RPC as an Active Medium for a Digital HCAL

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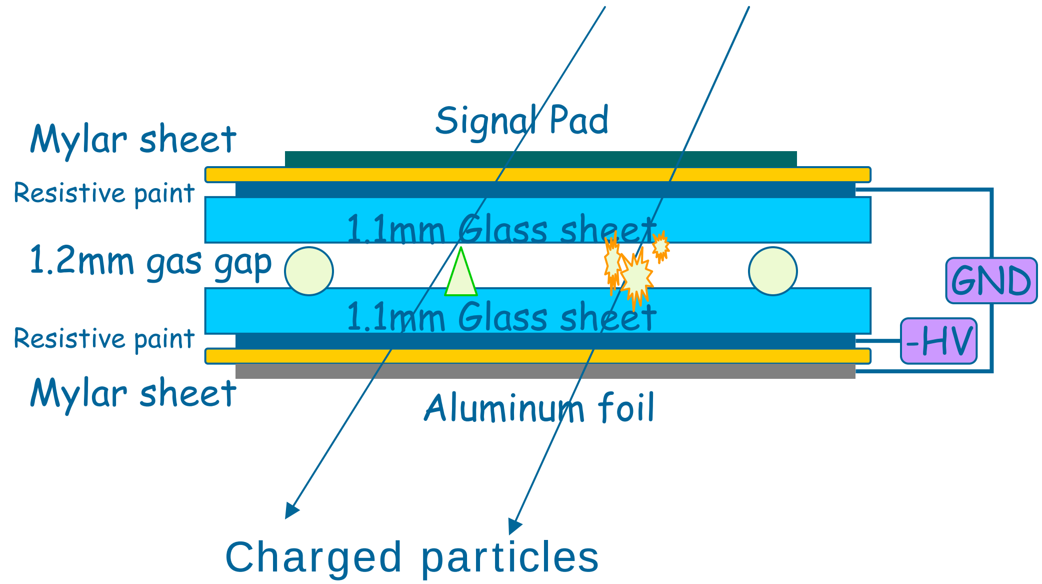
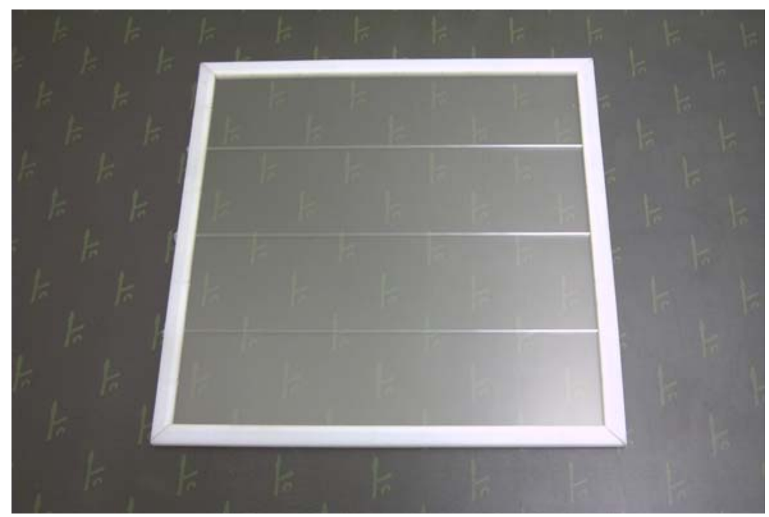
- Introduction
- RPC signal properties and efficiency
- Multiple signal pads and digital readout
- RPC rate capability
- Other studies
- Summary

Introduction: what is RPC

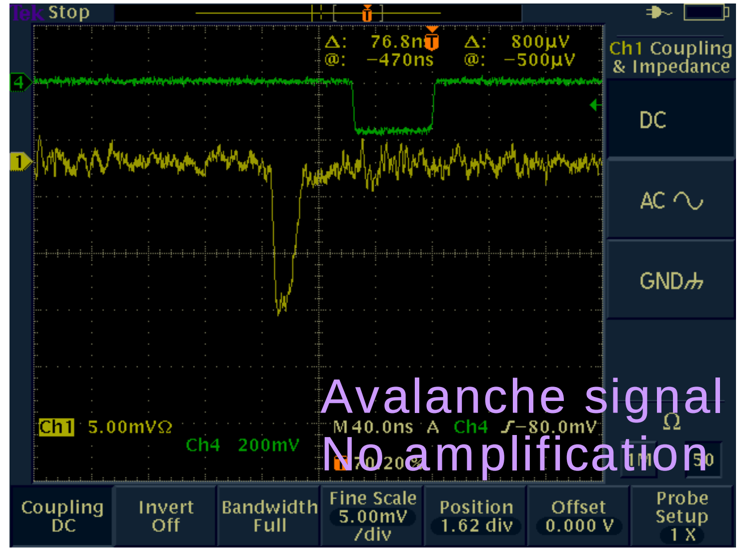
- Glass
  - Normal floating glass
- Resistive paint
  - Graphite or conductive ink
  - Spray or silk screen printing
  - Controlled resistivity (0.1 – 10 MΩ/❑)
- Spacer
  - Fishing line
- RPC is simple and reliable
  - No aging effect has ever been observed for glass RPC
  - Easy to construct, low cost
  - High efficiency and good position resolution – perfect for a DHCAL
- So far, built over 10 RPCs at Argonne
  - 1 gap / 2gaps
  - Paint resistivity
  - Chamber configuration
  - Chamber size

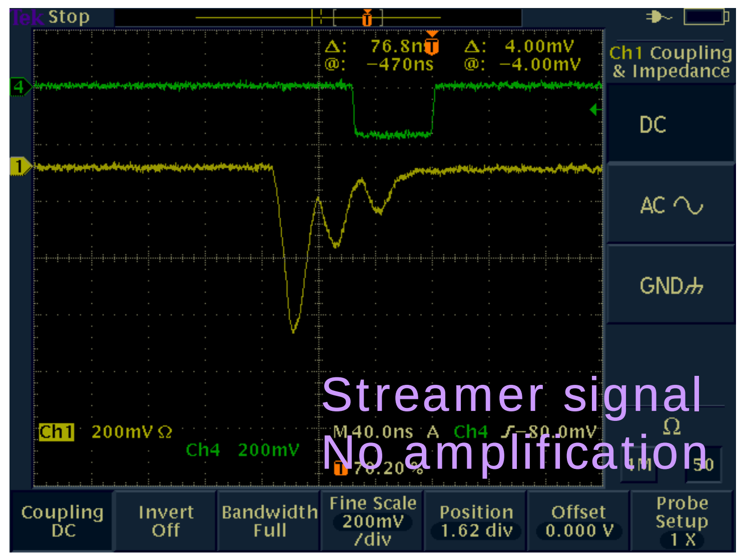




RPC signal: avalanche and streamer

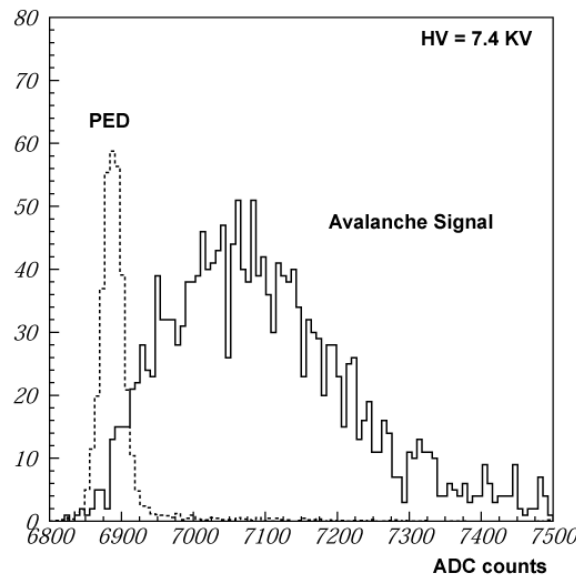
- Gas mixture
  - R134A:IsoButane:SF6
  - (Ar:R134A:Isobutane)
- Typical operating voltage:
  - 7 - 10 KV
- Two types of signal
  - Avalanche
    - 2 – 10+ mV, without amplifier
    - Fast rising time
    - Signal width ~ 20ns
  - Streamer
    - > 100 mV, without amplifier
    - Signal width 40 – 100+ ns
    - Multiple (N) streamers per particle passing is normal
      - ✓ N = 1 - 3

