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Tracking of Moving Fiducial Markers during Radiotherapy using a CMOS APS

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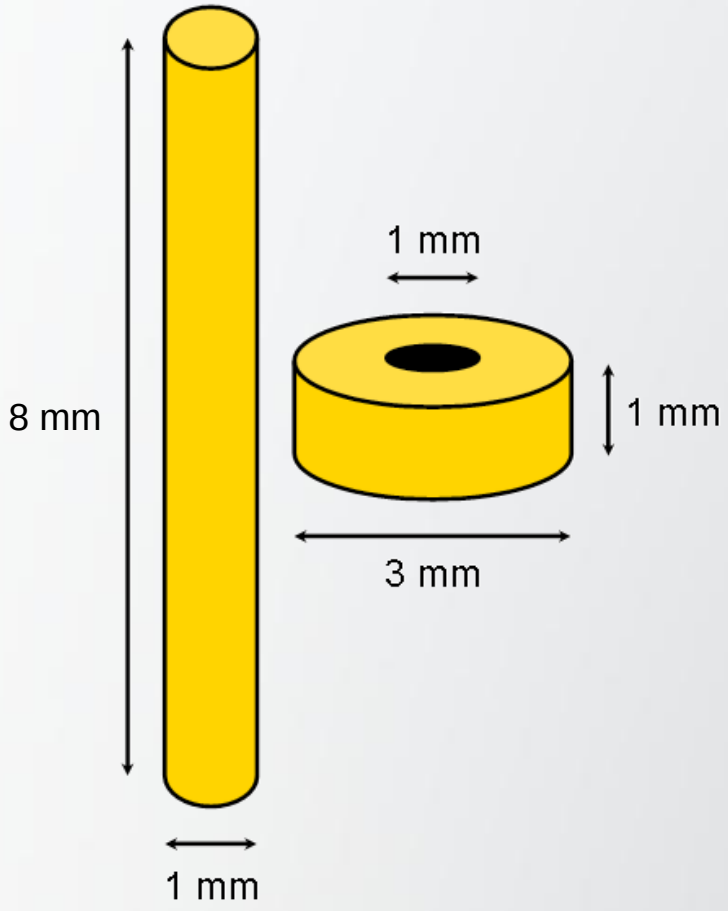
Radiotherapy of Moving Tumours

- Modern radiotherapy provides highly conformal dose distribution.
- Moving tumours treated with stationary target volume which includes tumour at all times.
- Need to measure motion to adapt treatment to spare healthy tissue.
- Imaging treatment beam provides beam's-eye-view of tumour position relative to collimator.

Fiducial Markers

- Energetic treatment beam + similar density of tumour tissues = low image contrast.
- Fiducial markers are x-ray opaque to increase contrast.
- Implanted into tumour using biopsy needle or sewn into breast cavity.



