EP-DT
Detector Technologies

Task 7.2.3: Eco-friendly gas mixtures for RPCs

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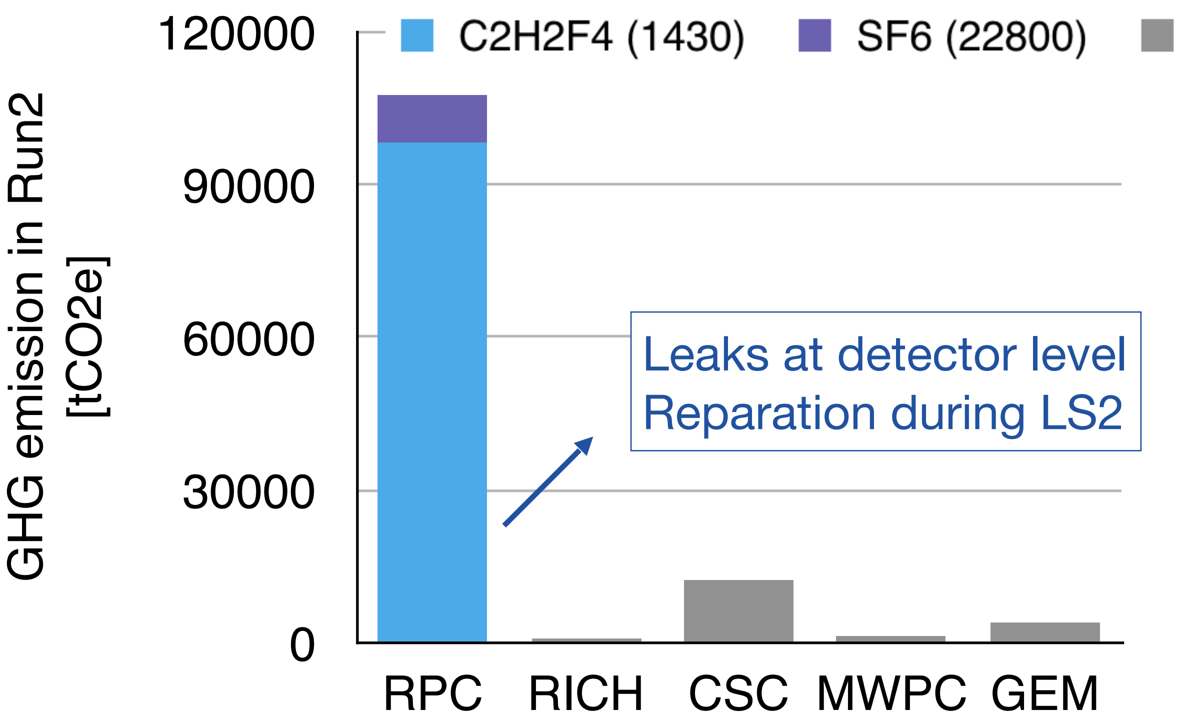
on behalf of the EcoGas@GIF++ Collaboration

CERN

AIDAinnova 2nd Annual Meeting

25 April 2023

GHG emissions at CERN and EU regulation



CERN GHG emissions from particle detectors

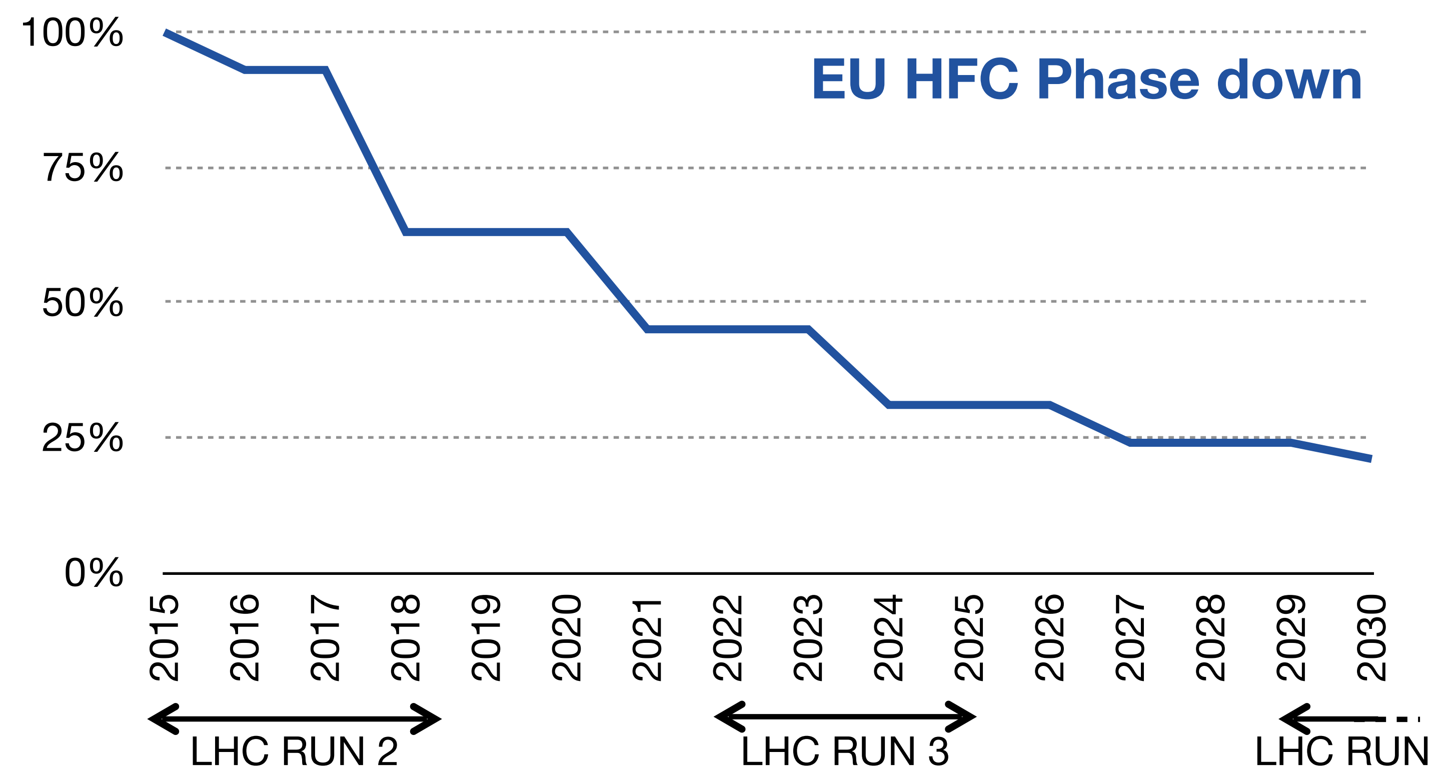
- **Main contributor is $C_2H_2F_4$** used for ALICE, ATLAS and CMS RPC systems
- **Emissions mainly due to leaks** at detector level (fragile connectors) in ATLAS and CMS.
- **Campaign** for leaks reparation in LS2

RPC gas mixture

~95%$C_2H_2F_4$ - ~5%iC_4H_{10} - 0.3%SF_6

European Union "F-gas regulation":

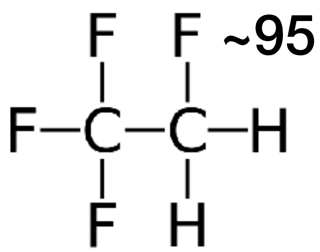
- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases where less harmful alternatives are widely available.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery



Prices are increasing in EU and availability in the future is not known.

Reduction of use of $C_2H_2F_4$ is fundamental for next LHC Runs and future applications

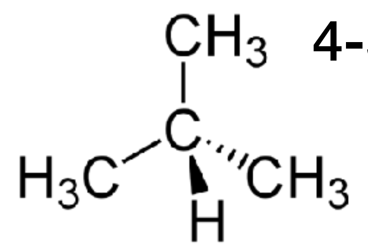
The RPC gas mixture



~95%

$C_2H_2F_4$: GWP 1430

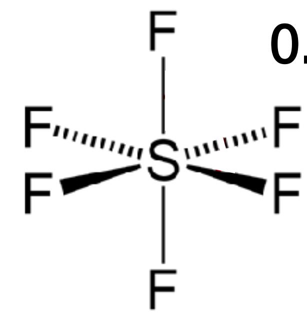
+



4-5%

iC_4H_{10}: GWP 3

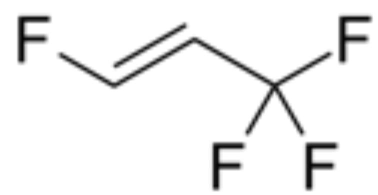
+



0.3%

SF_6: GWP 22800

RPC gas mixture used
in ATLAS and CMS experiments
(very similar for ALICE)



HFO-1234ze. ($C_3H_2F_4$)
GWP 6

Hydro-Fluoro-Olefin (HFO)

- C=C double bond
- fluorine-containing
- hydrogen-containing

Table 3. Percentage composition, in volume, of the gas mixtures used for these tests, their GWP with respect to CO_2, and their CO_2e, in grams, for one liter of mixture. For the calculations of the GWP and CO_2e, the gas densities at STP (p = 1013 hPa, T = 273.15K) of the component gases, reported in the penultimate line of the Table and taken from [17], were used.

	R134a (%)	HFO-1234ze (%)	CO_2 (%)	i-C_4H_{10} (%)	SF_6 (%)	GWP	CO_2e (g/l)
STD	95.2			4.5	0.3	1485	6824
ECO2		35	60	4	1	476	1522
ECO3		25	69	5	1	527	1519
Density (g/l)	4.68	5.26	1.98	2.69	6.61		
GWP	1430	7	1	3	22800		

Values mainly driven by SF_6

[17] NIST Chemistry WebBook, the NIST Standard Reference Database Number 69, https://webbook.nist.gov/chemistry/", retreived on April 2, 2023

New eco-friendly liquids/gases have been developed for industry as refrigerants… not straightforward for RPC operation

AIDA WP 7.2.3 eco-gas studies

Deliverable:
Report on performance studies of several eco-friendly gas mixtures for RPCs operated at different background conditions

Motivation

- Different RPC communities testing eco-friendly gases
- Up to now no eco gas mixture was found to fulfill requirements for already installed RPCs at LHC
  - Layout is fixed, not possible to change FEB and HV cables
- It is fundamental to search for new eco-gases for RPC detectors for LHC and not-LHC experiments as well as for future applications

Studies in the AIDainnova Task WP 7.2.3

- Validation of suitable eco-friendly gas mixture for RPC operation under gamma irradiation
- Long term performance studies on RPC detectors operated under gamma irradiation
- Detector performance with muon beam and gamma background
- F-based impurities production measurements

The ECOGAS@GIF++ collaboration is a joint effort between CERN Gas Team, ATLAS-RPC, ALICE- RPC, CMS-RPC, LHCb-SHIP communities

Institutes involved in the task

Institute	Main contact person
CERN *	Beatrice Mandelli
INFN LNF *	Davide Piccolo
INFN Bari	Alessandra Pastore
INFN Bologna	Davide Boscherini
INFN Roma 2	Barbara Liberti
INFN Torino	Alessandro Ferretti
Ghent University	Michael Tytgat

*Beneficiaries

Lots of other people contributing to the project

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PUGLIESE, GABRIELLA, (INFN Ba),
RAMOS LOPEZ, DAYRON, (INFN Ba),
GALATI, GIULIANA (INFN Ba),
CONGEDO, LILIANA (INFN BA)
AMRUTHA SAMALAN (Ghent University)
BARROSO FERREIRA FILHO, Mapse, (Rio De Janeiro Univ.)
DE JESUS DAMIAO, Dilson (Rio De Janeiro Univ.)
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ALESSANDRO ROCCHI (INFN RM 2)
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SESSA, MARCO (INFN RM 2)
VERZEROLI, MATTIA (Lyon Univ.)

