Pixel Imaging Mass Spectroscopy (PImMS)

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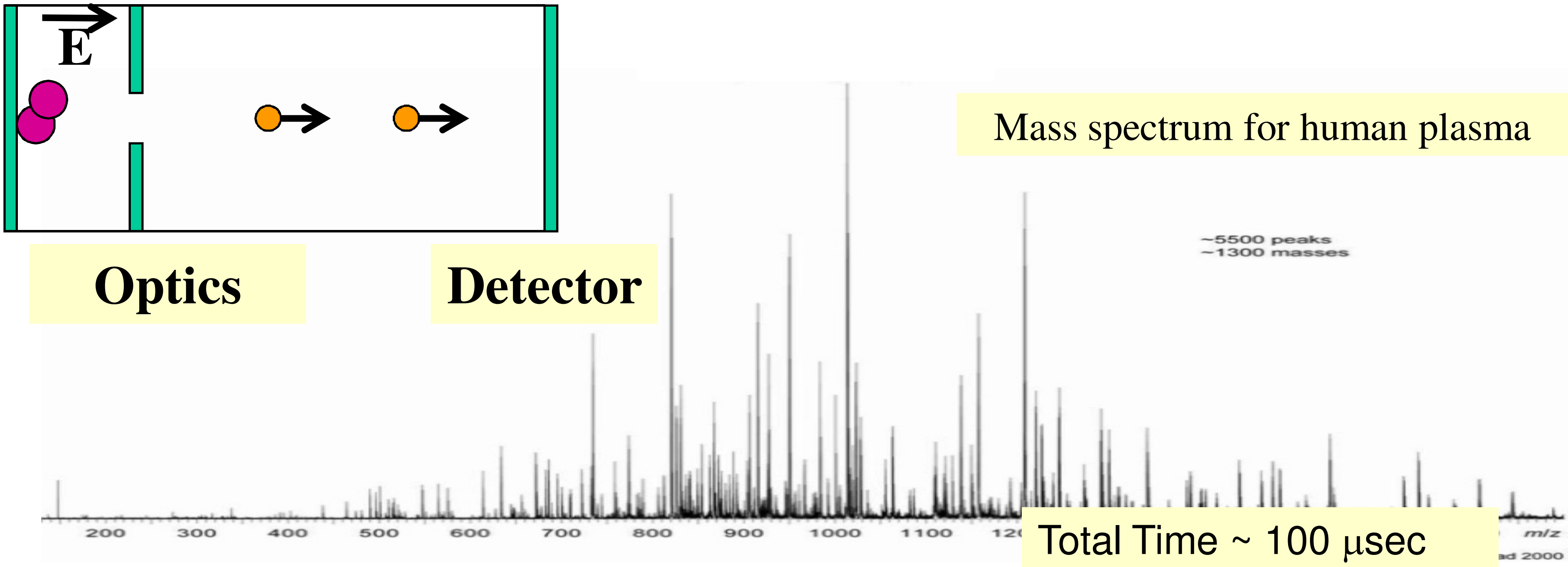
Outline

- Mass Spectrometry and Ion Imaging
- Pixel Imaging MS
- PImMS Sensor

Introduction: Mass Spectrometry

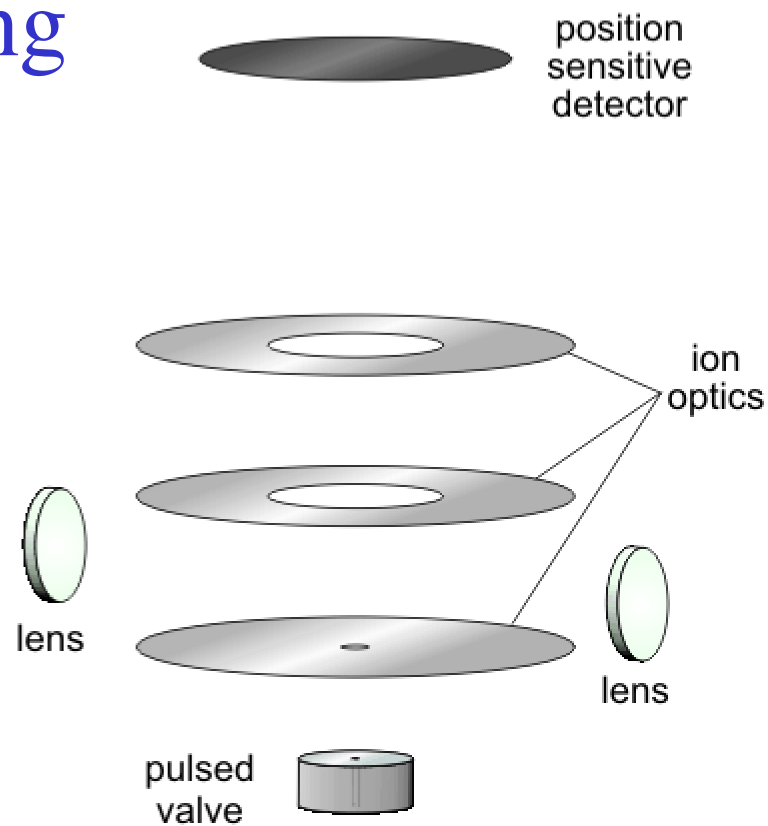
- Mass spectrometry: very popular tool in chemistry, biology, pharmaceutical industry etc.
- TOF MS: Heavier fragments fly slower

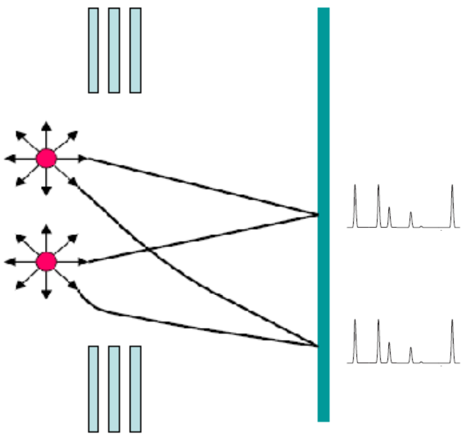


- Measure detector current: limited to one dimension
- Ion imaging : go beyond 1D by providing 3D information for each mass peak

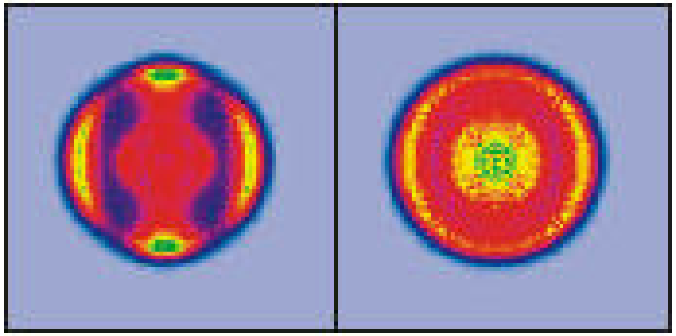
Ion Imaging

- Fix a mass peak
- Measure full scattering distribution of fragment ions
  - Velocity maping
  - Different fragmentation processes give the ions specific speed and angular distributions





