RD51 Collaboration Meeting and Topical
Workshop on FE electronics for gas detectors

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Update on the Fast Timing MPGD development: performance of resistive DLC foils

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The small-size FTM: design and goals

Amplification foil placed (not glued!) on ground electrode

μRWELL uses "normal" holes with copper anode

FTM uses "inverted" holes with DLC anode

R&D goals

- Systematic foil performance study and comparison → **done!**
- Re-demonstrate working principle with variable number of layers in cosmics and test beam → **ongoing**

Prototype specifications

- Small active area (2 cm² foil area)
- Modular design, variable number of layers
- Mylar windows (for x-ray tests) + quartz windows (laser tests)
- Top and bottom readout electrodes

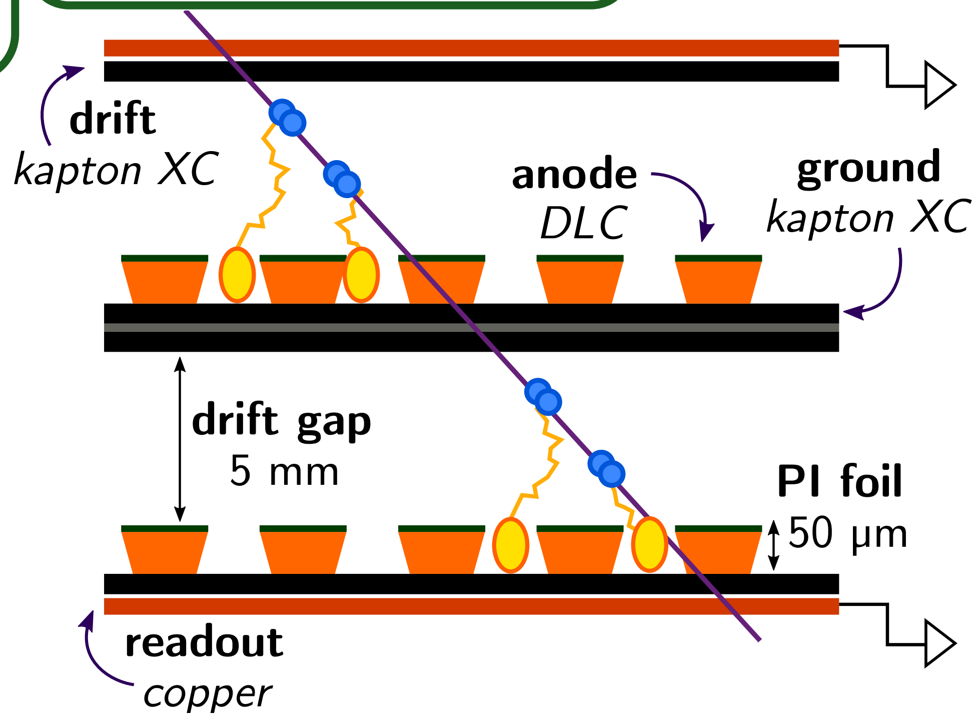
Electrode materials

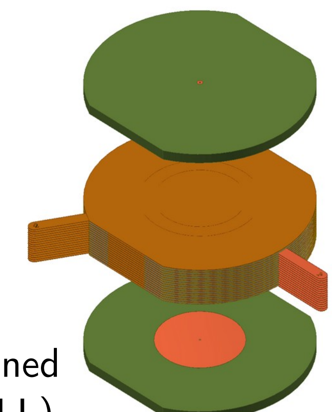
- **Drift and ground**: kapton XC
- **Anode**: resistive DLC
- **Readout:** copper

Drift gap: 5 mm

Readout options:

- *"bare"* oscilloscope
- Cividec C2HV current preamplifier (100 dB gain)
- ORTEC 142PC charge-preamplifier (nominal sensitivity 4 mV/fC)





Focus on foil performance: main results shown here obtained on a single-layer FTM (analogous to a fully resistive μRWELL)

Laser test setup for the small-size FTM

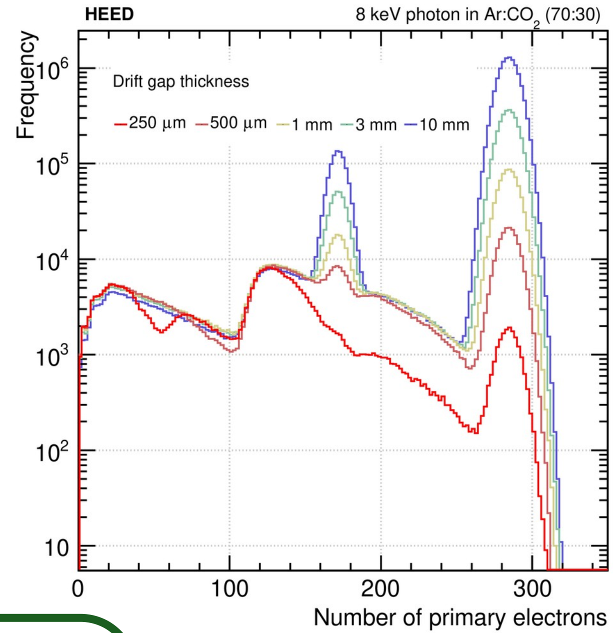
Detectors with thin gaps

- **Typically**, characterization done with **x-rays** e.g. GEM detectors in CMS

  γ → 1 or 2 delta e⁻ → many primary e⁻

- In **gaps < 500 μm**, energy released by primary "delta" electrons in the gas is subjected to **large fluctuations**

→ **non-monochromatic spectrum** of primary electrons: difficult to make a gain calibration



Simulation: number of primary electrons created by an 8 keV photon in a drift gap with decreasing thickness

Gain measurement by x-rays has been challenging ever since the first FTM prototypes

A. Pellecchia et al 2020 JINST 15 C04011

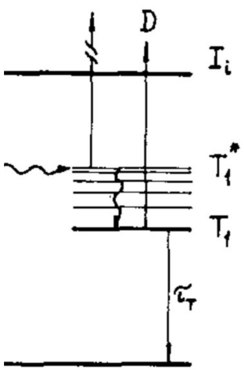
Previous RD51 presentation Feb20

Laser-gas interaction

- Energy of single laser photon: **4.7 eV** @ 266 nm
- Lower than typical gas ionization energy: **13-15 eV**
- Solution: two-photon ionization of gas impurity molecules [8]

$$\frac{dR}{dxdydz} = \frac{N\sigma^{(2)}}{(h\nu)^2} I(\rho, z)^2$$

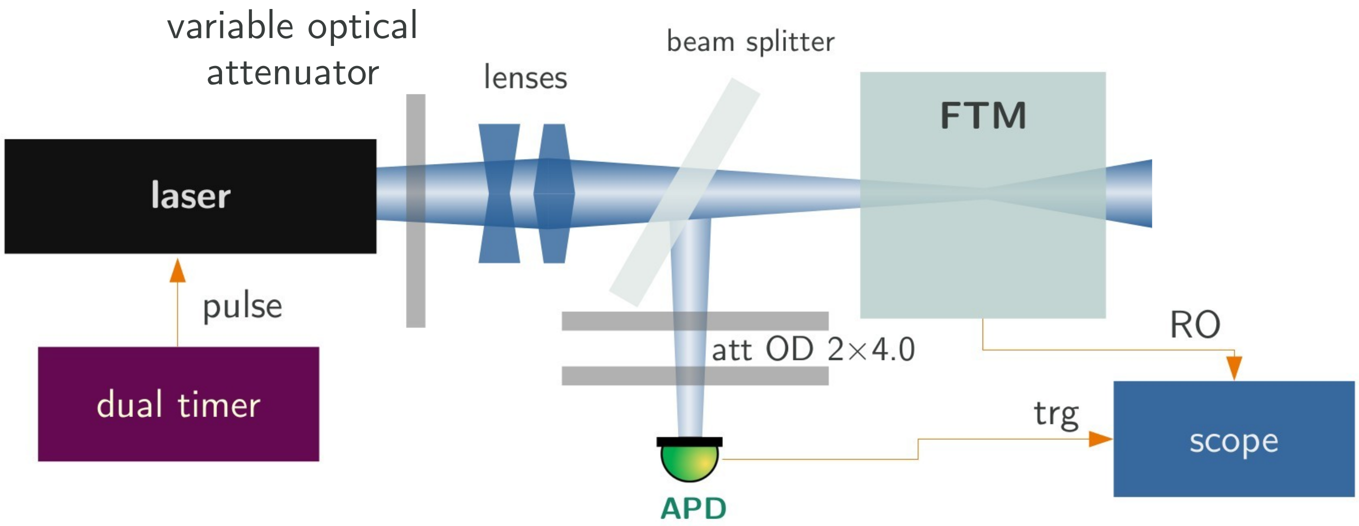
Ionization rate density — **2-photon cross-section equivalent** — **Laser beam intensity**

