
# FlashCam:

## A fully digital IACT camera system

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For the FlashCam group

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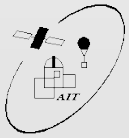
CTA Consortium Meeting, Madrid, Spain

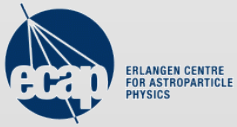

Universität Zürich[UZH]


MPIK - Heidelberg

AGH University of Science and Technology


Universität Tübingen

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich


# FlashCam – a versatile camera

## *Properties of FlashCam*

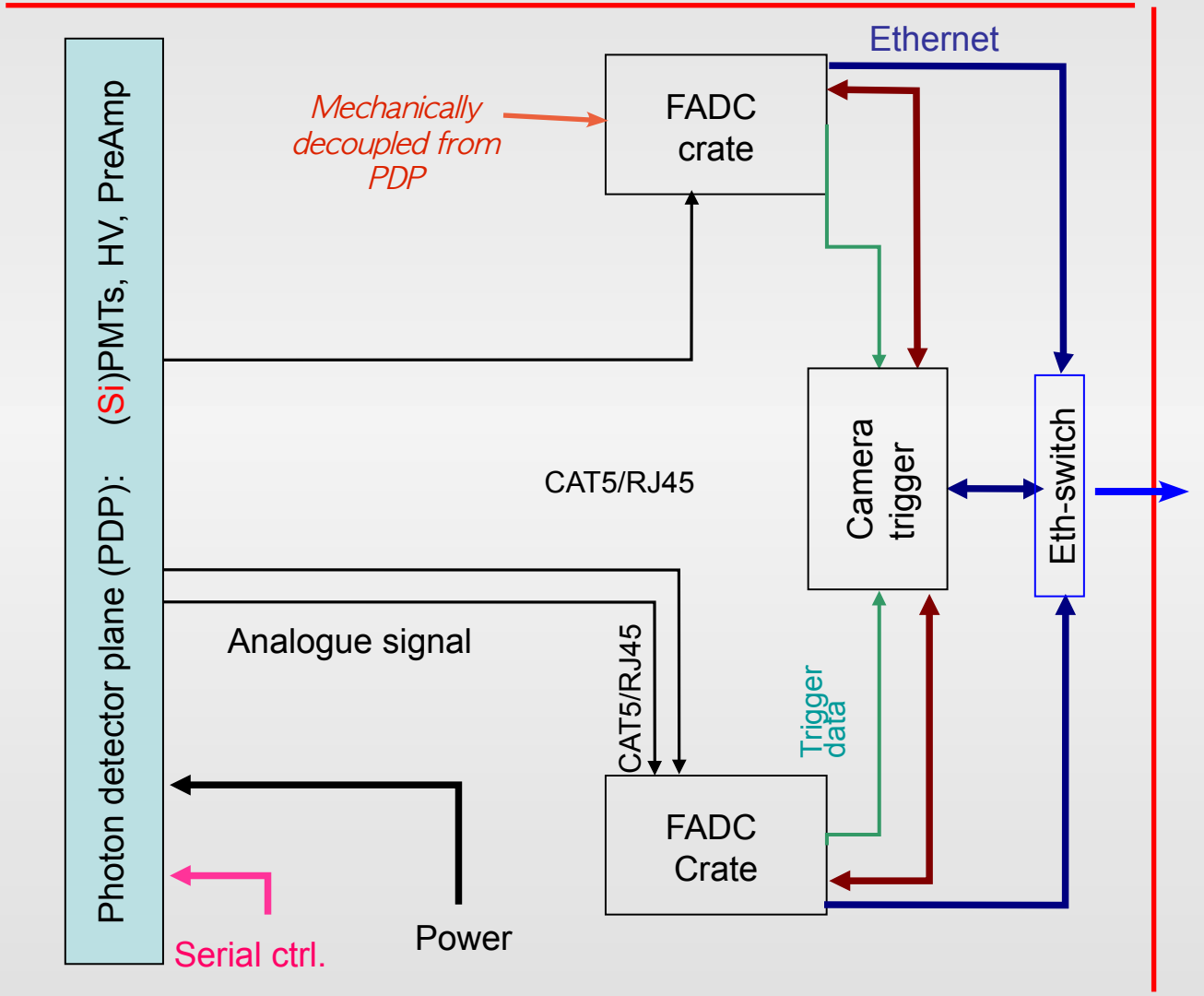
- Simple concept based on commercially available chips
- Trigger decision based on digitized signals
  - No separate trigger path
  - Programmable and flexible
  - Nearly deadtime free

Number of pixels: 900-3600
Dynamic range: ~0.2-3000 PE
Local trig. Rate: ~10 kHz
Record full waveform

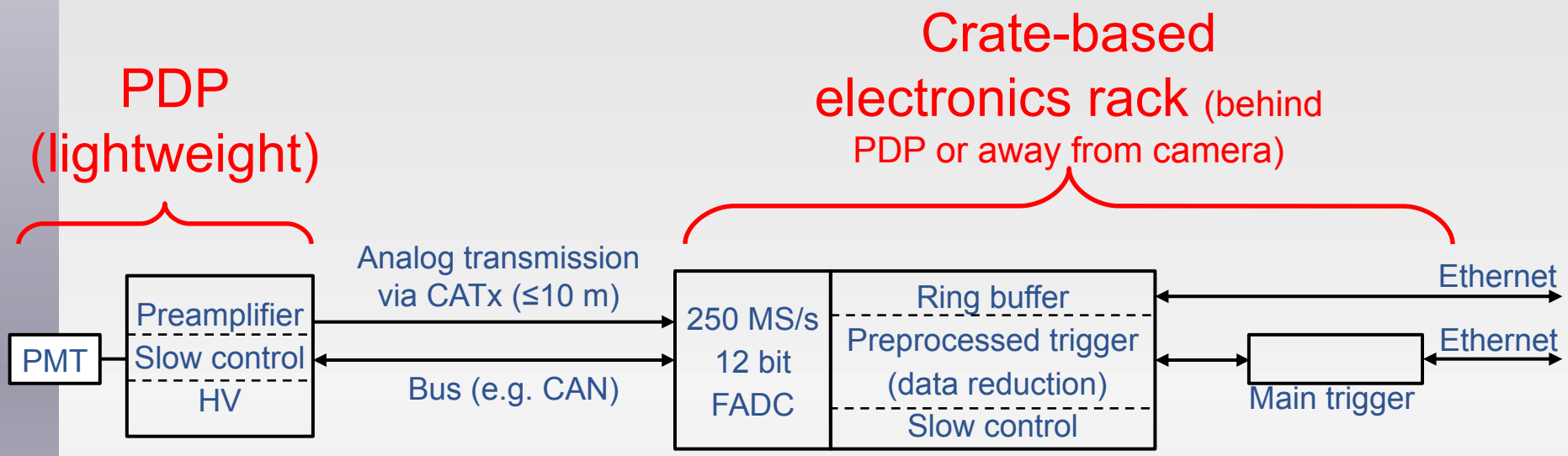
- Low power ( <0.5 W/channel) 12-bit FADCs currently available only up to 250 MS/s.
  - Extensive simulations incl. time jitter, NSB, etc., have shown that trigger performance with digital trigger options is very competitive with higher (e.g. 2 GS/s) sampling speeds.
  - Resulting data rate (~600 MB/s) allows transmission of full pixel event information over standard gigabit ethernet infrastructure (incl. commercial switches).

# FlashCam Architecture

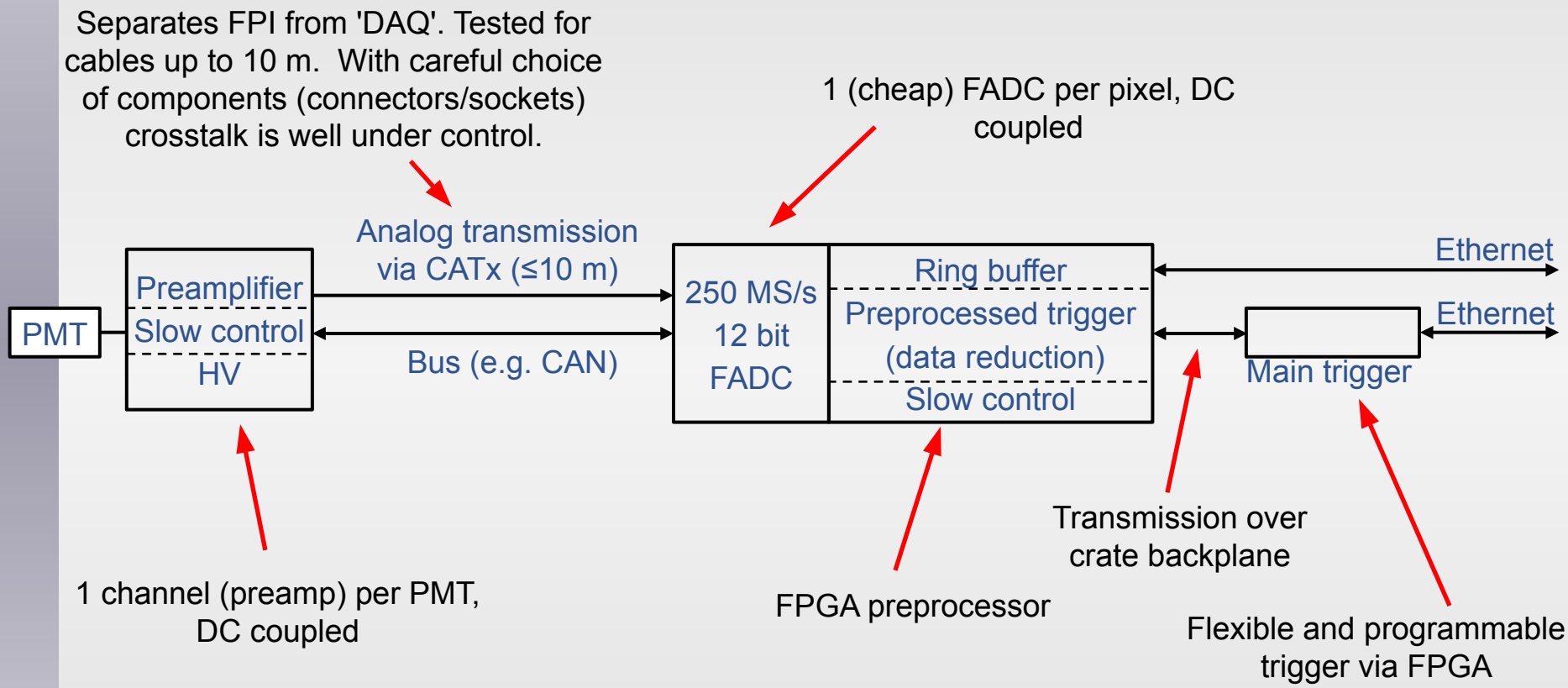
- *Separation of PDP and ADC electronics, with analog signal over CAT5*
  - Allows adaptation of various photon detectors, pitches, and avoids heavy electronics at the focal plane
- *Horizontal integration*
  - Reduces costs
- *Data transport via ethernet*
  - Commercial switches
- *Digital trigger based on FACD data*
  - Flexible, programmable, powerful



