Single electron avalanches in Gas Electron Multipliers

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REGARD
RMKI ELTE Collaboration on Gaseous Detector Research and Development

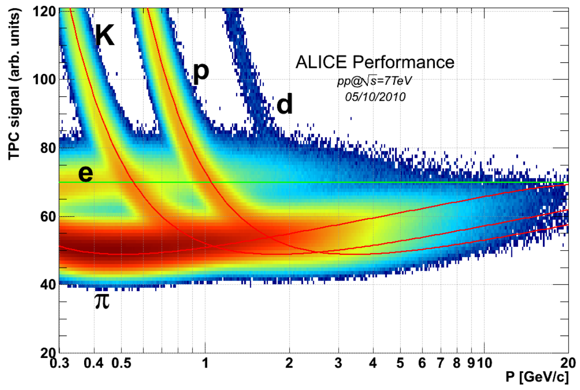
Outline

- Motivation
- Gaseous detectors in general & Micropattern Gaseous Detectors
- Avalanche processes
- Detector concept and measurement setup
- Single electron avalanche distributions in different gases
- Single electron spectra
  - Direct measurement and Fourier methode
- Summary and outlook

Motivation

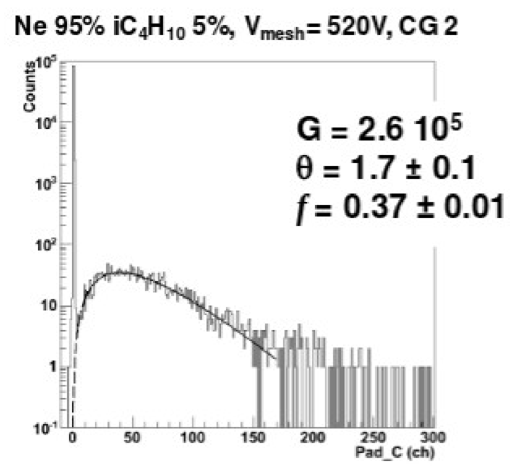
Heavy ion physics:

- particle identification is crucial
- PID: momentum and dE/dx or TOF or Cherenkov
- TPC (the most favoured detector):
  - p, dE/dx
  - Need for good dE resolution
  - Limit from avalanche fluctuations?
- RICH:
  - Cherenkov photon detection
  - Need for high efficiency for single electron signal
  - Limits from avalanche distribution?

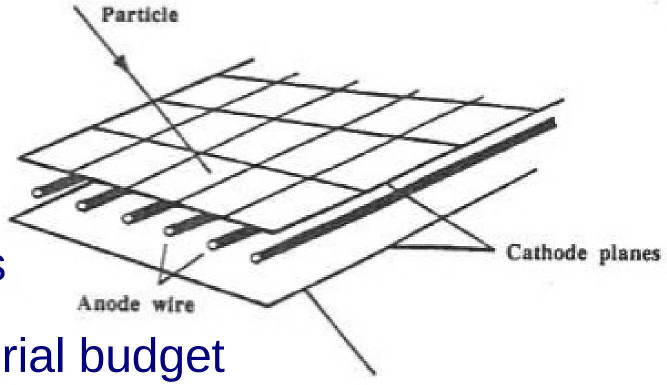


Motivation

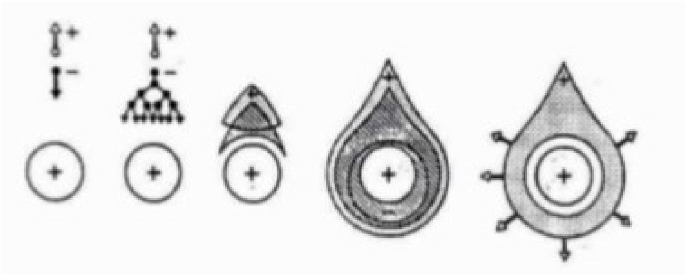
- Avalanche fluctuation contributes to energy resolution
- Single photon detection efficiency depends also on the distribution
- Gain fluctuation in MWPC:
  The distribution of the size of single electron avalanches is exponential
  Alkhazov: NIM 89 (1970) 155, NIM 75 (1969) 161
- „New results on gas gain fluctuations
  in a Micromegas detector"
  T.Zerguerras et al.: NIM A608 397 (2009)
- **GEM gains are relatively low**
  → hard to measure on a single GEM



Gaseous detectors



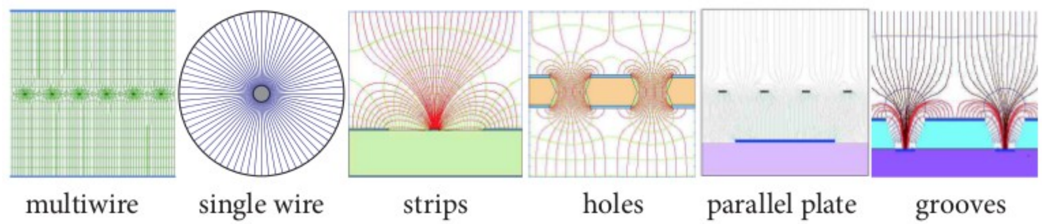
- Well-known technique, used for many decades:
  GM counters, MWPCs, drift tubes, TPCs
- Cost-efficient solutions for large areas or volumes
- Tracking and dE/dx measurements with low material budget
- Possible application in RICH detectors
- Adequate for heavy ion experiments
- Working principles:
  ionization → e^- collection →
  → amplification → signal readout



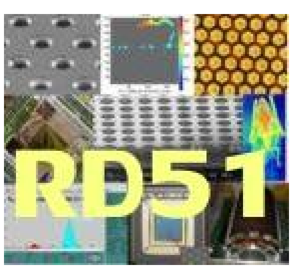
- Several examples of currently operating gaseous detectors:
  - TPCs: STAR @RHIC, CERN NA61, ALICE
  - Drift tubes at ATLAS, CMS

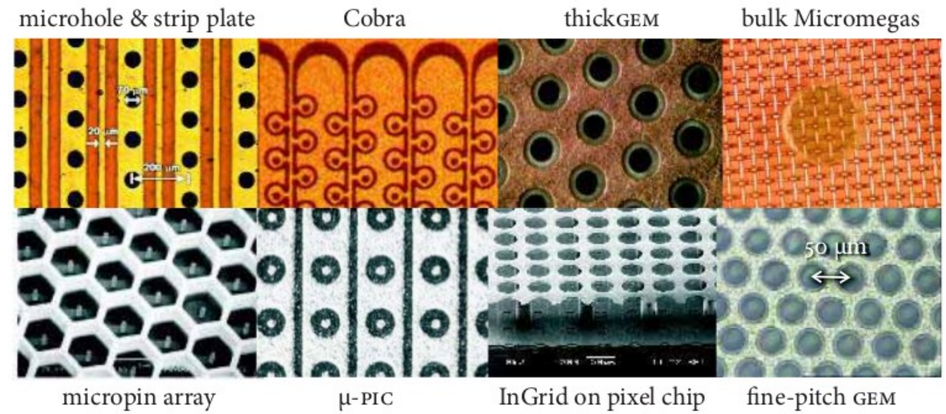
Micropattern gaseous detectors

- Why use MPGDs:
  - Geometrical flexibility
  - Higher rate capability
  - Low material budget
  - Reduced ion backflow
  - Industrialization of production (eg. photolitography, microelectronic and PCB technology)