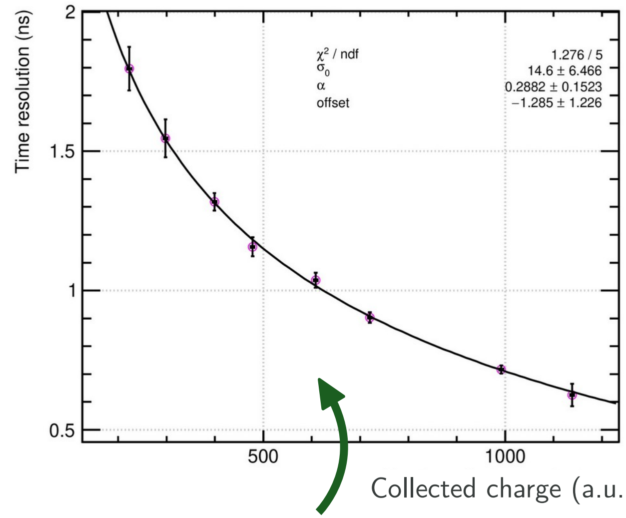


Laser setup advantages

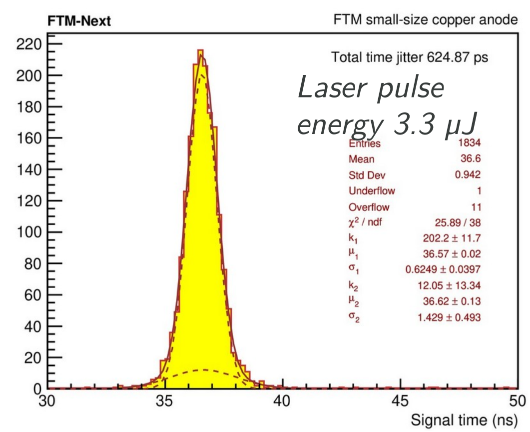
- Can provide **trigger** → not only gain, but also single-layer **timing** measurements
- **Position** of primary ionization precisely **adjustable** → can test different layers separately
- Pulse repetition rate and beam power can be both adjusted separately → can **test separately** different primary charges *and* different event rates

Setup for gain and efficiency measurements

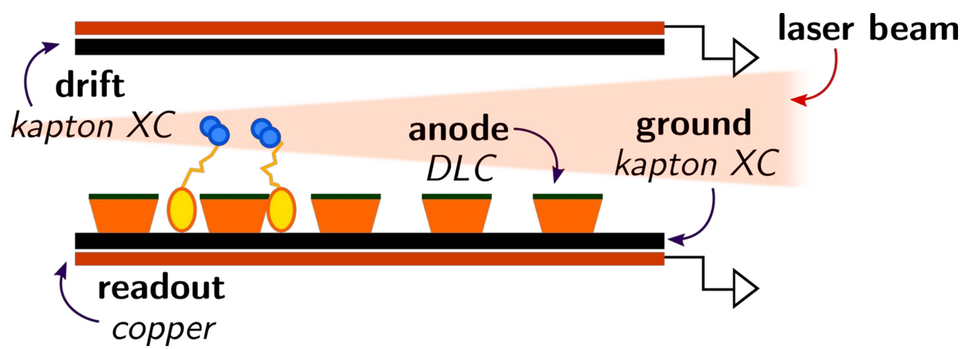




Example of single-layer time resolution measurement with laser: time jitter decreasing at increasing number of electrons



