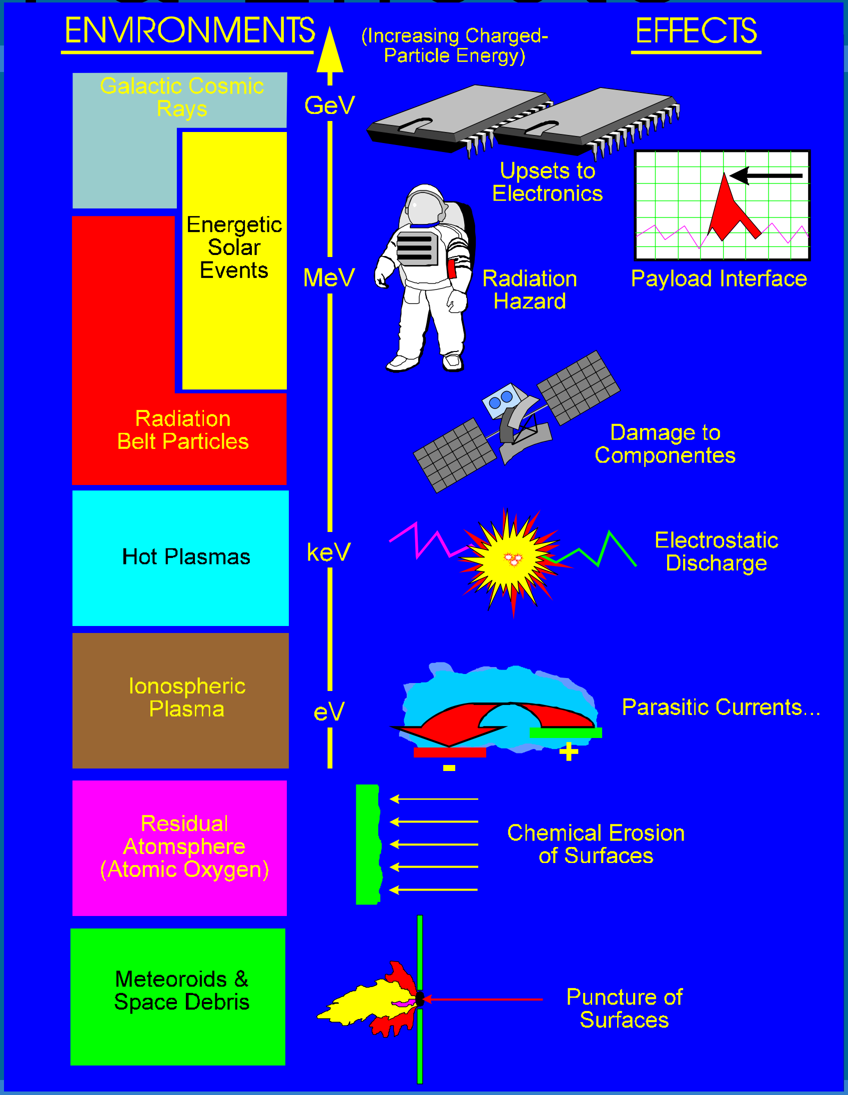
The Radiation Assurance Test Facility at LNS-INFN in Catania

Behcet ALPAT
INFN Sezione di Perugia

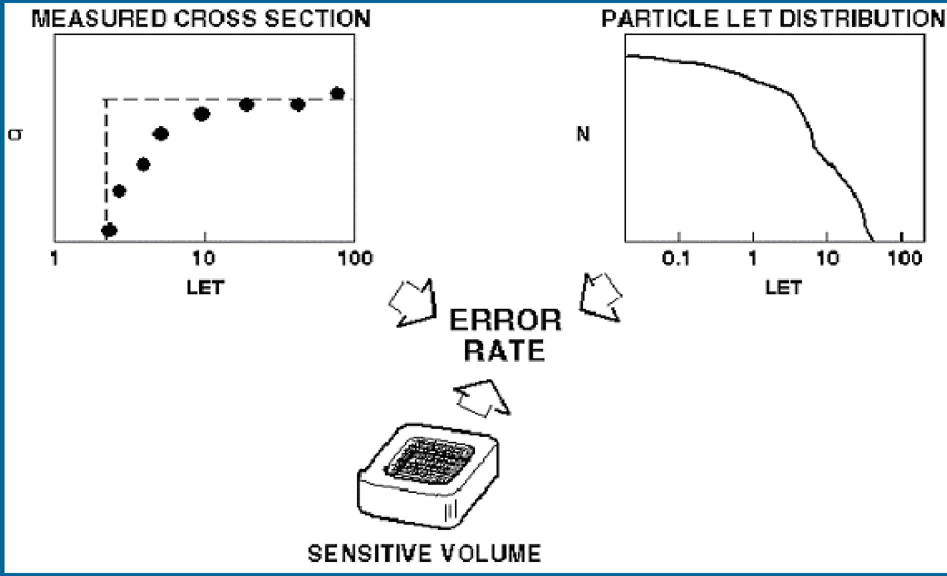
Radiation & Effects

- Total Ionising Dose
  - Cumulative long term ionising damage due to protons & electrons
- Displacement Damage
  - Cumulative long term non-ionising damage due to protons, electrons, & neutrons
- Single Event Effects
  - Event caused by a single charged particle - heavy ions & protons for some devices



Expected SEE Rate Calculations

- Involves 3 different quantities;
  1. The cross section of the device, often determined empirically;
  2. The distribution of particles expected in the space environment, which depends on assumptions about solar flare activity, radiation belt activity, and shielding;
  3. The critical charge, sensitive area and sensitive volume associated with the SEE phenomenon of interest.

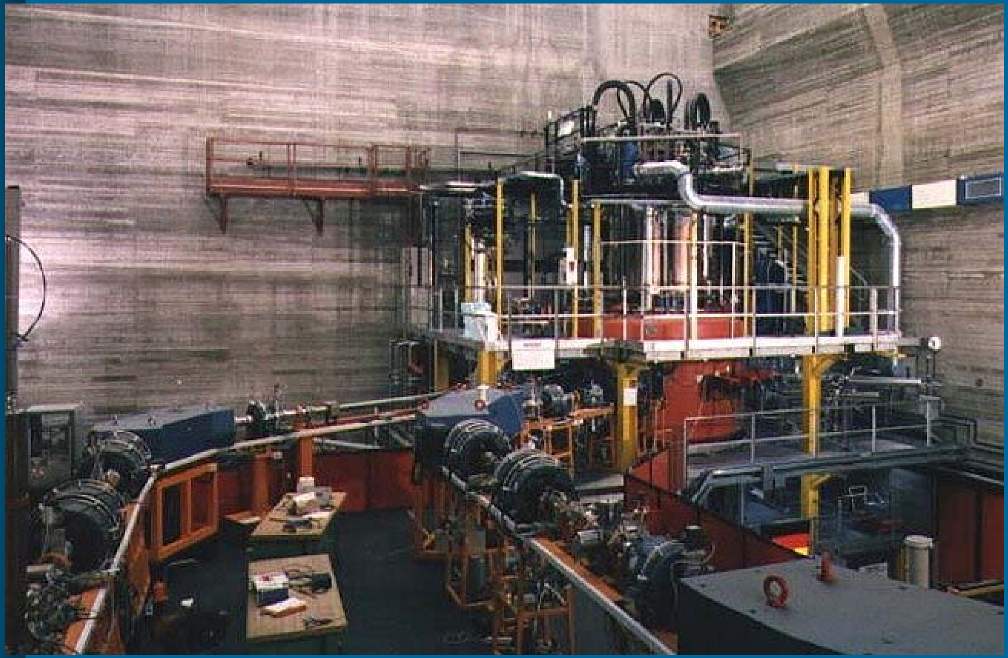


SEE Ground Testing

- Heavy-Ion Testing (according to ESCC 25100)
  - Must be well-defined in E and specie (LET determination)
  - Uniform over DUT surface (flux values may be varied between 10^2-10^5 ions/(cm^2-s)) both within 10%
  - LET values between 0.7-70 MeV/(mg/cm^2) at normal incidence
  - Range larger than 30 μm
  - Specific beam dosimetry that
    - measures the flux and fluence of selected beam by scintillator/PM and Si detector
    - Permits energy calibration before (and during) the operation
  - Tilt the incident angle to allow wider range of LET values (cosine law)

Single Event Effects Tests at Accelerators

SEE Test: **Cyclotron at LNS** (Catania), of Italian National Institute for Nuclear Physics (INFN).



The **LNS Cyclotron** has 15 to 48 MHz RF system;

the ion energies range is between **8 and 100 A MeV** in harmonic mode h=2. The expected maximum energies of the machine are of 20 MeV/amu for the heaviest ions, like $^{238}U_{38+}$, and 100 MeV/n for fully stripped light ions

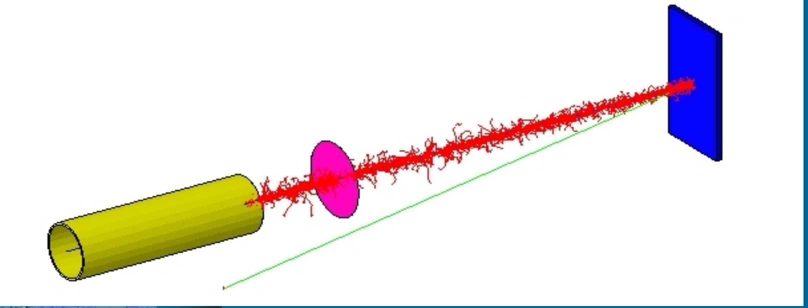
LNS Beams Used for RH Qualification Tests

- For SEE test Gaseous Beams at 20 MeV/nucleon
  - ^{20}Ne
  - ^{40}Ar
  - ^{84}Kr
  - ^{129}Xe
- All “Contianed” Events with range in Si of 70um to 450 um

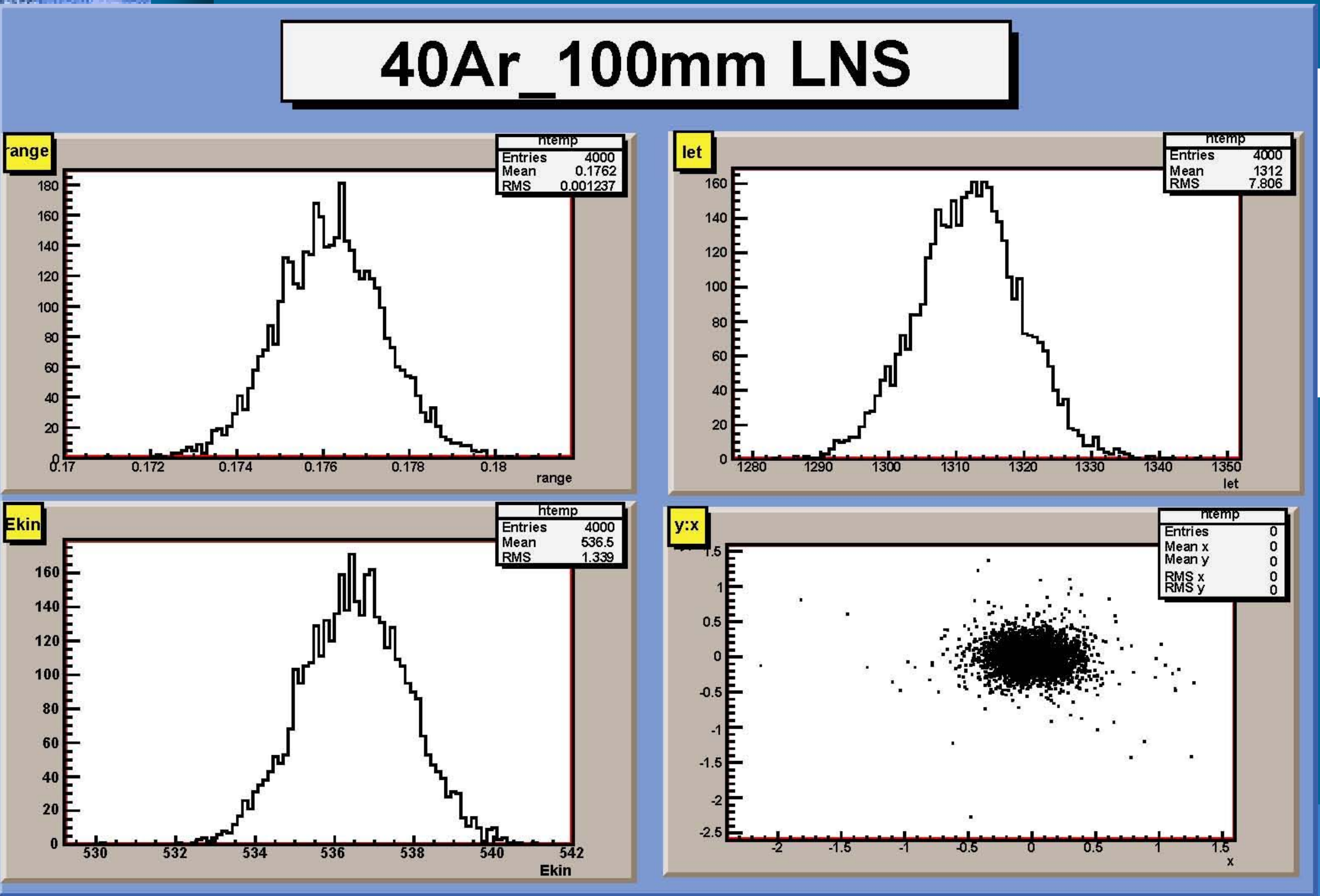
- For DD tests protons of 20-to-60 MeV

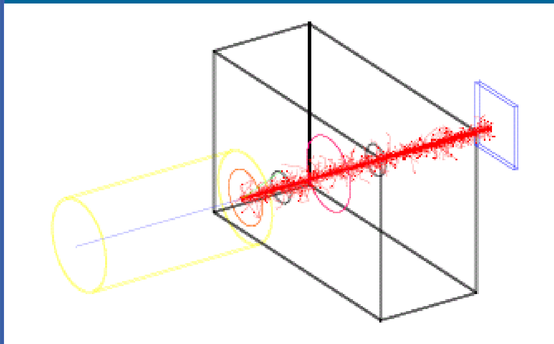
Dosimetry System Features

- Thin scintillator (50 and 100 um) is to obtain a circular beam spot and for the online fluence measurement >99 % efficiency
- Motorized stage with submicron accuracy of position repeatability (X,Y max 20 cm and Z max 30 cm). The rotator for measuremnts with theta angle up 60 degrees.
- 1.5 mm thick double sided microstrip detector with 170 um spatial resolution.
  - All the selected ions are stopping inside hence calorimetric measurements
  - To localize and measure the beam spot (3-D profile of the beam is obtained);
    - Each event is
      - time tagged with 125 ns resolution
      - Energy tagged through dE/dX measurements in silicon
- SELDP (Single Event Latchup Detector and Protector)
  - Custom module to monitor and count the SEL behaviour of DUT (wide range of DUTs are covered)
- Online Monitoring of Environmental parameters (T, RH)