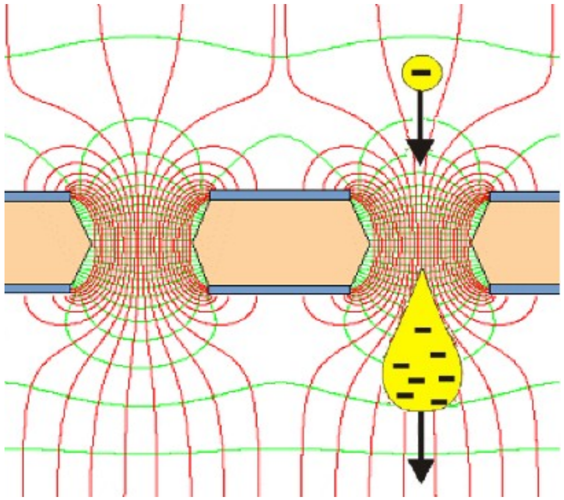
- Research field with high activity
  CERN RD51 Collaboration

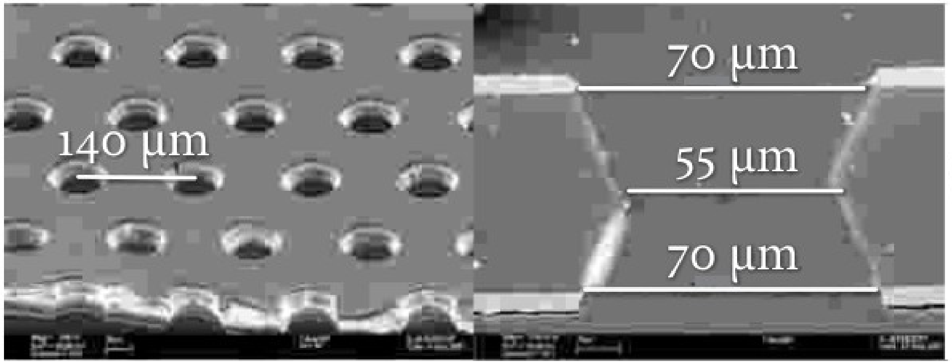


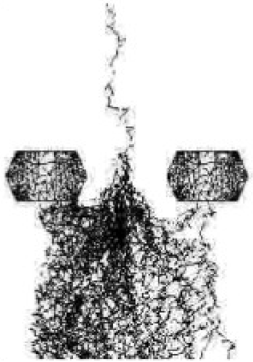


GEM

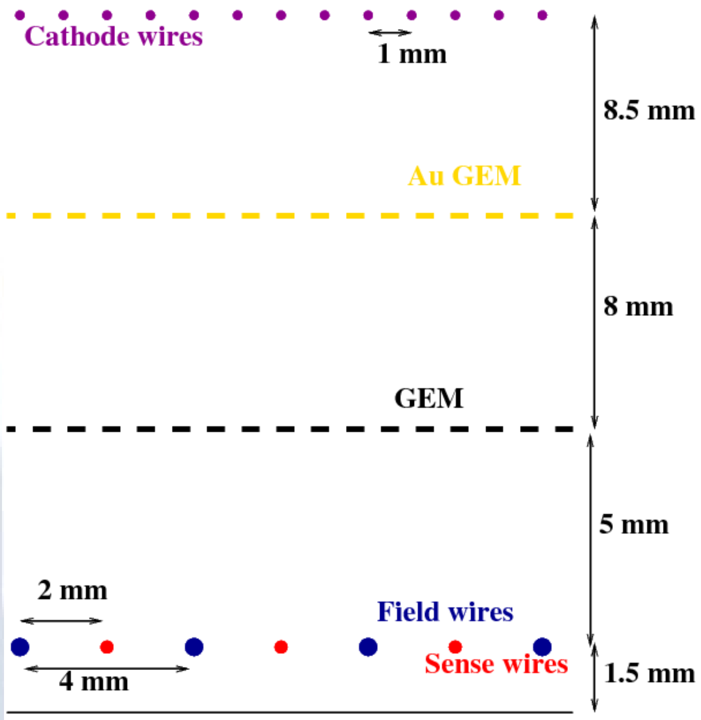
- Gas Electron Multiplier (F. Sauli, 1997)
- Metallized kapton foil on both sides
- Avalanche: 10-1000
- Standard usage as triple GEM
- Separated signal amplification and readout
- Working GEM-based detectors at HERA-B,COMPASS, TOTEM, LHC-B, PHENIX
- To be used for upgrades: COMPASS, ALICE, CMS



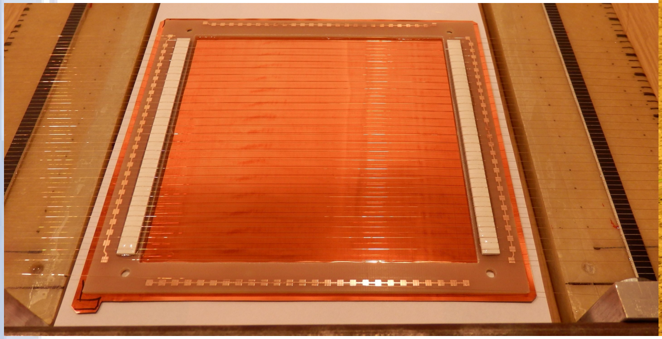


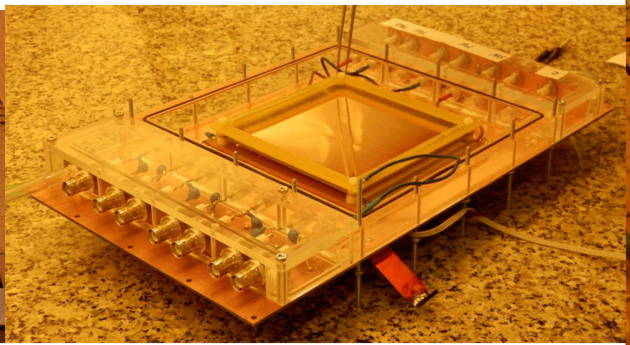


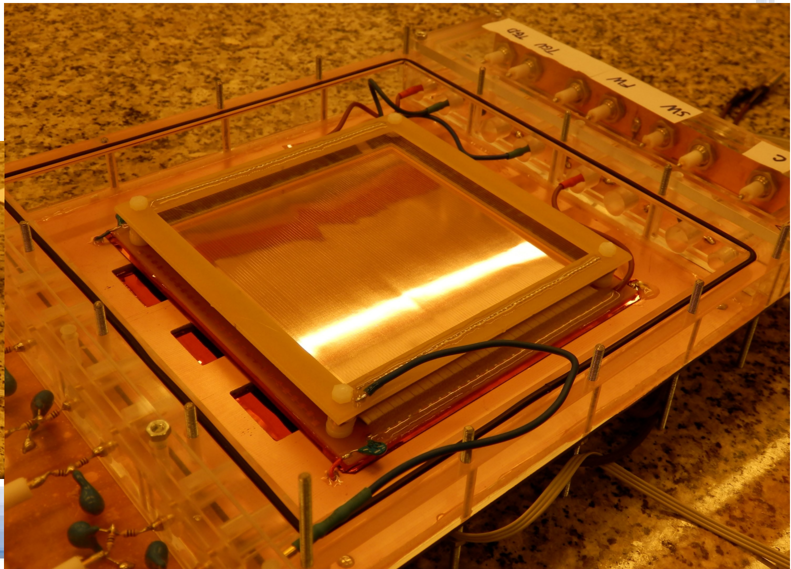
Our detector concept



- Pulsed UV light is used to emit single photo-electrons from a gold coated GEM
- GEM in investigation
- Wire chamber (CCC) as high gain amplifier
- Standard GEMs made @ CERN
  (50/70µm diameters, 140µm pitch, 50µm thick)
- Standard CCC
  (21µm and 100µm wires)

