EXPLORING THE PERFORMANCE LIMITS OF THE NEW GENERATION OF ATLAS RPCS

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FOR THE ATLAS MUON SPECTROMETER SYSTEM

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THE ATLAS RPC UPGRADE CONCEPT

MAXIMUM TRACK SELECTION PERFORMANCE WITH A MINIMAL SET OF DETECTORS

- MAXIMUM SINGLE DETECTOR PERFORMANCE
  - FRONT END THRESHOLD SENSITIVITY
  - GAS GAP WIDTH
  - GASEOUS TARGET DENSITY
  - DRIFT VELOCITY
- MINIMUM NUMBER OF INDEPENDENT DETECTORS
  - FARADAY CAGE NOISE IMMUNITY
  - HIGHLY INDEPENDENT SINGLETS
- LOW COMPLEXITY AND RELIABILITY
  - THINNER (LIGHTER) ELECTRODES
  - LIGHT AND RIGID STRIP PANELS (THIN PAPER HONEYCOMB CORE)
  - EMBEDDED HV AND GAS CONNECTION POINTS

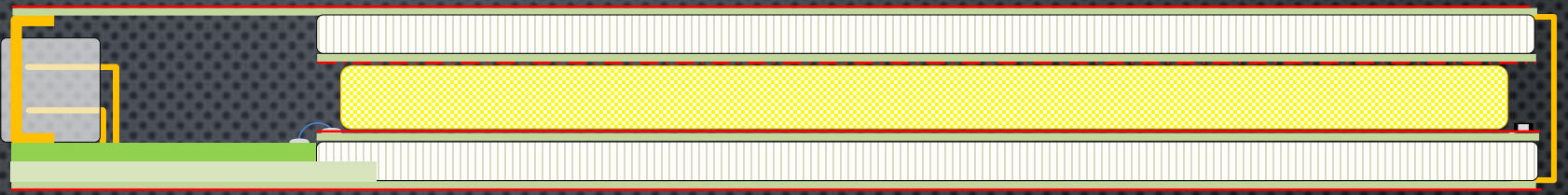
BIS78 RPCs designed for the ATLAS upgrade:

- Gas gap 1mm
- FE threshold 1-4 fC
- 3 independent singlets providing 3D+t particle localization

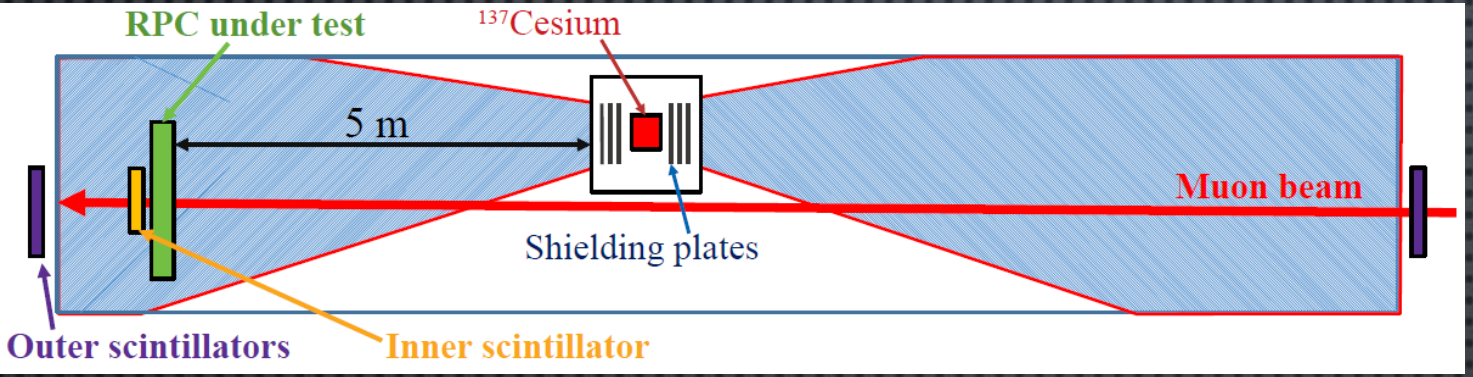
SINGLET STRUCTURE

A SINGLET IS MADE OF

- A RPC GAS GAP
- TWO READOUT STRIP PANELS
  - STRIP PCB FACING THE GAP
  - LOW ε_R DIELECTRIC FILLER
  - REFERENCE GROUND PLANE
  - FRONT END ELECTRONICS
  - MATCHING RESISTORS
- GROUND REFERENCE INTERCONNECTIONS
- A SINGLET IS A INDEPENDENT FARADAY CAGE INSENSITIVE TO THE EXTERNAL WORLD
- A NUMBER OF SINGLETS CAN BE BOXED FREELY AND INTERLEAVED WITH OTHER MATERIALS



THE TEST BEAM SETUP AT GIF++



- WE TESTED THE BIS7 MODULE-0 AT GIF++ USING THE H4 BEAM
- CHAMBER SIZE **990 x 1820**
- 3 SINGLETS WITH 32 + 64 ORTHOGONAL STRIPS EACH
- TRIGGER USED:
  - EXTERNAL: 3 BEAM SCINTILLATORS
  - INTERNAL: 2 OUT OF 3 MAJORITY
  - RANDOM
  - TRIGGER-LESS

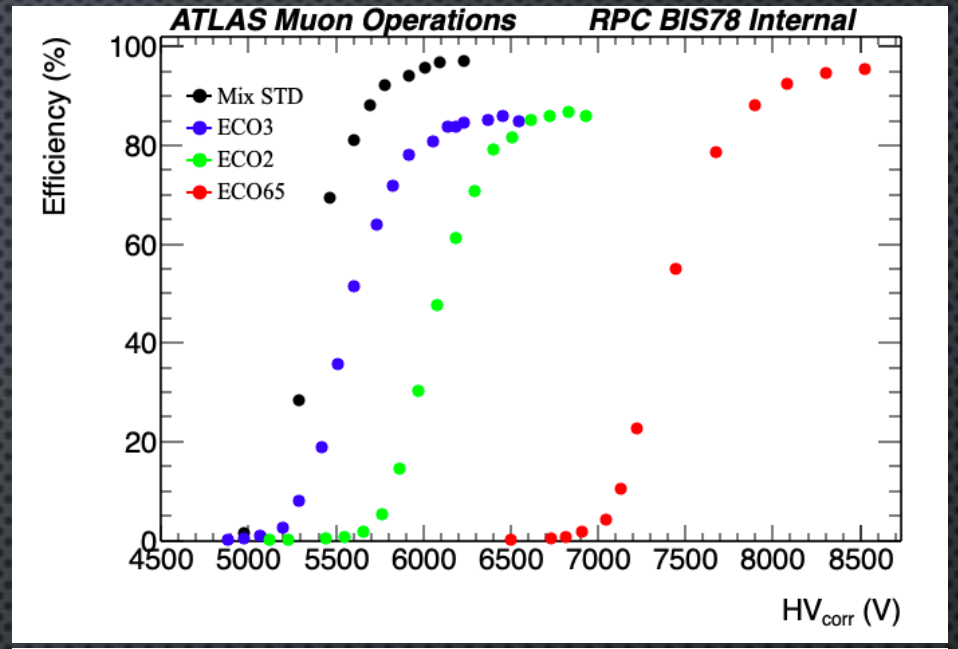
READOUT SYSTEM:

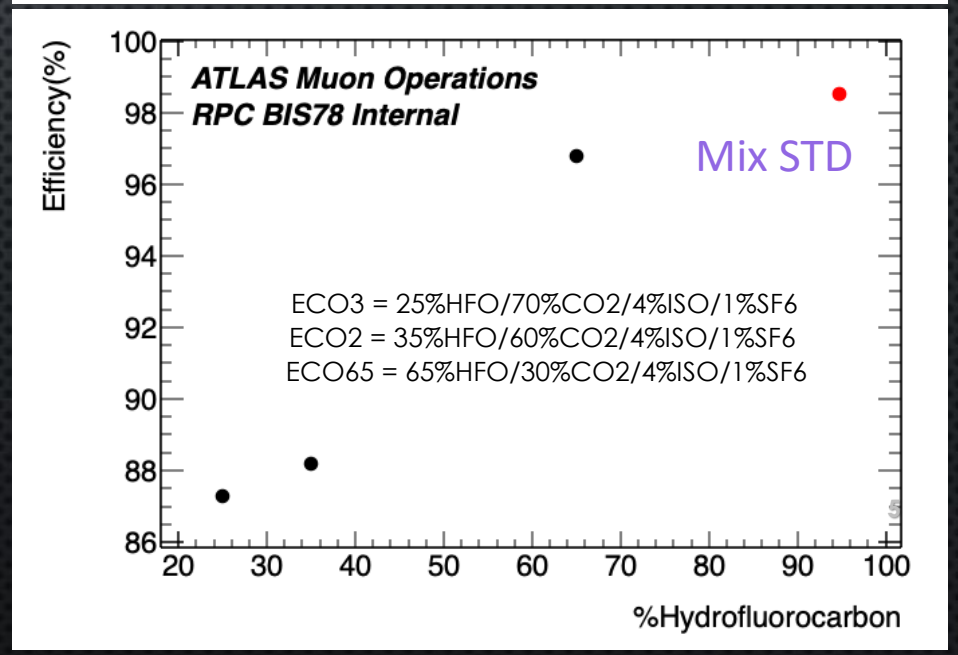
- BIS78 PRODUCTION SYSTEM BASED ON 18 HP-TDC CHIPS CUSTOMIZED FOR THE BIS78 SYSTEM
- READOUT PERFORMED BY A DEDICATED FPGA CAPABLE TO IMPLEMENT THE LOCAL 2 OUT OF 3 MAJORITY

SINGLE DETECTOR PERFORMANCE – EFFICIENCY VS GAS MIX

EFFICIENCY DEPENDS ON

- PRIMARY IONIZATION ALLOWED BY THE GASEOUS TARGET
  - 1 MM
  - VARIOUS FRACTIONS OF CO2 (LOW DENSITY) WRT. FLUORINATED GAS (HIGH DENSITY): STD (0%), ECO65 (30%), ECO2 (60%), ECO3 (70%)
- FRONT END SENSITIVITY → MINIMUM THRESHOLD 1 FC MAX. 4 FC
- DEAD AREAS → 2% DUE TO SPACERS
- THE EFFICIENCY ALMOST REACHES PLATEAU AT 65% OF HFO (1% DIFFERENCE WRT. STD)
- SAME HAPPENS IN THE LOWEST END: AT 25% OF HFO THE EFFICIENCY IS ABOUT 84% AND ITS VARIATION IS AT MOST 1% PER 10% VARIATION OF HFO FRACTION
- THIS SETS THE INTERESTING RANGE OF VARIATION OF HFO FOR 1 MM GAS GAP



