Some Developments for the future Photocathode Gun at SPring-8

~ Coherency of Photocathode laser light source should be killed or utilized !? ~

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JASRI/SPring-8

***Kill*) fiber bundle laser profile homogenizer with backward illumination (transparent cathode)**

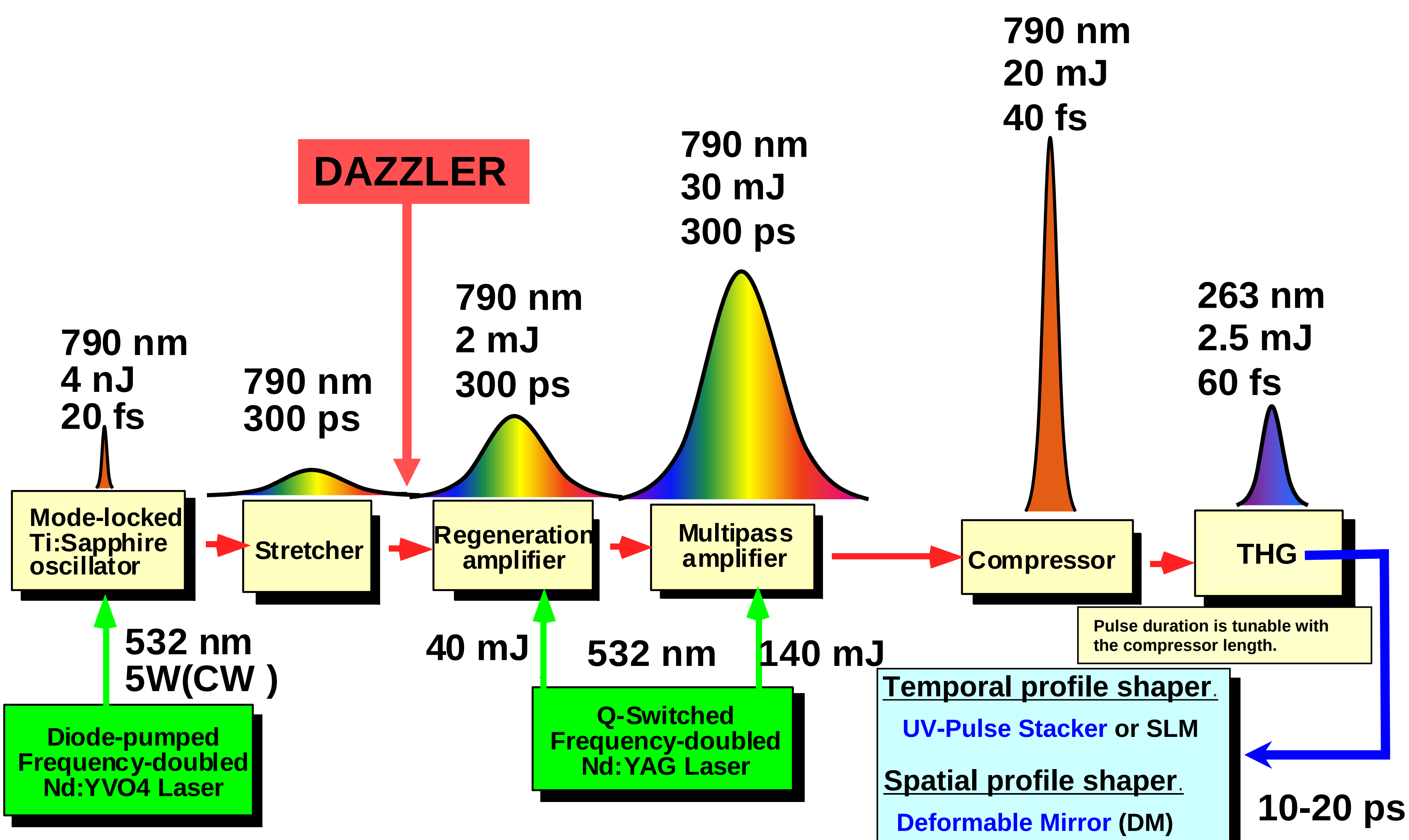
***Use*) Z-polarized laser on the cathode & field emission with Schottky effect (It's not proved yet!)**

1. Introduction

- 1.1 Present our 3D laser shaping
- 1.2 Interference Problem for shaping
- 1.3 Difference between x- & y- emittance

Normal incidence → Hollow incidence

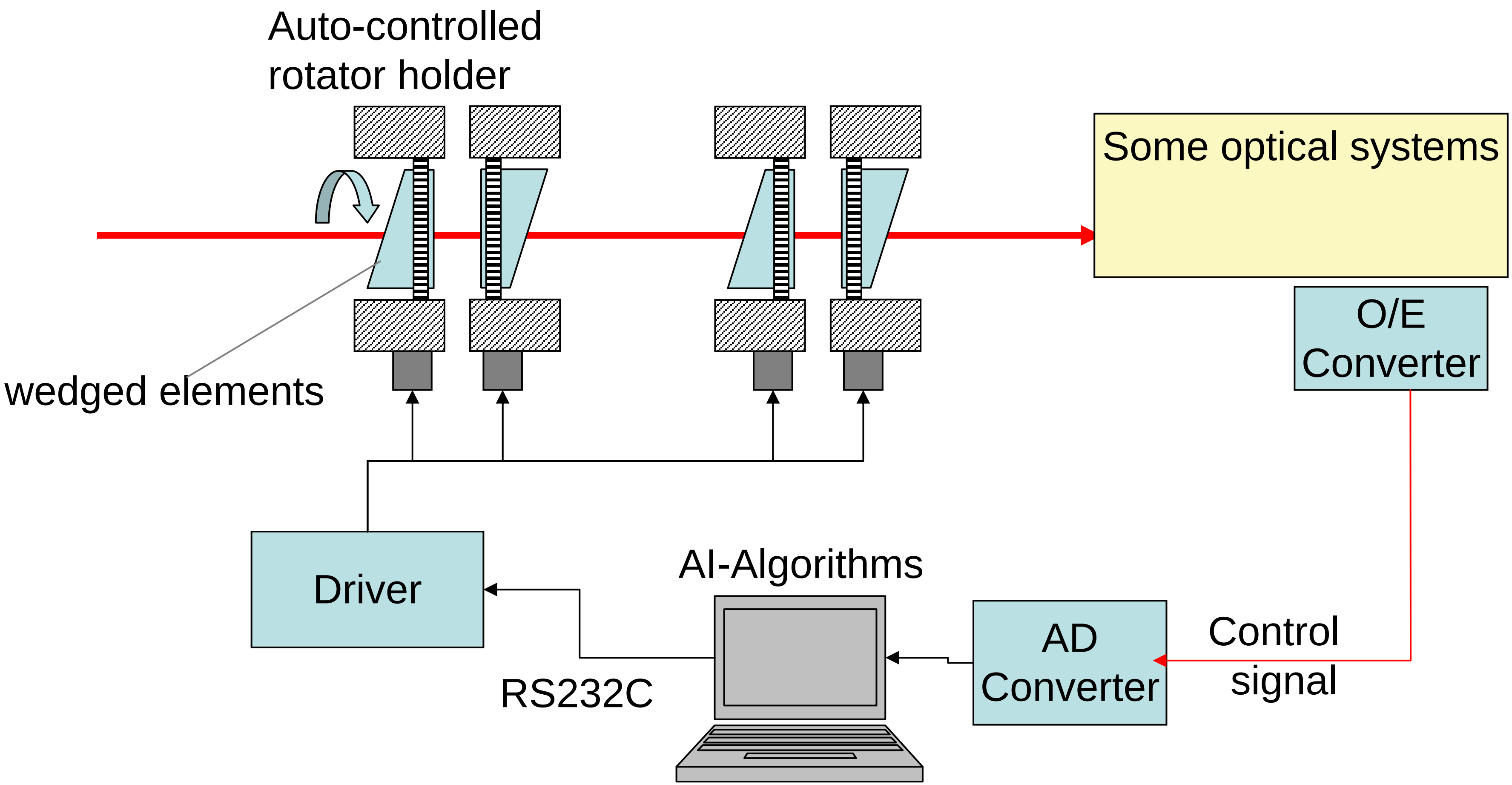
1.1 Laser System Configuration



Pointing stabilizer

Risley Prism Configuration for Beam Steering

The Risley Prism is a high resolution beam steering device consisting of two pairs of rotatable wedged elements.



1-2. Optimization of laser profiles

~ Spatial & Temporal ~

Beam Quality Control by

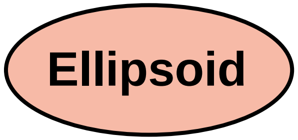
Spatial Shaping

Deformable Mirror (Wave Front Control, also!)

Pulse (Temporal) Shaping

SLM (Spatial Light Modulator)

UV- Pulse Stacker



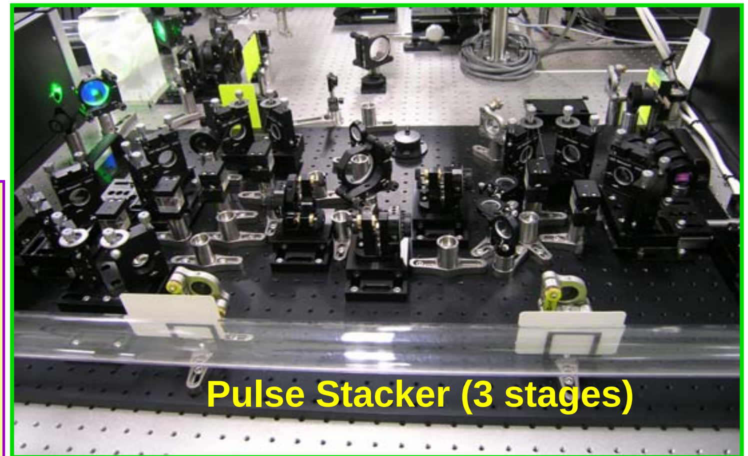
3D-laser pulse shaping (ellipsoidal)

Fiber Bundle

Start from femtosecond pulse

Z-polarization with Schottky effect

In 2006, 3D-shaping system was completed!



UV- Laser source (total stability!)

Laser Pulse Energy : 1.4% @THG

24 hrs; 1.5 month long

Pointing Stability & Reproducible

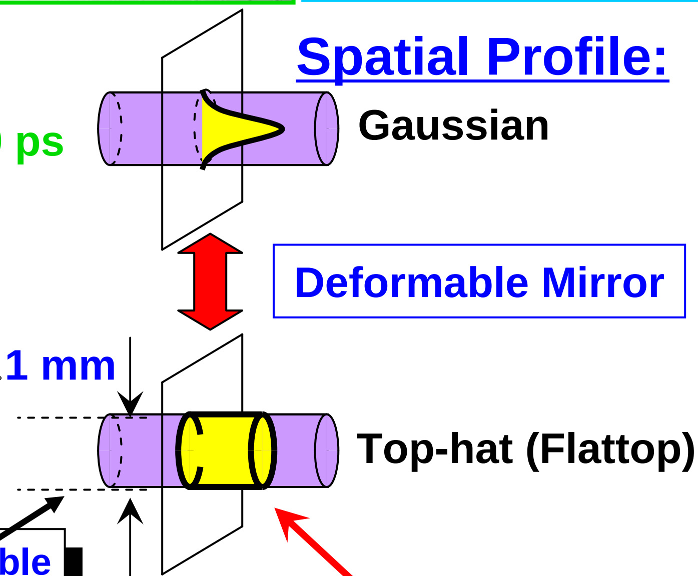
Timing Jitter < 0.3 ps

Temporal Profile:

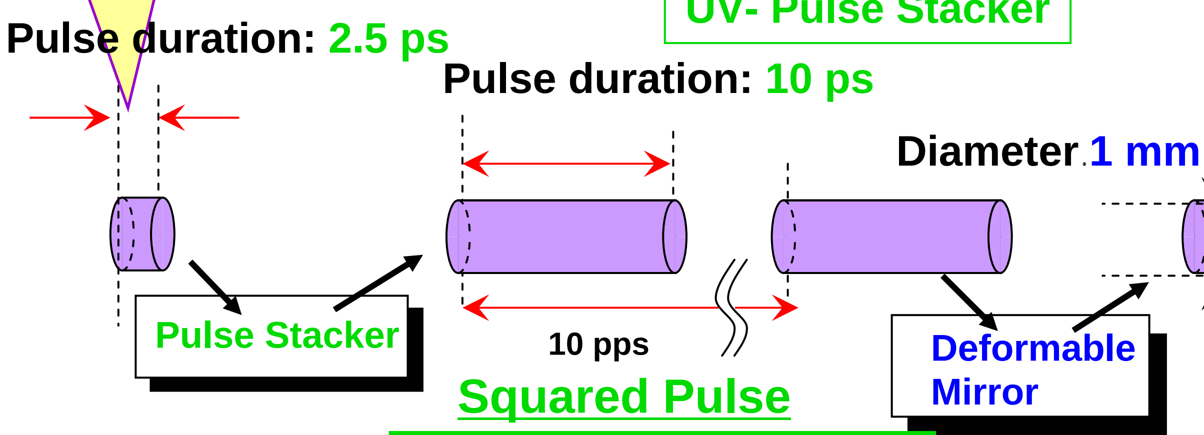
Pulse duration: 2.5 ~ 20 ps

UV- Pulse Stacker

Spatial Profile:

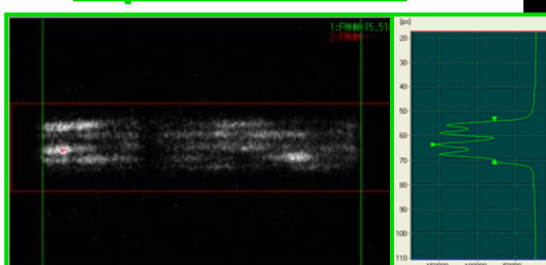


Deformable Mirror



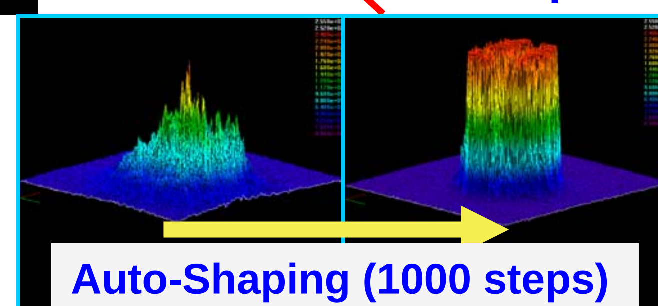
Squared Pulse

Pulse Stacking



Streak Image of stacked pulses

Flattop



Present 3D-laser pulse shaping

Cylindrical

DAZZLER:
micro pulse shaping

↓

THG

↓

UV-Pulse Stacker:
macro pulse shaping

↓

Deformable mirror:
transverse shaping

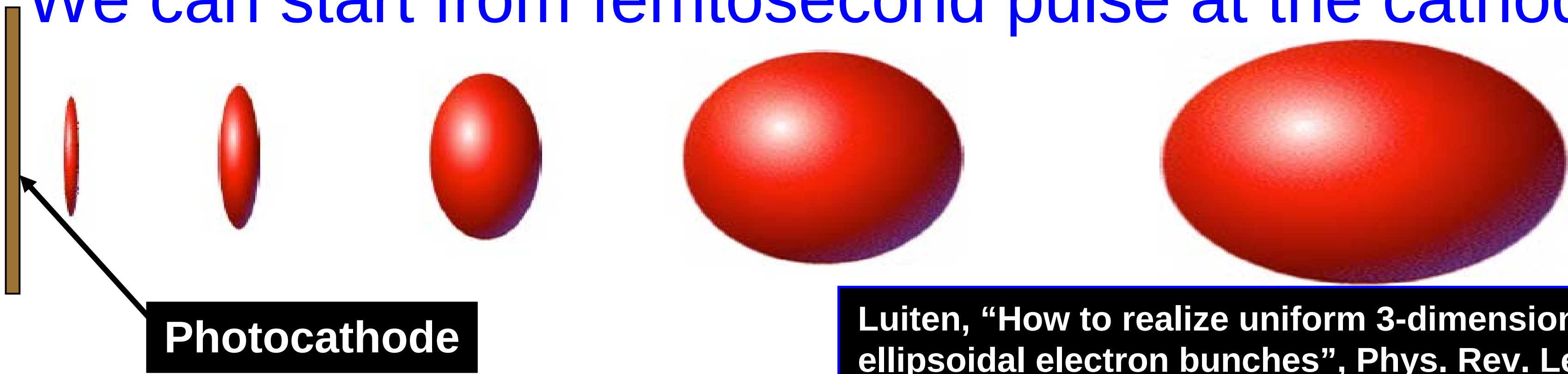
↓

Normal incidence to the cathode

Water bag: Luiten scheme Evolution of ellipsoid

<u>If it works, we can generate ultra-low emittance.</u>

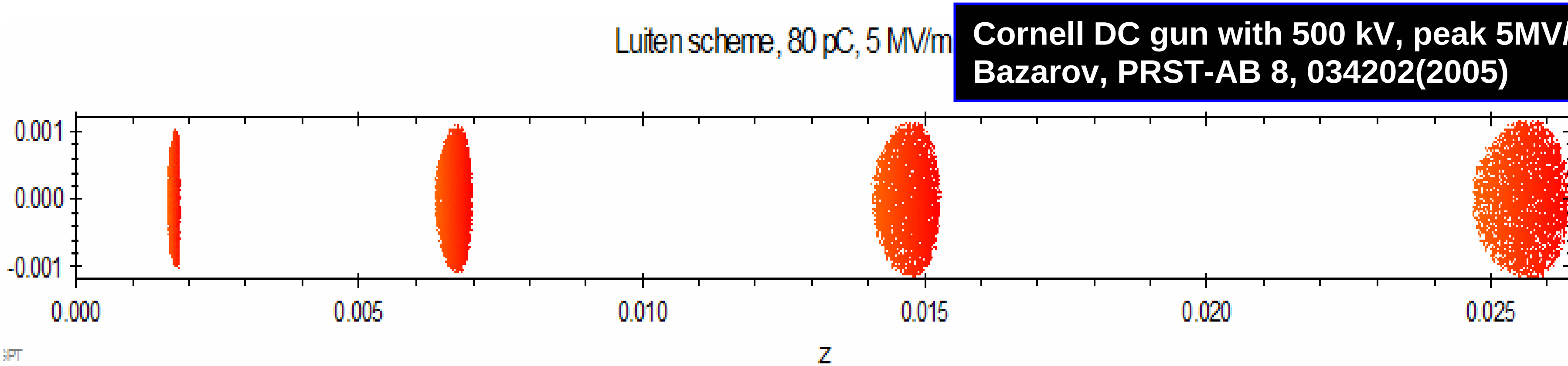
We can start from femtosecond pulse at the cathode.



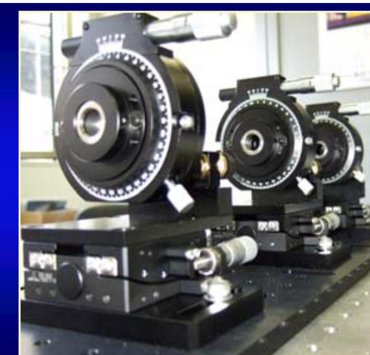
Luiten, “How to realize uniform 3-dimensional ellipsoidal electron bunches”, Phys. Rev. Letters 93, 094802 (2004)

Laser: 100 fs with parabolic transverse distribution with 1 mm radius

Cornell DC gun with 500 kV, peak 5MV/m
Bazarov, PRST-AB 8, 034202(2005)



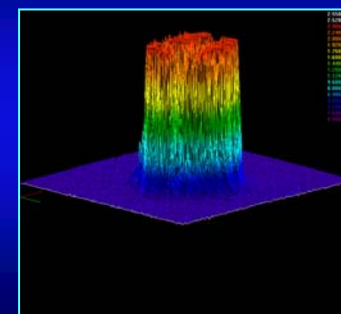
Laser source status & interference problems



A. We realized stable laser system

Oscillator : 24 hours, 10 months, non-stop
TW- Amp. : 24 hours, 1.5 months, non-stop
THG: 1.4% rms stability

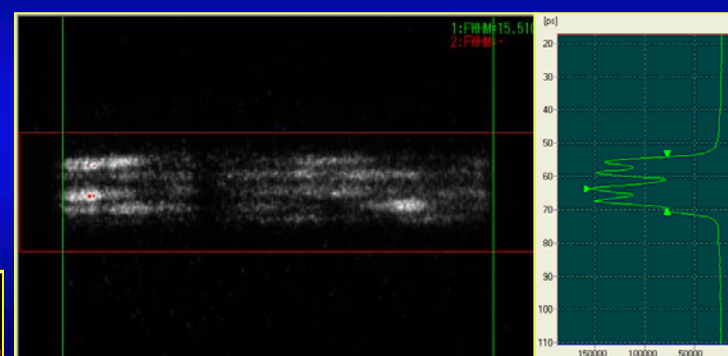
B. Automatically shaping Spatial Profile with DM + GA was successful! (Gaussian or Flattop)



~ Arbitrary Laser Shaping ~

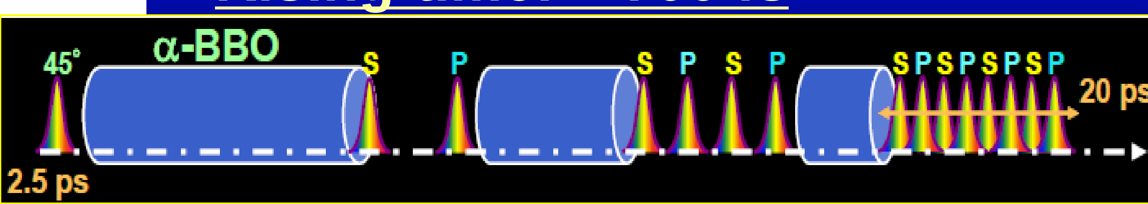
~ However, it takes 1 hour to optimize.

