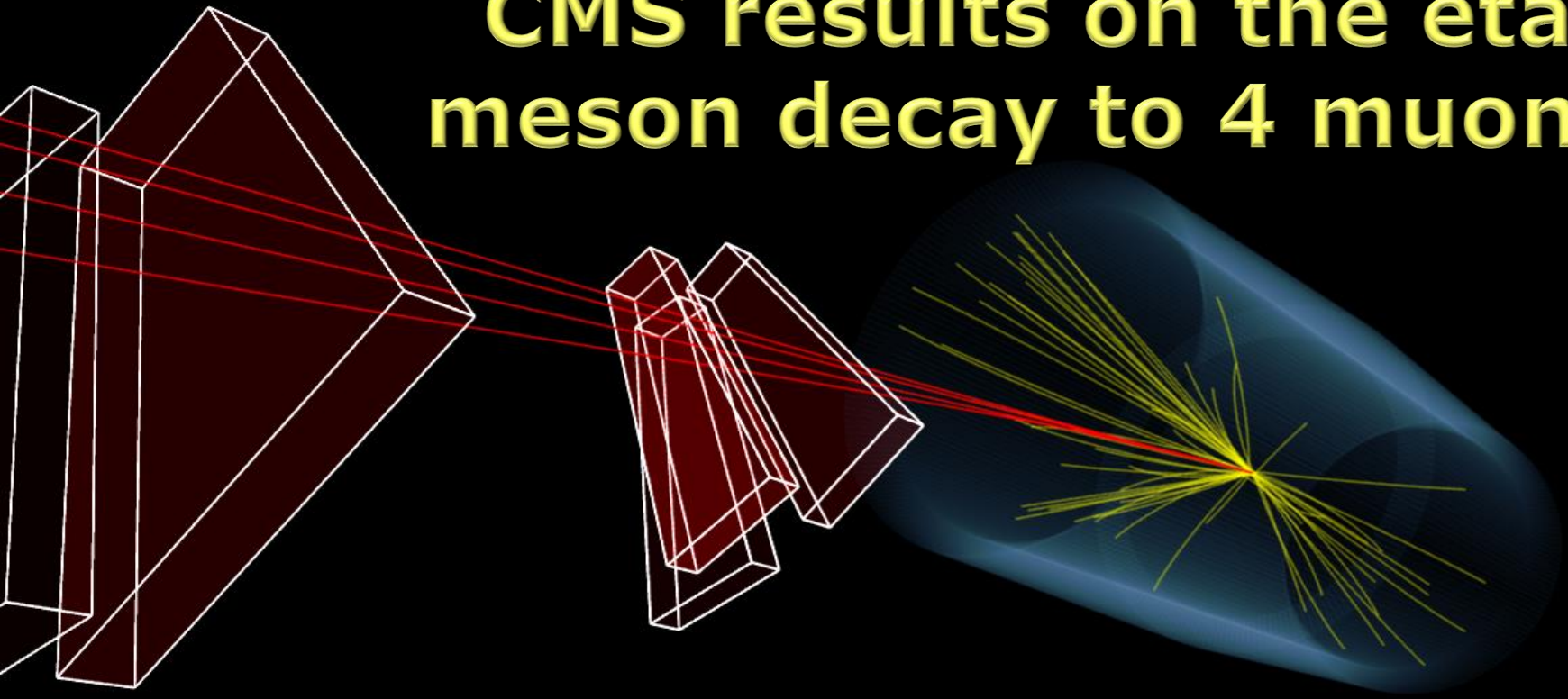
CMS Experiment at the LHC, CERN
Data recorded: 2017-Sep-26 01:42:22.588353 GMT
Run / Event / LS: 303885 / 1462573361 / 1071

CMS results on the eta meson decay to 4 muons



Alessandra Fanfani* on behalf of the **CMS** Collaboration

* Bologna University and INFN

HADRON 2023

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Genova, Italy

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

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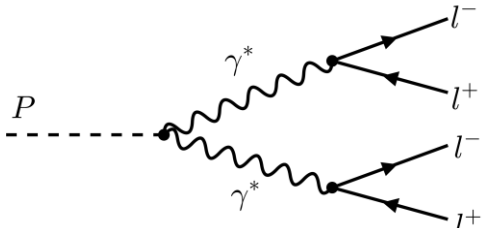
Motivations