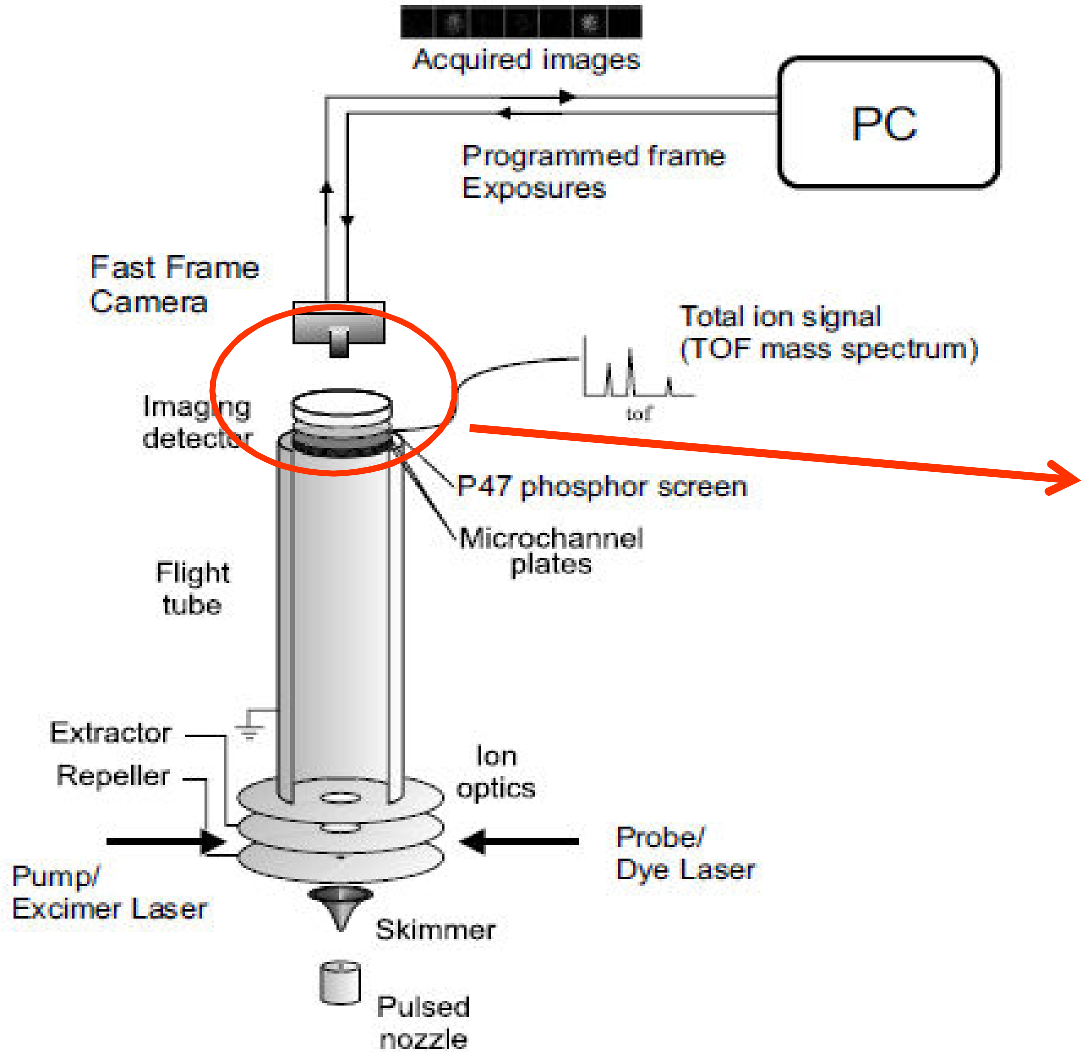
Velocity mapping

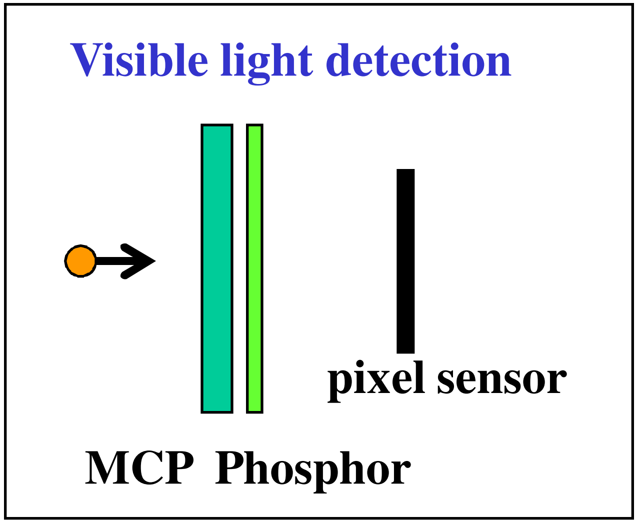


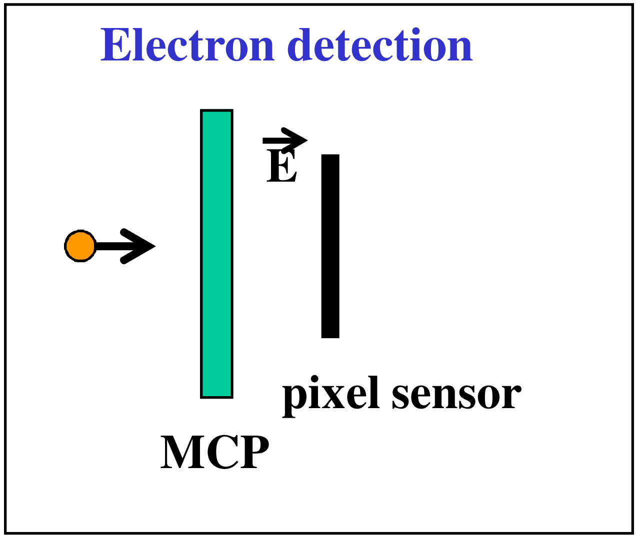
S atom ion images for OCS photodissociation at 248nm

Visible Light vs Direct Detection

- Typically use visible light but direct detection of electrons after MCP is possible







Pixel Imaging Mass Spec: PImMS

PImMS = Mass Spectroscopy X Ion Imaging

- Recent progress in silicon technologies: fast pixel detectors overcome the single mass peak limitation
- Direct spin-off of ILC sensor work, pixel design inspired by TPAC (DECAL MAPS sensor)
- Now a 3-year knowledge exchange project funded by STFC to build a fast camera for mass spec applications

