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JENNIFER2 WP4 NEW PHOTODETECTORS DEVELOPMENT

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WP4 OBJECTIVES

- Develop and test few types of **new photodetectors** aiming to different applications in particle physics, while building an high level of knowledge exchange among the developers.
- Explore a very **innovative** and interdisciplinary **technique** to detect photons, based on **organic** substrates, through a strong partnership with Japanese institutions.
- Provide high quality **training** opportunities in the field of photon detection both for ERs and for ESRs, including contacts with technology industries operating in this field.

WORK PACKAGE TASKS & DELIVERABLES

Task	Name	Partners	Responsible contact	Deliverables
4.1	R&D of Silicon-PMs as single photon counters in neutron irradiated areas	JSI,FBK, KEK	**Rok Pestotnik**	Report on the design and performance of the prototype module (M35)
4.2	Development of long-lived MCP photomultipliers	INFN, KEK	**Ezio Torassa**	Report on the lifetime properties of the MCP PMTs (M24)
4.3	Development of multi PMTs for a large water Cherenkov detector	INFN,NCBJ, CAEN,U-Tokyo	**G. De Rosa, Vincenzo Berardi**	Milestone: Report on the Acrylic properties for the external vessel of the mPMT module (M12) + Realisation of the mPMT module prototype (M24).
4.4	Study of innovative organic photosensors	INFN, KEK	**Alberto Aloisio, P. Branchini**	Milestone: Report on electrical characterization of photo-transistors (M24) Deliverable: Final R&D report on organic light detection (M48)

Common deliverable: Support organization and participation to photon detectors training sessions for PhD students at NDIP 2020 conference (month 18)

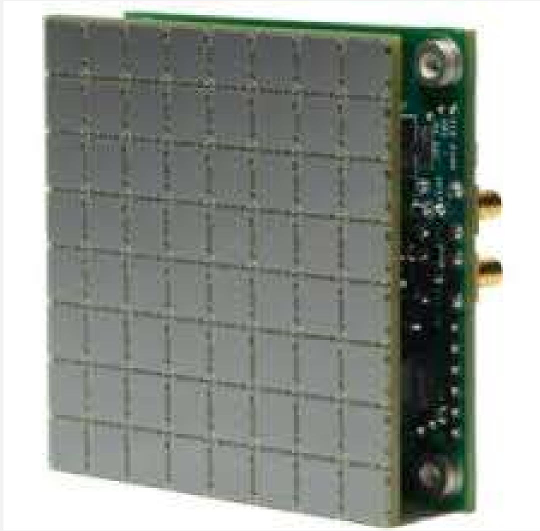
TASK 4.1 R&D OF SIPMS AS SINGLE PHOTON COUNTERS IN NEUTRON IRRADIATED AREAS

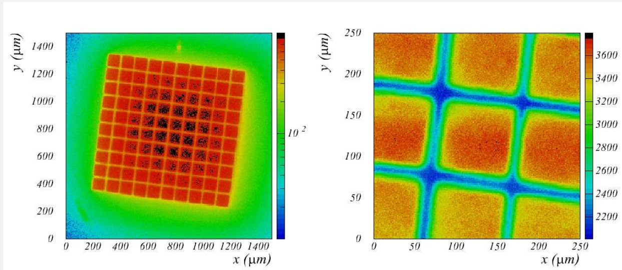
JSI,FBK,KEK

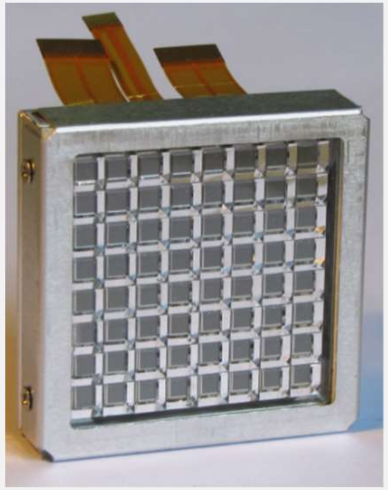
SiPMs as a photon detector for Belle II ARICH upgrade:

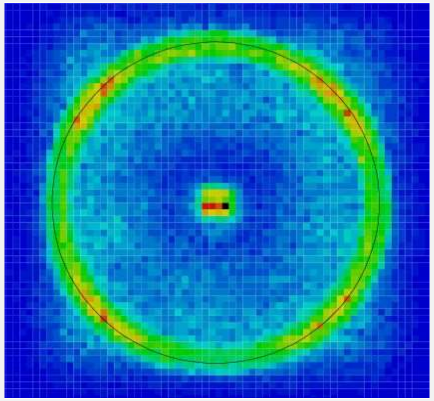
Tested as a candidate for current photon det. of Belle II RICH :

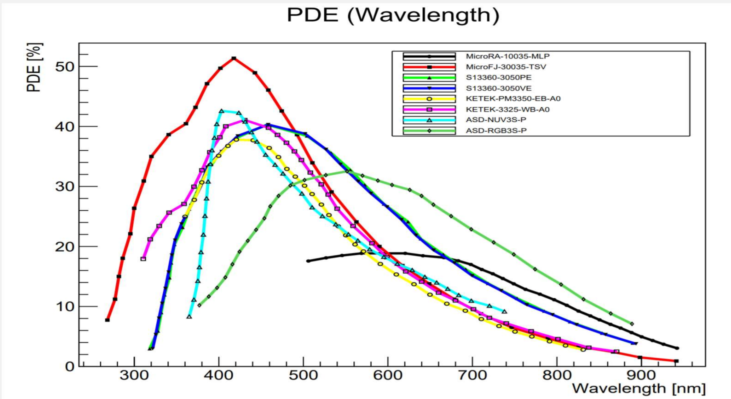
- ❑ Array of APDs working in a limited Geiger mode
- ❑ Easy to operate Vbias ~20-70V
- ❑ High Gain ~10^6
- ❑ Works in a magnetic field
- ❑ High PDE 40-50%
- ❑ Disadvantages:
    - ❑ high background. rate
    - ❑ Sensitivity to neutrons





