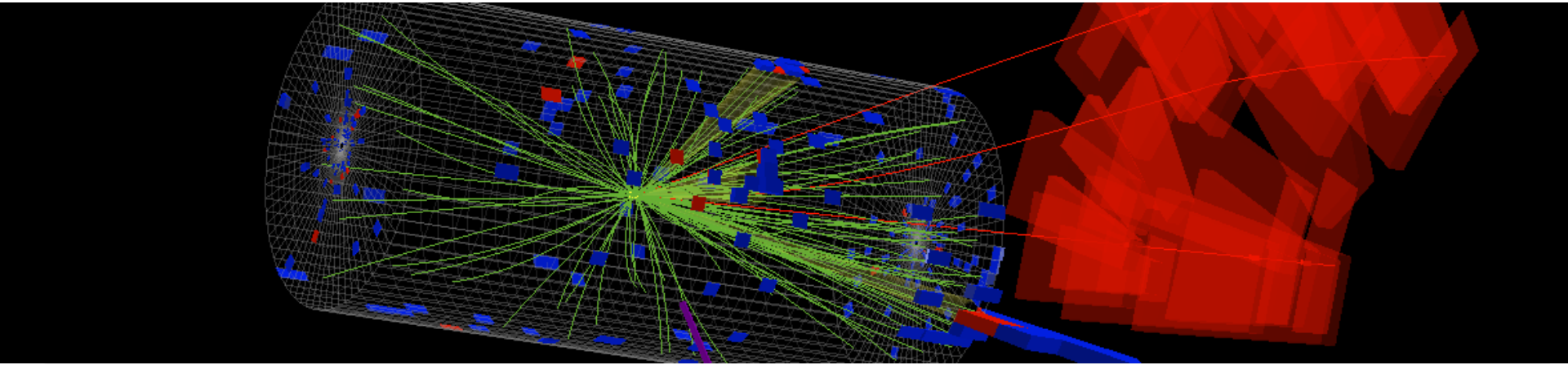
Karlsruhe Institute of Technology

Institut für Experimentelle Teilchenphysik

Validation of the τ-embedding method of CMS for the LHC Run-3 data-taking period

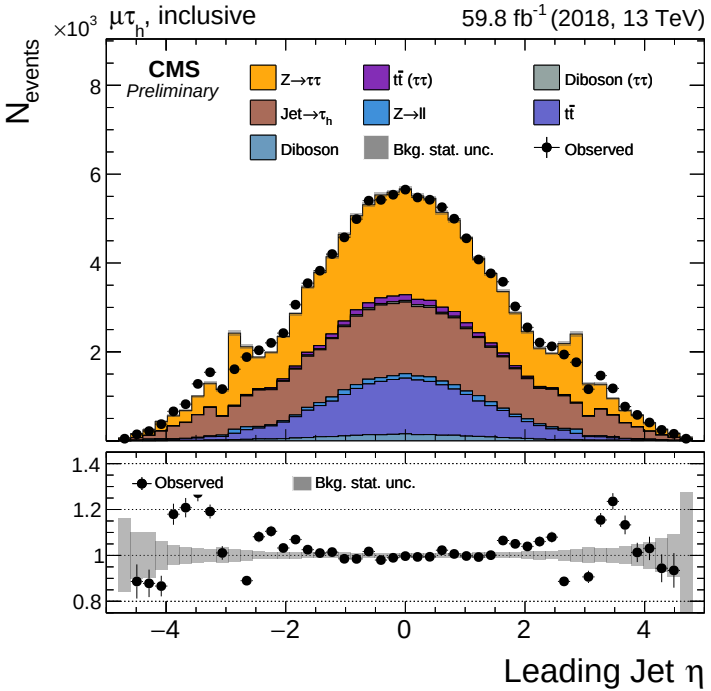
Final presentation

Jannik Demand, Christian Winter, Roger Wolf



Background modeling with classic Monte Carlo

- Simulation struggles with description of pile-up and jets
- Detector model deviates from reality

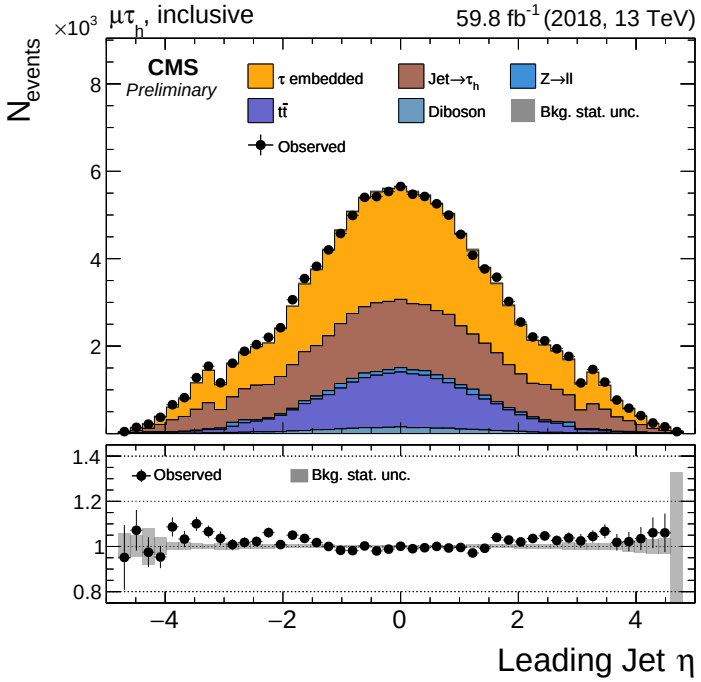


Created by Artur Monsch

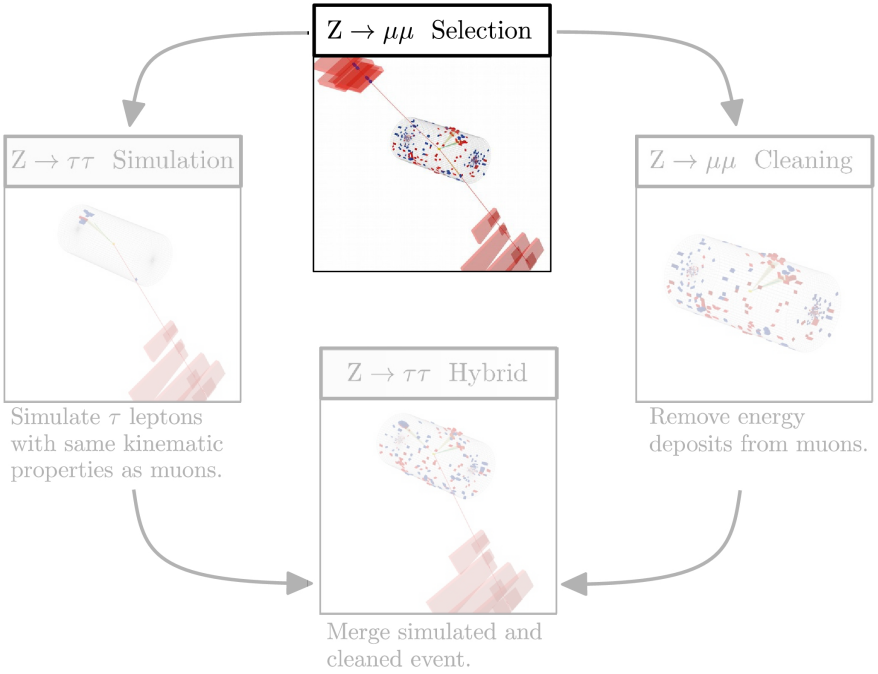
Background modeling with embedded data

- Simulation struggles with description of pile-up and jets
- Detector model deviates from reality

- Embedding is an alternative way for generating ττ test samples
- The technique aims to convert easily detectable μμ events into ττ



