ILC Injector

ILC Summer Camp at Toyama Kureha-heights

2013/7/20-23

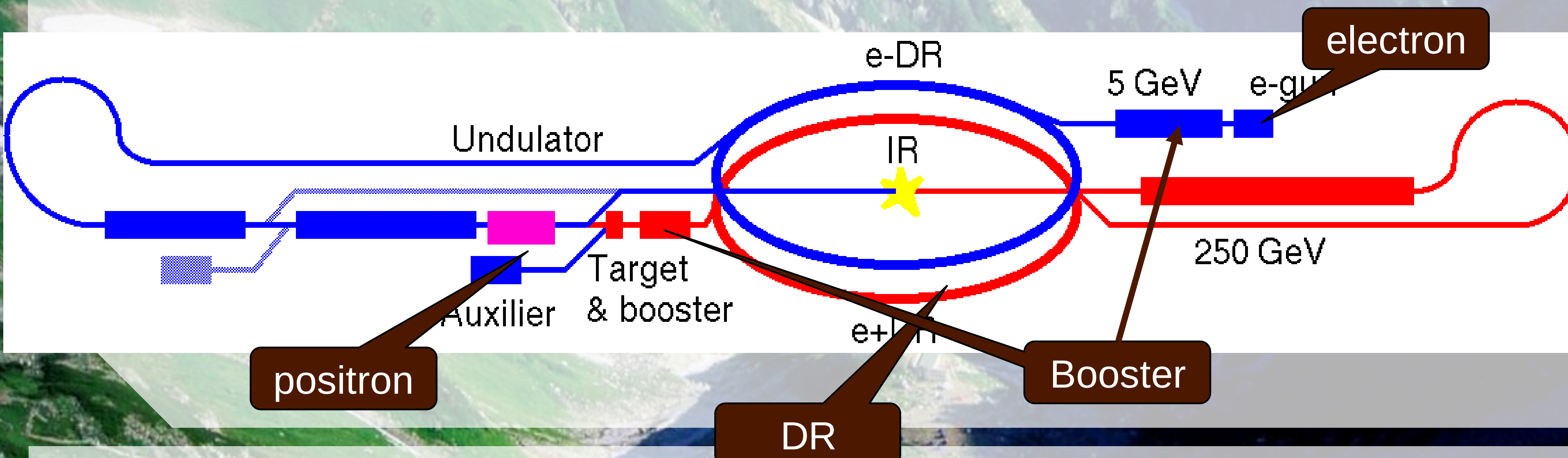
Masao KURIKI (Hiroshima/KEK)

- ILC injector
- Electron source
- Positron source
- Summary

Role of the Injector

- Role of the injector is providing accelerat-able beam to the main linac.
  - Sources: generates electrons and positrons.
  - Booster : boost up the beam for DR injection.
  - DR: store the beam for the radiation damping.
  - BC: compress the bunch length before the main linac.

Omori-san
Kubo-san



Electron and Positron Generation

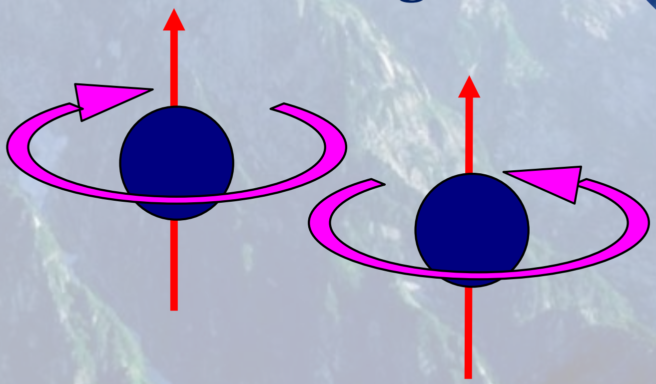
- Polarized Electron : Photo-electron effect from GaAs cathode with circulary polarized laser.
- (Polarized) Positron: Pair creation from Gamma ray in material. Several concepts have been proposed.

Importance of Polarzation

- Electron/Positron is spin ½ fermion. Two eigen states.
- Two spin states are belong to different doublet (singlet) in SU(2)xU(1).

$$l_L \equiv \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix} \qquad I_W = \frac{1}{2}, \quad Y_W = -1$$

$$e_R \qquad I_W = 0, \quad Y_W = -2$$



- Well defined initial states are essential for LC.
- Spin must be aligned (polarized) in LC.

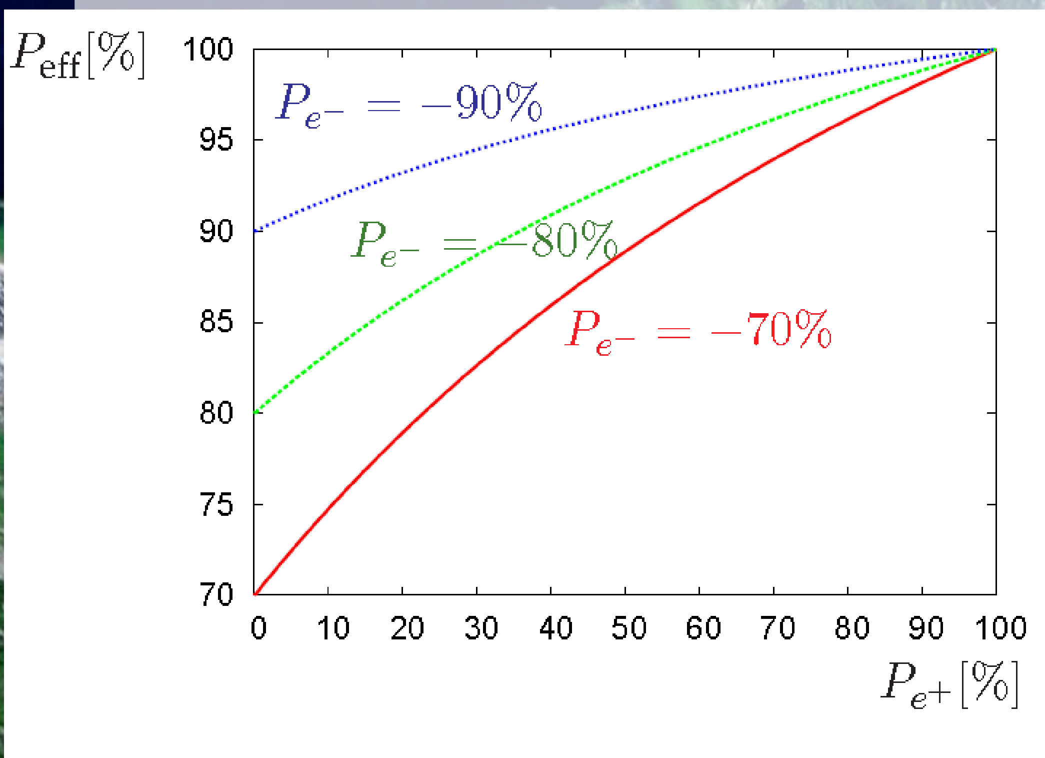
$$P \equiv \frac{N_R - N_L}{N_R + N_L}$$

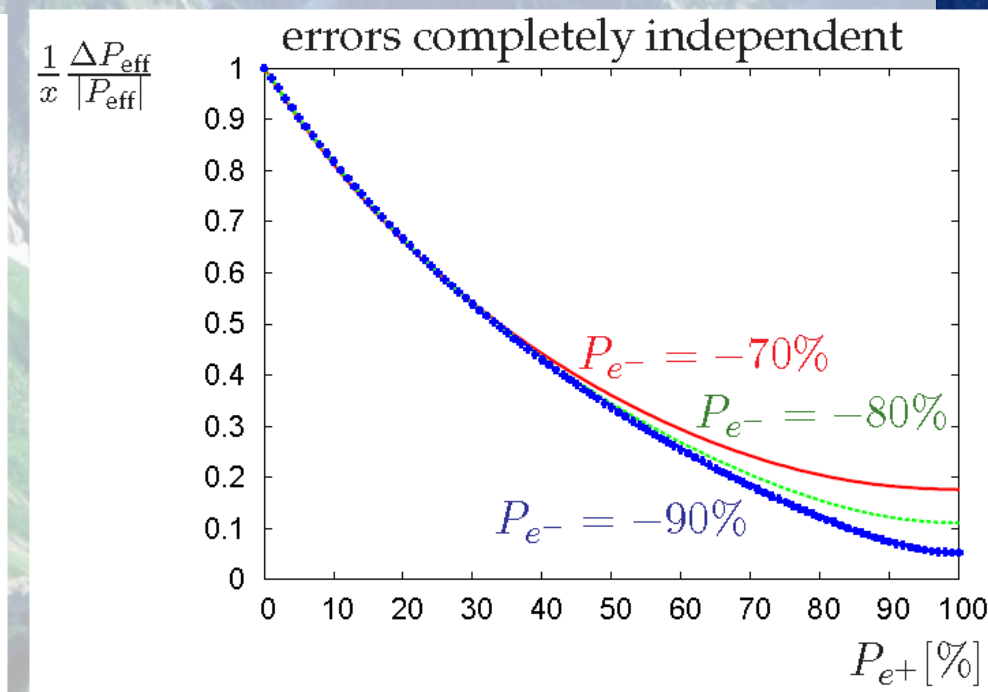
Additional enhancement from Positron Polarization

$$P_{eff} \equiv \frac{P_e - P_p}{1 - P_e P_p}$$

$$\frac{\Delta P_{eff}}{P_{eff}} = \frac{1 - P_e P_p}{1 + P_e P_p} \frac{\Delta P_e}{P_e}$$

G. Moortgat-pick





ILC electron source

GaAs photo-cathode

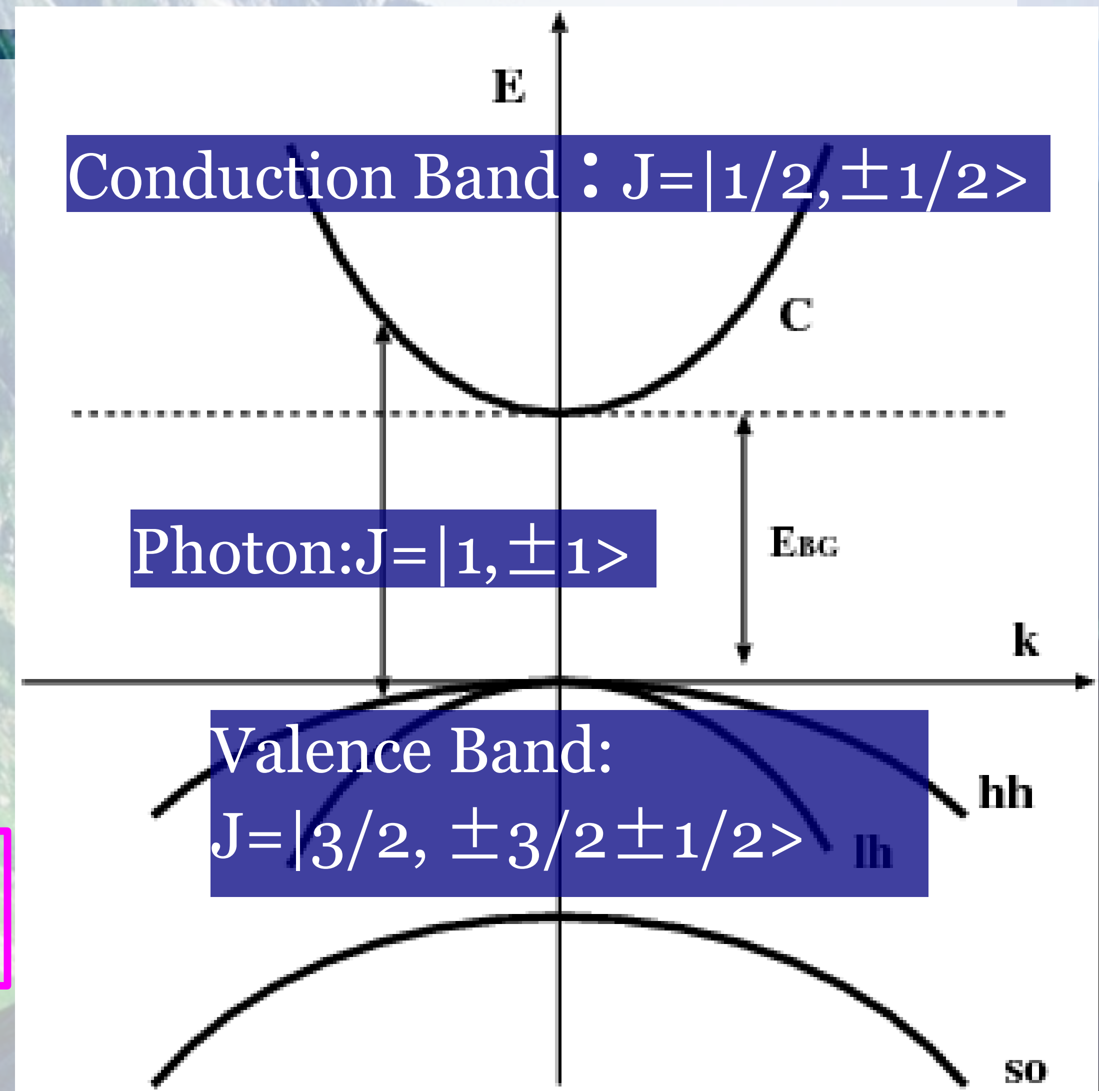
- Direct Transition at Γ point.

$$W_{i\to f}=\frac{2\pi}{\hbar}M^2 D(h\omega)f(E)$$

  - M: Matrix element.
  - D: Combined states of density.
  - f：Distribution function.
- M~Clebsh-Gordon coeff.

