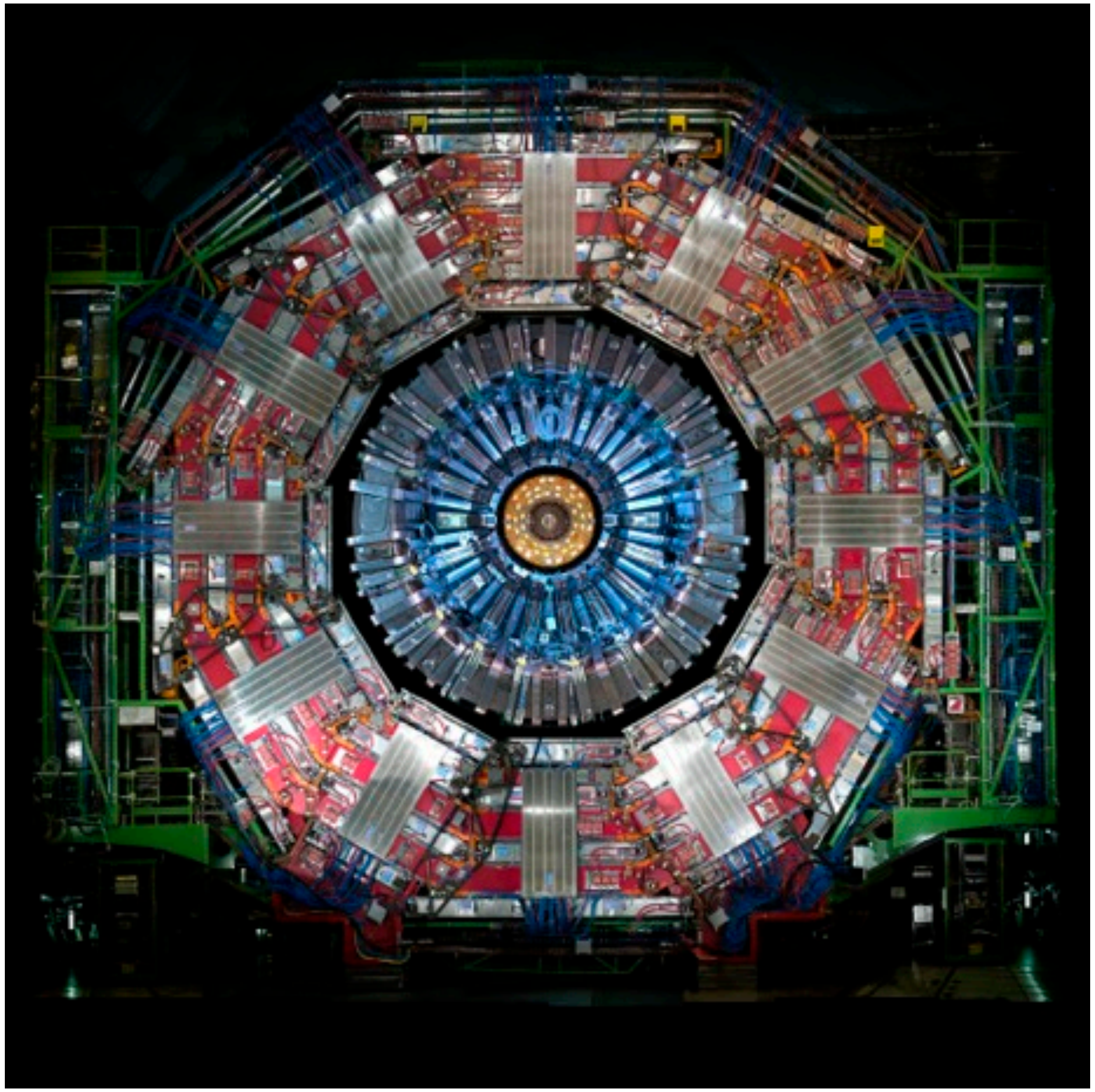
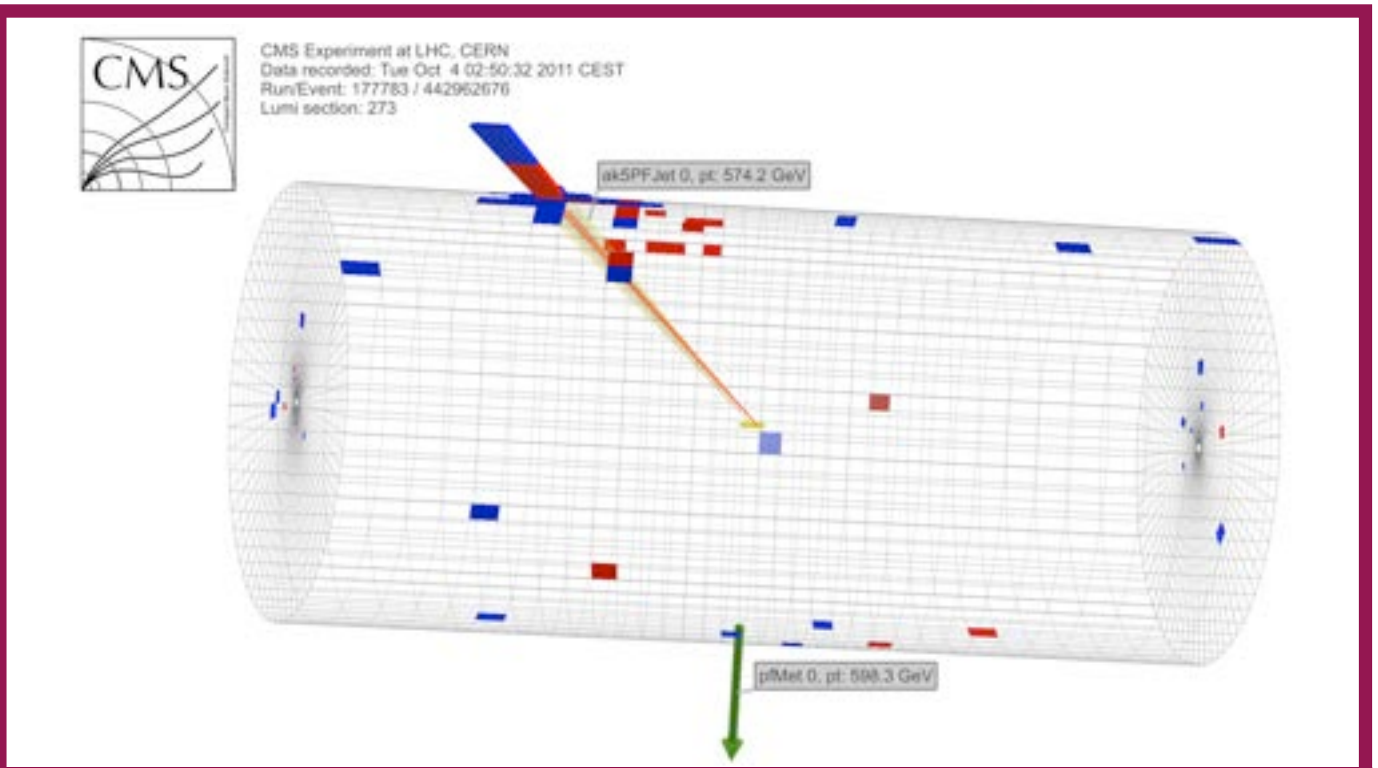
Search for Dark Matter at the CMS Experiment



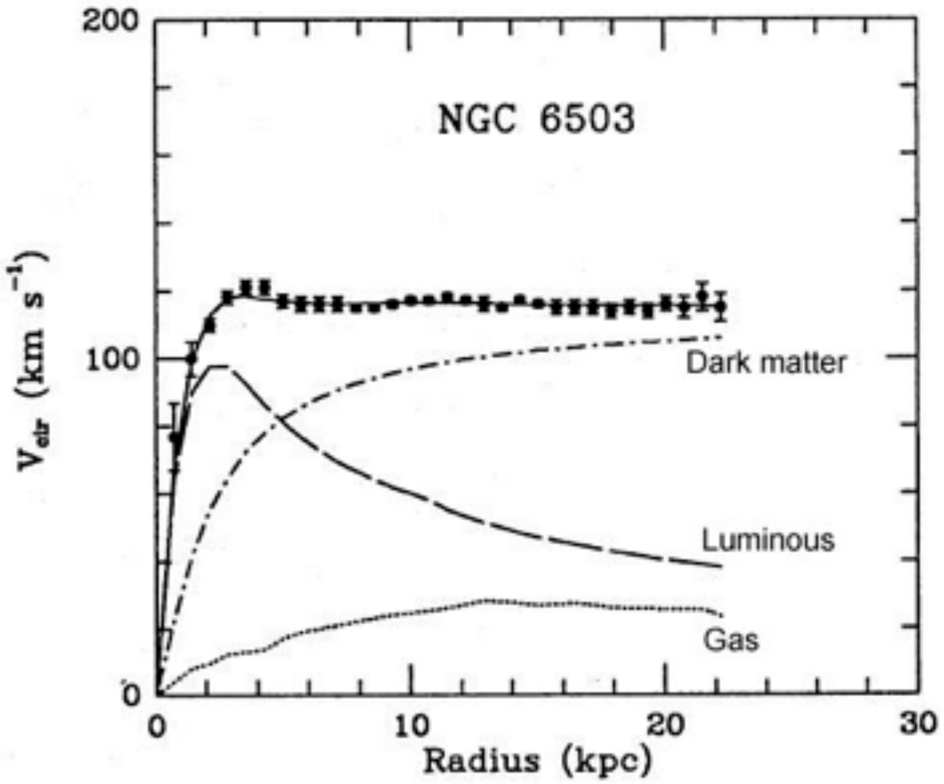


Norraphat SRIMANOBHAS (Chulalongkorn U., Thailand)
on behalf of the CMS Collaboration

DARK2012: Dark Forces at Accelerators
The Istituto Nazionale di Fisica Nucleare (INFN)
laboratory of Frascati, Frascati, Lazio, ITALY

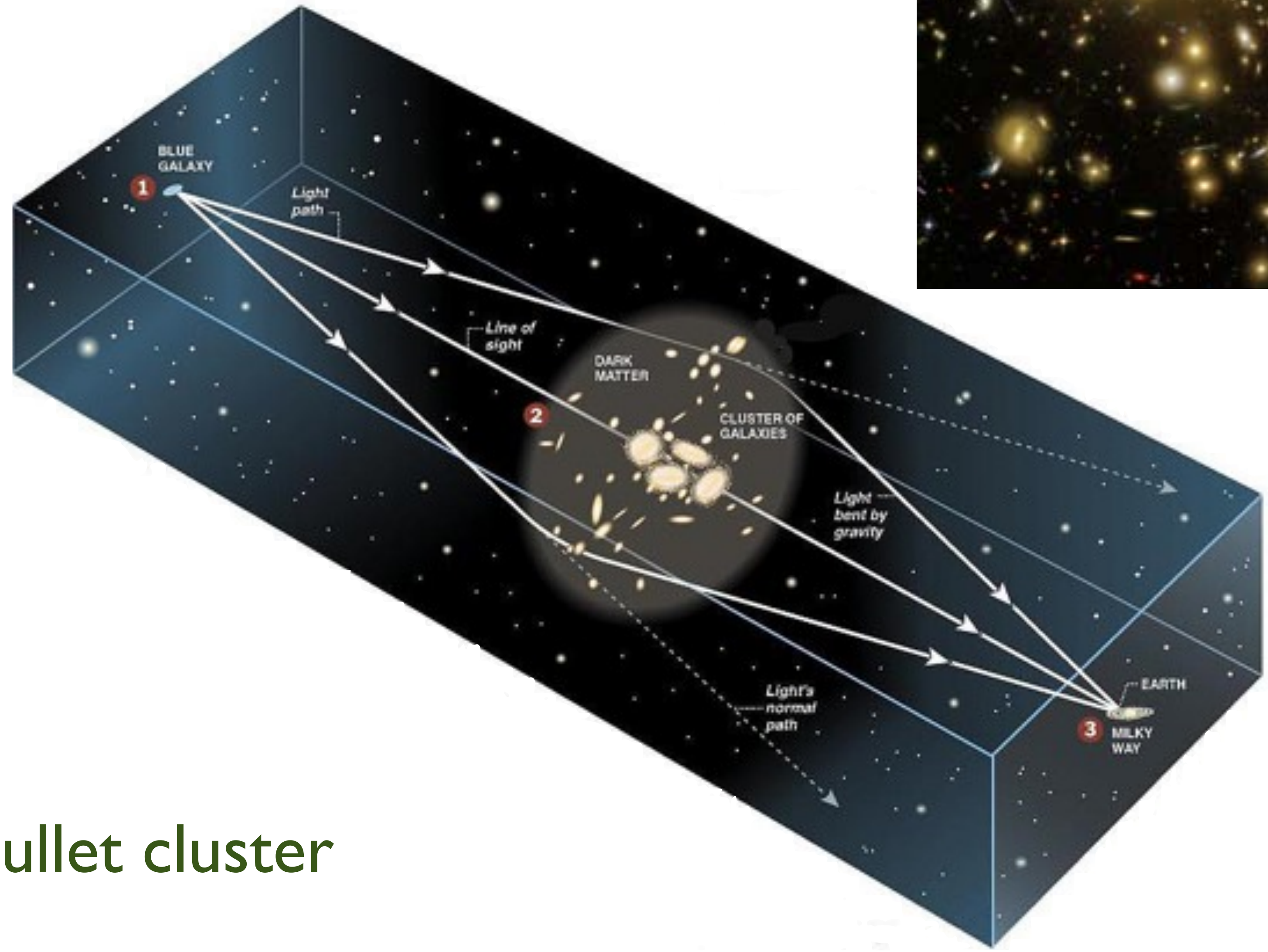
Search for Dark Matter

Strong evidences for the existence of dark matter, i.e. :



