Imaging capabilities of position sensitive Silicon radiation detectors

Exemplary Illustrations

International Linear Collider Physics and Detector Workshop

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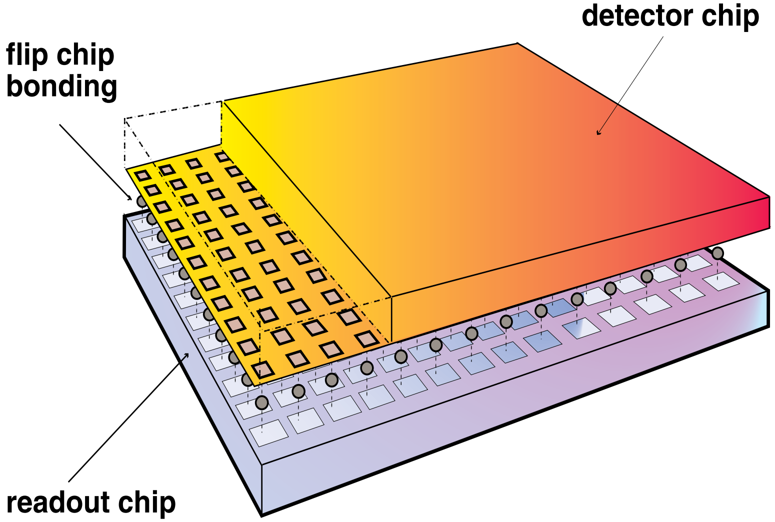
The Opponent

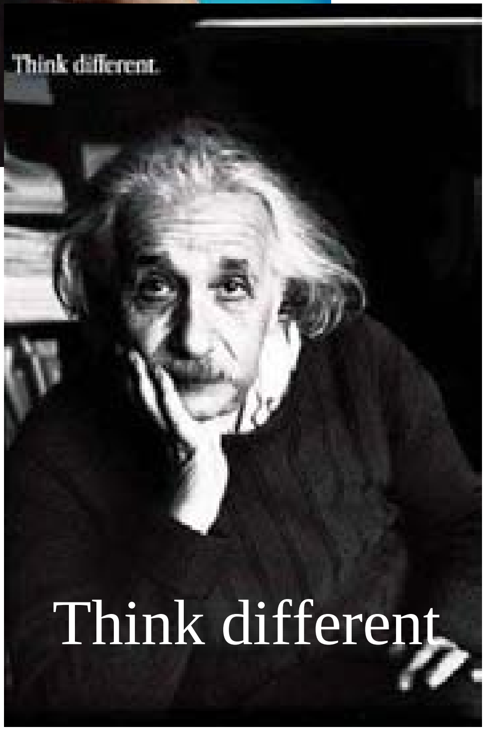


- highly granular
- optimized for single particle detection (high gain, high S/N, limited dynamic range)
- quick readout of sparsified significant data
- time stamping of hit pixels ~ 40 MHz; efficient reset
- radiation tolerant

The Defender

- highly granular
- optimized for the detection of a particle flux (global shutter, extended dynamic range)
- slow readout of dense significant data, possibly over the full frame
- significant image lag on the retina
- severely annoyed by radiation

Is there a way for the opponent to beat the defender?



A different way of building up an image

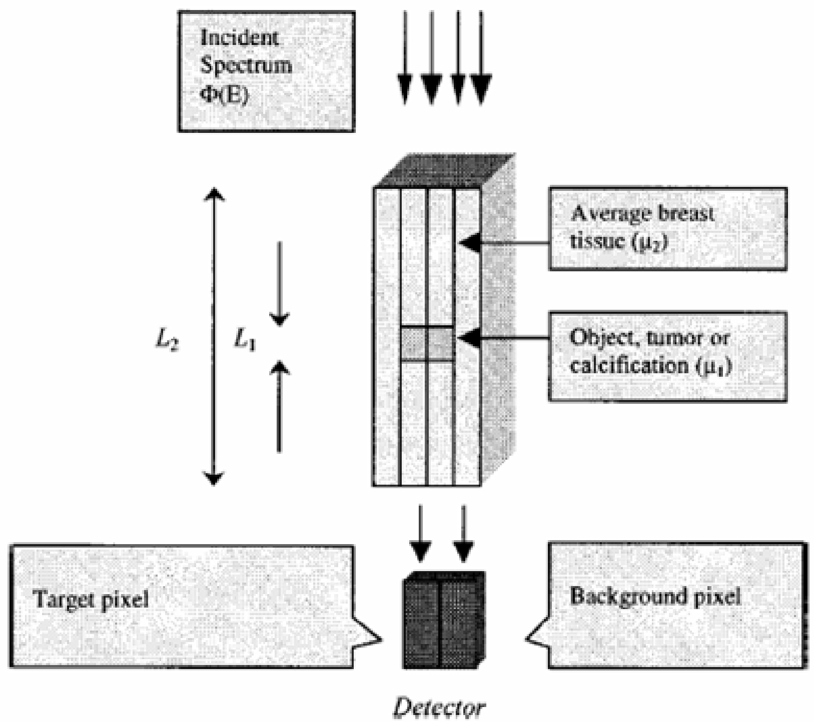


FIG. 1. Micro-calcification or tumor embedded in average breast tissue with notation used in the text.

Mammography screening

- the standard way: integrating the flux

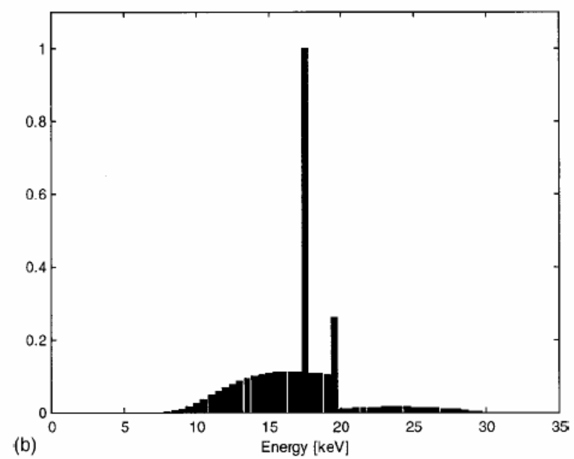
– op... the flux

– the... ally corr... y:

Where ni is the number of pixels of energy Ei = the weight in defining he sig...

I can imagine to find a way to enhance the information content of the transmitted flux!

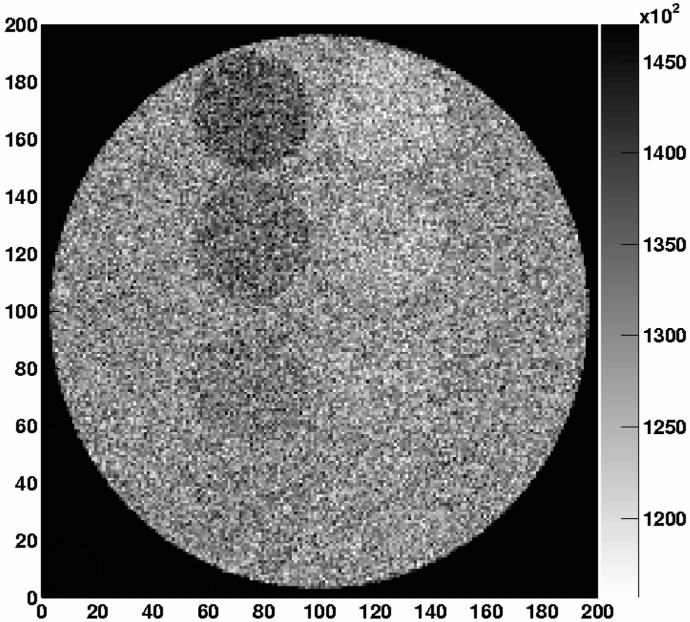
- since the X-ray tube spectrum is far from being monochromatic



- And the cross section features quite a strong dependence on the energy

$$\tau(E) = 24.15 Z^{4.2} E^{-3} + 0.56 Z,$$

Is it the OPTIMAL WAY to achieve my goal, i.e. getting the maximum contrast between the calcification and the tissue?