Imaging Challenge

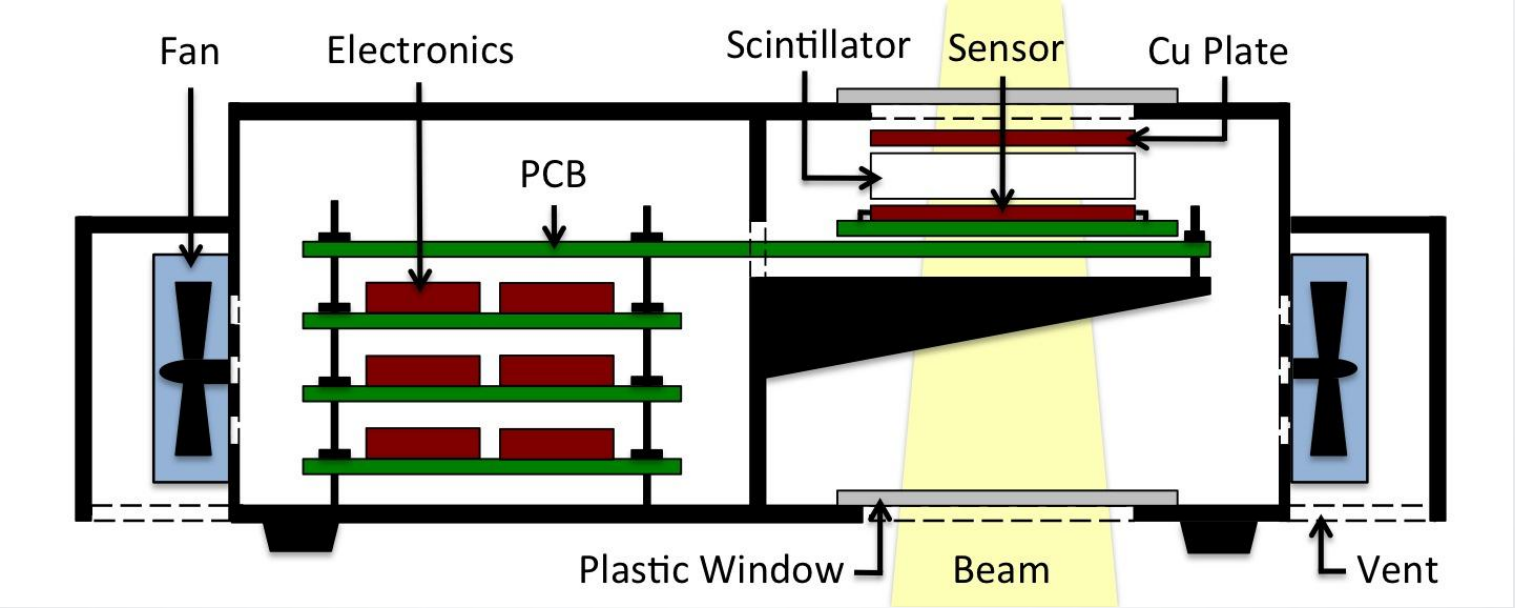
- Need to image small features moving at <15 mm s^{-1}.
- Current a-Si EPIDS read out at 2.5 frame s^{-1} producing <6 mm motion blur.
- Low resolution and noisy.
- CMOS APS may address these problems.
- Prototype APS (LAS) developed by MI^3 consortium. Compare image quality to EPID and demonstrate simple tracking.

APS vs EPID

	CMOS APS	a-Si EPID
Pixel Size	40 x 40 μm	400 x 400 μm
Detector Size	5.4 x 5.4 cm	41 x 41 cm
Read-Out Rate	20 frame s^{-1}	2.5 frame s^{-1}
Scintillator Material	$ZnWO_4$	Gd_2O_2S
Scintillator Density	3048 mg cm^{-1}	133 mg cm^{-1}
Q.E.	8%	0.34%

- Why not use thicker scintillator with existing technology?

