Compton Schemes
for Polarised Positrons

CLIC Workshop
CERN 17/10/2007

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Introduction

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Compton based positron sources
Introduction: Basics and nomenclature

- Compton schemes are based on the following steps:

1) An high energy electron beam collide with a (or more) light pulse. This electron beam is called "drive" or "Compton" beam. The corresponding machine is called the "Driver"
2) In the collision gammas are created (Compton effect). If the light pulse is circularly polarized the positrons will be polarized. Light linear polarization will result in an un-polarized positron beam.
3) These gammas impinge on a target and it is converted in e+ / e- pairs. The target is called "converter".
4) Pairs are collected by a capture system (capture section).
5) After capture the particles are post accelerated and subsequently the positrons are separated from the electrons.
6) Positrons bunches are injected in the accumulator/damping ring. Due to Compton peculiarities stacking is probably required.

Polarised positrons => The Alternative for polarised positrons is the undulator solution : undulator in the main beam arm @ very high energy to produce the gamma. So the driver is the main electron beam.

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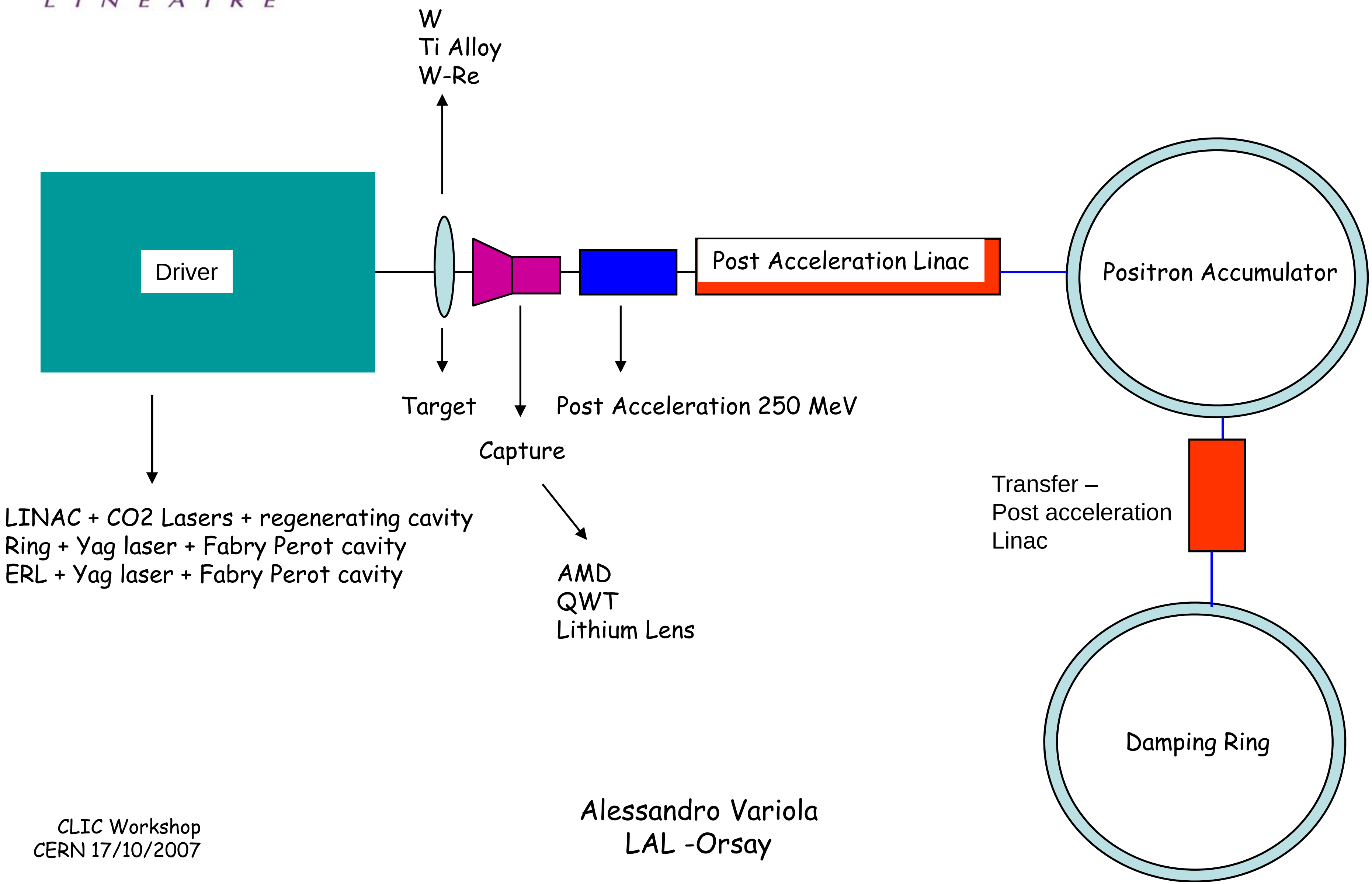
BASIC SCHEME



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- Basic Idea : Have a Compton effect based polarized positron source

- Advantages in respect the undulator schemes :

-Independent system
-Easy polarization flip @ 5Hz + non polarized (linear laser polarization).
-Higher polarization possible (>70%)
-Not disturbing the main beam
-Operability of the positron arm (especially low energy operation)
-Not considerable target heat problem (slow e^+ production even Linac scheme)
-Wide Applications in many fields
-If ring/ERL can be shared with gamma factory
-depending on the schemes and on choices, part of the Compton driver can be integrated in the e^- Linac

Compton problem

- What is the problem of a Compton based polarised positron source?

Photon/collision = $\sigma\, n_e\, n_g\, f_{overlap}$ where $\sigma = \frac{8\pi r_0^2}{3}$ = 6.65 10^{-29}m

EXTREMELY LOW.

So to compensate, as far as the single collision is concerned, it is evident that we have to increase the densities of the photons and electrons bunches and optimise the collision overlap. => ACCELERATORS TECH, LASER + OPTICAL CAVITIES

And…stacking!!!!!!

And….High flux of gammas cannot cross cavities mirrors : Holes or crossing angle in collision (decrease in the cross section).

The main question is
What is the best driver?

