Transition to eco-friendly RPC detectors for HEP: the experience of the Bari LHCb/SHiP group

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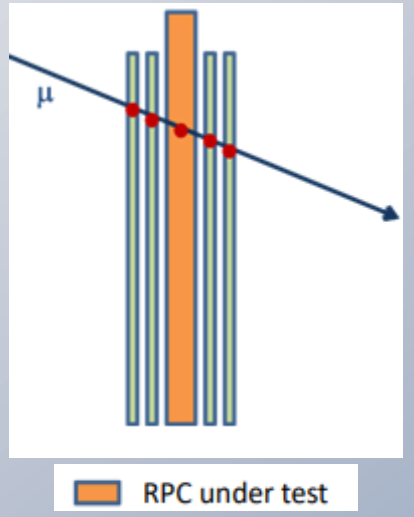
on behalf of the Bari LHCb/SHiP group

RPC lab @ INFN Bari

Activities on RPC detectors started for NESSiE and SHiP proposals, at rates $O(10^2)$Hz/cm^2

Cosmic test stand:

- up to 12 chambers (~3x1 m^2) operated in streamer mode for triggering and tracking
- RPC(s) under test

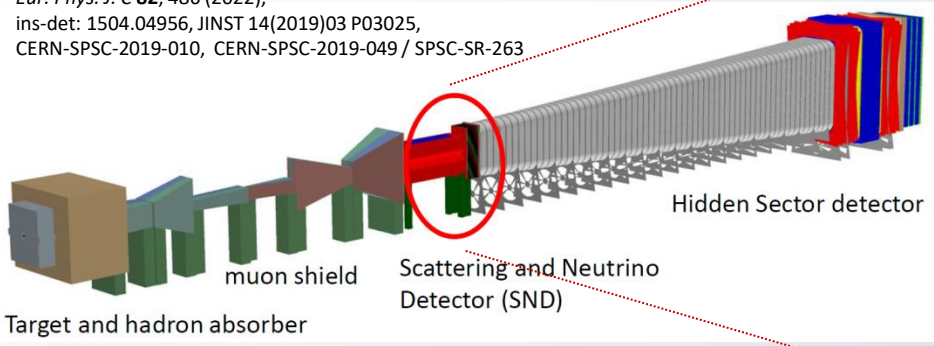


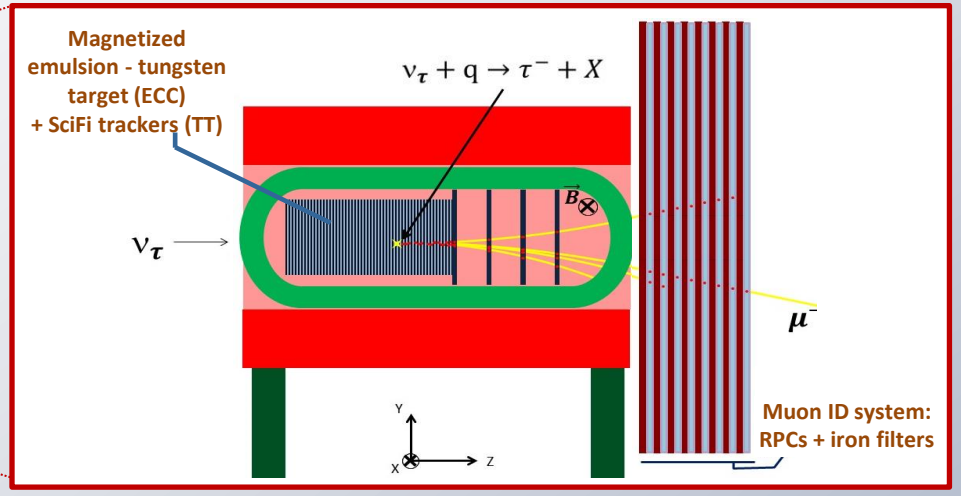
Gas distribution systems:

- 3 gas distribution systems
  detectors can be operated/tested with different gas mixtures and/or premixed gas

RPCs for the SHiP-SND project

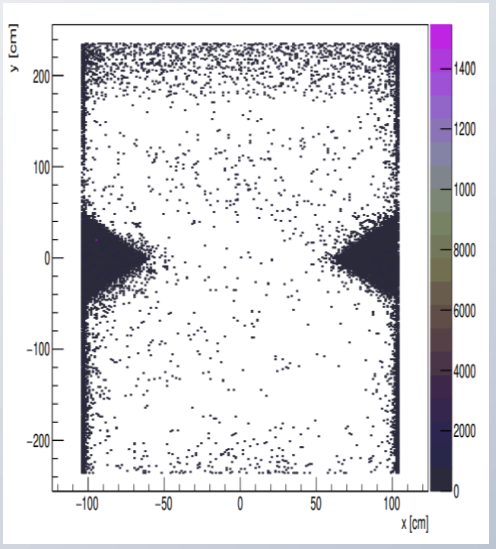
Eur. Phys. J. C **82**, 486 (2022),
ins-det: 1504.04956, JINST 14(2019)03 P03025,
CERN-SPSC-2019-010, CERN-SPSC-2019-049 / SPSC-SR-263

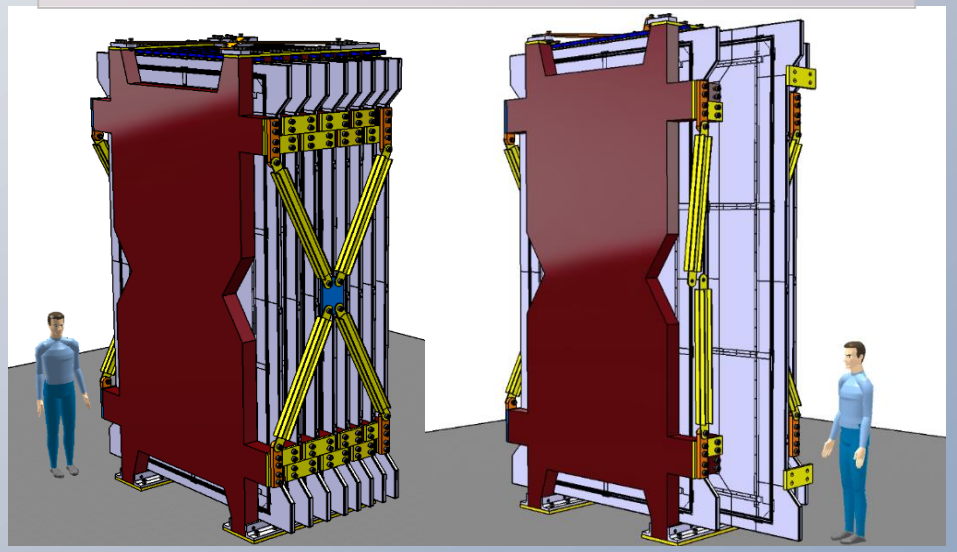




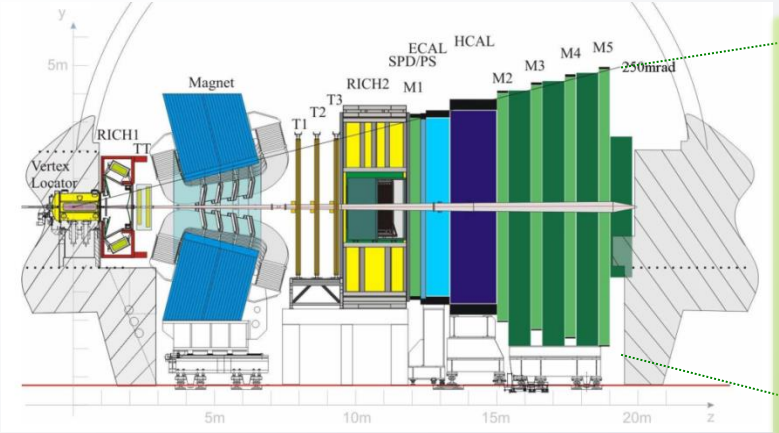
RPC tracking planes sensitive area ~2×4 m^2

Maximum expected charged particle rate ~400 Hz/cm^2





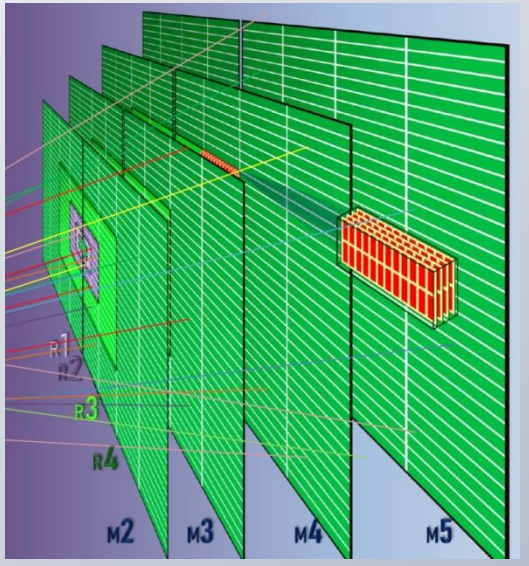
RPCs for the LHCb Upgrade II project



LHCb detector@ Run 1 and Run 2 of LHC

Muon Detector:

- **400 m^2 of sensitive area**
- **M2-M5 MWPC 4-gaps**
- **$\varepsilon_{\mu ID}$ >95% in 25 ns window**
  >99% in a single station
- **≈ 4 orders of magnitude flux-variability across the sensitive area**



RPCs for the LHCb Upgrade II project

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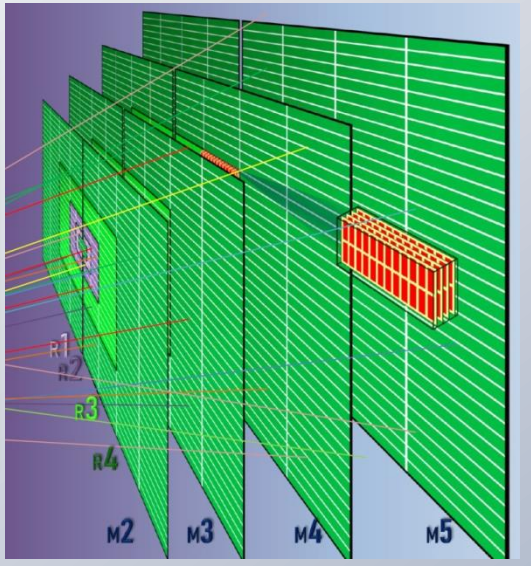
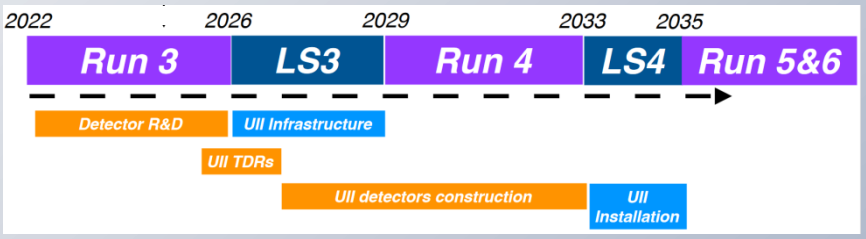


expected @ U2

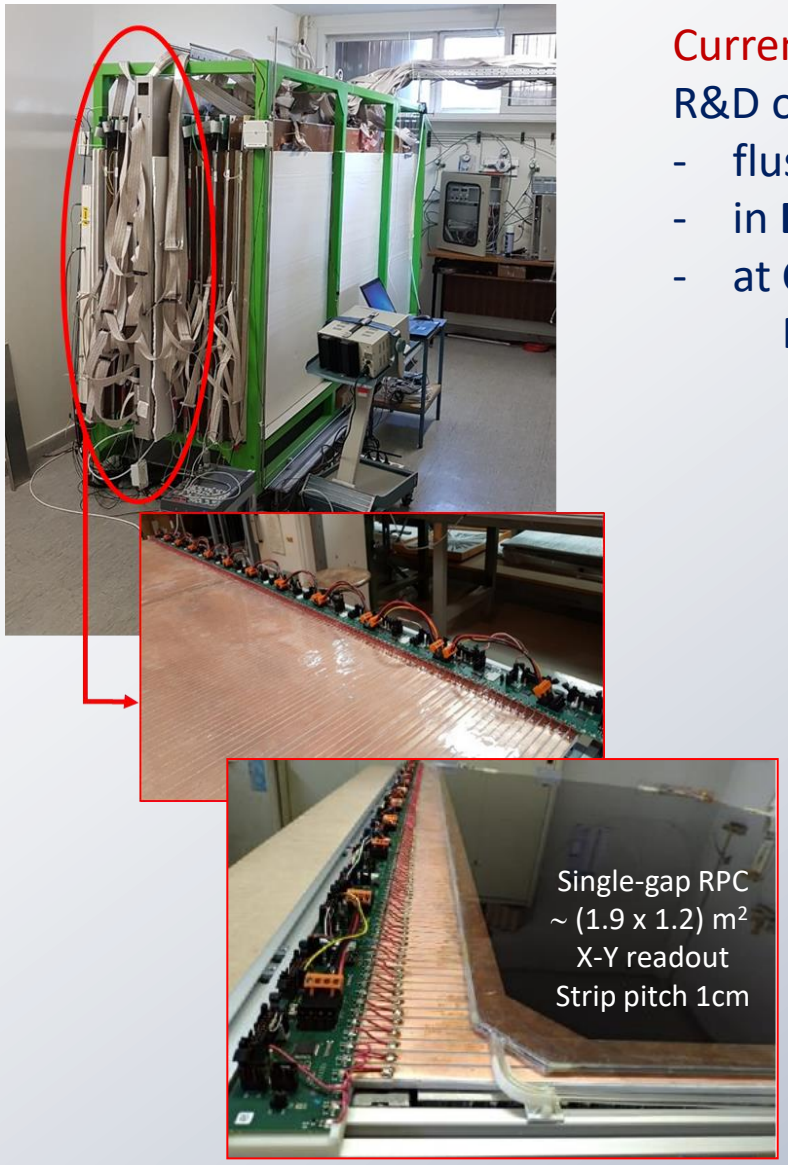
region		max rate (kHz/cm2)	MWPC
M2	R1	998	replace
	R2	98	
	R3	13	replace/reuse
	R4	10	
M3	R1	575	replace
	R2	72	
	R3	8	replace/reuse
	R4	3	
M4	R1	211	replace
	R2	30	
	R3	5	replace/reuse
	R4	2	
M5	R1	179	replace
	R2	20	
	R3	4	replace/reuse
	R4	2	



new detector technologies

- R1-R2 option (exp. rate *O*(MHz/cm^2)): μRWELL
- R4 options (exp. rate *several* kHz/cm^2): **RPCs** or SCI-Tiles

Ongoing R&D activities



Current studies

R&D on avalanche RPCs (**2mm** and **1.6 mm**-thick gas gaps):

- flushed with **Freon-based** and **Freon-free** gas mixtures
- in **Bari** (large area RPCs)
- at **CERN GIF++** (smaller area RPC, within the **RPC EcoGas@GIF++ Collaboration** and **AIDAINNOVA**)

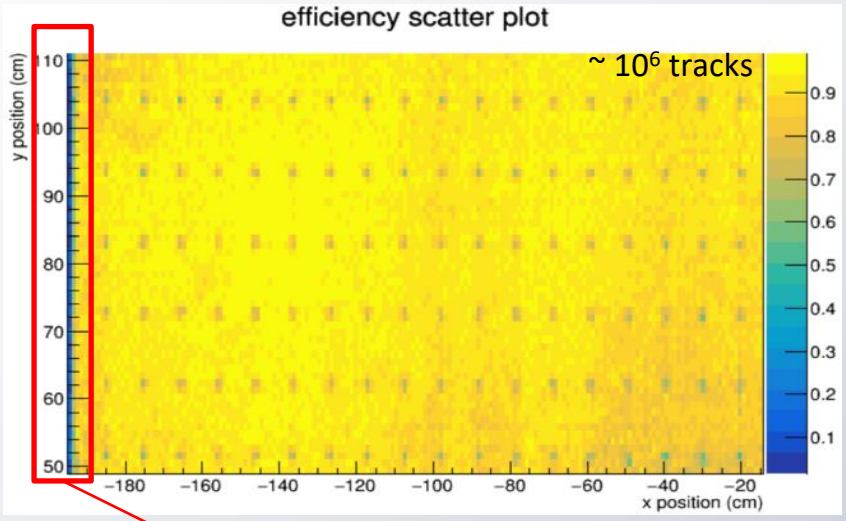
Experimental set-up in Bari

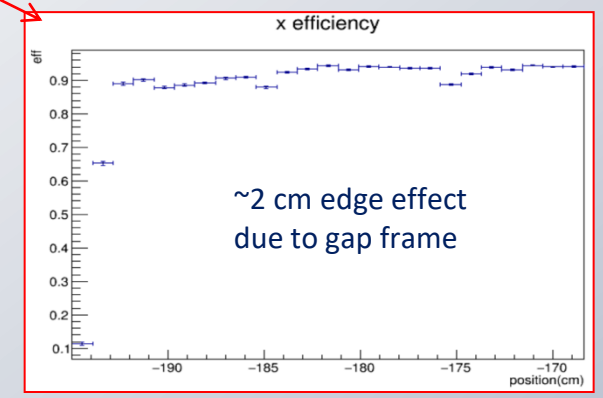
- FE boards equipped with 2 FEERIC chips (ALICE exp., *JINST 9 (2014) C09013*)
- Custom FPGA-based readout boards and trigger supervisor
- Trigger provided by 4 chambers (streamer RPCs)
- Tracking

