Dark Matter Production with Boosted W / Z Bosons at Large Hadron Collider - LHC

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Outline

- The Large Hadron Collider (LHC)
- The Compact Muon Solenoid (CMS) detector
- Dark matter and its study at LHC
- Analysis of Monte Carlo simulations
- Results and Conclusion

The Large Hadron Collider(LHC)

- World's largest particle accelerator
- Purpose:origin of mass, nature of dark matter, investigate the missing anti-matter, creation of quark-gluon plasma
- 6 detectors: ATLAS, CMS,ALICE, LHCb, TOTEM, and LHCf

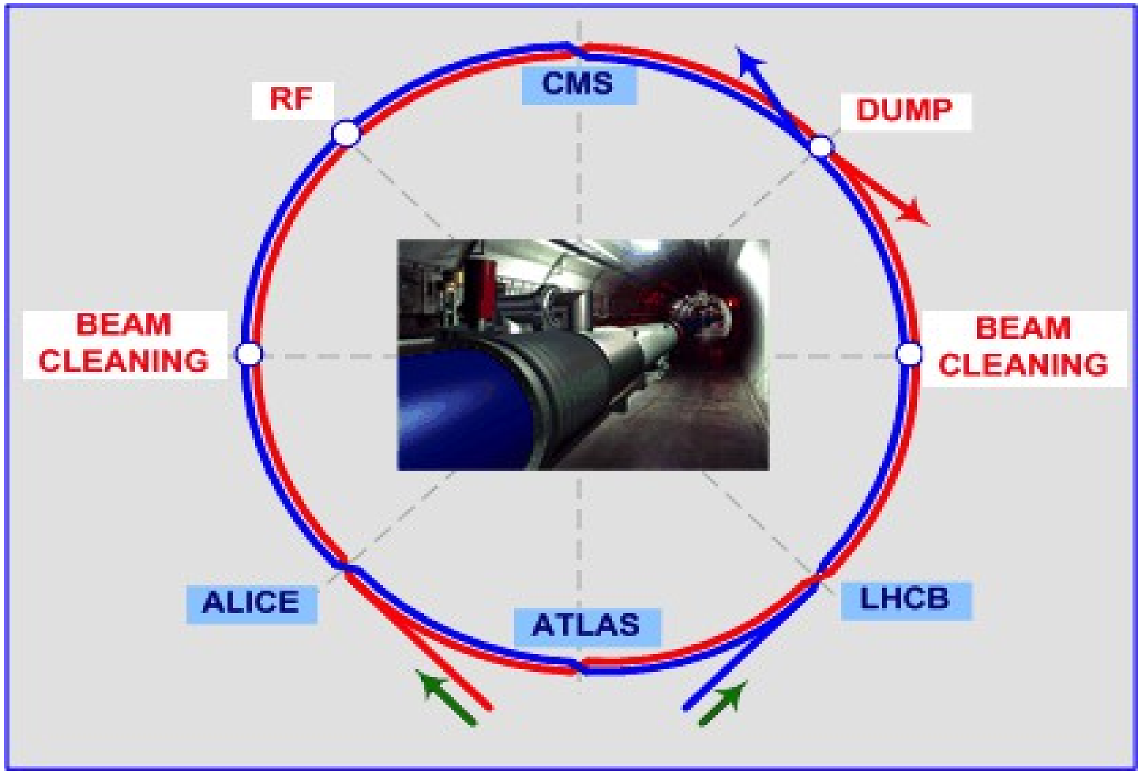

Fig. 1: The LHC tunnel and detectors

The Compact Muon Solenoid(CMS)

- Dimension: 21.5m long, 15m in diameter and weighs12,500 tons.
- The point of interaction: collision location

