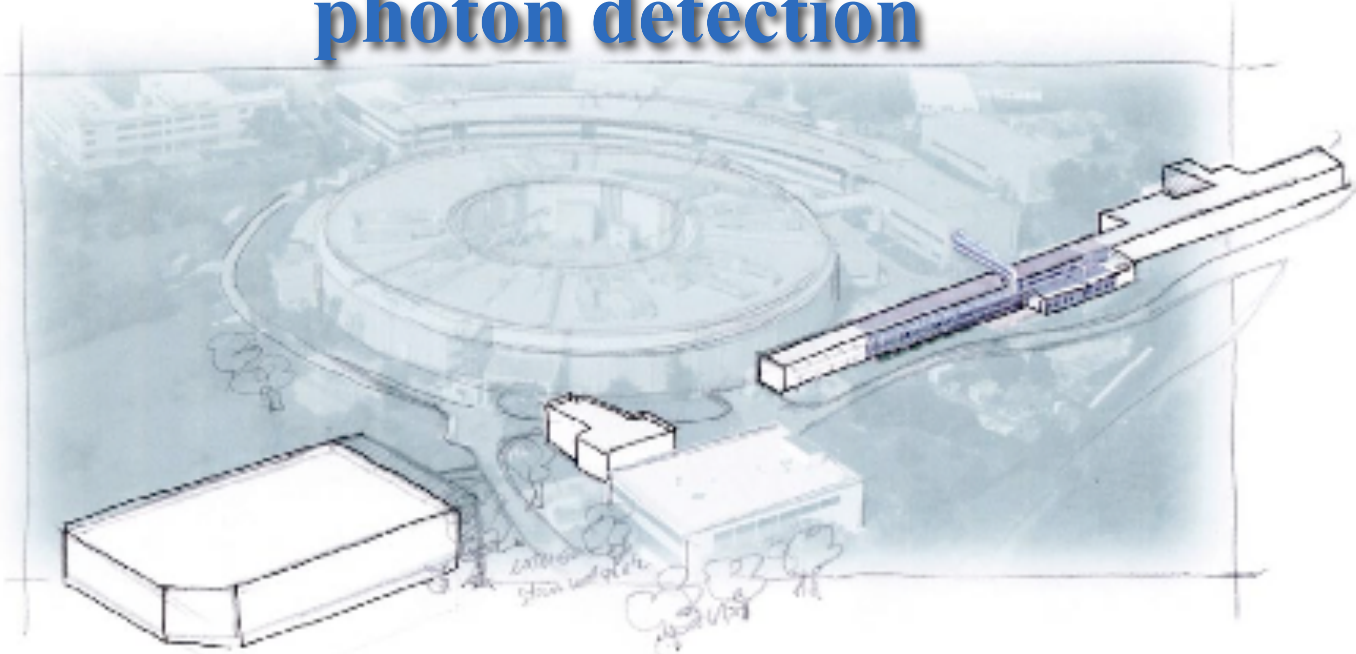
Quantum Well Structures for multi band photon detection



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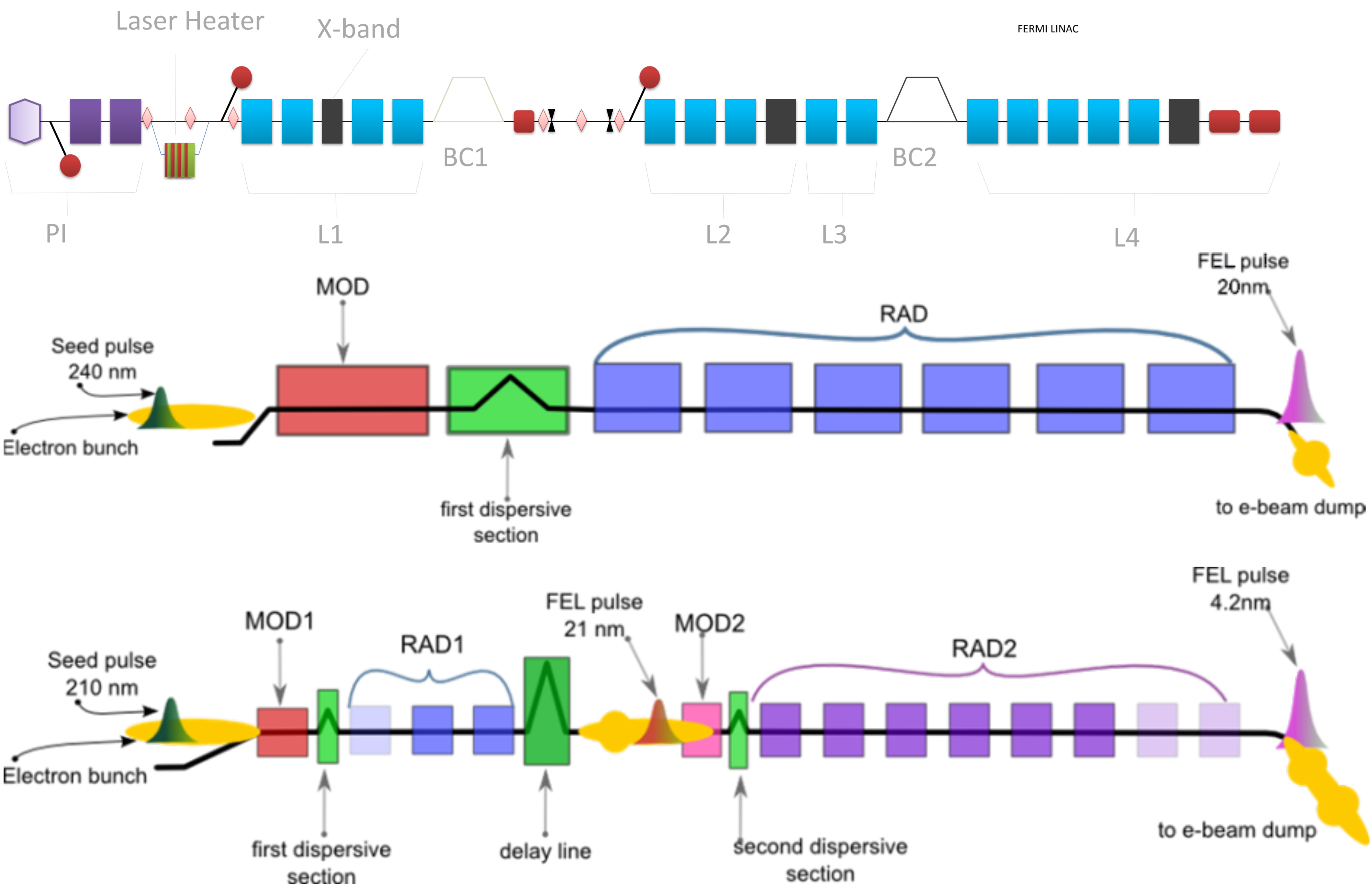
[4]*Nest-Nanoscience CNR, Pisa, Italy*

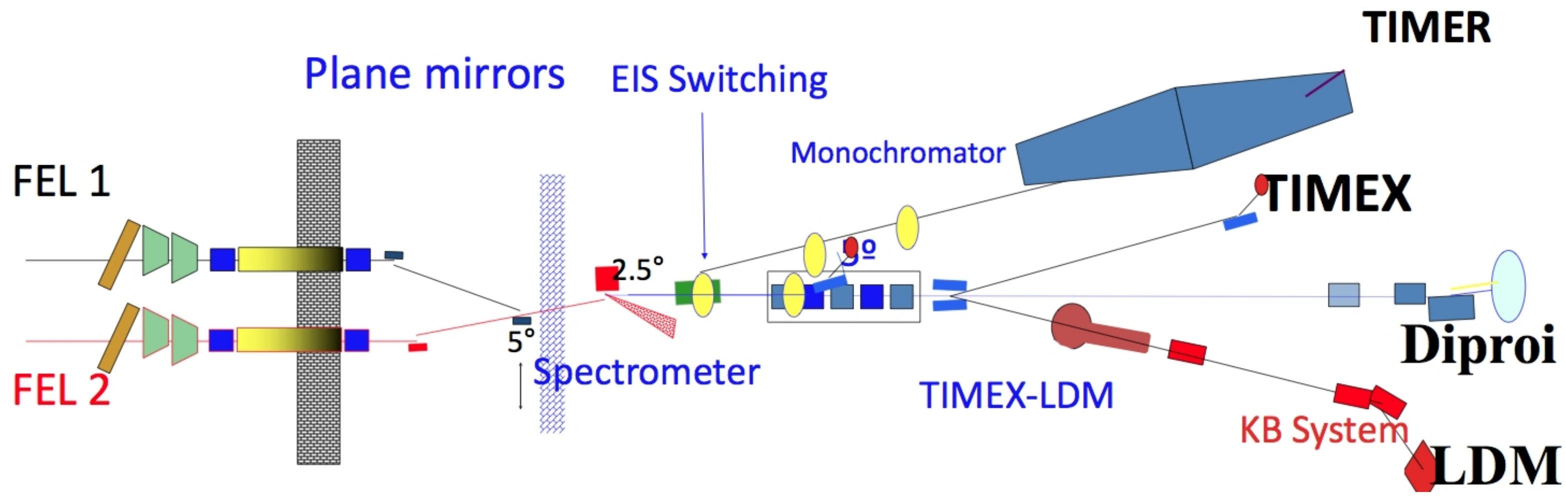

Elettra Storage Ring
Undulator Hall
IOM CNR TASC
Experimental Hall
Linac Building Extension

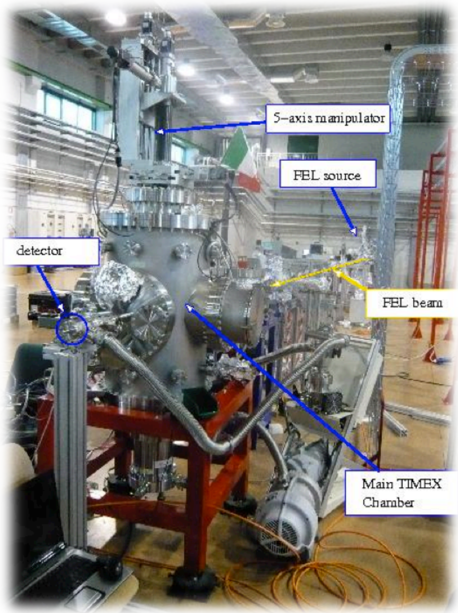
FERMI 1 & 2



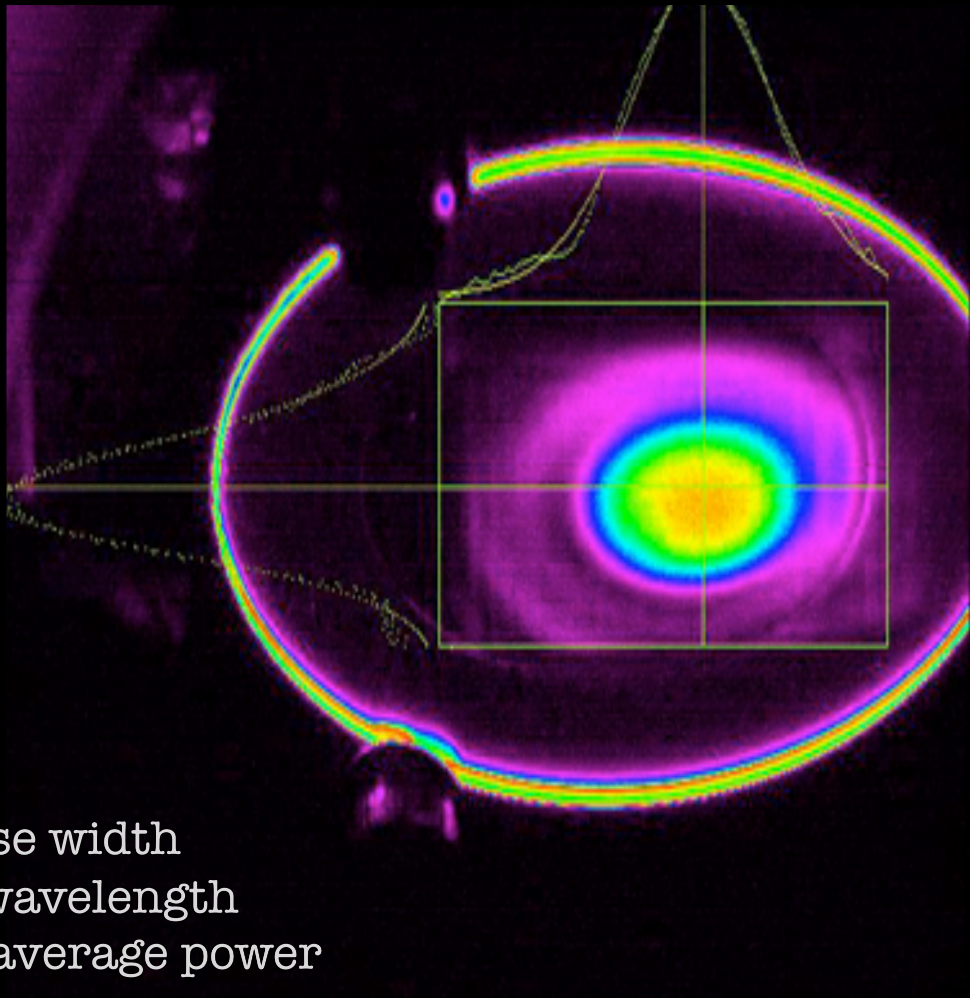
Laser Heater
X-band
FERMI LINAC
BC1
BC2
PI
L1
L2
L3
L4
MOD
RAD
FEL pulse 20nm
Seed pulse 240 nm
Electron bunch
first dispersive section
to e-beam dump
MOD1
RAD1
FEL pulse 21 nm
MOD2
RAD2
FEL pulse 4.2nm
Seed pulse 210 nm
Electron bunch
first dispersive section
delay line
second dispersive section
to e-beam dump

FERMI 1 & 2


TIMER
Plane mirrors
EIS Switching
Monochromator
FEL 1
TIMEX
2.5°
Diproi
5°
Spectrometer
FEL 2
TIMEX-LDM
KB System
LDM