- Leptonic radiative decays of η and η'
  - proceed via E.M. coupling of pseudoscalar mesons to the photon, where photon convert into l^+l^-



double Dalitz decay

- Highly suppressed
- So far, the following modes have been observed:
  - $\eta \to \mu^+\mu^-$ (SERPUKHOV-134,1980; Saturne SPES2,1994),
  - $\eta \to e^+e^-e^+e^-$(KLOE-2, 2011)
  - $\eta' \to e^+e^-e^+e^-$ (BESIII, 2022)

PDG 2022

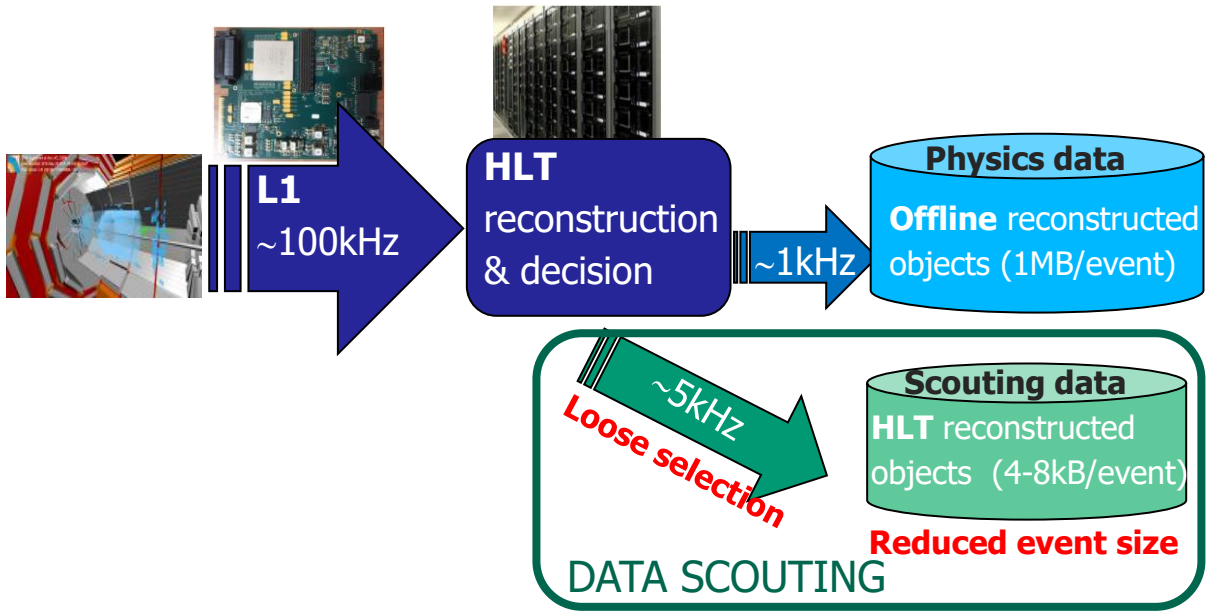
Charged modes

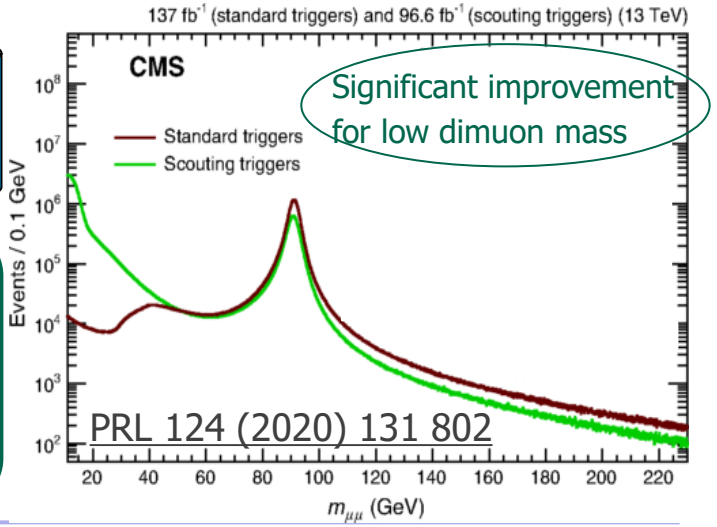
Γ_8	charged modes	(28.04±0.30) %		S=1.3
Γ_9	$\pi^+\pi^-\pi^0$	(23.02±0.25) %		S=1.2
Γ_{10}	$\pi^+\pi^-\gamma$	(4.28±0.07) %		S=1.1
Γ_{11}	$e^+e^-\gamma$	(6.9 ±0.4)	$\times 10^{-3}$	S=1.2
Γ_{12}	$\mu^+\mu^-\gamma$	(3.1 ±0.4)	$\times 10^{-4}$	
Γ_{13}	e^+e^-	< 7	$\times 10^{-7}$	CL=90%
Γ_{14}	$\mu^+\mu^-$	(5.8 ±0.8)	$\times 10^{-6}$	
Γ_{15}	$2e^+2e^-$	(2.40±0.22)	$\times 10^{-5}$	
Γ_{16}	$\pi^+\pi^-e^+e^-(\gamma)$	(2.68±0.11)	$\times 10^{-4}$	
Γ_{17}	$e^+e^-\mu^+\mu^-$	< 1.6	$\times 10^{-4}$	CL=90%
Γ_{18}	$2\mu^+2\mu^-$	< 3.6	$\times 10^{-4}$	CL=90%
Γ_{19}	$\mu^+\mu^-\pi^+\pi^-$	< 3.6	$\times 10^{-4}$	CL=90%
