Light Pseudoscalar –Scalar Particle Search (LIPSS): status

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for the LIPSS Collaboration

3rd Joint ILIAS-CERN-DESY Axion-WIMPS Training Workshop

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LIPSS collaboration

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LIPSS goal: test (particle interpretation of) the PVLAS result in a photon regeneration experiment

PVLAS results may be explained by a region . . .

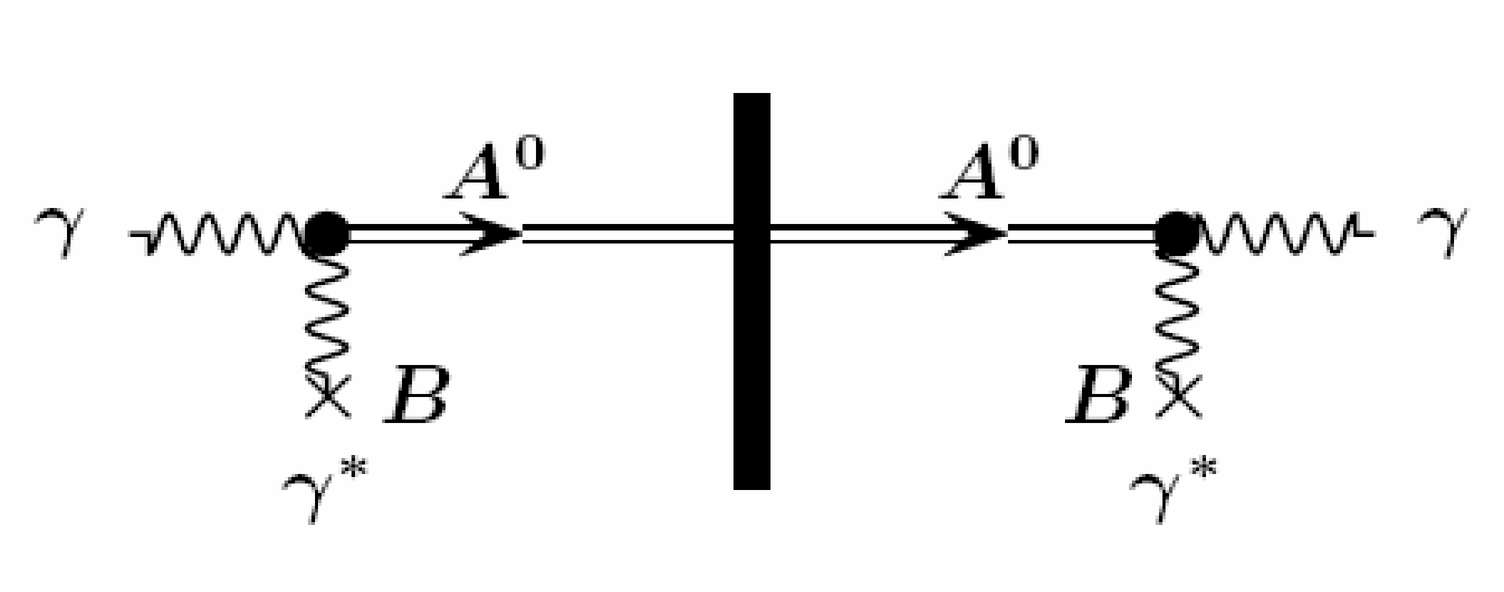
$1.7 \times 10^{-6} < g < 5.0 \times 10^{-6}\ \mathrm{GeV}^{-1}$

$1.0 < m < 1.5\ \mathrm{meV}$

PVLAS rotation effect is 10^{28} stronger than QED (Heisenberg-Euler) prediction!

Photon Regeneration
‘light shining through a wall’

BFRT Collab, Phys. Rev. D47 3707 (1993)



- light, neutral boson coupling to photons

pseudoscalar particle or

pseudoscalar interaction

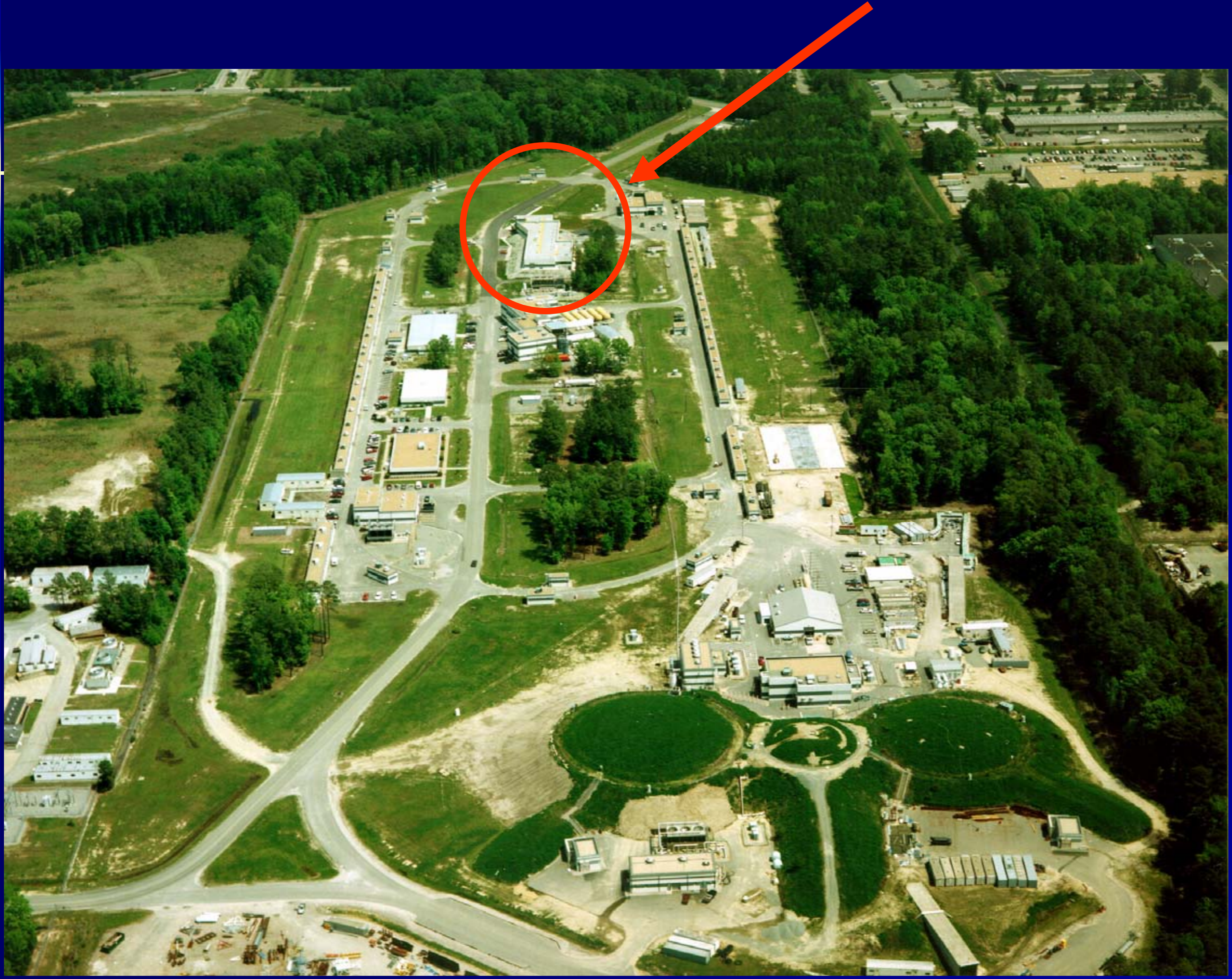
$$L_{\varphi\gamma\gamma} = -\frac{1}{4M}\varphi F_{\mu\nu}\widehat{F}^{\mu\nu} = \frac{g\varphi}{4}\vec{E}\cdot\vec{B}$$

couple polarized laser light with magnetic field

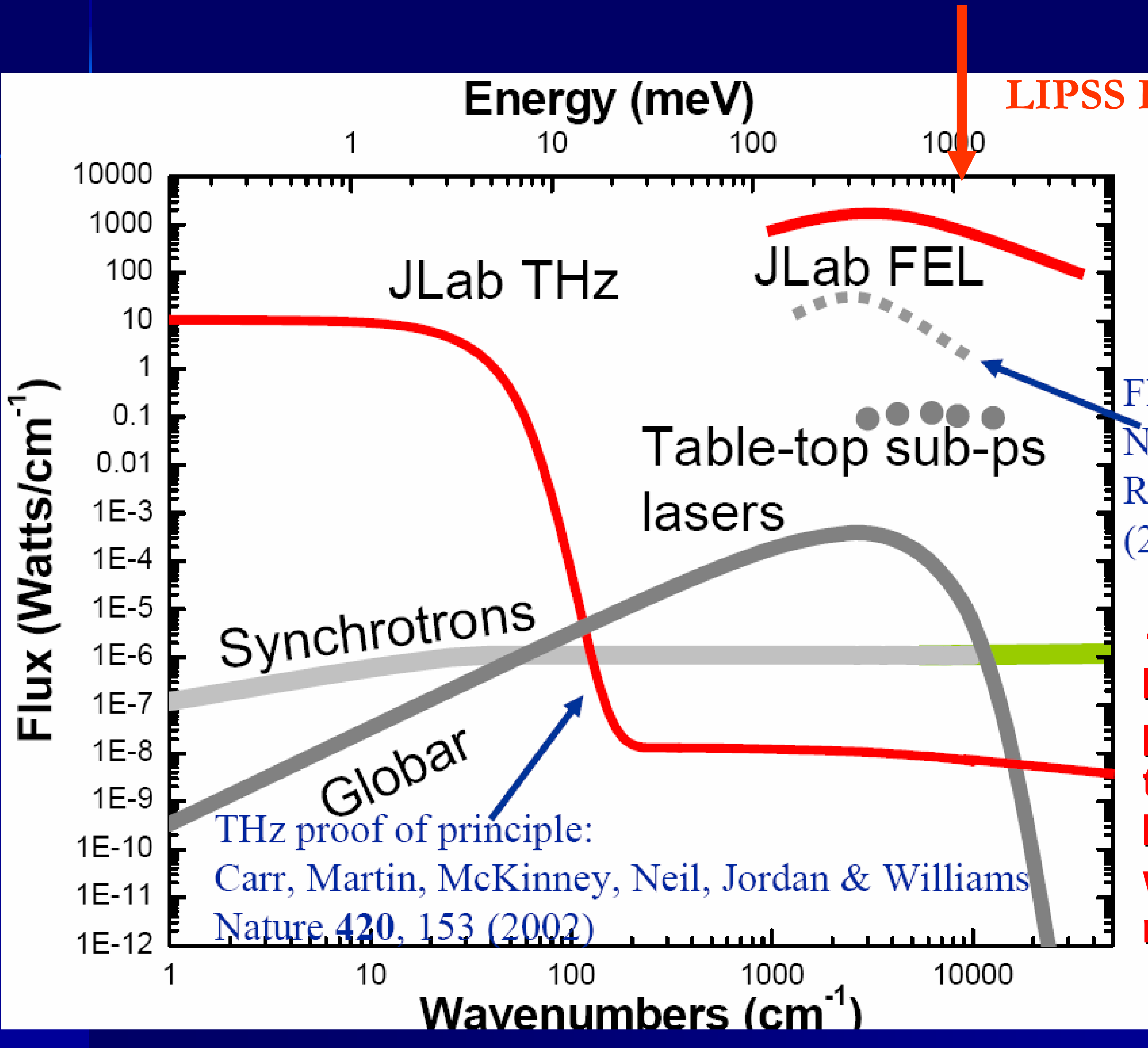
Sikivie (1983);
Ansel’m (1985);
Van Bibber et al (1987), Raffelt et al (1988)

