CPV in b-quarks from $t\bar{t}$ events
&
Performance studies of the RPC detector and L1 Muon Barrel Trigger

PhD admission to the 3rd year

Daniele Truncali

Supervisors: Prof. Lucio Cerrito, Prof. Umberto De Sanctis

October 8th, 2025

CERN
ATLAS EXPERIMENT
INFN ROMA
Istituto Nazionale di Fisica Nucleare
Sezione di Roma Tor Vergata
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

References

- CP violation analysis

[1] Abazov, V. M., Abbott, B., Acharya, B. S., Adams, M., Adams, T., Agnew, J. P., ... & Hobbs, J. D. (2014). *Study of CP-violating charge asymmetries of single muons and like-sign dimuons in pp collisions*. Physical Review D, 89(1), 012002.

[2] ATLAS collaboration. (2016). *Measurements of charge and CP asymmetries in b-hadron decays using top-quark events collected by the ATLAS detector in pp collisions at* $\sqrt{s} = 8$ *TeV*. arXiv preprint arXiv:1610.07869.

[3] Belle Collaboration, I. Adachi et al., *Precise measurement of the CP violation parameter sin* $2\phi_1$ *in* $B^0 \to (c\bar{c})K^0$ *decays*, Phys.Rev.Lett. 108, 171802 (2012) [arXiv:1201.4643 [hep-ex]].

[4] BaBar Collaboration, B. Aubert et al., *Measurement of Time-Dependent CP Asymmetry in* $B^0 \to c\bar{c}K^{(*)0}$ *Decays*, Phys. Rev. D79, 072009 (2009) [arXiv:0902.1708 [hep-ex]].

[5] Aaij, R., Abdelmotteleb, A. S. W., Beteta, C. A., Abudinén, F., Ackernley, T., Adefisoye, A. A., ... & Campana, P. (2025). *Updated measurement of CP violation and polarisation in* $B^0_s \to J/\psi\ \overline{K}^*(892)^0$ *decays*. arXiv preprint arXiv:2506.22090.

- Work for qualification as an ATLAS author

[6] Atlas Collaboration. (2021). *Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at* $\sqrt{s} = 13$ *TeV*. arXiv preprint arXiv:2103.01029.

Summary

- CP violation analysis
- Work for qualification as an ATLAS author
- Other activities

Summary

- CP violation analysis
- Work for qualification as an ATLAS author
- Other activities

CPV in $t\bar{t}$ events: research focus

Objective:

➔ Investigate the Charge-Parity Violation (**CPV**) in b-hadron decays from $t\bar{t}$ production within the ATLAS experiment

Research overview:

➔ *CPV studies* : Studying **asymmetries** in the behaviour of **matter-antimatter** that may indicate CPV

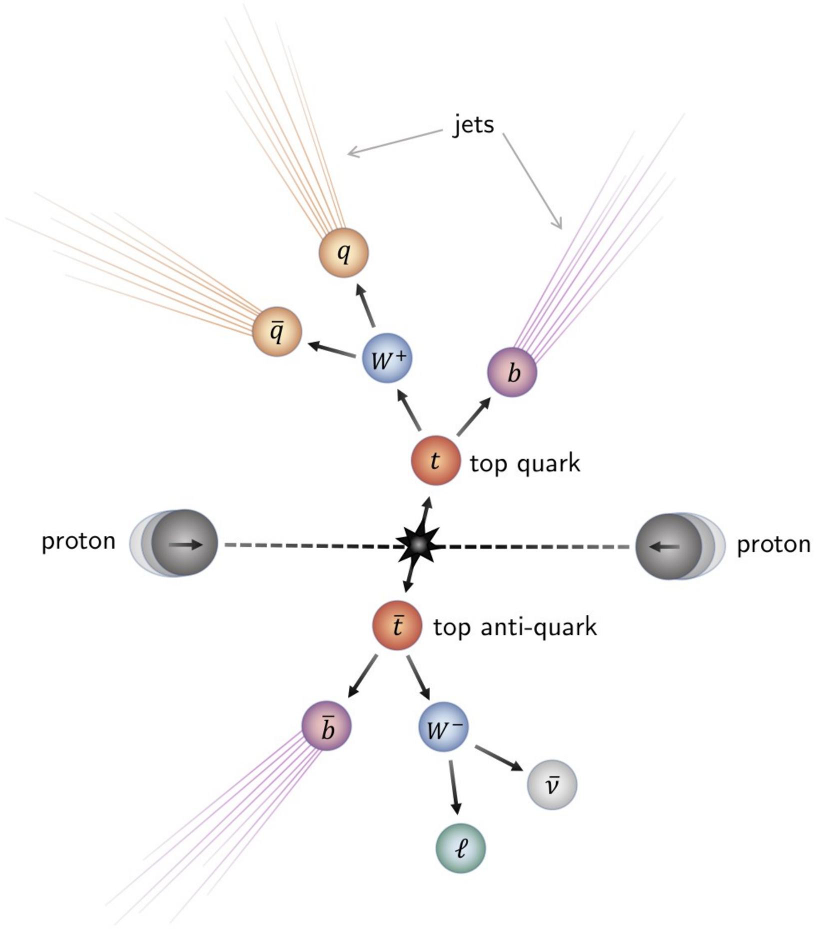
➔ *Top quark role* : As the heaviest quark, the **top quark's decays** can be used as a source of **b-hadrons**, which are used to study CPV

➔ *Observable quantities* : Analysis focuses on a **charge asymmetry** in decay products (e.g. leptons, jets) that are sensitive to CPV

Methodology:

➔ *Event selection* : Using data from pp collisions at **√s = 8, 13 TeV**, focusing on events with high purity $t\bar{t}$ signatures

➔ *Simulation & comparison* : Comparing observed **data** with **MC simulations** to identify potential deviations that may suggest CPV



CPV in $t\bar{t}$ events: theory & physics

- CPV refers to the non-conservation of **charge** and **parity** symmetries, implying that the laws of physics differ between **matter** and **antimatter**
- The DØ experiment has observed a discrepancy on the charge asymmetries from b-hadron decays, showing a **3.6σ deviation from the Standard Model**, which is **not sufficient** to claim a discovery [1]
- The **top quark** is abundantly produced at LHC, allowing us to study CPV in b-hadron processes. It mainly decays into a **W boson** and a ***b*-quark,** whose charge can be determined when the W decays into a **prompt lepton** and a neutrino or when the b-hadron decays semileptonically into a muon, the so-called **Soft Muon Tagged** (**SMT**)
- To study the charge asymmetry from b-quarks, it is **first** necessary to **assign the lepton and the SMT to jets**, based on their kinematics, and **then examine their charge.** If they originate from the same $t\bar{t}$ side, they will have opposite charge (**Same-Top**). Conversely they will have same charge (**Different-Top**)
- Equations (1)-(6) represent $t\bar{t}$ decay chains that generate leptons with either the same or opposite charge (N_r is the number of SMT in the appropriate configuration). Equations (18)-(22) define CP asymmetries, both in $B_q - \bar{B}_q$ mixing and in direct b-/c- decays [2]

$$N_{r_b} = N\left[t \to \ell^+\nu\left(b \to \bar{b}\right) \to \ell^+\ell^+X\right], \tag{1}$$

$$N_{r_c} = N\left[t \to \ell^+\nu\left(b \to c\right) \to \ell^+\ell^+X\right], \tag{2}$$

$$N_{r_{c\bar{c}}} = N\left[t \to \ell^+\nu\left(b \to \bar{b} \to c\bar{c}\right) \to \ell^+\ell^+X\right], \tag{3}$$

$$N_{\tilde{r}_b} = N\left[t \to \ell^+\nu b \to \ell^+\ell^-X\right], \tag{4}$$

$$N_{\tilde{r}_c} = N\left[t \to \ell^+\nu\left(b \to \bar{b} \to \bar{c}\right) \to \ell^+\ell^-X\right], \tag{5}$$

$$N_{\tilde{r}_{c\bar{c}}} = N\left[t \to \ell^+\nu\left(b \to c\bar{c}\right) \to \ell^+\ell^-X\right]. \tag{6}$$

$$A^{b\ell}_{\text{mix}} = \frac{\Gamma\left(b \to \bar{b} \to \ell^+X\right) - \Gamma\left(\bar{b} \to b \to \ell^-X\right)}{\Gamma\left(b \to \bar{b} \to \ell^+X\right) + \Gamma\left(\bar{b} \to b \to \ell^-X\right)}, \tag{18}$$

$$A^{bc}_{\text{mix}} = \frac{\Gamma\left(b \to \bar{b} \to \bar{c}X\right) - \Gamma\left(\bar{b} \to b \to cX\right)}{\Gamma\left(b \to \bar{b} \to \bar{c}X\right) + \Gamma\left(\bar{b} \to b \to cX\right)}, \tag{19}$$

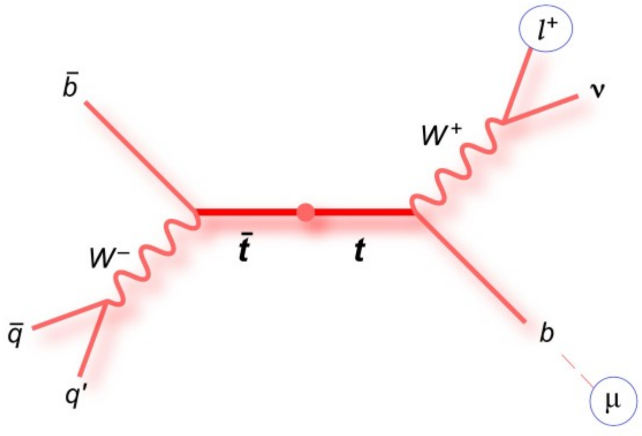
$$A^{b\ell}_{\text{dir}} = \frac{\Gamma\left(b \to \ell^-X\right) - \Gamma\left(\bar{b} \to \ell^+X\right)}{\Gamma\left(b \to \ell^-X\right) + \Gamma\left(\bar{b} \to \ell^+X\right)}, \tag{20}$$

$$A^{c\ell}_{\text{dir}} = \frac{\Gamma\left(\bar{c} \to \ell^-X_L\right) - \Gamma\left(c \to \ell^+X_L\right)}{\Gamma\left(\bar{c} \to \ell^-X_L\right) + \Gamma\left(c \to \ell^+X_L\right)}, \tag{21}$$

