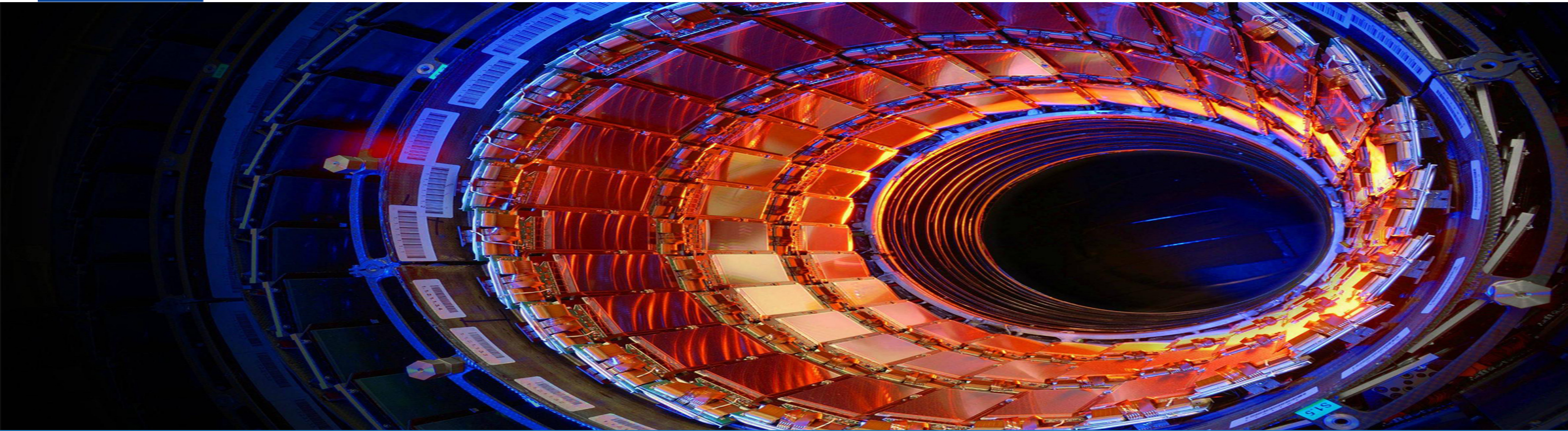


WP 32 – JRA14: MPGD-HP
Micropattern Gaseous Detectors for Hadron Physics

Fulvio Tessarotto – INFN Trieste   **Bernhard Ketzer** – University of Bonn

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

WP 32 – JRA14: MPGD-HP
Micropattern Gaseous Detectors for Hadron Physics

Coherent effort on MPGD by world experts from:

University of Aveiro,

Österreichische Akademie der Wissenschaften,

University of Glasgow,

Technische Universität München,

Rheinische Friedrich-Wilhelms-Universität Bonn,

GSI,

INFN-Bari, INFN-Trieste,

CEA-Saclay,

Work package title	JRA14-Micropattern Gaseous Detectors for Hadron Physics (MPGD_HP)							
Participant number	40	10	2	8	44	30	13	24
Short name of participant	UAVR	UBO	OeAW	GSI	UGLASGOW	INFN	TUM	CEA
Person-months per participant:	6	12	3	4,5	3	14,5	5,5	5,5

Objective: *improve gaseous detector capabilities for:*

Tracking

Photon detection

Particle identification

Timing

4 tasks:

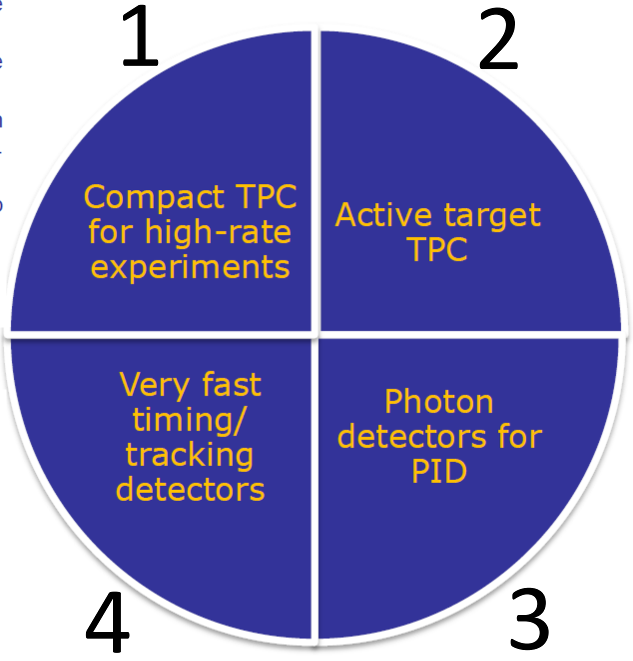
Goal: Prepare foundations for 3D continuous tracking with minimal material budget in environments with extremely high intensities and track densities.

Tasks:

- investigate properties of MPGD components at very high rates or local charge densities in terms of charge transport, ion backflow, possible instabilities and aging
- develeop numerical simulations for MPGDs with the power to make quantitative predictions
- construct detector vessels with very low material budget in combination with ultra-thin solenoid magnet structures will be developed in cooperation with the JRA CryPTA (H. Dutz et al.)
- characterize prototype detectors in particle beams and intense sources in order to optimize their performance

Deliverables: small-scale prototype of the high-rate TPC. Delivery: month 48.

Applications: JLAB (tagged DIS), RHIC (SPHENIX), CBELSA/TAPS, EIC



Goal: Develop TPC which acts as an active target and at the same time performs tracking of low-energy recoil particles from interactions in the active volume.

Tasks:

- perform detailed simulations of the setup including beam-induced noise, space-charge effects, etc. at different gas pressures from 1 to 20 bar in order to define the granularity of the readout structure
- optimize energy resolution by studying detectors with and without gas amplifications and the associated low-noise readout electronics
- A collaboration with the Proton Radius European Network (PREN) on the impact of this technology for the solution of the proton charge radius puzzle

Deliverables: Simulation results on energy ranges and resolutions in active target TPC (Task 2). Delivery: month 48

Applications: COMPASS++/AMBER, MAMI, AMADEUS

Goal: Micromegas-based tracking technology combining good spatial resolution (~100µm), very good time resolution (~100ps) and high rate capability

Tasks:

- Improved photocathode material to stand large particle flux: DLC, metal (in common with Picosec), also diamond grains (task 3)
- Alternative methods of primary electron production in order to reduce spatial distribution of emission: metal plate, secondary emission, thinner Cerenkov radiator
- Development of prototypes with larger active area size (~10cm) and anode strips at small pitch (~500µm), read-out by multi-channel electronics
- Evaluation of existing multi-channel readout electronics for time resolution vs rate vs compactness vs cost optimization

Deliverables: prototype of the Fast Cherenkov Micromegas Detector (Task 4). Delivery: month 42.

Applications expected for trackers at low angle in high rate environments (electron-ion collider, fixed target experiments)

Goal: Develop a modular hybrid MPGD (Micromegas + THGEM or GEMs) with high-granularity readout elements for the detection of single photons in harsh environment

Tasks:

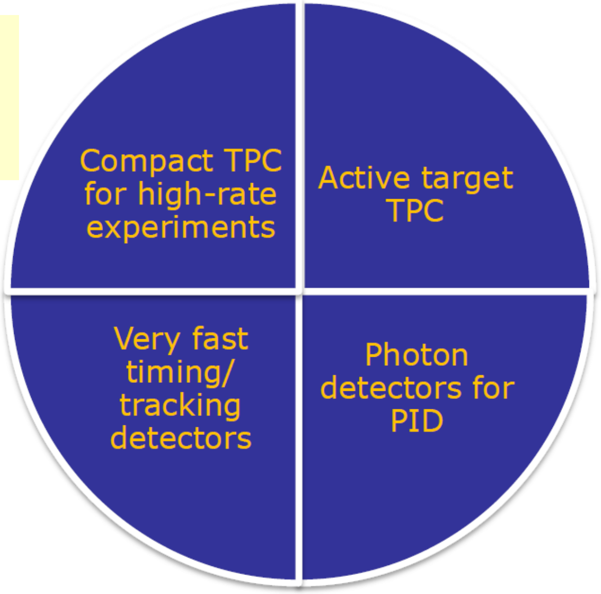
- develop a modular hybrid MPGD with miniaturized readout elements, high photosensitivity, minimal dead area and an architecture suppressing the ion back-flow ⇨ already started with a preliminary prototype
- characterize photon response in various conditions, in particular operation in windowless mode and pure CF_4 ⇨ will start in 2020
- explore the possibility to use graphite-rich nano-crystalline diamond grains as photoconverters in gaseous detectors for single photons ⇨ to be done, very first trials are ongoing

Deliverables:

- fully characterized prototype of the Minipad Modular PD. Delivery: month 36.
- publication of the diamond-based photoconverter performance in gaseous PDs. Delivery: month 48.

