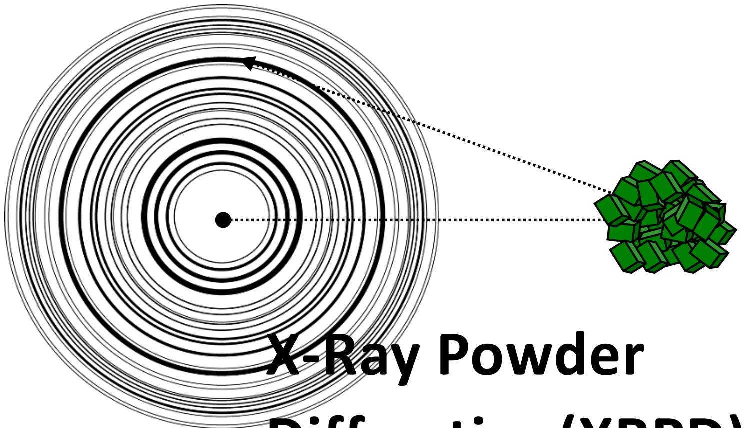
Roberto Dinapoli :: PSD Detector Group :: Paul Scherrer Institut

MYTHEN-III, a high performance, single photon counting strip detector

15th Pisa meeting on advanced detectors 22-28.05.2022

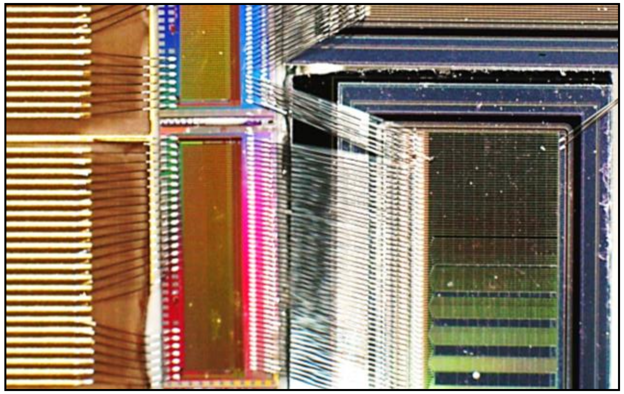
Why strips? *Chip designer's view*

- Several applications in Photon Science (PS) are 1D do not require pixels
- 1D ASIC design less challenging
- Smaller ASIC required
- Simpler control/readout logic
- Less channels per area
  - Faster frame rate
  - Smaller data throughput
  - Resources much less critical
- Wire- instead of bump- bonding
  - Cheaper
  - Smaller pitches possible
  - Simpler
- Playground for new ideas
- Up-to-date ASICs required



X-Ray Powder Diffraction(XRPD)

Easier, cheaper, faster



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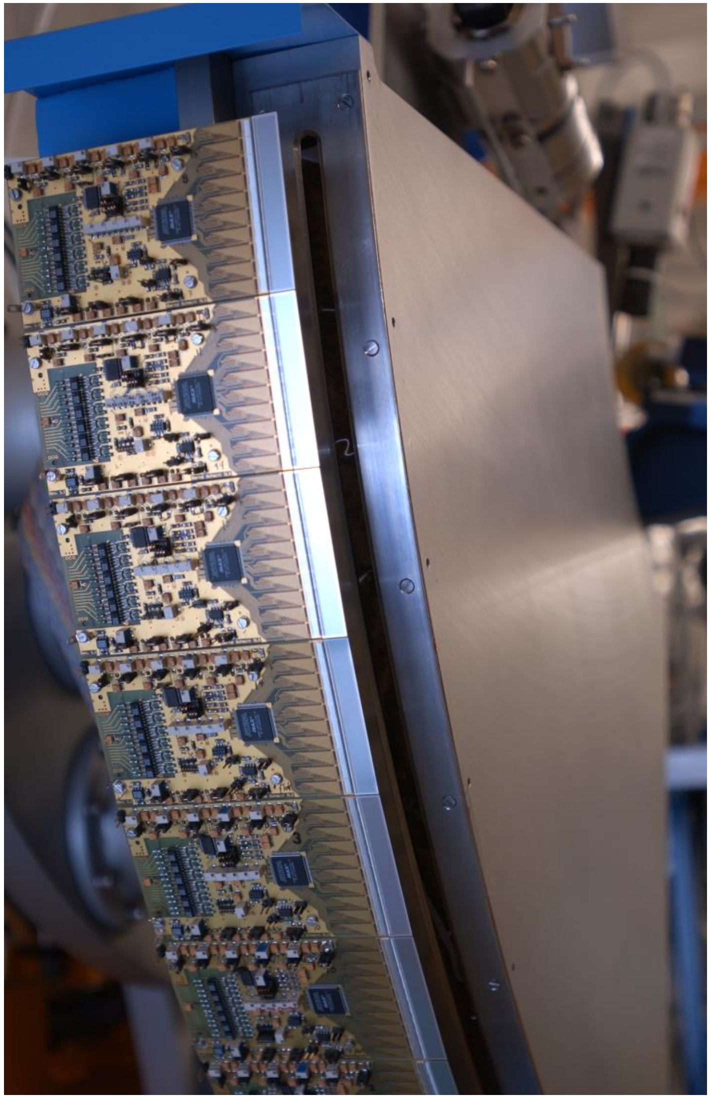
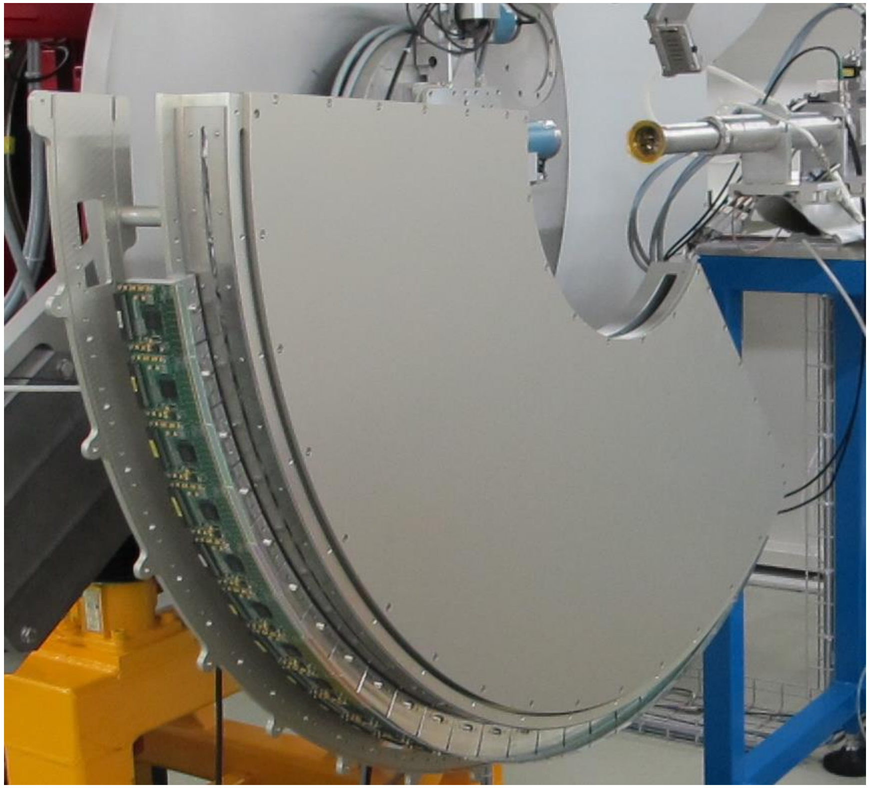
MYTHEN I (2001-2006)

MYTHEN II (2007-present)



Schmitt,et al, Nucl. Instr. Meth. Phys. Res. A 501 (2003), 267-272

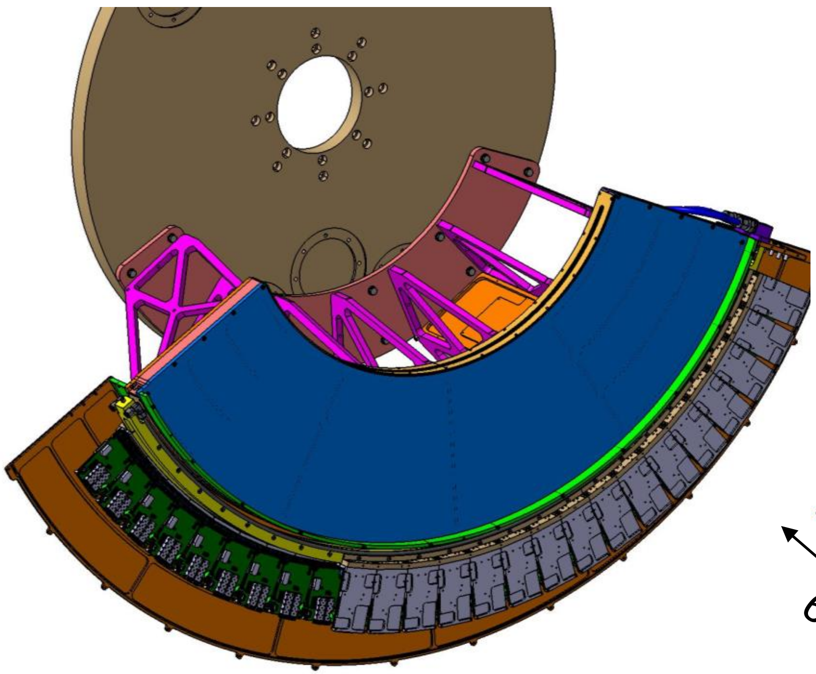


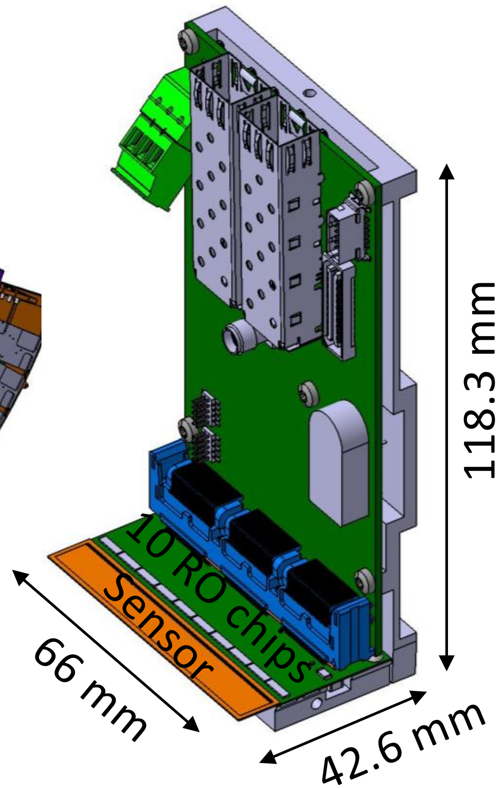
A. Bergamaschi al., J. Synchrotron Rad. 17, 653-668 (2010)

- Huge impact in 1D photon science, in particular XRPD

Mythen III for powder diffraction

- Same sensors as Mythen II: 1280 strips/module, 50 µm pitch, 8 mm length
- 120 degrees on two rows without gaps (24 x 2 modules)
  - 76 cm distance from diffractometer center
  - 4 mdeg intrinsic angular resolution
- Sensor material and characteristics can be changed (e.g.LGADs, HighZ)



