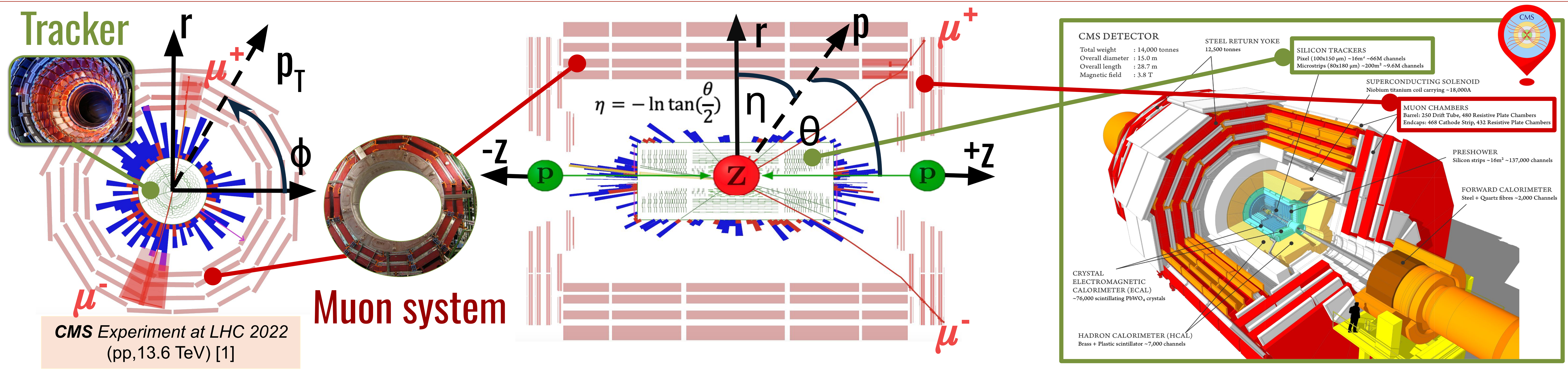
Tag and Probe technique tracking efficiency results at CMS

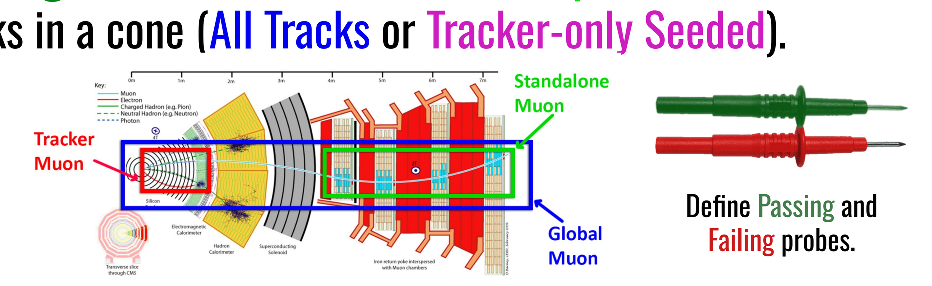
Brunella D'Anzi[1], Michele Barbieri[1]
on behalf of the CMS Collaboration