Applications: EIC, fixed target

3 milestones, 5 deliverables



Work package number	32
Work package acronym	MPGD_HP
Work package title	JRA14-Micropattern Gaseous Detectors for Hadron Physics

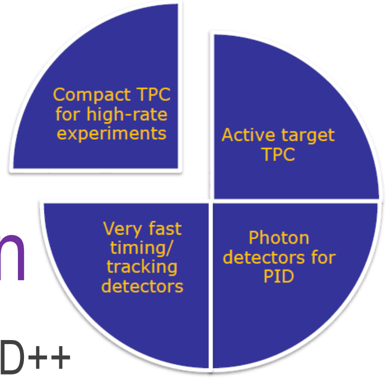
TASKS/Subtasks	**Year 1**				**Year 2**				**Year 3**				**Year 4**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Compact micro-pattern TPC for high-rate experiments																
1.1 Numerical simulations for MPGDs																
1.2 Development of prototype TPC for high rates																
2. Active target TPC																
2.1 Active target TPC																
3. Photon detectors for PID																
3.1 Construction of a Minipad Modular PD																
3.2 Test of diamond-based photoconverters																
3.3 Test of windowless RICH PD prototype																
4. Very fast timing by Micromegas-based Cherenkov PDs																
4.1 Fast Cherenkov MM																

D32.1	Minipad Modular PD	WP32	30 - INFN	Demonstrator	Public	36
D32.2	Fast Cherenkov Micromegas Detector	WP32	24 - CEA	Demonstrator	Public	42
D32.3	A small-scale prototype of the high-rate TPC	WP32	13 - TUM	Demonstrator	Public	48
D32.4	Simulation results on energy ranges and resolutions in active target TPC	WP32	10 - UBO	Report	Public	48
D32.5	Publication of the diamond-based photoconverter performance in gaseous PDs	WP32	30 - INFN	Report	Public	48

Milestone title	**Due Date (in months)**	**Means of verification**
Design of prototype high-rate TPC	24	CAD production drawings
Investigation of beam-induced noise	27	Report
Diamond-based photocathode QE in gas	30	Submission of journal article to International Peer Review

No milestones or deliverables in the first 18 months: we foresee to meet the ones of the next period despite the Covid-19 delays

Task 1: compact TPC for high rate



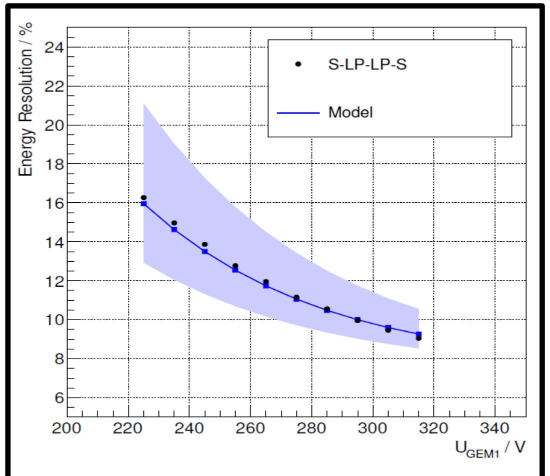
U. Bonn

Studies of Charge Transfer in MPGD

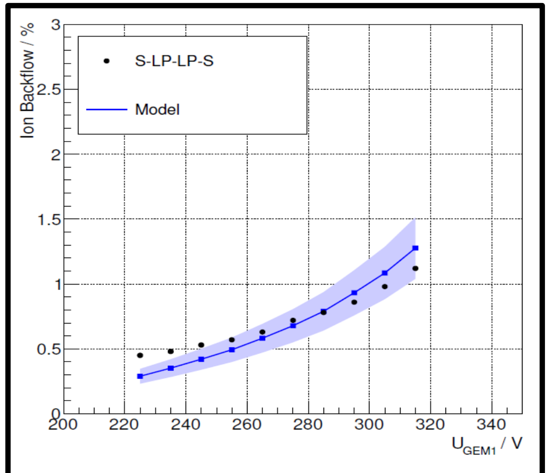
1. Analytic model for charge transfer based on electric flux calculations
   - collection and extraction efficiencies for electrons and ions
   - energy resolution
   - ion backflow

   as a function of geometry of GEM / Micromegas and external fields

2. Comparison and tuning to measurements and simulations
   - systematic measurements with small detector prototypes
   - GARFIELD++ simulations



(a) $U_{\mathrm{GEM2}} = 235$ V

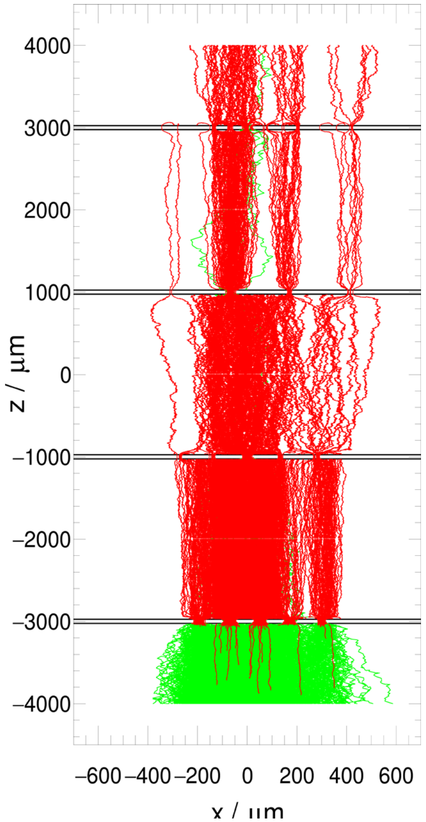


(a) $U_{\mathrm{GEM2}} = 235$ V

Viktor Ratza PhD thesis: http://hdl.handle.net/20.500.11811/8421

Optimizing Field Configuration

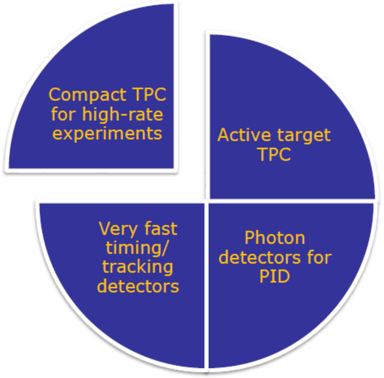
Full simulation of multi MPGD-stacks in GARFIELD++



	Simulation		Messung	
	ALICE	Optimiert	ALICE	Optimiert
$G_{\mathrm{eff},1}$	$10{,}55 \pm 0{,}31$	$5{,}05 \pm 0{,}15$	$7{,}42 \pm 0{,}08$	$4{,}1 \pm 0{,}5$
$\varepsilon_{\mathrm{coll},1}$	$100^{+0}_{-0{,}0010}$ %	$99{,}990^{+0{,}010}_{-0{,}373}$ %		
$\varepsilon_{\mathrm{extr},1}$	$61{,}9^{+0{,}6}_{-0{,}6}$ %	$34{,}0^{+0{,}6}_{-0{,}6}$ %		
IB_1/IB_{tot}	$69{,}98^{+0{,}05}_{-0{,}04}$ %	$4{,}978^{+0{,}010}_{-0{,}010}$ %	$(51{,}1 \pm 2{,}3)$ %	$(3{,}3 \pm 0{,}5)$ %
$G_{\mathrm{eff},2}$	$0{,}616 \pm 0{,}024$	$0{,}583 \pm 0{,}022$	$0{,}519 \pm 0{,}021$	$0{,}52 \pm 0{,}11$
$\varepsilon_{\mathrm{coll},2}$	$16{,}1^{+0{,}6}_{-0{,}6}$ %	$31{,}3^{+1{,}1}_{-1{,}1}$ %		
$\varepsilon_{\mathrm{extr},2}$	$65{,}3^{+0{,}8}_{-0{,}8}$ %	$29{,}3^{+0{,}8}_{-0{,}7}$ %		
IB_2/IB_{tot}	$13{,}77^{+0{,}11}_{-0{,}10}$ %	$3{,}837^{+0{,}010}_{-0{,}010}$ %	$(12{,}6 \pm 2{,}7)$ %	$(2{,}1 \pm 0{,}6)$ %
$G_{\mathrm{eff},3}$	$0{,}552 \pm 0{,}025$	$9{,}11 \pm 0{,}17$	$0{,}44 \pm 0{,}05$	$15{,}05 \pm 0{,}30$
$\varepsilon_{\mathrm{coll},3}$	$17{,}9^{+0{,}8}_{-0{,}8}$ %	$90{,}7^{+0{,}9}_{-0{,}9}$ %		
$\varepsilon_{\mathrm{extr},3}$	$16{,}5^{+0{,}4}_{-0{,}4}$ %	$45{,}46^{+0{,}34}_{-0{,}34}$ %		
IB_3/IB_{tot}	$5{,}02^{+0{,}11}_{-0{,}10}$ %	$8{,}877^{+0{,}008}_{-0{,}008}$ %	$(4{,}2 \pm 2{,}7)$ %	$(5{,}5 \pm 0{,}7)$ %
$G_{\mathrm{eff},4}$	$56{,}2 \pm 0{,}7$	$52{,}51 \pm 0{,}26$	$97{,}7 \pm 1{,}1$	$59{,}80 \pm 0{,}33$
$\varepsilon_{\mathrm{coll},4}$	$100^{+0}_{-0{,}028}$ %	$99{,}899^{+0{,}030}_{-0{,}038}$ %		
$\varepsilon_{\mathrm{extr},4}$	$57{,}10^{+0{,}14}_{-0{,}14}$ %	$53{,}37^{+0{,}05}_{-0{,}05}$ %		
IB_4/IB_{tot}	$11{,}22^{+0{,}11}_{-0{,}10}$ %	$82{,}3068^{+0{,}0033}_{-0{,}0032}$ %	$(10{,}9 \pm 3{,}5)$ %	$(87{,}4 \pm 0{,}8)$ %
$G_{\mathrm{eff,tot}}$	202 ± 14	$1\,410 \pm 73$	$164{,}0 \pm 1{,}0$	$1\,932 \pm 120$
IB_{tot}	$3{,}23^{+0{,}5}_{-0{,}5}$ %	$5{,}54^{+0{,}32}_{-0{,}32}$ %	$(2{,}82 \pm 0{,}05)$ %	$(3{,}030 \pm 0{,}011)$ %

