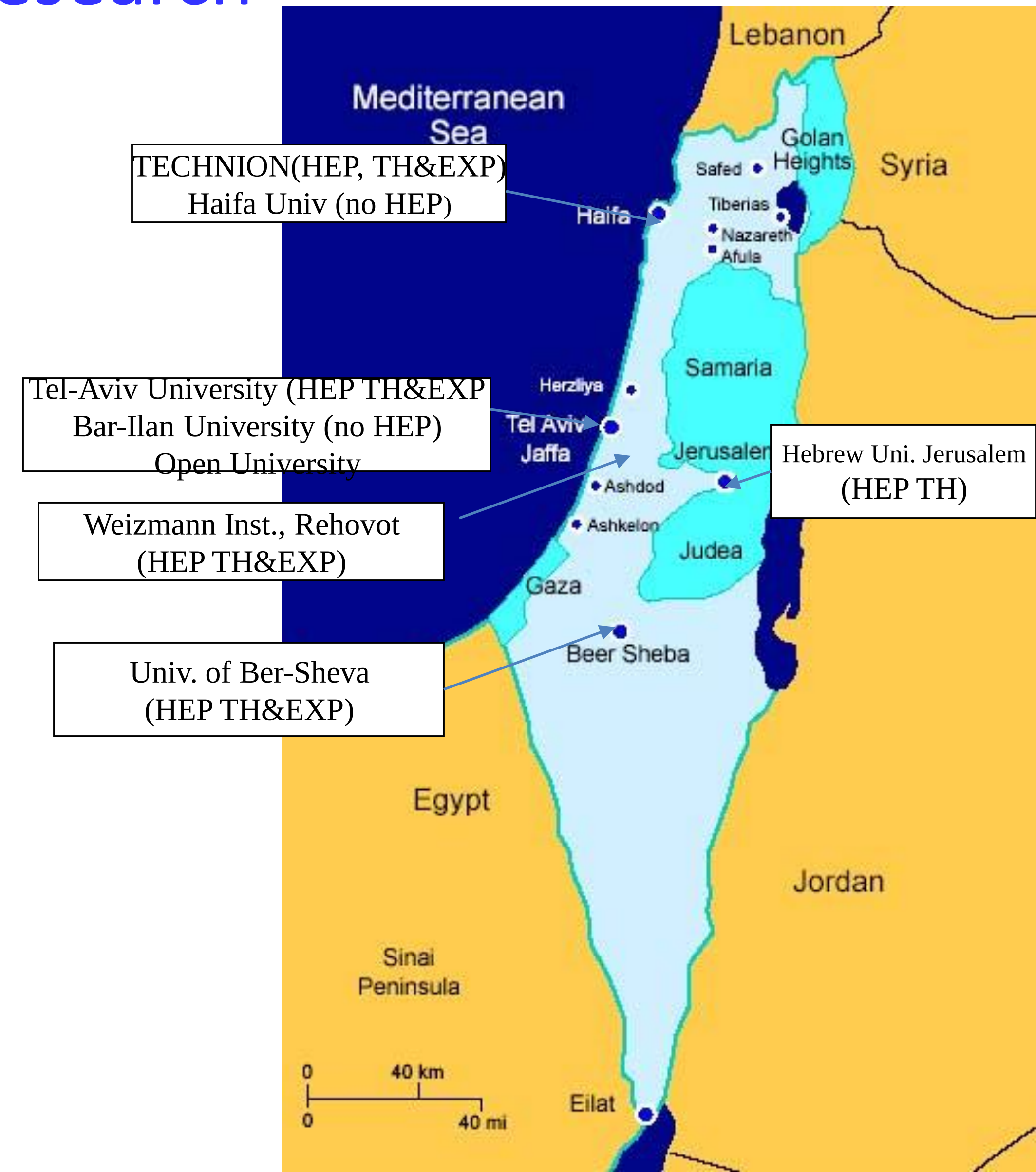
How a Small Country with High Tech could contribute to the discovery of the Higgs Boson

Israeli Participation in the construction of the largest Microscope in the world, the LHC

- Introduction to the Israeli educational system and its influence in the High-Tech revolution
- Israeli relations with CERN
- The Physics of the LHC
- The largest High Energy Physics Experiment in the world, ATLAS and the Israeli participation.
- First results and expectations
- Conclusions.

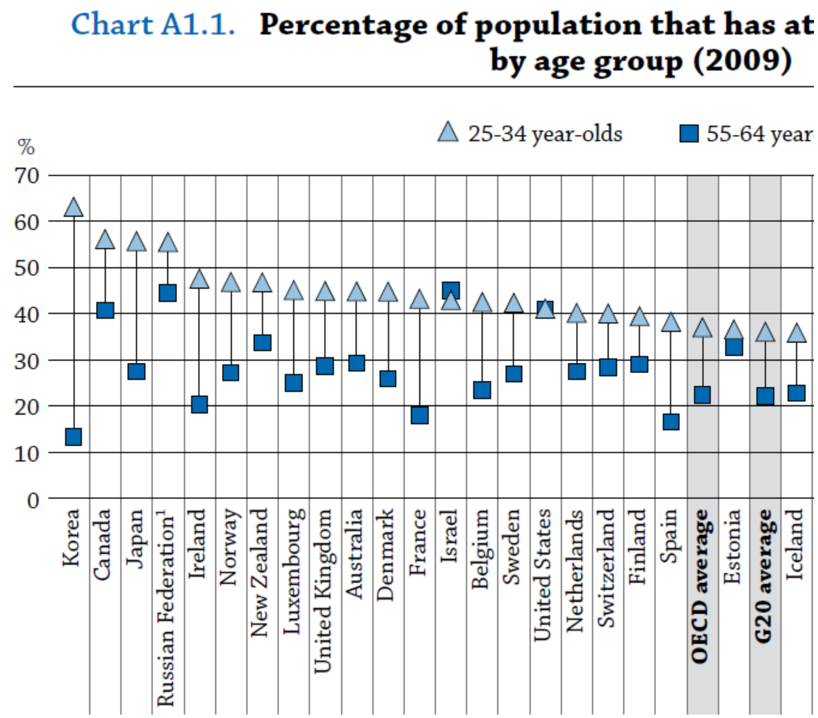
General Comments on Israeli Education and Research

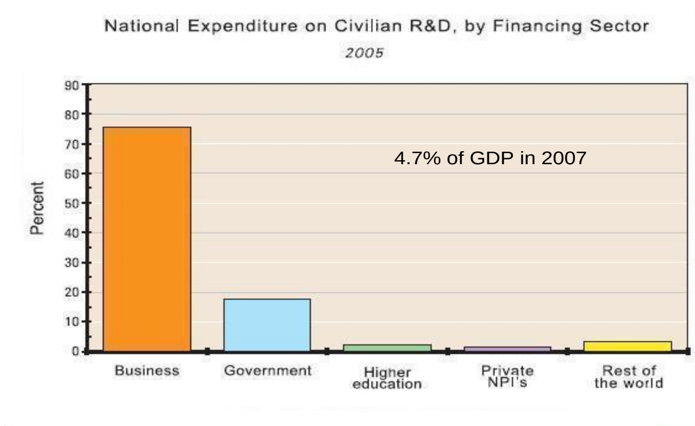
- Israeli Population 8 Millions habitants (=CH)
- GDP (PPP)/capita=33.7K$ (~IT, > GR, <CH=53.7, CL=21.9)
- Unemployment ~6% (not very high taking into account 1M immigration wave, and in particular the present economic crisis) (IT=13%, CH=3%, CL=6%)
- 8 Universities (7 with large Research Programs) & 60 Academies/Colleges.
- Average monthly wage:2.8K$ (IT=3.1K$, GR+2.1K$, CH=7.5K$)
- TECHNION created in 1924 & HU Jerusalem in 1925, Weizmann in 1935 (in 1948: 1,600 students, 90,000 in 1990, >290,000 now)



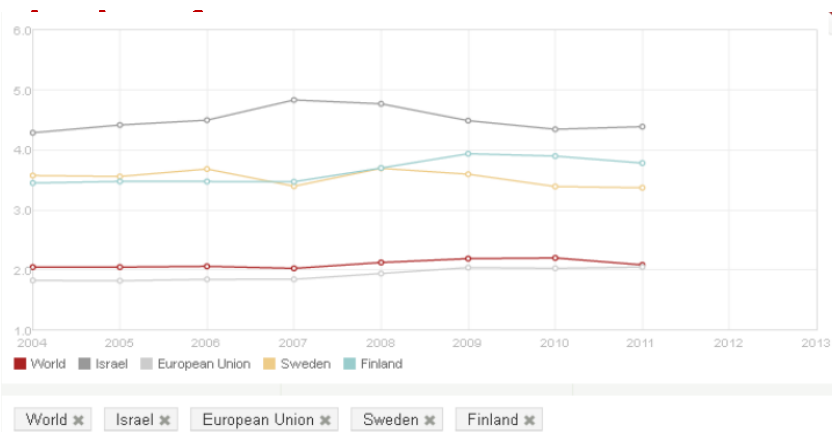
General Comments on Israeli Education and Research

- Education has always been a priority in Israel and the first two Universities were established 24 years before the existence of the State of Israel.
- **47% of the age group 55-64 years old have 16+ years of education (mainly due to the Russian immigration) , while the same % is also for the youngers.**
- Serious Industrial Research only started in the late 70's early 80's (mainly electronics and communication).
- In 85 Law to Encourage Industrial R&D was approved. Fund was established, that reached 400M$ in 2000-1.
- **4.3% of the GDP goes into civilian R&D**
- **High Tech exports have reached 24B$ in**

