Dark Matter Search @ LHC

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The 3rd KIAS Workshop on Cosmology and Structure Formation

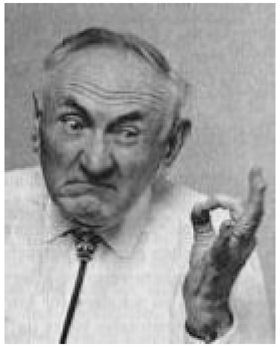
Contents

- Evidence for CDM
- DM candidates in particle physics
- (Indirect searches: HEAT, PAMELA,…)
- (Direct searches: DAMA, CDMS, XENON,…)
- What is LHC ?
- DM searches @ LHC
- Conclusions

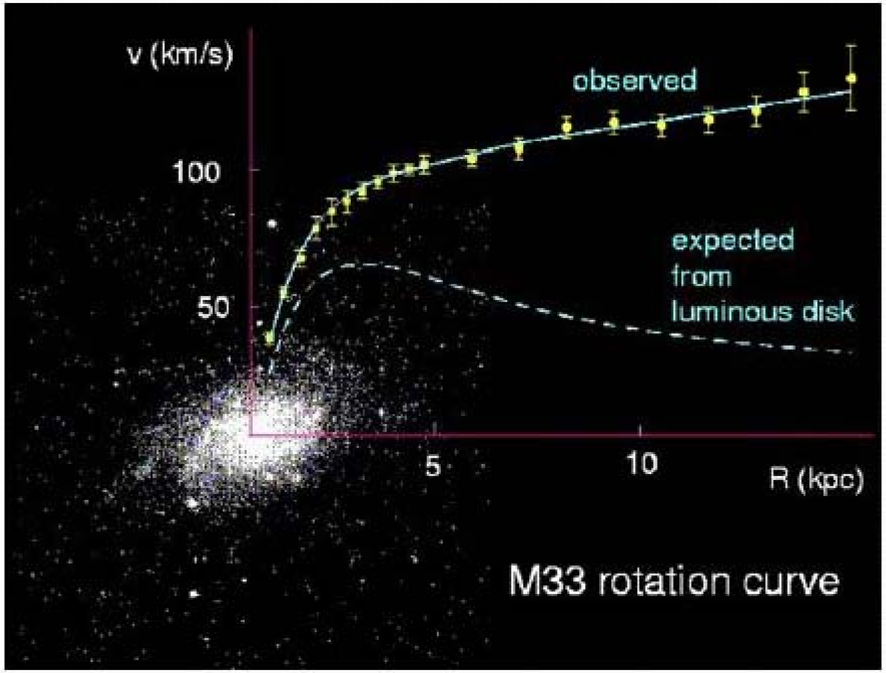
Evidences for DM

Rotation Curve

$v(r) \propto \sqrt{M(r)/r}$
$M(r)$: the mass inside the orbit of radius r

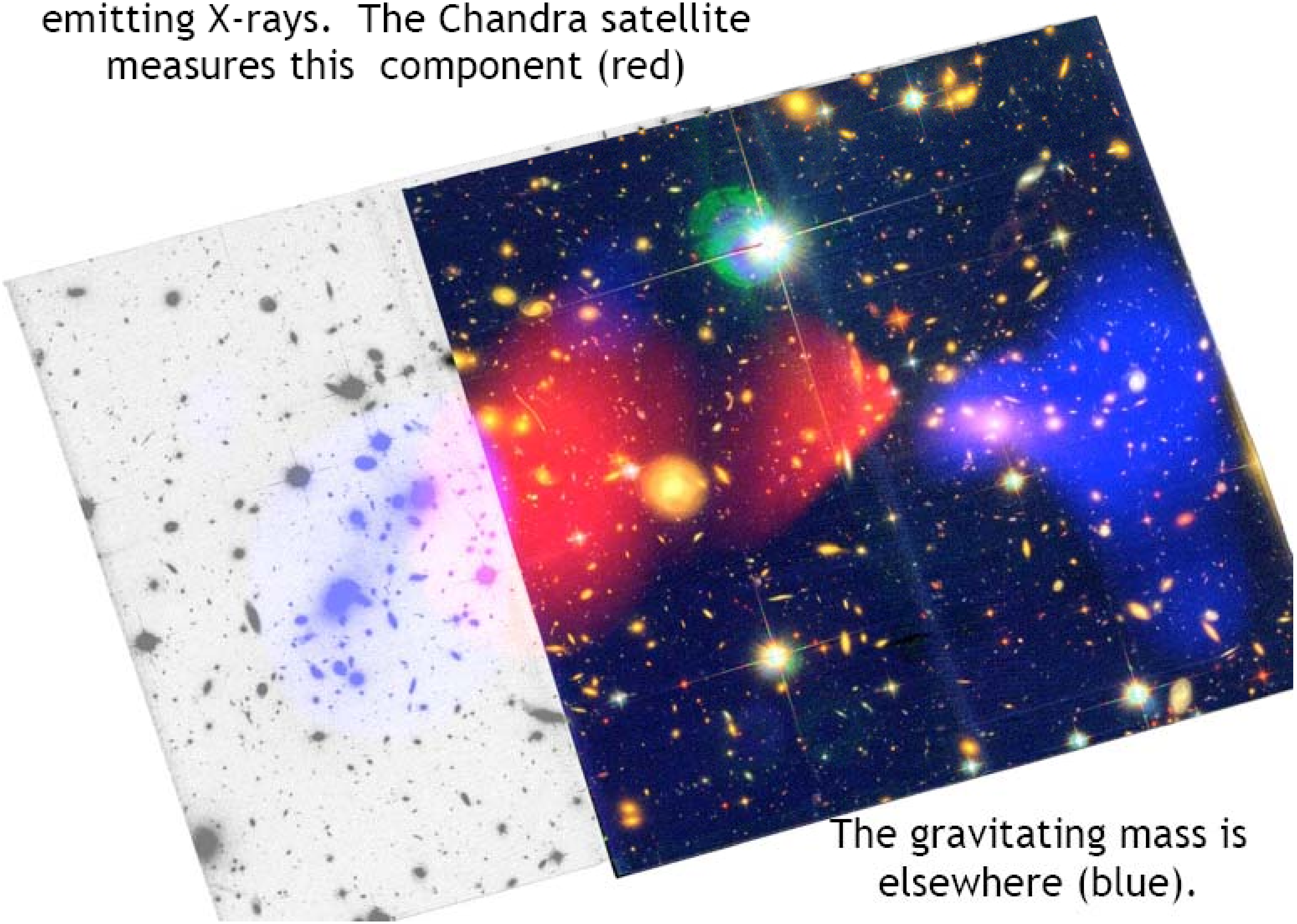


Fritz Zwicky



Bullet Cluster

The atomic matter is mainly in hot gas, emitting X-rays. The Chandra satellite measures this component (red)

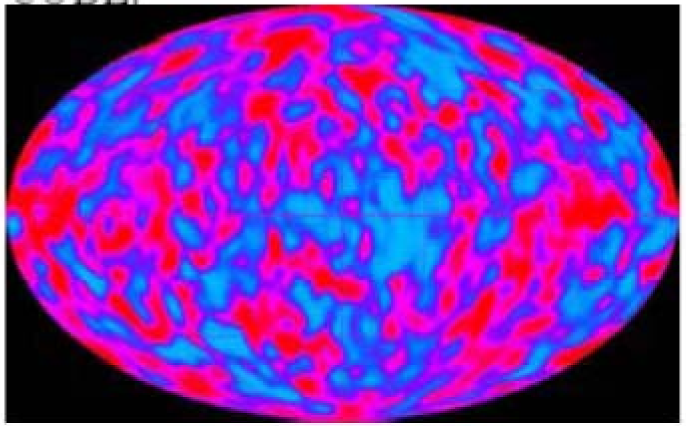


The gravitating mass is elsewhere (blue).

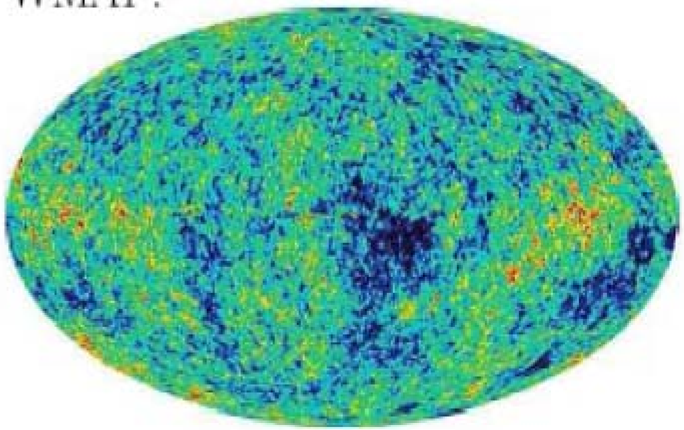
WMAP

- WMAP measures Anisotropy of CMB
- $\Omega_{\mathrm{NonBaryonic}} h^2 = 0.111 \pm 0.006$
  $h =$: the Hubble constant in unit of 100 km/(s $\cdot$ Mpc)
- $\Omega_{\mathrm{Baryonic}} h^2 = 0.023 \pm 0.001$
  including MACHOs, cold molecular gas clouds, etc.
  Nucleosynthesis : $0.012 \leq \Omega_{\mathrm{Baryonic}} h^2 \leq 0.025$
  $\rightarrow$ Evidence for Nonbaryonic DM

COBE:



WMAP:



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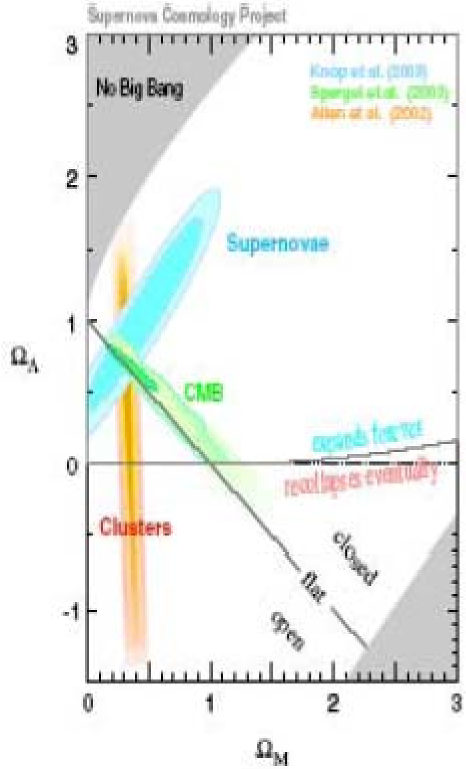

Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
Ω_Λ
Ω_M

Elementary Particle Zoo

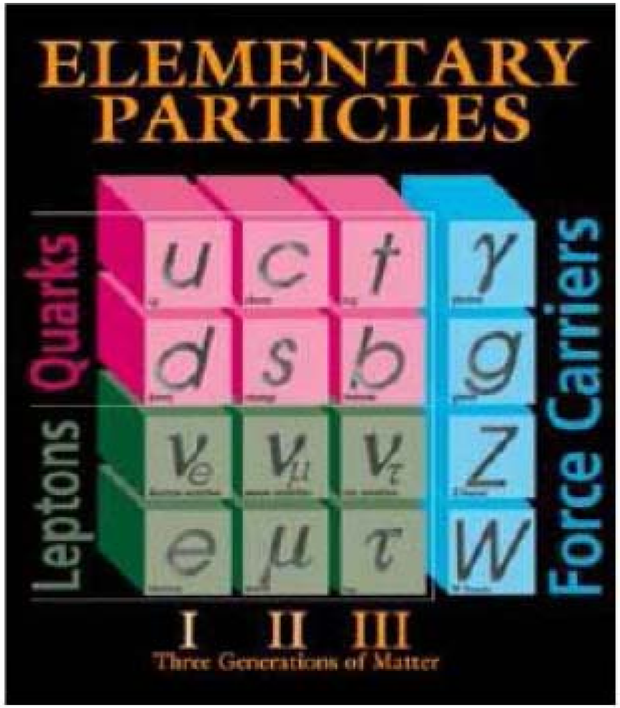
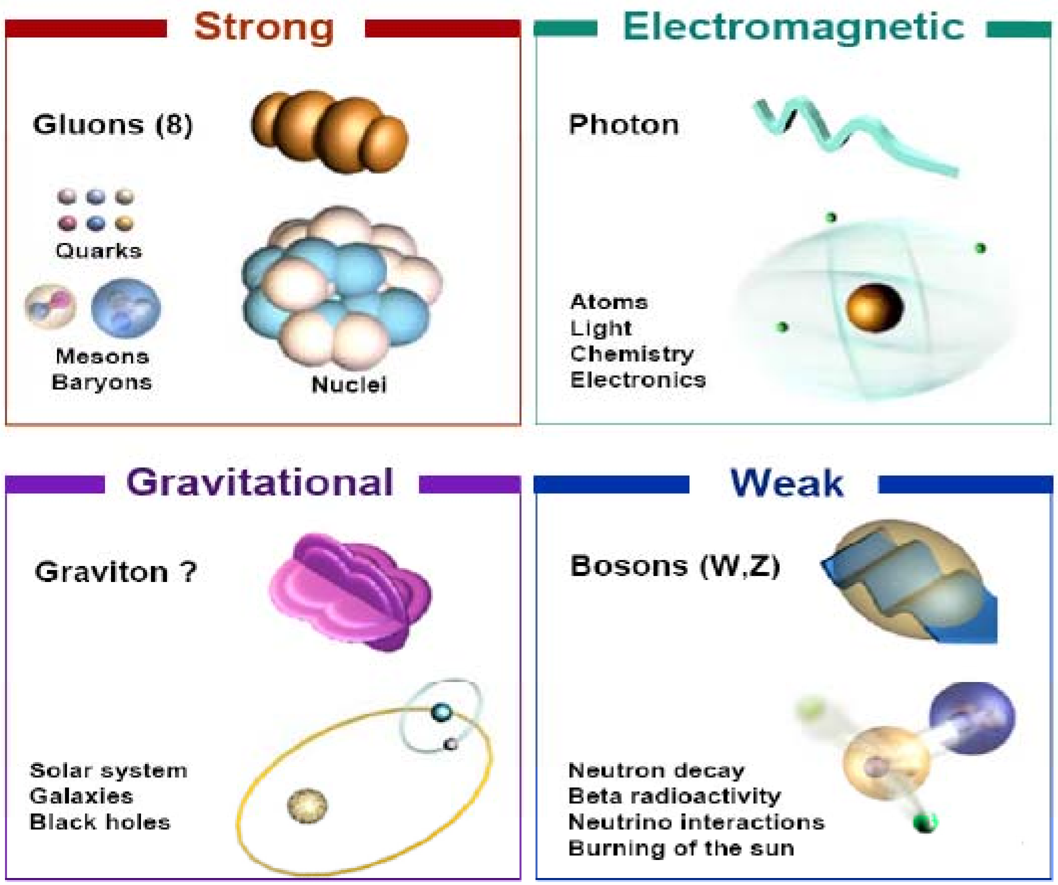


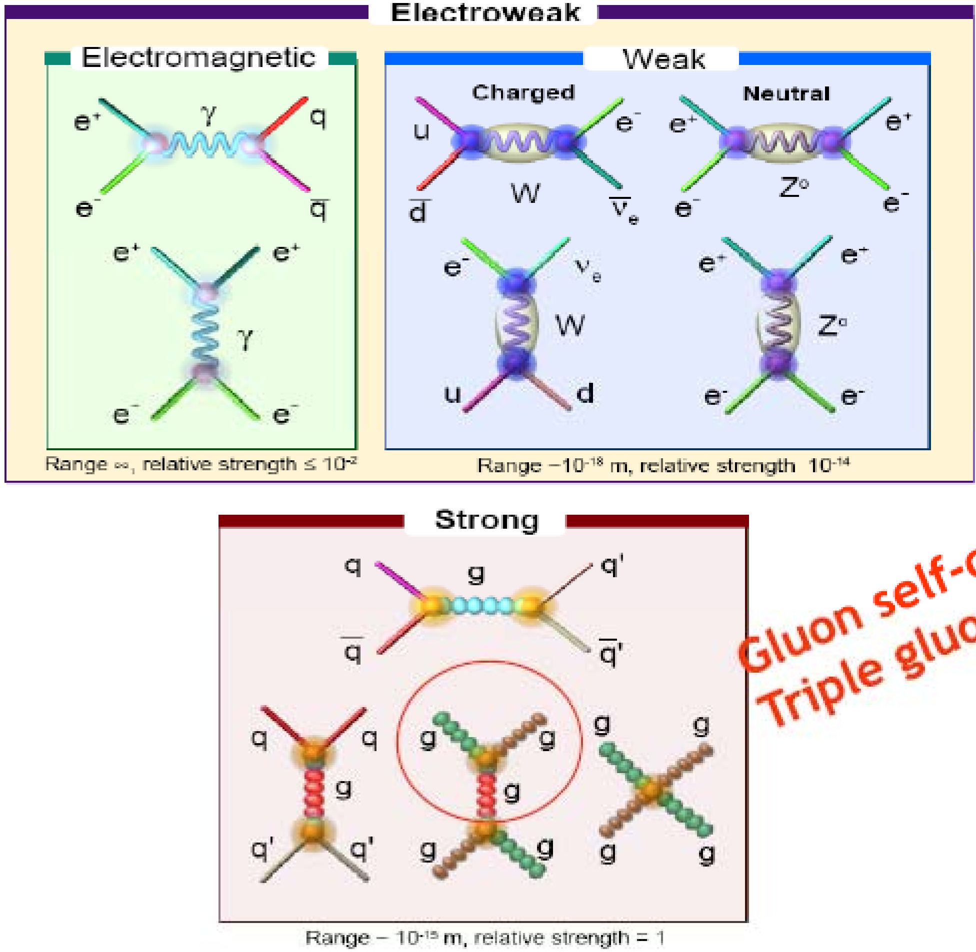
Figure 1: The ubiquitous chart of quarks, leptons, and force carriers.