C. Square pulse generation with UV-pulse stacker was successful at THG (263 nm) !

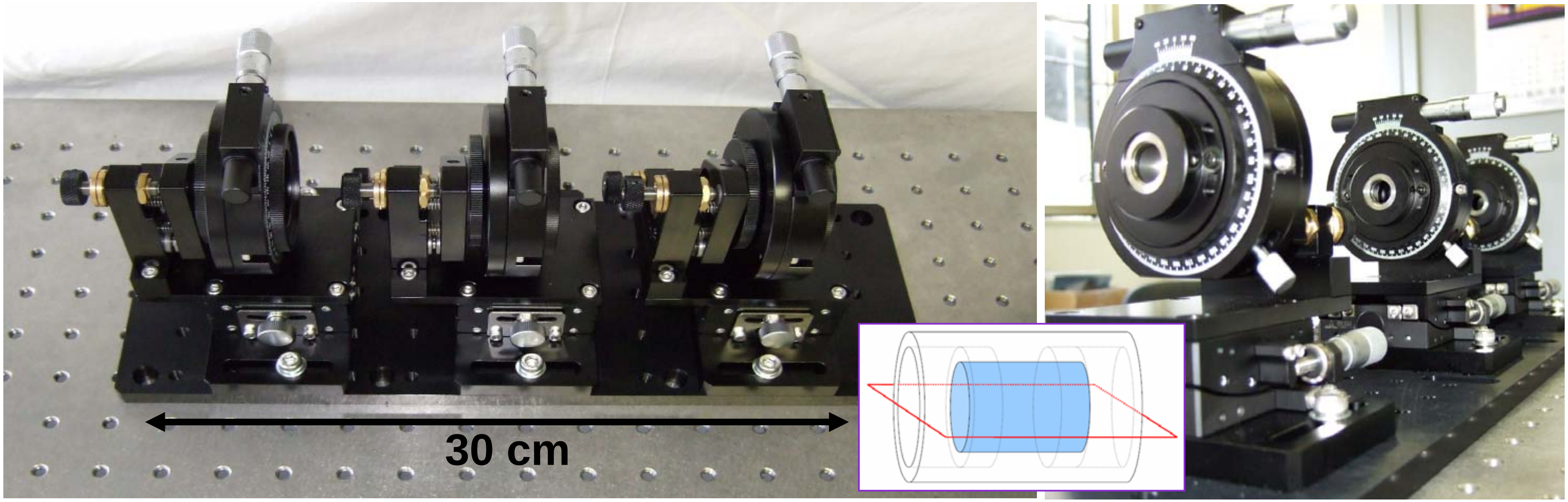


<u>Square Pulse: ~2.5 - 20 ps</u>;

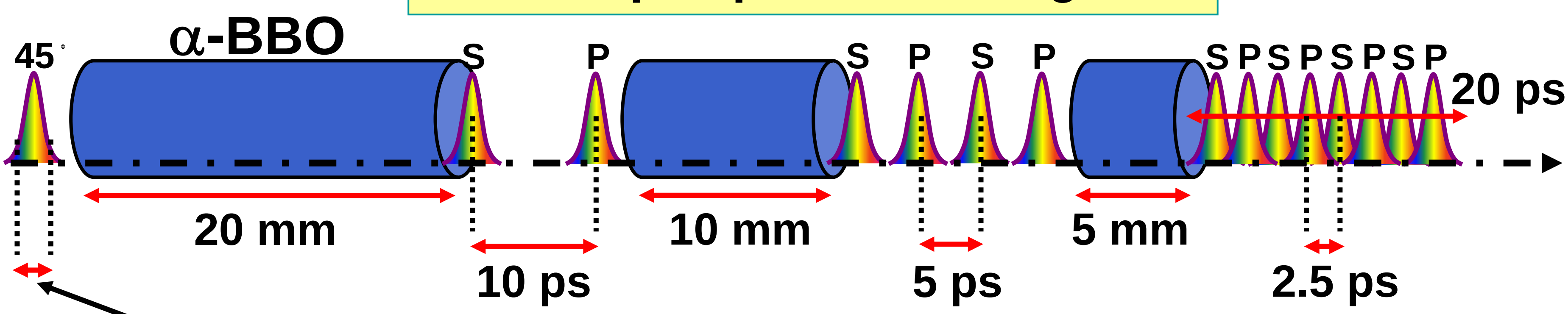
<u>Rising-time: ~ 700 fs</u>



Pulse Stacking Rods ~directly shaped in UV!

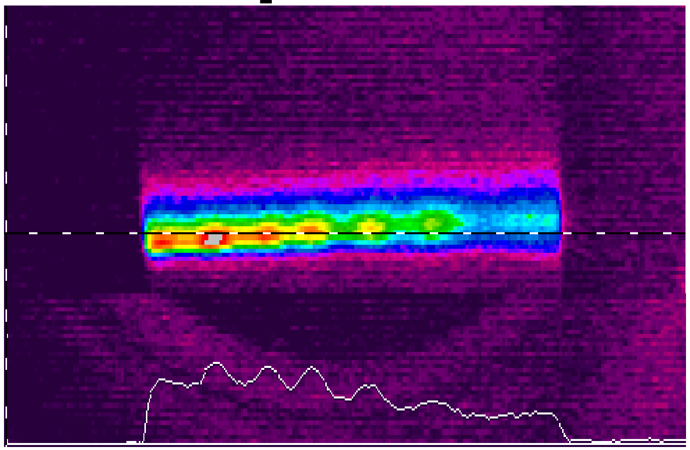


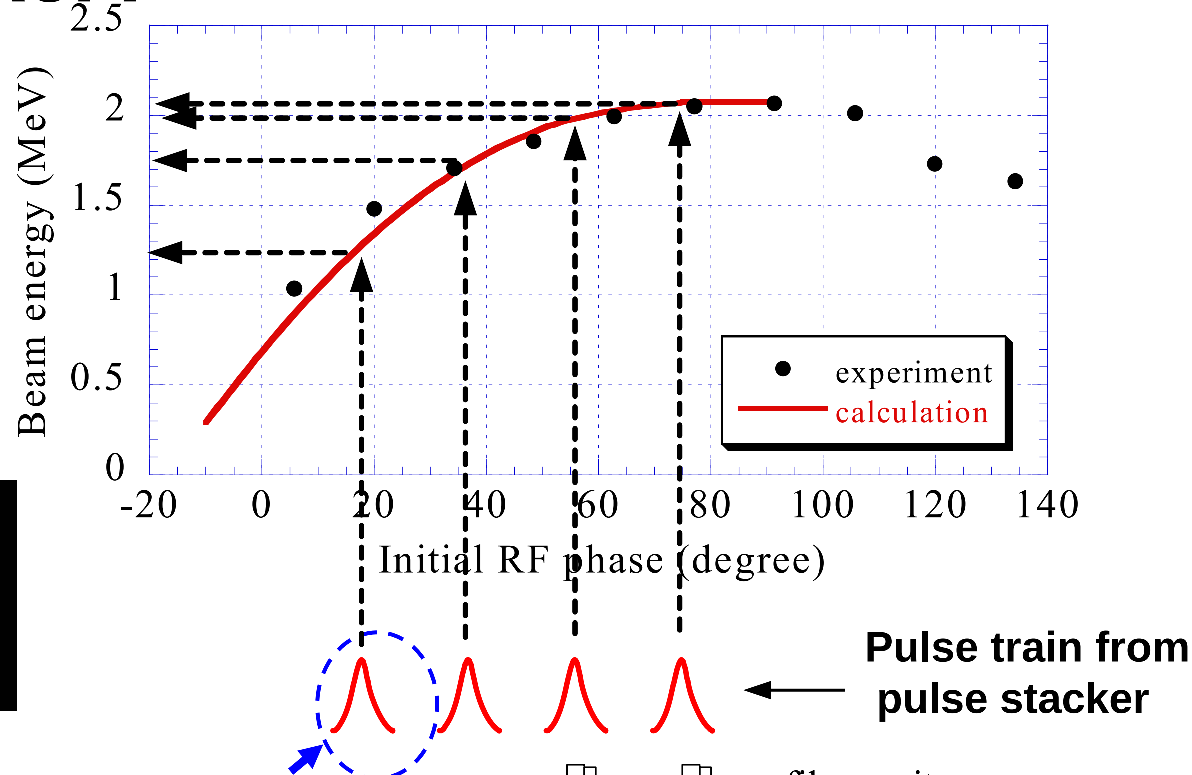
UV- chirped pulse stacking rods



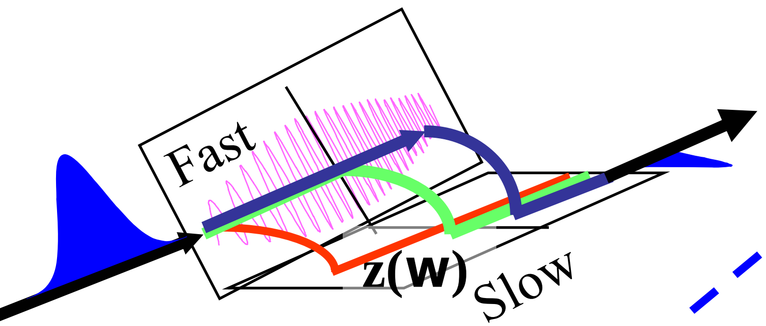
It is optimized with DAZZLER. Note that, this pulse duration is defined at the cathode as a stretched pulse due to the dispersion through the transparent optics in laser transport (All together 7.5-cm-thick fused silica!!).

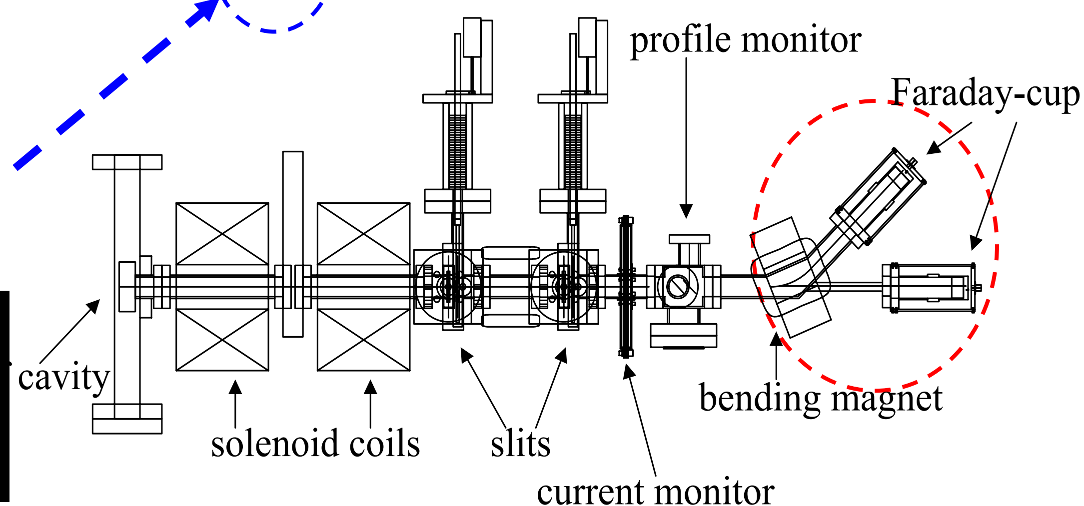
How can we optimize macro & micro pulse with pulse stacker?





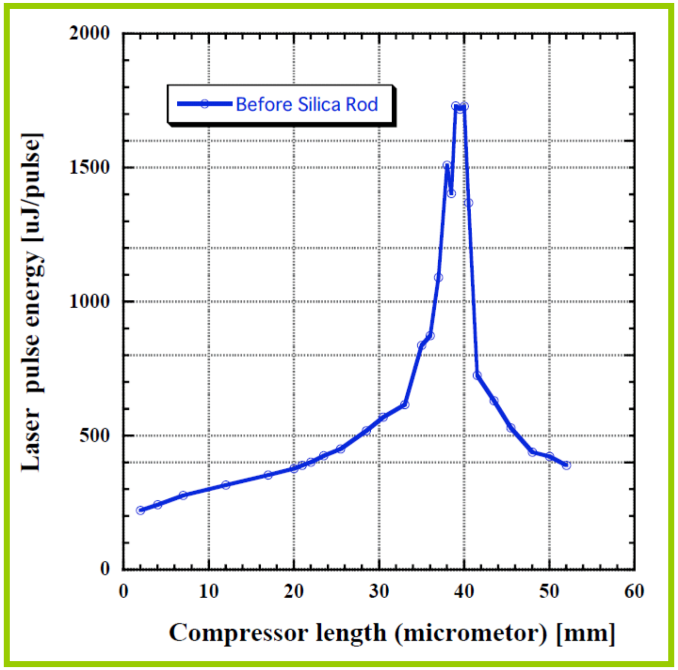
With Pulse stacker
Interval of micro pulses
are equalized.





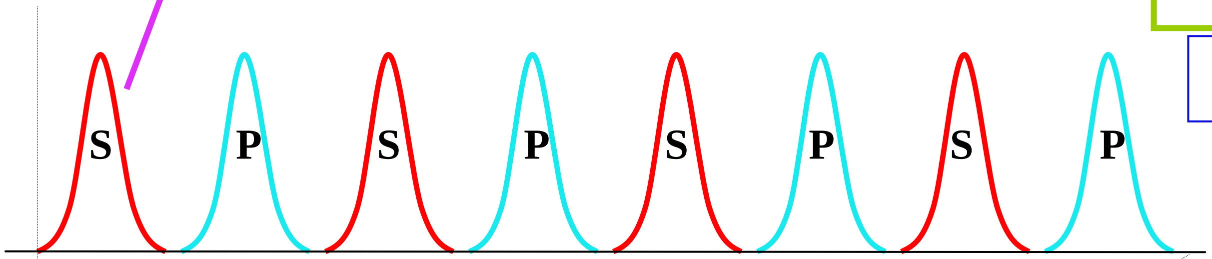
With DAZZLER.AO-modulator.
Pulse duration .shape.chirp.
are optimized.

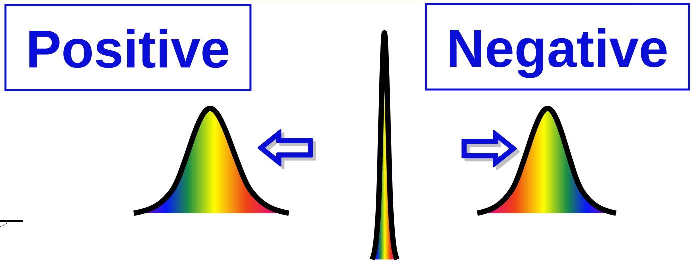
Optimization system of temporal profile



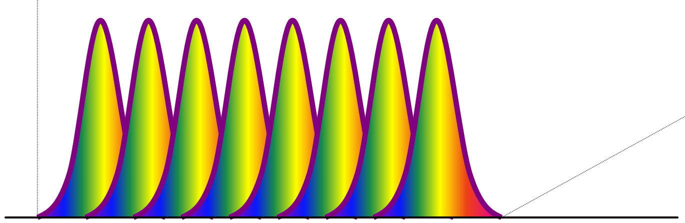
Changing compressor length,
2.5-ps original pulse is generated

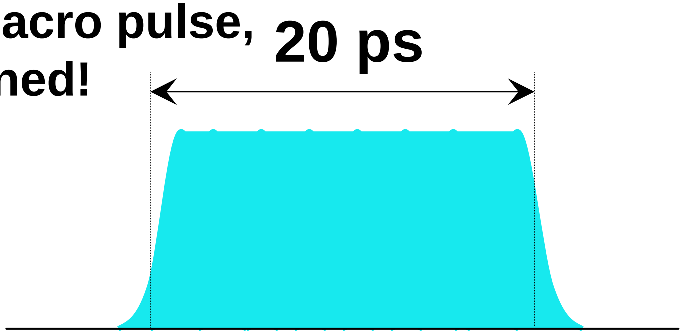
Not that, laser pulse will be positively chirped & stretched through the silica material !





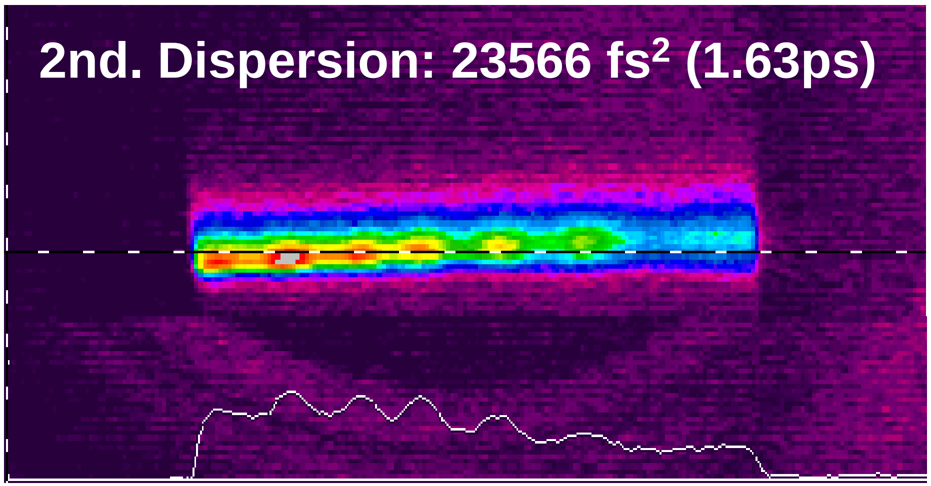
To avoid interferences on the plateau of stacked macro pulse, S- and P- polarized pulses are alternatively positioned!

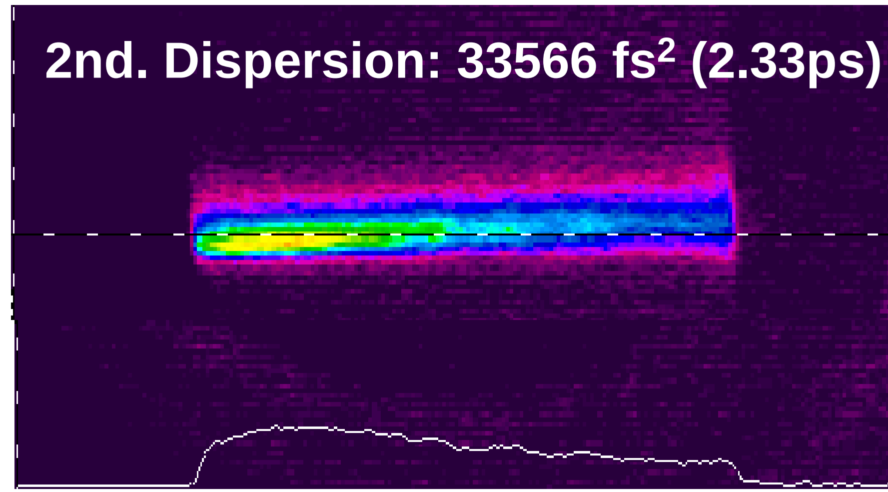




Usage Photocathode with energy analyzer as a streak camera

2nd. Dispersion given by DAZZLER





Input micro pulse is too short!
Micro pulse energy & intervals are not equivalently optimized!

Micro pulse width, energy, and intervals are optimized!

