ILC Beam for Outside Users Version 1

K. Yokoya, KEK

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- Beam parameters of 250GeV ILC for possible users from outside
  - Number of bunches per pulse is 1312
  - Do not consider the possible energy upgrade (far future)
  - There is a possibility to double the number of bunches later. But it requires reinforcement of RF system and cost several 100M$. This possibility is not considered here.
  - Pulse repetition rate is 5Hz in normal operation. The rate can be increased up to 10Hz with an investment less than to double the bunches. But it is still uncertain if the positron target can survive under higher repetition rate. So, fix at 5Hz.
  - Positron beam is assumed to be produced by the undulator scheme. Electron-driven scheme might be adopted, depending on the situation.
- Main concern is parasitic mode use under Higgs experiments.

Fundamental Parameters

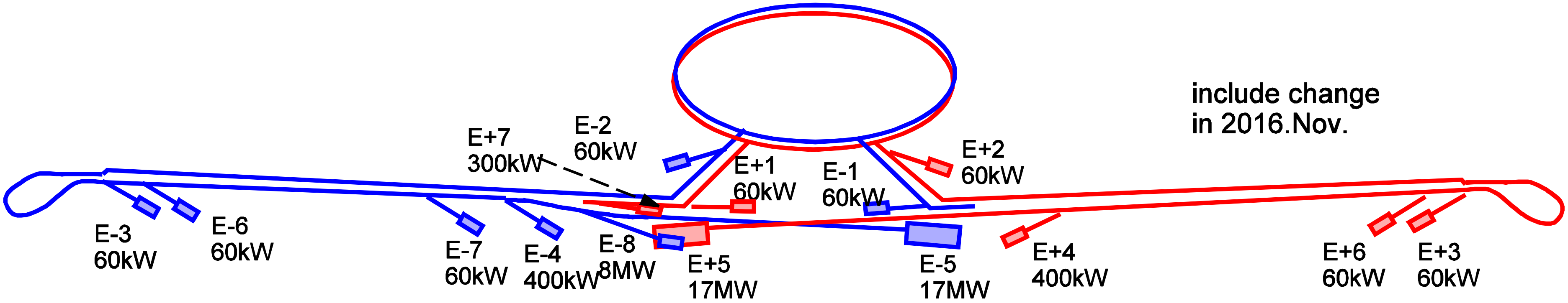
- Pulse repetition rate 5 Hz
- Damping Rings
  - Beam energy 5 GeV
  - Circumference 3238.7 m
  - Stored bunches 1312
  - Bunch interval 6.15 ns
    (There are several gaps between trains)
  - Number of e+/e- in a bunch 2×10^{10}
  - Equilibrium bunch length (rms) 6 mm
  - Equilibrium energy spread (rms) 0.11%
  - Equilibrium emittance (normalized)
    - horizontal 4.0 μrad (less than in TDR)
    - vertical 20 nrad
- Interaction Point
  - Beam energy 125 GeV
  - Number of bunches per pulse 1312
  - Bunch interval 554 ns
  - Pulse length 0.73 ms
  - Bunch length (rms) 0.3 mm
  - RMS energy spread (e-/e+) 0.19/0.15 %
  - Emittance before collision (normalized)
    - horizontal 5.0 μrad (less than in TDR)
    - vertical 35 nrad

Parasitic Mode Use

- Destructive use of a part of the beam (extraction)
  - part of the 1312 bunches (head or tail)
    - Requires high speed kicker (rise/fall < 0.5μs)
  - part of 5Hz pulse (rise/fall < 200ms)
    (The Japanese version contains a mistake here. Eliminated)
- Non-destructive use of a whole or part of the beam
  - e.g., insert an undulator in the beam line
  - In case of straight section it is necessary to insert a chicane to separate photons and electrons
  - Must not degrade the emittance of the main beam
- Other possible uses with no influence to the collision experiment
  - Use if the beam after collision
  - Use of the photons from the undulators for positron production
  - Operate the electron injector (5GeV) at 10Hz. Use 5Hz for the parasitic experiment (need to reinforce the power supply, but not expensive)