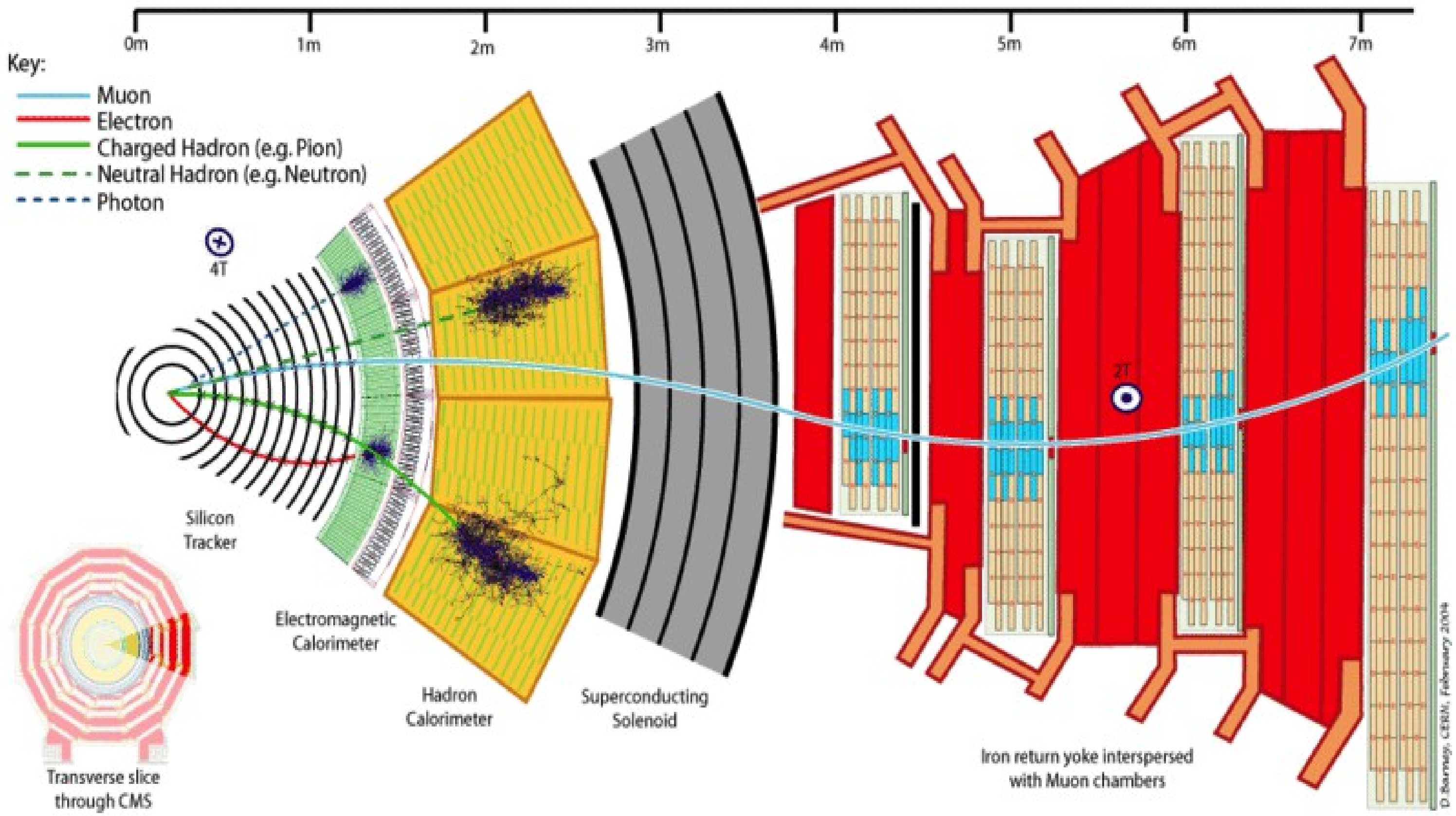

Fig. 2: CMS detector

Dark Matter

- Components of the universe

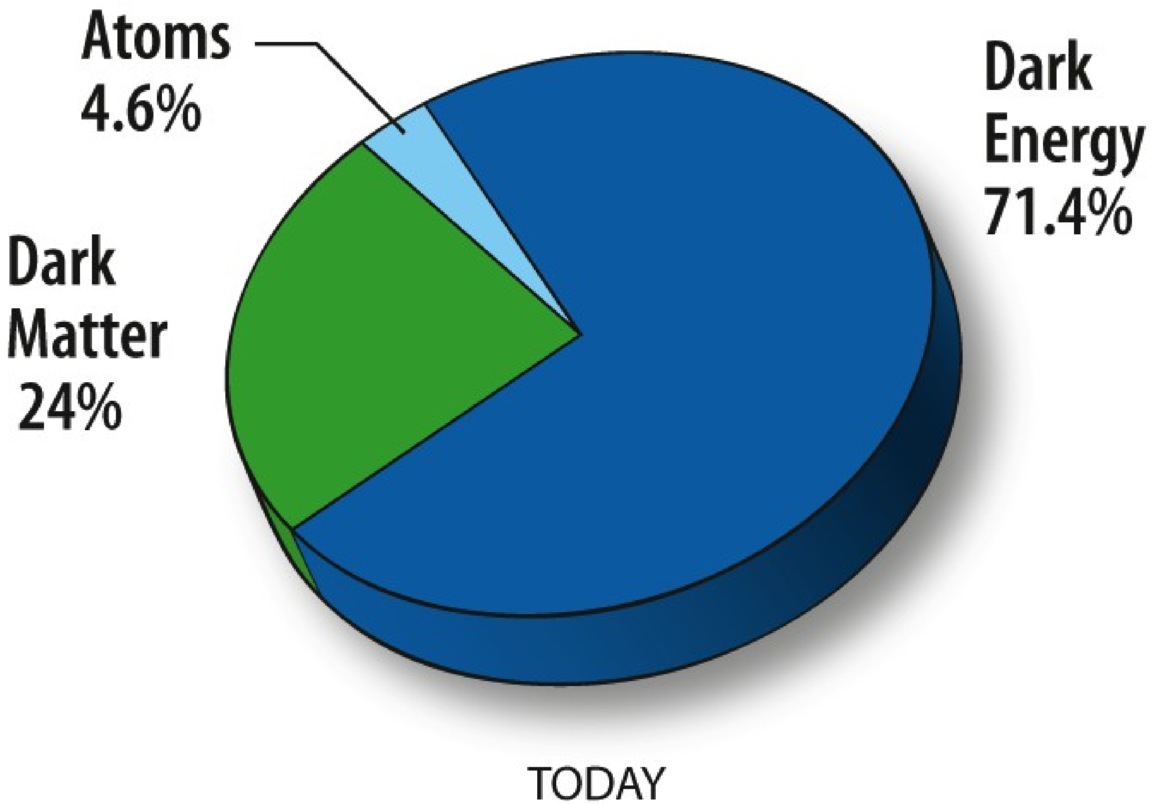

Fig. 3: Components of the Universe

Evidences of dark matter existence

- Missing mass for orbital velocity of galaxies clusters measured
- Distribution of temperature of hot gases in galaxies
- Gravitational lensing of background radiation

