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RMKI ELTE Collaboration on Gaseous Detector Research and Development

Gain fluctuations in GEM detectors

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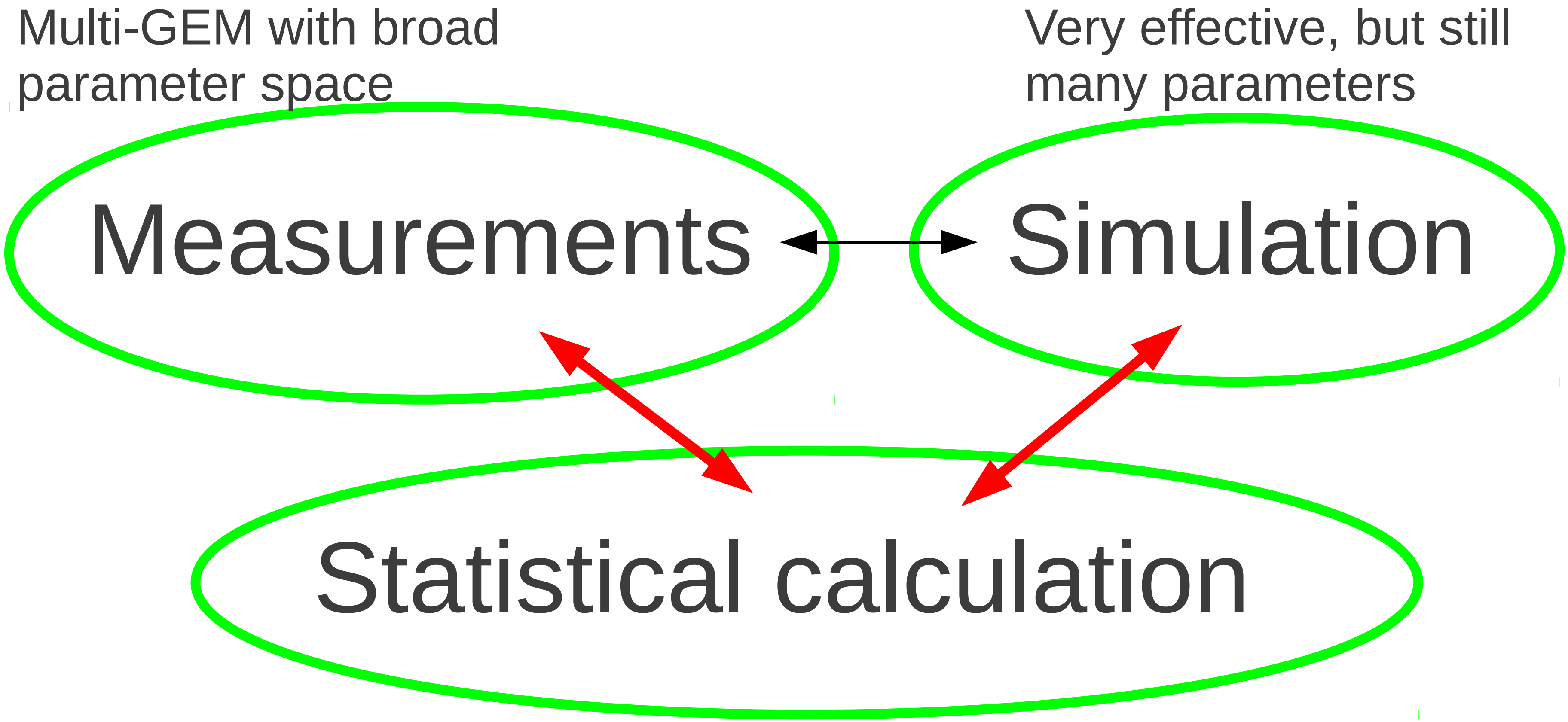
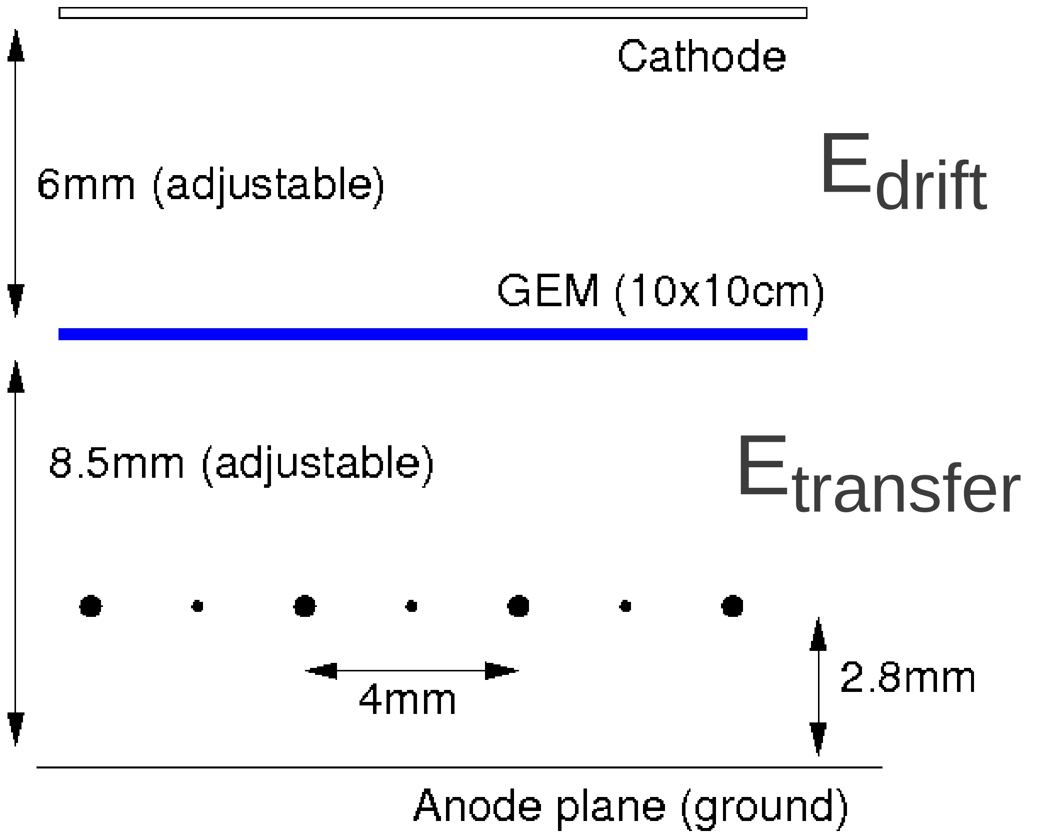
- Motivation: problem of gain fluctuation statistics for combined GEM-s
- Steps of the avalanche / charge collection, analytic formulae for superimposed processes
- Experimental test: prediction for ^{55}Fe energy resolution
- Comparison to simulations (from Taku Gunji)



- Energy resolution: contributions from all sources of fluctuations
- In “Single” gain stage, such as MWPC or MM, the avalanche fluctuation is the main source
- For multiple stages such as GEM, there is fluctuation from **collection, extraction** in all steps: how to account for these?

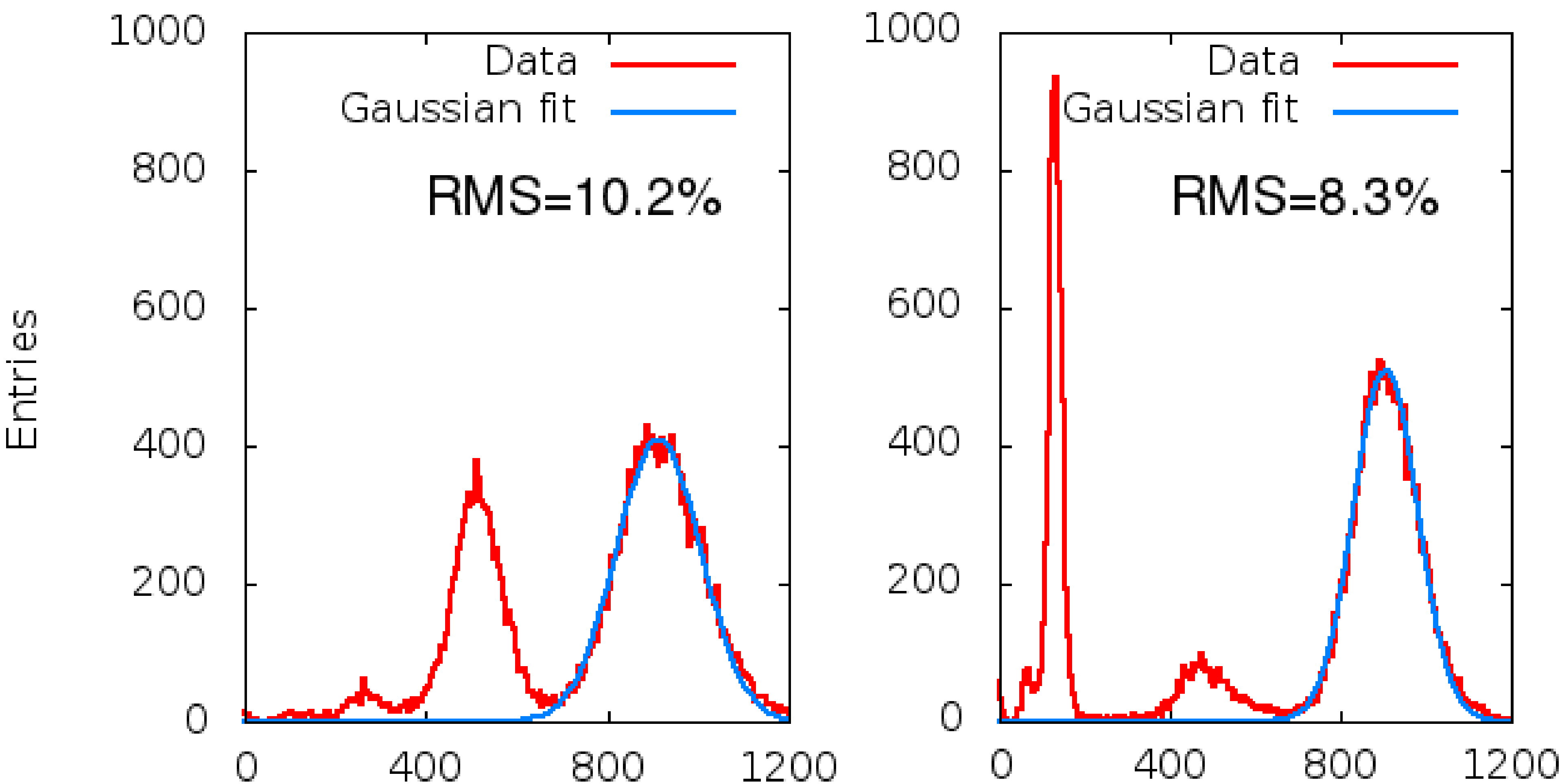
Simplest "multi-stage" system: measurements with GEM+MWPC