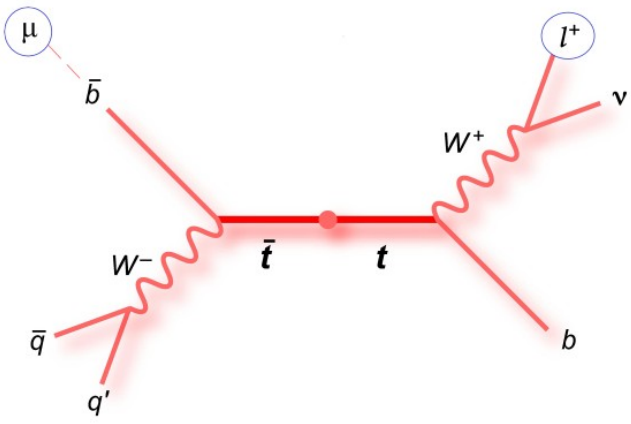
$$A^{bc}_{\text{dir}} = \frac{\Gamma\left(b \to cX_L\right) - \Gamma\left(\bar{b} \to \bar{c}X_L\right)}{\Gamma\left(b \to cX_L\right) + \Gamma\left(\bar{b} \to \bar{c}X_L\right)}, \tag{22}$$

CPV in $t\bar{t}$ events: event selection

- The analysis uses the **$t\bar{t}$ lepton+jets** channel with exactly **one prompt lepton**
- **JETS**:
  - events are required to have a **soft muon** ($p_T > 4$ **GeV**), which comes from the semileptonic decay of the b/c-hadron originated from the b/$\bar{b}$-quark
  - The **number of jets** must be at least **4**, with **$p_T > 30$ GeV**. The jet associated with the SMT must have **$p_T > 25$ GeV**. In the end, there must be at least **1 b-jet** (using DL1r algorithm at **77%** efficiency working point)
- For events where the **prompt lepton** and **soft muon** come from opposite sides of the $t\bar{t}$ system, we change the **jet assignment** to determine the **Same-Top (ST)** and **Different-Top (DT)** configuration



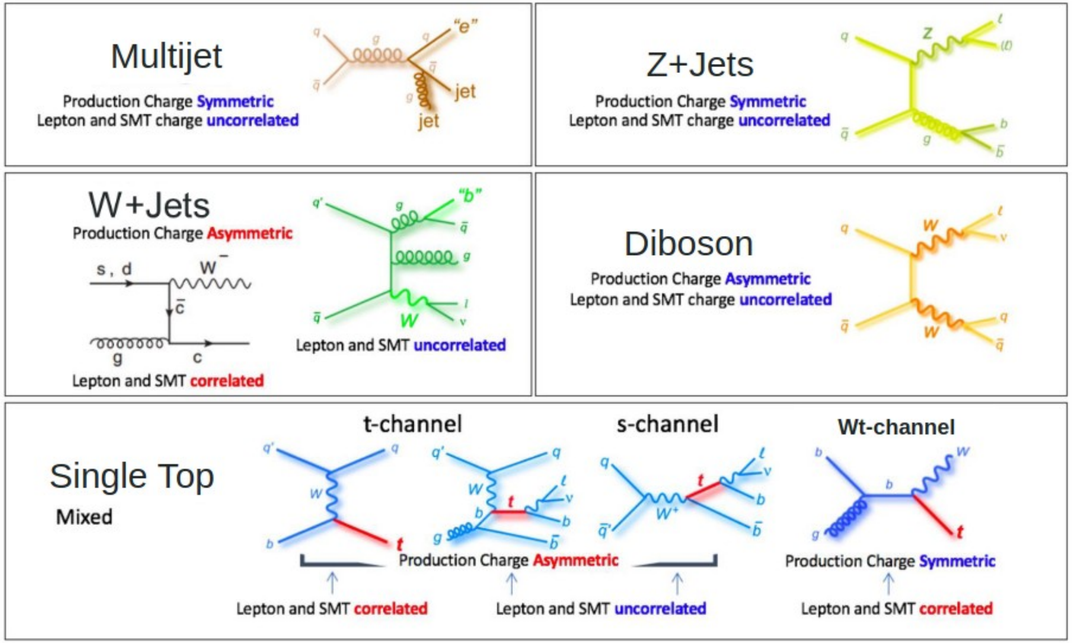
(a) Same-top SMT muon



(b) Different-top SMT muon

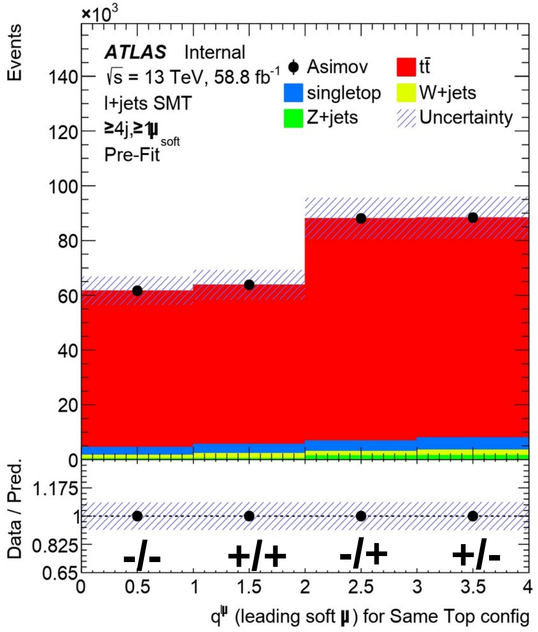
CPV in $t\bar{t}$ events: backgrounds

- The possible background sources for this process are:
  - **Multijet**
  - **Z+jets**
  - **W+jets**
  - **Diboson**
  - **Single top**
  - **ttV / ttH**
- There is also a background source due to **misidentification** between **prompt** and **soft muons** from within $t\bar{t}$. For example, prompt muons can be produced close to jet and passing soft muon selection

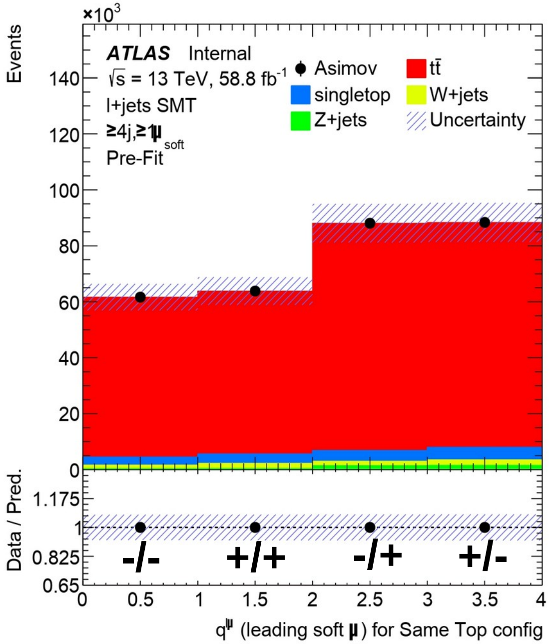


$q^{l\mu}$ distribution

All Systematics
(detector + modeling + theory)



Detector systematics



The **$q^{l\mu}$ distribution** represents the number of events in which the product of the **charge of the prompt lepton and the soft muon** (SM) is **-/-, +/+, -/+, +/-**

The selection is:

- p_T > 25 GeV, |η| < 2.5
- ≥ 4 jets
- ≥ 1 b-jet
- SM p_T > 4 GeV
- SM ΔR < 0.4 from nearest jet

These plots are produced according to a selection on the angular separation ΔR between the prompt lepton and the SM object:

$$\Delta R = \sqrt{\Delta\phi(l,\mu)^2 + \Delta\eta(l,\mu)^2} < 2.0$$

Asymmetry: Same Sign (SS) and Opposite Sign (OS)

The **charge asymmetry** can be computed as follows:

$$P(b \to \ell^+) = \frac{N(b \to \ell^+)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{++}}{N^{+-} + N^{++}} = \frac{N^{++}}{N^+},$$

$$P(\bar{b} \to \ell^-) = \frac{N(\bar{b} \to \ell^-)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{--}}{N^{--} + N^{-+}} = \frac{N^{--}}{N^-},$$

$$P(b \to \ell^-) = \frac{N(b \to \ell^-)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{+-}}{N^{+-} + N^{++}} = \frac{N^{+-}}{N^+},$$

$$P(\bar{b} \to \ell^+) = \frac{N(\bar{b} \to \ell^+)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{-+}}{N^{--} + N^{-+}} = \frac{N^{-+}}{N^-},$$

$$A^{\mathrm{SS}} \equiv \frac{P(b \to \ell^+) - P(\bar{b} \to \ell^-)}{P(b \to \ell^+) + P(\bar{b} \to \ell^-)} = \frac{\frac{N^{++}}{N^+} - \frac{N^{--}}{N^-}}{\frac{N^{++}}{N^+} + \frac{N^{--}}{N^-}},$$

$$A^{\mathrm{OS}} \equiv \frac{P(b \to \ell^-) - P(\bar{b} \to \ell^+)}{P(b \to \ell^-) + P(\bar{b} \to \ell^+)} = \frac{\frac{N^{+-}}{N^+} - \frac{N^{-+}}{N^-}}{\frac{N^{+-}}{N^+} + \frac{N^{-+}}{N^-}},$$

where:

- $N^{l\mu}$ is the **number of events** with **lepton charge** $l = \pm 1$ and **SM charge** $\mu = \pm 1$
- $N^+ = N^{++} + N^{+-}$ and $N^- = N^{-+} + N^{--}$ represent the **total number of positively and negatively charged W-boson leptons**, respectively

Asymmetry: Same Sign (SS) and Opposite Sign (OS)

Asymmetry expected from the MC simulation at 58.8 fb^{-1} (13 TeV)

$$A^{SS}_{sim} = \Big(-0.1 \pm 0.8\,(\text{MC stat.}) \Big) \times 10^{-3}$$

$$A^{OS}_{sim} = \Big(0.1 \pm 0.6\,(\text{MC stat.}) \Big) \times 10^{-3}$$

Asymmetry expected from the MC simulation at 20.3 fb^{-1} (8 TeV) [2]

$$A^{SS}_{sim} = \Big(0.5 \pm 1.6\,(\text{MC stat.}) \Big) \times 10^{-3}$$

$$A^{OS}_{sim} = \Big(-0.3 \pm 0.9\,(\text{MC stat.}) \Big) \times 10^{-3}$$

Asymmetry measurement from the data at 20.3 fb^{-1} (8 TeV) [2]

$$A^{SS} = \Big(-0.7 \pm 0.6\,(\text{stat.})^{+0.2}_{-0.2}\,(\text{expt.}) \pm 0.5\,(\text{model}) \Big) \times 10^{-2}$$

$$A^{OS} = \Big(0.41 \pm 0.35\,(\text{stat.})^{+0.13}_{-0.11}\,(\text{expt.}) \pm 0.27\,(\text{model}) \Big) \times 10^{-2}$$

