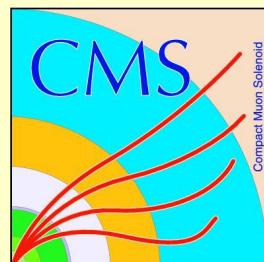


Search for Long-Lived Neutral Particles in Final States with Delayed Photons and Missing Transverse Energy in proton-proton collisions @ $\sqrt{s}=8$ TeV

Norbert Tambe Ebai

Oral Exam

Oct, 30th, 2015



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MENU

- Introduction
- ECAL Timing
- Search Analysis
- Result
- Summary

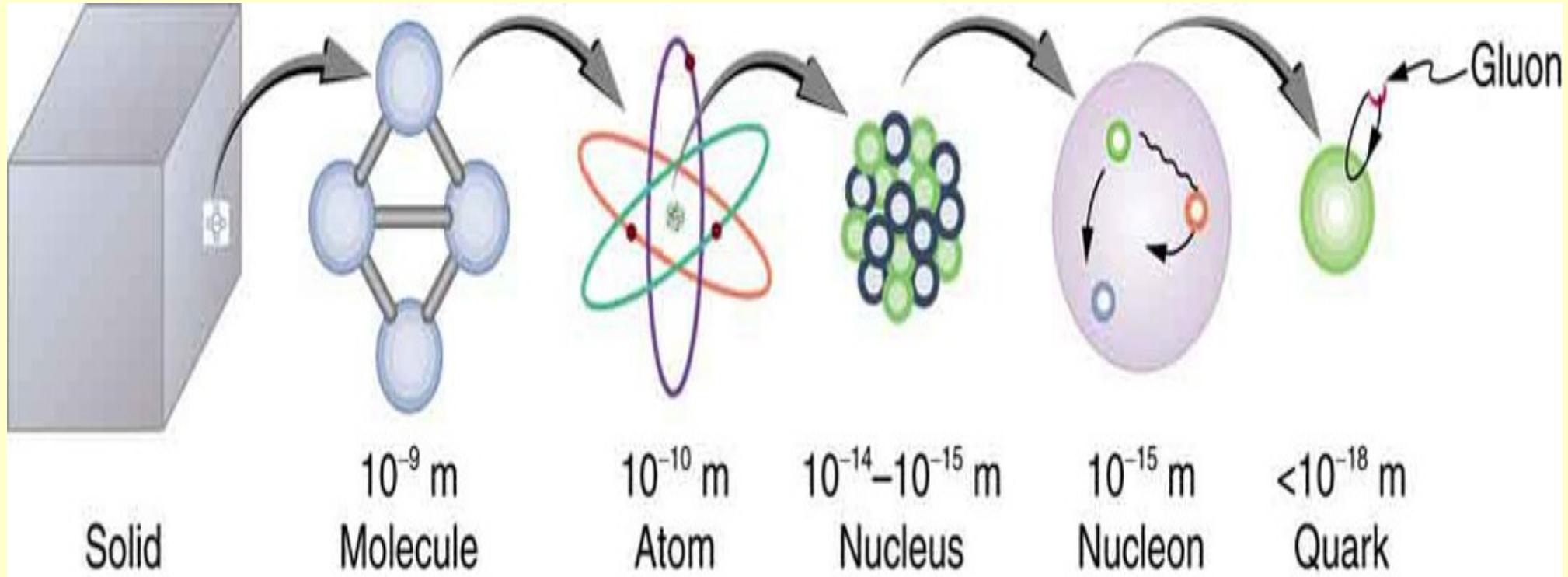


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Introduction

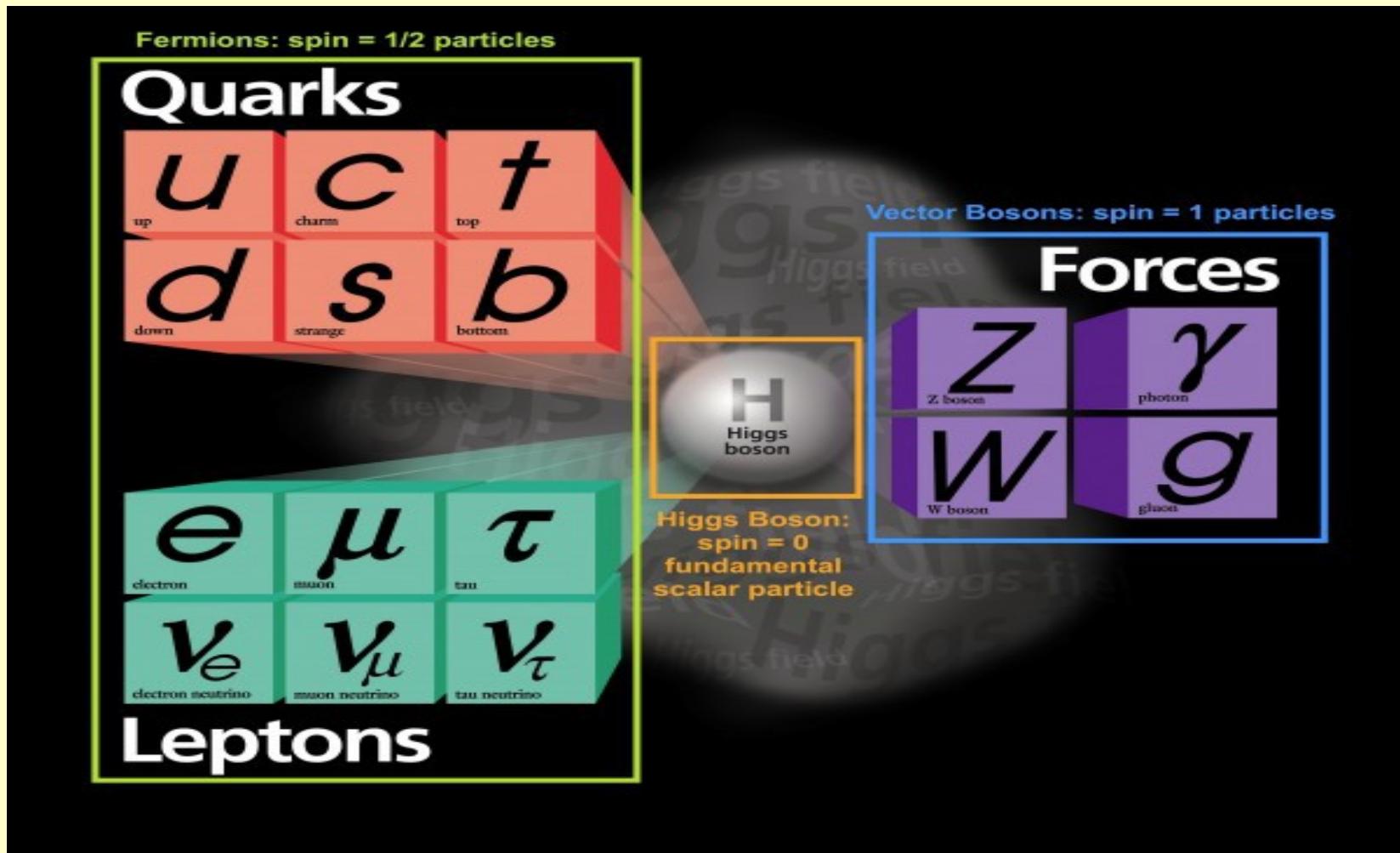


Introduction



- Matter description at lengths of about one billionth of a billionth of a meter.

The Standard Model



- Describes visible matter in the entire universe.



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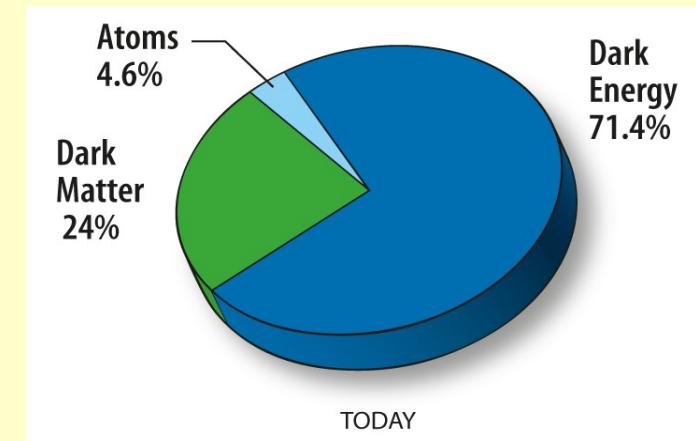
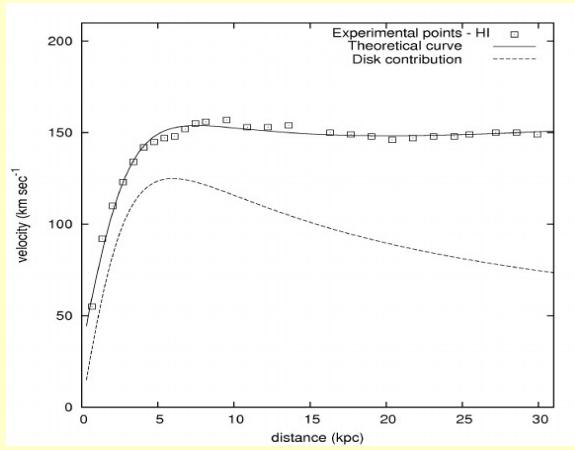
SM: Interactions & Lifetimes

Boson	Interaction	Symmetry	Lifetime
W, Z	Weak	$SU(2)_L \otimes U(1)_Y$	10^{-8} to 10^{-13} s
<i>Photon</i>	Electromagnetic	$U(1)_Q$	10^{-14} to 10^{-20} s
<i>Gluons</i>	Strong	$SU(3)_C$	$< 10^{-22}$ s

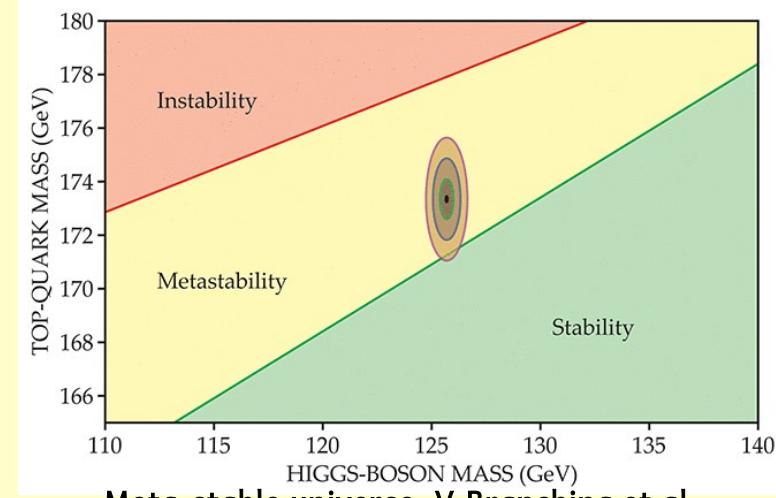
- The SM does not describe gravity for which the typical lifetime is about the age of the universe (about 13.7 billion years).

Exotic Forms of Matter

- Non-Visible or Dark Matter.



- Massive Long-Lived particles.
 - Mass $> 1 \text{ GeV/cc}$,
 - Lifetimes from one billionth of a second to 13.7 billion years,
 - Neutral or charged.

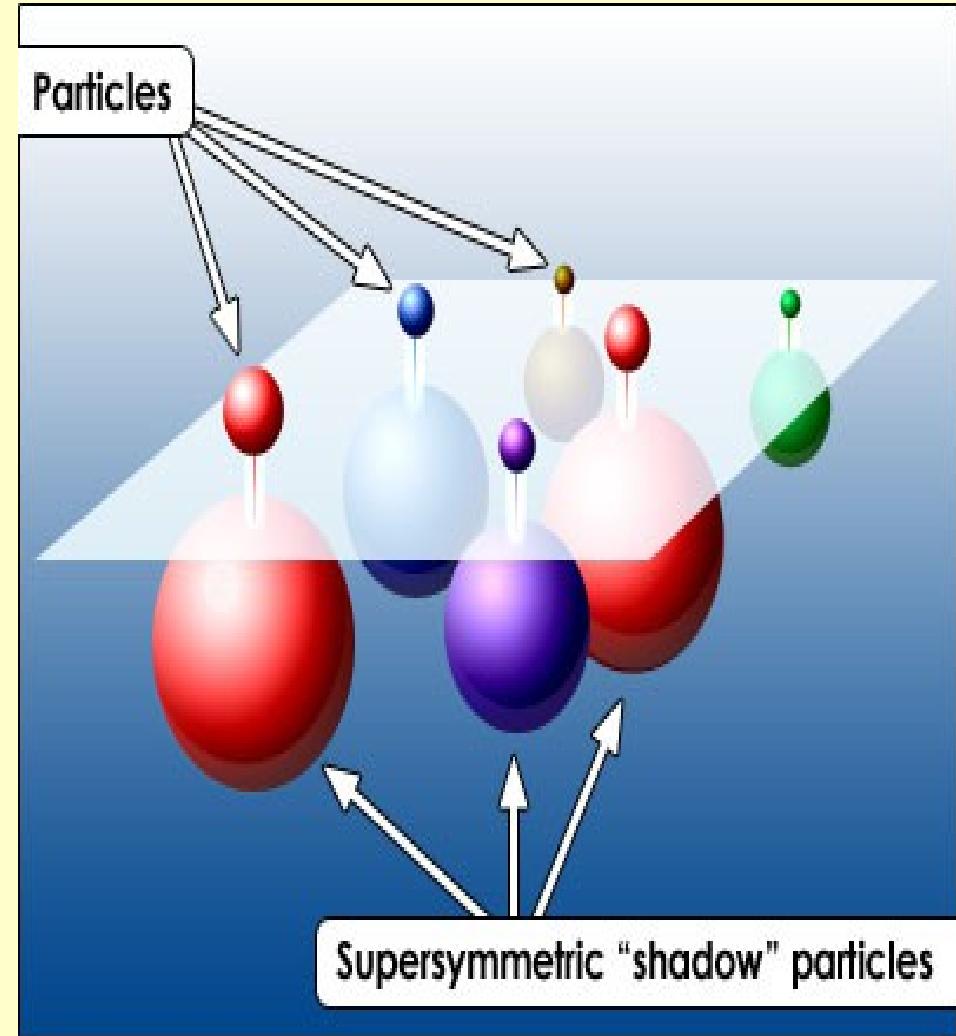


Meta-stable universe: V.Branchina et al:

[http://dx.doi.org/10.1007/JHEP09\(2014\)182](http://dx.doi.org/10.1007/JHEP09(2014)182)