Ionization at fixed position inside gap

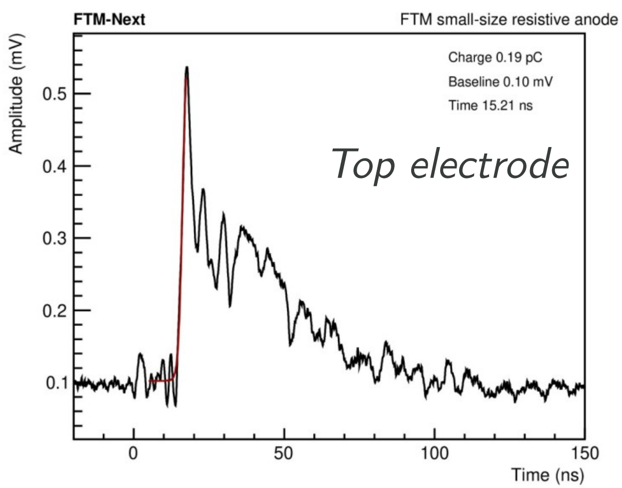


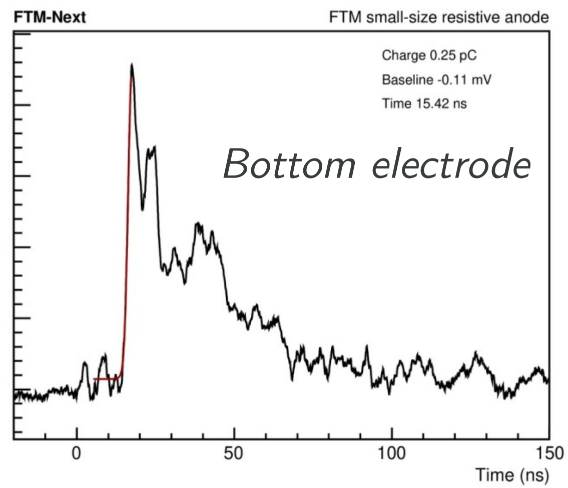
Setup components

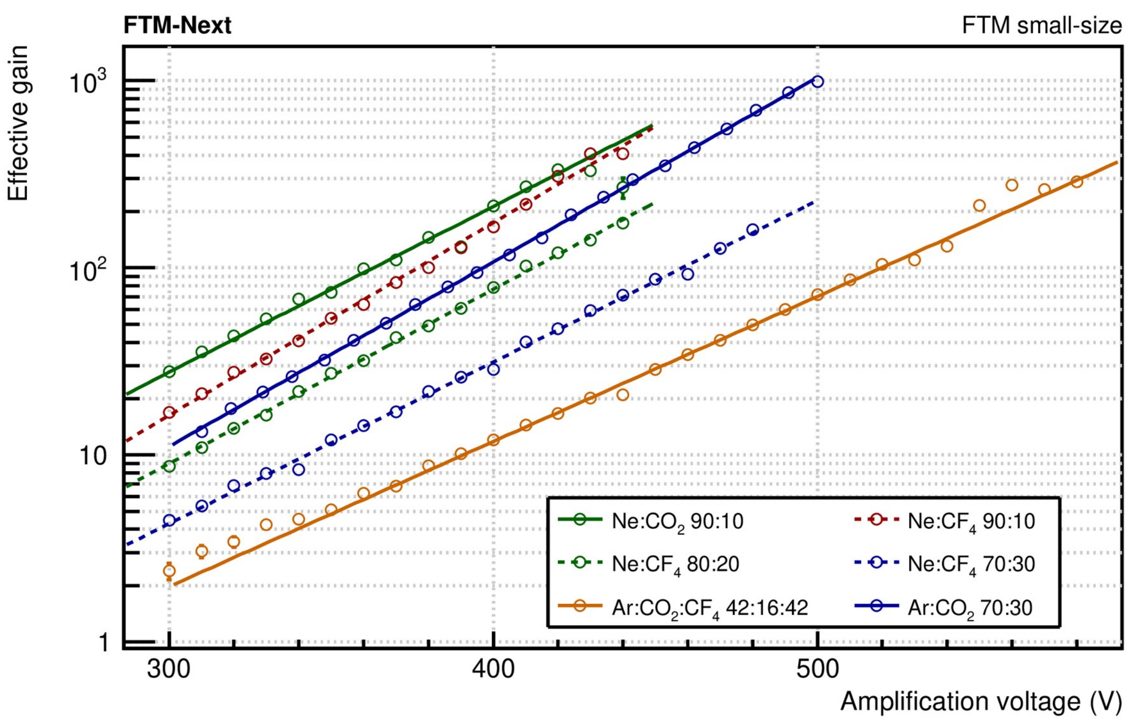
- UV laser: λ **266 nm**
  Beam intensity up to **51 μJ**
- Pulse duration **1 ns**
  Lower than single-layer time resolution
- Laser beam focused in FTM drift gap
  25 μm spot size
- Signal preamplified and read by oscilloscope
- **APD as trigger** with **50 ps** time resolution

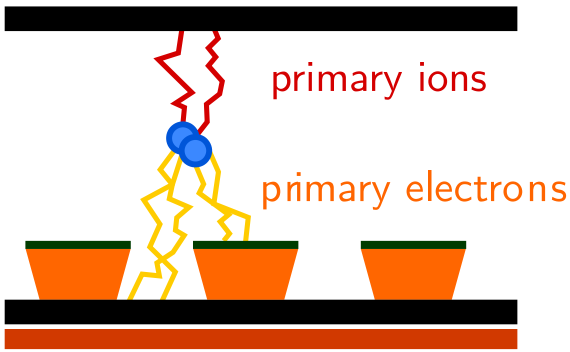
First results: signal and gain

Signal transparency: simultaneous readout of top and bottom electrodes









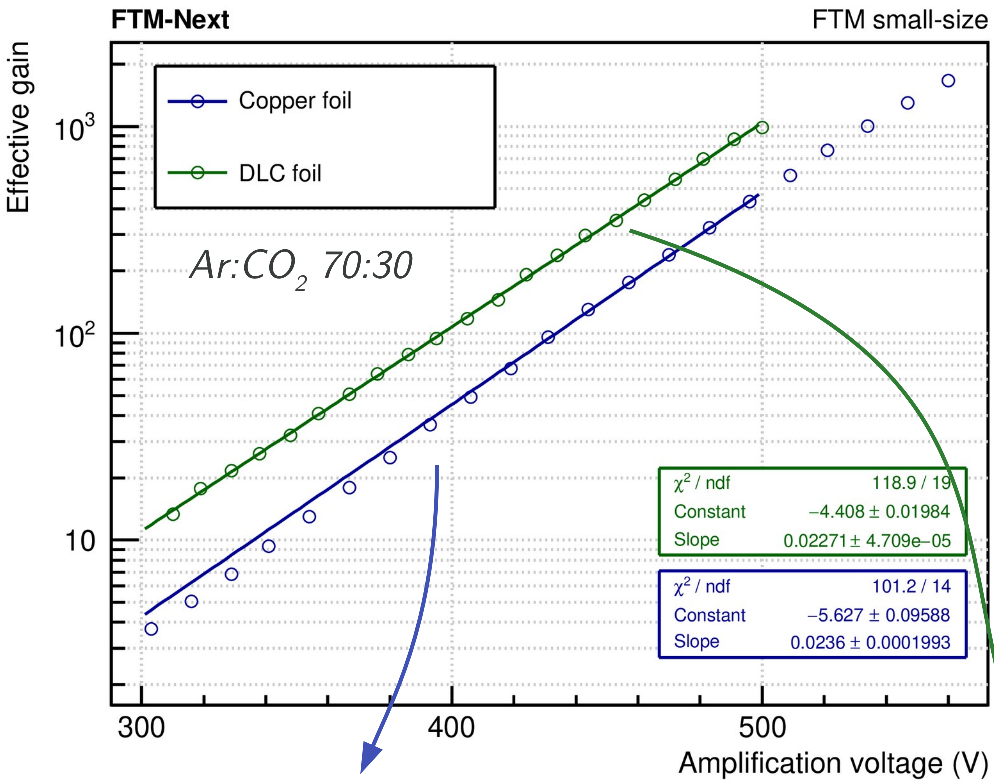
Gain measurement method

- **Amplified current** measured from ground with femtoammeter
- **Primary current** measured in primary **ionization regime**: low field in holes, no amplification
  → Primary electrons collected partly by the anode and partly by the ground, positive ions all collected by drift

Result: low gain measured with several Ar and Ne mixtures with CO_2 and CF_4

Measured gain up to 1000, however to be efficient we need 10^4 per layer!

Comparison: conductive and resistive foils



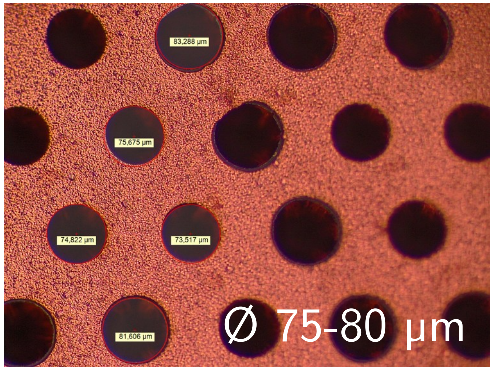
Copper anode 5 µm
"normal" holes

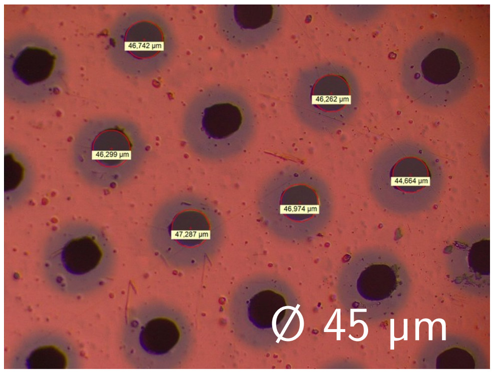
DLC anode 100 nm
"inverted" holes

Lessons from comparison with copper foil

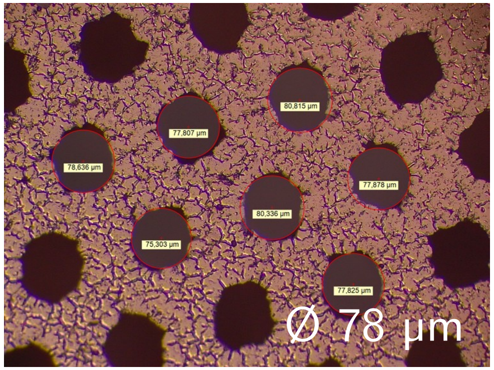
- **Higher gain at equal applied voltage** for DLC foil
  → Due to inverted well shape
- **Lower** overall **amplification voltage achievable** with DLC foil
  → Due to hole irregularities in both **DLC and kapton**
- **Overall lower gain** with DLC foil