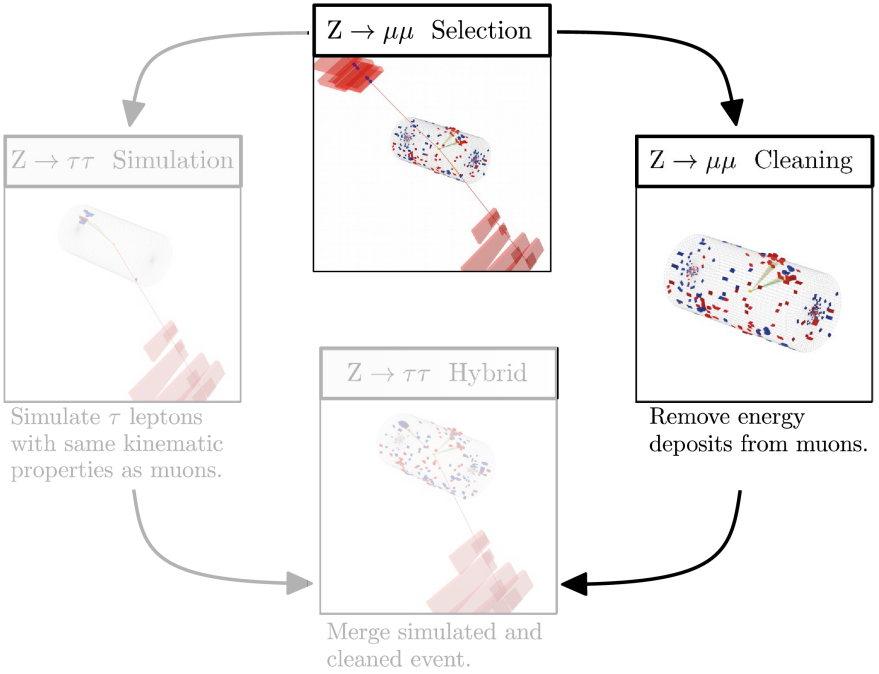
The τ embedding method



1 Selecting Z → μμ

Taken from A.M. Sirunyan et al 2019 JINST 14 P06032

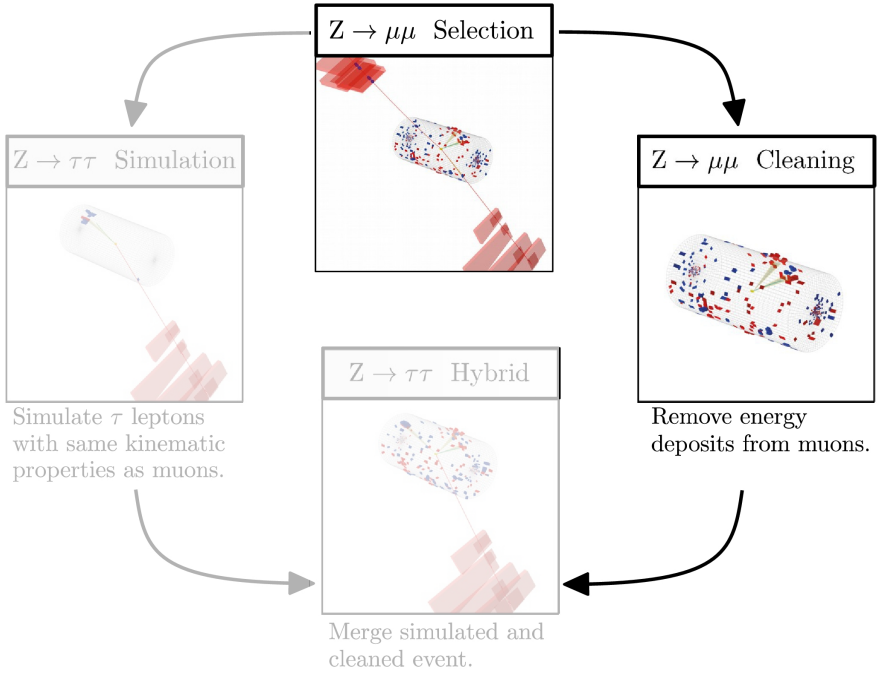
The τ embedding method



1. Selecting $Z \to \mu\mu$
2. Removing energy deposits from event

Taken from A.M. Sirunyan et al 2019 JINST 14 P06032

The τ embedding method



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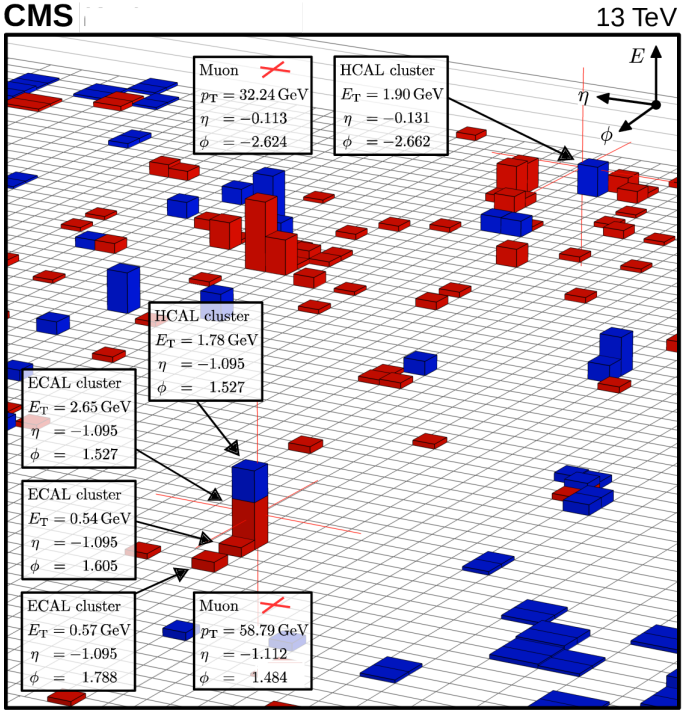

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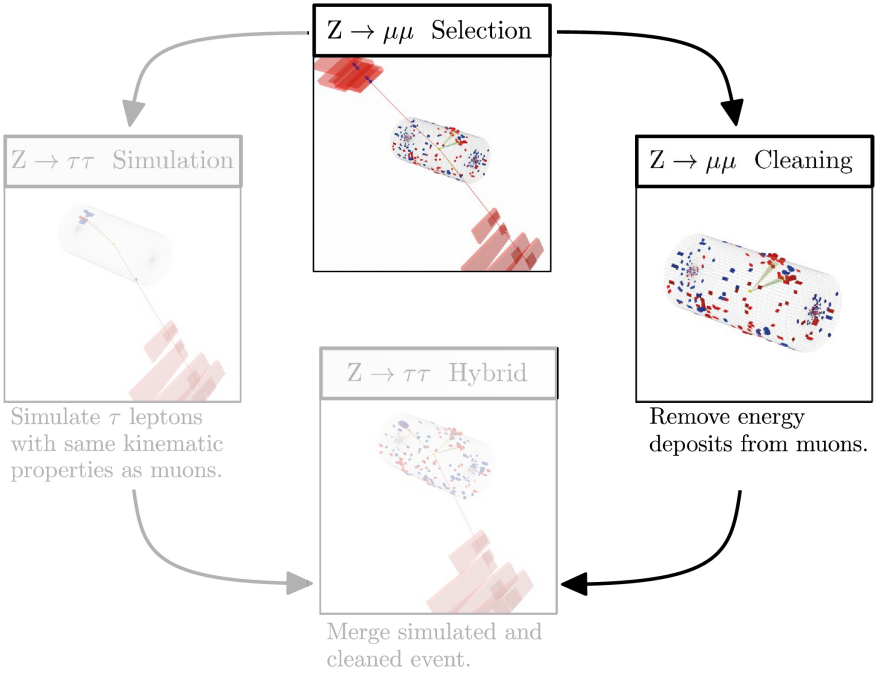
The τ embedding method