Γ_{20}	$\pi^+e^-\overline{\nu}_e$ + c.c.	< 1.7	$\times 10^{-4}$	CL=90%
Γ_{21}	$\pi^+\pi^-2\gamma$	< 2.1	$\times 10^{-3}$	
Γ_{22}	$\pi^+\pi^-\pi^0\gamma$	< 6	$\times 10^{-4}$	CL=90%
Γ_{23}	$\pi^0\mu^+\mu^-\gamma$	< 3	$\times 10^{-6}$	CL=90%

- Observations of these rare decays
  - Allow precision tests of the SM (Phys.Rep. 945 (2022) 1)
  - Impact the knowledge of hadronic contributions to the anomalous magnetic moment of the muon (Phys.Lett.B 787 (2018))

CMS trigger system & scouting

- CMS events are selected by a two-tiered trigger system
  - L1 (Level-1) : hardware-based trigger to select events at ~100kHz
  - HLT (High-Level trigger): processors's farm running high-level physics algorithms with output rate ~1kHz
- «Data scouting» trigger strategy
  - High-rate triggers with loose selection
  - Limited event-level information saved (only HLT reconstructed objects)

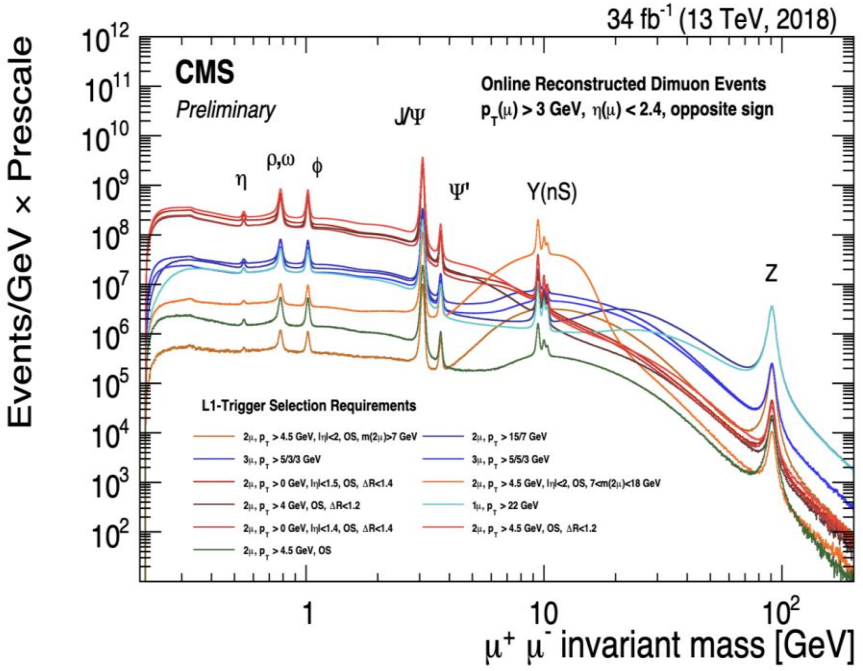




Dimuon scouting data

- Run 2 pp collision data at $\sqrt{s} = 13\ TeV$
- Dedicated set of high-rate **dimuon** triggers:
  - Several **L1** selection requirements