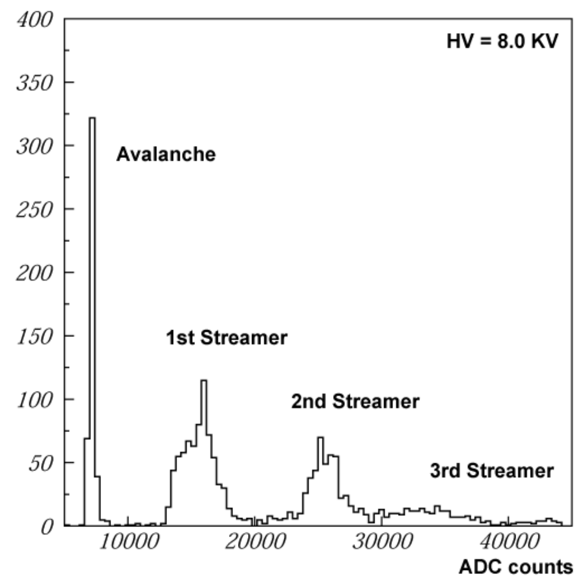




RPC signal: charge distribution

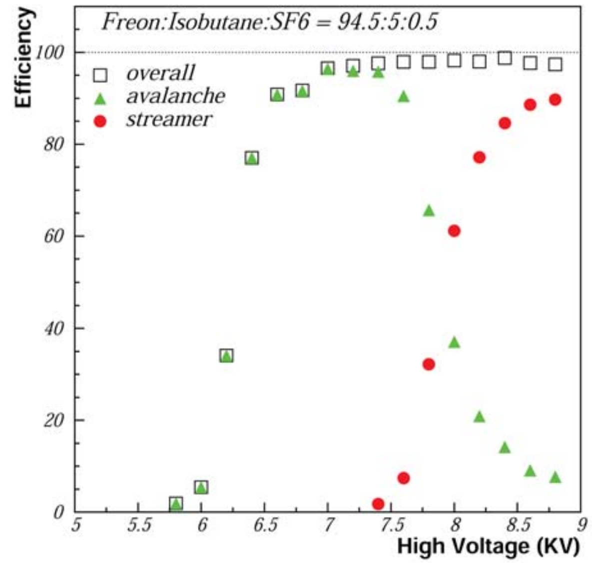
- Signal charge for cosmic ray, measure by charge integration amplifier
  - Avalanche
    - Landau shape distribution, average 0.2 – 10+ pc
    - High efficiency (>95%), low noise
    - Avalanche has small lateral size
    - Higher rate capability
      - ✓ ~ 100 Hz/cm^2
  - Streamer
    - Charge distribution has multiple peaks, due to multiple streamers, average 20 – 100+ pc
    - Always have some avalanche component
    - Good efficiency (~90%)
    - Streamer has larger lateral size
    - Lower rate capability
      - ✓ <10 Hz/cm^2

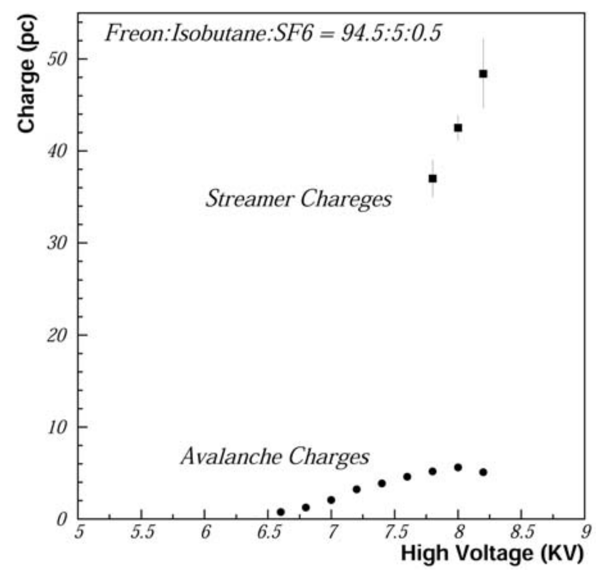




RPC signal: efficiency

- Signal charge and efficiency is a function of operating voltage
  - At low voltage: avalanche plateau (6.6 – 7.4 KV in plot)
    - Almost pure avalanche signal
    - Efficiency > 95%
    - Streamer component < 3%
    - Avalanche charge shows "threshold", and a linear increase
  - At higher voltage: streamer region
  - Avalanche mode is our preferred running mode
- For a DHCAL, small signal pads (~ 1 x 1 cm^2) are needed
  - Digital readout
  - Cross-talk / charge sharing between pads
  - Noise rate





