XXI LNF SPRING SCHOOL “BRUNO TOUSCHEK” IN NUCLEAR, SUBNUCLEAR AND ASTROPARTICLE PHYSICS
8TH YOUNG RESEARCHERS' WORKSHOP

THE SEARCH OF MAGNETIC MONOPOLES WITH MISSING TRANSVERSE ENERGY TRIGGERS WITH THE CMS EXPERIMENT

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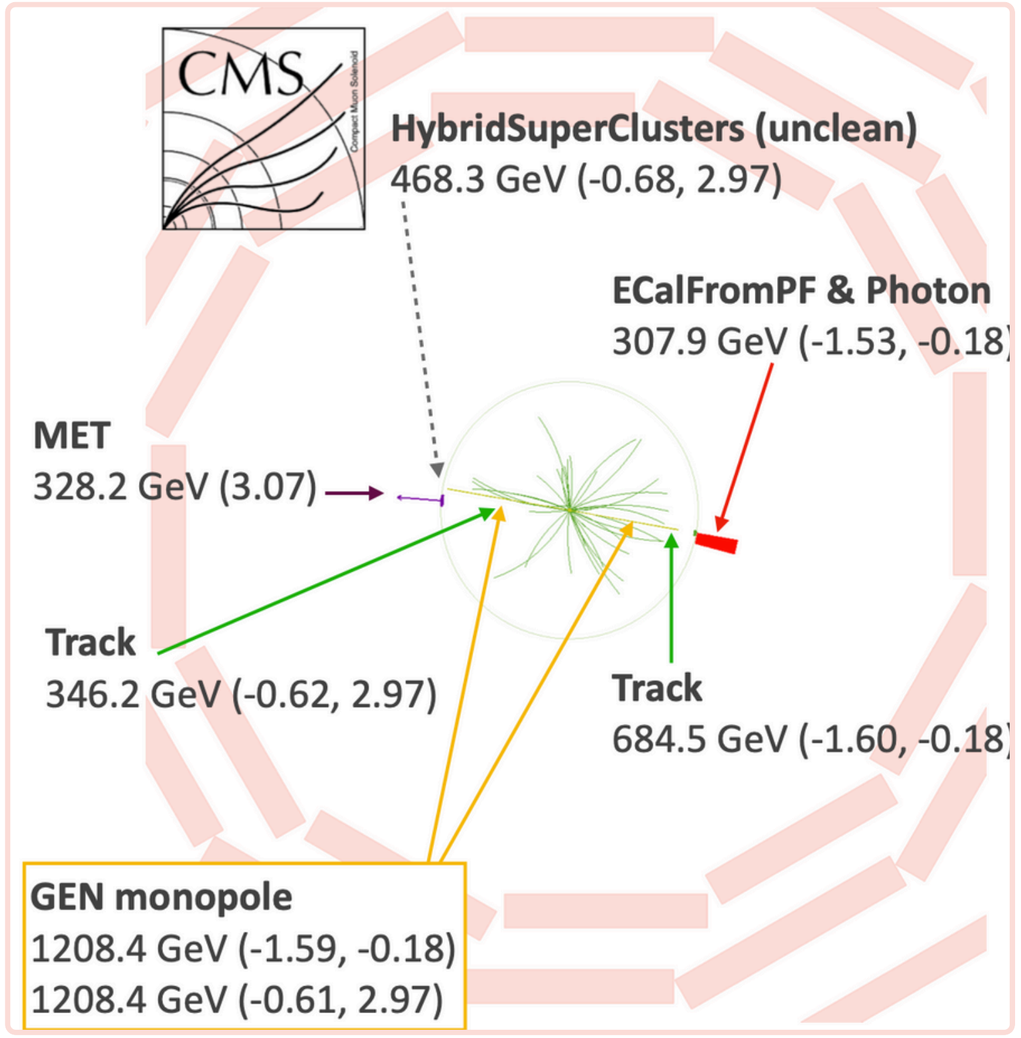
Outline

- Theoretical Motivation and search strategy;
- Analysis Strategy:
  - Tracking, MET;
- Triggers and MC Samples:
- Systematic Uncertainties;
- Preliminary results:
  - Background estimation;
  - Cross-section upper Limits;
- Conclusions and Next Steps.



