

# Percival CMOS Imager

Alessandro Marras

on behalf of the  
Percival collaboration





## The Percivallians:



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G. Cautero, D. Giuressi, A. Khromova, R. Menk, L. Stebel, G. Pinaroli

U. Pedersen, T. Nicholls, N. Tartoni, H. Yousef

H. Hyun, K. Kim, S. Rah

## Beamline(s) support:

*P04 (Petra III):*

S. Klump, F. Scholz, J. Seltmann, J. Viefhaus

*Twinmic, Cipo (Elettra):*

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N. Zema, S. Rinaldi, D. Catone

*I10 (DLS):*

P. Steadman, M. Sussmuth

*BL2 (FLASH):*

S. Toileikis, S. Duesterer

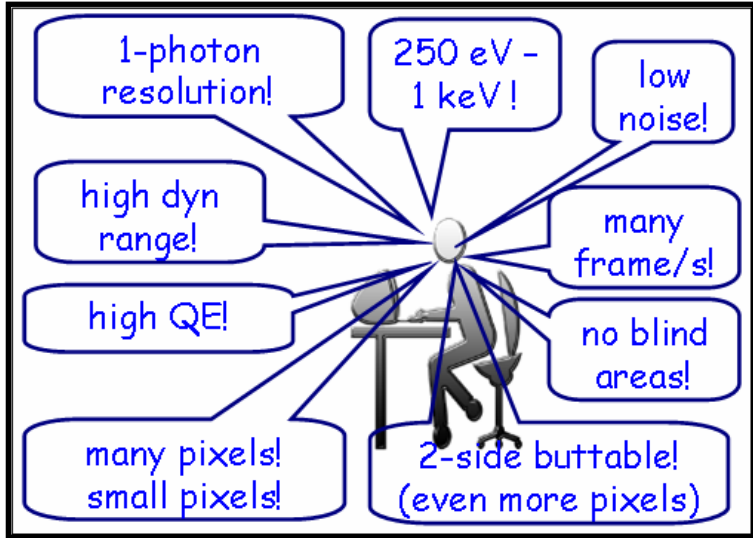
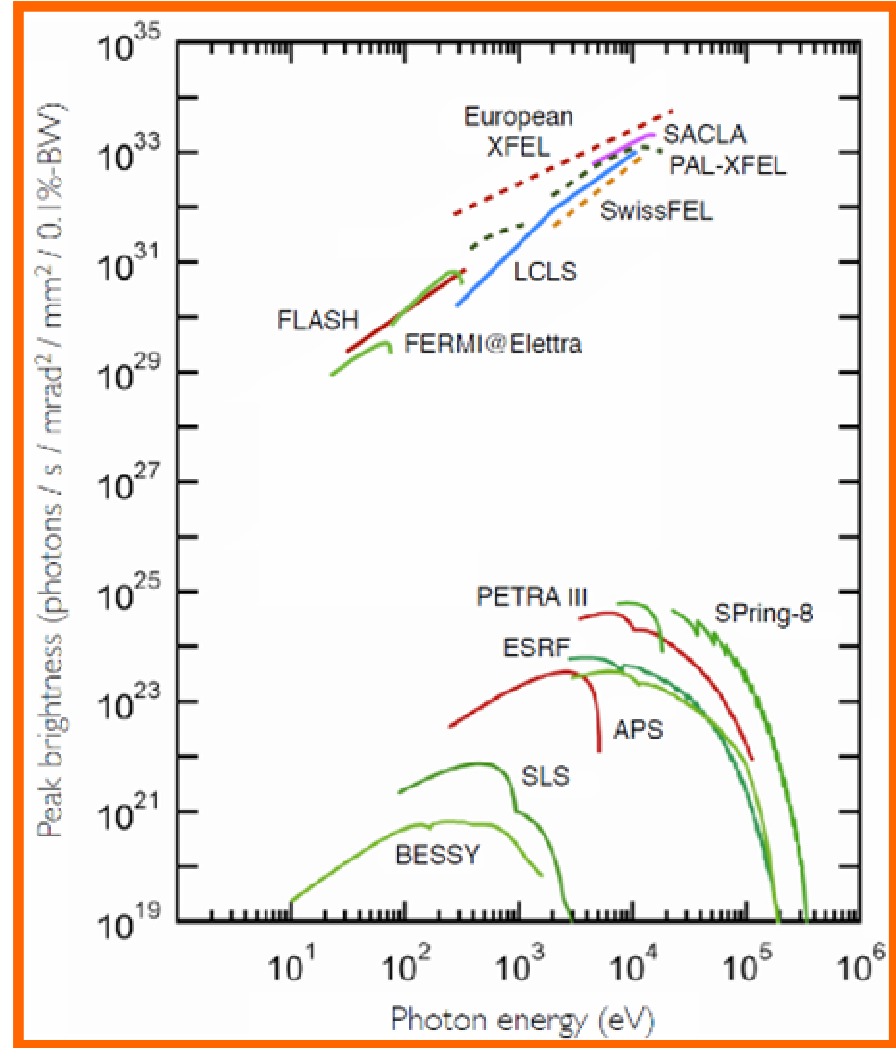
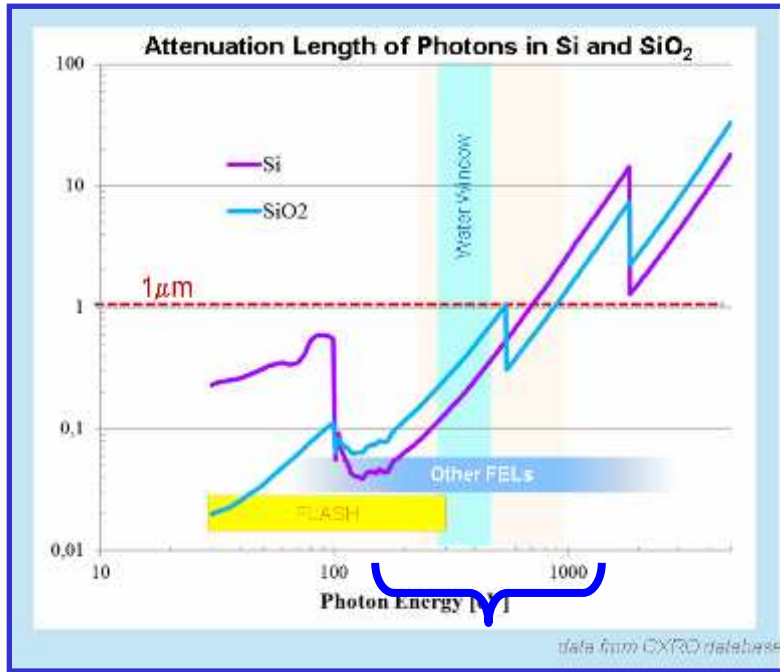
*PTB (in BESSY II ring):*

C. Laubis

## JPL acknowledgements:

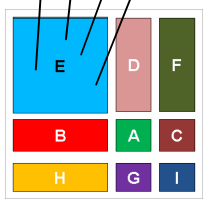
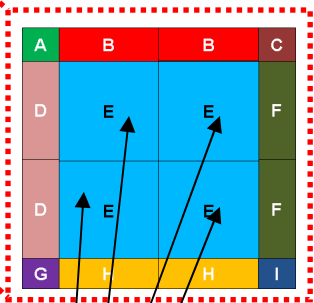
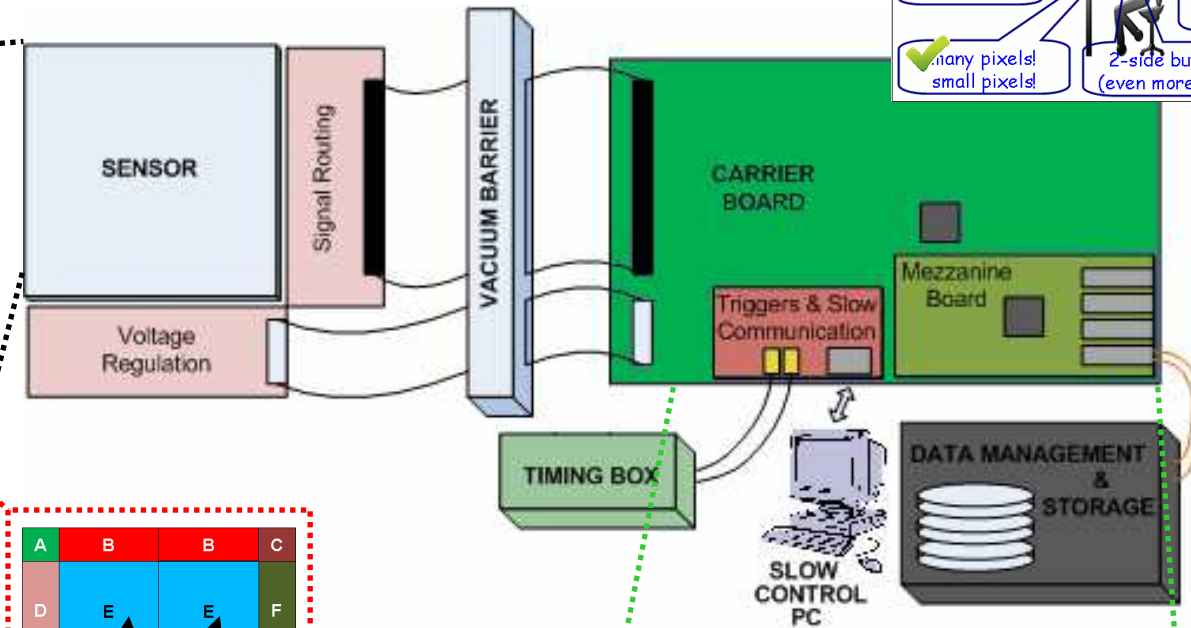
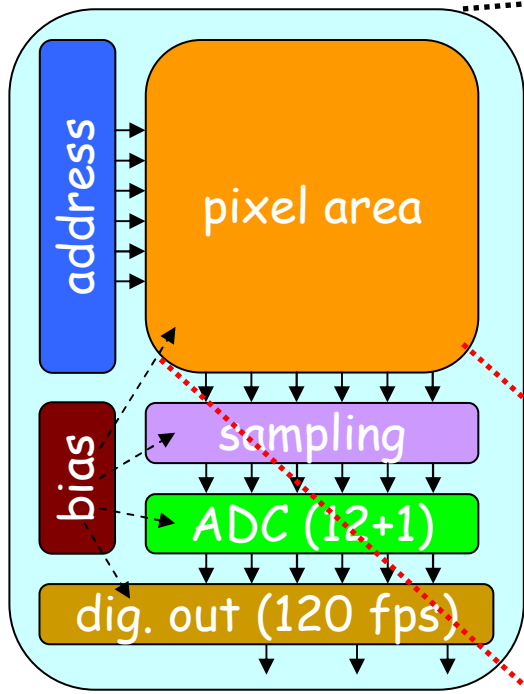
A. Jewell, T. Jones, M. Hoenk, S. Nikzad

# Motivation



# The full PERCIVAL system

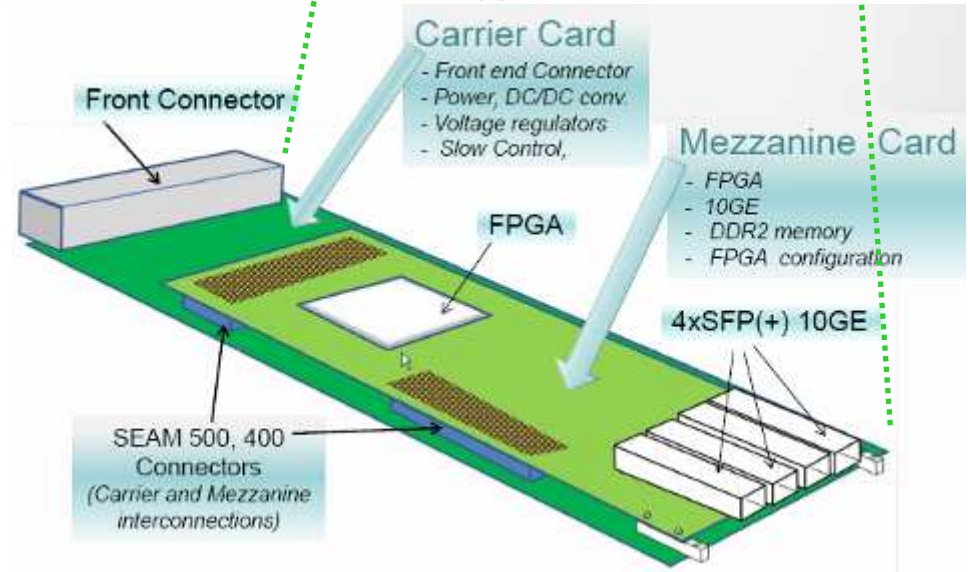
- 1-photon resolution!
- 250 eV - 1 keV!
- low noise!
- high dyn range!
- many frame/s!
- high QE!
- no blind areas!
- many pixels! small pixels!
- 2-side buttable! (even more pixels)



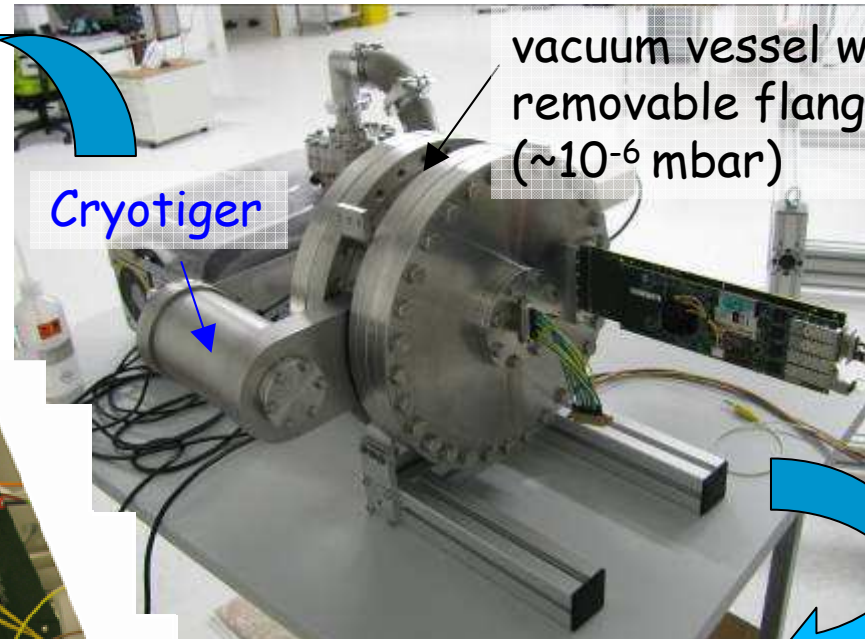
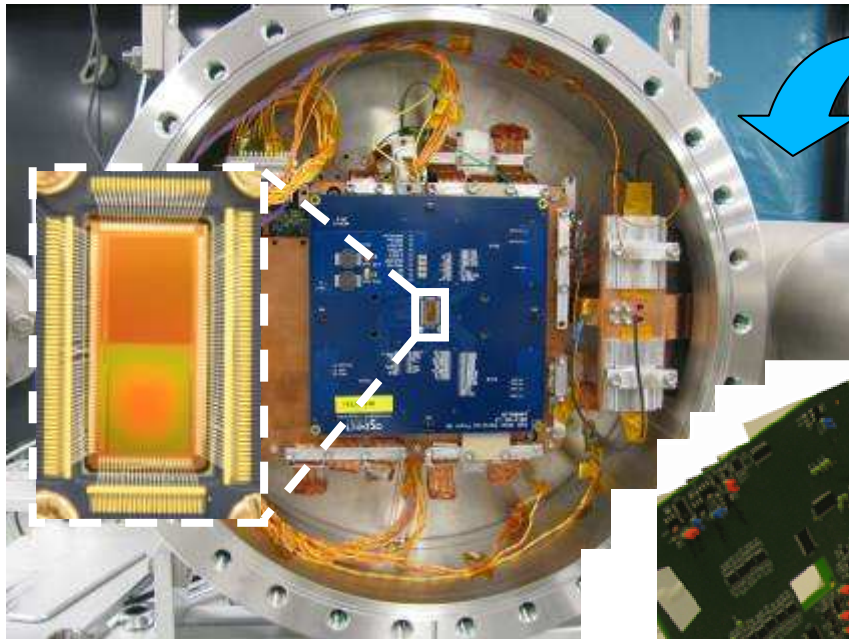
layout stitching

