Rresults from a search for Dark Matter production in the CMS experiment with monophotons

Jordan Damgov
Texas Tech University
On behalf of the CMS Collaboration

Outline

- Introduction
- CMS detector
- Analysis details
  - Triggers
  - Event selection
  - Background modeling
- Dark Matter samples
- Limits
- Summary

Dark Matter

❖**There is strong astrophysical evidence for the existence of dark matter**

- ➢Evidence from bullet cluster, gravitational lensing, rotation curves

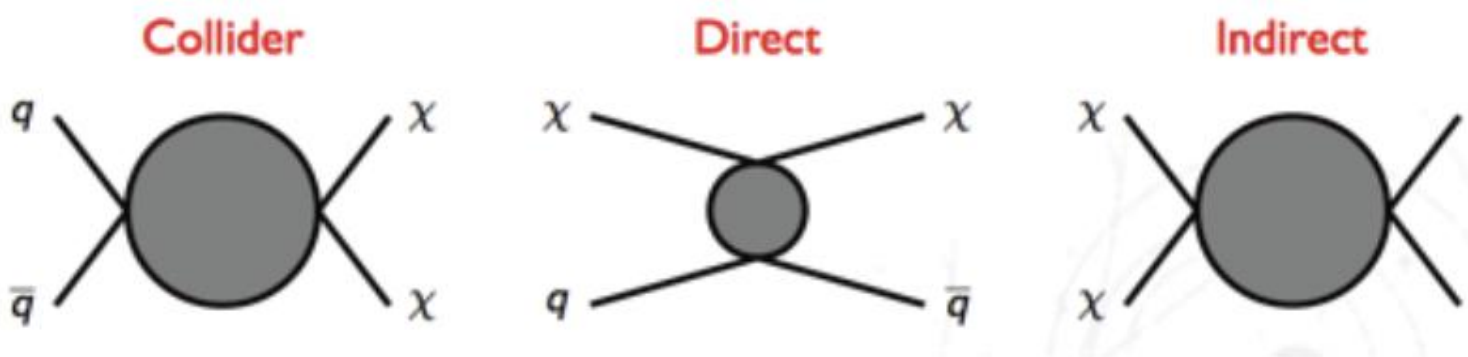
❖**Direct detection experiments**

- ➢ Aim to observe recoil of dark matter off nucleus
- ➢ Excesses observed by several experiments

➢ **Need for independent verification from non-astrophysical experiments**

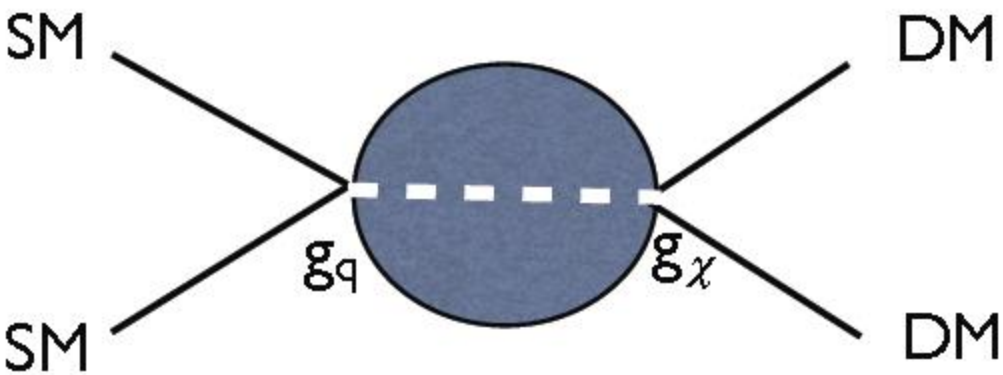
- ✓ Low mass region not accessible to direct detection experiments
- ✓ Limited by threshold effects, energy scale, backgrounds; less sensitive to spin-dependent couplings

Colliders provide alternative, complementary way to search for dark matter



Production of Dark Matter at colliders

- **In framework of effective theory, assume DM(χ) is a Dirac fermion and interaction is characterized by *contact interaction***
  - Set mass of mediator (M) to very high value