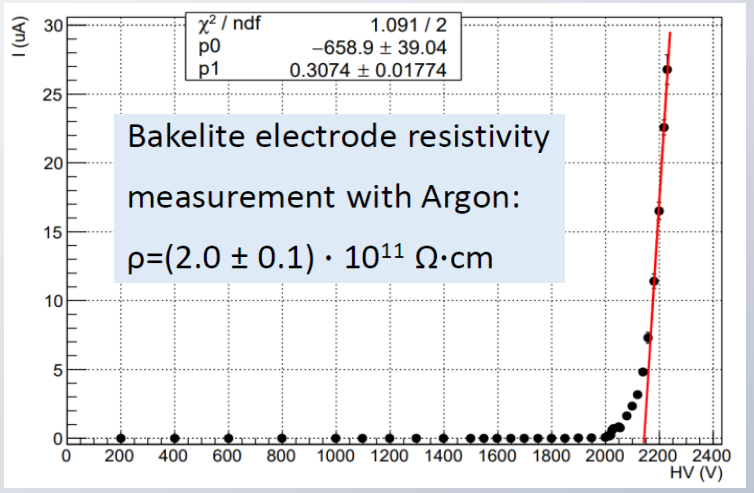
Performance of 2mm large area gaps

@Bari

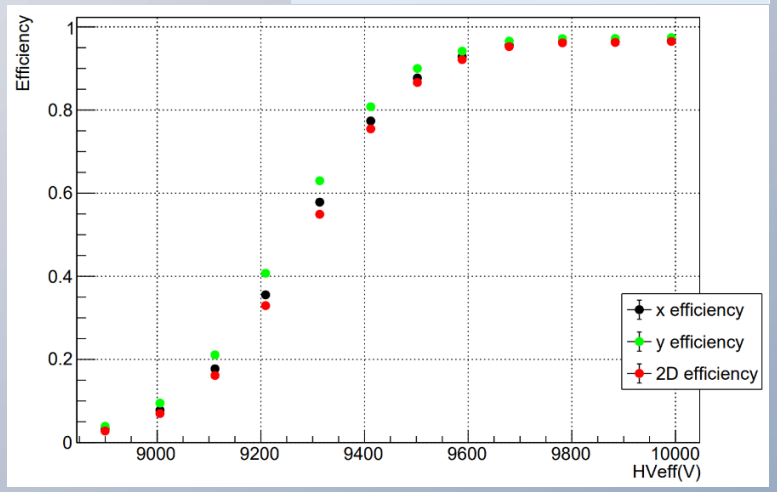
- Dimension: ~(1.9 × 1.2) m^2 ;
- Gap width: 2 mm;
- Readout by 2 panels of orthogonal strips ~1 cm pitch;
- Bakelite electrodes thickness: 2 mm





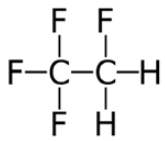


Std: 95.2% R134a-4.5% iC_4H_{10}-0.3%SF_6



Towards new-generation RPCs

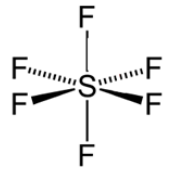
Future applications (e.g. HL-LHC) require significant progress in detector rate capability and longevity, together with **eco-compatibility of the gas mixture**



R134a

($C_2H_2F_4$)

GWP 1300

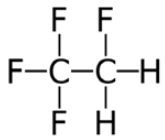


SF_6

GWP 23900

F-gases with high Global Warming Potential in avalanche RPCs standard mixture

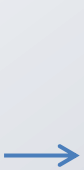
First approach: R134a replacement with HFO-1234ze

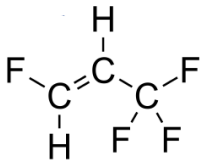


R134a

($C_2H_2F_4$)

GWP 1300





HFO-1234ze

($C_3H_2F_4$)

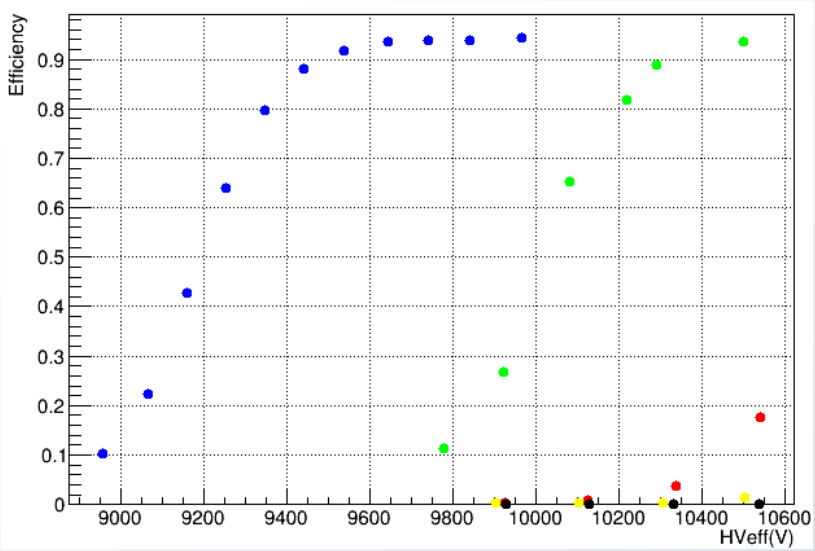
GWP 6

- 84.5% R134a - 10.0% HFO - 5% iC_4H_{10} - 0.5% SF_6 (-10%)
- 74.5% R134a - 20.0% HFO - 5% iC_4H_{10} - 0.5% SF_6 (-20%)
- 69.5% R134a - 25.0% HFO - 5% iC_4H_{10} - 0.5% SF_6 (-24%)
- 0.0% R134a - 94.5% HFO - 5% iC_4H_{10} - 0.5% SF_6 (-90%)

Reduction of the impact on the environment wrt STD mix

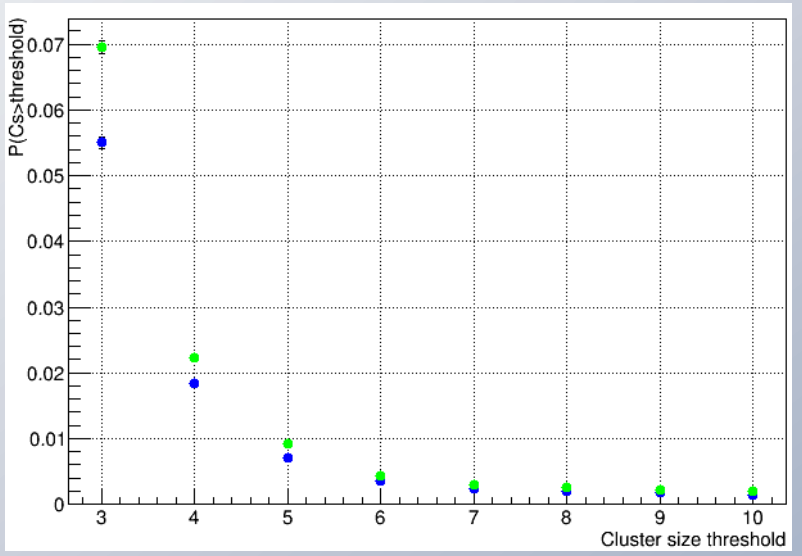
Investigating the 'HFO' option

@Bari



- Standard gas mixture: 94.5% R134a - 0% HFO- 5% iso - 0.5% SF_6
- 84.5% R134a - 10% HFO - 5% iso - 0.5% SF_6
- 74.5% R134a - 20% HFO - 5% iso - 0.5% SF_6
- 69.5% R134a - 25% HFO - 5% iso - 0.5% SF_6
- 0% R134a - 94.5% HFO - 5% iso - 0.5% SF_6

Probability cluster size > Threshold (horizontal strips)