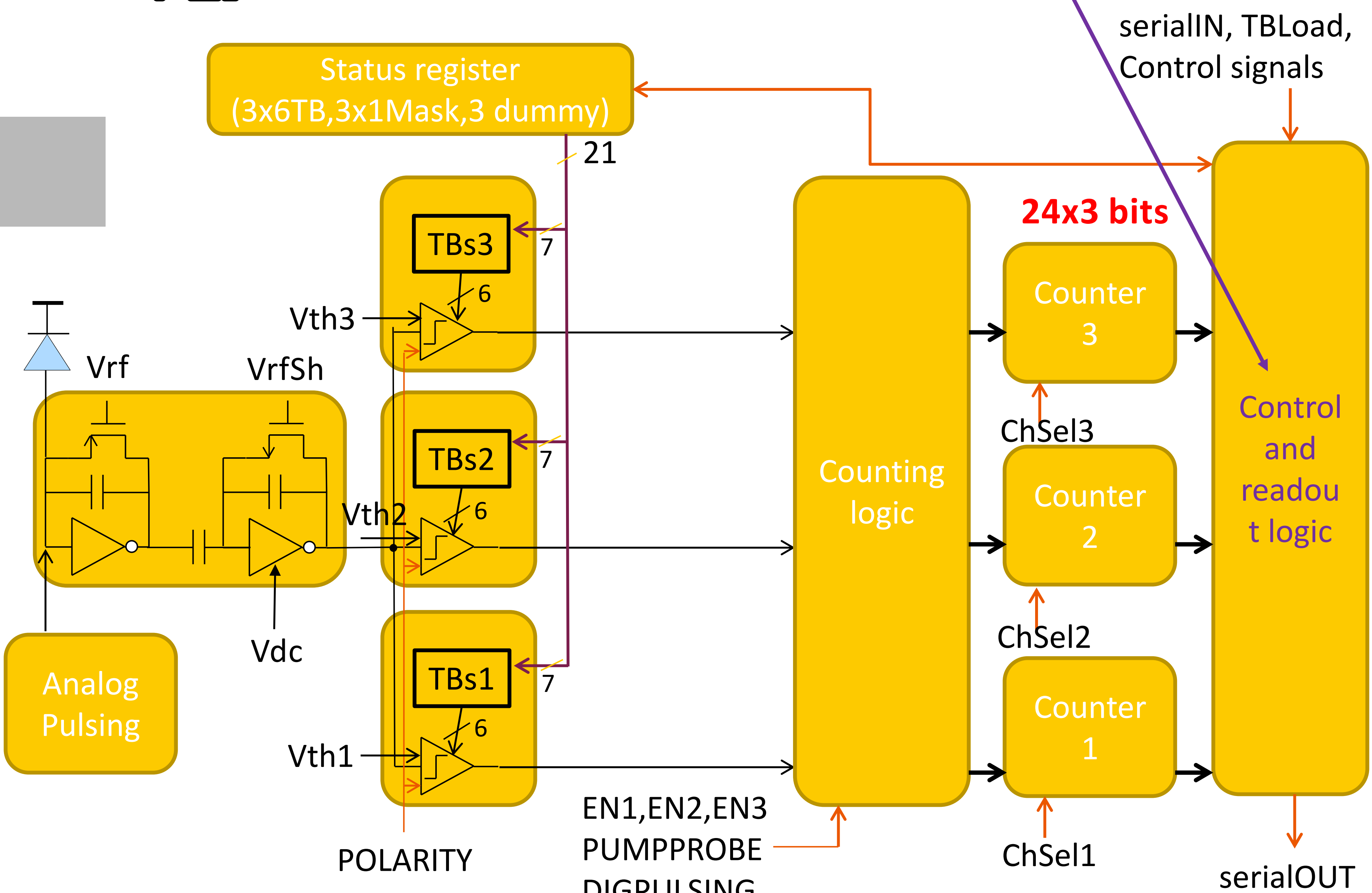


MY3 design specifications

	MYTHEN II (250nm)	MYTHEN III (110nm) specs		
Noise Min. Thresh.	200-250e- ~4.5keV	150-200e- ~3.5keV	→	Lower energies detectable Better fluorescence suppression
Threshold dispersion	ca. 25 e-	15-20e-	→	Better flat field
Count rate capability @90%	0.1-1 Mcnts/(s*strip)	Up to 2.5 Mcnts/(s*strip)	→	Higher fluxes
Frame rate Dead time free	0.1-1 kHz No	>10 kHz Yes	→	Time resolved experiments
Temperature stability	???	"Good enough"	→	Reliable calibration
Polarity	h+	h+/e-	→	Use with High Z materials or LGADs
Counters	1, no logic	3, with counting logic	→	New operational modes, new applications

The channel

Violet= backup material available



Modes of operation

The chip can work in different modes of operation:

1. Normal counting mode
   a) My2 equivalent
   b) With energy windowing
   c) With multi-threshold rate correction
2. Pump-probe mode
3. Time over threshold
4. Interpolation mode
5. Improved performance in pulsed mode
6. Analog pulsing mode
7. Digital pulsing mode
8. Trim bits load mode
9. Chip status load

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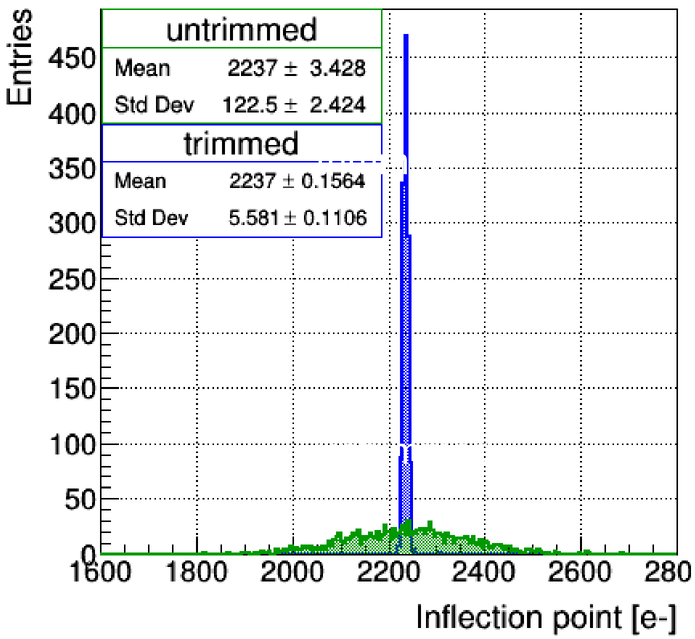
Not tested

6. Analog pulsing mode
7. Digital pulsing mode
8. Trim bits load mode
9. Chip status load

Trivial

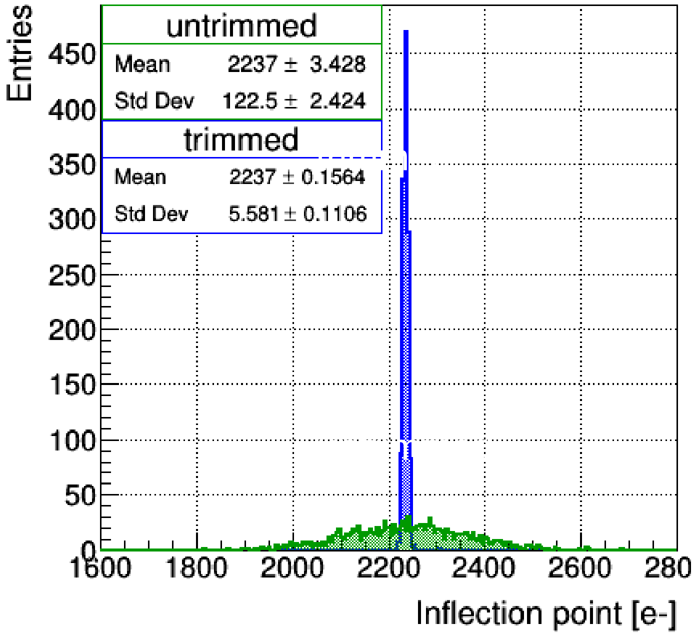
Chip performance



TRIMMING

Reduce threshold dispersion from 123 e- untrimmed to < **6e-** trimmed

Chip performance



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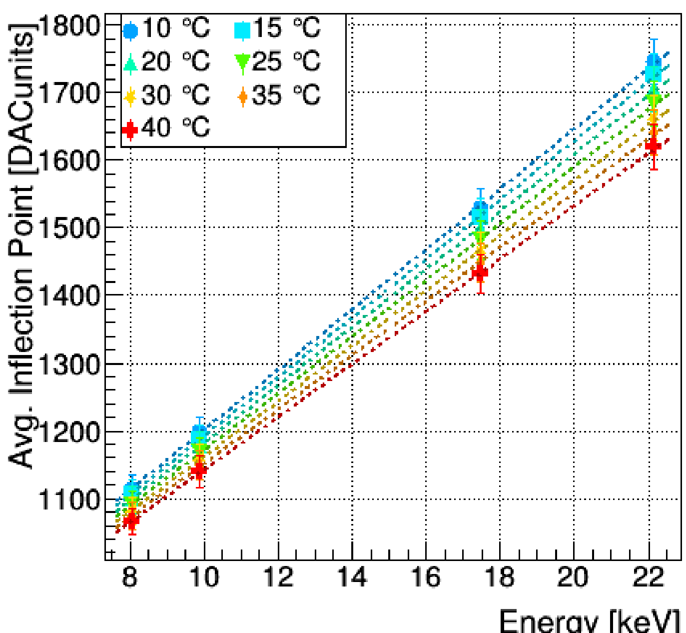
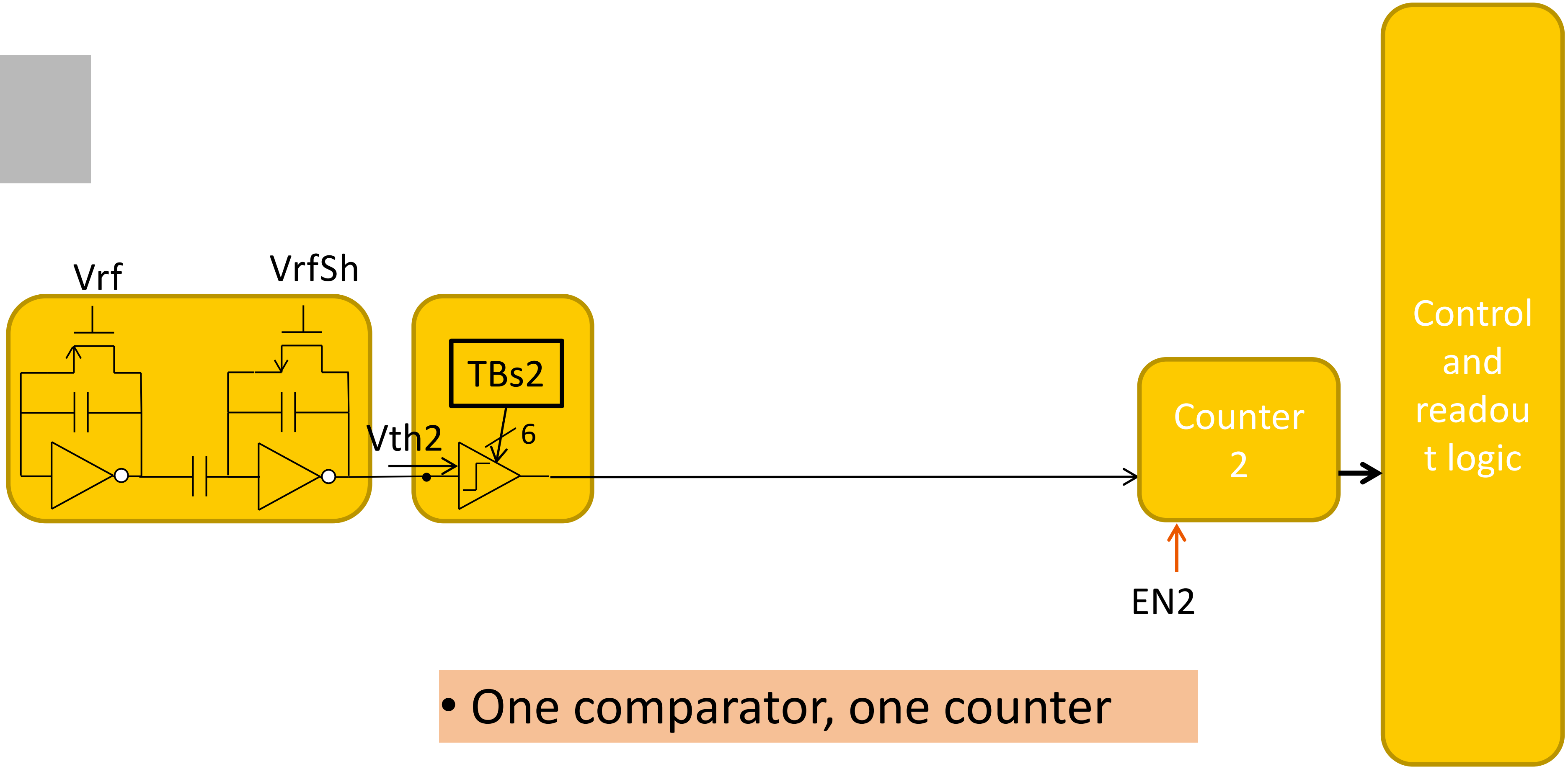