Eco Gas activities and the EcoGas@GIF++ Collaboration

The EcoGas@GIF++ Collaboration

AidaInnova startup

2021 test beam

2022 test beam

August 2022 start of aging

2018

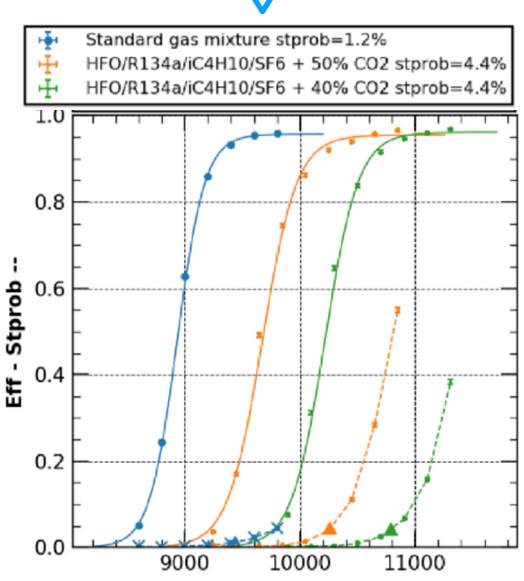
2021

Independent studies in laboratories Atlas-CMS-EPDT

⇩

HFO most promising replacement for r134a

⇩



Setup of the system and first HFO-CO_2 mixtures tested under irradiation @ GIF++

⇩

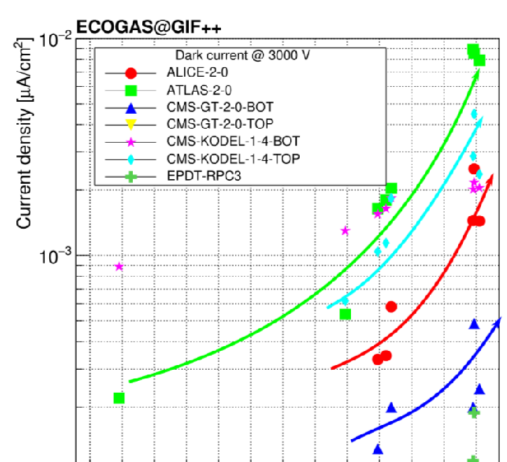
ECO1: CO_2 50%, HFO 45%, iC_4H_{10} 4%, SF_6 1%
High current increase of dark current
After ~ 20 mC/cm^2 integrated charge

⇩

ECO2: CO_2 35%, HFO 60%, iC_4H_{10} 4%, SF_6 1%

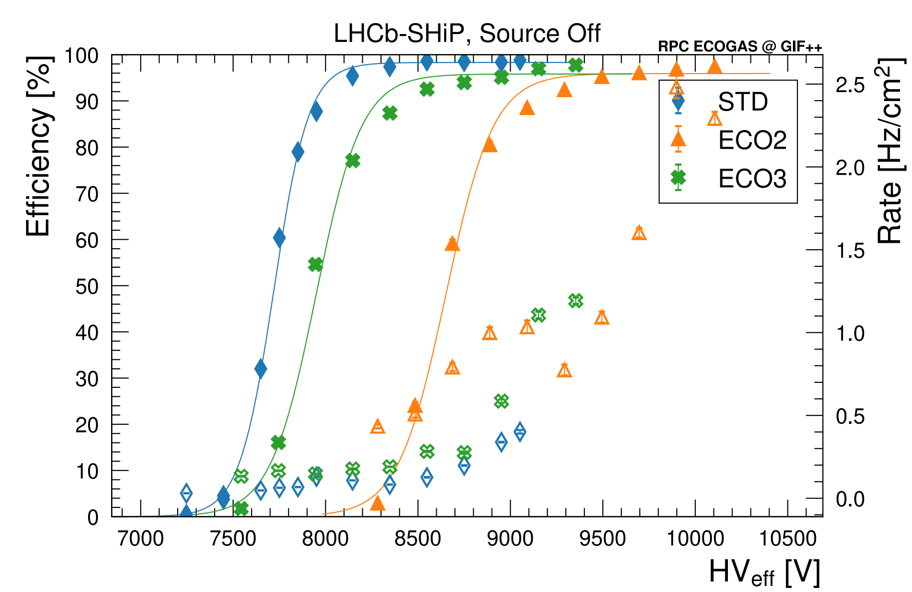
ECO3: CO_2 25%, HFO 69%, iC_4H_{10} 5%, SF_6 1%

PoS(EPS-HEP2019)164



STD, ECO2 and ECO3 mixtures Tested under irradiation

⇩



Set-up at GIF++

- Set-up installed at GIF++
  - 12.2 TBq ^{137}Cs + H4 SPS beam line
- Gas mixer unit to provide up to 4 component gas mixture (humidified)
  - $C_2H_2F_4$, iC_4H_{10}, SF_6, CO_2, Ar, HFO

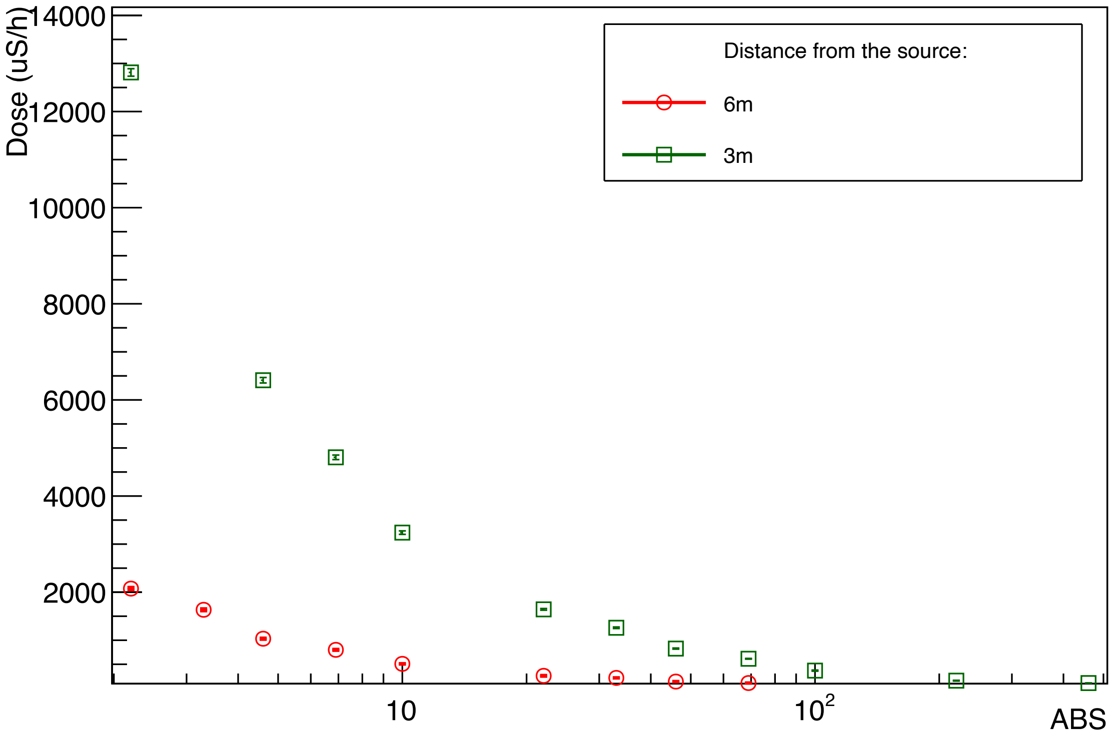
FEBRUARY 2023: upgrade of the gas mixture system with AidaInnova budget

STD: R134A 95.2%, iC_4H_{10} 4.5%, SF_6 0.3%

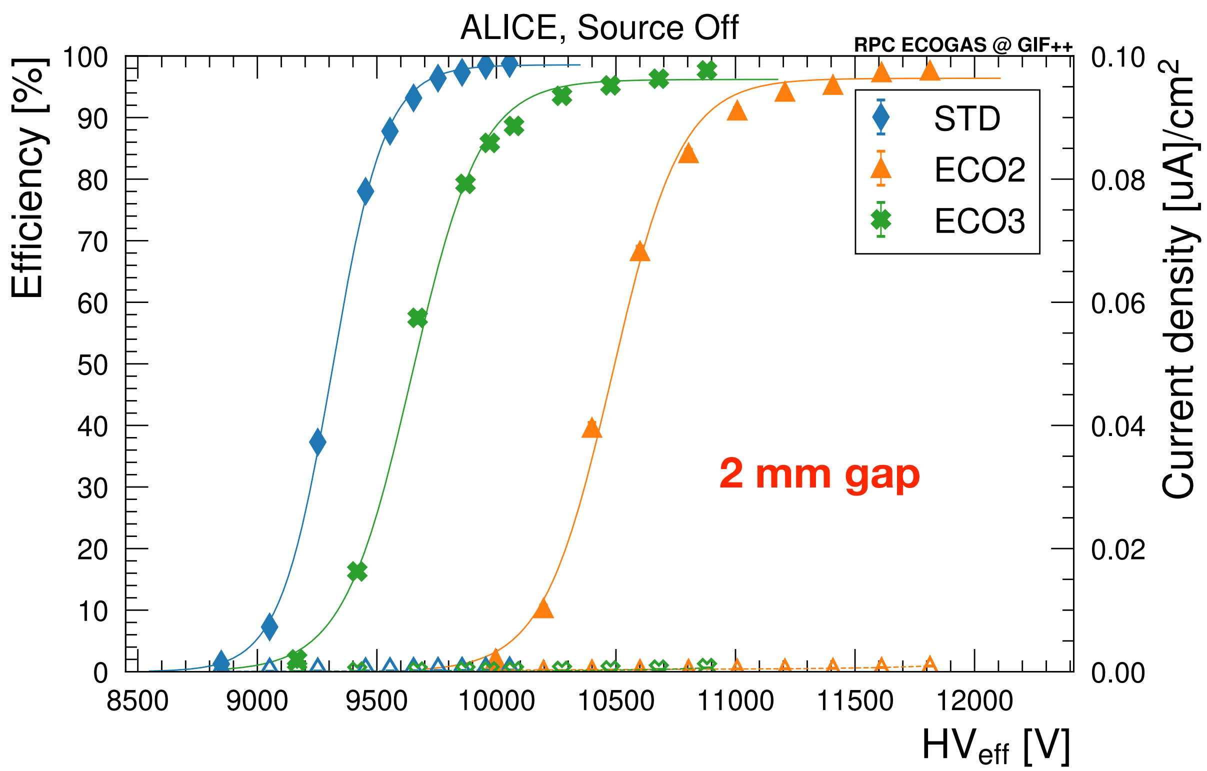
ECO2: CO_2 60%, HFO 35%, iC_4H_{10} 4%, SF_6 1%

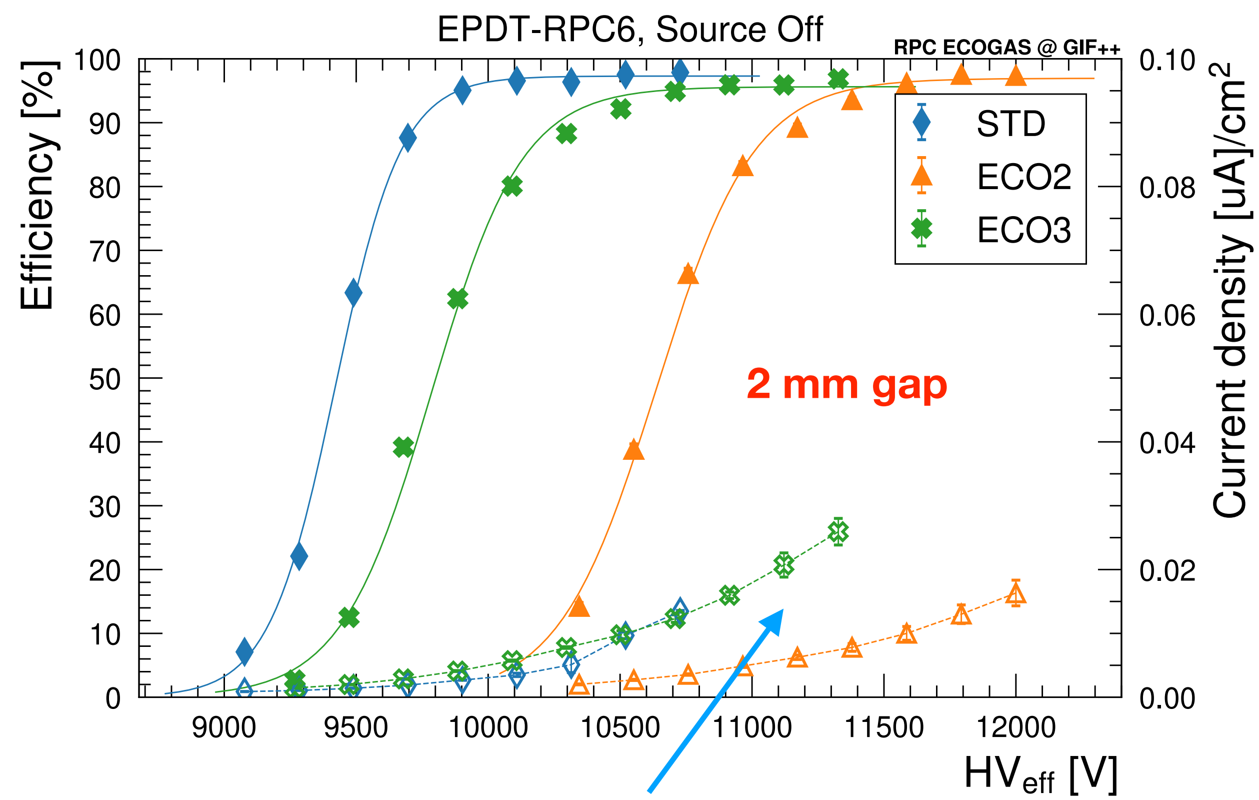
ECO3: CO_2 69%, HFO 25%, iC_4H_{10} 5%, SF_6 1%