Stacked Pulse Duration: 20 ps

(Input pulse width @ cathode: 2.5 ps)

Emittance measurements
low emittance electron beam generation

~ we are testing with different 3D-parameter ~

Result of X-emittance measurement: 2.0π mm mrad @1.0 nC

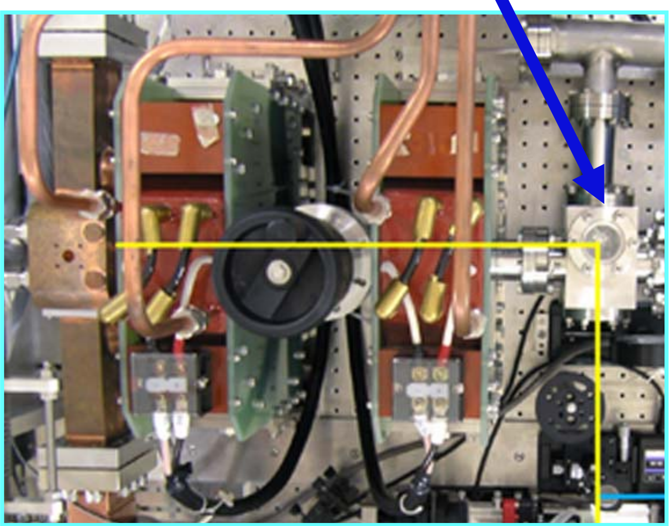
Pulse duration 20 ps

1.8π mm mrad @ 0.5 nC; 15 ps

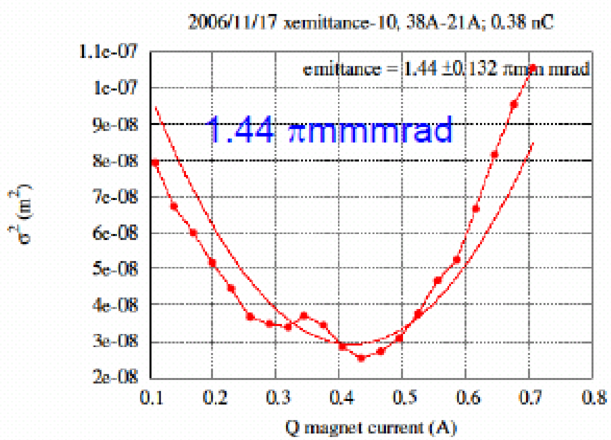
1.4π mm mrad @ 0.4 nC; 10 ps

Y-emittance is always 1.5 times larger!

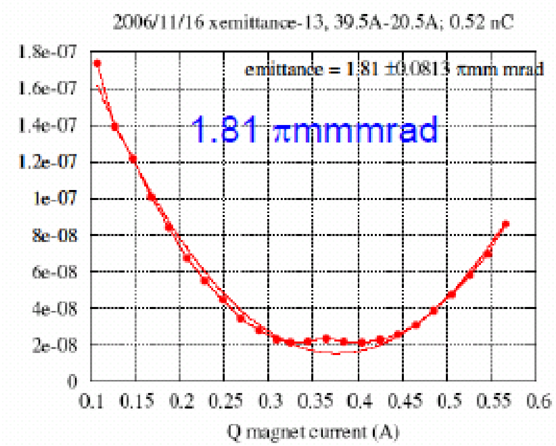
Normal incident mirror ?



Q-scan fitting



10 ps, 0.38 nC



15 ps, 0.52 nC

***3D-Laser pulse shaping*:**

~ some problems as followings~

- **getting more complicated**
- **Interference due to shaping**
- **Monitoring of UV-profile**

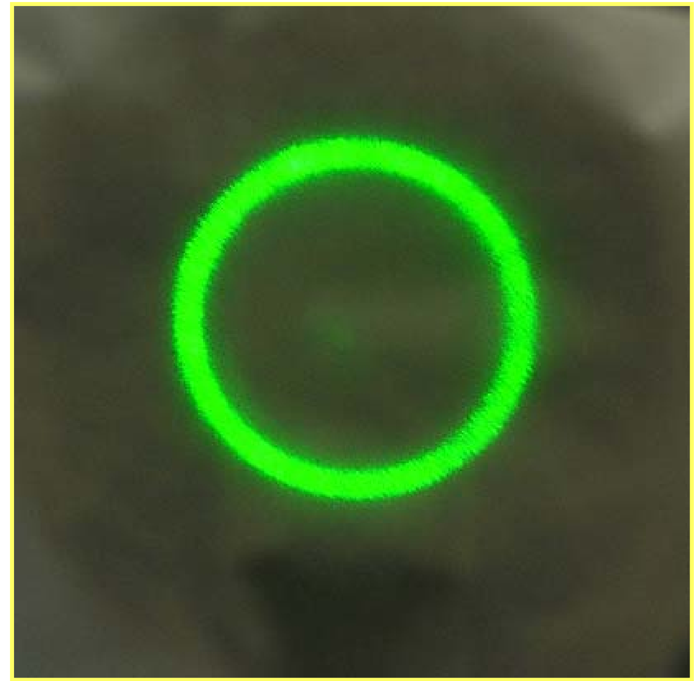
***Asymmetry of transverse emittance*:**

~ Mirror in Vacuum is problem~

- **How to minimize wake-field**
- **How to avoid from charging-up on mirror**
- **Backward illumination**
  ~ vanishing mirror ~
- **Hollow beam incidence**
  ~ keep mirror away ~

Laser Incidence methods:

- Oblique incidence
- Normal incidence
- Backward incidence
- Hollow beam incidence



Influence of normal incidence mirror

~ In the case of higher charge~

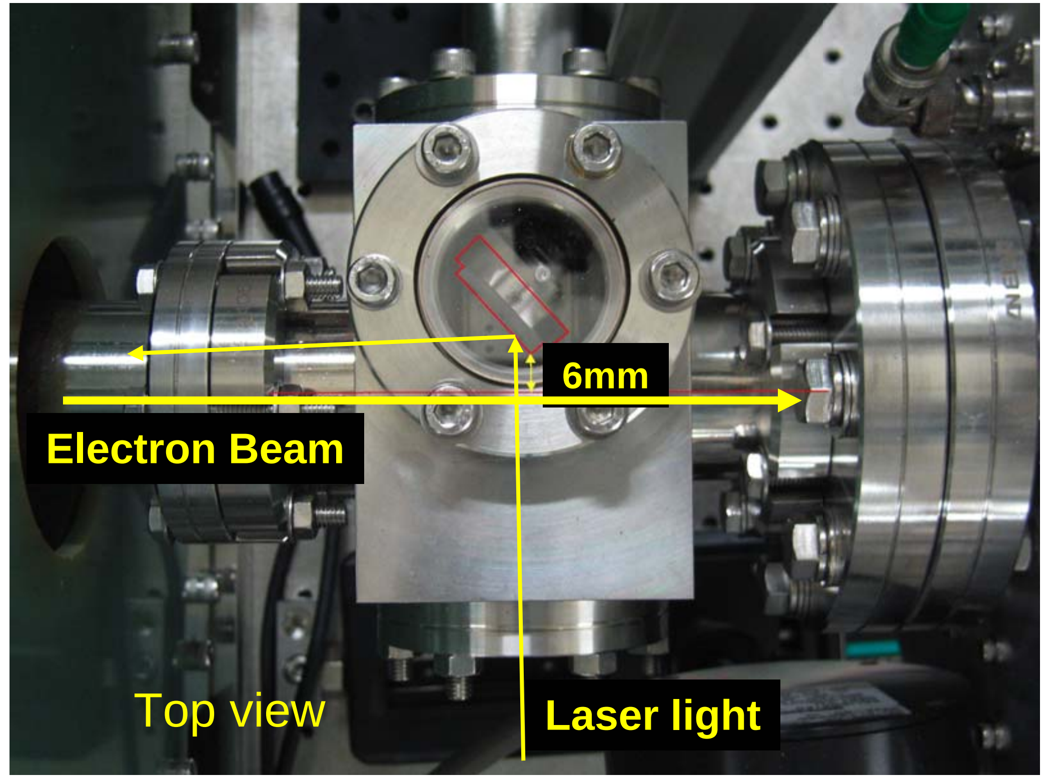
From the cathode 560mm Downstream

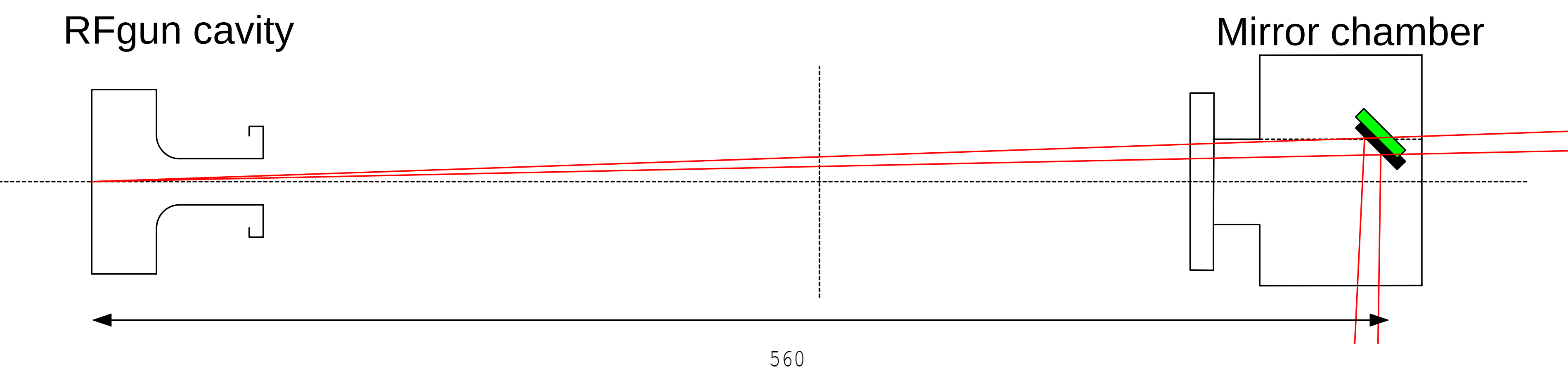
Normal incidence mirror

↓

Distance from beam axis 6 mm

Wakefield

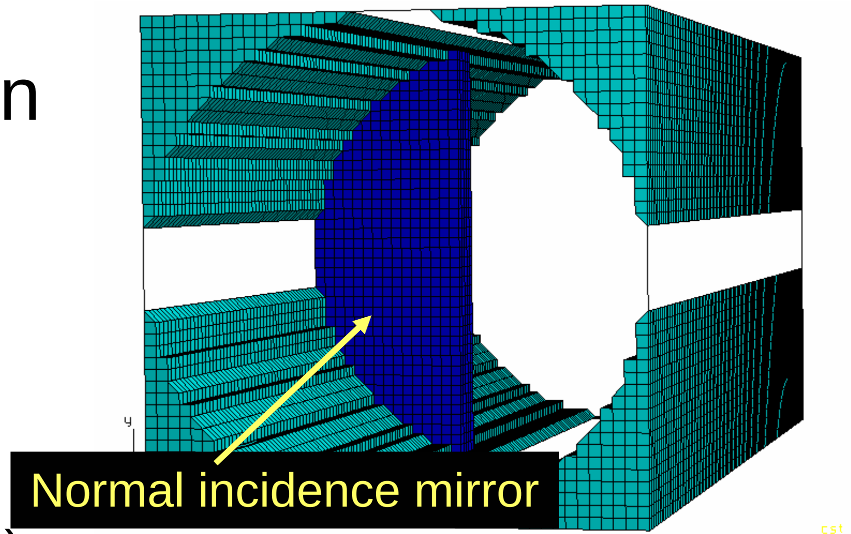




Simulation results with MAFIA

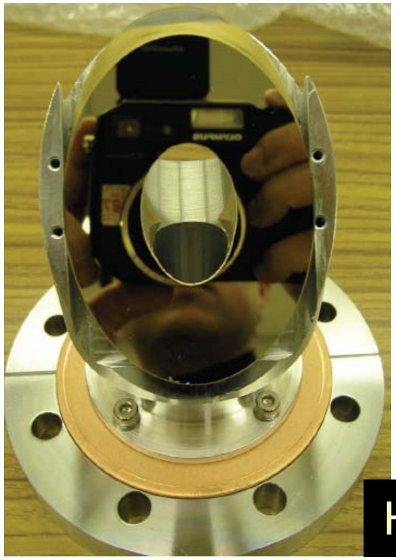
The condition of this simulation

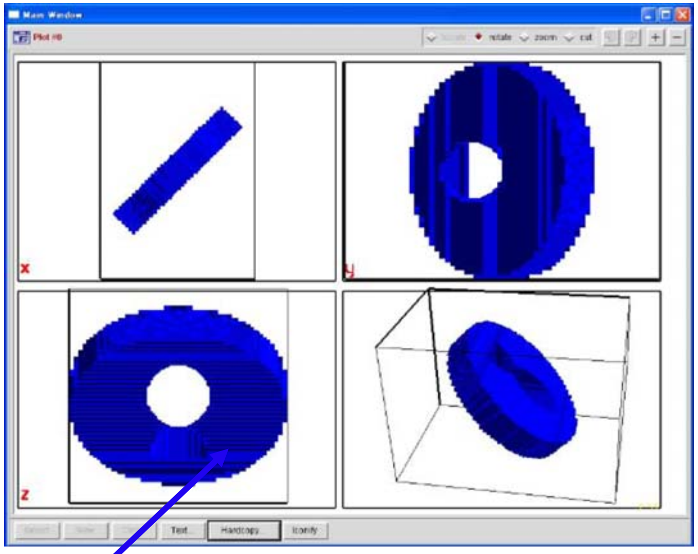
Metal Pipe: ϕ:40mm, L:100mm
Metal plate vertical to the beam axis
6mm from beam axis



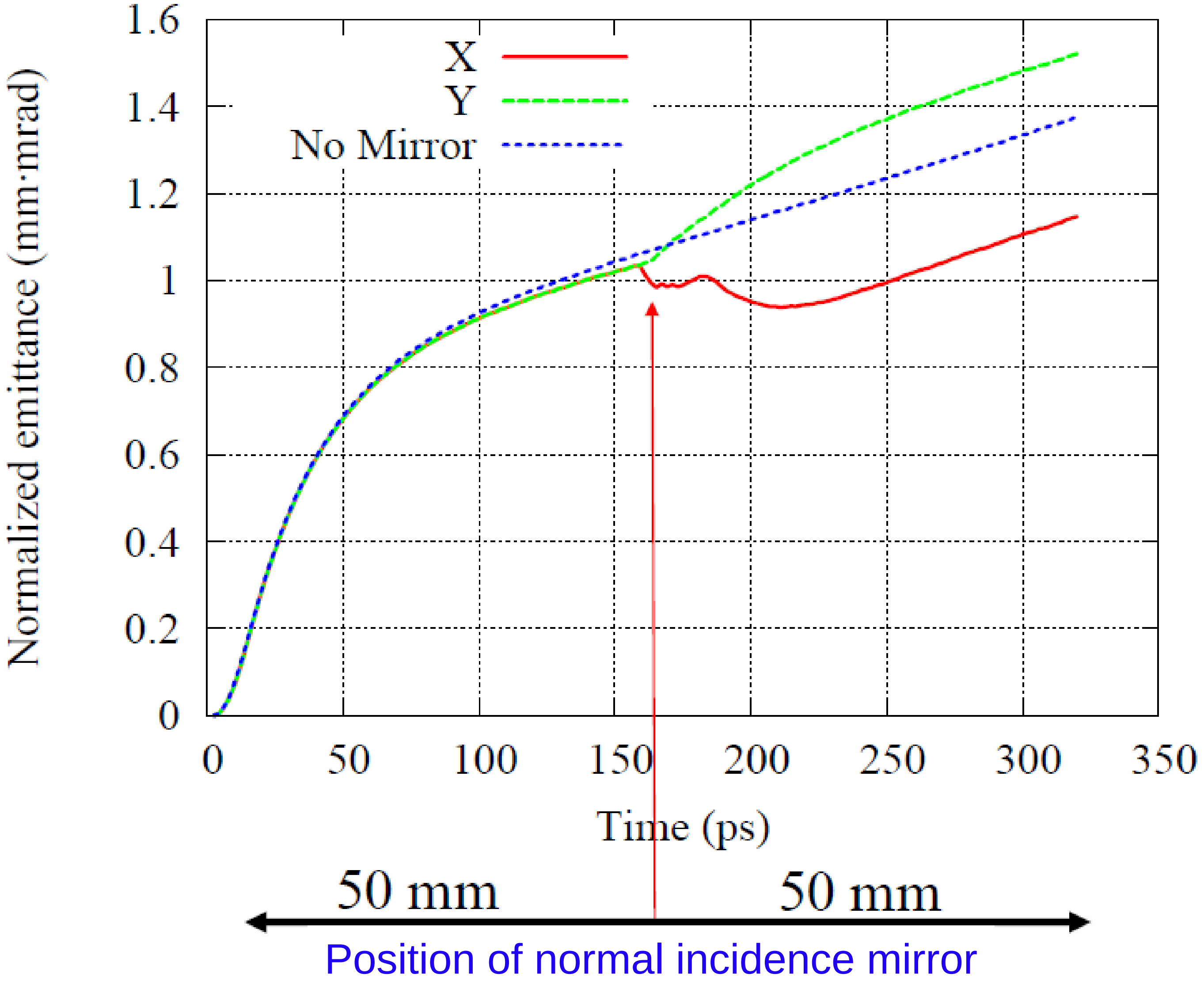
Beam condition (almost same as experiment)
(Charge distribution took from particle tracking code)

Bunch charge:	0.83 nC
Beam energy:	3.6 MeV
Tem. Profile:	4.5 ps (1σ)
Trans. Profile:	3.5 mm (1σ)





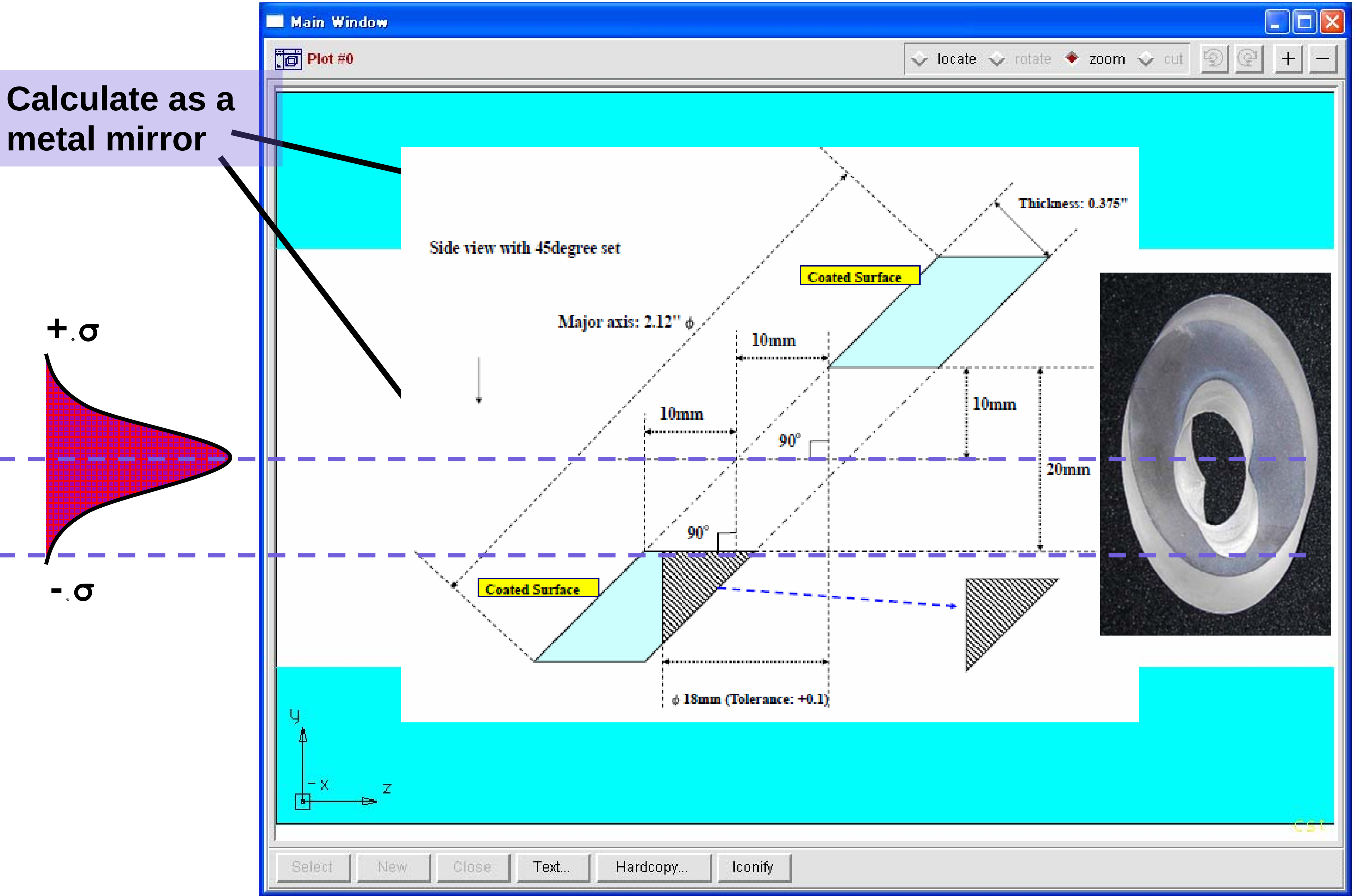
Influence on X,Y-emittance due to normal incidence mirror (Beam behaviors nearby mirror)