Distribution of the Beam Dumps

- Most practical use of extracted beam is the ones at the location of the beam dumps (Otherwise, extraction system must be added, which occupies a longitudinal length. Must be planned early.
- Distribution of the Beam Dumps is shown below
- blue: electron, red: positron
- The numbers shown are the upper limit of the beam power to be dumped (20% margin included)
    - Mostly for commissioning or emergency except E-5, E+5, E+7, E-8
    - Hence the power of the full beam power at the beam line nearby is more than the number here
    - The full beam can be dumped only at E-5, E+5, E+7 (The upper limit of the dumps exceeds the full power because future upgrades are taken into account)
- E-8 will not be built in ILC250GeV



Beam Dump Specification

- PB max = The maximum beam power at the nearby beamline for ILC250GeV
- W = Upper limit of beam dump power (20% margin included)

Name	Purpose of the dump	E	PB max	W
		GeV	kW	kW
E-1	Commissioning of electron injector	5	100	60
E-2	Electron beam extracted from DR	5	100	60
E-3	Just before electron bunch compression	5	100	60
E-4	Tuneup of electron ML	125	2500	400
E-5	Electron main dump	125	2500	17000
E-6	Just after electron bunch compression	15	300	60
E-7	Emergency dump right after electron ML (protect undulatc	125	2500	60
E-8	Spent electron after producing positron (for 5+5Hz operat	150	3000	8000
E+1	Positron before injection to DR	5	100	60
E+2	Positron beam extracted from DR	5	100	60
E+3	Just before positron bunch compression	5	100	60
E+4	Tuneup of positron ML	125	2500	400
E+5	Positron main dump	125	2500	17000
E+6	Just after positron bunch compression	15	300	60
E+7	Photons from undulator	~0.008	60	300

[E-1]

- Use of 5GeV electron injector
- It is presumably possible to operate the injector at 10Hz, using 5Hz for collider and 5Hz for parasitic experiment
  - No problem in klystron 10Hz operation (Euro-XFEL)
  - Electron gun (polarized) is perhaps OK (must be confirmed)
  - Marx modulator?
  - Must reinforce the AC power supply
  - No influence on the collision experiments
  - Beam dump E-1 must be upgraded (to 120kW?)
  - Some tunnel extension needed for the experiment.
- The beam properties are similar to those in Euro-XFEL except the beam energy
  - repetition rate, number of bunches, bunch length, emittance
- Note: [E+1] (positron right after production) is presumably useless because of its bad quality

[E-2,E-3,E+2,E+3]

- Exit from Damping Ring [E-2,E+2] and just before bunch compression [E-3,E+3]
- 5GeV, low emittance (~4μrad x 20nrad)
- But long bunch（6mm）
- Same pulse structure as in ML. Bunch separation 554ns, 1312 bunches, 5Hz
- Energy spread ~0.11%
- Average current is low (5.8mA)

[E-6, E+6]

- Just after bunch compression
- 15GeV, low emittance (~4μrad x 20nrad)
- Short bunch（0.3mm）
- Energy spread is a bit large ~1.2%
- Full beam power ~300kW, Dump < 60kW
- In case of `stealing’ ~10%, the reinforcement of beam dumps E-6, E+6 is not needed