- RPCs under test: Alice (2mm), EP-DT (2mm), CMS (2mm), Bari_CMS (1mm), LHCb/SHIP (1.6mm), ATLAS (2mm)
- Aging studies
  - Monitoring of currents
- Detector performance (test-beam)
  - CMS FEB for CMS RPC
  - ALICE FEB FEERIC for ALICE and LHCb/SHIP RPCs
  - Dedicated digitizer for EP-DT and ATLAS RPCs

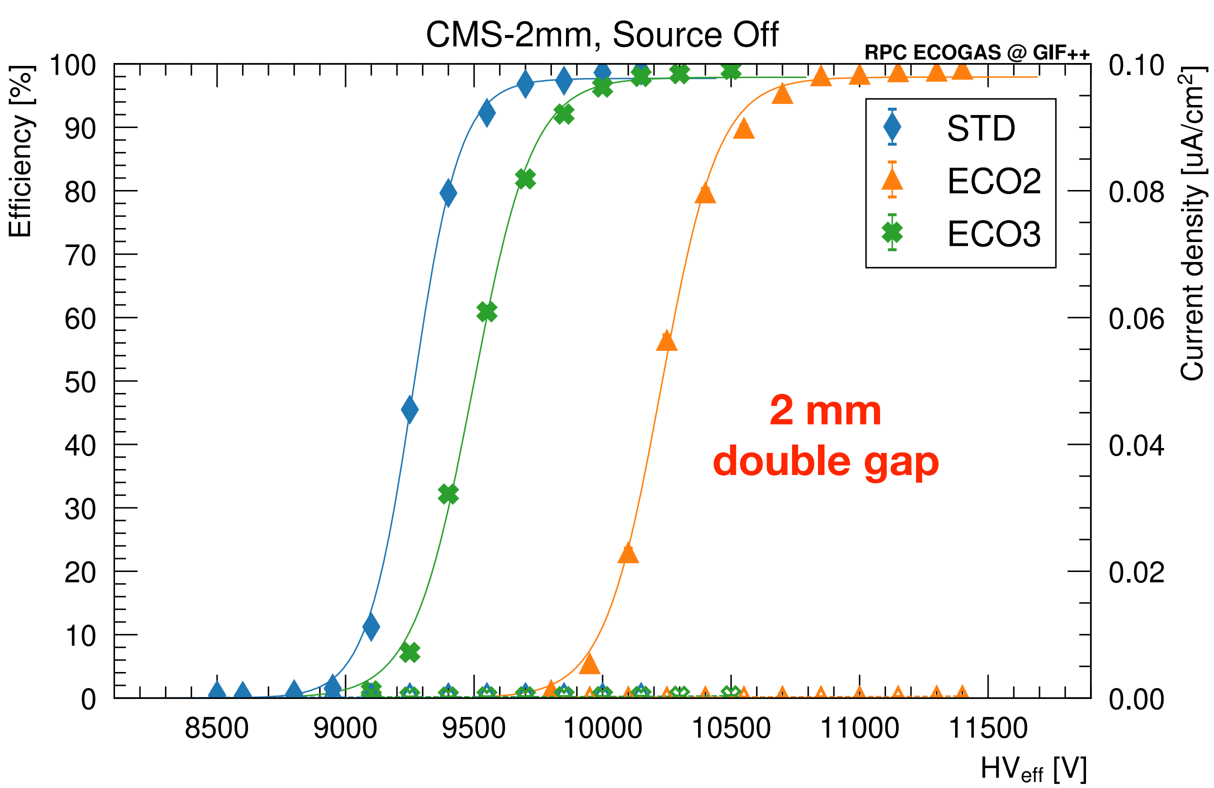


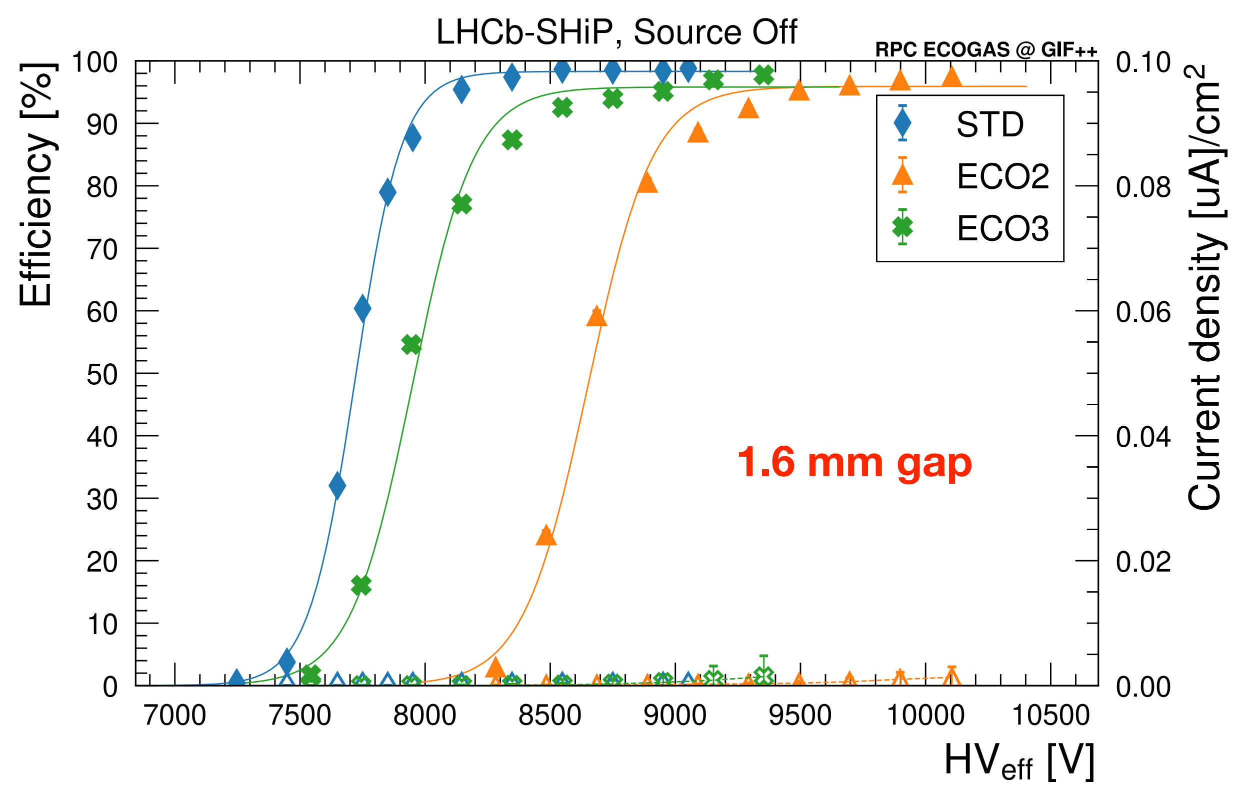
AidaInnova 2021 Test Beam results - source off





Intrinsic current higher for EPDT chamber

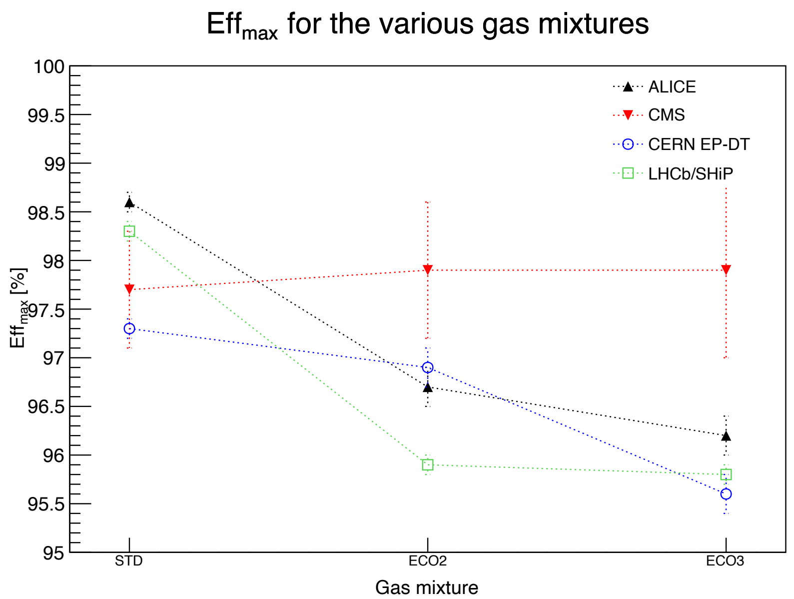


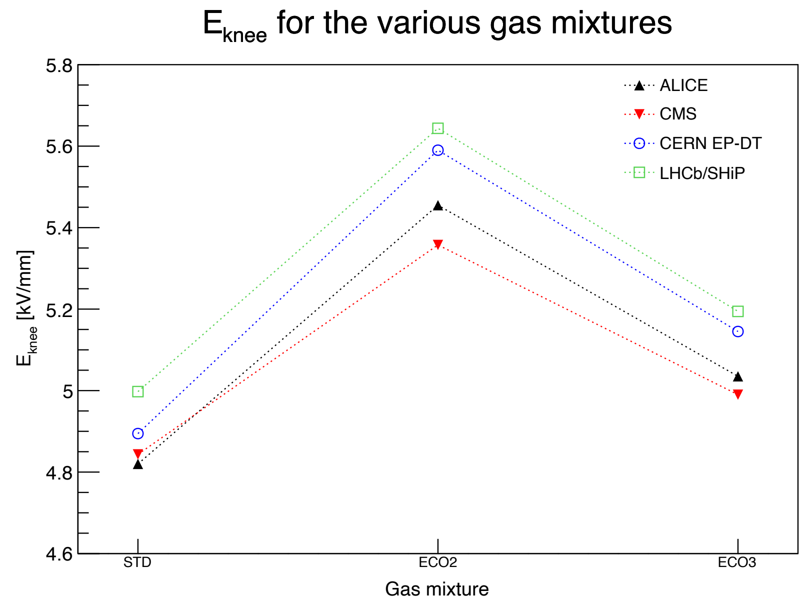


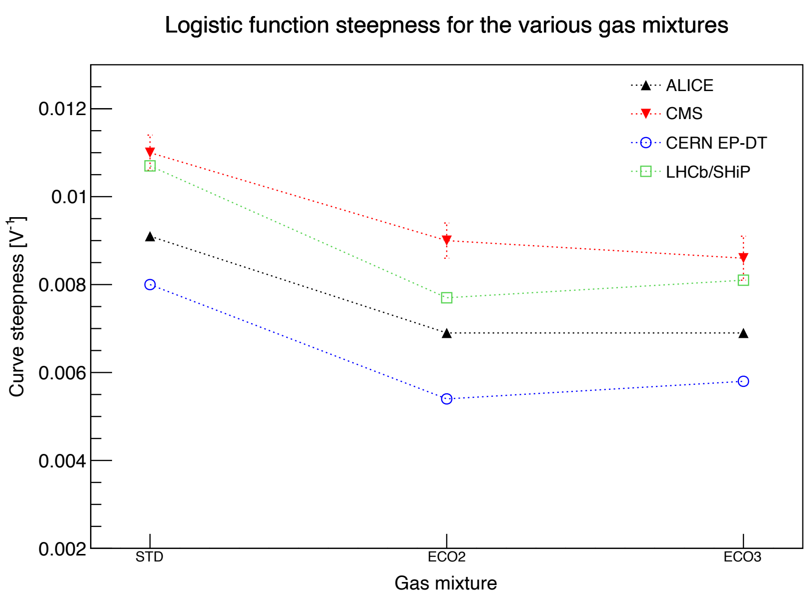
AidaInnova 2021 Test Beam results - source off

