Recent photocathode and sensor developments for the PICOSEC Micromegas detector

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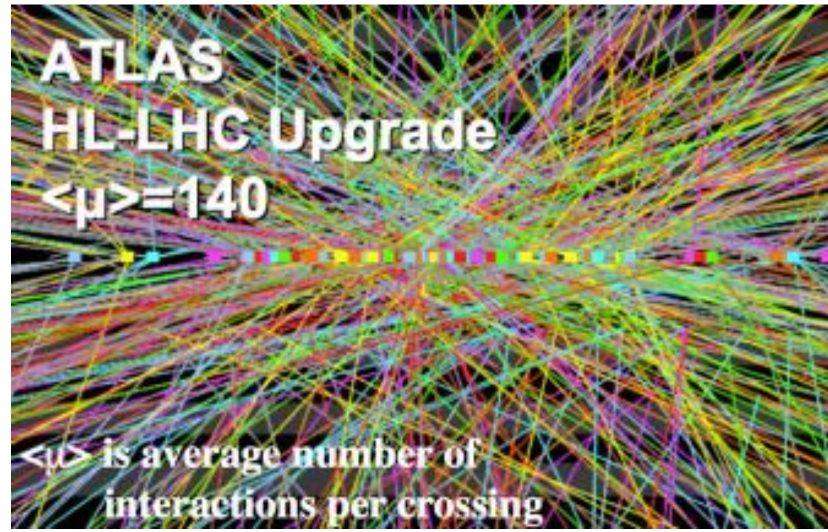
Outline

1. Introduction:
   - Motivation
   - PICOSEC detector concept
2. Study of single-channel prototype with CsI photocathode
3. Study of robust photocathode and resistive anode
4. Conclusion

Motivation

High Luminosity Large Hardon Collider

- Typically 140 collisions per bunch crossing
- High pile-up effect
- Tens ps timing & Tracking information



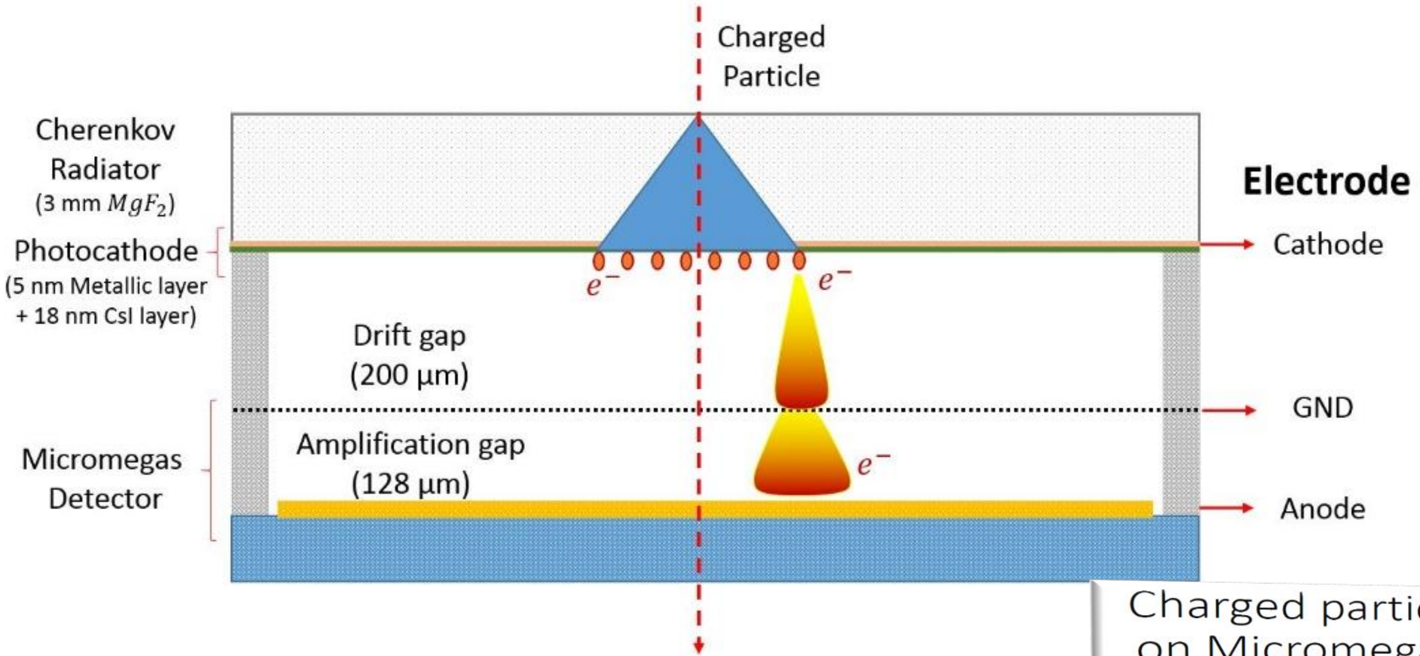
PID techniques: Alternatives to RICH methods, J. Va'vra, NIMA 876 (2017) 185-193.

Detectors' performance requirement

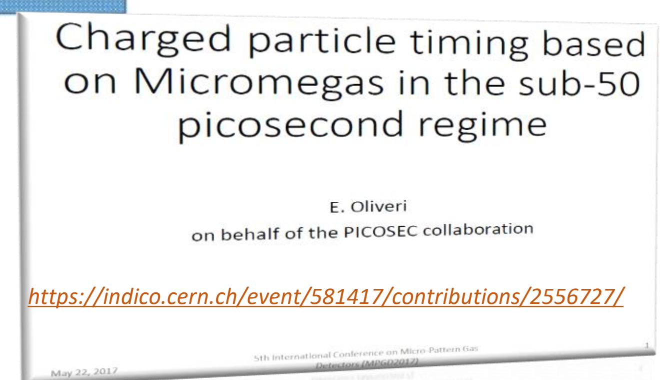
- Good time resolution (a few tens ps)
- Hige rate & High Radiation
- High granularity

PICOSEC Detector Concept

A Novel fast timing Micromegas detector: **Cherenkov Light Detection**



- Cherenkov Radiator & Photocathode
- Smaller drift gap
- Higher drift electric field


Charged particle timing based on Micromegas in the sub-50 picosecond regime

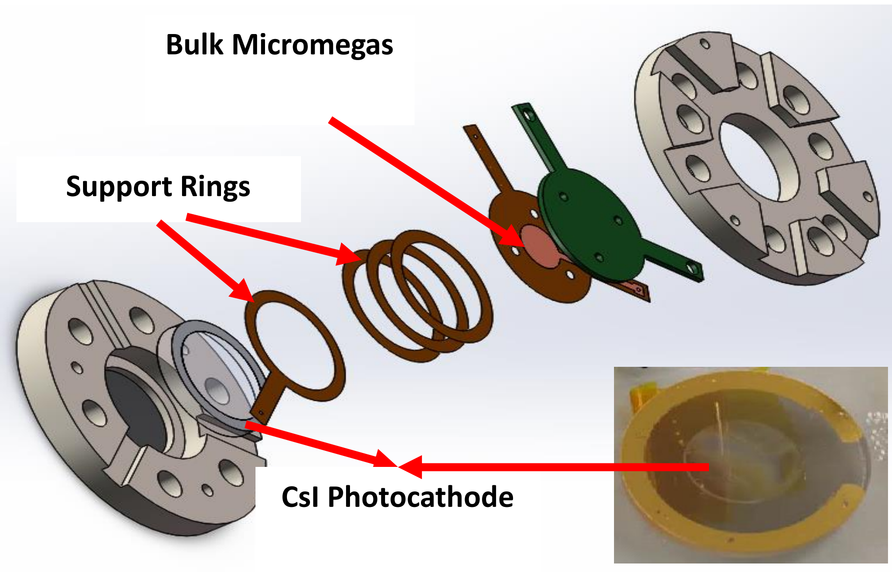
E. Oliveri
on behalf of the PICOSEC collaboration

