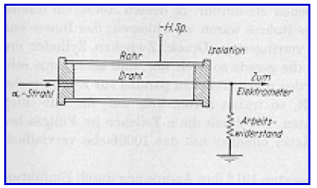


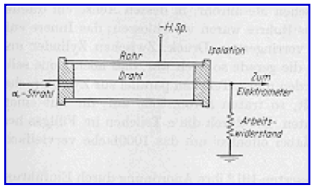
TASK 7.5.1

Photon detectors for hadron particle identification at high momenta

A bridge between gaseous detectors and PID world

Silvia Dalla Torre

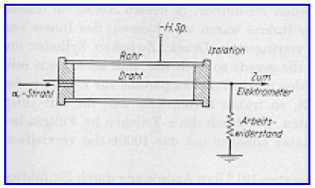
on behalf of the Task 7.5.1 team



INTRODUCTARY REMINDER

WP7-TASK 7.5, WHO ?

GAS DETECTORS



	Participating Institute/Compagny	Type	Country	Main contact person	e-mail
EU beneficiaries	Charles University	University	Czech R.	Miroslav Finger	Miroslav.Finger@cern.ch
	INFN, Bari	Research Institute	Italy	Giacomo Volpe	giacomo.volpe@ba.infn.it
	INFN, Bologna		Italy	Roberto Preghenella	Roberto.Preghenella@bo.infn.it
	INFN, Trieste		Italy	Silvia Dalla Torre	Silvia.DallaTorre@ts.infn.it
non-EU no financial obbligations	USTC	University	China	Jianbei Liu	liujianb@ustc.edu.cn
	Incom, Inc.	Company	USA	Michel J. Minot	mjm@incomusa.com

Task Leader: S. Dalla Torre, INFN-Trieste

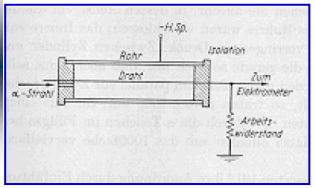
About the non-EU participants

University of Science and Technology of China (USTC), Hefei, China

- USTC will be contributing to the development of the compact RICH concept by a complementary approach to the gaseous MPGD-based photon detection, developing and prototyping a photo-sensor making use of two grid layers.

INCOM, Inc., Charlton, USA

- INCOM has built a first-version LAPPDs (large-size Micro Channel Plate-Photo Multipliers, MCP-PMT) prototype and provided it for evaluation by the INFN collaborators. In a second step, a revised prototype, taking into account the indications of the evaluation process, will be designed, built and provided to collaborators for a second evaluation campaign.



The scientific motivations

MOTIVATIONS

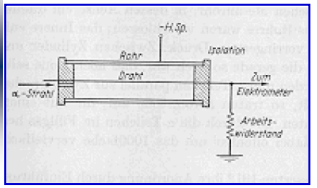
- the challenging requirements of a high-momentum RICH counter in a collider environment with hermetic detector architecture:
  - high momenta → gaseous radiator for h-PID → low Cherenkov photon rate per radiator unit length
  - collider hermetic detector → short radiator namely a compact RICH
  - collider hermetic detector → operation in magnetic field and in high-rate environment

- Two concrete options:

(i) a windowless RICH with gaseous PDs operated with the radiator gas itself → enlarge the number of photons by moving the wavelength detection window to extremely VUV photon (~120 nm)

(ii) making use of the wide band of the visible light with PDs adequate for high rate and operation in magnetic field
  - these PDs are also good candidates for low-momentum imaging Cherenkov counters as DIRCs and aerogel RICHes, where only visible light can be detected

POTENTIAL APPLICATIONS



DOMAIN OF POTENTIAL APPLICATIONS

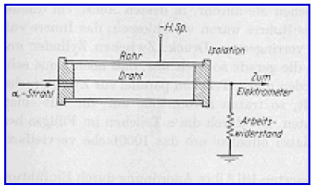
- A **compact RICH** is a MUST for the hermetic detectors at the **EIC** (now approved project in USA)

- **Compact RICHes** can enlarge the physics reach of circular e+e- colliders (**FCC-ee, CepC**)

- and, then, all gaseous RICHes

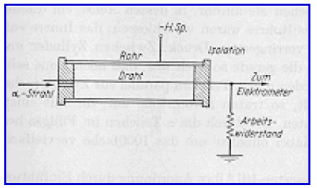
- establishing either LAPPDs or SiPM arrays as sensor for Cherenkov imaging applications → beneficial to all RICH detector, also those requiring the **detection of visible light**:
  - **DIRCs** (EIC, PANDA @ FAIR)
  - **Aerogel RICHes** (EIC, AMBER, ALICE, LHCb)

Task 7.5.1, R&D activity



- **The R&D activity is dedicated to developments for the detection of single photoelectrons → 3 R&D lines :**

1. **MPGD-based PDs *(INFN-TS, Charles U., USTC)***
   - Increasing the space resolution by the miniaturization of the pad-sizes
   - Coupling the PDs with novel low-noise FE electronics: VMM3
   - Improved detector architectures including, for instance, double mesh MICROMEGAS
   - Complete with an optimized prototype (deliverable, month 44)
2. **visible light PDs insensitive to magnetic field *(INFN-BA, INFN-BO, INFN-TS, USTC, INCOM)***
   - Qualify Si PMs for single photoelectron detection in imaging devices
   - Qualify LAPPDs for single photoelectron detection in imaging devices
3. **Comparative assessment by simulations using as input the photosensor performance as from R&D lines 1. and 2. *(INFN-BA, INFN-TS)***

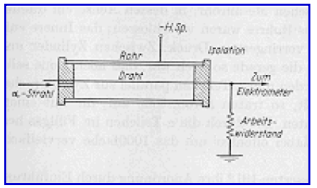


REPORT

Second year of activity

(April 2022- March 2023)

Task 7.5.1, R&D activity



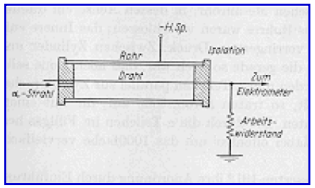
- **The R&D activity is dedicated to developments for the detection of single photoelectrons → 3 R&D lines**

1. **MPGD-based PDs** ***(INFN-TS, Charles U., USTC)***
   - Increasing the space resolution by the miniaturization of the pad-sizes
   - Coupling the PDs with novel low-noise FE electronics: VMM3
   - Improved detector architectures including, for instance, double mesh MICROMEGAS
   - Complete with an optimized prototype (deliverable, month 44)

2. **visible light PDs insensitive to magnetic field** ***(INFN-BA, INFN-BO, INFN-TS, USTC, INCOM)***
   - Qualify Si PMs for single photoelectron detection in imaging devices
   - Qualify LAPPDs for single photoelectron detection in imaging devices

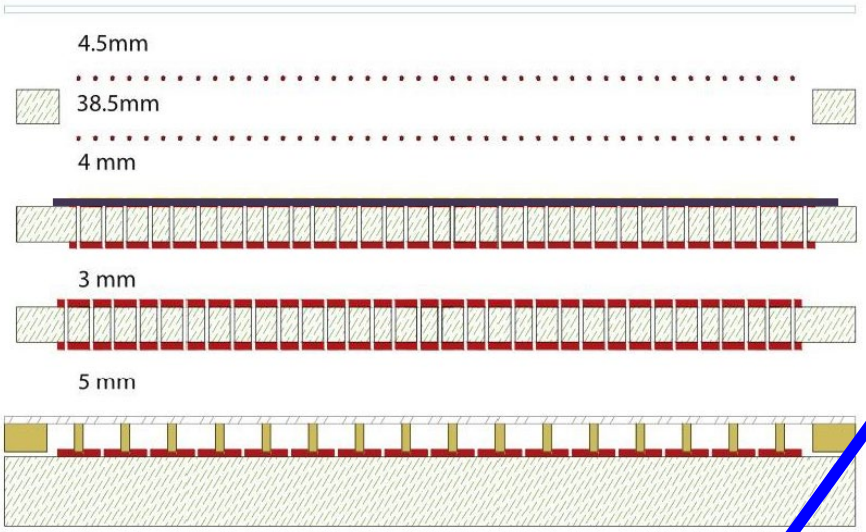
3. **Comparative assessment by simulations using as input the photosensor performance as from R&D lines 1. and 2.** ***(INFN-BA, INFN-TS)***