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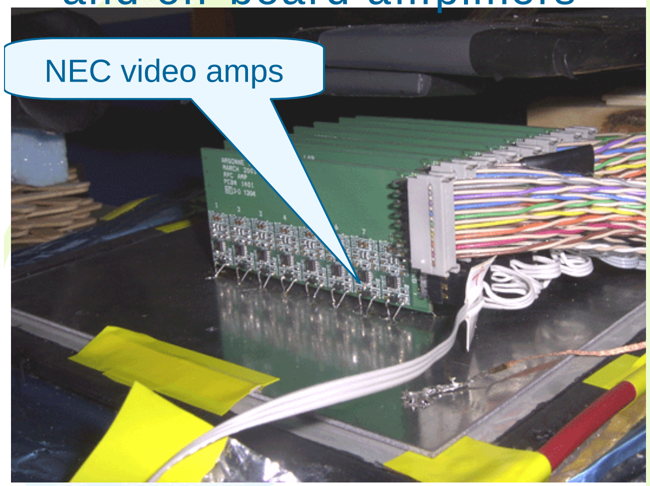
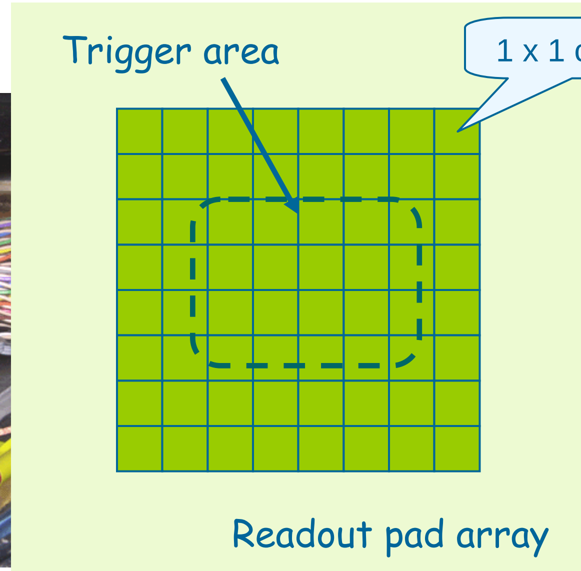
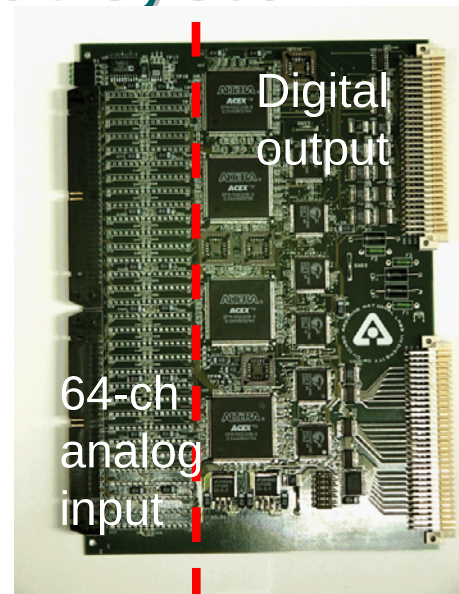
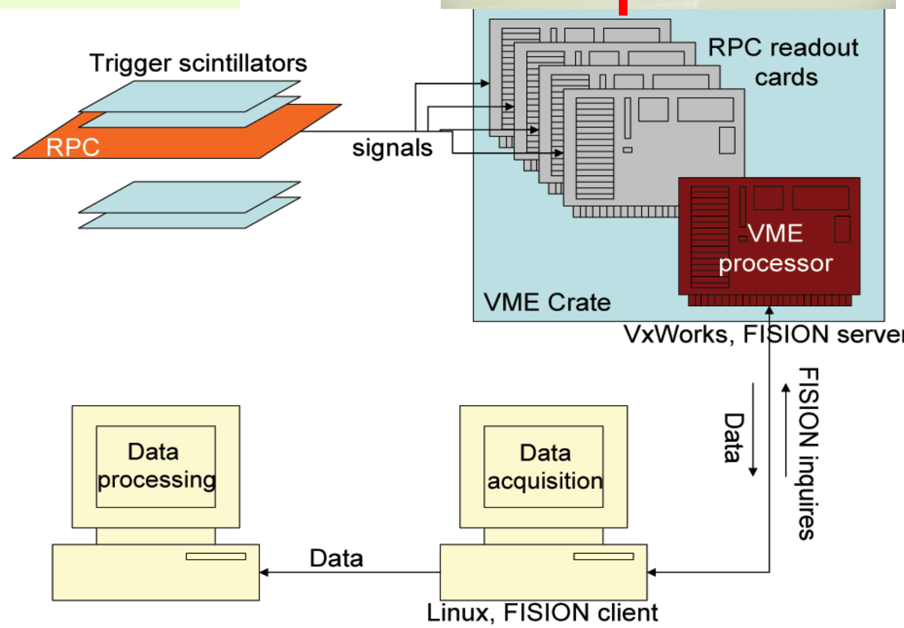
RPC multi-pad test: digital readout system

RPC with multi-pad
and on-board amplifiers





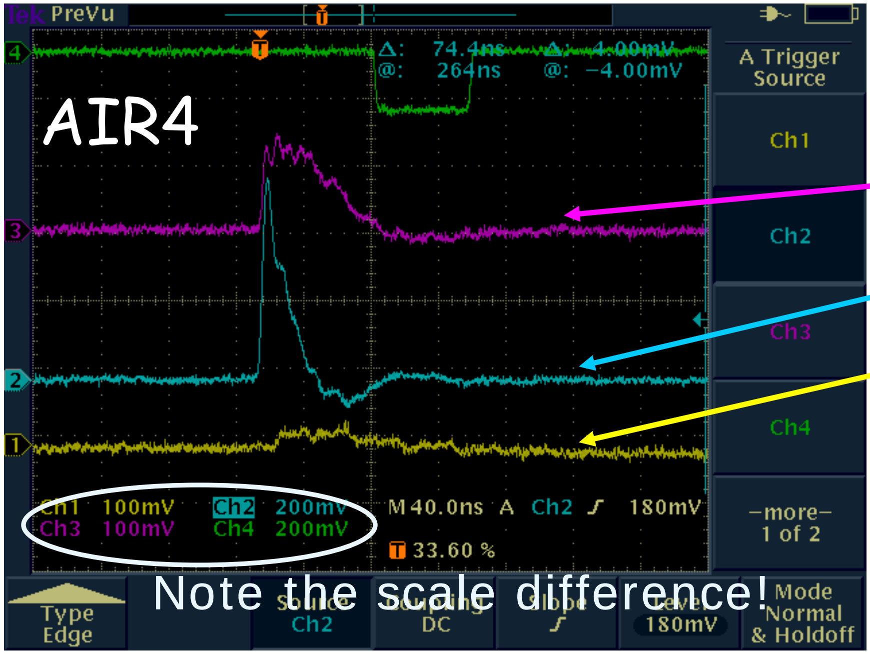


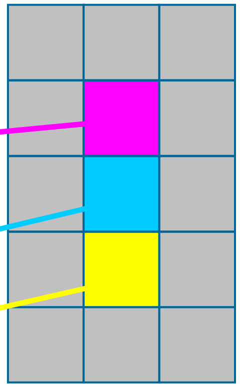


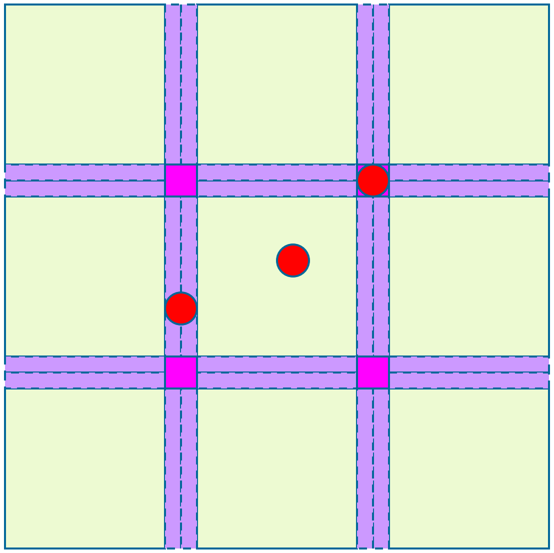
VME readout system

handles 64 channels
Programmable threshold
provides time stamp and hit pattern
100 ns time resolution
self-triggered readout