Monopole Search Strategy

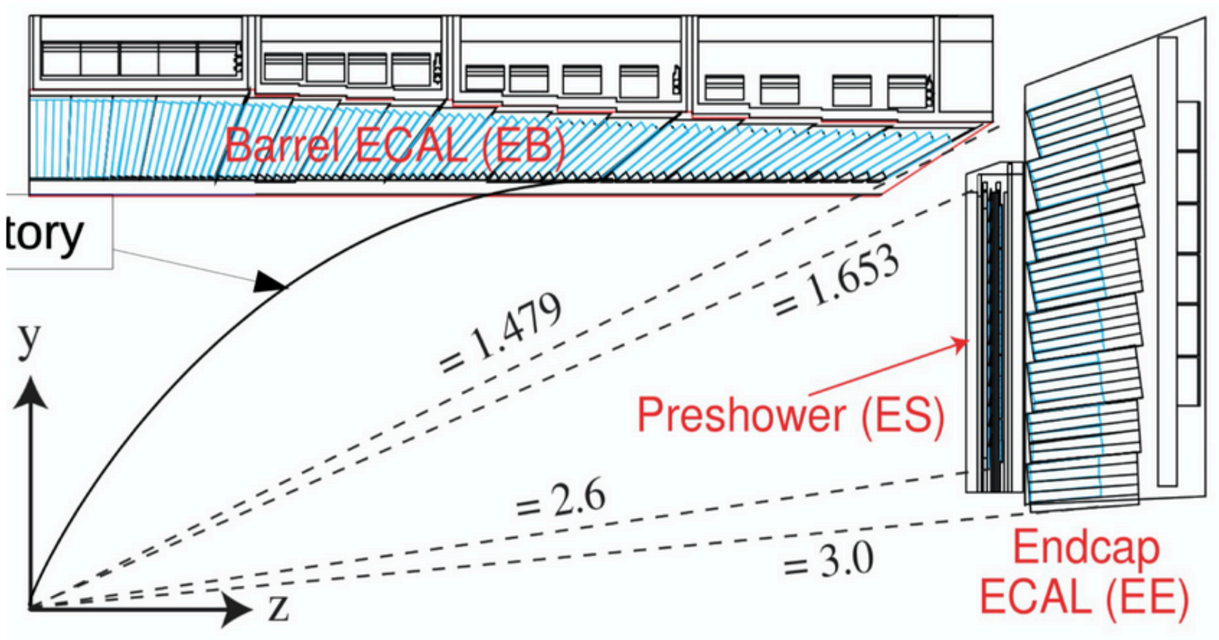
- **Proposition:** complete the electromagnetic duality;
- **Dirac:** presence of a monopole, quantisation of the electric charge and angular momentum;

$$eg = n/2 \quad , \quad n \text{ integer}$$

(Dirac's quantisation)

- **'t Hooft and Polyakov:**
  - **U(1):** topological magnetic monopoles solutions for SSB gauge.

$$F_{\mu\nu} = \frac{1}{|Q|} Q_a G^a_{\mu\nu} - \frac{1}{e|Q|^3} \varepsilon_{abc} Q_a (D_\mu Q_b)(D_\nu Q_c)$$

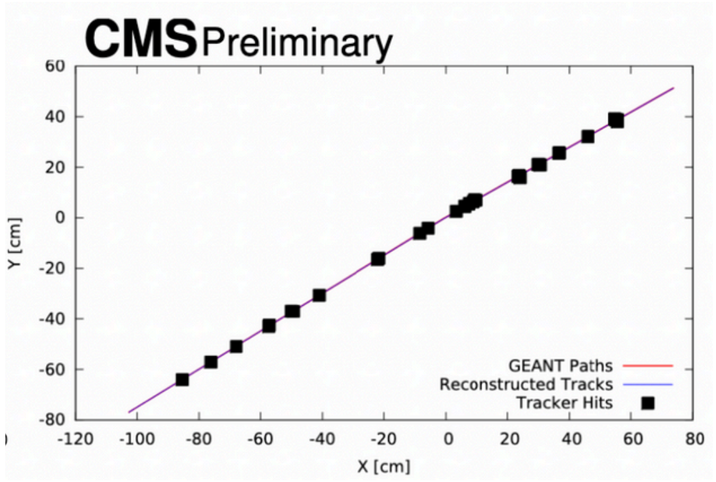


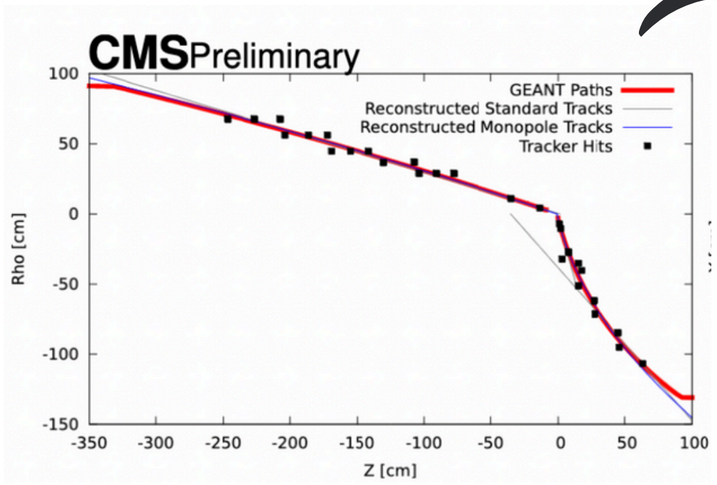
- **Monopoles @ Colliders:**
  - pair production and highly ionising particles;
  - few TeV, acessible in the LHC.
- **Monopole Identification:** combination of tracks and ECAL deposits:
  - **High ionization capacity:** large number of saturated strips,
  - **Energy deposition:** narrow and concentrated in the ECAL (η strips).

Monopole Tracking Reconstruction

- **Magnetic charge:** expected curvature along (opposite) direction of the CMS magnetic field;
- **HIP:** Energy loss in the tracker several orders of magnitude higher than a normal track;
- **Strong** inefficiency of the CMS Standard Reconstruction Track.