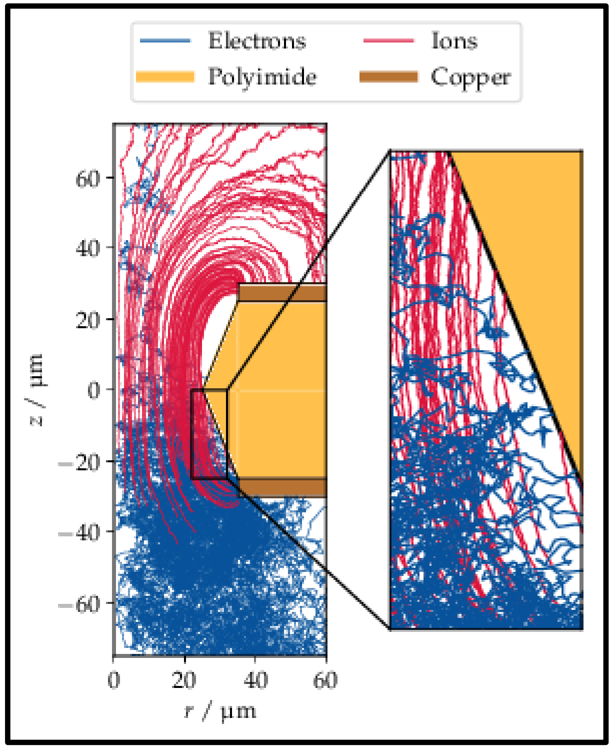
Jonathan Ottnad PhD thesis: http://hdl.handle.net/20.500.11811/8516

Task 1: compact TPC for high rate

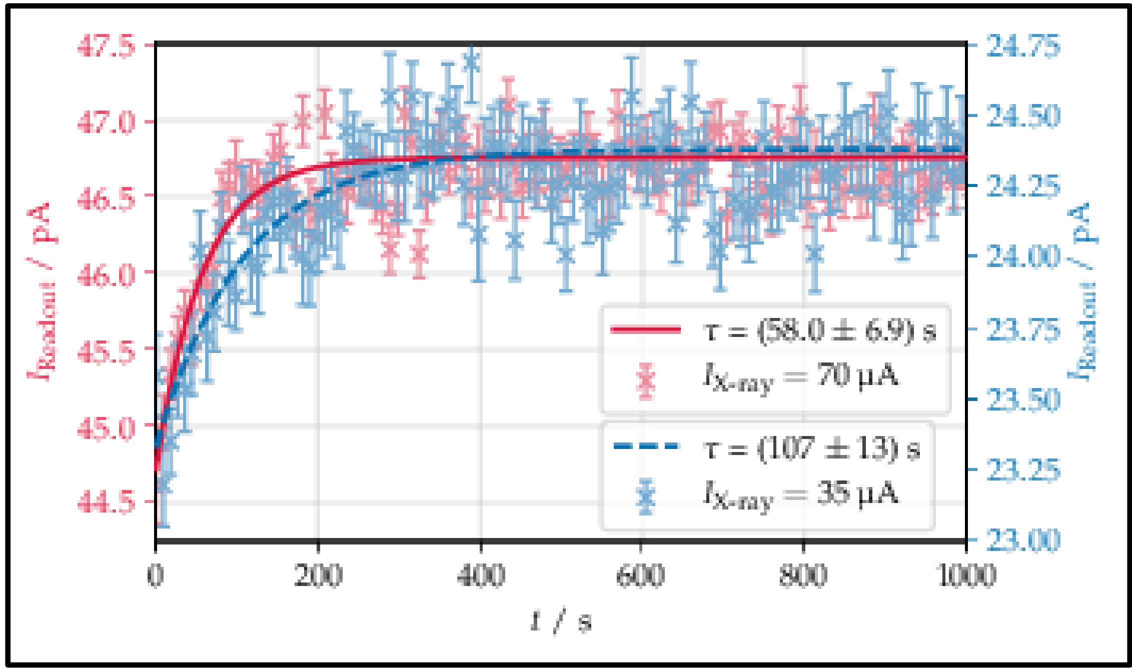


U. Bonn

- Study of charging-up effect by detailed measurements with a single GEM foil
- Exponential behavior studied under different rates and different voltages
- Often other effects mimic genuine charge-up

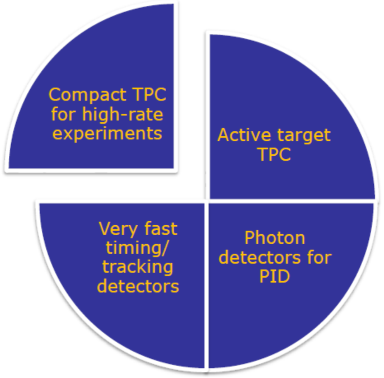


- Rate dependence understood in terms of total charge inside GEM hole for constant GEM voltage
- Residual voltage dependence observed ⇒ movement of charges on insulator surface and through material bulk, water content, etc.?



P. Hauer et al., Nucl. Instr. Meth. A 976 (2020) 164205 https://doi.org/10.1016/j.nima.2020.164205

Task 1: compact TPC for high rate



U. Glasgow

- Development of the design of the multiple time projection chamber (mTPC) via simulations

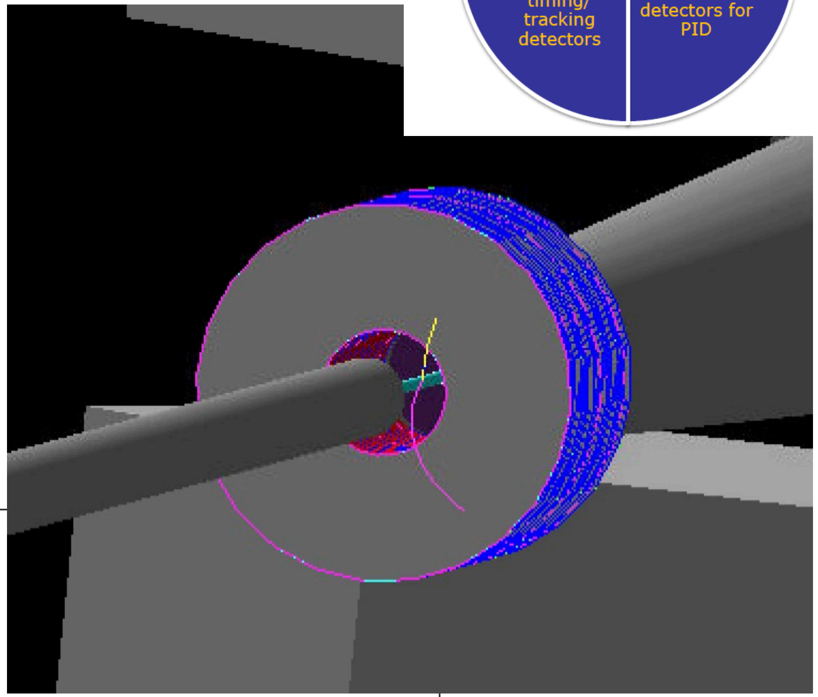
- mTPC will be used for a meson structure experiment at Jlab in which the signal is accompanied by several hundreds of MHz of background particles with similar kinematics

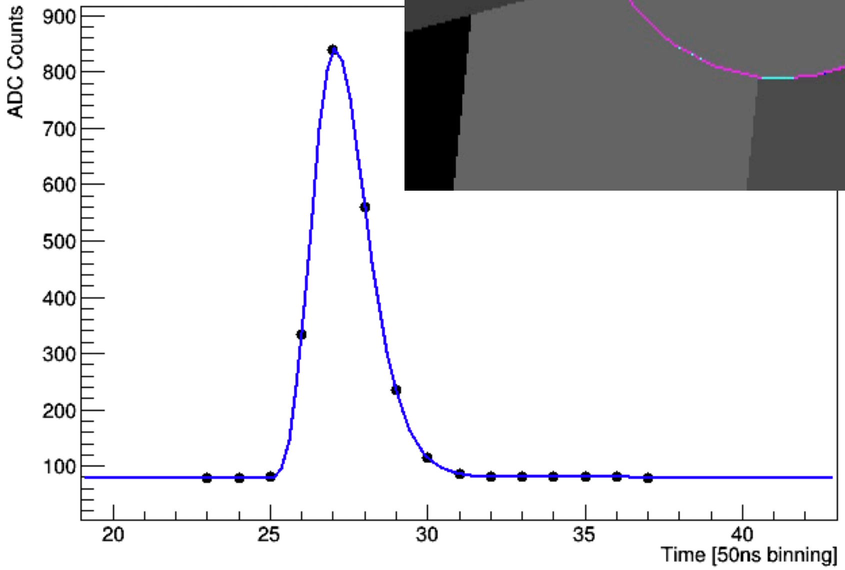
- mTPC immediately surrounds the target and is segmented along the beamline to reduce resultant rates in each chamber of the mTPC