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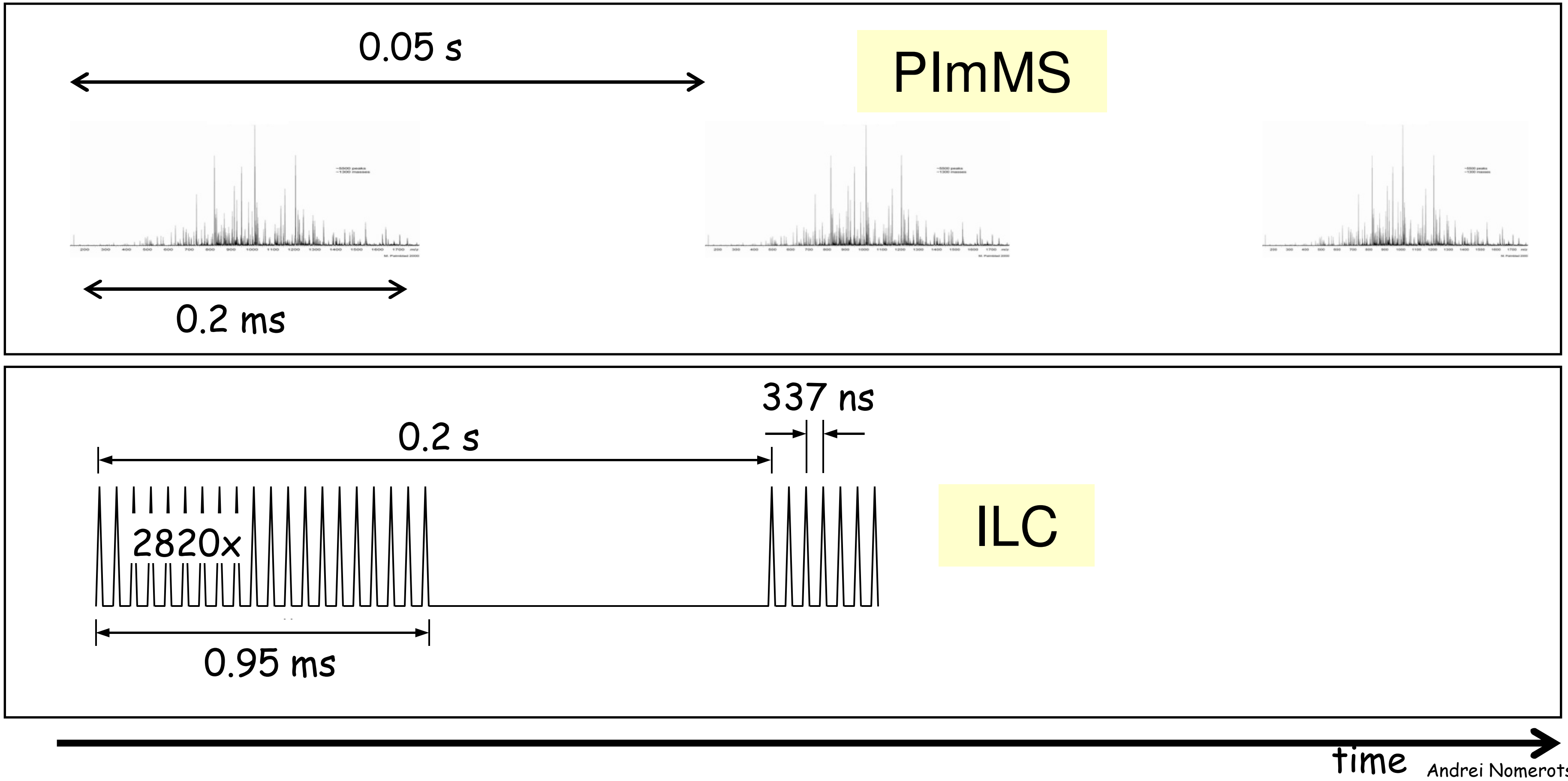
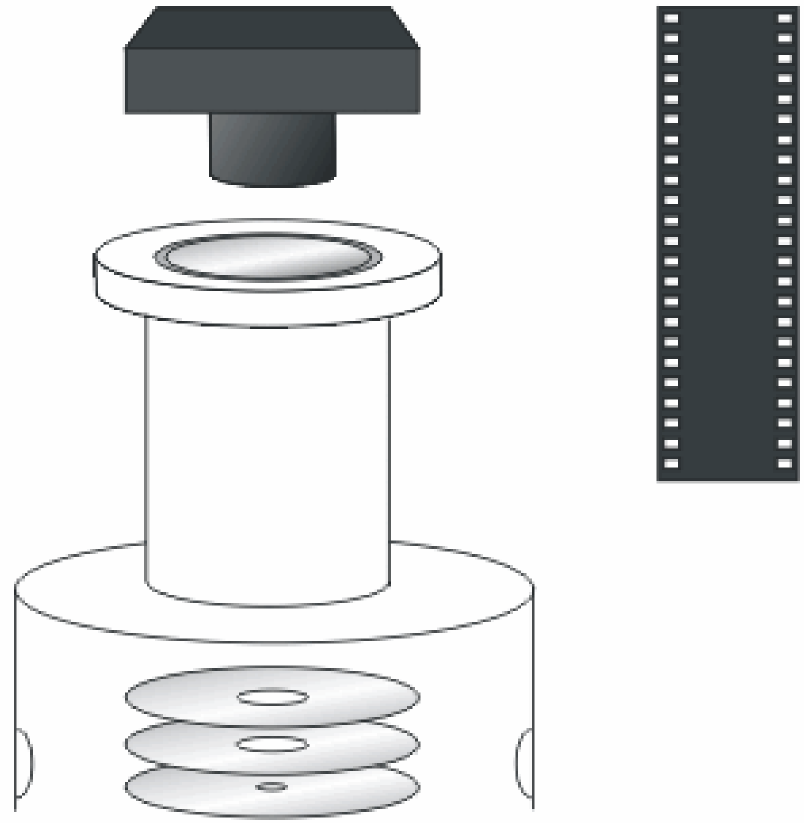
ILC and PImMS

- PImMS and ILC have similar data structure
  - PImMS : 0.2 ms duration @ 20 Hz
  - ILC: 1.0 ms duration @ 5 Hz
  - Time resolution required: ~100 ns for similar occupancy



Pixel Imaging Mass Spec: PImMS

- Imaging of multiple masses in a single acquisition
- Gives access to new information, provides scope for a range of new techniques
- Mass resolution determined by flight tube, phosphor decay time and camera speed

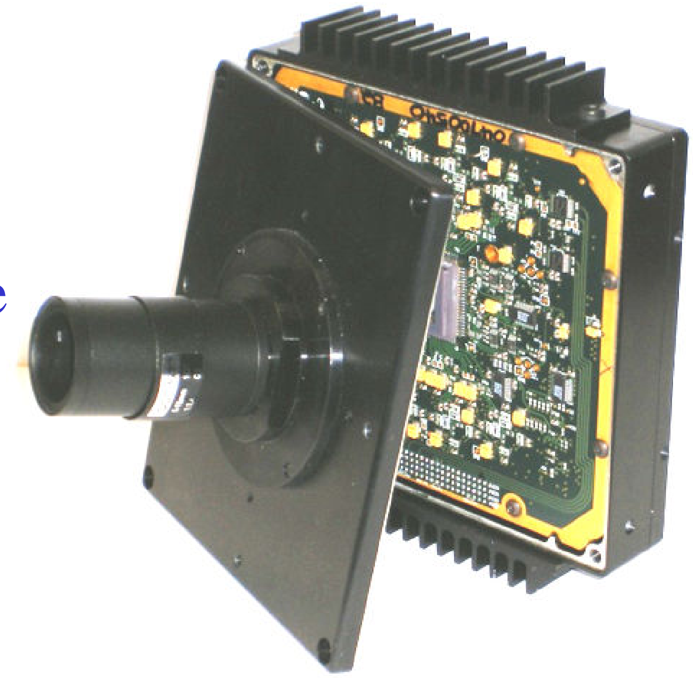


Fast Framing CCD Camera

Technology currently in use in our lab:

- CCD camera by DALSA (ZE-40-04K07)
  - 16 sequential images at 64x64 resolution
  - Pixel : 100 x 100 sq.micron
  - Max frame rate 100 MHz (!)

