high luminosity searches at JLab: mixing, Compton, and beam dump

OK Baker
(for the LIPSS collaboration)
JLAB Workshop
September 20, 2010

overview

- Recent and near-term LIPSS DM searches at FEL
  - hidden sector photons, millicharged particles, axion like particles, . . .
- Compton scattering: near-term search
  - uses electron beam and laser light in FEL vault
  - lower mass boson search (up to ~25 keV)
- FEL and CEBAF beam dump: longer-term search
  - require modest excavation at FEL dump
  - higher mass boson search (above e+e- threshold)

LIPSS at JLab collaboration

A. Afanasev, R. Ramdon

Hampton University

G. Biallas, J. Boyce, M. Shinn

Jefferson Lab

K. Beard

Muons, Inc

M. Minarni

Universitas Riau

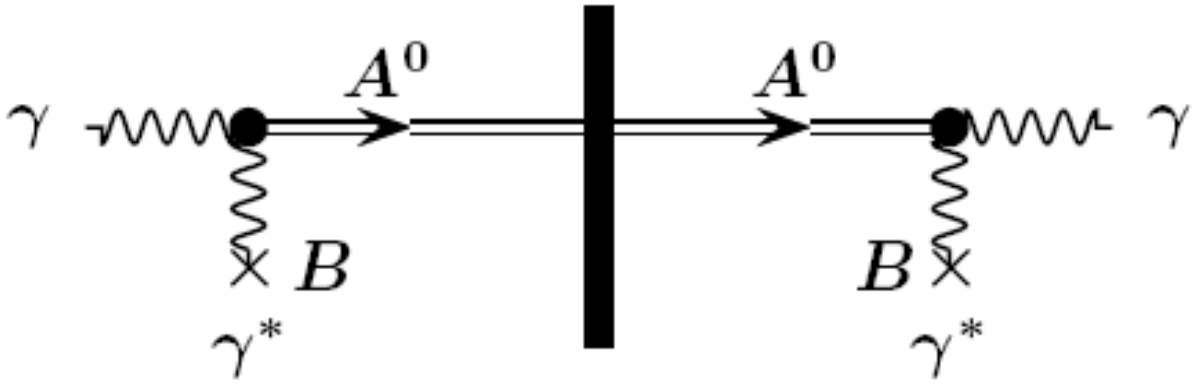
O.K. Baker, P. Slocum

Yale University

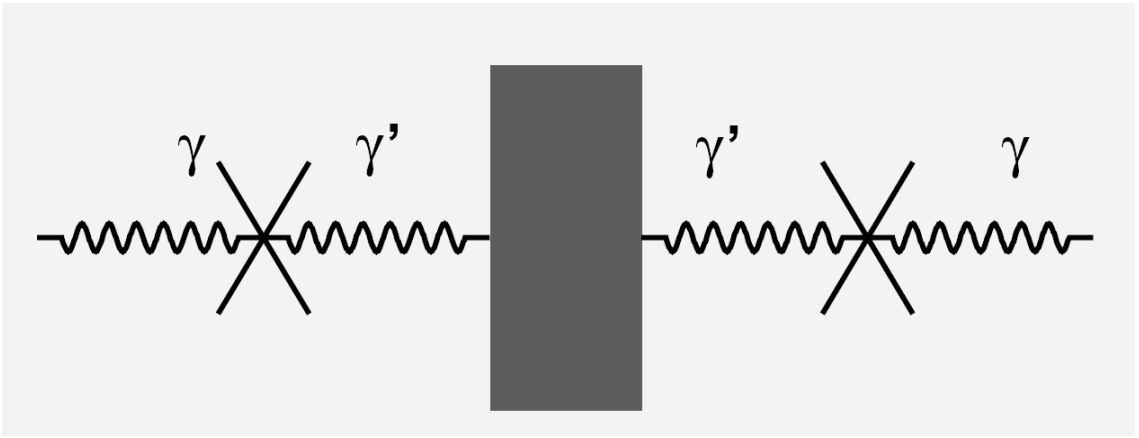
light shining through a wall

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

kW lasers, ultra low noise detectors, . . .

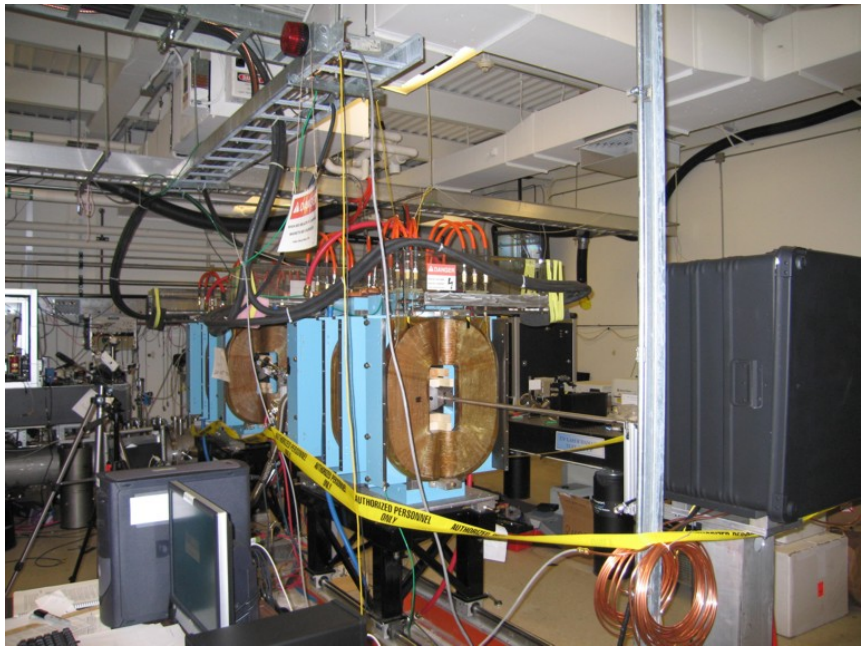


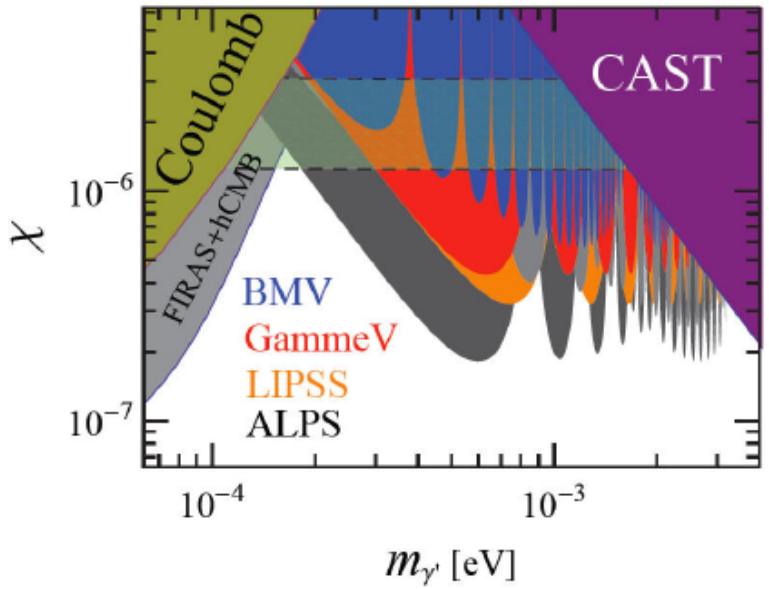
- couple polarized laser light with magnetic field
- Sikivie (1983); Ansel'm (1985); Van Bibber et al (1987)

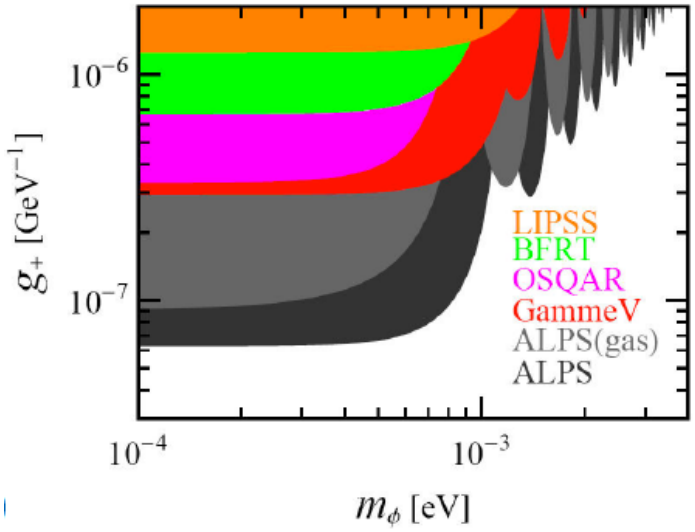


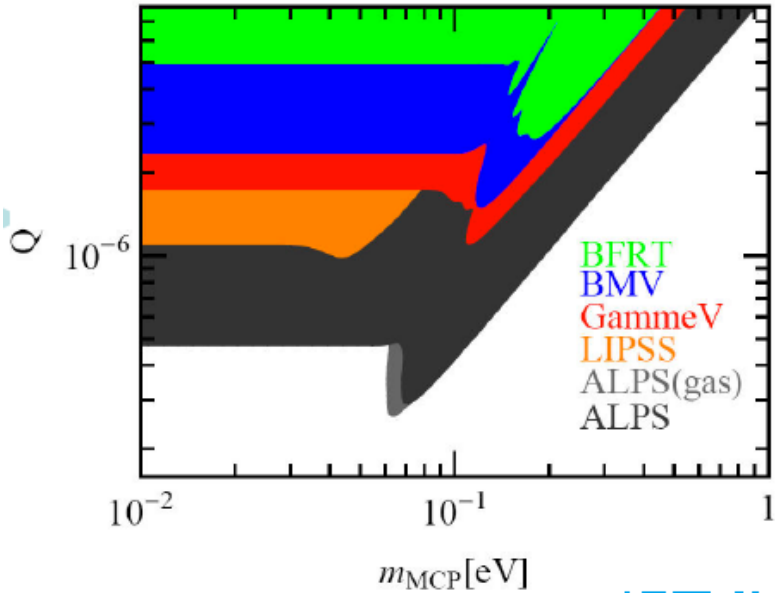
- kinetic mixing
- no magnetic field
- Afanasev et al (2009)