- Simulations have verified design can cope with expected rates

- Simulations of readout electronics' rate capability underway

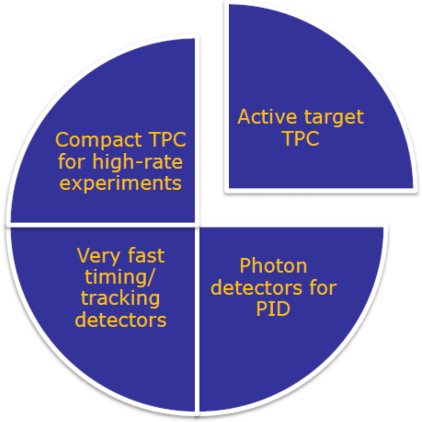
- Upcoming plans include construction of prototype to optimise mTPC design features, test rate capabilities and tune simulations





Task 2: active target TPC

U. Bonn



Whole COMPASS++/AMBER setup in TGeant

TPC implemented with all elements (windows, electrodes, …)

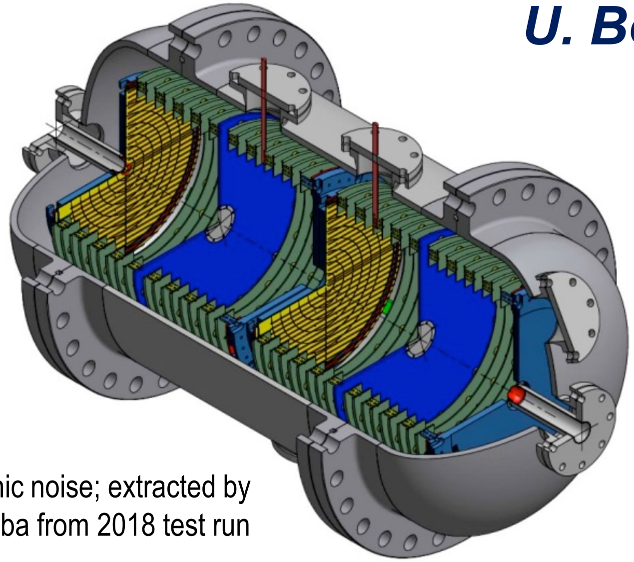
100GeV/c muons shoot on target
- Elastic scattering with protons (Rosenbluth cross-section)
- Energy loss in TPC

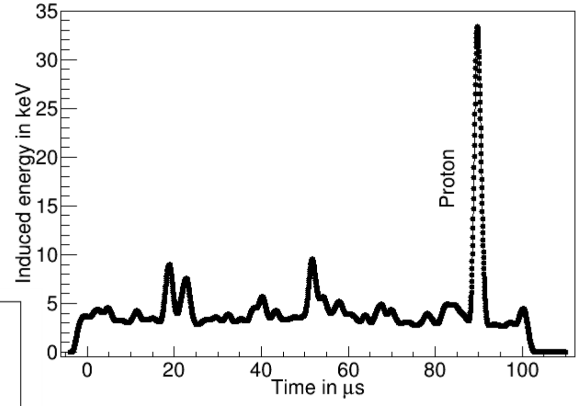
Electron-ion-creation from energy loss

Drifting electrons down to the Frisch grid
- Taking into account drift velocity and diffusion

Signal induction in the TPC read-out including pile-up and electronic noise; shaped with electronics

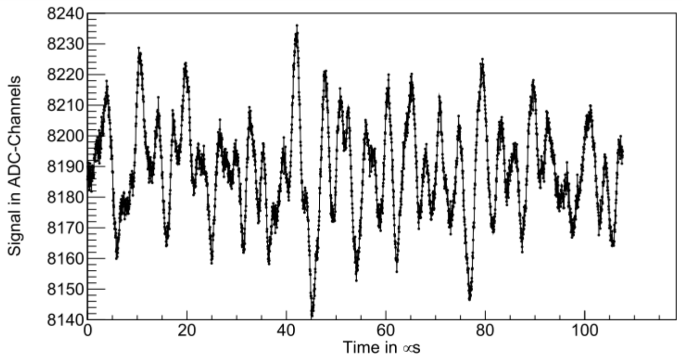
Region	E in kV cm^{-1}	p in bar	v_{drift} in cm ms^{-1}	$\tilde{D}_{\mathrm{T}}$ in µm cm$^{-0.5}$	$\tilde{D}_{\mathrm{L}}$ in µm cm$^{-0.5}$
drift	0.464	4.0	417.1 ± 0.4	158.7 ± 2.2	125.5 ± 1.3
	2.32	20.0	417.0 ± 0.4	70.6 ± 0.8	57.6 ± 1.4
induction	2.0	4.0	841.6 ± 0.7	131.6 ± 1.9	87.8 ± 1.6
	10.0	20.0	841.8 ± 0.7	58.7 ± 0.8	38.5 ± 0.8





Signal read-out by a pad

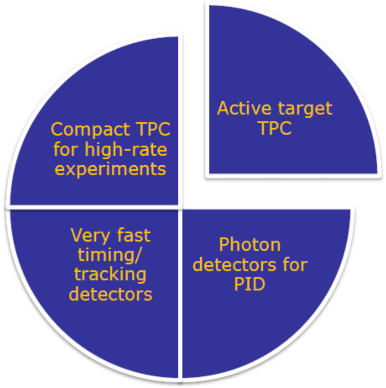
Electronic noise; extracted by A. Dzyuba from 2018 test run



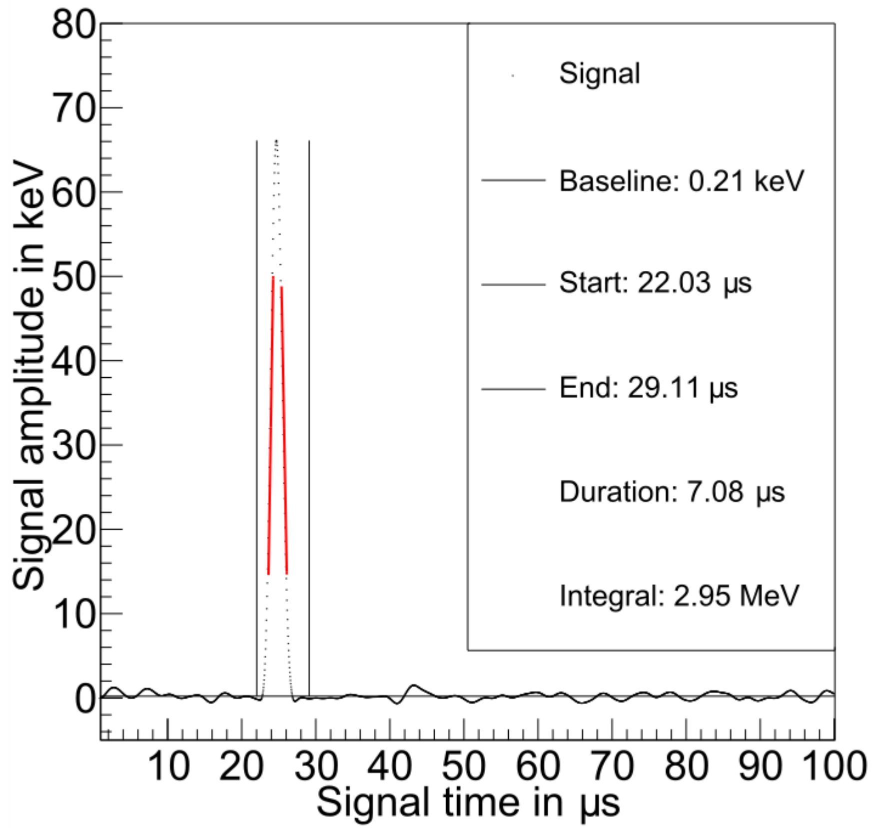
COMPASS++/AMBER: Proposal for Measurements at the M2 beam line of the CERN SPS Phase-1: 2022-2024