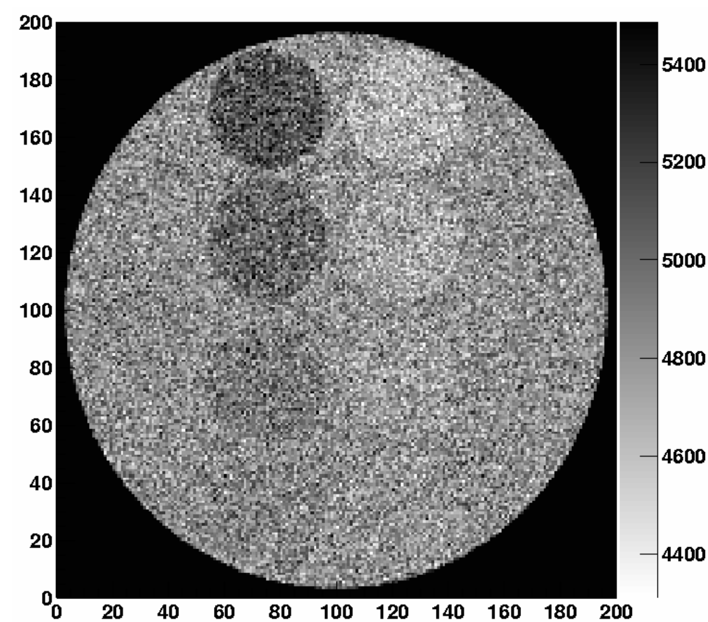


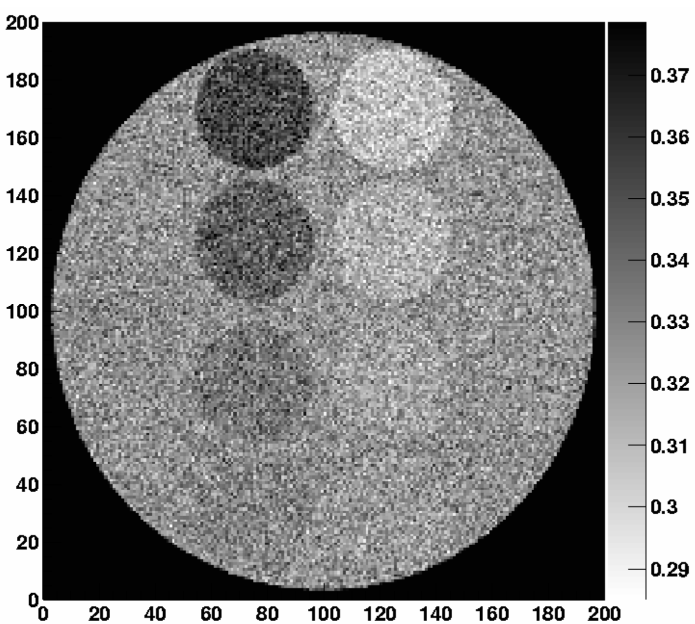
Integrating

[I record the transmitted flux; the weight of each photon ÷ E]

Counting

[I identify each photon and I count the number of photons in every pixel; weight = 1]





Weighting

[I identify each photon, I measure the energy and I assign a weight ÷ E^{-3}]

SNR enhancement	Water/ Breast	Adipose/ Breast
Integrating	1.0	1.0
Counting	1.3	1.2
Weighting	2.0	1.8

[Natalie Diekmann – NIKHEF]

So, for specific applications, Silicon eyes detecting the single occurrency, possibly measuring the deposited energy, can provide a *better* image

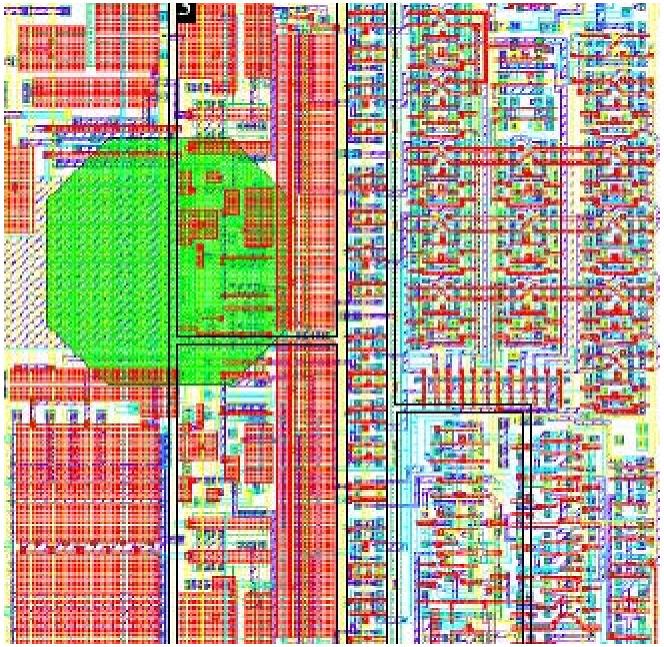
... a few exemplary illustrations

The MEDIPIX family

MEDIPIX 2; main characteristics:

- squared pixels, 55 μm pitch
- 256 x 256 pixel matrix
- leakage current compensation
- energy windowing with lower and upper thresholds, tunable on each pixel by a 3 bit DAC
- 13 bit counter, integrated in each pixel cell
- maximum counting frequency ~ 1 MHz
- maximum readout frequency ~ 100 MHz
- designed in 0.25 μm technology
- 500 transistors/cell

(33 million transistors/chip)



http://www.cern.ch/MEDIPIX

MEDIPIX I – applications
….X raying sardines…

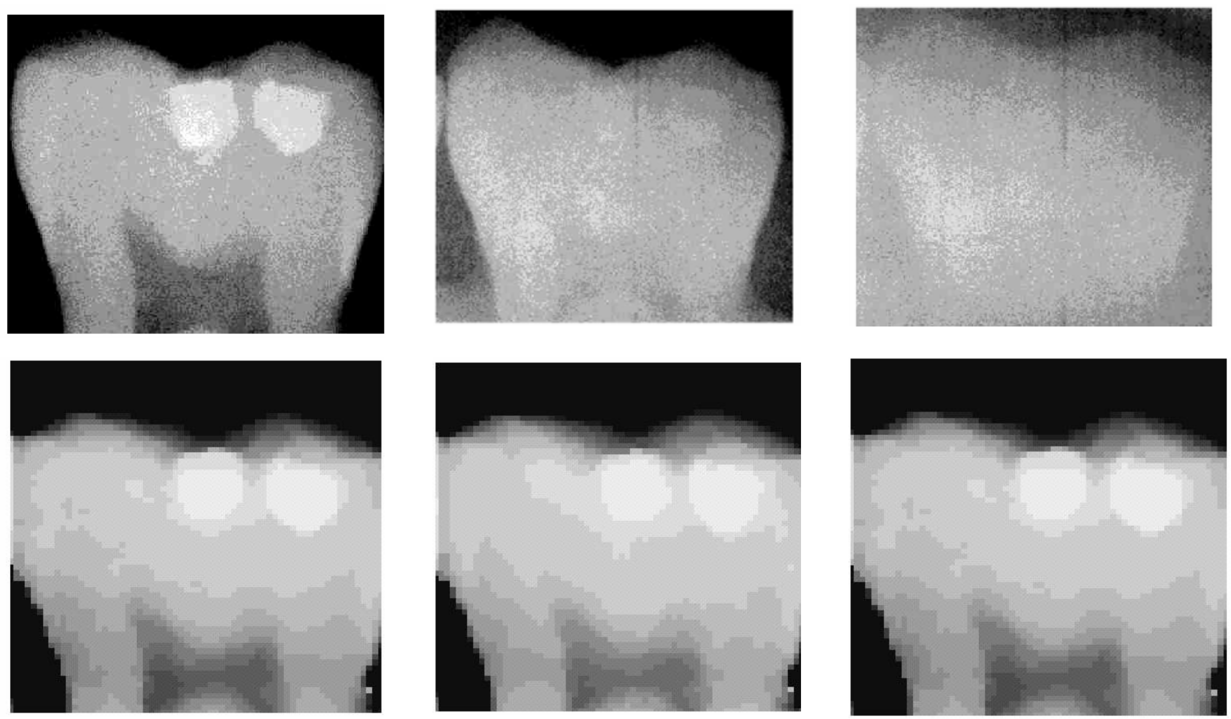
- Mo X ray tube + 30 μm Mo filter, 25 kV
- Source- detector distance 50 cm
- chip interconnected to a Si detector, 300 μm thick
- integration time: 500 ms

MEDIPIX I; applications
Dental radiography

Bechmark: 1-3 mGy dose with conventional film emulsions

Sens-A-Ray
dental CCD system
(*Regam Medical*)