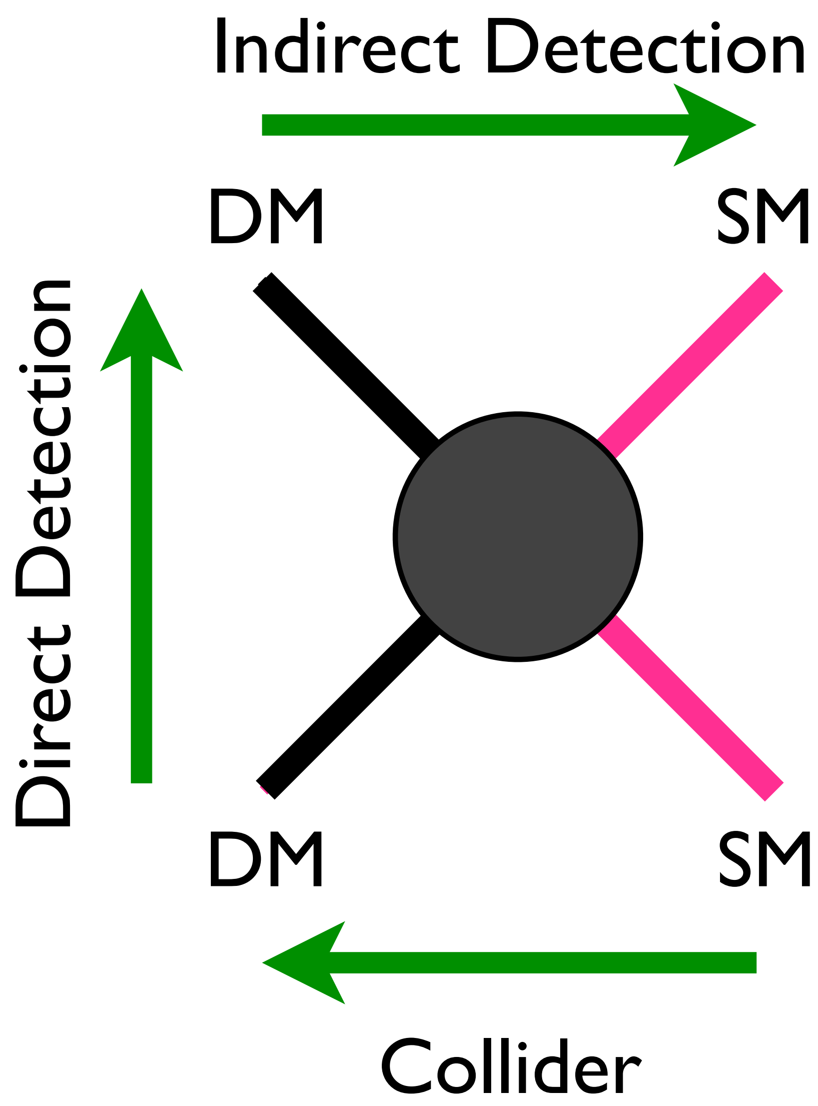
Galactic rotation curves

Strong Gravitational Lensing



Bullet cluster

Search for Dark Matter



[1. Direct Detection Experiments]

- Dark Matter-nucleus scattering.
- Low mass DM particles not probed yet.
- Less sensitive to spin-dependent coupling.
- XENON-100, CDMS, CoGeNT

2. Indirect Detection Experiments

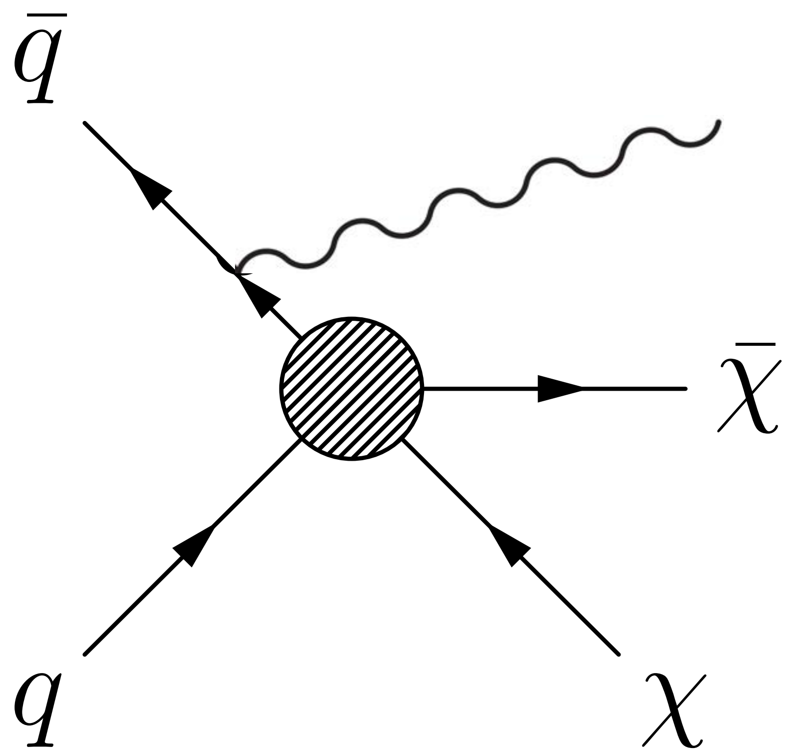
- Observe annihilation products.
- Low mass DM particles not accessible.
- Depends on DM density and annihilation model.
- Super-Kamiokande, IceCube

3. Collider Experiments

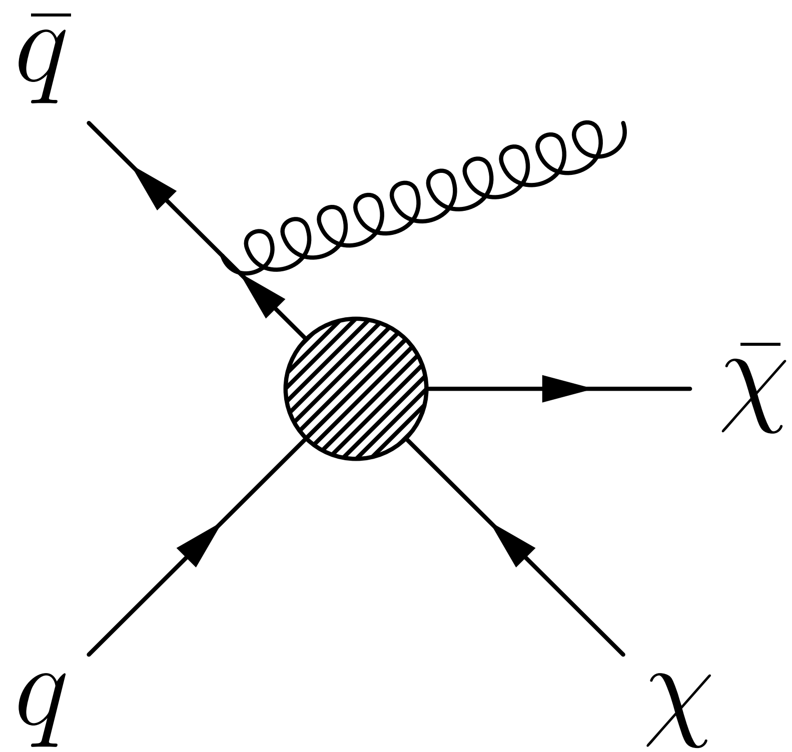
- Laboratory production of DM particles.
- Sensitive to huge mass range.
- Both spin-dependent and spin-independent couplings.
- Tevatron, LHC

Needs independent verifications from various astrophysical and non-astrophysical experiments.

Search for Dark Matter at the Collider



Monophoton + MET

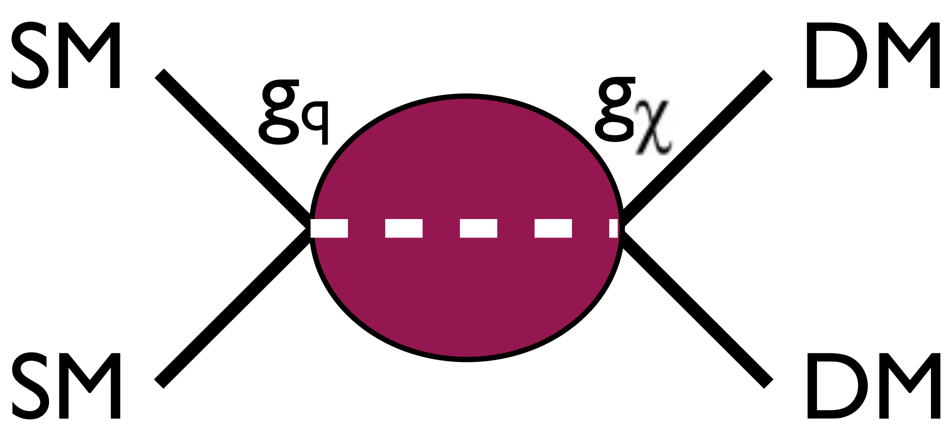


Monojet + MET

Signal Characteristics

- Missing transverse energy (MET) results from the Dark Matter production.
  - ✻ Vector sum of all reconstructed particles (Particle Flow method)
- Photons or jets can be radiated from quarks.
- Trigger on a single photon or a single jet with the large missing transverse energy.

Search for Dark Matter at the Collider



[Bai, Fox and Harnik, JHEP 1012:048 (2010)]

[Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu, Phys.Rev.D82:116010 (2010)]

Cross section depends on the mass of DM, and the scale Λ,

$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4}$$

$$\sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4}$$

where $\mu = \dfrac{m_\chi m_p}{m_\chi + m_p}$

Assumtions:

- DM particle is only new state accessible to the collider.
- Mediator is heavy, and can be integrated out.

$$\Lambda = M/\sqrt{g_\chi g_q}$$

- Contact ınteractıon.

For vector mediator (Spin-Independent):

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

For axial- vector mediator (Spin-Dependent):

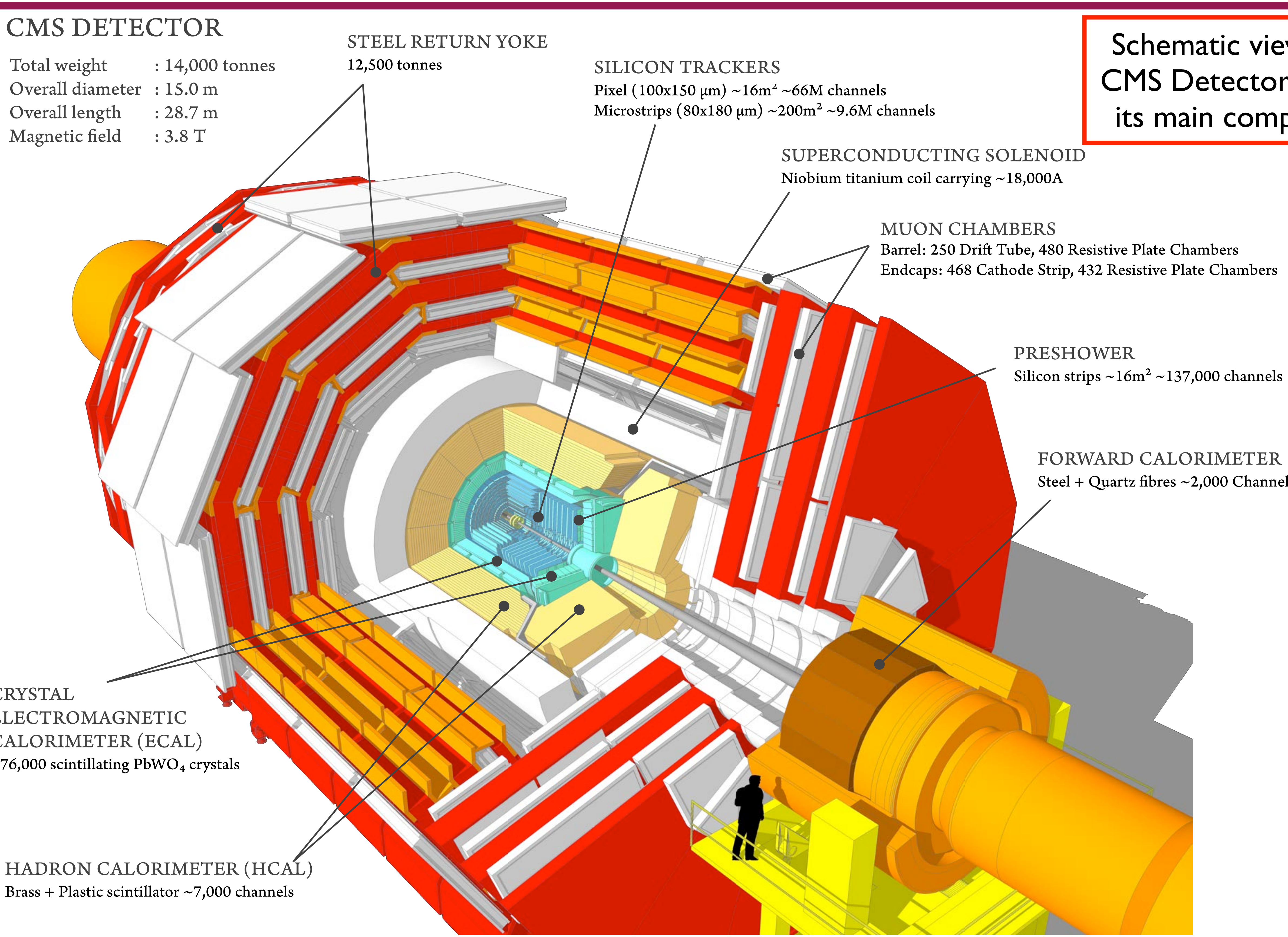
$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

Signal Generator:

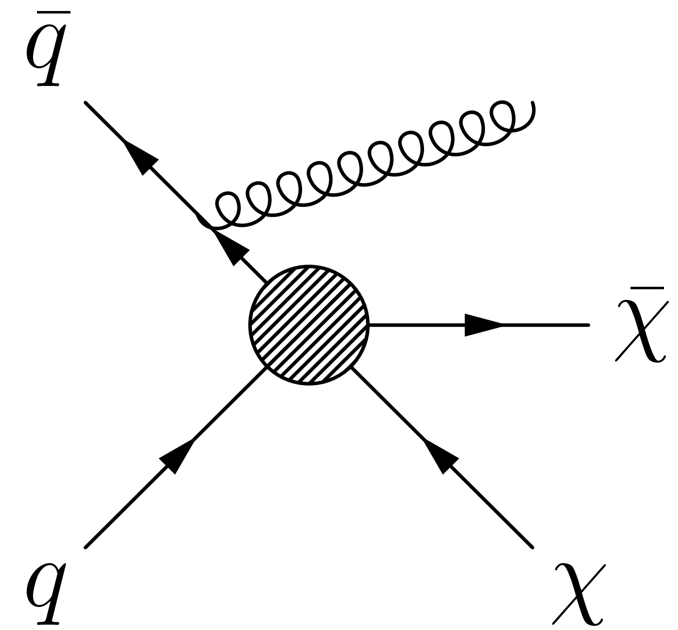
Madgraph4 + Pythia6.