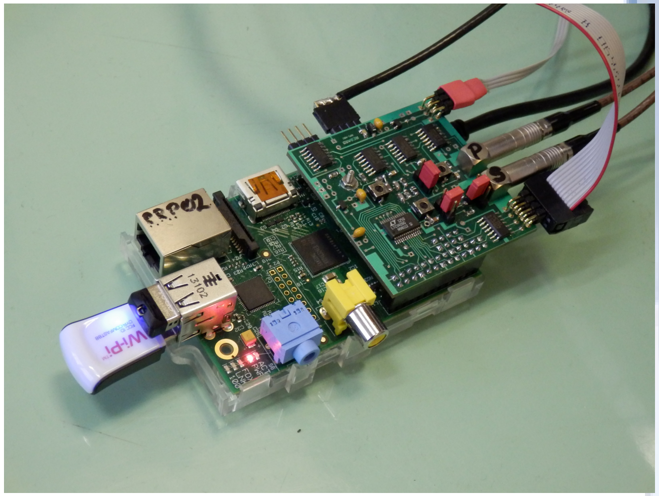




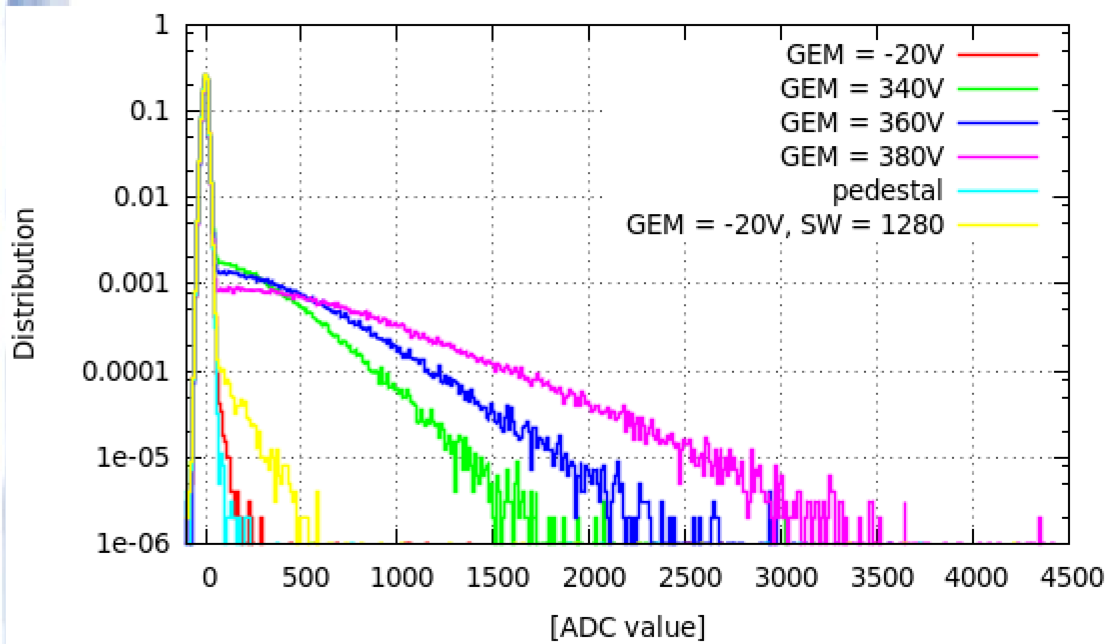


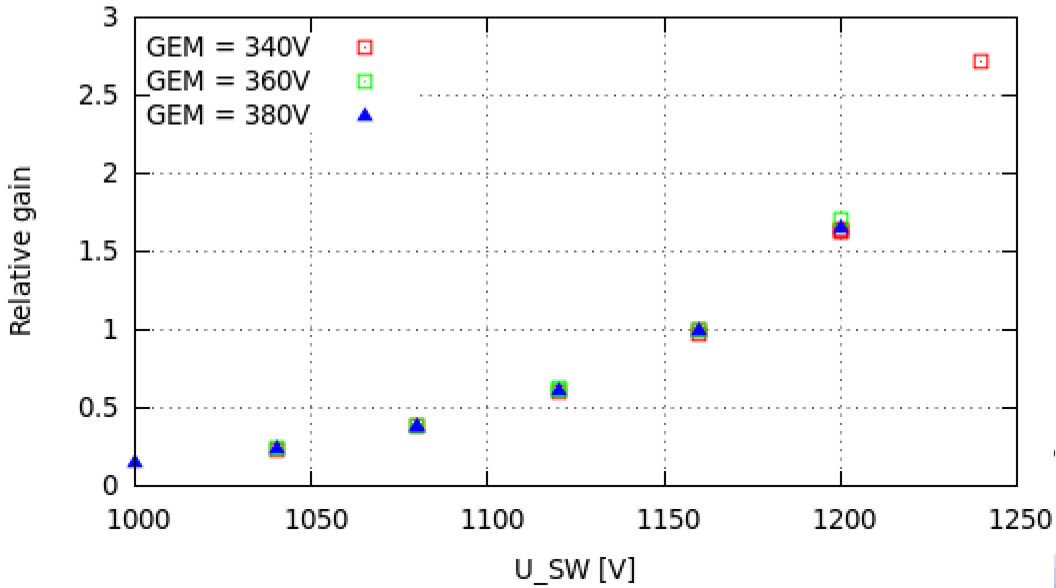
Measurement setup

- Ar-CO_2 (80:20), Ne-CO_2 (90:10), CH_4
- Pulsed UV LED source (SETI UVTOP 240)
  - Intensity tuned to have <<1 PE/event
- Signal from connected sense wires
- DAQ: 12bit ADC controlled by a RaspberryPi
- Leopard type data acqusition (see: PoS TIPP2014 056)
- Data taking @ 20kHz to avoid signal overlapping
- 1M events per run