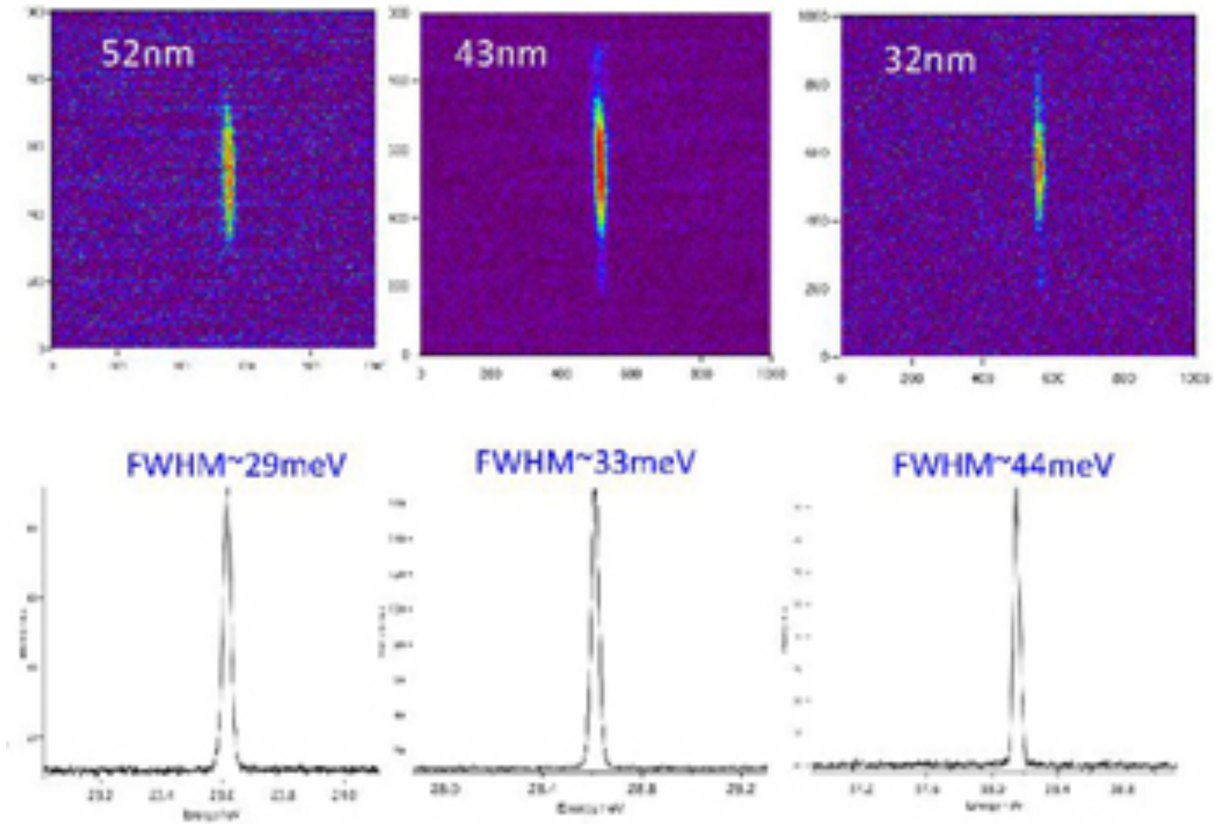

5-axis manipulator
FEL source
detector
FEL beam
Main TIMEX Chamber

FERMI 1

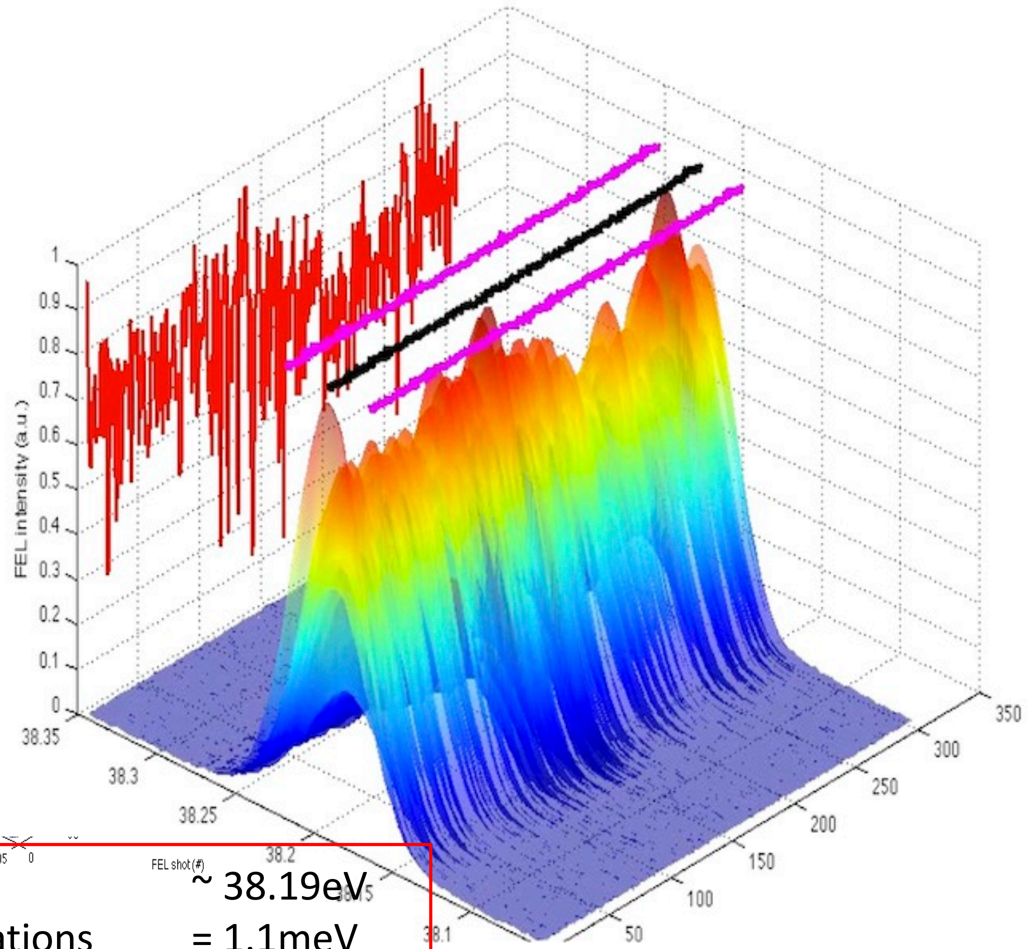


10 Hz rep rate
10 - 100 fs pulse width
100 – 20 nm wavelength
10 – 1000 mJ average power
GJ peak power

FERMI 1: first seeded laser with little energy spread

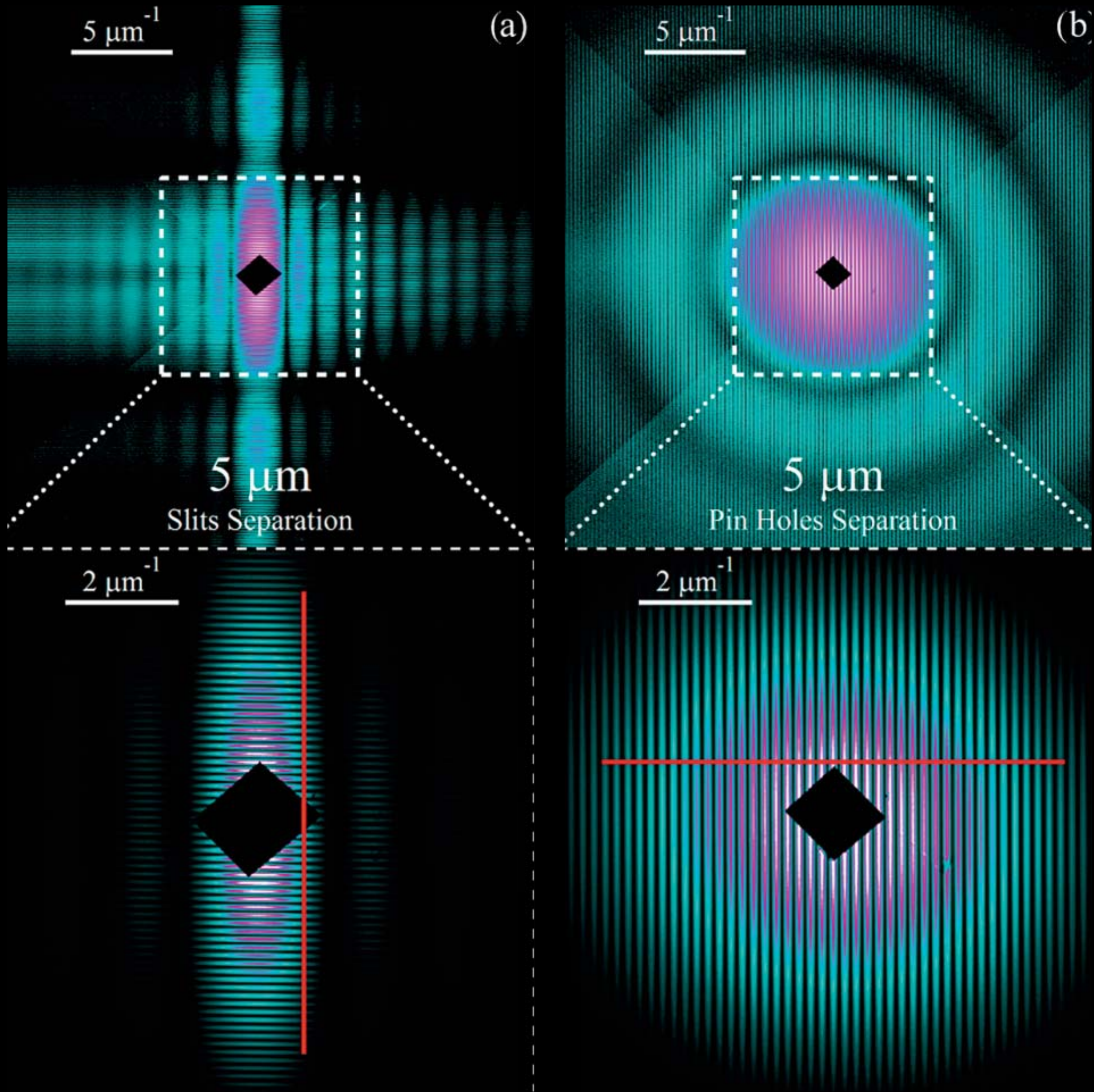


FERMI 1

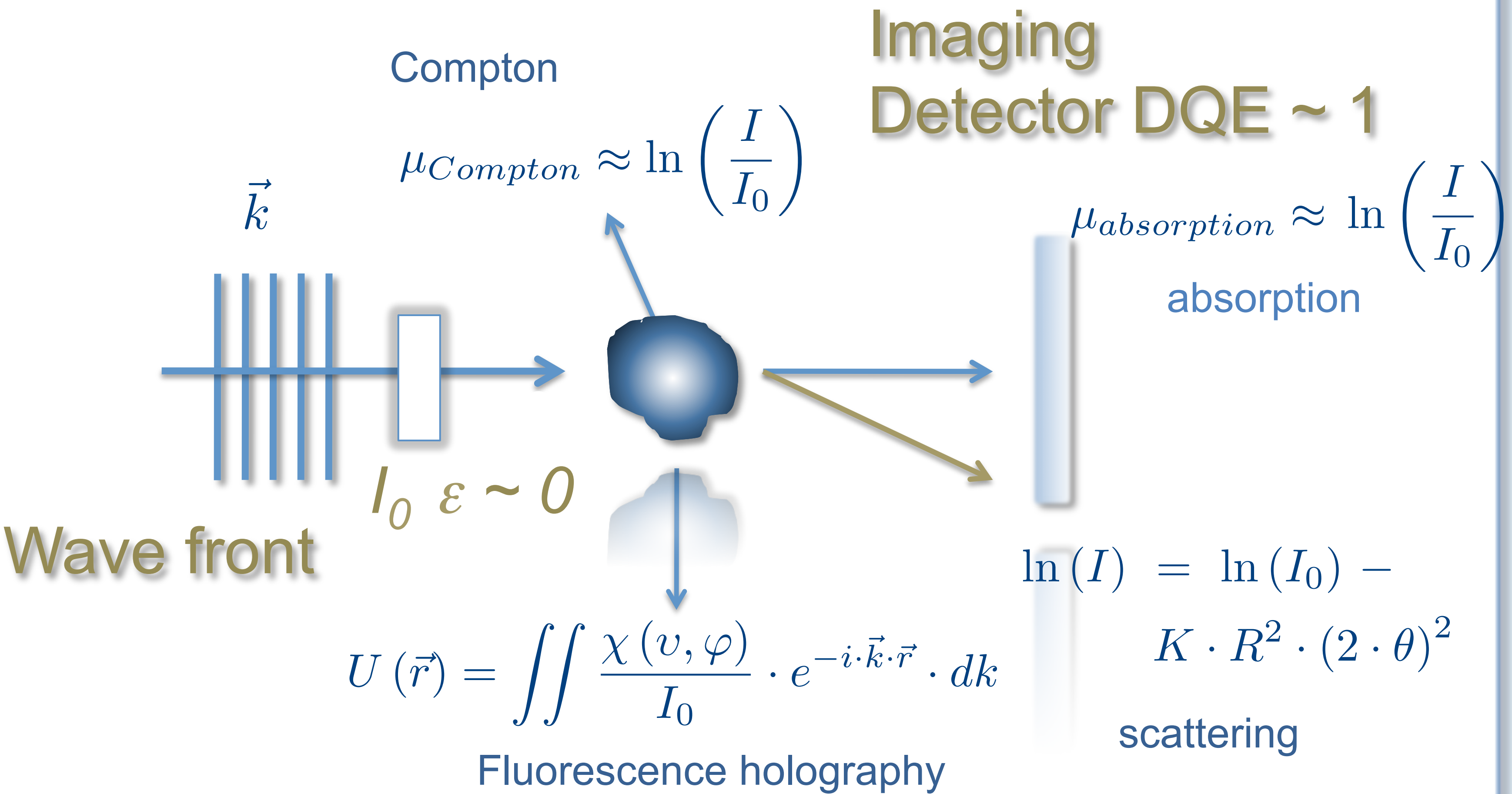


FEL photon energy ~ 38.19eV
Photon energy fluctuations (RMS) = 1.1meV
FEL bandwidth = 22.5meV
(RMS) = $5.9e^{-4}$
(RMS)
FEL bandwidth fluctuations = 3% (RMS)

Excellent coherence

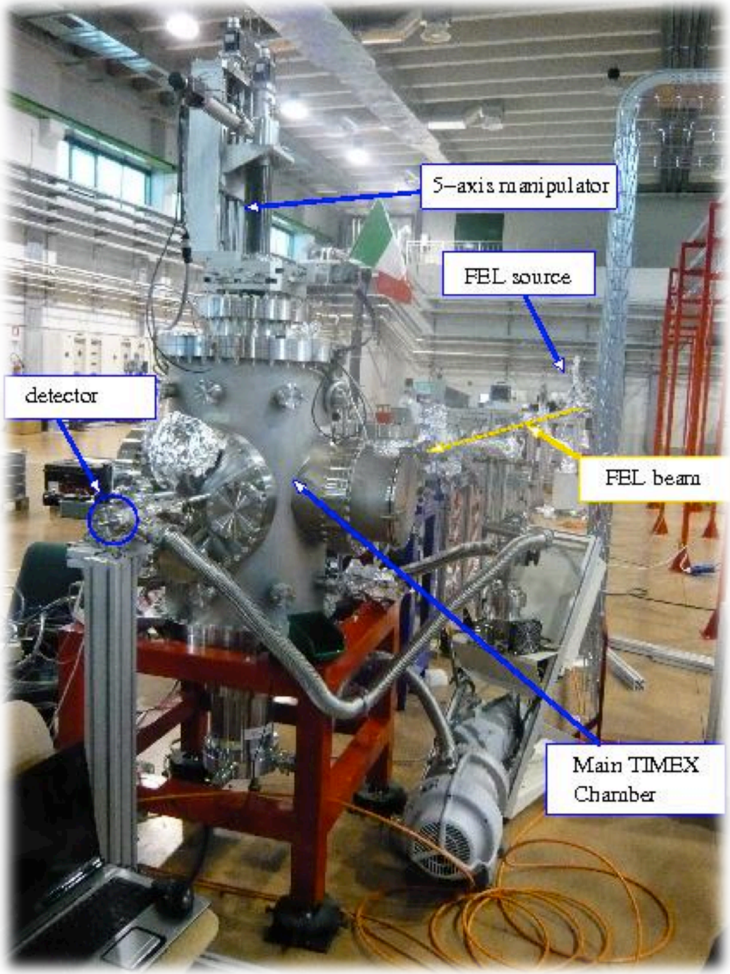


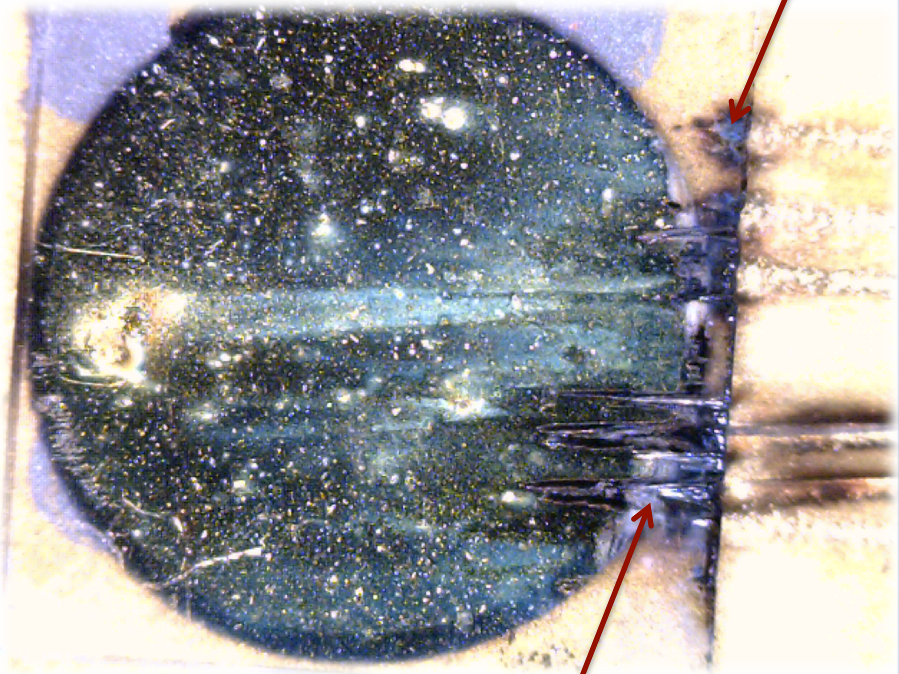
Quantitative SR & FEL measurements



it requires I_o for quantitative FEL experiments

The problem: Appropriate detectors are missing!