TEMPERATURE STABILITY
More pronounced in high-gain (slow) settings

Change in gain: **~0.3% /°C**

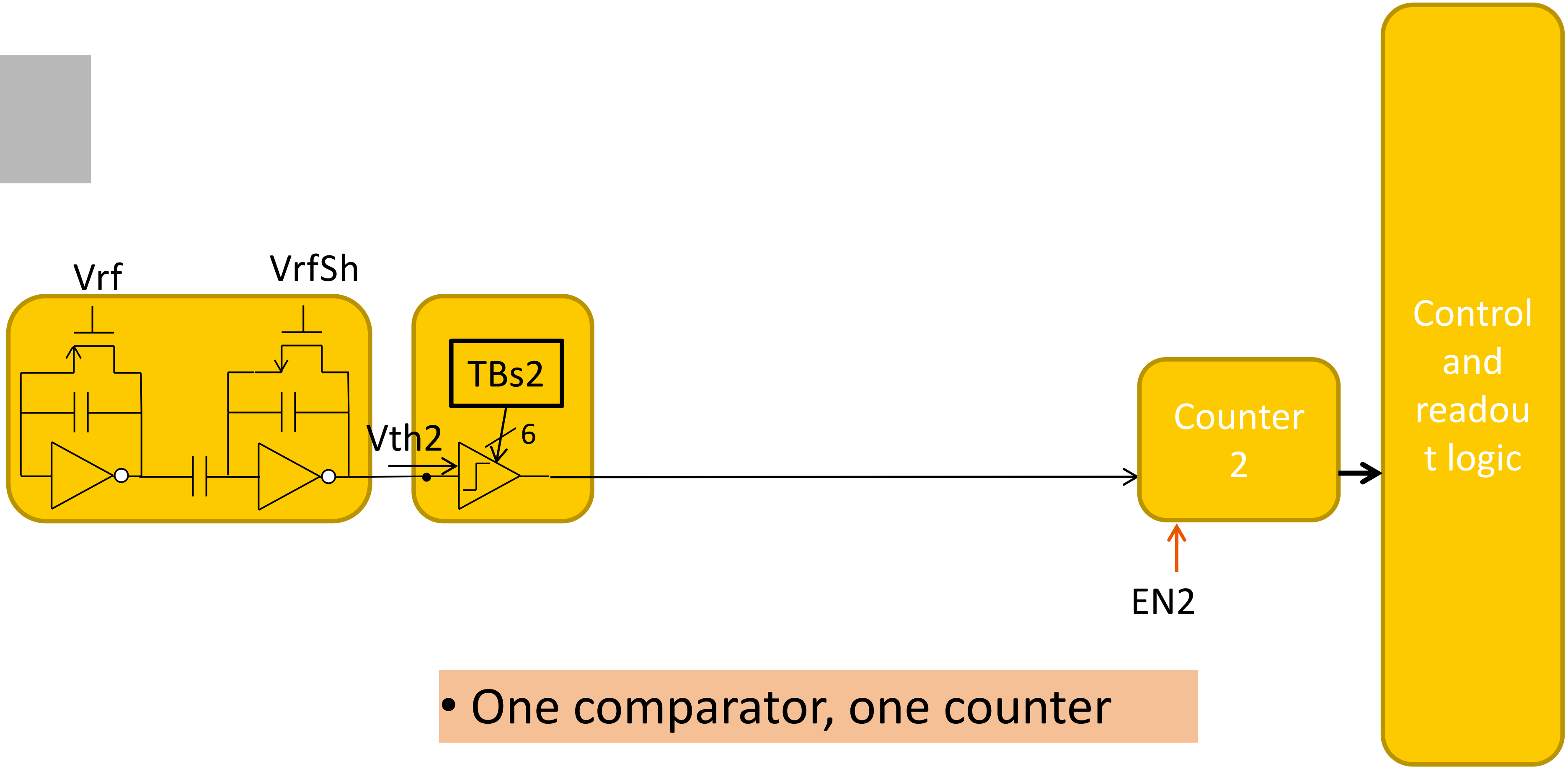
Mythen 2 mode configuration



- One comparator, one counter

- Maximum readout speed: 390 kHz in 8bit and dead-time free mode
- Time resolved experiments e.g. : In situ multilayer reacting foils

Mythen 2 mode configuration ✓



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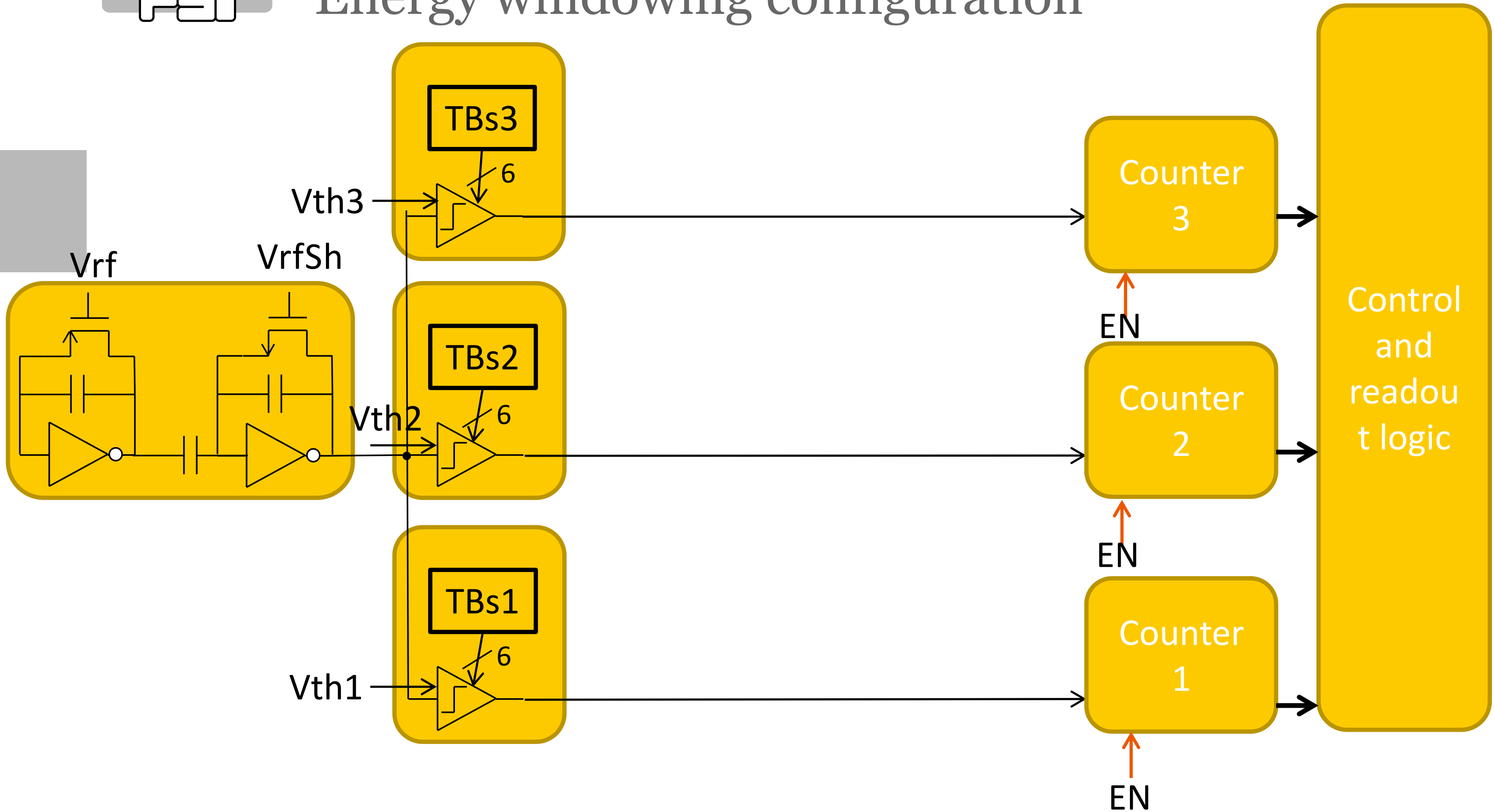
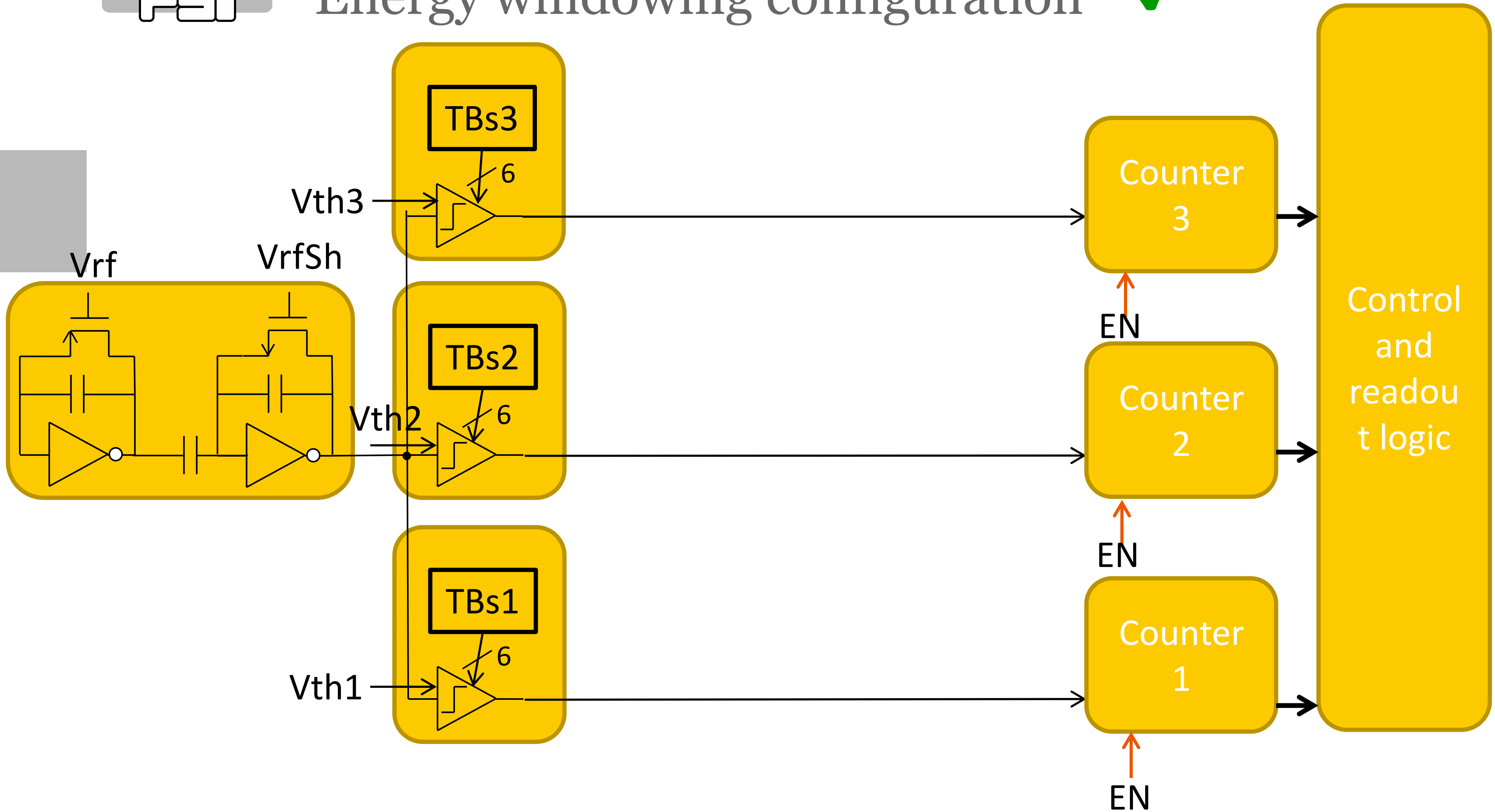
Energy windowing configuration



• One comparator per counter, 3 thresholds, one Enable

➢ Selection of the characteristic line, synchrotron higher harmonic suppression

Energy windowing configuration ✓



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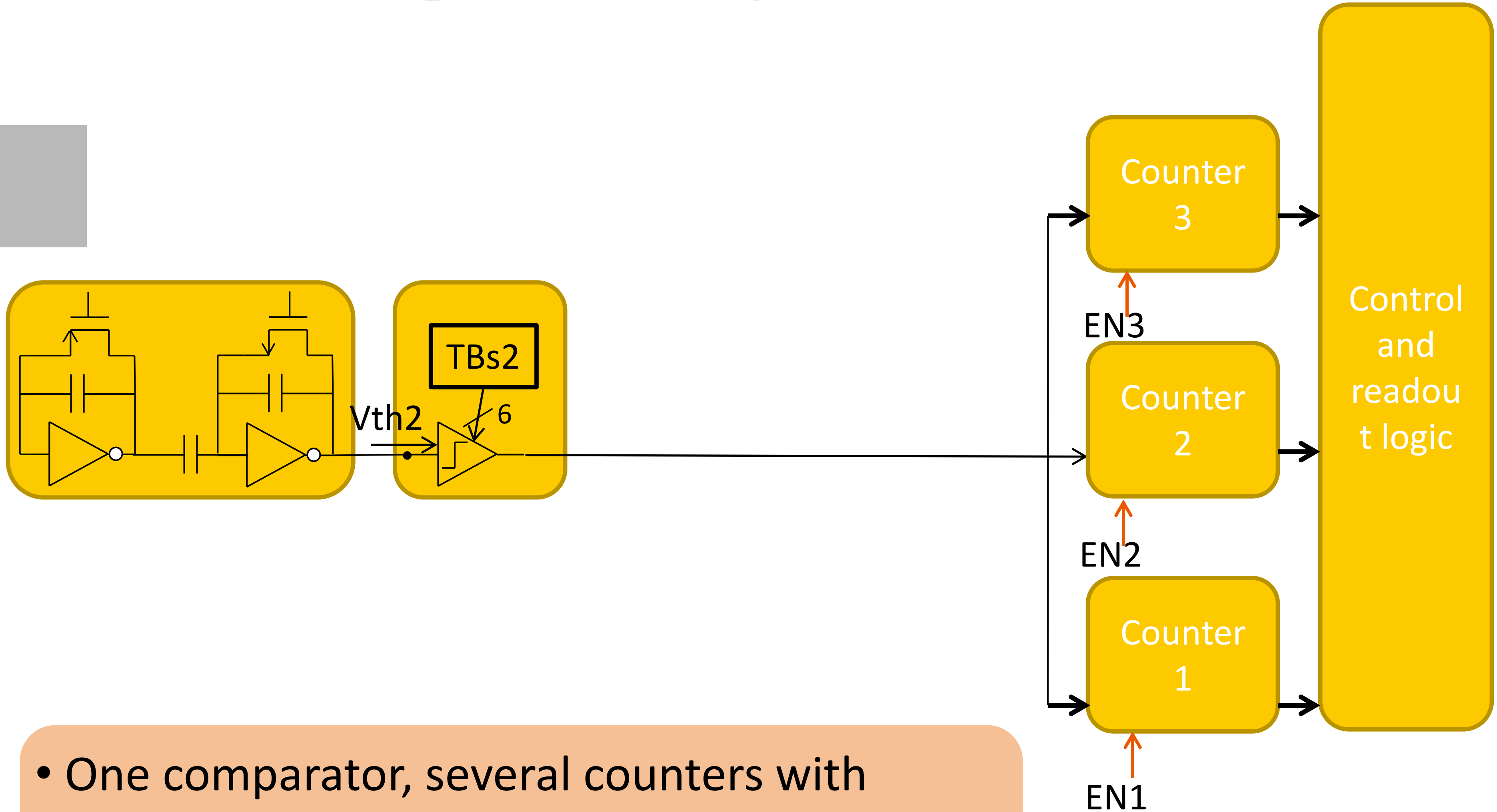
Pump-Probe configuration

