ILC-Based Gamma-Gamma Collider

K. Yokoya

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Introduction

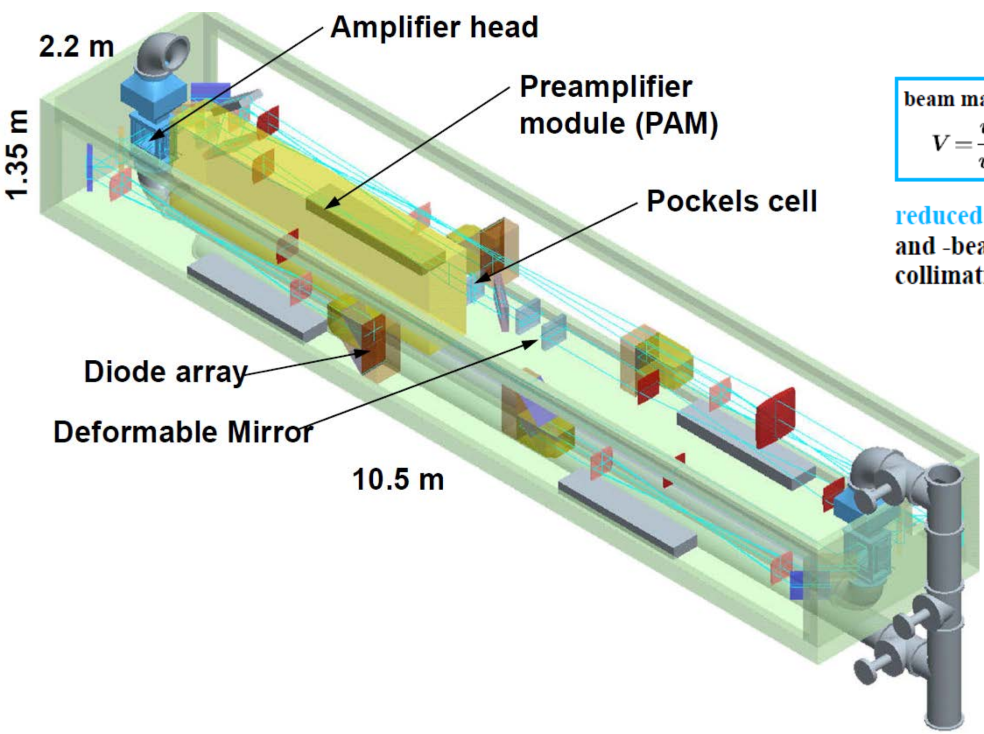
- Gamma-gamma for ILC has been an important topics since many years ago including TESLA/JLC/NLC time
- Nonetheless, the technology/design progress has been slow
  - The motivation for $\gamma\gamma$ has been too weak compared with e+e-
  - There was an impact of X750 in ~December 2015 but it is gone by now
- Design of the first stage of ILC is going to be fixed
  - The 1st stage CM energy will be ~250GeV
- Need strong voice for $\gamma\gamma$
- The present slides were mostly prepared when X750 was alive

Basics of $\gamma\gamma$ collider

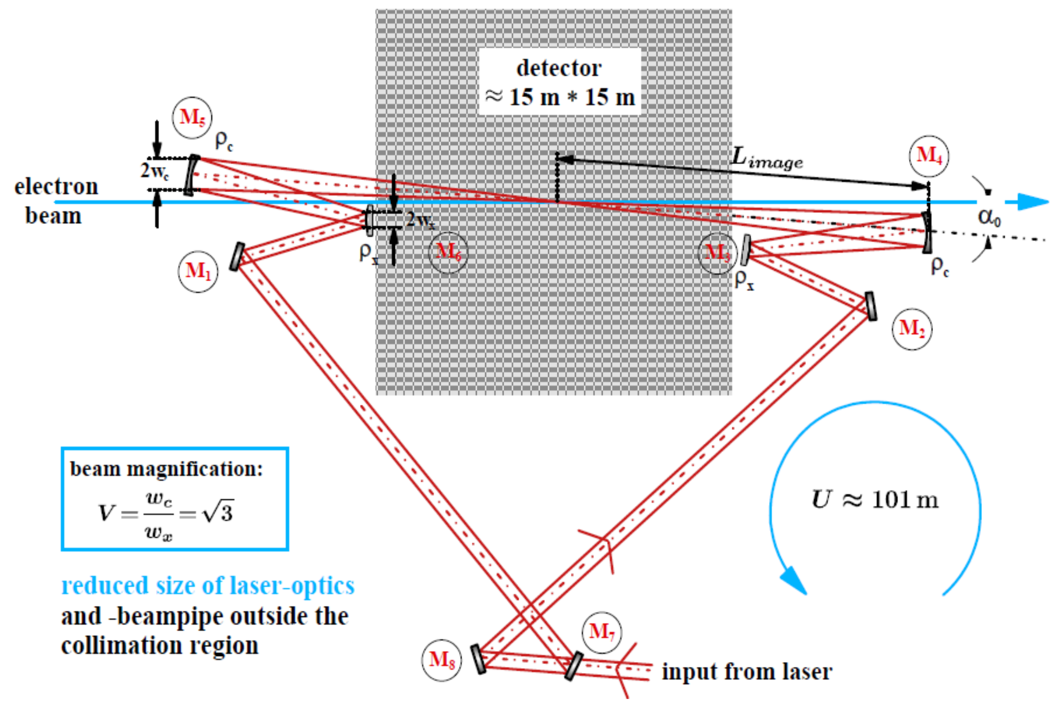
- Convert ee collider into $\gamma\gamma$ by Laser-Compton scattering
  - Needs longitudinally polarized electron
- Maximum photon energy $E_{\gamma max} = xE_e/(1+x+\xi^2)$
  - ➢ $x = 4E_e\omega_{laser}/m^2$
  - ➢ $\xi^2 = 0.3$ (non-linear Compton parameter)
  - ➢ Optimum of x : $x_{opt} = 2[\sqrt{2}+1] = 4.8$
    - Large x for higher energy gamma
    - But generated gamma is lost by pair creation in the same laser if $x > x_{opt}$
    - The threshold of this phenomena is a bit soft
    - Including nonlinear effects, $x_{opt} \sim 4.8(1+\xi^2)$
  - ➢ → $E_{\gamma max} = 0.8E_e$
- Choice of laser wavelength
  - ➢ For E_e=500GeV,
    - ➢ $\lambda_{laser} = 1.5\sim2\mu m$, $E_{\gamma max} \sim 400$GeV
    - ➢ 1TeV e-e- collider is just suited for $E_{\gamma\gamma}$=700~800GeV
  - ➢ For E_e=125GeV, (ILC 1st stage)
    - ➢ $\lambda_{laser} = 1.8\mu m$ gives $\gamma\gamma$ → Higgs (x~1.3)

Laser

- Laser parameters
  - λ_{laser} = 1.5~2μm
    - 1μm may be OK (major problem is the out-coming angle). Simulation needed
  - Flush energy ~ several Joule
  - Pulse length ~ 1-2 ps
  - Must match with ILC beam pattern
  - Average power O(100kW)
- Candidates of Laser system
  - Big laser like LIFE (NIF: National Ignition Facility)
  - Optical cavity with (relatively) low-power laser
  - FEL
- None of these are ready now for $\gamma\gamma$
- But if serious R&D is done, at least one of these would become feasible by the time ILC reaches 1TeV.
- If not, never progress.
- Listen to T. Takahashi



Proposed telescopic, passive, resonant external cavity



beam magnification:

$$V = \frac{w_c}{w_x} = \sqrt{3}$$

reduced size of laser-optics and -beampipe outside the collimation region

Example Parameters for 1TeV

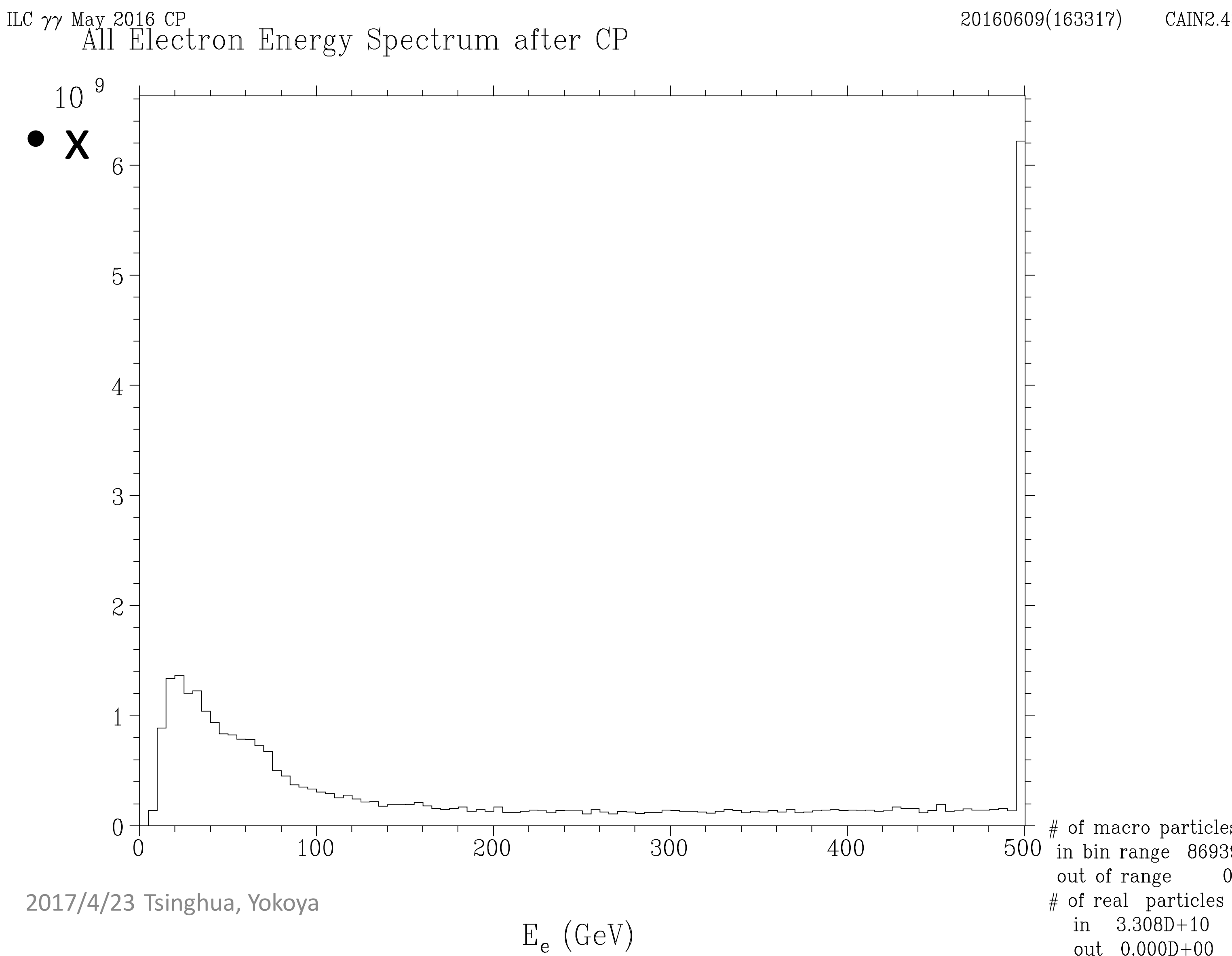
			TESLA gg	ILC gg	ILC e+e-
Electron Parameters					B
	Beam energy	GeV	400	500	500
	Number of electrons / bunch	10^10	2	1.74	1.74
	Number of bunches / pulse		2820	2450	2450
	Repetition frequency	Hz	5	4	4
	Bunch length	mm	0.3	0.225	0.225
	Electron polarization			0.9	0.9
	Normalized horizontal emittance	rad.m	2.50E-06	1.00E-05	1.00E-05
	Normalized vertical emittance	rad.m	3.00E-08	3.00E-08	3.00E-08
	Horizontal beta at IP	mm	1.5	3	11
	Vertical beta at IP	mm	0.3	0.3	0.23
	Horizontal beam size at IP	micron	0.088	0.1751	0.335
	Vertical beam size at IP	nm	4.3	3.0328	2.7
Electron-electron collision parameters					
	Horizontal disruption parameter		8.6	0.723	0.2
	Vertical disruption parameter		175	41.74	25.13
	ee Geometric luminosity	1/cm^2/s	1.91E+35	4.45E+34	2.65E+34
	Maximum Upsilon		1.564	0.92449	0.487
	Number of beamstrahlung photons		9.24	3.4433	1.97
	Energy loss by beamstrahlung	%	97	27.964	10.6
Laser Parameters					
	Wavelength	micron	1.06	1.5	
	Pulse flush energy	Joule	5	5	
	Laser pulse length	mm	0.45	0.45	
	Rayleigh length	mm		0.35	
	Laser RMS spot size	micron		6.4636	
	IP-CP distance	mm		2.5	
	rho = d(IP-CP)/sigy			0.8424	
Compton parameter					
	x parameter		7.2	6.33089	
	xi^2 parameter		0.4	0.41627	
	Maximum photon energy (1st harm)	GeV		408.59	
	Compton crosssection (unpol)	cm^2		1.647E-25	
	Compton crosssection (pol.term)	cm^2		1.959E-26	
	Compton crosssection	cm^2		1.471E-25	
	CP luminosity per bunch	/cm^2		1.251E+35	
	kappa = lumCP/N*sig(Compt)			1.0579	
	minimum electron energy E0/(1+11*x)	GeV		7.078	
Simulation					
	number pf photons after CP (2 beams)	10^10		13.867	
	numbber of positrons after CP (2 beams)	10^10		0.5635	
	minimum electron energy after CP (low edge of bin, width 0.5GeV)	GeV		6	
	number of final photons (2 beams, incl. beamstr)	10^10		26.32	
	beamstr. Photons	10^10		12.453	
	number of final positrons (2 beams, incl. coh.pair)	10^10		0.5665	
	positrons from coh.pair	10^10		0.003	
	total gg luminosity	E34		11.600	
	gg(--) luminosity (z>0.8)	E34	1.7	0.254	

Multiple Compton Scattering

- Contribution of multiple Compton scattering is large with the conversion coefficient $\kappa \sim 1$
- Probability of n-times scattering is $\kappa^n/n!$ (Poison distribution)
- The minimum electron energy after n-times scattering is
  $E_e / (1+nx)$
- n~10 must be taken into account
  - Larger x → lower electron energy
- These low energy electrons are deflected by the Coulomb field of the on-coming beam with large angles and cause background