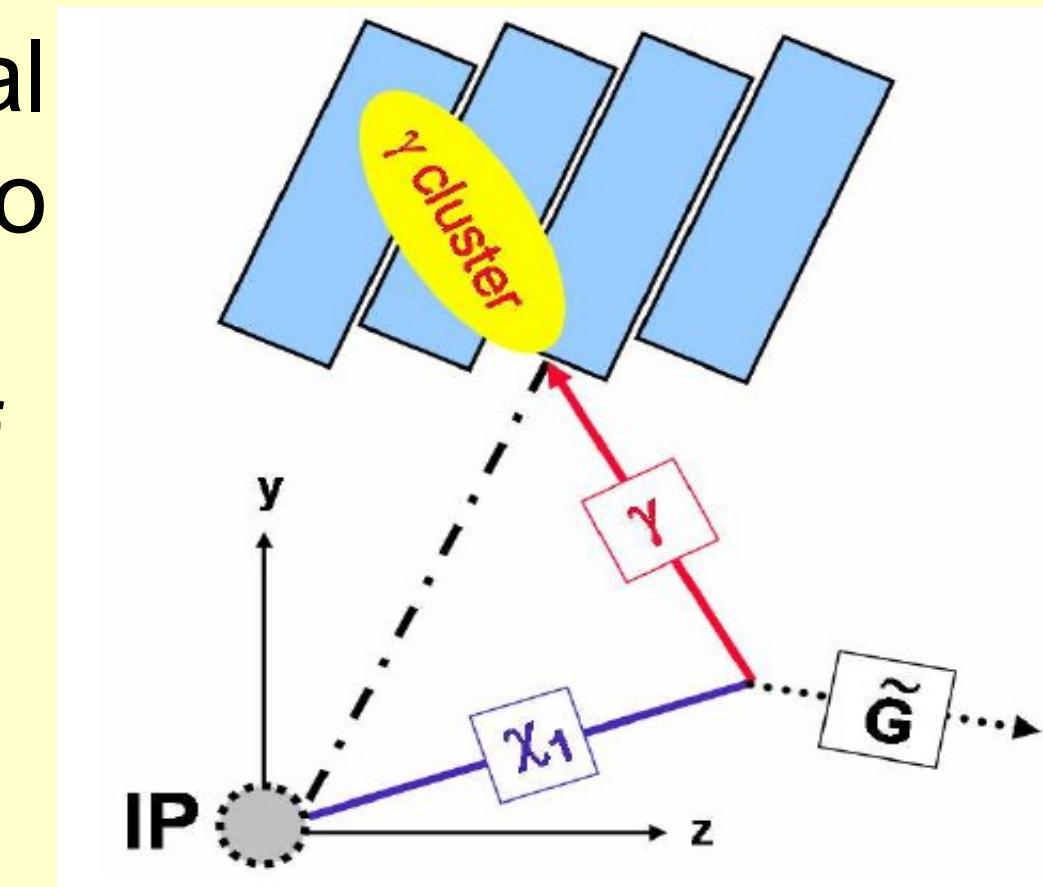
Long-Lived Particles Models

- Supersymmetry ,
- ADD or Large Extra dimension models,
- “Hidden Valley” models,
- Exotic models.



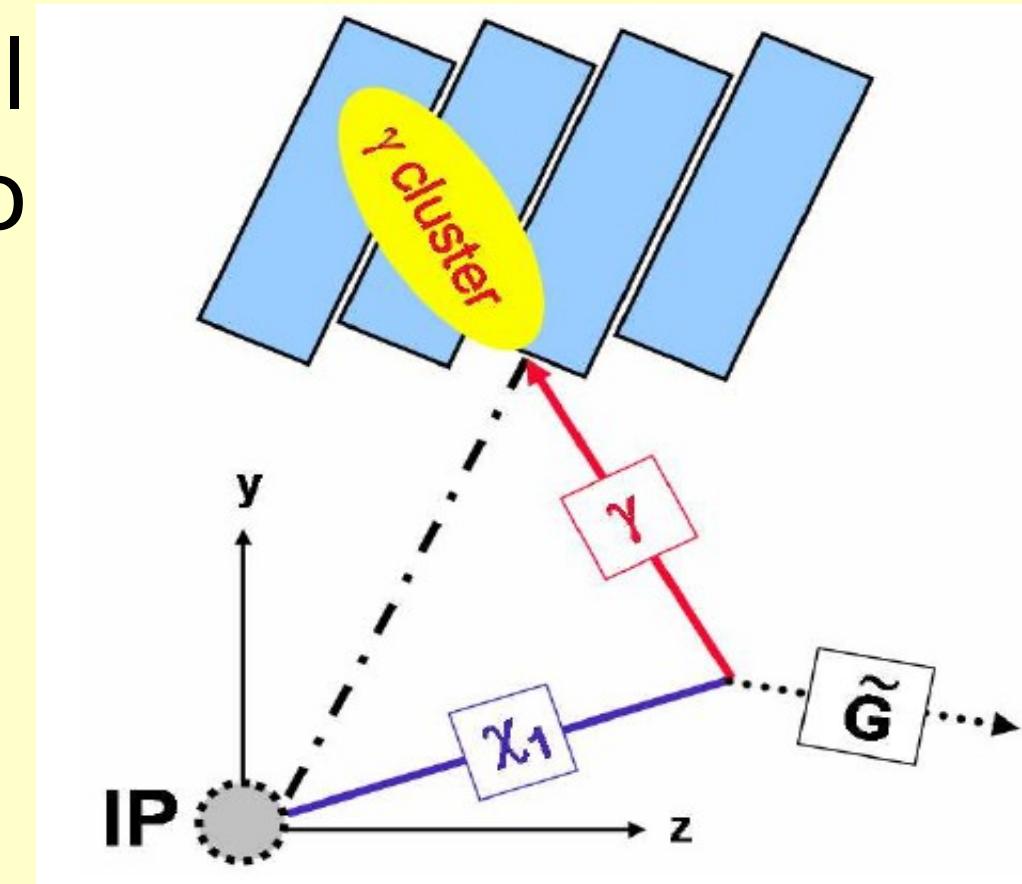
GMSB SUSY Long-Lived Models

- The decay of a neutral long-lived particle into a **photon** results in large **arrival time** of the photon at detector.
- **Supersymmetry** long-lived particles can decay into dark matter candidate particles.



SPS8 Benchmark GMSB Models

- The decay of a neutral long-lived particle into a **photon** results in large **arrival time** of the photon at detector.



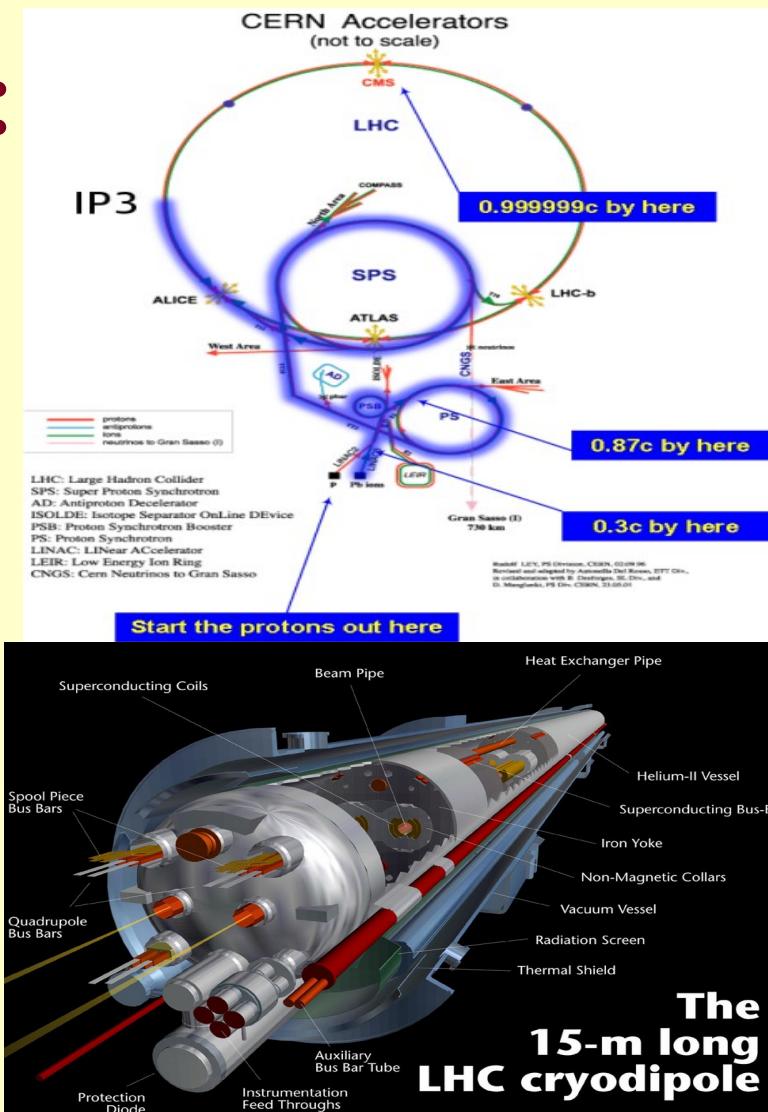
- Supersymmetry** long-lived particles can decay into dark matter candidate particles.

ECAL Timing

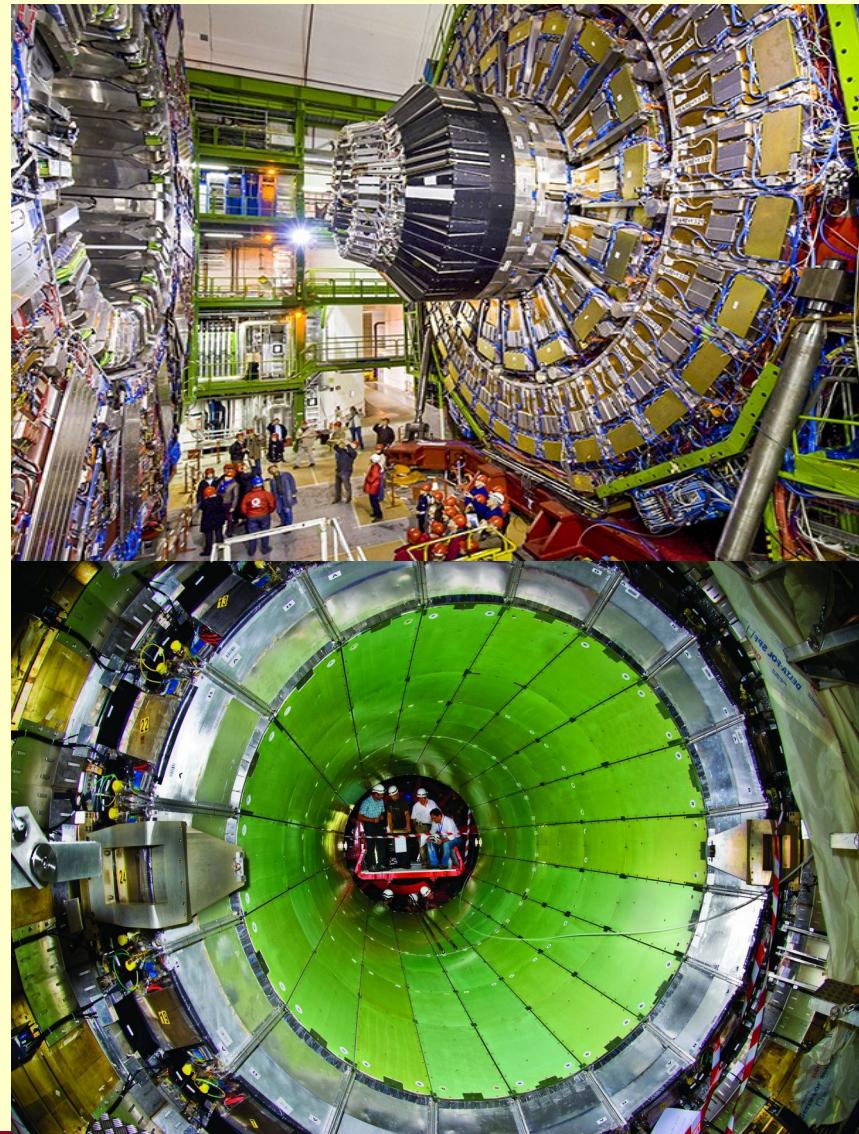
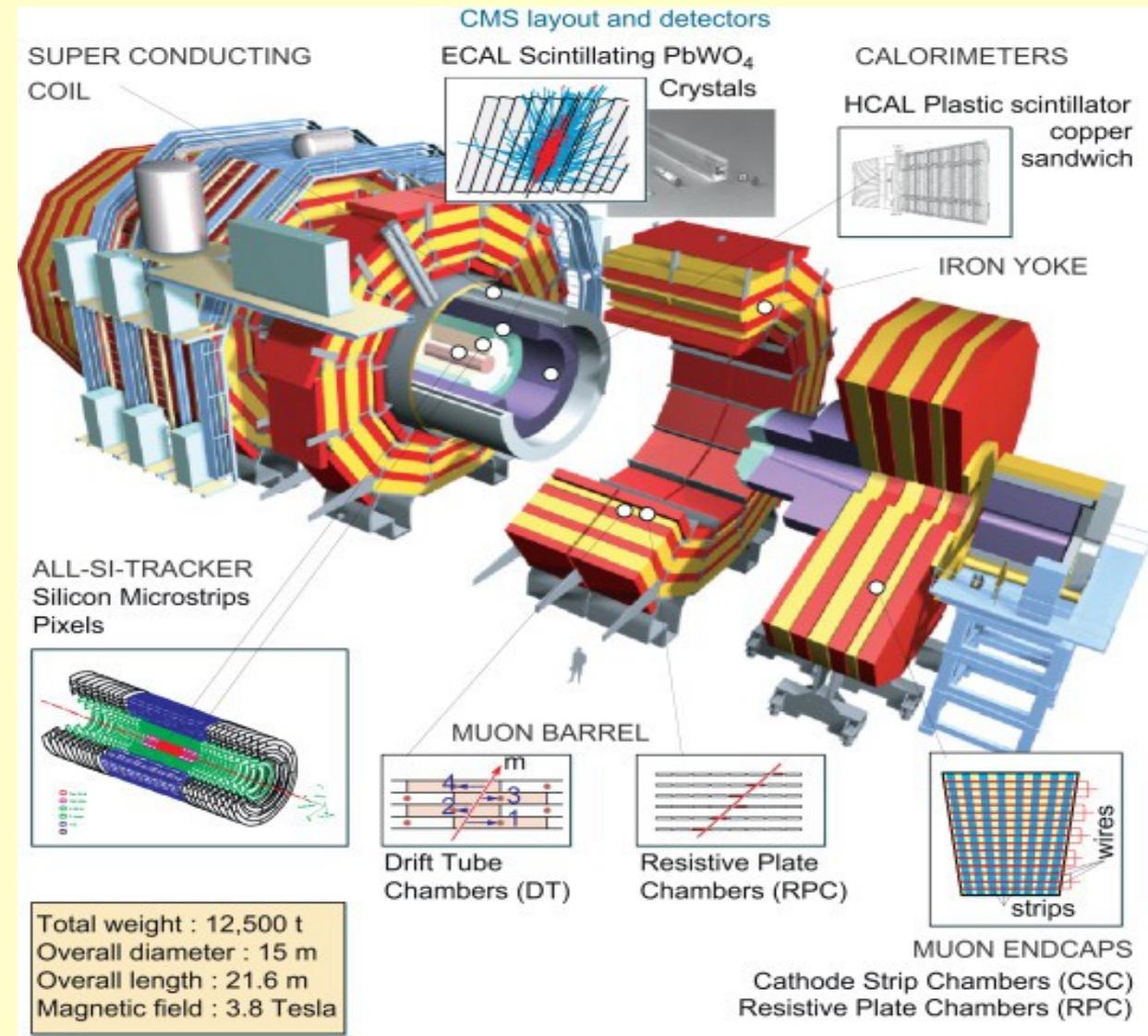