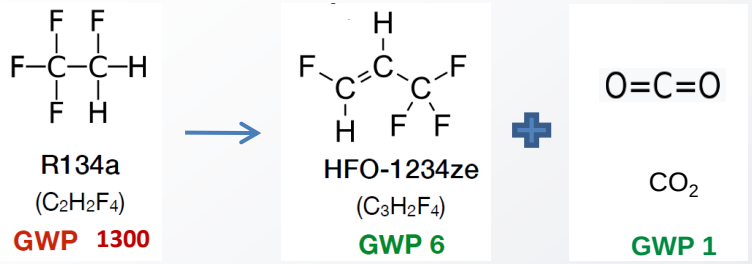


The replacement of R134a with HFO results in a significant increase of the operating voltage
$\Rightarrow$ addition of CO_2

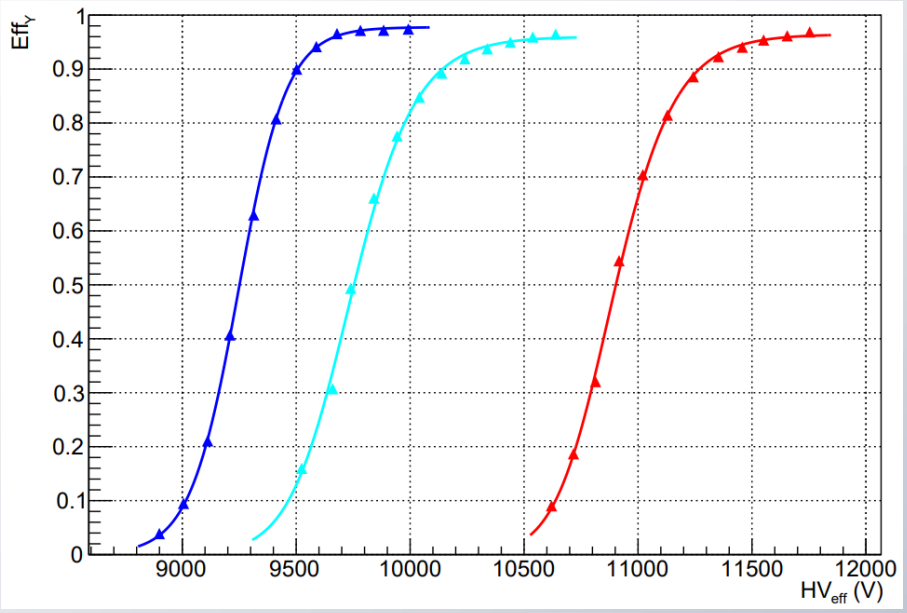
Investigating the 'HFO-CO_2' option

@Bari

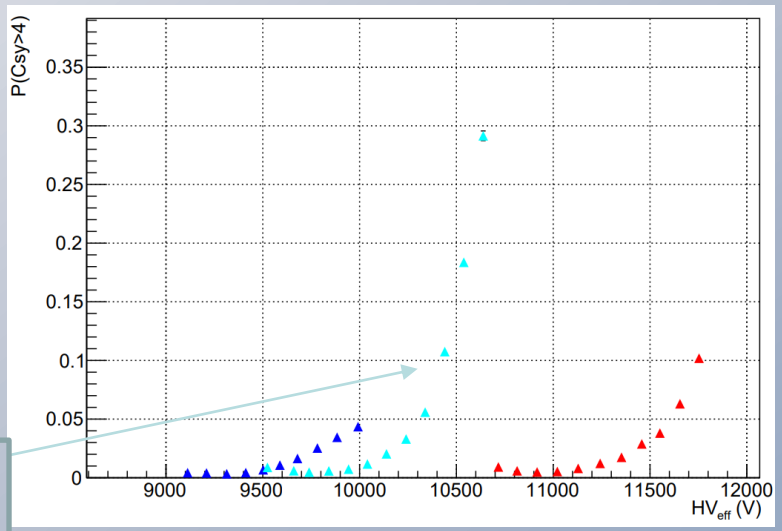
Reduction of the impact on the environment wrt STD mix (70÷90)%



- 25%HFO -20% R134a -49.5% CO_2-5.0% iC_4H_{10}- 0.5% SF_6
- 25%HFO - 0% R134a -69.5% CO_2-5.0% iC_4H_{10}- 0.5% SF_6
- 35%HFO - 0% R134a -60.0% CO_2-4.5% iC_4H_{10}- 0.5% SF_6
- 35%HFO - 0% R134a -60.0% CO_2- 4.0% iC_4H_{10} -1.0% SF_6



- 95.2% R134a/ 4.5% iC_4H_{10} / 0.3% SF_6 (standard)
- 60% CO_2/ 35% HFO/ 4.5% iC_4H_{10} / 0.5% SF_6
- 69.5% CO_2/ 25% HFO/ 5% iC_4H_{10} / 0.5 % SF_6

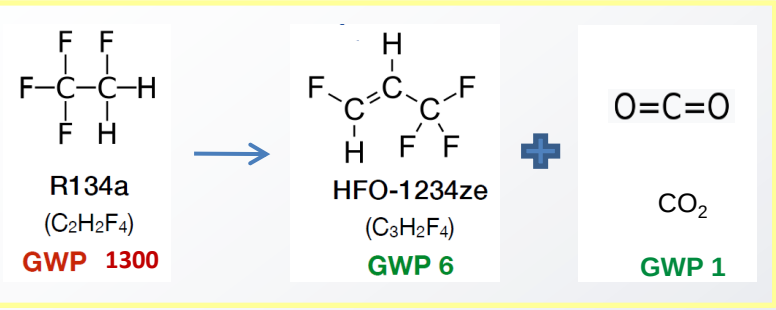


- Fraction of events with *large charge content* > 10% at the WP increasing very rapidly with applied HV

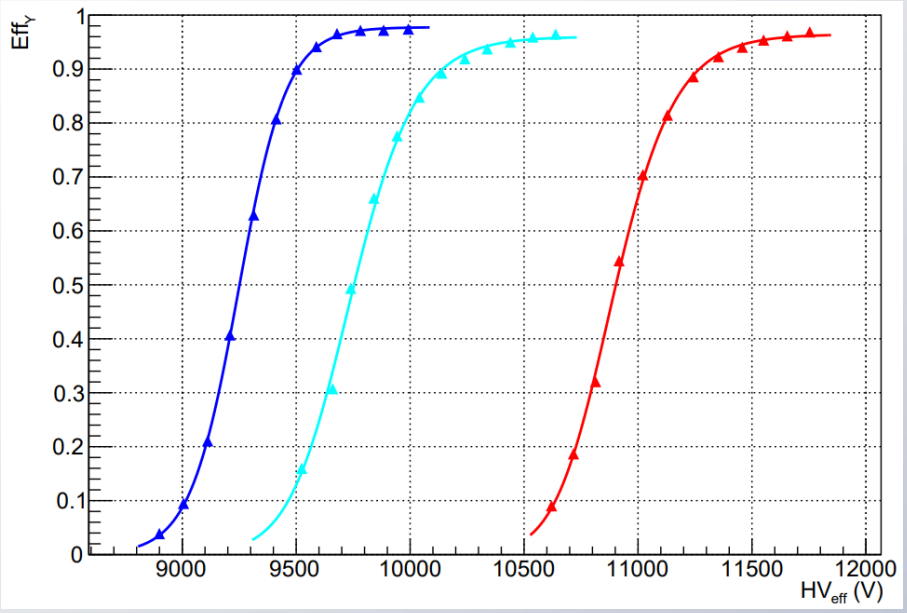
Investigating the 'HFO-CO_2' option

@Bari

Reduction of the impact on the environment wrt STD mix (70÷90)%



- 25%HFO -20% R134a -49.5% CO_2-5.0% iC_4H_{10}- 0.5% SF_6
- 25%HFO - 0% R134a -69.5% CO_2-5.0% iC_4H_{10}- 0.5% SF_6
- 35%HFO - 0% R134a -60.0% CO_2-4.5% iC_4H_{10}- 0.5% SF_6
- 35%HFO - 0% R134a -60.0% CO_2- 4.0% iC_4H_{10} -1.0% SF_6