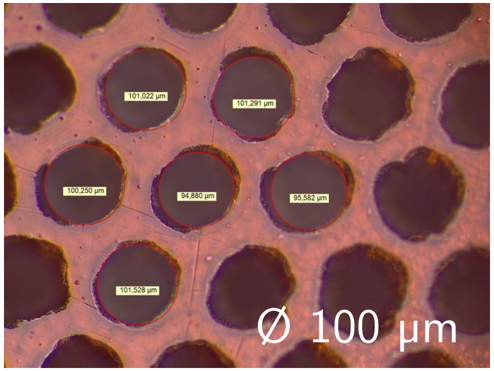
Conductive foil (top copper/bottom PI)

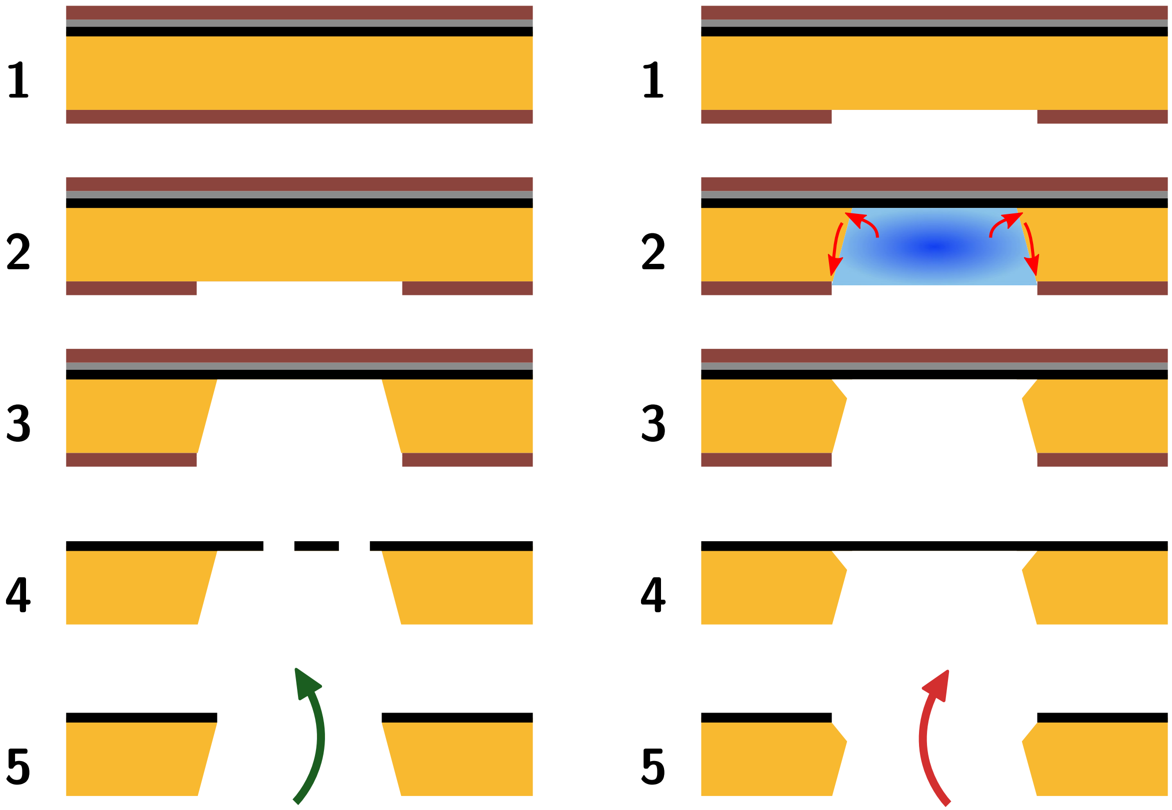




Resistive foil (top DLC/bottom PI)







Layer	Thickness
Copper	7 µm
Cromium	10 nm
Resistive DLC	100 nm
Polyimide	50 um
Copper	5 µm

Starting FCCL

- Produced by magnetron sputtering; DLC covered by Cr layer to improve adhesion
- Suggestions for future FCCL improvements: better adhesion by sputtering assisted by secondary ion beam

FTM foil production procedure

1. Starting FCCL
2. Coating with photoresistive layer and bottom Cu etching
3. PI etching in chemical bath
4. Top Cu etching, Cr removal, DLC loss
5. DLC cleaning with water jet

What is going wrong

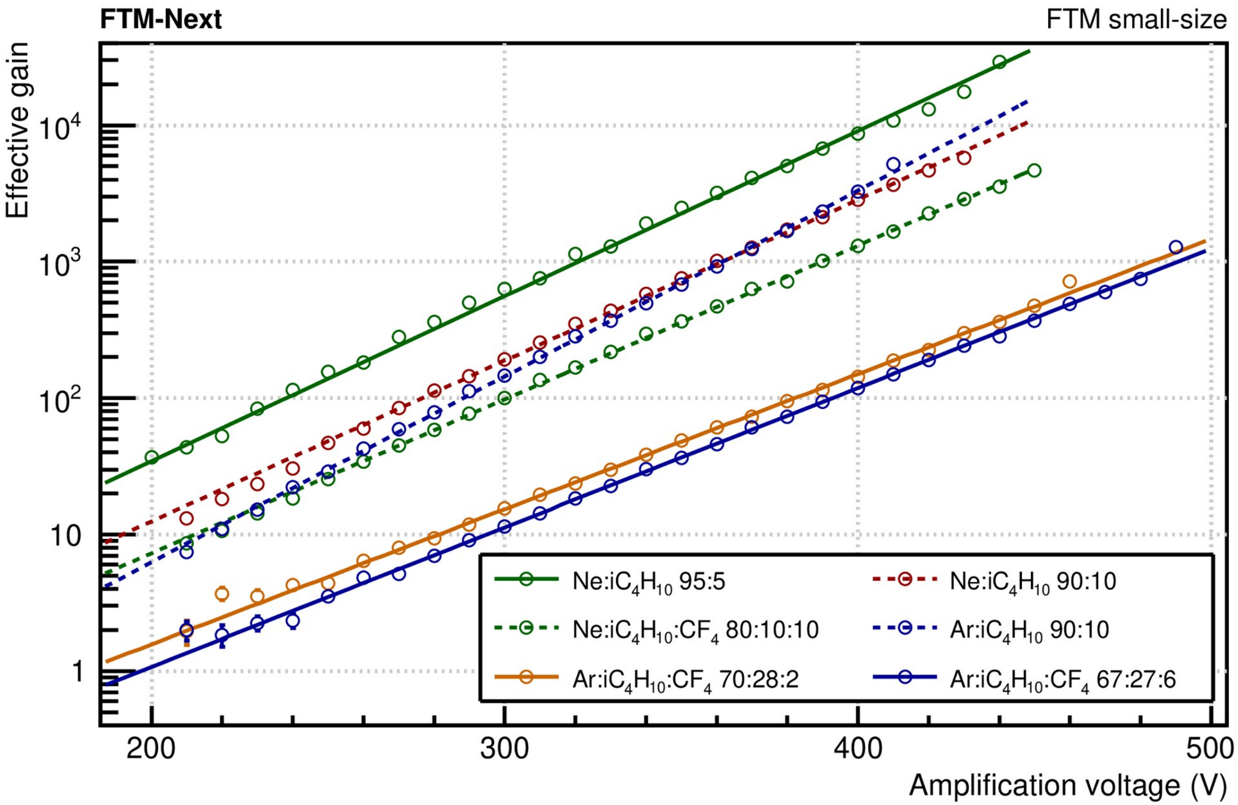
2. Over-etching of PI in DLC pores
3. Larger holes, irregular DLC and PI hole walls

Possible solution: rim around DLC to reduce hole irregularities

Other solutions under investigation

- DLC removal with plasma etching
- Starting etching from top: DLC breaking with sand blasting → PI etching from DLC side
- Faster tests will be available once DLC machine available at CERN