- use FEL laser light and magnetic field

Jefferson Lab's Free Electron Laser



JLAB facility spectroscopic range



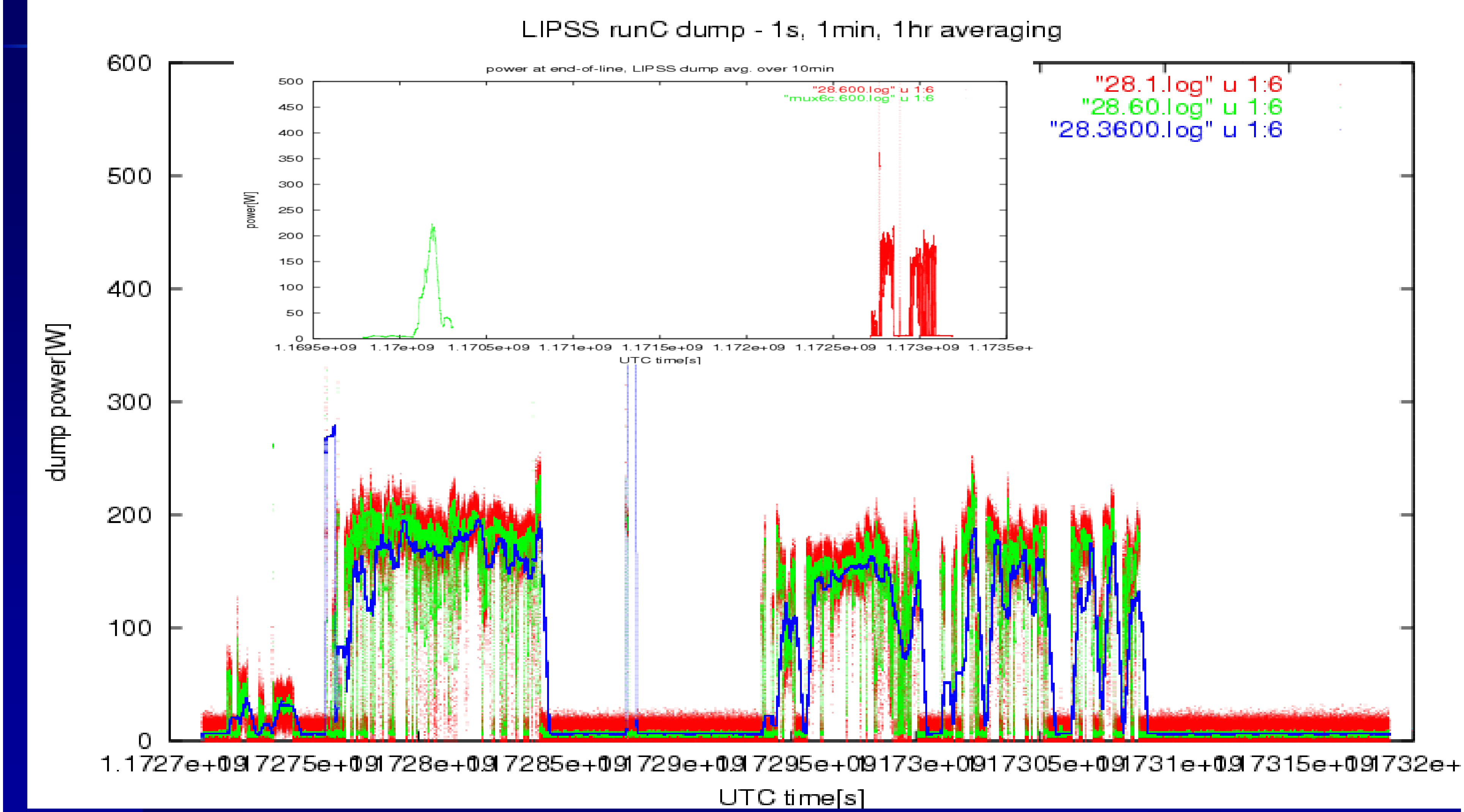
LIPSS IR run at 935 nm

FEL proof of principle: Neil et al. Phys. Rev.Letts **84**, 662 (2000)

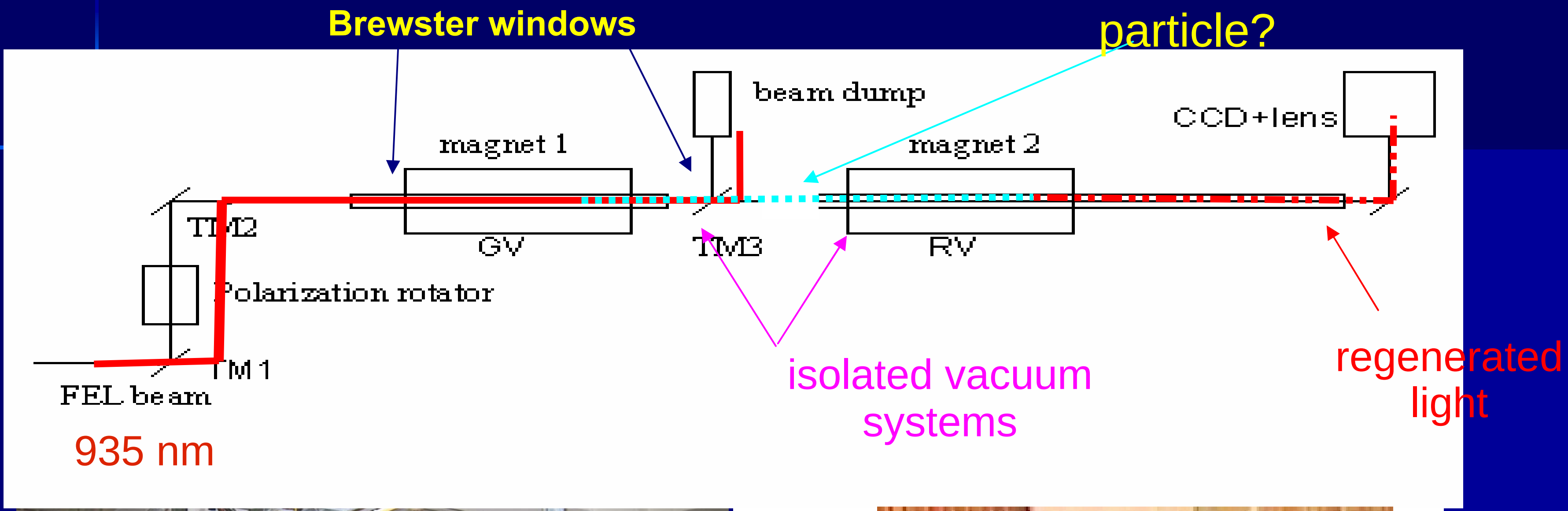
THz proof of principle:
Carr, Martin, McKinney, Neil, Jordan & Williams
Nature **420**, 153 (2002)

~100% linearly polarized light tuneable over large wavelength range

actual power delivered to the LIPSS dump over 5 days
laser beam power remarkably stable



LIPSS apparatus.



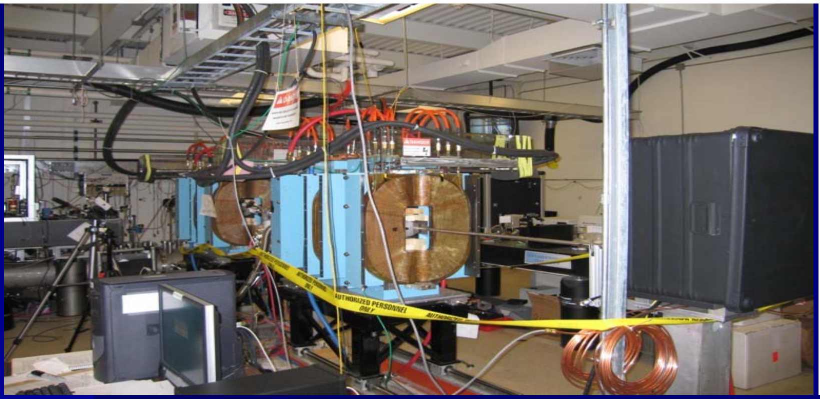
Brewster windows

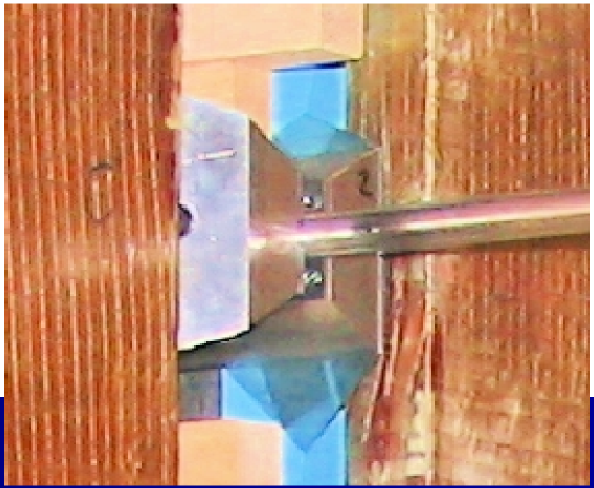
particle?