Medipix1

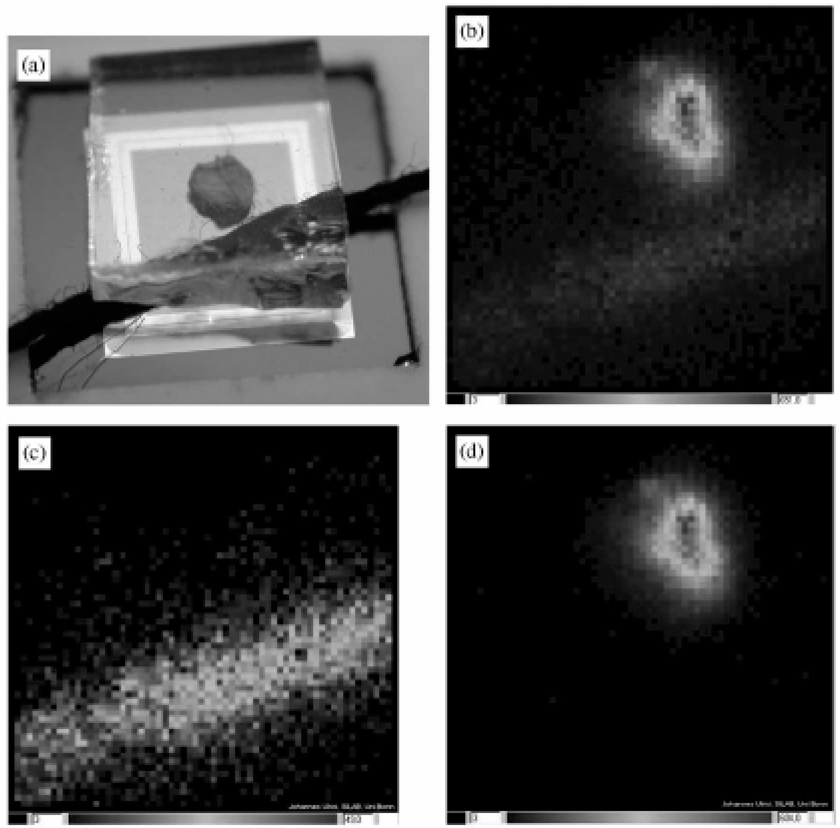


160 μGy **80 μGy** **40 μGy**

Universities of Glasgow, Freiburg and Mid-Sweden

Relevance of energy measurement in autoradiography
The DEPFET results

J. Ulrici et al. / Nuclear Instruments and Methods in Physics Research A 547 (2005) 424–436



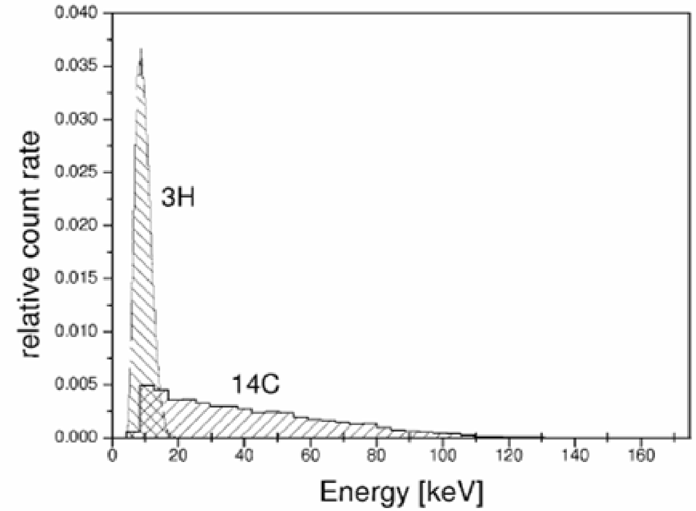


Fig. 15. Measured energy distribution for ^{3}H and ^{14}C.

	3H	14C
Mean energy [keV]	5.7	49.5
End point [keV]	18.6	240

Fig. 16. (a) Simultaneous measurement of ^{3}H- and ^{14}C-decays with a piece of a ^{3}H-labelled leaf and a ^{14}C-labelled twine. (b) Hit distribution if no energy information is used. (c) Hit distribution for ^{14}C-events. The twine but not the leaf is seen in the image. (d) Hit distribution for ^{3}H-events. The leaf but not the twine is seen in the image.

SUCIMA – selected results

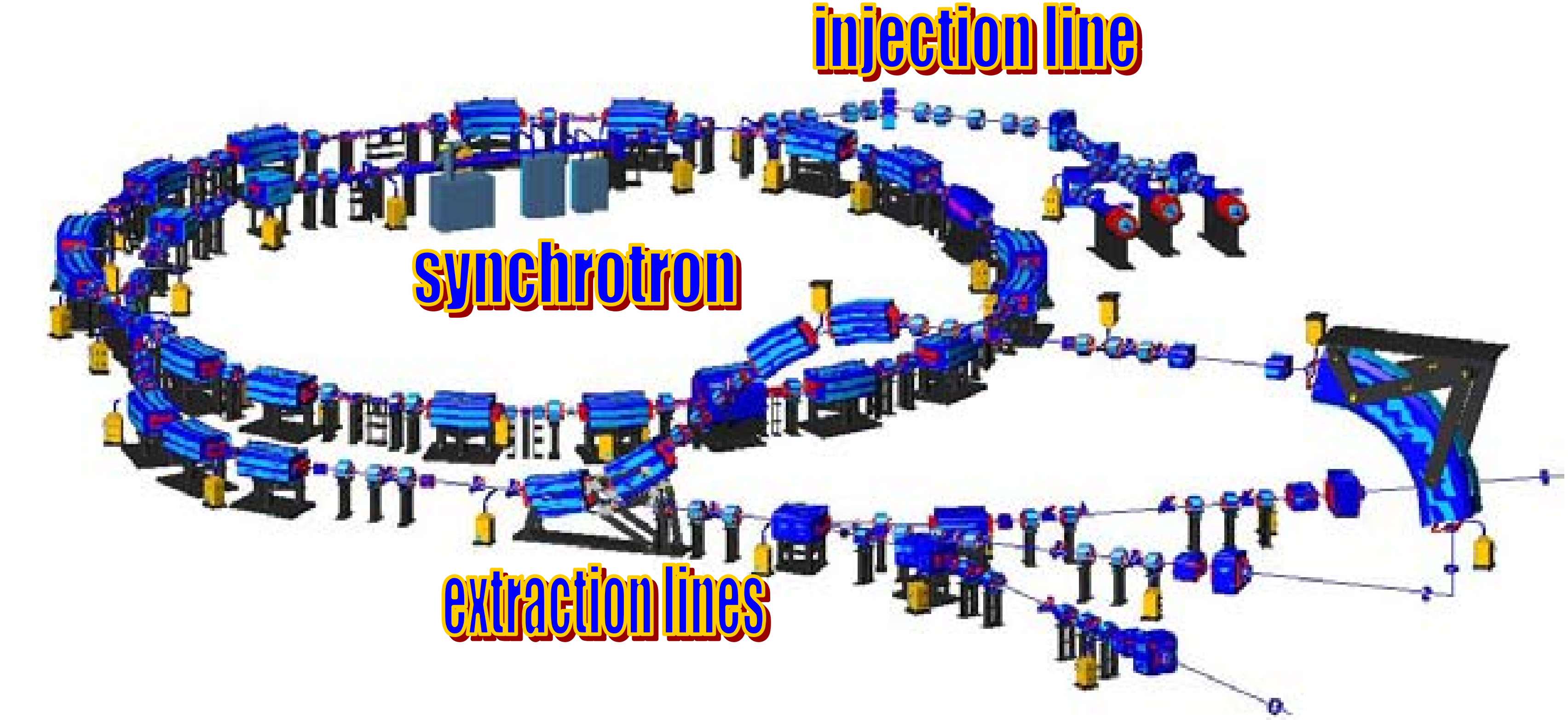
Explored *Imaging* applications:

- dosimetry of brachytherapy sources
- real time monitoring of a hadrontherapy beam
- radiotherapy beam profilometry
- sensitive element into a HPD
- 3H imaging
- e-scopy
- solar spectra recording
- calibraton/imaging with a cristallography beam

General purpose advances (flowing back to HEP as well!):

- SOI development
- extreme backthinning
- radiation hardness to ionizing radiation
- characterization in terms of “unusual” figures (e.g. efficiency of the reset mechanism (image lag); image blooming)