Multiple signal pads: charge sharing



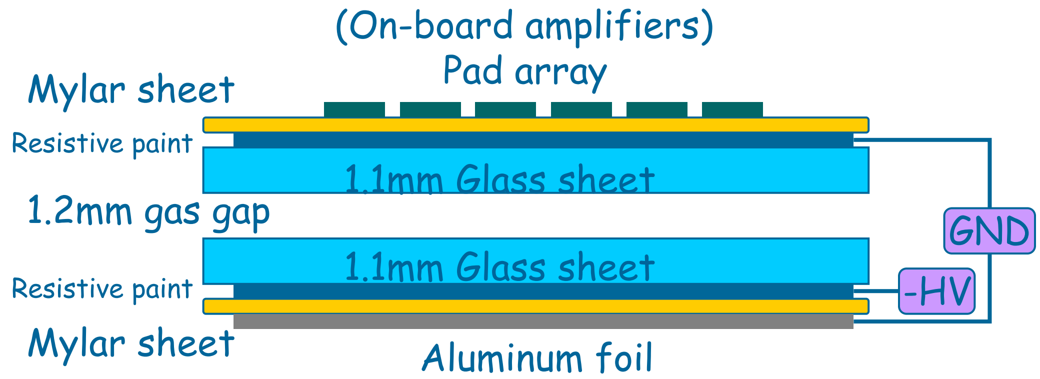


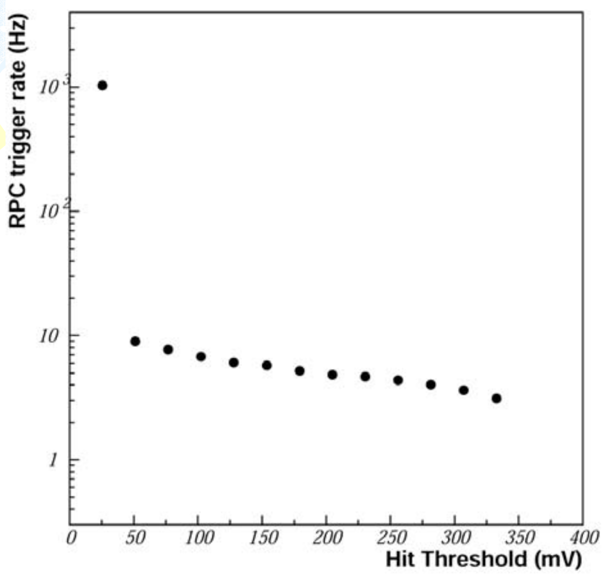


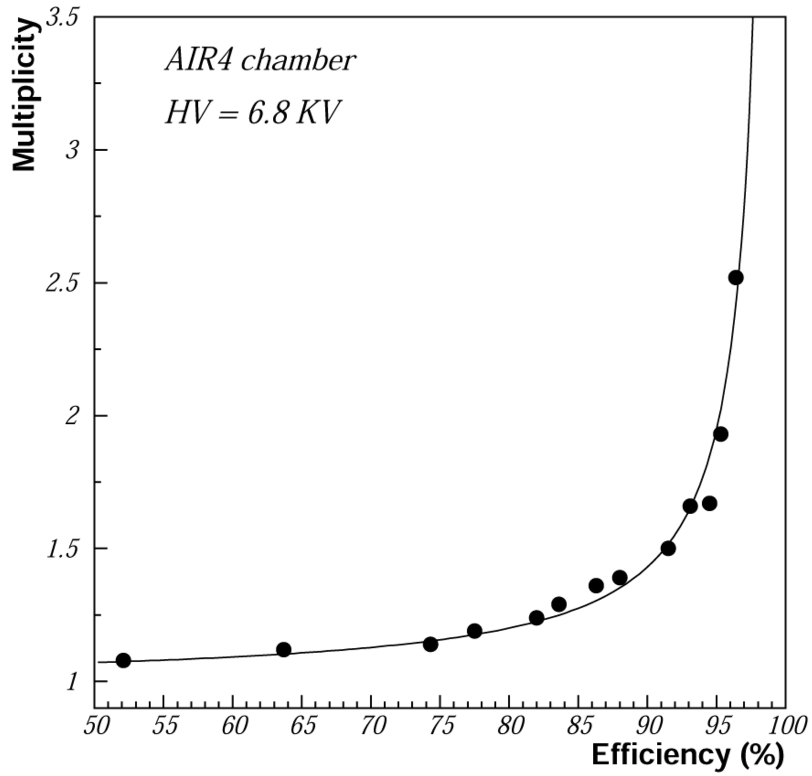
- Avalanche signal has a finite lateral size (~ gap size)
- Charge sharing will occur when a particle passes near pad boundary
- It can be understood with 'black disk' model of charge distribution, with effective radius R(Thr)
  - Charge can share between 2 – 4 pads
  - Hit multiplicity measurement -> R (~1 mm)

Hit multiplicity: standard chamber

- AIR4: standard RPC
  - 1.2 mm single gap
  - 1.1 mm glass sheet
  - 1 MΩ/❑
- Operate at 6.8KV, ~5pc
  - For eff = 95%, M = 1.6 – 1.7
  - For eff = 90%, M = 1.4 – 1.5
- Noise rate ~0.2 Hz/cm^2







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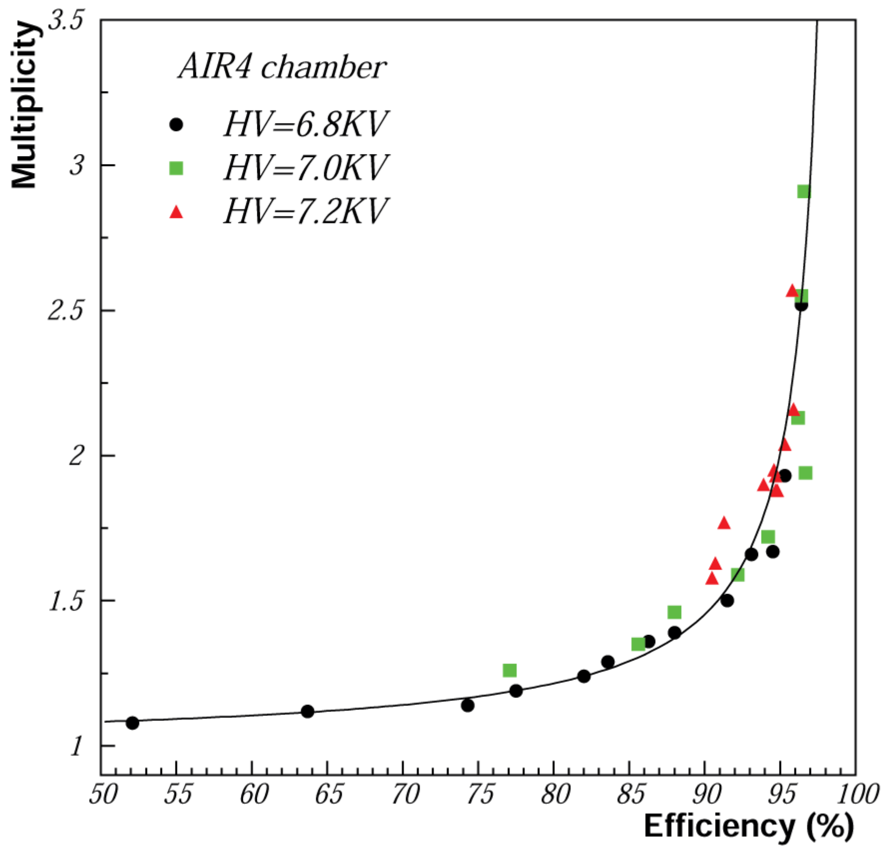
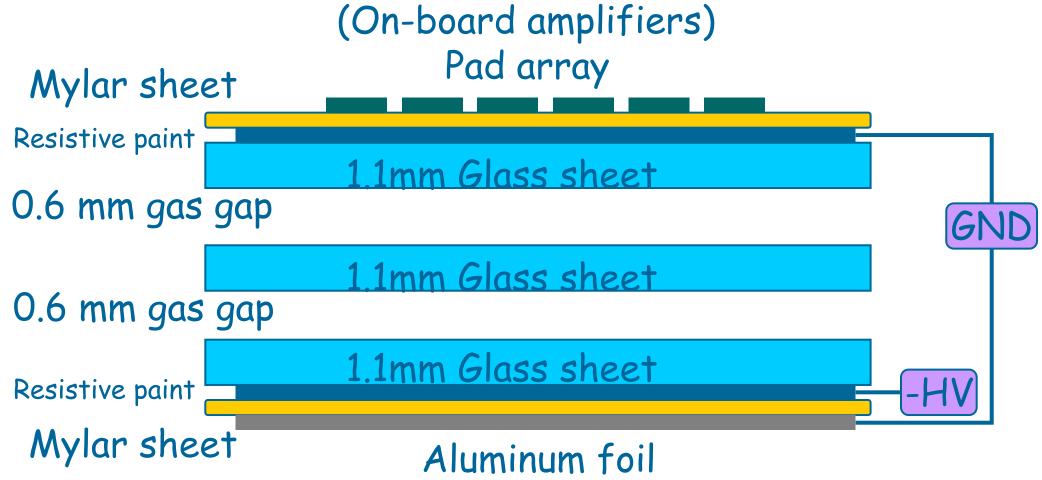
Hit multiplicity: operating voltage