LIPSS at FEL Lab 1

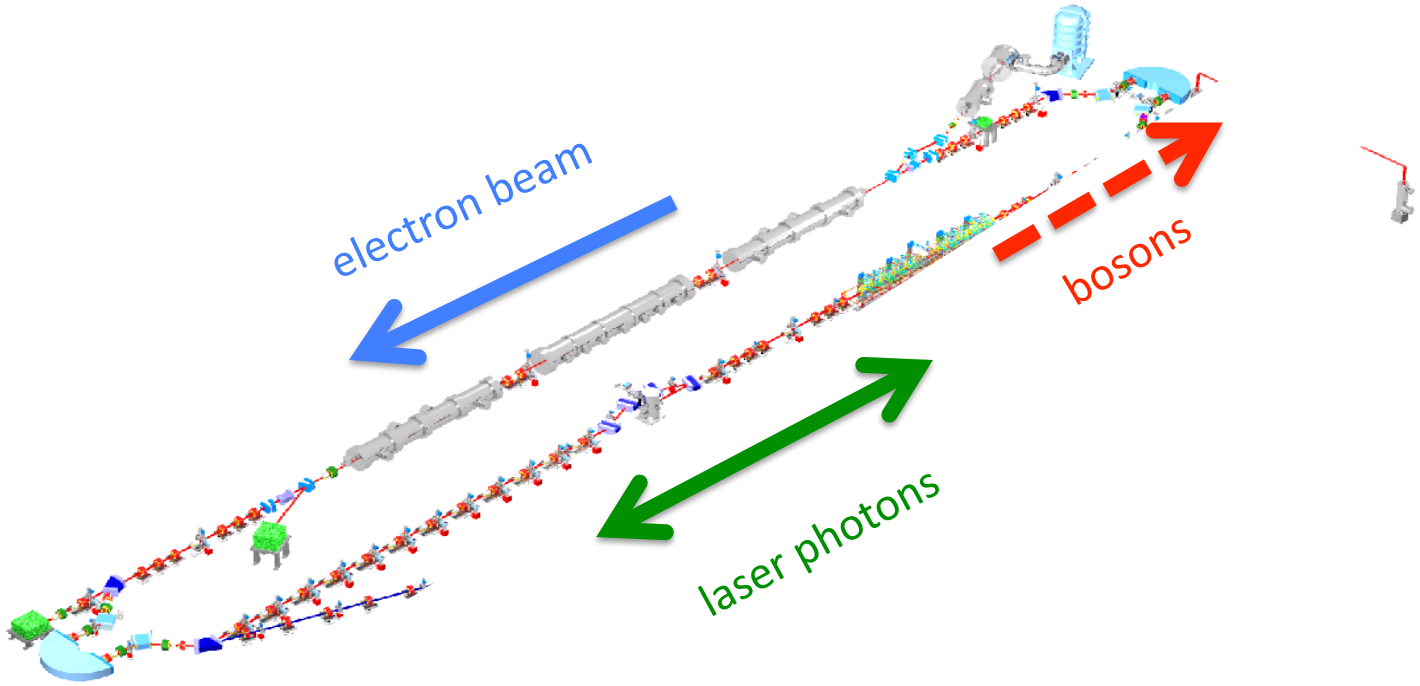








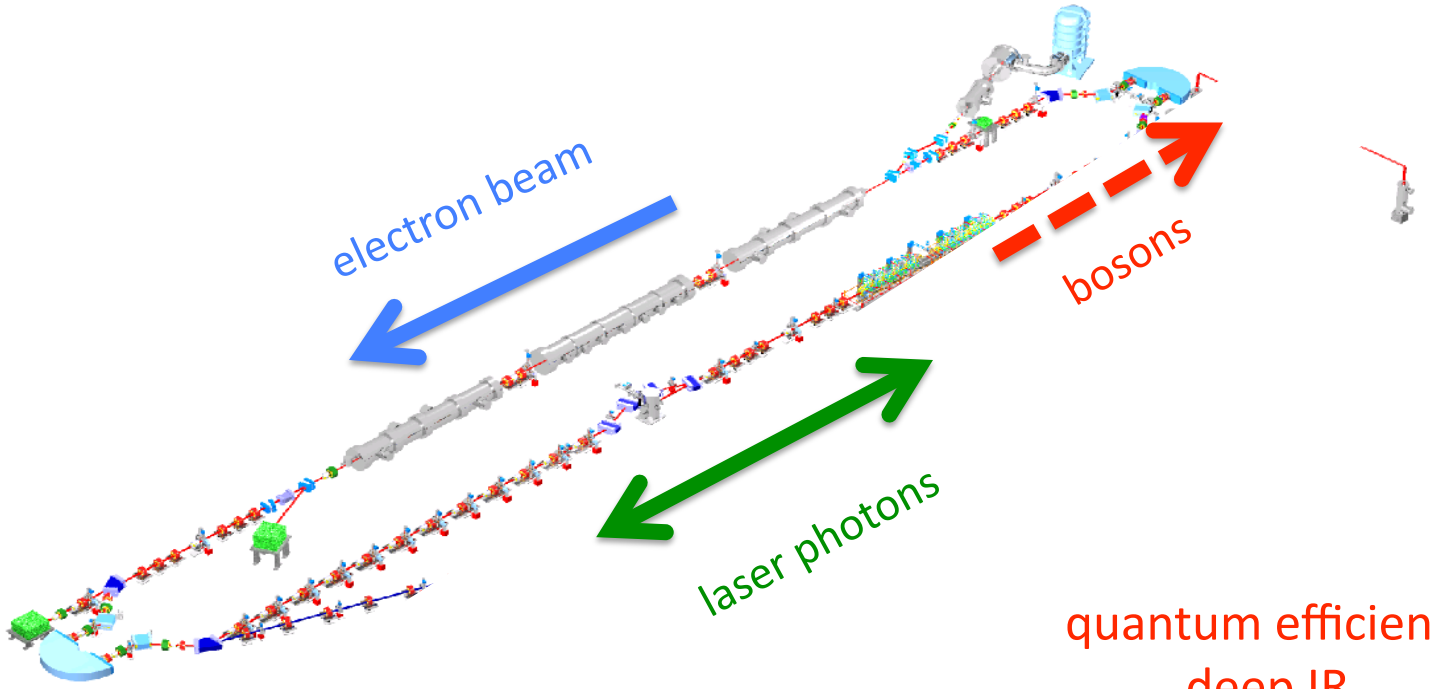
photon-boson kinetic mixing; next steps



LIPSS 2

detector in line with cavity

photon-boson kinetic mixing; next steps

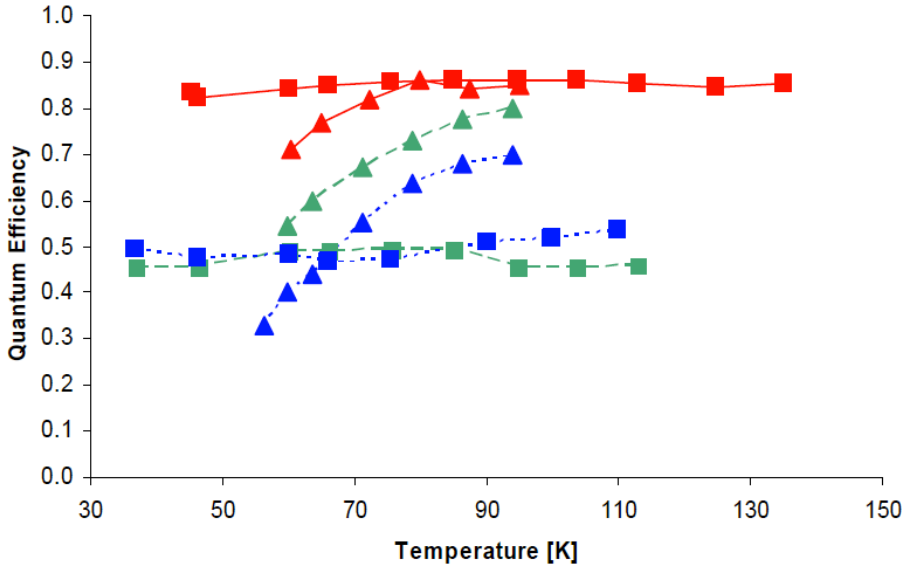


bosons

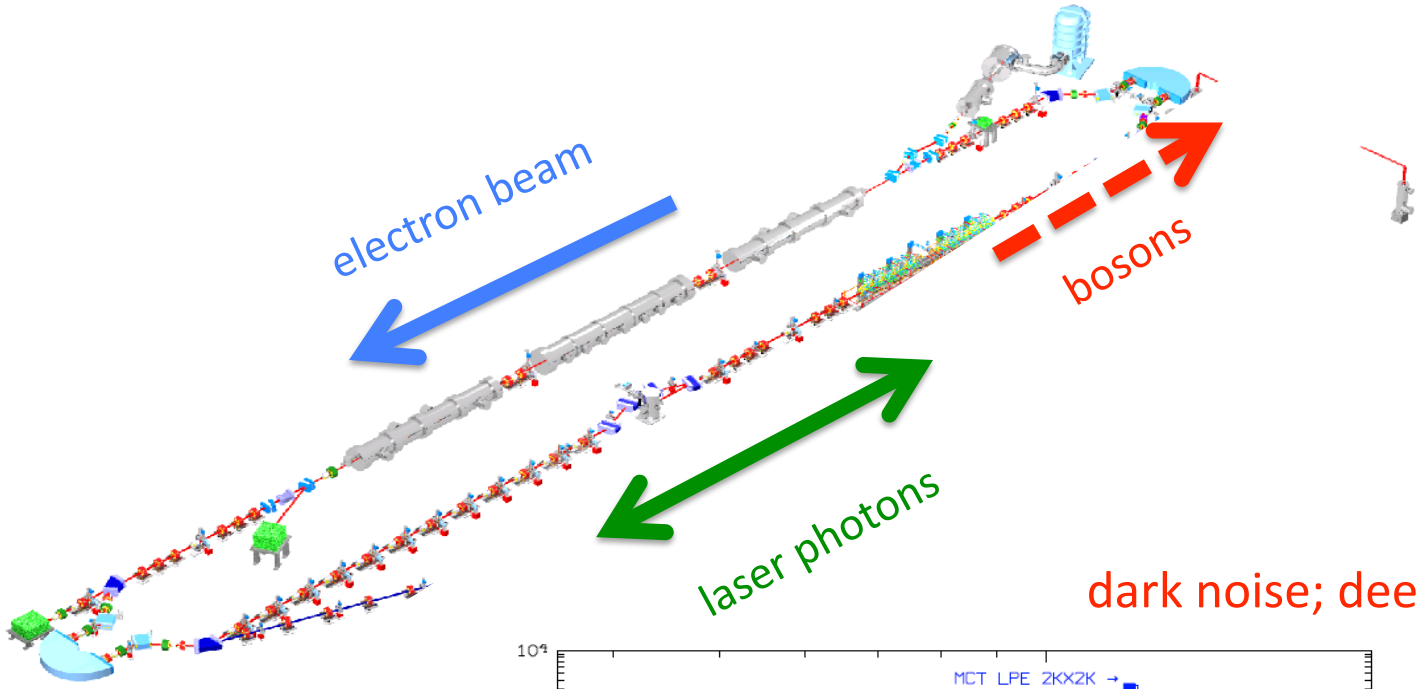
LIPSS 2

1.6 micron CCD camera HgCdTe ROCKWELL

quantum efficiency; deep IR



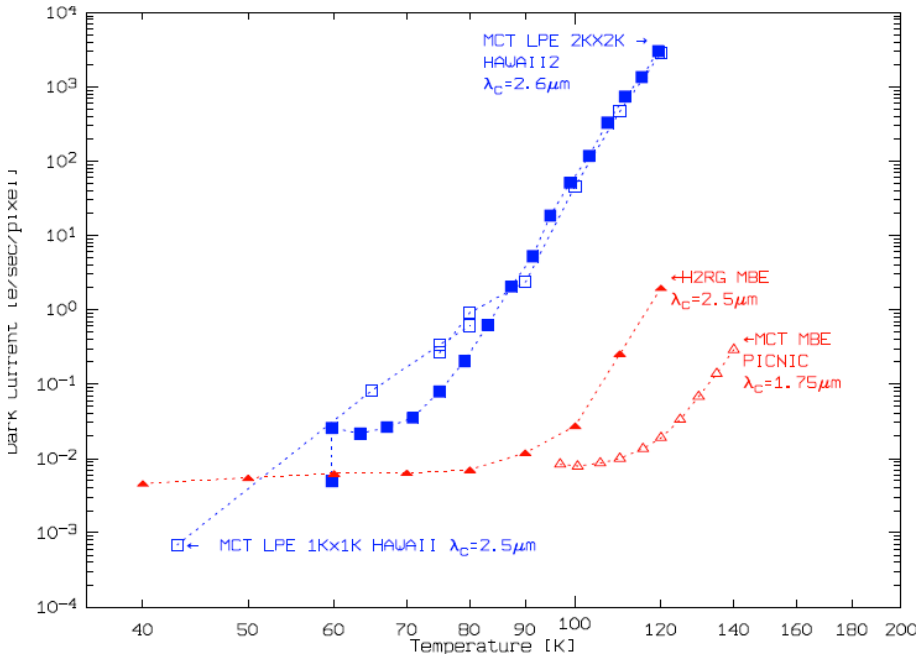
photon-boson kinetic mixing; next steps



