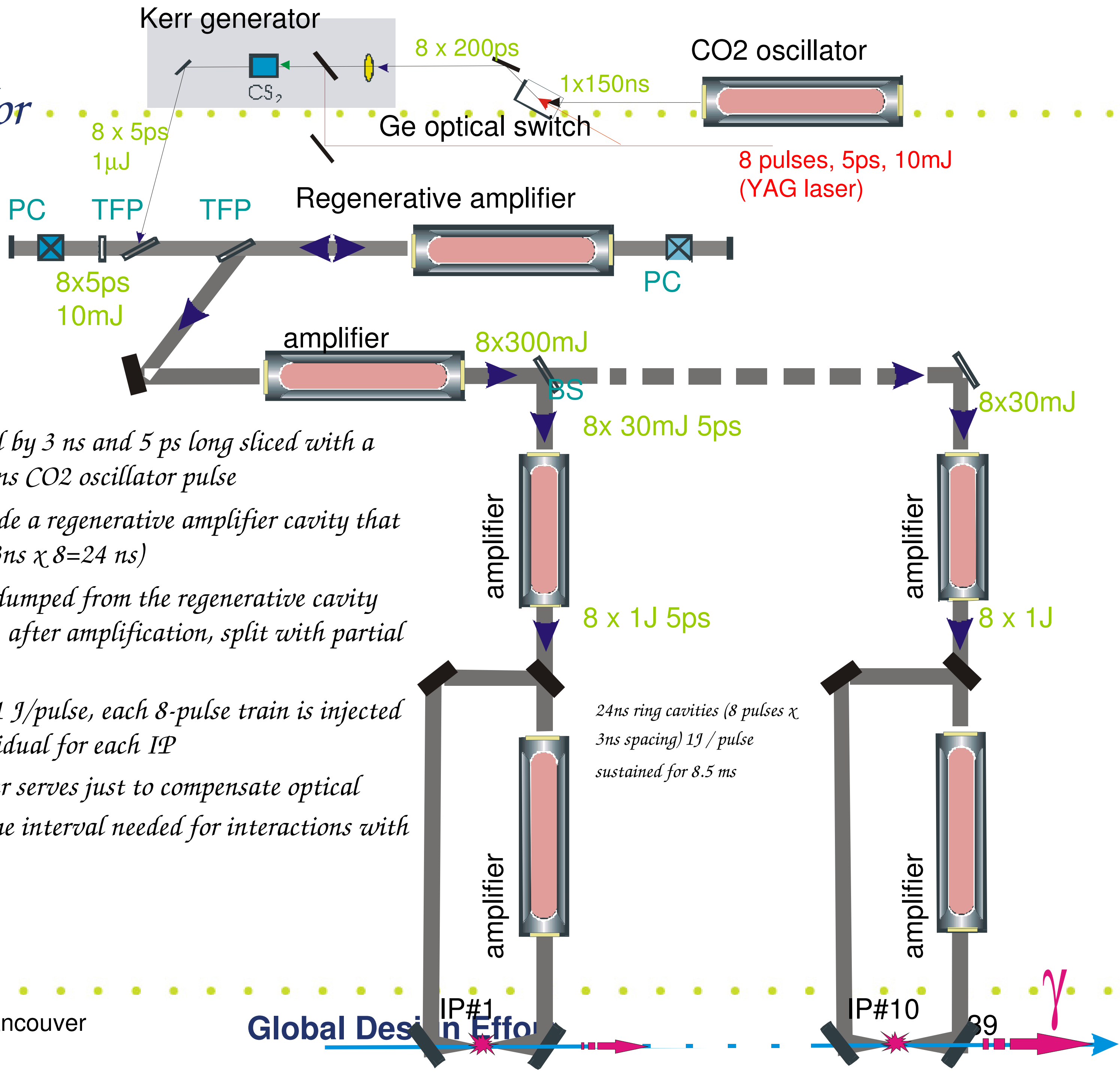
Parameter	Symbol	Single Shot Injection		Storagemode	Unit
Rep rate	f_{rep}	5		150	Hz
e^- per bunch	n_e	$8x10^{10}$		$8x10^{10}$	
Bunches per pulse	N_b	2820		100	
Bunch Spacing	τ_b	6	3	12	ns
Beam current (ave./pulse)	I_{beam}	0.2/2	0.2/4	0.2/1	mA/A
Average e-beam power	P_{beam}	1		1	MW
Number of laser IPs	N_{laser}	30	15	5	
Laser pulse length	τ_{laser}	5			ps
Intra cavity energy	E_{laser}	4 x 0.8	8x0.8	2x0.8	
Ave. laser power (5% losses)	P_{laser}	30x0.4	15x0.7	5x0.7	kW
Size at focus	σ_{laser}	40			μm
Efficiency per laser IP	$N\gamma/Ne^-$	~1			
Number of γ	$N\gamma$	$1.5x10^{12}$			

Ring or Linac?

Stacking or No-stacking?

- RMS energy spread in 6 GeV Compton ring ~2% for CO_2 laser interaction with 4MW in synchrotron radiation. Difficult ring and very difficult laser (high repetition rate, average power, cavity stacking).
- Head on Compton back scattering will be realized in the Linac design (electron beam will pass through small halls in the mirrors.)
- Aperture requirements for the ring design dictate less efficient small angle Compton back scattering scheme.
- For scheme without accumulation the main issue is high current ~4A in macro pulse (requires short accelerator sections, more klystrons and longer linac or a ring to change bunch spacing from ~12ns to 3ns).
- The average beam power is increased with higher repetition rate required for the scheme with accumulation. It is 3MW for 150Hz. SC and NC linac structures can be used. Very difficult laser
- Simpler damping ring and laser system at 5Hz for the scheme without accumulation might offset linac complexity.

