Esperimenti di Gr5 @Padova 2016

E.Conti, CdS 9/7/2015

Nel 2015

APIX2 (dotaz.)
CHAOS_MIUR (premiale)
CHIPIX65 (call)
COSA
SCALTECH28
SEED

Elettronica, computing

DORELAS
NIRFE

Rivelatori

NEUTARGS

Acceleratori

MITRA
TECHN_OSP

Fisica medica, interdisciplinare

Nel 2016

APIX2
CHIPIX65 (call)
COSA
SCALTECH28
SEED

Elettronica, computing

AXIOMA (call tematica)

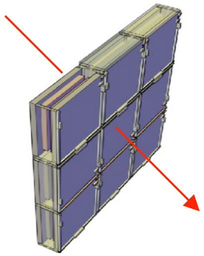
Rivelatori

NEUTARGS

Acceleratori

TECHN_OSP

Fisica medica, interdisciplinare



APiX

CdS INFN Padova
2015/7/9

Development of an Avalanche Pixel Sensor for Tracking Applications

INFN Pisa/Uni Siena (2.6FTE): P.S. Marrocchesi (resp. nazionale)

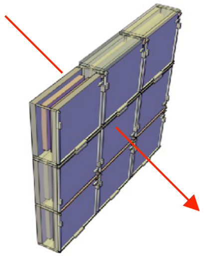
INFN/Uni Padova (0.5FTE): G.Collazuol (resp.loc.)

INFN Pavia (1.0FTE): L.Ratti (resp.loc.)

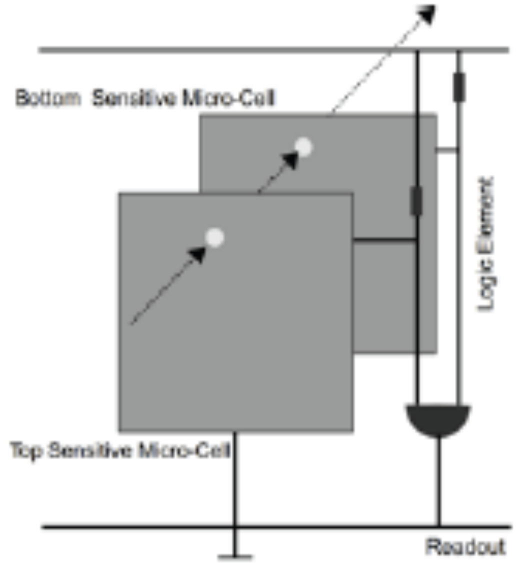
TIFPA/Uni Trento (1.8FTE): L.Pancheri (resp.loc.)

International institutions:
Laboratoire APC , Université Paris-Diderot/CNRS
(resp. A. Savoy Navarro)

Institute of Applied Mathematics, Russian Academy of Science, Moscow, Russia
(resp. V. Saveliev)



Overview



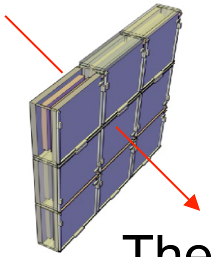
The APiX concept
• CMOS avalanche cells providing internal gain
for charged particle detection
• Coincidence between vertically aligned cells pairs
to drastically reduce Dark Count Rate (DCR):

→ dual tier Avalanche PiXel detector

Main technological challenges:
1) CMOS sensor design:
optimized for charged particle detection
starting from the experience with CMOS SPAD development
2) Vertical integration of electronics for signal processing

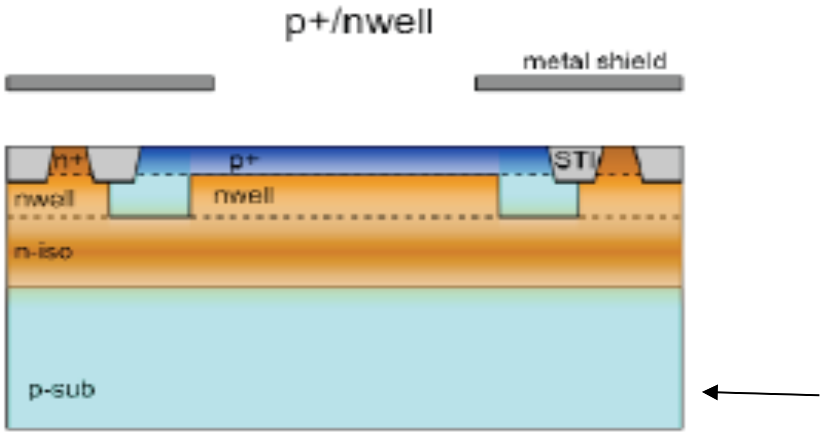
Mature technology:
3) Thinning
4) Readout architecture

Workplan and milestones



Basic detector element

The basic element of the APiX detector is an avalanche diode based on a CMOS process and operated in quenched Geiger mode

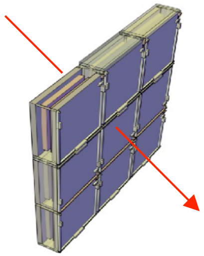


- Several possible implementations in standard CMOS or CMOS imaging (CIS) or CMOS HV technologies
- Inheritance from CMOS SPAD detector design

Example: p+/n active area junction + Guard Ring + buried isolation layer

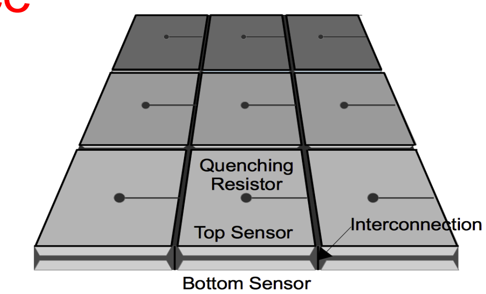
¬ Large internal gain provided by the detector itself → no pre-amplification → less power
¬ no amplitude measurement, pure binary information (hit/no hit)
¬ sensitive layer of the device is very thin, limited to the depleted region around the pn junct.
→ virtually no charge loss if the substrate is thinned down.
¬ readout electronics integrated in the same substrate as the sensor
BUT
- an avalanche detector is affected by a large dark count rate DCR ~ O(100 kHz/mm2)

APiX concept: the coincidence of vertically aligned cells drastically reduces DCR problem



APiX concept:
dual tier Avalanche pixel detector

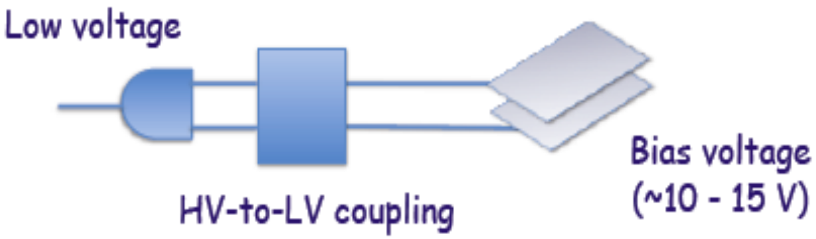
Goal: reducing Dark Rate effects by using coincidence between two overlapping pixels (sensor pairs)



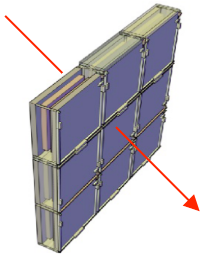
Accidental coincidence rate (estimate)
Assuming a dark count rate DCR = 100 kHz/mm2 and
Δt = 10ns coincidence, with N=50 μm x 50 μm pixels,
the rate of fake 2-fold coincidence is
2 R2 Δt/N = 0.5 Hz/mm2
For 1cm2 detector is would be close to 50 Hz

Main assets:

- Internal Gain
- → reduces dramatically the material budget (few μm sensitive thickness)
- Readout electronics on chip → digital signal out
  → reduction of the power consumption
- Vertical alignment and coincidence
- → overcome the dark rate probability and sensitivity to photons
- Flexibility in layout → improving detection efficiency for ionizing particles

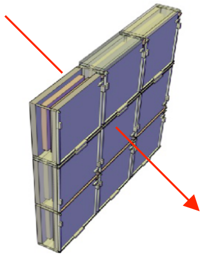


Sensor Power consumption (readout power excluded)
Assuming a 100MHz/cm2 hit rate on 1cm2 detector,
the average current ~16μA @gain = 106
i.e. a power dissipation of about **0.32 mW/cm2**
for 2 layers in the case of 10 V bias in the cell for
full avalanche operation

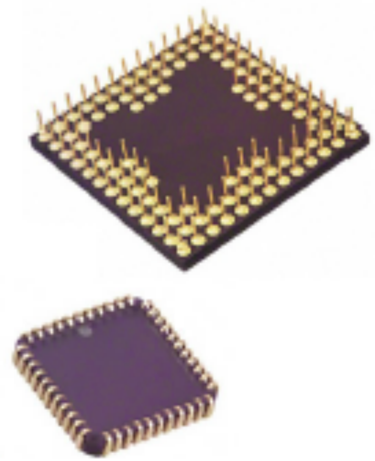


Status of the project

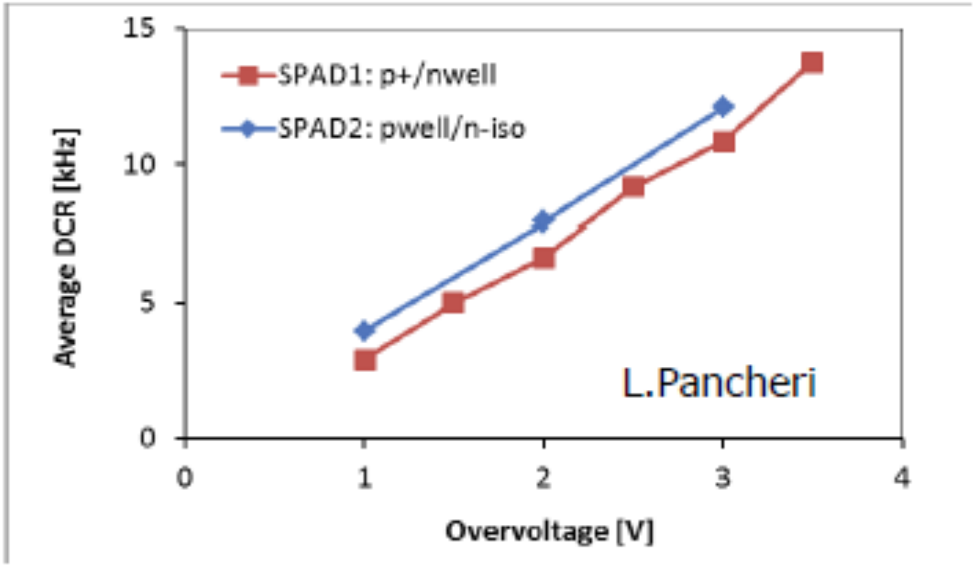
- APIX2 funded by CNS5 for 3 years
- Project kick-off in July 2014
- First submission: Nov. 2014 to LFoundry (0.15um)
- SPAD chip ("son") + SPAD and logic chip ("father")
- → received in end April 2015
- → preliminary lab tests: DCR is lower than expected, logic is OK
- → vertical integration by IZM scheduled end summer 2015
- Second submission: May 2015 to XFAB 180nm CMOS HV (40V)
- → delivery expected Sep. 2015
- Vertical integration: with micro bump-bonding in Autumn 2015

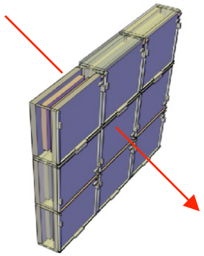


Preliminary tests (June 2015)



- A small number of samples of chip 1 mounted on PGA100 and chip 2 mounted on JLCC44 package for **pre-integration tests**
- Preliminary characterization performed on **chip2** show that SPADs and chip electronics are **fully functional**
- Dark Count Rate (DCR) measured on 24 SPAD pixels with the maximum active area (43um x 45um)
- **DCR reduced by a factor > 5** after foundry transfer from Rousset to Avezzano
- Small changes in V_{BD} (< 10%) with the new process
- Test board suitable for both chip 1 and stacked sensor is in fabrication





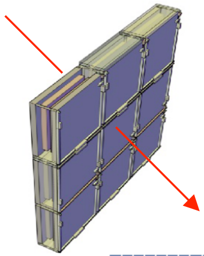
Workplan

First year (July 2014 – July 2015)

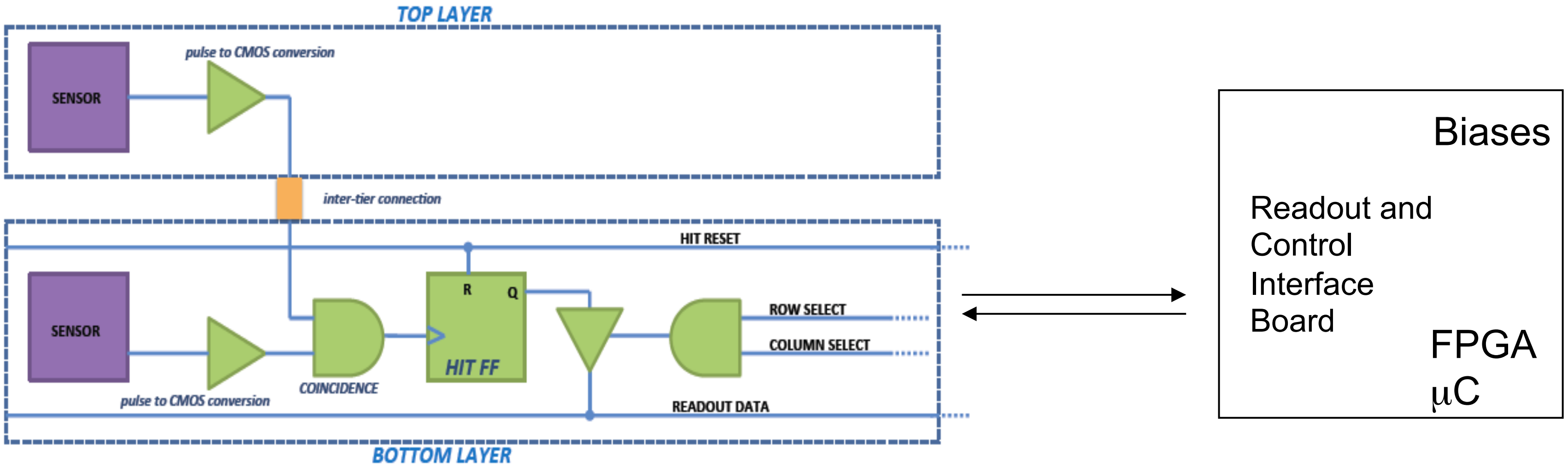
• simulation and design of avalanche pixel sensors
(different pixel options for performance optimization)
• modeling of the vertical interconnected structure
• prototype fabrication and test
• 1st vertical integration (end 2015)
• design and configuration of a multipurpose lab test bench

Activity in 2016

• development of vertically integrated detector prototype
(eg 8mmx13mm each 3-sides buttable ~ 200x200 pixels;
LFoundry Multi-Level Mask: 8mmx26mm ~ 60keuro)
• beam test at CERN
• study of radiation tolerance of the device
(from the standpoint of both ionization and bulk damage)



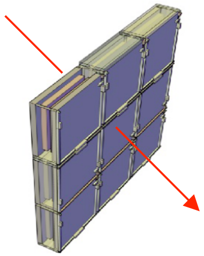
APIX Padova



APIX Padova took care of Readout and Control Board: ReadOut and digital processing by Microcontroller (Arduino 2) (or FPGA) designed and realized by

- **G.Rampazzo/servizio elettronica INFN**

- **G.Viola (Unipd)**



APIX Padova – Richieste 2016

Personale:
- G.Collazuol al 10% → resp. loc. “APIX2_DTZ”
- C.Checchia al 40%
- G.Viola (Unipd)

Richieste budget 2015:
- Missioni estere 3k€
  → test beam CERN
- Consumo 4k€
  → scheda elettronica readout test chip 2nd prod.