TrackCombiner Algorithm:





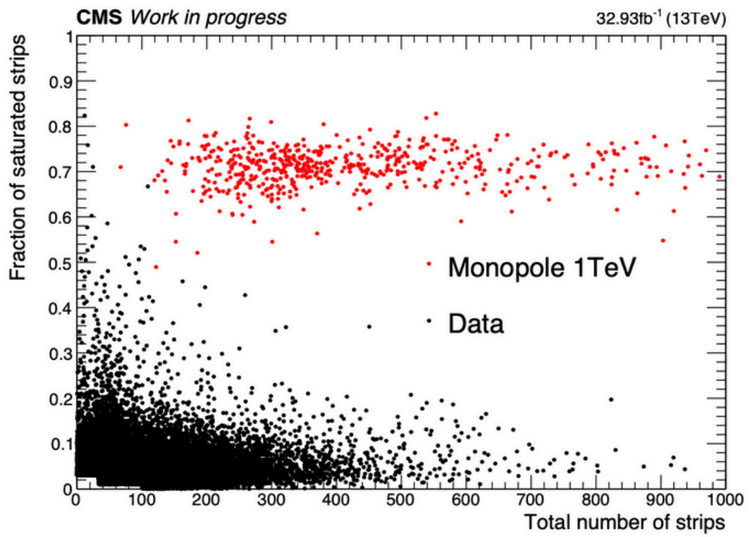
- **Preselection parameters.**

$\|\mathrm{XYPar0}\| \rightarrow d_0 = \sqrt{(a-c)^2 + b^2} - \|c\|$	< 0.6 cm
$\|\mathrm{XYPar2}\| \rightarrow \|\phi_0 - arctan(\frac{b}{c-a})\|$	< 1000

$\|\mathrm{RZPar0}\| \rightarrow Z_0 = \|d\|$	< 10 cm
$\|\mathrm{RZPar1}\| \rightarrow \eta_0 = \|f\|$	< 999
$\|\mathrm{RZPar2}\| \rightarrow \rho - Z$ curvature $= \|g\|$	< 0.005 cm^{-1}

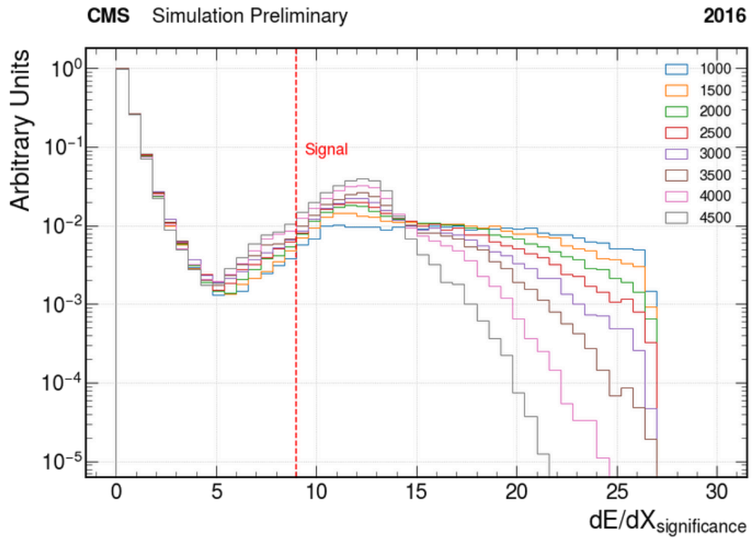
- **Combination** of standard track segments to form the monopole curved track.
- **Two fits** at the combined tracks:
  - **Circular Fit in the XY-plane:** (possible) electrical charged monopoles;
  - **Parabola in the pZ-plane:** account for the curvature.

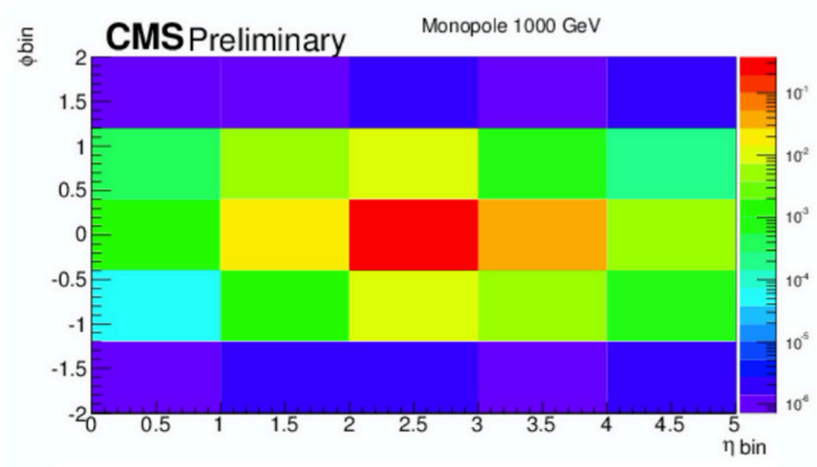
Monopole Identification



- **Ionisation** of the established track set;
- Probability of **strip saturation**;
- MIP Background Hypothesis: **0.07**.