isolated vacuum systems

regenerated light

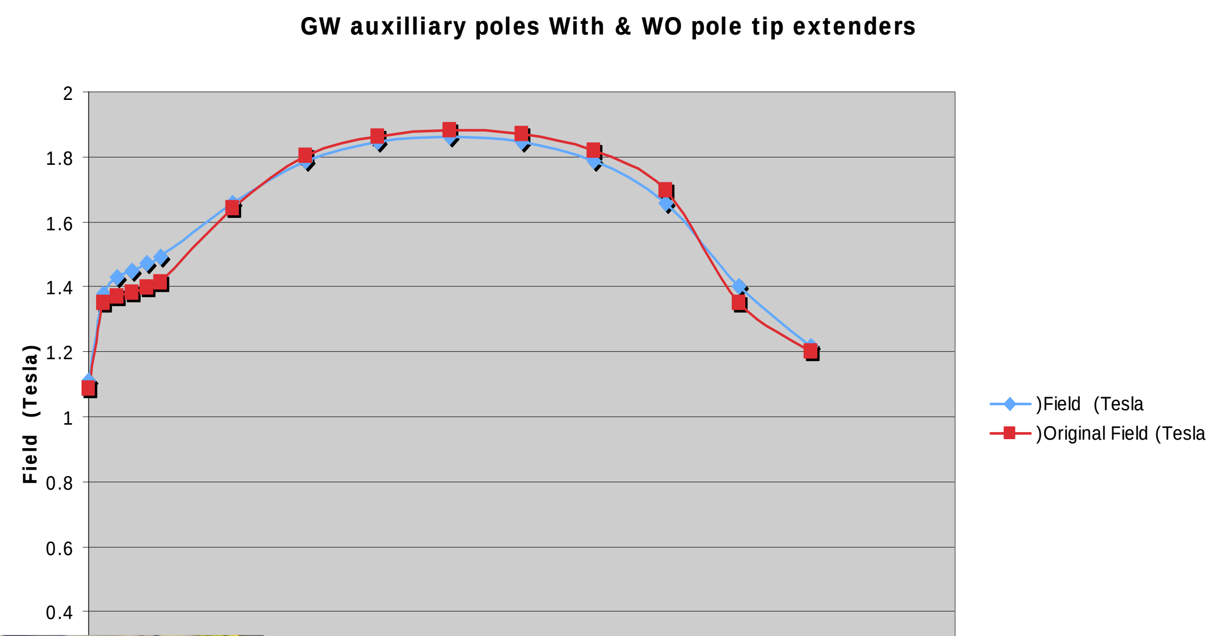
935 nm

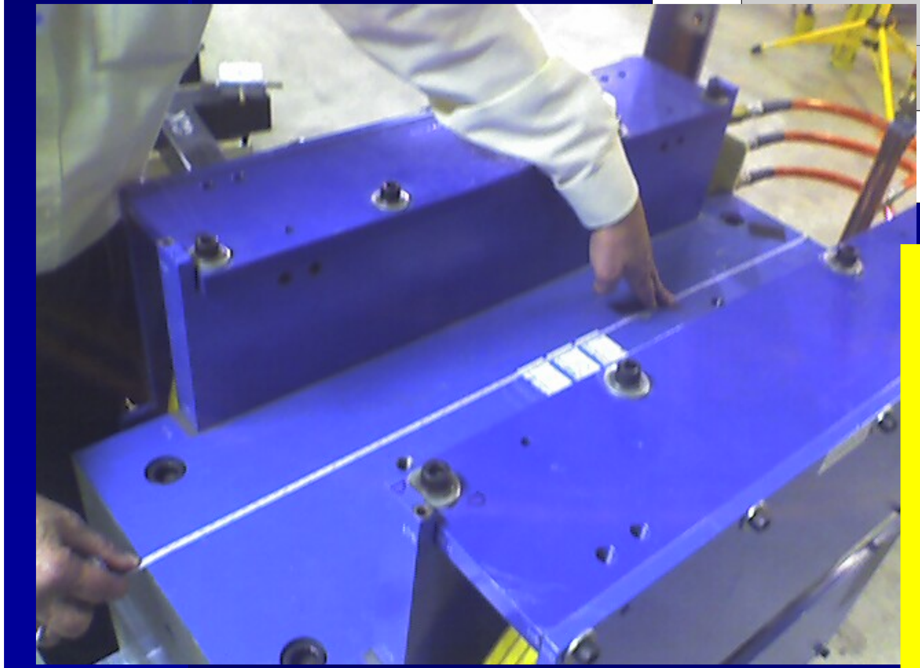




LIPSS setup in Lab 1 at FEL

GW magnet field map



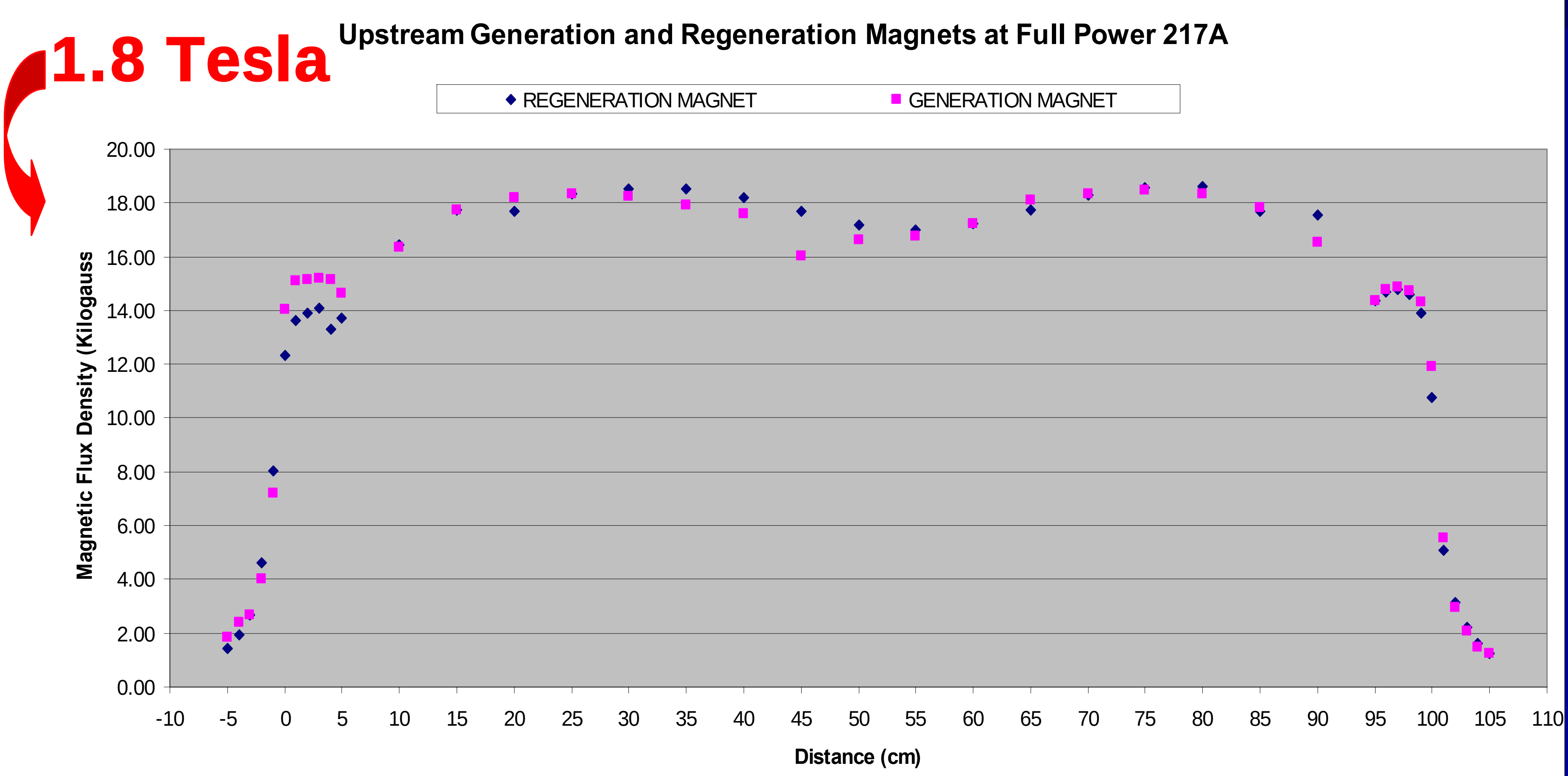


each GW magnet is 0.5 m long.

two GW magnets are paired together to form a generation magnet 1 m long; two more to form a regeneration magnet 1 m long average magnet length: 1.05 meter