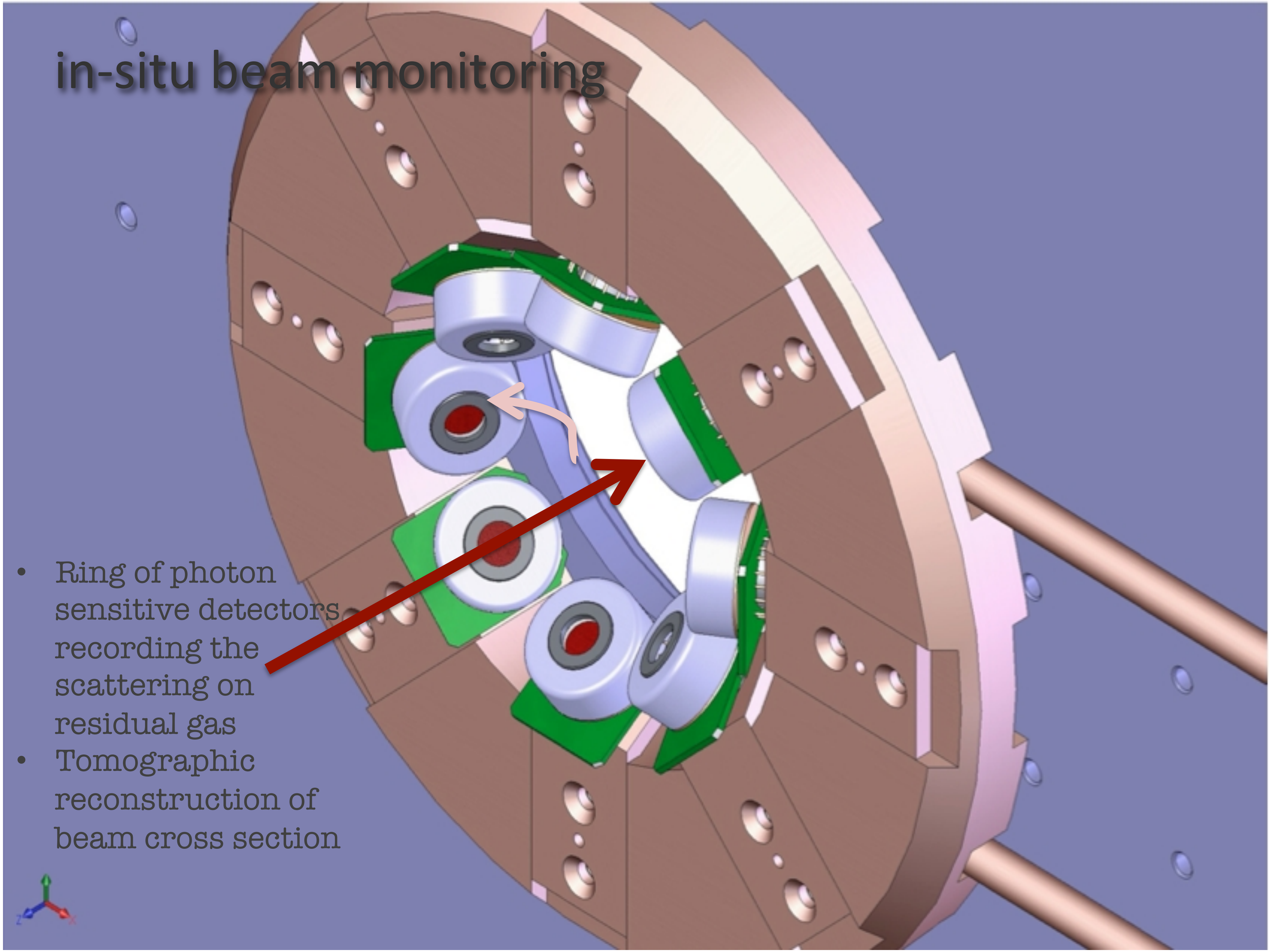




Si ~ 1-2 pulses

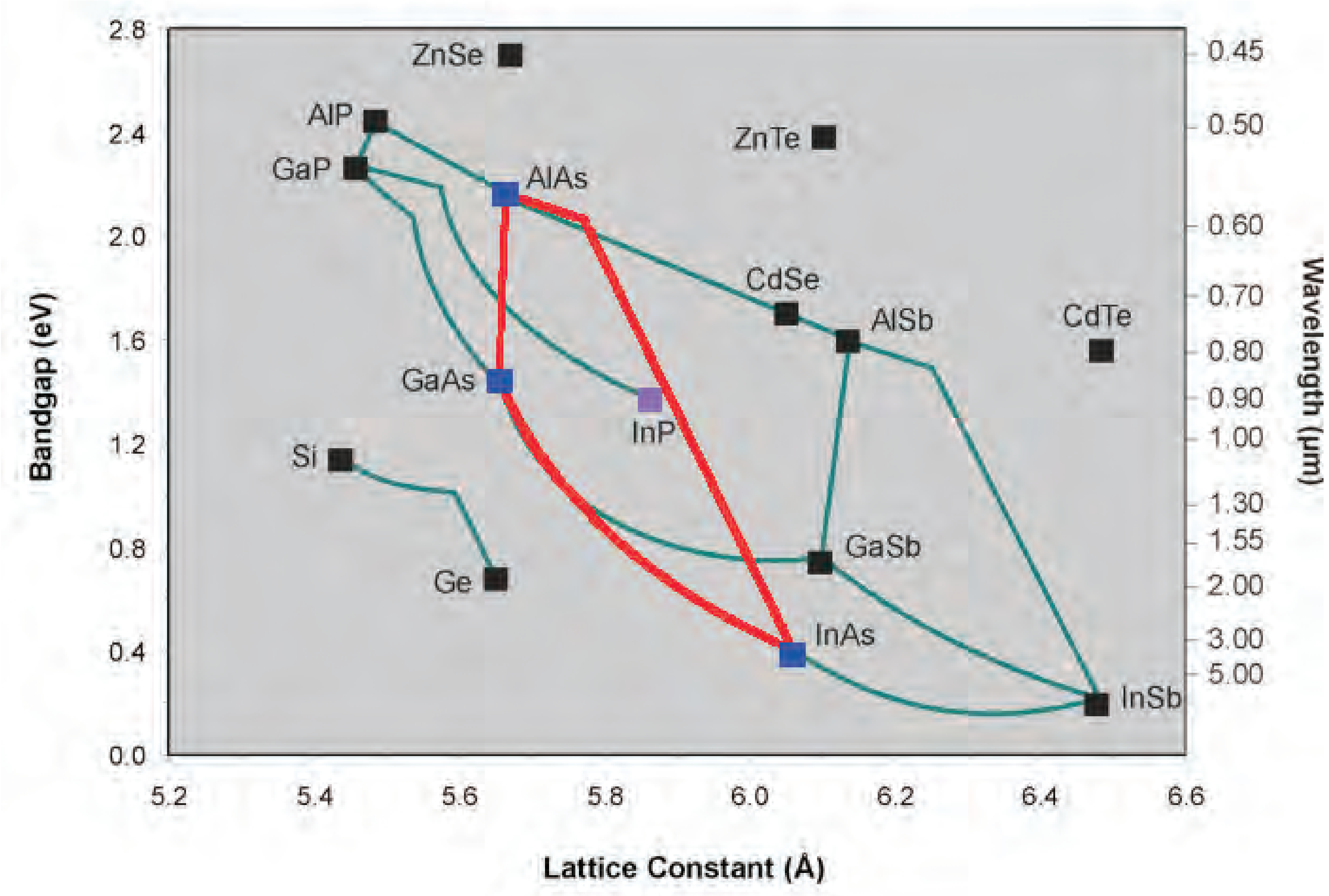
λ = 40 nm ~ 30 eV
10^{13} photons
Δt = 100 fs
Spot size 150 µm x 150 µm

in-situ beam monitoring

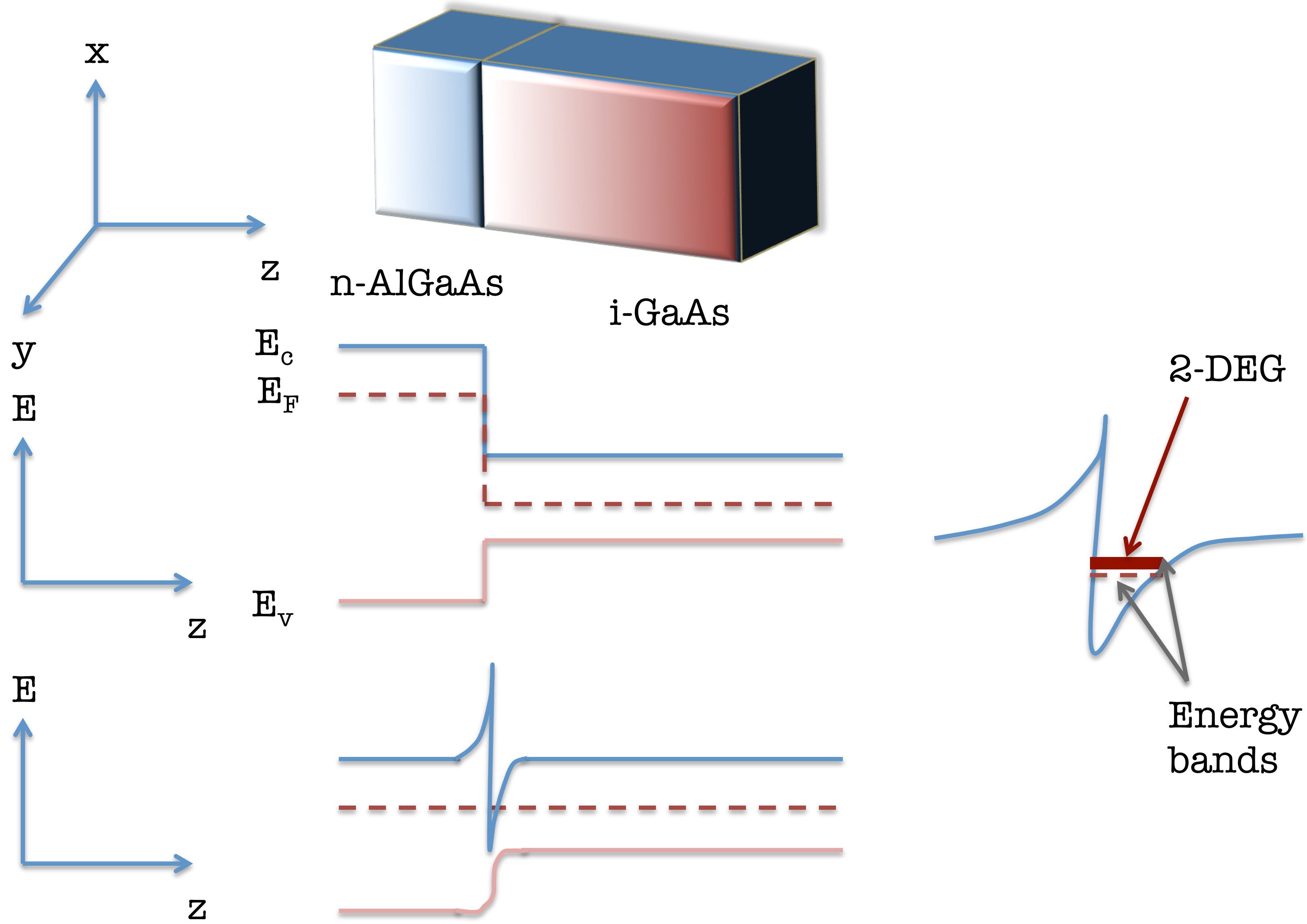


- Ring of photon sensitive detectors recording the scattering on residual gas
- Tomographic reconstruction of beam cross section

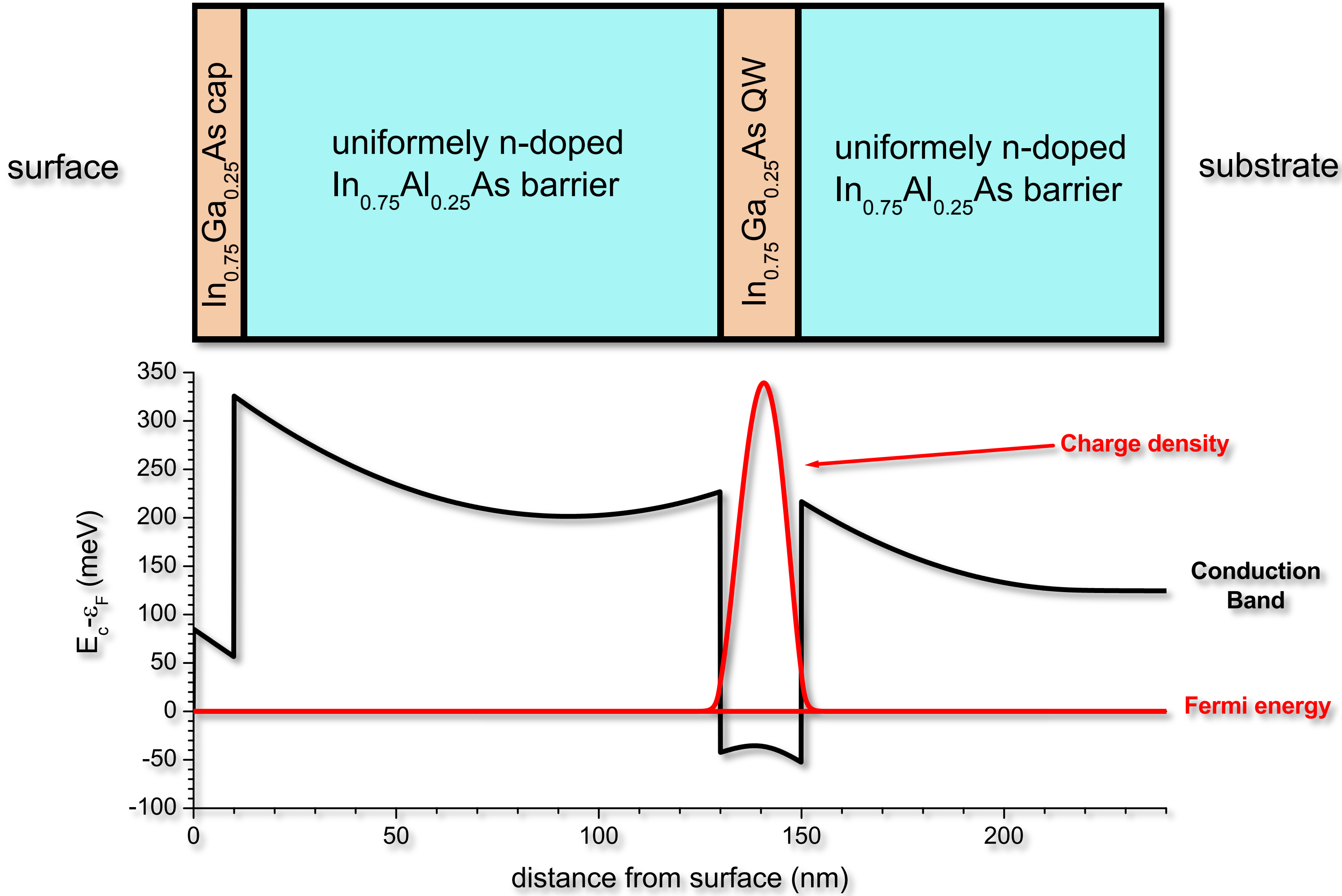
Search for new concepts / materials / detectors