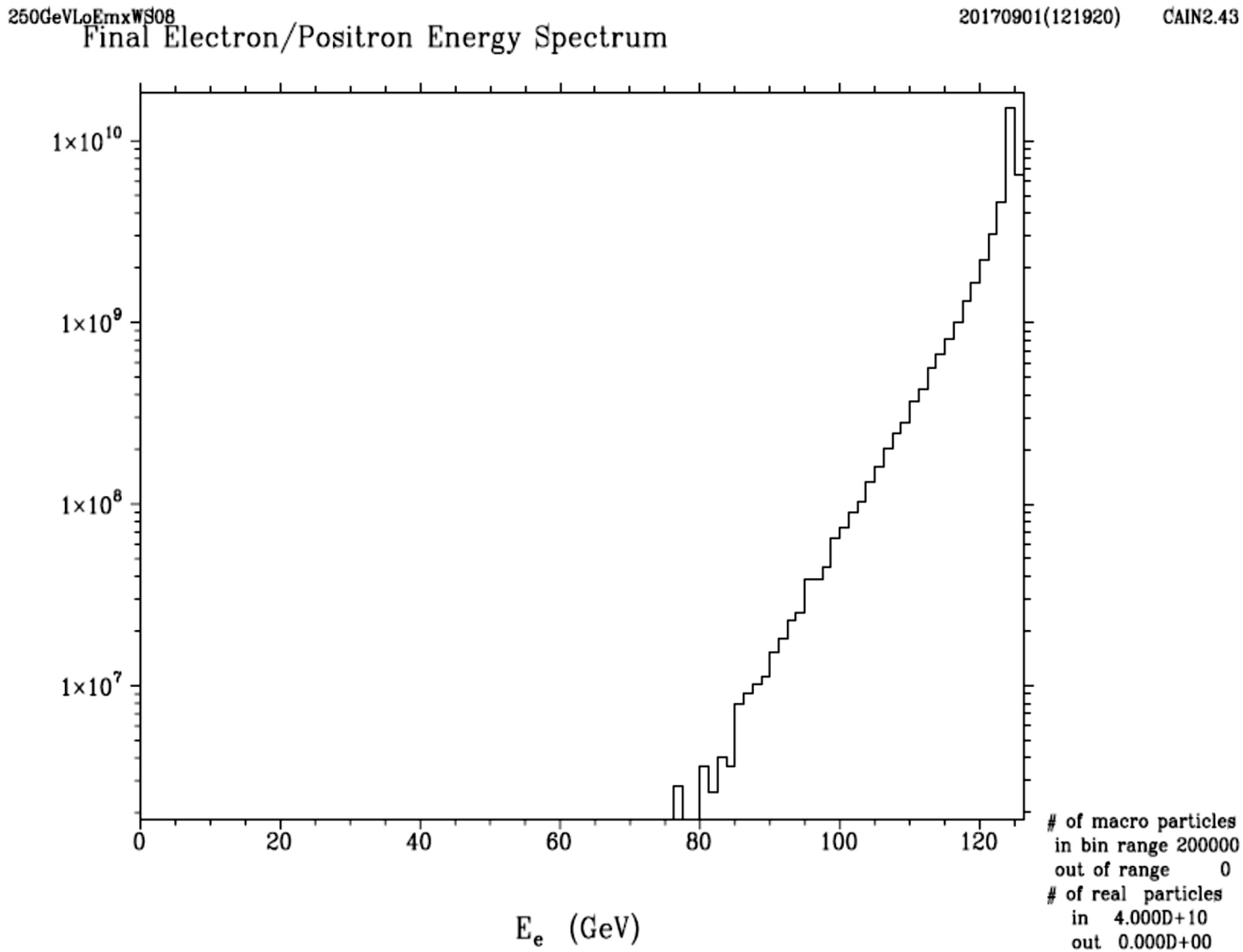
[E-4, E+4]

- Right after ML (main linacs)
- Energy 125 GeV
- emittance 5μrad x 35 nrad
- Bunch length 0.3mm
- Energy spread   0.19% (e-), 0.15% (e+)
- Full beam power 2.5MW, beam dump < 400kW
- In case of `stealing' ~10% the reinforcement of beam dump is not needed
- Note: The beam parameters at [E-7] are similar to above but the maximum power for this dump is limited to 60kW (because [E-7] is an emergency dump to protect the undulators) . Therefore, the use of [E-7] is presumably less useful than at [E-4, E+4]

[E-5, E+5]

- Main beam dump
- Energy 125 GeV
- In case of parasitic mode, the beam quality is poor because of the beam collision
  - Especially the energy spread is large (several percent) with long low-energy tail
  - An example of the electron energy spectrum after collision is shown in the next page
- Main dump is located at 300m from the interaction point (IP) in TDR. Since the crossing angle is 14mrad, the beam going to the IP is separated horizontally by 300m x 14mrad = 4.2m. May make `300m’ a bit large.
- Caution
  - The beam can be destroyed. But the beam is extremely strong. Quite risky. Looks almost impossible?)
  - Photons from beamstrahlung come together. Their number is about twice of electrons, the power is 2.6% of electron, average energy 1.7GeV. The energy spread is very large.