The TERA accelerator complex for radiotherapic treatments



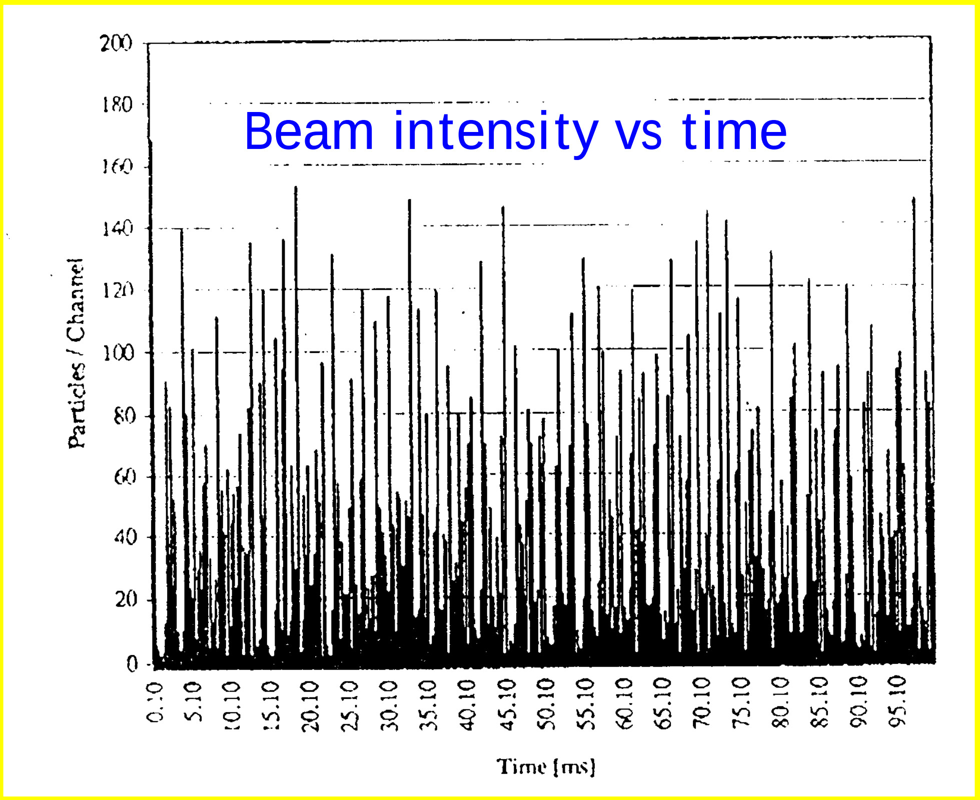
energy: 7 MeV p, 7 MeV/u $^{12}C^{6+}$

average intensity range: 15 μA ($^{12}C^{6+}$) ÷ 1.1 mA (p)

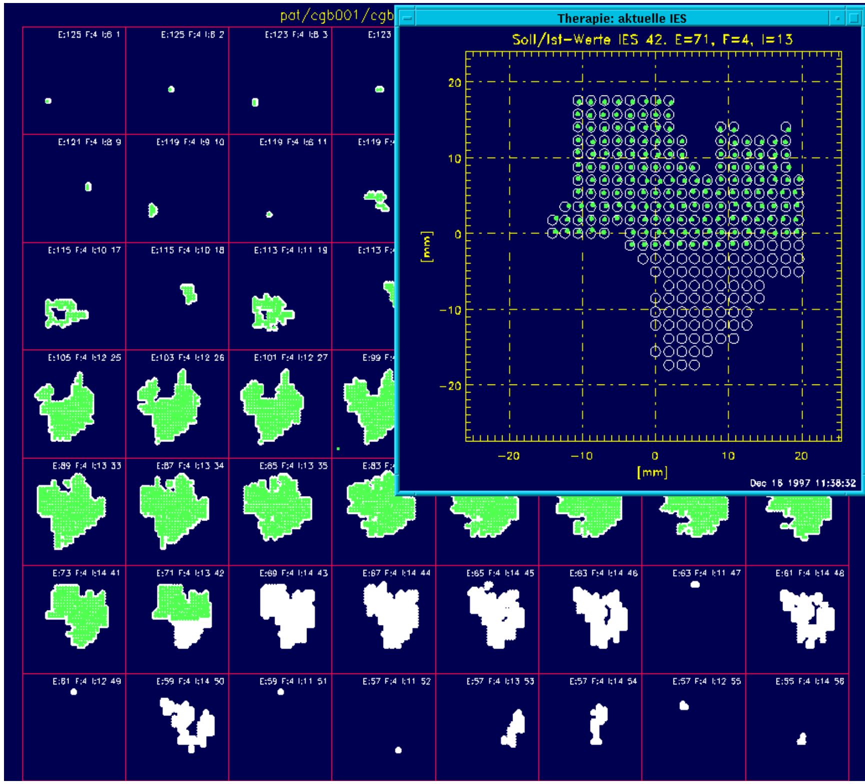
energy: 60 ÷ 250 MeV p, 120 ÷ 400 MeV/u $^{12}C^{6+}$

average intensity range: 2 pA ($^{12}C^{6+}$) ÷ 8 nA (p)

Treatment quality



dose uniformity: ± 2 %



dosimetry ionization chamber (80 kHz)

(GSI – Darmstadt)

Real-time monitor of a proton beam

'on-line' monitoring (DURING the patient treatment)

⇩

efficient operation of the accelerator complex
multiple measurements on the same beam
maximum safety to the patient

very low beam intensities (a few pA to a few nA)

⇩

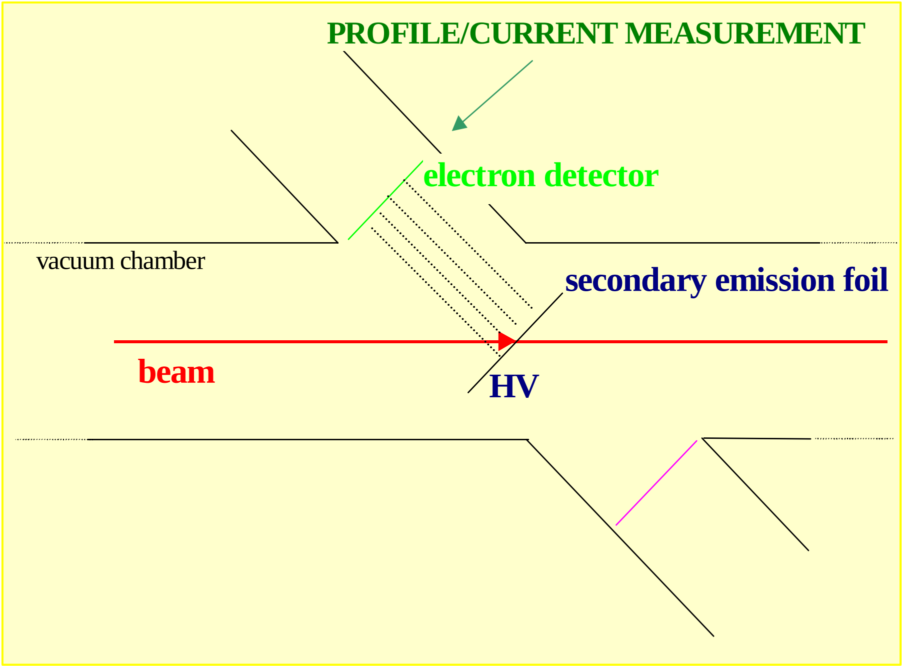
instrumentation **interceptive**

standard monitors (thickness > μm)