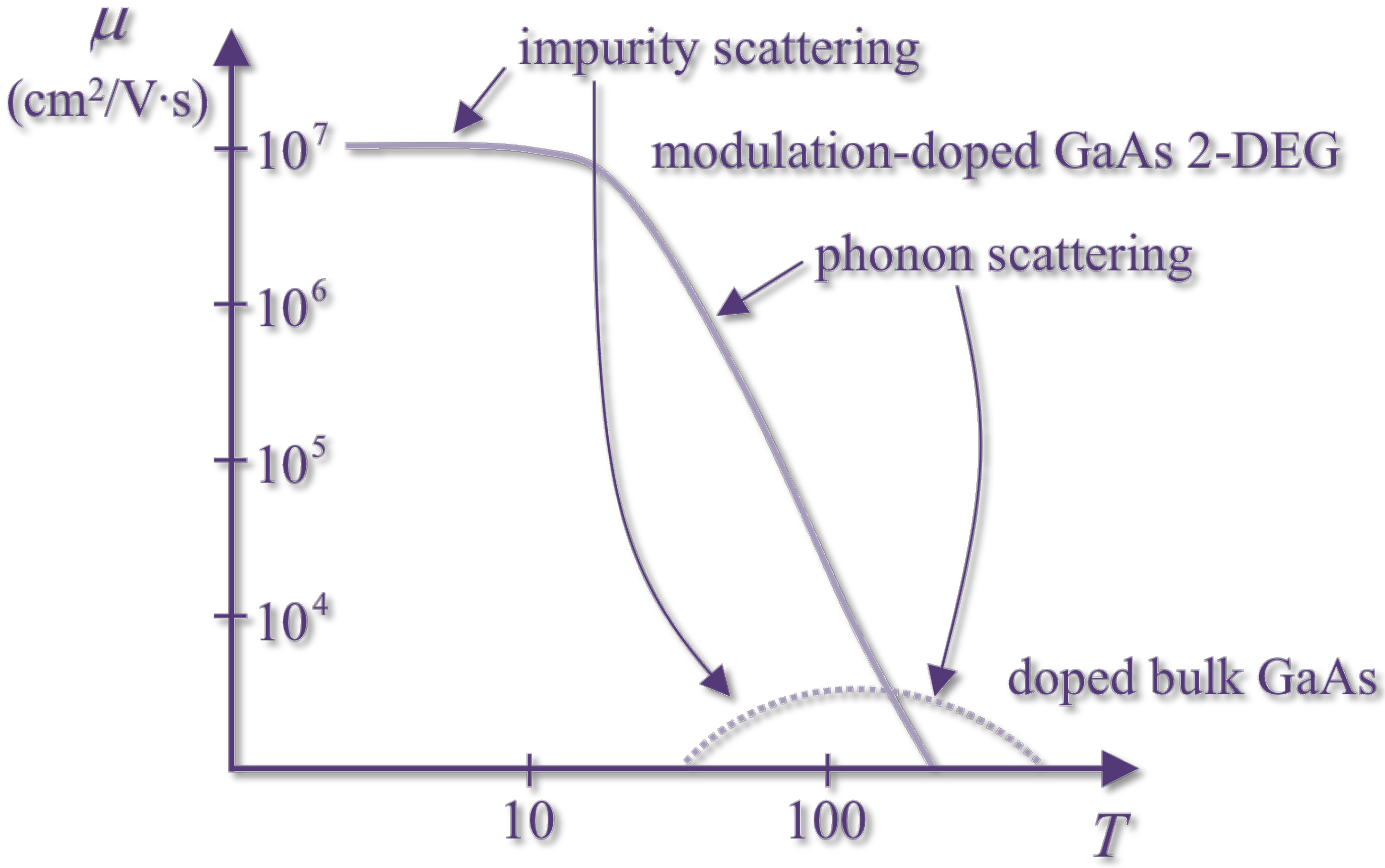
Quantum Well Detector



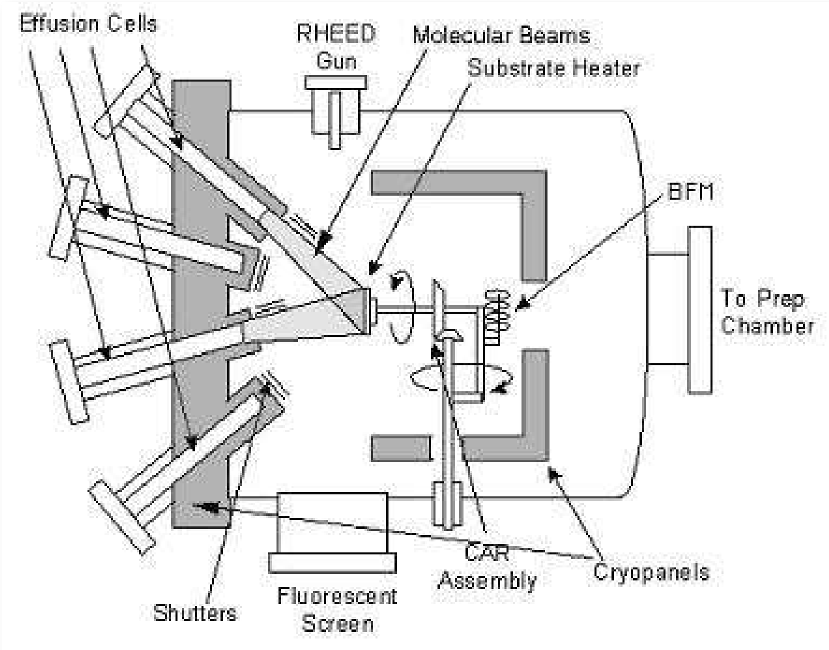
Quantum Well Detector

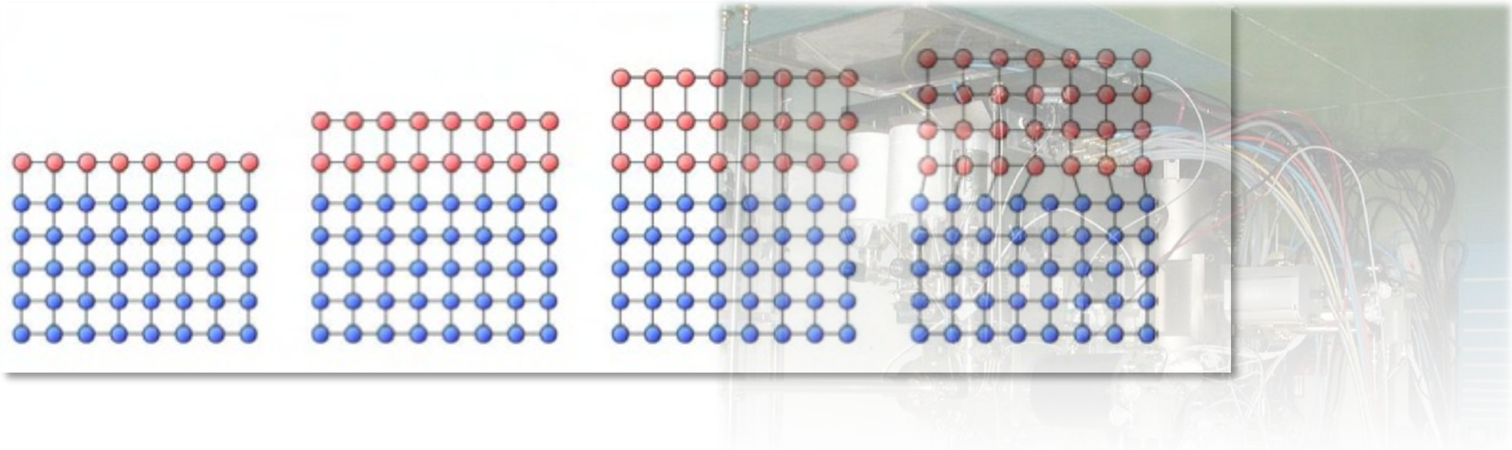


Quantum Well Detector

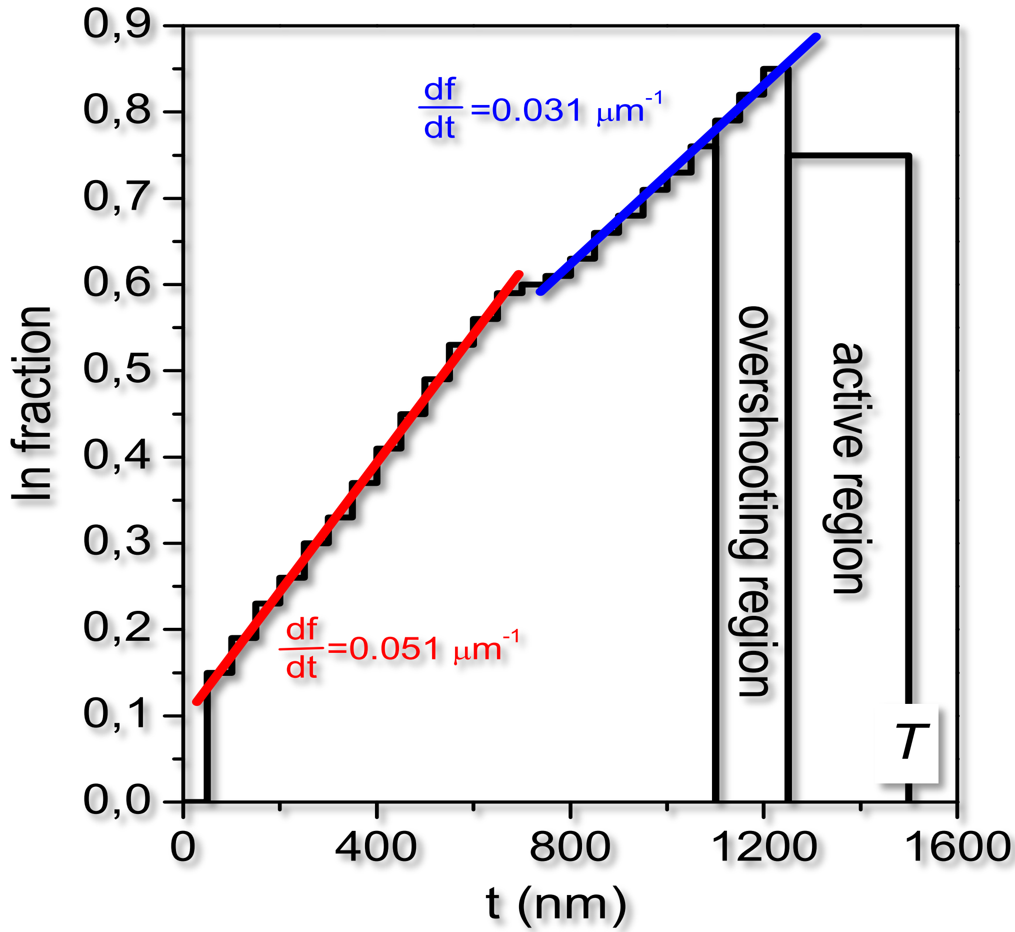


MBE Quantum Well Detector

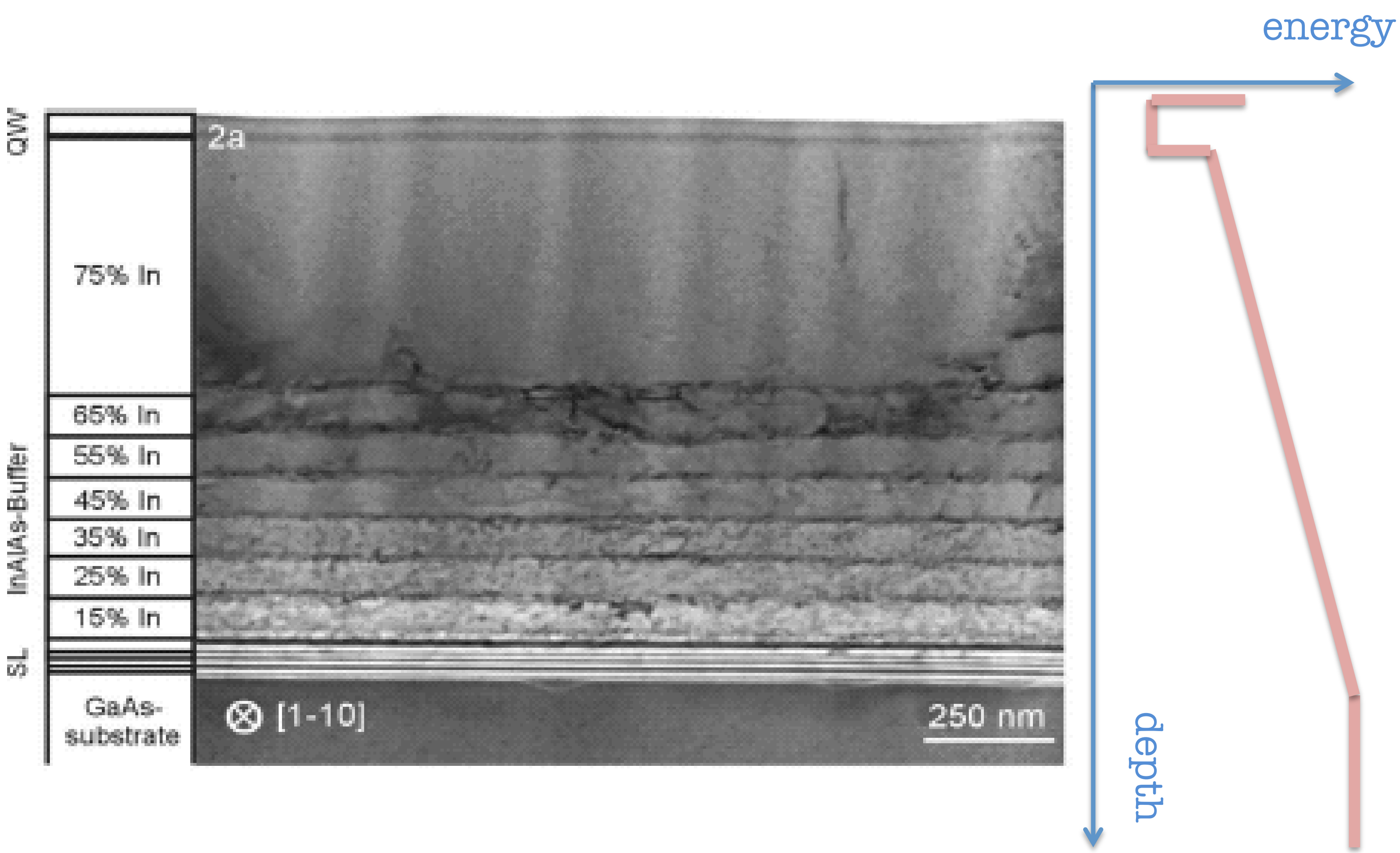




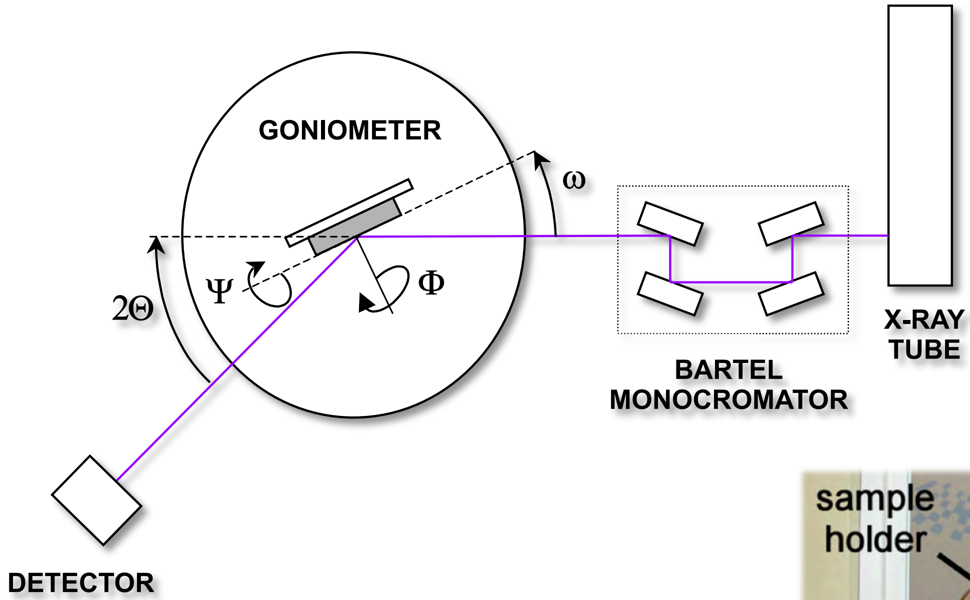
MBE Quantum Well Detector

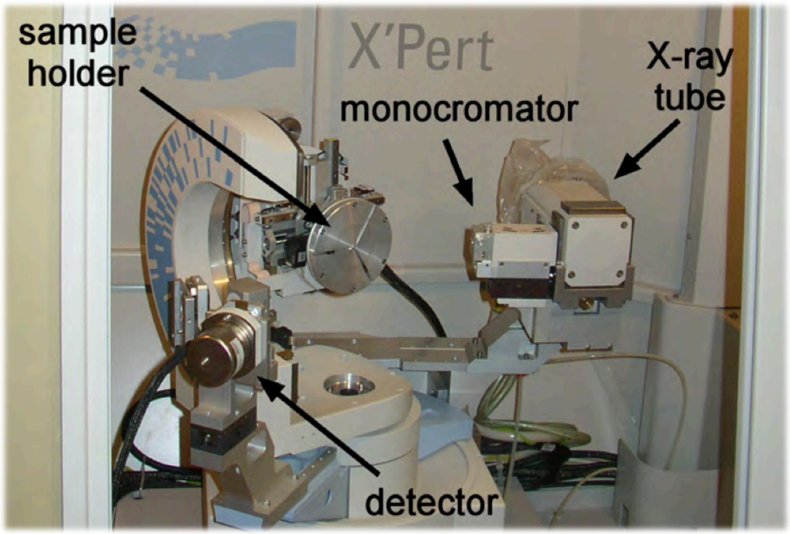


Quantum Well Detector

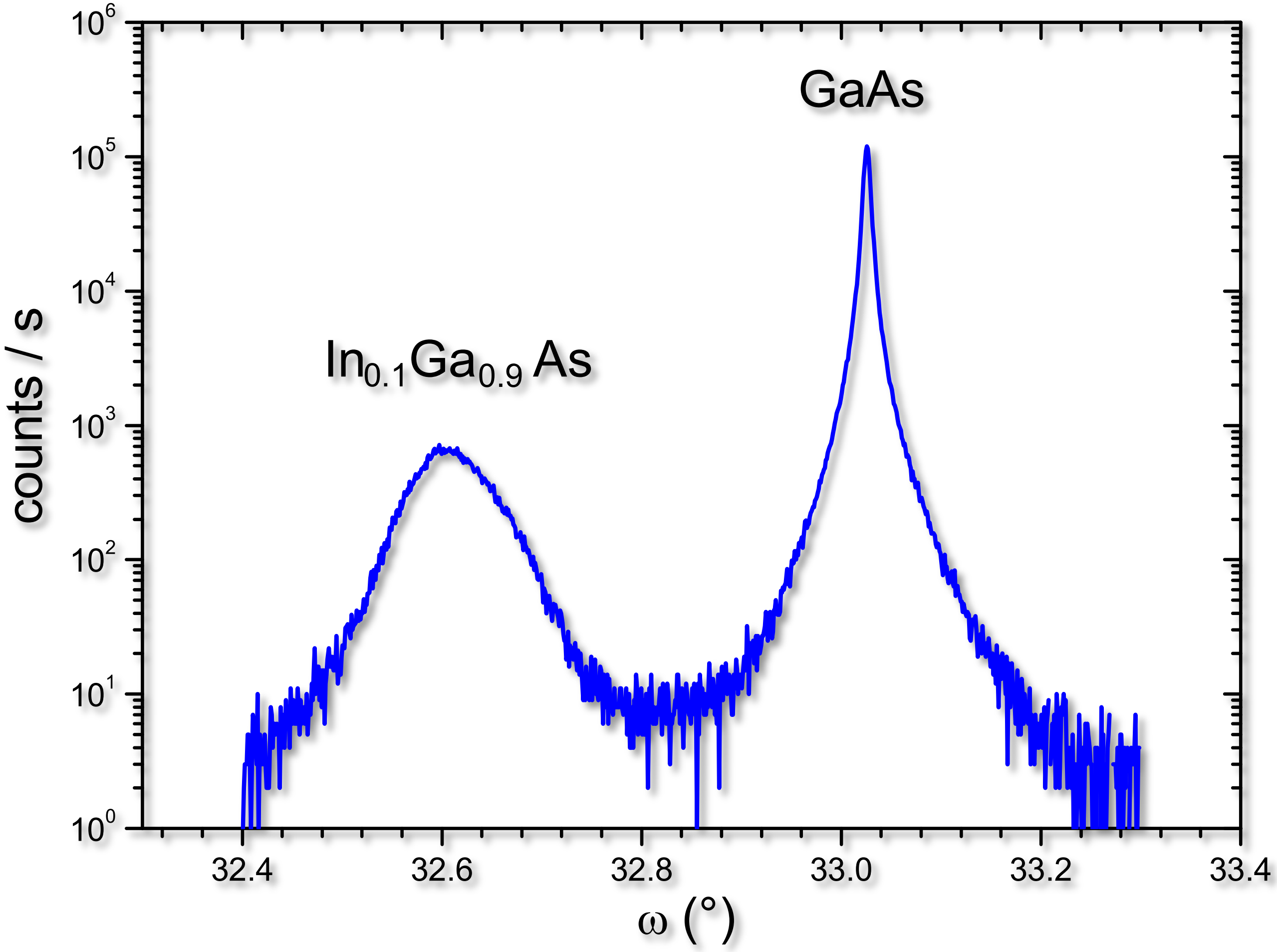


MBE Quantum Well Detector

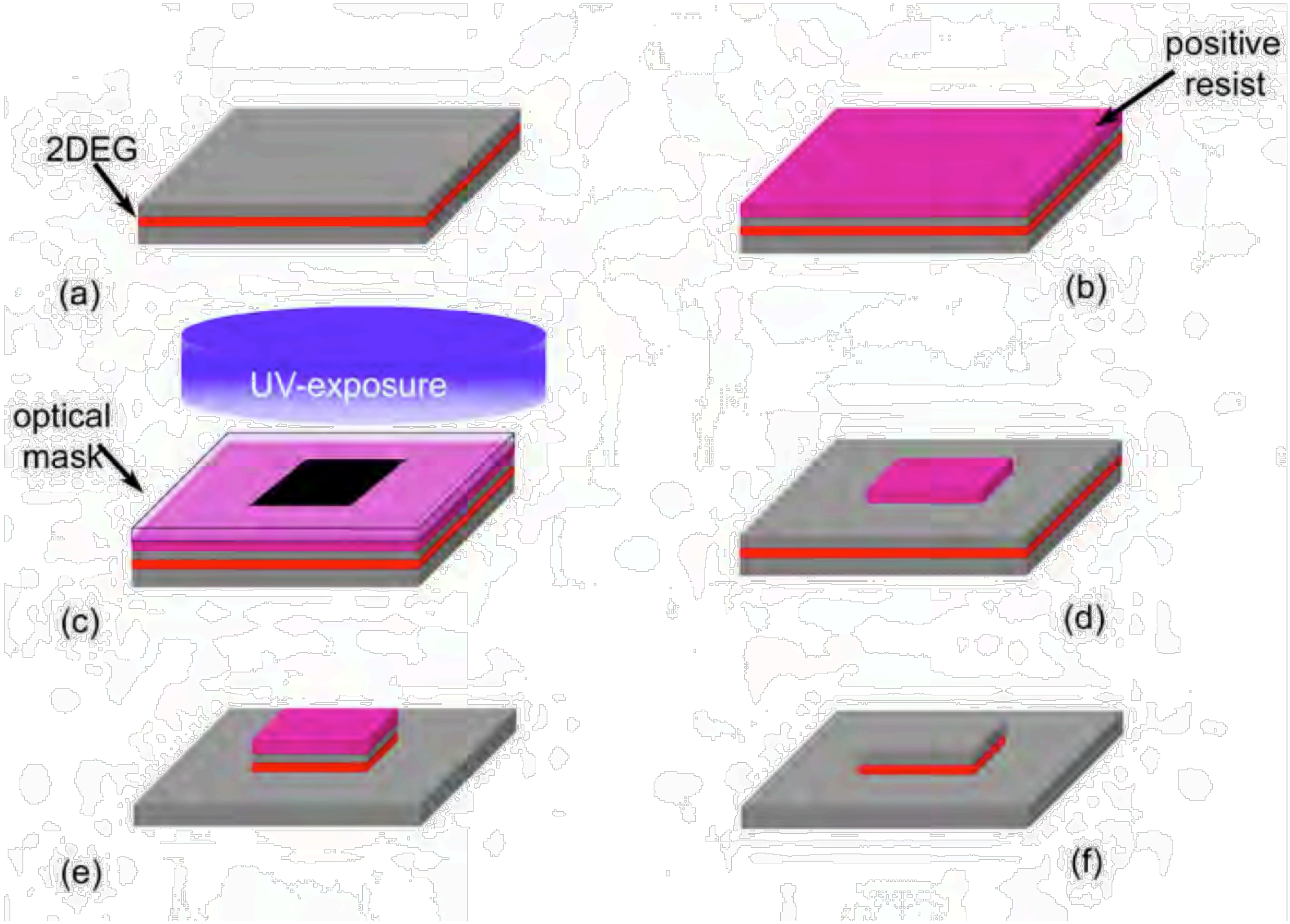




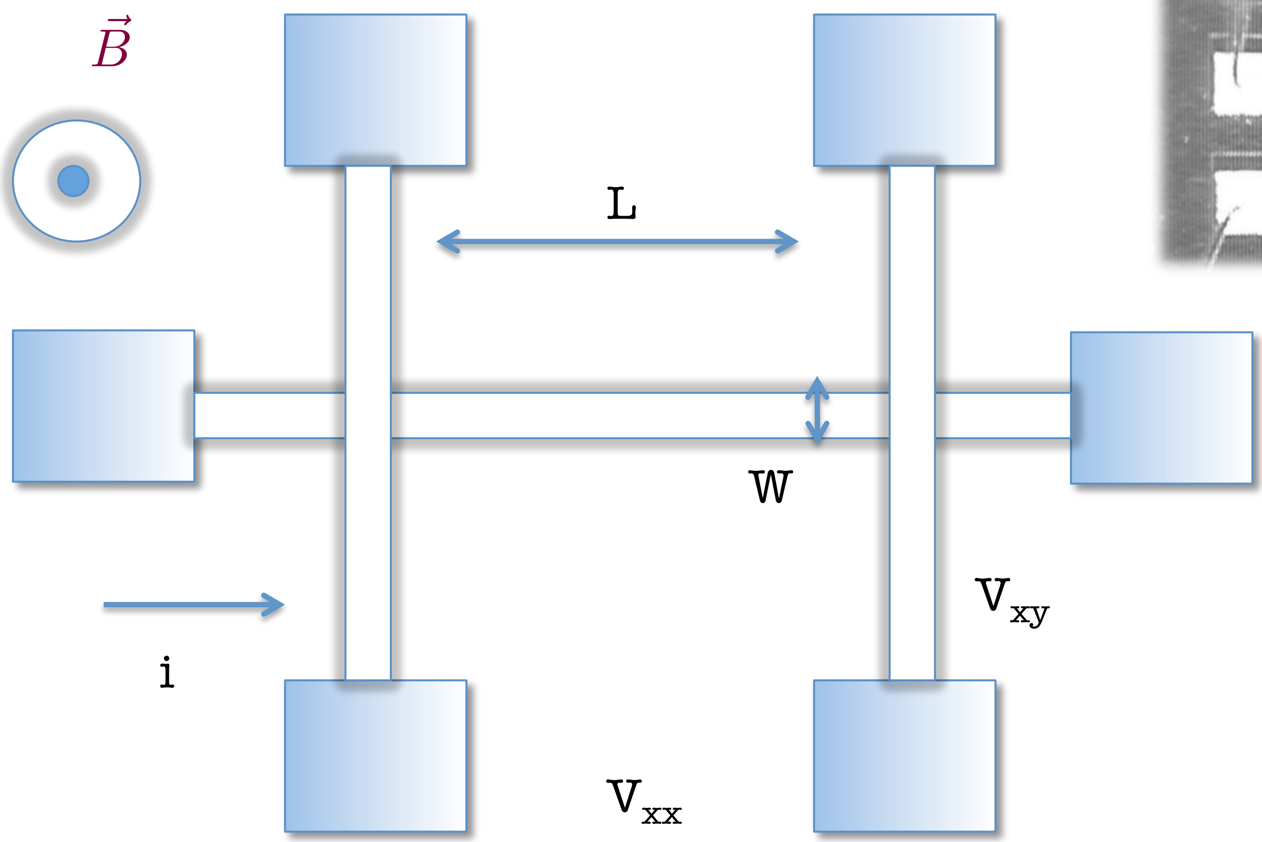
MBE Quantum Well Detector

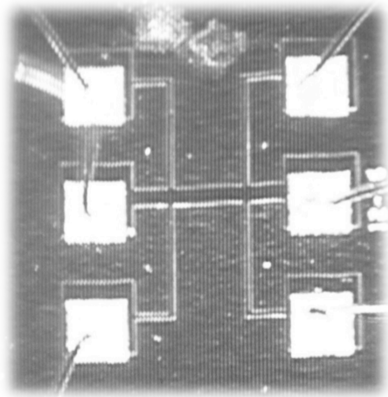


Quantum Well Detector



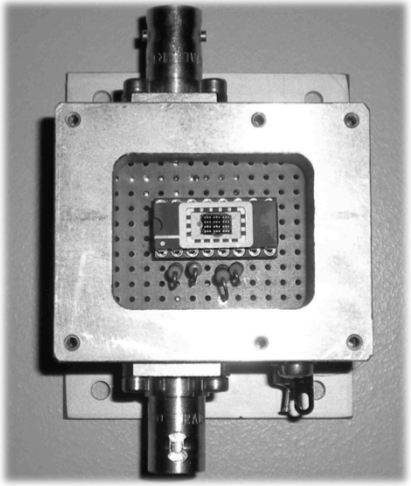
