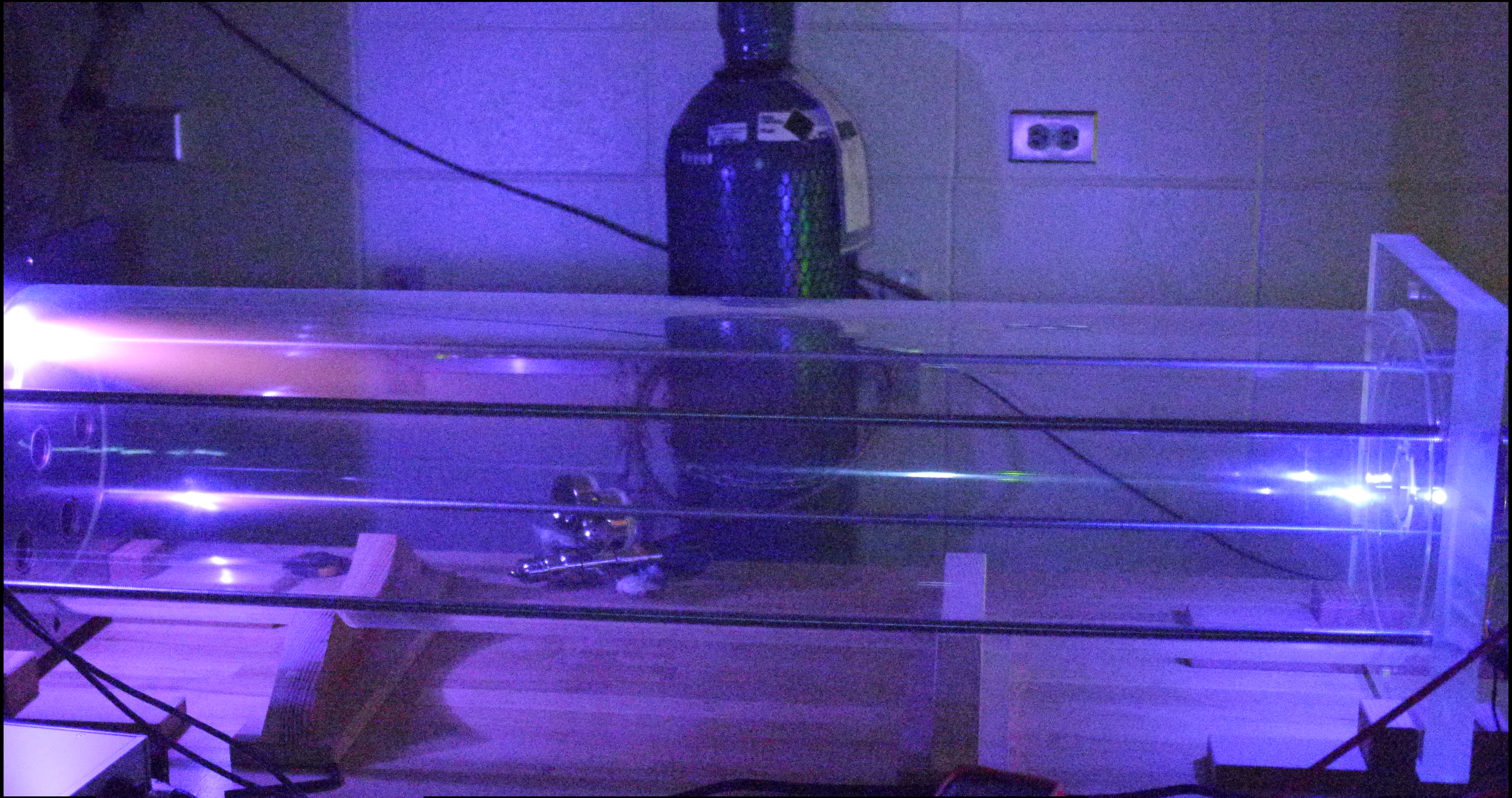
A Gas Gain Study with Multiple GEM Stages



22-10-2019

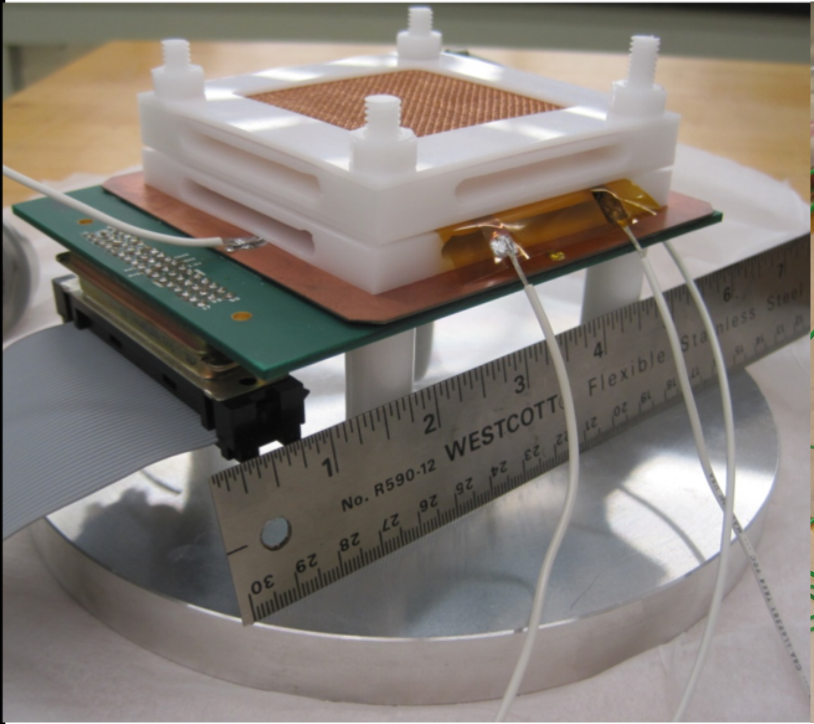
Tom Thorpe – RD51 Collaboration Meeting - CERN

Outline

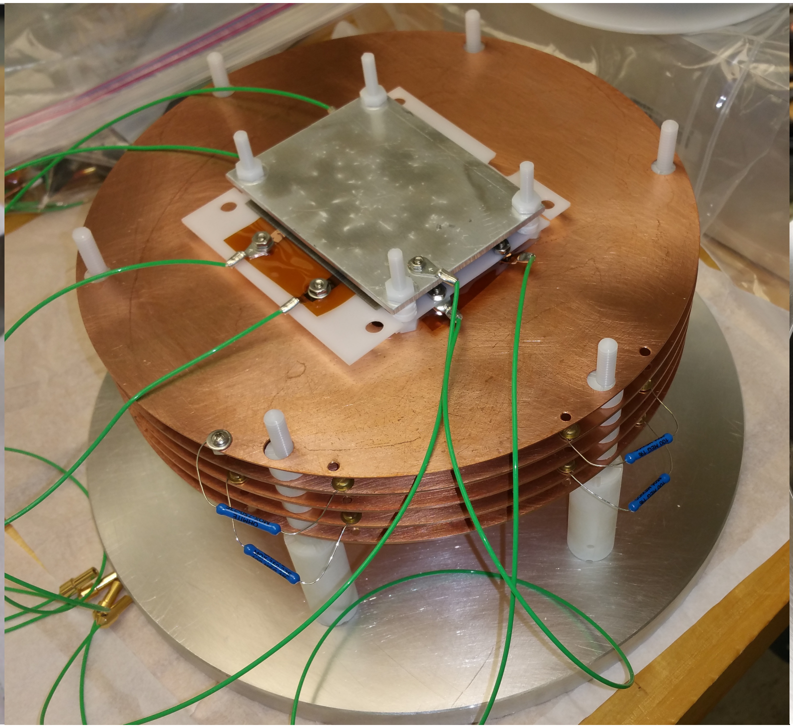
- Setups in Hawaii
- Gas gain with GEMs
- Townsend coefficient
- $HeCO_2$ gas gain
  - Thin GEMs
  - Thick GEMs (THGEMs)
- $ArCO_2$ gas gain
- SF_6 – Negative Ion (NI) gas gain
- Conclusion

D^3 Prototypes

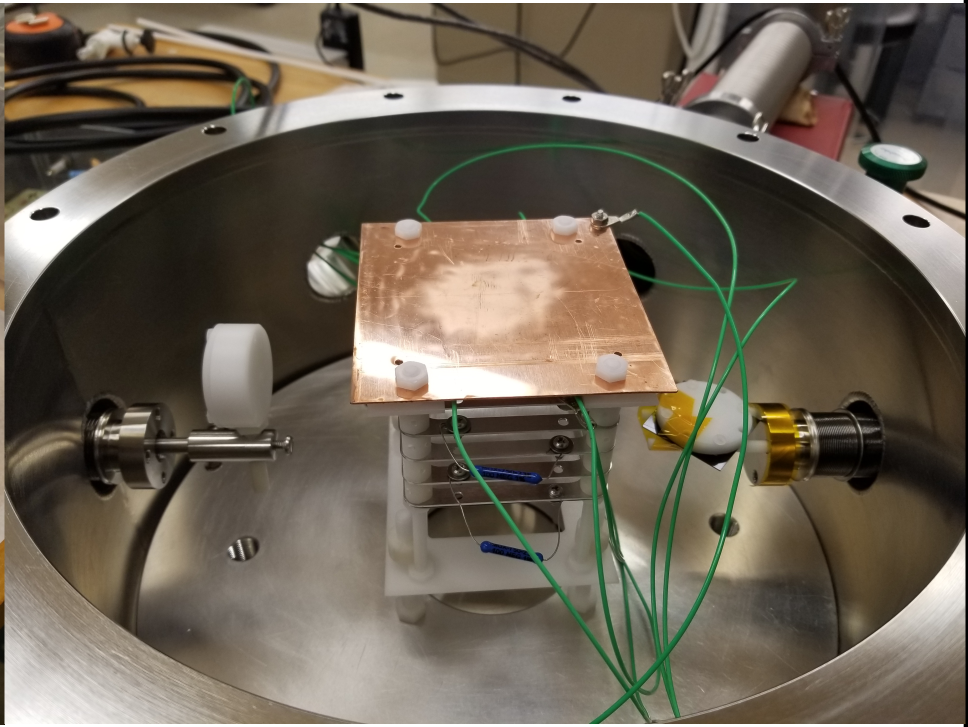
Micro
(2011 - 2013)



Milli - stage 1
(2014 – 2017)



Milli - stage 2
(2017 – 2018)

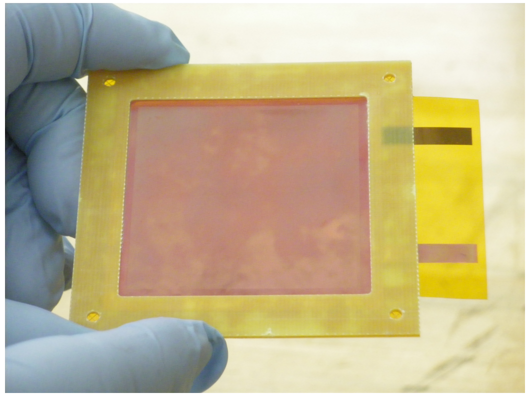


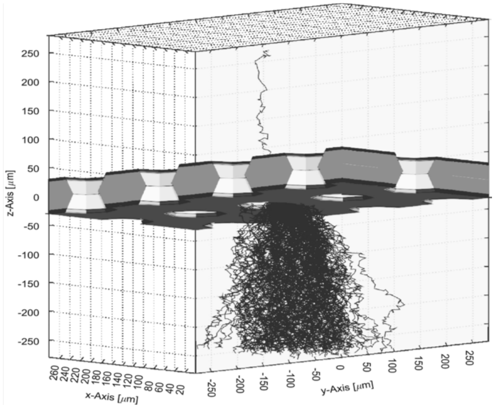
Details:
GAIN RESOLUTION STUDIES AND FIRST DARK MATTER SEARCH WITH NOVEL 3D NUCLEAR RECOIL DETECTORS, Ph.D. Thesis, Thomas N. Thorpe, Dec. 2018.

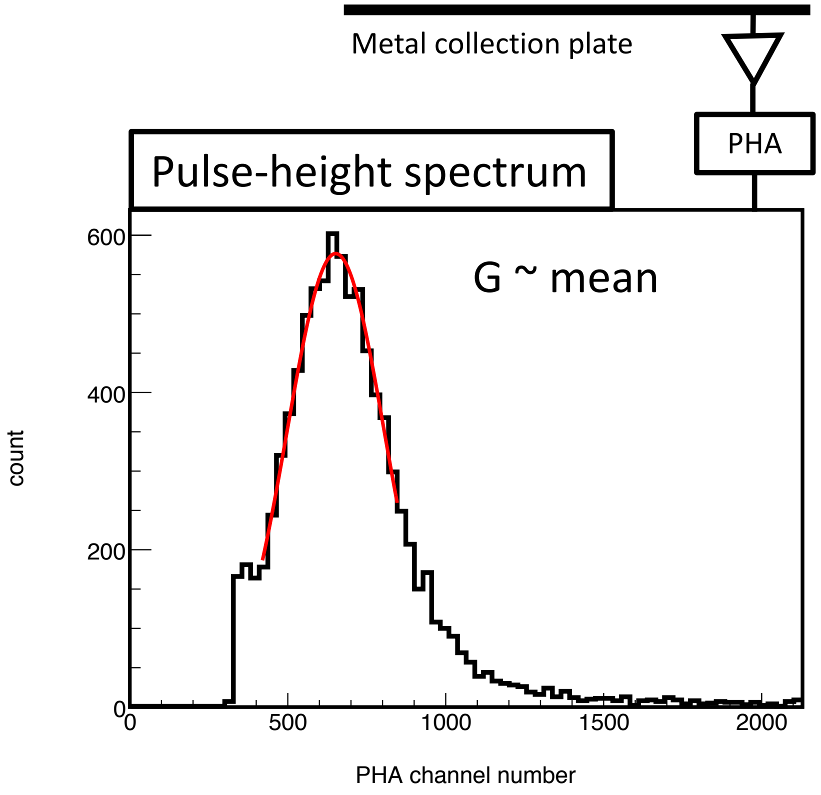
Townsend's Equation with GEMs

- α = 1st Townsend coefficient
- n is number of electrons in avalanche
- r is path along the avalanche
- G = gain
- t = GEM thickness

$$\boxed{\frac{dn}{n} = \alpha dr}$$







Townsend's Equation with GEMs

- α = 1st Townsend coefficient
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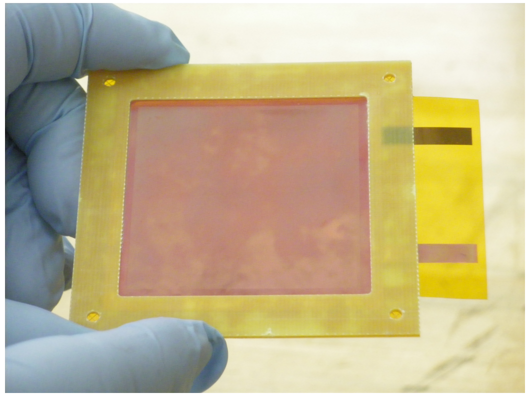
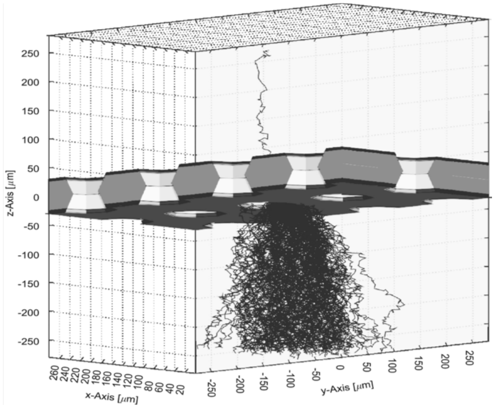
- G = gain
- t = GEM thickness

