Role of CF4 in gas amplification in gems

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(For Gems for CMS collaboration)

Outline

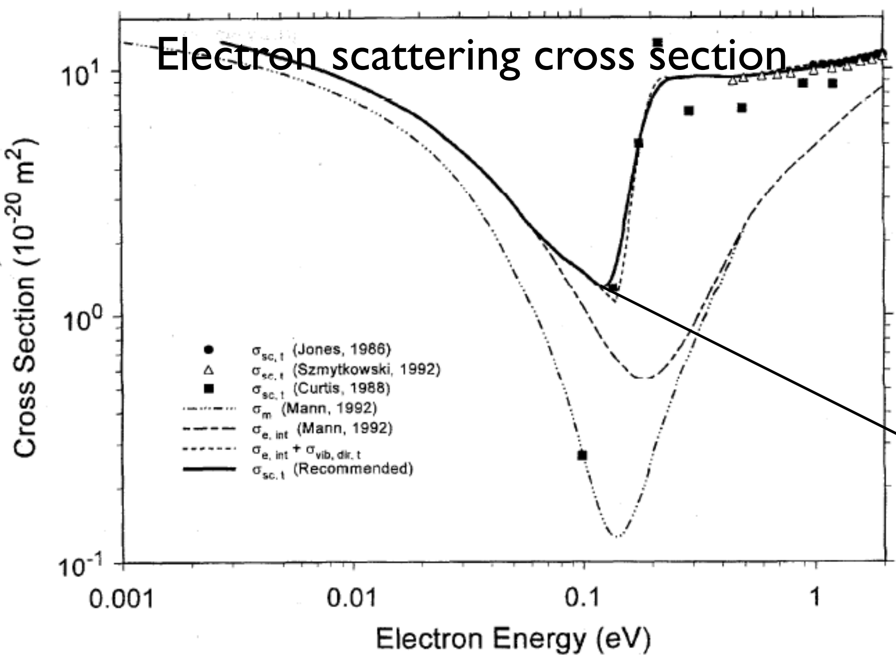
- A bit of discussion on CF_4
- Gain in case of single gems for CF_4 mixtures
- Loss rates in case of single gems
- Gain in **triple gem** and comparison with data

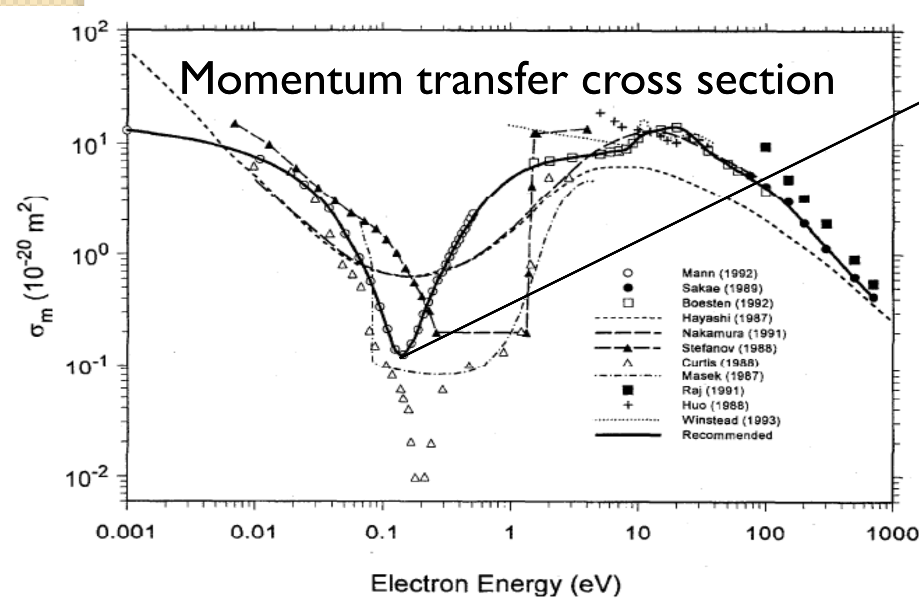
The Gas called "CF_4"

- A Fast gas because of large electron scattering cross-section > 0.5 eV. This lowers the energy of the electrons in the mixture to less than 0.5 eV . (Effectively acting like a pillow rather than a hard surface)
- At this energy the cross-section is less in case of Argon.
- Hence the mean free path is large, and so an increase in drift velocity over a range of E/p values.

The Gas called "CF_4"

- 4 fundamental vibrational modes
  - Symmetric stretch (0.112 eV), symmetric bend (0.054 eV)
  - Asymmetric stretch, (0.157 eV) Asymmetric bend (0.078 eV)
  - Studies have revealed strong vibrational excitation by electron impact below 2.0 eV. (We know it is a fast gas !)
- Excitation energy of asymmetric stretch very near the Ramseur minimum in momentum and electron scattering cross-section at 0.16 eV.





One Can see the Ramseur dip at 0.16 eV

LG Christophorou et al,
J. Phys. Chem. Ref. Data
Vol 25, No-5, 1996

Attachment in CF_4

- Resonant electron attachment to CF_4 occurs mainly in 6-8 eV via two negative ion states.
- Ground state of CF_4^- at 6.8 eV producing F^- and CF_3^- via complementary channels.

$$CF_4^- \rightarrow F^- + CF_3$$

$$CF_4^- \rightarrow F + CF_3^-$$

F atoms produced

First electronically excited state of CF_4^{*-} at 7.6 eV producing only F^- .

$$CF_4^{*-} \rightarrow F^- + CF_3^*$$

- An interesting thing to note is that CF_4^- not observed in gas phase as, only seen in van der waals clusters of CF_4, where auto-detachment is slow.

Ionization Of CF_4

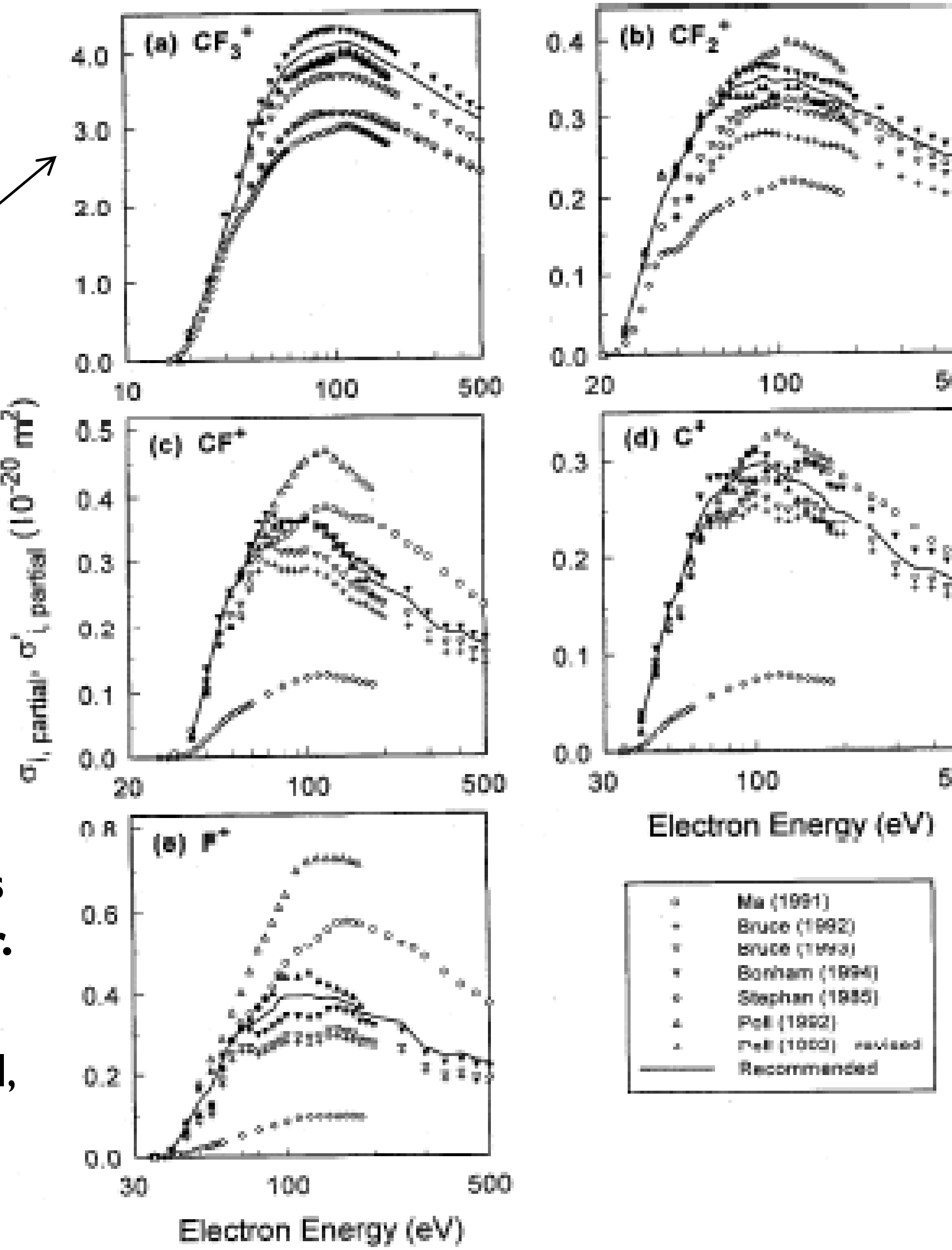
Dissociative Ionisation – dominant in CF_4 above 30-35 eV.