Quantum Well Detector (Hall bar)

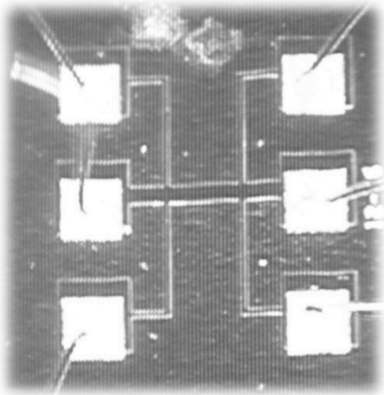




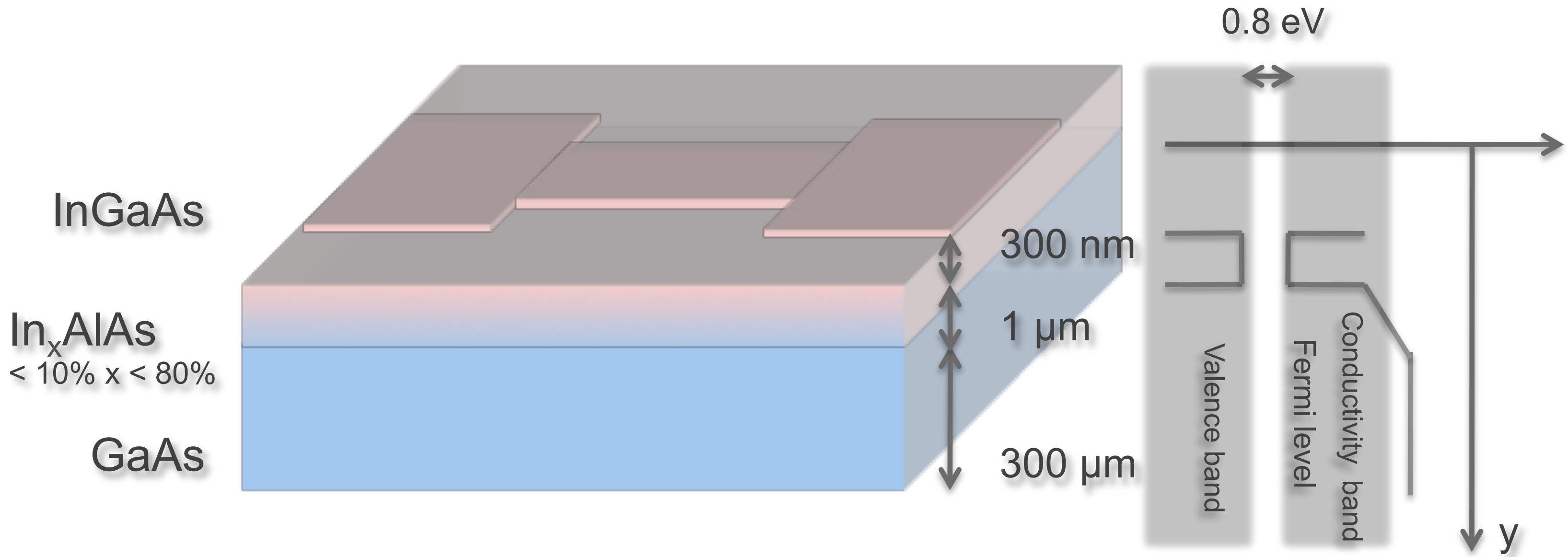
$$\mu = \frac{1}{B} \cdot \frac{V_{xy}}{V_{xx}} \cdot \frac{L}{W} \qquad n = \frac{B \cdot I}{e \cdot V_{xy}}$$

Quantum Well Detector

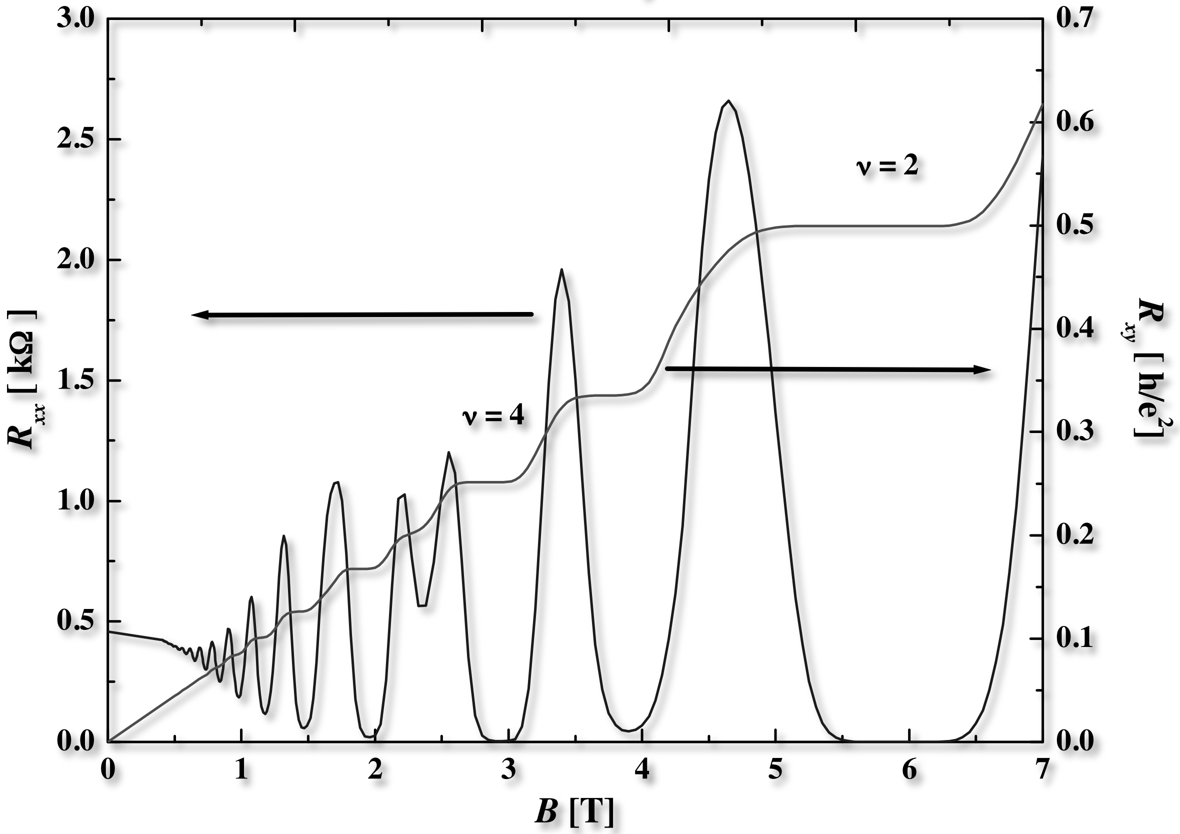




Direct band gap
- fast < ns
- $E_b = W_{ion}$ (soft x-rays)



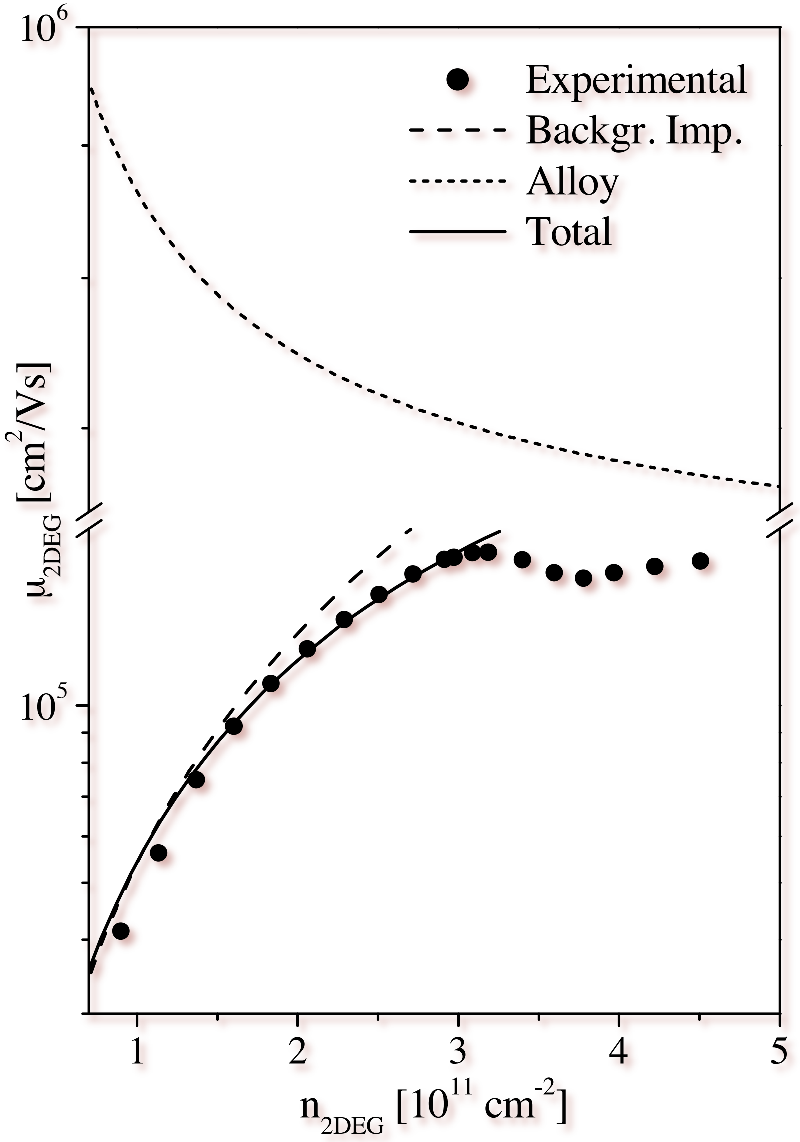
Quantum Well Detector (Quantum Hall effect)



$$R_{xy} = \frac{h}{\nu \cdot e^2} \qquad \nu = 2,3,4,\ldots,8$$

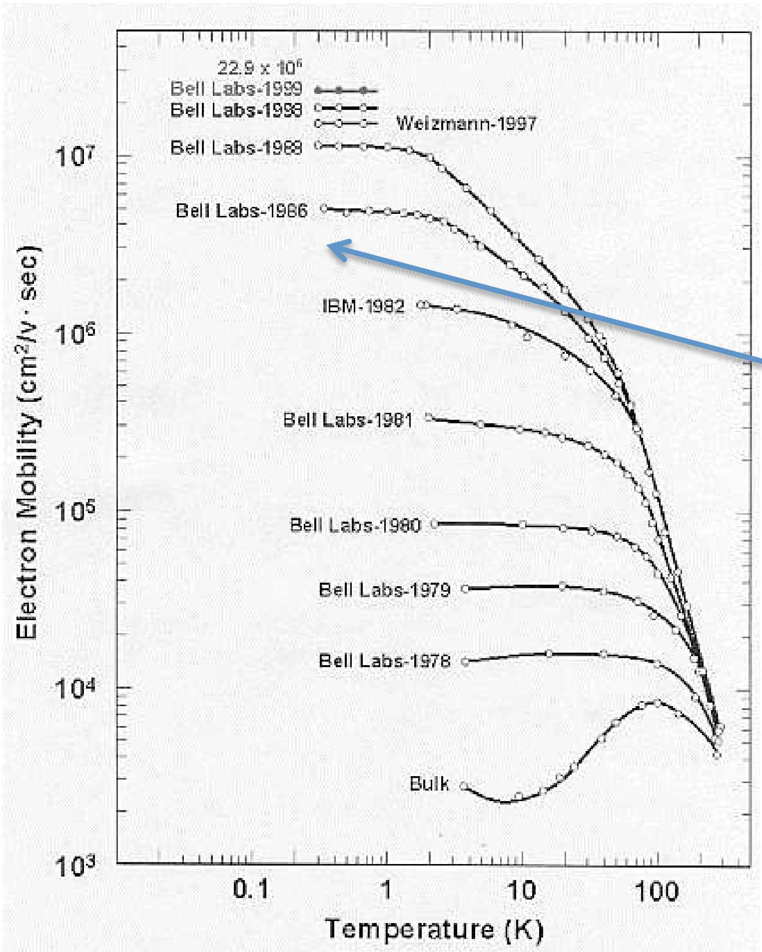
Quantum Well Detector (Hall bar)

$$\mu = \frac{1}{B} \cdot \frac{V_{xy}}{V_{xx}} \cdot \frac{L}{W}$$



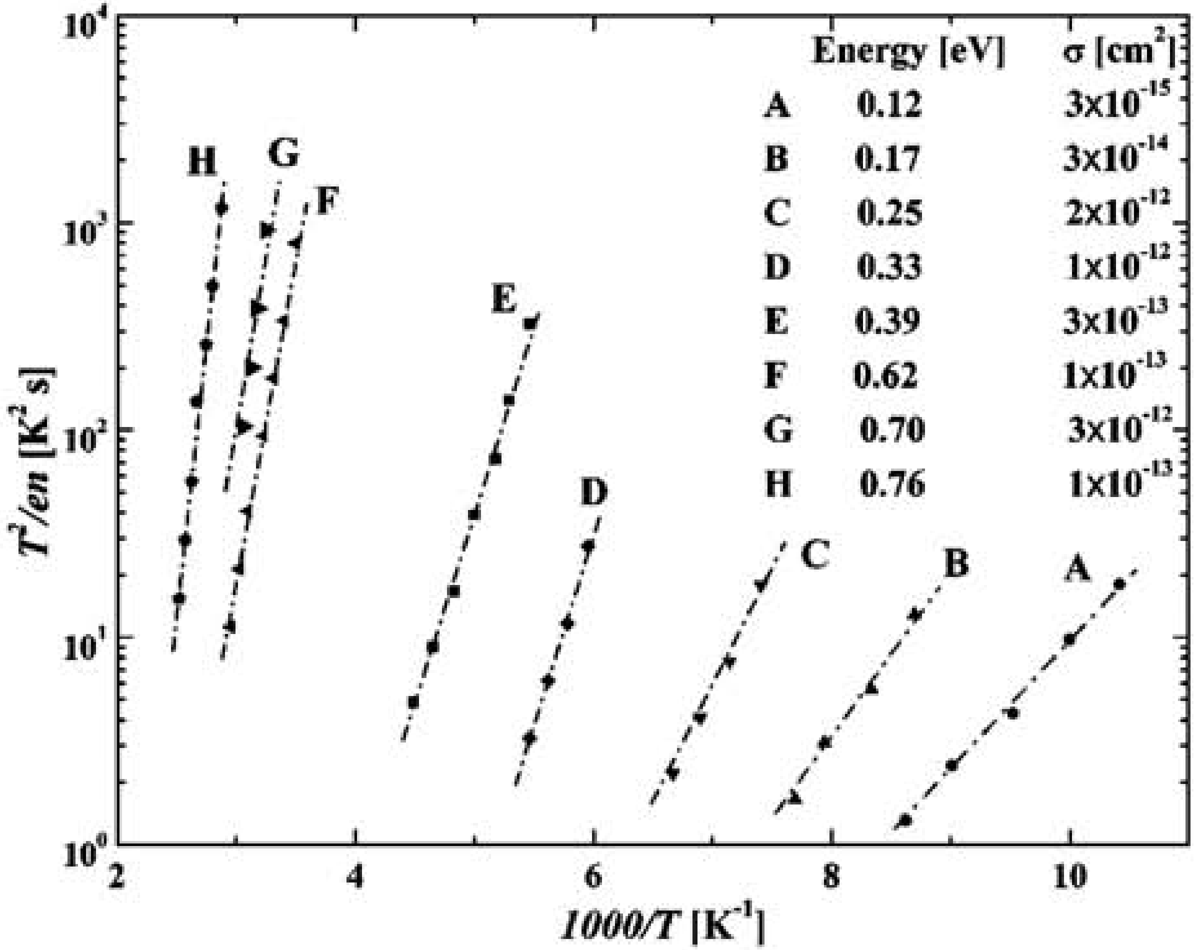
$$n = \frac{B \cdot I}{e \cdot V_{xy}}$$