Parameters in the game :

	Charge (now)	Charge (desired)	mode	Beam charact.	Lasers	Cavities
LINAC	3 nC	10 nC	pulsed	Source Ad.damping Sub-mm	CO2 High power More photons	Regenerative 1J X 300 turns
RING	10 nC	10 nC	Pulsed / CW	Very little mm (> 6)	Yag Fiber lasers High Frep	FP Very high gain - CW
ERL	0.13 nC	3-5 nC	Pulsed / CW	Source Ad damping Sub-mm	Yag Fiber lasers High Frep	FP Very high gain - CW

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DRIVERS

LINAC

Advantages : Drive beam => low emittance beam, short bunch, possibility of head on collision, no reusing after collision, easy AMD (pulsed regime), good for no stacking
Disadvantage : Not high charge as ring, difficult high polarisation, **pulsed or / low frep**

CO_2 + regenerative cavity
Advantages : Exist with very high pulse power, 10 times more photons in respect the Yag at the same power
Disadvantages: **pulsed or / low frep**, need regenerative cavity (to be tested at high power), bigger waist

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RING :
Advantages : High charge per bunch, **very high frep** (**possible CW**),, very low emittances, good polarisation.
Disadvantage : Long bunches (need compression or crab), need reusing (Compton regime), crossing angle, stacking

ERL :
Advantages : Short bunches, **high frep** (**possible CW**),, possible very high polarisation, no reusing (only re-circulation)
Disadvantages : low charge, crossing angle, capture section (CW), stacking

YAG + FP
Advantages : **Very high frep** (**possible CW**),High power fiber laser very promising, possible very high gain in the cavity, very small waist.
Disadvantages : Crossing angle, high power /pulse @ high frep to be demonstrated, less photon / energy in respect to CO_2

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- Compton Schemes are not mature now !!
- Needed R&D
- Both in drivers & Lasers

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Compton schemes are very attractive but needs Drivers & Laser R&D

- All Compton schemes need R&D
- High charge/bunch ERL
- Ring stability under Compton regime
- Very high charge/bunch e^- guns
- CO2 lasers + regenerative cavities
- Fiber lasers + FP cavities

We must demonstrate light pulse circulating in the Joule regime (@ different frep)

Example for drivers….future projects

JLab	AES JLAB	Cornell	Dares. ERLP	JAERI Th.Ionic	BINP Th.Ionic	Boeing	LANL AES	LUX	AES BNL	4GLS	
DC	DC	DC	DC	DC	Dc	NCRF	NCRF	NCRF	SRF	SRF	
1.5	0.75	1.3	1.3	0.5	0.18	0.433	0.7	1.3	0.7	1.3	RF (GHz)
0.075	0.75	1.3	0.08	0.01 (0.083)	0.011 (0.09)	0.027	0.033 (0.35)	1.3	0.35	1.3	frep
0.133	0.133	0.077	0.08	0.5	1.7	4.75	3.0	1.0	1.4	0.08	Q (nC)
10	100	100	6.5	5 (40)	20 (150)	32	100 (1050	1300	500	100	I (mA)
<7	1.2	<1	1.5	30	32	~7	6		2.1	0.5	ε (μm)
3.2	6.3	2	4		50				15		ERL bl (ps)
44	44	30	20			53	16			10	Laser bl (ps)
527	527	527	527			527	527		527	527	Laser wl (nm)

EXAMPLE : FIBER LASER

State of the art

• High average power femtosecond fiber amplifier

Röser et al., Opt. Lett., vol. 30, no. 20 (2005) Jena group (J. Limpert)

131 W 220 fs 73 MHz

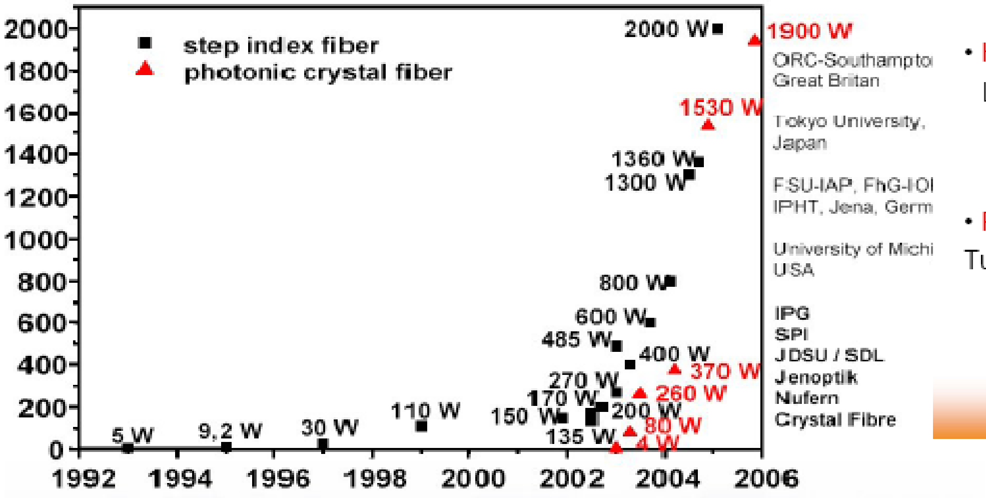
• High energy femtosecond fiber amplifier

Liao et al. CLEO 2006 postdeadline CPDB4 Michigan group (A. Galvanauskas)

500 µJ 520 fs 5 kHz

• Review paper

Tunnermann et al., Topics in applied physics vol. 96, pp.35-53 (2004)



CW fiber laser output power

Transverse monomode

R&D for the kW regime + lock to FP cavity

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Present R&D at Orsay (funded by EUROTEV & IN2P3:CNRS)

- 2 Goals:

1) To operate a very high finesse Fabry-Perot cavity in pulsed regime
   - 2 mirrors cavities Gain: 10^4-10^5
   - NOW @ 10^3

2) reduction of the laser beam size (waist @ ~ 10 μm)
   - 4 mirrors non-planar cavity
   - NOW @ < 20 μm

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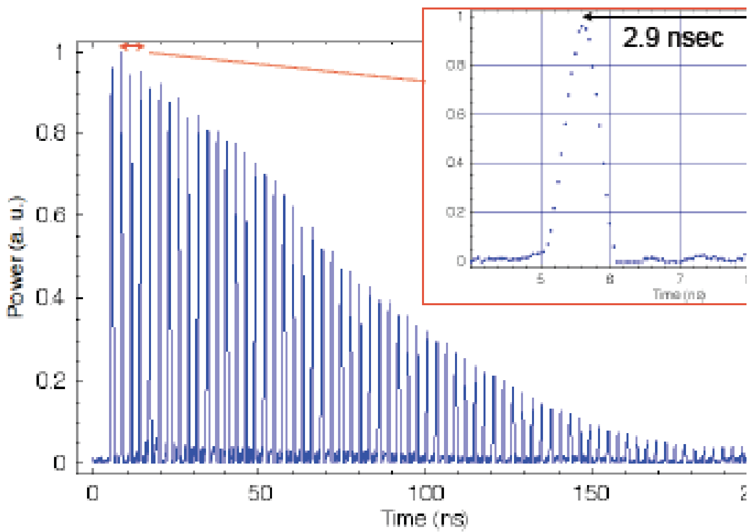
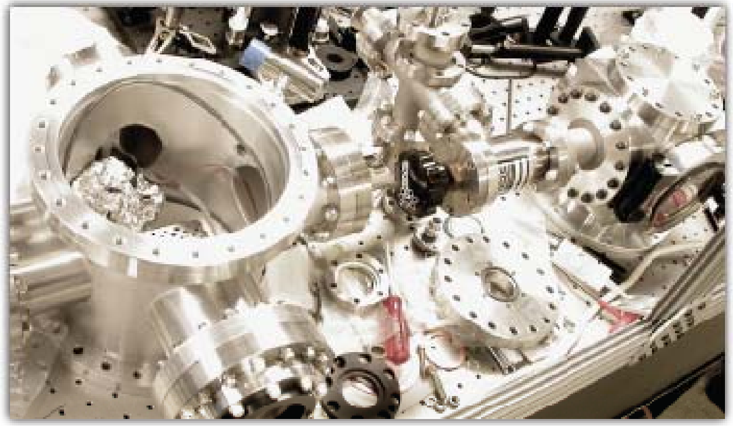
CO_2 laser+cavity

Measured cavity enhancement was 28.5x



- Green signal measured on the photodiode after the RING cavity.
- Repetition rate is equal to the cavity roundtrip time
- 80 µJ of green at pulse duration of 10 ps and ~3 mm FWHM
  - ➡ We achieved recirculation of up to 500µJ @ 1 ps, corresponding to 7 GW/cm² in the green.

