# Cut-Based Photon Identification Studies at CMS


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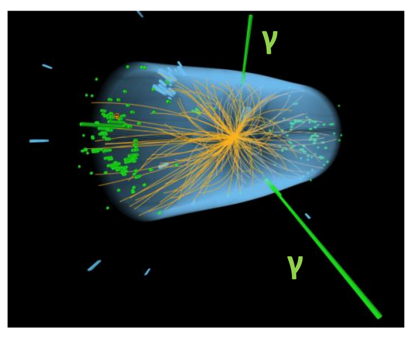
## Introduction

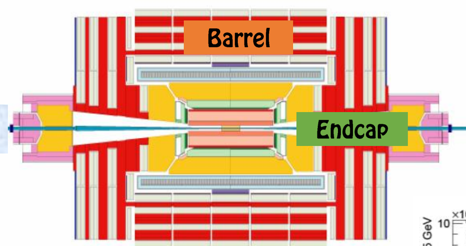
### Why are Photons important?

Photons provide a cleaner channel amidst the messy hadronic environment in proton-proton (p-p) collisions at the LHC. Nothing highlights its importance more than the discovery of **Higgs decaying into two photons** which has a **branching ratio of only 0.002 !!!**

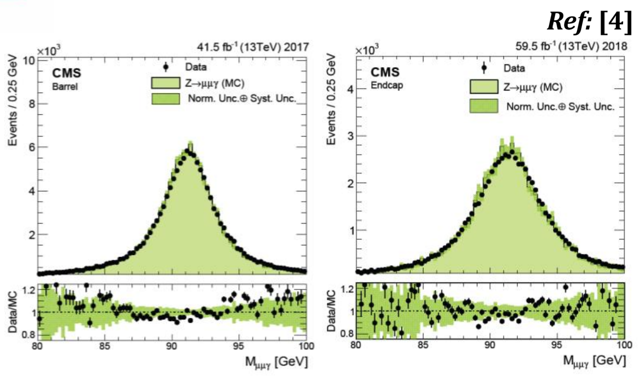



H → γγ event

Energy Resolution within 1% (3%) in Barrel (Endcap)



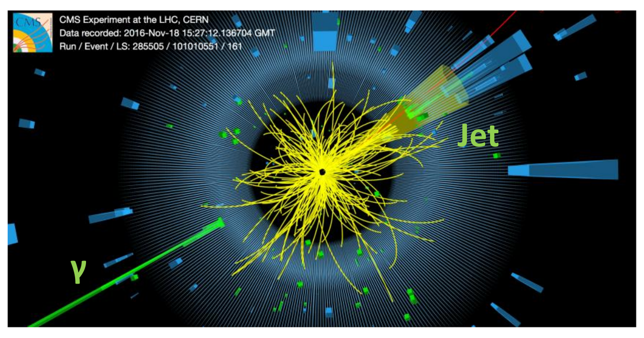

Ref: [4]



Ever since Higgs-discovery, it has been used as a probe in **Beyond Standard Model (BSM)** searches. One such analysis, for instance, looks for the decay of Higgs into a dark photon and an SM photon and uses the **cut-based photon identification (ID)** for selecting the SM photon[5]. Many other searches which have a photon as one of the final state particles use this ID.

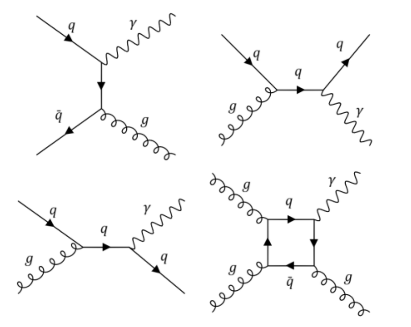
### Objective

- Photons come from two sources: i) **prompt photons** → produced in hard scattering processes **(signal)** ii) **non-prompt photons** → produced abundantly in hadron decays and fragmentation processes **(background)**.
- **ID variables** discriminate against these two "kinds" of photons. Combination of these variables are taken and the ID values - the value at which the discrimination threshold is kept, are tuned using **Genetic Algorithm (GA)** for **three working points (WP)** at **90% (loose), 80% (medium) and 70% (tight)** signal efficiency.