$$e + CF_4 \rightarrow CF_3^+ + F + 2e$$

This being the dominant reaction

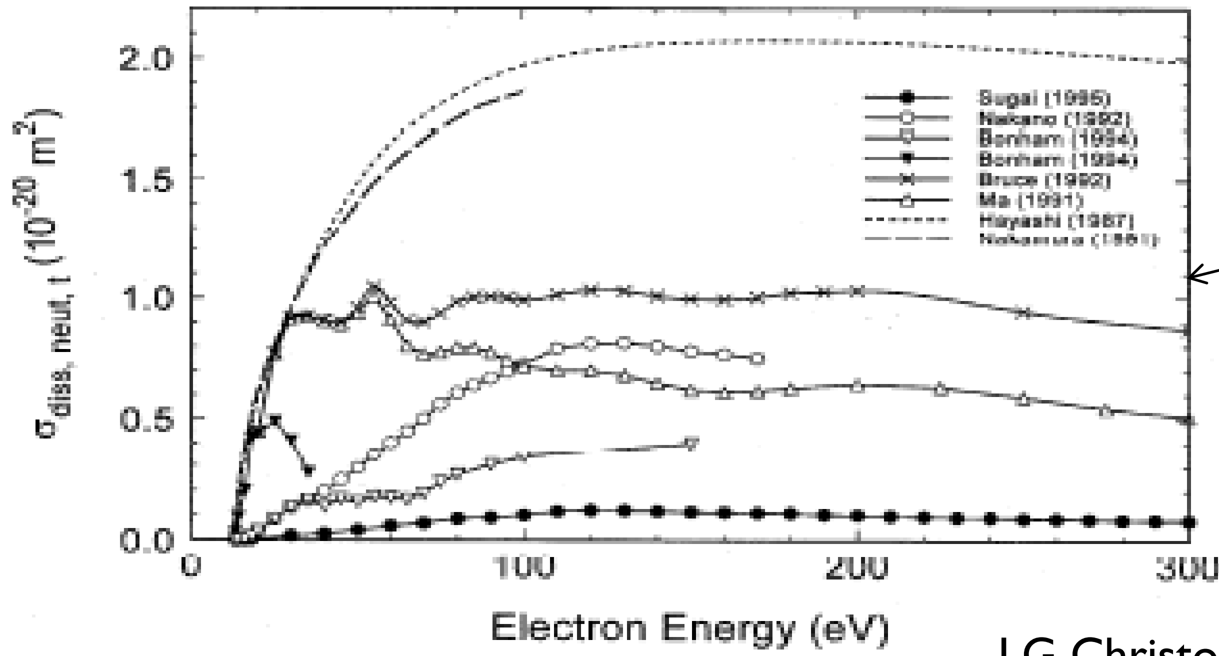
Fluorine again

A look at the partial ionization cross section For production of CF_3^+ and other radicals !



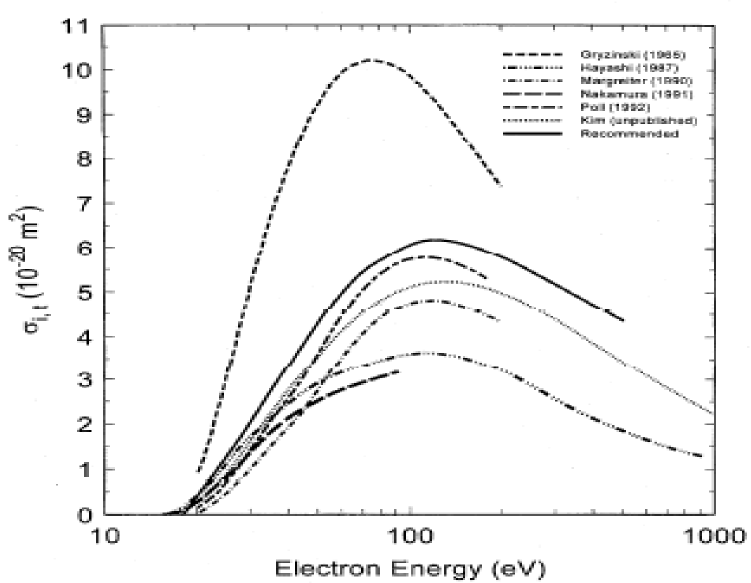
Clearly CF_3^+ cross-sections are a factor of ~ 10 greater.

LG Christophorou et al, J. Phys. Chem. Ref. Data Vol 25, No-5, 1996



Neutral Dissociation cross-section

Total ionisation cross section

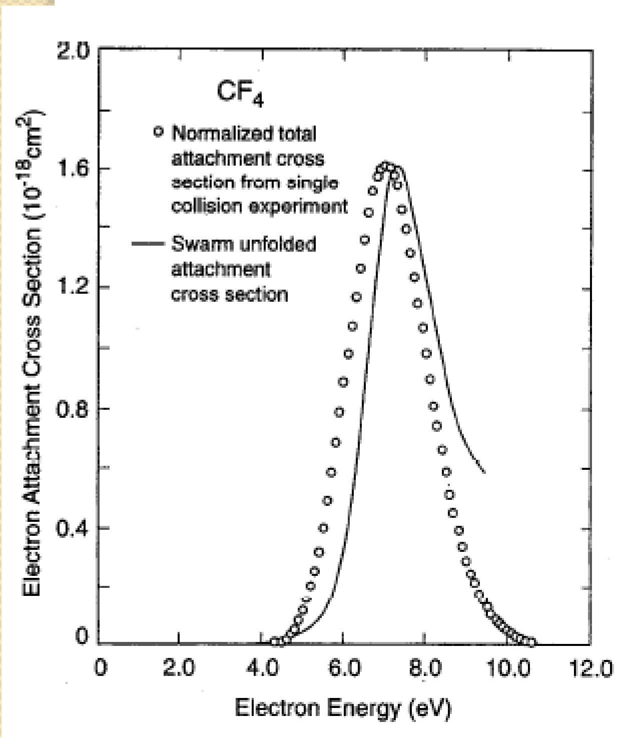


LG Christophorou et al,
J. Phys. Chem. Ref. Data
Vol 25, No-5, 1996

Important observation being that below ~16.2 eV dissociation into neutrals dominates, whereas at higher energies, dissociative ionisation takes over. (about 30-35 eV)

- The threshold for generating neutral fragments is about 12.5 eV.
- This value being lower than the ionization potential of CF_4 (16.2 eV), neutral dissociation dominant at low electron energies.
- At energies below neutral dissociation threshold, dissociation occurs via electron attachment.
- So
  - Electron attachment < neutral < ionic