- Effective GEM gain: 2-10 (directly measured)
- Total gain 4000-6000
- Amplifier+ADC nonlinearity carefully checked

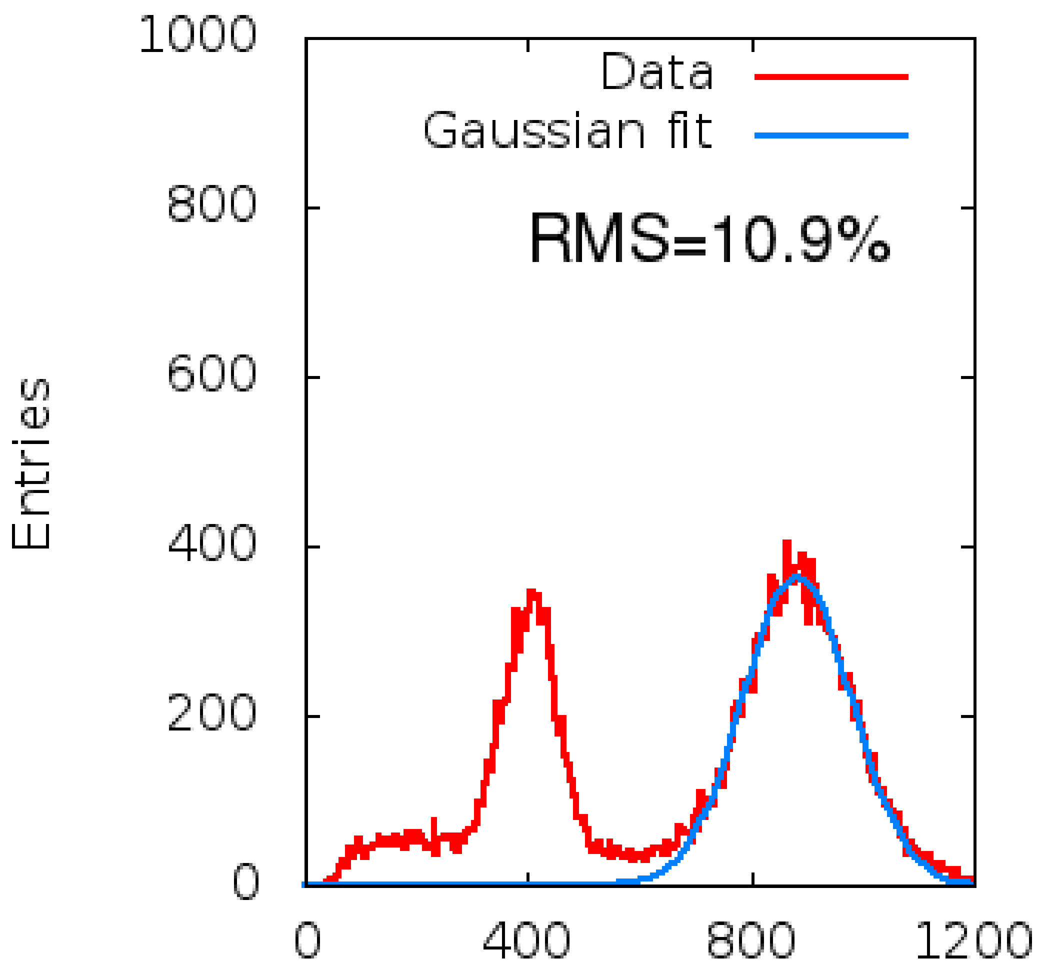
Measurements in Ar+CO2 (80:20)

- Effective gain 1.8
- Effective gain 7

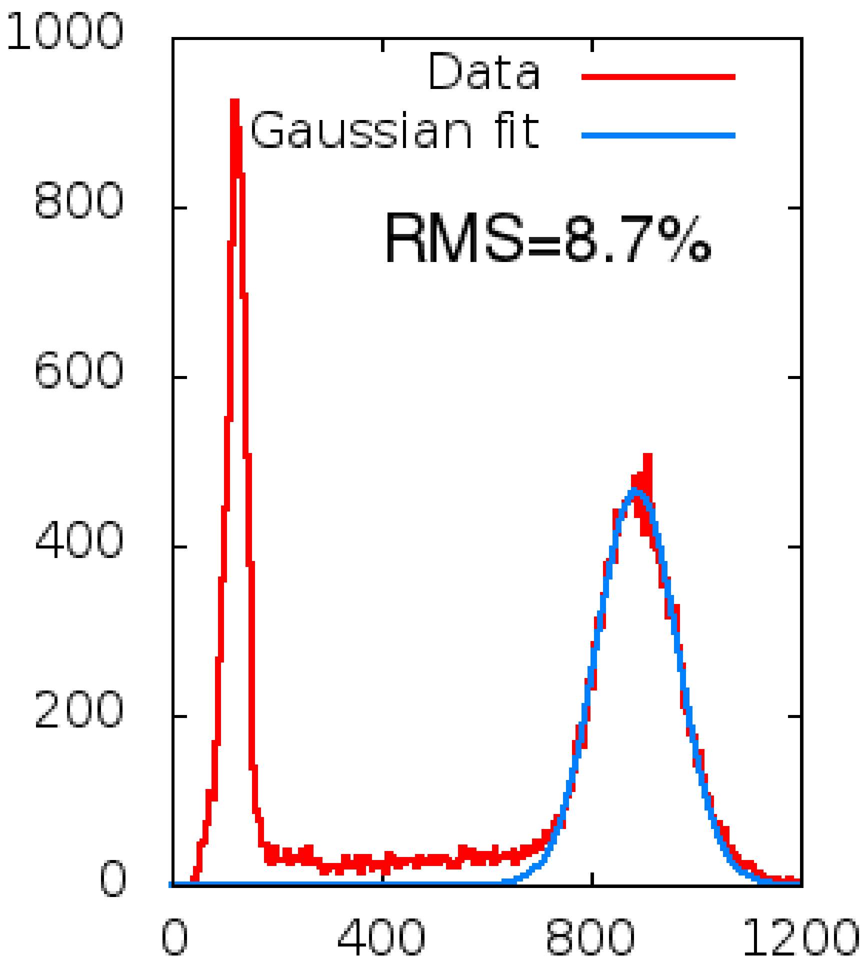


Measurements in Ne+CO2 (90:10)