Task 2: active target TPC

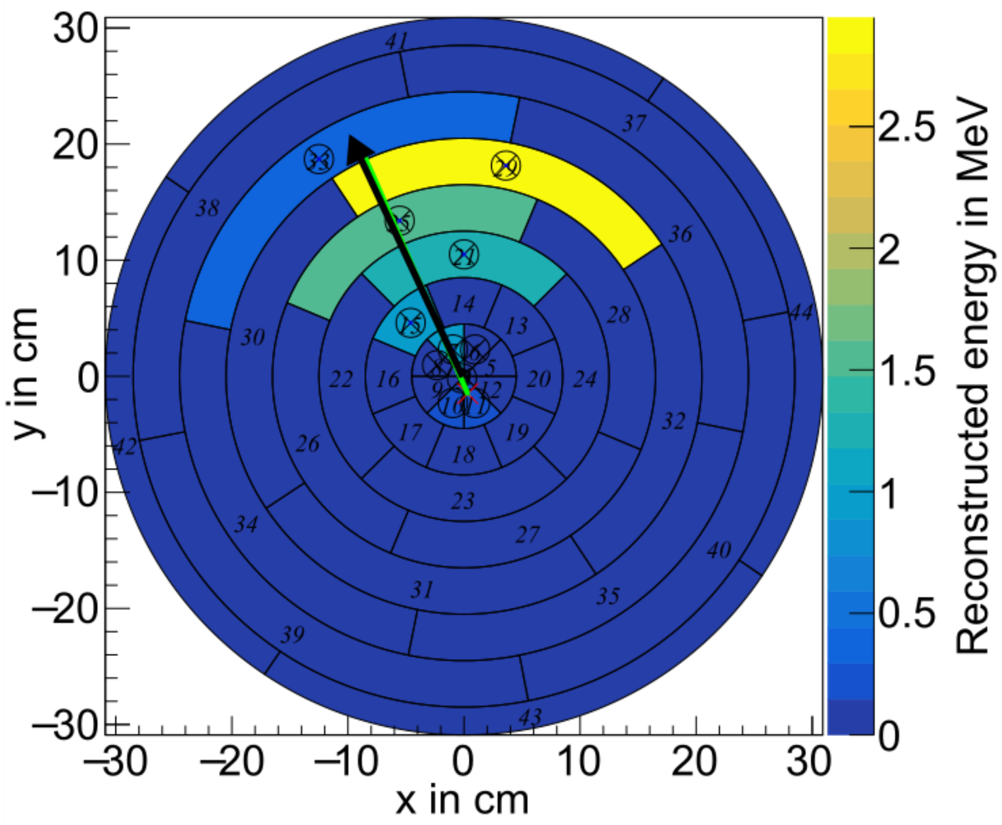
U. Bonn



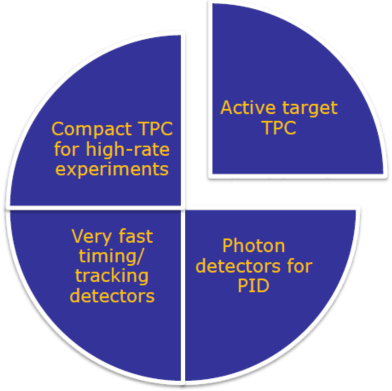
Analysis of the signals:



MC track in green; recontructed track in black; vertex in red



Task 2: active target TPC

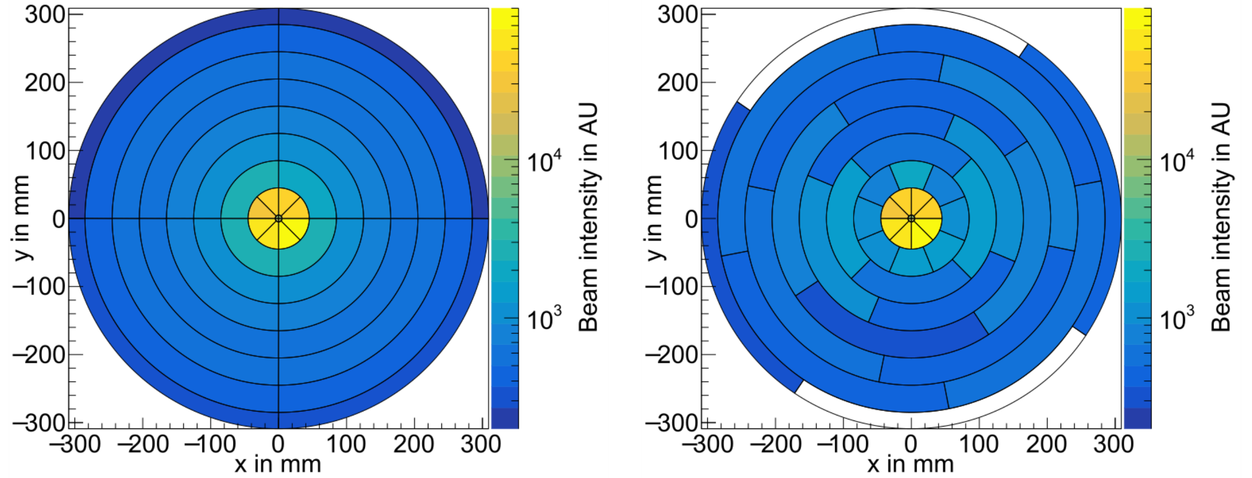


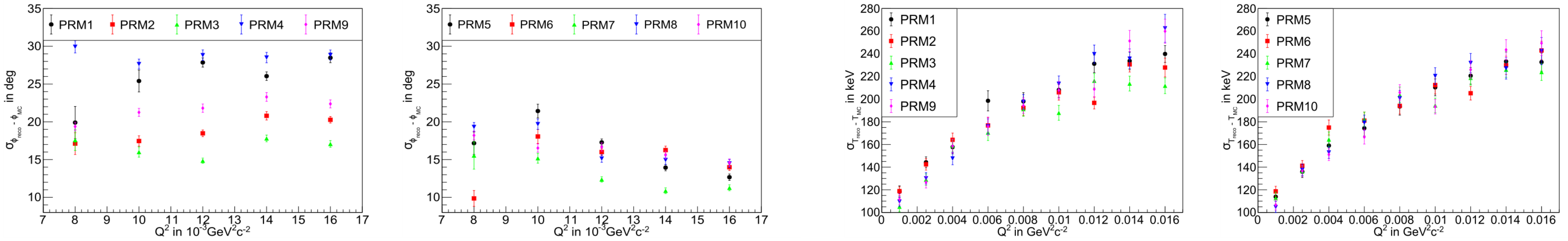
Pad plane geometry optimization

Beam files projected onto pad planes

Different pad planes implemented in TGeant
- With pad response functions
- With different geometries
  - Radial segmentation
  - Angular segmentation

Studies of energy and angular resolution

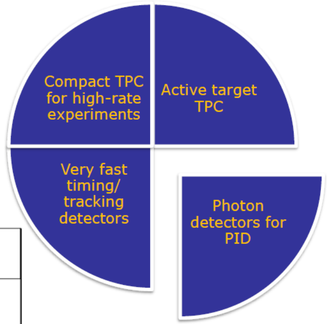




STRONG 2020

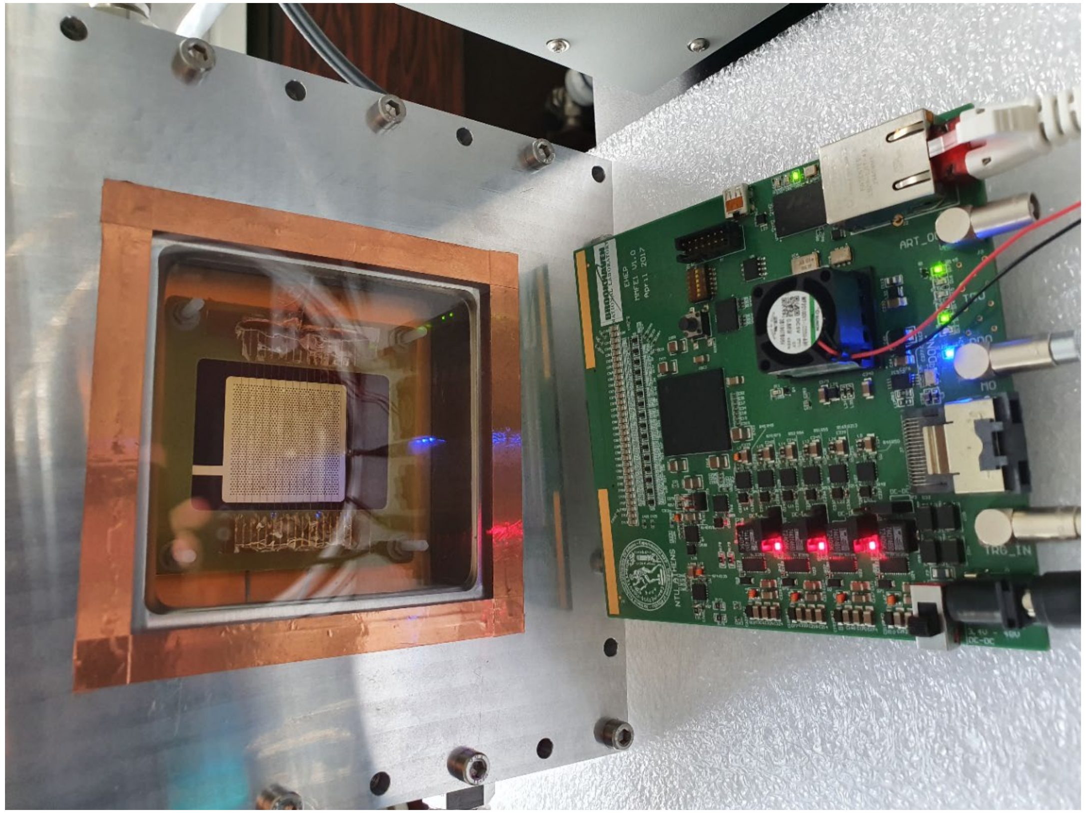
Task 3: photon detectors for PID

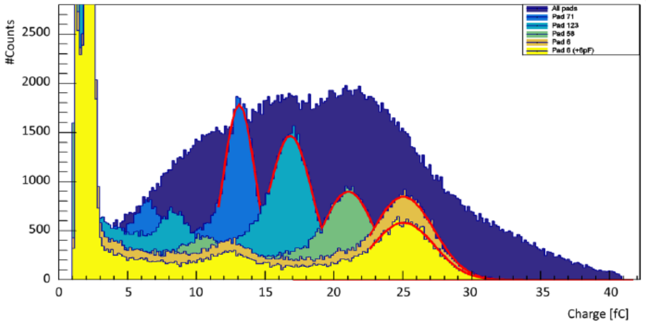
INFN - Trieste



Modular minipad detector of single photons

New prototype built

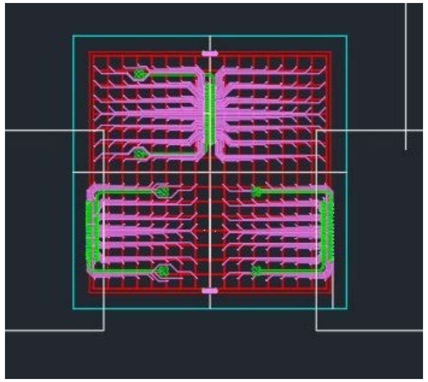




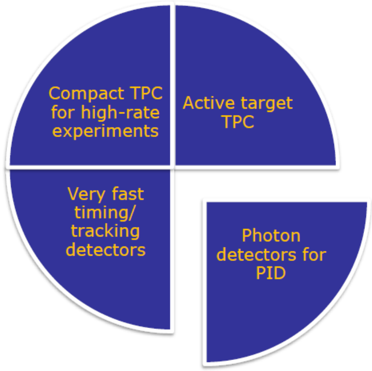
The 1024 pads of 3mm x 3 mm prototype has been systematically tested with APV25 and SRS readout.

