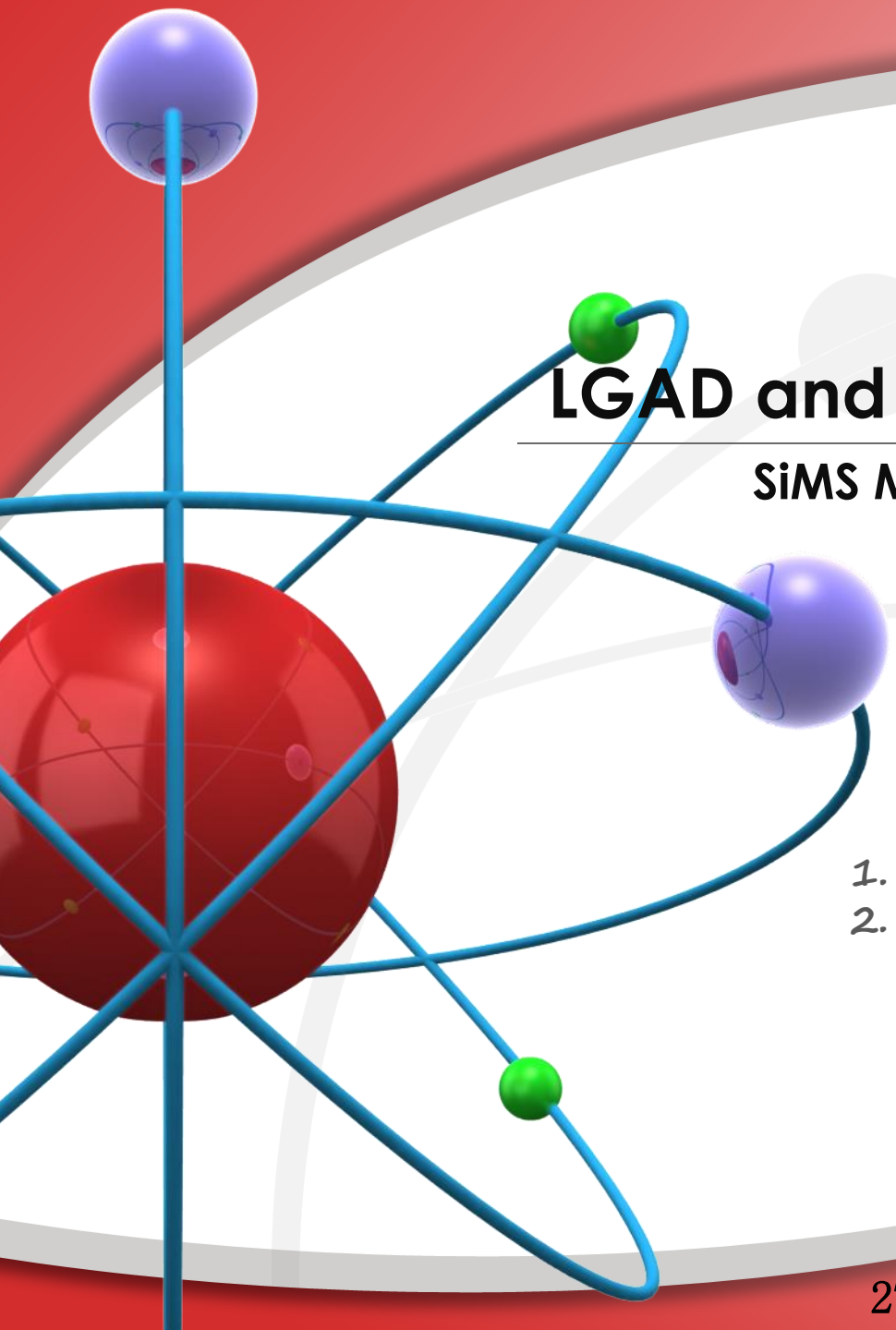

LGAD and Irradiated doping Profiles

SiMS Measurements & Simulations

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27th RD50 Workshop – CERN, December 2015

Overview

- Introduction
  - Reminders
    The SiMS-Simulation Calibration project & Irradiations
- SiMS Principles
  - Calibration and Uncertainties
    Depth and dose Quantification
- p-spray samples
  - Irradiated Profiles
    Radiation effect on total dopant
- LGAD SiMS
  - CNM Boron Run
    Measurements and Simulations
- LGAD Gallium
  - Gallium Simulation and SiMS
    Expected profiles and comparison
- Future plans
  - Irradiation and Gallium projects
    Test productions and JIS Irradiation Campaign
- Conlusions
  - Radiation effect, LGAD SiMS- Simulation

•Reminders

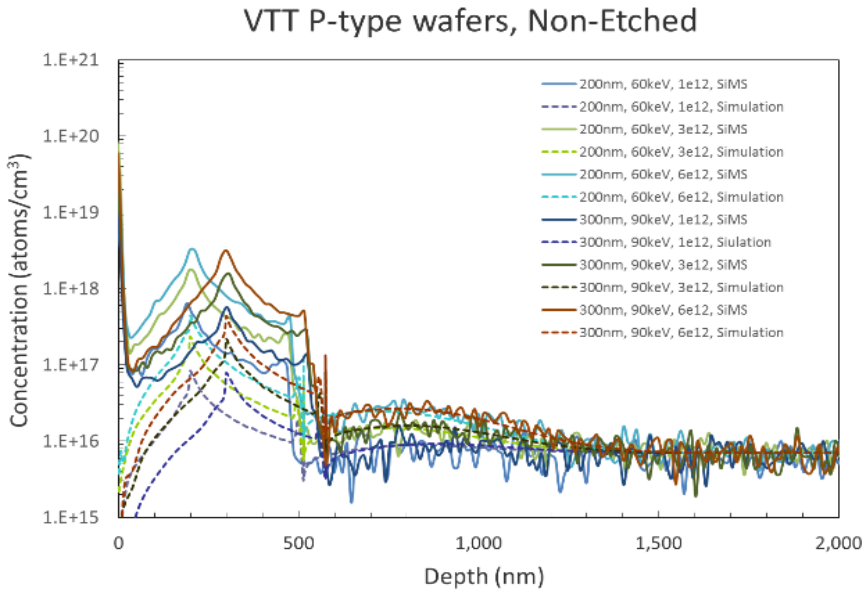
SiMS – Simulation Calibration Project & Irradiations

