THE SEARCH OF MAGNETIC MONOPOLES IN THE CMS EXPERIMENT

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In behalf of the CMS Collaboration

Theoretical Motivation and Search Strategy

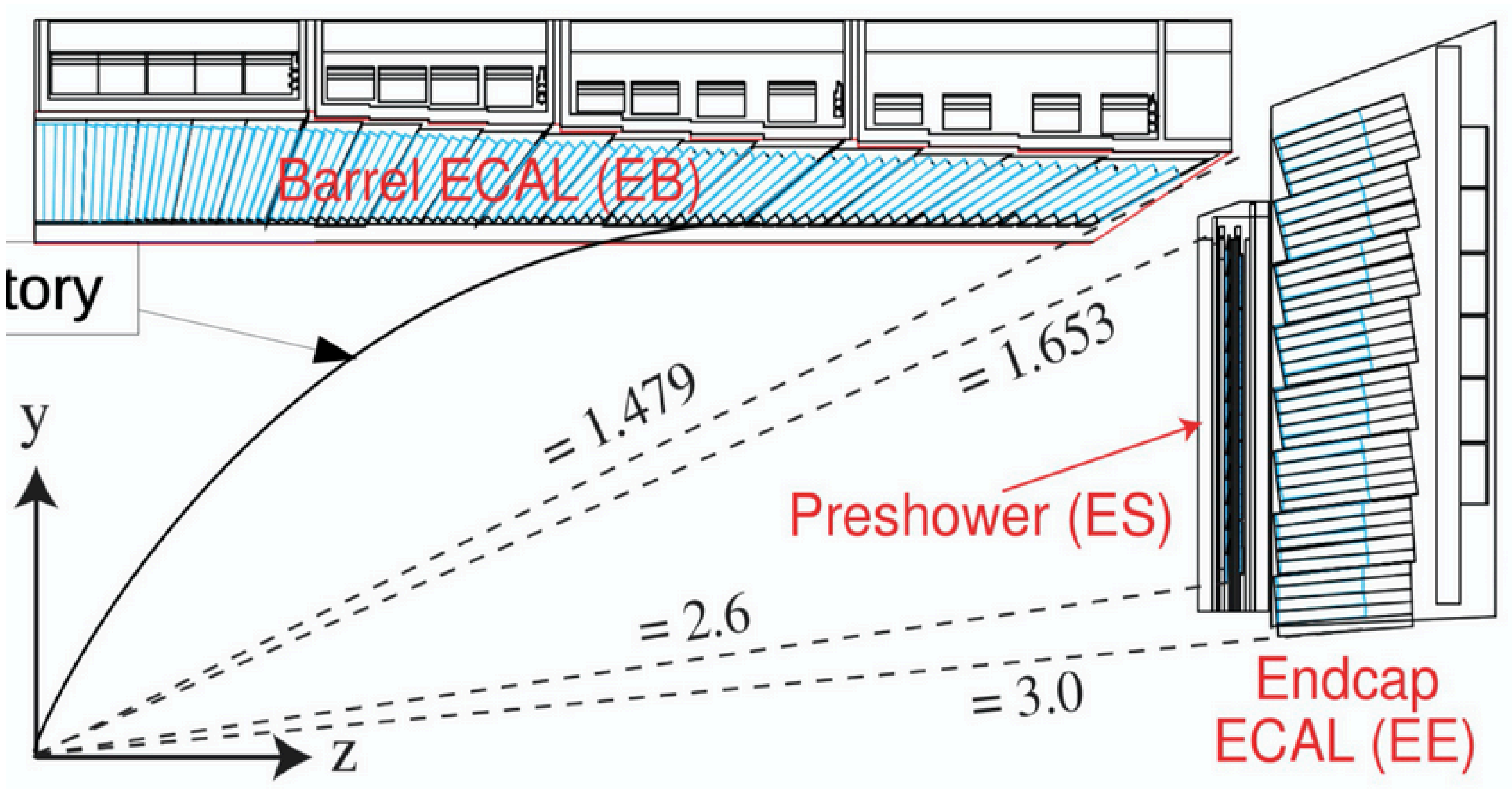
- **Proposition:** complete the electromagnetic duality;
- **Dirac:** presence of a monopole, quantisation of the electric charge and angular momentum;