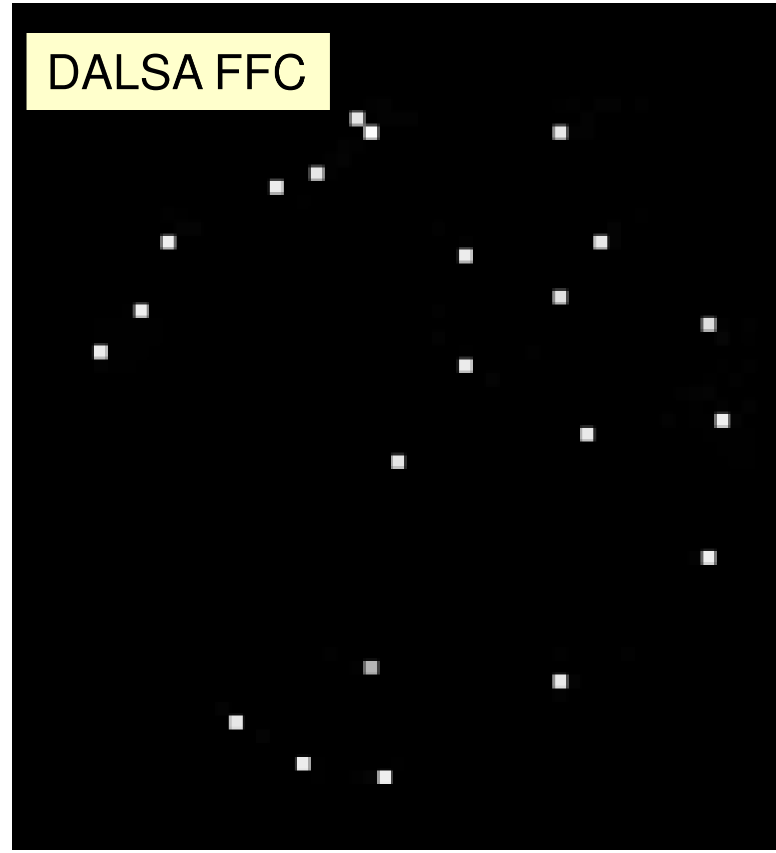
- ISIS Principle: local storage of charge in a CCD register at imaging pixel level
- Limitations
  - **Number of frames**
  - Images between mass peaks are not useful

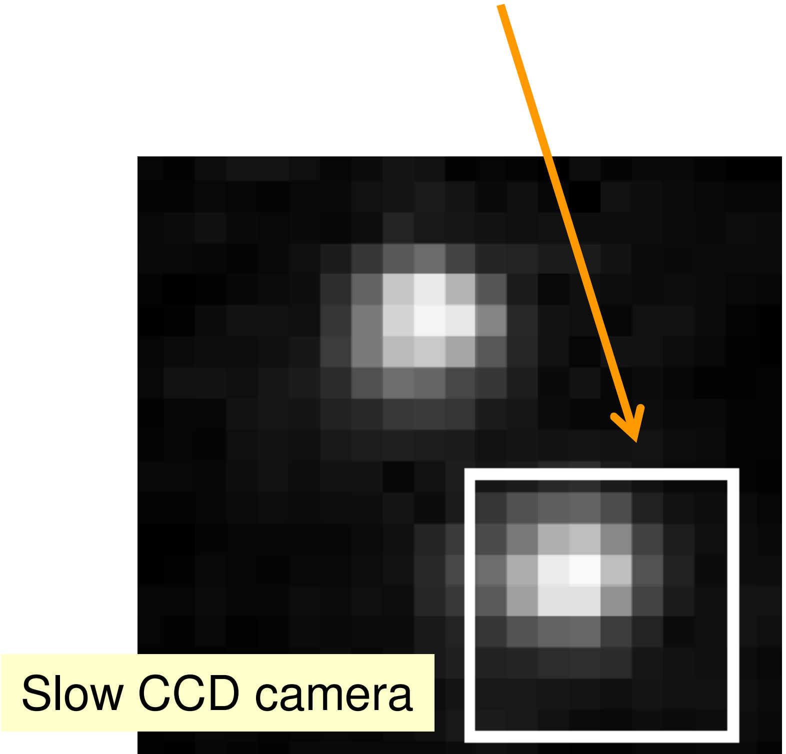


Fast framing camera currently in use

Data with DALSA FFC

- Single frame shots with DALSA and normal CCD cameras
  - Slow CCD camera pixels 12x12 μm^2
  - Square is 100x100 μm^2





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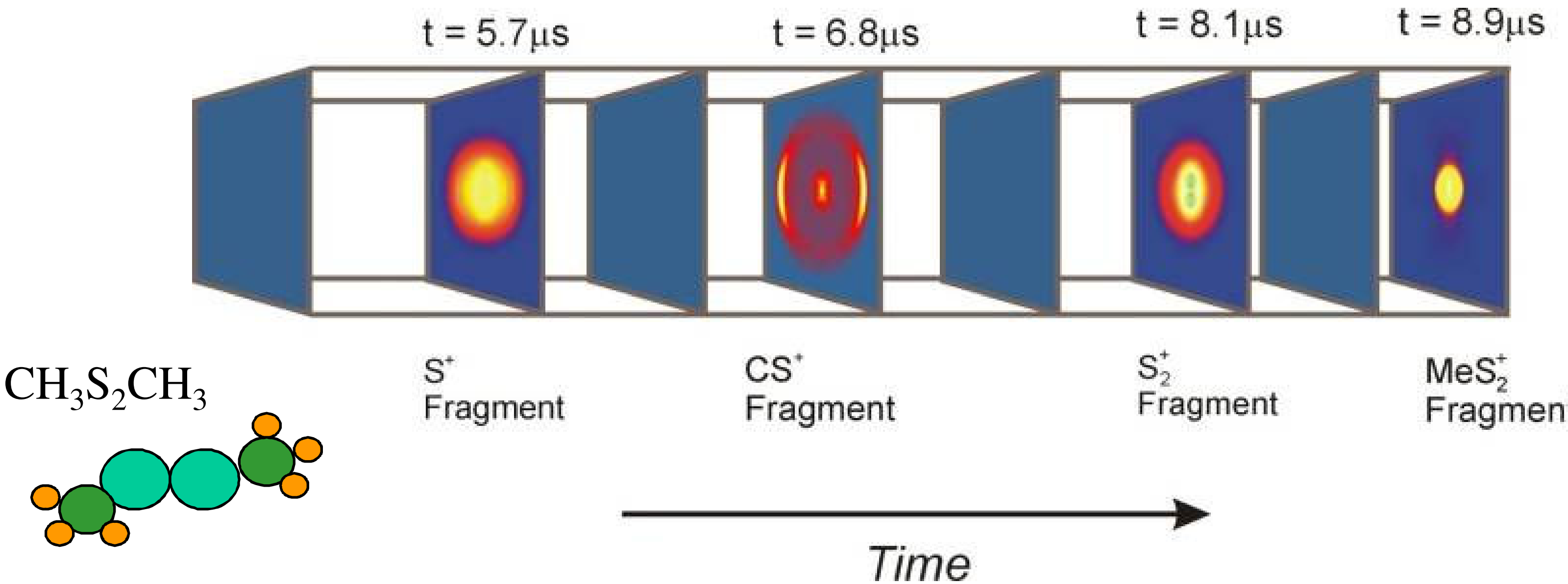
Velocity Mapped PImMS (1)



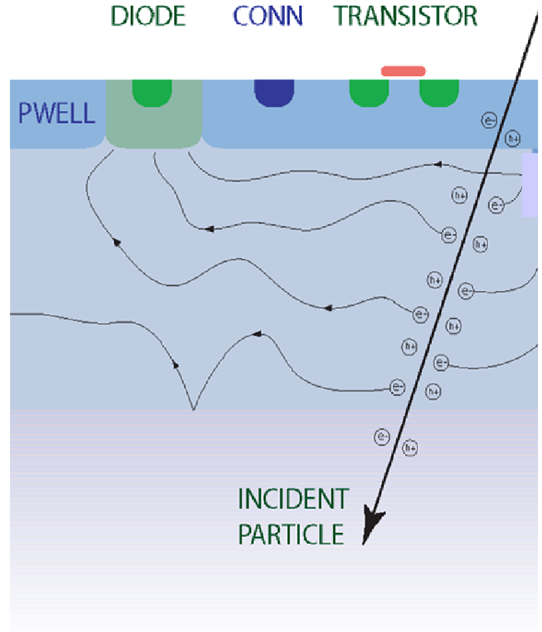
- 2007-2008: Proof of concept experiment successfully performed on dimethyldisulfide (DMDS)[3]
- Ionization and fragmentation performed with a polarized laser, data recorded with DALSA camera.