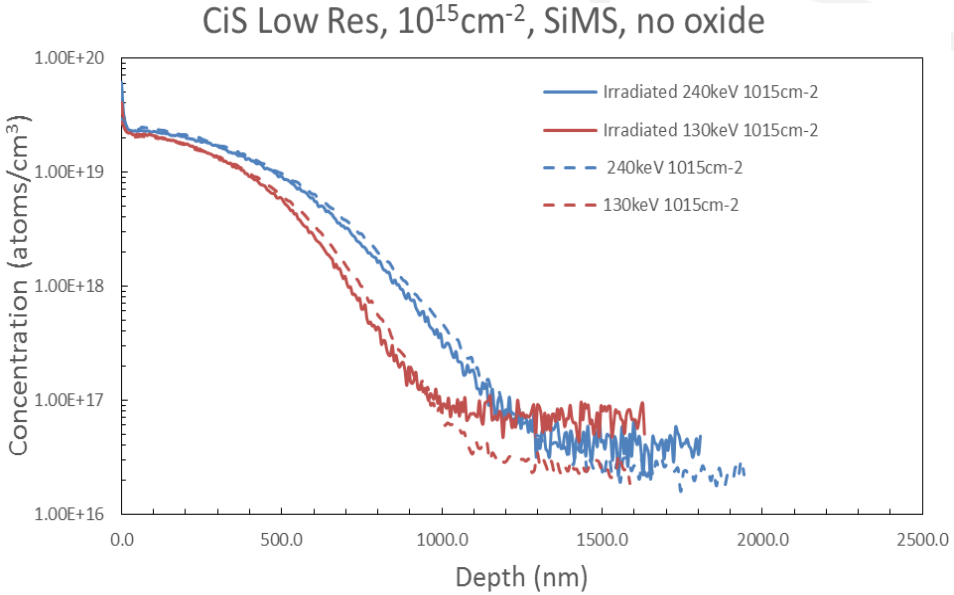
P-Spray Samples

- A simple production with known process parameters
- No masks or lithographic steps
- Samples for n and p implant at the most common doses
- Investigate simulation-SiMS agreement
- Very good agreement, exceptional for p-samples

Irradiated n- implant

1. **Investigate doping profile effect after irradiation**
2. **10^{16} @ 25GeV protons at KIT**
3. **No visible effect in n-implanted samples**
4. **P-implant (boron?)**

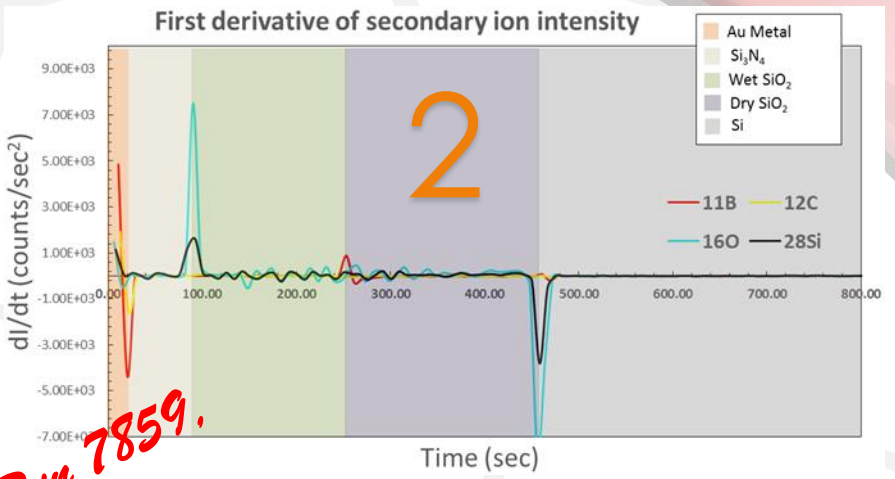


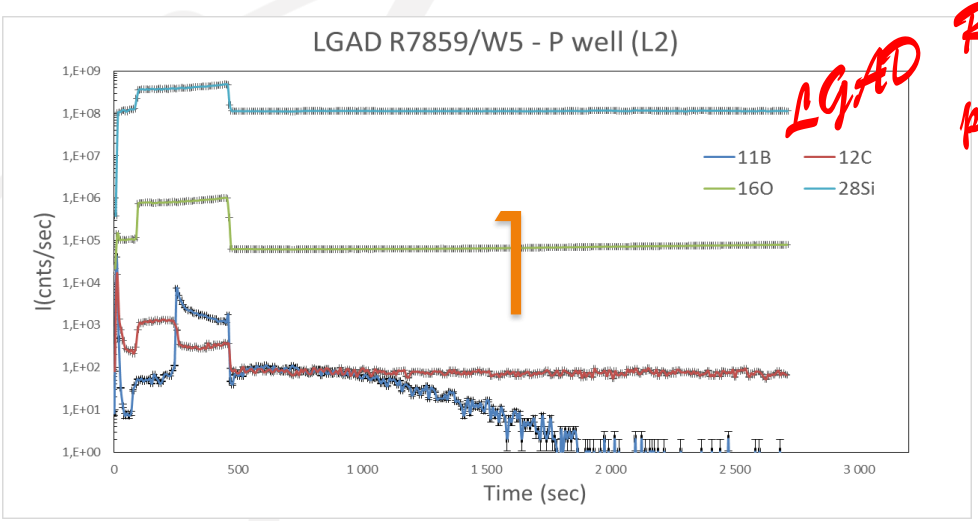


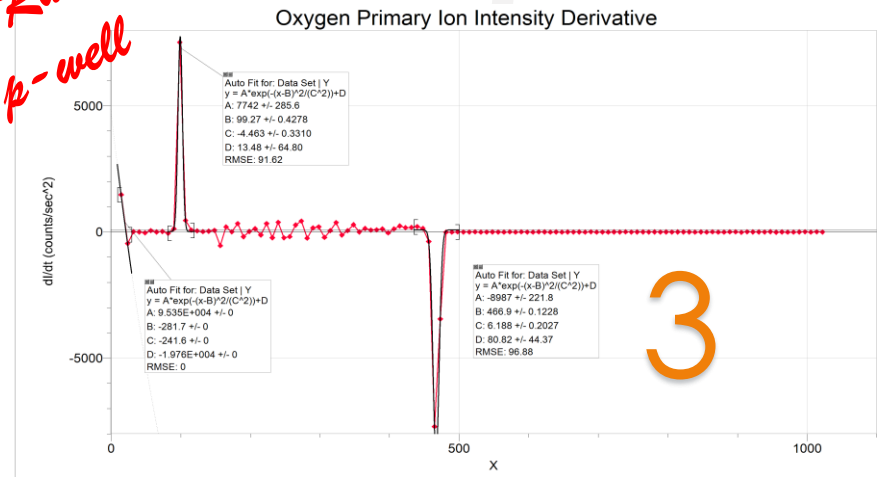
•SiMS Analysis Principles

Depth & quantification and uncertainties

- Typically several elements related to the technology are monitored
- Scattered Ion intensity is recorded vs Time
- In an interface region (change of "matrix") extraction work abruptly changes
- This potential difference leads to a @Dirac-like" effect
- Approximated by a Narrow width Gaussian because of atomic layer mixing
- Layer transition point and uncertainties calculated by Gaussian fit on first derivative