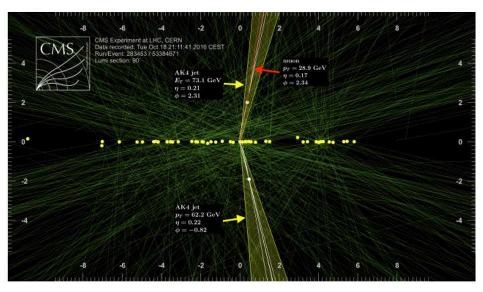

γ-jet event

Study done using **Monte Carlo (MC) samples** of **γ-jet** with latest pile-up (PU) conditions i.e. Run 3 conditions (CoM energy 13.6 TeV) for p-p collisions.



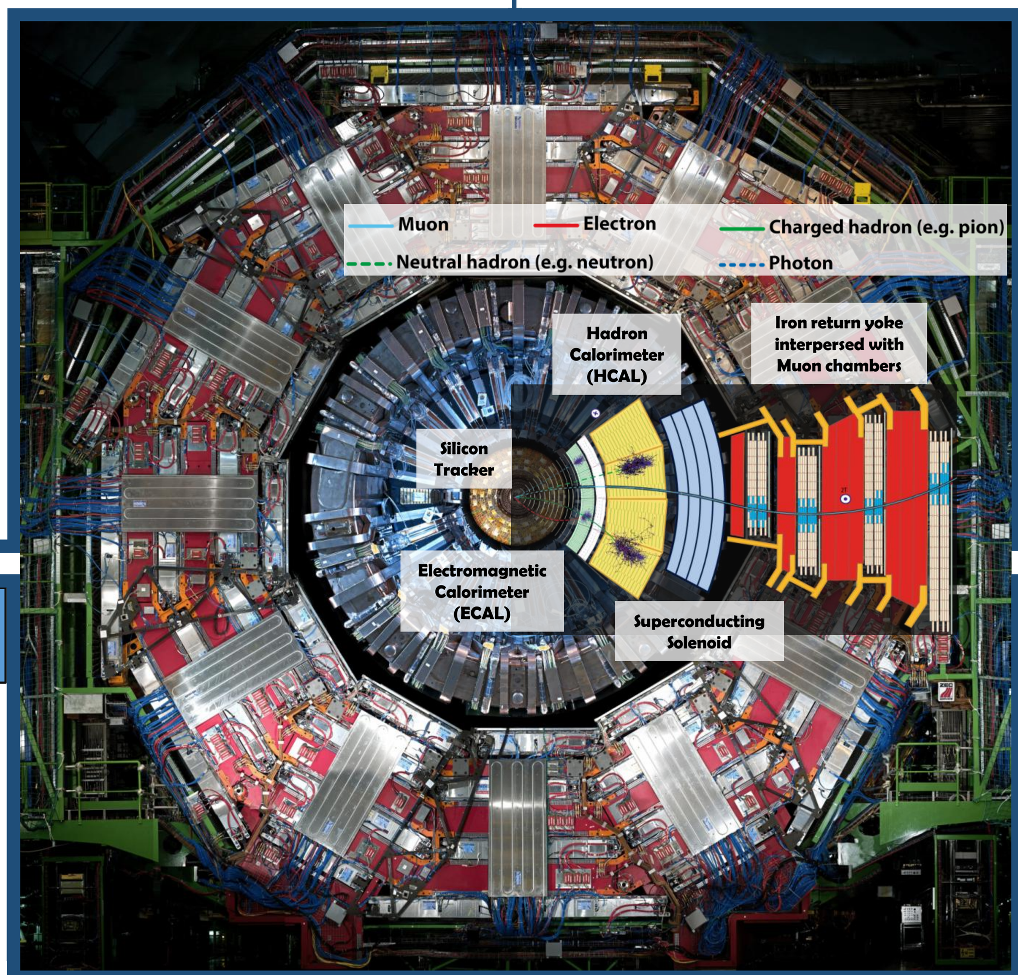
γ-jet MC sample physics process

### Pile-up



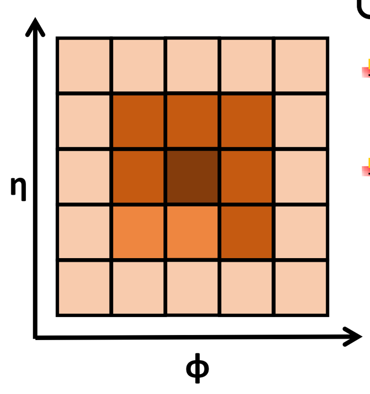
Pile-up events

- Multiple interactions within the same p-p bunch crossing.
- Increases with luminosity and energy
- Run 3 has an expected pile-up of about 52 interactions