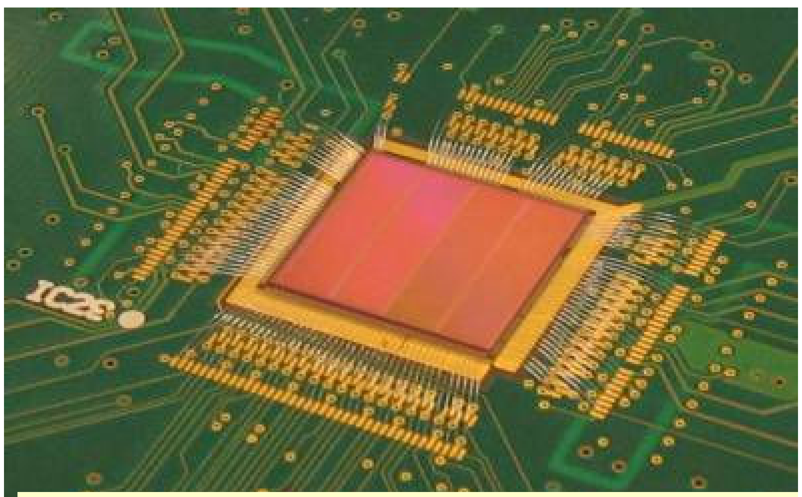
3: M. Brouard, E.K. Campbell, A.J. Johnsen, C. Vallance, W.H. Yuen, and A. Nomerotski, *Rev. Sci. Instrum.* **79**, 123115, (2008)

PImMS Sensor

Monolithic Active Pixel Sensors

- Signal detected in thin epitaxial layer < 20 μm
- Limited functionality as only NMOS transistors are allowed
  - PMOS transistors compete for charge



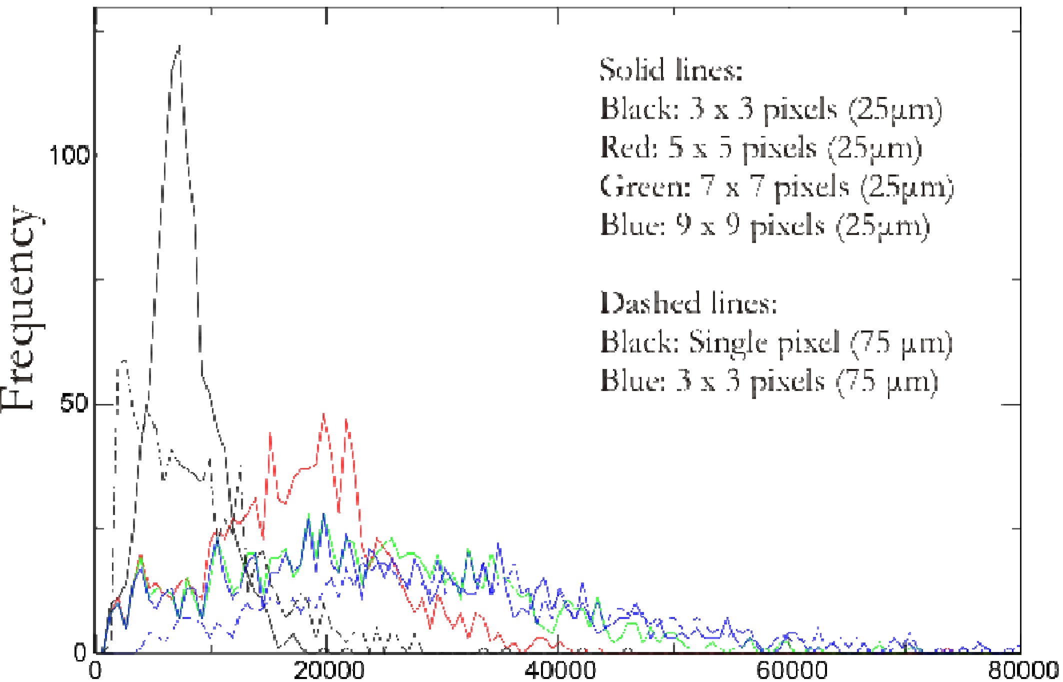


TPAC sensor for ILC digital calorimetry using INMAPS process

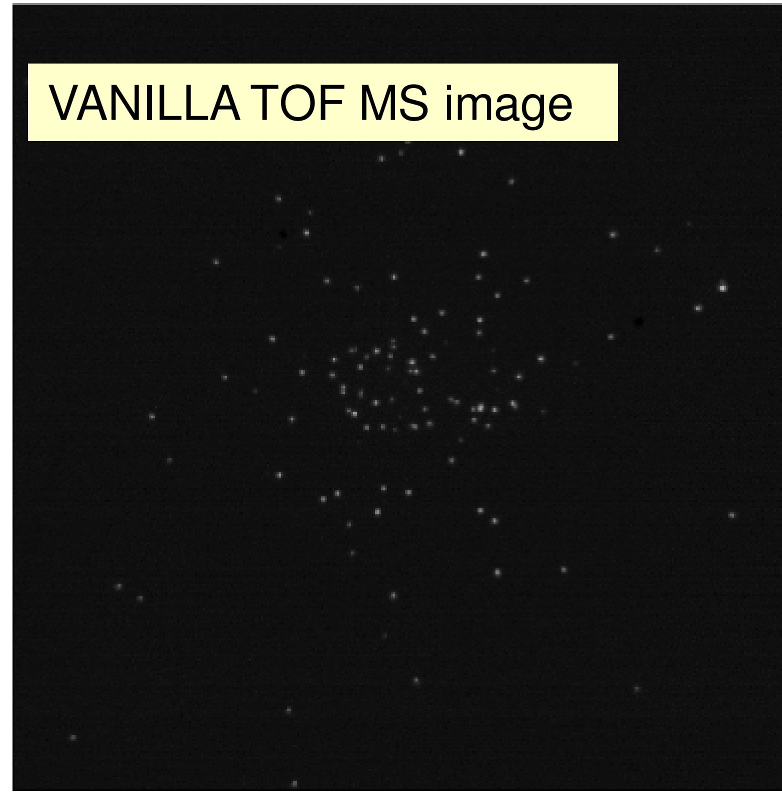
- INMAPS process developed at RAL
  - **Shields n-wells with deep p+ implant**
  - **Full CMOS capability**
  - **Substrate choice for improved charge collection efficiency and radiation hardness**
  - **Developed on a 180nm CMOS platform, transferable to smaller feature size, e.g. 130 nm**

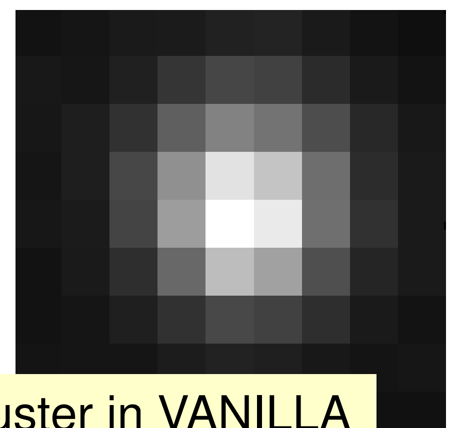
PImMS and MAPS

- Performed measurements in 2009 with existing CMOS sensors, Vanilla, designed by RAL
  - Similar detection technology (not INMAPS) but slow frame rate
- Used to formulate specifications for PImMS sensor



Signal in VANILLA, electrons





Single cluster in VANILLA

Dark subtracted hit

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Fast Framing vs Time Stamping