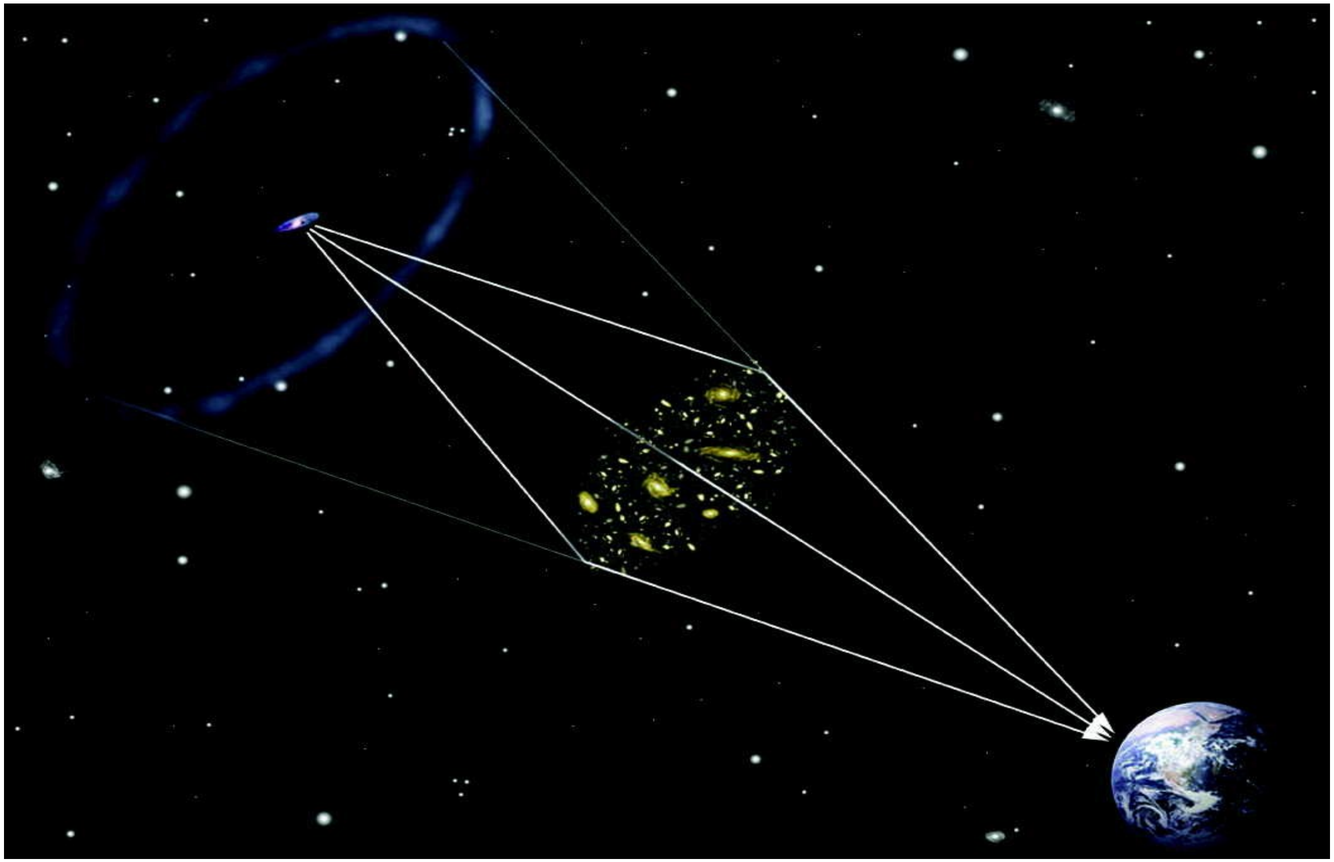

Fig.4: Gravitational Lensing

Nature of Dark Matter

- Massively compact halo Objects (**MACHO's**) ?
- Weakly interacting massive particles **(WIMPs**) ?