Not fully satisfactory results because of non uniform response and difficult noise control

New anode layout geometry developed, compatible with APV25 and VMM readout systems



Task 3: photon detectors for PID



THGEM discharge stability

Formation of primary discharges (discharges that occur within THGEM holes) has been shown to be caused by the charge density inside the holes exceeding a certain limit

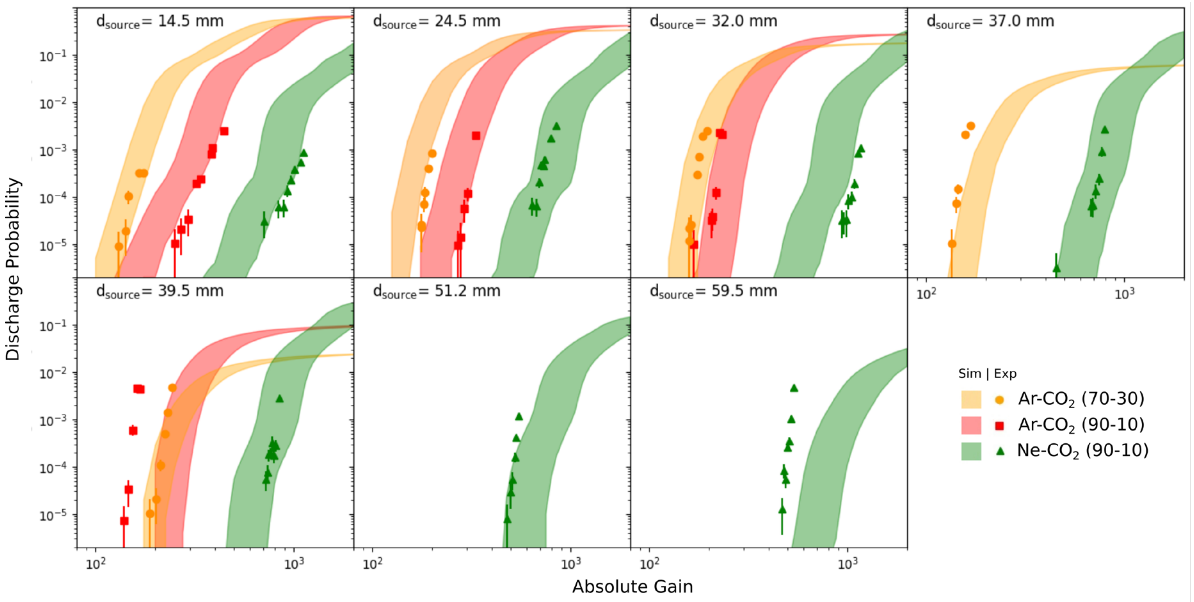
- Similar mechanism observed with standard GEMs [P. Gasik et al. NIM A, 870 (2017) 116-122]

Experimentally observed reduced stability of THGEMs (compared to GEMs) can be explained with increased charge density due to hole geometry

Gas	Q_{crit}
Ne–CO_2 (90–10)	$(5.9 \pm 1.4) \times 10^6$
Ar–CO_2 (90–10)	$(3.5 \pm 0.7) \times 10^6$
Ar–CO_2 (70–30)	$(2.0 \pm 0.3) \times 10^6$

Critical charge limits for different gas mixtures, obtained through simulations using a geometrical model.

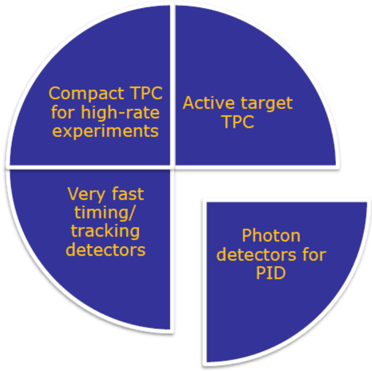
Primary THGEM discharge stability



Simulated and experimental results of primary discharge stability studies with THGEMs, conducted with different gas mixtures at different source distances.

L. Lautner Master Thesis
http://www.das.ktas.ph.tum.de/DasDocs/Public/Master_Theses/Master_Thesis_LukasLautner.pdf

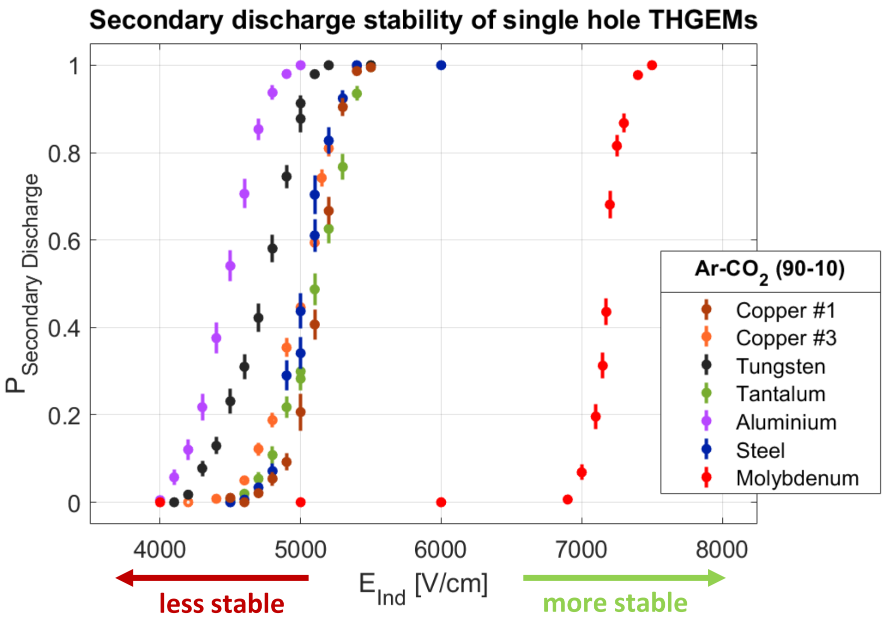
Task 3: photon detectors for PID



Delayed secondary discharges in (TH)GEMs

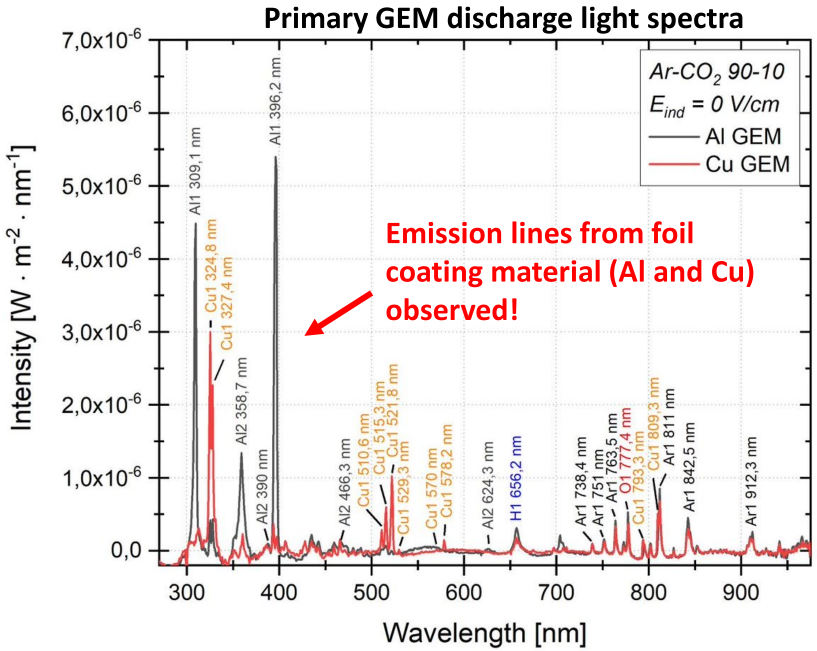
First comprehensive study comparing GEM & THGEM foils produced with various "exotic" coating materials in terms of their discharge stability

- Material dependence observed on the unexplained delayed secondary GEM discharge phenomenon