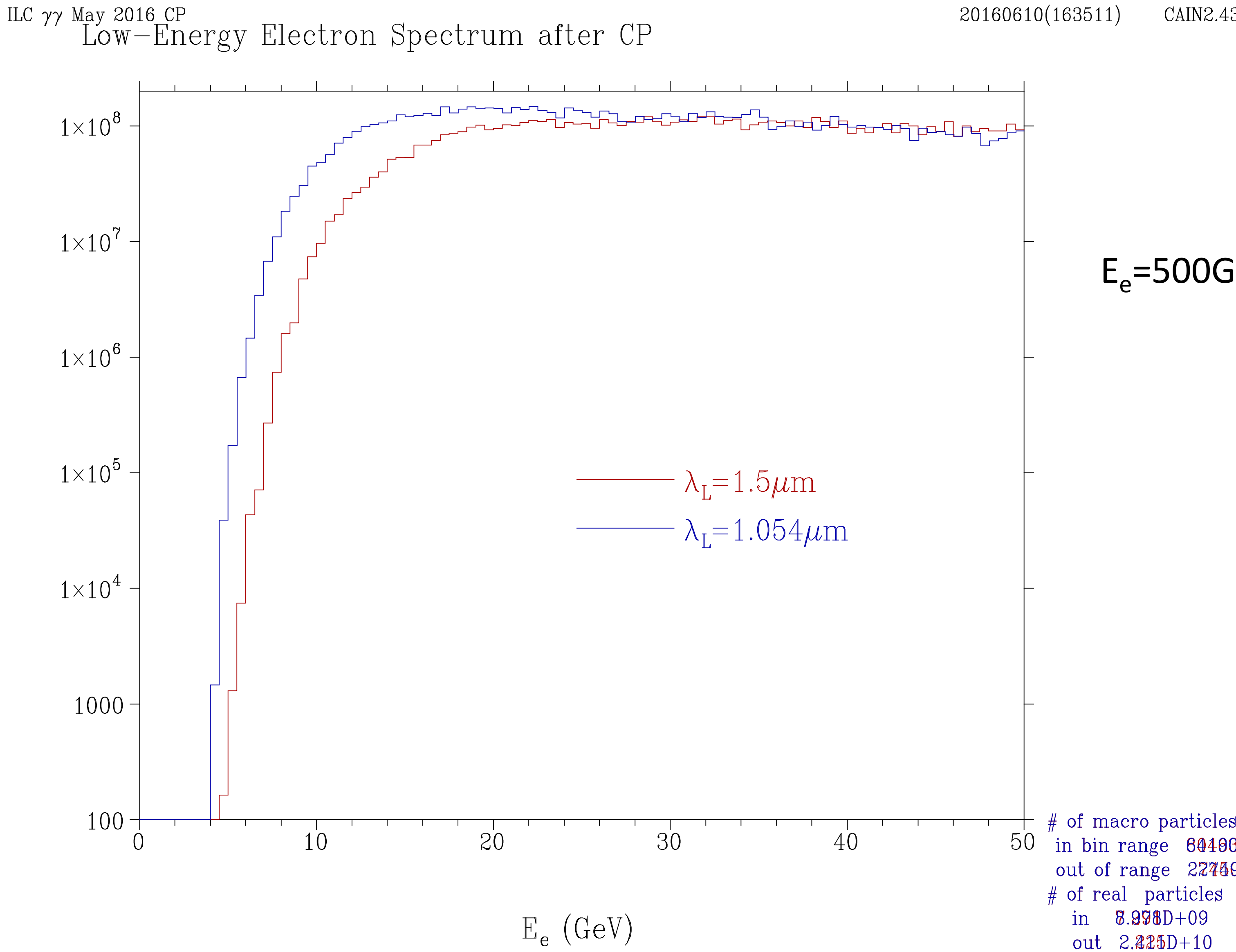
Electron Spectrum after CP

- x



λ_L = 1μm,
E_e=500GeV

Electron Tail Spectrum



E_e=500GeV

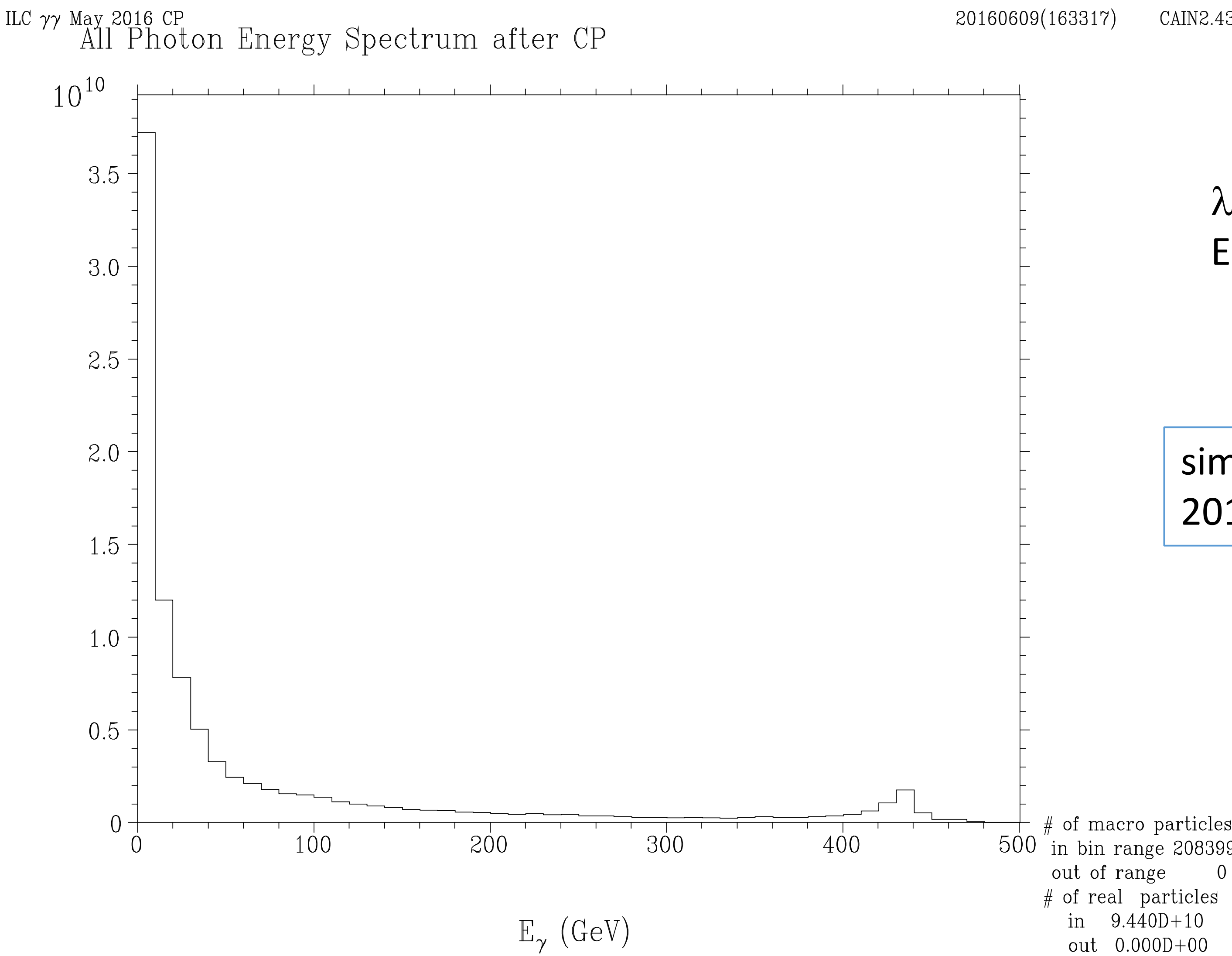
Deflection by Beam Force

- Deflection angle of low energy electrons by the Coulomb force of the on-coming beam

$$\sqrt{\frac{Nr_e}{\gamma' \sigma_z} \log[\ ]}$$

- γ' = Lorentz factor of electron, proportional to E_0/x
- log[ ] contains details of the electron beam size but the dependence is weak because [ ] is large
  - The deflection angle mainly depend on the long tail of the Coulomb field, and hence determined more or less by the line charge density