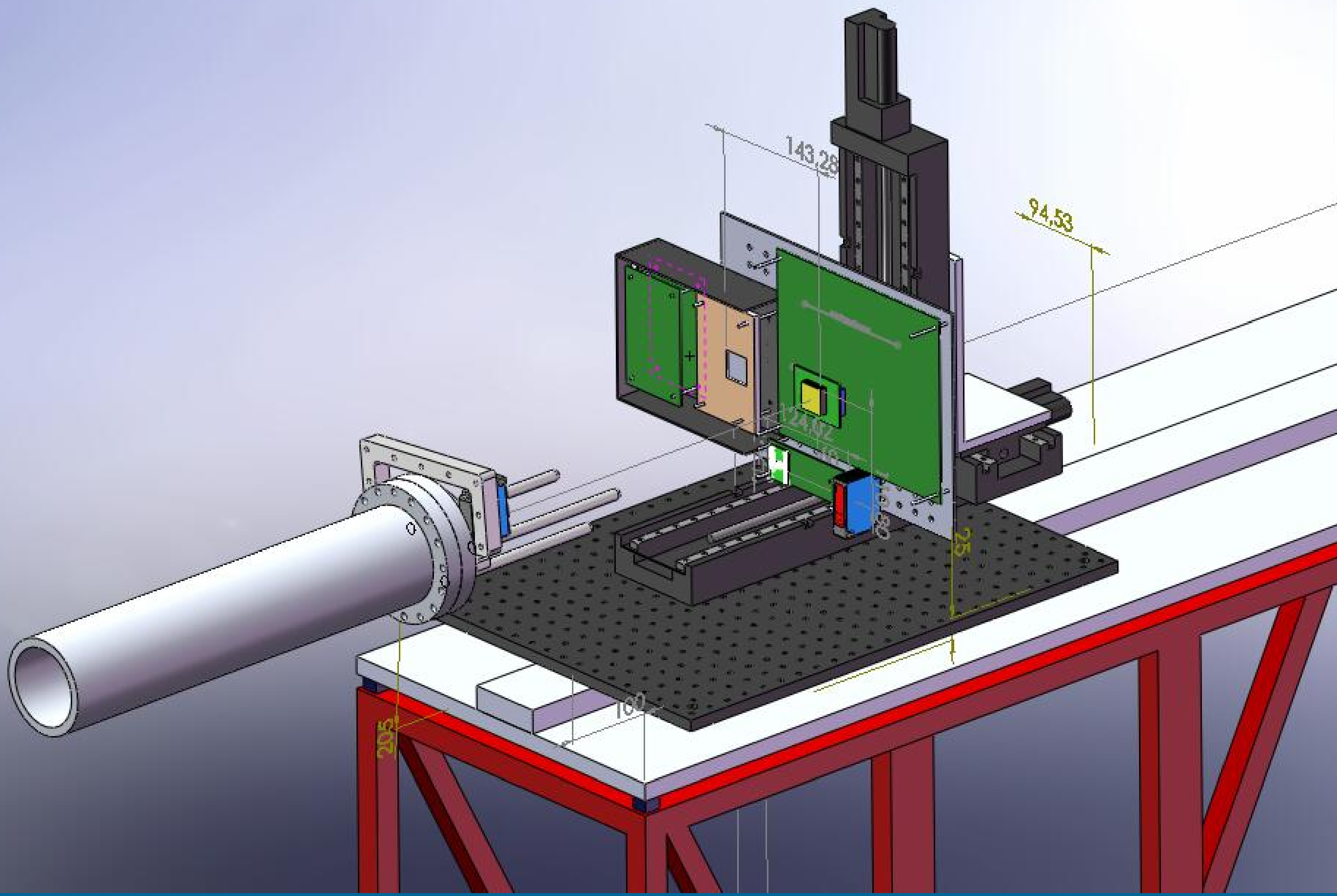


GEANT4 and FLUKA Simulations

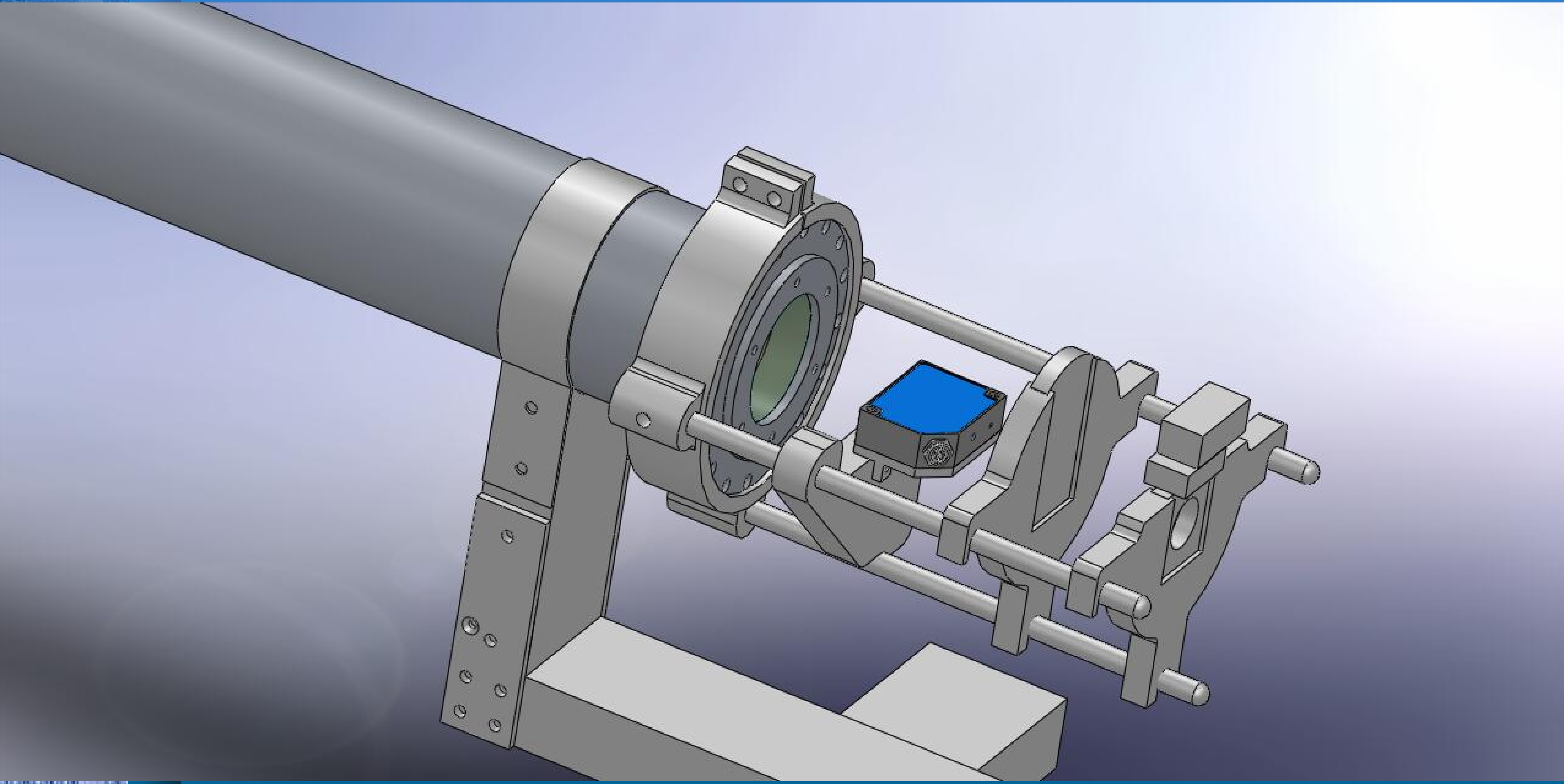




CAD design of LNS Setup

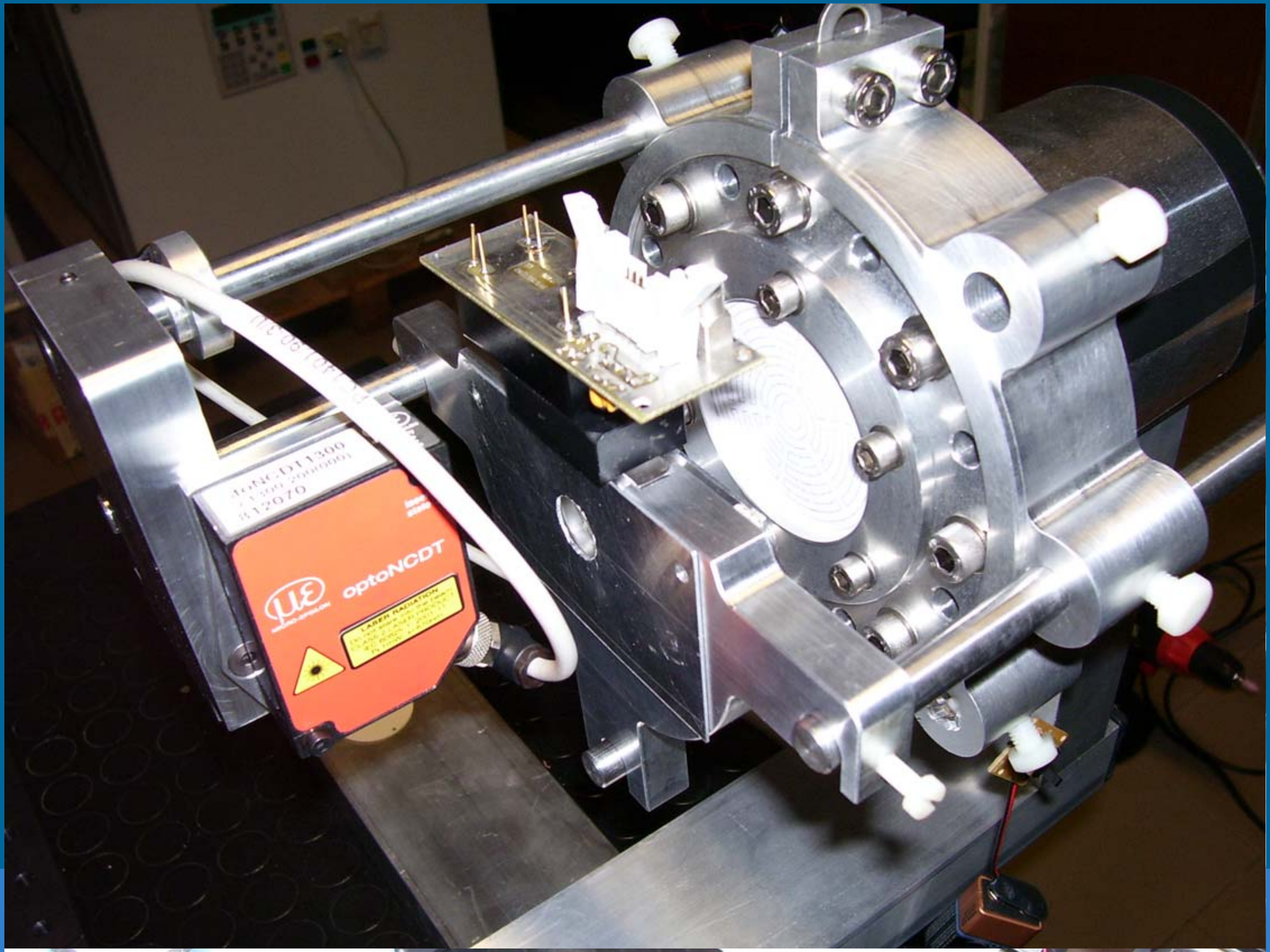


CAD design of LNS Setup

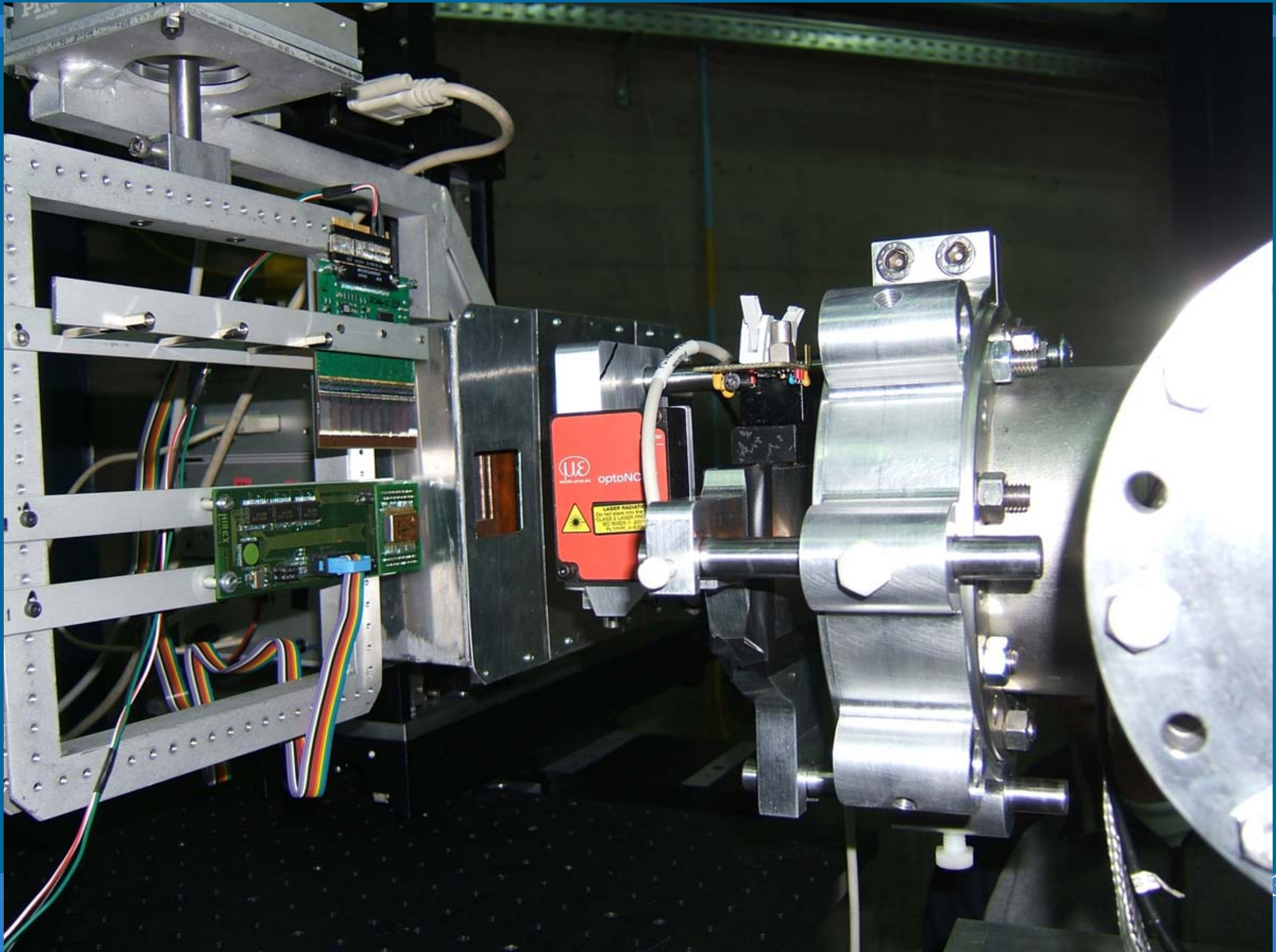


LNS Beam SETUP
Mock-up at MAPRAD labs (March 2009)

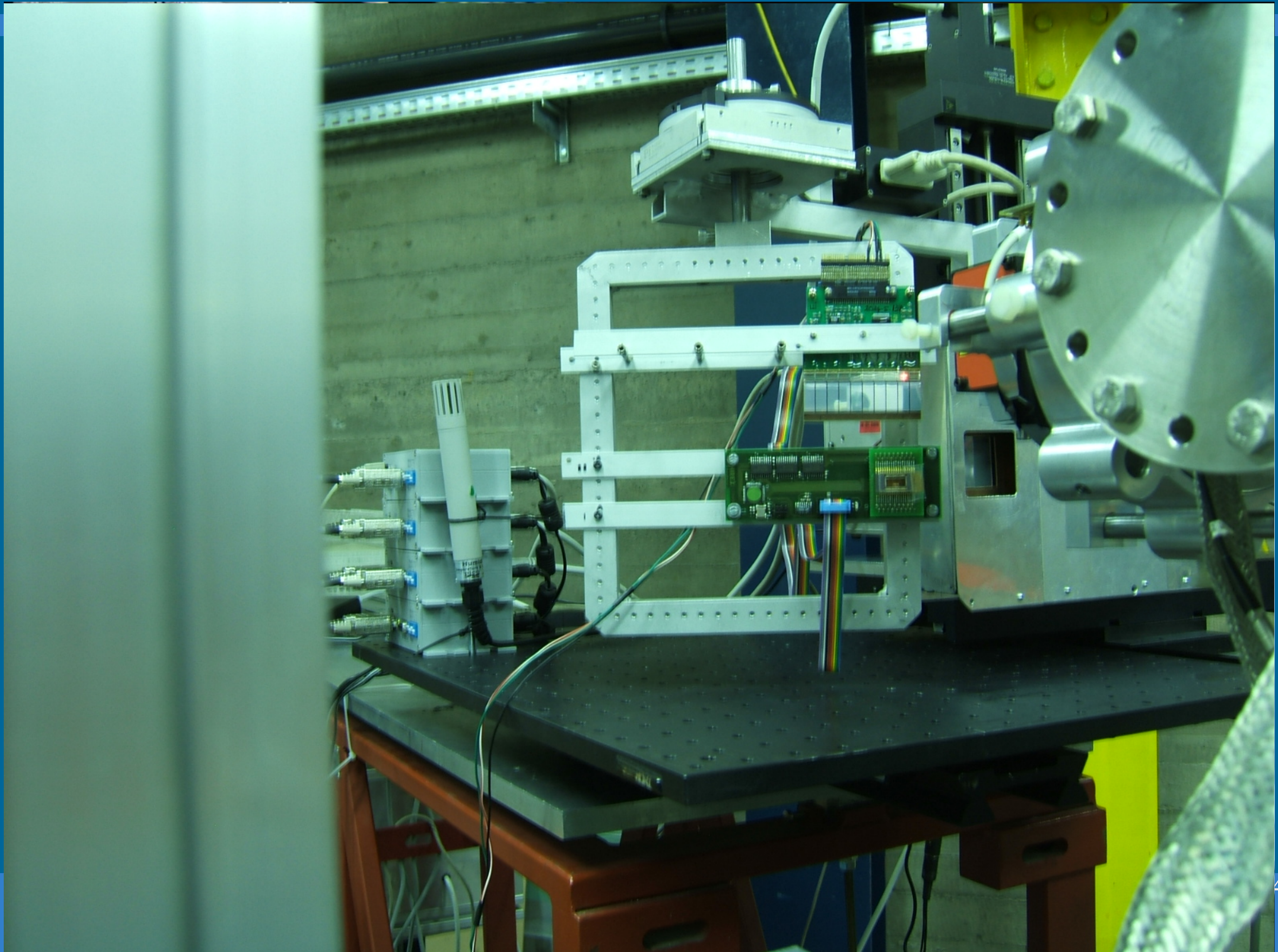
LNS Beam SETUP Mock-up at MAPRAD labs (March 2009)