- Quantified by **no. of vertices (nvtx)** and **ρ**, which is the **pile-up transverse momentum ($p_T$) density**.

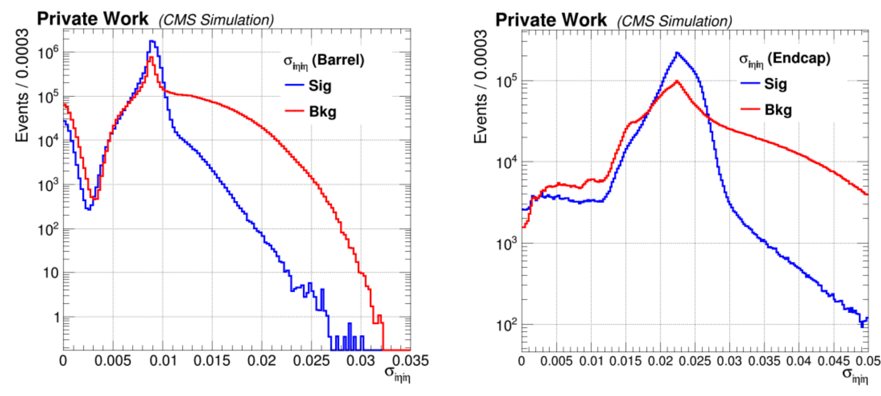



## ID Variables

### $\sigma_{i\eta i\eta}$

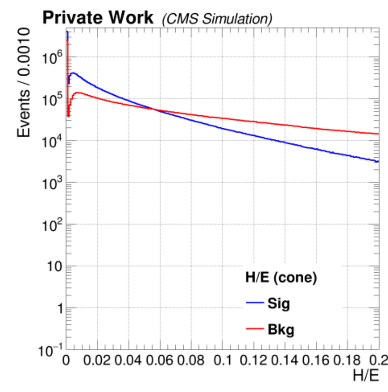


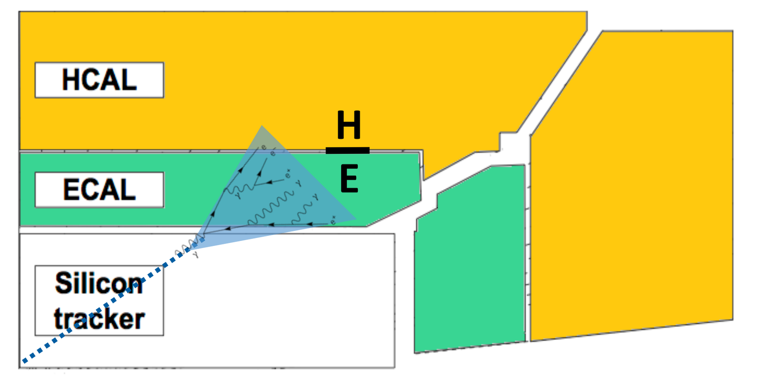

- Energy-spread along **η-direction** for a **5×5 cell array** in ECAL
- Prompt photons have lower values of $\sigma_{i\eta i\eta}$ since their shower is narrower than that of jets