FTM gas mixture selection



Isobuthane mixtures with CF_4

- In other **resistive detectors**, **CF_4**-based mixtures were able to reach high gains due to stability to very **high fields**
- CF_4 mixtures also chosen for **improved timing** (high electron drift velocity), e.g. LHCb
- In **FTM** case, instability due to **discharges** prevents reaching much higher fields
  → Overall lower gain than non-CF_4 mixtures

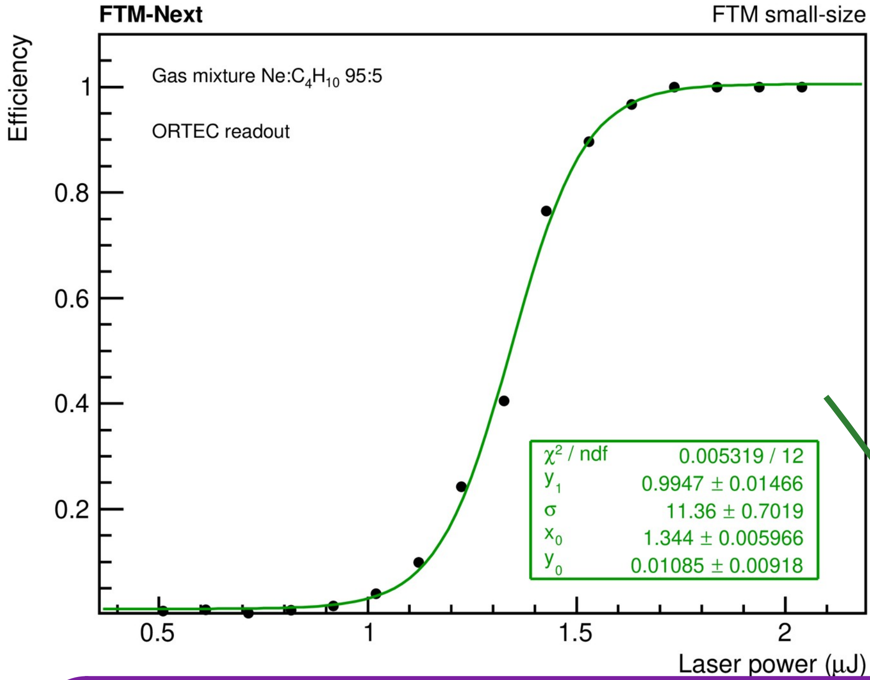
Results from latest gas mixture tests

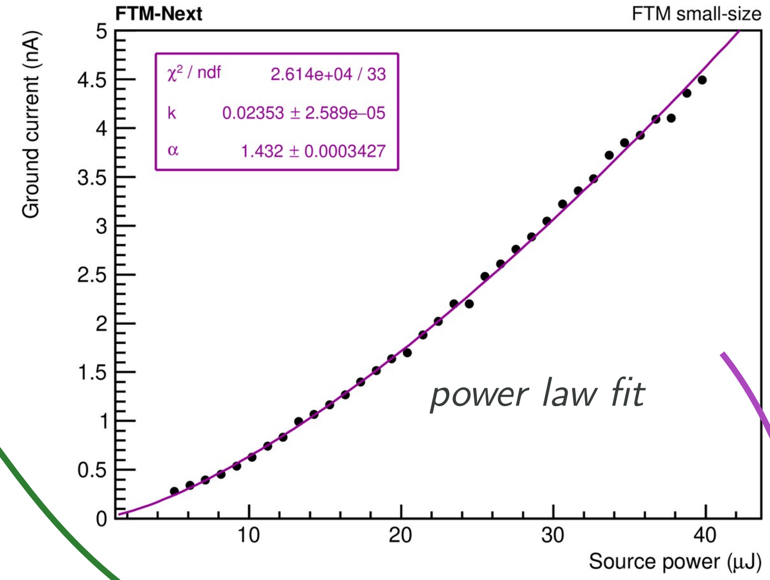
- All **isobutane**-based mixtures reach gains **over 1000**
- Highest gain: **Ne:iC_4H_{10} 95:5**
- Small differences between Ar and Ne-based mixtures

Result from gas mixture comparison

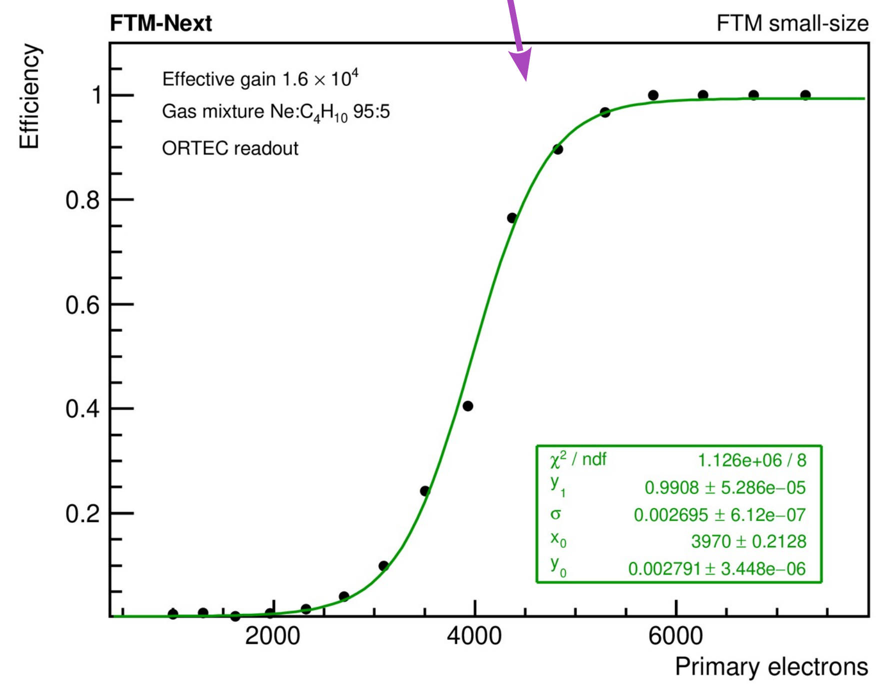
Isobutane mixtures suitable for an FTM layout efficient to MIPs → **choice for future R&D**

However, future developments will need to rely on improvements of FCCL production





Primary charge as a function of laser pulse energy obtained as amplified current/gain