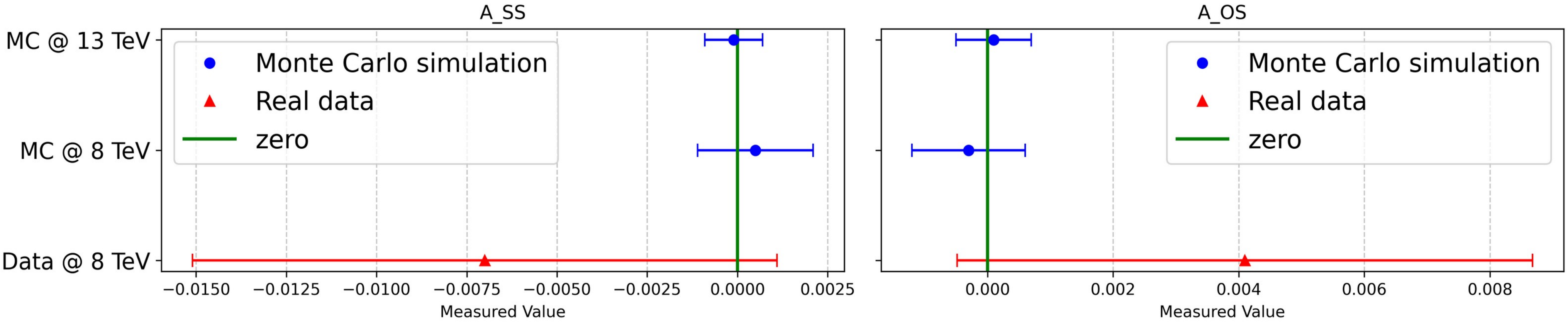
Asymmetry measurement expected for data at 58.8 fb^{-1} (13 TeV)

$$A^{SS} = \Big(x.xx \pm 0.24\,(\text{stat.}) \Big) \times 10^{-2}$$

$$A^{OS} = \Big(x.xx \pm 0.12\,(\text{stat.}) \Big) \times 10^{-2}$$

Asymmetry: Same Sign (SS) and Opposite Sign (OS)

Graphic representation of the measurements reported in slide 10



- The **uncertainties** reported for the measurements at **8** and **13 TeV** with **MC simulation** include **only the MC statistical** component, while the measurement with **data at 8 TeV** include **statistical**, **experimental systematics** and **modelling** ones
- **All three measurements are compatible with 0 within 1σ confidence level**
- The next step is to determine the **systematic uncertainty** of **13 TeV** measurement

CPV measurements from other B-factories

BaBar/Belle [3, 4]:

Belle and BaBar B-factories measured CP violation in the B^0 system by determining **$\sin 2\phi_1$ (complex phase of the CKM matrix)** through the time evolution of the asymmetry between B^0 and $\bar{B}^0$ as CP eigenstates

$$\left(\sin 2\phi_1\right)_{Belle} = 0.667 \pm 0.023 \pm 0.013 \qquad \left(\sin 2\phi_1\right)_{BaBar} = 0.687 \pm 0.028 \pm 0.012$$

LHCb [5]:

A time-integrated angular analysis of the decay $\mathbf{B^0_s \to J/\psi\ \bar{K}^*(892)^0}$ with $\mathbf{J/\psi \to \mu^+\mu^-}$ and $\mathbf{\bar{K}^*(892)^0 \to K^-\pi^+}$ is performed, with $\sqrt{s}$ = 13 TeV and luminosity = 6 fb^{-1}

$$\mathcal{A}_0^{CP} = 0.014 \pm 0.029\,(\text{stat}) \pm 0.007\,(\text{syst}), \qquad \mathcal{A}_0^{CP} = 0.021 \pm 0.026\,(\text{stat}) \pm 0.007\,(\text{syst}),$$

$$\mathcal{A}_{\parallel}^{CP} = -0.055 \pm 0.065\,(\text{stat}) \pm 0.007\,(\text{syst}), \qquad \mathcal{A}_{\parallel}^{CP} = -0.073 \pm 0.060\,(\text{stat}) \pm 0.007\,(\text{syst}),$$

$$\mathcal{A}_{\perp}^{CP} = 0.060 \pm 0.057\,(\text{stat}) \pm 0.016\,(\text{syst}). \qquad \mathcal{A}_{\perp}^{CP} = 0.057 \pm 0.049\,(\text{stat}) \pm 0.014\,(\text{syst}).$$

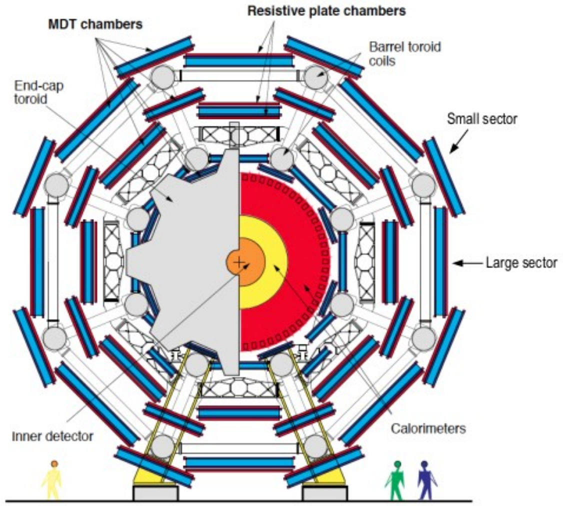
where $A_k^{CP} = \frac{\overline{\Gamma}_k - \Gamma_k}{\overline{\Gamma}_k + \Gamma_k}$ is a ratio of partial decay rates

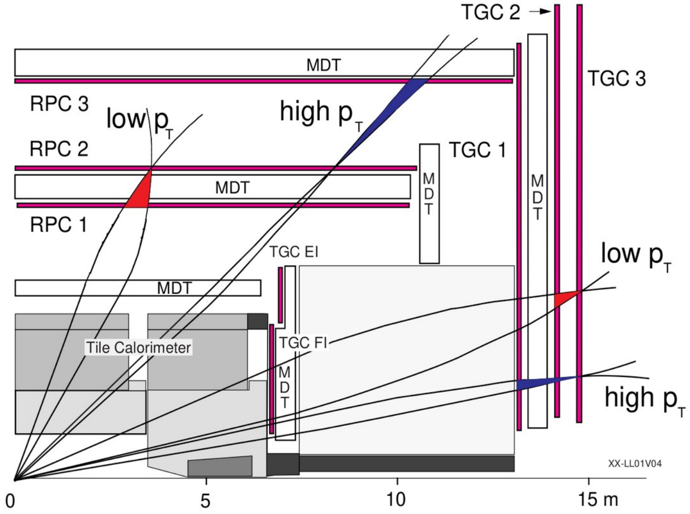
Summary

- CP violation analysis
- Work for qualification as an ATLAS author
- Other activities

The Resistive Plate Chambers (RPCs)

- The **RPCs** provide a **high-efficiency muon trigger** in the **Muon Spectrometer Barrel region** and assist in muon tracking
- About **3700 gas volumes** for a total **area** of about **4000 m²**, within a **0.5 T** toroidal **magnetic field**
- Each chamber is composed of **2 independent layers (doublets)**, arranged in **3 concentric cylindrical** doublet layers, known as **"middle confirm layer"** (RPC1), **"middle pivot layer"** (RPC2) and **"outer confirm layer"** (RPC3) [7]





The **1-year qualification work** was supervised by **Dr. M. Sessa** (INFN Rome Tor Vergata) and **Prof. C. Luci** (Rome Sapienza)

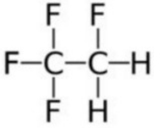
New RPC gas mixture

The **RPCs** were continuosly **flushed** with a **gas mixture** (until Summer 2023):

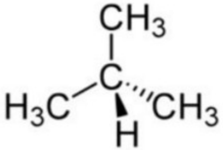
- $C_2H_2F_4$ (gas **target** for the **primary ionisation**);
- $i\text{-}C_4H_{10}$ (**quencher** component helping to **avoid propagation of the discharge**);
- SF_6 (**electronegative** component helping to **limit growth of avalanches**)

Period	GWP	Gas mixture	WP (V)
–2023	1450	$C_2H_2F_4$ 94.7% $i\text{-}C_4H_{10}$ 5% SF_6 0.3%	9600
Aug 2023–2024	1150	$C_2H_2F_4$ 64% CO_2 30% $i\text{-}C_4H_{10}$ 5% SF_6 1%	9350
2025	1050	$C_2H_2F_4$ 64.5% CO_2 30% $i\text{-}C_4H_{10}$ 5% SF_6 0.5%	9000