Large Hadron Collider

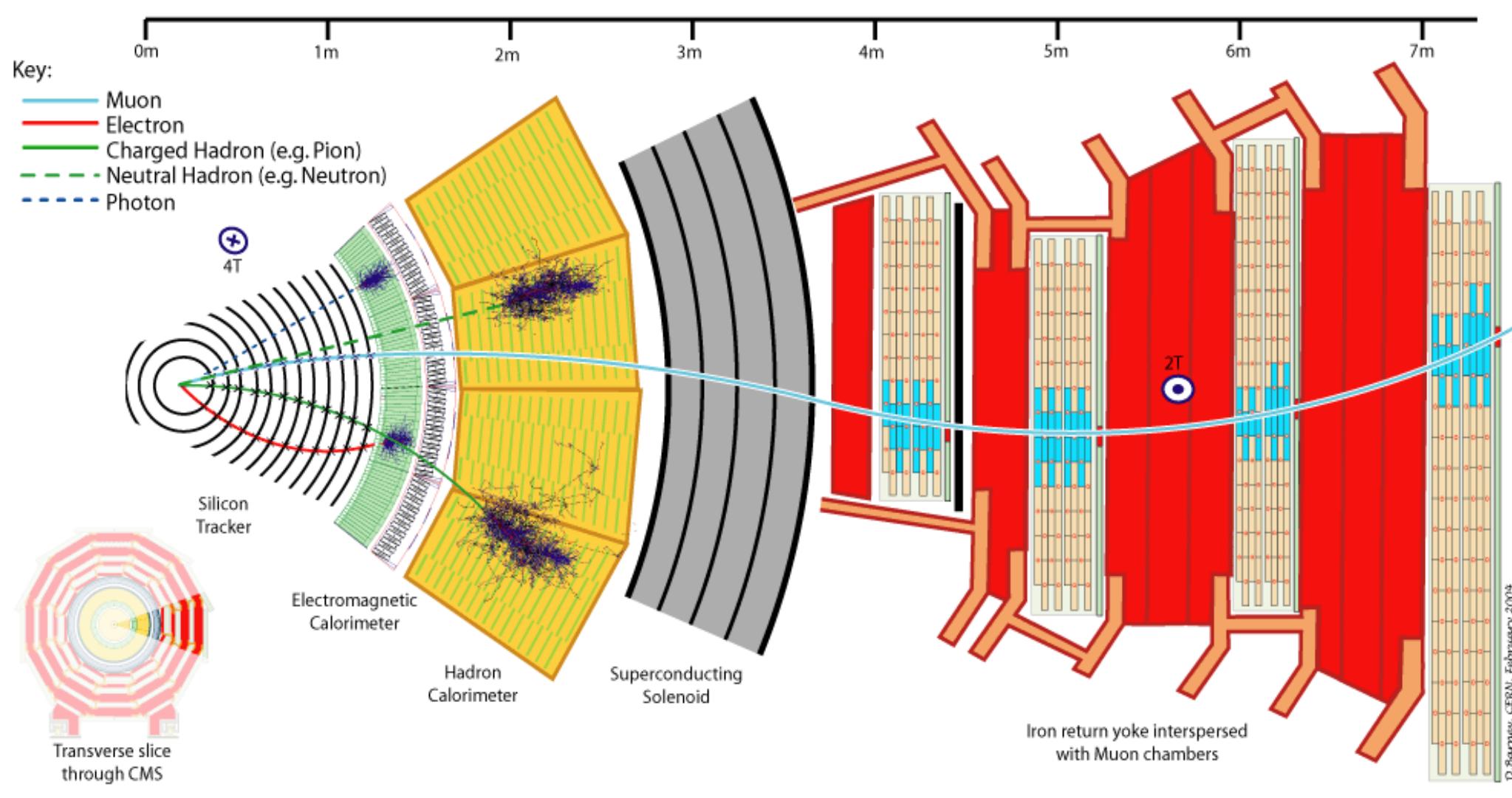
- Aim is to search for Signatures of :
 - Origin of mass
 - Supersymmetry
 - Dark matter
- Designed Specifications :
 - Proton-Proton bunch circulating in 26659m circumference synchrotron.
 - Accelerate protons up to 7TeV.
 - 1.1×10^{11} protons **collide every 25ns**.
 - Dipole and quadrupole magnets steer proton beams.



Compact Muon Solenoid



Particle Detection

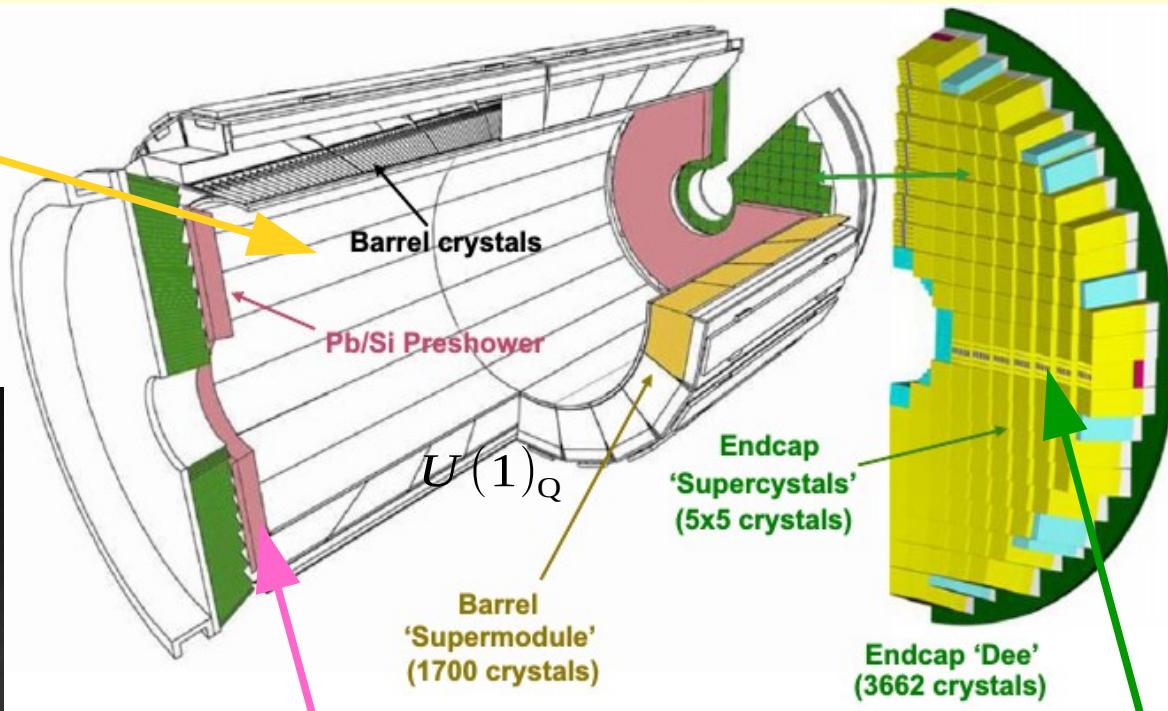
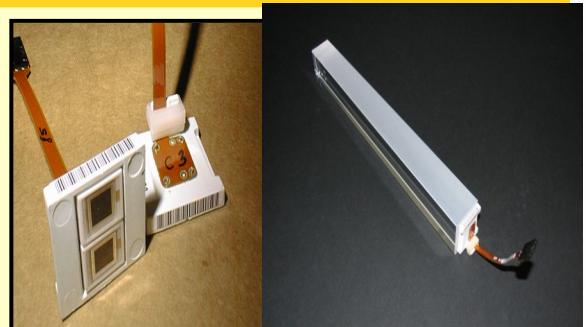


Electromagnetic Calorimeter

Lead Tungstate Homogeneous crystal calorimeter

Barrel(EB)

- 61200 crystals
- Covers $|\eta| < 1.48$
- Uses APDs



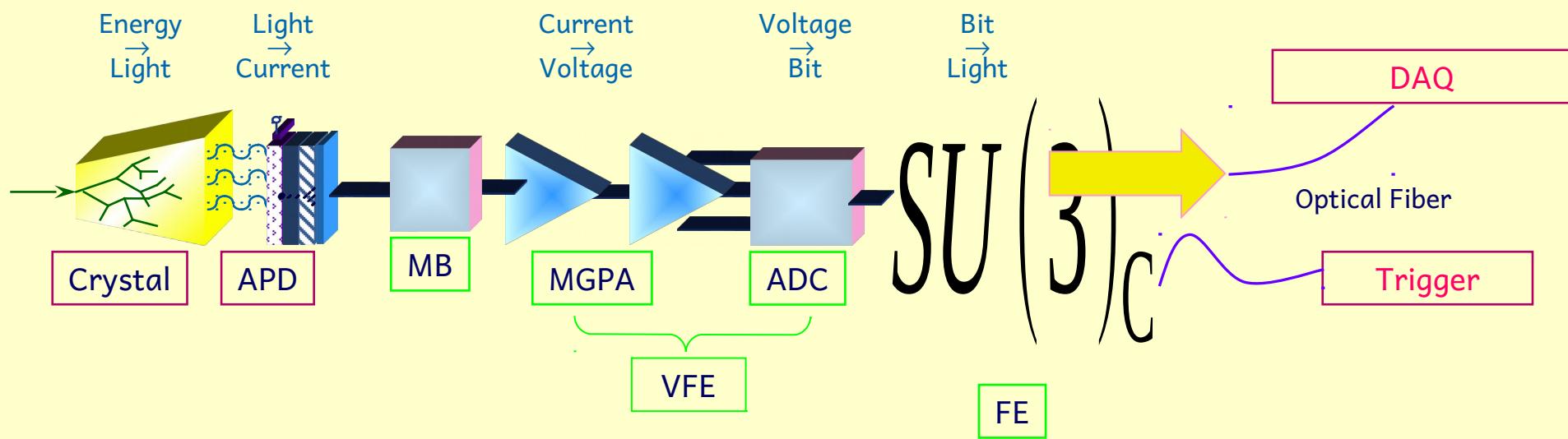
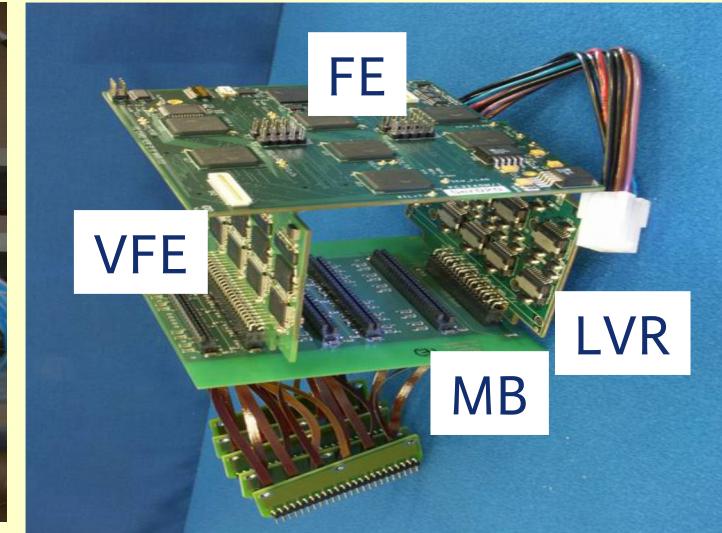
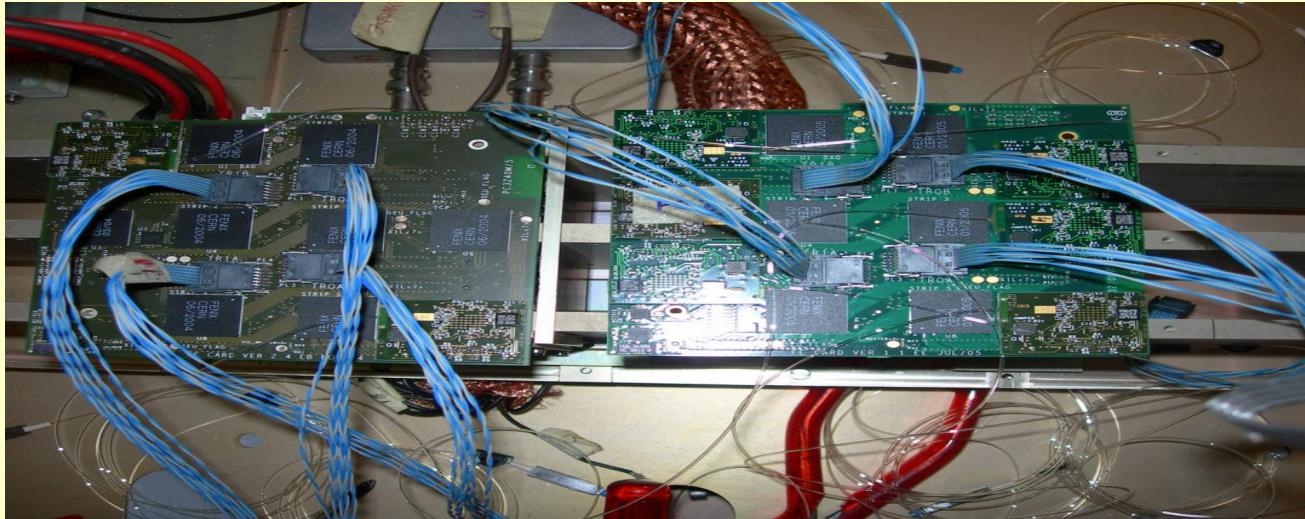
Preshower(ES)

- Pb/Si sampling calorimeter
- Covers $1.65 < |\eta| < 2.6$
- 137216 Silicon Strips