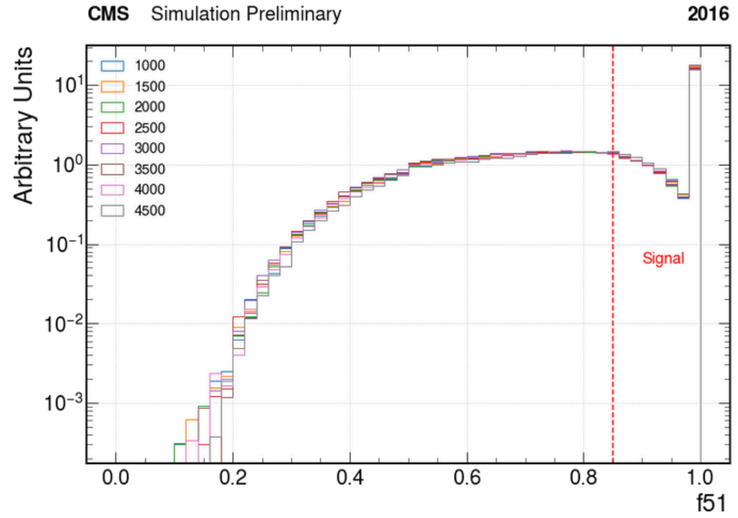
$$\sqrt{-\log(\mathrm{BinomialI}(0.07, \mathrm{TotalStrips}, \mathrm{SaturatedStrips}))}$$





- **5000** electrons-charge equivalent;
- **Single crystal** energy deposition;
- High energy **“spike”**.

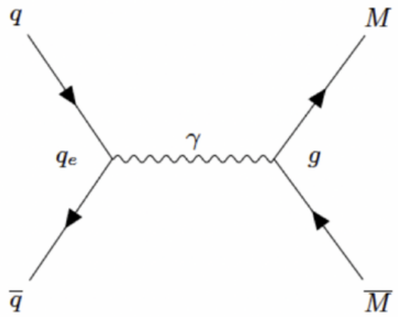
$$f_{51} = \frac{E_{5\times1}}{E_{5\times5}} \qquad f_{15} = \frac{E_{1\times5}}{E_{5\times5}}$$



- **Run2: S**ignal **R**egion definition in **dEdXSig > 9.0** and **f51 > 0.85.**

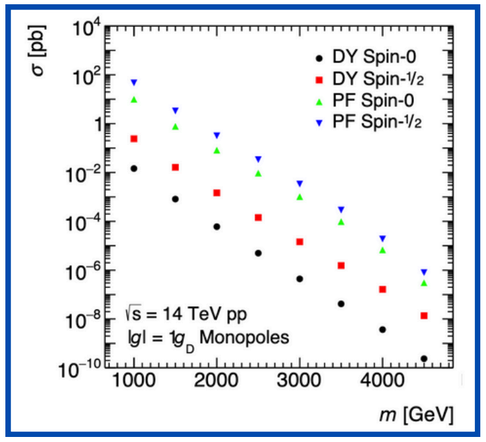
Monopole Search: Triggers and Datasets

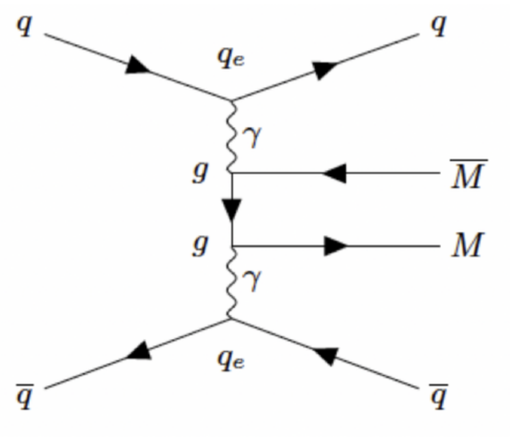
- DY and PF as **benchmarks** for HIP production;



Property	Parameter
Process	Drell-Yan
Spin	0, 1/2
Charge	1 g_D (Dirac monopole)
$\sqrt{s}$	13 TeV
Mass points (TeV)	1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5
particle ID (PID)	± 4110000
PDF model	NNLOPDF

- **Improvement in the CMS analysis sensitivity:**
- **Photon-Fusion** process @ LO; s=0,1/2 g= 1gD.





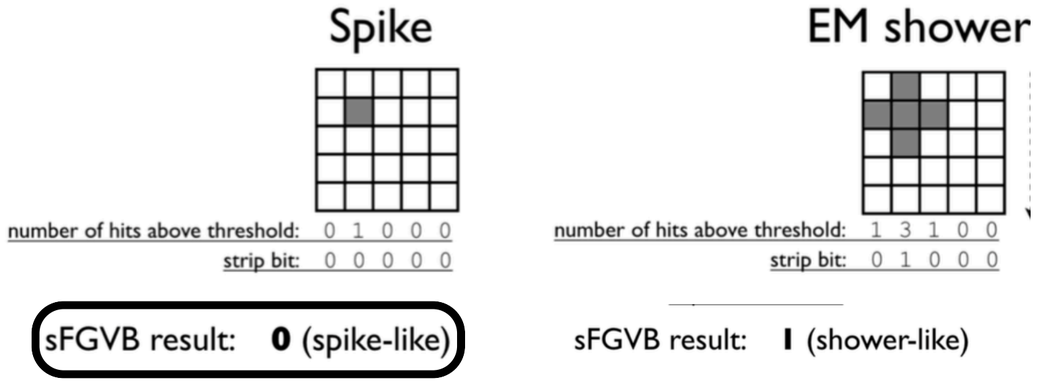
- No dedicated monopoles trigger at CMS:

- **SinglePhoton:**
  - Photon-Monopole similarities:
    - Electromagnetism interaction;
    - stopped in the ECAL;
  - **2016:** HLT_Photon175_v*;
  - **2017/2018:** HLT_Photon200_v*;

- **MET:**
  - undetectable particles, **neutrinos** mostly known;
  - Violation of the momentun conservation;
  - Higher trigger efficiency (MC study);
  - **Conjecture:**
    - one monopole is lost due to the trigger;
    - large MET contribution.

MET Triggers Approach

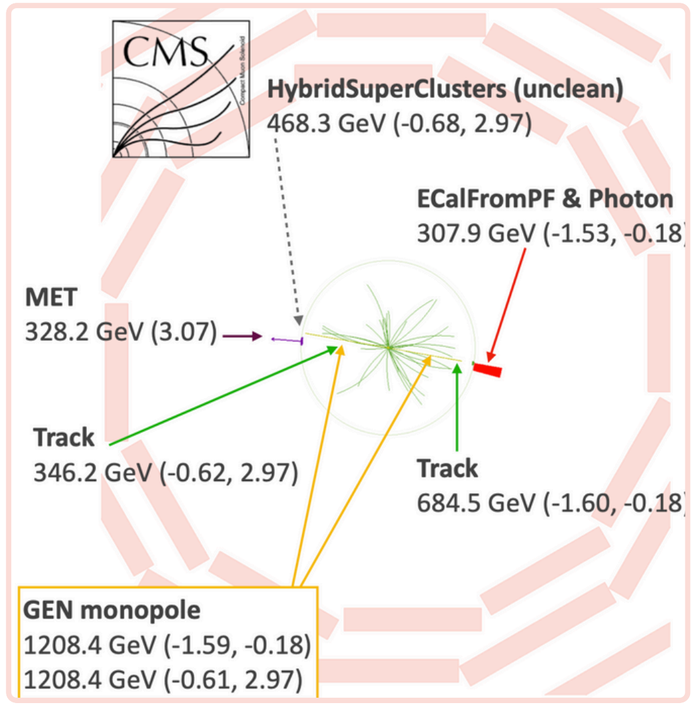
- **Monopole @ (MET) Triggers:**
  - **spike-like** signature in the ECAL;
  - **L1 and HLT:** implementation of spike filters;
    - rejection of the monopole signals;
  - **High MET** signature in the event.



- **MET trigger paths:**
  - **CaloMET:** pT from Calo Towers; **lower efficiency**;
  - **PFMET: pT from Particle Flow reconstruction.**

- **Particle Flow MET trigger:**
  - **Monopoles:** PF and fakePF candidates;
  - **Efficiency calculation:** two matches
    - RECO and GEN; PF and matched.

- **New analysis strategy:**
  - triggered photons and unclean clusters (simulation);
  - MET-related systematic uncertainties.