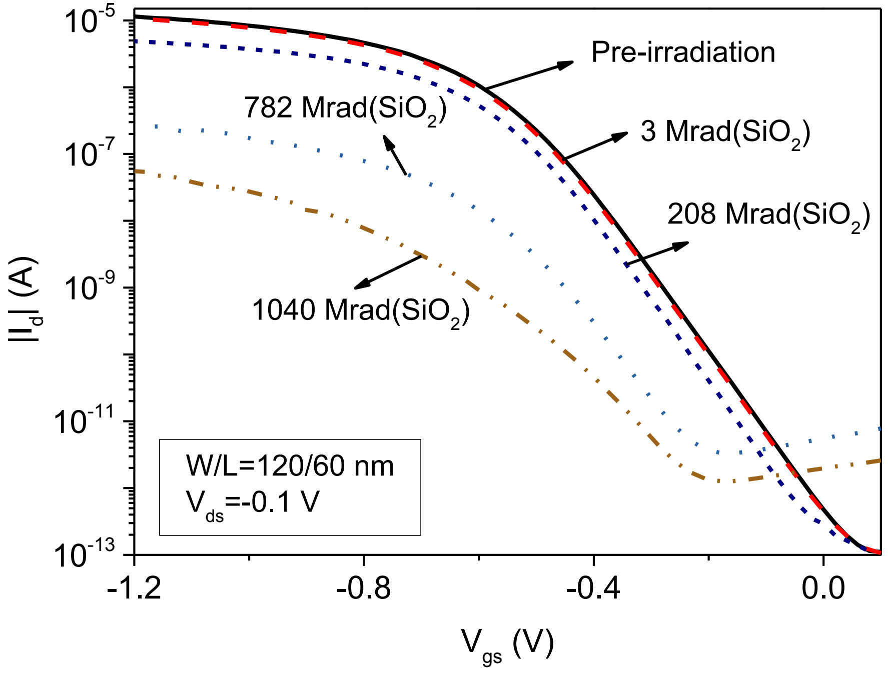
Richieste servizi locali:
- Elettronica: 1 m.u. per modifiche scheda prima
- generazione chips e realizzazione nuova scheda
-

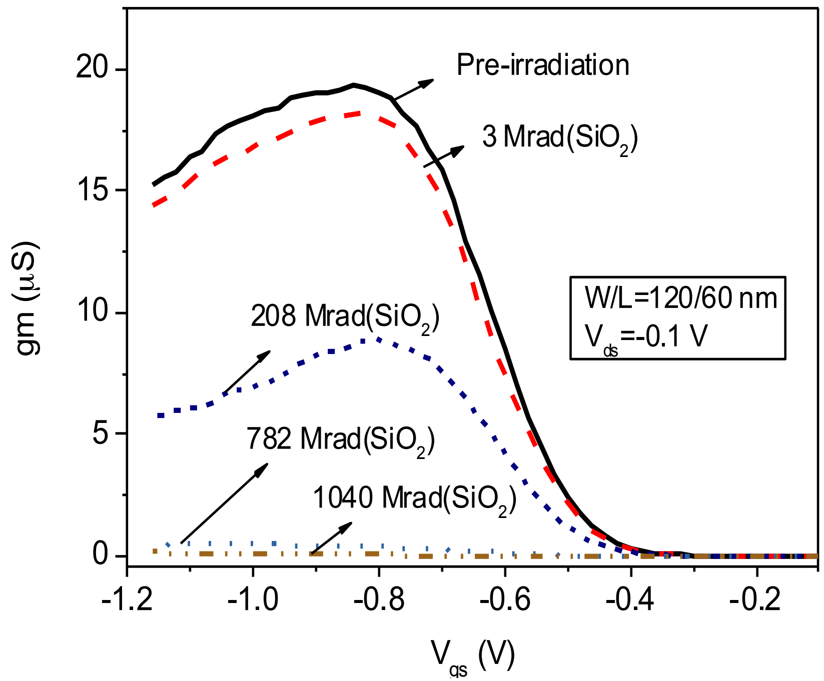
CHIPIX65@Padova

- Studio della resistenza alle radiazioni della tecnologia CMOS 65 nm di TSMC
- Disegno di alcuni IP
- In prospettiva collaborazione al disegno del ROC del pixel detector di Phase 2.
- L'attività si inserisce nella CALL di GR V

  Mi, Pv/Bg, Pi, Ba, To, Pd

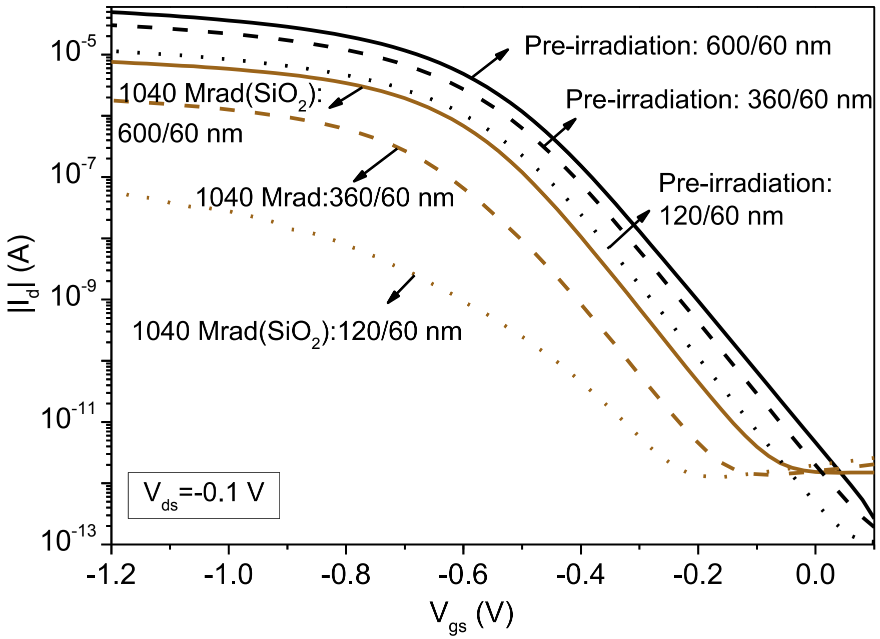
Degradation as a function of dose

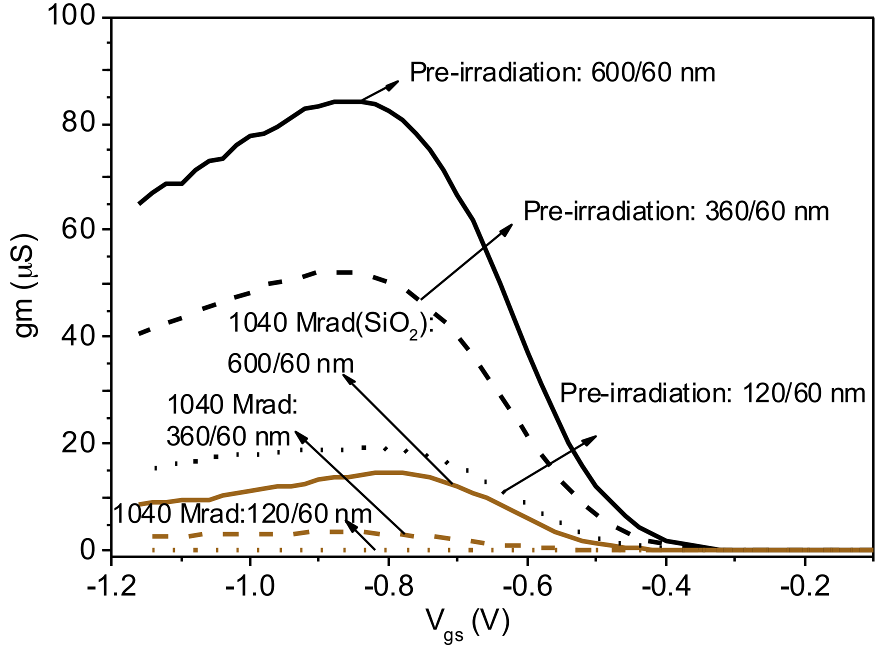




- The irradiation campaigns carried out in 2015 by UNIPD/INFN-PD with x rays and low-energy protons at room temperature, on a number of 65-nm test chips has highlighted a severe degradation, particularly in PMOSFETs.

Geometry dependence





- The geometry dependence of the degradation at very high doses is not trivial at all and does not simply reproduce previously-observed trends
- The analysis performed so far points out that well-known phenomena related to charge trapping and interface state generation in the shallow trench isolation cannot fully account for the observed degradation

Activity for 2016

- Further experimental investigation (irradiation, annealing) is needed at different temperature/bias etc. and with different geometries, to gain more insight about the physical mechanisms and to provide realistic degradation estimates in the final application, starting from accelerated tests at very high dose rates
- We plan to perform another comprehensive test campaign using x rays and low-energy protons at UniPD and LNL

CHIPX65: Padova activity on PLL IP design

- TSMC 65nm NDA signed at the end of 2014.
  Design kit received and installed in February 2015
  Followed CERN Training course on technology
- Due to the delay vs others RD53 IP Groups we have decided to start from a our previos work
  - Design of a 6.5-18.4 GHz PLL in 65nm CMOS for the local oscillator (LO) generation in a short-range radar front-end (M. Caruso et al., proceedings of ESSCIRC 2013)

  (developed in a same node technology from another vendor)
- We have started to port the project in TSMC technology
  - Rad-hard redesign
  - Starting to evaluate different oscillator topology due to RD53 project constraints on layer use
- The goal is to submit a first prototype at end 2015/beginning 2016

Personale e richieste

Personale

- Fisica
  - D. Bisello 10%
  - G. Gao (assegnista) 50
  - L. Silvestrin 20

DEI

S. Gerardin 20

A. Paccagnella* 20

A. Neviani 50

D. Vogrig 50

* RL

Richieste budget 2016

- Budget fissato dal piano finanziario della Call
- Consumo 3 keuro
- Missioni

parte dei 30 keuro indivisi

Total FTE = 2.2

Richieste servizi

Programma

- Vasta campagna di irraggiamenti alla macchina radiogena, CN, Tandem
- Preparazione board di test e per irraggiamento
- Caratterizzazione elettrica pre e post irraggiamento dei devices prodotti
- Manutenzione degli apparati di irraggiamento, di misura, e clean-room

Richieste

- 11 m/u LOE
- 2 m/u OM

COSA

- COSA = COmputing on SoC Architectures
- COSA ha lo scopo di valutare sul campo, utilizzando applicazioni in uso presso la comunitá scientifica internazionale, le potenzialitá, le prestazioni e i costi di esercizio di sistemi di calcolo basati su System-on-Chip (SoC) low-power, e di acquisire competenze tecnologiche che possano essere utili in futuro per l'utilizzo efficace su larga scala di tali dispositivi in ambito INFN.