Laser system for PPS



- *Train of 8 pulses spaced by 3 ns and 5 ps long sliced with a YAG beam from a 150 ns CO2 oscillator pulse*
- *This train is seeded inside a regenerative amplifier cavity that has a round-trip time (3ns x 8=24 ns)*
- *Amplified 8 pulses are dumped from the regenerative cavity with a Pockels cell and, after amplification, split with partial reflectors in 10 beams.*
- *After amplification to 1 J/pulse, each 8-pulse train is injected into a ring cavity individual for each IP*
- *An intracavity amplifier serves just to compensate optical losses during 8.5 µs time interval needed for interactions with 2820 electron bunches.*

Laser system for PPS

- Optical slicing and amplification of 5 ps CO_2 pulses has been demonstrated and utilized in routine ATF operation for user experiments.
- CO_2 oscillator and initial amplifiers are commercially available lasers from SDI and operate at rep. rate up to 500Hz.
- Final intracavity amplifiers shall operate at average power ~0.75 kW in non standard mode of operation.
- Another issue to be addressed by industry is fabrication of optical elements to withstand high intracavity laser power.

Lasers from SDI

http://www.lightmachinery.com/SDI-CO2-lasers.html

		WH20	WH100	WH350	WH500
Wavelength			9 – 11µm, Line Tunable		
Continuous	20 Hz	100 Hz	350 Hz	500 Hz	
Repetition Rate					
Pulse Energy			1.5 J		
Mode Type		Multimode			
Optional:	TEMoo, custom beam shapes, SLM				
Beam Size		13 x 13 mm^2			
Average Power		30 W	150 W	525 W	750 W
Power Stability		< 7 %			

WH10

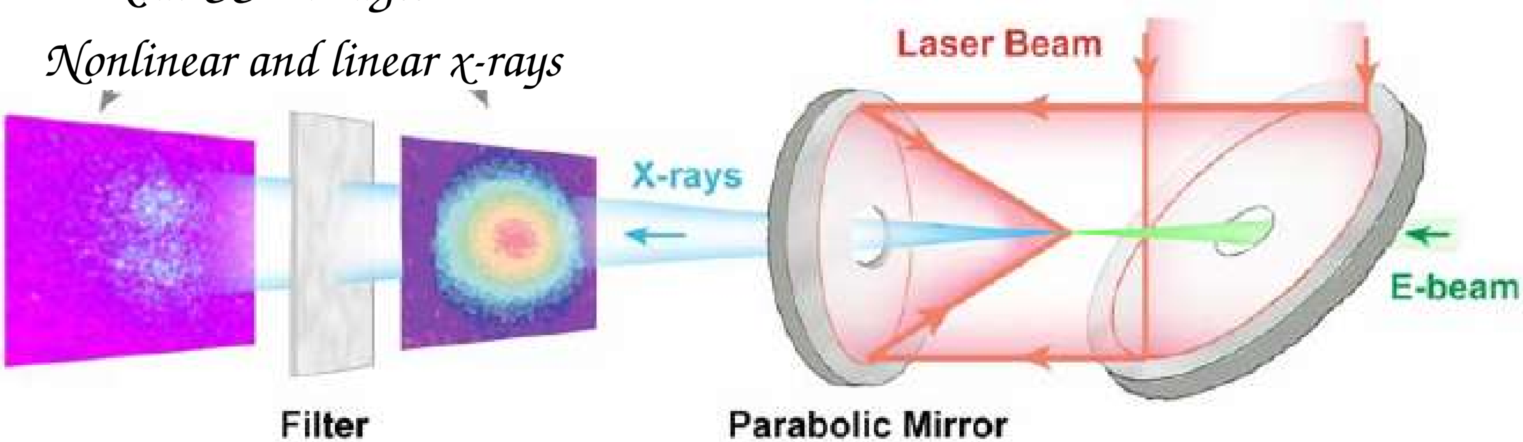
Compton Experiment at Brookhaven ATF

(record number of X-rays with 10 μm laser)

- More then 10^8 of x-rays were generated in the experiment PRST 2000. N_x/N_{e-} ~0.1.
- (0.35 as of April 2006- limited by laser/electron beams diagnostics)
- Interaction point with high power laser focus of ~30μm was tested.
- Nonlinear limit (more then one laser photon scattered from electron) was verified. PRL 2005.