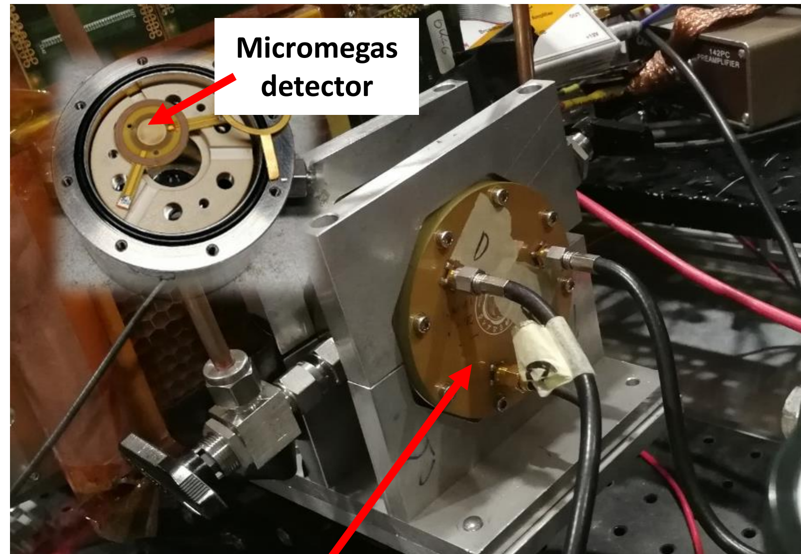
https://indico.cern.ch/event/581417/contributions/2556727/

May 22, 2017

Good time resolution should be achieved.

Single-channel prototype





- 1 cm diameter active area
- 6 pillars form 128 µm amplification gap
- Several support rings form 200 µm drift/pre-amp gap
- 3 mm thick MgF_2 (Cherenkov radiator) + thin photocathode

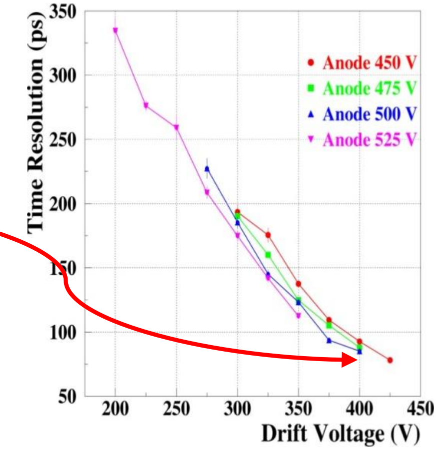
One of the prototype detectors in beam test

- ✓ Flowing gas: 80% Ne + 10% CF_4 + 10% C_2H_6
- ✓ Study the prototypes' performance with **metallic photocathode** (laser test) and **CsI photocathode** (muon beam test)

Measurements

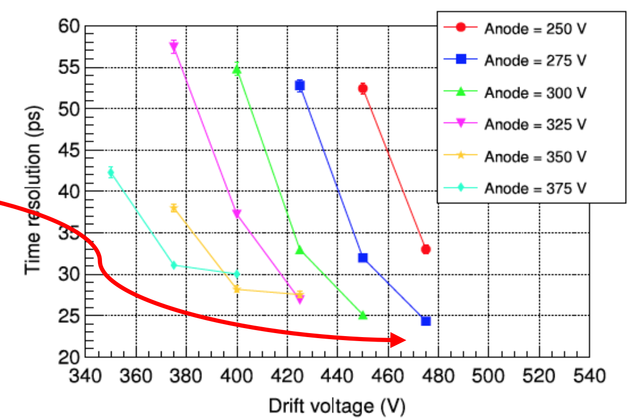
- **Laser test**: response to single photoelectron

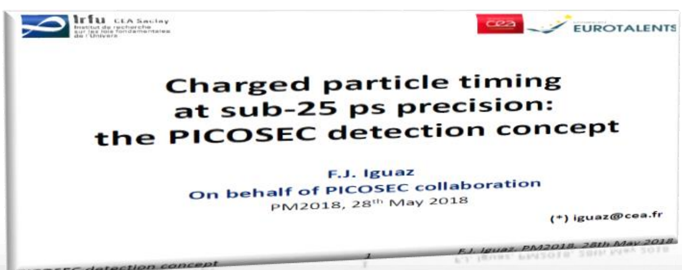
Time resolution 76 ps achieved for single photoelectron @Drift/Anode: -425V/+450V



- **Muon beam test**: response to MIPs

Best time resolution for 150 GeV muons:
about 10 photoelectrons (PEs) generated
24 ± 0.3 ps @ Drift/Anode -475V/+275V





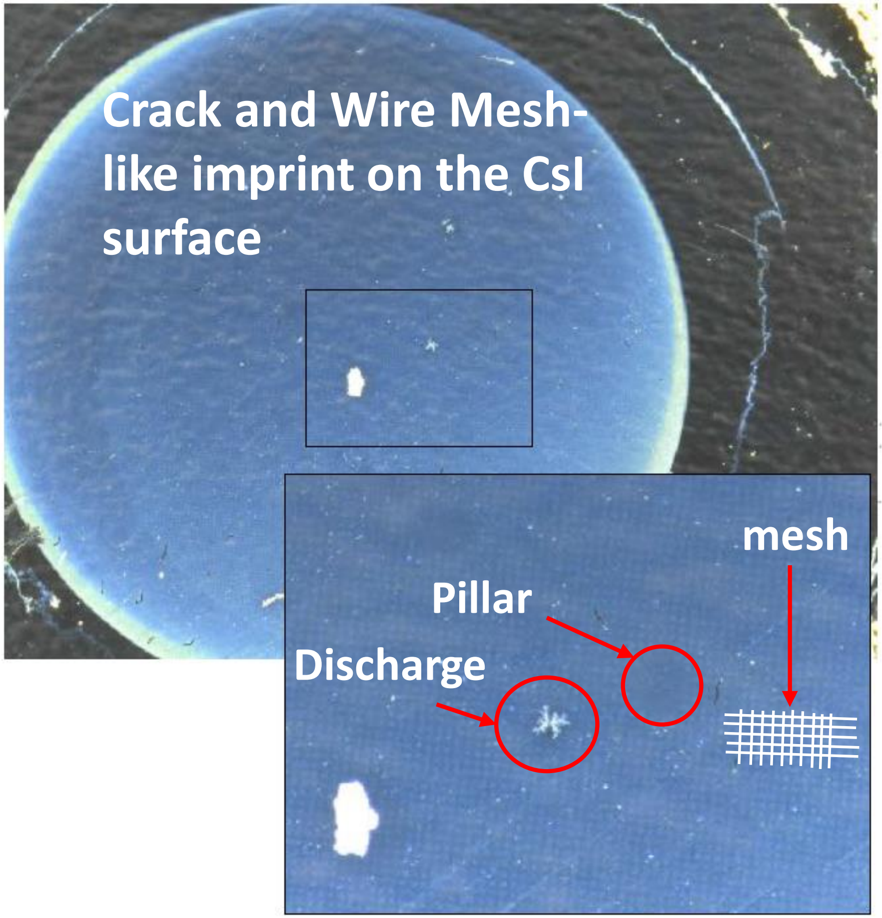
"PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector", J. Bortfeldt et. al. NIM A, 2018

