An Update on the Timepix2 (It's Finely Here!)

The Principal Acknowledgments

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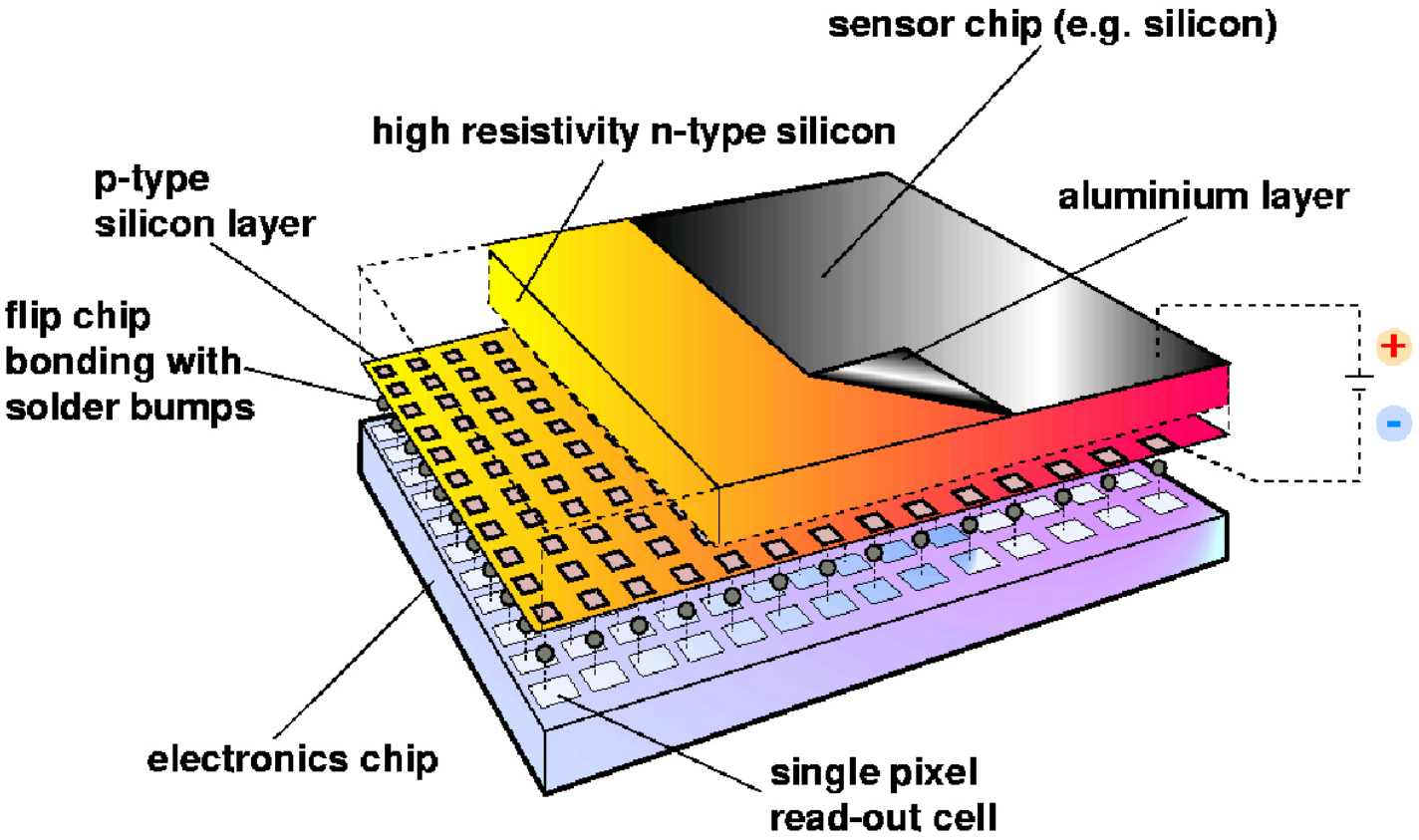
Some Medipix Collaborations Genealogy

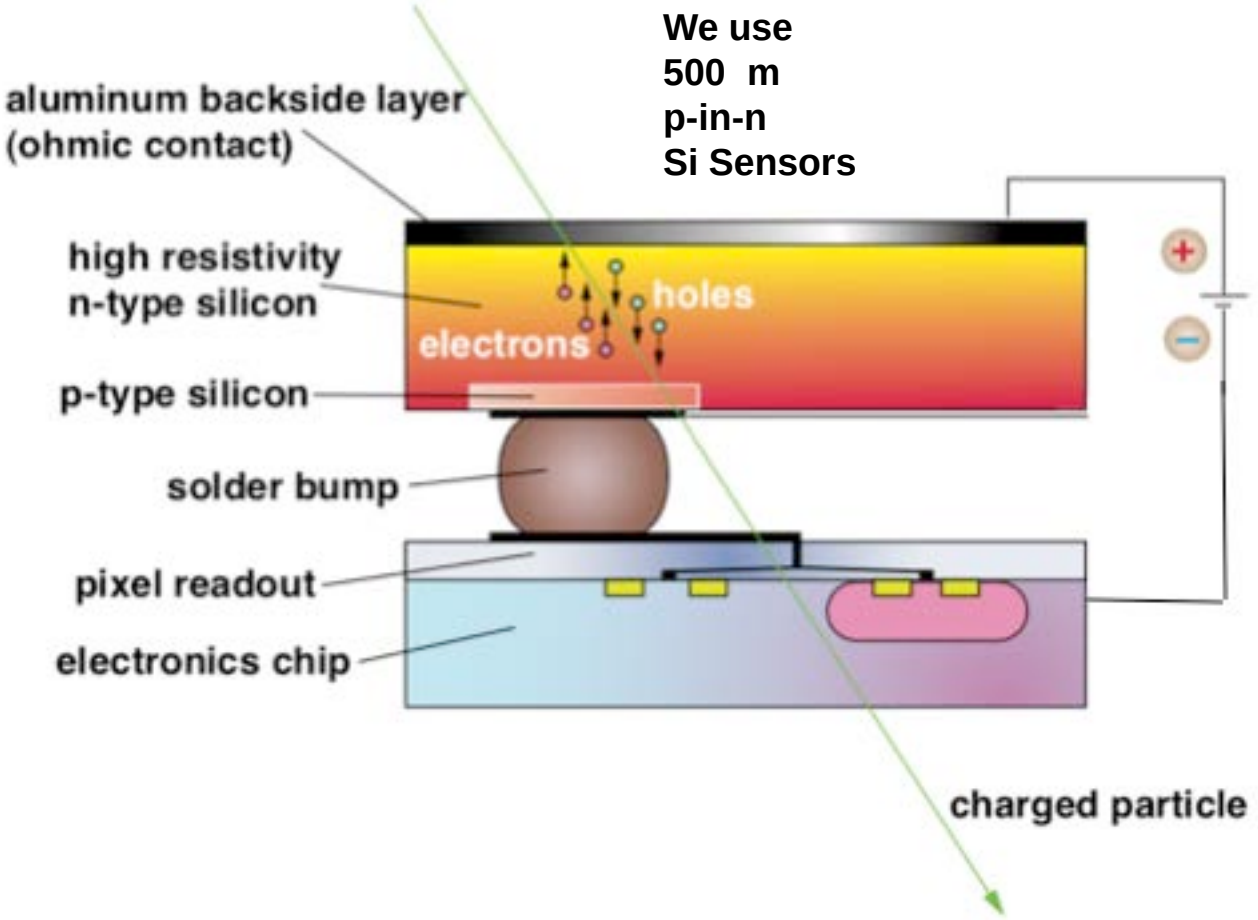
- **Medipix (1)—Formed in the early 1990's and ended with the formation of Medipix2…**
  - Medipix Chip—64 x 64 170 m pixel Photon Counting (PC)
- **Medipix2—Formed in the late 1990's (still active)**
  - Medipix2 MXR—256 x256 55 m 2-Threshold PC Frame (250 nm IBM)
  - Timepix (2006)—256 x256 55 m TOT *or* TOA & PC Frame (250 nm IBM)
  - Timepix2 (2018)—256 x256 55 m TOT+TOA & PC Frame (130 nm TSMC)
- **Medipix3—Formed in 2006 (still active)**
  - Medipix3, Medipix3.1…
  - Medipix3RX (~2012)—256 x256 55 m pixel, Charge Summing PC
  - Timepix3 (2014)—256 x256 55 m pixel TOT+TOA & PC Frame & Data-Driven Readout… (135 nm IBM)
- **Medipix4—Formed in late 2016 (just starting up)**
  - Medipix4 (PC) and Timepix4 (TOT+TOA & PC) Frame & Data Driven (65 nm TSMC) 55 m pixel, but number TBD…

Both the Timepix and Timepix2 are Hybrid Pixel Detectors Using the same Sensors



Detector and electronics readout are optimized separately
Bonding is done with the FlipChip ® process…

Schematic Cross Section of a Hybrid Pixel Detector for Penetrating Charged Particles



Common Digitization Methods

Time-Over-Threshold (TOT)

This is a "Wilkison" type Analog to Digital Convertor (ADC)

A "Pulse-Shaping" circuit regularizes the input current into a pulse whose pulse-height is proportional to the total charge collected over the shaping time.

The input voltage pulse is matched to a Threshold discriminator to output a digital "1" level for the duration of the time that the input is above the Threshold.

The input voltage is discharged by a constant current during which a clock is counted to determine the digital value for the input charge. (Note: the Timepix TOT counts any time the discriminator output is "1" and the frame is open…)

Time-Of-Arrival (TOA)

The discriminator output described in the TOT method above, triggers a counter to begin counting as soon as the digital level changes to "1".

The end of the Frame stops the TOA counters. (A Common Stop Time to Digital Convertor (TDC).

The 100 MHz clock frequency limits the resolution in both Timepix and Timepix2 cases…

How are the Timepix and Timepix2 SIMILAR

- **They have the SAME:**

Pixel footprint (55 m square).

256 x 256 square matrix.

Sensor chips and bump-bonding.

Can be connected to interfaces by wire-bonds (Although some pad placements differ.).

Both use a “Frame-Based” DAQ.

So, what does the Timepix2 ADD?

The Timepix2 has the following additions:

TSMC 130 nm CMOS Technology (Timepix uses GF/IBM 250 nm)

Can be connected to interfaces with "Through Vias."

A 28-bit pseudo-random output register (compared to 14-bits)

Simultaneous TOT *and* TOA mode (compared to TOT *or* TOA)

Employs "Ghost" track rejection.