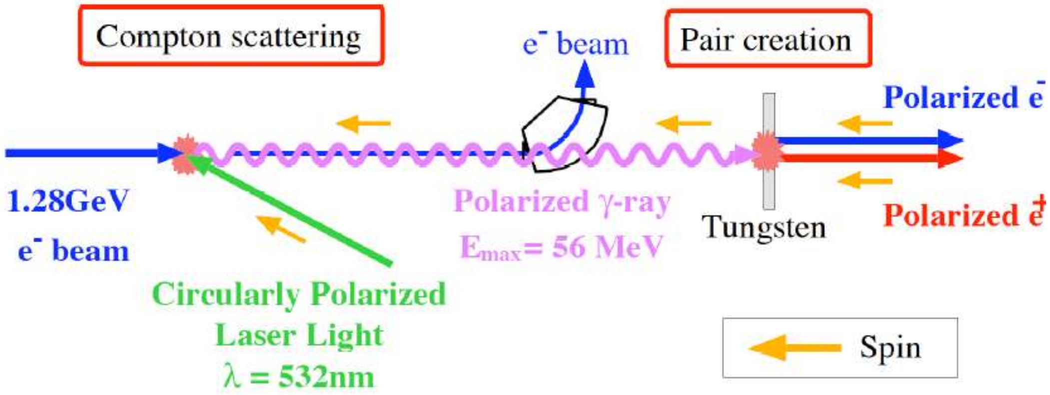
Real CCD images

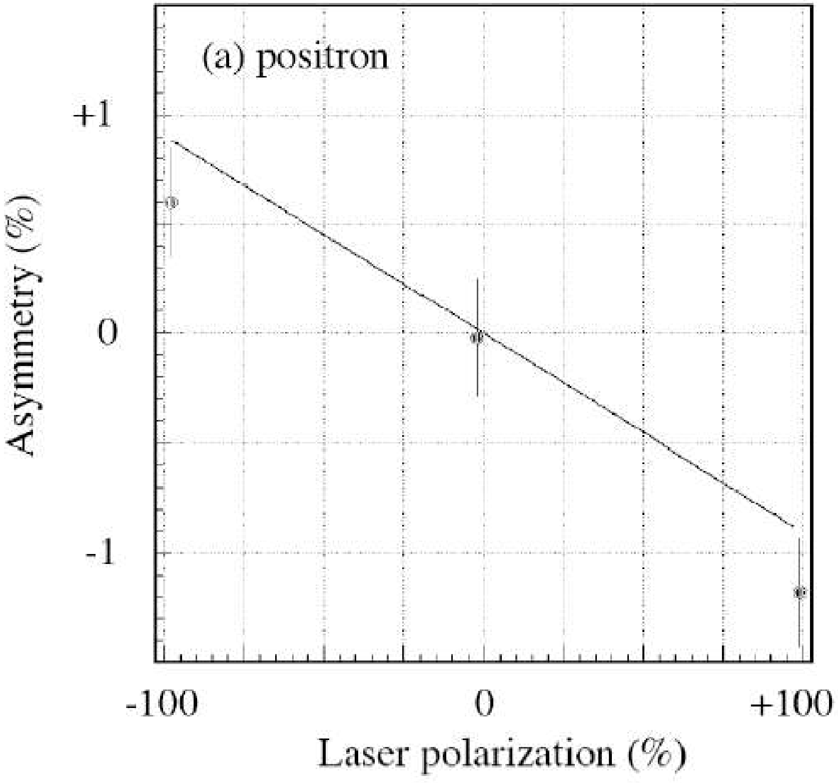
Nonlinear and linear x-rays



Compton Experiment at KEK ATF (polarized positrons with 532 nm laser)

- *Experiment demonstrated beam of 10^6 polarized γ-rays (PRL 91/16, 2003)*
- *Experiment demonstrated 10^4 positron beam with 79% polarization level (KEK Preprint 2005-56, PRL 2005)*





Laser R&D

- 1[st] year: (2 Post Doc + $250K equipment)
  - Demonstrate slicing of a train of eight 5-ps CO2 pulses (based on existing ATF laser systems)
  - Simulations of the ILC laser system.
  - Design and purchase of custom CO2 amplifier ~5J/pulse, 150 Hz
  - Design of photocathode/slicing laser
- 2[nd] year: (2 Post Doc + $700K equipment + room)
  - Dedicated YAG oscillator and amplifiers
  - Purchase of standard CO2 oscillator and amplifier @150 Hz
  - 8-pulse train amplification to 1J/pulse.
  - Delivery of custom CO2 amplifier ~5J/pulse, 150 Hz, 10 atm
- 3[rd] year (2 Post Doc + $500K equipment)
  - Injection of 2-pulse train into interaction cavity and maintaining 100 intra cavity passes (total 200 pulses @ 1J/pulse, 150 Hz).
  - Intracavity laser/e-beam (60 MeV) interaction with production of trains of 100 6.5 keV x-ray pulses @ 6 Hz between trains with efficiency N_γ/N_{e-} ~1.

- At the end of 3 year program we will have full scale prototype with one (out of five) interaction cavity @150Hz. The laser injection part will be fully functional.

- *The accelerator part of PPS proposal is based on the existing technologies and design can be completed in about 1 year.*
- *2nd and 3rd years of R&D will be focused on risk reduction*

Cost speculation

to prioritize R&D areas

- *@5Hz, 3 ns (no storage , 2820 per pulse)*
  - **CO2 Laser system @5Hz** ~10M$
  - **4Gev, 4A 5 Hz linac 10MV/m** ~300M$
  - **Damping ring (2.5 km)** ~200M$
- *@5Hz, 6ns (no storage, 2820 per pulse)*
  - **CO2 Laser system @5Hz** ~15M$
  - **4Gev, 2A 5 Hz linac 15MV/m** ~150M$
  - **Damping ring (5 km)** ~300M$
- *@150Hz (beam storage: 30 pulses 100 bunches each)*
  - **CO2 Laser system @150Hz** 5-10M
  - **4GeV, 0.8A 150Hz linac 20MV/m** ~100M$
  - **Damping ring (2.5 km)** ~200M$

- *Optimization is needed !*

Conclusion

- *We propose Polarized Positron Source based on Compton back scattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.*
- *The proposal requires high power picosecond CO2 laser mode of operation tested at ATF to generate* **1 gamma per 1 electron per 1 laser IP**.
- *The proposal utilizes commercially available units for laser and accelerator systems.*
- *3 year laser R&D is needed to verify laser operation in the non standard regime.*
- *CLIC beam needs are easily satisfied due to lower beam intensity requirement and same rep. rate.*