GWP: Global Warming Potential with respect to CO_2



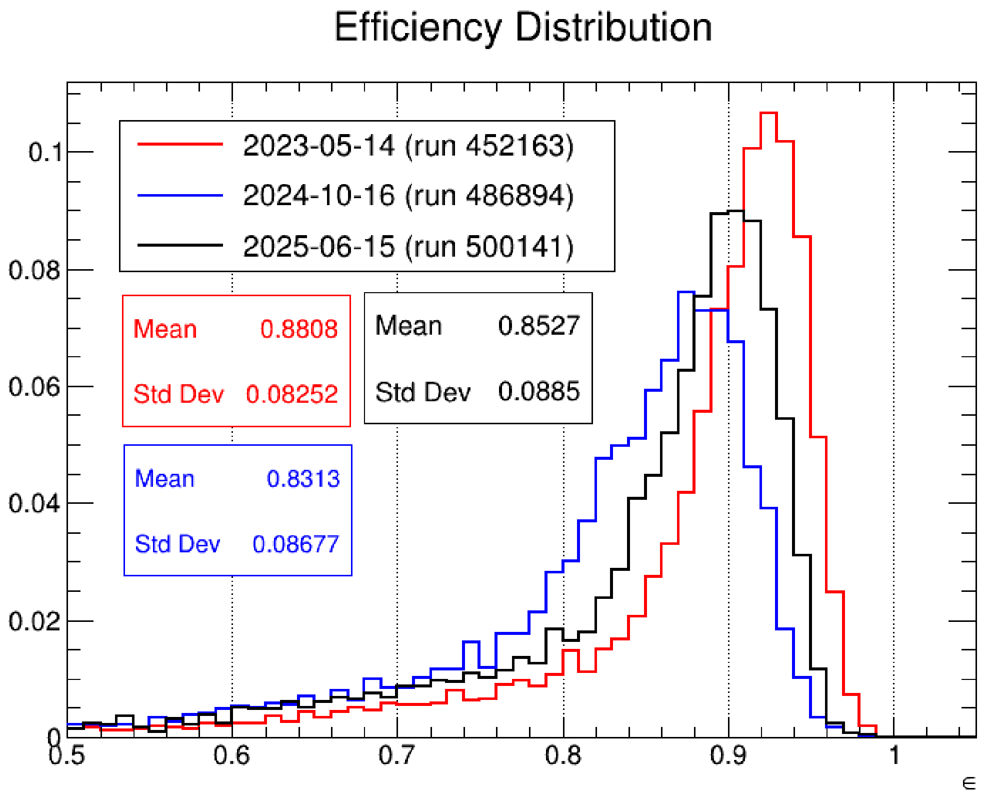
$C_2H_4F_4$ (R-134a)
GWP: 1430



$i\text{-}C_4H_{10}$
GWP: 3.3

SF_6
GWP: 22800

RPC efficiency with 2023, 2024, 2025 gas mixtures



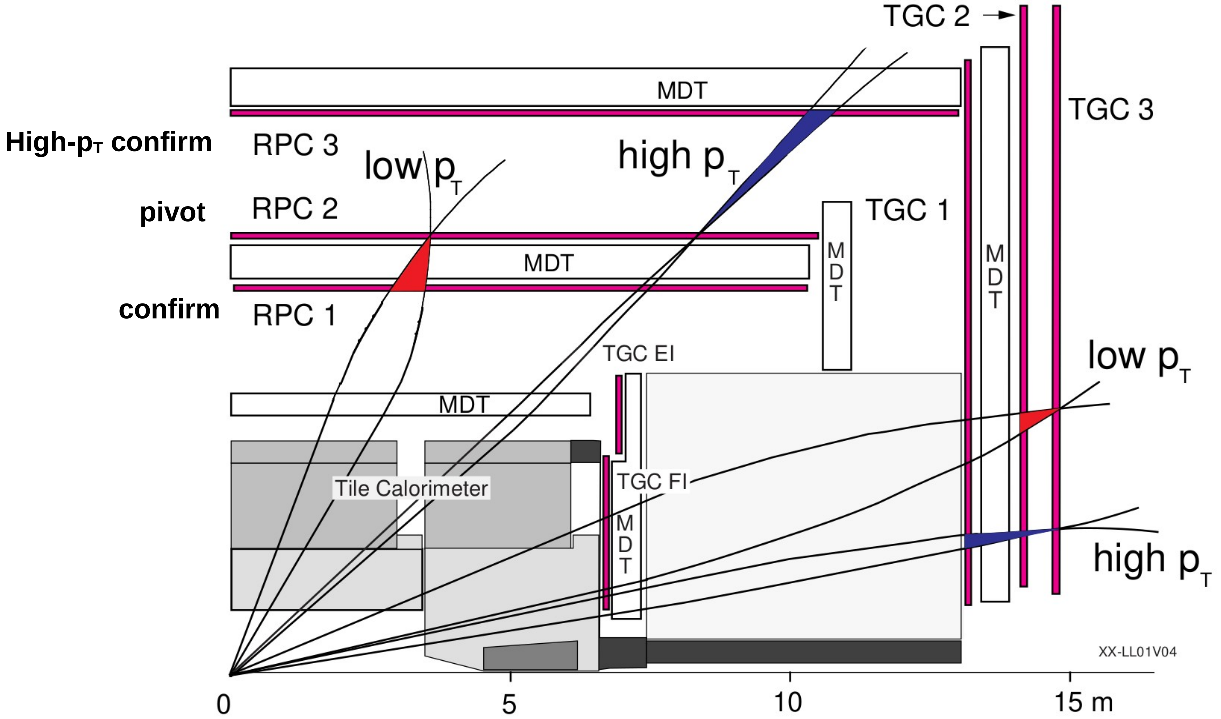
$$\varepsilon_{2023} = (88.1 \pm 8.3)\%$$

$$\varepsilon_{2024} = (83.1 \pm 8.7)\%$$

$$\varepsilon_{2025} = (85.3 \pm 8.9)\%$$

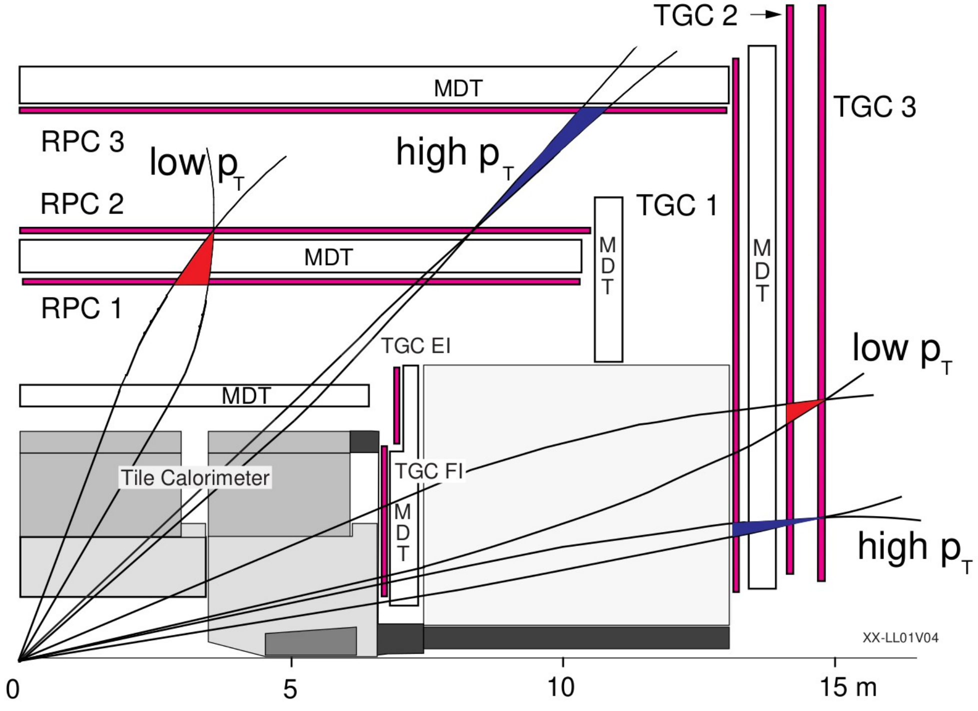
2024 gas mixture shows a **lower efficiency** with respect to **2025**, despite **similar gas composition.** Further investigation needed...

Simulation of Level-1 (L1) Muon Barrel Trigger Efficiency

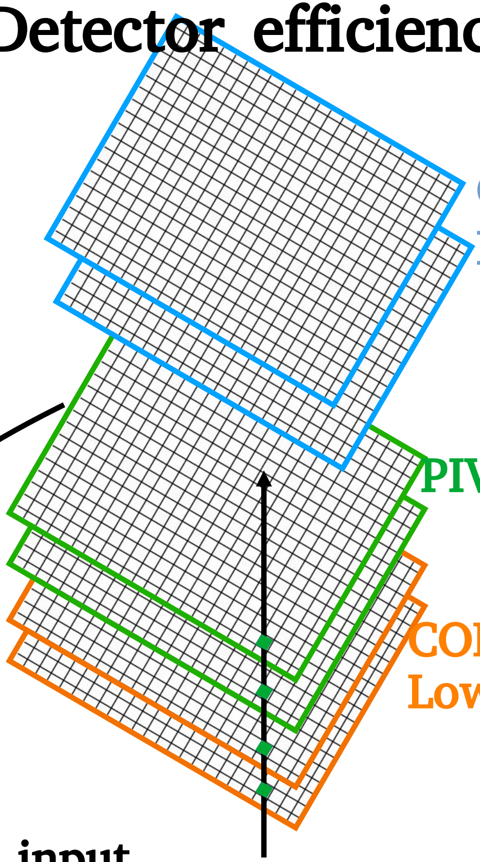


Low-p_T / High-p_T trigger efficiency

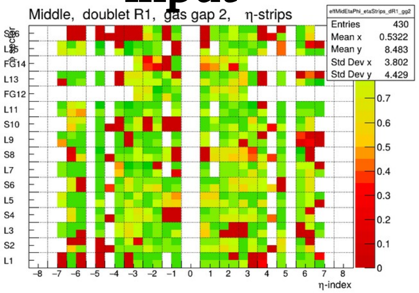
- The goal is to **simulate the L1 barrel trigger when muons pass through the detector** with a tool I have developed for my Qualification Task, under certain constraints:
  - ➔The **low-p_T** algorithm starts with a signal in an **RPC2 (pivot)** strip and then checks for matching signals in **RPC1 (confirm) layers** within a narrow cone pointing back to the collision point.
    It requires signals to be present in **at least 2 out of 4** detector layers.
  - ➔The **high-p_T** algorithm starts with a muon candidate identified by the low-p_T algorithm and then checks for the presence of matching signals in **at least 1 out of 2 RPC3 (confirm) layers** within a narrower cone pointing back to the collision point.