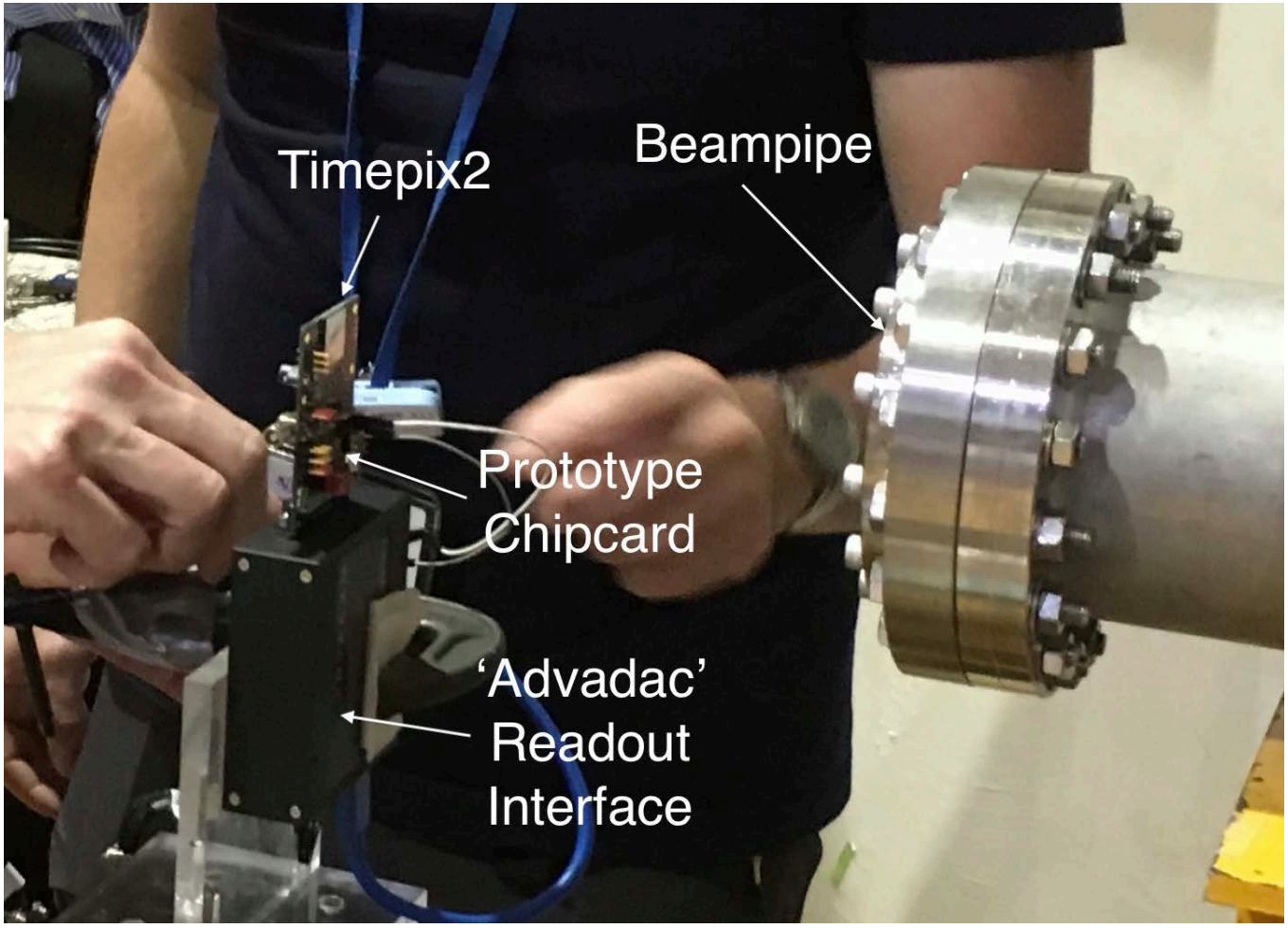
Employs and increased optional Adaptive Gain frontend preamp

Frontend designed to collect "holes."

Has 8 externally accessible "Digital-Pixels."

Direct access to Bias-Voltage "Backside Pulse."

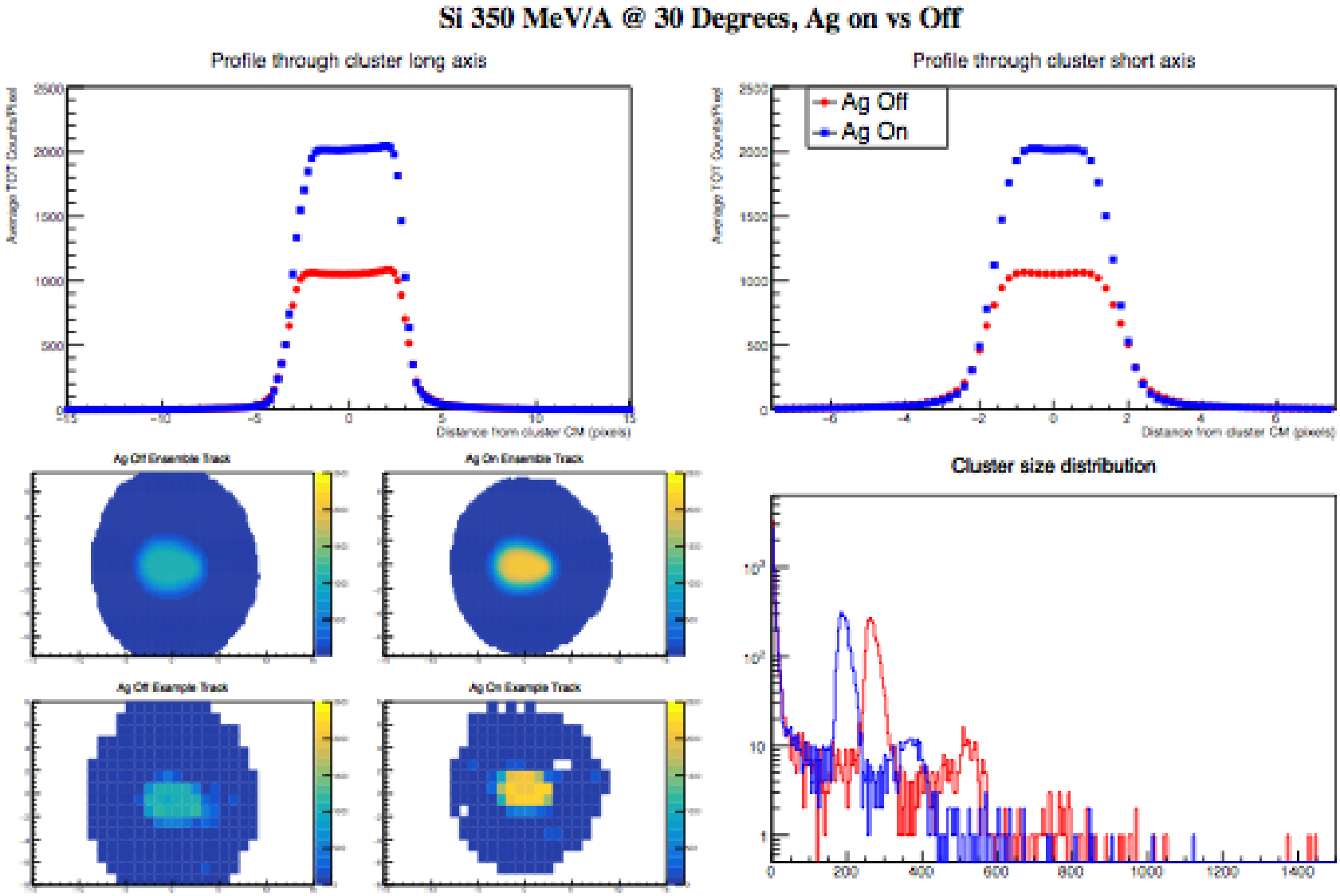
Uses separate readout and digitization clocks


Timepix2
Beampipe
Prototype
Chipcard
'Advadac'
Readout
Interface

Example Data

- Plots show example and ‘average’ clusters.
- Cut on cluster size for primary peak
- Average/ensemble clusters formed by stacking clusters on top of each other aligned by the center of mass (assumption - all clusters within cut are approximately similar’)
- Profile plots show ‘lines’ through average clusters (i.e. not a projection, where columns/rows are summed)
- Timepix2 tested with Adaptive Gain (AG) turned on and off.