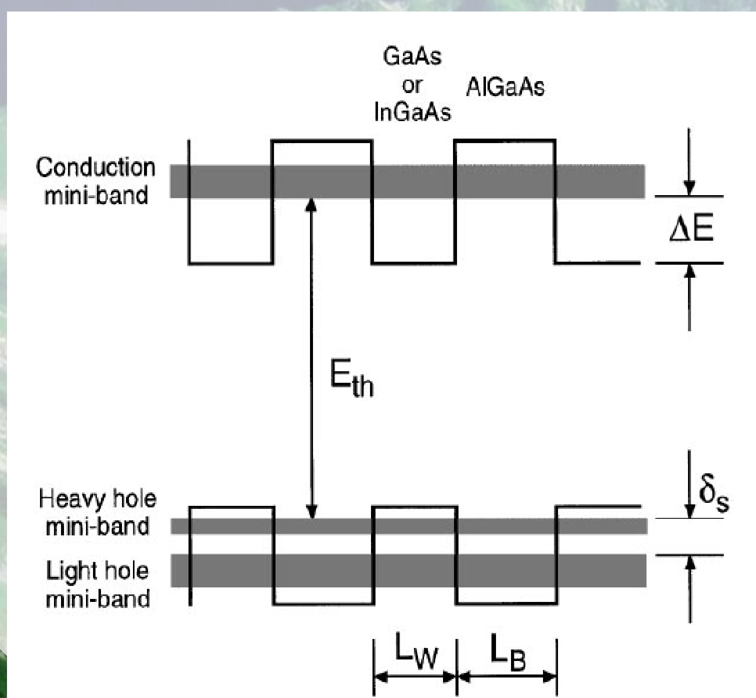
$$\left(\frac{1}{2},\frac{1}{2}\right)=\frac{\sqrt{3}}{2}(1,-1)\left(\frac{3}{2},\frac{3}{2}\right)+\frac{1}{2}(1,1)\left(\frac{3}{2},-\frac{1}{2}\right)$$

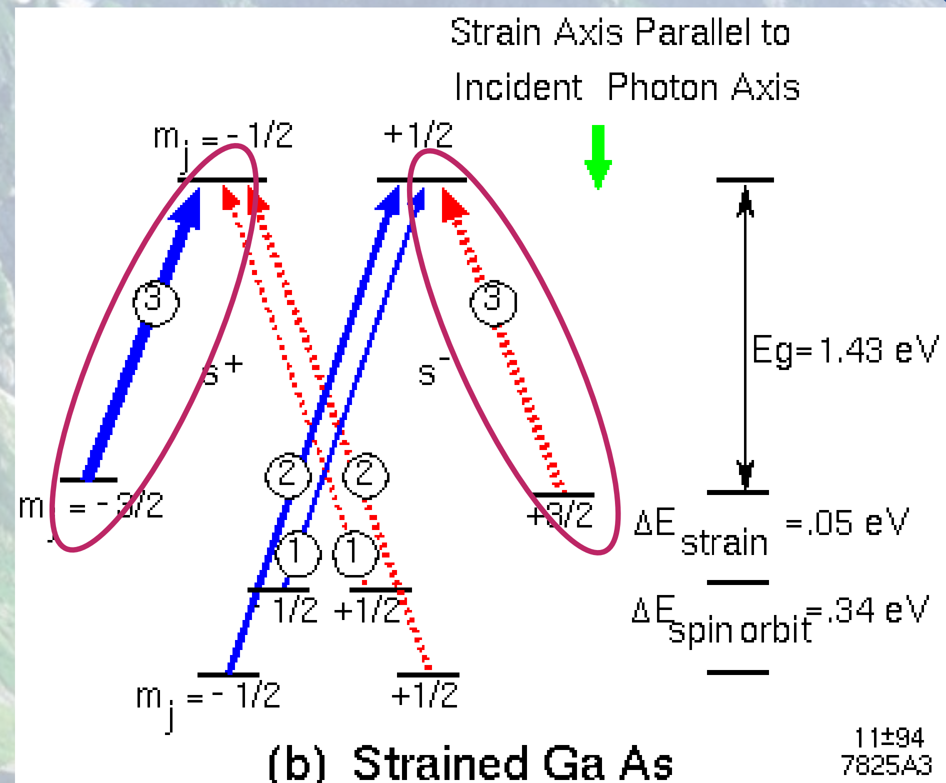
$$\left(\frac{1}{2},-\frac{1}{2}\right)=\frac{\sqrt{3}}{2}(1,1)\left(\frac{3}{2},-\frac{3}{2}\right)+\frac{1}{2}(1,-1)\left(\frac{3}{2},\frac{1}{2}\right)$$



Polarized Electron

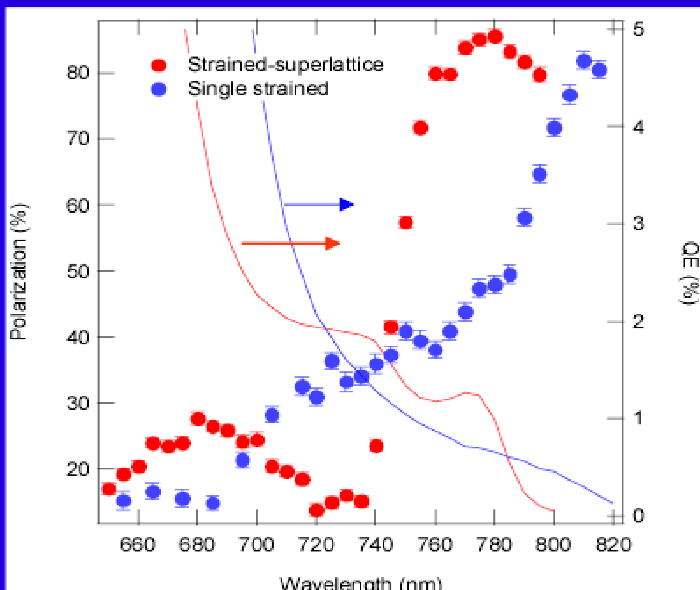
- Degenerate ：50% pol.
- Non degenerate：100% pol.
- Strain and/or super-lattice Crystal.



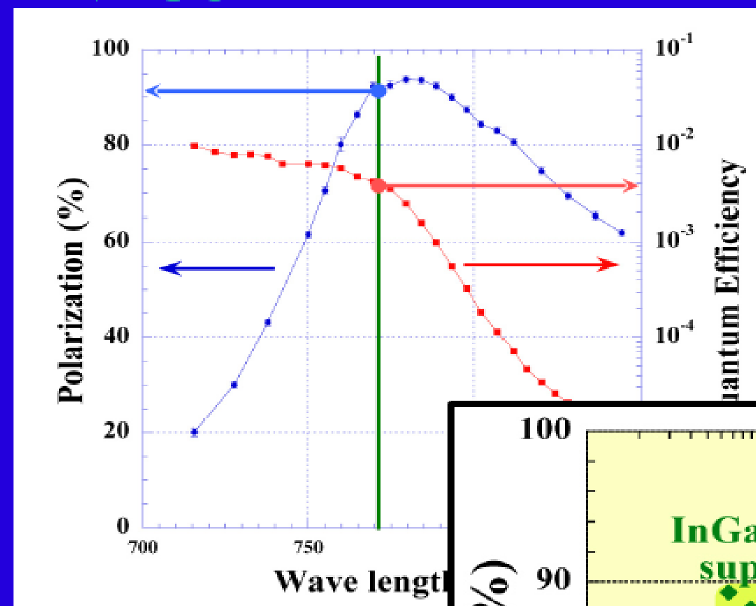


Performance of GaAs/GaAsP superlattice

SLAC

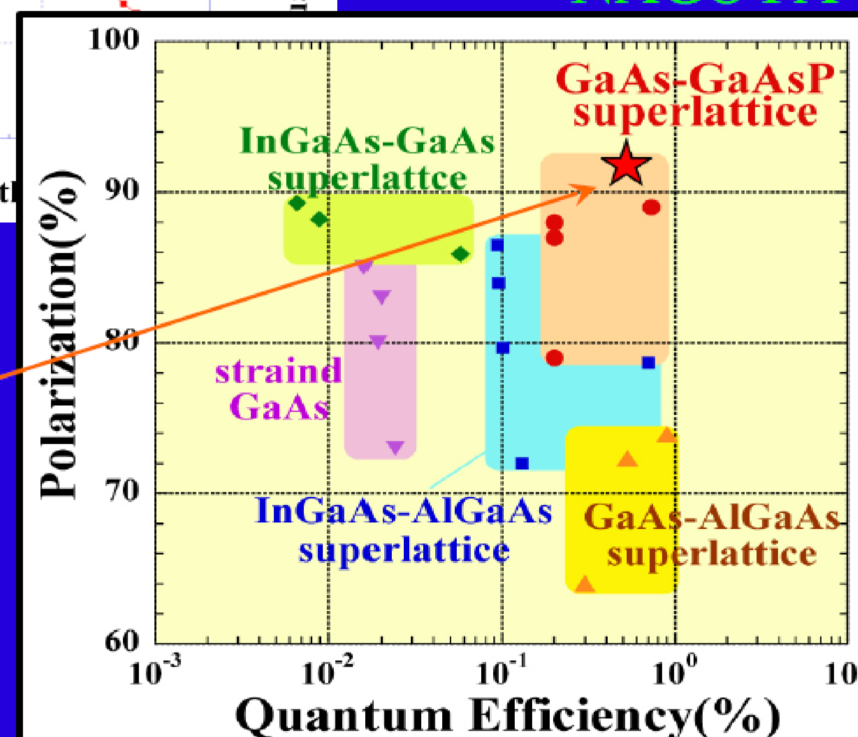


NAGOYA



By T. Nishitani

NAGOYA



GaAs-GaAsP superlattice shows the best performance !