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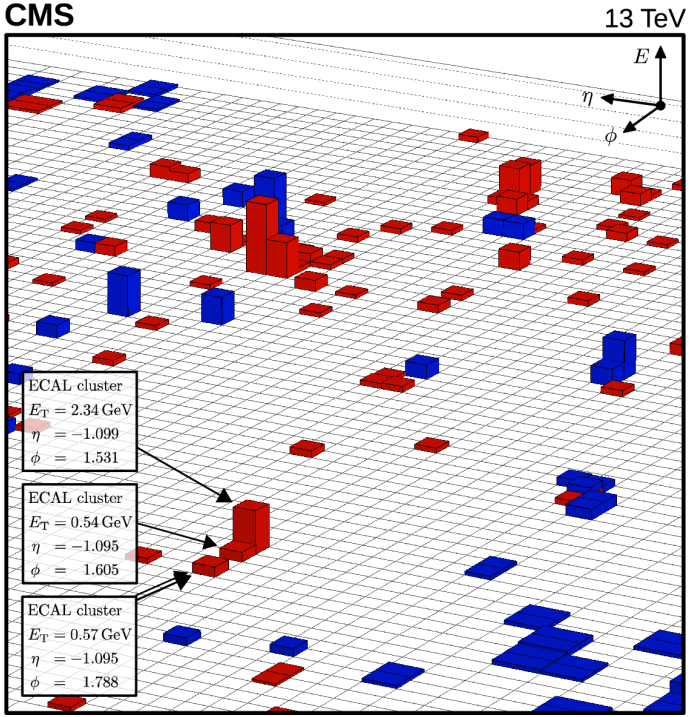

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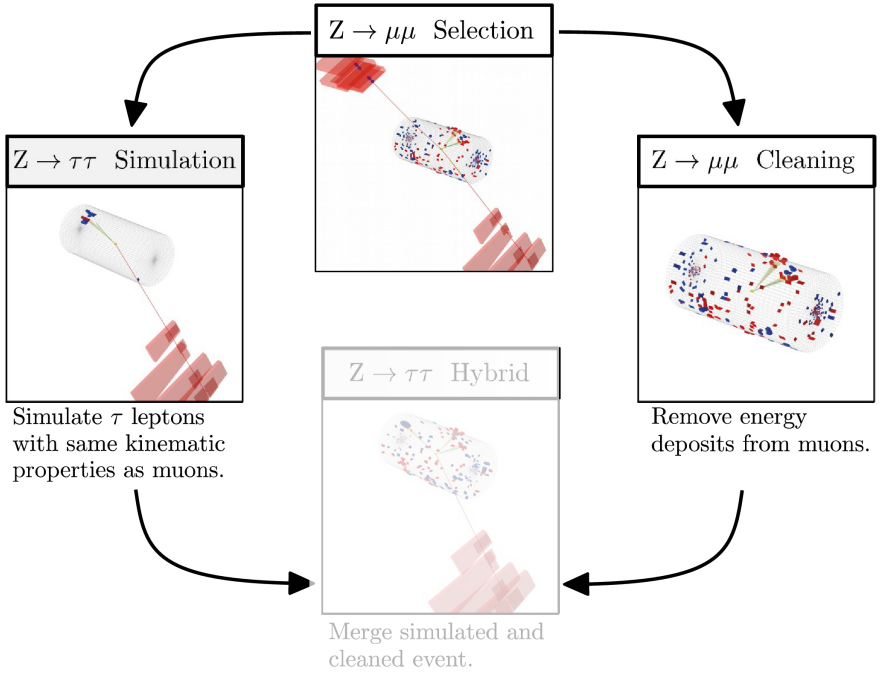
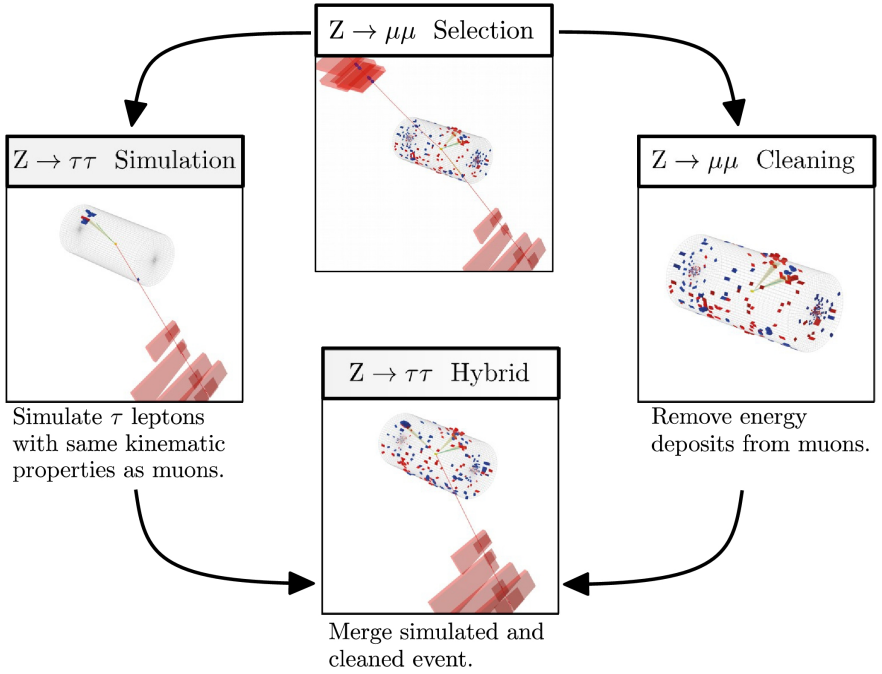
The τ embedding method



1. Selecting $Z \to \mu\mu$
2. Removing energy deposits from event
3. Simulating τ pair with kinematics of the μ pair

Taken from A.M. Sirunyan et al 2019 JINST 14 P06032

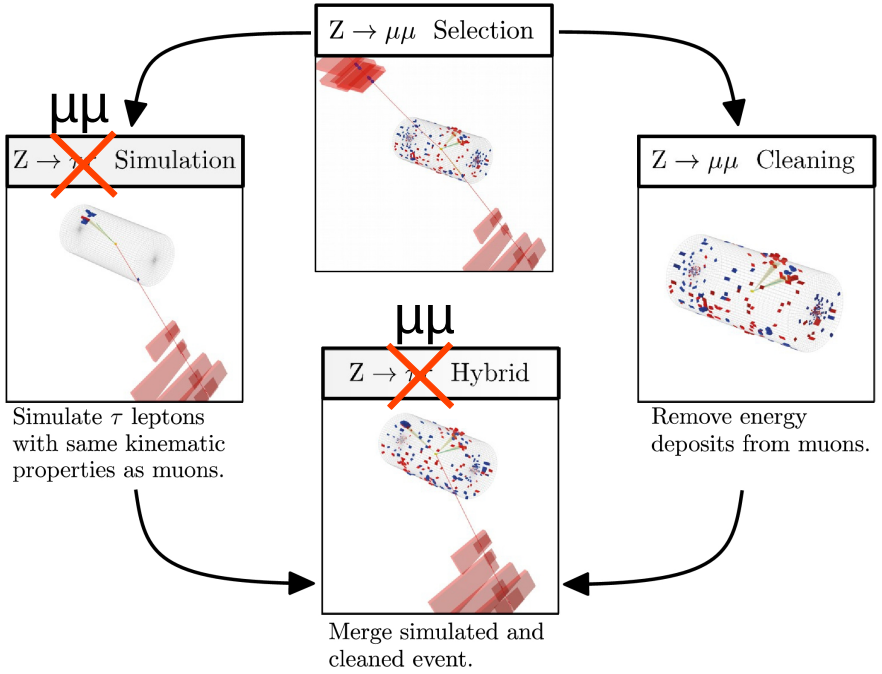
The τ embedding method



1. Selecting Z → μμ
2. Removing energy deposits from event
3. Simulating τ pair with kinematics of the μ pair
4. Merging simulated and cleaned event

Taken from A.M. Sirunyan et al 2019 JINST 14 P06032

Validating τ embedding



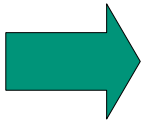
Taken from A.M. Sirunyan et al 2019 JINST 14 P06032