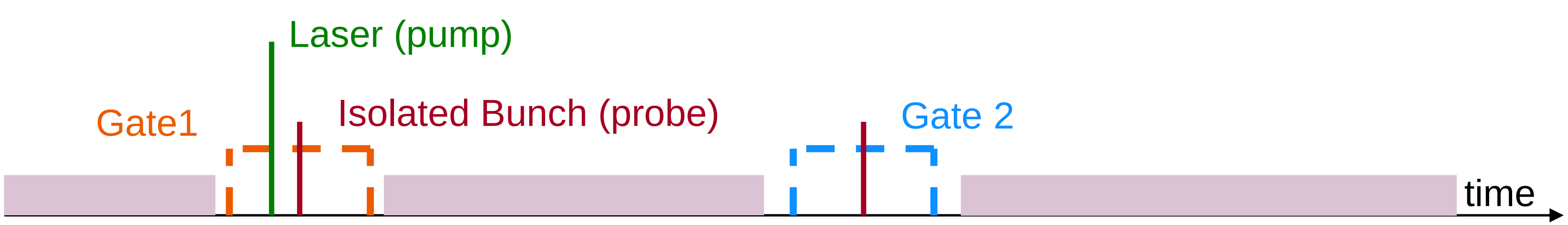


- One comparator, several counters with different enable (gate) windows
- Good timing control of gate signals (some ns)

Pump-Probe configuration

- Stroboscopic measurements with up to 3 temporal counting slots

  - Pumped-unpumped measurements with isolated/sliced bunch



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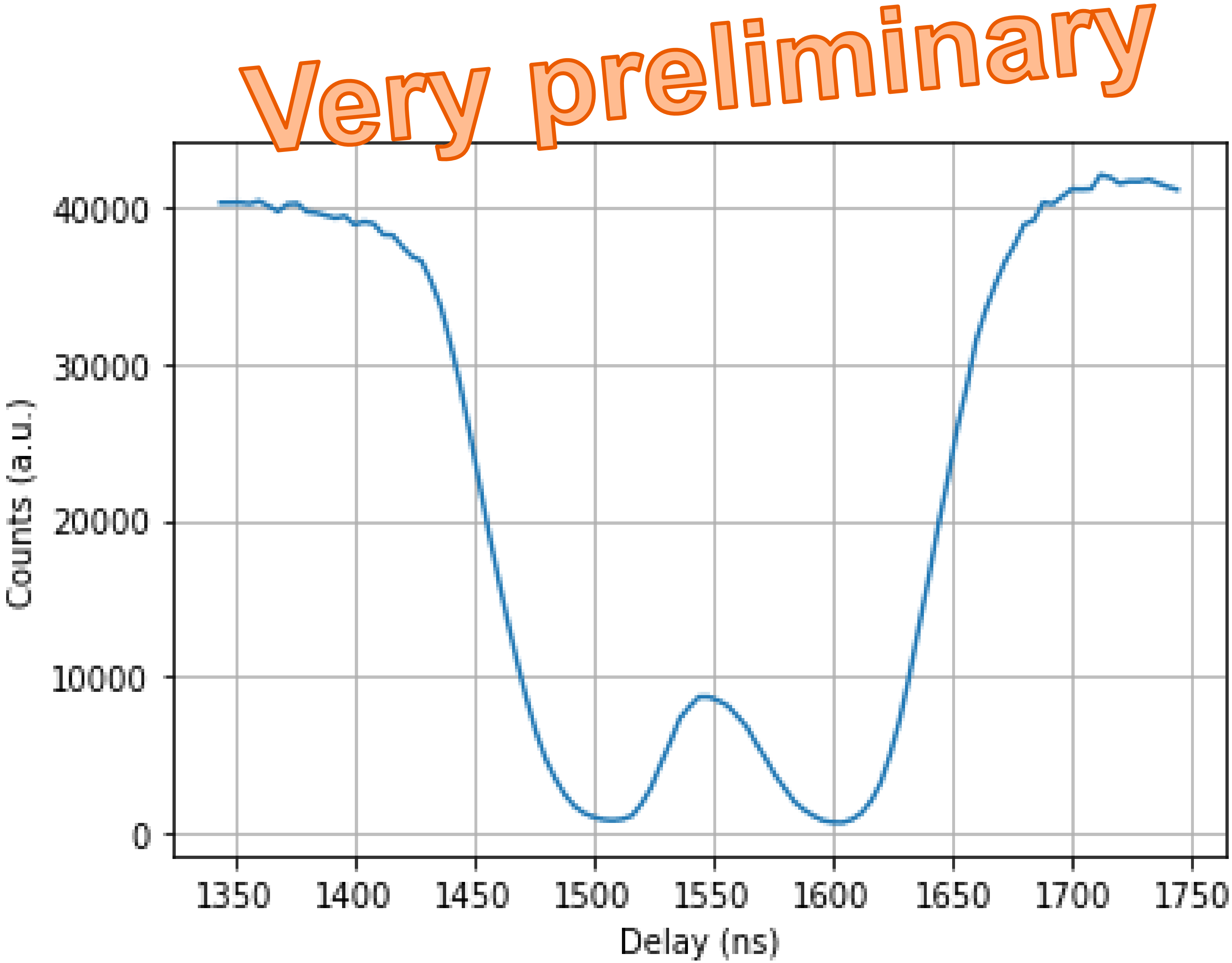
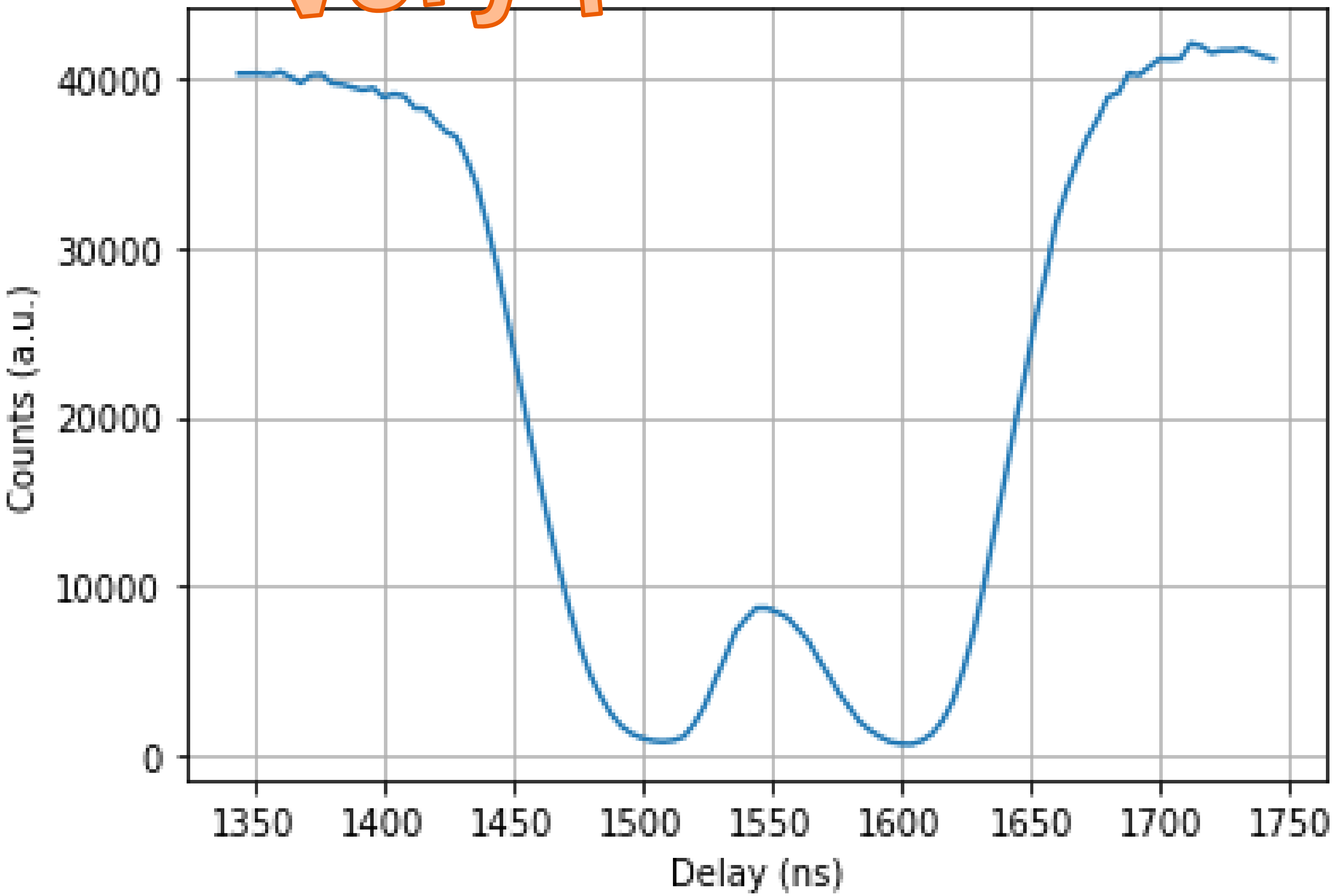
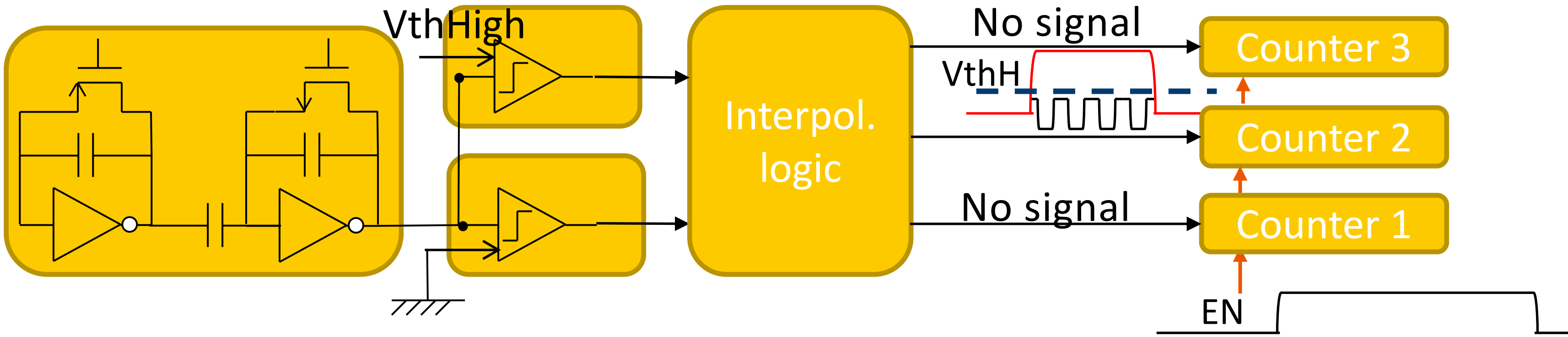


Pump-Probe configuration ✓

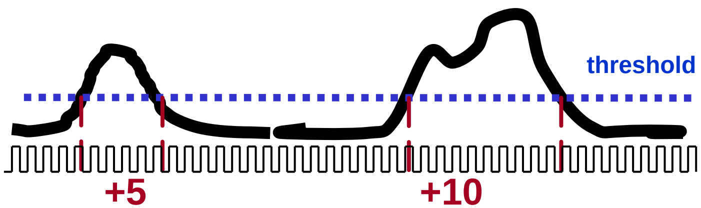
Very preliminary



Time-over-threshold operation with int. oscillator



- Two comparators, one generates clock. One counter: internally clocked if signal >Vth.