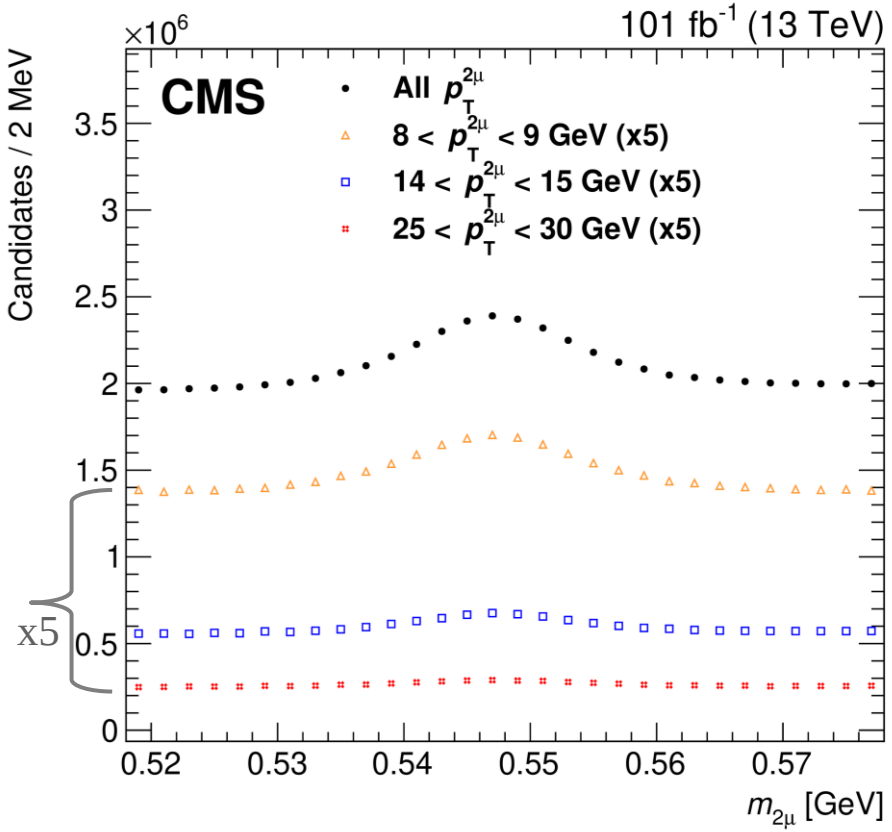
L1 path	p_T [GeV]	$\lvert\eta\rvert$	ΔR	$m_{2\mu}$ [GeV]	Charge	4μ selection Fraction
#1	>4.0 (4.5)	–	<1.2	–	OS	90%
#2	–	< 1.5	< 1.4	–	OS	48%
#3	>15, >7	–	–	–	–	46%
#4	>4.5	< 2.0	–	7–18	OS	9%



  - At **HLT** : 2 muons with $p_T > 3\ GeV$
- Information stored: muons reconstructed online (at HLT)
- in 2017 and 2018 collected **101 fb^{-1}**

$\eta \to \mu^+\mu^-$ in scouting data

Two oppositely charged muons, consistent with common origin



- Around $\mathbf{4.5 \times 10^6}$ $\eta \to 2\mu$ decays in the scouting data!

$$\mathcal{B}(\eta \to 2\mu) = (5.8 \pm 0.8) \times 10^{-6}$$ (PDG)