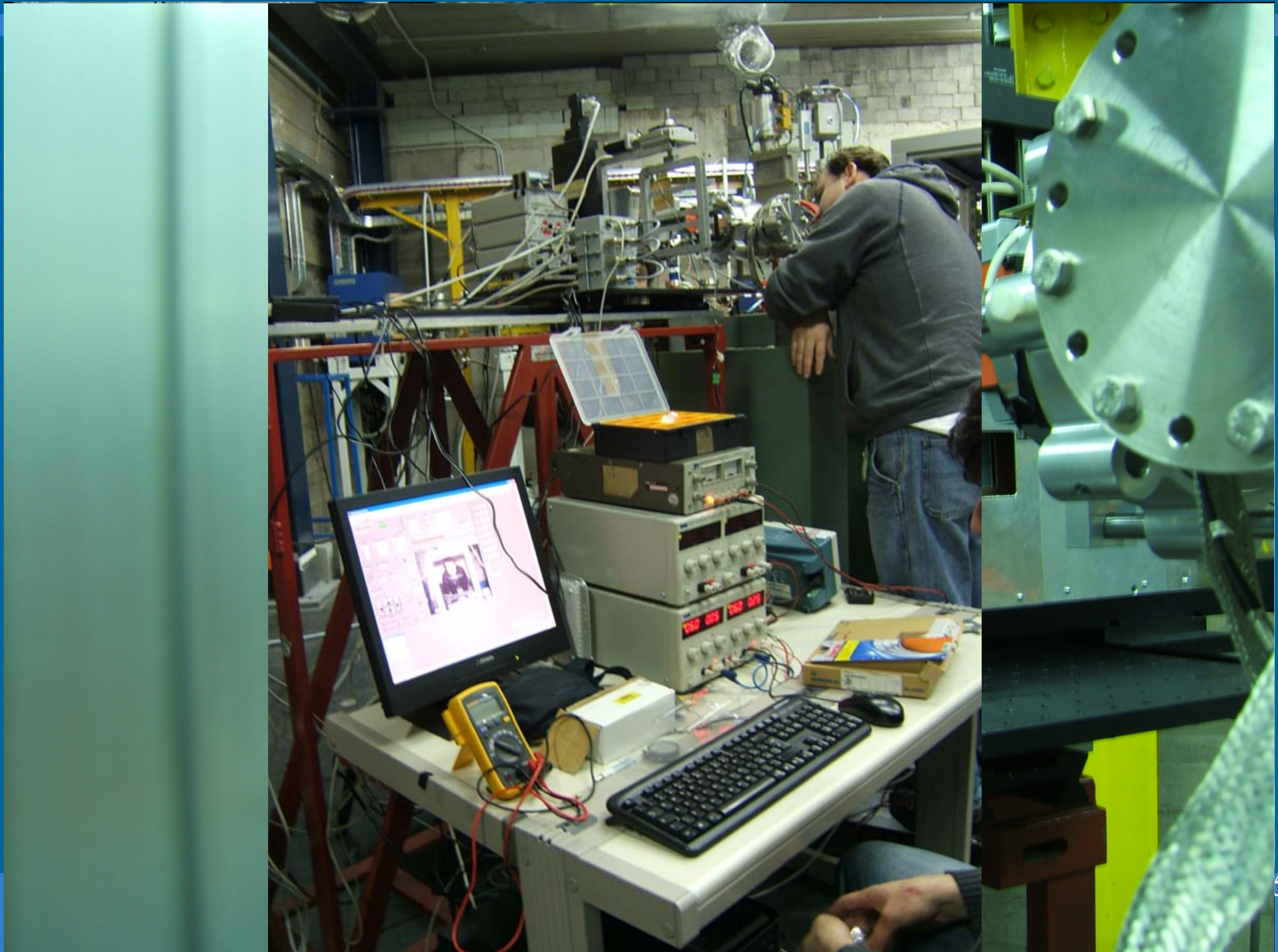
LNS Beam SETUP (April 2009)



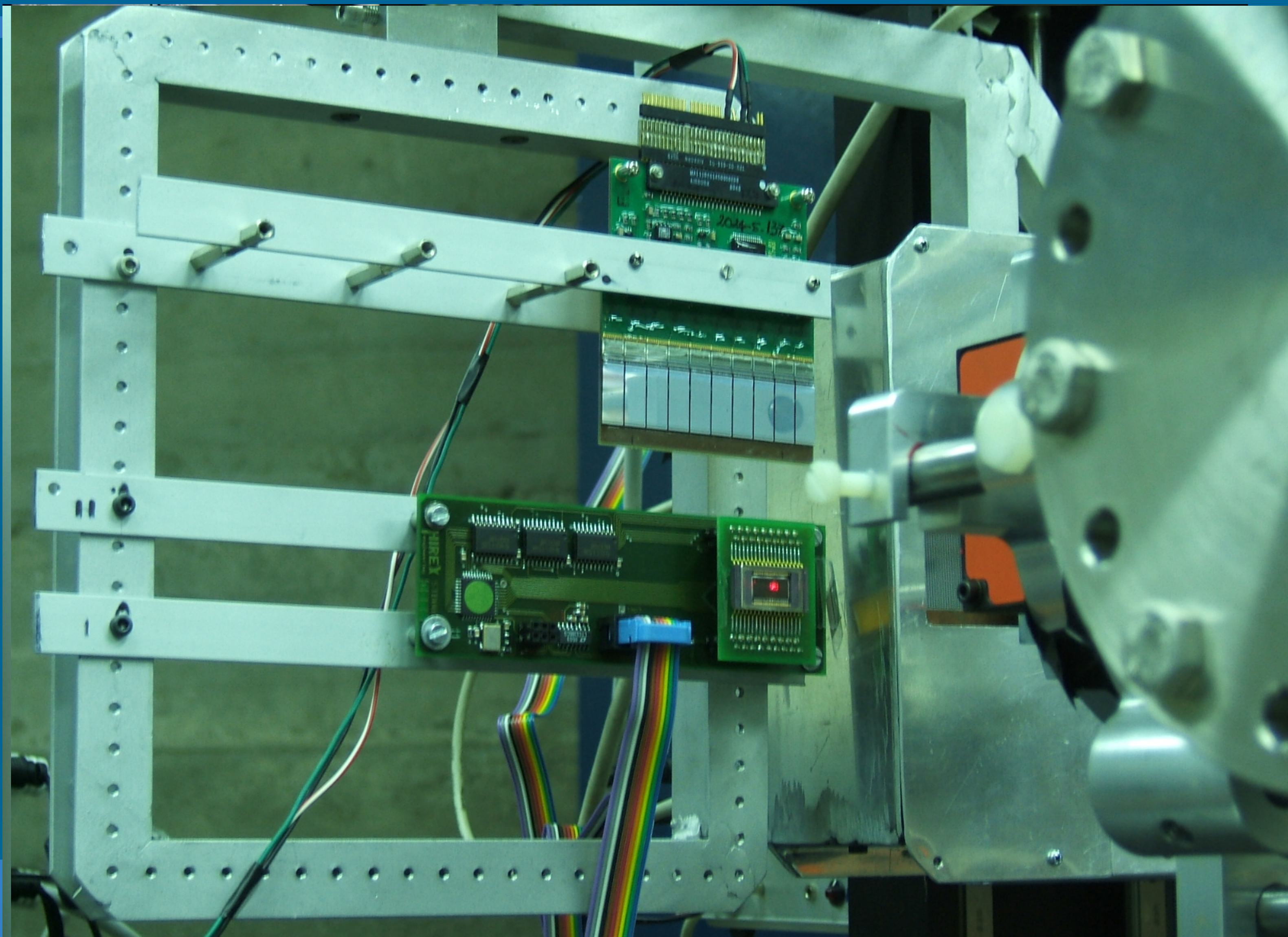
LNS Beam SETUP
(April 2009)



LNS Beam SETUP (April 2009)



LNS Beam SETUP
(April 2009)



Software for Monitoring OnLine

Diviso in diverse aree:

Random data

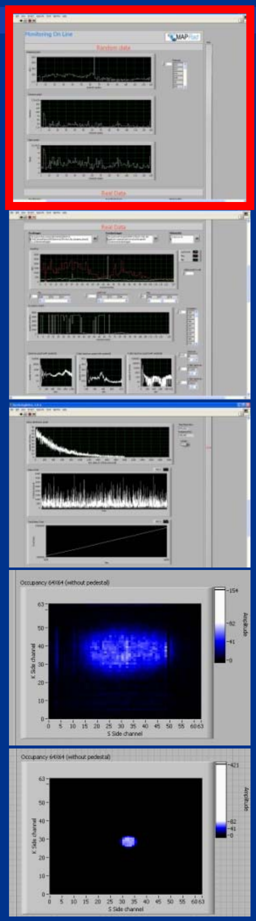
Real data

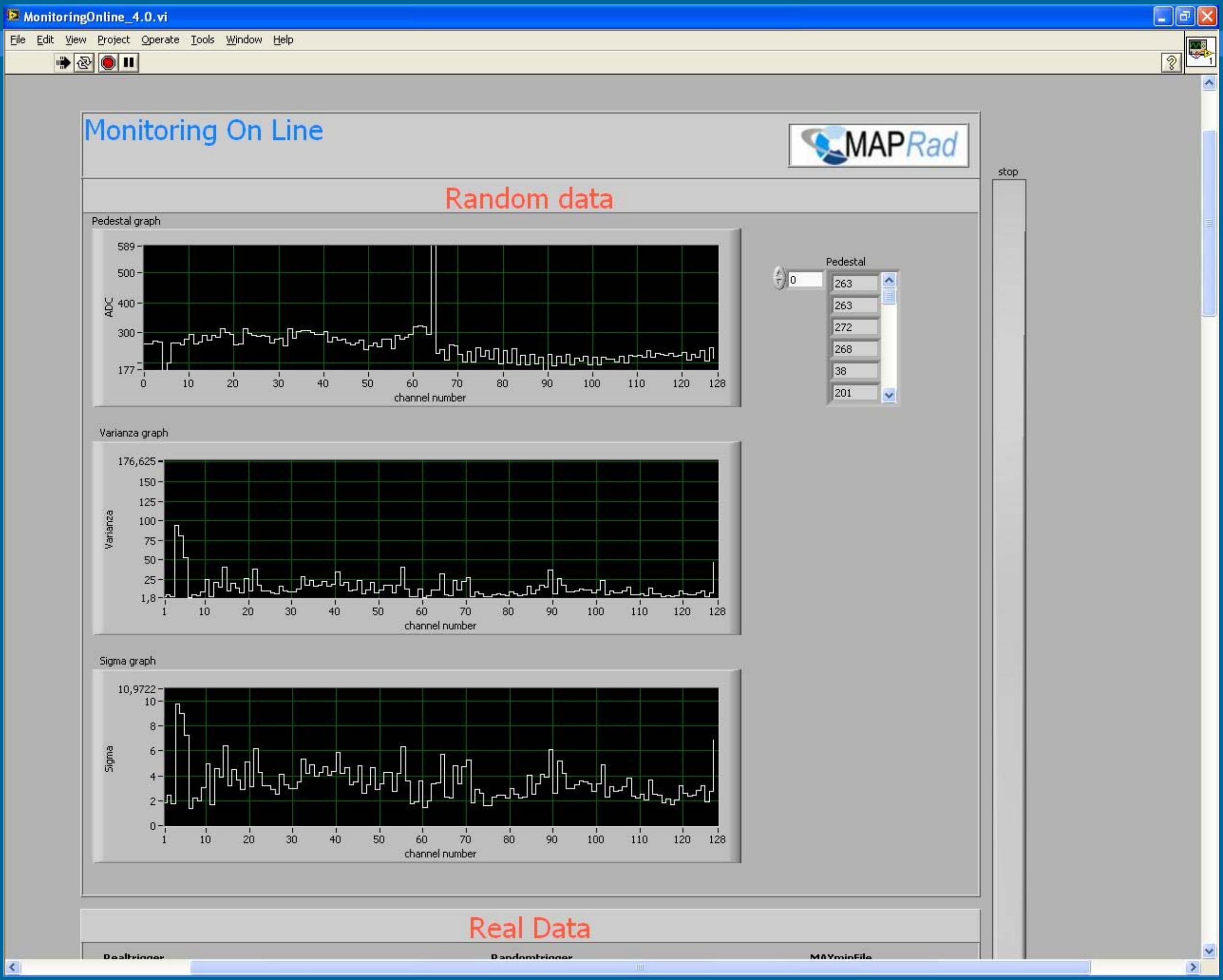
Timing

Beam profile

Protoni

Cm 244 collimata





Software for Monitoring OnLine

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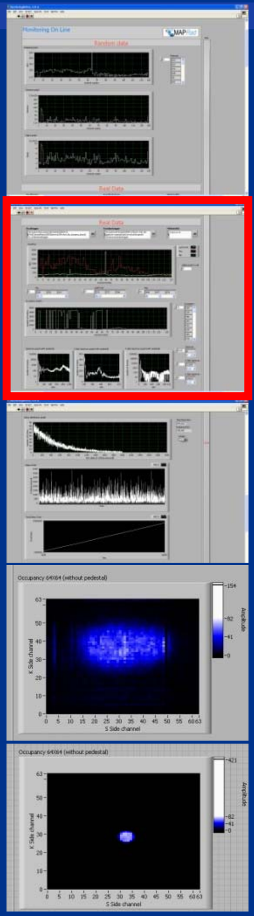