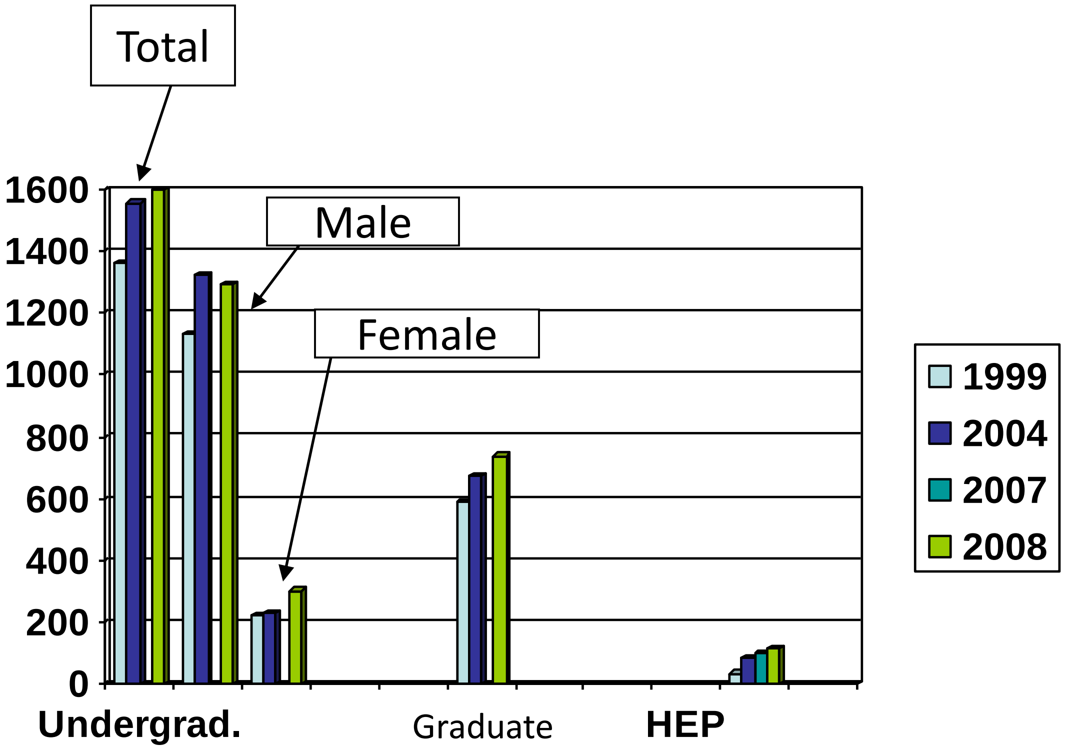




Source: Central Bureau of Statistics, Israel



Physics Students in Israel



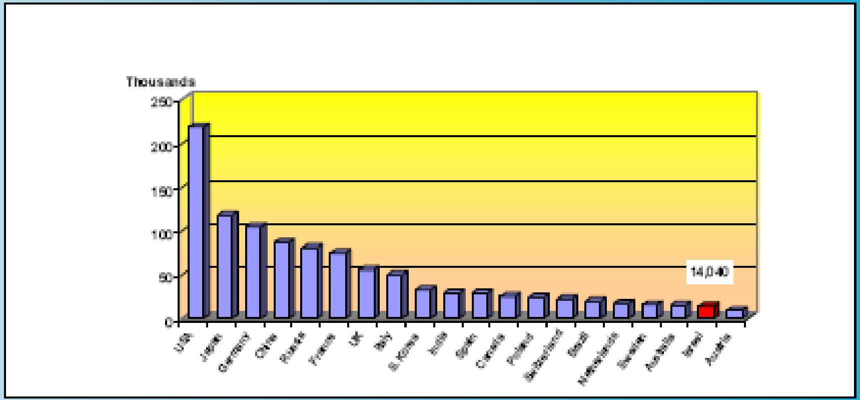
- Although there was a general drop of Physics Students in the late 90's, this trend has changed considerably, mainly due to the immigration from Science minded Students from Russia as well as the High-Tech boom.

Including in Physics

Top Countries in Physics

(1997-2007)

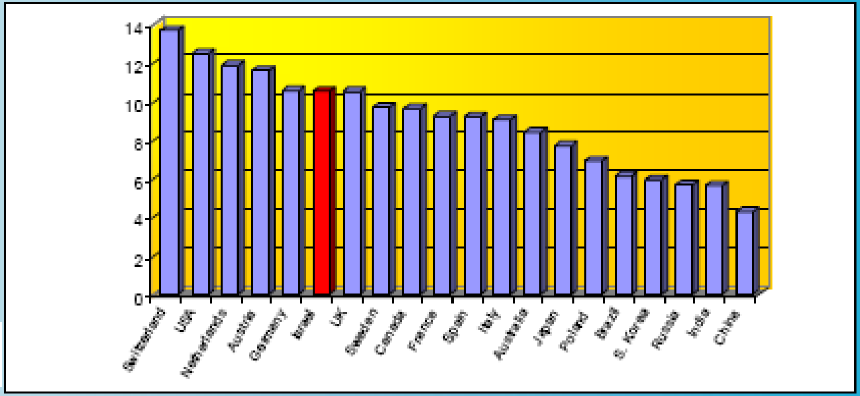
Israel ranked 19th by total N° of Papers



But…

Ranked 6th by importance

(Citations per Paper)



THOMSON REUTERS

Relations with CERN

- Israel has been the first paying Observer State of CERN. This Status includes now India, Japan, Russia, Turkey and the USA.
- In August 1991 a Protocol to the Agreement was signed and renewed several times since then (last time in December 2006). The agreement is financed by the Ministries of Science and Technology (13%) and of Industry Trade and Labour (87%).
- The last version of the agreement includes an overall contribution corresponding of 25% of what would be the total contribution of Israel as a CERN Member State. The framework of this agreement provides 27% in cash and 73% in-kind, by Israeli firms participating in CERN tenders.
- In October 2004 an additional Protocol to the Agreement was signed, by which Israel increases its contribution by 50% for a period of 2 years. The additional contribution was intended to help the LHC Experiments and the GRID Project, by covering 50% of the cost of products purchased in Israeli Industry.
- Typically during these years (2004-2005), the Israeli returns was 130%, while for the normal contribution varies between 90-110%.
- Since December 2013, Israel is a full Member of CERN. This is an important step in the recognition of Israeli Contribution to CERN, both Technologically and Scientifically.

Relations with CERN before applying for membership

Cash contribution support a number of programs:

- 1) Fellows and Associates Program:
  - The regular fellowship program was expanded to include Israeli Fellows, competing on equal footing as their European colleagues, as well as CASS.
- 2) Industrial Associates program:
  - engineers from Israeli Industries have spent various periods at CERN working in the large LHC Experiments and in IT. Over 10 such posts have been funded in the last 5 years (from firms like CHIARO, BATM, INTEL, NICE, MEKOROT, etc.) working for long periods at CERN.

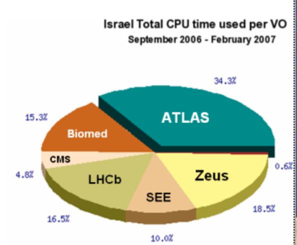
4 Have become Professors at Technion and Weizmann

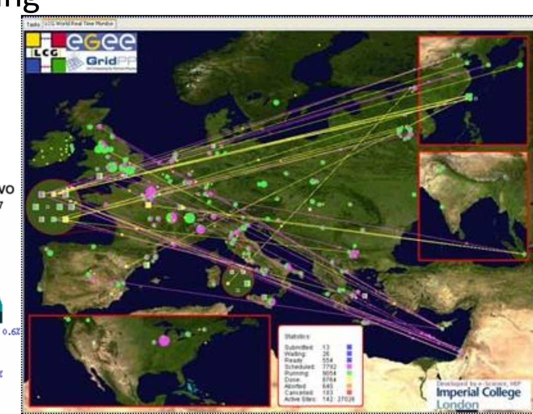
2 Have positions of responsibility in Industry
1 is the director of ta school to train High School students in science

1 is working as Assistant Professor in the USA

- 3) Doctoral Technical and Summer Students programs:
  - 32 Summer Students in the last 10 years (7 Palestinians)
  - 2 PhD students worked on CLIC and on Signal Processing.

- 4) Israeli Technical Associates:
  - The program supports Engineers and Physicists from European Countries working for the TC of the large LHC Experiments (12 until 2011).
- 5) GRID project (mainly Israeli software engineers working on the central GRID development, spending part of the time in Israel).





Relations with CERN

- In-kind Contributions:
  - Although at the start of the program there was good contact and interest from the Machine side, later on most of the purchasing was done by the experiments, including network equipment. Examples of such contracts are:
    - Optical transmission equipment for the synchronization of the LEP-200 RF signal (This tender allowed the firm Phasecom to get involved in very high frequency transmission equipment)
    - Construction of an aqueous cleaning system not involving Freon
    - Heat Shields for the ATLAS End-Cap Toroid (HATEHOF). This has allowed the firm to develop new Al welding techniques and get involved in the field of Cryogenics.
    - Optical Fibers and optical splitters. The firm (FIBERNET) has become one of the main Optical Fibers supplier of the two Large LHC Experiments.
    - Control and Supervision software from the firm AXEDA (this is being used for the LHC cooling control).
    - All high precision resistors used in the machine (VISHAY).
    - Network Switches from BATM, that are widely used by the two Large LHC Experiments.
    - Network equipment from Silicom
    - A large number of high precision detector-support structures for the LHC Experiments TAL, Maresco).
    - Various CAD Systems and System Interfaces (SmarTeam)
    - High precision Al profiles for various support structures (EXTAL, Mishor Haadumim)