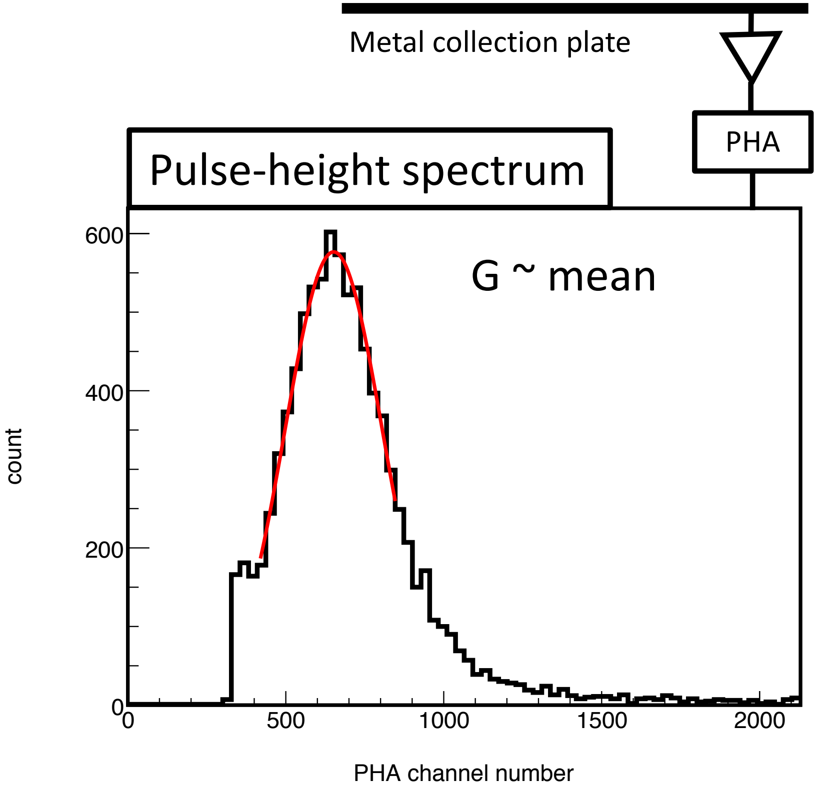
$$\frac{dn}{n} = \alpha dr$$

If the field is constant then:

$$\ln(G) = \alpha t$$







Generalizing the Townsend Coefficient

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(-L\left(\frac{N}{E}\right)^{1-m}\right)$$

- General interpretation allows the interaction cross section to depend on fractional powers of the reduced field
- This manifests into the Townsend coefficient dependence
- Where $0 \leq m \leq 1$
- We will consider two cases:
  - $m = 1$
  - $m = 0$

Generalizing the Townsend Coefficient; m = 1

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(-L\left(\frac{N}{E}\right)^{1-m}\right)$$

If m = 1:
$\alpha \sim E$

Generalizing the Townsend Coefficient; m = 1

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(-L\left(\frac{N}{E}\right)^{1-m}\right)$$

If m = 1: $\alpha \sim E$	Recall: $\ln(G) = \alpha t$

Generalizing the Townsend Coefficient; m = 1

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(-L\left(\frac{N}{E}\right)^{1-m}\right)$$

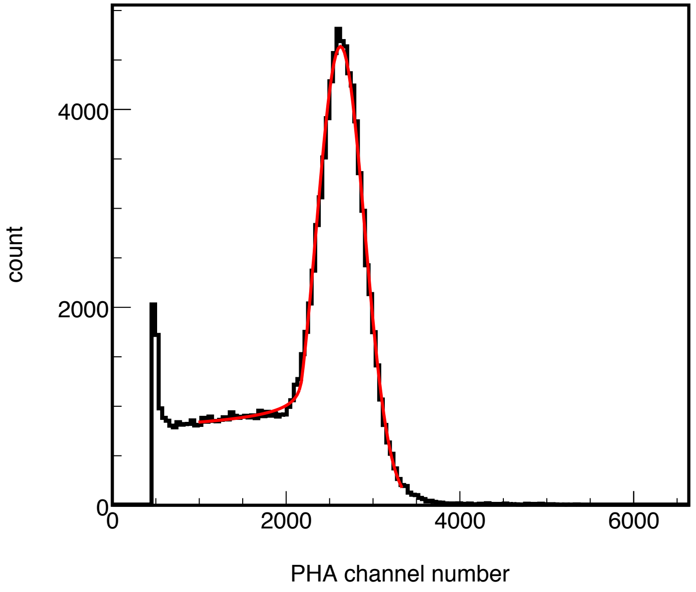
If m = 1:
$\alpha \sim E$

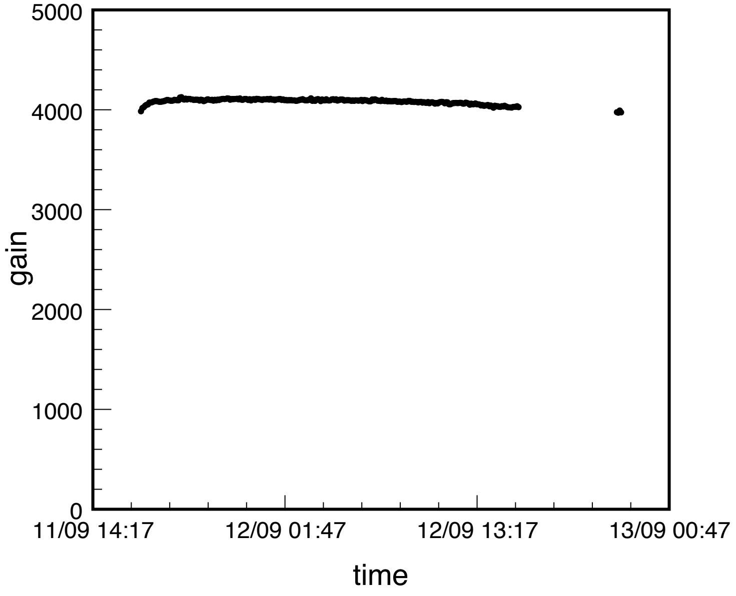
Recall:
$\ln(G) = \alpha t$

$$\boxed{G = 10^{(V_{GEM}-V_1)/V_2}}$$

Operationally useful

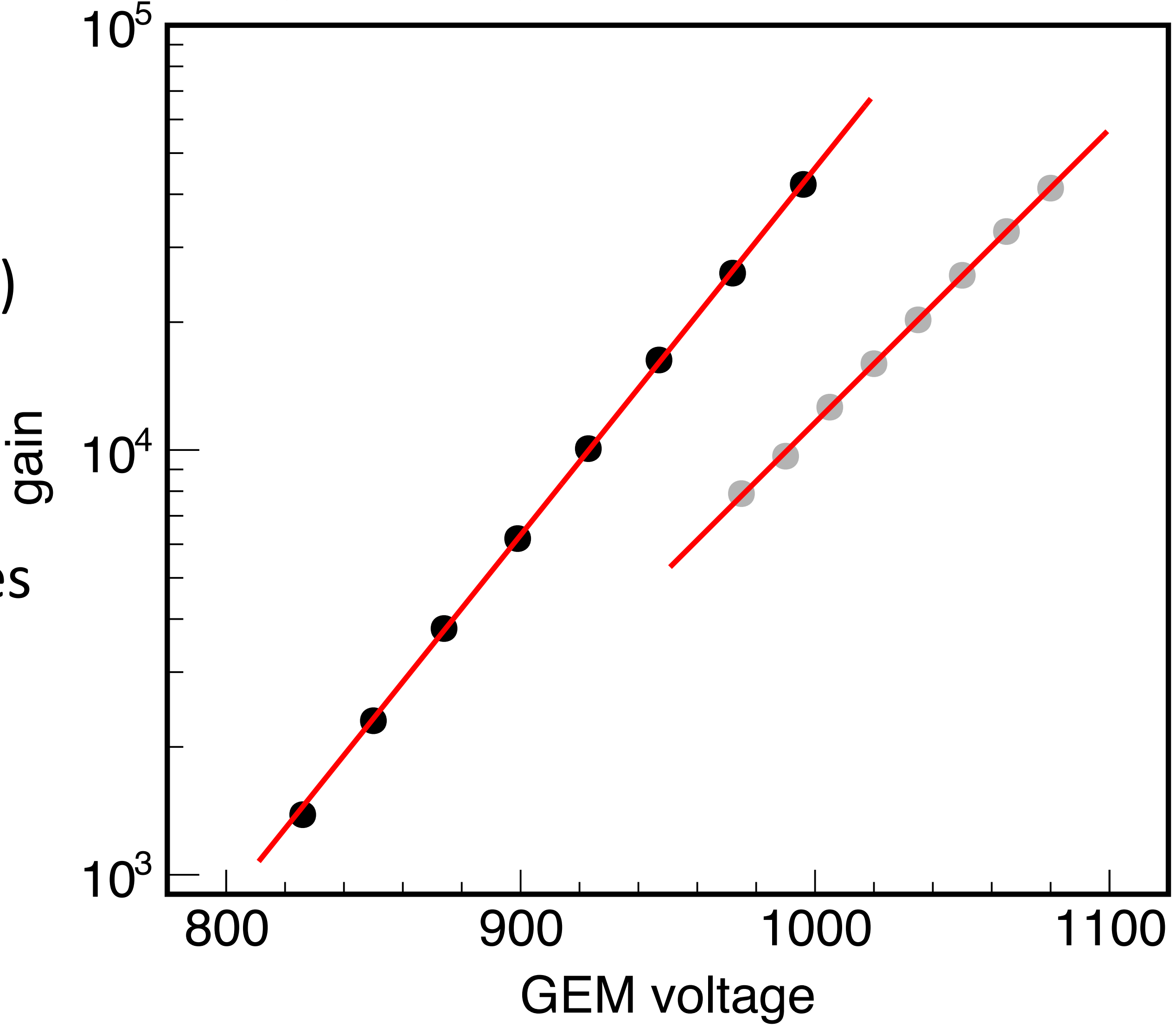
$HeCO_2$ – Double Thin GEMs



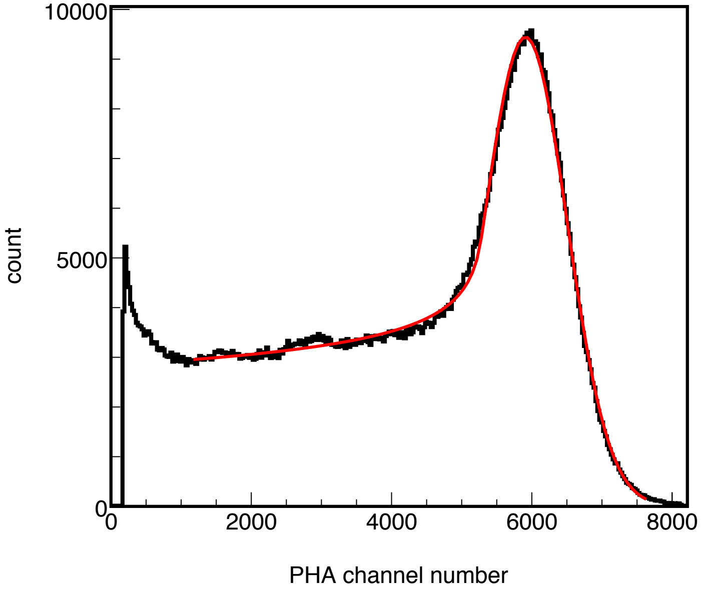


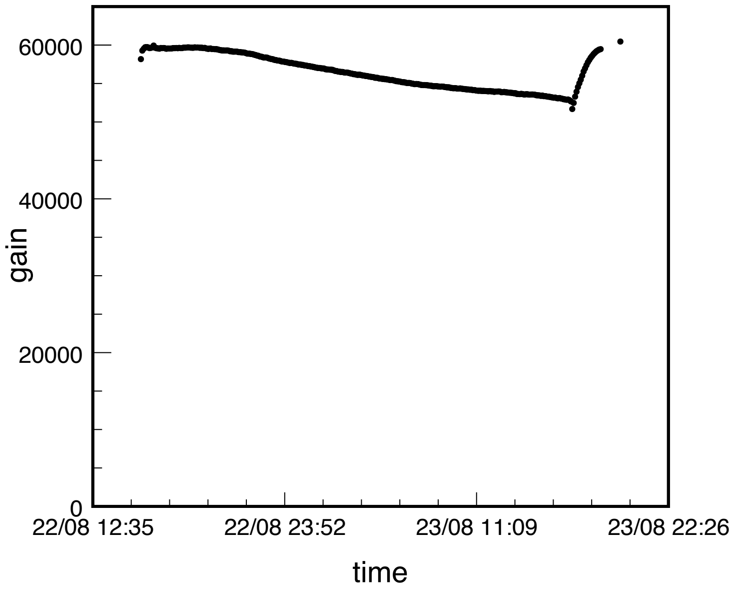
- D^3 – Micro
- D^3 – Milli2
- Thin GEM; t = 0.005 cm
- 1 atm. (70/30)
- ^{55}Fe x-rays ~5.9 keV
- Typical stability curves
- Two very stable detector systems