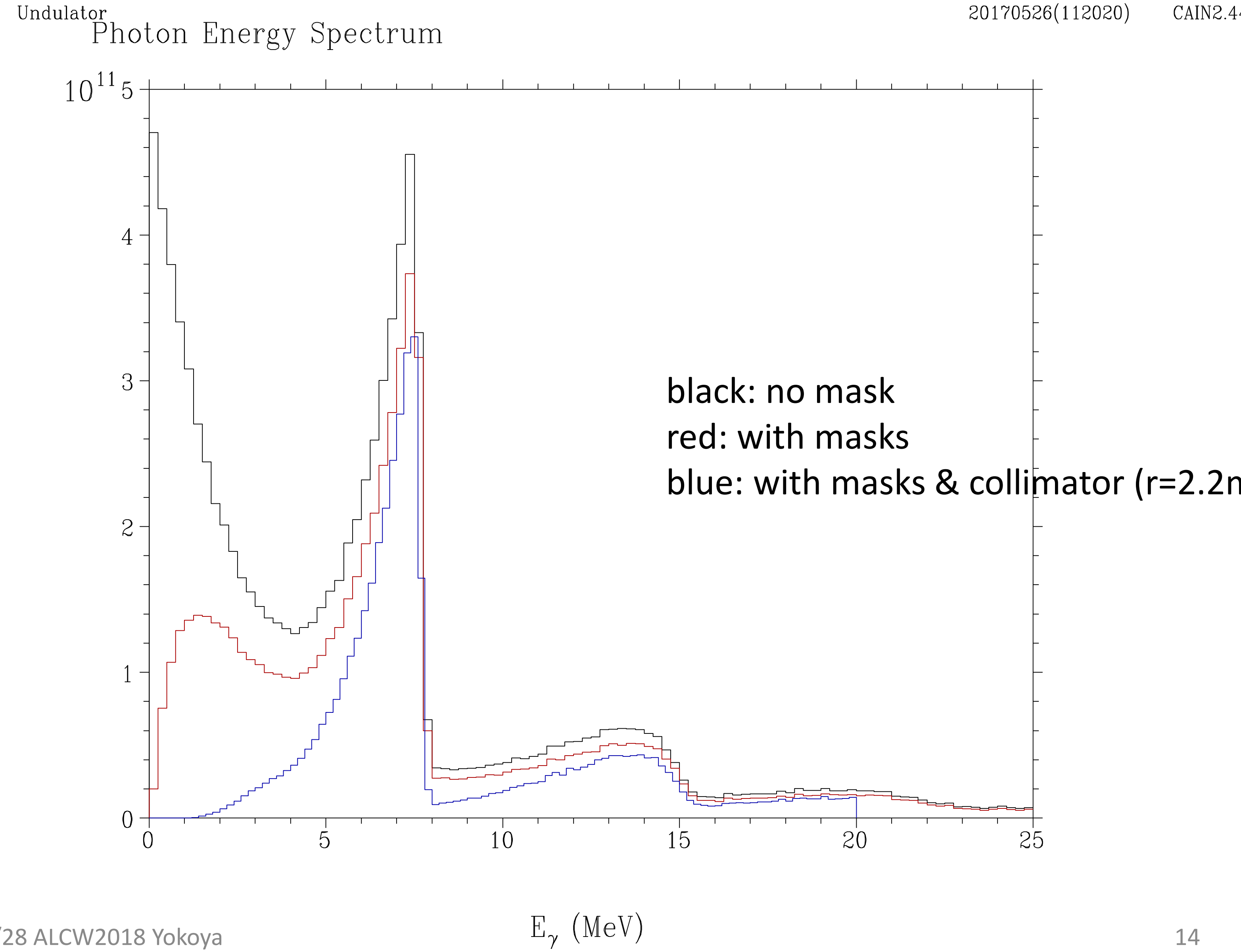
Example of electron energy spectrum after collision



[E+7]

- Photons from the undulators to produce positron
  - This is absent if the e-driven scheme is chosen for positron production
- No variety in the operation mode in case of ILC250GeV
  - Electron energy 125GeV
    (more precisely, 128GeV at undulater section entrance and 125GeV at exit)
  - Average energy of all photons 6.3 MeV
  - Number of photons generated (about 400 photons from each electron)
    - per bunch 8×10^{12}
    - per second 5.2×10^{16}
  - Average energy of photons reaching the target 9.7 MeV
    (Low energy part is eliminated at the masks/collimators)
  - Photon power at the target ~ 50 kW
- The target is thin ($0.2X_0$). Most photons go through the target and reach the photon dump