- Effective gain 2.2

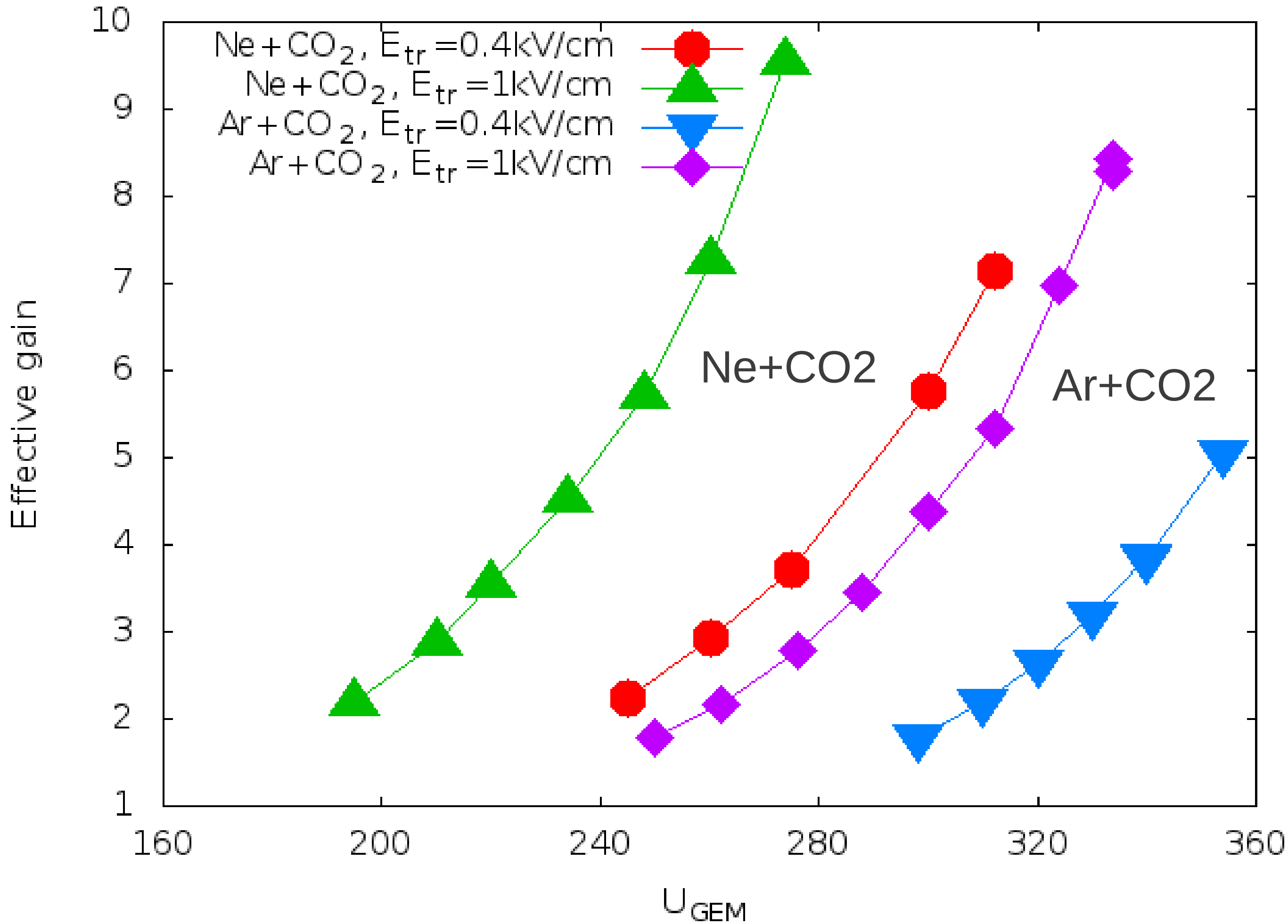


- Effective gain 7.3

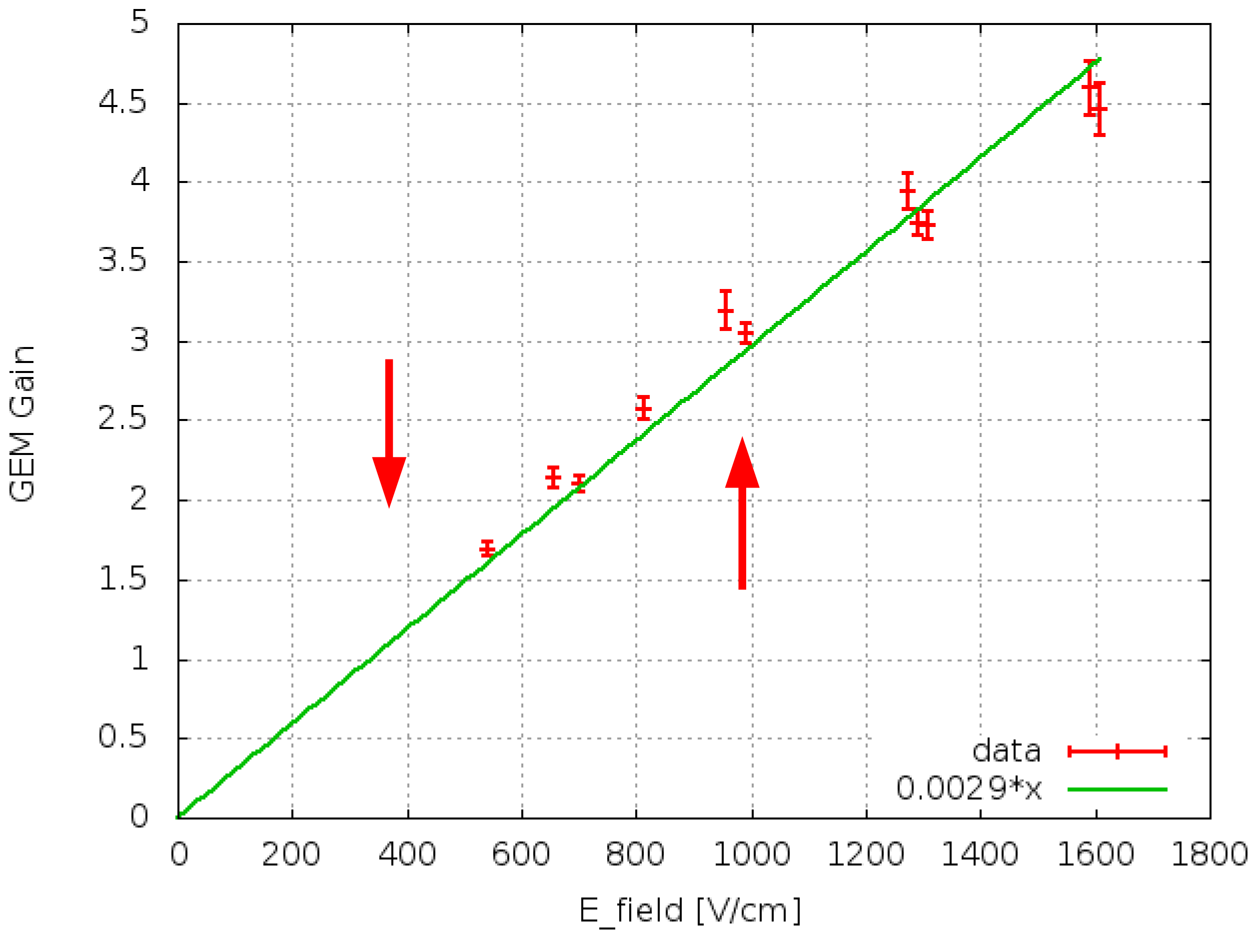


Effective gain vs. U_{GEM}

- Note strong dependence on transfer field!