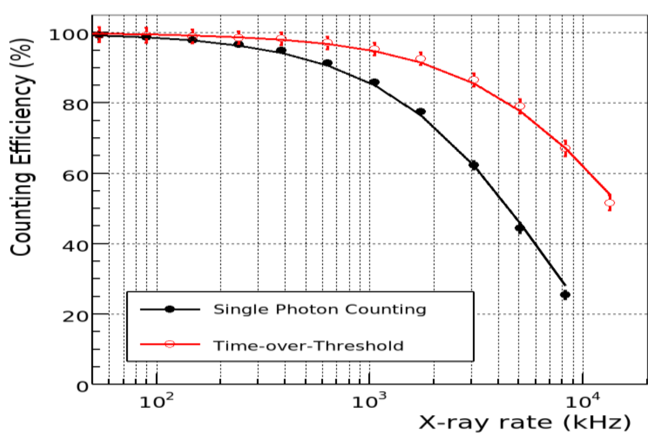


Single Photon Counting +2 X-rays

Time over Threshold +15 clocks

+3 X-rays

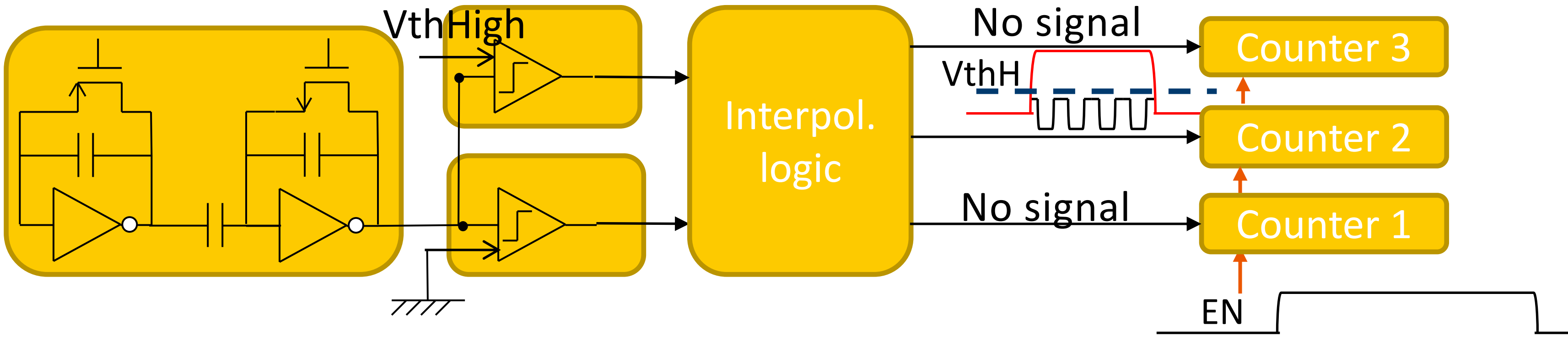
Improvement of count rate capabilities



Bergamaschi al., J. Synchrotron Rad. **18**, 923–929. (2011),doi: 10.1107/S0909049511034480

- Smaller rate corrections
  - –less influenced by mismatches between channels
- ToT also possible clocking EN externally

Time-over-threshold operation with int. oscillator ✓



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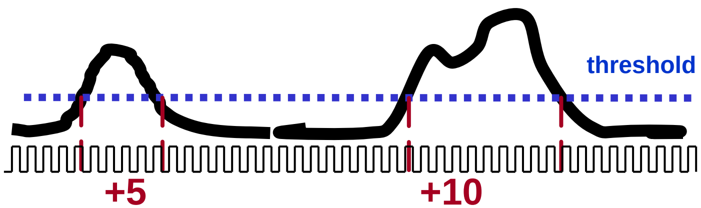

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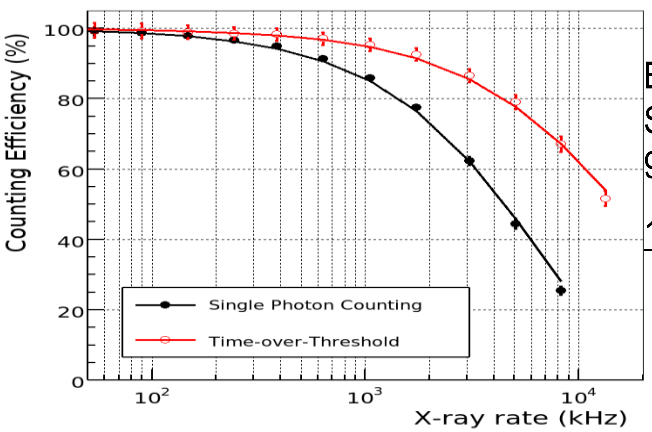

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- Smaller rate corrections
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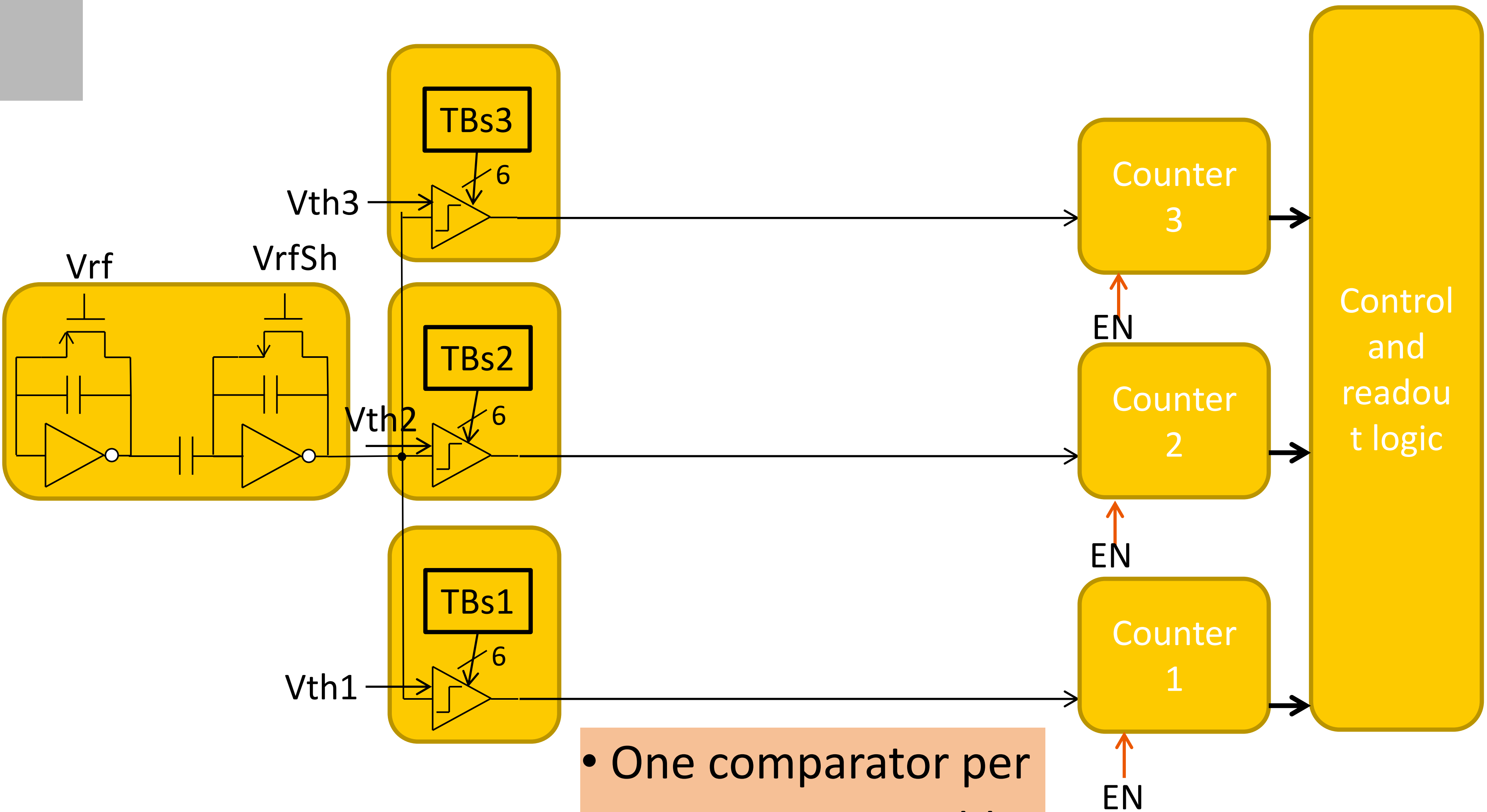
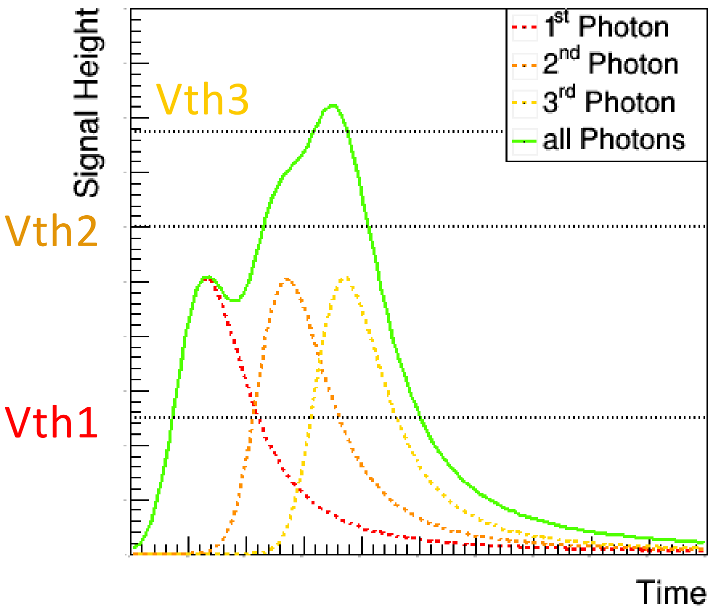
Rate Capability: Pile-up tracking with 3 counters

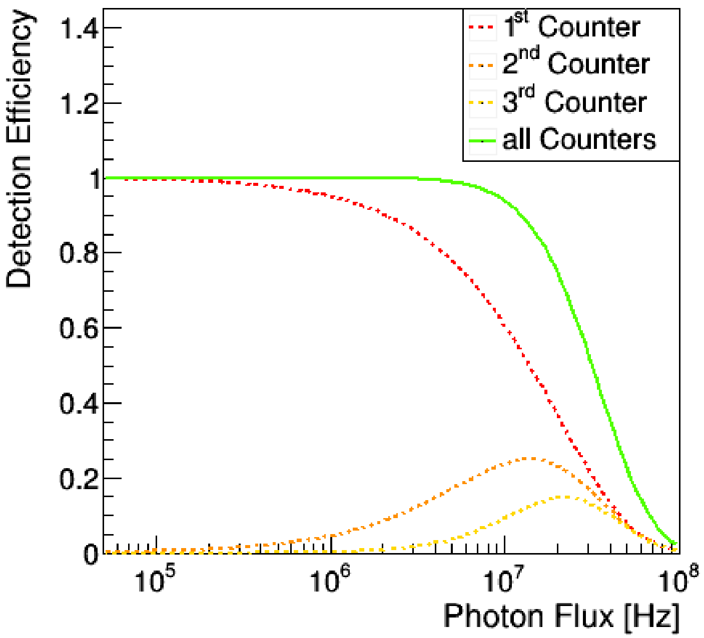
- same as energy windowing



- One comparator per counter, one Enable

Rate Capability: Pile-up tracking with 3 counters



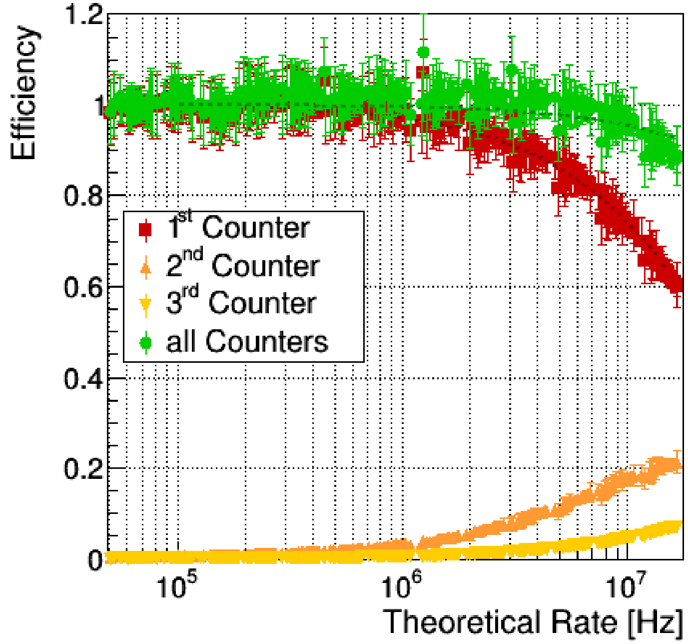


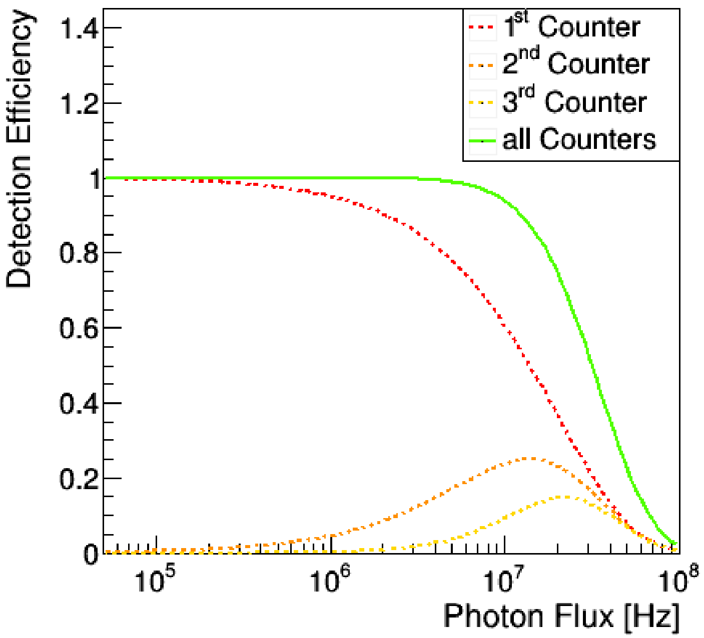
- Rate scan with 3 thresholds to track pile-up
- Pile-up model: (paralyzable)

$$\epsilon_1(\phi_0) = e^{-\phi_0 \tau_d}$$
$$\epsilon_2(\phi_0) = e^{-\phi_0 \tau_d} \cdot (1 - e^{-\phi_0 \tau_d})$$
$$\epsilon_3(\phi_0) = e^{-\phi_0 \tau_d} \cdot (1 - e^{-\phi_0 \tau_d}) \cdot (1 - e^{-\phi_0 \tau_d})$$
$$\epsilon_{sum} = \epsilon_1 + \epsilon_2 + \epsilon_3 > \epsilon_1.$$