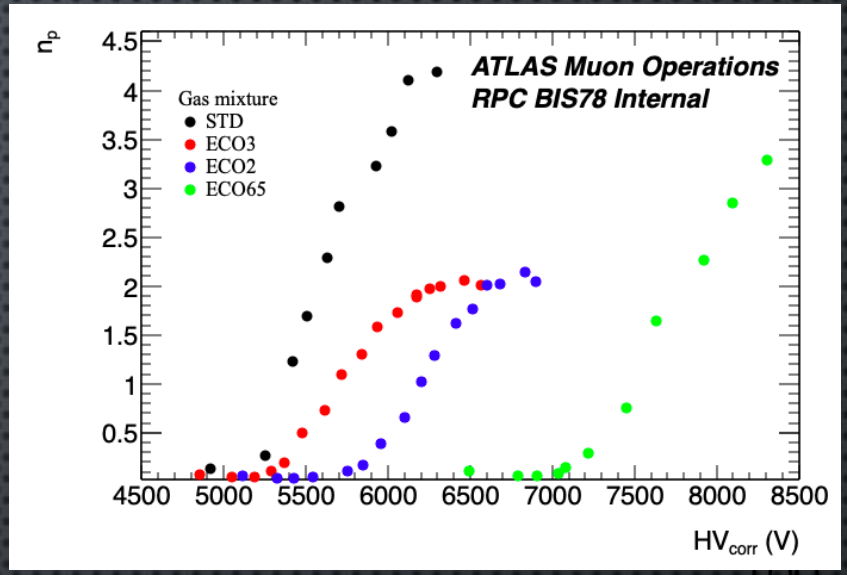


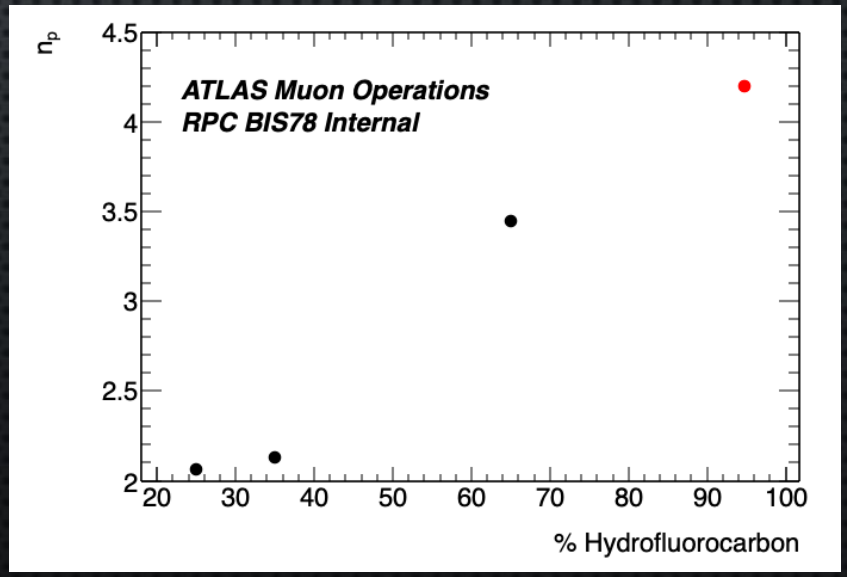
MAXIMUM SINGLE DETECTOR PERFORMANCE – EFFECTIVE PRIMARY CLUSTERS

THE INTRINSIC INEFFICIENCY (DEPURATED BY ACCEPTANCE AND DEAD AREAS) CAN PROVIDE THE NUMBER OF EFFECTIVE PRIMARY CLUSTERS THROUGH THE P(0) FUNCTION:

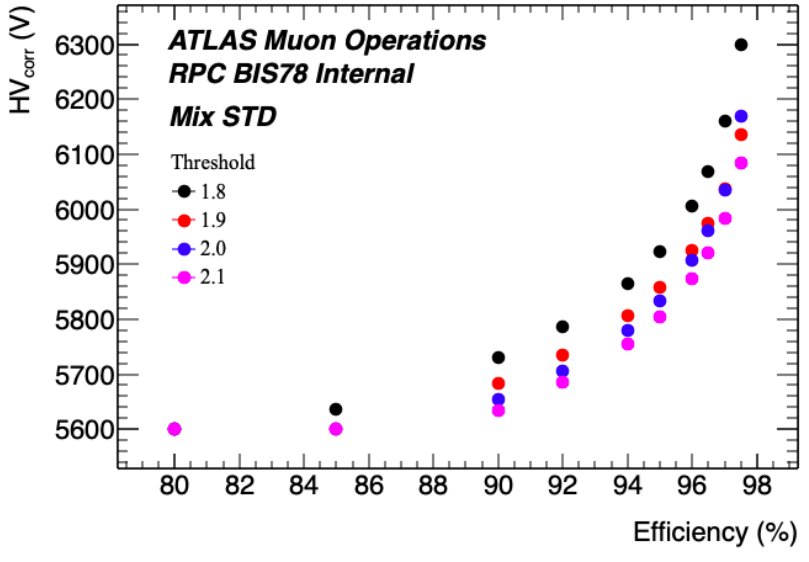
$$< np >= ln(\frac{1}{1-\epsilon})$$

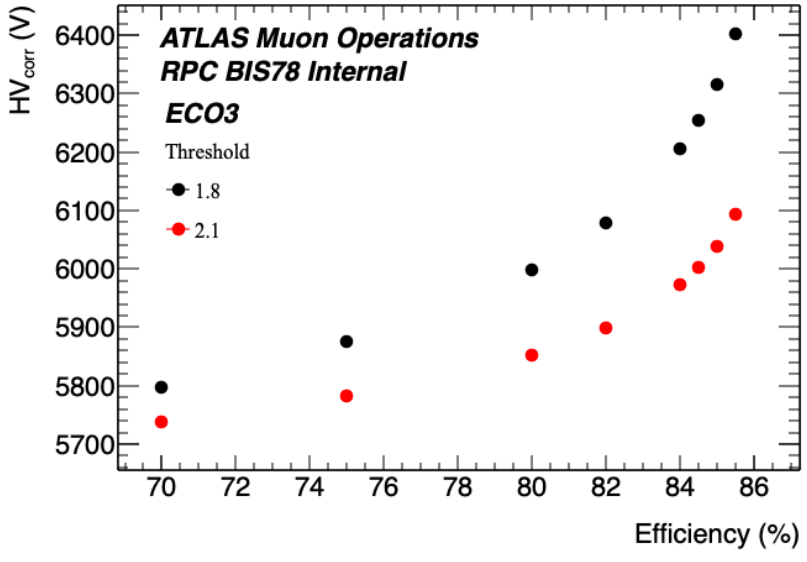
- "EFFECTIVE" MEANS A PRIMARY CLUSTER CAPABLE TO DELIVER A SIGNAL ABOVE THE THRESHOLD
- THE NUMBER OF EFFECTIVE CLUSTERS DEPENDS ON BOTH THE ELECTRIC FIELD AND THE FE THRESHOLD

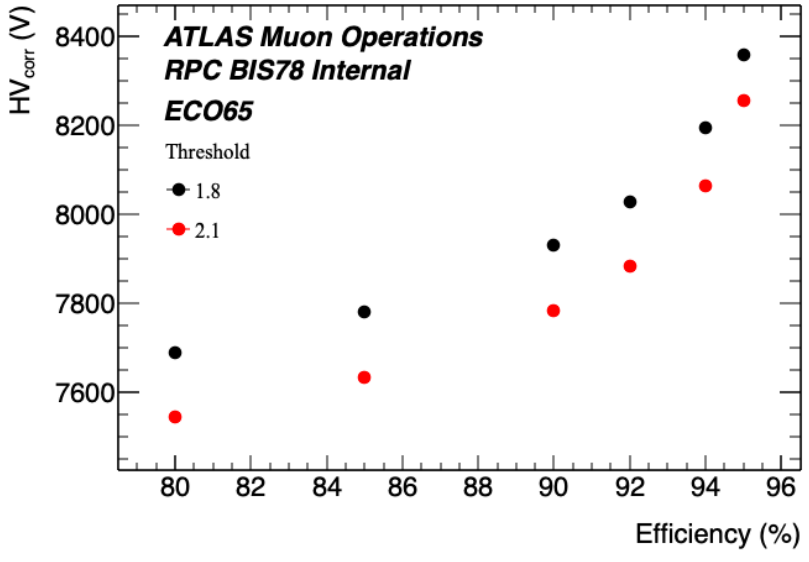




MAXIMUM SINGLE DETECTOR PERFORMANCE – FE ELECTRONICS SENSITIVITY







THE NEW FE ELECTRONICS IS BASED ON A VERY PERFORMING SET OF AMPLIFIER-DISCRIMINATOR WITH HAVING A MINIMUM OPERABLE THRESHOLD OF JUST 1 FC (5 X RMS NOISE OF 1200 ELECTRONS)