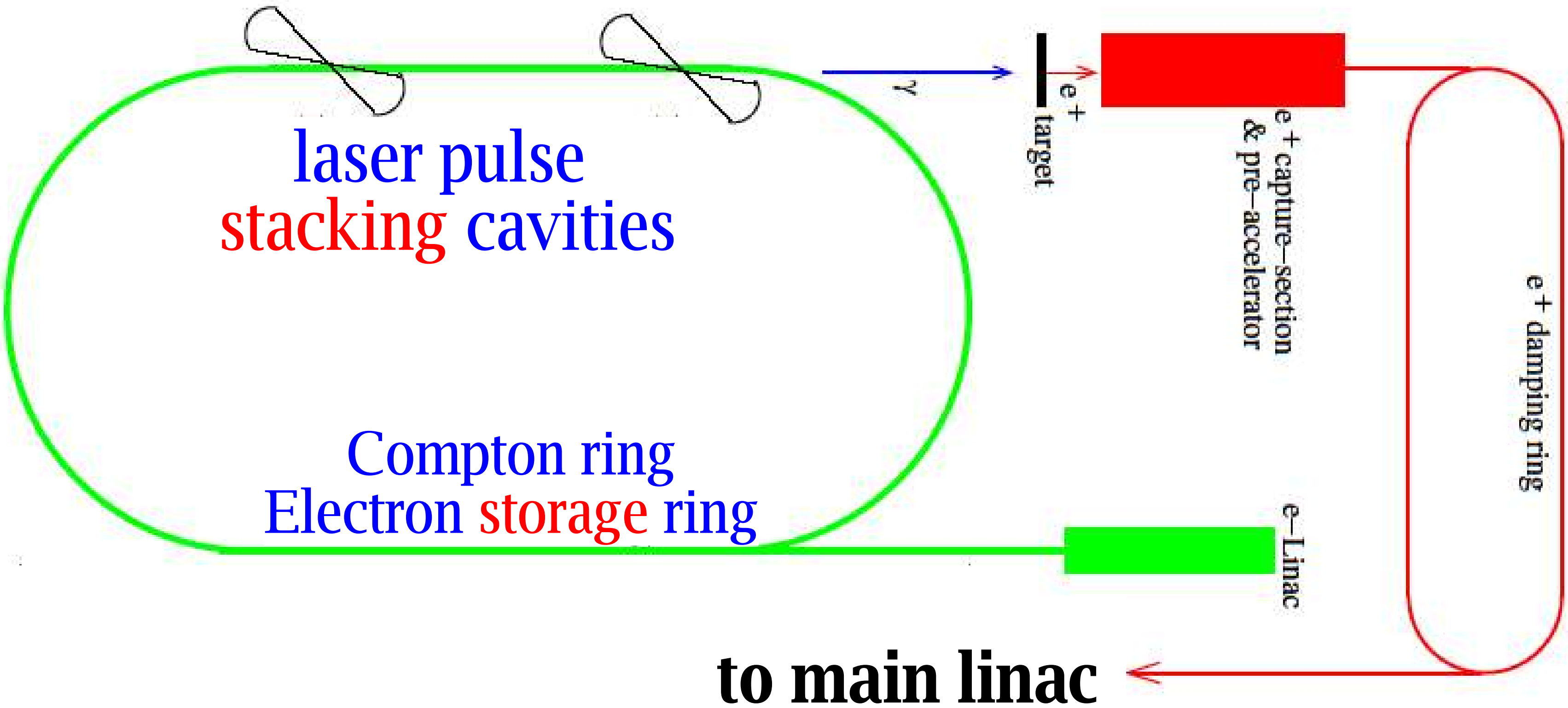
ILC Source Requirement

Parameter	Value	Unit
Bunch charge	3.2(1.6)	nC
Bunch length	4.3	ps
Norm emittance (DR acceptance)	0.09	m.rad
Bunch separation	308 (154)	ns
# of bunches in a pulse	2800(5600)	
pulse length	0.9	ms

- **Undulator scheme has been selected as a baseline.**
- **Laser-Compton scheme is a future alternative.**
- **Conventional scheme is a backup option.**