Internal focus RING cavity designs



... experimental work on 1mJ recirculation is in progress

Then pass to 4 mirrors Regenerative cavity for Joule regimes

M.Shverdin

Important : Compton cross section parameters optimization depending on the driver (scheme)

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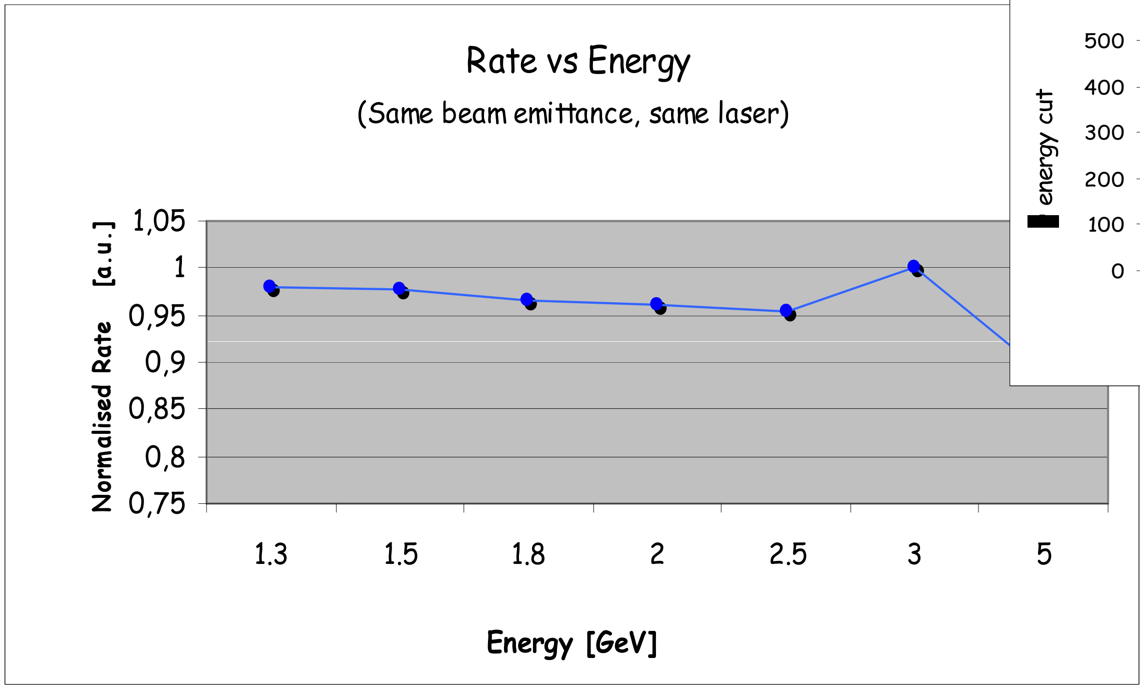
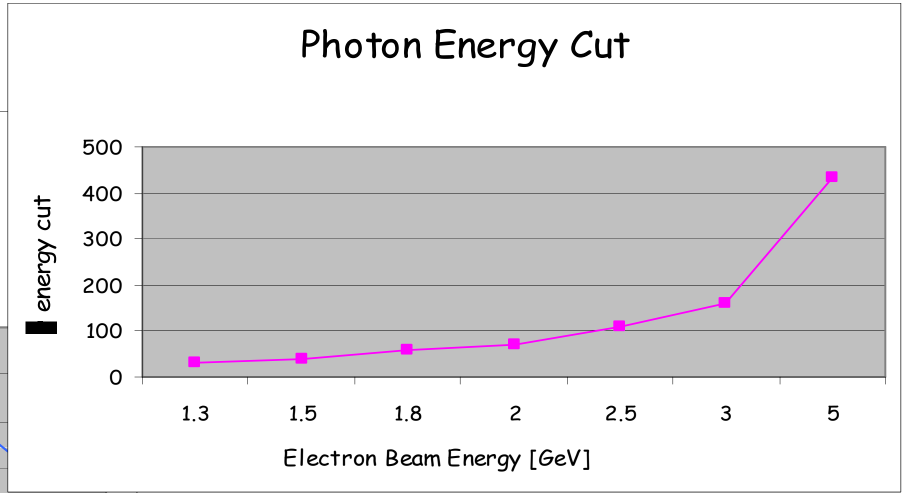
First parenthesis
Compton Cross Section Analysis
Energy & Cutoff





This must be taken into account
Since the Acceptance of the AMD is limited.
Higher the energy cut for photons
higher the positrons one => reducing
of the capture efficiency

No gain increasing the beam energy
Photon energy cut increases and so does the energy spread of the produced positrons

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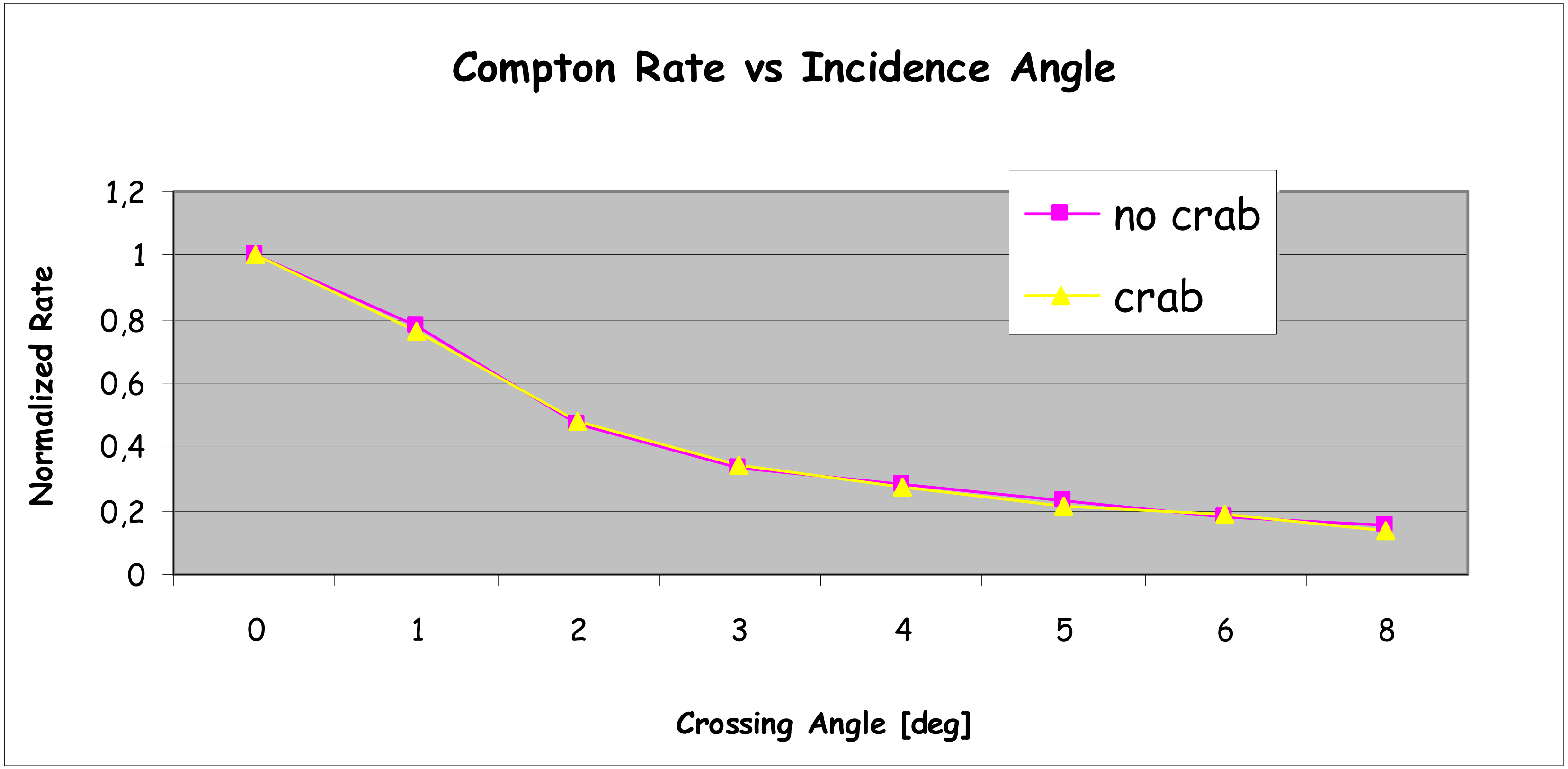
Crossing Angle