- THRESHOLD SETTING = 2.2V-VTH
- VTH = 1.8V →4 FC
- VTH = 2.1 → 1 FC

- THE VARIATION OF WORKING POINT IS OF THE ORDER OF A FEW 100TH OF VOLTS CHANGING THE VTH ACCORDINGLY

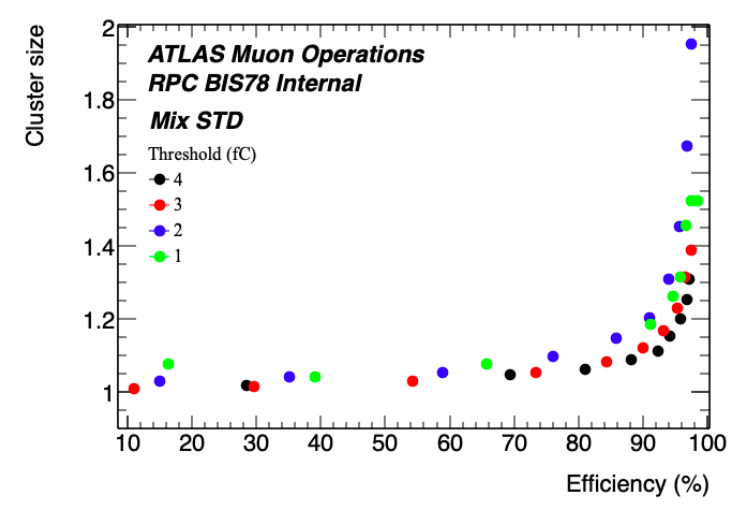
CHARGE PER COUNT AND AGEING IMPACT

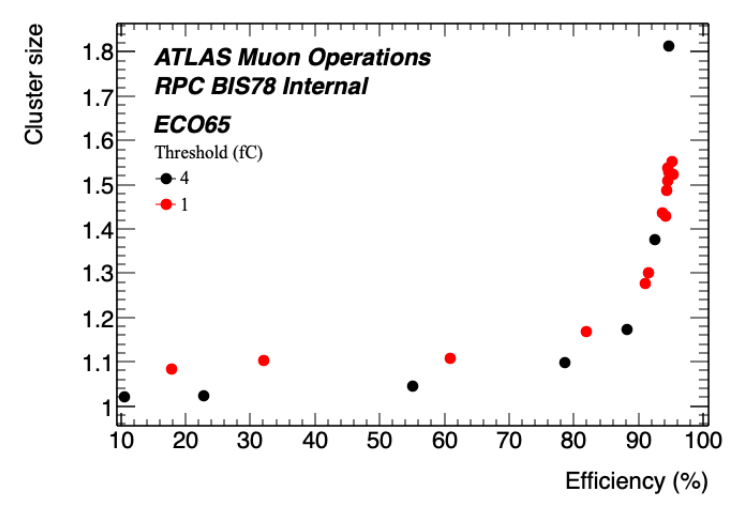
AGEING IMPACT

- THE BIS78 FRONT END ALLOWED TO LOWER THE CHARGE PER COUNT FROM **30 PC PER PHOTON COUNT TO 6 PC**
- THIS RESULT WAS OBTAINED WITH A CONSERVATIVE THRESHOLD SETTING OF **4 FC**
- AN EARLY TEST (L. PIZZIMENTO RPC2018) SHOWN THAT FORCING THE SETUP WITH A MUCH LOWER THRESHOLD, OF **1 FC, ONE CAN ACHIEVE 3 PC/COUNT**.
- THE BIS78 MODULE ZERO ALLOW TO OPERATE NORMALLY WITH SUCH THRESHOLD VALUE AS WILL BE SHOWN
- THIS IMPLIES THAT THE SAME RPC TECHNOLOGY CAN EXTEND BY AN ORDER OF MAGNITUDE THE CERTIFIED AGEING FEATURES:
- 10 YEARS@100 HZ/CM^2 → 1KHZ/CM^2

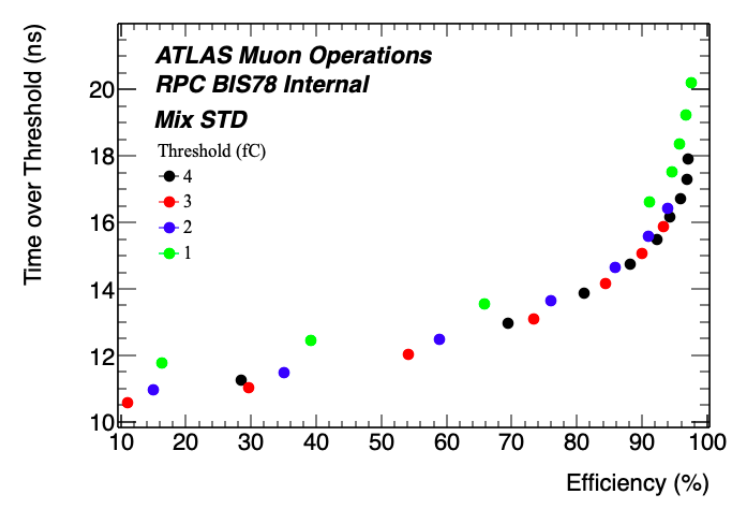
CLUSTER SIZE AND TOT FOR DIFFERENT GASES:

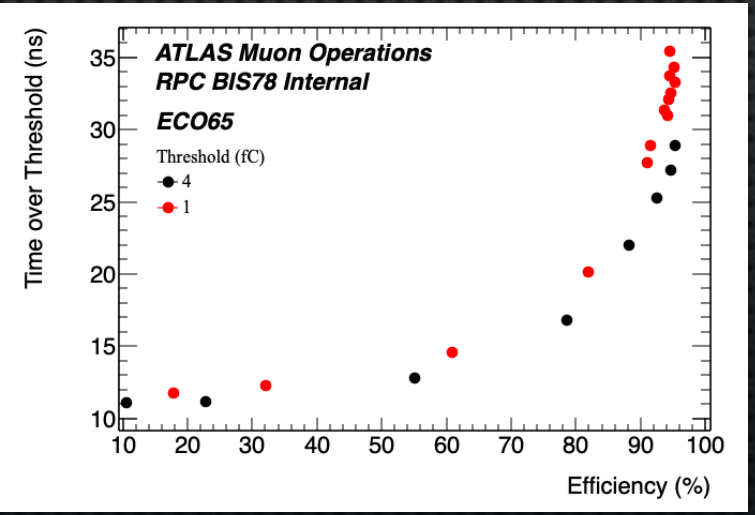
- CLUSTER SIZE





- TIME OVER THRESHOLD





Culster size increases with both increasing applied HV and lowering the discriminator threshold.