LIPSS 2

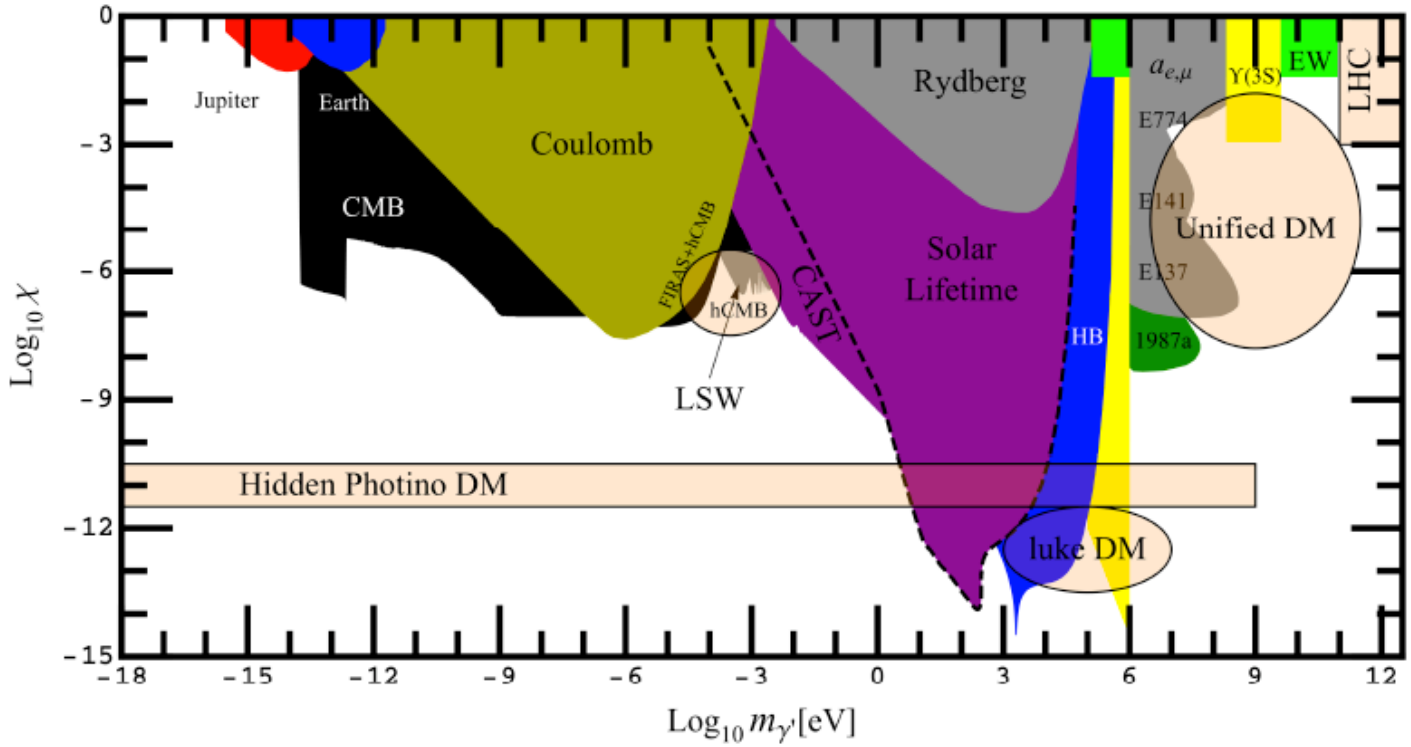
1.6 micron CCD camera HgCdTe ROCKWELL

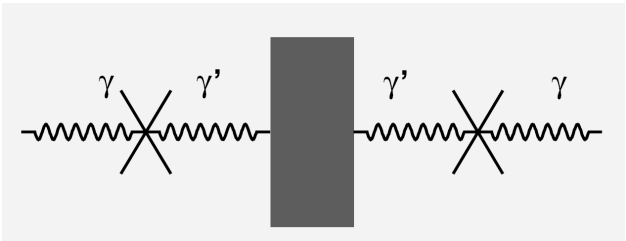
dark noise; deep IR



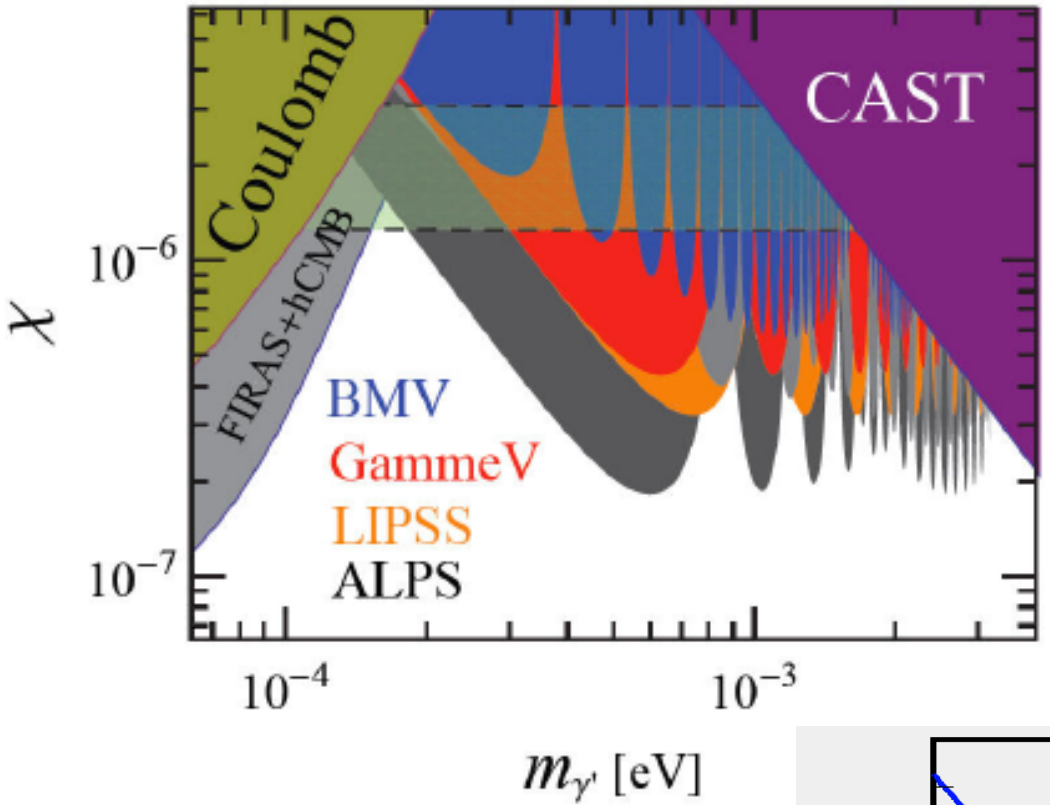
kinetic mixing

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

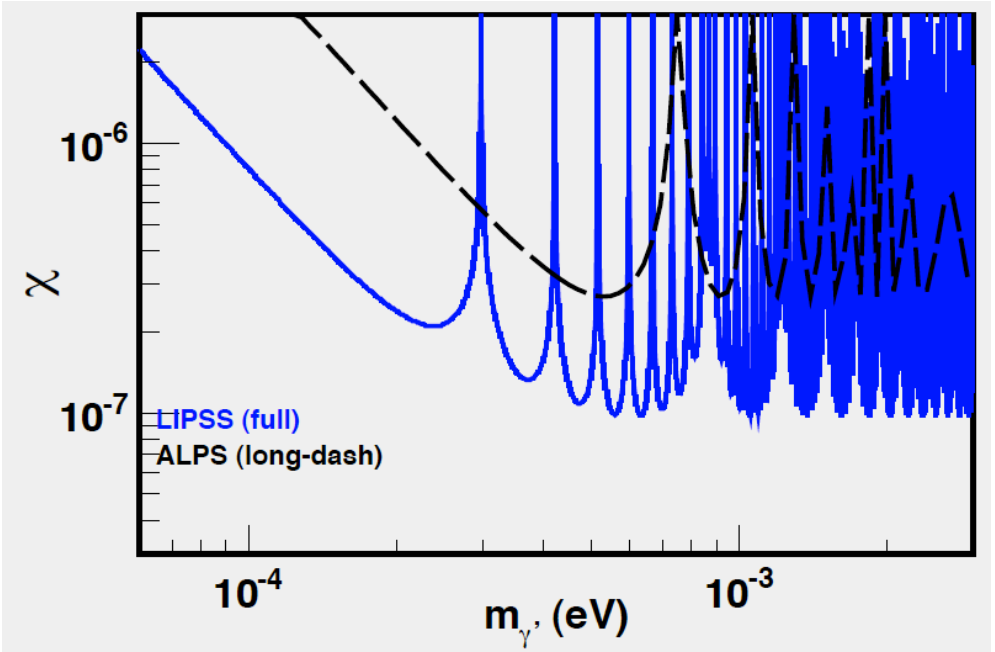
$L_1 = 25\ m$

$L_2 = 2.5\ m$

$\lambda = 1.6\ \mu$

70 KW laser power

$t \sim 10$ days

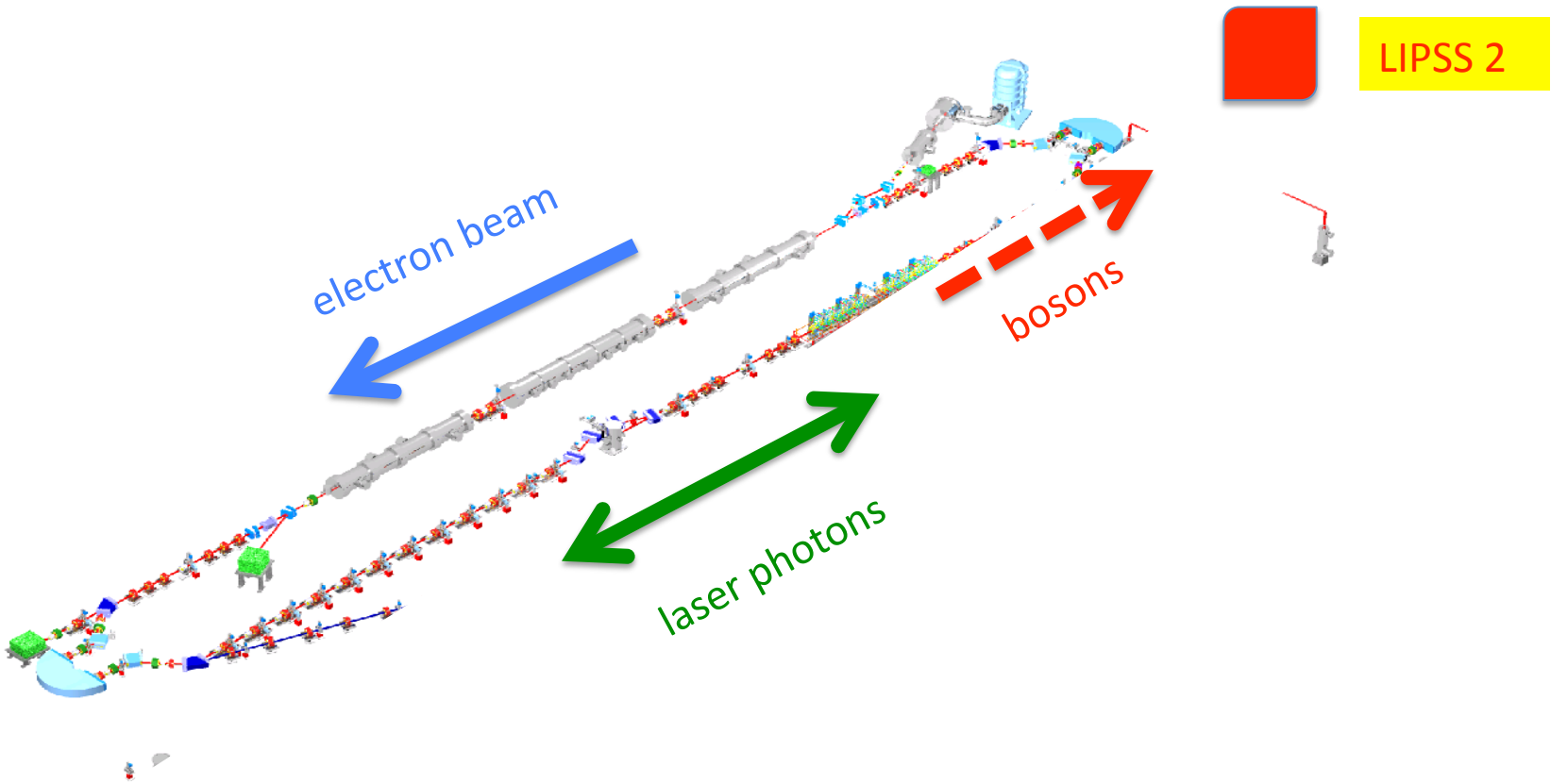


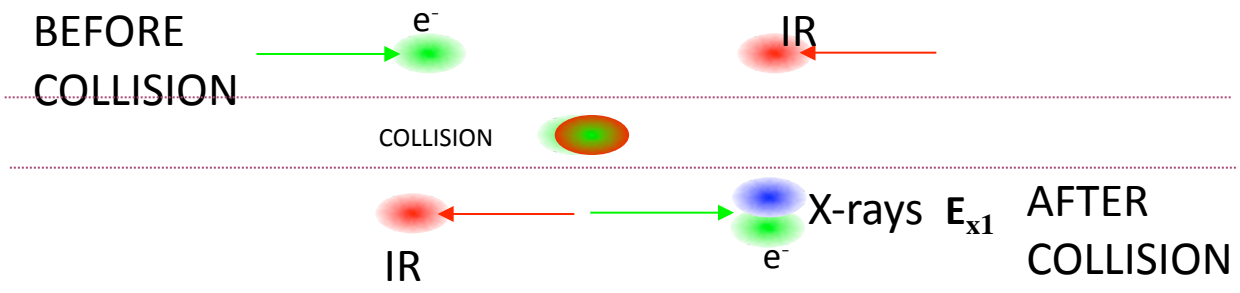