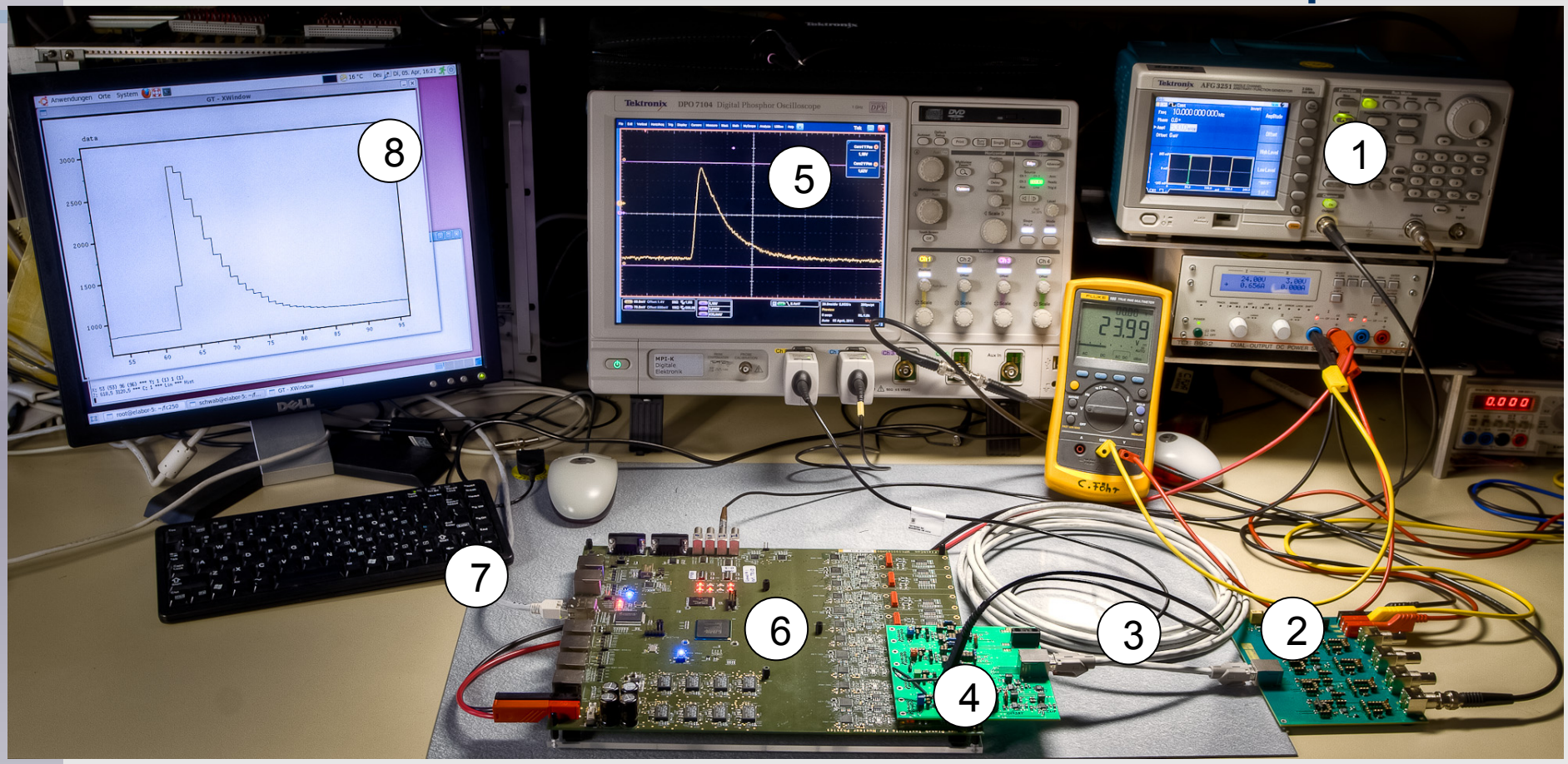
# FlashCam Architecture



# FlashCam Architecture



# FlashCam demo board setup

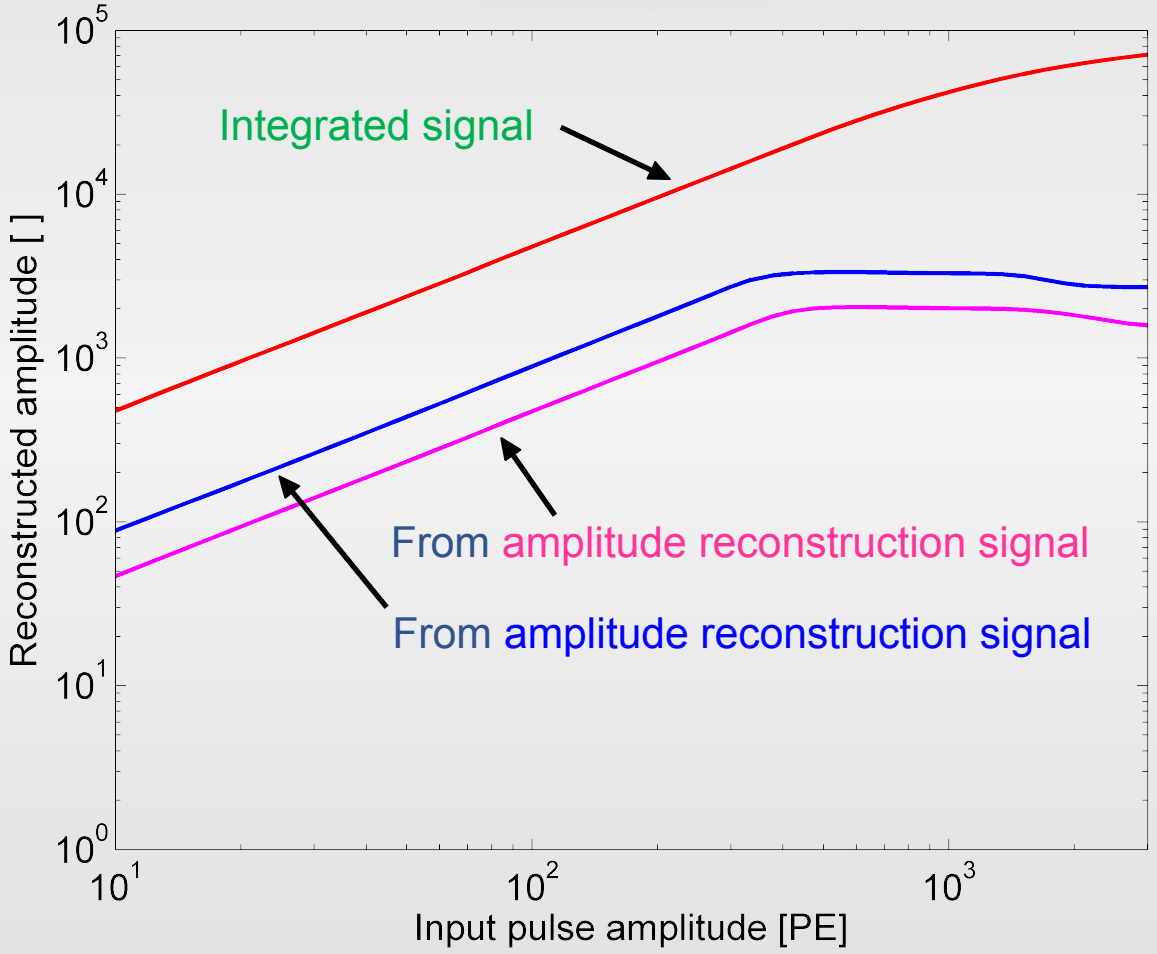



**1** PMT pulse generator
**2** Preamplifier board
**3** Analogue signal transmission (CAT5)
**4** ADC driver board
**5** Analogue pulse before ADC
**6** Demo board with 8 parallel FADCs and FPGA
**7** Event transmission via LAN
**8** Digitized pulse (4 ns / step)

