# Searching for Dark Matter Candidates with Compton Gamma-Sources

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# overview

- LIPSS DM Searches at JLAB FEL
  - hidden sector photons, millicharged particles, axion like particles, . . .
- FEL Compton Scattering
  - uses electron beam and laser light in FEL vault
  - lower mass boson search (up to ~25 keV)
- FEL beam dump
  - require modest excavation at FEL dump
  - higher mass boson search (above e+e- threshold)

# LIPSS at JLab collaboration

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Jefferson Lab

K. Beard

Muons, Inc

M. Minarni

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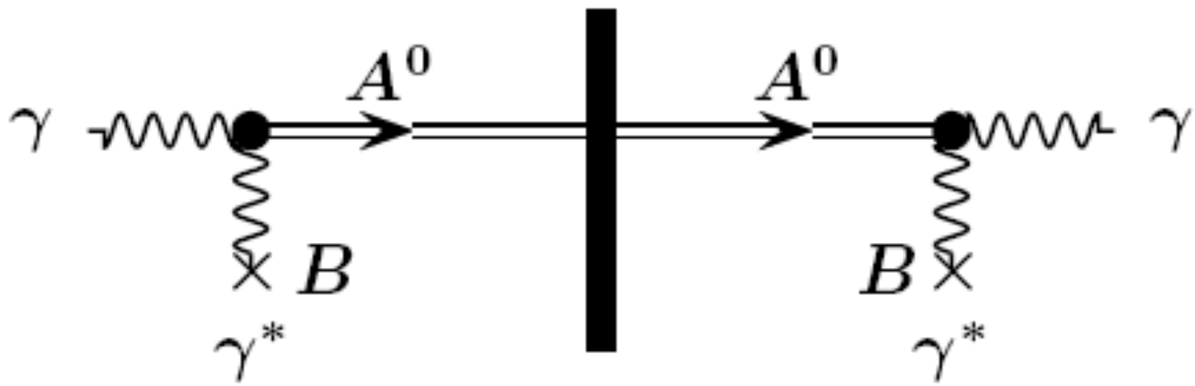
O.K. Baker, P. Slocum

Yale University

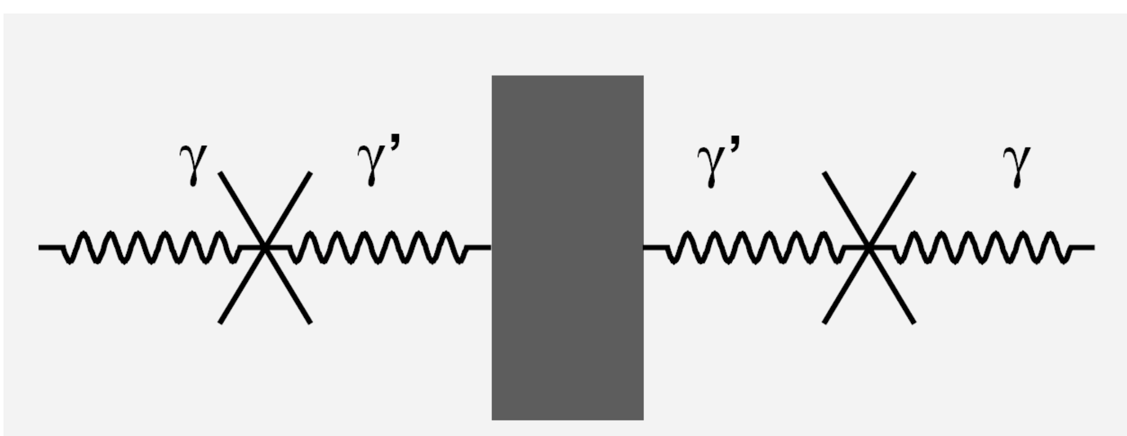
# light shining through a wall

**can suppress background by over 20 orders of magnitude ! ! !**

**kW lasers, ultra low noise detectors, . . .**



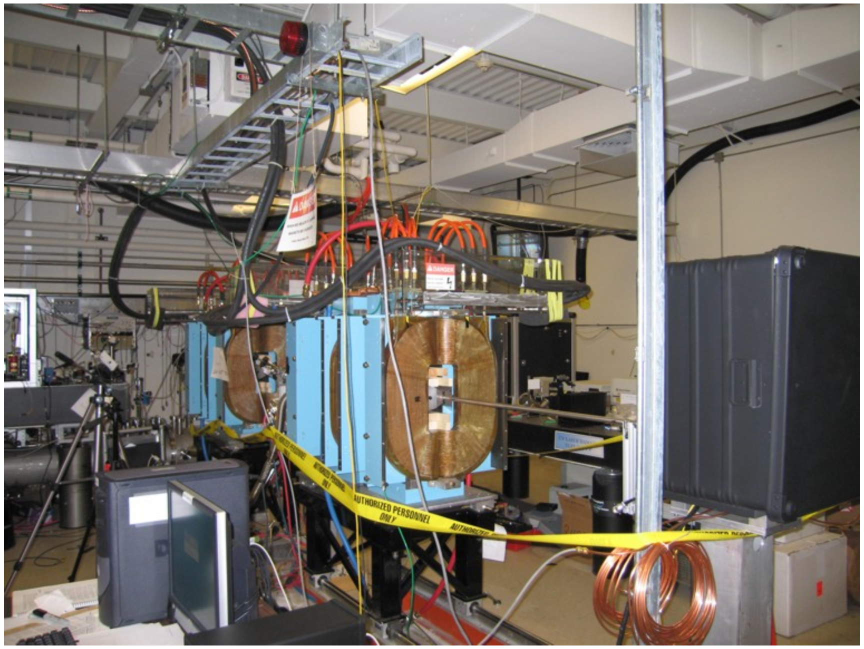

- couple polarized laser light with magnetic field
- Sikivie (1983); Ansel'm (1985); Van Bibber et al (1987)

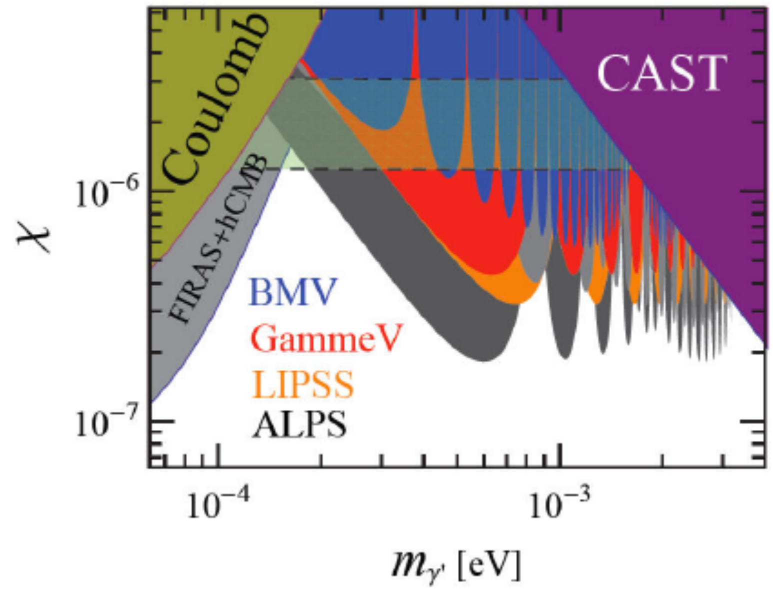


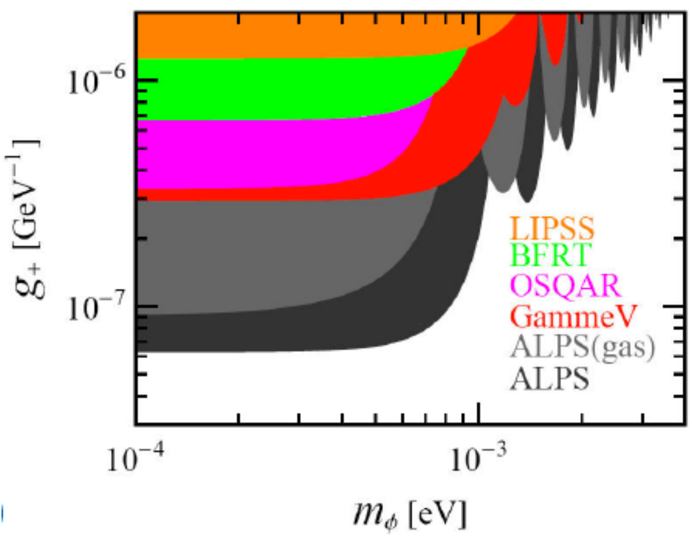

- kinetic mixing
- no magnetic field
- Afanasev et al (2009)