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Bunch Length & Angle Correlation

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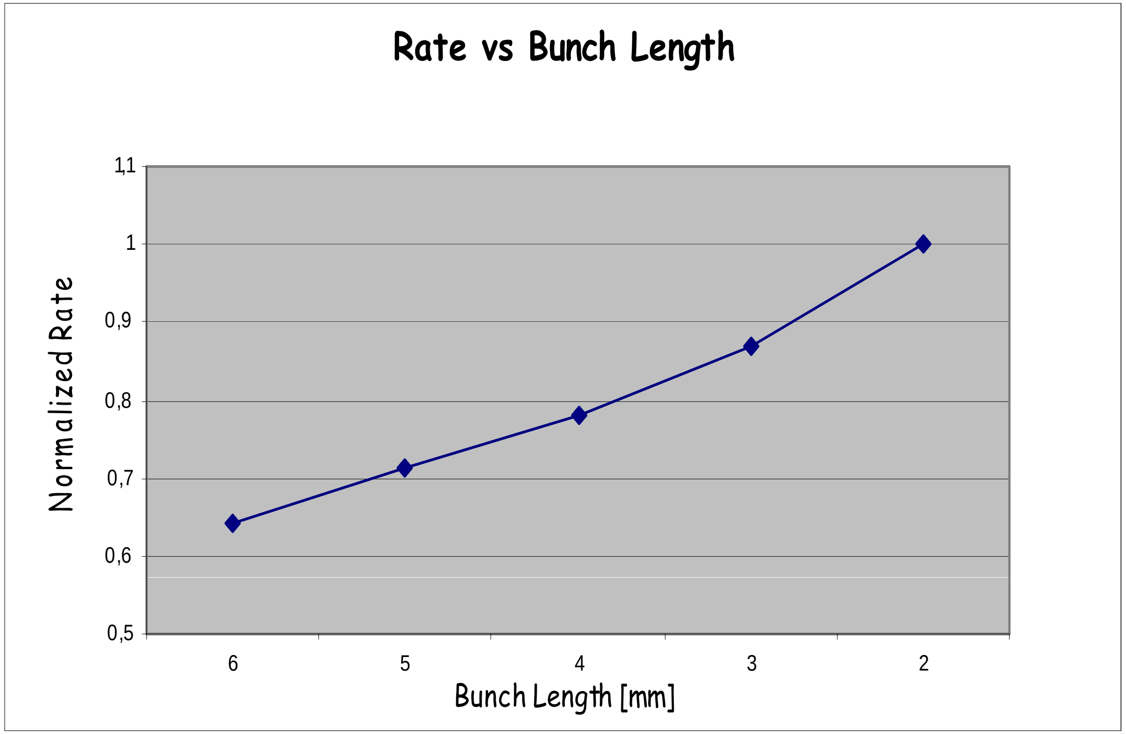
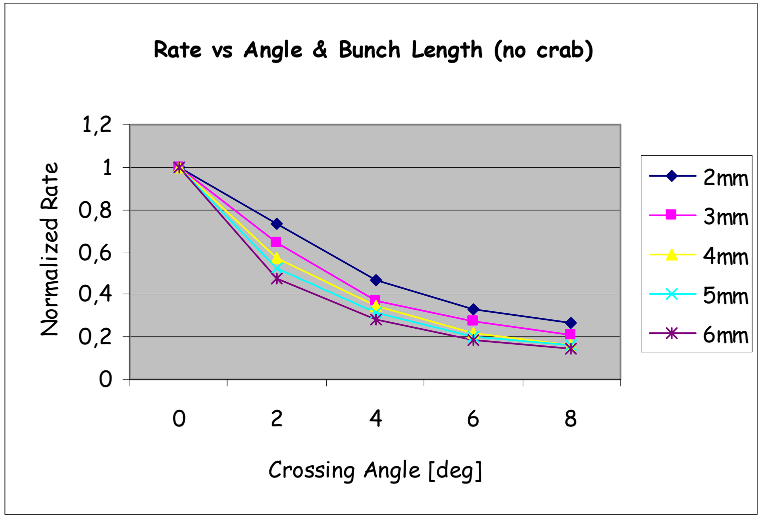
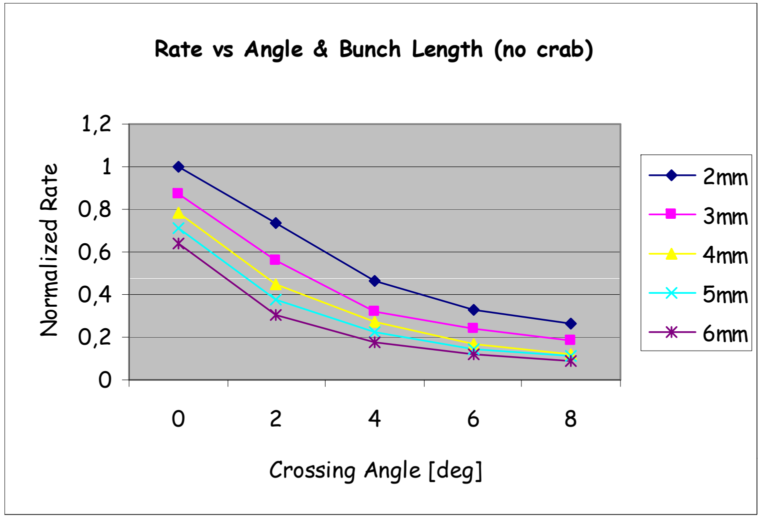