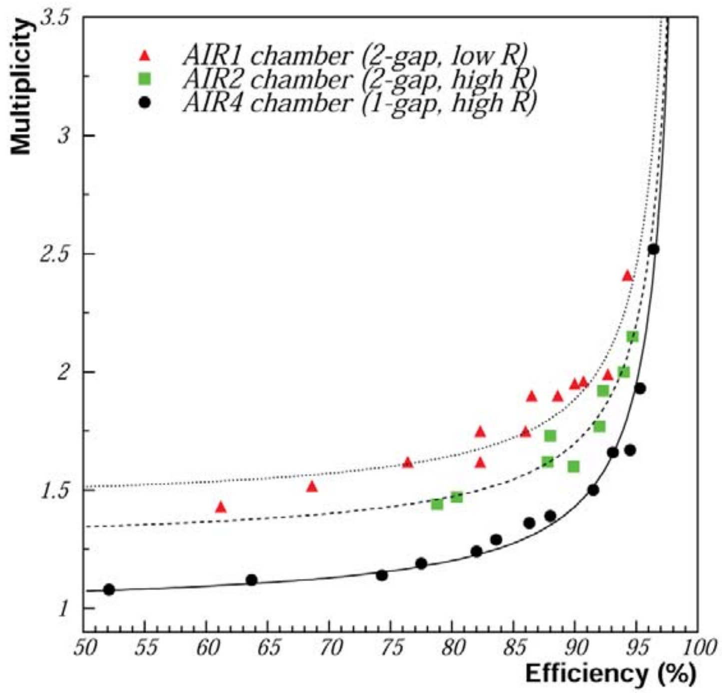
- AIR4 chamber operating at different voltages
  - 6.8KV, signal charge ~5pc
  - 7.0KV, signal charge ~8pc
  - 7.2KV, signal charge ~11pc
- For similar efficiency, AIR4 get similar hit multiplicity (but different hit threshold!) for different operating voltages
- The whole avalanche plateau would be good for operating the chamber, concerning hit multiplicity
- To compare two chambers, any operating HV on the avalanche plateau would be good



Hit multiplicity: 1gap/2gap, Hi R/Low R

- AIR1, AIR2, AIR4 has the same total gap size
  - Air1: 2 gaps, 0.2 M Ω/❑
  - Air2: 2 gaps, 1 M Ω/❑
  - Air4: 1 gap, 1 M Ω/❑
- Operating point
  - Air1: 8.4KV, ~5pc
  - Air2: 8.4KV, ~5pc
  - Air4: 6.8KV, ~5pc
- 1 gap chamber gives lower/better hit multiplicity
- High R gives lower/better hit multiplicity





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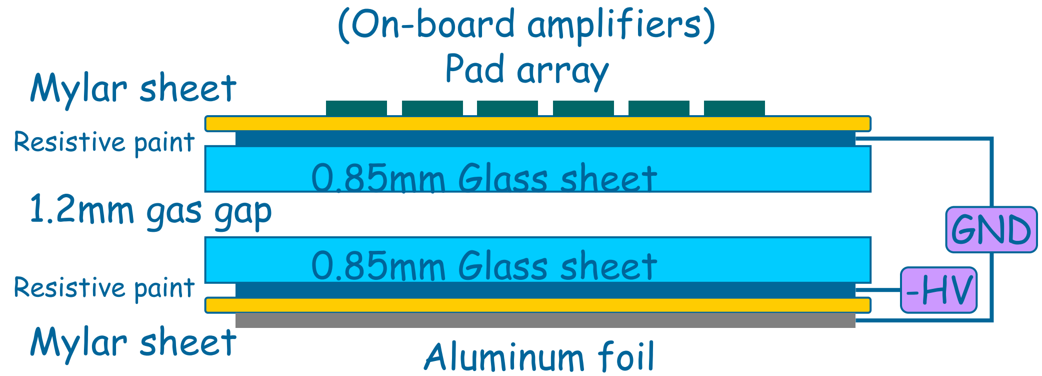
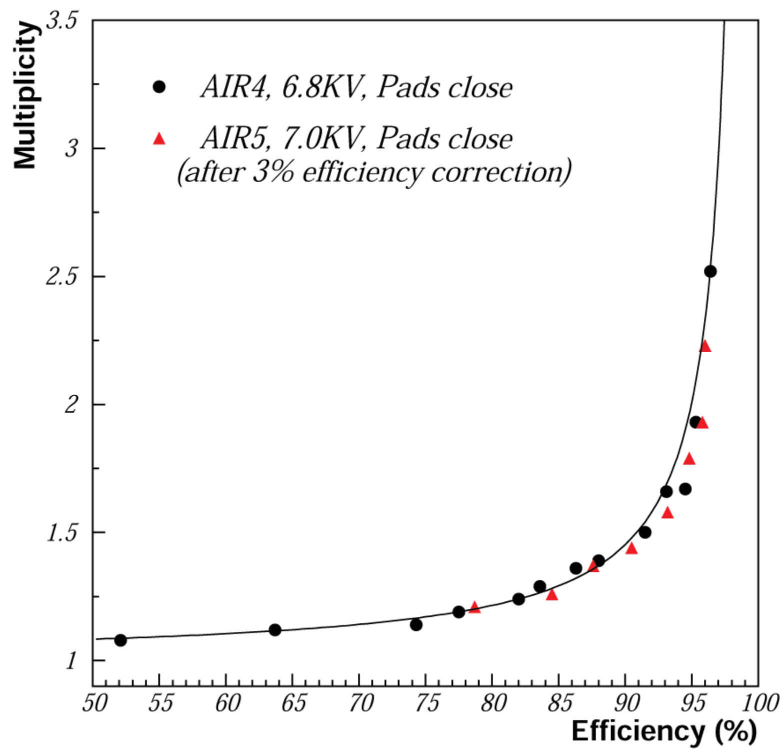
Hit multiplicity: thinner glass

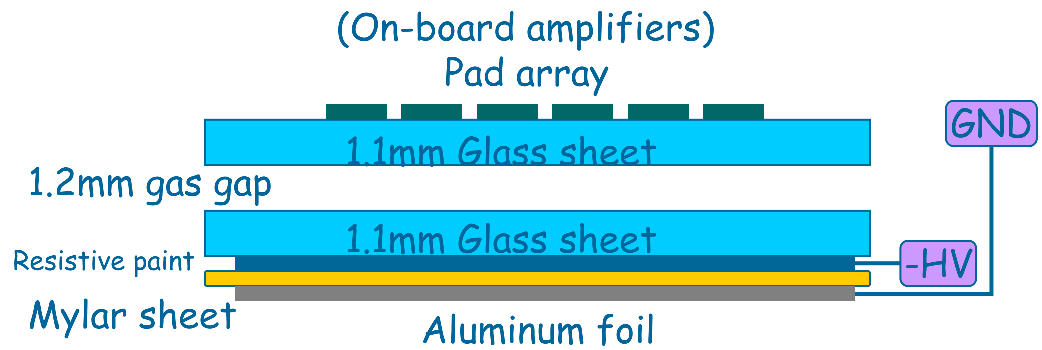
- AIR5 used thinner glass
  - 0.85mm glass sheet
  - 1-gap of 1.2mm
  - ~ 1M Ω/□ on paint layer
- Run AIR5 at 7.0KV
  - Avalanche signal ~5pc
- Compare to AIR4, AIR5 gives slightly lower hit multiplicity
  - For eff = 95%, ~1.6
  - For eff = 90%, ~1.4 - 1.5
- Configuration with pads closer to avalanche gives lower hit multiplicity