@778nm

Polarization ~ 90%

Q.E. ~ 0.5%

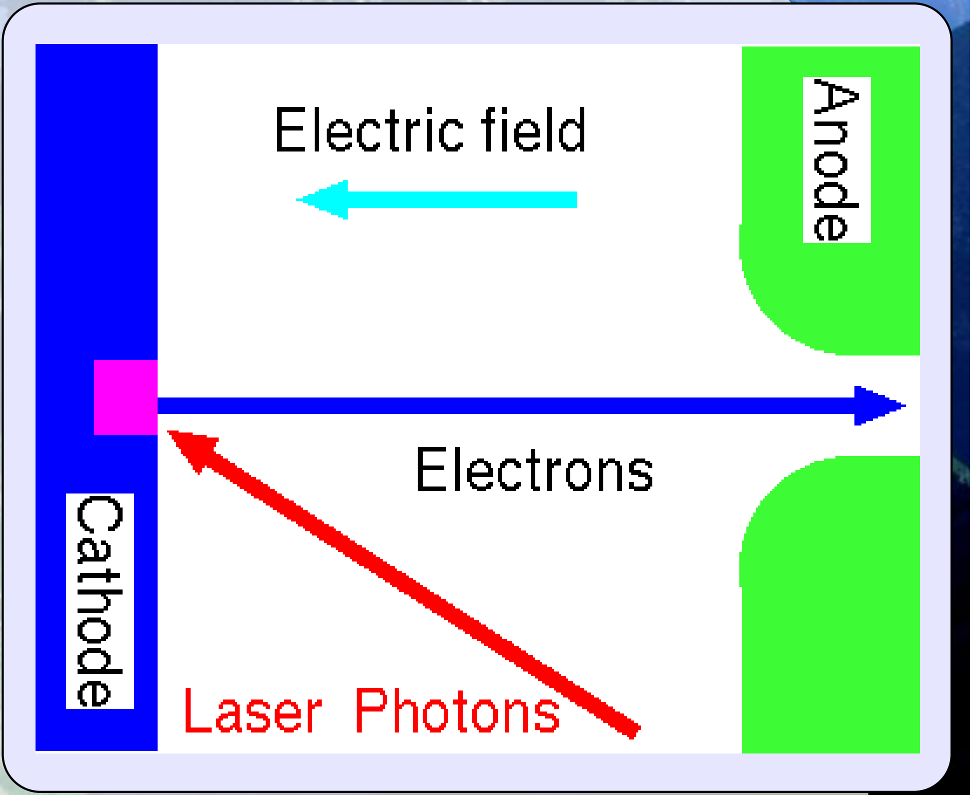
ILC Electron Source

- NEA GaAs photo-cathode DC electron gun.
- Bunching by SHB.
- 76 MeV NC accelerator + 5 GeV SC booster.
- Spin rotator and energy compressor.

Parametersn	Nominal
Pulse length	730μs
Pulse repetition	10 Hz (5Hz for e+)
# of bunches in a pulse	1312
Bunch interval	554 ns
Bunch charge	3.2 nC
Bunch length (at Gun)	1ns (full width)
Bunch length (at IP)	300 μm (1ps, rms)
Beam Polarization	>80%

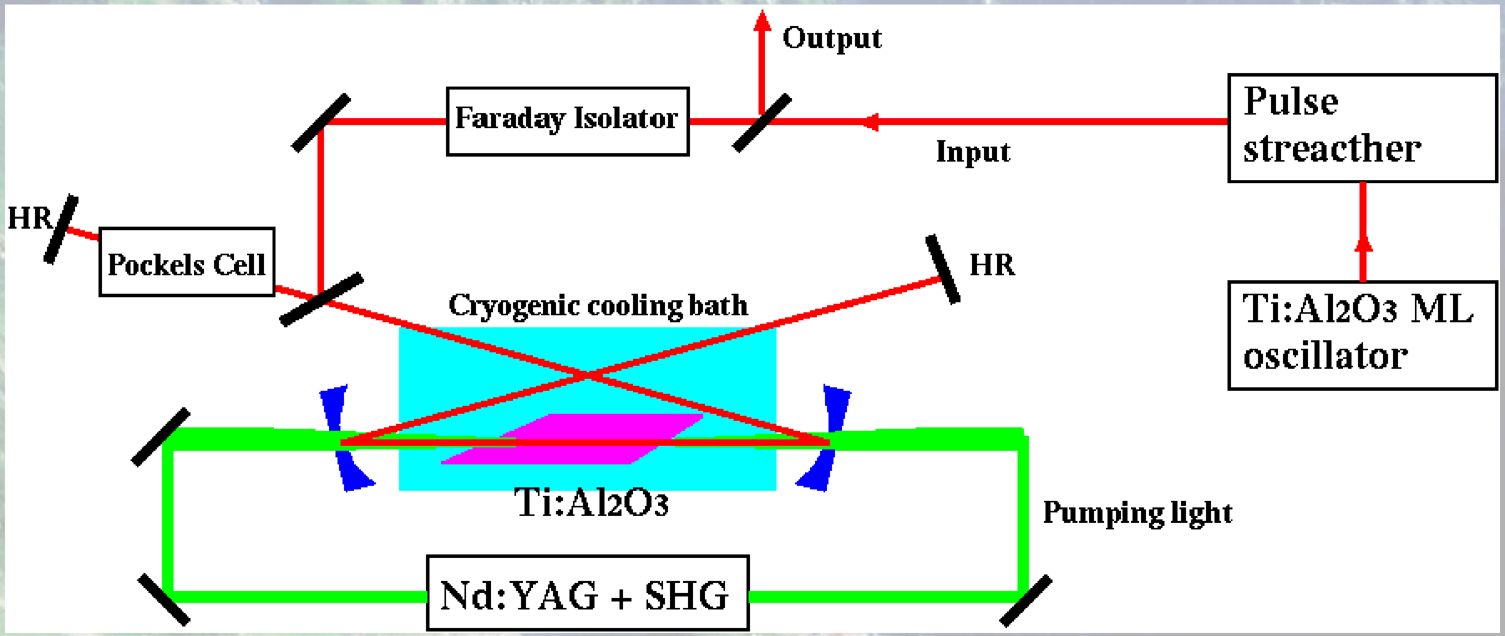
DC Photo-cathode Gun

- Photo-electron emission from NEA GaAs cathode with Circularily polarized laser
- 200kV DC extraction field.
- Current density is limted by space chage. 3.2nC is extracted in 1ns duration.



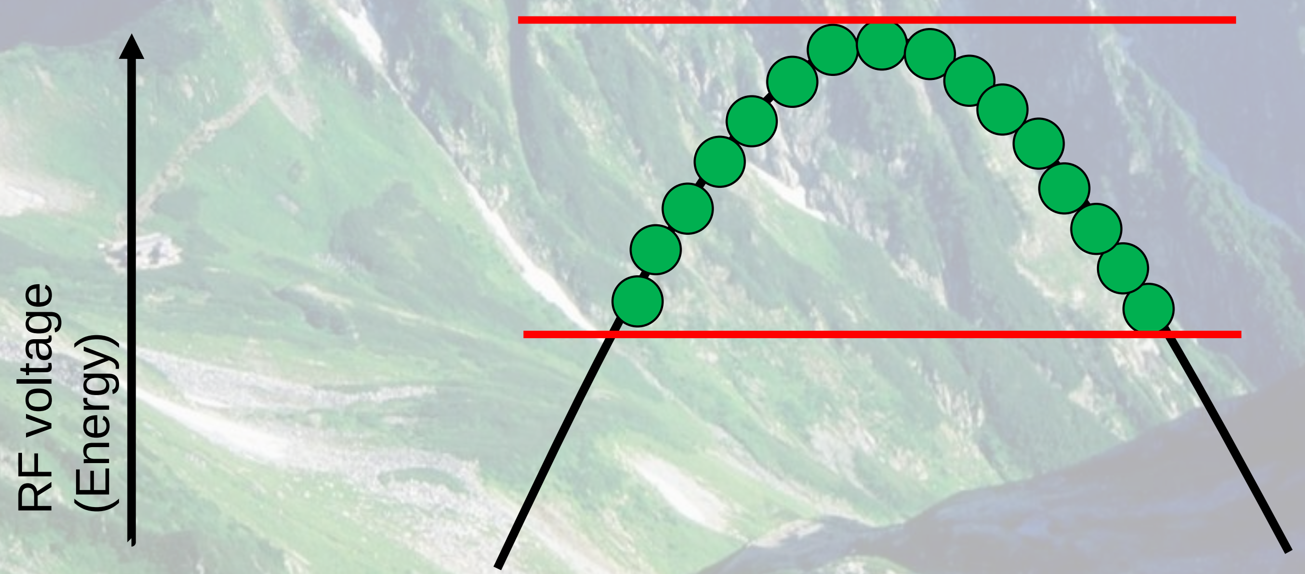
Electron Drive Laser

- Electron beam driver in macro pulse format.
- Wavelength tunability for optimum polarization is implemented by Ti:Al_2O_3 mode lock + 3MHz pulse picker.
- Amplification with Ti:Al_2O_3 regenerative amplifier.



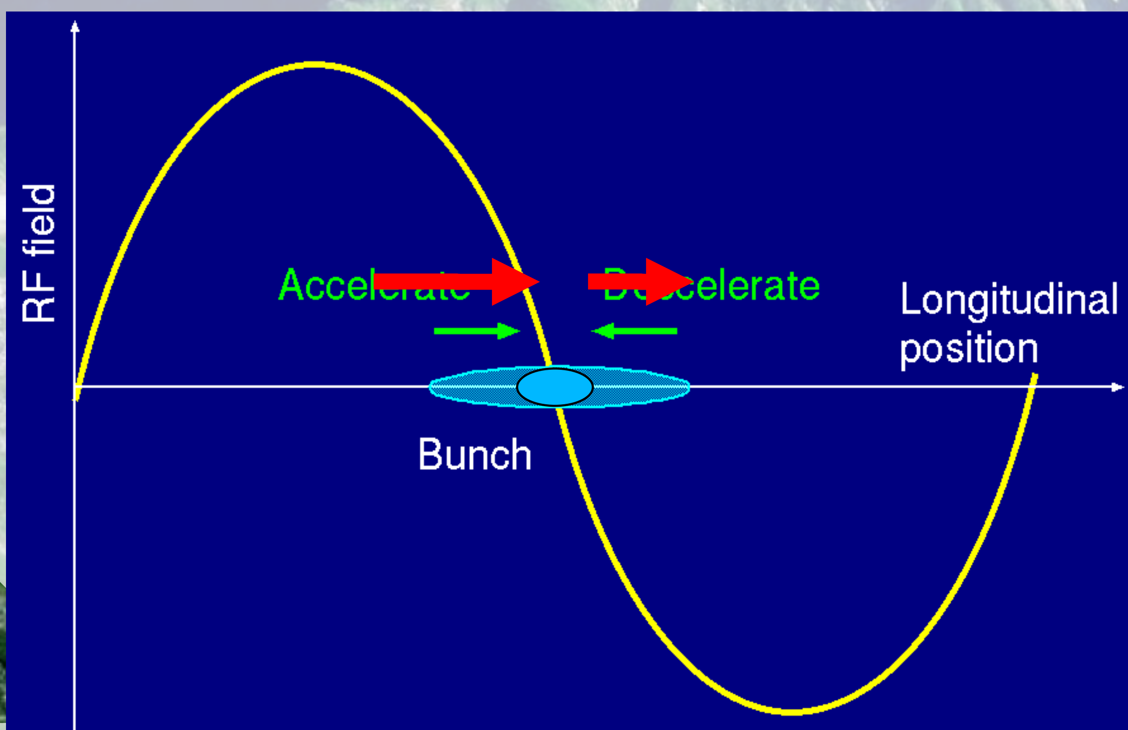
Bunching

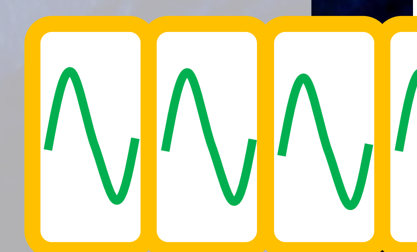
- For good acceleation by RF field, the beam is concentrated in a small phase area.
- Bunching: shorten the bunch length.
- Velocity modulation.



