Simulation Study of Space-Charge and IBF

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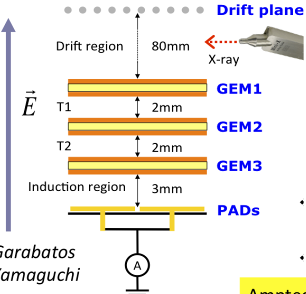
February 12, 2013

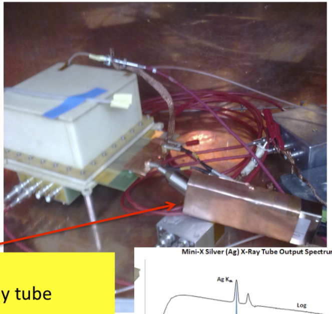
IBF Measurements at CERN

- Systematic measurements at RD51 lab. in CERN.
  - Field dependence (ΔV_{GEM}, T1, T2, Induction)
  - Rate, x-ray position dependence (charge current density)



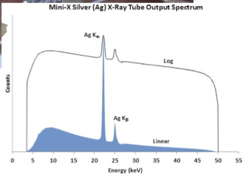
C. Garabatos
Y. Yamaguchi

- ❖ Currents at readout pads & drift plane are measured.
- ❖ The current of primary ions is measured with only HV ON for drift plane.
  - ✓ Gain = $I_{pad}/I_{prim.ion}$
- ❖ Always E_{drift} = 400V/cm



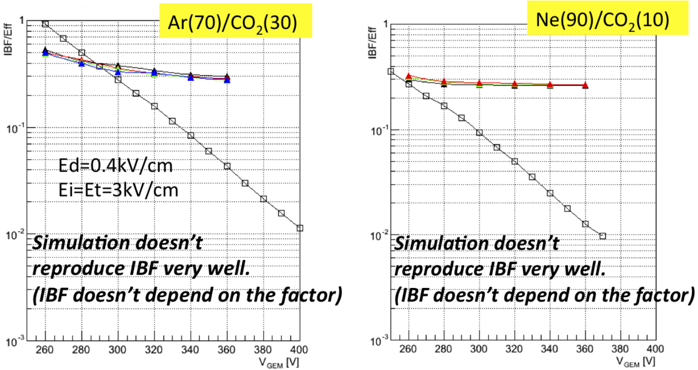
Ampteck
Mini X-ray tube

Ag target: Kα=22KeV
Rate (Ar(70)/CO2(30))
= 5e7 estimated by I_d



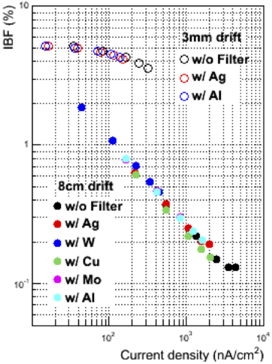
First comparison of IBF between real and simulations

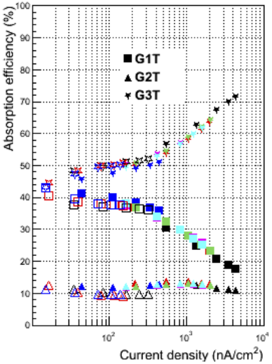
- Simulation (Penning factor) is tuned to reproduce the gain.
- However, IBF in simulation doesn't agree with the measurements.
- Strong dependence on V_{GEM} in the measurements

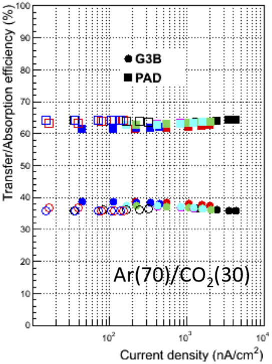


More results from the measurements

- Rate, Energy (target), drift-space (3 mm or 80 mm) dependence
- Clear rate and drift-space dependence of IBF.
- Indicating space-charge effect ($\propto$ rate$\times$gain$\times$seed) to IBF...