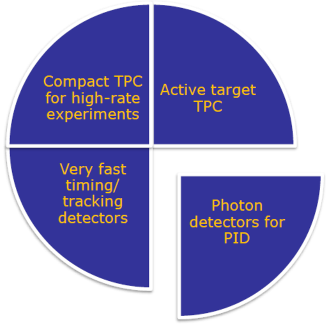
The light emitted during GEM discharges is studied using spectroscopy to uncover new clues

- Evaporated foil material observed inside GEM discharge plasma via the identification of the metal emission lines



following the study in A. Deisting et al. NIMA 937(2019) 168

Task 3: photon detectors for PID



INFN - Trieste

PCBs and THGEMs coated with H-ND:

INFN - Bari

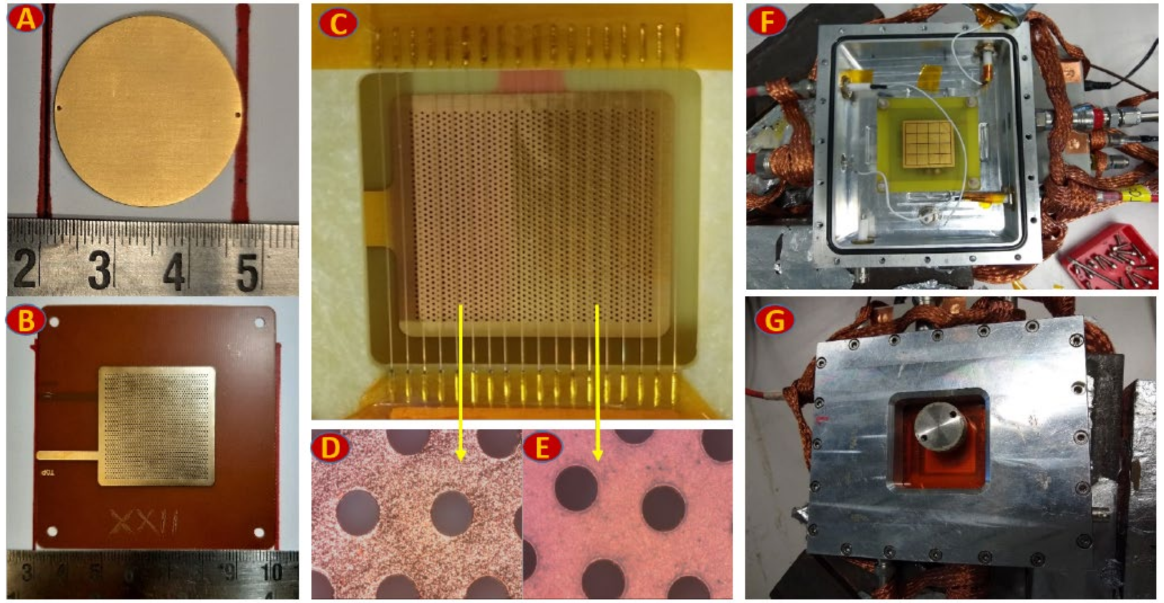
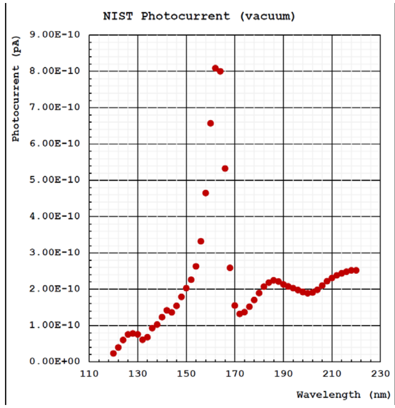
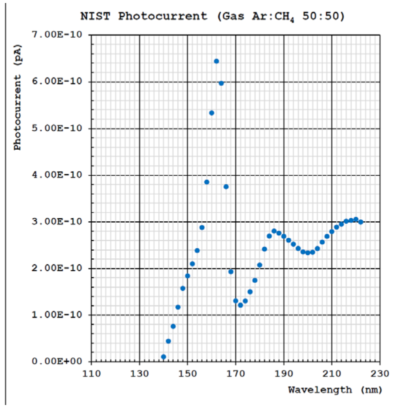


Figure 2. (A) Au_PCB of 1 inch diameter substrate used for the QE measurement. (B) Uncoated THGEM of active area 30 mm×30 mm. (C) Half uncoated and half coated THGEM, mounted into the test chamber and zoomed view of the both coated (D) and uncoated (E) part. (F) test chamber with readout pad where the THGEMs are tested. (G) The test chamber after installation of a THGEM, illuminated by an ^{55}Fe X-ray source.

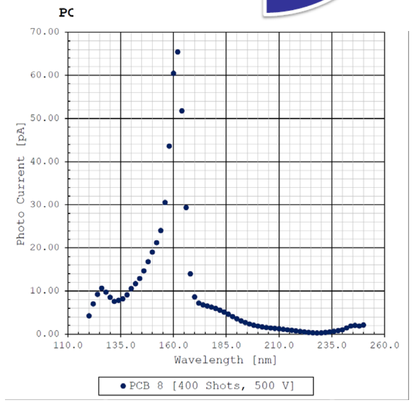
F.M. Brunbauer et al. JINST 15 (2020) C09052

Systematic study of Q.E. and H-ND coated TGEM response are ongoing





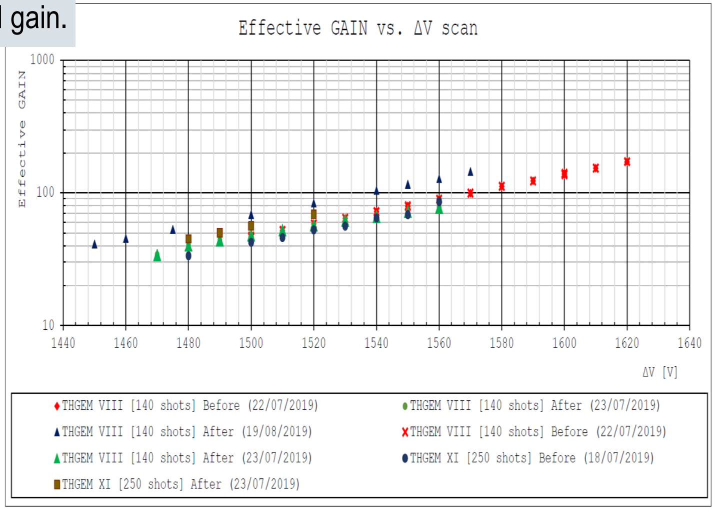
NIST photocurrent in vacuum and Ar:CH_4 50/50 gas at atm. pr.

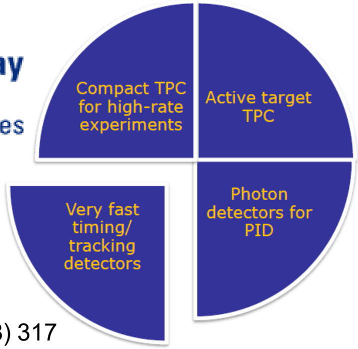


H-ND coated PCB photocurrent.

H-ND coated THGEM gain.

- THGEM used: THGEM IX [d = 0.4 mm; t = 0.4 mm; p = 0.8 mm; RIM < 5 µm];
- Gas Misxture: Ar:CH_4 50:50.
- CAEN N1471H HV PS
- Voltage Configuration: Drift = 2520 V; Top = 2020 V; Bottom = 500 V;
- ^{55}Fe X – Ray source.
- Cremat CR – 110 Preamp + ORTEC 590A Amplifier + AMPTEK MCA 8000A.
- Calc. Eff. Gain ~ 122





Task 4: very fast timing/tracking

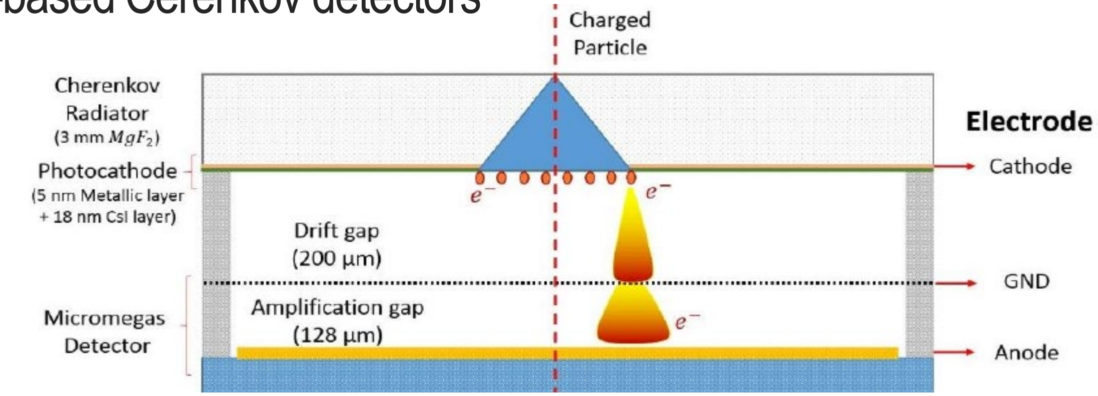
by Micromegas-based Cerenkov detectors

Picosec Micromegas progress:

Primary electron produced on photocathode using Cerenkov light from 1-5 mm-thin MgF_2 radiator

Thin (100-300 μm) drift region to minimize diffusion effects + preamplification → time resolution ~47 ps for single photoelectrons, ~24 ps for 150 GeV muons