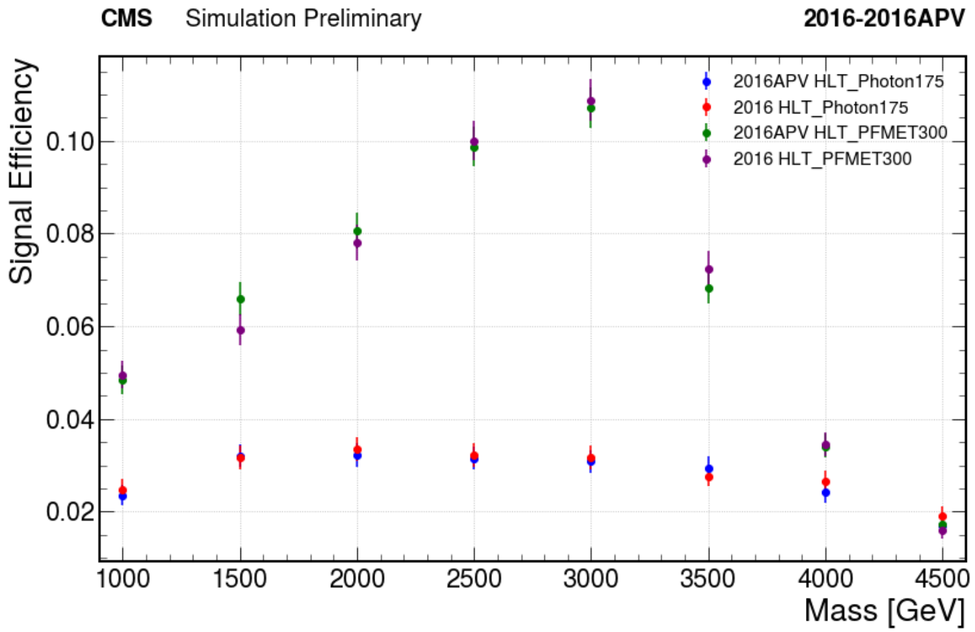


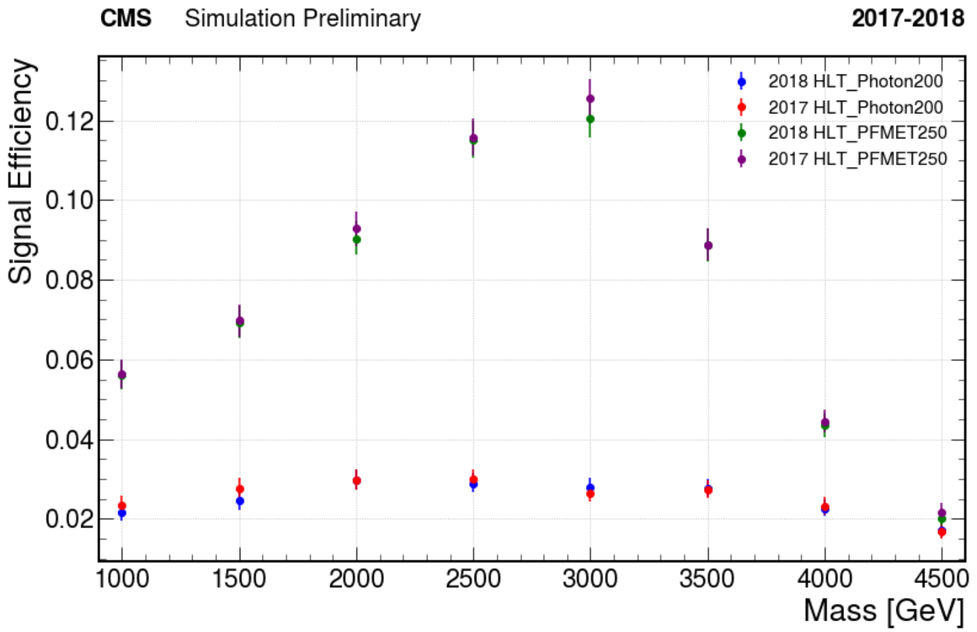
Signal Efficiency

- **Motivation:** Evaluate the fraction of events that passes through a set of requirements;

$$\epsilon_{\text{sig}} = \frac{\text{no. of events after selection}}{\text{no. of total events}}$$

- **HLT_Photon:** one photon detection.
- **HLT_PFMET:** reconstruction as a Particle Flow object.