⇩

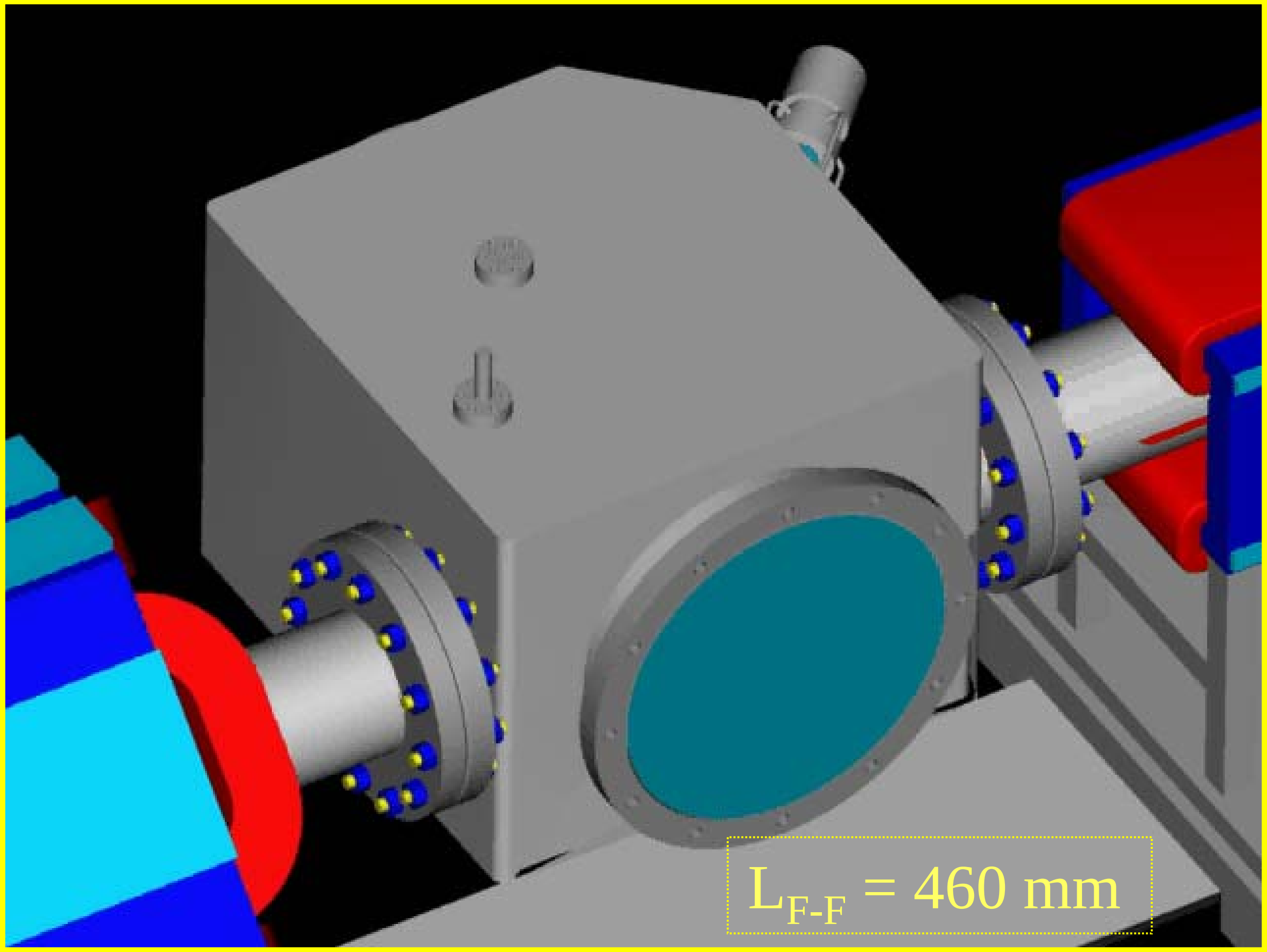
strongly **perturbative**

Main goal of SUCIMA connected to real-time monitoring: SLIM ≡ Secondary Emission for Low Interception Monitoring



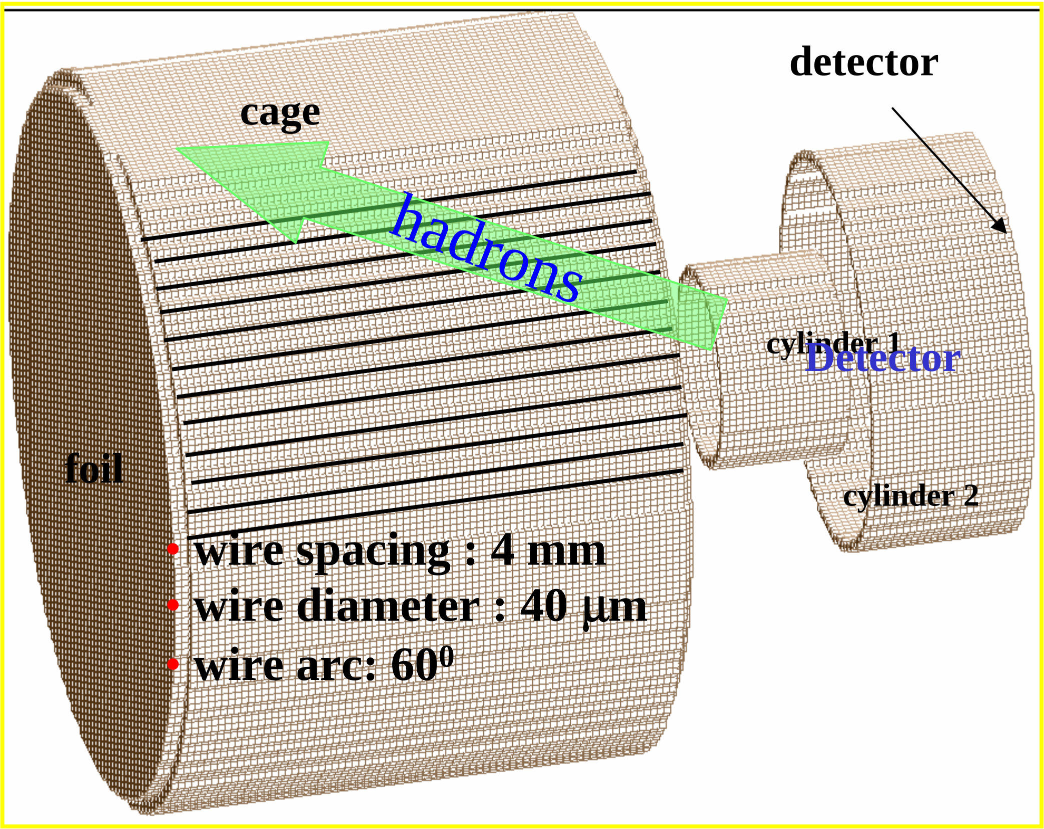
Basic principle: collection and imaging of secondary electrons emitted by thin Aluminum foils ($t \cong 0.2 \div 0.4$ μm, $\phi \cong$ **60 ÷ 70** mm) as the beam is delivered