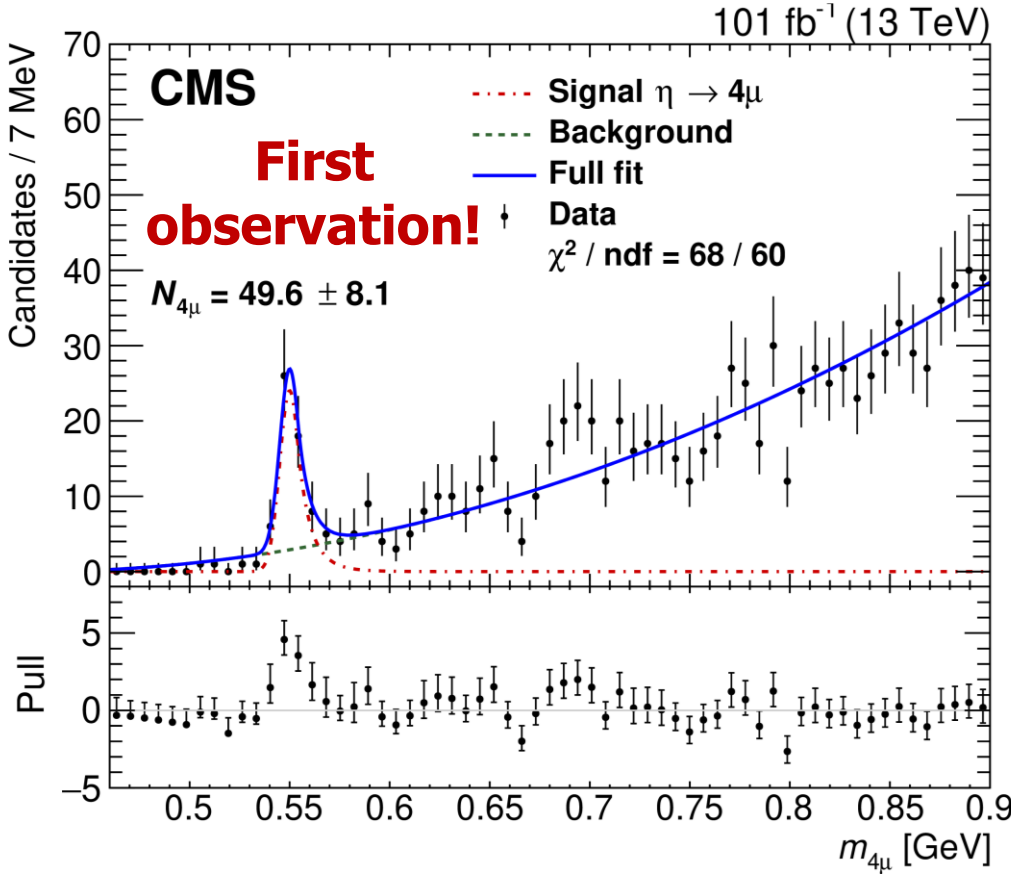
$\Rightarrow$ **~10^{12} η** produced in "CMS acceptance"
(even more after correcting for efficiency)

- Huge η production rate critical to study its rare decays

- $\eta \to \mu^+\mu^-$ used as normalization channel and to calibrate η meson production in MC

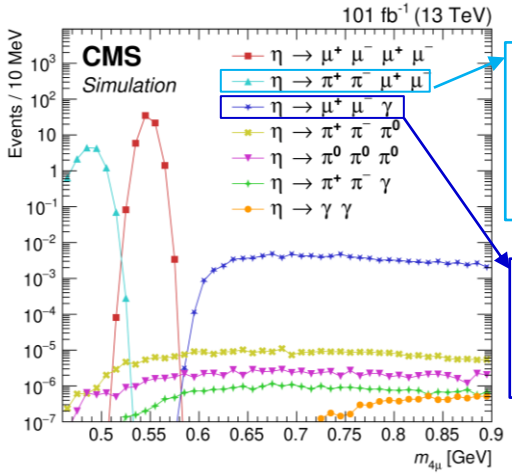
First $\eta \to \mu^+\mu^-\mu^+\mu^-$ observation

Four muons with 0 net charge, consistent with same-vertex production



arXiv:2305.04904 *Submitted to PRL*

- A clear narrow peak of ~50 events
- Fit with Crystall-Ball + threshold $(m_{4\mu} - 4m_\mu)^\beta$
- **Significance > 5σ**
- Several misreconstructed decays were shown to not be able to produce such a peak