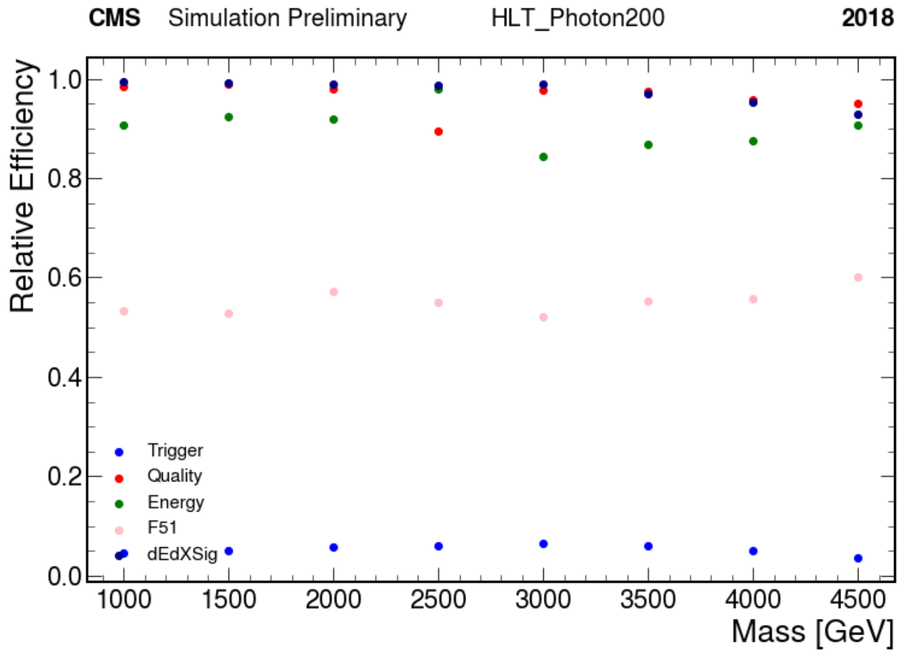


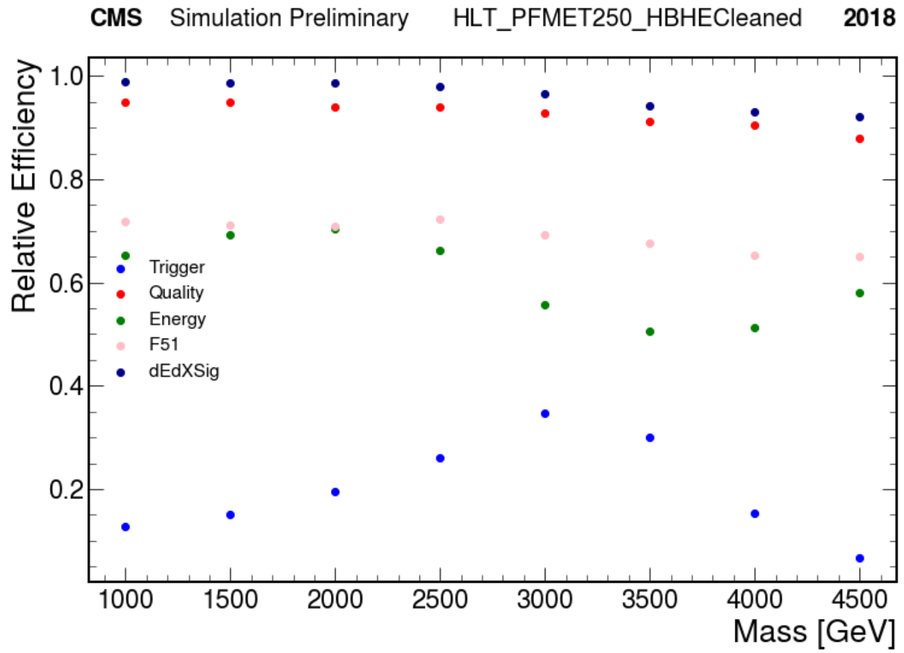
- **Significant** higher signal efficiency for PFMET trigger paths:
- Peak values at **2000-3500 GeV** and no improve at 4500 GeV.

Relative Efficiency for Different Triggers

- **Motivation:** Evaluate the efficiency of each step of the analysis cuts, relative to the previous;

$$\epsilon_{rel} = \frac{number\ of\ events\ after\ selections}{number\ of\ events\ of\ the\ previous\ selection}$$

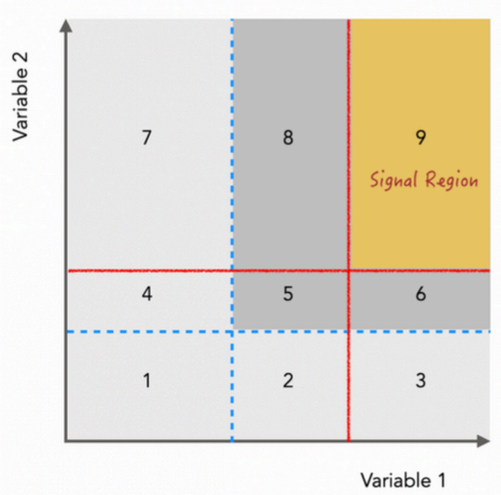




- Relative efficient monopole identification;
- **Trigger** as the main source of **inneficiency** in the analysis;
- Higher overall relative efficiency for F51 cut for the PFMET250.

Background Estimation

- **(Double-)ABCD Method:** 1 Signal (SR), 3 Cross-check (CR), 5 background dominated regions.



2016:

$$0 \leq f_{51} \leq 0.6, \quad 0.6 < f_{51} \leq 0.85, \quad 0.85 < f_{51} \leq 1$$
$$0 \leq dE/dx_{sig} \leq 7, \quad 7 < dE/dx_{sig} \leq 9, \quad 9 < dE/dx_{sig} \leq \infty$$

2017 and 2018:

$$0 \leq f_{51} \leq 0.75, \quad 0.75 \leq f_{51} \leq 0.85, \quad 0.85 \leq f_{51} \leq 1$$
$$0 \leq dE/dx_{sig} \leq 7, \quad 7 \leq dE/dx_{sig} \leq 9, \quad 9 \leq dE/dx_{sig} \leq \infty$$

$\text{sig}_{dE/dx}$

7	8	9
4	5	6
1	2	3

f_{51}

- Regions 5,6,8 and 9 are blinded first;
- Expected background calculation:
  - **CR:** obtained with 1,2,3,4 and 7.
  - **SR:** CR + background regions.
- Unblind of the Signal Region.
  - Number of **observed** and expected background.

7	8	9
4	5	6
1	2	3

7	8	9
4	5	6
1	2	3

7	8	9
4	5	6
1	2	3

Systematic Uncertainties

- Related to nature of the measurement apparatus, assumptions made by the experimenter, or the **model** used to make inferences based on the **observed data**.

MC

- **Delta-Ray production: (9-20% for each mass point)**
  - additional energy loss component;
  - affects measurements of dE/dX and shower shapes;
- **ECal-spike algorithm: (1% from MC 2018)**
  - effects of the offline spike algorithm on the monople signal;
  - (un)clean cluster collections, broad energy (E5x5) spectrum;
  - E55 cut higher than threshold for ECAL noise rejection;