Case study



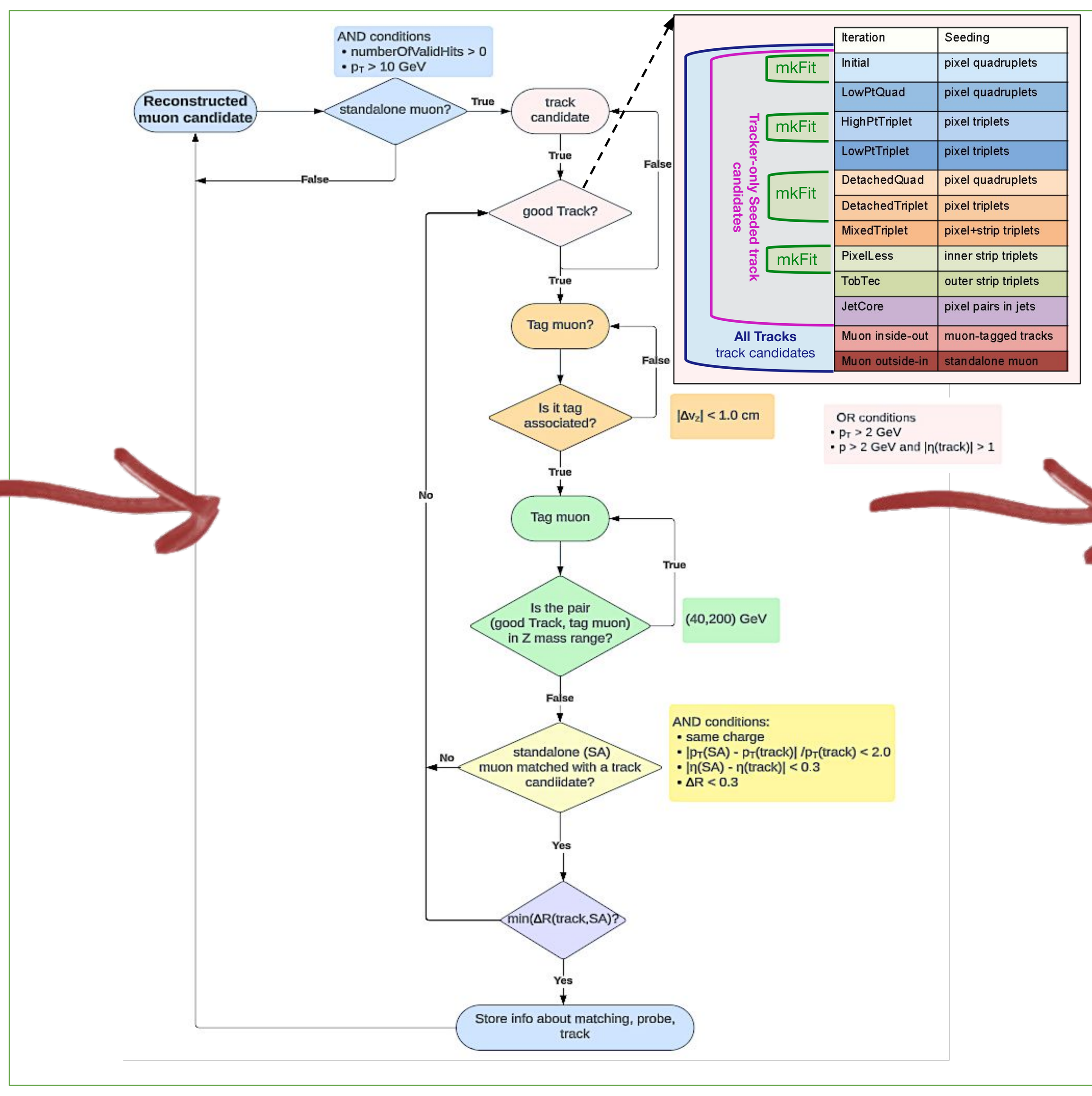
The Tag and Probe method [2] for Muon Tracking Efficiency

- **Define and Classify Probes**: loose criteria, reconstructed with muon system (standalone muon probe).
  - **Passing Probes**: Verify standalone probes match tracker tracks in a cone (All Tracks or Tracker-only Seeded).



- **Define Tags**: Tight ID selection [3], reconstructed using both muon chambers and the tracker.
- **Pairing**: Opposite charge di-muon pairs, invariant mass near Z.
  - Exclude interchangeable pairs.
- **Measured Efficiency** (ϵ): Fraction of pairs with probes passing tighter selection.
  - Background subtraction via simultaneous fit procedure.
- **Fake Matching Rate [4]** ϵ_F : Before probes classification, remove tracks near Z mass (40-200 GeV).

Selection strategy



Challenges and Control Measures

Measuring true tracking efficiency ϵ_T involves matching tracks between the inner tracker and the muon system, presenting two main challenges that must be controlled:

- **Underestimation Risk:**
  - Inner tracker track not associated with standalone muon.
  - Mitigate with loose matching criteria.
- **Overestimation Risk:**
  - Standalone muon associated with spurious tracker track.
  - Worsens with looser matching criteria, need to compute matching fake rate.