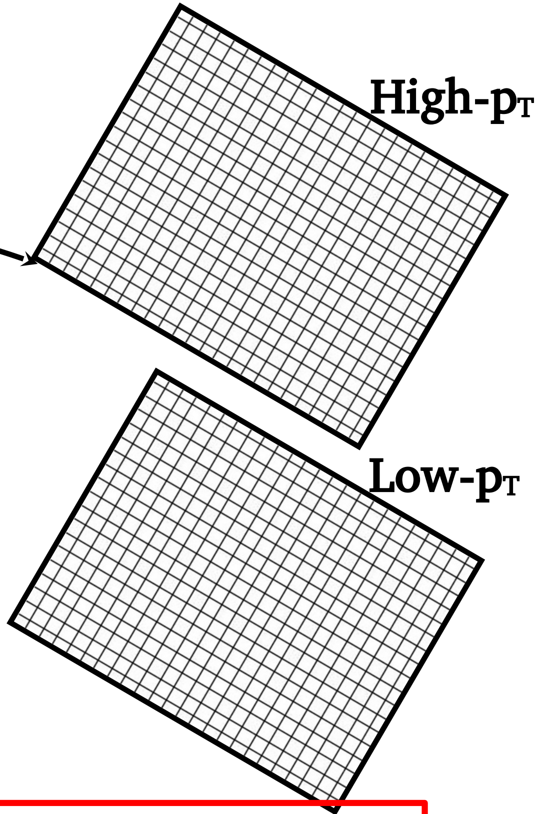
Detector efficiency



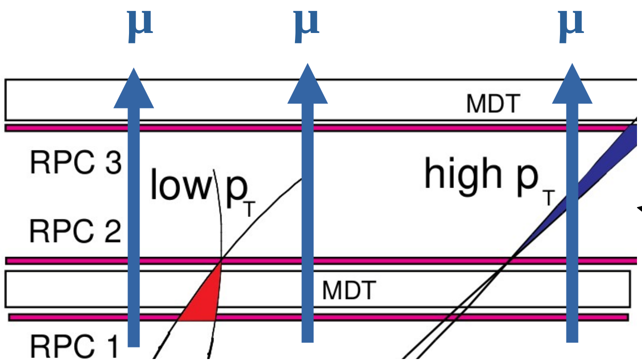
input



L1 muon barrel trigger efficiency



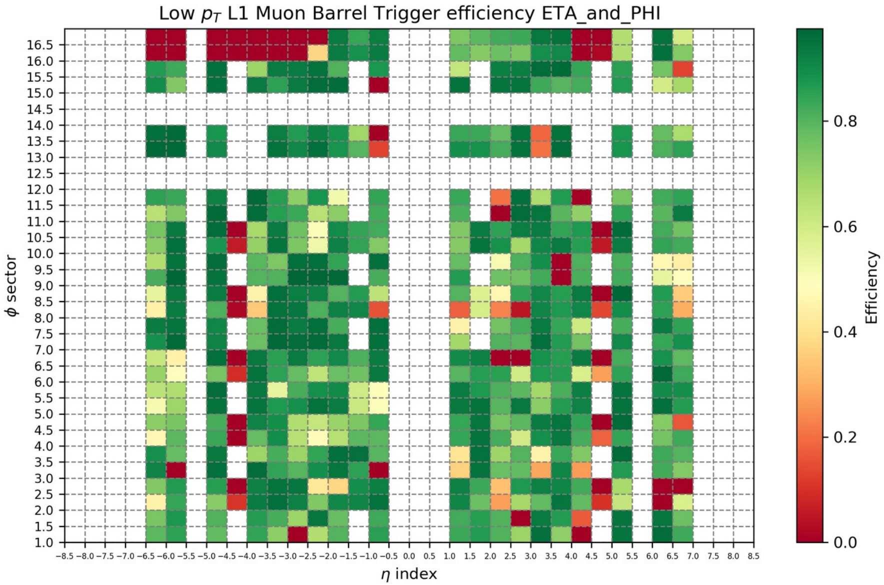
- Given the detector efficiency per layer, we compute the probability of ≥2/4 BM hits for low-p_T and ≥1/2 BO hits for high-p_T triggers.
- Trigger efficiency is computed with granularity of the strip readout panel



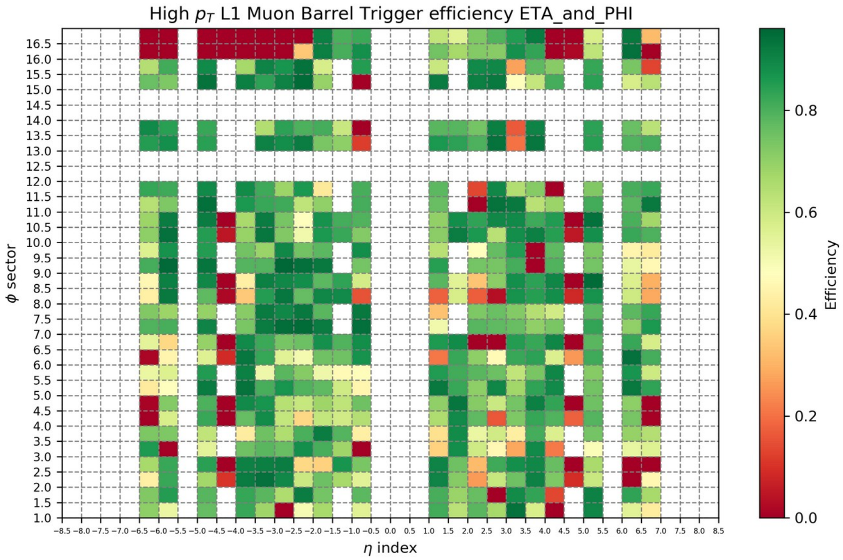
<u>Tool approximation</u>: the trigger efficiency has been estimated by considering the **muon tracks** as perfecty **orthogonal** to the various **RPC layers**

Simulated trigger efficiency using panel efficiency measured from data

Low-p_T



High-p_T

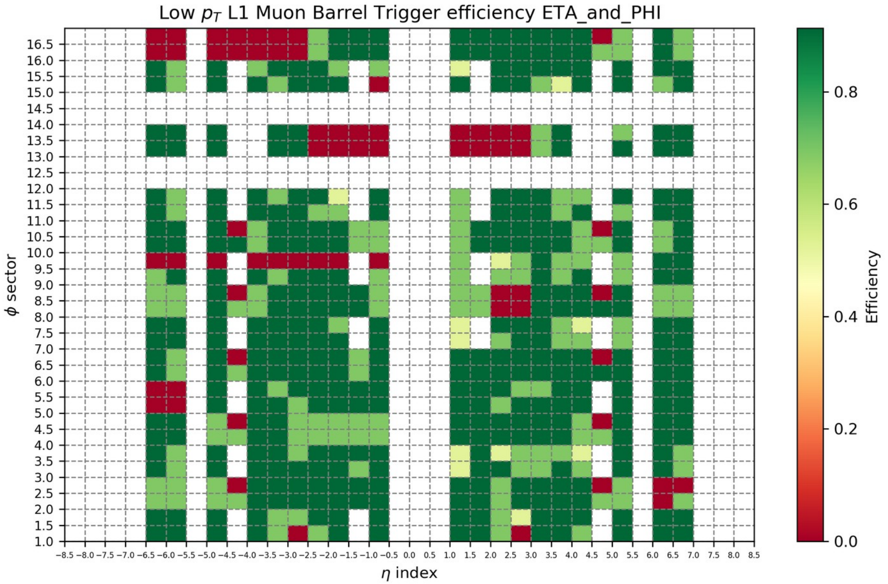


The **measured panel efficiencies** were computed starting from **data** by using the **MTV framework** developed and maintained by Roma1 group. Then this **output** is used as **input** for the **trigger efficiency tool.**

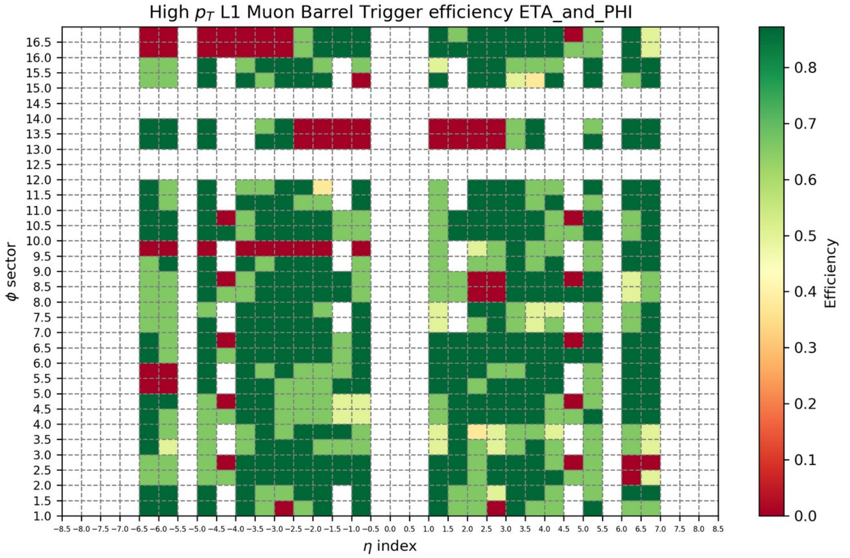
To obtain the **data,** a processing time of about **1 week** is required. The developed trigger tool was therefore designed to **provide a reliable estimation without this delay**

DCS information for dead & off panels

Low-p_T



High-p_T



The purpose of the tool is **to predict the impact on trigger efficiency performance using real-time information,** such as that provided by the **Detector Control System (DCS)** for the not working panels (**dead/off panels**):

- We put **zero efficiency** for the dead/off panels found by the DCS, otherwise the **mean efficiency value** expected in the eff range **[0.5, 1]** (**~0.85** in this case)
- Given <u>**only**</u> the DCS info, the **trigger holes** can be easily spotted

Summary of the trigger efficiencies

Source	low-p_T [%]	high-p_T [%]	Time to wait
DCS (dead/off panels + tool)	~ 75	~ 69	None
MTV (MTV panels eff + tool)	~ 73	~ 66	~ 1 week
Real data (trigger eff measured)	~ 70	~ 64	~ 1 week

- The **DCS** source is very useful to have a **general idea of the trigger efficiency IMMEDIATELY**, without waiting for the processed data after 1 week
  - For example, imagine to have a large number of **disconnected gas volumes**. What is the impact on the trigger efficiency? This tool **aims to predict the impact on the trigger performance**
- We can observe a **difference** about **2-3%** between **DCS** and **MTV sources**. The possible causes of this discrepancy can be:
  - A possible inefficiency in the **trigger readout chain**
  - The approximation in the tool developed of the muons **orthogonal** to the RPC layers
- Keep monitoring this difference for the whole 2025 data taking

Summary

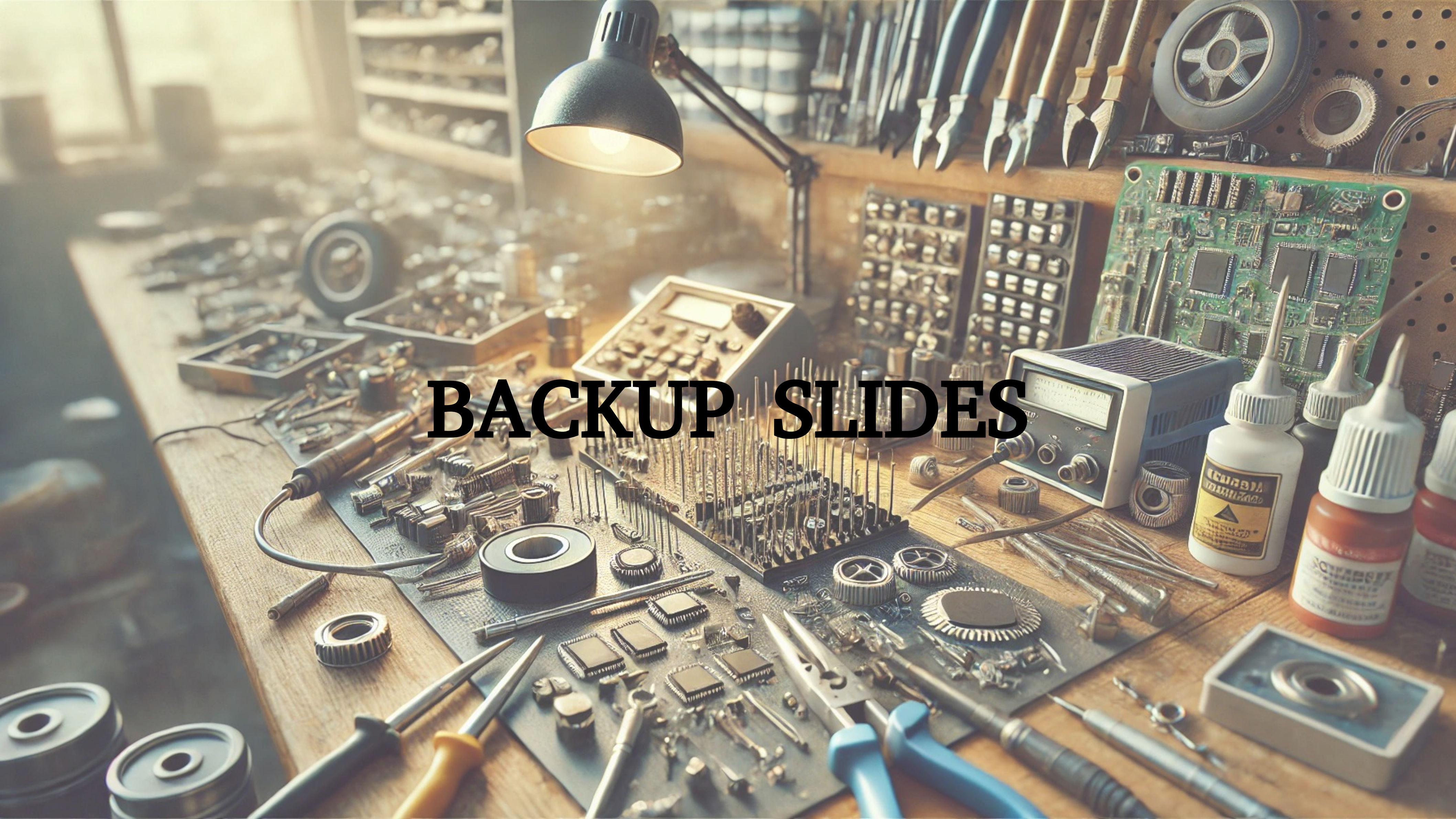
- CP violation analysis
- Work for qualification as an ATLAS author
- Other activities