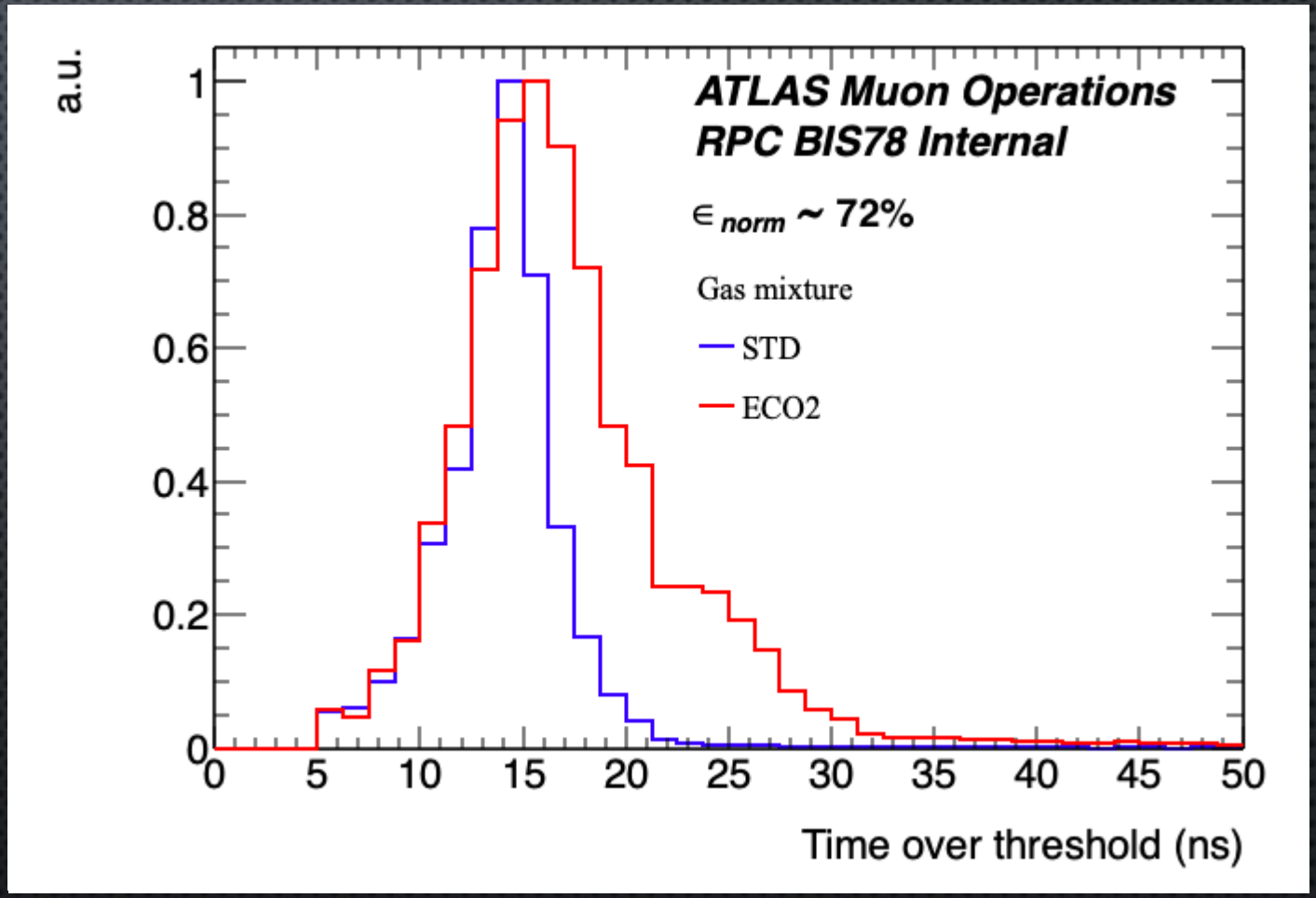
In this case a given efficiency is obtained at a lower applied voltage by using a lower threshold. Giving a good CS behavior at the most sensitive threshold

Operation with ecogas at lowest threshold is subject to the effect of larger avalanche events