# Preamp linearity

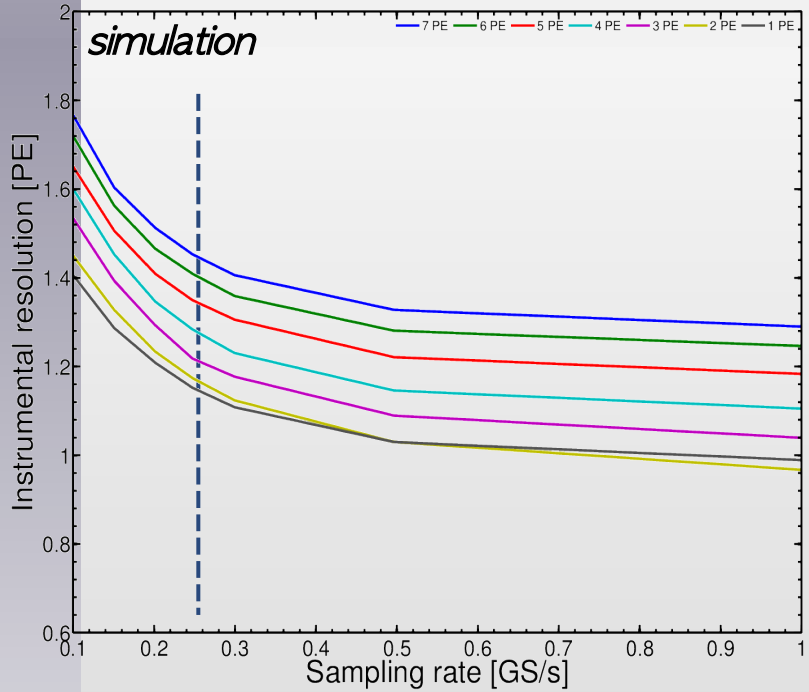
*Measured with FlashCam demo board*

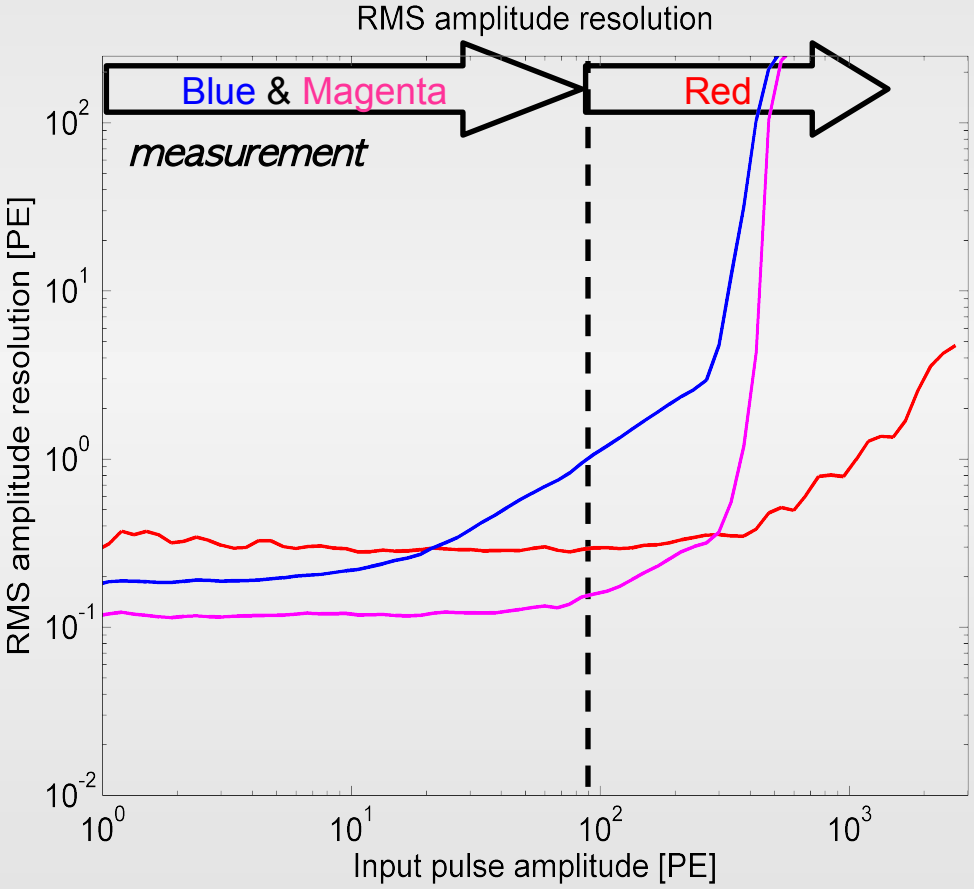
- Non-linear preamp allows for a wide dynamic range with only one channel per pixel.
- The pulse amplitude saturates (in a documented way), while the pulse area maintains the signal reconstruction.
- Ongoing measurements indicate stable behavior with temperature.



# Amplitude resolution

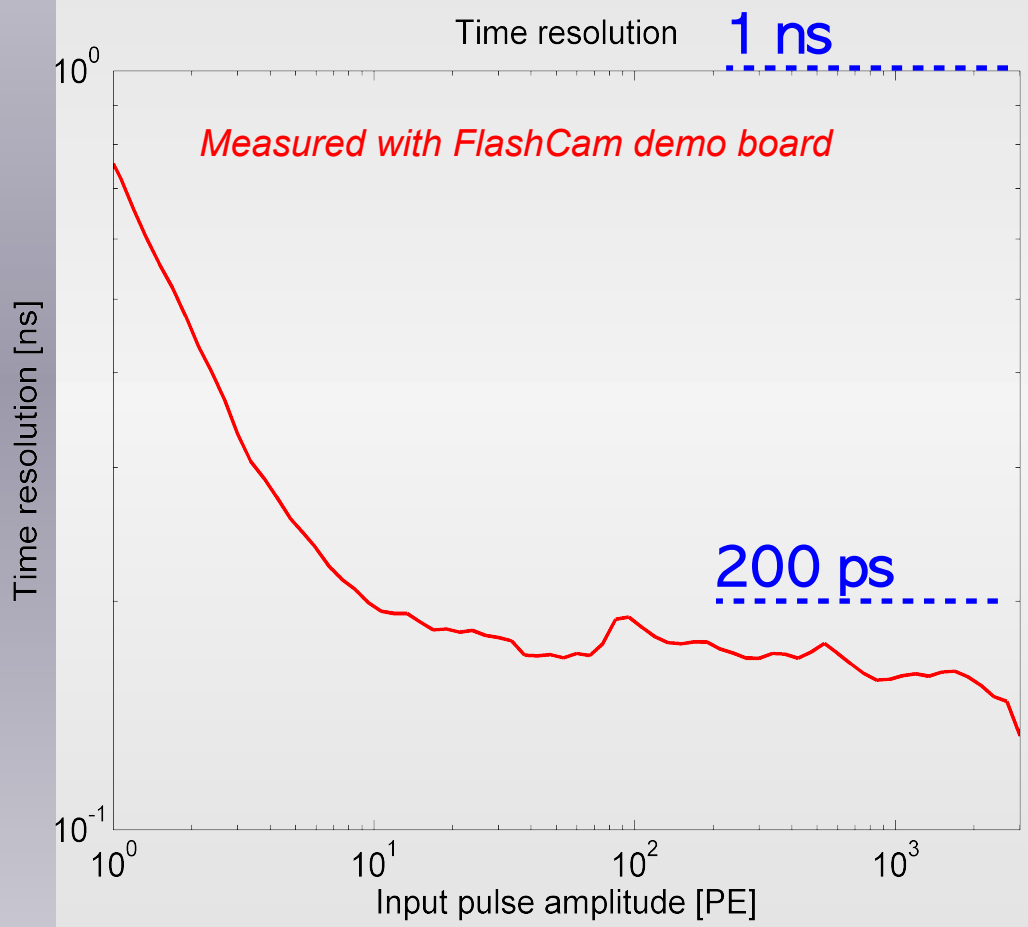
- Initial simulations showed amplitude res. saturates at ~1PE for ≥250 MS/s
- **Measurements** with 250 MS/s show amplitude res. even better, as low as ~0.1 PE.



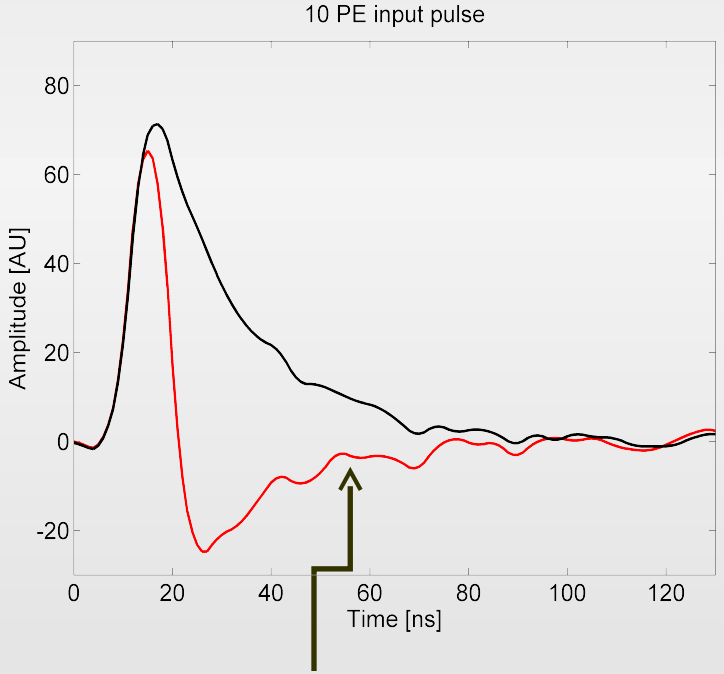




*Measured with FlashCam demo board*

# Timing res. of electronics chain

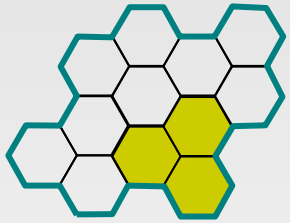



4 ns sampling interval does not mean 4 ns timing resolution!
We measure better than 200 ps resolution above 10 PE!