To make the PICOSEC concept applicable

Study of robust photocathode and resistive anode

Aging problem of CsI

Microscopic pictures of a used CsI photocathode

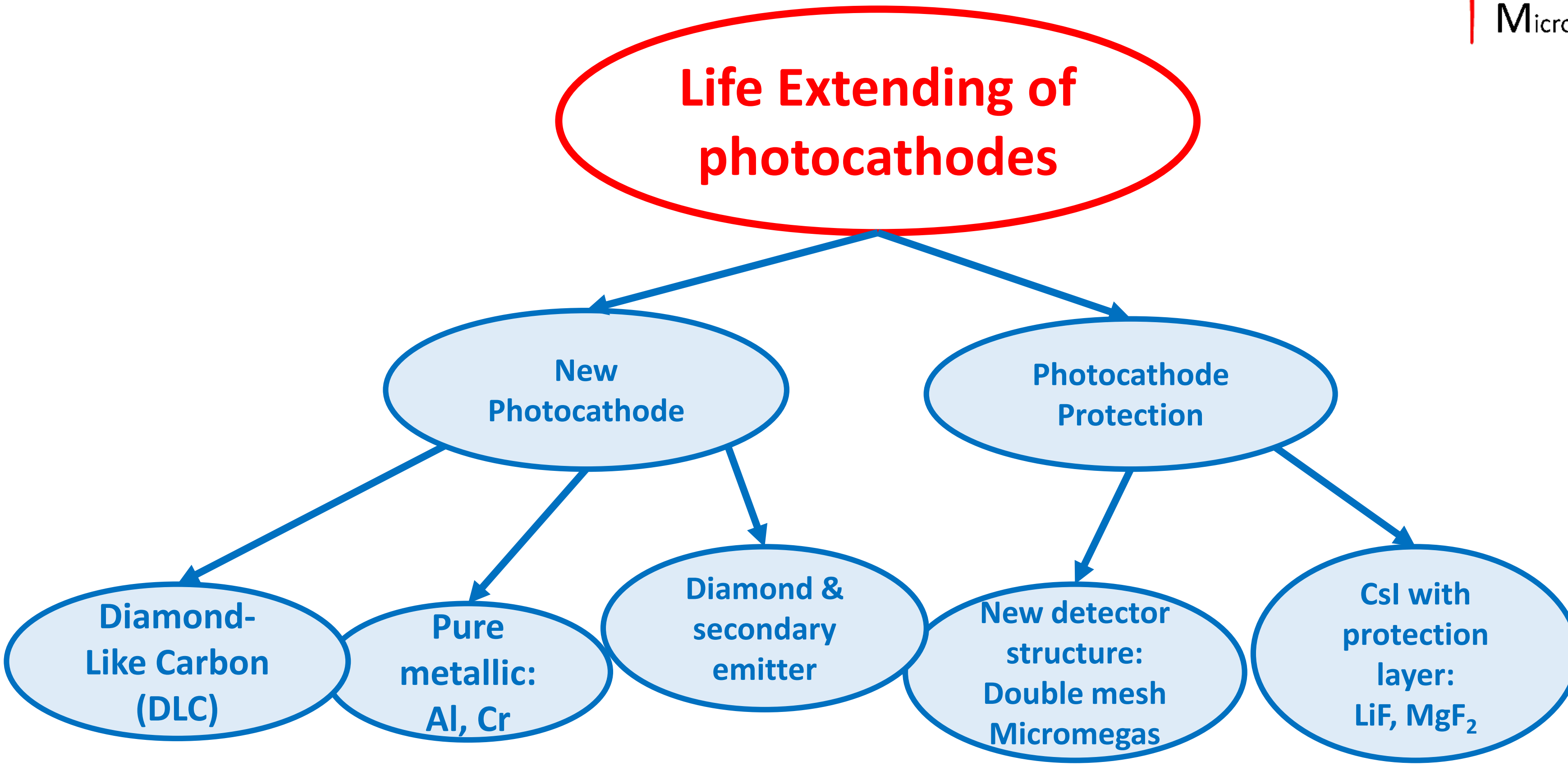


1. the high hydrophobicity poses a challenge for storage, which must be stored in vacuum

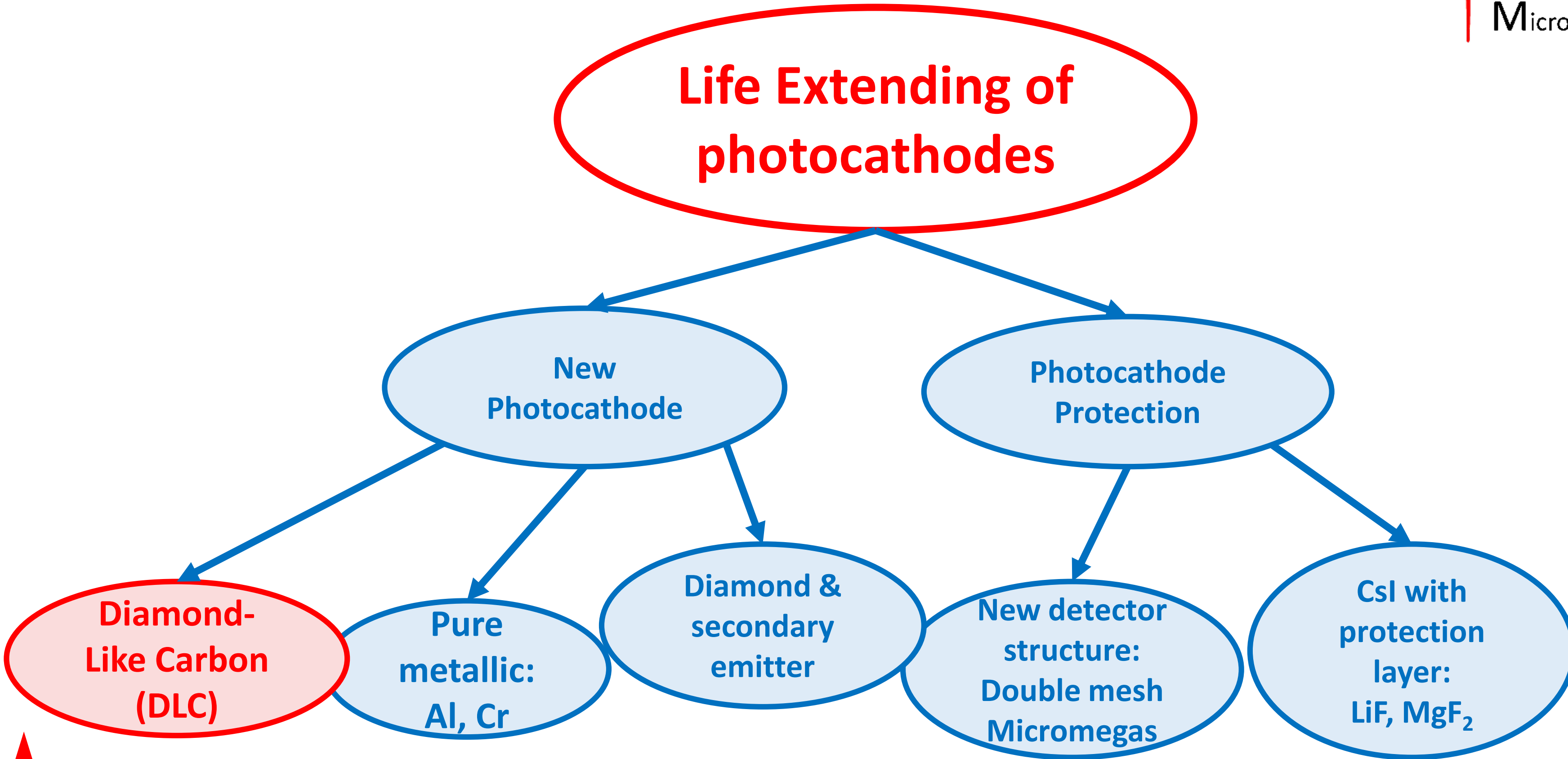
2. CsI photocathode is easily damaged during pion beam : sparks, high ions bombardment…