Effective gain vs. transfer field



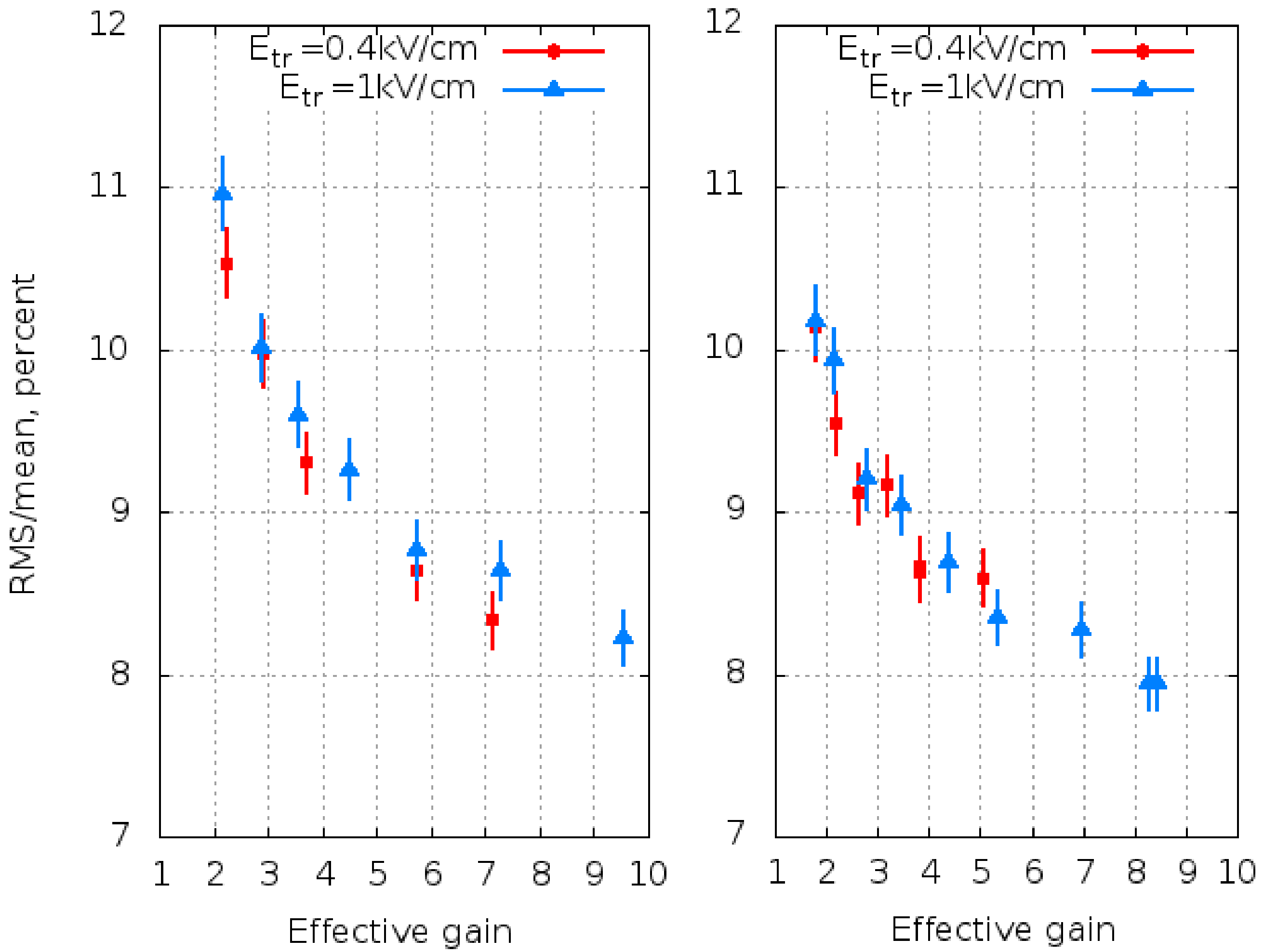
GEM voltage: 280V

In Ar+CO2

- **Linear dependence** (no plateau) for a given GEM voltage: low fraction of the avalanche is extracted
  (arrows indicate the energy resolution measurements)

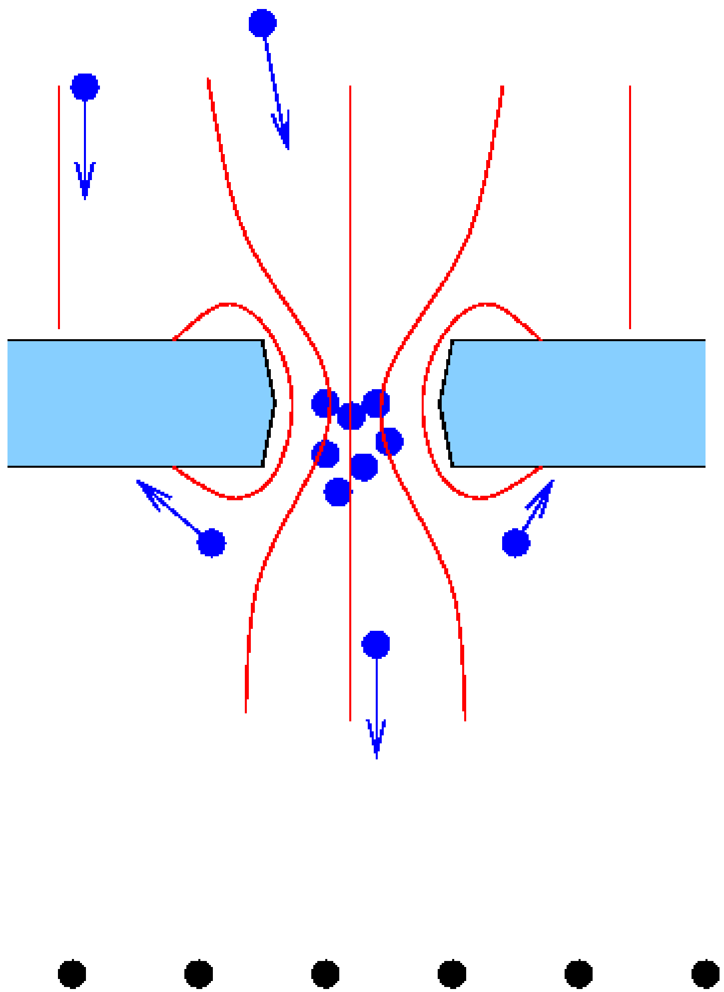
Fe55 RMS resolution vs. effective gain

- Ne+CO_2 (90:10)
- Ar+CO_2 (80:20)



Observation: energy resolution seem to depend to first order on **effective gain**!

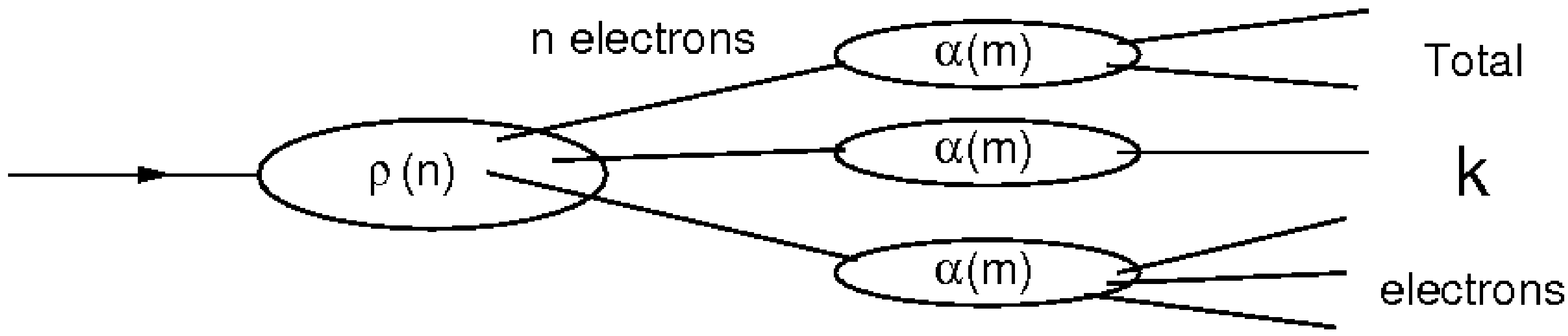
Relevant processes contributing to avalanche and transfer fluctuations



- **A**: transfer to GEM hole with probability **c** (collection)
- **B**: avalanche with mean of **N** and relative variance **f**
- **C**: transfer from GEM avalanche, random selection of electrons with probability **t** (extraction)
- **D**: avalanche in subsequent stages (for MWPC, assume infinitely **large** exponential distribution)

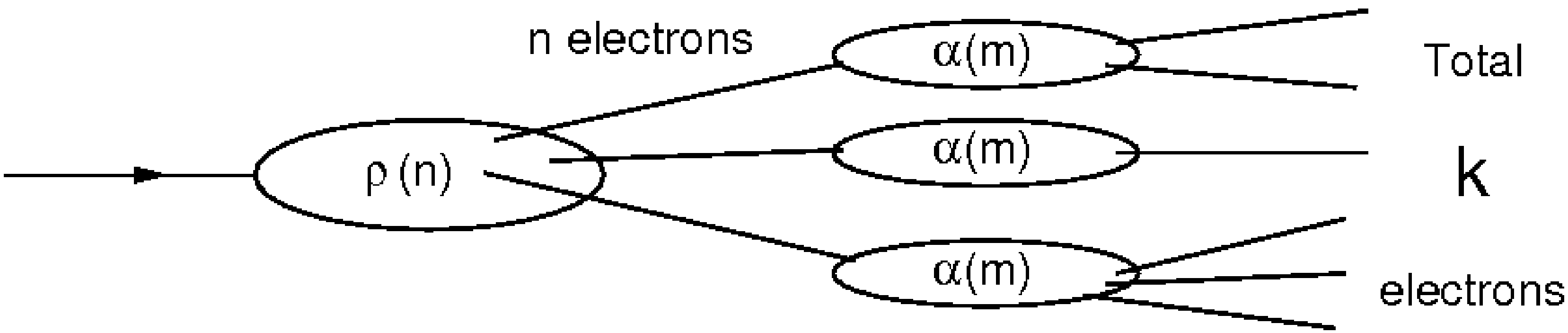
Note: GEM effective gain is **G=cNt**

Fluctuations for general subsequent processes



- First process, starts with 1 electron, emerging random n electrons, probability distribution **ρ(n)**
- Second process, starts with n electrons, and each electron gives rise to random m electrons with probability distribution **α(m)**
- The two processes result in **total of k** electrons. Mathematical question: what is the probability distribution for k? Which are the moments (mean, RMS) of k?