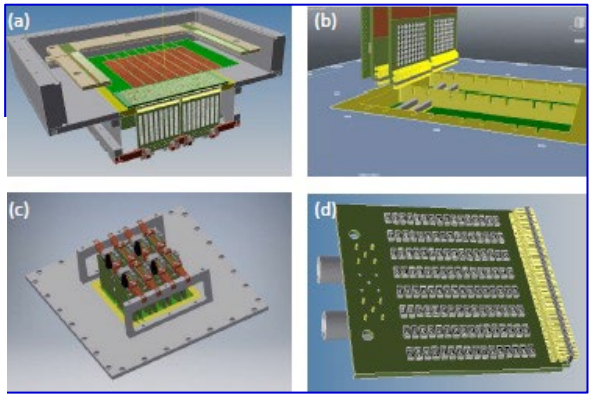
MPGD-based PDs

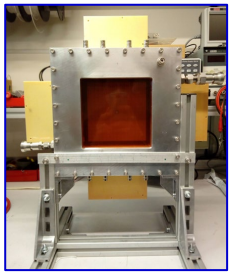


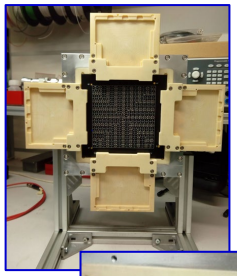
DETECTOR architecture

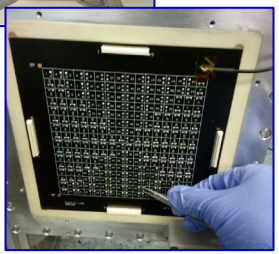
- Hybrid: 2 THGEM + 1 MM





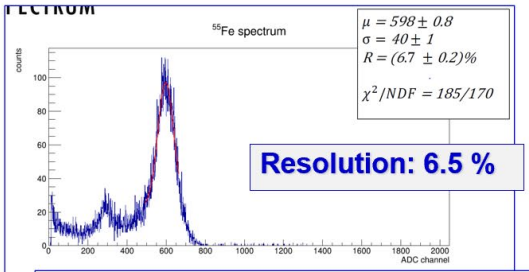




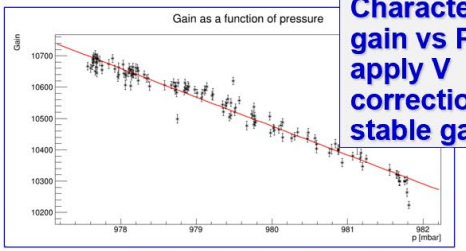


1 year ago, report on:

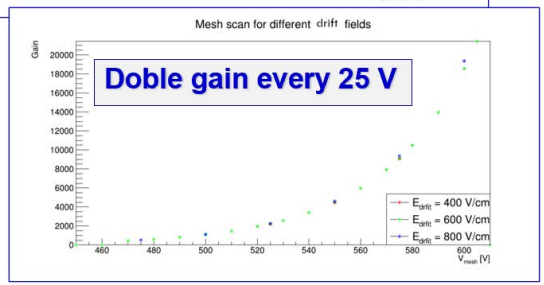
- Design and construction
- Characterization of the MICROIMEGAS layer



Resolution: 6.5 %



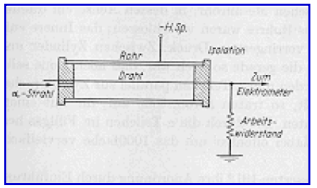
Characterize gain vs P, T → apply V correction for stable gain



Doble gain every 25 V

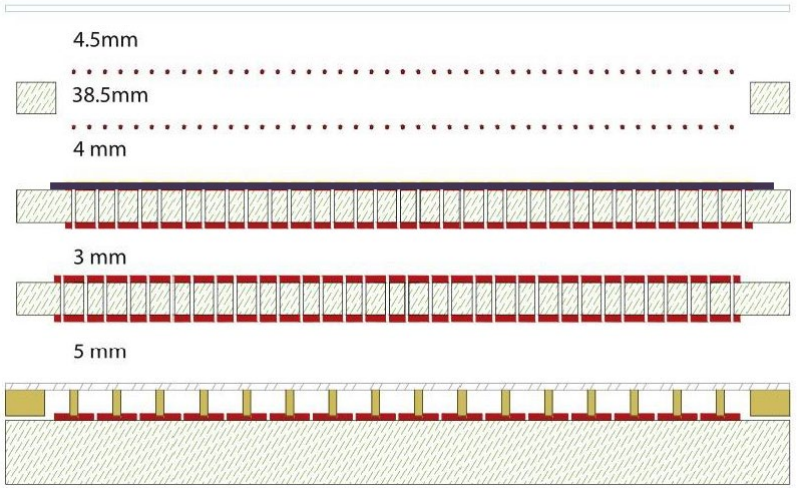
No sizeble charging-up observed

MPGD-based PDs



DETECTOR architecture

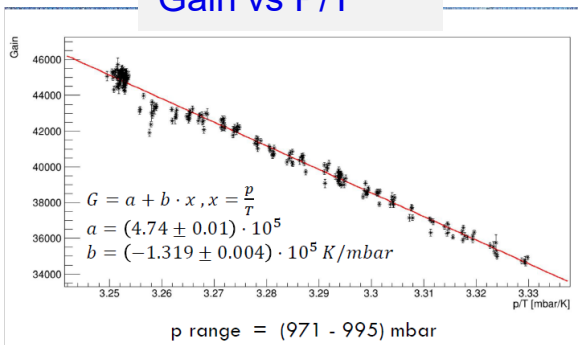
- Hybrid: 2 THGEM + 1 MM



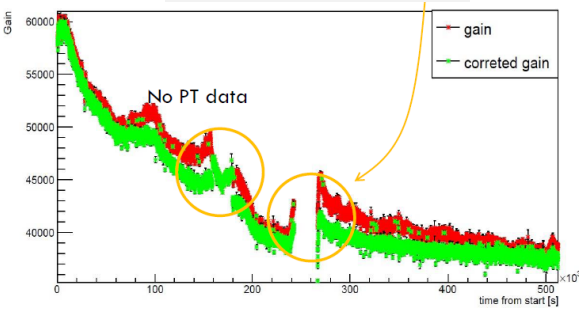
New (last year activity, 1/2):