boson beam dump

- 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.

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

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

$$\sigma \sim 200\,\mu m$$

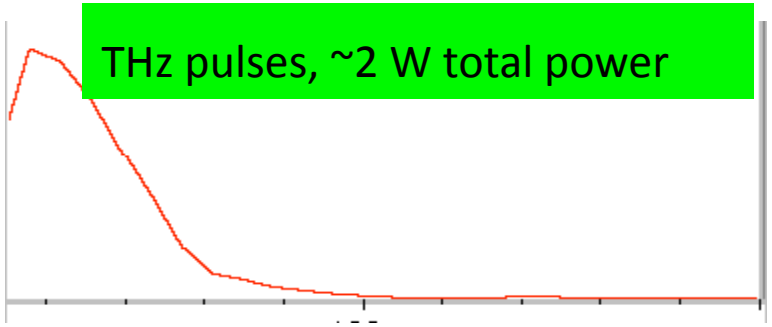
beam diameter

from J. Boyce 2003

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

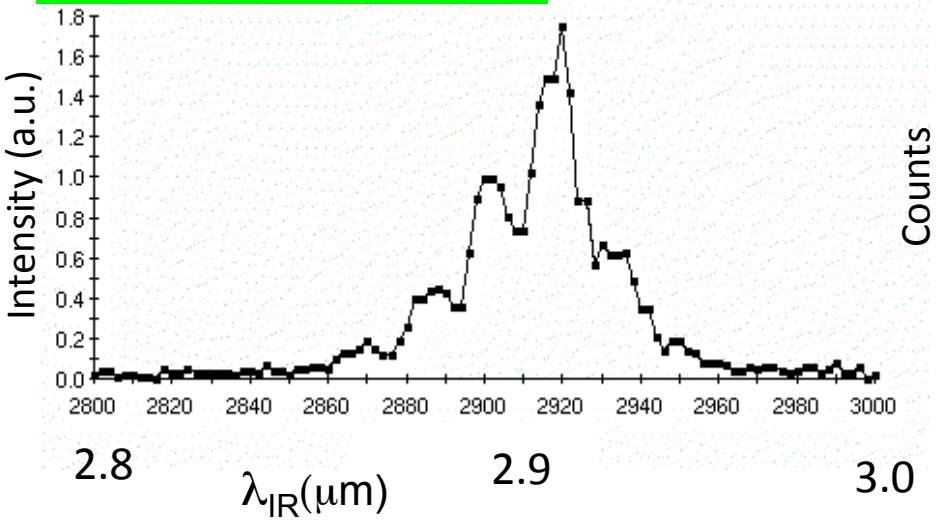
- picosecond pulses at 37.4 MHz
- synchronized to femtosecond levels