## P2M

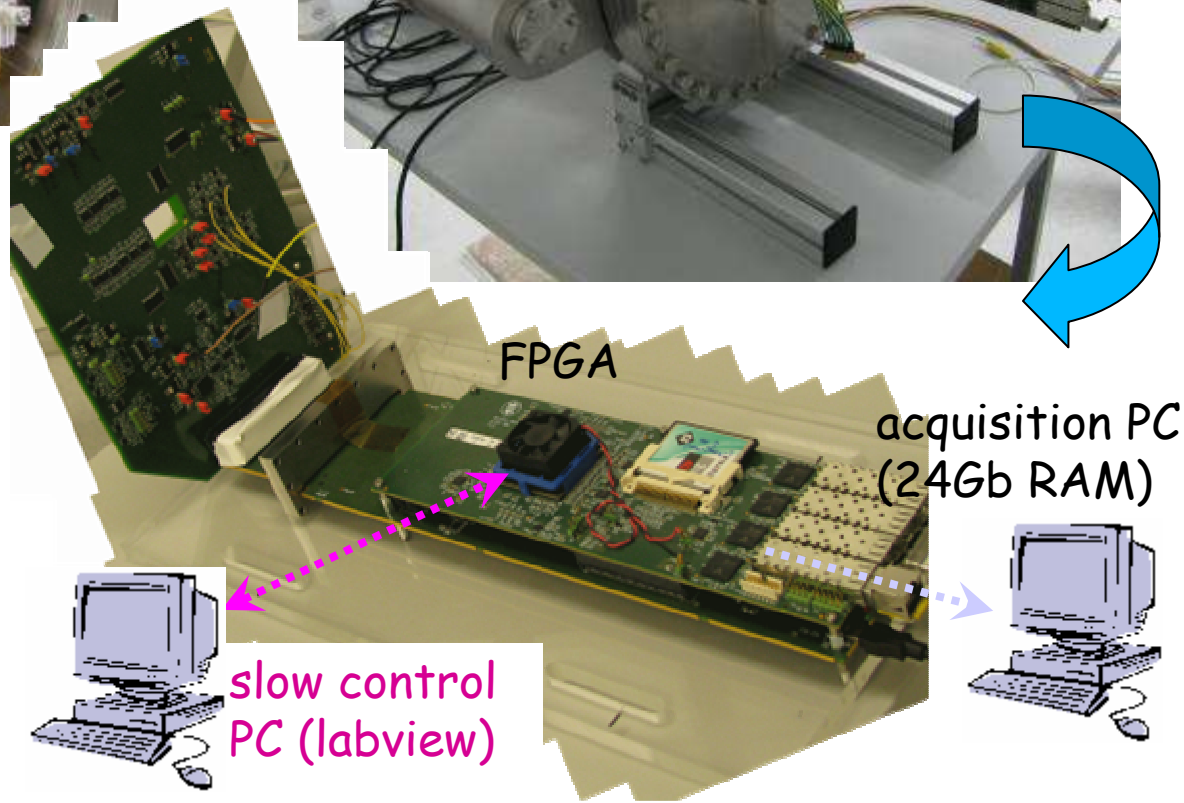
- 2Mpixels
- ~4x4cm<sup>2</sup> sens. area
- no gaps/blind areas
- 2-side buttable
- 27um pixel pitch
- manif. in progress, postproc. ~early 2017



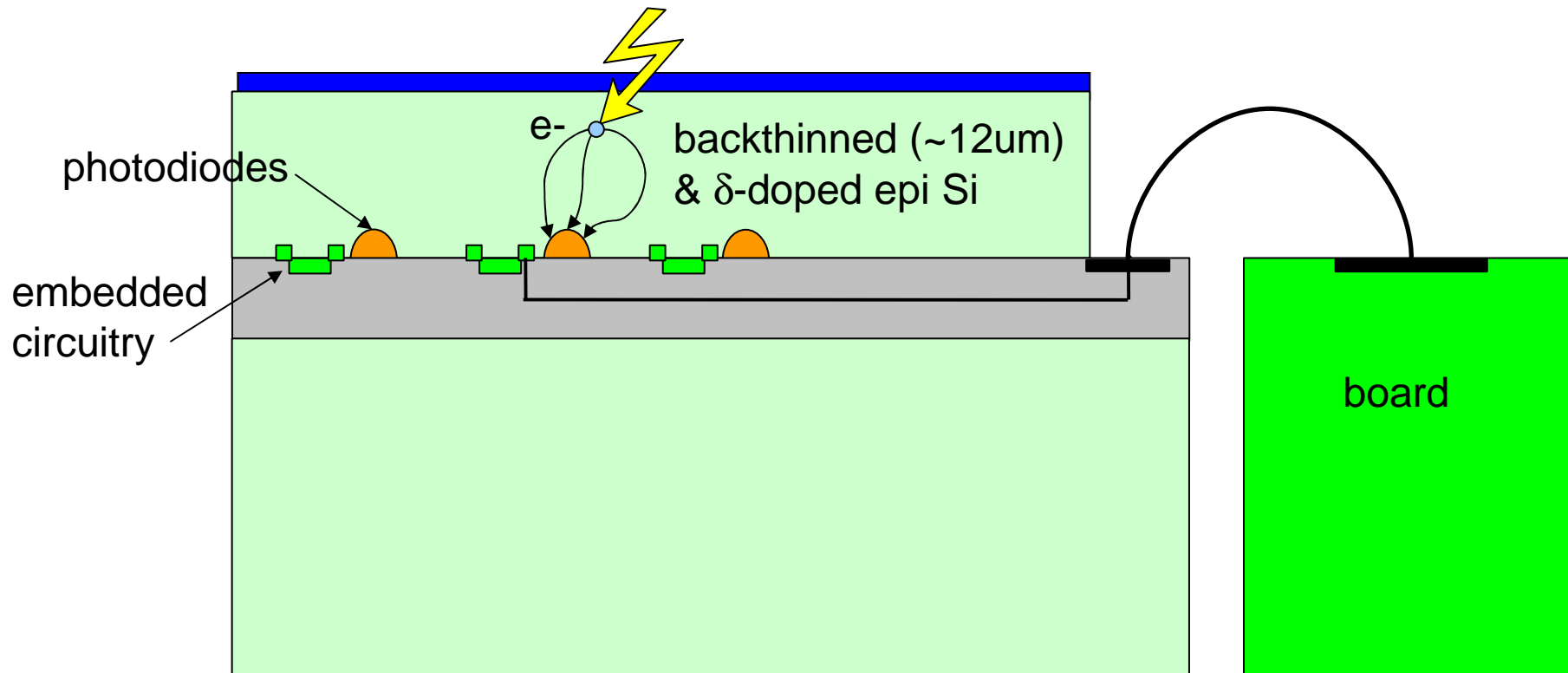
# The PERCIVAL prototype



- TestSensor 1.0/1/2**
- 33k pixels
  - 6+4 pixel flavours
  - ~0.4x0.5 cm<sup>2</sup> sens. area
  - 25um pixel pitch
  - FSI & BSI
  - FEL & Synchr. mode



# Monolithic Active Pixel Sensor



Monolithic: Collecting diodes & readout circuitry share the same substrate  
TowerJazz 0.18um CMOS techn, over high-resistance thick epi  
Coupled to handling wafer, back-thinned, back-illuminated: 100% fill factor



# detector classification



hybrid detector



sensor



bump bonding

readout & signal- proc ASIC

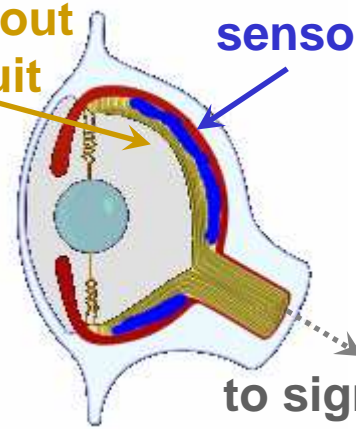
monolithic detector

Front-Illuminated



readout circuit

sensor



human eye

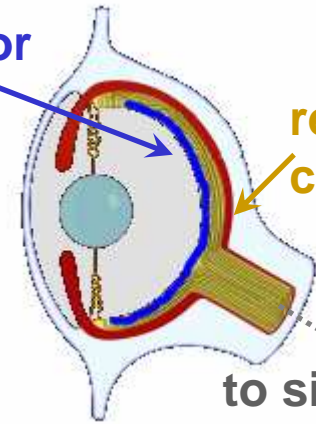
to signal-processing circuits

Back-Illuminated



sensor

readout circuit

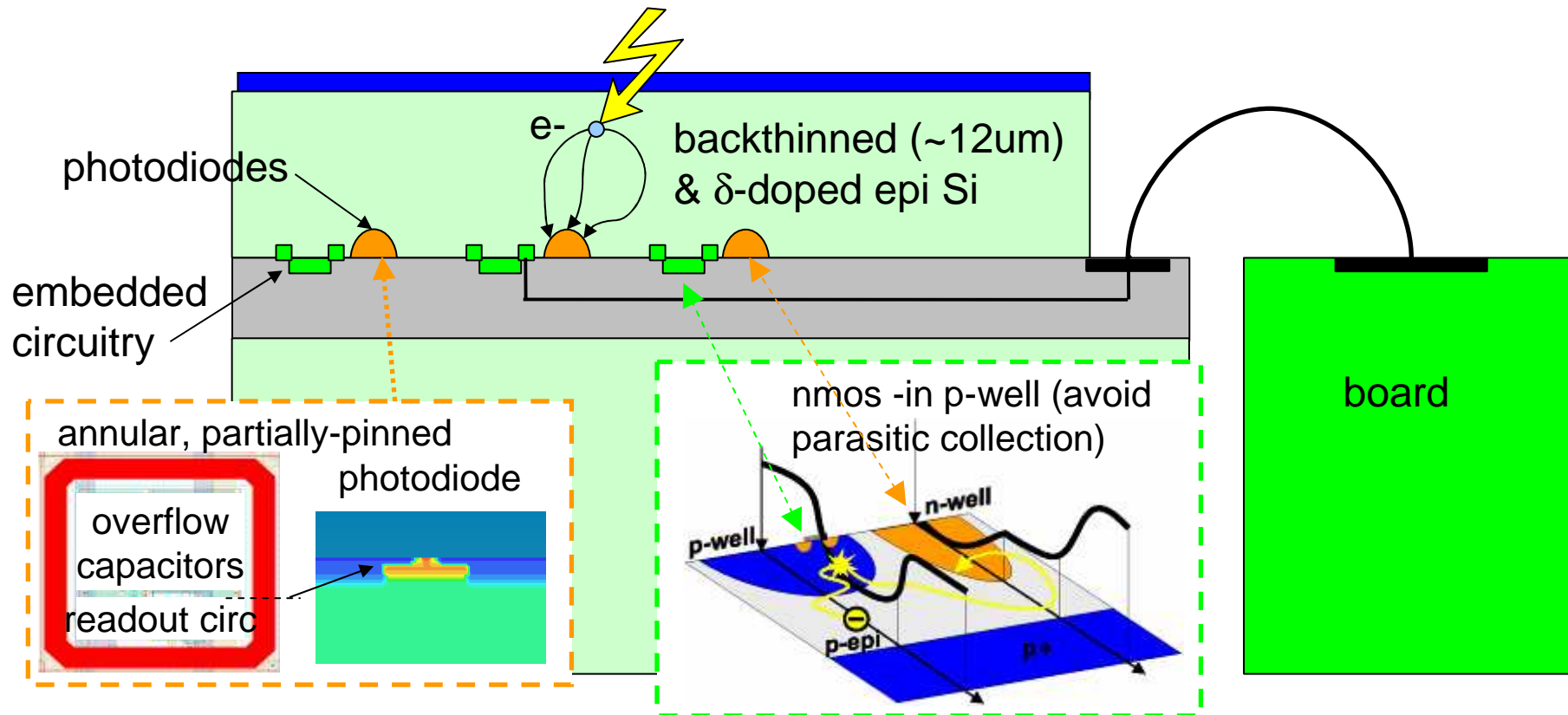


octopus eye

to signal-processing circuits



# Monolithic Active Pixel Sensor

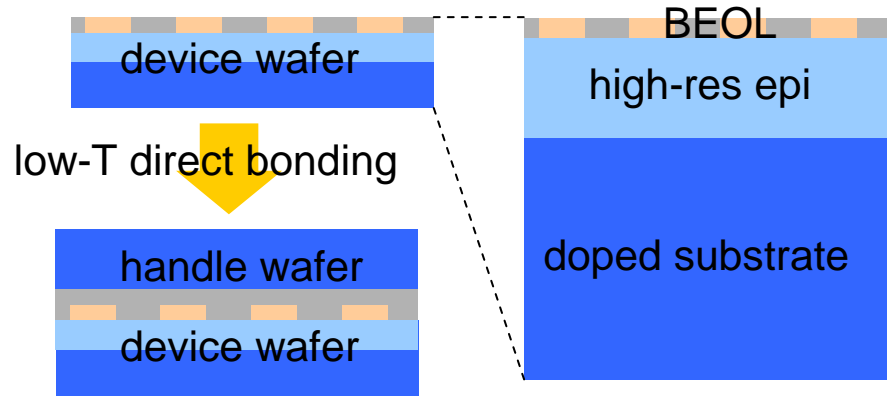


Monolithic: Collecting diodes & readout circuitry share the same substrate  
TowerJazz 0.18um CMOS techn, over high-resistance thick epi  
Coupled to handling wafer, back-thinned, back-illuminated: 100% fill factor  
Back surface delta-doped, post-processed: almost no entrance window



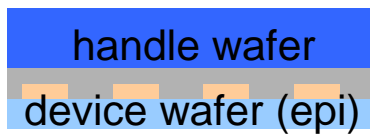


# delta-doping of back-surface



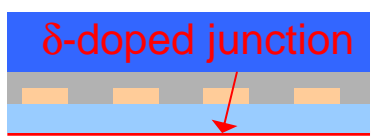
low-T direct bonding

CMP + etching (doping-sensitive)