Other activities

- Participation to several conferences and schools (**ATLAS Italy Workshops, ATLAS Weeks, …**)
  - Next week I will attend the **2025 European School of High-Energy Physics**
- Participation to the **ATLAS Run-3 data taking**
  - Access to the **Control Room** as a **Run Control & Trigger shifter**
  - Already got several **credits (OTPs)** this year
- A total of **3 months out of 6** spent **abroad** between schools, conferences and Control Room activity

Thank you for your attention

BACKUP SLIDES



CPV in $t\bar{t}$ events: full event selection

PROMPT ELECTRON:

- Tight likelihood
- Gradient isolation
- $p_T > 15$ GeV
- $d_0 sig < 5$
- $|z_0 \sin\theta| < 0.5$ mm
- $|\eta| < 2.47$
- $1.37 < |\eta| < 1.52$ excluded

PROMPT MUON:

- $p_T > 25$ GeV
- $|\eta| < 2.5$
- $|d_0 sig| < 3$
- $|z_0 \sin\theta| < 0.5$ mm
- $\Delta R > 0.4$ from nearest jet
- Gradient isolation
- Medium quality

SOFT MUON:

- $p_T > 4$ GeV
- $|\eta| < 2.5$
- $|d_0| < 3$ mm
- $|z_0 \sin\theta| < 3$ mm
- $\Delta R < 0.4$ from nearest jet
- Only keep highest p_T muon for each jet
- Not prompt
- Tight quality

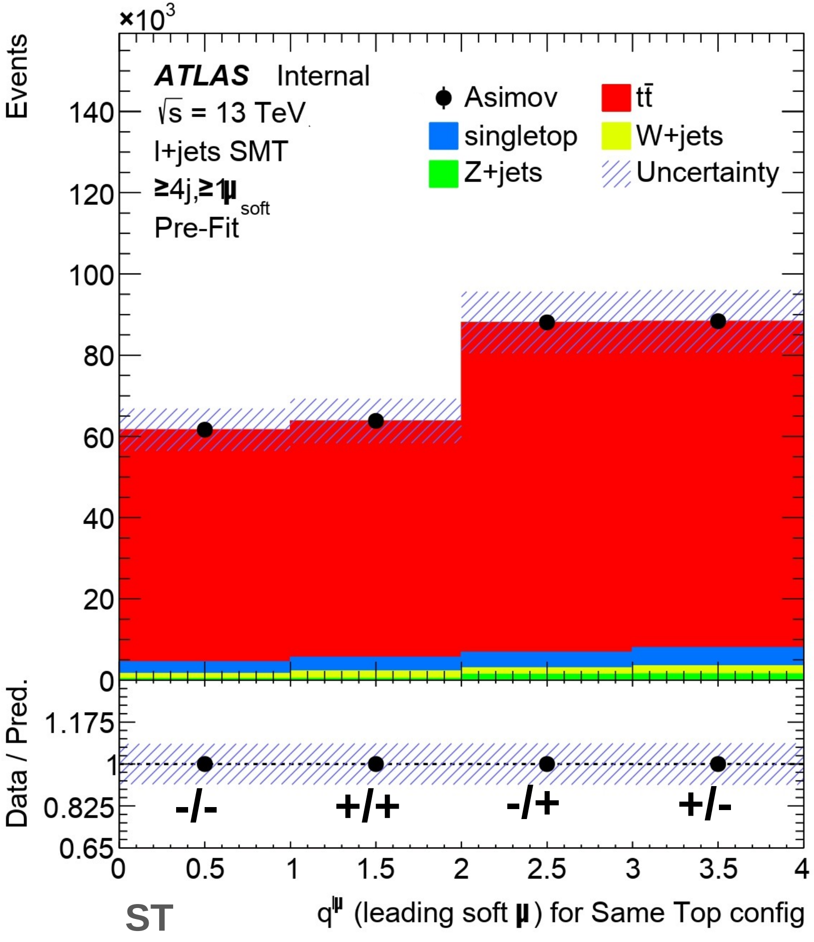
JETS:

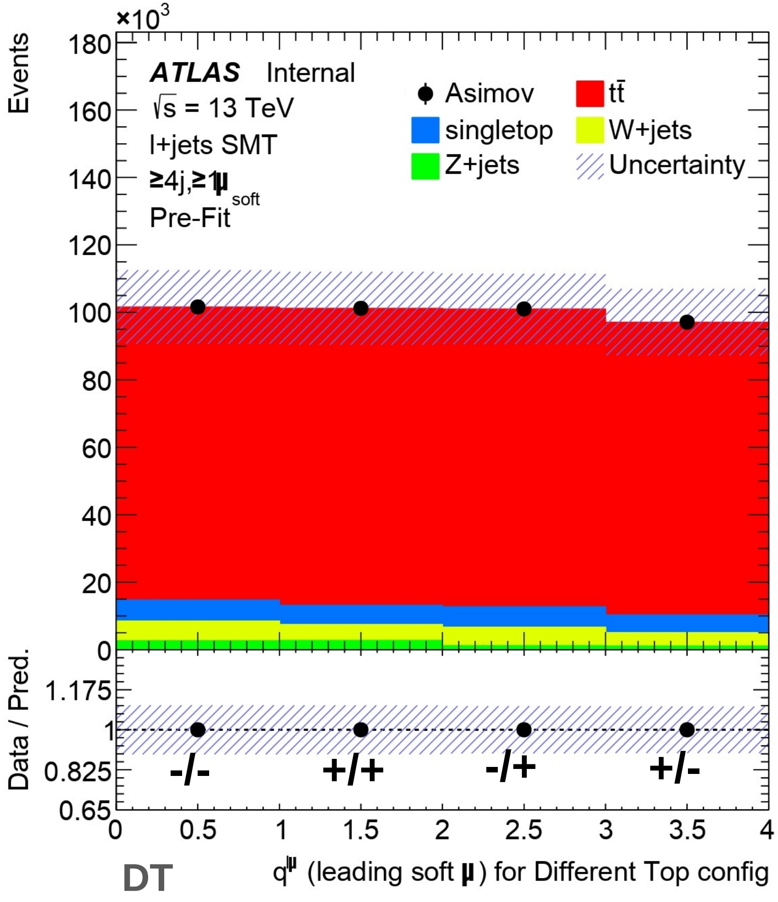
- Particle flow algorithm
- $p_T > 25$ GeV
- $|\eta| < 2.5$
- JVT > 0.59 if $p_T < 60$ GeV, $|\eta| < 2.4$
- ≥ 4 jets with $p_T > 30$ GeV (excl. SMT-tagged jet)
- ≥ 1 b-jet (DL1r at 77% efficiency working point)

MET:

- MET > 30 GeV
- MET + $M_T(W) > 60$ GeV

QLMU distribution (Same Top/Different Top configuration)





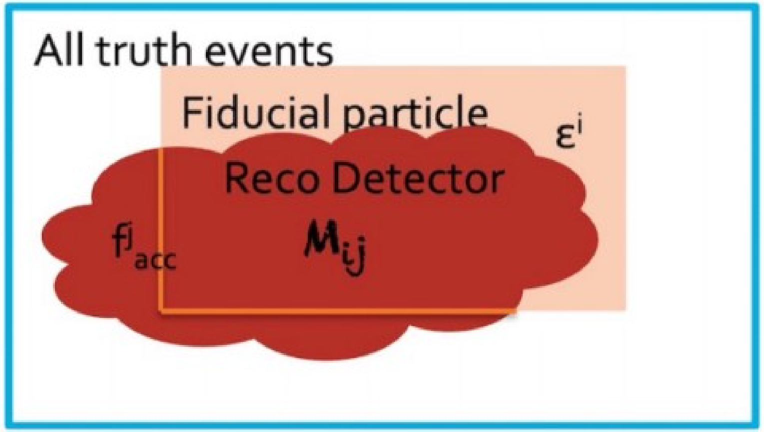
According to the **ttbar system side** where the **prompt lepton** and the **soft muon** come, we can determine the **jet assignment** to **Same-Top** (ST) and **Different-Top** (DT)