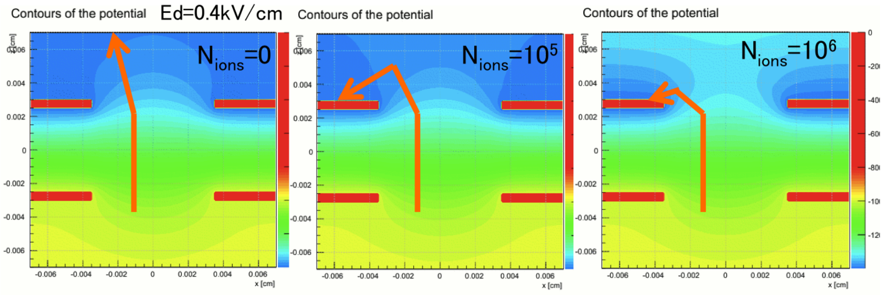






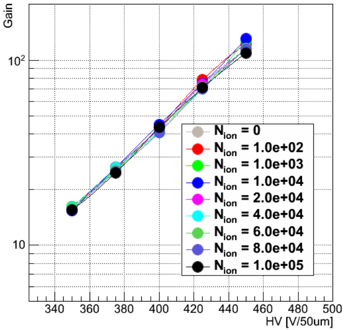
Space-charge simulations: Method

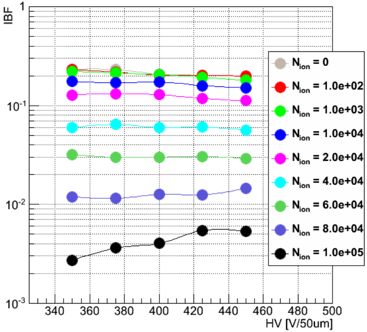
- Slice the space in drift direction by 100 μm
- Uniformly distribute ions in space $z \in [Z, Z + 100\mu\mathrm{m}]$
- Calculate the field by ANSYS and evaluate gain/IBF by Garfield++
- Example of the field around GEM1 with N_{ions}=0, 10^5, 10^6 with E_{drift}=0.4kV/cm. less IBF with huge N_{ions}?



Space-charge above GEM1

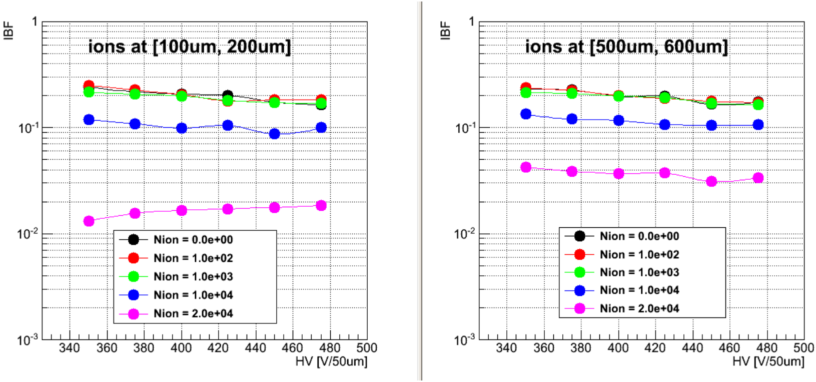
- Ions at $z \in [0, 100\ \mu\mathrm{m}]$ above GEM1. $E_{drift} = 0.4$kV/cm. Ar/CO_2=(70/30). N_{ions}: from 0 to 10^5
- Gain doesn't change. Onset of decrease of IBF around $N_{ions} \sim 10^4$
- For $N_{ions} \geq 10^4$, IBF gets much smaller with more N_{ions}.





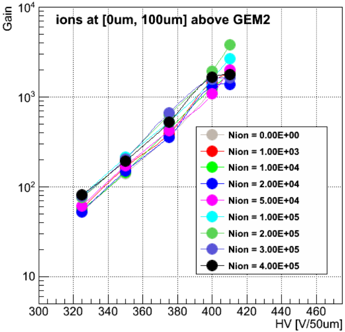
Space-charge above GEM1

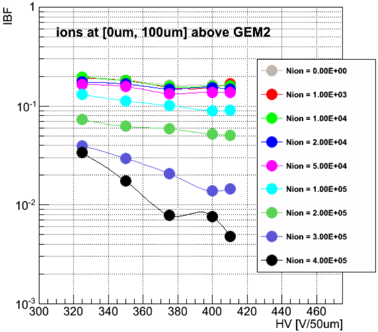
- Ions at $z \in [100, 200\ \mu\mathrm{m}]$ (left) and $z \in [500, 600\ \mu\mathrm{m}]$ (right) above GEM1. N_{ions}: from 0 to 2×10^4
- For $N_{ions} \geq 10^4$, IBF gets smaller ($\times10$) with more N_{ions}.
- N_{ions} cannot be 4×10^4. In this case, the field is reverted (no electrons going into GEM).