Compact Muon Solenoid (CMS) Detector

Schematic view of the CMS Detector showing its main components.

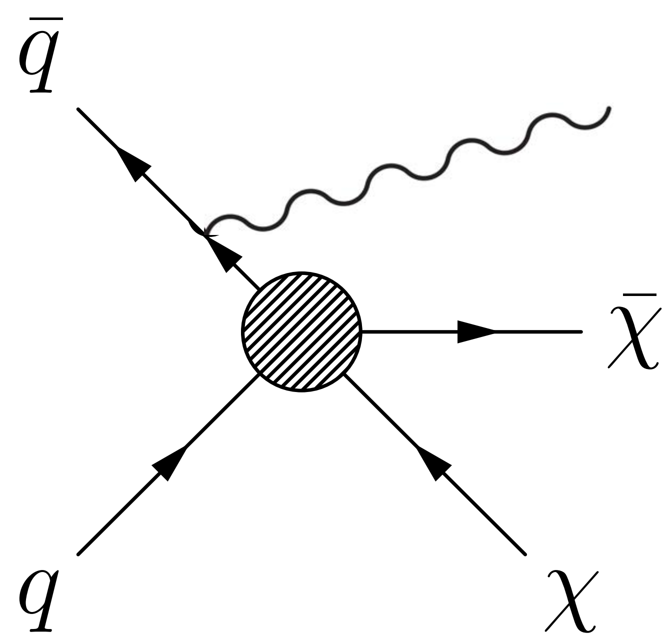


Triggers used for Dark Matter search at CMS



Monojet + MET

- Unprescaled jet+MET triggers.
- Fully efficient with $|\eta_{jet}| < 2.4$ and $P^{T}_{jet} > 110$ GeV/c.
- Fully efficient with MET > 200 GeV.



Monophoton + MET

- Unprescaled single-photon triggers.
- Fully efficient with $|\eta_{photon}| < 1.442$ and $P^{T}_{photon} > 145$ GeV/c.

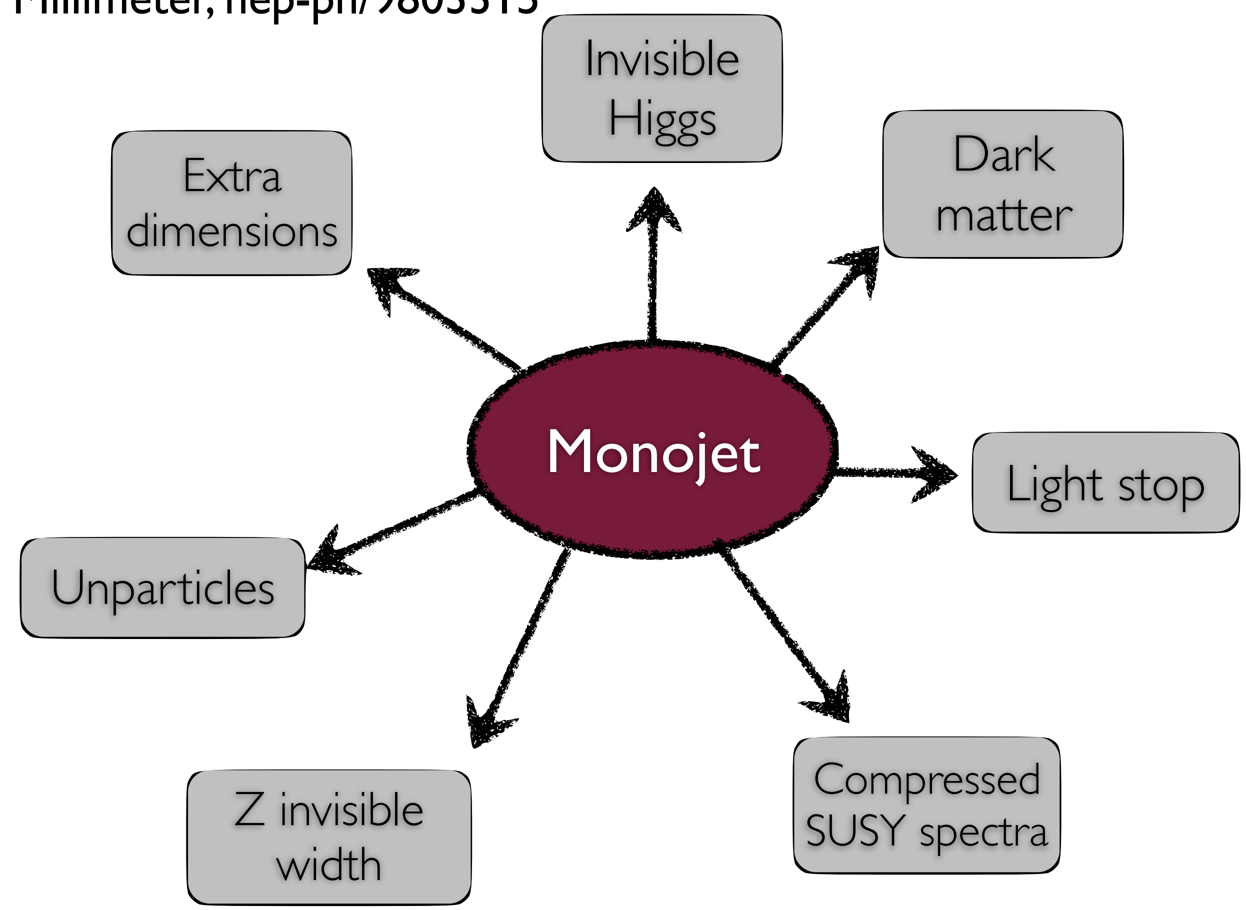
Monojet study at CMS

Extra Dimensions : The Hierarchy Problem and New Dimensions at a Millimeter, hep-ph/9803315

Unparticles : Unparticle Physics, hep-ph/0703260

Dark Matter

Missing Energy Signatures of Dark Matter at the LHC, 1109.4398
Taking a Razor to Dark Matter Parameter Space at the LHC, 1203.1662
Inelastic Dark Matter at the LHC, 1109.4144
Constraints on Light Majorana Dark Matter from Colliders, 1005.1286
Constraints on Dark Matter from Colliders, 1008.1783
LHC Bounds on Interactions of Dark Matter, 1108.1196
LHC Bounds on UV-Complete Models of Dark Matter, 1111.2359
Light dark matter and Z' dark force at colliders, 1202.2894
LHC and Tevatron bounds on the dark matter direct detection cross-section for vector mediators, 1204.3839



Light stop and compressed mass spectra

Light Stop Searches at the LHC with Monojet Events, 1201.5714
Light Stop Searches at the LHC in Events with two b-Jets and Missing Energy, 1011.5508
Light Stop Searches at the LHC in Events with One Hard Photon or Jet and Missing Energy, 0808.2298 Searching for Direct Stop Production in Hadronic Top Data at the LHC, 1205.5816
How low can SUSY go? Matching, monojets and compressed spectra, 1207.1613

Higgs

Direct detection of Higgs-portal dark matter at the LHC, 1205.3169
Reconstructing Higgs boson properties from the LHC and Tevatron data, 1203.4254

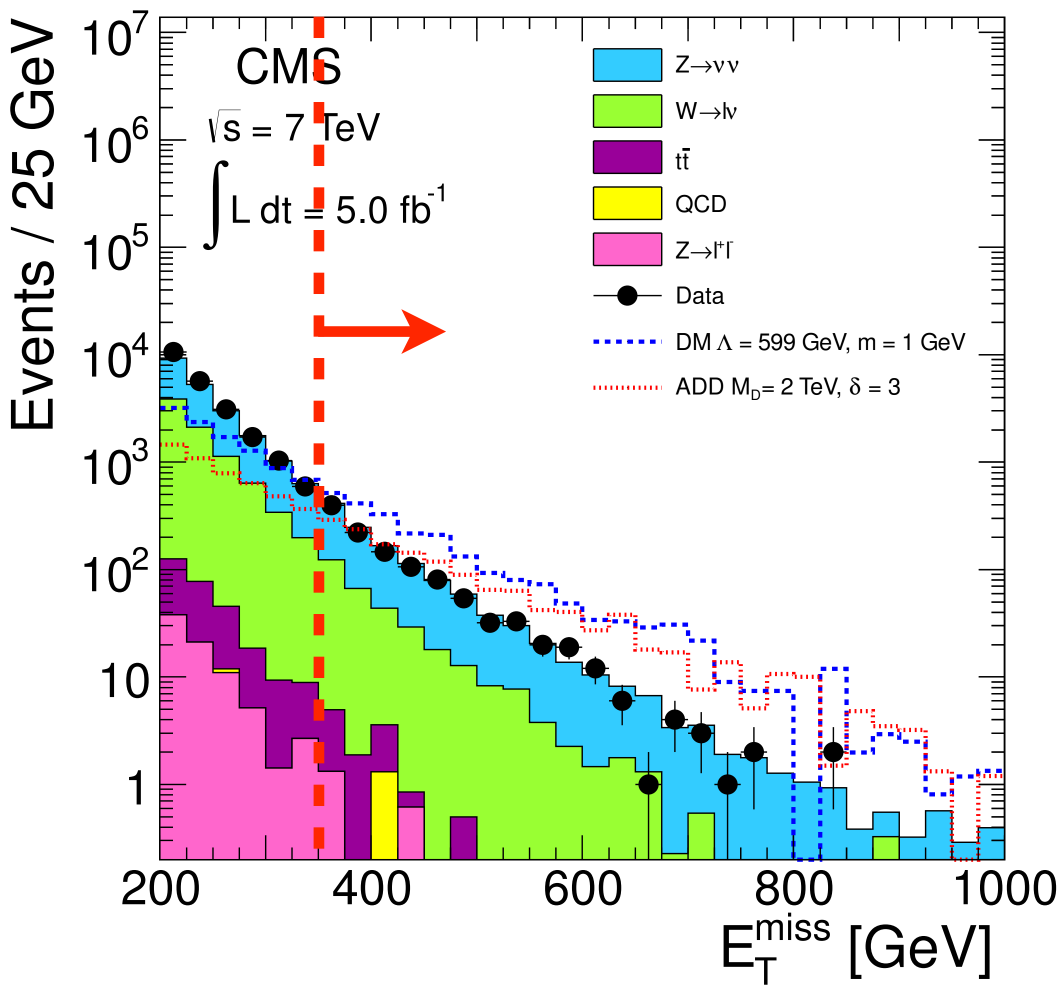
Other

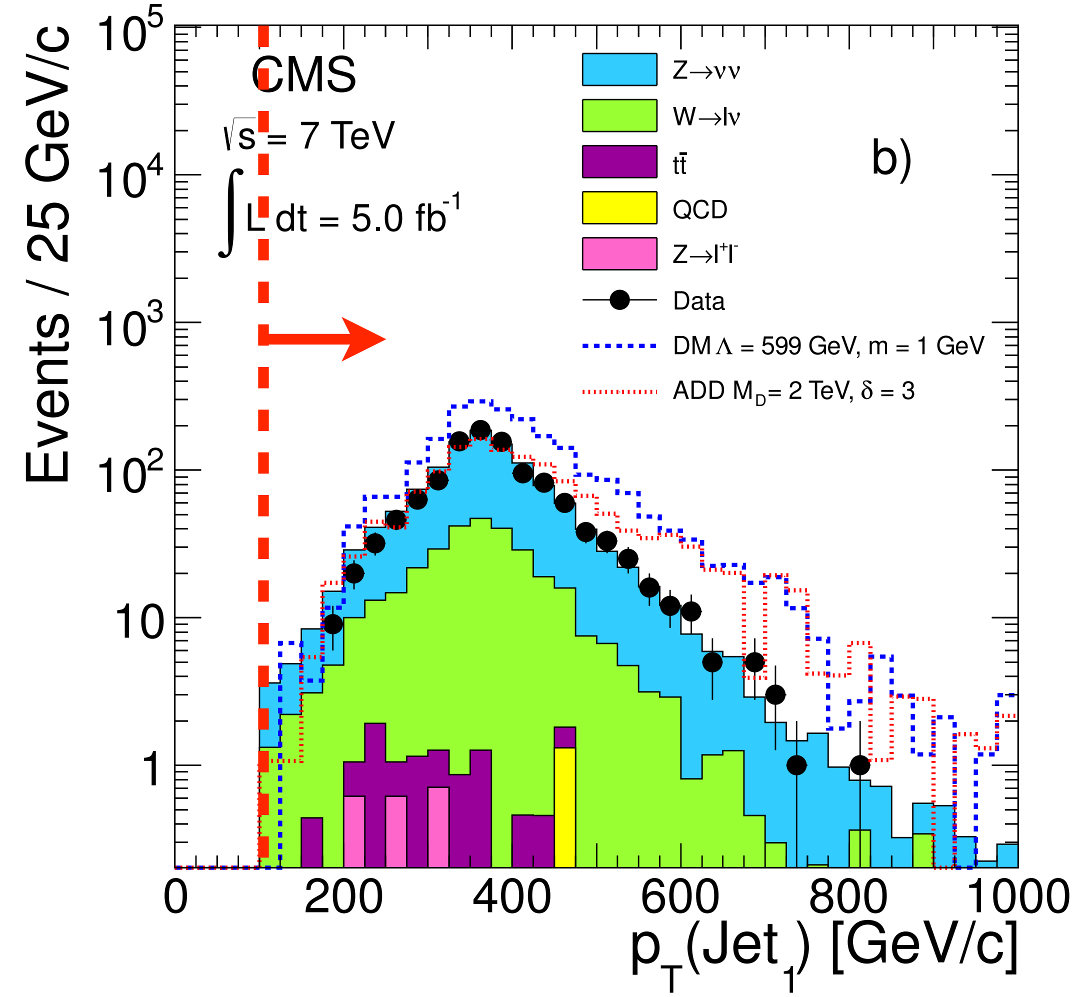
Searches for New Physics: Les Houches Recommendations for the Presentation of LHC Results, S. Kraml et al, 1203.2489
Supersymmetry production cross sections in pp collisions at sqrt(s) = 7 TeV, 1206.2892
Monotops at the LHC, 1106.619
Supersymmetric Monojets at the Large Hadron Collider, 1010.4261