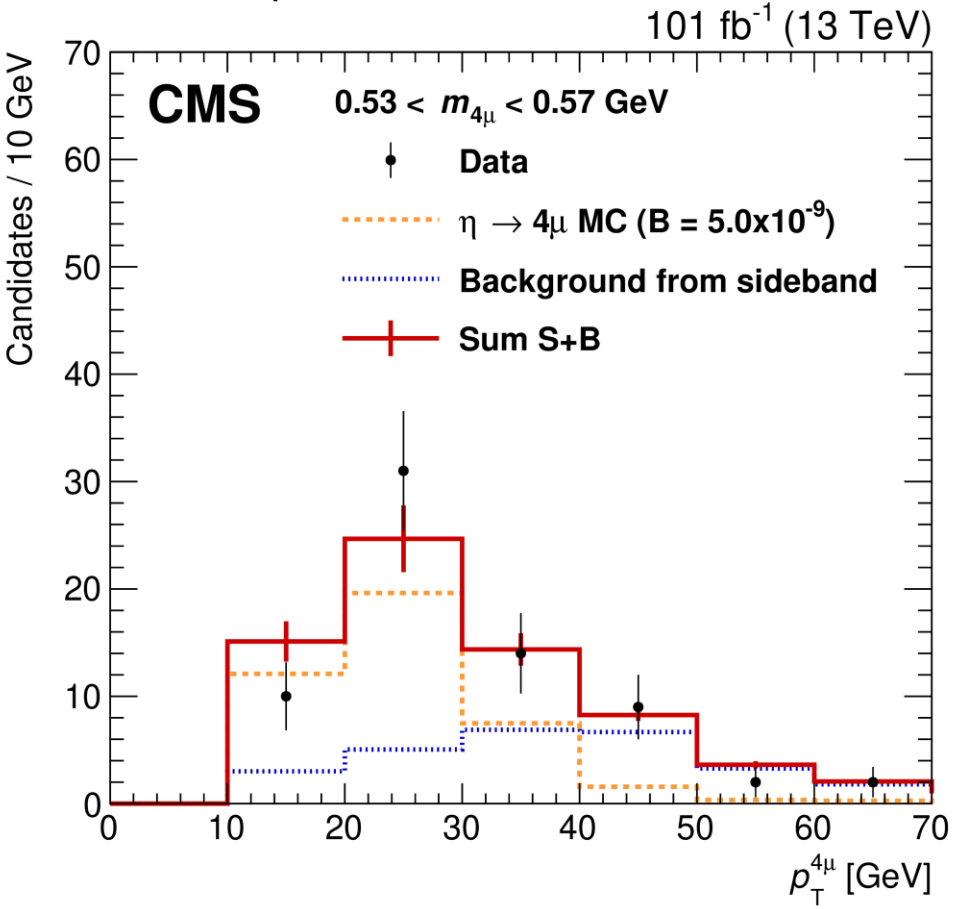


with $\pi \to \mu$ fake: shifted to lower $m_{4\mu}$, with $\mathcal{B}$ exp. upper limit (never observed)

with γ conversion in material: non peaking, shifted to higher $m_{4\mu}$

Four-muon p_T spectrum ($p_T^{4\mu}$)

- Signal MC prediction reweighted based on η meson p_T differential production rate measured with $\eta \to \mu^+\mu^-$ channel
- Background shape from $m_{4\mu}$ sideband [0.6-0.9 GeV]



- $p_T^{4\mu}$ spectrum consistent with MC prediction + Background

Brancing fraction: Analysis strategy

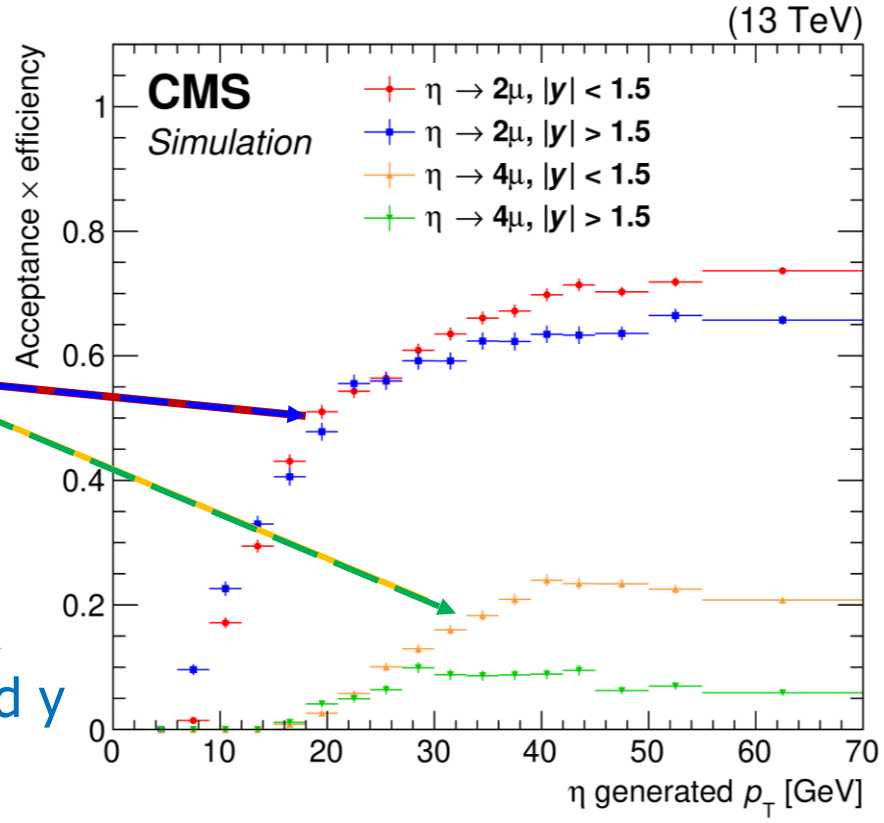
- The branching fraction $\mathcal{B}_{4\mu} \equiv \mathcal{B}(\eta \to 4\mu)$ is determined relative to $\mathcal{B}_{2\mu} \equiv \mathcal{B}(\eta \to 2\mu)$