Space-charge above GEM2

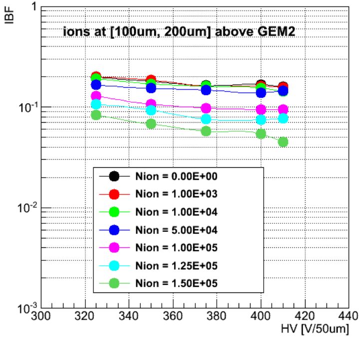
- Ions at $z \in [0, 100\ \mu\mathrm{m}]$ above GEM2. $E_{drift} = 0.4$kV/cm, E_{T1}=3.5kV/cm, T1=2mm, N_{ions}: from 0 to 4×10^5
- Gain changes by 2. (due to the improvement of electron collection? Ions lead to higher potential around.)
- Onset of decrease of IBF around $N_{ions} \sim 5\times10^4$. Onset depends on underlying field.

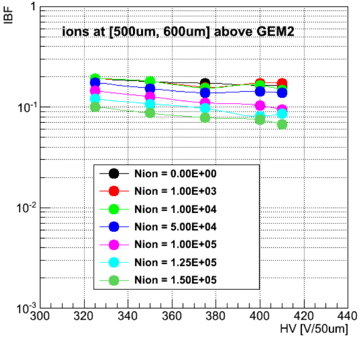




Space-charge above GEM2

- Ions at $z \in [100, 200\ \mu\mathrm{m}]$ and $z \in [500, 600\ \mu\mathrm{m}]$ above GEM2. N_{ions}: from 0 to 1.5×10^5
- IBF changes for $N_{ions} \geq 5\times10^4$. Onset depends on underlying field.
- N_{ions} cannot be 4×10^5. The field is reverted (no electrons going into GEM).

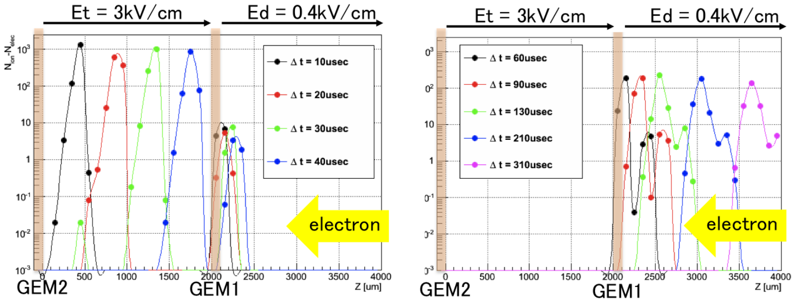




A little more dynamical simulations

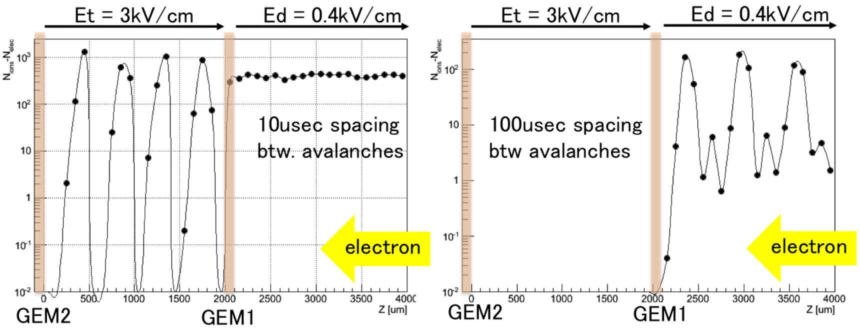
- Look at the spacial ion profile along drift direction for each 10μsec after avalanche.
  - Ion profile from 10μsec to 40 μsec (left) and from 60μsec to 300μsec (right) after the avalanche (at the gain of 10000)
  - Ions are swept sway from T1 quickly (3kV/cm) and stays above GEM1 due to low field (0.4kV/cm)
- No transverse profile is taken into account.