Time reconstructed from timing signal
Shown is comparison to reference signal
Reference signal has ~ 100 ps resolution

# Focal plane architecture



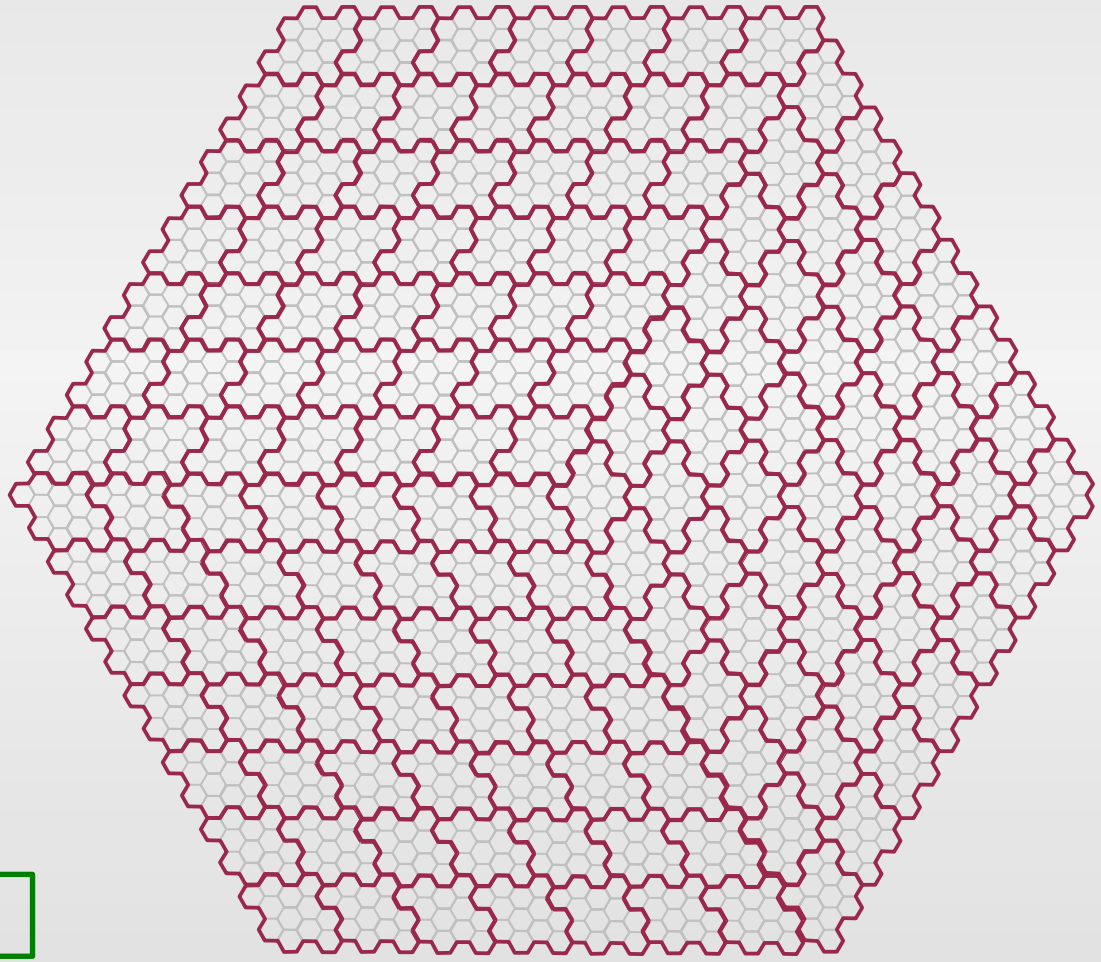
3 pixel patch

***Mechanical group of 12 PMT pixels***

3 sectors, rotated by 120 deg

Hexagonal structure

Perfect edges



***Possible sizes***

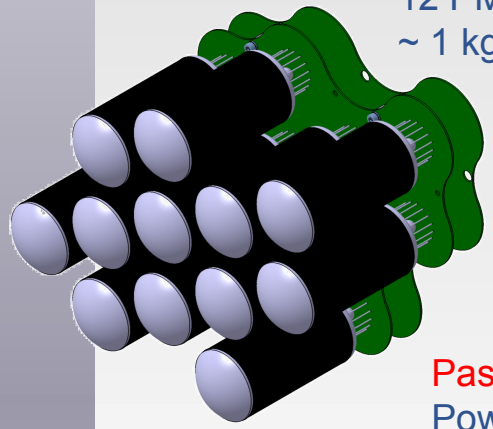
*Fully populated 12 pixel modules*

| | | |
|---|---|---|
| 5 x 5 x 12 x 3 = | 900 | SST |
| 6 x 6 x 12 x 3 = | 1296 | SST |
| 7 x 7 x 12 x 3 = | 1764 | MST |
| 8 x 8 x 12 x 3 = | 2304 | LST |
| 9 x 9 x 12 x 3 = | 2916 | |

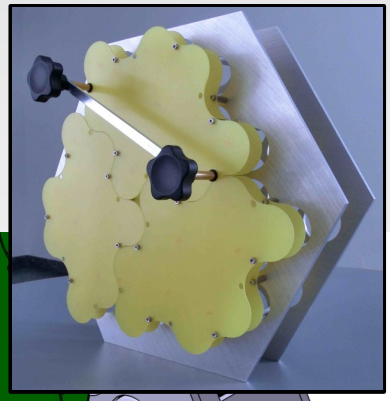
Using as an MST prototype

# Focal plane design and prototyping

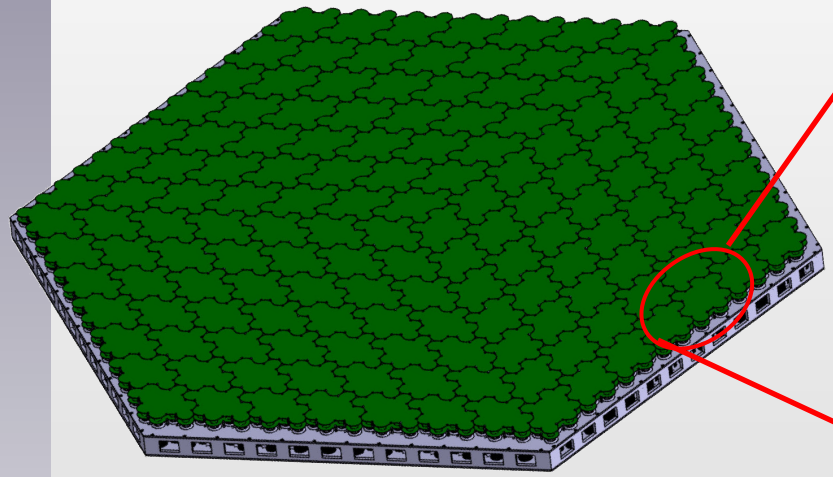
12 PMTs module, preamp and HV incl.
~ 1 kg / module