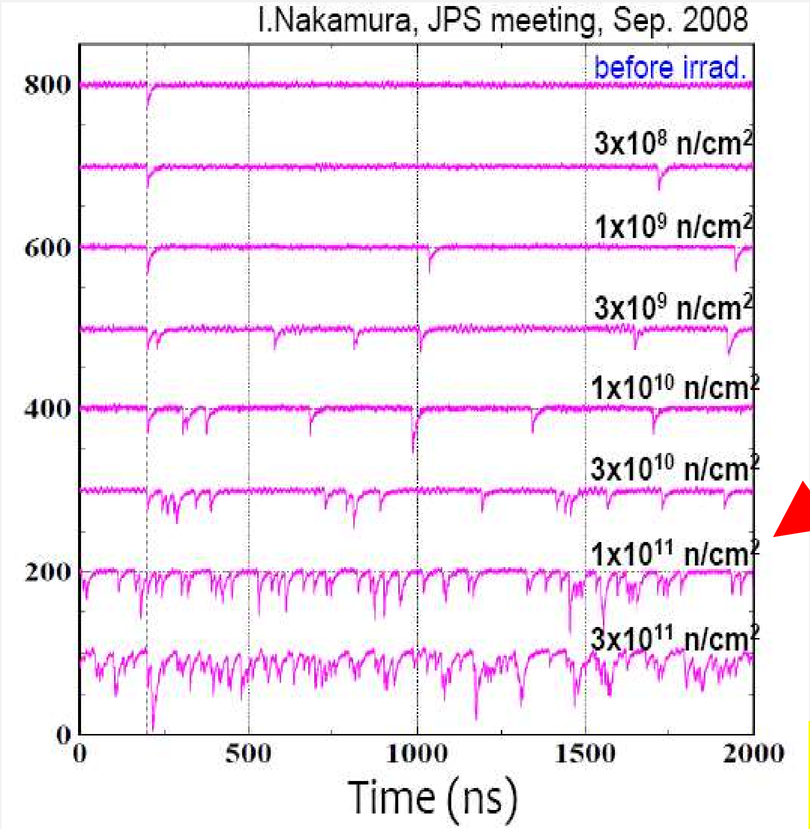




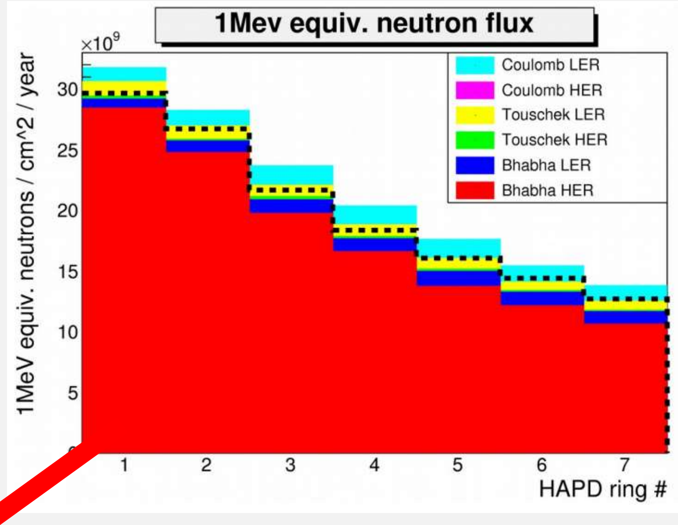


Sensitivity to neutron irradiation

Time evolution of a SiPM signal



Expected neutron fluence per year
as a function of
the distance from the beam



~10^{11}n/cm^{2}year

Noise hits after one year

Unfortunately due to such a neutron load, we decided not to use it in Belle II

OBJECTIVES

- Study of silicon PM samples before and after irradiation with neutrons:
- time and pulse height distribution, waveform analysis, background noise counts, effect of annealing .
- Design requirements, selection of SiPM, design and fabrication of readout electronics.
- Development of light concentrator to increase signal to noise.
- Integration of the module and study of the module in the relevant environment .
- technology design and validation in the lab and in the test beam,
- system prototype demonstration in operational environment.

- Key people: Rok Pestotnik (JSI), Prof. Samo Korpar (JSI), prof. Nishida Shohei (KEK), Alberto Gola (FBK) custom technology team leader.

TASK 4.2 DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

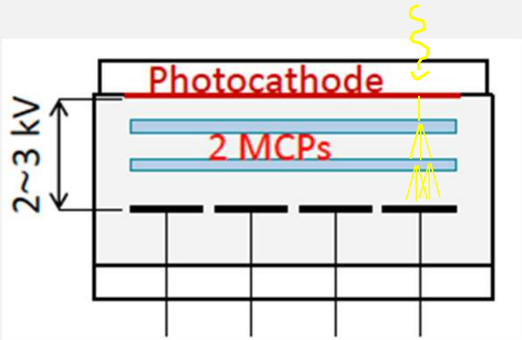
INFN,KEK

LONG LIVED MCP PMTS

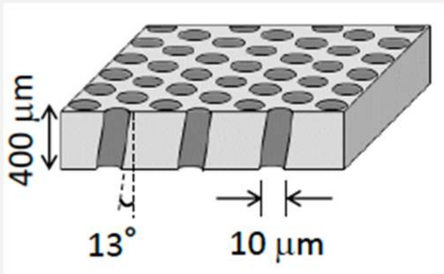
Introduction

The Time-Of-Propagation (TOP) detector must measure the arrival time of Cherenkov photons with a time resolution lower than 100 ps. Inside high background environment the quantun efficiency of the photocatode is degraded by gas or positive ions desorbed form the MCP layer during the electron multiplication inside microchannels.

MCP-PMT suqare shape for high fill factor (73%)



Two MCP to have enough gain(5 10^5) to detect single photon. Charge collected with 16 (4x4) anodes.