Ion profile per one seed (Ar/CO2=70/30, Gain~1000)



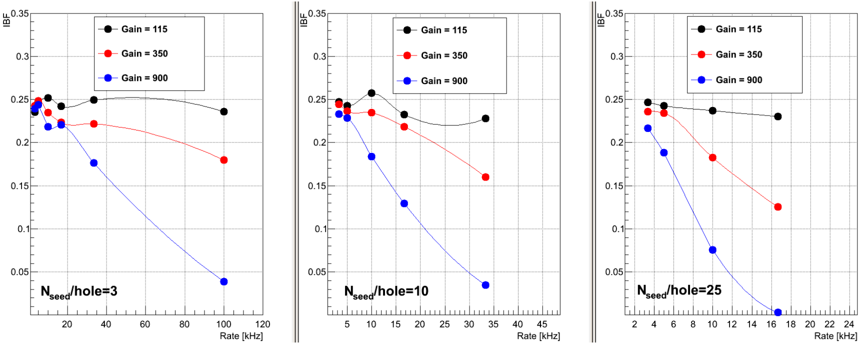
Ion Profile

- Summed up the ion profile at each time step and make ion profile corresponding for various rate.
  - If rate/hole = 100kHz, ion profiles for each 10μsec are summed up.
  - Ion profile under 100kHz (left) and 10kHz (right) avalanches at the gain =1000 and the number of seeds/hole (N_{seed})=1
- Scale this profile according to gain and N_{seed}



Ion Back Flow vs. Rate/Seed

- IBF vs. Rate and $N_{seed} = (3, 10, 25)$ at Gain = 115, 350, 900
- Clear rate dependence and dependence is much larger for higher gain
- IBF gets smaller with higher rate and high gain
  - Rate at CERN $\sim$ 25kHz. N_{seed} = 20-40. Gain $\sim$ 2000
  - Large effect of space-charge to IBF
- More dynamical and iterative simulations will be done!!

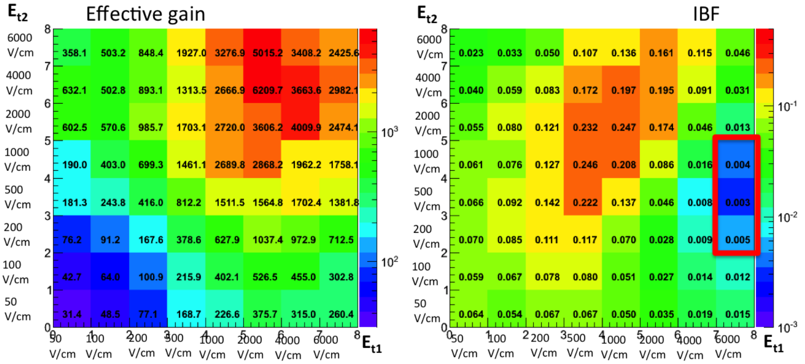


IBF studies with various configurations

- Motivation
  - To search for the optimal solutions for the suppression of IBF
  - For example, 0.25% of IBF at gain=2000 (ALICE GEM-TPC upgrade)
- What have been studied so far.
  - 3 GEM configurations under Ar/CO_2 and Ne/CO_2(/N_2)
  - 4 GEM configurations under Ne/CO_2(/N_2)
  - Hole Alignment Dependence
  - Conical GEMs
  - Extoic GEMs (Flower-GEM, COBRA-GEM)

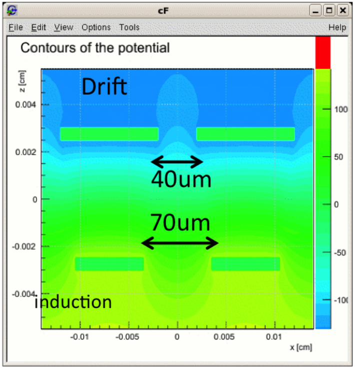
3 GEM configurations

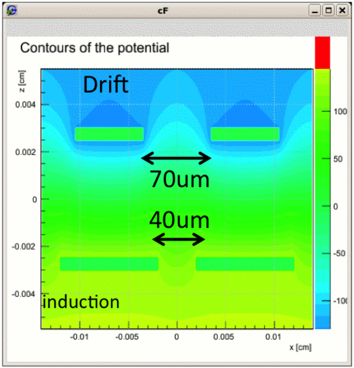
- 3 GEM configurations. Ar/CO_2=(70/30)
- GEM2 is mis-aligned with respect to GEM1 and GEM3.
- $V_{GEM1} = 260$, $V_{GEM2} = 360$, $V_{GEM3} = 460$
- 0.3-0.5% of IBF with high $E_{T1\ (GEM1-GEM2)} \sim$ 6kV/cm and low $E_{T2\ (GEM2-GEM3)} \sim$ 0.5kV/cm.