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

(Dirac's quantisation)

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

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

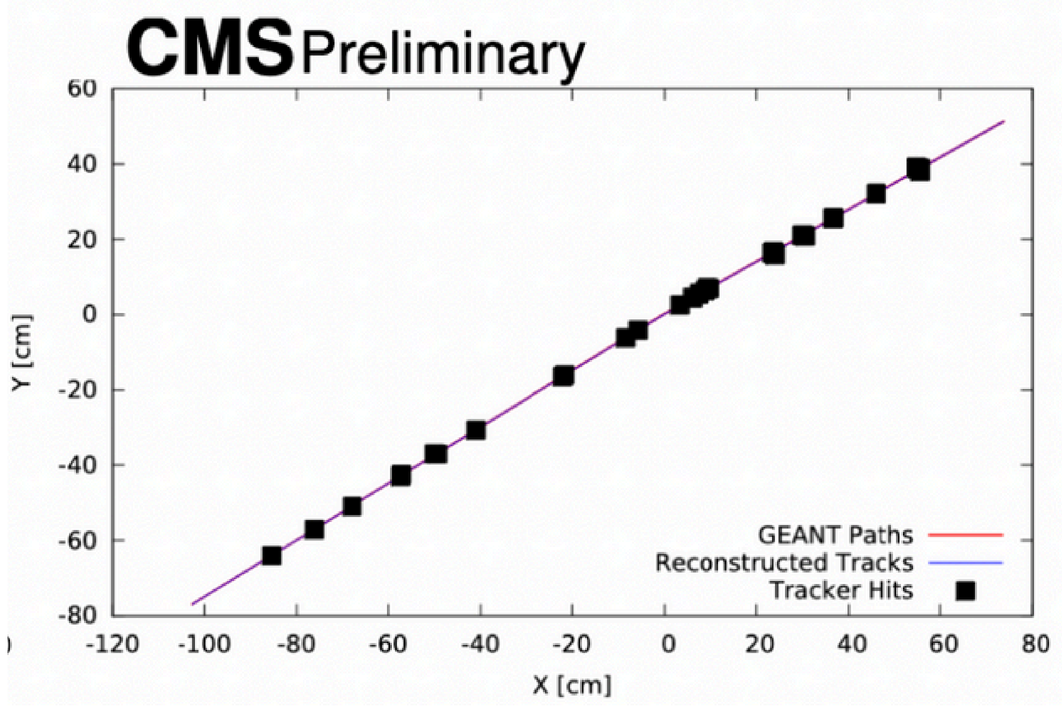


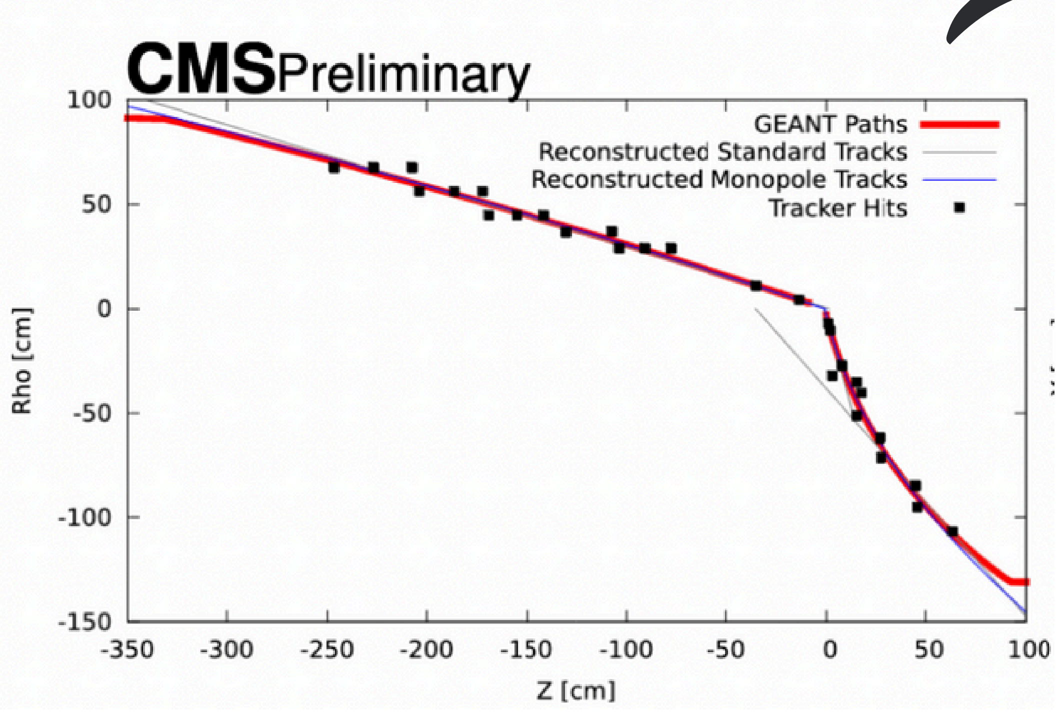
- **Monopoles @ Colliders:**
  - pair production and highly ionising particles;
  - few TeV, acessible in the LHC.
- **Monopole Identification:** combination of tracks and ECAL deposits:
  - **High ionization capacity:** large number of saturated strips,
  - **Energy deposition:** narrow and concentrated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