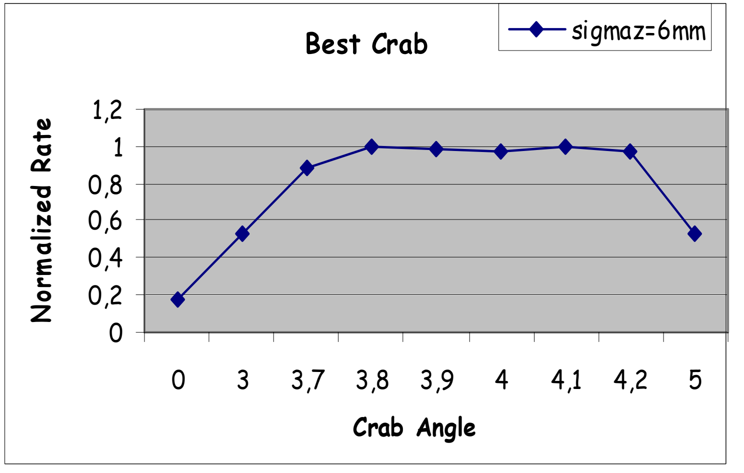


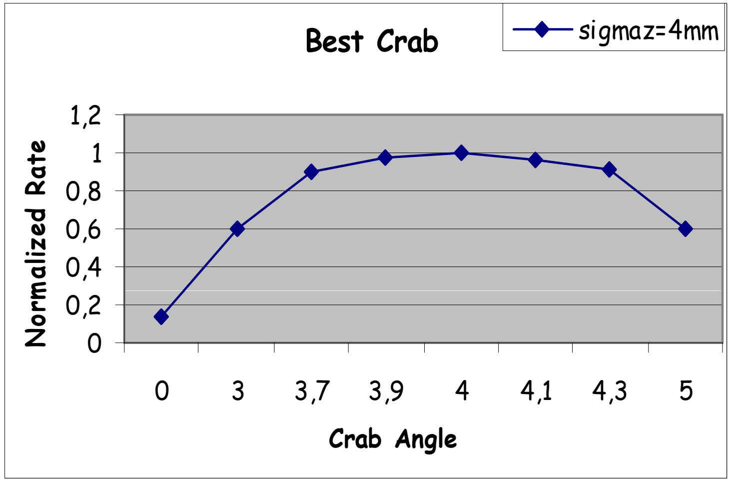


-Reducing the bunch length gives an important gain (~ linear)
-The shorter the bunch length the less sensitive to the angle loss effect

BUT…….Crab Angle Optimisation

θ_0=8°





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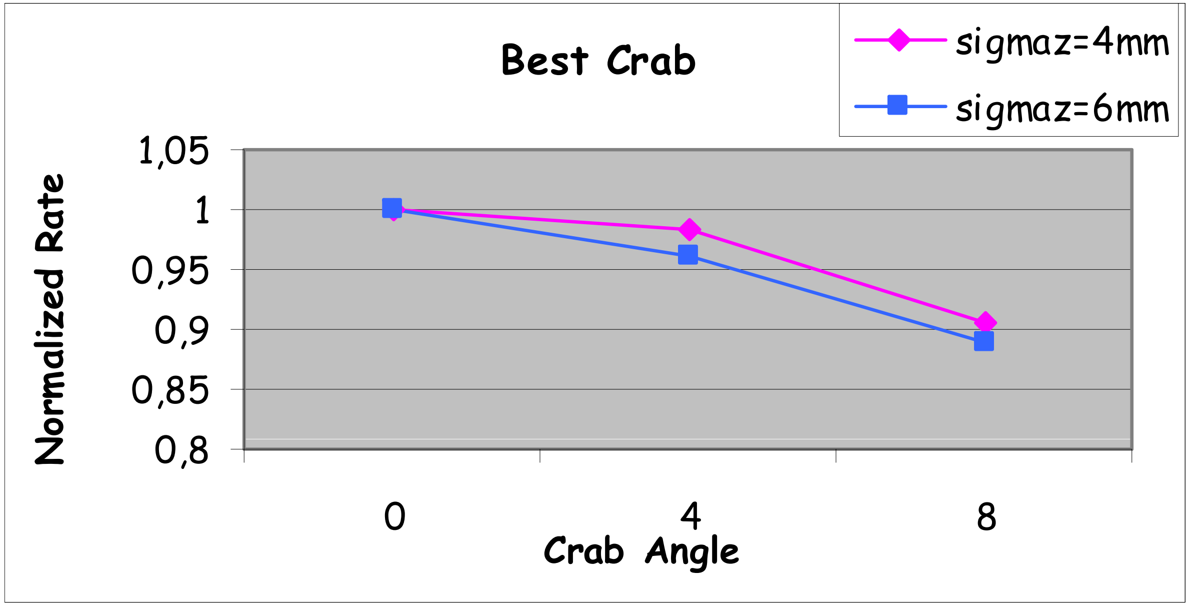
Best Crab



Taking into account the 8 deg case it is already a gain factor ~ 4.5

- Crabbing is important
- Best crab is at ~ crossing angle/2
- Shorter bunches are less sensitive to crab

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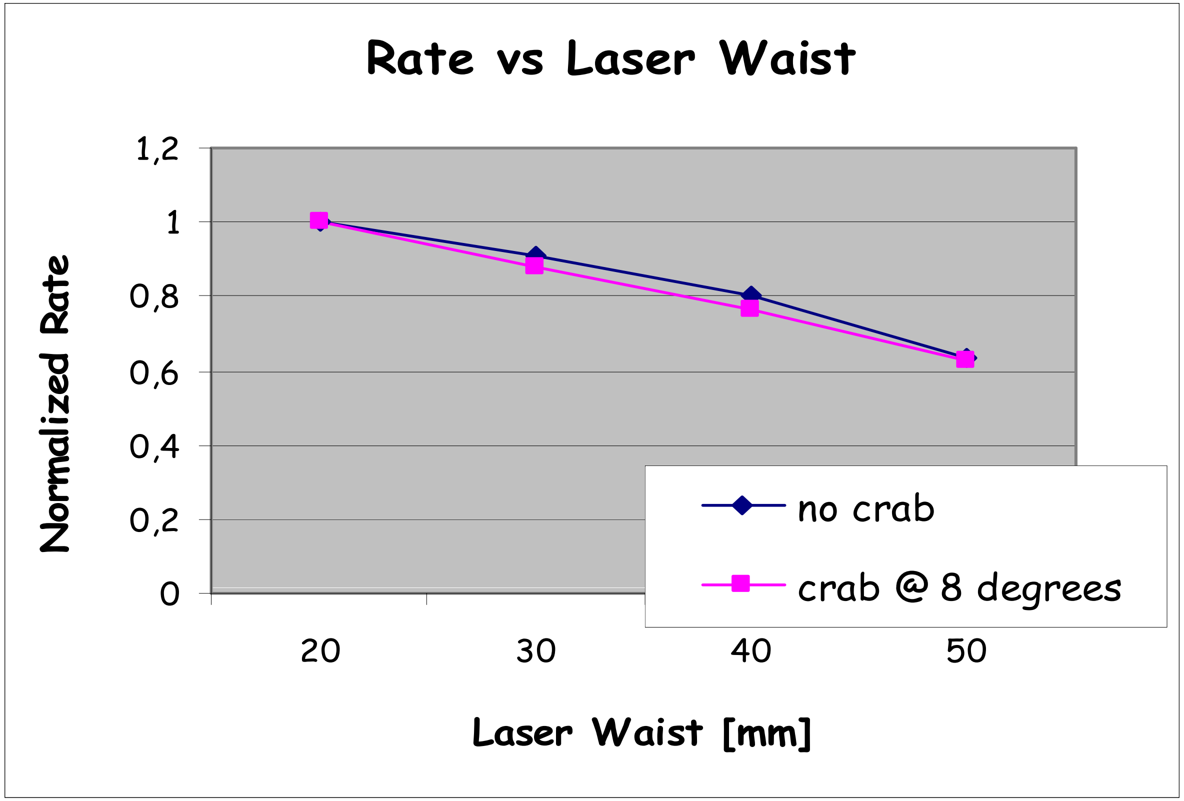
Long Electron Beam – Short Laser Pulse: effect on laser waist (hourglass)