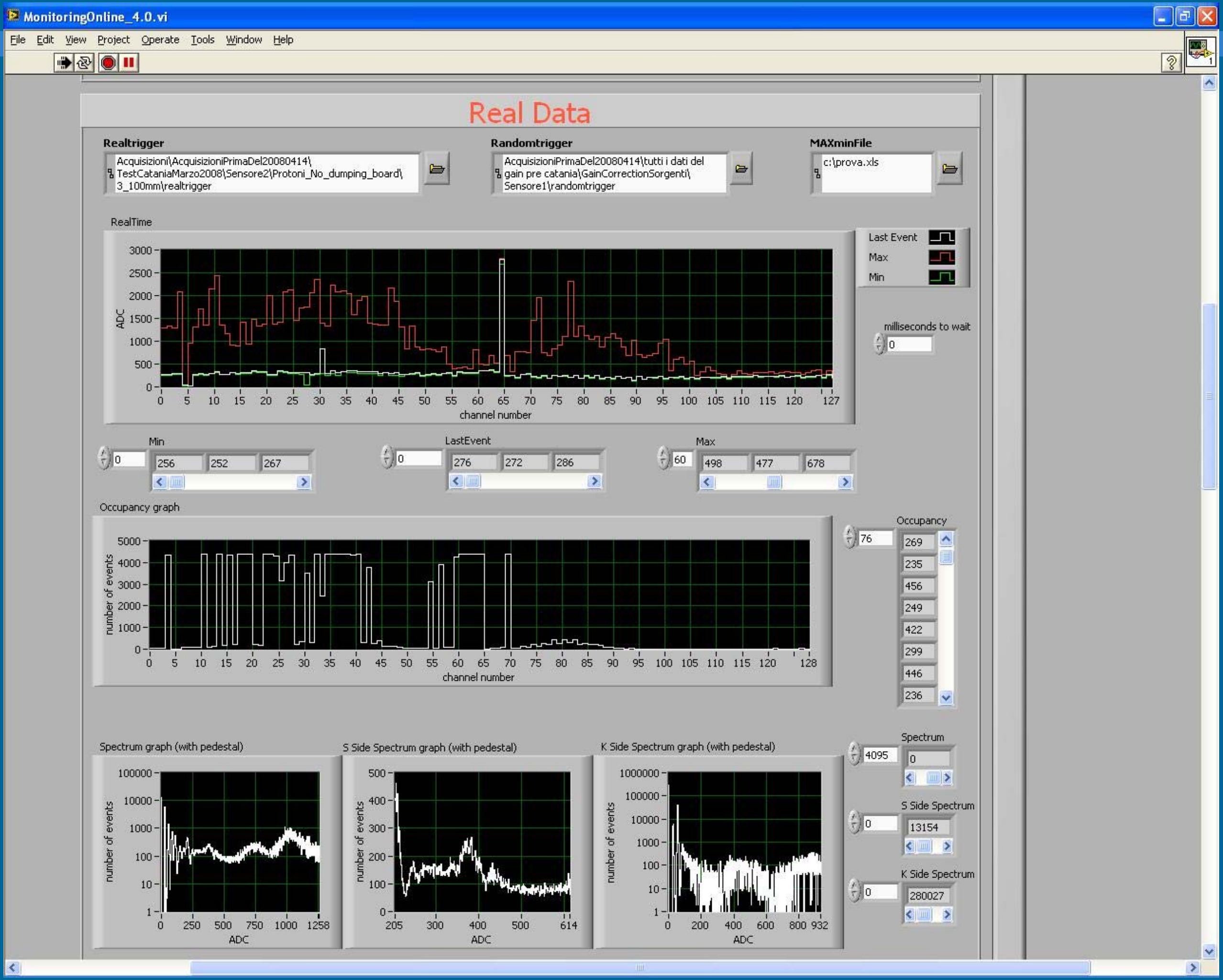

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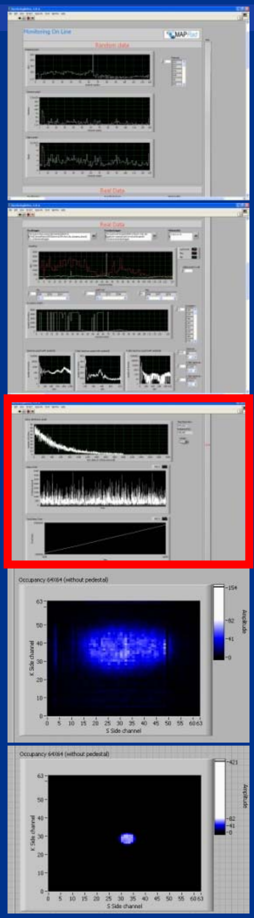
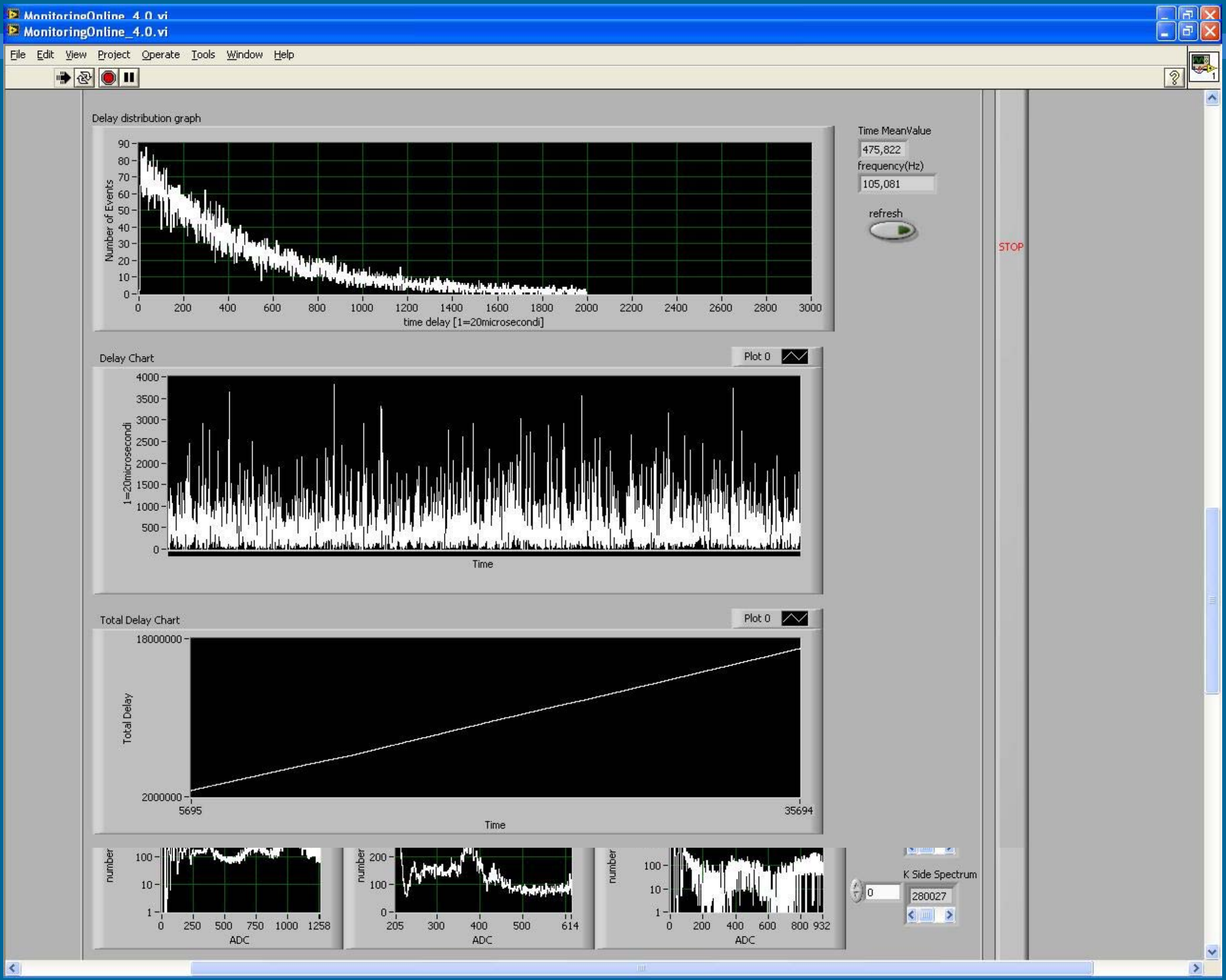
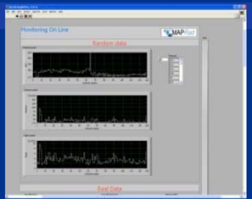




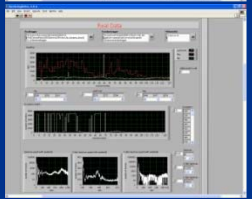
Software for Monitoring OnLine

Diviso in diverse aree:

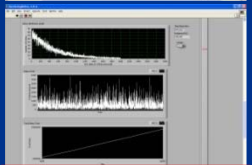
Random data



Real data

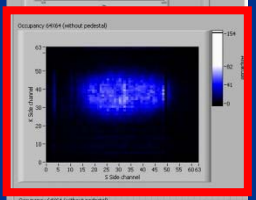


Timing

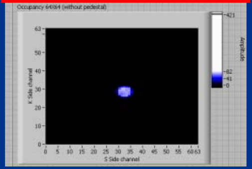


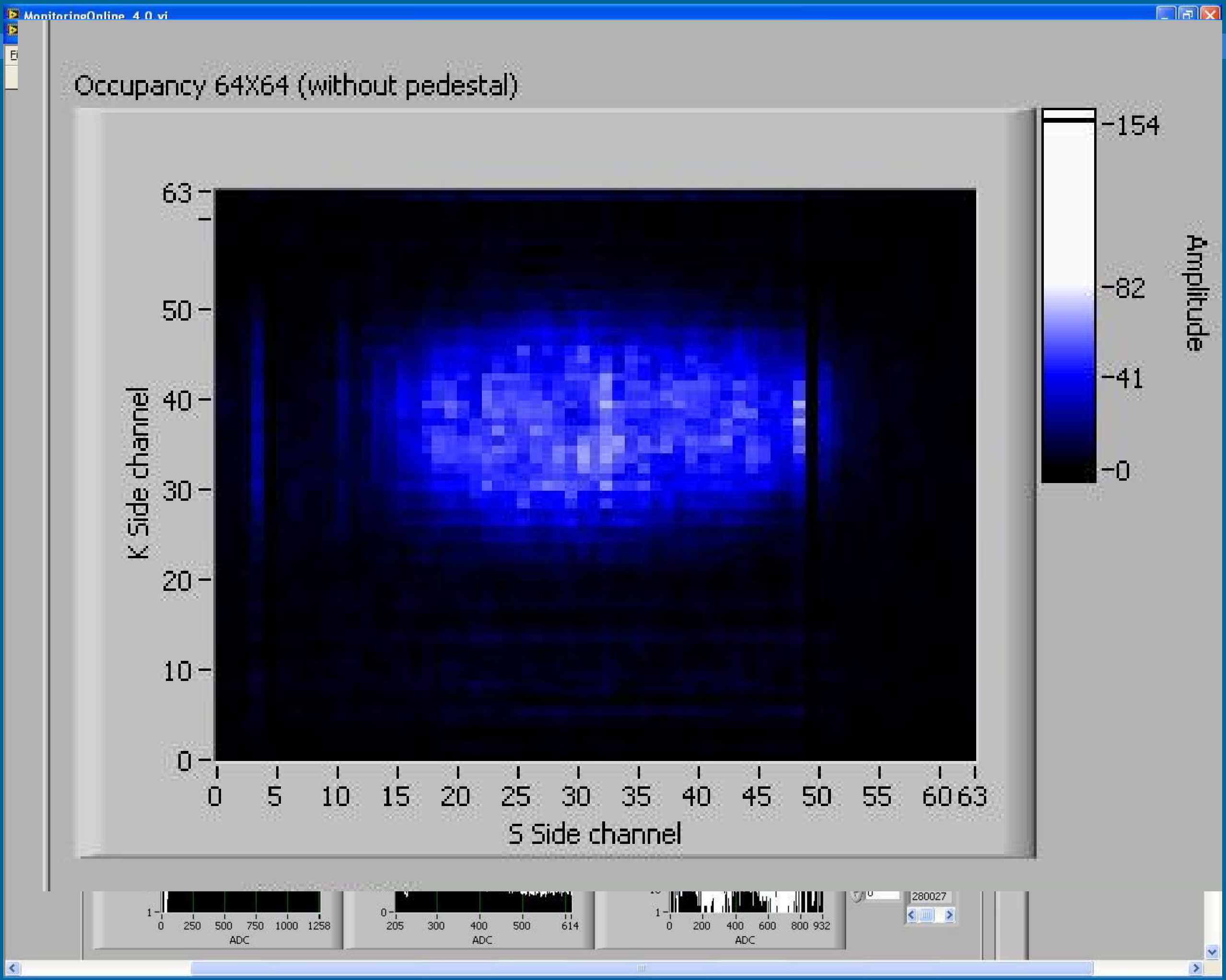
Beam profile

Protoni



Cm 244 collimata





Software for Monitoring OnLine

Diviso in diverse aree:

Random data

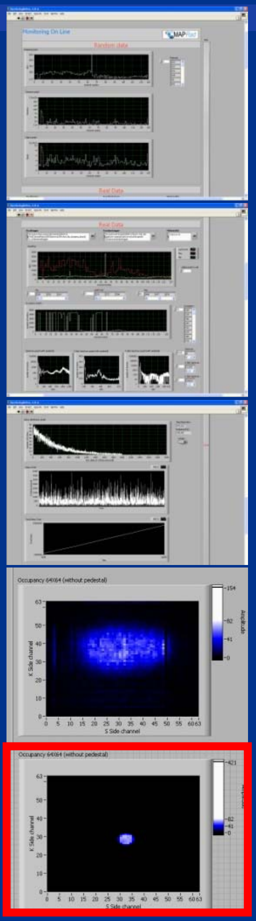
Real data

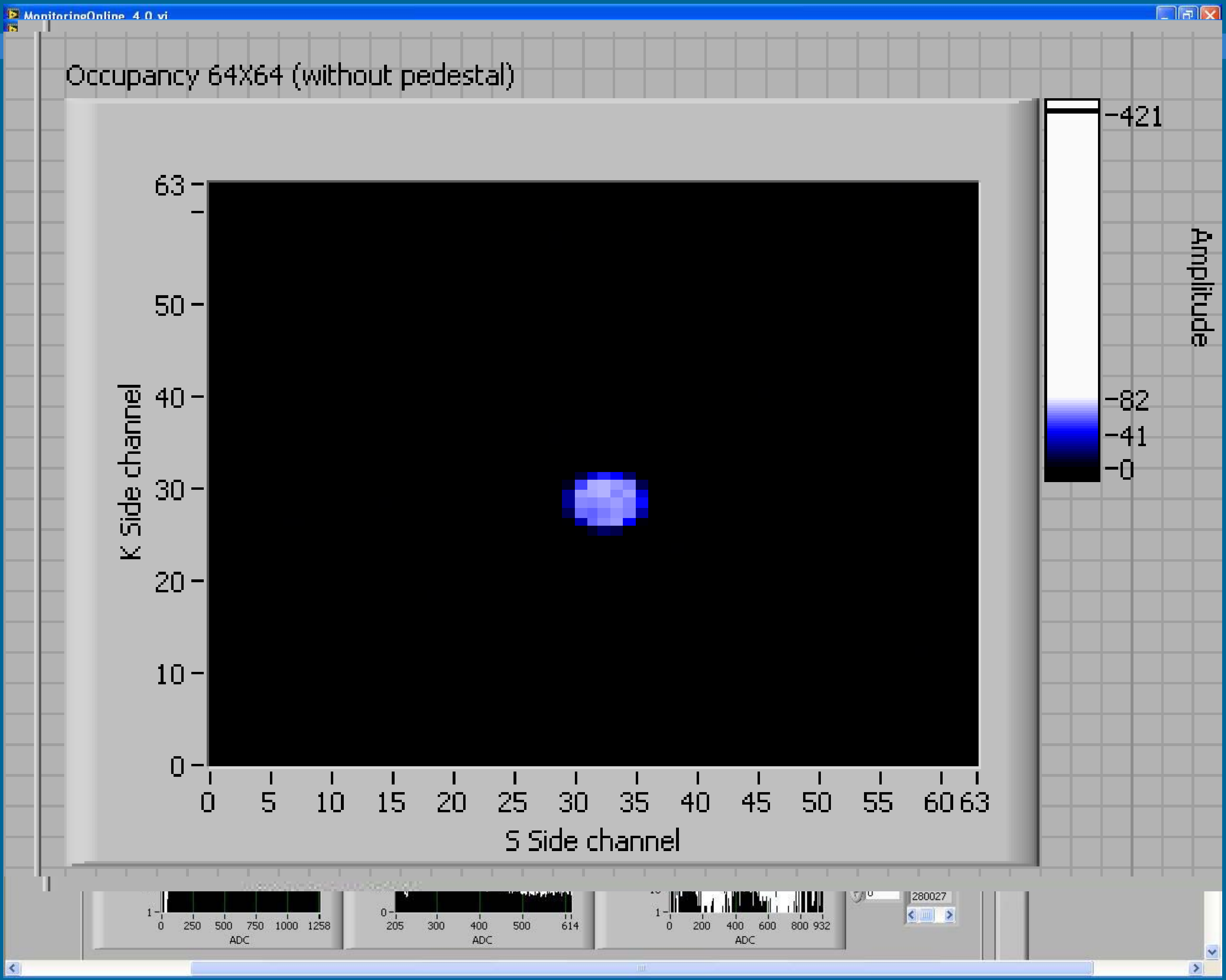
Timing

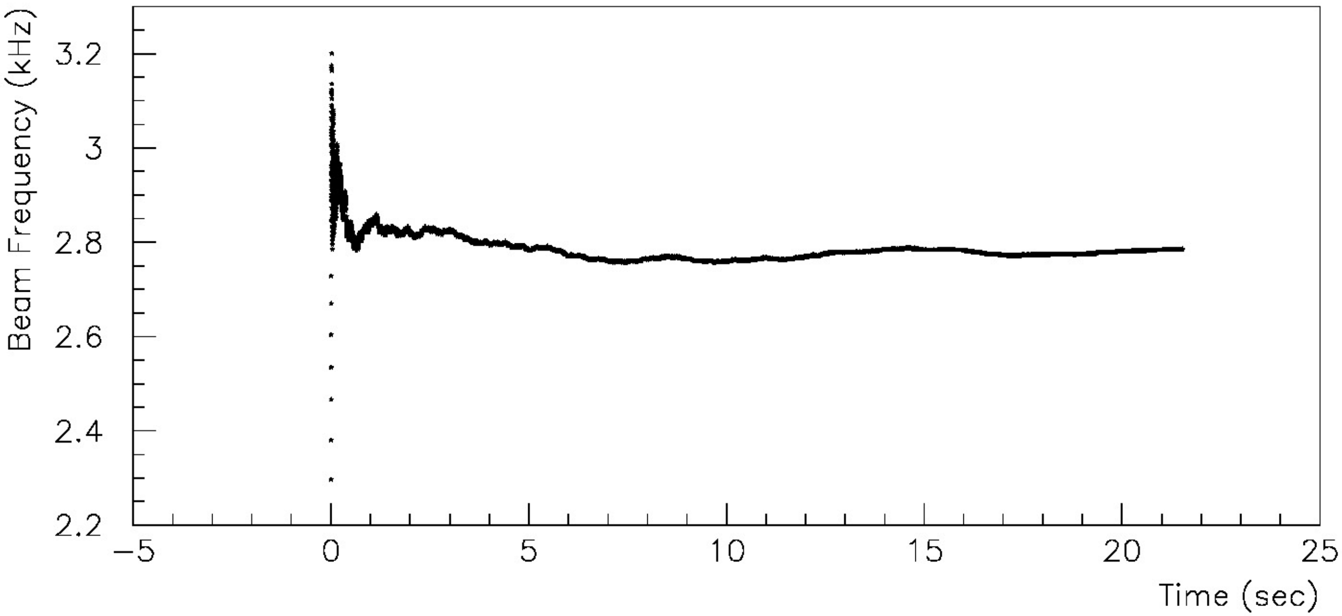
Beam profile

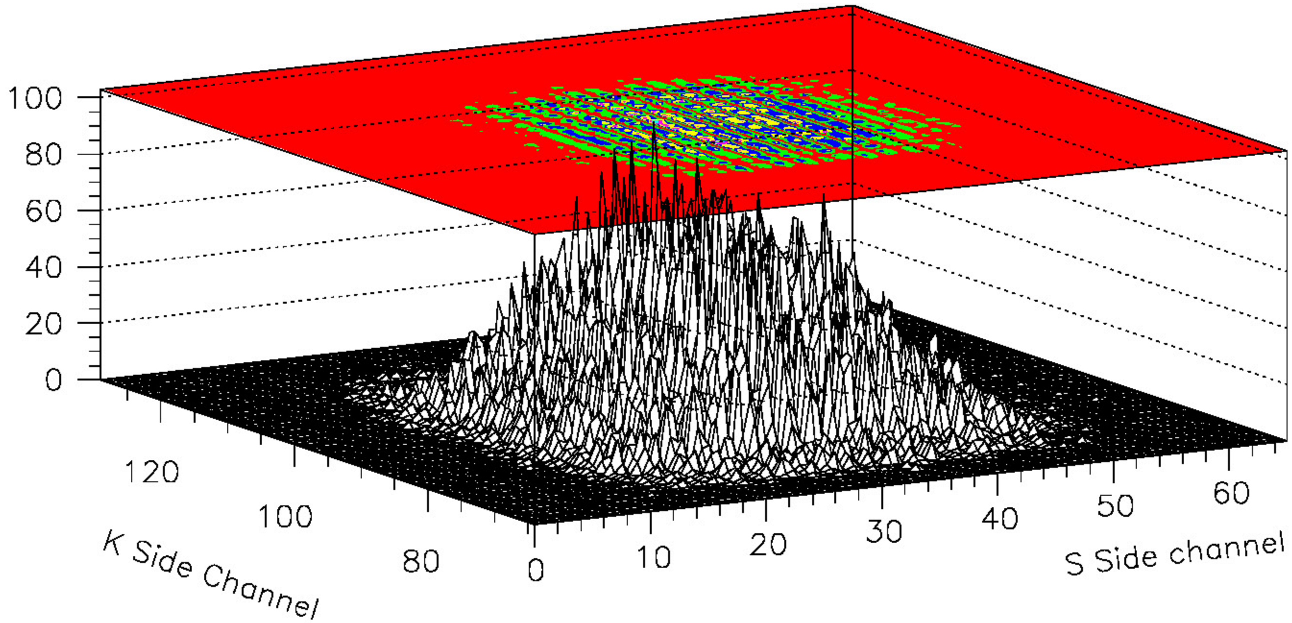
Protoni

Cm 244 collimata

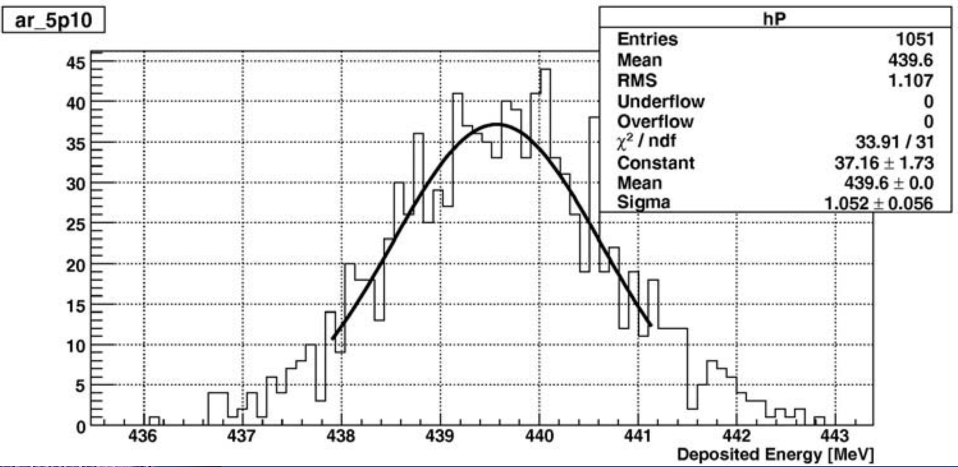


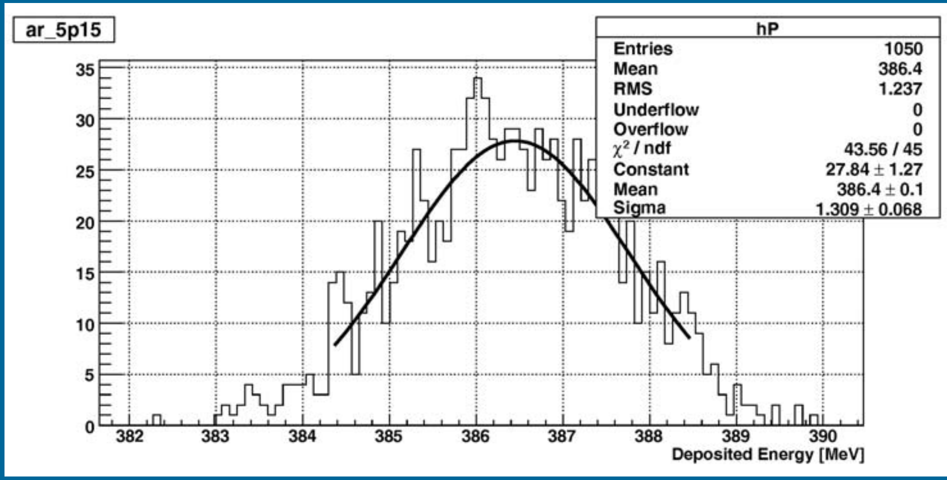


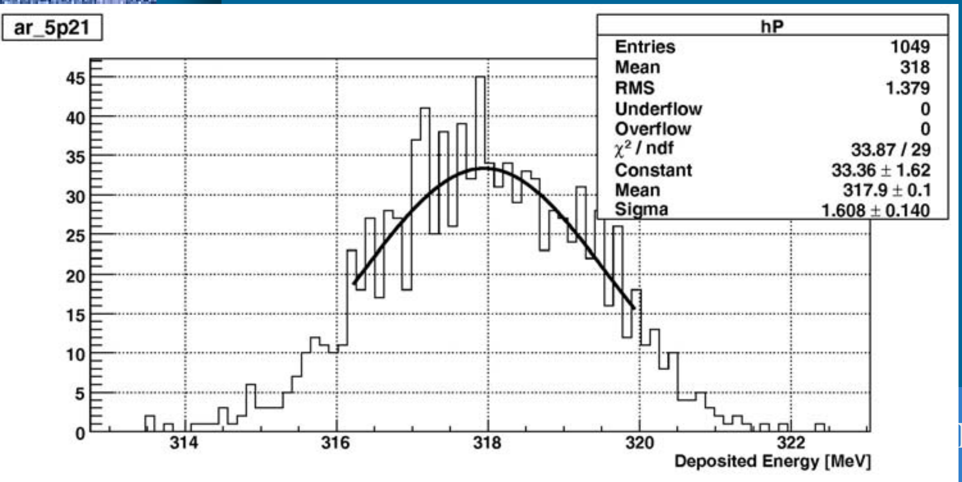

Beam Frequency (kHz)
3.2
3
2.8
2.6
2.4
2.2
−5
0
5
10
15
20
25
Time (sec)

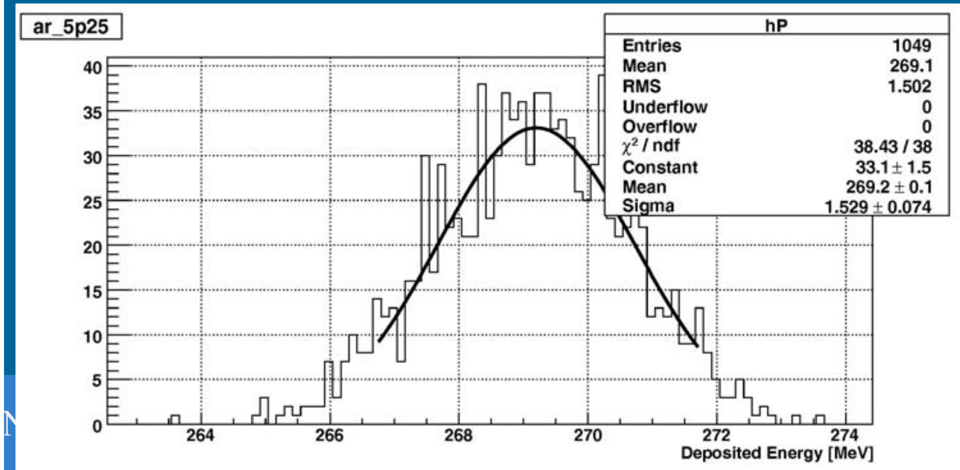

100
80
60
40
20
0
120
100
80
K Side Channel
0
10
20
30
40
50
60
S Side channel

From G4 Montecarlo, Standard Physics, Charge Distributions for ^{40}Ar, air2=10,15,20,25 cm

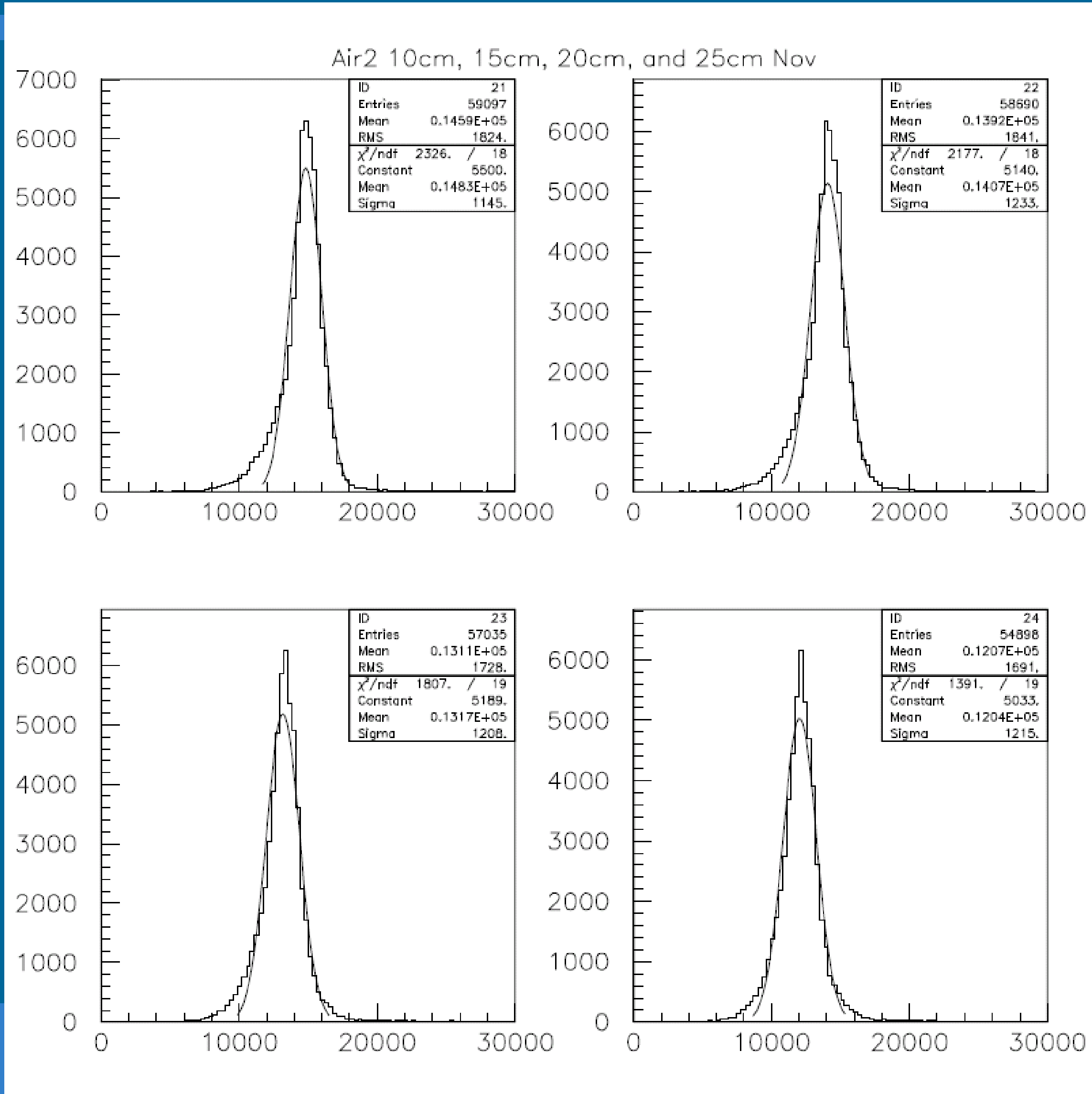




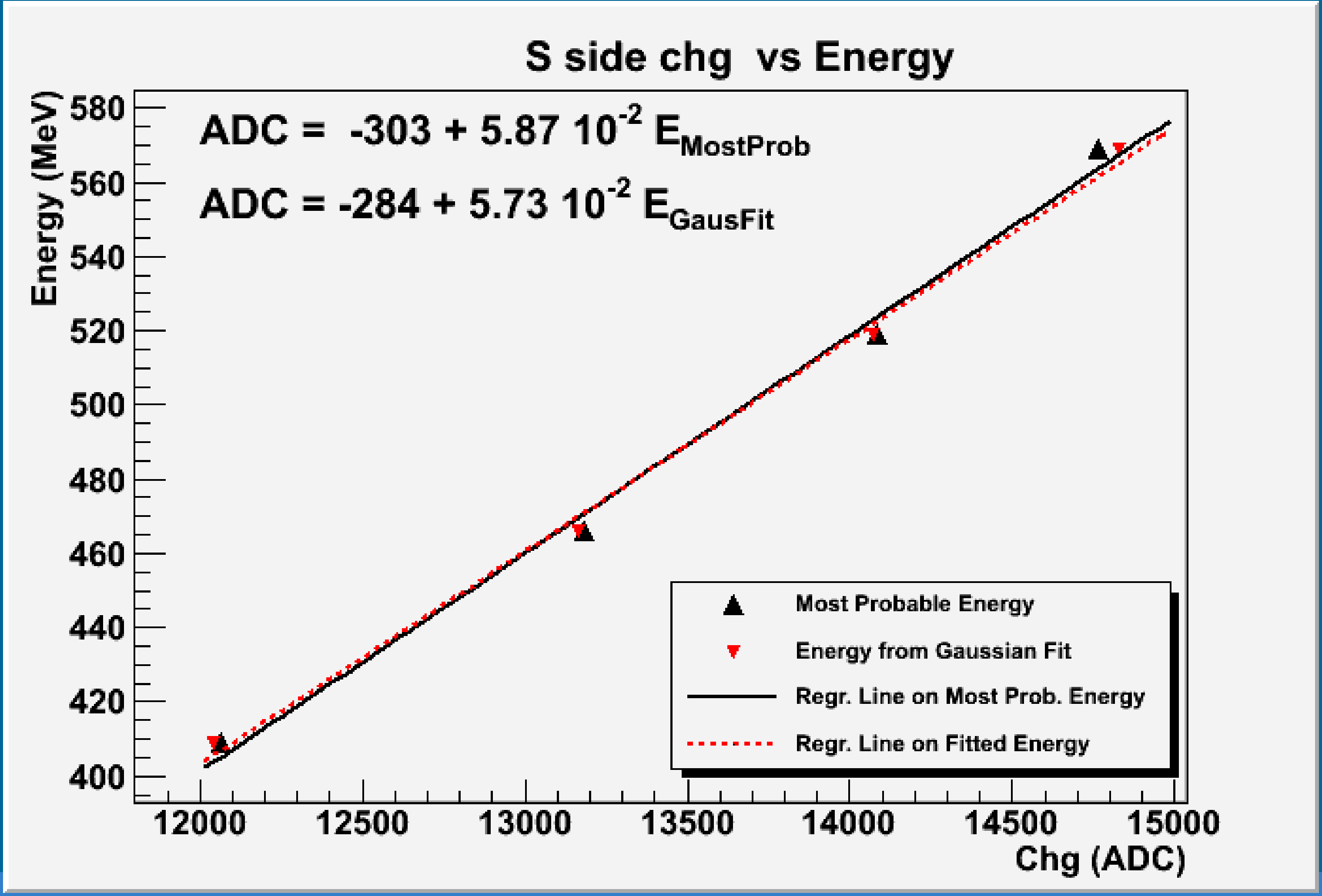




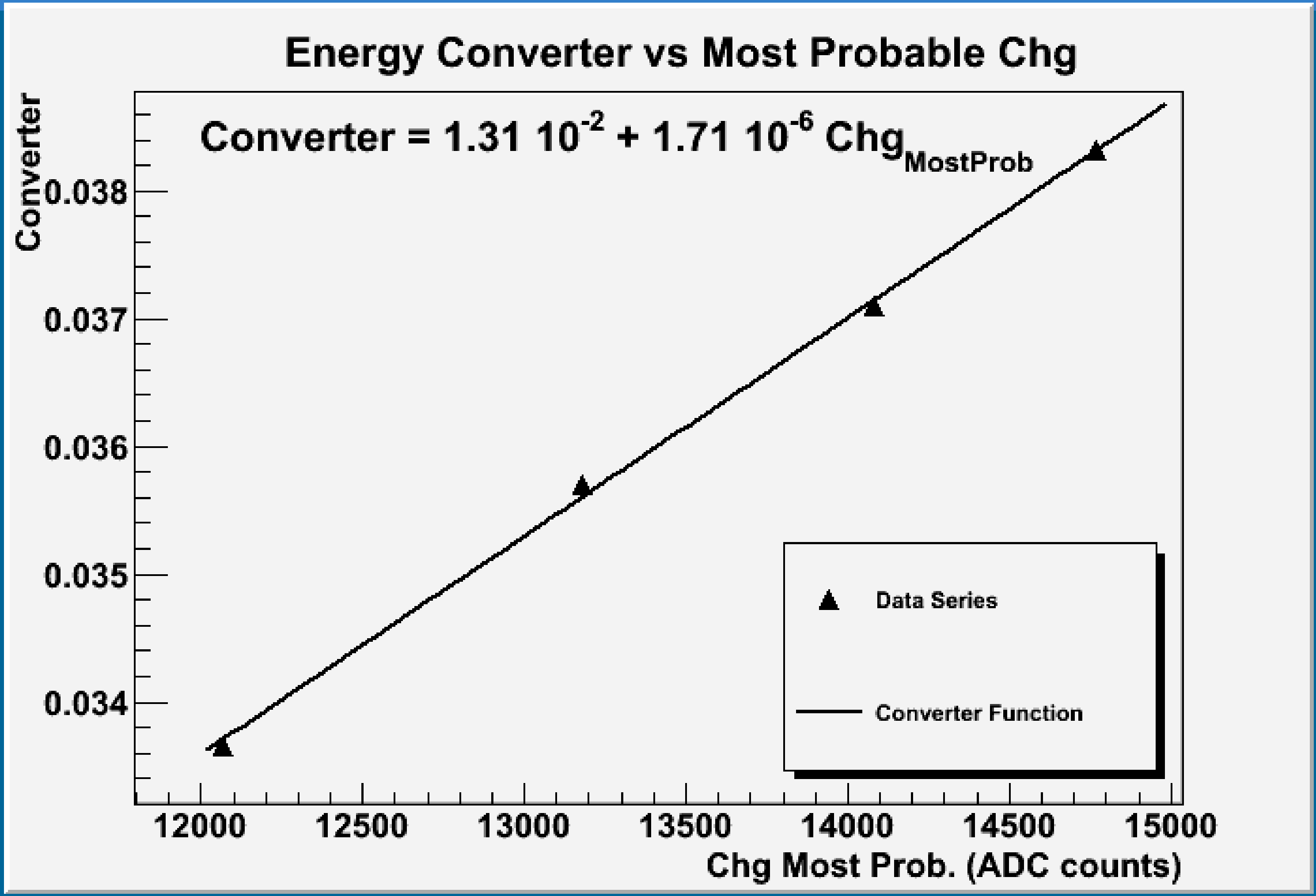
From LNS dataset, Charge Distributions for ^{40}Ar, air2=10,15,20,25 cm