Pulse height distribution

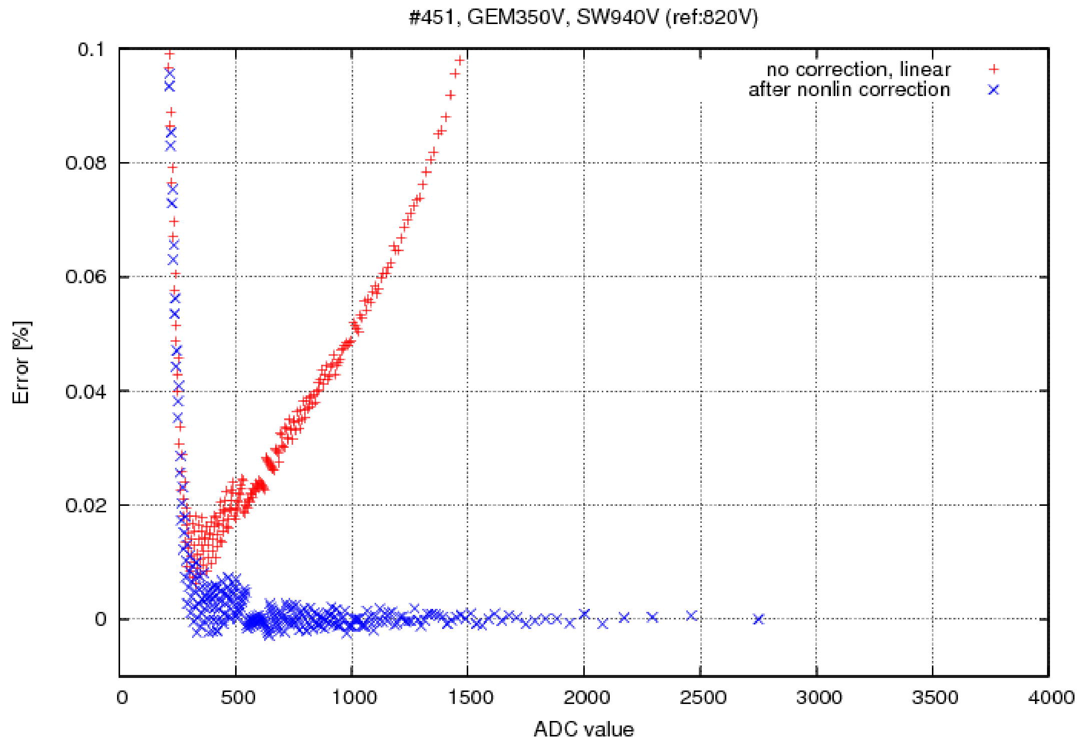




- 2 amplification stages:
  - GEM (10-50)
  - Wires (10^3 - $4*10^4$)
- Single PE distributions at different voltage setups
- Distribution is dominated by the first amplification stage
- Exponential distribution for wire gain
- Clearly not exponential for GEM
- Factorization of Wire and GEM gains
- Electronics linearity?

ADC nonlinearity correction

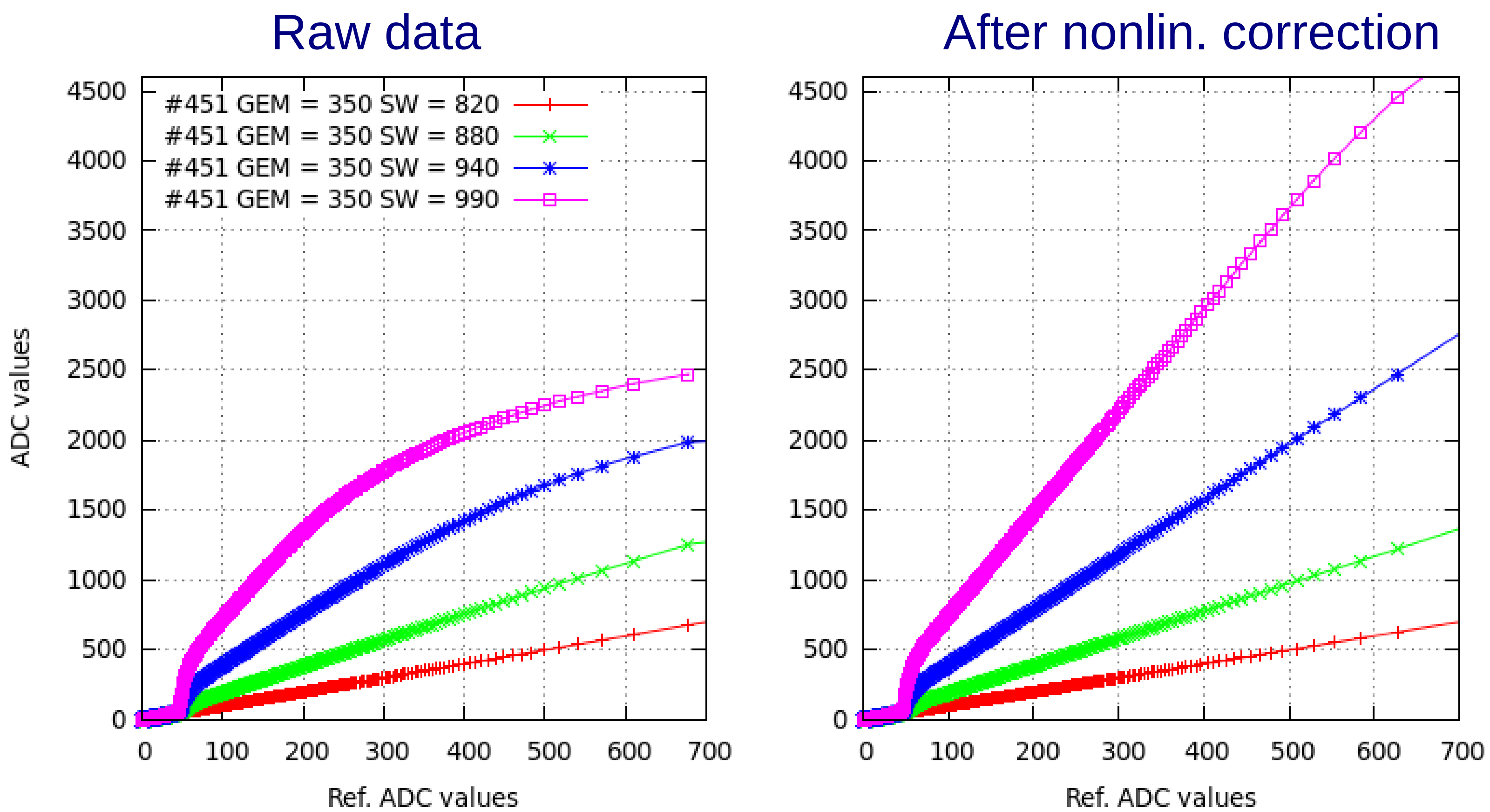
- **Need for high effective dynamic range**



- A small effect in the measured region
- Same GEM gain
- Nth Percentil vs. Nth percentil

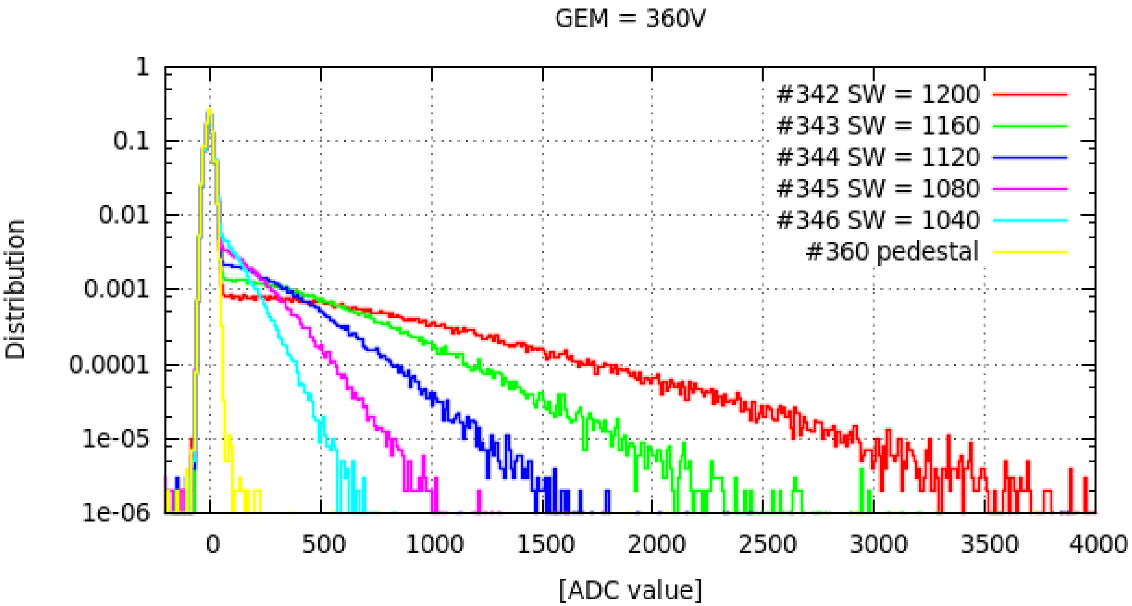
- Corrected ADC values = f(measured ADC values) where f(x) is polynomial