### H/E

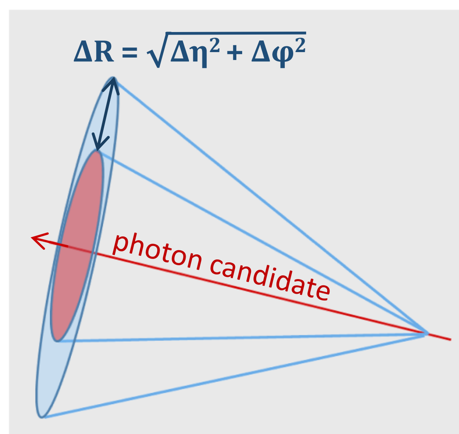
- Ratio of energy deposited in HCAL to that in ECAL
- Prompt photons have higher energy deposit in ECAL relative to HCAL, so low value of H/E

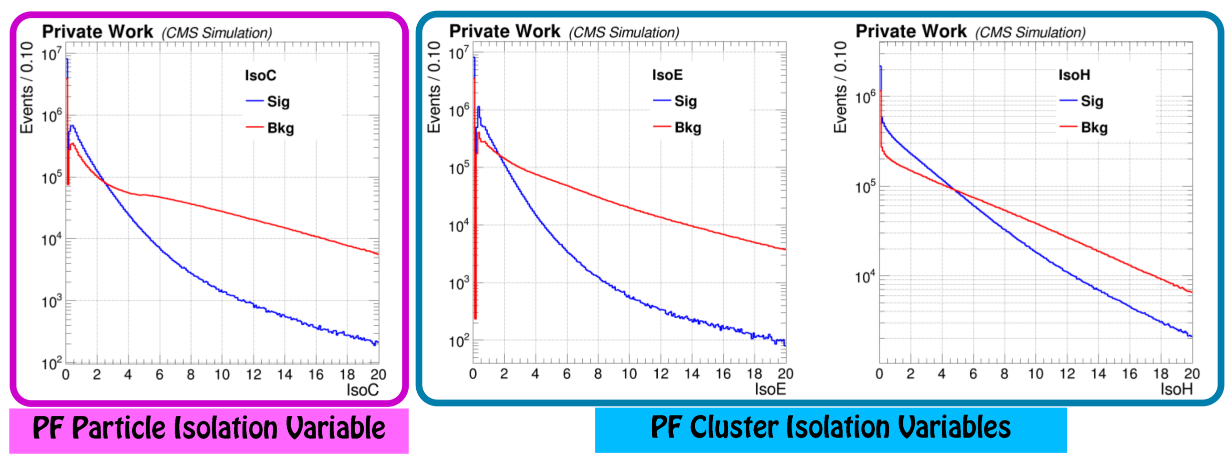



### Isolation

- **Σscalar transverse momentum ($p_T$)** of all detected particles within a hollow cone of **ΔR radius** around the photon candidate.
- Jets will typically have more particles surrounding it and thus, a higher value of $\Sigma p_T$
- **Two categories** of isolation variables:
  - **Particle Flow (PF) Cluster Isolation** → calculated based on the energy-deposit clusters in the sub-detectors, viz. **Tracker (IsoT), ECAL (IsoE)** and **HCAL (IsoH)**
  - **PF Particle Isolation** → calculated after forming particle candidates, **Charged hadrons (IsoC), Photons (IsoP)** and **Neutral hadrons (IsoN)**