Sarah Alam Malik

Search for Dark Matter in Monojet events

- Event Cleaning using cuts based on jet constituents.
- Large missing transverse energy, MET > 350 GeV.
- One energetic jet, p_T > 110 GeV/c, $|\eta|$ < 2.4.
- Allow one additional jet (if it has p_T>30 GeV/c).

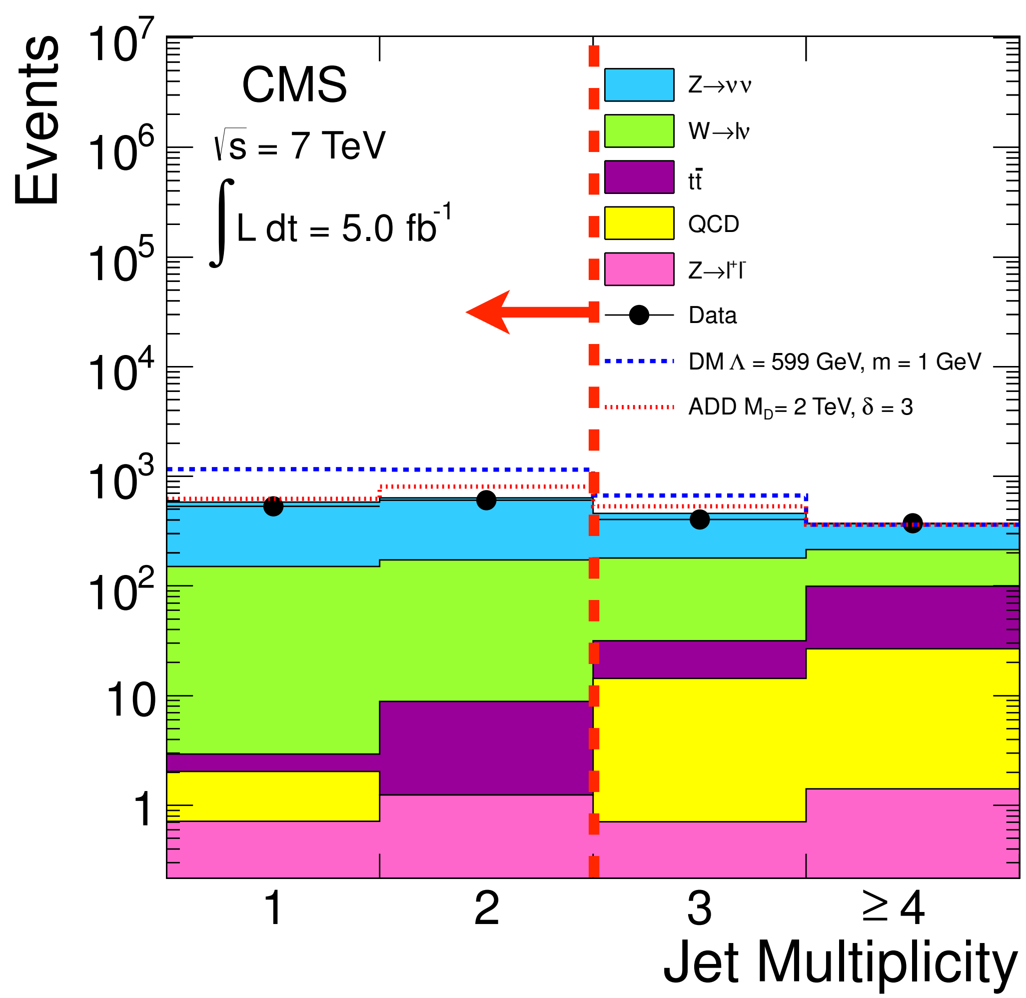


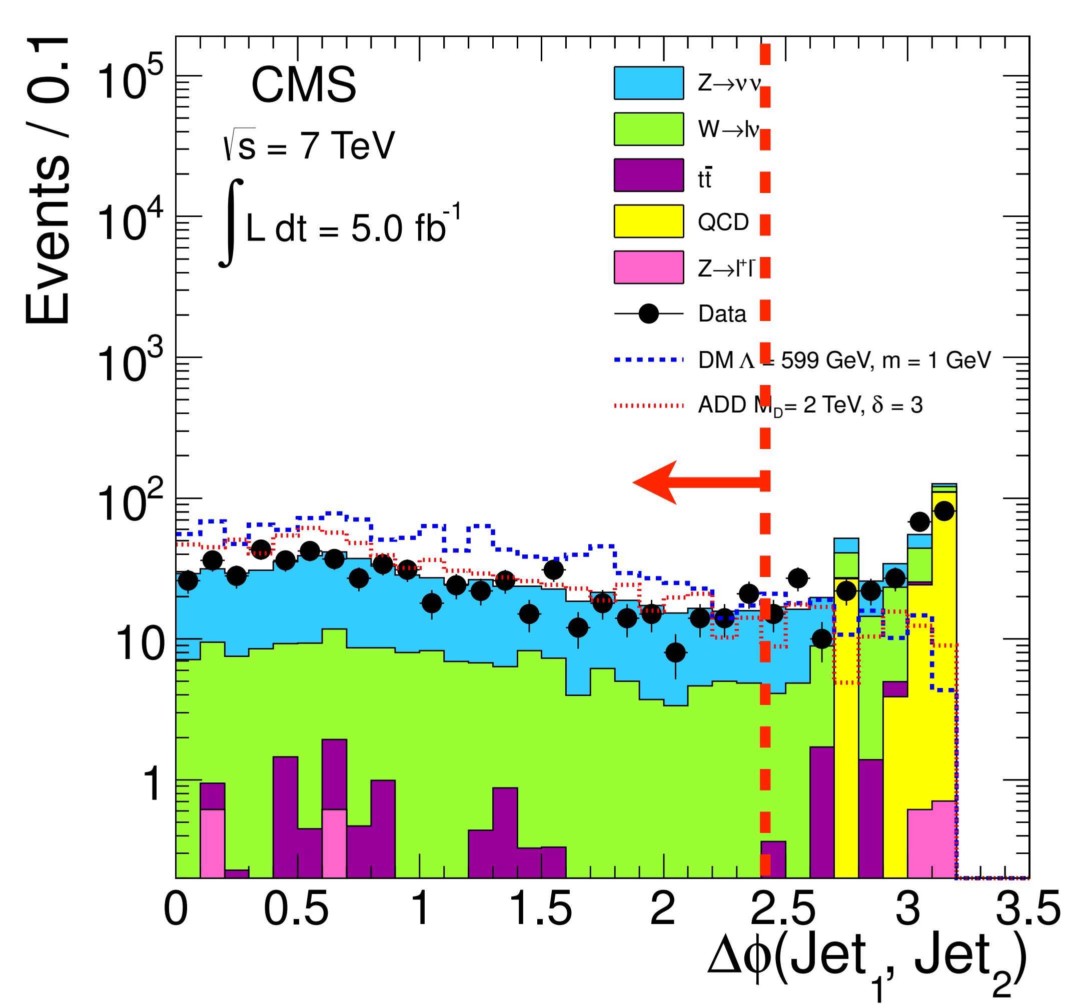


https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11059

Search for Dark Matter in Monojet events

- Reject event if it has more than 2 jets (p_T>30 GeV/c).
- Reject event if $\Delta\phi$(jet1,jet2)>2.5, QCD rejection.
- Reject event if it has an isolated electrons, an isolated muons, or isolated tracks with p_T>10 GeV/c.





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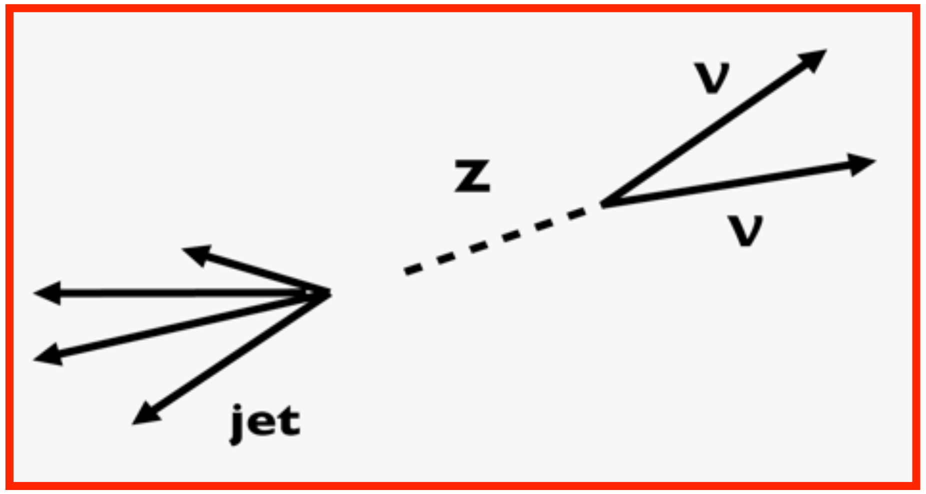
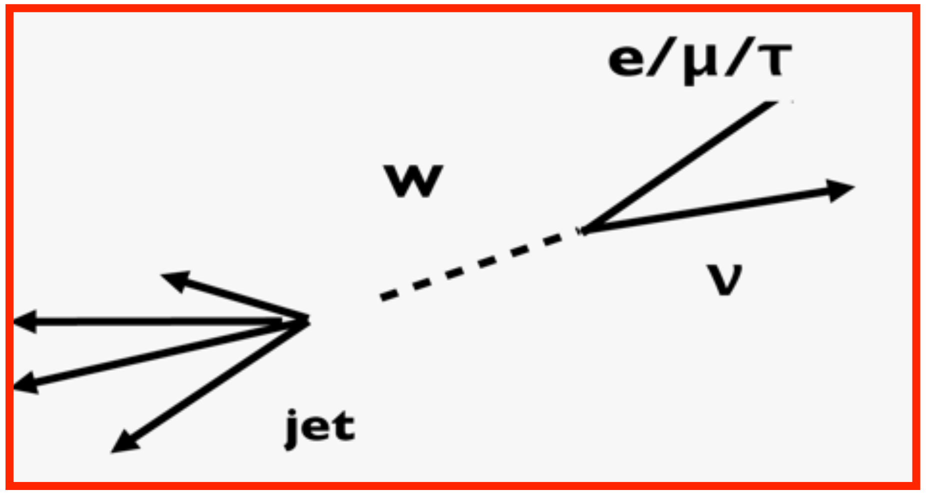
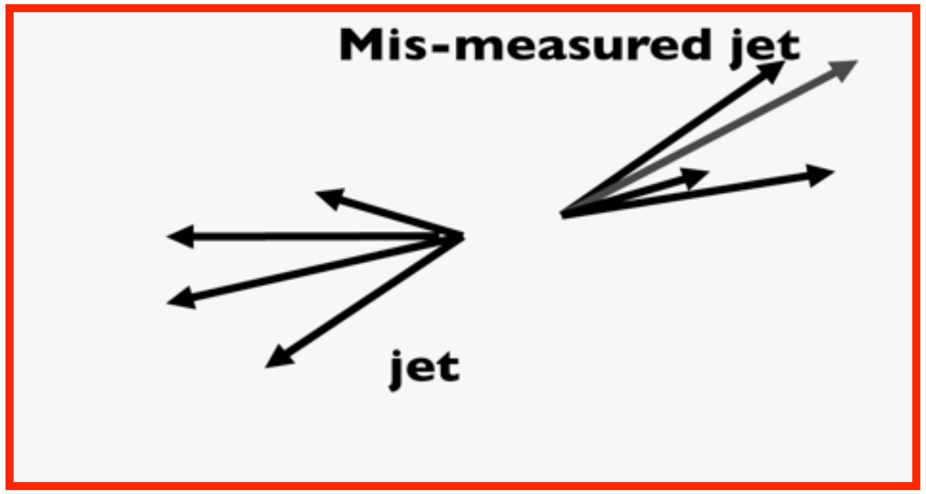
Background of DM Monojet events