Forces

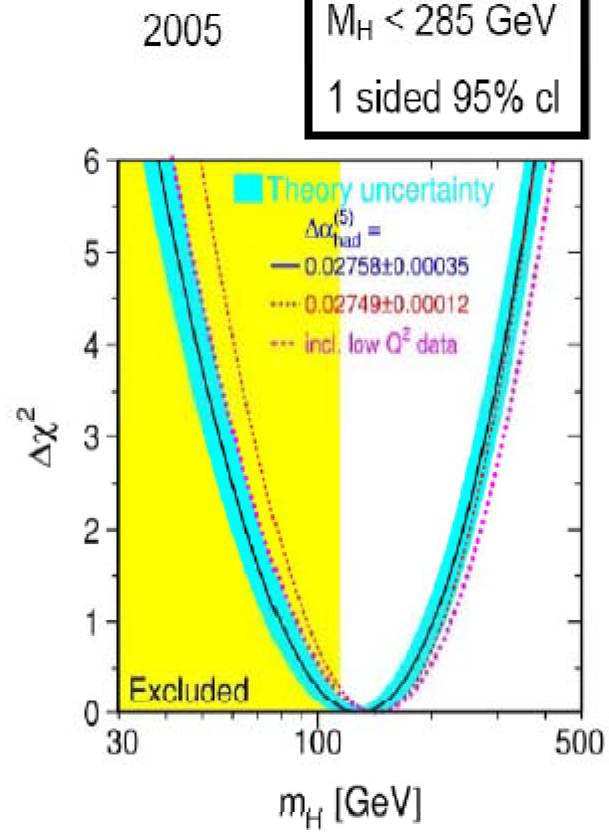


The particle drawings are simple artistic representations

Interactions: coupling of forces to matter



Gluon self-coupling
Triple gluon vertex

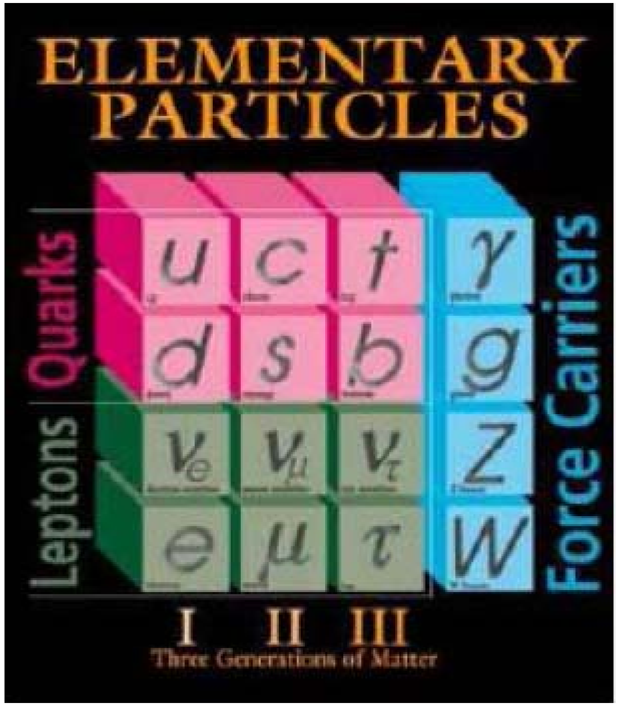


$M_H < 285$ GeV

1 sided 95% cl

SM with light Higgs works pretty well!

DM in SM ? No !



No Candidates within SM → Need New Physics

What is it ? Mass ? Spin ? Other quantum numbers ?

DM candidates in particle physics

Properties of the DM Candidtaes

Clear evidence for New Physics beyond the SM

- Stable on cosmological time scale
- Weakly interacting with EM radiation to be dark
- Have right relic abundance
- Structure formation of the universe $\longrightarrow$ mostly COLD DM:
  nonrelativistic at the onset of galaxy formation (when there was a galactic mass inside the causal horizon)
- Candidates: primordial blackholes (BH's), neutrinos, singlet scalar, axion and axino, and WIMP(weakly interacting massive particle)'s, SIMP, WIMPZILLA,.....

New Physics for DM candidates

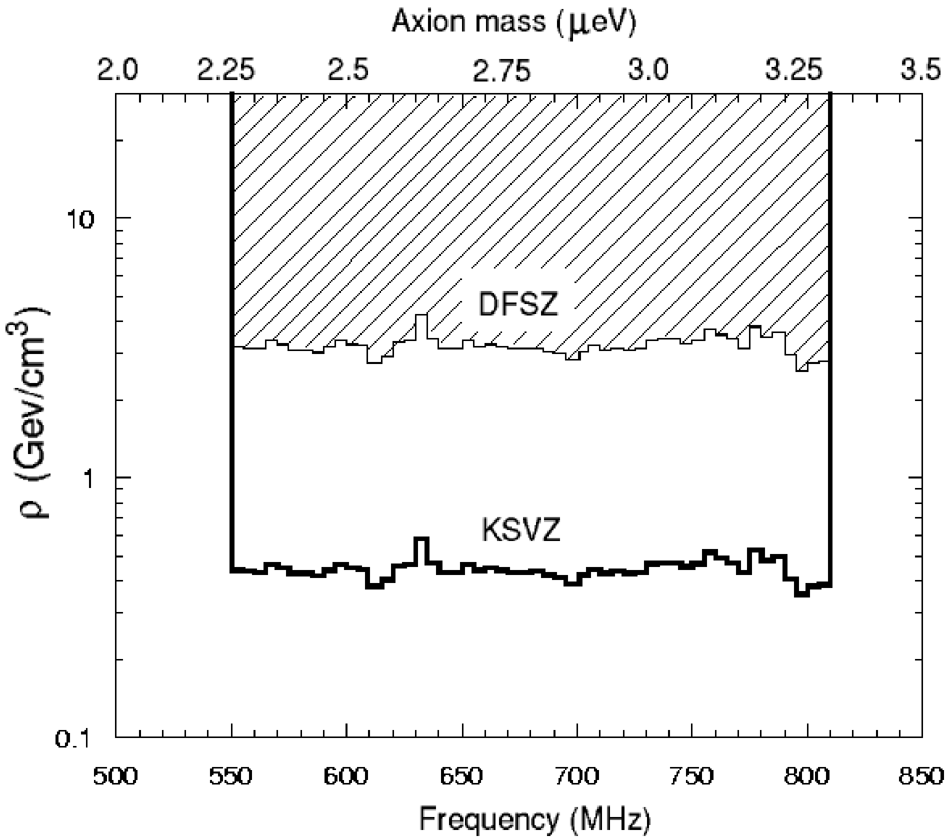
- No good candidate within the SM
- Another evidence for New Physics (NP) along with neutrino oscillations
- Many candidates in NP beyond the SM
  - Well motivated: neutralino, gravitino, axion, axino, branon, lightest KK particle, WIMPZILLA, your own recipe
  - Minimality: singlet scalar (just one more d.o.f.)
- Here mainly concerned with the DM candidates which can be detected at KIMS

Axion DM

- A solution to string CP problem of QCD
- Naturally present in superstring theory, which is the only known theory of quantum gravity that is mathematically consistent
- Pseudo NG boson associated with global $U(1)_{\rm PQ}$ symmetry,
  $\longrightarrow$ Spontaneously broken at scale f_a
- Chiral symmetry breaking $\longrightarrow$ axion gets mass
  $m_a \simeq 0.6$ meV $\cdot 10^{10}$ GeV / f_a
- Current limits on f_a
  $5 \cdot 10^9$ GeV $\leq f_a \leq 10^{12}$ GeV
- Very light, but produced nonthermally $\longrightarrow$ Cold DM

Axion-Cont'd

- KSVZ : hadronic axion (tree level couplings to quarks only)
  DFSZ : axion couples to both quarks and leptons
- Search in $a \to \gamma$ conversion in strong B field due to a coupling $g_{a\gamma\gamma}$ (depending on the axion models)
- $\Omega_a h^2 = \kappa_a \left(f_a/10^{12}\mathrm{GeV}\right)^{1.175} \ \theta_i^2$
  $0.5 \lesssim \kappa_a \lesssim$ (a few)
- LLNL (California) excludes $2.9\mu V < m_a < 3.3\mu V$ ($f_a \simeq 4 \times 10^{13}$ GeV as a major component of the dark halo of our galaxy, if $g_{a\gamma\gamma}$ is near the upper end of the theoretically expected range)
- CARRACK (Kyoto)

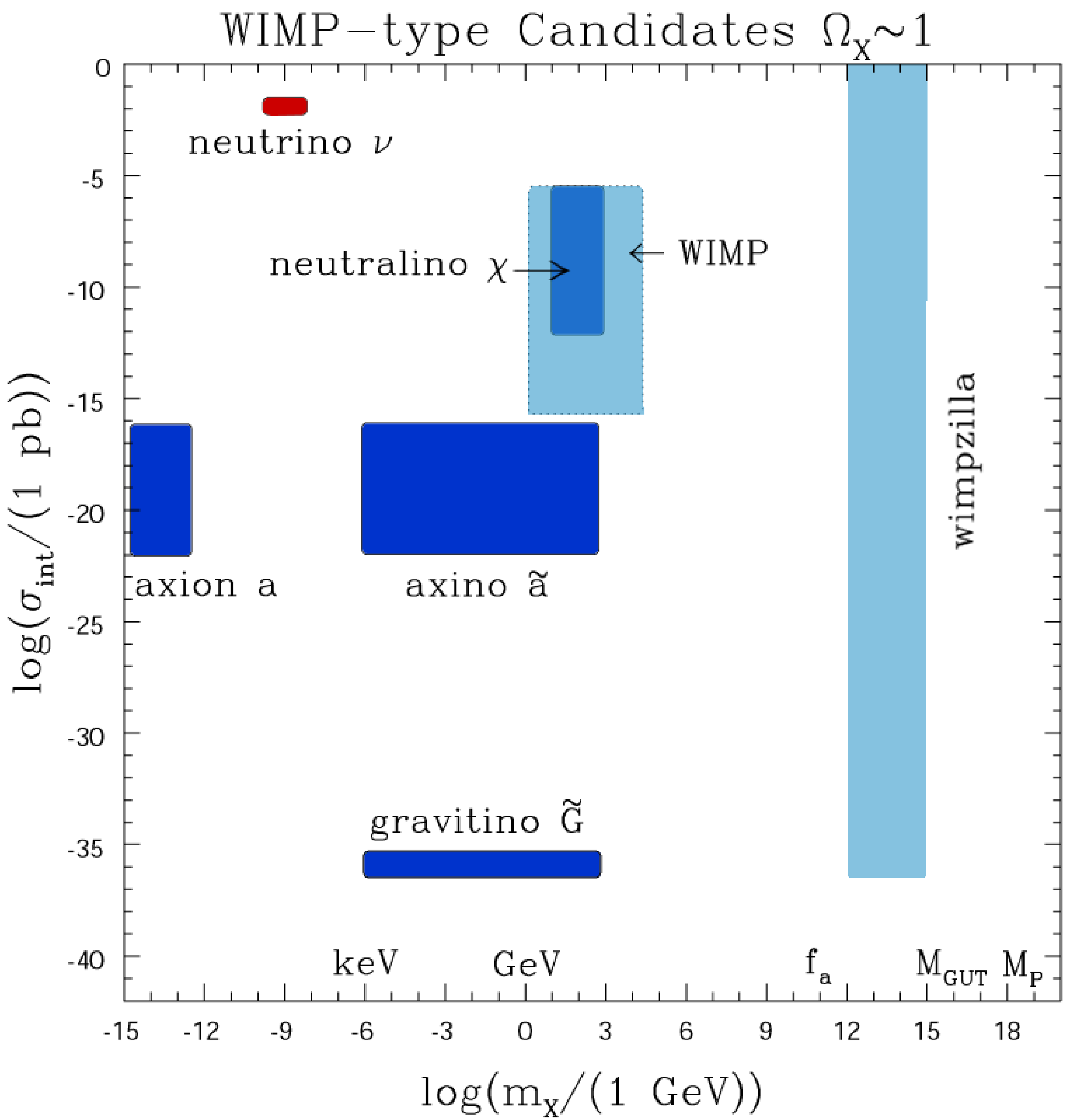


LLNL Col. (Asztalos et al.)

WIMPs (χ)

- $10\text{GeV} \lesssim m_\chi \lesssim$ a few TeV
- Thermal relic density can be calculated reliably
  $\Omega_\chi h^2 \simeq \text{const}\ \frac{T_0^3}{M_{Pl}^3 \langle \sigma_A v \rangle} \simeq \frac{0.1\text{pb}c}{\langle \sigma_A v \rangle}$
  $T_0 = 2.73\text{K}$: the current CMB temperate
  M_{Pl} : PLanck mass
  σ_A : the annihilation cross section of a pair of χ's into the SM particles
  v : the rel. vel. in their cm frame
  $\langle ... \rangle$: thermal average
- Freeze out at $T_F \simeq m_\chi / 20$: nonrel. when decouples
- Heavy neutrino : not easy to make it stable

WIMPs



WIMP−type Candidates $\Omega_X \sim 1$
neutrino ν
neutralino χ
WIMP
wimpzilla
axion a
axino $\tilde{a}$
gravitino $\tilde{G}$
keV
GeV
f_a
M_{GUT}
M_P
0
-5
-10
-15
-20
-25
-30
-35
-40
-15
-12
-9
-6
-3
0
3
6
9
12
15
18
$\log(\sigma_{int}/(1\ \mathrm{pb}))$
$\log(m_X/(1\ \mathrm{GeV}))$

Neutralino DM

- Neutralino : LSP in many SUSY scenarios
- Good candidate for DM
- Can be detected directly by underground experiments via elastic scattering on target nuclei
- DAMA, CDMS, EDELWEISS, ZEPLIN, KIMS, etc.
- DAMA signal region : completely ruled out by CDMS
  cf. (In)direct DM detection is important in Split SUSY scenario,
  where all the scalar fermions (squarks, sleptons) are very heavy, and
  charginos and neutralinos are light ($\sim O(0.1) - O(1)$ TeV)
  (Masiero, Profumo, Ullio)

Heavy gravitino LSP

- Gravitino : spin 3/2 superpartner of graviton
- Interaction strength : $1/M_{pl} \longrightarrow$ extremely weak coupling
  $\longrightarrow$ No hope to observe it in the lab
- In supergravity theories, $m_{3/2} > m_{\text{SUSY}}$ in many scenarios
- If $\tilde{G}$ is heavy and LSP, rich collider phenomenology (Feng et al. ; Buchmuller, Hamaguchi, et al.)

Light gravitino ($\tilde{G}$)

- Light gravitino : LSP in Gauge Mediation SUSY Breaking
- (in)direct detection impossible
- NLSP $\longrightarrow \tilde{G}$ + X
  $\chi^0 \longrightarrow \tilde{G} + \gamma$ or $\tilde{\tau}_1 \longrightarrow \tilde{G} + \tau$
  or stau can be long lived, does not decay inside the detector
  $\longrightarrow$ Charged particle with heavy mass
  cf. axino (spin 1/2 super partner of axion) shows a similar behavior inside the detector
  (Brandenburg et al.)

Lightest KK particle

- Extra Dimension $\rightarrow$ Extra massive particles

$$(\partial_\mu \partial^\mu + \partial_y \partial^y)\ \phi(x) e^{iky} = 0 \quad \rightarrow (\partial_\mu \partial^\mu + k^2)\phi(x) = 0$$

  Single valuedness of the Wave function in the 5-th dim $\rightarrow k = n/R$ (n=1,2,3....)

- Introduce some discrete parity (e.g., Z_2) to make it stable
  cf. R parity in SUSY models
- Lightest KK particles : Bosonic CDM candidate
  cf. Fermionic LSP in SUSY models
- Universal Extra Dimension (UED), Randall-Sundrum (RS), ...

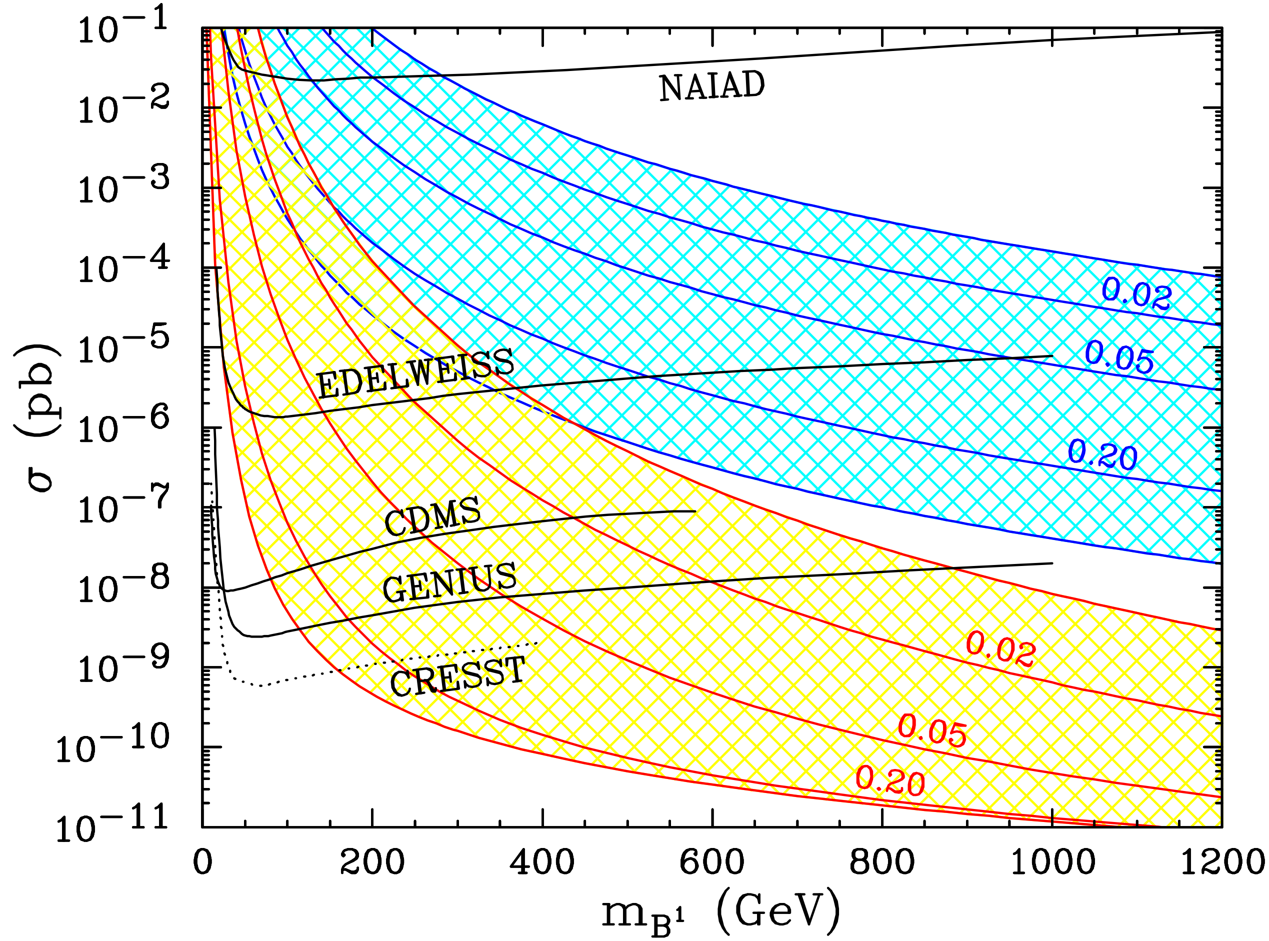
UED-I (Appelquist, Cheng, Dobrescu)

- One extra dim S^1/Z_2 with the size R
- SM particles propagate in the bulk
- All the 1st KK modes have mass $1/R$, which is modified by radiative corrections
- Electroweak precision tests $\to 1/R > 300$ GeV
  Close to the current Tevatron sensitivity
- LHC can probe upto $1/R \lesssim 1.5$ TeV