Some alternative **robust photocathodes** need to be studied

Study of photocathode



Study of photocathode

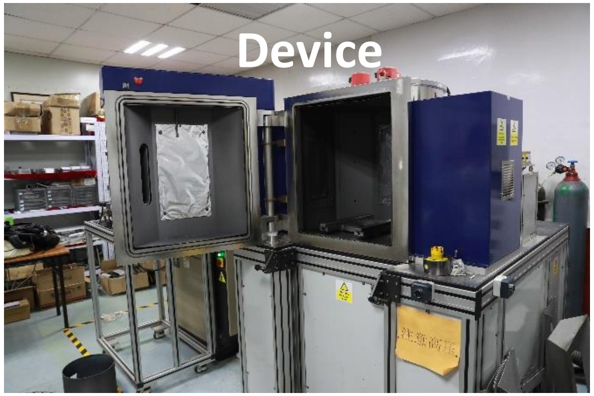


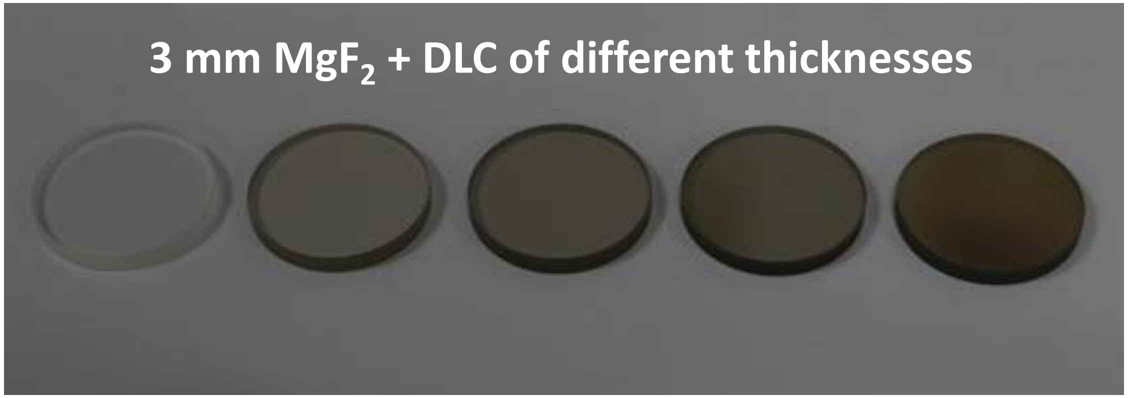
Most promising results have been obtained:

- Robust to atmospheric conditions, sparks and ions bombardment than CsI
- Suitable QE performance

Diamond-Like Carbon (DLC)

DLC is deposited on a MgF_2 substrate (3 mm thick) by the **magnetron sputtering deposition**





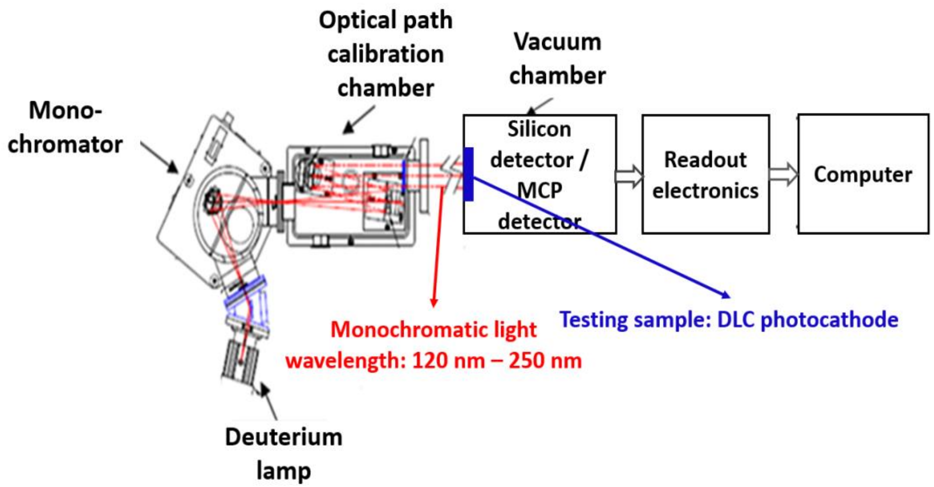
More details about deposition can be found in Lunlin Shang's report: "Development of high-performance DLC resistive electrodes for MPGD" ***in this conference***

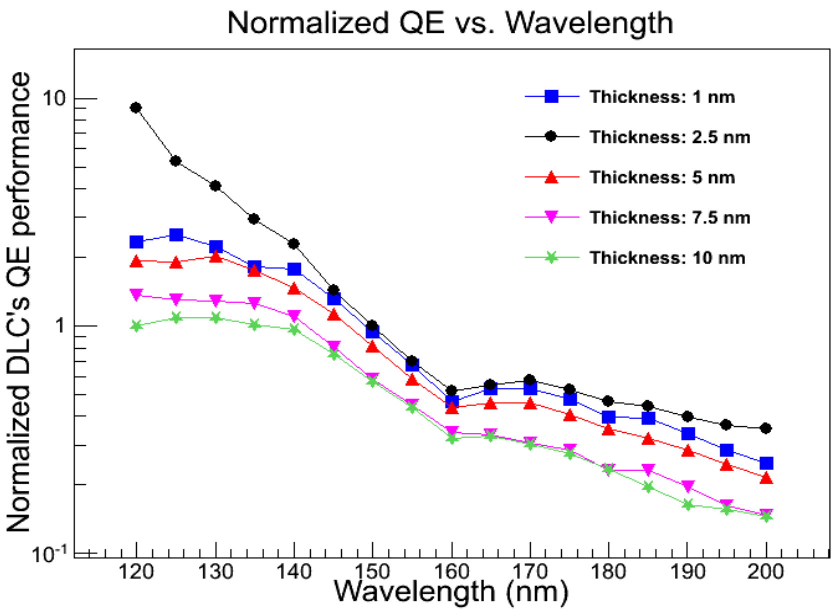
Study the performance of DLC photocathode

1. QE test by using ultra violet (UV) light in laboratory
2. Beam test with MIPs at CERN SPS H4 secondary beamline
3. Aging test of DLC photocathode (high intensity pions and laser)

QE test in Lab

Quantum efficiency test system





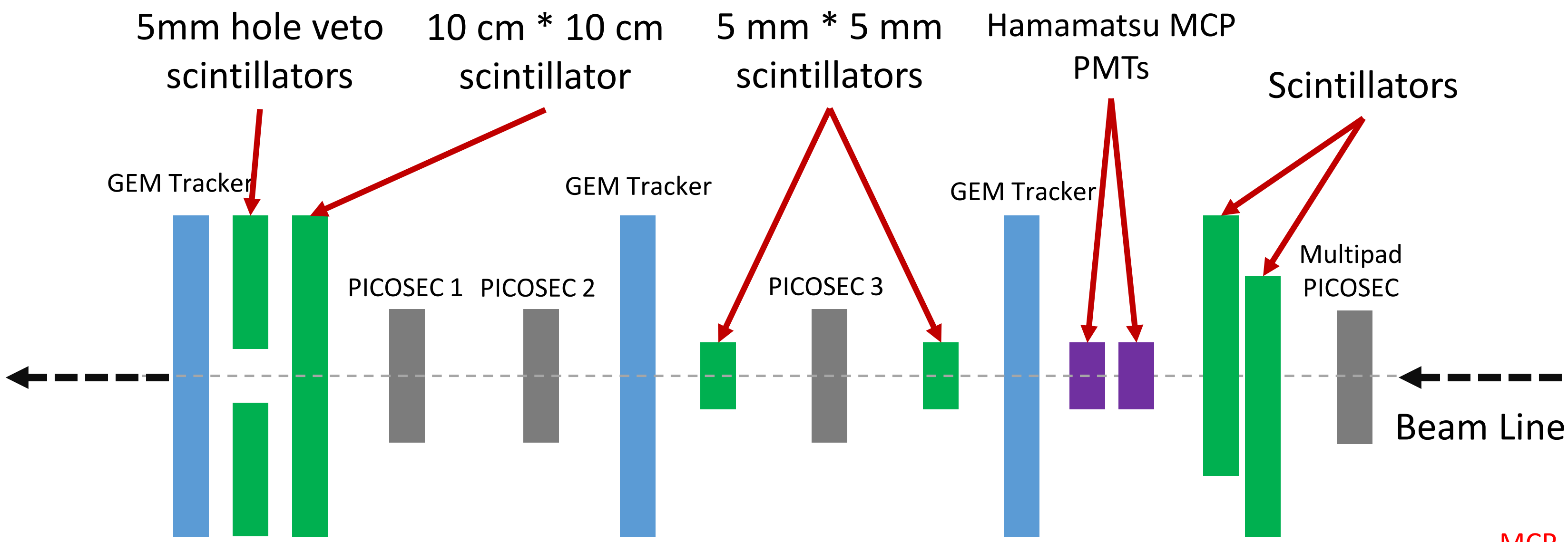
1. MCP detector (DLC sample)
   Photoelectrons generation rate (N_e)
2. Silicon detector (No DLC sample)
   Incident photons flux (N_p)