Z(νν)+jets, just like signal.
(Data-Driven)



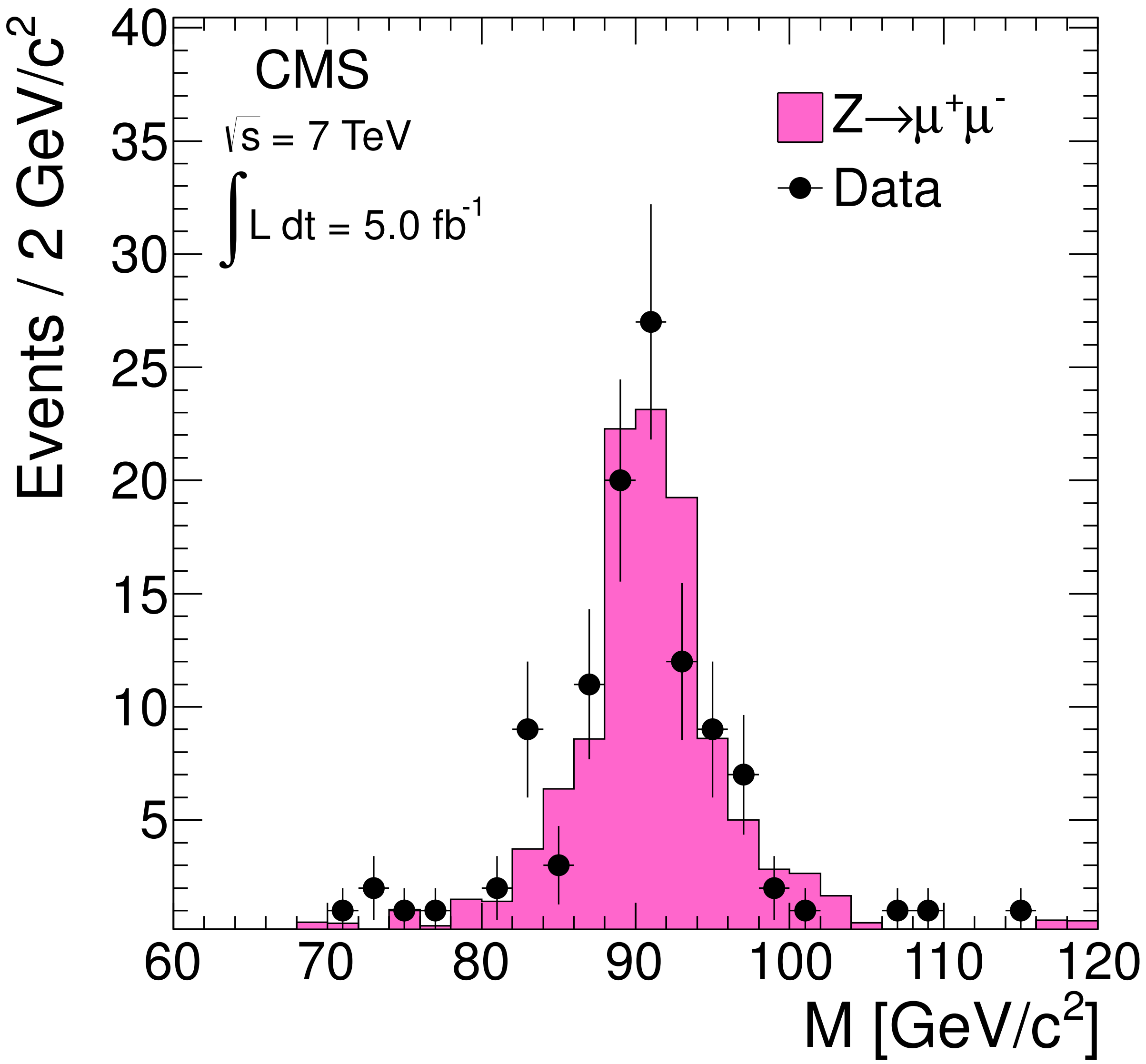
W+jets, e or μ is not identified (Data-Driven),
or τ decays hadronically (MC).



QCD, jet is mismeasured, producing MET (MC).

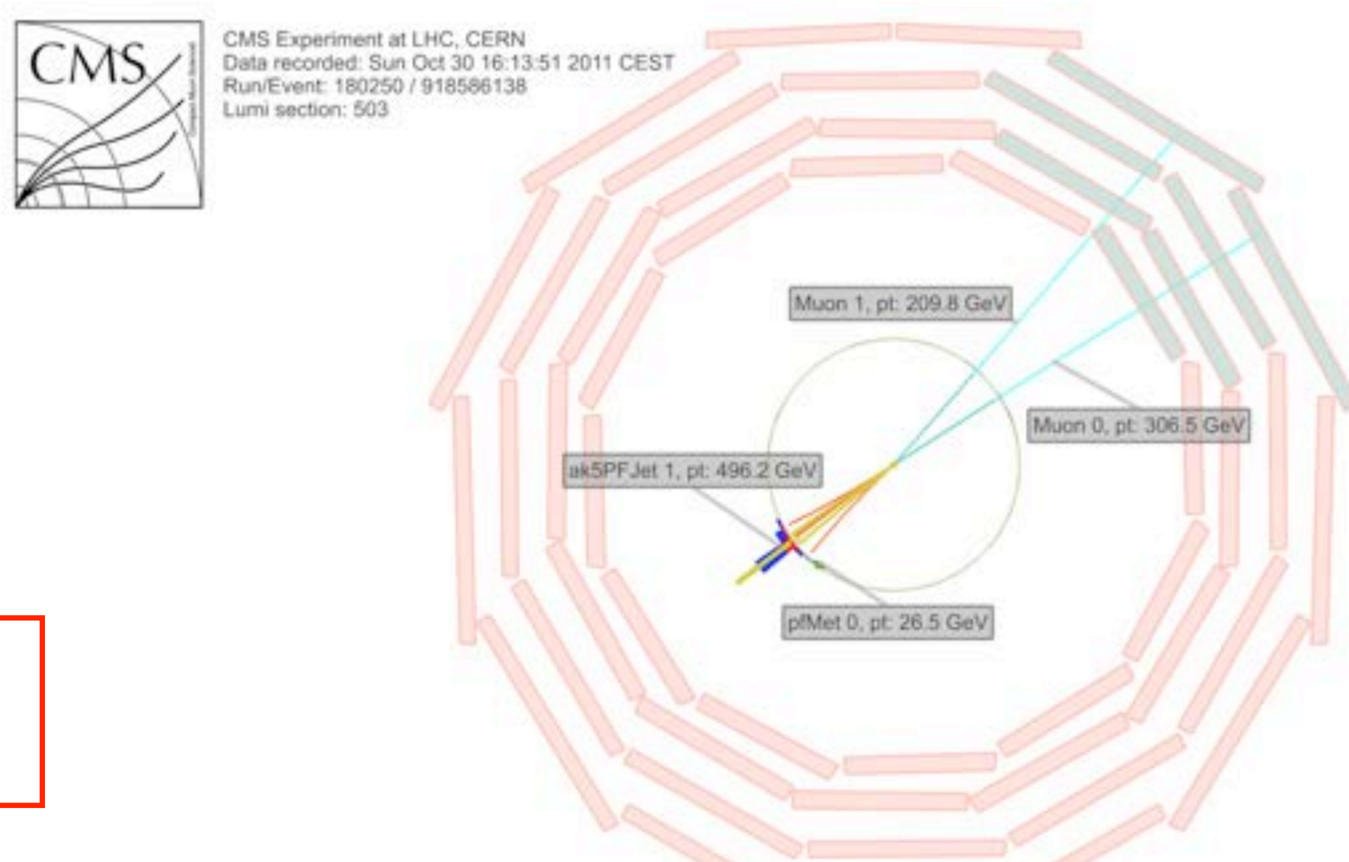
Background of DM Monojet events

Data-driven estimation: Z→νν



$$N(Z \to \nu\nu) = \frac{N^{obs} - N^{bgd}}{A * \epsilon} \cdot R(\frac{Z \to \nu\nu}{Z \to ll})$$

- Control sample Z→μμ.
- Select 2 opposite sign muons same as signal.
- Well isolated muons p_T>20 GeV/c, $|\eta| < 2.1$.
- Invariant mass between 60-120 GeV/c^2.
- Uncertainty ~11% mainly from stats 10%.



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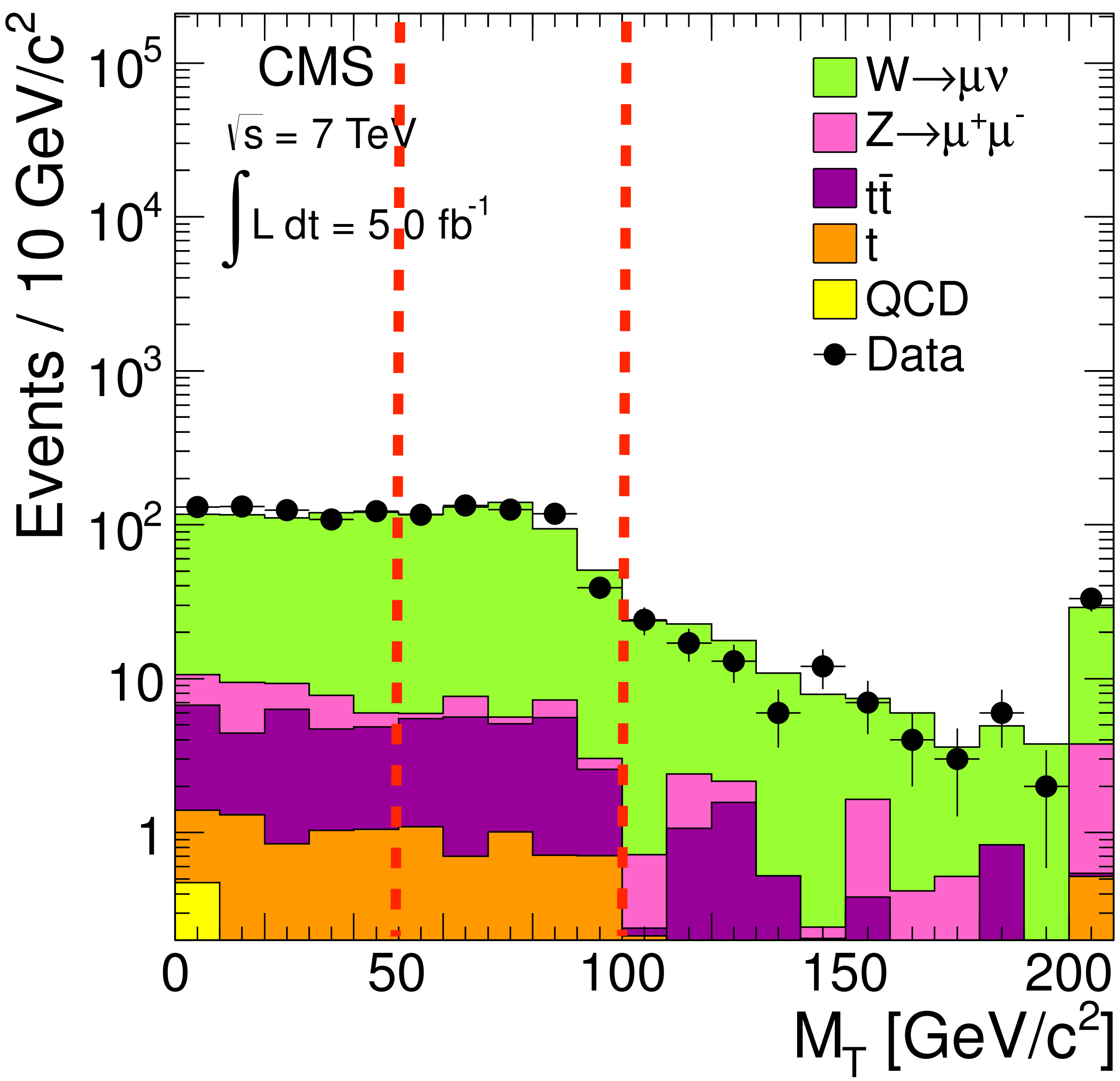
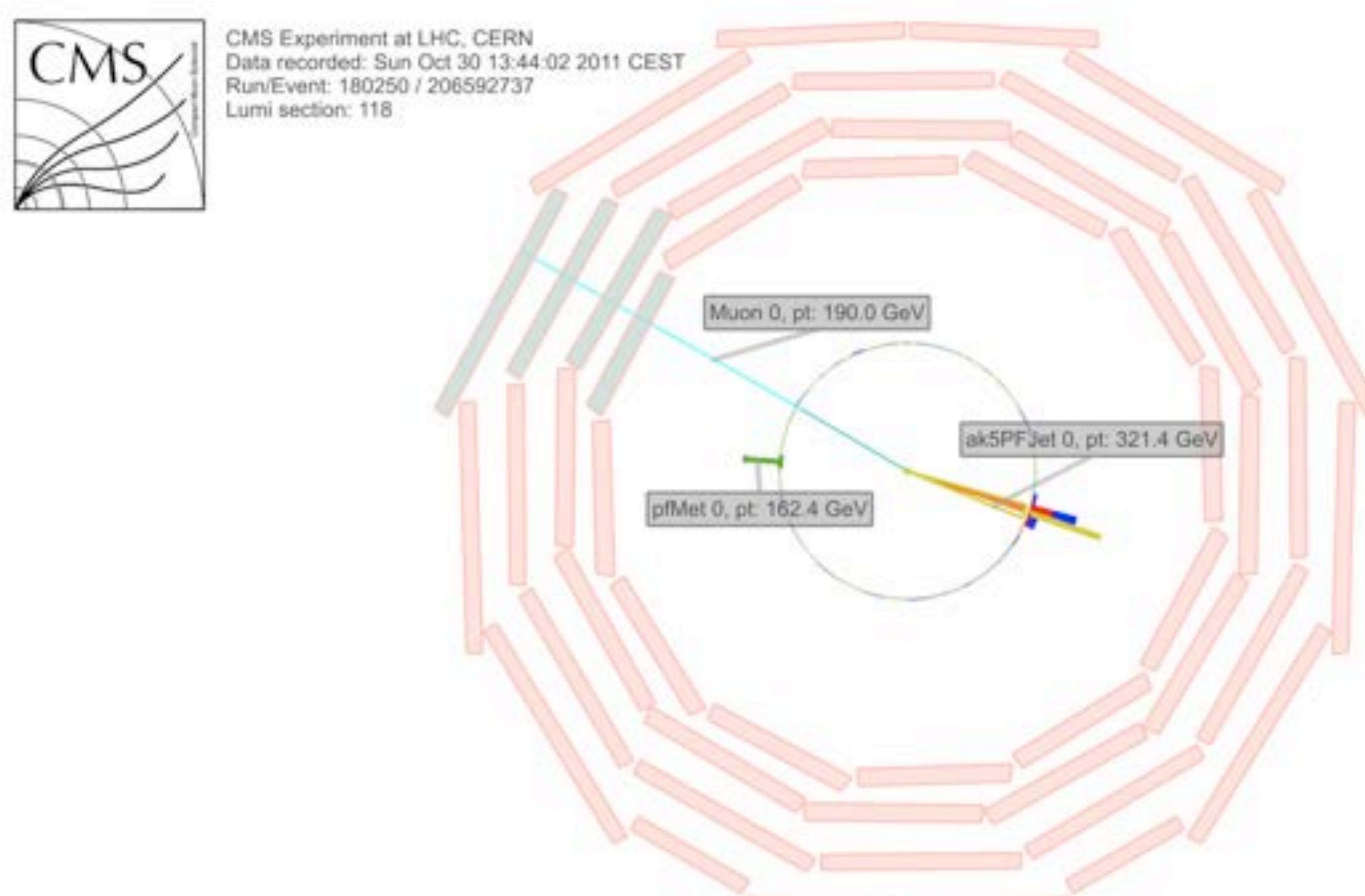
Background of DM Monojet events