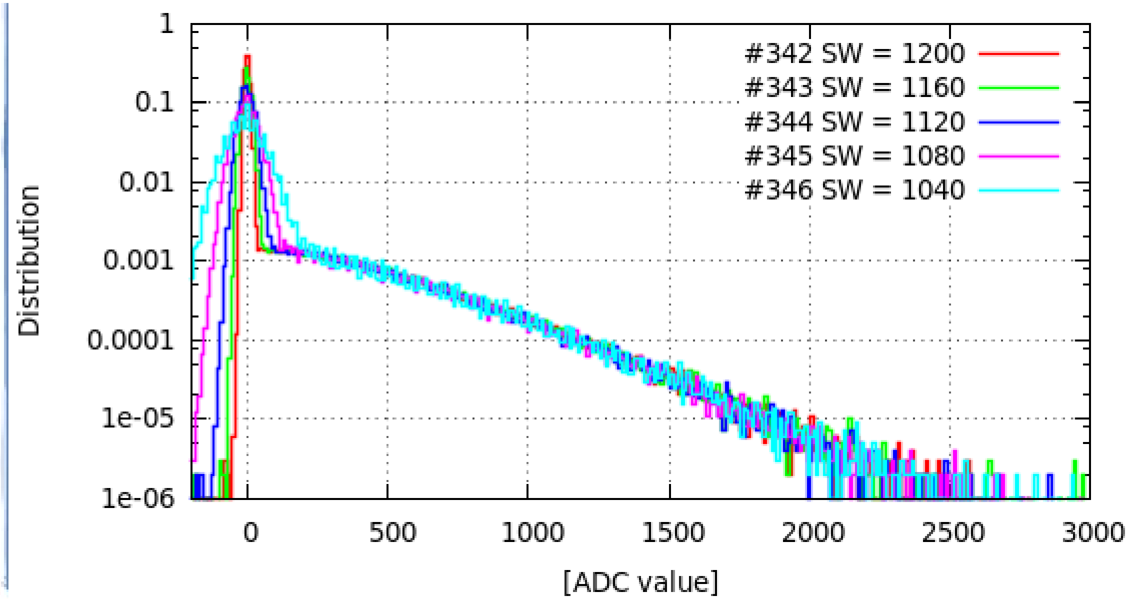
ADC nonlinearity correction



- Slope → relative gain
- Successful correction over the whole range

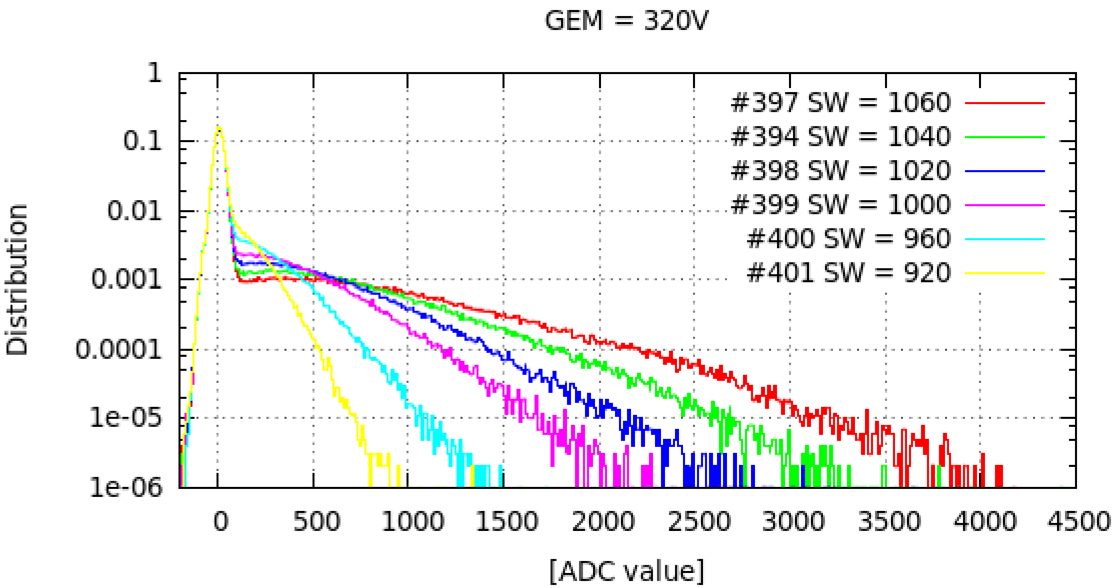
Avalanche distribution in Ar-CO_2

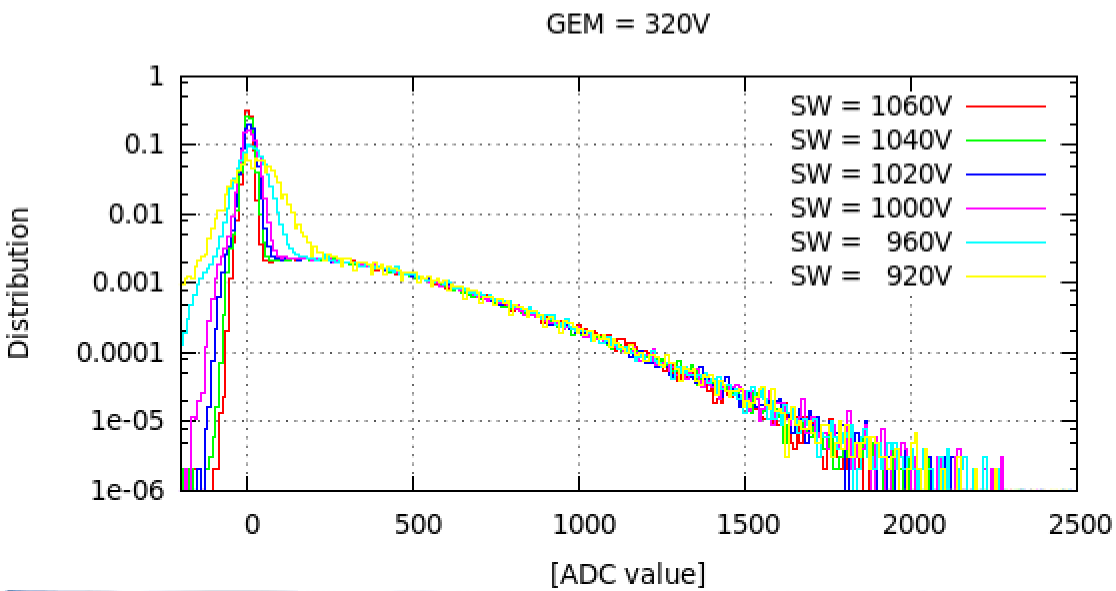




- U_{GEM} = 360V (gain: ~15)
- The gain on the wires does not change the shape of the avalanche distribution
- Similar results for other GEM gains (10-50)