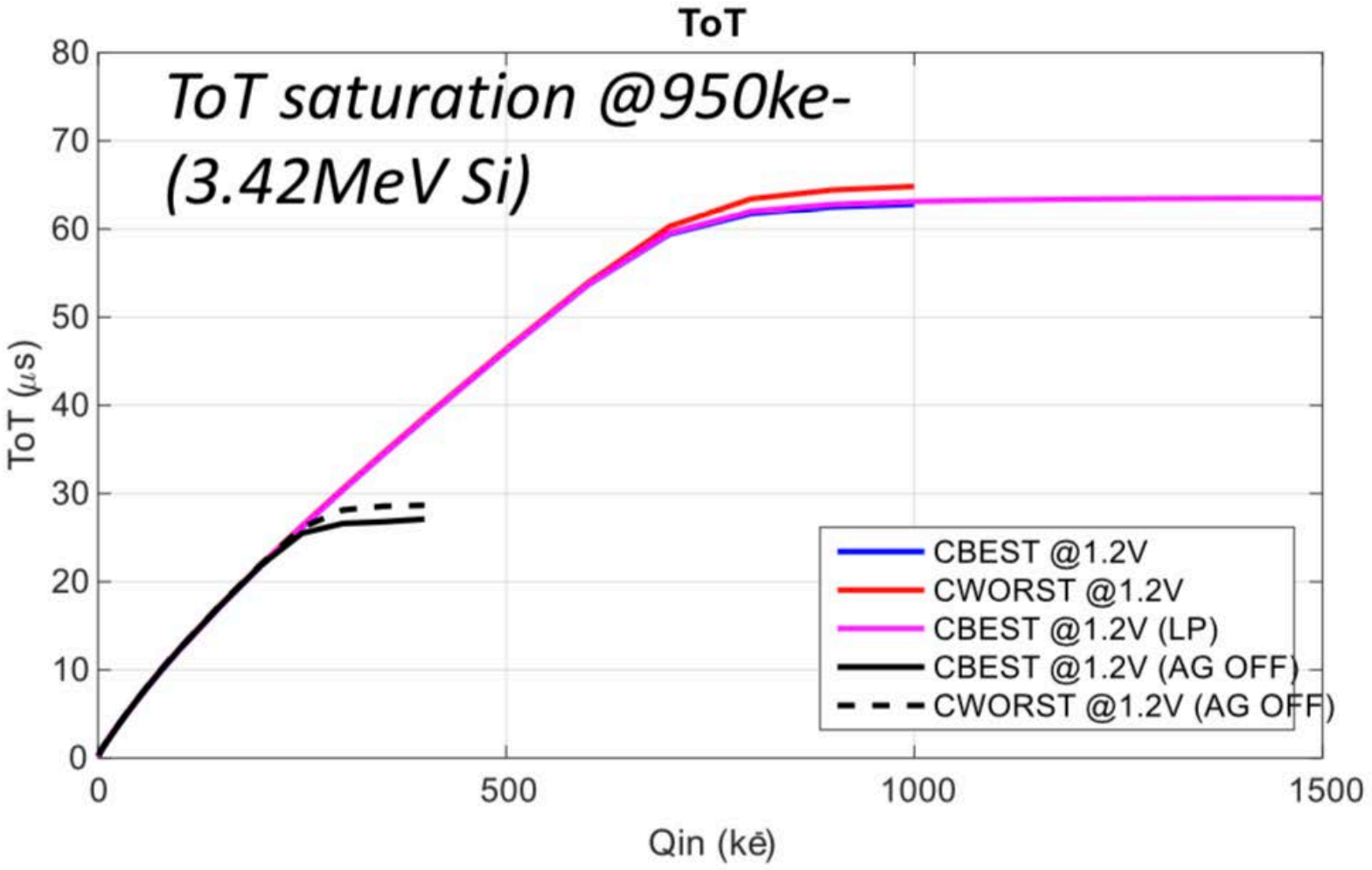
Ag mode max TOT ~2x non Ag mode



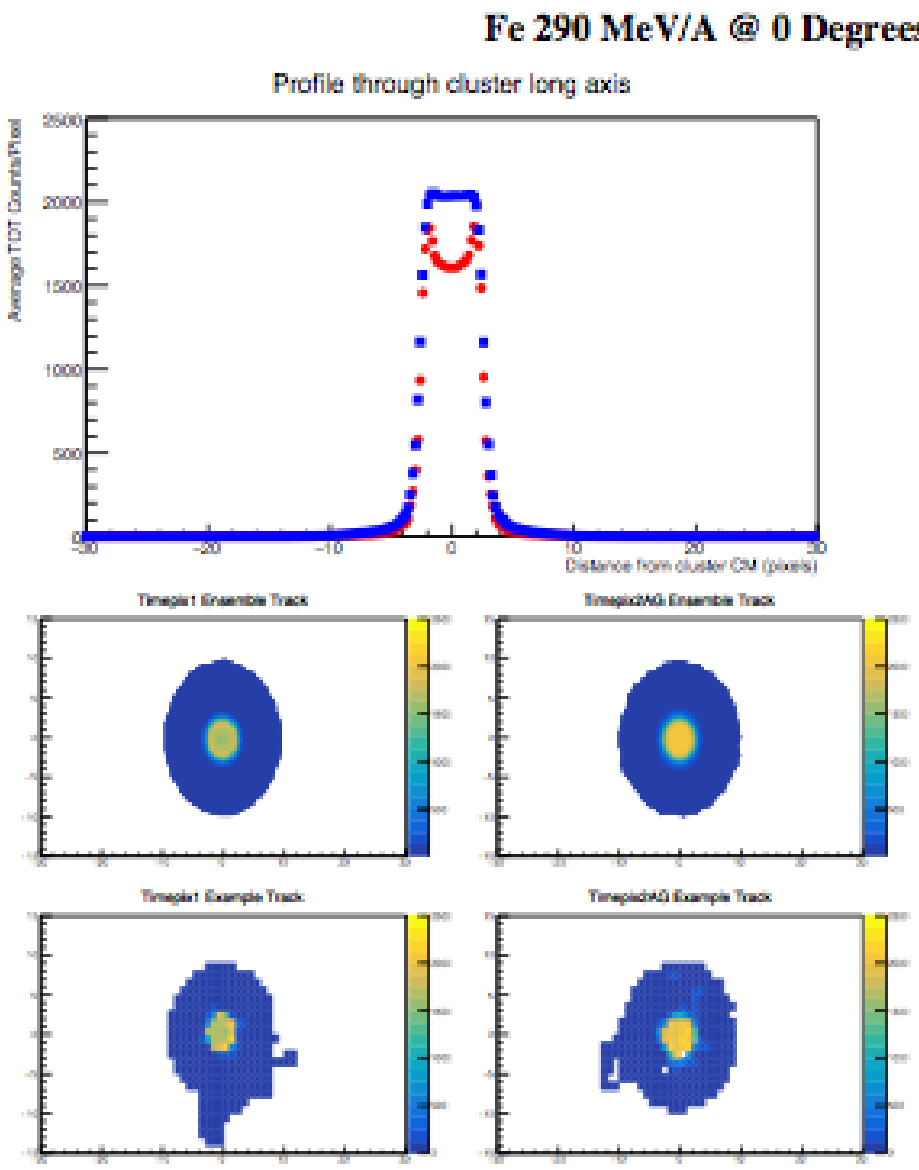
In this case 1.92x (undershoots simulation predictions, generally observed throughout data)

Previous Simulation Results

Note TOT at saturation with AG on is approximately 2x saturation with AG Off

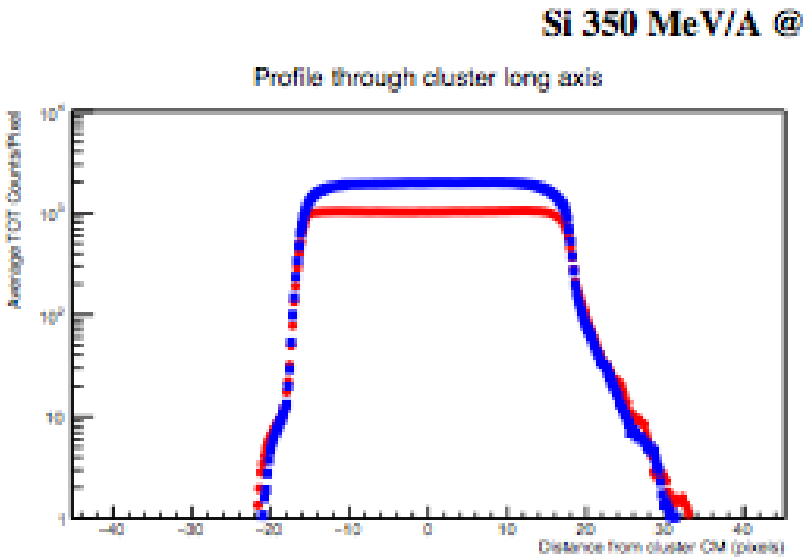


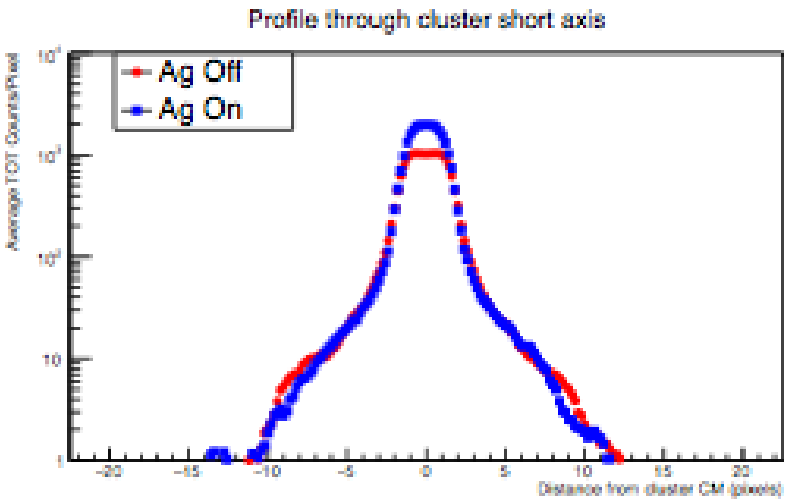
No Volcano (Comparison to TPX 1)

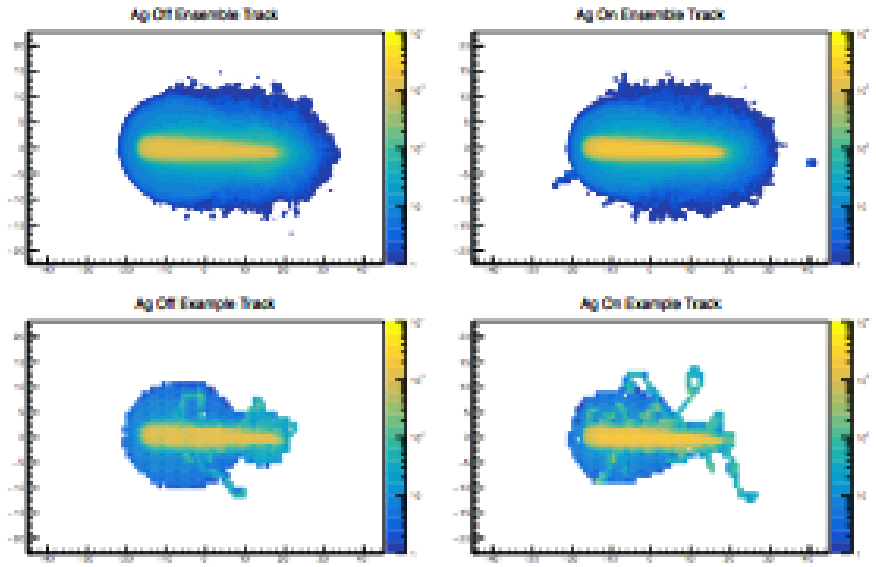


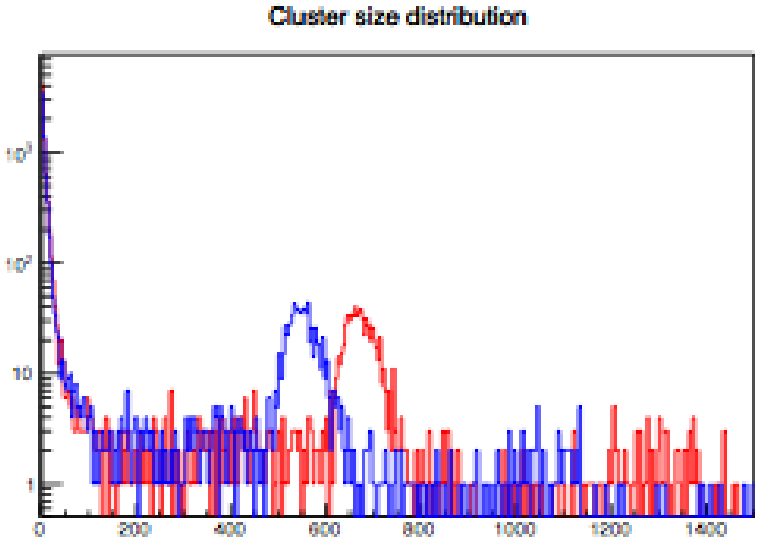
Classic Timepix1 Volcano shown in red, estimated 20+ MeV/pixel in cluster center

Ag mode effects cluster skirt shapes



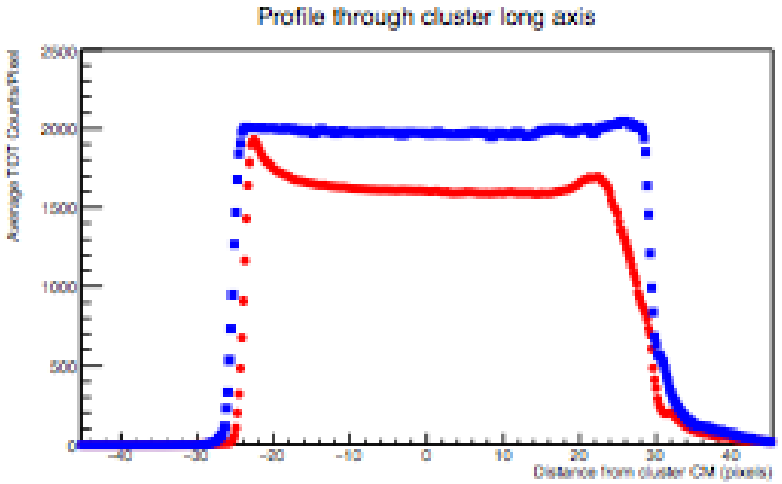


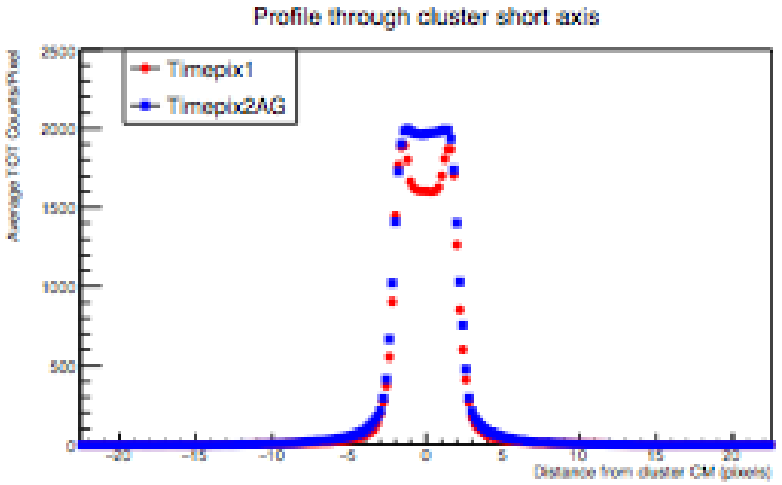


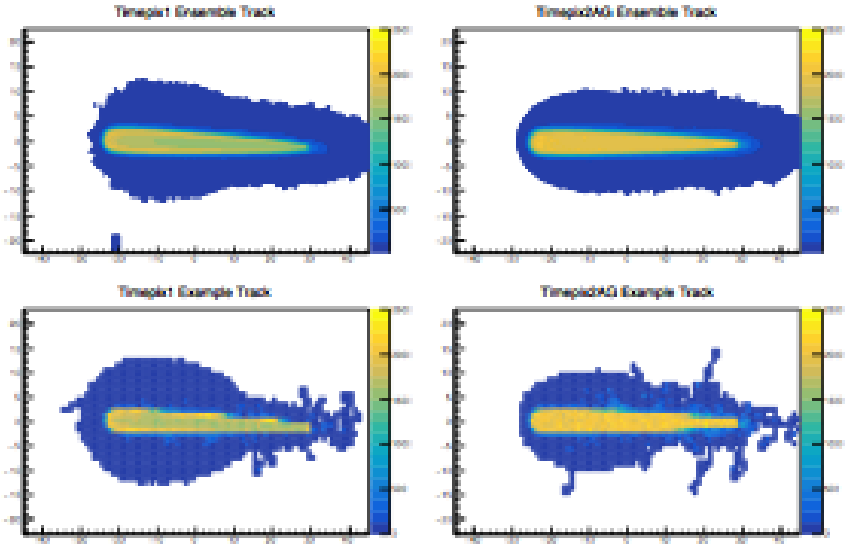


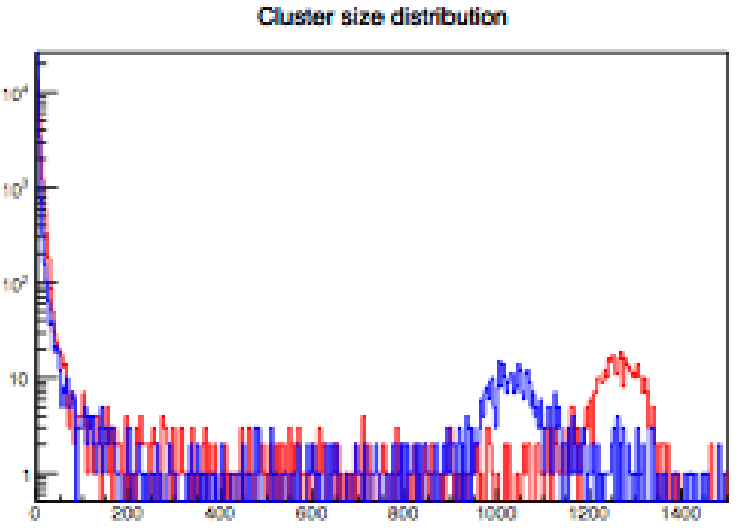
Skirt larger and different shape with Ag off