COSA

L'esperimento procede come previsto.
Gli acquisti hardware procedono a rilento perche' non escono nuovi processori, in particolare gli ARM a 64 bit

	CNAF	FE	PD	PR	ROMA1	PI	LNL	TOT
INV./CONS. WP1								
INV. WP2	5		5					10
INV. WP3	5							5
INV. WP4					50			50
CONSUMO WP3	1							1
CONSUMO WP4					2			2
INV. WP5		10						10
CONSUMO WP6			2					2
LICENZE SW		??						
TOT INV./CONS	11	10	7		52		0	80
Missioni	2	2	2	2	2	2	0	12
TOT	13	12	9	2	54	2	0	92

COSA

Nome	Ricercatore	Tecnologo	FTE [%]
Michelotto Michele		X	70
Morandin Mauro	X		10
Zangrando Lisa		X	20

- Non ci sono richieste ai servizi

Responsabile Nazionale
e Locale padovano: **Jeffery Wyss**
wyss@pd.infn.it
345-3163072

NEUTARGS

https://sites.google.com/site/neutargs/general

INFN Istituto Nazionale di Fisica Nucleare

GOAL: develop high power neutron production targets

- **WP1:** ***SEE*** *(Single Event Effects in micro-electronics)*
- WP2: ***FARETRA*** *(Fast Reactor Simulator for Transmutation studies)*
- WP3: ***BNCT*** *(Boron-Neutron Capture Therapy of cancer)*
- WP4: ***BSA*** *(Beam Shaping Assembly target test setup)*

3 sezioni INFN:

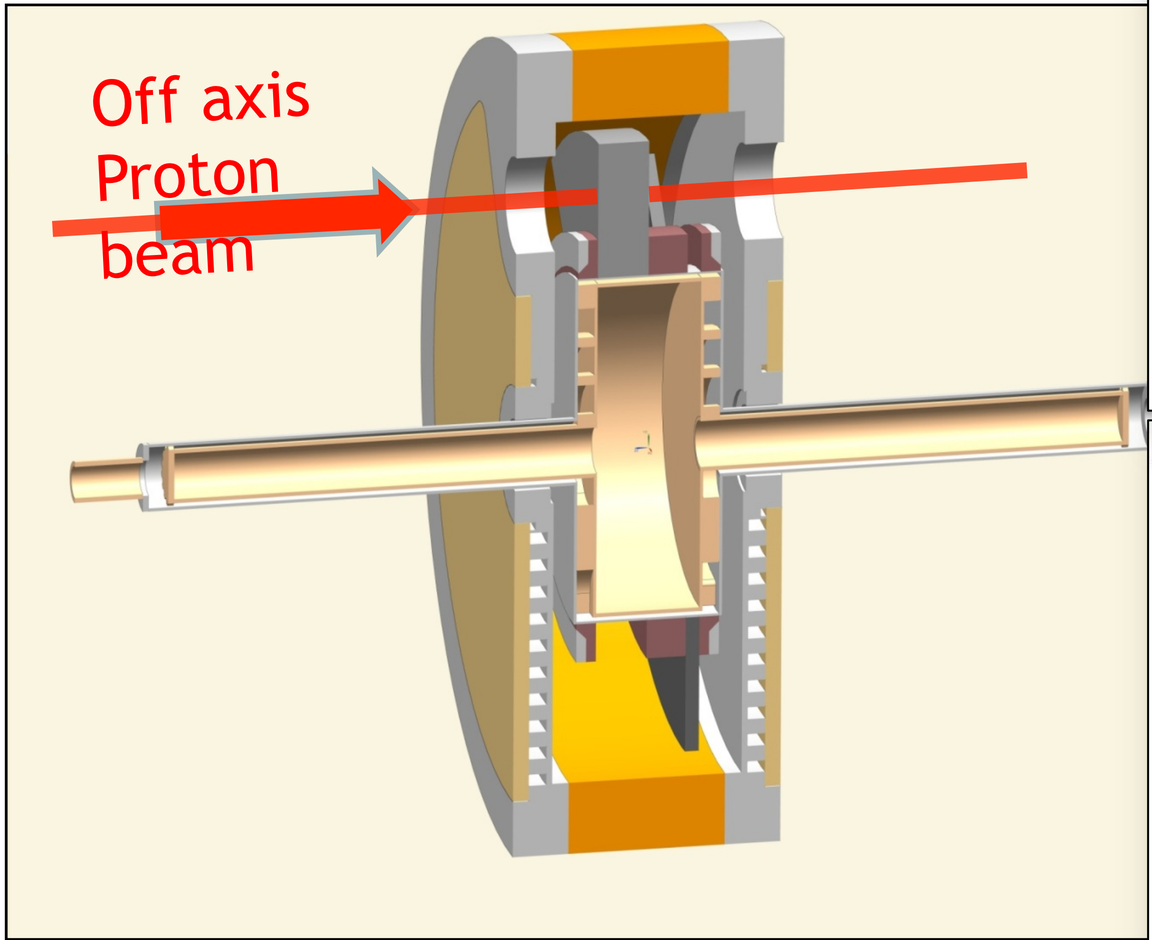
- **Padova** (WP1) → **continues 2016**
- **LNL** (WP1, WP2, WP3) closing
- **Pavia** (WP4) closing

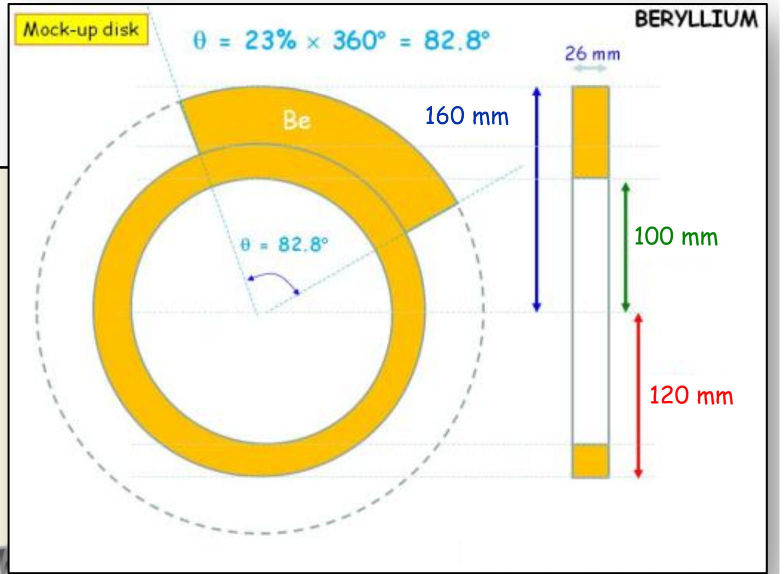
SEE-PD

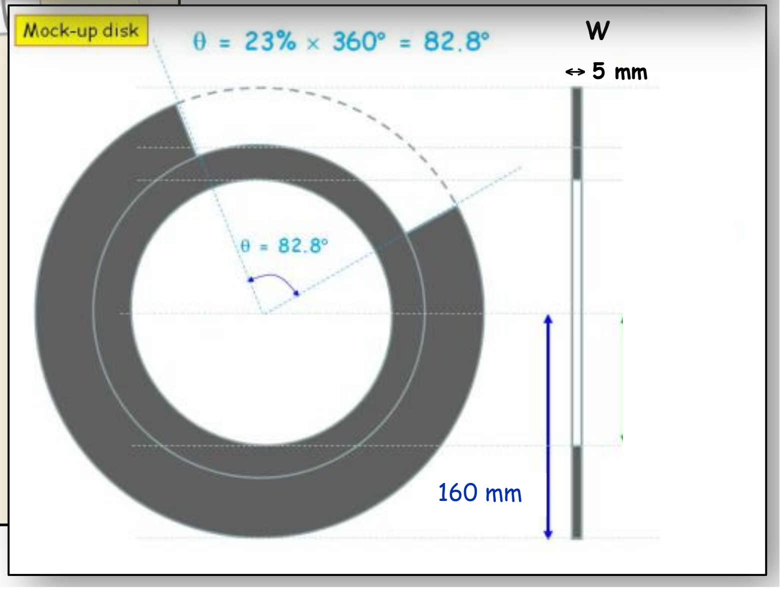
Atmospheric Neutron Emulator (ANEM)

A rotating (few 10s rpm) composite target made of **Be** and **W** to produce an effective atmospheric-like neutron spectrum in the 1-70 MeV range (without the use of moderators).

Note! Prototype sectors have half radius of original design. Cheaper!

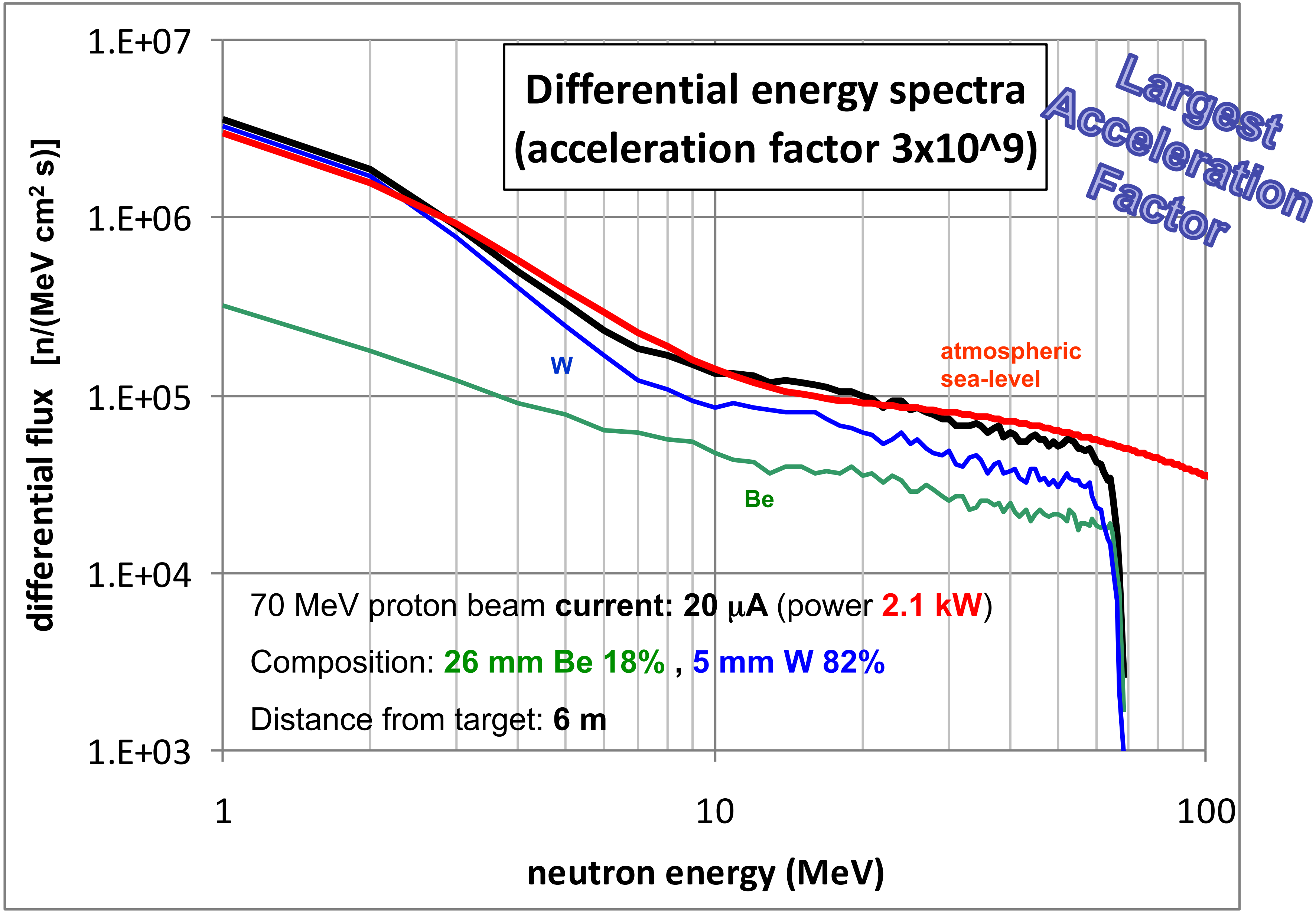






SEE-PD

Effective spectra of rotating target @ SPES



SEE-PD

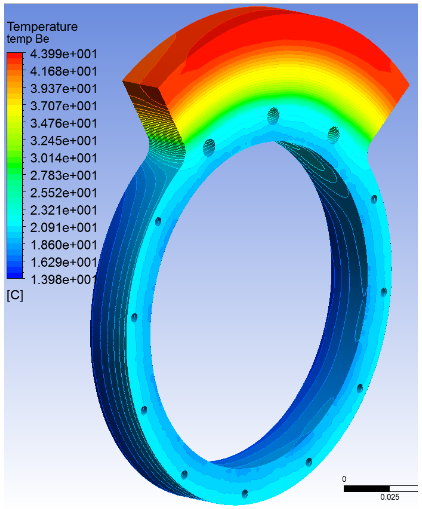
Temperature is not the problem,… *however*

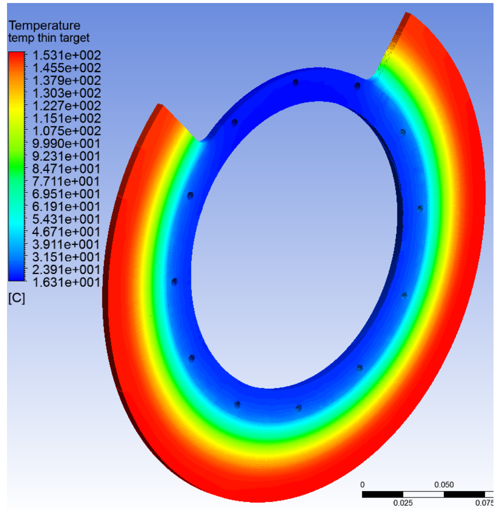
Impinging proton beam

- power 2.5 kW (I_{proton} = 35.7 μA)
- Gaussian beam spot (FWHM 1 cm)

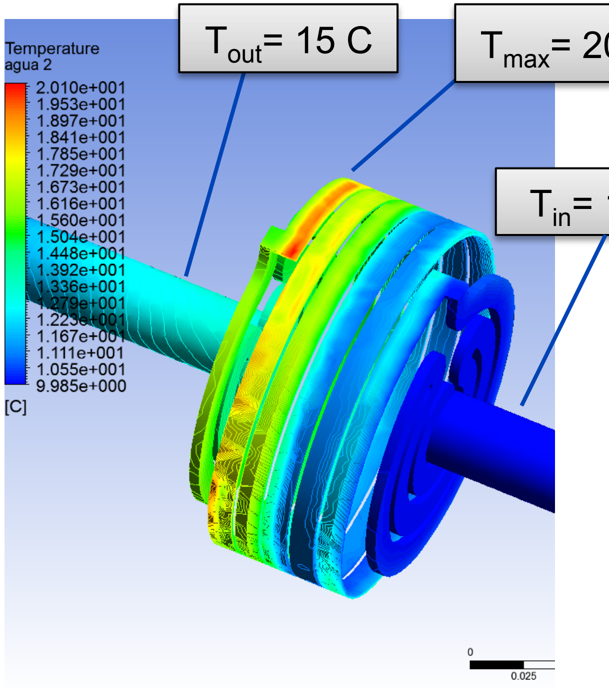
Results

- Be max temp 44 °C (melting point 1287 C),
- W max temp 153 °C (melting point 3422 C).