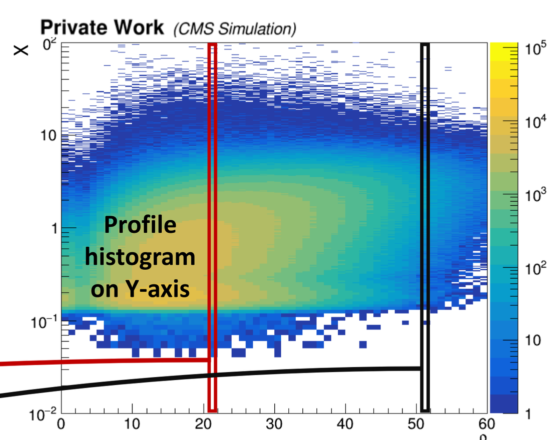



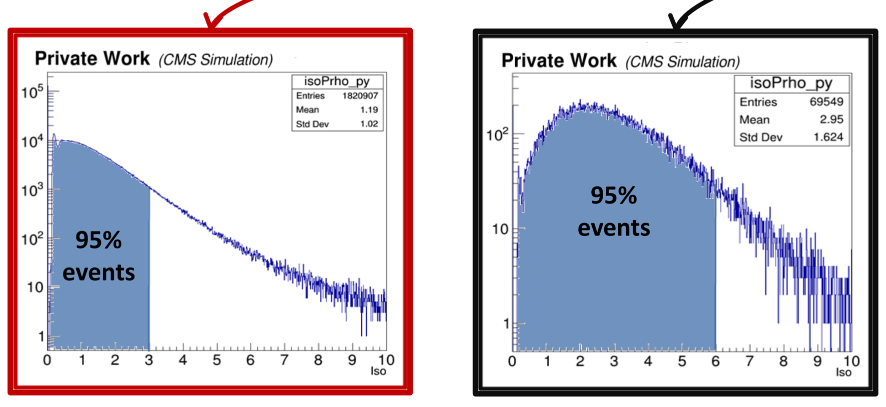

PF Particle Isolation Variable

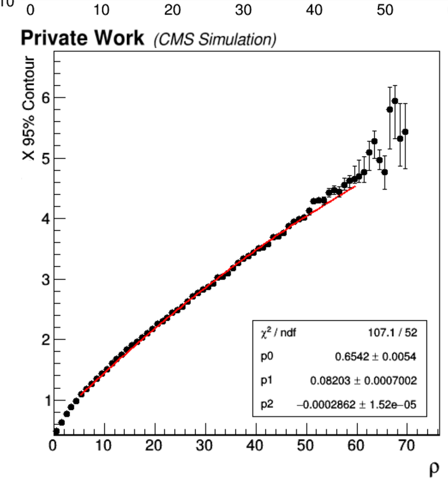
PF Cluster Isolation Variables

## Outline of Workflow

- **Isolation** and **H/E** are **PU-corrected**
  Effective areas (EA) are extracted with **95% contour profile** after separating the samples in **seven η-bins**
  $X_{p\text{-corrected}} = X - (\rho^2 \times EA2 + \rho \times EA1)$
  **EA2, EA1** → Coefficients of the fitted polynomial
- **$p_T$-scales** are calculated similarly for **IsoE, IsoH, IsoP** and **IsoN** for $p_T$-correction
- ID-training for **loose, medium and tight** is done. Five variables are used:
  **$\sigma_{i\eta i\eta}$, H/E,** and a combination of **three variables** from **PF Cluster** and **PF Particle isolation**
- Stability of the ID cut-values are checked by plotting the **efficiency** over **$p_T$, η** and **nvtx** range for the best performing combination