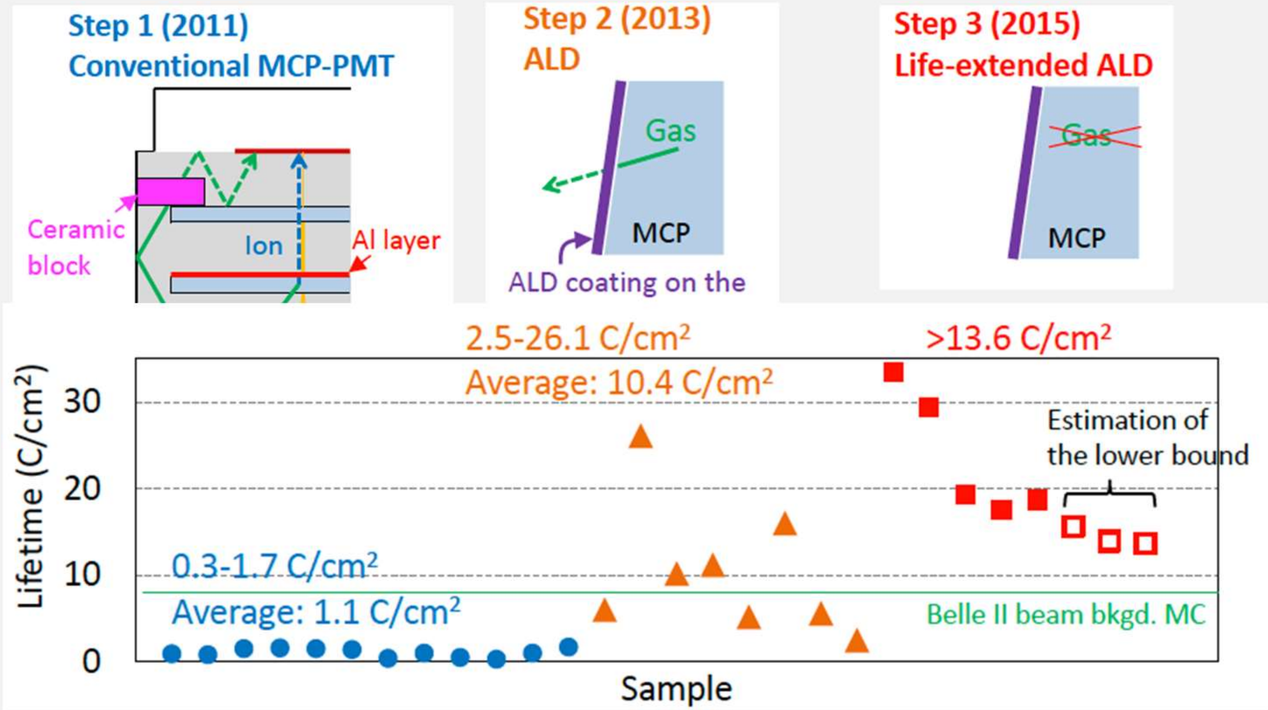
Small channels (10 µm) for a limited transit time spread (TTS < 40 ps)

TASK 4.2: DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

Goal

Improve the MPC-PMT photocathode lifetime as much as possible:

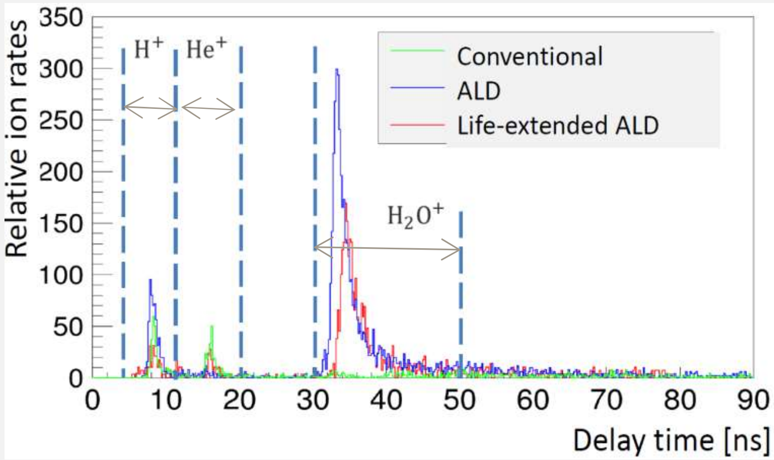
- to replace older MCP-PMT;
- to survive many years with high luminosity (high background) conditions.



TASK 4.2: DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

MPC-PMT developments

To understand the mechanism of photo-cathode deterioration, we measure feed-backed ion's signals using different developed MCP-PMTs. The three different delay times correspond to feed-backed H^+, He^+ and H_2O^+. There is no evident correlation between secondary signal height and type of MCP-PMTs. The main responsible of photo-cathode deterioration are not charged ions, could be are neutral residual gas ions. Additional test and studies will be performed. Currently the priority is to restart the long-lived MCP-PMTs production reducing test failure rate and increasing production rate.