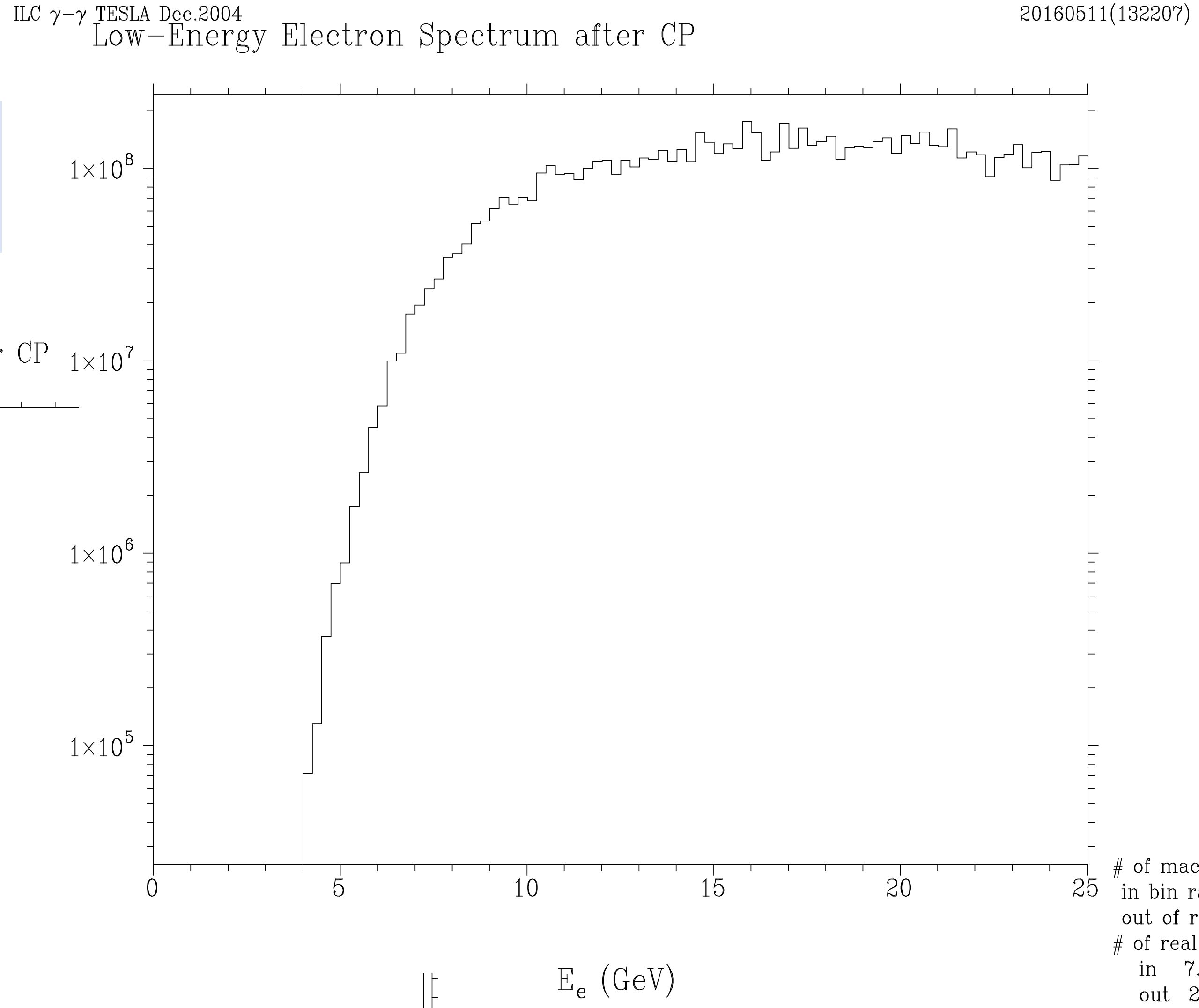
Photon Spectrum after CP

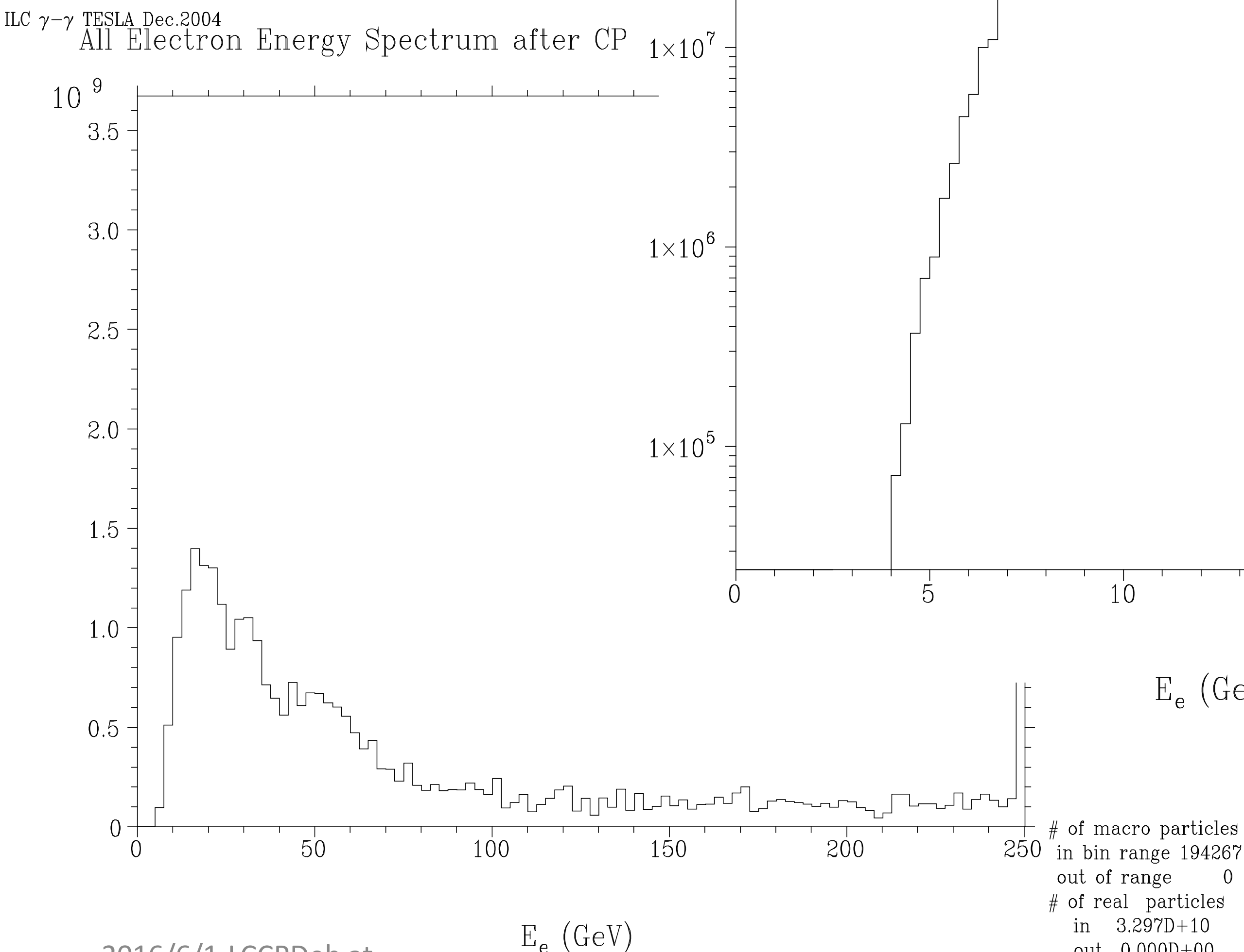


λ_L = 1μm,
E_e=500GeV

simulation 2016

An example of electron spectrum with old TESLA parameters

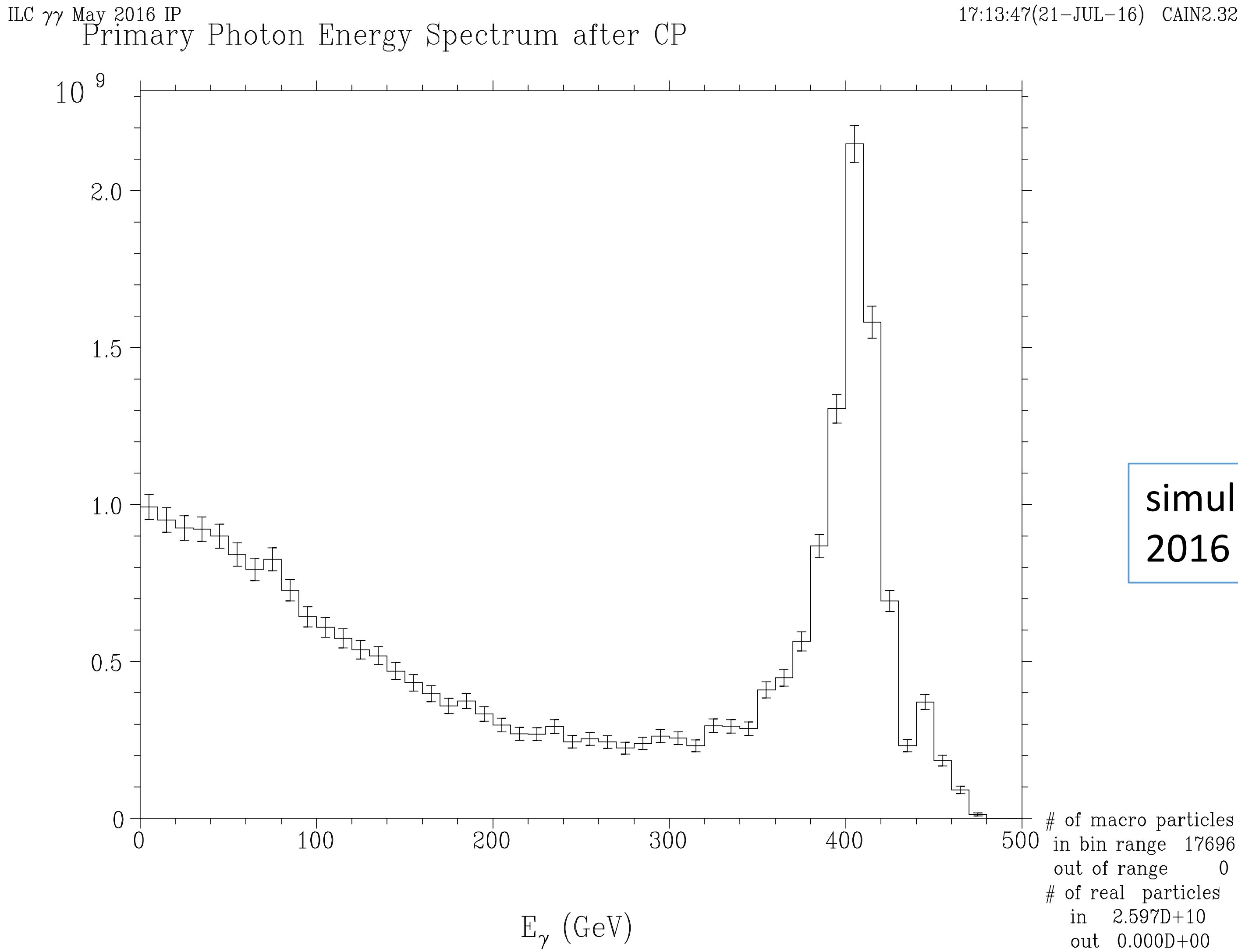




$E_{min} \sim E_0/(1+nx)$

$n \sim 10$

Photon Energy Spectrum after one scattering

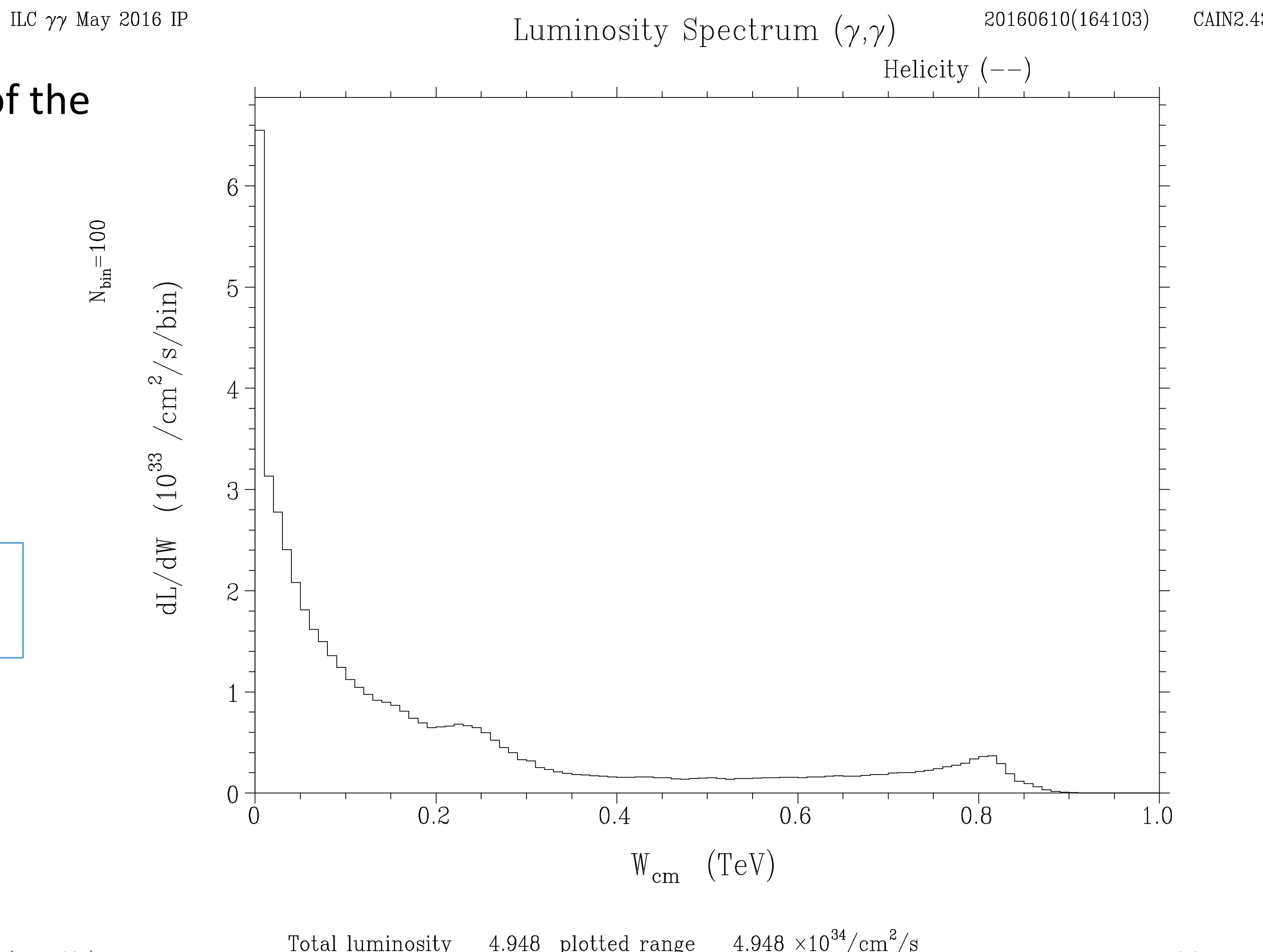


simulation
2016

γγ Luminosity

- Include of the desired helicity

simulation 2016



Crossing Angle

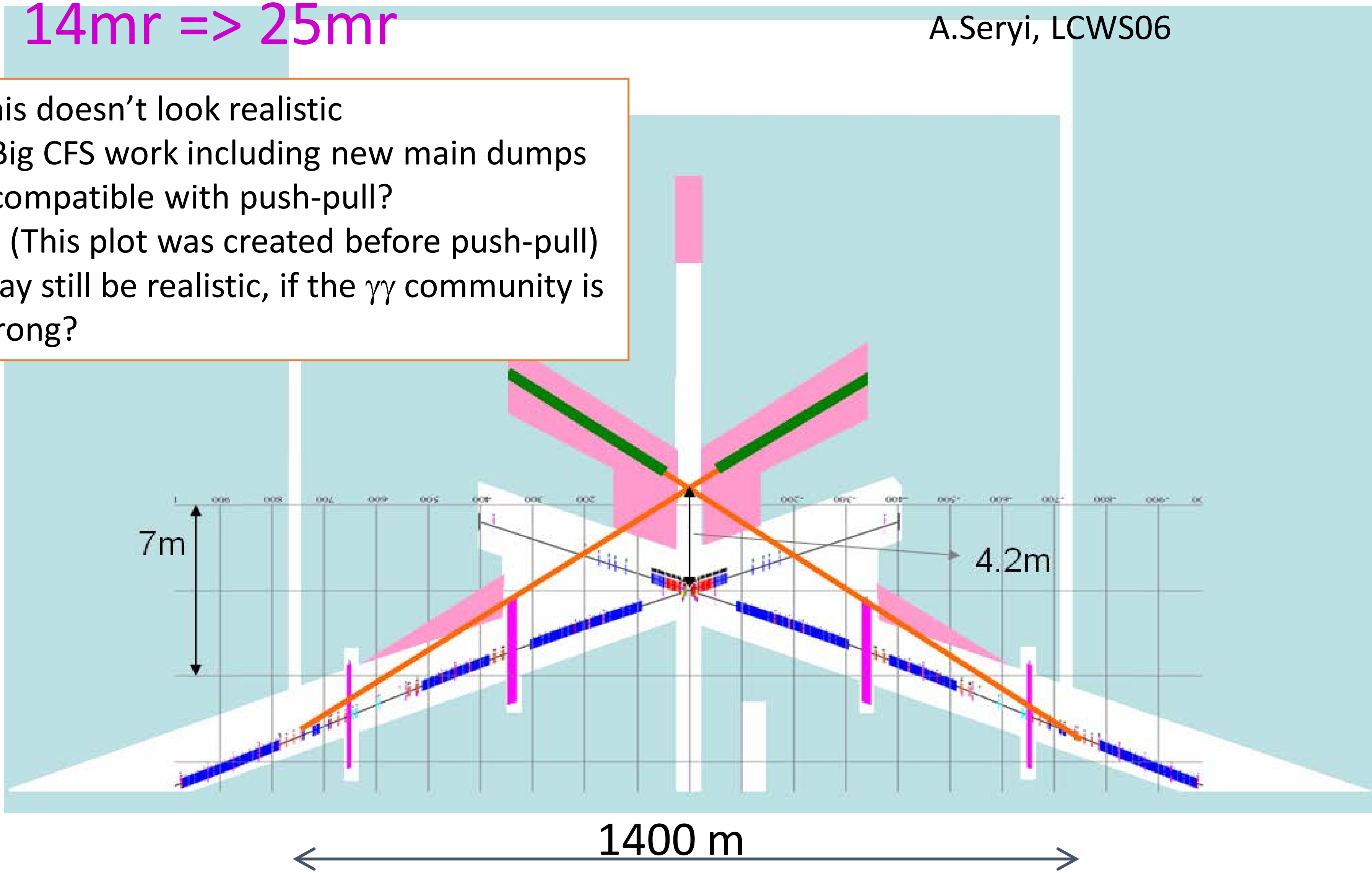
- The IP region geometry must have large crossing angle to accept the low energy electrons
  - Best is thought to be around 25mrad for γ-γ .
- ILC TDR
  - crossing angle 14mrad
  - γ-γ is not mentioned
- 20mrad had been adopted for e+e- in early stage of ILC design
  - ➢ At the time of RDR study it was agreed to reduce the angle for e+e- from 20mrad to 14mrad
  - ➢ When changing the angle for γ-γ later on
    - Beam dump must be reconstructed
    - To change 20mrad→25mrad, old and new beam dumps overlap. Civil engineering almost impossible.
    - The change 14mrad→25mrad is easier in this respect
  - ➢ To go back to e+e- again is indispensable

14mr => 25mr

A.Seryi, LCWS06

This doesn't look realistic
- Big CFS work including new main dumps
- compatible with push-pull?
  (This plot was created before push-pull)

May still be realistic, if the $\gamma\gamma$ community is strong?