Data-driven estimation: W+jets where lepton is lost



$$\begin{aligned} N_{!A} &= N_{tot} * (1 - A) \\ N_{!\epsilon} &= N_{tot} * A * (1 - \epsilon) \end{aligned}$$

- Control sample $W \rightarrow \mu\nu$.
- Select single muon same as signal.
- Well isolated muon p_T >20 GeV/c, $|\eta| < 2.1$.
- Transverse mass between 50-100 GeV/c^2.
- Uncertainty ~11% mainly from acceptance (8%), and selection efficiency (7%)



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Search for Dark Matter in Monojet events

E_T^{miss} (GeV/c) $\rightarrow$	≥ 250	≥ 300	≥ 350	≥ 400
Process		Events		
$Z(\nu\bar{\nu})$+jets **~74%, Data-Driven**	5106 ± 271	1908 ± 143	900 ± 94	433 ± 62
W+jets **~25%, Data-Driven**	2632 ± 237	816 ± 83	312 ± 35	135 ± 17
$t\bar{t}$	69.8 ± 69.8	22.6 ± 22.6	8.5 ± 8.5	3.0 ± 3.0
$Z(\ell\ell)$+jets	22.3 ± 22.3	6.1 ± 6.1	2.0 ± 2.0	0.6 ± 0.6
Single t	10.2 ± 10.2	2.7 ± 2.7	1.1 ± 1.1	0.4 ± 0.4
QCD Multijets	2.2 ± 2.2	1.3 ± 1.3	1.3 ± 1.3	1.3 ± 1.3
Total SM	7842 ± 367	2757 ± 167	1225 ± 101	573 ± 65
Data	7584	2774	1142	522
Expected upper limit non-SM	779	325	200	118
Observed upper limit non-SM	600	368	158	95

~1% MC

The Standard Model background prediction compared with data passing selection cuts for various MET thresholds in number of events corresponding to integrated luminosity of 5 fb^{-1}.

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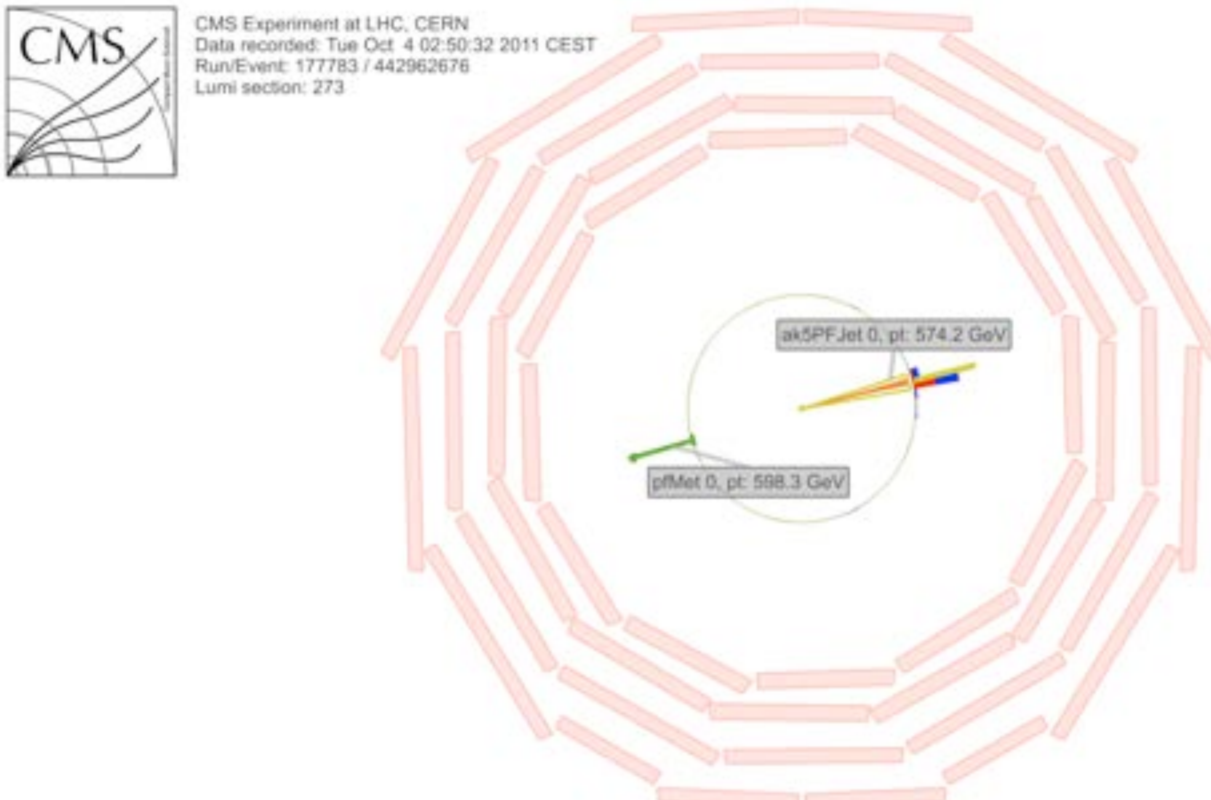
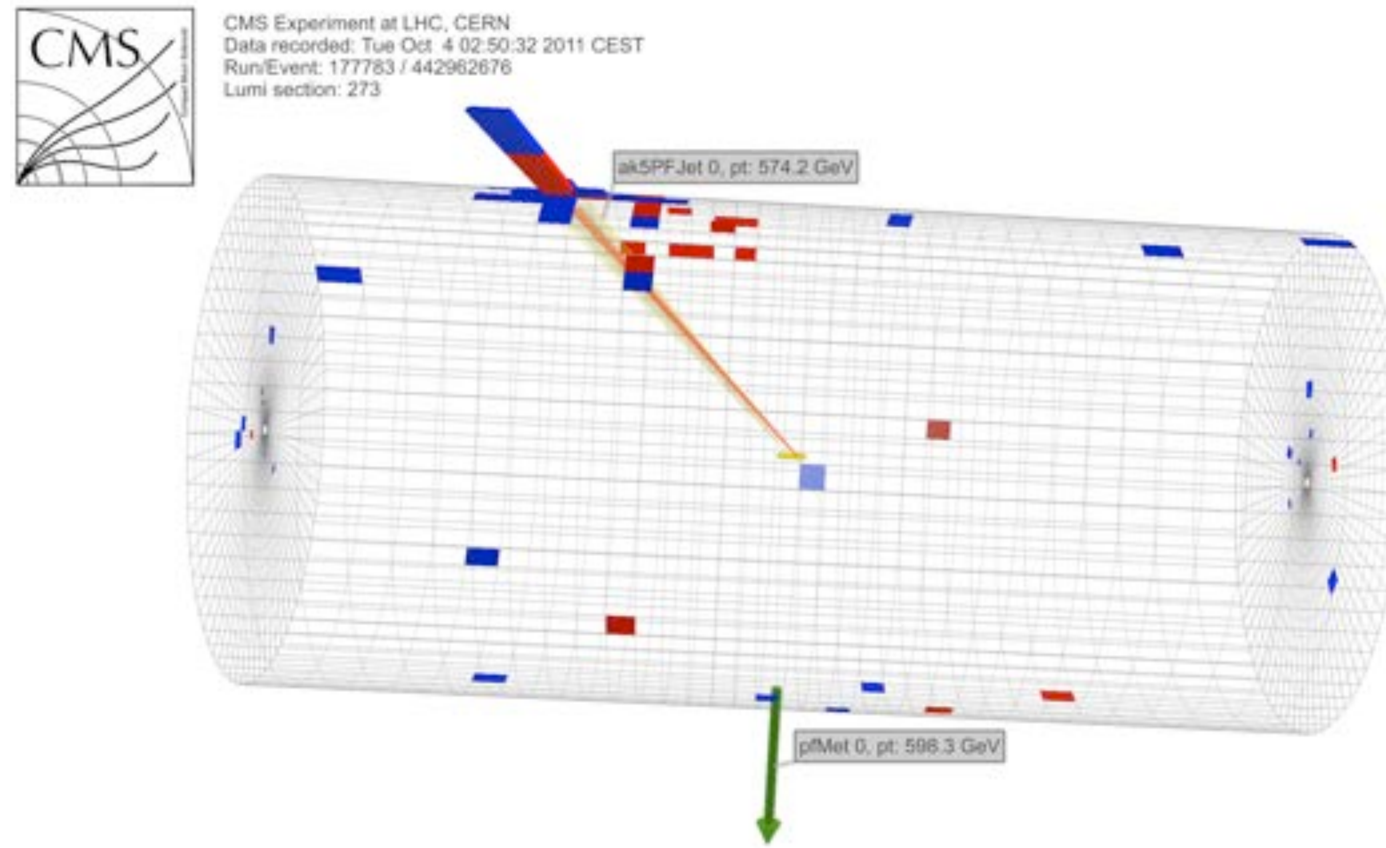
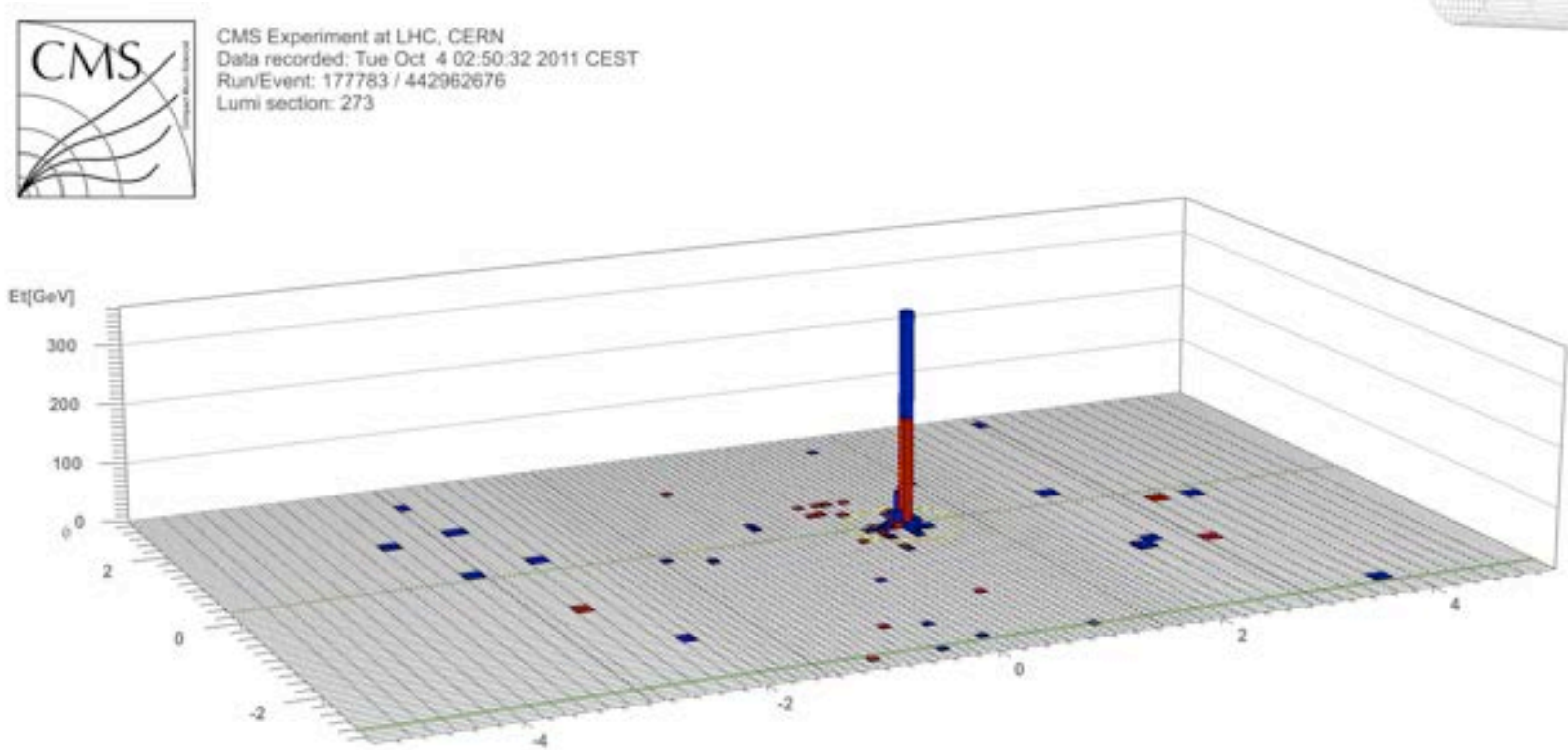
Search for Dark Matter in Monojet events