MAXIMUM SINGLE DETECTOR PERFORMANCE – CHARGE DISTRIBUTION

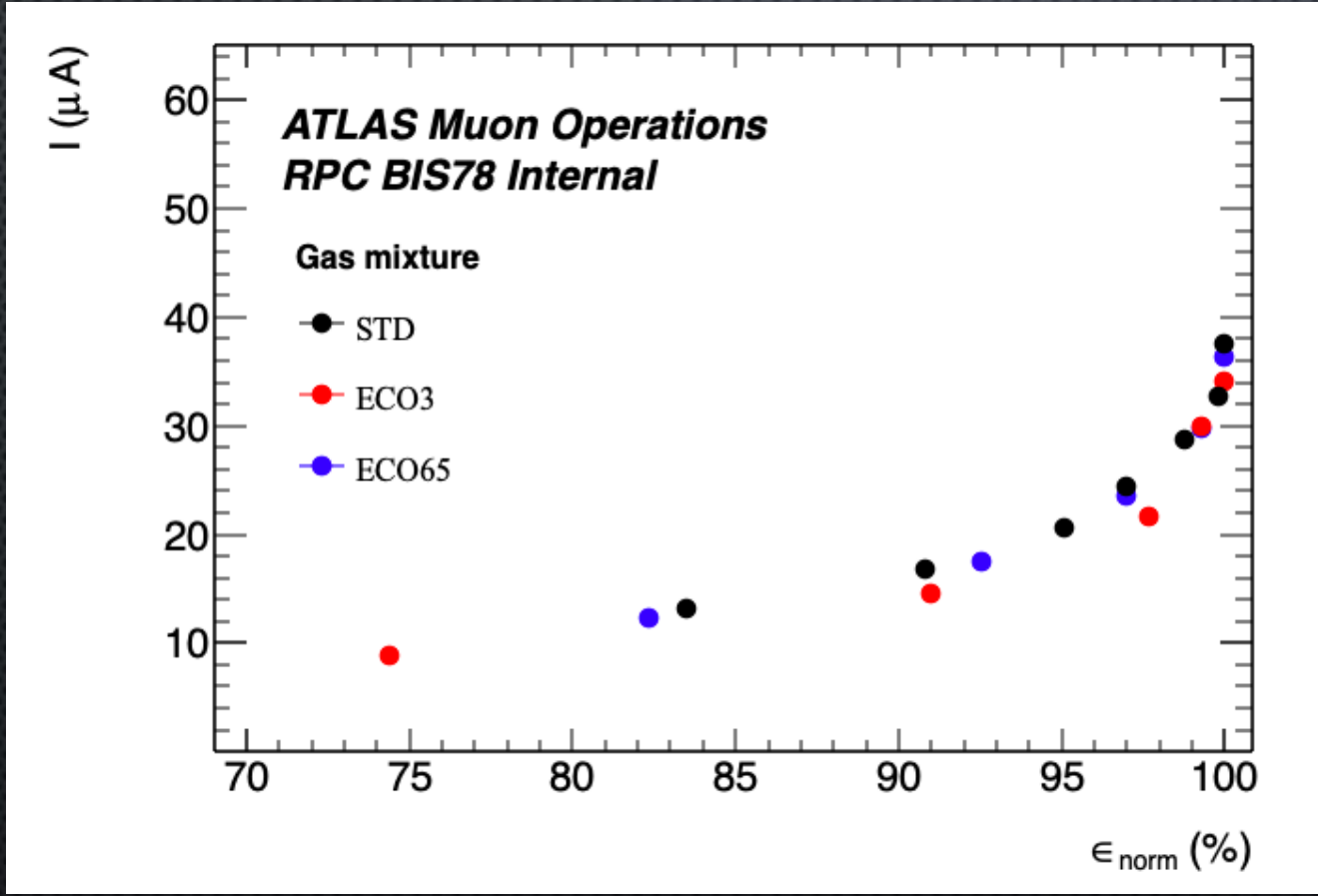
THE CHARGE DISTRIBUTION COMPARISON BETWEEN ECO AND STD

- STD HAS AN HIGHER SHOULDER AT THE LOWEST DISTRIBUTION END OF LOW EFFICIENCY DISTRIBUTIONS, DISAPPEARING AT HIGHER FIELD.
- SINCE THEN THE DISTRIBUTIONS RAISING EDGE IS THE SAME INDEPENDENTLY ON GAS
- THE FALLING EDGE FOR ECO IS DUE TO HIGHER CHARGE EVENTS
- THIS CAN BE EXPLAINED BY AN EARLIER SATURATION WITH A FRACTION OF CO2 CREATING HIGHER DENSITY AVALANCHES



Ecogas operation is presently limited by the presence of extra charge per count for MIPS

CURRENT VS WORKING POINT VS GAS MIXTURE

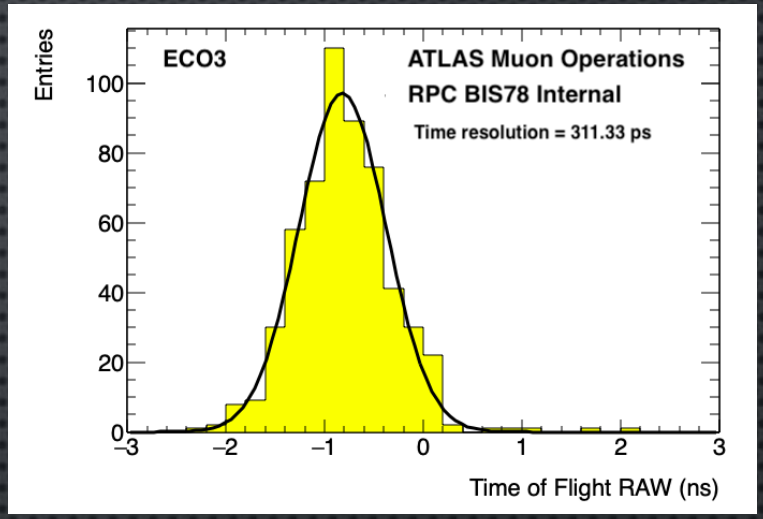


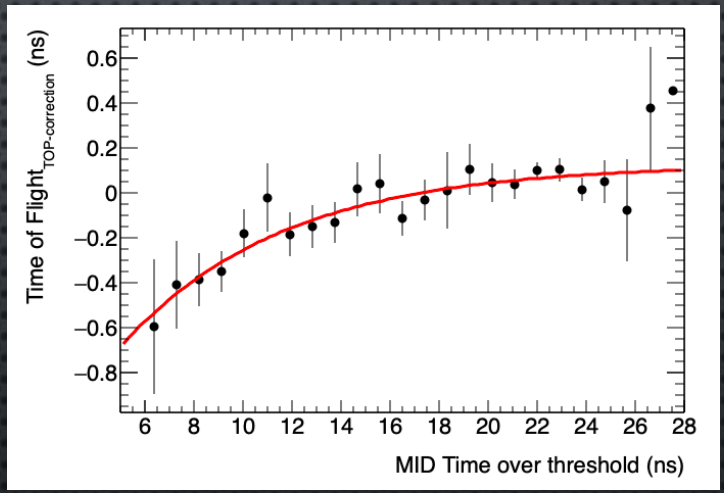
- Efficiency to MIPS normalized to the plateau asinthotic value
- Photon induced operating Current measured off spill with ABS=22 for different mixtures
- Operating current from photons vs. percentile of the efficiency curve for MIPSare very similar for different mixtures