- Model total efficiency as sum of 3 counters
- Fit with paralyzable model → dead time τ_d (1 to 3 counters)

Rate Capability: Pile-up tracking with 3 counters





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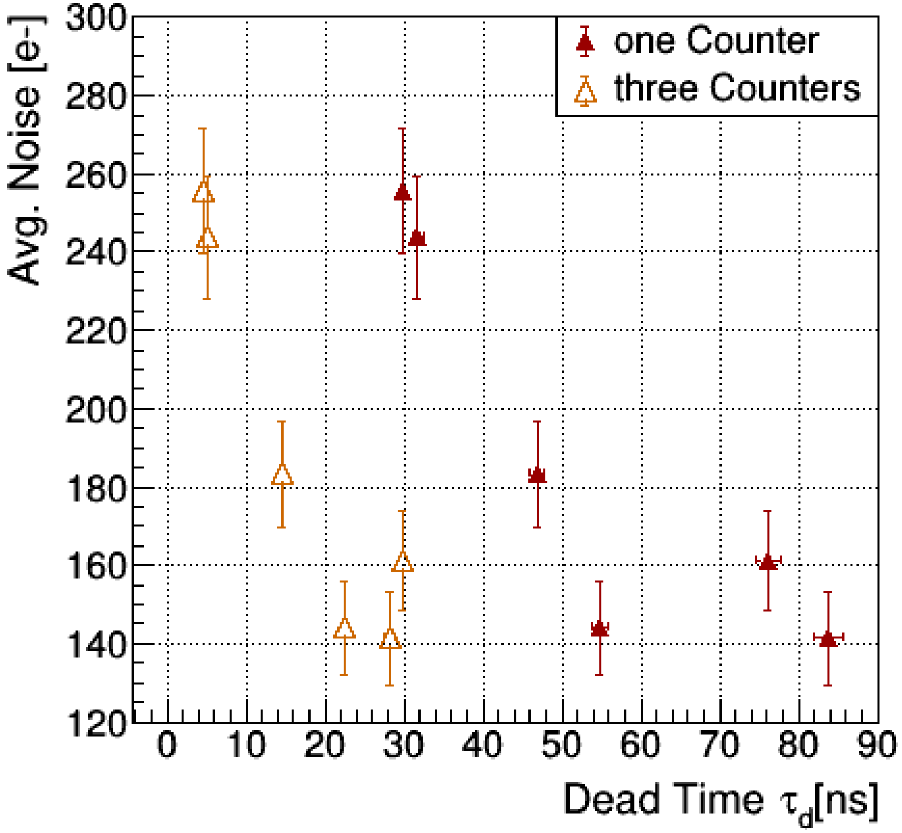
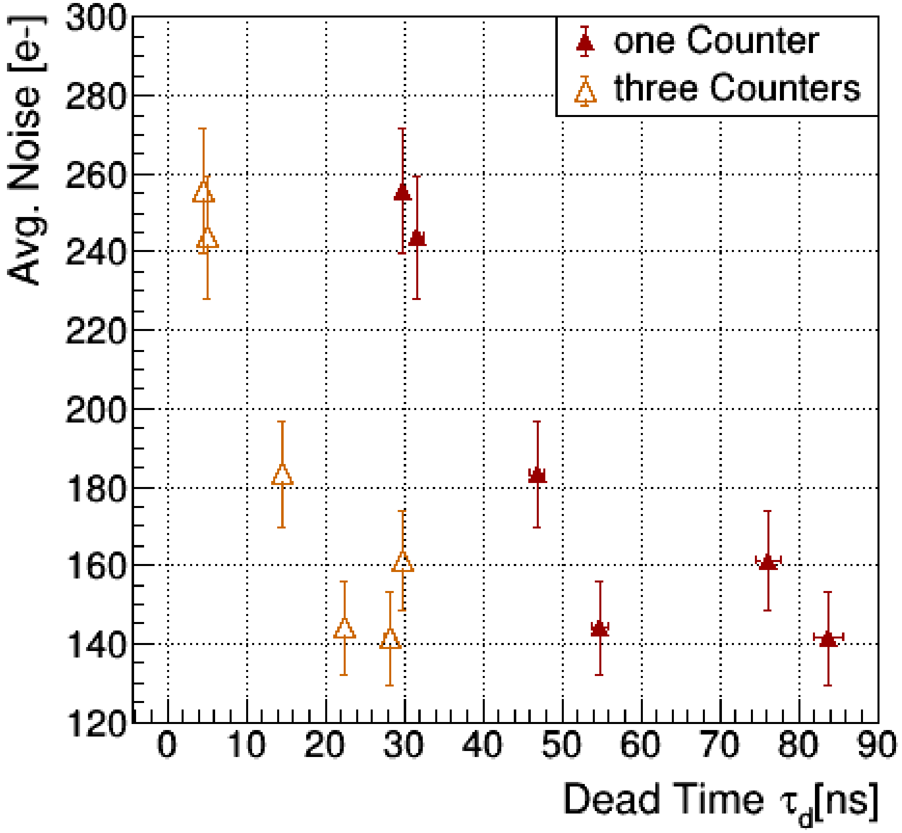


- Determine dead time and noise
  - If gain ↑ : noise ↓ and dead time ↑
- Calculate rate per strip at 90% efficiency:
  - $\varepsilon_{sum} = \varepsilon_1+\varepsilon_2+\varepsilon_3$

settings	1 counter	3 counters
Slow	1.3 MHz	7.4 MHz
Medium	1.4 MHz	8.2 MHz
Fast	3.5 MHz	20.9 MHz

Minimum achievable noise: 110 e- rms (not shown)

Rate Capability: Pile-up tracking with 3 counters ✓



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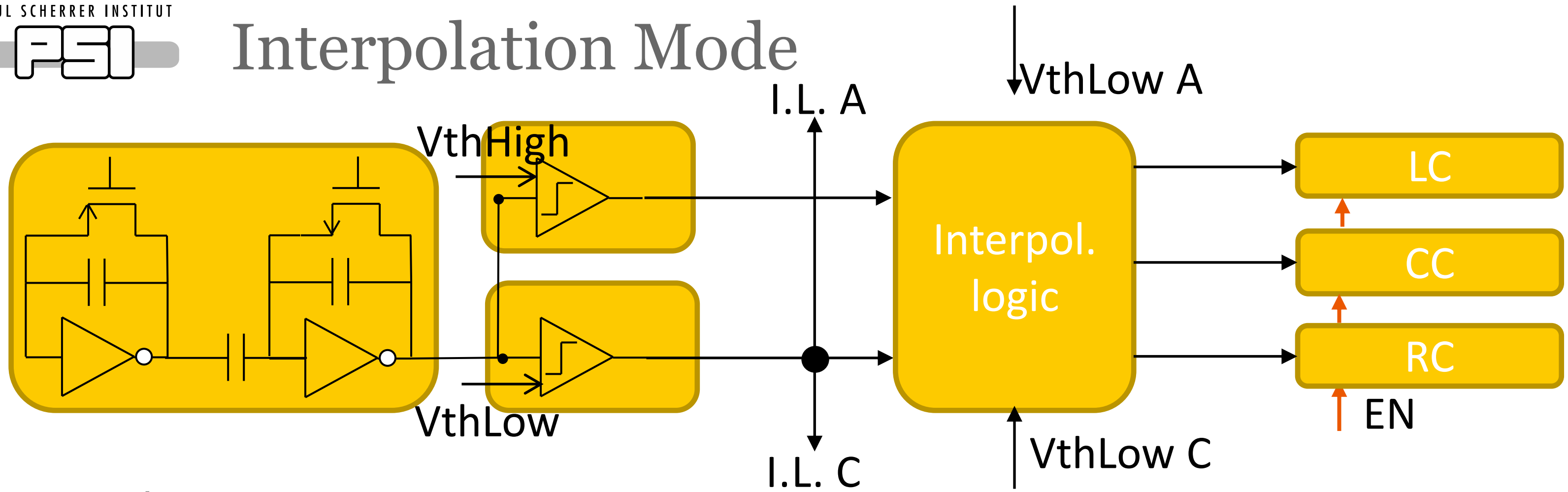
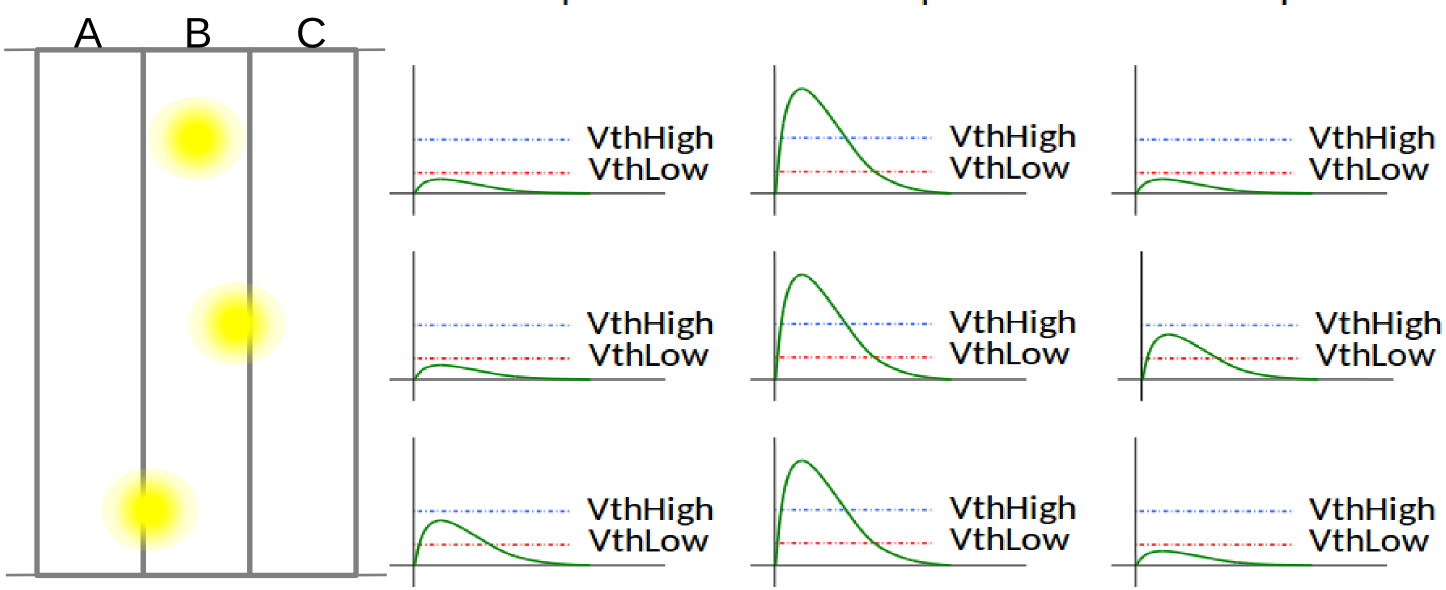
→ Meets requirements for SLS 2

Minimum achievable noise: 110 e- rms (not shown)

Interpolation Mode



Sensor top view



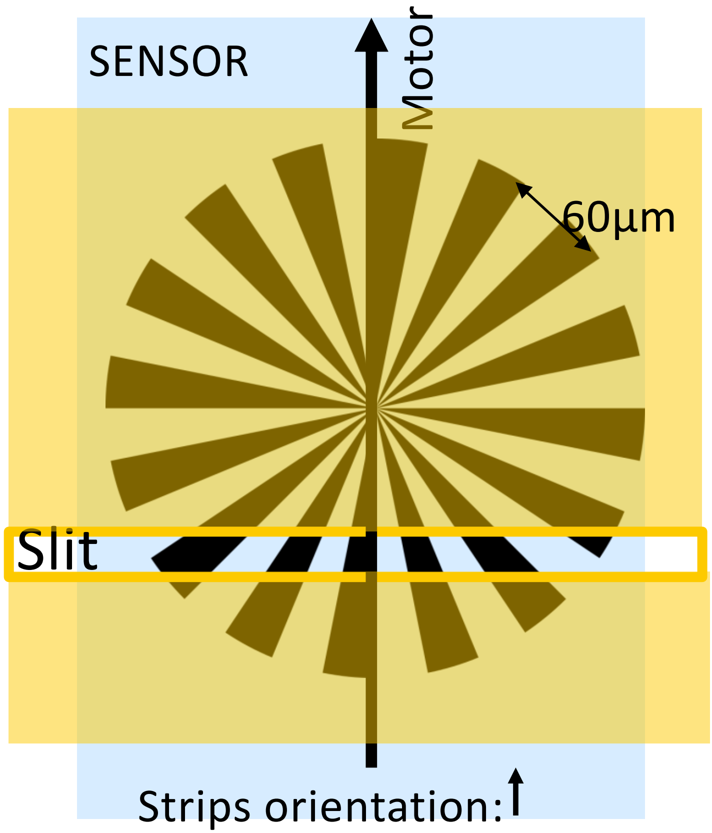
Strip B

LC	CC	RC
	+1	
		+1
+1		

- Inter-strip communication between neighbors
- Redistribute counts: left, central, right counter