The SEM beam monitor

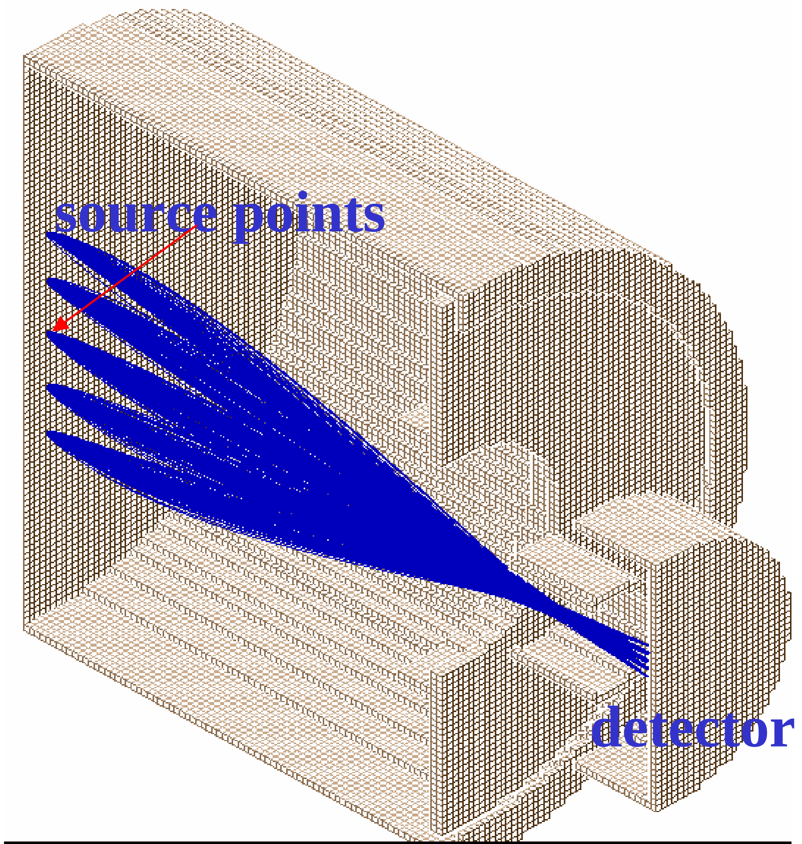


Mirco Nodari

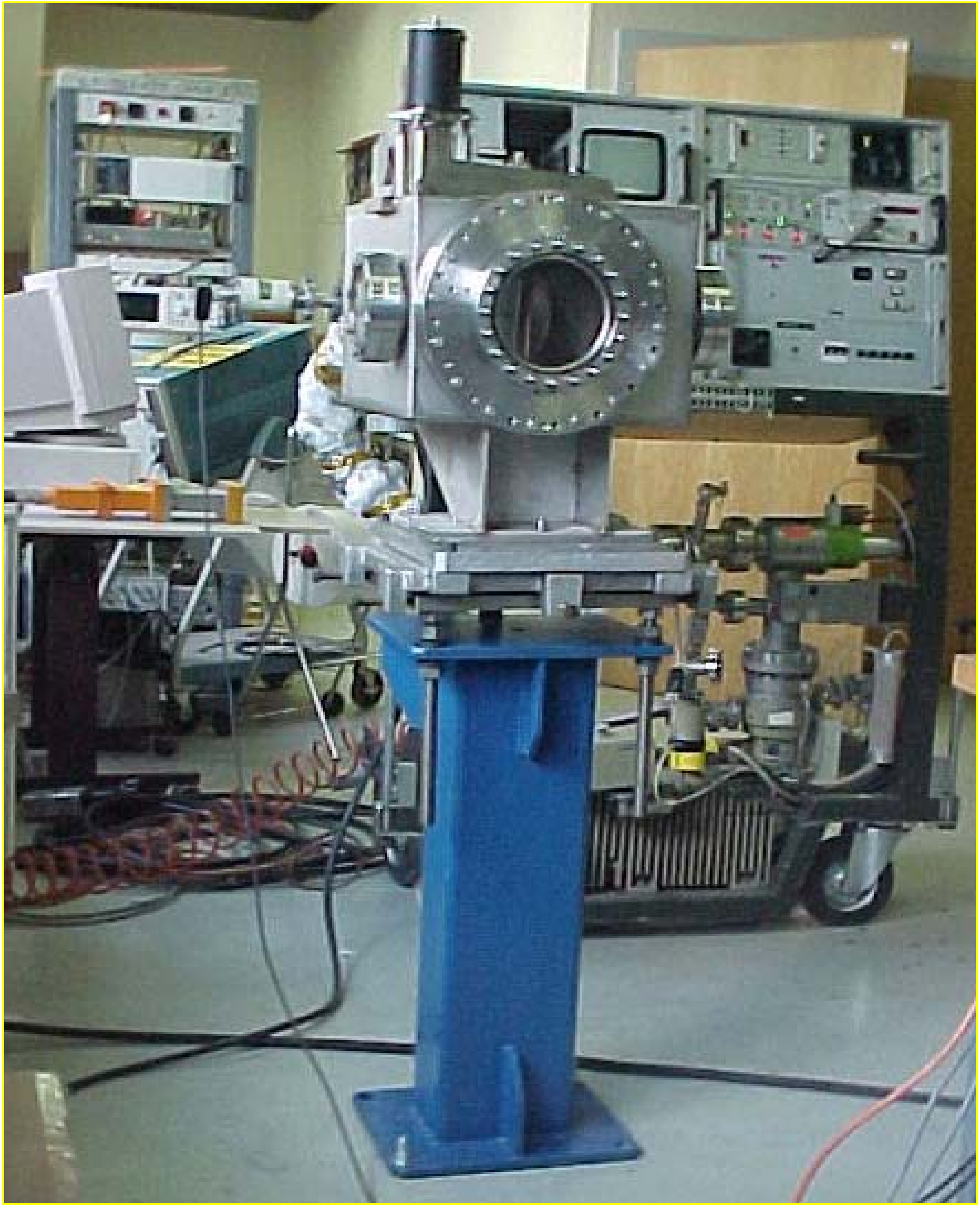
A closer look at the FOCUSING SYSTEM:



Secondary emission electrons drifted and focalized through a 20 kV field

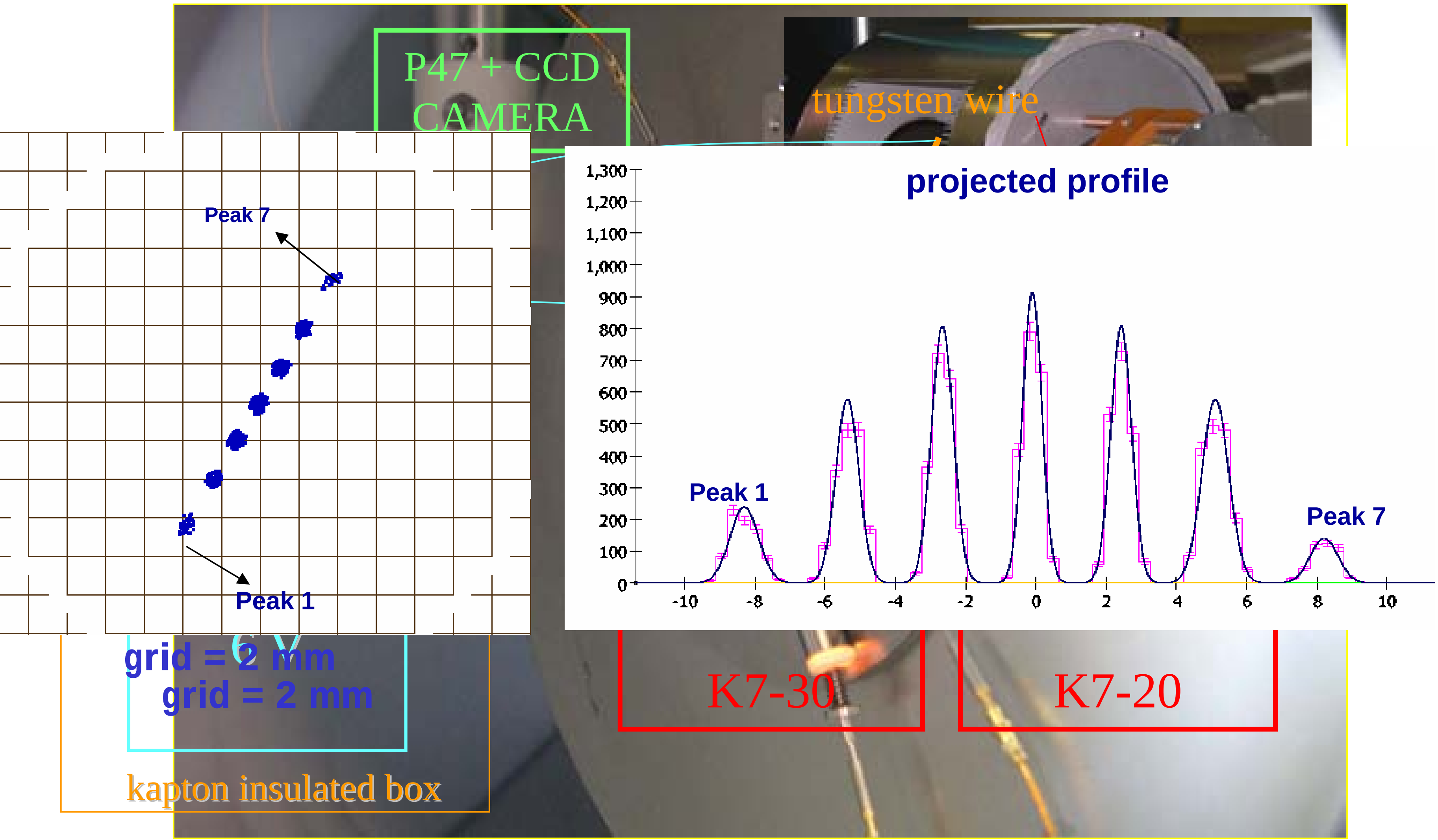


Demagnifying factor ~ 5

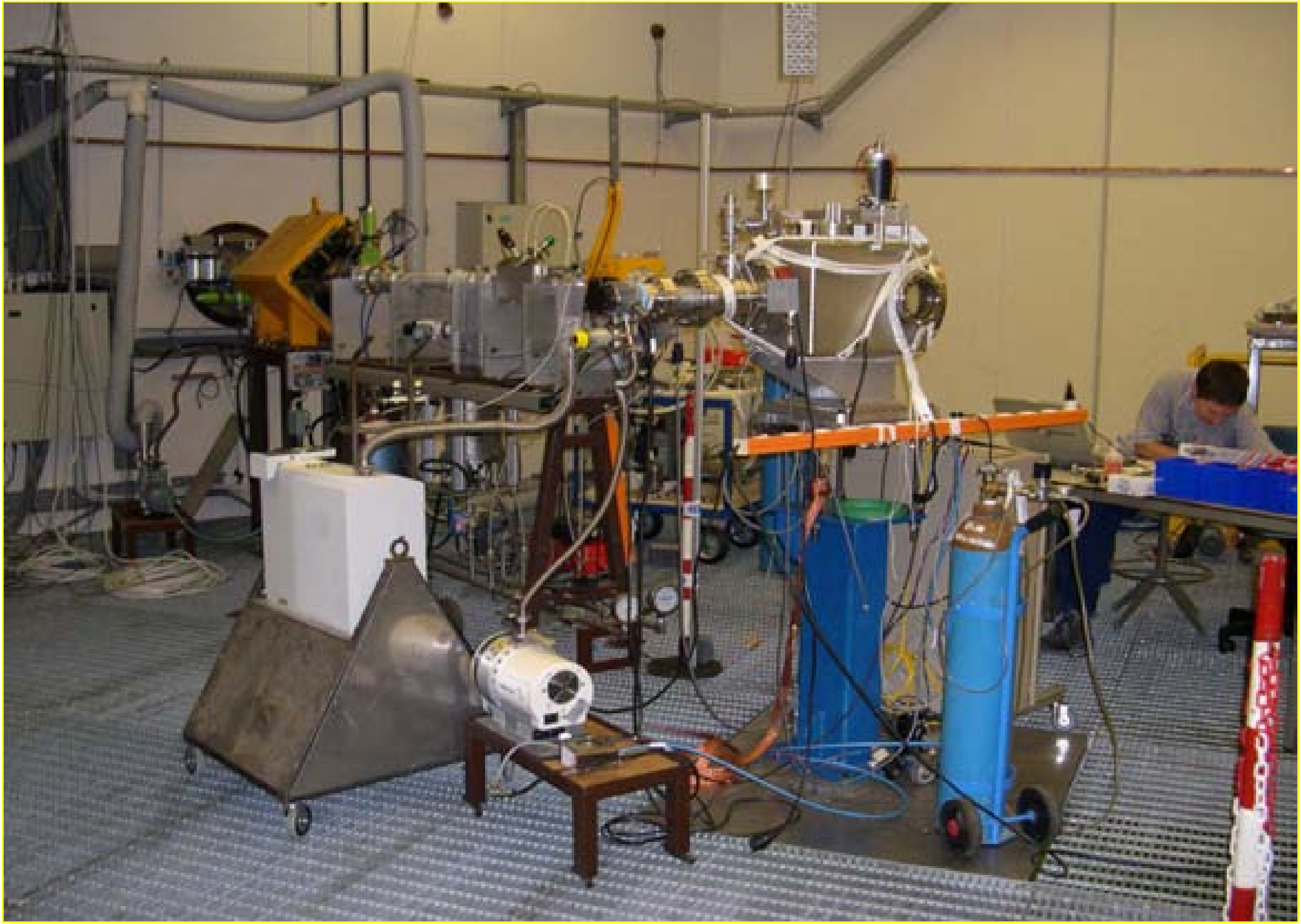


The integrated system
at CERN

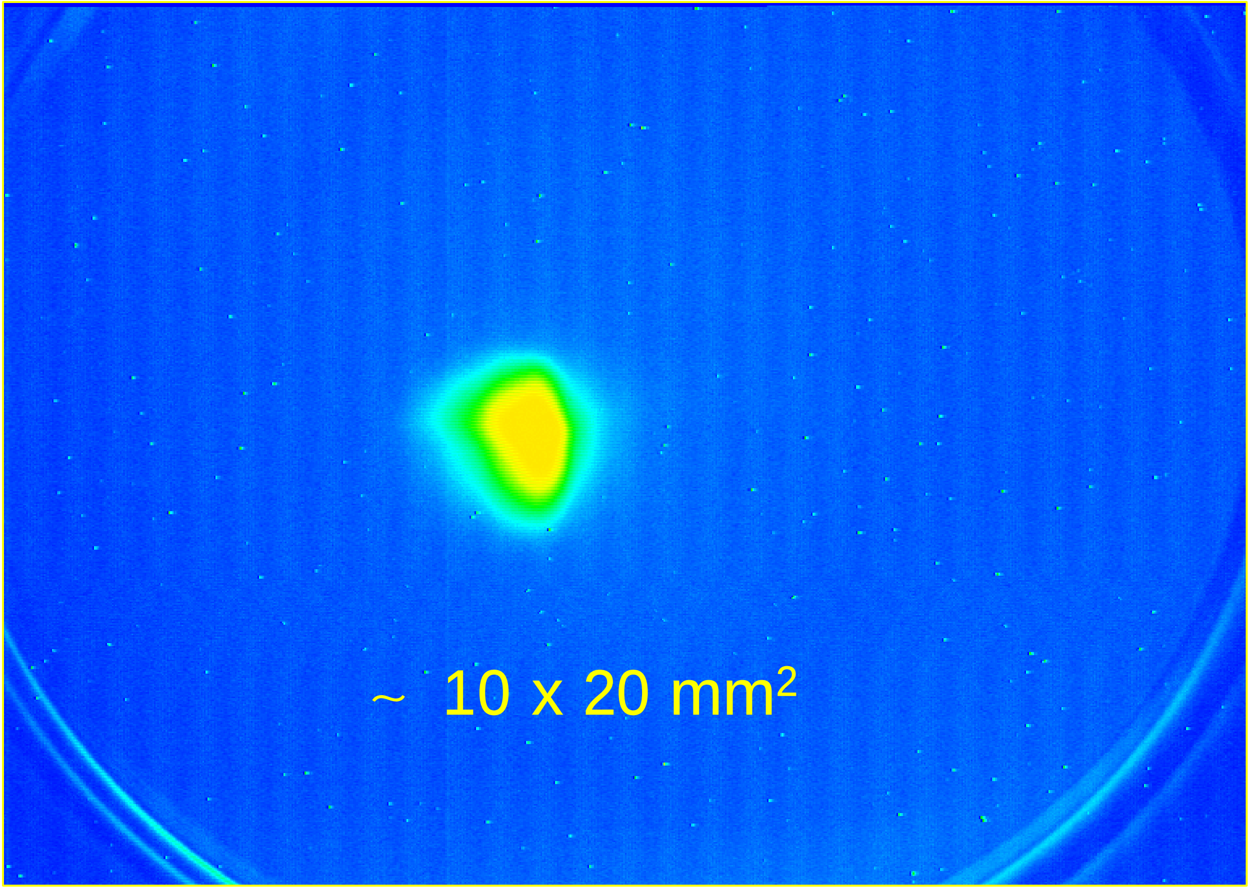
Preliminary tests of the Focalization System using thermo-ionic emission by a hot tungsten wire:



The SLIM installed on an extraction line at the Ispra JRC-Cyclotron (p, 2H, 4H at energies 8-38 MeV, 100 nA- 100uA)



First images of a beam, imaging the focalized Secondary Electrons by a Multichannel-plate+Phosphor screen+CCD camera system