- Characterization of the THGEM layers

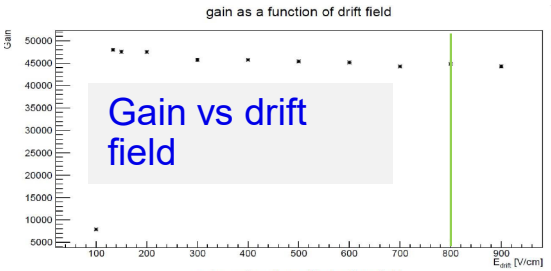
Gain vs P/T



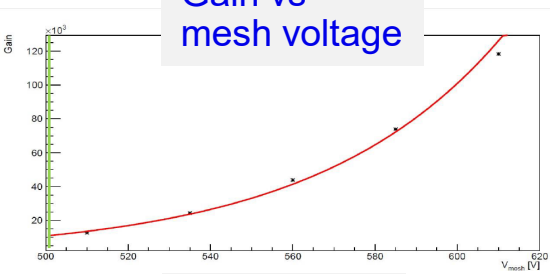
Gain vs time



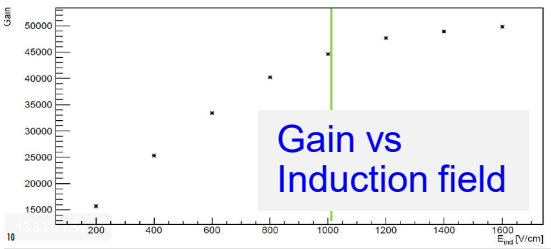
Gain vs drift field



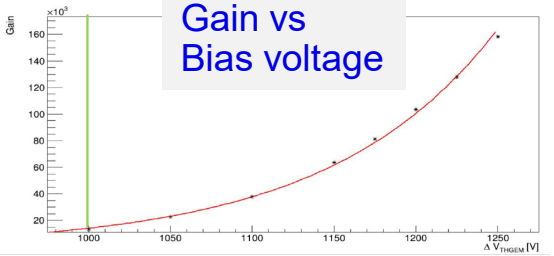
Gain vs mesh voltage



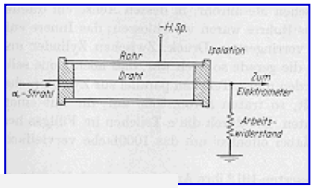
Gain vs Induction field



Gain vs Bias voltage

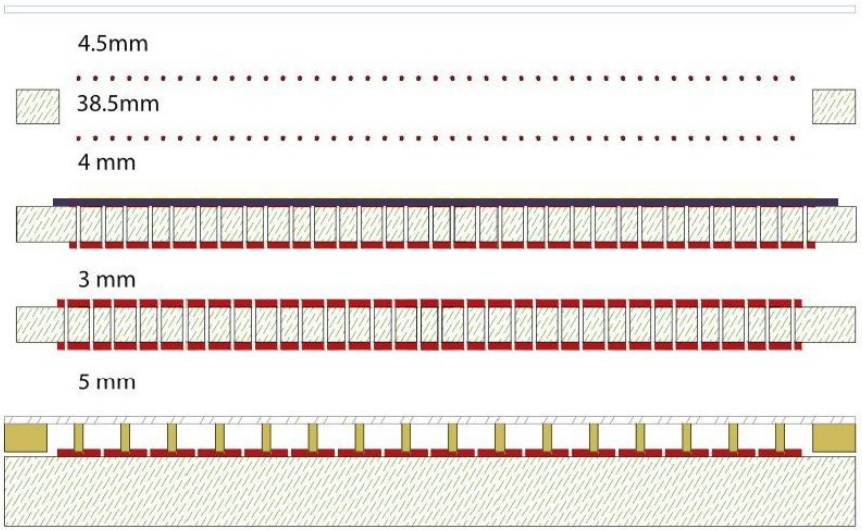


MPGD-based PDs



DETECTOR architecture

- Hybrid: 2 THGEM + 1 MM

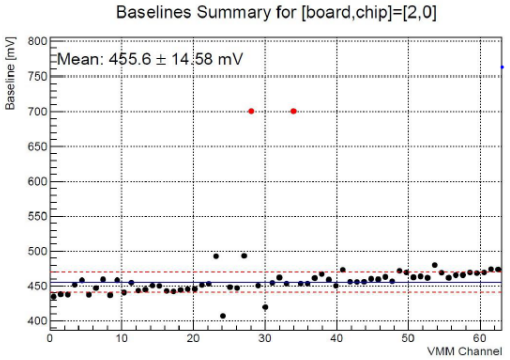


New (last year activity, 2/2):

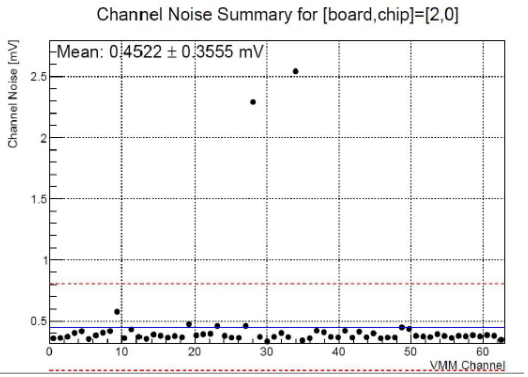
- Characterization of the proposed FE-ASIC: VMM3

Coming activity: coupling the prototype and the FE electronics

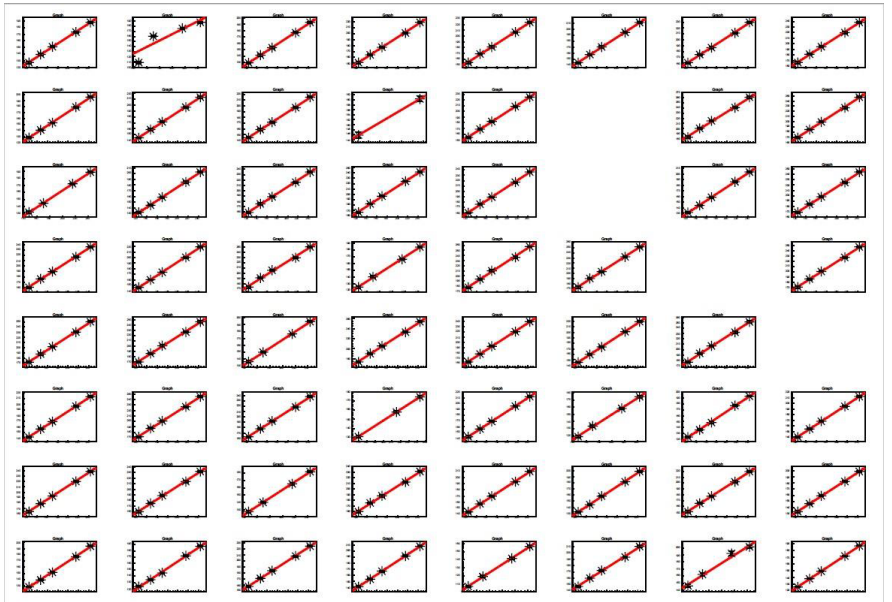
Baseline vs channel



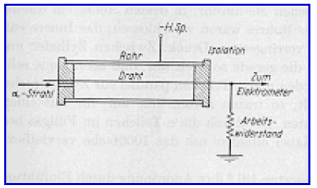
Noise vs channel



Calibration of each channel



Task 7.5.1, R&D activity



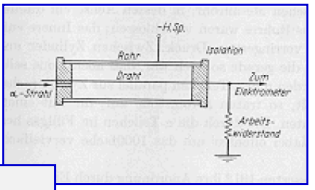
- **The R&D activity is dedicated to developments for the detection of single photoelectrons → 3 R&D lines**

1. **MPGD-based PDs *(INFN-TS, Charles U., USTC)***
   - Increasing the space resolution by the miniaturization of the pad-sizes
   - Coupling the PDs with novel low-noise FE electronics: VMM3
   - Improved detector architectures including, for instance, double mesh MICROMEGAS
   - Complete with an optimized prototype (deliverable, month 44)

2. **visible light PDs insensitive to magnetic field *(INFN-BA, INFN-BO, INFN-TS, USTC, INCOM)***
   - Qualify Si PMs for single photoelectron detection in imaging devices
   - Qualify LAPPDs for single photoelectron detection in imaging devices

3. **Comparative assessment by simulations using as input the photosensor performance as from R&D lines 1. and 2. *(INFN-BA, INFN-TS)***

SiPMs



Establish SiPMs for single photon detection in Cherenkov imaging devices ←→ limit the dark noise rate due to radiation damage

Commercial SiPMs under study

board	sensor	uCell (μm)	V_{bd} (V)	PDE (%)	DCR (kHz/mm^2)	window	notes
HAMA1	S13360 3050VS	50	53	40	55	silicone	legacy model Calvi et. al
	S13360 3025VS	25	53	25	44	silicone	legacy model smaller SPAD
HAMA2	S14160 3050HS	50	38	50		silicone	newer model lower V_{bd}
	S14160 3015PS	15	38	32	78	silicone	smaller SPADs radiation hardness
SENSL	MICROFJ 30035	35	24.5	38	50	glass	different producer and lower V_{bd}
	MICROFJ 30020	20	24.5	30	50	glass	the smaller SPAD version
BCOM	AFBR S4N33C013	30	27	43	111	glass	commercially available FBK-NUVHD

HAMAMATSU PHOTON IS OUR BUSINESS

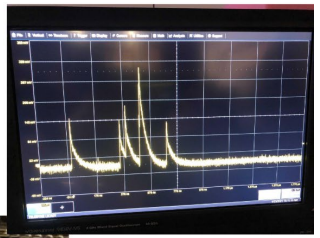
ON Semiconductor

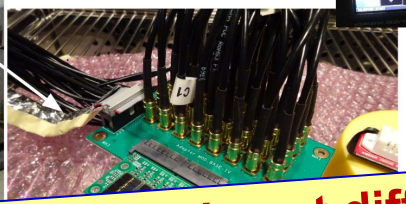
BROADCOM

I-V curves and DCR at different temperatures

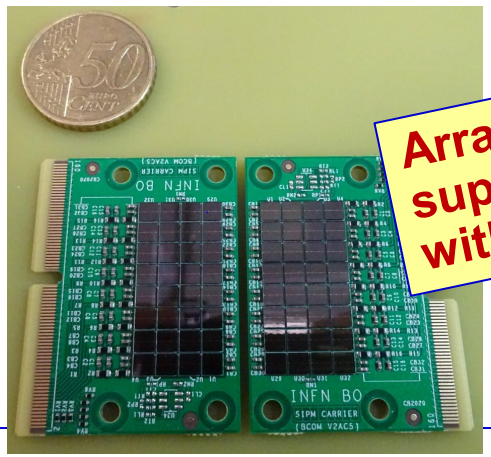
+20 C −10 C −30 C

- Memmert climatic chamber
- Keithley source meter
- Keysight power supply
- Cividec amplifier
- Lecroy oscilloscope