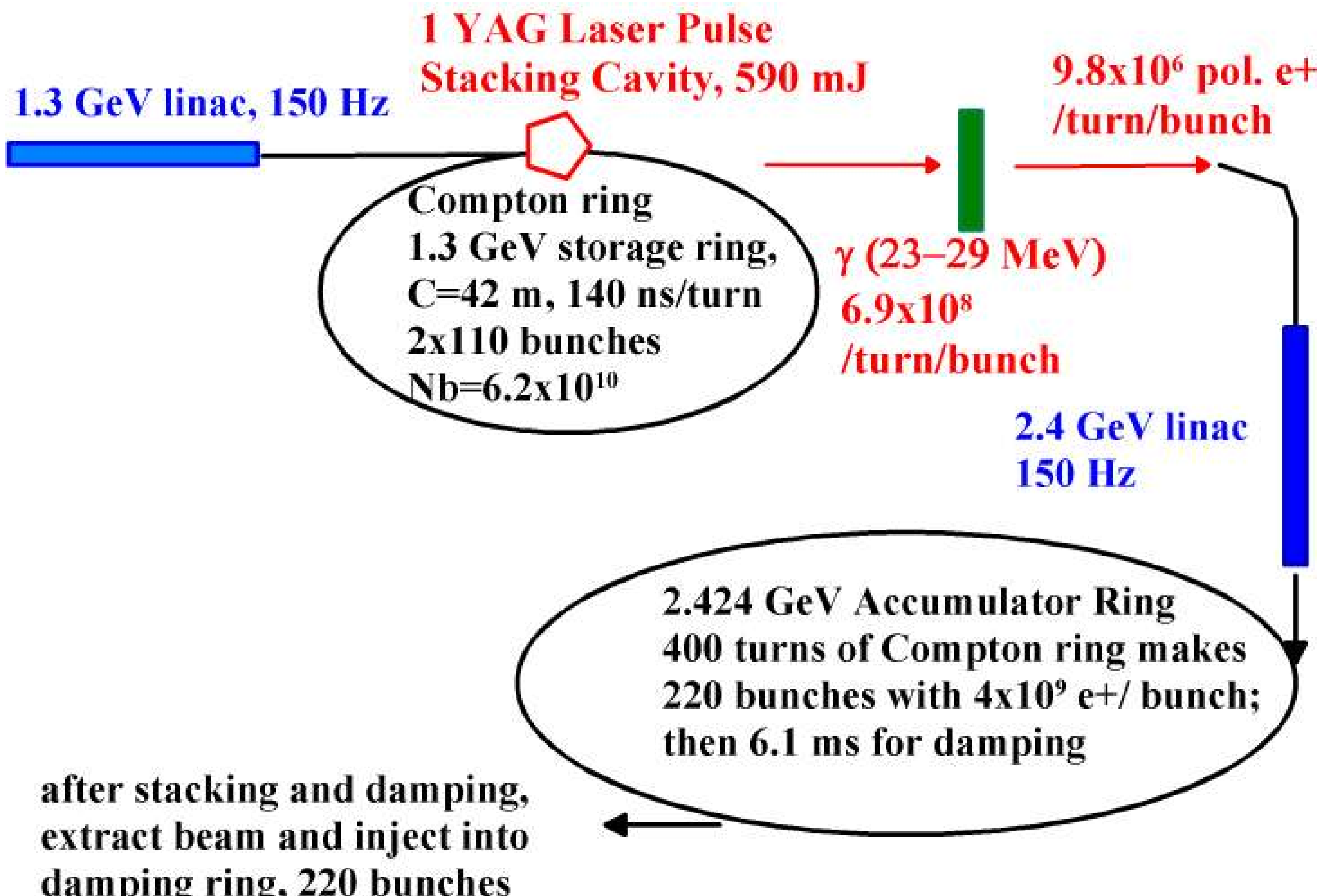
New design

Re-cycling Concept

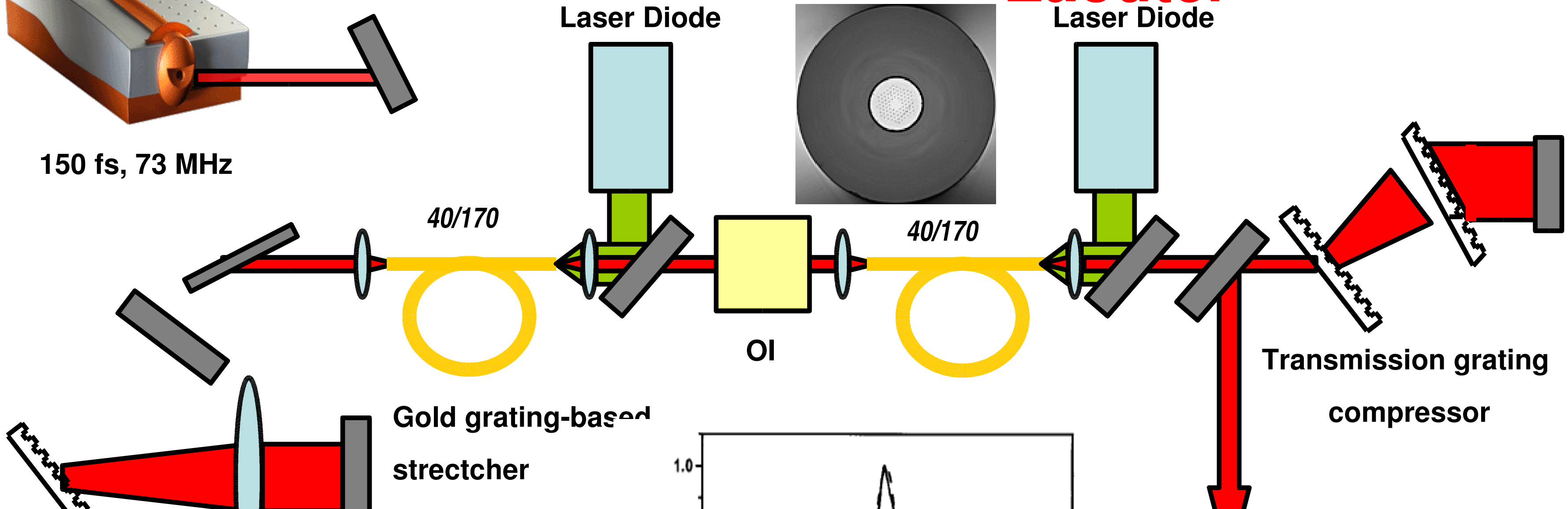


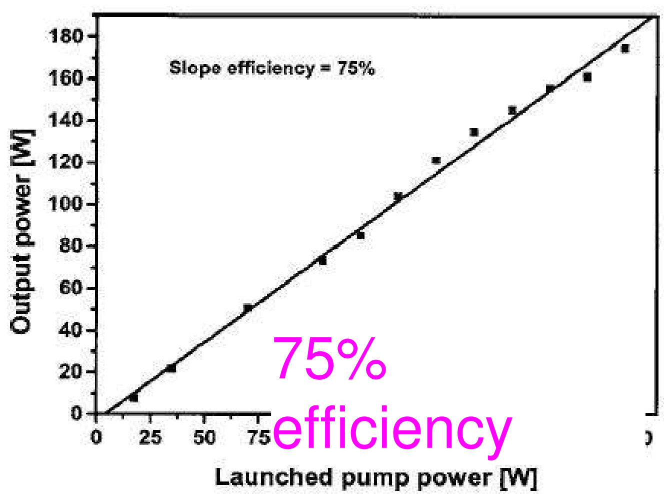
positron stacking in main DR

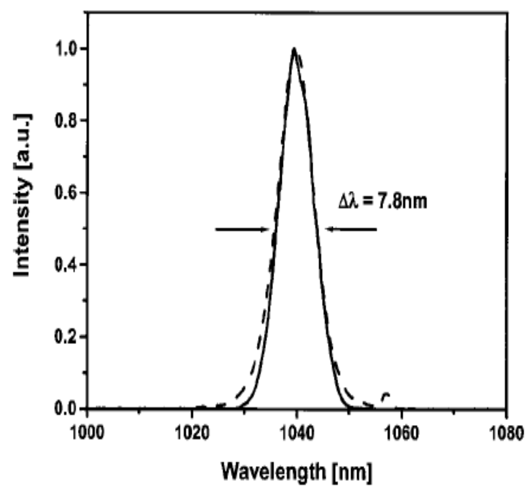
CLIC scheme by F. Zimmermann



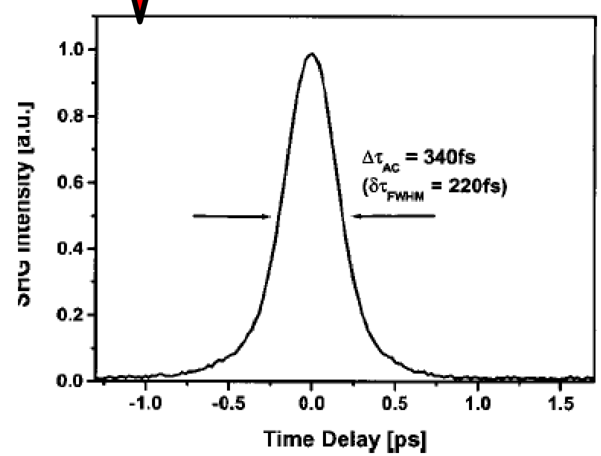