$$G = 10^{(V_{GEM} - V_1)/V_2}$$



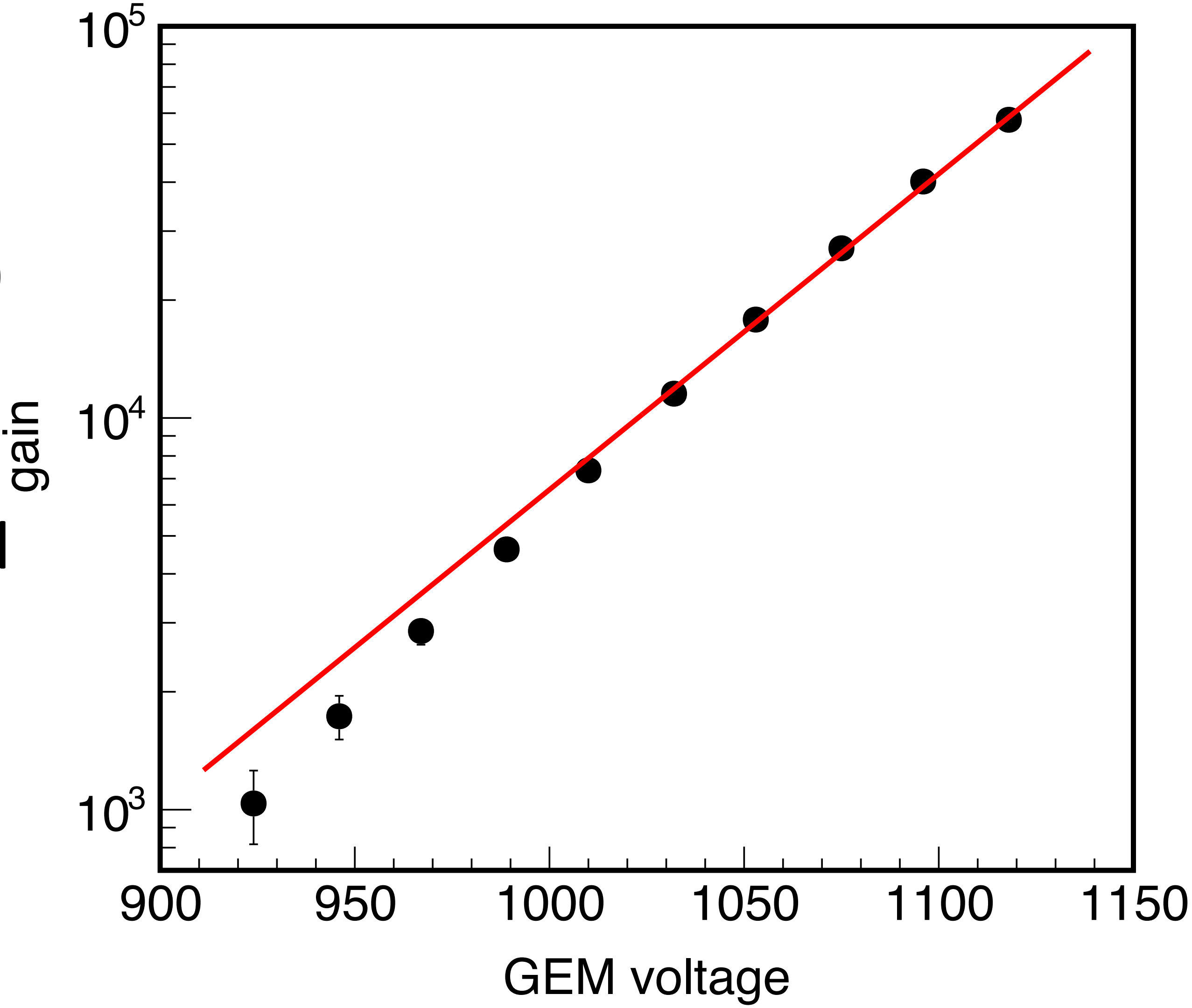
$HeCO_2$ – Triple Thin GEMs



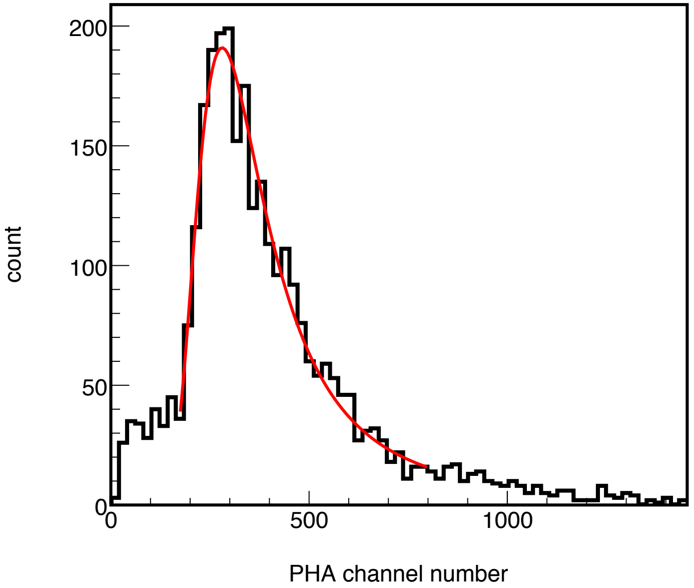


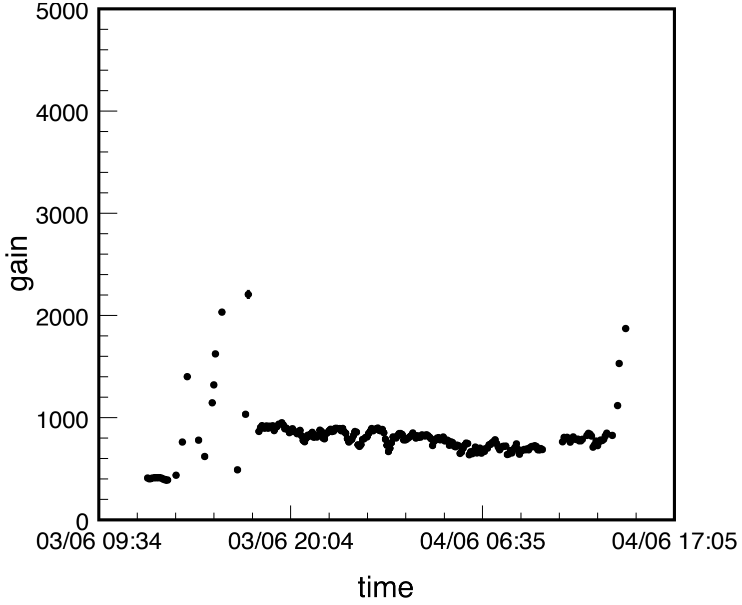
- D^3 – Milli1
- Thin GEM; t = 0.005 cm
- 1 atm. (70:30)
- ^{55}Fe x-rays ~5.9 keV
- More material mass here
- Highest gain "decay" observed

$$G = 10^{(V_{GEM} - V_1)/V_2}$$



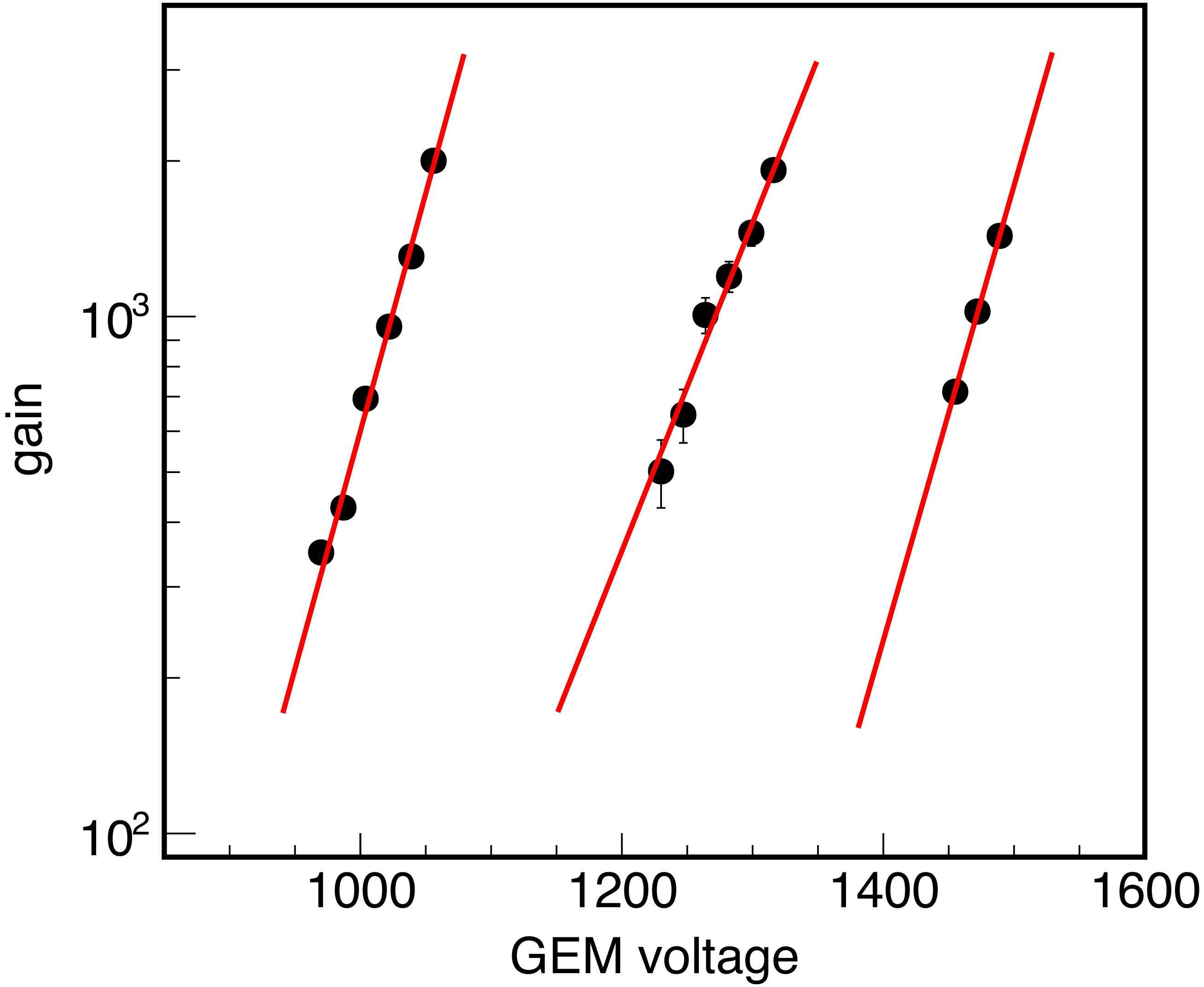
$HeCO_2$ – Single THGEM



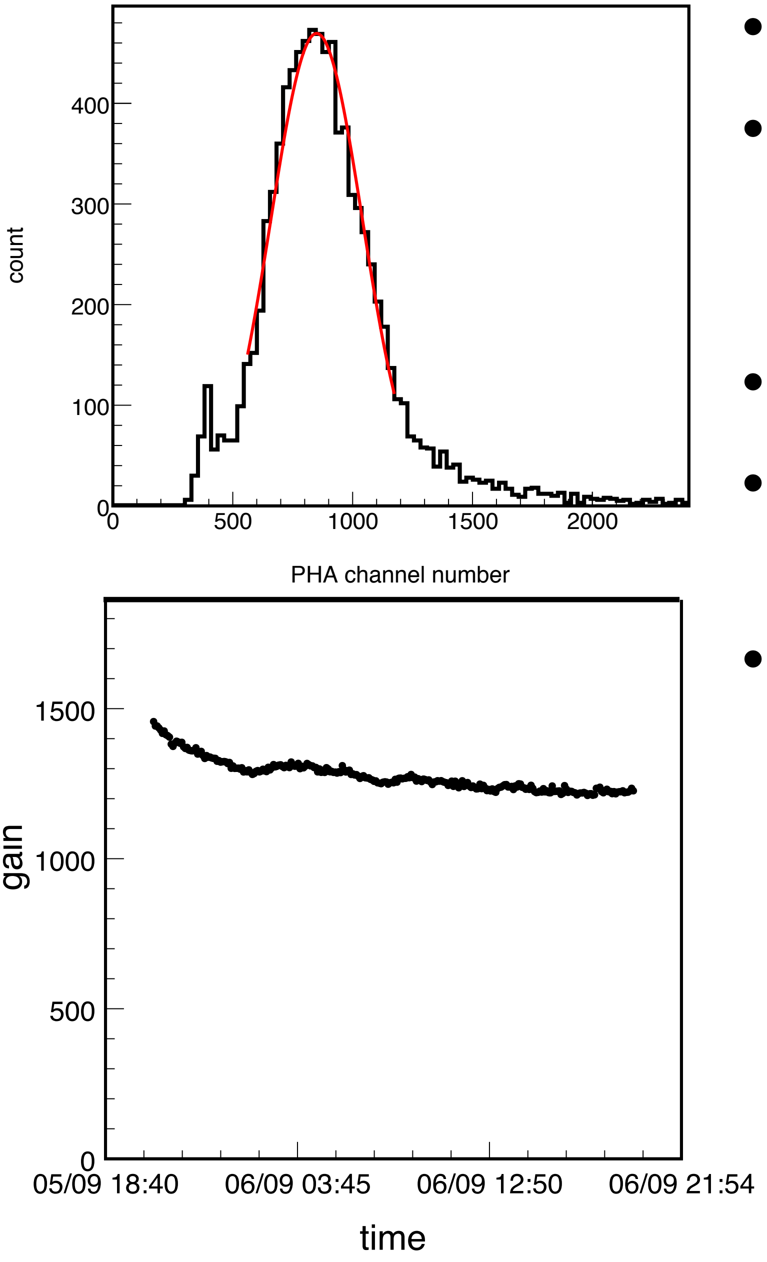


- D^3 – Milli1
- Thick GEM (THGEM); t = 0.04mm
- 1, 0.75, and 0.5 atm. (70:30)
- ^{55}Fe x-rays ~5.9 keV
- 0.75 atm. suffered from not letting detector stabilize after filling gas