Fitted logistic function

$$Eff(HV_{eff}) = \frac{Eff_{max}}{1 + e^{-\beta(HV_{eff} - HV_{50})}}$$





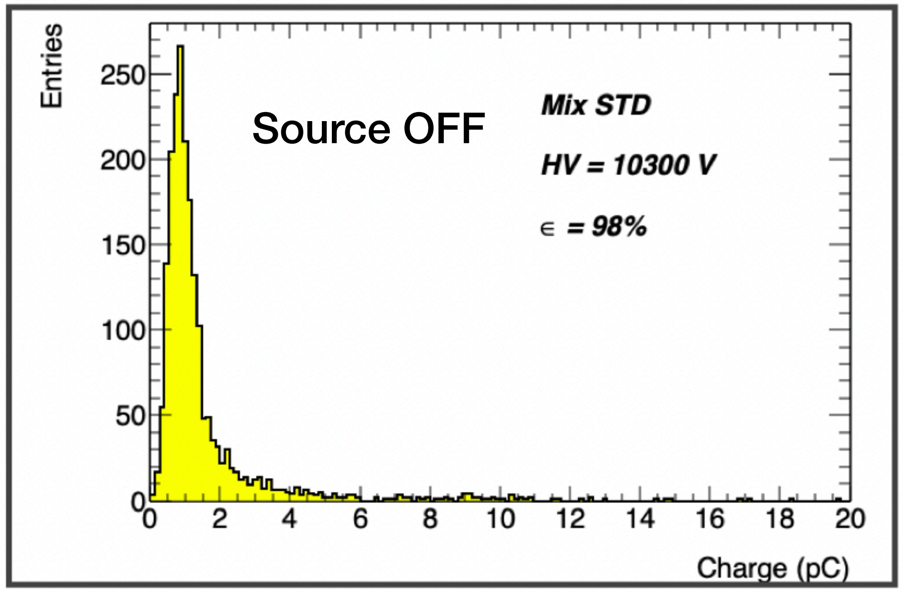


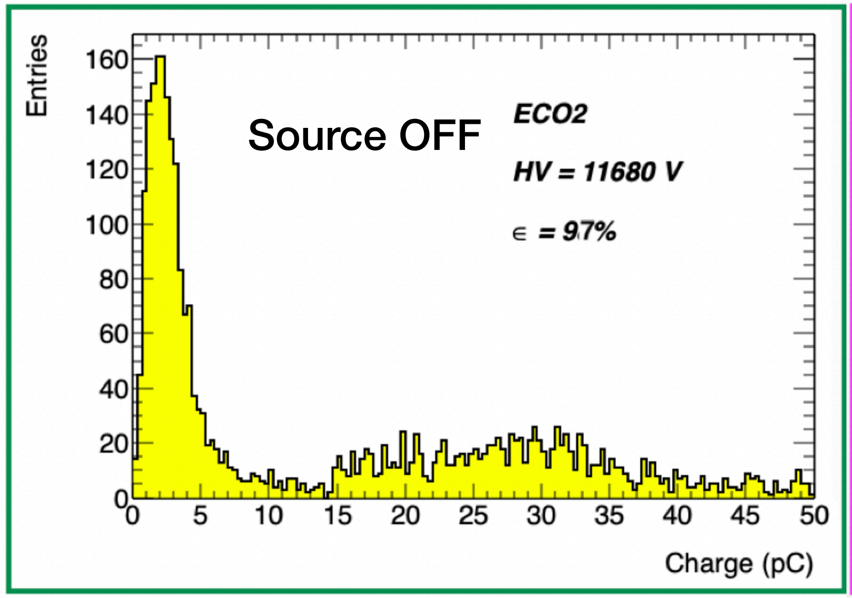
Eff_{max} well above 95% decreases for ECO2 and ECO3 (lighter target due to CO_2)
Double gap CMS is less sensitive

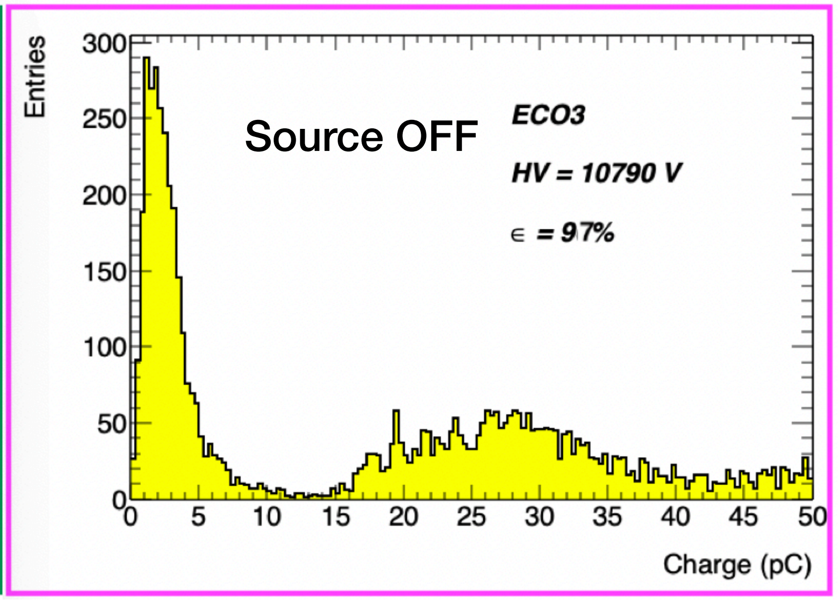
Electric field @ knee higher for ECO2 and ECO3

β reduced for ECO2 and ECO3 (less saturated mixture)

Atlas 2mm gap chamber







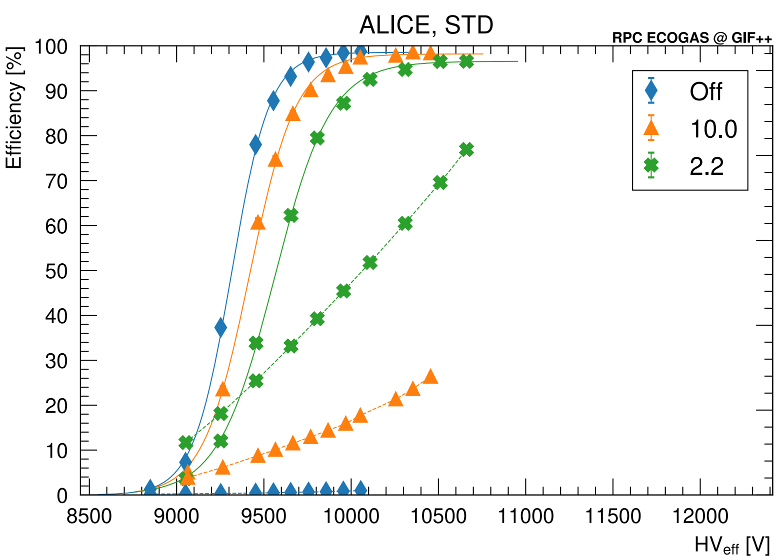
AidaInnova 2021 Test Beam results - source ON

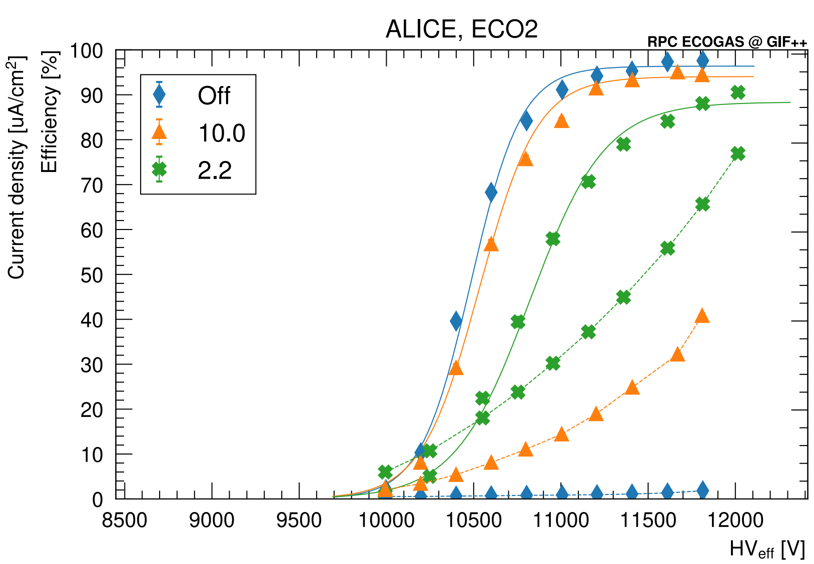
Data taken at different ABS:
- ALICE-LHCb/Ship (6 m far from source)
  - OFF
  - ABS 10 (510 uSievert/hour; 70* Hz/cm² @knee)
  - ABS 2.2 (2070 uSievert/hour; 280* Hz/cm² @knee)

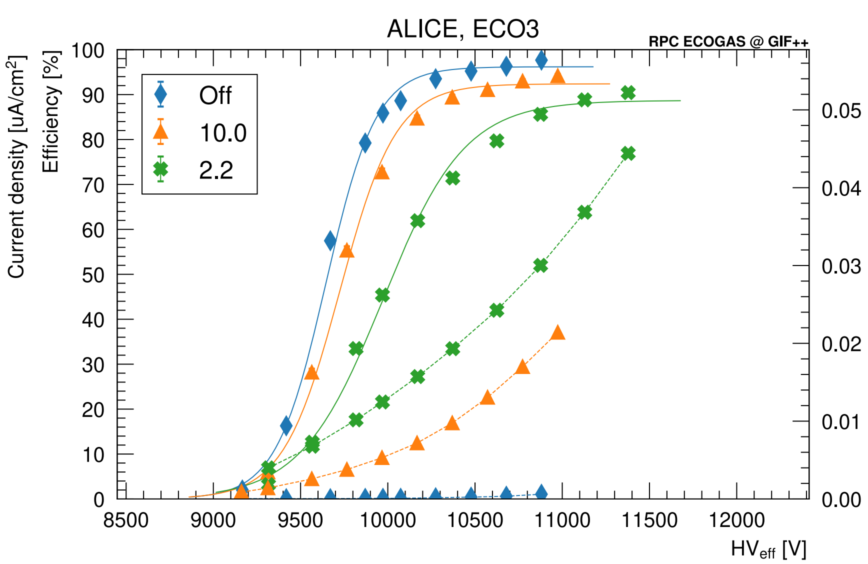
Data taken at different ABS:
- CMS-EPDT (3m far from source)
  - OFF
  - ABS 69 (700 uSievert/hour; 80* Hz/cm² @knee)
  - ABS 22 (1800 uSievert/hour; 200* Hz/cm² @knee)

* caveat: The value is just an indication. Measured rate depends on chamber layout, electronic threshold.