- Validation method:
  Replacing μ pair from data with simulated μ pair
- μ-embedded events should behave exactly like the original event
- Topic of my thesis:
  Validate embedding for Run 3 data

Data

- Input: 2022G muon dataset with 723821 events
- Output: 32861 events (4.5%)

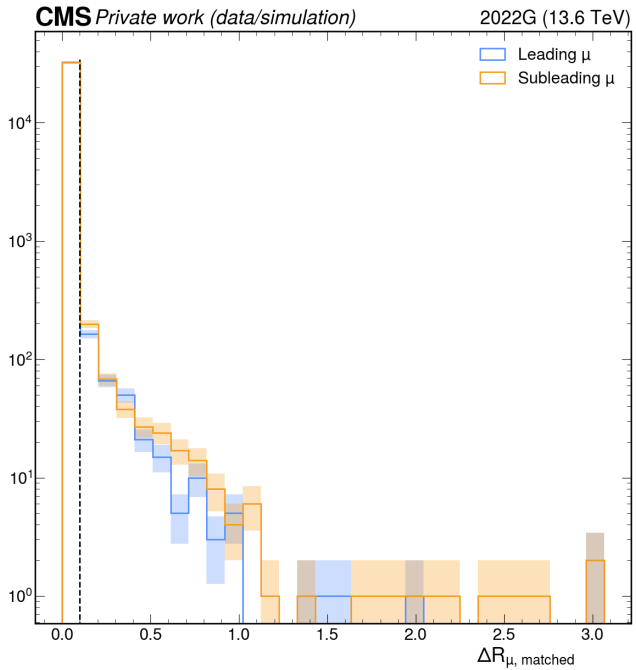
- Quality cuts:
  - Leading μ (Lμ) p_T>16 GeV
  - Only muons with p_T>8 GeV are considered
  - At least 2 loose muons



32389 events (98.6%) pass

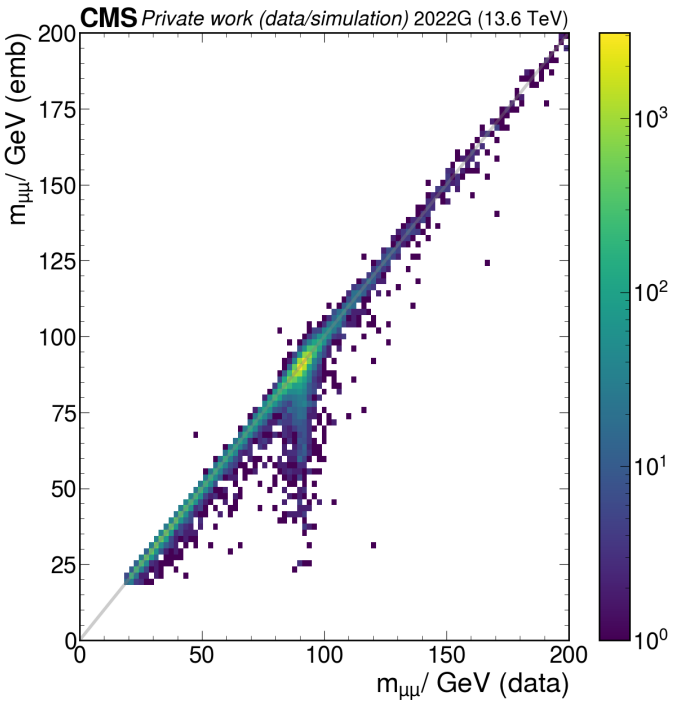
Muons

Validation of Z → μμ candidate direction



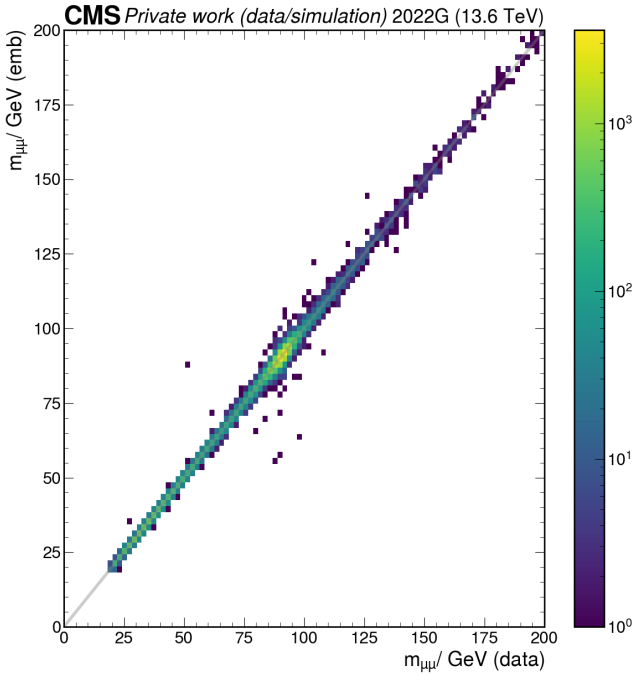
- Matching Z → μμ candidates on embedded data
- Match if
  $\Delta R = (\Delta\phi^2+\Delta\eta^2)^{1/2} < 0.1$
- Result:
  - 97.6% of filtered event meet criterion
  - 350 Lμ + 428 Slμ pairs with higher ΔR

Validation of combined mass m_{vis}



- $m_{\mu\mu}$ is the combined μμ mass in the Z restframe
- Ideally all datapoints would lie on the diagonal

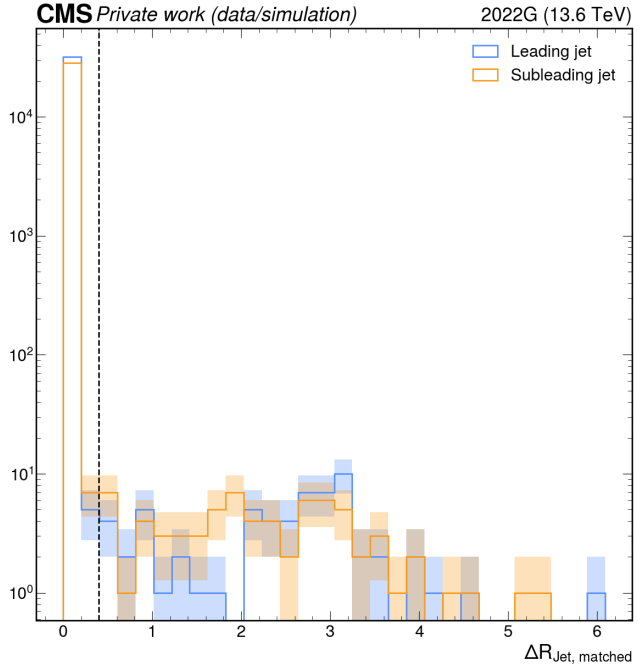
Validation of combined p_T and m_{vis}



- Reproduced events without FSR
- 99.7% pass the filters
- No bad match
- Resulting uncertainties
  - $\sigma_\phi = 0.0002$
  - $\sigma_\eta = 0.03$
  - $\sigma_{m_{\mu\mu}} = 1.18$ GeV (1.5%)

Jets

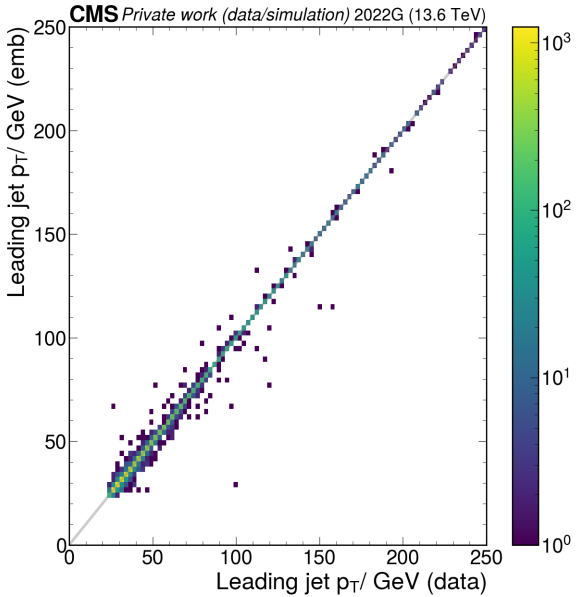
Validation of Jets



- Only jets with p_T>25 GeV considered
- Leading Jet (LJ) found in 97.2% of events, subleading jets (SJ) in 86.3%
- 99% of LJ and SJ matches with ΔR<0.2