Increasing electr… energy



Total Electron attachment cross section for CF_4

LG Christophorou et al,
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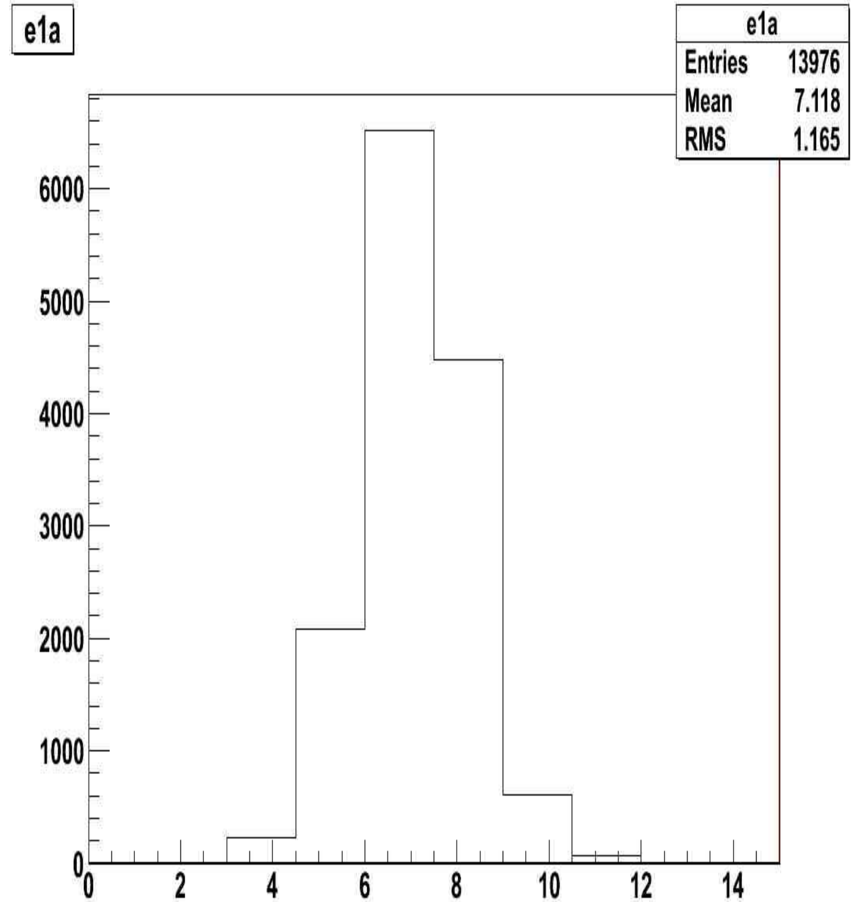


Electron energy (eV) ⟶

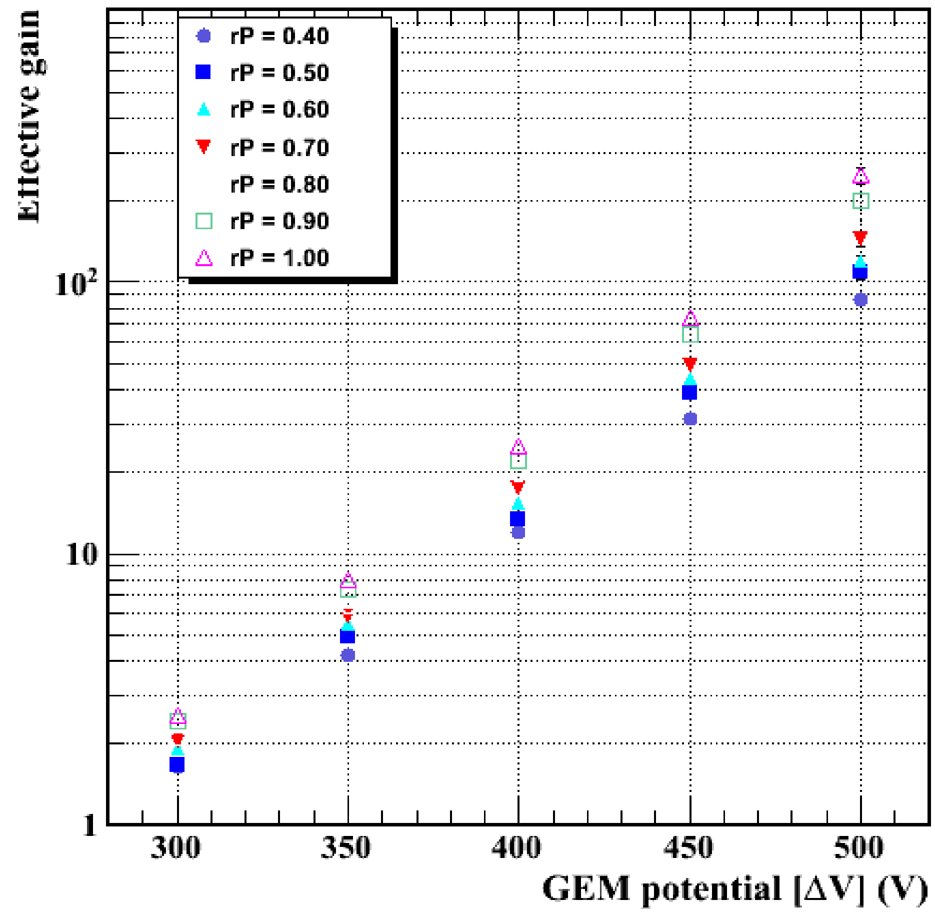
Simulated attachment in case of single gems in Ar (45)/CO_2(15)/CF_4(40) gas mixture

Penning transfer?

- Looks unlikely from the preceding discussion.
  - High ionization energy of **16.2** eV, which is also higher than the ionization energy of Argon !
  - Hopefully no penning transfer from Ar to CF_4 .
  - No stable excited state of CF_4
  - So penning transfer from CF_4 to CO_2 unlikely
  - Any data for CF_4 in single gems?
- As a conclusion, we can take home the fact that gain should be lower in case of CF_4 mixture

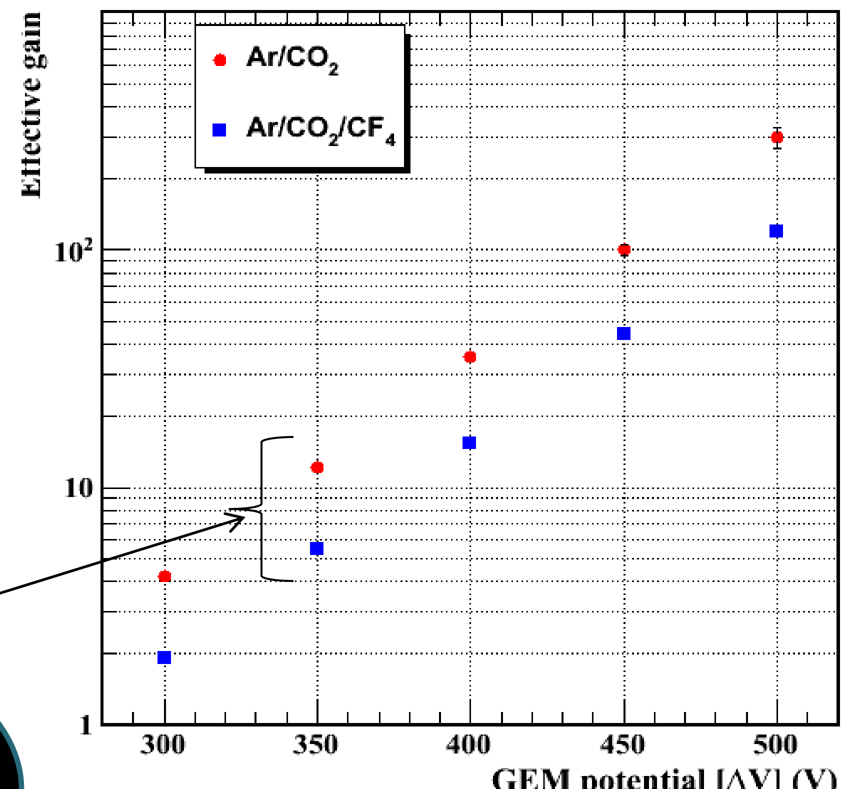
Single gem plots ($Ar(45)/CO_2(15)/CF_4(40)$)

- The effective gain in case of single gem for $Ar/CO_2/CF_4$ mixture is shown for varying gem potentials and penning parameters.
- The parameters in simulation being
  - Drift field – 2 kV/cm
  - Induction field – 3 kV/cm
  - Drift /induction space – 3/2 mm



Comparison of effective gains

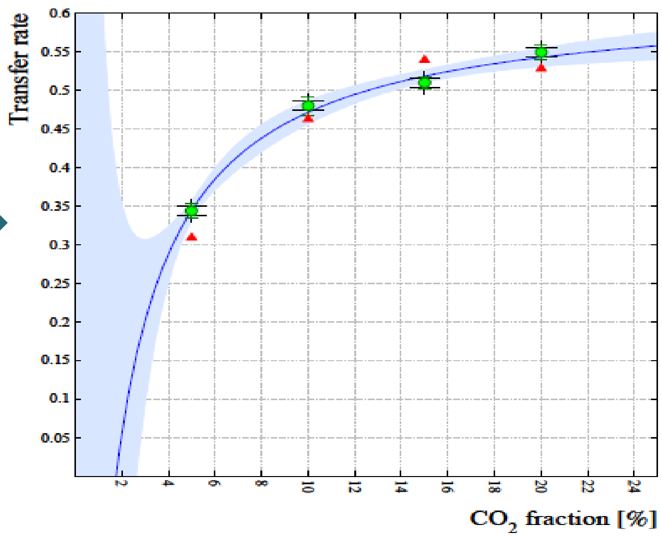
- The value of gain in $Ar/CO_2/CF_4$ is compared with $Ar(70)/CO_2(30)$ (which compares well with the data)
- The penning parameter chosen is 0.6.