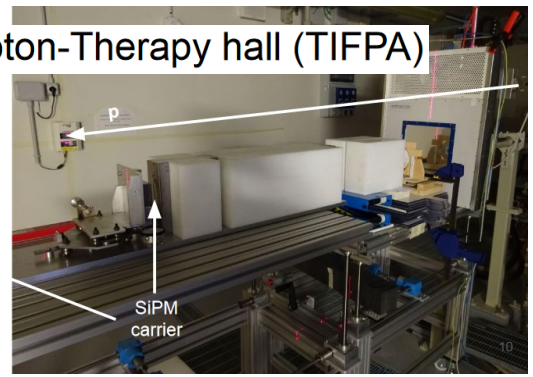
Systemati characterization at different temperatures before and after irradiation



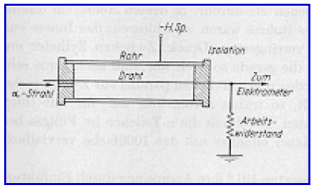
Arranged on support cards with services

Reported 1 year ago

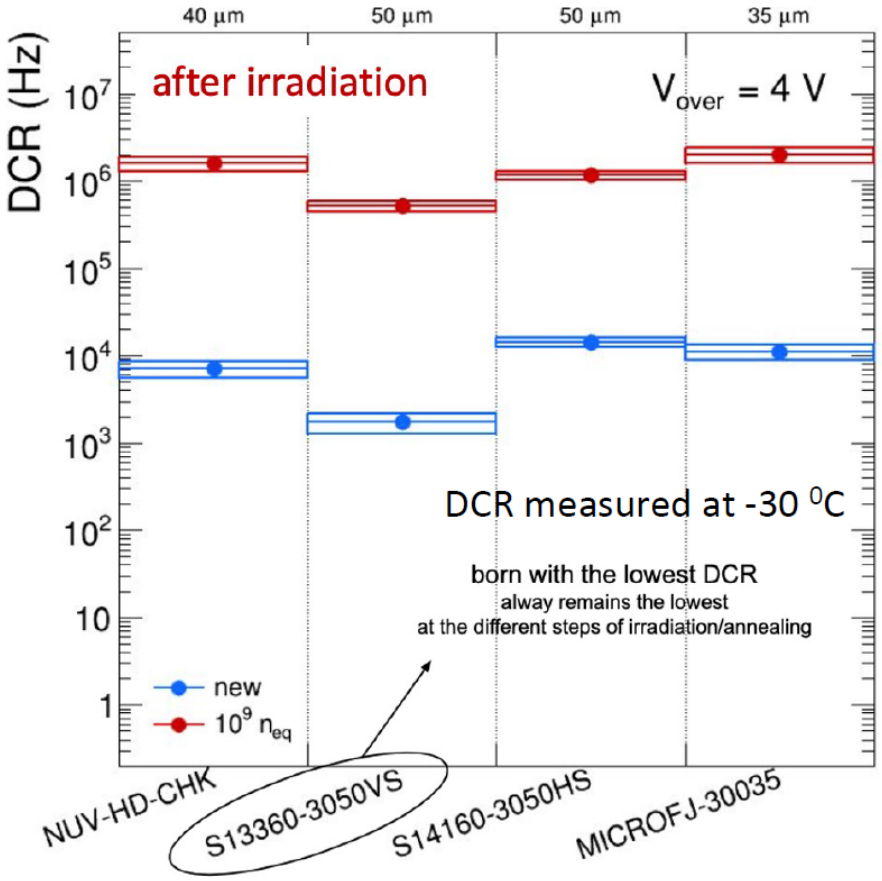
Irradiation at Trento Proton-Therapy hall (TIFPA)



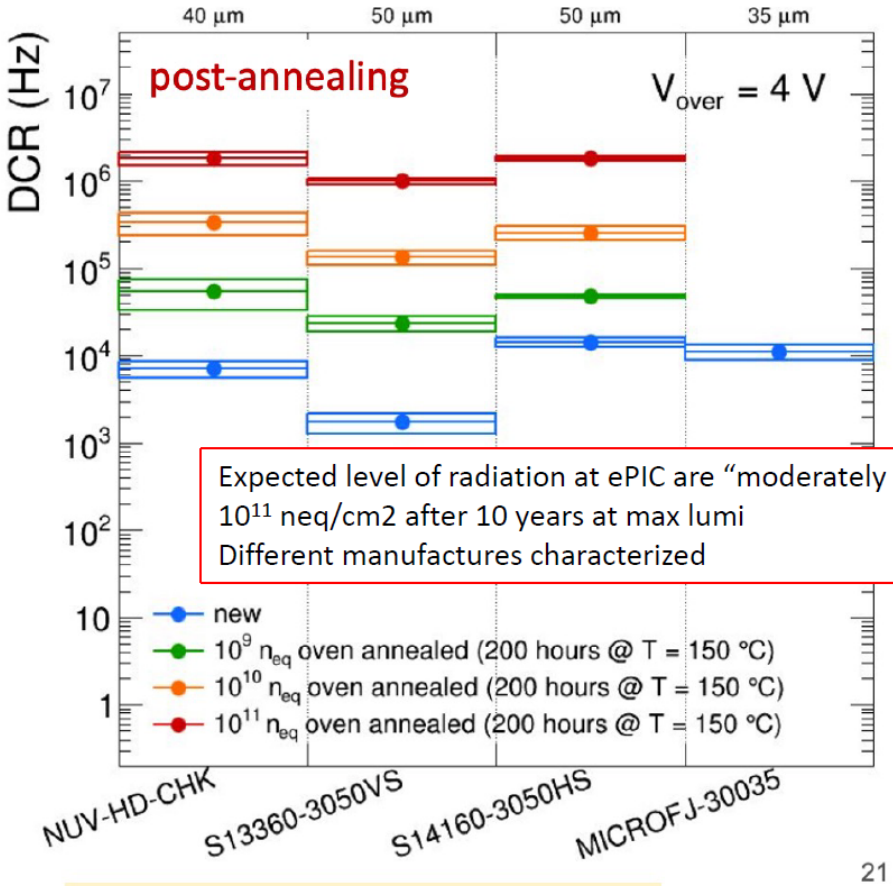
SiPMs



NEW: preliminary results



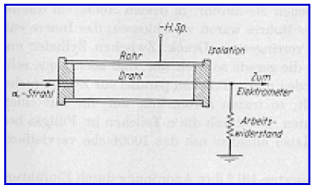
O(100) DCR increase after 10^{11} n_{eq}