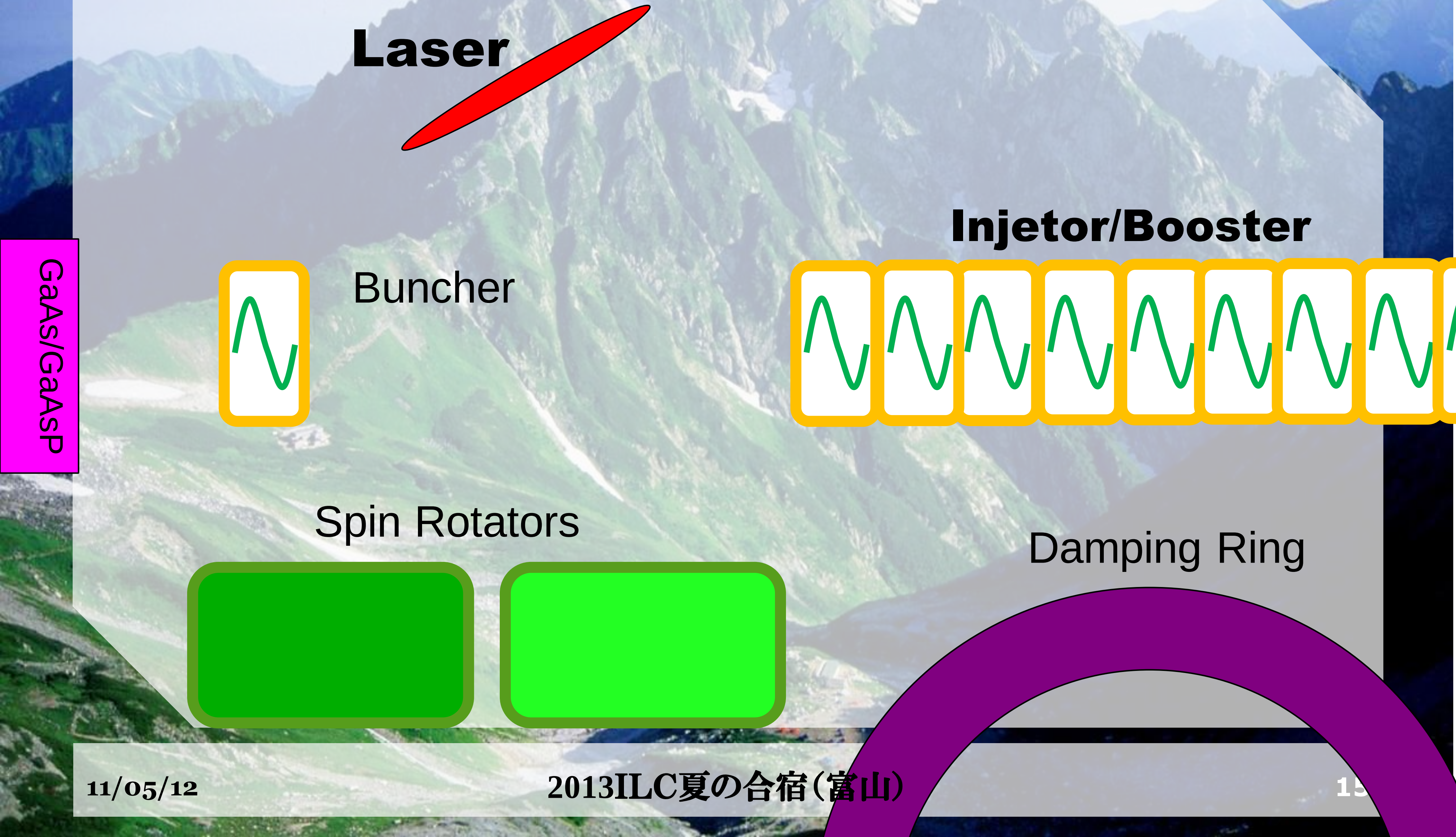
Velocity Bunching

- ►Velocity modulation within a bunch. Tail is accelerated and head is decelerated.
- ►Modulation is made by RF cavity.





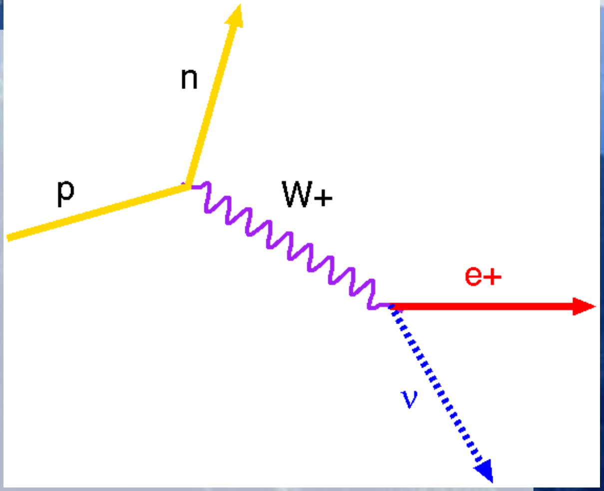
Electron Injector Summary

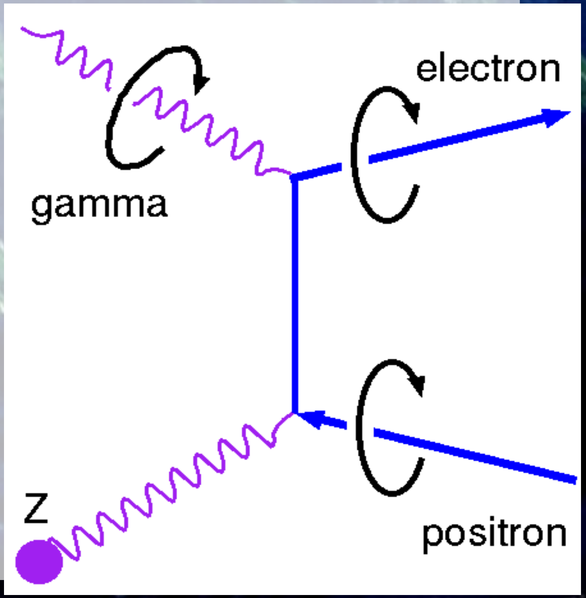


Positron Source

Positron Generation

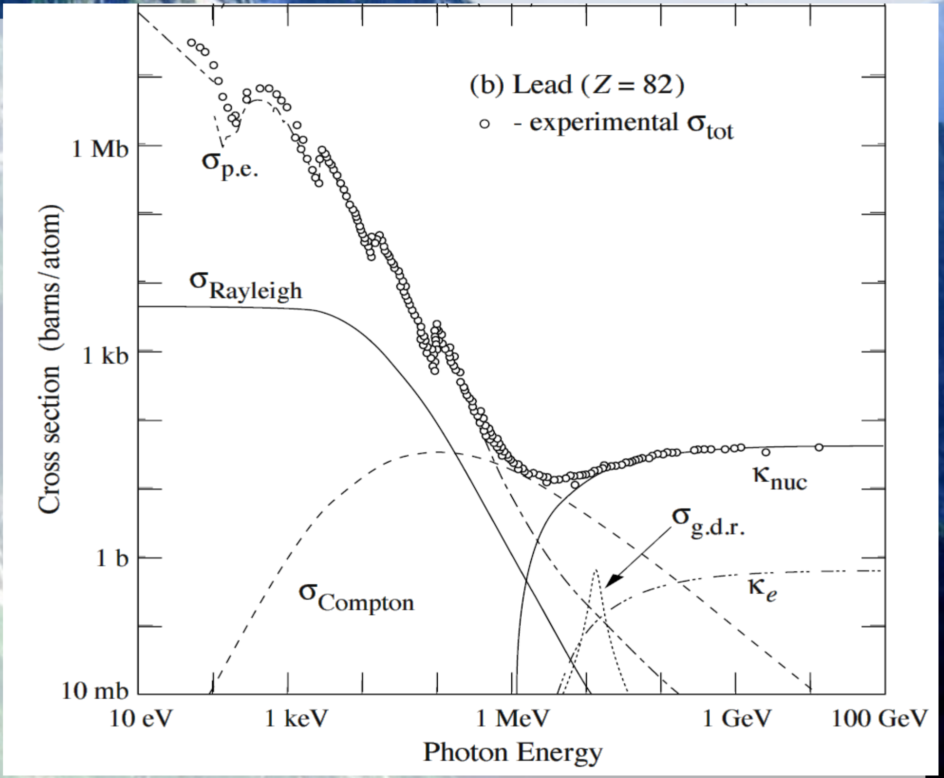
- No stable positron in the nature. Positron is generated by
  - β^+ decay
  - Pair-creation
- Only pair creation is applicable for positron in bunched format.





Pair-creation

- Photon material interaction
  - <1MeV:Photo-electron)
  - 1-10MeV:Compton
  - >10MeV: Pair-creation
- >10MeV gamma ray for efficient pair-creation.



$\sigma_{p.e.}$: photo-electron

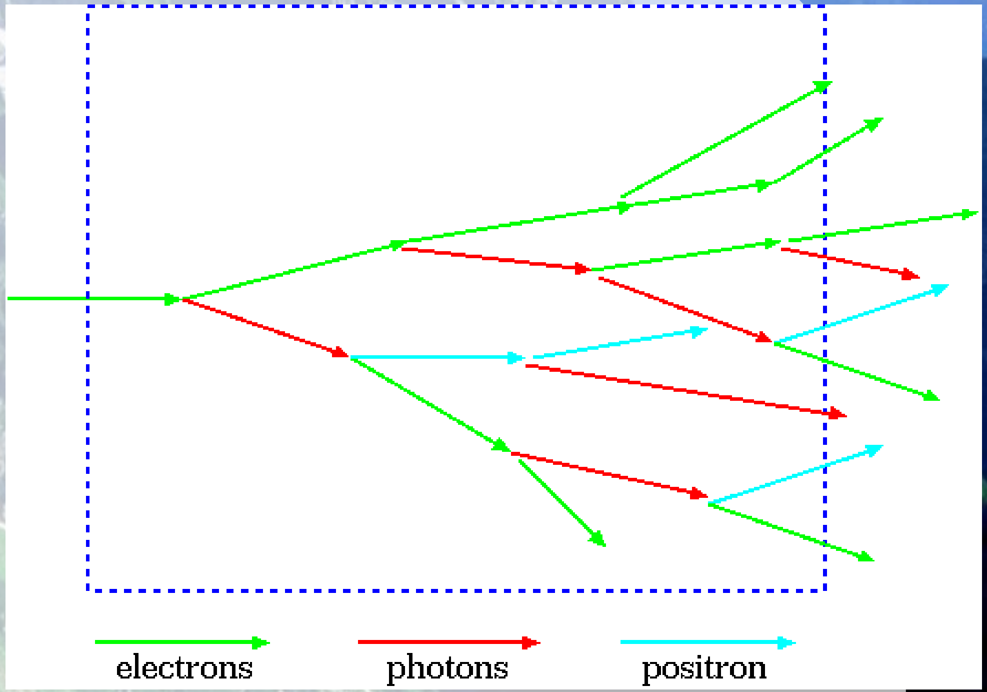
$\sigma_{Compton}$:Compton scattering

κ_{nuc}, κ_{e}: pair creation

(from Particle Data Group, http://pdg.lbl.gov)

EM shower

- Interactions with E>100 MeV electrons:
  - Bremsstrahlung
  - Electron excitation
  - Pair creation,
  - Compton scattering,
- Electrons, positrons, and gamma flux : EM shower

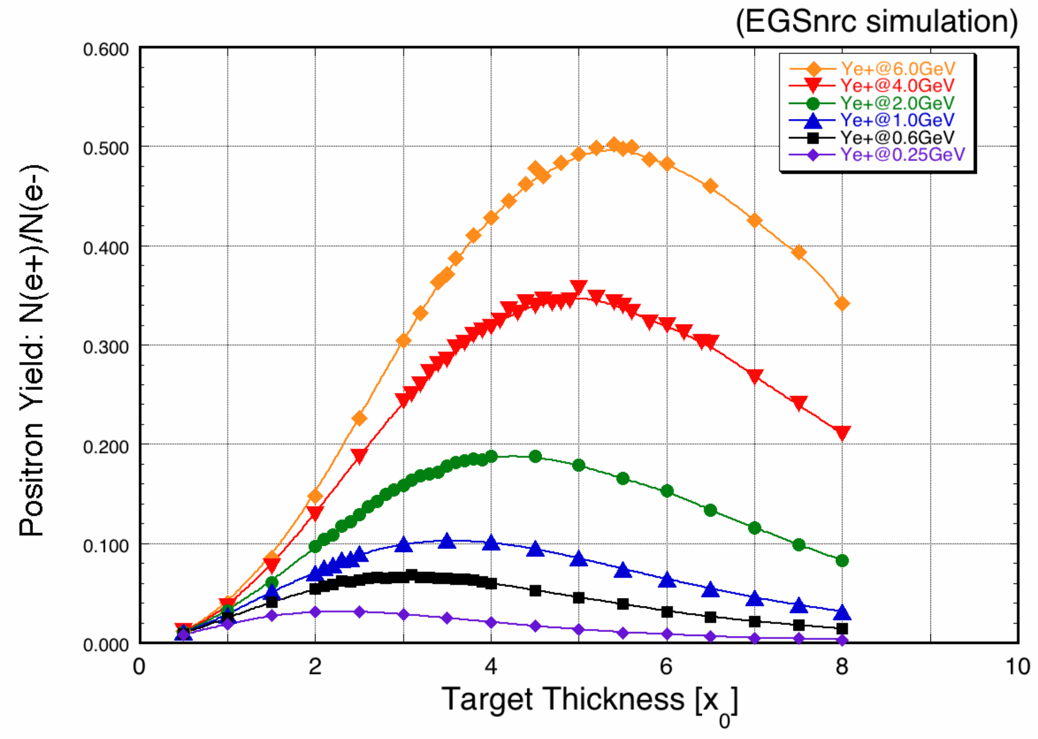


EM shower (2)