- Normalization factor: QE at 120nm @ 10nm
- Absolute QE is unpersuasive
- Relative QE of different samples are compared and credible

$QE = \frac{N_e}{N_p}$ (Transmissive mode ,background counts are removed)

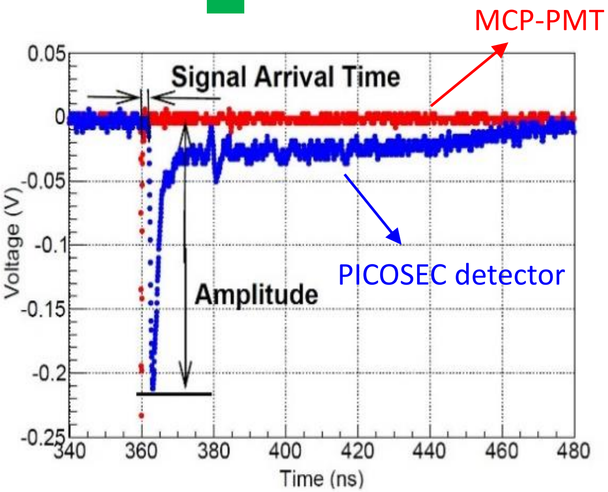
Highest QE was obtained with the thickness of 2.5 nm

Beam test of DLC



With DLC photocathode:

- Detection efficiency
- Timing response of PICOSEC detector
- Estimation of PEs yield

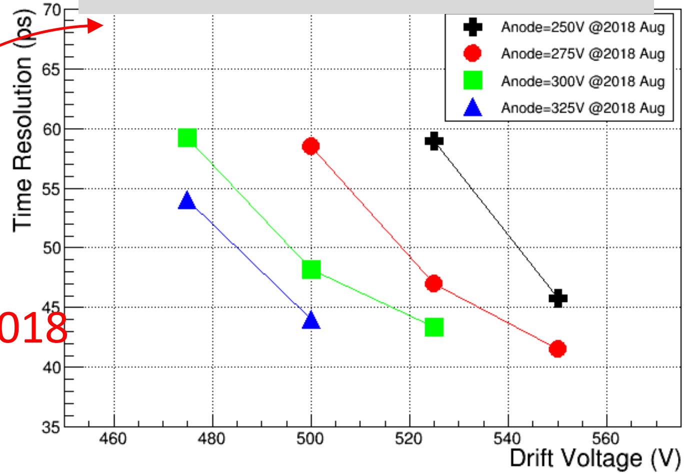


Results of Beam test

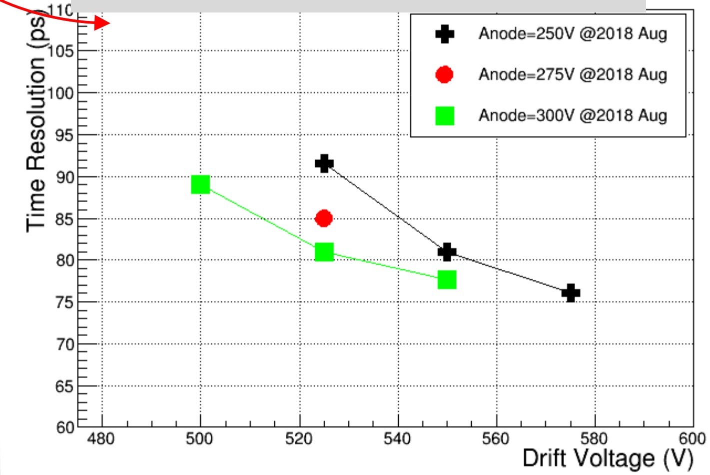
Thickness of DLC film (nm)	Detection efficiency for muons
2.5	**97%**
5	94%
7.5	70%
10	68%
CsI photocathode	100%

Time resolution of 2.5 nm DLC

Aug. 2018



Time resolution of 10 nm DLC

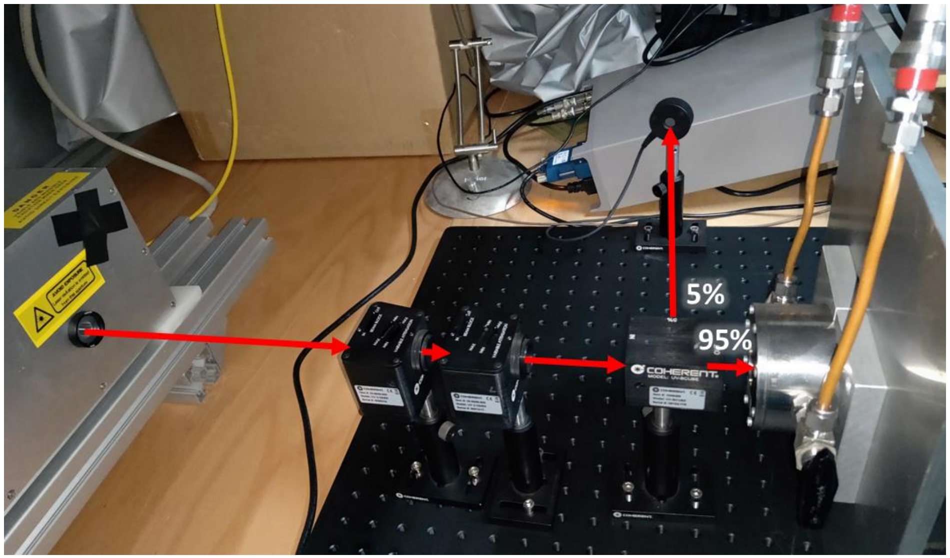


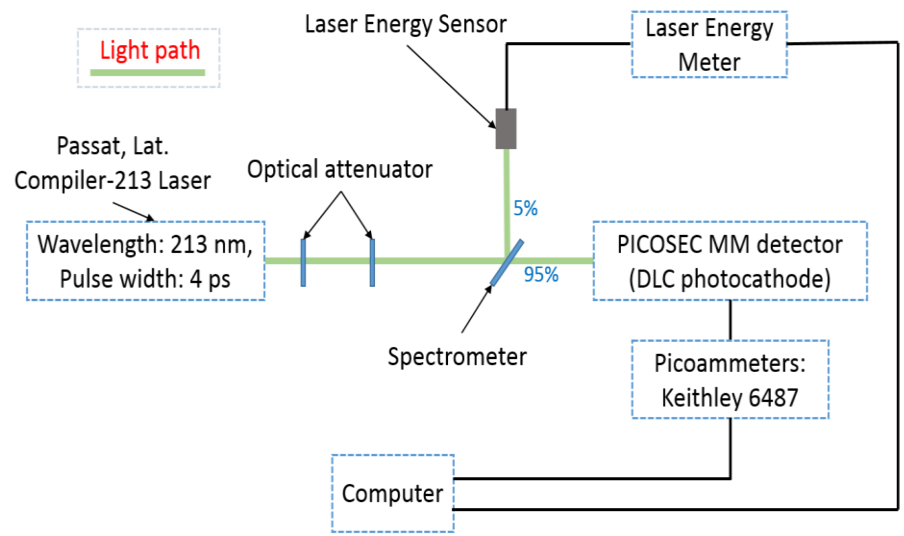
- 2.5 nm is the optimized thickness (the best one in laser test): 97% efficiency
- Time resolution: 40 ps level with 2.5 nm DLC