UED-II

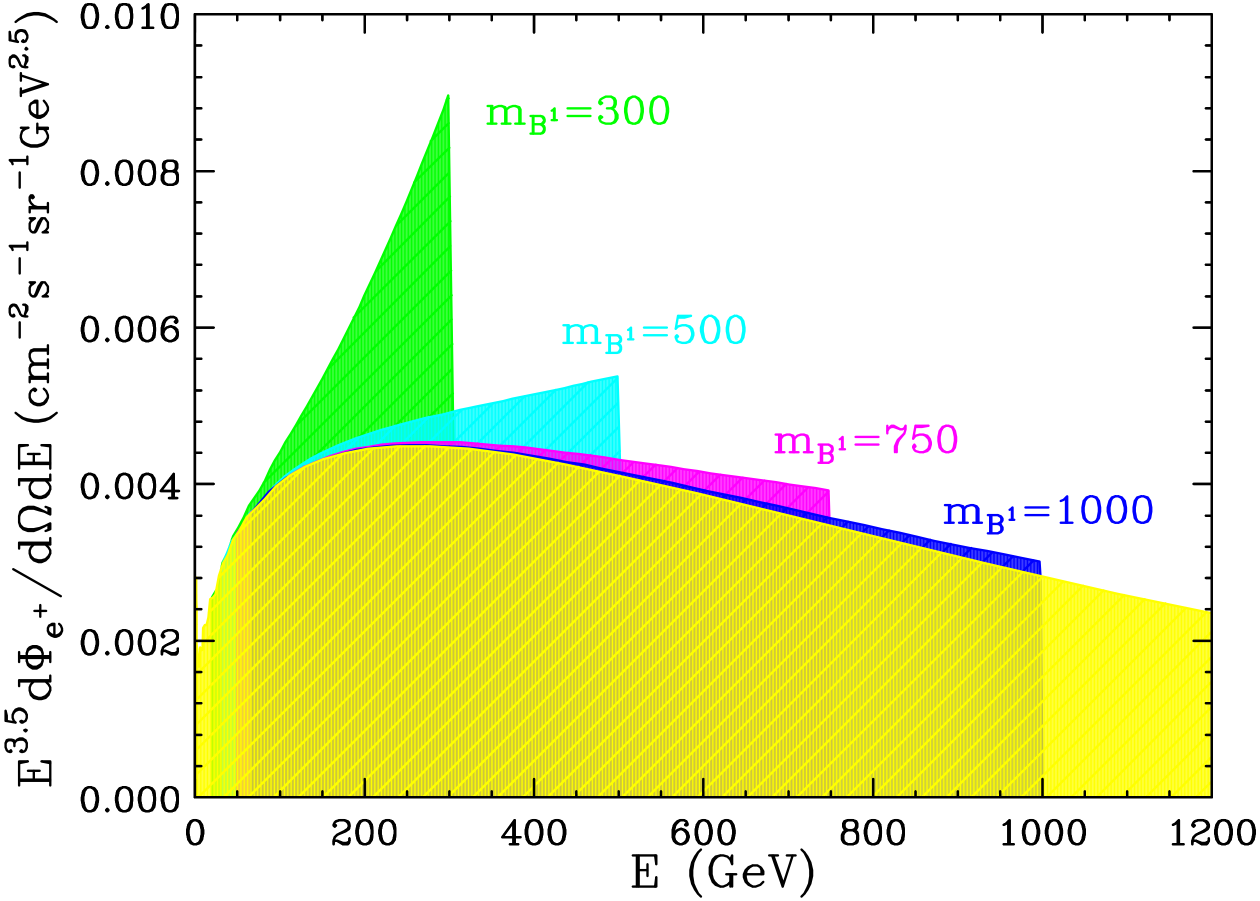
- B_1 : the lightest KK particle after radiative correction
  $\longrightarrow$ Natural candidate for CDM
  $\longrightarrow$ Produce primary e^+ and ν, unlike the SUSY LSP
- B_1 is bosonic, can annihilate effectively through S wave, unlike the neutralino LSP (P wave annihilation)
  $\longrightarrow$ Heavier m_{B_1} can accommodate the relic density (several hundred GeV to a few TeV)
  $\longrightarrow$ Harder e^+, γ and ν compared to the SUSY LSP
- Elastic scattering of B_1 on nuclei (Cheng, Feng, Matchev, PRL)
- Both direct and indirect searches in better shape compared to the SUSY LSP

UED-III



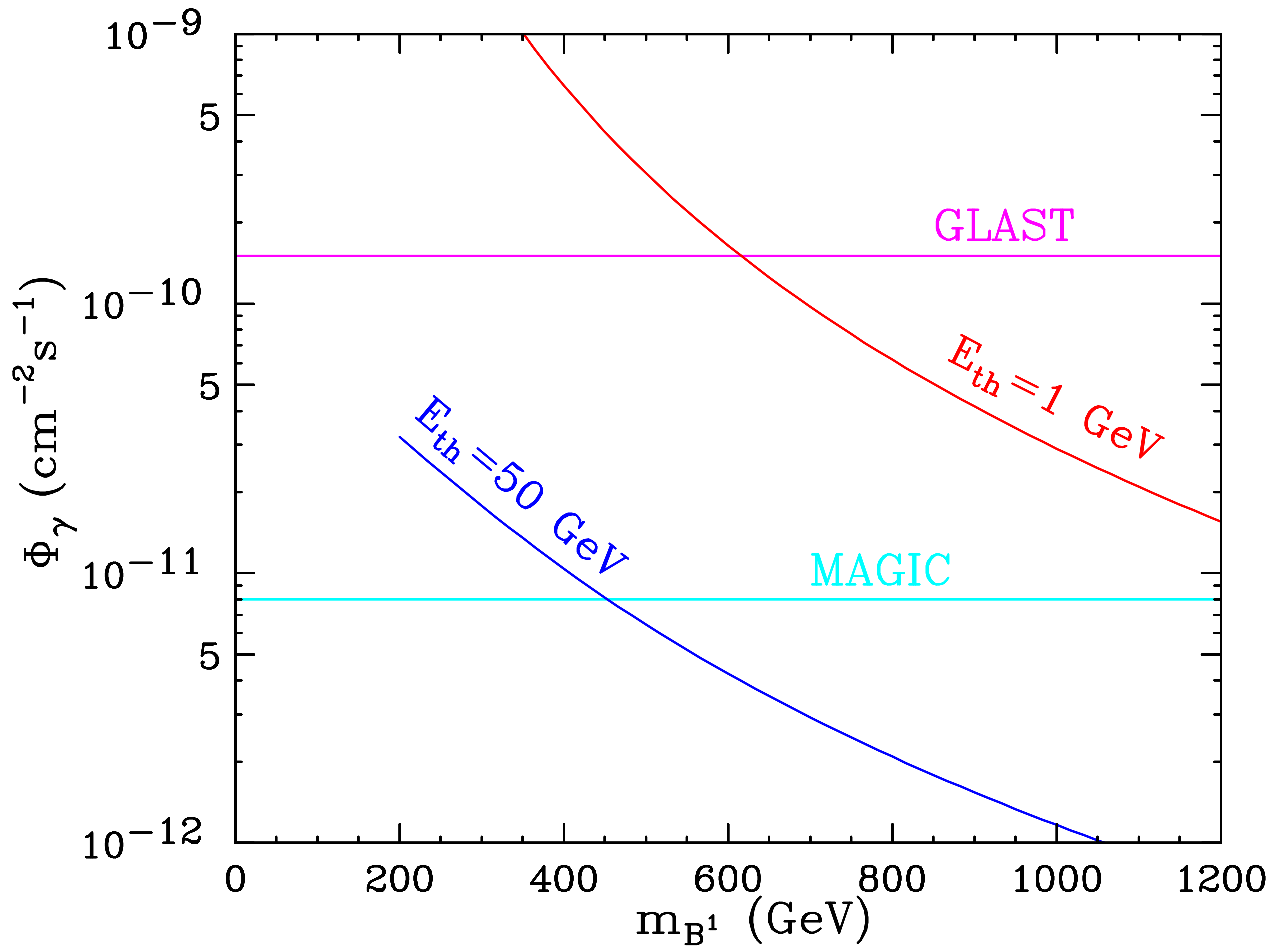
Spin-dep. proton cross sections (blue), along with the projected sensitivity of a 100 kg NAIAD array; and predicted spin-indep. proton cross sections (red), along with the current EDELWEISS sensitivity, and projected sensitivities

UED-IV



Predicted positron signals (dark shaded) above background (light shaded) as a function of positron energy for $= m_{e_L^1} = m_{e_R^1} = 100$, 500, 750, and 1000 GeV.

UED-V



Integrated photon flux as a function of for energy thresholds of 1 and 50 GeV. Projected sensitivities for GLAST and MAGIC are also shown.

Singlet scalar

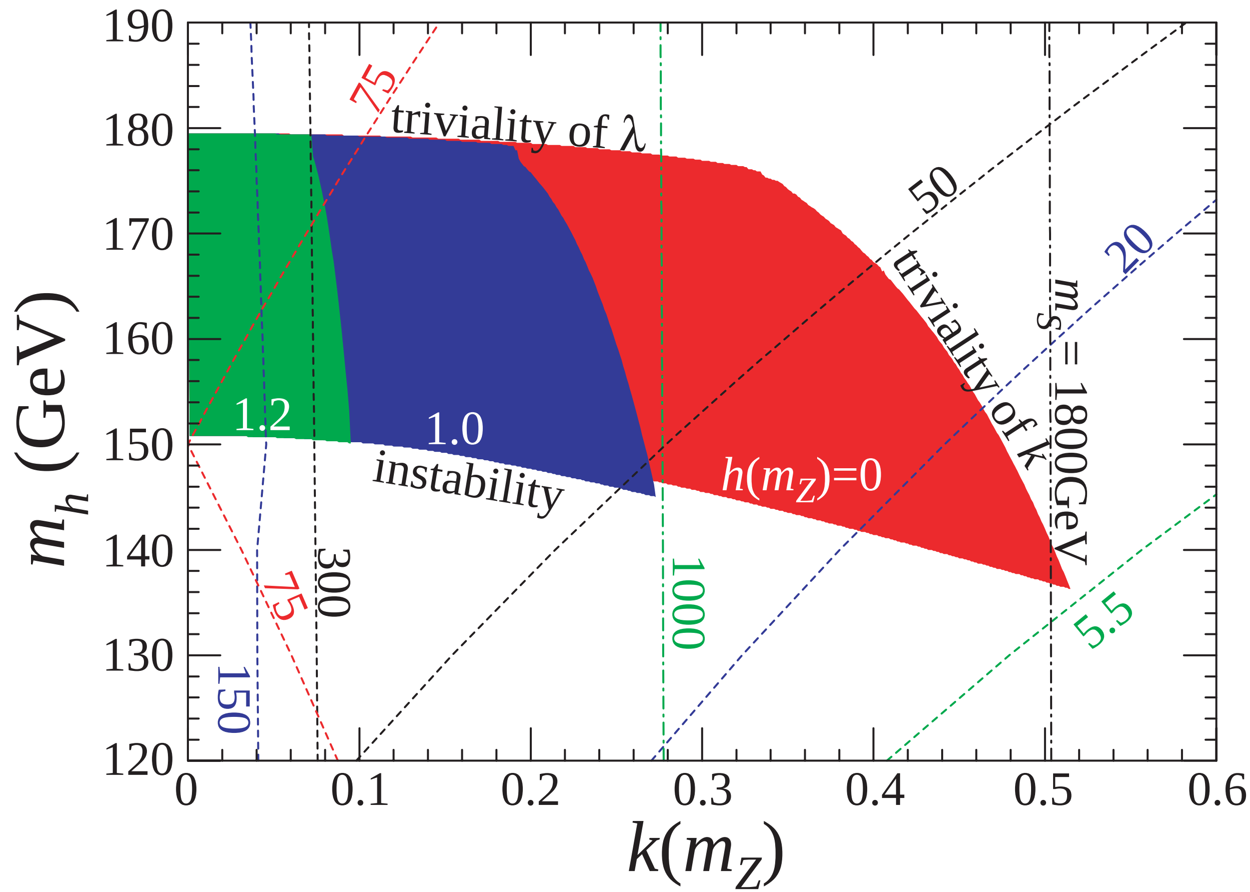
- The simplest extension of the SM for DM
  Just add one more additional degree of freedom
- One real scalar S with Z_2 parity -1
  $\longrightarrow$ Stability of S

$$\mathcal{L}_S = \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2} m_S^2 S^2 - \frac{k}{2}|H|^2 S^2 - \frac{h}{4!} S^4$$

H : the SM Higgs
(C. Burgess et al.; Murayama et al)

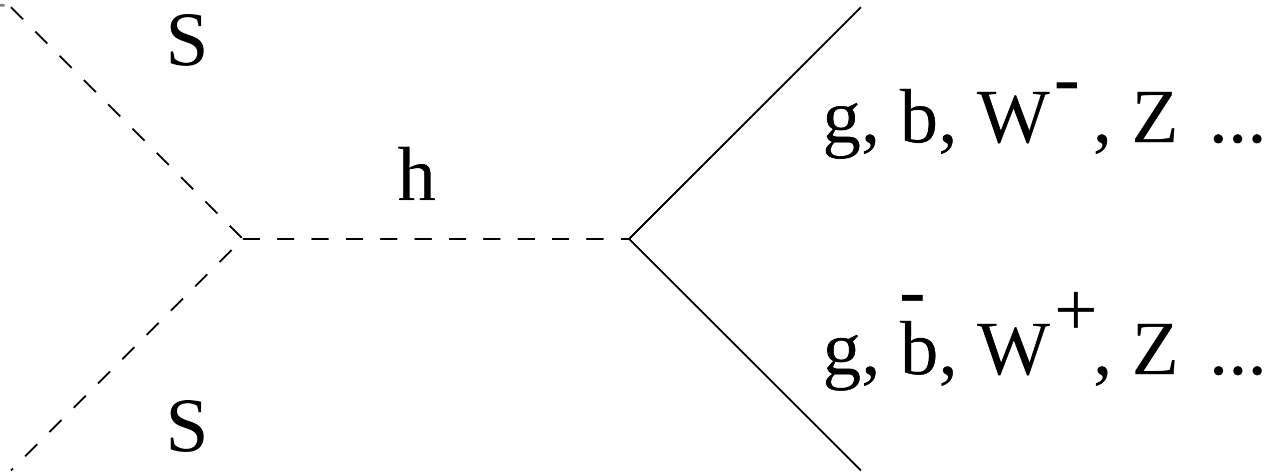
Singlet scalar-Cont'd

- prediction: 130 GeV $\lesssim m_h \lesssim$ 180 GeV



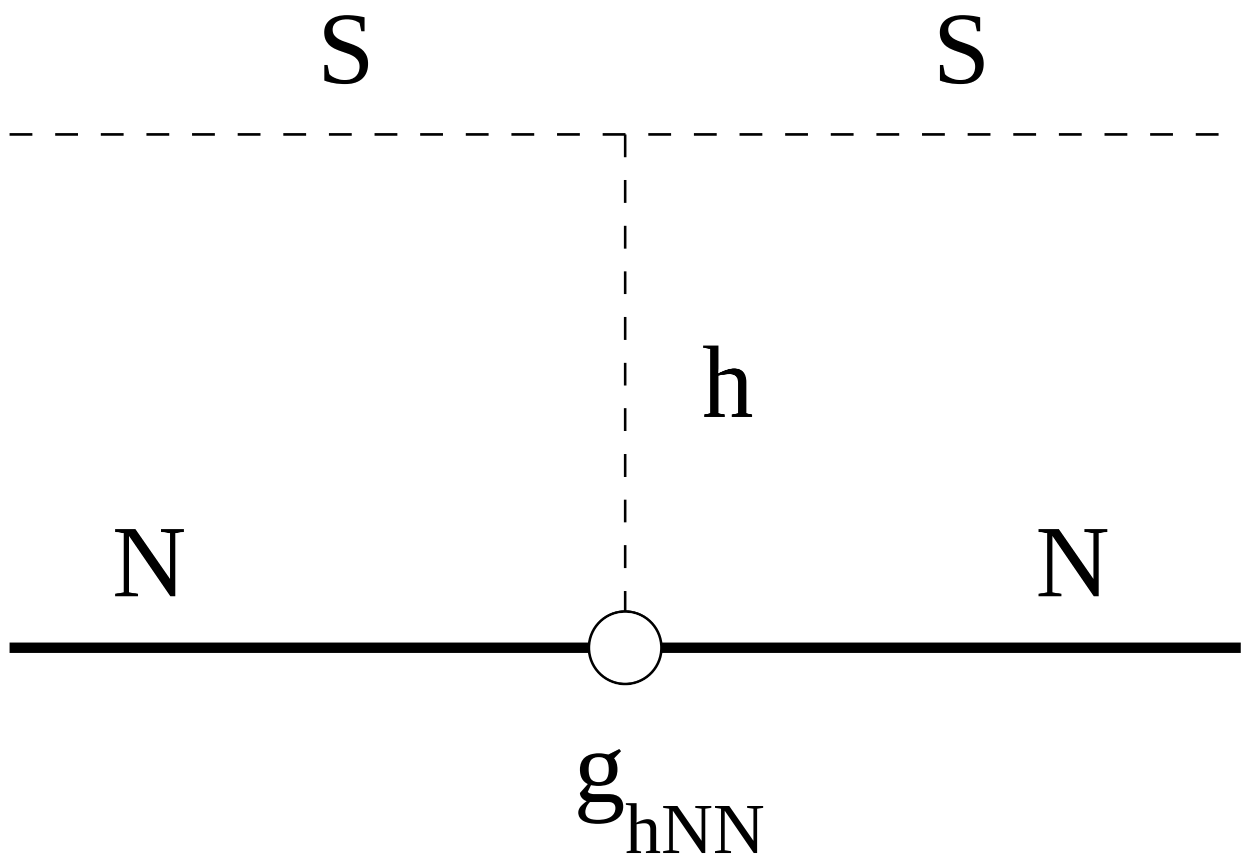
- Triviality and unitarity bound: 5.5 GeV $\lesssim m_S \lesssim$ 1.8 TeV