Data

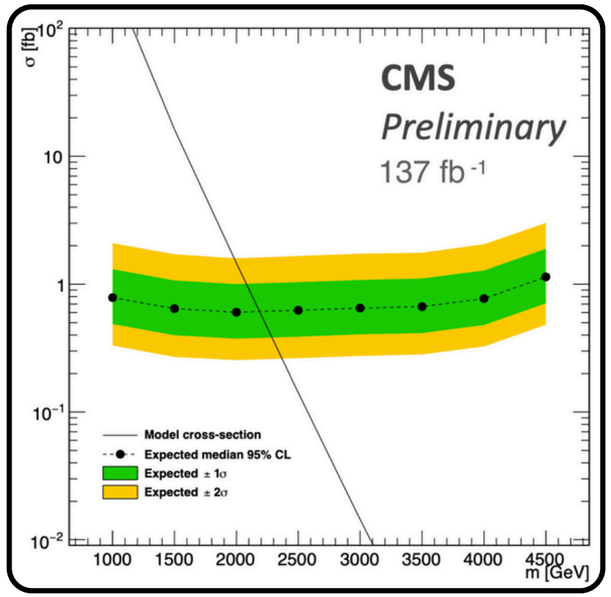
- **Data-driven background estimation: (conservative 99%)**
  - varying range of loose cuts, not strong dependency;
- **Luminosity** from LUM POG official numbers;
  - **2016: 2,6%**; **2017: 2.3%** and **2018: 2.5%** overall uncertainty.
- **Tracker - dE/dX cross-talk: (0.10%)**
  - Electronic cross-talk between central strip and its neighbours
  - Change of 10% in the main strip cross-talk parameter.

- Inclusion of the MET-related systematic uncertainties.

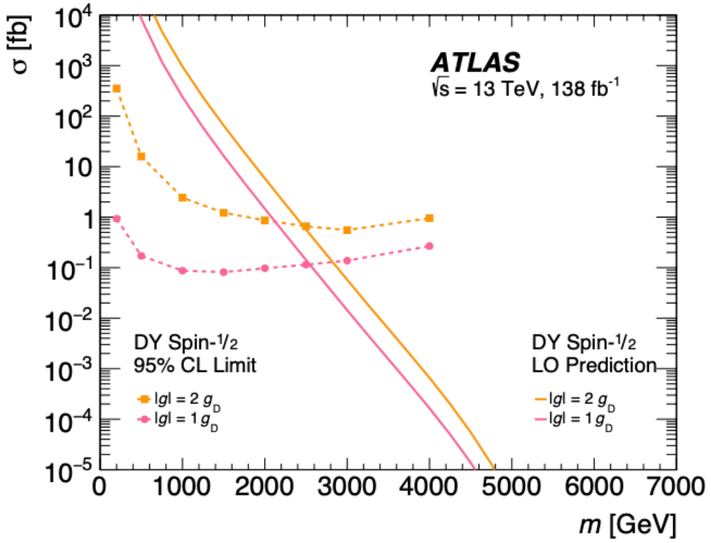
Preliminary Limits

[2] 2308.04835
[3] 1903.08491

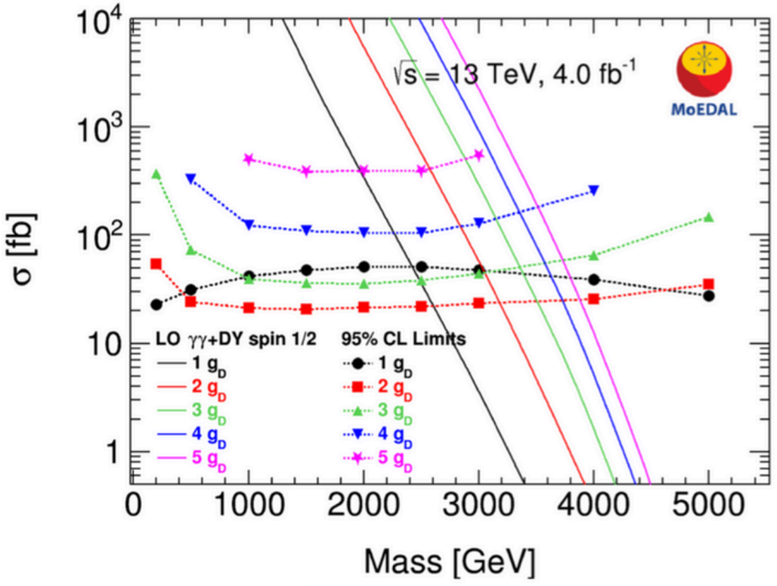
- **Experiment sensitivity:** terms of the cross-section upper limit;
- **Expected** 95% CL **upper limits** on the production cross-section for Drell-Yan spin-1/2.
  - investigation of the monopole mass range occurence.



- **SinglePhoton:** 2320 GeV
- **MET:** 2480 GeV.
- Newer results soon!



- **ATLAS:**
- dedicated trigger;
- First limits on HECO production for Run 2 [2];



- **MoEDAL:** [3]
  - dedicated experiment;

Process / coupling	Spin	Magnetic charge [g_D] 1	2	3	4	5
		95% C.L. mass limits [GeV]				
DY	1/2	1320	1730	1770	1640	–

Conclusions and Perspectives

- The **MET trigger** approach:
  - provide a better description of the process(?) with a higher trigger efficiency;
  - signficant improvement of the signal and relative efficiencies;
  - increase in mass liimit and in the CMS sensitivity;
  - similar to ATLAS results.

- The inclusion of the Photon-Fusion process to the further improvement in the sensitvity due to its higher cross-section;

- **Completion of the MET Analysis Strategy:**
  - Skimmed Data with MET;
  - The inclusion of the MET-related systematic uncertainties.

- Further exploration of lower thresholds MET trigger paths.