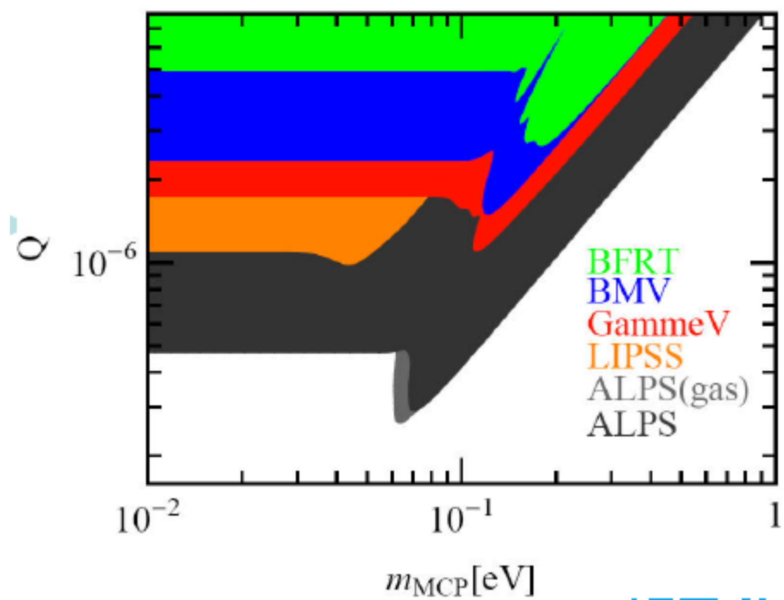
# LIPSS at FEL Lab

Afanasev et al, Phys. Rev. Lett. 101, 120401

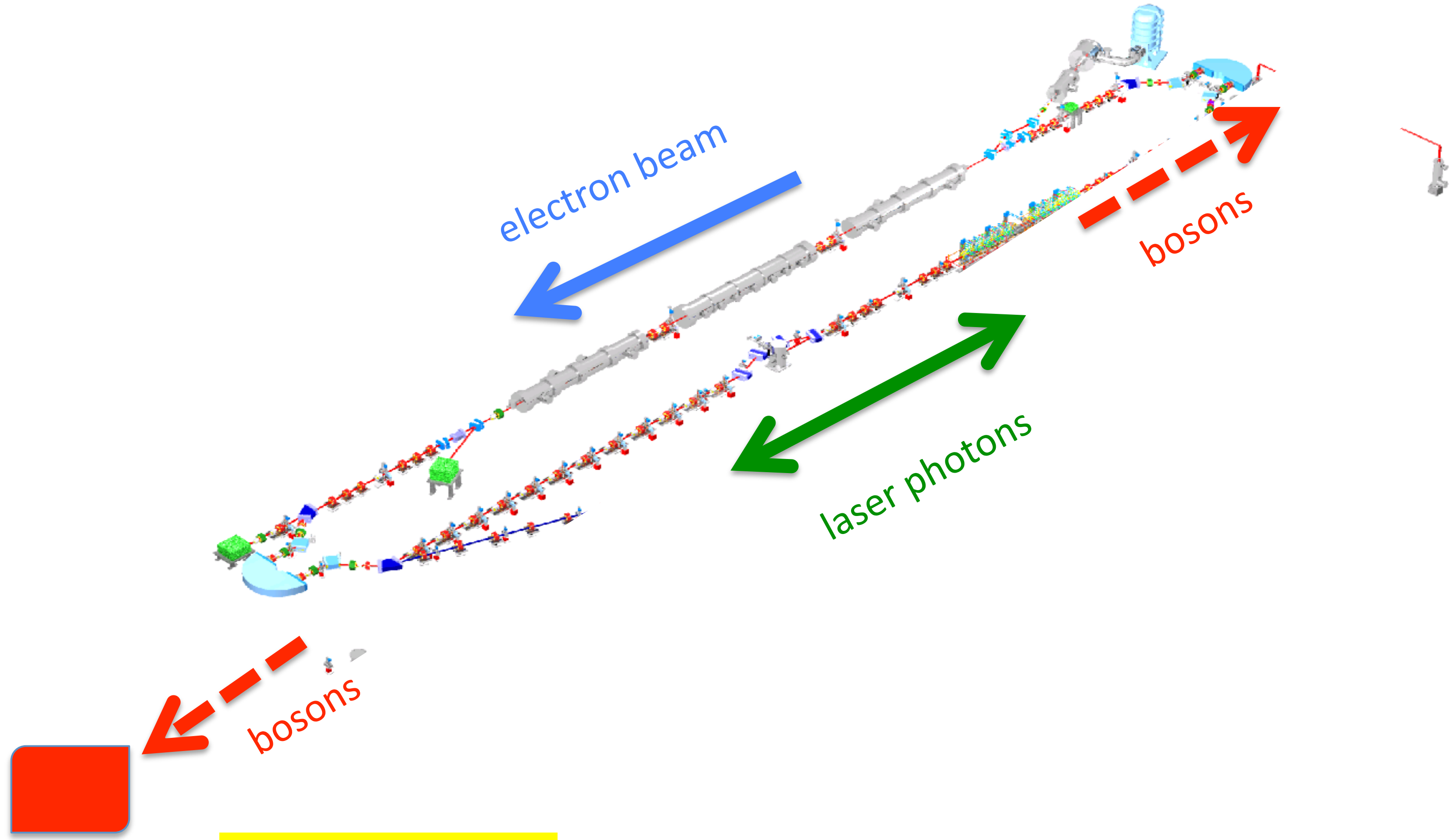




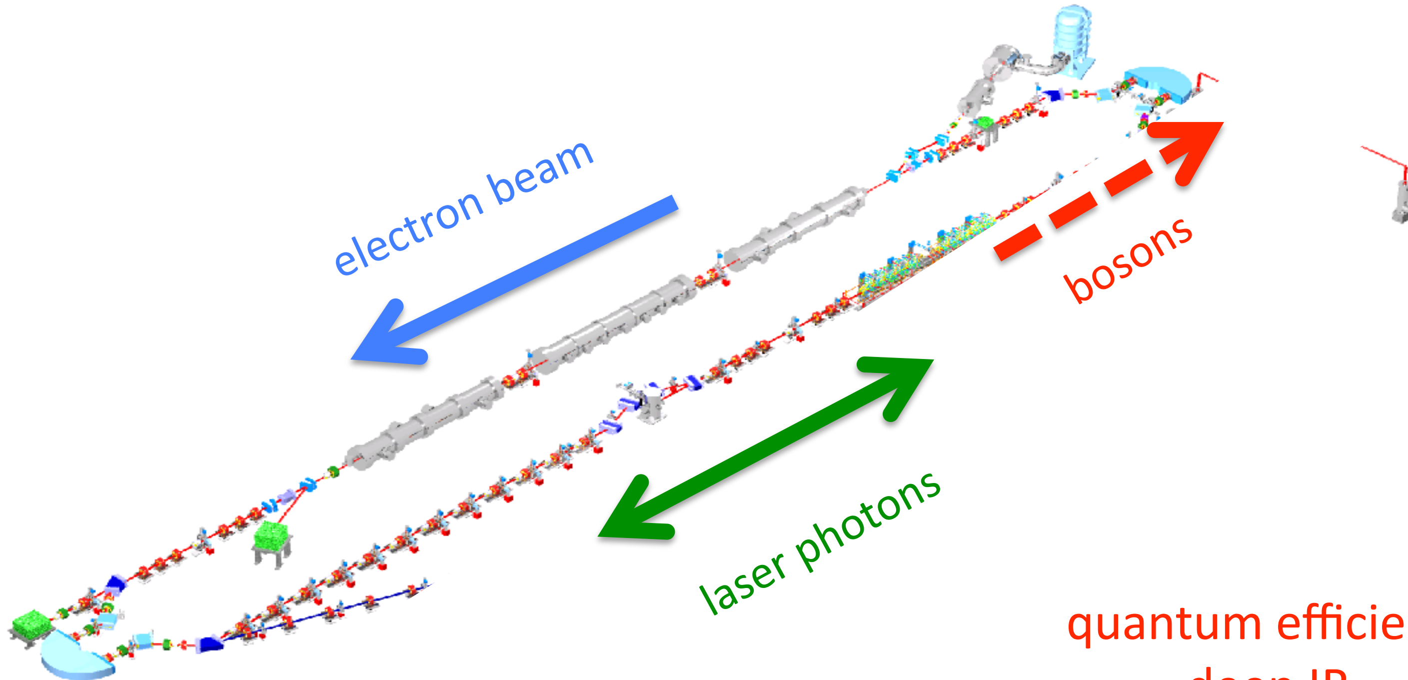
# photon-boson kinetic mixing; next steps