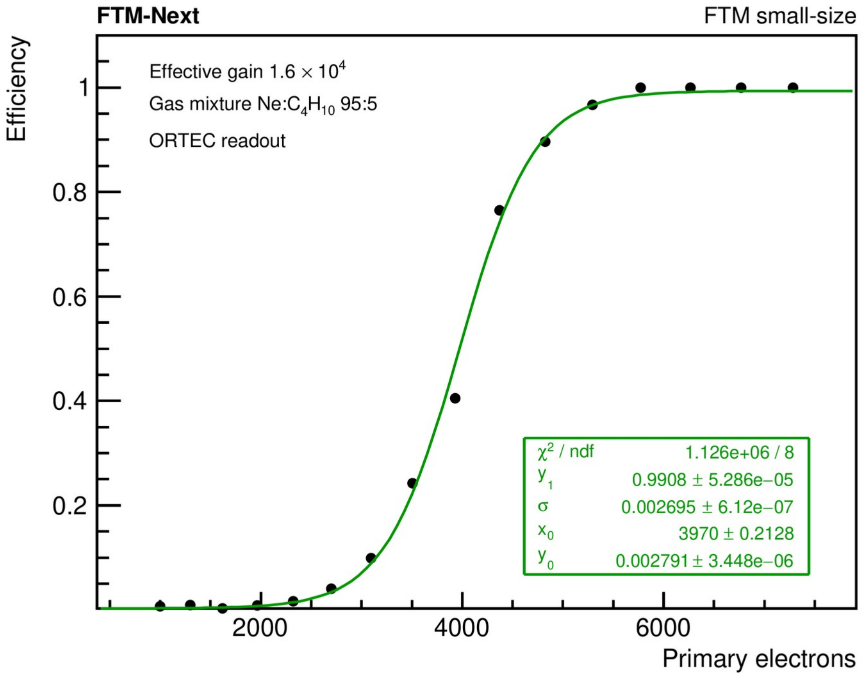


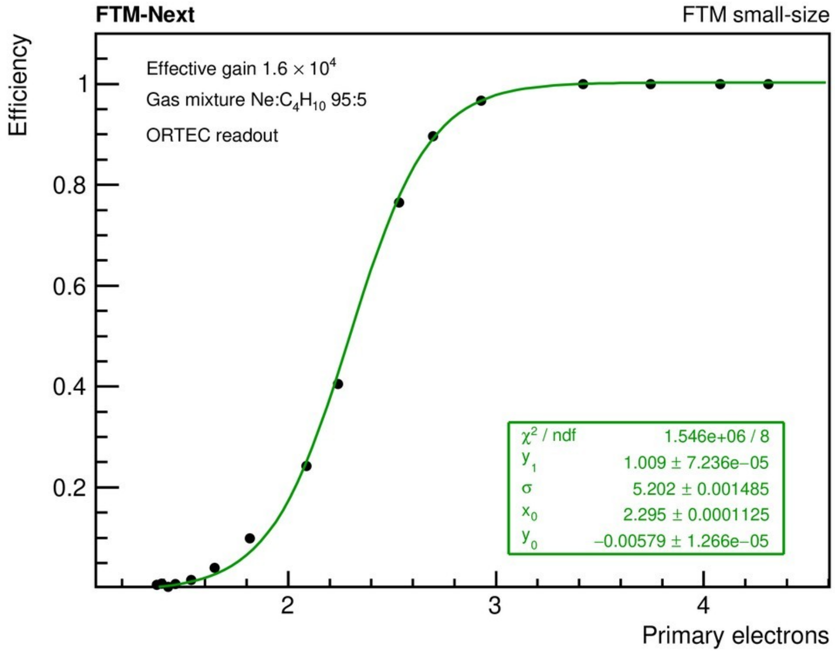
Method Efficiency measured as a function of laser **pulse energy**, ortec preamp readout
Efficiency = #FTM signals/#trigger signals

To know efficiency vs number of primary electrons, we need to use the calibration curve of **primary current vs laser pulse energy**

Result: At *"current"* gain of 1.5×10^4, detector is fully efficient only at **5000 primary electrons!**

Efficiency measurement results





Result At *"current"* gain of 1.5×10^4, detector is fully efficient only at **5000 primary electrons!**

- Not enough for MIPs
- Incompatible with effective gain measured in current mode

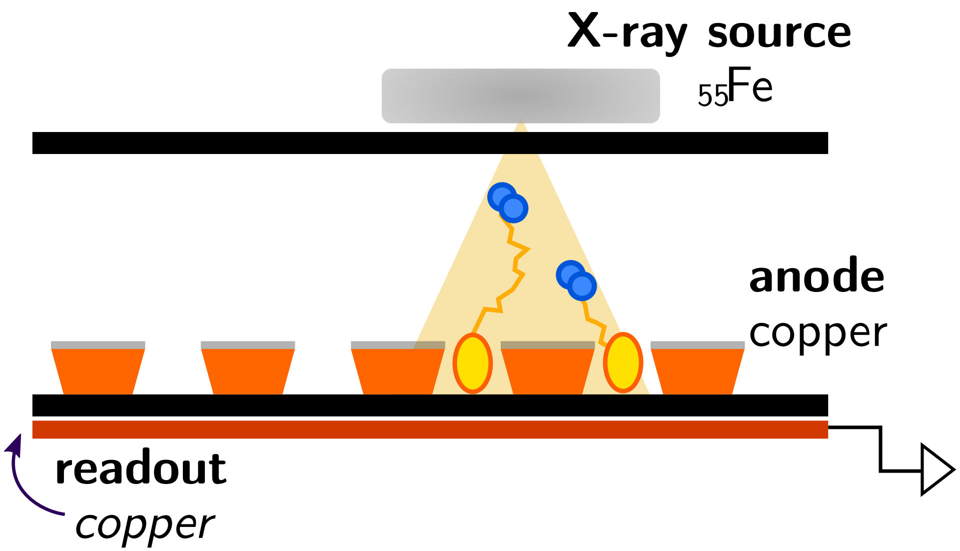
Conclusion Induced signal to R/O is strongly attenuated with respect to amplified charge

Main focus for present debugging

If you "trust" the signal charge and calculate the number of primary electrons as **signal charge/gain**, efficiency reached at **3 primary e^-**!

"Signal gain" is much smaller than "charge gain"

More details on efficiency and induced signals



Signals from $_{55}$Fe source **not observable** on readout neither with DLC foil nor with conductive foil

No signals observed in **cosmic tests**

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If you "trust" the signal charge and calculate the number of primary electrons as **signal charge/gain**, efficiency reached at **3 primary e$^-$**!

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FTM outlook: efficiency, timing, perspectives

Status of foil performance studies

Obtaining high gains per layer by optimizing gas mixture → **done!**

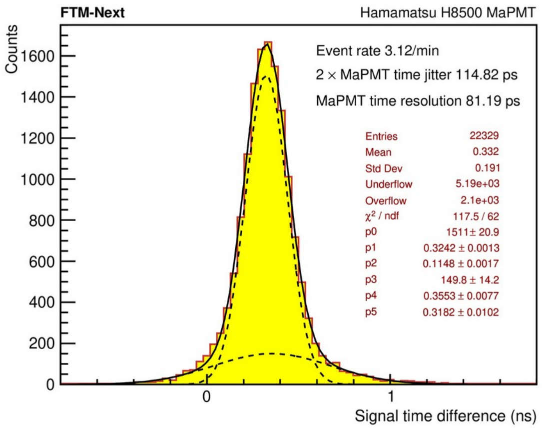
Good efficiency to low primary charges → **debugging ongoing**
Why is the signal attenuated so much with respect to amplified charge?

This is an absolutely necessary step to go verify the performance of the FTM in test beam and with cosmics

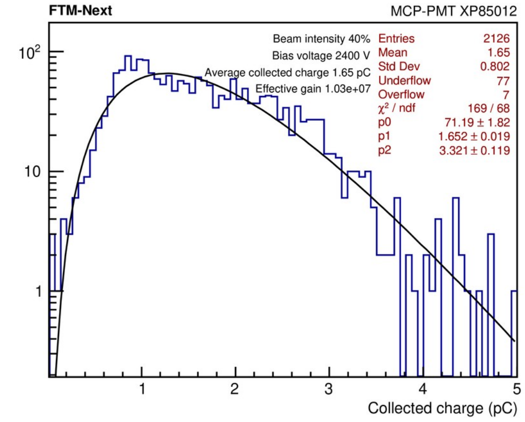
Ongoing tests with cosmics, preparation for test beam

Cosmic setup to be later re-adapted for test beam

- 2× **trigger MaPMT** (80 ps time resolution measured with cosmics)
- Time reference: **MCP-PMT** (<30 ps expected time resolution)