CPV in $t\bar{t}$ events: unfolding

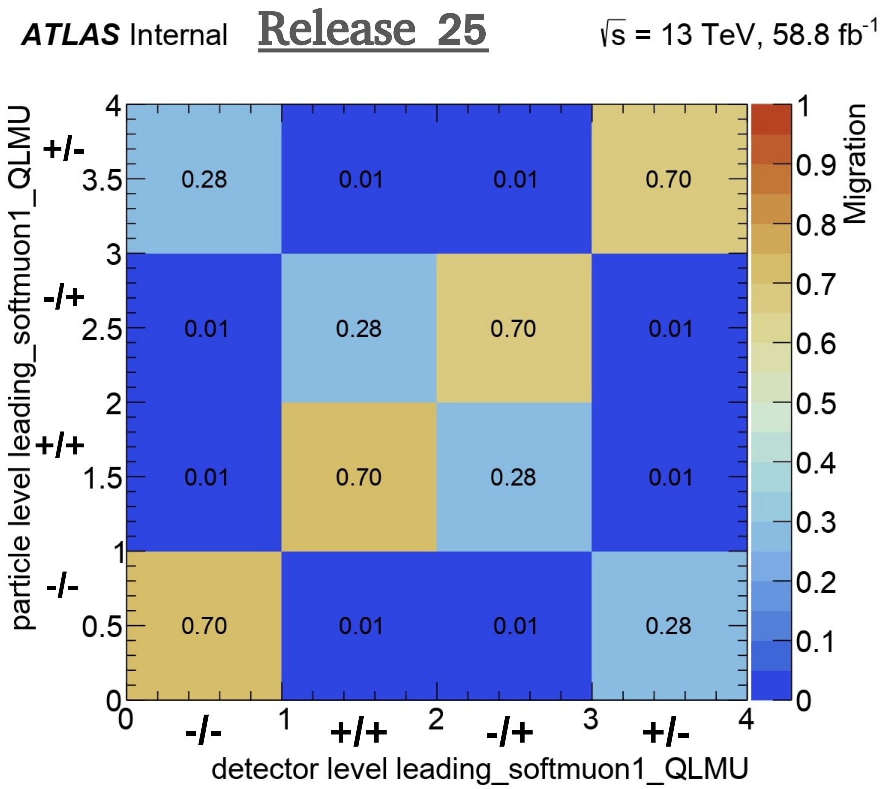
- The profile likelihood unfolding is being performed using TRExFitter

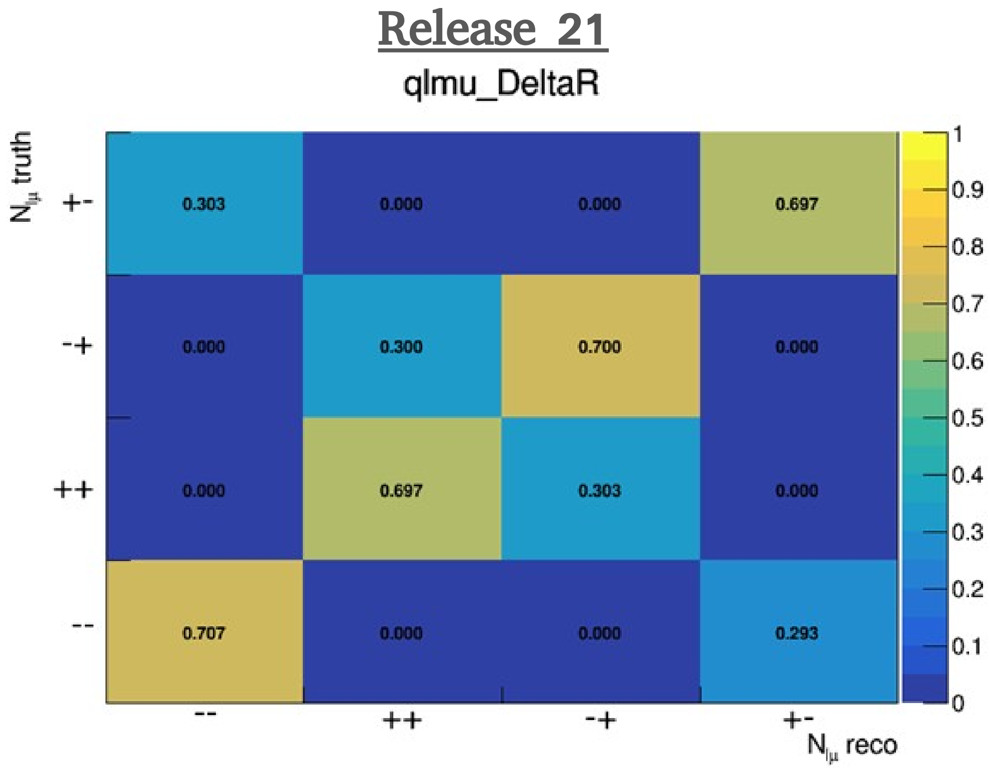
$$N^{j}_{particle} = \frac{1}{\varepsilon^{j}} \sum_{i} M^{-1}_{ij} f^{i}_{acc} \left(N^{i}_{reco} - N^{i}_{bkg} \right)$$

  - $N^{j}_{particle}$: particle level histogram
  - N^{j}_{reco}: reco level histogram (after subtracting non-$t\bar{t}$ backgrounds)
  - M^{-1}_{ij}: migration matrix
  - ε^{j}: efficiencies (corrected at particle level)
  - f^{i}_{acc}: acceptances (corrected at reco level)



Unfolding: QLMU migration matrix





Asymmetry: Same Sign (SS) and Opposite Sign (OS)

RELEASE 25 (mc20e):

A_{SS} = $(-0.10 \pm 2.37) \times 10^{-3}$ (stat)

A_{OS} = $(0.05 \pm 1.21) \times 10^{-3}$ (stat)

A_{SS} = $(-0.10^{+4.60}_{-4.65}) \times 10^{-3}$ (stat+sys)

A_{OS} = $(0.05^{+2.40}_{-2.33}) \times 10^{-3}$ (stat+sys)

RELEASE 21 (run-2 with detector sys):

A_{SS} = $(7.8 \pm 1.4) \times 10^{-3}$

A_{OS} = $(-4.1 \pm 0.7) \times 10^{-3}$

RELEASE 25 (2018 with detector sys):

A_{SS} = $(-0.10 \pm 2.44) \times 10^{-3}$

A_{OS} = $(0.05 \pm 1.24) \times 10^{-3}$

The asymmetries are derived after the application of the migration matrix

Asymmetry: Breakdown Uncertainties contributions

All systematics

Source	A_{SS} (10^{-3})	A_{SS} (10^{-3})	A_{OS} (10^{-3})	A_{OS} (10^{-3})
Statistical Error	+2.34	-2.40	+1.31	-1.12
FT_EFF_Eigen_B_0	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_B_10	+0.03	-0.03	+0.01	-0.01
FT_EFF_Eigen_B_12	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_B_2	+0.06	-0.06	+0.03	-0.03
FT_EFF_Eigen_B_3	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_B_4	+0.02	-0.02	+0.01	-0.01
FT_EFF_Eigen_B_6	+0.02	-0.02	+0.01	-0.01
FT_EFF_Eigen_B_7	+0.03	-0.03	+0.01	-0.01
FT_EFF_Eigen_B_9	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_C_15	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_Light_0	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_Light_13	+0.01	-0.01	+0.00	-0.00
FT_EFF_Eigen_Light_8	+0.00	-0.00	+0.00	-0.00
GEN_PDF_90902	+0.01	-0.01	+0.00	-0.00
GEN_PDF_90905	+0.02	-0.02	+0.01	-0.01
GEN_PDF_90919	+0.01	-0.01	+0.00	-0.00
GEN_Var3c	+0.39	-0.39	+0.20	-0.20
GEN_fsr	+3.18	-3.21	+1.66	-1.61
GEN_muF	+0.05	-0.05	+0.02	-0.02
GEN_muR	+0.19	-0.19	+0.10	-0.10
JET_BJES_Response	+0.06	-0.06	+0.03	-0.03
JET_EffectiveNP_Modelling1	+0.04	-0.04	+0.02	-0.02
JET_EtaIntercalibration_Modelling	+0.05	-0.05	+0.02	-0.02
JET_EtaIntercalibration_NonClosure_PreRec	+0.02	-0.02	+0.01	-0.01
JET_EtaIntercalibration_TotalStat	+0.03	-0.03	+0.01	-0.01
JET_Flavor_Composition	+0.05	-0.05	+0.02	-0.02
JET_Flavor_Response	+0.04	-0.04	+0.02	-0.02
JET_InSitu_NonClosure_PreRec	+0.20	-0.19	+0.10	-0.10
JET_JERUnc_Noise_PreRec	+0.00	-0.00	+0.00	-0.00
JET_JER_DataVsMC_MC16	+0.13	-0.13	+0.07	-0.07
JET_JER_EffectiveNP_1	+0.28	-0.27	+0.14	-0.14
JET_JER_EffectiveNP_2	+0.01	-0.01	+0.00	-0.00
JET_JER_EffectiveNP_3	+0.21	-0.21	+0.11	-0.11
JET_JER_EffectiveNP_4	+0.17	-0.17	+0.09	-0.09
JET_JER_EffectiveNP_6	+0.03	-0.02	+0.01	-0.01
JET_JER_EffectiveNP_7	+0.06	-0.06	+0.03	-0.03
JET_JER_EffectiveNP_8	+0.01	-0.01	+0.00	-0.00
JET_JER_EffectiveNP_9	+0.016	-0.01	+0.00	-0.00
JET_JESUnc_Noise_PreRec	+0.00	-0.00	+0.00	-0.00
JET_JESUnc_VertexingAlg_PreRec	+0.01	-0.01	+0.00	-0.00
JET_NNJvtEfficiency	+0.01	-0.01	+0.00	-0.00
JET_Pileup_OffsetMu	+0.07	-0.07	+0.03	-0.03
JET_Pileup_OffsetNPV	+0.11	-0.11	+0.06	-0.06
JET_Pileup_RhoTopology	+0.22	-0.22	+0.11	-0.11
MUON_EFF_ISO_MLLWINDOW	+0.00	-0.00	+0.00	-0.00
MUON_EFF_TrigSystUncertainty	+0.02	-0.02	+0.01	-0.01
PRW_DATASF	+0.01	-0.01	+0.00	-0.00
WjetsXsec	+0.65	-0.64	+0.34	-0.33
ZjetsXsec	+0.09	-0.09	+0.04	-0.04
luminosity	+0.02	-0.02	+0.01	-0.01
stXsec	+0.01	-0.01	+0.00	-0.00
ttbar_PowHer721	+0.39	-0.39	+0.21	-0.20
ttbar_PowPy8_A14Var	+0.26	-0.26	+0.14	-0.13
ttbar_PowPy8_ATLCR1	+1.11	-1.10	+0.57	-0.56
ttbar_PowPy8_ATLCR2	+1.13	-1.11	+0.58	-0.57
ttbar_PowPy8_Trec	+0.36	-0.35	+0.18	-0.18
ttbar_PowPy8_hdamp3mt	+1.34	-1.32	+0.69	-0.67