Israeli contributions to general CERN Infrastructure from 1992 to 2011

year	LEP	LHC	IT	Tech Serv	Admin.	Exp. Inf.	ATLAS	CMS	ALICE	Others	TOTAL
1992	0.63										0.63
1993	0.22		0.04	0.19							0.45
1994				0.53							0.53
1995	0.02		0.18	0.18	0.29						0.67
1996	0.09	0.11	0.1	0.06	0.04						0.4
1997	0.04	0.16	0.1								0.3
1998	0.37	0.01	0.11	0.51							1
1999	0.05	0.47	0.73	0.25	0.01						1.51
2000		0.43	0.32	0.15	0.28	0.06					1.24
2001		0.42	0.63	0.03	0.02		0.49				1.59
2002		0.59	0.45	0.06	0.01		0.25		0.01		1.37
2003		0.21	0.21	0.46		0.13	0.61	0.01			1.63
2004		0.14	0.41	0.01			0.91	0.05			1.52
2005		0.15	0.08	0.03		0.09	1.76	0.2	0.12		2.43
2006			0.08	0.09		0.01	1.5	0.55			2.23
2007		0.11		0.19			0.55	0.44	0.1		1.39
2008		0.22	0.06	0.52			0.43	0.34	0.02		1.59
2009			0.12	1.18	0.03		0.23	0.12			1.68
2010		0.28	0.3		0.03		0.44	0.08	0.2		1.33
2011		0.34	0.12		0.03	0.01	0.46	0.16			1.12
TOTAL	1.42	3.64	4.04	4.44	0.74	0.3	7.63	1.95	0.27		24.43
Cash Cont	0.3	0.1									0.4
Undefined 1999		0.2	0.3	0.1							0.6
Tot aft. Corr	1.72	3.94	4.34	4.54	0.74	0.31	7.63	1.95	0.27		25.44
Tech. Ass.							2.76	1.17			3.93
Ind. Ass.			0.04	0.11			0.47	0.05			0.67
GRID-LCG										0.56	0.56
CLIC										0.06	0.06
TOTAL	1.72	3.94	4.38	4.64	0.74	0.31	10.86	3.17	0.27	0.62	30.66
Progr. IL										2.84	2.84
TOTAL											33.55

Educational aspects

Israeli High School and University Students

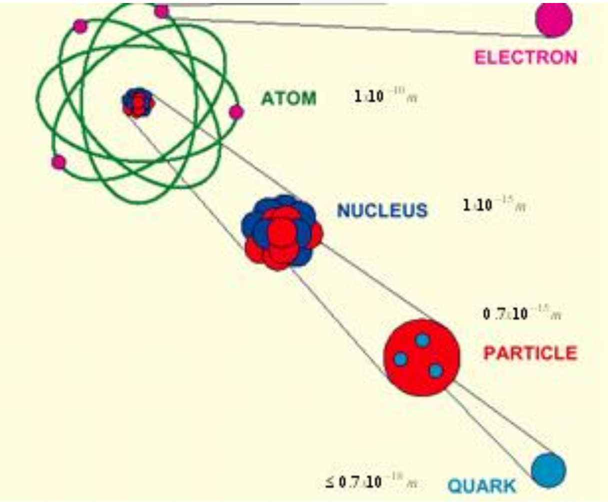
- Israeli teachers:
  - 1 in 2011
  - 2 in 2012
  - 3 in 2013
  - ~70 expected next year
- High School groups from Israel:
  - 20 High School Students 2012
  - 110 High School students 2013
- Israeli BSc Physics & Engineering Students
  - 32 Summer Students (+7 Palestinians) since 2003.
- Israeli MSc & PhD students involved in ATLAS: 25

מגדל בבל של

המאה ה-21

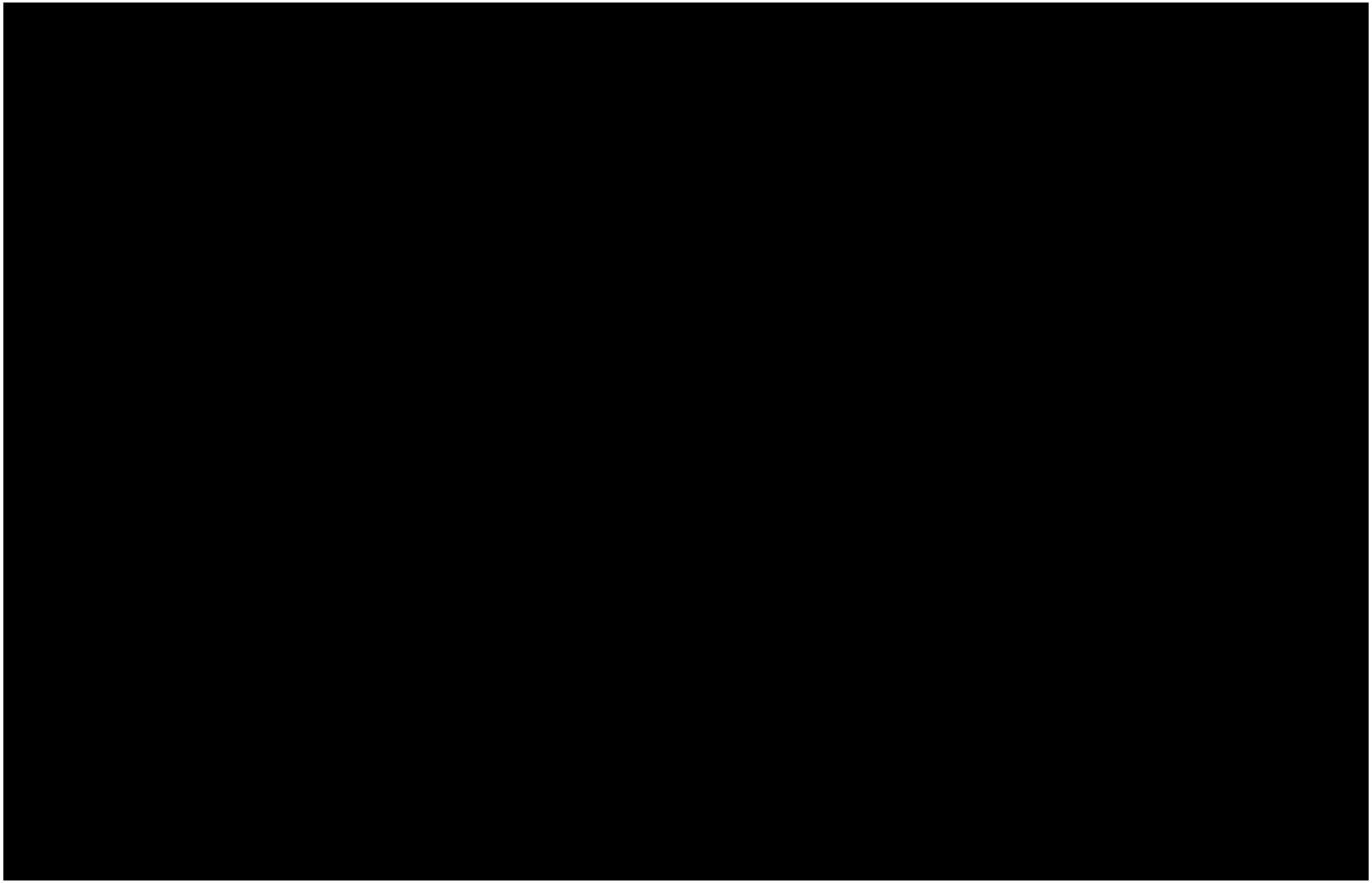
משלחת נוספת של תלמידי פיזיקה חזרה מביקור במאיץ החלקיקים ב-CERN שבשוויץ

What is matter made off?