G4-to-Data/Charge-to-Energy Conversions (1)



G4-to-Data/Charge-to-Energy Conversions (2)



Error Evaluation (1)

- The systematic errors contributing to the overall error on LET and Fluence values are;
  - **Error on LET Value**
    - Distance meauserements (air thickness).
      - This is done with 200 um accuracy laser system only once during the initial calibration phase. All other positions are relative to that point with submicron precision 4-D stage (X,Y,Z, Theta)
    - Fragmentation (i.e. $<10^{-4}$ per ^{40}Ar at 15 cm air)
      - Simulations with **BinaryLightIoncascade and G4wilsonAbrasionModel**
    - Determination of energy deposited and Range in DUT
      - Deposited charge in silicon; from data
      - Deposited energy and range in silicon; from G4 simulation
      - Charge-to-Energy Conversion

Error Evaluation (2)

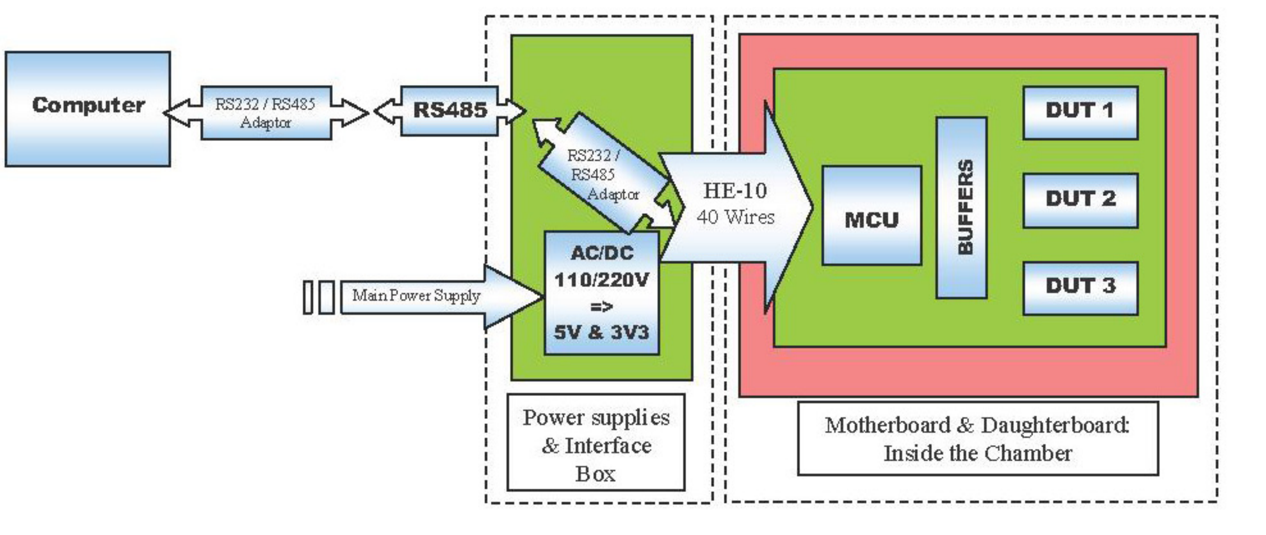
- The systematic errors contributing to the overall error on LET and Fluence values are (cnt'd);
  - **Error on Fluence Value**
    - Positioning of beam spot center to the center of DUT
      - This is done through positioning of beam spot first on double sided thick silicon with 170 um spatial resolution. Then it is shifted on to DUT center (the DUT reference crosses wrt to Silicon reference crosses are measured once during the initial calibration phase)
    - Fluence measurement from thin scintillator and from silicon detector

Overall Error Estimation on LET values

With average trigger efficiency of ~88 %

Ion/LET ($MeV/mg/cm^2$)	Error on LET ($MeV/mg/cm^2$)
Neon-20/3.7	0.1
Argon-40/13.13	0.2
Krypton-84/30.6	0.7
Xenon-129/52.9	0.8

SEU Monitor (ESA/ESTEC)



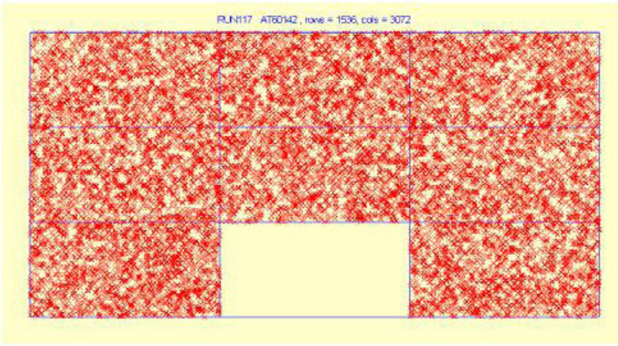


Figure 7. Physical location of SEUs - confirming uniform beam.

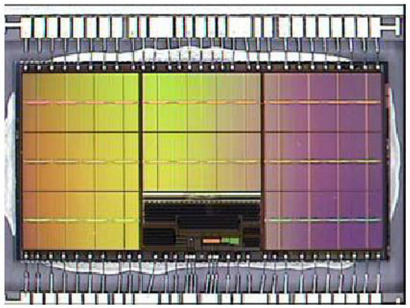


Figure 6. Atmel 4-Mbit SRAM – 8 blocks of 512K x 1.

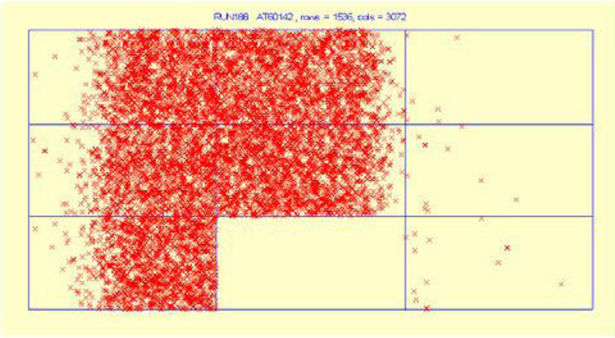
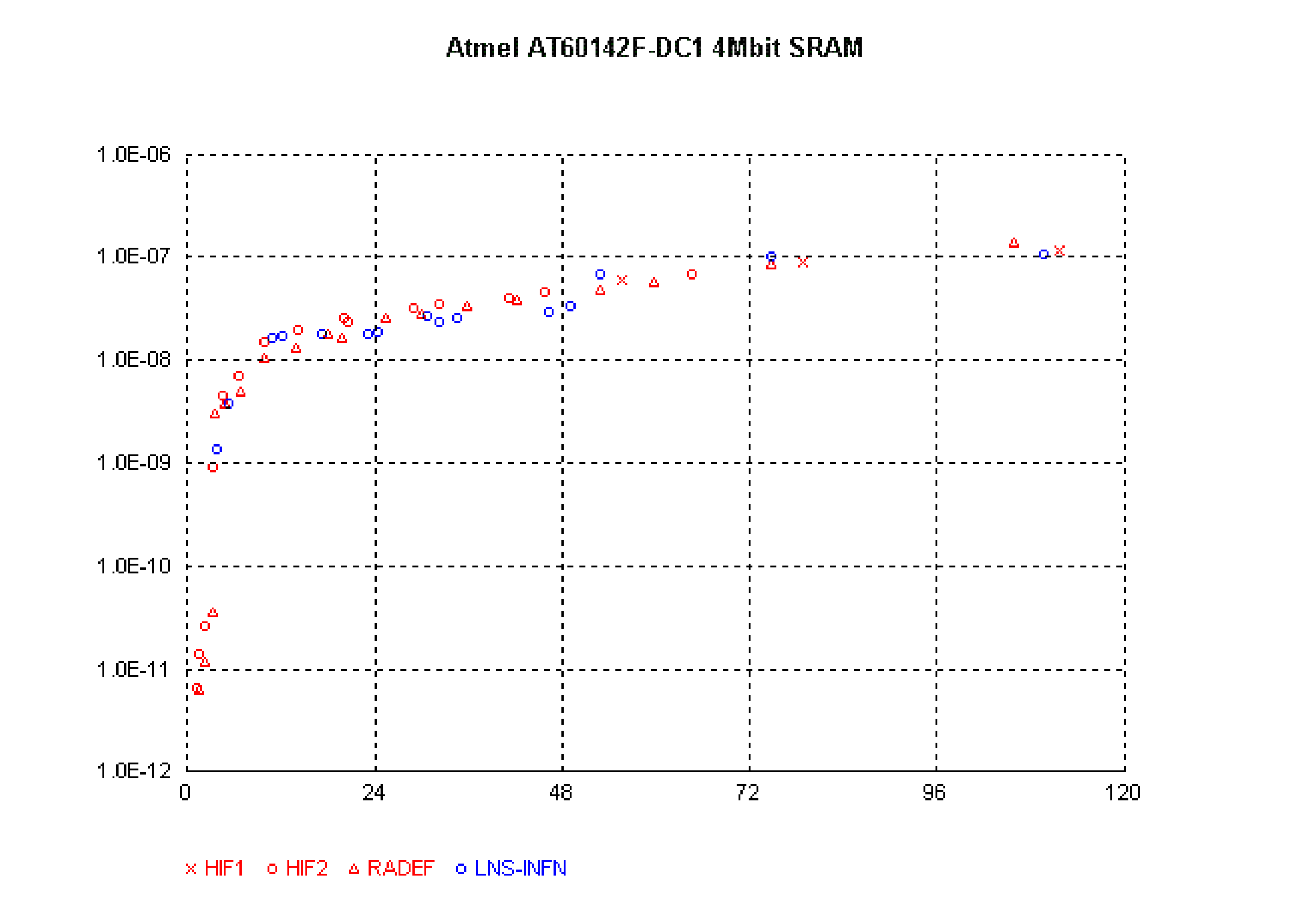


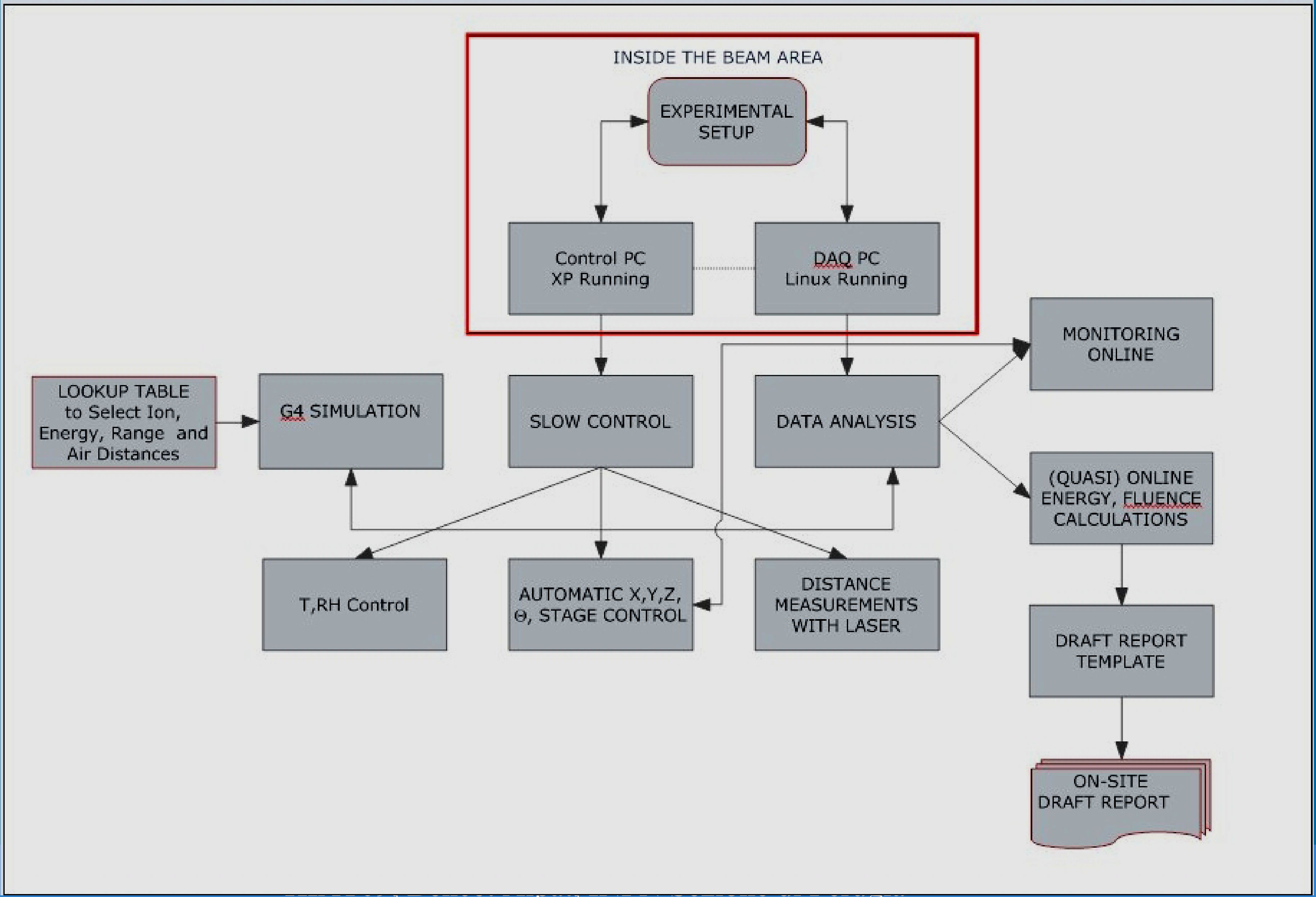
Figure 8. Physical location of SEUs – revealing a faulty beam.

Reference: R.Harboe-Sorensen, et al., RADECS2005 Proceedings

SEU Monitor and LNS Site



On Site Report Preparation - Process Flow -



Displacement Damage at LNS with SiPMs (1)

- 58 MeV Protons

7.0 Displacement Damage Data (With Protons at LNS)

The Table 1 summarizes all relevant quantities, both measured and calculated, for each irradiation step. The Total Dose are calculated as

$$\text{Dose (Rad(Si))} = \text{Let (Si)*Fluence*}1.610^{-5}.$$

Session Number	Date (dd(mm/yy)	Start Time	Stop Time	Measured pps	Spot Size (cm2)) (FWHM: 0,74*0.56 cm2	Effective Duration (mins)	Measured Fluence (p/cm2) incl. 15% ThinScin ineff.	Total Dose (Rad) (Si)	Total Dose Gy(Si)	Dose Rate (Rad/s)
1	20/05/08	16.40	17.05	4,881E+05	0,4144	25	**4,822E+09**	**725,26**	7,25	483,51
2	20/05/08	19.10	20.14	5,197E+05	0,4144	64	**1,569E+10**	**2359,37**	23,59	614,42
3	20/05/08	22.21	22.52	5,866E+06	0,4144	31	**4,959E+10**	**7458,91**	74,59	4010,17
4	21/05/08	00.49	01:23	6,676E+06	0,4144	34	**9,569E+10**	**14391,81**	143,92	7054,81
5	21/05/08	22.36	00.10	9,659E+06	0,4144	84	**4,106E+11**	**61761,25**	617,61	12254,22
6	22/05/08	06.36	08.35	9,317E+06	0,4144	119	**7,818E+11**	**117586,26**	1175,86	16468,66
7	22/05/08	16.56	20.03	7,891E+06	0,4144	187	**1,117E+12**	**168043,13**	1680,43	14977,11

Table 2. The relevant measured and calculated parameters are listed.

Displacement Damage at LNS with SiPMs (2)

The I-V histograms for each device are traced below in Figure 7, Figure 8 and Figure 9.

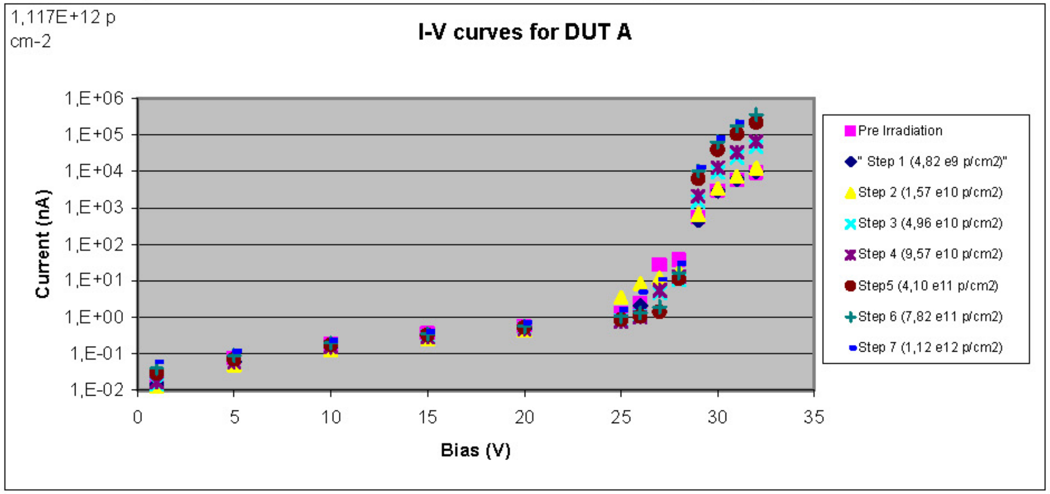


Figure 7 I_V curves for device A prior to irradiation and after each step.