- 95.2% R134a/ 4.5% iC_4H_{10} / 0.3% SF_6 (standard)
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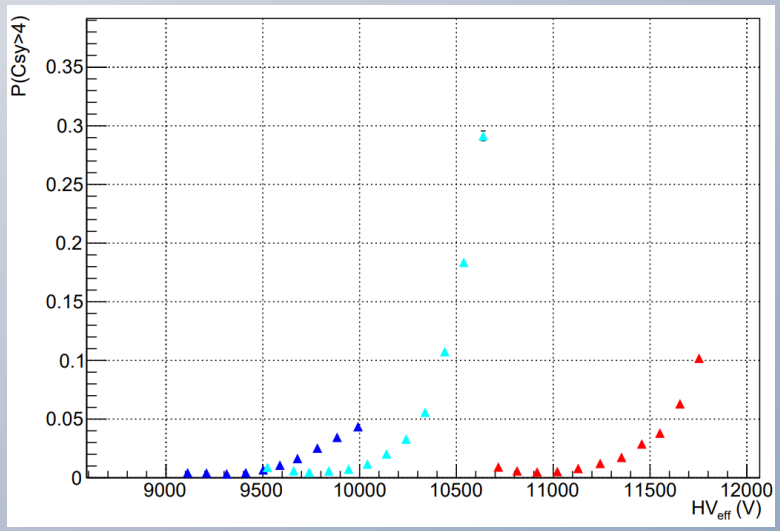
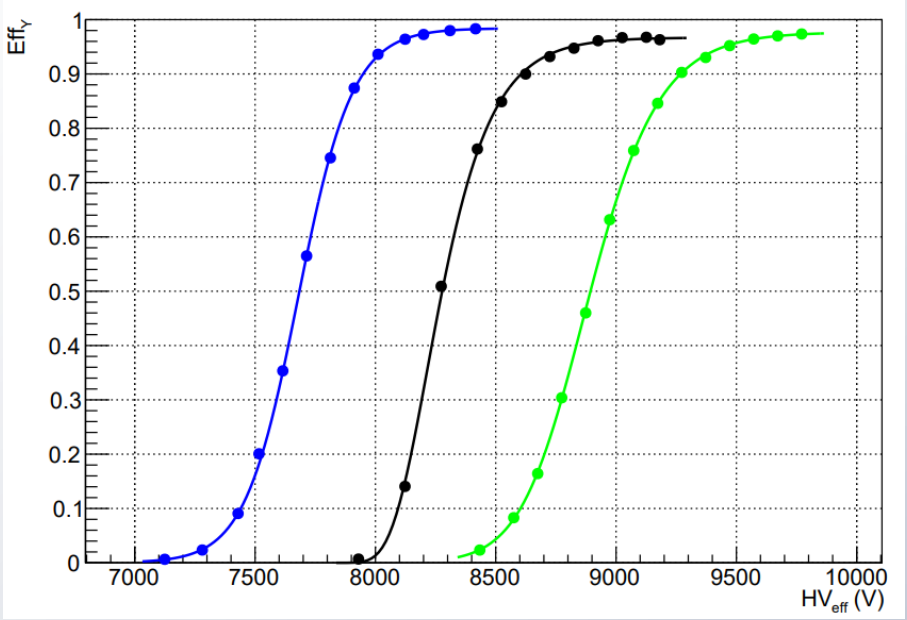


- Performance comparable with standard mixture
  WP still above 11 kV

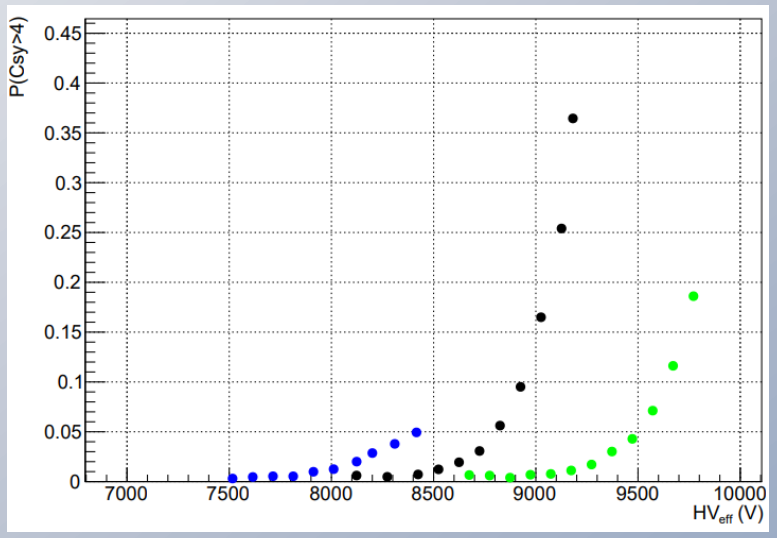
Investigating the 'HFO-CO_2' option with thinner gaps

@Bari

Similar gas mixtures were tested using a 1.6 mm thick gap, comparable performance, WP shifted towards lower values



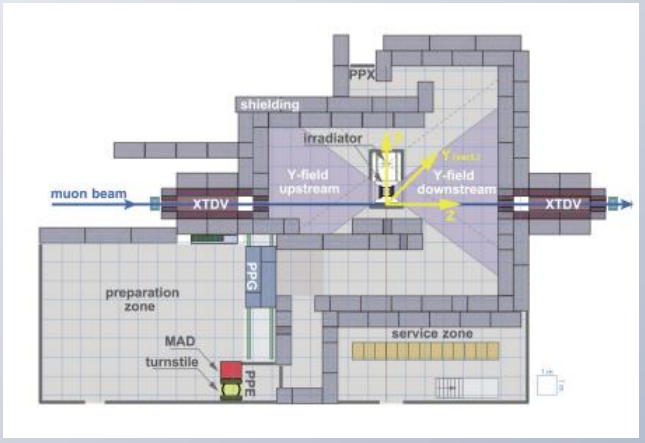
- 95.2% R134a/ 4.5% iC_4H_{10} / 0.3% SF_6 (standard)
- 60% CO_2/ 35% HFO/ 4% iC_4H_{10} / 1% SF_6 (*eco2*)
- 69% CO_2/ 25% HFO/ 5% iC_4H_{10} / 1 % SF_6 (*eco3*)



Studies within the RPC EcoGas@GIF++ Collaboration

Parallel studies ongoing at the CERN Gamma Irradiation Facility with a *small* chamber (1.6 mm thick gap and electrodes)

GIF++



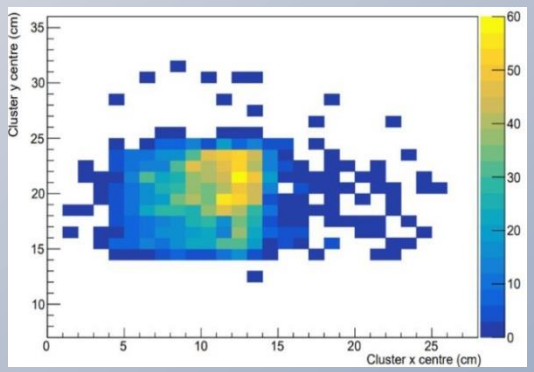
- ^{137}Cs source, activity 14 TBq
- System of filters providing different attenuation factors (ABS)
- Muon beam, energy 100 GeV

Studies within the RPC EcoGas@GIF++ Collaboration

Parallel studies ongoing at the CERN Gamma Irradiation Facility with a *small* chamber (1.6 mm thick gap and electrodes)

GIF++

- TDC readout
- Trigger: two beam scintillators + two additional scintillators, effective area ~(10 × 10) cm²
- No tracking