Recent Results Y. Zaouter







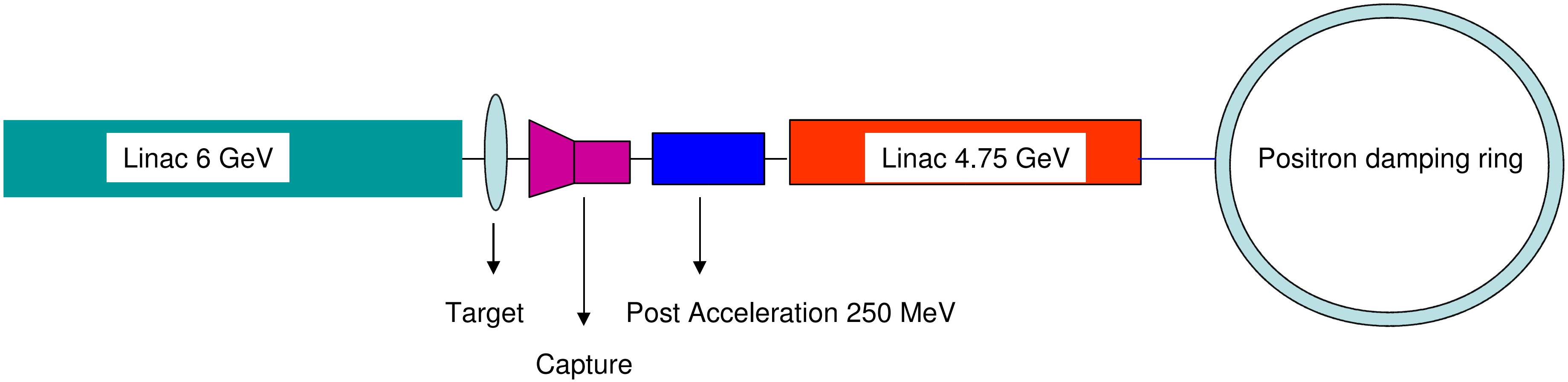
F. Röser et al. Optics letters, 30, p2754, 2005



Posipol scheme: we are working on a proposal for a unique "lepton source" ERL based

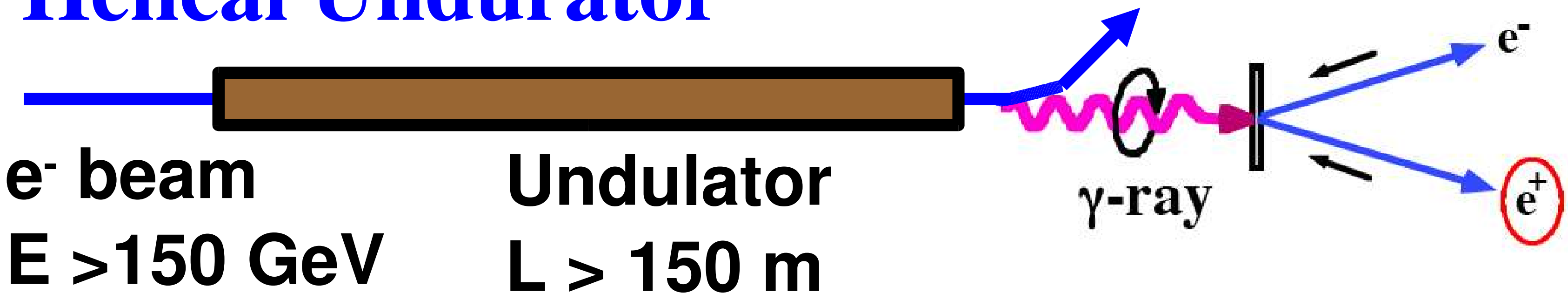
1) We have a Post Doc !!!!!!