Increasing the laser waist does not entail a dramatic loss

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Round Beam – Flat Beam

The reference for the flat beam
is always the case illustrated before (5 and 20 μm)

If we vary the beta functions at the collision point to
make the electron beam round we have that:

Round beam σ		Rate round / Rate flat
20 μm		0.73
18 μm		0.81
16 μm		0.93
15 μm		0.99

No evident need for a round beam

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Summary on cross section

- 1) Short drive beam bunch length and short laser pulse ok.
- 2) Long bunch and short laser pulse + angle = loss (can be considerable)
- 3) Solutions : 1 - bunch compression, 2 - crab
- 4) Varying waist or bunch aspect ratio (when the waist is fixed) not drastic.

- REMEMBER : For the three schemes

Linac+CO2 : short bunch, head on, stacking limited, at present charge per bunch 3 nC

Ring + YAG : long bunch, crossing angle, beam re using , high frep for stacking, 10nC

ERL+Yag : short bunch, high frep for stacking, 1-2 nC, crossing angle

Examples

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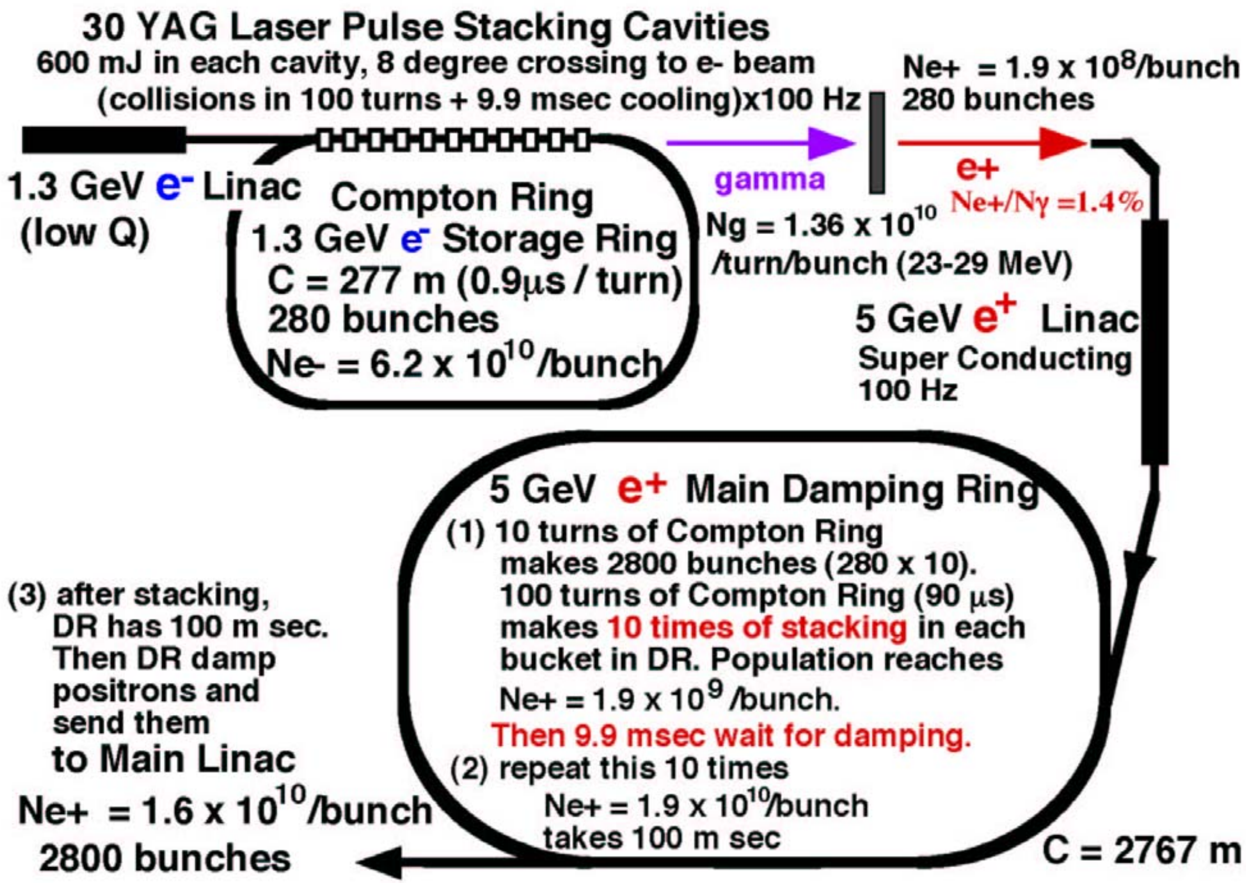
ILC Snowmass proposal



EXAMPLES : CAIN Simulation=> LINAC & ERL

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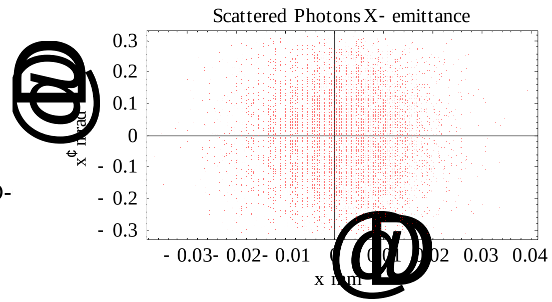
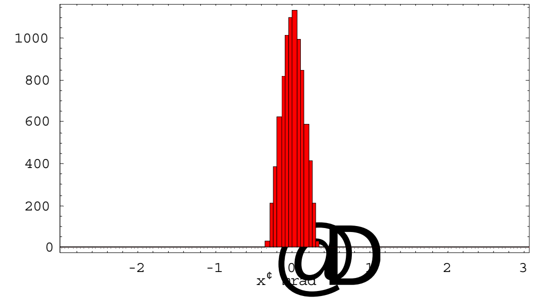
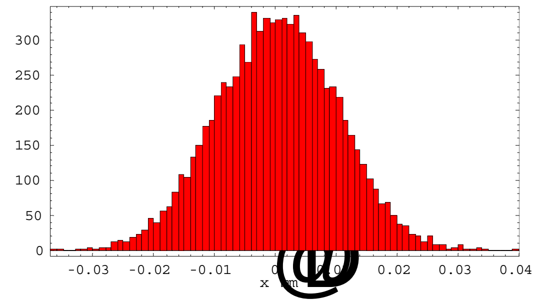
Linac - ERL solution
Can we compensate the charge reduction with bunch compression?