Mean and RMS/mean (fluctuation) for the subsequent processes



$$(Mean)_{\rho,\alpha} = (Mean)_{\rho} * (Mean)_{\alpha}$$

$$\left(\frac{RMS}{Mean}\right)^2_{\rho,\alpha} = \left(\frac{RMS}{Mean}\right)^2_{\rho} + \frac{1}{(Mean)_{\rho}}\left(\frac{RMS}{Mean}\right)^2_{\alpha}$$

Formula for **(RMS/Mean)** of the complete avalanche process

- Collection with c prob. **(collection efficiency)**

  $$\mathbf{(RMS/mean)^2 = 1/c - 1}$$

- Avalanche with **mean N** and **variance** of **f=(RMS/mean)**

  $$\mathbf{(RMS/mean)^2 = (1/c-1) + (1/c)\, f^2}$$

(Avalanche fluctuation is not exponential, f = 0.6 – 0.8)

Formula, cont'd

- Extraction step with t probability:

  → **SINGLE GEM CASE**

$$\left(\frac{RMS}{Mean}\right)_S^2 = \left(\frac{1}{c} - 1\right) + \left(\frac{1}{c}\right) f^2 + \left(\frac{1}{Nc}\right)\left(\frac{1}{t} - 1\right)$$

- Including **gain stage** (MWPC or later GEM-s), compounded gain fluctuation F=(RMS/gain)

$$\left(\frac{RMS}{Mean}\right)_{all}^2 = \left(\frac{1}{c} - 1\right) + \left(\frac{1}{c}\right) f^2 + \left(\frac{1}{Nc}\right)\left(\frac{1}{t} - 1\right) + \left(\frac{1}{Nct}\right) F^2$$

Rewriting with more practical notation: 1GEM + (other stages)

- Effective gain of the stage G:

G=cNt (collection * multiplication * extraction)

$$\left(\frac{RMS}{Mean}\right)^2_{all} = \left(\frac{1+f^2}{c} - 1\right) + \left(\frac{1}{G}\right)\left(1+F^2-t\right)$$

- f, F: true gain fluctuations for GEM and “all other”
- As a function of **1/G**, the $(RMS/Mean)^2$ should be a **straight line** (other parameters change only slowly with GEM voltage)

Relating to measured ^{55}Fe resolution

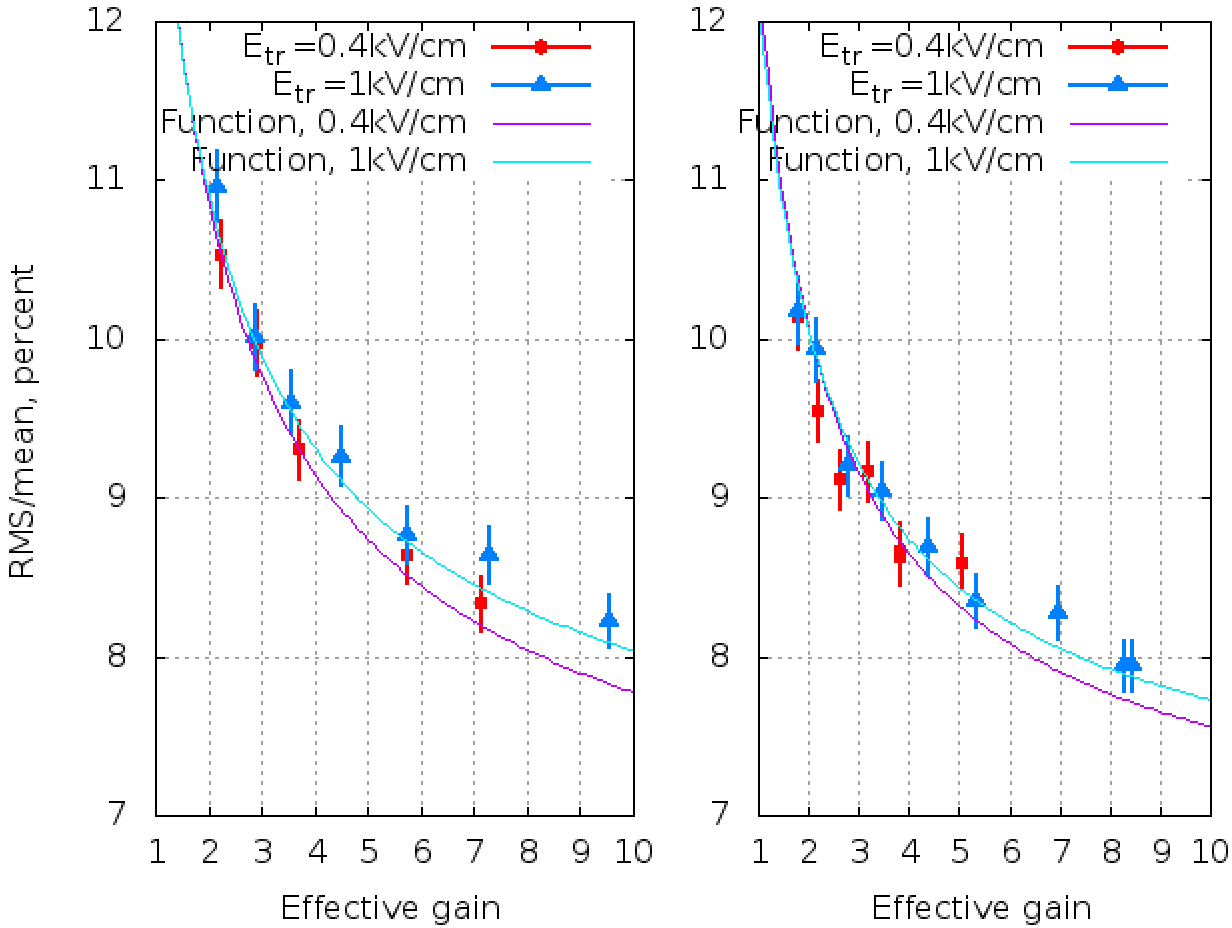
- Adding primary fluctuation (with Fano factor) and total gain fluctuation

$$\left(\frac{RMS}{Mean}\right)^2_{Fe55} = \frac{1}{primary}\left(\left(Fano\right) + \left(\frac{RMS}{Mean}\right)^2_{all}\right)$$

- Fano at 6keV = 0.15 – 0.2

Fe55 RMS resolution vs. effective gain
(full collection case)

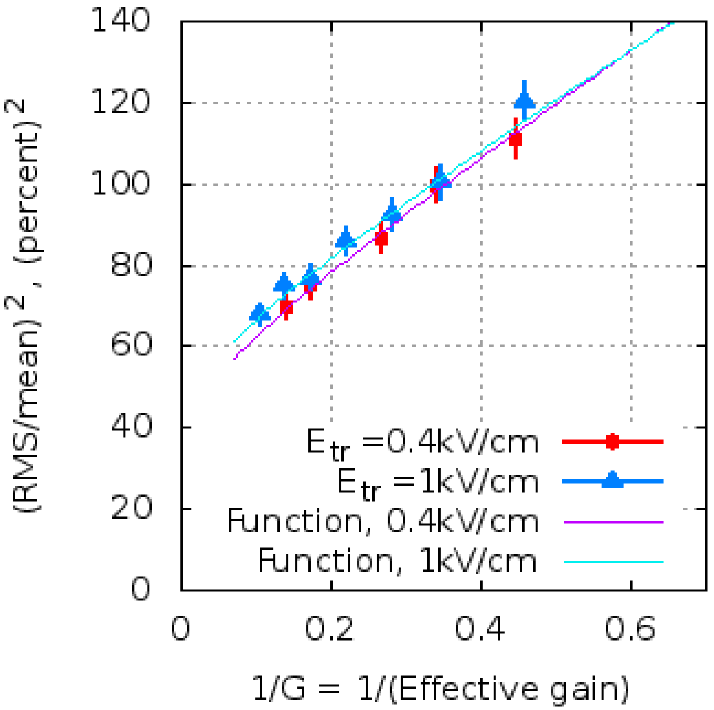
- Ne+CO2 (158 primary)
- Ar+CO2 (200 primary)



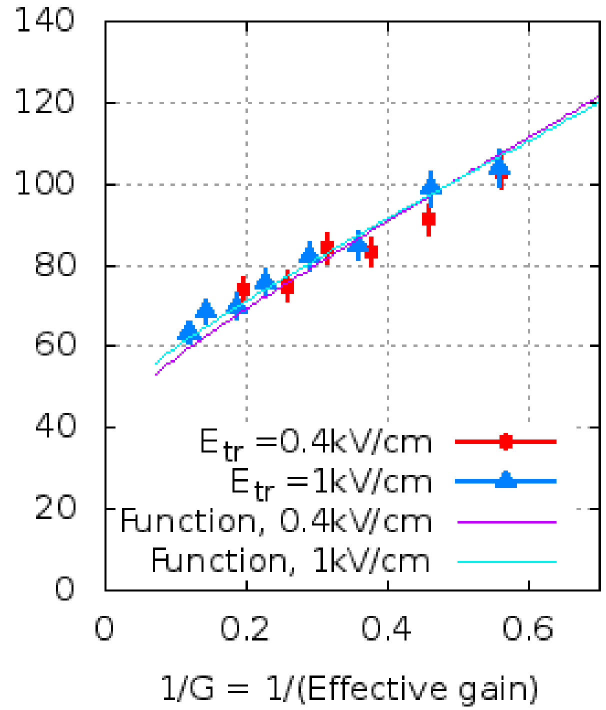
(Assume <**1% instrumental** fluctuations in both cases)

Resolution^2 vs. 1/(effective gain)

- Ne+CO2 (158 primary)



- Ar+CO2 (200 primary)



The prediction seems to hold!