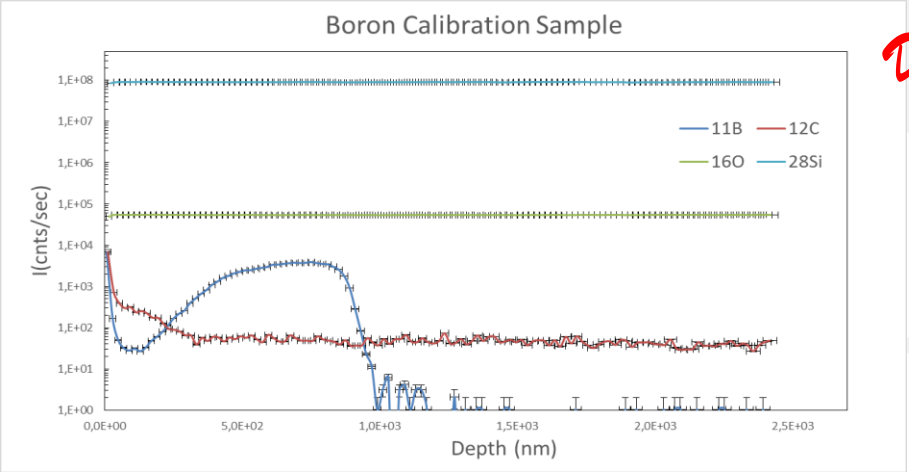


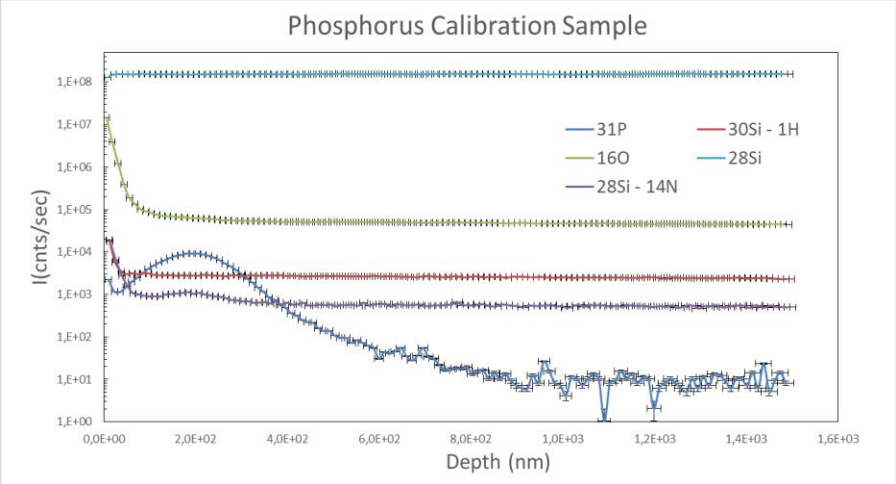




•SiMS Analysis Principles

Implanted dose Quantification



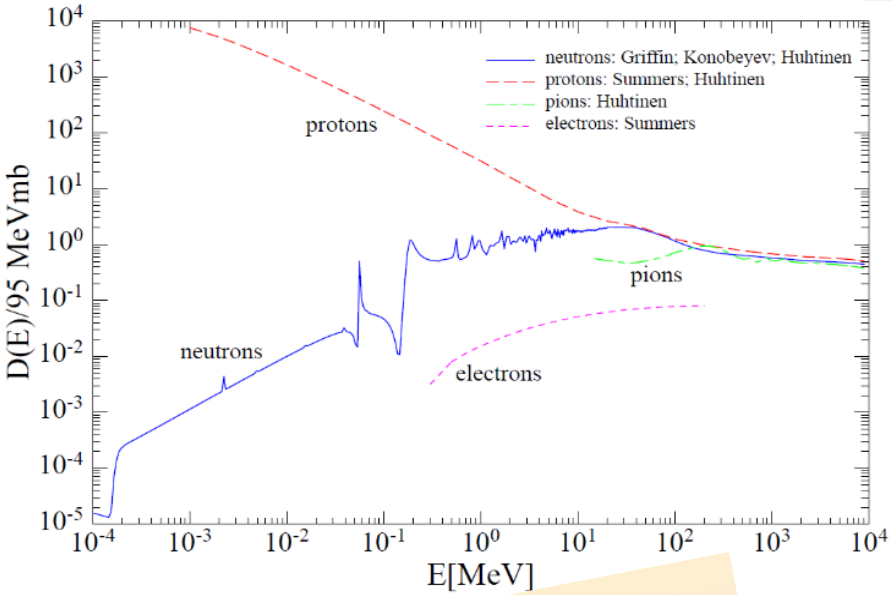


Dose Calibration

1. Each measurement is different and needs to be separately calibrated
2. Dedicated samples with known profiles are included
3. Calibration Sample needs to have the element of interest implanted on the same material as the probed sample
4. In case of several dopants, on sample is include for each dopant
5. Signal integrals are used and a global factor is estimated for each analytre
6. Calibration samples are of a single matrix (our case only Si)

•P-Spray Samples

Radiation effect and equivalent damage



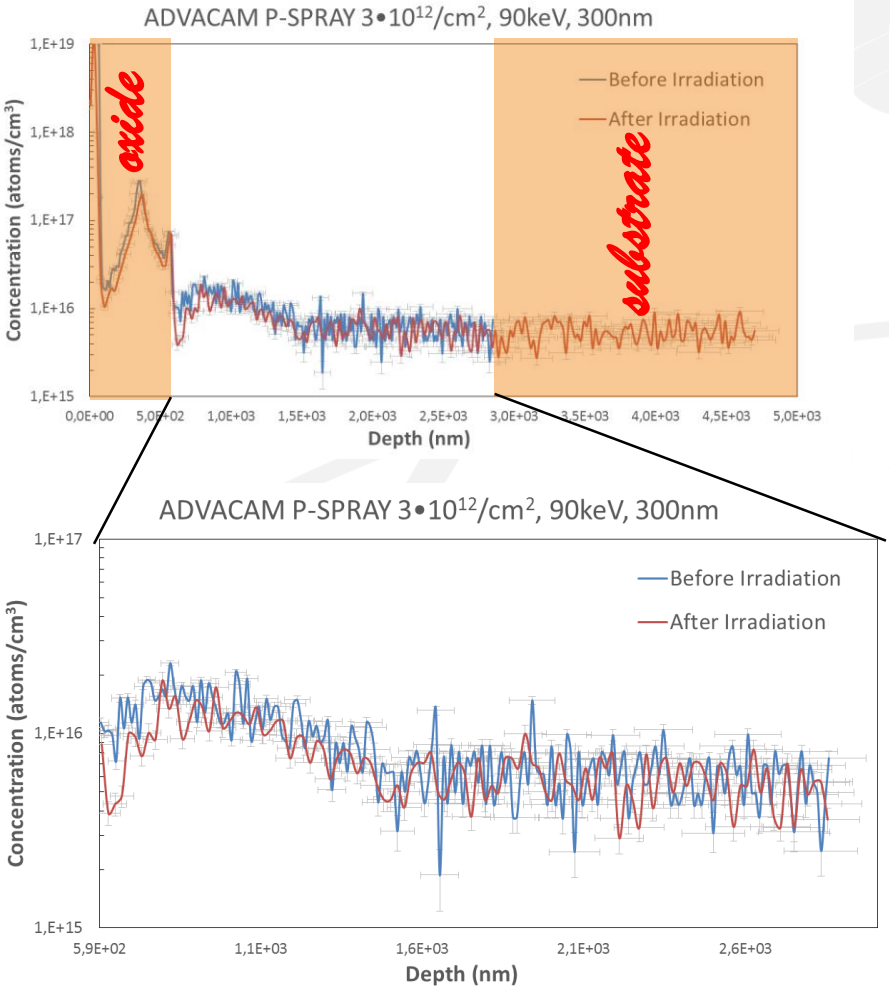
- Two p-spray samples where selected
- Equivalent non-ionizing energy loss for 25GeV protons with respect to neutrons is 1/ 2.5
- Total delivered dose is $5*10^{15}$ protons/cm^2
- At 25MeV, stopping power is 10.85keV/µm, assume constant energy for the 5 first µm of the sample
- Samples were annealed, this should have no effect on total dopant but on active