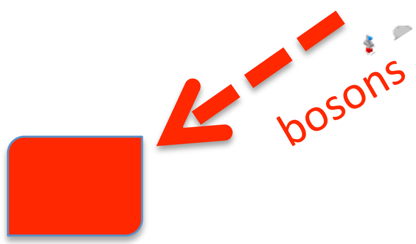

LIPSS 2

detector in line with cavity

# photon-boson kinetic mixing; next steps

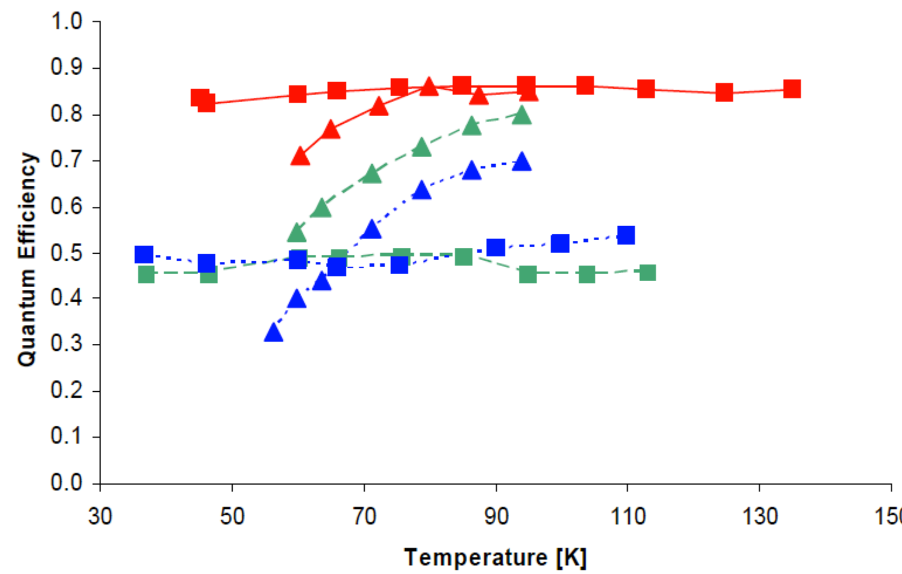



quantum efficiency;
deep IR

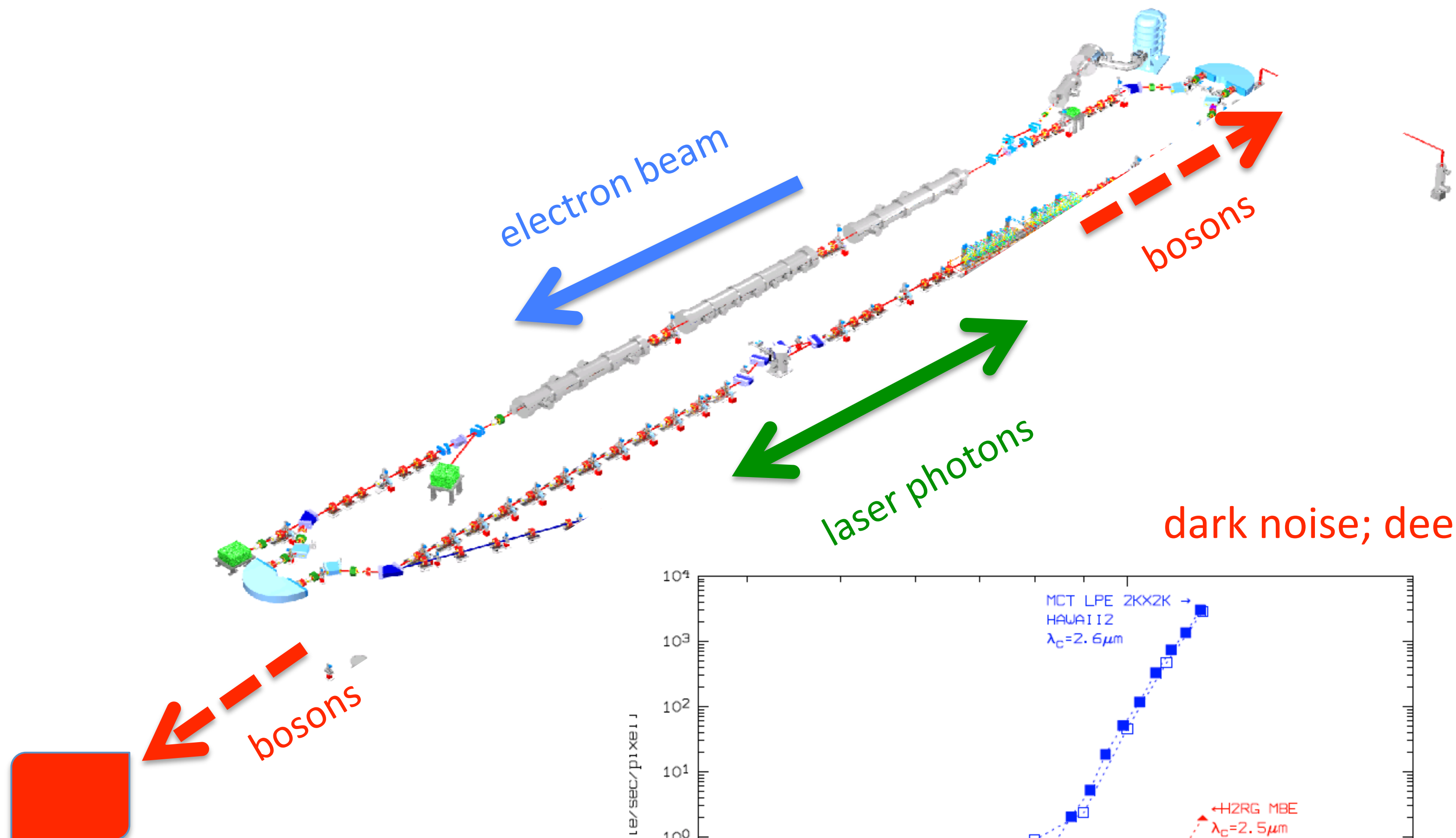



LIPSS 2

1.6 micron CCD
camera HgCdTe
ROCKWELL



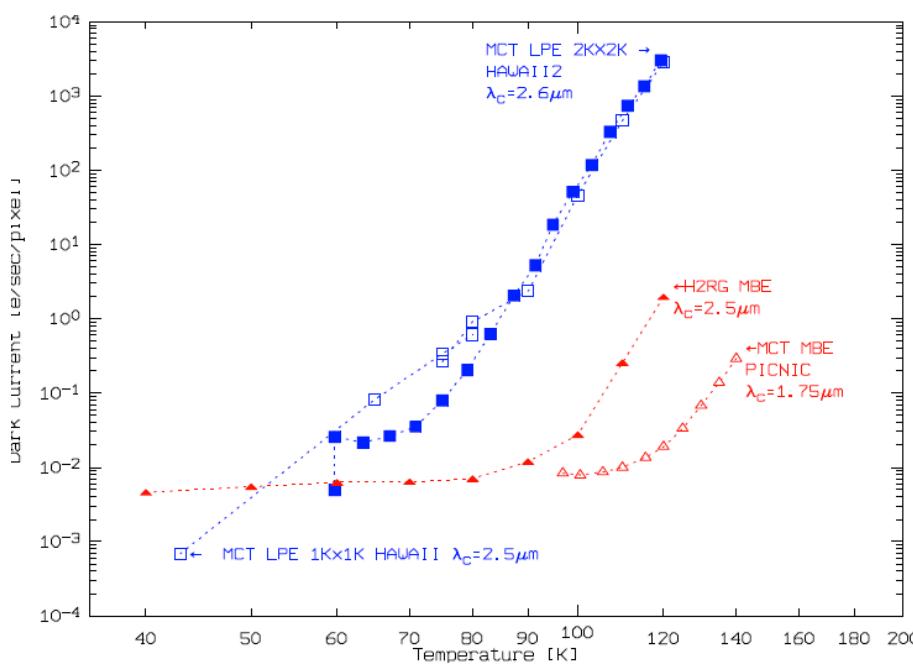
# photon-boson kinetic mixing; next steps




LIPSS 2

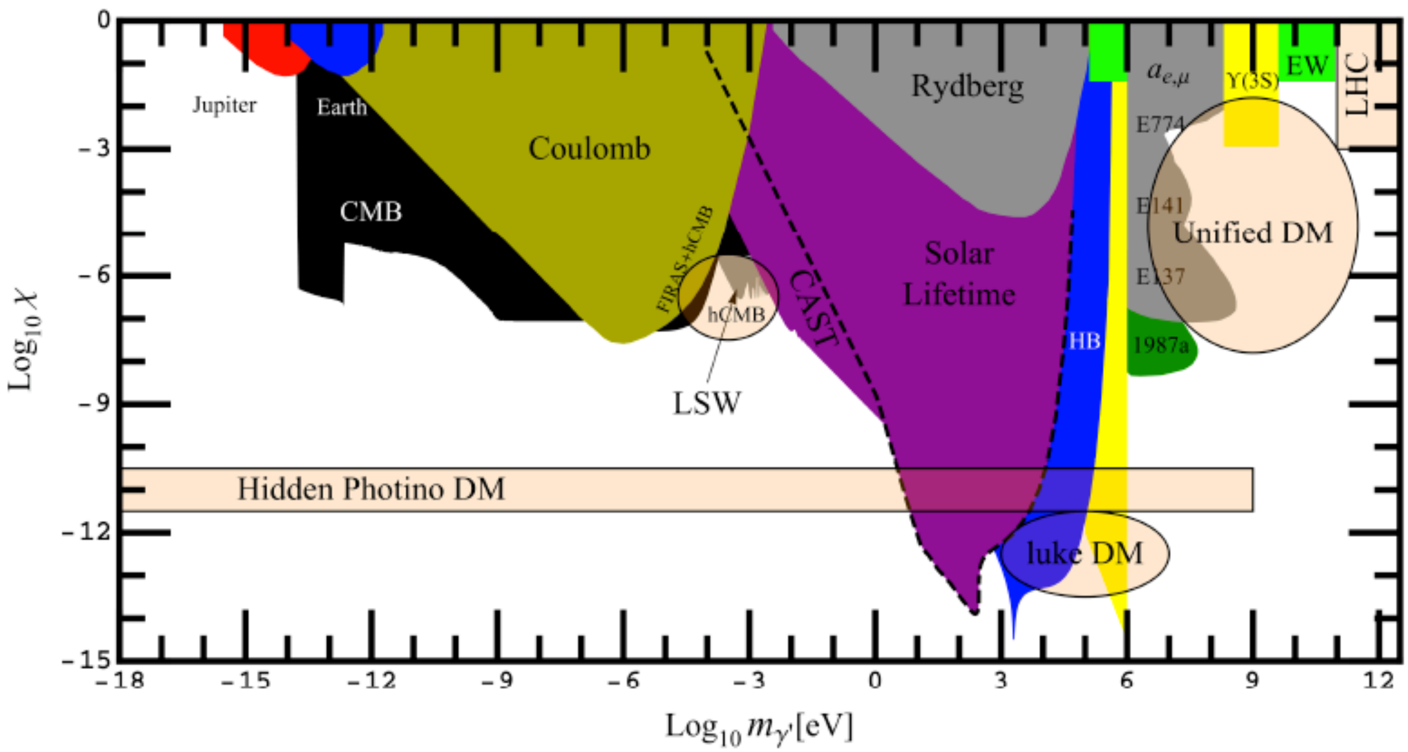
**1.6 micron CCD camera HgCdTe ROCKWELL**