✓heavy mediator can be integrated out

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

❖ Consider two possibilities:

a) Vector mediator:
   - Spin dependent

b) Axial-Vector mediator:
   - Spin independent

Effective operators

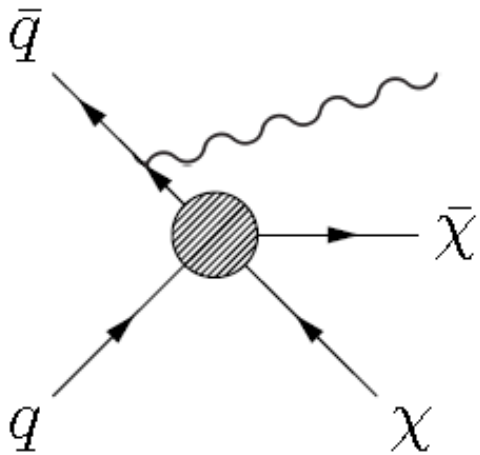
$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

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

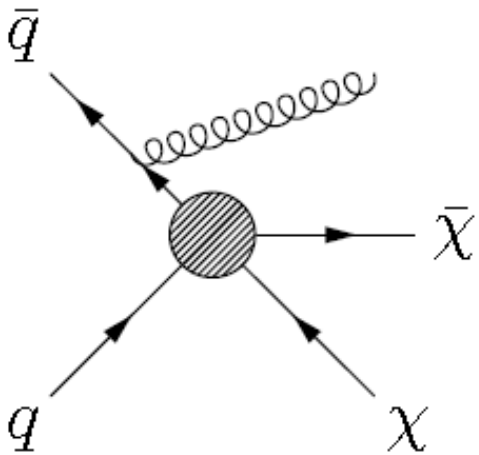
Production of Dark Matter at colliders

- Dark Matter production results in missing transverse energy (MET)

- Photons (or jets from a gluon) can be radiated from quarks
  - monophoton (or monojet) plus MET