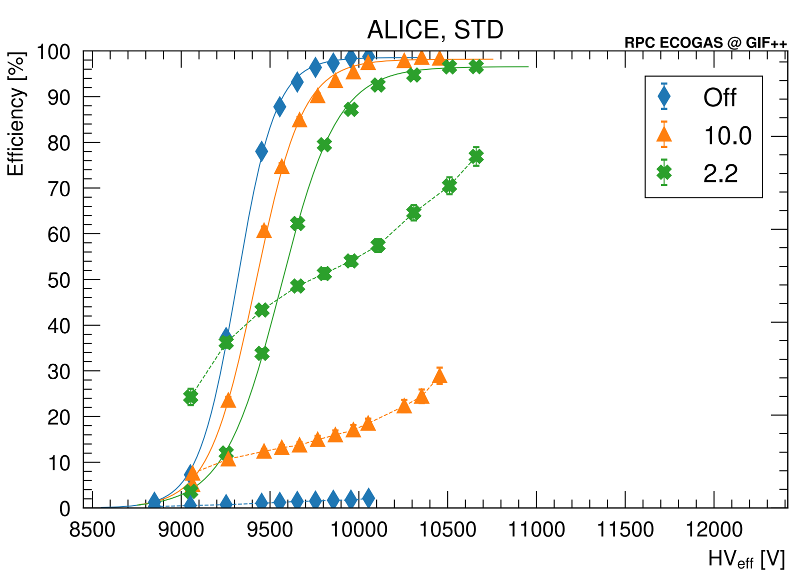
Efficiency and Currents example

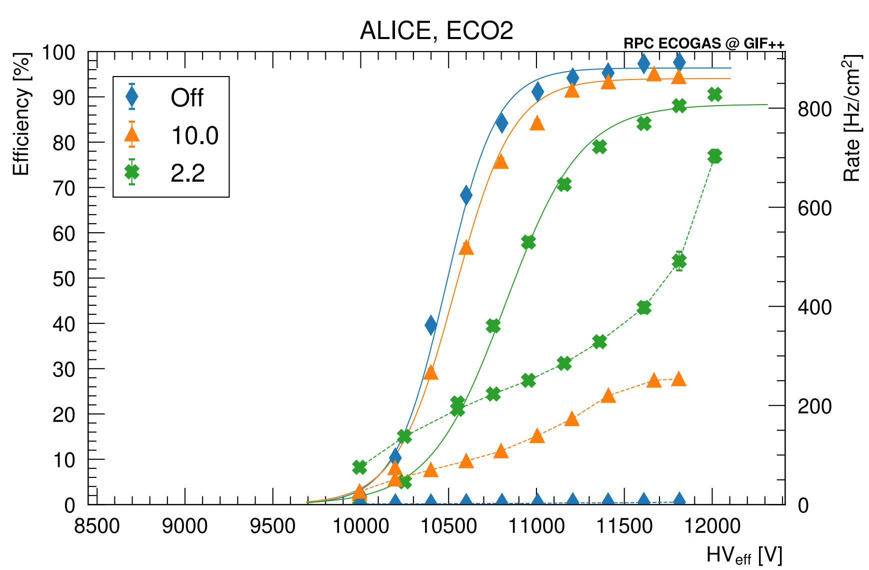


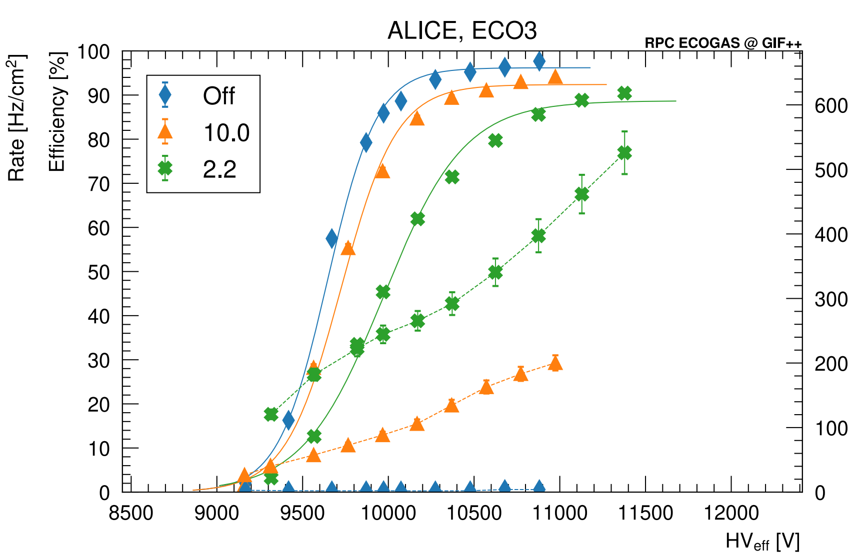




Efficiency and Rates example







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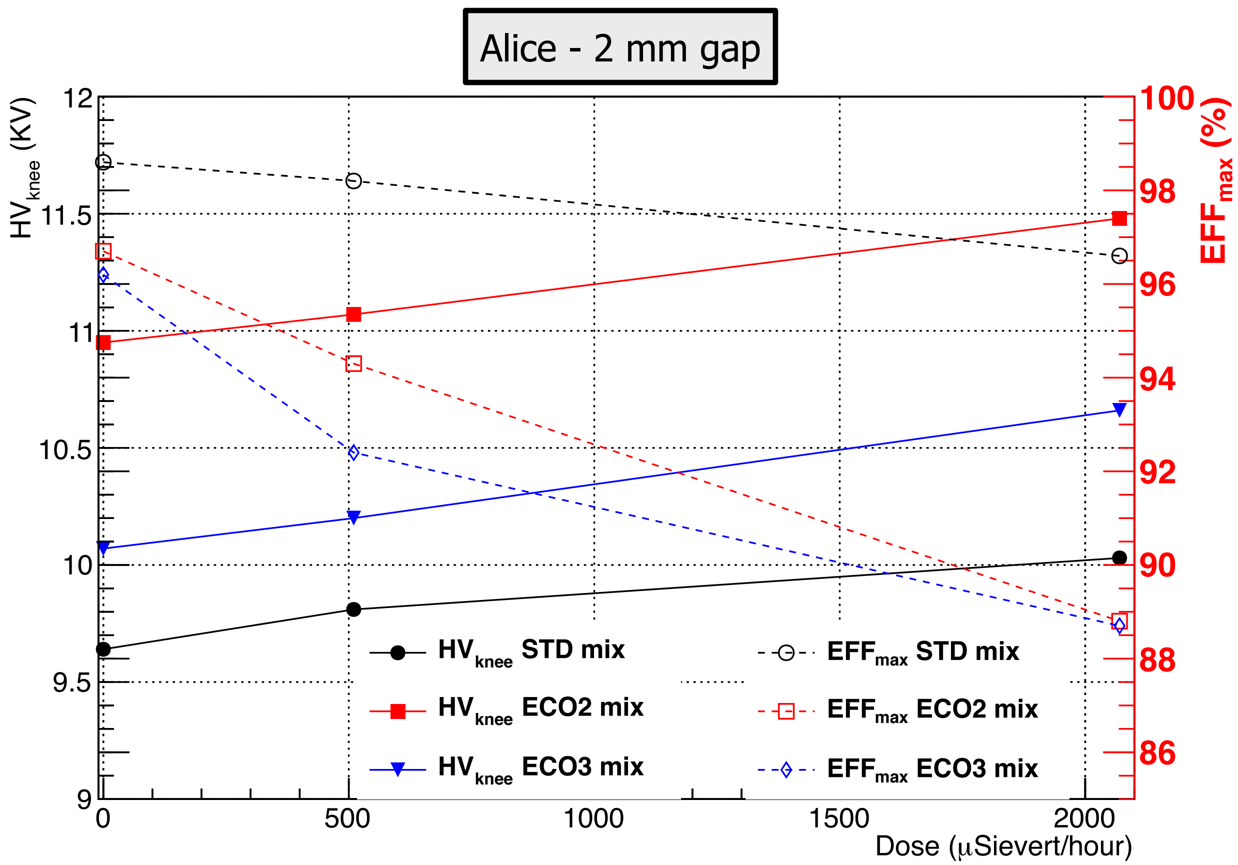
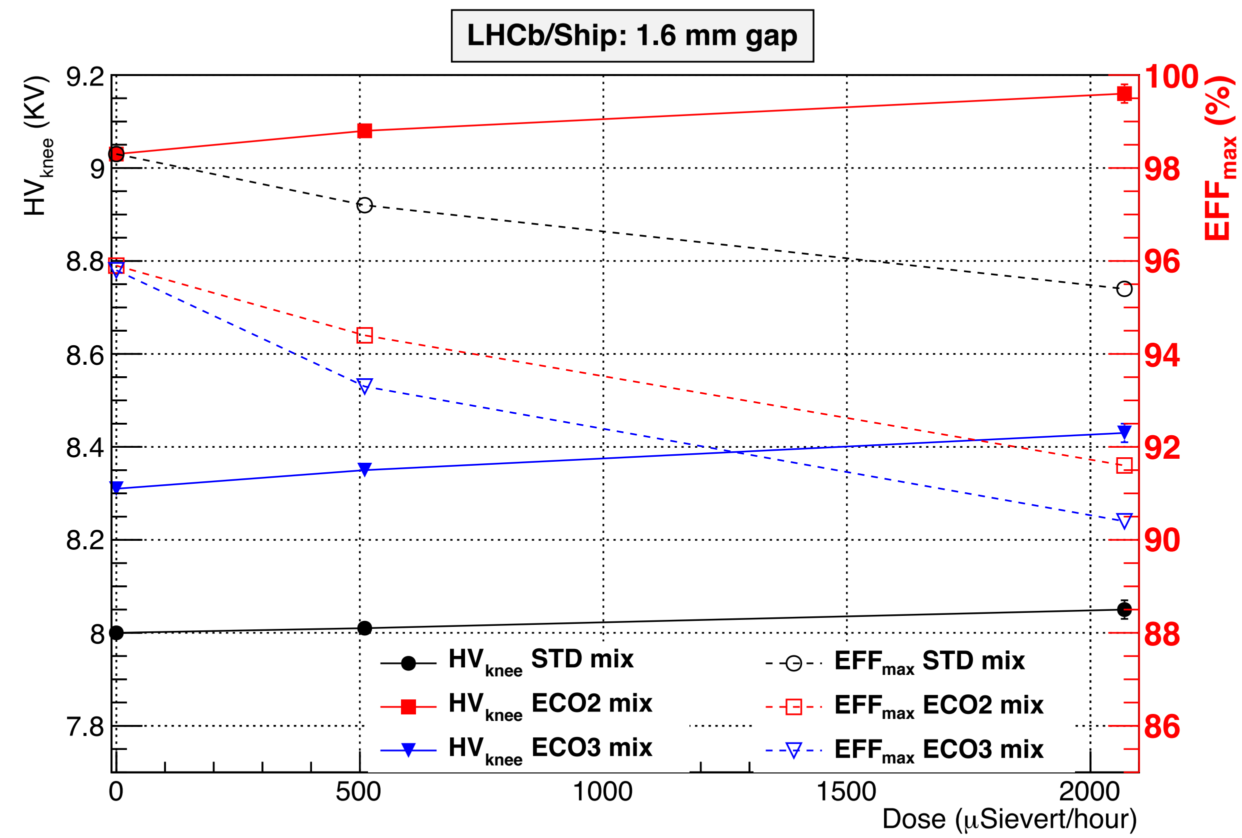
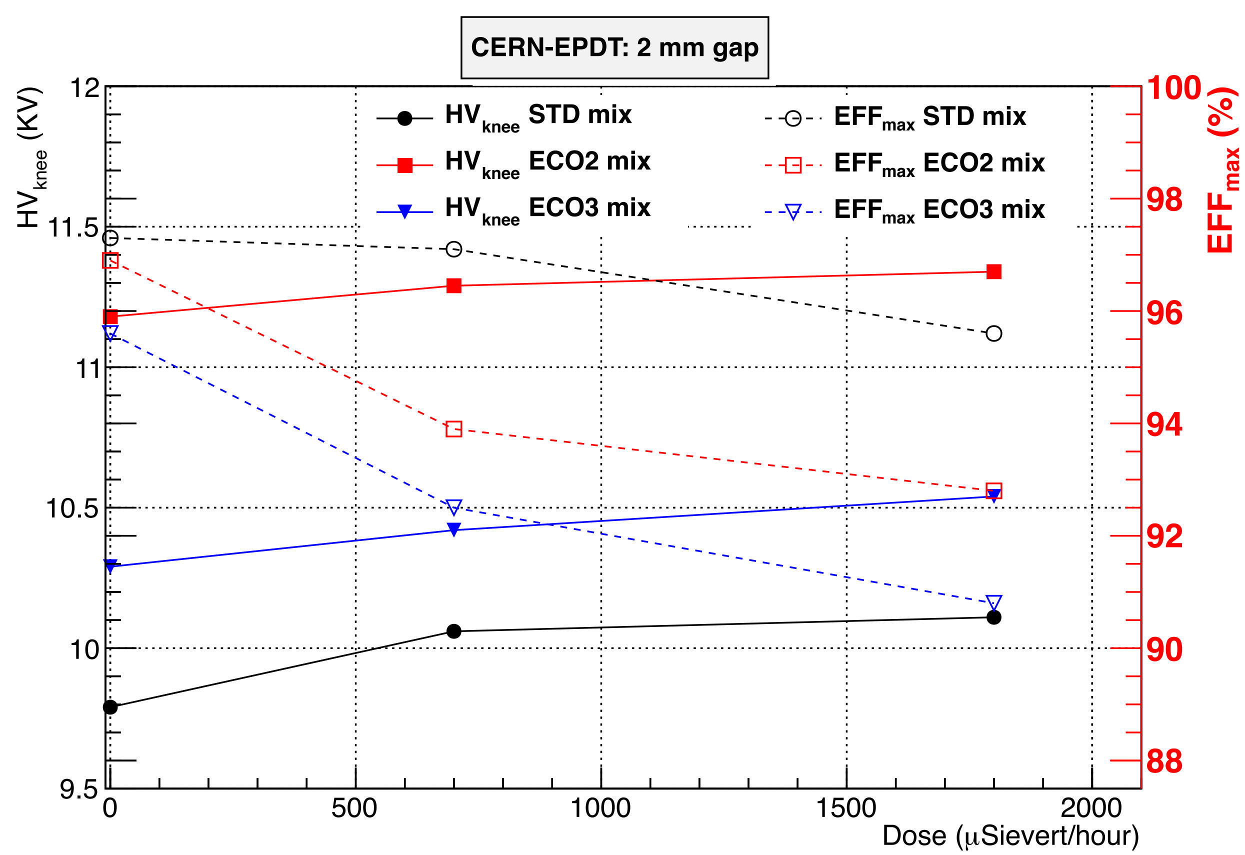
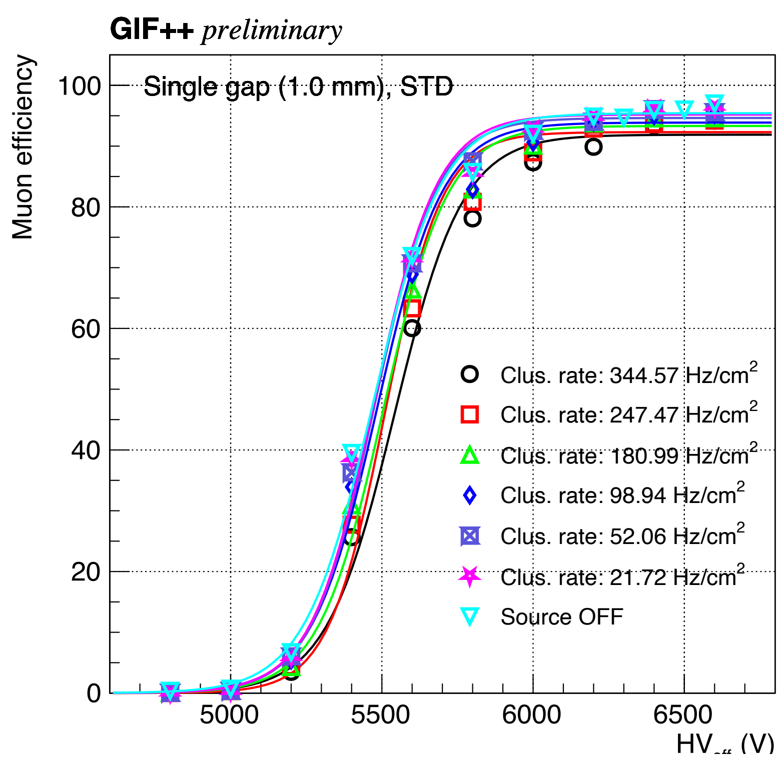