  Axions: neutral and less massive

  neutralinos : slower, massive neutrino

  photinos: 10-100 massive photons

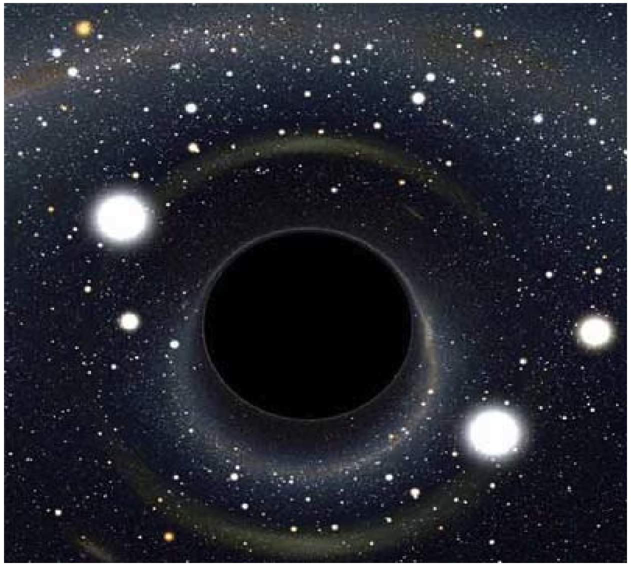

Fig. 5: Black hole

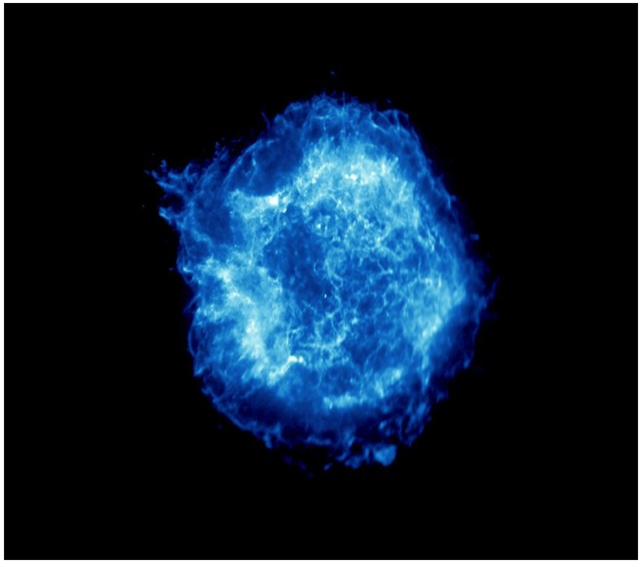

Fig. 6: Neutron Star

Dark matter study at LHC

Feynman diagram for dark matter pair production

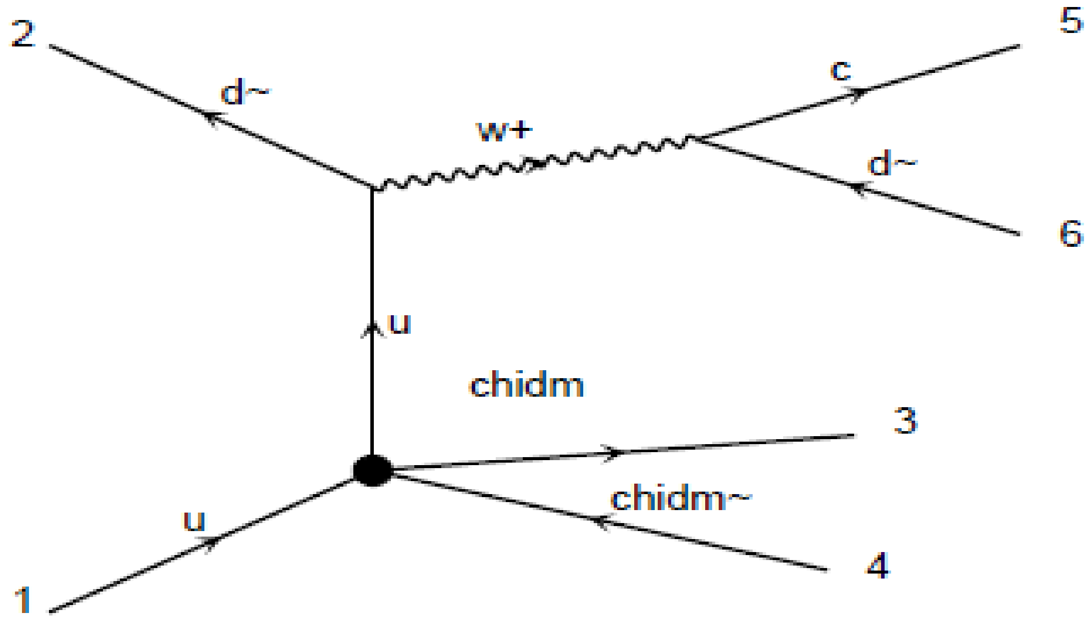

Fig. 7: A Feynman Diagram of W(JJ) DM DM~

dark matter mass = 100GeV/c^2

Backgrounds Reduction using MC

- Two types of cuts: kinematics & groomed jet substructure
- Particle Flow Jets: Kinematical variables

→ Number of jets >= 1

→ Leading Jet Pt > 130 GeV/c

→ $|\eta| < 1.5$

→ Missing Pt > 150 GeV/c

- Jet Substructure Information:

→ Lead jet mass in the W / Z range [65 – 105]GeV/c^2

→ Variables depending on the quarks from W / Z decay

Plots of the QCD Background & Signal after cuts

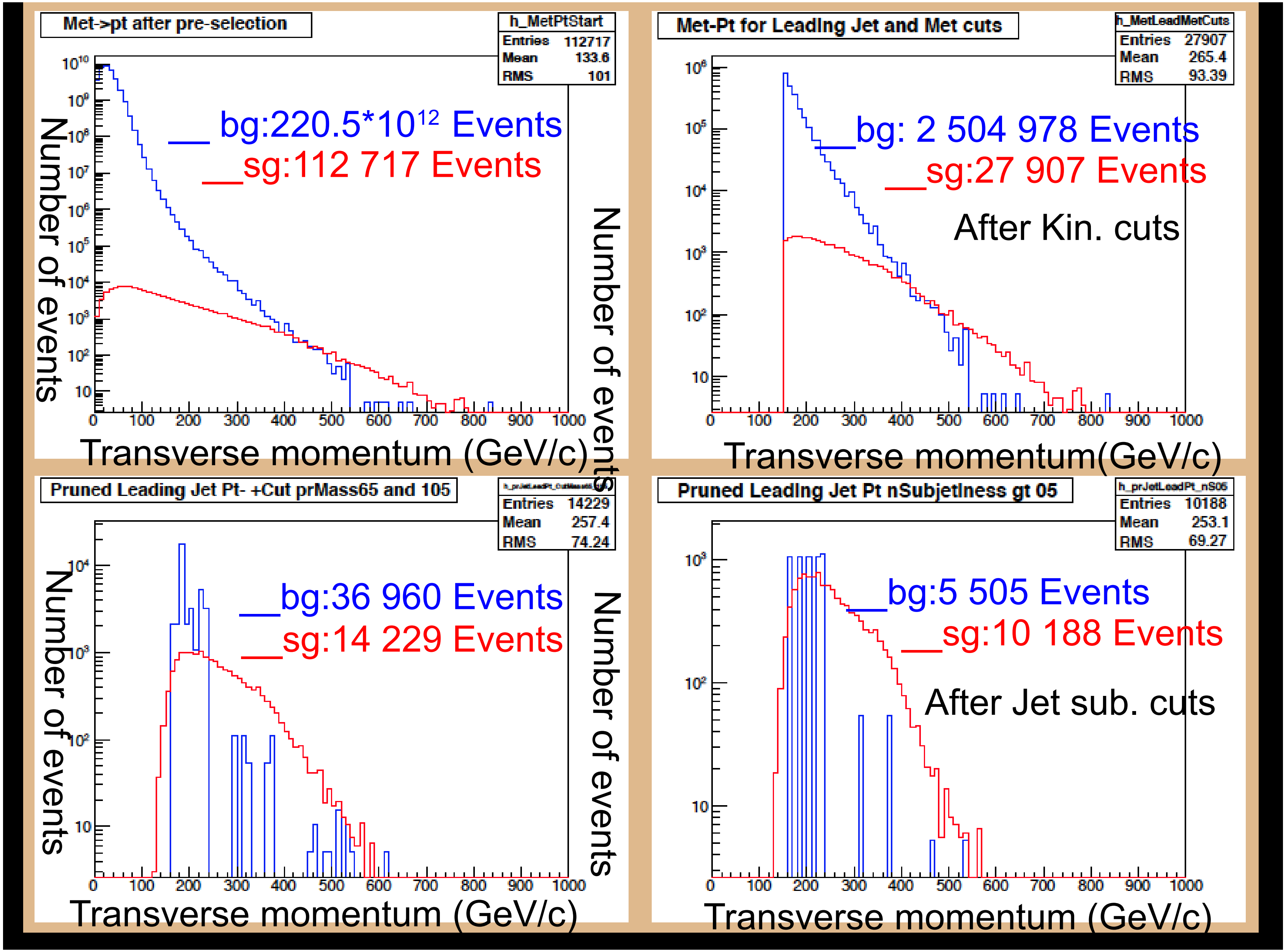

Fig. 8: QCD Background Reduction and the Signal

Signal and Background before and after cuts

Sample Name	σ(pb)	# Events Before Cuts	# Events After Cuts	# For 20 fb^{-1}
$W^{+/-}$(J J) DM DM~	0.62	112740	10188	
Bg:$W^{+/-}$(J J)$\mathcal{V}\mathcal{V}\sim$ signal	1.22	219202	1665	
Bg:QCD	192332	34.9×10^{9}	5499	
Bg:W+Jet	7669	1.4×10^{9}	82338	
Bg: ZJ$\mathcal{V}\mathcal{V}$	588	0.11×10^{9}	69153	
Sum_ Bg			158655	
Sqrt(Sum_Bg)			398.32	
Significance: Signal/sqrt(Sum_Bg)			25.58	8.5

Table 1: Signal and Backgrounds Before and After Cuts

Significance Values

- Significance Table

A	B	C	D
zσ	**Percentage within CI**	**Percentage outside CI**	**Fraction outside CI**
0.674490σ	50.00%	50.00%	1 / 2
0.994458σ	68.00%	32.00%	1 / 3.125
1σ	68.27%	31.73%	1 / 3.1514872
1.281552σ	80.00%	20.00%	1 / 5
1.644854σ	90.00%	10.00%	1 / 10
1.959964σ	95.00%	5.00%	1 / 20
2σ	95.45%	4.55%	1 / 21.977895
2.575829σ	99.00%	1.00%	1 / 100
3σ	99.73%	0.27%	1 / 370.398
3.290527σ	99.90%	0.10%	1 / 1,000
3.890592σ	99.99%	0.01%	1 / 10,000
4σ	99.99%	0.01%	1 / 15,787
4.417173σ	100.00%	0.00%	1 / 100,000
4.891638σ	100.00%	0.00%	1 / 1,000,000
5σ	100.00%	0.00%	1 / 1,744,278
5.326724σ	100.00%	0.00%	1 / 10,000,000
5.730729σ	100.00%	0.00%	1 / 100,000,000
6σ	100.00%	0.00%	1 / 506,797,346
6.109410σ	100.00%	0.00%	1 / 1,000,000,000
6.466951σ	100.00%	0.00%	1 / 10,000,000,000
6.806502σ	100.00%	0.00%	1 / 100,000,000,000
7σ	100.00%	0.00%	1 / 390,682,215,445