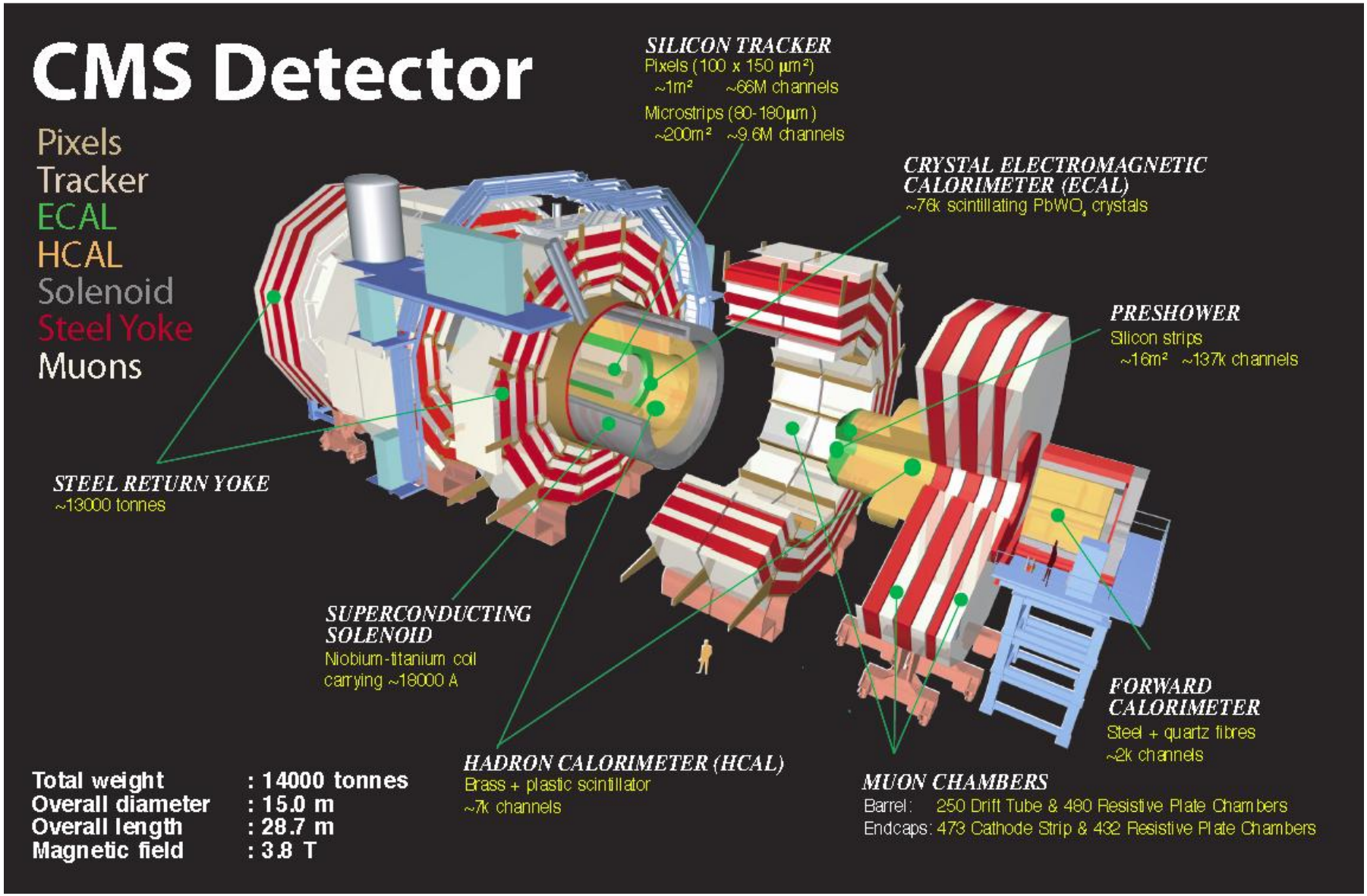


Monophoton + MET



Monojet + MET

CMS detector



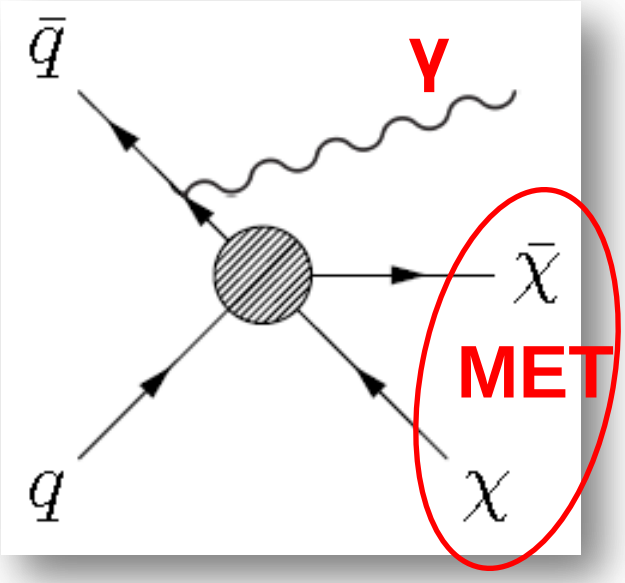
Monophoton- Search Details

- Require a **photon** in the event :
  - ✓High energy photon: **$E_T(\gamma)$ > 145 GeV/c**
  - ✓In the central part of the detector: **$|\eta|$ < 1.442**
  - ✓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* ($\Delta R < 0.4$, $E_{HCAL}/E_{ECAL} < 0.05$)
  - ✓*Shower shape* consistent with photon: $\sigma_{i\eta i\eta} < 0.013$
  - ✓ All reconstructed vertices are used for isolation calculations.

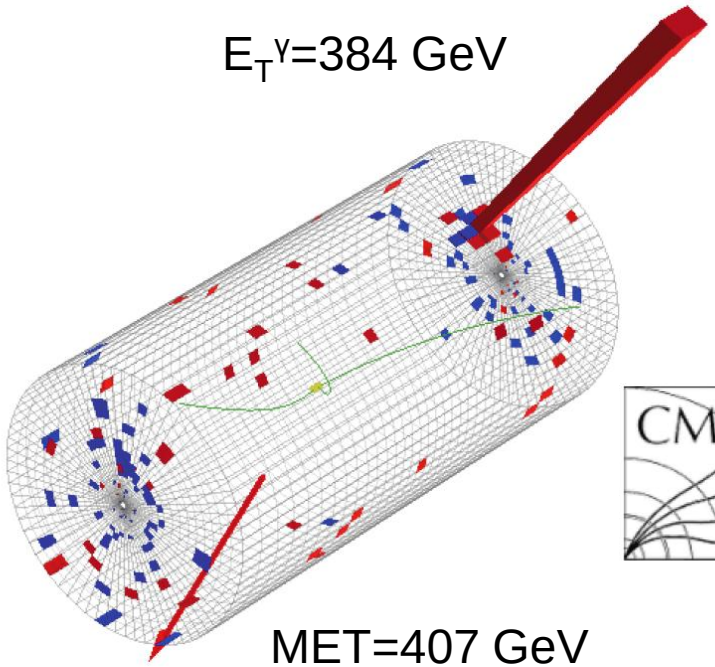
- **MET** > 130 GeV, using a particle flow method