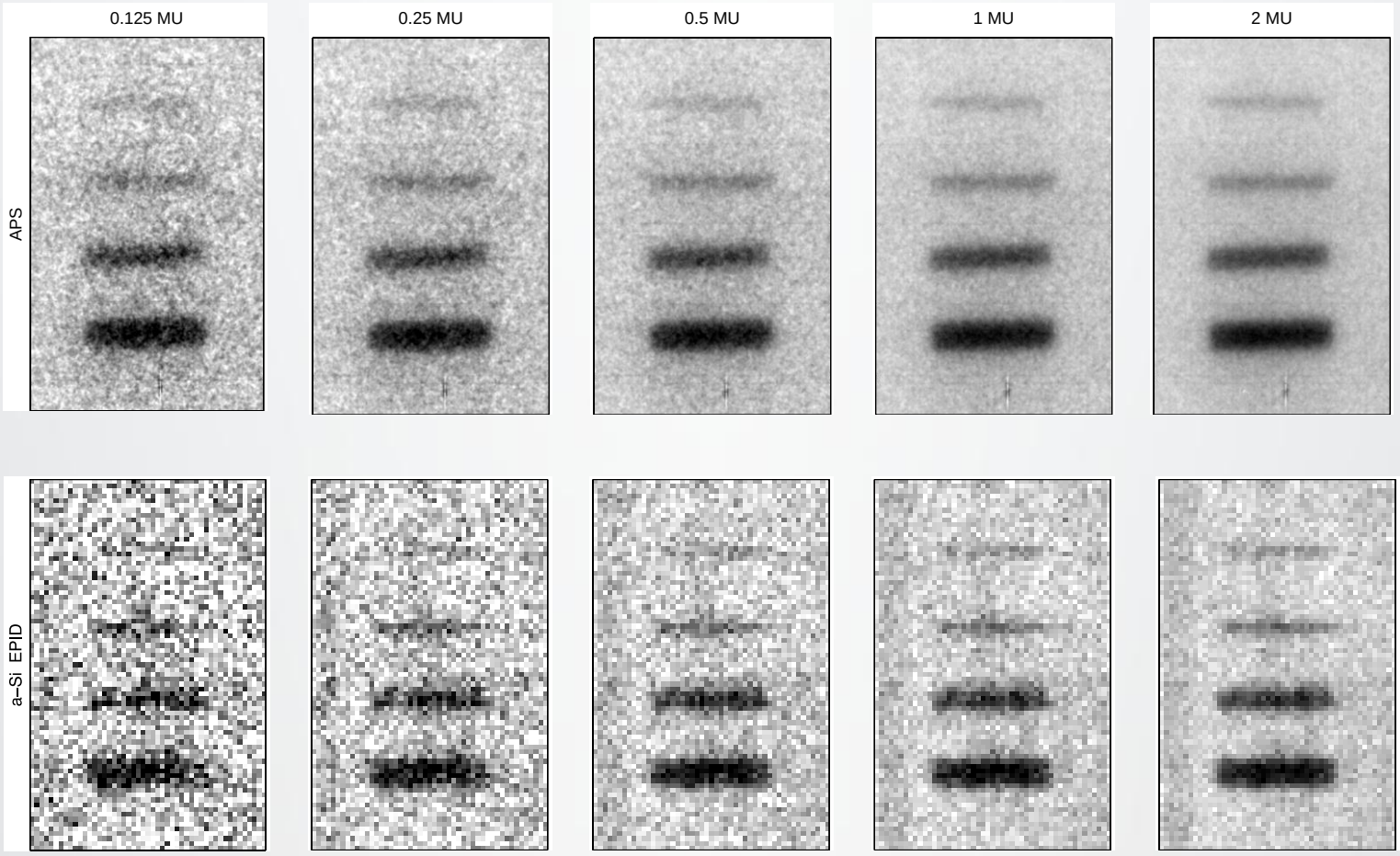
Experimental Set-Up



- Four cylindrical gold markers of diameter 0.8, 1.2, 1.6 and 2 mm placed 5 mm apart.
- Markers placed on motion platform 10 cm above sensor.