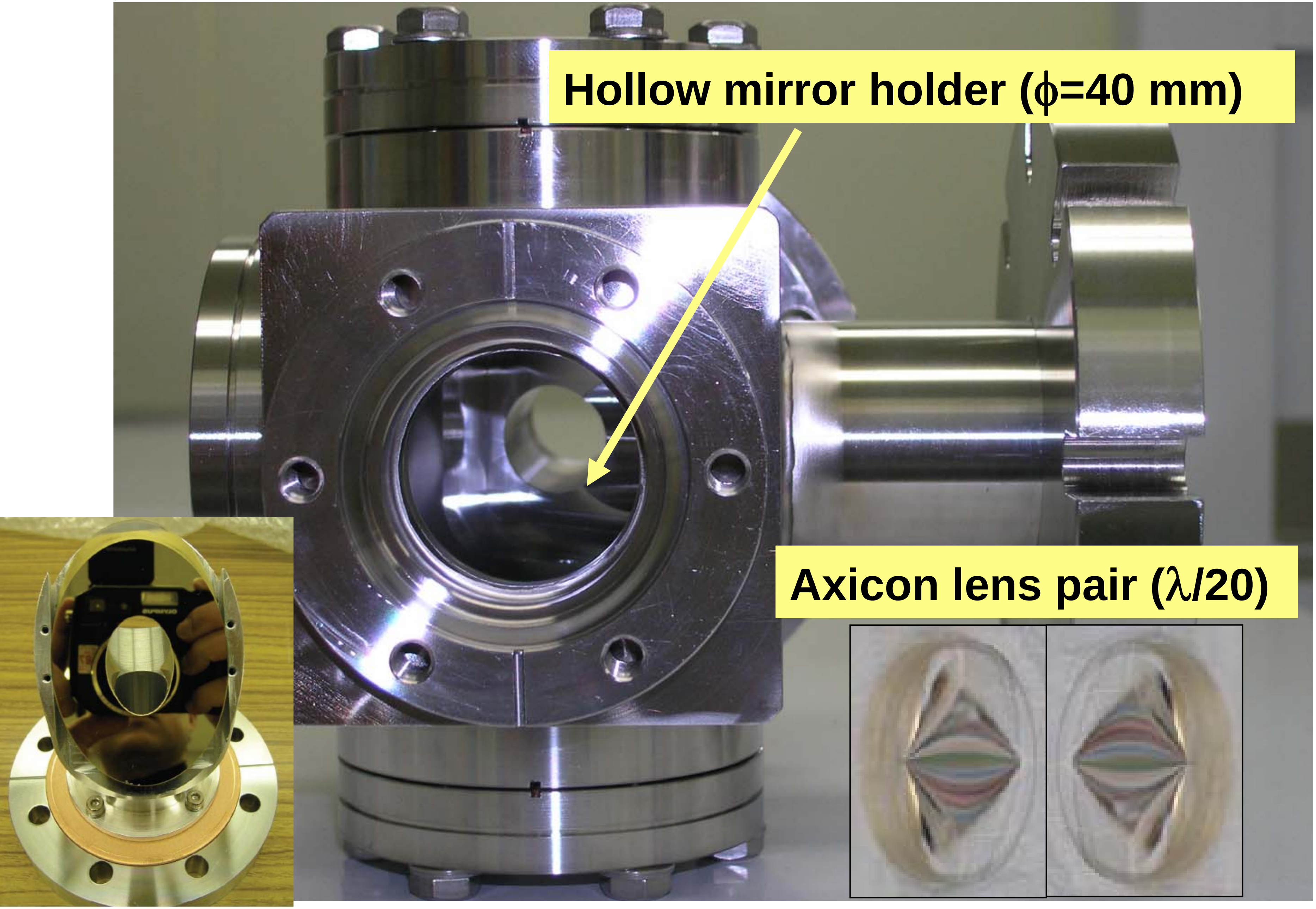
The simulation reproduces that Y-emittance is larger than others.

The third incidence method: Hollow beam incidence

Calculate as a metal mirror

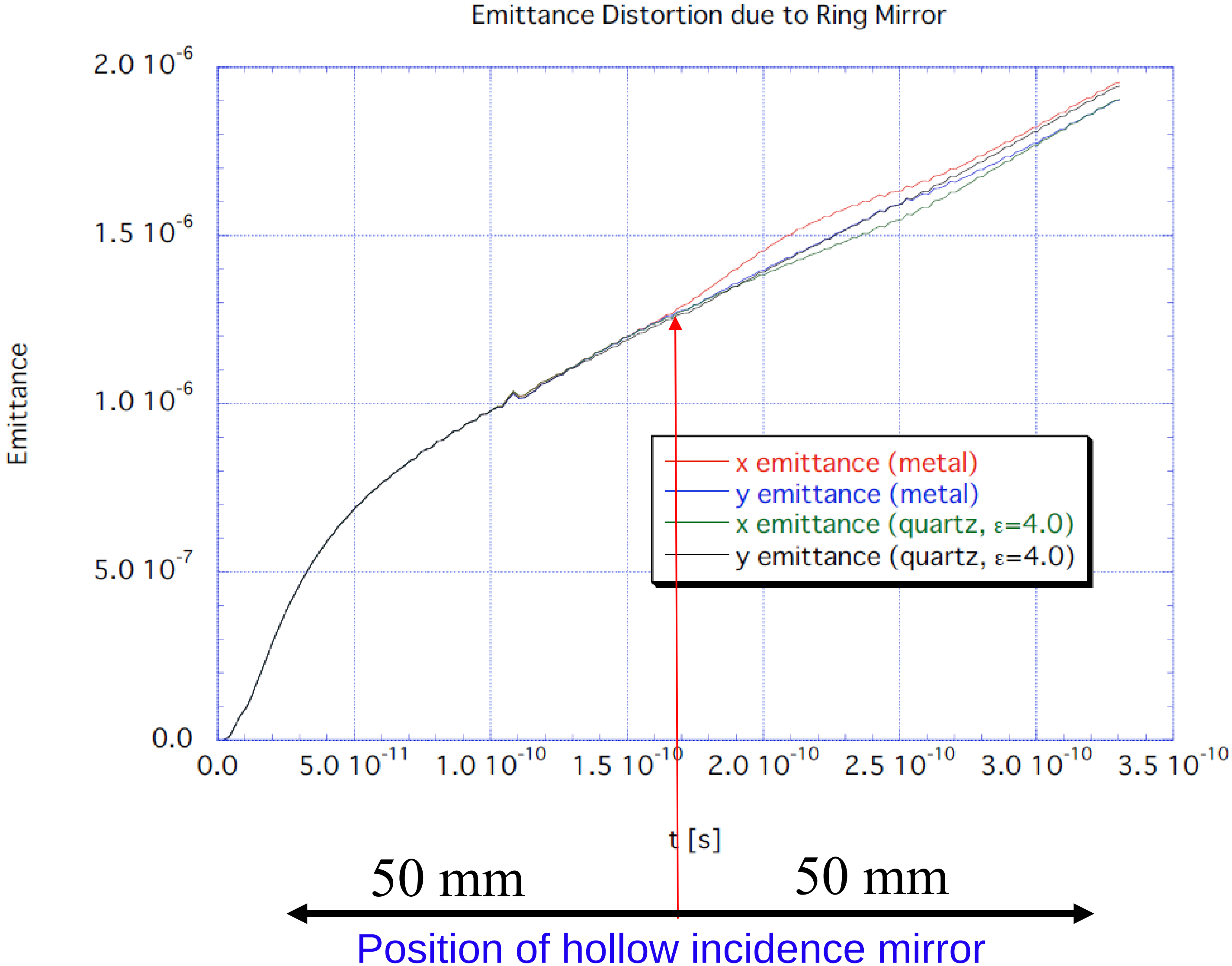


Hollow mirror chamber and hollow optics



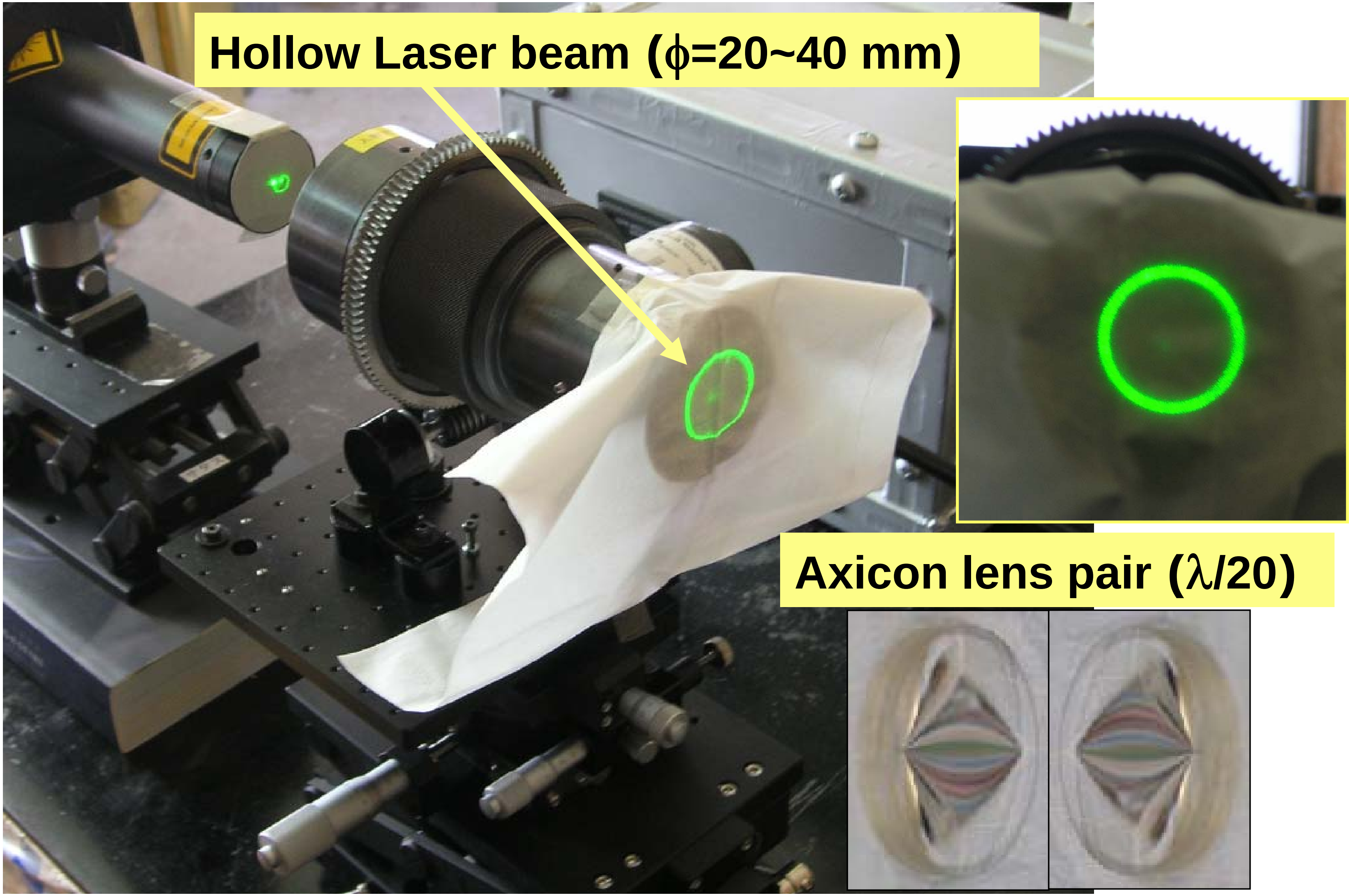
Influence on X,Y-emittance due to hollow incidence mirror

(Beam behaviors nearby hollow mirror)

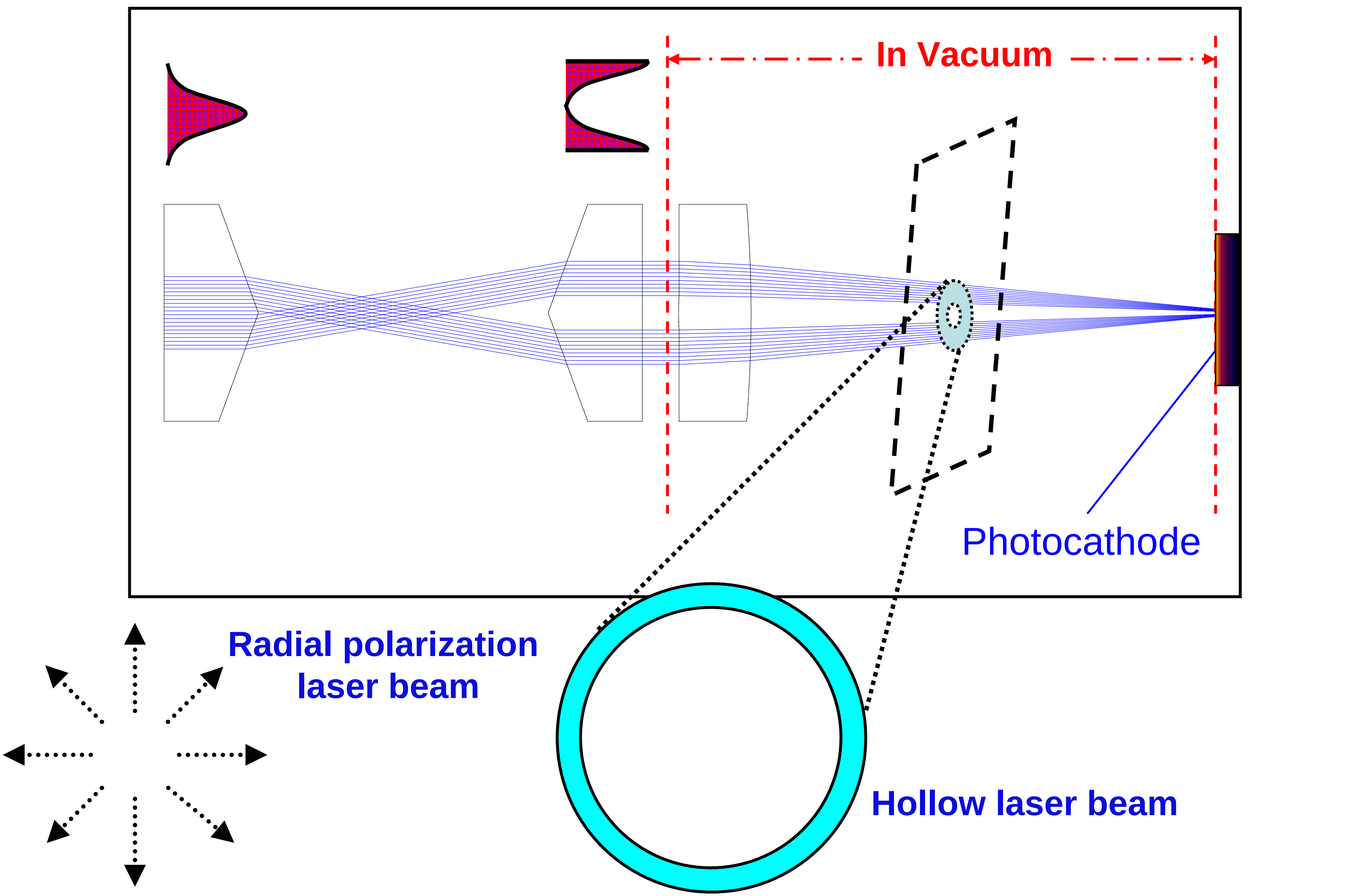


Not significant influence on emittance with metal & dielectric hollow mirror.

Generation of hollow laser beam

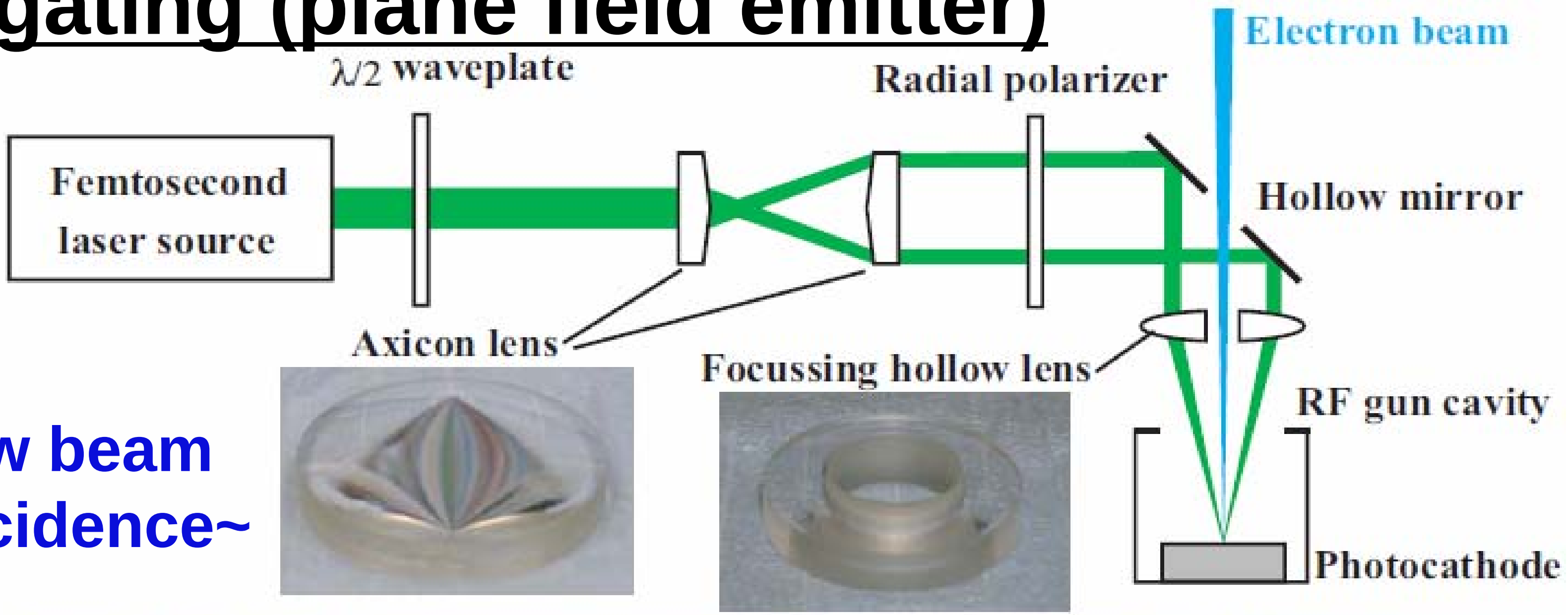


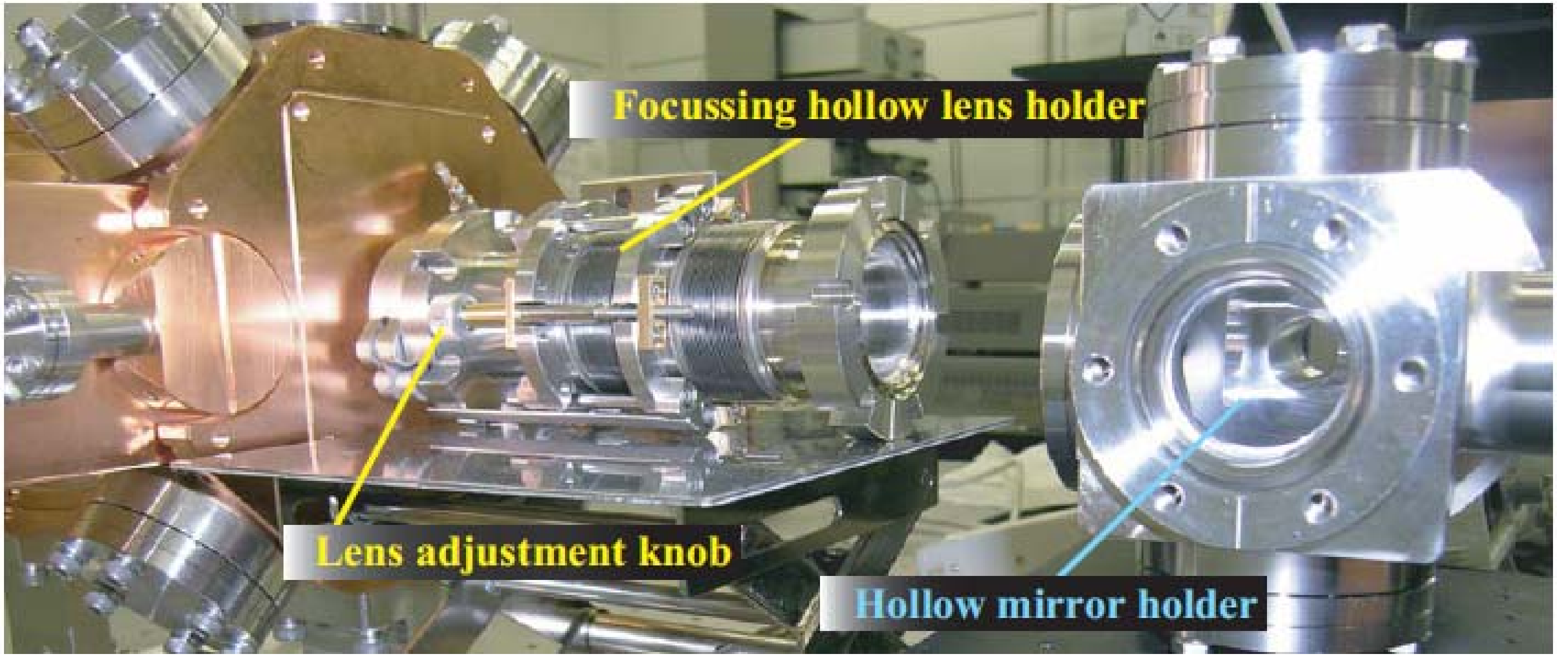
Generation of hollow laser beam



Z-polarization RF gun with laser–induced field gating (plane field emitter)