Clearly one can see a reduction of in gain in case of CF_4 mixture

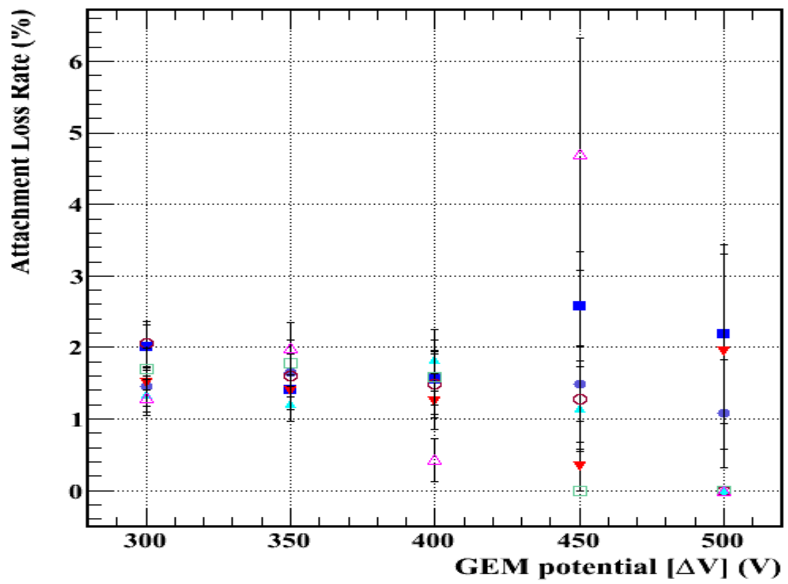
- Possible reasons
- Less Argon would mean less ionization electrons and less CO_2 which would mean less penning transfer.
- Also presence of both CO_2 and CF_4 would lead to an increase in attachment loss.

Transfer rate as a function of CO_2 fraction

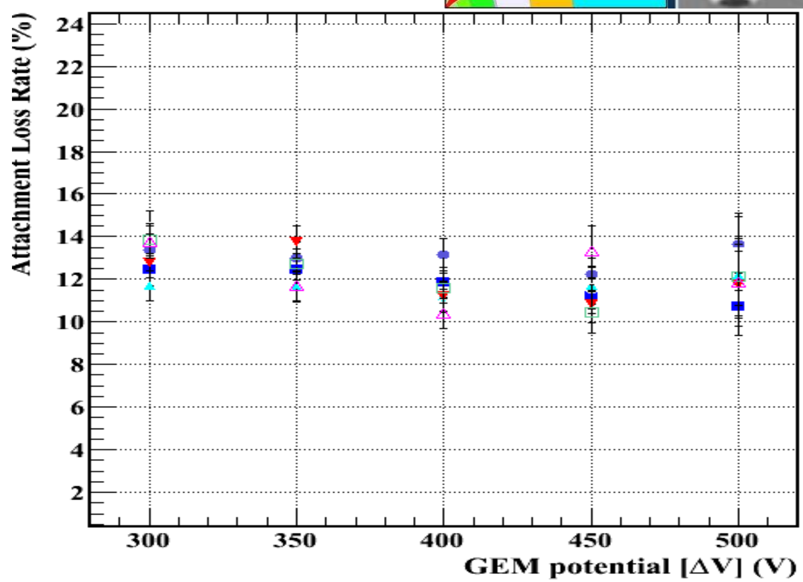


Ozkan Sahin et al, J. Instrum. 5 (2010) P05002

- The loss rate plots for both the primary and secondary electrons are shown as :
  - Attachment loss rate
  - Geometric loss rate
  - Overall loss rate
- The values of the loss rate are compared with Ar/CO_2 mixture.



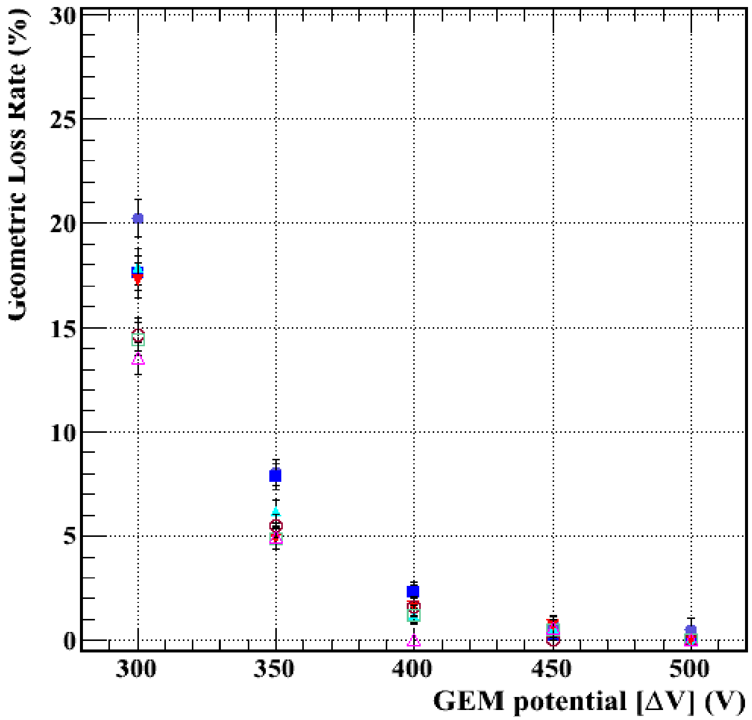
Ar/CO_2

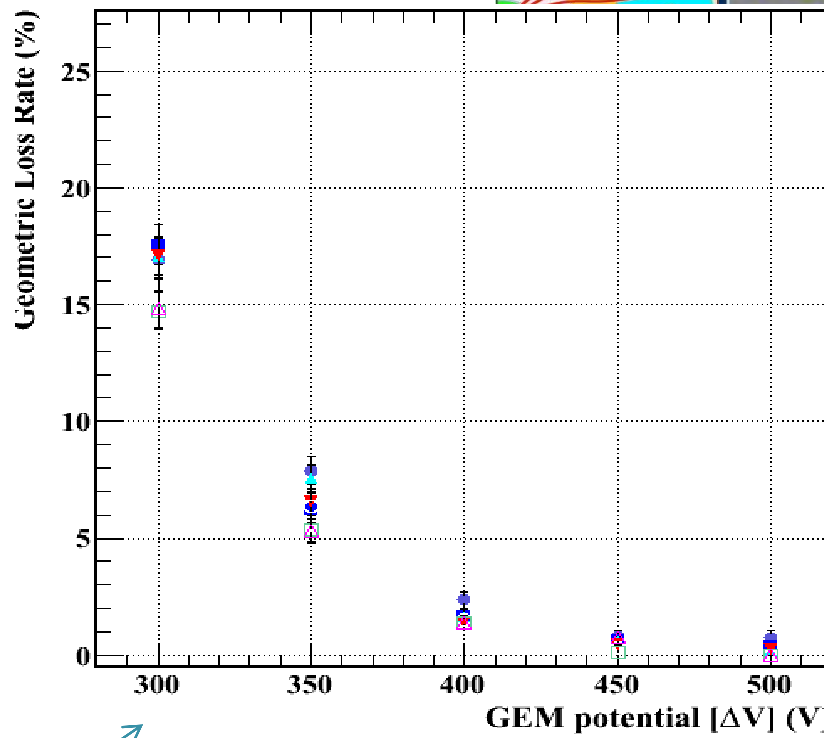


$Ar/CO_2/CF_4$

A much higher value seen in CF_4 mixture (About a factor of 6-7 higher)