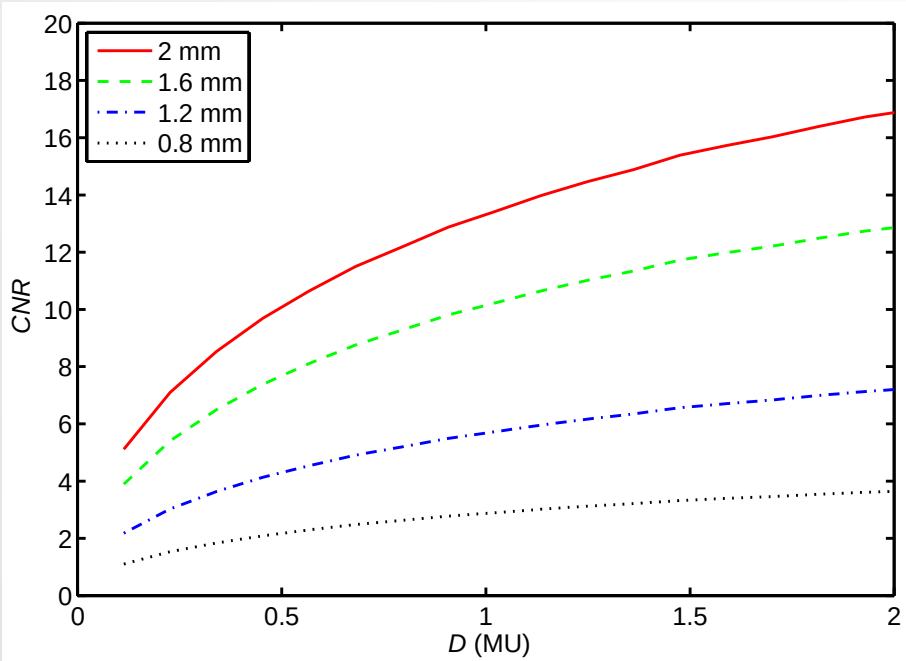
APS and Packaging

Stationary Markers

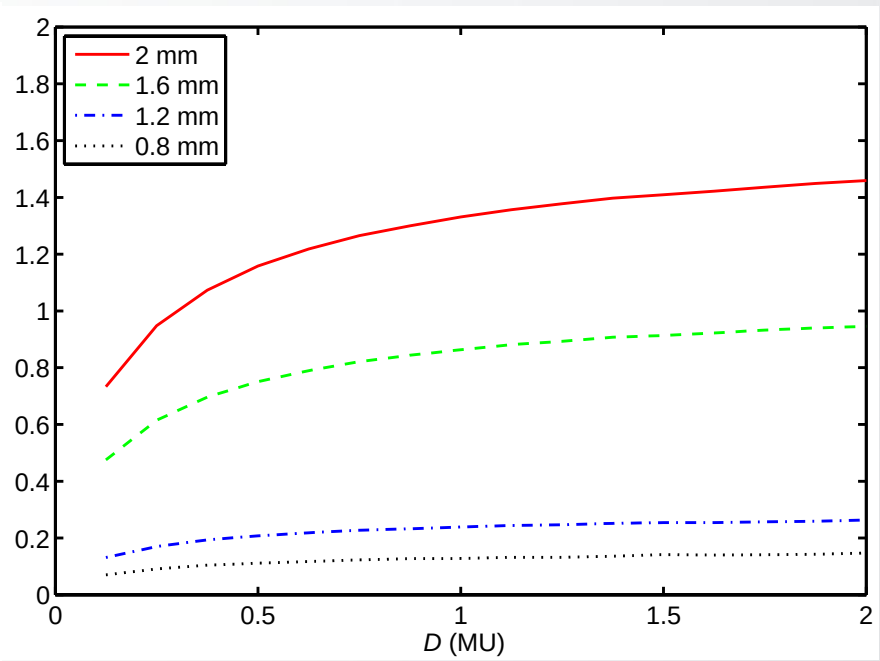


Contrast to Noise Ratio (CNR) vs Dose

CMOS APS



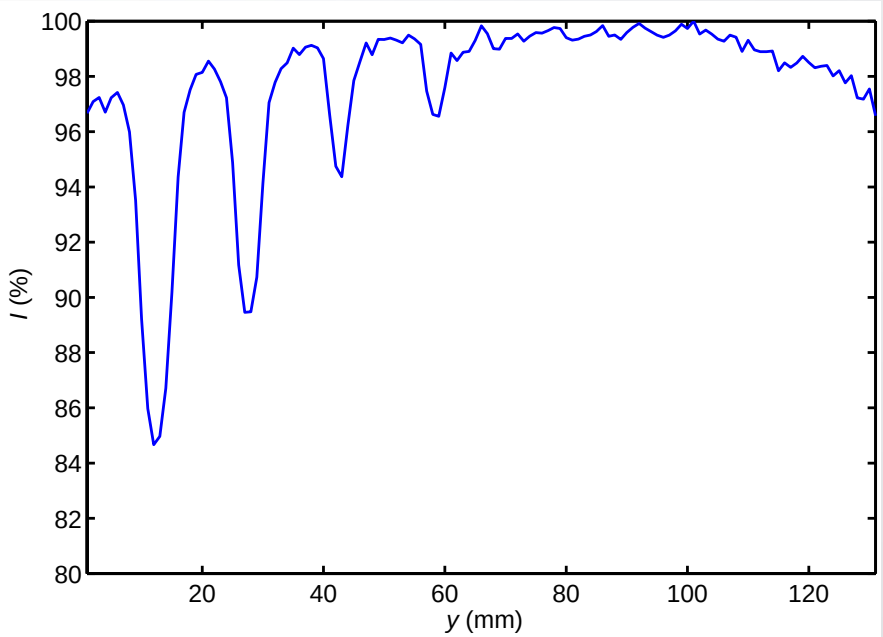
a-Si EPID



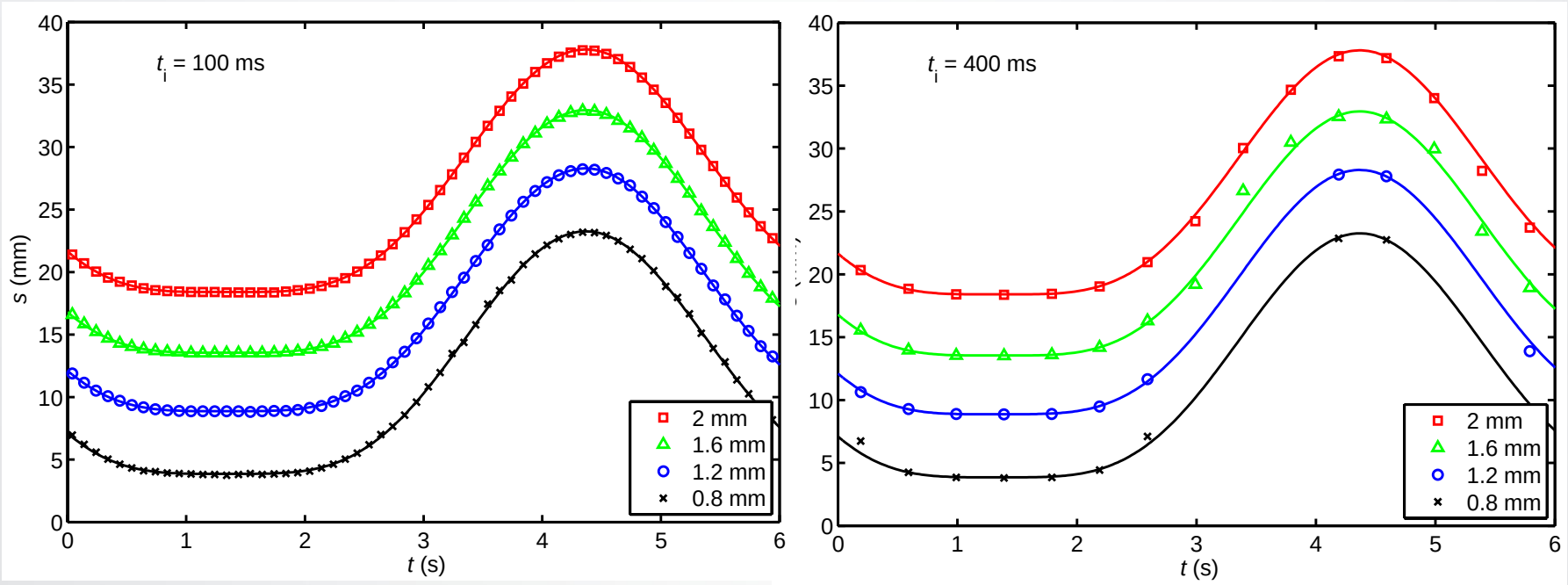
- CNR ~10x greater in APS than EPID.

1D Marker Tracking

- Markers moved using Lujan approximation to breathing motion (20mm, 6s).
- Region containing markers at all times selected.
- 1D profile calculated.
- Convolved with filter describing marker profile.
- Integration time 40-1000 ms.