Singlet scalar-Annihilation

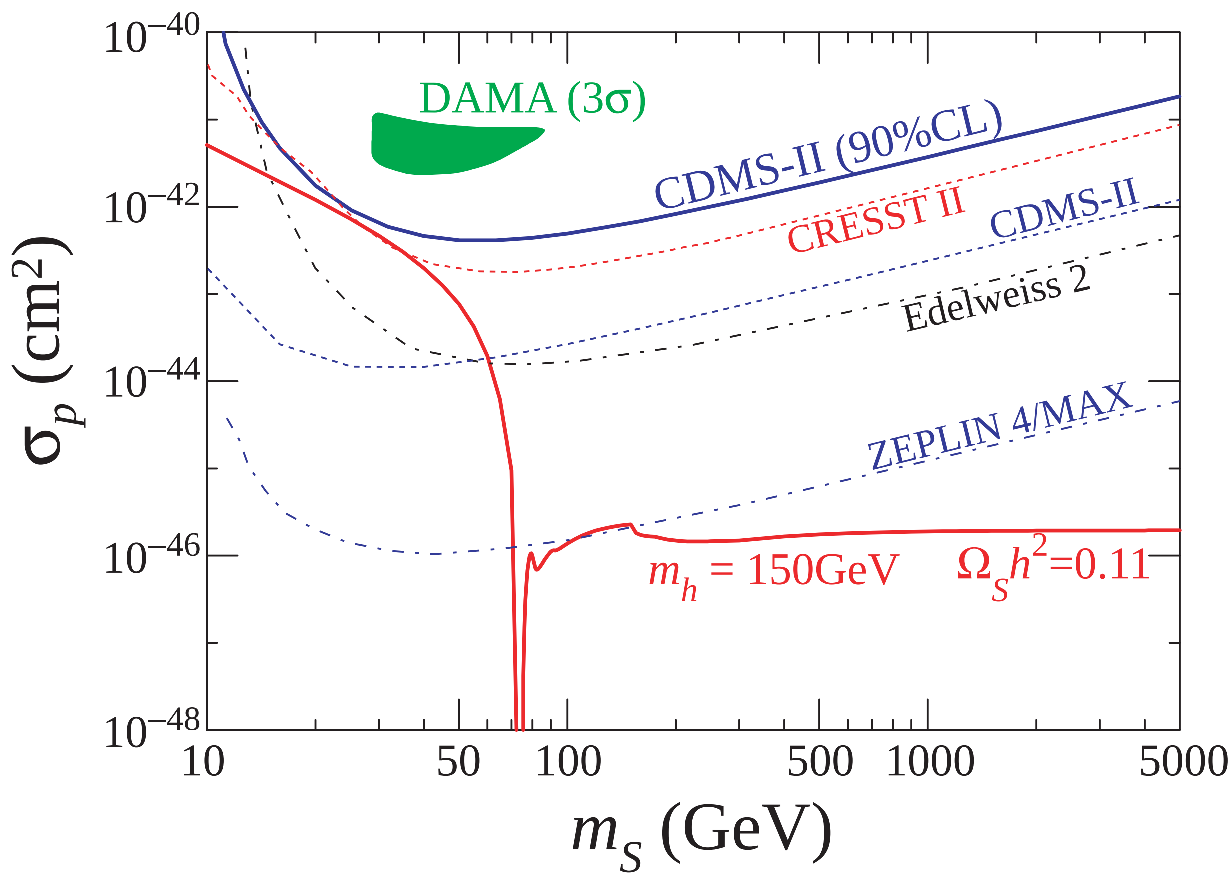


Easy to satisfy WMAP data (previous fig. for $\Omega_S h^2 = 0.11$)

Singlet scalar-Direct detection of relic S



Singlet scalar-Cont'd



$m_S = 75$ GeV : Annihilation through Higgs pole

Hidden Sector Technicolor with CDM

Basic Picture

Singlet scalar S
RH neutrinos
etc.

SM
Quarks
Leptons
Gauge Bosons
Higgs boson

Hidden Sector
Quarks Q_h
Gluons g_h
Others

Similar to ordinary QCD

Model-II

- Introduce a real singlet scalar S
- Modified SM with classical scale symmetry

$$
\begin{aligned}
\mathcal{L}_{\rm SM} &= \mathcal{L}_{\rm kin} - \frac{\lambda_H}{4}\,(H^\dagger H)^2 - \frac{\lambda_{SH}}{2}\,S^2\,H^\dagger H - \frac{\lambda_S}{4}\,S^4 \\
&+ \Big(\overline{Q}^i H Y^D_{ij} D^j + \overline{Q}^i \tilde{H} Y^U_{ij} U^j + \overline{L}^i H Y^E_{ij} E^j \\
&+ \overline{L}^i \tilde{H} Y^N_{ij} N^j + S N^{iT} C Y^M_{ij} N^j + h.c.\Big)
\end{aligned}
$$

- Hidden sector lagrangian with new strong interaction

$$
\mathcal{L}_{\rm hidden} = -\frac{1}{4}\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu} + \sum_{k=1}^{N_{HF}} \overline{\mathcal{Q}}_k (i\mathcal{D}\cdot\gamma - \lambda_k S)\mathcal{Q}_k
$$

Model-II

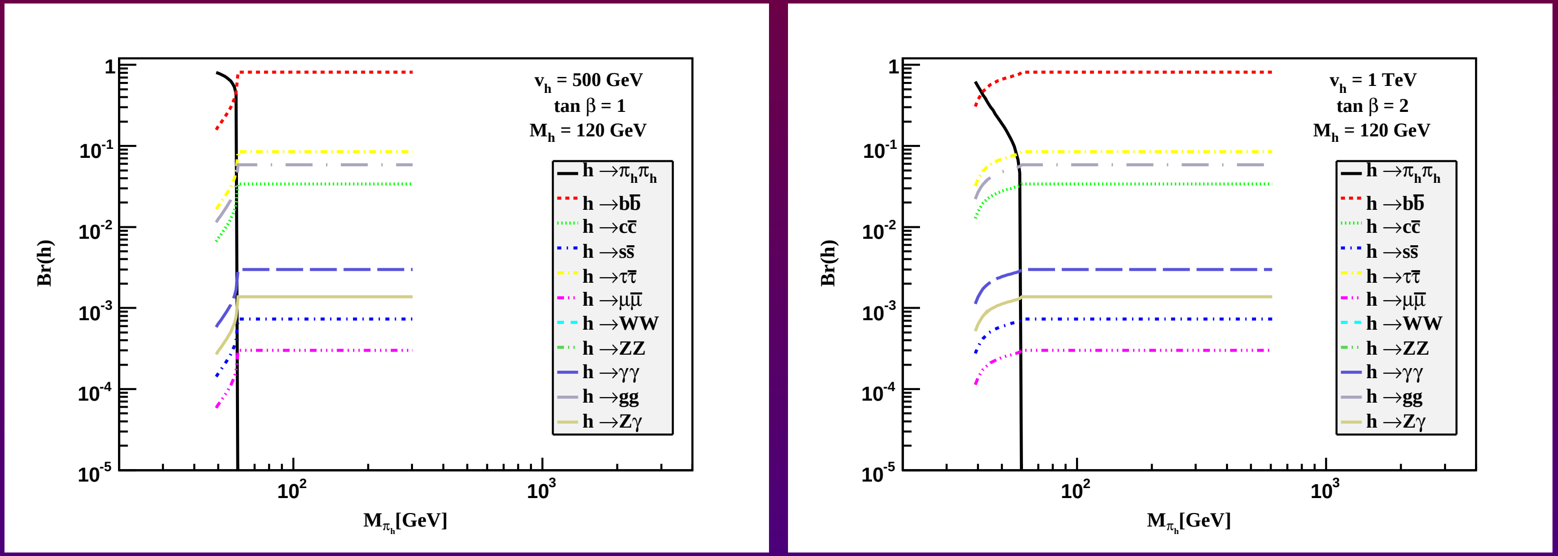
Effective lagrangian far below $\Lambda_{h,\chi} \approx 4\pi\Lambda_h$

$$
\begin{aligned}
\mathcal{L}_{\rm full} &= \mathcal{L}^{\rm eff}_{\rm hidden} + \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm mixing} \\
\mathcal{L}^{\rm eff}_{\rm hidden} &= \frac{v_h^2}{4}{\rm Tr}[\partial_\mu \Sigma_h \partial^\mu \Sigma_h^\dagger] + \frac{v_h^2}{2}{\rm Tr}[\lambda S \mu_h (\Sigma_h + \Sigma_h^\dagger)] \\
\mathcal{L}_{\rm SM} &= -\frac{\lambda_1}{2}(H_1^\dagger H_1)^2 - \frac{\lambda_{1S}}{2} H_1^\dagger H_1 S^2 - \frac{\lambda_S}{8} S^4 \\
\mathcal{L}_{\rm mixing} &= -v_h^2 \Lambda_h^2 \left[\kappa_H \frac{H_1^\dagger H_1}{\Lambda_h^2} + \kappa_S \frac{S^2}{\Lambda_h^2} + \kappa_S' \frac{S}{\Lambda_h} \right. \\
&+ \left. O(\frac{S H_1^\dagger H_1}{\Lambda_h^3}, \frac{S^3}{\Lambda_h^3}) \right] \\
&\approx -v_h^2 \left[\kappa_H H_1^\dagger H_1 + \kappa_S S^2 + \Lambda_h \kappa_S' S \right]
\end{aligned}
$$

Model-II

- First neglect κ terms and calculate the VEV
- $\tan\beta \equiv v_s/v_1$
- Input parameters : $\tan\beta$, v_h, m_{π_h} and λ_1
- Calculate the particle spectra, the relic density and the direct detection rates
- Successful EWSB and DM relic density
- All the masses from dimensional transmutation in the hidden sector
- CDM without ad hoc Z_2 symmetry
- See the following figures

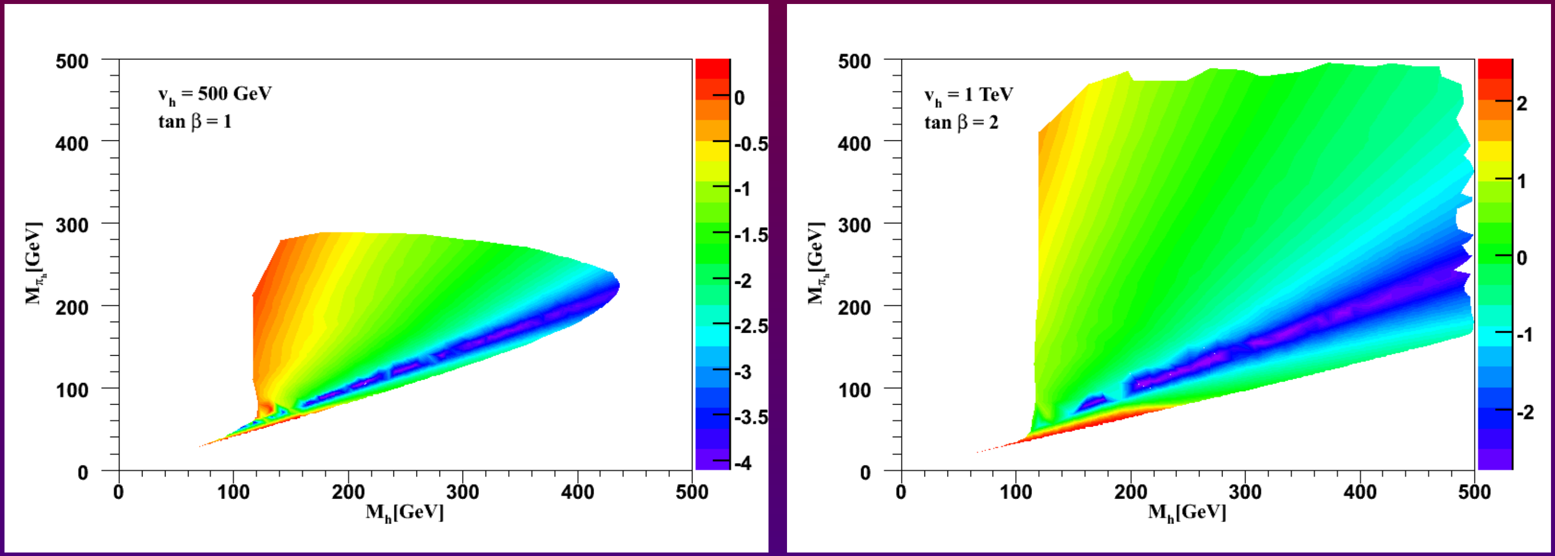
Model-II: Branching ratios of h



Br's of h owith $m_h = 120$ GeV as functions of m_{π_h} for
(a)$v_h = 500$ GeV and $\tan\beta = 1$

(b) $v_h = 1$ TeV and $\tan\beta = 2$.

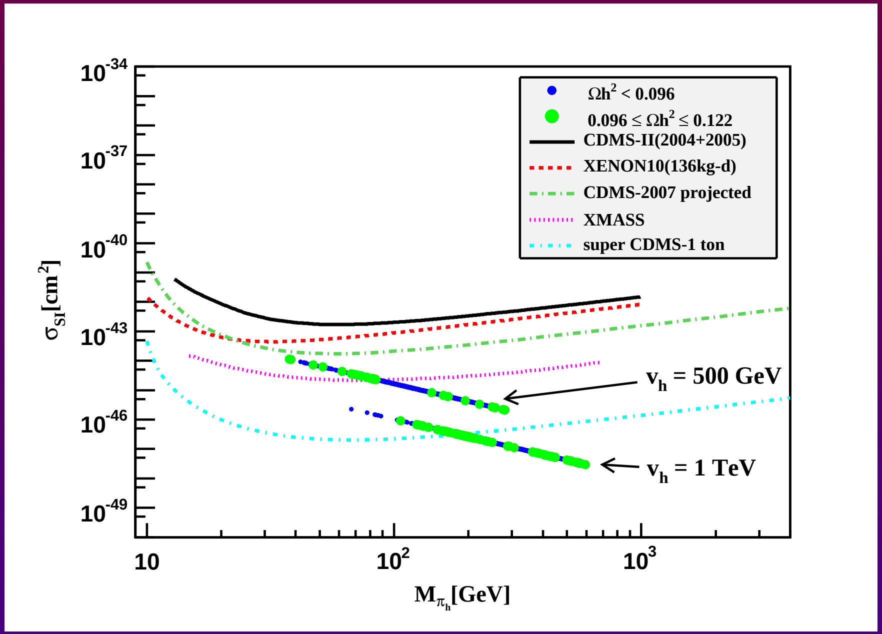
Model-II: Relic densities of $\Omega_{\pi_h} h^2$



$\Omega_{\pi_h} h^2$ in the (m_{h_1}, m_{π_h}) plane for
(a) $v_h = 500$ GeV and $\tan\beta = 1$,

(b) $v_h = 1$ TeV and $\tan\beta = 2$.

Model-II: Direct detection rates



$\sigma_{SI}(\pi_h p \to \pi_h p)$ as functions of m_{π_h}.

the upper one: $v_h = 500$ GeV and $\tan\beta = 1$,

the lower one: $v_h = 1$ TeV and $\tan\beta = 2$.

Summary and Outlook

- Hidden sector: could be present, but not completely hidden
- All the mass scales may be generated from scale symmetry breaking in the hidden sector, and communicated to the SM sector by H and S (and N_R)
- (Partial) Resolution of Naturalness Problem by scale symmetry
- Particle Physics Signal:
  - Invisible Higgs decay width
  - Could be more scalars, but qualitatively different from the usual two-Higgs doublet models
  - No problem with FCNC at all or new CPV

Summary and Outlook-Cont'd

- Cosmology
  - Dark matter from the hidden sector (technipions, additional gauge bosons or technibaryons in the hidden sector)
  - Proper relic density possible, and sizable SI DM scattering x-sections
- Future problems
  - Radiative corrections to the scalar potential ?
  - Gauge coupling unification ?
  - SUSY version ?
  - Baryogenesis in our model ?
  - Can we say $\Omega_{\rm baryon} \sim \Omega_{\rm DM}/5$ could be natural ?
- Many interesting possibilities from the hidden sector

DM candidates in particle physics

Table 1:

DM	Motivation	(In)Direct Det.	Collider	Spin
singlet scalar	minimality	Y	Y	0
axion	Strong CP	Y	N	0
axino	axion + SUSY	N	Y	1/2
neutralino	SUSY	Y	N	1/2
light gravitino	Gauge mediation	N	Y	3/2
heavy gravitino	SUGRA	N	Y	3/2
LKP	extra dim	Y	Y	1
branon	Brane world	Y	Y	0
Hidden Sector	Possible, Generic	Y	Y	0,1/2,1

What is LHC ?

What is LHC ?

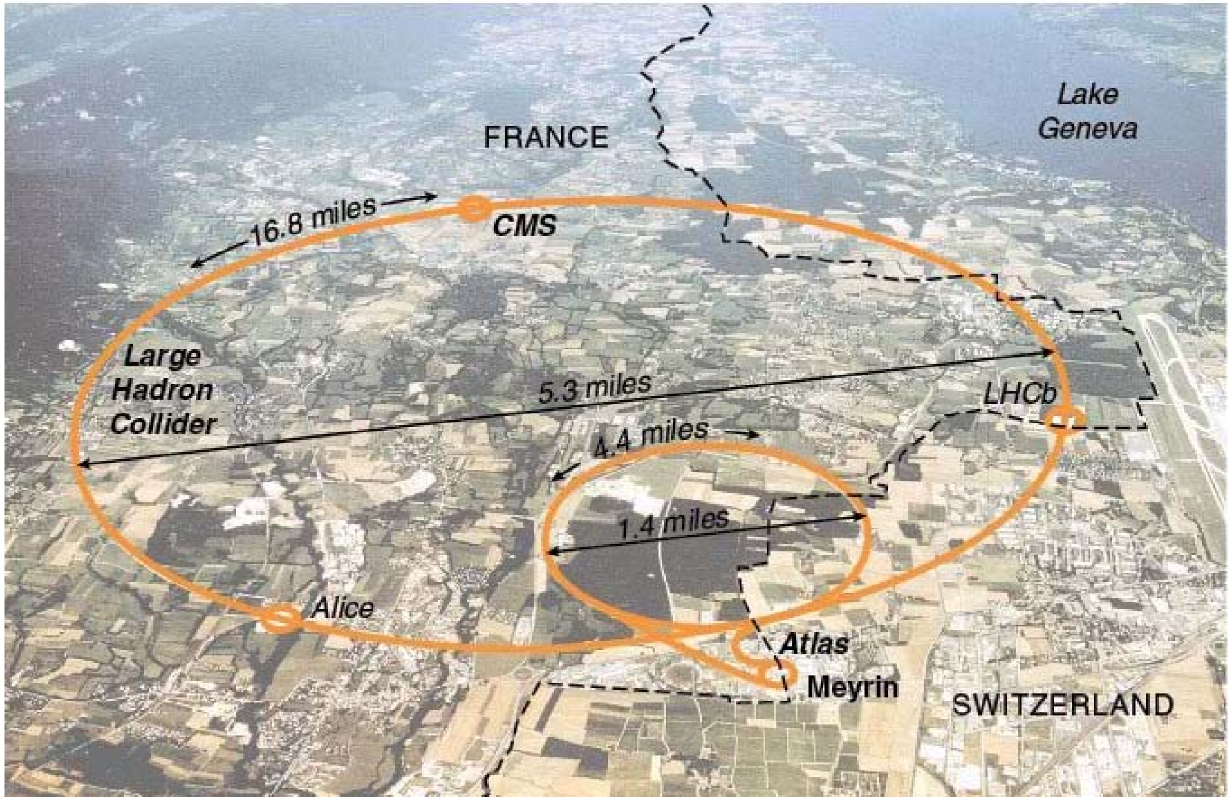
- Large Hadron Collider (LHC)
- proton-proton collider @ CM Energy =14 TeV

  cf. proton mass ~ 1 GeV
- 400 ton TGV with 150 km/h
- $E = mc^2$ → New heavy particles (including DM, if lucky) can be produced @ the LHC
- 27 km circumference , ~100m depth
- The Coldest Spot in the universe (1.9K)
- Ultrahigh vacuum (10 times more than Moon)