Beam STATISTICS				
+++Right-going photon	25034 macro particles	1.562D+09 real		
Average (t,x,y,s)	4.000D-04	5.161D-08	1.431D-08	4.002D-04 m
R.m.s. (t,x,y,s)	1.138D-17	8.025D-06	4.693D-06	1.711D-04 m
Min (t,x,y,s)	4.000D-04	-3.212D-05	-2.013D-05	-2.618D-04 m
Max (t,x,y,s)	4.000D-04	3.005D-05	2.815D-05	1.070D-03 m
Average (En,Px,Py,Ps)	1.474D+07	1.699D+01	3.052D+01	1.474D+07 eV
R.m.s. (En,Px,Py,Ps)	9.279D+06	2.658D+03	2.672D+03	9.279D+06 eV
Min (En,Px,Py,Ps)	3.095D+02	-7.827D+03	-8.248D+03	3.082D+02 eV
Max (En,Px,Py,Ps)	2.987D+07	8.207D+03	8.557D+03	2.987D+07 eV
Stokes (|Xi|,Xi1,Xi2,Xi3)	0.00709	0.00128	0.00675	0.00175

- Laser power density 1.90349132D+21
- Laser pulse Energy [Joule]= 6.00000000D-01
- Laser pulse length [m]= 2.40000000D-04
- Laser pulse wavelength [m= 1.06000000D-06
- Laser waist size [m]= 1.00000000D-05
- Laser Rayleigh length [m]= 2.96376665D-04
- Compton cut off [x beam energy]= 2.27627018D-
- Beam Energy [eV]= 1.30000000D+09
- Particles per bunch9.36000000D+09
- Collision beta function x= 1.60000000D-01
- Collision beta function y= 1.60000000D-01
- Beam size sigma x [m] = 1.00000000D-05
- Beam size sigma y [m] = 1.00000000D-05
- Beam length sigma z [m] = 2.00000000D-04
- Emittance x= 6.25000000D-10
- Emittance y= 6.25000000D-10
- Energy Spread= 3.00000000D-03
- Collision angle [rad]= 8.72664626D-02
- ***********************************
- ***********************************







@ 1.8 nC

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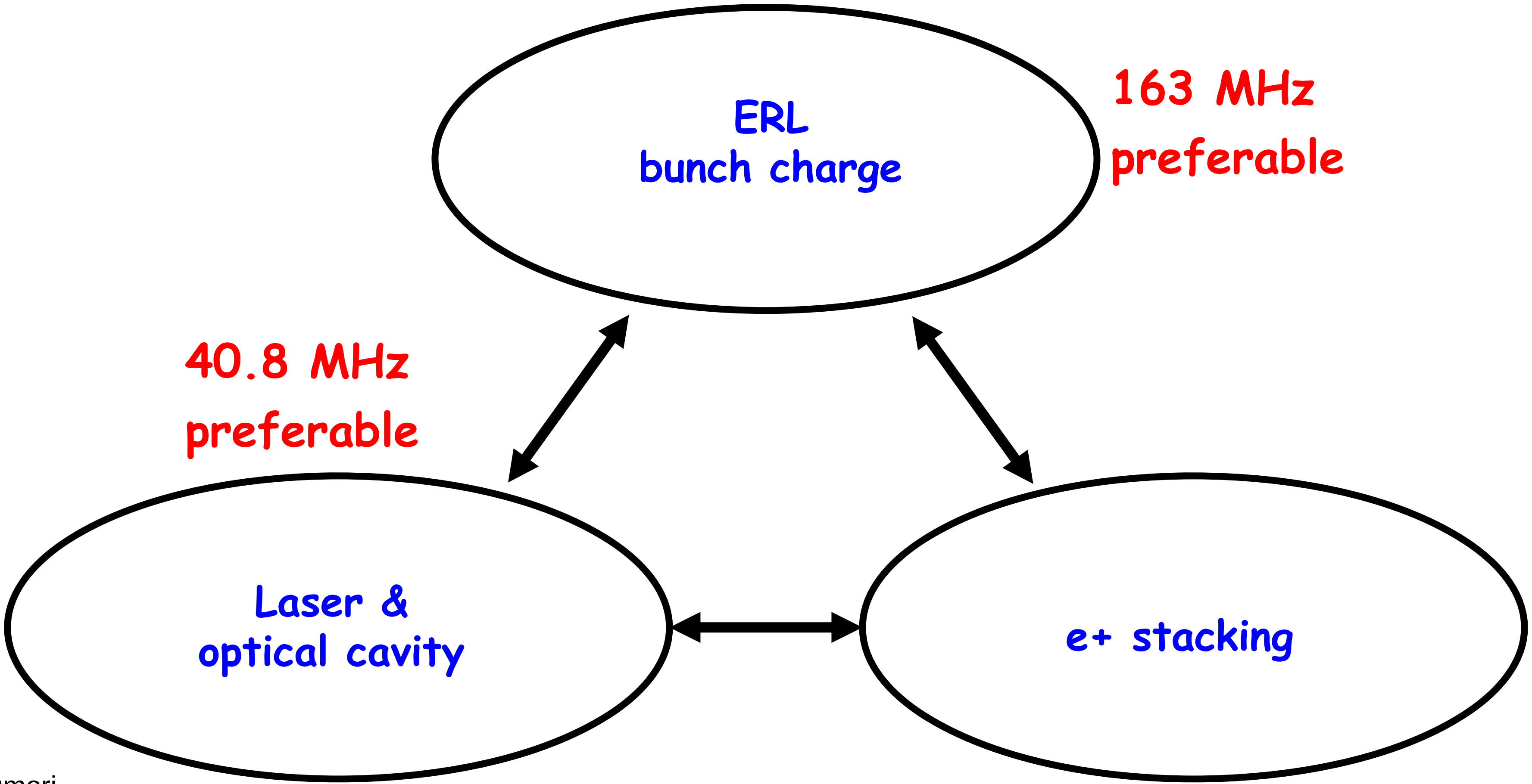
CW MODE => Selection of bunch repetition: f_{rep}

3 factors to determine f_{rep}



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Main beam parameters comparison

At the entrance of the Main Linac for e^- and e^+

		NLC (1 TeV)	**CLIC 2007 (3 TeV)**	**ILC (Nominal)**
Energy E	GeV	8	9	**15**
Bunch population N	10^9	7.5	4 - 4.1	**20**
Nb bunches / train n_b	-	190	311	**2625**
Bunch spacing Δt_b	ns	1.4	0.667 (8 RF periods)	**369**
Train length t_{pulse}	ns	266	207	**968625**
Emittances $\gamma\varepsilon_x$, $\gamma\varepsilon_y$	nm, nm.rad	3300, 30	600, 10	**8400, 24**
rms bunch length σ_z	µm	90-140	43 - 45	**300**
rms energy spread σ_E	%	0.68 (3.2 % FW)	1.5 - 2	**1.5**
Repetition frequency f_{rep}	Hz	120	50	**5**
Beam power P	kW	219	91	**630**