Fe 290 MeV/A @ 80 Degrees, Comparison to Timepix





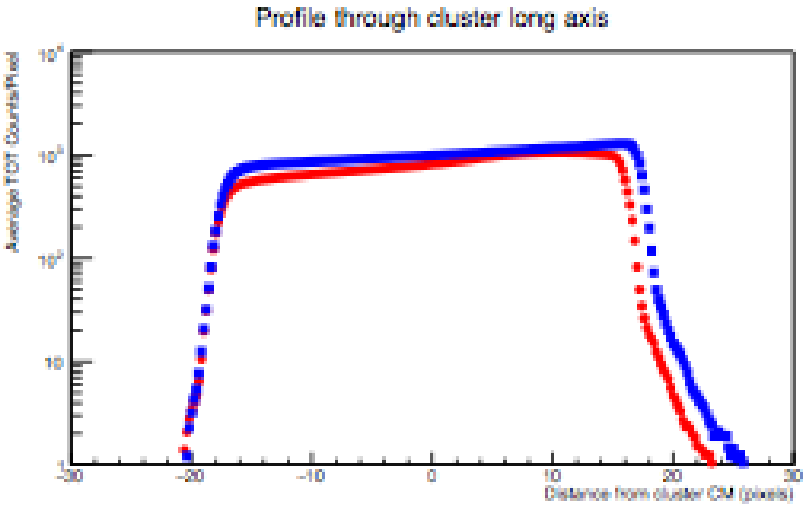


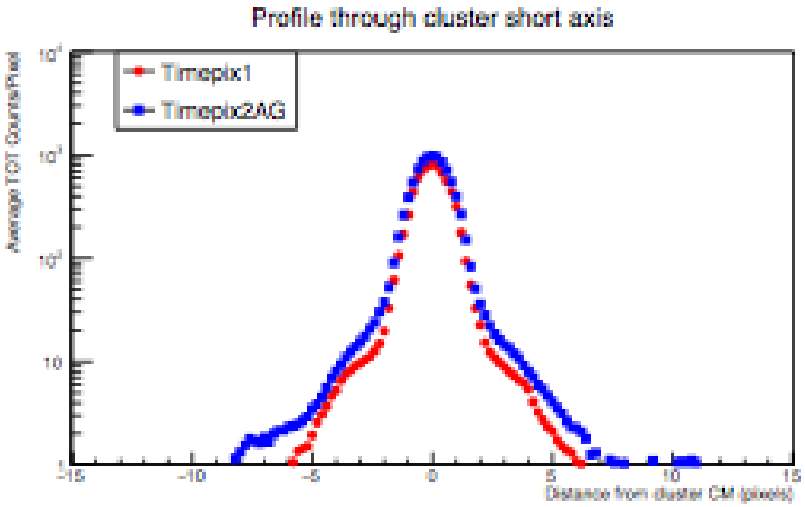


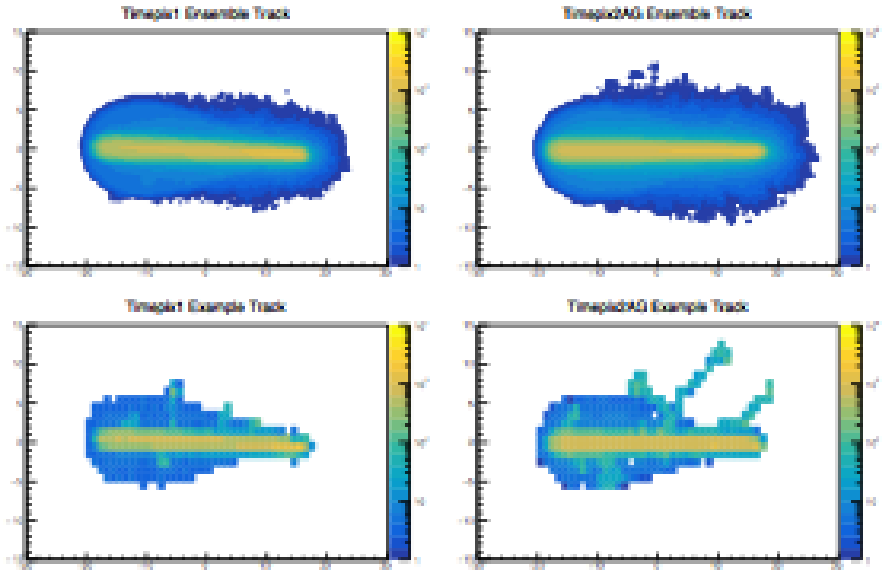
Here when compared to reference Timepix1 skirt is larger

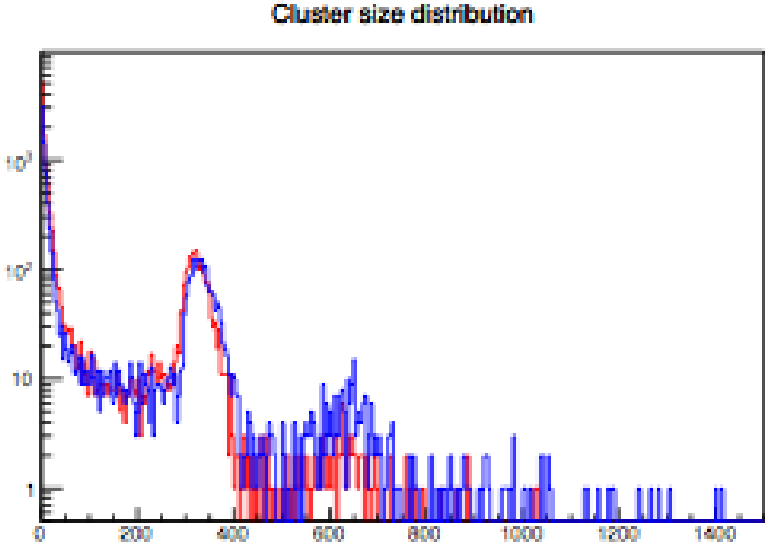
Here when compared to reference Timepix1 skirt is the same size (much lower LET)

N 430 MeV/A @ 75 Degrees, Comparison to Timepix







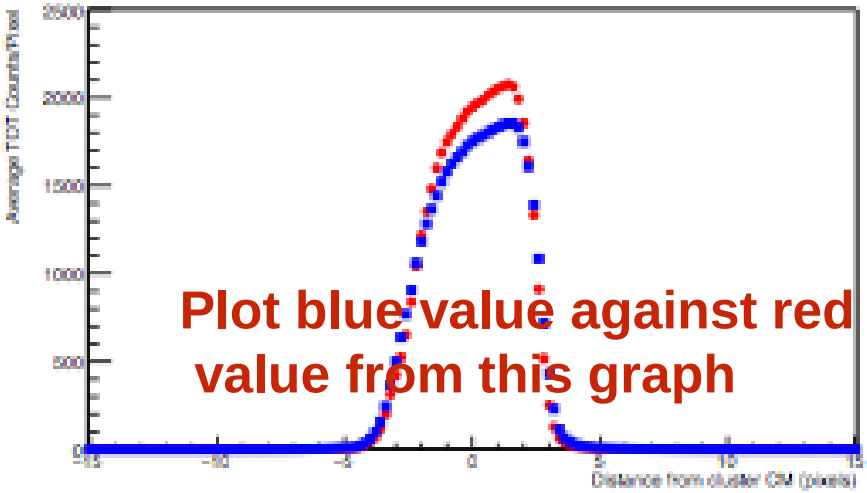


Comparison of front end to Timepix1

- Tested Timepix and Timepix2 both had 500um sensors at 100V.
- In principal average clusters should be directly comparable.
- Can test Timepix2 by comparing to the ADC counts to the calibrated Timepix energy at the same cluster position…

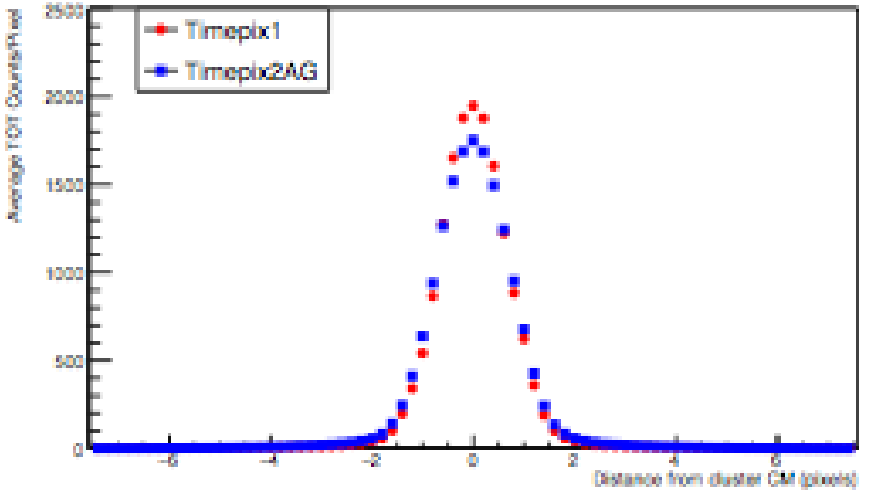
N 430 MeV/A @ 30 Degrees, Comparison to Timepix

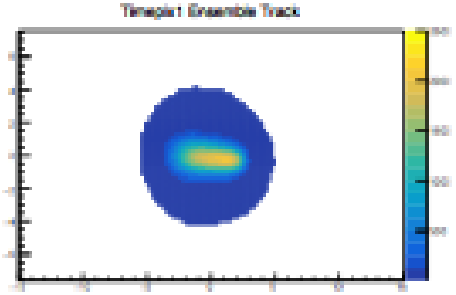
Profile through cluster long axis

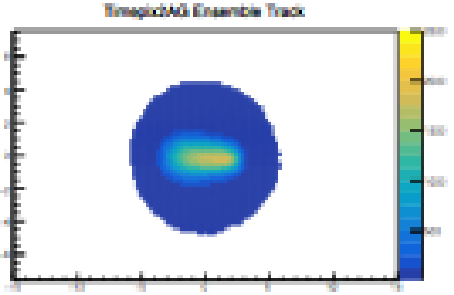


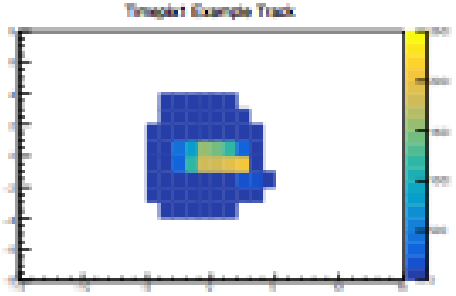
Plot blue value against red value from this graph