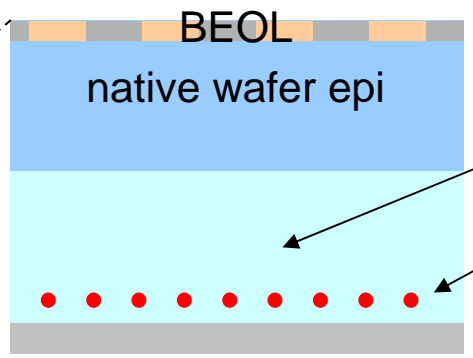
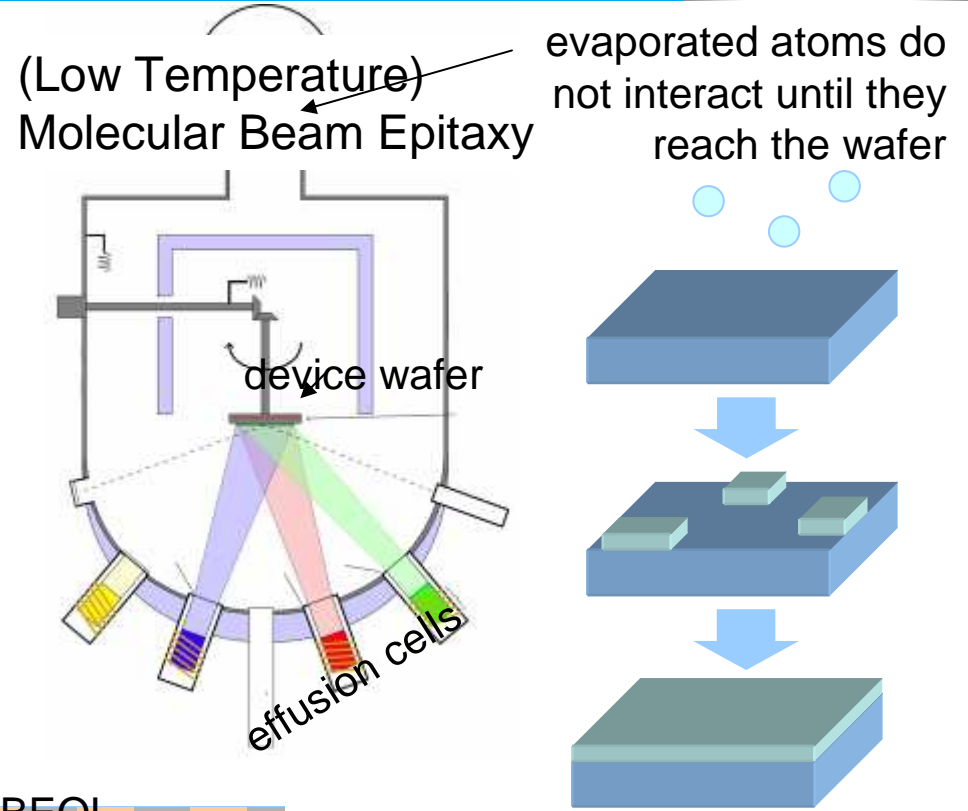
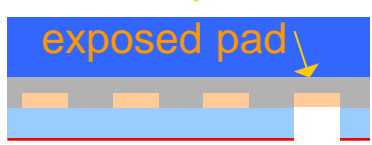


epi acts as etch-stop

MBE growth of doped Si



selective etching



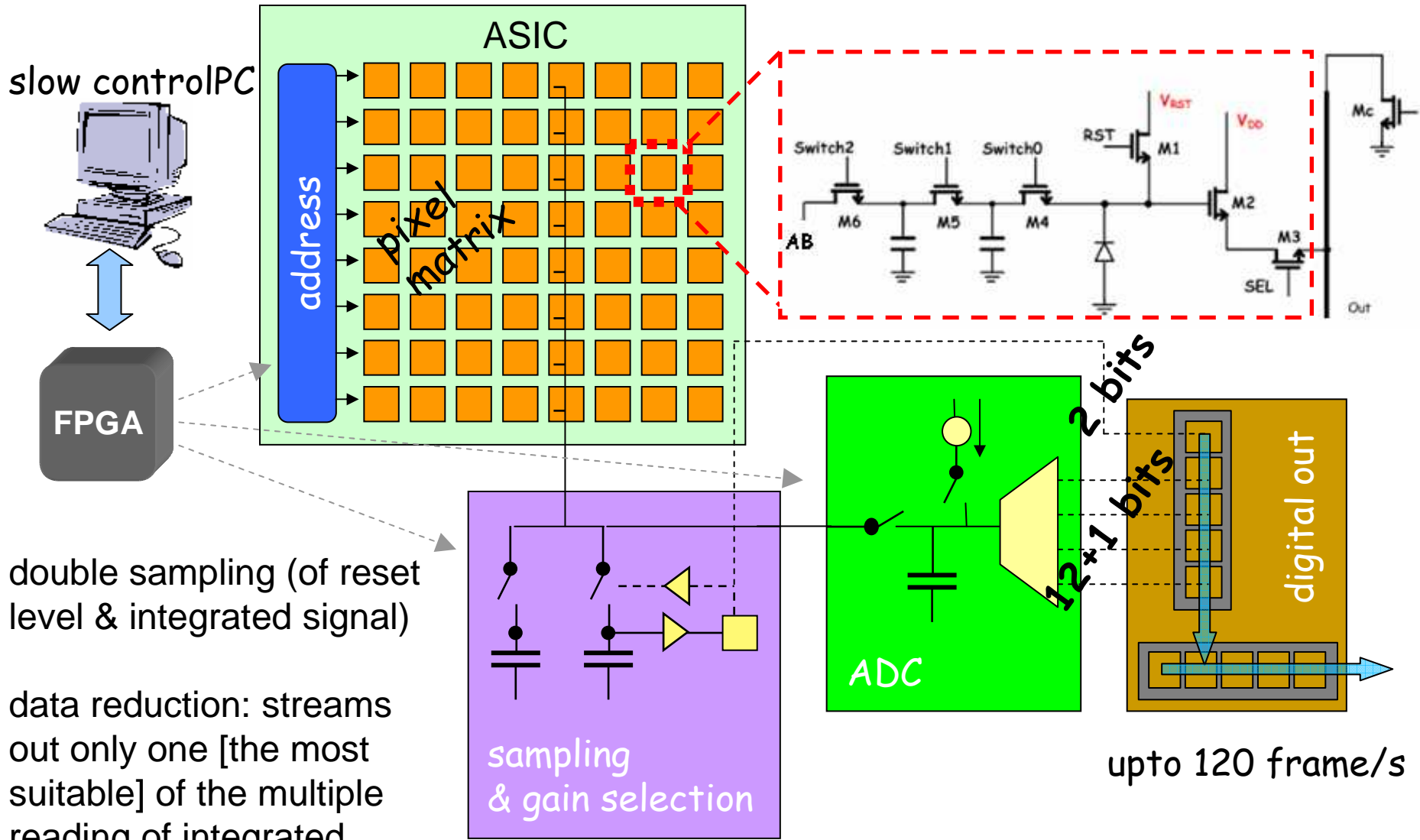
MBE growth (few nm)

dopant down to single atomic layer

oxide (~1nm)



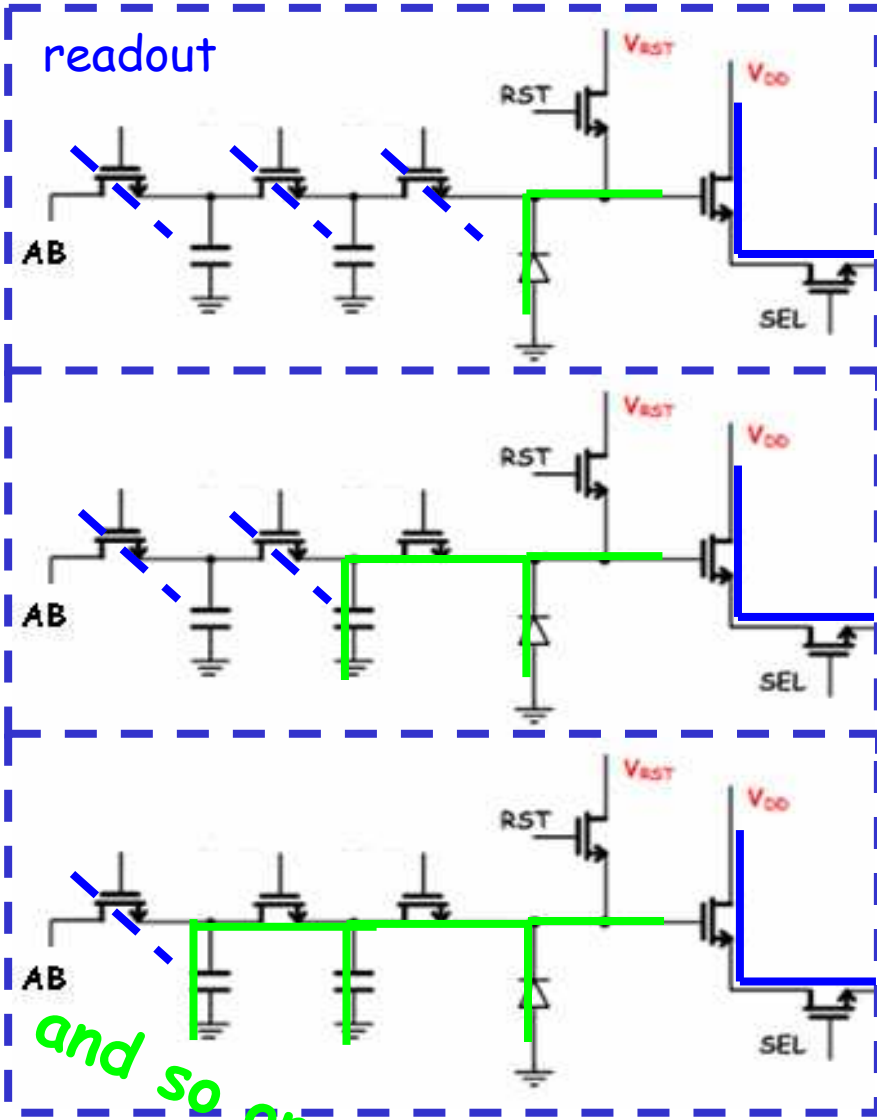
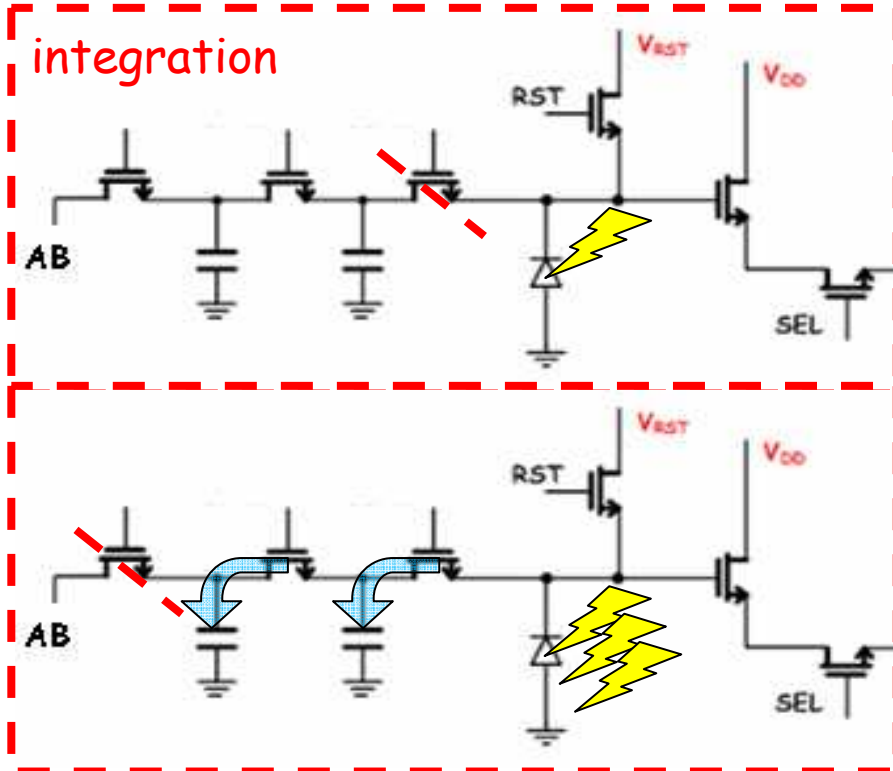
# The PERCIVAL core



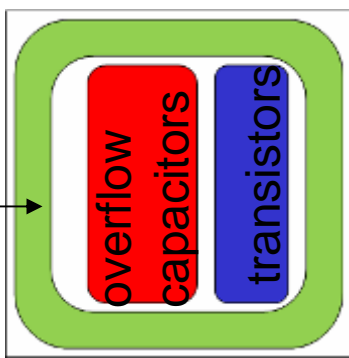
double sampling (of reset level & integrated signal)

data reduction: streams out only one [the most suitable] of the multiple reading of integrated signal (+2 sel. bits)

# Lateral Overflow



annular-shaped  
partially-pinned  
photodiode

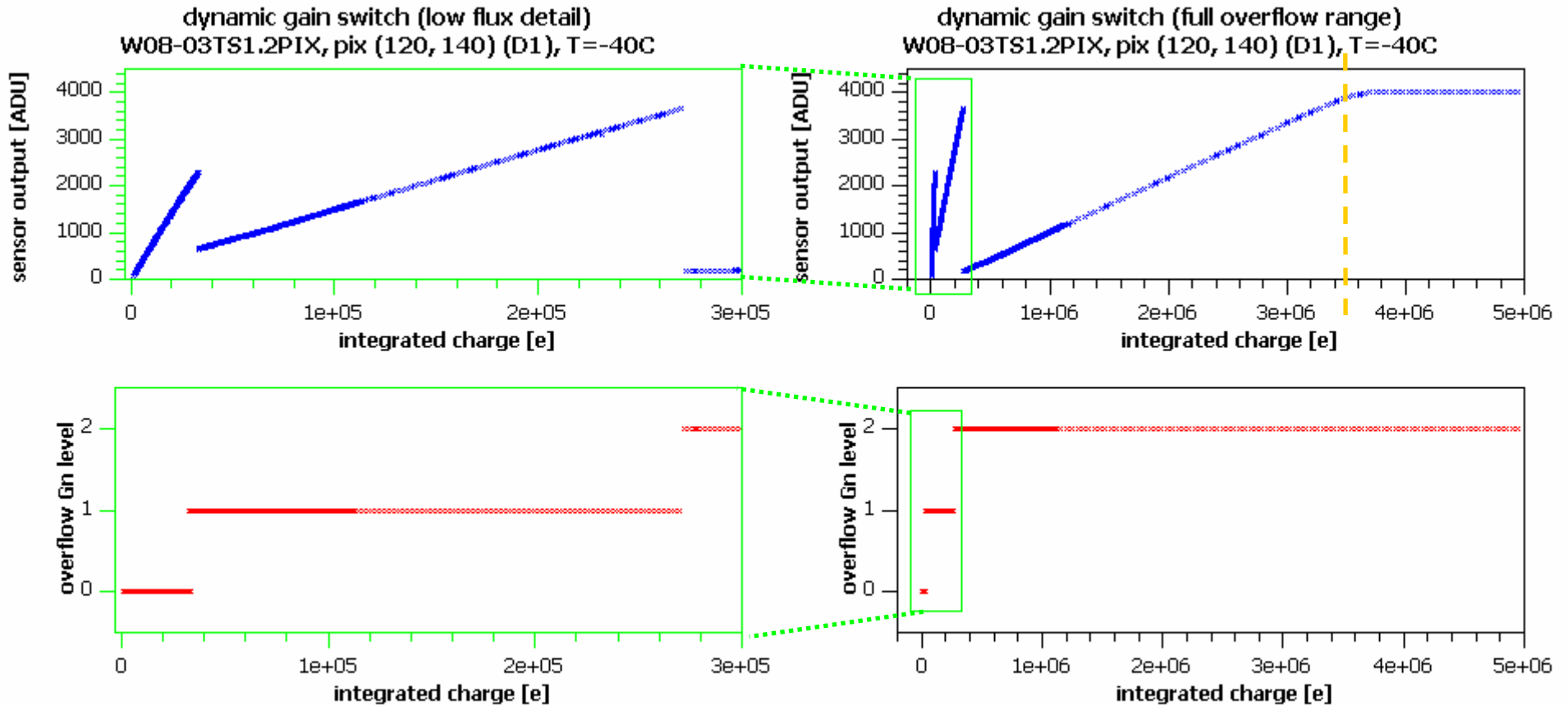
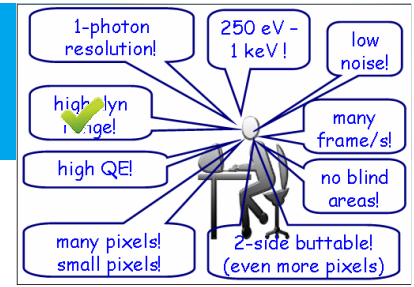