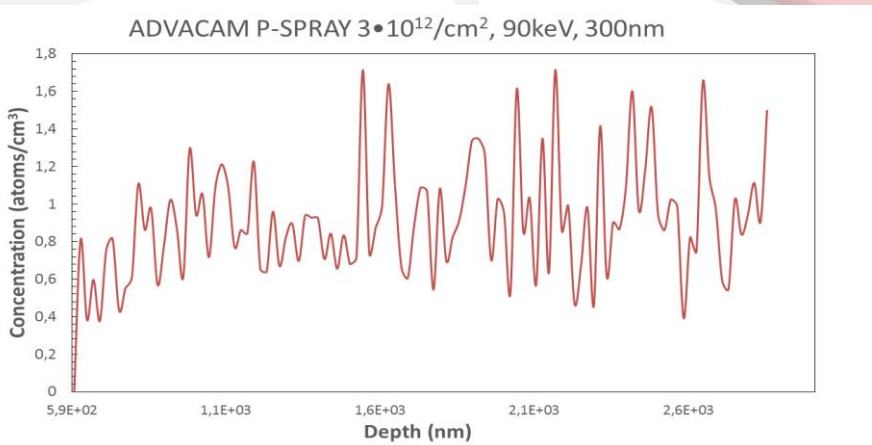
Does the profile Change???

P-Spray Irradiated Samples				
Dose	Energy	Screen Oxide	Fluence	Implnat
$6 \cdot 10^{12}$cm^{-2}	90keV	300nm	10^{16}n$_{eq}$/cm^2	$^{11}_{5}$B
$3 \cdot 10^{12}$cm^{-2}				

•P-Spray Samples

3•10^{12}cm^{-2} @ 90KeV implanted sample





- A slight reduction in the total integrated dopant is observed
- Within statistical uncertainties

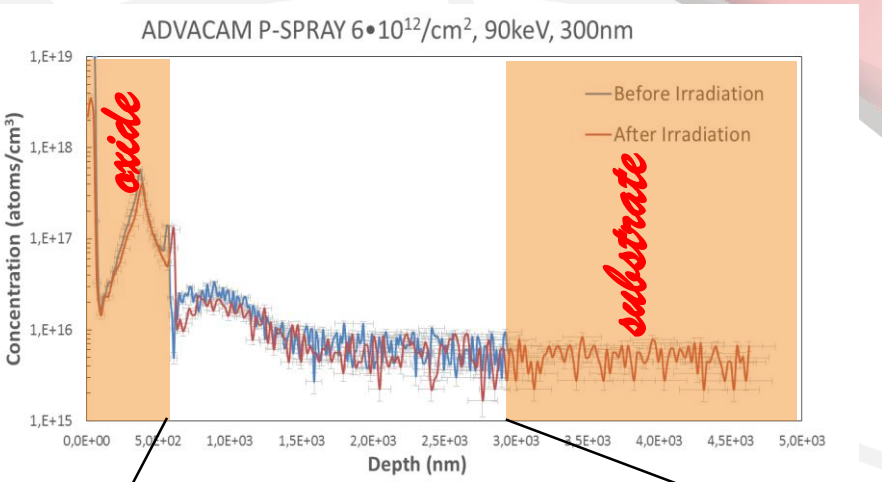
Implanted Dose in Silicon		
	d [atoms/cm^2]	δd [atoms/cm^2]
Brefore Irradiation	1,95E+12	9,74E+11
After Irradiation	1,66E+12	6,46E+11
Reduction	15%	54%

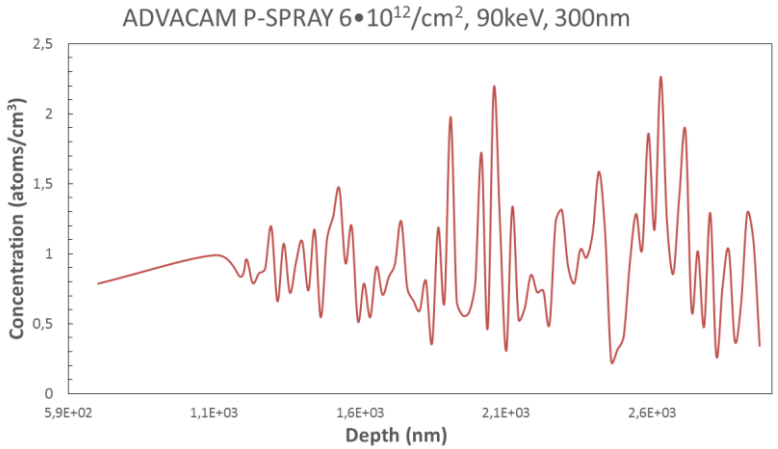
•P-Spray Samples

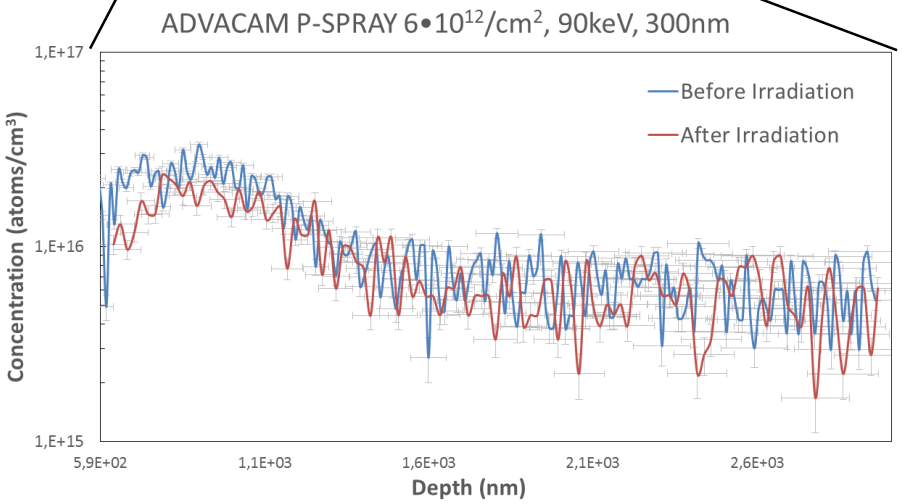
6•10^{12}cm^{-2} @ 90KeV implanted sample

Implanted Dose in Silicon		
	d [atoms/cm^2]	δd [atoms/cm^2]
Brefore Irradiation	2,58E+12	1,11E+12
After Irradiation	2,05E+12	8,51E+11
Reduction	21%	47%

- A more pronounced dopant reduction is observed for the higher concentration
- Uncertainties estimation could still account for the effect







•P-Spray Samples

Possible Effects

A possible Nuclear Reaction??