average magnetic field strength 1.76 T

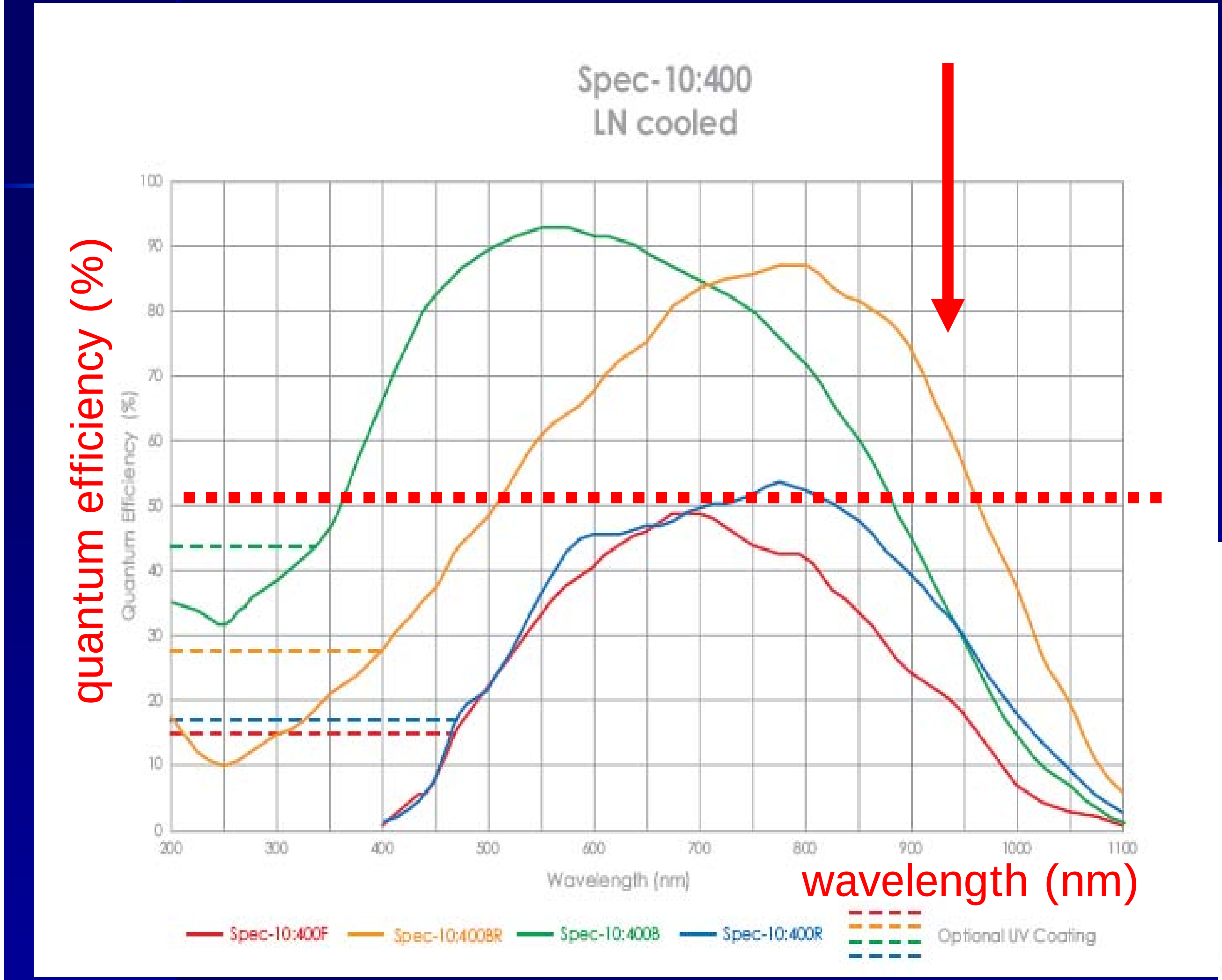
field uniformity: adequate



1.8 Tesla

Upstream Generation and Regeneration Magnets at Full Power 217A

Princeton Instruments ACTON 10:400BR-LN

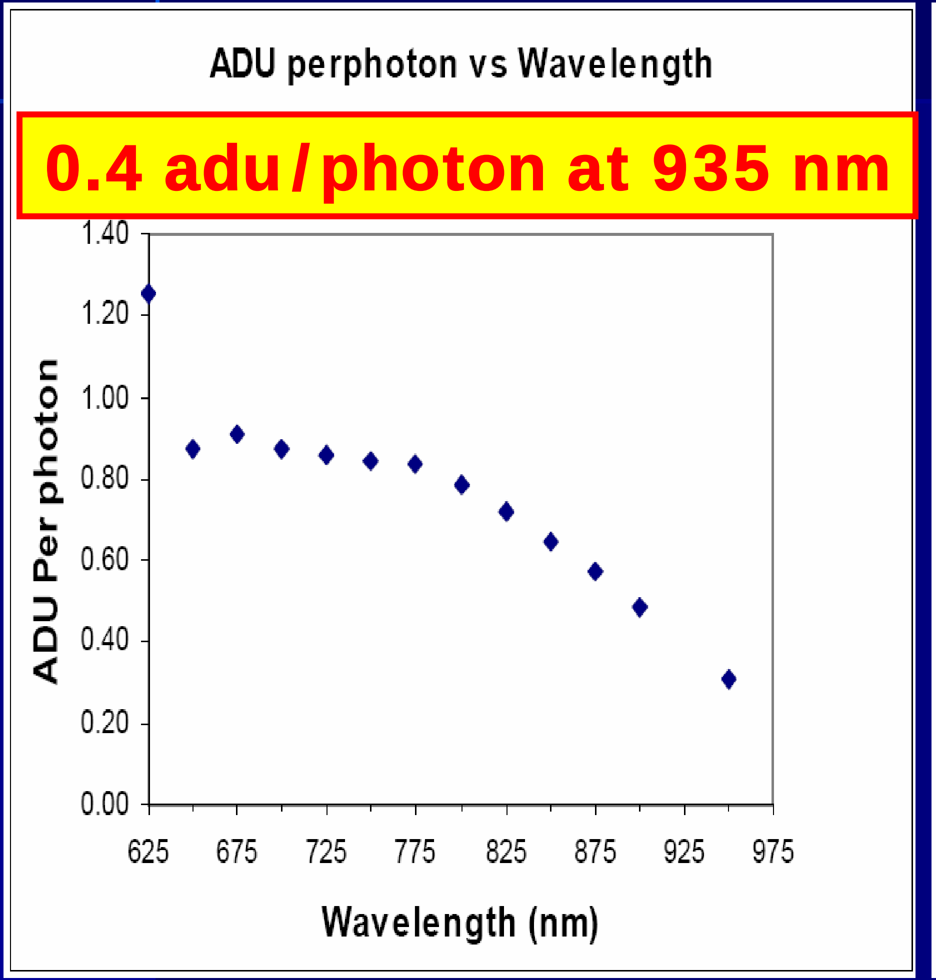


q.e. high at 935 nm

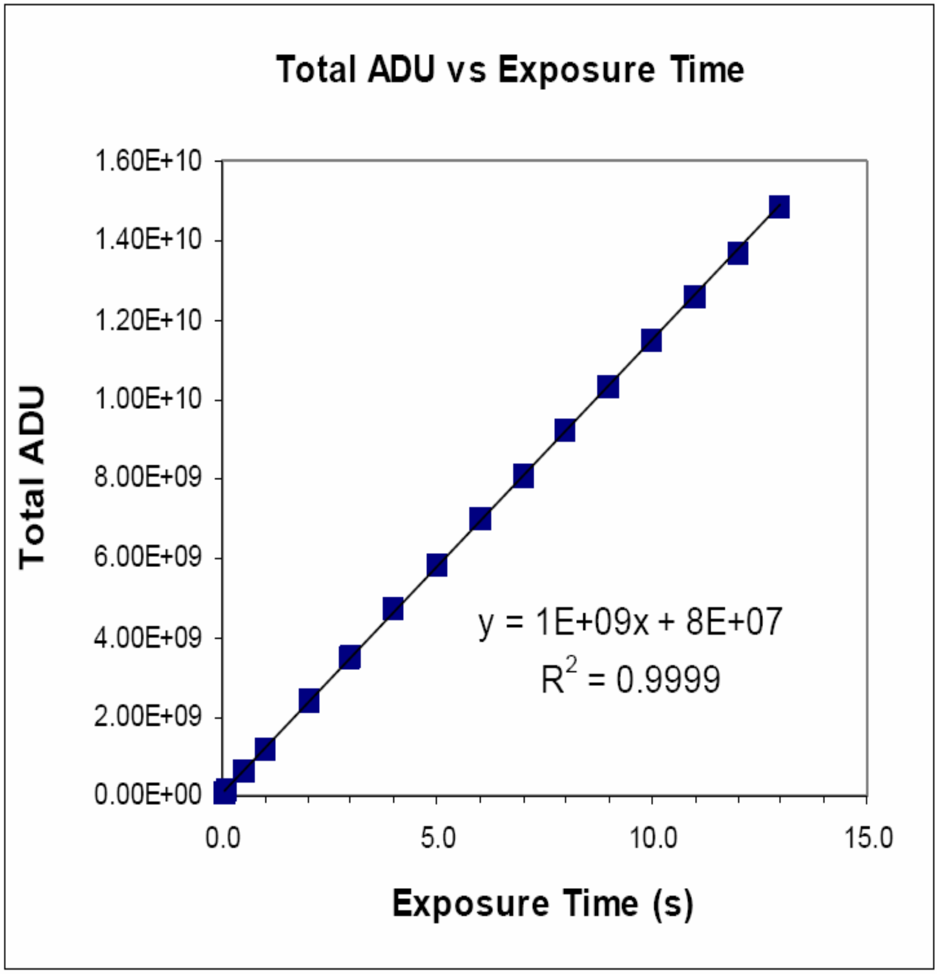
50%

LN2 cooled: 1.3 e/pix/hour dark noise !!!
used 100 kHZ readout rate

PI Acton 10:400BR-LN CCD tests examples

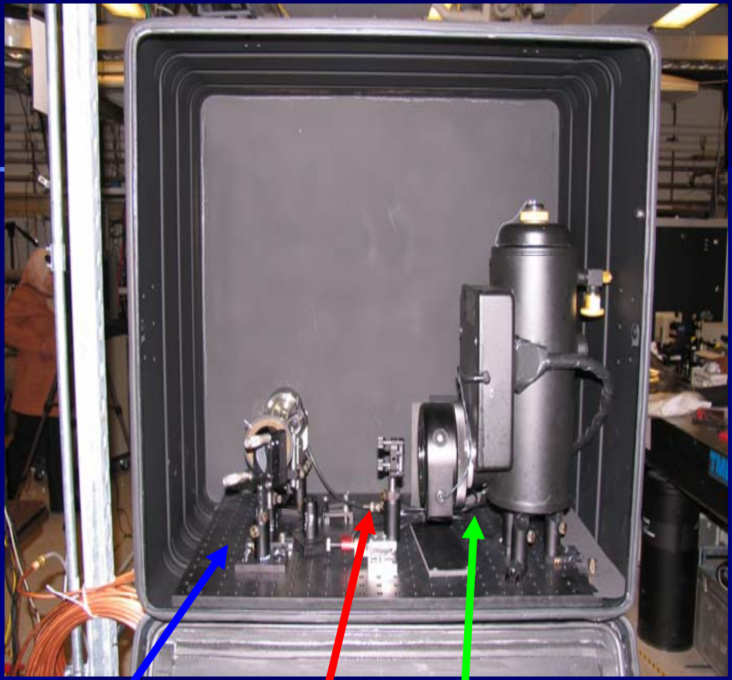


0.4 adu/photon at 935 nm



tests under controlled conditions to verify manufacturer specs

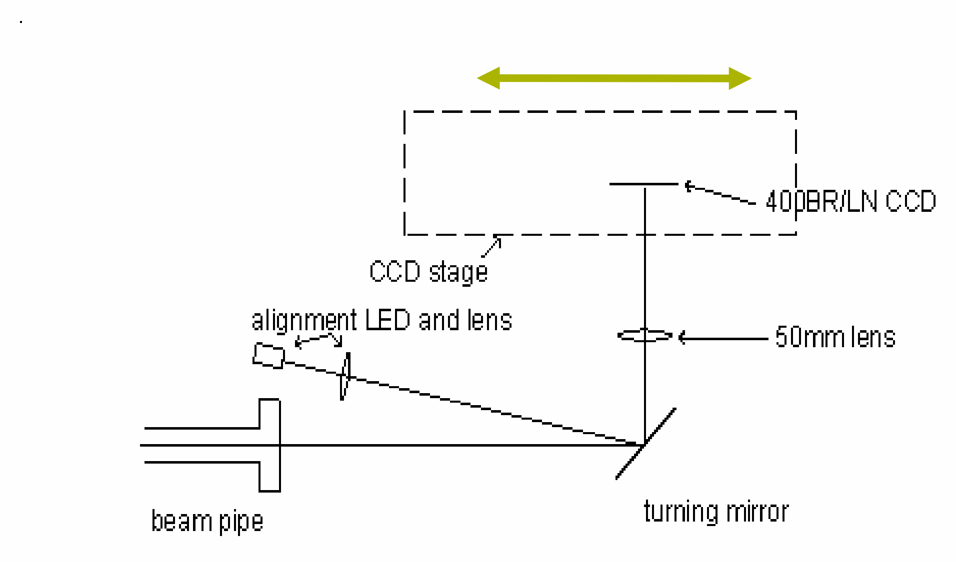
detector optics

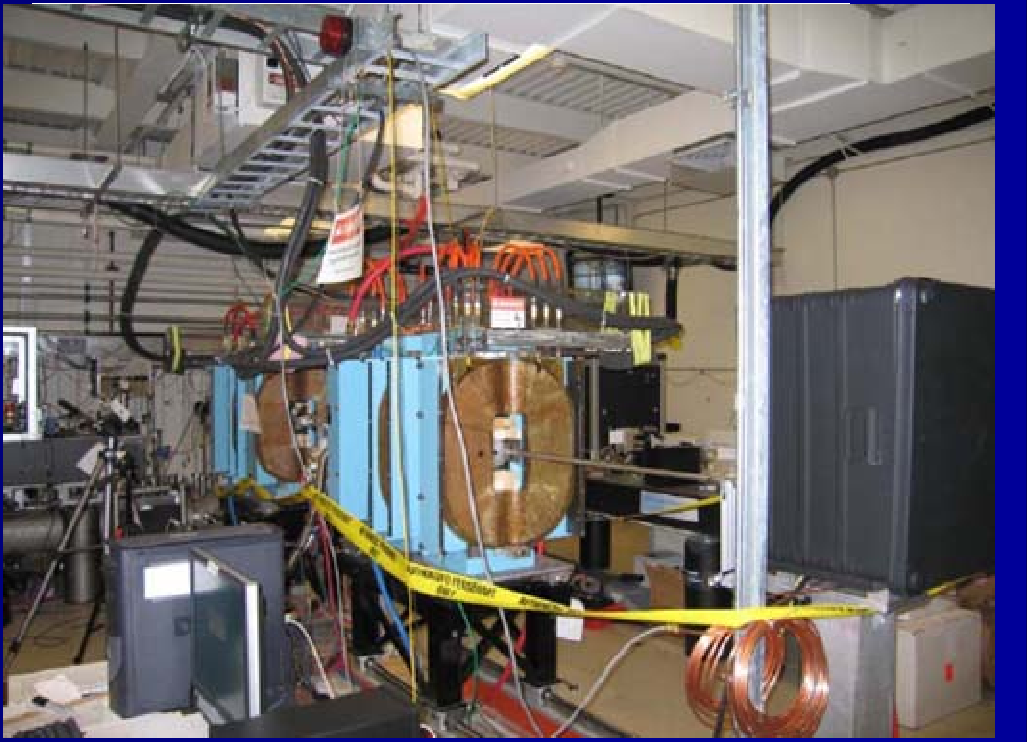


mirror

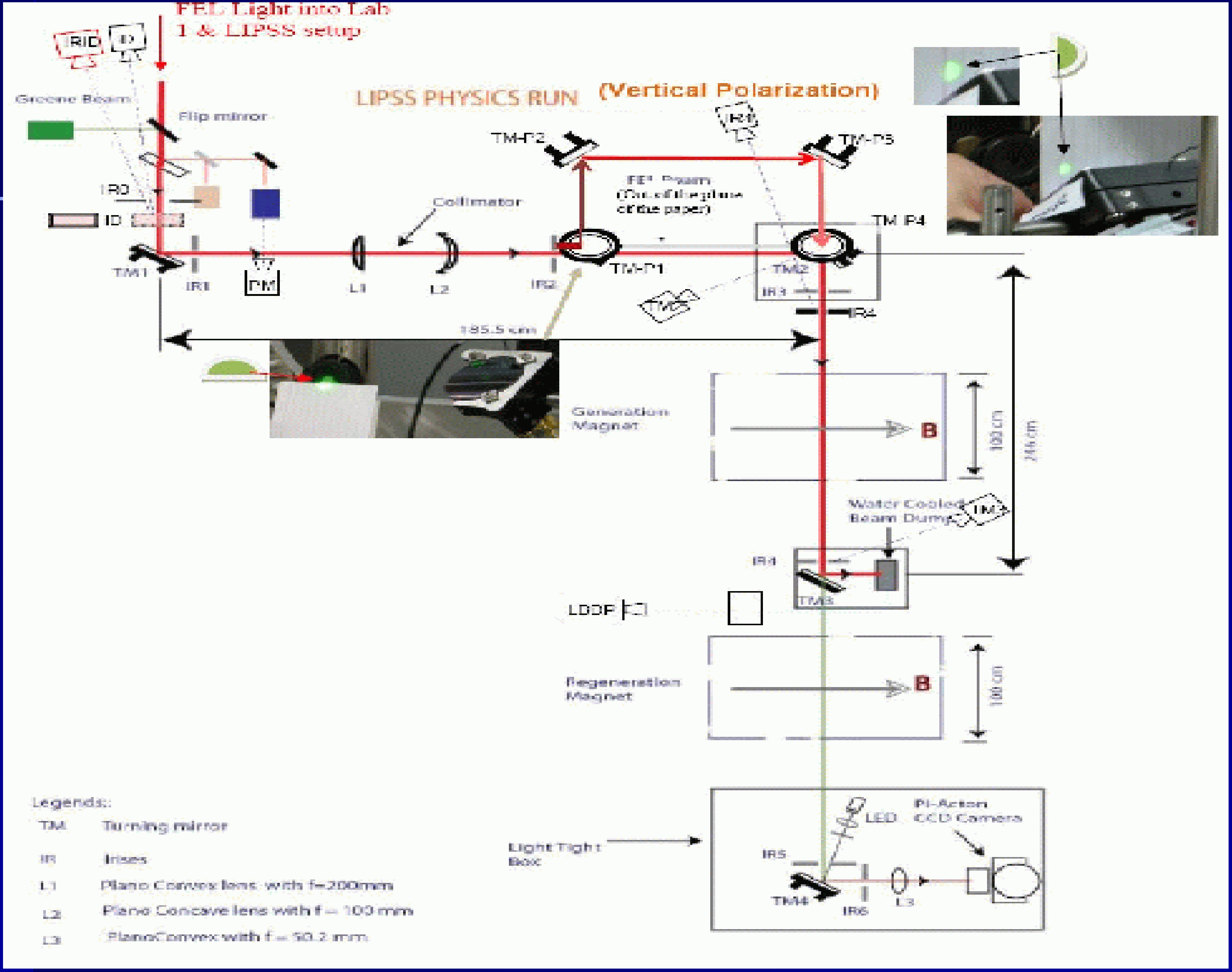
lens

Spec10:400BR-LN camera





details of LIPSS layout *(not to scale)*