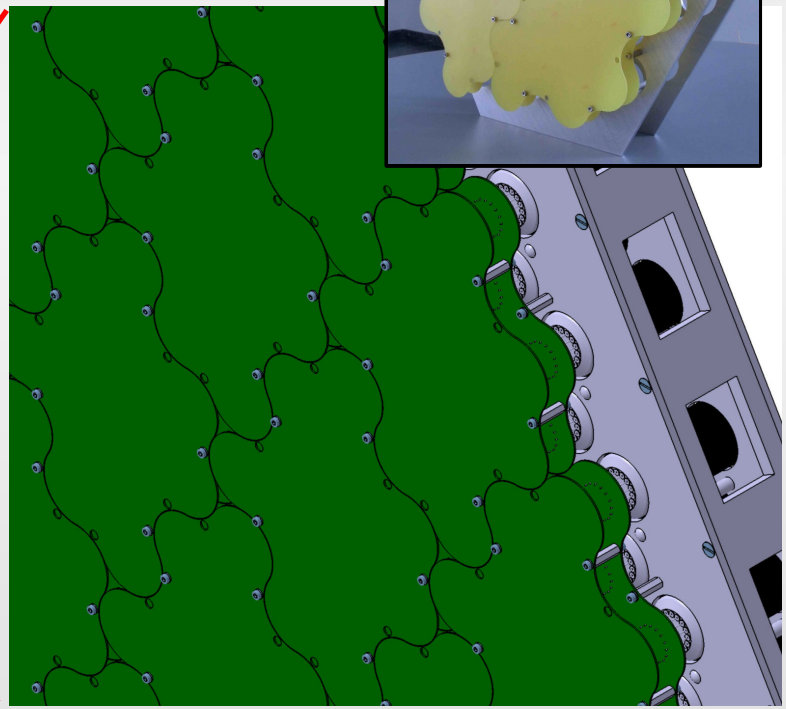


36 pixel prototype



Passive cooling of PDP
Power for 1764 pixels < 300 W

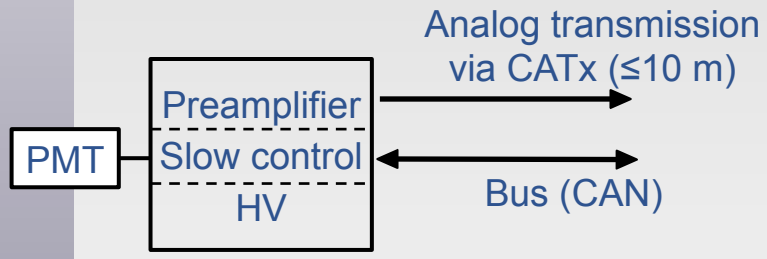




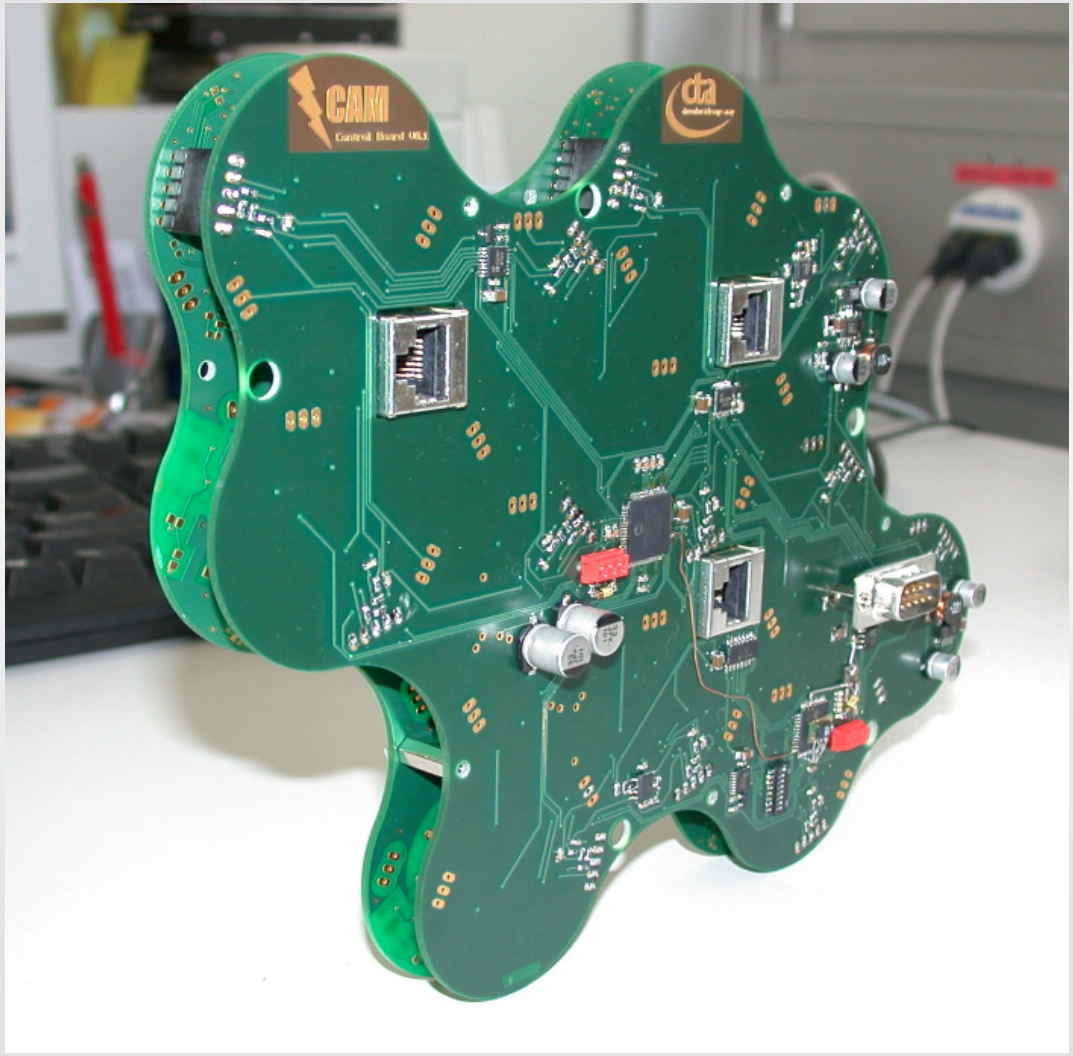
Structure weight: 81 kg
Flat to flat: 2170 mm
FEM calculation: 180 kg load at 90°→ 0.68 mm sagging

147 modules, 1764 PMTs
~ 180 kg (incl. electronics)

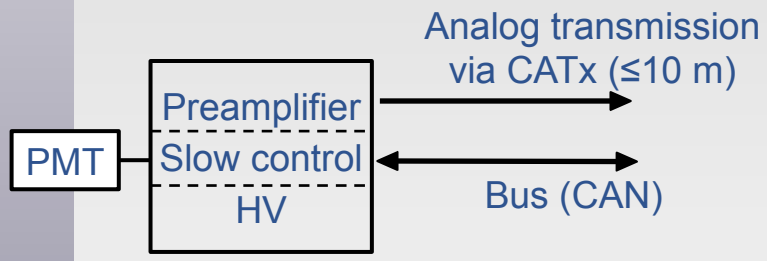
# Focal plane design and prototyping



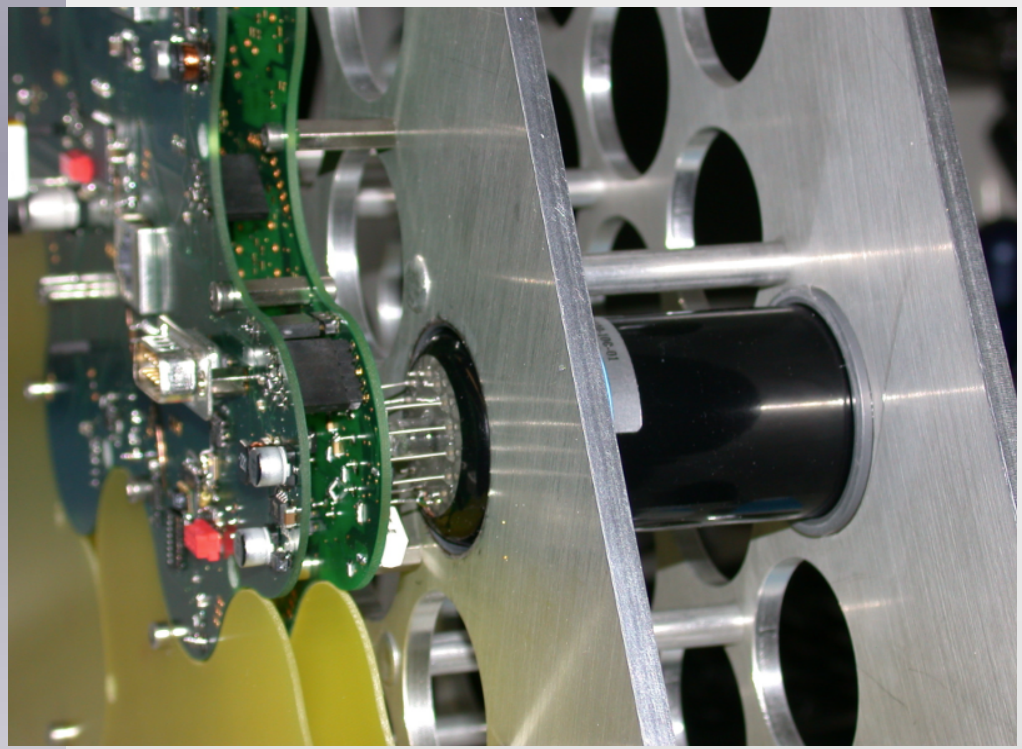

- CAN bus for SC
- Requires only +24V
  - LV and HV generated on board
- HV individ. Controllable
  - Adapted from KH Sulanke's (DESY) design
  - Off → On〔800-1500〕V
- Preamp gain individ. Controllable
- Temp/humidity readout
- < 2 W/cluster of 12 pixels
- Current components: € 47/pix (price will drop)