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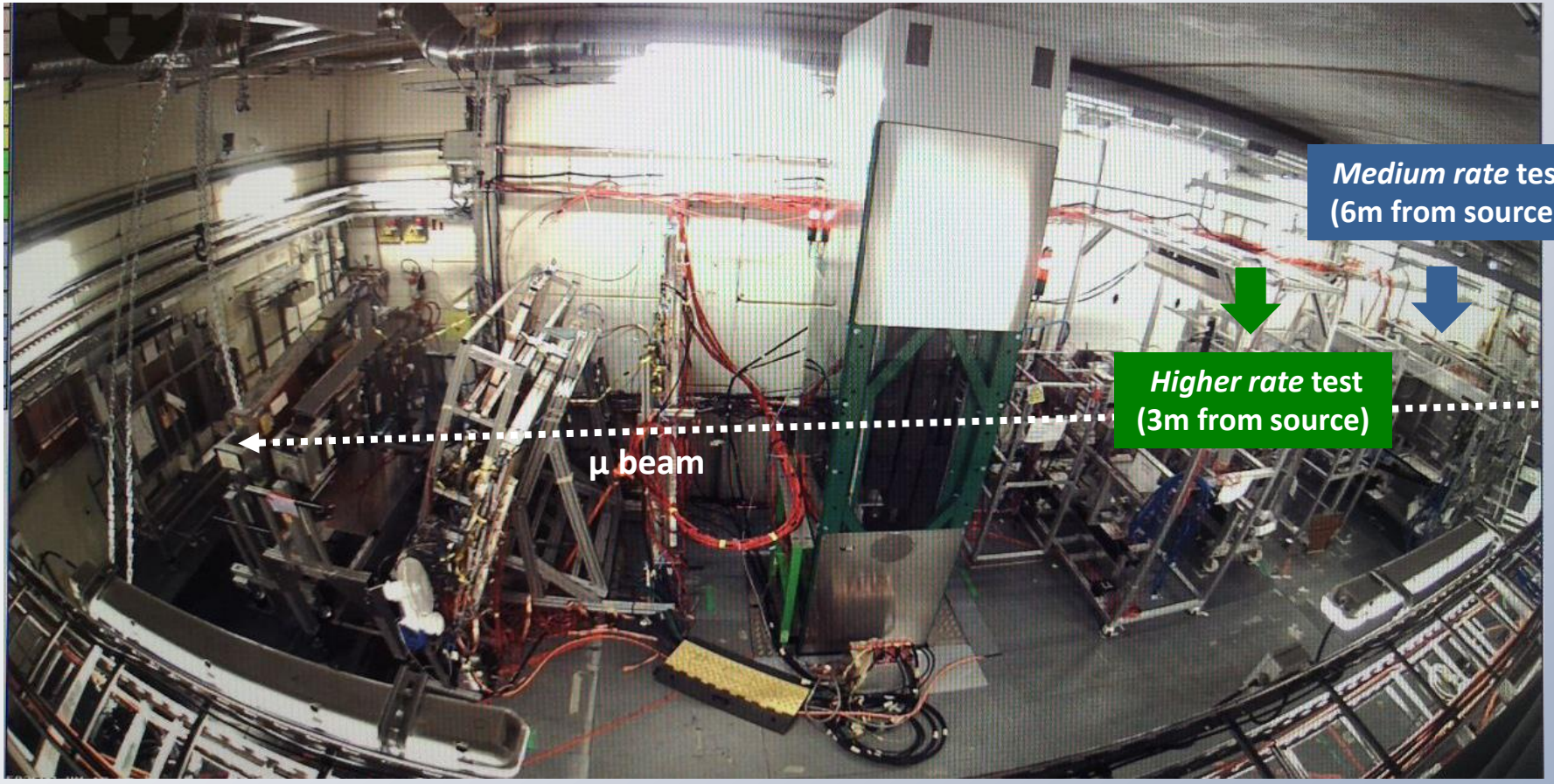
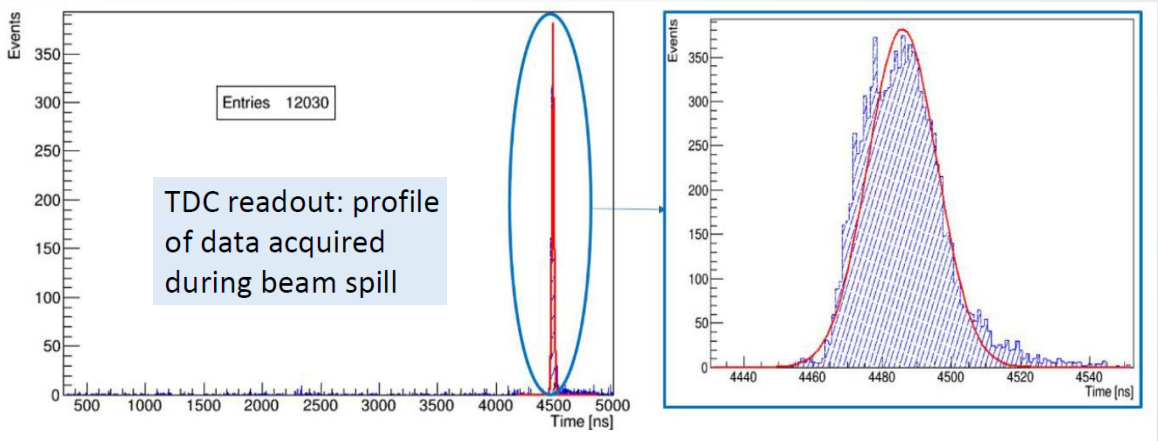


Three mixture tested with several ABS:

Std: 95.2% R134a/4.5% iso/0.3% SF_6
Eco2: 60%CO_2/35%HFO/4%iso/1%SF_6
Eco3: 69%CO_2/25%HFO/5%iso/1%SF_6

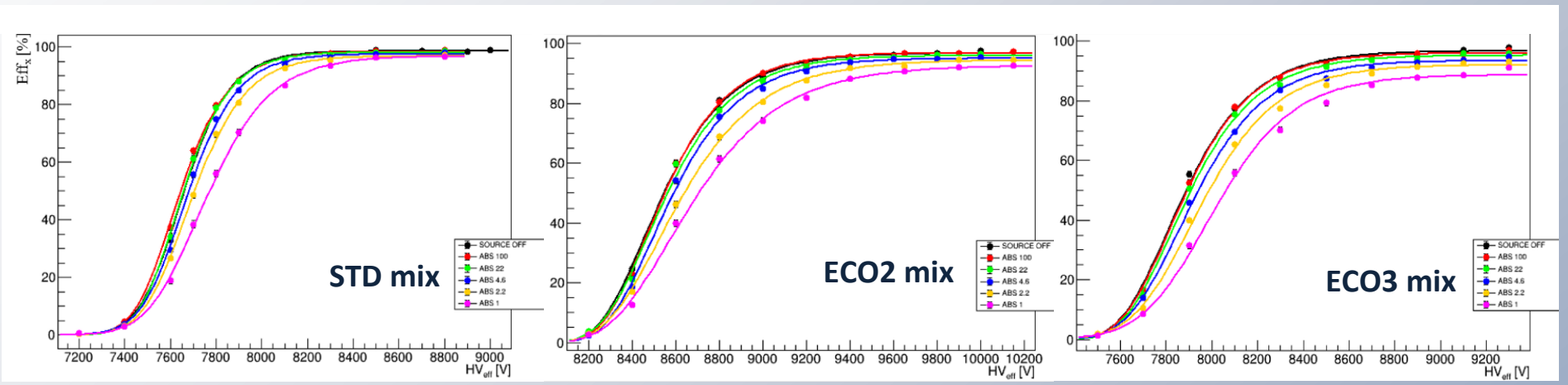
Results at CERN GIF++ @6m from the source

Source Off



muon window defined as $[t_\mu-3\sigma, t_\mu+3\sigma]$

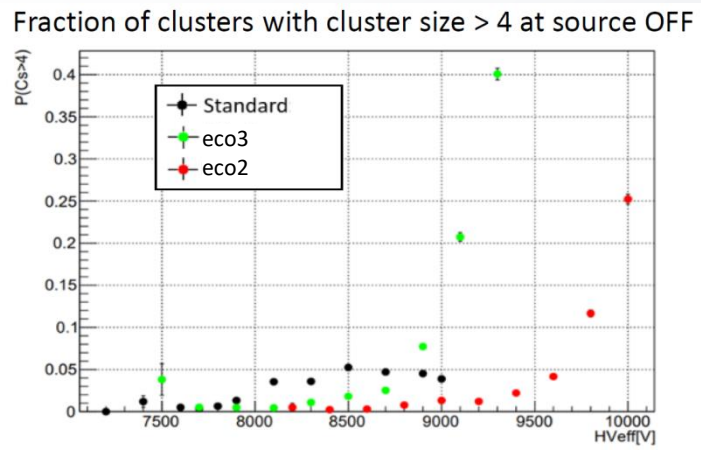
$$Eff = \frac{num.events\ with\ at\ least\ one\ hit\ in\ \Delta t}{num\ triggers}$$



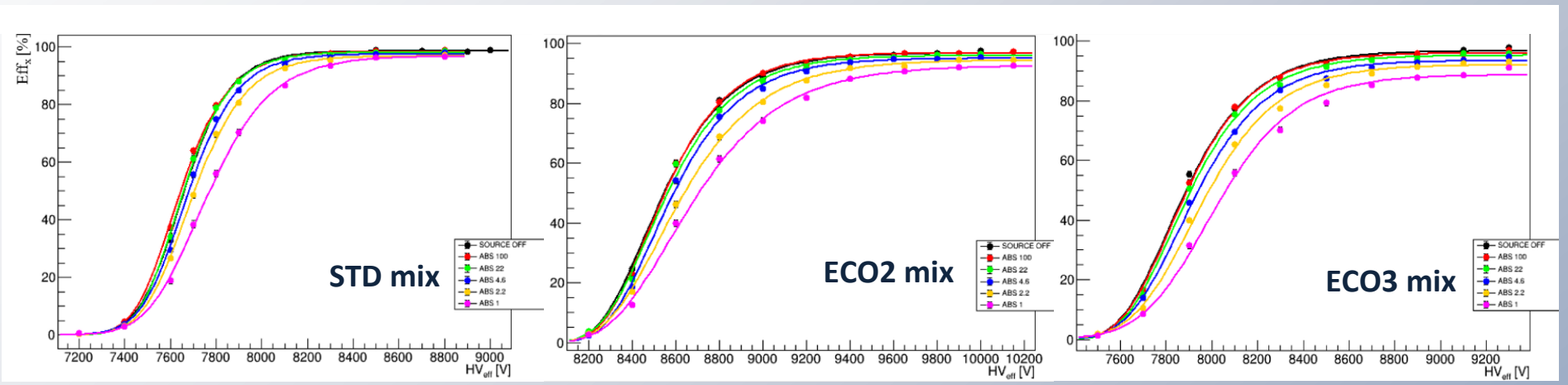
→ At WP, comparable efficiency (>95%) for all mixtures at Source Off or low irradiation

