91st PRC Meeting
CMS Physics Highlights at DESY

Mykola Savitskyi on behalf of the DESY CMS group

4 May 2021

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY

CMS Group at DESY
our core activities

- Detector Upgrade
- Detector Operation
- Computing
- MC simulation
- Data Analysis (Higgs, QCD, SUSY, Top, Exo)
- Object reconstruction & calibration
- Management & Coordination

CMS Group at DESY
our core activities

- Detector Upgrade
- Detector Operation
- Computing
- MC simulation
- Data Analysis (Higgs, QCD, SUSY, Top, Exo)
- Object reconstruction & calibration
- Management & Coordination

This talk:
recent highlights in physics analysis

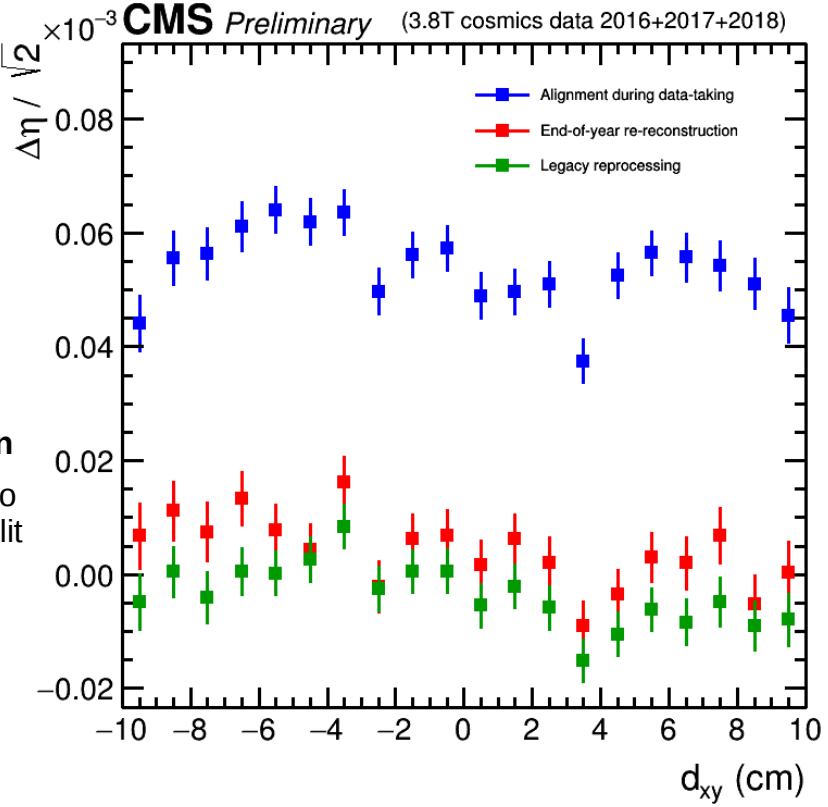
CMS Tracker Alignment in Run 2

performance results for full Run 2 Legacy reprocessing

Comprehensive paper on Run 2 alignment strategy close to completion

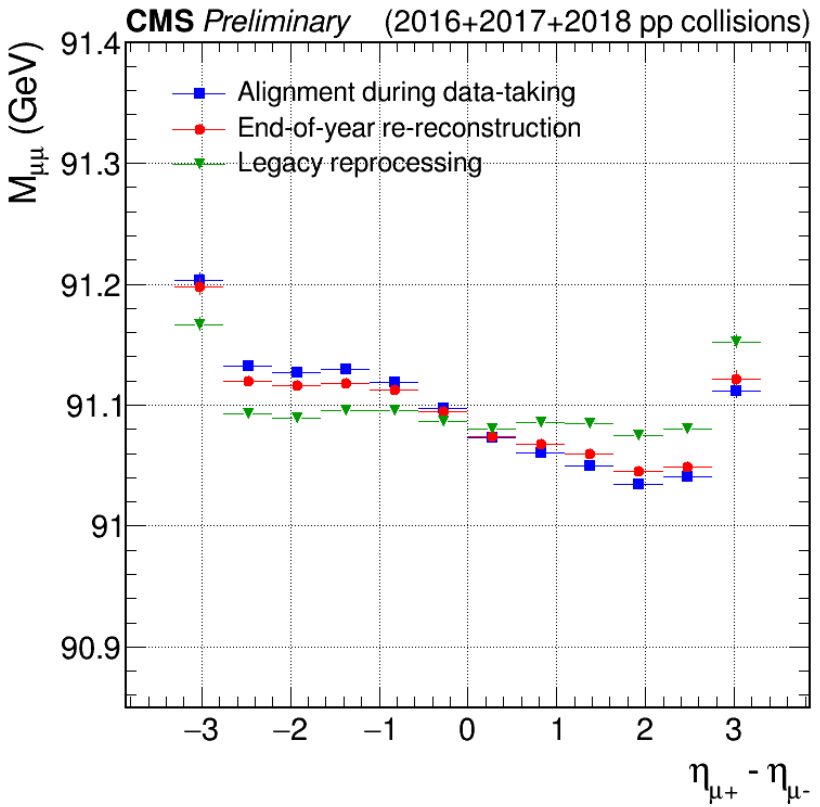
- demonstrates full power of tracker alignment performed for Legacy reprocessing
- visible improvement over prompt and end-of-year reprocessing alignment

more public results at [↗]



Muon Track-Split validation

- difference in η between two halves of cosmic tracks split near detector center



Z → μμ validation

- significant improvement in uniformity of reconstructed Z → μμ mass

Integrated Luminosity at Ultimate Precision

precision luminosity measurement in pp collisions at 13 TeV in 2015 and 2016

First-ever luminosity paper from CMS: [arXiv:2104.01927] sub. to EPJC

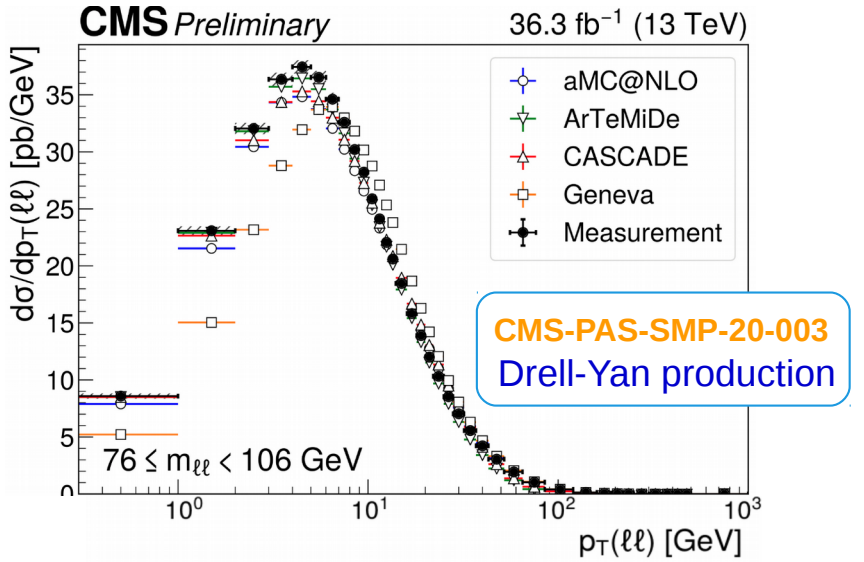
- integrated luminosity for 2016:

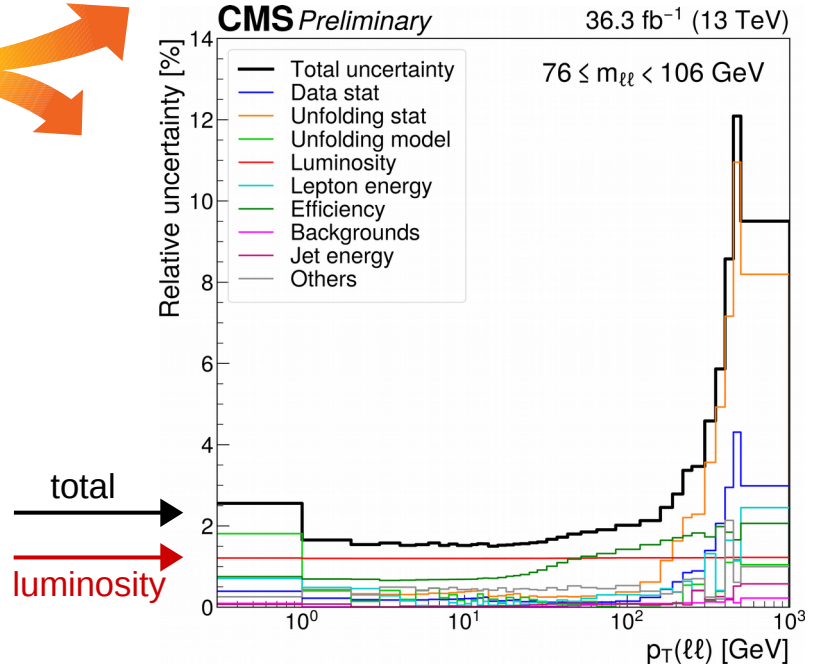
  36.3 fb^{-1} (from 35.9 fb^{-1} → central value shifts by about 1%)

- total uncertainty:

  1.2% (from 2.5% → substantial improvement of uncertainty)

- crucial input to cross section measurements (TOP, SMP)
  - e.g., differential DY production: total uncertainty in bulk region now 1.5%, previously 2.8%
- four years of pioneering developments





Contributions from DESY

- beam position monitoring
- length scale calibration
- transverse factorization
- detector stability

also published CMS-PAS-LUM-19-001 "Luminosity for the pp Run at 5 TeV (2017)"

Integrated Luminosity at Ultimate Precision

precision luminosity measurement in pp collisions at 13 TeV in 2015 and 2016

public as [arXiv:2104.01927]

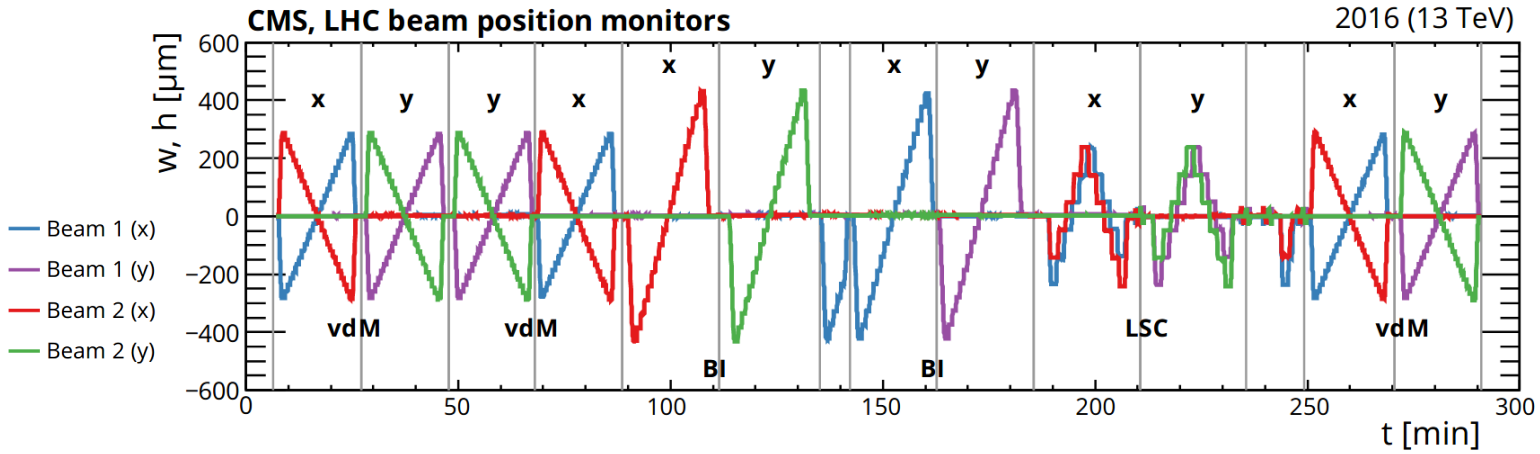
Measurement of σ_{vis} (normalization) from Van-der-Meer scan campaign:

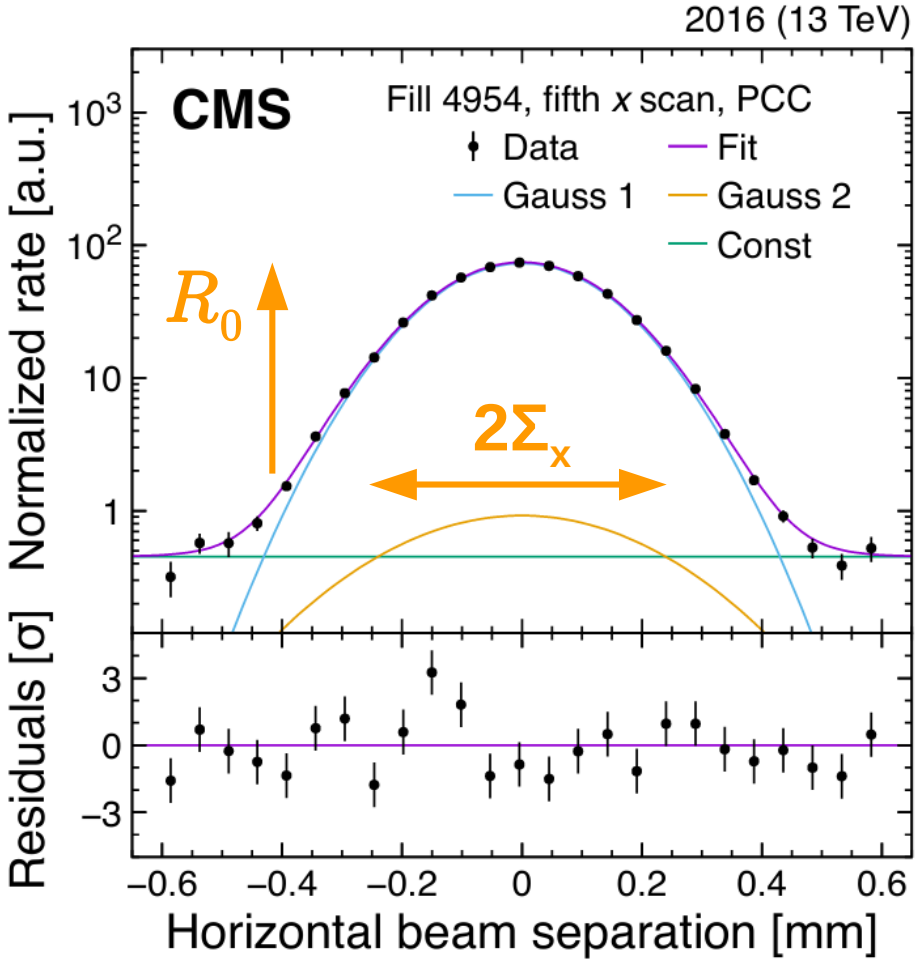
- determine beam shapes in x and y from scan of rates for different transverse beam separations
- beam positions are key to precise measurements of Σ_x and Σ_y

Instantaneous luminosity:

$$R(t) = \mathcal{L}(t) \cdot \sigma_{vis}$$

$$\sigma_{vis} = \frac{2\pi\Sigma_x\Sigma_y}{N_1 N_2 f_{LHC}} \cdot R_0$$



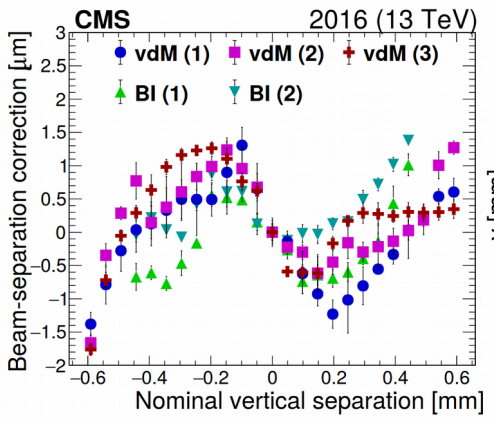


Integrated Luminosity at Ultimate Precision

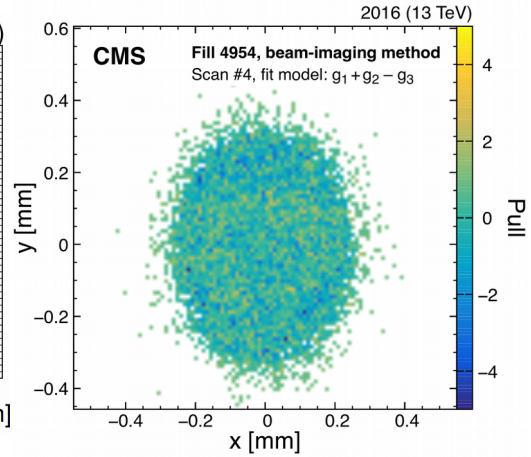
precision luminosity measurement in pp collisions at 13 TeV in 2015 and 2016

public as [arXiv:2104.01927]

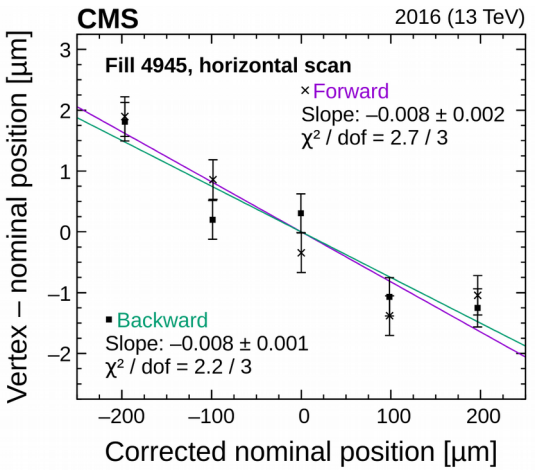
Beam position monitoring



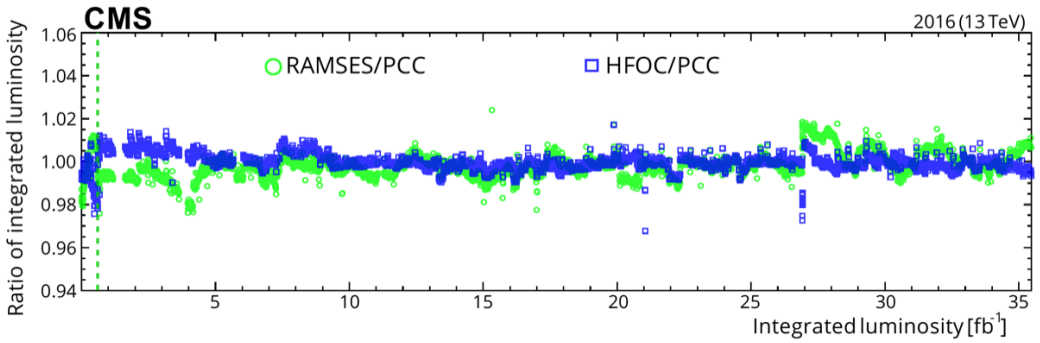
Transverse factorizability



Length scale calibration



Integration: rate measurement over the full year



Length scale calibration

- goal: determine actual beam separation using vertex positions measured in CMS
- corrections of about 1%

DESY contributions highlighted in table

Source	2015 [%]	2016 [%]
Normalization uncertainty		
Bunch population		
Ghost and satellite charge	0.1	0.1
Beam current normalization	0.2	0.2
Beam position monitoring		
Orbit drift	0.2	0.1
Residual differences	0.8	0.5
Beam overlap description		
Beam-beam effects	0.5	0.5
Length scale calibration	0.2	0.3
Transverse factorizability	0.5	0.5
Result consistency		
Other variations in σ_{vis}	0.5	0.2
Integration uncertainty		
Out-of-time pileup corrections		
Type 1 corrections	0.3	0.3
Type 2 corrections	0.1	0.3
Detector performance		
Cross-detector stability	0.6	0.5
Linearity	0.5	0.3
Data acquisition		
CMS deadtime	0.5	<0.1
Total normalization uncertainty	1.2	1.0
Total integration uncertainty	1.0	0.7
Total uncertainty	1.6	1.2