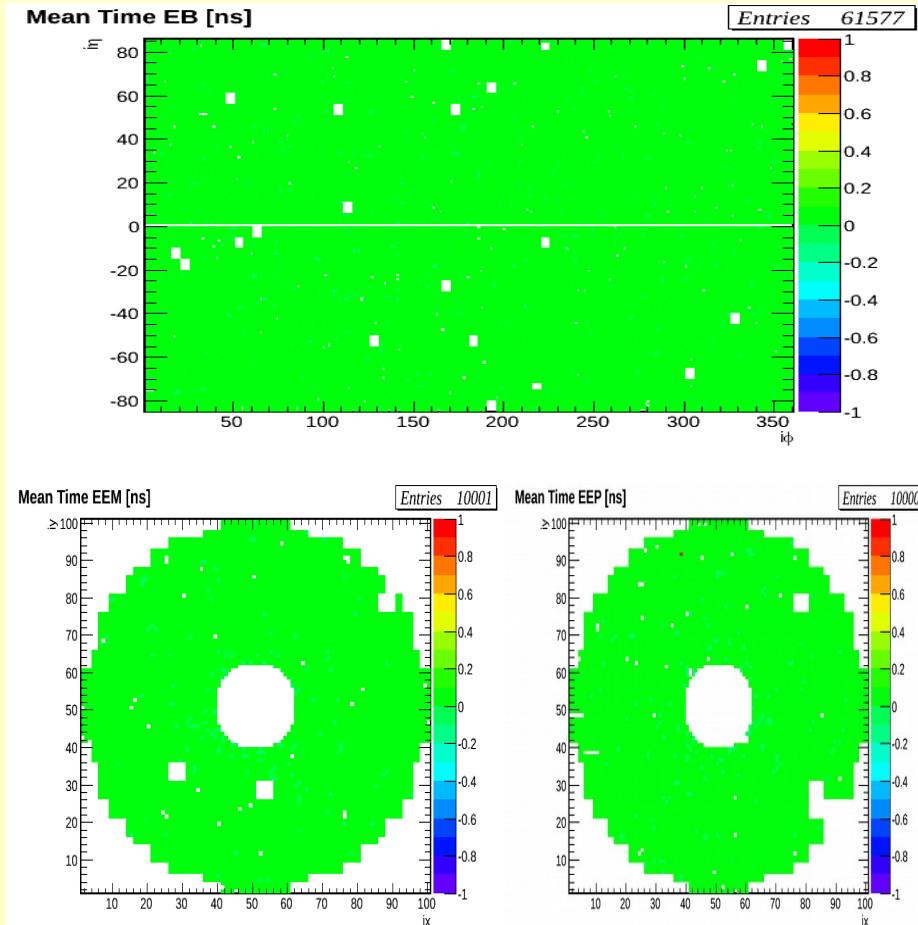
Endcap(EE)

- 2 Endcap sides each 7324 crystals
- Covers $1.48 < |\eta| < 3.0$
- Uses VPTs photodetectors

ECAL ReadOut Electronics

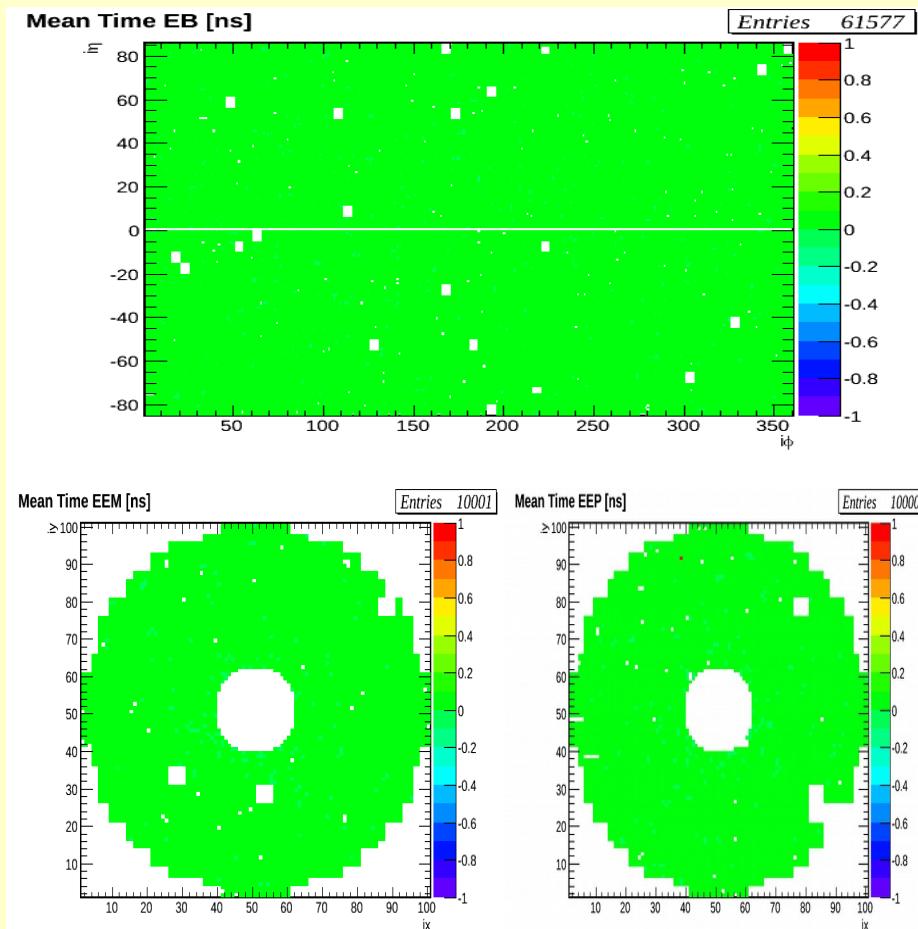
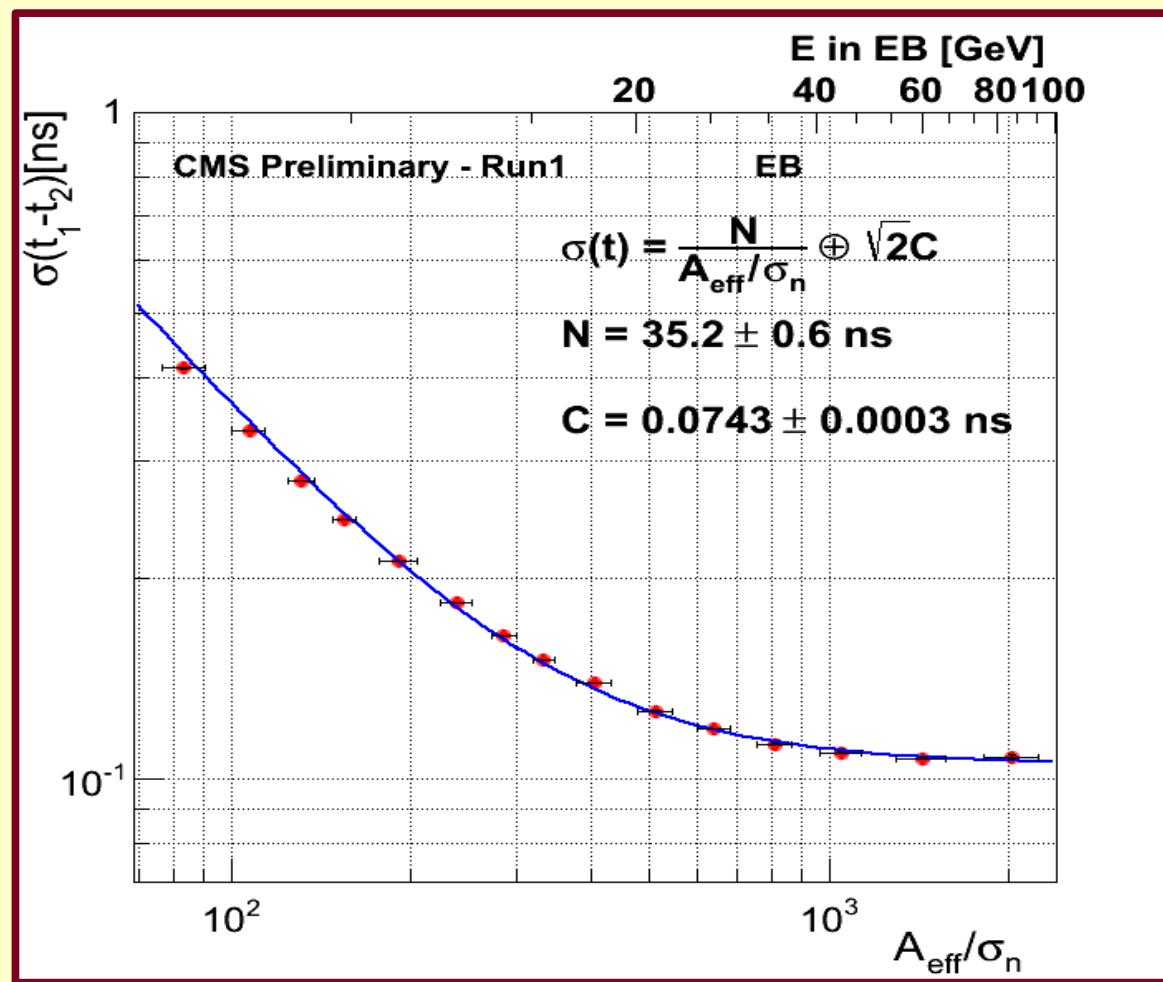


ECAL Time Measurement



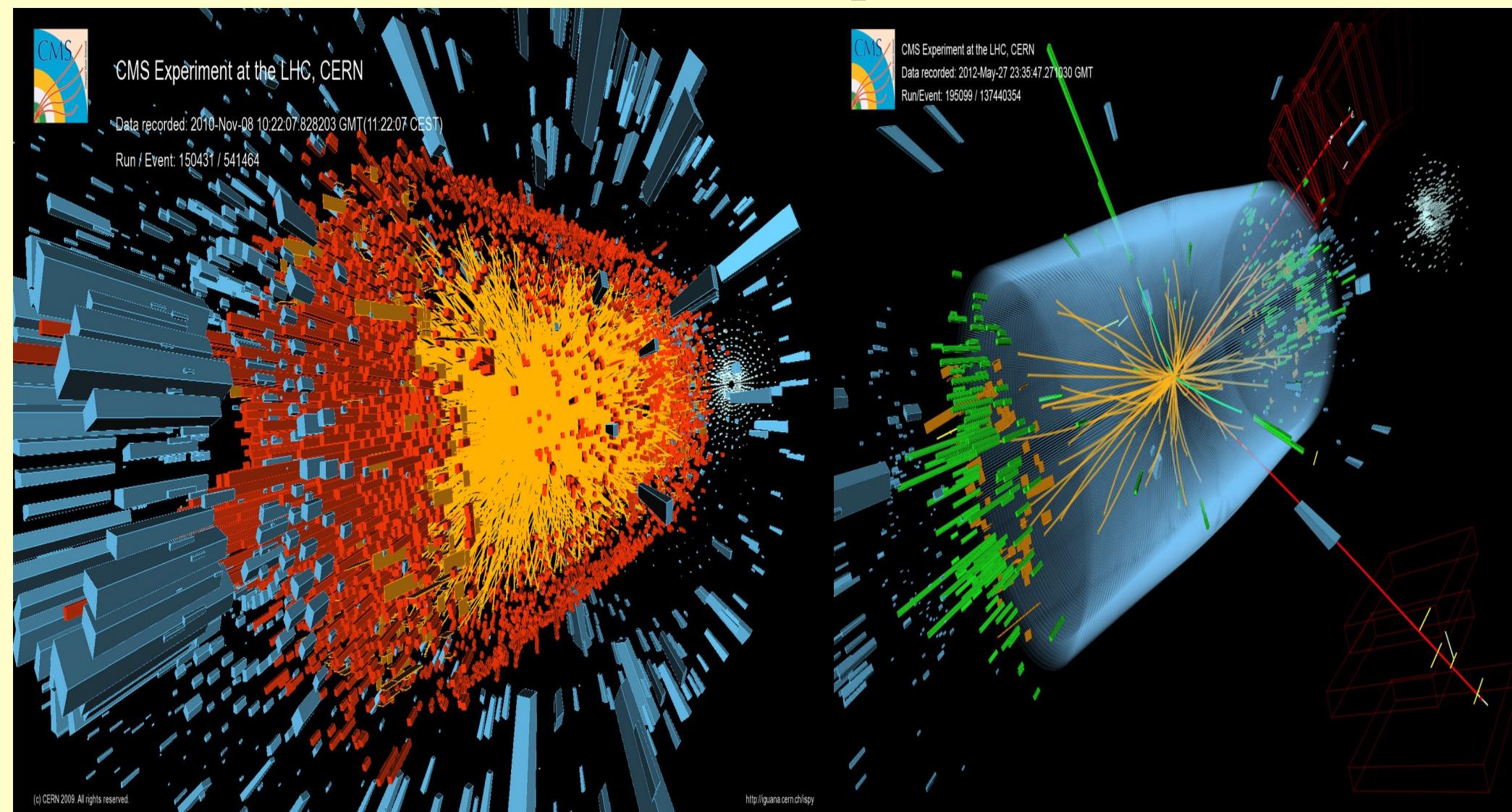
ECAL timing resolution better than 400ps.

ECAL Timing Resolution



ECAL timing resolution better than 400ps.