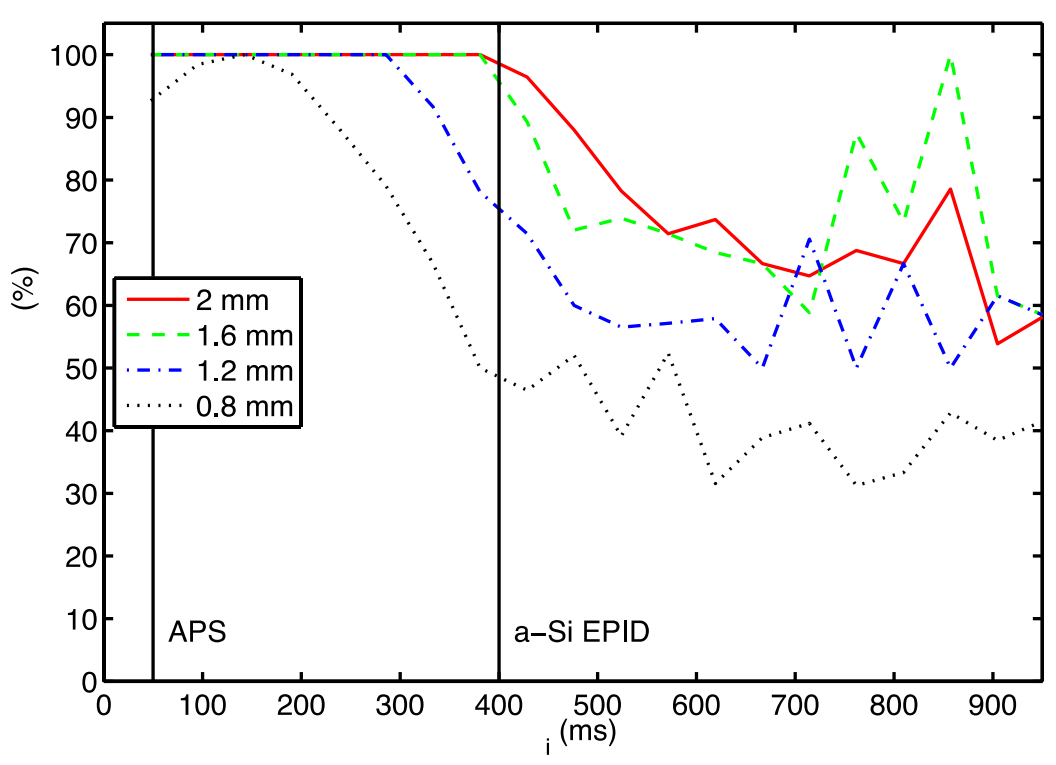


Marker Displacement vs Time



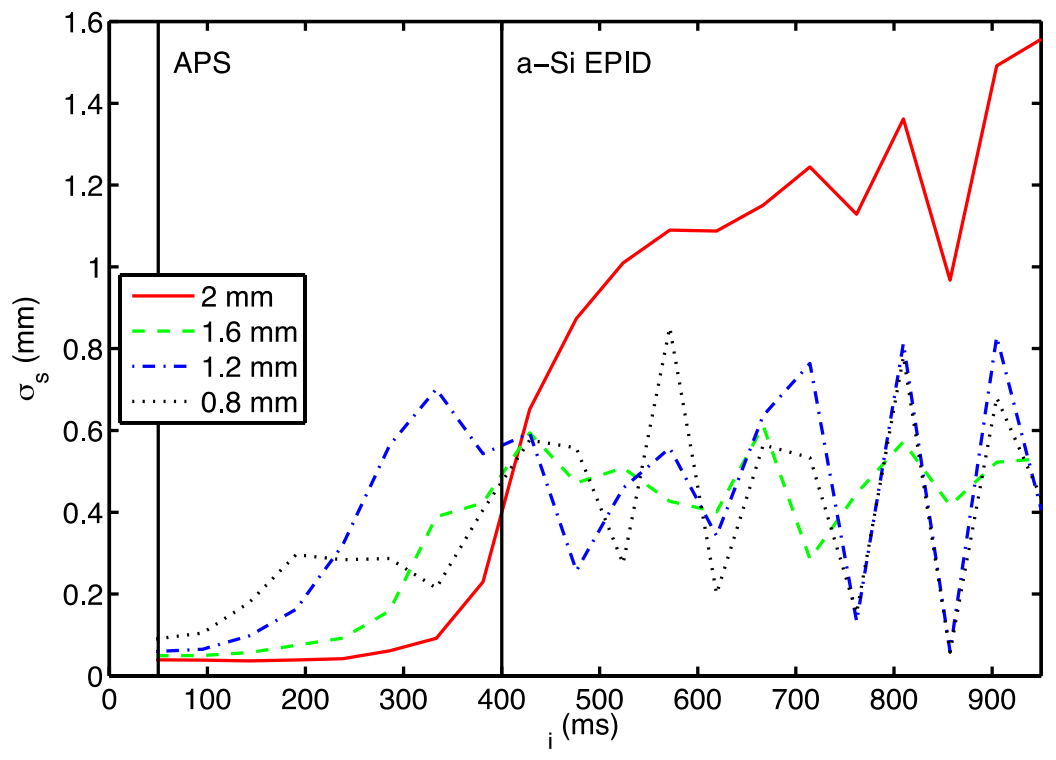
- At 100 ms all markers well located at all times.
- At 400 ms only 2 mm marker is well located.
- Greater marker travel results in attenuation over greater area.