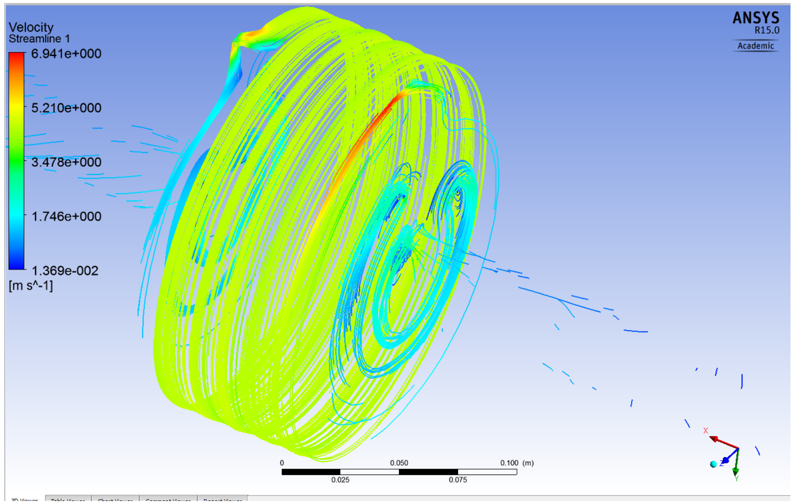


Thermal maps of Be and W



Temperature map of the cooling circuit

Temperature distribution in cooling circuit is everywhere well below the boiling point. The flux is 0.2 l/s, the water speed 4 m/s in the coil.



Water speed in the cooling circuit

ANSYS CFX module was used to perform thermal simulations

SEE-PD

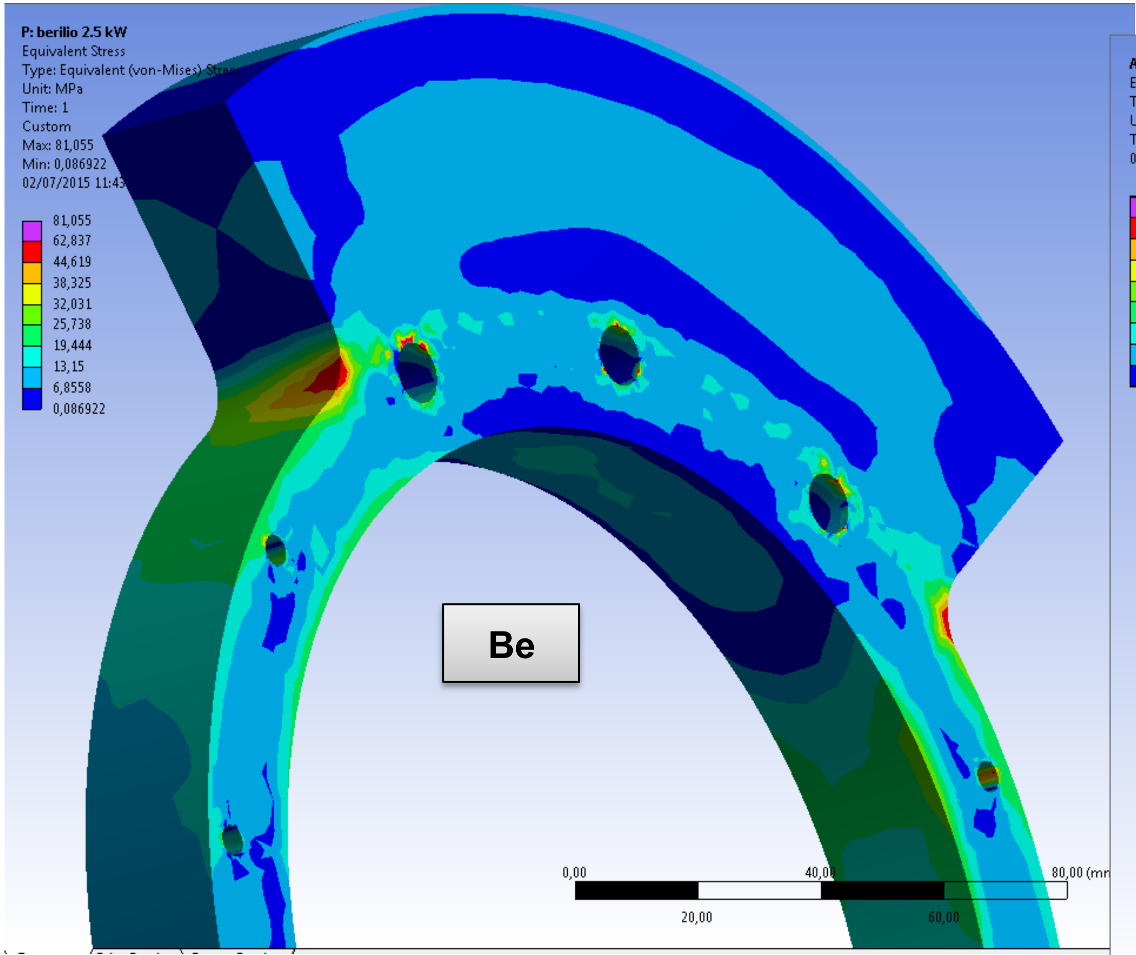
Maximum stress depends on temperature!

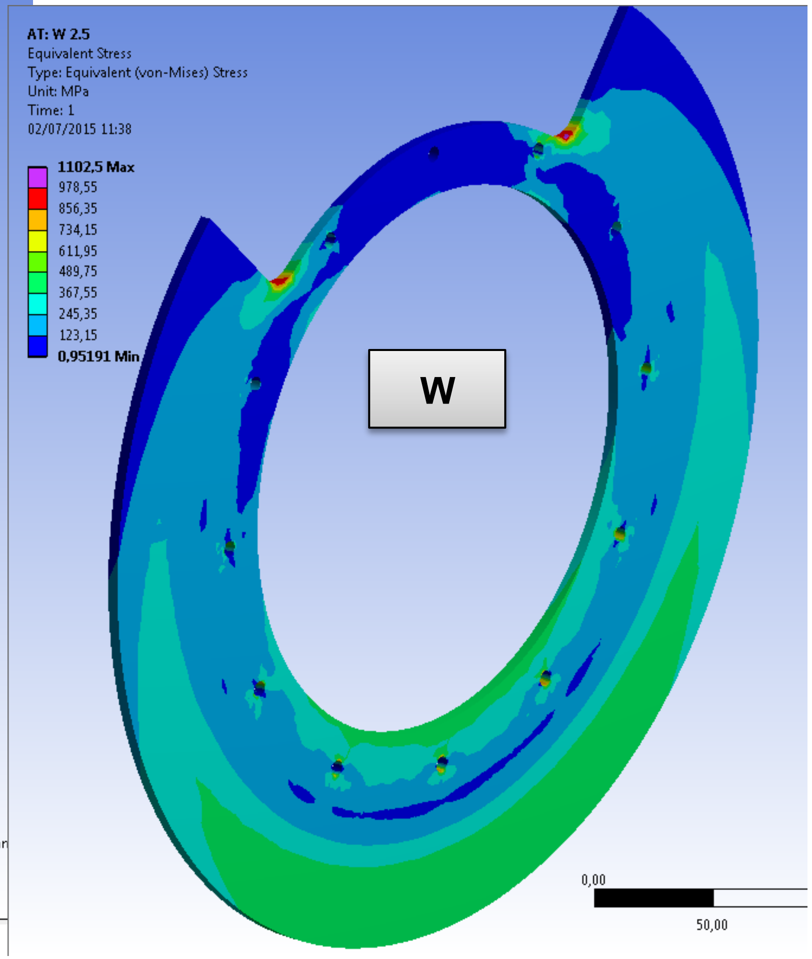
Impinging proton beam
- power 2.5 kW (I_{proton} = 35.7 μA)
- Gaussian beam spot (FWHM 1 cm)

Results
- Be max stress 81 MPa (50% yield strength @ 44 °C: 194 MPa),
- W max stress1103 MPa (50% yield strength @ 153 °C: 1014 MPa)

The maximum stress must be below the “yield strength” value where materials loses elasticity and become plastic.
For safety we will consider 50% of the yield strength.

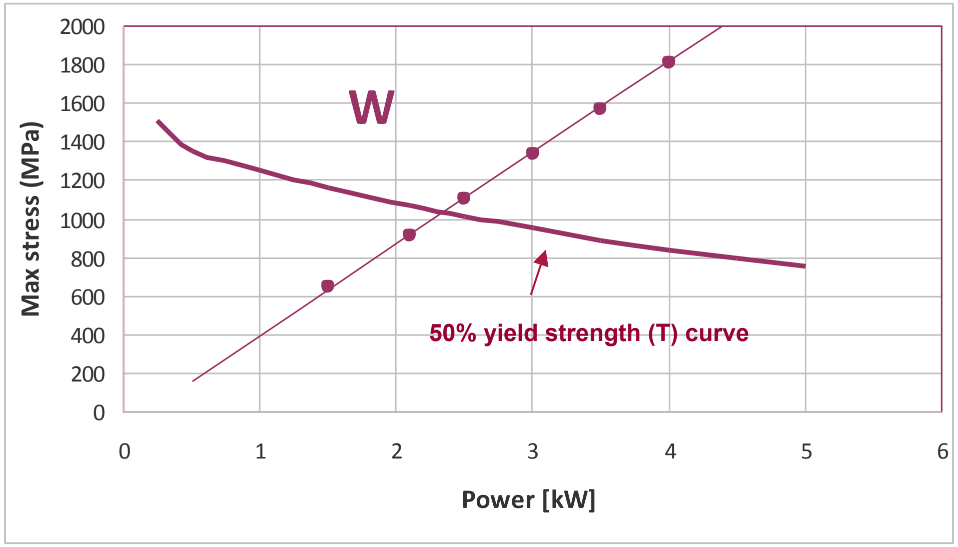
Note: the yield strength depends on the temperature.



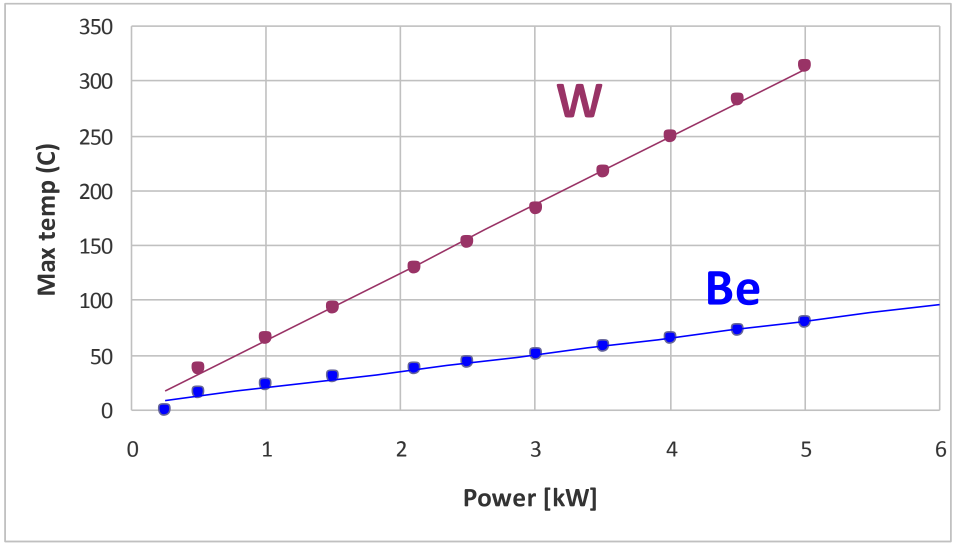


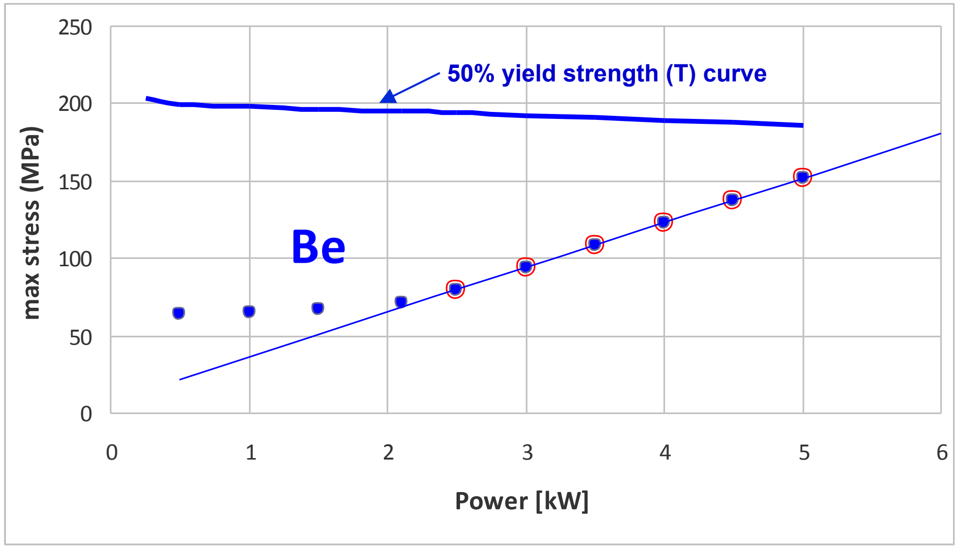
Summary

max stress vs power



max temperature vs power





The stress in Be target shows a behavior different from the stress in W: it's linear only over ~30 μA (corresponding to 2.1 kW power deposition). This is probably due to the presence of the bolts that induce stress on this element even when no thermal power is supplied. When the thermal expansion dominates, the stress increases linearly (red circles).

- NEUTARGS sarebbe dovuta concludersi nel 2015.
  Ritardo nell’acquisto/delivery del power e-gun per test ha fatto slittare il termine nel 2016
- Si chiede la continuazione della sigla nel 2016 per la sola sez. di Padova

SEE-PD

Richieste NEUTARGS PADOVA 2016

Richieste sezione 2016:

Officina meccanica: 1 m.u.