~Hollow beam incidence~



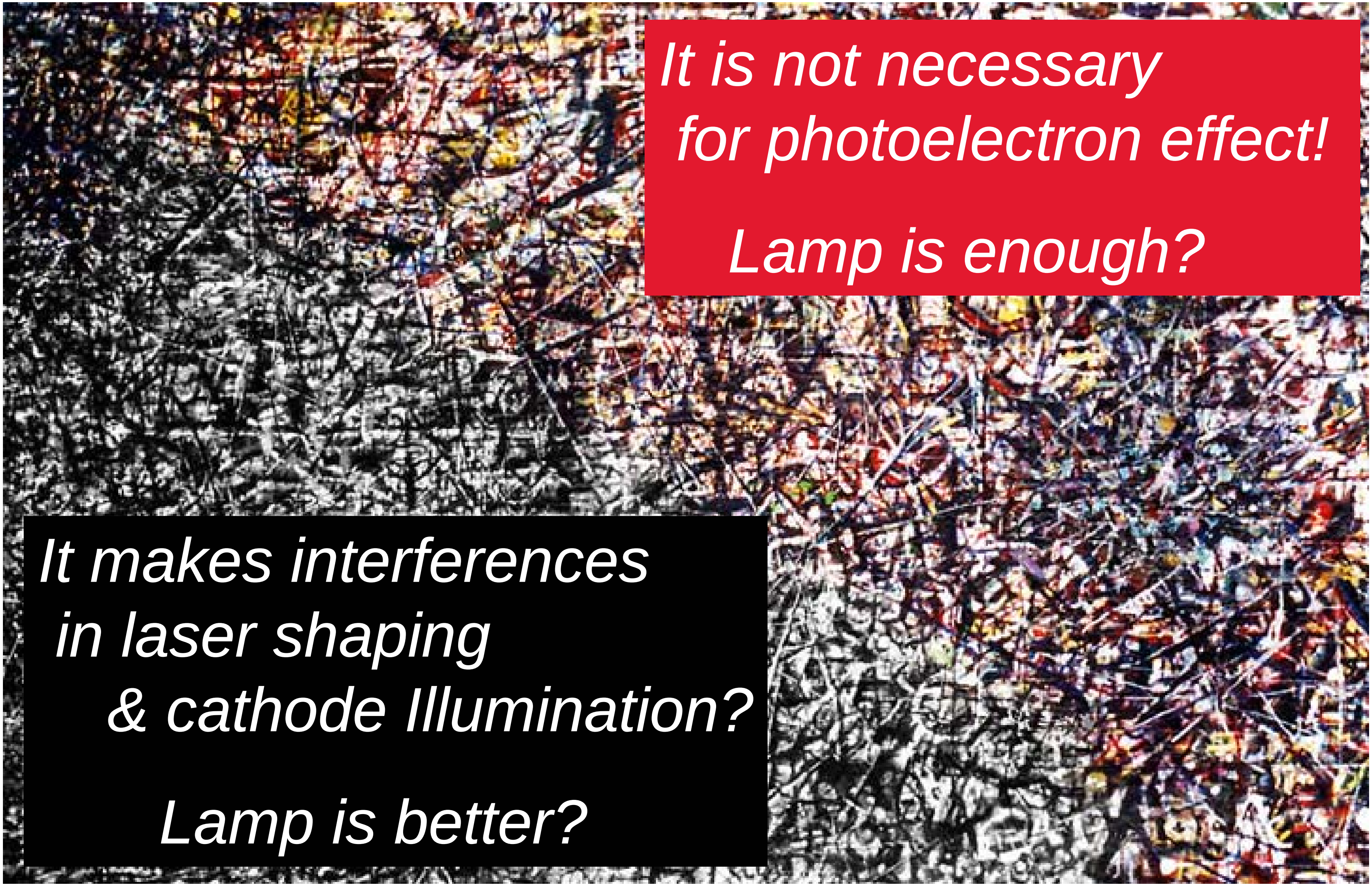


2. How should we make deal with Laser’s coherency?

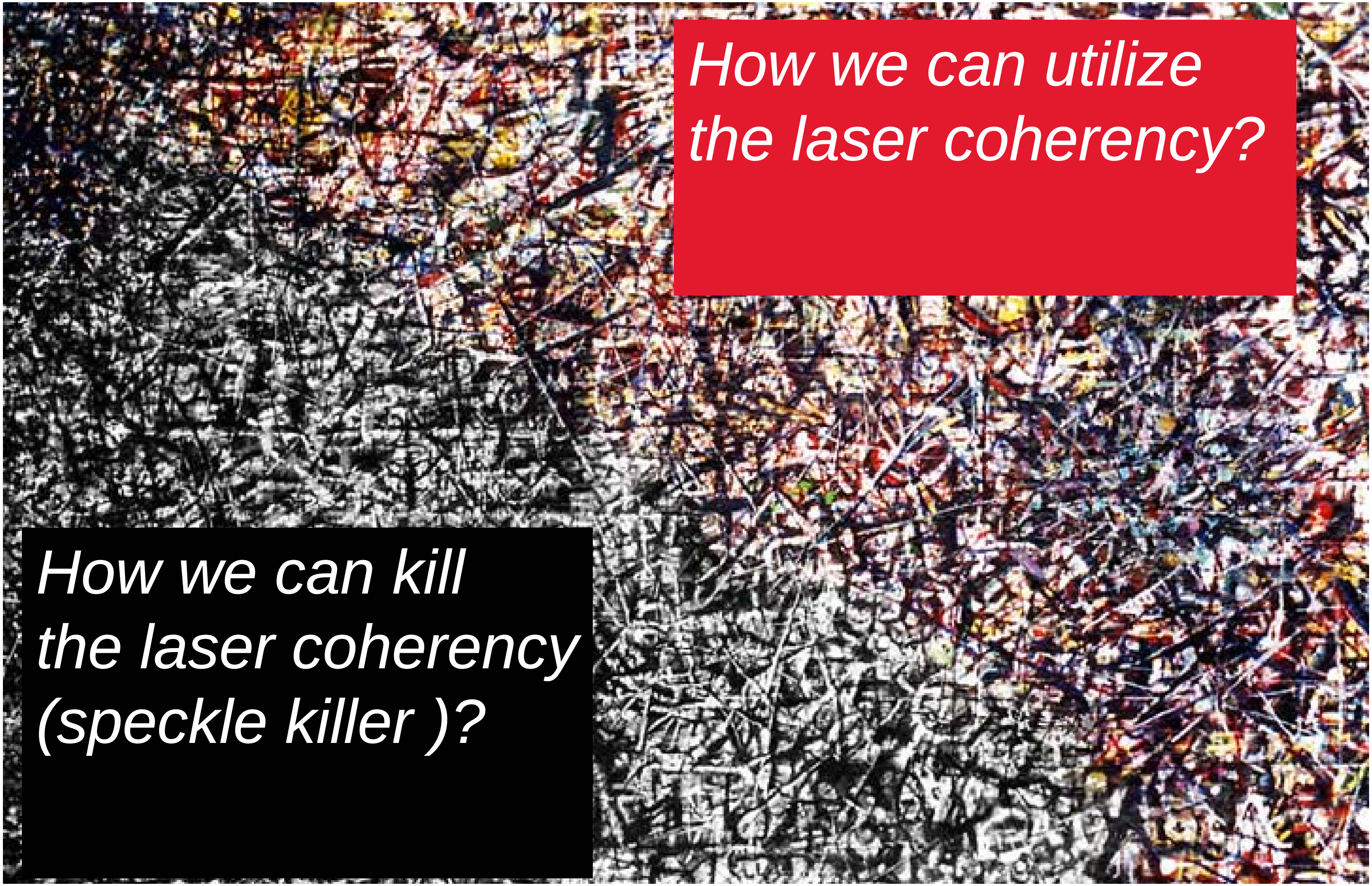
- 1.1 Kill coherency with fiber bundle to shape 3D-ellipsoidal for backward illumination
- 1.2 Utilize coherency with Z-polarization with hollow beam incidence

  (Schottky effect on the metal cathode)

Coherency of Laser is good or bad!?



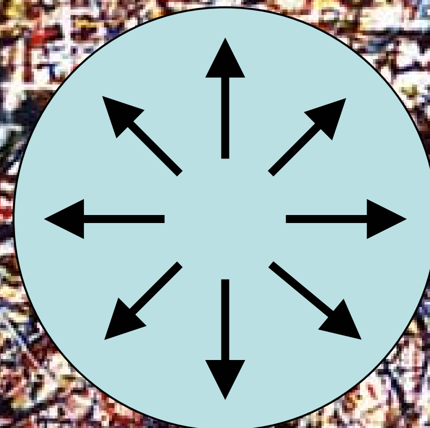
Coherency of Laser is good or bad!?



How we can utilize the laser coherency?

How we can kill the laser coherency (speckle killer)?

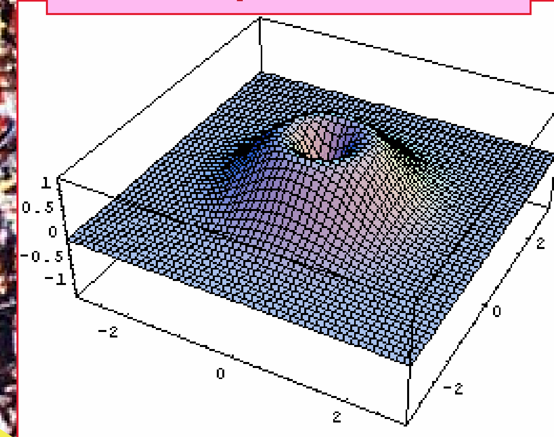
Coherency of Laser is good or bad!?

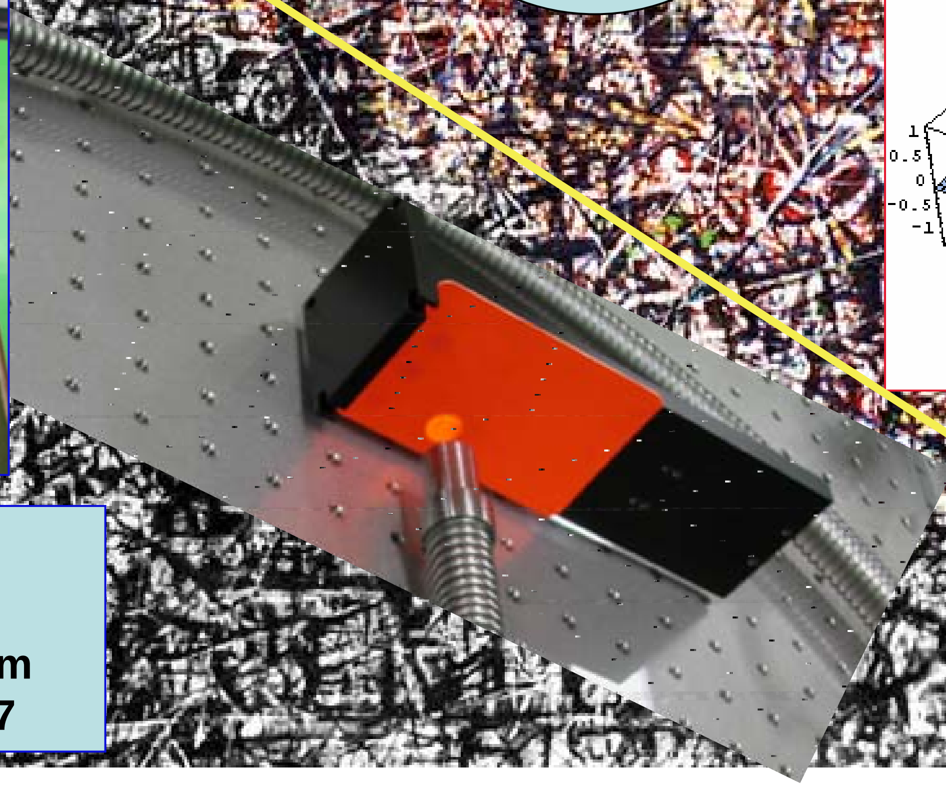


Z-polarization:

Field: ~GV/ m
Schottky ~2 eV

Radial polarization





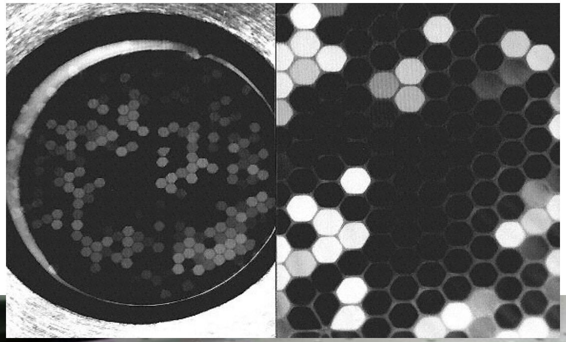
Fiber Bundle:

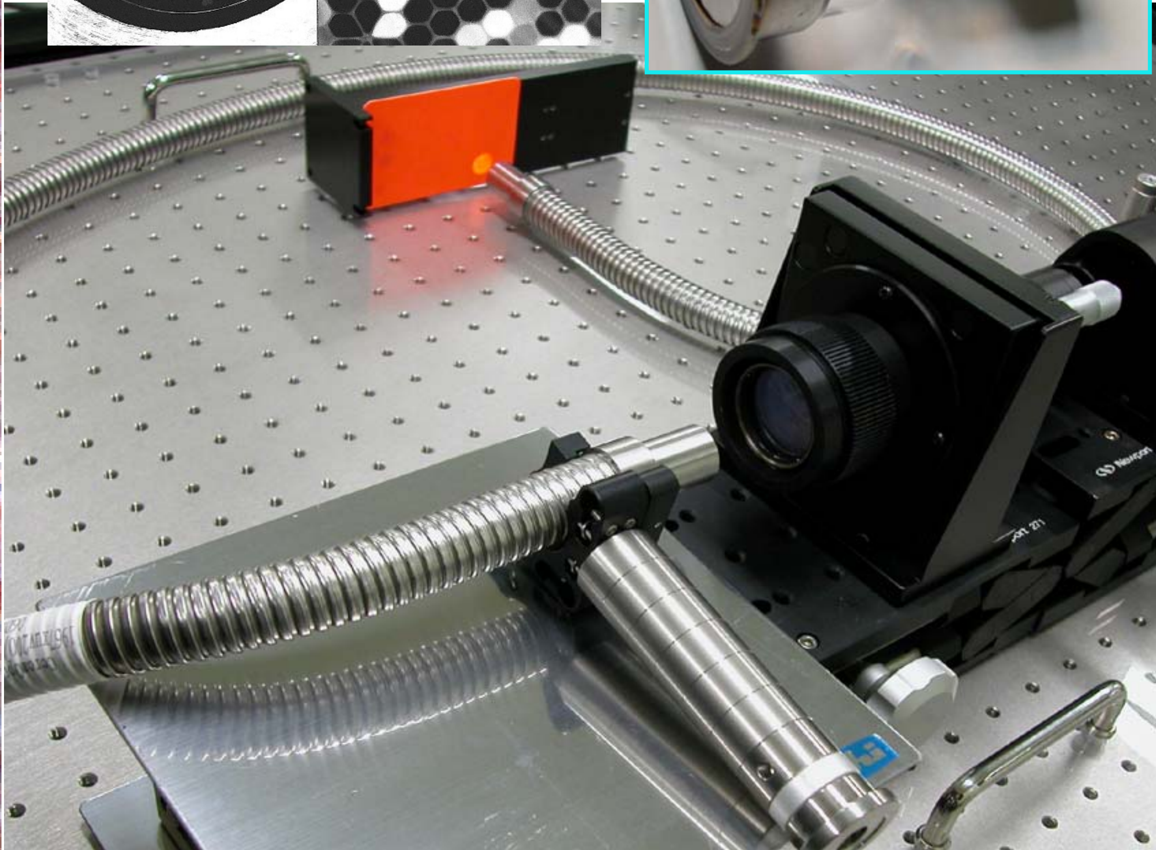
Length: 2.0 m
Bundle size 12 mm
No. of Fibers 1967

Kill) fiber bundle laser profile homogenizer with backward illumination (transparent cathode)

~ Transparent Cathode with Fiber Bundle ~

Pulse Stacking with 2,000 different Optical Passes

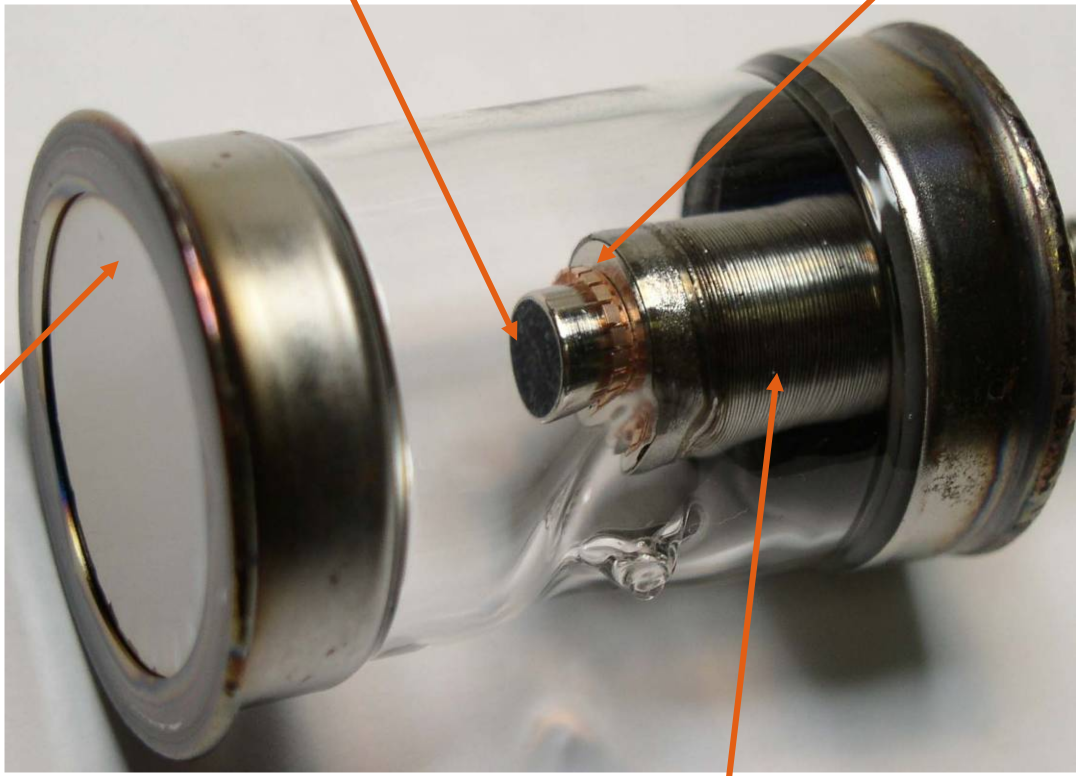




Cartridge-type Cathode

Cathode plug

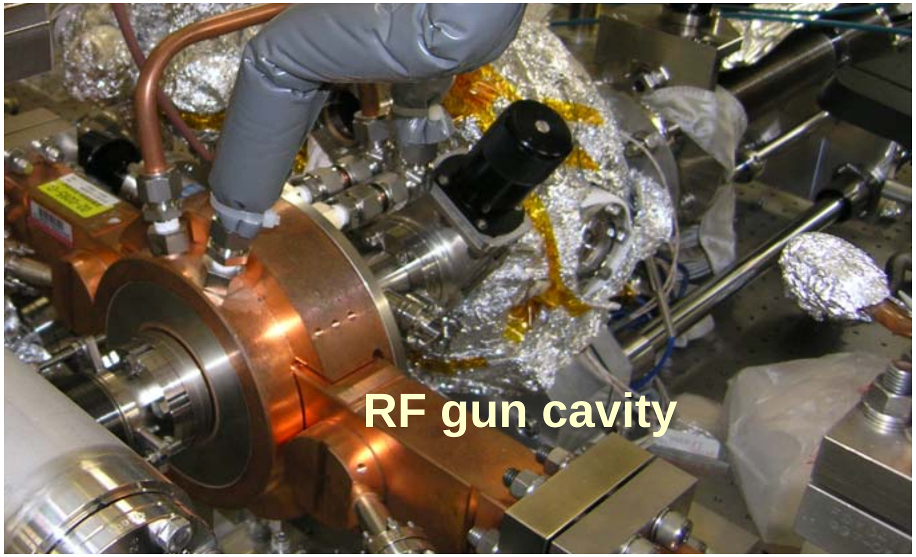
RF contact (Cu-Be)