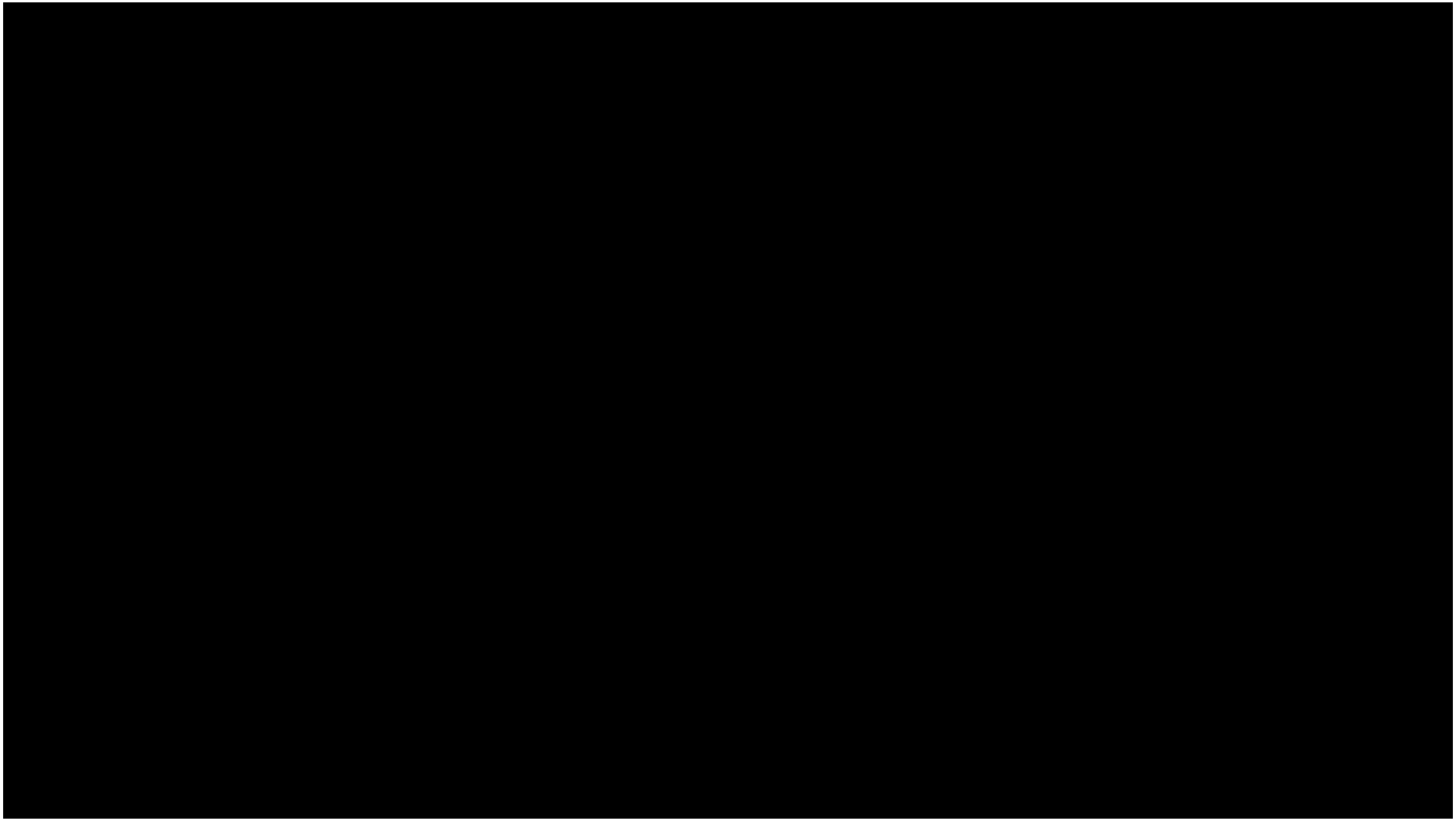


- But if particles have no dimensions, how can they have mass?
- If energy can become pairs of matter and anti-matter, where is the anti-matter?
- Are there other basic particles besides those that we know?

Our understanding of the Big-Bang

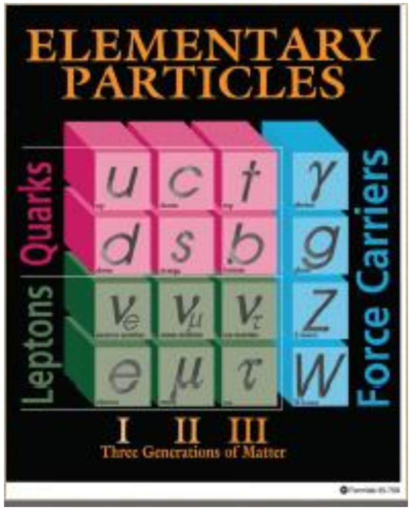


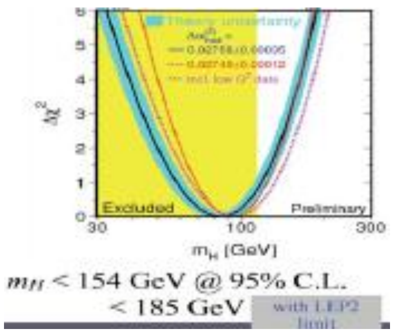
How can we observe this?

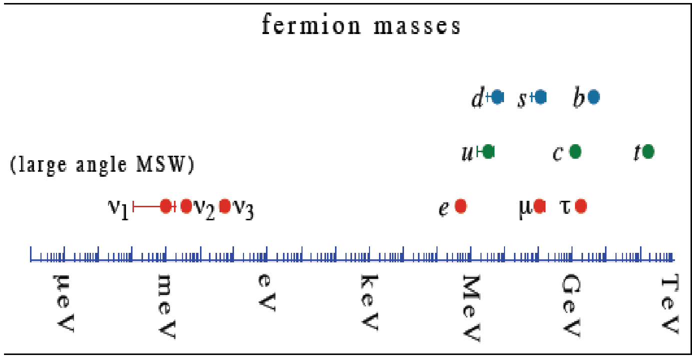


The Standard Model and its problems

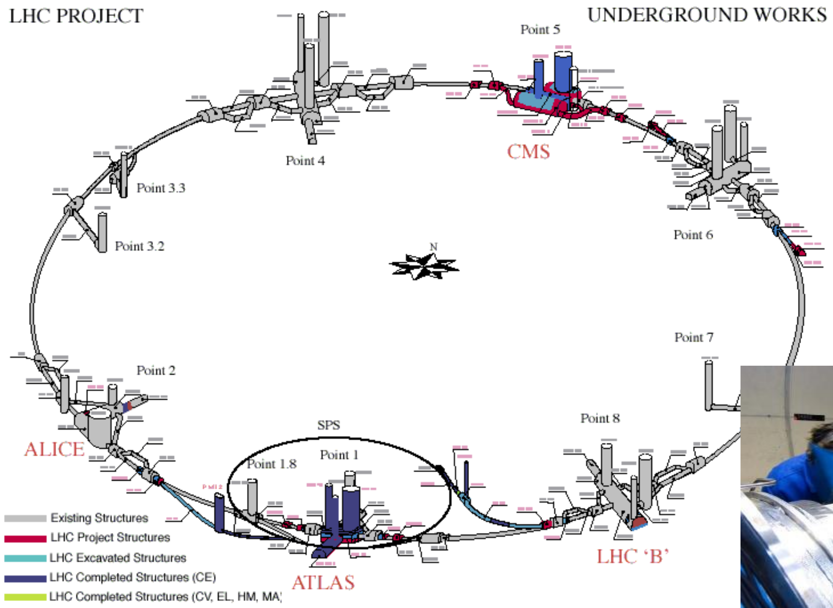
- The SM provides us an excellent description of the basic interactions between quarks and leptons, with tests of Electro-weak radiative corrections at the level of 10E-3.
- There are, however, number of open questions:
  - The Higgs boson(s), responsible for the mechanism of providing mass to all particles, has finally been found.
  - We have no understanding of the large mass differences between the basic components of matter.
  - The SM has no explanation for the non-zero neutrino masses.