- EM shower evolution is characterized by radiation length X_0.

$$X_0 = \frac{716.4[g.cm^{-2}]A}{Z(Z+1)\log\frac{287}{\sqrt{z}}}$$

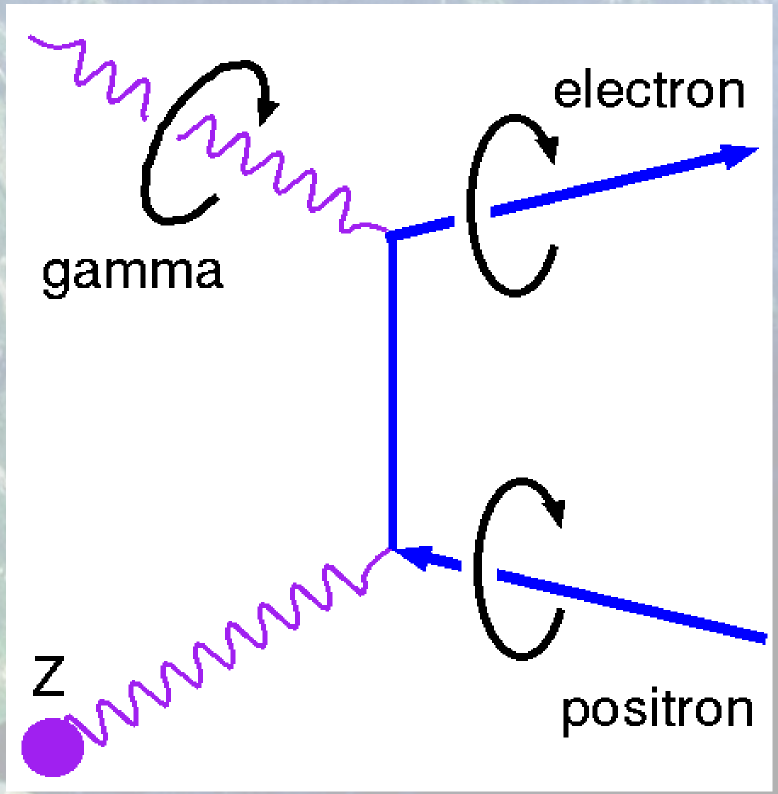
Large z is better for efficient shower development.



Courtesy of T.Kamitani

Non Shower Regime

- 10s MeV photon (gamma) causes pair-creation in material.
- No shower development (no multiplication).
- Due to the simplicity, the positron inherite the photon helicity; The polarized positron is generated if the photons are polarized.

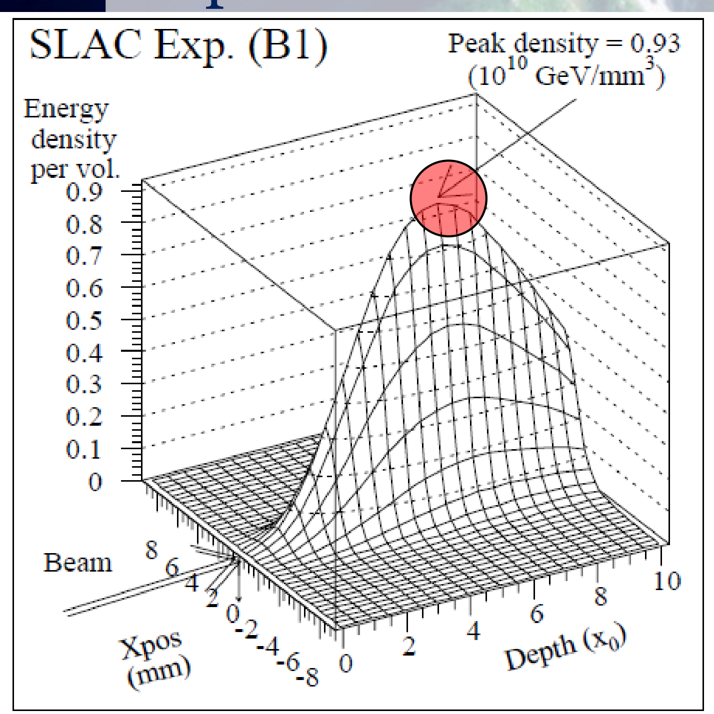


ILC Positron Source

- Three concepts (Electron driven, undulator, and laser Compton) have been proposed.
- Undulator method is the baseline, other methods are back-ups.
- It is difficult to demonstrate the technical feasibility of the undulator scheme prior to the real LC construction.

Electron Driven Scheme (1)

- Several GeV drive beam impinges on W-Re target.
- Due to the high energy density, target vitality is issue.
- If the beam format is identical to the nominal ILC (5554ns, 3.2nC), the target should be rotated with 400m/s tangential speed.



400m/s to several m/s

Facility	N/bunch	Bunhc/sec	N/sec
ILC	2.0e+10	5x2625 (1312)	2.6e+
SLC	4.0e+10	120	4.8e+

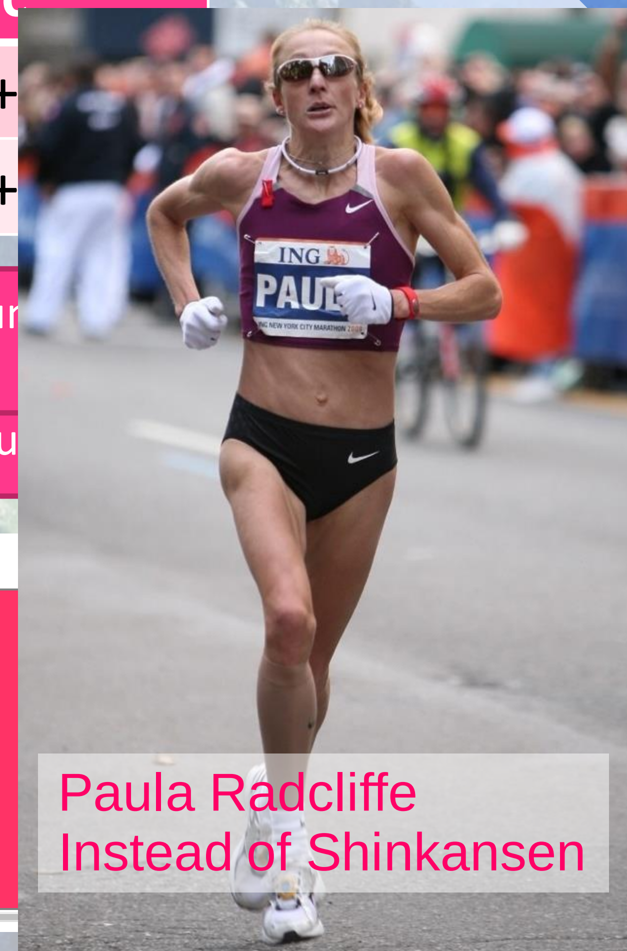
!

$$P = \kappa \frac{E[GeV]Q[nC]}{V\rho} \frac{2rN_b}{vt_p}$$

Nur

adju

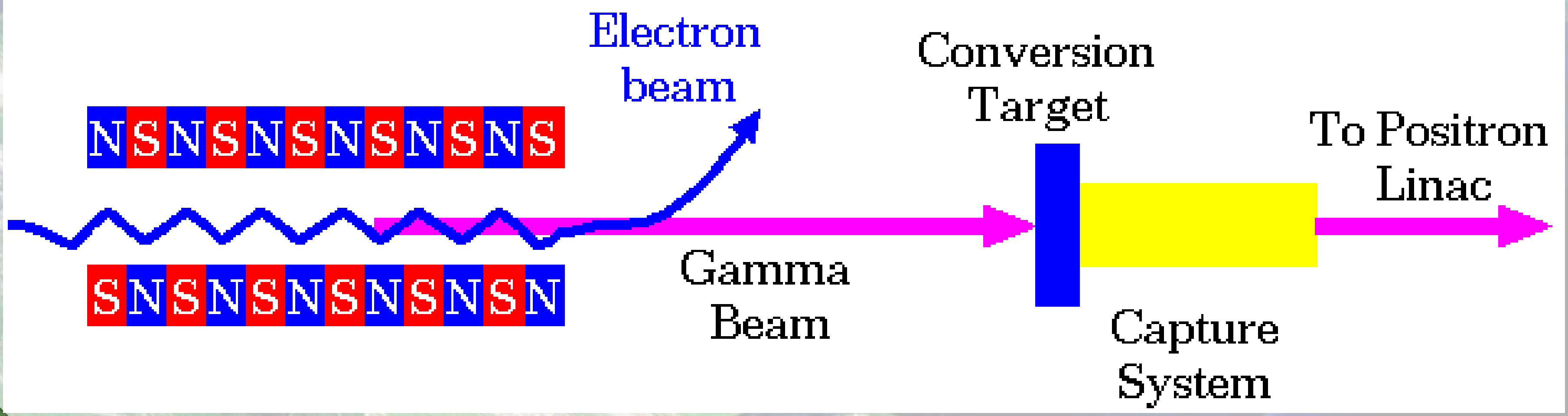
Energy Deposition Density



Paula Radcliffe
Instead of Shinkansen

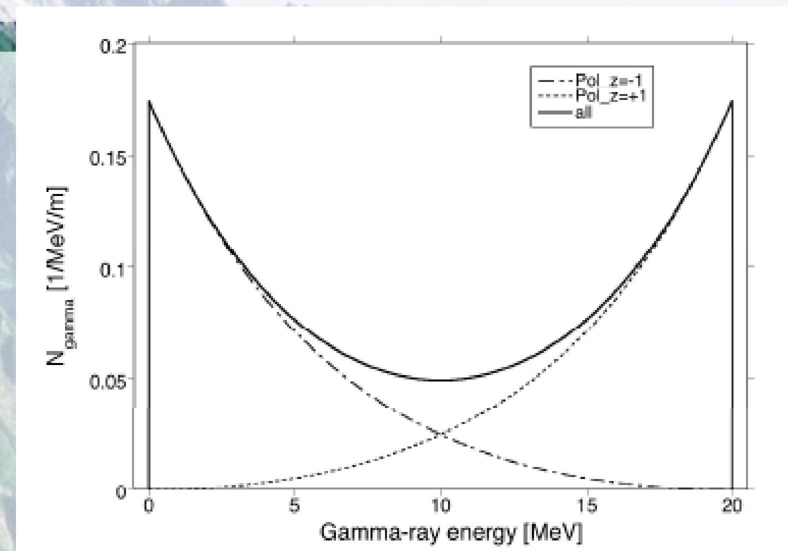
Undulator Scheme

- γ ray (>10MeV) is generated by undulator radiation with electron beam more than 130 GeV energy.
- Employing helical undulator, generated positron is polarized.
- Several technical issues + potential risks.



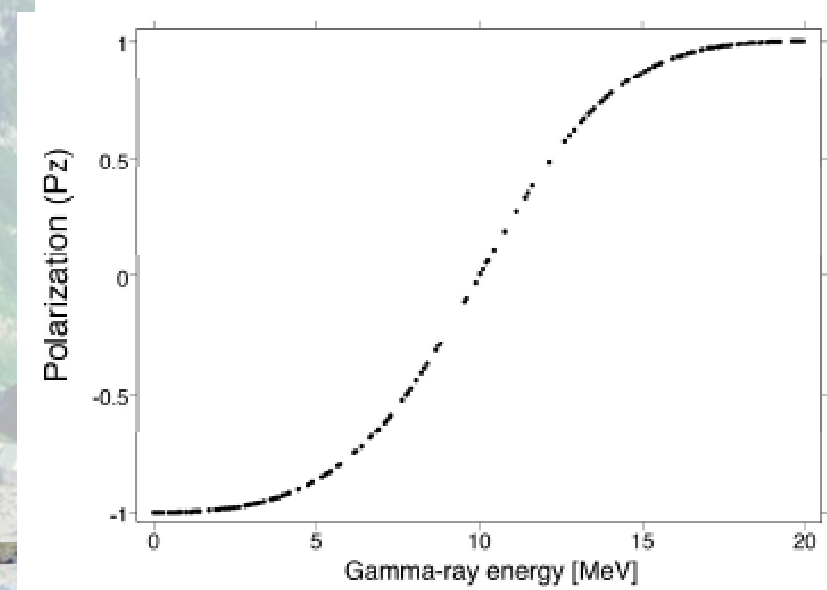
Polarized Positron

- γ-ray Polarization depends on its energy and angle.
- Taking super-forward high energy γ-ray, polarized g-ray is obtained.