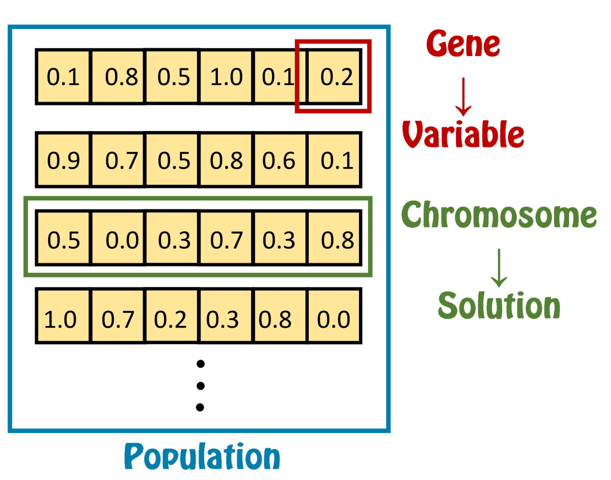


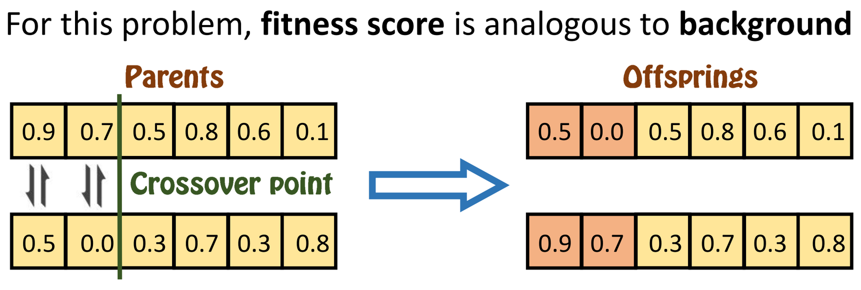



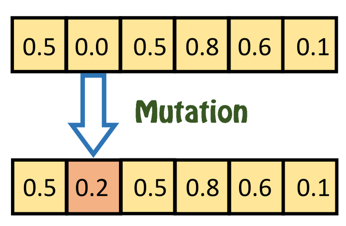




### Genetic Algorithm

- Optimization algorithm which is based on the idea of **'Survival of the Fittest'**
- Each **variable** is analogous to a **gene**, can take any value
- Set of **genes** form **chromosome** of an **individual**, represents **solution**
- Each chromosome has survivability or fitness score – a score associated with each solution. Individuals with high fitness score are more likely to be chosen as parents.
- For this problem, **fitness score** is analogous to **background rejection**