Improved identification of tau leptons

identification of the hadronic decays of tau leptons with a deep neural network

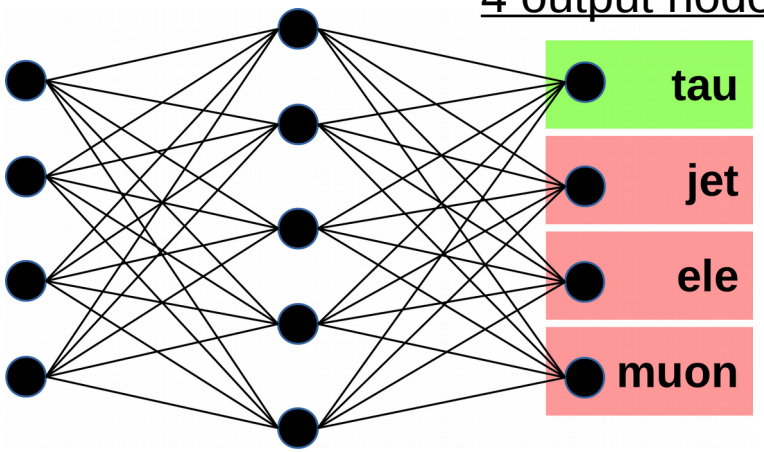
public as [CMS-DP-19-033]

New tau ID “DeepTau” deployed in CMS during Run 2

- convolutional NN combining low-level detector information and high-level observables
- significant improvement in performance w.r.t. previous algorithm:
  - increase in hadronic tau-ID efficiency by ≈ 20%
  - decrease in mis-ID rate of fakes → hadronic tau by ≈ 20%
- offers substantial increase in sensitivity for analyses with tau leptons

Inputs:

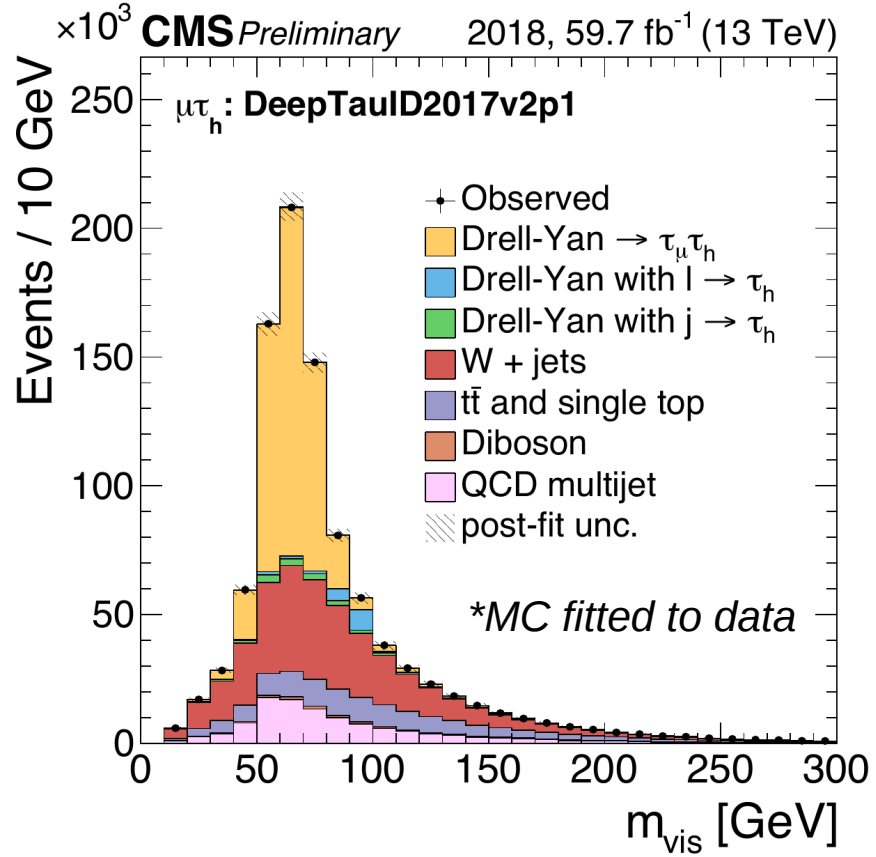
- low-level:
  tracks and energy deposits of particle-flow candidates
- high-level:
  transverse momenta, decay mode, etc., of tau candidate + global event properties



$$\frac{P_\tau}{P_\tau + P_{obj.}}$$

classifiers for mis-ID rate reduction

m_{vis} distribution using DeepTau IDs



Improved identification of tau leptons

identification of the hadronic decays of tau leptons with a deep neural network

public as [CMS-DP-19-033]

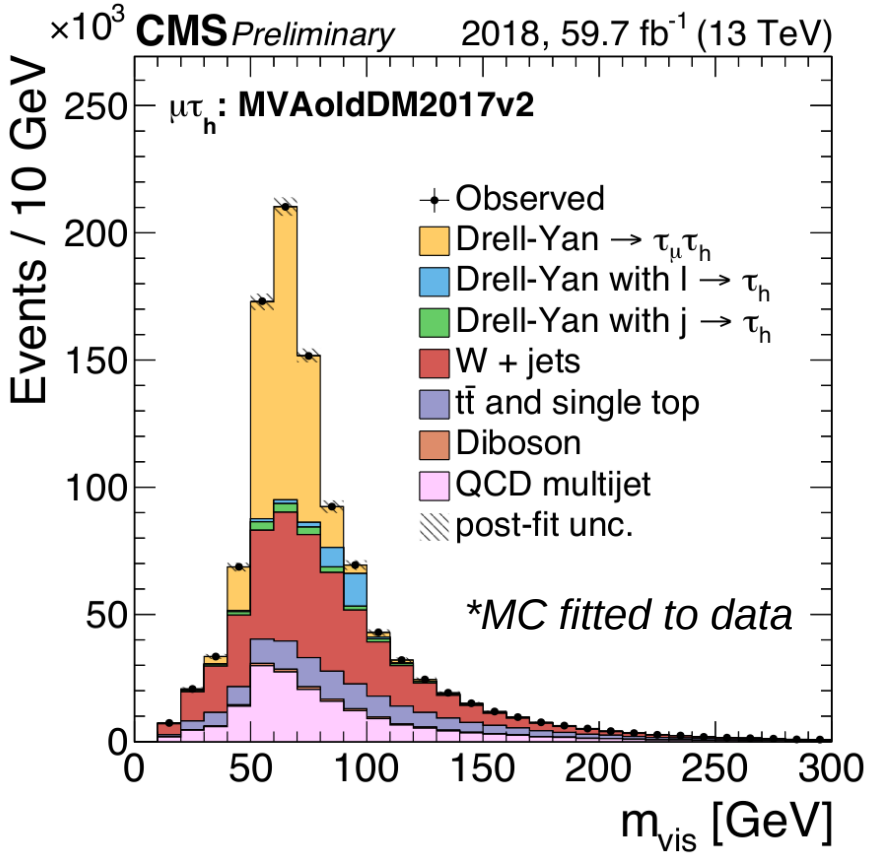
New tau ID “DeepTau” deployed in CMS during Run 2