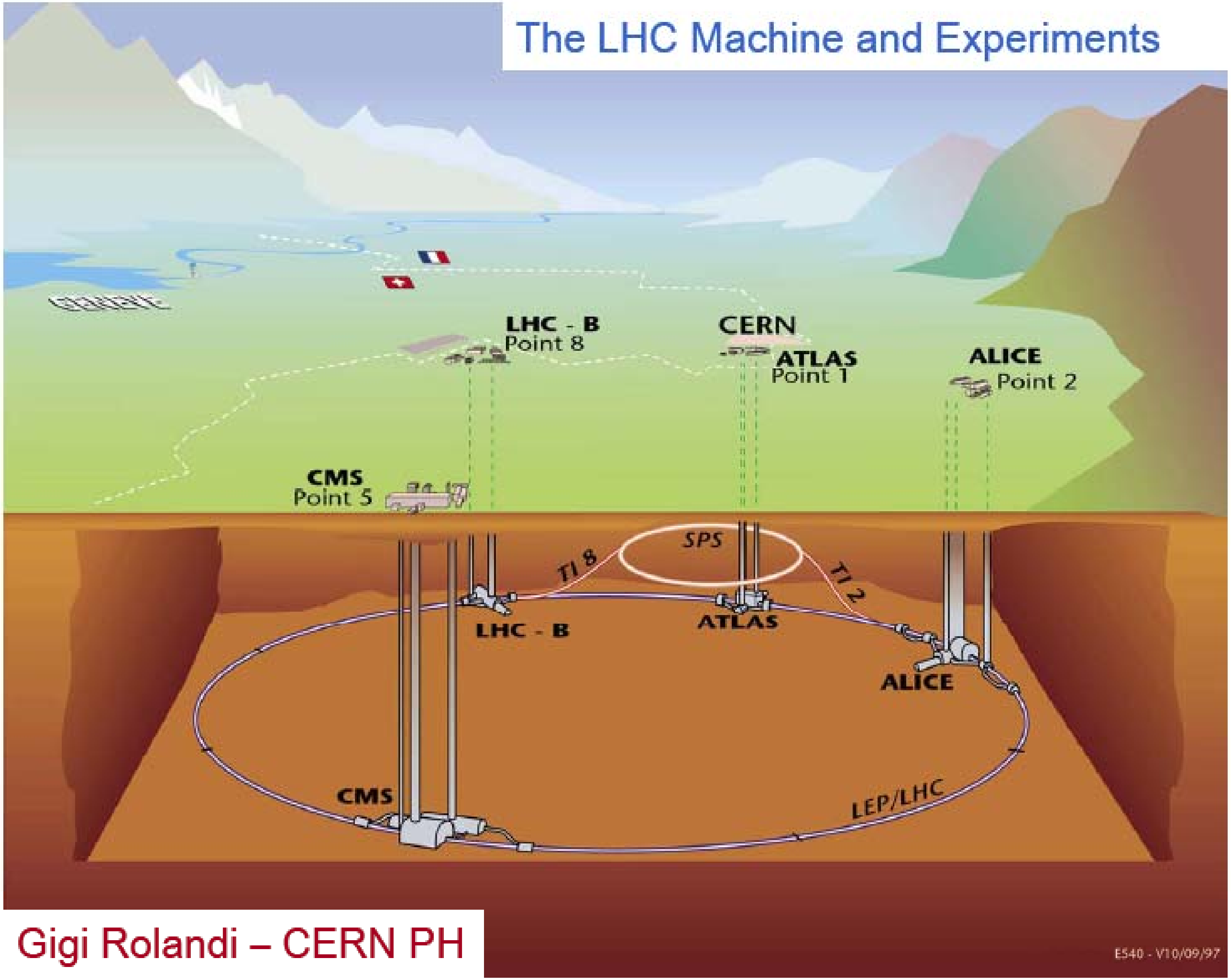
The size of the LHC

The Large Hadron Collider of Cern (European Organization for Nuclear Research)

In a tunnel 300 feet below Switzerland and France, scientists succeeded in sending a beam of protons around a 16.8 mile long particle accelerator that will smash protons together in an attempt to create forces and particles that existed shortly after the Big Bang and rarely, if ever, today.



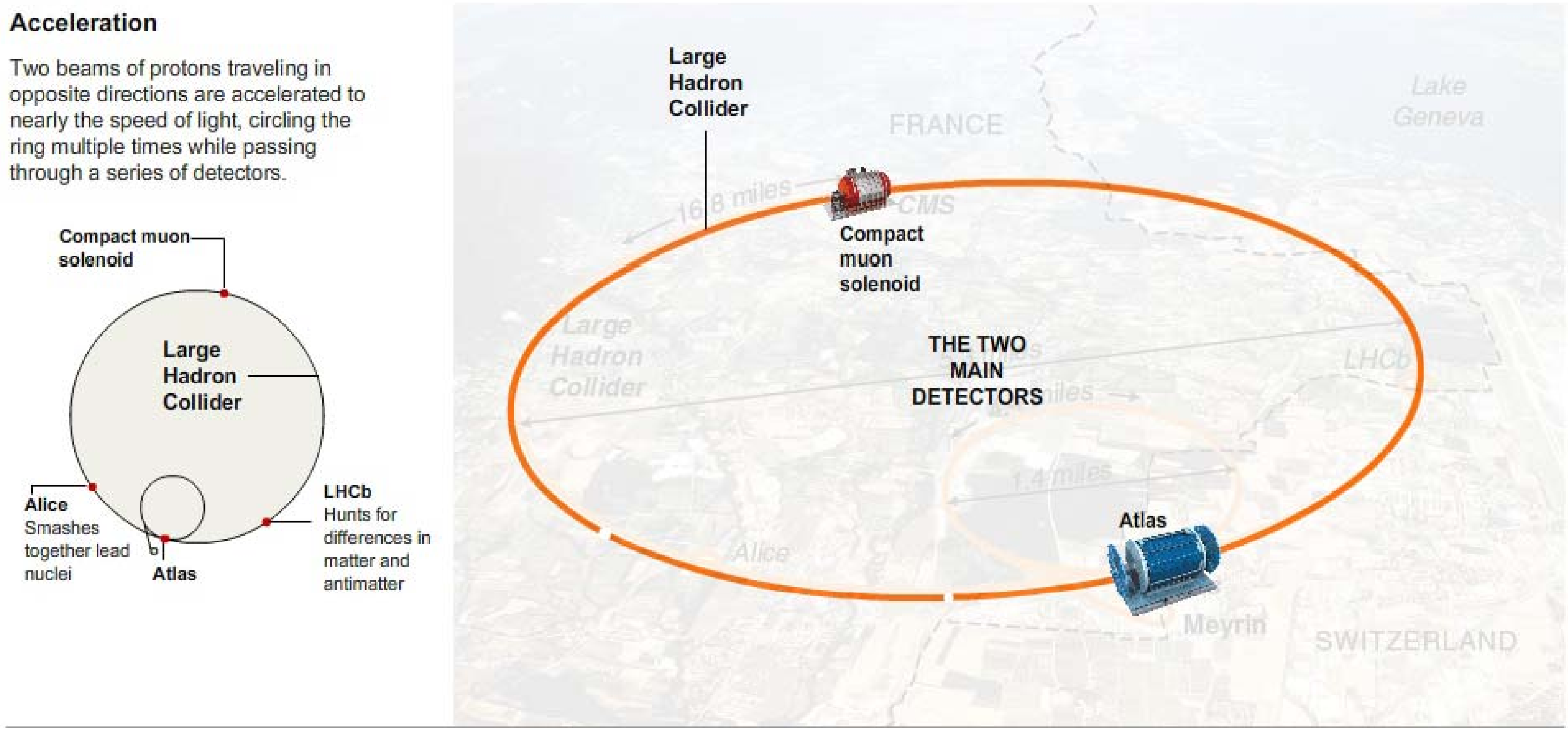
The LHC Machine and Experiments



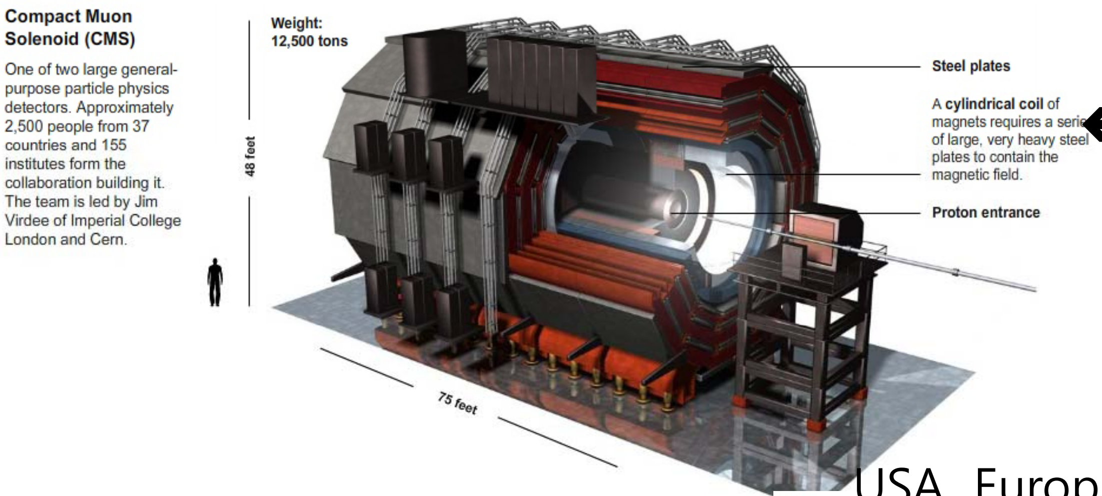
Gigi Rolandi – CERN PH


LHC in Seoul
CMS
ATLAS
상대거리 8.54km
총거리 8.54km
도보 약 2시간 8분
자전거 약 32분
마우스 오른쪽 버튼을 누르시면 끝마칩니다.