Attachment Loss rate for primaries



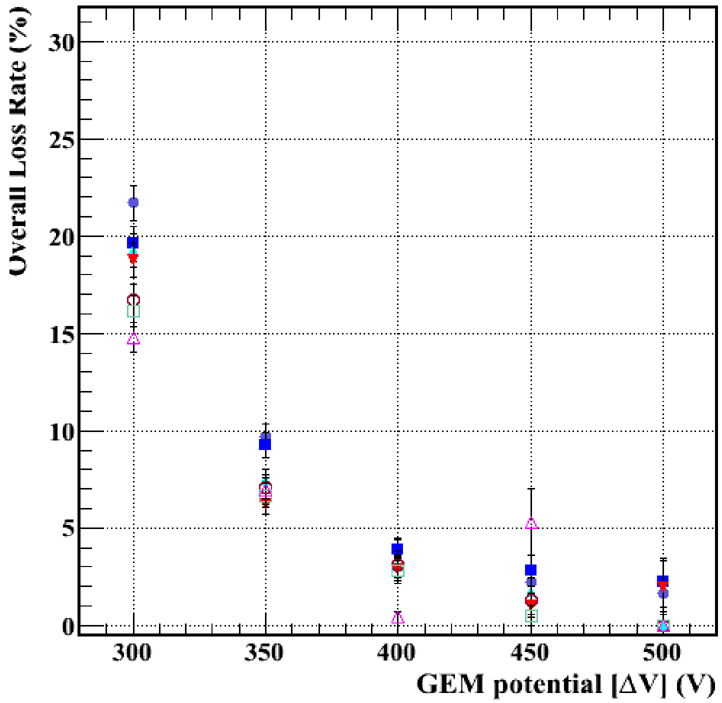


Ar/CO_2

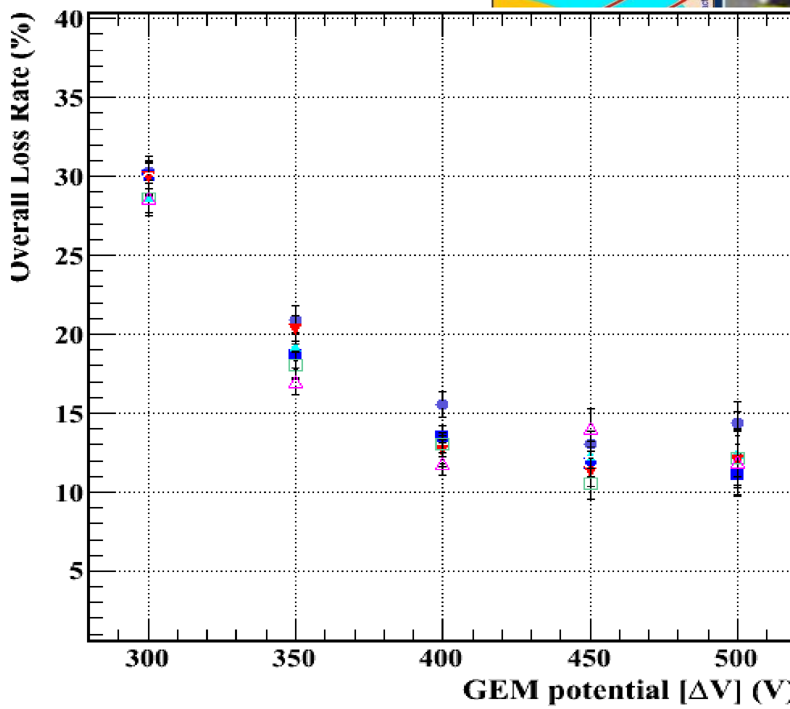
Ar/CO_2/CF_4

Almost the same for both gases, as expected

Geometric Loss rate for primaries



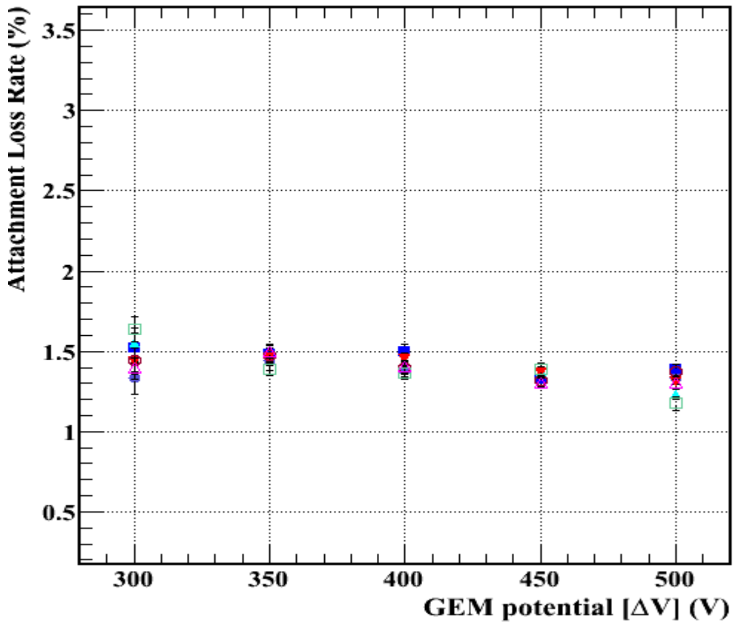
Ar/CO_2

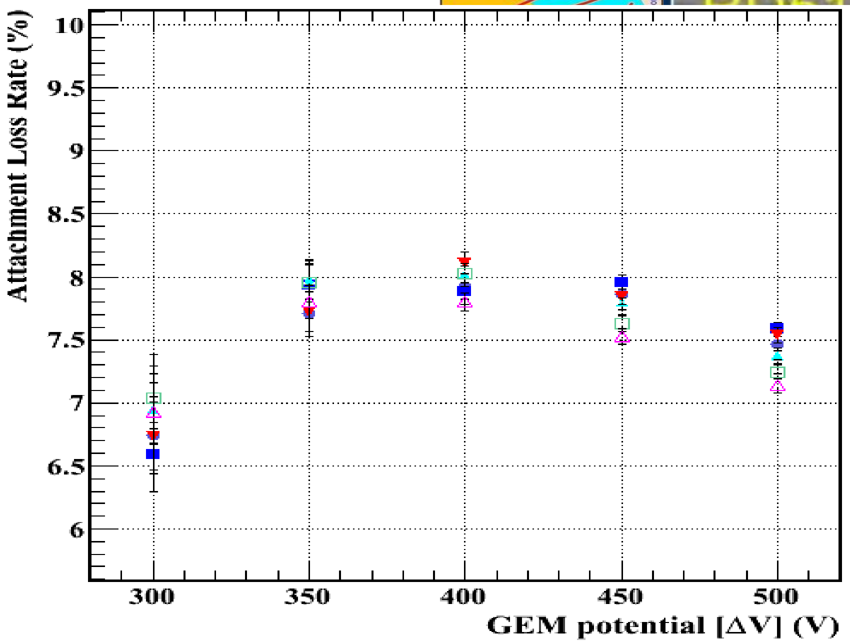


Ar/CO_2/CF_4

As a result, the overall loss rate higher in case of CF_4 mixture.