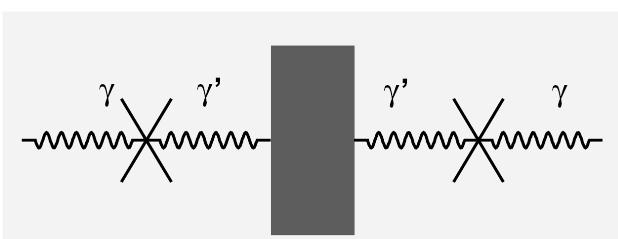
dark noise; deep IR



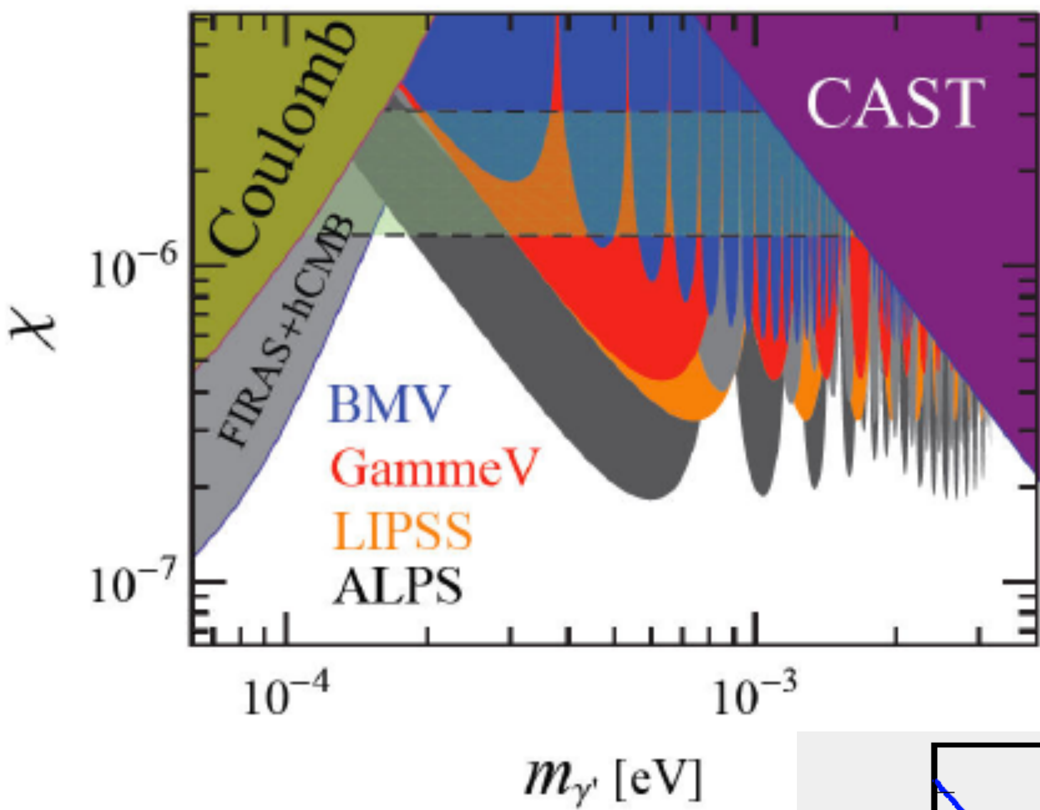
kinetic mixing

J. Jaeckel, A. Ringwalk arXiv:1002.0329



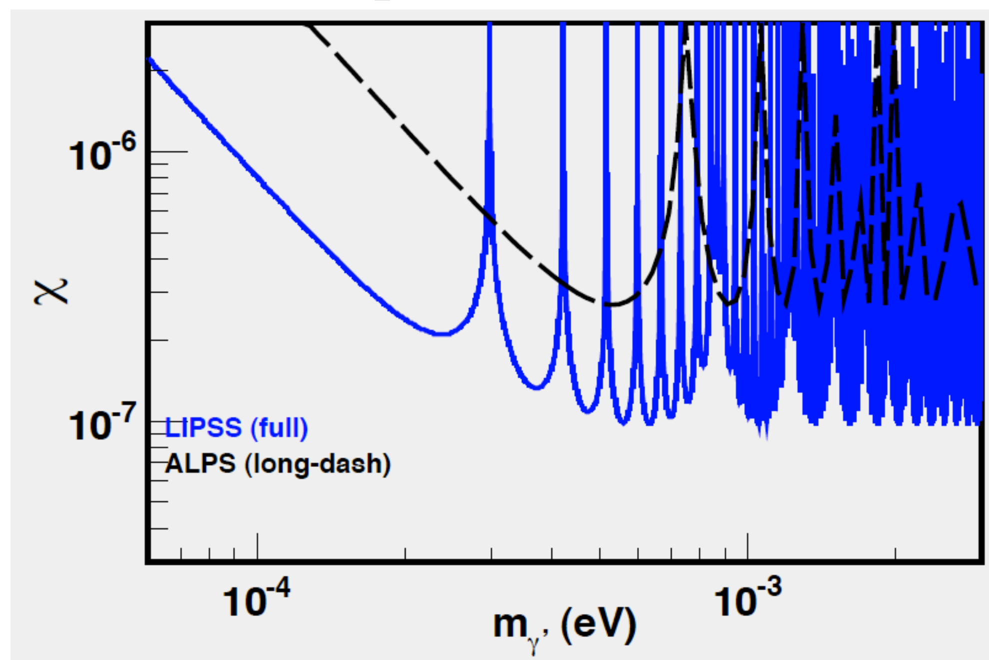




$$P_{trans} = 16\chi^4 \sin^2\left(\frac{\Delta k L_1}{2}\right) \sin^2\left(\frac{\Delta k L_2}{2}\right)$$




K. Ehret et al,
ALPS results
arXiv:1004.1313

predicted LIPSS results




$L_1 = 25\ m$

$L_2 = 2.5\ m$

$\lambda = 1.6\ \mu$

70 KW laser power

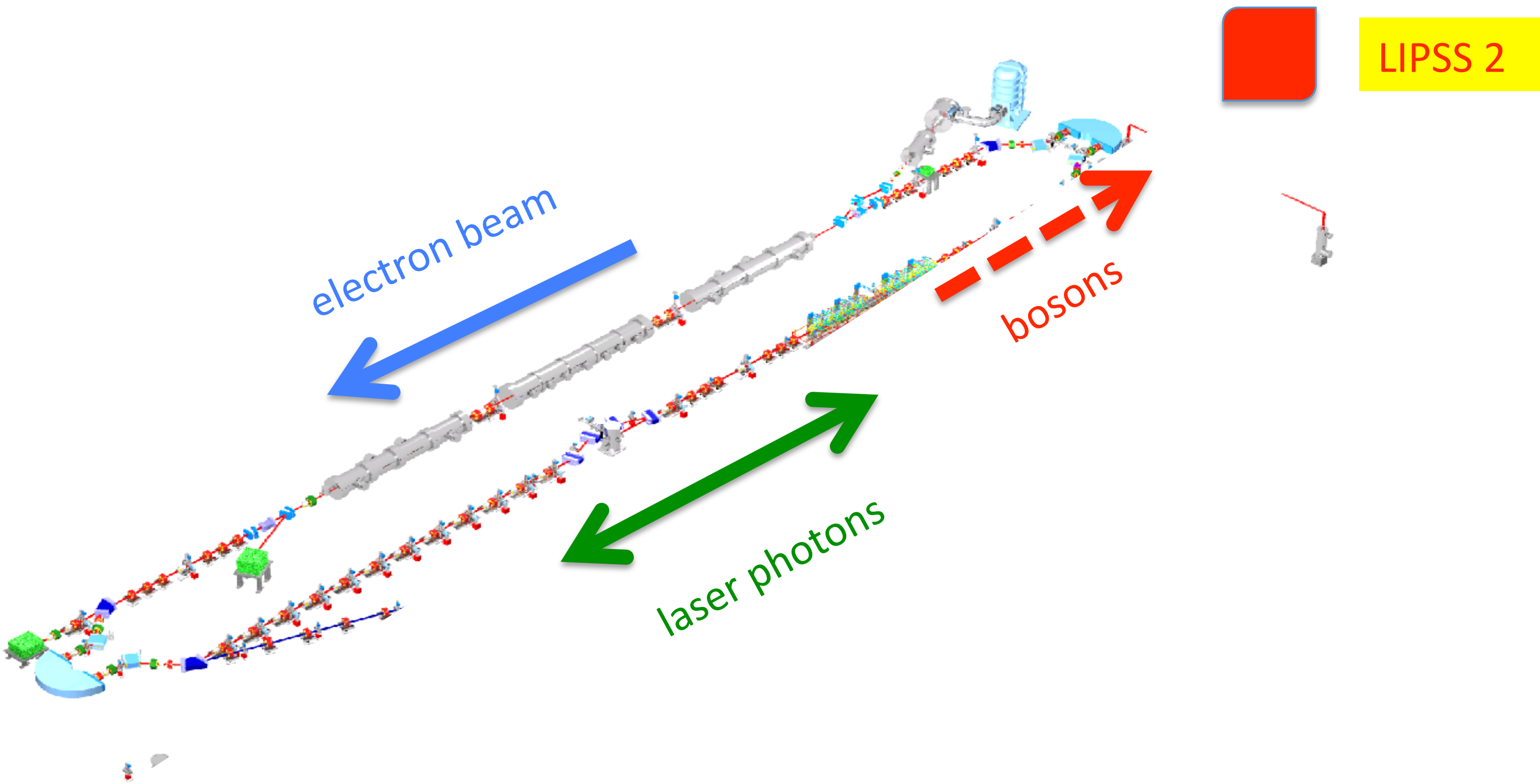
$t \sim 10$ days

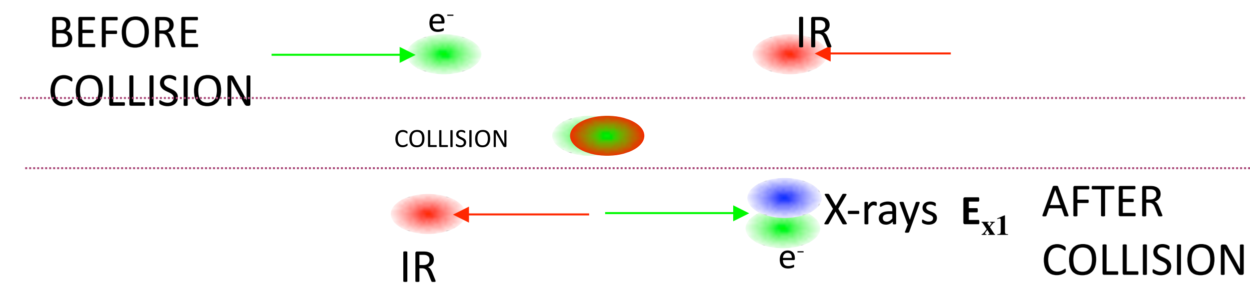
# boson beam dump

- based upon LSW principle of photon regeneration
- Compton scattering at FEL
- long lifetimes