Assigned to NEUTARGS PADOVA in 2015	
Missions	2 k
consumables	5 k
inventory	12 k SJ
total	7 + 12 SJ

2016

Travels	Missioni PD-LNL, Trento (riunioni, misure), conferenze	**4k**

Consumables	*Ancillary parts:* ○ *temperature measurements* ○ *set up for proton beam tests;* ○ *"equivalent" test disks and sectors (aluminum, lead, copper disks)*	 **1 k** **2 k** **2 k**
	total consumables	**5 k**

Inventory	• if necessary, definitive chamber	12 SJ
	total invent.	**12 SJ**

totale	**9 + 12 SJ**

SEE-PD

NEUTARGS INFN PADOVA composition and tasks

COMPOSITION

Ricercatori:

- Silvestrin L. (Assegnista) 70%
- Candelori A. 30%
- Acosta. G (assegnista) 100%

Tecnologi:

- Wyss J. (RESPONSABILE NAZIONALE) 70%

Totale ***2.7 FTE***

TASKS 2016 (4° anno)

- completamento campagna di misure con e-gun
- ottimizzazione e congelamento del progetto

Se possibile:

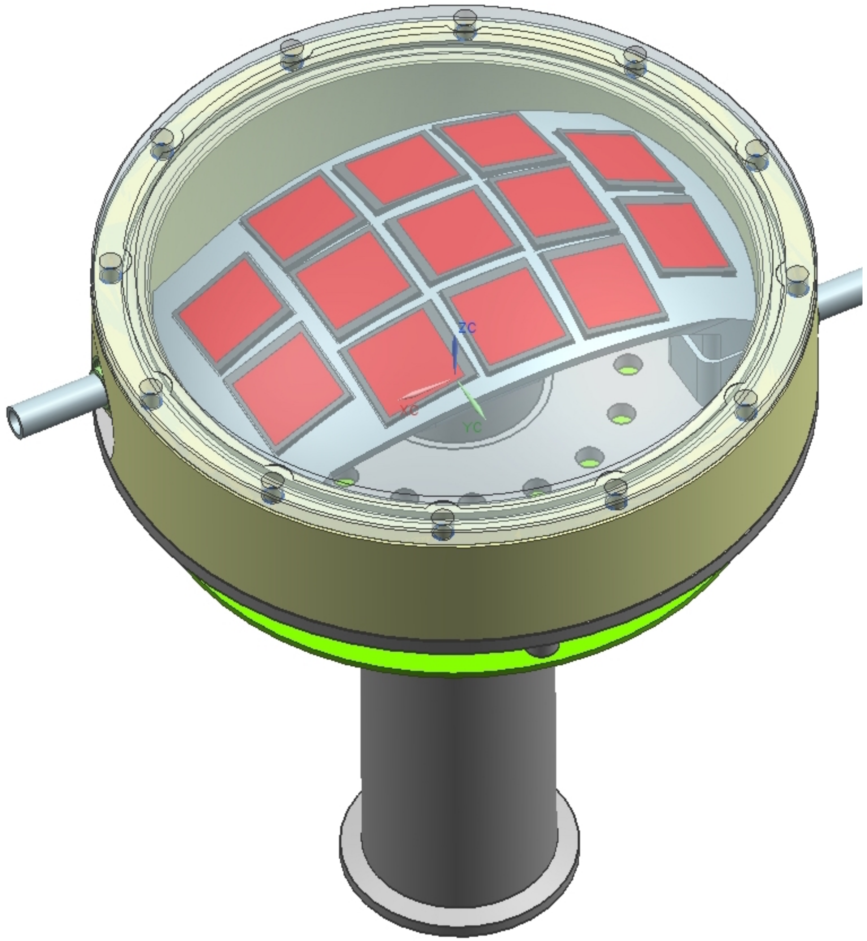
- test di attivazione con disco «equivalenti»
- test di potenza con protoni con disco «equivalente» (altri fondi)

NIRFE

- NIRFE: costruzione di un prototipo per la rivelazione della fluorescenza infrarossa dell'atmosfera prodotta da UHECR
- NIRFE si conclude nel 2015 nella CSN5.
- Next step: raccolta dati presso il sito di AUGER in Argentina. Serve approdo in CSN2 per finanziare trasferta.
- D'accordo con il presid. di CSN2, presentiamo un "proposal" in CSN2. Cerchiamo di avere fondi nelle dotaz. di gruppo.
- FTE: Conti 100%, Gonella 20%, Zotto 20% => TOT 1.4 FTE

NIRFE

NIR detector



ScalTech28

INFN Proposal (Gr. 5)
Milano-Bicocca, Padova, Pavia + EPFL (& CERN)
June, 30th, 2014

Low-power rad-hard circuit design in scaled technologies

… send some scouts in advance

ScalTech28: intro

- New areas of concern for total dose effects in 28-nm vs 130-nm and 65-nm CMOS
  - High-k gate oxide
  - Increased transistor-to-transistor variability
- Goals of the project:
  - thorough characterization and understanding of radiation effects
  - development of suitable SPICE models for simulating degraded circuits
  - design few significant blocks RH & LP

Test Chips

- Finalized content of first test chip containing MOSFETs with:
  - different widths and lengths
  - standard threshold voltage and high threshold voltage
  - 0.9 V and 1.8 V variants
  - nominally-identical transistors to study variability
- Measurements and irradiations with x rays will begin as soon as chips are back (fall) from the foundry
  - Focus on geometry dependence and sample-to-sample variability

Next year

- Compare simulated and measured irradiation effects
- Move from transitors and test structures to a front-end chip and digital blocks
- Large irradiation and test campaign
- Get an answer on the prospect of 28 nm technology at HL-LHC

Personale e richieste

Personale

- Fisica

D. Bisello	10%
A. Candelori	30
G. Gao	50
L. Silvestrin	10
J. Wyss	20
D.Pantano	*50*
DEI	
S. Gerardin*	20
A. Paccagnella	10

Tot. FTE = 1.5

* RL

Richieste servizi

attività

- Assumiamo che le manutenzioni sono «a carico» di CHIPIX65
- Produzione di board per test ed irraggiamenti e preparazione campioni
- Irraggiamenti a macchina radiogena, CN, tandem

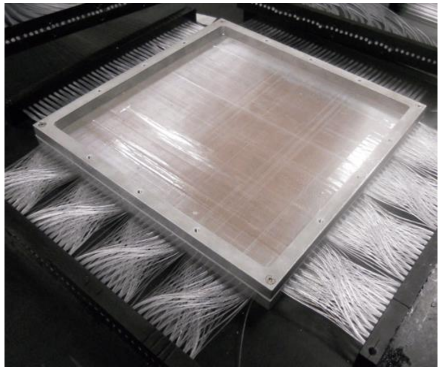
Richieste budget e servizi

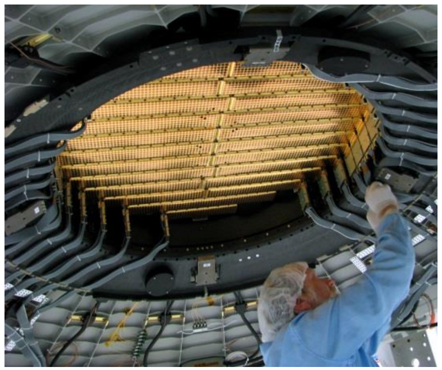
- Consumo 6 keuro
- Missioni 5.5

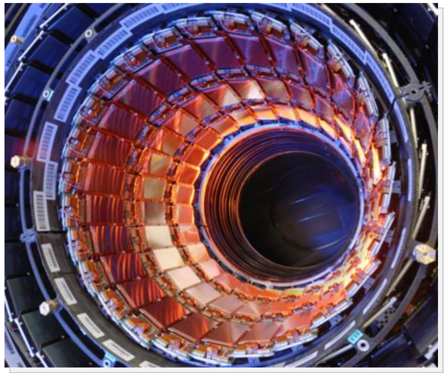
- 6 m/u LOE
- 1 m/u OM

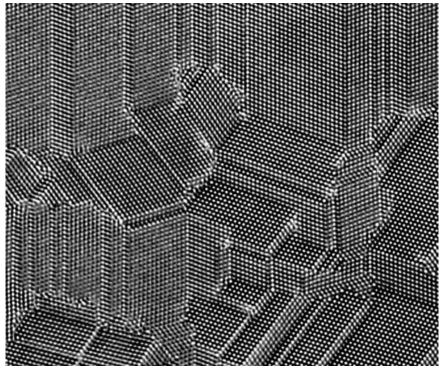
SEED

Sensor with Embedded Electronic Development


Solid state detectors for medical applications


Space-born trackers and telescopes

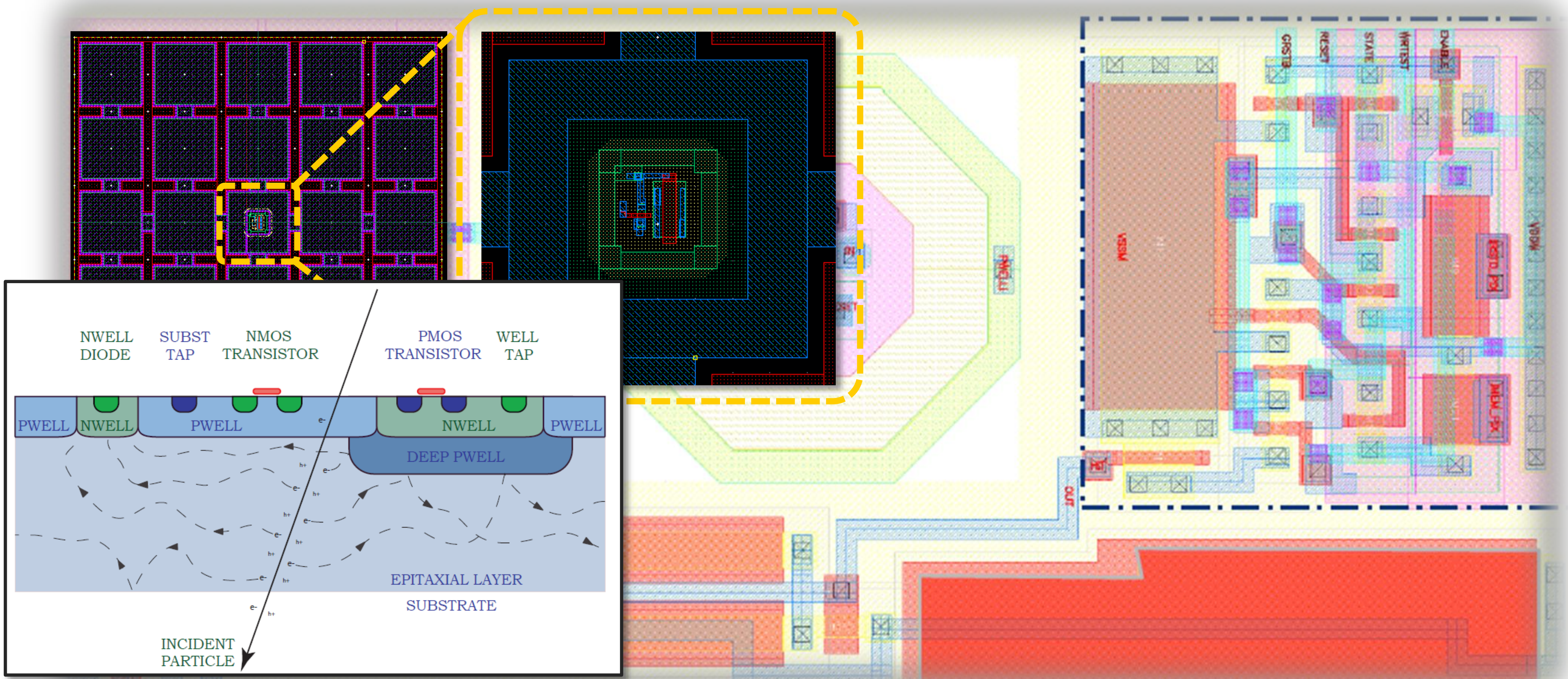

HEP trackers and calorimeters


Electron microscopy sensors

Less power consumption, higher granularity, lower assembly cost, simpler assembly and better reliability. Cannot address every issue in present solid state pixel physics detectors, but definitely most of them.