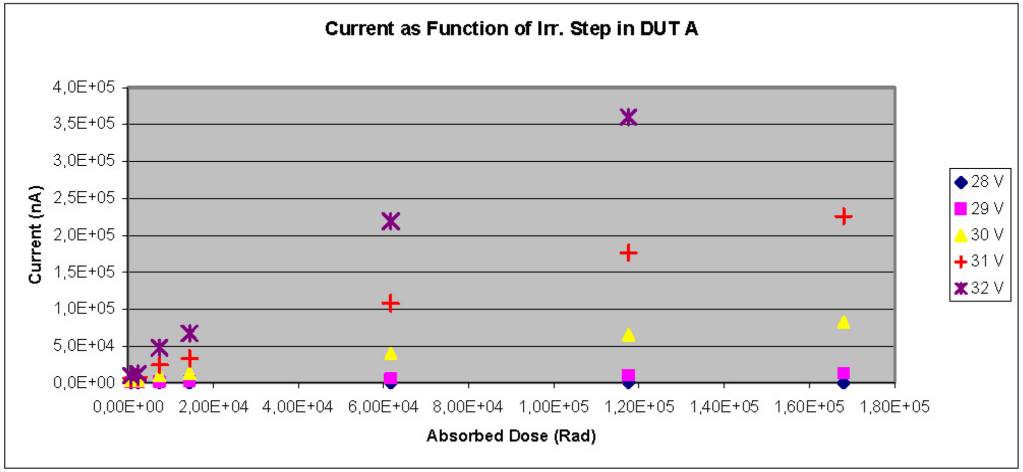


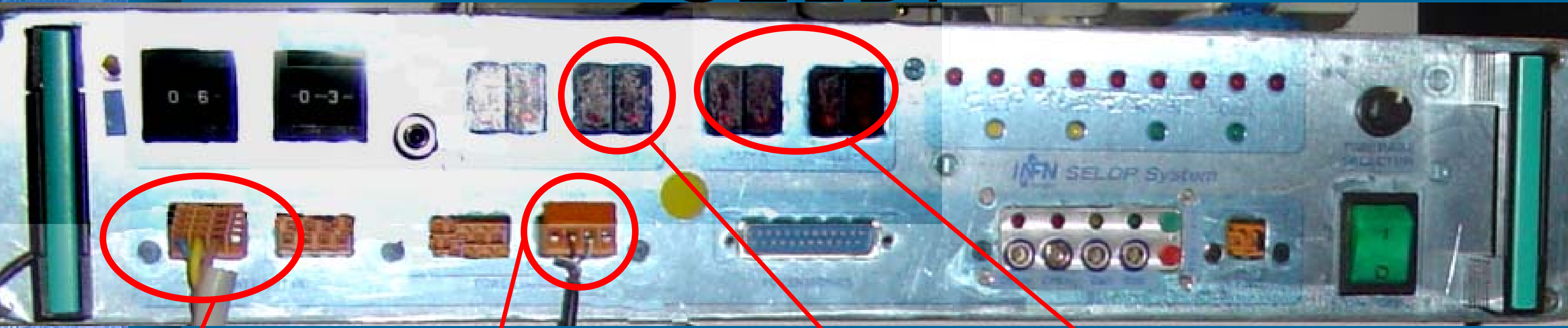
Figure 10 DUT A current as a function of irradiation step at various Bias values around break-down: notice that at 32 V the current was too high for the source meter after step 6.

Conclusions

- An automatic dosimetry system for beam parameters monitoring for SEE and DD test (ESCC 25100) in LNS has been realised and used successfully
- Results are cross-checked with ESA based “Reference SEU monitor” system
- With four gaseous ions of 20 A·MeV it is possible to fulfill ESCC 25100 requirements. Minimum range in Si is 45 µm and we can go as high as 110 MeV/mg/cm^2
- Beam changing time is relatively short (few hours) and flux and beam size are stable in time
- LET values can be “fine-tuned” by using air as degrader
- Great easiness provided by operation in air

Extras & Links

Analog/Digital Signals Acquisition System (1/2): SELDP



Power IN from Supply

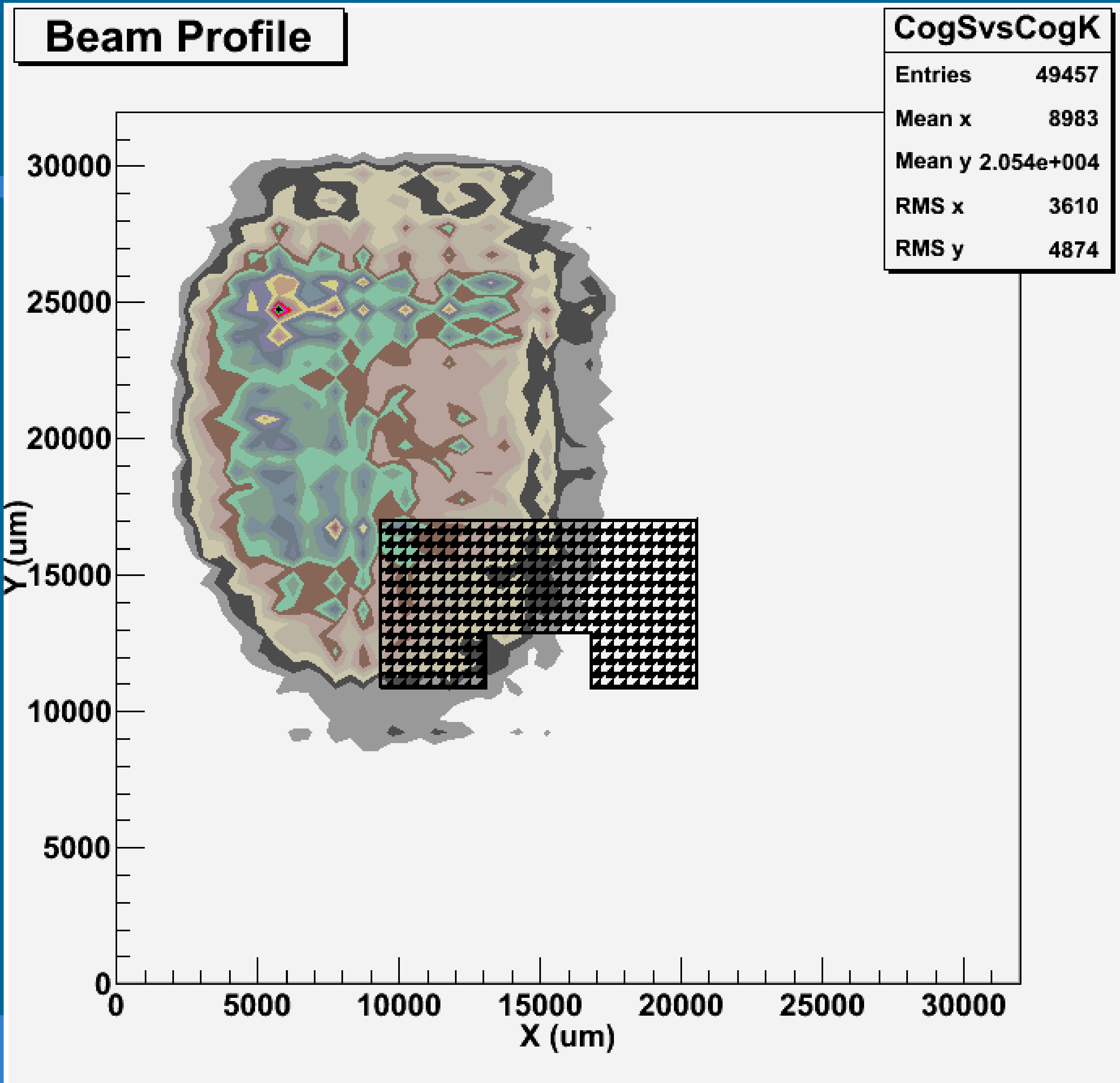
Power OUT to DUT

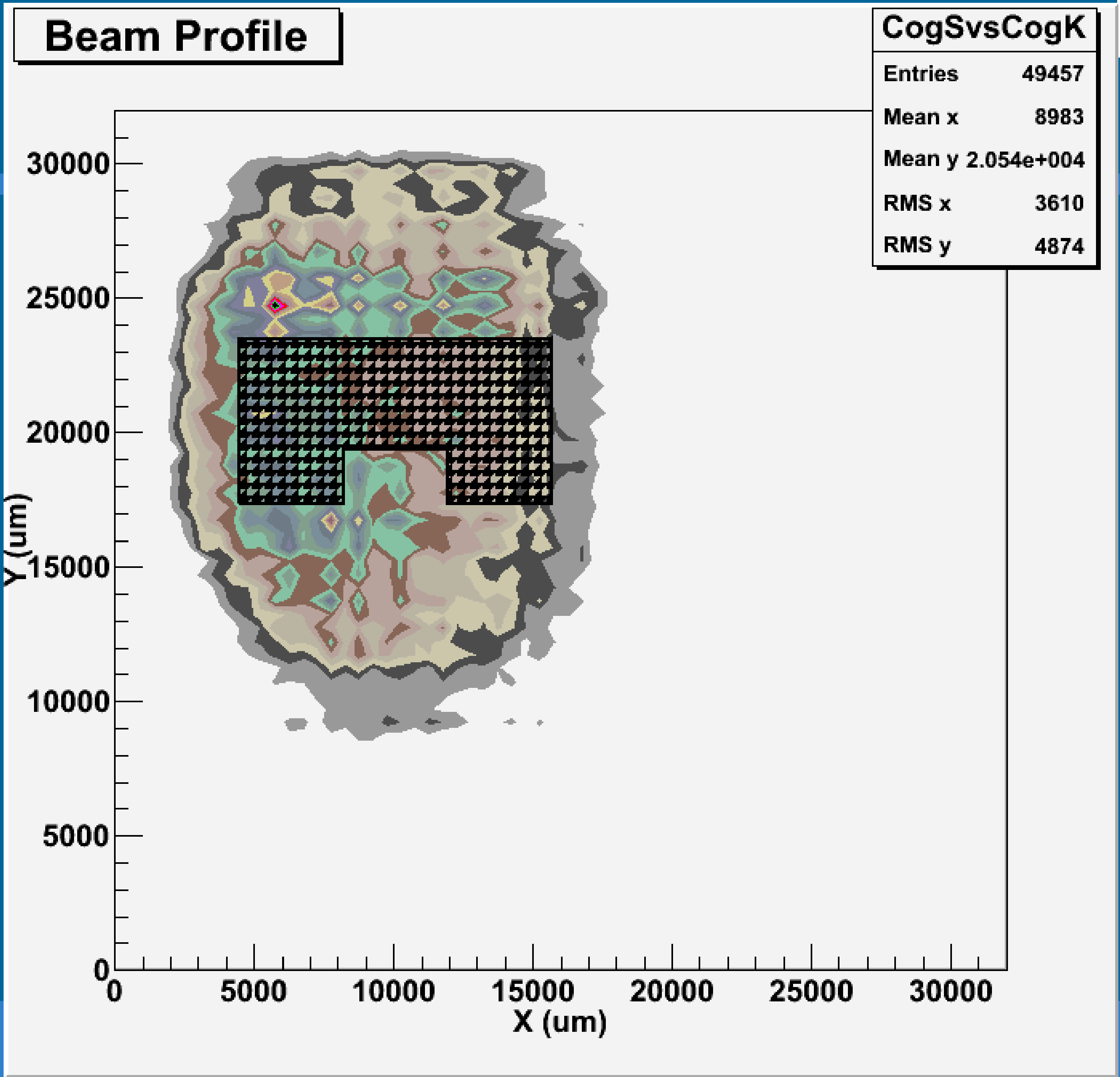
Counter

Delay presetting

SELDP (Single Event Latchup Detector and Protector):

Developed at INFN sez. Perugia, it monitors the input current of DUT in an adjustable range (±12V-100mA); if a SEL is detected (SEL produces an exponential rising of the current) it suspends power supply (at a preset delay, 1 ms up to 99 s), counts the number of events.


Beam Profile
CogSvsCogK
Entries 49457
Mean x 8983
Mean y 2.054e+004
RMS x 3610
RMS y 4874
Y (um)
X (um)
0
5000
10000
15000
20000
25000
30000


Beam Profile
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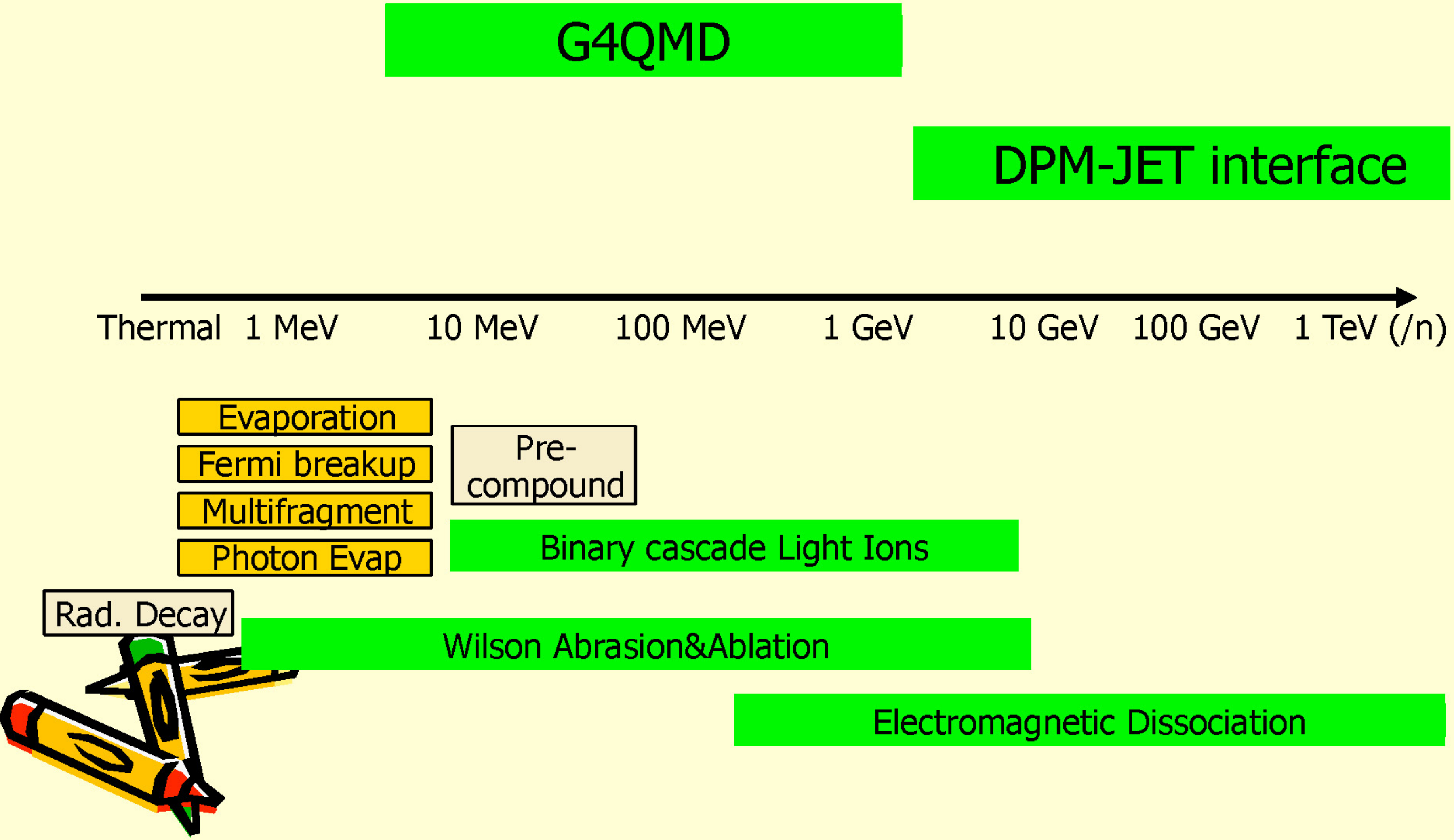
RMS x 3610
RMS y 4874
Y (um)
X (um)
0
5000
10000
15000
20000
25000
30000