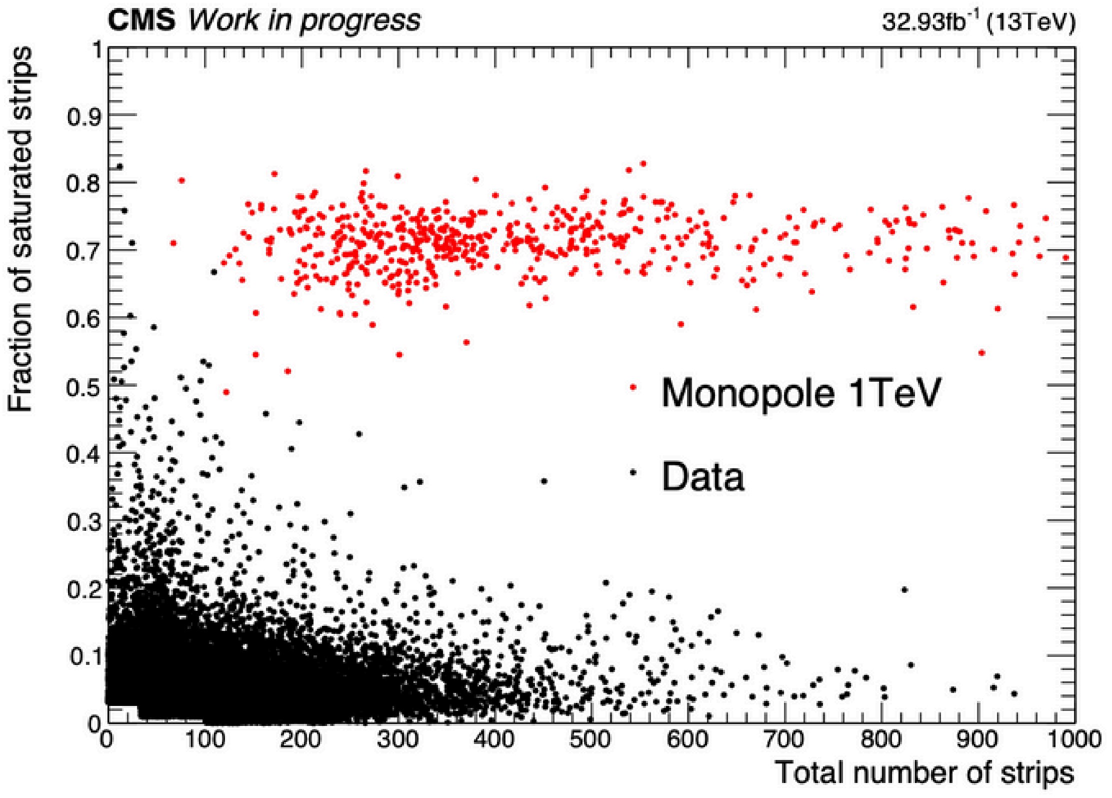
- **Preselection parameters.**

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

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

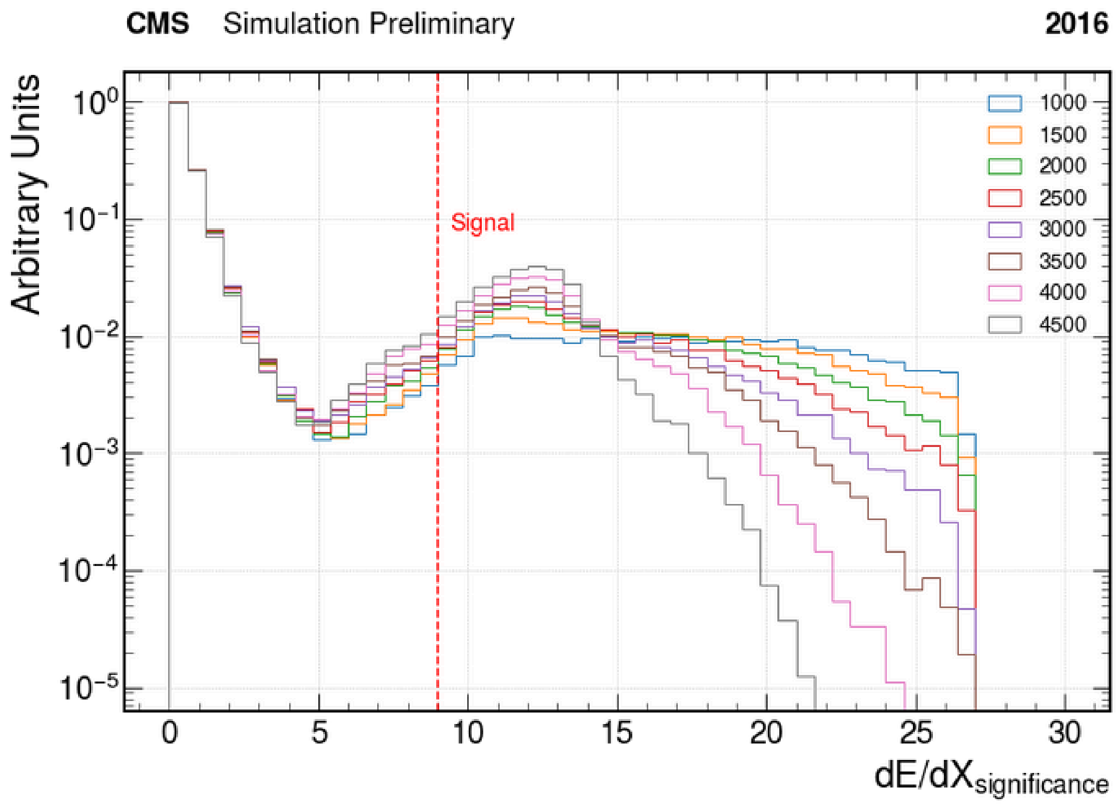
- **Combination** of standard track segments to form the monopole curved track.
- **Two fits** at the combined tracks:
  - **Circular Fit in the XY-plane:** (possible) electrical charged monopoles;
  - **Parabola in the pZ-plane:** account for the curvature.