automatic  
selection of  
appropriate  
overflow  $G_n$   
level (only  
relevant data  
streamed out)

and so on

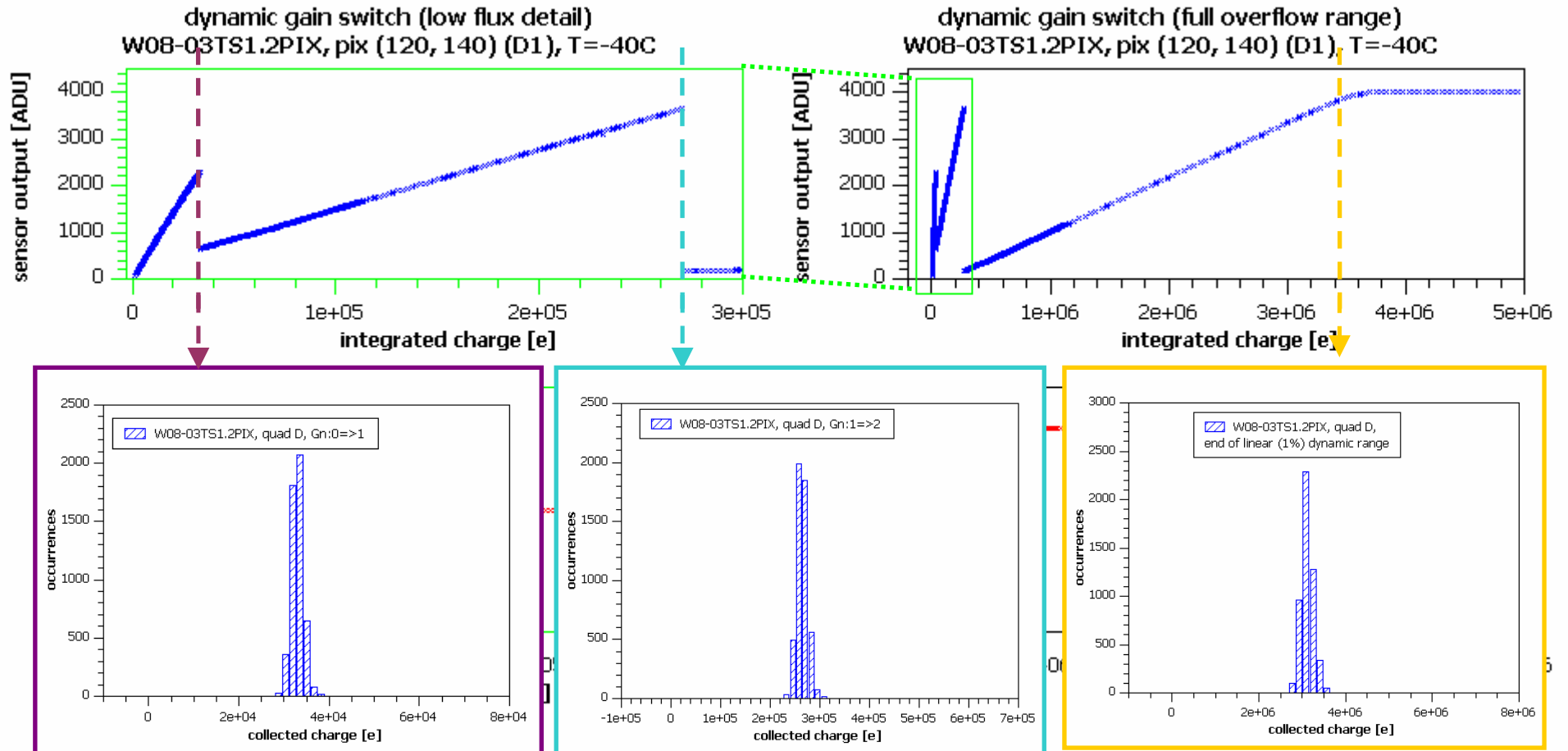
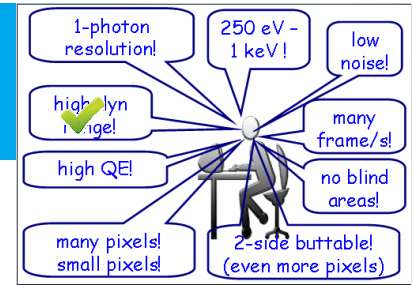


# Lateral Overflow, dynamic range: test results



dyn. range: 3.5Me ~ 50k photons @ 250eV

# Lateral Overflow, dynamic range: test results

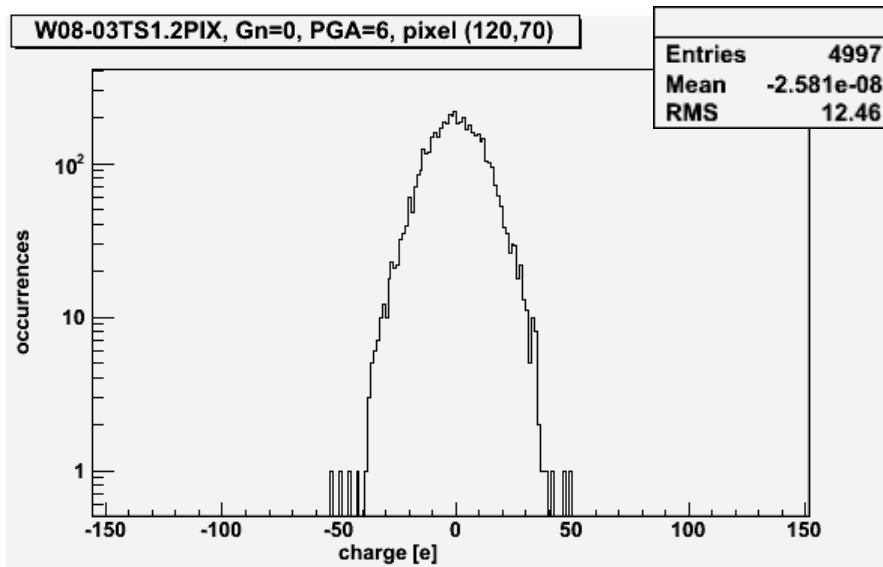
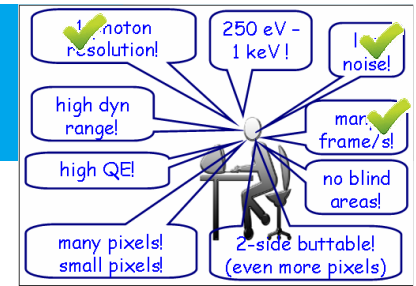


dyn. range: 3.5Me ~ 50k photons @ 250eV

reasonably narrow pixel-to-pixel

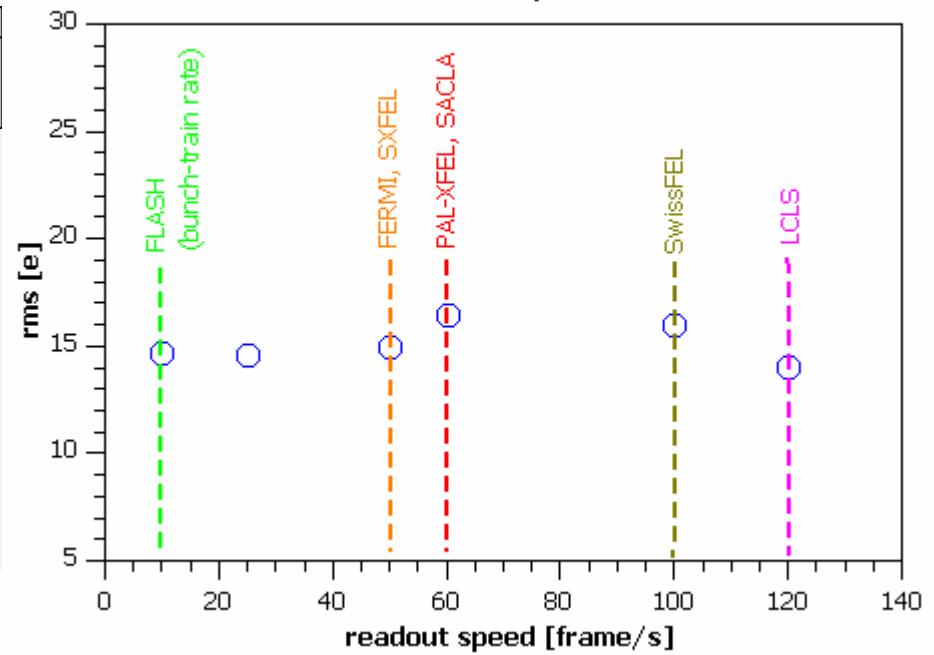
parameter dispersion

# noise: test results



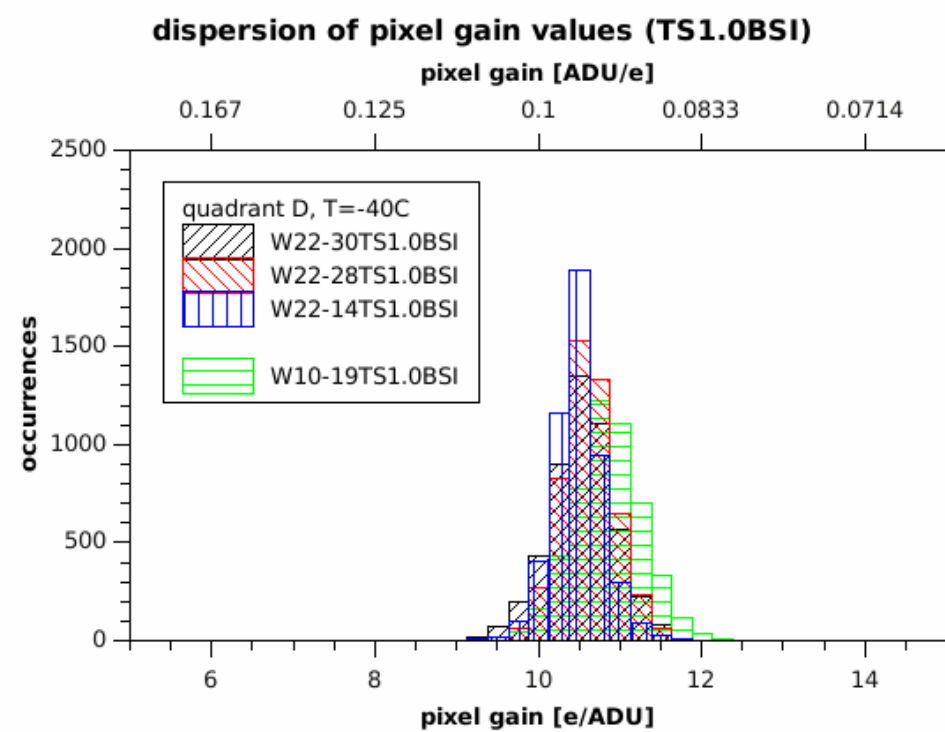
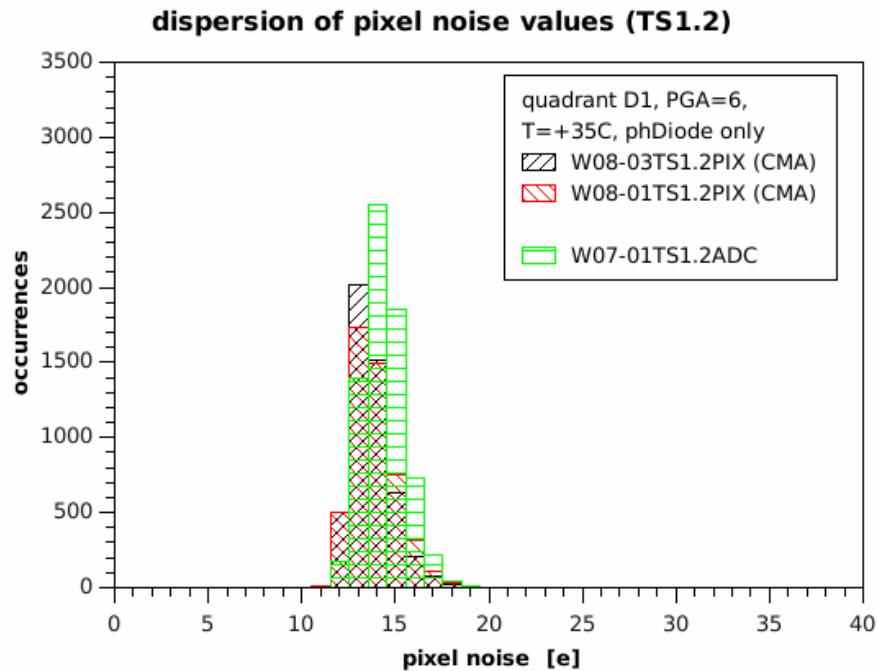
noise (low flux condition)

noise vs. readout speed  
W08-03TS1.2PIX, T=-40°C



compatible with most FEL frame rates

# parameter dispersion



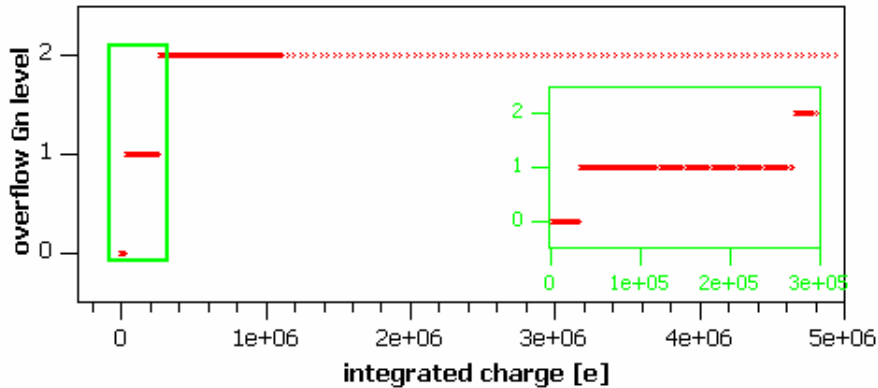
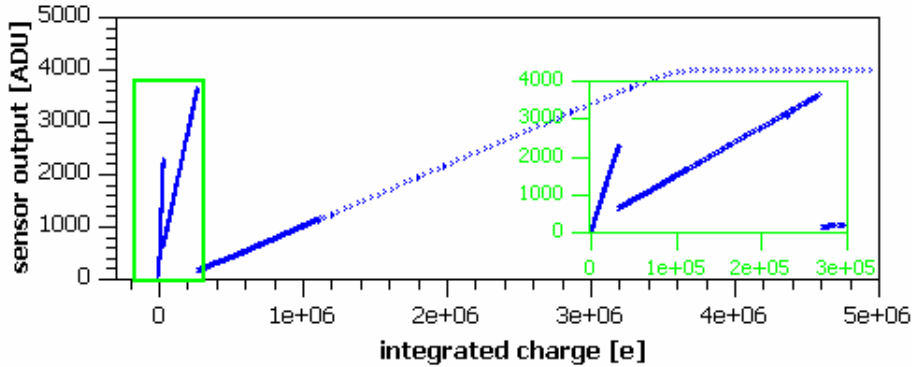
reasonably low parameter dispersion  
between different samples  
(also from different wafers)