1-ϵ_F is typically around (0.9-0.95)% in the sample used in this study.
1-ϵ_M is estimated to be below 0.1% except for high p_T standalone muon bins. We neglect it and consider it an additional systematic uncertainty.

ϵ : measured efficiency
ϵ_M : matching efficiency
ϵ_T : true tracking efficiency
ϵ_F : fake matching rate

$$\epsilon = \epsilon_T\epsilon_M + (1-\epsilon_T\epsilon_M)\,\epsilon_F$$

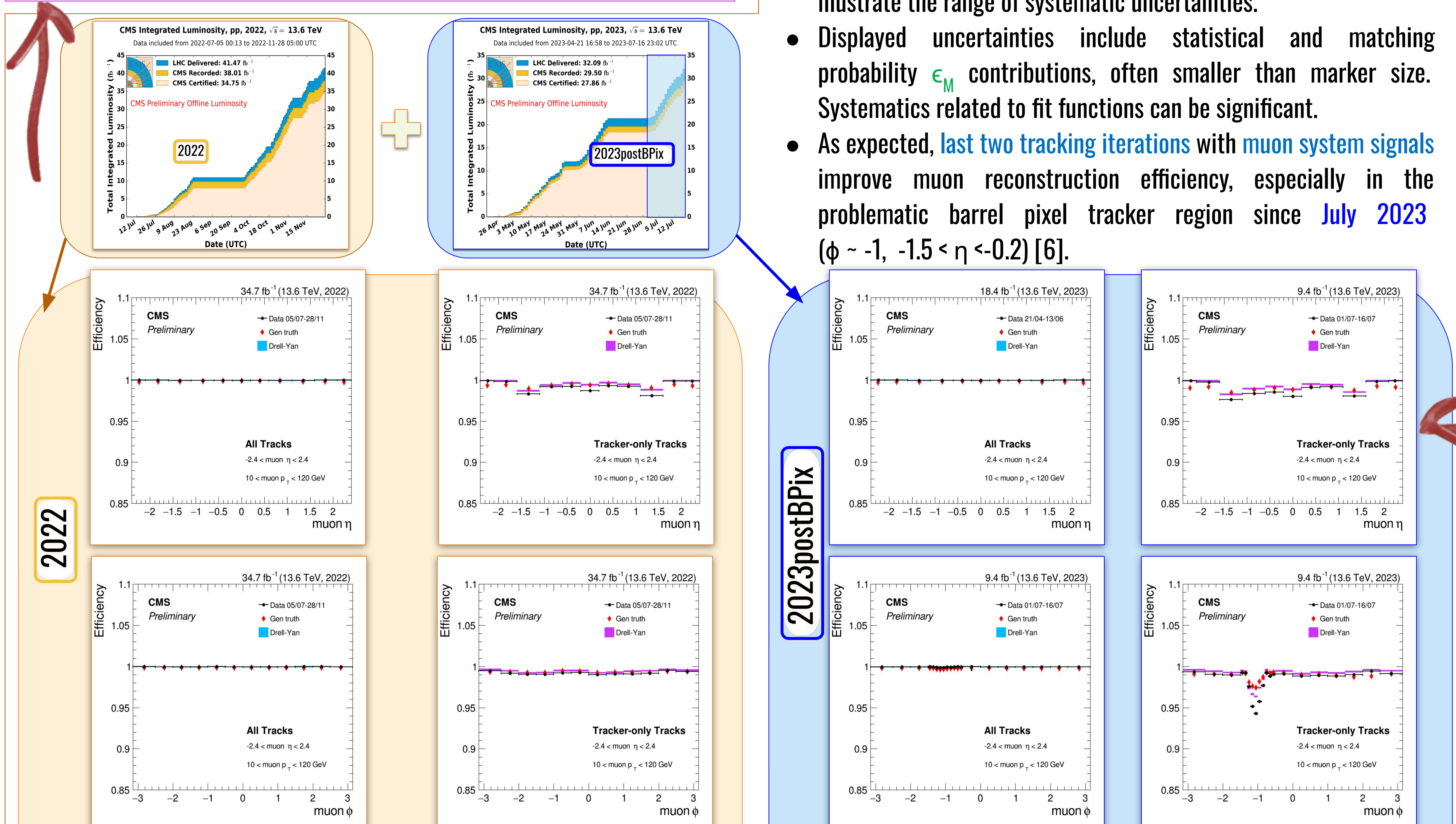
$$1-\epsilon_T\epsilon_M = \frac{1-\epsilon}{1-\epsilon_F}$$