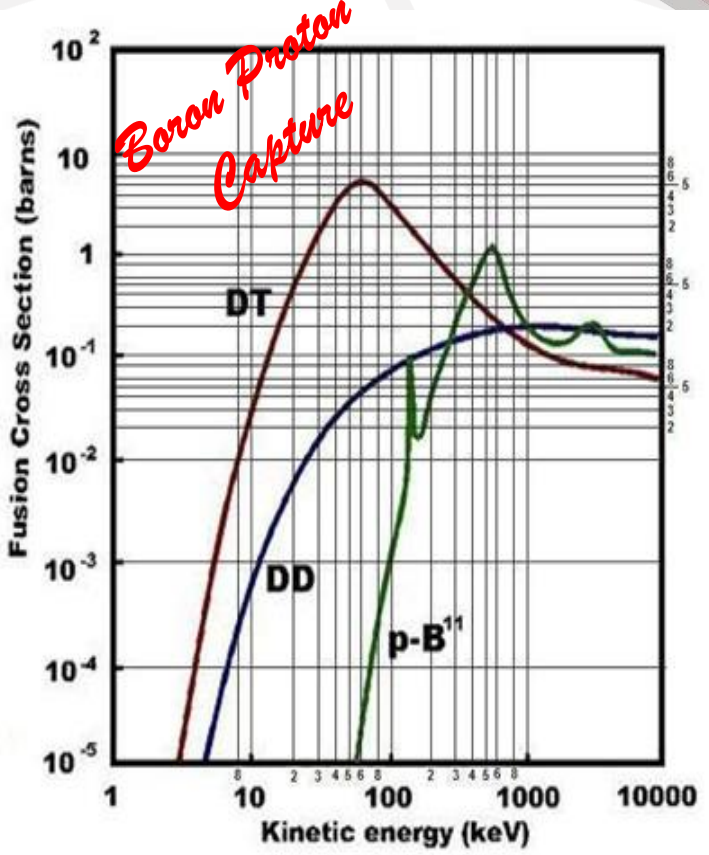
$^{11}B + p \rightarrow {}^{12}C^{*} \rightarrow \alpha_0 + {}^{8}Be \rightarrow \alpha_0 + \alpha_{01} + \alpha_{02}$

$^{11}B + p \rightarrow {}^{12}C^{*} \rightarrow \alpha_1 + {}^{8}Be^{*} \rightarrow \alpha_1 + \alpha_{11} + \alpha_{12}$

$^{11}B + p \rightarrow {}^{12}C^{*} \rightarrow \alpha_2 + \alpha_3 + \alpha_4$

$^{11}B + p \rightarrow {}^{12}C^{*} \rightarrow {}^{12}C + \gamma$

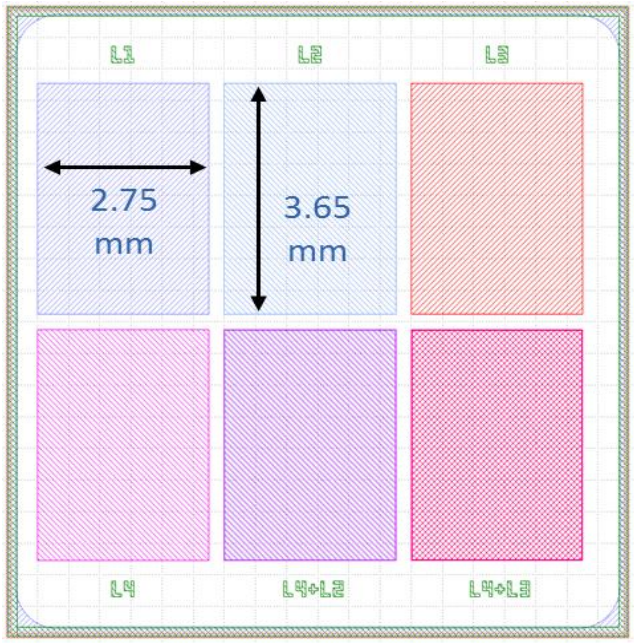
Reaction	Cross-section	
	σ (mb)	δσ (mb)
$^{11}B \rightarrow {}^{7}Be$	20	3
$^{10}B \rightarrow {}^{11}C$	45	5
$^{10}B \rightarrow {}^{7}Be$	22	5
$^{10}B \rightarrow {}^{10}C$	0.1	
$^{11}B \rightarrow {}^{11}C$	38	estimated



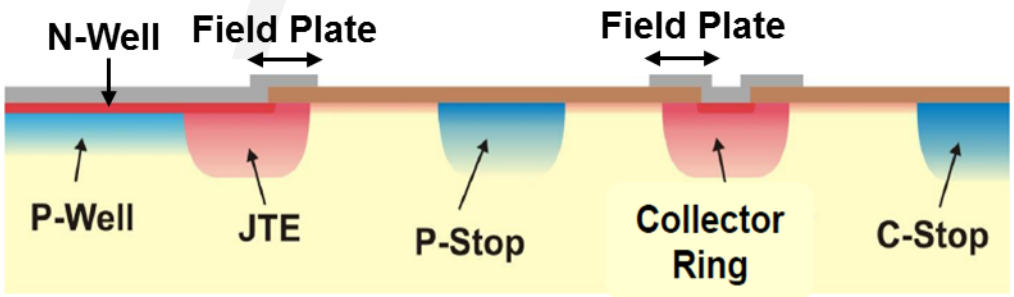
- **Accounting for the total cross-section and the real proton fluence, the effect should be of 1% !!!!**

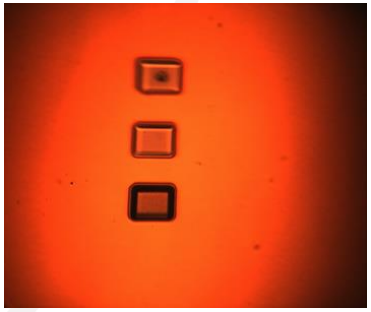
•LGAD Doping profiles

The structure



1. Jointly designed mask with CNM to accommodate for SiMS limitations
2. 6 individual regions:
   - L1 P-Stop, C-Stop Well
   - L2 P-Well (P Multiplication)
   - L3 JTE
   - L4 N-Well
   - L4 + L2 N-Well over P-Well
   - L4 + L3 N-Well over JTE
3. September Run that was delivered in February