- convolutional NN c
- significant improver
  - increase in hadro
  - decrease in jet / e
- offers significant inc

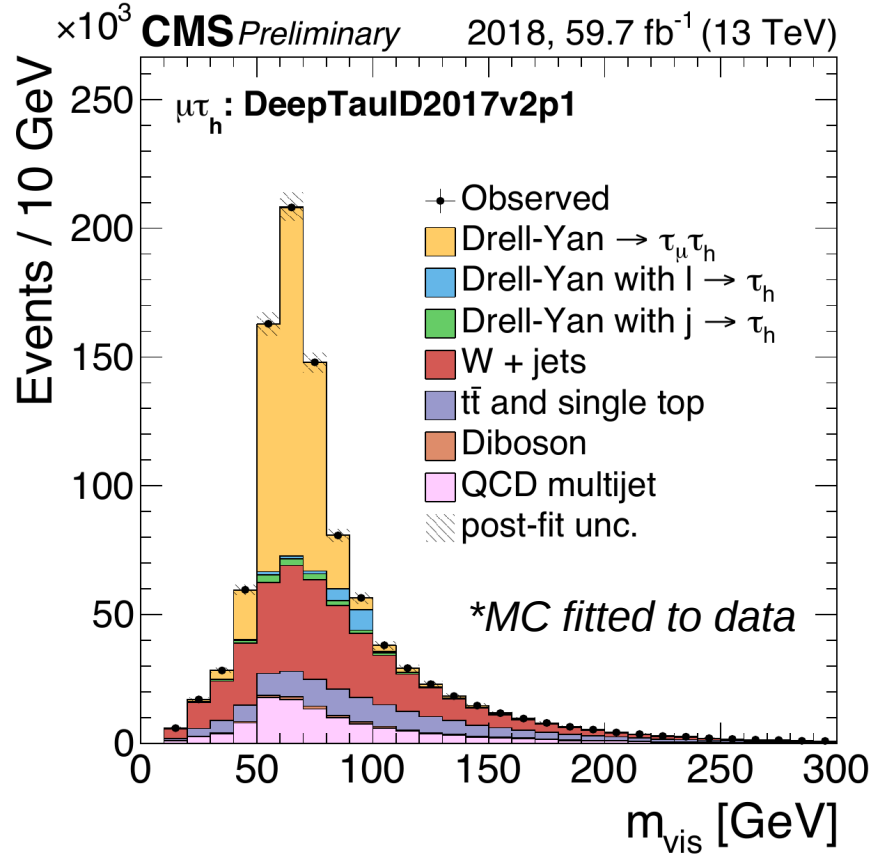
Inputs:

- low-level:
  tracks and energy depos
  of particle-flow candidate
- high-level:
  transverse momenta, de
  mode, etc., of tau candid
  + global event properties

m_{vis} distribution using JINST 13 (2018) P10005



m_{vis} distribution using DeepTau IDs



Improved identification of tau leptons

identification of the hadronic decays of tau leptons with a deep neural network

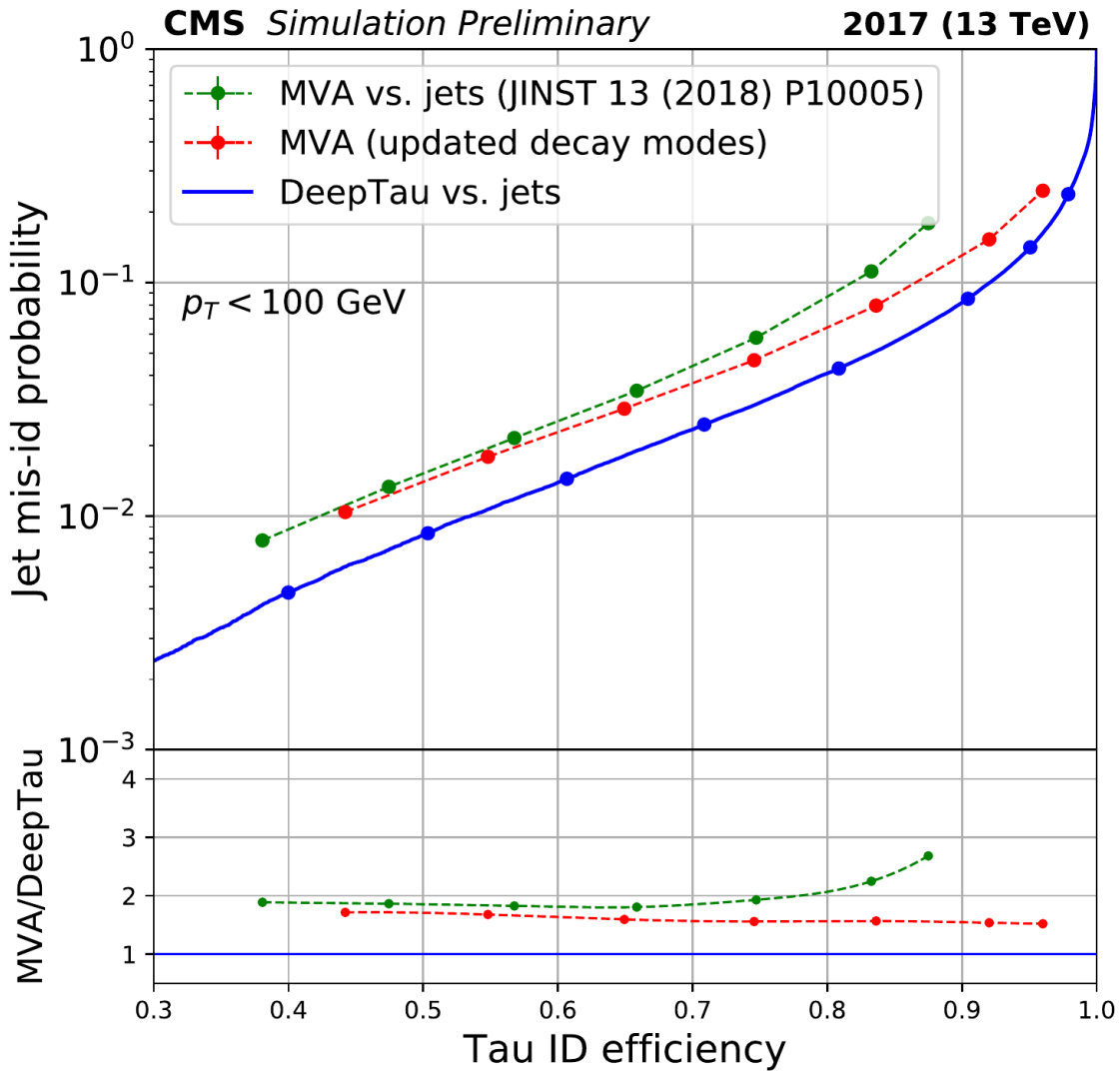
public as [CMS-DP-19-033]