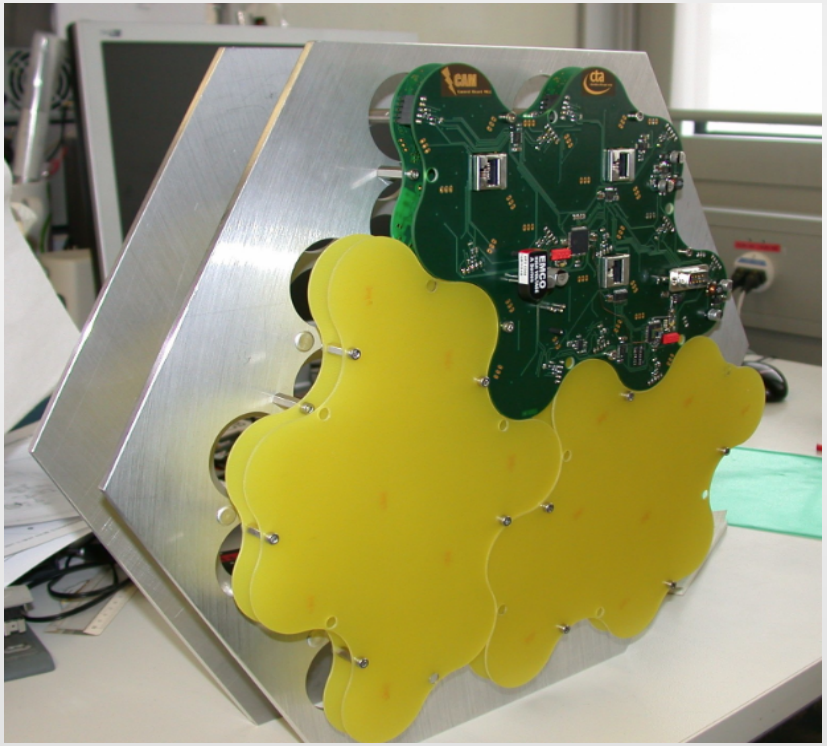


# Focal plane design and prototyping

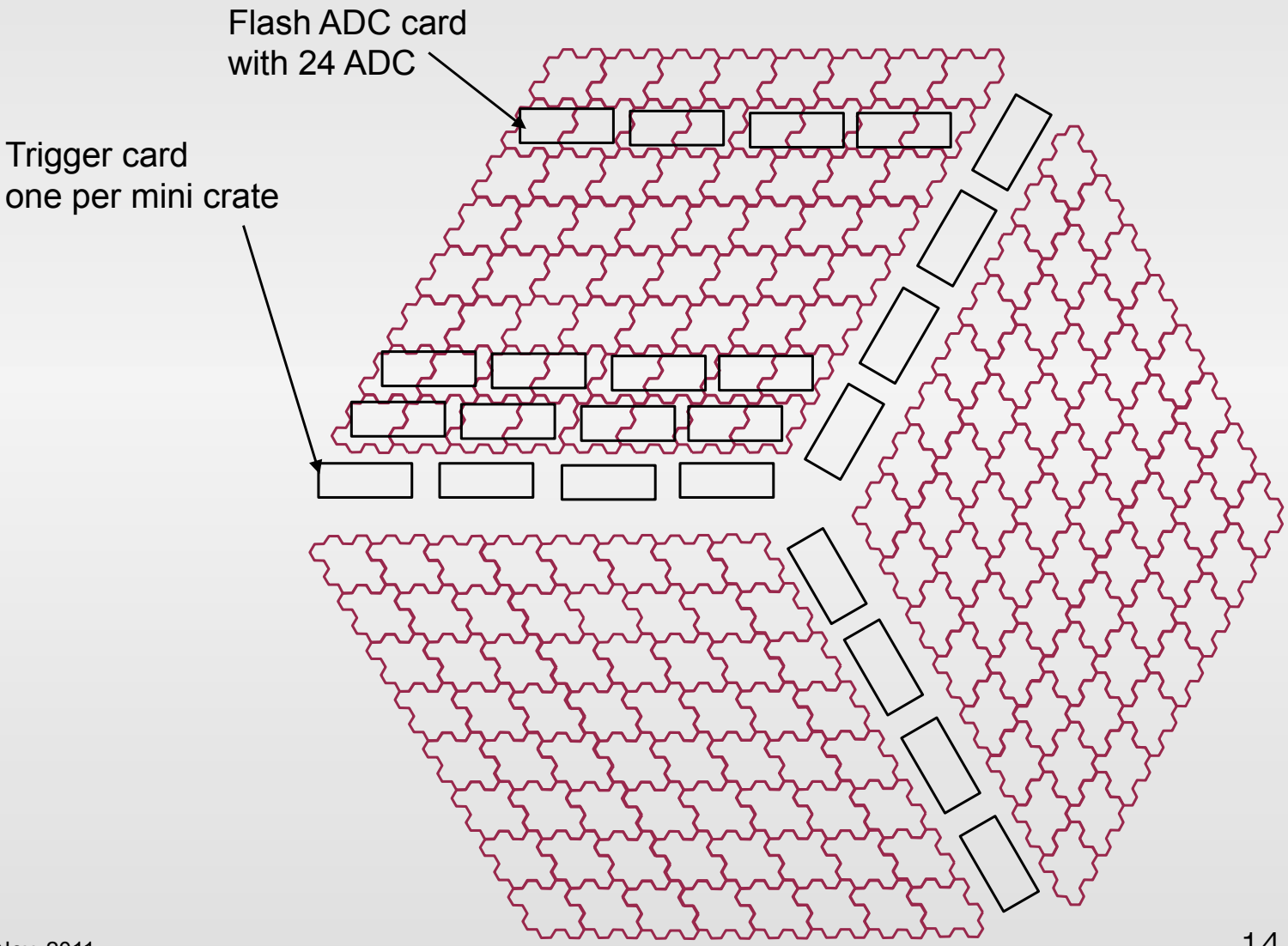



When scaled to a full camera (147 clusters=1764 pixels), total PDP weight (including aluminum plates) is less than 220 kg.