Quantum Well Detector

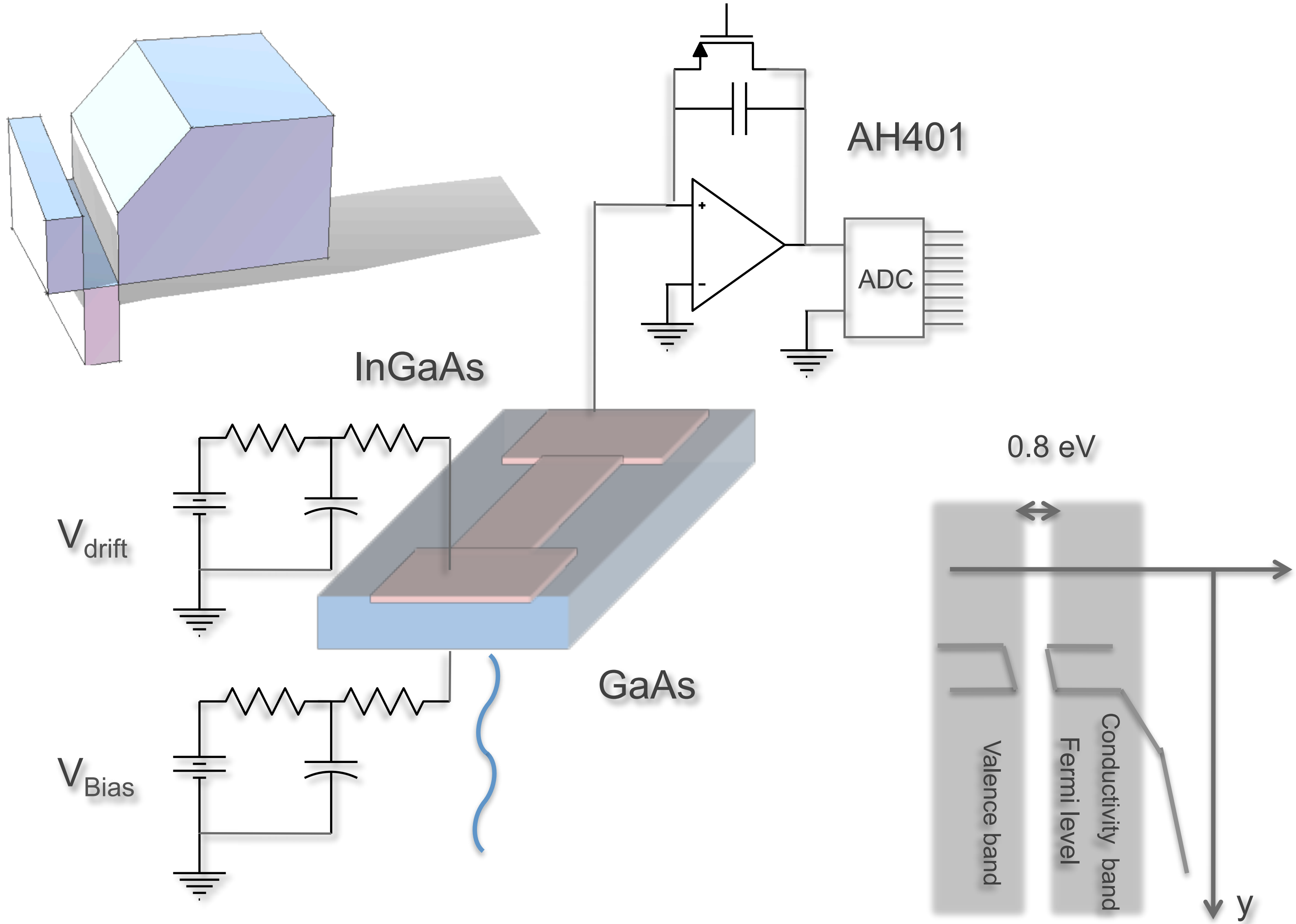


MBE at CNR IOM /TASC

Quantum Well Detector (Hall bar)



Quantum Well



Electronics

4 # Analog integrators (unipolar) + 20 bit ADCs

- sampling frequency 1 kHz time (max)
- resolution 50 fA for 50 nA FSR (min)
- TCPIP, USB, RS 232
- Triggerable

4 # transimpendance (bipolar) + 24 bit ADCs

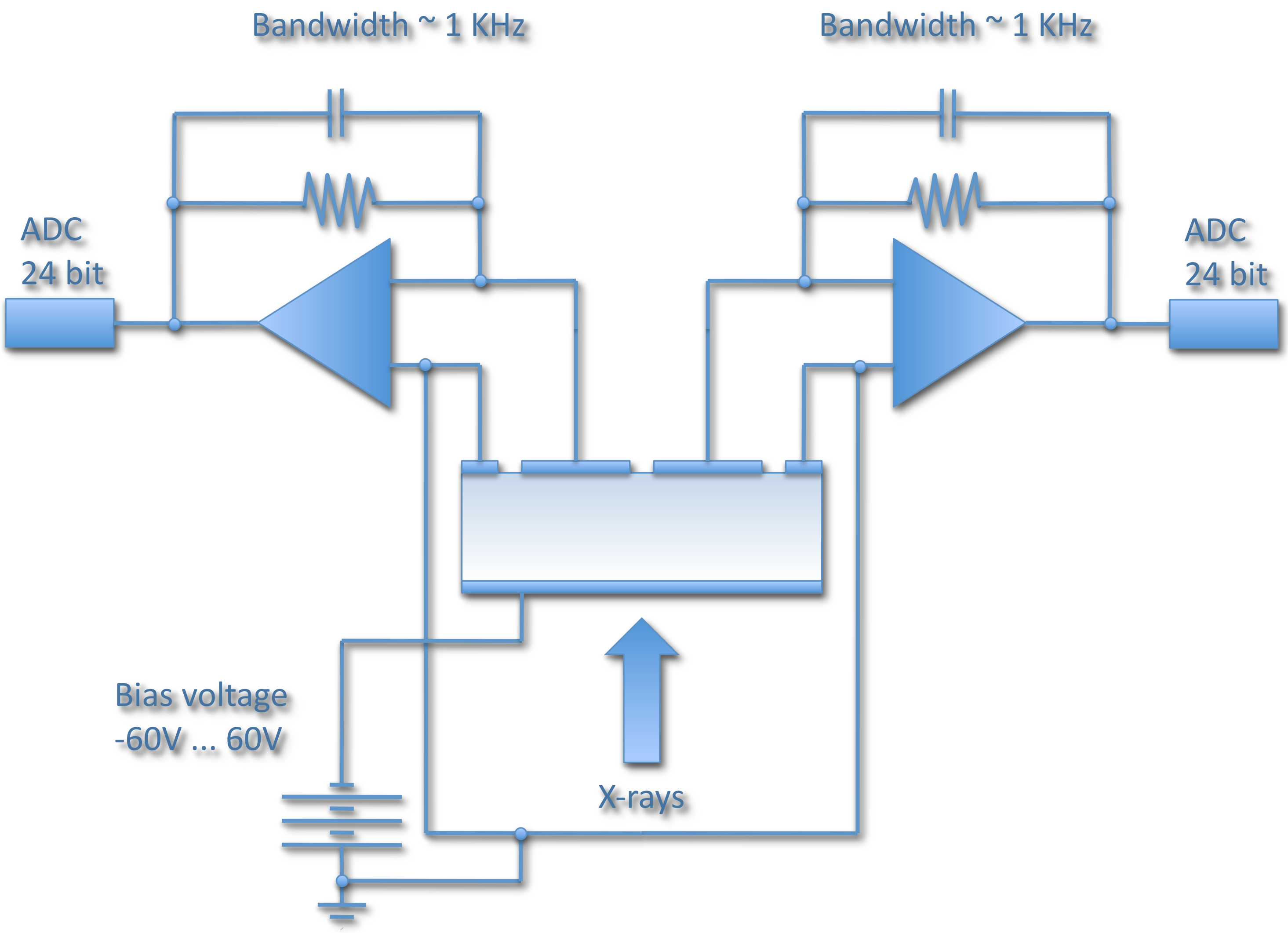
- sampling frequency 6.4 kHz (max for 4 # & 24 bit)
- resolution 300 aA for 5 pA FSR (min)
- TCPIP, USB, RS 232
- Triggerable
- bias voltage supply(1000V)

RF pulse amplifiers

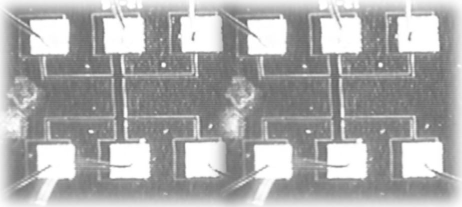
- BW 8GHz or 2 GHz
- gain 20 – 40 dB

Detectors and electronics can be purchased through
http://ilo.elettra.trieste.it/ or CAENELS,

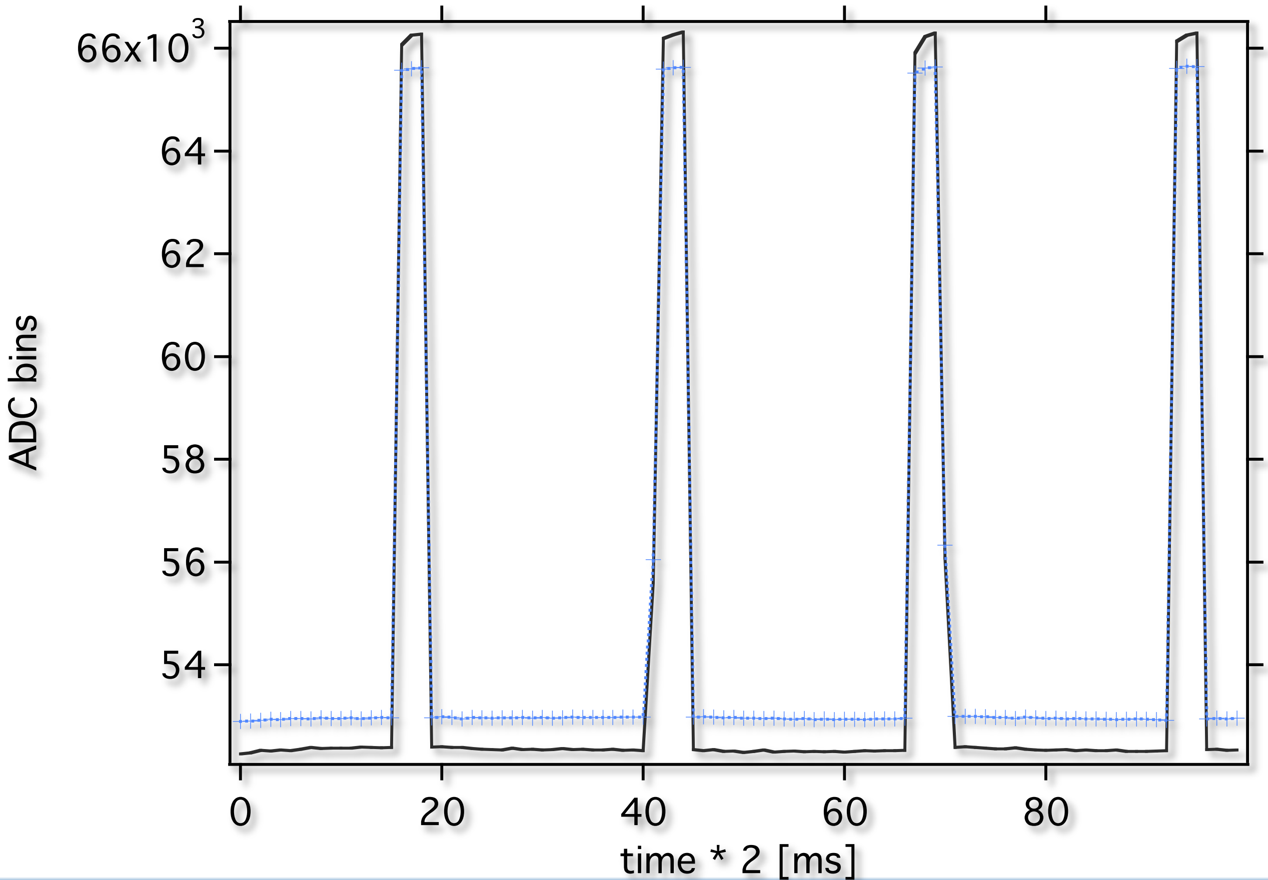
Wiring of the Hall bar QW (room temperature)



2 channel Quantum Well Detector (integrating)

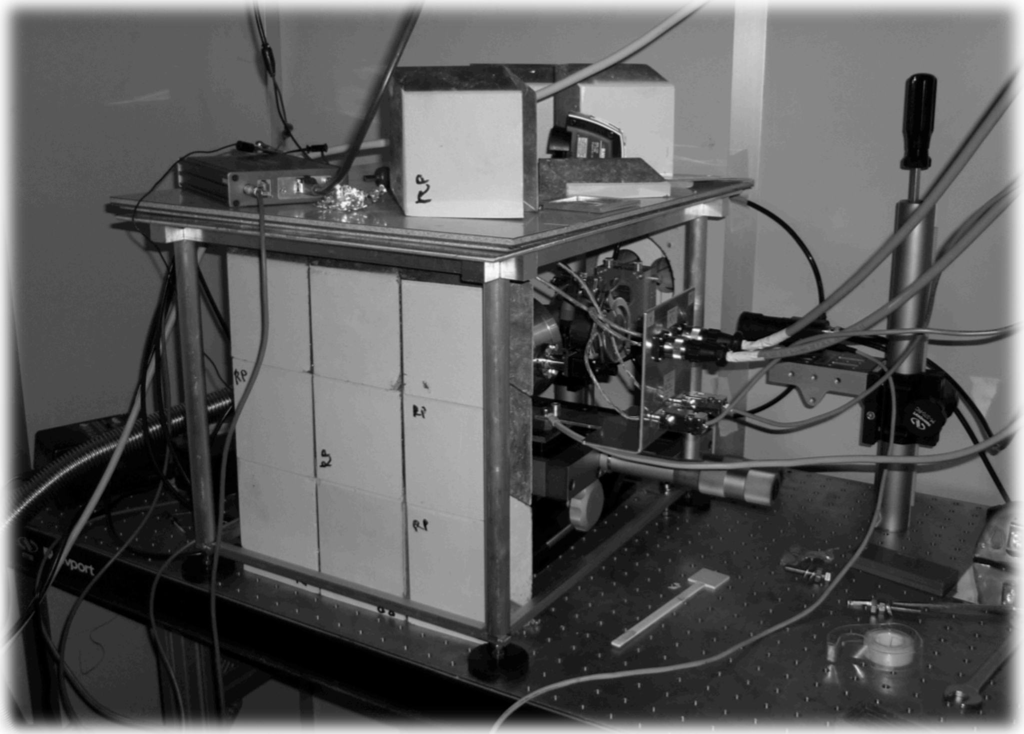


Sensitive from IR (terahertz?) to hard x-ray (neutrons?)