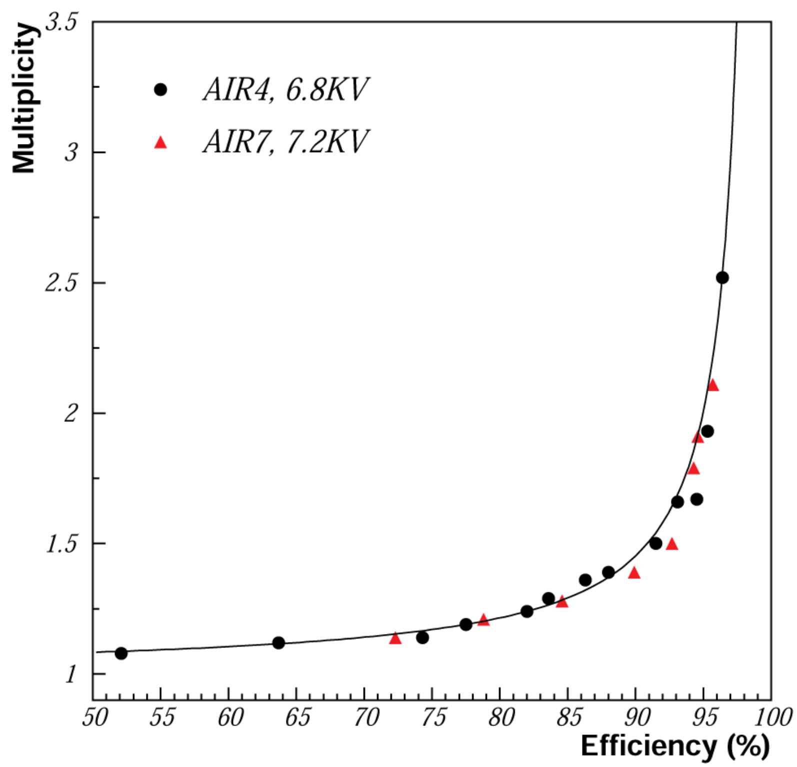




Hit multiplicity: pads on glass

- AIR7 has only one resistive paint layer
  - Pads sit on bare glass sheet directly
  - 1-gap of 1.2mm
  - ~ 1MΩ/□ on paint layer
  - Run AIR7 at 7.2KV
- Compare to AIR4, AIR7 gives slightly lower hit multiplicity
- Configuration with pads closer to avalanche gives lower hit multiplicity
- Electric contact between pads and glass could be a concern for this kind of design
  - Observed operating voltage change due to contact condition
  - May result in non-uniform detector performance
  - Could be the reason for higher noise rate (x5) for this chamber

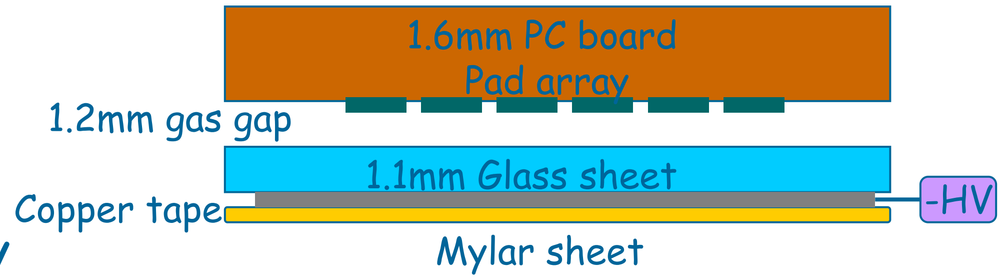


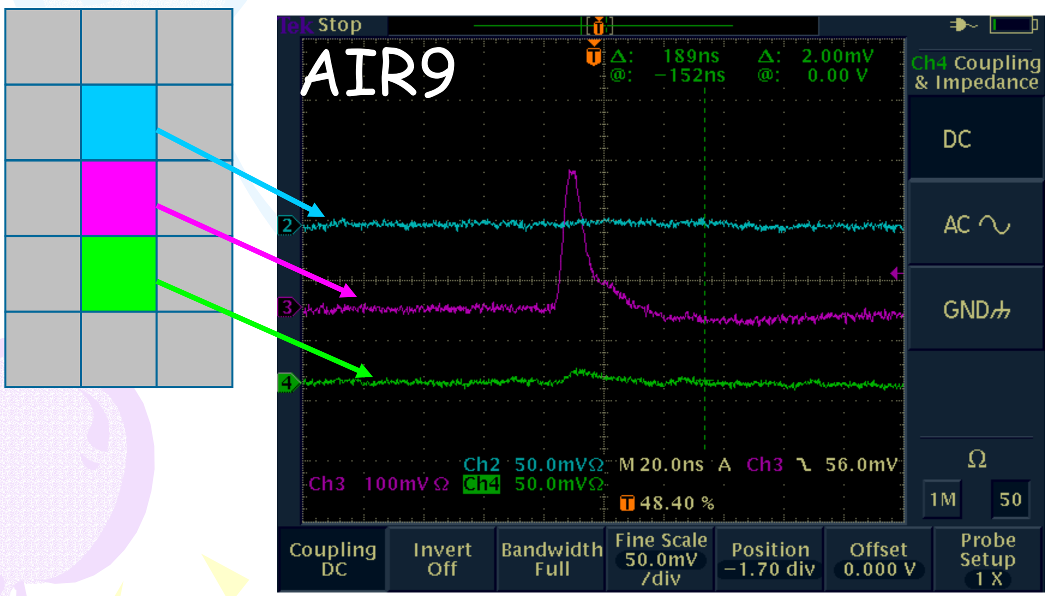


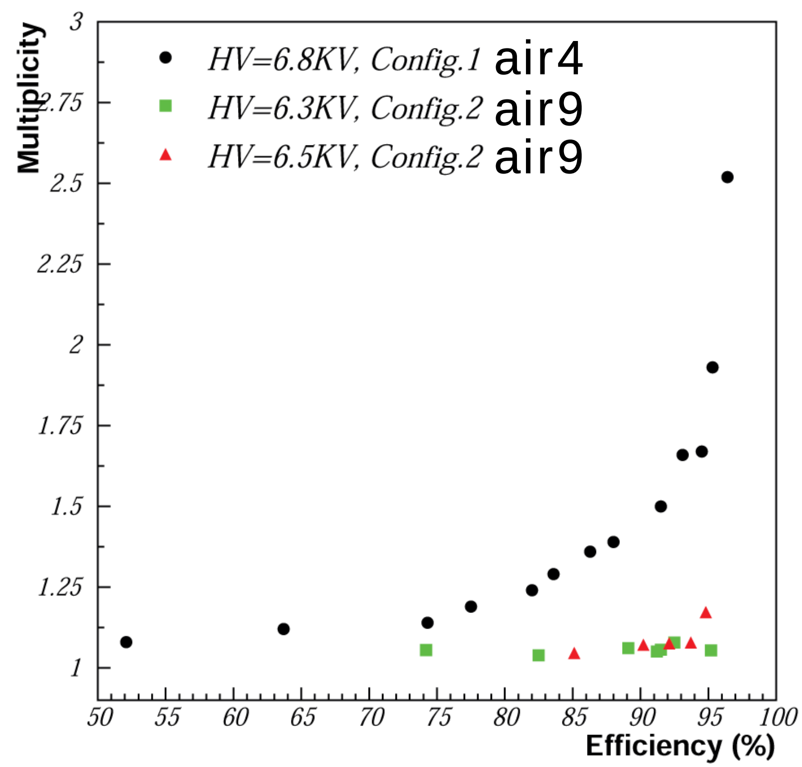
Hit multiplicity: pads on gas volume

- AIR9 built with one glass sheet
  - Pads face glass volume directly, and collect electrons from avalanche
- Amazingly low hit multiplicity
- Reasonable noise rate
  - X2, compares with AIR4