Limitations: spatial resolution at mm level, fragility of the CsI layer on photocathode



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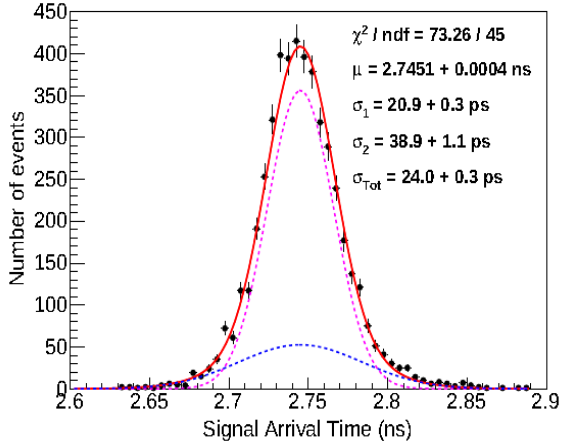
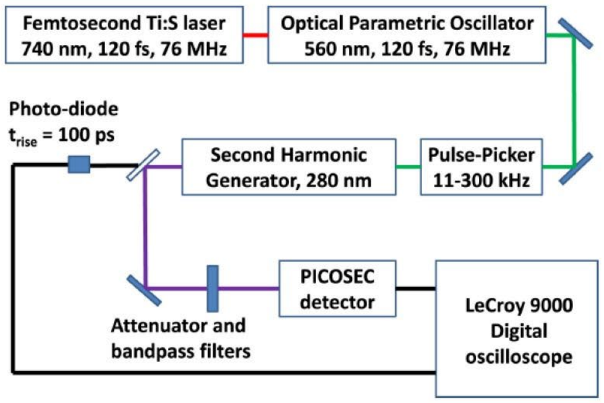
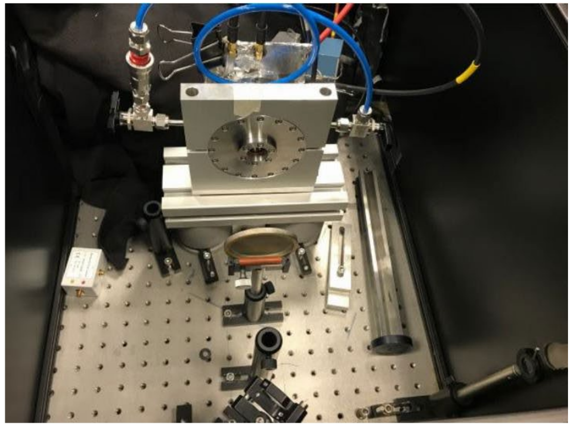
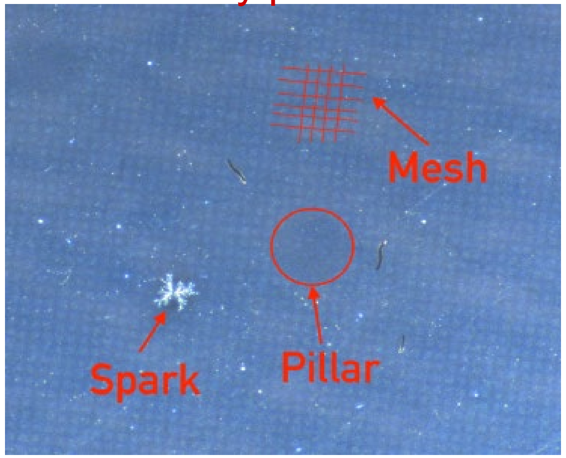


Photocathode material studies:





CsI layer after high-intensity pion beam



Alternative solutions:

- Carbon photocathodes: diamonds films or nanoparticles, boron-doped diamond films
- Thick carbon or metal layers as primary emitters

Studies with FLUME 100 fs UV laser (CEA Saclay) 2 materials look promising: Al layer and CsI protected with MgF2 ~50ps resolution although lower numbers of photoelectrons (factor 2 to 5 less than CsI)

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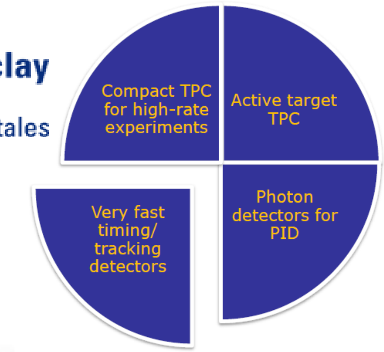
Task 4: very fast timing/tracking

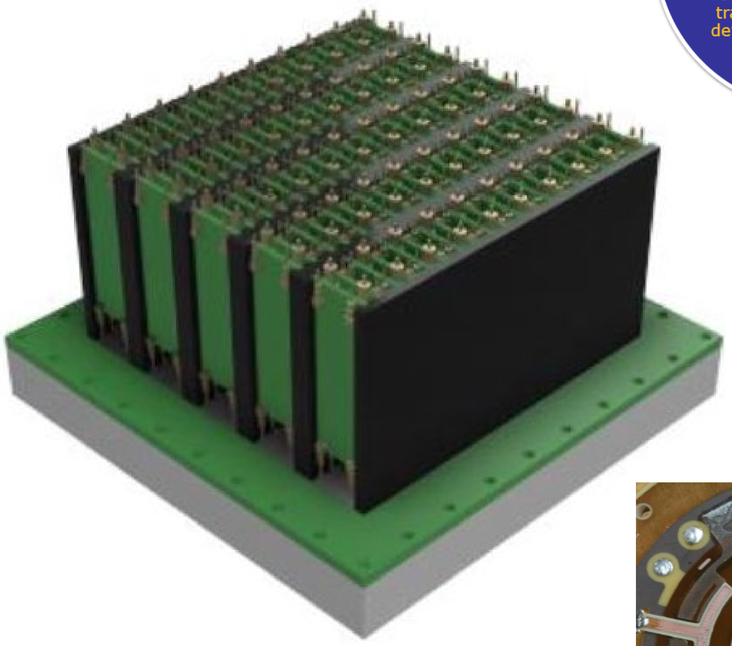
by Micromegas-based Cerenkov detectors

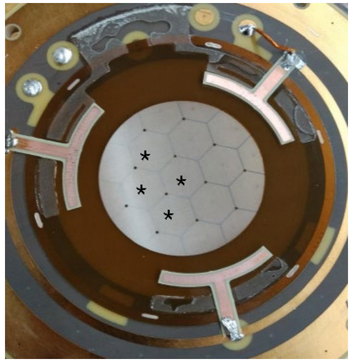


Multi-channels prototype:

1 prototype 5cm-large showing degraded time resolution for multi-pad events due to deformations, however can be corrected with off-line analysis

Development of 10x10cm² prototype ongoing with specific electronics developed at CEA Saclay, ceramic base to control deformations





Perspectives:

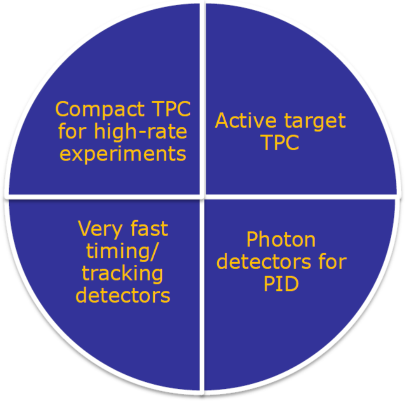
Primary electron production

- Further studies on photocathode materials and materials as primary emitters
- Goal: robustness, resistance to radiations, 50 ps time resolution

Large prototype for hadronic physics

- 20x20cm prototype with DLC and/or metallic primary emitter, depending of the results of the present studies
- Based on PCB to study impact of deformations and software corrections for larger size

STRONG-2020 WP 32 manpower and publications



- **Chandradoy Chatterjee: post-doc, INFN - Trieste**
- **Martin Hoffmann: PhD student, University of Bonn**
- **Triloki Triloki: post-doc, INFN - Trieste**

Pubblications:

P. Hauer et al., “Measurements of the charging-up effect in Gas Electron Multipliers”
Nucl. Instr. Meth. A 976 (2020) 164205

K. Kordas et al. Progress on the PICOSEC-Micromegas Detector Development: Towards a precise timing, radiation hard, large-scale particle detector with segmented readout
Nucl. Instr. Meth. A 958 (2020) 162877

M. Baruzzzo et al., “Direct measurements of the properties of Thick-GEM reflective photocathodes”,
Nucl. Instr. Meth. A 972 (2020) 164099

J. Agarwala et al., “ Study of MicroPattern Gaseous detectors with novel nanodiamond based photocathodes for single photon detection in EIC RICH”,
Nucl. Instr. Meth. A 952 (2020) 161967

J. Agarwala et al., “A modular mini-pad photon detector prototype for RICH application at the ElectronIon Collider”,
Journal of Physics: Conference Series 1498 (2020) 012007

C. Chatterjee et al., “Nanodiamond photocathodes for MPGD-based single photon detectors at futureEIC”,
Journal of Physics: Conference Series 1498 (2020) 012008

J. Agarwala et al., “MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond” (2020),
JINST 15 (2020) C09063

F. M. Brunbauer et al., “Nanodiamond photocathodes for MPGD-based single photon detectors at future EIC”,
JINST 15 (2020) C09052

The WP 32 activities are on track, great progress despite Covid-19, milestones and deliverables expected in due time