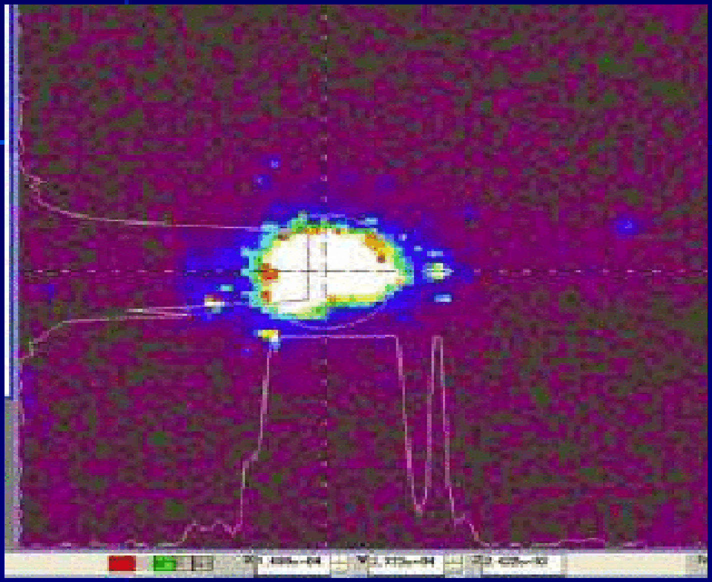
Legends:

TM	Turning mirror
IR	Irises
L1	Plano Convex lens with f=200mm
L2	Plano Concave lens with f = 100 mm
L3	PlanoConvex with f = 50.2 mm

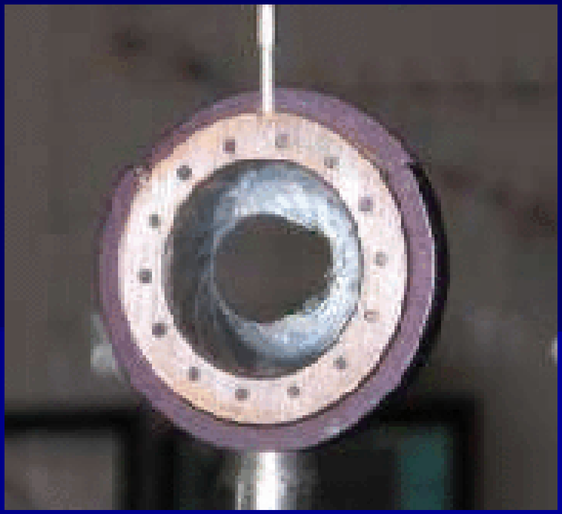
alignment

- used HeNe laser to align to CCD
- used FEL in alignment mode (pulsed laser, ~0.5W) to align to same iris set (6 ea), including the iris in front of CCD
- focusing lens with focal length 50.2 mm in front of CCD.
- used picomotor on TM2 and TM3 to adjust beam position; kept constant during run

laser beam alignment



beam spot occasionally drifted and had to be adjusted using picomotors; the spots were logged to VHS tape.

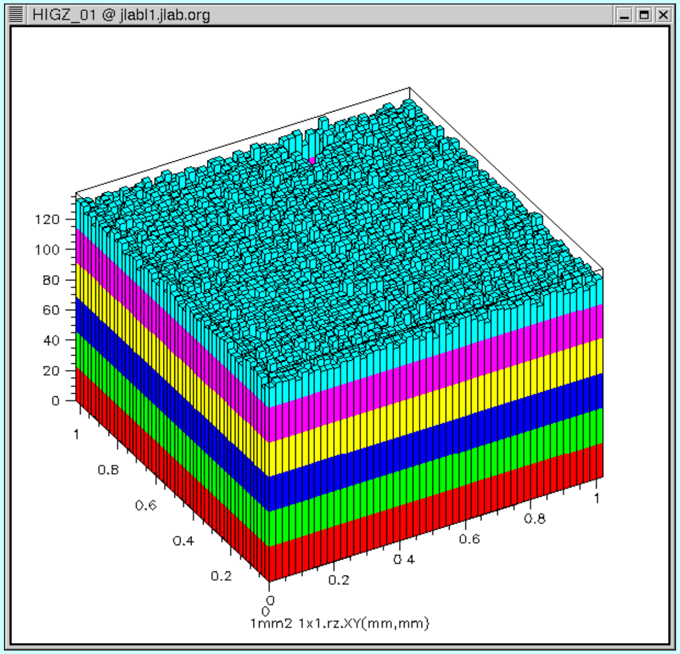


high power laser can cause damage to equipment if not monitored and held stable!!