Needs idea on f

(Note also funny factor 2 in slope)

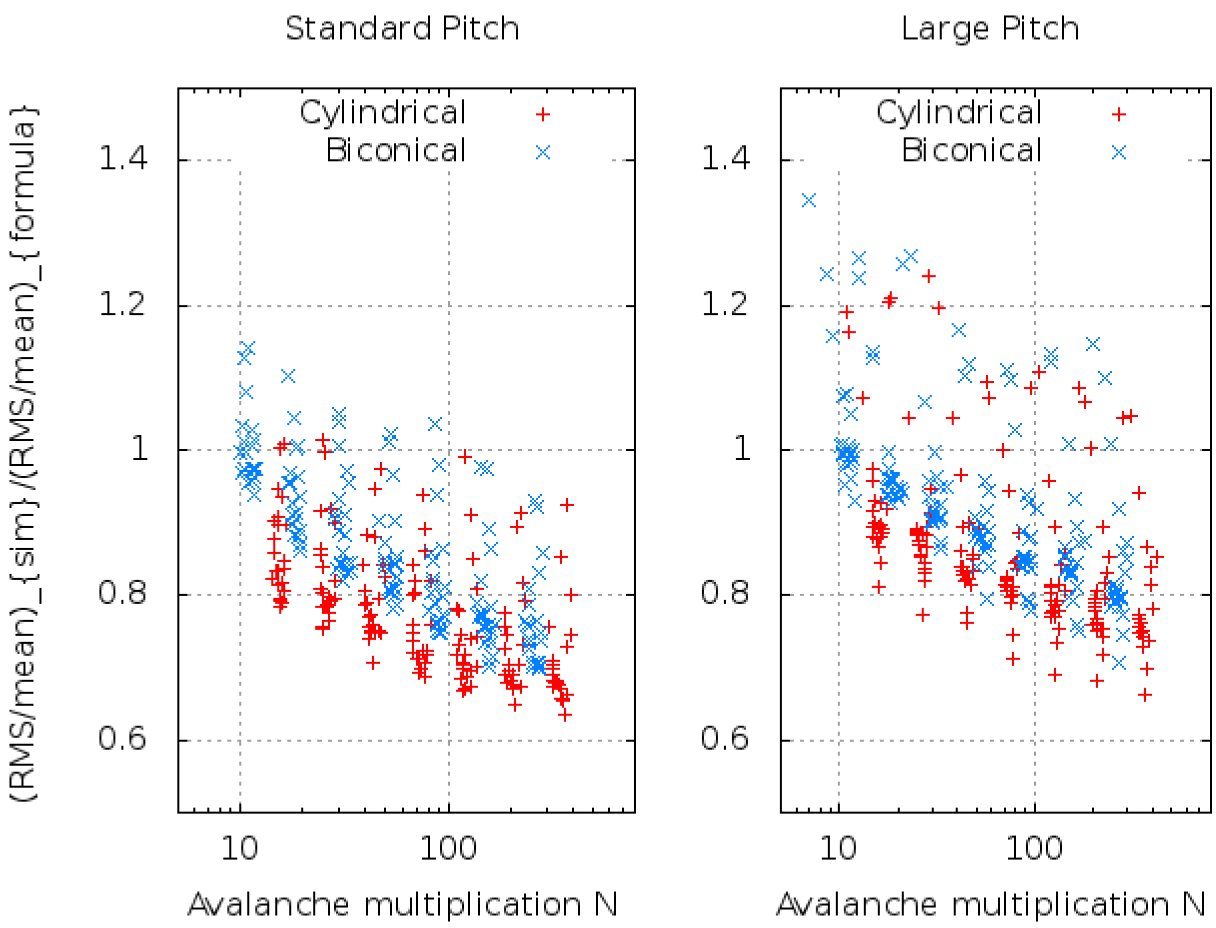
$$\left(\frac{RMS}{Mean}\right)^2 \approx \frac{1}{primary}\left(1+\frac{2}{G}\right)$$

Comparing simulations with calculation

- Simulations done by Taku Gunji
- Single GEM case, in very **broad range** of parameters: aim now to see the main trends
- Many details to be understood in these preliminary comparisons: capture on kapton, attachment to gas, etc...

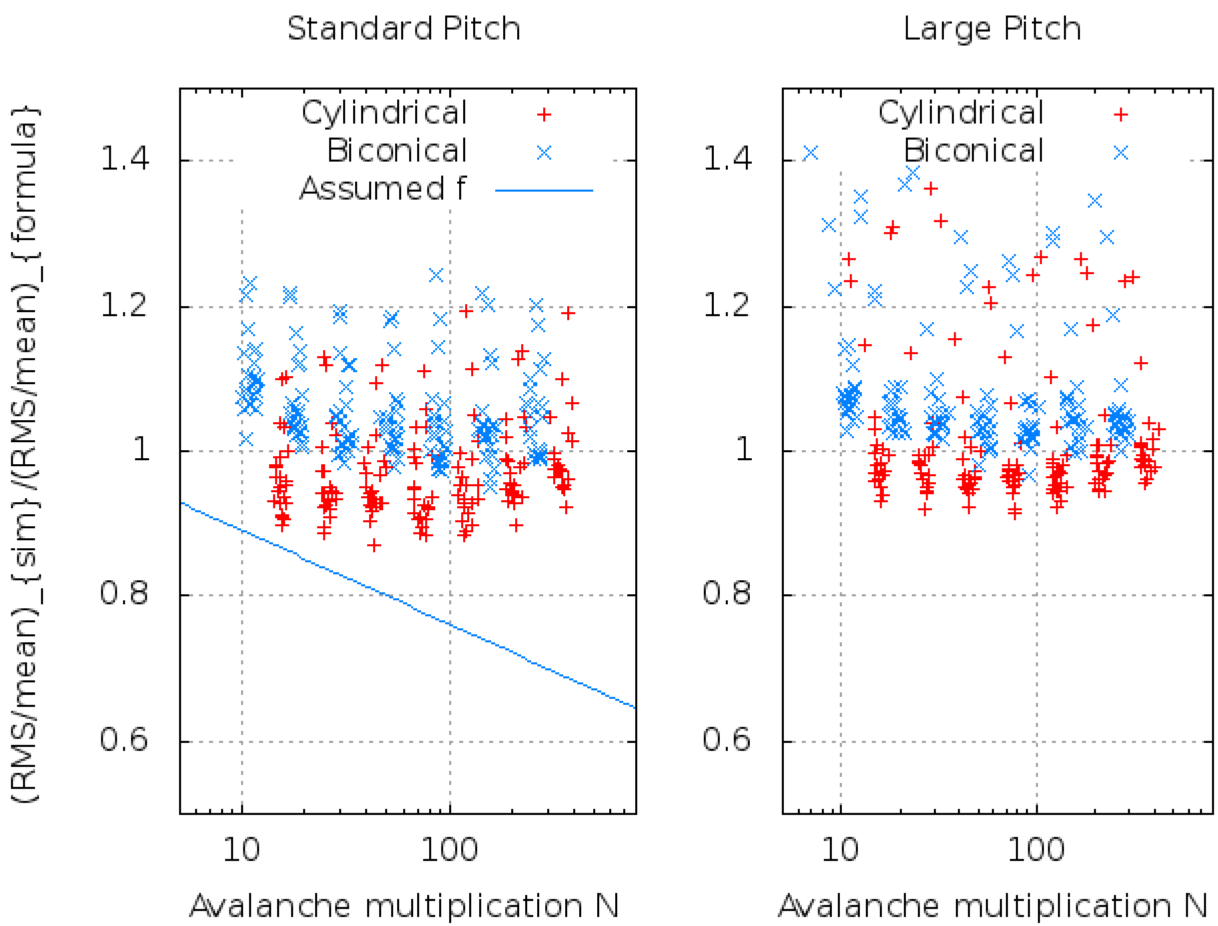
Gain fluctuation: (simulation)/(formula)

- Assume f=1 (exponential avalanche)
- Note LP and SP offset
- Note Bic/Cyl offset