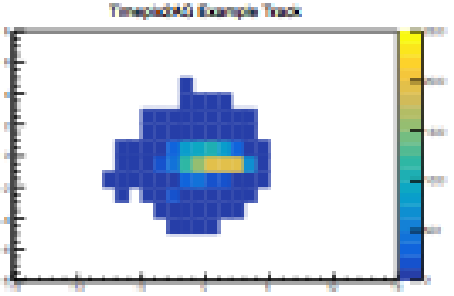
Profile through cluster short axis



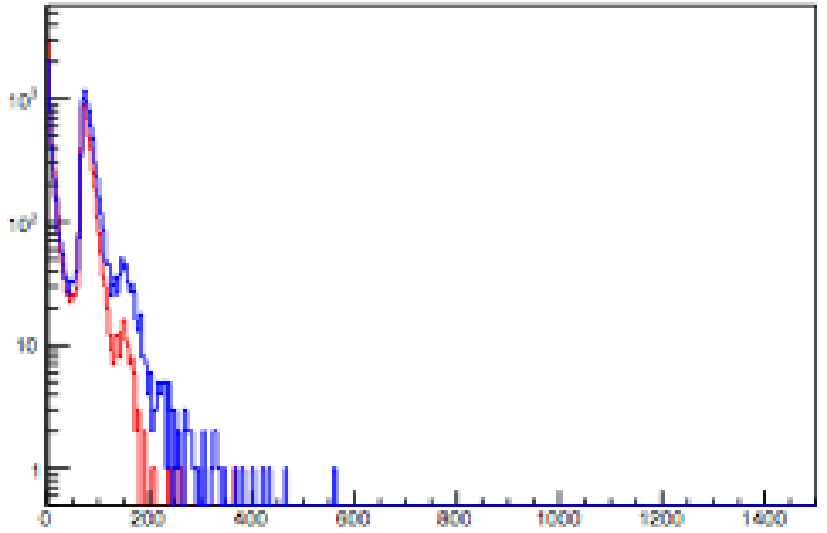








Cluster size distribution



Photon calibration:

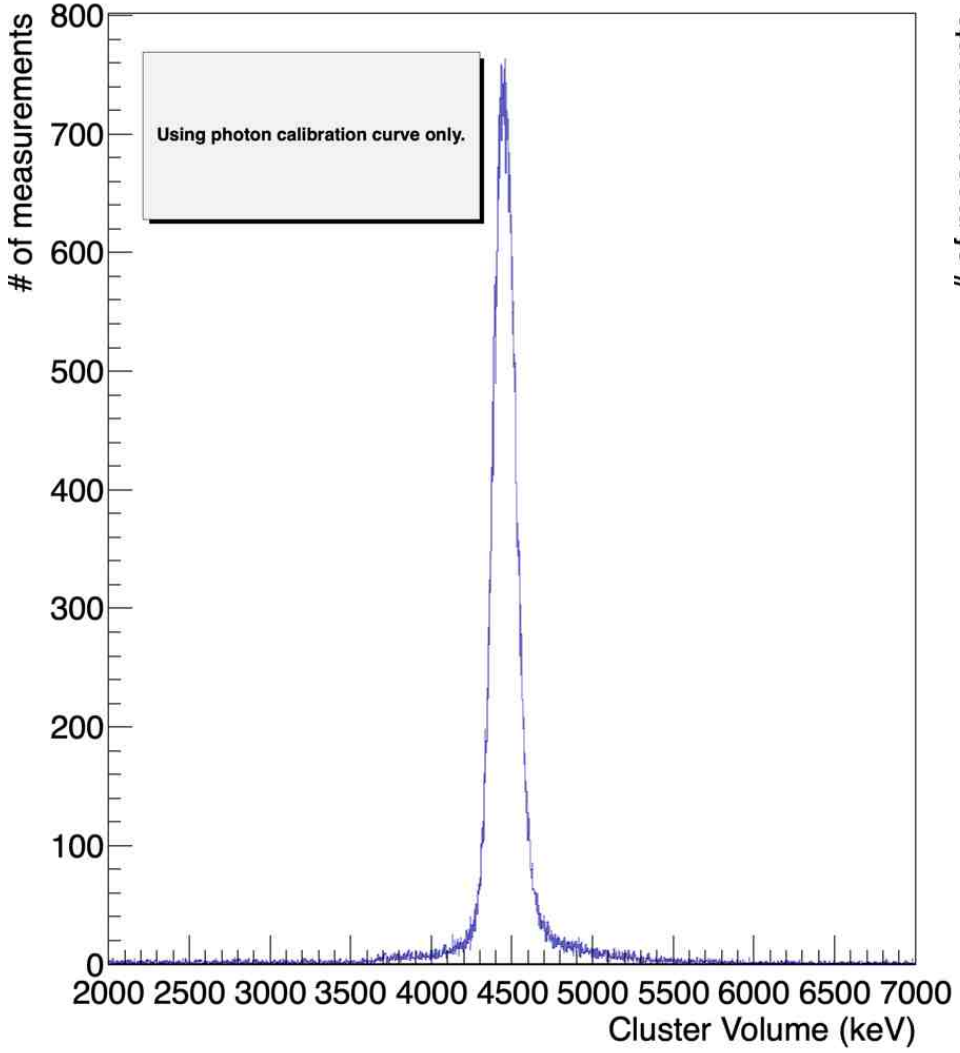
where is time over threshold,

and is energy,

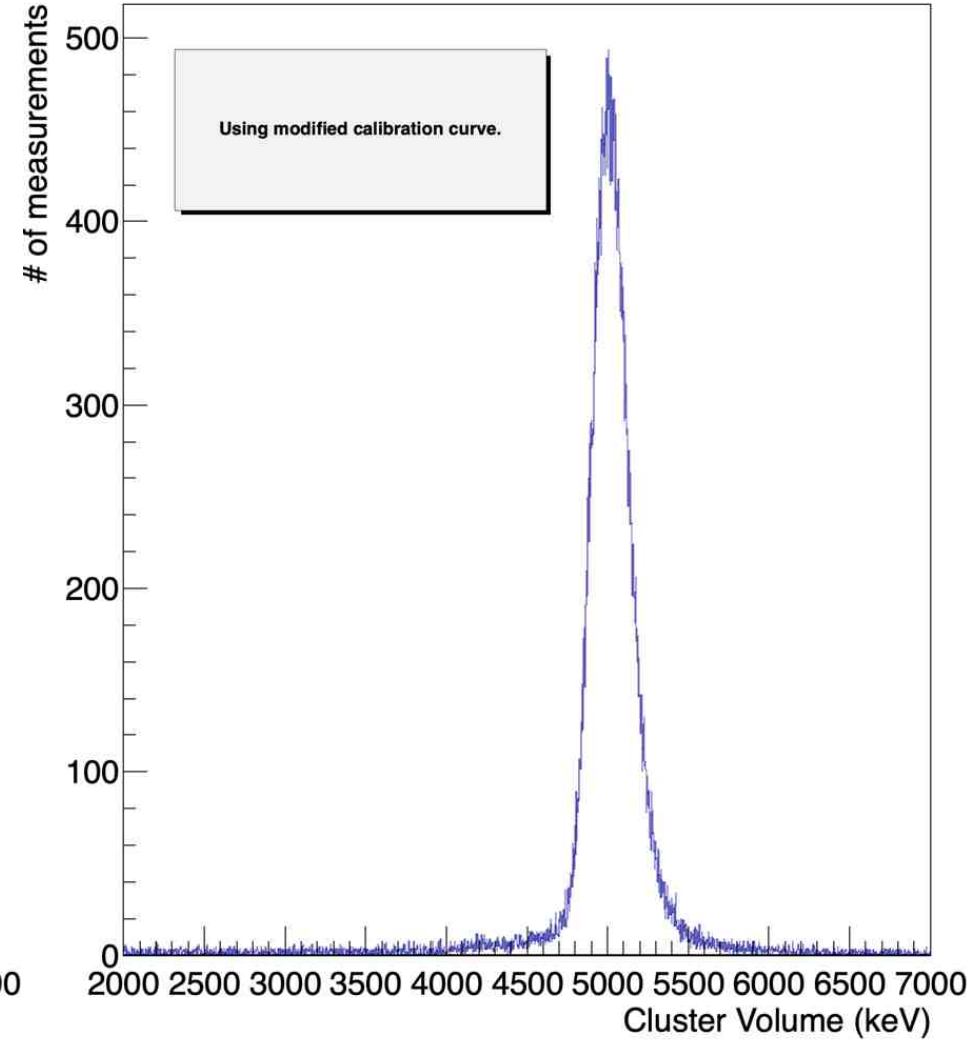
becomes inaccurate above ~100 keV.

Pixel behavior is still unclear above ~1400 keV.

Cluster Volume 5 MeV Hydrogen at 60° polar angle

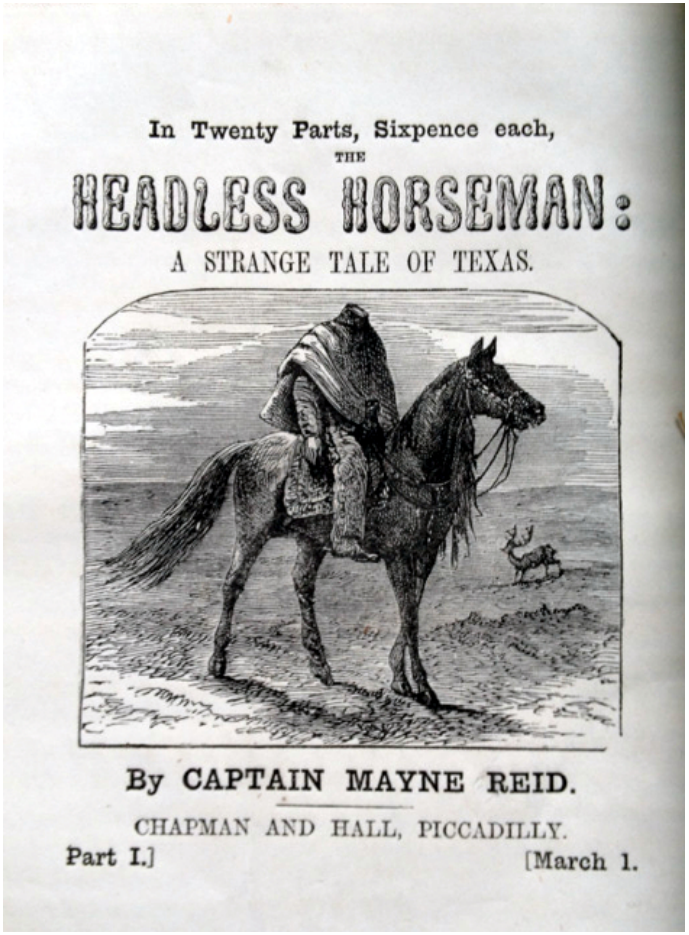


Cluster Volume 5 MeV Hydrogen at 60° polar angle



Ghost Tracks

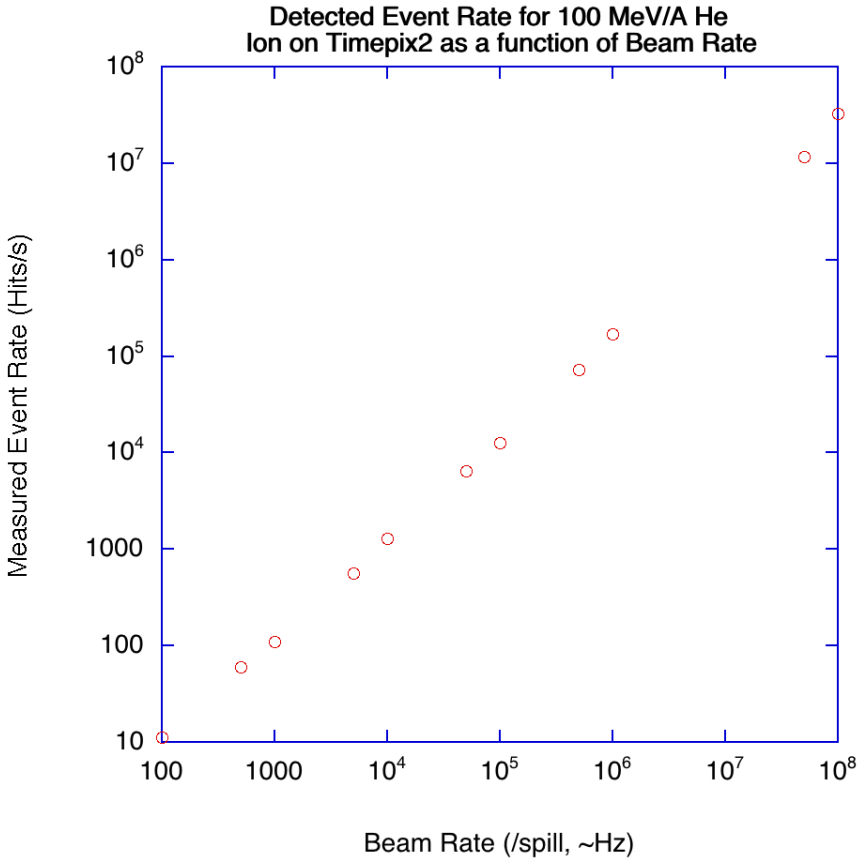
- "Ghost tracks" occur when the shutter overlaps a high TOT signal. This either cuts off the TOT signal prematurely, or counts ongoing TOT inputs due to events occuring just prior to the Frame opening
- Gives the cluster a 'decapitated' appearance, and results in incorrect measurement of TOT.
- For ISS, with lots of stopping protons effectively limits the minimum frame time to 10 mS, and the rate in an isotropic field to a few kHz depending on how many overlaps are acceptable.
- Timepix2 has special logic to stop this problem occurring. In principal this means we can now exploit one of the principal advantages of pixels - their high rate capabilities!