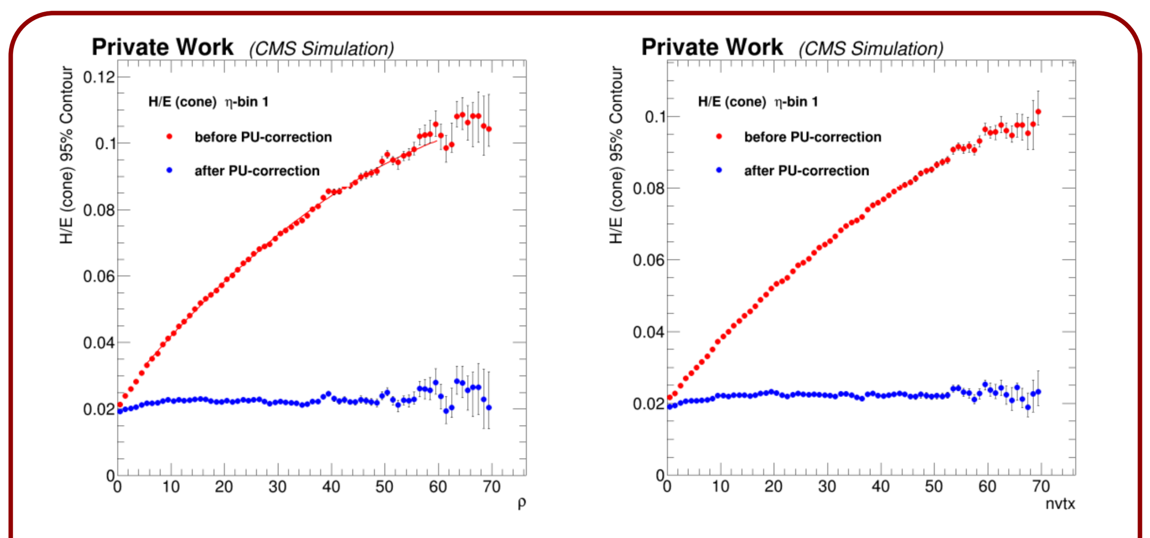


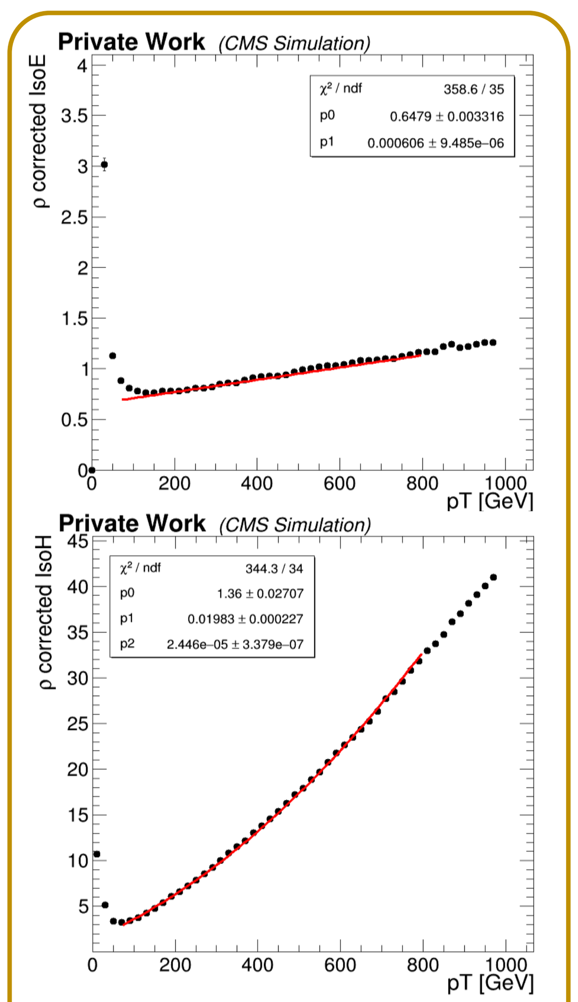




- The population in the next generation thus, has higher average fitness score.
- **Mutation** fosters exploring more optimum solutions.