2018 test

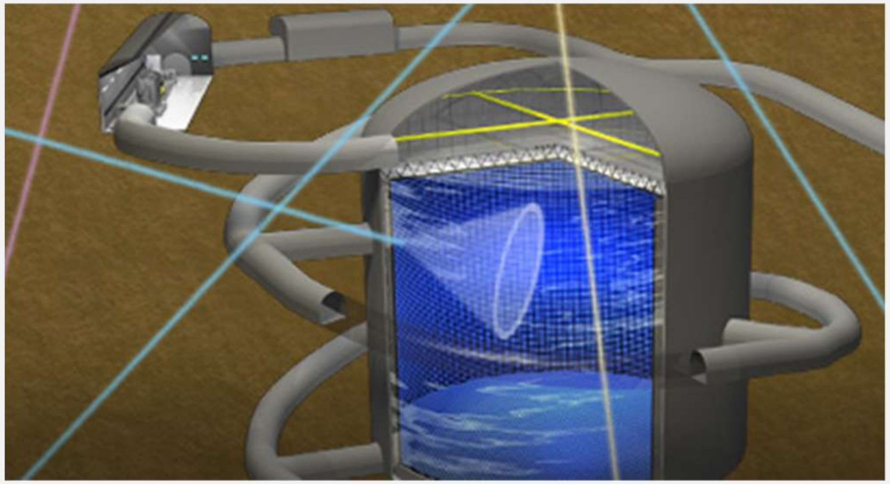
TASK 4.3 DEVELOPMENT OF MULTI PMTS FOR A LARGE WATER CHERENKOV DETECTOR

INFN,NCBJ,CAEN,U-Tokyo

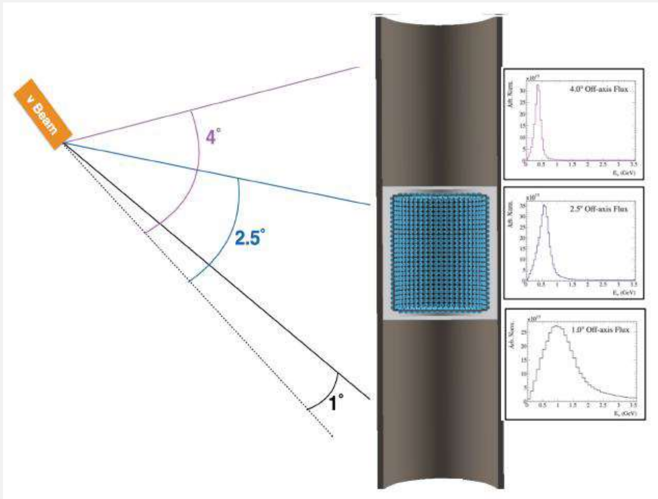
(SCIENTIFIC) PROBLEM

- Photodetection in Water Cherenkov Detectors
  - Large area photon counting detectors
  - Timing at nanosecond level to suppress backgrounds
  - Synchronisation of large detector arrays at sub-nanosecond precision
  - high efficiency and low cost per channel
- Hystorical approach: large area PMT inside a pressure vessel or with a protective cover

HYPERKAMIOKANDE



Hyper-Kamiokande Project
60 m(H)x74m(D)
Total volume 260 kt
Fiducial volume 190 kt ~10x Super-K



E61 – Intermediate detector for HyperKamiokande Project
Movable Water Cherenkov detector
Inner diameter 8 m
Inner detector height 6-8 m

OBJECTIVES
DEVELOPMENT OF MULTI PMTS TO:

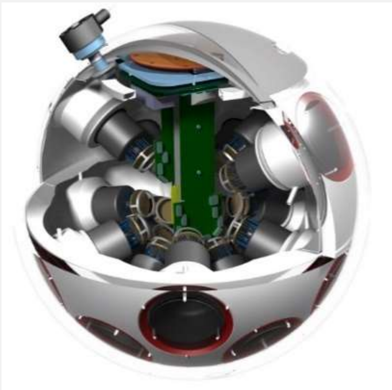
- increase the yield of the effective area of the optical system introducing intrinsic directional sensitivity
- reduce costs
- improve reliability for long term experiments
- improve physics sensitivities of HyperKamiokande experiment

PROPOSED RESEARCH AND INNOVATION ACTIVITIES

Use systems of small PMTs to increase the yield of the effective area of the optical system introducing intrinsic directional sensitivity: **multi-PMT system**

<u>Advantages</u>:

- **Increase of photocathode area**
- **Superior photon counting**
- **Smaller transit time spread**
- **Negligible effects due to magnetic fields**
- **Improved angular acceptance**
- **Extension of dynamic range**
- **Intrinsic directional sensitivity**
- **Local coincidences**
- **Cost / photocathode area**
- **Reduced risk**