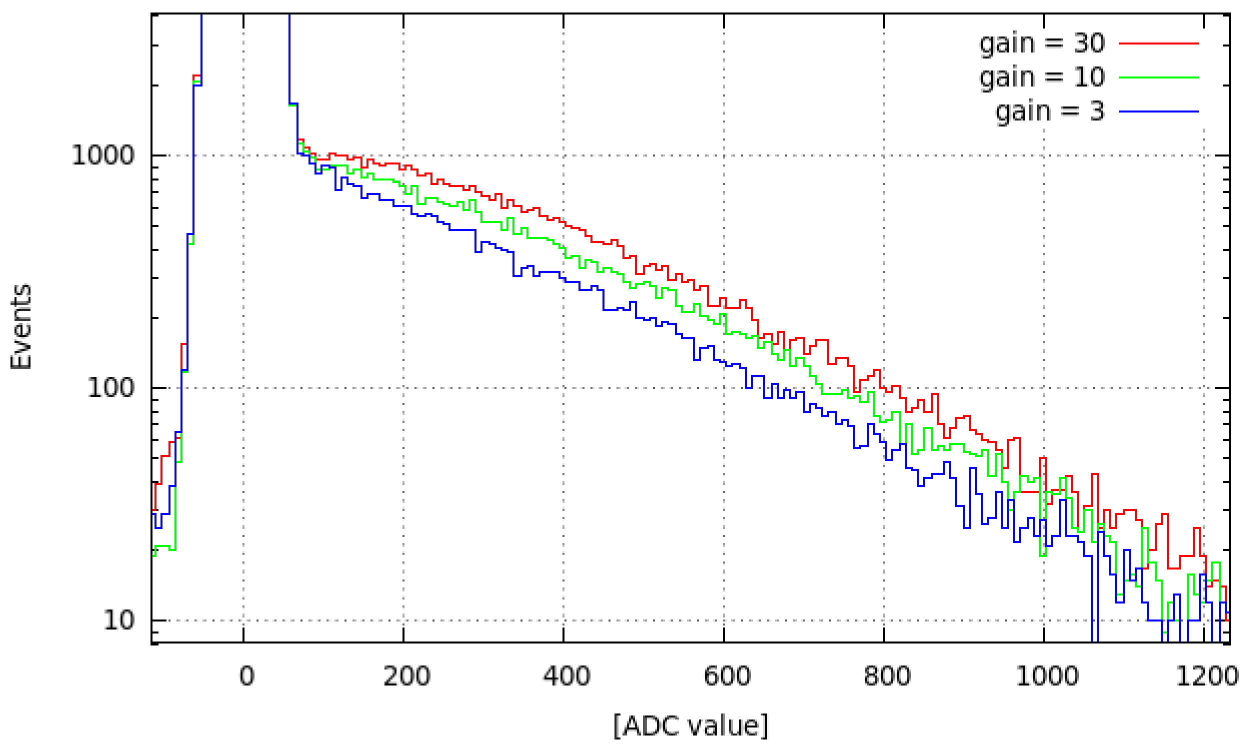
Avalanche distribution in Ne-CO_2





- Similar results in Ne-CO_2
- GEM Gain: ~15

Avalanche distribution in methane



Extracting single electron response in GEM

Measured signal:

(1) Poisson statistics of PE

(2) Avalanche fluctuation in GEM

(3) Extraction from GEM

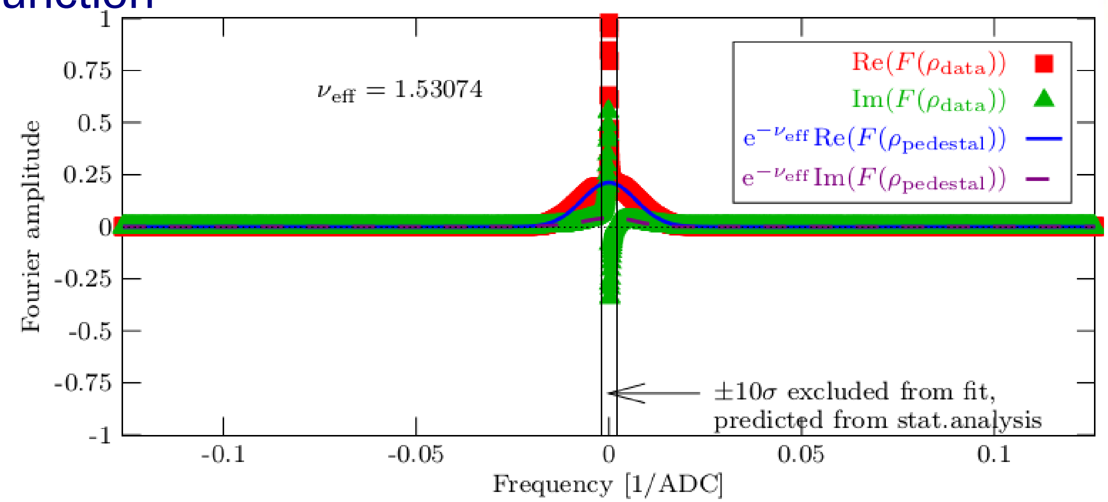
(4) Avalanche on MWPC

} ⇒ Large effective GEM gain supresses the distortions

PE Poisson statistics unfolding (A. László)

$$g = n * \sum_{k=0}^{\infty} f^{*(k)} P_\nu(k),$$ Fourier transformation → $$G = N \sum_{k=0}^{\infty} F^k P_\nu(k),$$

- g: measured probability distribution function
- n: electronic noise distribution (easily measurable with a pedestal run)
- **f: unknown single electron avalanche response distribution**
- P_ν (k): per trigger PE emission with expectation value ν (Poisson)



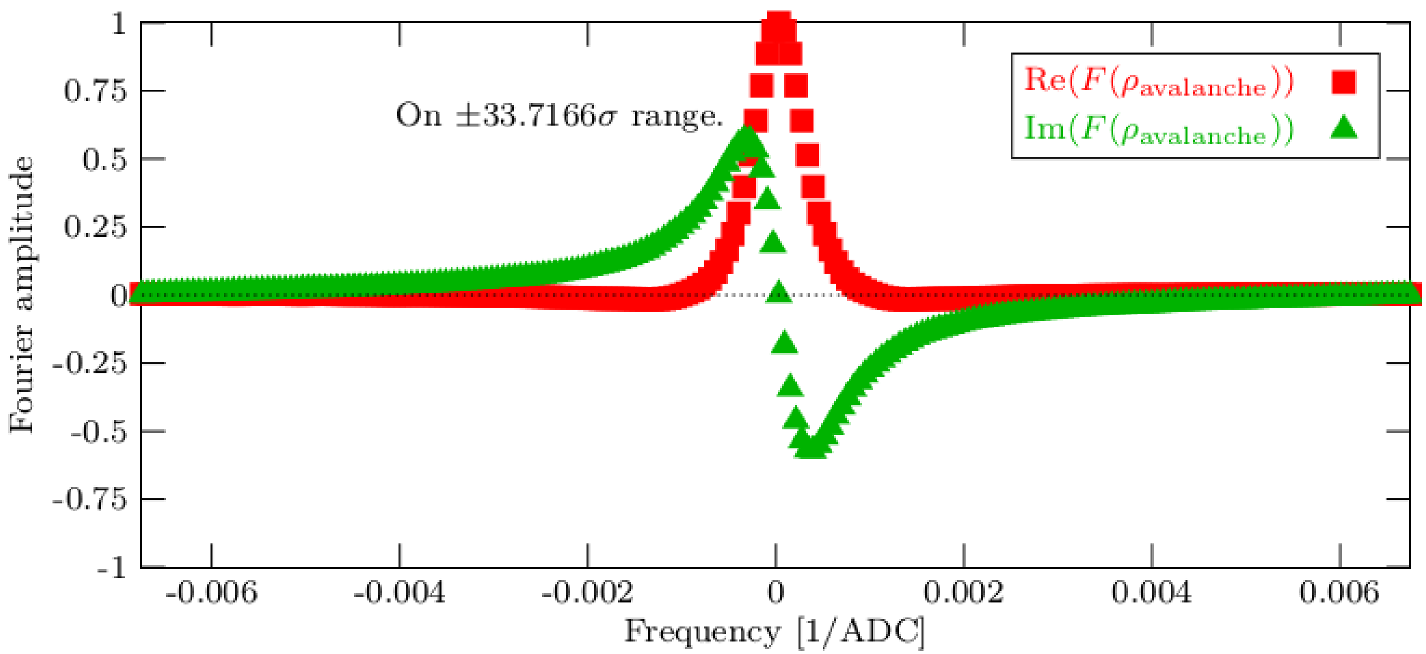
$$G = N \sum_{k=0}^{\infty} F^k \frac{\nu^k}{k!} e^{-\nu} = N \exp\left(\nu \left(F - 1\right)\right).$$