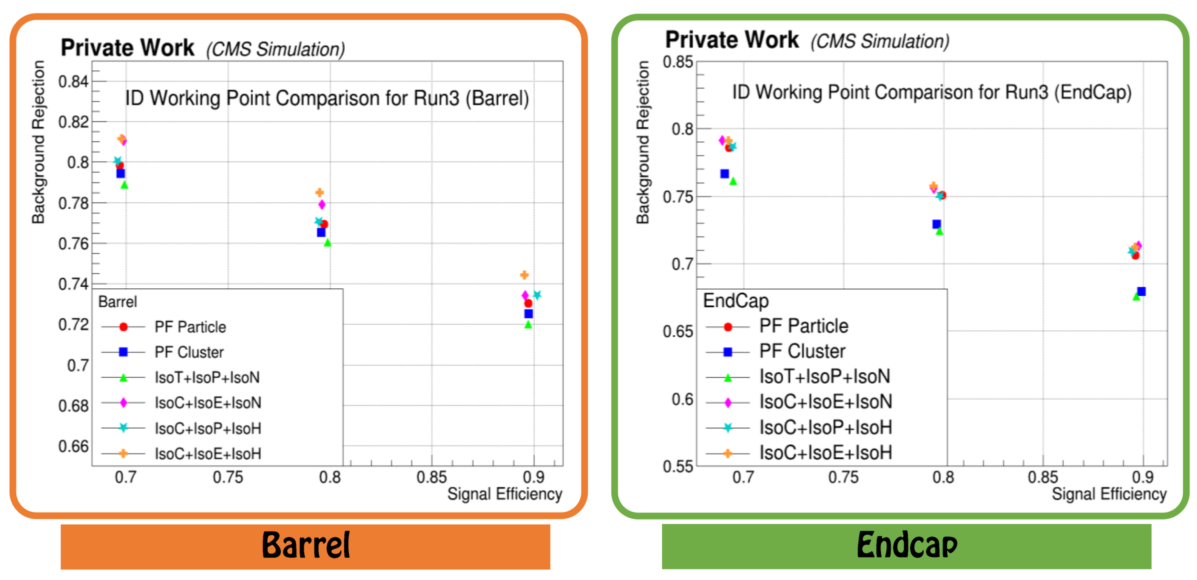
## Results




Flat profile of the variables after the PU-correction




IsoE and IsoP have linear dependence while IsoH and IsoN have quadratic dependence




Barrel | Endcap

The combination IsoC + IsoE + IsoH gives the best performance

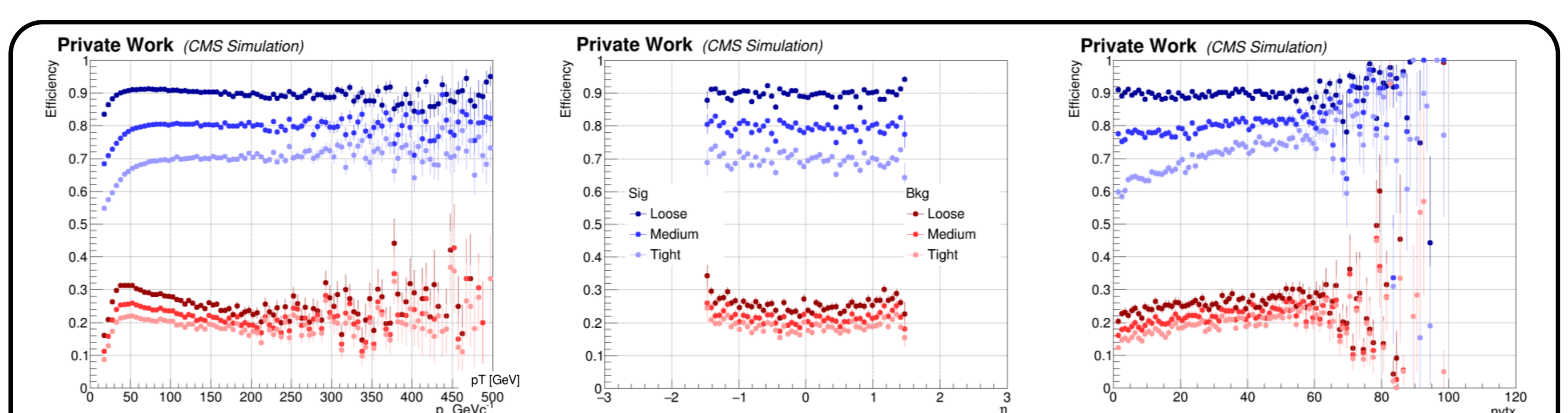
### Run 3 Photon ID for BARREL & ENDCAP

BARREL:

| WP | $\sigma_{i\eta i\eta}$ | H/E | IsoC | IsoE | IsoH |
|---|---|---|---|---|---|
| Loose | 0.0114 | 0.1299 | 1.8852 | 0.7038 | 6.3439 |
| Medium | 0.0100 | 0.0583 | 0.9393 | 0.2277 | 2.1890 |
| Tight | 0.0099 | 0.0418 | 0.3163 | 0.1419 | 0.3906 |

ENDCAP:

| WP | $\sigma_{i\eta i\eta}$ | H/E | IsoC | IsoE | IsoH |
|---|---|---|---|---|---|
| Loose | 0.0277 | 0.1534 | 1.6539 | 6.6158 | 1.8588 |
| Medium | 0.0269 | 0.0052 | 0.9703 | 1.1240 | 0.0337 |
| Tight | 0.0269 | 0.0025 | 0.2927 | 1.0427 | 0.0293 |




Stability of efficiency over pT , η and nvtx range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