91st PRC Meeting
CMS Physics Highlights at DESY

Mykola Savitskyi on behalf of the DESY CMS group

4 May 2021
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
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Detector Upgrade
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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

Muon Track-Split validation
  • difference in $\eta$ between two halves of cosmic tracks split near detector center

$Z \rightarrow \mu\mu$ validation
  • significant improvement in uniformity of reconstructed $Z \rightarrow \mu\mu$ mass
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

Measurement of $\sigma_{\text{vis}}$ (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 $\Sigma_x$ and $\Sigma_y$

### Instantaneous luminosity:

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

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

**Diagram:**
- CMS, LHC beam position monitors
- Horizontal beam separation [mm]
- Normalized rate [a.u.]
- Instantaneous luminosity: $R(t) = \mathcal{L}(t) \cdot \sigma_{\text{vis}}$
- Parameters:
  - $R_0$
  - $2\Sigma_x$

**Equation:**

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

**Notes:**
- arXiv:2104.01927
- Data, Fit, Gauss 1, Gauss 2, Const
Integrated Luminosity at Ultimate Precision

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

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 typically 1%

Beam position monitoring

Transverse factorizability

Length scale calibration

Integration uncertainty

Source

<table>
<thead>
<tr>
<th>2015 [%]</th>
<th>2016 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch population Ghost and satellite charge</td>
<td>0.1</td>
</tr>
<tr>
<td>Beam current normalization</td>
<td>0.2</td>
</tr>
<tr>
<td>Beam position monitoring Orbit drift</td>
<td>0.2</td>
</tr>
<tr>
<td>Residual differences</td>
<td>0.8</td>
</tr>
<tr>
<td>Beam overlap description Beam-beam effects</td>
<td>0.5</td>
</tr>
<tr>
<td>Length scale calibration</td>
<td>0.2</td>
</tr>
<tr>
<td>Transverse factorizability</td>
<td>0.5</td>
</tr>
<tr>
<td>Result consistency Other variations in $\sigma_{vis}$</td>
<td>0.5</td>
</tr>
</tbody>
</table>

DESY contributions highlighted in table

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[arXiv:2104.01927]
Improved identification of tau leptons
identification of the hadronic decays of tau leptons with a deep neural network

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 \( \approx 20\% \)
  - decrease in mis-ID rate of fakes \( \rightarrow \) hadronic tau by \( \approx 20\% \)
- 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

**4 output nodes**

\[
\frac{P_{\tau}}{P_{\tau} + P_{\text{obj}}} \quad \text{classifiers for mis-ID rate reduction}
\]

\( m_{\text{vis}} \) distribution using DeepTau IDs

*MC fitted to data*
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\( m_{\text{vis}} \) distribution using DeepTau IDs

*MC fitted to data

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

*MC fitted to data

\( \mu_{\text{T}} \) : MVAoldDM2017v2

\( \mu_{\text{T}} \) : DeepTauD2017v2p1

\[ \text{CMS Preliminary} \quad 2018, 59.7 \text{ fb}^{-1} (13 \text{ TeV}) \]
Improved identification of tau leptons

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

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 $\bar{t}t$ dilepton decays
toward optimal particle-level definition in top sector at LHC

$\bar{t}t$ 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 $\bar{t}t$ decay modelling

Comparisons presented in LHCTopWG [charted:] and available at [charted:]
- 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
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  \( q\bar{q} \rightarrow l^+l^- \)
  - **PI**: photon-induced process  \( \gamma\gamma \rightarrow l^+l^- \)

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

CASCADE3 already applied to LHC processes: Drell-Yan production
- also applicable to ep DIS [H1-prelim-21-031], presented at DIS’21

Manual and Physics:
[arXiv:2101.10221] submitted to EPJC
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!
Improved identification of tau leptons
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public as [CMS-DP-19-033]
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](http://tmdplotter.desy.de)