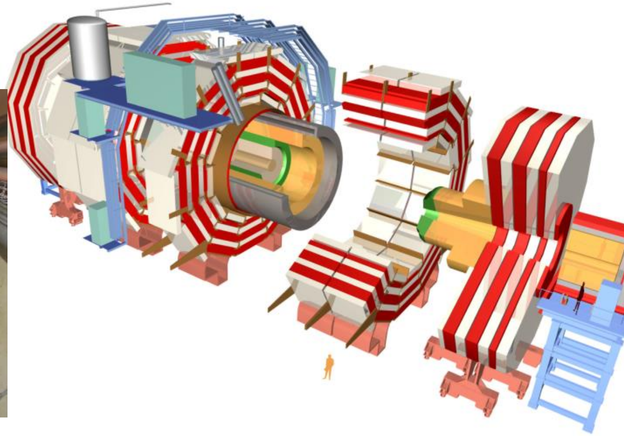


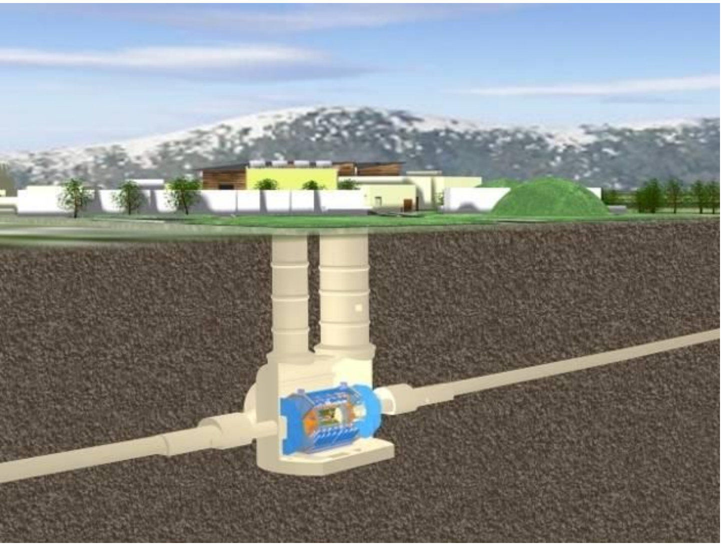
LHC and its Experiments

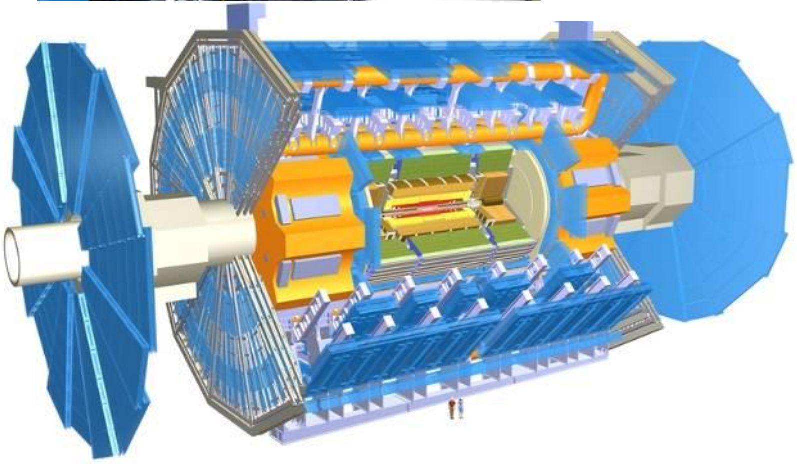


LHC machine

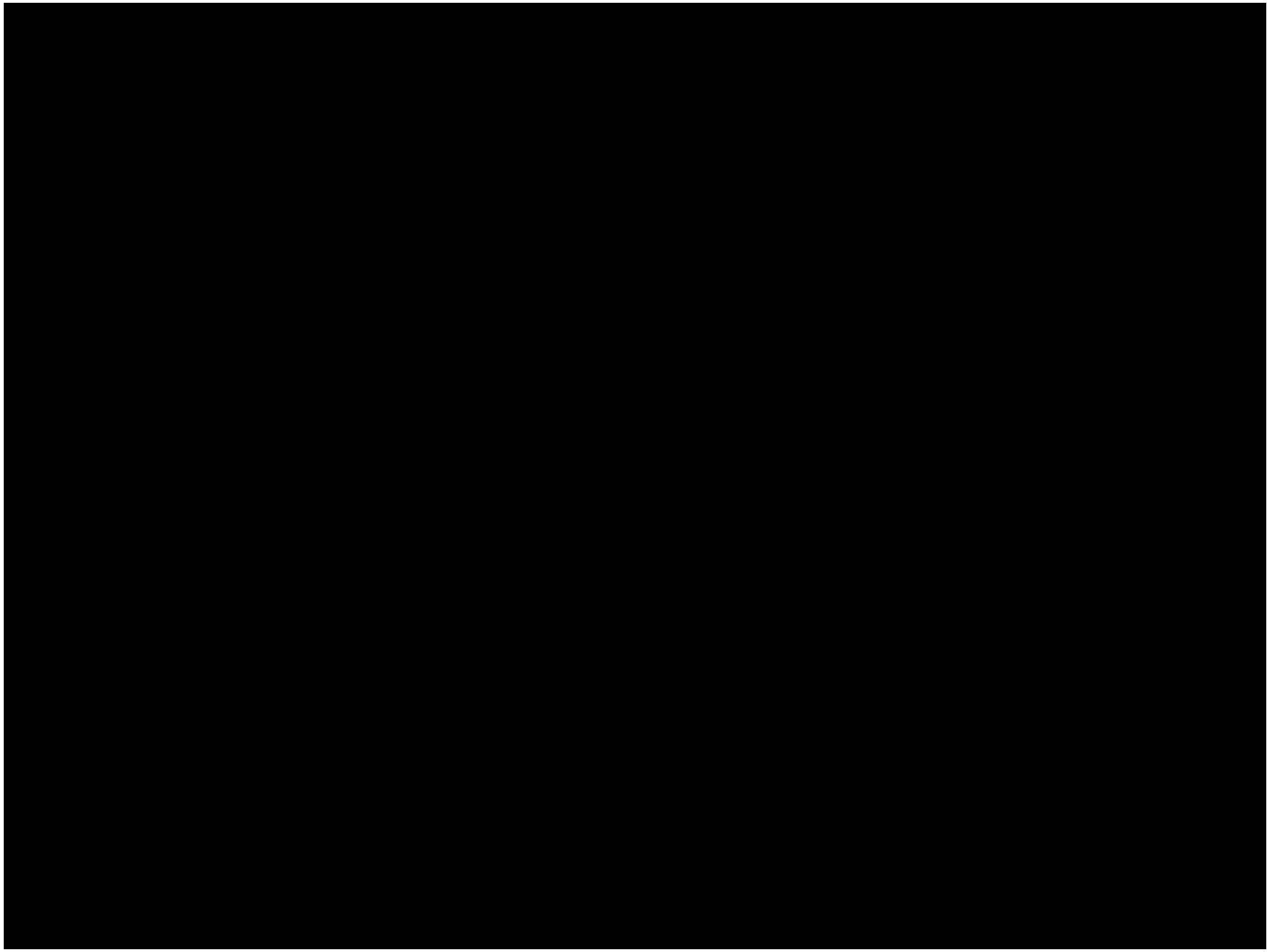
P-P collisions at 3.5+3.5TeV
Start : Spring 2010
7+7 TeV in 2014



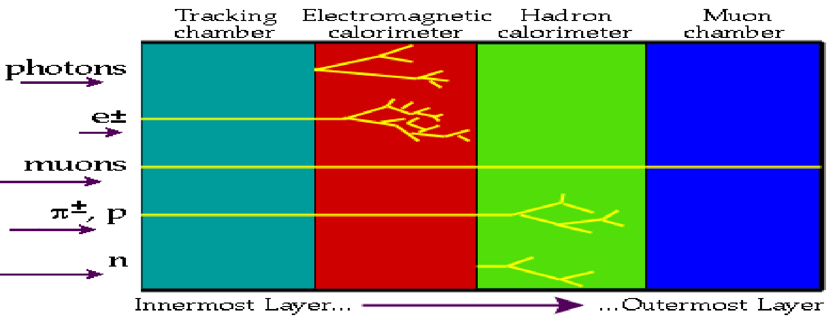


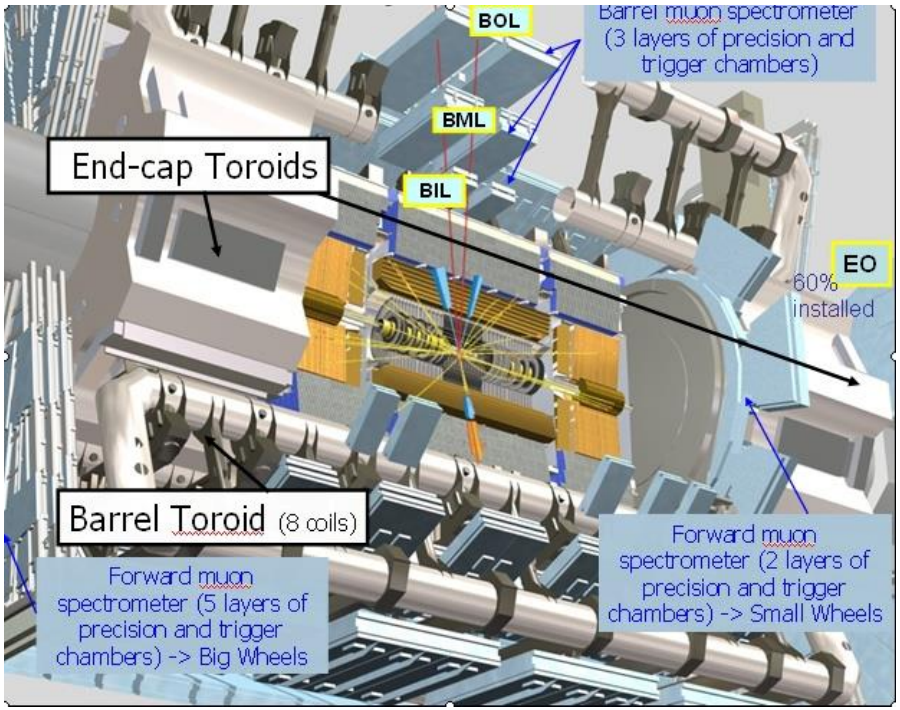


How do we measure the particles?



The ATLAS Experiment



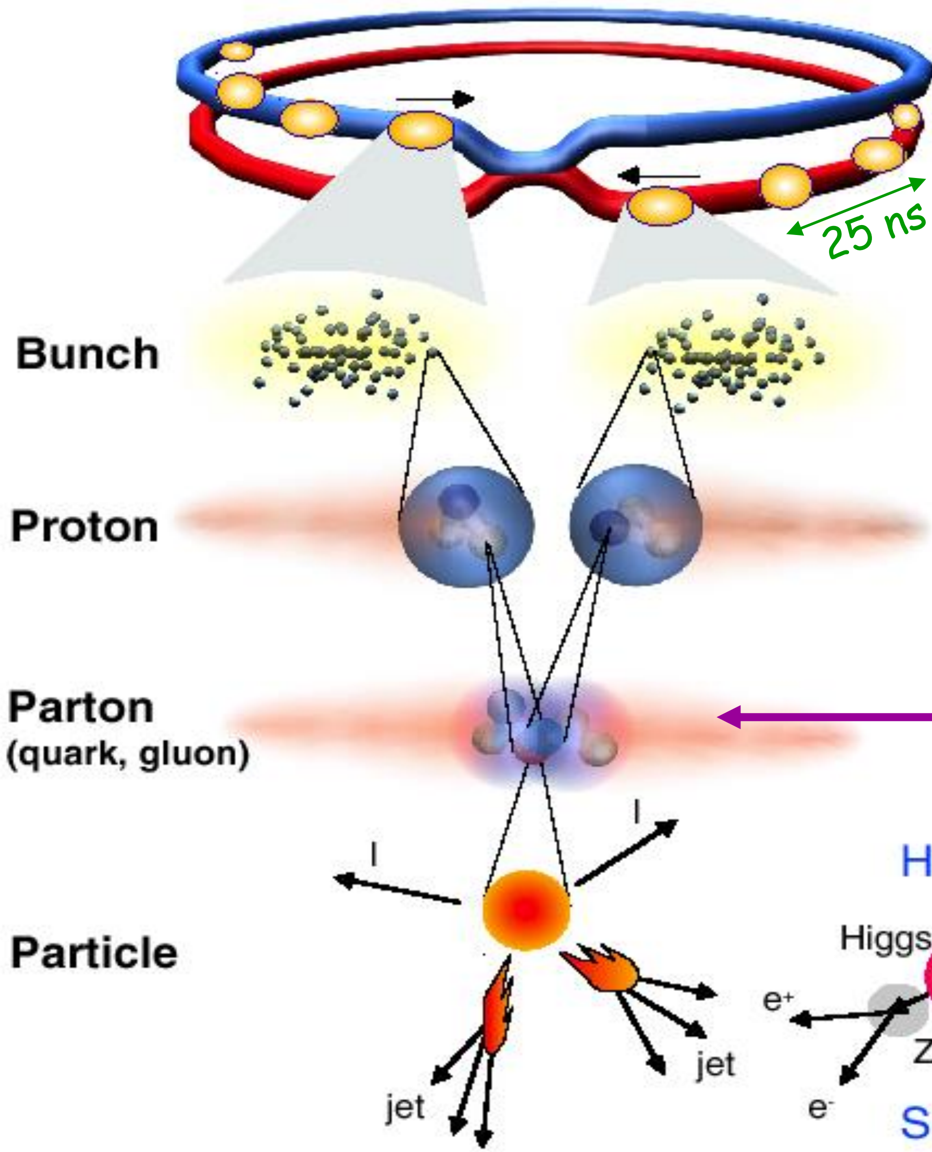


- **Tracking (|η|<2.5, B=2T) :**
  -- Si pixels and strips (3 layers of pixel to optimize b tagging)
  -- Transition Radiation Detector (e/π separation)

- **Calorimetry (|η|<5) :**
  -- EM : Pb-LAr (to obtain high granularity, with a pre-sampler to achieve a vector measurement for lower background in H->gamma-gamma)
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)(to achieve full hermeticity up to rapidity of 5)

- **Muon Spectrometer (|η|<2.7) :**
  air-core toroids with muon chambers (to achieve a uniform DELTA(p)/p response throughout the full rapidity range).