DESY contributions:

- maintain the DeepTau ID code
- measure tau-ID efficiency
- measure jet / lepton → tau mis-ID rate
- provide data / simulation corrections

Classifier against quark jets

Lower mis-ID probability is better



New top quark definition at particle level in $t\bar{t}$ dilepton decays

toward optimal particle-level definition in top sector at LHC

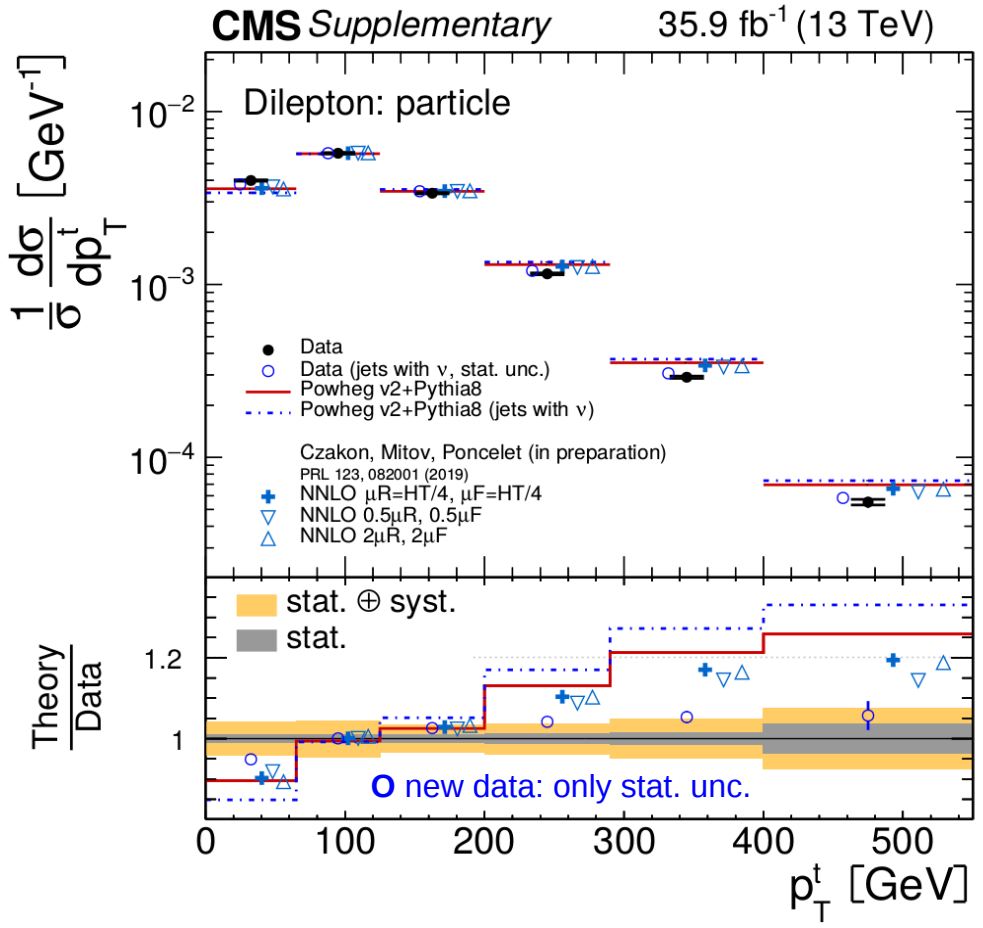
Study for LHCtopWG in context of paper [JHEP 02 (2019) 149] (2016 data):
$t\bar{t}$ differential spectra remeasured using an updated particle-level definition

- update: inclusion of neutrinos from hadronic decays to jet clustering
- work in collaboration with M. Czakon, A. Mitov, R. Poncelet
  - identified key differences in theoretical and experimental setups
  - will benefit next generation of results in Run 2 and beyond
- data compared to NNLO QCD predictions with $t\bar{t}$ decay modelling

Comparisons presented in LHCtopWG [↗] and available at [↗]:

- absolute and normalized differential cross sections for 17 observables
- to assess agreement, confront new data (**O**) with QCD NNLO (**+**)
  - data-to-theory agreement greatly improves with new definition

Normalized differential cross section
in bins of **top quark p_T**

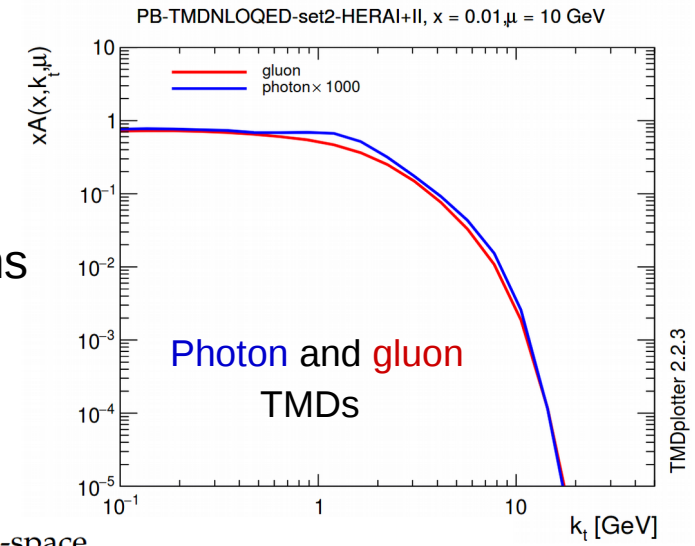


First determination of TMD photon densities

… or how many photons inside protons?