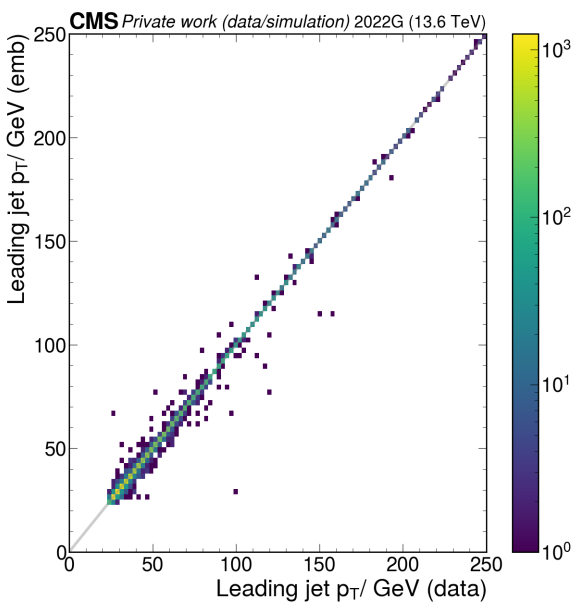
- LJ: $\sigma_\phi = 0.10$, $\sigma_\eta = 0.07$
- SJ: $\sigma_\phi = 0.08$, $\sigma_\eta = 0.10$

Comparison of jet p_T agreement



- Jets in the remaining event
  $\sigma_{p_T} = 1.49$ (2.8%)

Comparison of jet p_T agreement



- Jets in the remaining event
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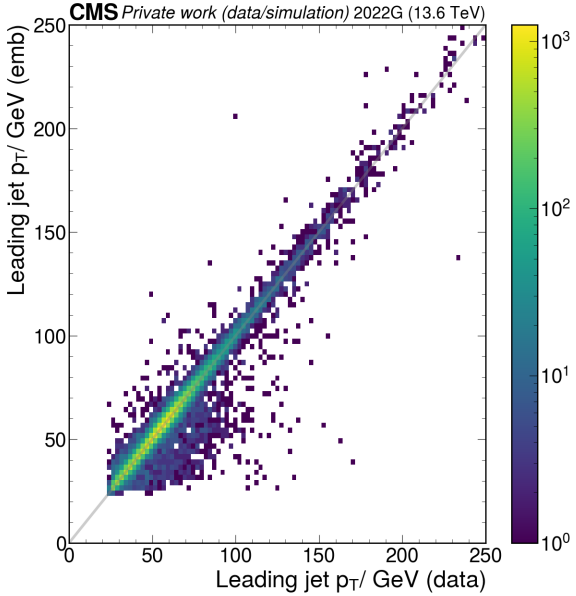
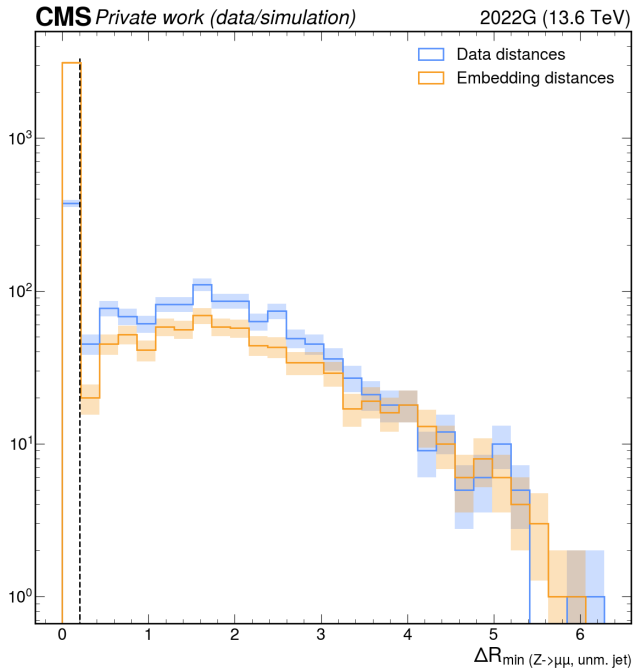


- Jets nearby the embedded μ
  $\sigma_{p_T} = 5.33$ (9.2%)

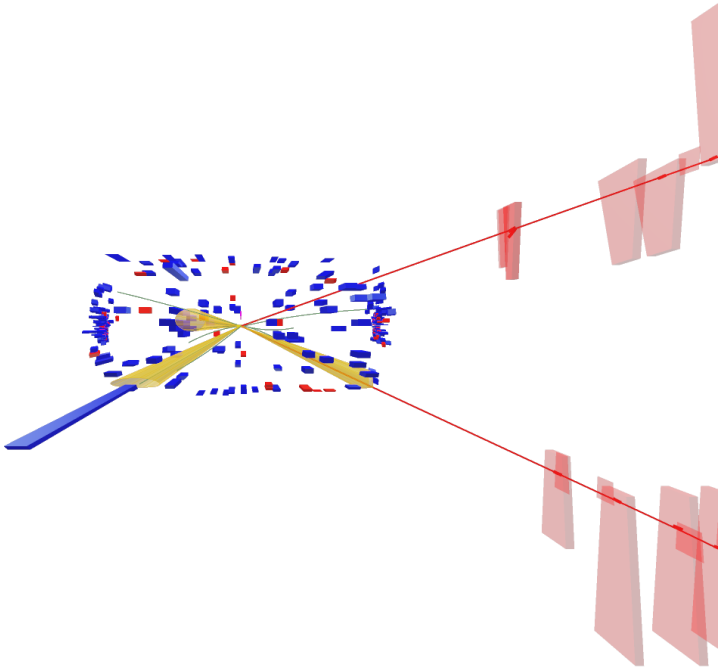
Dis-/ Appearing of jets in the event

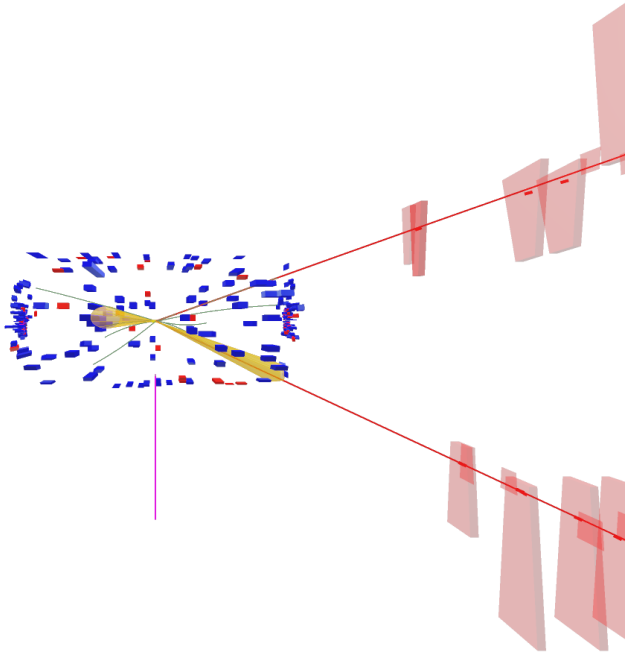
- Removing all matchable jets leaves only particles without counterpart
- Plot shows unm. jets as function of distance to closest embedded muon

- 13.0% of events affected
  - Most unm. Embbedding jets enclose the embedded particles
  - Most jets remain even if the 25 GeV cut is applied