Success Rate vs Integration Time



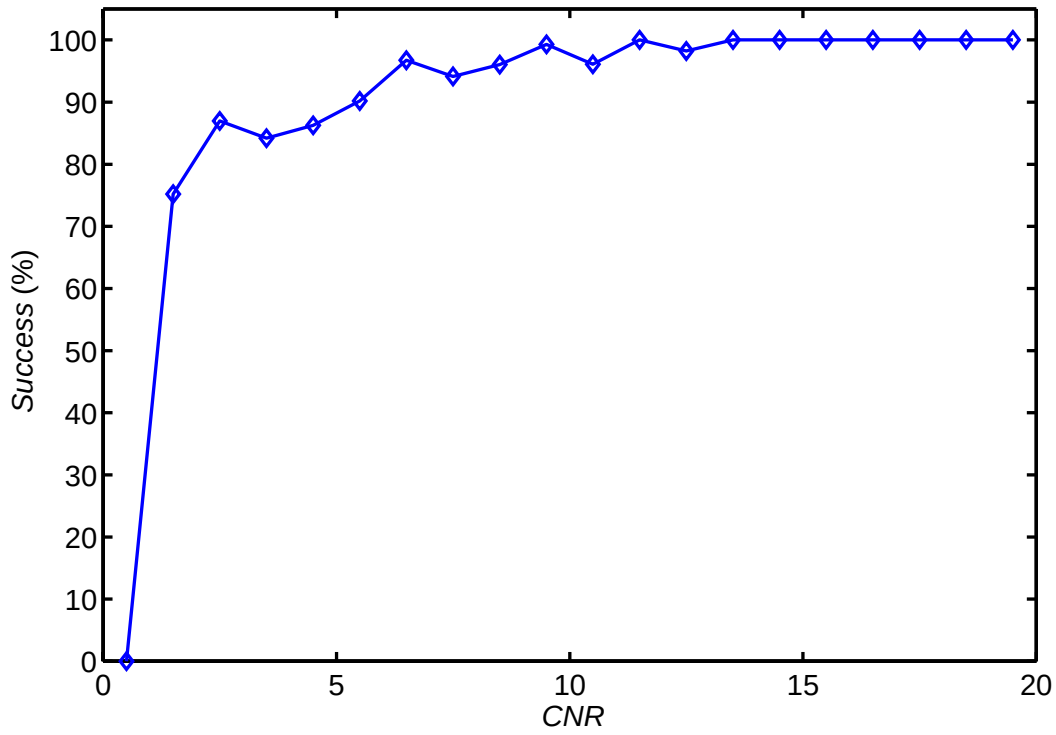
- At 40 ms 3 largest found 100% and smallest 92%.
- At 400 ms 2 smallest markers found 71% & 46%.

Displacement Error vs Integration Time



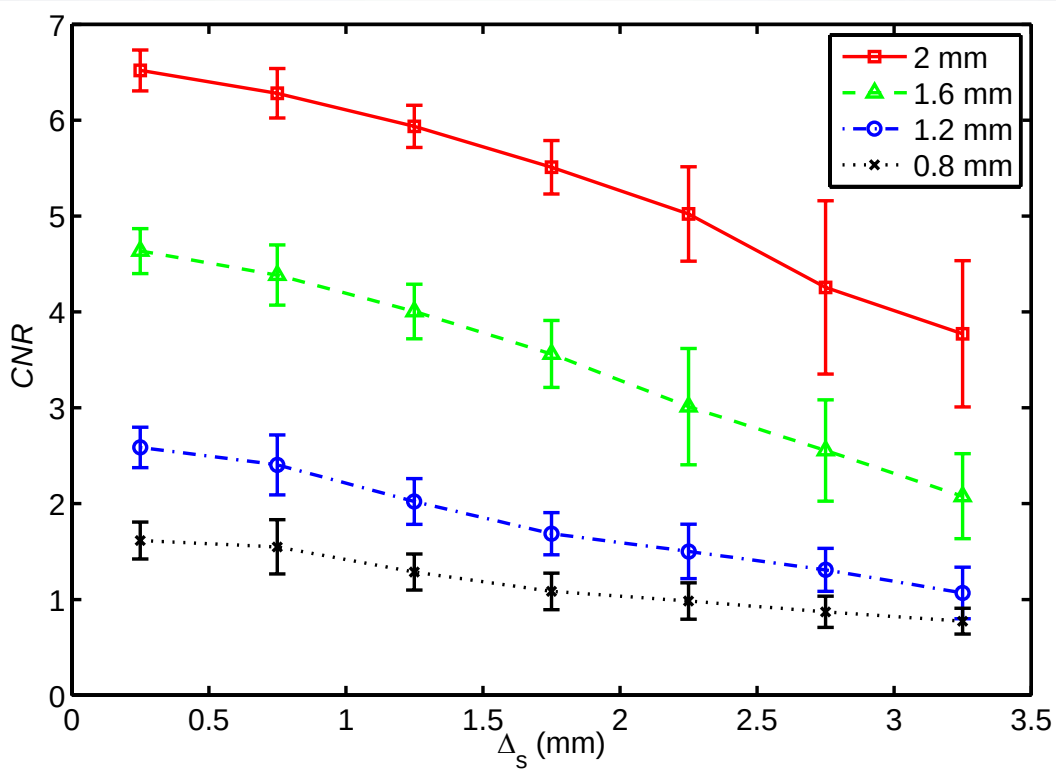
- At 40 ms markers found with error 40-60 micron (pixel size).
- At 400 ms markers found with error 0.41-0.54 mm.