→ Virtually split strips → better resolution

Interpolation: Siemens star



- Imaging with 1D detectors: thin slit in front of detector, scan sample, 25 µm steps in vertical
- External pitch of star: 60 µm, 2 mm diameter

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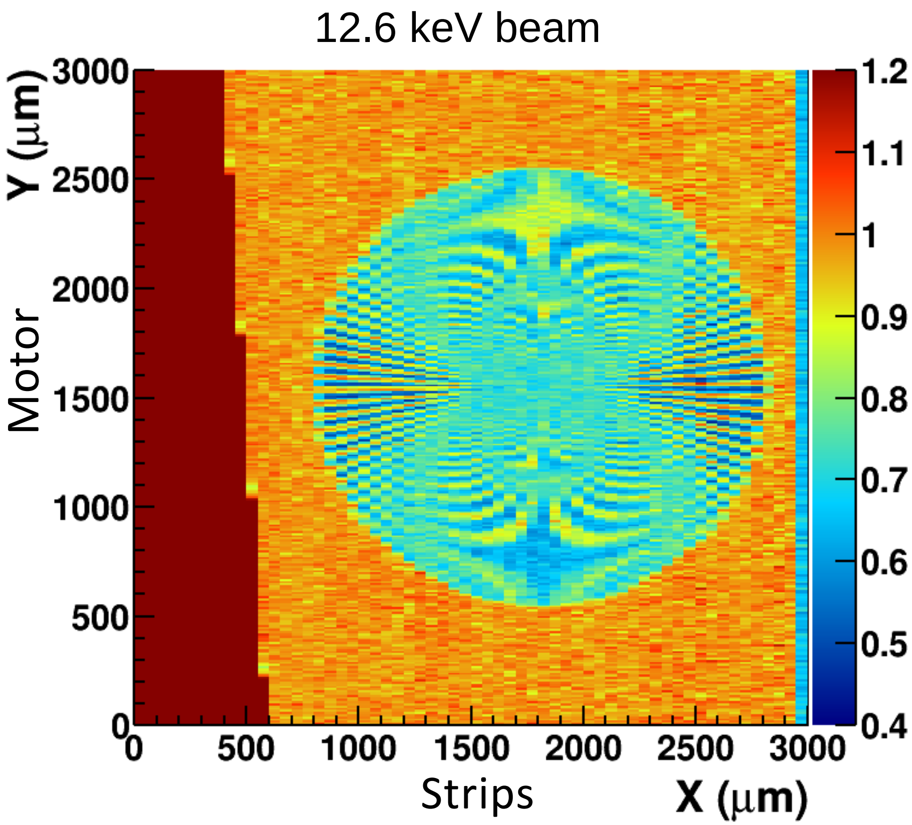

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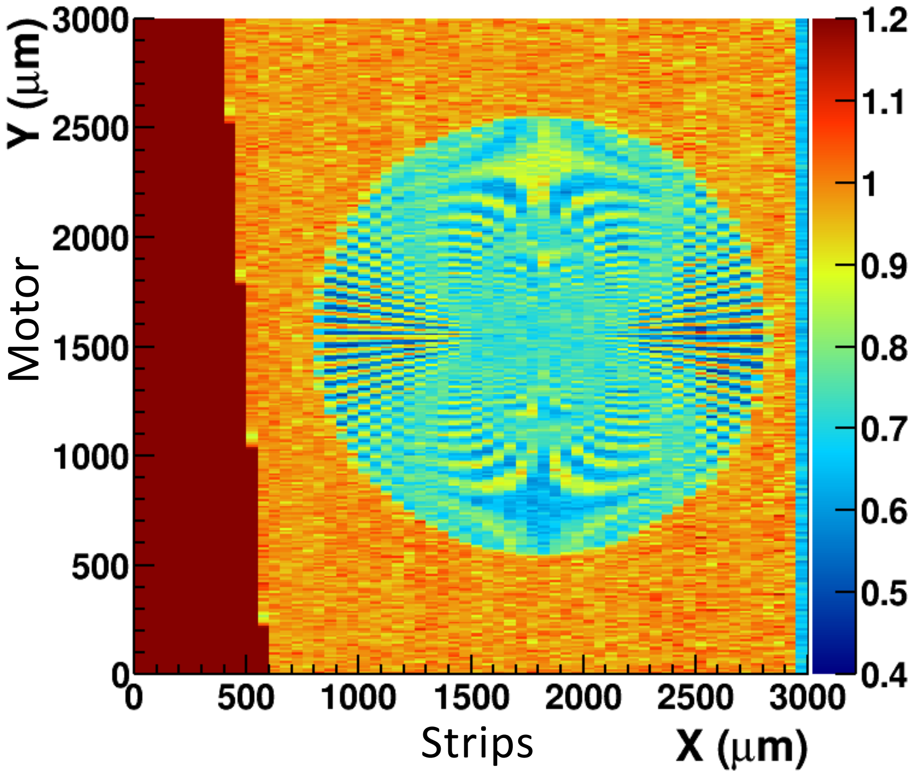
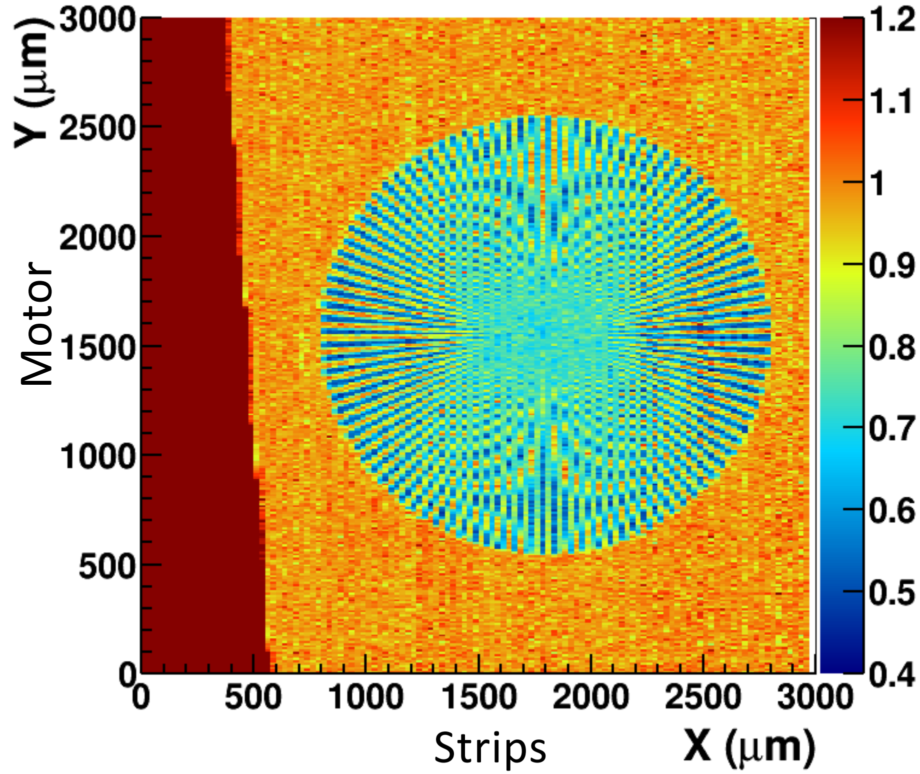
→Impossible to resolve spikes (in horizontal) in normal mode

Interpolation: Siemens star

12.6 keV beam





- Imaging with 1D detectors: thin slit in front of detector, scan sample, 25 μm steps in vertical
- External pitch of star: 60 μm, 2 mm diameter

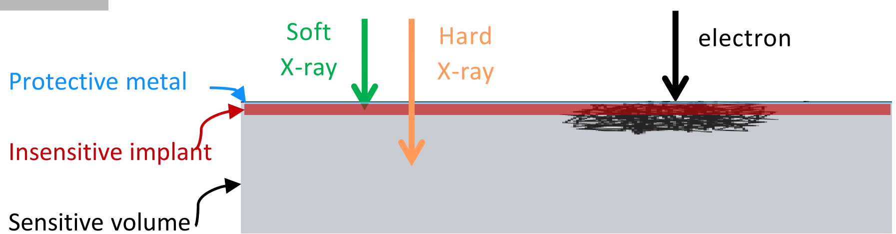
→Impossible to resolve spikes (in horizontal) in normal mode

→Distinguishable in interpolation mode!

→More quantitative tests are ongoing

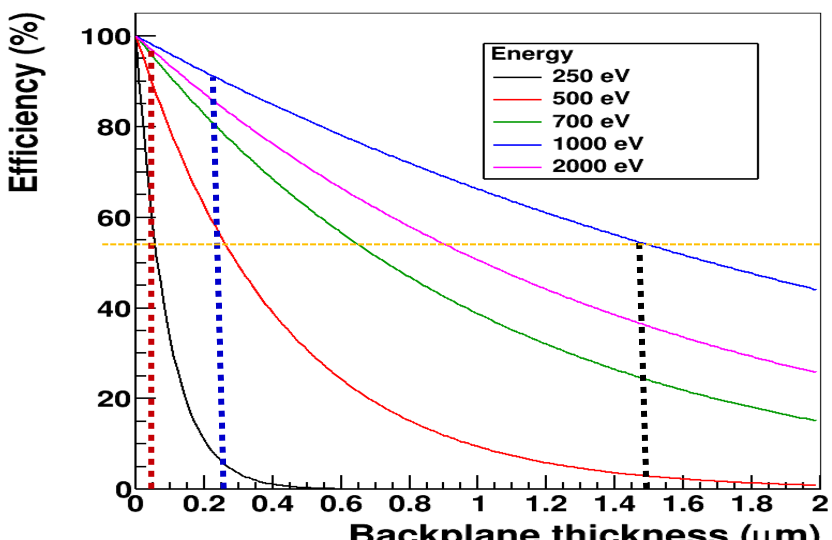
LGADs in photon science: low energy X-rays

- **Improve quantum efficiency**

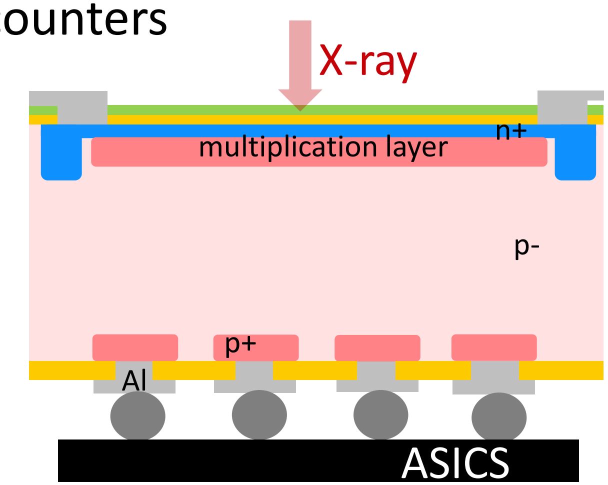


QE>50%

Standard	E>1 keV
Current	E>500 eV
Goal	E>250 eV



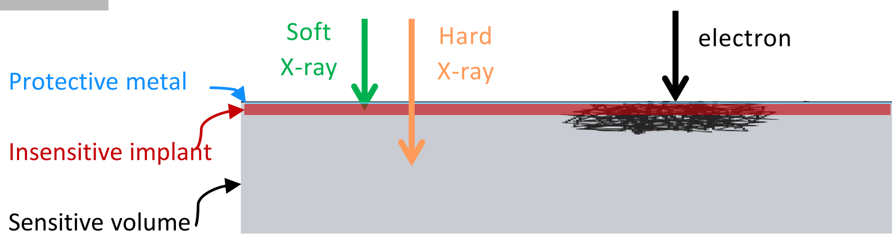
- Increase SNR
  - Low Gain Avalanche Detectors (LGADs)
  - Segmented avalanche photodiodes with limited gain, no dark counts
  - Timing not important for PS
  - Already proven with other detectors SNRx5
  - Ideal for soft X-ray single photon counters