MaPMT time resolution measured in cosmic setup



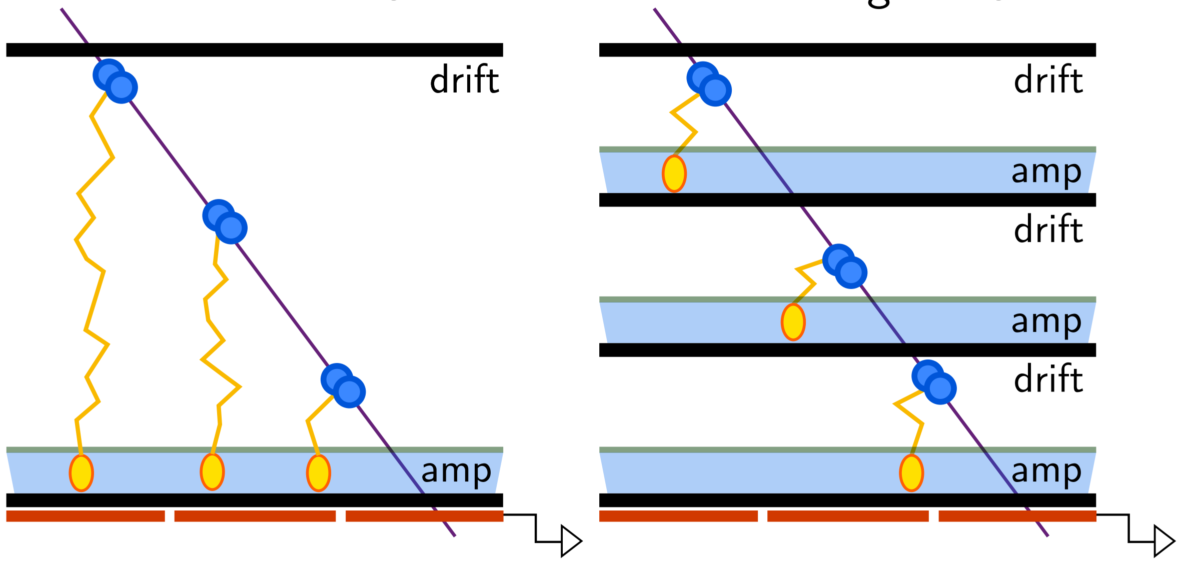
Single-photon MCP-PMT charge spectrum observed with UV laser

Conclusion FTM agenda full of tasks in the upcoming months. Support from **MPGD community** and communication with **foil production** specialists will continue being indispensable in this stage of development

Backup

Fast timing MPGD

Traditional MPGD | Fast Timing MPGD



MPGD time resolution to MIPs dominated by **drift time of the primary electrons**

$$\sigma_t \propto \frac{1}{\lambda N v_d}$$

primary clusters/cm → λ

e⁻ drift velocity → v_d

number of gaps → N

Working principle in one sentence: **reducing** the RMS of the **distance between creation point** of the primary ionization cluster **and amplification** region

In principle, valid with **any amplification** structure

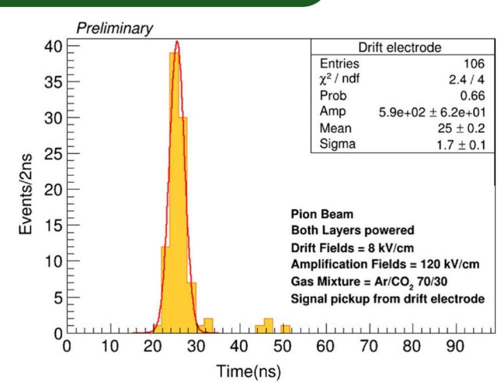
External readout strips → **Electrically transparent structure** → **Resistive electrodes**

Bonus: intrinsically spark resistant

Comparison with other *fast timing* gaseous detectors:

Work in **proportional region**, expected to have good **rate capability**

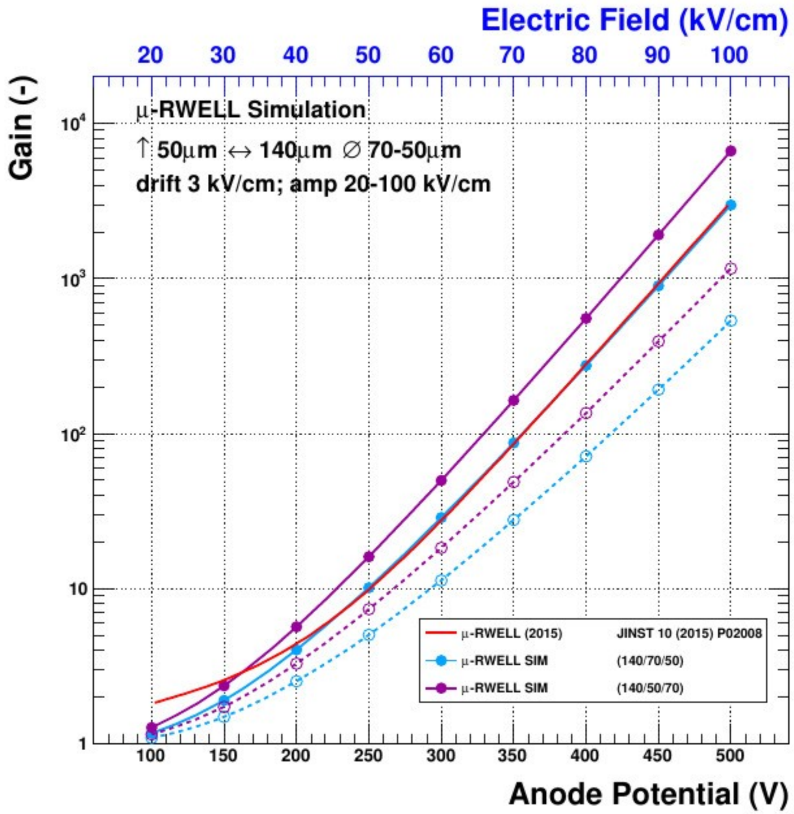
Ionization happens in gas: no need for external radiator → less expensive to **scale to large areas**, materials are radiation-hard

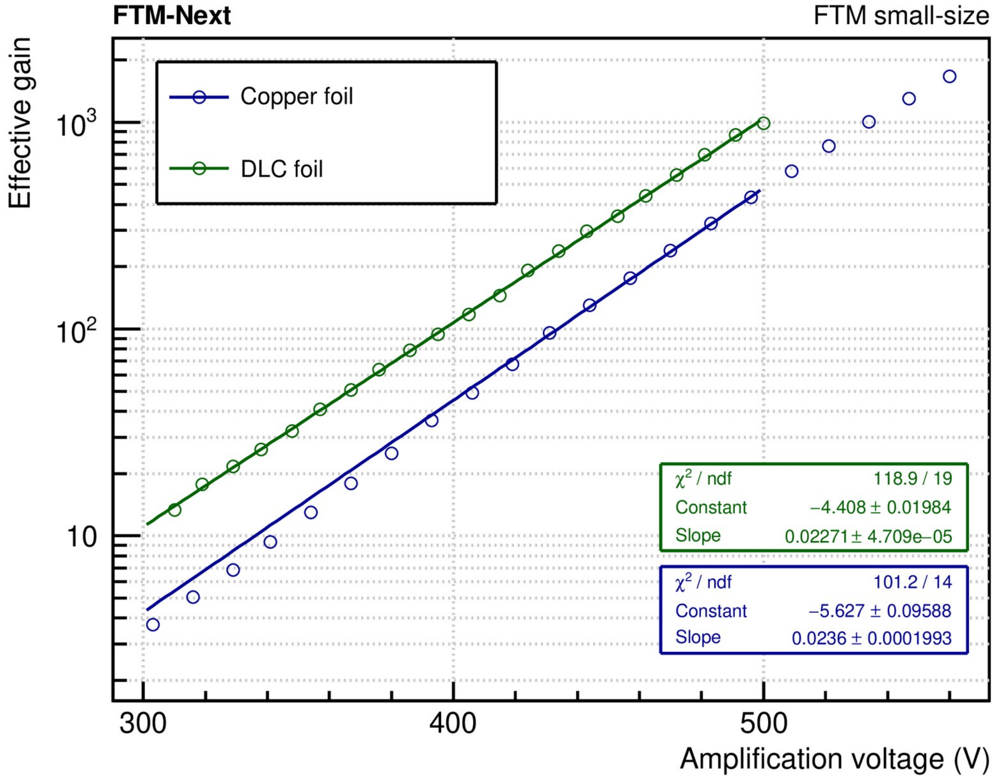


First test beam on FTM in 2015, 2 ns time resolution measured [1]