Overall Loss rate for primaries



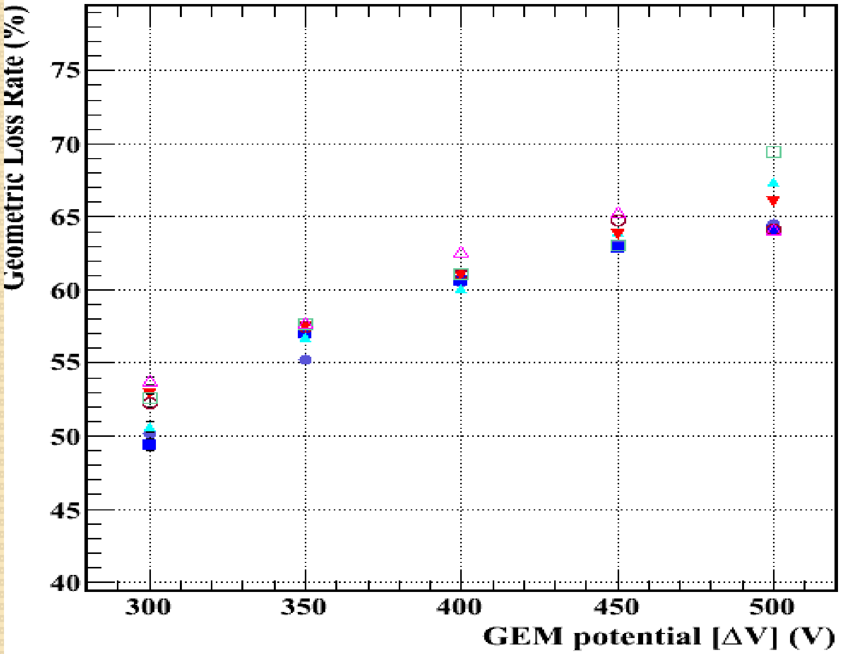


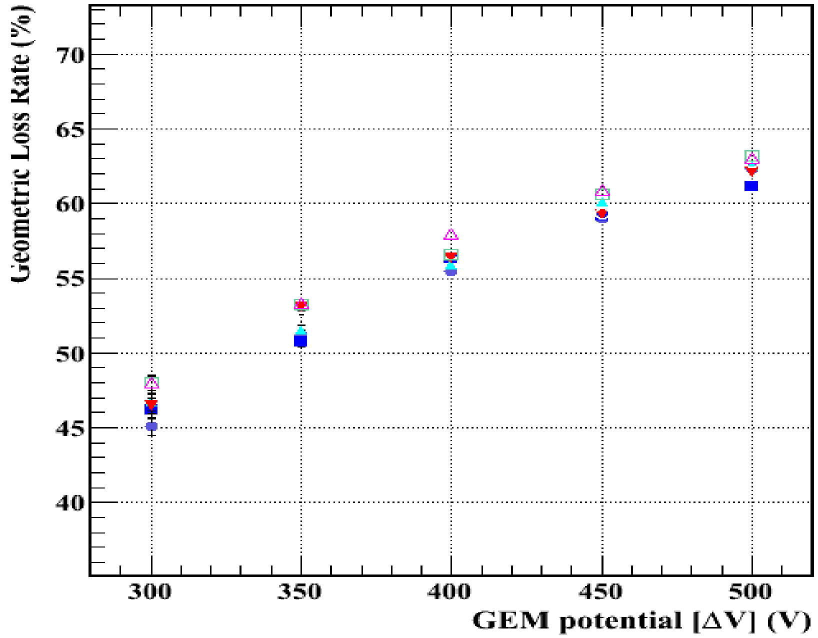
Ar/CO_2

Ar/CO_2/CF_4

Attachment rate for secondary electrons higher in case of CF_4 mixture.

Attachment Loss rate for secondary electrons



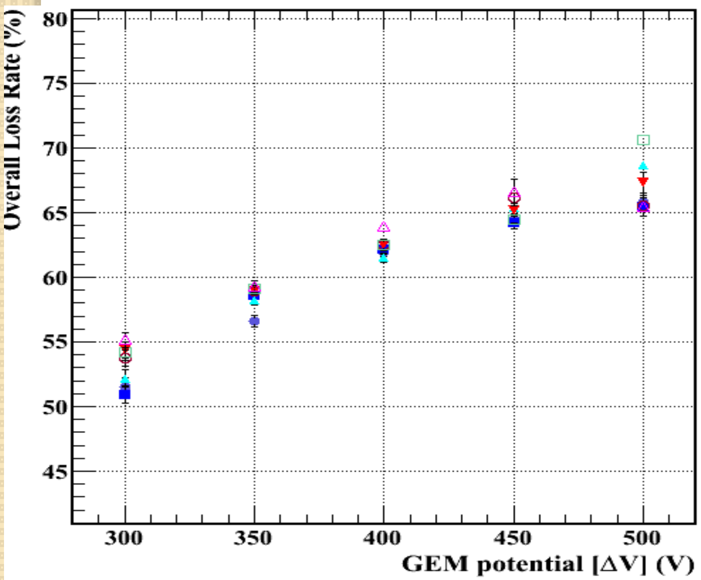


Ar/CO_2

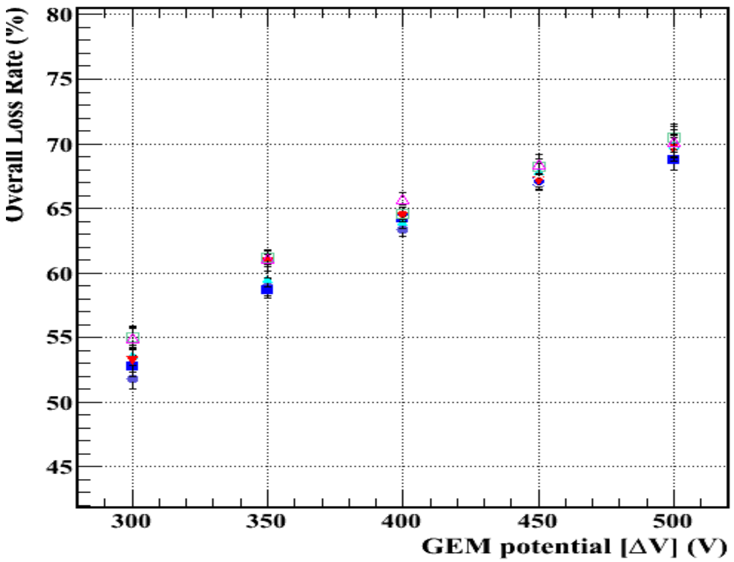
Ar/CO_2/CF_4

However, the geometric loss in case of CO_2 is a bit on a higher side (diffusion)

Geometric Loss rate for secondary electrons



Ar/CO_2

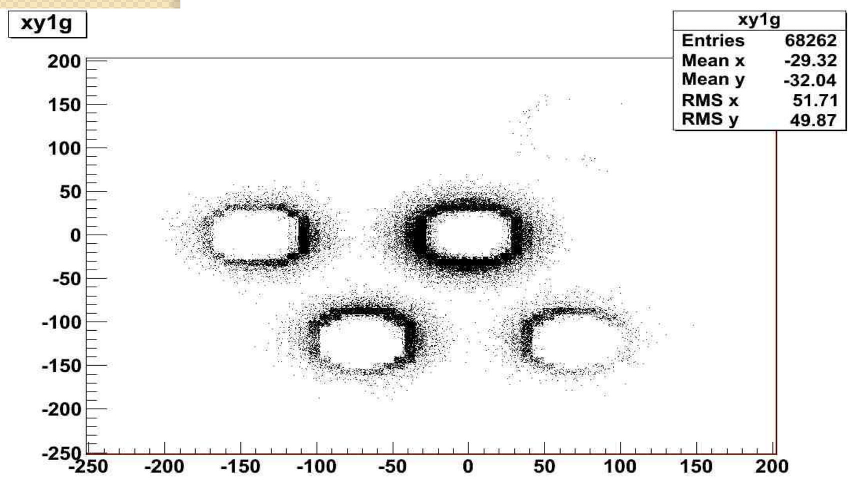


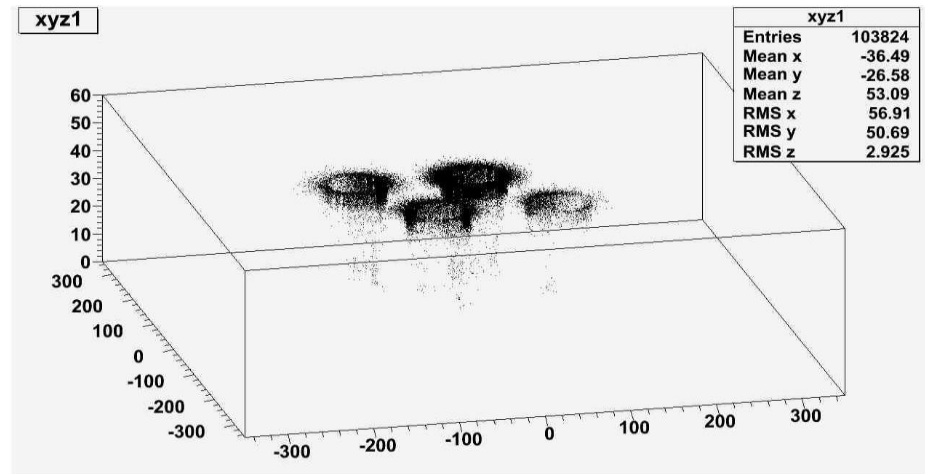
Ar/CO_2/CF_4

Surprisingly, the overall loss rate is quite the same for both the mixtures

Overall Loss rate for secondary electrons

- Plotting the electron endpoints in the gem, gives us a good picture of the geometric loss in gems.