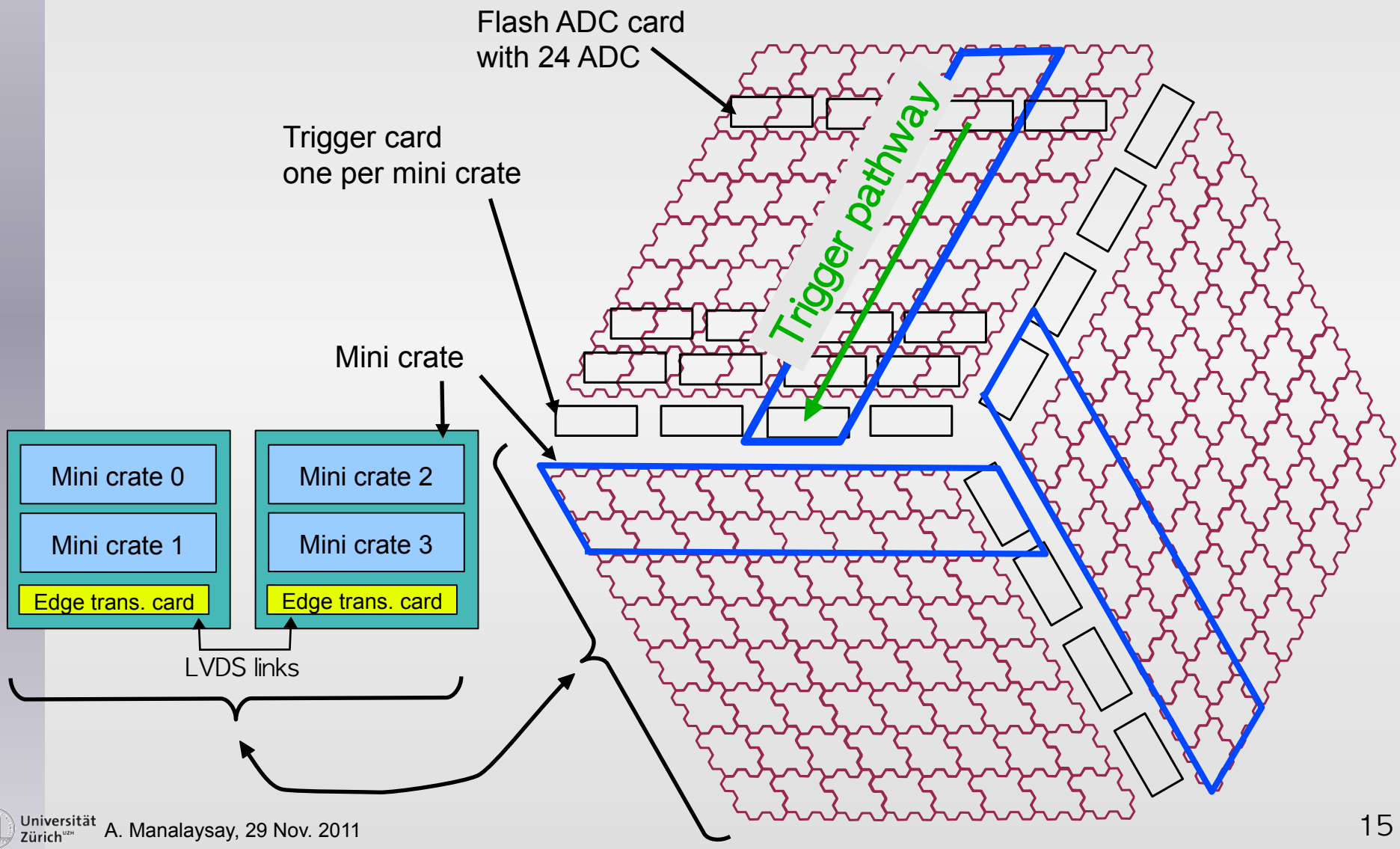




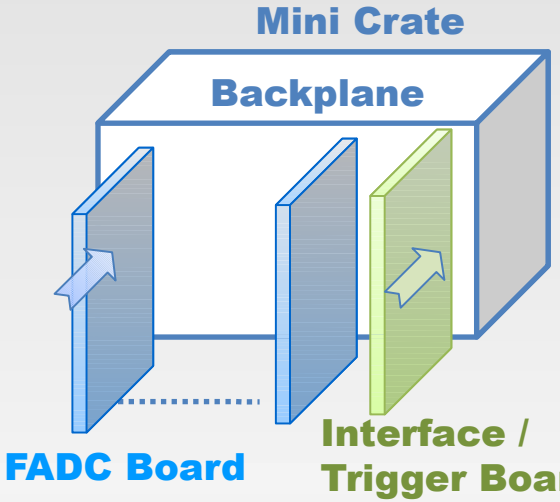
# Camera Topology

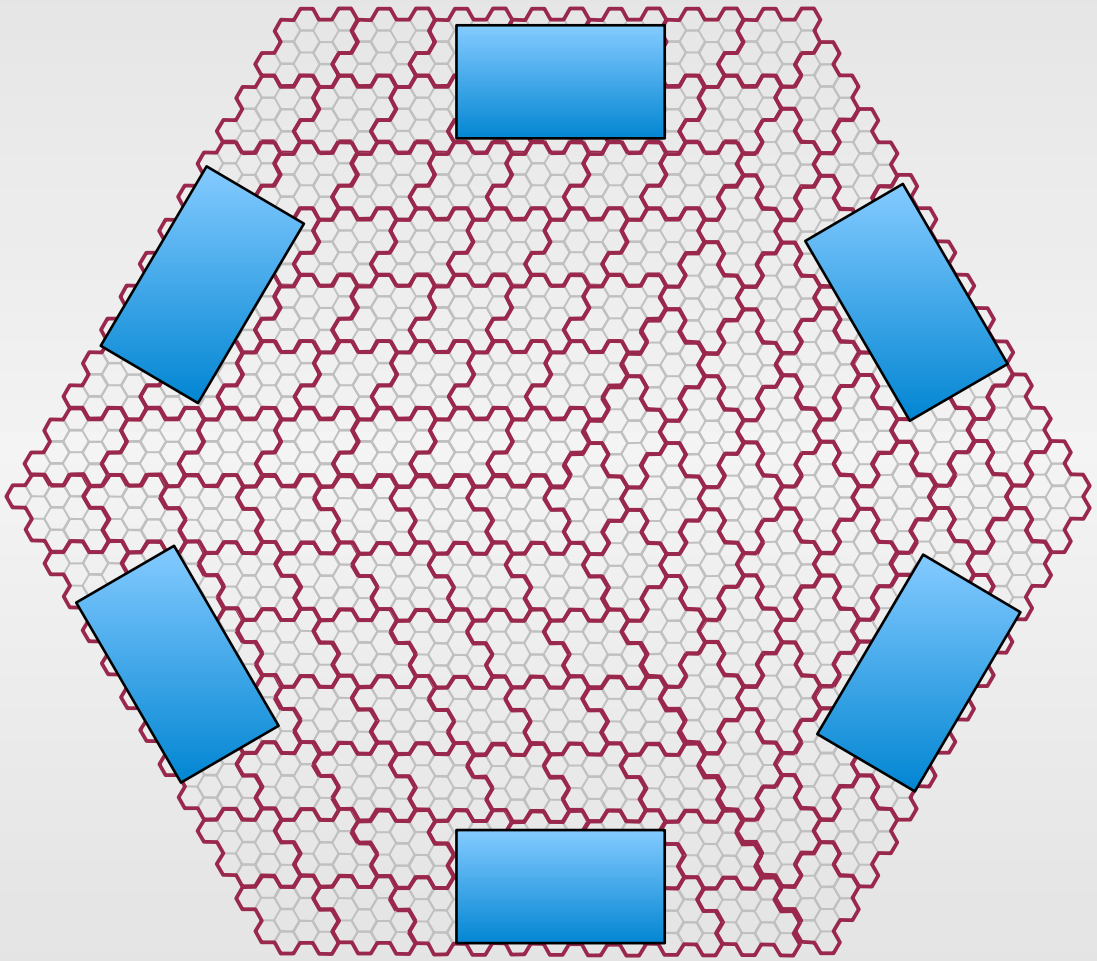


# MST Camera Topology



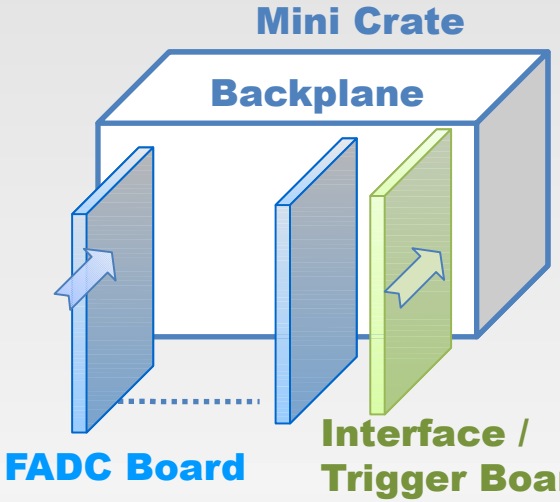
# Towards an MST prototype

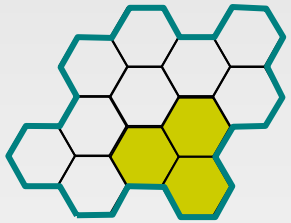


- 24-channel FADC boards, which are next iteration of the current FlashCam demo board, currently being laid out.
- 2 mini crates per 9-U rack requires 6 racks, mechanically distributed to allow short analog transmission cables.

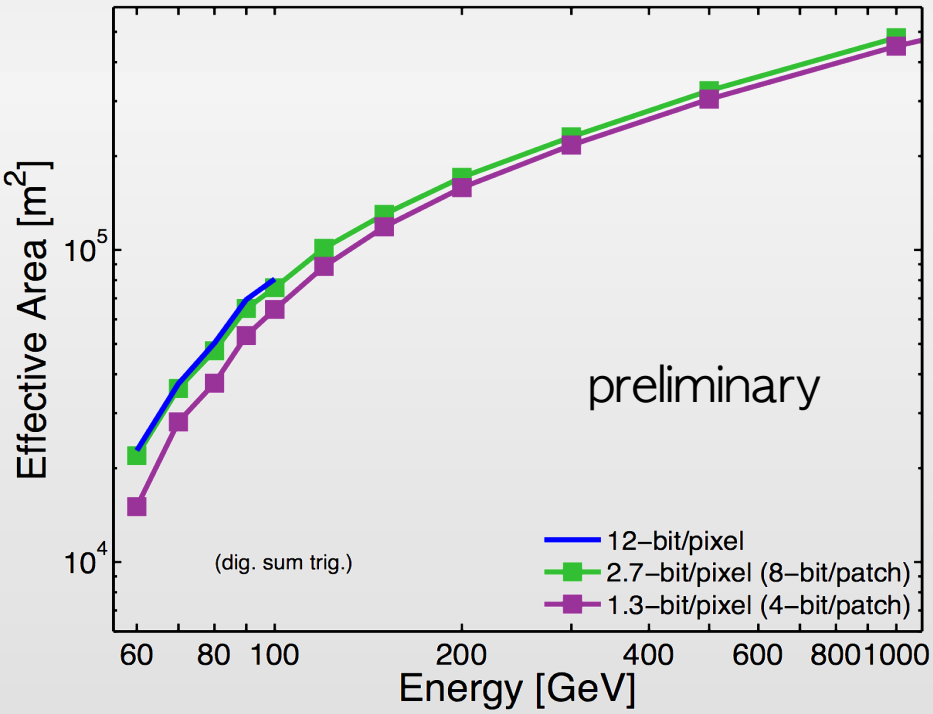
# Trigger bandwidth simulations



ch1(12-bit)<br>ch2(12-bit)<br>ch3(12-bit) } patch trig. info (4-bit, 8-bit)

- Amplitude info of the patch is reduced in bandwidth before being sent (via backplane) to the trigger board of each mini crate.
- Results of trigger info simulations depend strongly on how the e.g. 4-bit fullscale is chosen. (here $2^4$ fixed at max patch amplitude: 3*clip; NSB accidental rate fixed $\leq$500 Hz)
- No significant penalty for 1.3 bit/pixel.



# Power budget (ex: 1764 pixel camera)

| | Single Pixel[W] | Module[W] | Count | Camera[W] | Cooling |
|---|---|---|---|---|---|
| **Focal Plane** | | | | | |
| Preamp | 0.04 | | 1764 | 71 | **Passive** |
| Slow Control | 0.02 | | 1764 | 35 | |
| HV | 0.1 | | 1764 | 176 | |
| **Crates** | | | | | |
| FADC Card (current) | 1.5 | | 1764 | 2646 | **Active by forced air flow** |
| Trigger Card (est.) | | 20 | 12 | 240 | |
| Master Card (est.) | | 20 | 1 | 20 | |
| Cooling | | 80 | 3 | 240 | |
| **Network** | | | | | |
| Switches | | 100 | 3 | 300 | |
| Slow Control | | 3 | 20 | 60 | |
| **Camera** | | | | **3788** | |
| **TOTAL** | including power efficiency 85% | | | **4457** | |

These (and following) numbers are updated since the camera review:
http://www.cta-observatory.org/indico/materialDisplay.py?contribId=19&materialId=slides&confId=81

# Weight budget

| | Module[kg] | Quantity | Camera[kg] |
|---|---|---|---|
| **Focal Plane (PDP)** | | | |
| PDP structure | 72 | 1 | 72 |
| 12 PMT Module/Electr. | 1.0 | 147 | 147 |
| **Crates** | | | |
| Mini crate electronics | 6 | 12 | 72 |
| Mini crate mechanics | 5 | 12 | 60 |
| Power Supply | 5 | 3 | 15 |
| Analog cables 5m (worst case) | 0.25 | 441 | 110 |
| Trigger cables 3m | 0.25 | 48 | 12 |
| **Network** | | | |
| Switches | 5 | 2 | 10 |
| Slow Control | 5 | 3 | 9 |
| Cables | 0.25 | 100 | 25 |
| **Camera (w/o body and skin)** | | | **532** |

# Price budget

| | Module[€] | Quantity | Camera[€] |
|---|---|---|---|
| **Focal Plane** | | | |
| Structure | 10000 | 1 | 10000 |
| 12 Pix electronic no PMT, incl HV | 560 | 147 | 82320 |
| **Crates** | | | |
| Backplane | 300 | 12 | 3600 |
| FADC card | 1100 | 84 | 92400 |
| Trigger card | 500 | 12 | 6000 |
| Master card | 500 | 1 | 500 |
| Mini crate mechanics | 200 | 12 | 2400 |
| Power supply | 1000 | 3 | 3000 |
| Analog/Trigger cables 5m (worst case) | 3 | 500 | 1500 |
| **Network+DAQ** | | | |
| Camera server | 5000 | 1 | 5000 |
| Switches | 1500 | 3 | 4500 |
| Slow control + div. | 10000 | 1 | 10000 |
| Network cables | 3 | 100 | 300 |
| **Camera (w/o Structure, Skin, PMT)** | | | **221520** |
| PMTs, light guides (assume 160+20 EUR/ch.) | 180 | 1764 | 317520 |
| **Camera (w/o Structure, Skin)** | | | **539040** |
| Body + skin + cooling (guess) | 150000 | 1 | 150000 |
| **Camera** | | | **689040** |