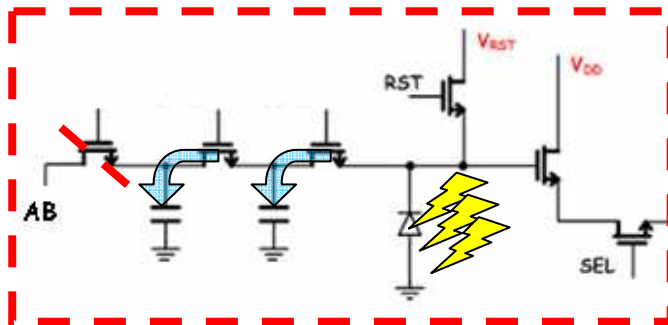
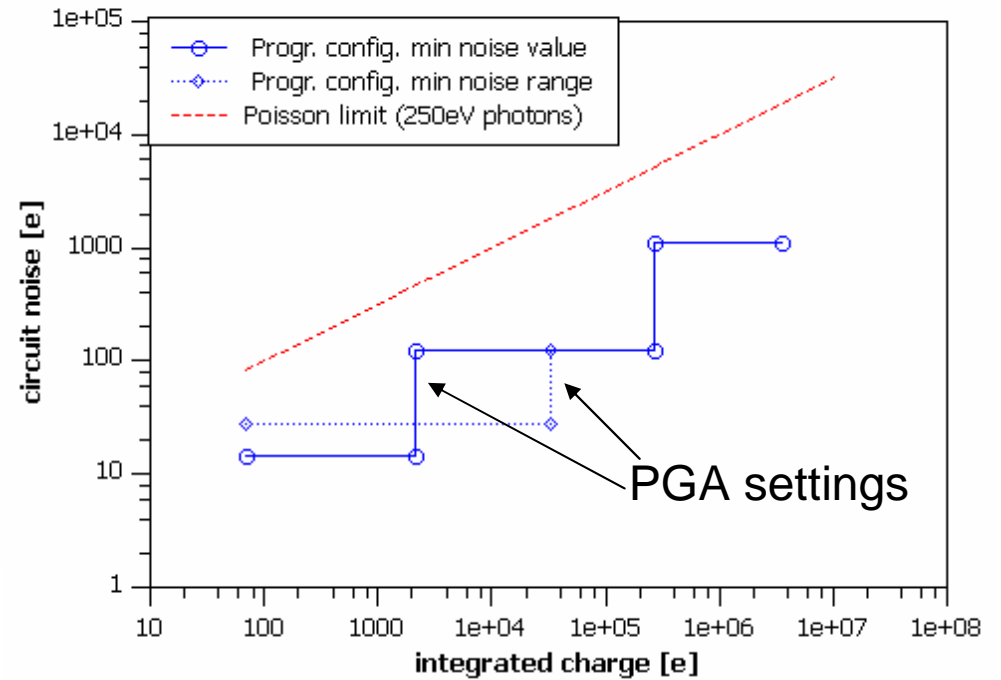
# noise: test results (high flux)

- 1-photon resolution!
- 250 eV - 1 keV!
- low noise!
- high dyn range!
- many frame/s!
- high QE!
- no blind areas!
- many pixels! small pixels!
- 2-side butttable! (even more pixels)

dynamic gain switch (full overflow range)  
W08-03TS1.2PIX, pix (120, 140) (D1), T=-40C



noise vs. overflow Gn level  
W08-03TS1.2PIX, T=-40°C

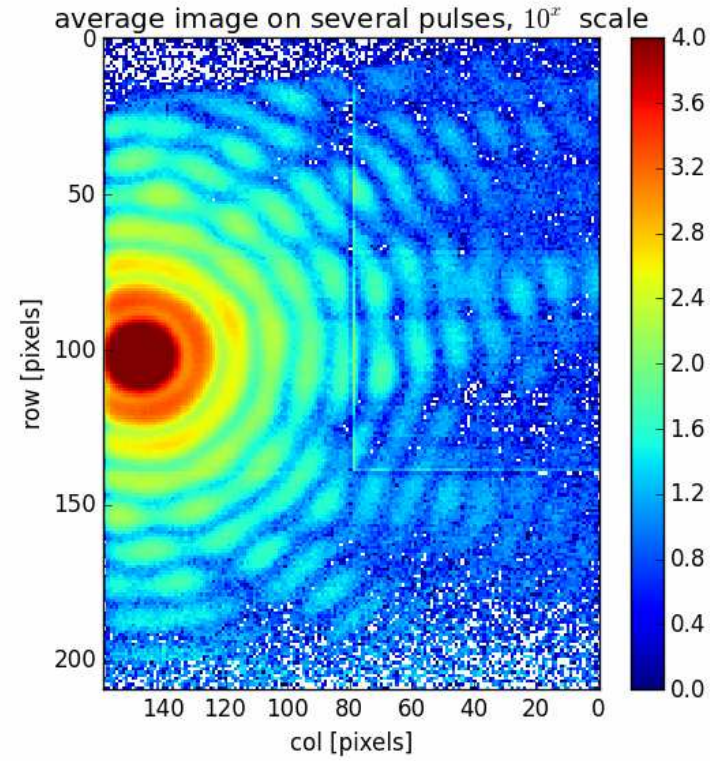
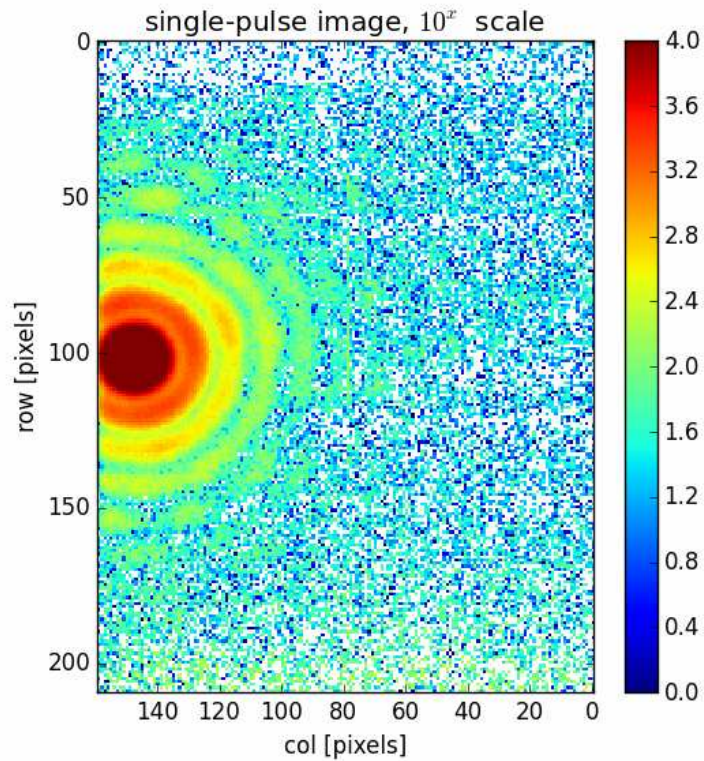
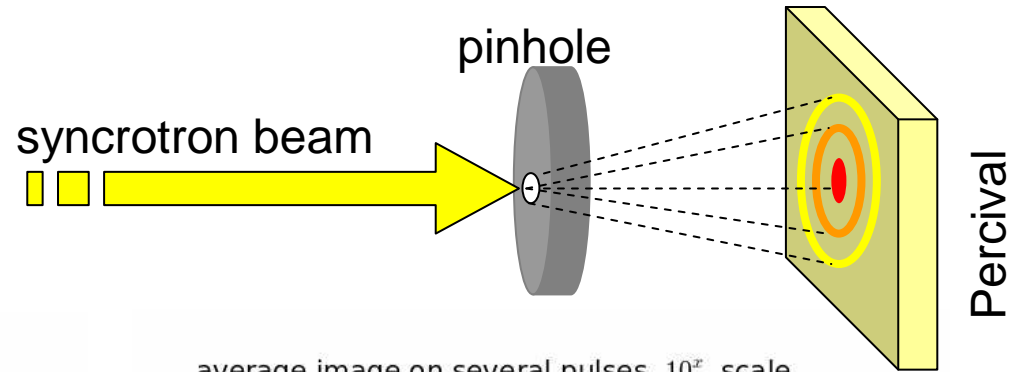




# single pulse imaging @ FEL: test results

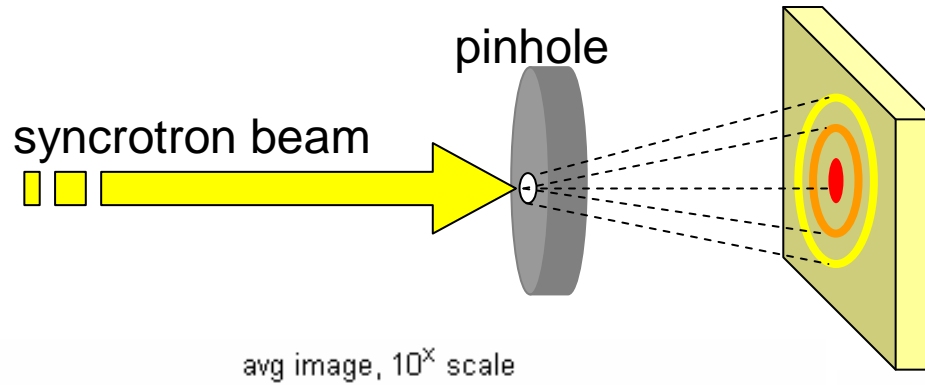


tests at BL2 (Flash)  
single-pulse imaging (10Hz)



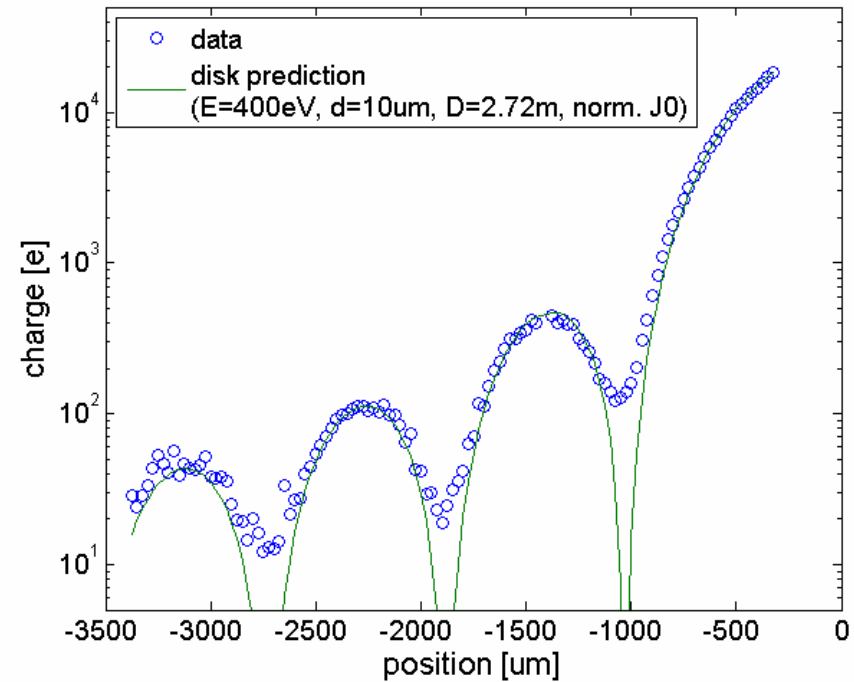
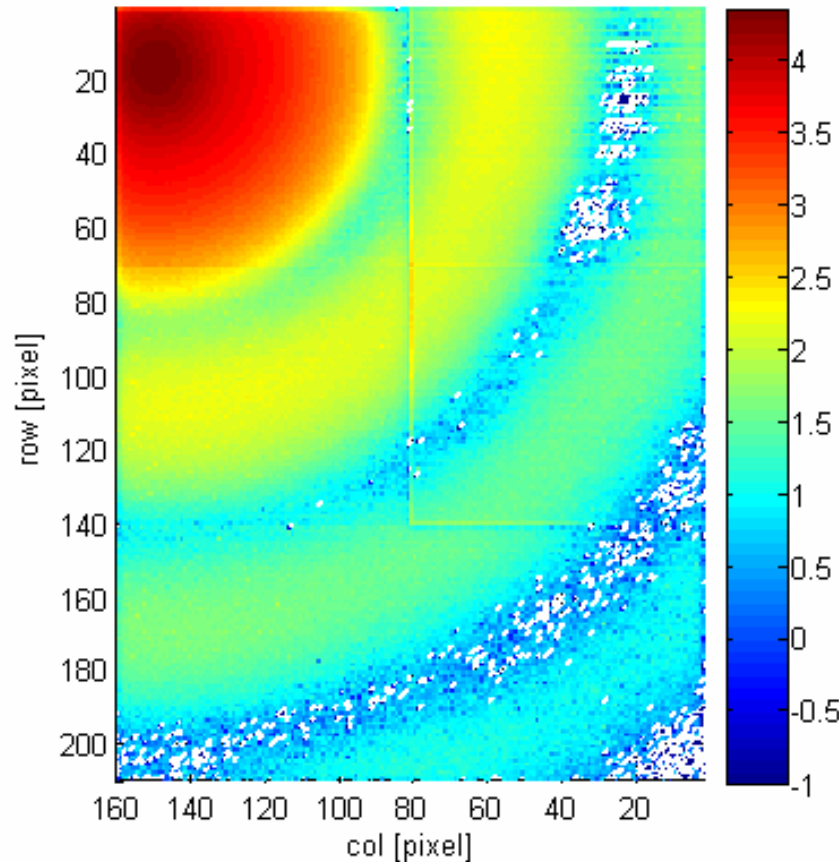
# Low-Energy photons: test results

- 1-photon resolution!
- 250 ✓ 1 keV!
- low noise!
- high dyn range!
- many frame/s!
- high QE!
- no blind areas!
- many pixels! small pixels!
- 2-side buttable! (even more pixels)