Subsequent R&D focused on improving gain and efficiency

Gain comparison DLC-copper w/ simulations





Cu Foil: top: 70um, bottom: 50um
DLC Foil: top: 50um, bottom: 70um

Gain factor 2 higher for small top diameter

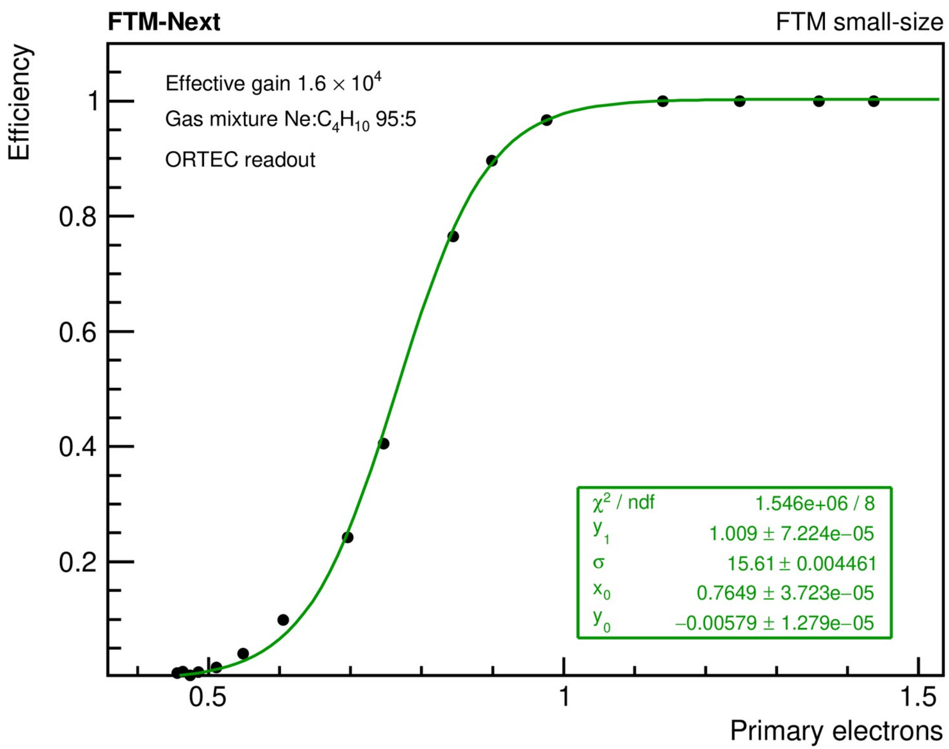
Cu Foil: top: 75-80um, bottom: 45um
DLC Foil: top: 78um, bottom: 100um

Gain factor 2 higher for DLC foil

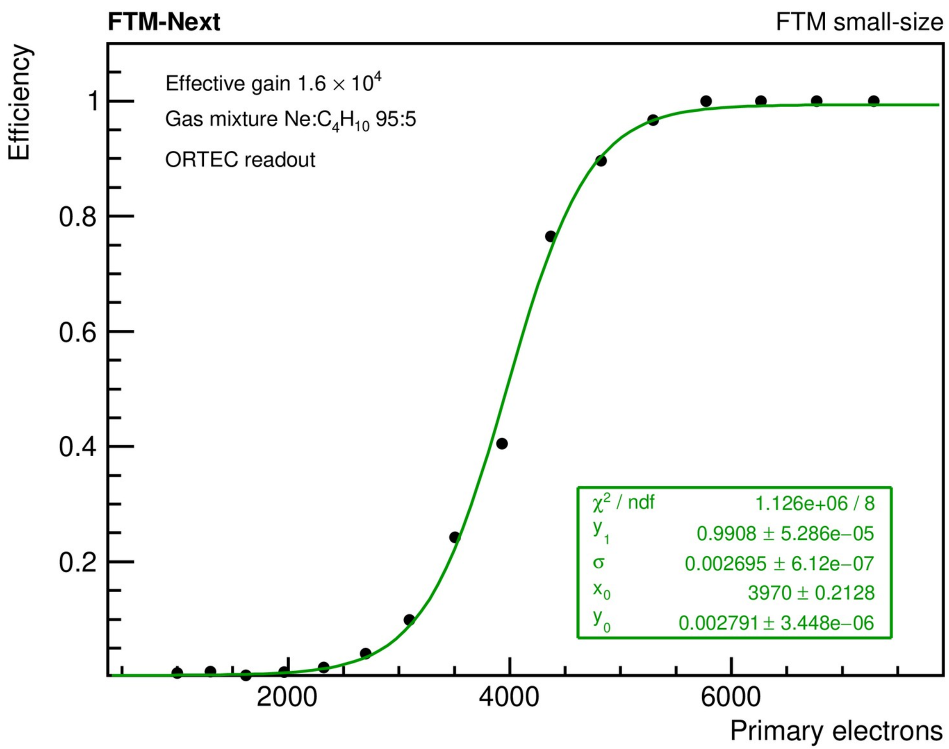
Result: efficiency vs primary charge

Result: the primary charges obtained from the two methods are in **large disagreement**

Method #1: primary charge calculated from signal amplitude and current gain



Method #2: primary charge calculated from plot of primary ionization current



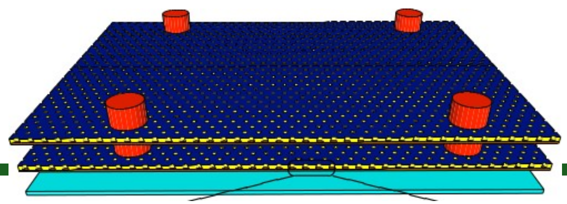
According to the *current method*, the FTM should be **efficient at 5000 primary electrons,** which is not realistic for a detector operated at **gain 1.5 × 10^4**

→ The gain measured in "current mode" is different from the signal gain

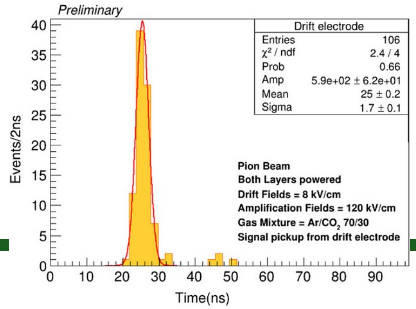
Why is the induced signal attenuated so much?

Timeline of the FTM development

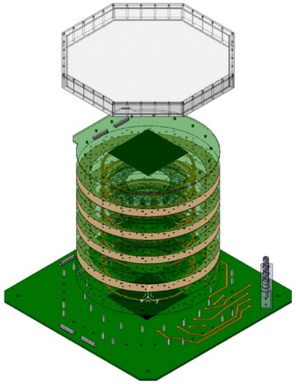
2015
Concept and first GEM-based prototype at CERN [4]



2016
Test beam at CERN [5]



- Two-layer prototype
- Resolution of 1.7 ns measured
- Very thin drift gaps 250 μm
- Low gain
- Efficiency < 20%

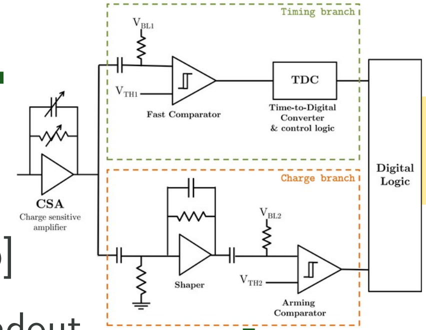


2016-17
Prototypes based on MicroMegas and THGEM

Goal: increasing gain and efficiency
Results: sparks on resistive electrodes

2018-19
Prototypes in Bari/Pavia/Ghent [6]

Goal: more layers, readout electronics



2020→
Small-size FTM

Goal: Demonstrate multi-layer principle with small-area detector
Main source for this talk