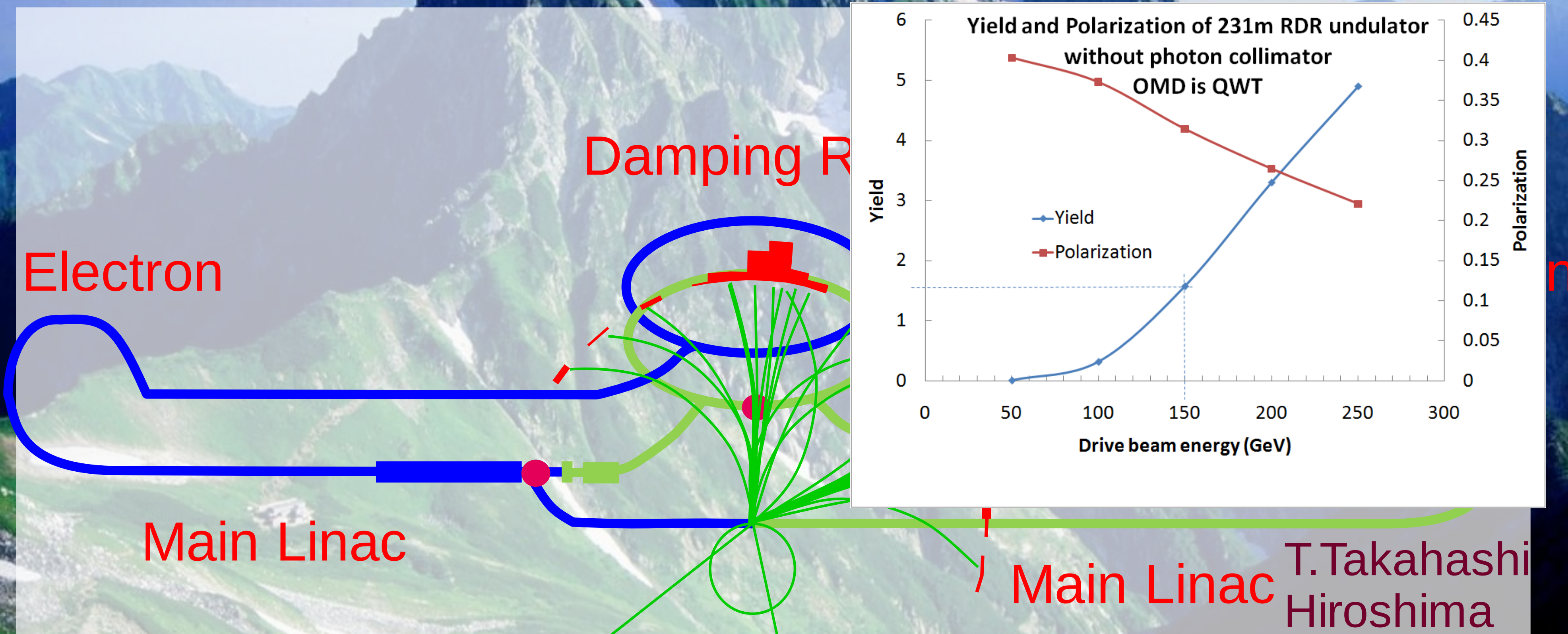


$$\frac{dN_n}{dE}\left[\frac{1}{MeV}\right]=\frac{10^6 e^3 L}{4\pi\epsilon c^2 h^2}\frac{K^2}{\gamma^2}\left[J_n^{'}(x)^2+\left(\frac{\alpha_n}{K}-\frac{n}{x}\right)^2 J_n(x)^2\right]$$

$$\theta=\frac{1}{\gamma}\sqrt{n\frac{\omega_n(1+K^2)}{\omega}-1-K^2}$$



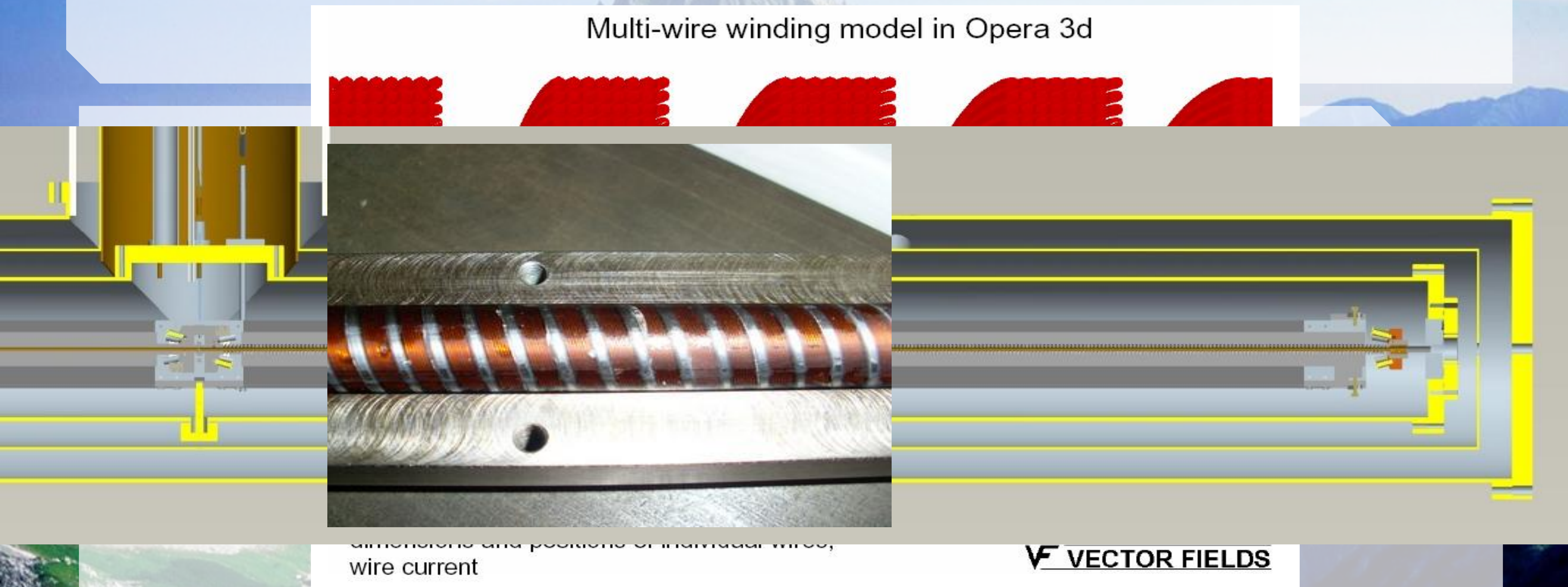
Real Operation

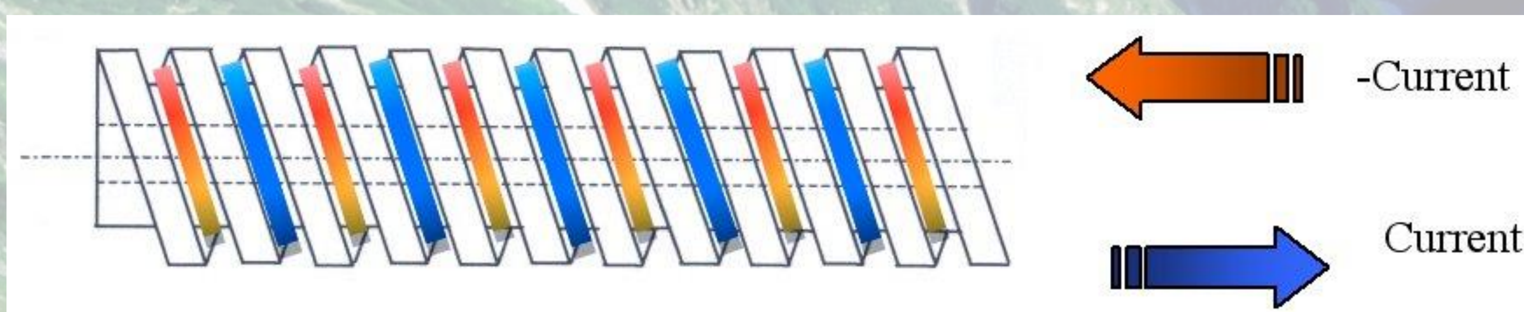


T.Takahashi
Hiroshima

- High energy electron for collision is used also for positron generation.
- Generated positron will be used for next collision.
- In low E collision case, additional pulse >130GeV is operated.

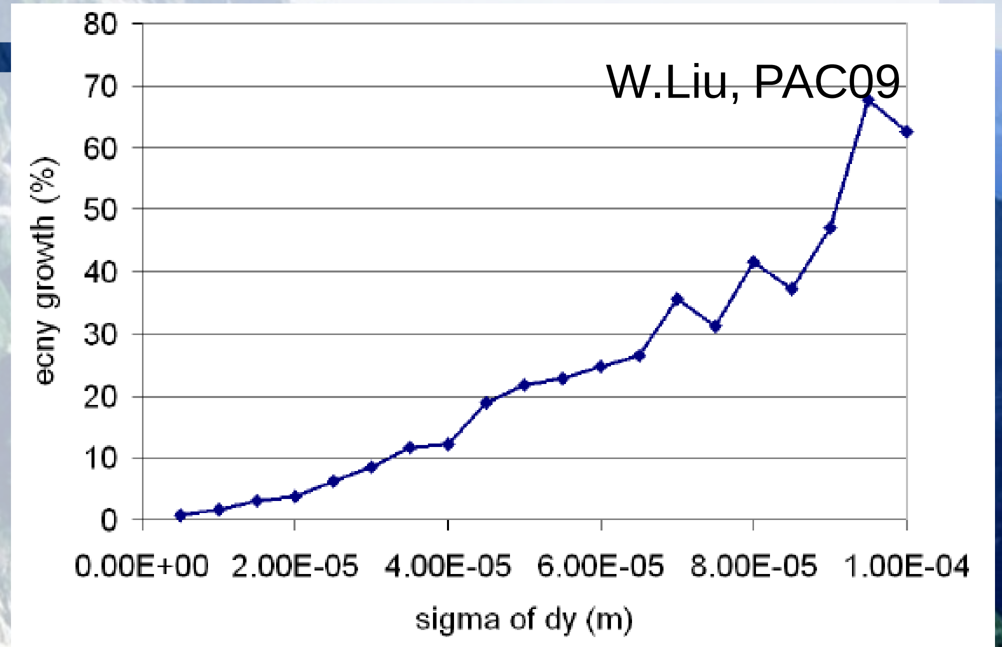
Helical Undulator



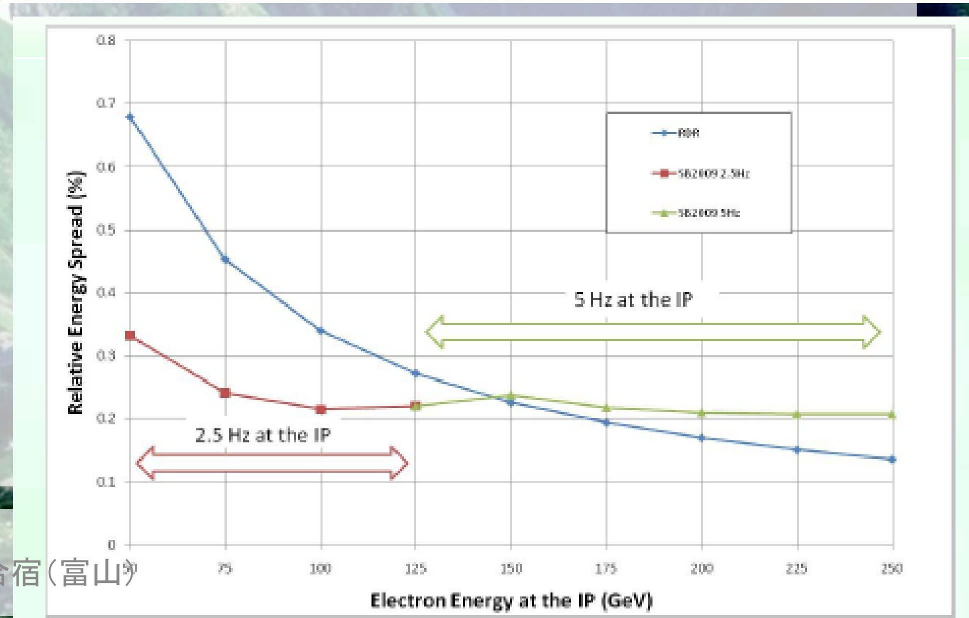


Effects on the electron beam

Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield
50GeV	**~225MeV**	**N/A**
100GeV	**~900MeV**	**~9.9GeV**
150GeV	**~2GeV**	**~4.6GeV**
200GeV	**~3.6GeV**	**~3.7GeV**
250GeV	**~5.6GeV**	**~3.96GeV**