The Main ring

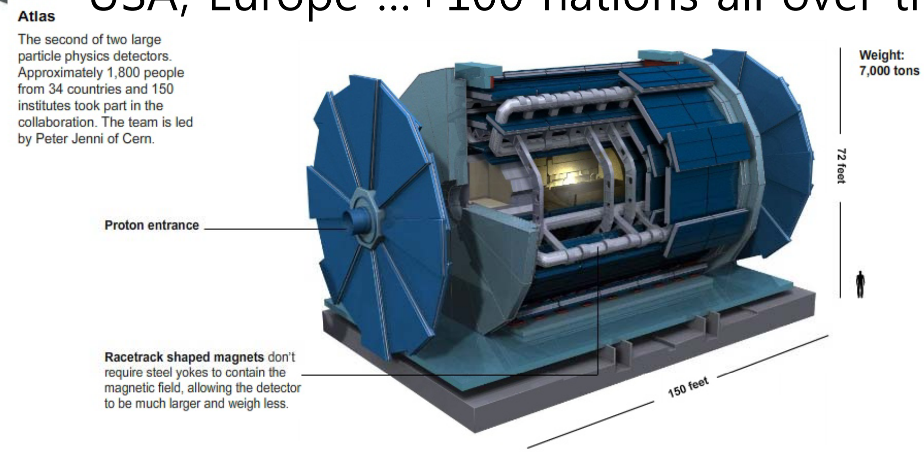


CMS & ATLAS



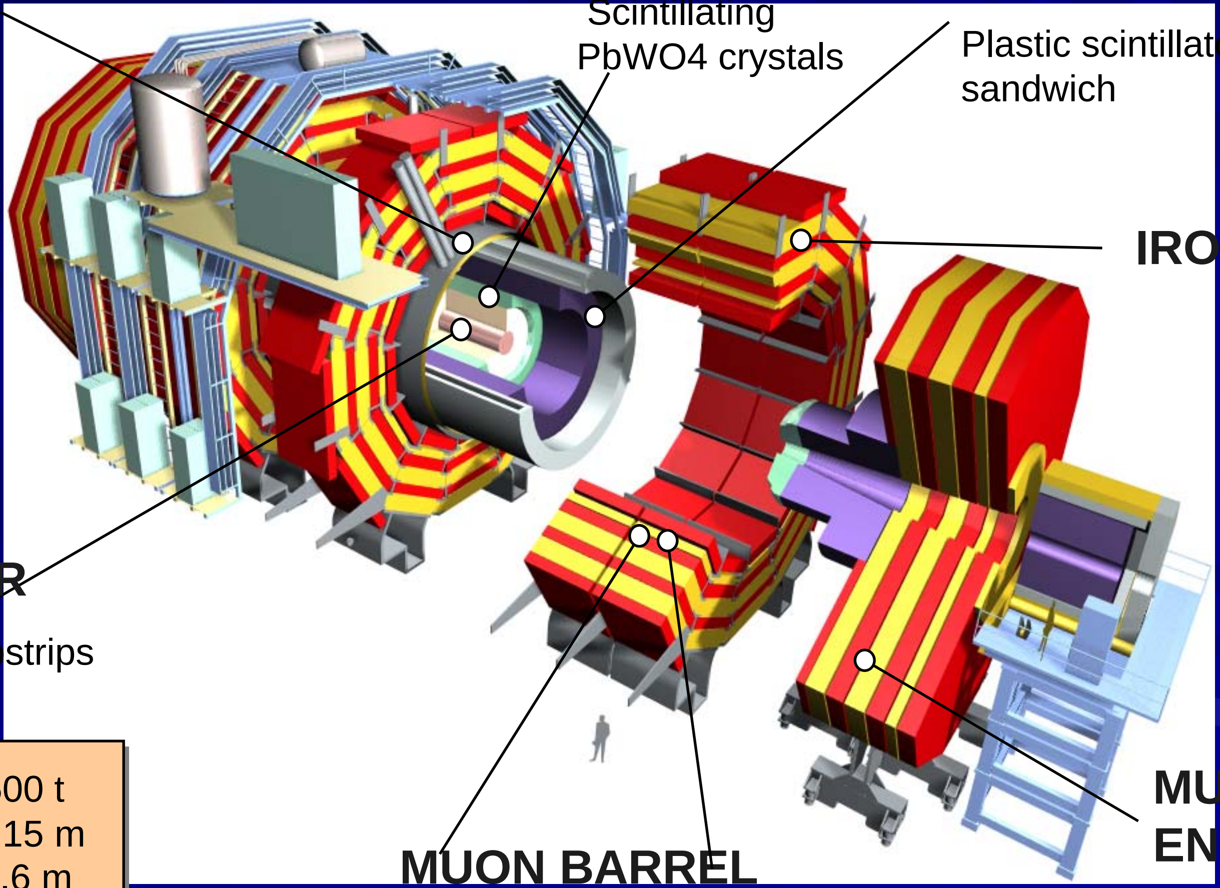
KOREA

USA, Europe …+100 nations all over the world



JAPAN

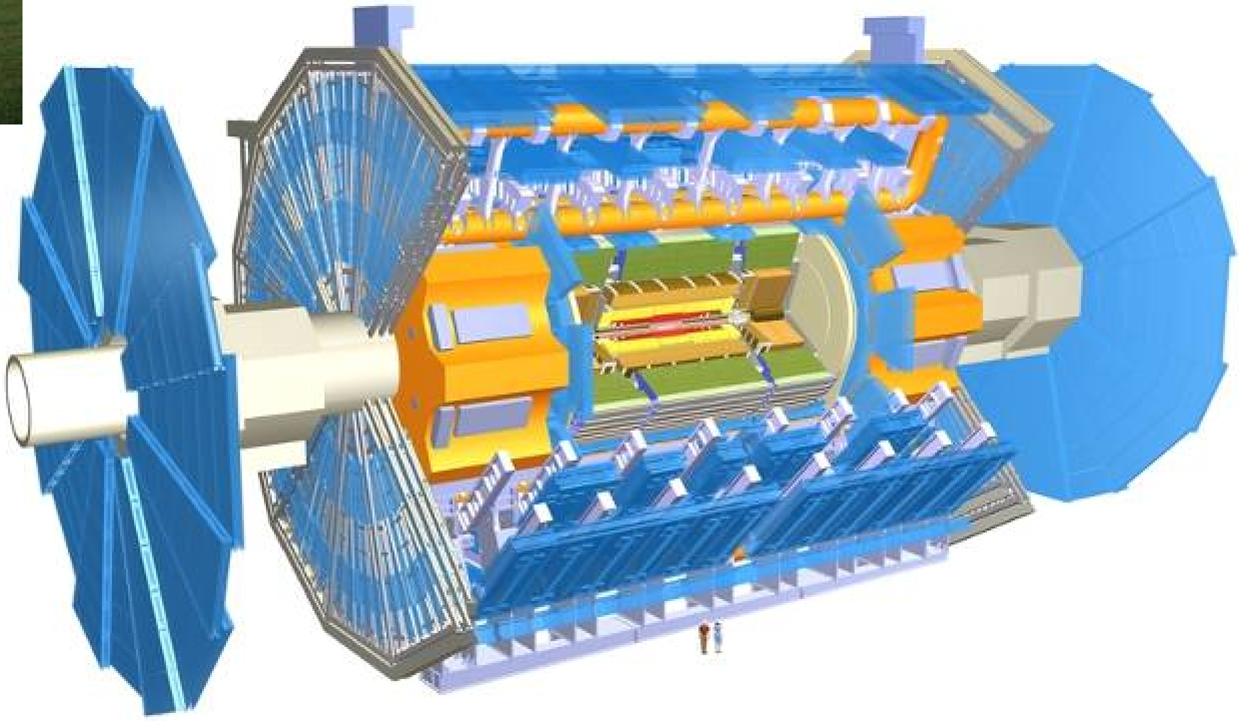
Compact Muon Solenoid



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

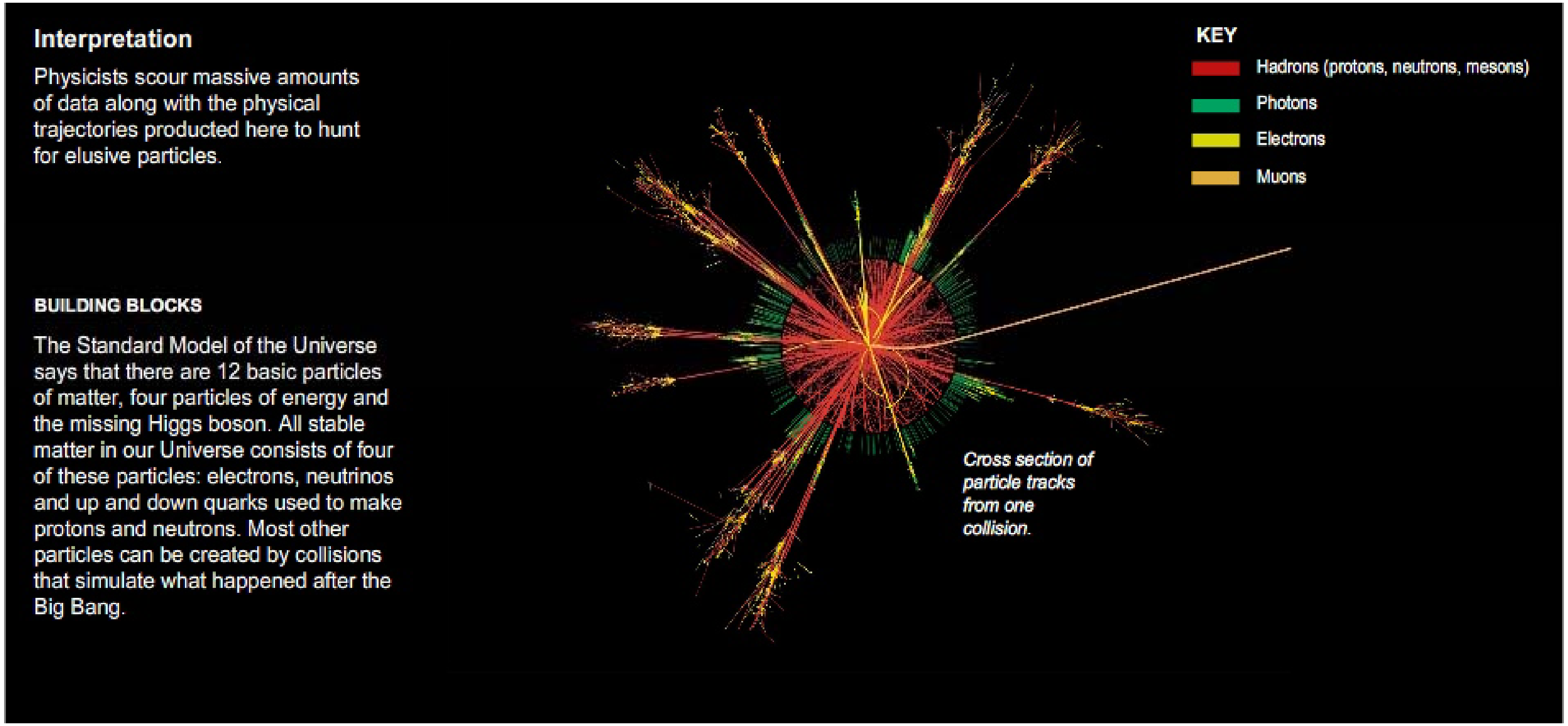
ATLAS

ATLAS superimposed to
the 5 floors of building 40

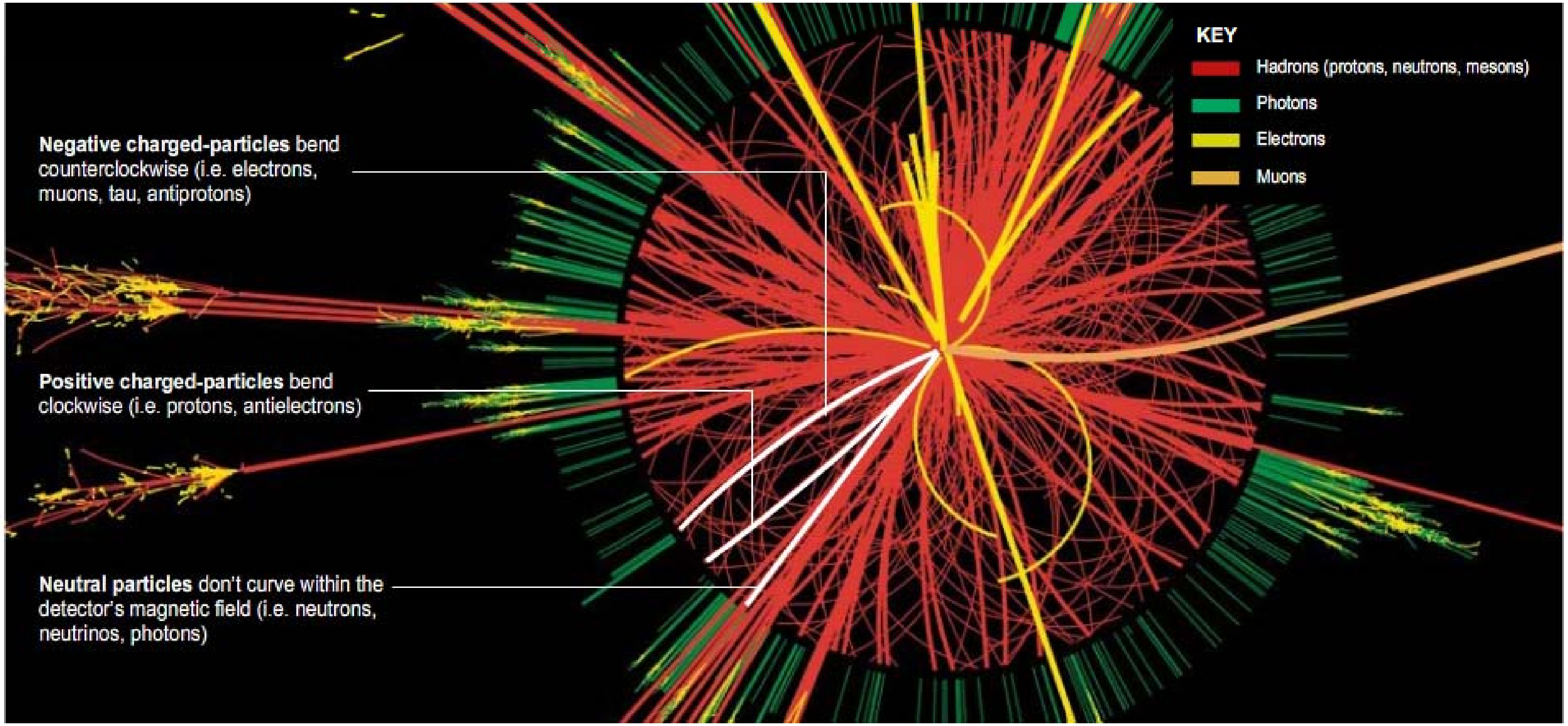


Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

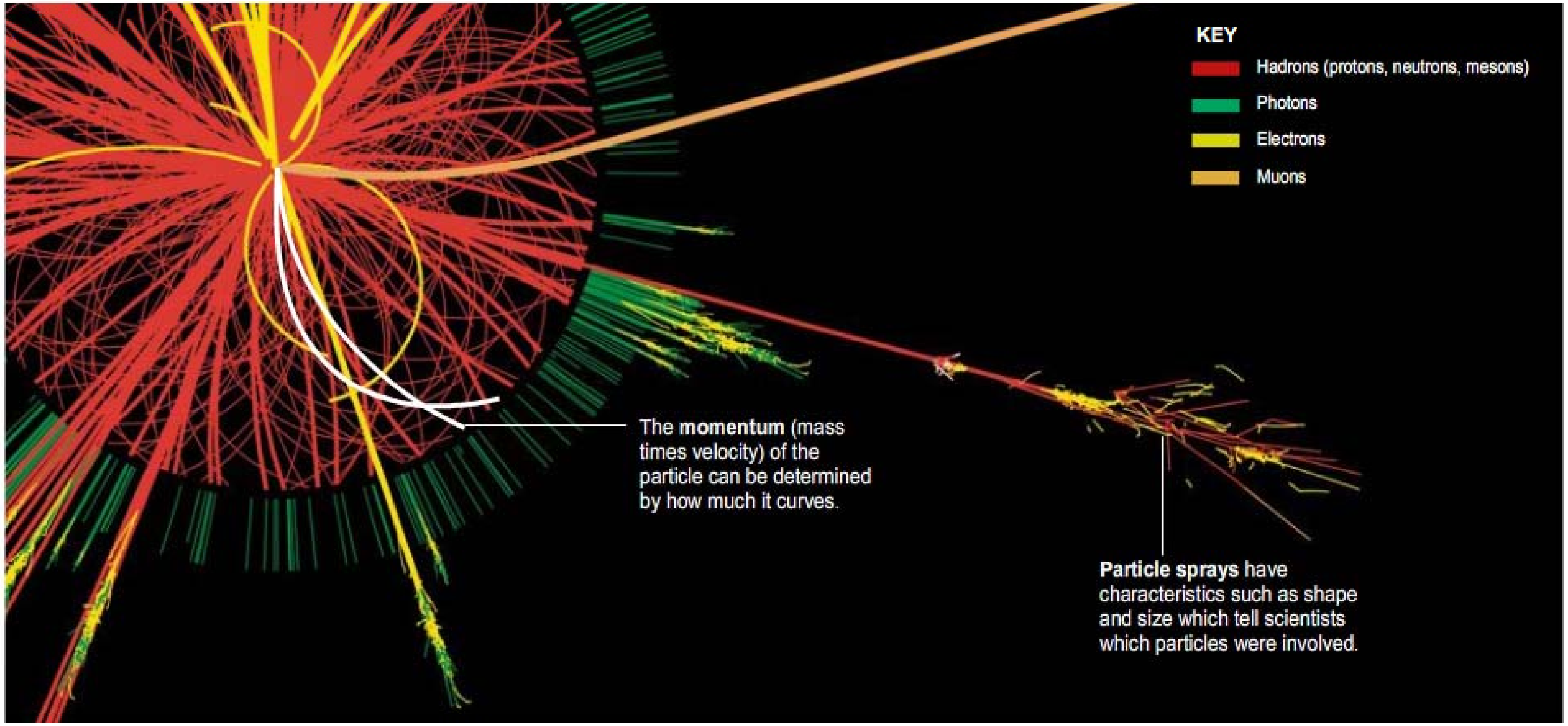
Signals

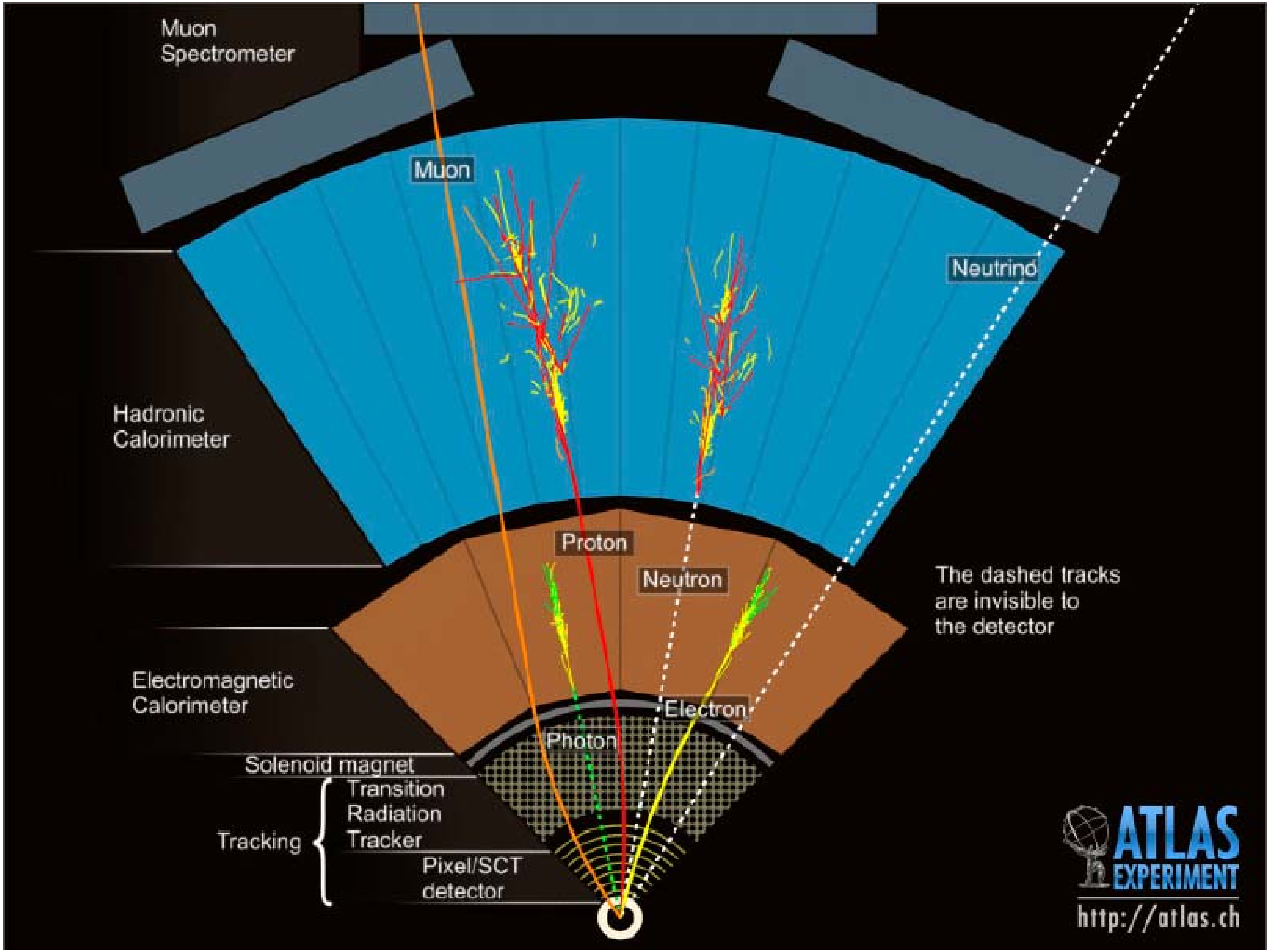

Interpretation
Physicists scour massive amounts of data along with the physical trajectories producted here to hunt for elusive particles.
BUILDING BLOCKS
The Standard Model of the Universe says that there are 12 basic particles of matter, four particles of energy and the missing Higgs boson. All stable matter in our Universe consists of four of these particles: electrons, neutrinos and up and down quarks used to make protons and neutrons. Most other particles can be created by collisions that simulate what happened after the Big Bang.
KEY
Hadrons (protons, neutrons, mesons)
Photons
Electrons
Muons
Cross section of particle tracks from one collision.

Information: charge



Momentum, quantum numbers..





Muon
Spectrometer
Muon
Neutrino
Hadronic
Calorimeter
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Transition
Radiation
Tracker
Tracking
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch

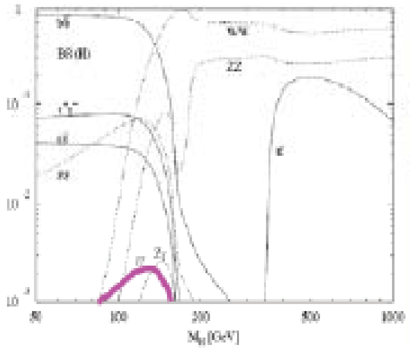
New Era with LHC

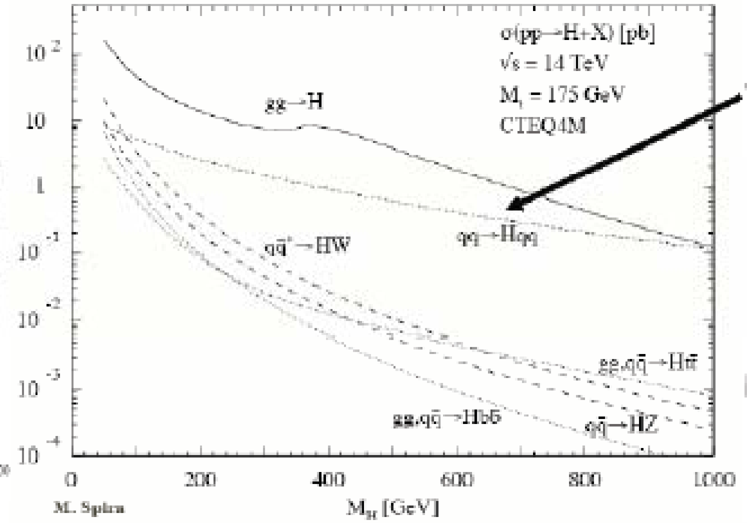
- ~1900 reached atomic scale 10^{-8} cm ~ α/m_e
- ~1970 reached strong scale 10^{-13} cm ~ $Me^{-2\pi/\alpha s b0}$
- ~2010 will reach weak scale 10^{-17} cm
- Known since Fermi (1933), finally there !
- Presumably it could be a derived scale

  (from SUSY breaking, extra dimension, new strong force, etc.)
- We expect rich spectra of new particles
- Start with the SM Higgs boson

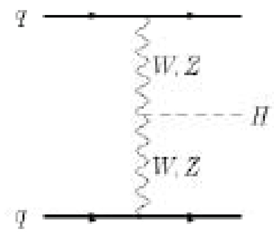
SM Higgs, LHC

- Very large Higgs production cross-section, ~1000 Higgses/day !



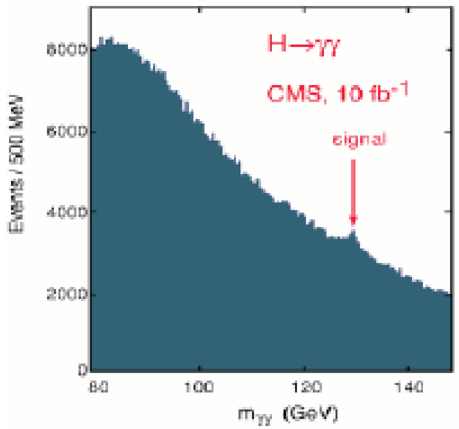


Vector Boson Fusion



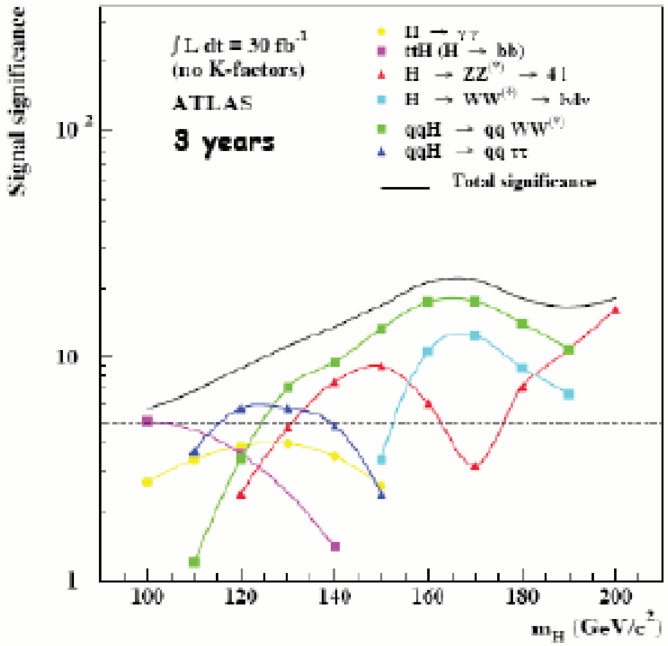
Forward tagging jets

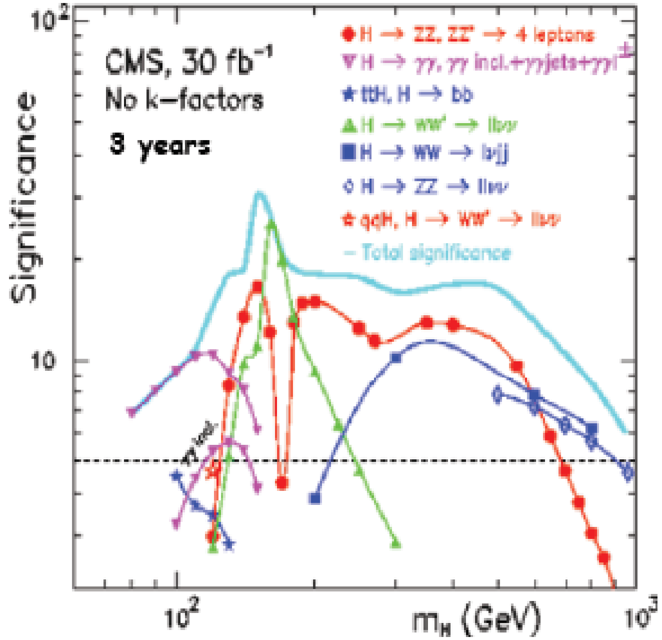
- em calorimeter with precise energy resolution, lead-tungsten crystals (CMS) and liquid argon (ATLAS), to observe γγ bump



SM Higgs, LHC

- H→ ZZ → 4 leptons clean signal for heavier Higgs
- ttH → WbWb+bb for light Higgs





- Higgs discovery up to high masses within first years, measure ratio of couplings, decay width, etc.