$$G = 10^{(V_{GEM} - V_1)/V_2}$$

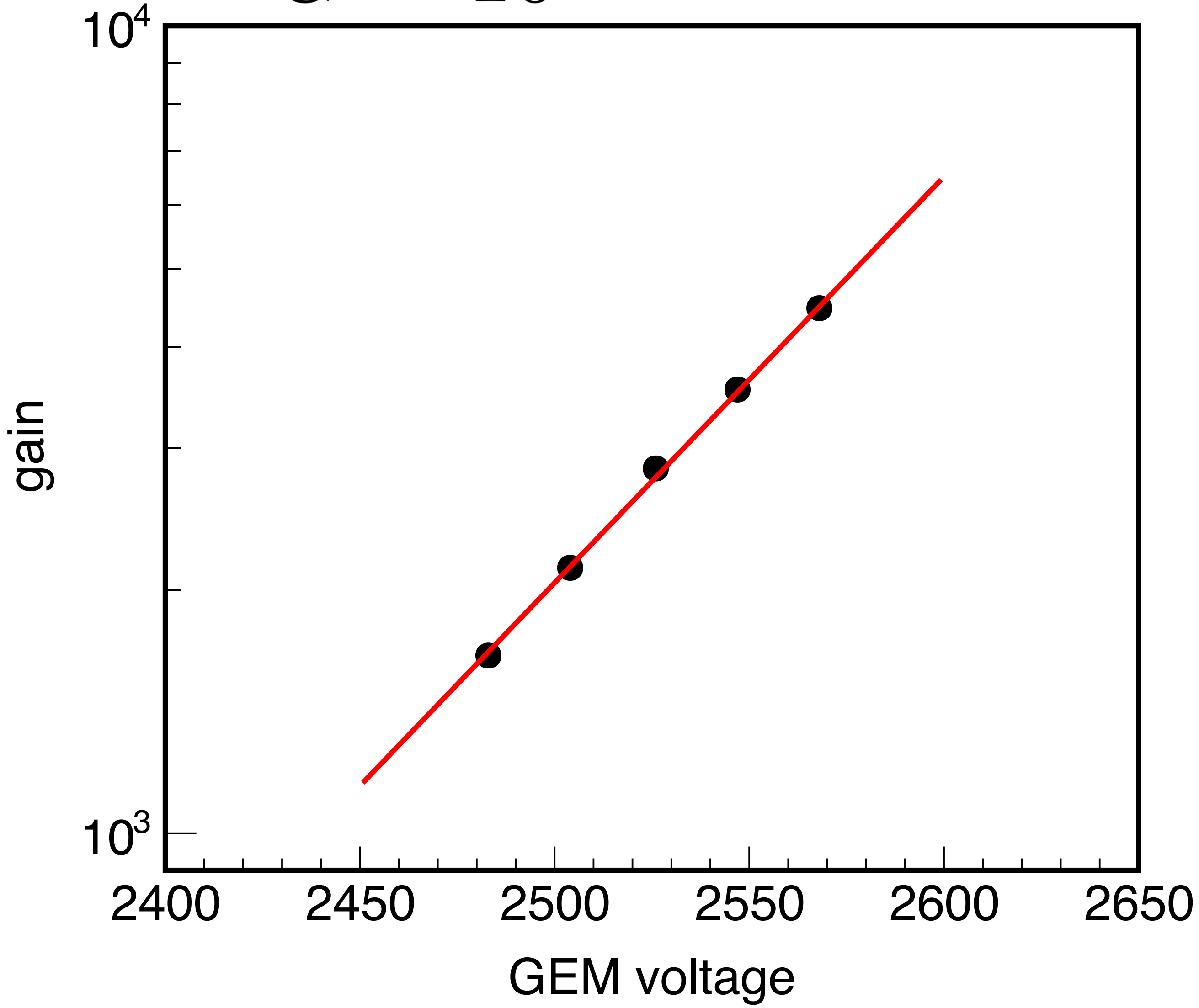


$HeCO_2$ – Double THGEM

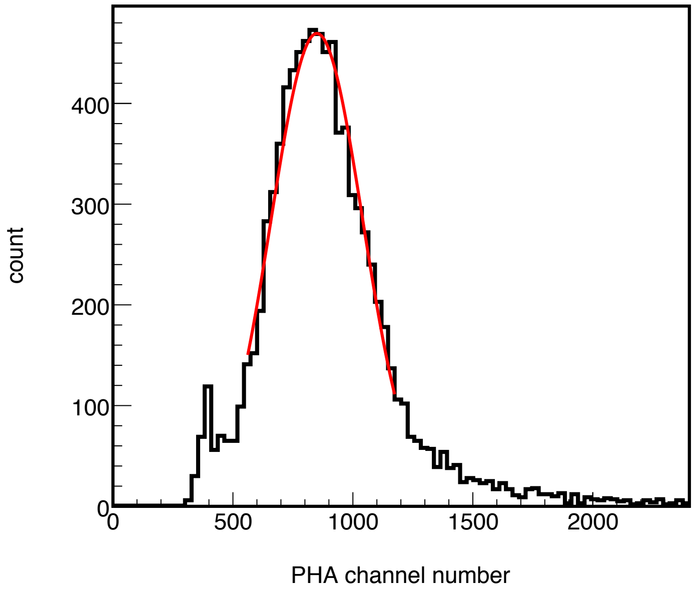


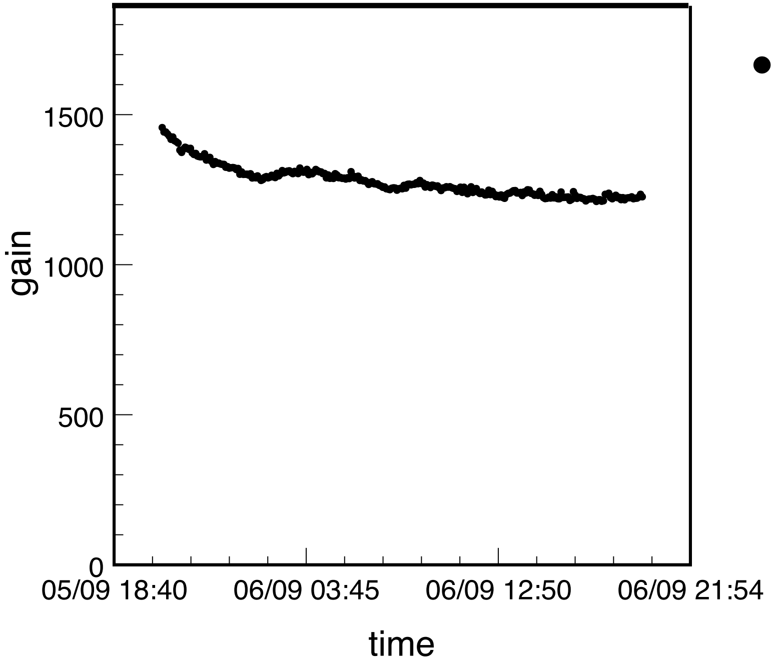
- D^3 – Milli2
- Double THGEM; t = 0.04mm
- 1 atm. (70:30)
- ^{55}Fe x-rays ~5.9 keV
- More stable than a single THGEM

$$G = 10^{(V_{GEM} - V_1)/V_2}$$



$HeCO_2$ – Double THGEM

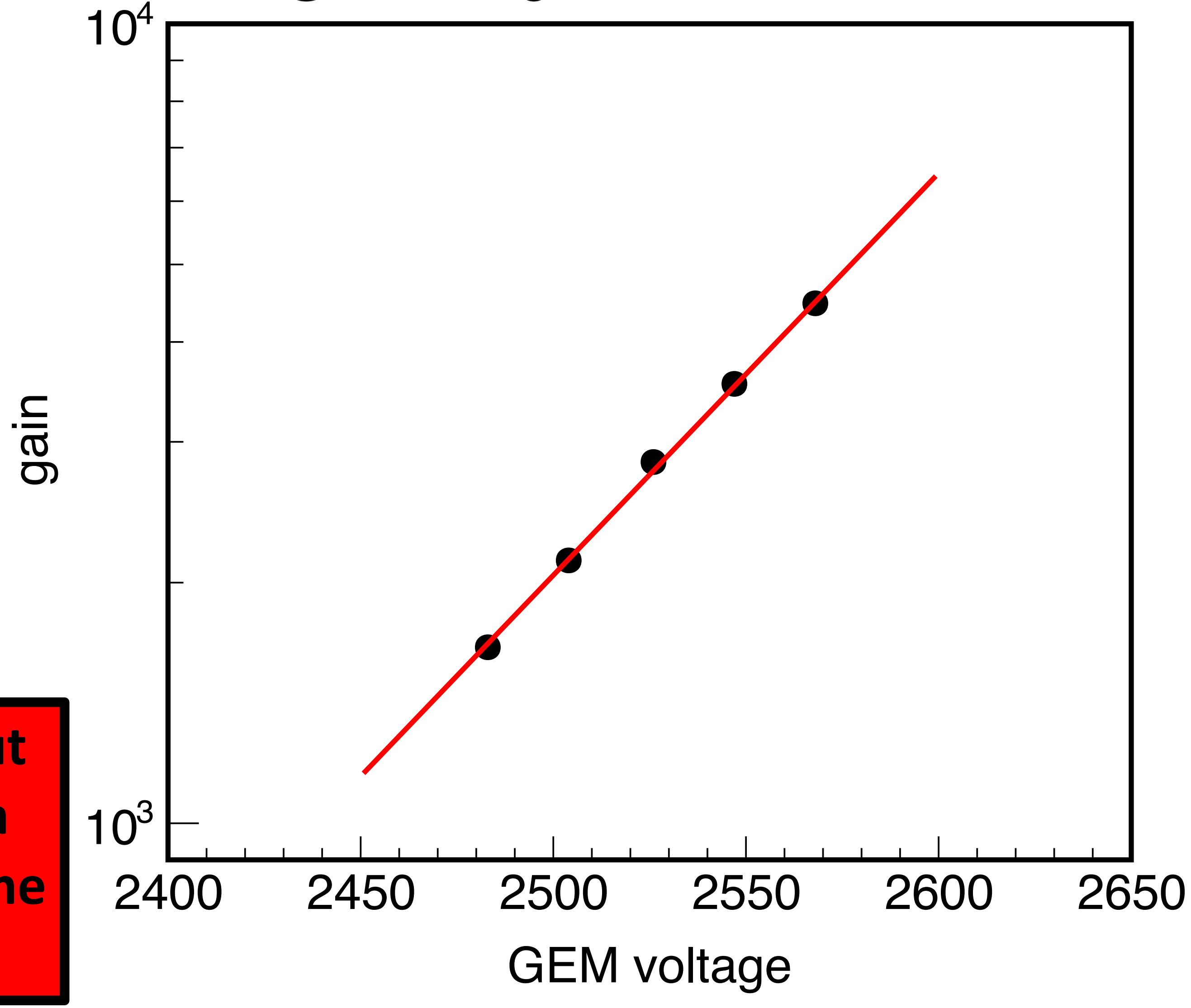




- D^3 – Milli2
- Double THGEM; t = 0.04mm
- 1 atm. (70:30)
- ^{55}Fe x-rays ~5.9 keV
- More stable than a single THGEM

How do we put different data sets on the same plot?

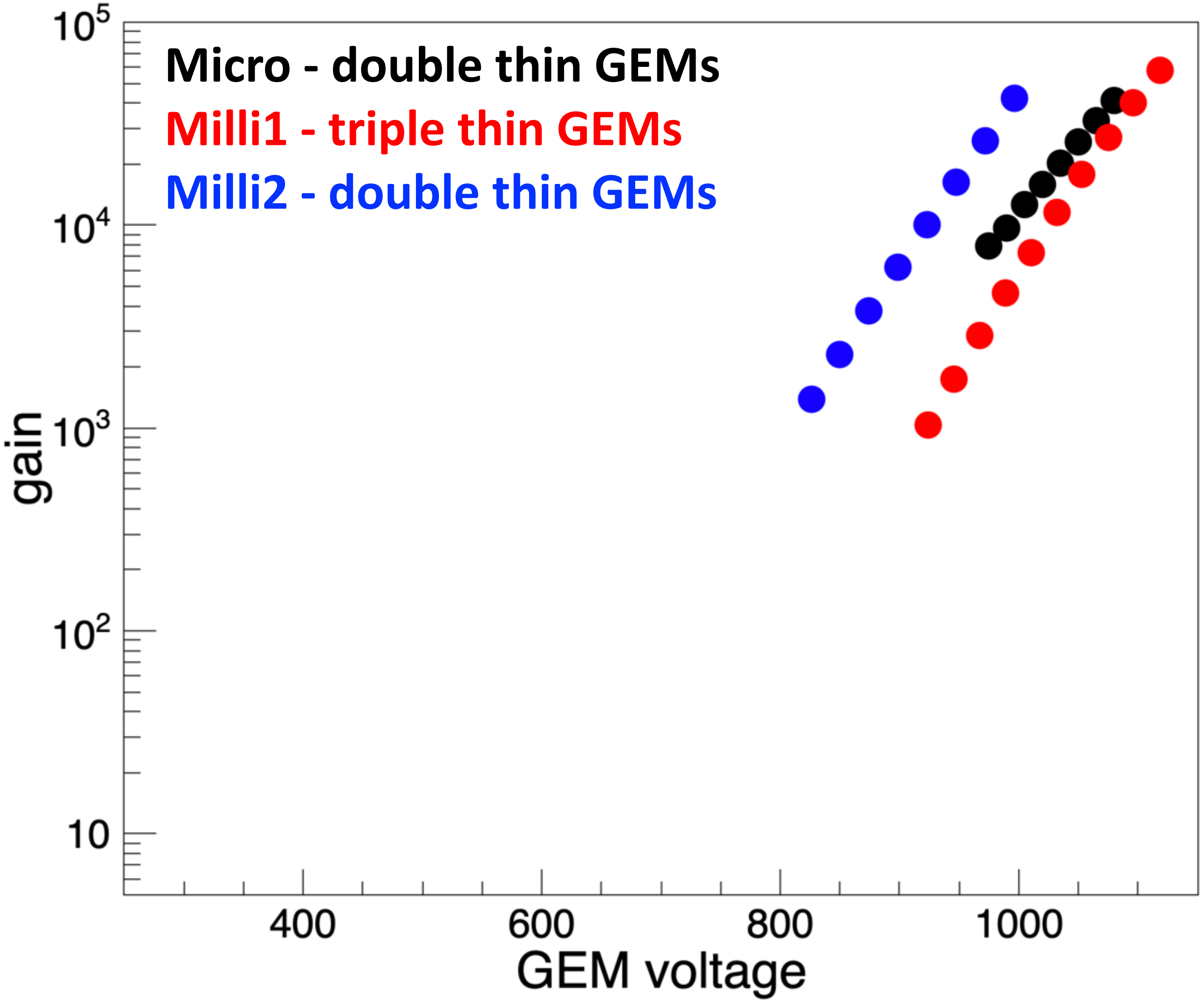
$$G = 10^{(V_{GEM} - V_1)/V_2}$$



Gain Per GEM - Before

- Consider multiple GEMs
- If the total voltage is evenly divided among them then the log of the gain should be as well
- n is the number GEMs
- * quantities are per GEM
- So G* is the gain per GEM

$$\boxed{\ln(G) = \alpha t}$$



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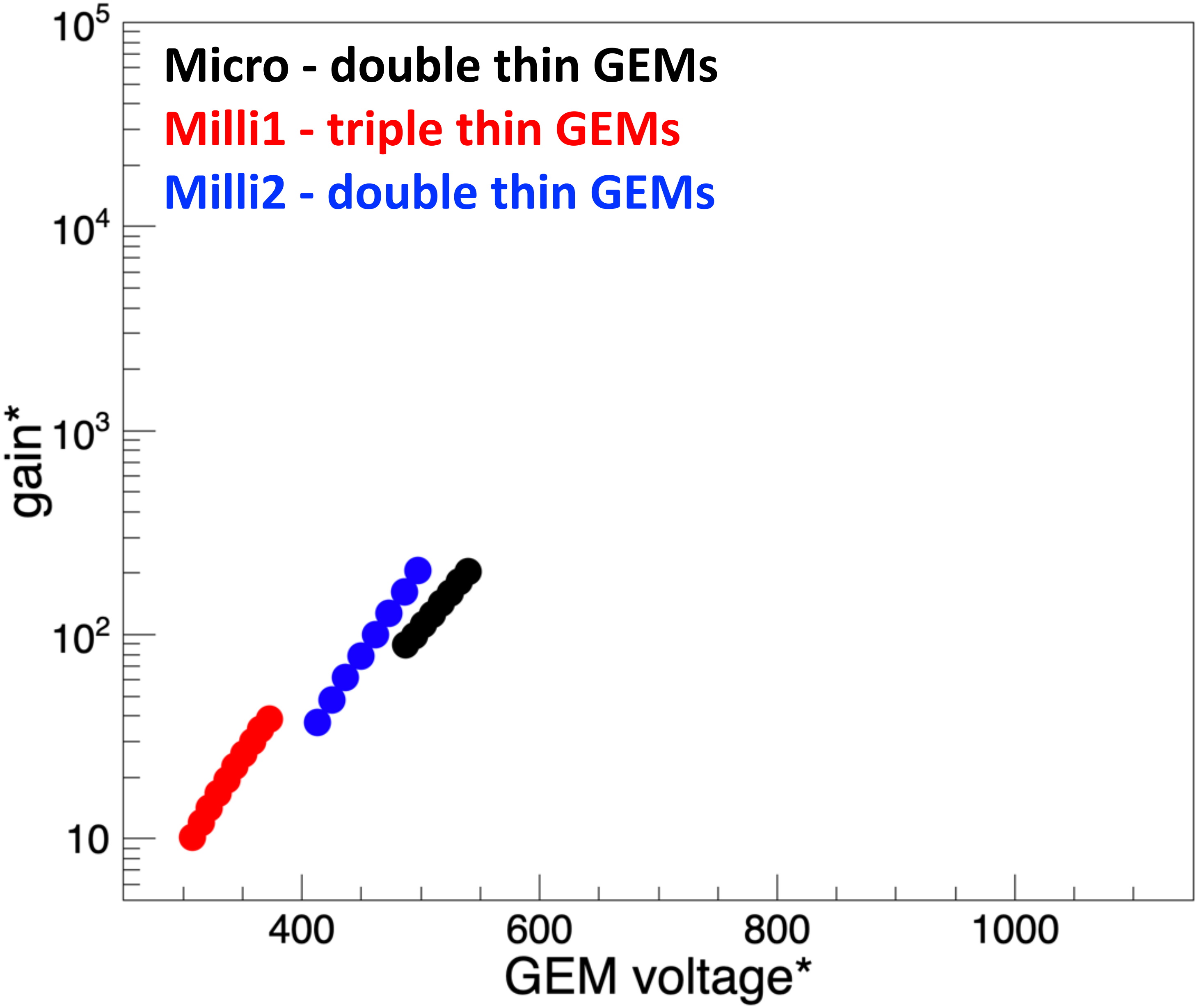
$$\boxed{\ln(G^*) = \alpha t}$$