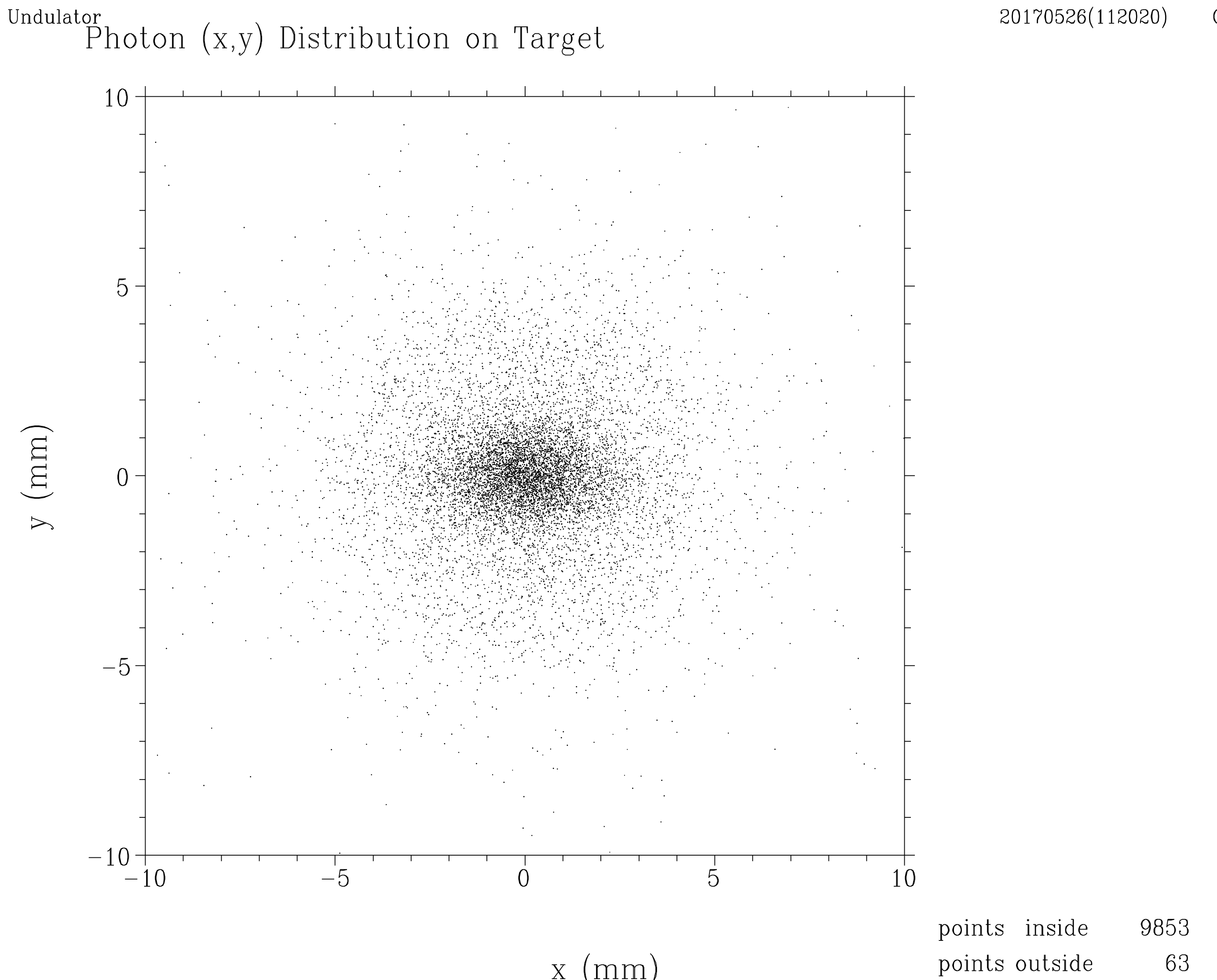
Photon Energy Distribution on Target



black: no mask
red: with masks
blue: with masks & collimator (r=2.2mm)

Photon (x-y) Distribution on Target

- With masks
- See slightly larger horizontal size due to horizontal emittance (horizontal betatron oscillation in the undulator section)
- Only randomly selected particles are plotted here
- Total number of macro particles is ~400k



Photon Data

- Photon data are stored in
  - http://lcdev.kek.jp/~yokoya/temp/BeamOnTarget2017-0526.txt
    (survived photons on the target. no collimator. Contains some 400k photons)
  - http://lcdev.kek.jp/~yokoya/temp/LostPhotons2017-0531.txt
    (lost photons. Lost position preserved, Contains some 80k photons)
- These photons are measured just before the target. The shower developed in the target (thickness $0.2X_0$) are not included.
- Format (macro-particle data from 1 electron bunch)
  - 1st line: title
  - Then (I2, 11X, 12E20.12)
  - I2: 1 for photon, 2 for electron
  - 12E20: w, ct, x, y, s, E, p_x, p_y, p_s, ξ_1, ξ_2, ξ_3,
  - w: 1 macro-particle represents w real particles
  - ct : delay time with respect to the bunch center (meter)
  - x, y: transverse coordinate at the target (meter)
  - s: longitudinal position (same value for all photons = target position)
  - E, p_x, p_y, p_s : enery-momentum (eV, eV/c)
  - ξ: Stokes parameters (ξ_2= circular polarization)