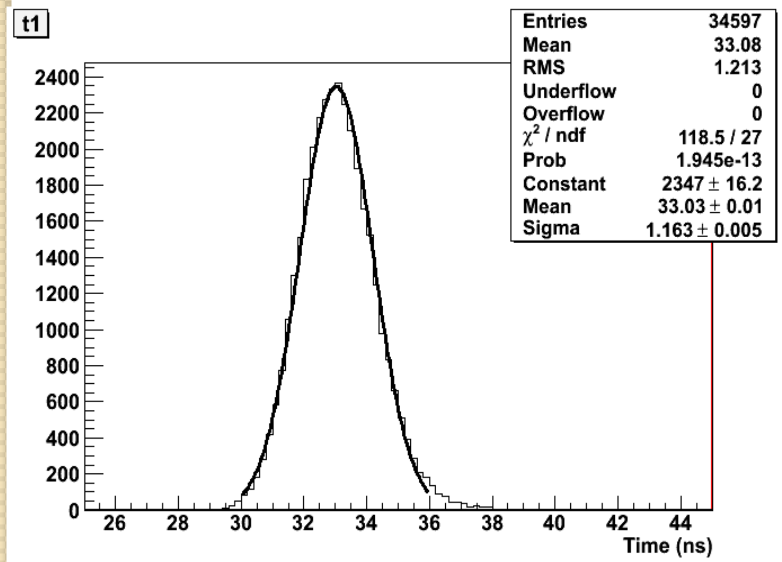


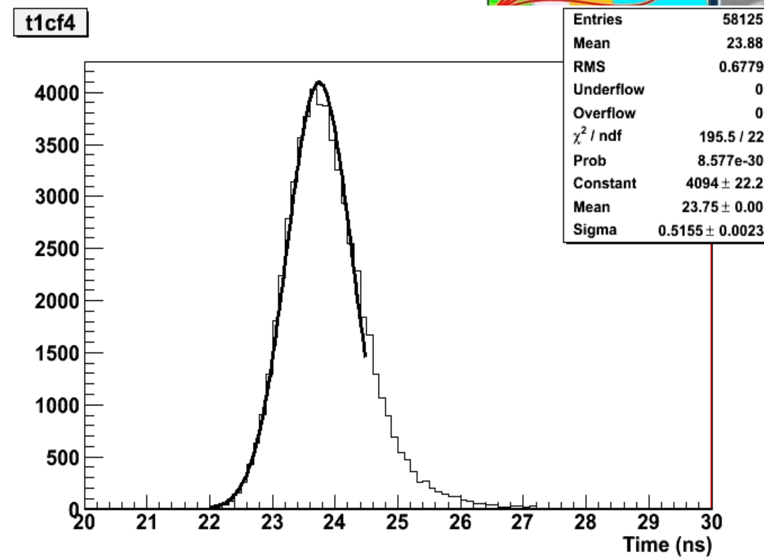
X-Y profile

3-D plot

So how fast?

- Plotting the time taken by the electrons to reach the anode in case of Ar/CO_2 and comparing the result with Ar/CO_2/CF_4 should give an indication.
- We fit it with a Gaussian function to get an estimate of the time resolution !





Ar/CO_2
(~33 ns)

$$\sigma = 1.194$$

$$\sigma = 0.6289$$

Ar/CO_2/CF_4
(~24 ns)

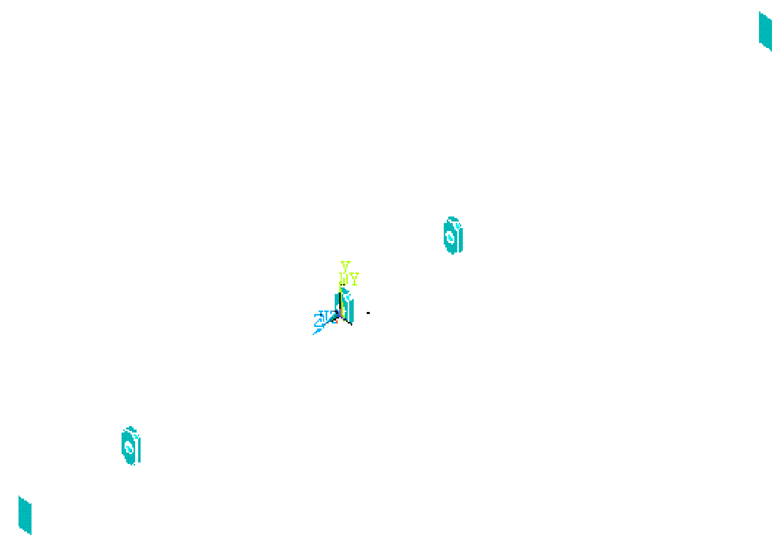
Clearly, The mean of the time taken reveals the fact that CF4 mixture is faster than general CO_2

Clearly, The sigma value shows the resolution to be better in case of CF_4

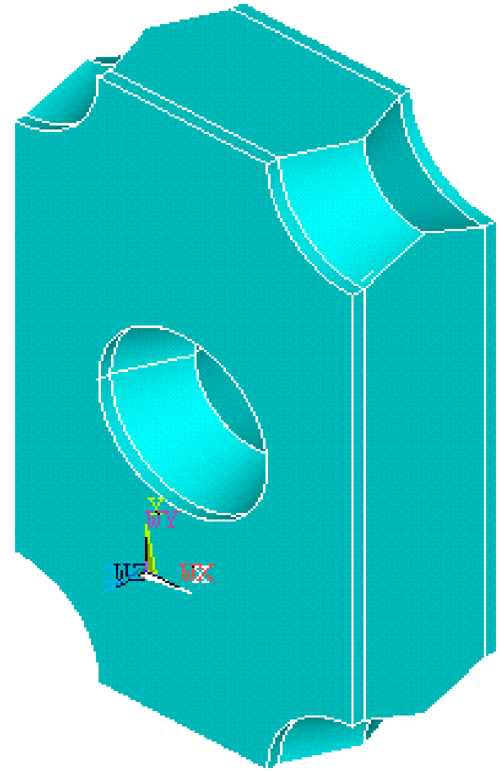
Triple gem

- The gap for the triple gem were :
  - Drift space : 3 mm
  - Transfer-1 space : 1 mm
  - Transfer-2 space : 2 mm
  - Induction space : 1 mm

- The value of the various fields and potentials were taken from the group.
- Gas mixture was Ar(45)/CO_2(15)/CF_4(40)