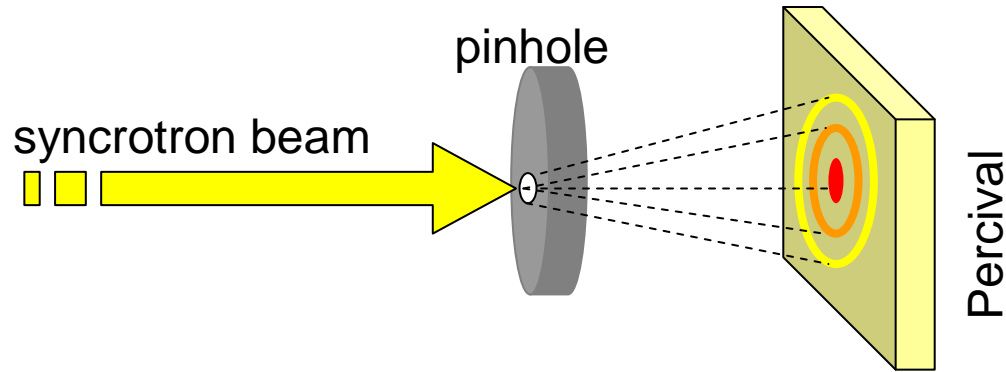
Percival  
 1-2keV tests at P04 (Petra III)  
 400eV tests at I10 (DLS)  
 100-300eV tests at Twinmic,  
 Cipo (Elettra)

avg image, 10<sup>x</sup> scale

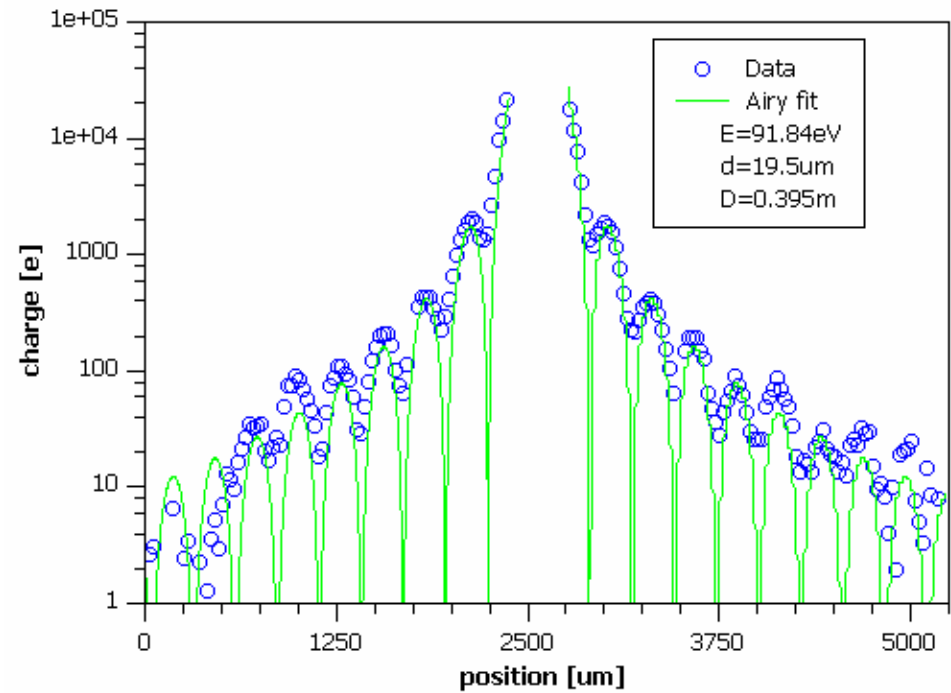
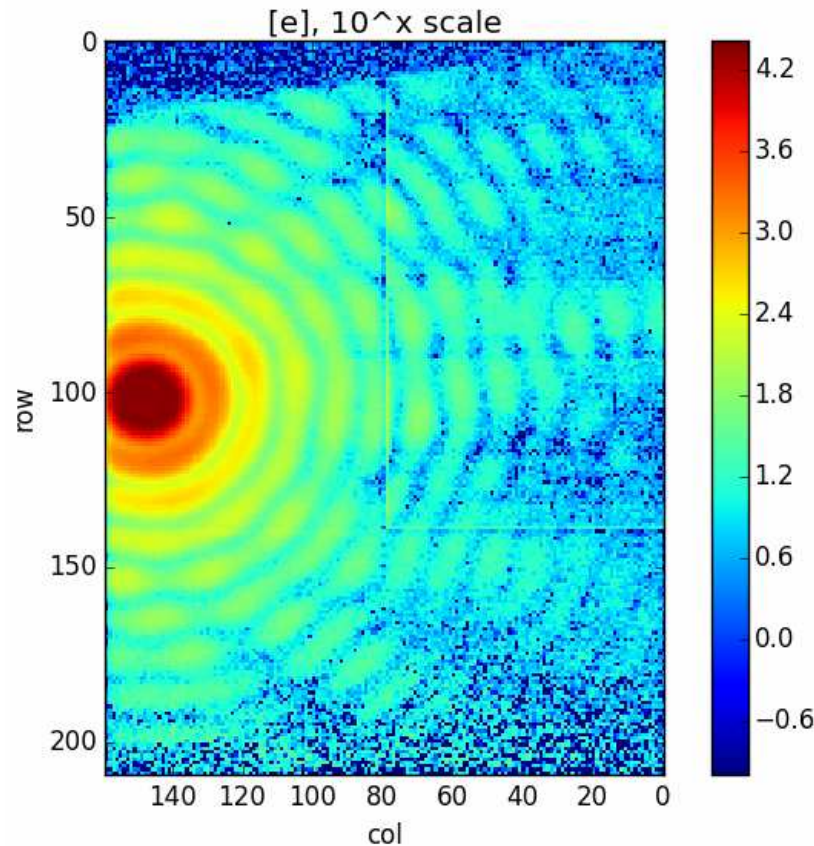


# Lower-Energy photons: test results

- 1-photon resolution!
- 250 ✓ 1 keV!
- low noise!
- high dyn range!
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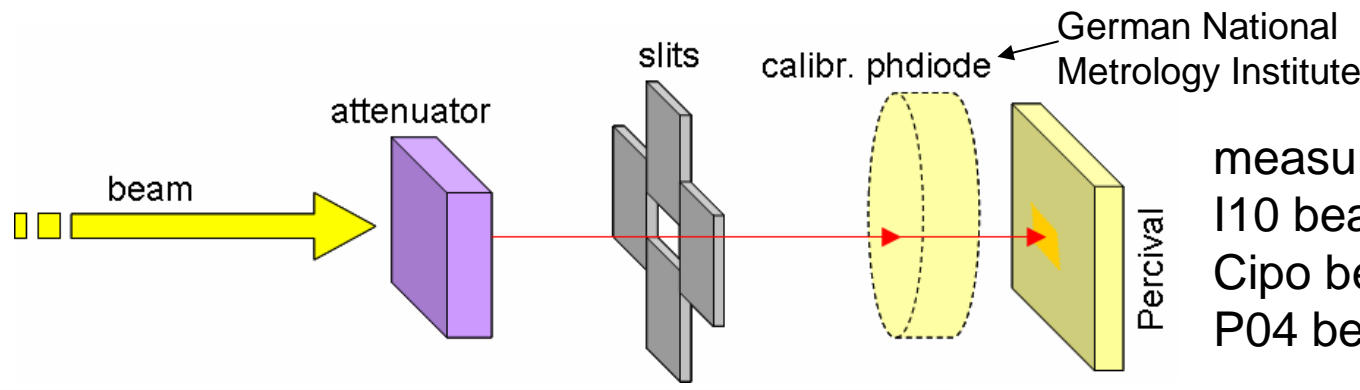
91.84eV tests at BL2 (Flash)



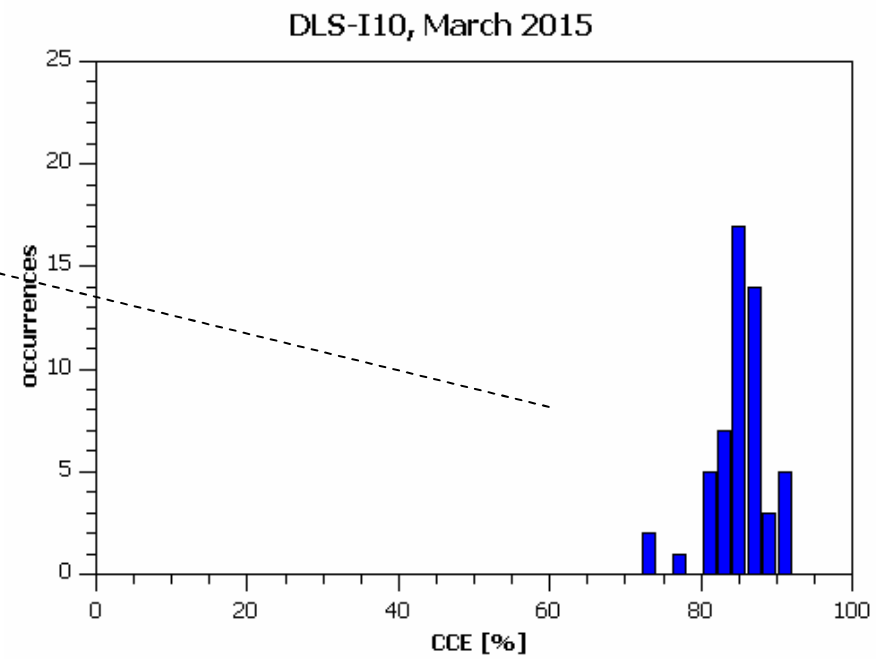
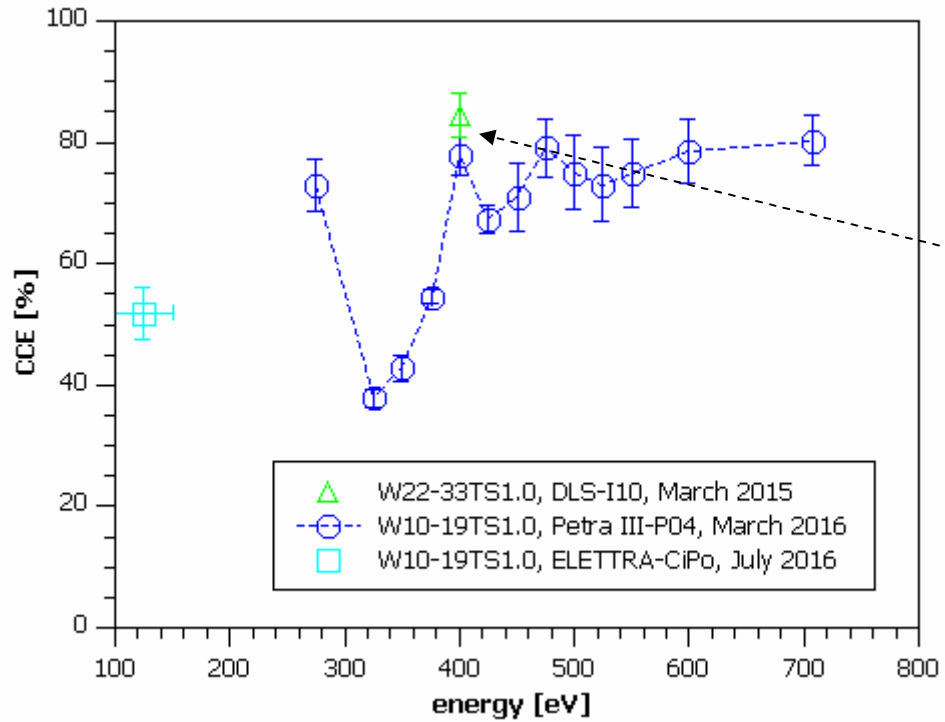
# Charge Collection Efficiency: test results

**Promising**

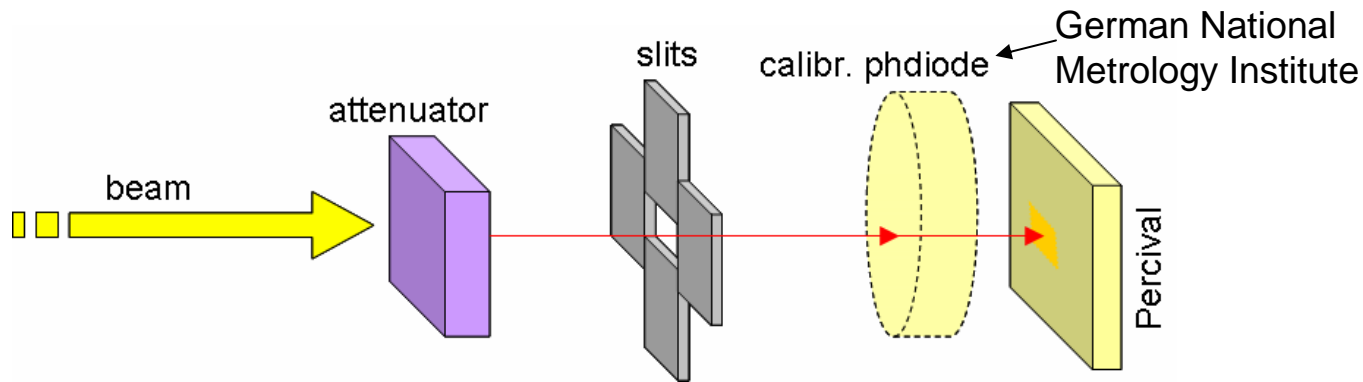
- 1-photon resolution!
- high dyn range!
- high QE!
- many pixels! small pixels!
- 250 eV - 1 keV!
- low noise!
- many frame/s!
- no blind areas!
- 2-side buttable! (even more pixels)



measurement at  
 I10 beamline (DLS)  
 Cipo beamline (ELETTRA)  
 P04 beamline (Petra III)



# Charge Collection Efficiency: test results



**Promising**

- 1-photon resolution!
- high dyn range!
- high QE!
- many pixels! small pixels!
- 250 eV - 1 keV!
- low noise!
- many frame/s!
- no blind areas!
- 2-side buttable! (even more pixels)

## **P.E.R.C.I.V.A.L.**

(Pixellated Energy-Resolving Cmos Imager Versatile And Large)

### **tests on prototypes**

- ✓ Lateral Overflow
- ✓ low noise (~15e)
- ✓ high dynamic range (3.5Me – 50k ph.)
- ✓ up to 120 frame/s
  - ✓ compatible most FEL
- ✓ tested 92eV-2KeV
- ✓ measured CCE (down to 50eV)

### **P2M**

- ✓ 2M pixels
- ✓ ~4×4cm<sup>2</sup> sensible area
- ✓ no gaps or blind
- ✓ 2-side buttable
- ✓ 27um pixel pitch
- ✓ manif. started ~spring 2016,  
FSI expected ~ fall/winter of 2016  
postproc. BSI ~spring of 2017