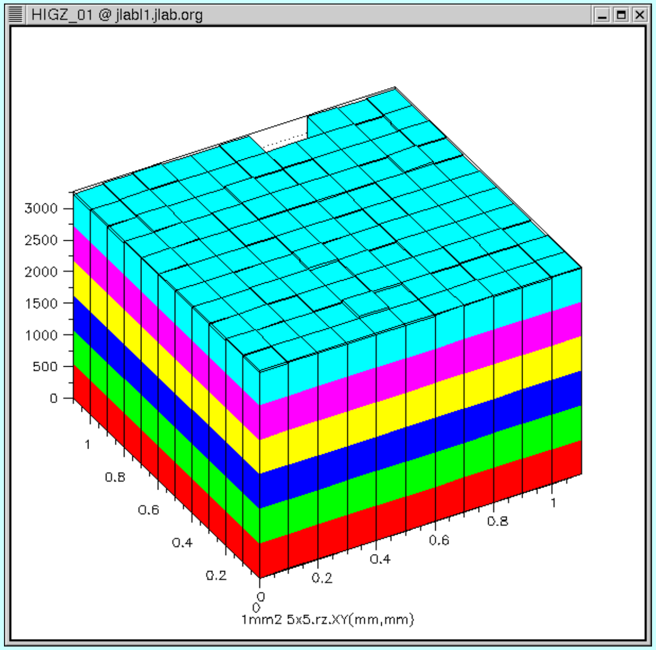
calculated that the beam pointing motion was < 50 microns on CCD

will verify this with measurement

binning



1 X 1



5 X 5

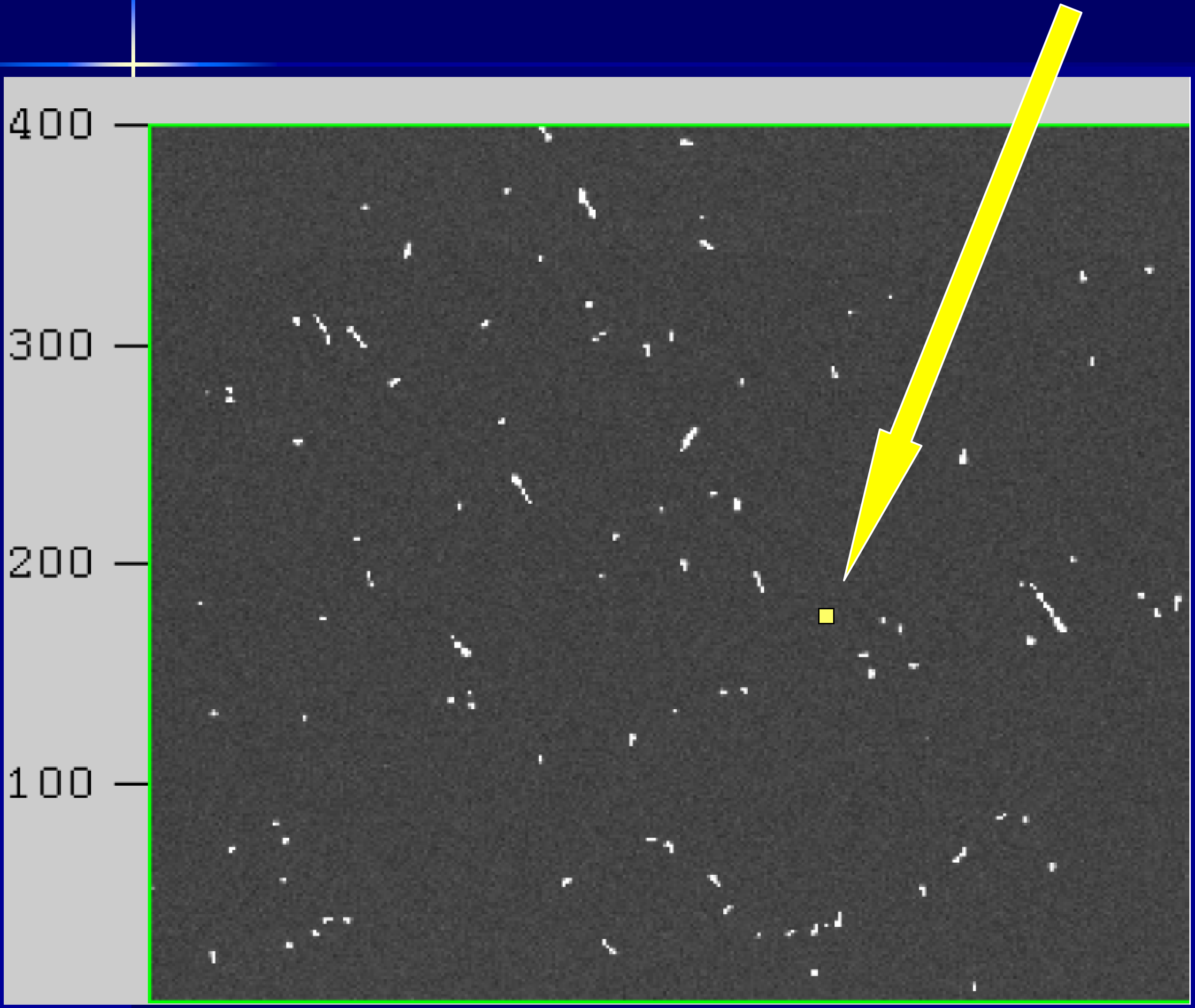
1mm X 1mm region

binning *can* be done **on chip** ***before*** readout to minimize noise,
but one must choose the binning wisely to optimize the signal

readout noise per pixel reduced with coarse binning.

contribution from dark noise may increase if not binned properly.

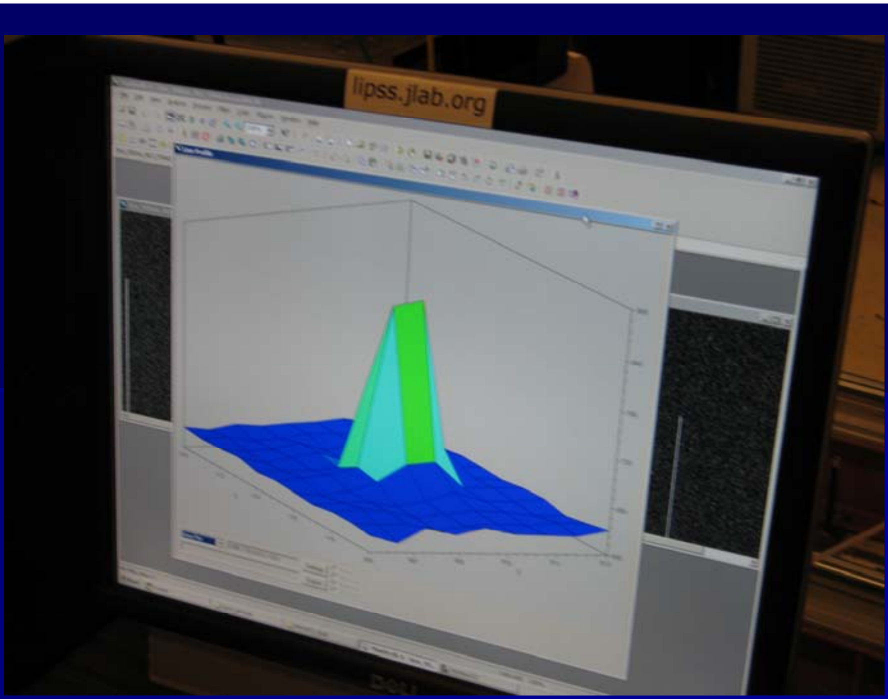
2 hour exposure; cosmic ray hits obvious exclude all regions where there were CR hits 5x5 pix array area shown in yellow

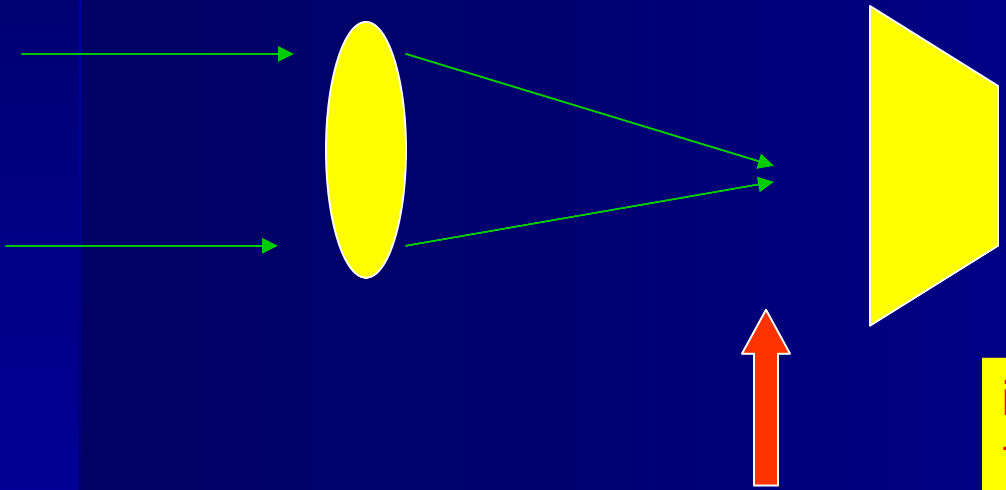


run procedure:

1. take short (bias) exposure
2. take LED exposure
3. take long (physics) exposure
4. if CR hit ‘near’ signal region, discard run

increase S/N: focusing light

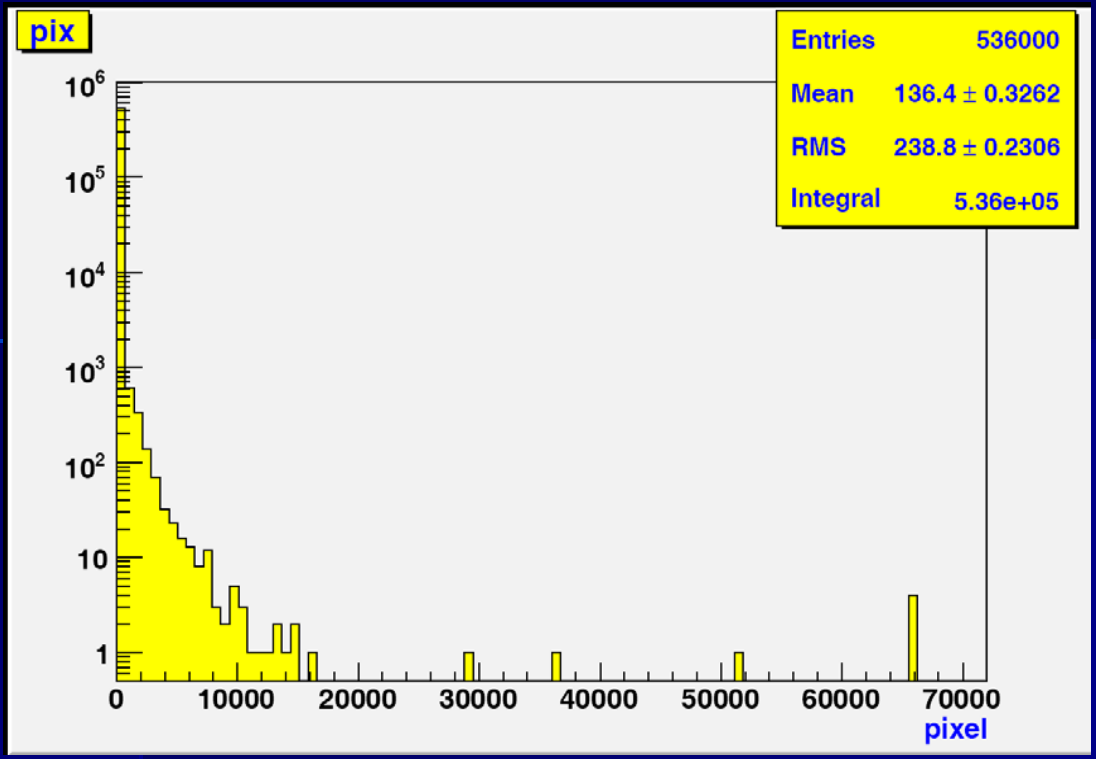




< 10 μm
spot size

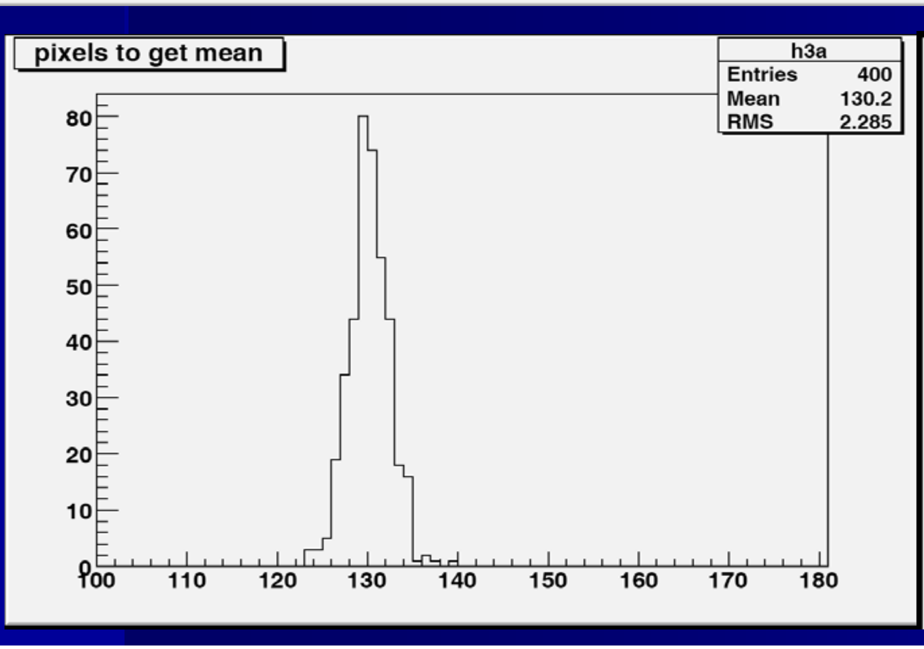
in this analysis, we assumed that the beam illuminated a 3x3 array of 20 micron x 20 micron pixels

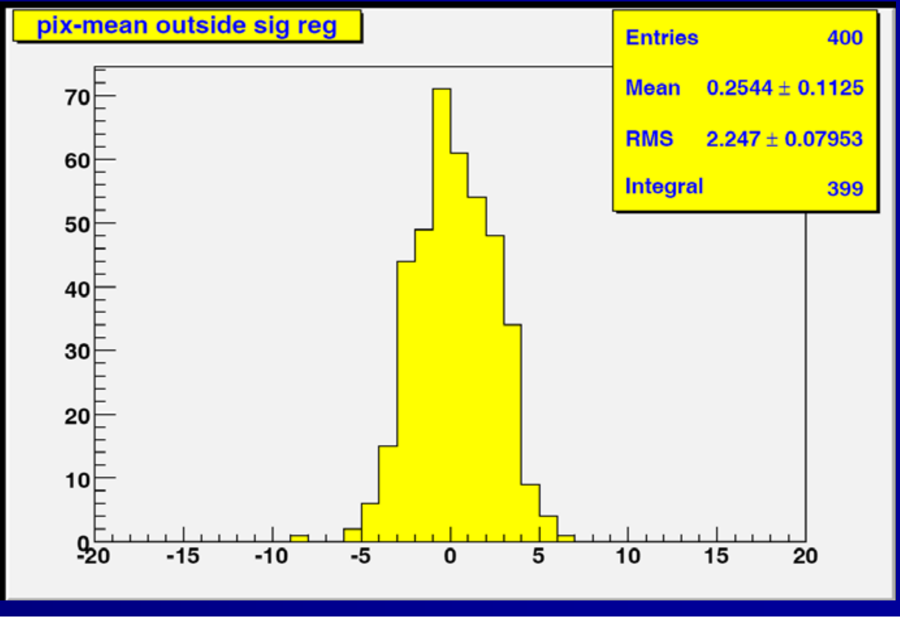
actual value should be less than this; will be verified