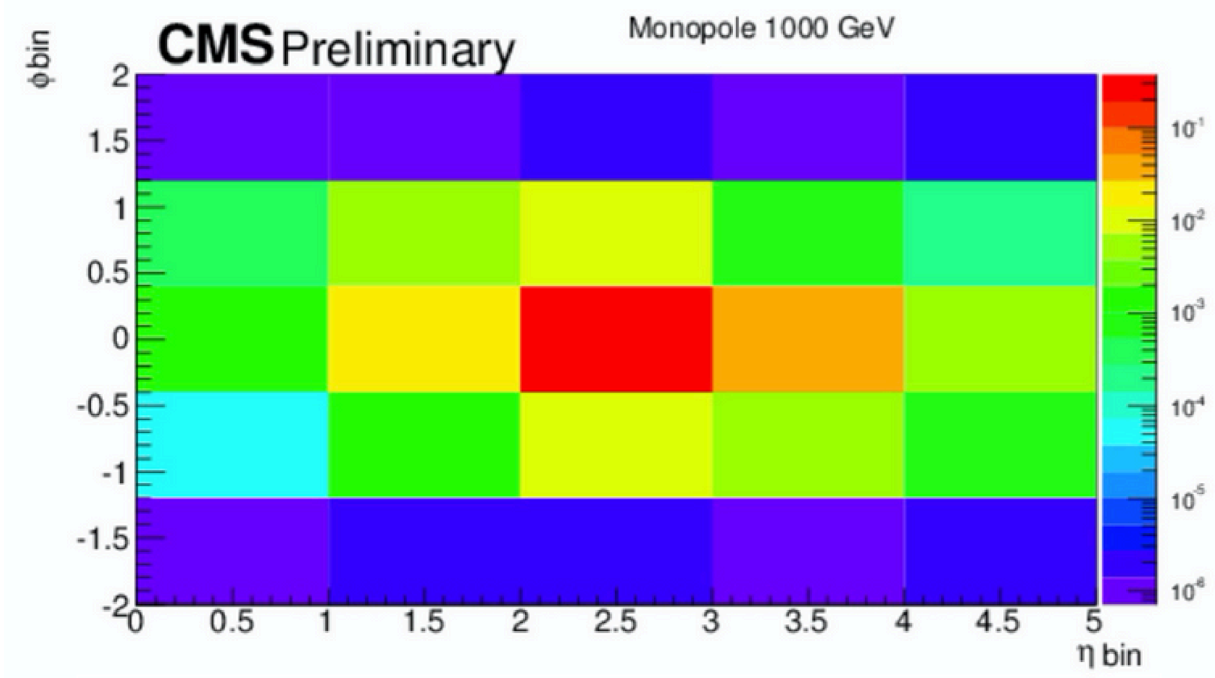
Monopole Identification



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

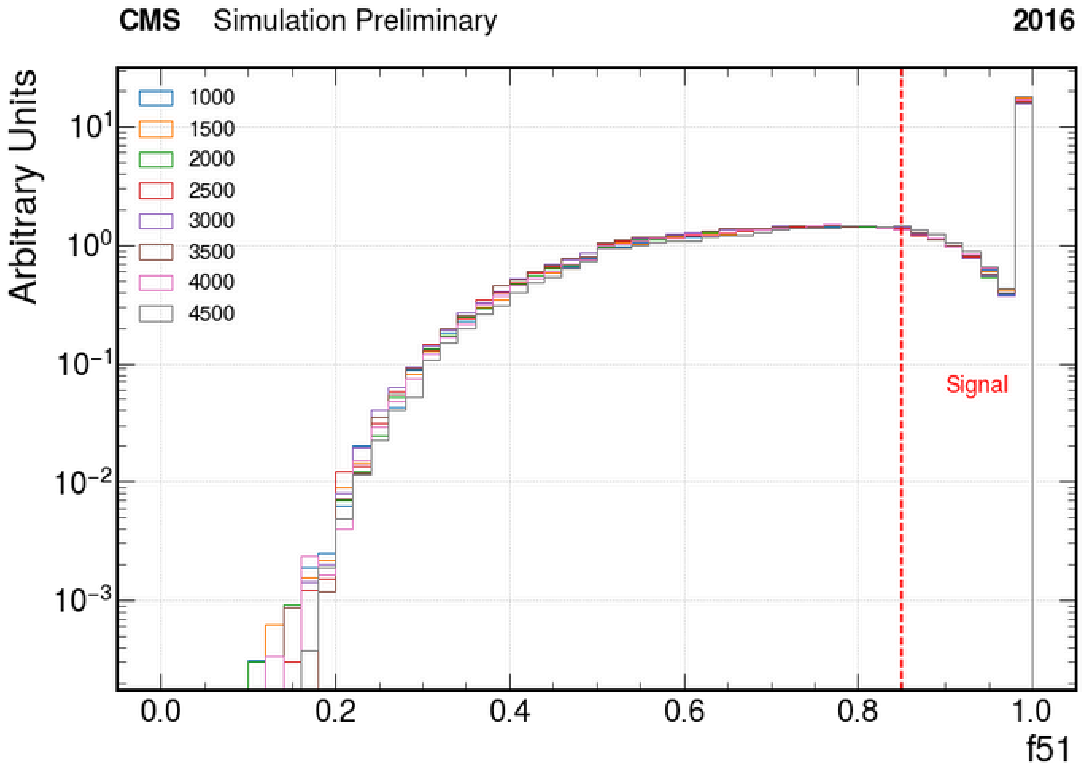
$$\sqrt{-\log(\text{BinomialI}(0.07, \text{TotalStrips}, \text{SaturatedStrips}))}$$