$$F = \frac{1}{\nu} \ln\left(\frac{G}{N}\right) + 1$$

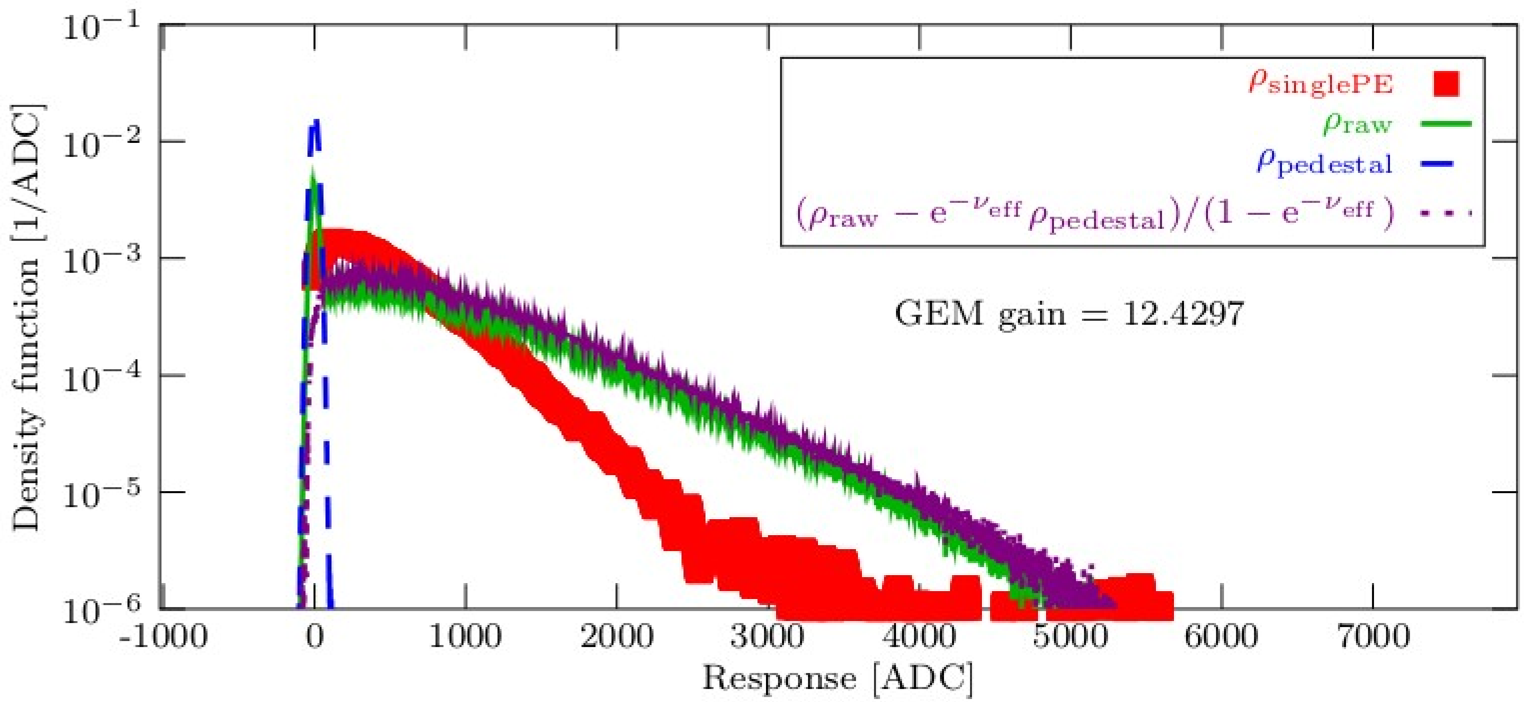
where: $G \approx N \exp\left(-\nu\right)$ (for large frequencies).

PE Poisson statistics unfolding

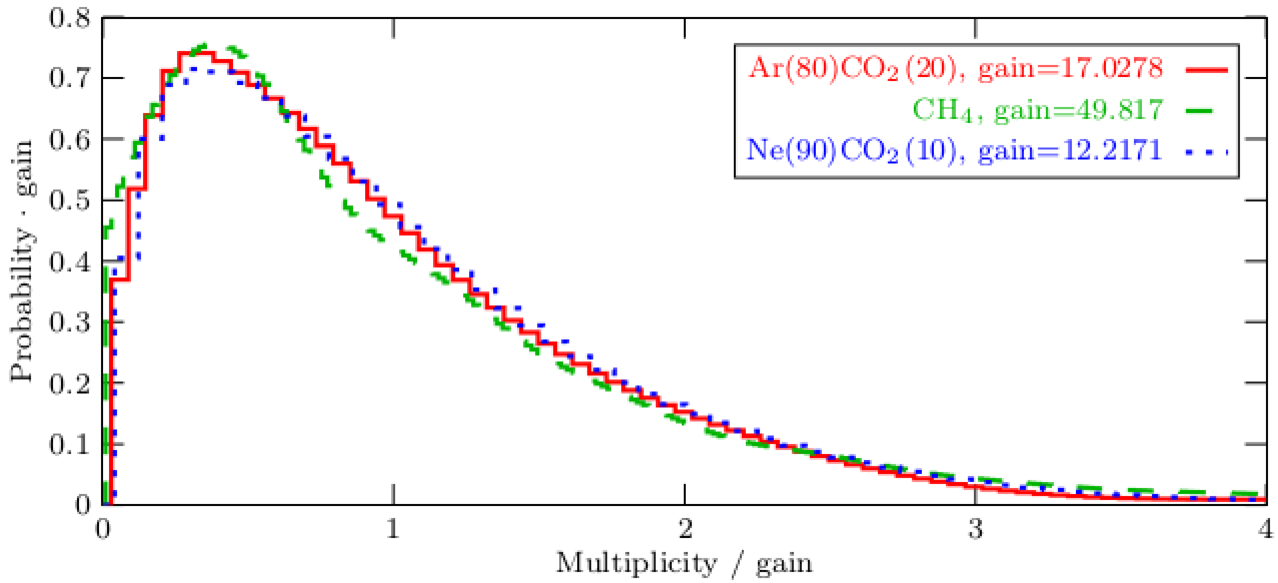
- Fourier spectrum of the signal (pedestal extracted)



Single avalanche response



Avalanche distributions



- Approximately universal shape of the avalanche distributions in a wide range of gain settings and working gases