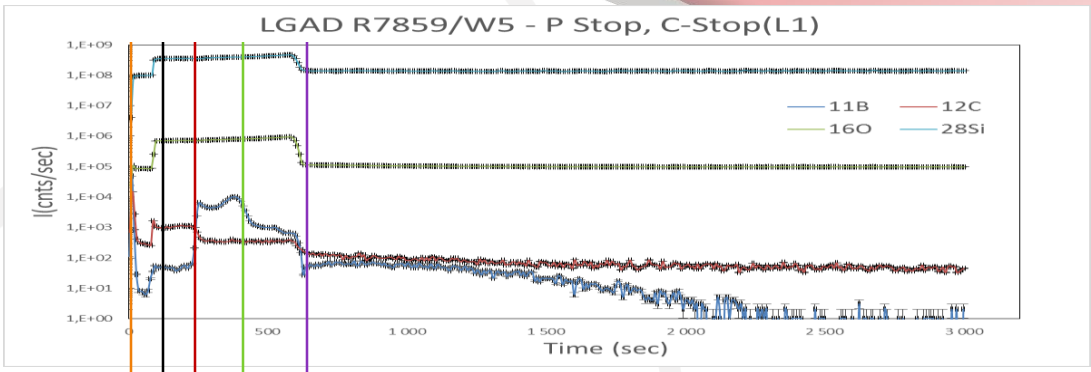


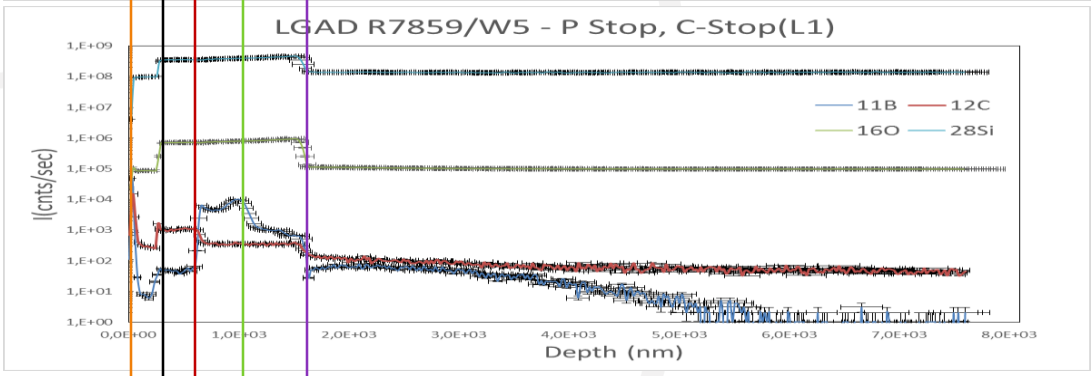


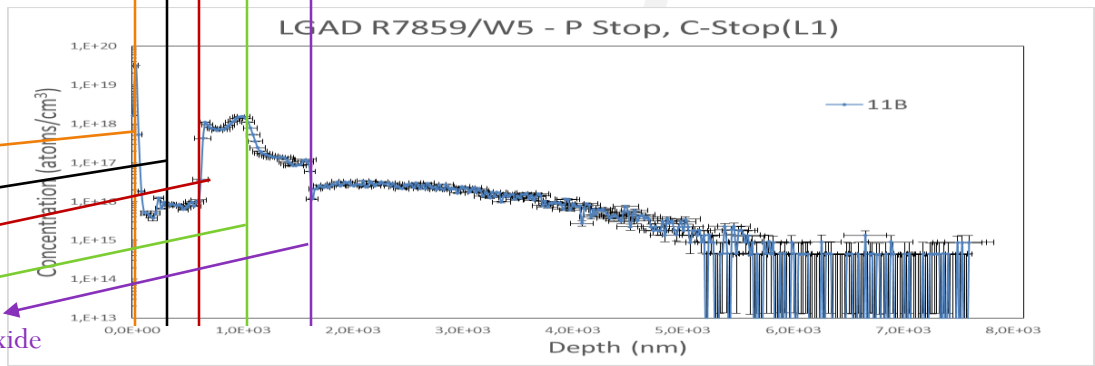
•LGAD SiMS Measurements

Boron Run 7859 – P Stop

- P-Stop Boron Implant at the initial steps of the process
- The implant extends 3.5µm in the silicon substrate
- An initial oxide layer was used as screen while at least two subsequent thermal oxidations are apparent
- Nitride and metal layers are on top of the sample.
- Total thickness of surface layers is around 1.5µm
- A carbon diffusion is observed at the initial screen oxide, possibly from the preceding mask