							GEANT 4 with scintillator (Low Energy EM) 1 micron cut			GEANT 4 WITHOUT SCINTILLATOR (Low Energy EM) 1 micron CUT			
beam	beam energy (MeV/n)	air1 (cm)	air2 (cm)	impact angle (degree)	thickness scintillator (um)	Ek (MeV) Total	Ek (MeV) at Si Surface	Range in Si (cm)	Let in Si (MeV/mg/cm2) = (Ekin/Range)*(1/density)	Ek (MeV) at Si Surface	Range in Si (cm)	Let in Si (MeV/mg/cm2) = (Ekin/Range)*(1/density)	
Ne-20	20	2,0	2,0	0	50	400	358	0,0437	3,53	372	0,04663	3,44	
Ne-20	20	2,0	5,0	0	50	400	349	0,042	3,58	363	0,04483	3,49	
Ne-20	20	5,0	5,0	0	50	400	341	0,0402	3,66	355	0,04306	3,55	*
Ne-20	20	5,0	10,0	0	50	400	325	0,0372	3,77	340	0,04012	3,65	
Ne-20	20	5,0	15,0	0	50	400	309	0,0343	3,88	325	0,03718	3,77	
Ne-20	20	5,0	20,0	0	50	400	294	0,0313	4,05	309	0,03431	3,88	
Ne-20	20	5,0	25,0	0	50	400	276	0,0283	4,20	293	0,03125	4,04	
Ne-20	20	5,0	30,0	0	50	400	259	0,0254	4,39	277	0,02837	4,21	*
Ne-20	20	15,0	30,0	0	50	400	221	0,0196	4,87	240	0,02246	4,60	
Ne-20	20	20,0	30,0	0	50	400	200	0,0165	5,22	221	0,01956	4,87	
Ne-20	20	25,0	30,0	0	50	400	179	0,0137	5,65	200	0,01656	5,20	
Ne-20	20	30,0	30,0	0	50	400	153	0,0106	6,22	178	0,01361	5,64	
Ar-40	20	2,0	2,0	0	50	800	672	0,0287	10,09	715	0,03162	9,74	
Ar-40	20	2,0	5,0	0	50	800	645	0,027	10,31	689	0,02986	9,94	
Ar-40	20	5,0	5,0	0	50	800	617	0,0252	10,56	663	0,02812	10,16	*
Ar-40	20	5,0	10,0	0	50	800	569	0,0222	11,02	617	0,02519	10,55	
Ar-40	20	5,0	12,8	0	50	800	541	0,0206	11,32	591	0,02354	10,82	
Ar-40	20	5,0	15,0	0	50	800	519	0,0193	11,59	569	0,02225	11,02	
Ar-40	20	5,0	20,0	0	50	800	466	0,0164	12,27	519	0,01931	11,58	
Ar-40	20	5,0	25,0	0	50	800	409	0,0134	13,13	466	0,01643	12,22	
Ar-40	20	5,0	30,0	0	50	800	347	0,0105	14,26	411	0,0135	13,12	*
Ar-40	20	10,0	30,0	0	50	800	282	0,0076	16,02	349	0,01056	14,23	
Ar-40	20	12,0	30,0	0	50	800	255	0,0064	17,17	323	0,00937	14,86	
Kr-84	20	2,0	2,0	0	50	1680	1255	0,0185	29,19	1402	0,02152	28,06	
Kr-84	20	2,0	5,0	0	50	1680	1166	0,0168	29,88	1317	0,01977	28,70	
Kr-84	20	5,0	5,0	0	50	1680	1074	0,015	30,76	1230	0,01806	29,35	*
Kr-84	20	5,0	7,5	0	50	1680	995	0,0136	31,51	1156	0,01662	29,97	
Kr-84	20	5,0	10,0	0	50	1680	915	0,0122	32,41	1079	0,01515	30,70	
Kr-84	20	5,0	12,5	0	50	1680	836	0,0107	33,52	1001	0,0137	31,47	
Kr-84	20	5,0	15,0	0	50	1680	751	0,0093	34,69	922	0,01228	32,36	*
Kr-84	20	5,0	17,5	0	50	1680	665	0,0079	36,23	840	0,01085	33,36	
Xe-129	20	2,0	2,0	0	50	2580	1795	0,016	48,38	2070	0,019	46,95	
Xe-129	20	2,0	5,0	0	50	2580	1636	0,0143	49,40	1917	0,01732	47,70	
Xe-129	20	5,0	5,0	0	50	2580	1473	0,0109	57,99	1759	0,01559	48,63	*
Xe-129	20	5,0	6,0	0	50	2580	1419	0,012	50,93	1706	0,01502	48,92	
Xe-129	20	5,0	9,0	0	50	2580	1253	0,0103	52,33	1546	0,01332	50,02	
Xe-129	20	5,0	10,0	0	50	2580	1198	0,0098	52,91	1491	0,01275	50,37	
Xe-129	20	5,0	15,0	0	50	2580	923	0,007	56,62	1217	0,00995	52,69	*

INFN Istituto Nazionale di Fisica Nucleare

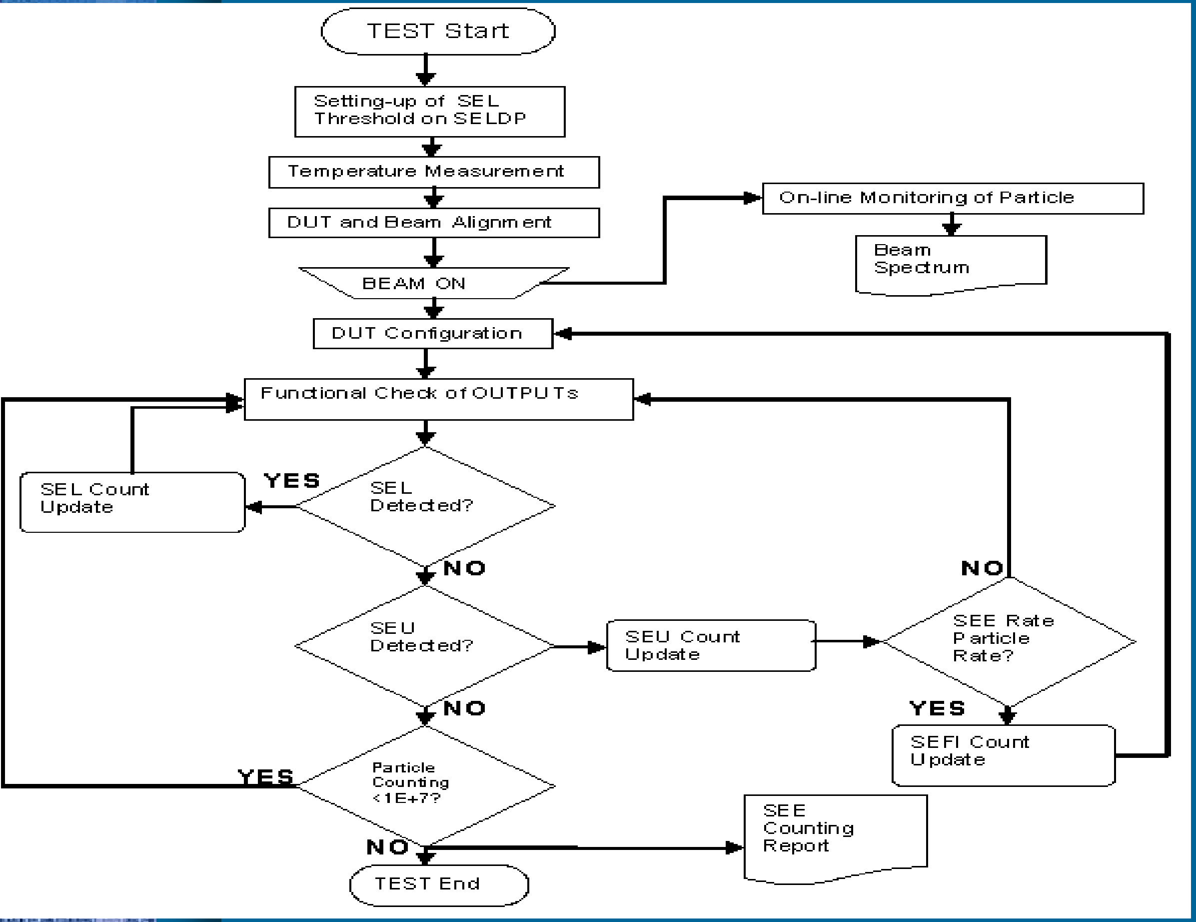
Ion Models Inventory

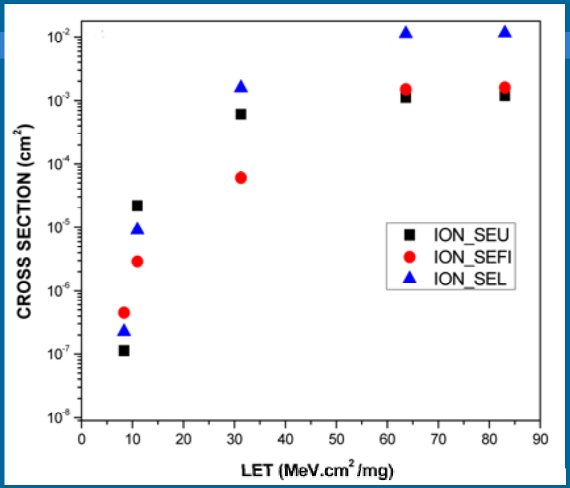


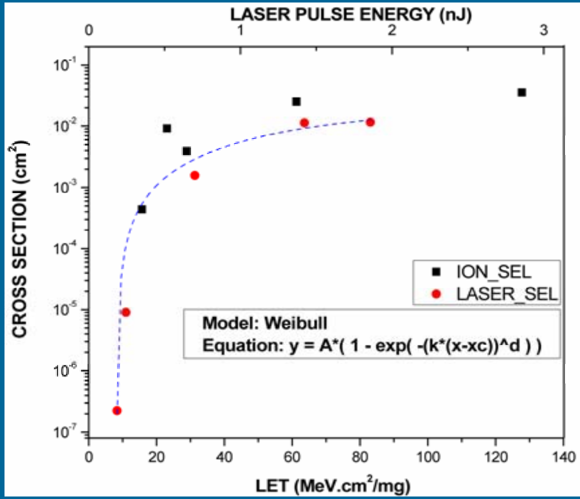
Few Samples DUTs Tested at LNS

Device	Manufacturer	Application	Technology	Power Supply	Data Rate	Data Storage
CC1020	CHIPCON	Transceiver RF 400-940 MHz	CMOS 0.35um	3.3V	153.6kbit	-
AT45DB321CTI	ATMEL	Flash RAM	-	3.3V	40Mbit	4.3MB
EX128TQ100	ACTEL	FPGA	CMOS 0.22um	3.3-5V	-	10k gates
FM20L08	RAMTRON	Ferroelectric RAM	-	3.3V	33MHz	1Mbit
PIC 18F8680	MICROCHIP	Microcontroller	-	5V	40MHz	64kb

SEU Test Flow Diagram, XSection vs LET (ions/laser)

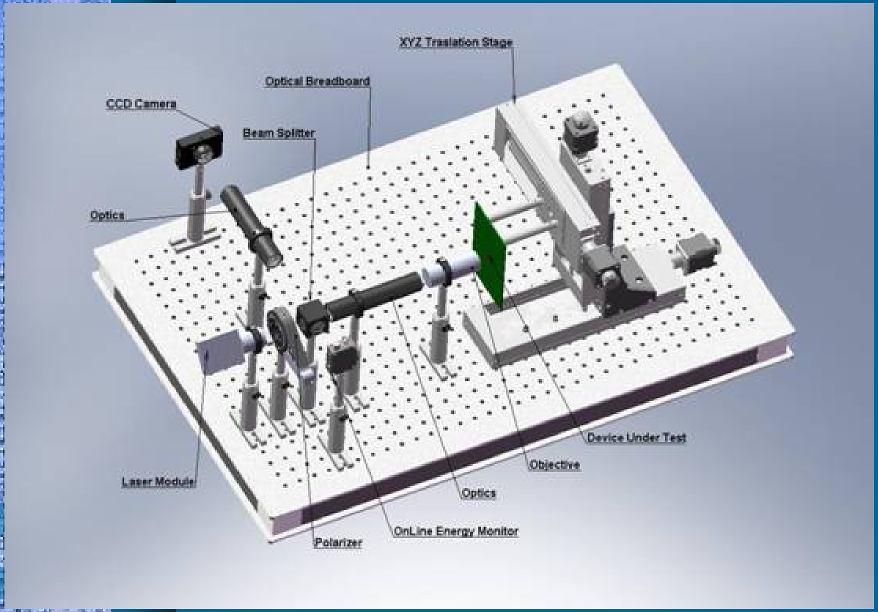


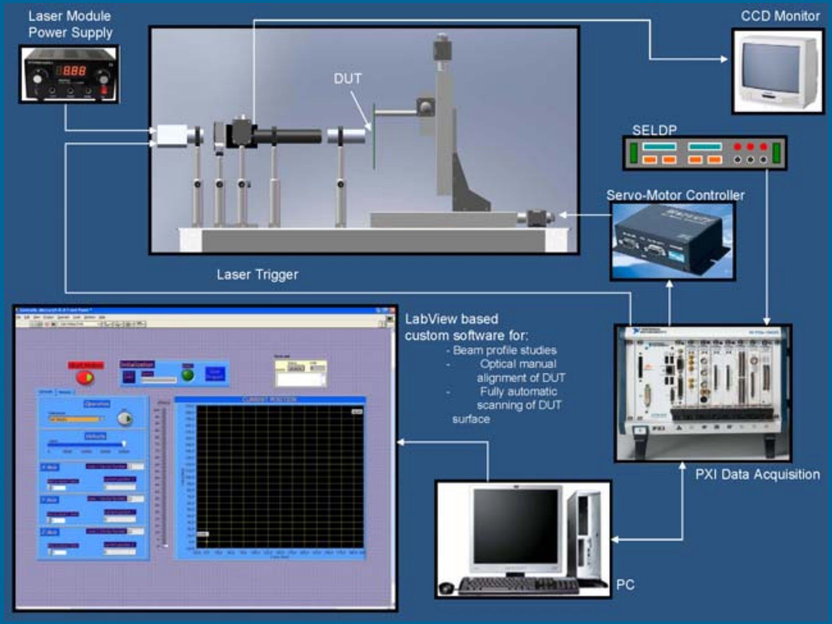




Calibrated Laboratory Tests (Laser 1)

SEE Cross Section vs LET Measurements and Radiation Sensitivity Mapping of ICs by the IR pulsed LASER SYSTEM





Technical Notes:

•λ=915 nm

•Pulse width=15ns@10kHz repetition rate

•Laser spot waist (FWHM)=10 µm

•Adjustable Laser Peak Power Intensity up to 25W

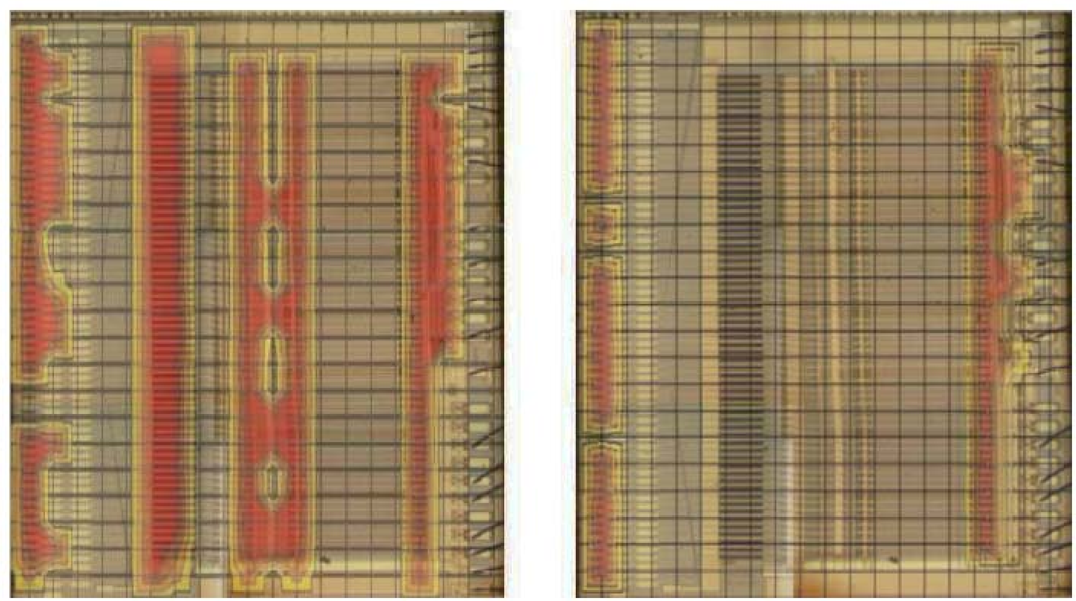
•XYZ Spatial Bidirectional Resolution=0.2 µm

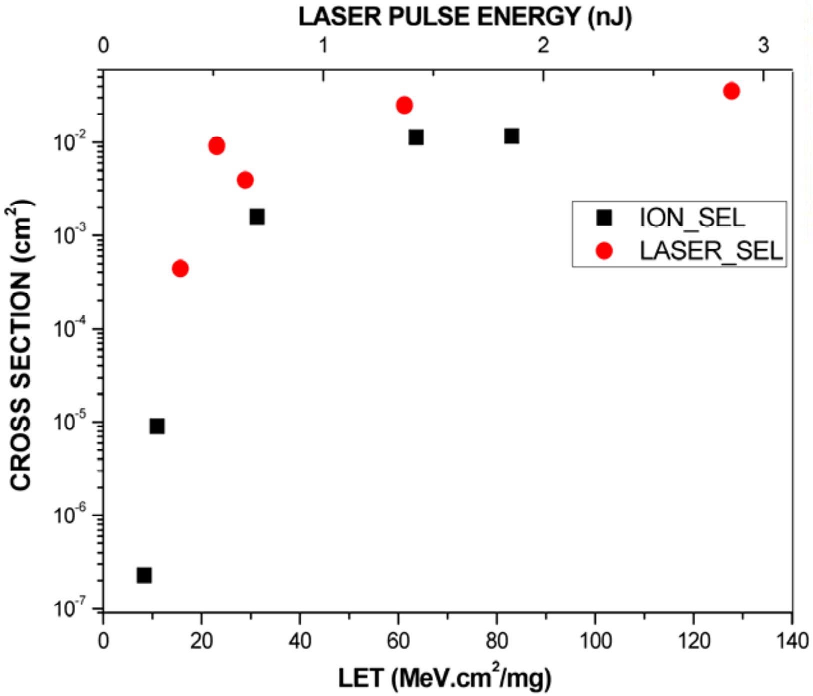
•Automatic Chip Surface scanning system

•Patented **ITRM20020382** - 2004-01-16

Calibrated Laboratory Tests (Laser 2)

Laser Radiation Sensitivity Mapping (*) of the VA64 – Ideas (NO)





Comparison between c.s. vs LET of Ions and Laser plots

(*) Alpat B., Petasecca M. et al. – Microel. Reliability 43 (2003) pp. 981-984

SEE Test Board Assembly and Pre Irradiation Functionality Check

- SEE Test board and mechanical assembly at our premises (Nov-Dic 2006)