- coupling at vertex enters twice
- limited to ~25 keV mass boson production

# boson beam dump






“Standard” 180° Thomson Scattering. X-rays produced are traveling with electron bunch after IR scatters off electrons at interaction region.

$$\ell \sim \frac{n_e \cdot n_\gamma}{\sigma_e \cdot \sigma_\gamma} \sim 2 \times 10^{43} \ \ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$ luminosity

$$n_e \sim 5\ mA = 3 \times 10^{16}\ Hz$$ electron current

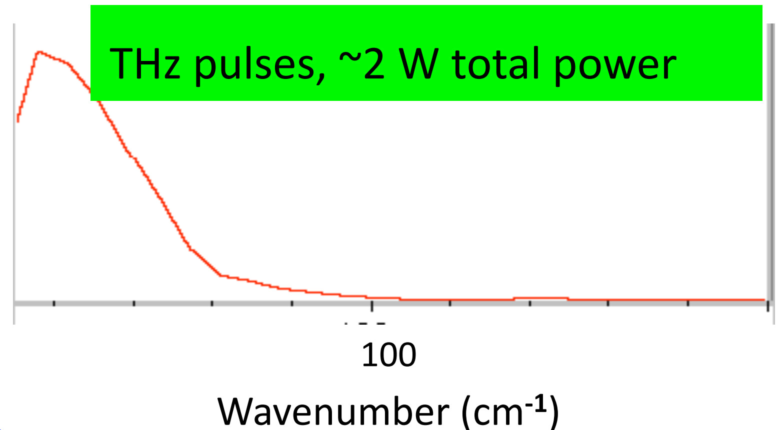
$$n_\gamma \sim (50KW\ \ , 1.6\mu m) = 3 \times 10^{23}\ Hz$$ photon flux

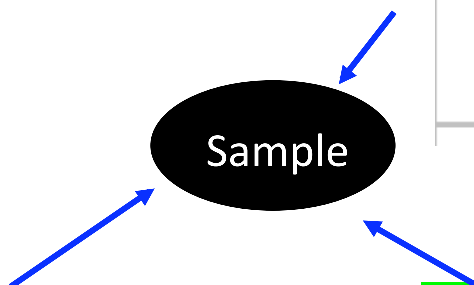
$$\sigma \sim 200\mu m$$ beam diameter

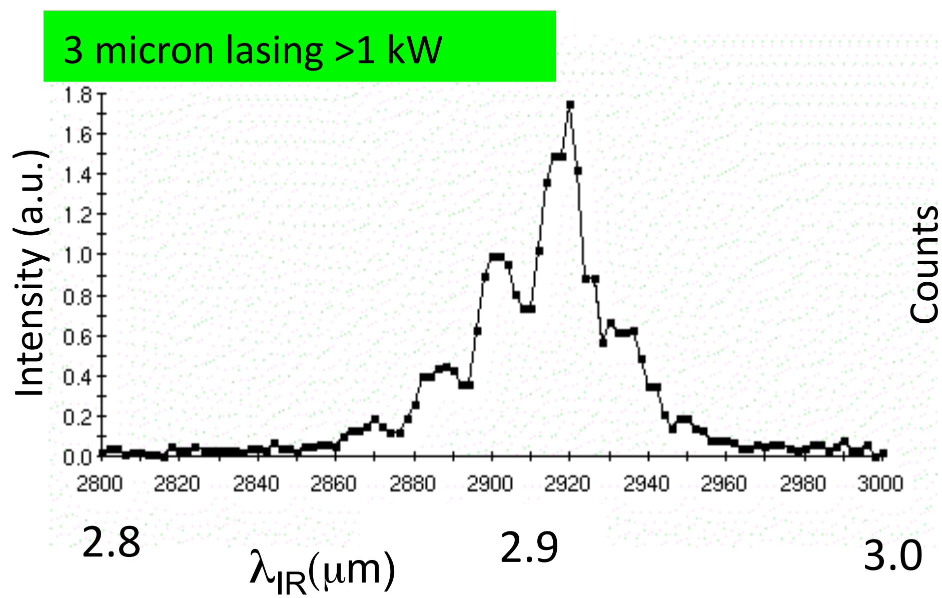
from J. Boyce 2003

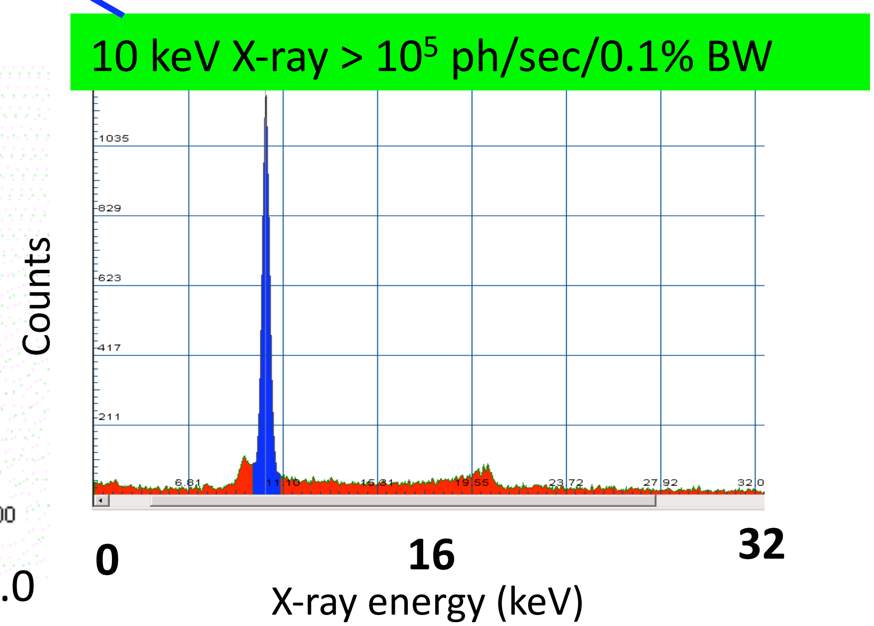
# simultaneous production of THz, 3 micron, and 10 keV X-rays