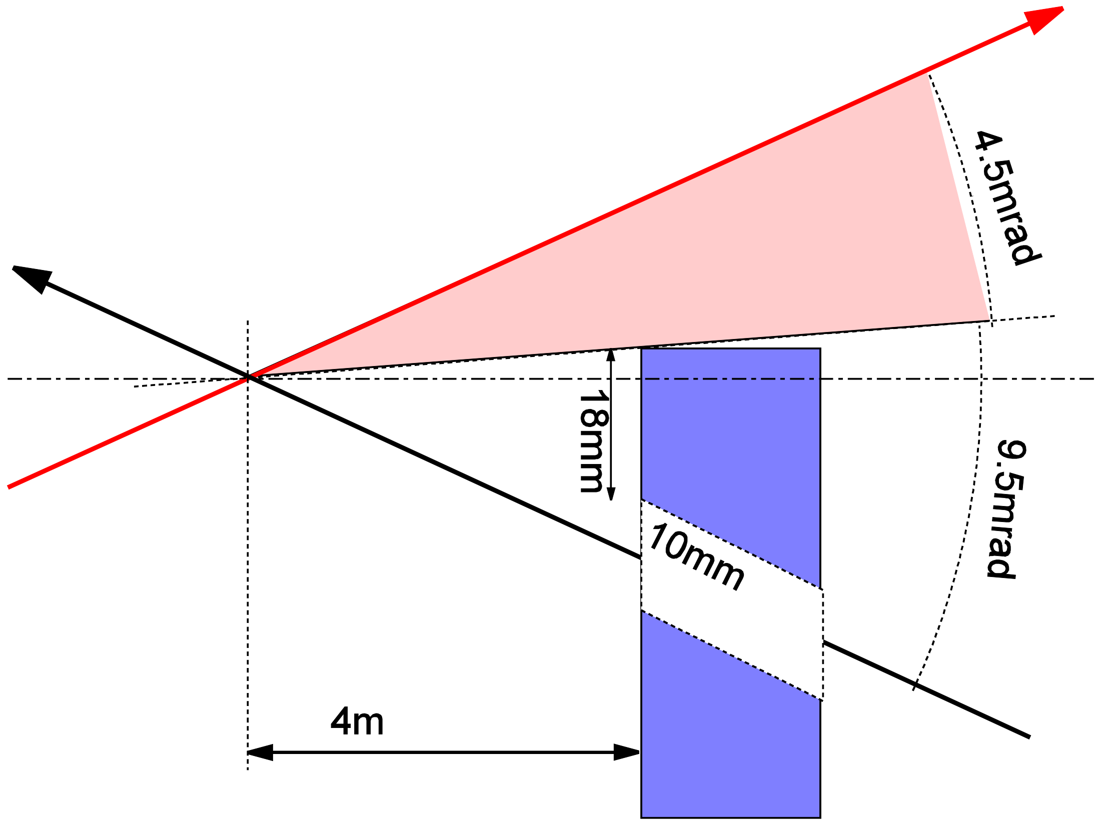


- additional angle is 5.5mrad (=(25-14)/2) and detector need to move by about 3-4m

IR Geometry

crossing angle	angle for outgoing beam
14 mrad	4.5 mrad
20 mrad	10.5 mrad
25 mrad	15.5 mrad

The required angle for outgoing beam is proportional to sqrt(N/σ_z), independent of E_{CM}



$\gamma\gamma$ Luminosity Reduction due to Small Crossing Angle

- Sqrt($N/\sigma_z\lambda_L$) should be proportional to θ (θ = angle reserved for out-going beam)
- → N is proportional to $\theta^2\ \sigma_z$
- → Luminosity proportional to $(\theta^2\ \sigma_z)^2 \times \lambda_L^2$
- Longer σ_z causes hour-glass problem. May be OK up to x 1.5
- → If crossing angle is 20mrad, luminosity is about same or half compared with 25mrad. Too small if 14mrad

λ_L=2μm

crossing angle	θ	σ_z	L/L0
14 mrad	4.5 mrad	450μm	0.064
20 mrad	10.5 mrad	450μm	0.94
25 mrad	15.5 mrad	300μm	1

λ_L=1μm

crossing angle	θ	σ_z	L/L0
14 mrad	4.5 mrad	450μm	0.016
20 mrad	10.5 mrad	450μm	0.47
25 mrad	15.5 mrad	300μm	1

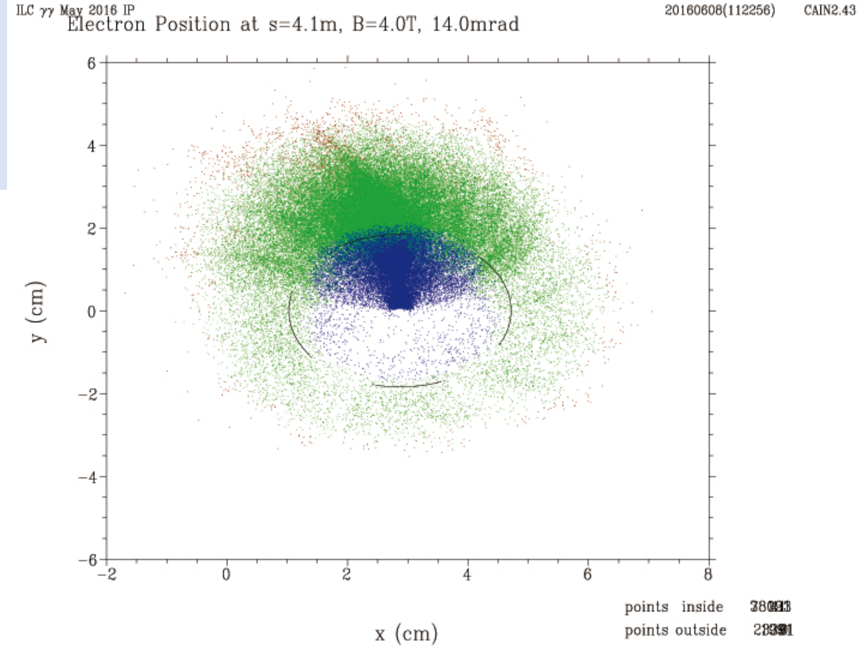
Maybe, we can do a bit better with 14mrad but not much

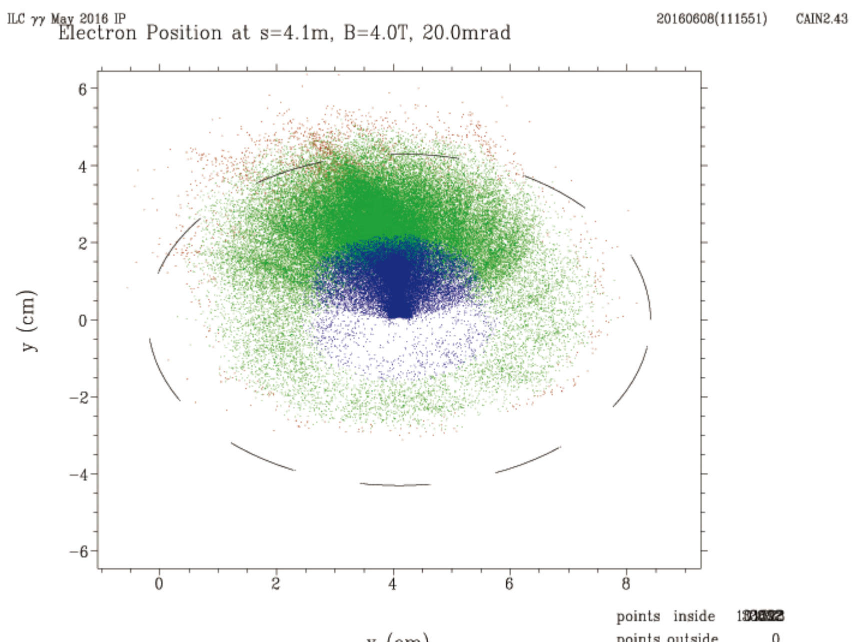
- At Ee=500GeV
- Accept some more background

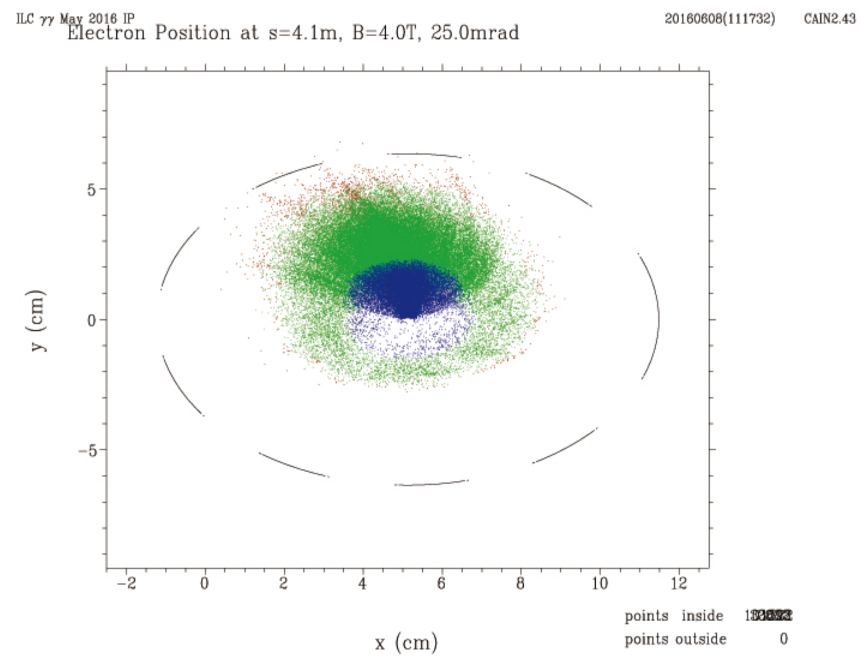
Scaling from old design only. Need detailed simulation again.