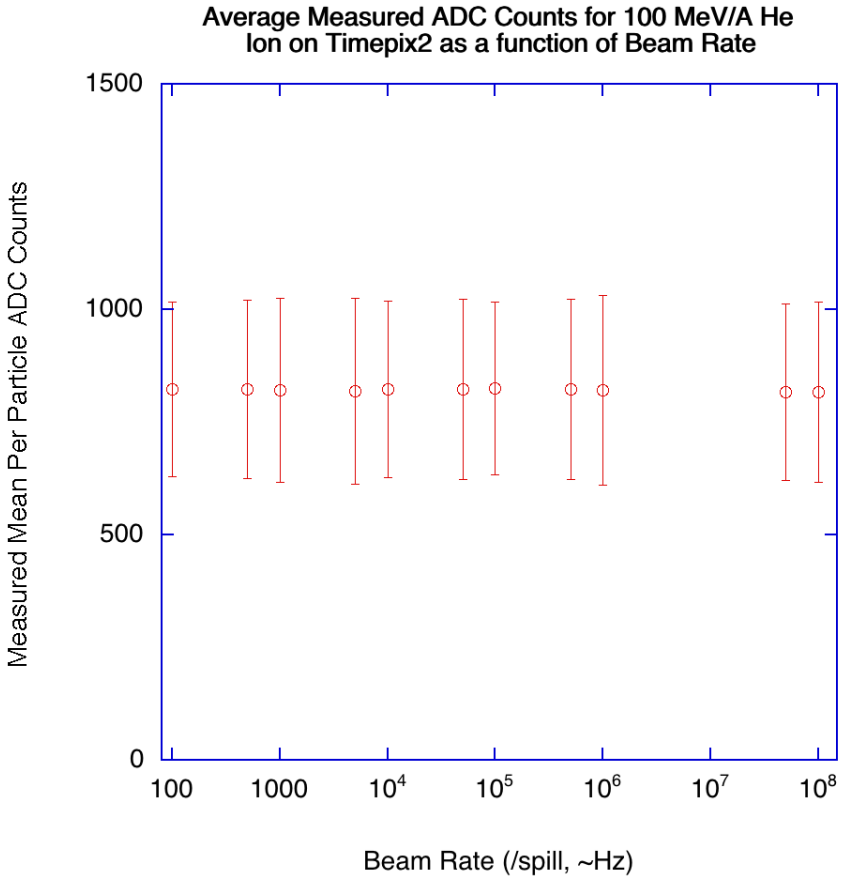


Timepix2 Olympics @ HIMAC

- Previous testing with a Neon beam measuring very short frame lengths has indicated that the ‘ghost track’ suppression logic works. At the most recent HIMAC run we decided to exercise the Timepix2 under high particle fluxes.
- Beam starting at 100 particles per spill (PPS). Measured up to 1E8 PPS. Timepix2 measurement does not exactly correspond to this, as some particles miss Timepix2.
- Frame length set to measure single clusters (0.1 s at 100 PPS) and then scaled down proportional to the PPS.
- So at 1E8 PPS we had a 100 nS frame length (it was not clear if the Advadac readout system would handle frame lengths this short correctly, but no problems were observed)