→ efficiency plateau drop at maximum level of irradiation (ABS1) : ε_{STD} ~ 2%, ε_{ECO2} <5%, ε_{ECO3} ~ 8%

Results at CERN GIF++ @6m from the source



- P(Cs>4) at WP comparable for the 3 mixtures
- at (WP+200V), below 5% for std mix and eco2, increased to 8% for eco3

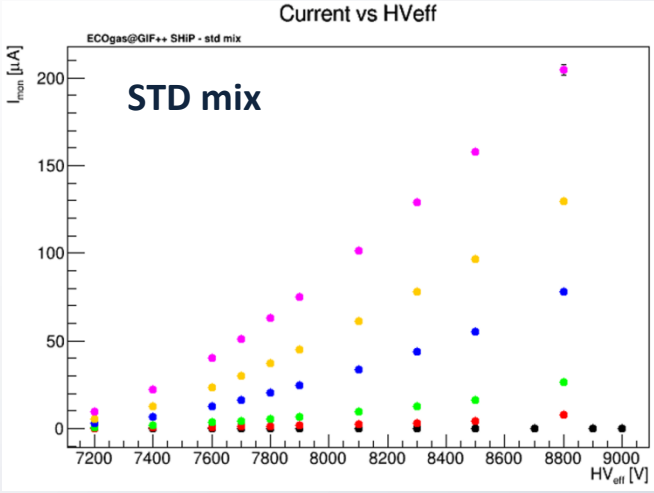


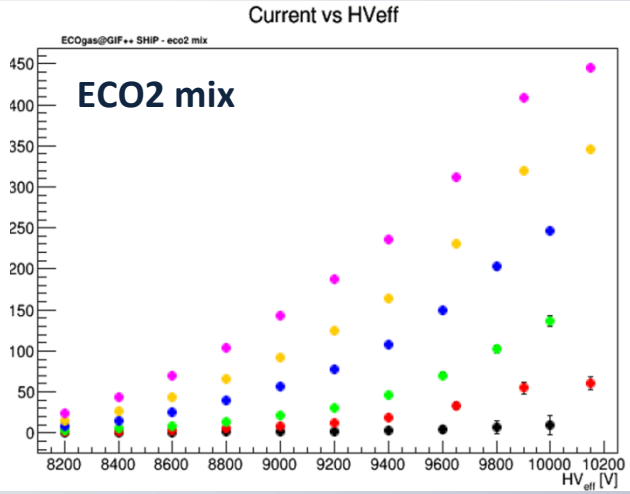
→ At WP, comparable efficiency (>95%) for all mixtures at Source Off or low irradiation

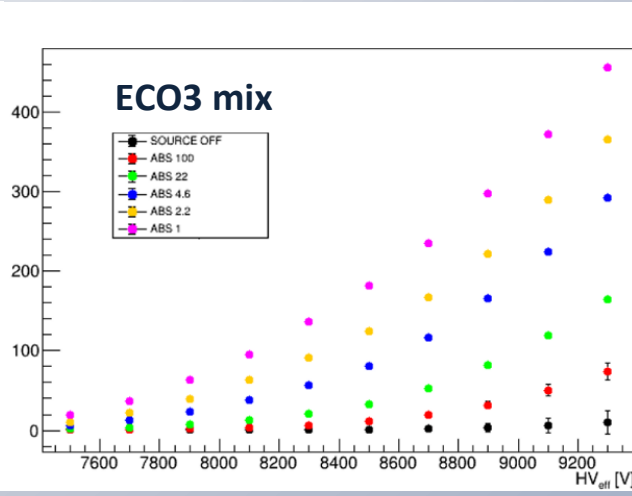
→ efficiency plateau drop at maximum level of irradiation (ABS1) : $\varepsilon_{STD} \sim 2\%$, $\varepsilon_{ECO2} < 5\%$, $\varepsilon_{ECO3} \sim 8\%$

Results at CERN GIF++ @6m from the source

average of the current values sampled every second both during beam spill and interspill

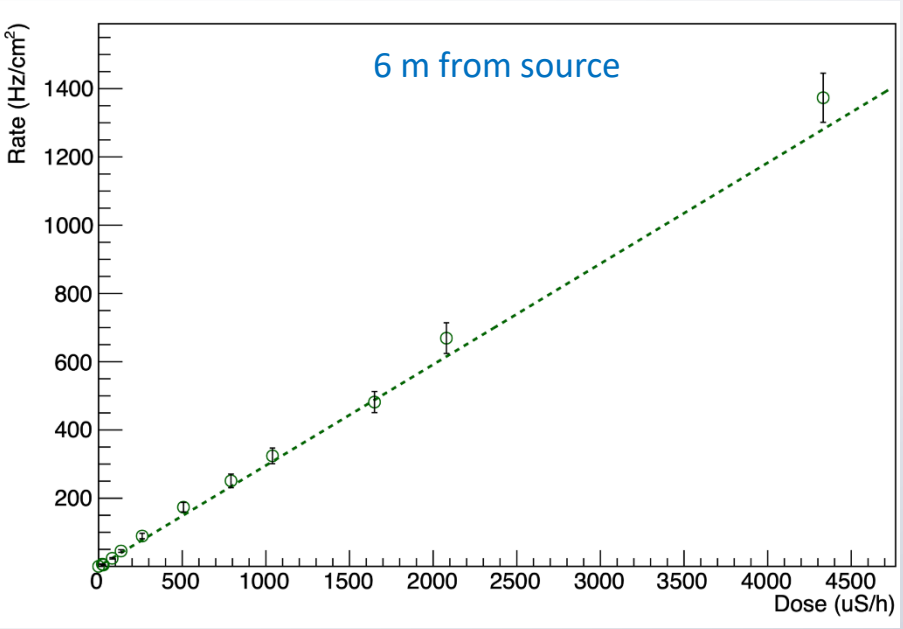


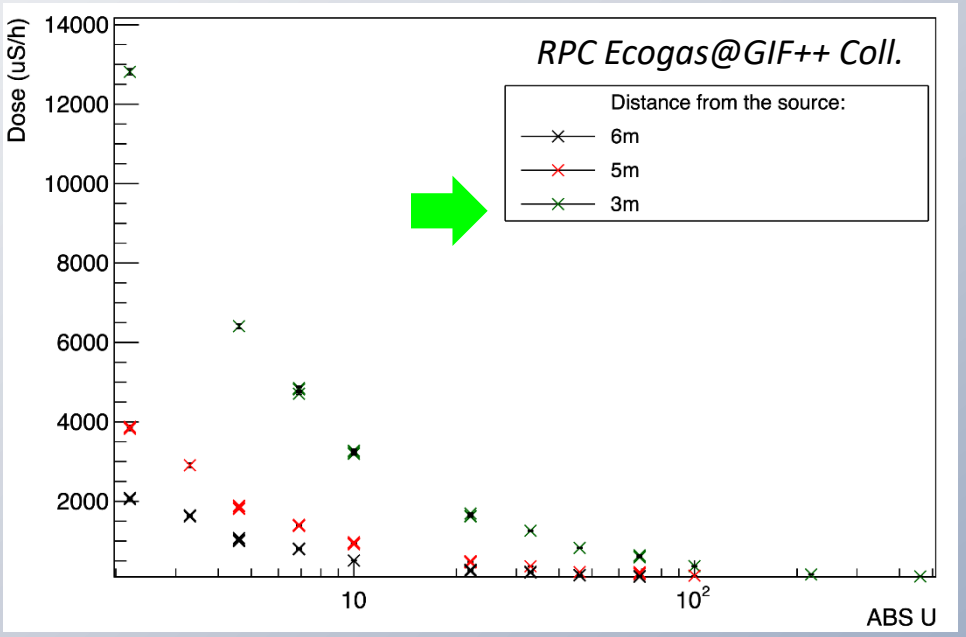




Currents for ABS 1 at WP with eco-friendly gas mixtures doubled w.r.t. std

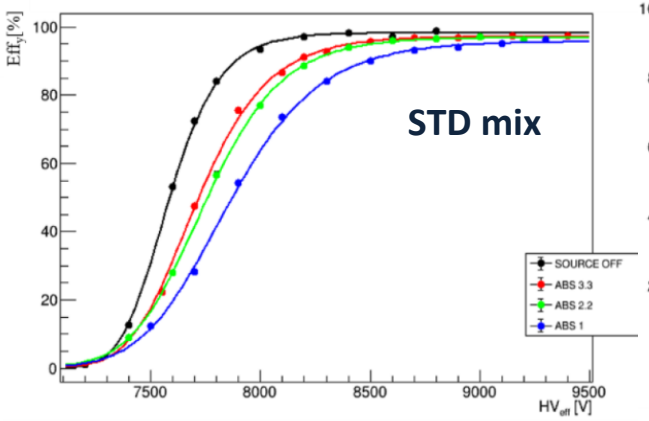
Results at CERN GIF++ @6m from the source