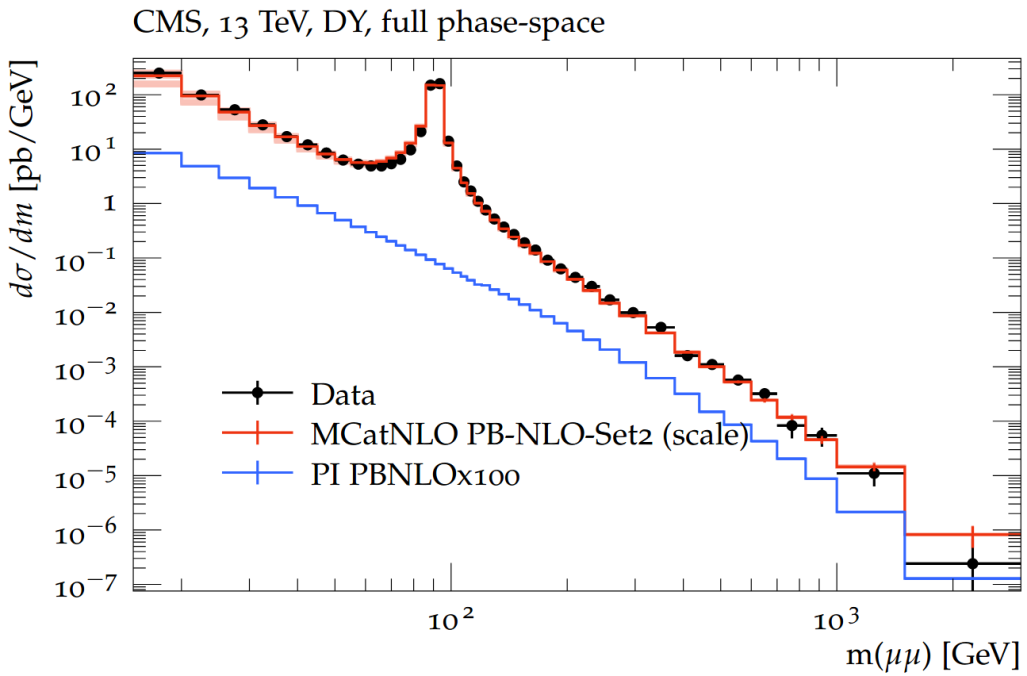
Paper [arXiv:2102.01494]: complete set of Transverse-Momentum-Dependent and collinear photon densities over full phase space

- photon density appears when evolving parton distributions with QED corrections
  - non-negligible effects for precise predictions at LHC, but even more at energies of HE-LHC and FCC-hh
- photons generated by perturbative radiation using Parton Branching method
- QCD partons constrained by fit to HERA data



Application: lepton pair production at high masses

- calculation with CASCADE3
  - DY: using PB-TMDs $q\bar{q} \to l^+l^-$
  - PI: photon-induced process $\gamma\gamma \to l^+l^-$



published in PLB 817 (2021) 136299
presented at Moriond'21 and DIS'21

CASCADE3: the only MC generator using TMDs

event generator based on Transverse-Momentum-Dependent parton densities

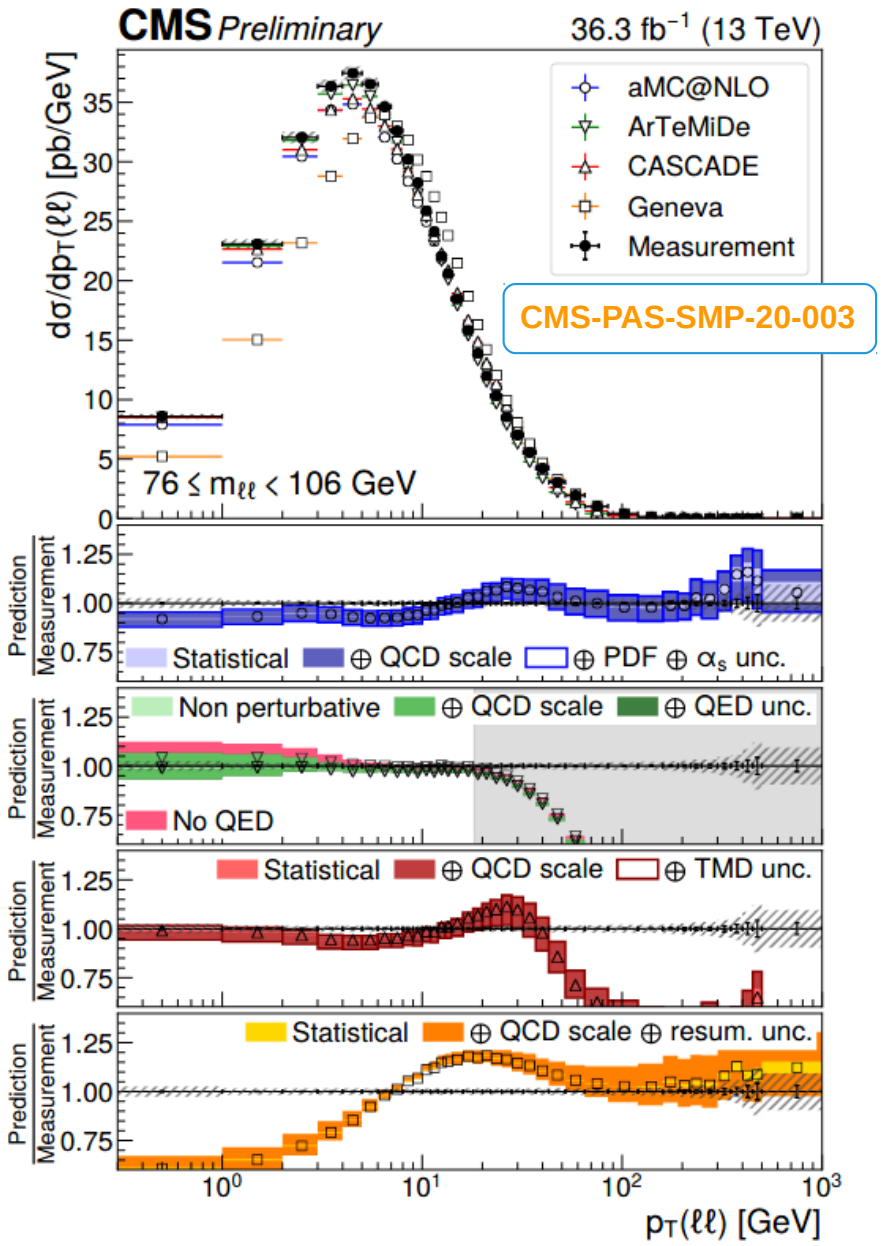
CASCADE3 extends upon hard processes generated in collinear factorization

- compatible with LO-multileg/NLO MEs through LHE interface
- adding transverse momenta to initial partons according to TMD densities
- applying dedicated TMD parton showers and hadronization
  - using Parton Branching TMDs fitted to HERA data
  - access to TMD parametrizations via **TMDlib2** library [arXiv:2103.09741]
- initial state parton shower tied to TMD distribution: no further tuning

Manual and Physics:
[arXiv:2101.10221] submitted to EPJC

CASCADE3 already applied to LHC processes: Drell-Yan production

- also applicable to ep DIS [H1-prelim-21-031], presented at DIS'21



Wide variety of activities by DESY CMS group

Physics highlights covered today

- remarkable tracker alignment in Run 2
- luminosity measurement at ultimate precision in 2015 / 2016
- improved identification of hadronic tau leptons
- studies toward optimal particle-level definition in top sector at LHC
- first photon TMD parton density + next generation of tools for SM physics

… many more results in Higgs, QCD, SUSY, Top & Exotica are being prepared!