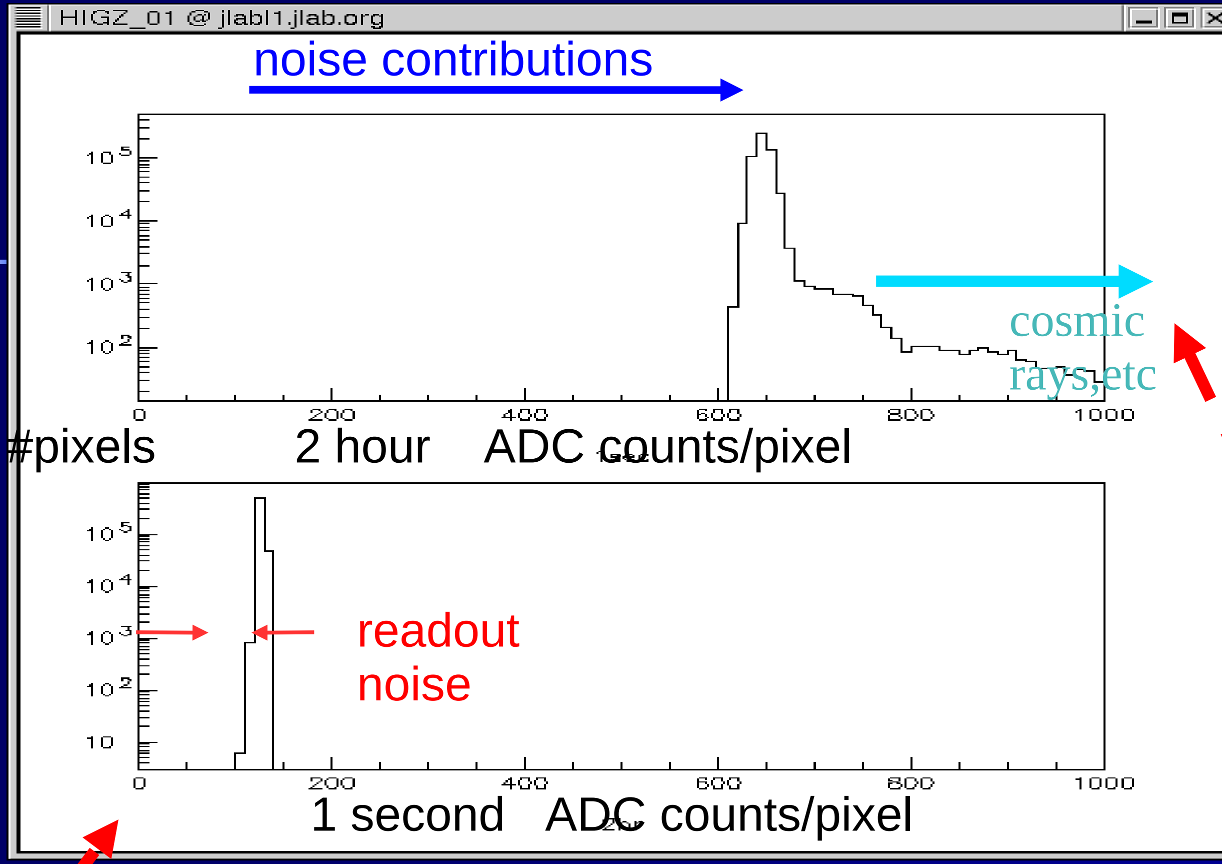


1340 x 400 = 536000

(20 x 20 μm) pixels

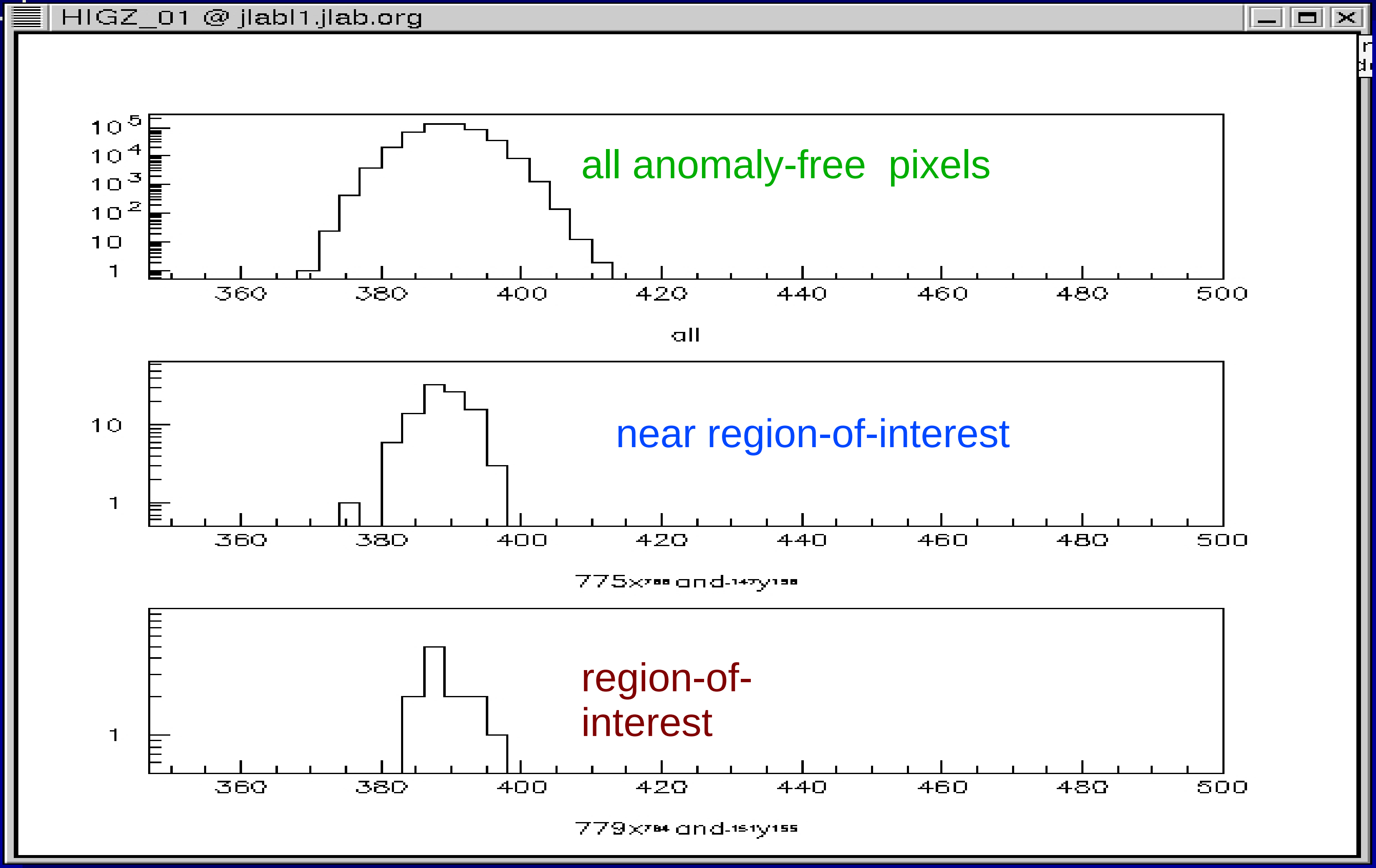






- determine light leaks from long run with room lights on and then off
  - determined to be less than 1 count per hour
- determine read noise from short run with room lights off.
  - approximately 3 counts per pixel per read

- define ‘signal region’ from alignment
- for each run, get pixel mean near ‘signal region’ and in ‘signal region’.
- Look for excess events in signal region compared to background (over 500 thousand background detectors)



$$P_{\gamma\to\varphi} \approx \frac{1}{4}(gBL)^2 \left\{ \frac{\sin\left(\frac{m_\varphi{}^2 L}{4\omega}\right)}{\frac{m_\varphi{}^2 L}{4\omega}} \right\}^2$$

photon-ps coherence; {} ~ 1

$m_\phi^2 < 4\omega/L$

- g = coupling constant (1/M)
- B = magnetic field
- L = magnet length
- ω = light wavelength

- $Y = n P_1 P_2 \varepsilon (\Delta\Omega/\Omega)$ yield (#/s)
  - n = photon flux (#/s)
  - P1 (P2) = production (regeneration) probability
  - ε = quantum detection efficiency
  - ΔΩ/Ω = solid angle for detection

parameters: initial run

B-field:	1.75 T
magnet length:	1.05 m
IR FEL power	0.20 kW
IR FEL wavelength	935 nm (1.3 eV)
quantum efficiency	0.40
linear polarization	100%
acceptance	90%
expt'l efficiency	~ 90%

- expected signal rate > 0.01 Hz
  at $g_{a\gamma\gamma}$ > 1.9 x 10^{-6} GeV^{-1}

LIPSS initial (IR) run

$$S \equiv \frac{R_s \times t}{\sqrt{R_b \times t}}$$

significance:

R_s signal rate:

R_b background (dark count) rate

$$S \geq 5$$

for discovery

$$t_{\min} = 50 \times \frac{R_b}{R_s^{\,2}}$$

minimum running time required

rate estimate, as example . . .

$$P = \frac{g^2 B^2 L^2}{4} \quad ; \qquad (B = 1.75 \text{ Tesla} \; ; \quad L = 1.05 \text{ meters})$$

$$= 6.2 \times 10^{-12}$$

axion-photon conversion probability, *P*

$$n_i = 200 \; watts \; (935 \text{ nm})$$

$$= 1.0 \times 10^{21} \; \gamma\text{'s} / s$$

photon rate, *n (200 W)*

$$r_s = n_i \bullet P^2 \bullet \frac{\Delta\Omega}{\Omega} \bullet \varepsilon_q \qquad (\frac{\Delta\Omega}{\Omega} = 0.9 \; ; \quad \varepsilon_q = 0.40)$$

$$= 0.012 \;\; \text{Hz}$$

photon regeneration rate , *r*

1.7 T; 1 m magnet

ε~ 0.4;

ΔΩ/Ω ~ 0.9

rate estimate, as example . . .

$$S = \frac{r_s \times t}{\sqrt{r_b \times t}}$$

$$t_{\min} = S^2 \times \frac{r_b}{r_s^2} \quad \times \text{ (overall expt'l eff } \sim 50\%)$$

$$= 25 \times 2 \times \frac{r_b}{r_s^2}$$

$$r_s = 0.012 \text{ Hz}$$

$$r_b = 0.009 \text{ Hz}$$

note :

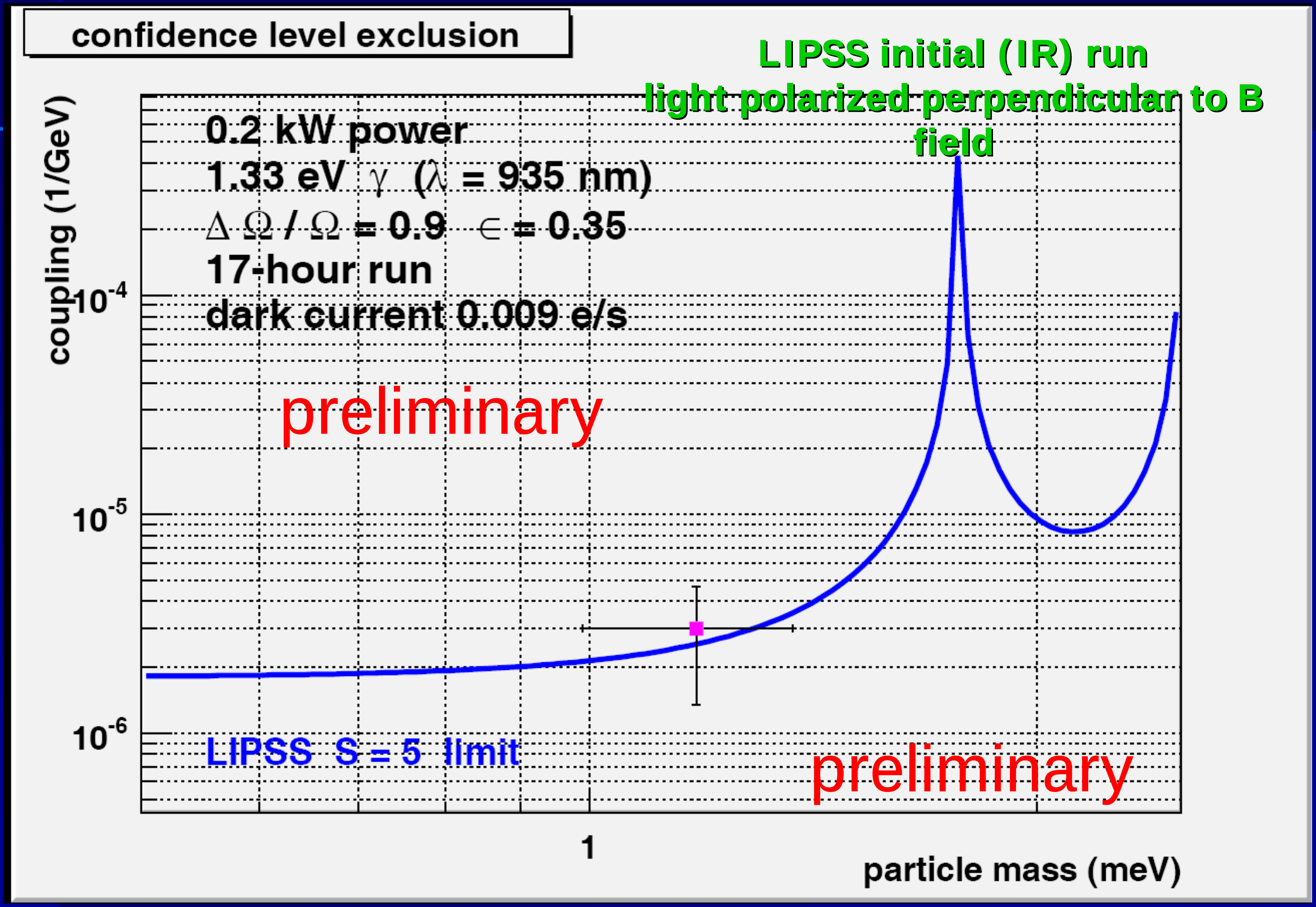
$$\text{t}_{\min} \sim \text{g}^{-8} n_i^{-2} r_b$$

significance =5 for discovery

minimum run time

run time very sensitive to coupling !!

not sensitive enough yet to cover full parameter space of PVLAS result, however did reach the sensitive region for scalar coupling



run specifics

- several runs in Dec’06-Feb’07 to optimize experimental conditions.
- run C was the first physics run; March 2007
- acquired a good set of data with polarization ⊥ to magnetic field; need a similar set with the polarization || to the magnetic field
- **~12 MJ** of photons were delivered in 12 good 2-hour runs
- the only detectable sources of uncertainty were read noise and dark current.
- our task is to get to a sensitivity that would enable the PVLAS boson hypothesis to be definitively confirmed or rejected .

summary

- LIPSS has begun to test axion interpretation of PVLAS result
  - – data in scalar configuration
- uses JLAB FEL and its facilities
    - use dipole magnets that are on-hand (~1.8 T)
    - used ultra-low noise CCD array
    - 200 watts average power; light polarized perpendicular to B
- ran in Spring 2007 24 hours, 935 nm
  - – some reach into sensitive region of parameter space
- **continue experiment in ~winter 2008**
  - – **upgrade optics to get higher power**
  - – **additional diagnostic monitoring equipment**
  - – **get pseudoscalar data**