References

[1] https://fireworks.cern.ch/.
[2] Documentation of the CMS TagAndProbe package, N. Adam, J. BerryHill, Z. Gecse et al., CMS Twikipage TagAndProbe (2010).
[3] Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at √s = 13 TeV, CMS Collaboration, JINST 13 (2018) no.06, P06015.
[4] Description and performance of track and primary-vertex reconstruction with the CMS tracker, CMS Collaboration, TRK-11-001, JINST 9 (2014), P10009.
[5] MadGraph5_aMC@NLO, arXiv:1405.0301 [hep-ph].
[6] Operation and performance of the Pixel Detector, CMS-CR-2023-282.
[7] https://twiki.cern.ch/twiki/bin/view/CMSPublic/DataQuality.
[8] CMS Tracking performance using Tag and Probe with Z → μ⁺μ⁻ in 2022 and 2023, CMS-DP-2024-054.
[9] CMS Tracking Efficiency from Tag & Probe in Early Run-3 data, CMS Collaboration, CMS-DP-2022-046.

Results in Run 3 [8,9]

- Estimate of true tracking efficiency ϵ_T is computed as a function pseudorapidity (η) and azimuthal angle (ϕ) of probe standalone muons using All Tracks and Tracker-only seeded track candidates .
- Data (black dots), MC DY (light blue/violet rectangles) and Gen truth matching study (red diamonds). The latter study evaluates the average tracker track matching outcome by using DY MC hard-process generator-level muon particles instead of reconstructed (both tag and probe) muons. Different methods illustrate the range of systematic uncertainties.
- Displayed uncertainties include statistical and matching probability ϵ_M contributions, often smaller than marker size. Systematics related to fit functions can be significant.
- As expected, last two tracking iterations with muon system signals improve muon reconstruction efficiency, especially in the problematic barrel pixel tracker region since July 2023 (ϕ ~ -1, -1.5 < η <-0.2) [6].



Fit procedure

Simultaneous fit to the signal and the background tag-probe invariant mass (for both passing and failing probes, data and Madgraph DY MC [5]). Tracker momentum is used for passing probes and tag muons to improve mass resolution.

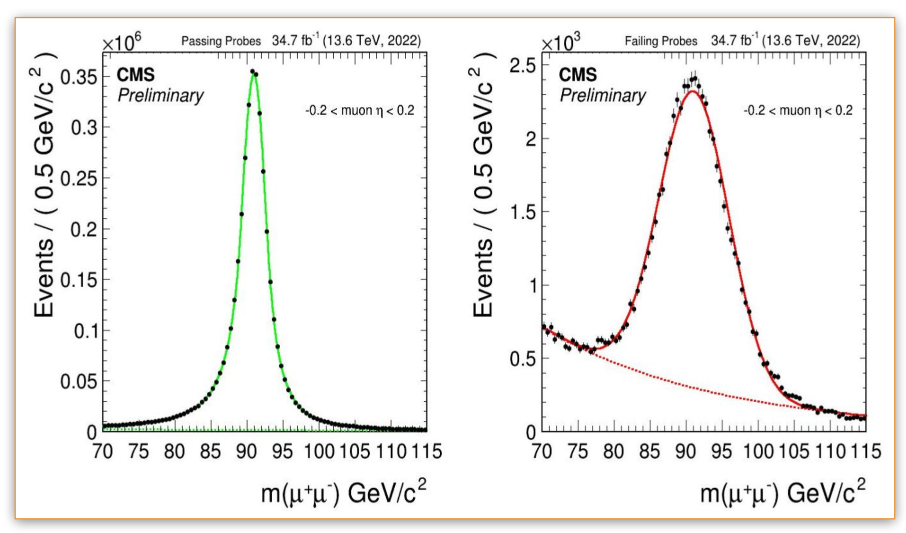
$$N_{pass} = f^s_{pass}(m_{\mu\mu})N^s_{pass} + f^b_{pass}(m_{\mu\mu})N^b_{pass}$$
$$N_{fail} = f^s_{fail}(m_{\mu\mu})N^s_{fail} + f^b_{fail}(m_{\mu\mu})N^b_{fail}$$