MET = 598.3 GeV
P^T_{Jet} = 574.2 GeV/c

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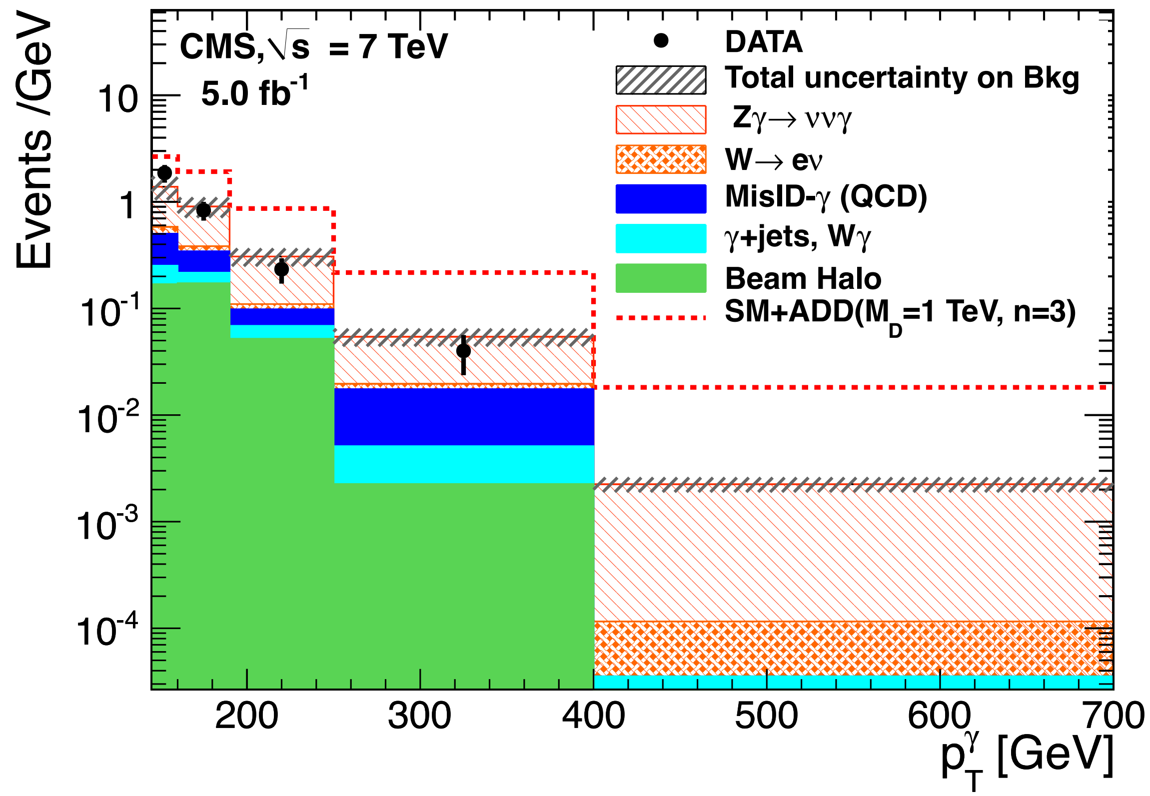
Search for Dark Matter in Monophoton events

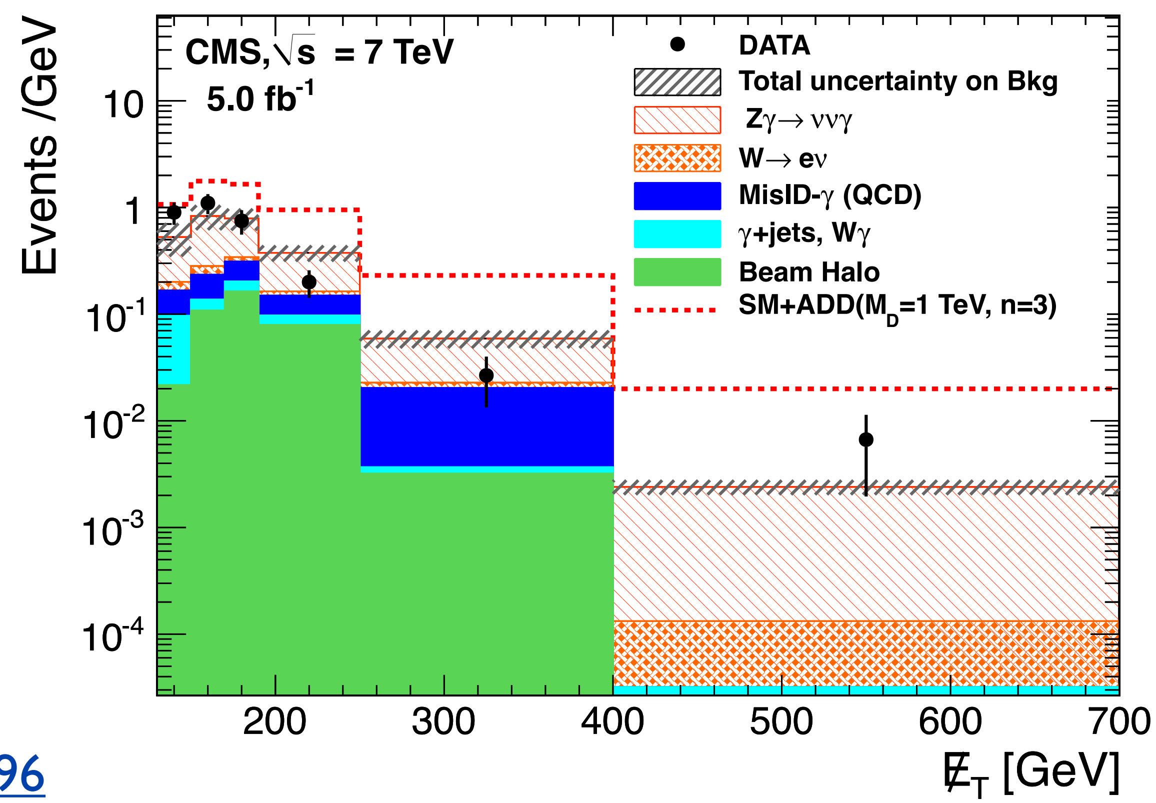


Selection:

- High energy photon, p_T > 145 GeV/c.
- Central region of detector, $|\eta| < 1.442$.
- Shower shape in calorimeter consistent with photon.
- Large missing transverse energy, MET > 130 GeV.

Remove events with excessive nearby activity:

- Veto events with nearby tracks or pixel stubs
- Veto events with significant electromagnetic calorimeter activity ($\Delta R < 0.4$)
- Veto events with significant hadronic activity ($\Delta R < 0.4$, EHCAL/EECAL< 0.05)
- No central jet: veto events with p_T(jet) > 40 GeV/c and $|\eta_{jet}| < 3.0$



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Background of DM Monophoton events

Backgrounds from pp collisions

- pp → Z γ → νν γ	Irreducible background (MC)
- pp → W → eν	Electron mis-identified as photon (Data-Driven)
- pp → jets → "γ" + MET	One jet mimics photon, MET from jet mismeasurement (Data-Driven)
- pp → γ + jet	MET from jet mis-measurement (MC)
- pp→Wγ→lνγ	Charged lepton escapes detection (MC)
- pp → γ γ	One photon mis-measured to give MET (MC)

Backgrounds unrelated to pp collisions

- Showers induced by cosmics

  Identified and removed (Data-Driven)

- Neutron-induced signals

  Identified and removed (Data-Driven)

- Beam halo

  Mostly removed, A residual contribution estimated (Data-Driven)

Source	Estimate
Jet Mimics Photon	11.2 ± 2.8
Beam Halo	11.1 ± 5.6
Electron Mimics Photon	3.5 ± 1.5
$W\gamma$	3.0 ± 1.0
γ+jet	0.5 ± 0.2
$\gamma\gamma$	0.6 ± 0.3
$Z(\nu\bar{\nu})\gamma$	45.3 ± 6.9
Total Background	75.1 ± 9.5
Total Observed Candidates	73