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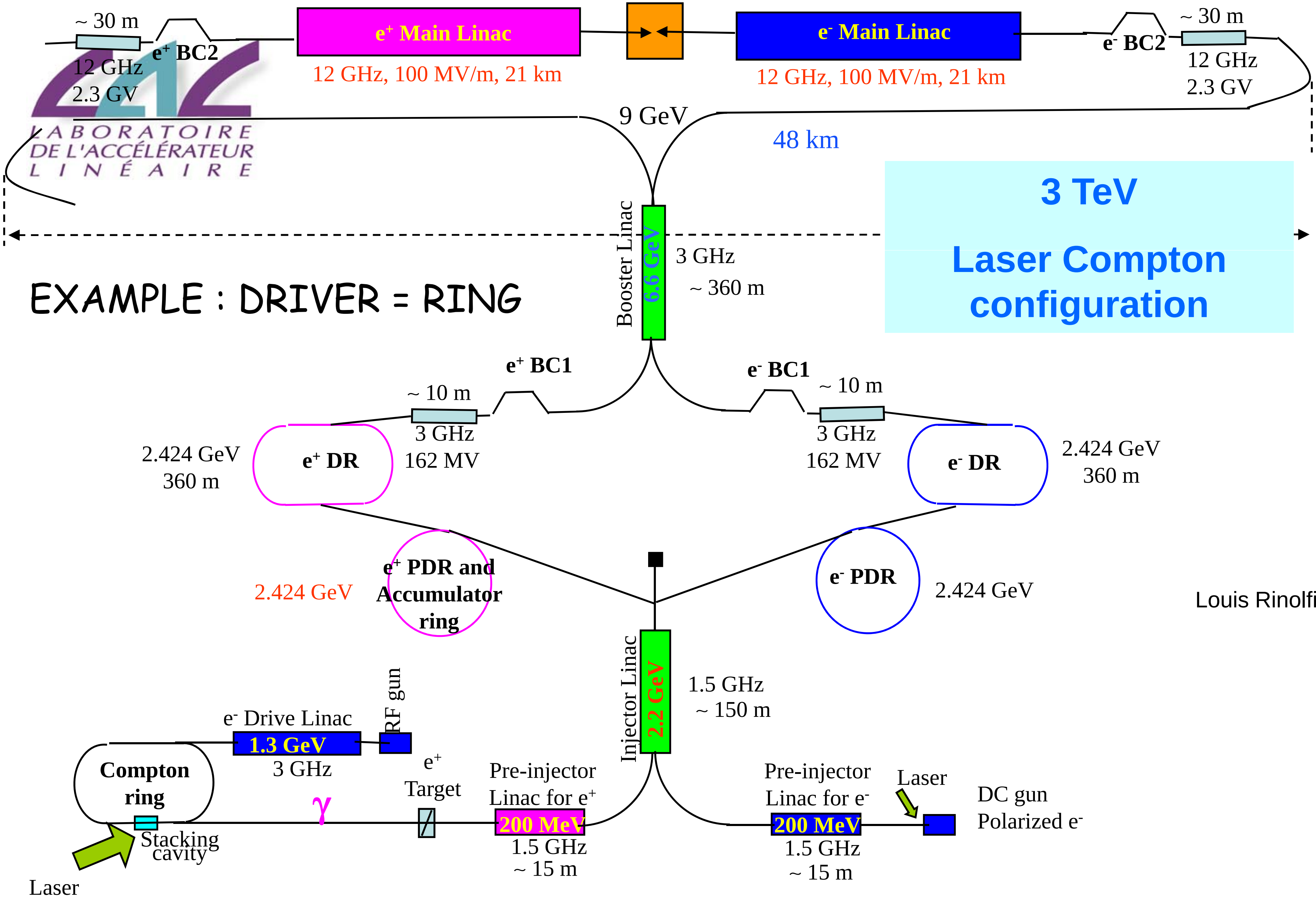

The CLIC Injector complex

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Scaling the CLIC Parameters

Need : 300 bunches of 4 10^9 positrons @ 50 Hz.
Assuming capture efficiency ~ 2% => 2 10^{11} gammas per bunch (the double with safety margin)

-Case => All photons in one shot , CO2 Laser + Linac. @ 1J/1nC/1 cavity ~ 6 10^9 gammas
So 10 cavity => 3-4 nC if capture efficiency is maintained (difficult). Think about a Ring but expensive (Energy)

-Case=> Low stacking in accumulator, Ring + Yag, @ 0.6 J, 10nC/ 1 cavity ~ 3 10^9 gammas
10 cavities => needs 4-10 STACKING in the accumulator

-Case=> High stacking in accumulator, ERL + YAG, @ 0.6 J, 2nC/ 1 cavity ~ 1 10^9 gammas (short bunch effect)
10 cavities => needs 20-50 STACKING in the accumulator

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EXAMPLES : AMD CAPTURE EFFICIENCY (Short bunches)

drive beam energy	comments	gamma diaphragm	target	capture	polarisation	rms emittance [pi mm mrad]	energy spread rms - [%]	bunch length 4 sigma - mm
1 GeV		yes	0.4 X0 W	0.87%	0.62	35.31	6.83	36.3
1 GeV		no	0.4 X0 W	0.86%	0.49	28.26	7.79	29.6
1.3 GeV		yes	0.4 X0 W	1.93%	0.47	32.32	7.17	34.5
1.3 GeV		no	0.4 X0 W	2.04%	0.48	32.31	7.39	37.9
1.3 GeV	10 interaction points	no	0.4 X0 W	0.6-0.8%	0.4	41.38	6.62	41.9
1.5 GeV		yes	0.4 X0 W	2.8%	0.43	28.3	6.65	45.7
1.5 GeV		no	0.4 X0 W	2.67%	0.35	28.32	6.28	33.5
1.8 GeV		yes	0.4 X0 W	4.06%	0.29	31.29	6.25	48.5
1.8 GeV		no	0.4 X0 W	3.92%	0.28	31.29	6.02	41.9

COMPTON ->All the results illustrated concern a beam @ 150GeV . Emittances are not normalised

Capture % : for diaphragmed cases this takes into account the SURVIVING gammas.

10 interaction points -> 4 meters interspace

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Stacking Constraints

- frep is not a problem for production
- Can be for injection
- LARGE acceptance (determined by AMD and injection energy)
- Damping time
- Syncro between accumulator and damping ring (can we use the damping ring as a second accumulation ring by stacking?)

Conclusions

- Compton Schemes are extremely attractive for the polarized positron sources since they present many advantages on the undulator schemes
- Need of strong R&D on lasers and cavities
- Careful optimization of the interaction point is necessary
- CLIC is a machine that can surely benefit from these schemes.
- What scheme to chose? It depends from the future R&D results and the accumulator design. If large acceptance => stacking so ERL or Ring allowing high degree of polarization. If not => Linac with anyway polarization bigger than 40%

- Thanks for your attention
- Thanks to all the colleagues that provided the transparencies

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