## P.E.R.C.I.V.A.L.

(Pixellated Energy-Resolving Cmos Imager Versatile And Large)

tests on pro

✓ Lateral O

✓ low noise

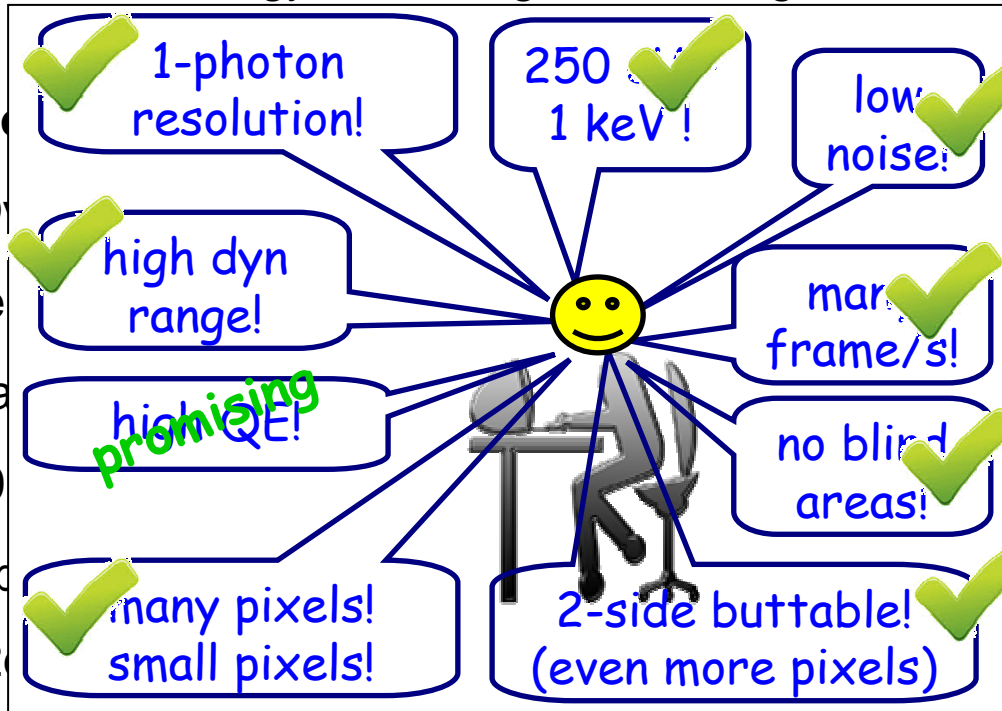
✓ high dyna

✓ up to 120

✓ comp

✓ tested 92

✓ measured CCE (down to 50eV)



nsible area

blind

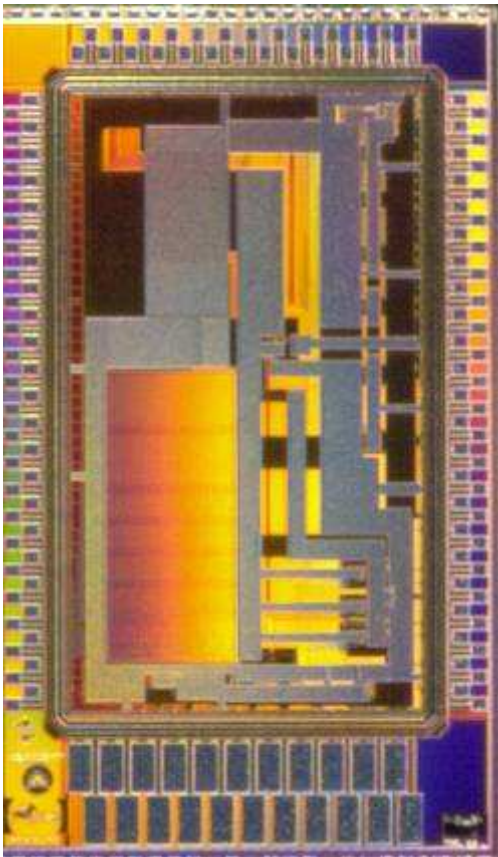
ble

itch

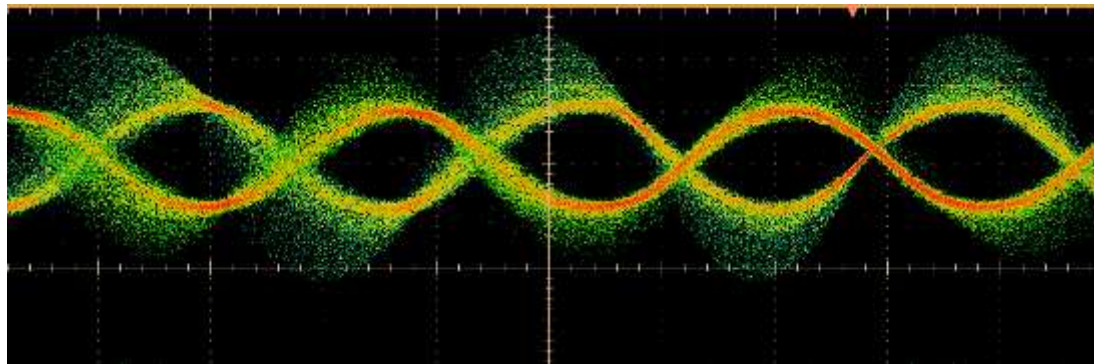
ed ~spring 2016,  
FSI expected ~ fall/winter of 2016  
postproc. BSI ~spring of 2017

backup

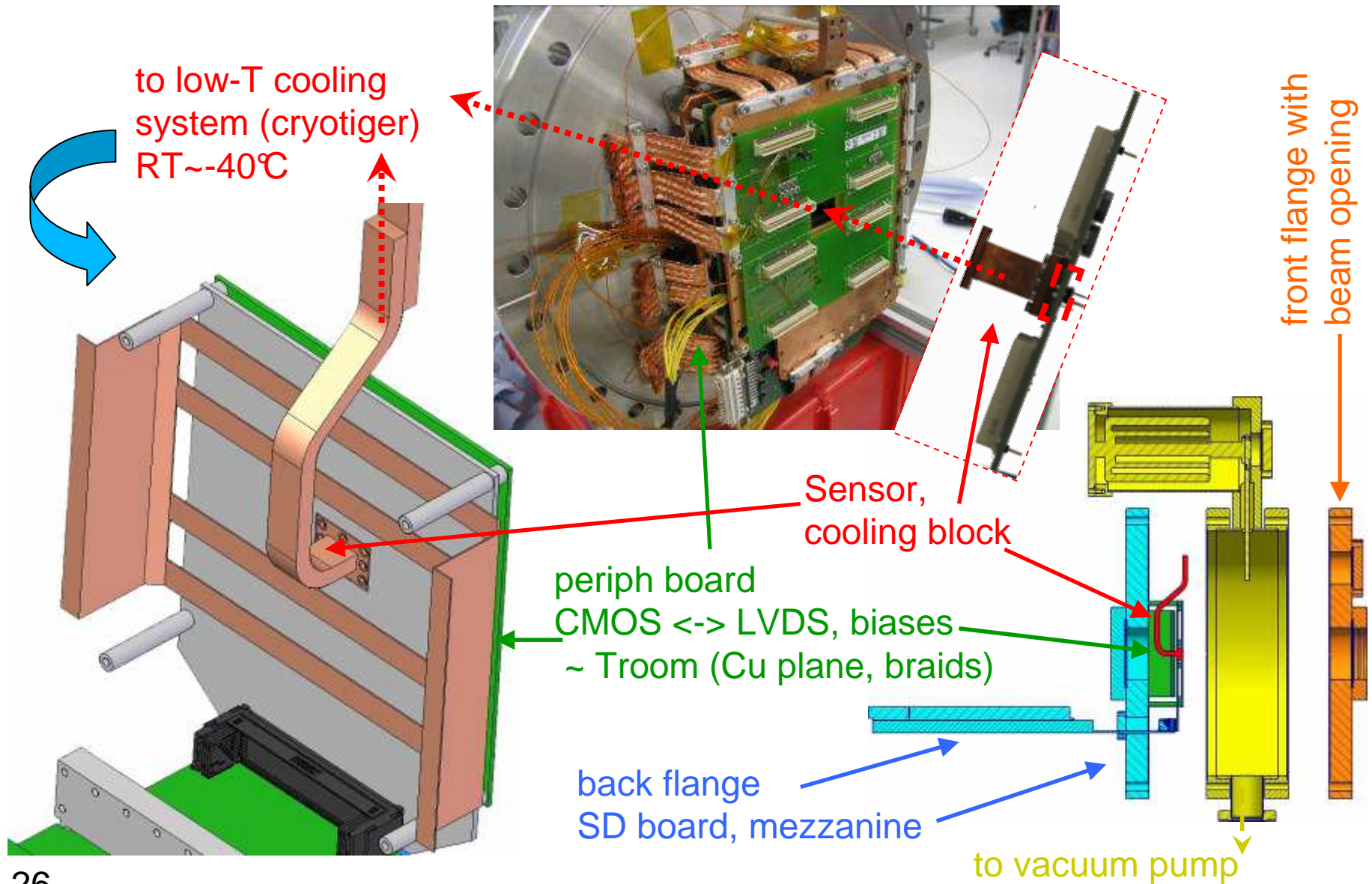




- PLL: Operating up to 400MHz
- LVDS Stages: Operating at 800Mbits/s (limited by DAQ system)



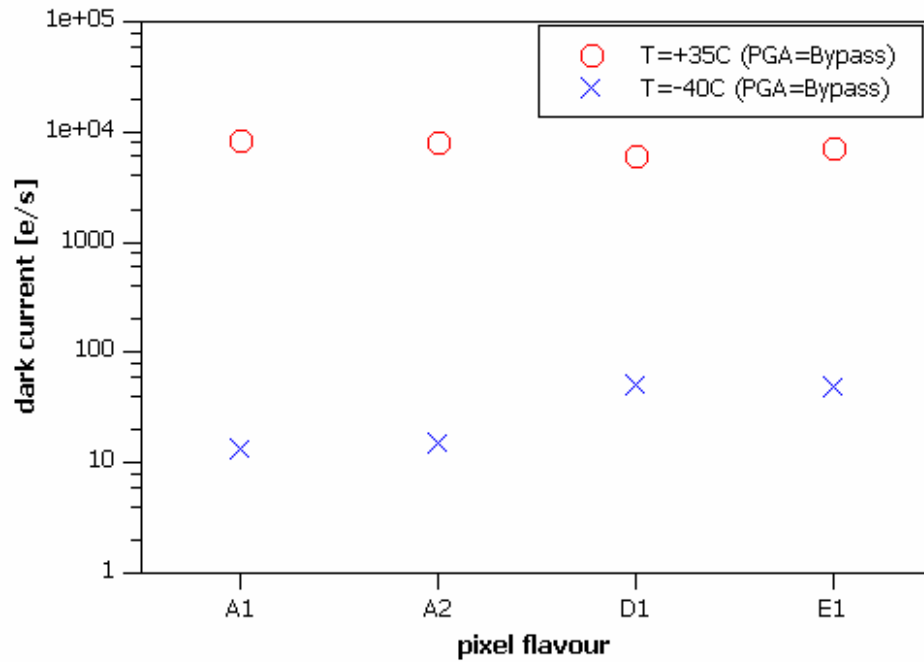
# The PERCIVAL prototype



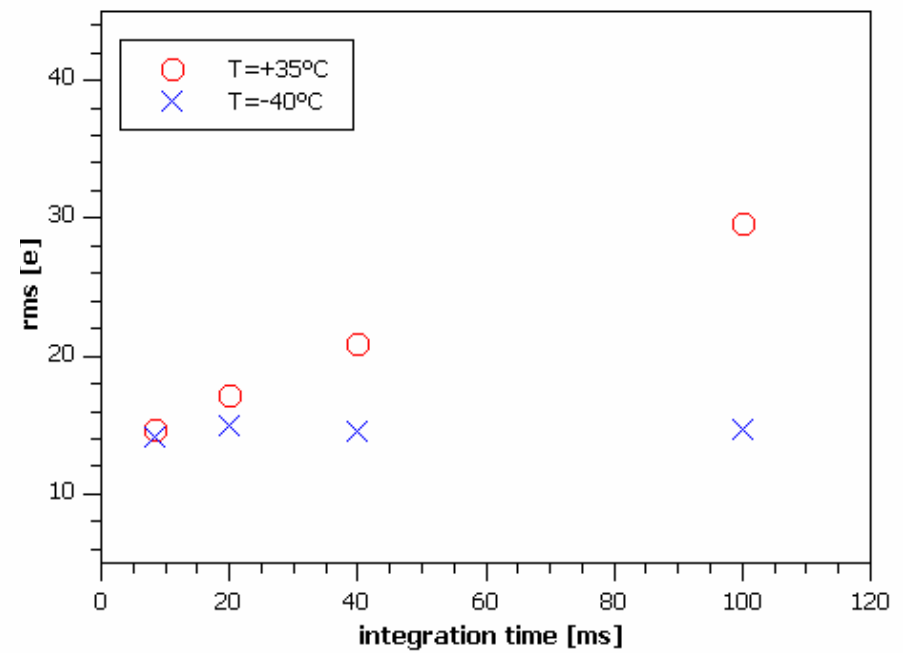
# Temperature effects



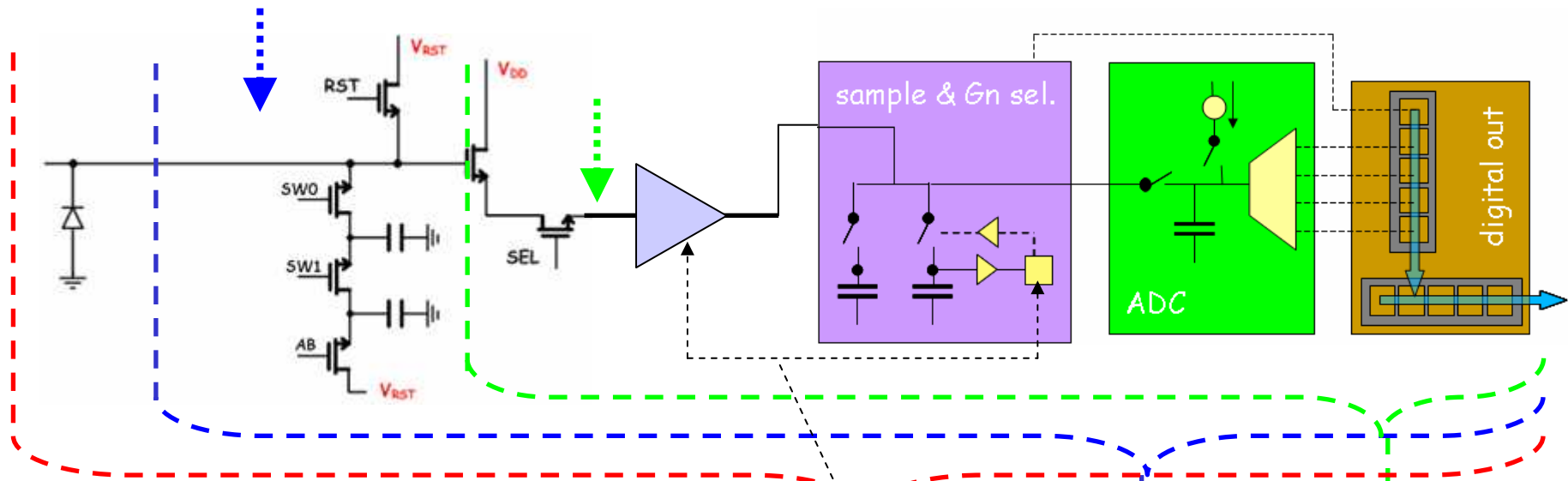
dark current  
W08-03TS1.2PIX



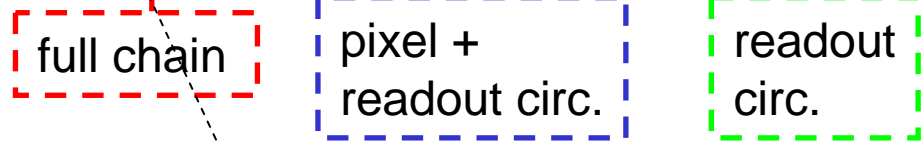
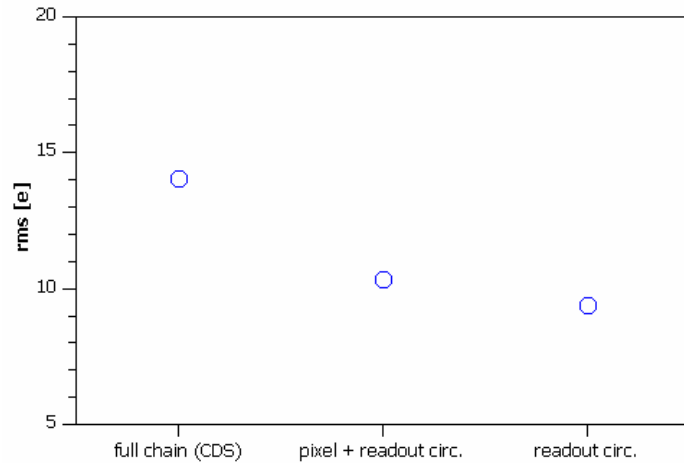
noise vs. Temperature  
W08-03TS1.2PIX