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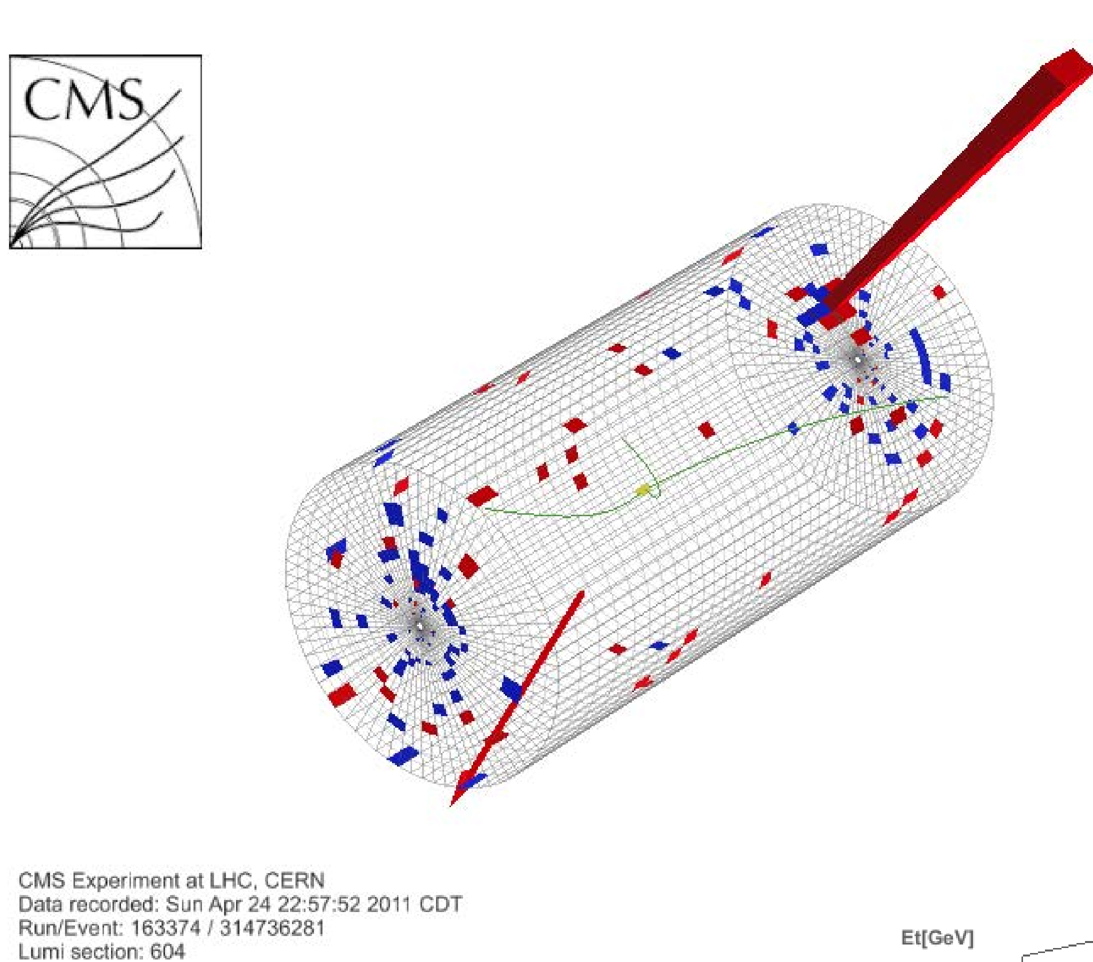
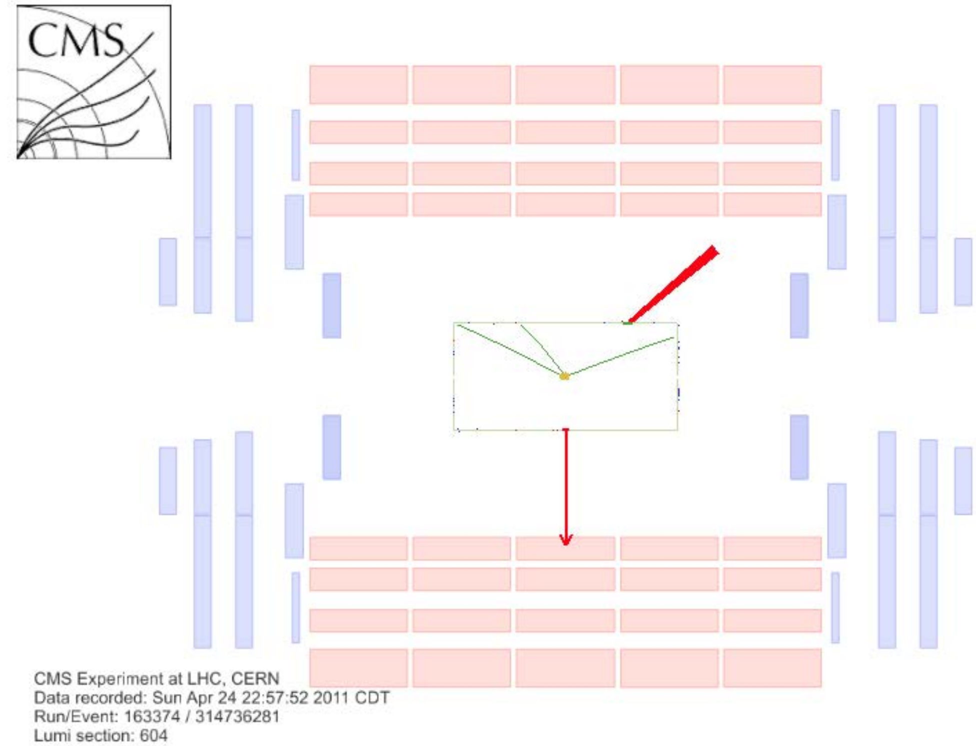
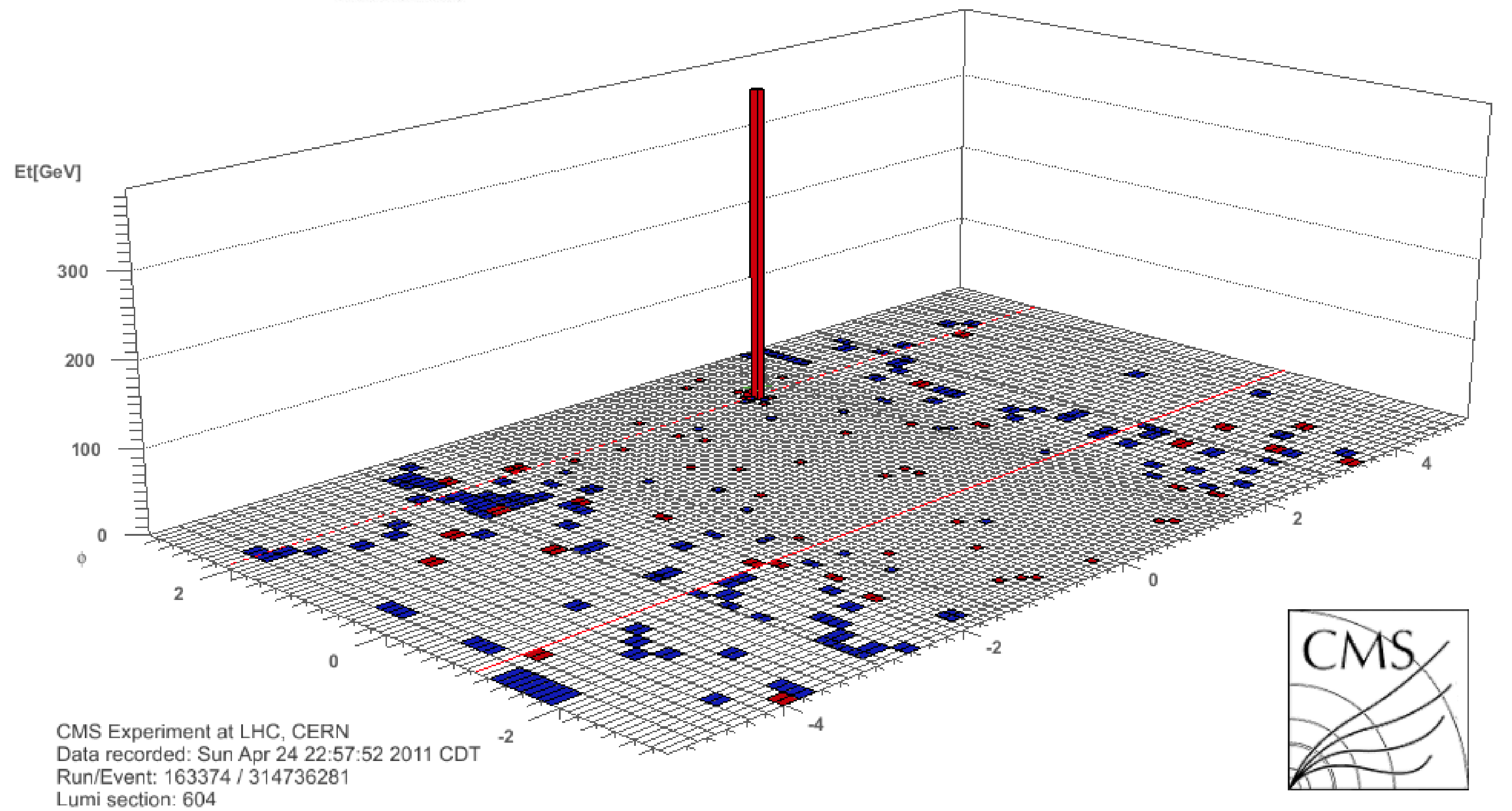
Search for Dark Matter in Monophoton events





MET = 407 GeV
P^{T}_{photon} = 384 GeV/c



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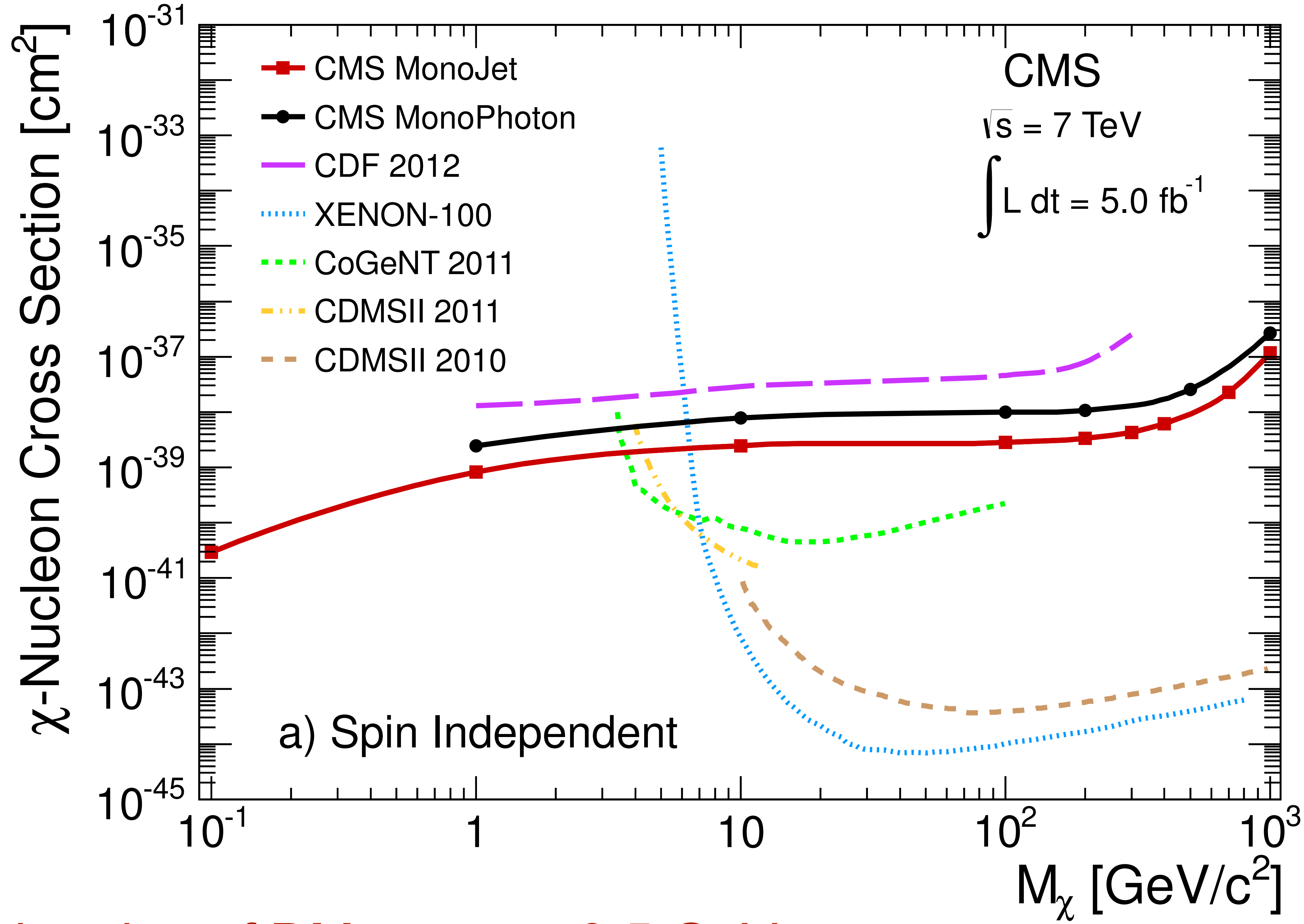
Limits

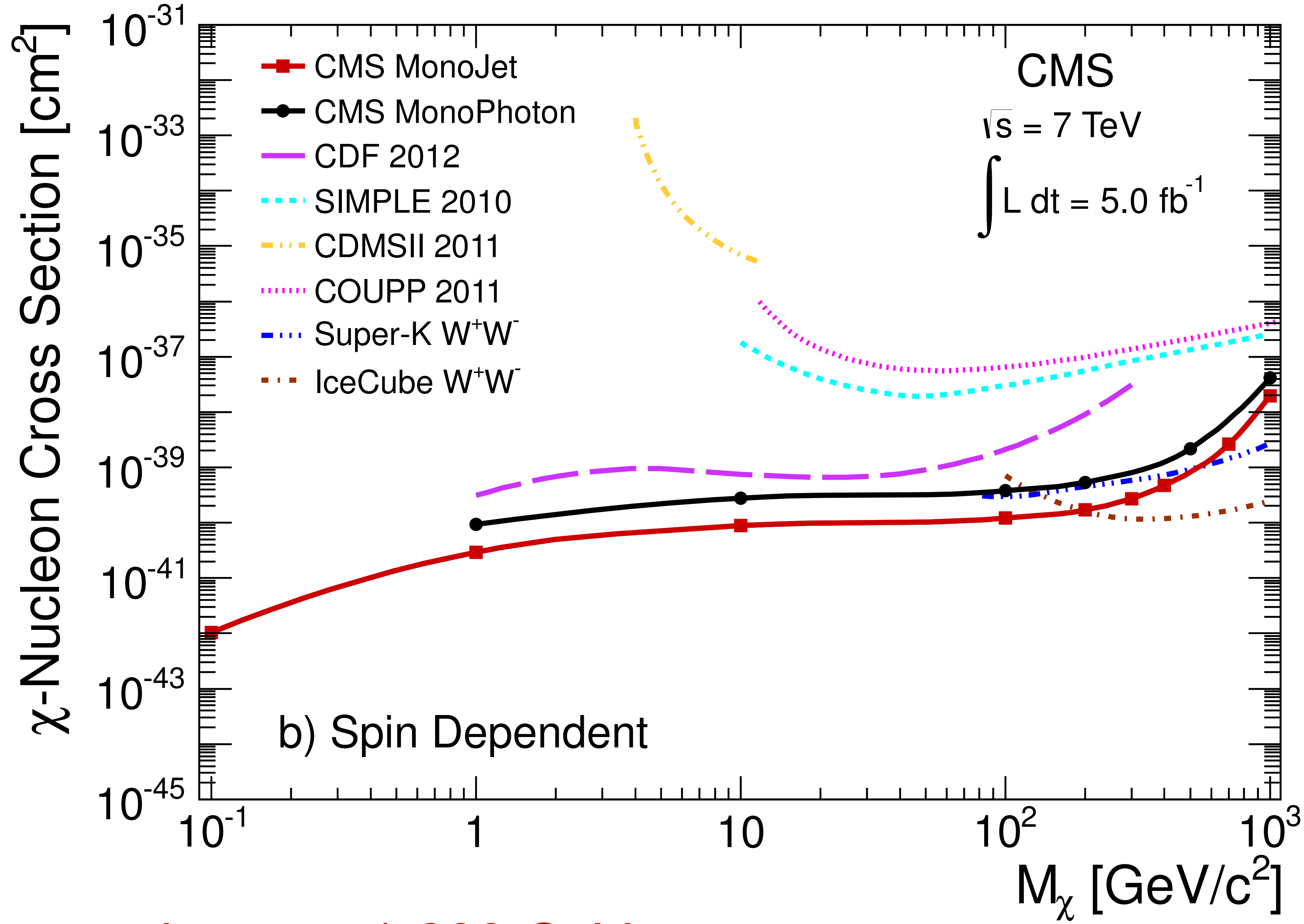
The 90% CL upper limits on the dark matter-nucleon scattering cross section versus dark matter mass for the spin-independent models.



Unexplored region of DM mass < 3.5 GeV.

Limits

The 90% CL upper limits on the dark matter-nucleon scattering cross section versus dark matter mass for the spin-dependent models.



Stringent constrains over 1-200 GeV mass range.

Summary

- Presented the results from searches for dark matter from monojet+MET and monophoton+MET channels at CMS using 5.0 fb^{-1} of 2011 LHC Data (7TeV).

- Predictions for Standard Model background consistent with observed data.

- Limits were set on DM-Nucleon scattering cross-section, to compare with direct and indirect detection measurements.

- Looking forward for 2012 Data.

References

Monophoton+MET
Phys. Rev. Lett. 108 (2012) 261803
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11096

Monojet+MET
JHEP 1209 (2012) 094
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11059