Photodetectors and electronics arranged inside a pressure resistant vessel

WORK PLAN

HyperK MultiPMT:

- Define adequate design for application in HyperK
  - Study more realistic configurations for the MultiPMT
  - Check for different photodetector options
- Study of optical module components (time and pulse height distribution, waveform analysis, background rates)
- Design, fabrication end test of multi-PMT optical module to demonstrate technical feasibility of MultiPMT
- Test in WC test detector in at Tokai site

MILESTONES

Main limits of KM3NeT solution for HK project:

- Vessel:

  Glass spheres as used in KM3Net are characterized by high ^{40}K and other radioactive contamination

  → Comparative studies on commercial acrylics:
  - Optical propertied
  - Radioactive contamination
  - Mechanical tests
  - Pressure tests

- PMT Read-Out and HV:

  Time over threshold (ToT) strategy is exploited in KM3Net; in HK charge measurement is important

  → HV: Cockcroft-Walton (CW) voltage multiplier
  PMT Read-out: Sample&Hold+ADC based on discrete components

Realisation of the mPMT module prototype

TASK 4.4: STUDY OF INNOVATIVE ORGANIC PHOTOSENSORS [INFN,KEK]

A. Aloisio - P. Branchini

MOTIVATIONS

- large area, thin and flexible sensors are needed to detect ionizing radiation impinging on complex geometrical structures in real time and at affordable costs, but the technologies today available cannot deliver all these features in one single object.