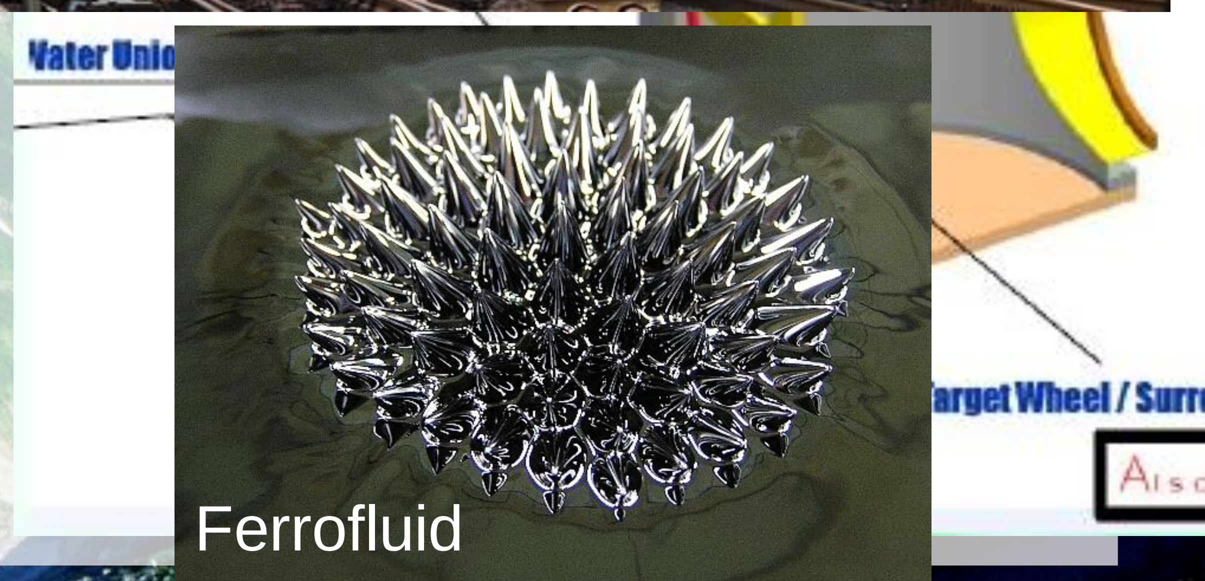


Drive beam energy	Yield	Polarization
50GeV	**0.0041**	**0.403**
100GeV	**0.3138**	**0.373**
150GeV	**1.572**	**0.314**
200GeV	**3.298**	**0.265**
250GeV	**4.898**	**0.221**



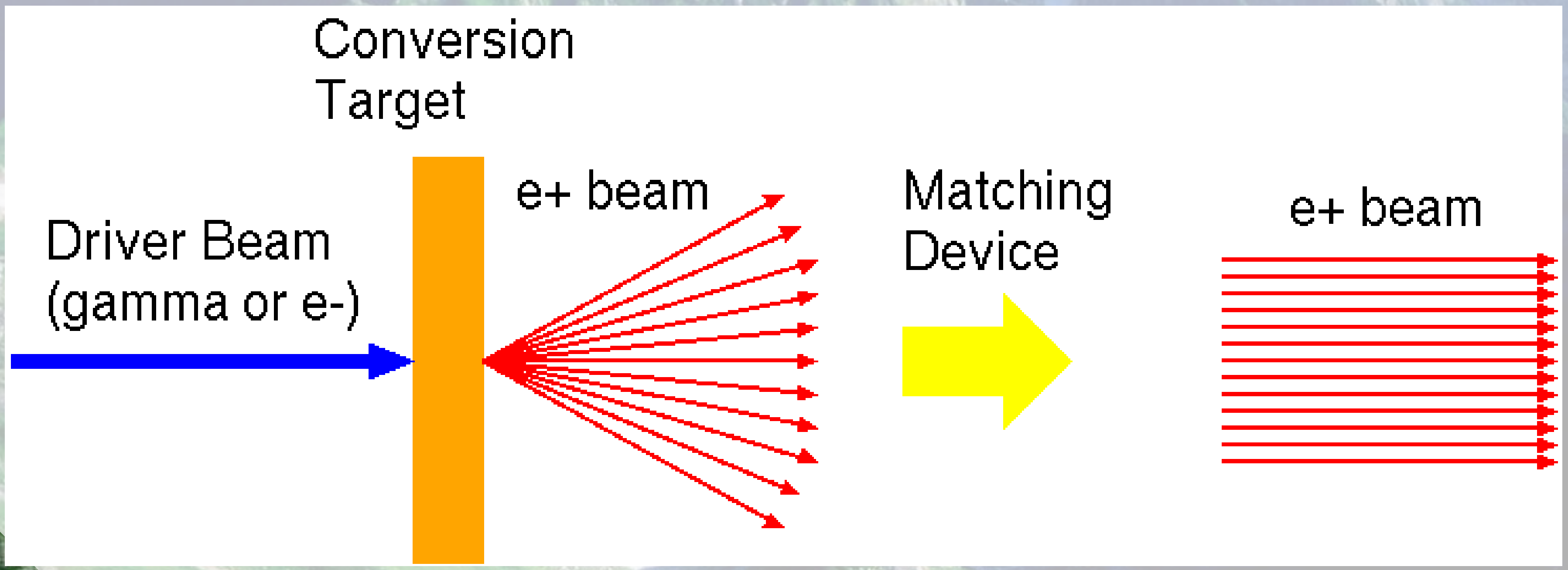
Positron Generation

- 15mm Ti-all
- 100m/s tang
- There is no r optimization structure is f
- Thechnical design of the water joint and vacuum seal.



Positron Capture

- Generated positrons have wide angle spread. It should be focused for further acceleration. Capture devices are:
  - QWT (Quarter Wave Transformer)
  - AMD (Adiabatic Matching Device)



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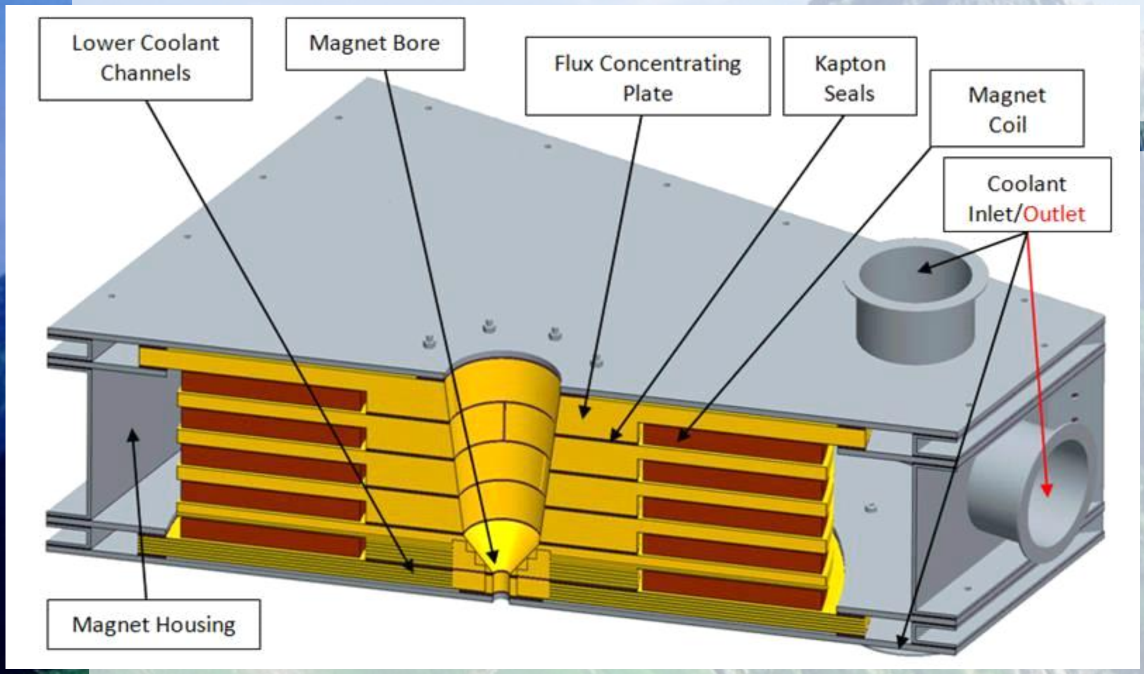
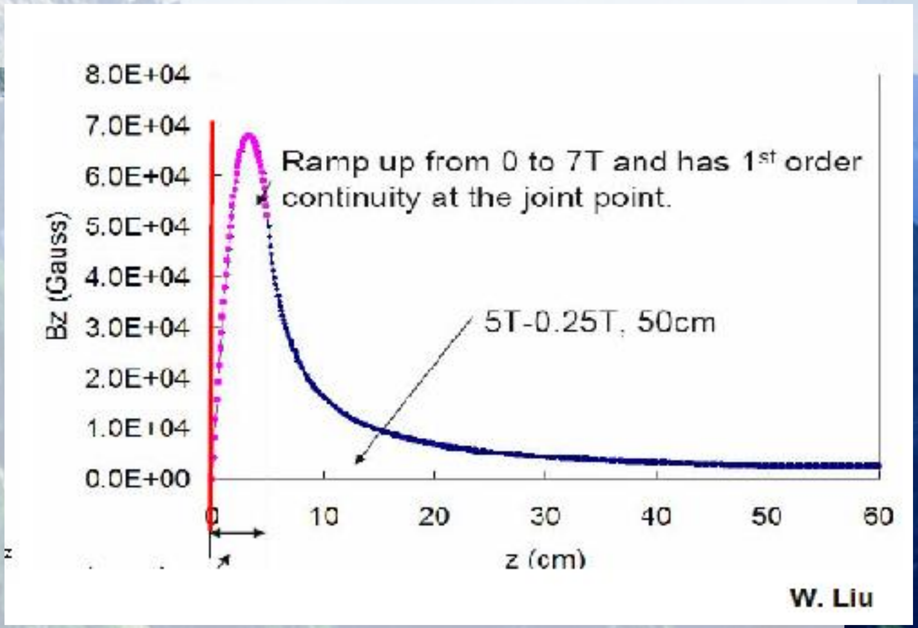
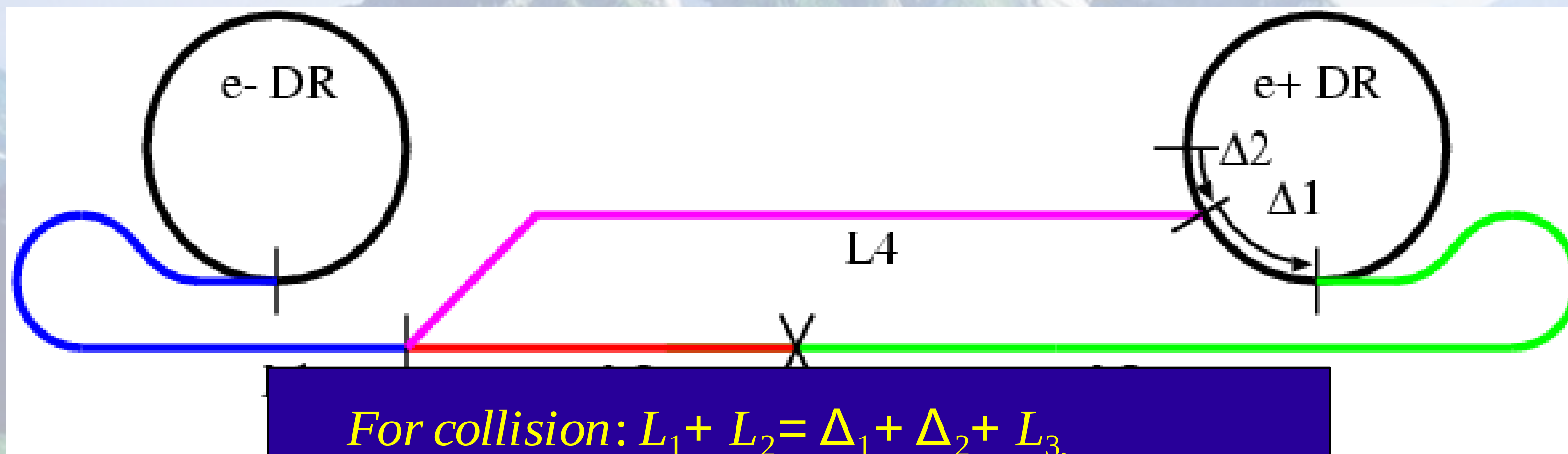




- Solenoid like B-field.
- Transverse momentum is compensated by adiabatic condition.
- Strong B-field is generated by eddy-current.
- 1ms long pulse generation is challenging.