CMS Event Display



Search Analysis



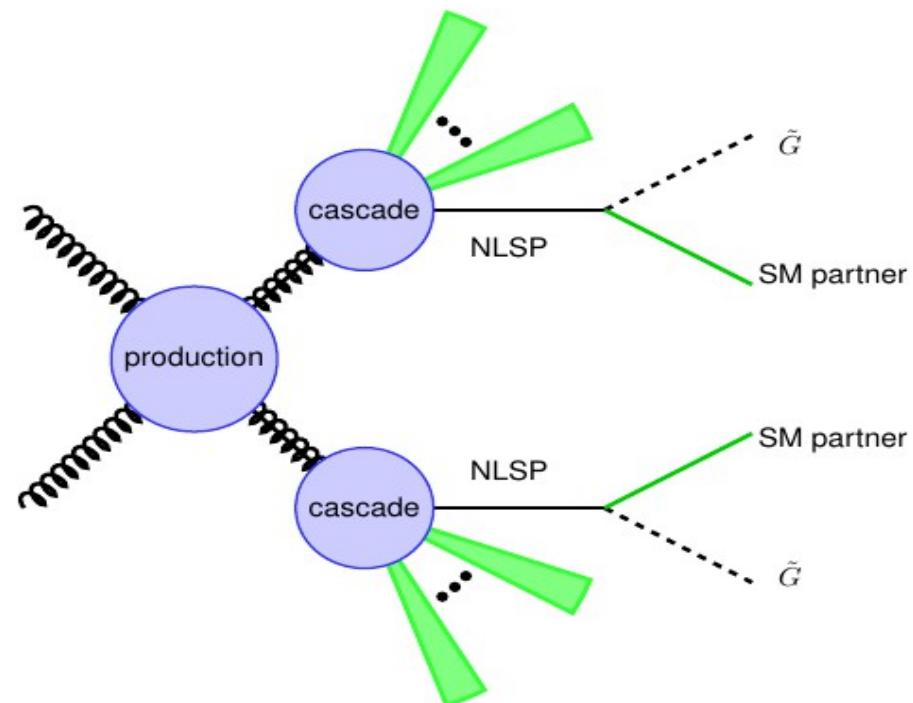
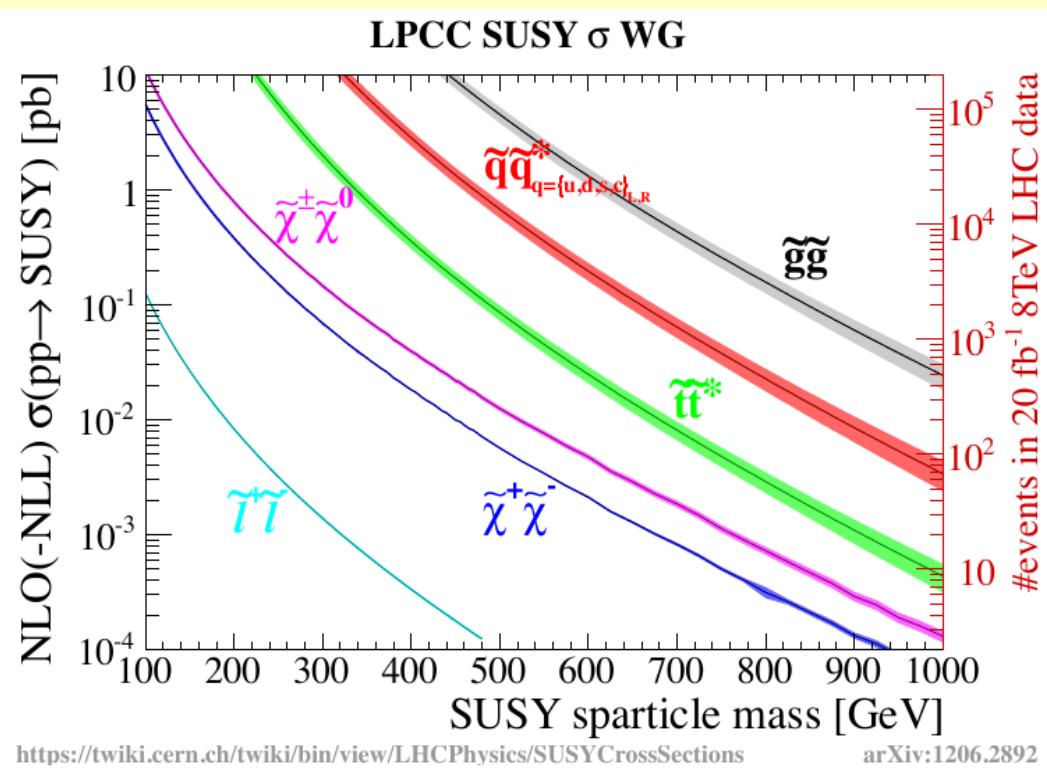
GMSB-Theory Model

- GMSB=*Gauge Mediated Supersymmetry Breaking Model.*
 - Long-lived particle is the supersymmetry **Neutralino**.
 - Neutralino disintegrate into a **Delayed Photon** and a weakly interacting particle called **Gravitino** observed in the detector as **Missing Transverse Momentum(MET)**.
 - We use photon arrival time(**TIME**) at electromagnetic calorimeter to observed delayed photon.
 - Parameters Decay length (**ctau[mm or ns]**) and supersymmetry breaking energy scale, (**Lambda[TeV]**) determines the **Lifetime[mm or ns]** and **Mass[GeV/c^2]** and **momentum[GeV/c]** of neutralino.

New Particles @ LHC

Event Rate = Cross Section(E)[cm²]*Luminosity/[s cm²]*Efficiency

- 1 barn[b] = 10⁻²⁴cm²

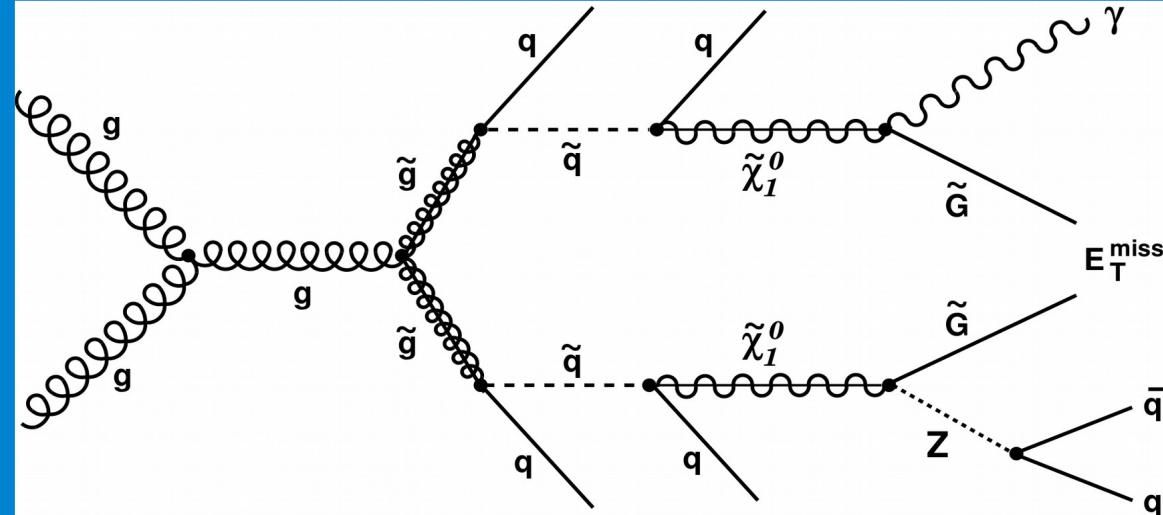


Supersymmetry produced at LHC in strong interactions.

Signal & Background

Signal Events

- ≥ 1 Late Photons +
- ≥ 2 Jets +
- Large MET



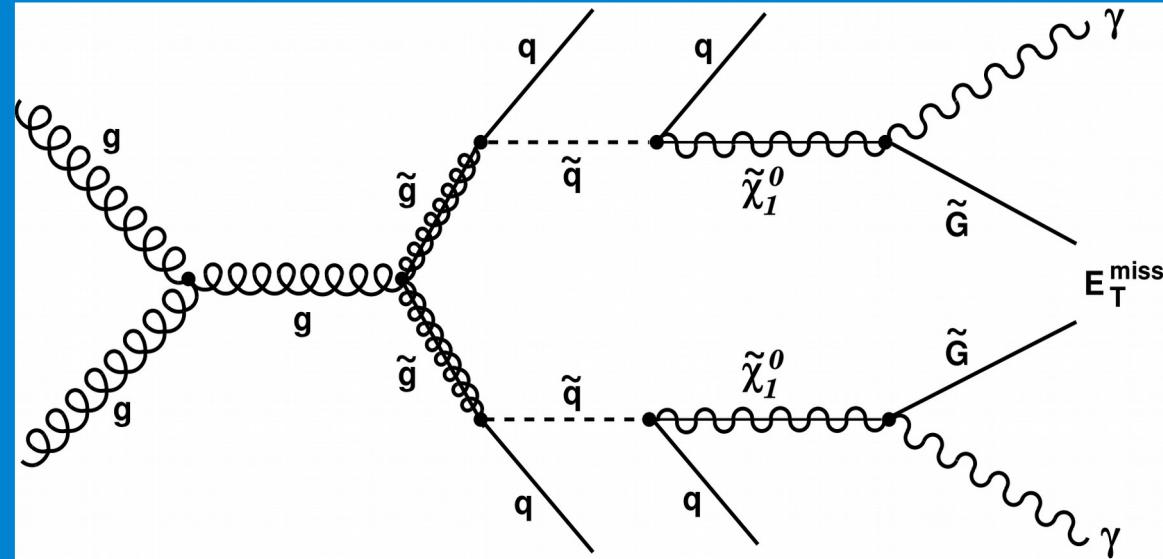
Background Events

I. Collision Events

- Events with similar topology,
- Anomalous events.

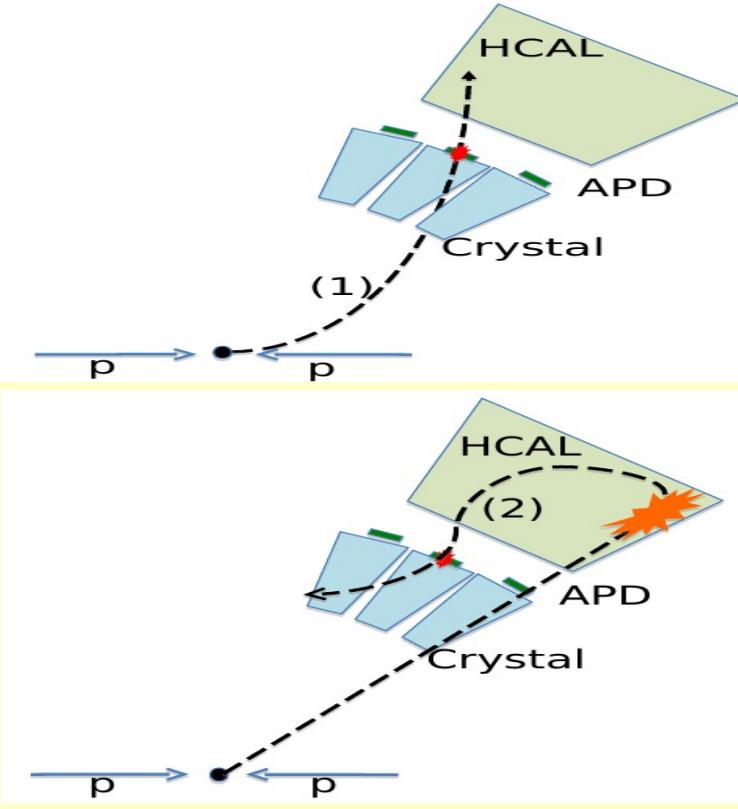
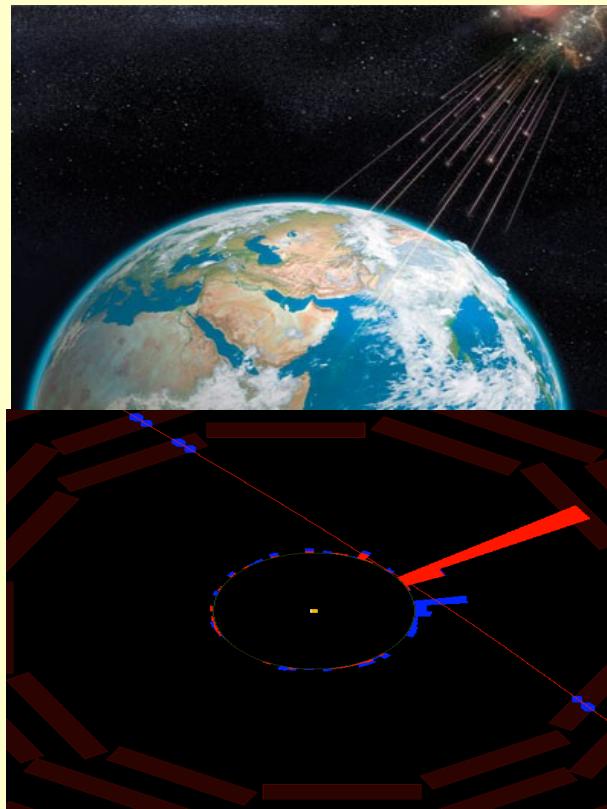
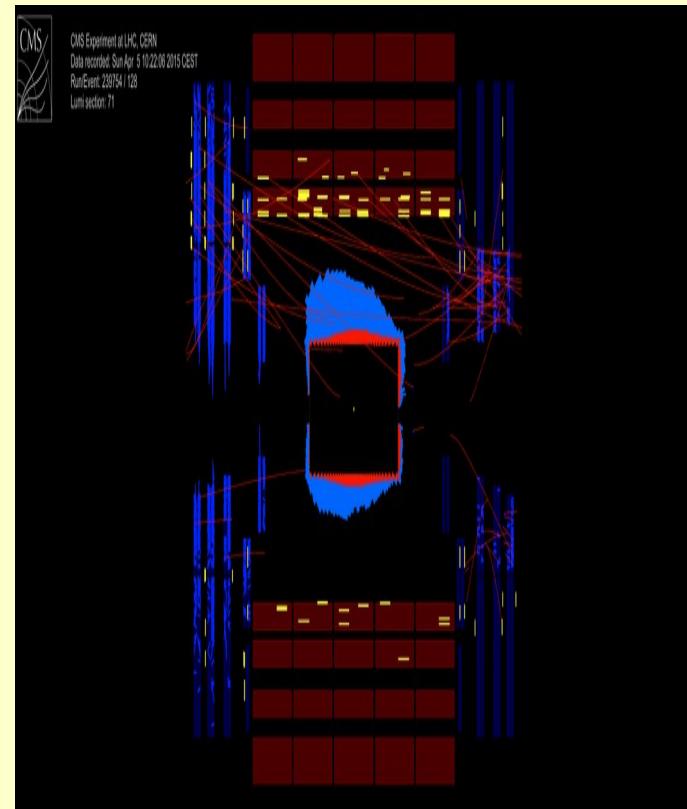
II. Non-Collision Events

- Beam Halo Muon Events,
- Cosmic Muon Events.



Non Collision Events

- Can arrive late as delayed real photons.
- Can also pass our event selection criteria.