Stacked histogram of backgrounds after cuts

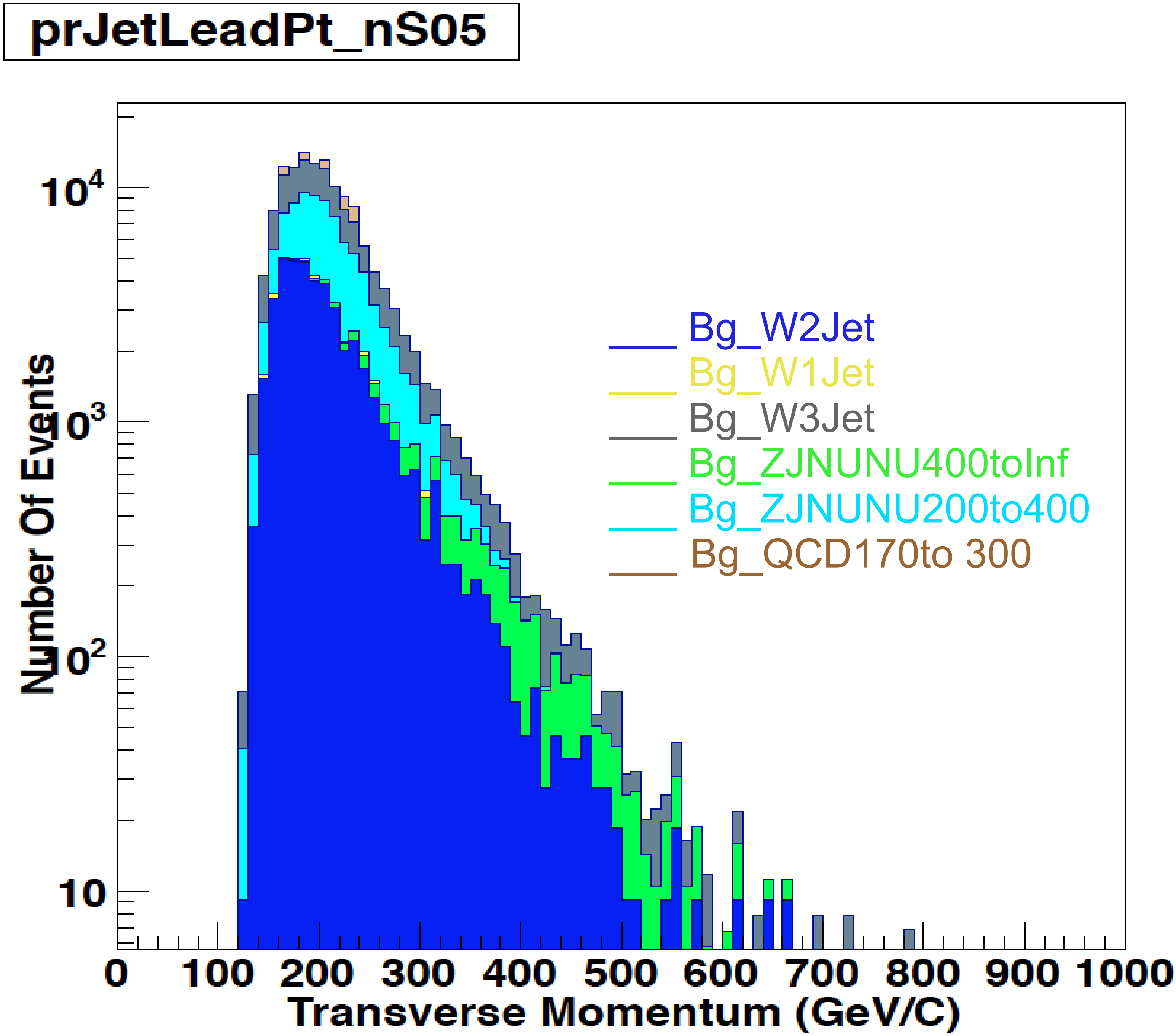

Fig. 10: Stacked Histogram of Backgrounds After Cuts

Conclusion and Future Work

- Backgrounds were significantly reduced
- Good significance value
- discrepancy between the backgrounds and all data

  → Possible dark matter candidate

- Otherwise, in the framework of the WIMPS, we set a limit for the dark matter above 100 GeV/C^2

Acknowledgement

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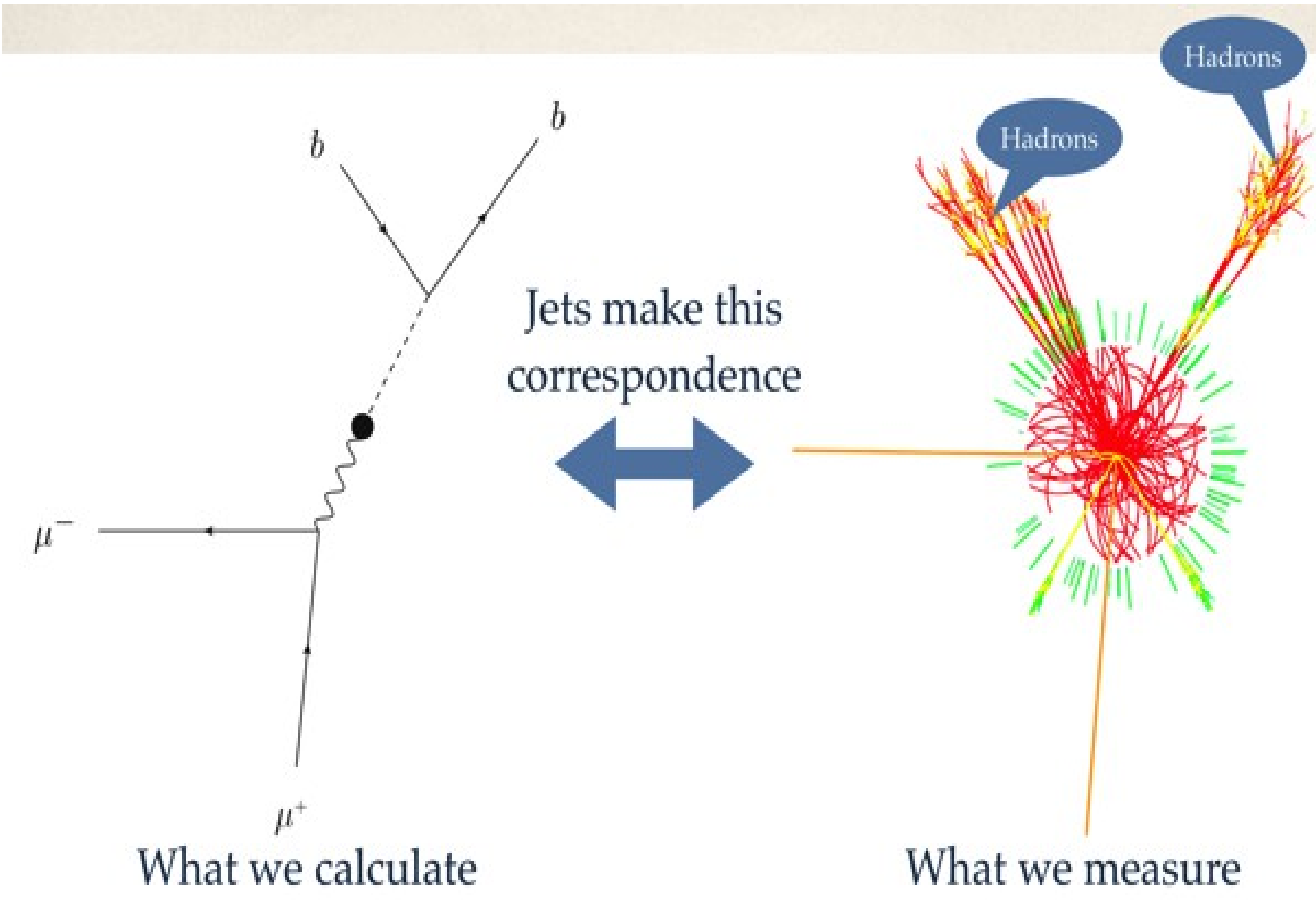
Questions ?

Jets


Hadrons
Hadrons
b
b
Jets make this correspondence
μ^-
μ^+
What we calculate
What we measure

Sub-detectors of CMS(cont.)