THz pulses, ~2 W total power

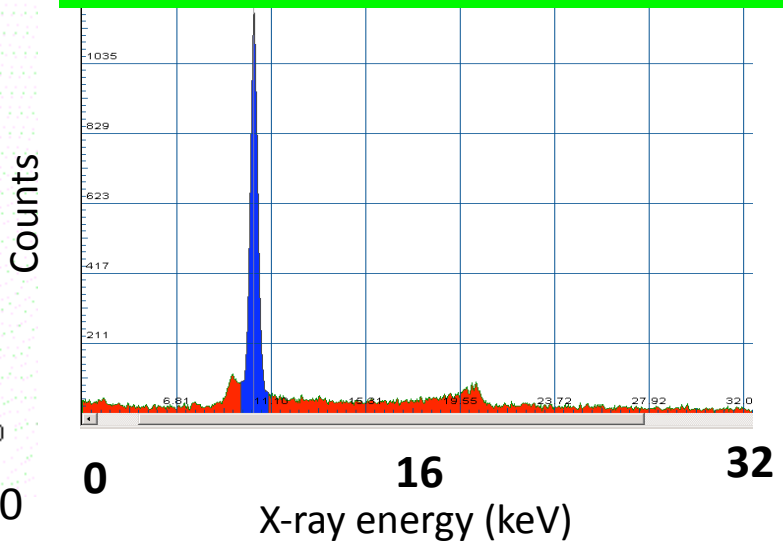


Sample

3 micron lasing >1 kW

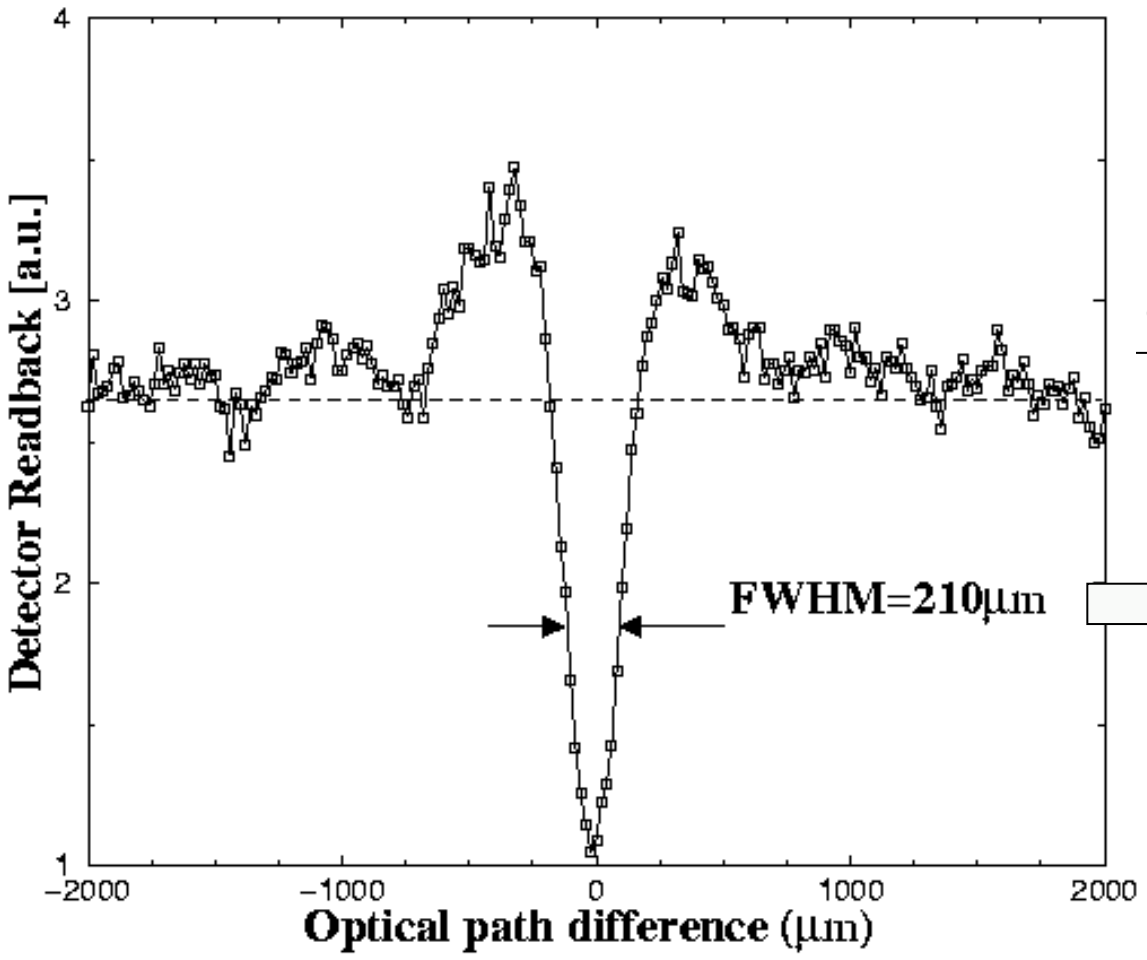


10 keV X-ray > 10^5 ph/sec/0.1% BW



from J. Boyce 2003

CTR electron bunch length measurement



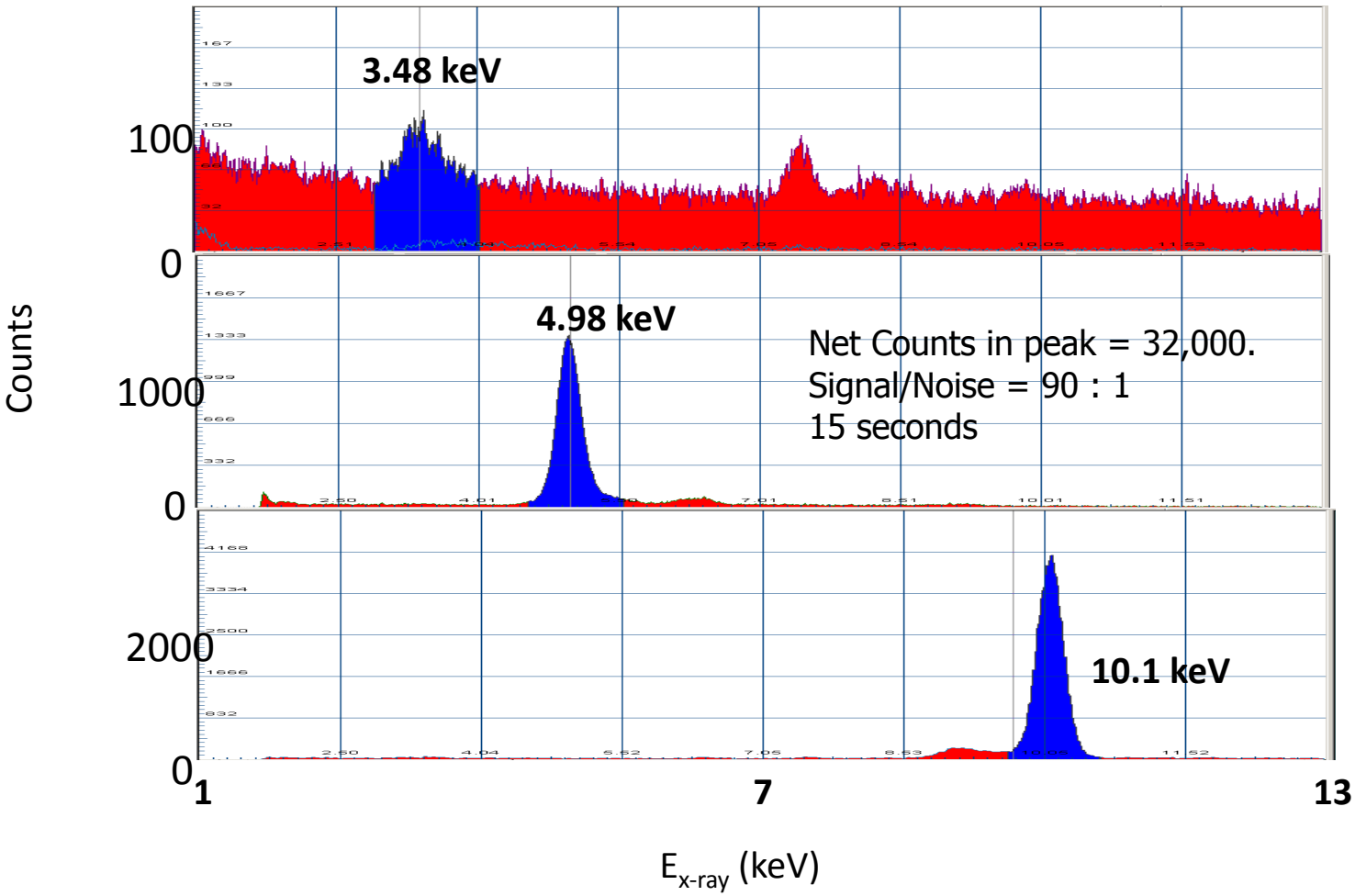
$$\sigma_{bunch} = \frac{FWHM}{2.354} = 89.2\ \mu m$$

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

300 fsec

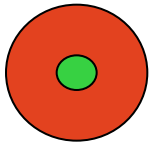
from J. Boyce 2003

actual typical spectra



Compton scattering and high luminosity

from J. Boyce 2003



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

IR/e-beam overlap limited.

LIPSS 2

elevated ~ 15 cm
above beamline
at end of cavity

IR can be focused to e-beam spot
minimum e-beam size is 200 μm.

Intra-cavity X-rays

boson beam dump

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

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

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

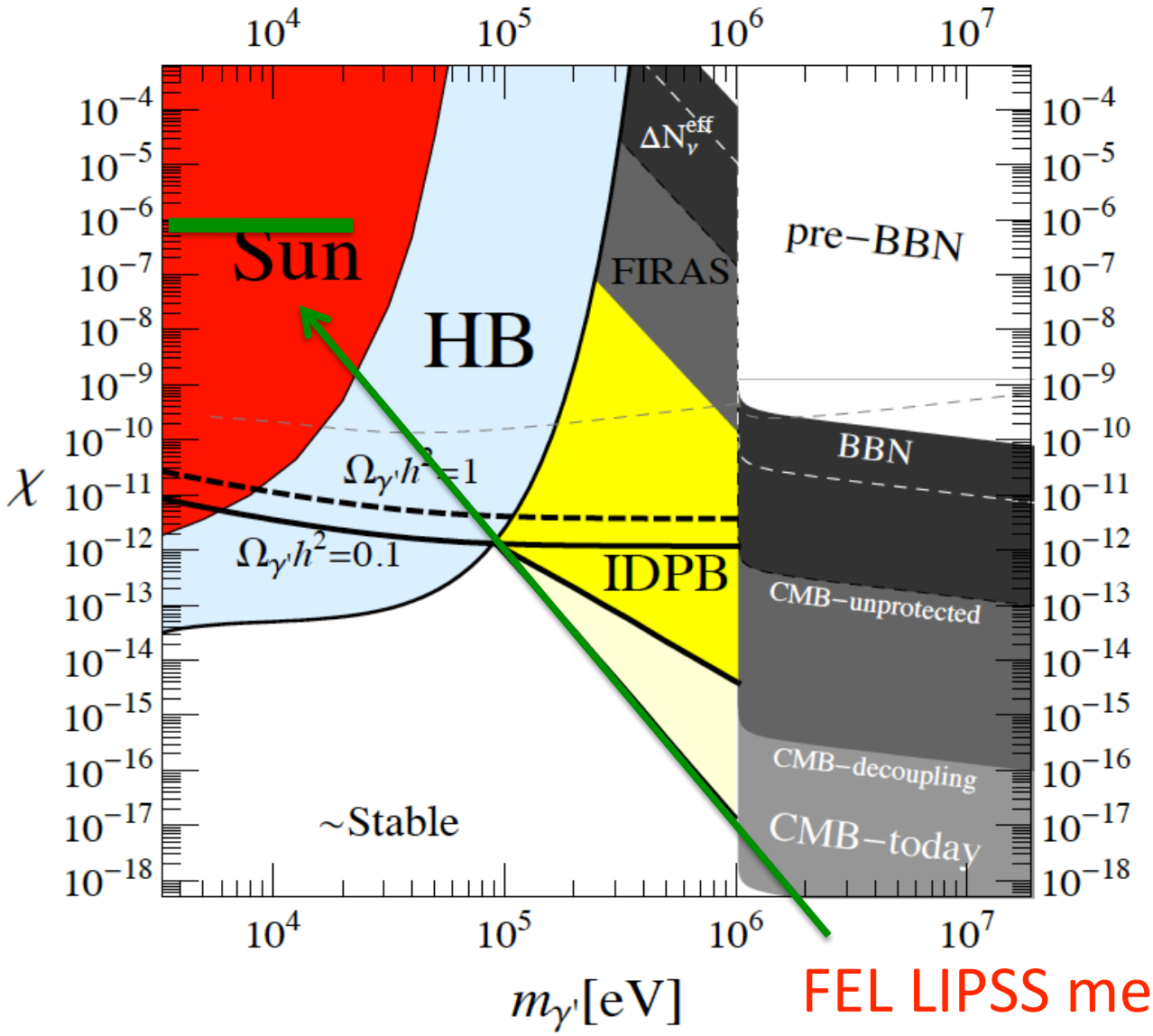
$Y_i \sim r_{A^0}\cdot n_t\cdot t\cdot\sigma\cdot\varepsilon = 1\cdot\sigma\cdot\varepsilon$ experimental yield, Hz