Conventional positron source

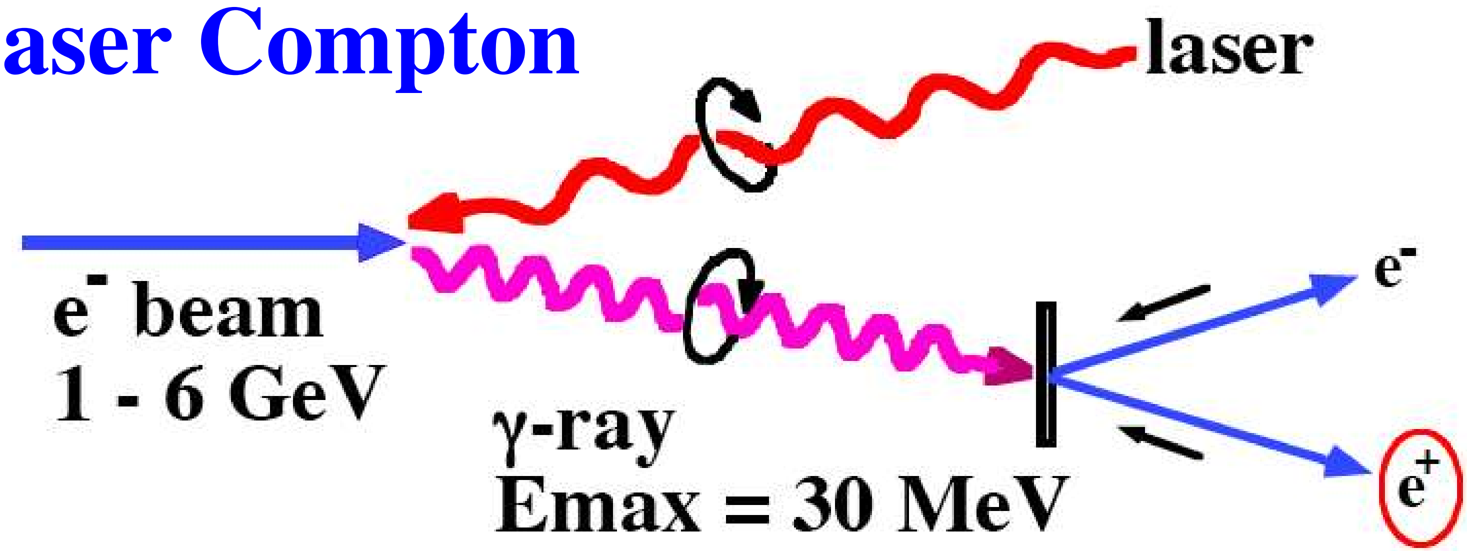


Two ways to get pol. e^+

(1) Helical Undurator

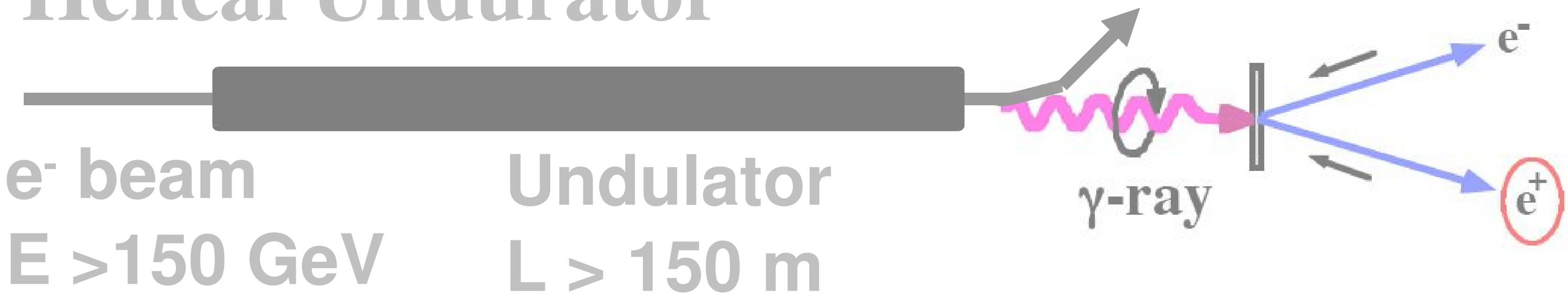


(2) Laser Compton

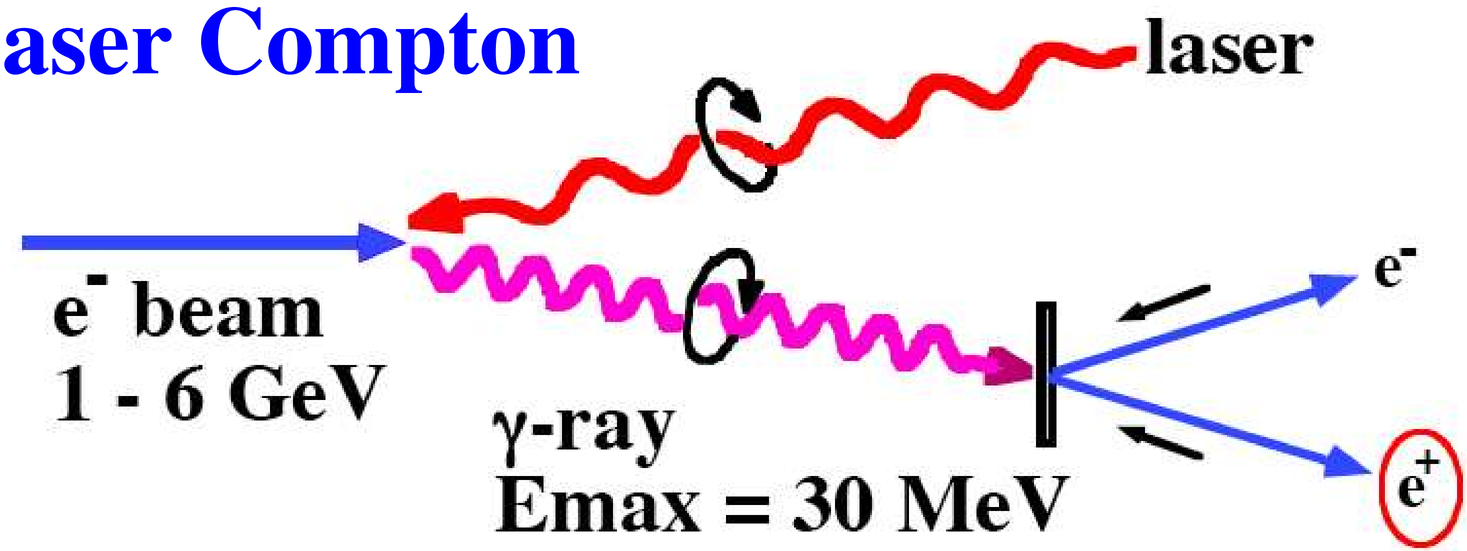


Two ways to get pol. e^+

(1) Helical Undurator



(2) Laser Compton

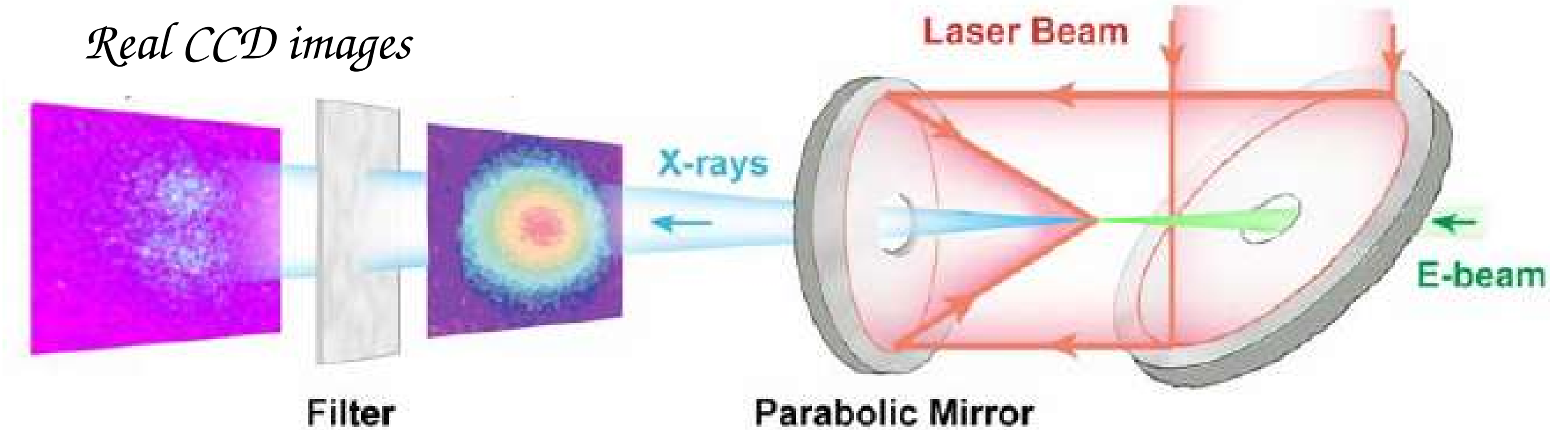


Experiment at BNL ATF

(record number of X-rays with 10 μm laser)

- *More then 10^8 of x-rays were generated in the experiment PRST 2000. N_x/N_{e-} ~0.1.*
- *(0.35 as of April 2006- limited by laser/electron beams diagnostics)*
- *Interaction point with high power laser focus of ~30μm was tested.*
- *Nonlinear limit (more then one laser photon scattered from electron) was verified. PRL 2005.*

Real CCD images



CLIC – ILC differences

- beam structure: CLIC has a
  smaller bunch charge (about 10x less) and
  less bunches per pulse (about 20x less)

- **bunch spacing** in DR: **0.533 ns instead of 2.8 ns**
  → layout of optical cavities more challenging
  → multiple pulses stored in one cavity?

- damping ring; CLIC damping ring needs beam with extremely small emittance, limited dynamic aperture;
  →**pre-damping ring** is required;
  - Optimize pre-damping ring for stacking polarized e+ from Compton source

- CLIC **repetition rate is 150 Hz instead of 5 Hz** for ILC

Why Laser Compton ?

- Positron Polarization.
- Independence
  - Undulator base e^+ source has inter-system dependency.
  - Laser base e^+ source is independent.
  - Easier construction, operation, commissioning, maintenance.
- Low energy operation
  - Undulator-base e^+ : need deceleration.
  - Laser-base e^+ has no problem.