Summary

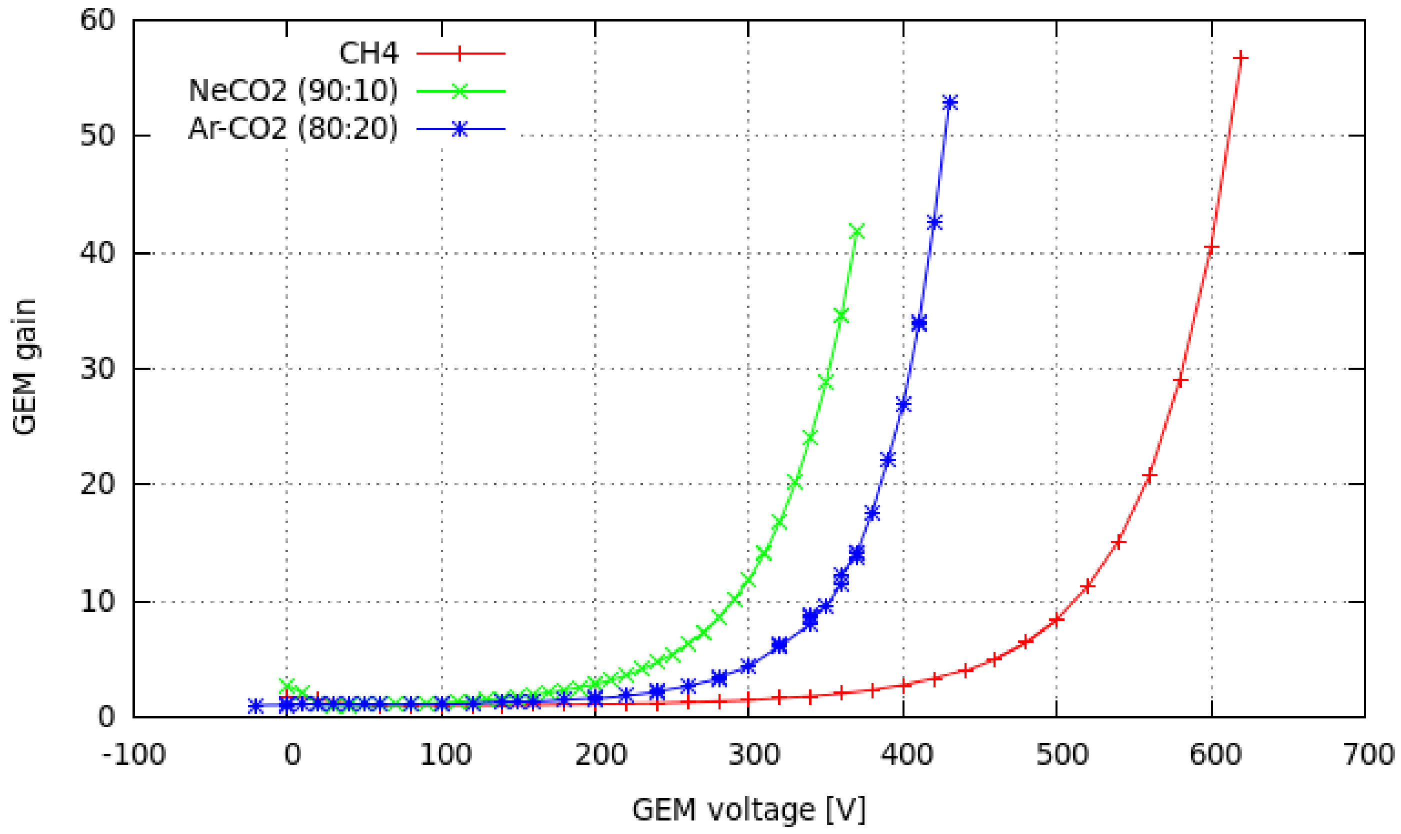
- Single PE distributions with a GEM+CCC detector has been measured
    - Separation of the 2 amplification stages
    - Evidence for non-exponential distribution
- Method for determining single PE avalanche distribution in GEM

Further plans

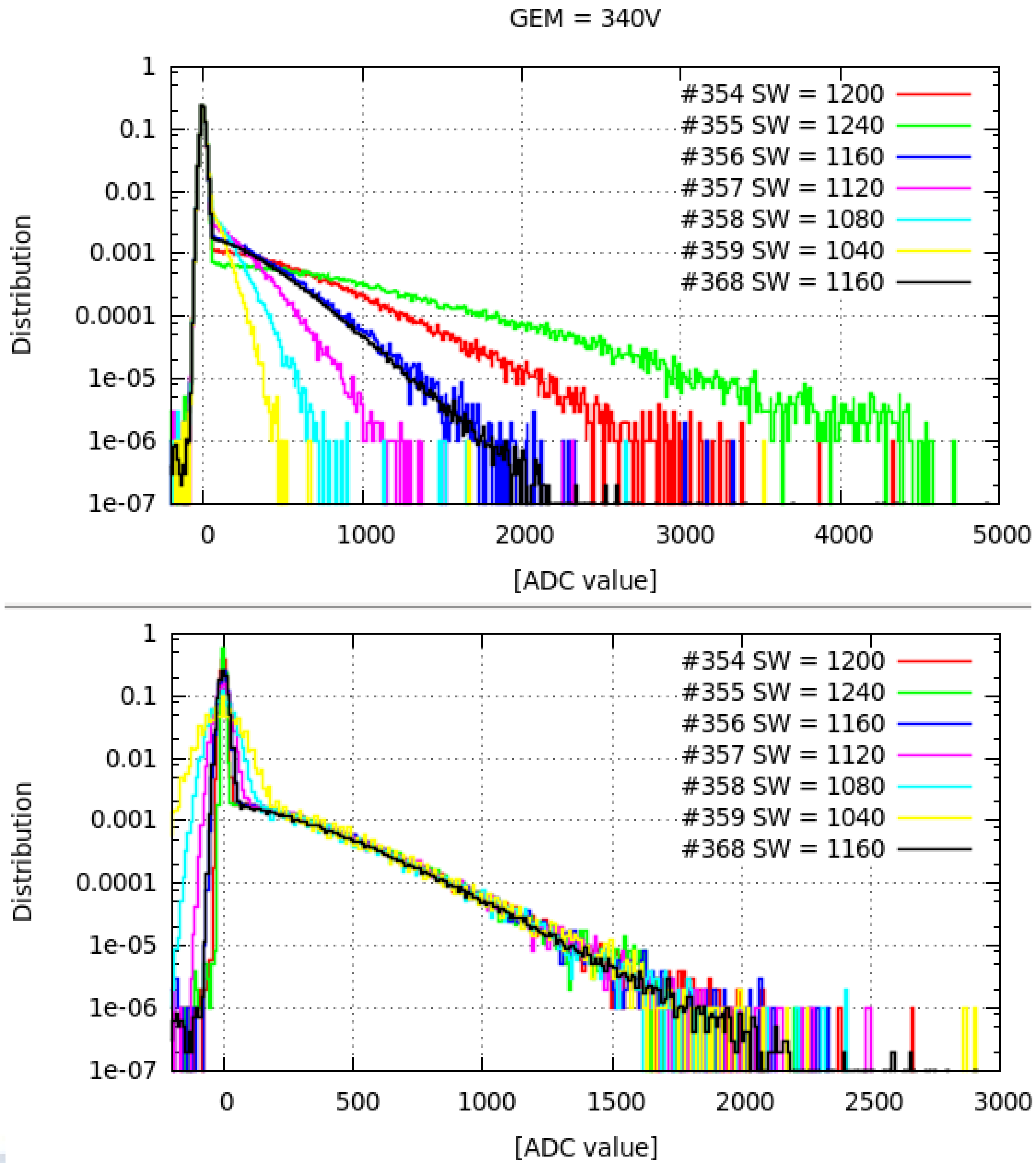
- Investigation of different gas mixtures
- Detailed comparison to microscopic simulation
- Measurements on Thick GEM

Thank you for your attention!

GEM gain in various gases



Avalanche distribution in Ar-CO_2



Avalanche distribution in Ar-CO_2