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

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

$\varepsilon \sim 0.01$

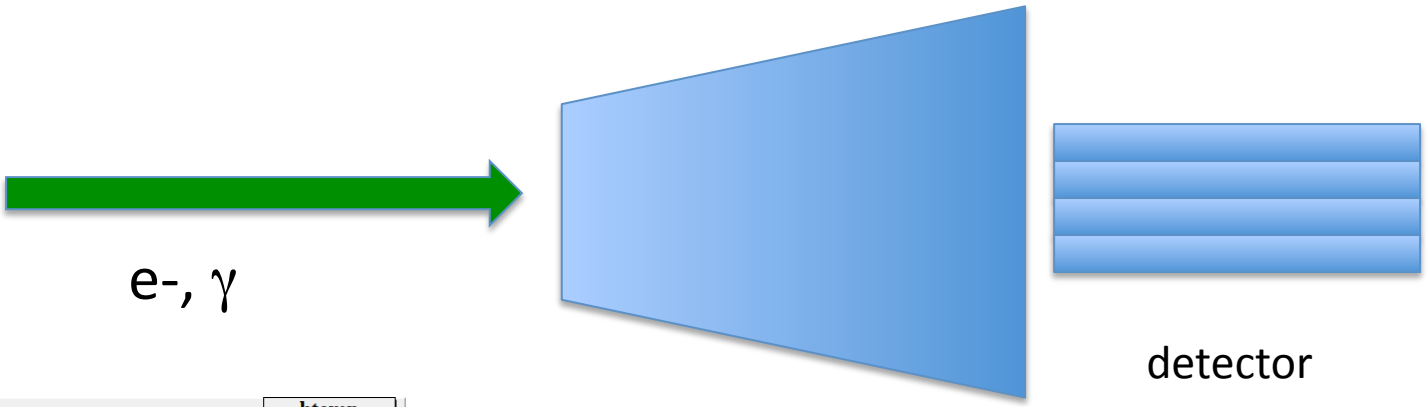
boson beam dump

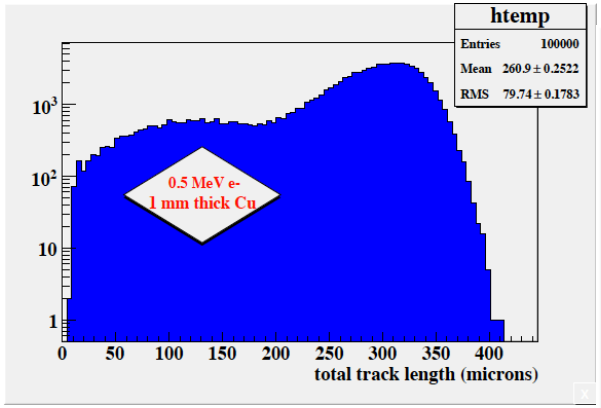


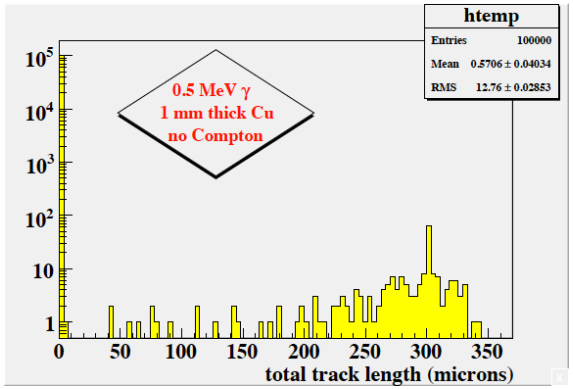
Marieke Postma, Javier Redondo, JCAP 0902:005,2009; arXiv:0811.0326