- Time stamping provides same information generating much less data
- BUT needs low intensity (one pixel hit only once or less)

- PImMS is a good match for time stamping

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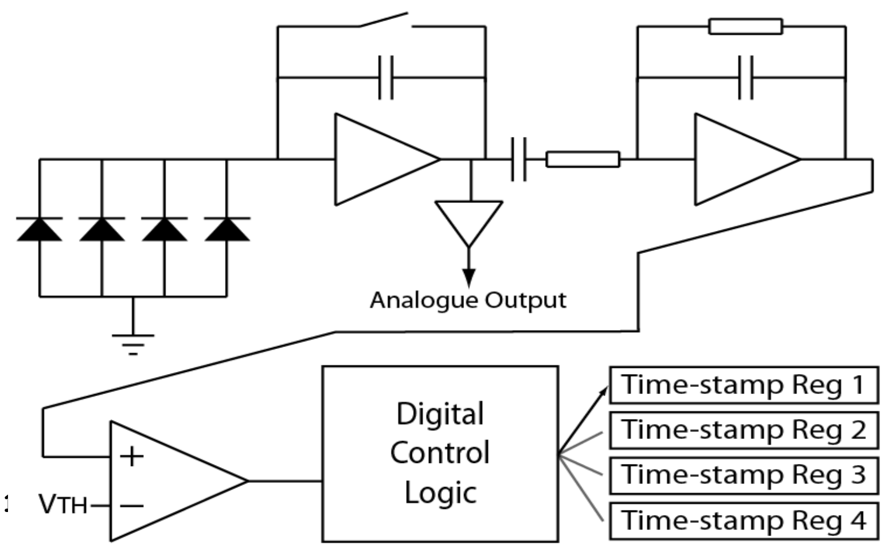
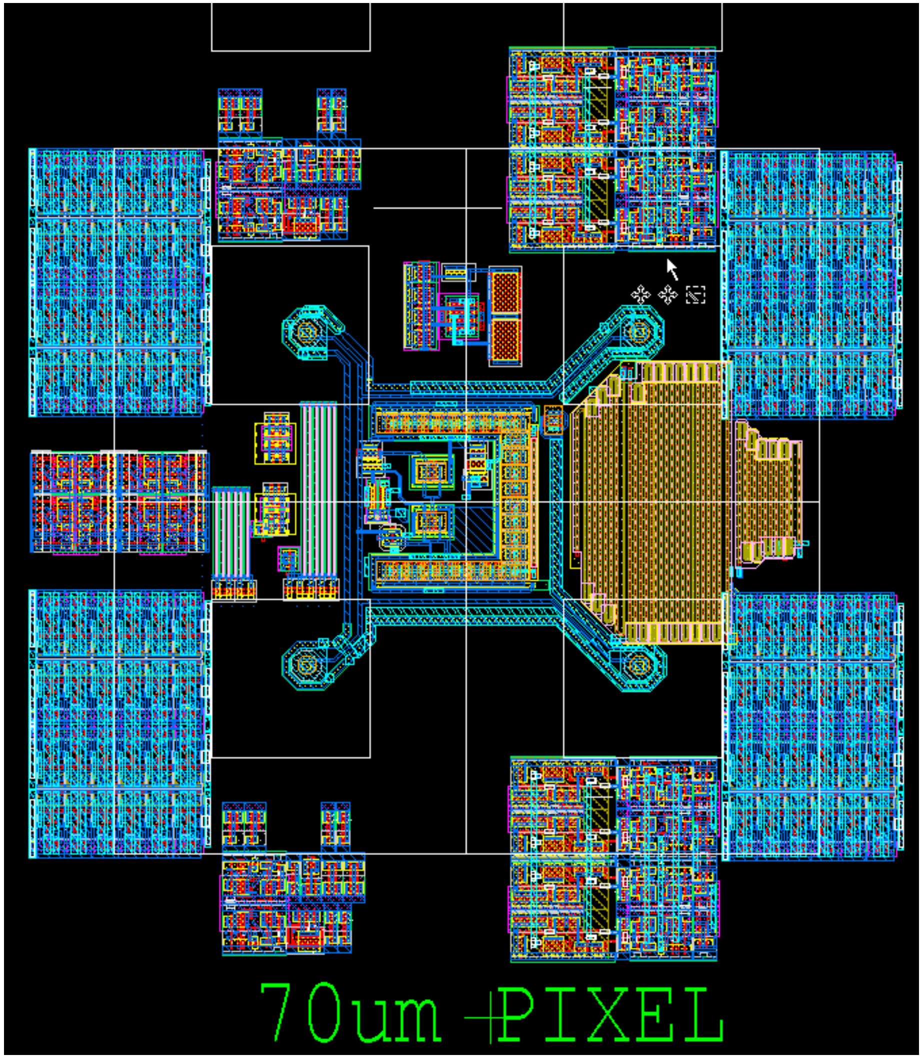
PImMS Sensor

- Targeted specifications
  - 512 x 512 pixels
  - Pixel dimensions 70x70 μm^2
  - 12 bit counter
  - 40 MHz clock, distributed to all pixels
  - Time resolution < 100 nsec
  - Each pixel can record 4 time stamps
  - 30 μW/pixel
  - 25 MHz 12-bit parallel digital output
  - 10 MHz analogue output(s) for calibrations
  - 20 Hz rate, possible with USB2.0





Preliminary (incomplete) layout
Total transistor count ~700/pixel

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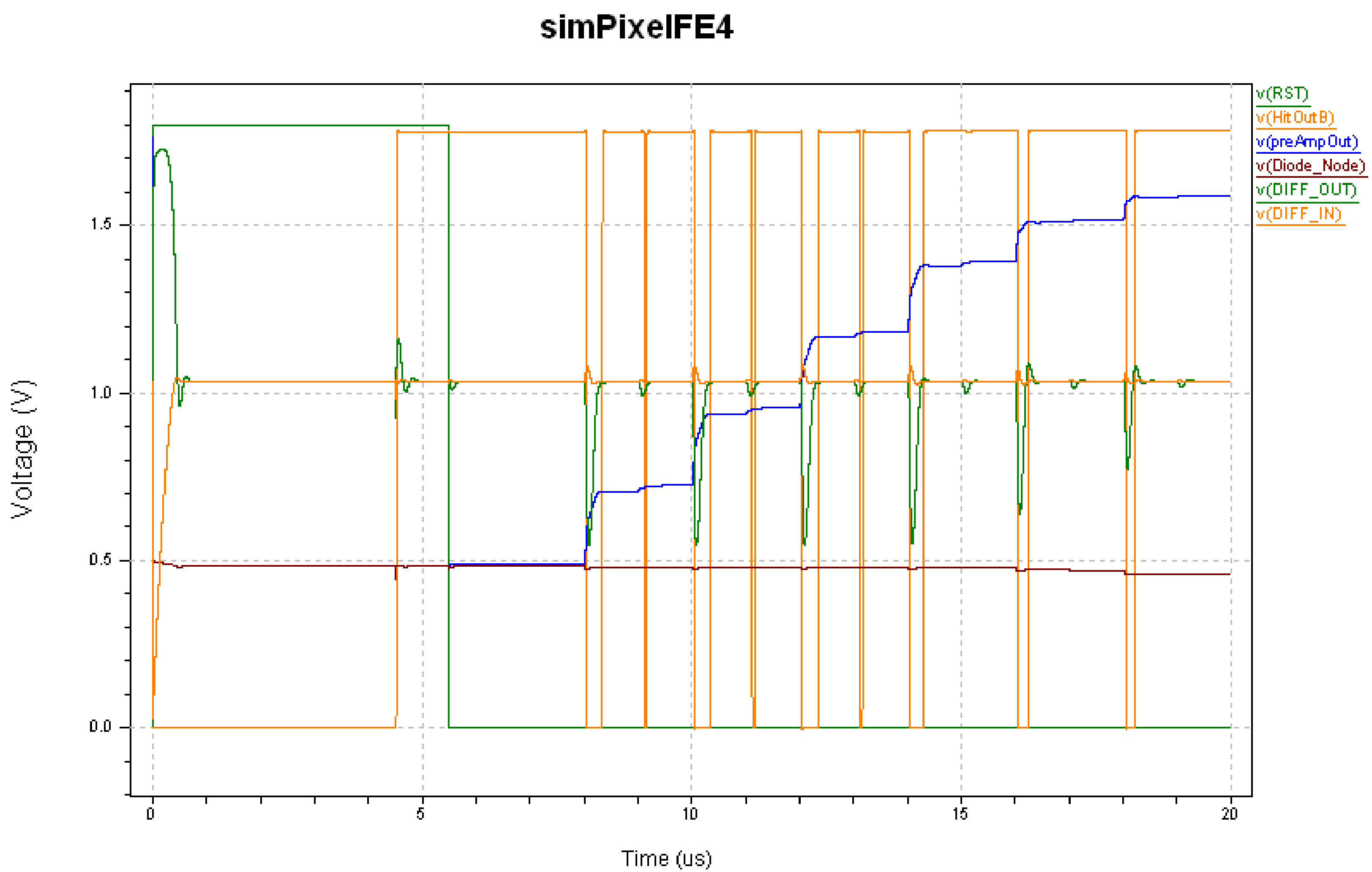
Simulations of PImMS FE Performance