Beyond SM Higgs boson

- Neutrino masses and Mixings → Seesaw, R-parity violating SUSY, Radiative mechanisms, ….
- Nonbaryonic DM of the Universe → Axion, WIMP's (LSP, LKP, LTP, LZP,…)
- Hierarchy Problem (Fine tuning of Higgs mass^2)
- Physics behind Higgs mechanism (or electroweak symmetry breaking)

→ Suggest new rich physics around TeV scale

After Higgs is found

- Is it just the SM Higgs boson ?
- Is the Higgs boson fundamental or not ?
- If not, what is the Higgs made of ?
- Weakly interacting (such SUSY) or New Strong Force (such as Technicolor type) ?
- Similar to the Ginzburg-Landau vs. BCS in superconductivity
- Some of these important questions can be studied at the LHC

DM searches @ LHC

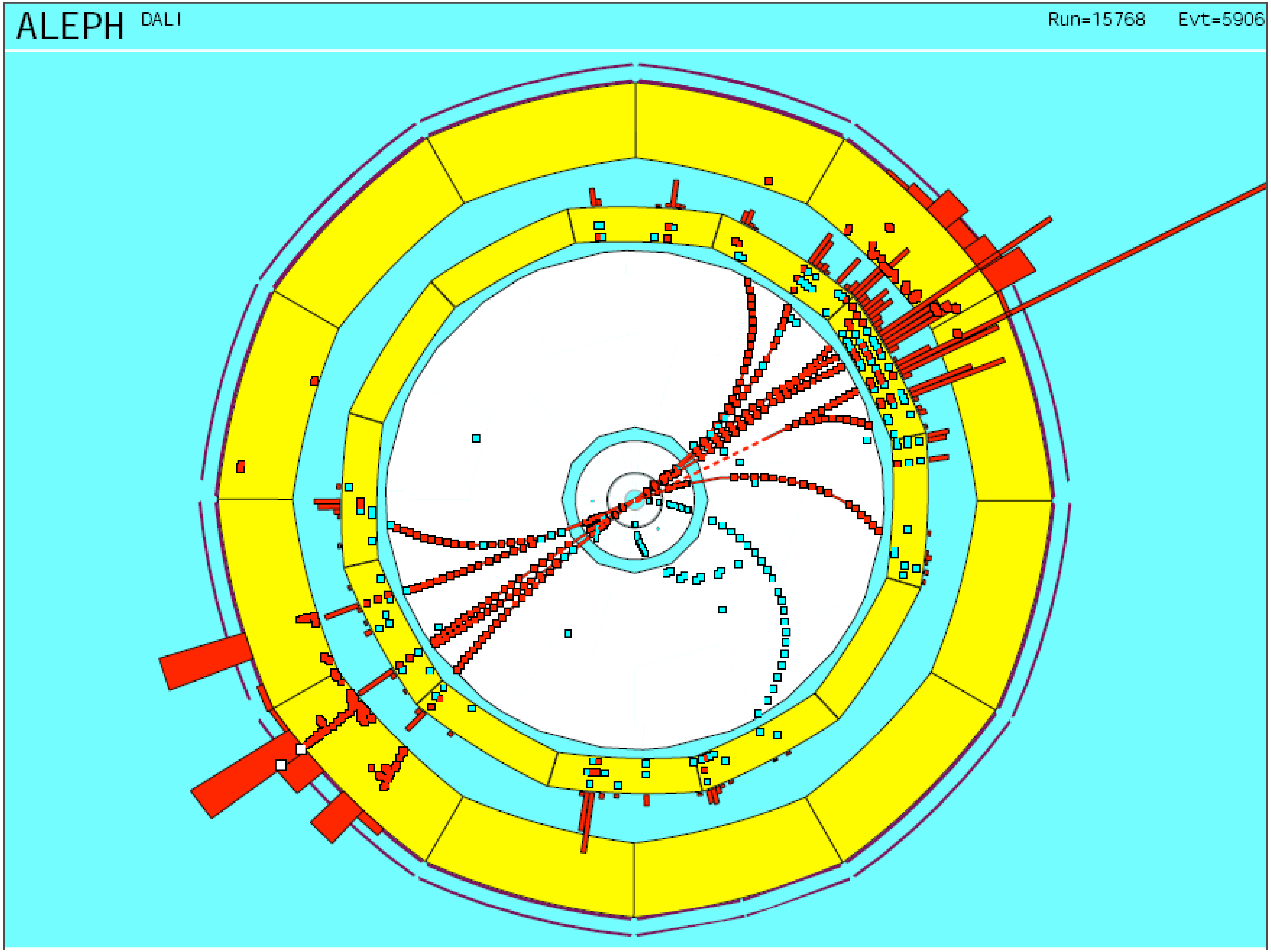
DM searches @ LHC

- Should determine
  - mass
  - spin: scalar, vector or Dirac/Majorana
  - SU(3)xSU(2)xU(1) quantum numbers
  - Mixing of states
- Interactions
  - SU(3)xSU(2)xU(1) gauge invariance
  - Yukawa interactions

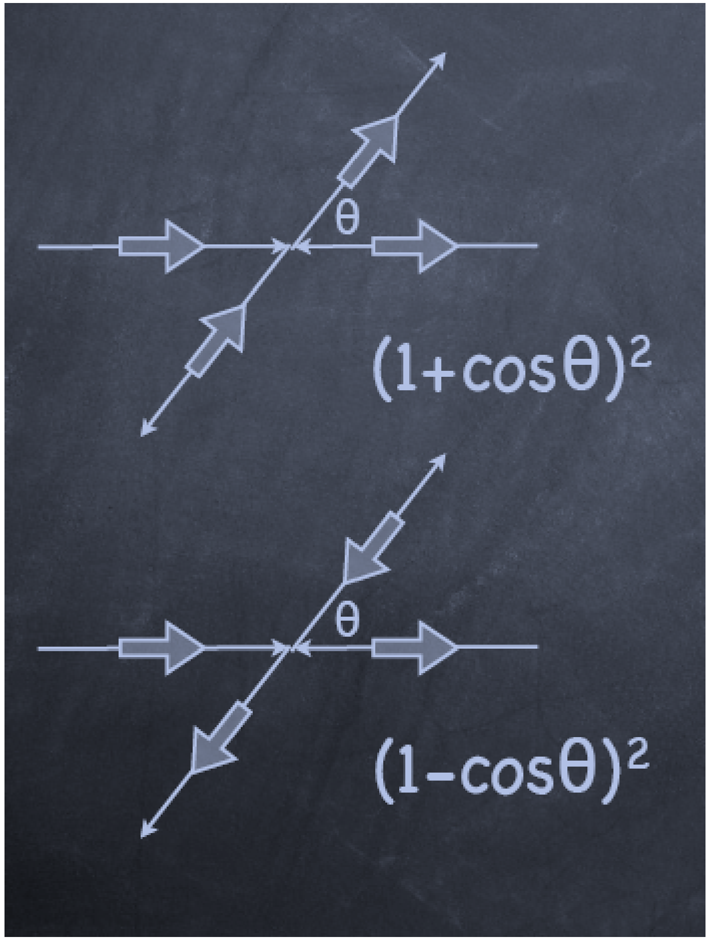
→ Lagrangian (Law of Mother Nature)

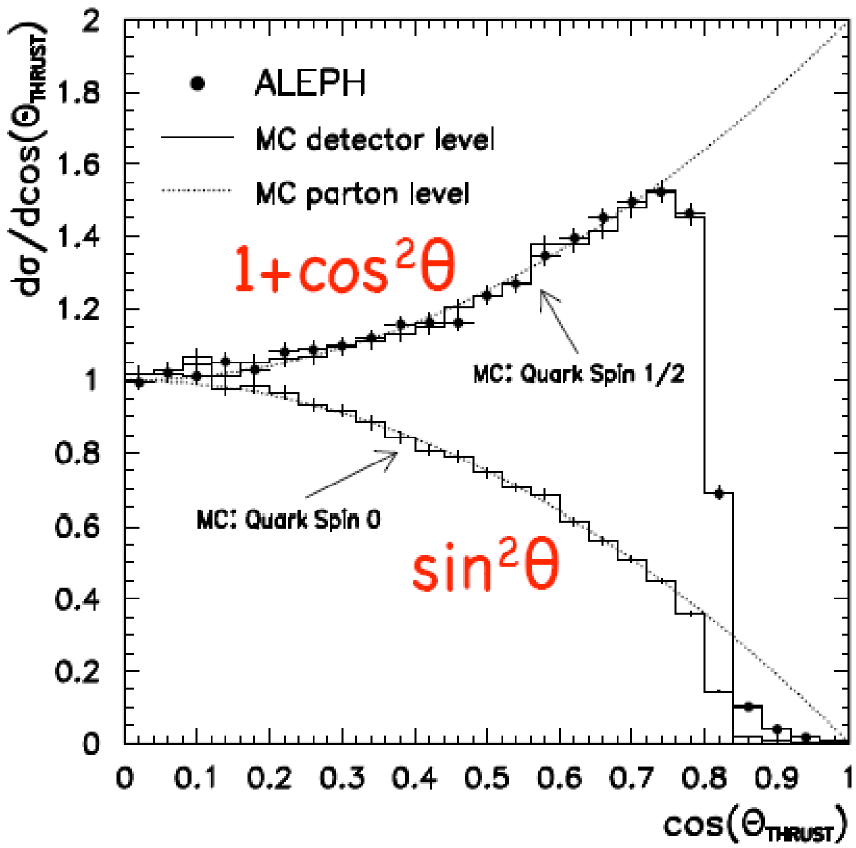
Problems @ LHC

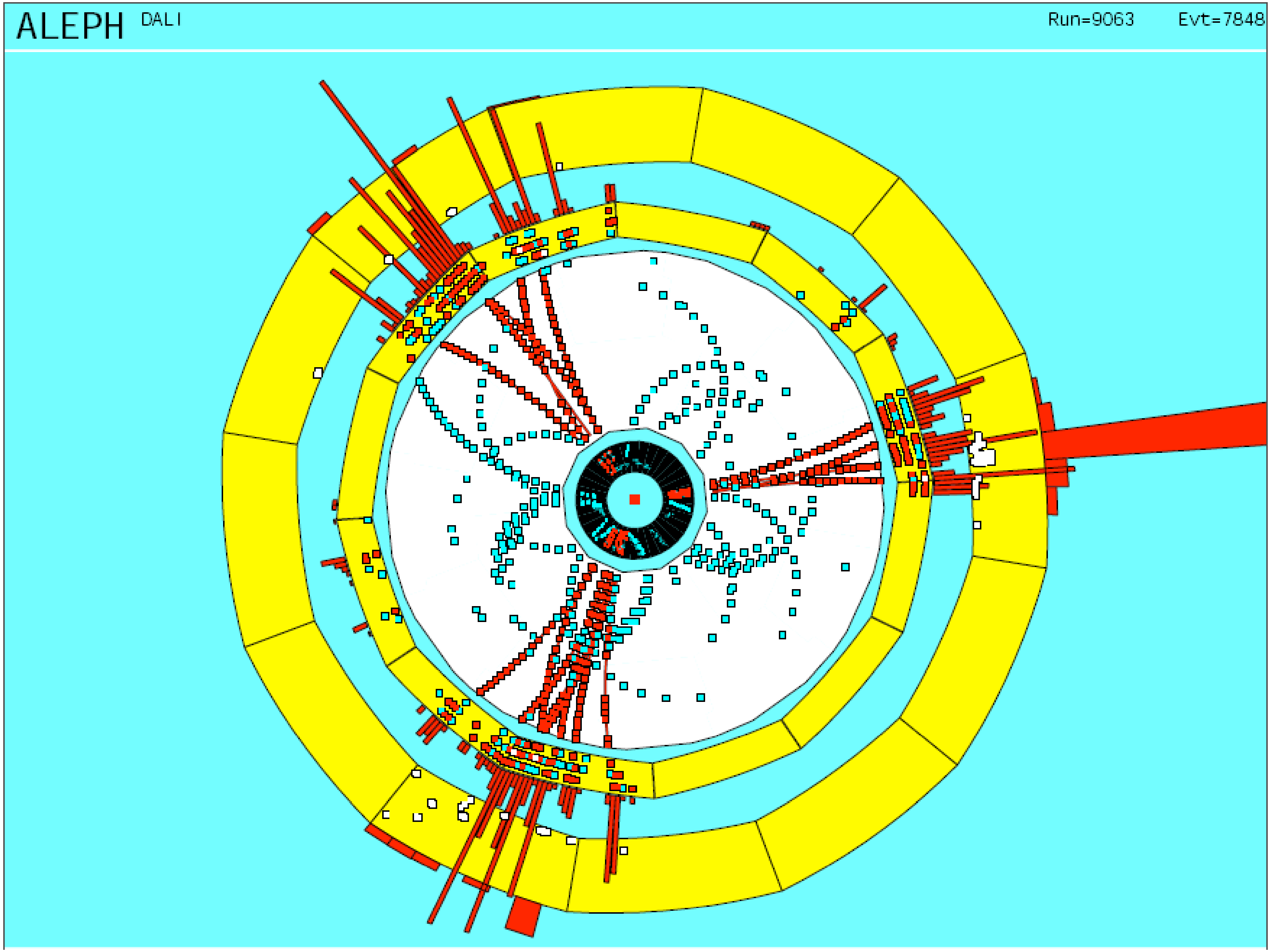
- The biggest issue: loss of particles along the beam direction. Less kinematic constraints because of the unknown longitudinal momentum
- Hadronic final states are very hard, branching ratio may not be measured, hence not the total cross sections
- Linear collider (e^+ e^-) is more powerful for determination of the mass and the spin of new particles → Some historical examples