Collisions at LHC



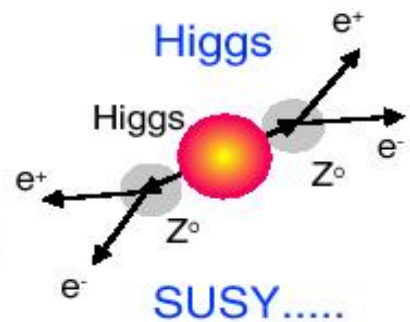
Proton-Proton	
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate in ATLAS :

$N = L \times \sigma(pp) \approx$ 10^9 interactions/s

Mostly soft (low p_T) events

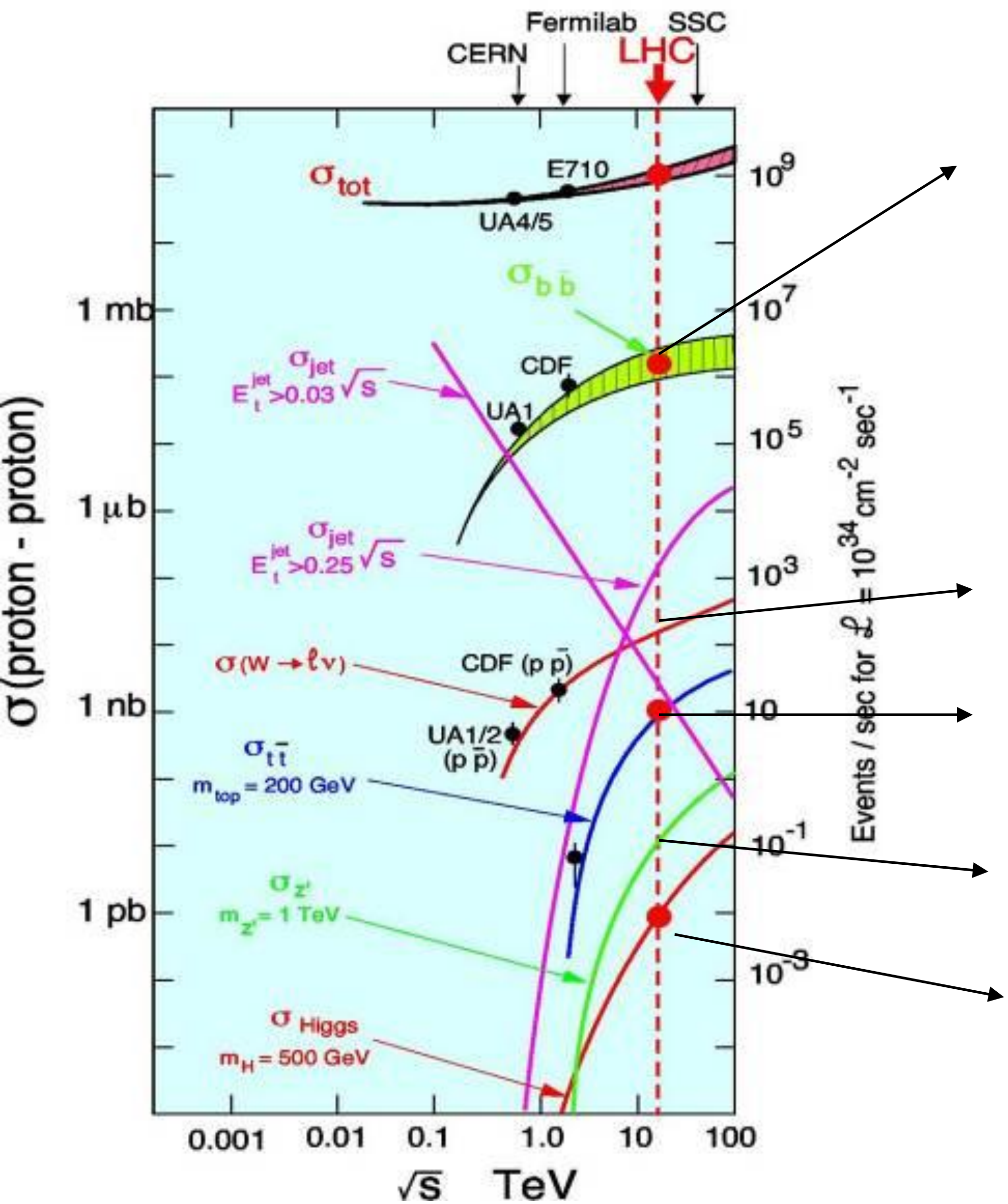
Interesting hard (high-p_T) events are rare



Selection of 1 in 10,000,000,000,000

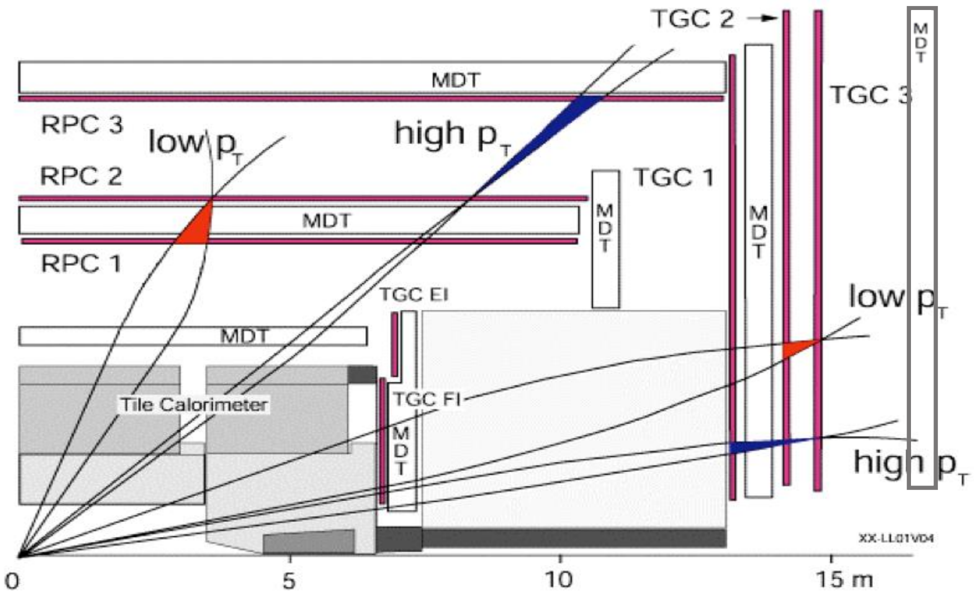
→ Main Problem is to select right collisions

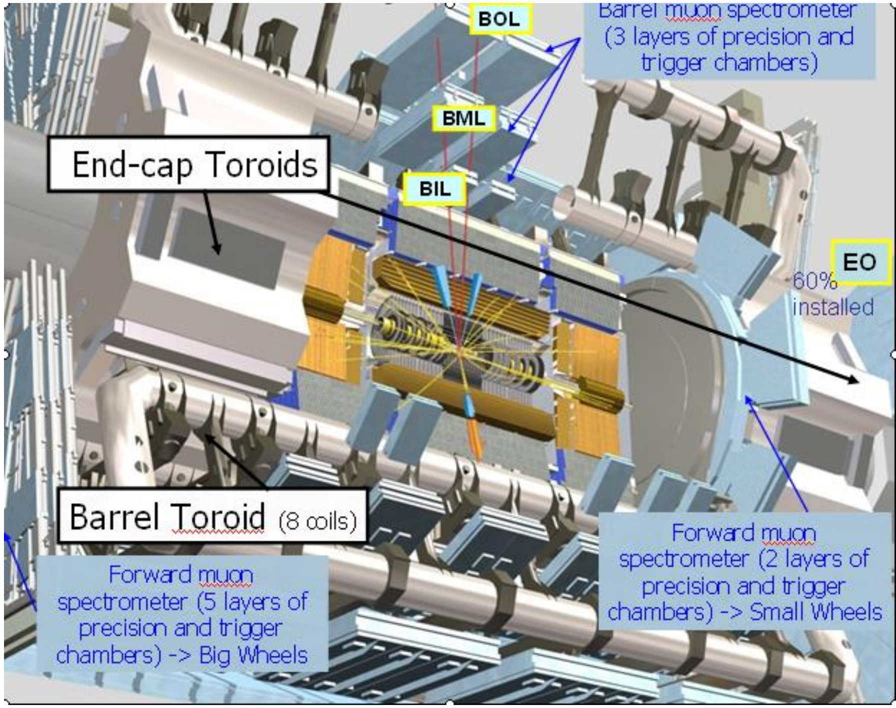
Main Physics Goals at LHC



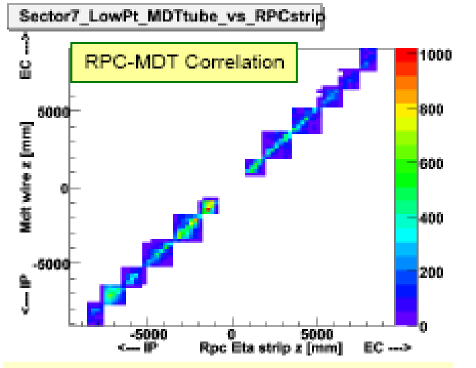
- B-physics: CP violation, rare decays, B^0 oscillations.
- QCD jet cross-section and α_s.
- Precise measurement of W mass.
- Precise measurement of Top mass, couplings and decay properties.
- Z' and W' discoveries?
- Measurement of Higgs properties