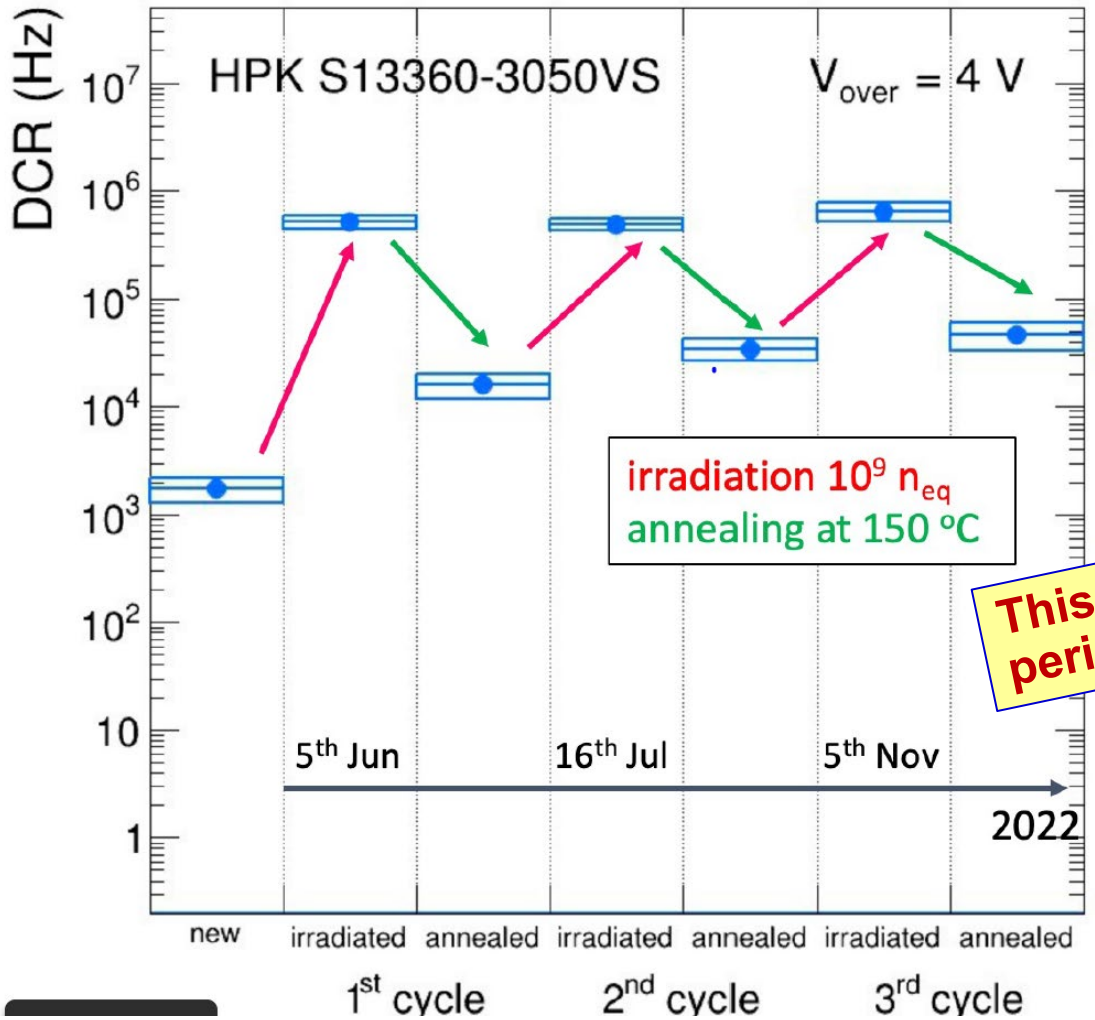
Expected level of radiation at ePIC are "moderately hostile"
10^{11} neq/cm2 after 10 years at max lumi
Different manufactures characterized

21

O(10) DCR recovery post-annealing

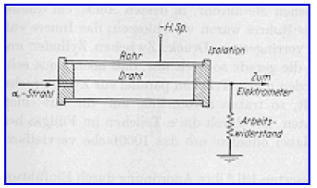


NEW: preliminary results



This opens the wait to periodical annealing in situ

Task 7.5.1, R&D activity

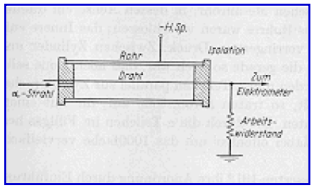


- **The R&D activity is dedicated to developments for the detection of single photoelectrons → 3 R&D lines**

1. **MPGD-based PDs *(INFN-TS, Charles U., USTC)***
   - Increasing the space resolution by the miniaturization of the pad-sizes
   - Coupling the PDs with novel low-noise FE electronics: VMM3
   - Improved detector architectures including, for instance, double mesh MICROMEGAS
   - Complete with an optimized prototype (deliverable, month 44)

2. **visible light PDs insensitive to magnetic field *(INFN-BA, INFN-BO, INFN-TS, USTC, INCOM)***
   - Qualify Si PMs for single photoelectron detection in imaging devices
   - Qualify LAPPDs for single photoelectron detection in imaging devices

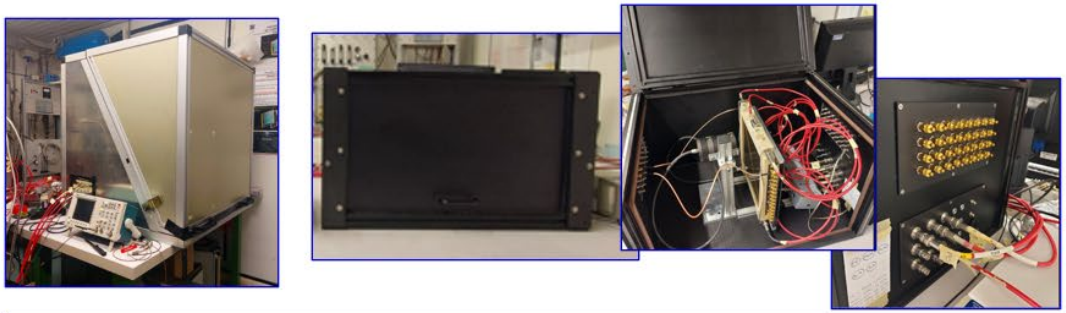
3. **Comparative assessment by simulations using as input the photosensor performance as from R&D lines 1. and 2. *(INFN-BA, INFN-TS)***



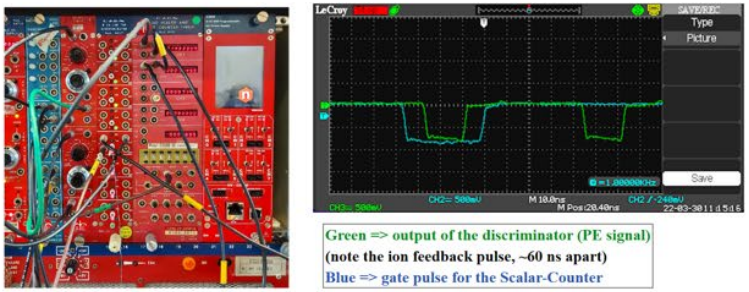
LAPPDs

Extremely initial 1 year ago, ~ all in the last year

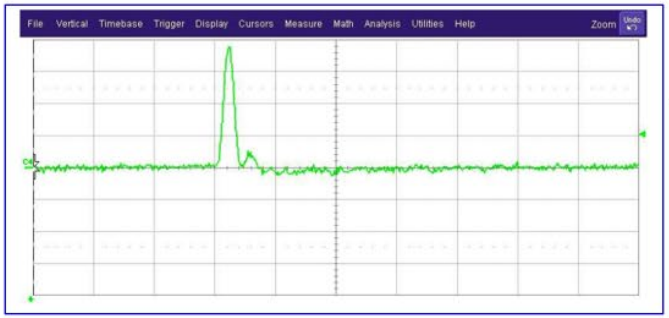
Lab activity, 1/2



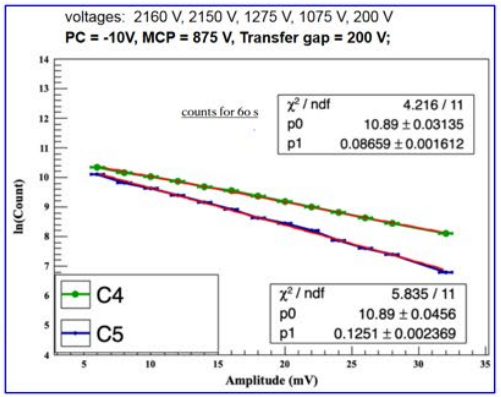
Initial dark-box; then, optimized dark-box modified to improve light-tightness and operative needs

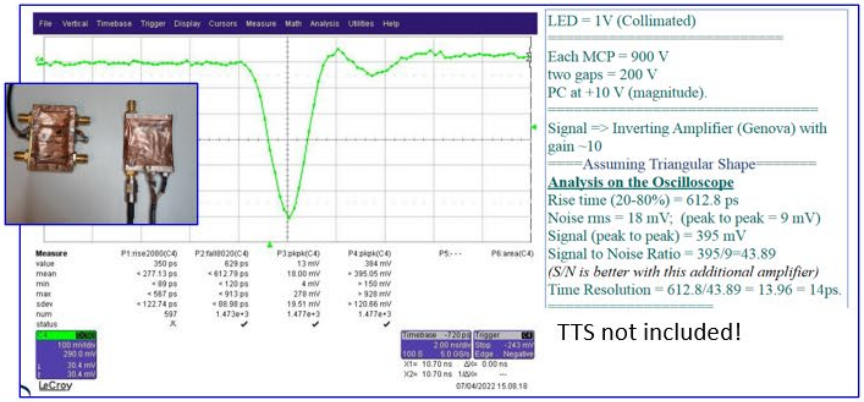


Single photoelectron condition using a pulse LED



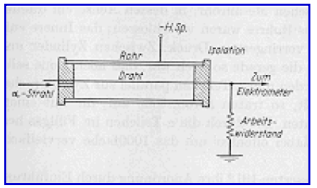
Example of dark-pulse signal and studies of the dark-pulse rate