Preamp, **Shaper**, **Comparator** outputs for test signals (4000e followed by 300e)

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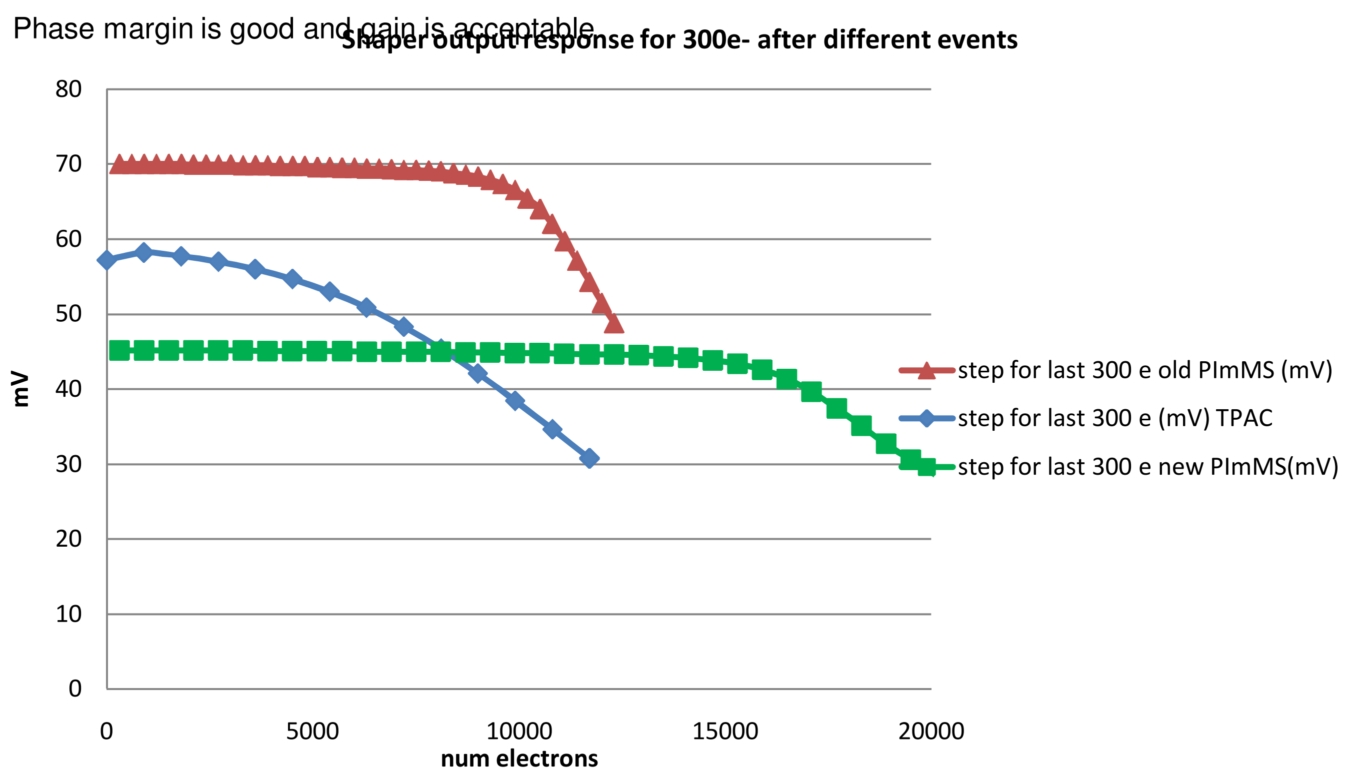
Simulations of PImMS Sensor Performance

- Improved design with respect to ILC-TPAC design
  - → Increased dynamic range and response to large signals
  - → Good linearity (gain change <5% for 300e signal up to 15000e)
  - → Noise 50 e



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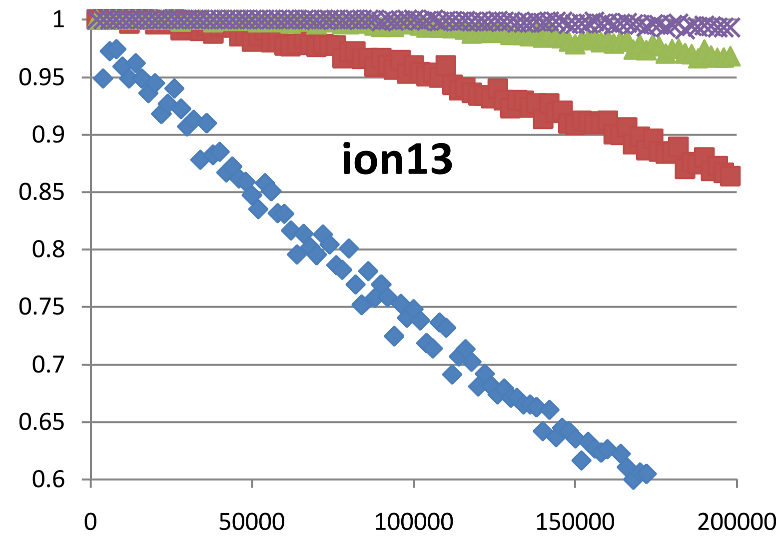
Timing Resolution

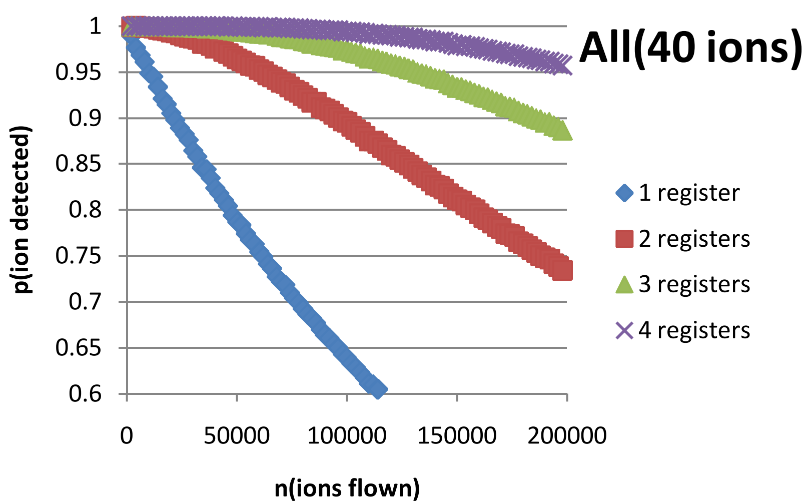
- Timing determines mass resolution – important
  - Best Mass Spectrometers : ~ 0.1 ns but many interesting applications with 10-100 ns
- In PImMS will be limited by time walk for different amplitudes (not by diffusion!)
  - Clock skew for large sensor ~25 nsec
  - Saturated MCP may improve the timing resolution
- Recovery time determines pixel dead time (~1%) until next time stamp can be accepted