Piero Giubilato – Padova University

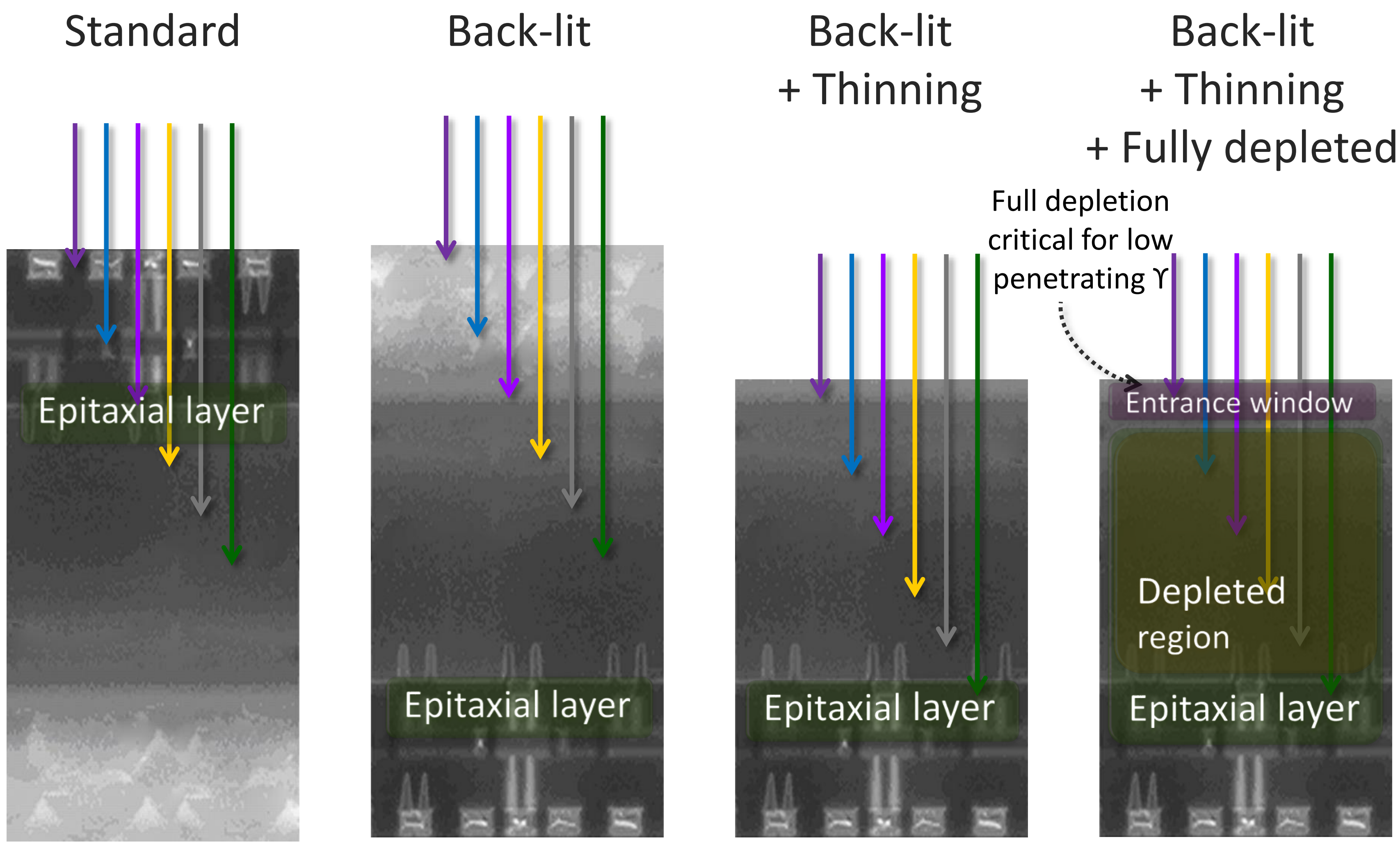
SEED – low power, low mass, low cost but high speed



Commercial 0.11 µm **CMOS** process allow embedding the electronic within the detector.

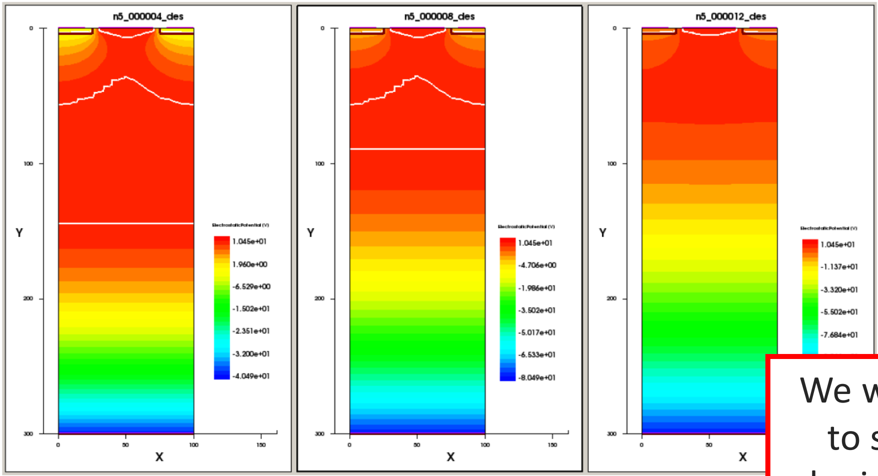
- **Lower capacitance** (less power consumption and/or higher speed) than hybrid detectors
- No assembly (**no bump or other bonding**) limitation and costs: **low material budget**.
- Commercially available (**cheap**) production ideally suited for **large area detectors**.
- Extreme reliability and low power: **space applications**.

SEED – effective depletion and backside processing are the keys

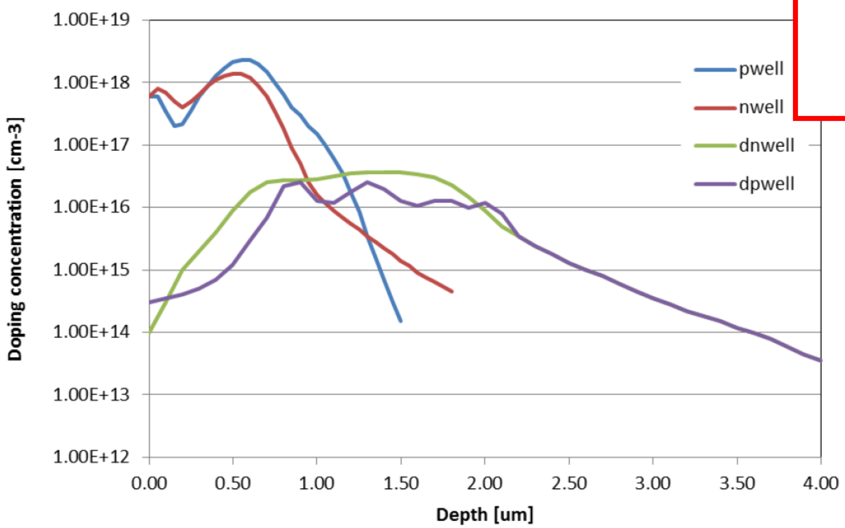


SEED – first extensive simulation results absolutely promising

Pixel depletion simulation…

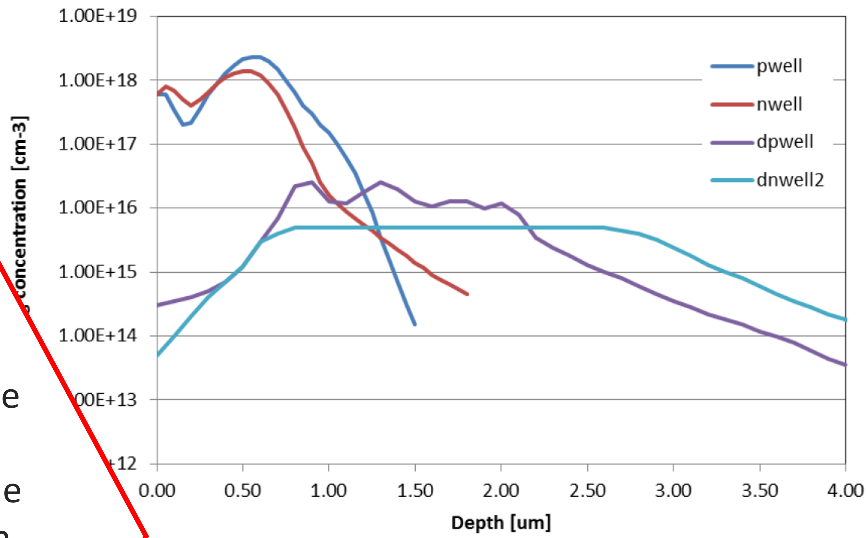


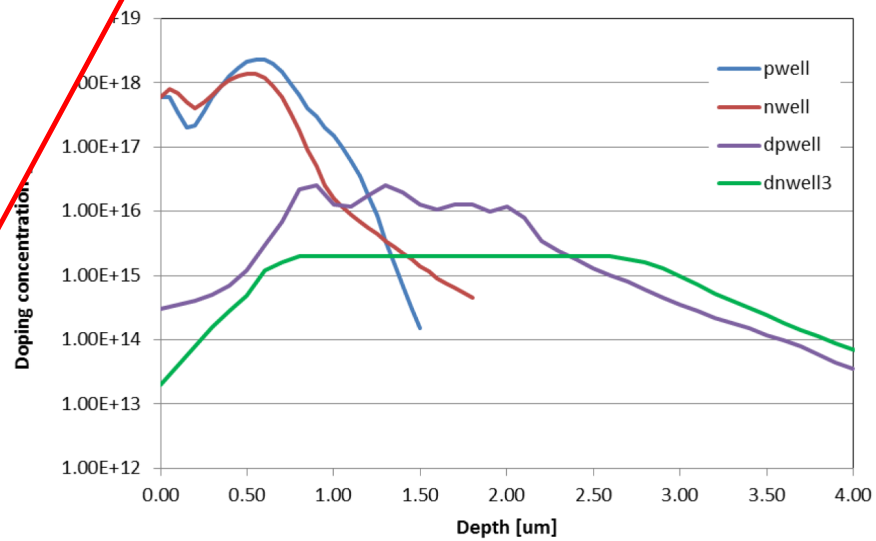
Using **real process doping profiles**



We were able to suggest doping profile modification based on simulation results

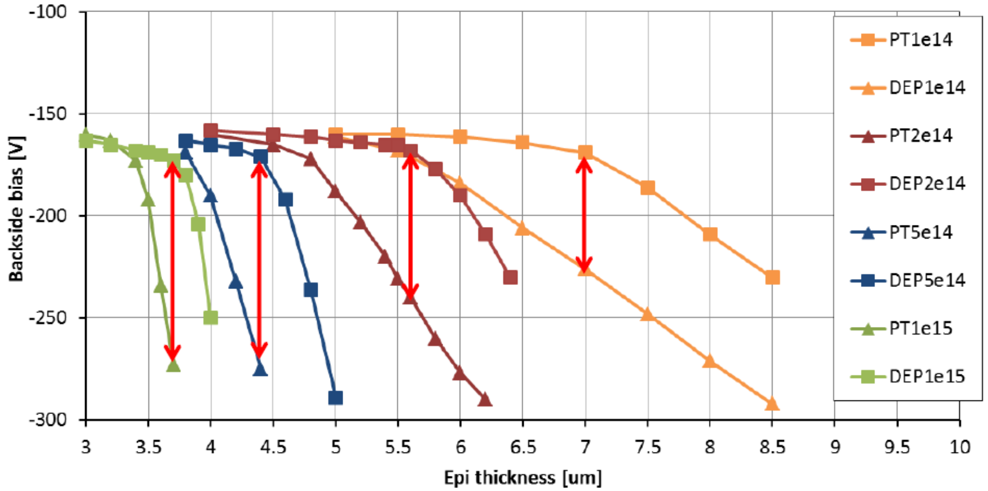
Proposed profiles to optimize depletion





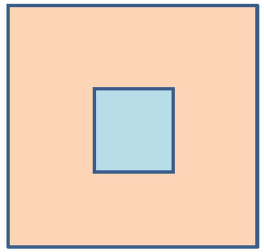
SEED – first extensive simulation results absolutely promising

Extensive epy-layer doping and thickness simulations

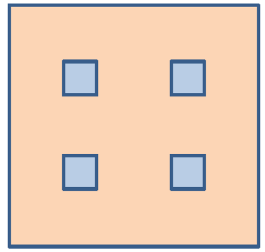


First cell layout under evaluation

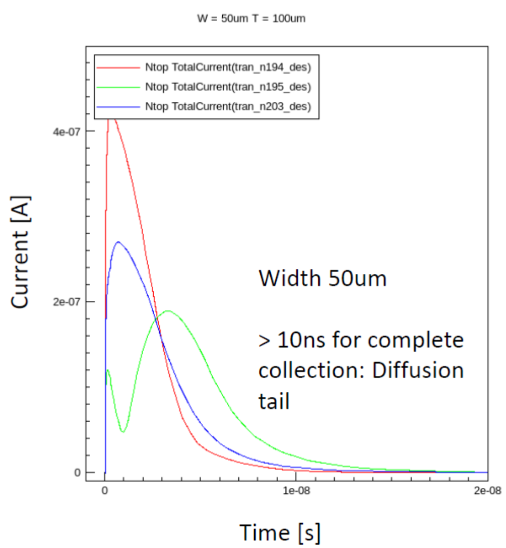
- Square – 20um x 20um
- Smaller capacitance:
  80um perimeter (20fF)
- Slower charge collection

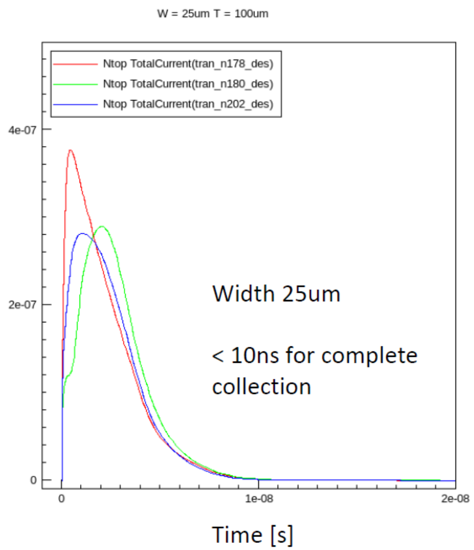


- 4 squares – 10x10um
- Perimeter: 4 x 40um
  (larger C = 40fF)
- Faster charge collection



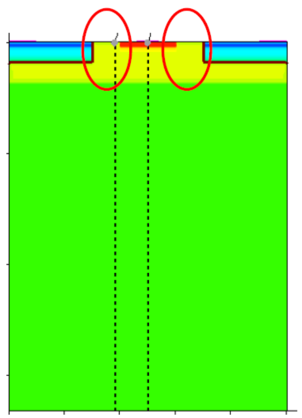
Charge collection times in 100 um detector (30V bias)





Collection node capacitance

Dominant contribution:
perimeter capacitance



T [um]	W[um]	Vbias	Cap ntop/ptop [fF/um]
300	100	200	0.45
300	50	200	0.42
100	25	30	0.48

weak dependence from
T and W at operation voltage

Approximate perimeter cap. (for rough estimation):

0.25fF/um

SEED – next steps

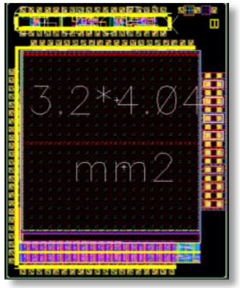
Deadline	Task
Aug 2015	Decision on what structure (different pixel cells) to be implemented in silicon (likely 2-4 flavors. General prototype layout definition.
Dec 2015	Design of the first sensor (prototype 1).
Feb 2015	Production of prototype 1.
Apr 2015	Testing of prototype 1.
Jul 2016	Design of the second sensor (prototype 2) based on what found in prototype 1
Oct 2016	Production of prototype 2.
…	Testing of prototype 2.