Trigger is a crucial element in LHC Physics

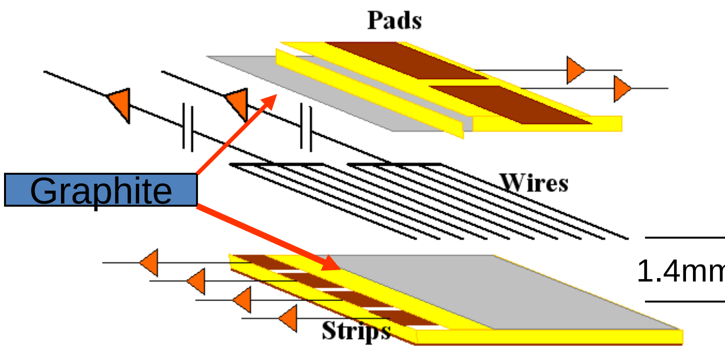




- The MUON trigger philosophy is based on opening a cone (which defines a given p(t) threshold) around a point in a pivot plane (that contains non-overlapping geometry).
- The barrel includes a a 3-out-of-4 trigger logic for low p(t), combined with a 1-out-of-2 confirmation logic for high p(t)
- The end-cap requires a 3-out-of-4 logic combined with a 2-out-of-3 logic in the inner layer. The low p(t) is obtained by a non-linear combination in the inner layer, while linear for the high p(t)
- The end-cap has a more robust logic, due to the higher background conditions, combined with the fact that the stations are located in a non-magnetic region.

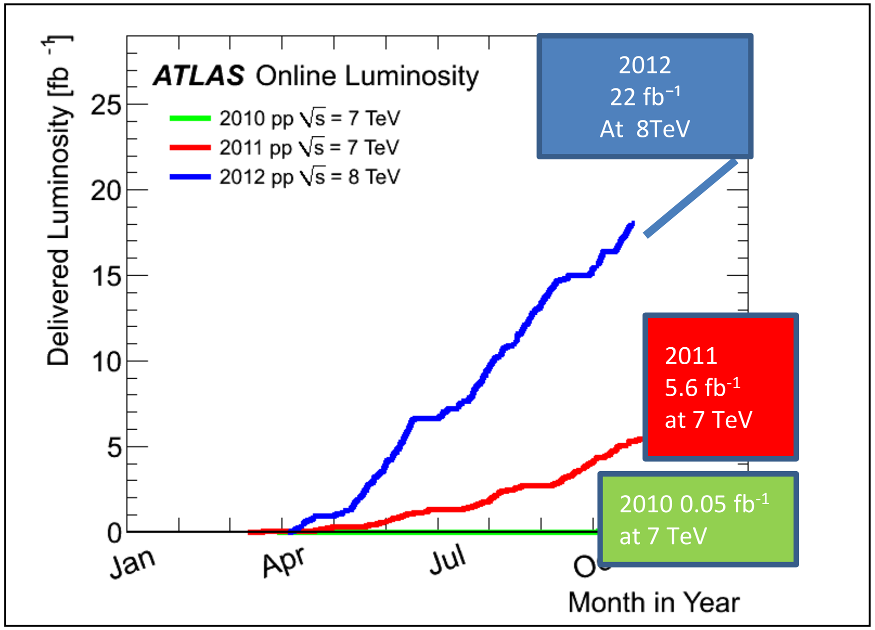


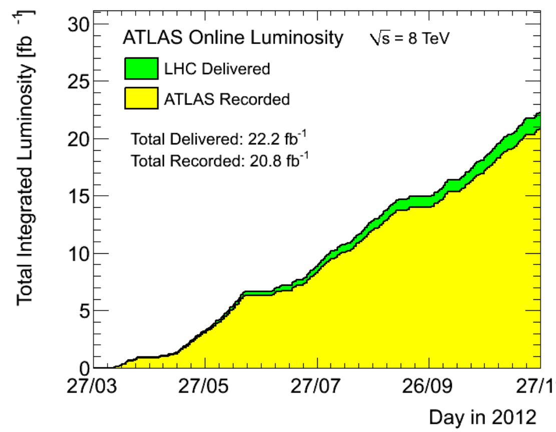
•End-Cap MUON TRIGGER SECTORS

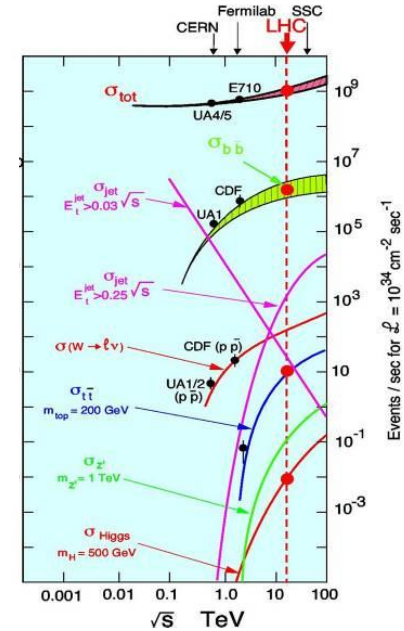


All 6 Big-Wheels that constitute the MUON Trigger System in the End-Cap (4000 detectors based on a technology developed in Israel) have been assembly and commissioned.
All mechanical components have been manufactured by Israeli Industry.
All support assembly elements have been fabricated by Pakistani Industry

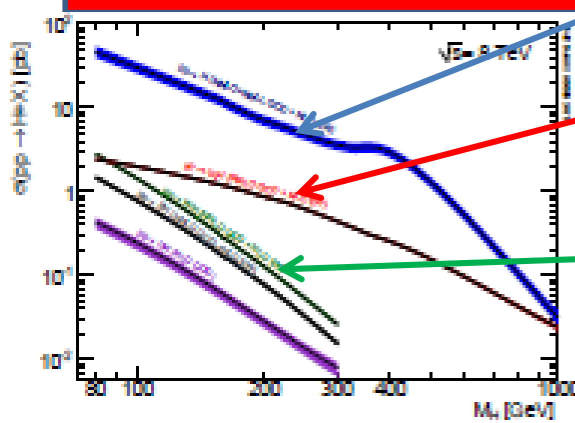
How did we find the Higgs Boson ?

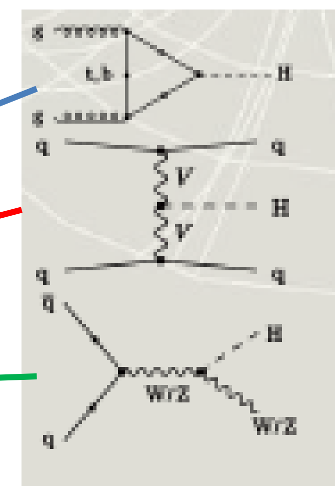






MAXIMAL LUMINOSITY
$7.7X10^{33}cm^{-1}sec^{-1}$

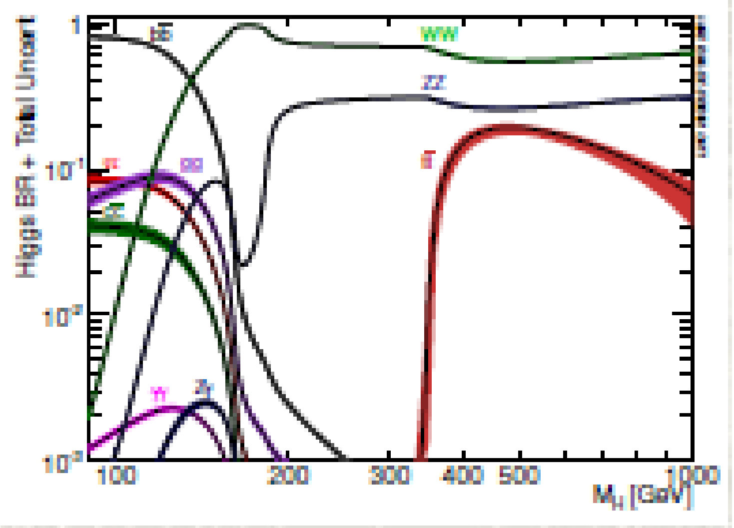


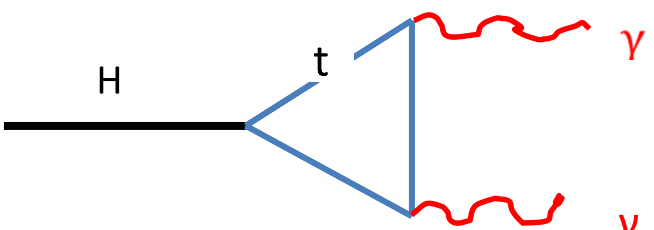


- The probability to find it is very low.
- The probability to recognize it, is lower than to find a needle in a hay-stack.