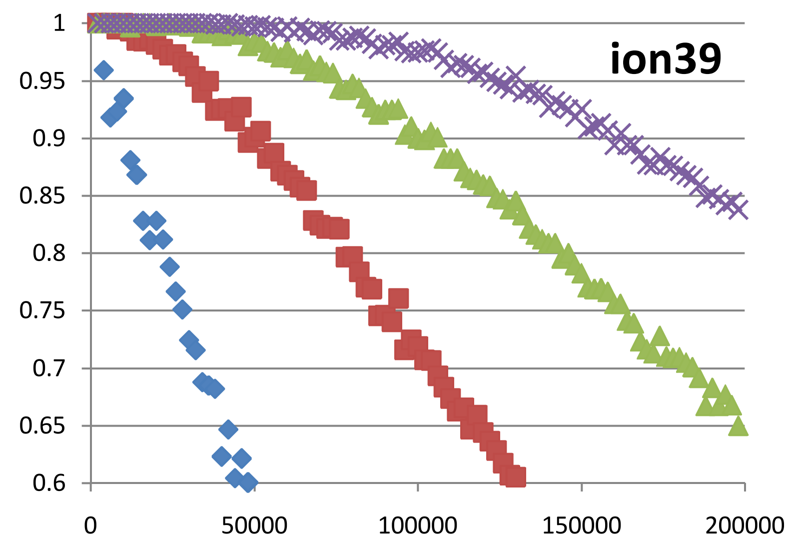
	PImMS Design
Time to 4σ 300e-/4000e- (ns)	65/24
Recovery Time for 4000e- (ns)	500
Peaking time (ns)	100

Ion Intensity Simulations

- It's important to be sensitive to heavy fragments
- Simulated probability to have N hits/pixel
- Four buffers allow higher intensity







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PImMS Pixel Power

Circuit Block	Average Power
Preamp	3
Shaper	3
Comparator	6.9
Digital Control	15
Time Code Dist. (SRAM)	0.8
Spec	30
Total	28.7

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Quantum Efficiency Estimate

- Fill factor 20%
- Expect QE around 6%, based on previous designs

- Discussing options with micro lenses or backthinning

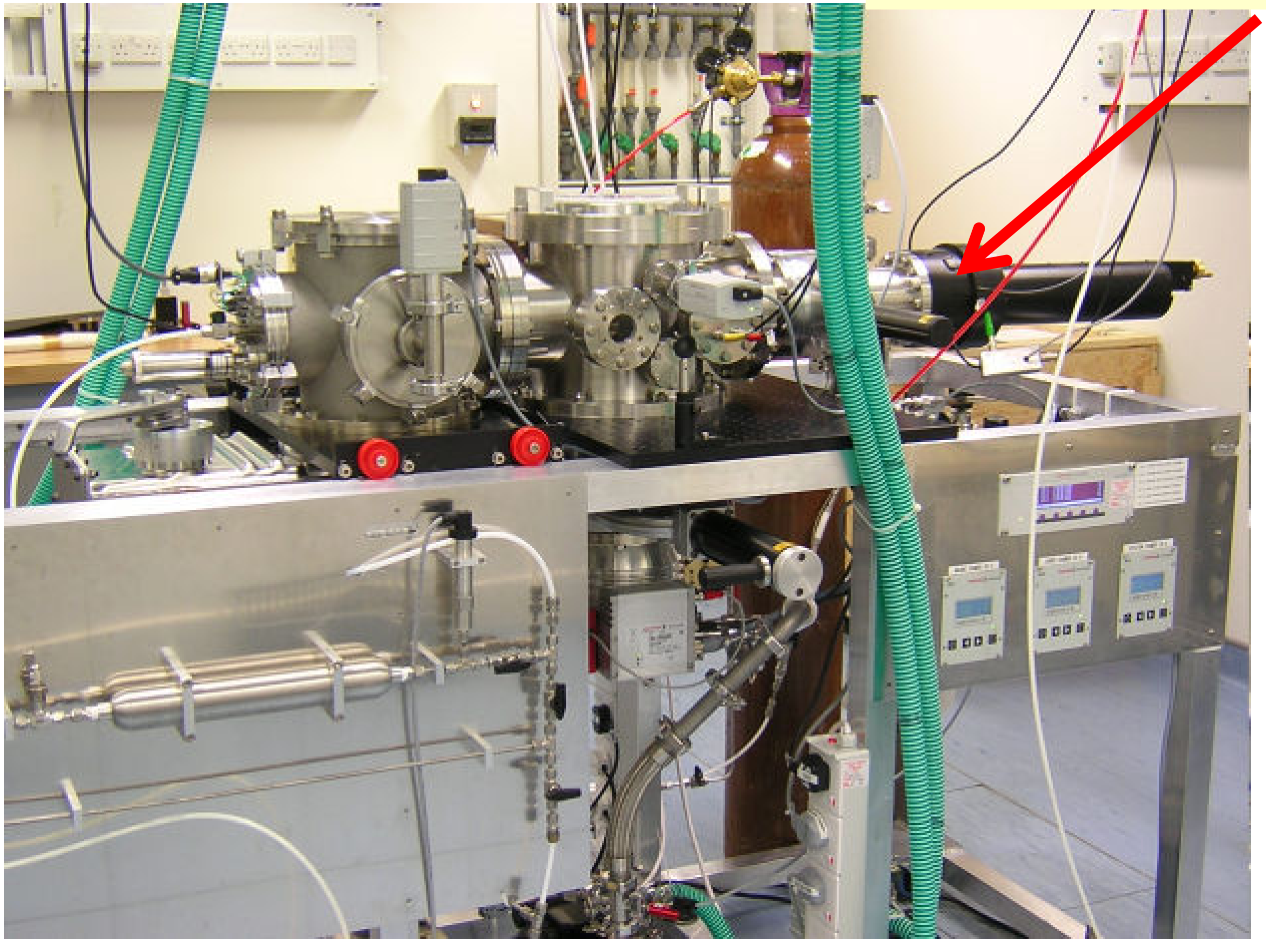
PImMS Timeline

- Currently in the design phase
  - Pixel schematics complete
  - Pixel layout review next week
- Submission PImMS1.0 : end of June 2010
  - Smaller prototype 80x80 pixels (7x7 mm^2)
  - Back in September
- First results: Dec 2010
- Large (512x512?) sensor ready: Dec 2011

Preparations in Oxford Chemistry

- TOF MS in Oxford Chemistry

PImMS sensor will be mounted here



Summary

- Pixel Imaging Mass Spectroscopy is a powerful hybrid of usual TOF MS and Ion Imaging
- Progress in sensor technologies allows simultaneous capture of images for multiple mass peaks
- PImMS specifications are similar in time resolution and data rates to ILC vertexing and digital calorimetry
- First PImMS sensor expected in 2010, final sensor in the end of 2011