Conical GEMs

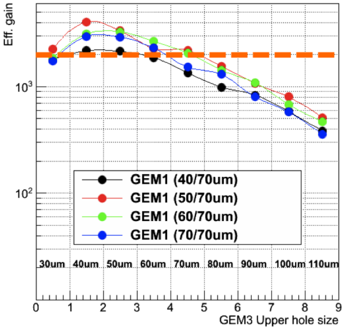
- Conical GEMs (different hole size on upper and bottom electrode)
- Left: Field of GEM1 in case Narrow(N)→Wide(W)
- Right: Field of GEM1 in case Wide(W)→Narrow(N)
- N→W is promissing. Better extraction of electrons and IBF.

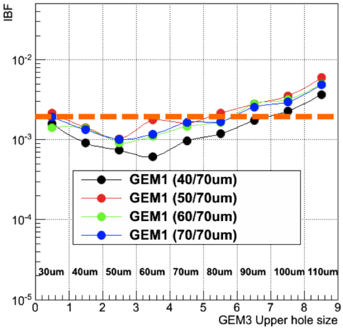




IBF with Conical GEMs

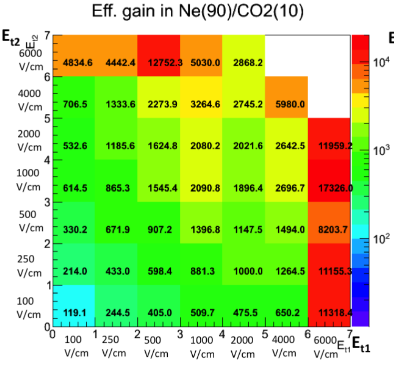
- IBF with conical GEMs with different hole size
  - $E_{T1} = 6\text{kV/cm}$, $E_{T2} = 0.5\text{kV/cm}$. Ar/CO_2=(70/30). GEM2 is mis-aligned.
  - GEM1 upper hole size: 40-70μm. bottom hole size: 70μm
  - GEM3 upper hole size: 30-100μm. bottom hole size: 70μm
- $\times$2-3 improvement of IBF with 40μm/70μm GEM1 and 40-70μm/70μm GEM3.

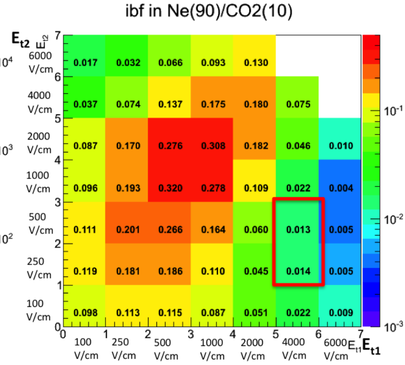




3 GEM configurations in Ne/CO_2

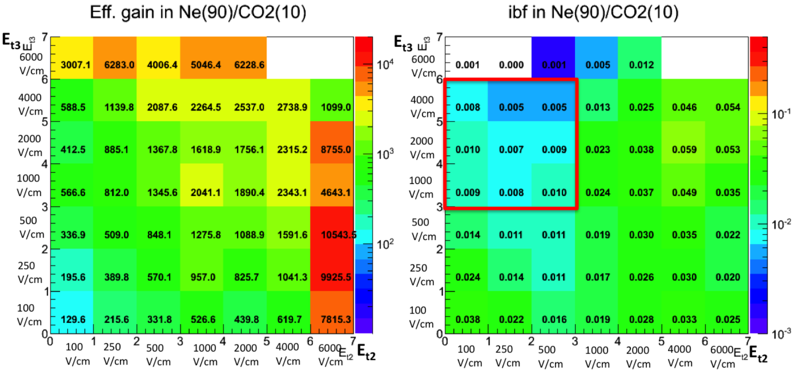
- 3 GEMs under Ne/CO_2=(90/10). GEM2 is mis-aligned.
- E_{T1} cannot go higher than 4kV/cm.
  - Townsend: $\sim$ 14/cm at 6kV/cm. $\times$7 gain in 2mm.
  - Adding N_2? 14/cm$\rightarrow$4/cm at 6kV/cm with 5% N_2
- 1-2% of IBF with $E_{T1} \sim$ 4kV/cm and $E_{T2} \sim$ 0.5kV/cm.