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

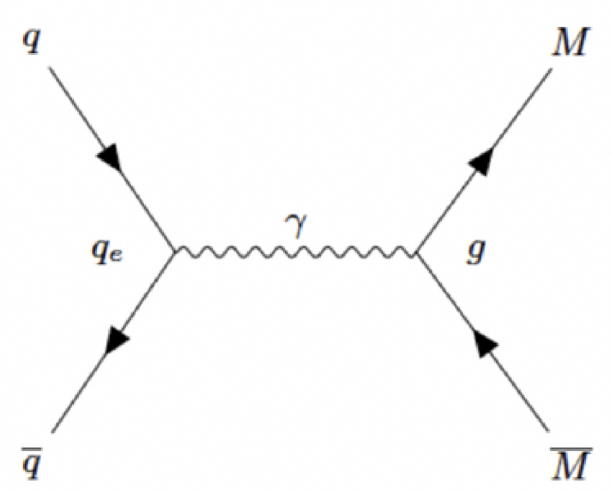
$$f_{51} = \frac{E_{5\times1}}{E_{5\times5}} \qquad f_{15} = \frac{E_{1\times5}}{E_{5\times5}}$$



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

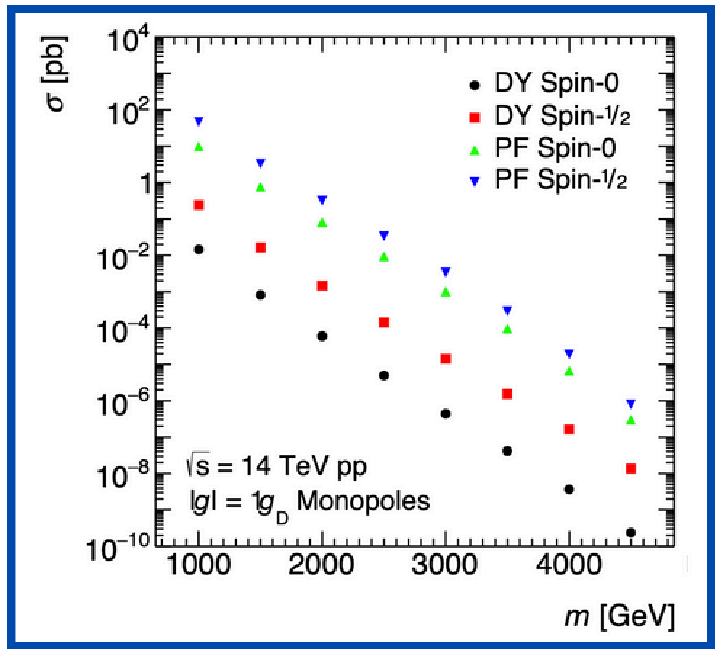
Monopole Search: Triggers and Datasets

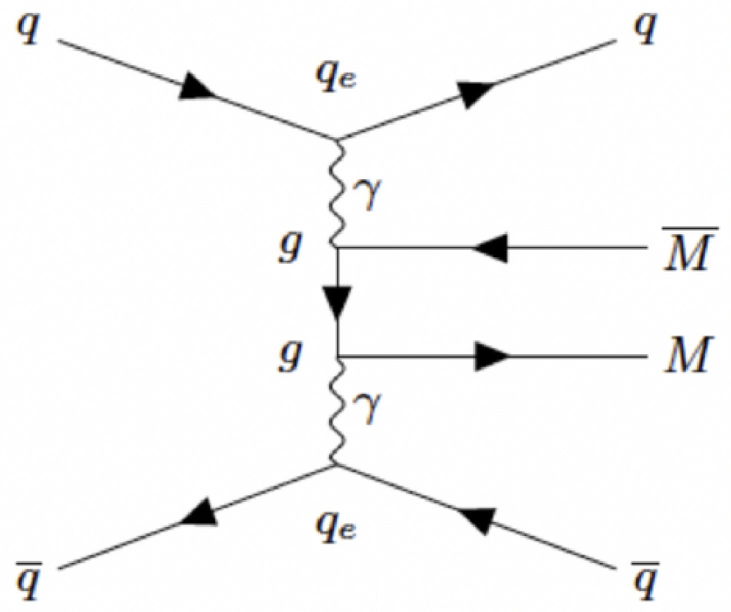
- DY and PF as **benchmarks** for HIP production;



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)	$\pm$ 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.

Background, Uncertainties and Limits

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

$sig_{dE/dx}$			
	7	8	9
	4	5	6
	1	2	3
	f_{51}		

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