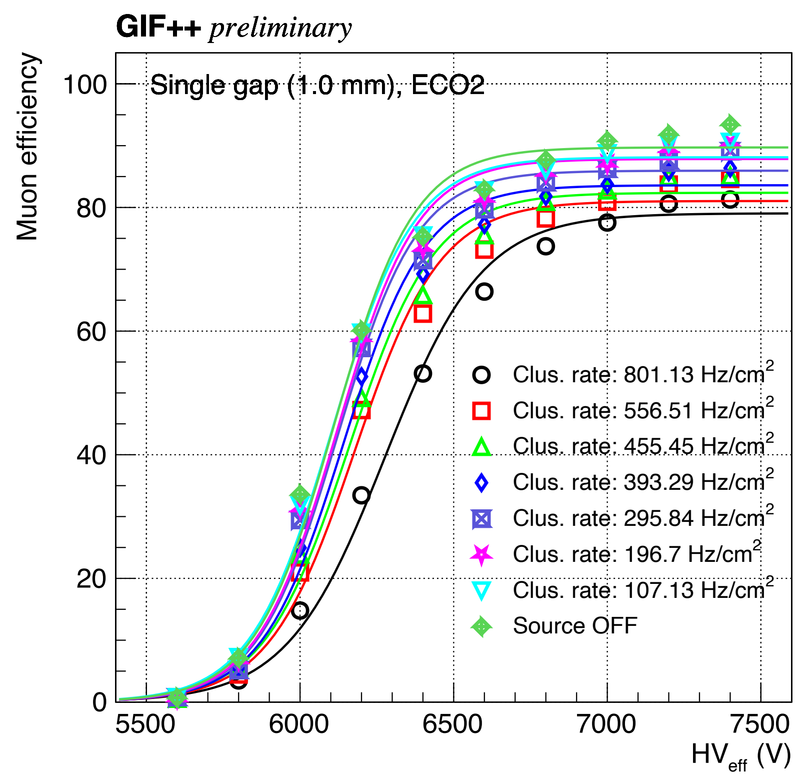


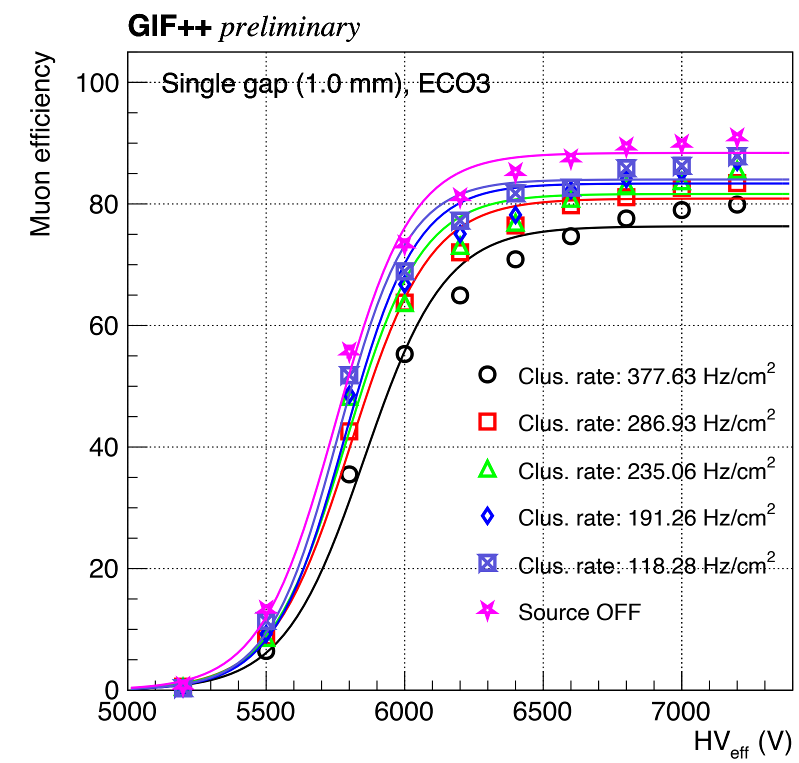


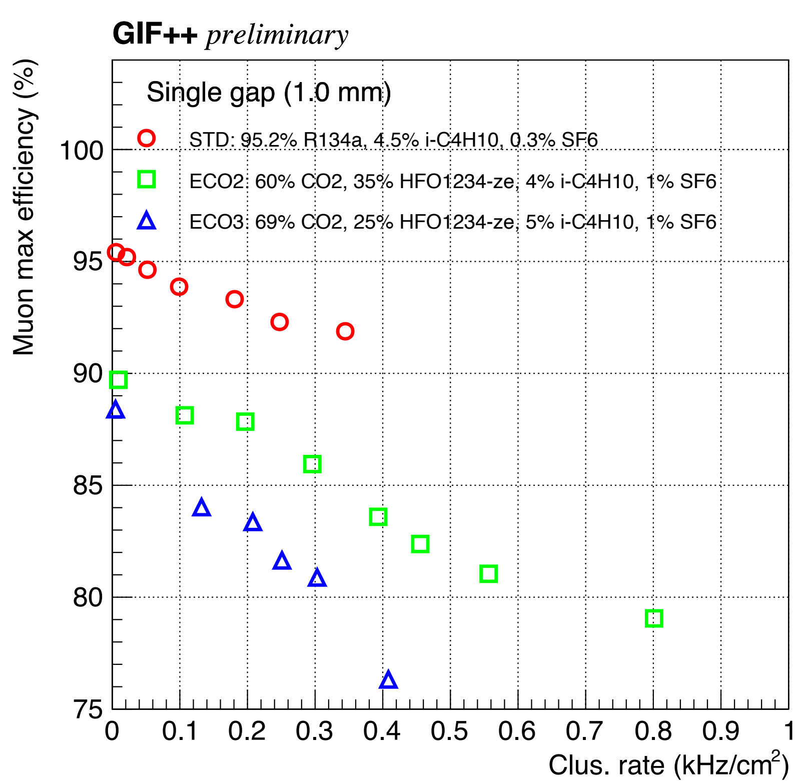
AIDAInnova 2022 Test Beam results results

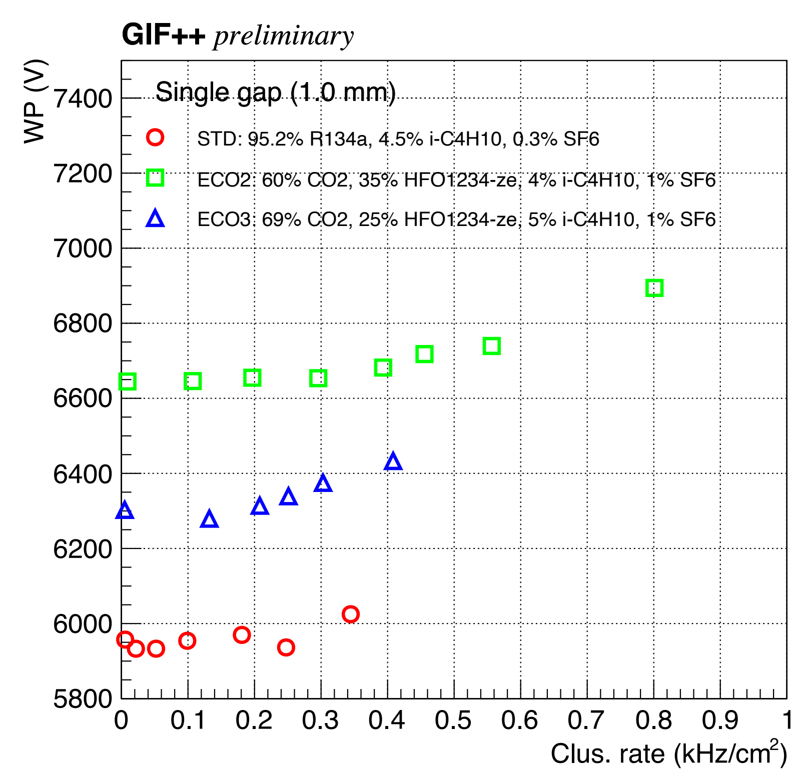
- Results from previous Test beam confirmed
- New chamber included: CMS RPC-Bari 1mm gas gap







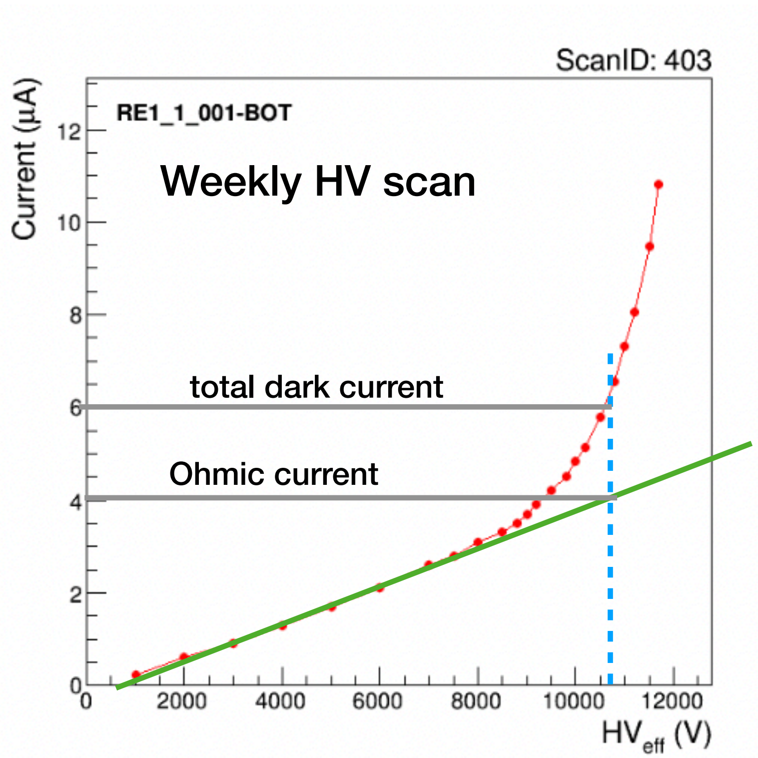




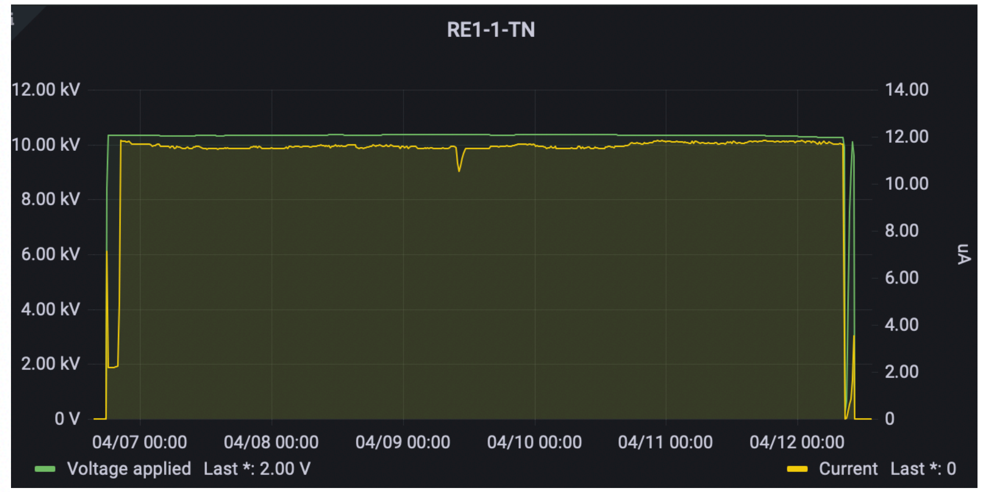
Adding CO_2 to 1 mm gap RPCs, limits the maximum achievable efficiency