(On-board amplifiers)







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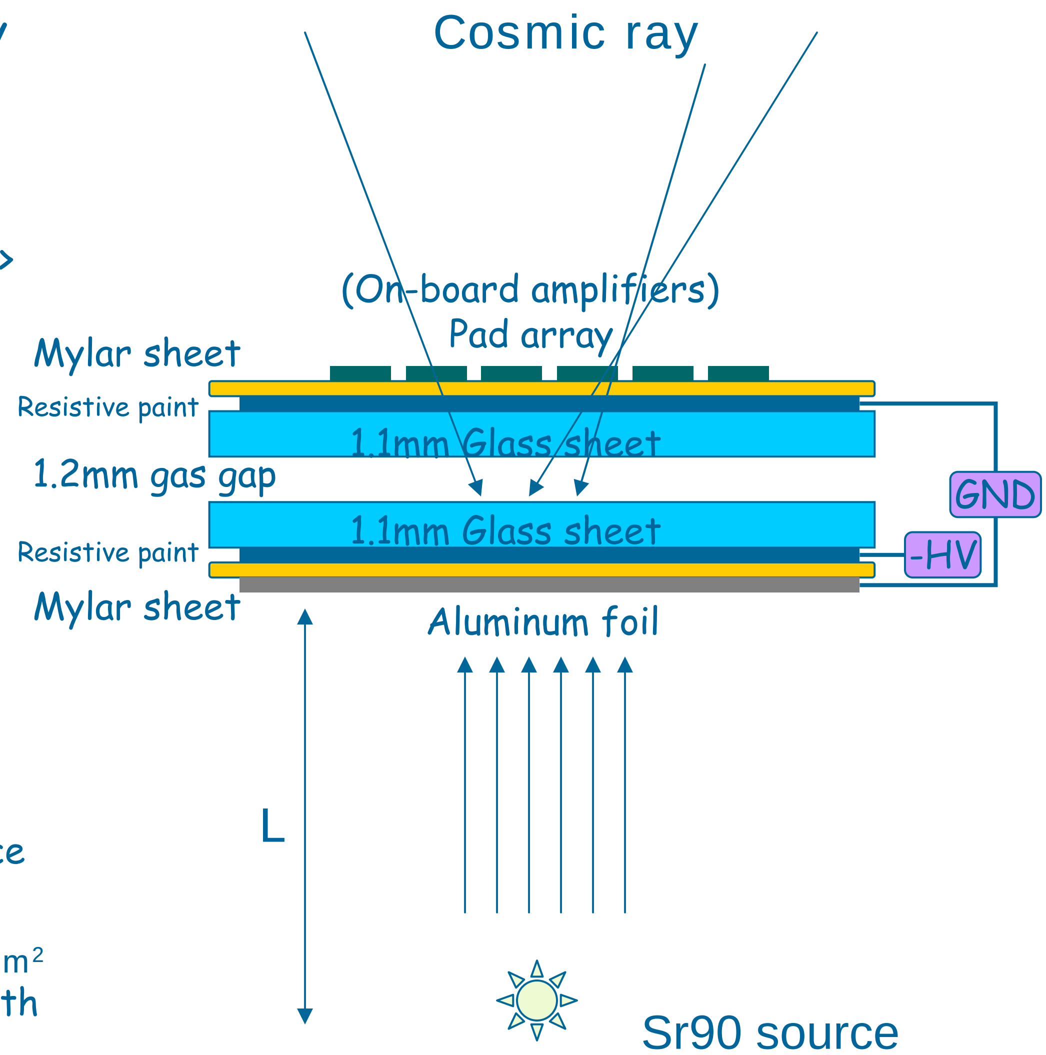
Hit multiplicity: summary

- Factors that can improve hit multiplicity
  - One gap chamber, instead of 2- or multi-gap design
  - Put pads as close to the avalanche as possible
    - Use thinner glass
    - Remove one paint layer and its insulation layer (electric contact could be a concern)
    - Build pads into chamber (one glass sheet design)
- Our base line design: AIR4
  - Conservative, proved design
  - Gives good hit multiplicity
    - 1.4 – 1.5 for 90% efficiency, 1.6 – 1.7 for 95% efficiency
  - If hit multiplicity is a concern, we have plenty of design choices that can meet whatever cross-talk requirement

RPC rate capability

- RPC has limited rate capability
  - Signal current need to pass through highly resistive glass sheets
  - High rate -> large current -> voltage drop on glass sheets -> smaller signal -> lower efficiency
- RPC rate capability measurement
  - Need to evenly illuminate the whole chamber
    - Illuminate small region of RPC will over estimate its rate capability
  - Need a way to figure out efficiency
- Our experimental setup
  - RPC was illuminated by Sr90 source
    - Emits electrons of 2.3MeV, 0.55MeV
    - Changing L, rate ~ 2 - 300Hz/cm^2
  - Signal efficiency was measured with cosmic rays



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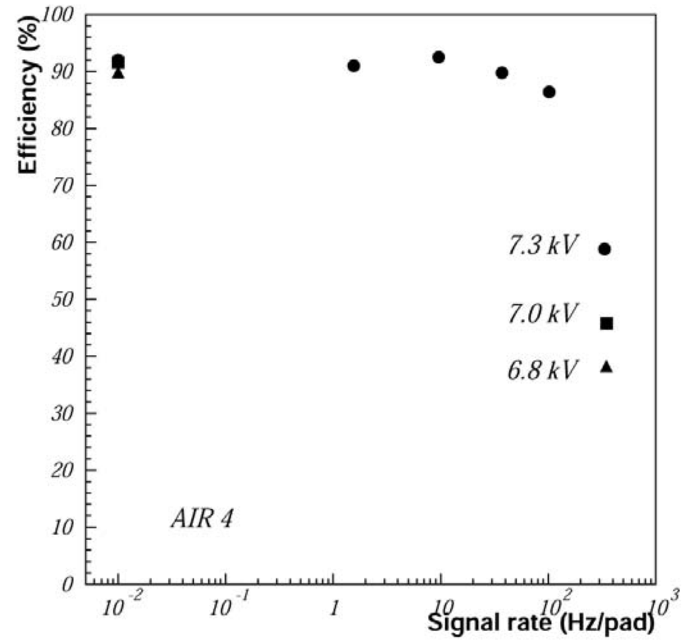
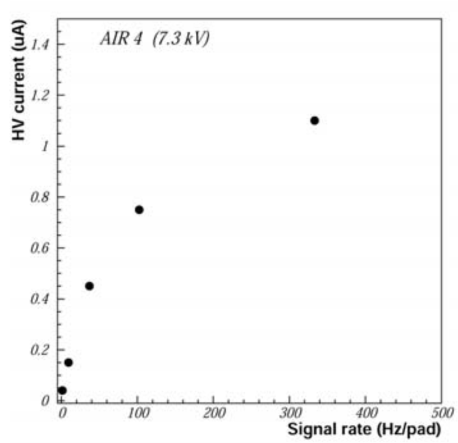
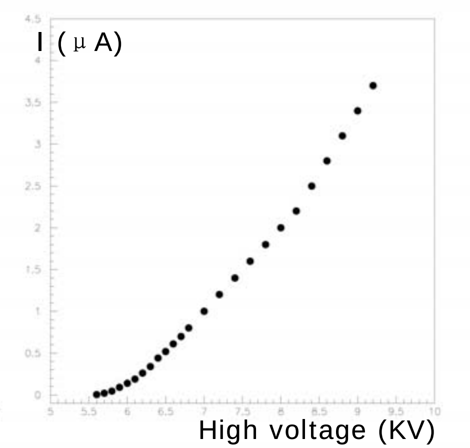
RPC rate capability: AIR4