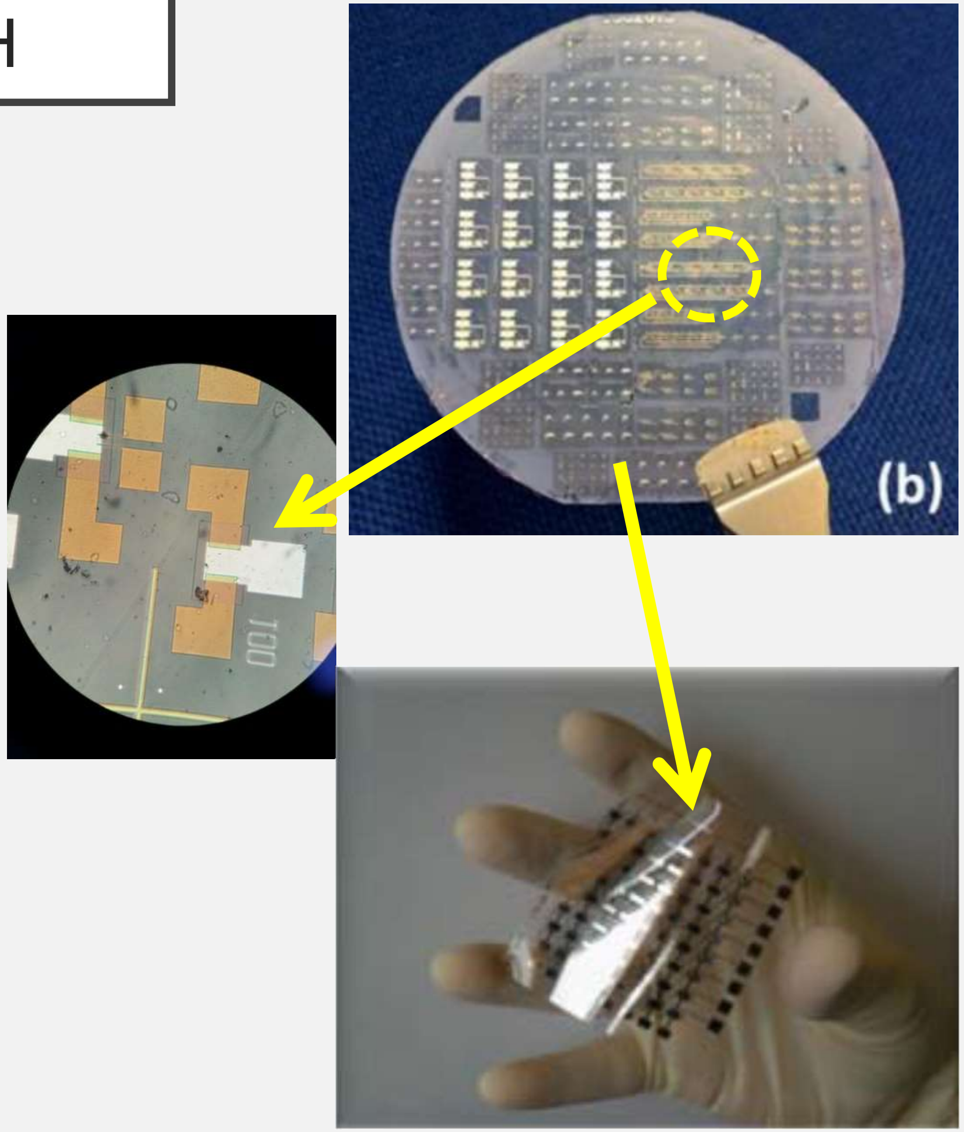
- PRESENT TECHNOLOGY DRAWBACKS

✓ Commercial plastic scintillators give a rather low light yield for X and gamma-rays. They are quite chemically unstable and prone to cracking after handling.

✓ Commercial solid state direct detectors (typically based on inorganic semiconductors), indeed offer excellent detecting performance, but are rigid, heavy, expensive, power-consuming, made with toxic processes and elements, and only allow a small active detection area.

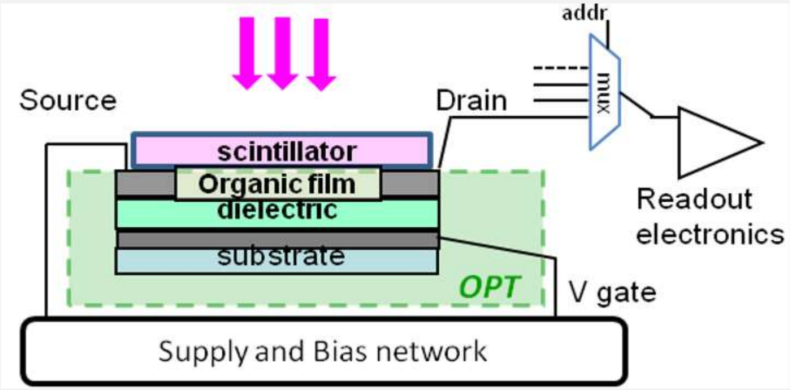
PROPOSED RESEARCH

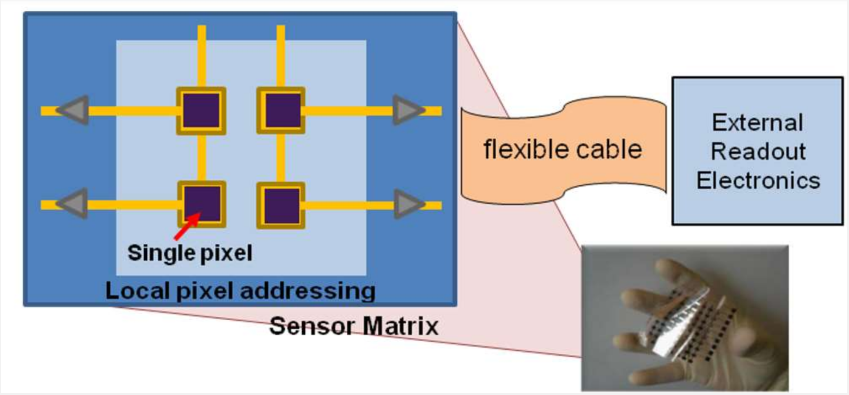
- In this Task, we propose to develop, characterize and test Organic Photo Transistors for innovative radiation detectors
- Organic Photo Transistors (OPTs) are derivatives of Field Effect Transistors, made with optically-active polymers
- Processes and fabrication steps are modified in order to enhance photon collection and optimize optical coupling
- Integration on flexible substrates makes it possible to model the sensors in arbitrary shapes



OBJECTIVES AND WORKPLAN

- In our road-map we have :
  - **indirect detectors based on Organic Photo Transistors (OPTs) coupled with specific plastic scintillators.**
    Organic semiconductors are very efficient for near UV-IR light detection. We will fabricate OPTs with a photoresponse optimized for the light emission of the most promising, application-specific, organic scintillators.
  - **Matrix of pixels on flexible substrates** (PEN, PET, …) could cover large area at low cost, addressing applications in real-time dosimetry and challenging traditional Flat Panel detectors.





WP4 SUMMARY

- Photon detection is very active area with lots of different activities
- In the framework of JENNIFER2 we will capitalize the knowledge to push the technologies into new particle detectors.