Path Length Condition



$$For\ collision: L_1 + L_2 = \Delta_1 + \Delta_2 + L_3,$$

$$For\ self-reproduction: L_1 + L_4 = \Delta_2 + nC_{DR},$$

$$L_3 + L_4 + \Delta_1 = L_2 + nC_{DR},$$

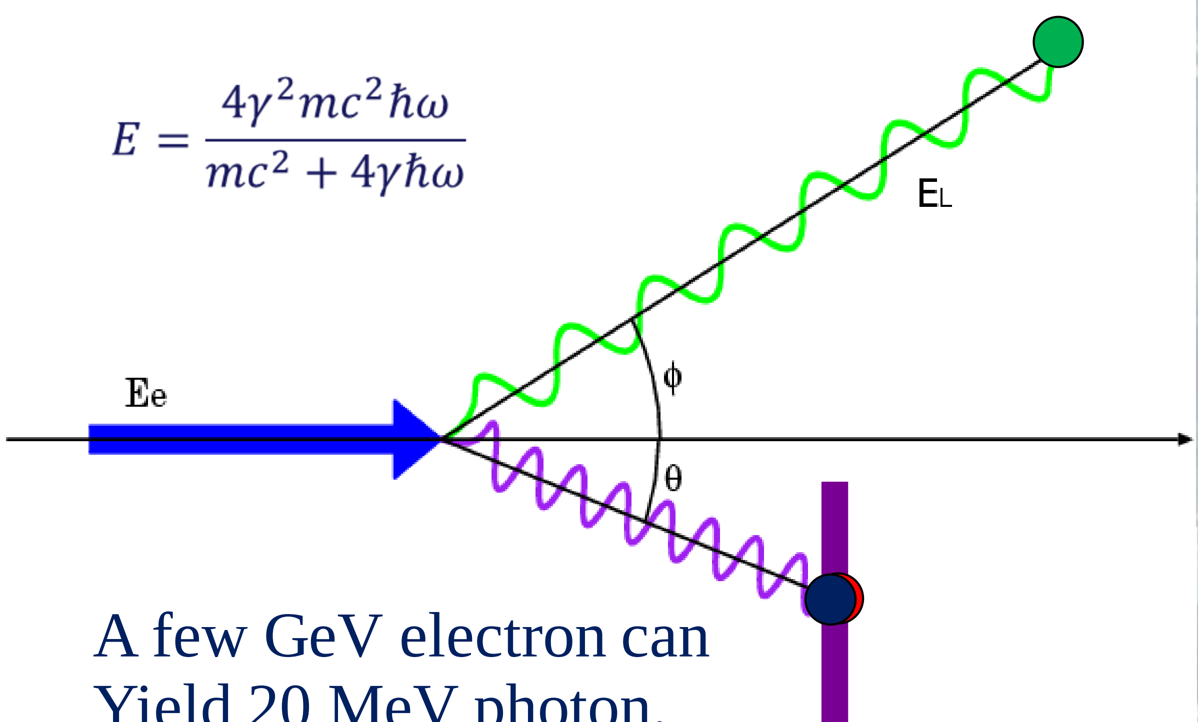
- Generated ... ucket should be vacant.
- Self-repro... a accommod... rtner (electron)

This path length should be adjusted within a few mm.

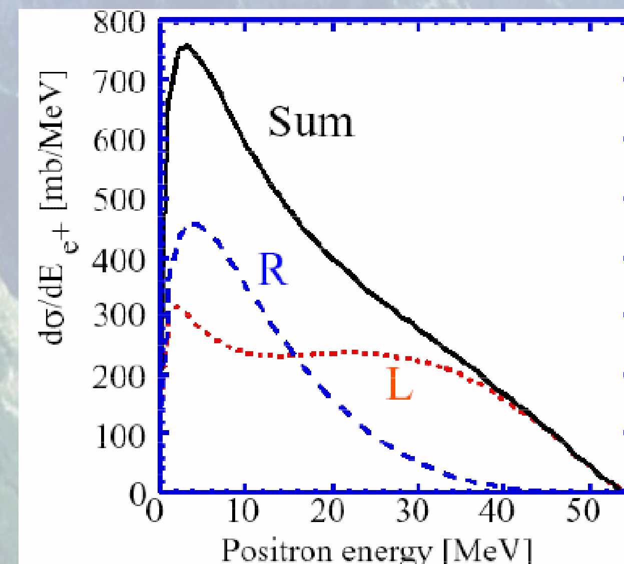
Laser Compton(1)

- Inverse Compton scattering between laser photon and electron beam.
- Laser photon is boosted by high energy electron.

$$E = \frac{4\gamma^2 mc^2 \hbar\omega}{mc^2 + 4\gamma\hbar\omega}$$

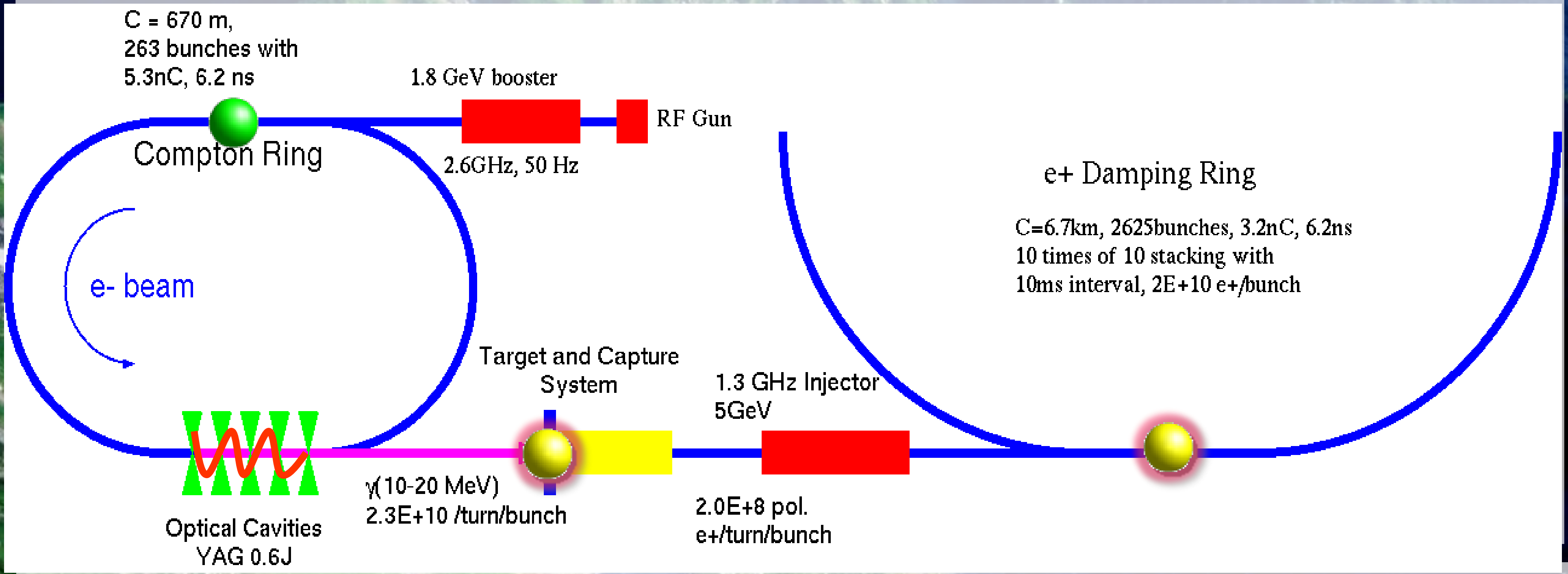


A few GeV electron can
Yield 20 MeV photon.



Laser Compton with Ring

- E-driver can be a few GeV (dedicated) + polarizaiton.
- The positron yield from one collision is not sufficient.
- Electron and photon recycling + positron accumulation.

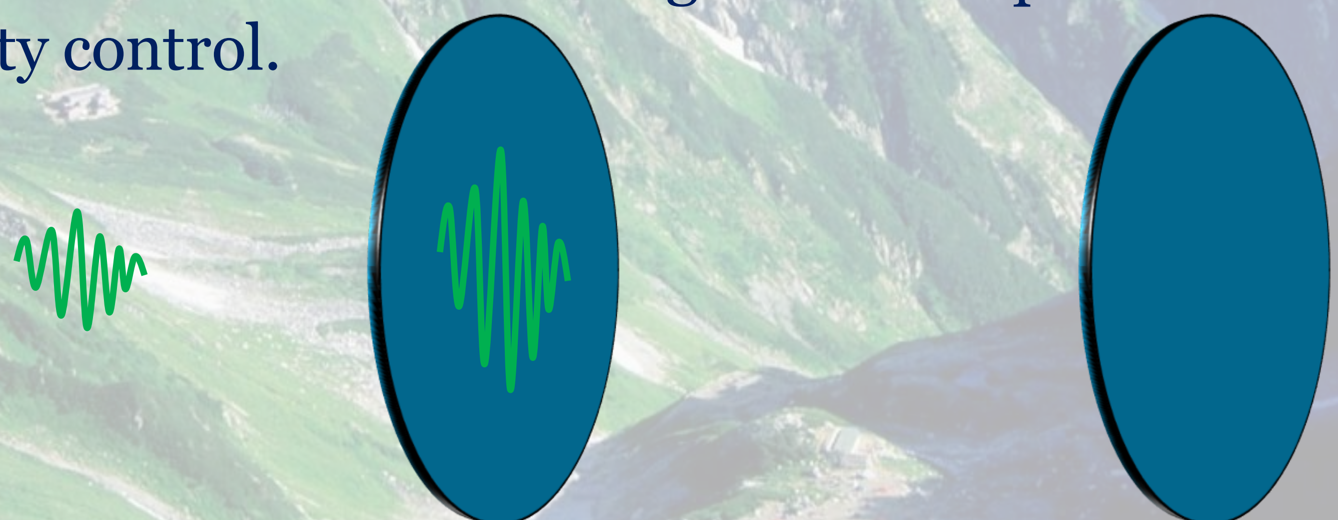


Pulse Stacking Cavity

- The cavity optical path has to satisfy two conditions simultaneously;

$$L_{cav} = m\frac{\lambda}{2} \qquad L_{cav} = nCT_M$$

- The many pulse is stacked and amplitude is enhanced until loss in the cavity is equal to one laser pulse.
- 10000 enhancement in design which requires sub-nm cavity control.



ILC Positron Source Summary

- Electron driven is the most feasible from a technical point of view, but no polarization.
- Undulator scheme maybe feasible, but concerns about
  - Non conventional undulator
  - Operation (availability) : small aperture, 200 m length
  - No established design on the production target.
- Laser Compton is challenging:
  - The system works only if all of the critical components works well.

– Realistic scenario : start with the un-polarized positron and upgrade to one of the polarized positron eventually.

Summary

- ILC electron and positron sources are explained.
- 80% polarized electron is generated by NEA GaAs photo-cathode.
- One baseline design (undulator scheme) and two back-ups for ILC positron source.
- A staging scenario not only for CME, but also for the positron source is desirable.