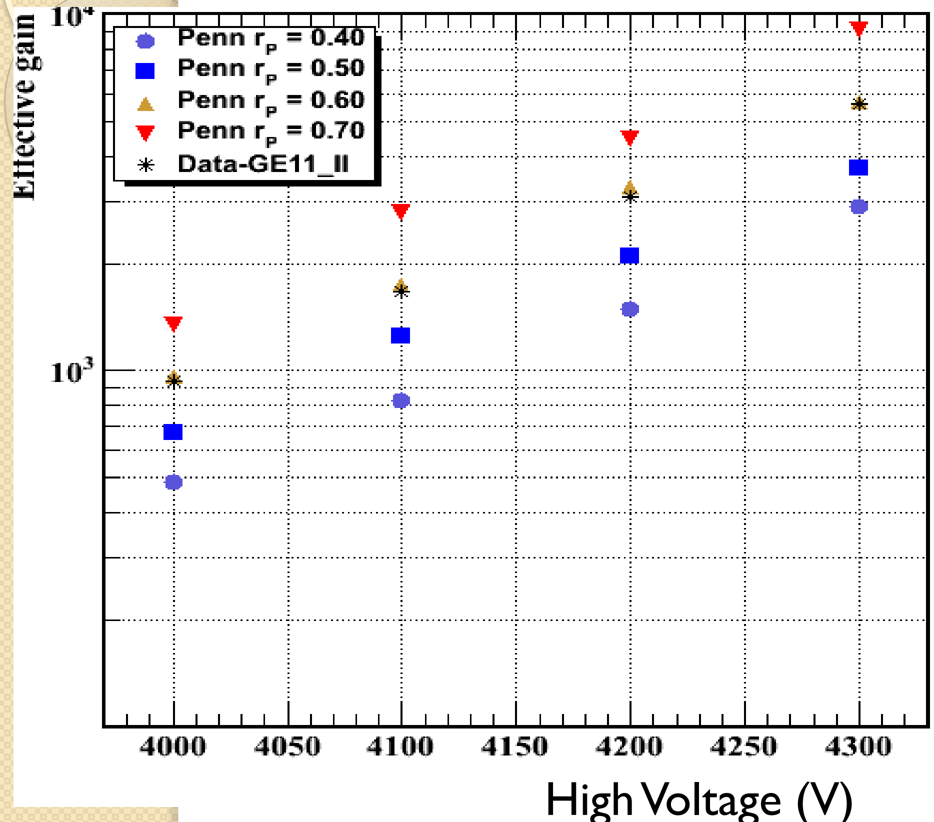


However we divided the triple gem into three separate single gems, and then multiplied the gain in these three single gems to get the total gain

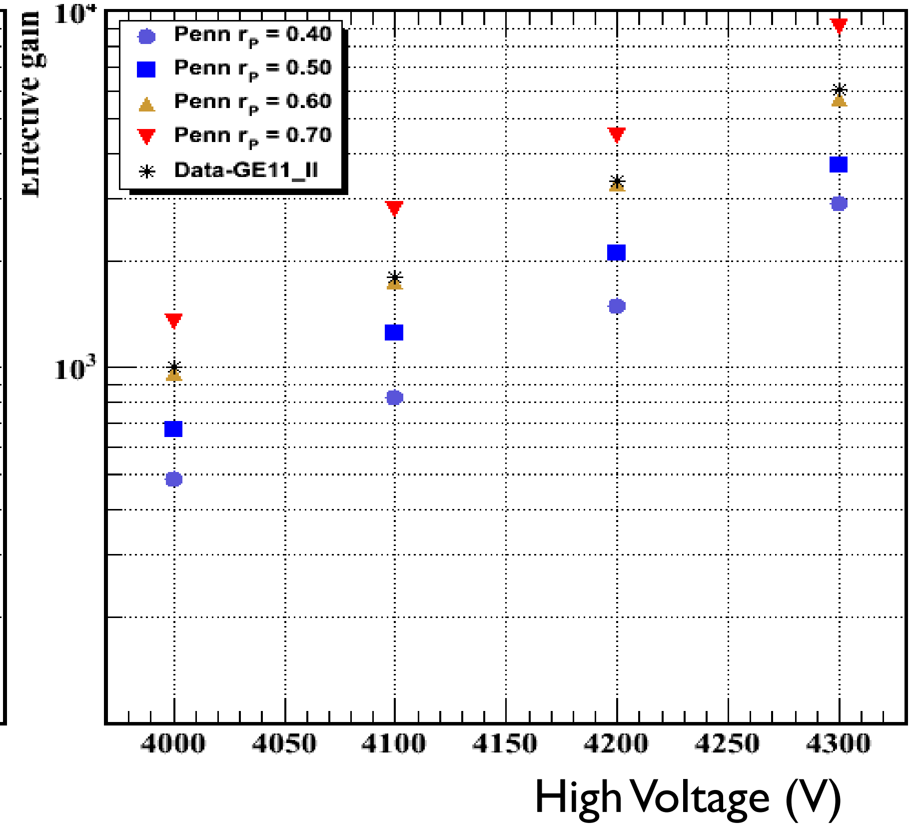


$$G_{\text{Total}} = G_1 \times G_2 \times G_3$$

Triple Gem results



1 layer Cu tape



2 layer Cu tape

- The simulated gain seems to be in good agreement with the experimental gain. (Laura/ Michal/Andrey)

- The simulated gain matches quite well for penning parameter of 0.60.
- The transfer rate is 0.55 for 15 % CO_2 from Ozkan's paper. So we are in good shape ! (No role played by CF_4 in penning transfer)

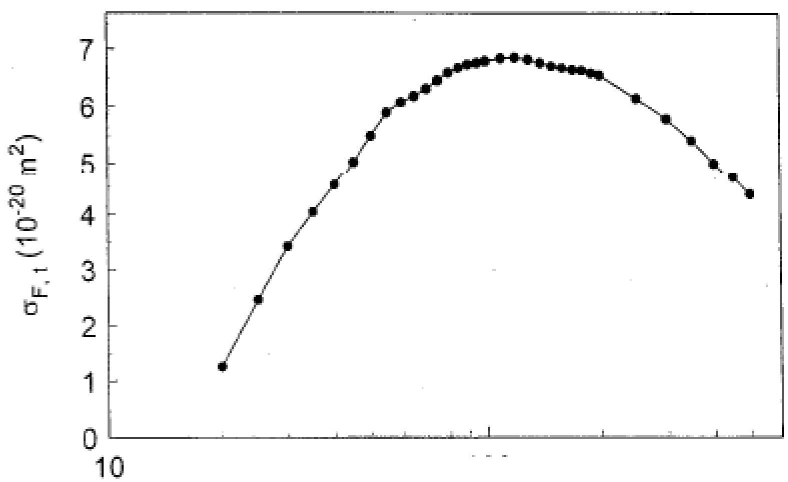
BUT…

- However when we simulate the gain in a triple gem structure, we are off-track !
- As an example, for HV supply of 4200, we get a value of ~ 1000 which is less compared to the experimental value of ~3000.
- Hopefully, we will get it sorted out !

Dangers of Using CF_4

- CF_4 is an active source of reactive neutral and ionic fragment atoms and molecules (especially neutral **F** atoms)
- Neutral F atoms are active species in etching process.
- Hopefully they don't eat the detector !

Cross-section for production of fluorine on impact of electron with CF_4



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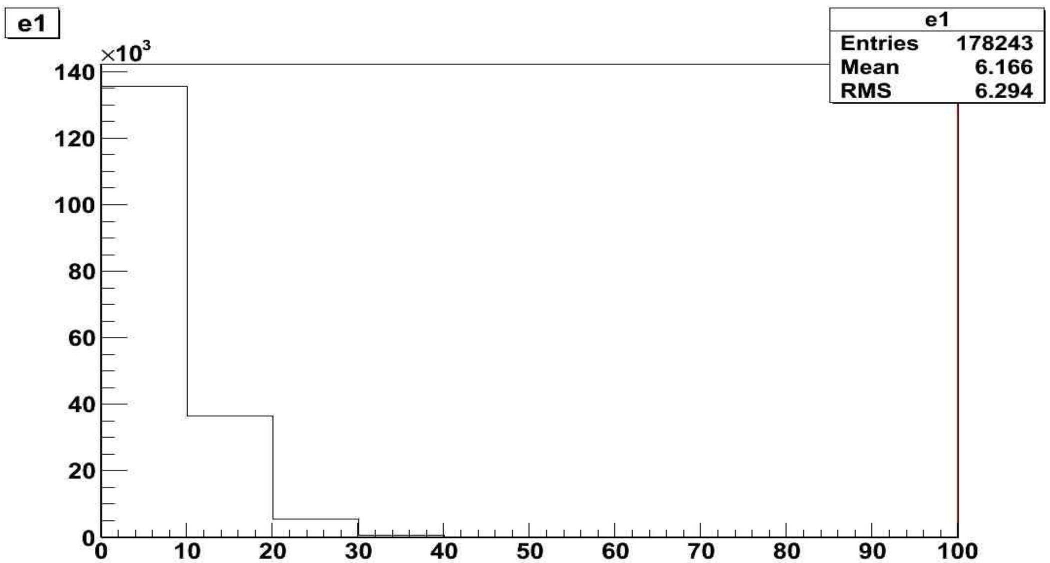
However …



Mean energies of ~ 6 eV.

Electron energy (in eV) ⟶

A fact which ageing studies on gems operated with CF_4 have shown

Claims that the Detector will work for 10 years

The electrons are not reaching that high energies in the Ar/CO_2/CF_4 Mixture in Gem detectors sufficient to Produce enough fluorine to damage the detector that fast !

Thank you

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