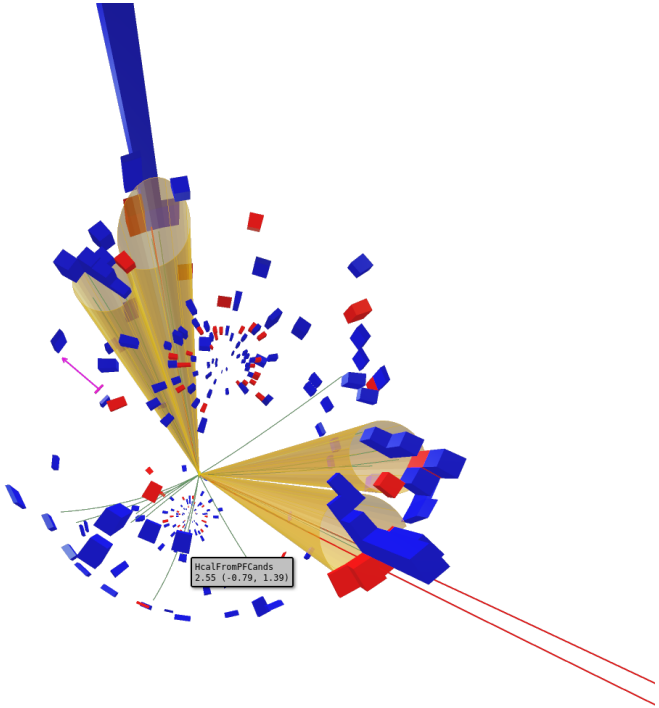


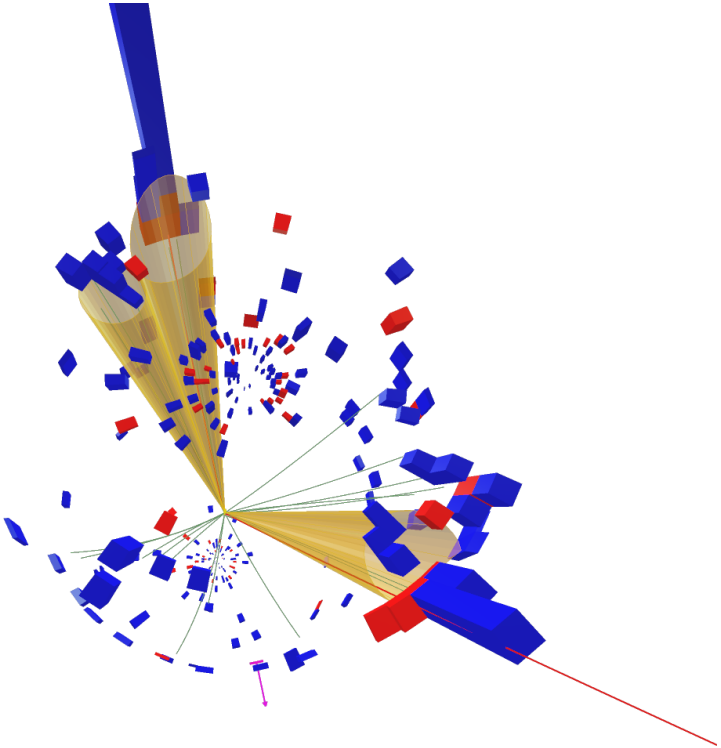
Random deposits going missing





Deposits are not clustered

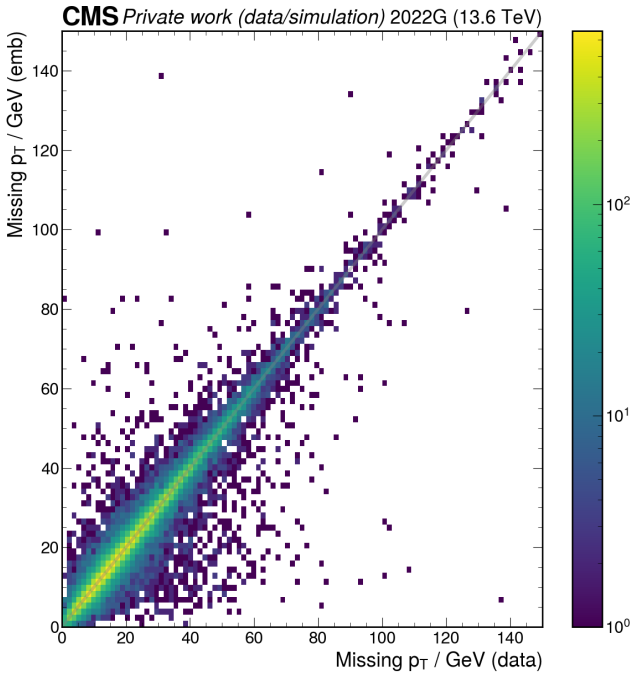




MPT

Validation of the missing p_T direction

- Higher inaccuracies than direction
  $\sigma_{p_T} = 4.88$ (21.0%)
- Correlation analysis shows:
  Deviations are mostly caused by deviations in jet momentum and number
- Low absolute values are more affected by jet fluctuations



Conclusion

Conclusion & Outlook

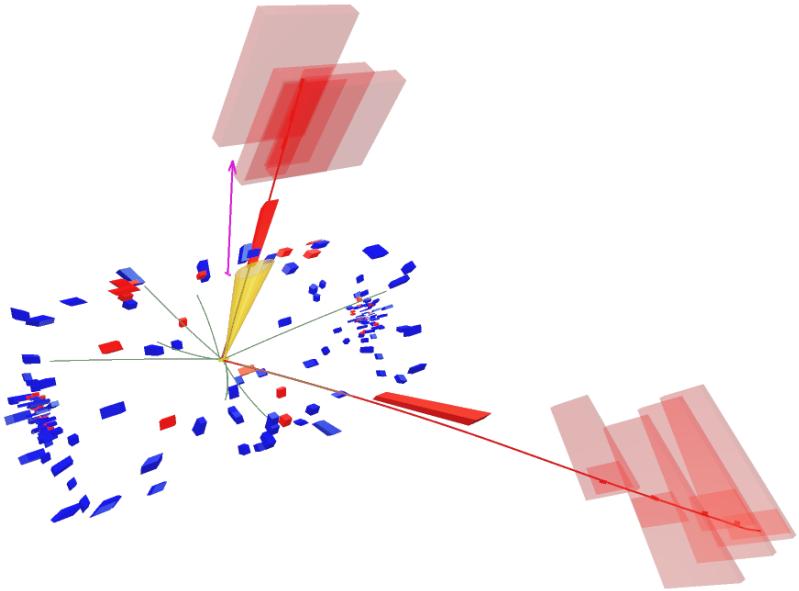
- Direction and momentum of muons are well described in embedded samples
- (Sub-) leading background jets are also well described on average
- Momentum of jets close to embedded muons had relatively high uncertainty
- 13.0% of events have a missing/ additional jet and deposits
- $P_{T,\,miss}$ has relatively high uncertainties but agrees on average

- Next Steps:
  - Why are jets dis-/appearing?
  - Run embedding on all available Run 3 events

Backup

Muons

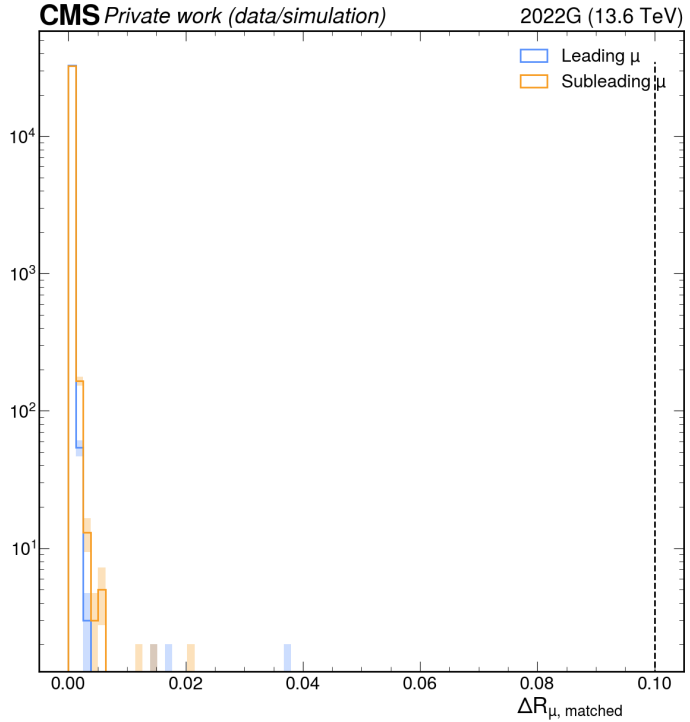
Validation of combined mass m_{vis}



- $m_{\mu\mu}$ is the combined μμ mass in the Z restframe
- Ideally all datapoints would lie on the diagonal
- 774 events near the Z boson mass with $m_{\mu\mu,\,data} - m_{\mu\mu,\,emb} > 10$ GeV