Aging study of DLC

PICOSEC Micromegas

High intense laser test in lab: effect of ions bombardment





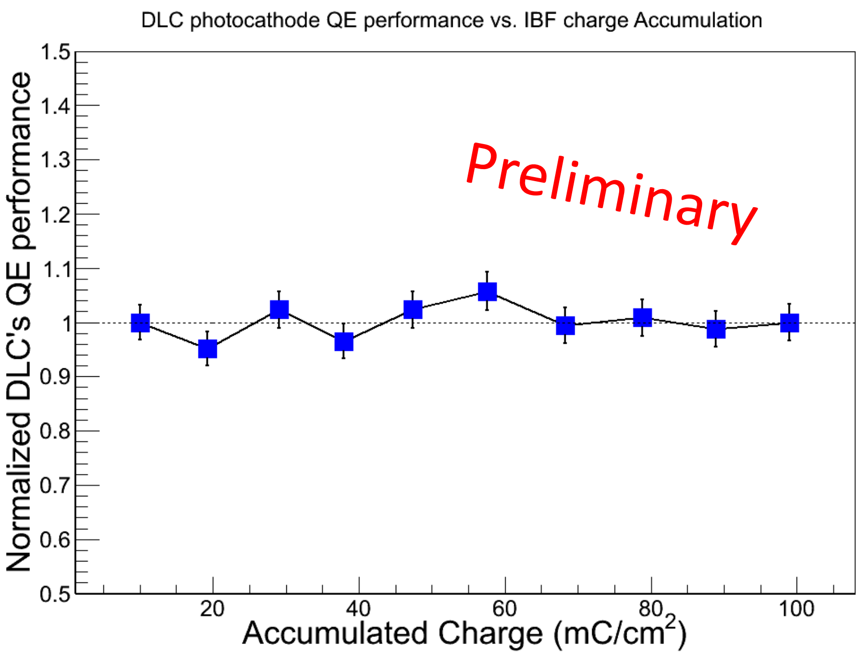
- UV light source: 213 nm laser
- Light intensity P(t): Laser Energy Sensor and Meter
- Current of detector I(t): Picoammeter

Characterization of DLC's QE performance with the accumulation of IBF charge:

$$I_1(t) = \frac{I(t)}{P(t)}$$

Results of aging study

PICOSEC Micromegas



Same photocathode tested in Aug. and Oct.

Anode/Drift Voltage (V)	Time resolution (ps)	
	Aug.	Oct.
250/-550	45	37
275/-525	47	38
275/-550	42	34
300/-500	48	39
300/-525	43	34

Preliminary

- $I_1(t)$: QE performance of DLC photocathode
- Preliminary results: No sign of performance decrease with an accumulated charge of **100 mC/cm²**

Typical value for CsI: a few mC/cm²

- Tested in **different detectors** but same way
- No performance decrease for a few months at atmospheric conditions and kept in a piece of paper

✓ Robust to ion bombardment

✓ Robust to air (water, O_2)

Further study of DLC

Some keys to obtain high QE for transmissive photocathodes

1. Improvement of band structure

P type semiconductor

2. Optimization of the ratio of sp^3/sp^2

More sp^3, higher QE

3. Reducing the surface affinity

Surface treatment, Negative electron affinity (NEA)

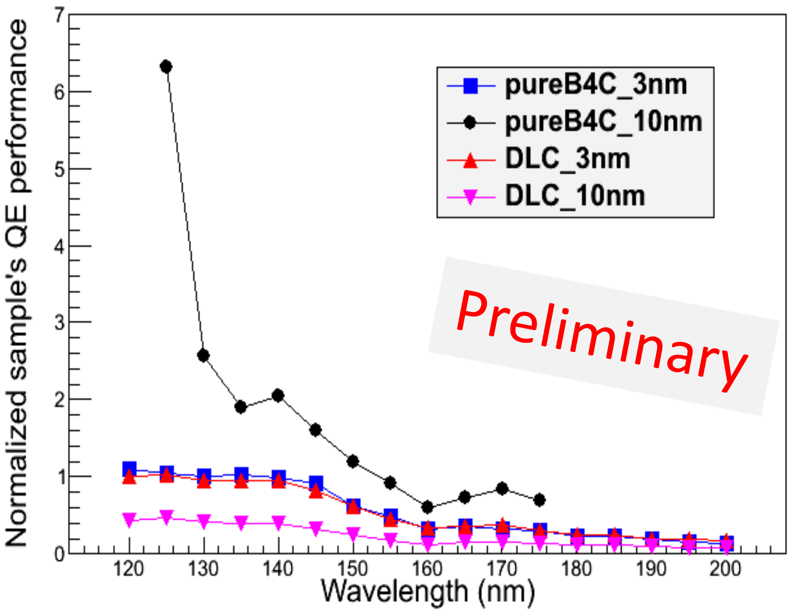
More details about deposition can be found in Lunlin Shang's report: "Development of high-performance DLC resistive electrodes for MPGD" ***in this conference***

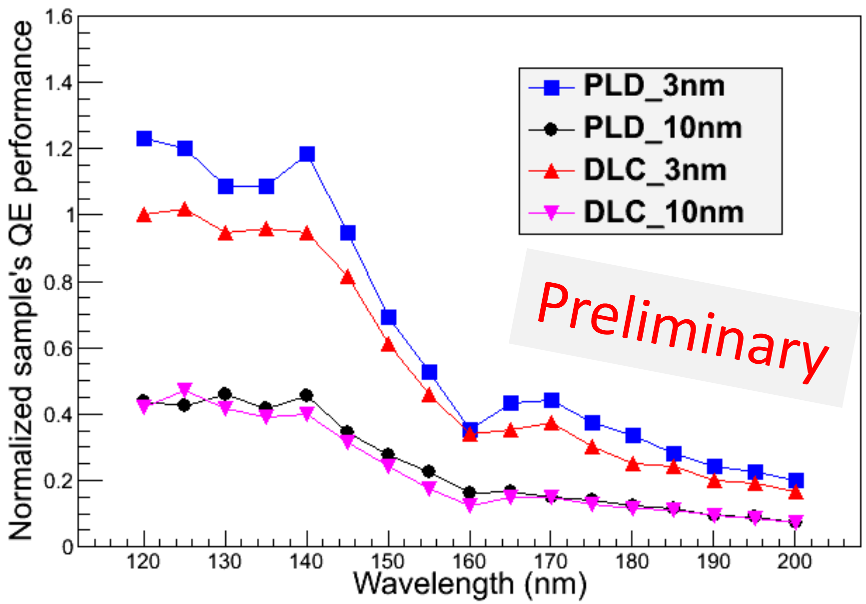
- Magnetron Sputtering Deposition
- Pulsed Laser Deposition (PLD)
- Vacuum Cathodic Arc Deposition

- Thickness optimization
- Boron (B) doping
- Hydrogen plasma treatment to form NEA
- Optimization of the ratio of sp3/sp2