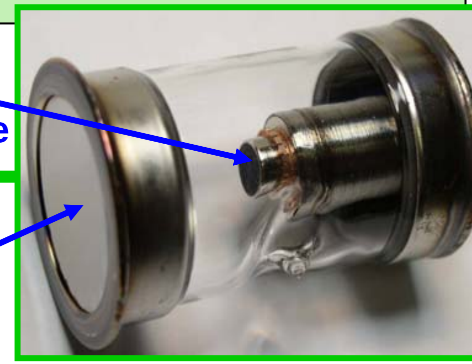
Kovar Foil

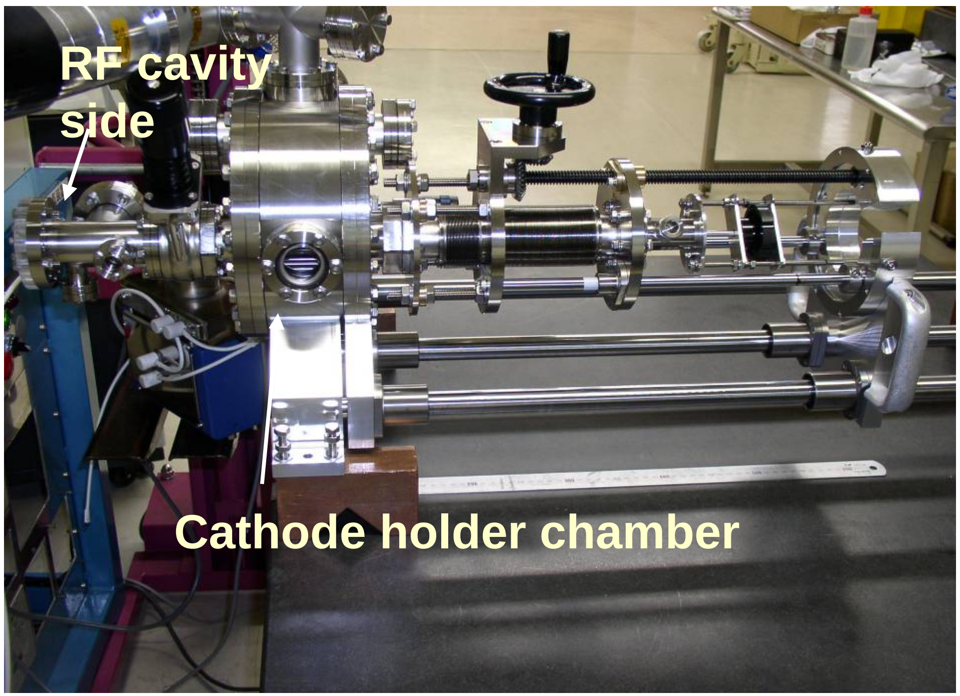
Vacuum Bellows

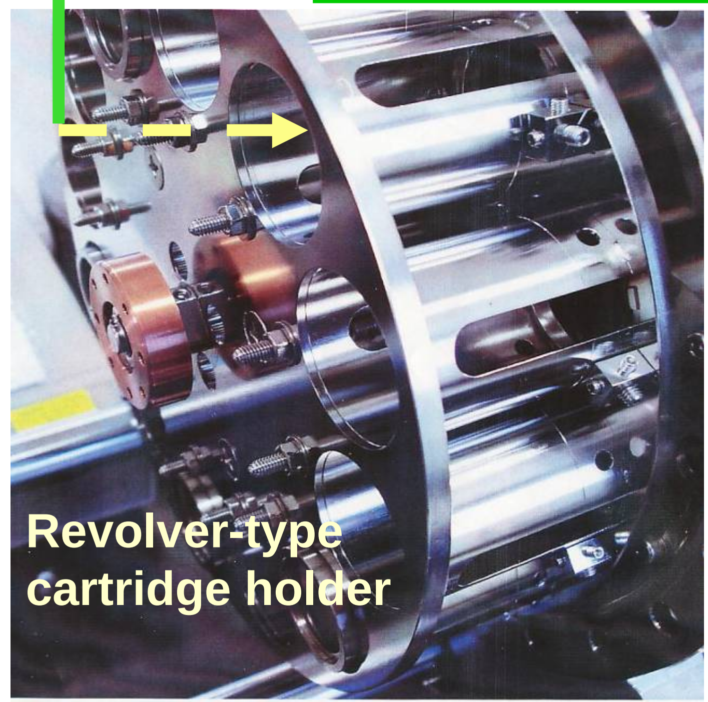
Experiment setup for different cathode test



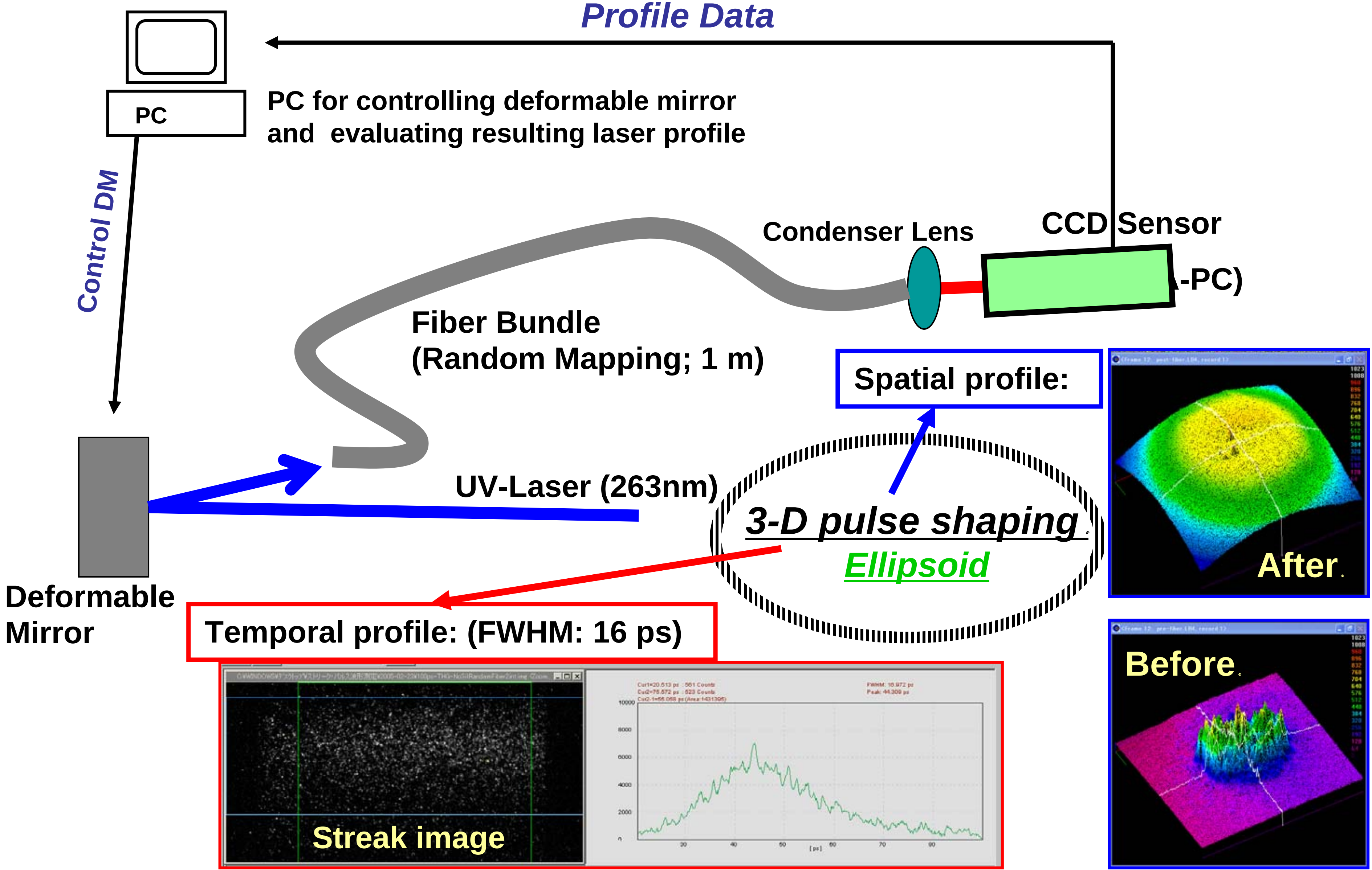
Cartridge type cathode holder accommodates up to 12 cartridges







Closed Control System for Fiber Bundle with computer-aided Deformable mirror

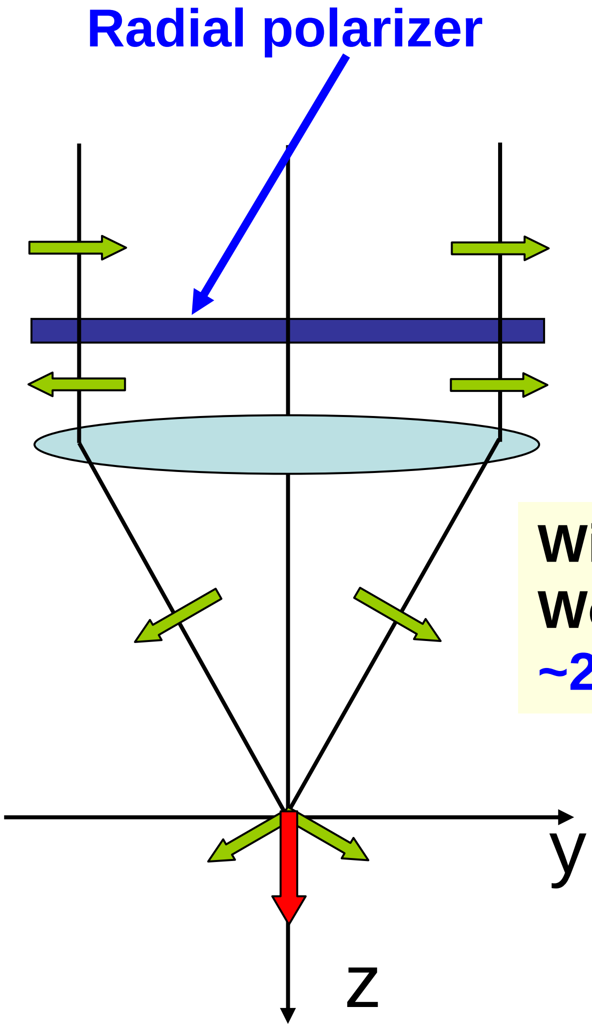


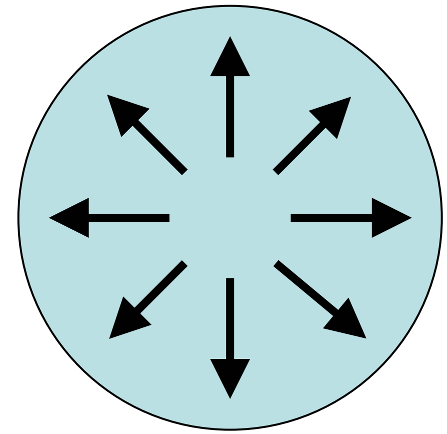
Short Summary of Laser shaping

- Shaping with computer-aided deformable mirror could generate Flattop. It is very flexible to optimize the spatial profile with genetic algorithm. Combining with pulse stacker, 3D- laser pulse shaper was completed.
- Fiber Bundle is ideal as a 3D-shaper (patent)
  - It is very simple to shape : You have to optimize the length of the Bundle for aimed pulse duration: 15 ps ~ 1-m long
  - 3D-laser profile: It can generate ellipsoidal from any profile.
  - Short working distance: It needs to develop back illumination.
  - Laser fluence limit: Laser fluence @ 100 fs <1.5 mJ/cm2

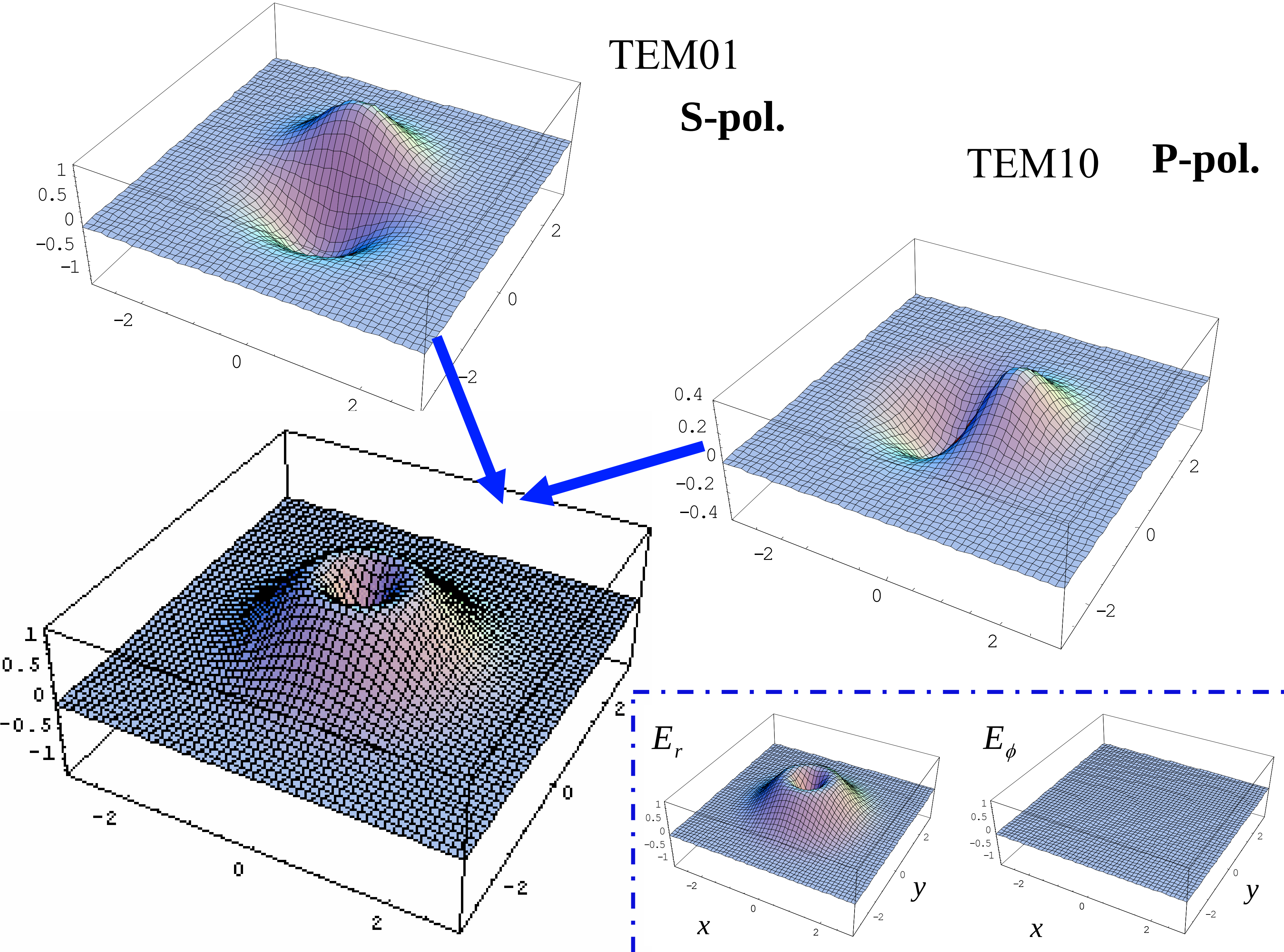
    It is possible to use as 3D-shaper down to 60 nJ/pulse.
- Transparent cathode for shaping complex system with fixed fiber bundle & adjustable deformable mirror might have a lot of possibilities with fine tuning.

Use) Z-polarized laser on the cathode & field emission with Schotkky effect (It's not proved yet!)



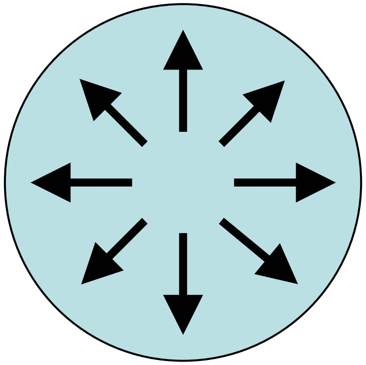


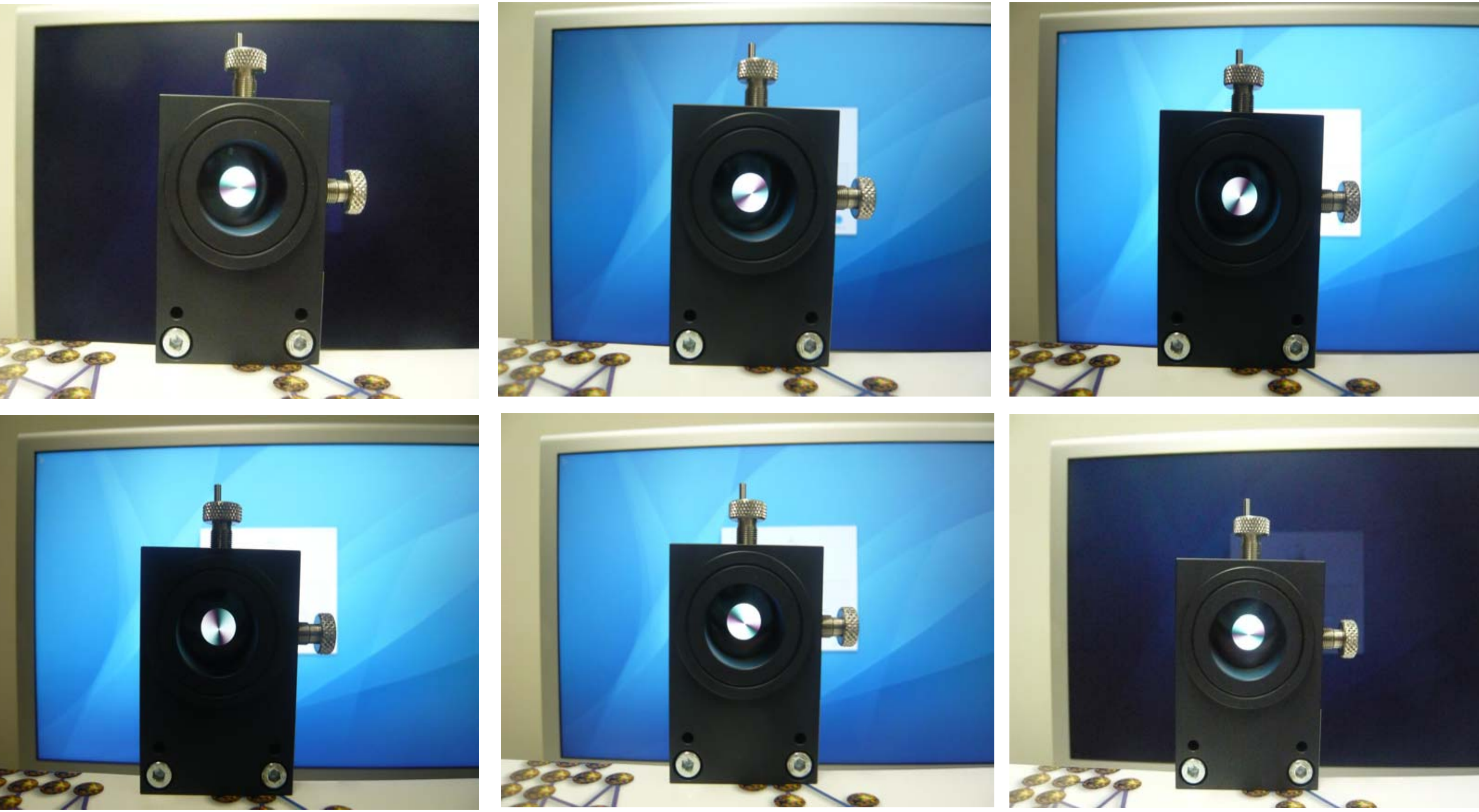
With 1GV/m field, Work function reduces ~2eV.