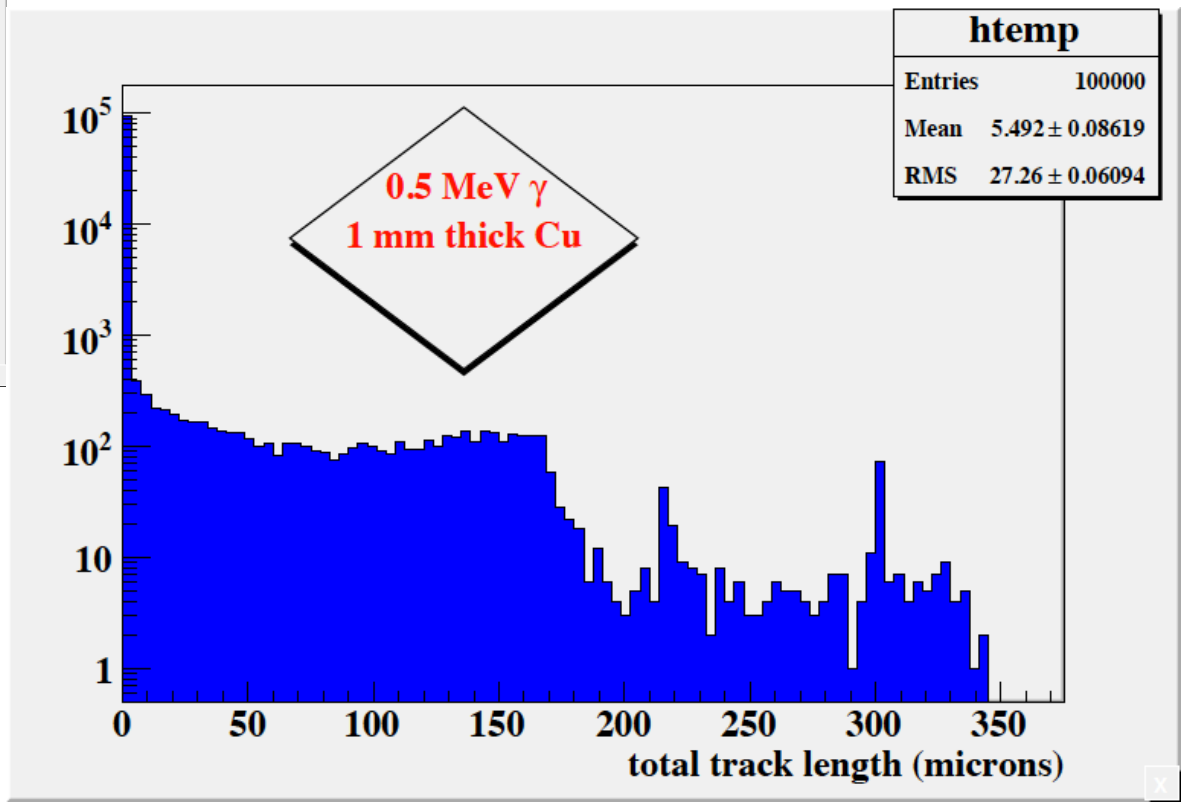
FEL LIPSS measurement:
~ one month

Geant4 mc studies



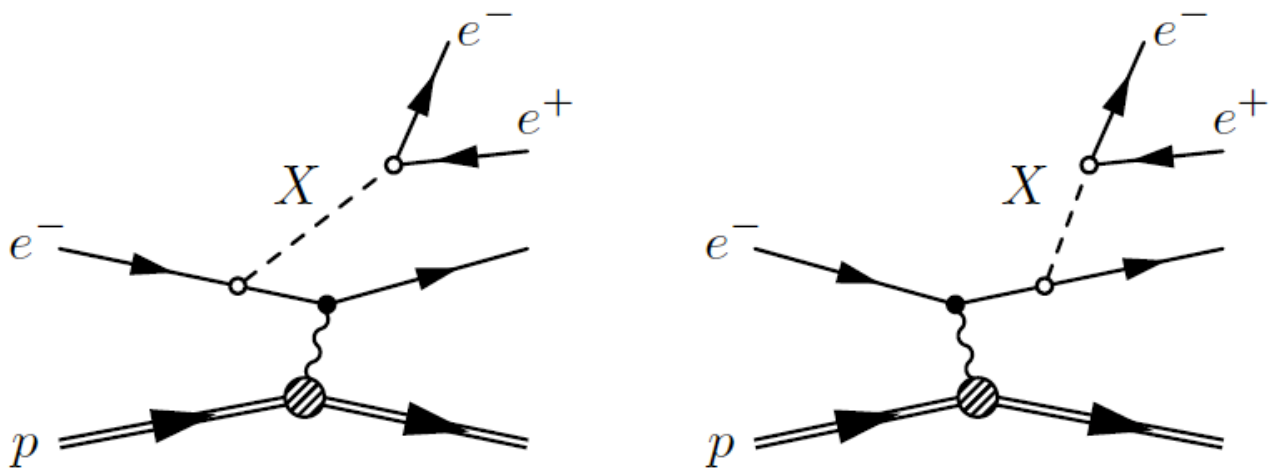




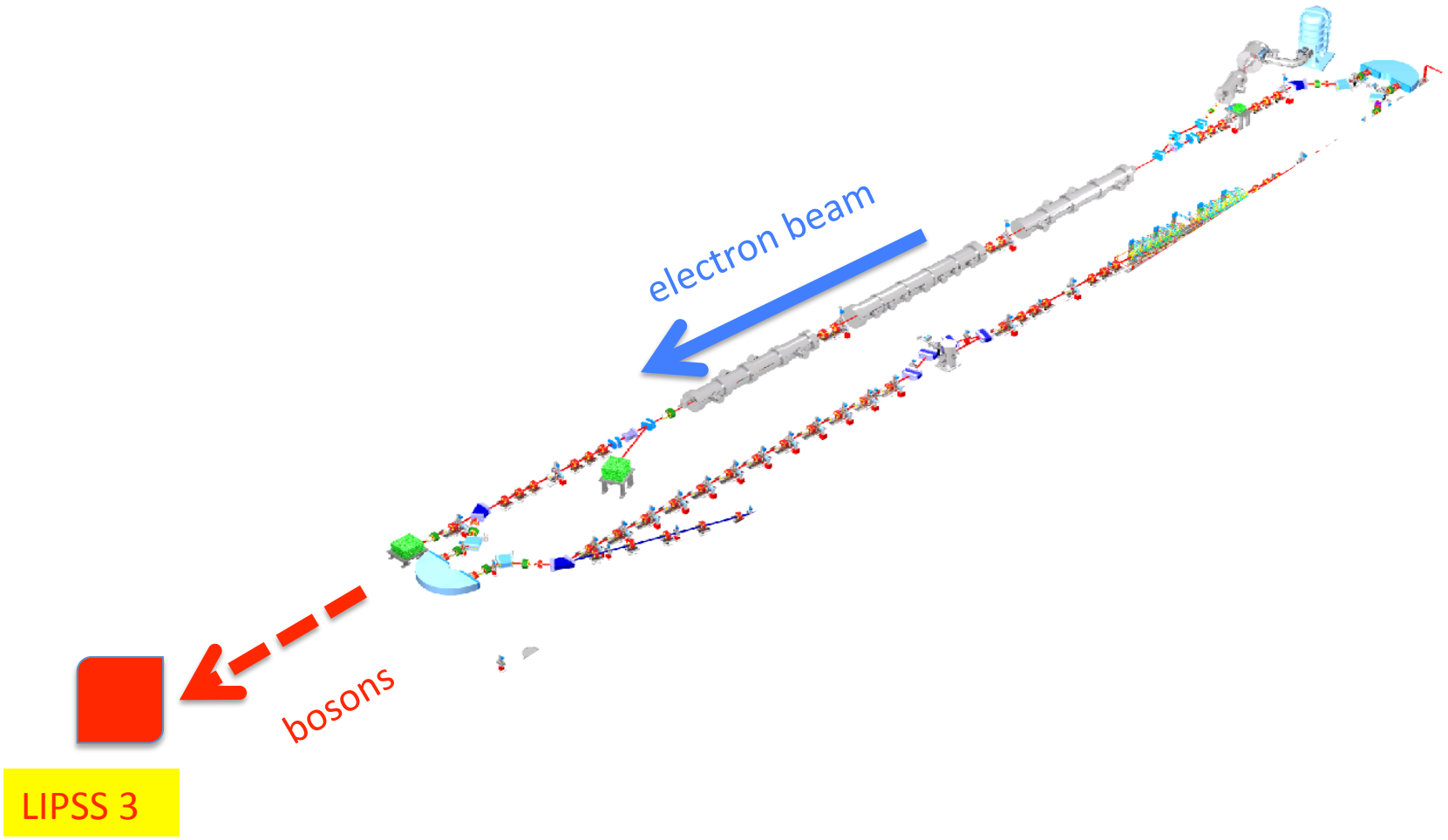


electron beam dump

- 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

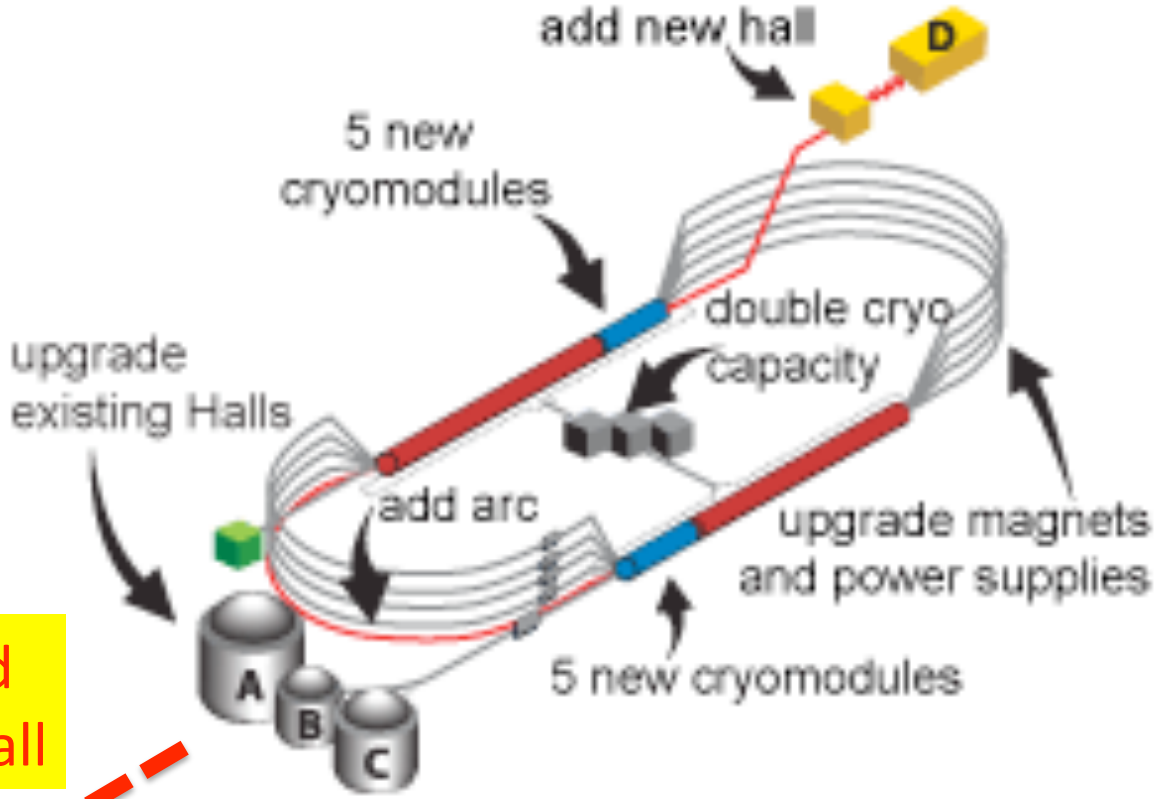


electron beam dump



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

electron beam dump



detector behind
experimental hall

high power beam dumps exists;
excavation behind CEBAF beam dumps(?)

electron beam dump

$Y_i \sim r_e \cdot n_t \cdot t \cdot \sigma \cdot \varepsilon = 1 \cdot \sigma \cdot \varepsilon$ experimental yield, Hz