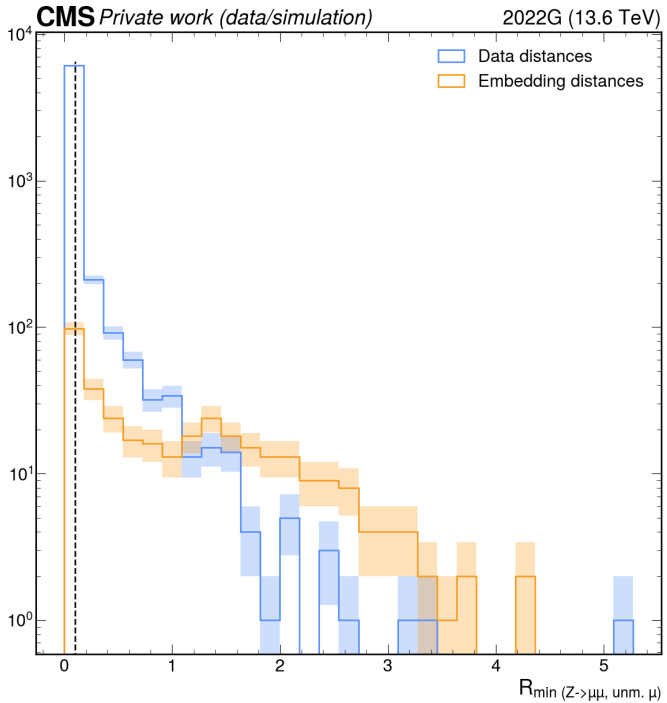
P_T of embedded μ underestimated due to Final State Radiation (FSR)

Repetition of matching without FSR



- Production repeated with FSR turned off
- 32861 events
- 99.7% pass the filters
- No bad match

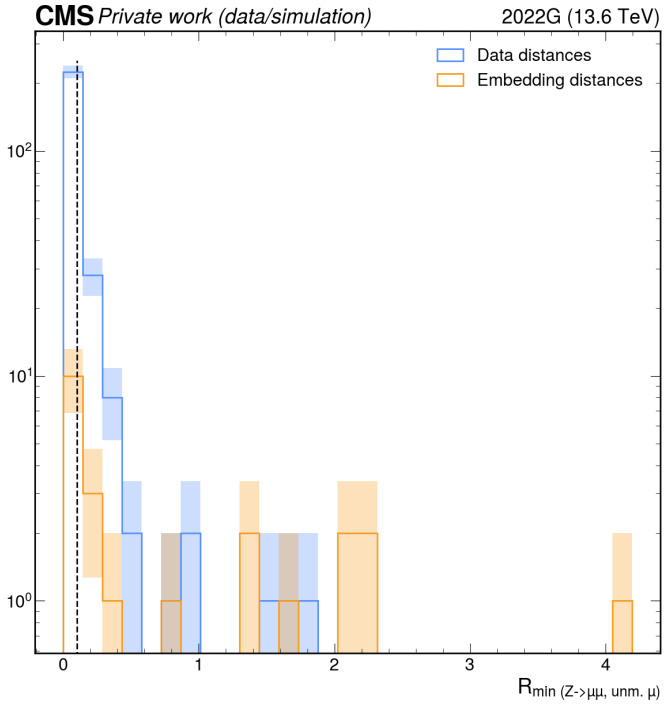
Dis-/ Appearing of muons in the event



- All μ from data are matched on all μ in embedding before applying quality cuts
- Matches are removed
- For the unmatchable μ the distance ΔR_{min} to the closest $Z \rightarrow \mu\mu$ candidate is calculated

- 6590 muons in data without match
- 350 muons in embedding

Dis-/ Appearing of muons in the event

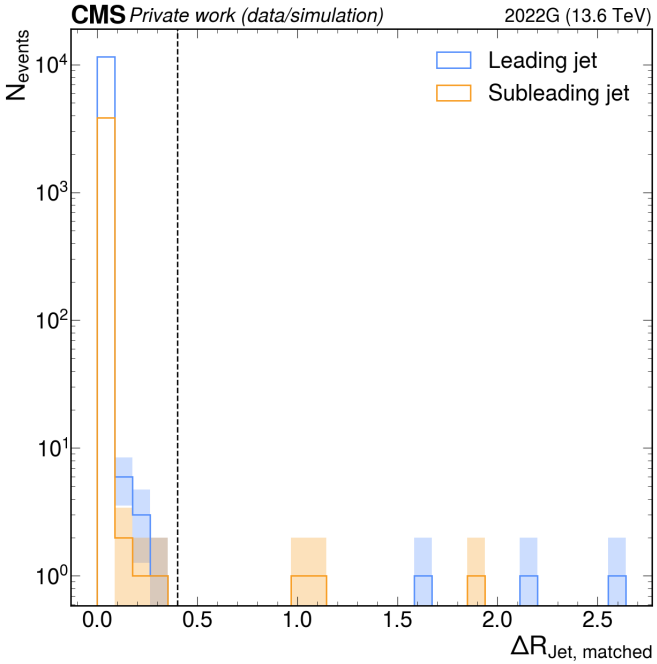


- Removing all matchable μ leaves only particles without counterpart
- Plot shows unm. muons as function of distance to closest embedded muon
- After cuts: >99.9% events without unmatchable muons
- 237 (82.2%) of unmatchable muons are close to $Z \rightarrow \mu\mu$

No significant amount of muons is removed or added

Jets

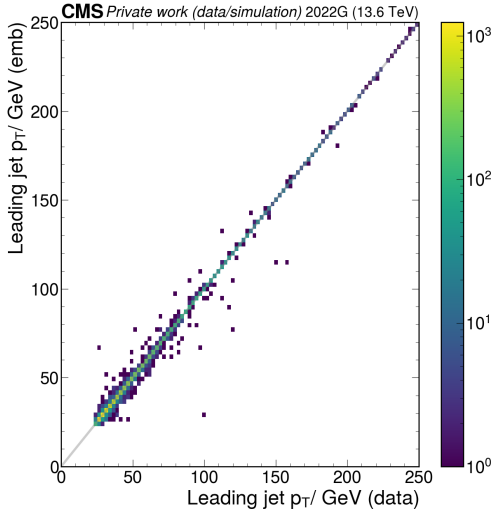
Matching of jets in the remaining event

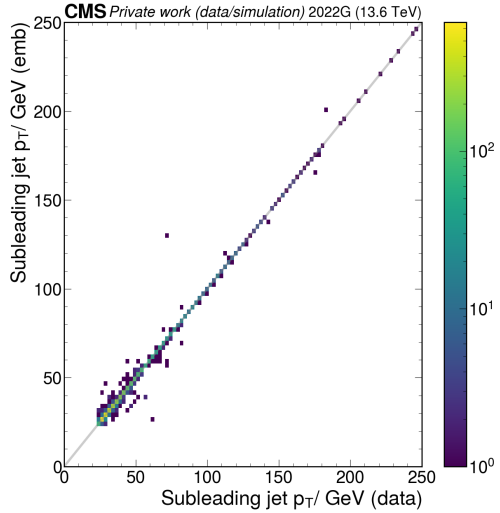


- Leading Jet (LJ) found in 34.9% of events
  Subleading jets (SJ) in 11.7%
- 19 bad matches with ΔR>0.2