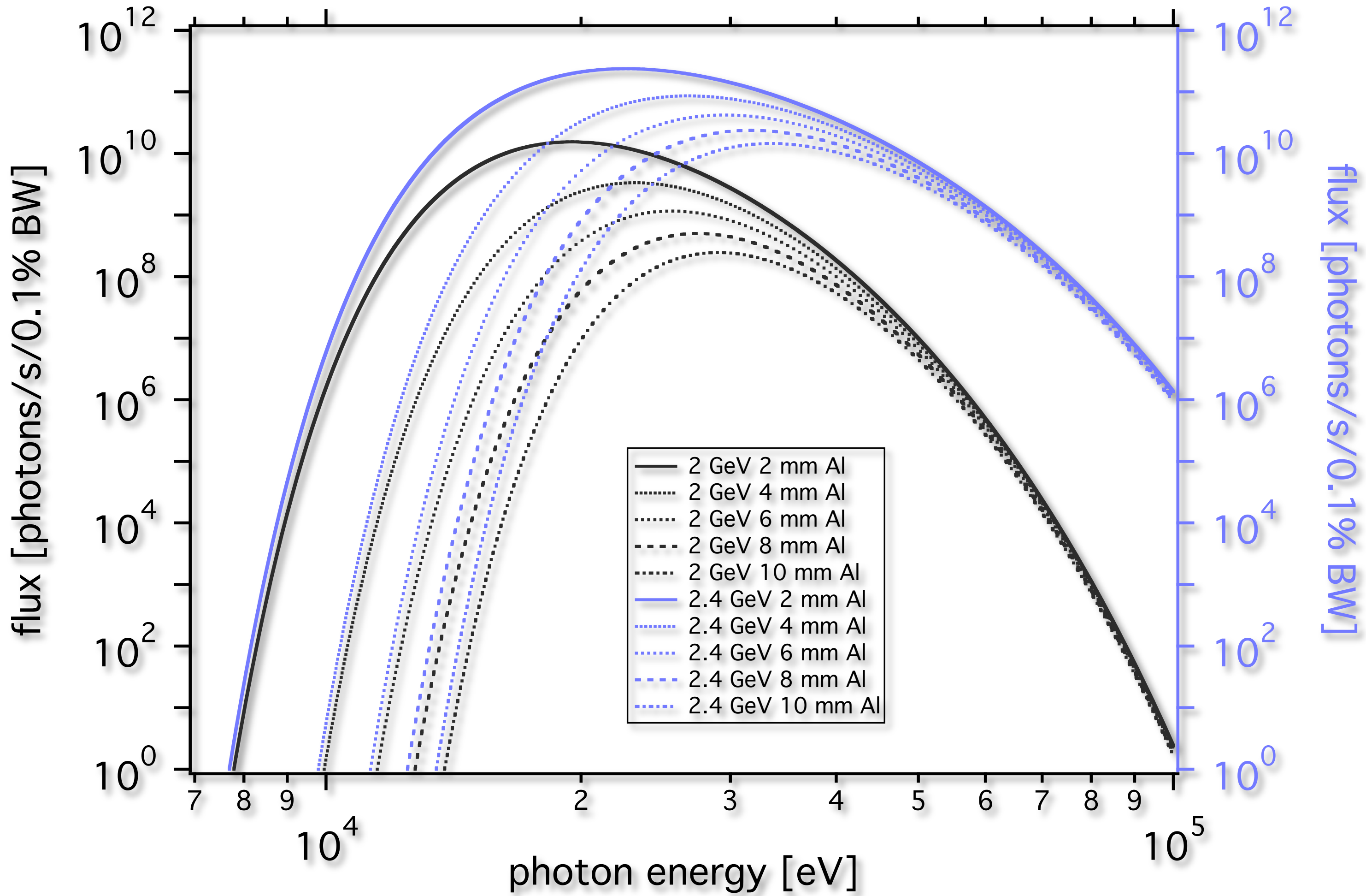
UV LED pulses
240 nm

Test station at μXRF beam line

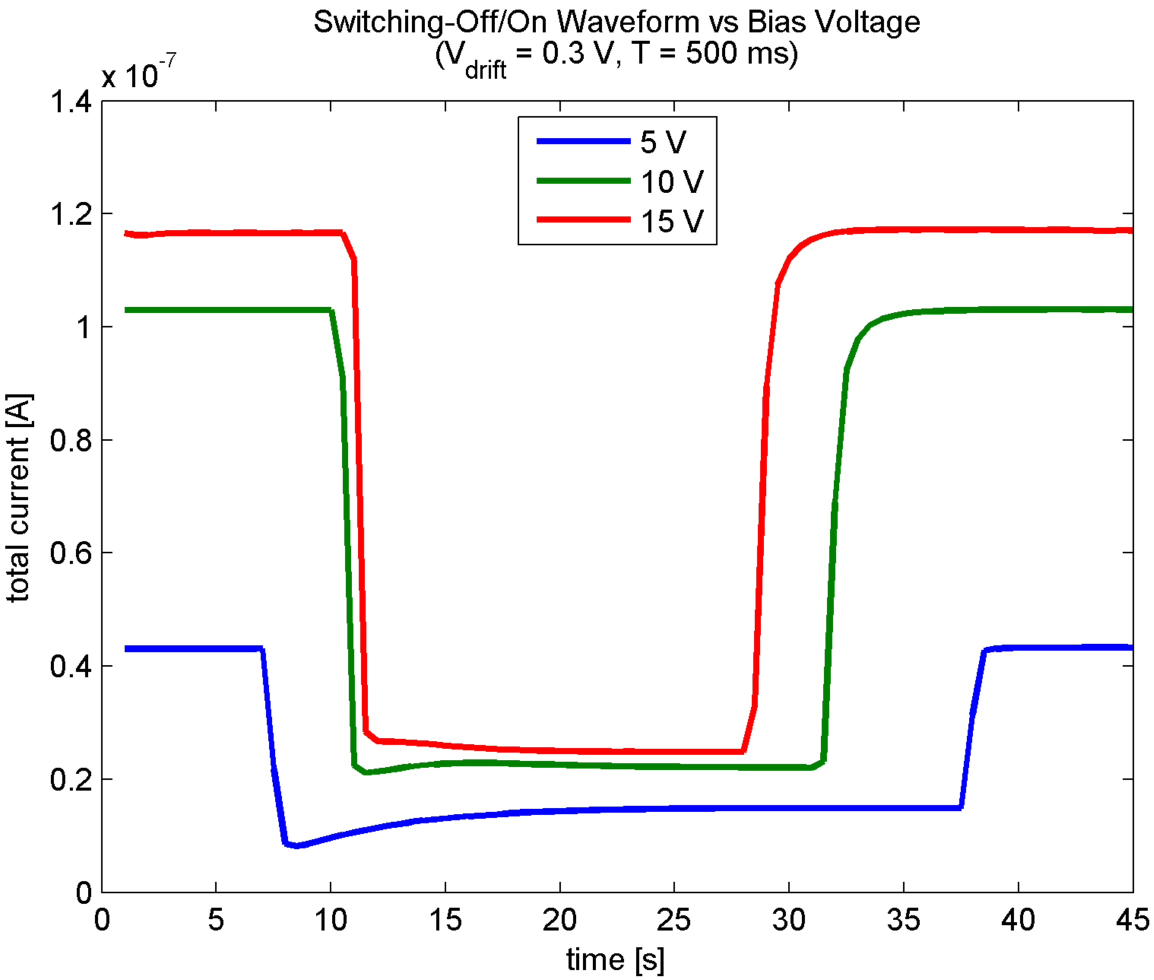


pink beam bending (μ-XRF beamline)

Spectra Pink beam



X-ray tube



Switching-Off/On Waveform vs Bias Voltage
(V drift = 0.3 V, T = 500 ms)
x 10-7
1.4
1.2
1
0.8
0.6
0.4
0.2
0
total current [A]
0
5
10
15
20
25
30
35
40
45
time [s]
5 V
10 V
15 V

Percival

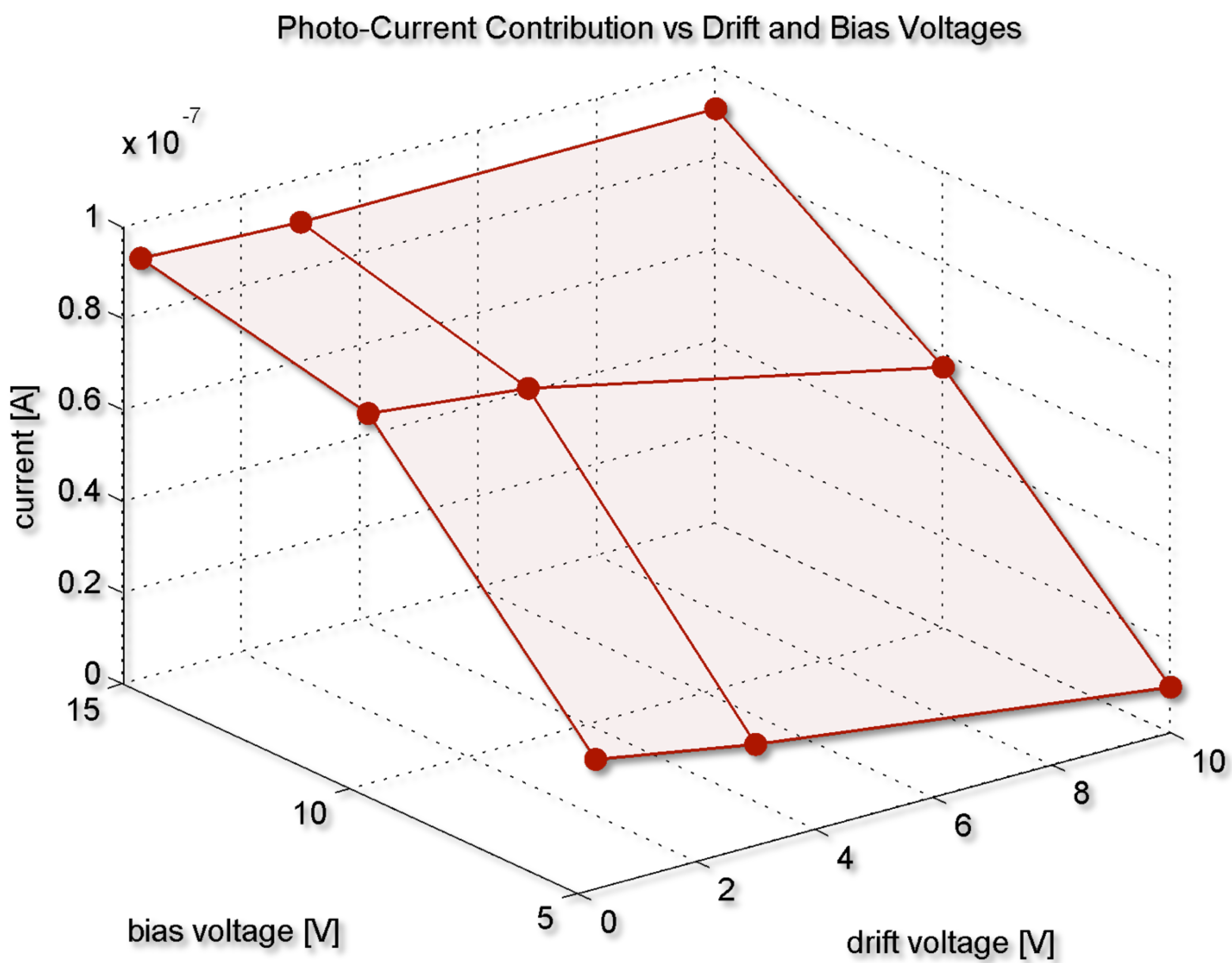
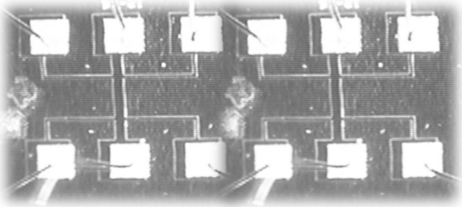
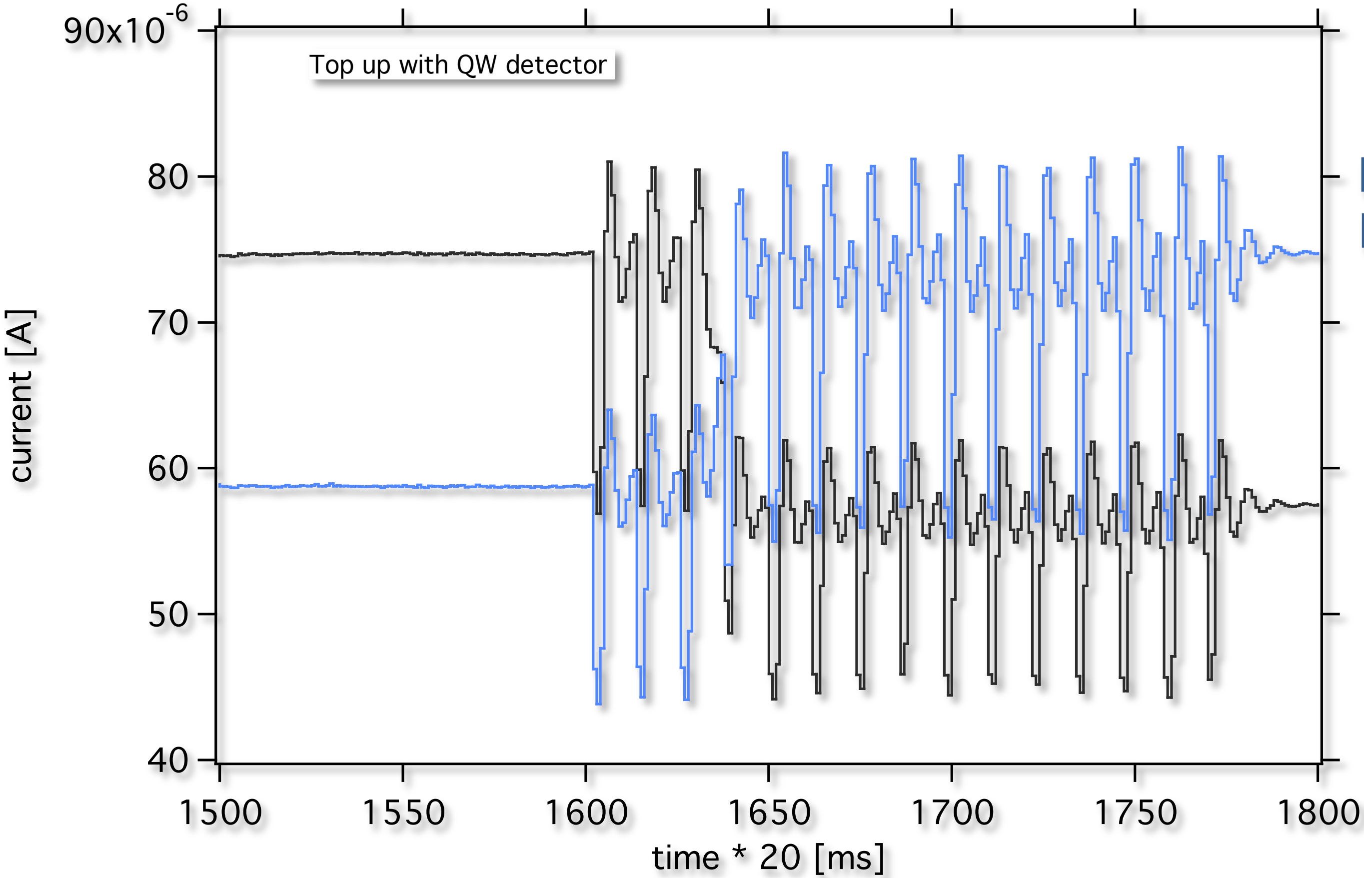


Photo-Current Contribution vs Drift and Bias Voltages
x 10^-7
1
0.8
0.6
0.4
0.2
0
current [A]
15
10
5
bias voltage [V]
0
2
4
6
8
10
drift voltage [V]

2 channel Quantum Well Detector (integrating)



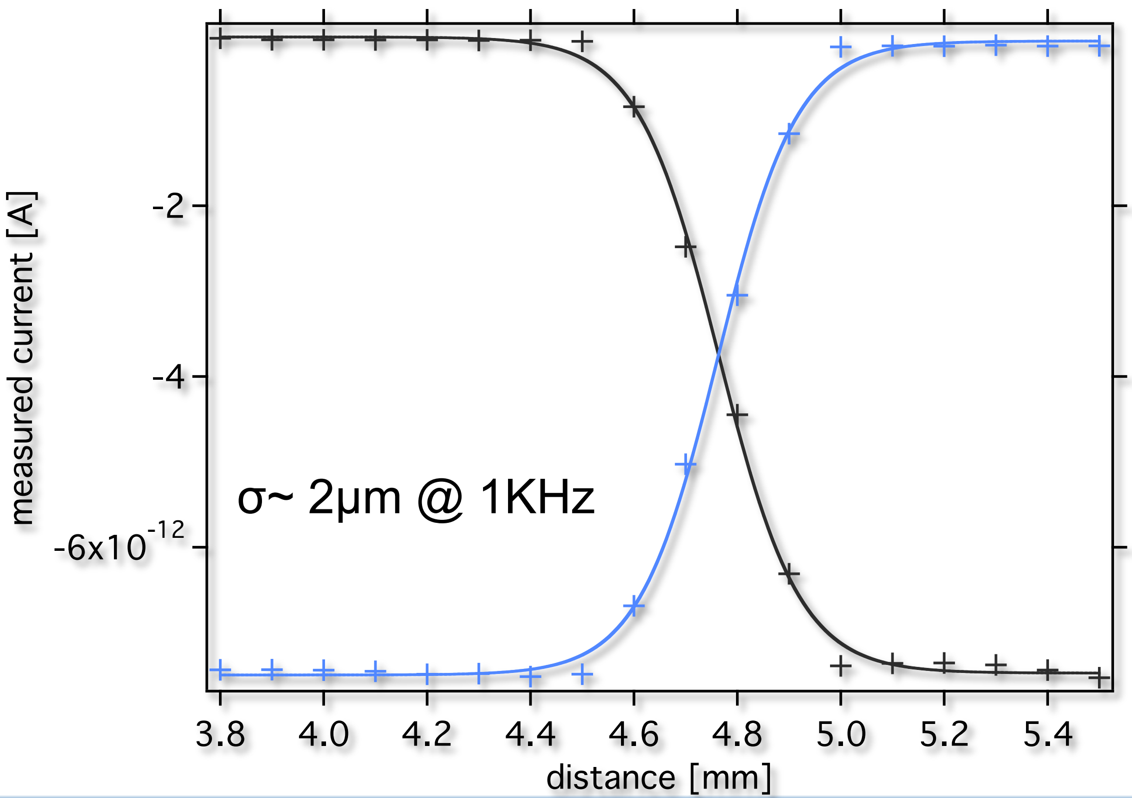


pink beam
µXRF

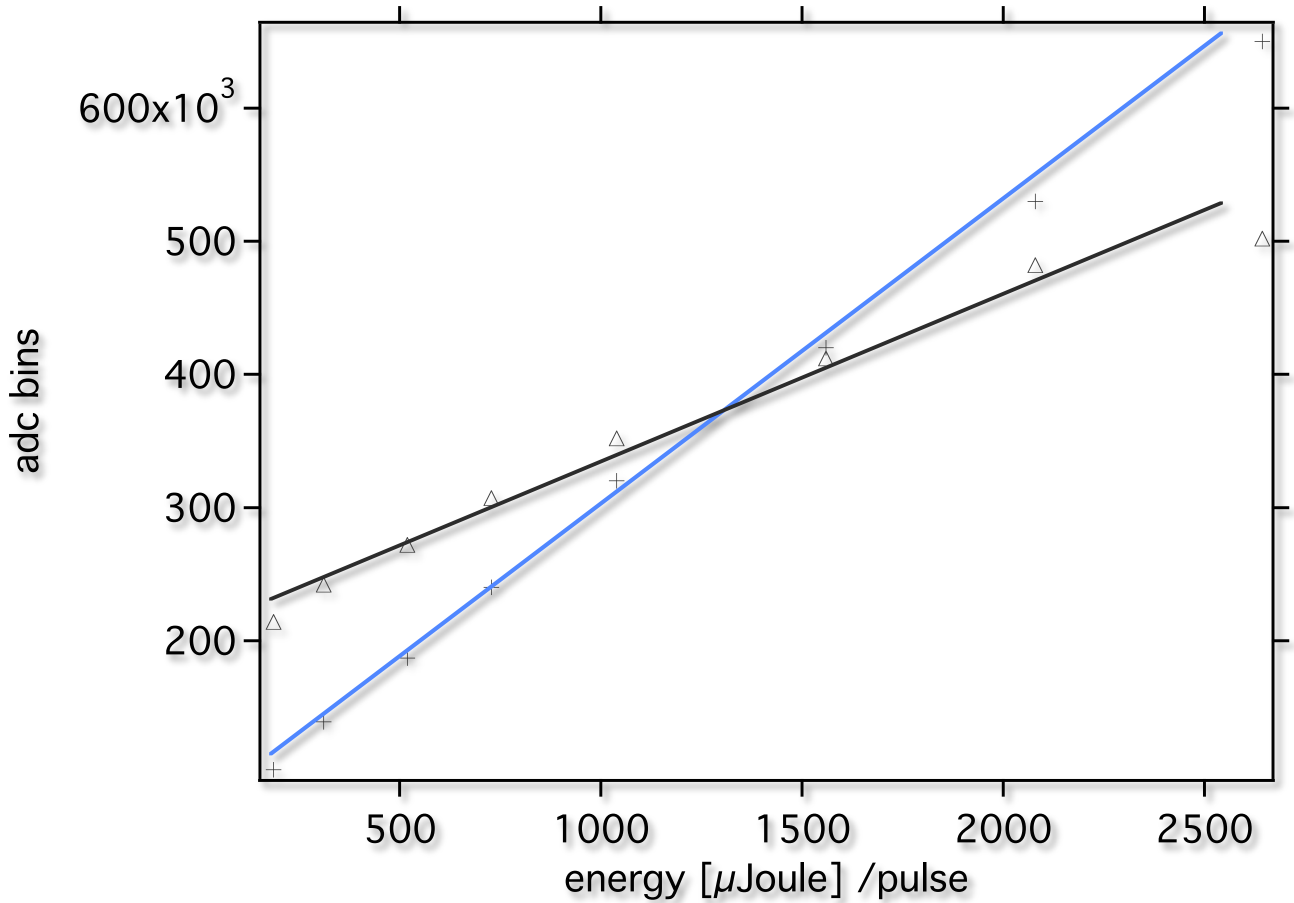
Spatial resolution

$$B_i = \sigma(x) = \int_{-a}^{a+w} \frac{-Q}{4\cdot L}\cdot\cosh\left(\frac{\pi\cdot x}{2\cdot L}\right)\cdot dx = \frac{-Q}{\pi}\cdot\left|\arctan\left(\frac{\pi\cdot x}{2\cdot L}\right)\right|_a^{a+w} \quad for\ a \geq 0$$

$$\sigma_y = \frac{\Delta y}{2}\cdot\sqrt{\frac{\varepsilon\cdot N+\sigma_{el}^2}{\varepsilon^2\cdot N^2}} \Rightarrow \sigma \approx \frac{1}{SNR}$$