Location of the Photon Dump

- 300kW is assumed with future beam upgrade in mind, but the actual power in ILC250GeV is 60kW at maximum
- TDR adopted a dump with high-pressure water and titanium alloy window placed at several 10s' of meters from the target. But later it turned out this window does not work due to the radiation degradation.
- Most probable candidates of the dump is located at 1-2km downstream from the target
- In this case the photons will fly through a pipe in the tunnel for the BDS (beam delivery system --- long beam line to focus the beam). 2 beam lines (positron line and BDS line) go in parallel on either side of the photon pipe with distance ~1.5m.
- This defines a limit on the size of the devices for the parasitic experim
- The most important is the safety in intercepting the strong photon beam for the parasitic experiment.

Use of the Beam in Damping Rings

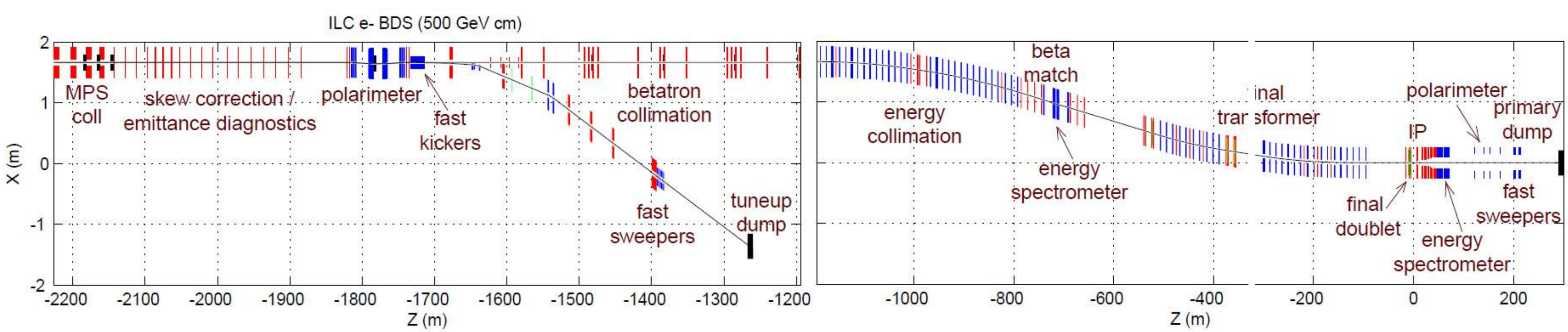
- Space for insertion devices are not reserved at present
- Beam current ~0.5A
- The equilibrium emittance is small. However, it takes time to reach the equilibrium and the beam is extracted immediately after equilibrium is reached.
- Therefore, the value of the beam as a light source is minimal during colliding experiments.

Extraction at midway in ML

- Extraction other than at the beam dumps is possible only under several conditions
- Must estimate the necessary space and device for extraction
  - kicker, pulsed magnet
- In the beginning there will be several empty places where accelerator modules are absent. They are reserved for the case the accelerating gradient were not sufficient. However, the detail of their location is still under consideration.

An example: Extraction of 45GeV Beam?

- Serious studies are needed for extraction at midaway
- It might be possible to adjust the beam energy to 45GeV at ML end by reducing the accelerating gradient once in several pulses.
    - To reduce the gradient once in a while
    - But it is hard to change the strengths of the quadrupole/steering magnets, i.e., orbit retuning is impossible
    - Final Focus System contains dipole magnets. The beam must be separated out before these bends. → should lead the beam to [E+4]
    - The figure below is the electron side., but the posistron side is almost the same. The dump near the center of this figure is [E+4] in the positron side.
    - However, there is a difficult problem: This dumpline is set up to accept 125GeV beam. Can it accept 45GeV beam?



Caution

- Extension of the tunnel
  - If built at the first construction, it is not too expensive (compared with the ILC project cost, not the cost of parasitic experiments).
  - The major problem of later extension of the tunnel is not the additional cost but the point whether the tunnel construction machine can be brought into the tunnel where the accelerator components are already sitting.