PIXELIZED iLGAD

LGADs in photon science: low energy X-rays

- Improve quantum efficiency



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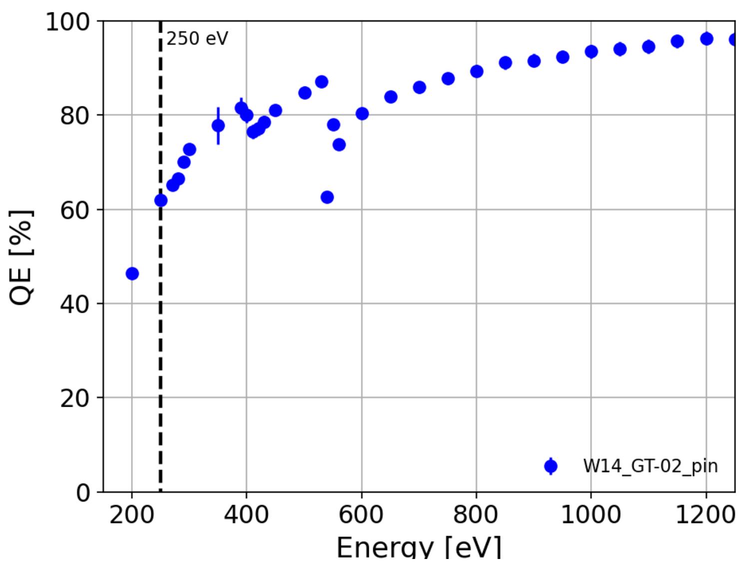

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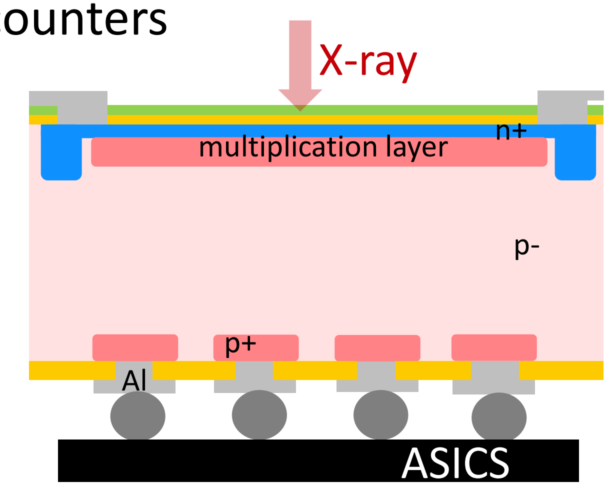
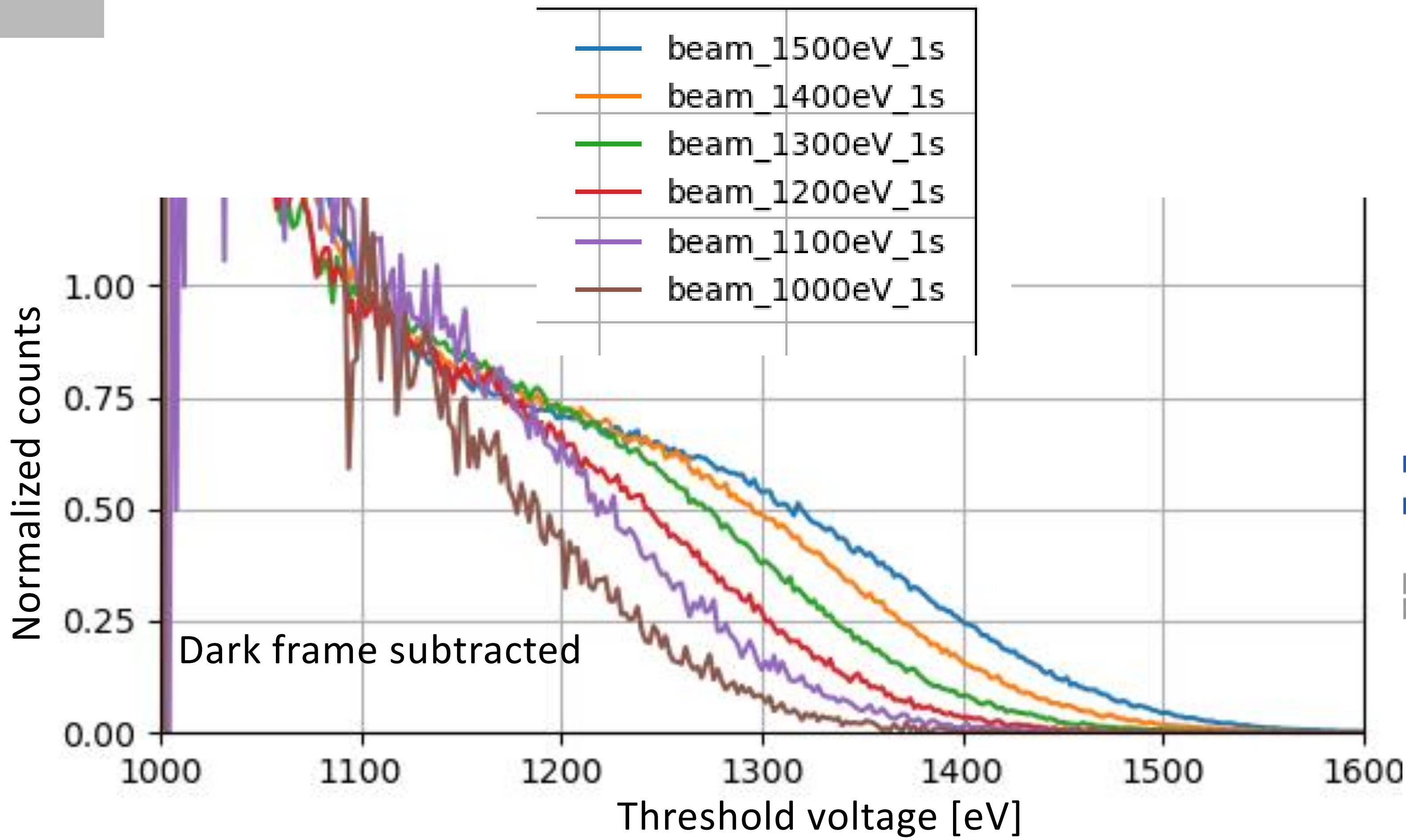


PIXELIZED iLGAD

Inverse LGADs with MYTHEN

Very preliminary



FONDAZIONE BRUNO KESSLER

Inverse LGADs with MYTHEN

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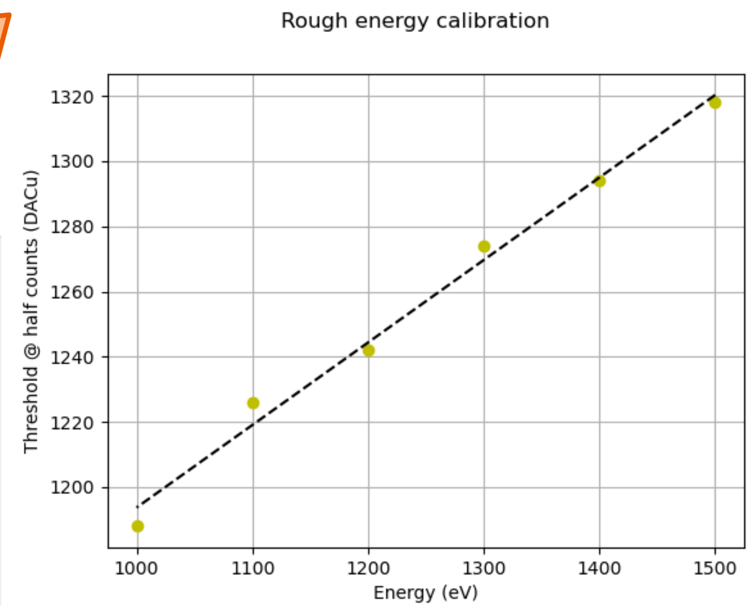

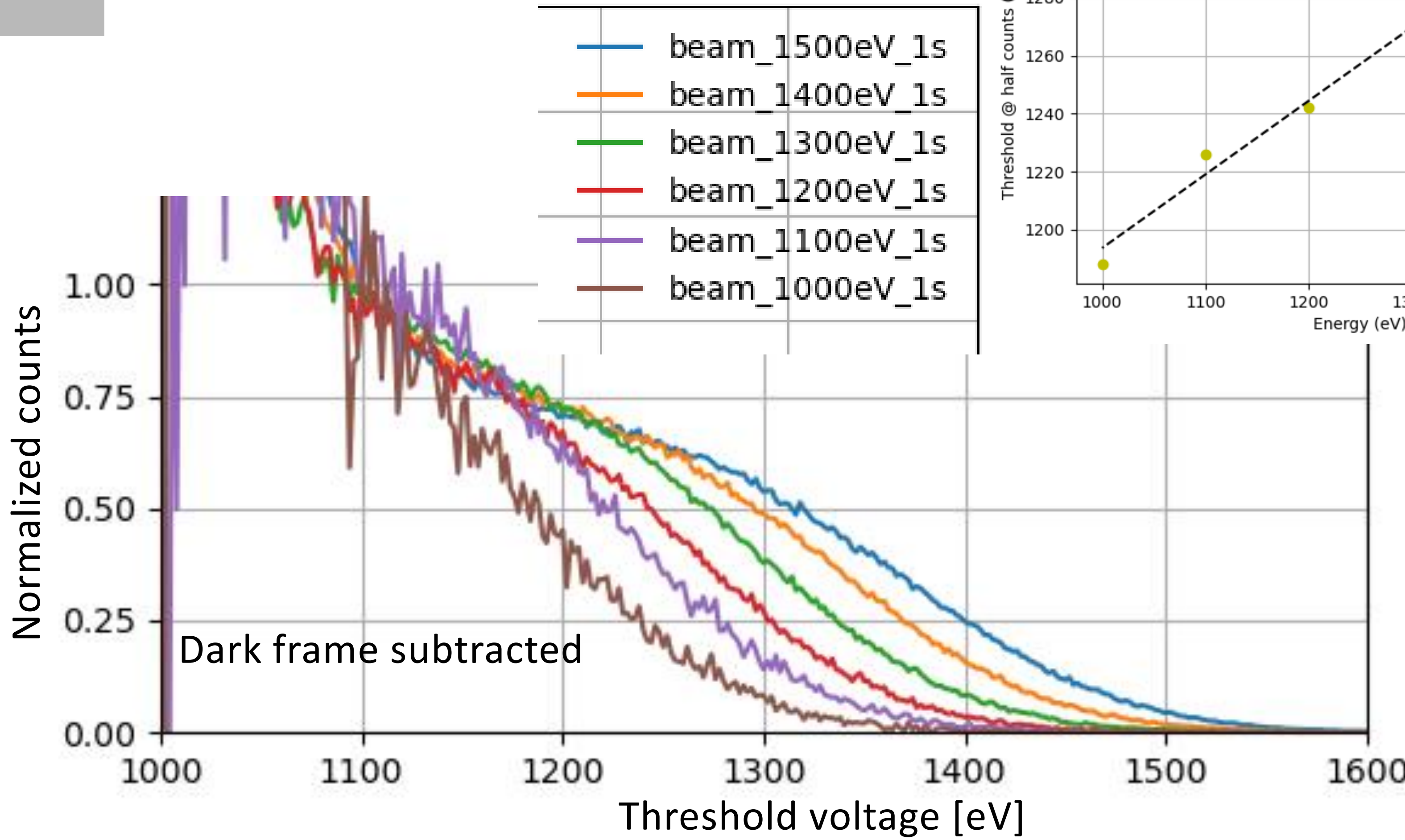

FONDAZIONE BRUNO KESSLER

Mythen III status

- Full detector (120 degrees) currently installed at Material Science (SLS)
  - The detector runs flawless
  - First experiments ongoing
- Several modules installed as beam monitors (polarization, I0 monitor, position(?))

PAUL SCHERRER INSTITUT PSI

Summary

	MYTHEN II (250nm)	MYTHEN III specs	MYTHEN III (110nm) meas
Noise Min. Thresh.	200-250e- ~4.5keV	150-200e- ~3.5keV	110-250e- ~3keV ✓
Threshold dispersion	ca. 25 e-	20e-	6e- ✓
Count rate capability @90%	0.1-1 MHz	>2MHz	*1 counter:* 1.3-3.5 MHz ✓ *3 counters:* 7.4–20.9 MHz
Frame rate Dead time free	0.1-1 kHz No	>10 kHz Yes	40-400 kHz ✓ Yes ✓
Temperature stability	???	"Good enough"	ca. 0.3%/°C ✓
Polarity	h+	h+/e-	✓
Counters	1, no logic	3, with counting logic	✓

→ Lower energies detectable
Better fluorescence suppression

→ Better flat field

→ Higher fluxes

→ Time resolved experiments

→ Reliable calibration

→ Use with High Z materials or LGADS

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Count rate capability @90%	0.1-1 MHz	>2MHz	*1 counter:* 1.3-3.5 MHz ✓ *3 counters:* 7.4–20.9 MHz
Frame rate **Dead time free**	0.1-1 kHz No	>10 kHz Yes	40-400 kHz ✓ Yes ✓
Temperature stability	???	"Good enough"	ca. 0.3%/°C ✓
Polarity	h+	h+/e-	✓
Counters	1, no logic	3, with counting logic	✓

Lower energies detectable
Better fluorescence suppression

Better flat field

Higher fluxes

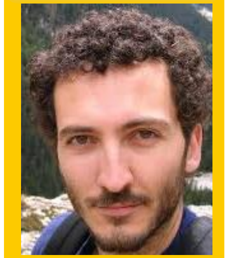
Time resolved

Standard mode
Pump-probe
Energy windowing
Rate correction
Interpolation
Time over threshold
Pulsed mode

Acknowledgements

MS beamline

Nicola Casati



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MS beamline

- Nicola Casati
- Antonio Cervellino