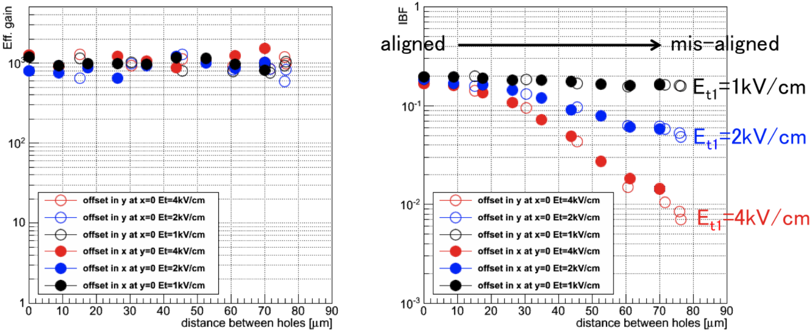
4 GEM configurations in Ne/CO_2

- 4 GEM configuration under Ne/CO_2. E_{T1}=4kV/cm
- GEM2 and GEM4 are mis-aligned.
- E_{T2} and E_{T3} scan.
- $\times$2-3 improvement with 4 GEM configurations. 0.5% of IBF can be achievable with low E_{T2} and high E_{T3}.



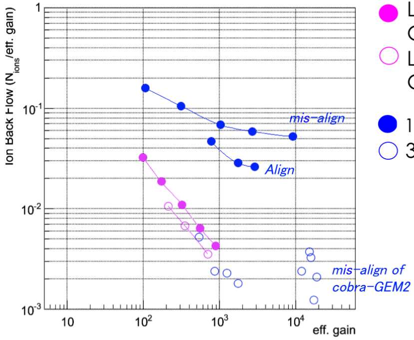
Hole Alignment

- IBF with 3 GEMs. Ne/CO_2=(90/10).
- IBF vs. hole distance between GEM1 and GEM2.
- Strong alignment dependence ($\times$10) for E_{T1} $\geq$2-4 kV/cm.
- No alignment dependence for E_{T1} $\sim$1 kV/cm. But IBF is worse.

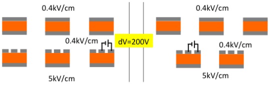


Exotic GEMs

- IBF simulations with Flower-GEM and COBRA-GEM
- 0.2% of IBF is achievable with Flower-GEM and 3 COBRA-GEMs
  - Need to control geometry for the Flower GEM
  - Less sensitive to the COBRA-GEM for the alignment.



- Large pitch GEM1 + standard GEM2 (Flower GEM structure)
- Large pitch GEM1 + standard GEM2 & GEM3
- 1 STD GEM + 1 cobra GEM
- 3 layers of cobra GEMs



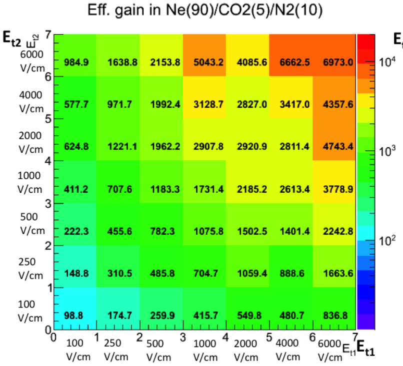
Next Steps

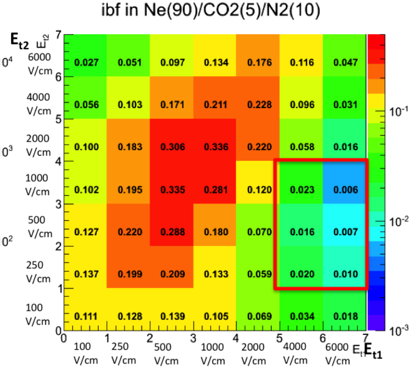
- More dynamical simulations for space-charge effects.
- Search for the optimal solutions for IBF
  - Combination of GEMs with different pitch, hole size, and hole shape (conical)
    - For example, opaque and conical GEM for GEM1 (high E_{T1}).
    - We have to rely on the ramdom alignment.
    - Need to check uniformity of gain and IBF.

Backup Slides

3 GEM configurations adding N_2

- 3 GEMs under $Ne/CO_2/N_2$=(90/5/10). GEM2 is mis-aligned.
- Townsend: $\sim$ 2/cm at 6kV/cm. $\times$1.3 gain in 2mm.
- 0.5% - 2% of IBF with $E_{T1} \sim$ 4-6kV/cm and $E_{T2} \sim$ 0.5kV/cm.





4 GEM configurations adding N_2

- 4 GEMs under $Ne/CO_2/N_2$=(90/5/10). GEM2 and GEM4 is mis-aligned. E_{T1}=4kV/cm
- 0.3% - 1% of IBF with $E_{T1} \sim$ 4-6kV/cm and $E_{T2} \sim$ 0.5kV/cm.
- ×2-3 improvement with 4 GEMs