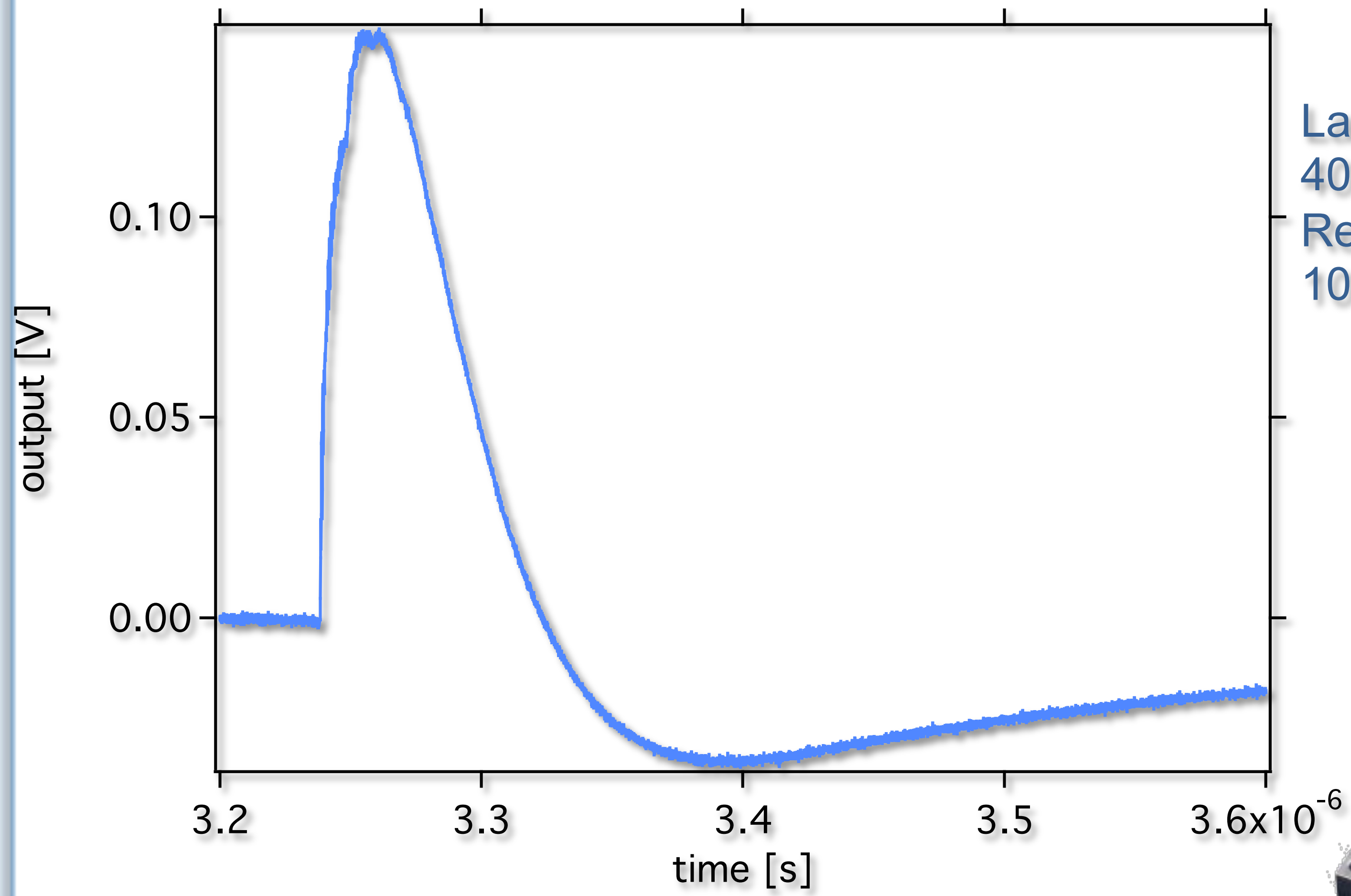


2 channel Quantum Well Detector (integrating)



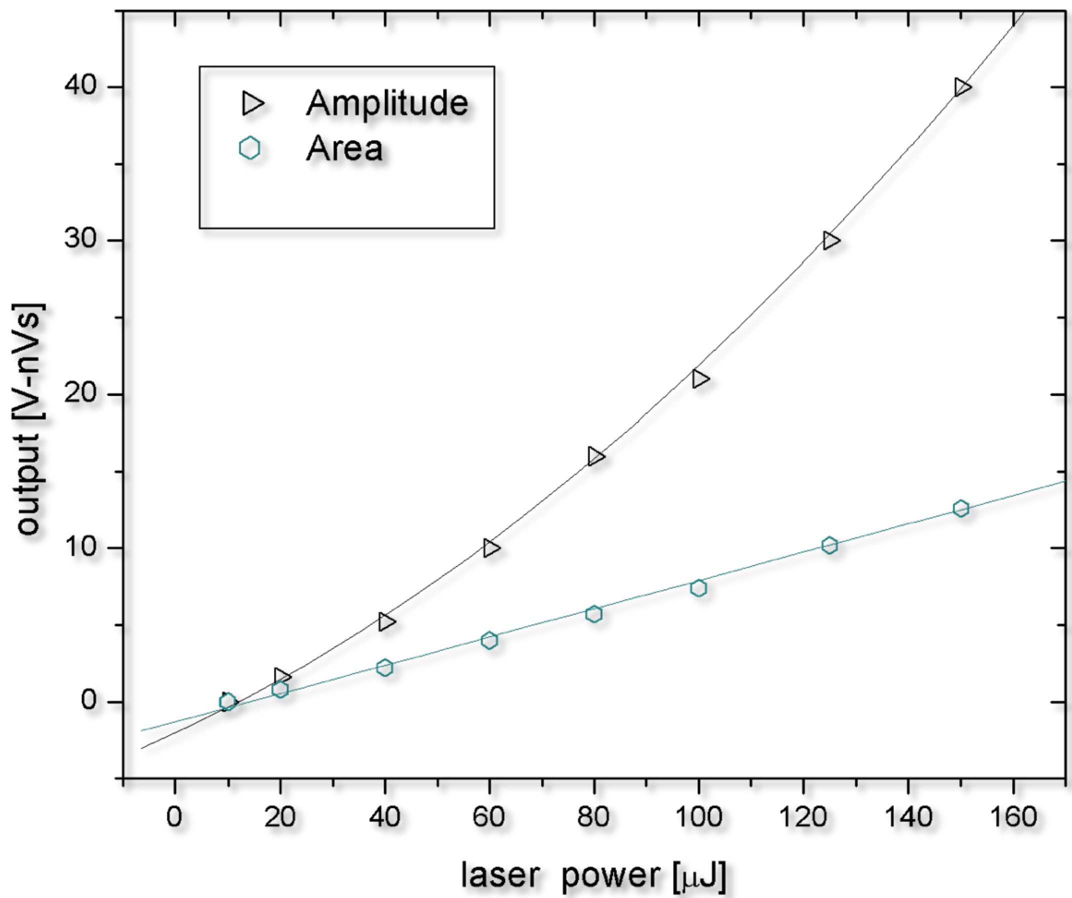
LASER
400 nm
Rep rate 10 Hz
100 fs length

2 channel Quantum Well Detector (pulse)



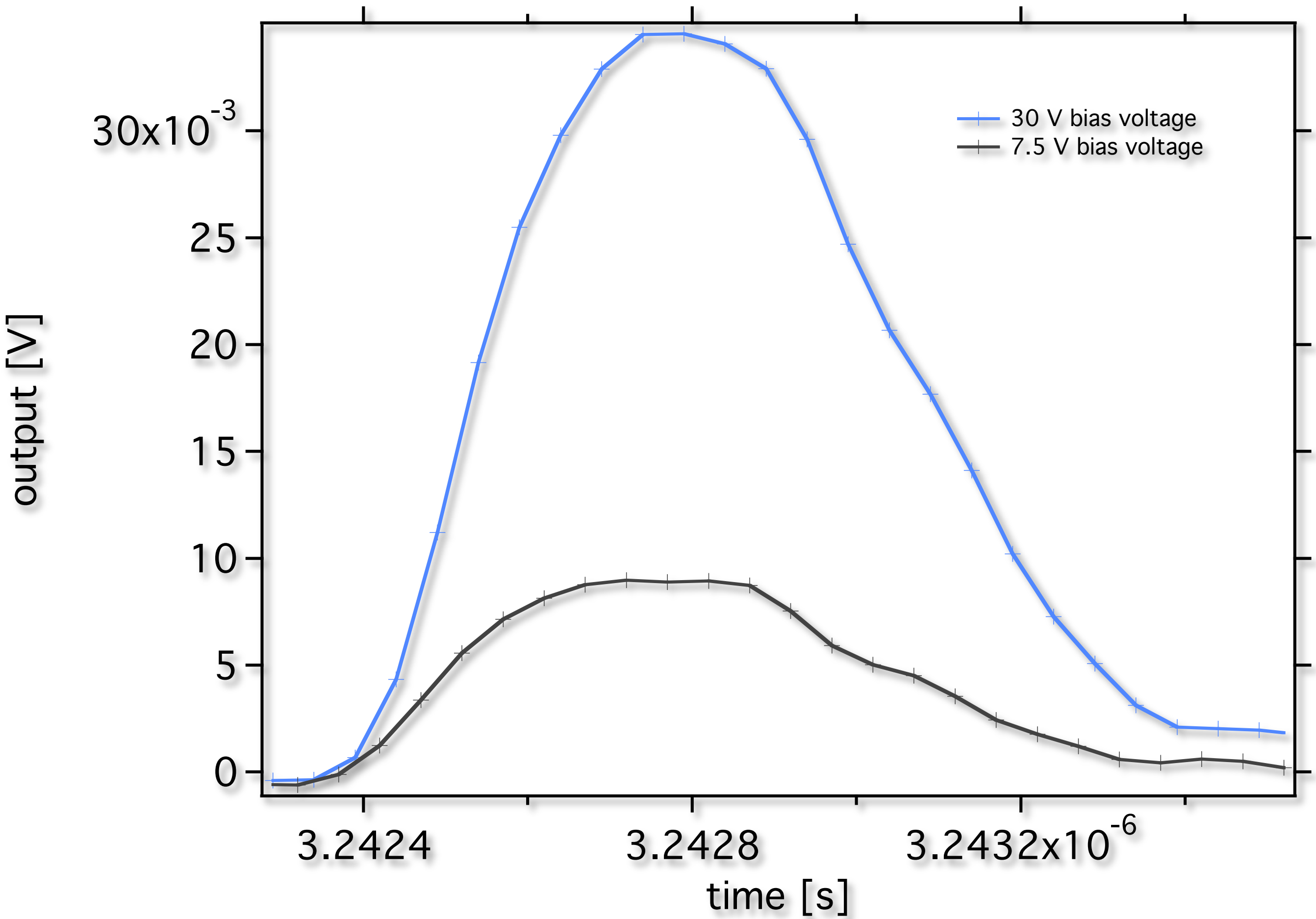
Laser
400 nm
Rep rate 1 KHz
100 fs length

2 channel Quantum Well Detector (pulse)



laser
400 nm
Rep rate 10 Hz
100 fs length

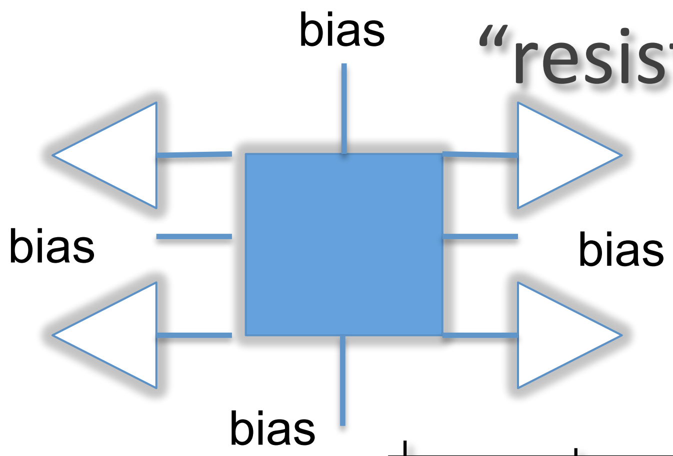
2 channel Quantum Well Detector (pulse)

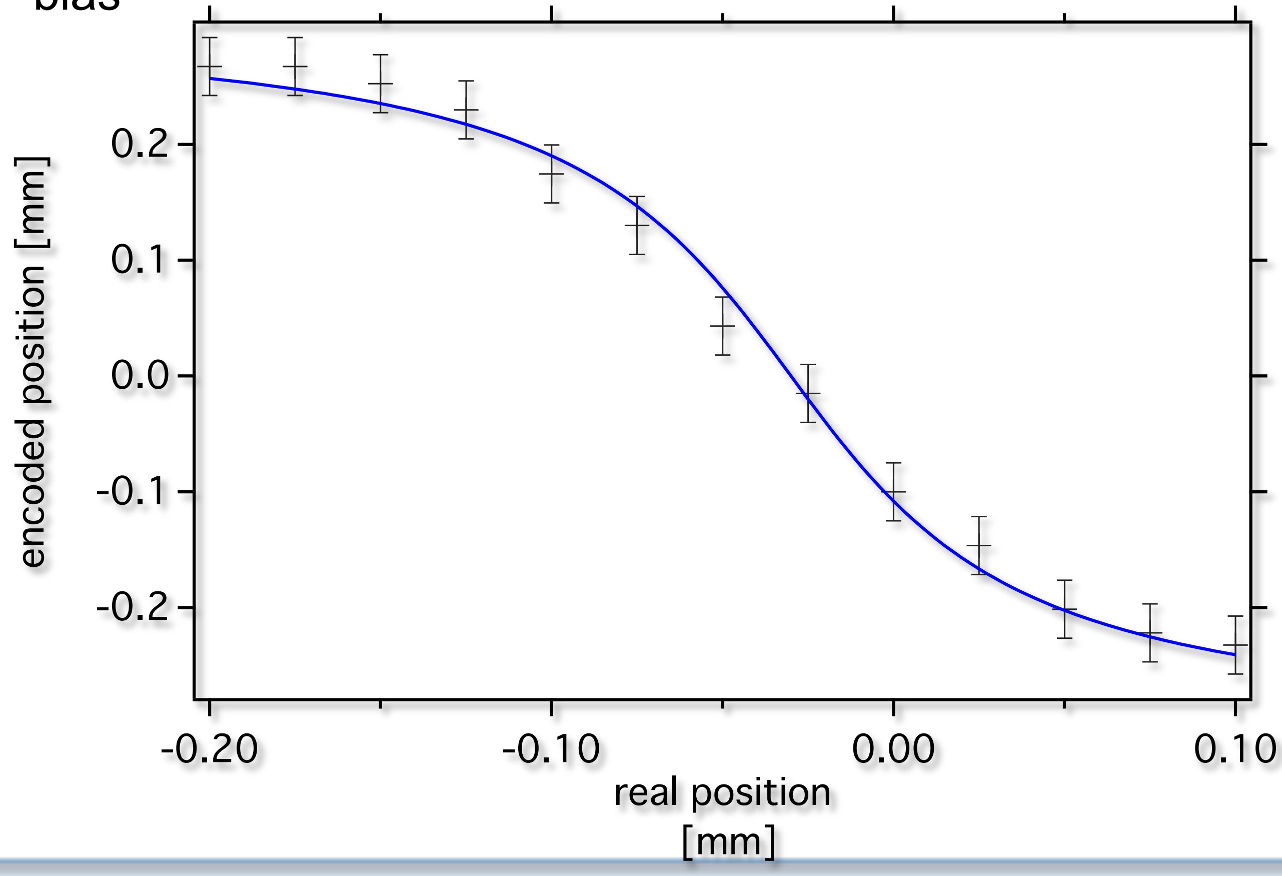


FEL
40 nm
Rep rate 10 Hz
100 fs length

“resistive anode” QW

694 nm Laser





Conclusion & outlook

- QW are promising devices for photon detection
- Intrinsically fast detectors
- Charge amplification capability
- Sensitive from IR to hard x-rays
- Position encoding possible

- Cooling concepts
- First tests of BPM capabilities at FERMI in July or November 2012
- Different readout schemes will be tested
  - Strips
  - Pixels
  - Interpolation
  - Three phase CCD clocking schemes.


Thank you