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

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

$t \sim 100$ cm

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

FEL beam dump luminosity

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

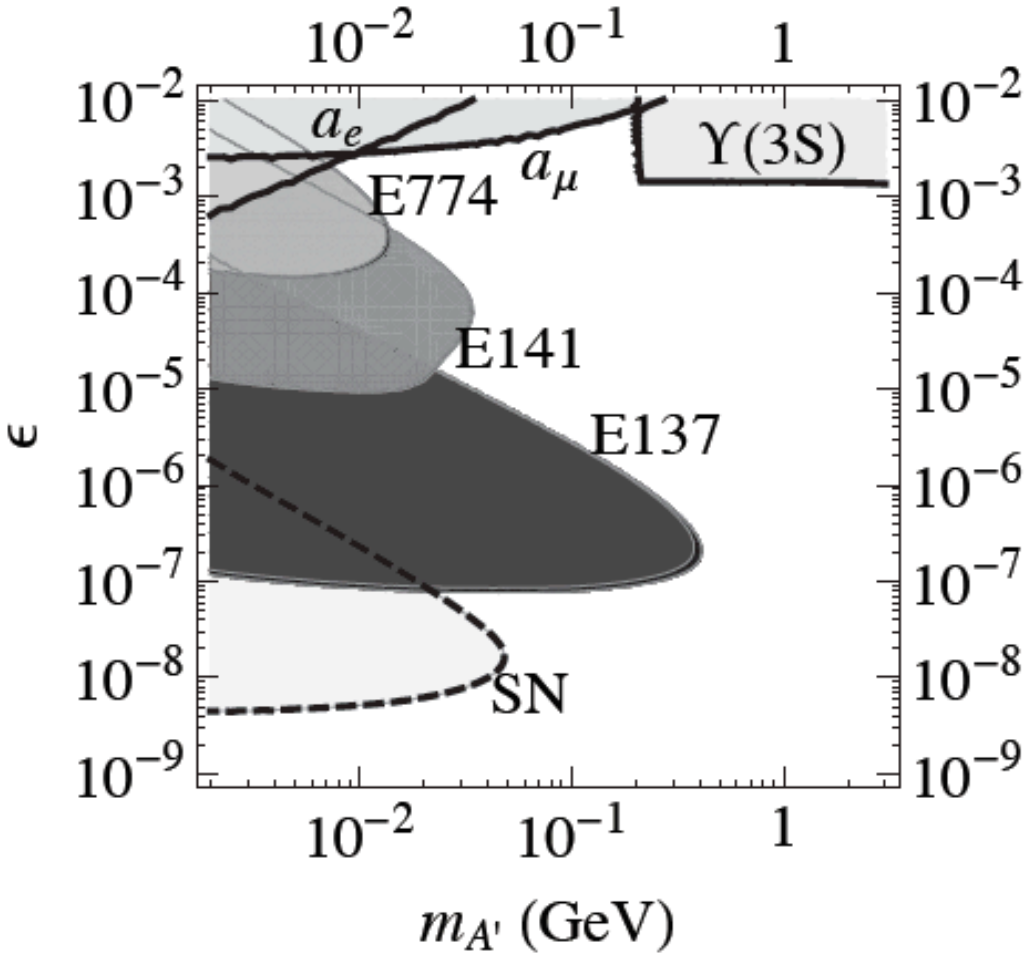
$n_t \sim 2 \times 10^{23}$ cm^{-3}

$t \sim 100$ cm

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

Hall A, C beam dump luminosity

electron beam dump

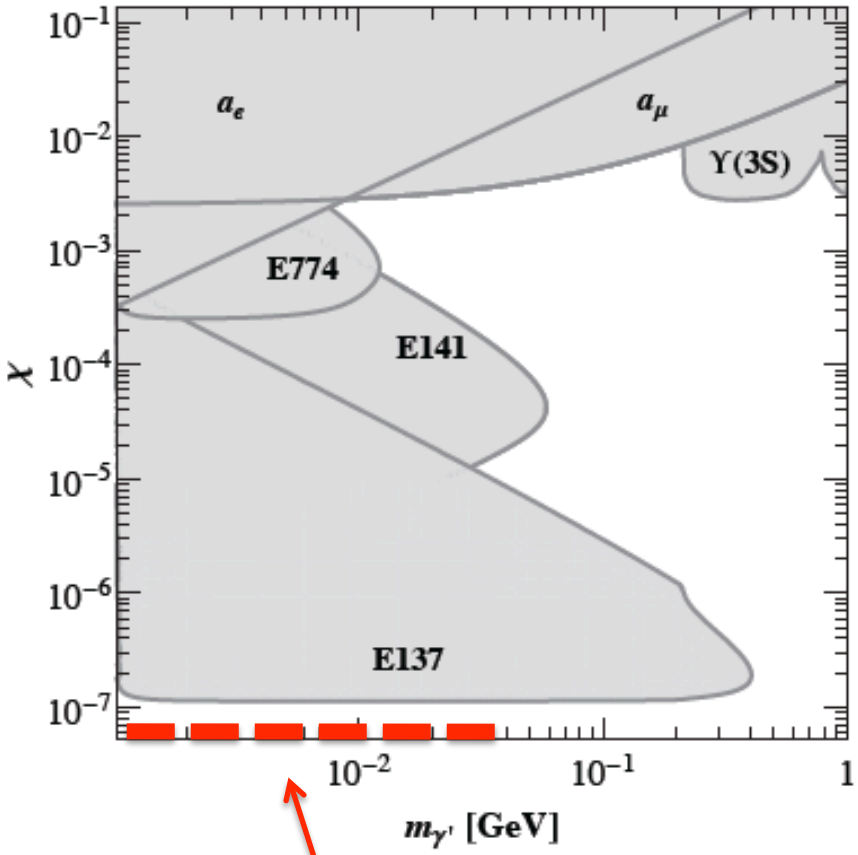


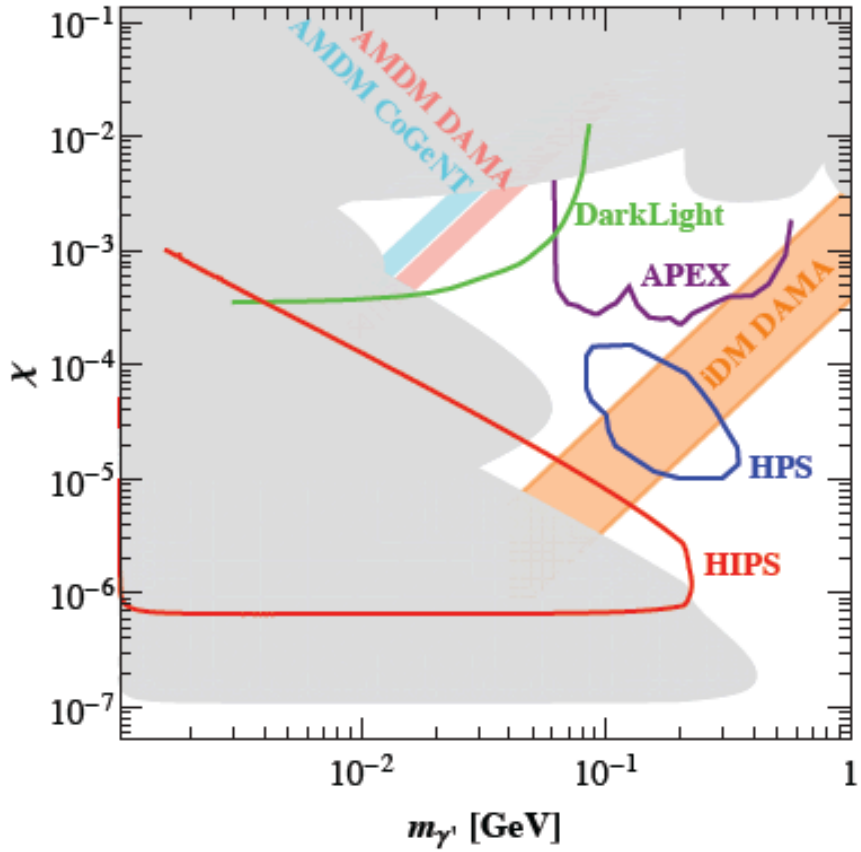
- SLAC E137
  - 2 x 10^{20} elec
  - 20 GeV
  - d ~ 400 m
- SLAC E141
  - 2 x 10^{15} elec
  - 9 GeV
  - d ~ 35 m
- **FNAL E774**
  - **5 x 10^{10} elec**
  - **275 GeV**
  - **t ~ 1 m**

JD Bjorken et al, PhysRevD.80.075018 (2009)

electron beam dump

S. Andreas, A. Ringwald contribution to 6th Patras Workshop on Axions, WIMPs and WISPs, Zurich University, Switzerland, 5-9 July 2010 arXiv:1008.4519



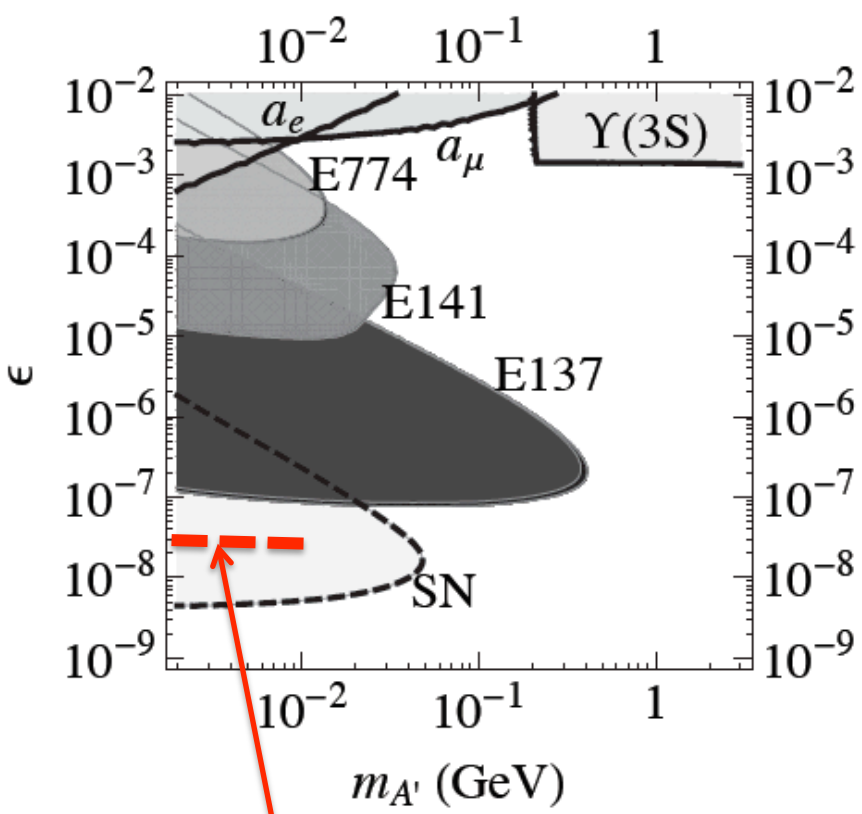


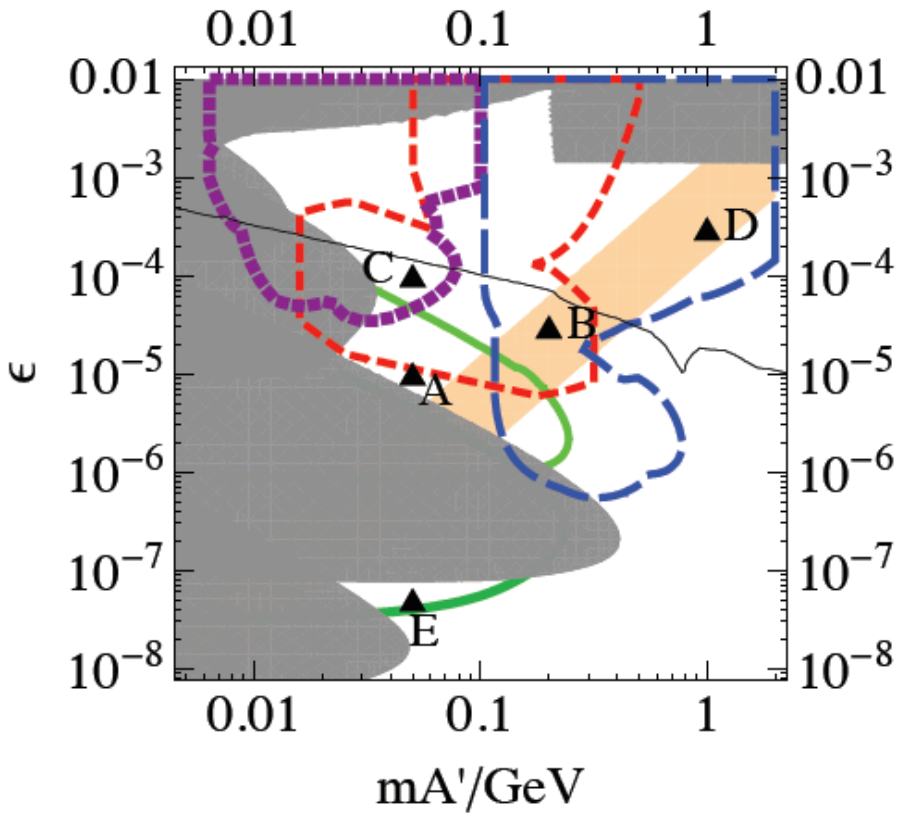
CEBAF LIPSS in ~ one month

χ : CEBAF LIPSS ~2 *x* E137

electron beam dump

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





FEL LIPSS in ~ one month

ε : FEL LIPSS 3 *x* E137

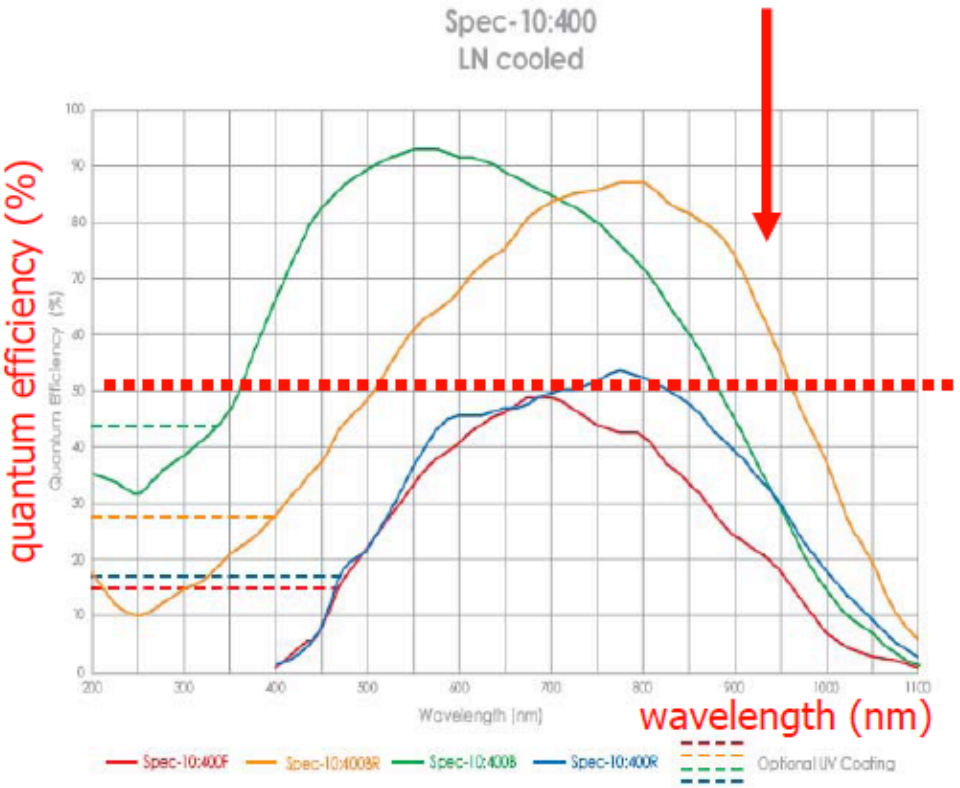
summary

- 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
  - mass reach exceeding electron-positron limit
  - Improve upon current SLAC and FNAL limits
- CEBAF beam dump experiment
  - Mass reach exceeding a GeV; long lived bosons
  - Improve upon current SLAC and FNAL limits
- experience from recent FEL experiments by LIPSS collaboration
  - photon regeneration Dark Matter studies

more info . . .

more info . . .

Princeton Instruments ACTON 10:400BR-LN



q.e. high at 935 nm

50%

LN2 cooled: <1 e/pix/hour dark noise !!!
used 100 kHZ readout rate