AidaInnova long term aging (preliminary)

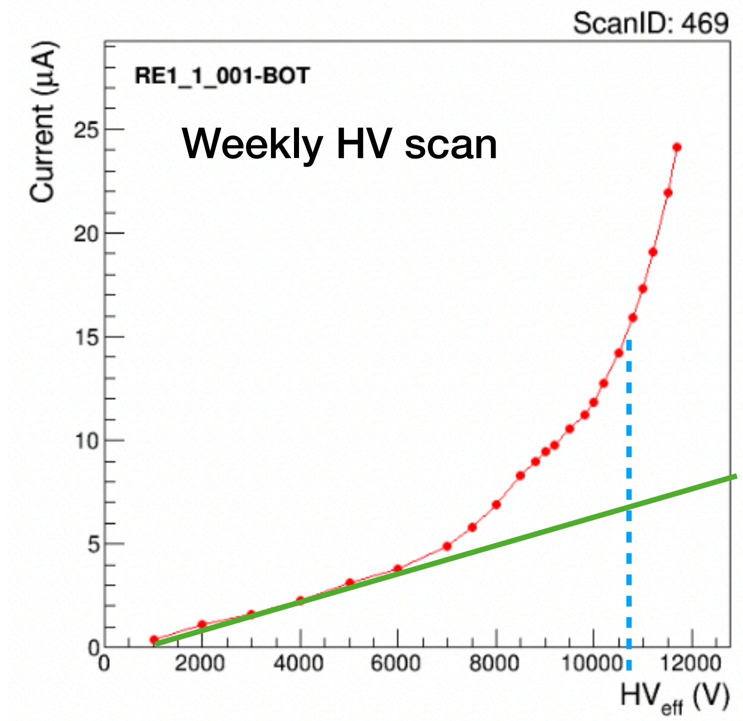
HV scan with source OFF



Chambers operated @ low efficiency



HV scan with source OFF



Irradiation for all the week

ABS 2.2 (ALICE and LHCb: 2000 uSievert/h 280* Hz/cm^2 @knee)

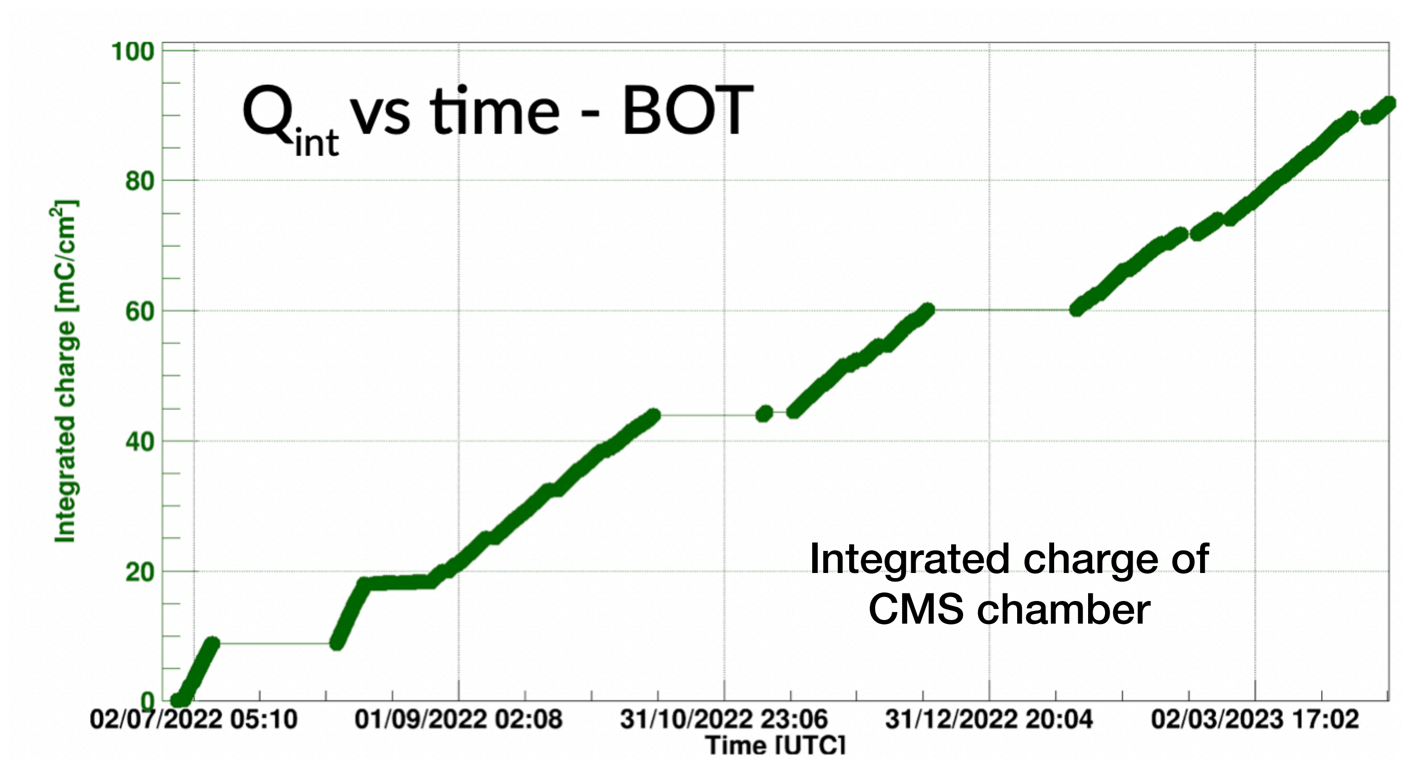
ABS 2.2 (CMS and EPDT: 13000 uSievert/h 1600* Hz/cm^2 @knee)

Every week:

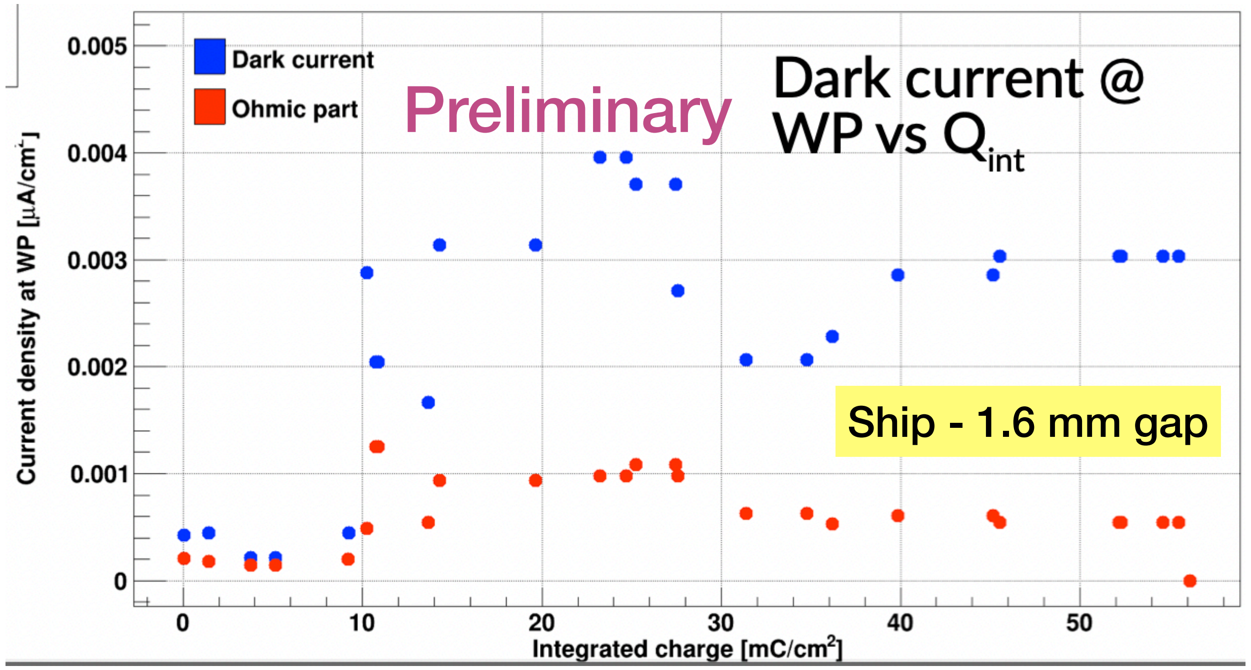
- HV scan with source off
- Extract the dark and ohmic current
- Chamber operated @ low efficiency under irradiation (ABS 2.2)