$$\frac{\mathcal{B}_{4\mu}}{\mathcal{B}_{2\mu}} = \frac{N_{4\mu}}{\sum_{i,j} N_{2\mu}^{i,j} \frac{A_{4\mu}^{i,j}}{A_{2\mu}^{i,j}}}$$

$\eta \to 4\mu$ yield

$\eta \to 2\mu$ yield

Total efficiencies (Axε) ratio $^{4\mu}/_{2\mu}$ from simulation, in bins of p_T and y



- several uncertainties cancel out when considering the ratio of quantities

Branching fraction: Results

- Relative branching fraction:

$$\frac{\mathcal{B}_{4\mu}}{\mathcal{B}_{2\mu}} = (0.86 \pm 0.14\,(\text{stat}) \pm 0.12\,(\text{syst})) \times 10^{-3}$$

  - Statistical uncertainty on $N_{4\mu}$ → 16%
  - Total systematic uncertainty →14%
    - Imperfect knowledge of efficiencies from simulation
    - choice of fit model to extract signal yields $N_{4\mu}$ and $N_{2\mu}$

Track p_T threshold	9.0%
Trigger p_T threshold	8.4%
Efficiency plateau	3.2%
Fit model	6.6%

- The branching fraction $\mathcal{B}(\eta \to 4\mu)$ (PDG)

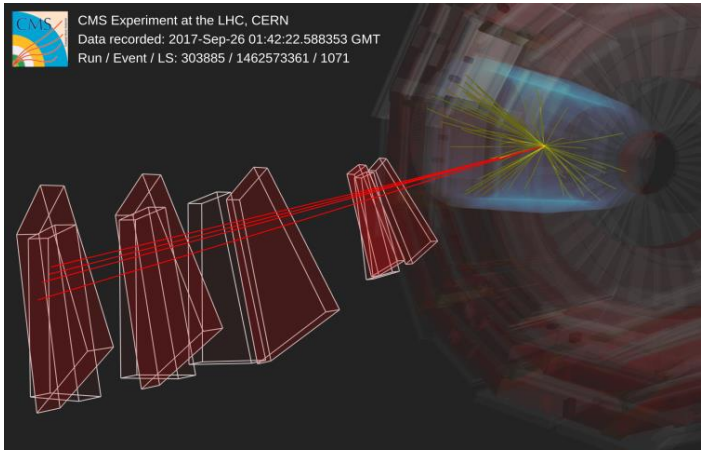
with $\mathcal{B}(\eta \to 2\mu) = (5.8 \pm 0.8) \times 10^{-6}$

$$\mathcal{B}(\eta \to 4\mu) = (5.0 \pm 0.8\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.7\,(\mathcal{B}_{2\mu})) \times 10^{-9}$$

uncertainty in $\mathcal{B}(\eta \to 2\mu)$ ~14%

- in agreement with theoretical prediction within uncertainties $(3.98 \pm 0.15) \times 10^{-9}$ [Chin.Phys.C 42 (2018) 2, 023109]

Summary



- First observation of η meson's rare double-Dalitz decay to four muons is reported
- Made possible by CMS high-rate dimuon triggers that collected 101 fb^{-1} in 2017 and 2018 at $\sqrt{s} = 13\ TeV$
- Branching fraction $\mathcal{B}(\eta \to 4\mu)$ is measured, in agreement with predictions