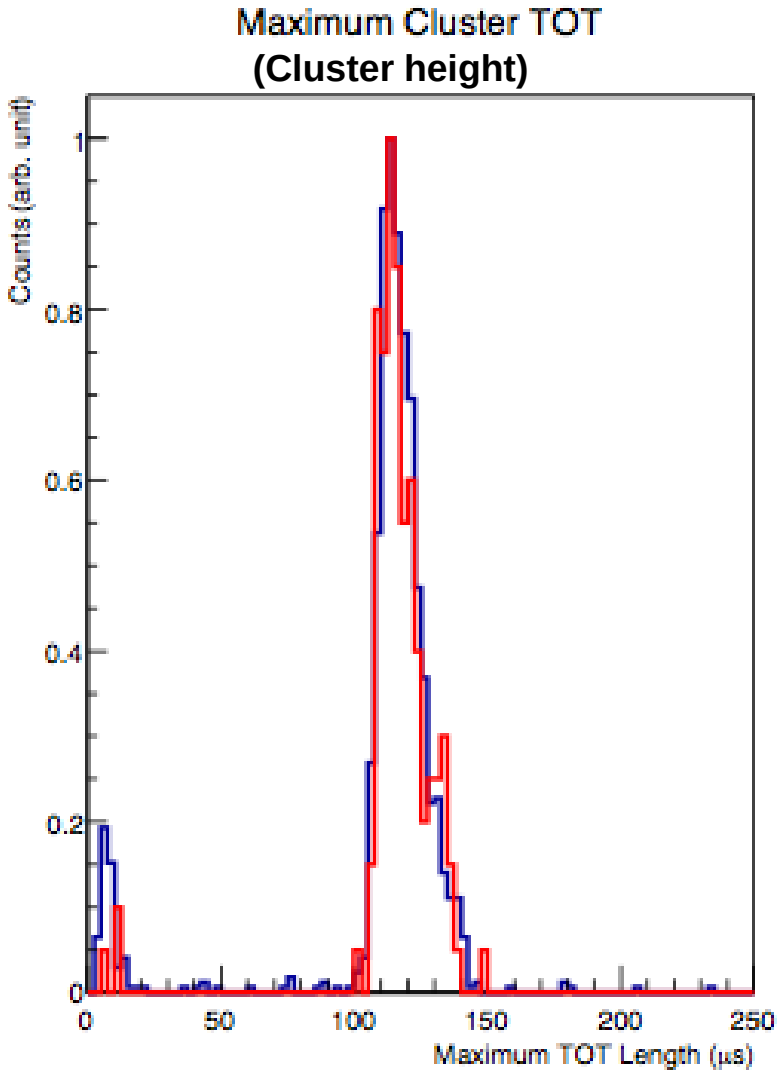
Results

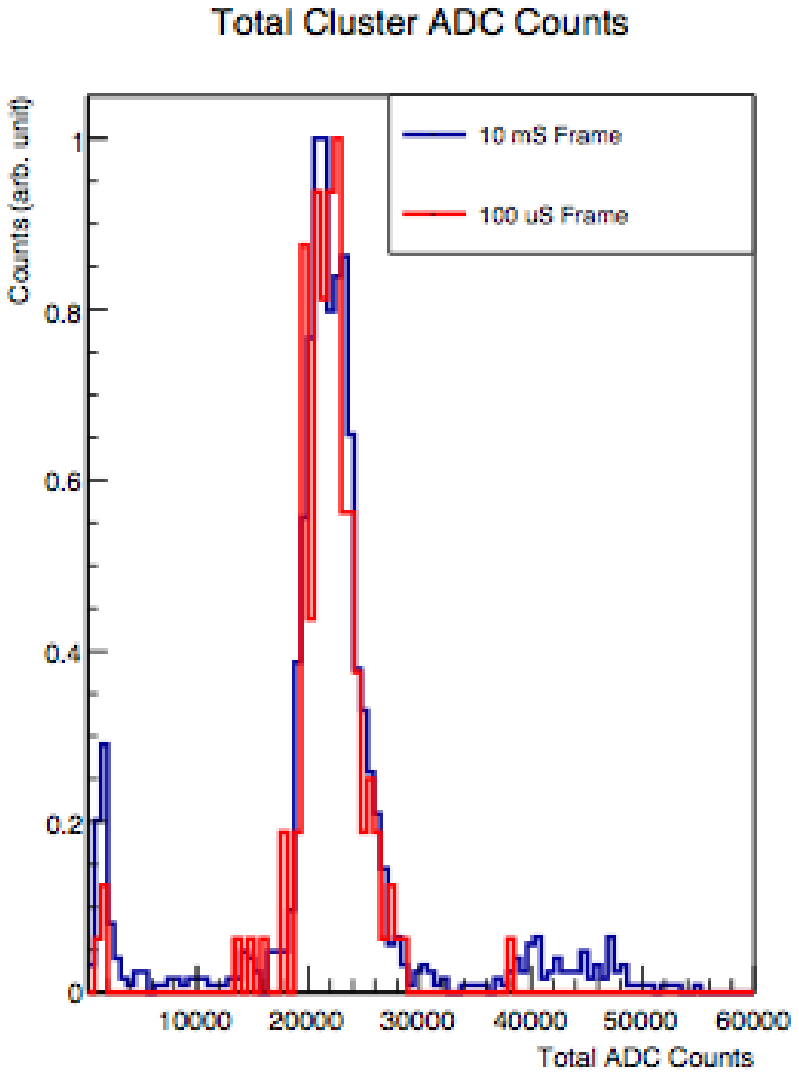




Error bar shows beam FWHM of beam

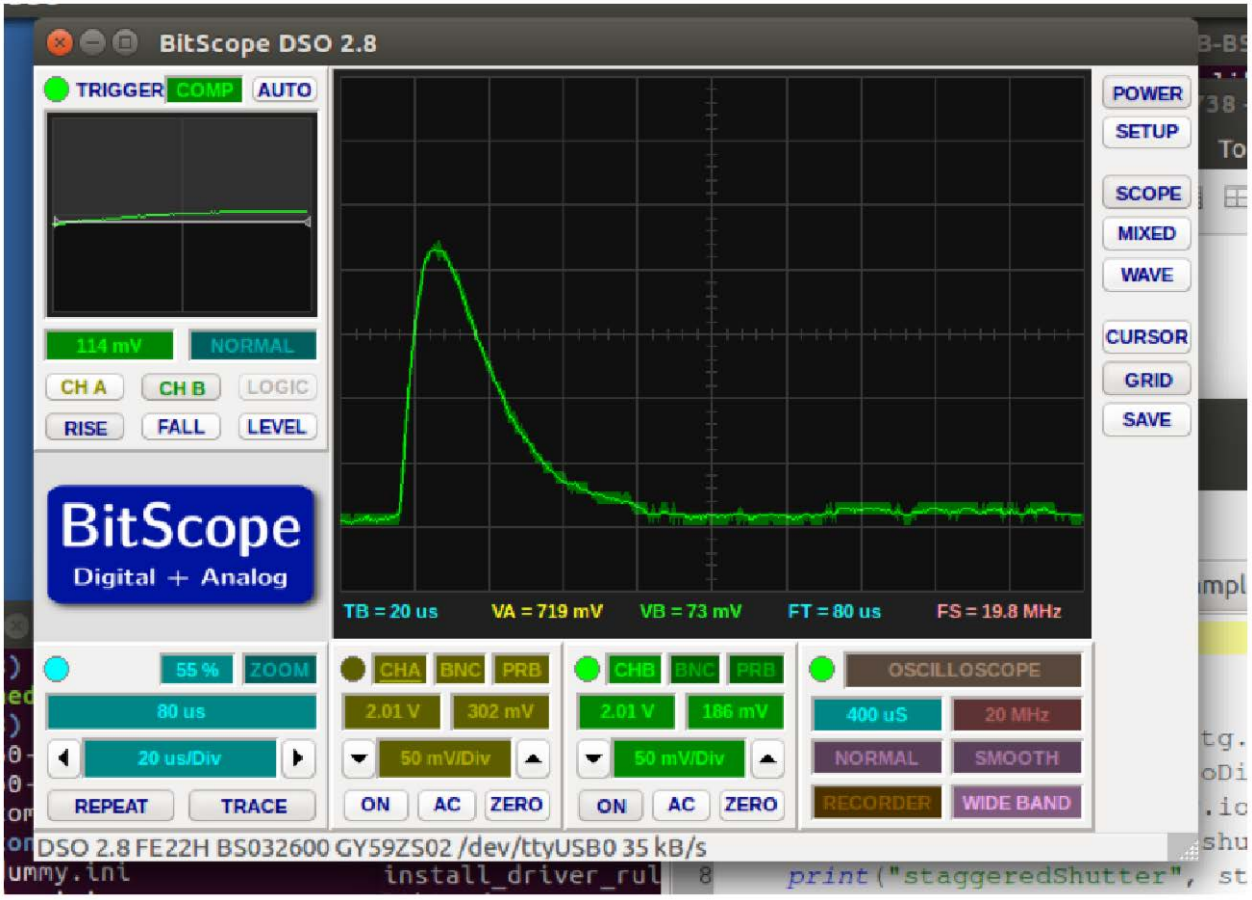
Ghost-Track Supression





350 MeV/A Si 28 beam
Timepix2 performs well for very short frame lengths

Backside Pulse Observed With a Scope at HIMAC

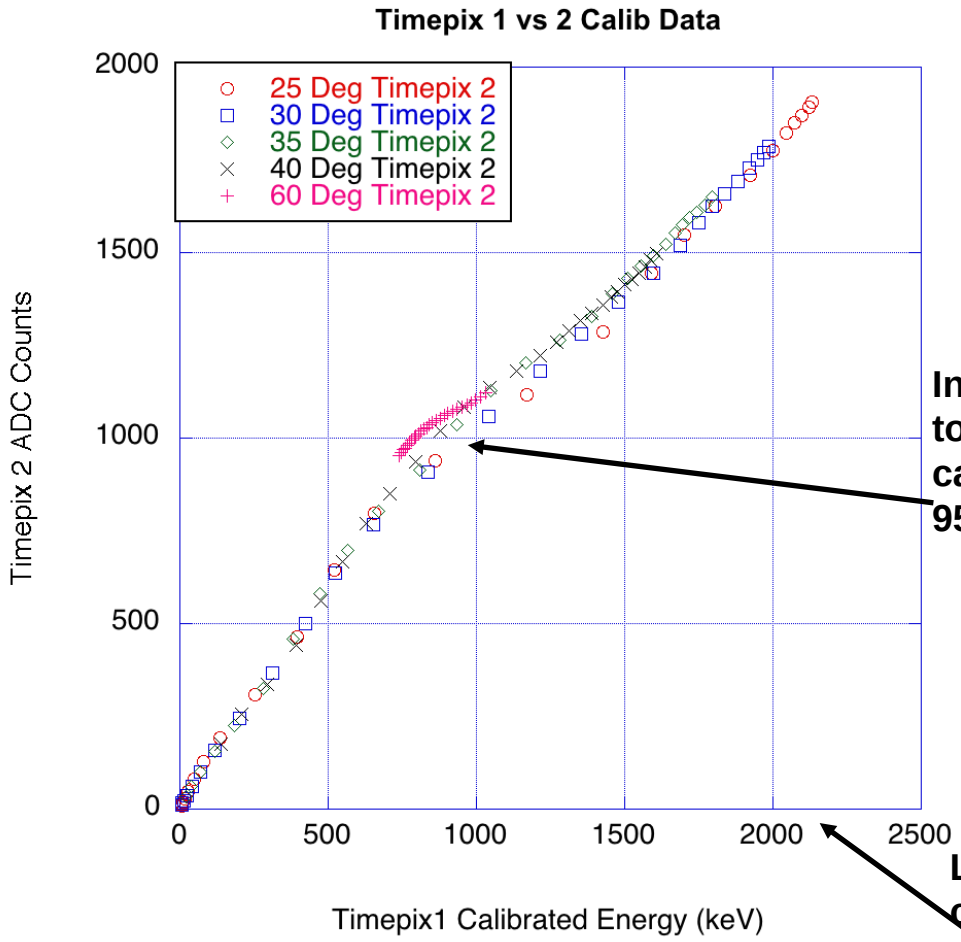


Backside pulse could probably be a bit more sensitive, signal was barely above noise for 100 MeV Ne strike at 0 degrees incident angle. Desired range is about 7 M electrons to about 300 M electron (higher would be nice!) *S. George*

Continuing Efforts

- Harnessing the *Backside Pulse* using one of more of the Digital Pixels to allow reasonable estimate of very high LET events
- Devising an economical *Calibration* routine for the Adaptive-Gain frontend.
- Settling on an optimal set of Operational *DAC values* and *supply voltage* (VDD & VDDA) for the 130 nm CMOS frontend.

Questions…?



ADC counts (not calibrated)

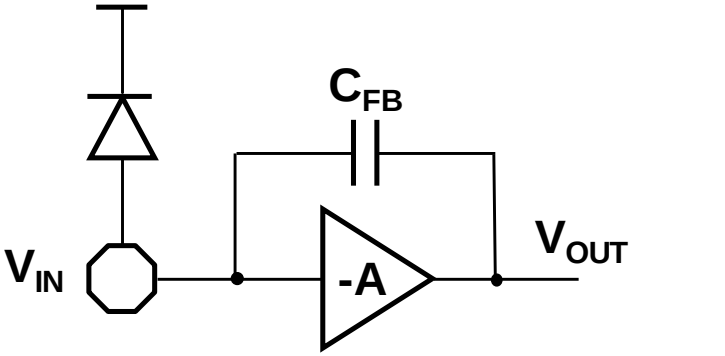
Inflection point may be due to Timepix 'advanced' calibration which starts at 950 keV for this assembly

Limit of Timepix 1 calibration/start of volcano (2.2 MeV)

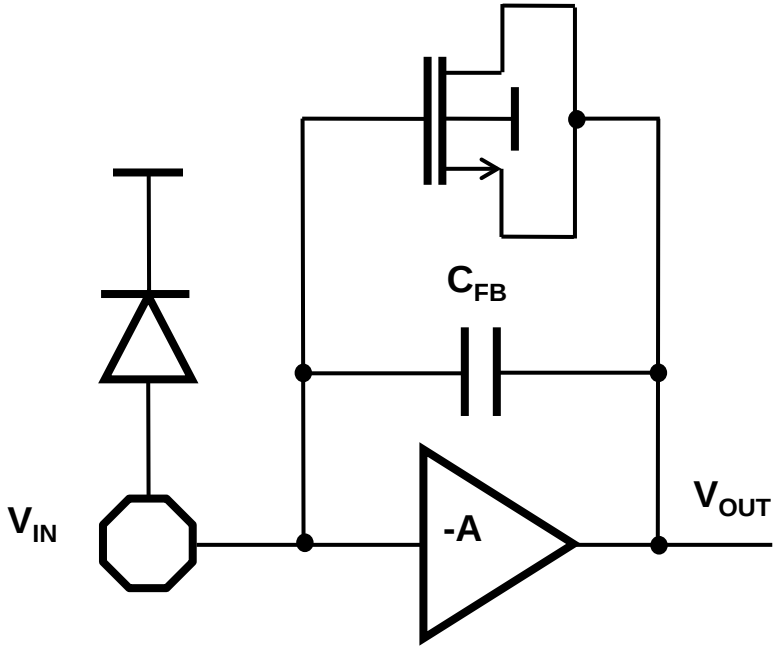
Different markers show different polar angles

Tpx2 appears to measure monotonically up to at least 2 MeV

Voltage-dependent feedback capacitance

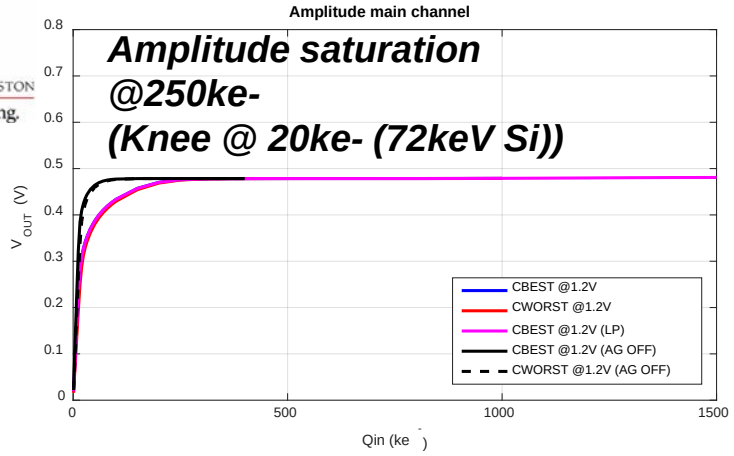


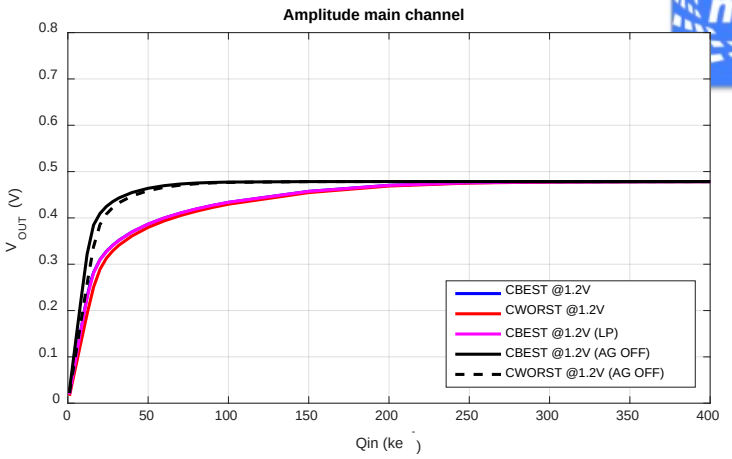
$$\frac{1}{\quad\quad}$$

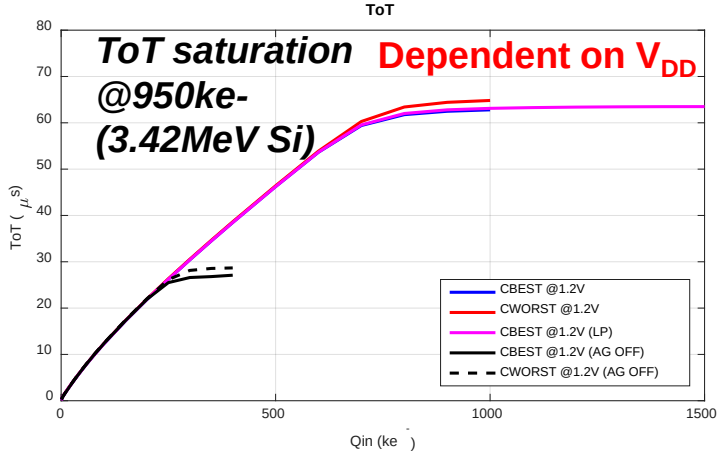


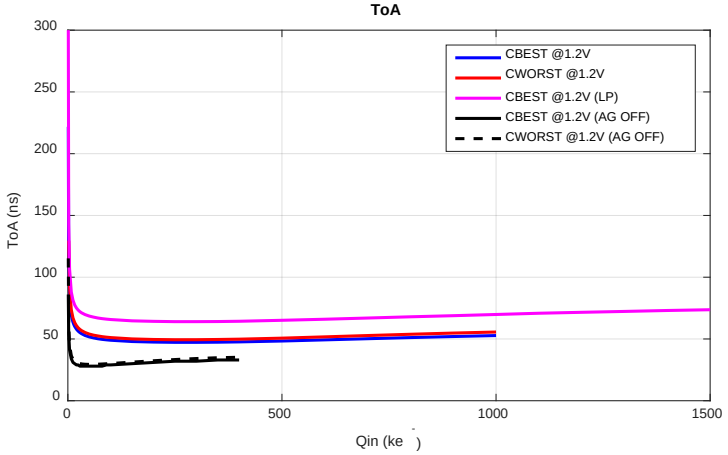
When the transistor is active, the feedback capacitance is ~125fF (Dimensions transistor 1/10)