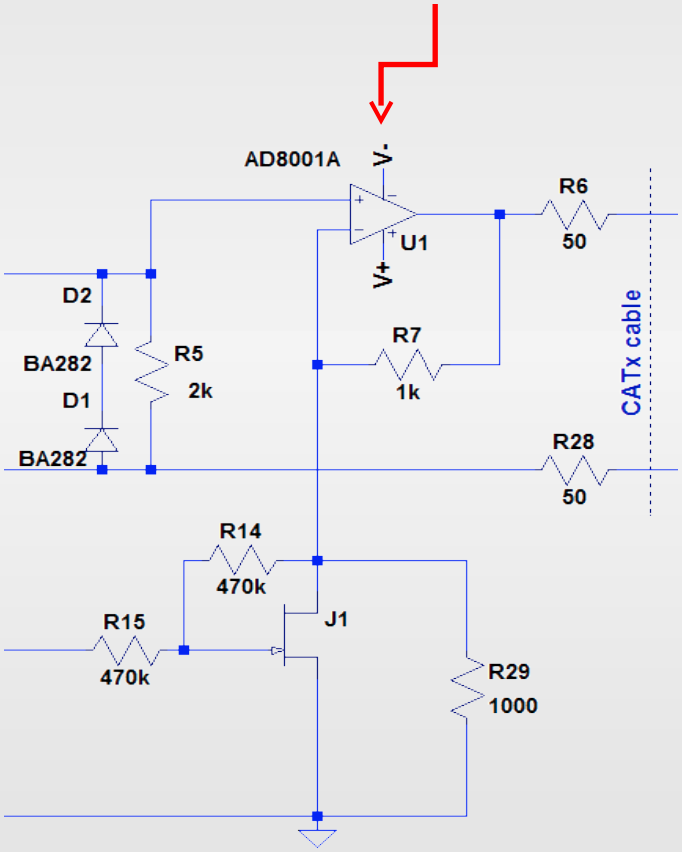
# Conclusions

- 250 MS/s system
  - *Measured* ~0.1PE (rms) ampl. res @100 PE, ~1PE @ 1000PE
  - *Measured* <200 ps timing rms >10PE, <600 ps rms @ 1PE
  - Flexible, programmable trigger, deadtime free
- FlashCam pursuing a complete camera, currently developing an MST prototype.
- Horizontal architecture approach, decoupling DAQ from PDP
- ~2.5 W/pixel, air cooling
- 532 kg camera weight (1764 pix, w/o body, skin)
- € 221520 per camera (w/o body, skin, PMTs)

# Fin.

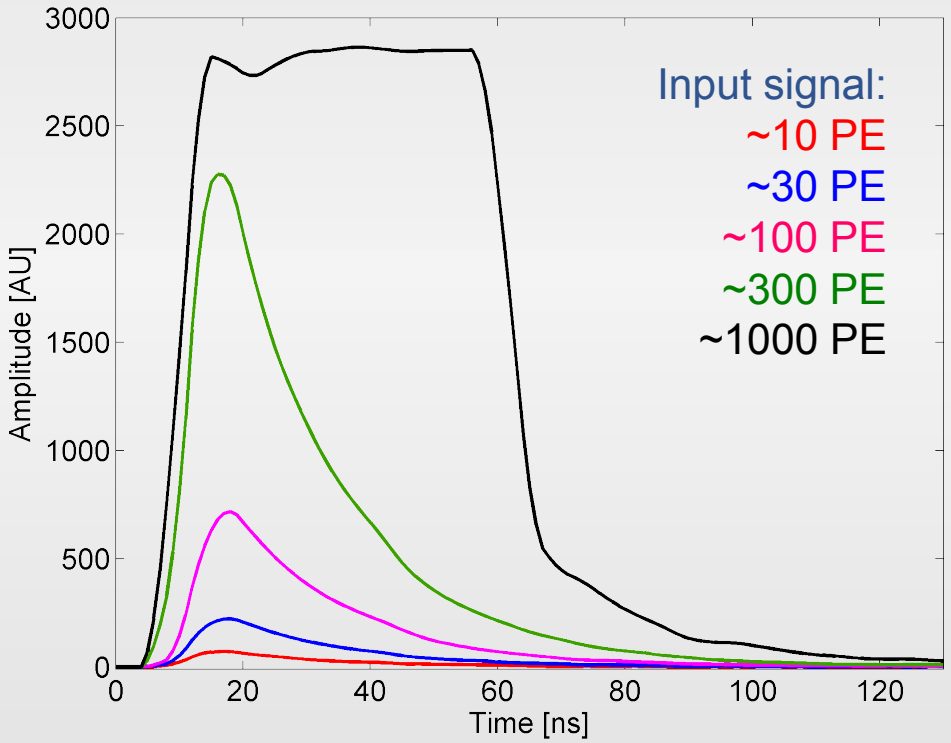
# Non-linear preamplifier with saturation

Saturation is a documented feature




Power consumption ~40 mW / ch

- Saturation sets in at ~400 PE (~ 8 LSB / PE) => signal gets broader
- Long tail due to large input resistor




Measured signals interpolated and smoothed
Resolution 1 ns / step

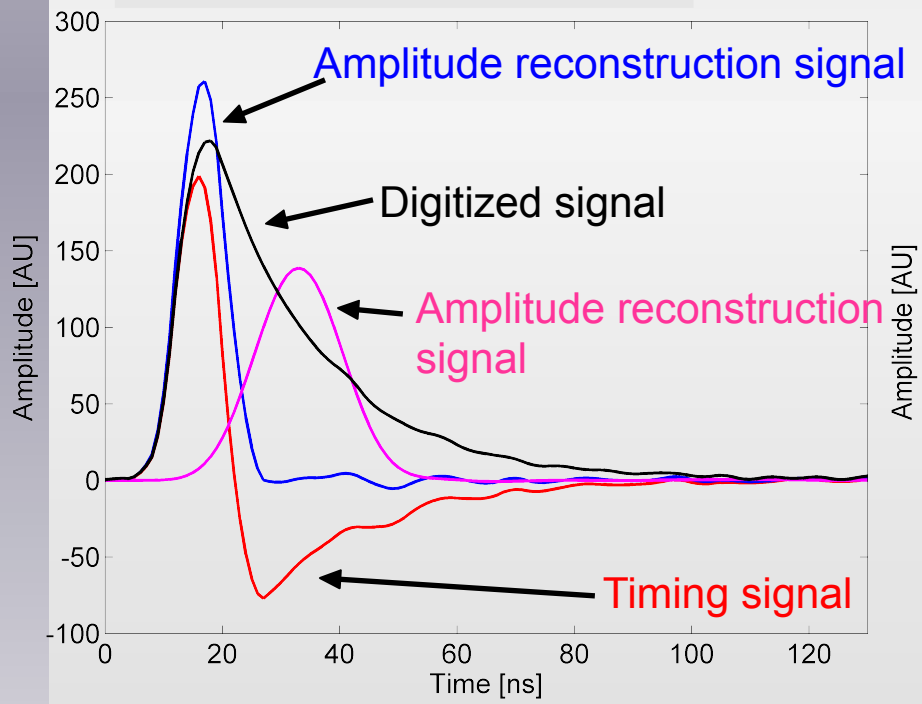
# Preamp and signal processing

- Digitized signal
- Timing signal
- Amplitude signals (10 ns width)
- Amplitude signals (20 ns width)

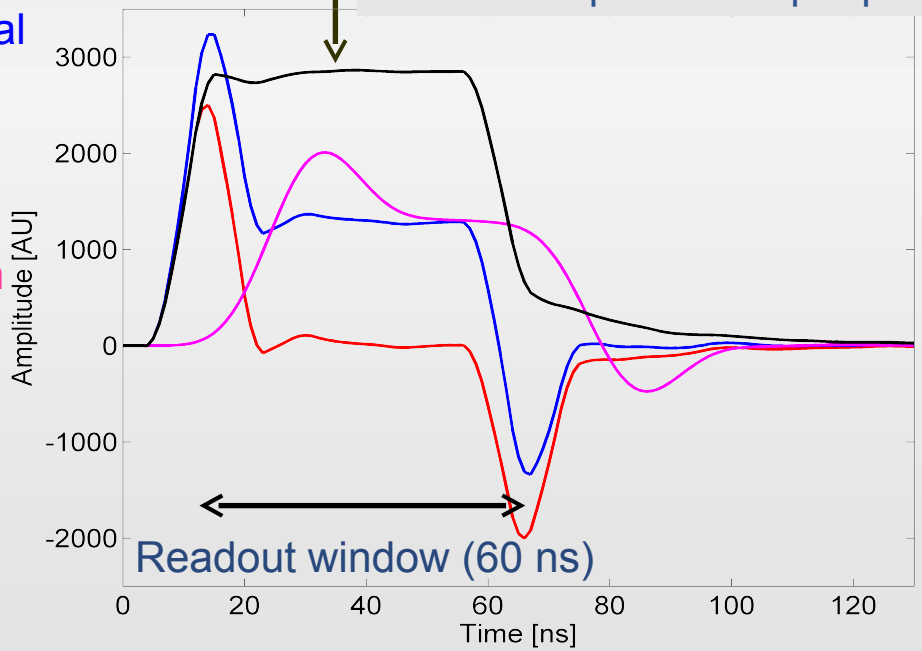
Saturation 'mode':

- Amplitude signals no longer useable
- Integrate digitized signal over 200 ns window in FPGA and subtract baseline for amplitude reconstruction (3000 PE signal is ~120 ns)

30 PE equivalent input pulse




1000 PE equivalent input pulse




*Measured with FlashCam demo board*