- Sub-detectors of CMS:
- The Tracker: made in silicon pixels and silicon microstrips,

  → high precision momentum of charged particles.
- The Electromagnetic Calorimeter (ECAL): made of crystals of

  lead tungstate($PbWO_4$). → energy momentum of electron and photons

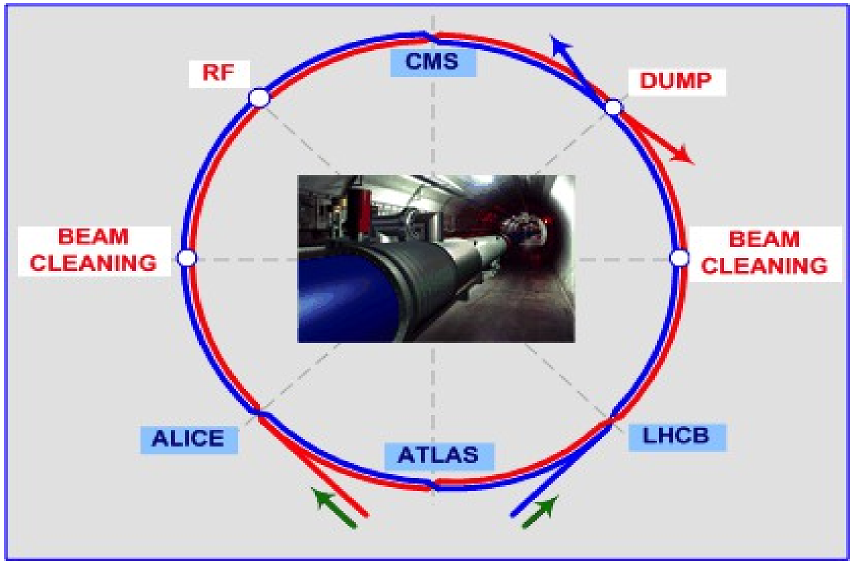
  with high precision
  - Hadronic Calorimeter (HCAL): measure hadrons' energy.
  - Magnet : bent the paths of charged particles
  - The muon detector and the return yoke: muons.

Acceleration Process at the LHC

- Linear Particle Accelerator (LINAC 2): accelerates protons up to 50 MeV.
- Proton Synchrotron Booster (PSB): protons are squeezed together and repeatedly circulated until they gain an energy of 1.4 GeV
- Proton Synchrotron (PS): protons are accelerated up to 26 GeV and they are 25 times heavier than at rest.
- Super Proton Synchrotron(SPS): protons gain energy up to 450 GeV.
- Main Ring: protons gain up to 8TeV of energy and they are 7000 times heavier than at rest

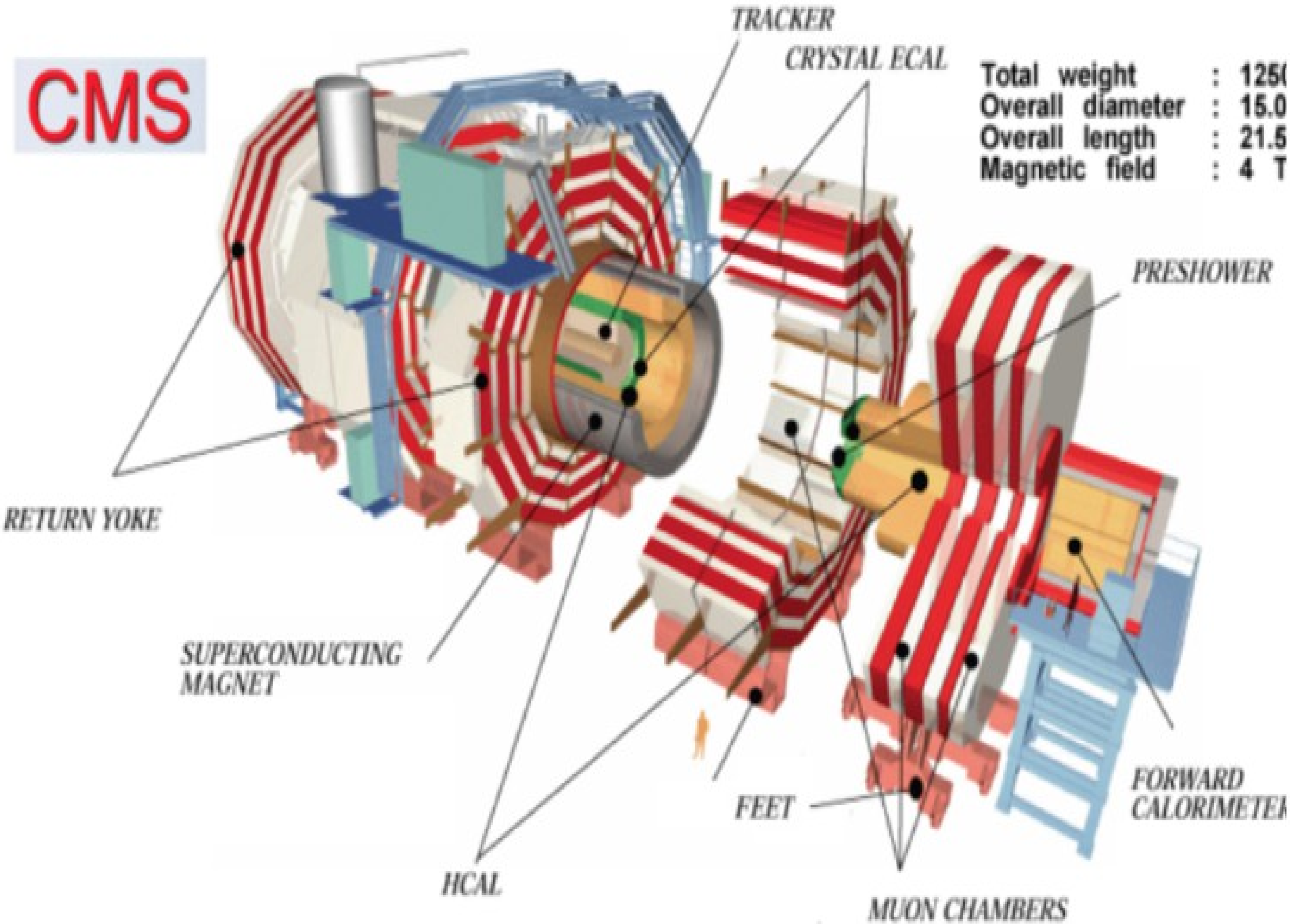
Acc. Process(cont.)