- AIR4 efficiency (7.3KV) keeps flat until rate > ~50Hz/cm2
  - Higher operating voltage gives better rate capability
- Chamber current is not a linear function of particle rate
  - Signal charge reduced at high particle rate
- I-V curve for constant (high) rate shows threshold, and then linear response
  - Both signal charge and glass sheets have linear response
  - Can read off directly the effective resistance of the chamber: ~1 GΩ
  - Resistance of glass sheet is in accessible range

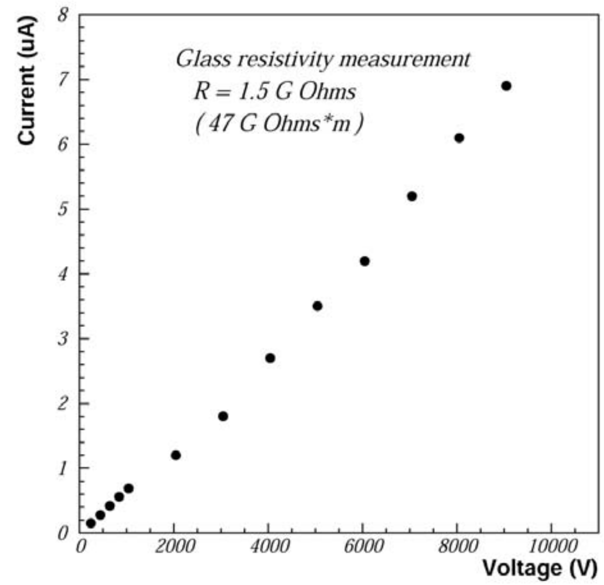


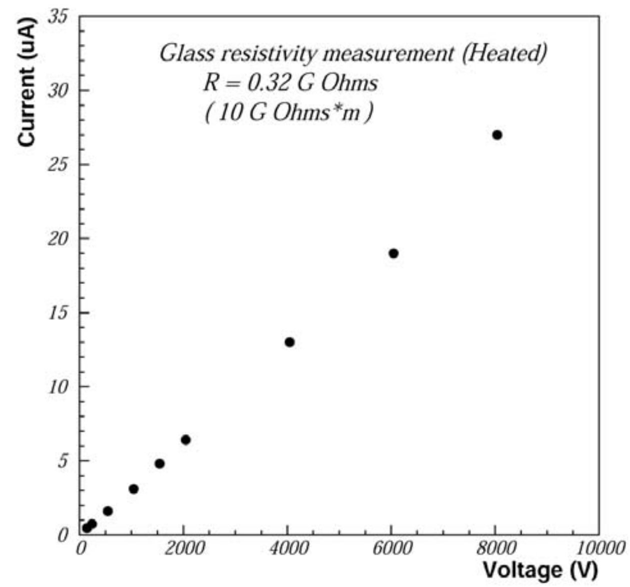




RPC rate capability: glass resistance

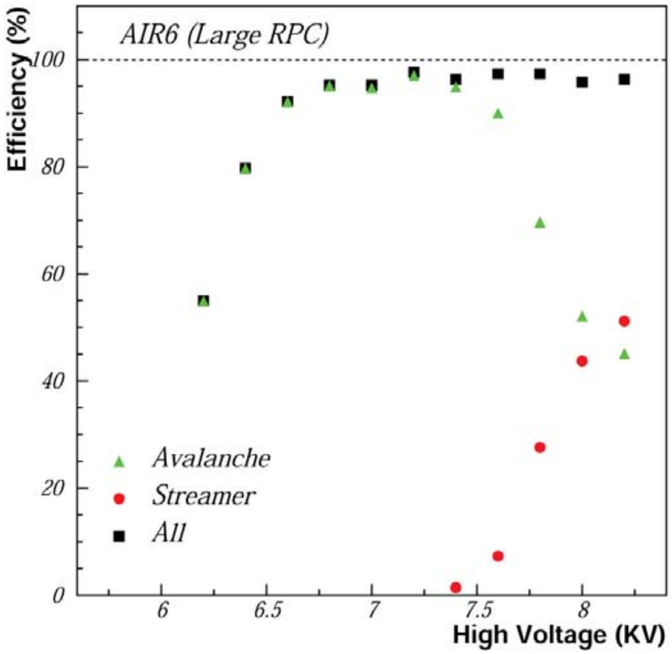
- 1^{st} measurement, 1.1mm glass sheet
  - R = 1.5 GΩ
  - Ρ = 4.7 x 10^{10} Ωm
  - Can not explain the effective resistivity!
- 2^{nd} measurement: bind signal pads and amplifiers to the glass sheet in the same way as for a real RPC, and power up the amplifiers
  - Glass sheet temperature is ~20°C higher
  - R = 0.32 GΩ
  - Ρ = 1.0 x 10^{10} Ωm
  - Gas volume has an effective resistance of 0.4GΩ, under constant flux of 300Hz/cm^2

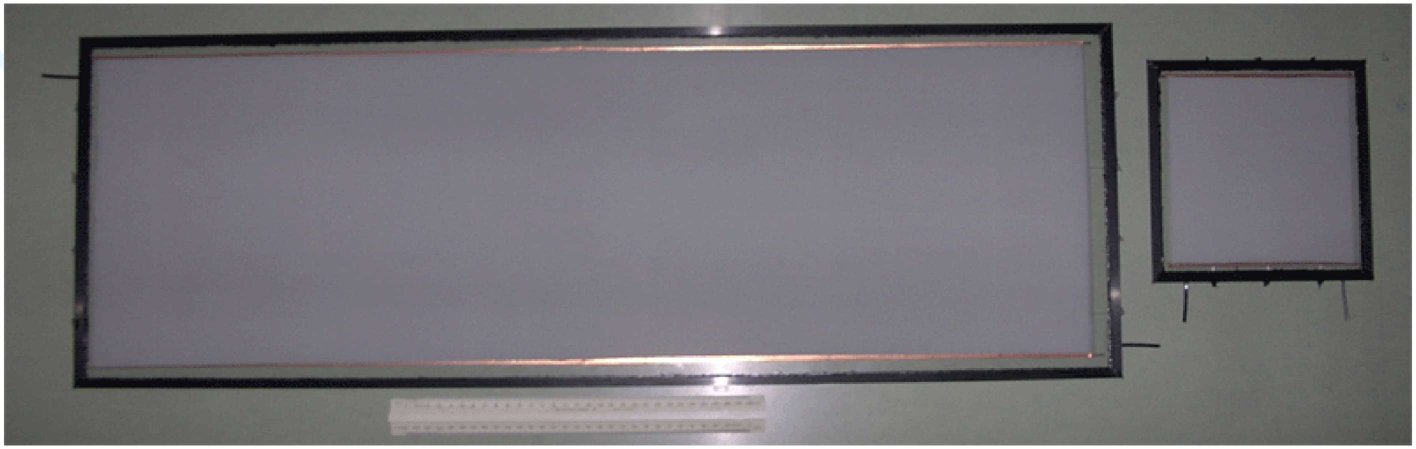




Full size RPC, other studies

- One full size RPC was built
  - 30.5 x 91.5 cm^2
  - 1 gap, 1.2mm
  - Resistive layer: ~ 1M Ω /❑
- Signal property is as expected
  - Signal charge, avalanche plateau, etc., identical to small chamber
- Other studies
  - Glass bending under pressure and electric force
  - Chamber aging study: no aging observed
  - ……





Conclusion

- We have built and tested over 10 RPCs, including a full size prototype chamber
- We did all the tests we planned to do:
  - Tests with single pad and multiple readout pad
  - Tests with analog and digital readout
  - Test of both large and small chambers
  - Test of rate capability
  - …

- **We totally understand our detector, and we are ready to build RPCs for the 1m^3 test beam section**