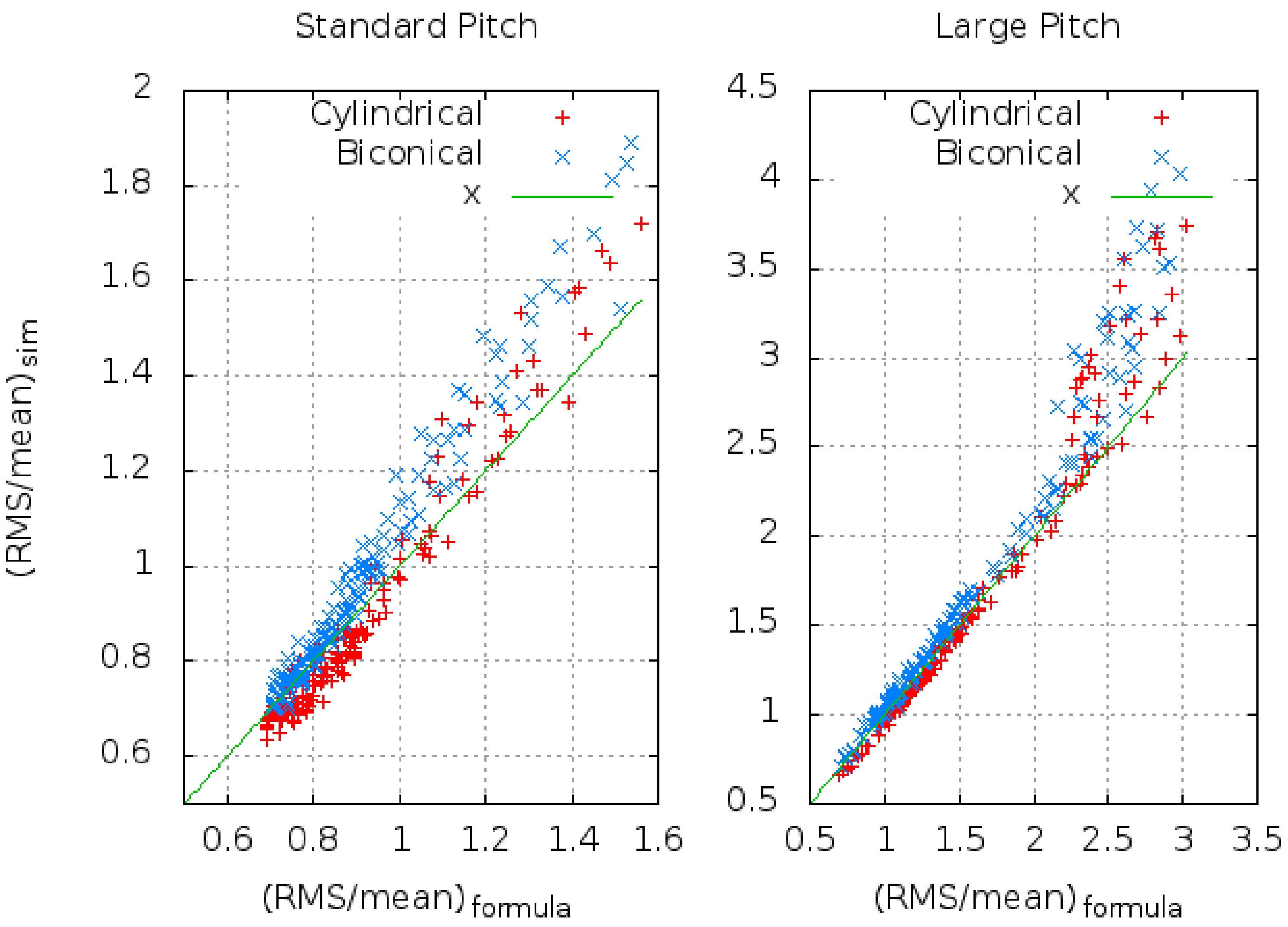


Assuming multiplication dependent fluctuation in $NeCO_2$ (f value)

- f=(RMS/mean) of avalanche **decreases** with N

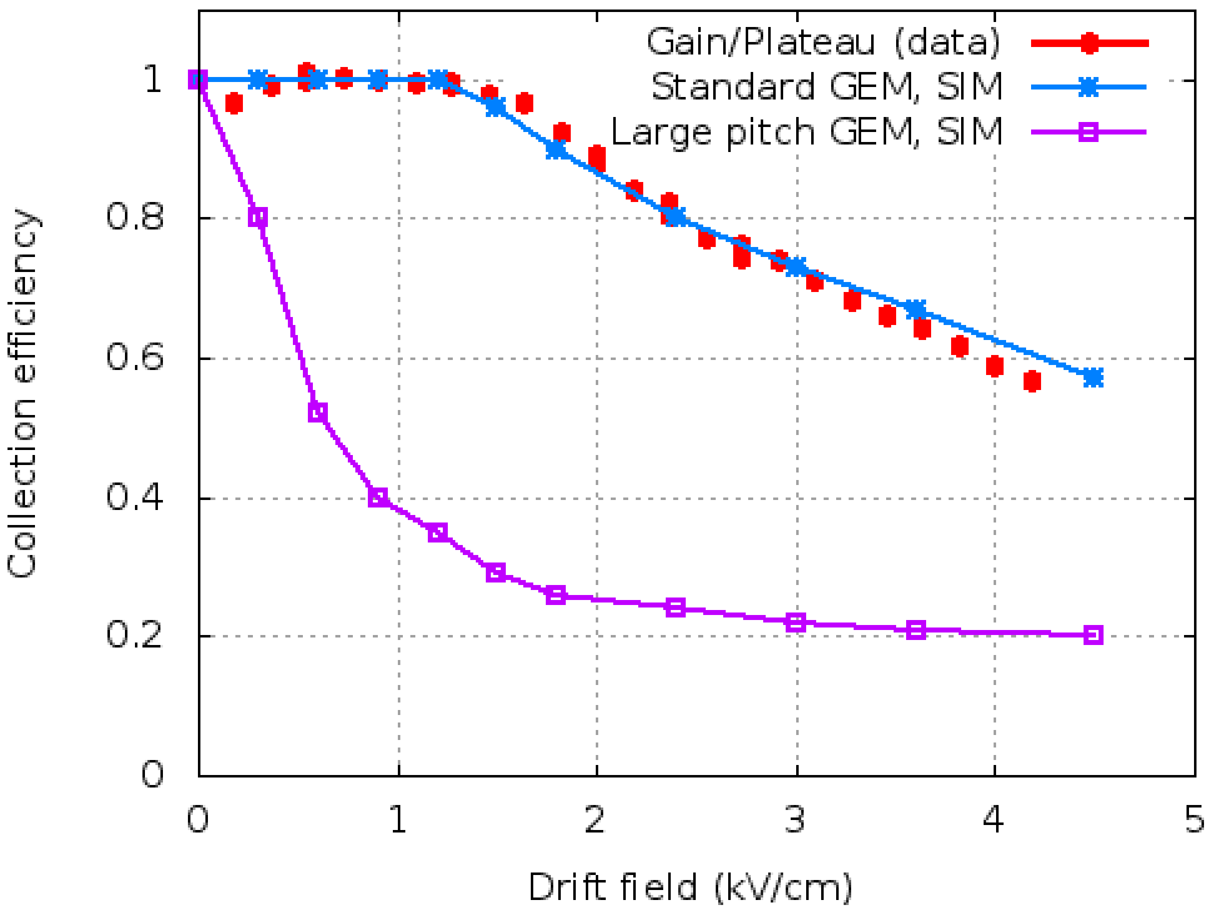


Comparing single GEM formula vs. simulation



Access to collection process: Drift (cathode) field dependence

- Collection efficiency measurement: assumed to be **(effective gain)/(gain plateau)**



U_{GEM}=300V

(Nice agreement)

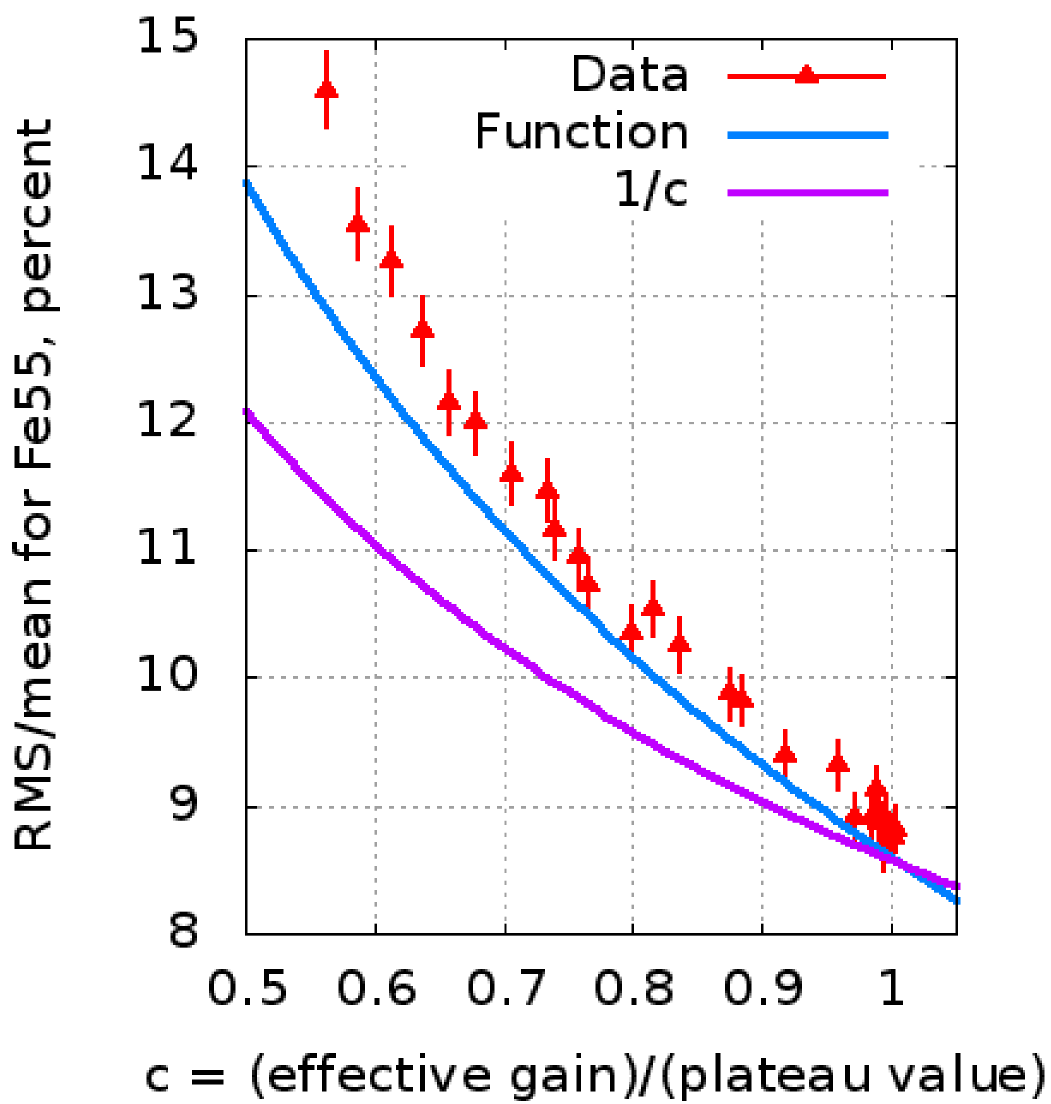
LP GEM drops faster than S GEM (known)