- picosecond pulses at 37.4 MHz
- synchronized to femtosecond levels



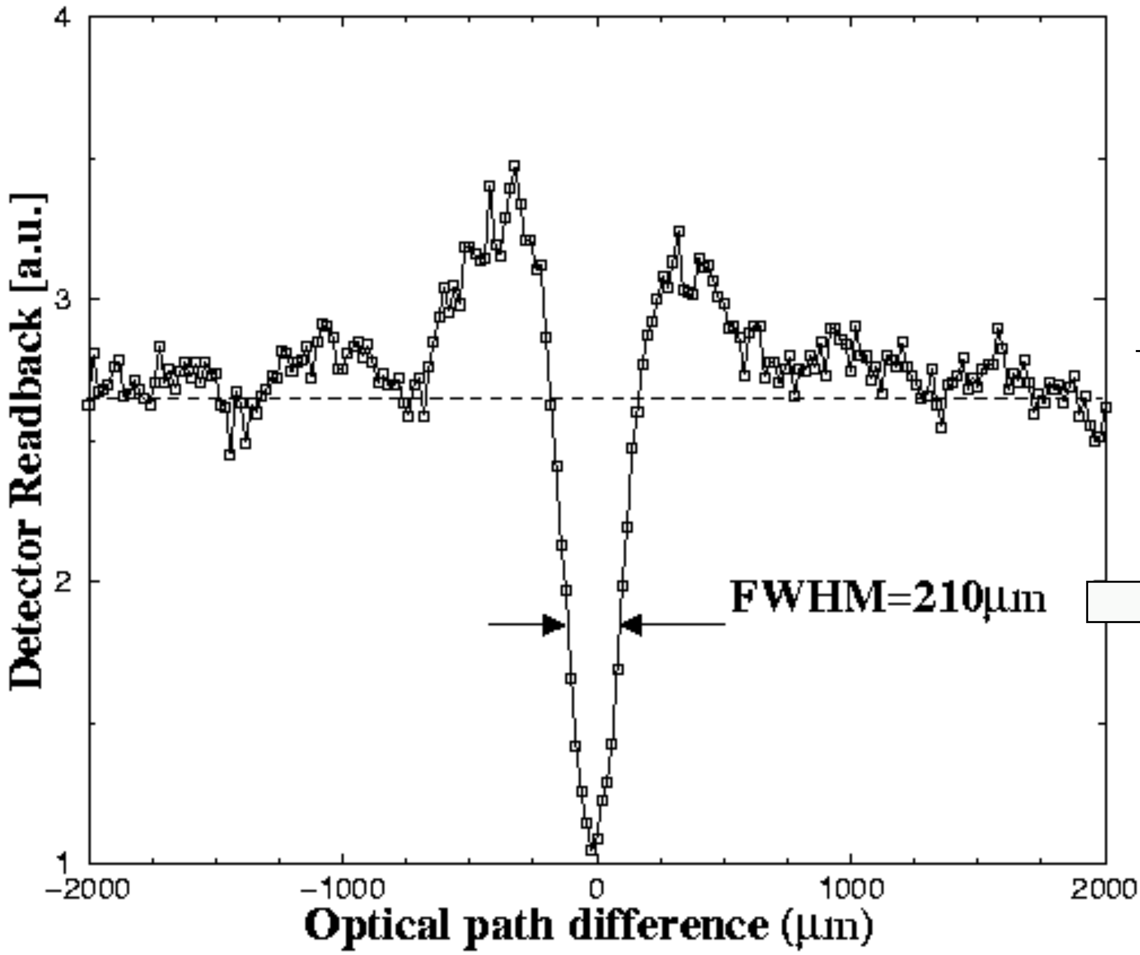



from J. Boyce 2003

# CTR electron bunch length measurement



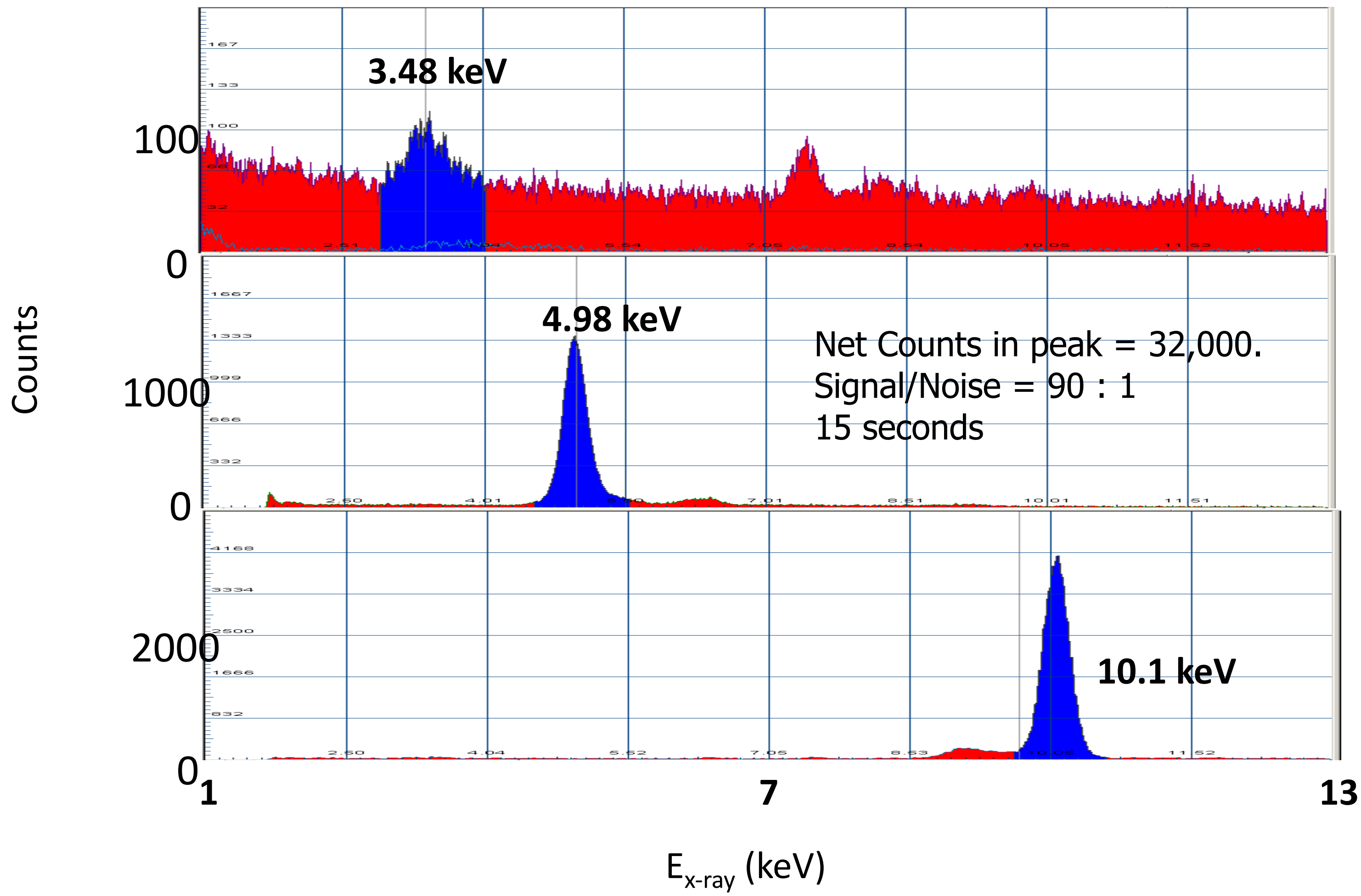

$$\sigma_{bunch} = \frac{FWHM}{2.354} = 89.2\ \mu m$$

$$\frac{\sigma_{bunch}}{c} = 298 \times 10^{-15}\ sec$$

300 fsec

from J. Boyce 2003

# actual typical spectra

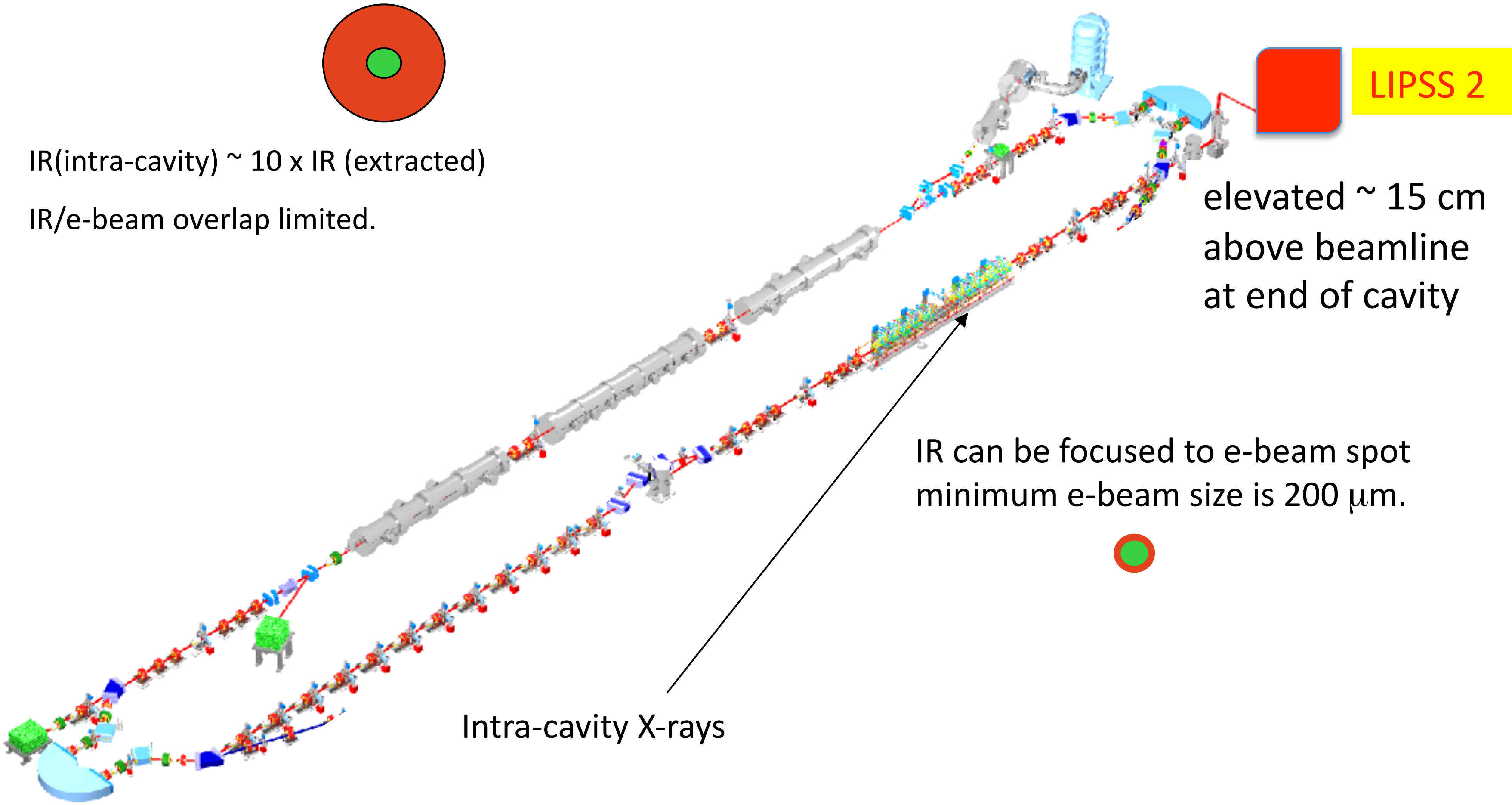


# Compton scattering and high luminosity

from J. Boyce 2003

IR(intra-cavity) ~ 10 x IR (extracted)

IR/e-beam overlap limited.



# boson beam dump

$$\sigma_{\gamma_2 e}(s) = \frac{2\pi\alpha^2\chi^2}{(s-m_e^2)^3}\left(\frac{\beta}{2s}\left(s^3+15s^2m_e^2-sm_e^4+m_e^6+\mu^2\left(7s^2+2sm_e^2-m_e^4\right)\right)+\right.$$

$$\left.+2\left(s^2-6sm_e^2-3m_e^4-2\mu^2(s-m_e^2-\mu^2)\right)\mathrm{Log}\left[\frac{s(1+\beta)+m_e^2-\mu^2}{2m_e\sqrt{s}}\right]\right)$$

- Compton production of boson
- inverse Compton production of photon (photon regeneration)
- high density, high-Z detector