ALEPH
DALI
Run=15768
Evt=5906

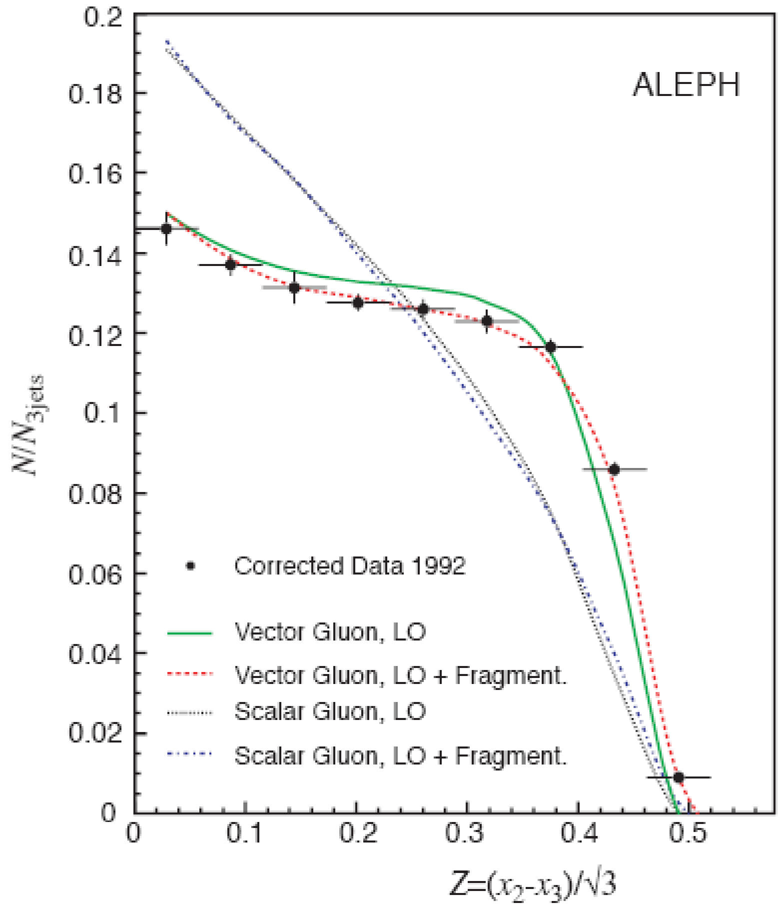
New particle(quark) has s=1/2





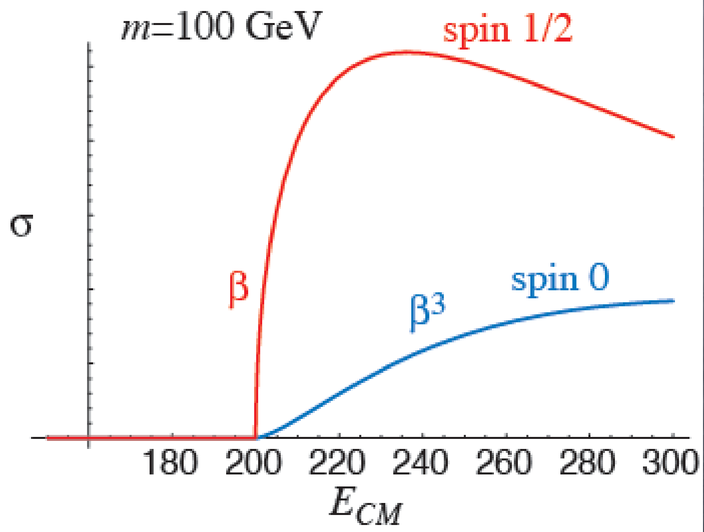

ALEPH
DALI
Run=9063
Evt=7848

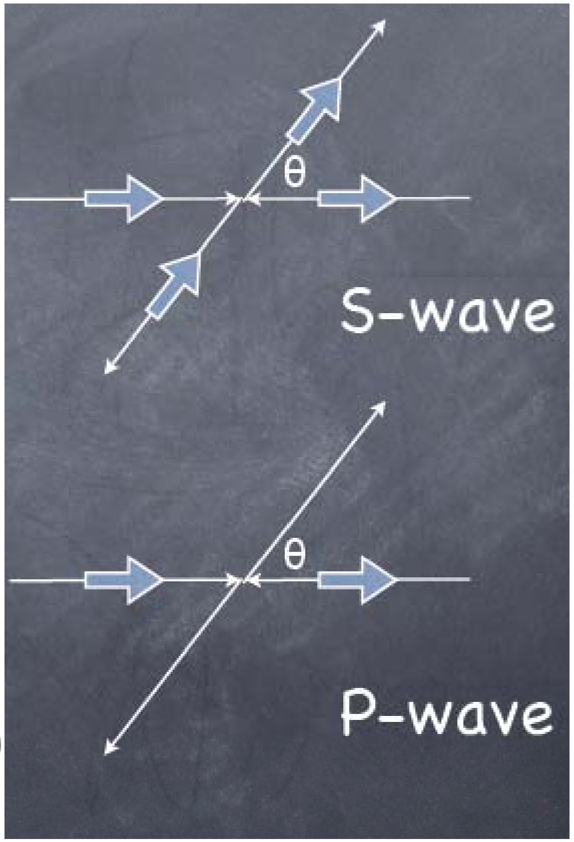
New particle (gluon) has s=1

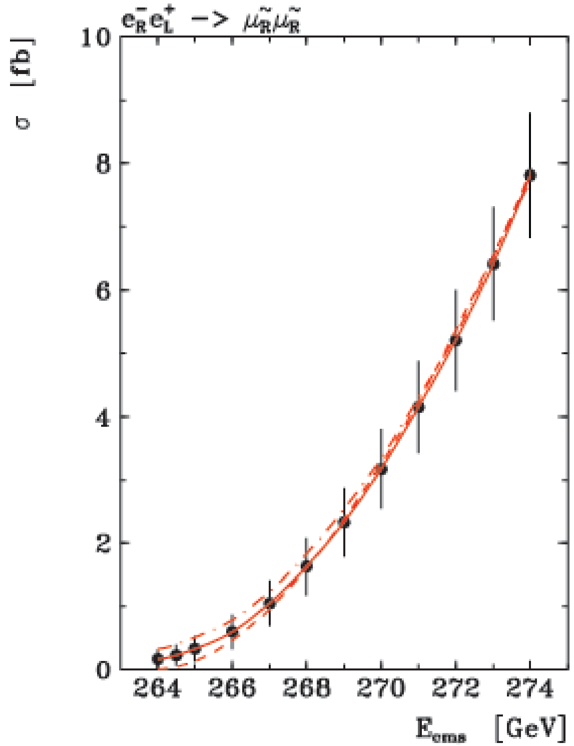


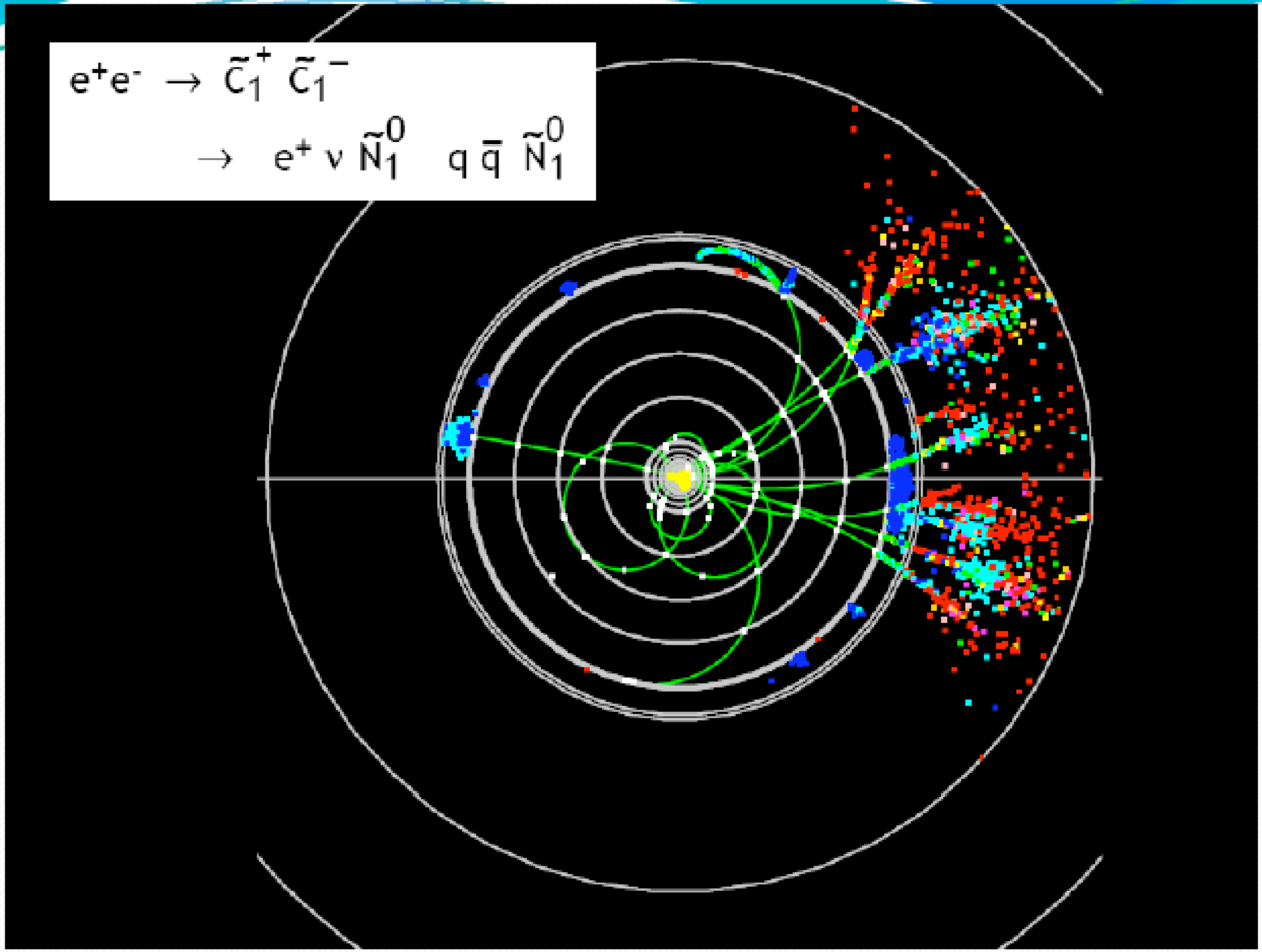
Threshold behavior

Nonrelativistic QM:
L & S conserved separately





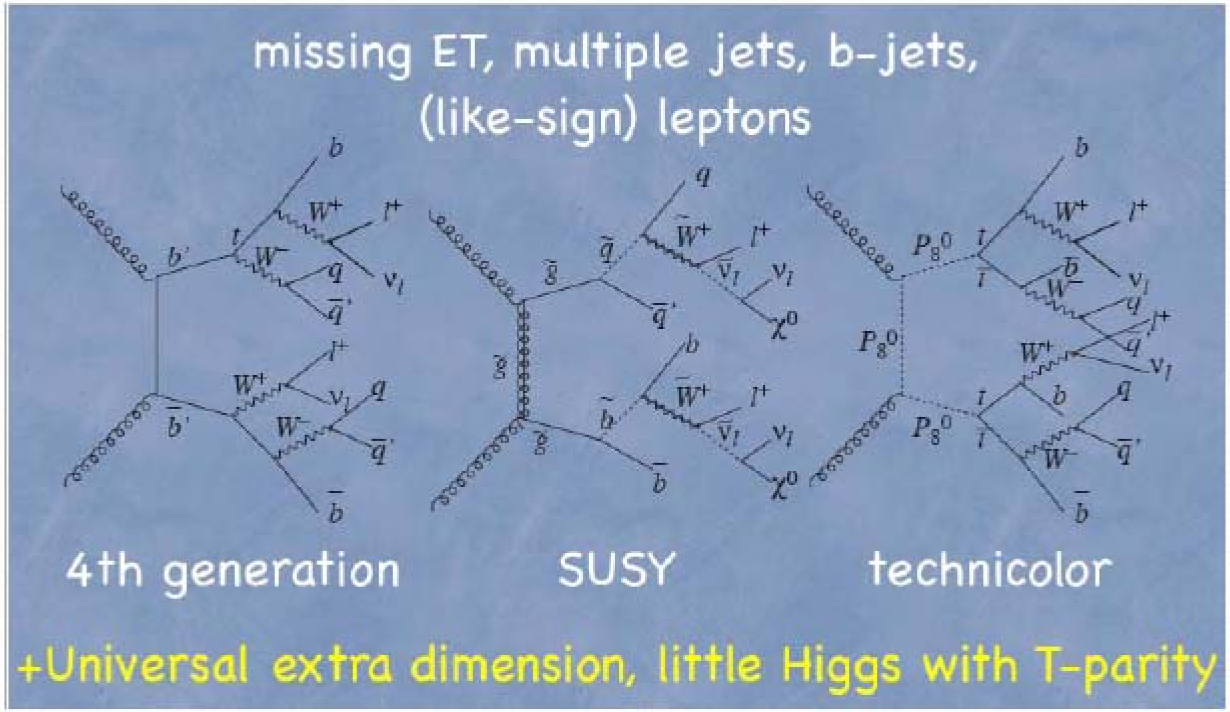



$e^+e^- \rightarrow \tilde{C}_1^+ \tilde{C}_1^-$
$\rightarrow e^+ \nu \tilde{N}_1^0 \quad q \bar{q} \tilde{N}_1^0$

Some Remarks

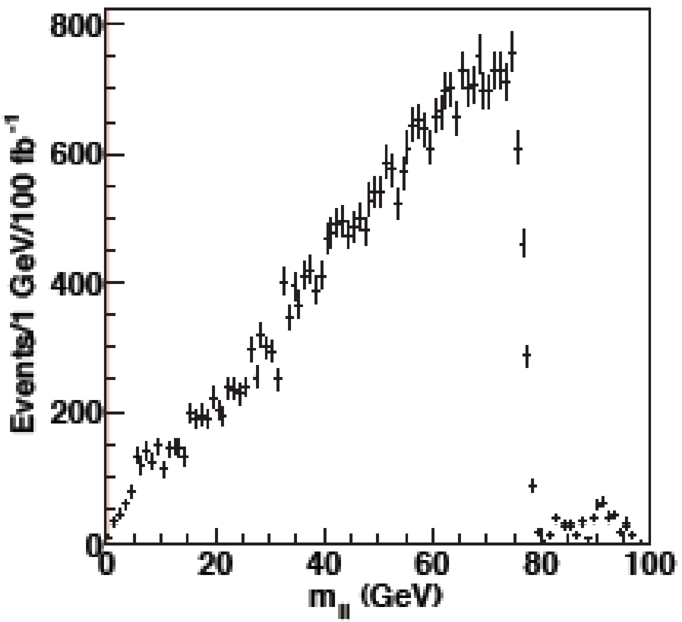
- One can determine the gauge quantum #'s, state mixings, and Yukawa couplings to some extent
- How well we can do depends on what Nature looks like
- Need many new particles @ LHC, with enough kinematic constraints
- Many new physics models have similar missing energy signature→ Big challenges (especially for LHC)
- Should be careful about model-dependent assumptions in data analysis

New Physics (with DM candidates)



Mass Measurement @ LHC

- Look for kinematic edges
- Missing particles make difficult the full kinematic reconstruction, unless there is a long enough decay chain and mass constraints

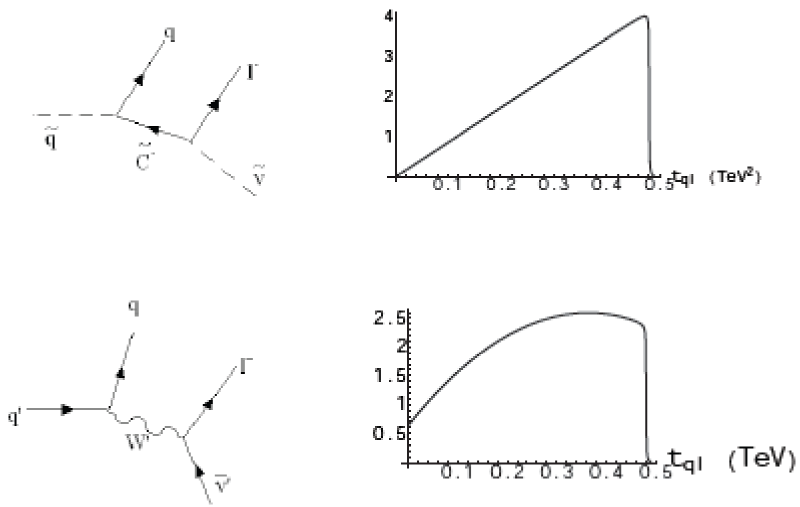


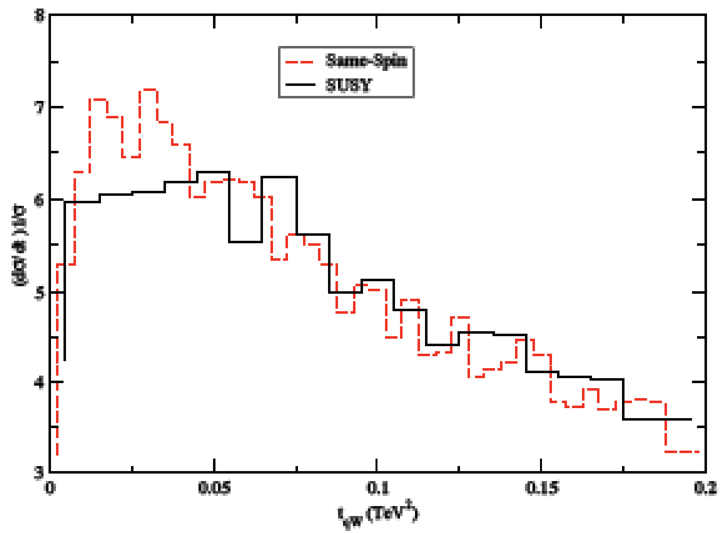
$$\tilde{\chi}_2^0 \to \ell^\pm \tilde{\ell}^\mp \qquad \tilde{\ell}^\mp \to \ell^\mp \tilde{\chi}_1^0$$

$$(m_{\ell\ell}^2)^{\text{edge}} = \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0})}{m_{\tilde{\ell}}^2}$$

Spin Measurement @ LHC

- Universal Extra Dim vs. SUSY





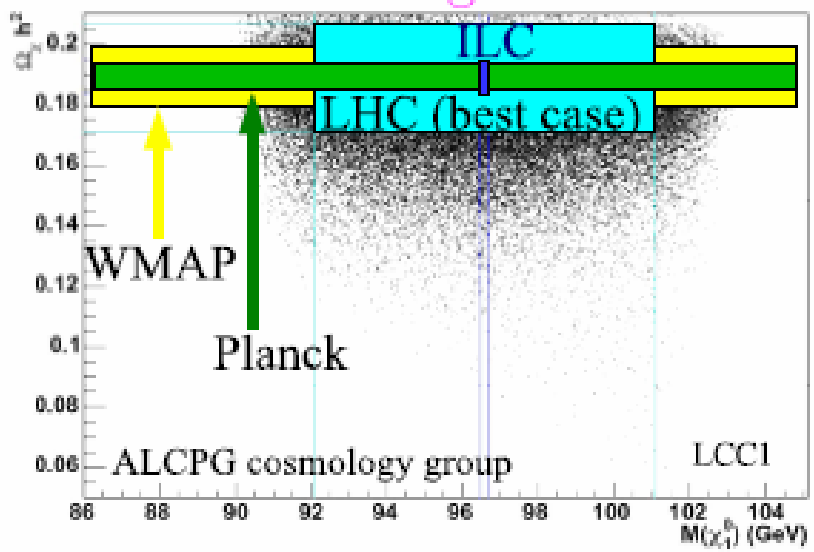
Is it useful at all?

- Of course !!!
- Knowing mass and spin of DM is important by its own, and a key ingredient for the fundamental lagrangian of Nature
- Furthermore, we can calculate the thermal relic density of DM, and compare with the observation
- If they agree, it is fine. If not, we need additional DM's (cocktail solution), nonthermal DM's, or nonstandard preBBN cosmology

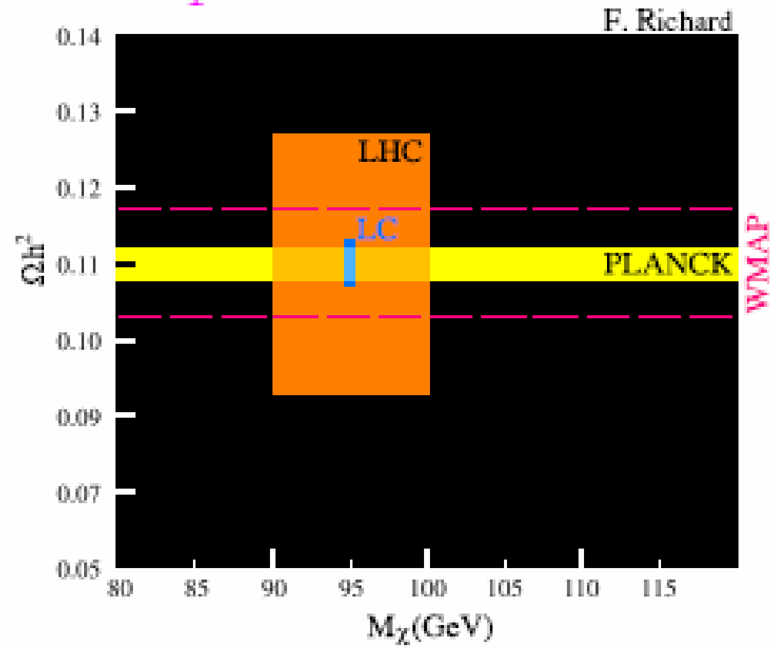
Reconstruction of dark matter

- WMAP and Planck measure the dark matter density to a few %
- Colliders then have to measure all relevant SUSY parameters to probe if the LSP accounts for all
- In the bulk region LHC does fairly well, ILC matches Planck
- E.g. in the $\tilde{\tau} - \tilde{\chi}_1^0$ coannihilation region both particles need to be seen to get the DM density in a model independent way
- Probably difficult for LHC
- Still possible (although challenging) for ILC

Bulk region



$\tilde{\tau} - \tilde{\chi}_1^0$ coannihilation region



Conclusions

- LHC will probe the origin of mass, namely electroweak symmetry breaking and Higgs
- LHC may be able to produce a pair of DM particles, if we are lucky
- Then we can cross check the DM relic density and the CDM properties determined at the LHC
- Anticipate a big progress in DM physics, with interplay of collider (LHC) and astro/cosmology, including direct and indirect detections of DM