M. Manghisoni et al. "Dynamic Compression of the Signal in a Charge Sensitive Amplifier: from Concept to Design" IEEE Trans. Nucl. Sci. Vol. 62, No. 5, 2015





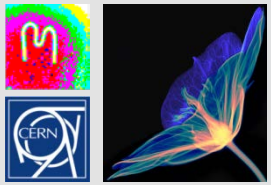




Amplitude, ToT and ToA for the front end with adaptive gain ON, front end power supply 1.2V

(a low power mode for the discriminator is also considered and has an impact on the ToA (discriminator propagation delay))

(Gain: ~20mV/ke- (CBEST), ~16mV/ke- (CWORST))

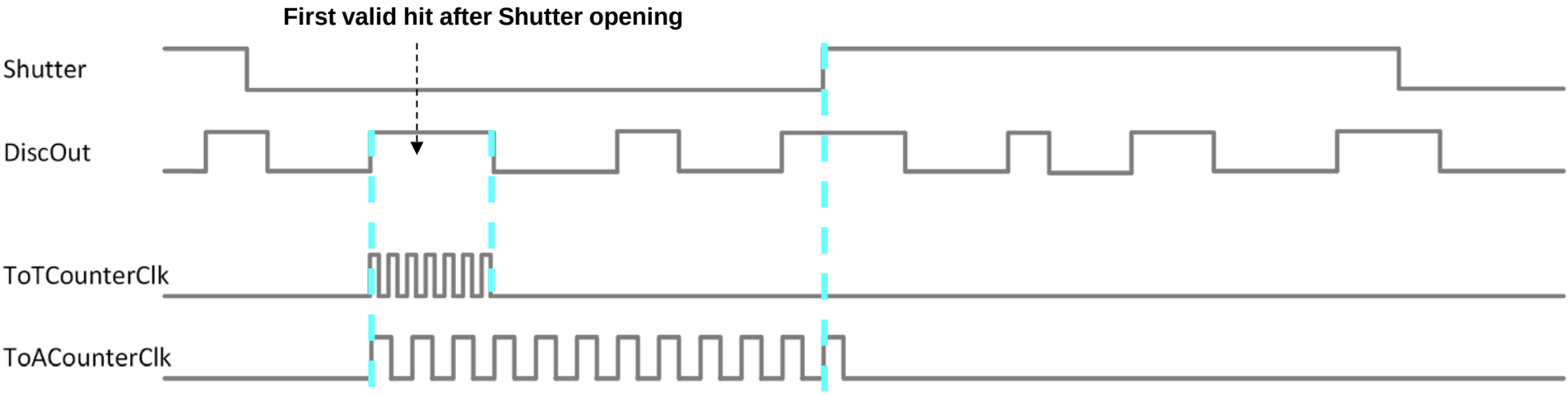


Pixel Digital Operating Modes

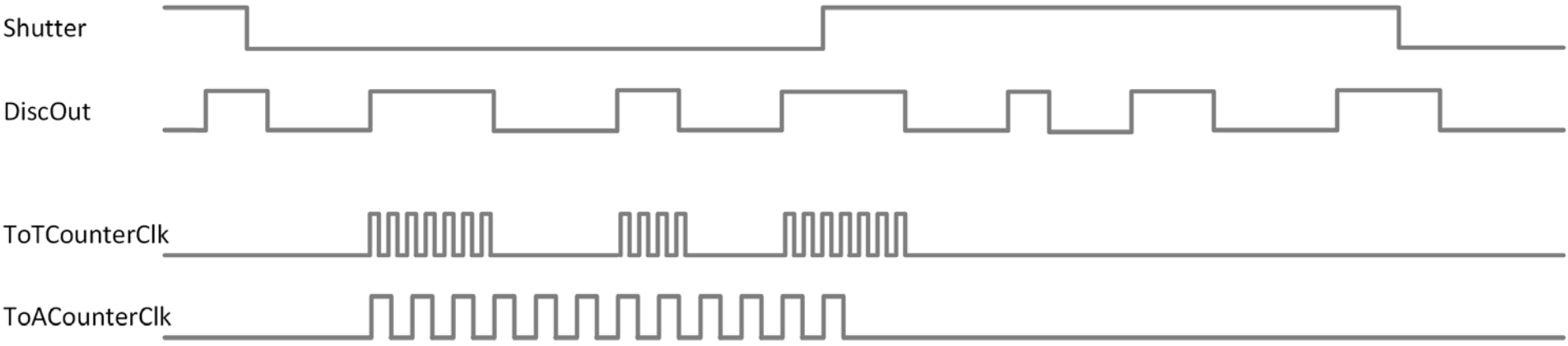
28 bits/pixel:
2 x 4b chains
2 x 10b chains

Mode Name	Description	1st Counter	2nd Counter
ToT10/ToA18	Simultaneous ToT and 1st hit ToA* Mode options (programmable): 1) 1st hit or integral ToT 2) Overflow (wraparound) of ToA counter	10-bit ToT	18-bit ToA
ToT14/ToA14		14-bit ToT	14-bit ToA
ContToT10/Event4	Continuous read/write ToT Mode options: 1) 1st hit or integral ToT (programmable) 2) Supplementary 4-bit eventing counting (readout optional)	10-bit ToT 4-bit #Events	10-bit ToT 4-bit #Events
ContToT14	Continuous read/write ToT Mode option: 1st hit or integral ToT (programmable)	14-bit ToT	14-bit ToT
ContToA10	Continuous read/write 1st hit ToA	10-bit ToA	10-bit ToA
ContToA14		14-bit ToA	14-bit ToA
ContEvent10	Continuous read/write event counting	10-bit #Events	10-bit #Events
ContEvent14		14-bit #Events	14-bit #Events

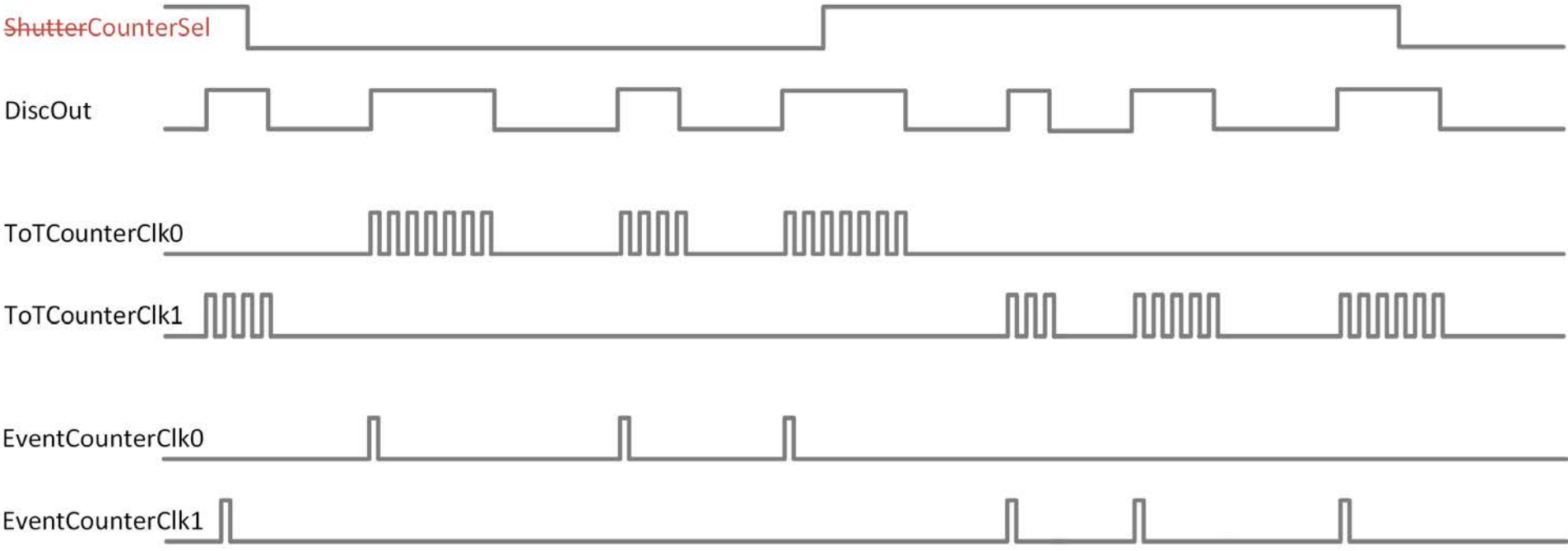
Mode Name	Description	1st Counter	2nd Counter
ToT10/ToA18	Simultaneous ToT and 1st hit ToA*	10-bit ToT	18-bit ToA
ToT14/ToA14	Mode options (programmable): 1) 1st hit or integral ToT 2) Overflow (wraparound) of ToA counter	14-bit ToT	14-bit ToA



Mode Name	Description	1st Counter	2nd Counter
ToT10/ToA18	Simultaneous ToT and 1st hit ToA*	10-bit ToT	18-bit ToA
ToT14/ToA14	Mode options (programmable): 1) 1st hit of integral ToT 2) Overflow (wraparound) of ToA counter	14-bit ToT	14-bit ToA



Mode Name	Description	1st Counter	2nd Counter
ContToT10/Event4	Continuous read/write ToT Mode options: 1) 1st hit or integral ToT (programmable) 2) Supplementary 4-bit eventing counting (readout optional)	10-bit ToT 4-bit #Events	10-bit ToT 4-bit #Events
ContToT14	Continuous read/write ToT Mode option: 1st hit or integral ToT (programmable)	14-bit ToT	14-bit ToT

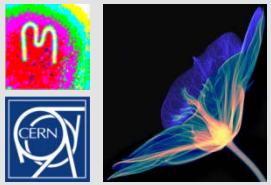


Power Consumption in the Matrix

- **Analogue:**
  - **5 µA/pixel @ 1.2 V**
  - **Unused pixels can be powered down to a few nA**
  - **With all 65536 pixels powered up: <400 mW**
- **Digital:**
  - **0.24 mW/superpixel during open Shutter in simultaneous ToT/ToA mode with 100 MHz ToTClk and 100 MHz ToAClk, assuming sparse activity and superpixel clock gating enabled**
  - **ToT and ToA clocks can run at lower frequencies**
    - **ToAClk is output from a clock divider taking ToTClk as input**
  - **The clocks in a double column are disabled when all pixels in the double column are masked**
  - **Full matrix digital power with sparse activity and 100 MHz clocks: <500 mW**
- **Total: <900 mW for the full matrix assuming sparse hits and both clocks @ 100 MHz**
  - **~2 W for the full matrix in cases of full occupancy (not relevant to dosimetry)**

Maximum Frame Rates

With a 100 MHz DCLOCK_IN:



Timepix2 v. TImepix

1. Improved Front-End TOT range and stability…
2. Simultaneous TOT an TOA (10 ns)…
3. Stable performance with 100 MHz clock…
4. Stable and linear internal digital and analog test pulses…
5. TSV capable (no wirebonds & secure mounting)…
6. 28-bit (Fungible) output buffer…
7. Improved DAC stability…
8. Multiple continuous operational modes…
9. Can use Timepix sensors…
10. Bonus—8 Digital Pixels to couple external devices