Source	A_{SS} (10^{-3})	A_{SS} (10^{-3})	A_{OS} (10^{-3})	A_{OS} (10^{-3})
Statistical Error	+2.37	-2.36	+1.21	-1.21
JET_BJES_Response	+0.06	-0.06	+0.03	-0.03
JET_EffectiveNP_Modelling1	+0.04	−0.04	+0.02	−0.02
JET_EtaIntercalibration_Modelling	+0.05	−0.05	+0.03	−0.03
JET_EtaIntercalibration_NonClosure_PreRec	+0.02	−0.02	+0.01	−0.01
JET_EtaIntercalibration_TotalStat	+0.03	−0.03	+0.02	−0.02
JET_Flavor_Composition	+0.05	−0.05	+0.03	−0.03
JET_Flavor_Response	+0.04	−0.04	+0.02	−0.02
JET_InSitu_NonClosure_PreRec	+0.20	−0.20	+0.10	−0.10
JET_JERUnc_Noise_PreRec	+0.01	−0.01	+0.00	−0.00
JET_JER_DataVsMC_MC16	+0.13	−0.13	+0.07	−0.07
JET_JER_EffectiveNP_1	+0.27	−0.27	+0.14	−0.14
JET_JER_EffectiveNP_2	+0.01	−0.01	+0.00	−0.00
JET_JER_EffectiveNP_3	+0.21	−0.21	+0.11	−0.11
JET_JER_EffectiveNP_4	+0.17	−0.17	+0.09	−0.09
JET_JER_EffectiveNP_6	+0.03	−0.03	+0.01	−0.01
JET_JER_EffectiveNP_7	+0.06	−0.06	+0.03	−0.03
JET_JER_EffectiveNP_8	+0.01	−0.01	+0.01	−0.01
JET_JER_EffectiveNP_9	+0.01	−0.01	+0.00	−0.00
JET_JESUnc_Noise_PreRec	+0.01	−0.01	+0.00	−0.00
JET_JESUnc_VertexingAlg_PreRec	+0.01	−0.01	+0.01	−0.01
JET_NNJvtEfficiency	+0.02	−0.02	+0.01	−0.01
JET_Pileup_OffsetMu	+0.07	−0.07	+0.04	−0.04
JET_Pileup_OffsetNPV	+0.12	−0.12	+0.06	−0.06
JET_Pileup_RhoTopology	+0.23	−0.23	+0.12	−0.12
PRW_DATASF	+0.01	−0.01	+0.01	−0.01

Detector systematics

RPC HV scan on May-June 2024

- **6** DCS HV channels selected, chosen in such a way to minimize any impact on trigger efficiency
  - **57** gas volumes –> **114** strip readout panels
- **8** HV points chosen besides the nominal run at 9350 V
  - 8800 V, 9000 V, 9200 V, 9250 V, 9300 V, 9350 V, 9400 V, 9450 V, 9500 V

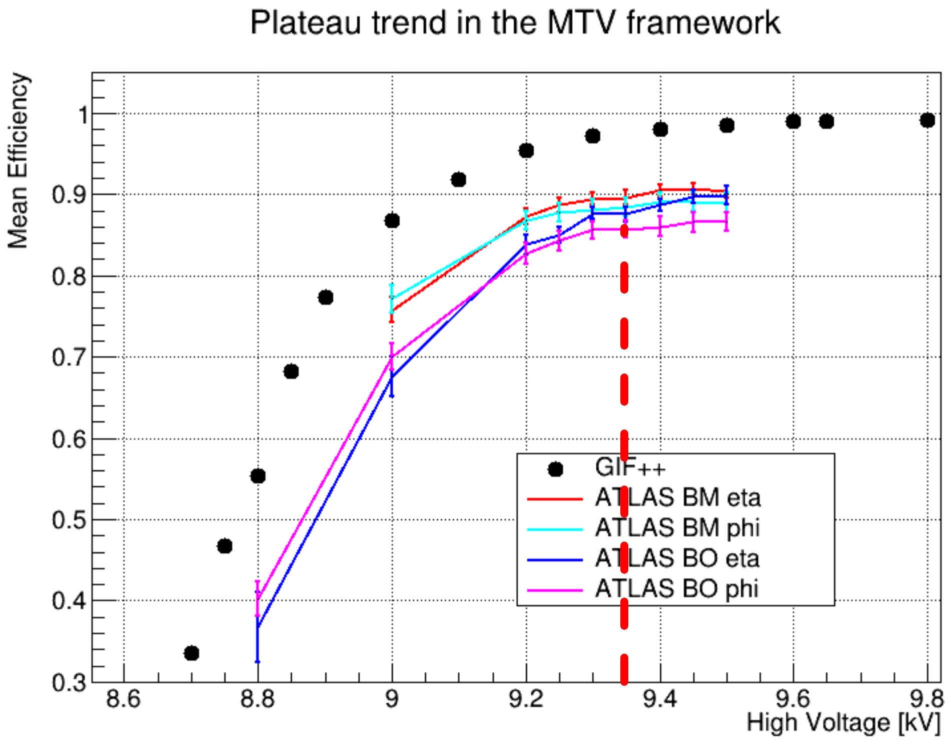
Runs

Run n.0 at 9350 V: 476718
Run n.1 at 9400 V: 476760
Run n.2 at 9450 V: 476785
Run n.3 at 9500 V: 476875
Run n.4 at 9300 V: 476929
Run n.5 at 9250 V: 476991
Run n.6 at 9200 V: 477002
Run n.7 at 9000 V: 477037
Run n.8 at 8800 V: 477048

HV channels

BOS.A2.10.CO.Ly0
BOS.A2.06.CO.Ly0
BOL.A1.15.CO.Ly0
BMS.C.10.CO.Ly1
BML.C.07.CO.Ly1
BML.A.05.CO.Ly1

RPC HV scan on May-June 2024



- For the **2024 gas mixture a RPC High Voltage (HV) scan was performed** to confirm if the nominal working point at **9.35 kV belongs to the efficiency plateau**
  - By looking at the plot, it is possible to **confirm this hypothesis**
- **No direct comparison** with the GIF**++** measurements
  - Efficiency was measured in a fiducial area **without spacers**, i.e. **a few percent** effect
  - Still some residual difference observed

Computing efficiencies script

```
# Efficiencies computation
eff_4_4 = eff_gap_0_CO_LOW * eff_gap_1_CO_LOW * eff_gap_0_PI_LOW * eff_gap_1_PI_LOW
eff_4_4_values.append(eff_4_4)

eff_3_4 = (
    eff_gap_0_CO_LOW * eff_gap_1_CO_LOW * eff_gap_0_PI_LOW * (1 - eff_gap_1_PI_LOW) +
    eff_gap_0_CO_LOW * eff_gap_1_CO_LOW * (1 - eff_gap_0_PI_LOW) * eff_gap_1_PI_LOW +
    eff_gap_0_CO_LOW * (1 - eff_gap_1_CO_LOW) * eff_gap_0_PI_LOW * eff_gap_1_PI_LOW +
    (1 - eff_gap_0_CO_LOW) * eff_gap_1_CO_LOW * eff_gap_0_PI_LOW * eff_gap_1_PI_LOW
)
eff_3_4_values.append(eff_3_4)

eff_2_4 = (
    eff_gap_0_CO_LOW * (1 - eff_gap_1_CO_LOW) * eff_gap_0_PI_LOW * (1 - eff_gap_1_PI_LOW) +
    (1 - eff_gap_0_CO_LOW) * eff_gap_1_CO_LOW * eff_gap_0_PI_LOW * (1 - eff_gap_1_PI_LOW) +
    eff_gap_0_CO_LOW * (1 - eff_gap_1_CO_LOW) * (1 - eff_gap_0_PI_LOW) * eff_gap_1_PI_LOW +
    (1 - eff_gap_0_CO_LOW) * eff_gap_1_CO_LOW * (1 - eff_gap_0_PI_LOW) * eff_gap_1_PI_LOW
)
eff_2_4_values.append(eff_2_4)

eff_trigger_lowpt = eff_4_4 + eff_3_4 + eff_2_4
```

```
# Efficiencies computation
eff_trigger_highpt_ONLY = 1 - (1 - eff_gap_0_CO_HIGH) * (1 - eff_gap_1_CO_HIGH)
eff_trigger_highpt = eff_trigger_lowpt * eff_trigger_highpt_ONLY
```

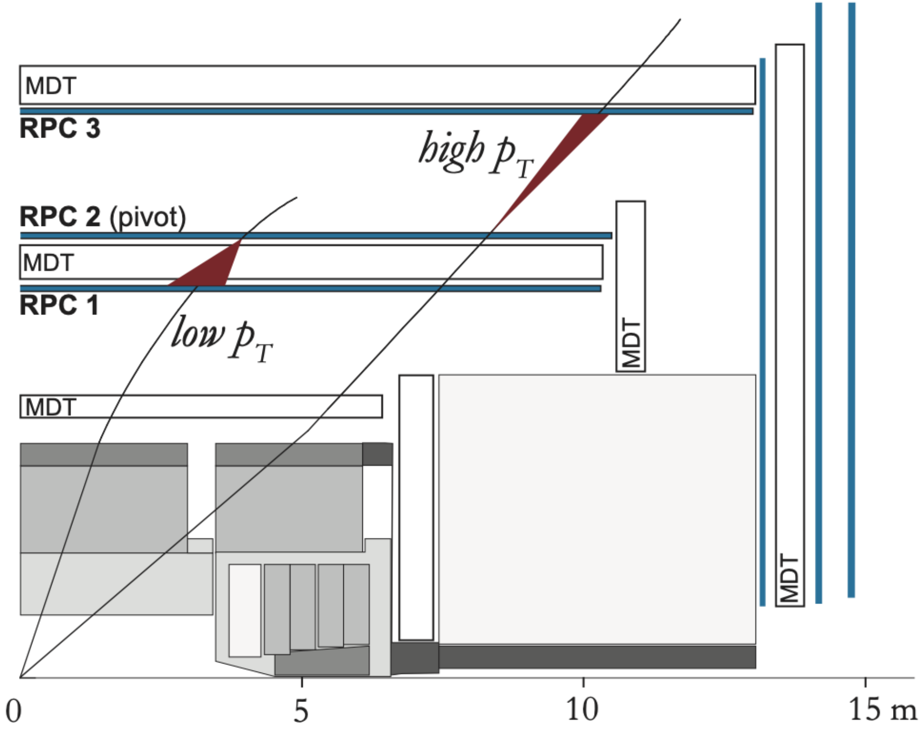
Muon Trigger Validation (MTV) from Rome1

- In order to get the **RPC panel efficiency**, calculated as

$$\varepsilon = \frac{N_{muons\ matched}}{N_{total\ muons}}$$

  and other plots that are reported in the RPC web page (see later on), we used the **MTV framework**

- A big thank to **M. Corradi** & **S. Rosati** for developing and maintaining this framework



https://gitlab.cern.ch/atlas-l1rpc-software/MuonTriggerValidation.git