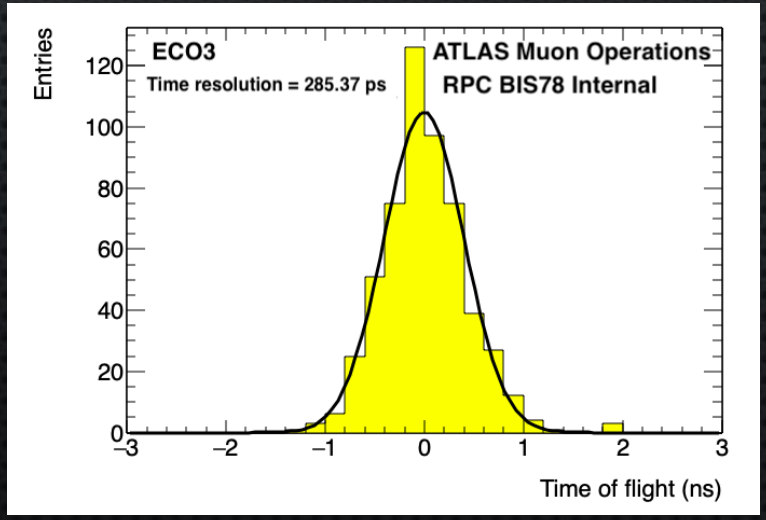
MAXIMUM SINGLE DETECTOR PERFORMANCE – TIME RESOLUTION

TIME RESOLUTION

- DEPENDS ON THE GAS GAP WIDTH AND THE DRIFT SPEED OF THE GAS.
- IT IS SPOILED BY PRIMARY AND SECONDARY IONIZATION STATISTICAL FLUCTUATIONS
- THE ELECTRONICS SKEW AND TIME PROPAGATION EFFECT CAN BE CALIBRATED (TIME WALK CORRECTION
- IF THE THRESHOLD IS LOW AND THE DISCRIMINATOR IS FAST, THE PROMPT RESOLUTION IS ALREADY VERY GOOD.

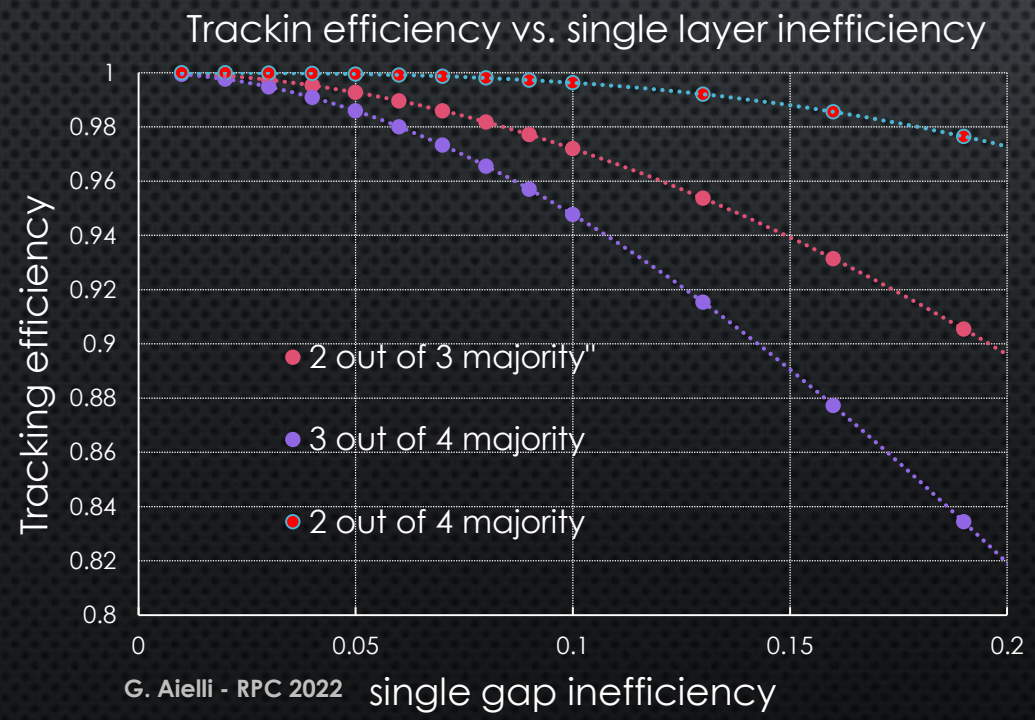






PERFORMANCE AS A TRACKER

- THE TRIGGER AND TRACKING EFFICIENCY →COMBINATION OF THE LAYERS
- 1MM SDT MIX 1-E=1.5%
- THE PERFORMANCE OF THE FARADAY CAGE ALLOWS TO MAKE A COMPACT STRUCTURE OF INDEPENDENT ELEMENTS



- THE BIS78 CHAMBER TRIPLET ALLOWS TO LOCALIZE A TRACK ELEMENT WITH THE 2 OUT OF 3 MAJORITY
- THE TOTAL INEFFICIENCY OF THE TRACKER IS THE SUM OF A CONSTANT TERM DUE TO THE DEAD AREAS (I.E. 2%) AND THE STATISTICAL INEFFICIENCY OF THE 2/3 WHICH IS PROPORTIONAL TO THE $(1-\varepsilon)^2$
- AN EFFICIENCY LOSS OF 5% ON A SINGLE GAS GAP (E.G. FOR USING ECOGAS) WOULD RESULT IN LESS THAN 1% OF THE TRIPLET TO BE COMPARED TO THE CONSTANT TERM OF DEAD AREAS
- COMBINED TIME RESOLUTION WOULD BE:

$$\frac{280\ ps}{\sqrt{3}} \leq 160ps$$

CONCLUSIONS

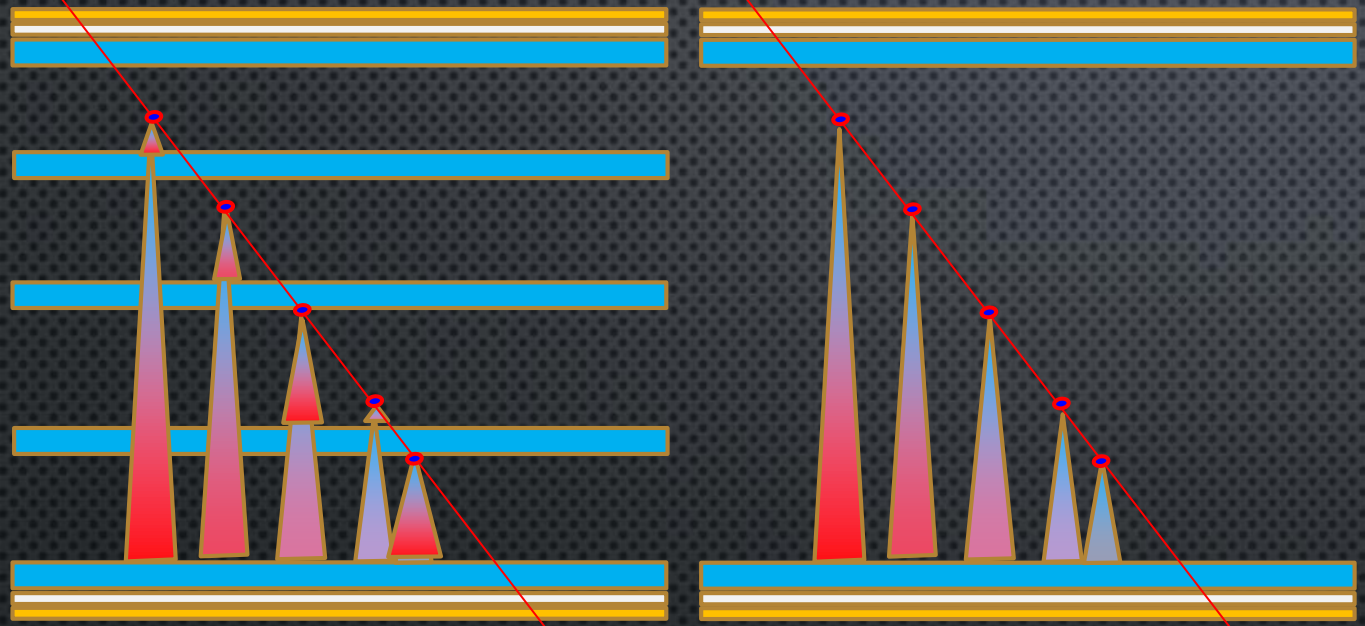
- We studied the performance range of the ATLAS upgrade RPCs based on single 1mm gas gap and down to 1 fC FE threshold
- The key role of the FE electronics sensitivity allows to reach as low as 3 pC/count operating charge extending by one order of magnitude the LHC generation RPCs longevity
- The detector faraday cage integration rejection power is crucial to ensure the tight integration of independent singlets
- The combination of high singlet performance and independence ensures to work at high tracking efficiency even with a substancial fraction of CO2 ans a tracking time resolution of the order of 150 ps with ecogas
- On the base of this study different configurations can be explored, to respond to new experiments requirements.

ACKNOWLEDGMENTS

- The gas mixtures ECO2, ECO3 and ECO65 have been kindly provided to ATLAS in the framework of the ECOGAS@GIF++ collaboration

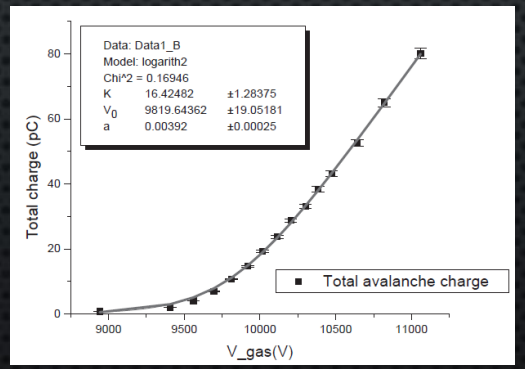
BACKUP

RESISTIVE PLATE CHAMBERS AT A GLANCE



$$Q(V) = \ln\left(1 + e^{a(V-V_0)}\right)$$
$$Q(x) = \ln(1 + e^{\alpha x})$$
Integral logistic growth

G. Aielli et al NIM A 508 (2003) 6–13



COMMON FEATURES

- HIGH R ELECTRODES → SPARK LESS
- UNIFORM ELECTRODE → SIMPLE
- UNIFORM FIELD → PROMPT SIGNAL
- WORKING AT ATM. PRESSURE
- 0.1MM 2D LOCALIZATION
- GAS MIXTURE

Feature	RPC vs	MRPC
# OF GAPS →	1 –	4 TO TENS
ρ(Ω CM) →	$5x10^{10}$ –	$5x10^{12}$
MODULE SIZE →	2 M^2 –	0.1 M^2
HZ/CM^2 →	10^4 –	$5x10^2$
σ_t →	500 PS –	50 PS

PRESENT LIMITS – RATE AND LONGEVITY

RATE CAPABILITY

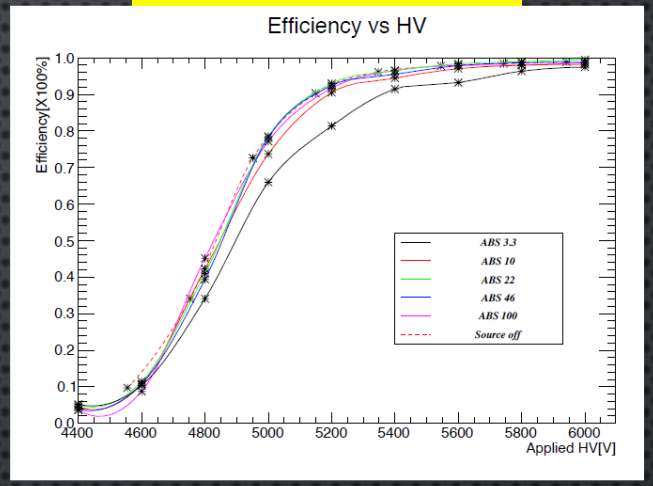
- ELECTRODE RESISTIVITY IS RESPONSIBLE FOR THE PROVERBIAL STABILITY OF RPCS
- ALSO LIMITS ITS RATE CAPABILITY BECAUSE OF THE VOLTAGE DROP
  - $\Delta V = \langle Q \rangle \times \text{FREQ.} \times R$

[Q IS THE AVERAGE CHARGE PER COUNT R IS THE TOTAL ELECTRODE RESISTANCE]

LONGEVITY

- RPC MATERIALS ARE INSENSITIVE TO RADIATION BUT:
  - RADICALS PRODUCED IN THE DISCHARGE AFFECT THE ELECTRODE QUALITY → NOISE
  - THE AMOUNT OF CONDUCED CHARGE CAN DEPLETE THE CARRIERS AFFECTING R

State of the art



1mm gap ATLAS upgrade
Resistivity → $5*10^{10}$
Noise → 4000 e-
ABS3.3 at GIF++ → ~10 kHz/cm^2

- LOWERING R IMPROVES RATE CAPABILITY ONLY
  - LOWER RESISTIVITY MATERIALS
  - THINNER ELECTRODES
- ACHIEVING HIGH RATE BY BRUTE FORCE REDUCTION OF R (WITHOUT REDUCING AT THE SAME TIME THE E FIELD) MAY LEAD TO INSTABLE DETECTORS
- REDUCTION OF <Q> IMPROVES RATE CAPABILITY AND LONGEVITY AT THE SAME TIME
  - BY IMPROVING THE S/N ON THE FE ELECTRONICS
  - BY IMPROVING THE SIGNAL COLLECTION EFFICIENCY

Keeping the gas clean is the key to preserve the electrode longevity