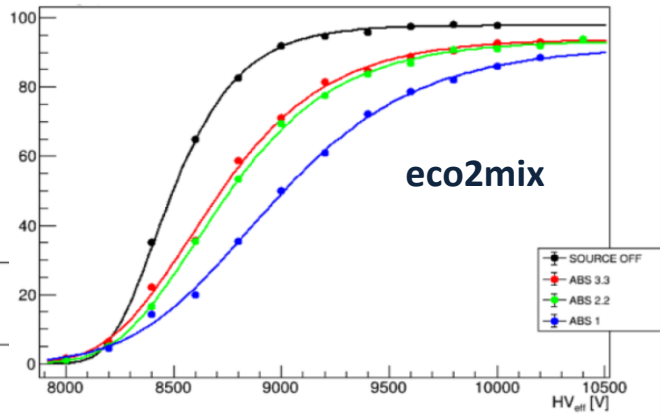


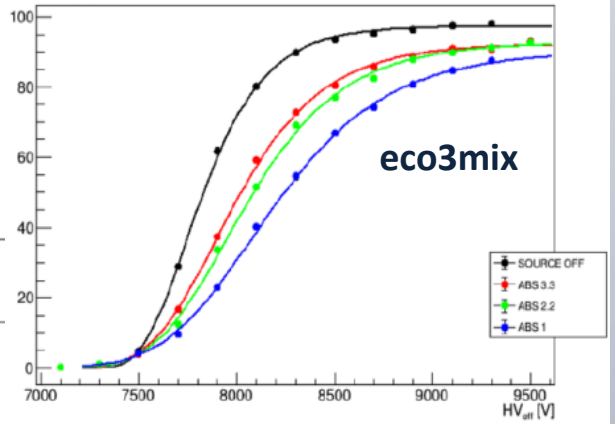


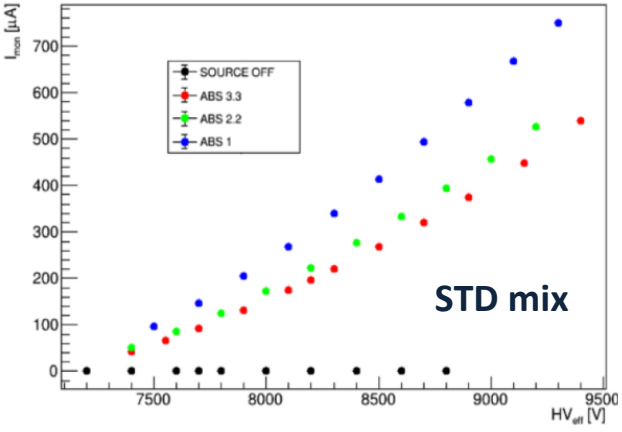
Moving towards the source (6 m → 3 m)

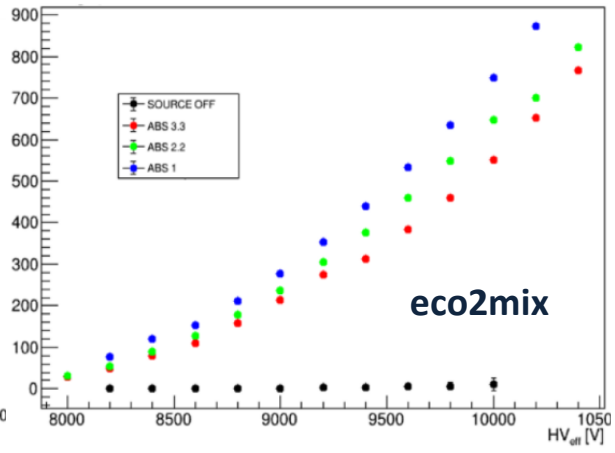
Results at CERN GIF++ @3m from the source

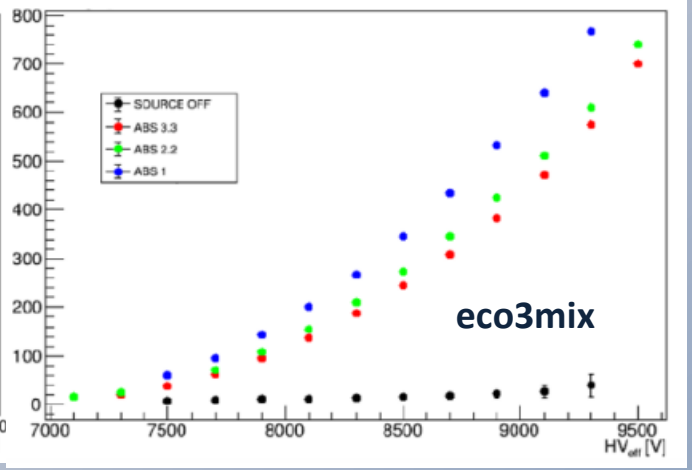








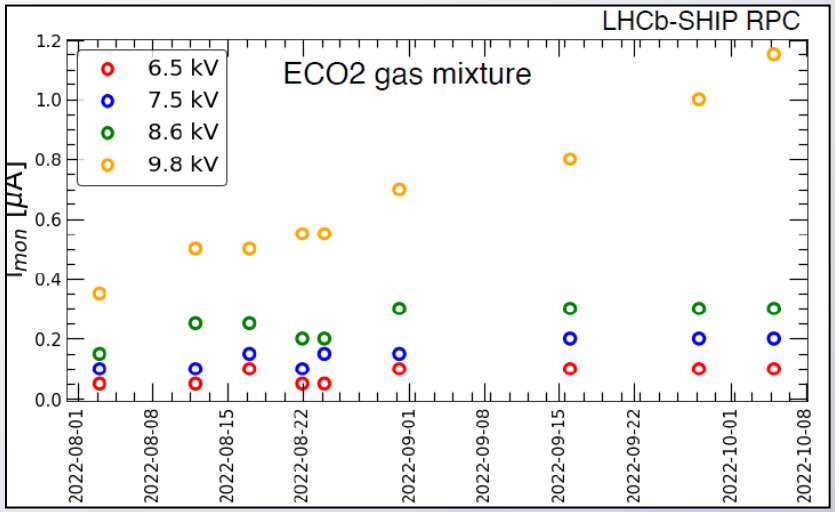




Long term performance studies at CERN GIF++

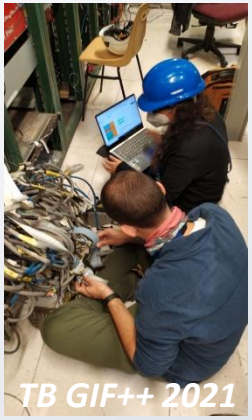
Irradiation campaign of RPCs to accumulate an equivalent charge of the HL-LHC Phase
Fundamental for the validation of new eco-friendly gas mixtures

RPC EcoGas@GIF++ Coll.

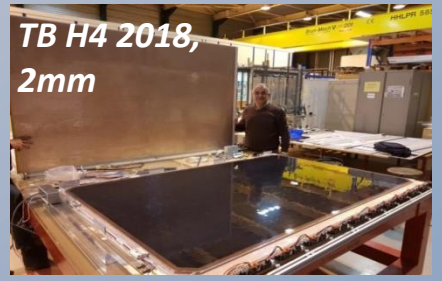


Started in August, with ECO2 mixture within the RPC Ecogas@GIF++ Collaboration currently on-going

Conclusions and Outlooks



- R&D on eco-friendly RPC detectors for medium and high rate HEP applications on-going, both at Bari RPC Lab and at CERN GIF++ within the RPC Ecogas@GIF++ Collaboration and AIDAInnova project
- Different HFO1234ze-based gas mixtures tested with cosmic rays, muon beam and gamma background
- Long term performance studies in presence of strong irradiation and HFO-CO2 based mixture are currently on-going at CERN GIF++ within the RPC Ecogas@GIF++ Collaboration



Thank you for your attention