$$N_6 = \frac{N_3 \times N_4}{N_1}, \quad N_8 = \frac{N_2 \times N_7}{N_1}$$

$$N_9 = \frac{(N_3 + N_6)(N_7 + N_8)}{(N_1 + N_2 + N_4 + N_5)}$$

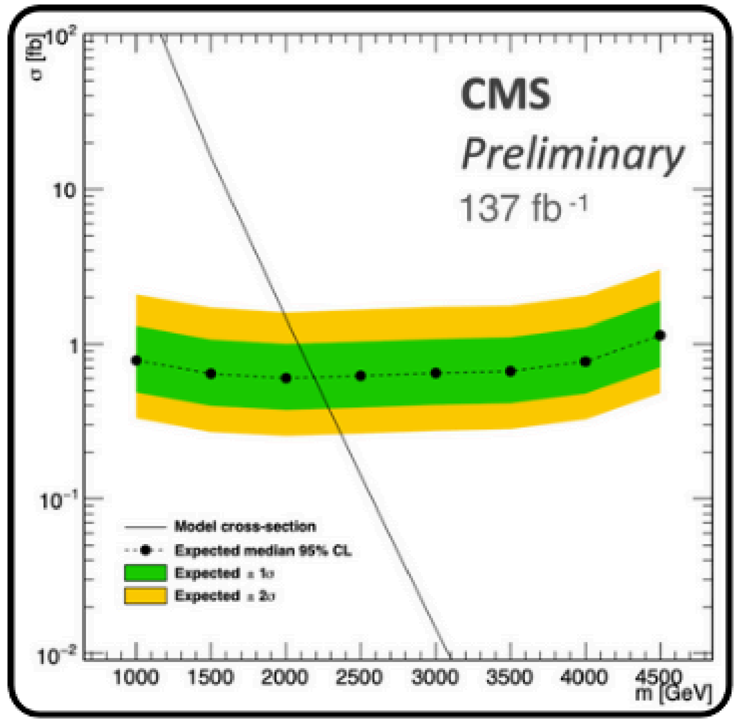
- Regions 5,6,8 and 9 are blinded;

- Absence of background MC;
- Expected background calculation:
  - **CR and SR**
- Unblind of the Signal Region.

Systematic Uncertainties

- **Delta-Ray production: (9-20% for each mass point)**
  - additional energy loss component;
  - affects measurements in the Tracking (dE/dX) and shower shapes
- **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.

95% CL Upper limits on the production cross-section



- Experiment sensitivity;
- Mass range;
- **Photon:** 2320 GeV
- **MET:** 2480 GeV.
- Newer results soon!