Using the pre-amplificator: signal analysis at the scope

LAPPDs



Lab activity, 2/2

VME Crate: CAEN 8004X, Digitizer: CAEN V1742

First exercises with the digitizer

Example Photon-Event from Digitizer

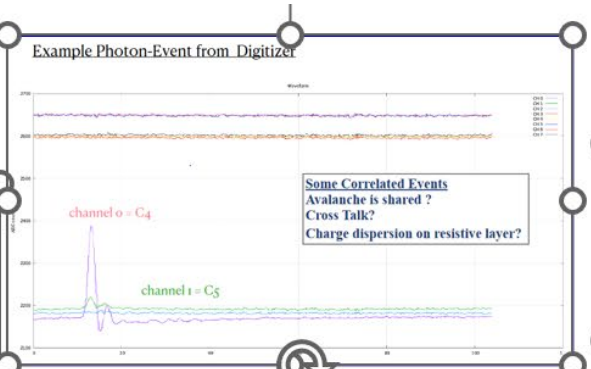
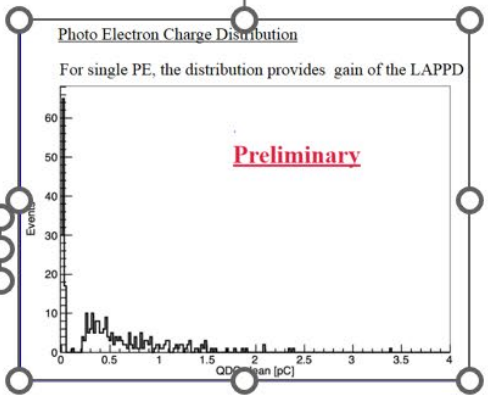
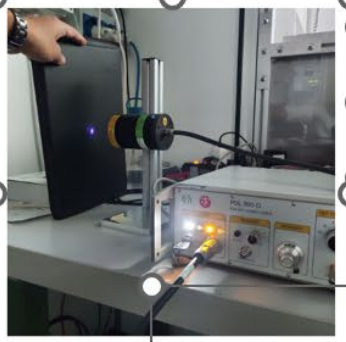


Photo Electron Charge Distribution

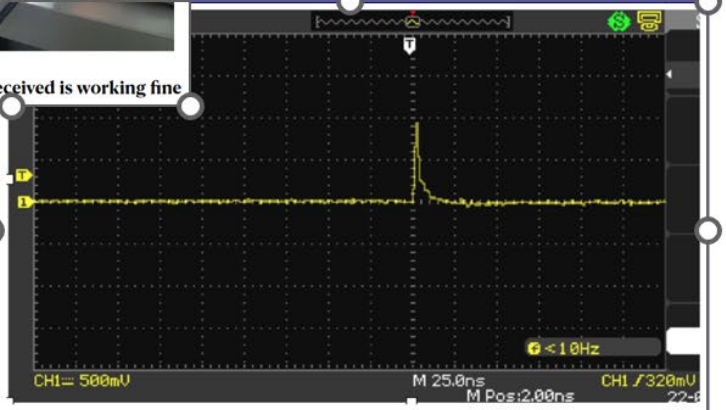
For single PE, the distribution provides gain of the LAPPD





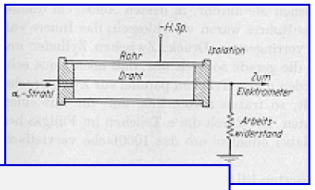
The LASER as we received is working fine

Getting familiar with the new head (405 nm) of the PICOQUANT pulsed laser source



A pulse from the LAPPD with the LASER incident on it

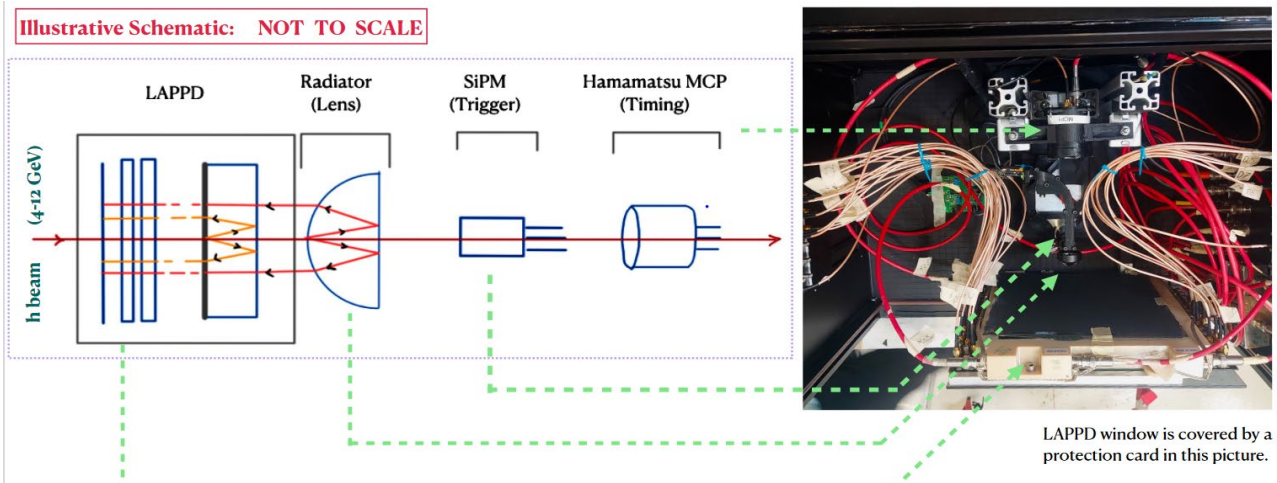
LAPPDs for RICH counters



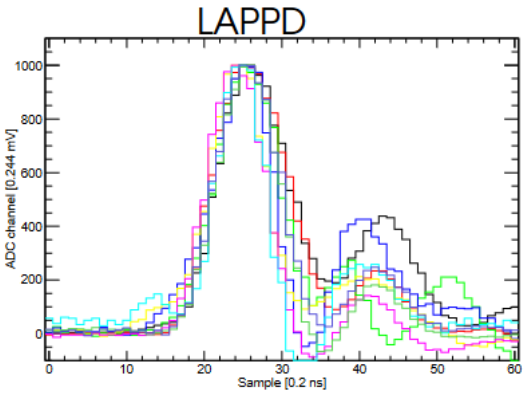
October test beam at CERN PS to measured LAPPD time resolution generating Cherenkov photon in a quartz radiator

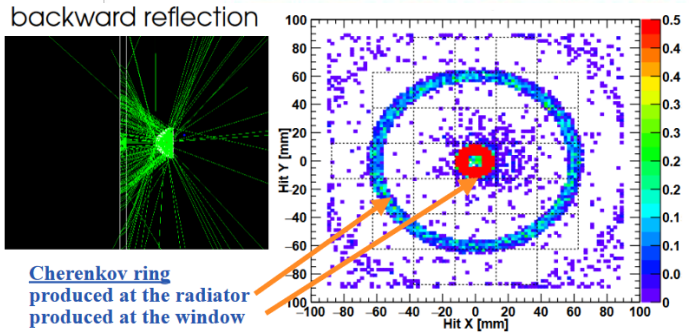
Not optimized LAPPD :

pore diam. 20 μm, anode substrate: 5mm glass, PC voltage: 50 V

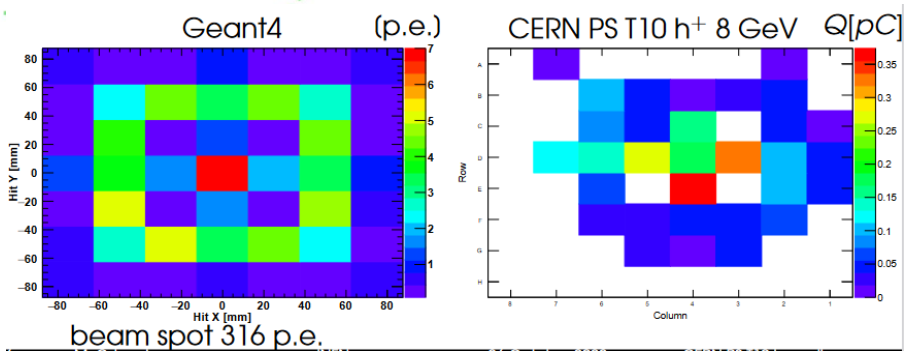


LAPPD window is covered by a protection card in this picture.