Done/in progress	2^{nd} year	3^{rd} year
• Extensive pixel cell simulations • Process tuning in collaboration with the foundry • Specification of the pixel cell layout for the first prototype	• First prototype production. • First prototype characterization, including radiation testing. • Design of the second prototype.	• Second prototype production • Second prototype characterization.

SEED – workgroups

National responsible: A. Rivetti (TO) & P. Giubilato (PD)

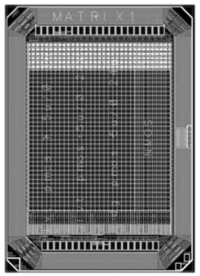
WP1
Torino,
Padova,
Perugia



Chip and IPs design, production cycle management, interface with the foundry. Long experience and expertise in pixel ICs design.

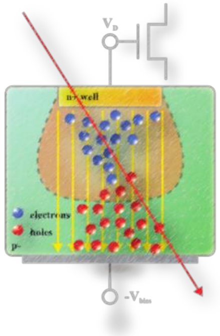
New entries

WP2
Padova,
Frascati



Commissioning, measurement and radiation hardness studies, plus help in design and simulation in collaboration with other working groups.

WP3
TIFPA



Device sensor simulation and process development in close collaboration with the foundry (a quite unique opportunity in the Ics world).

SEED – INFN Padova group

People	Role	Task	FTE
Piero Giubilato	Ricercatore	PI, radiation testing and measurements	**0.1**
Dario Bisello	Professore	Supervision	**0.1**
Jeffery Wyss	Professore	Test beam organization	**0.1**
Andrea Candelori	Associato	Test beam organization	**0.2**
Guang Meng	Tecnologo	IP Design	**0.3**
Simone Gerardin	Ricercatore	IP Design	**0.1**
Alessandro Paccagnella	Professore	IP Design	**0.1**
Devis Pantano	Tecnico	DAQ system development	**0.5**
Officina eletronica		Printed boards, glue electronics, misc.	4 MU
Officina meccanica		Irradiation supports, chip assemblies	1 MU

Total FTE = 1.0

TECHN-Osp

(2015-2017)

Sezioni partecipanti:

- LNL
- Ferrara
- Milano
- Padova
- Pavia
- (Bologna)

Coordinamento Nazionale: Juan Esposito- LNL

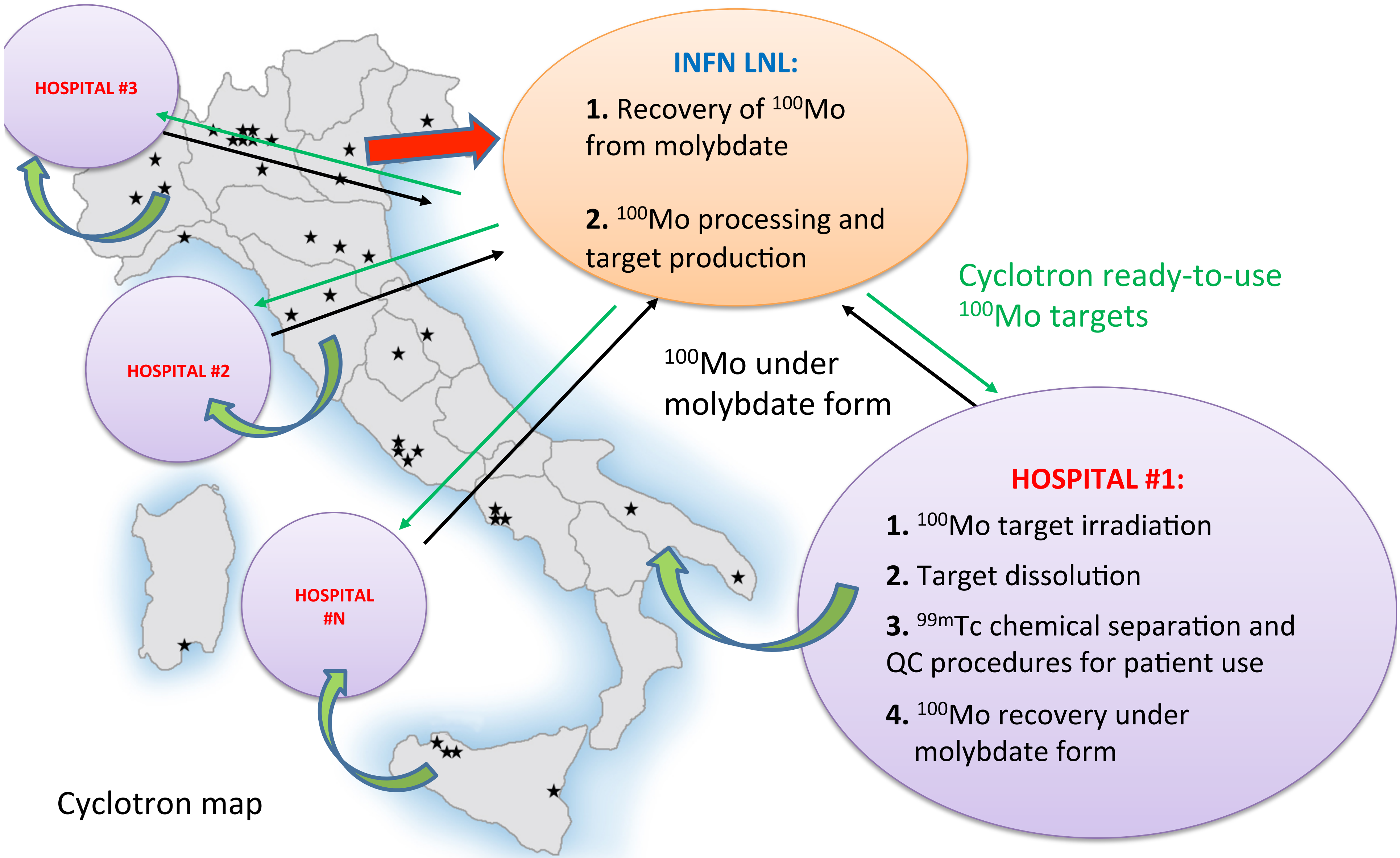
TECHN-Osp motivation

The principal medical isotope used in nuclear medicine is ^{99m}Tc, which is used in 80% of all nuclear medicine procedures. ^{99m}Tc is currently produced at only a few aging nuclear reactor facilities around the world, in the form of its parent isotope, ^{99}Mo. Since both isotopes have short half-lives (^{99}Mo – 2.7 days, ^{99m}Tc – 6 hours) and cannot be stock piled, this supply chain is fragile and prone to disruptions; when one reactor is removed from service, either unexpectedly or for planned maintenance, a world-wide medical isotope shortage results.
The solution may be the direct production of ^{99m}Tc through $^{100}Mo(p, 2n)$ reaction on a series of medium energy cyclotrons.

APOTEMA project as well as the IAEA project launched at international level (CRP code F22062: "Accelerator-based Alternatives to Non-HEU production of Mo-99/Tc-99 m") has demonstrated the feasibility (i.e. physical-chemical constraints) for an accelerator- ^{99m}Tc production (AP- ^{99m}Tc) quality as high as generator- ^{99m}Tc (GP- ^{99m}Tc).

TECHN-Osp aim is the development of ^{99m}Tc closed loop technology for a number of selected centers (Hospital cyclotrons), that could routinely supply the accelerator- ^{99m}Tc to other nearby Hospitals in case of ^{99}Mo shortage.

TECHN-Osp:the proposed network scheme



TECHN-Osp activities

^{100}Mo enrichment levels as high as 99% at least are required for a future, quality-level production of accelerator ^{99m}Tc on a routine basis.

Development of an industrial process for in-hospital Tc99m production

A
Development of a Mo100 recovery method in mass quantity

B
Optimisation of Mo100 target manufacturing for Tc99m production by Cyclotrons

C
Optimization of Tc99m chemical separation(s) methods from Mo100 targets

D
Quality Control (QC) procedures on both Tc99m and recovered Mo100 for targets manufacturing by developed techniques

TECHN-Osp PD

Attività svolta dalla sezione di Padova:

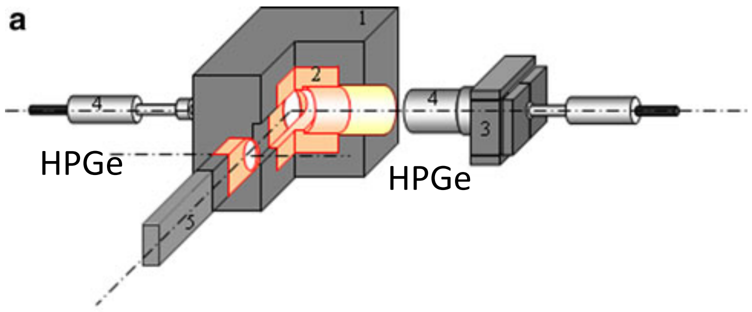
- controllo di qualità del ^{99m}Tc prodotto da diversi acceleratori mediante misure di spettrometria gamma;

- studio dell'influenza di altri isotopi del Tc sulla qualità delle immagini scintigrafiche;

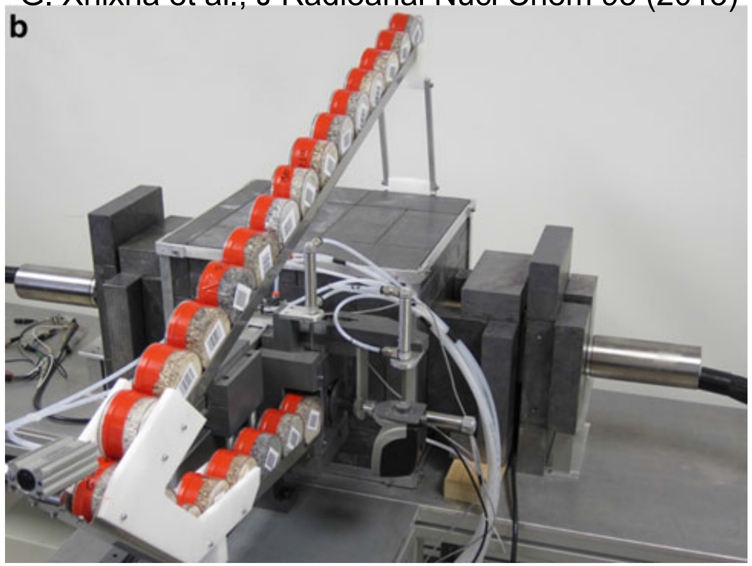
- dosimetria computazionale per il confronto delle dosi di radiazioni assorbite dai pazienti dopo utilizzo di traccianti contenenti ^{99m}Tc prodotto da acceleratore (AP- ^{99m}Tc) rispetto a quelle rilasciate da traccianti marcati con ^{99m}Tc prodotto da generatore (GP- ^{99m}Tc).

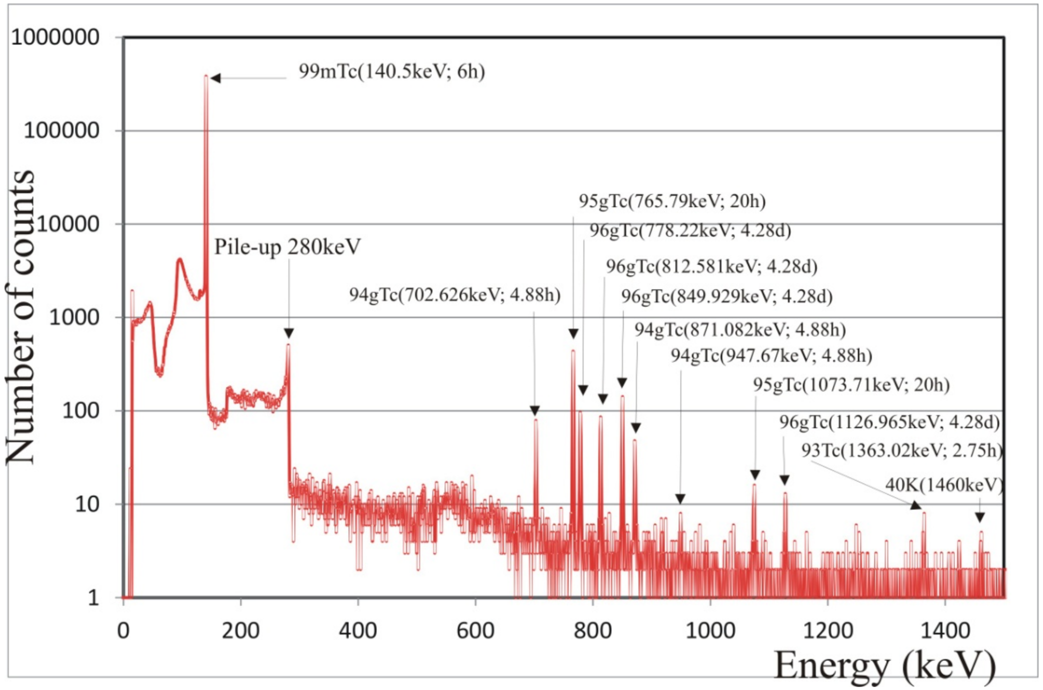
Gamma-spectrometry analysis of accelerator-produced (AP) ^{99m}Tc

The gamma-ray spectrometry measurements were carried out using a low-background setup of the Geophysics Laboratory of the LNL.



G. Xhixha et al., J Radioanal Nucl Chem 95 (2013)





Gamma-spectrometry analysis of accelerator-produced (AP) ^{99m}Tc

^{9x}Tc relative activities (EOB+9hrs, corresponding to the minimum value) on samples produced by proton bombardment (1hr time, 19 MeV, 25μA) on ^{100}Mo-enriched (99.05%) at JRC –ISPRA cyclotron

Nuclide	*Experiment I (June.2014)* A_{Tc9x} / A_{Tc99m} (%)	*Experiment II (Nov. 2014)* A_{Tc9x} / A_{Tc99m} (%)
^{96g}Tc	0.03 ± 0.01	0.029 ± 0.0045
^{95m}Tc	0.0013 ± 0.0003	0.0014 ± 0.0002
^{95g}Tc	0.20 ± 0.04	0.22 ± 0.03
^{94g}Tc	0.08 ± 0.02	0.12 ± 0.03
^{93g}Tc	0.07 ± 0.02	0.14 ± 0.04
Total	0.38% ± 0.09%	0.50% ± 0.11%

The common relative activity of Tc isotopes is less than 1% of the total activity.