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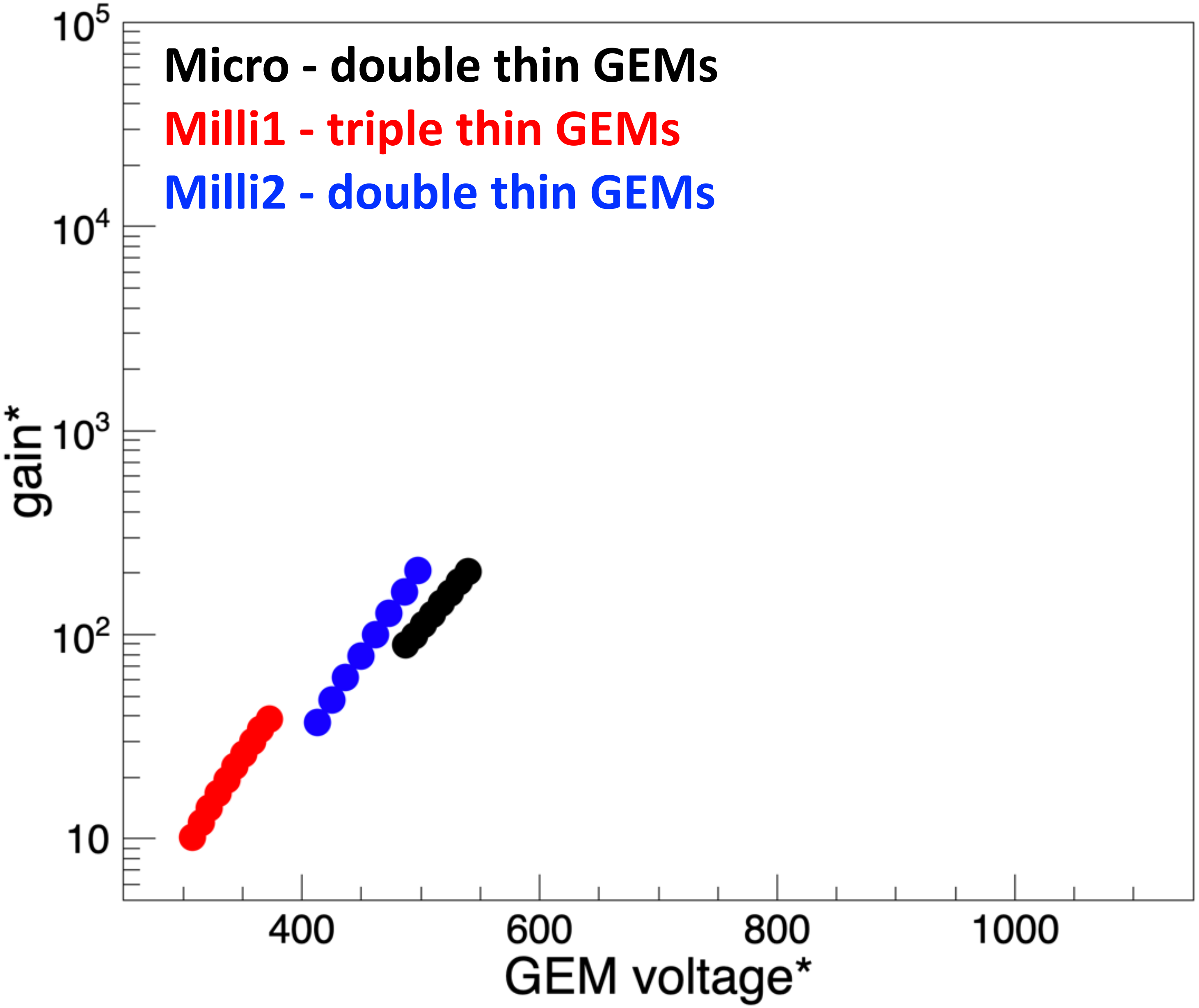
$$\boxed{\ln(G) = n\alpha t}$$



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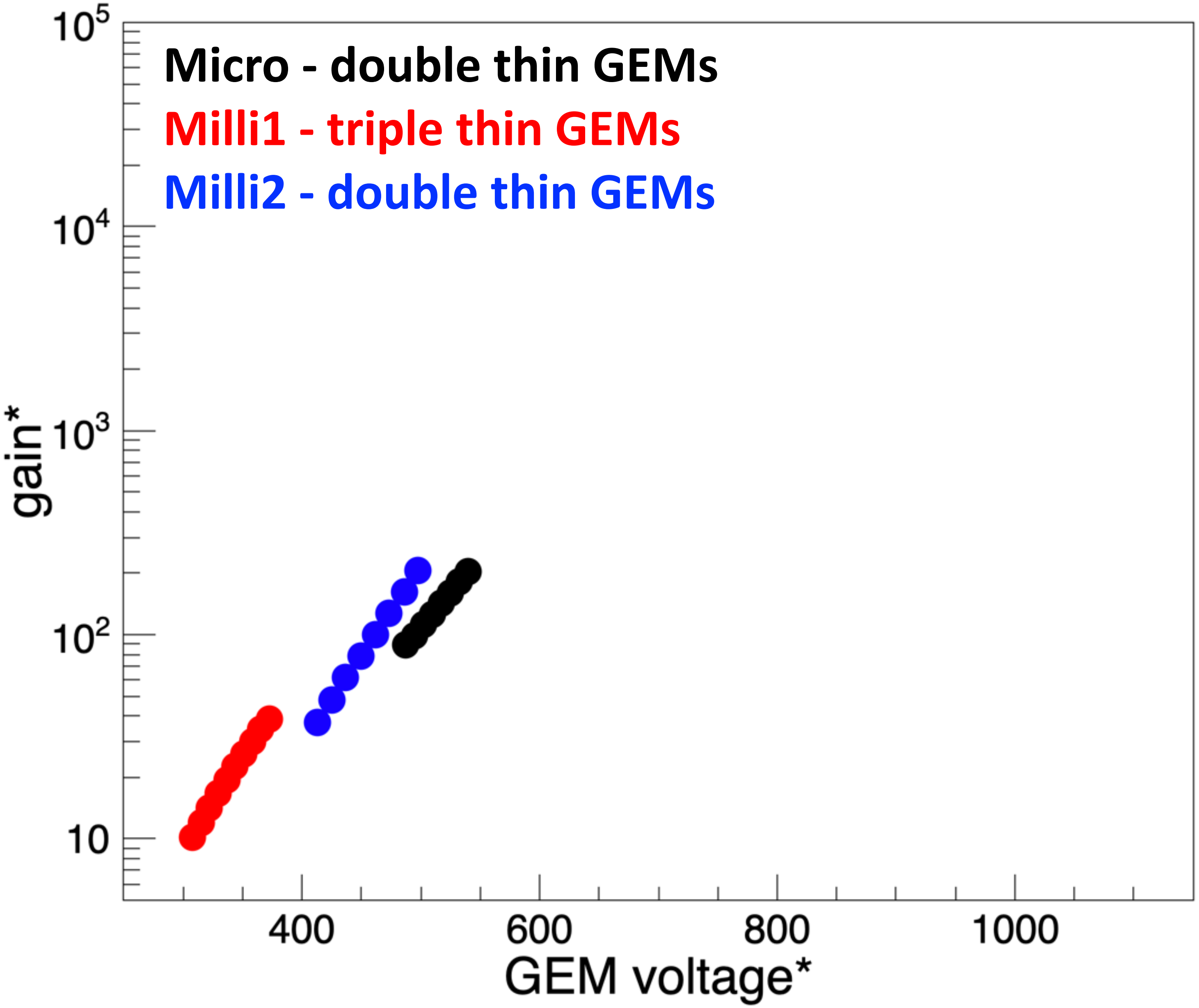
$$\boxed{\ln(G) = n\alpha t}$$

Now what?



Generalizing the Townsend Coefficient; m = 0

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(- L\left(\frac{N}{E}\right)^{1-m} \right)$$

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So if ln(G) = nαt

And m = 0

Generalizing the Townsend Coefficient; m = 0

$$\frac{\alpha}{N} = K\left(\frac{E}{N}\right)^{m} \exp\left(-L\left(\frac{N}{E}\right)^{1-m}\right)$$

p is the gas pressure

So if ln(G) = nαt

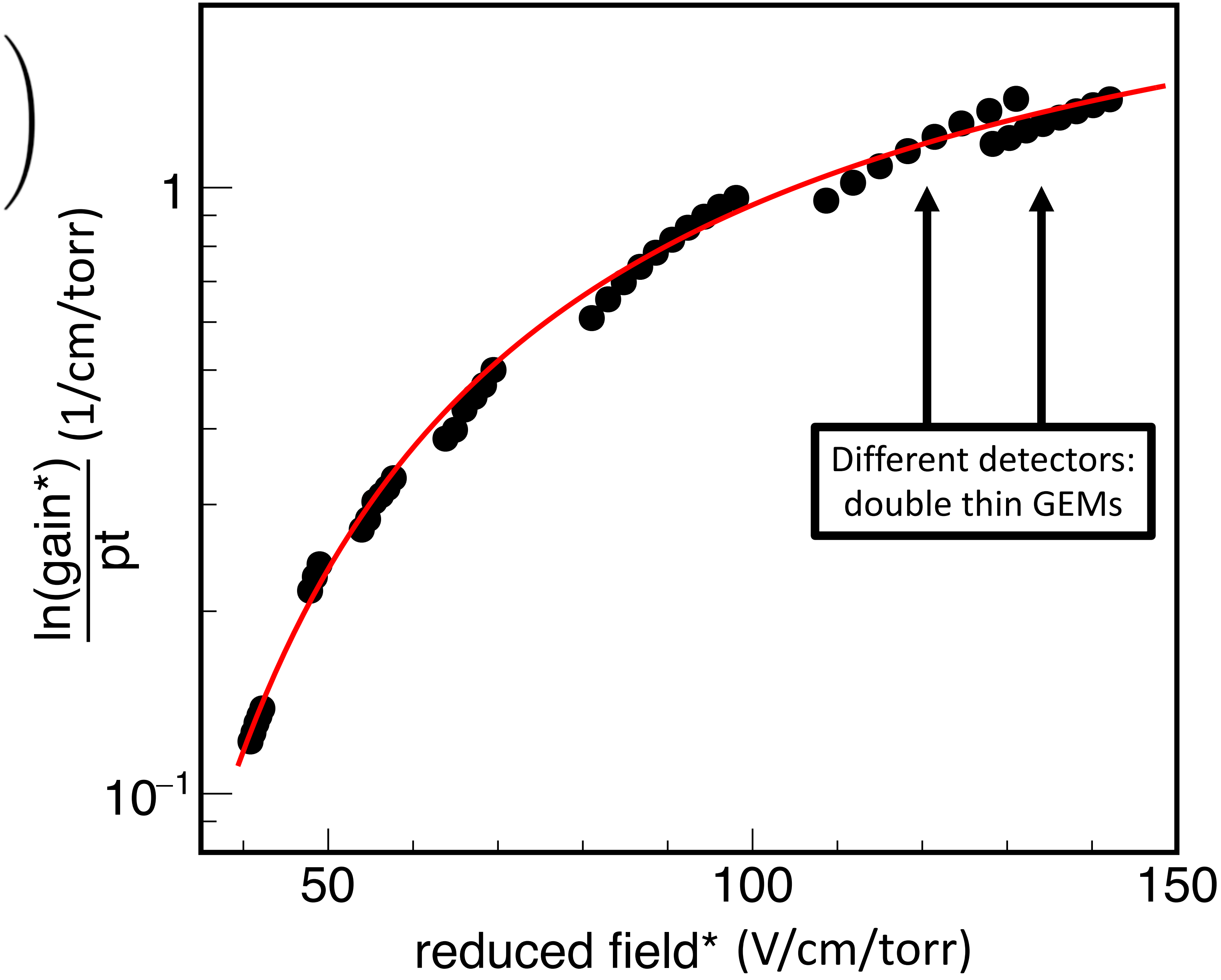
And m = 0

$$\boxed{\frac{\ln(G)}{npt} = A\exp\left(-B\frac{npt}{V_{GEM}}\right)}$$

Combining All $HeCO_2$ Data

$$\frac{\ln(G)}{npt} = A\exp\left(- B\frac{npt}{V_{GEM}} \right)$$

- Multiple detector setups over many years
- α ~ E would be a straight line on this plot
- Over large reduced field ranges the Townsend coefficient's dependence on the field is not linear
- At high reduced fields the slope is higher than this would predict