Cherenkov ring
produced at the radiator
produced at the window



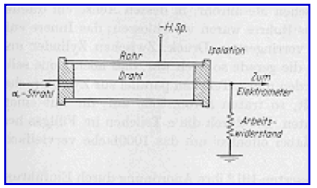
beam spot 316 p.e.

Time resolution:

80 ps

(preliminary)

Task 7.5.1, R&D activity



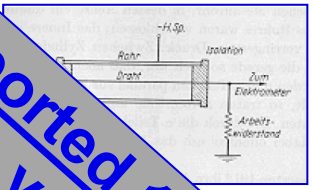
- **The R&D activity is dedicated to developments for the detection of single photoelectrons → 3 R&D lines**

1. **MPGD-based PDs *(INFN-TS, Charles U., USTC)***
   - Increasing the space resolution by the miniaturization of the pad-sizes
   - Coupling the PDs with novel low-noise FE electronics: VMM3
   - Improved detector architectures including, for instance, double mesh MICROMEGAS
   - Complete with an optimized prototype (deliverable, month 44)

2. **visible light PDs insensitive to magnetic field *(INFN-BA, INFN-BO, INFN-TS, USTC, INCOM)***
   - Qualify Si PMs for single photoelectron detection in imaging devices
   - Qualify LAPPDs for single photoelectron detection in imaging devices

3. **Comparative assessment by simulations using as input the photosensor performance as from R&D lines 1. and 2. *(INFN-BA, INFN-TS)***

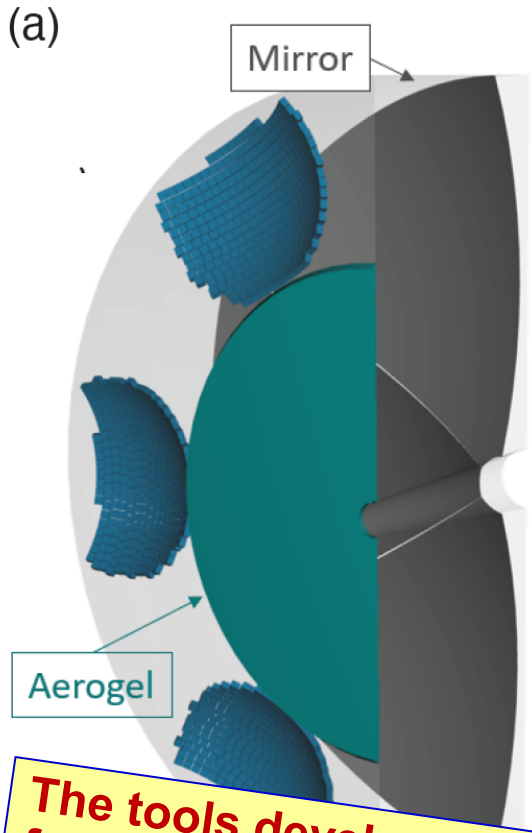
TOOLS for SIMULATION

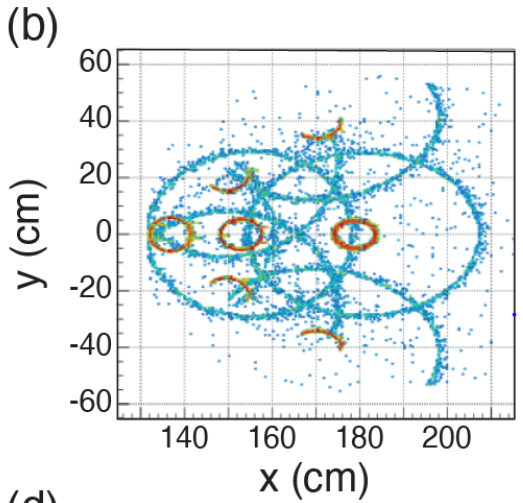


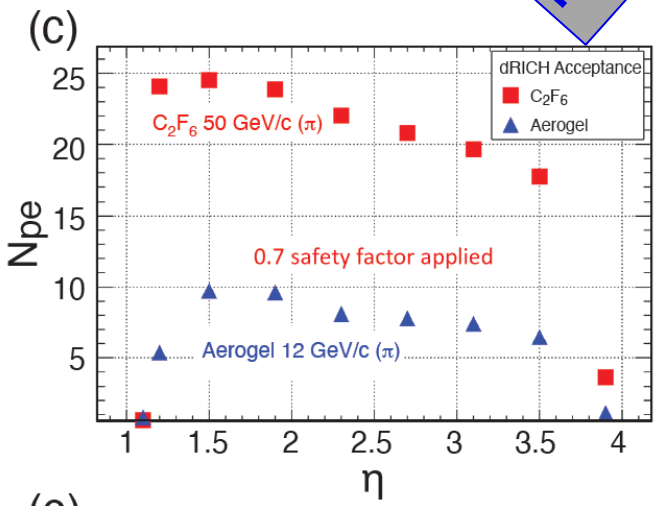
Reported 1 year ago

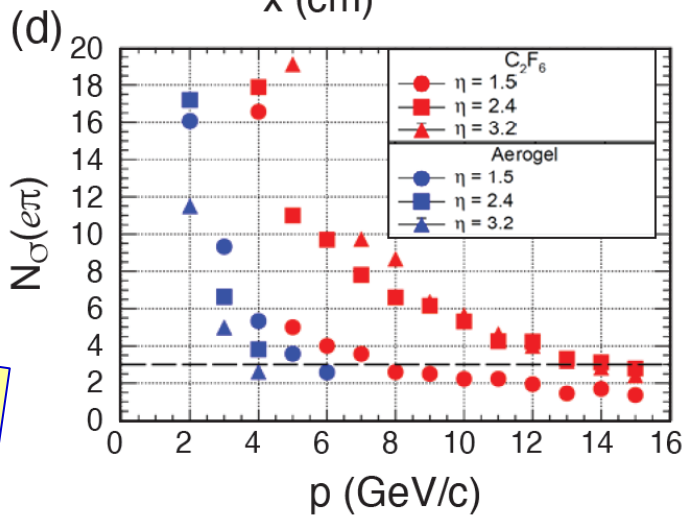
Tool development for performance comparison via simulations:

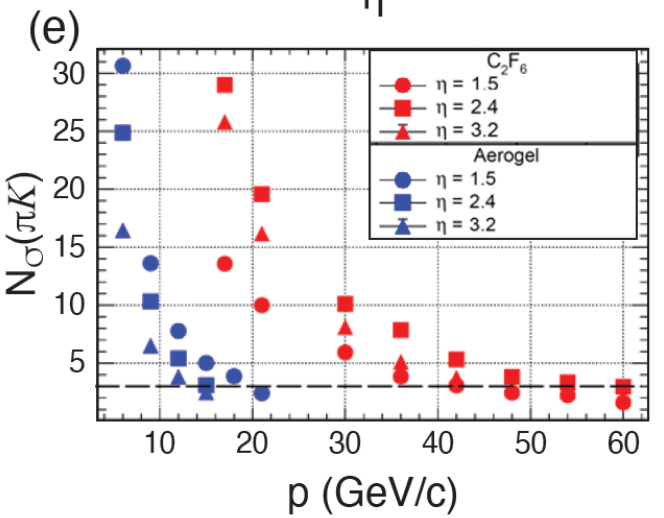
- Developed: Photon generation, photon reconstruction via ray-traceback algorithms
- Next tesp- PID algorithms











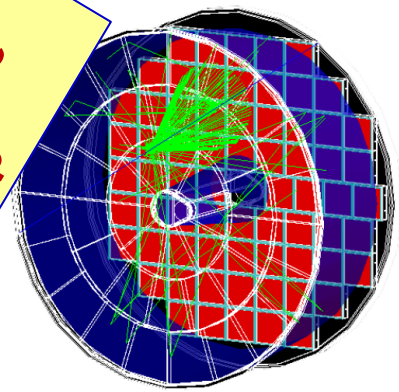
The tools developed so far applied in a case of study: the EIC dual RICH