# noise analysis

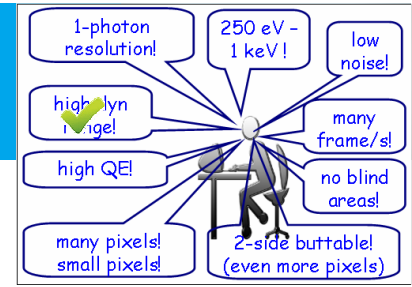


noise contributions  
W08-03TS1.2PIX, T=-40°C

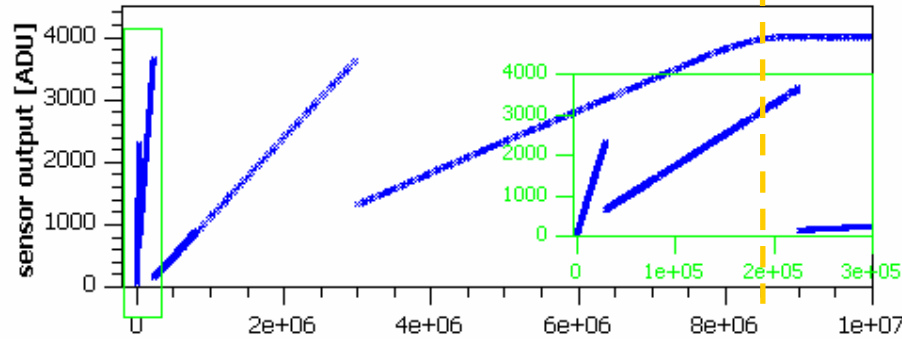


Programmable Gain Amplifier  
(to reduce noise when critical)

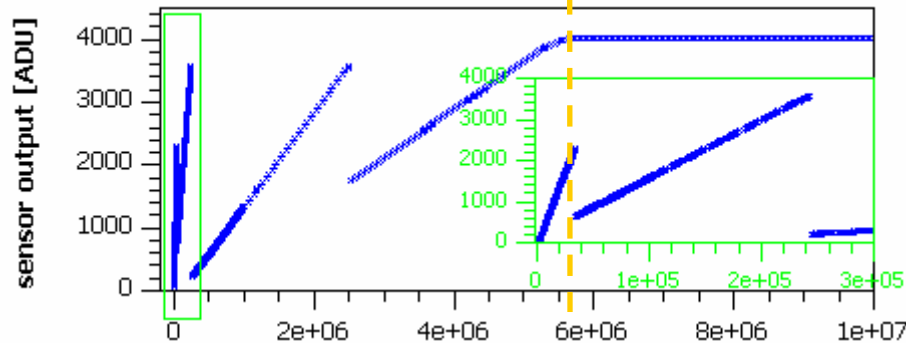
# Dynamic range



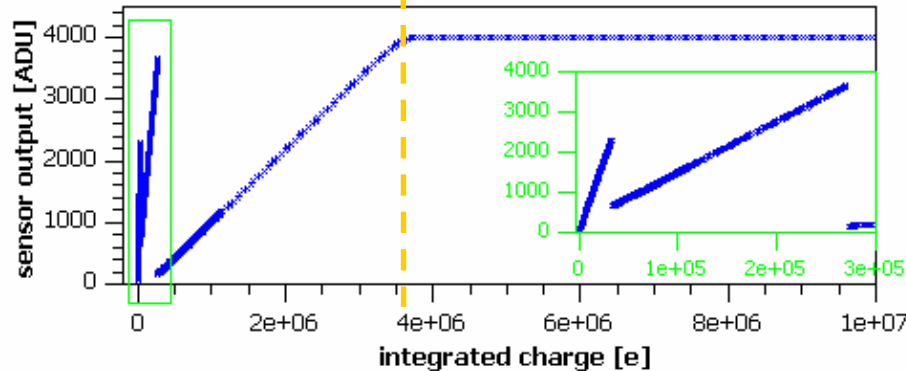
dynamic gain switch (full overflow range)  
W08-03TS1.2PIX, pix (120, 70) (A1), T=-40C



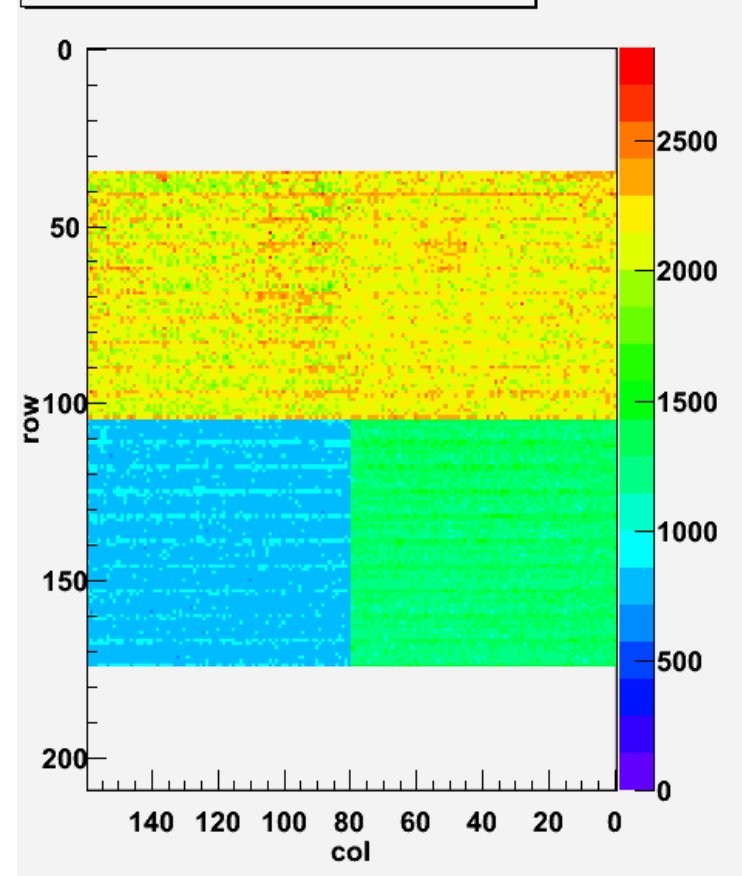
W08-03TS1.2PIX, pix (40, 140) (E1), T=-40C



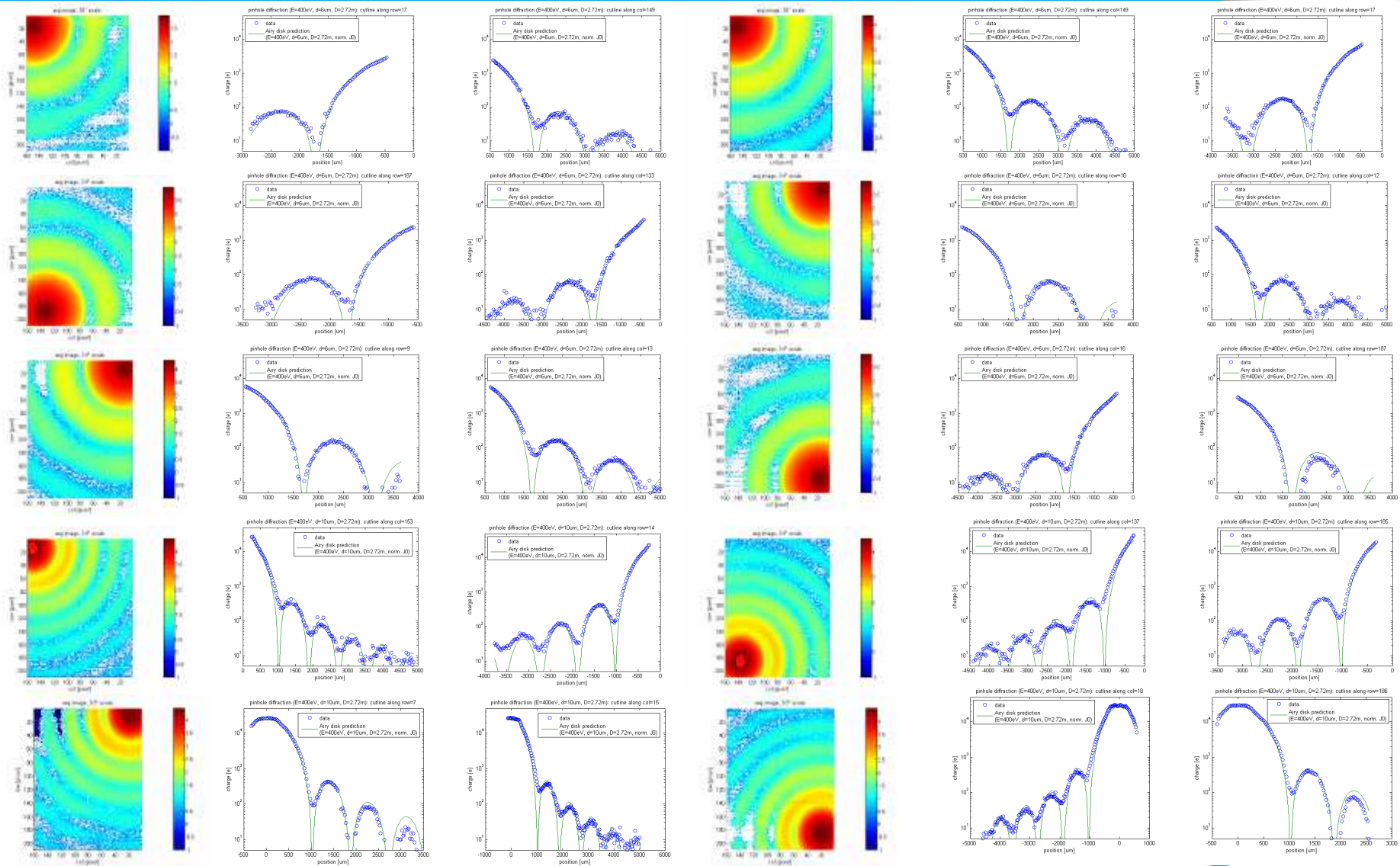
W08-03TS1.2PIX, pix (120, 140) (D1), T=-40C



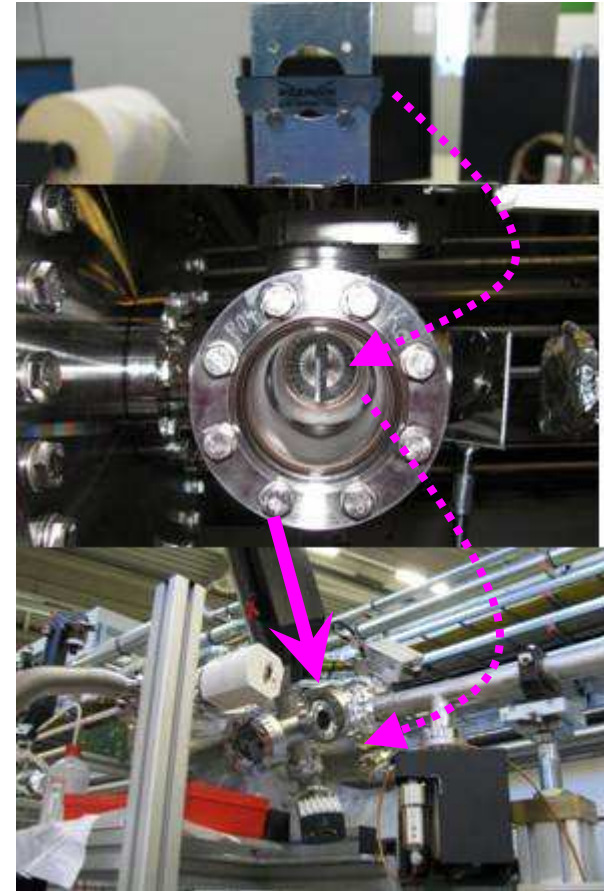
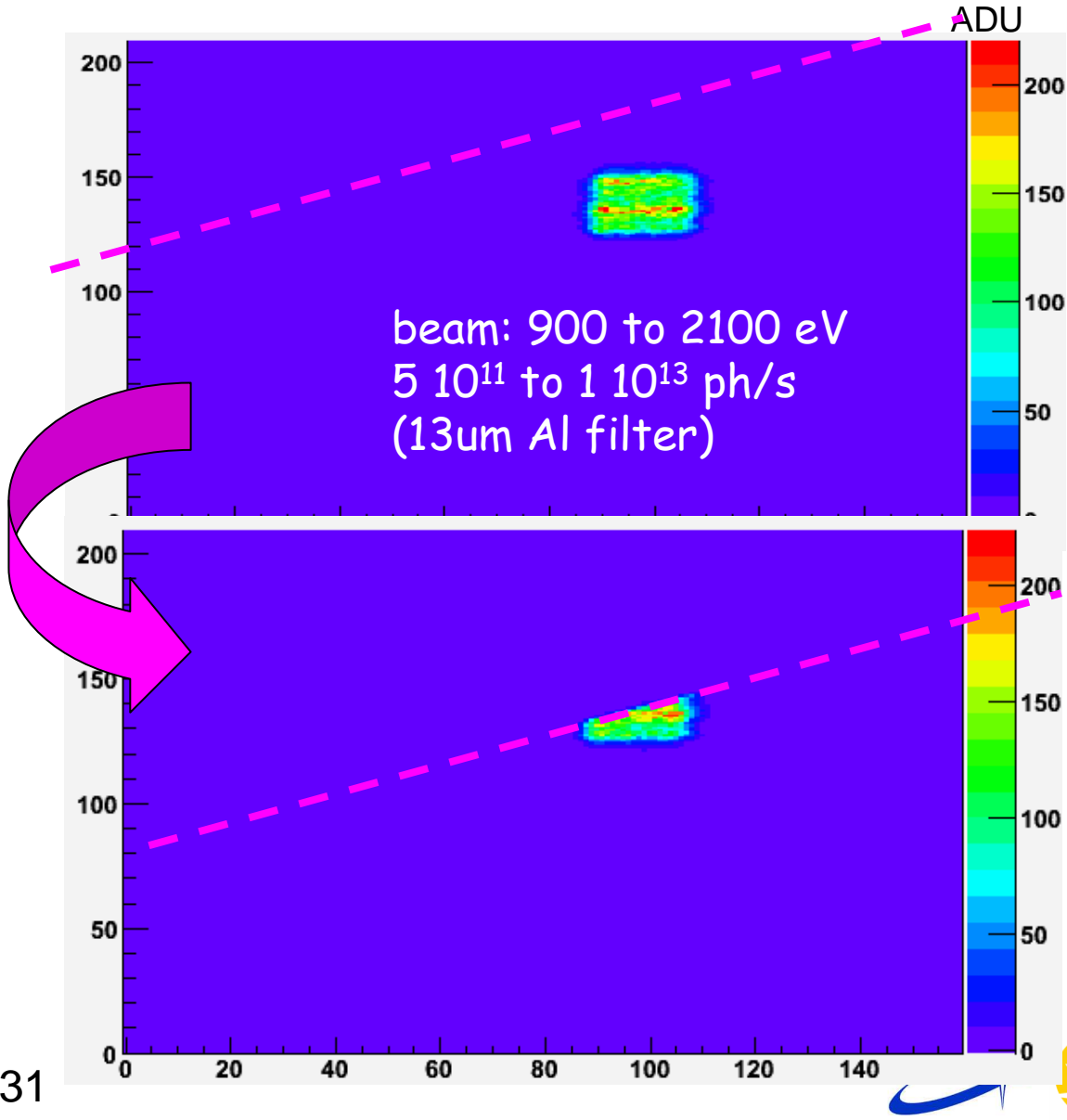
W08-03TS1.2PIX, Gn=3, PGA=B, e/ADU map



# response to low-Energy photons



# keV-Energy photons: test results



measurements at P04  
beamline (Petra III)