Tests with an extremely backthinned MIMOSA-5

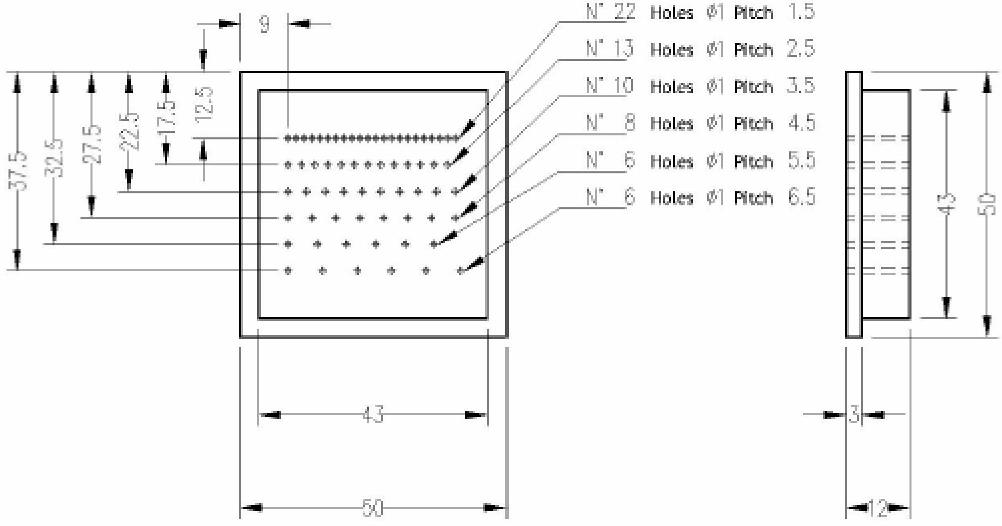
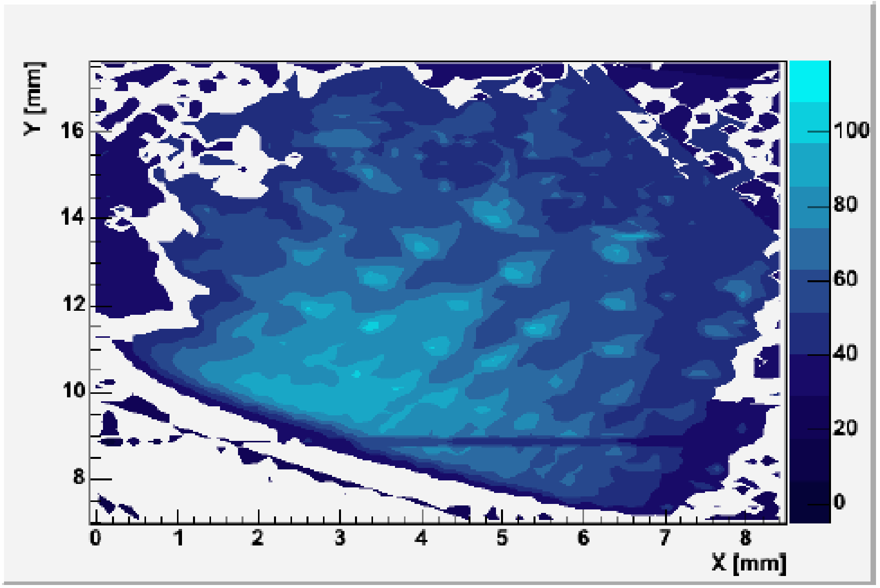
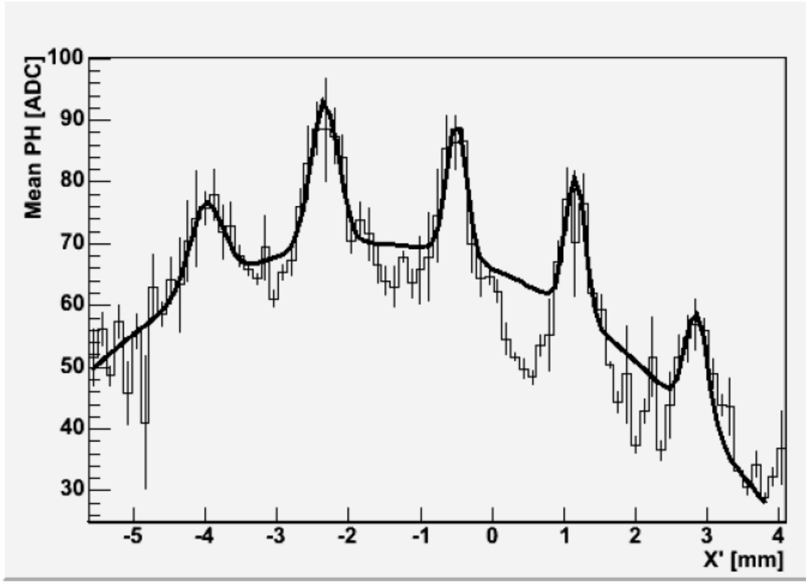


Figure 4.10: *Schematic drawing of the collimator placed on the beam path, consisting of a 12 mm-thick aluminum block with 6 rows of holes of 1 mm diameter. The hole pitches range from 1.5 up 6.5 mm.*



Raw image



Projected image along one row of holes

- measure the de-magnifying factor
- measure the “point spread function” (~140 μm)
- try understanding the origin of the background ⇒ study image blooming under saturating conditions

A dedicated sensor, with no dead time and a dynamic range up to 2000 mips/pixel/100 us frame has been designed, produced, backthinned and it is being hybridized

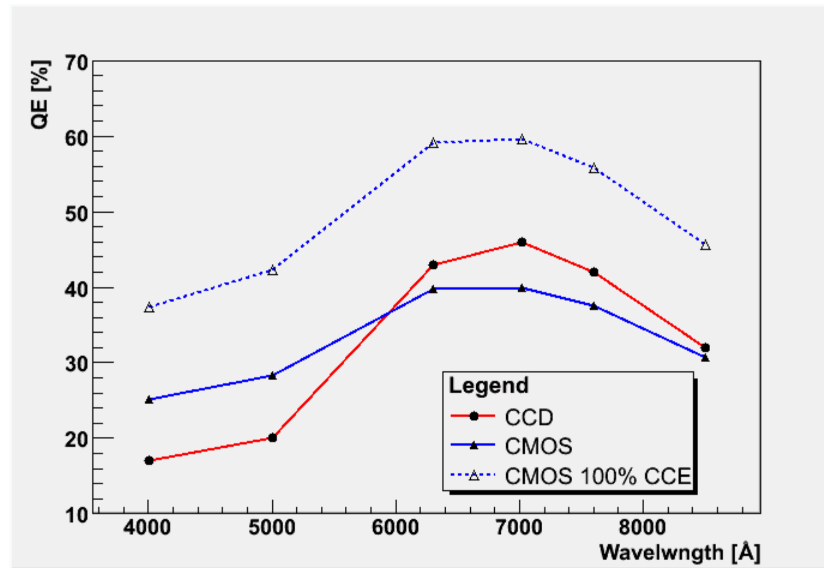
Back to light
Imaging the Solar spectrum with a 100% fill factor extremely backthinned MIMOSA5

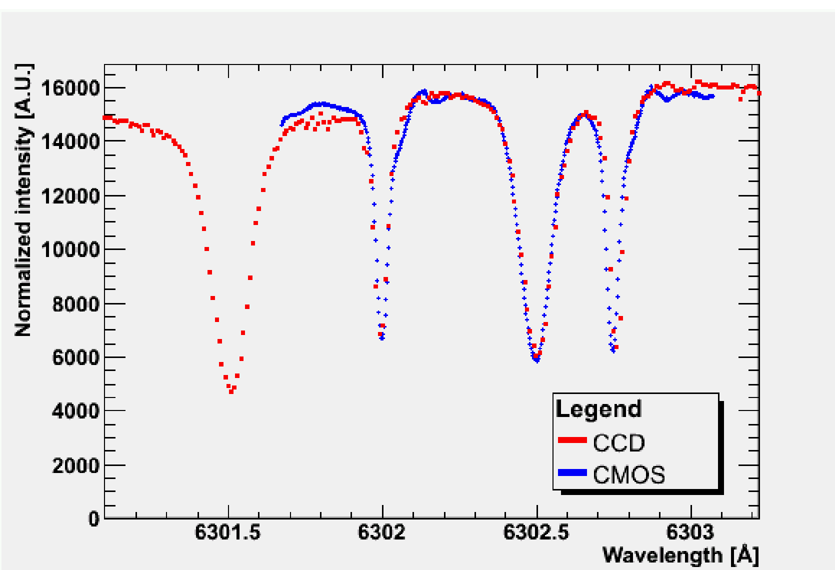
Analyze the polarization of the solar spectrum from the sun chromosphere (emission spectrum from a low density gas at ~10^4 K), overwhelmed by the absorption spectrum from the photosphere at any time but during a total eclipse

⇒ Get as many frames as you can over ~20”, scanning the spectrum and the polarization (then you will have a few years to analyze your data…)

It was interesting to perform an experiment comparing the visible light imaging properties of a MIMOSA 5 sensor to a “standard” CCD camera (by the way, manufactured by E2V), in view of the possible use of one of the SUCIMA chips, featuring a 10 kHZ frame rate

The solar telescope at IRSOL,
based in Locarno (Switzerland)





- QE comparison
- image blooming study
- image lag (reset efficiency study)

Conclusion

• non HEP applications may really be a great fun!

• HEP sensors most often are NOT what you really need but they are the "workhorse" for a demonstrator program and define the guidelines for application specific developments

• the impact on the sensor R&D is definitely non trivial

• these applications may generate a lot of enthusiasm in people who have the chance to see a "real" table-top experiment in an international collaboration, with a reasonable time scale and the possibility to understand any aspect from head to toes

• but success stories do not come for free and a real effort has to be invested!