Results of new DLC

QE test with UV light





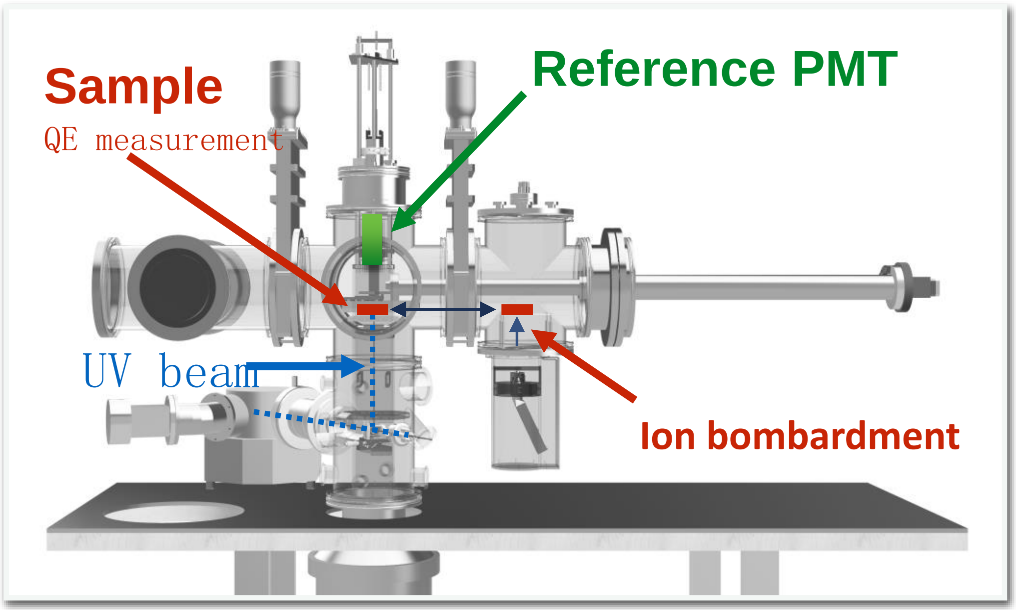
- **Sample B_4C_10nm** has the highest QE performance, surprising improvement was obtained

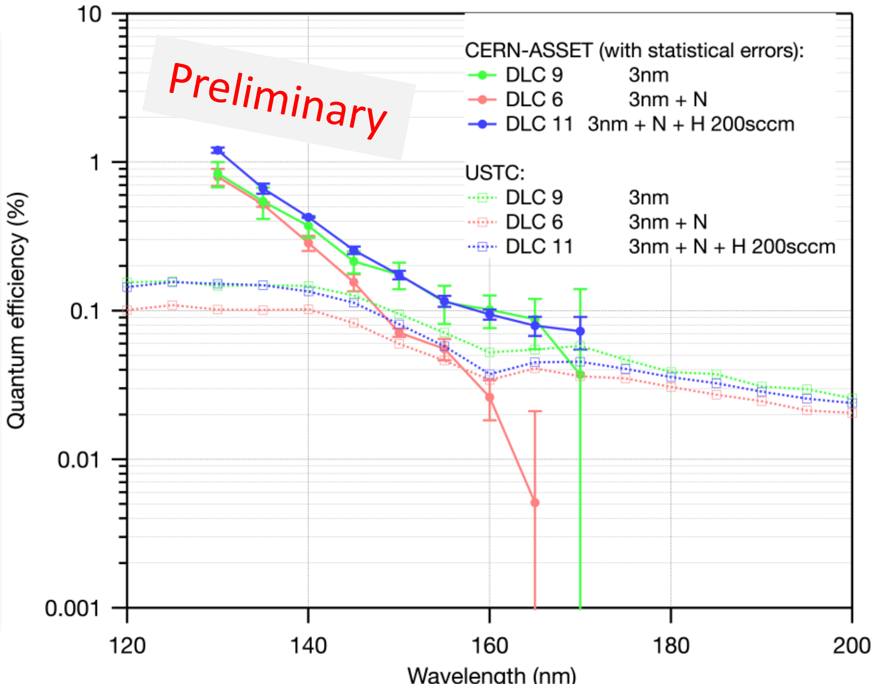
- The target of PLD and DLC both are pure graphite
- At the same thickness, the PLD samples shows a few improvement (~15%)

✓ QE performance improve through these further studied
✓ More study will be carried on

Test with ASSET setup

Wavelength resolved QE is measured by UV beam and samples are subjected to significant ion bombardment to quantify degradation





ASSET setup developed at CERN for absolute QE measurements and ion bombardment of photocathode samples
Measurements in vacuum and gas possible

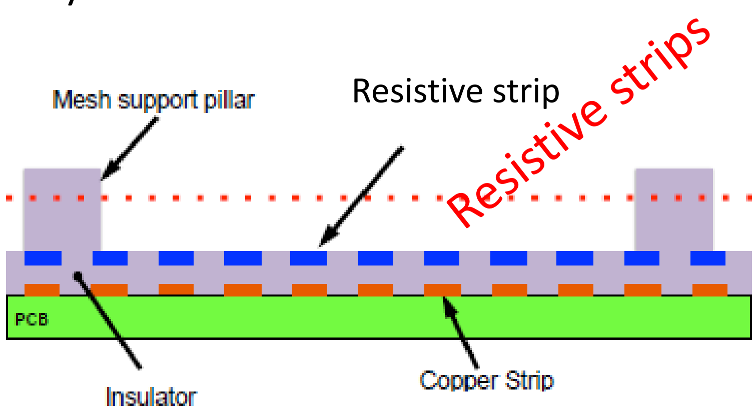
Preliminary QE measurements of DLC photocathodes: agreement in relative results but discrepancy in calibration

Study of Resistive Anode

- Weak point of the MM original design: fragility to sparking
- PICOSEC detector normally operate in high gain conditions

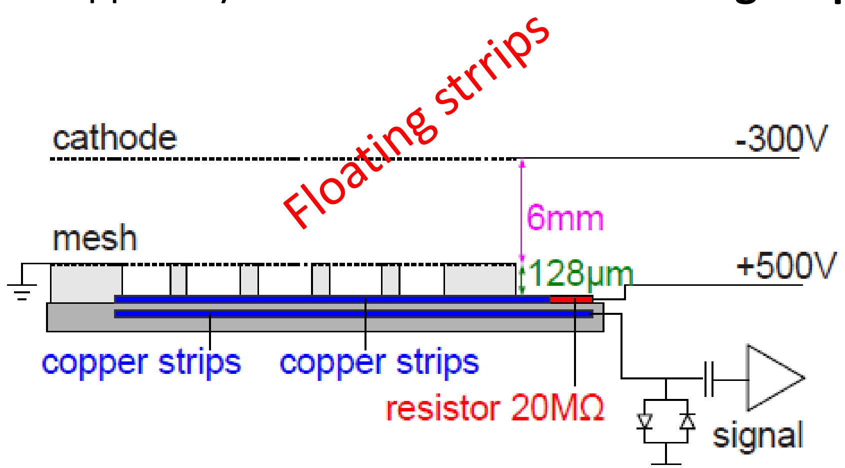
Spark-insensitive:

1: Add a **resistive layer** on top of a thin insulator directly above the readout electrode



ATLAS New Small Wheel TDR,
Micromegas detector technology and performance, 2013

2: Copper Layer to HV via resistor: **Floating strip MM**



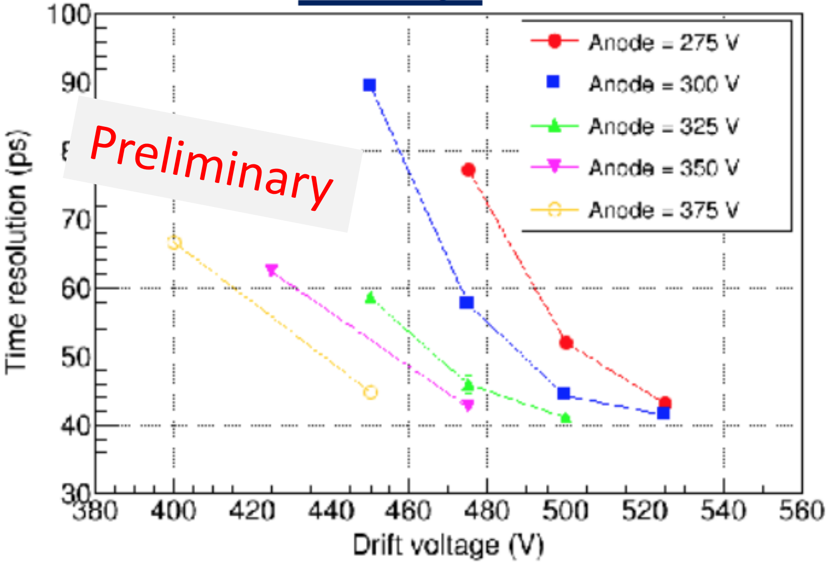
Development of Floating Strip Micromegas Detectors,
Jonathan Bortfeldt, 2014