Predicted energy resolution vs. collection efficiency (c)

- **Blue line**: correct formula, gives reasonable description

$$\frac{RMS}{mean} \approx \sqrt{\frac{2}{c} - 1}$$

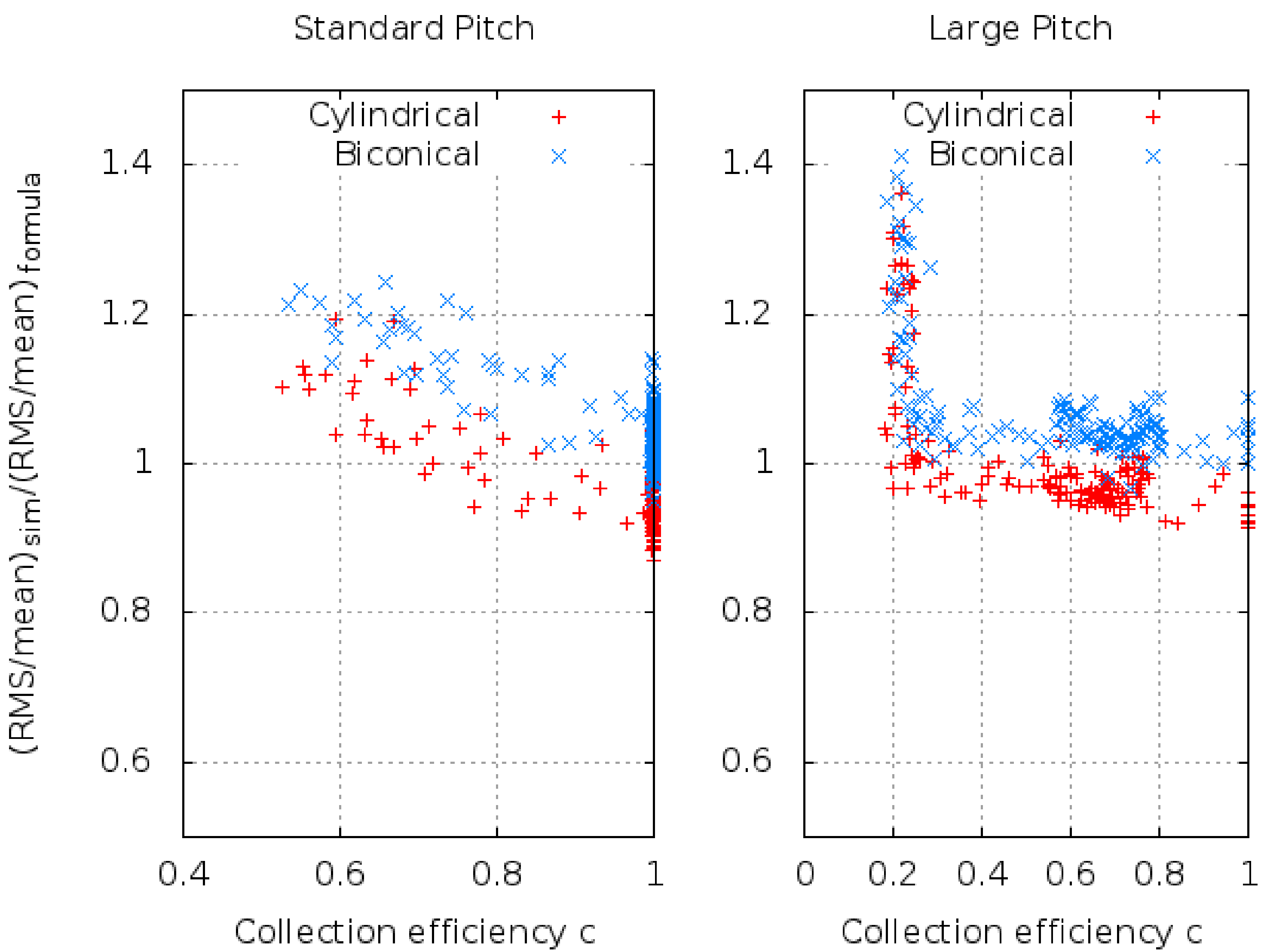
- **Blue line**: intuitive sqrt(1/c) function, incorrect slope
- Steeper than predicted – cloud size not much larger than pitch?



Comparison to simulations: dependence on collection efficiency

- ???

  to be understood...



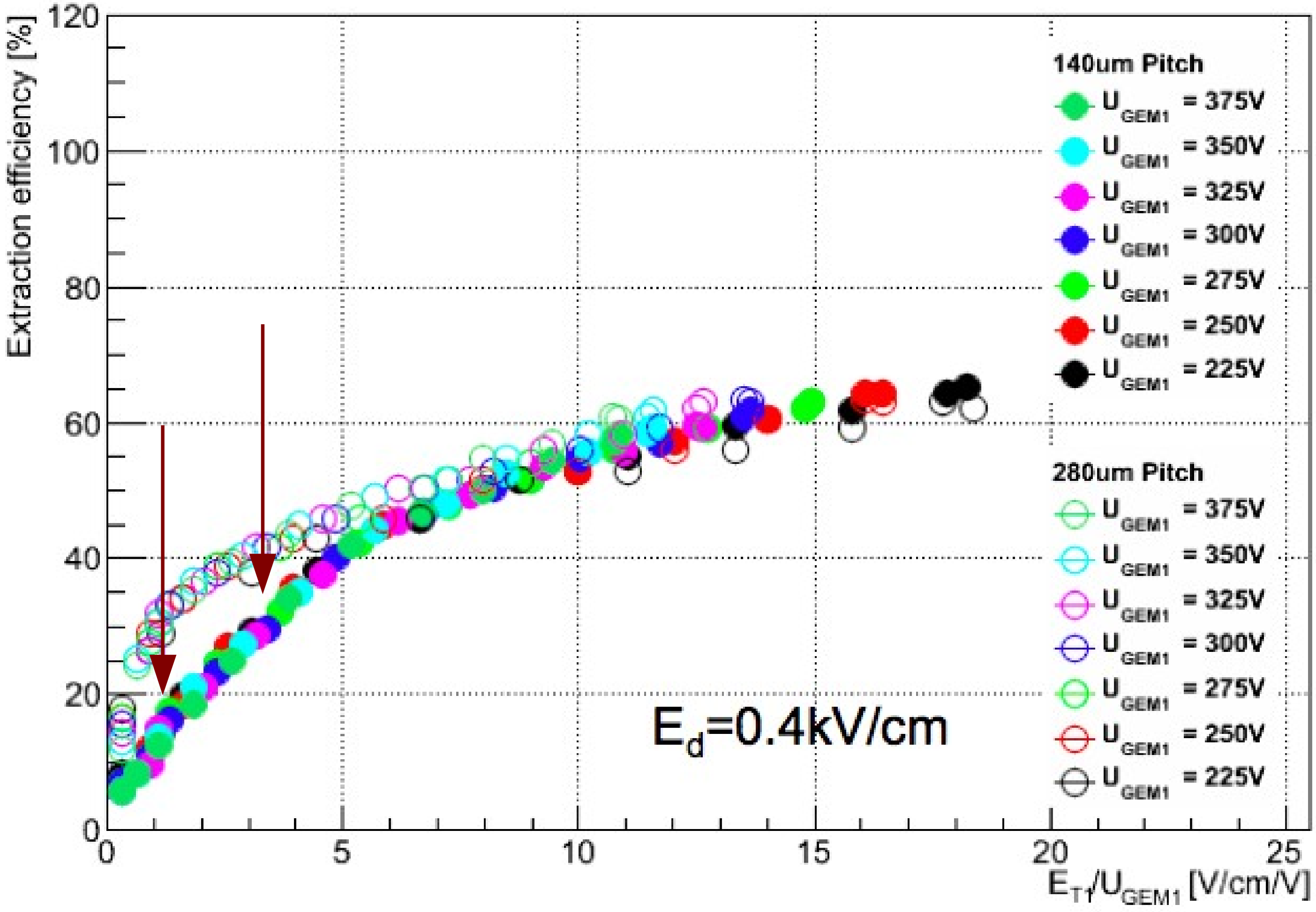
Conclusions

- Gain fluctuations in GEM-s: complex phenomenon involving all sources of amplification process
- Measured energy resolution may be reasonably predicted from statistical calculation
- Parameters: c, N, f, t for each layers
- Intrinsic avalanche fluctuation properties are important

Backup slides

Extraction efficiency from simulations

- Extraction efficiency is small, but non negligible!



Example: RMS/mean simulated for GEM

- Ar+CO2 90:10, simulation (from the thesis of dr. Heinrich Schindler, 2012)
- (Detailed comparison will be needed under same conditions)