- Remove events with excessive additional activity
  - ✓ No central jet: veto events with $p_T(\text{jet}) > 40$ GeV/c and $|\eta_{jet}| < 3.0$
  - ✓No tracks with $p_T > 20$ GeV/c

- Data is collected using single photon trigger
  - ➢ $E_T > 135$ GeV(or less)

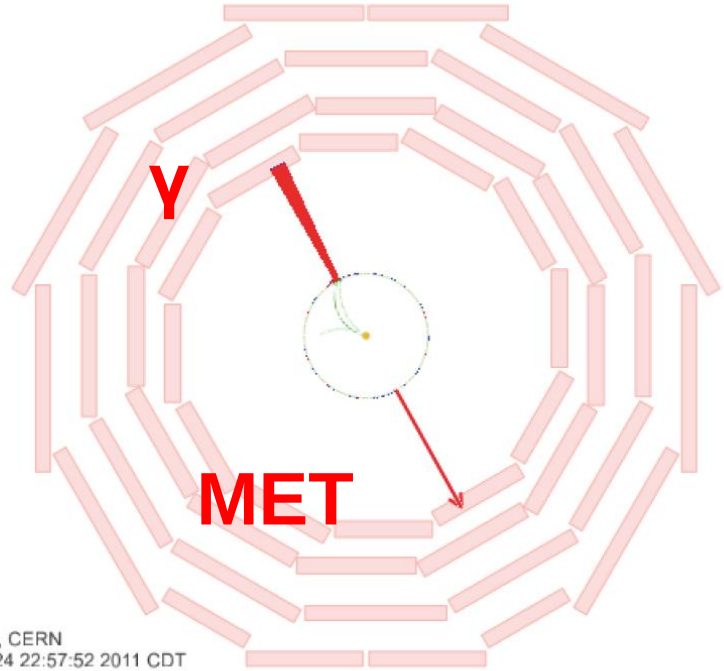


Monophoton- Event Display



CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

Event with the highest photon E_T



CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

- ❖Visible signal in only one sub-detector system
  - ❖ challenging measurement

Monophoton - Backgrounds

The procedure consists of estimating expected number of events from SM processes (and other backgrounds) and look for excess of events.