Results of Resistive Anode

Time resolution

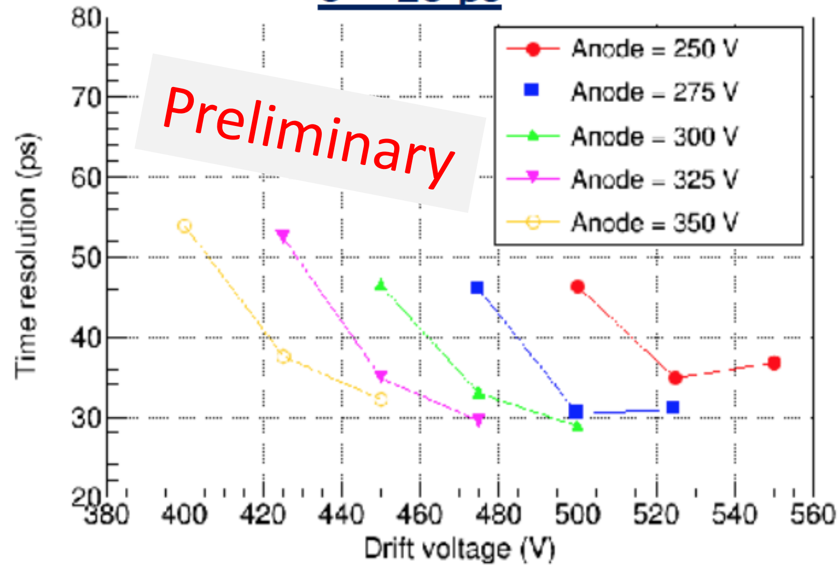
Resistive strips

σ = 41 ps



Floating strips

σ = 28 ps



- 1. PICOSEC detector with resistive readouts worked well in high intense pion beam
- 2. Time resolution not far from the PICOSEC bulk readout (without resistive anode)
  - Resistive strips: 41 ps (10 $M\Omega/\square$), 35 ps (300 $k\Omega/\square$)
  - Floating strips: 28 ps (25 $M\Omega$)

→ spark quenching and protection are needed to be properly evaluated.

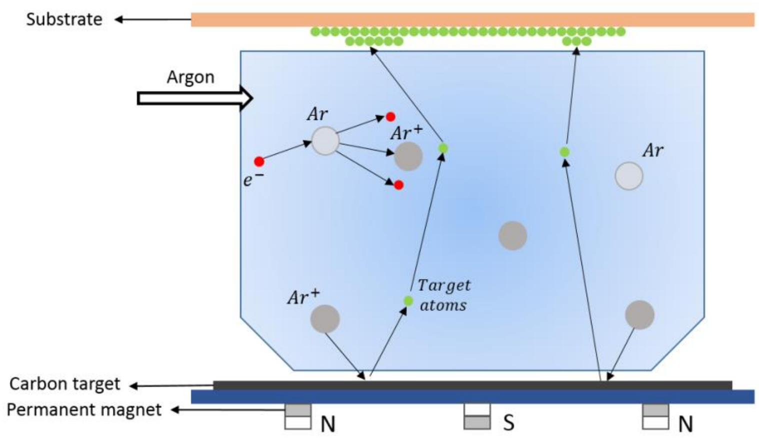
Conclusion

- PICOSEC detector concept: Fast timing
  - ➢ Time resolution: 24 ps for 150 GeV/c muons, 76 ps for single photoelectrons
  - ➢ Mean number of photoelectrons: ~10 per muon (with CsI photocathode)
- Robust photocathode: promising results
  - ➢ DLC photocathode optimized thickness: 2.5 nm (from 1, 2.5, 5, 7.5, 10 nm)
  - ➢ 40 ps level with 97% detection efficiency
  - ➢ Good robustness: No decrease with an accumulated charge of 100 mC/cm^2; atmospheric condition
  - ➢ More optimization is predictable: Boron doping and another deposition method
- Resistive readout
  - ➢ Worked well in high intensity particle beam
  - ➢ Timing performance doesn't decrease much

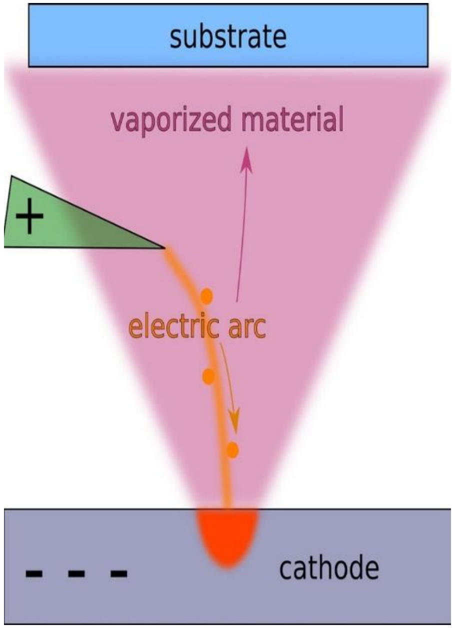
THANKS!

Back up

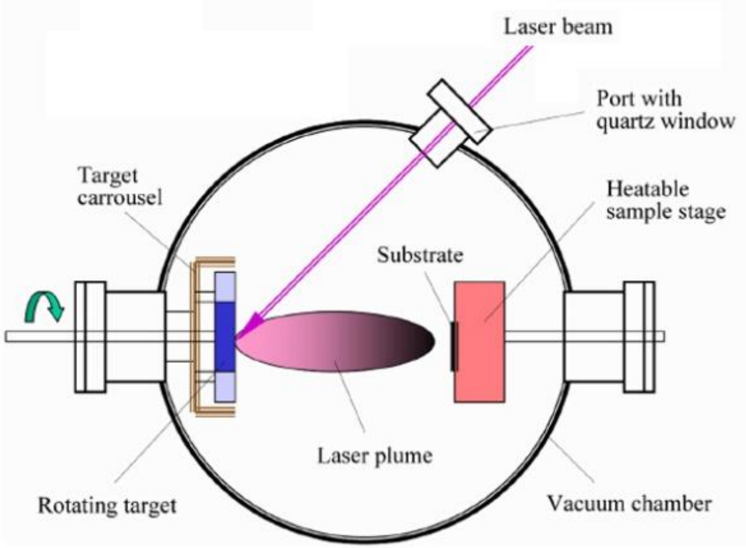
magnetron sputtering deposition



Vacuum Cathodic Arc Deposition



Pulsed laser deposition



Estimation of PEs yield

PICOSEC Micromegas

Electron peak charge distribution of
a: signal for single photoelectron
b: signal for 150 GeV muon

Estimation of **the number of photoelectrons**

(N_{pe}) per muon : Negative log likelihood

Thickness of DLC film (nm)	N_{pe}/per muon
2.5	**3.7**
5	3.4
7.5	2.2
10	1.7
CsI photocathode	7.4

Some discrepancies between QE measurement and N_{pe} results ?

- QE measurement: CsI is several dozens times or higher than DLC
- N_{pe} results: CsI is several time higher than DLC

Light source: Vertically incident laser and Cherenkov light
Gas environment: Vacuum and gas filled
Transmission mode… …