Not covered in this talk

- Detector R&D, Outer Tracker and HGCAL Phase-2 upgrades, BCM1F upgrade, computing, Open Data, and other service work

thank you for your attention!

BACKUP

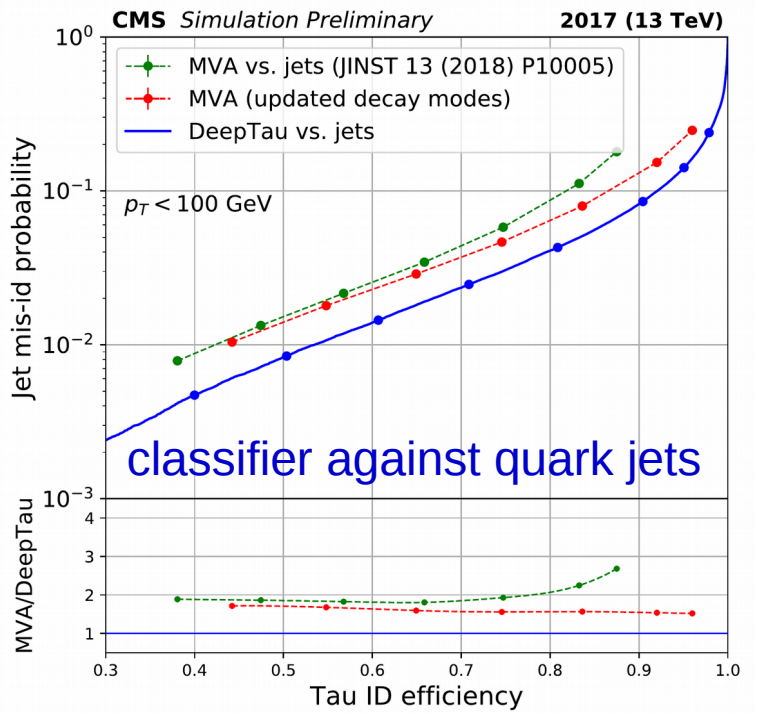
Improved identification of tau leptons

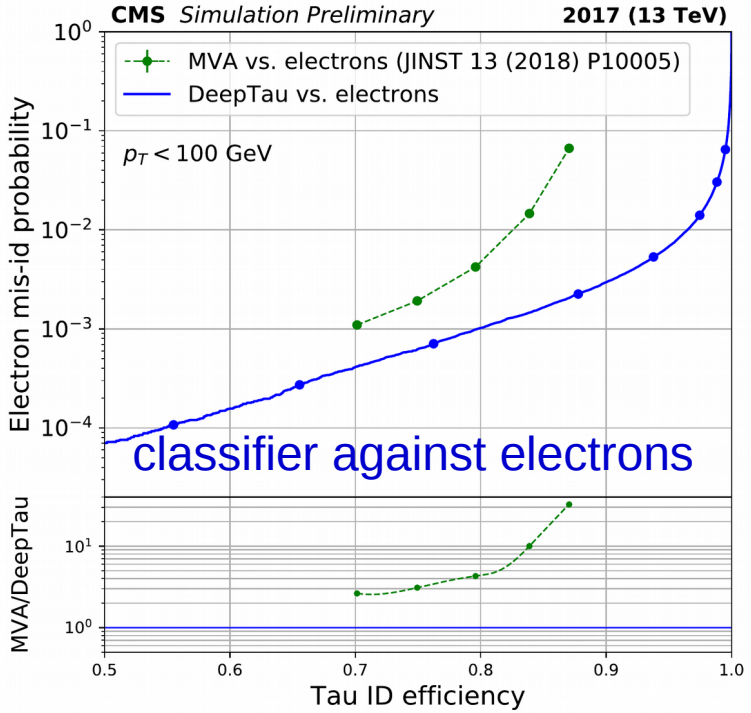
identification of the hadronic decays of tau leptons with a deep neural network

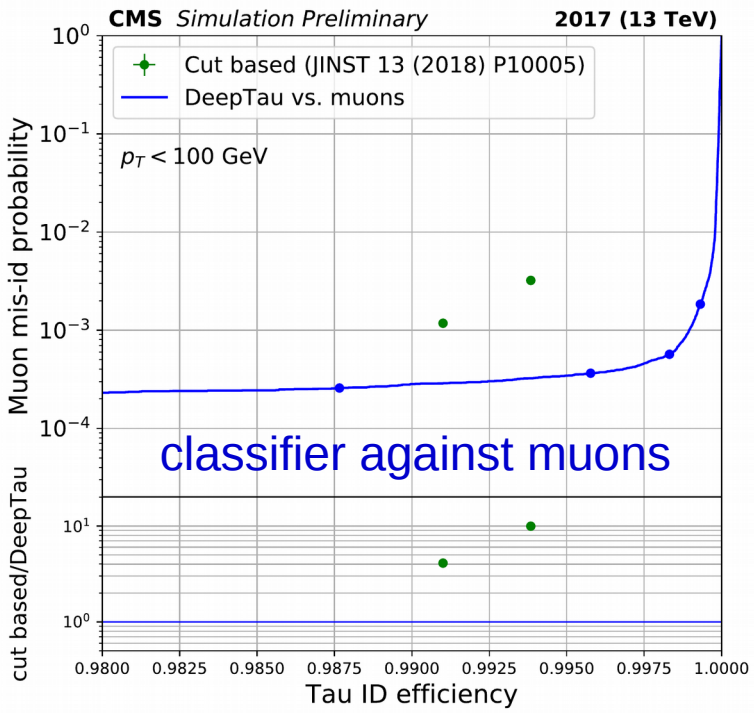
public as [CMS-DP-19-033]

DESY contributions:

- maintain the DeepTau ID code
- measure tau-ID efficiency
- measure jet / lepton → tau mis-ID rate
- provide data / simulation corrections







TMDlib2 and TMDplotter

common framework for TMD physics

TMDlib2: library for Transverse-Momentum-Dependent parton densities

- providing 3D picture of the partonic structure of hadrons
- easy access to large collection of TMD parametrizations
  - Parton Branching TMDs
  - CCFM/BFKL TMDs
  - traditional TMDs (a la Collins-Soper-Sterman approach)
- TMDlib2 stores TMDs as grids and provides tools for interpolation between grid points

TMDplotter: web-based plotting tool for TMDs and collinear PDFs

- available at http://tmdplotter.desy.de

Manual:
[arXiv:2103.09741] submitted to EPJC