SiMS Metal Layer

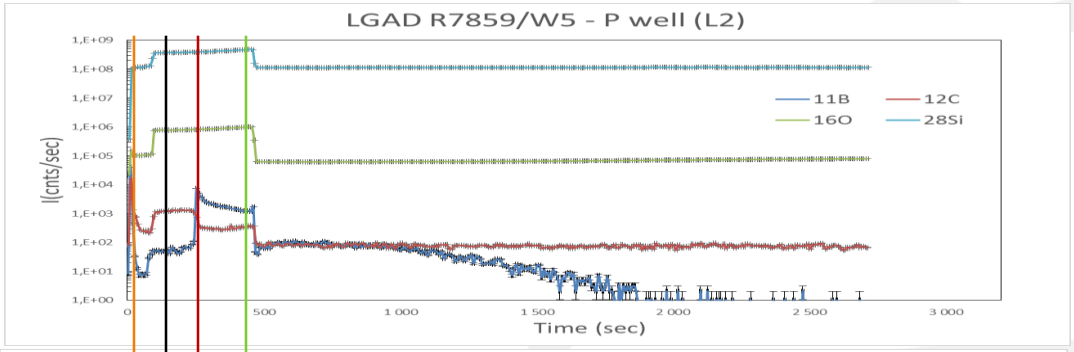
Nitride Passivation

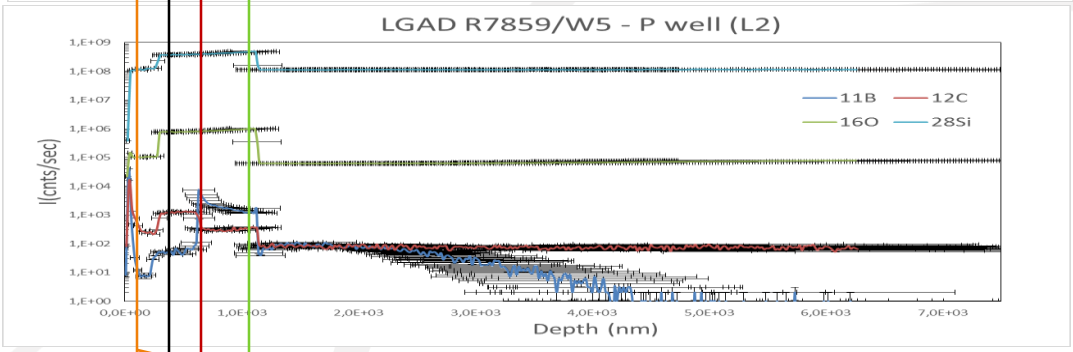
Screen Oxide

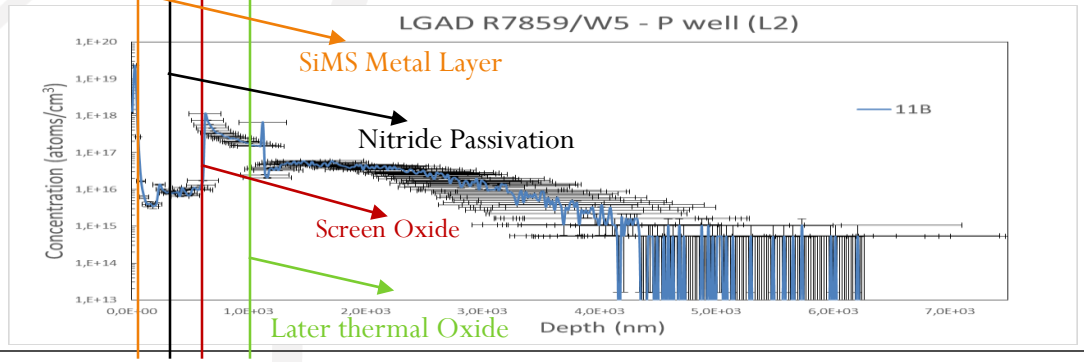
Later thermal Oxide

•LGAD SiMS Measurements

Boron Run 7859 – P Well



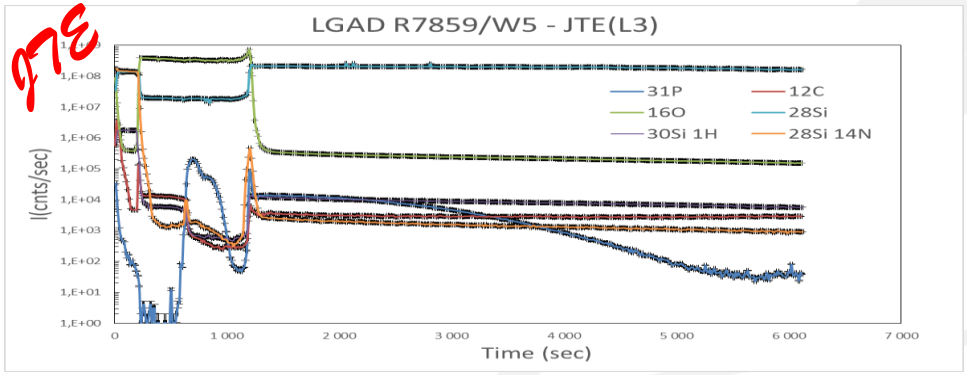


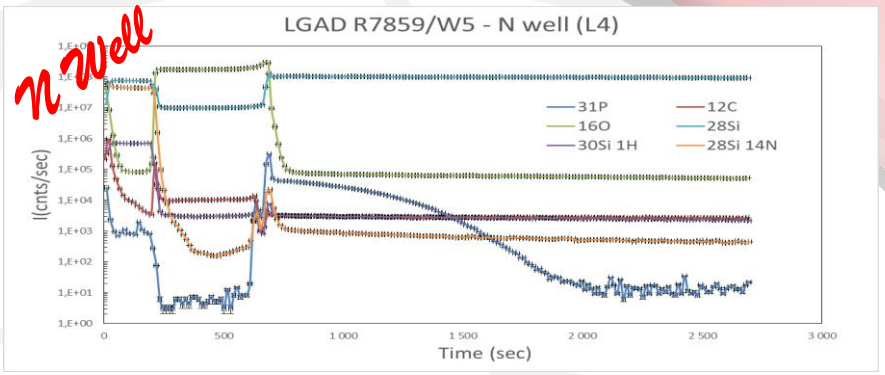


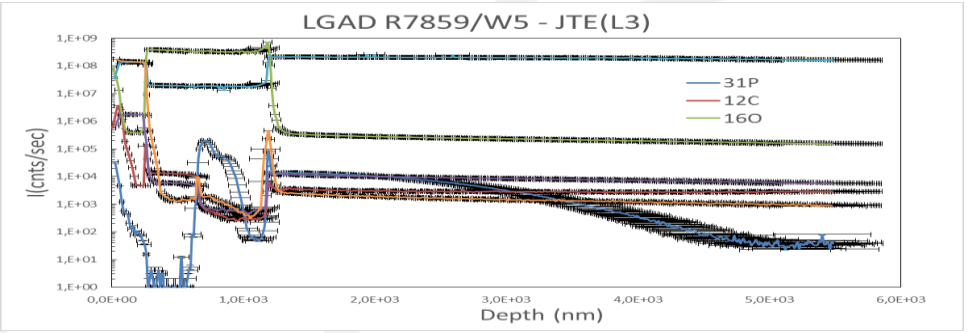
- Implant extends 2.7μm inside the silicon substrate
- It is performed in a later stage, after the p-stop implantation
- Same peak concentration as the p-stop implantation
- Depth Uncertainties are extremely higher due to analogical deduction of abrasion speeds, depth measurement is missing
- The same carbon diffusion on the screen oxide is observed, perhaps environmental pollution
- At least one thermal activation step