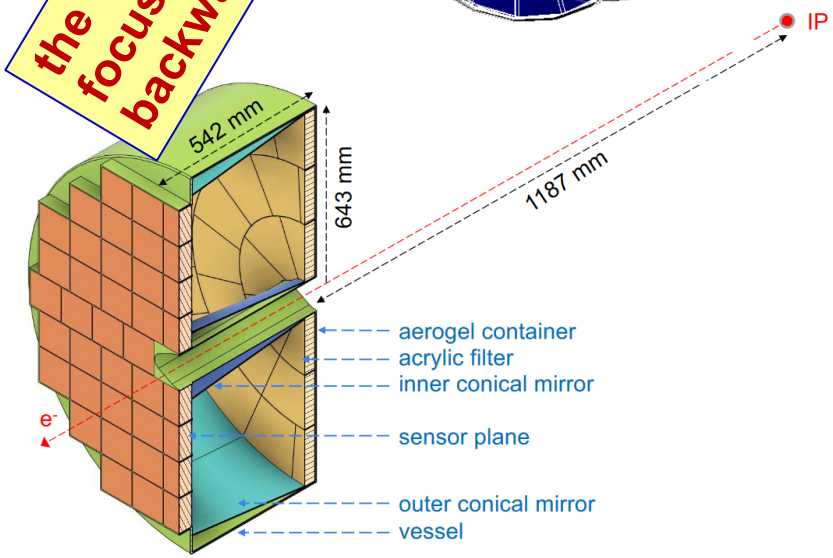
TOOLS for SIMULATION

NEW (1/2): last year activity

Application of the already developed tools to a new case of study

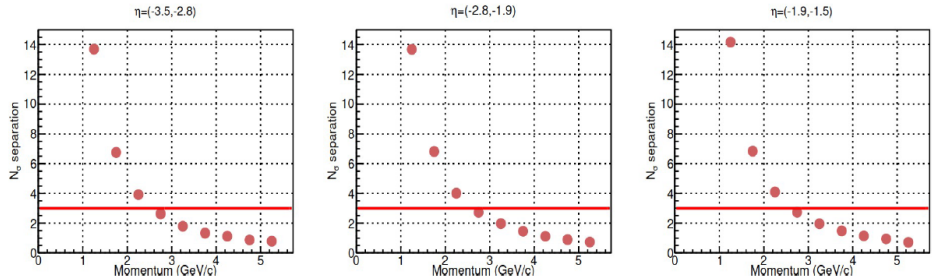
the EIC proximity focusing RICH for the backward endcap





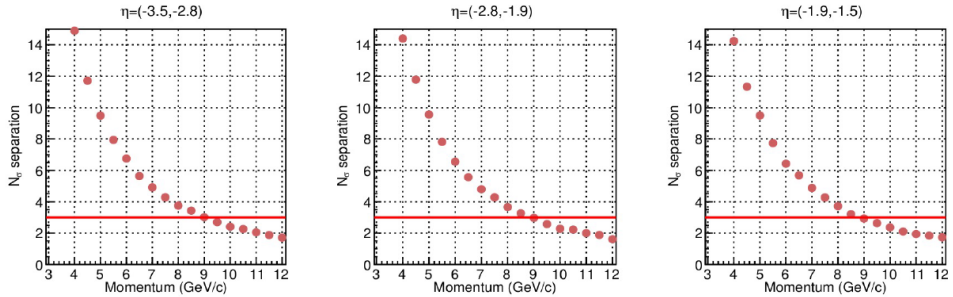
Performance: e/π & π/k separation

e/π



3σ at ~2.5 GeV

π/k



3σ at ~9.0 GeV

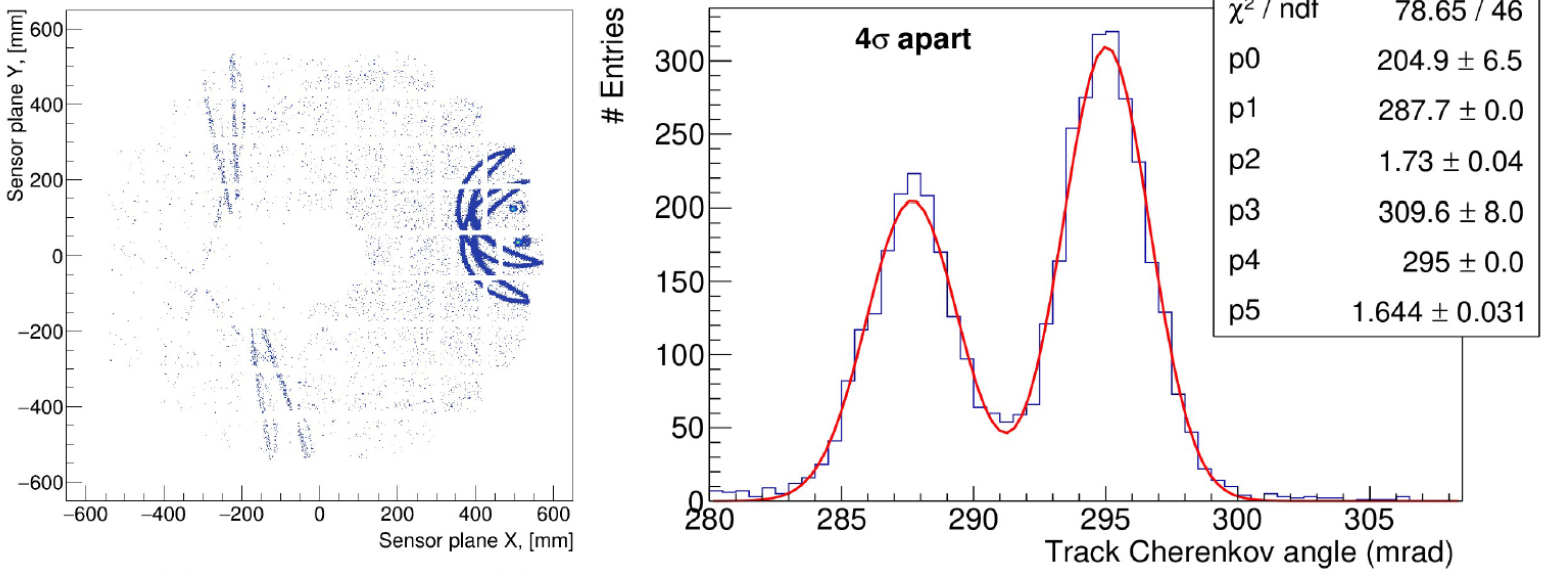
TOOLS for SIMULATION

NEW (2/2): last year activity

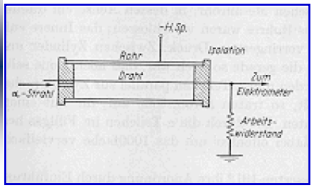
NEW TOOL: PID- tool based on χ^2

Effectiveness demonstrated identifying particles in extreme ring-overlap cases

7 GeV/c Momentum Vs Cherenkov angle (track)



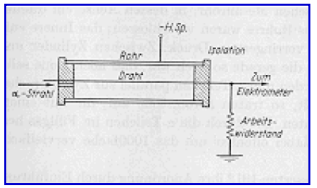
- **π** and kaon generated in same event.
- particle ϕ angle chosen to have overlapping rings at border pseudorapidity
- Event-based χ^2 model has a **95% accuracy** separating multi-particles



SUBSTANTIAL PROGRESS IN ALL R&D LINES

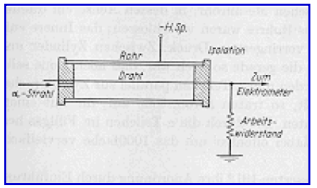
OF THE TASK 7.5.1

The R&D activity



BACKUP

The R&D activity



WP7 – task 7.5

D7.1	Characterisation of small size MRPC prototypes for fast timing and high rates	7.2	INFN-BO	R	PU	M36
D7.2	Validation of the eco-friendly gas mixtures for RPCs at GIF++	7.2	INFN-LNF	R	PU	M45
D7.3	Production with industry of small-size prototypes of μ-RWELLs	7.3	INFN-LNF	DEM	PU	M30
D7.4	A small-scale TPC prototype (~10 l) with hybrid charge/optical readout and a hydrogen rich gas mixture with high scintillation yield	7.4	RHUL	DEM	PU	M46
D7.5	Small-size prototype of a MPGD single photon detector for compact RICHs	7.5	INFN-TS	DEM	PU	M44

No MILESTONES for WP7 – task 7.5