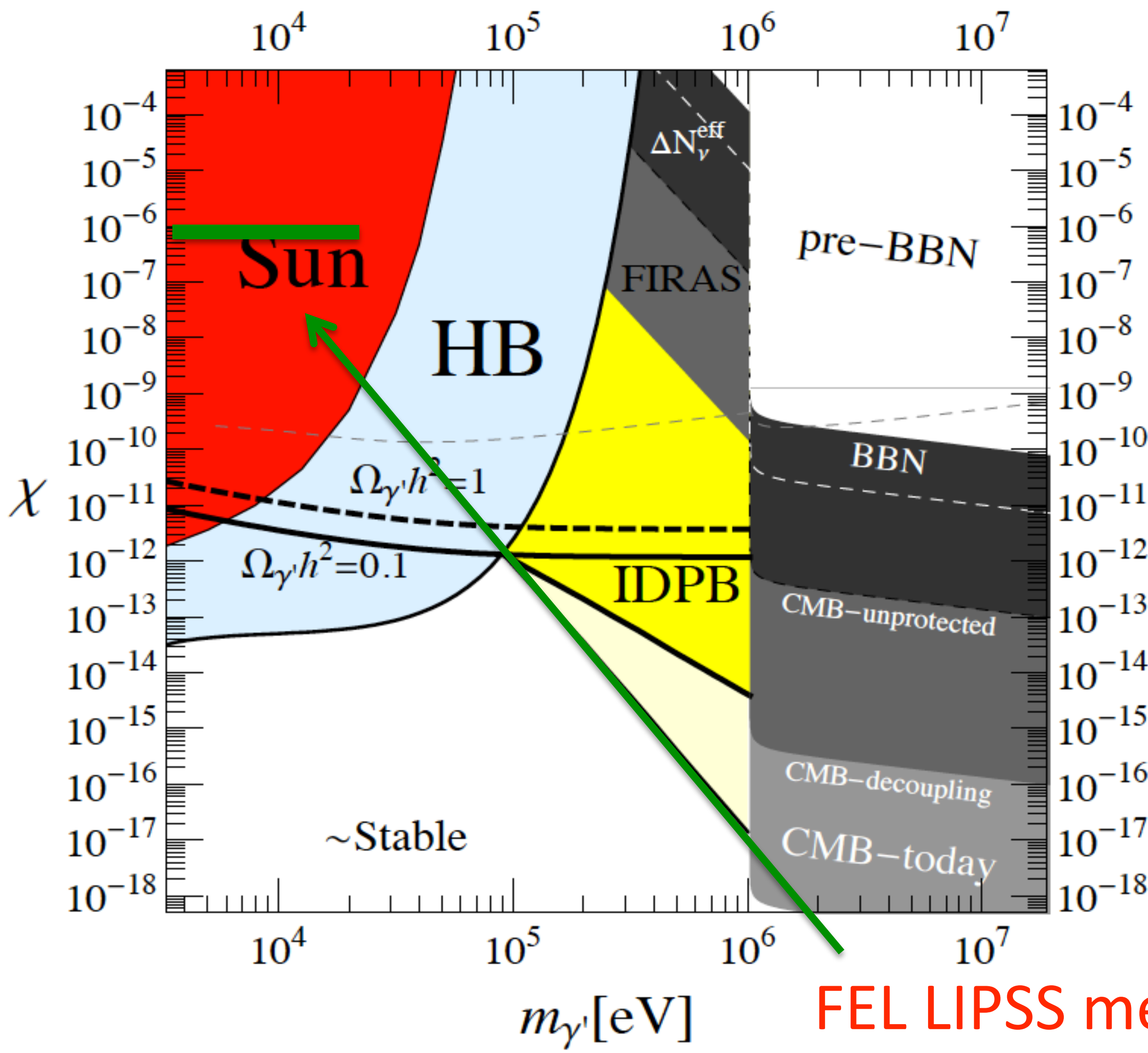
$Y_i \sim r_{A^0}\cdot n_t \cdot t \cdot \sigma \cdot \varepsilon \;= 1\cdot \sigma \cdot \varepsilon$ experimental yield, Hz

$\chi \sim 10^{-5}$ $\quad \sigma \sim 10^{-33}\,cm^2$ $\quad r_{A^0} \sim 10^{10}$ Hz

$n_t(Pb) \sim 10^{23}$ cm$^{-3}$ $\quad t \sim 100$ cm

$\varepsilon \sim 0.01$

# boson beam dump

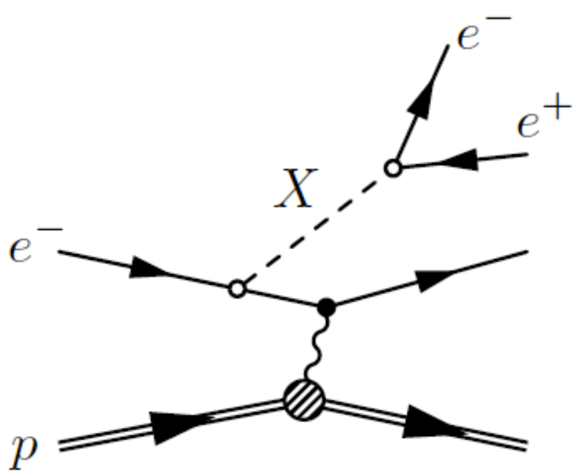


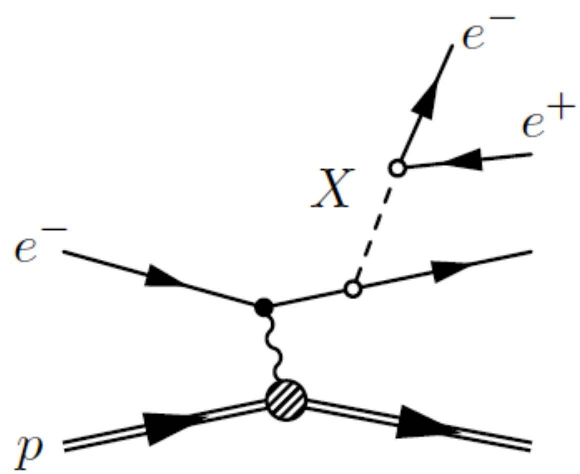

Marieke Postma, Javier Redondo, JCAP 0902:005,2009; arXiv:0811.0326

FEL LIPSS measurement:
~ one month

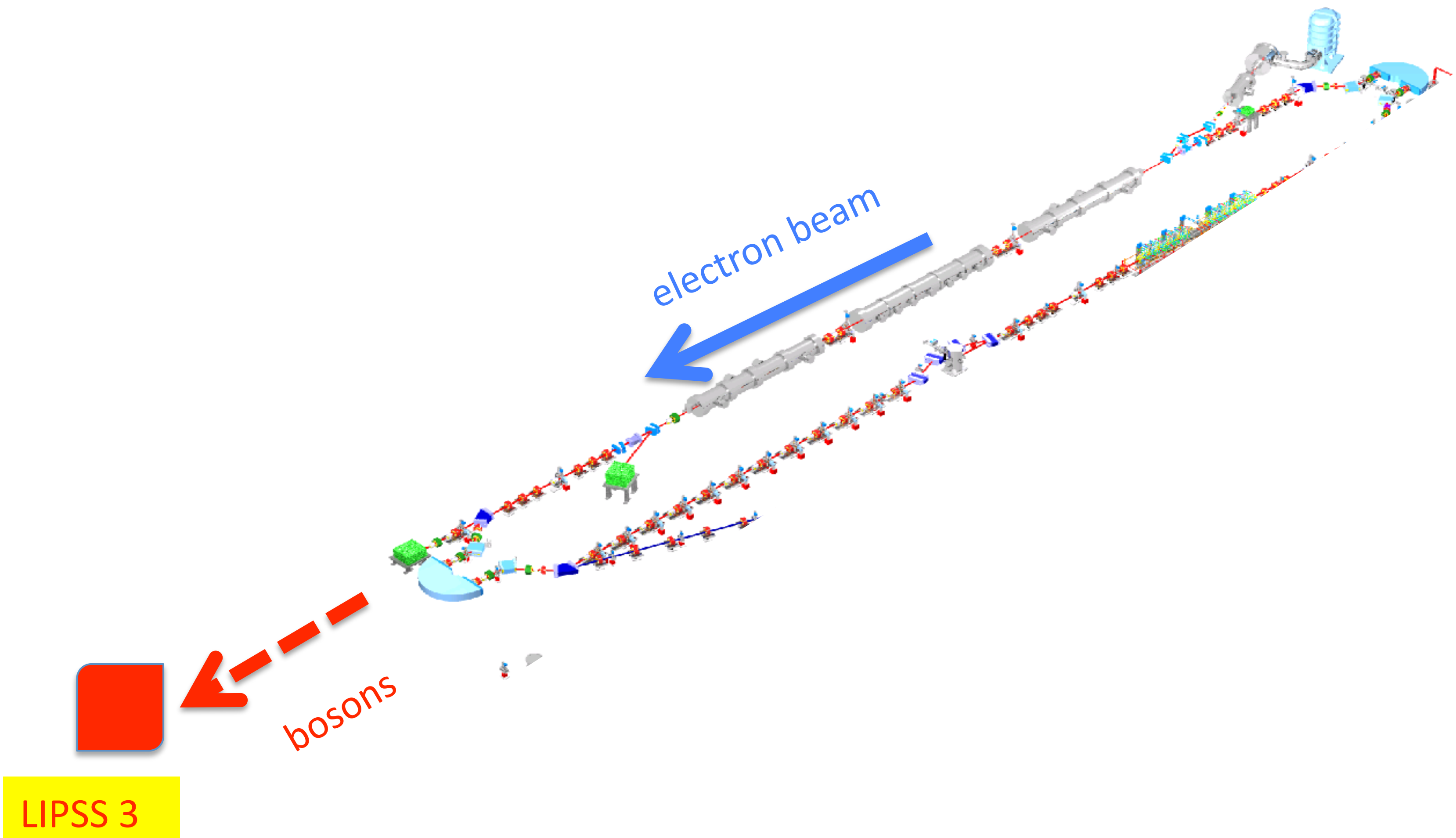
# electron beam dump

- also based upon LSW principle photon regeneration
- high power electron beam dump at FEL (phase 2)
- useful for large range of boson lifetimes
- coupling at vertex enters twice



# electron beam dump




~0.13 MW beam dump exists;
excavation behind FEL beam dump(?)