- **Counting Experiment**

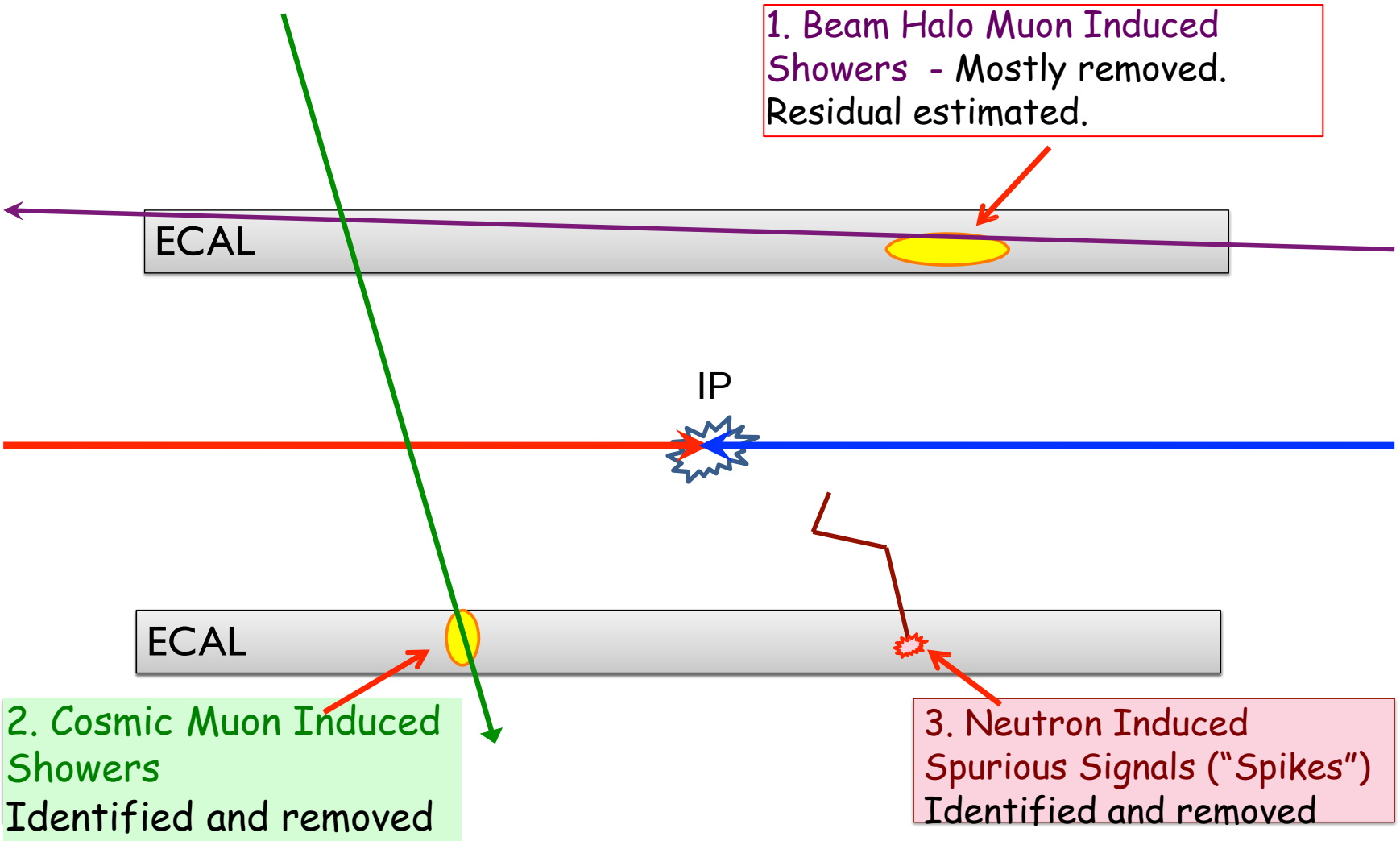
❖ *Backgrounds estimated from data-driven(DD) techniques and MC*

❑Backgrounds from ***pp collisions***

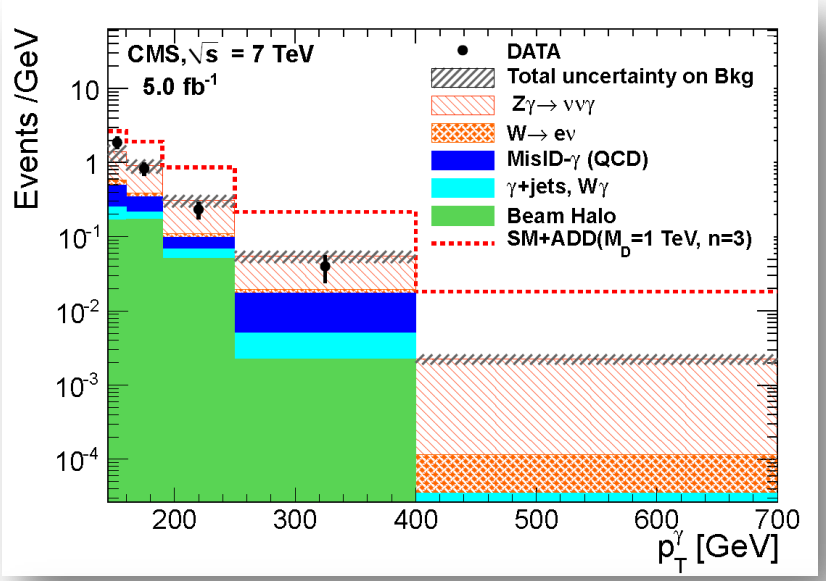
pp ➡ Z γ ➡ νν γ	***irreducible background*** *(MC, NLO BAUR)*
pp ➡ W ➡ **e** ν	electron mis-identified as photon *(DD)*
pp ➡ jets ➡ **"γ"** + MET	one jet mimics photon, MET from jet mis-measurement *(DD)*
pp ➡ γ + **jet**	MET from jet mis-measurement *(MC)*
pp ➡ W γ ➡ **l** ν γ	charged lepton escapes detection(*MC*)
pp ➡ γ **γ**	one photon is mis-measured - gives MET(*MC*)