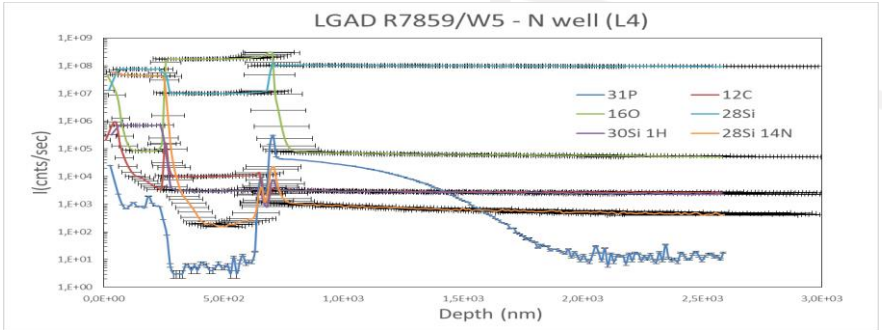
•LGAD SiMS Measurements

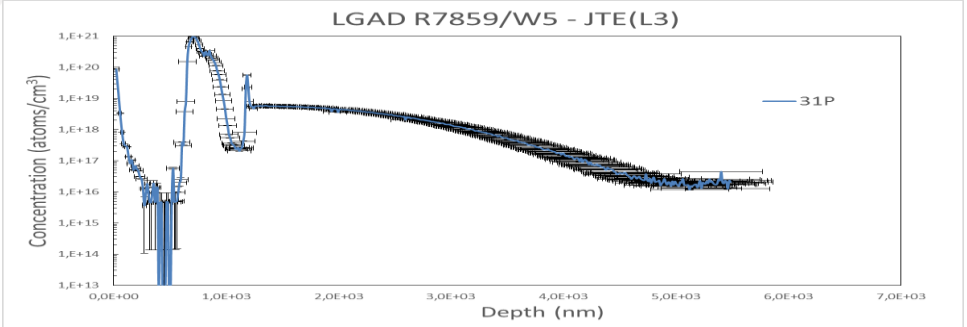
Boron Run 7859 – JTE, deep N-implant

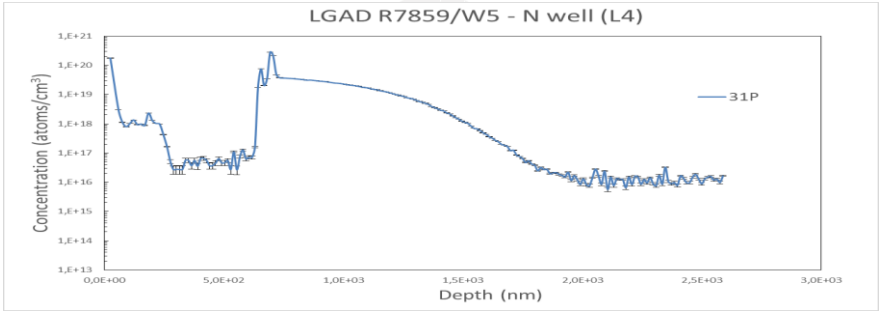






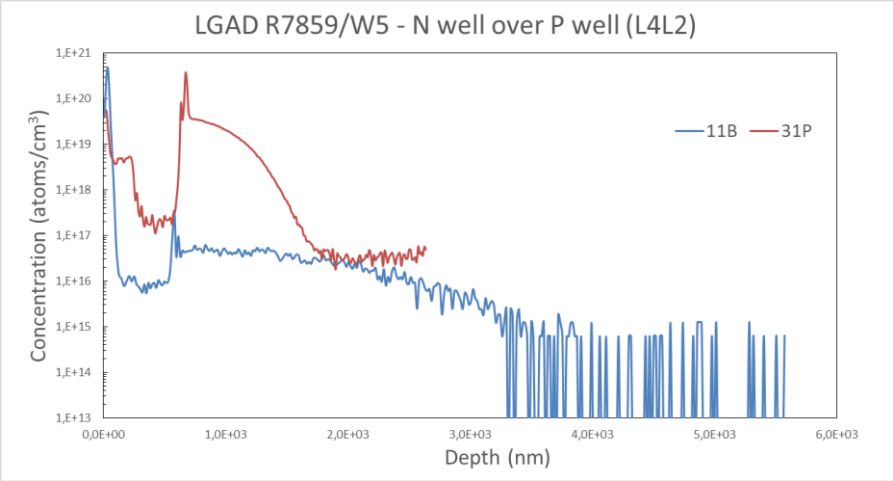


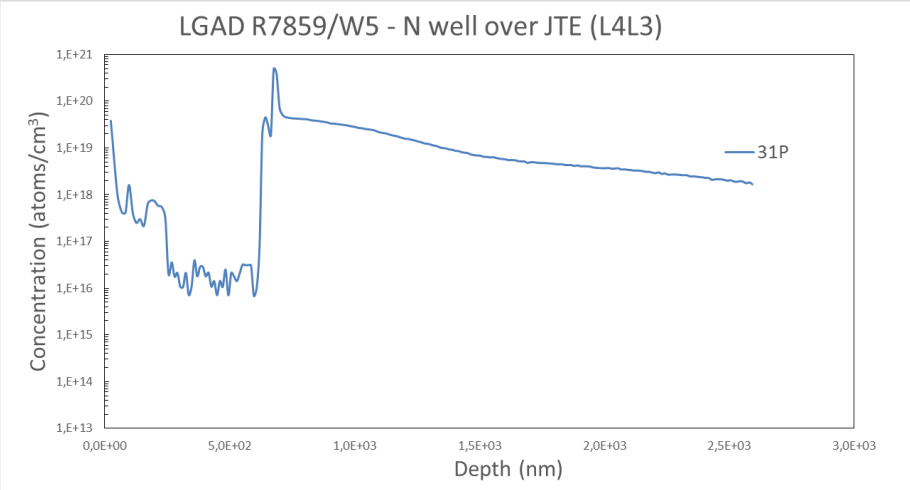




•LGAD SiMS Measurements

Boron Run 7859 – N Well over P Well and N+JTE

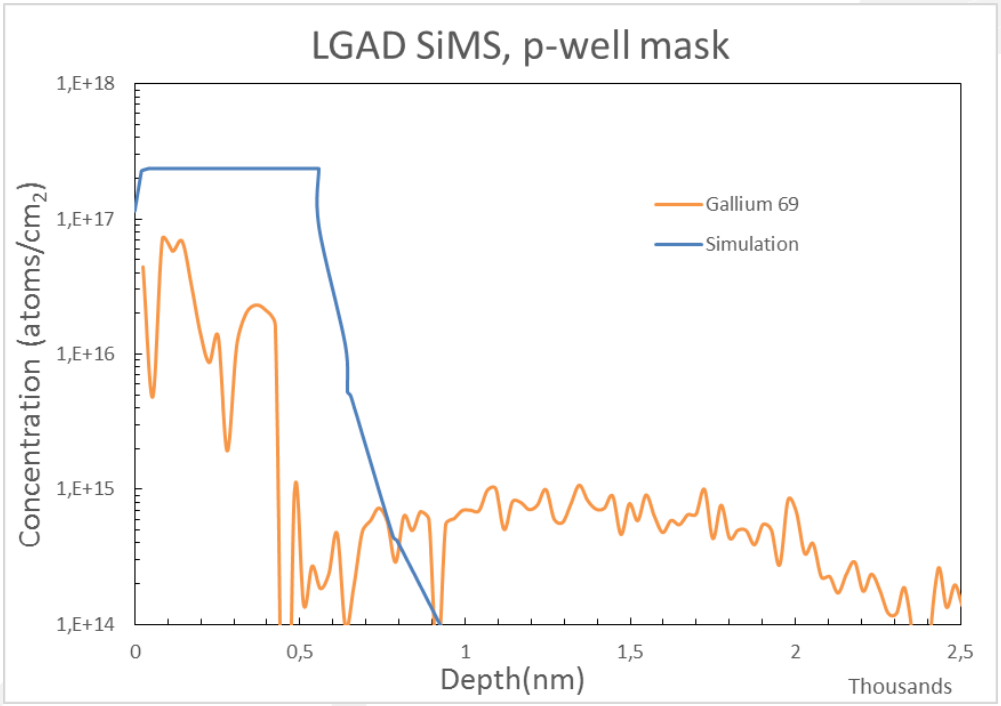


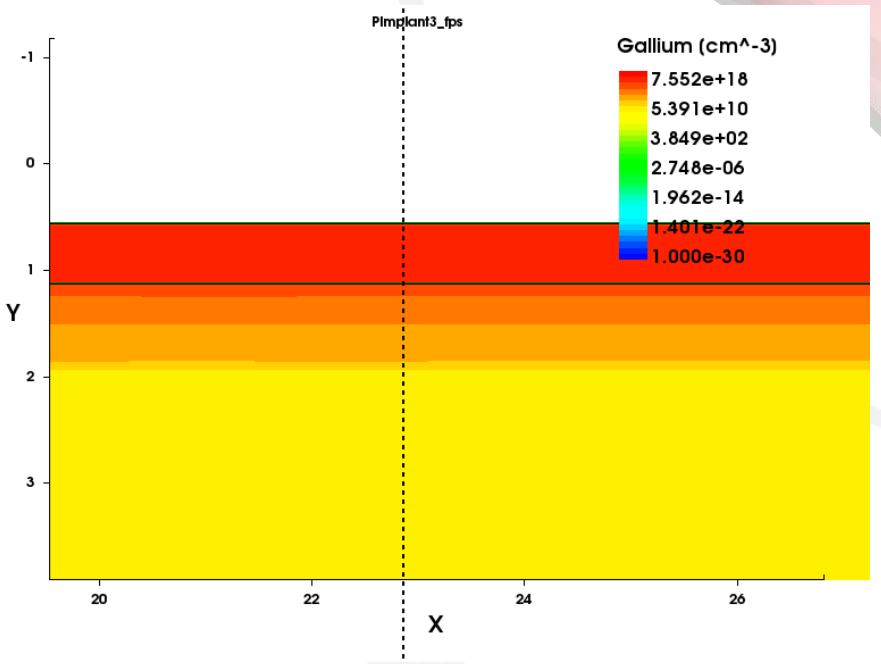


- **Superimposed implantations**
- **In the n+p case, the n-implant concentration of the multiplication region is three orders of magnitude higher than that of the p-implant**
- **Shallow n-implant extends 1µm inside substrate, p is diffused to 2.5 µm**
- **In combined p-implant case, doping profile is somehow constant in the first 3µm**
- **More care has to be taken for a smooth doping transition at the initial stages of the curve**

•LGAD Gallium Simulation

Gallium Run – P Well





- **Gallium implantation 1.4e13/cm^2 at 60keV**
- **No gallium in the substrate**
- **Simulation and SiMS agreement**

•LGAD SiMS Measurements

Boron Run 7859

- **Preliminary results indicate a reduction of the total dopant in the order of 15%-20%**
- **The effect is more pronounced in higher concentrations**
- **More doses and fluences are to be studies**
- **Statistical Uncertainties may partially account for the result**
- **More accurate simulations on gallium confirms observed SiMS effect**

PLans

- **P-spray samples also under irradiation in Lubiana with neutrons**
- **SiMS measurements to be repeated, especially on non-irradicated samples**
- **Same study to be repeated on LGAD p-implanted test structures**

We are not over yet…