Success Rate vs CNR



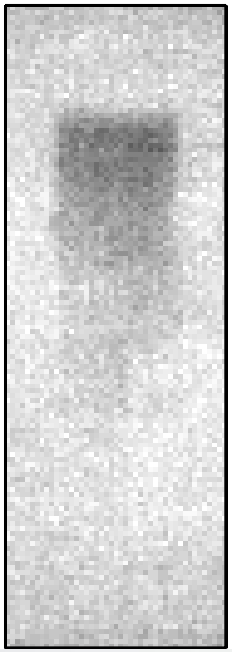
- Success rate of >90% requires CNR of >5.

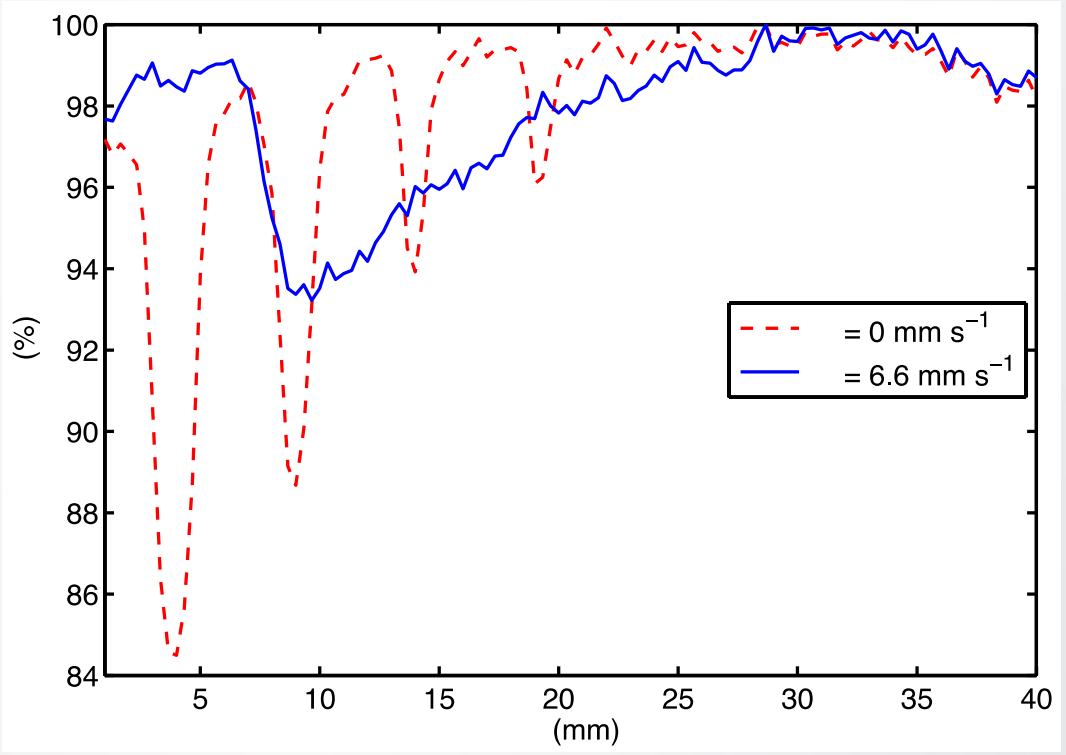
CNR vs Distance Travelled



- Smallest marker only has CNR > 1 at travel < 1.5 mm.
- Longest integration time of 114 ms or 8.8 frame s^{-1}.

Tracking with EPID





- Markers well resolved while stationary but blurred when moving.

Conclusions

- APS provides far greater CNR than EPID at equivalent dose.
- 0.8 mm marker tracked with 92% success & 90 micron error.
- 1.2-2 mm markers tracked with 100% success & 60 micron error.
- Can maybe reduce size of standard marker to increase comfort.
- a-Si EPID unable to track markers

Future Work

- Use larger sensor (12 x 12 cm).
- Include attenuation by anatomical phantom.
- Move markers in 3D and relative to each other.

Questions?