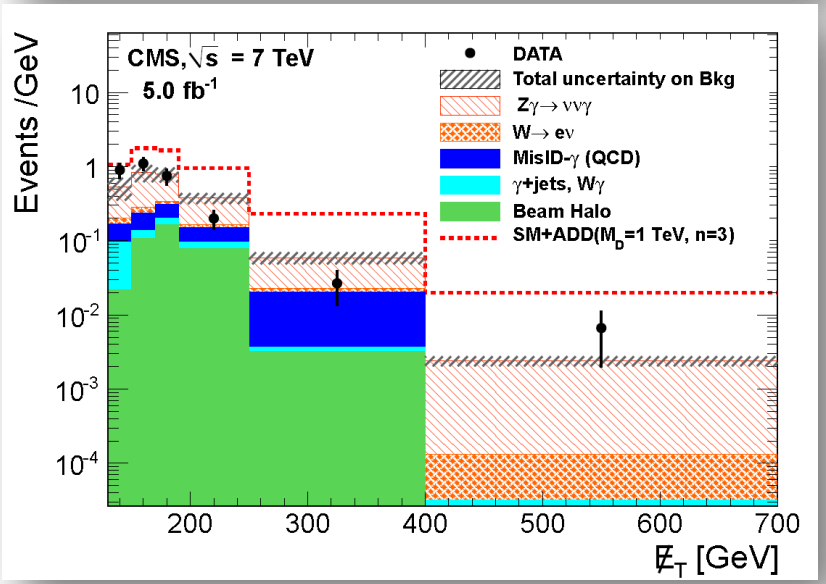
Monophoton – Backgrounds (cont.)

❖ *Backgrounds unrelated to pp collisions*



Monophoton – Search Results





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

Background processes describe the data well and no excess is observed.

Monophoton - Dark Matter Signal

- **Signal Generation**
  - Dark Matter model follows effective theory outlined in earlier slide
  - Madgraph4 + Pythia6 generation with 10 TeV mediator mass and assume cross section scales as Λ^{-4}. Photon ET > 125, $|\eta|<1.5$.
  - Similar sensitivity to spin-dependent and spin-independent

- **Acceptance times efficiency for Dark Matter signal**
  - $A \times \varepsilon \approx 0.3$, for both vector operator and axial-vector operator
  - Kinematics mainly from ISR photon; $A \times \varepsilon$ is fairly constant in the range m_χ = 1-1000 GeV

  - **Systematic uncertainties**
    - Stats. Uncertainty 1.7%
    - Photon ET uncertainty 2.3%
    - Jet Energy Scale 1.2%
    - MET modeling 0.5%
    - Pile-up modeling 2.4%
    - Jet veto modeling 10 %

Monophoton - limit setting

❖ **Limit-setting**

- Use Modified Frequentist CLs approach of PDG [J. Phys. G37 (2010) 075021].
- For an integrated luminosity of 5.0 fb^{-1} : 75.1 ± 9.5 expected and 73 observed
- 90% CL limits shown below, "expected" limits in parenthesis (95% also available)

❖ **Extraction of χ-nucleon cross section**

- Upper limits on cross sections give lower limits on the scale Λ, assuming a Λ^{-4} behavior
- The lower limits on Λ are then used to calculate the χ-nucleon cross section limits versus DM mass