- LJ: $\sigma_\phi = 0.04$, $\sigma_\eta = 0.01$
- SJ: $\sigma_\phi = 0.08$, $\sigma_\eta = 0.13$

Validation of jets in the remaining event

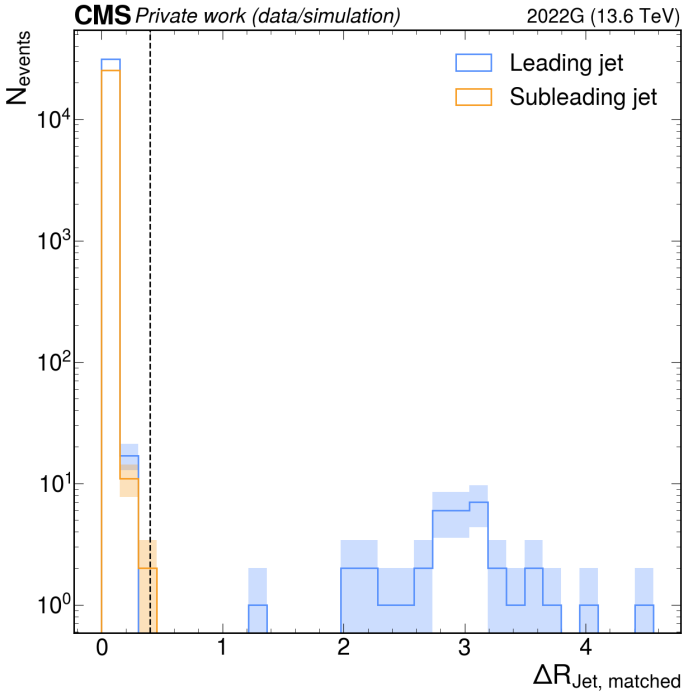




$\sigma_{p_T} = 1.5$ (2.8%)

$\sigma_{p_T} = 1.59$ (3.7%)

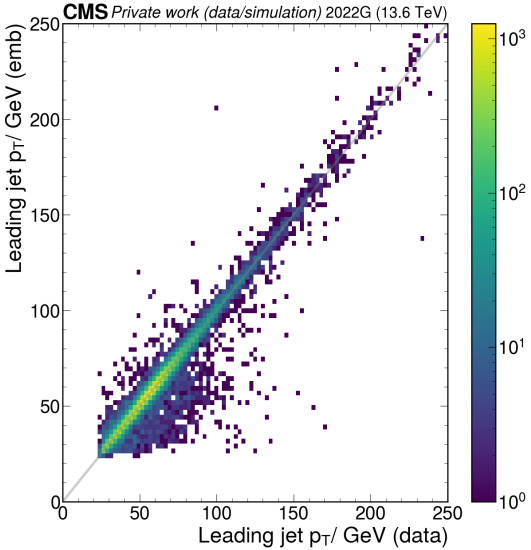
Matching of jets nearby embedded muons



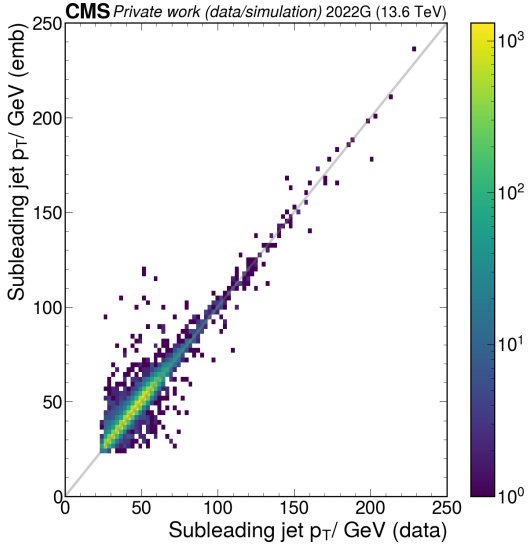
- Leading Jet (LJ) found in 95.5% of events, subleading jets (SJ) in 77.3%
- 99% of LJ and SJ matches with $\Delta R<0.1$

- LJ: $\sigma_\eta = 0.05$, $\sigma_\phi = 0.09$
- SJ: $\sigma_\eta = 0.01$, $\sigma_\phi = 0.01$

Validation of jet p_T near the $Z \rightarrow \mu\mu$ candidates



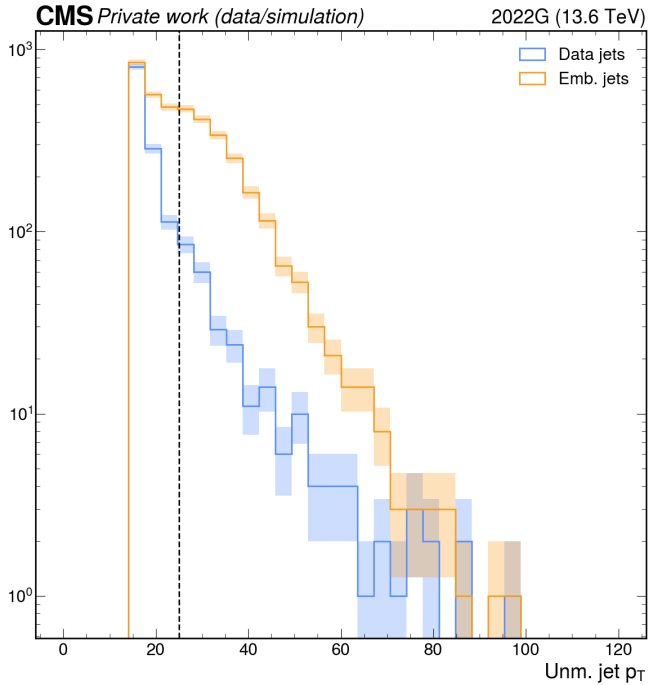
$\sigma_{p_T} = 5.33\ (9.2\%)$



$\sigma_{p_T} = 2.75\ (6.1\%)$

Dis-/ Appearing of jets in the event

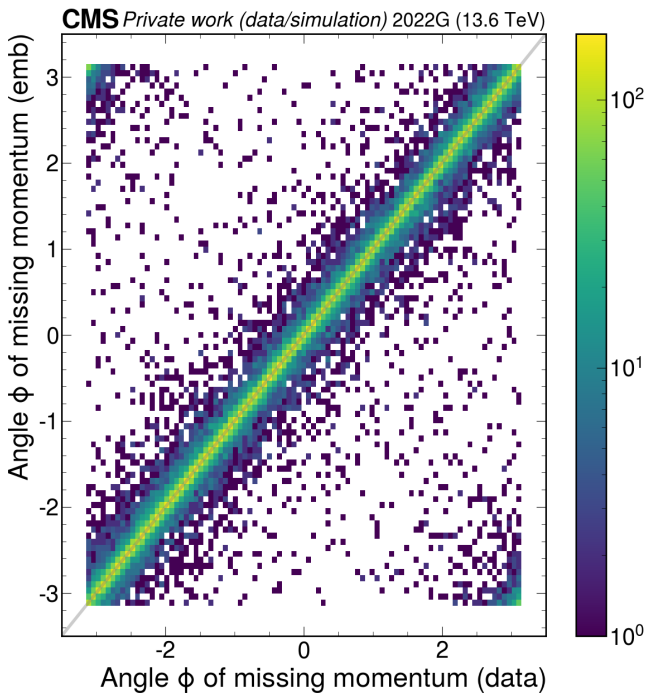
- Unmatchable jets have a broad P_T distribution
- P_T filter only removes 45.7% of unm. jets in embedding and 76.9% of unm. data jets



MPT

Validation of the missing p_T direction

- 66.4% events with $\Delta\phi<0.1$
  $\sigma_\phi = 0.33$
- Entries in the corners need to be shifted by 2π



MET control plots