- Super Proton Synchrotron(SPS):protons gain up to 450 GeV.
- Main Ring: protons gain up to 4TeV of energy and they are 7000 times heavier than at rest



LHC Progress

- Discovery of the Higgs boson
- Creation of quark-gluon plasma
- New particle : bottomonium state (Xb)

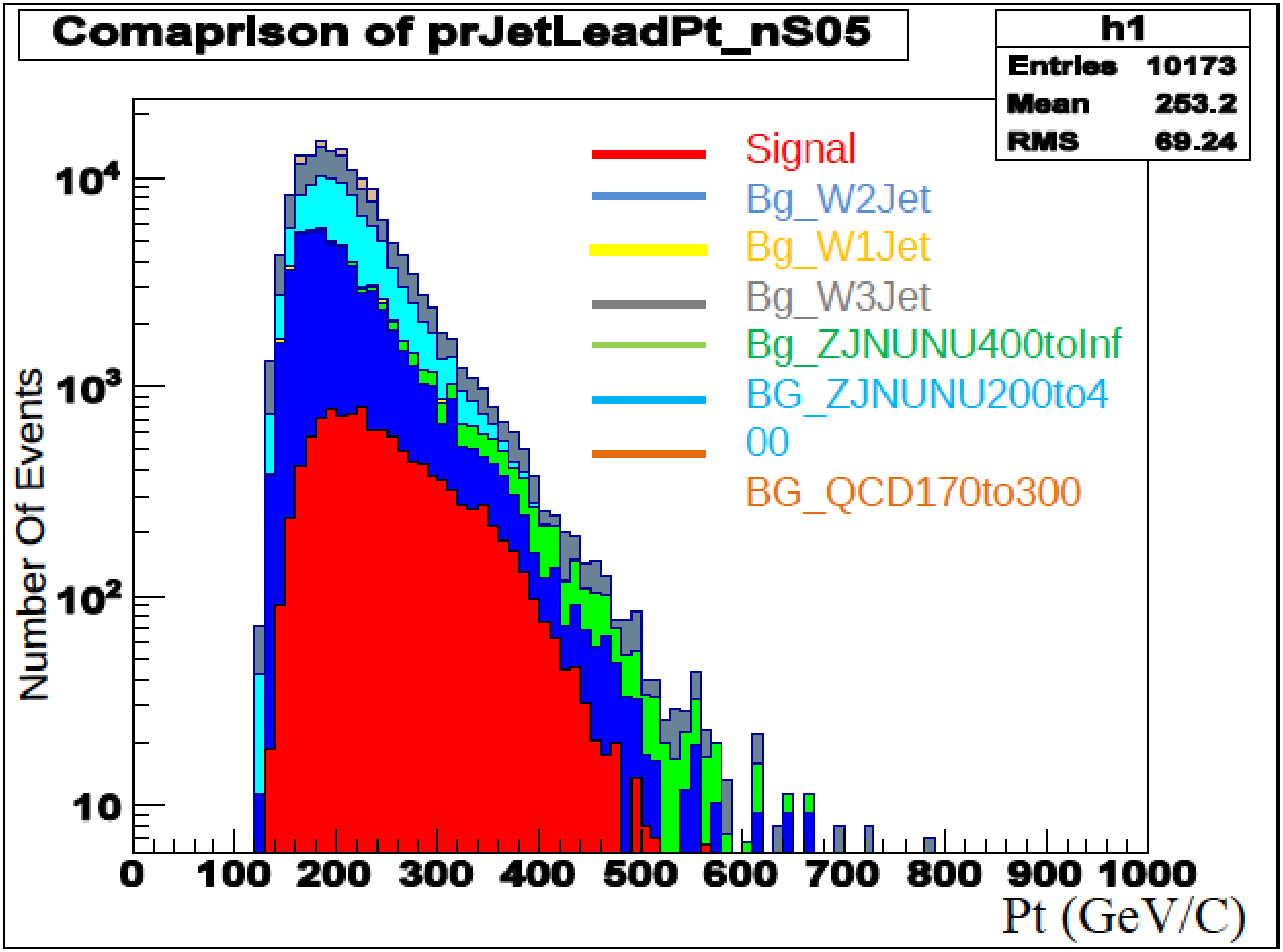


CMS
TRACKER
CRYSTAL ECAL
Total weight : 125(
Overall diameter : 15.0
Overall length : 21.5
Magnetic field : 4 T
PRESHOWER
RETURN YOKE
SUPERCONDUCTING MAGNET
HCAL
FEET
MUON CHAMBERS
FORWARD CALORIMETEI

Quantum Chromodynamics and Jets

- An extension of HCAL outside of the solenoid
- Used to detect energies of particle that went undetected through ECAL and HCAL
- Without HO → leakage in energy of particles for high P
- HO improve missing transverse energy (MET)

The stacked histogram of the signal and background after cuts



Why dark matter is not ordinary matter

- Theory of the big bang nucleosynthesis : 4-5 % of ordinary matter contribute to the universe
- Large astronomical searches for gravitational microlensing

  huge part of dark matter is not located
- Irregularities in the Cosmic microwave background (CMB)

  5/6 of matter do not interact
- Current status about dark matter