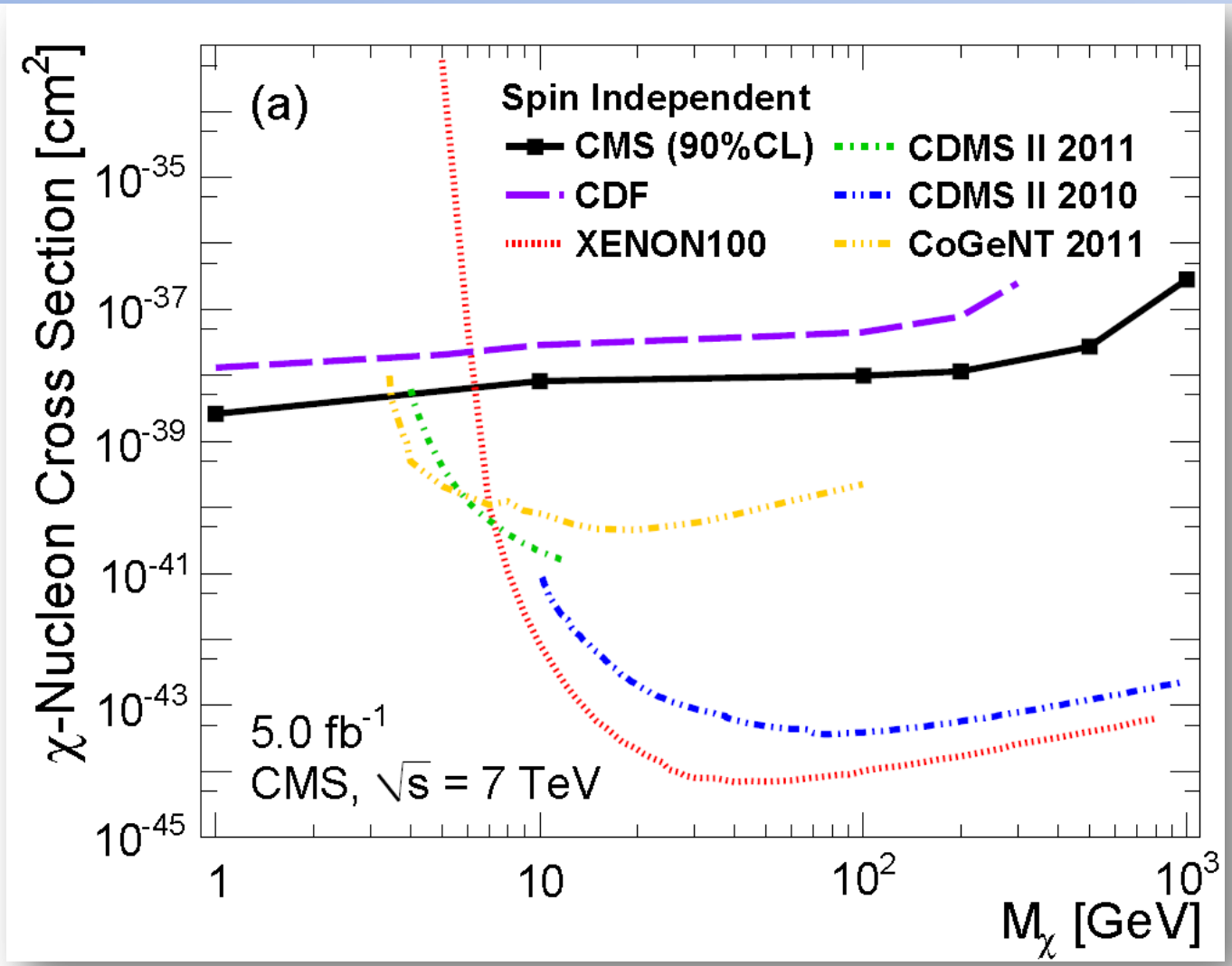
$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4} \quad \sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4} \quad \text{where } \mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

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

M_χ [GeV]	Vector		Axial-Vector	
	σ [fb]	Λ [GeV]	σ [fb]	Λ [GeV]
1	14.3 (14.7)	572 (568)	14.9 (15.4)	565 (561)
10	14.3 (14.7)	571 (567)	14.1 (14.5)	573 (569)
100	15.4 (15.3)	558 (558)	13.9 (14.3)	554 (550)
200	14.3 (14.7)	549 (545)	14.0 (14.5)	508 (504)
500	13.6 (14.0)	442 (439)	13.7 (14.1)	358 (356)
1000	14.1 (14.5)	246 (244)	13.9 (14.3)	172 (171)