E’ in corso l’analisi dei dati delle misure di spettroscopia compiute (26/06/2015) su un campione di Tc prodotto presso il ciclotrone di Bologna (PET TRACE da 16 MeV).

Influence of the higher-energy gamma-ray emitters on images' background

The energy window of diagnostic tools for standard ^{99m}Tc imaging procedure is usually set in a narrow interval around 140 keV, so that γ-rays from Tc impurities (200–1350 keV) that directly reach the scintillator do not affect the image quality. However, this energy window could be achieved by the gamma rays that have undergone large-angle Compton scattering, increasing the background signal and compromising the images quality during diagnostic procedures using AP-Tc.

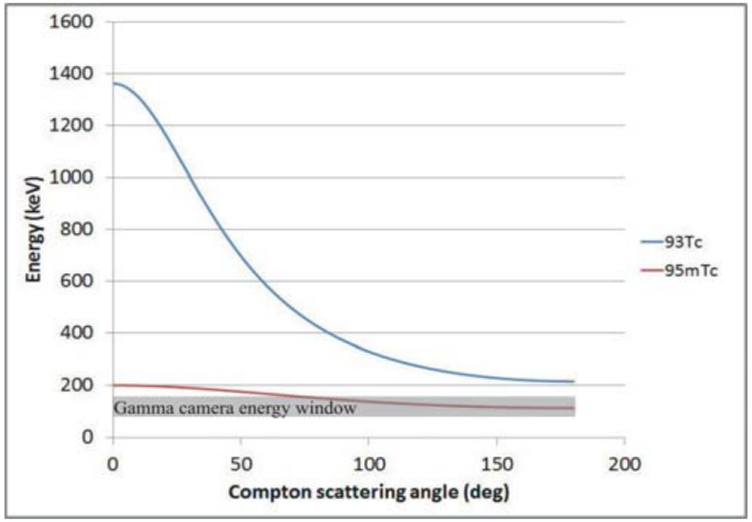


Fig. 1. Angular dependence of the energies of Compton-scattered gamma rays for the isotopes with the lowest and the highest energy emissions.

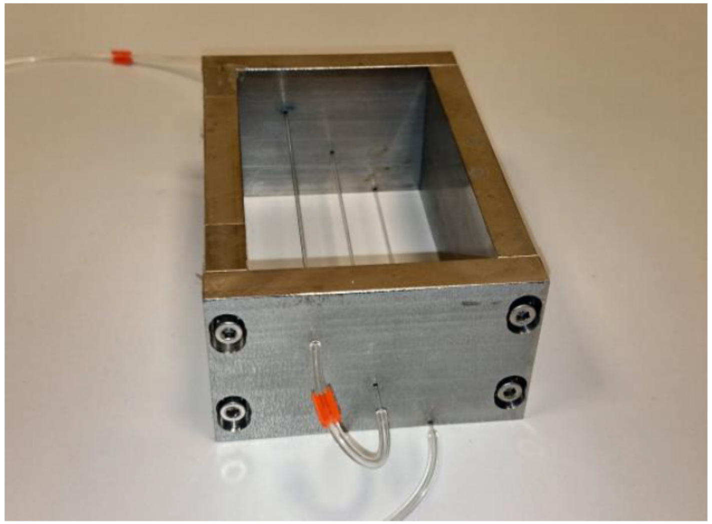


Figure 3. *A photograph of the setup for assessment the influence of the Compton scattering on the image quality.*

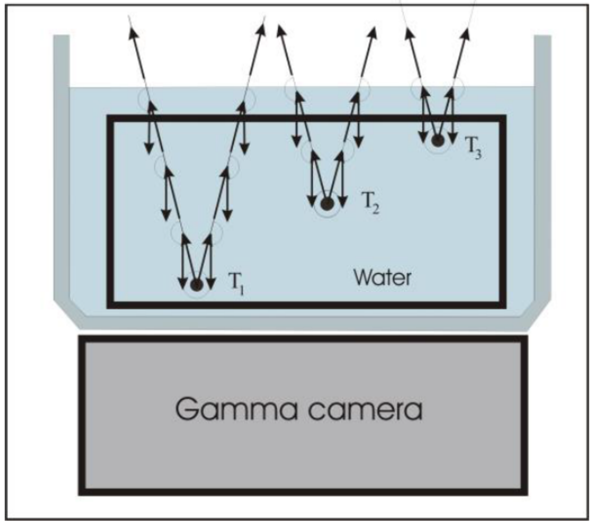


Figure 4. *A schematic presentation of the influence of the Compton scattering on the image of the capillary tubes.*

The gamma-ray background behavior was studied with a simple experimental setup of parallel capillary tubes filled with a circulating solution of the AP-^{99m}Tc immersed in water.

Influence of the higher-energy gamma-ray emitters on images' background

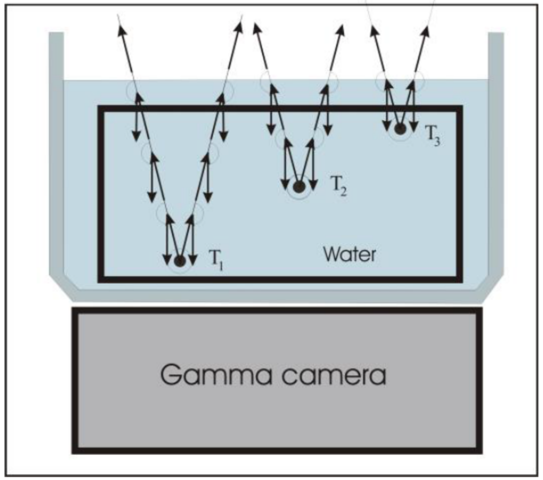
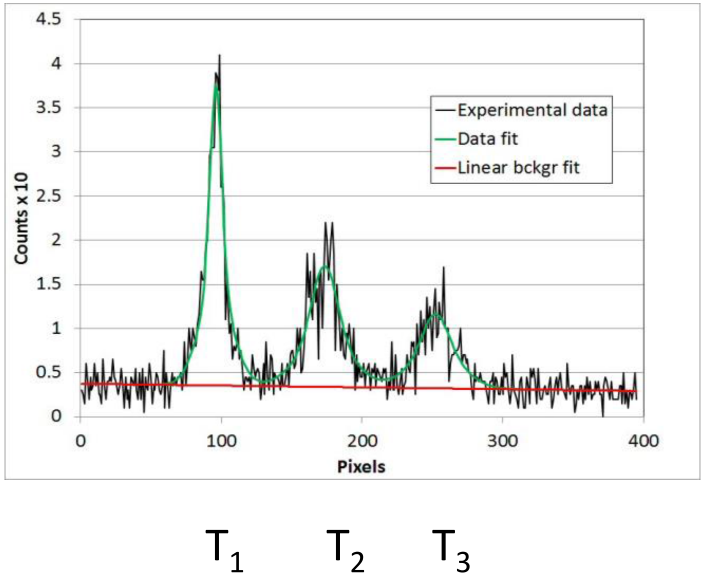
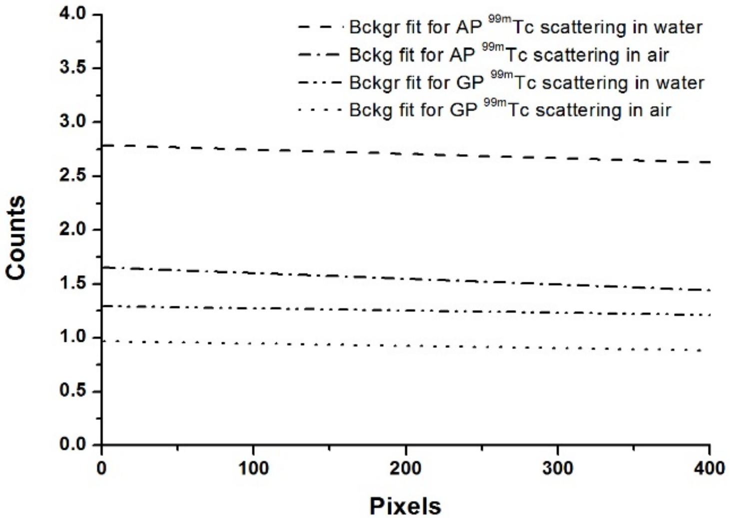


Figure 4. *A schematic presentation of the influence of the Compton scattering on the image of the capillary tubes.*



The amount of scattered gamma is higher around the zone of the closest to the detector capillary tube. As a result the image profile result in three peaks situated in a linearly decreasing background.



Images comparison reveals slightly higher background rate of the AP ^{99m}Tc images (a factor of 1.5 – 2) with respect to the GP ^{99m}Tc . The slope of the background for the images made with AP ^{99m}Tc is slightly higher pointing out Compton backscattering of higher-energies gamma rays, emitted by the other technetium isotopes.

Absorbed Dose Computational Studies

As the AP (accelerator produced) ^{99m}Tc contains some amounts of technetium impurities, it is important to calculate their impact on the patient radiation dose with respect to the GP (generator produced) ^{99m}Tc.

Four radiopharmaceuticals, commonly used in the nuclear medicine clinic, have been studied:

- Pertechnetate, used in clinical diagnostic of thyroid function and morphology;
- SESTAMIBI, widely used on cardiac scans for diagnosis of heart disease;
- Hexamethylpropyleneamine Oxime (i.e. HMPAO), used as tracers of brain function;
- Disodium Etidronate (i.e. HEDP), a phosphonate commonly used for defining bone metastasis.

The total absorbed dose in the main organs, after the administration of the four radiopharmaceutical was calculated for the AP-Tc at 3 different times after irradiation (9, 14, and 19 hrs post EOB) and compared to that due to GP-Tc (containing only ^{99m}Tc).

Absorbed Dose Computational Studies

Calculated Absorbed Dose in the main organs after administration of 4 radiopharmaceuticals prepared with AP ^{99m}Tc

	9h	14h	19h	Tc-99m
Tc Sestamibi (h) (Rest study)				
Brain	2.23E-03	2.28E-03	2.36E-03	2.12E-03
Heart wall	5.78E-03	5.85E-03	5.98E-03	5.54E-03
Kidney	3.53E-02	3.55E-02	3.59E-02	3.43E-02
Liver	8.48E-03	8.57E-03	8.74E-03	8.12E-03
Lung	3.04E-03	3.09E-03	3.19E-03	2.88E-03
Red marrow	3.91E-03	3.99E-03	4.13E-03	3.68E-03
Tc Pertechnetate				
Small intestine	1.66E-02	1.68E-02	1.71E-02	1.60E-02
Stomach wall	9.84E-03	9.92E-03	1.01E-02	9.47E-03
Kidney	4.88E-03	4.95E-03	5.07E-03	4.64E-03
Red marrow	3.80E-03	3.87E-03	4.02E-03	3.56E-03
Thyroid	2.25E-02	2.25E-02	2.27E-02	2.20E-02
Urinary bladder	1.85E-02	1.86E-02	1.90E-02	1.78E-02
Tc Phosphonate				
Kidney	8.60E-03	8.73E-03	8.98E-03	8.20E-03
Red marrow	4.79E-03	4.93E-03	5.19E-03	4.41E-03
Osteogenic cells	3.56E-02	3.60E-02	3.65E-02	3.49E-02
Urinary bladder	4.96E-02	4.98E-02	5.03E-02	4.82E-02
Tc HMPAO				
Brain	7.23E-03	7.42E-03	7.77E-03	6.77E-03
Small intestine	9.24E-03	9.37E-03	9.61E-03	8.83E-03
Stomach wall	4.03E-03	4.11E-03	4.26E-03	3.78E-03
Kidney	3.33E-02	3.37E-02	3.43E-02	3.22E-02
Liver	8.80E-03	8.91E-03	9.12E-03	8.40E-03
Red marrow	3.47E-03	3.56E-03	3.71E-03	3.23E-03

The small activities of other Tc isotopes contribute to a slight increase of the absorbed dose.
The highest difference between the absorbed dose obtained with a GP ^{99m}Tc and an AP ^{99m}Tc is obtained for Phosphonate in the bone marrow: 8.5% 11.8% and 17.7% for 9, 14, and 19 h post irradiations respectively.

TECHN-Osp (PD): Attività prevista 2016

• misure di spettrometria gamma su ^{99m}Tc prodotto da acceleratore (diverse energie/target);

• determinazione della frazione di impurezze, e dei conseguenti fattori di incremento della dose, attesi da vari tipi di AP-Tc, rispetto al ^{99m}Tc, mediante misure basate sull'utilizzo di un calibratore di dose (metodologia basata su una doppia misura dell'attività del campione effettuata con e senza schermatura di piombo);

Calibratore di dose

• imaging in vivo di farmaci standard marcati con ^{99m}Tc (MDP, MIBI, HMPAO, ecc) utilizzando un tomografo PET_SPECT per piccoli animali di ultima generazione (acquistato dall'Istituto Oncologico Veneto (IOV), sarà installato presso il laboratorio LARIM dei LNL probabilmente a fine 2015);

• dosimetria computazionale

TECHN-Osp (PD):
Richieste finanziarie e partecipanti *2016*

	Richieste finanziarie PD 2016	Spesa k€
CONSUMO	Sorgente di Test per calibratori di dose Co-57 (5,0 mCi/185,0 MBq) Materiale per schermature, componentistica elettronica e meccanica	2.0 1.0
INVENTARIO	Calibratore di dose con portacampione addizionale in Pb personalizzato per misure impurezze del Tc	7.0
MISS. INTERNE	Misure presso i LNL, riunioni di coordinamento	1.0
TOTALE 2016		**11**

INFN-Pd	FTE
Laura De Nardo	1
Paolo Sartori	0.3
Marta Paiusco (IOV)	0.2
Anna Negri (IOV)	0.3
Gisella Gennaro (IOV)	0.5
	2.3