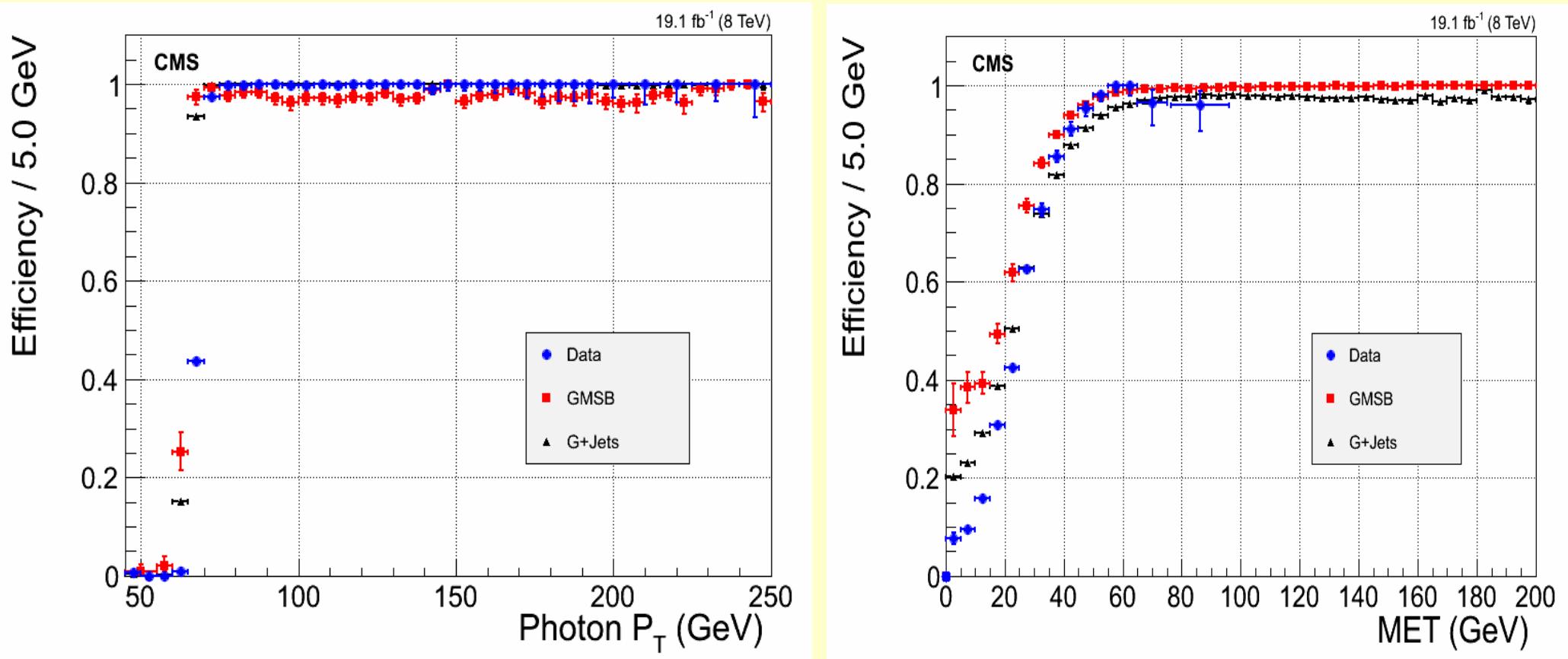
- Beam Halo Events

- Cosmic Muon Events

- Spike Events

Data & Triggers

Triggered SinglePhoton DataSet Total = 19.1/fb



We select events by cutting where efficiencies become flat.

Event Selection

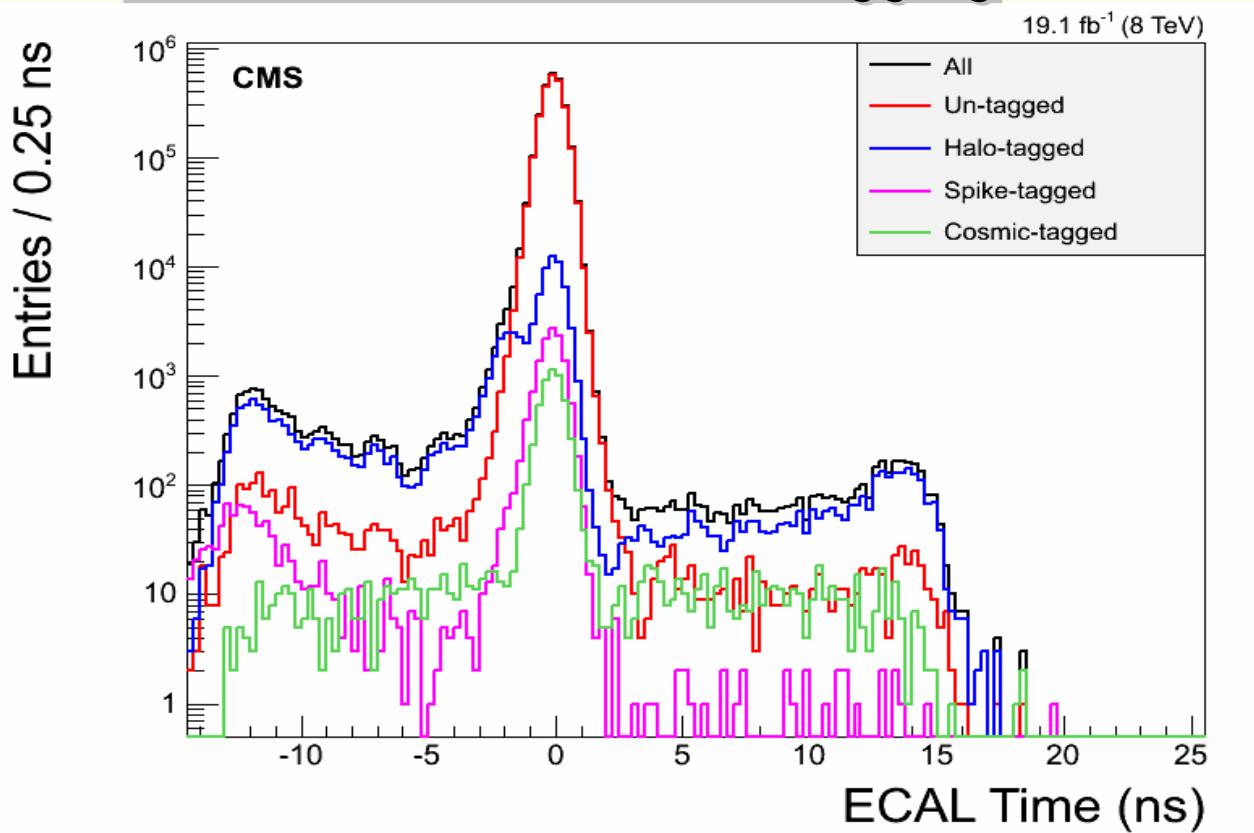
- Signal candidate events are selected by applying selection cuts on event properties and observables.

Quantity Description	Variable	Selection Cuts
Photon Transverse Momentum	Pt	> 80 GeV/c
Detector Acceptance Region	eta	< 1.48
Other Quality events Cuts		
Jets Transverse Momentum	Jet Pt	> 35 GeV/c
Number Of Jets in Event	Njets	≥ 2
Missing Transverse Momentum	MET	> 60 GeV
Photon Arrival ECAL Time	ECAL Time	> 3 ns



Background Estimation

After Event Selection & Tagging



Miss-Tag Event Rate

Beam Halo Muons.	5 %
Cosmic Muons.	6%
Anomalous or Spike.	1.5%

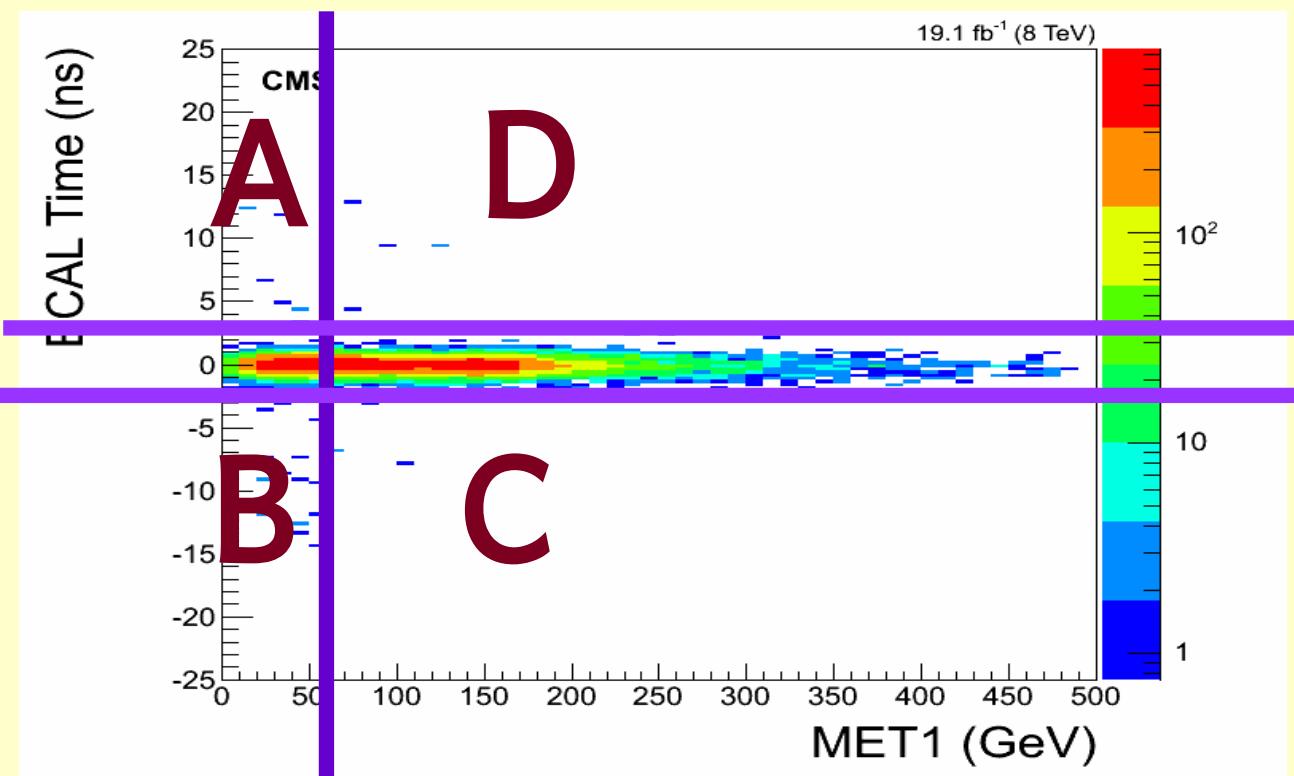
Our selection still does not completely remove ALL background events.



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Background Estimation

ABCD background estimation using observed variables TIME and MET.



$$A/B = D/C$$

$$\Rightarrow D = C * A/B$$

- Compare D **from expectation** with D **from observation** to validate method.



Results



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Results

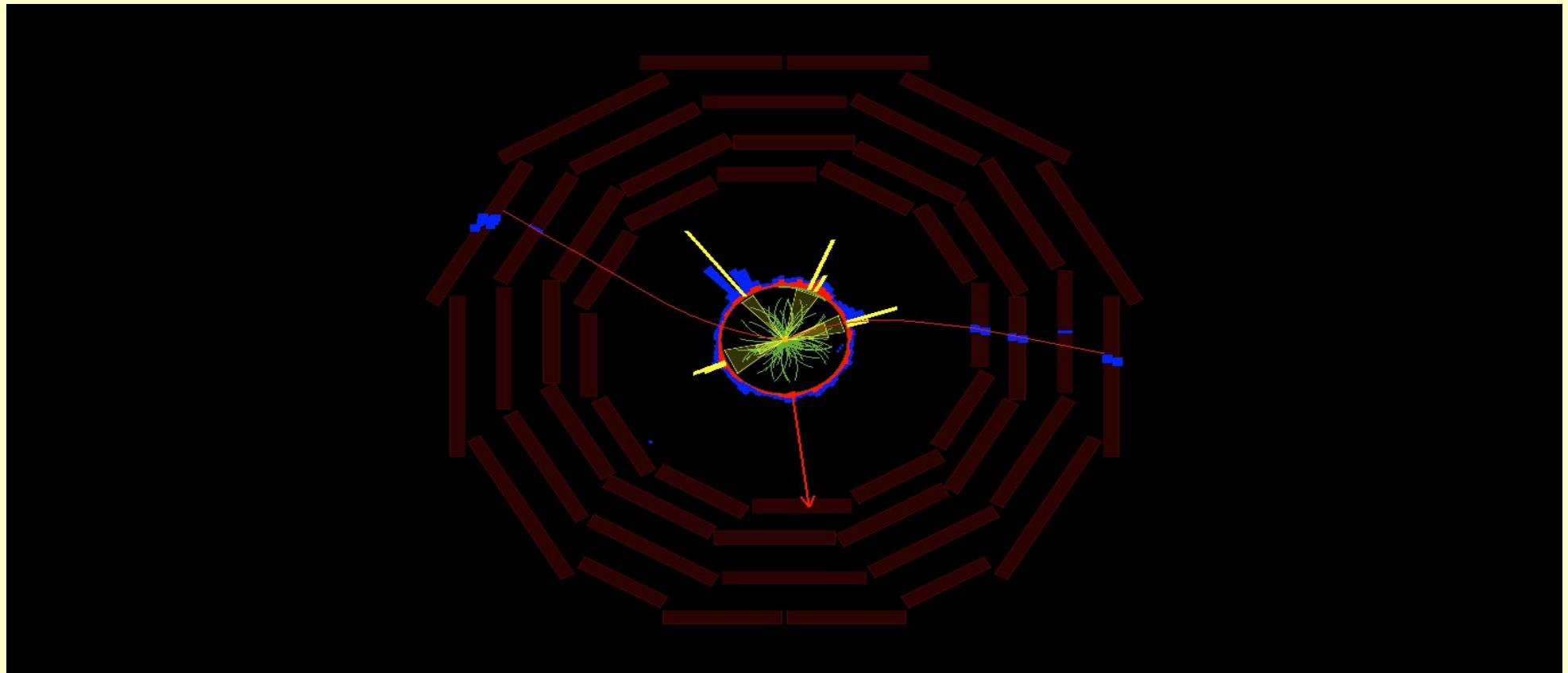
- **Expected Number of Events = 0.088**
- **Observed Number of Events = 1**
- This Observed event turns out to be a cosmic muon mimicking the signal of a new Long-lived particle.
- We produce limit on the mass and lifetime of a long-lived neutralino decaying to a delayed photon in the GBSM model.