Different detectors: double thin GEMs

Combining All $HeCO_2$ Data

$$\frac{\ln(G)}{npt} = A\exp\left(-B\frac{npt}{V_{GEM}}\right)$$

- Multiple detector setups over many years
- $\alpha \sim E$ would be a straight line on this plot
- Over large reduced field ranges the Townsend coefficient's dependence on the field is not linear
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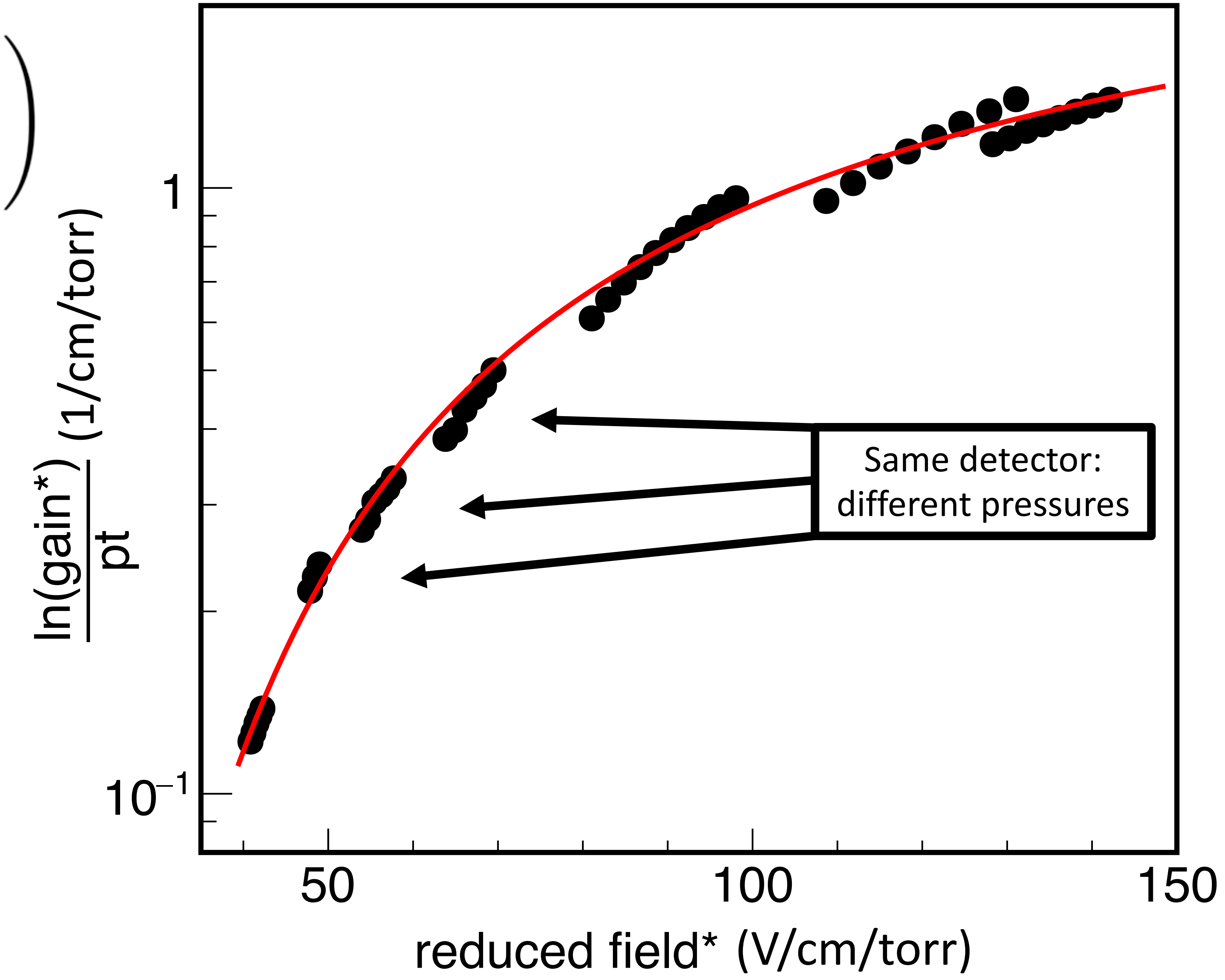
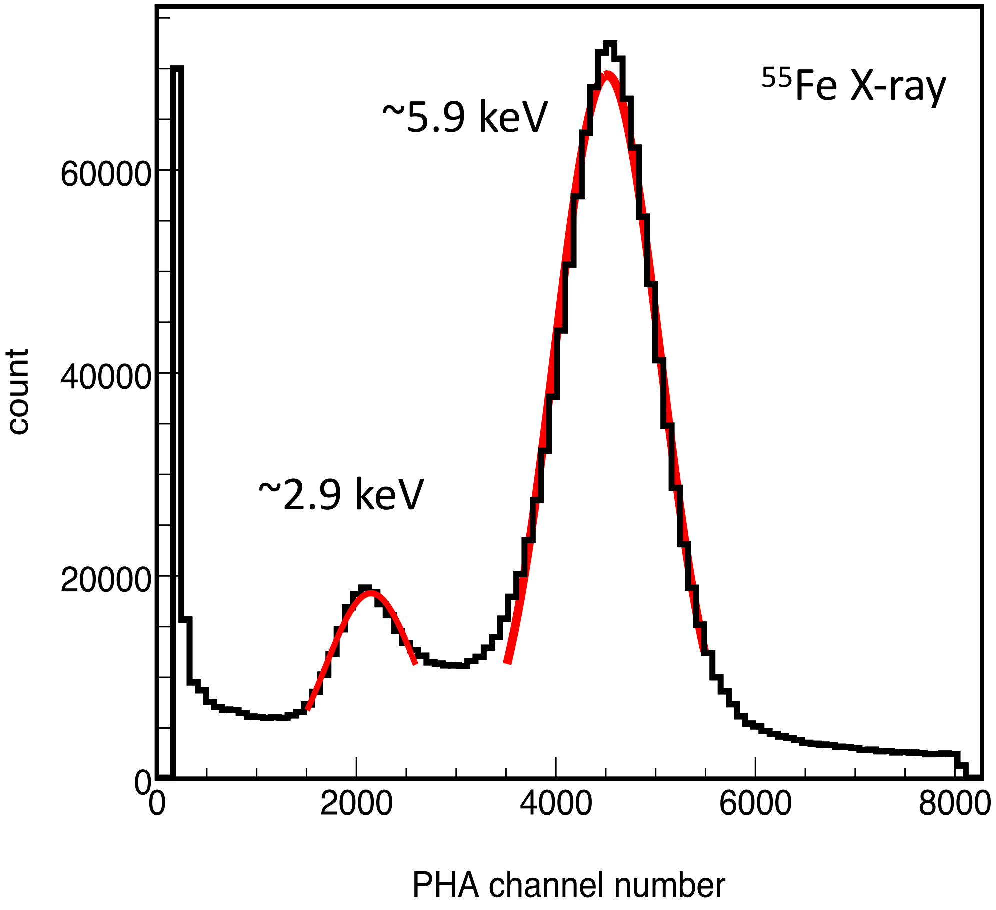
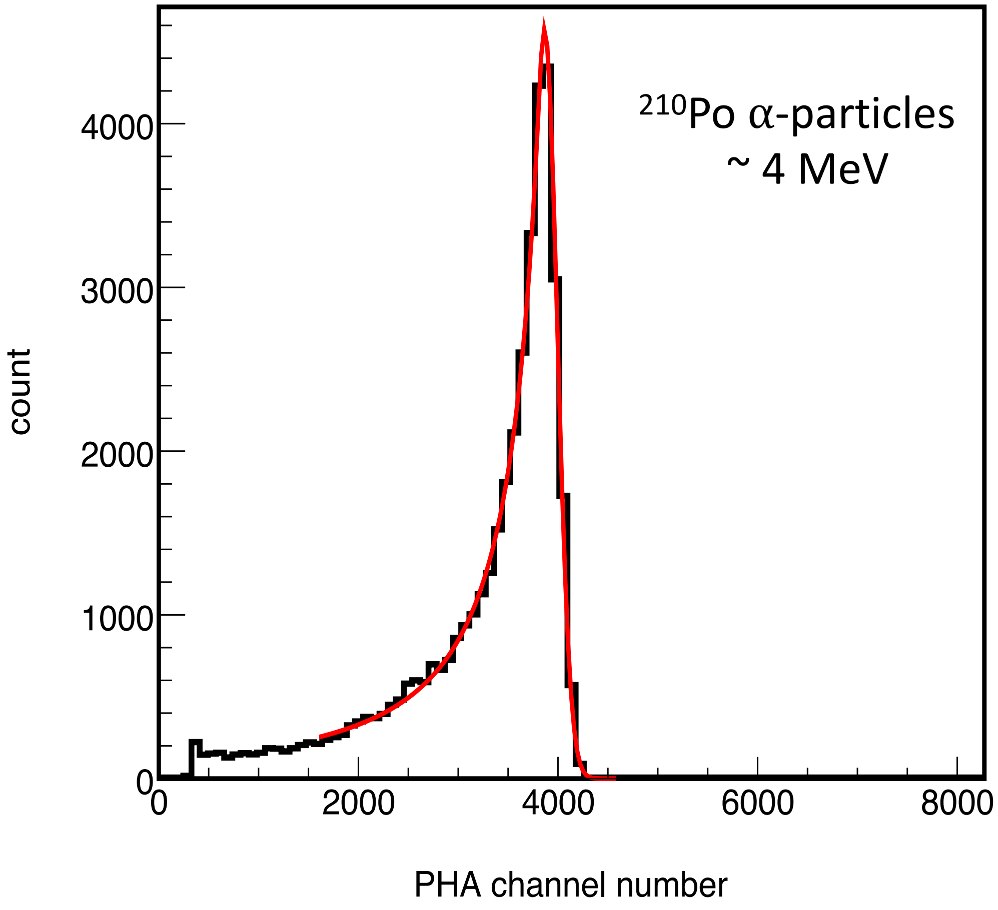


Same detector: different pressures

$ArCO_2$ – Double Thin GEMs

- $ArCO_2$ (70:30) @ 1 atm.
- First study done with D^3 – Micro
- Multiple energies
- How does the gain resolution depend on the incident energy?