Example of electron distribution at front face of QD0

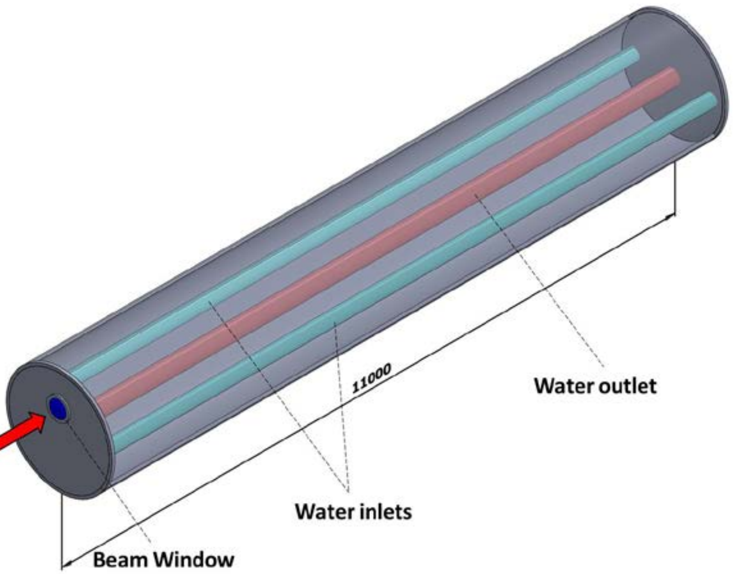
λ_L=1.5μm, E_e=500GeV
crossing angle 14, 20, 25mrad
L*=4.1m, B=4Tesla
red： < 8GeV
green：8-30GeV
blue： > 30GeV
dashed circle show the beam pipe for out-going beam





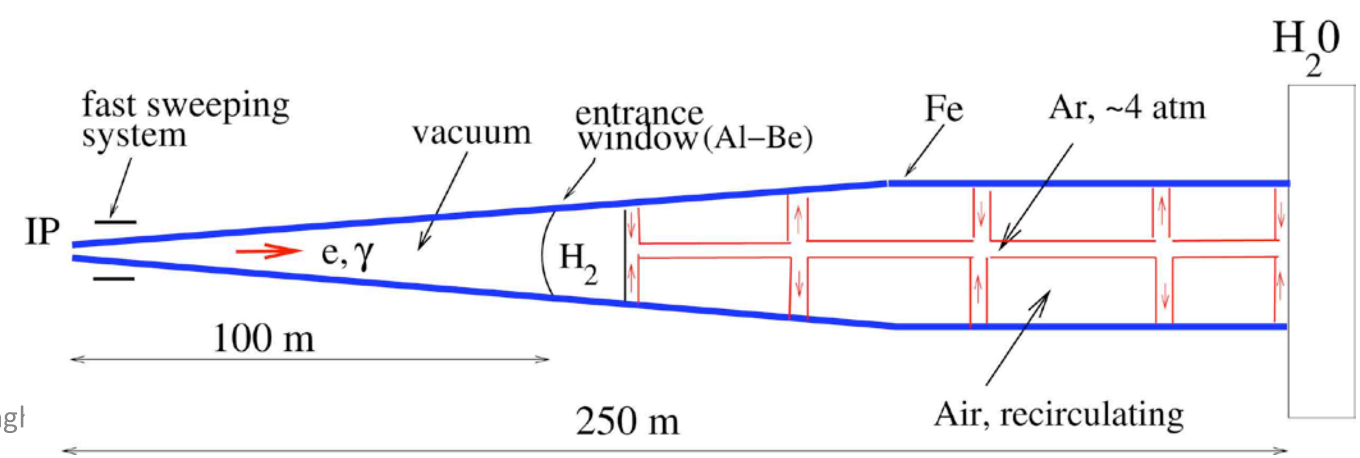


Beam Dump



TDR main dump

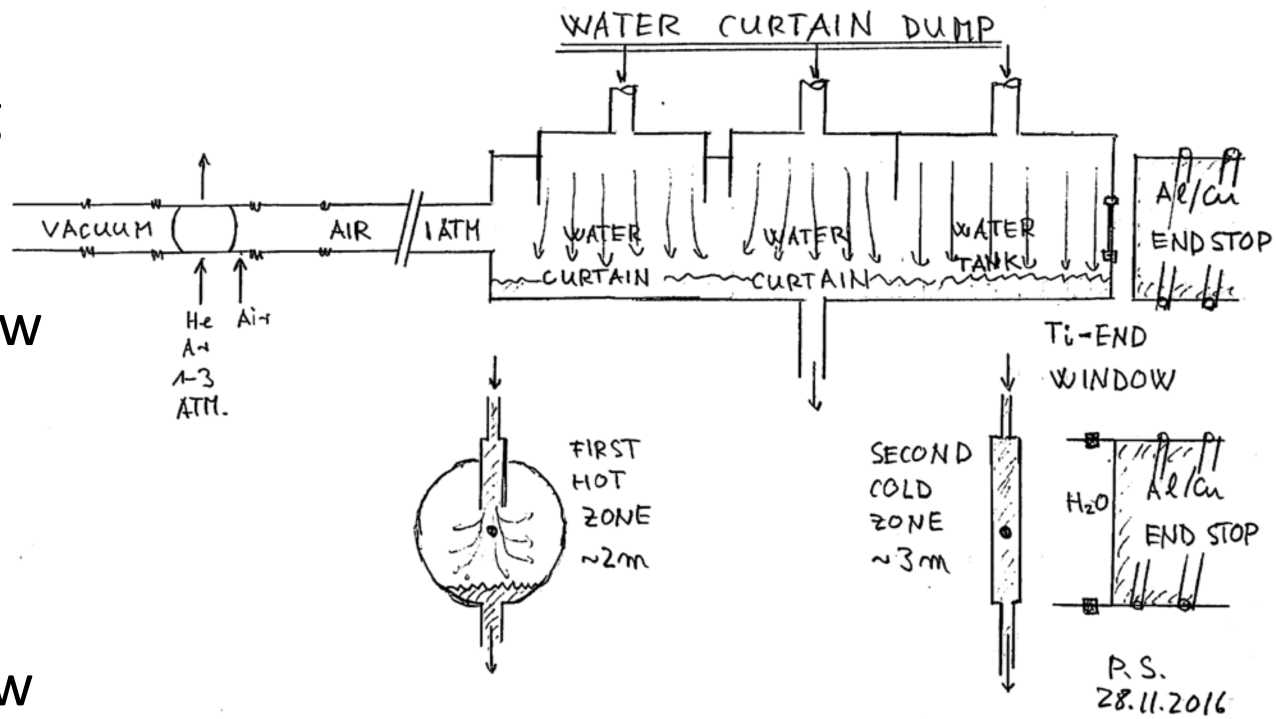
- Beam dump
  - Main dump must accept ~10MW photons
  - Laser-Compton is stronger than beamstrahlung (max. 1.4MW for 1TeV e+e-) and the angle is smaller ($1/\gamma$)
  - Cannot be bent/swept . The window for e+e- does not work
  - A candidate is Ar gas dump
  - No hardware detail yet