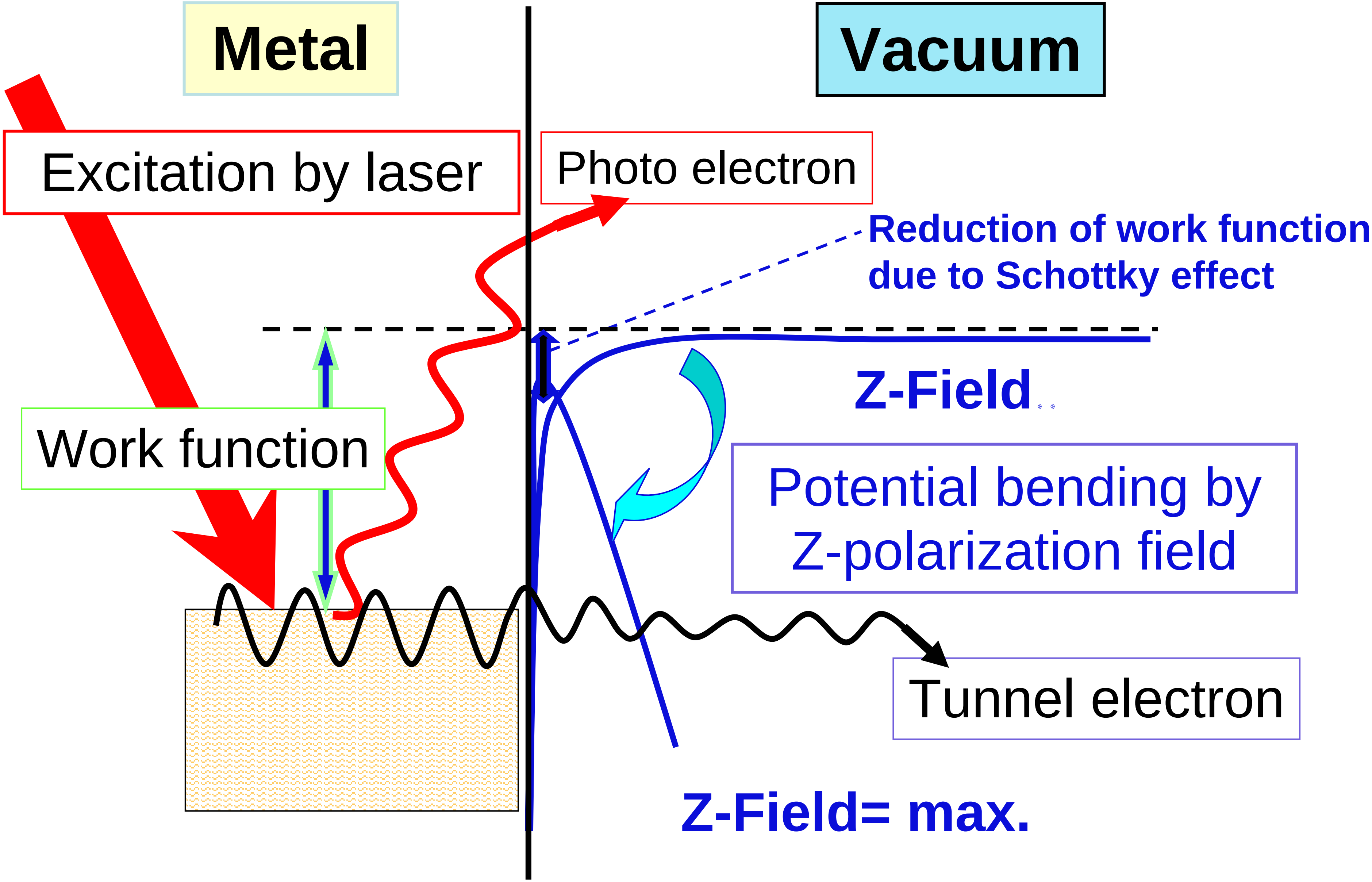
TEM01
S-pol.
TEM10
P-pol.
E_r
E_ϕ
x
y
x
y

Demonstration of Radial polarization



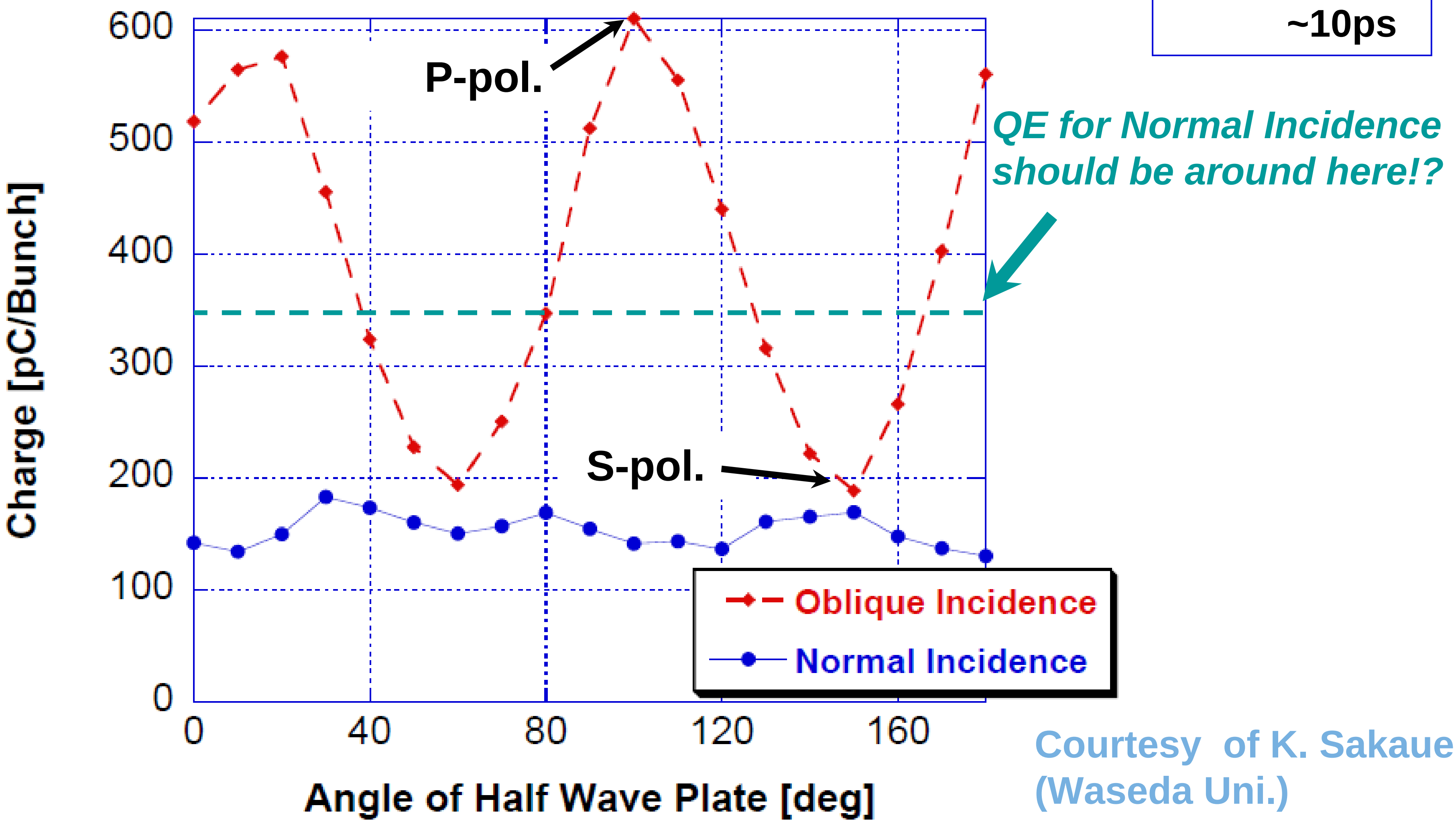


Is the response of metal cathode femtosecond ?



Incident angle dependency of QE (Cu)
Comparison between Normal & Oblique incidence between S & P polarization

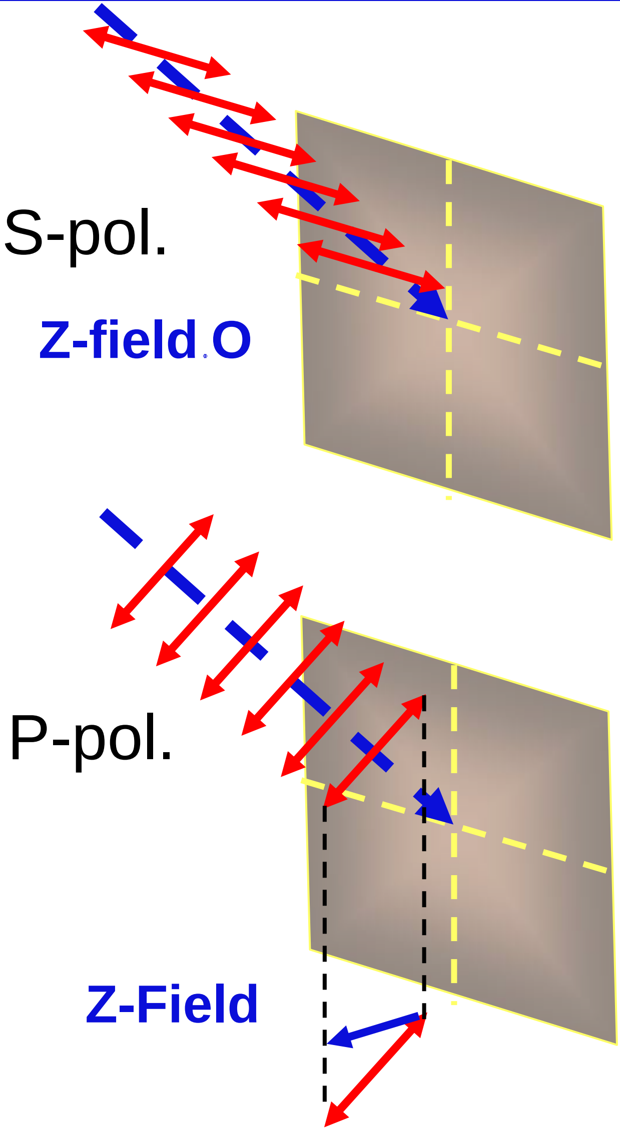
Laser: 165 uJ
~10ps

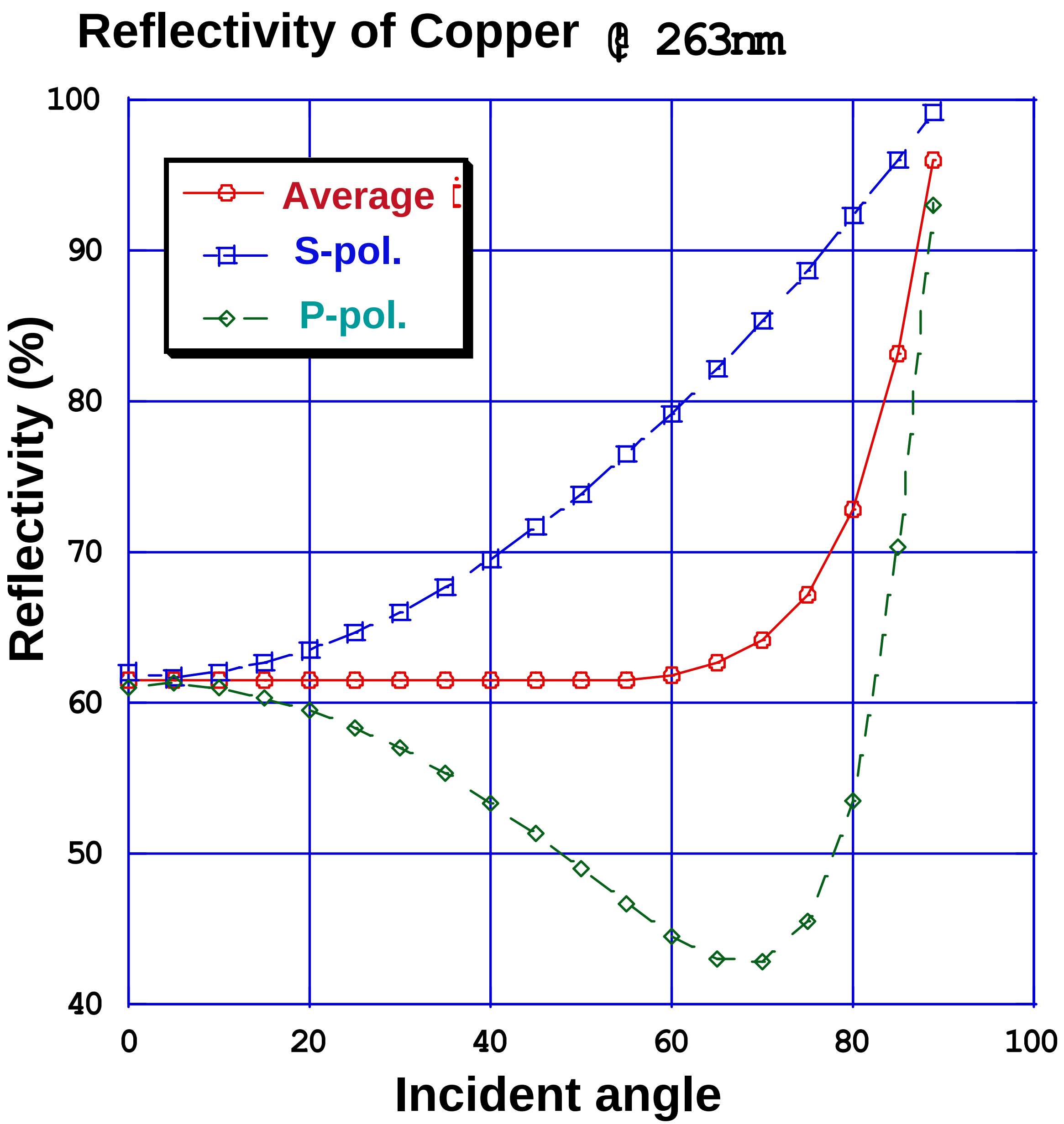


Courtesy of K. Sakaue (Waseda Uni.)

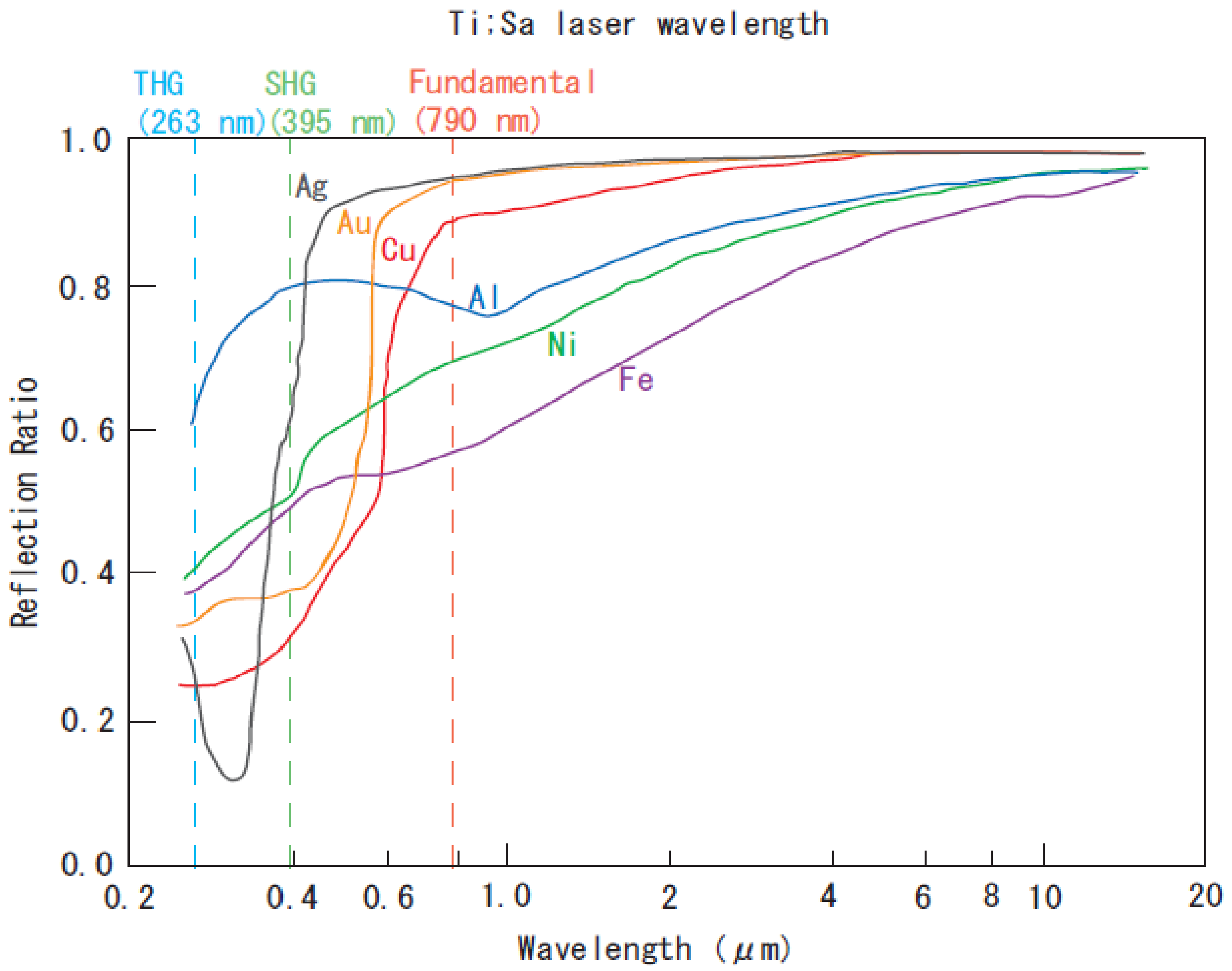
Incident angle dependence of reflectivity (Cu)

Why oblique incidence higher QE than normal





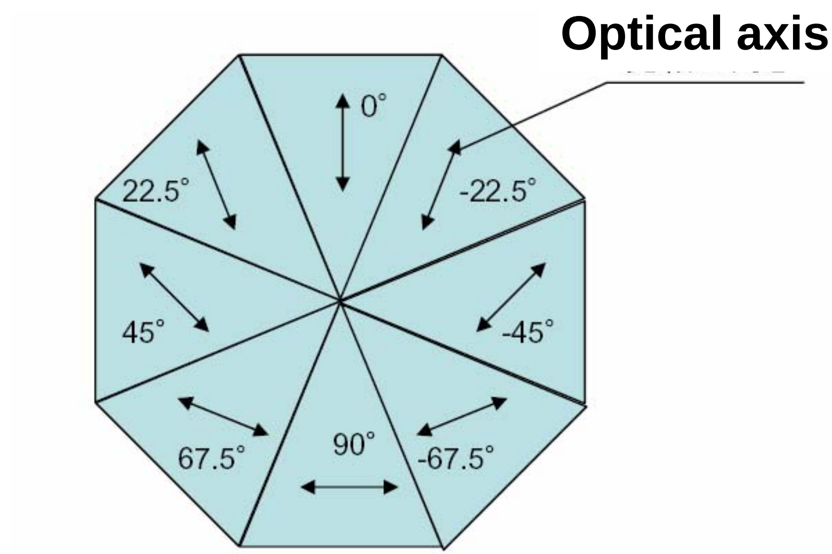
Reflection ratio of robust cathode candidates