$$\epsilon_{Data}\ (\epsilon_{MC}) = \frac{N^s_{pass}}{(N^s_{pass} + N^s_{fail})}$$

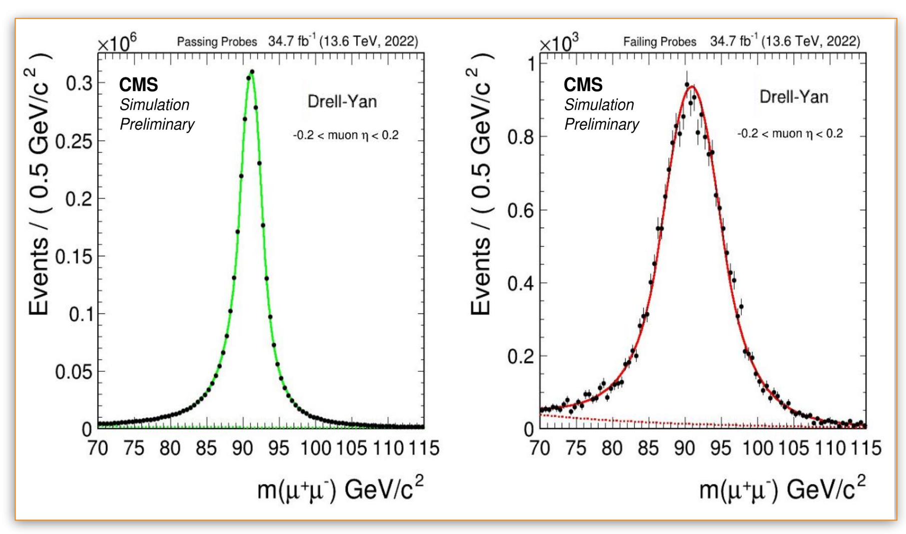
$$\sigma(\epsilon) = \frac{N^s_{fail}}{(N^s_{pass}+N^s_{fail})^2}\sigma(N^s_{pass}) \oplus \frac{N^s_{pass}}{(N^s_{pass}+N^s_{fail})^2}\sigma(N^s_{fail})$$

f^s_{pass}: fitting function for signal shape in **Passing Probes** = RooDCBShape(*)($m_{\mu\mu}$)
f^s_{fail}: fitting function for signal shape in **Failing Probes** = RooDCBShape(*)($m_{\mu\mu}$)

efficiency = (98.79 ± 0.01) %
χ^2/ndof pass: 12.982, fail: 2.686
--- parameters
Passing Probes
- nBkgP = (156.01 ± 2.99) × 10^3
- nSigP = (4046.16 ± 3.59) × 10^3
Failing Probes
- nBkgF = (29.11 ± 0.21) × 10^3
- nSigF = (49.51 ± 0.25) × 10^3



efficiency = (99.38 ± 0.01) %
χ^2/ndof pass: 8.260, fail: 1.530
--- parameters
Passing Probes
- nBkgP = (117.66 ± 2.30) × 10^3
- nSigP = (3399.07 ± 2.92) × 10^3
Failing Probes
- nBkgF = (1.34 ± 0.24) × 10^3
- nSigF = (21.32 ± 0.28) × 10^3



Poster ID: 35 | 17-24 July 2024 | 42nd International Conference on High Energy Physics (ICHEP 2024) | Prague

[1]University and INFN of Bari (Italy) Contact: brunella.danzi@cern.ch Images Credits: CMS Collaboration