A Candidate of Photon Dump for Undulator Positron System

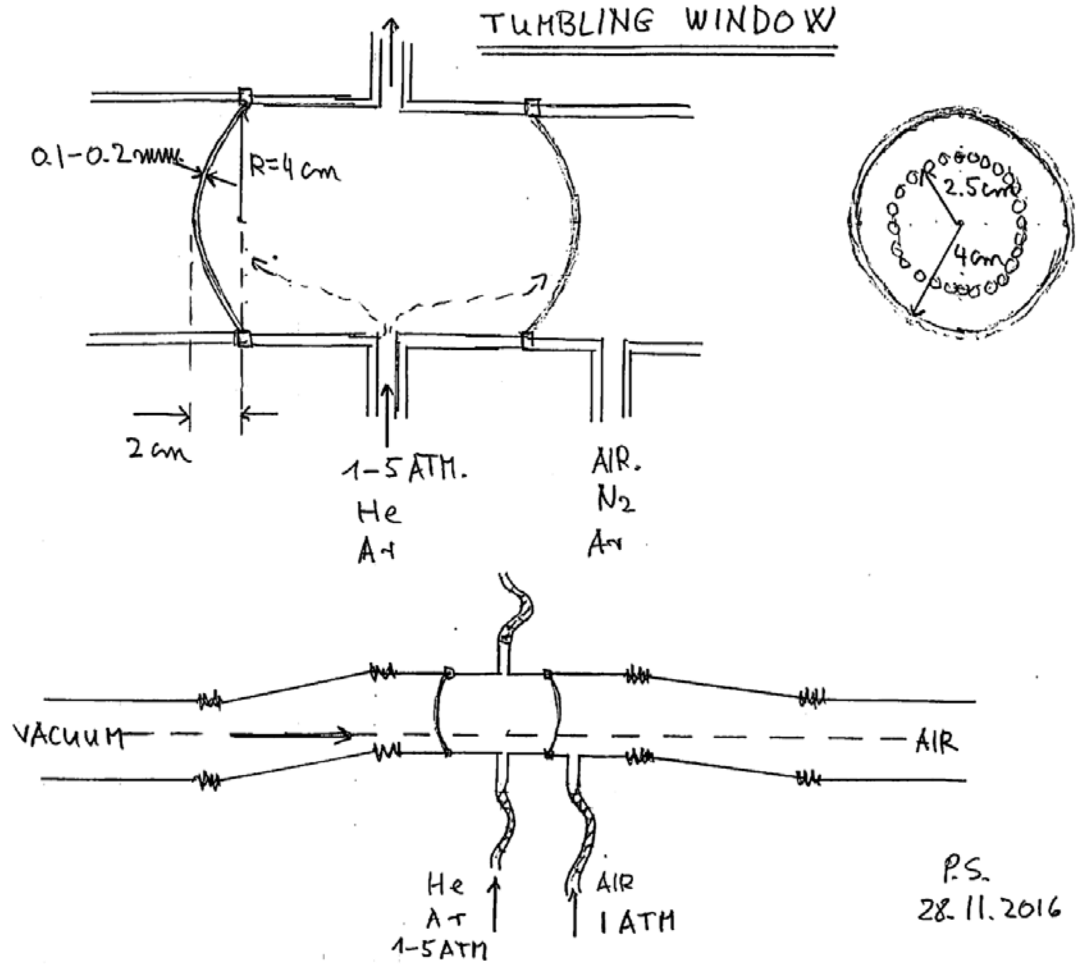
- Photons from undulator must be dumped after creating positrons
- O(10MeV), up to 300kW
- Water dump like the main dump does not work due to heating and radiation damage of the window

- A new water dump is being studied since last year
- Detach window and water
- Adopt free-falling 1atm water
- Thin Ti window cooled by He gas



Tumbling Window

- The window must be thin (0.1-0.2 mm thick) to avoid heating
- Move the window to lengthen the life due to dpa (dislocation per atom)
- Velocity cm/day
- Must be cooled by He gas of a few atm

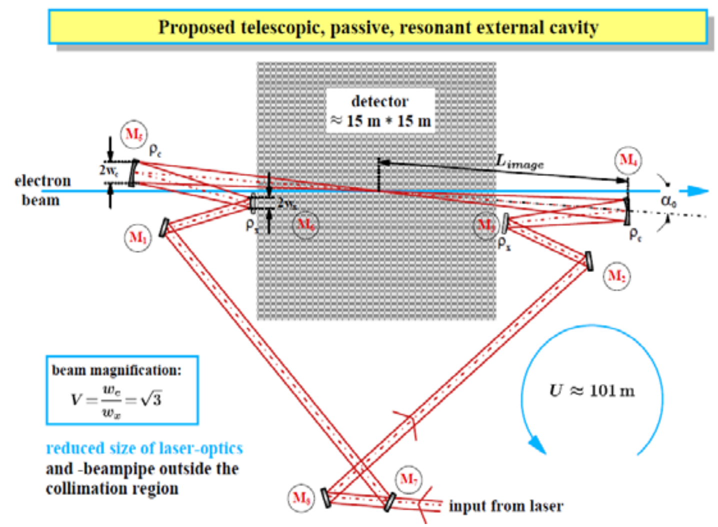


Other Issues

- In addition to the problems
  - Laser system
  - crossing angle Beam dump
  - Another polarized electron gun plus a few 100 MeV linac
    - Positron system can be used for acceleration to 5GeV and transport to DR

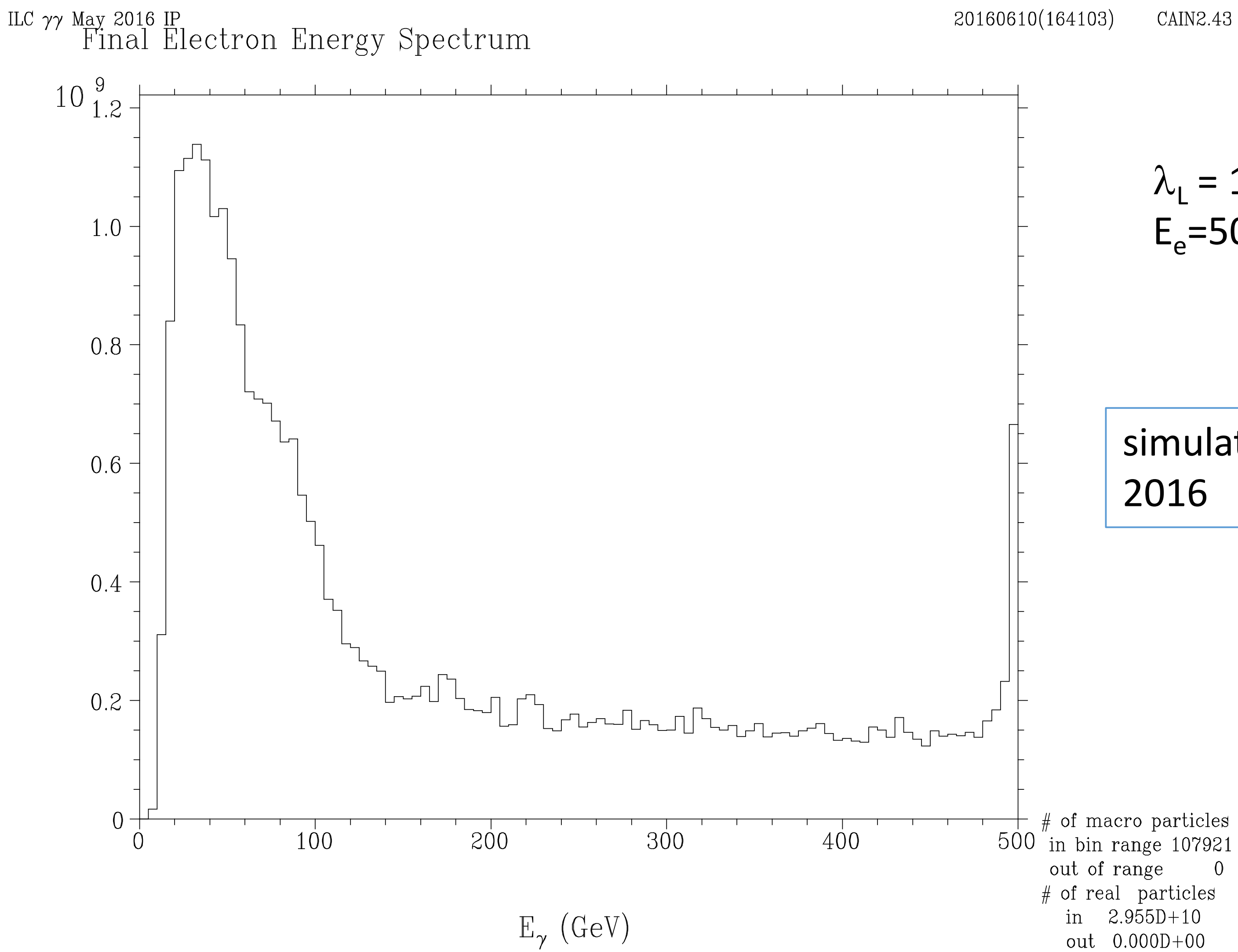
there are still lots of items to be studied

- Detector
  - Basically can use the same detector for e+e-
  - But must be checked in many respects
- Layout of the interaction region
  - Depends on the laser system



- Beam line from IP to the beam dump
  - The design of this beam line is not easy because of the 100% energy spread of the electron beam
  - ILC dump line for 1TeV with average beamstrahlung loss ~10% already has a problem of the back scattered particles from the line to the detector

Electron Spectrum after IP



λ_L = 1.5μm,
E_e=500GeV

simulation
2016

Conclusions

- The technology for $\gamma\gamma$ will be feasible by the time of the 2^{nd} stage of ILC, **iff** serious R&D is done.
- Luminosity of $\gamma\gamma$ is presumably too small if we stay at TDR crossing angle 14mrad
- To change the crossing angle at the time of transition to $\gamma\gamma$ is not realistic because of the big CFS work
- Therefore, if we go to $\gamma\gamma$ collider in the future, the angle should be ~20mrad from the beginning
- However, the major problem of $\gamma\gamma$ is its motivation
  - Additional cost is small (except laser, which we do not know yet)
  - Nonetheless, $\gamma\gamma$ is still a minority
  - X750 is gone