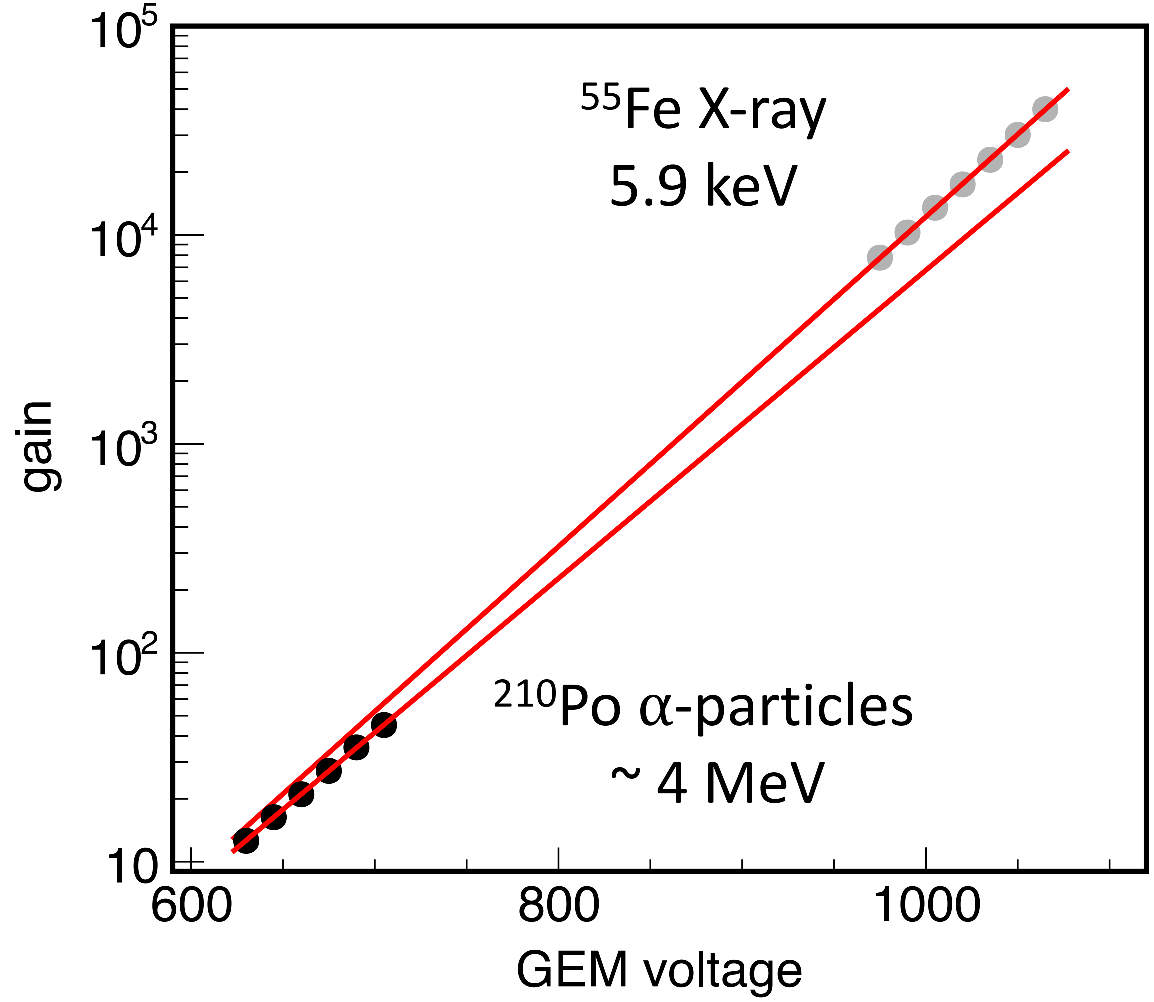




Energy →

$ArCO_2$ Gas Gain

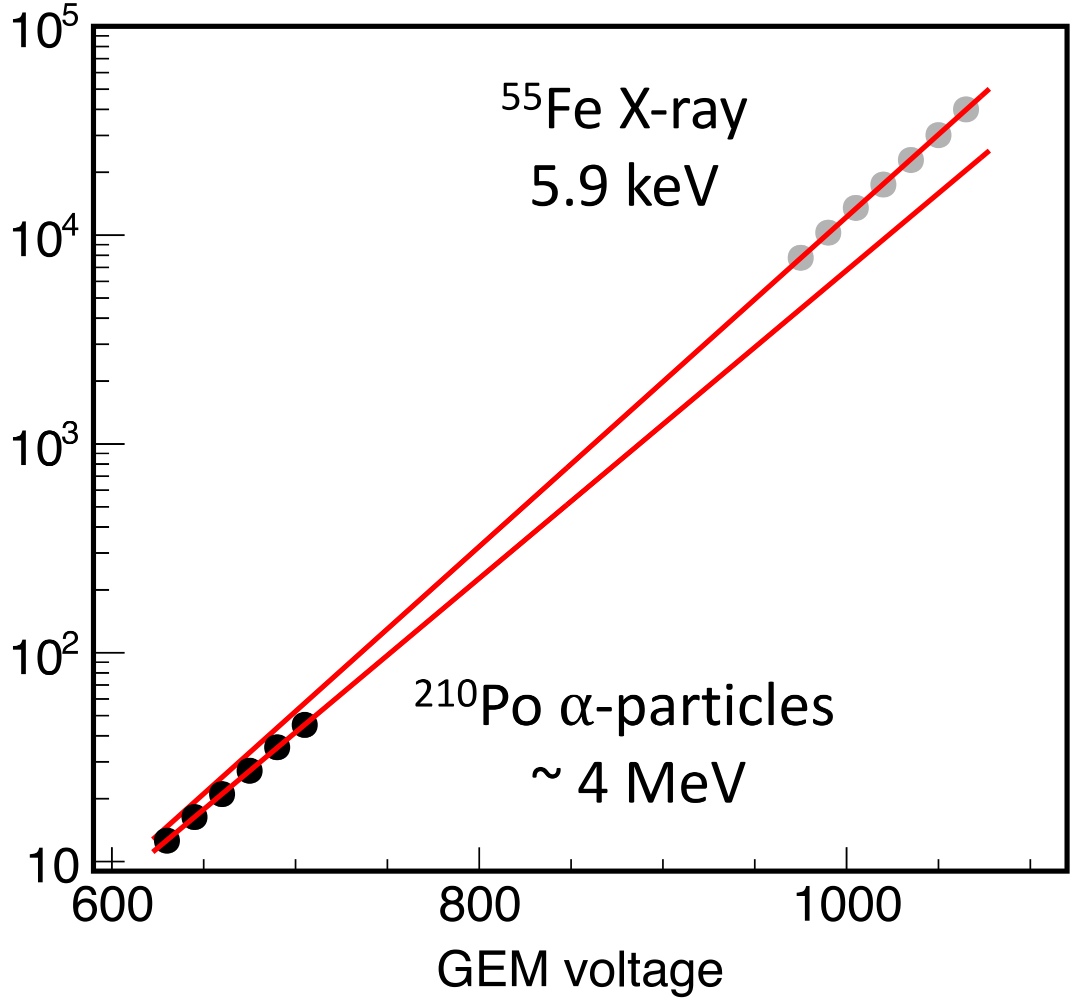
$$G = 10^{(V_{GEM} - V_1)/V_2}$$

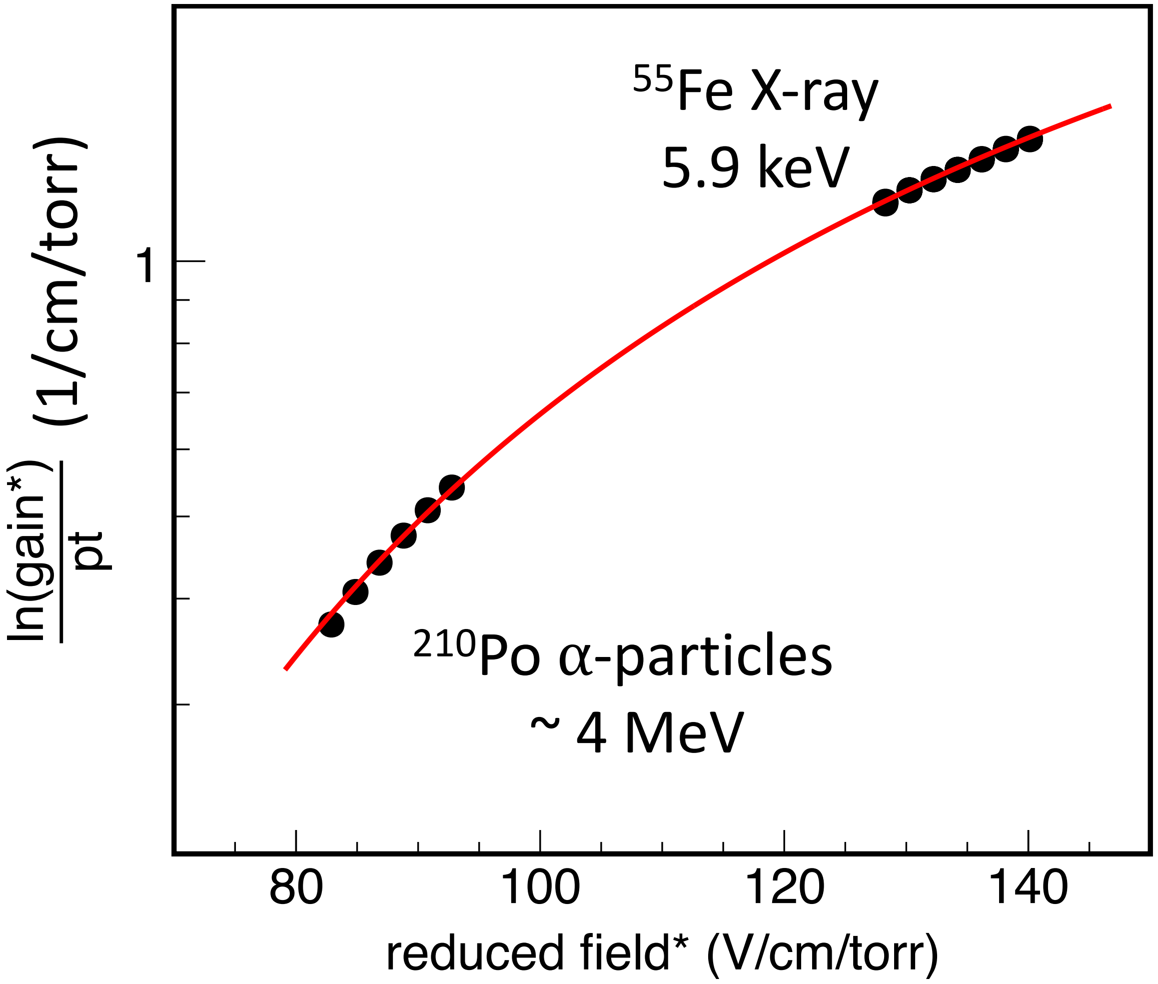


$ArCO_2$ Gas Gain

$$G = 10^{(V_{GEM} - V_1)/V_2}$$

$$\frac{\ln(G)}{npt} = A\exp\left(-B\frac{npt}{V_{GEM}}\right)$$

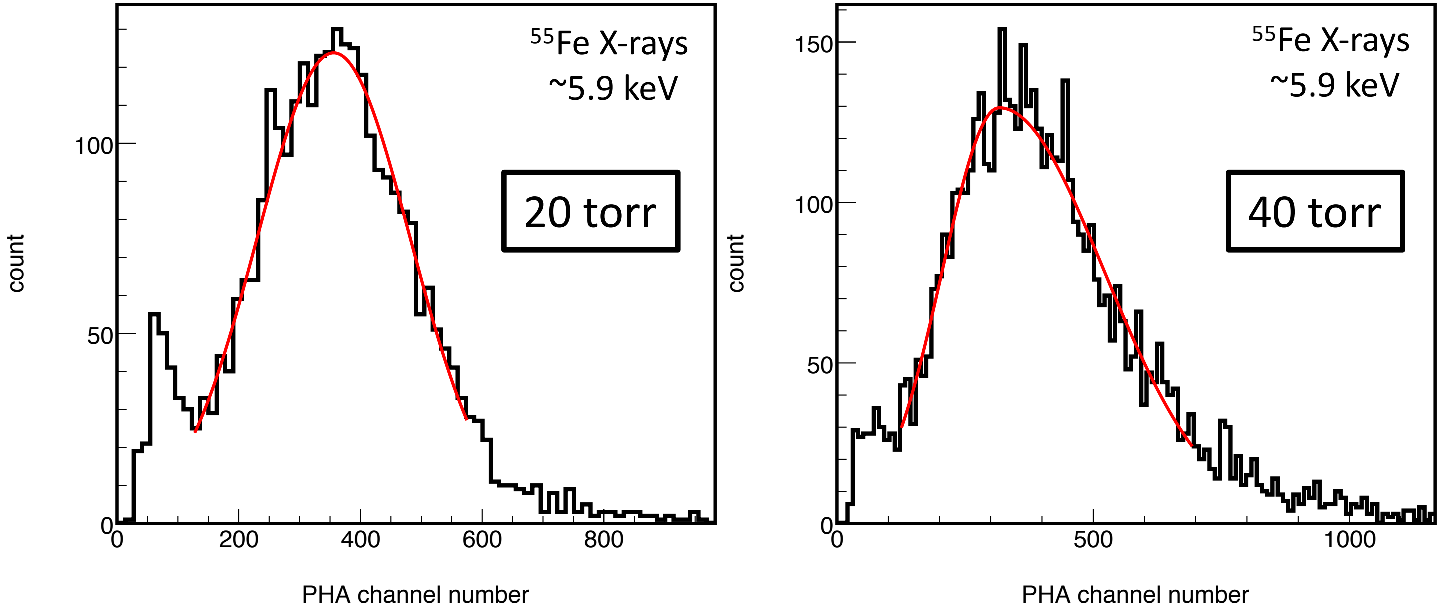


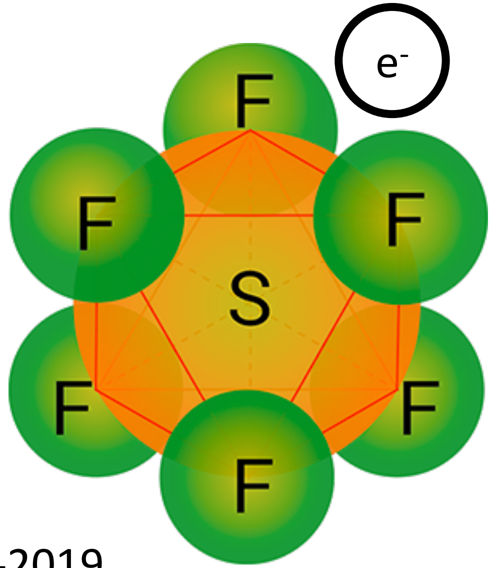


SF_6 - Negative Ion (NI) Gas – Single THGEM

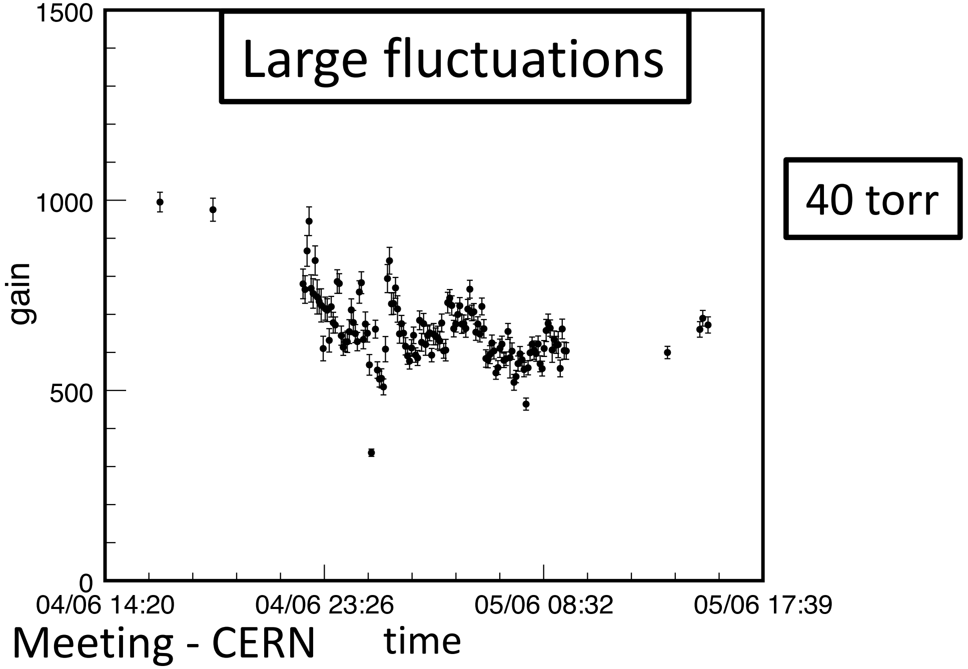
Why NI gas?

- Diffusion destroys recoil tracks
- Ions have much more mass
- Less diffusion (thermal limit?)
- Longer drift
- Larger fiducial volume



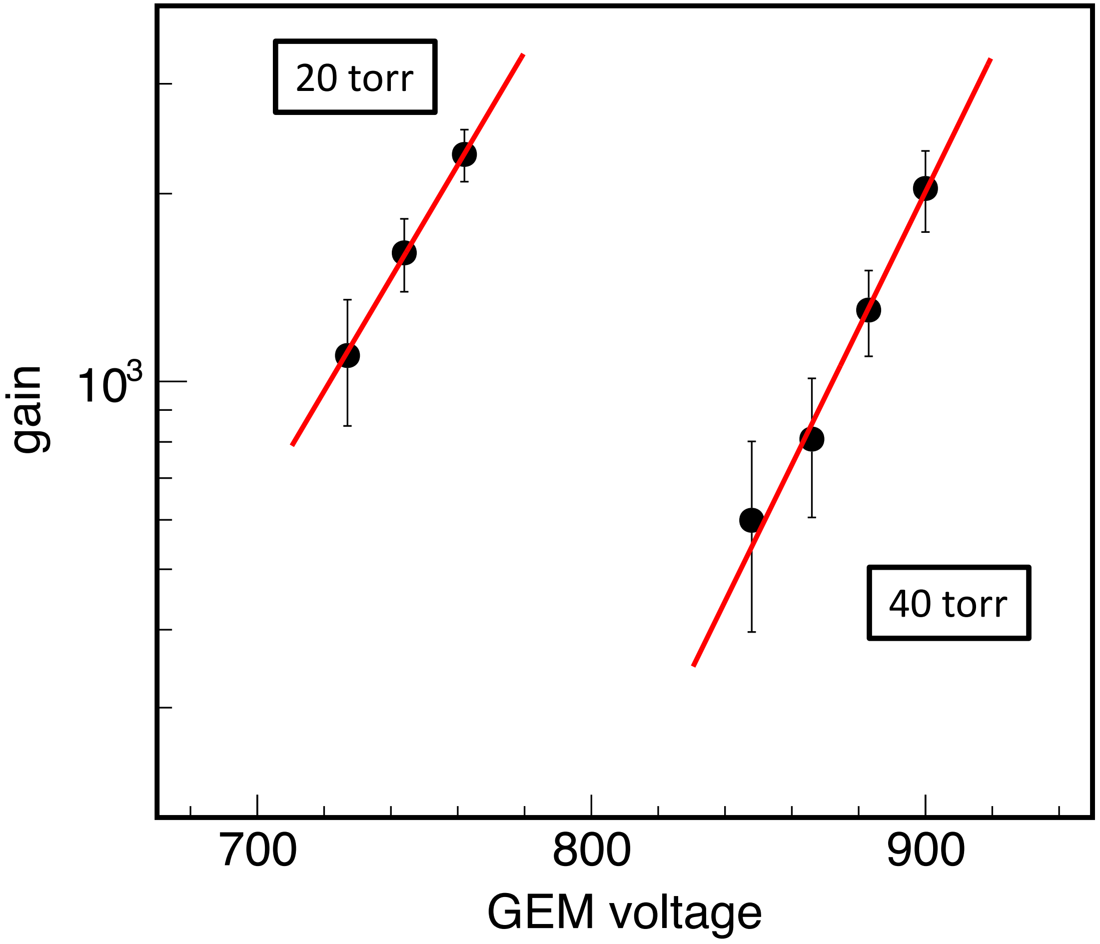


- 100% SF_6
- Low gain and poor resolution compared to electron gases
- Gas flow was required
- Still highly unstable