# electron beam dump

$$Y_i \sim r_e \cdot n_t \cdot t \cdot \sigma \cdot \varepsilon \;= \mathrm{l} \cdot \sigma \cdot \varepsilon$$ experimental yield, Hz

$$r_e(1\ mA) \sim 6 \times 10^{15} \ \ \mathrm{Hz}$$

$$n_t \sim 2 \times 10^{23} \ \ \mathrm{cm}^{-3}$$

$$t \sim 100 \ \mathrm{cm}$$

$$\mathrm{l} \sim 10^{41} \mathrm{cm}^{-2} \mathrm{s}^{-1} \quad \rightarrow \quad \sim 1/\mathrm{ab}/\mathrm{min}$$

FEL beam dump luminosity

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$$r_e(100\ \mu A) \sim 6 \times 10^{14} \ \ \mathrm{Hz}$$

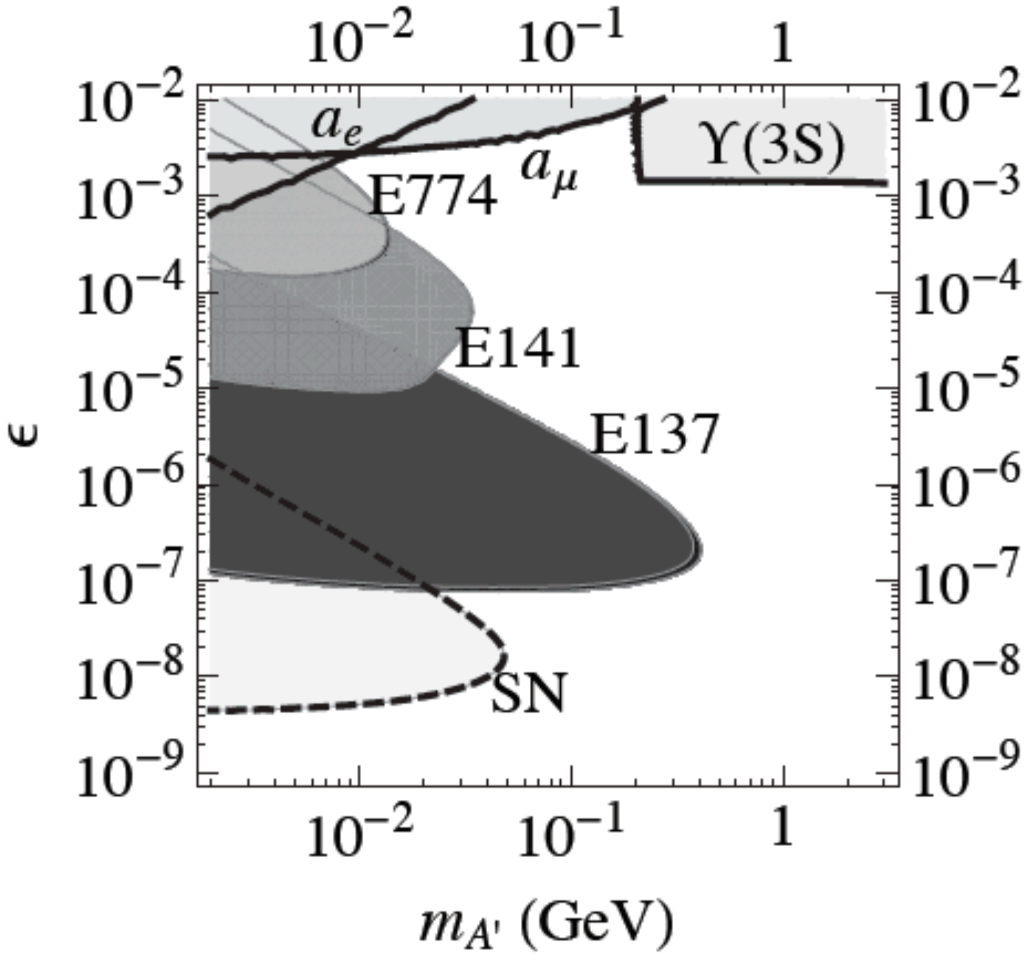
$$n_t \sim 2 \times 10^{23} \ \ \mathrm{cm}^{-3}$$

$$t \sim 100 \ \mathrm{cm}$$

$$\mathrm{l} \sim 10^{40} \mathrm{cm}^{-2} \mathrm{s}^{-1} \quad \rightarrow \quad \sim 1/\mathrm{ab}/\mathrm{hour}$$

Hall A, C beam dump luminosity

# electron beam dump

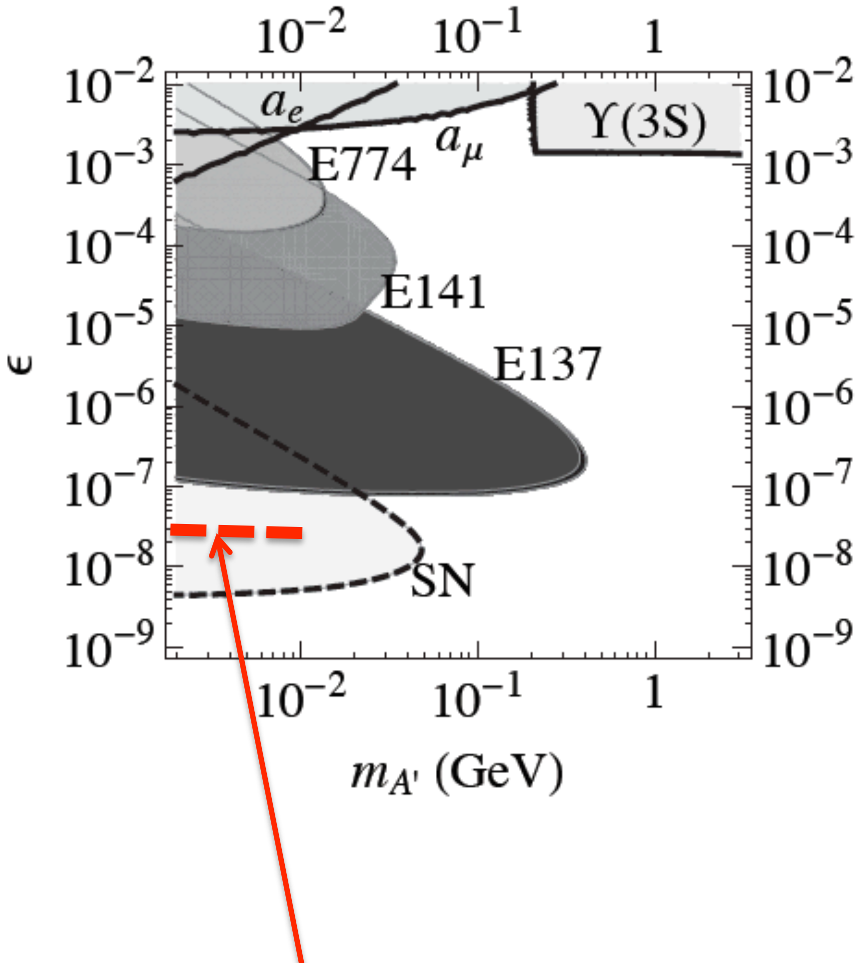



- SLAC E137
  - 2 x $10^{20}$ elec
  - 20 GeV
  - d ~ 400 m
- SLAC E141
  - 2 x $10^{15}$ elec
  - 9 GeV
  - d ~ 35 m
- FNAL E774
  - 5 x $10^{10}$ elec
  - 275 GeV
  - t ~ 1 m

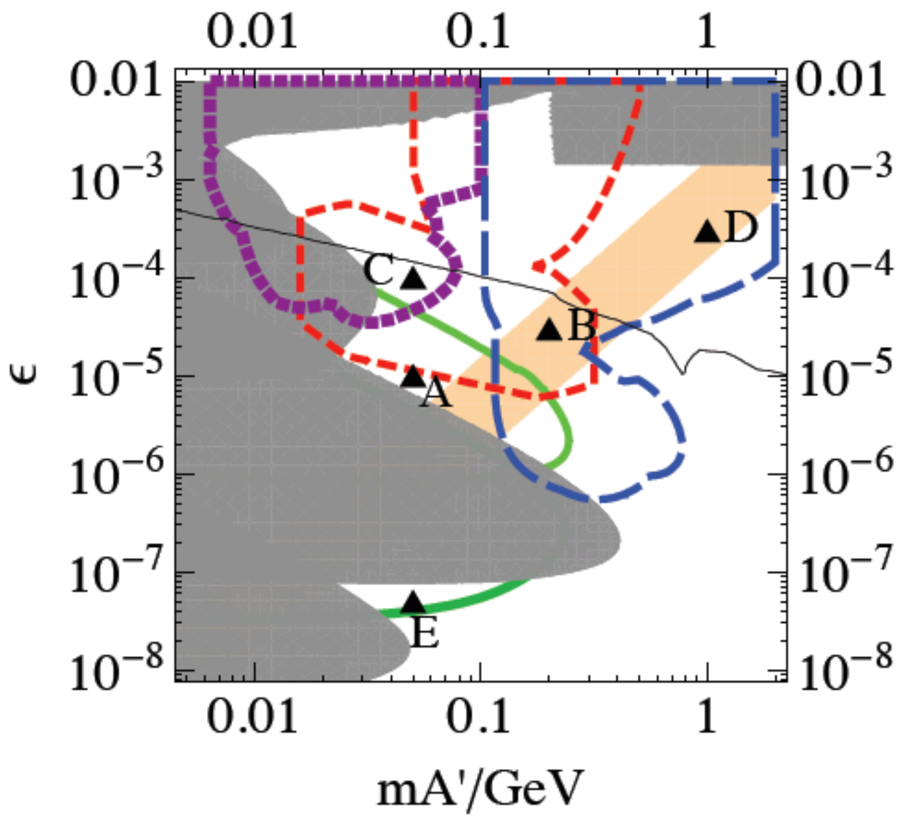
JD Bjorken et al, PhysRevD.80.075018 (2009)

# electron beam dump

JD Bjorken et al, PhysRev D80, 075018 (2009);
Freytsis, Ovanesyan, Thaler ; arXiv:0909.2862




FEL LIPSS in ~ one month




$\varepsilon$ : FEL LIPSS 3 *x* E137

# summary

- FEL LSW with high power laser
  - mass reach up to ~1 eV
  - new  kinetic mixing limits
- FEL Compton scattering experiment
  - mass reach up to ~25 KeV
  - comparison with solar limit
- FEL beam dump experiment
  - Lower masses vs CEBAF
  - higher luminosity compared to CEBAF