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Observed Event Display

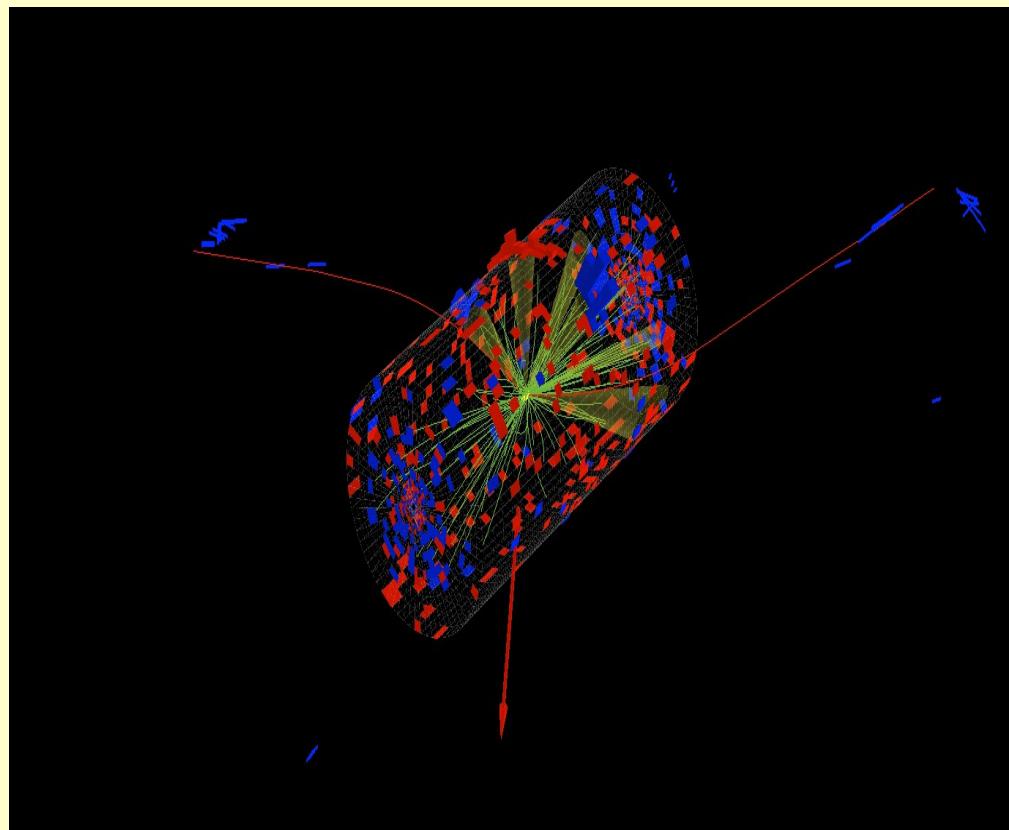
CMS Detector Transverse View



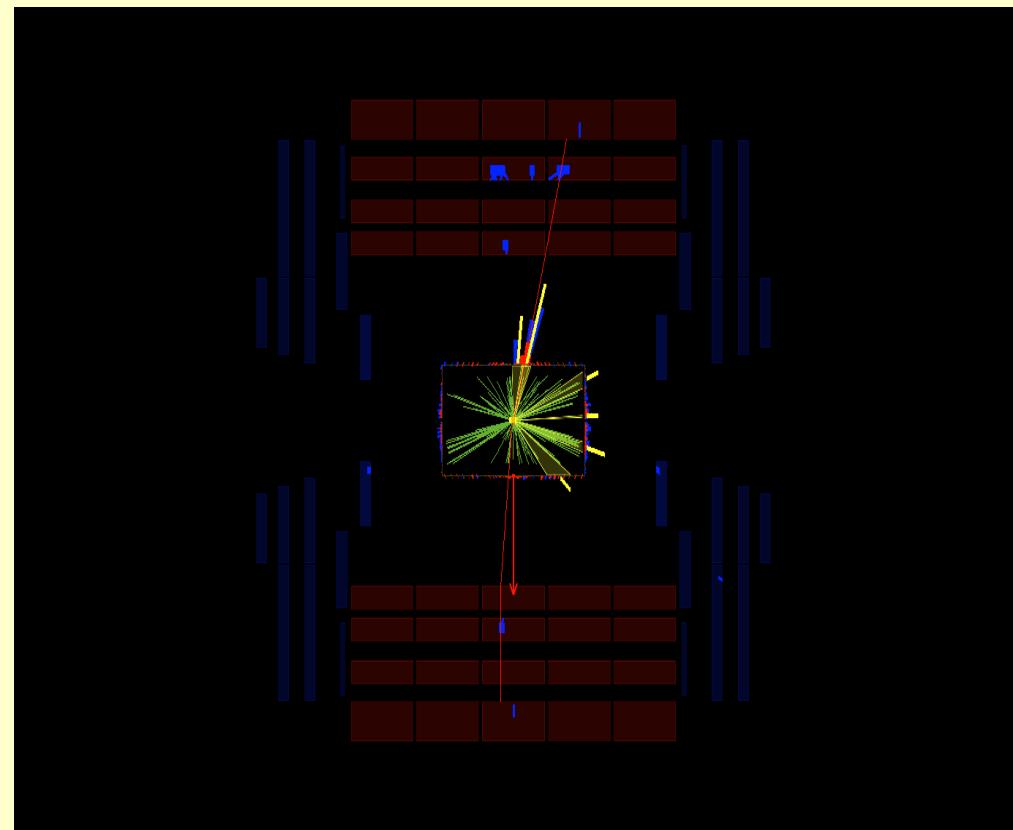
CMS event display of observed cosmic muon event in CMS detector.

Observed Event Display

3D View

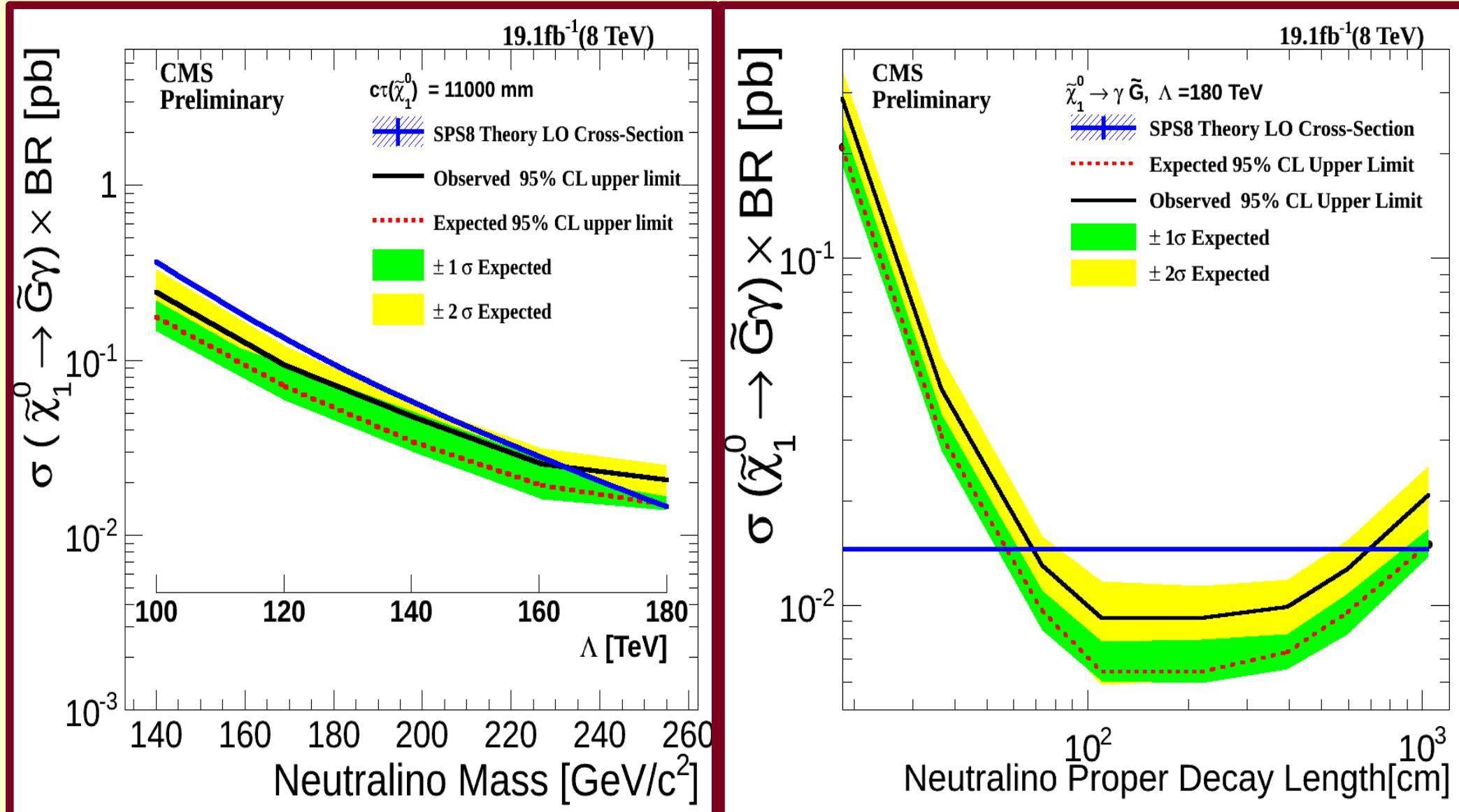


Rho – Z View

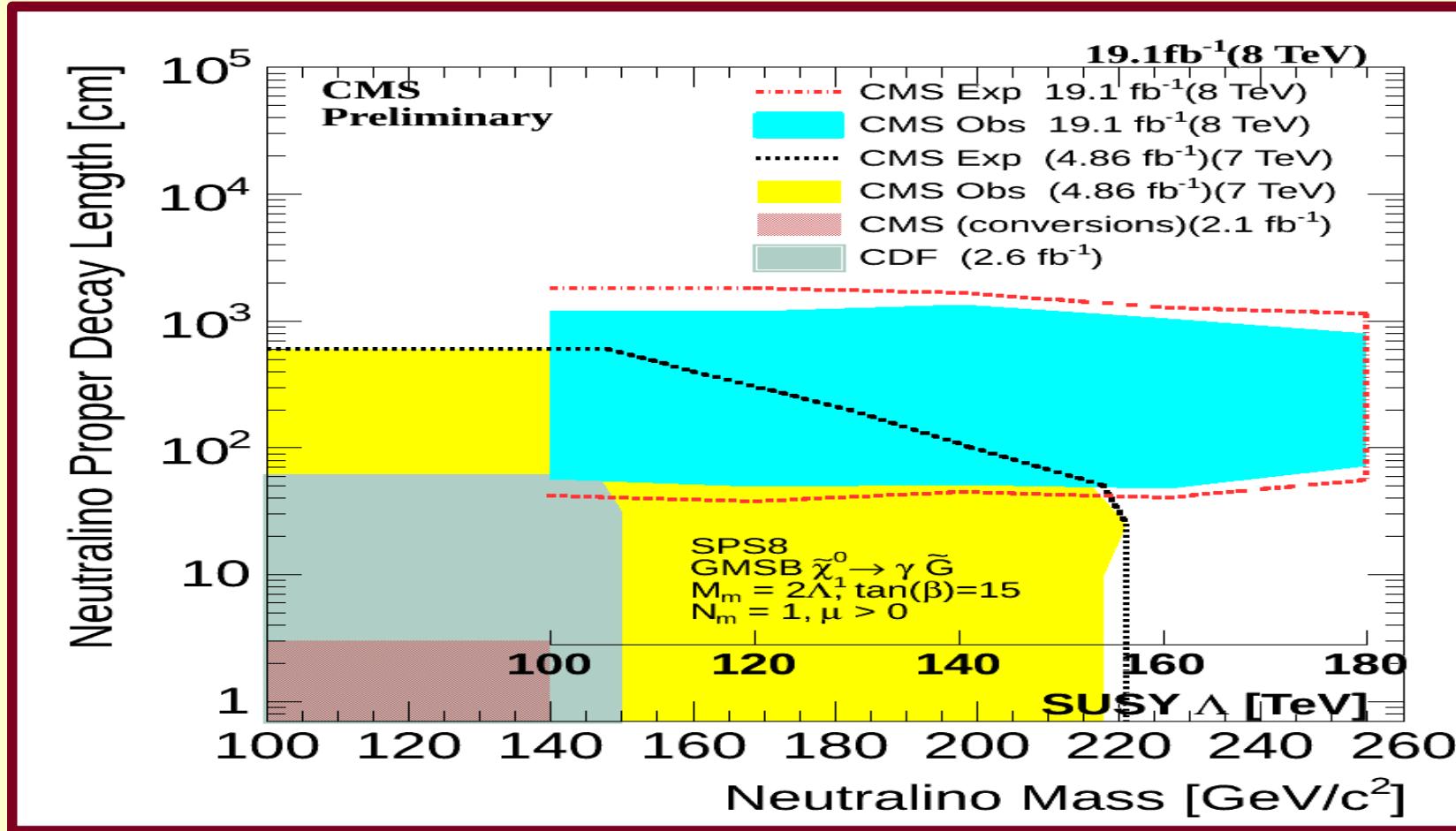


CMS event Display of observed Cosmic Muon event in CMS detector.

Limits: Mass & Lifetime



Limits: combined



Excluded Supersymmetry Neutralino particles
with **Mass < 258 GeV/C^2** and **Lifetime < 35 ns.**

Summary



Summary

- Motivation for performing a search for long-lived neutral particles at LHC.
- Brief description of LHC collider and CMS detector particularly the ECAL as used.
- We presented a search analysis for neutralino as a long-lived particle decaying to photon using CMS detector. ECAL timing measurement of the photon arrival time is used for identifying the delayed photon.
- The search result is presented and limits shown for neutralino mass and lifetime.
- Excluded regions relevant for future similar search for neutralino is also presented.