Simplest radial polarizer: divided waveplate

(a) 8-divided waveplate

(b) 8-divided waveplate

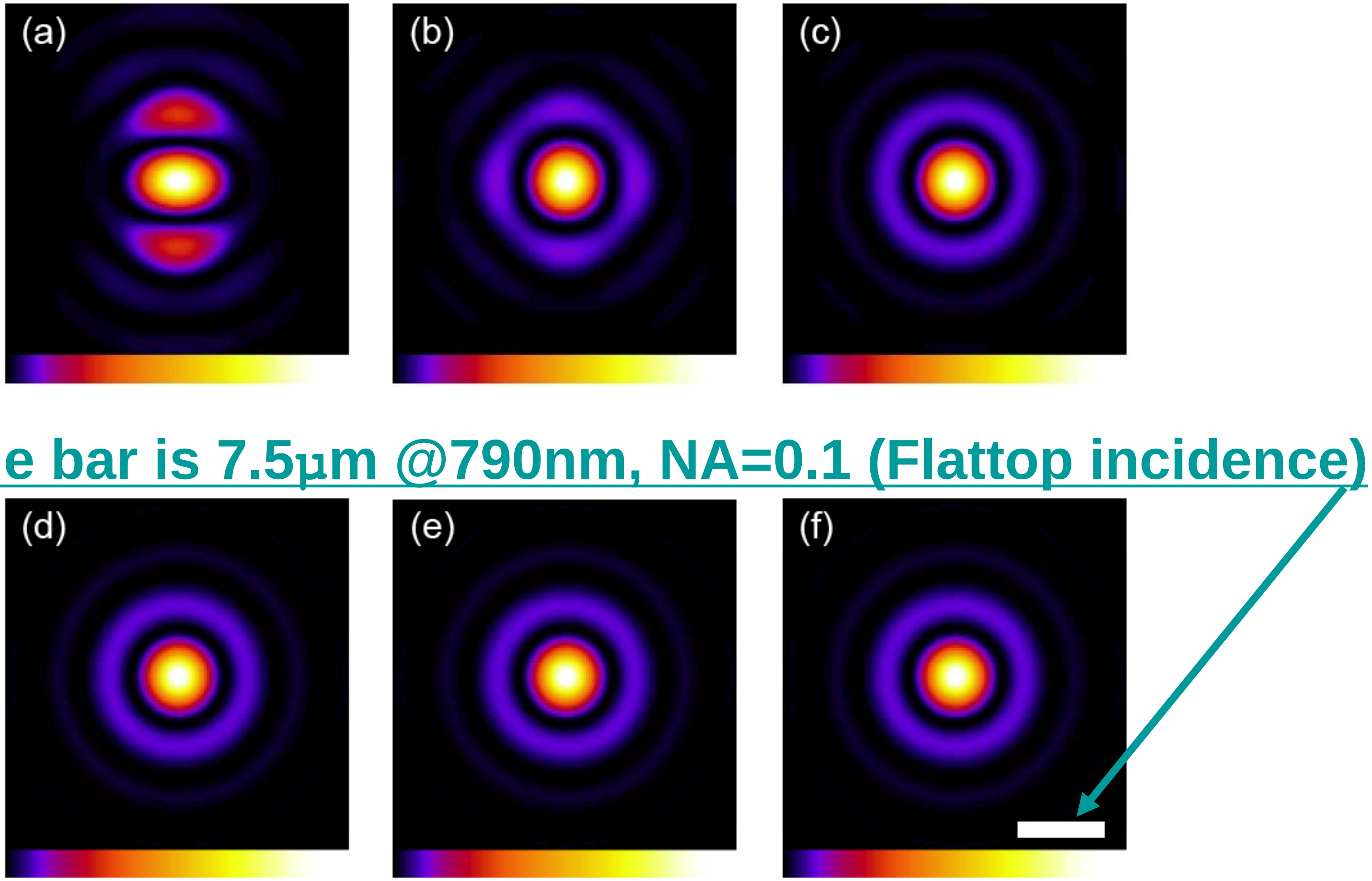


(c) 4-divided waveplate

(d) 8-divided waveplate

Z-polarization field on the cathode:

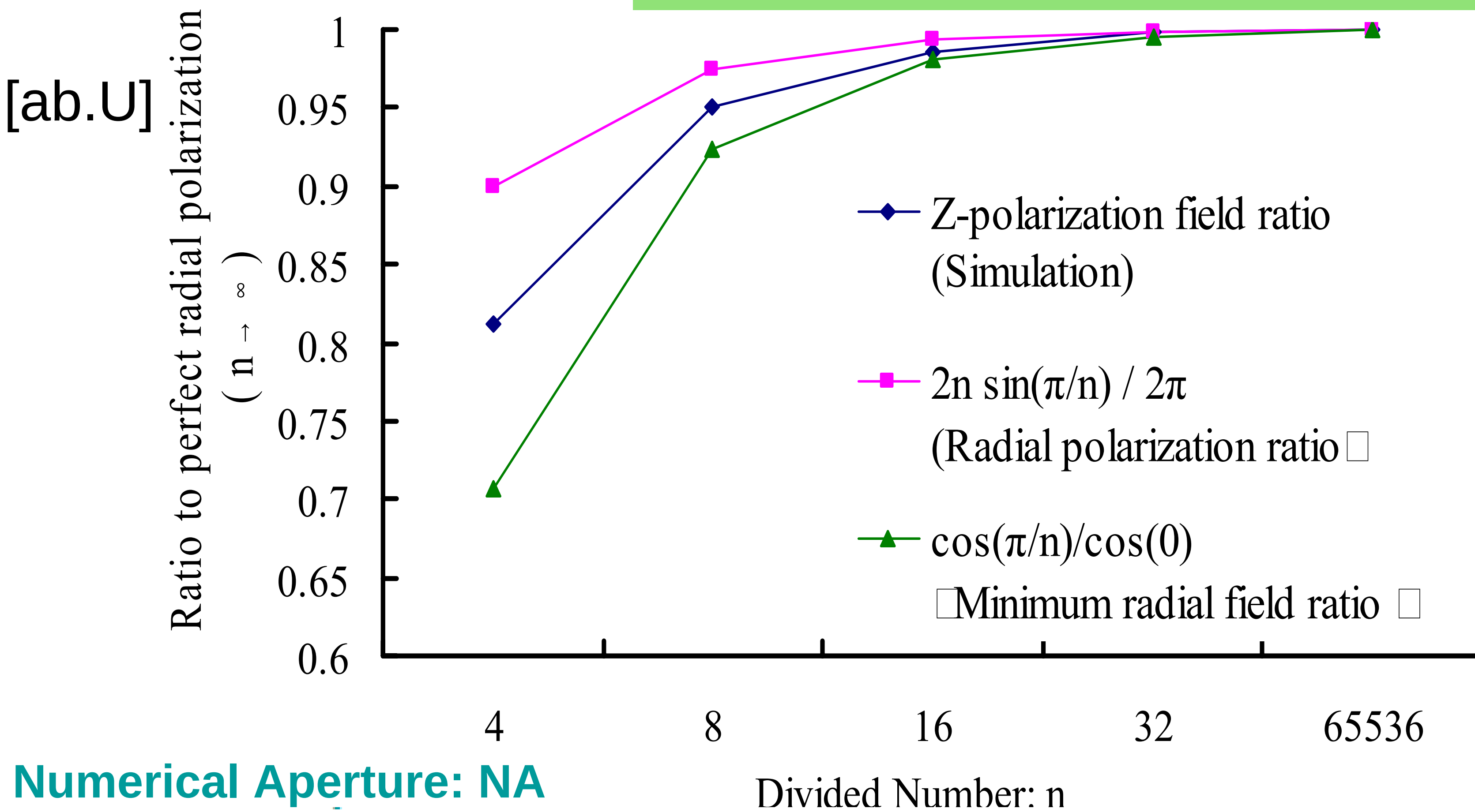
Divided number(2~32) dependence



Using divided waveplate, the distribution of strength of Z-polarization field $|E|^2$: (a)2-divied, (b)4-divided, (c)8-divided, (d)16-divided, (e)32-divided, (f) perfect radial polarization (n: infinity)

Z-polarization ratio with divided waveplate

More than n=8, ideal radial polarization



Numerical Aperture: NA

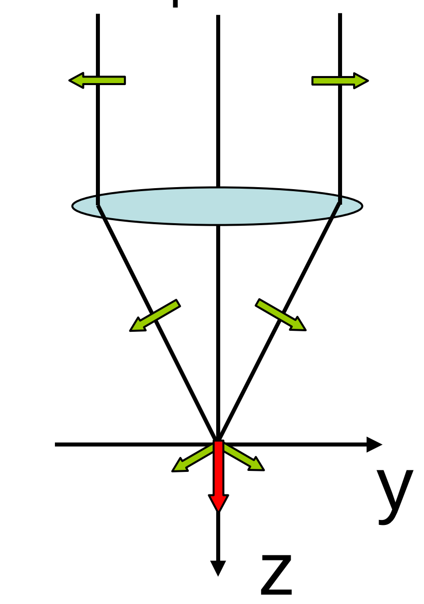
- The strength of Z-polarization field $\propto$ **1/(Wavelnrgth:λ)^2**
- The strength of Z-polarization field $\propto$ **(NA)^4**

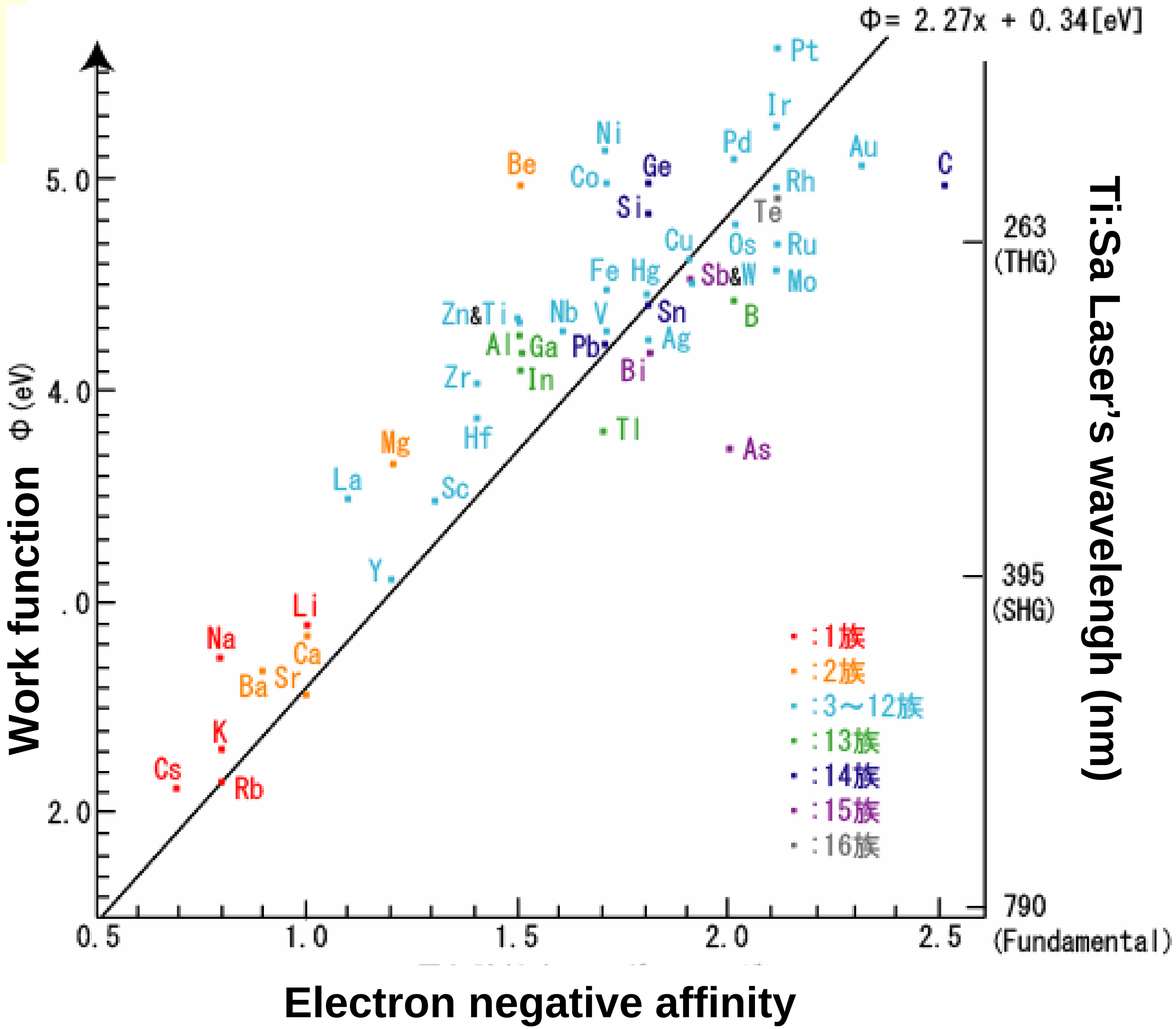
  $\propto$ **1/(Focus length)^4**

Work function of various metal cathode

With 1GV/m field, Work function reduces ~2eV.

Radial polarization





History & future plan of Z-polarization gun

2006 **1. Z-polarization gun & Hollow beam incidence method were proposed.**

2007 **2. Radial Polarizer, Axicon lens pair & their Optical coatings were developed & tested.**

Preparing Optics

Feasibility study

2008 **3. Feasibility test of Hollow incidence & electron emission with Z-polarization.**

2009 ~2010 **4. Feasibility test of Low-emittance beam generation & selection of ideal cathode.**

Feasibility test plan

(1) We can switch radial (max. Z-field) to azimuth (zero Z-field) with rotating half waveplate!

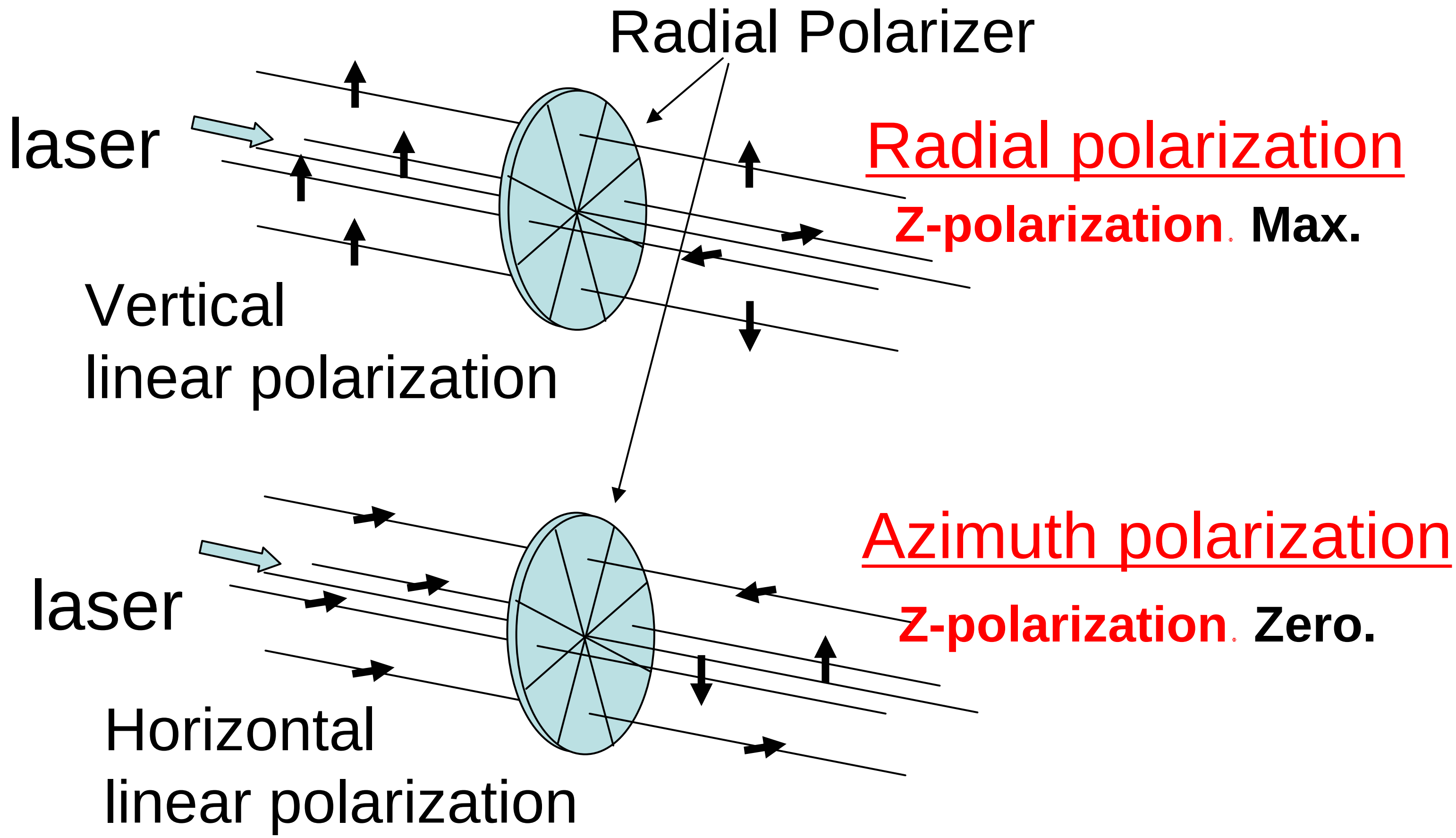
(2) Comparison between radial and azimuth polarization can tell Z-polarization effect on the cathode (The first test will be with copper cathode).

(3) Using cartridge type cathode (revolver RF gun), different metal cathode material (even for transparent & NEA- cathode) will be tested. We can find best material for this purpose.

(4) Gating laser pulse and photo emission laser source will be separated (in some cases) to optimized for Z-polarization gun (even for polarized electron source).

Feasibility test for Z-polarization effect

(Comparison between radial & azimuth polarization)



(1) **We can switch radial to azimuth with rotating half waveplate!**

(2) **Comparison between radial and azimuth polarization can tell Z-polarization effect on the cathode.**

Summary of Z-polarization

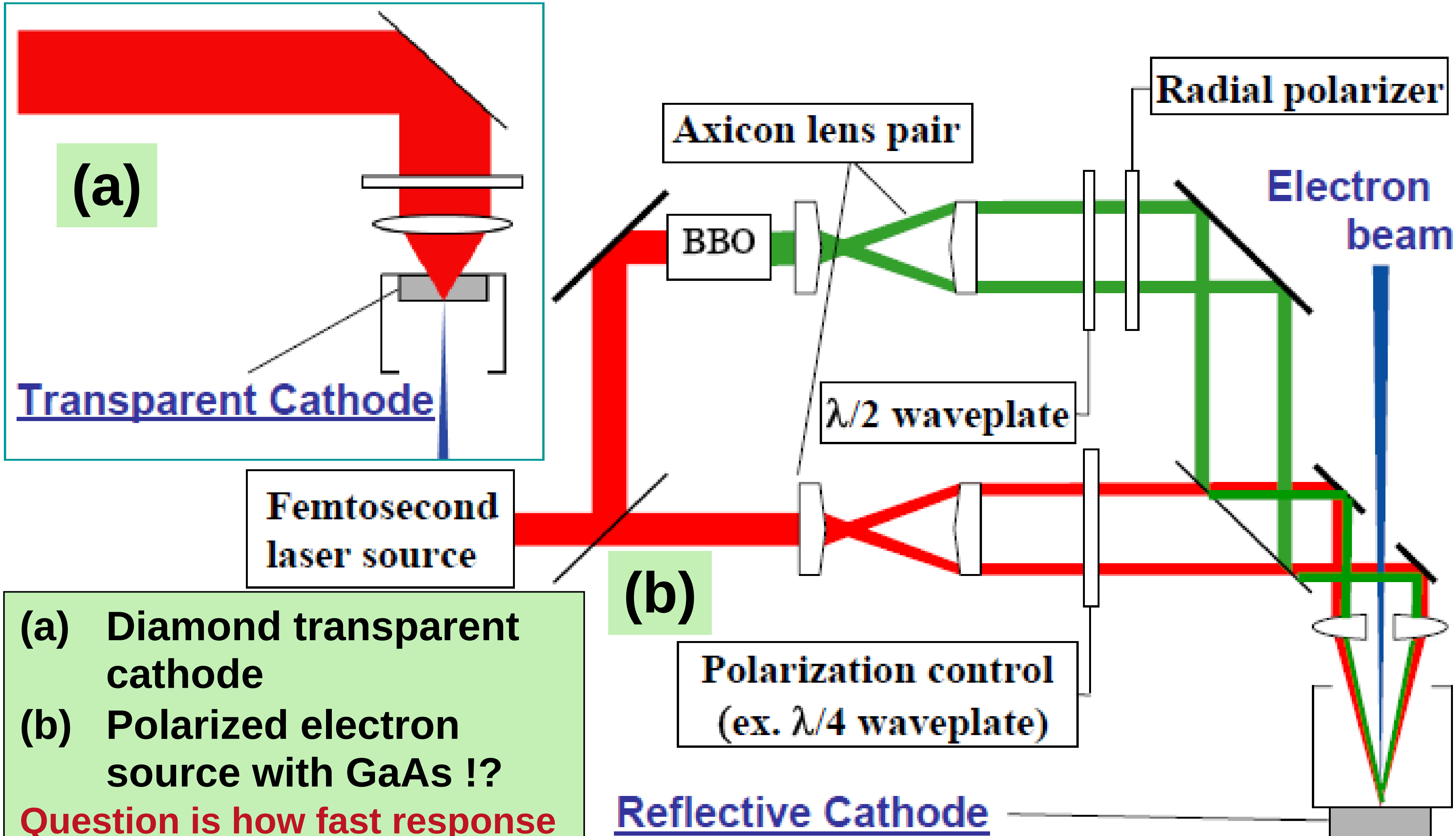
The generated Z-polarization can exceed an electrical field of 1 GV/m easily with fundamental wavelength from femtosecond laser oscillator (with long cavity).

According to our calculations (NA=0.15), the Z-field of 1 GV/m needs **1.2 MW** at peak power for **fundamental (790 nm)** and **0.31 MW** for **SHG**. In the field of 1 GV/m, the work function of copper cathode reduces ~2 eV.

It makes possible to drive copper cathode (normally need <288 nm) with **SHG (395 nm)**, robust diamond NEA-cathode (normally <226 nm) with **THG (263 nm**

This concept of laser-induced Schottky emission can be applied for photocathode DC gun (even for polarized electron source!?). We showed some designs for them.

Variation of Z-polarization RF gun with laser –induced field gating (plane field emitter)



(a) Diamond transparent cathode

(b) Polarized electron source with GaAs !?

Question is how fast response of photo cathode!