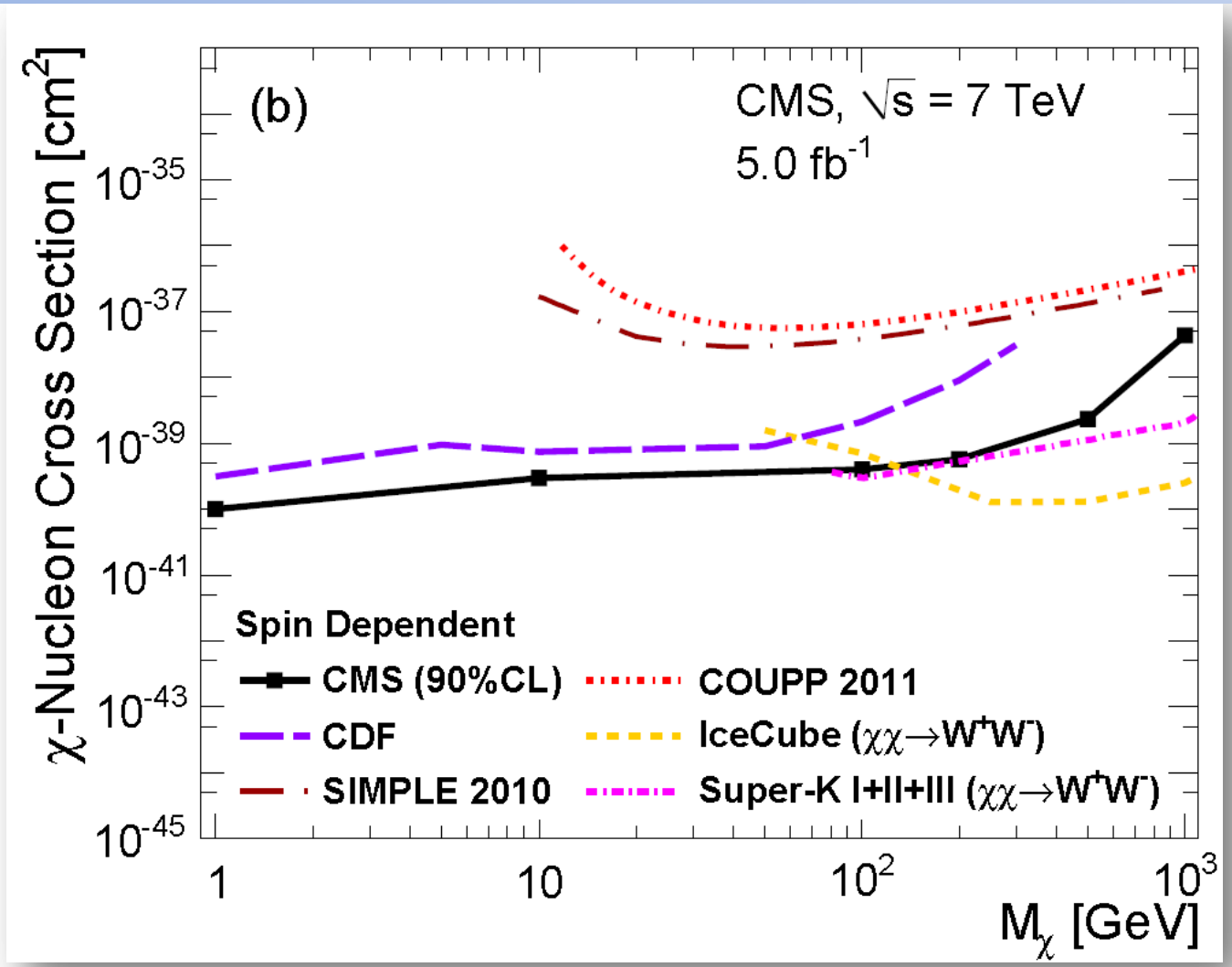
Observed(expected) 90% CL upper limits on the DM production cross section σ, and 90% CL lower limits on the cutoff scale Λ for vector and axial-vector operators as a function of the dark matter mass M_χ

Monophoton - spin-independent limits



[CDMS II: Science 327 (2010) 1619]
[CDMS II: Phys. Rev. Lett. 106 (2011) 131302]
[XENON100: Phys. Rev. Lett 17 (2011) 131302]
[CoGeNT: Phys. Rev. Lett. 106 (2011) 131301]

Monophoton - spin-dependent limits



[IceCube: PhysRevD. 85.042002]
[Super-K: Astrophys. J. 742 (2011) 78]
[SIMPLE: Phys. Rev. Lett. 105 (2010) 211301]
[COUPP: Phys. Rev. Lett. 106 (2011) 021303]

Summary

- Presented searches for Dark Matter in monophoton channels using 5.0 fb^{-1} of data at 7 TeV.

- Predictions for SM background consistent with observed data, ***no excess*** found. Limits are set on Dark Matter production, resulting in a significant extension of previously excluded parameter space:

- ***For spin-independent models, are obtained limits for low mass DM, below 3.4 GeV, a region as yet unexplored by the direct-detection experiments.***
- ***For spin-dependent models, limits represent more stringent over entire 1-80 GeV mass, w.r.t. the direct-detection experiments.***

References: 10.1103/PhysRevLett.108.261803 or EXO-11-096 (monophoton) at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Thank you !