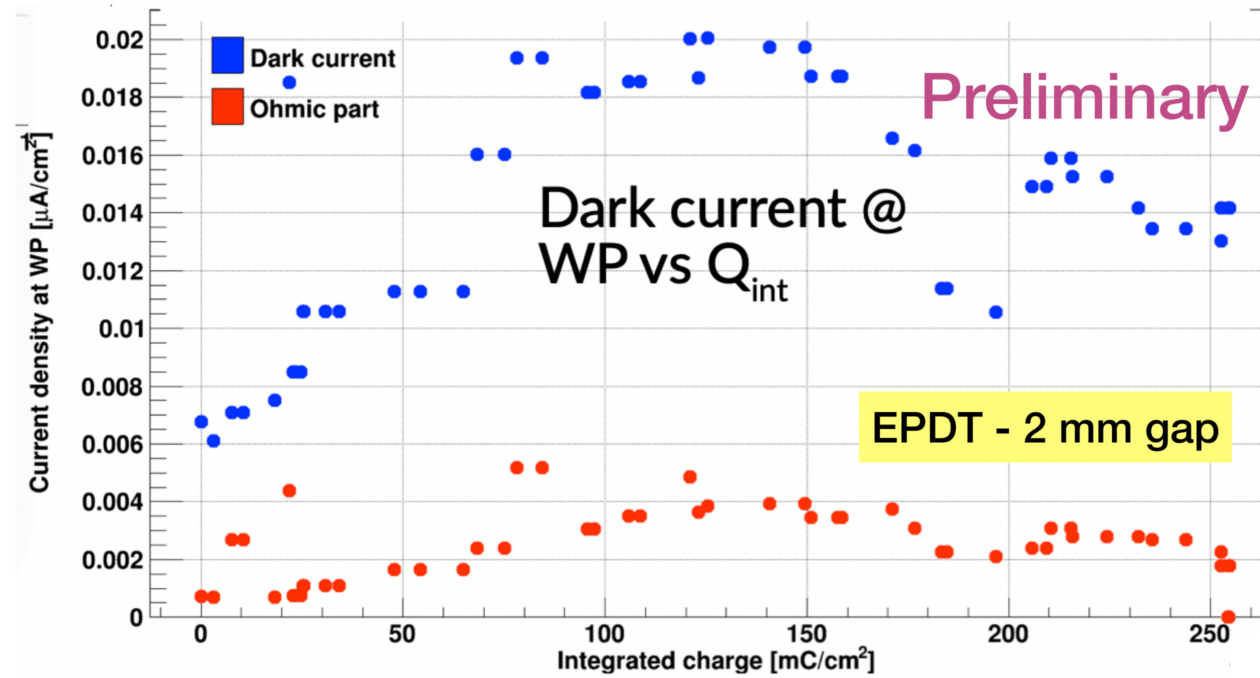
Aging started August 2022

50 - 250 mC/cm^2 according to chamber



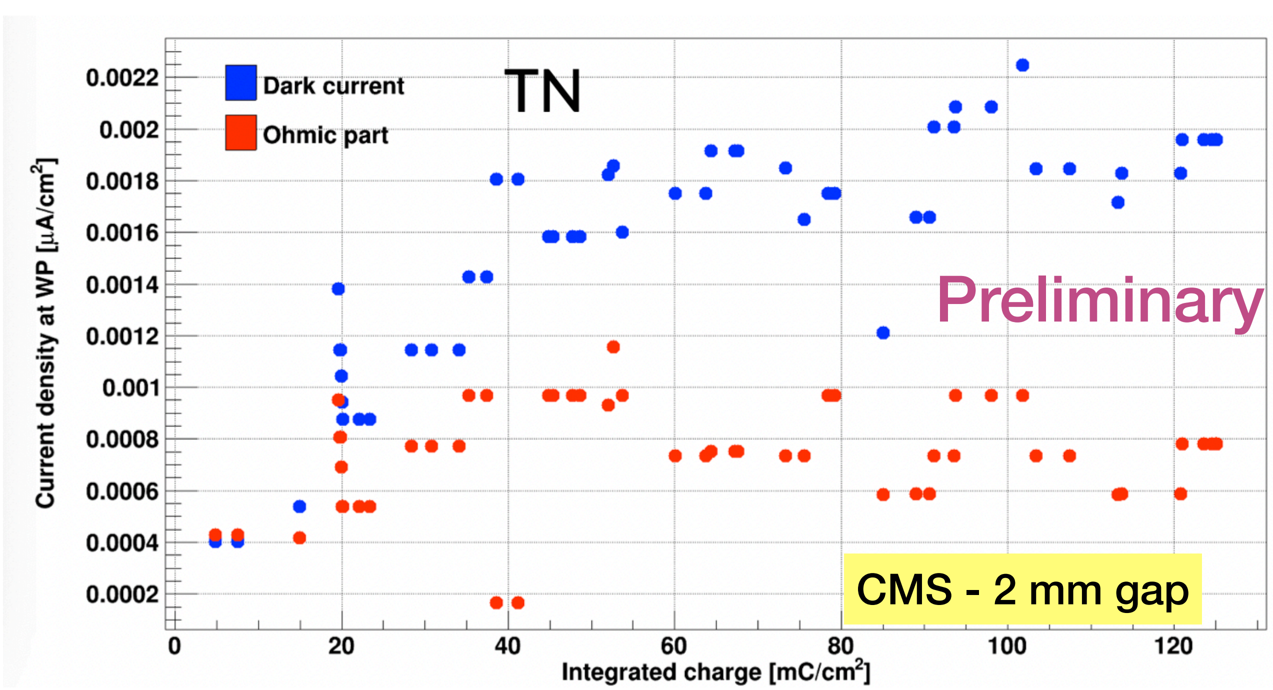
AidaInnova long term aging (preliminary)

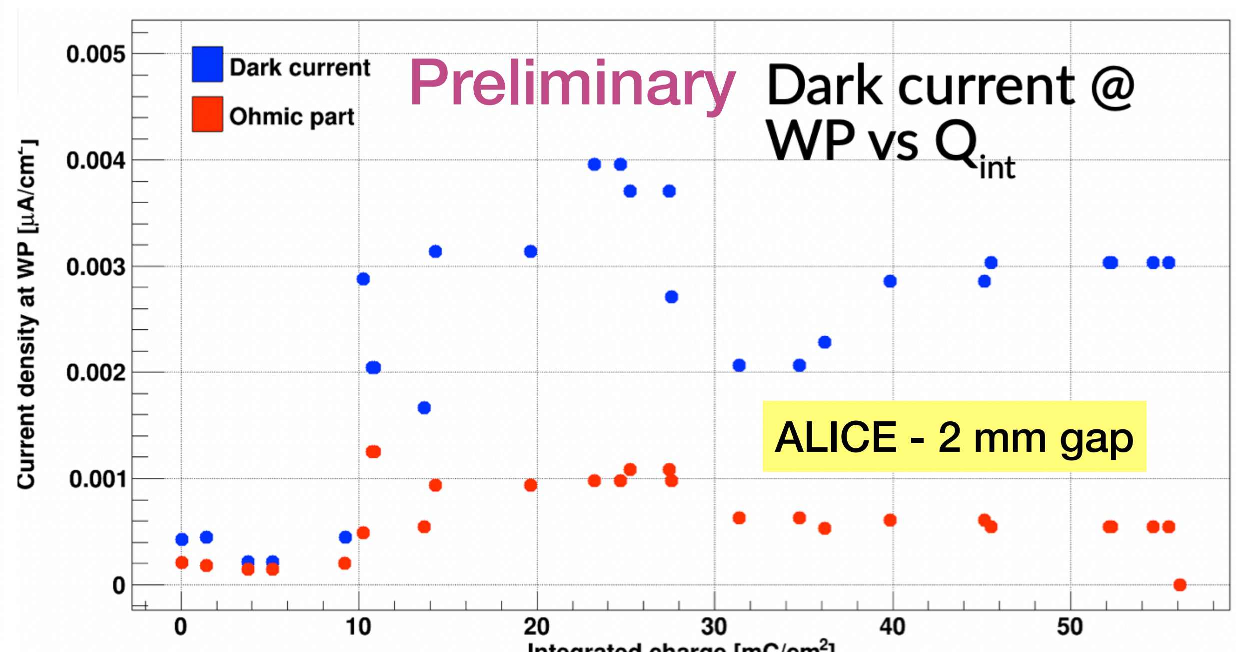




Examples of current trends

Small increase of ohmic current, but almost stable now
Larger increase of dark current, larger fluctuations





Budget - publications

Results presented in several conferences:

PSD12	Studies on tetrafluoropropene-CO2 based gas mixtures for the Resistive Plate Chambers of the ALICE Muon Identifier
10th LHCP	Searching for an eco-friendly gas mixture for the ALICE Resistive Plate Chambers
10th Beam Telescopes and Test Beam Workshop	Eco-friendly gas mixtures for future RPC detectors
ICHEP2022	Eco-friendly gas mixtures for future RPC detectors
ICNFP XI	Eco-friendly Resistive Plate Chamber detectors for HEP applications
RPC2022	Eco-friendly Resistive Plate Chamber detectors for future HEP applications
IFD2022	Greening Resistive Plate Chamber detectors for HEP applications
ICNFP 2021	Studies on environment-friendly gas mixtures for the Resistive Plate Chambers of the ALICE Muon Identifier
ENFPC e RTFNB 2022	Studies on Eco-friendly HFO-Based Gas Mixtures for Resistive Plate Chambers at the Gamma Irradiation Facility (GIF++)
11th Beam Telescopes and Test Beams Workshop	Tests of Resistive Plate Chambers with ecological gas mixture at GIF++ facility

Publications in preparation:
- *High-rate tests by the RPC ECOGas@GIF++ Collaboration on Resistive Plate Chambers filled with eco-friendly gas mixtures*

In preparation
- *Preliminary results on long term operation of RPCs with ecological gas mixtures under irradiation at GIF++*

AidaInnova Budget

- **Personell:**
- Two years of Assegno di Ricerca (co-financed 50% ALICE - 50% AidaInnova)

- **Hardware**

- construction of a new atex mixer with 4 components: ~20 kCHF
- construction of a new humidifier system with remote control: ~5 kCHF
- material for the measurements of HF: ~3 kCHF
- miscellaneous: ~ 5 kCHF

Conclusions and plans for 2023

Conclusions

- At least one RPC chamber for each group under test
- Aging studies of ECO1 show increase of currents for all RPC chambers tested
- Two more gas mixtures (ECO2 and ECO3) selected for irradiation campaign
  - RPC performance studied in several test-beams in both 2021 and 2022
- Start of long term test under irradiation with ECO2: about 50-250 mC/cm^2
  - Weekly shifts to monitor detector conditions and data taking
- Hardware upgrade: New gas mixture system

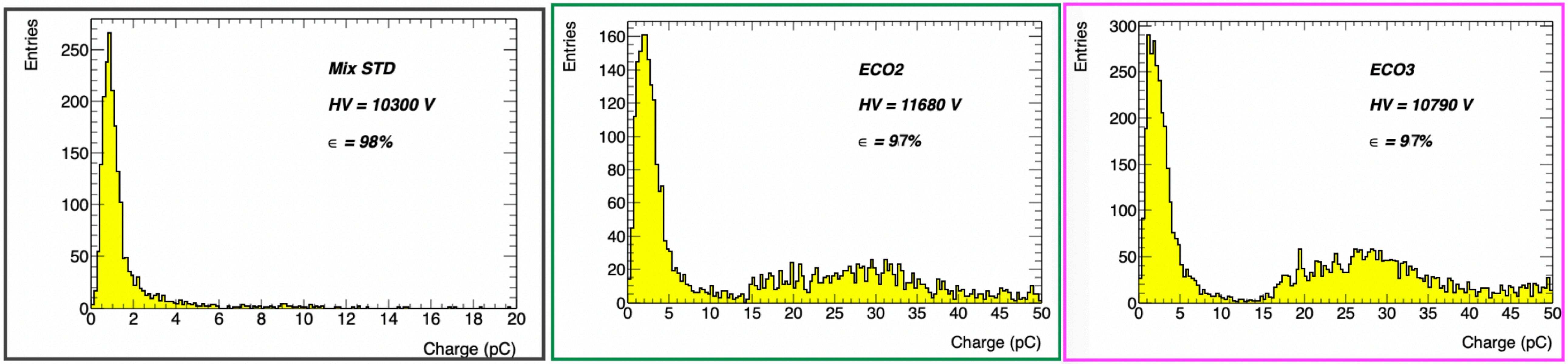
Plans for 2023

- Test-beam campaign
  - In July and October 2023
- Aging test for ECO2
  - Data taking will continue all the year
- More systematic HF measurements
- Paper with 2021 test-beam results almost ready
- Paper with 2022 test-beam results and preliminary aging test results in preparation

Spares

AidaInnova 2021 Test Beam results - source off

Atlas 2mm gap chamber



Source OFF

Detector	Gas Mix.	HV_{knee} (kV) (HV @95% efficiency)	Eff_{max} (%)	β (V^{-1})
ALICE	STD	9.64±0.01	98.6±0.1	0.0091±0.0001
ALICE	ECO2	10.91±0.01	96.4±0.2	0.0069±0.0001
ALICE	ECO3	10.20±0.01	96.2±0.2	0.0069±0.0001
CMS	STD	9.687±0.005	97.7±0.6	0.0110±0.0004
CMS	ECO2	10.715±0.005	97.9±0.7	0.0090±0.0004
CMS	ECO3	9.980±0.005	97.9±0.9	0.0086±0.0005
EP-DT	STD	9.789±0.007	97.3±0.1	0.0080±0.0001
EP-DT	ECO2	11.18 ±0.01	96.9±0.2	0.0054±0.0001
EP-DT	ECO3	10.29 ±0.01	95.6±0.2	0.0058±0.0001
LHCb/SHiP	STD	7.996±0.002	98.3±0.1	0.0107±0.0001
LHCb/SHiP	ECO2	9.030 ±0.004	95.9±0.1	0.0077±0.0001
LHCb/SHiP	ECO3	8.311 ±0.003	95.8±0.1	0.0081±0.0001

Fitted logistic function

$$Eff(HV_{\text{eff}}) = \frac{Eff_{\max}}{1 + e^{-\beta(HV_{\text{eff}} - HV_{50})}}$$

Working voltage higher for ECO2 and ECO3

Eff_{max} well above 95% decreases for ECO2 and ECO3 (lighter target due to CO_2)
Double gap CMS is less sensitive

β reduced for ECO2 and ECO3 (less saturated mixture)

Status of budget

Allocated AIDA Budget: 44 kCHF (CERN) + 30 kEURO (INFN)

12 months | 24 months | 36 months | 45 months

0. Selection of possible eco-friendly gas mixtures

- Hiring of PostDoc

1a. Long term operation at GIF++ with different eco-friendly gas mixtures

1b. Detector performance at GIF++ (test beam)

2. Studies on formation of impurities at GIF++ and impact on RPC operation

In 2022

- Upgrade of mixer to study the different eco-friendly mixture selected and allowing to test simultaneously at least 5 chambers (at least one from each experiment/institute): ~<u>20 kCHF</u>
- Humidifier (necessary for the operation of RPC detectors): ~<u>10 kCHF</u>

In 2022-25

- GC provided by GIF++ infrastructure
- F^- measurements:<u>~2 kCHF/year</u>

In 2021-25

Expenses in rental of epool material for electronics

- Spent <u>~1 kCHF</u> for minor upgrades