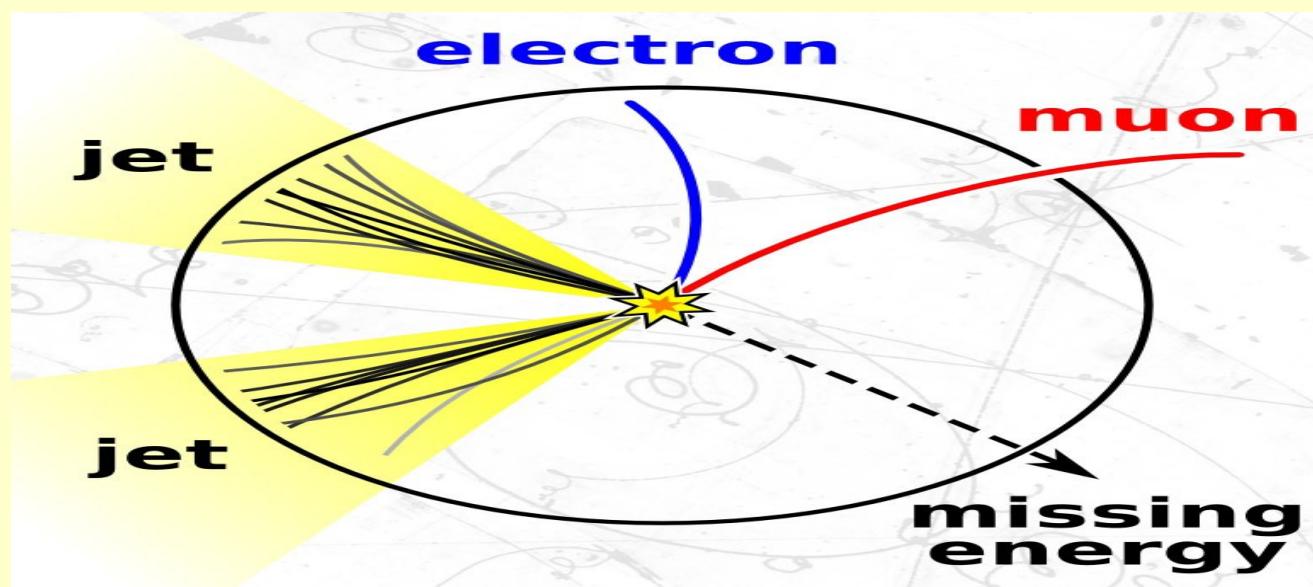
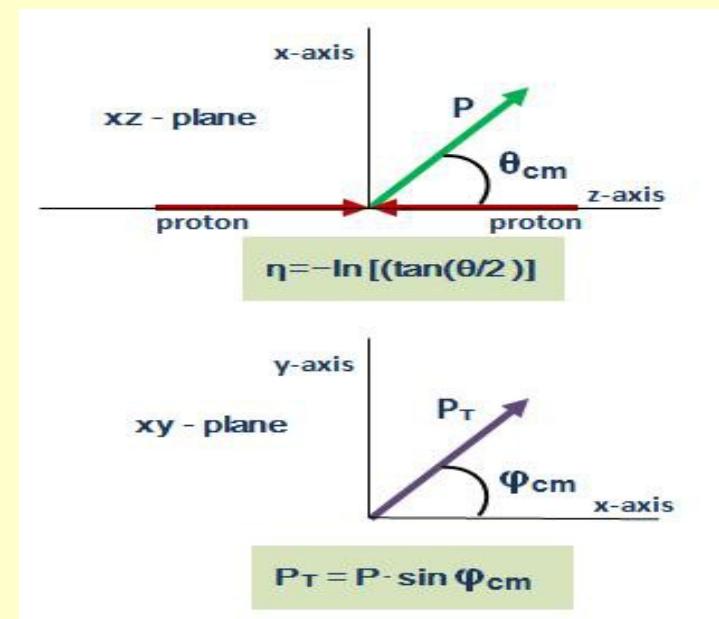
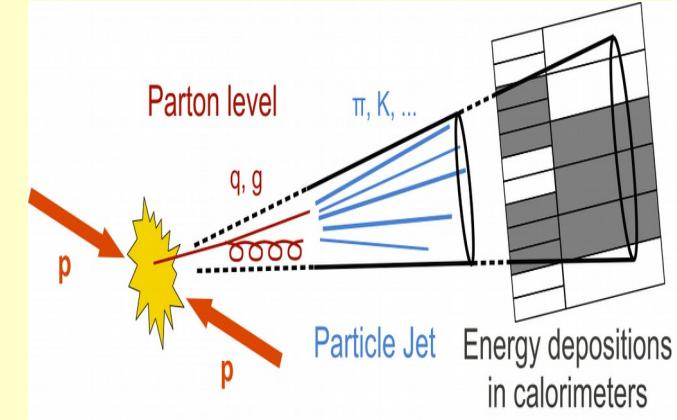
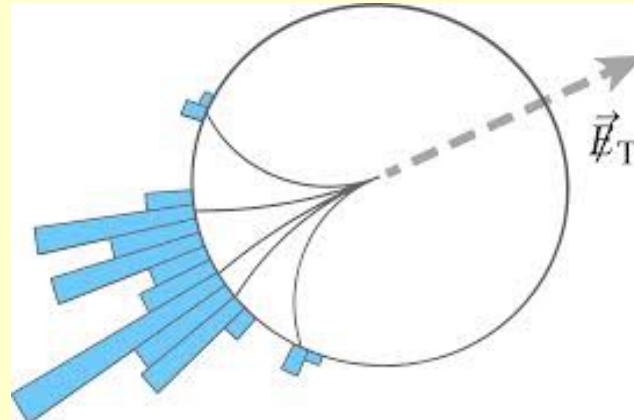
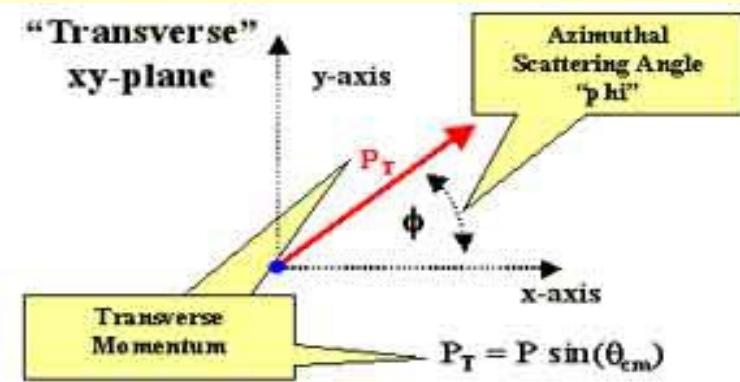


Thanks A LOT!



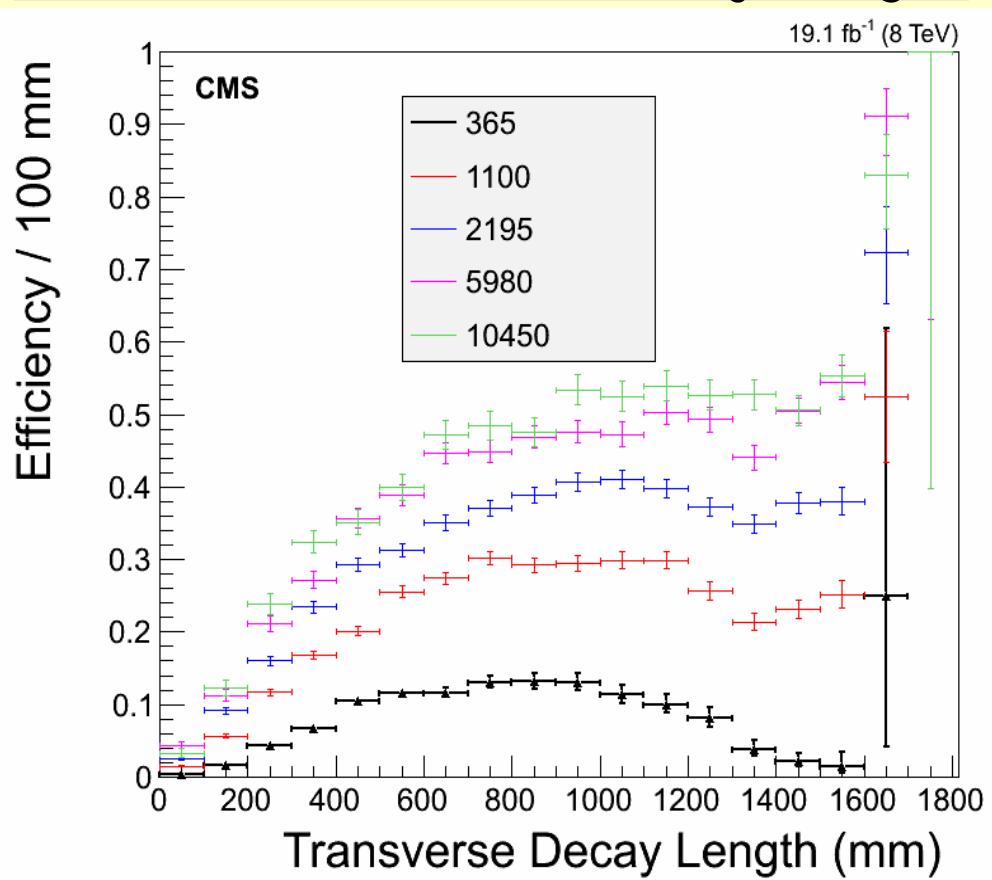
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BackUp: Physics Objects in CMS

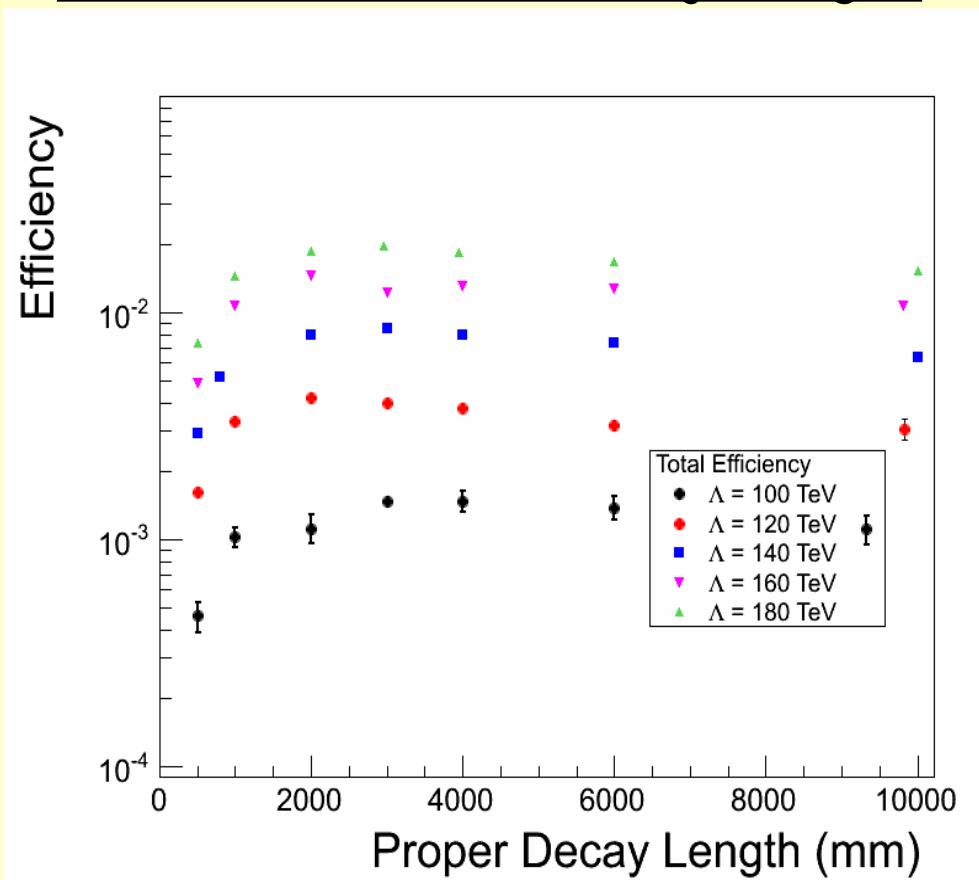


Efficiency & Acceptance

Transverse Detector Decay Length



Particle Inherent Decay Length



Efficiency and Acceptance determines our final Observed event rate.

Systematics

- The possible sources of systematics considered in this search analysis and their contribution.

Systematic Uncertainties.

<u>Systematic Source</u>	<u>Uncertainty(%)</u>
Absolute Reference ECAL Time	10% to 6%
Unclustered Energy	10% to 4%
Photon Energy Scale	4% to 2%
ECAL Timing resolution	5% to 2%
Jet Energy Scale	9% to 3%
Jet Energy Resolution	9% to 2%
Luminosity and Choice of PDF	2.6 and < 1%



Dark Matter?

Properties

- Stable(long-lived).
- Neutral; does not interact with light.
- Light or massive?



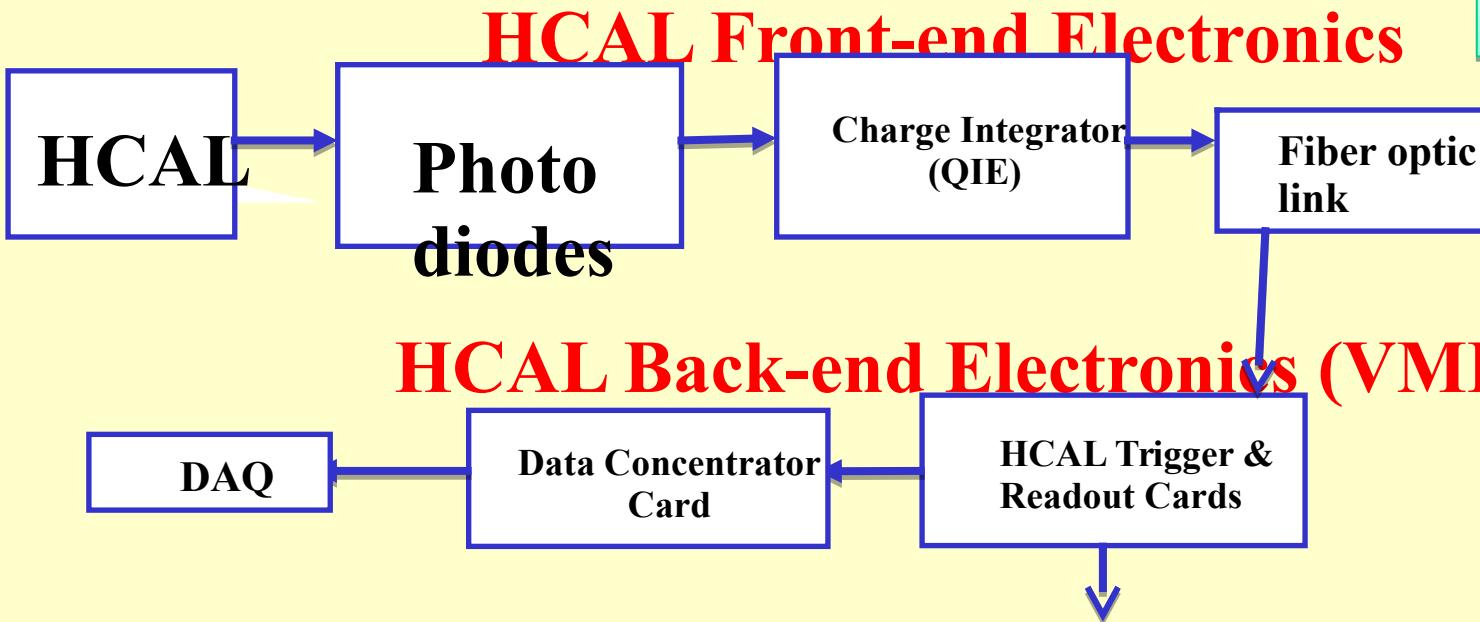
- Where are Dark Matter particles?



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HCAL Electronics Upgrade

How data flow from HCAL-front-end to back-end electronics



Current back-end (VME)



Future back-end (μ TCA)



Micro Telecommunication and Computing

Architecture(uTCA) to handle high bandwidth for global DAQ. Current data transfer rate based on VME is 1.6Gb/s compared to 4.8Gb/s for uTCA.



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