SF_6 - Negative Ion (NI) Gas Gain

$$G = 10^{(V_{GEM} - V_1)/V_2}$$



SF$_6$ - Negative Ion (NI) Gas Gain

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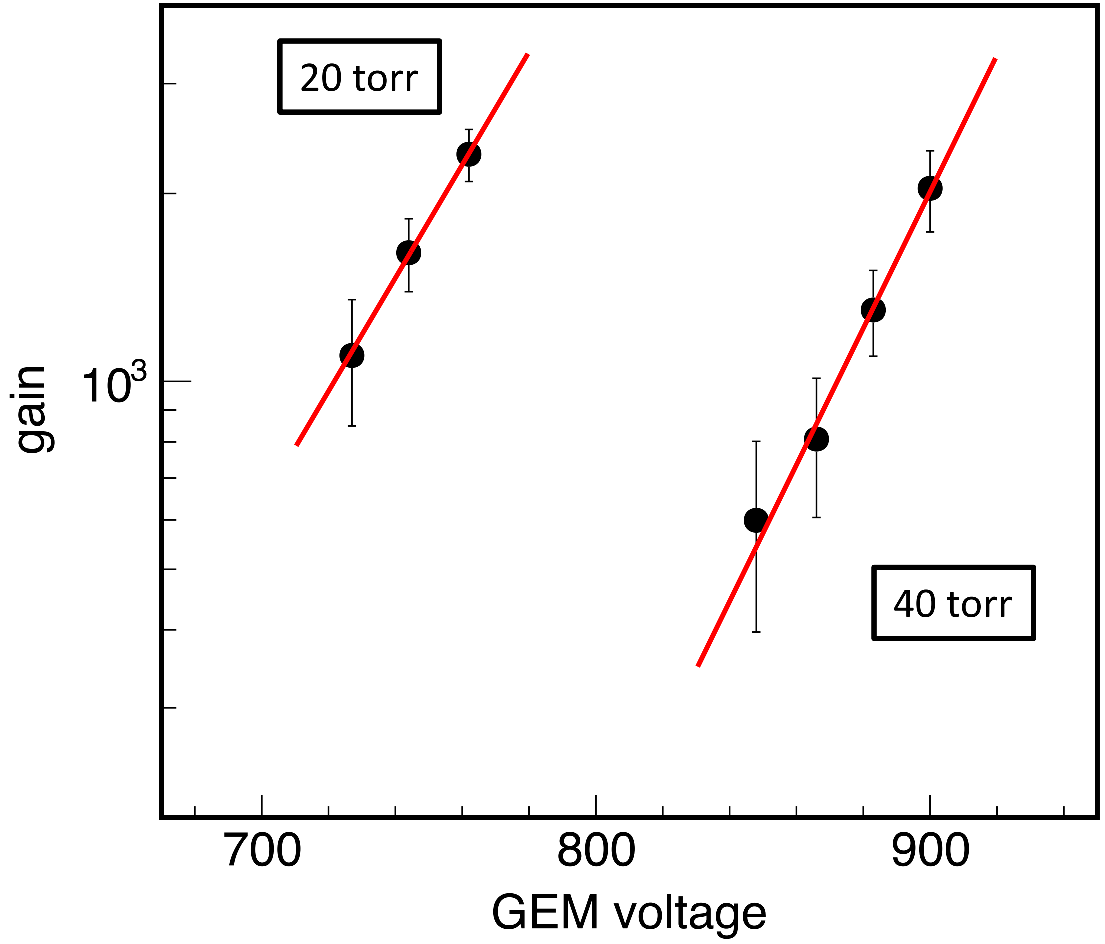
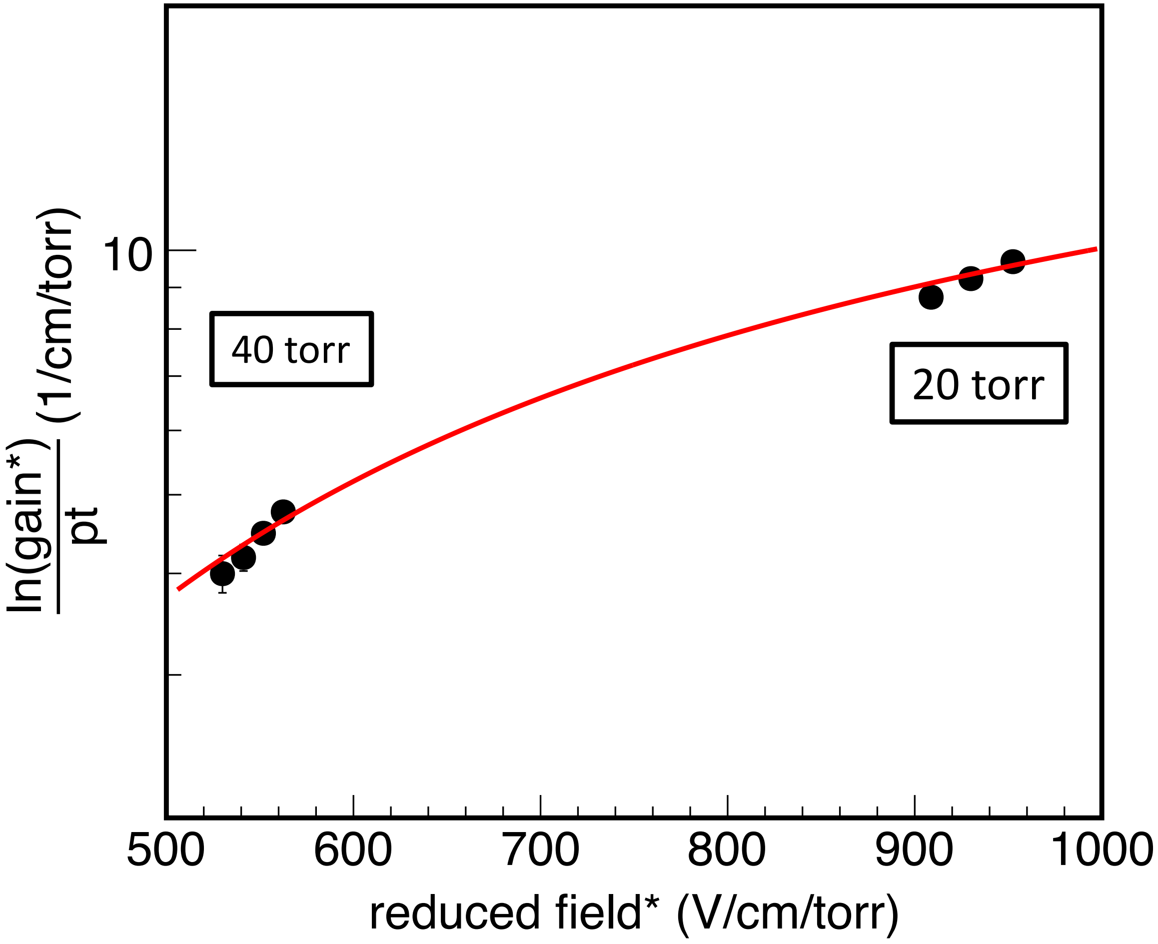
$$\frac{\ln(G)}{npt} = A\exp\left(-B\frac{npt}{V_{GEM}}\right)$$

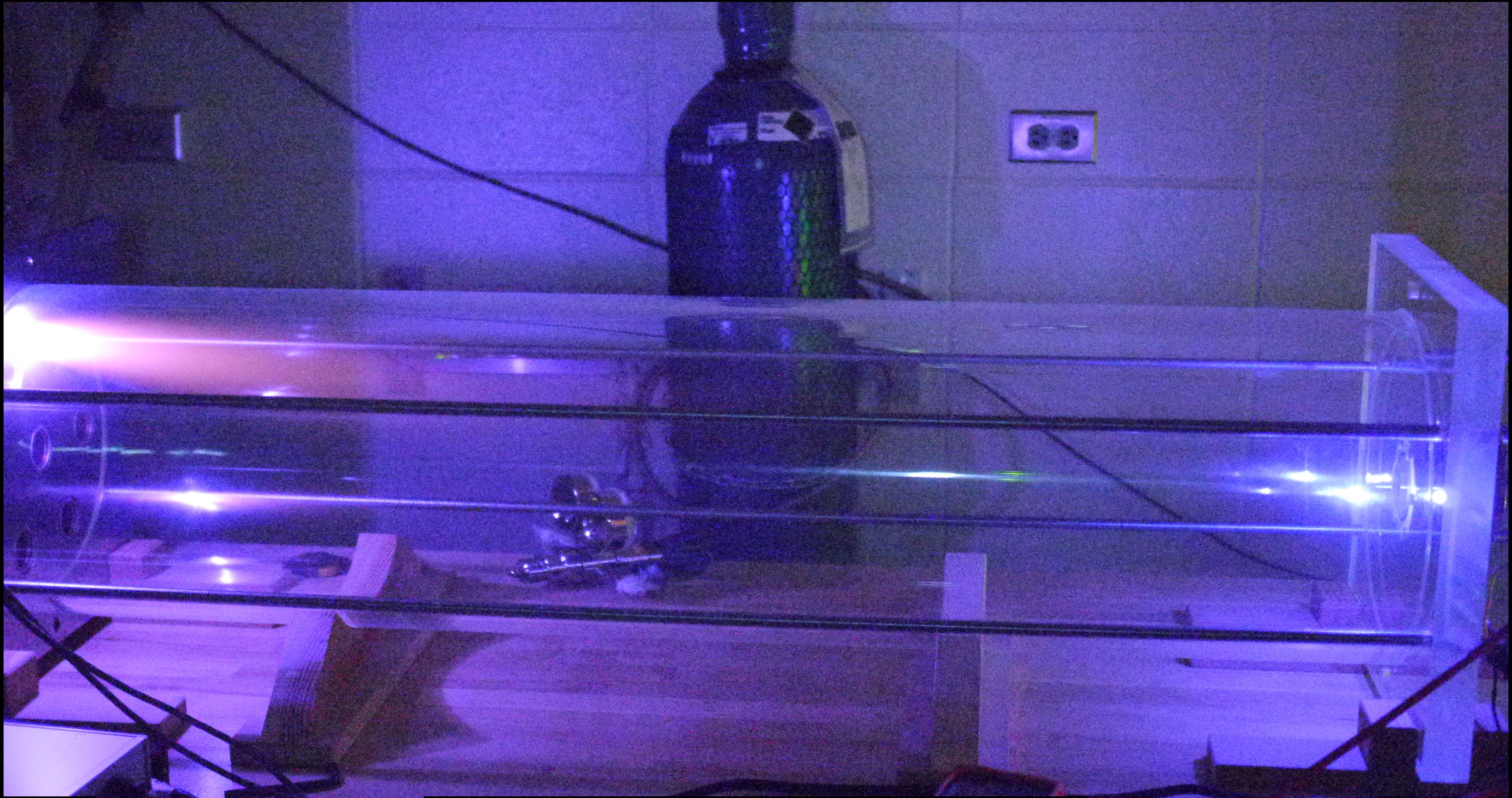




Conclusion

- Working on getting this in a publishable form; comments are encouraged
- Goal was to describe different GEM data together, fundamentally
- Simple closed form description
- Over a large reduced field range, the field dependence of the Townsend coefficient is not simply linear
- Large systematics between setups that are not possible to account for
- Original model is naïve about the gain process itself
- Smaller effects
  - Gain fluctuations during measurements; hard to account for
  - Error on voltage between GEMs; likely has larger effect on the gain itself
- Gain resolution is another talk…

Thank you!



Backup

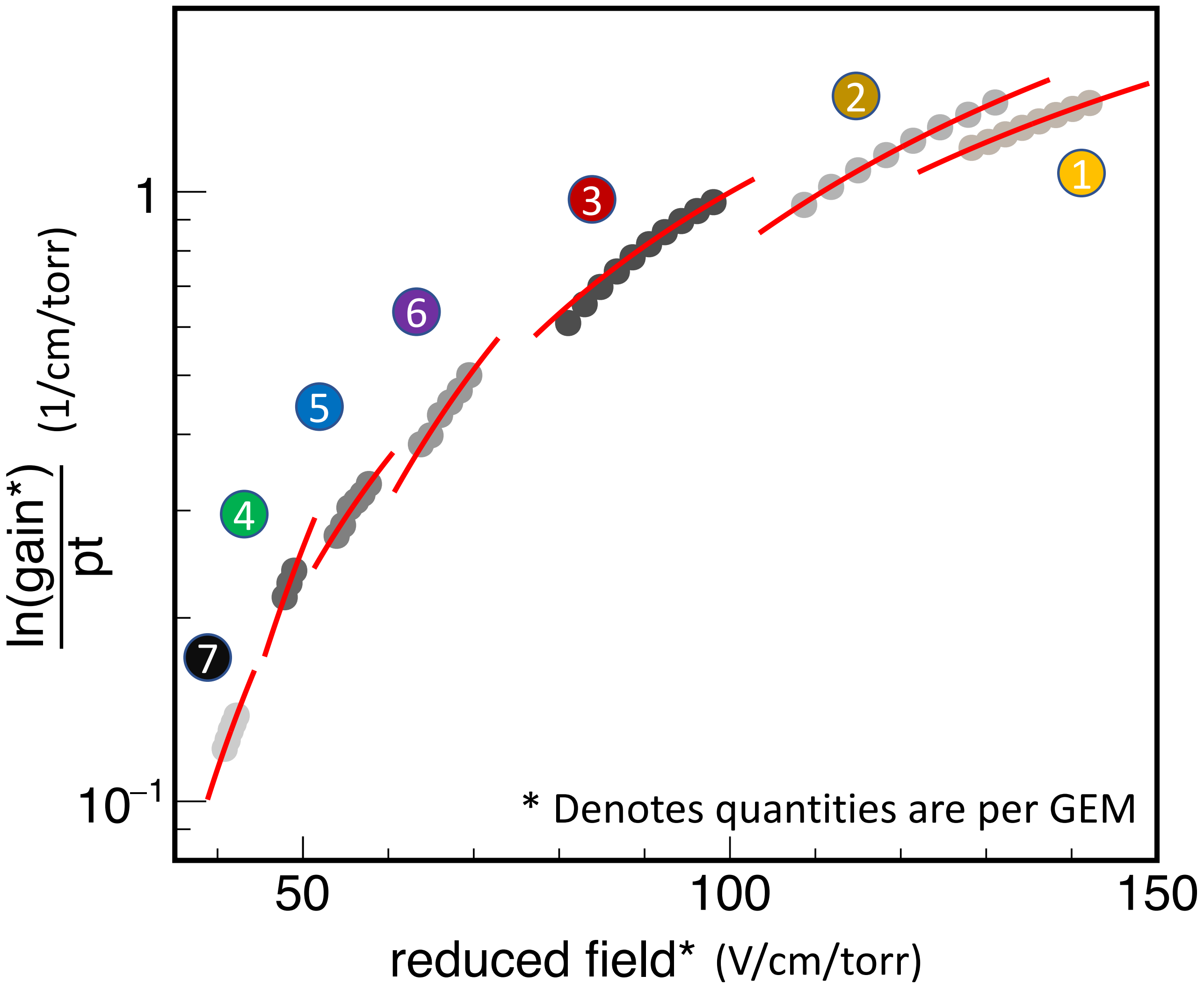
Backup

Combining All $HeCO_2$ Data - Individual Fits

$$\frac{\ln(G)}{npt} = A\exp\left(- B\frac{npt}{V_{GEM}}\right)$$

	Data set	B/A
①	Double thin GEMs (D^3 - Micro)	32.9 ± 0.7
②	Double thin GEMs (D^3 - Milli2)	27.2 ± 0.5
③	Triple thin GEMs	29.3 ± 0.6
④	THGEM - 1.0 atm	12.5 ± 0.3
⑤	THGEM - 0.75 atm	34.7 ± 0.7
⑥	THGEM - 0.5 atm	20.2 ± 0.4
⑦	Double THGEMs	29.6 ± 0.6
	Combined	37.0 ± 0.7

- More general interpretation
- W = 34.4 eV for initial gain values
- B/A gives back an "effective" ionization potential



* Denotes quantities are per GEM

GEM dimensions

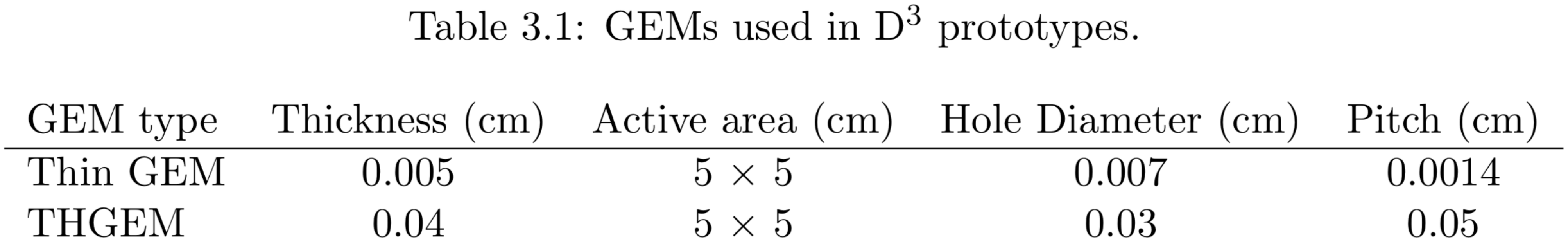


Table 3.1: GEMs used in D^3 prototypes.

GEM type	Thickness (cm)	Active area (cm)	Hole Diameter (cm)	Pitch (cm)
Thin GEM	0.005	5 × 5	0.007	0.0014
THGEM	0.04	5 × 5	0.03	0.05