The Higgs couples to mass

- The heaviest point-like particles that we know are:
  - The W and Z Bosons, then h->WW, ZZ, but to reduce the backgrounds, it should be observed in final states not containing quarks, i.e. W->e,μ + ν; Z->e^+e^-, $\mu^+\mu^-$.
  - The Top Quark (M~175GeV) but if M(H)~125GeV<2X175GeV, the coupling can only be virtual, while isolated high energy photons are rare:





Look for Final States containing:

4 energetic, isolated leptons (2e+2μ, 4μ, 4e)

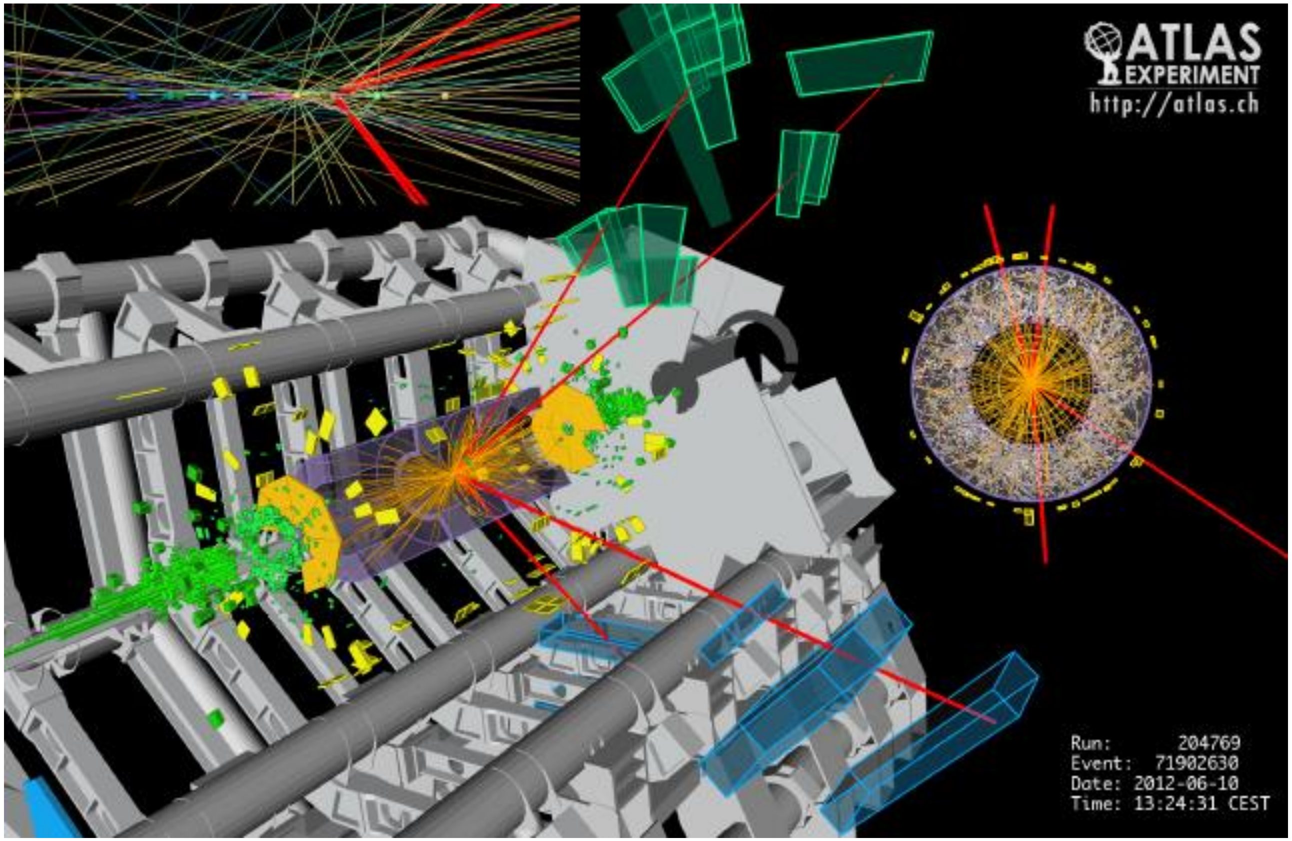
2 energetic , isolated leptons + missing ν

2 high energy isolated photons

Reconstruct their effective mass

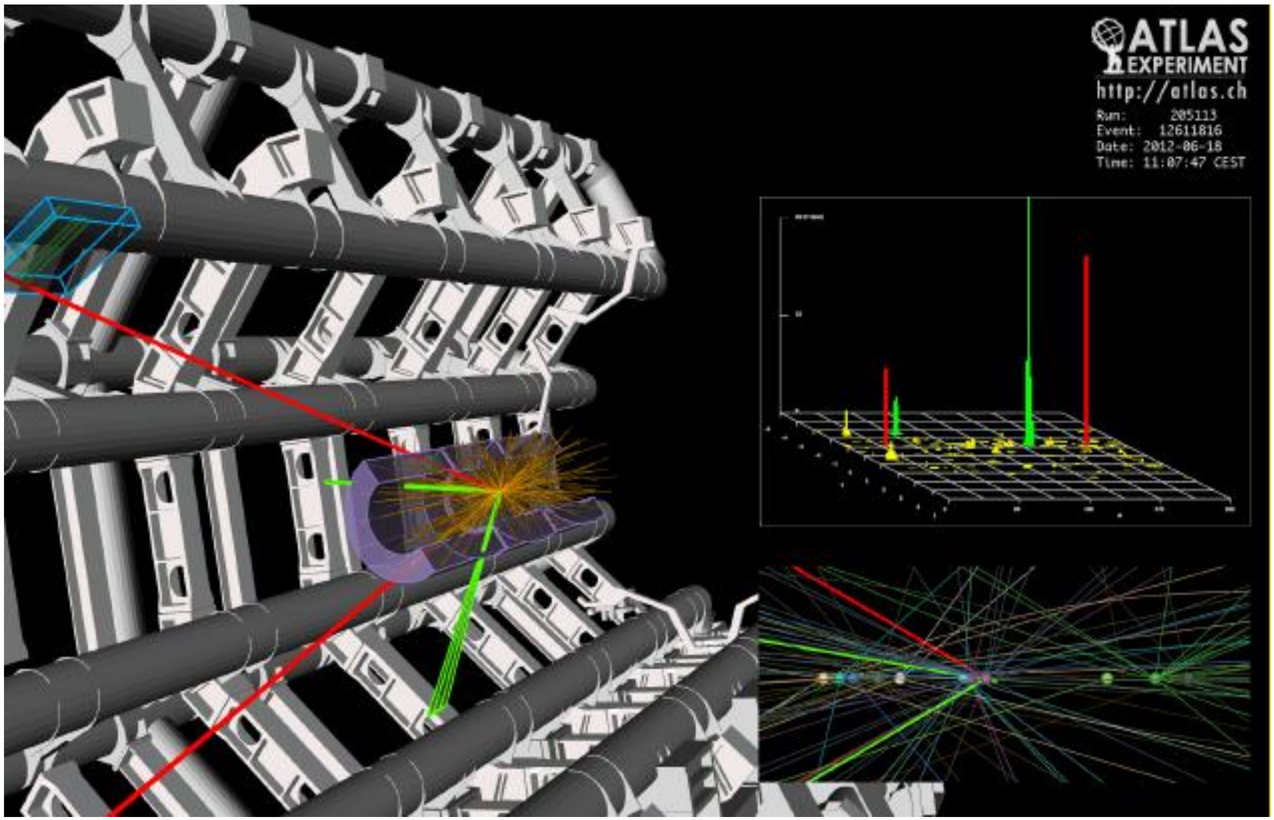
(transverse mass in the case of missing energy)

4μ



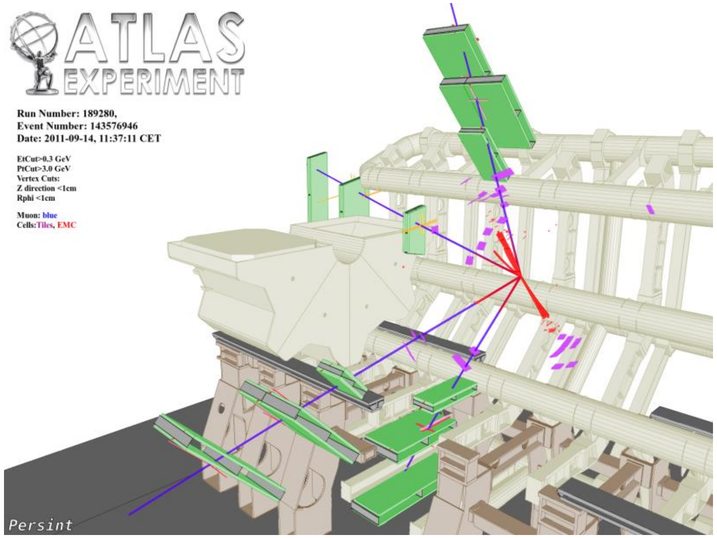
- Typical 4μ candidate, 80% of which were triggered by the system constructed mainly in Israel.

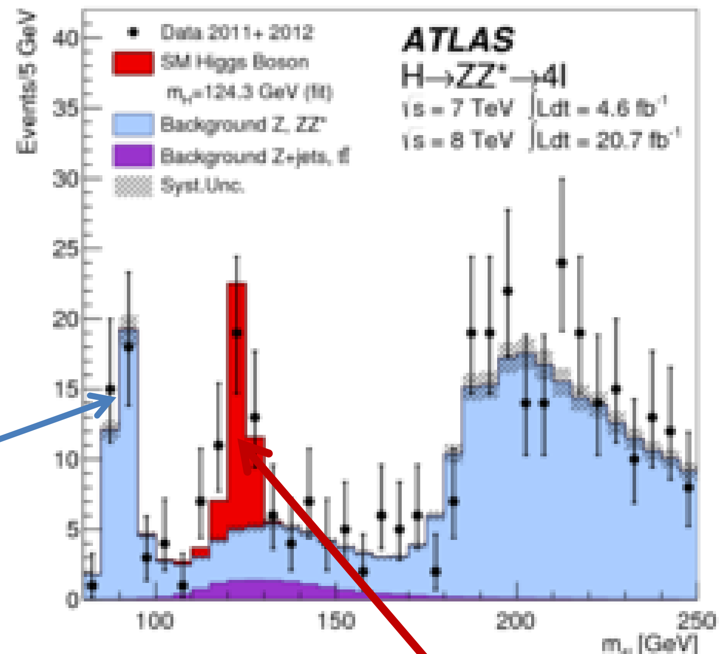
2e+2μ



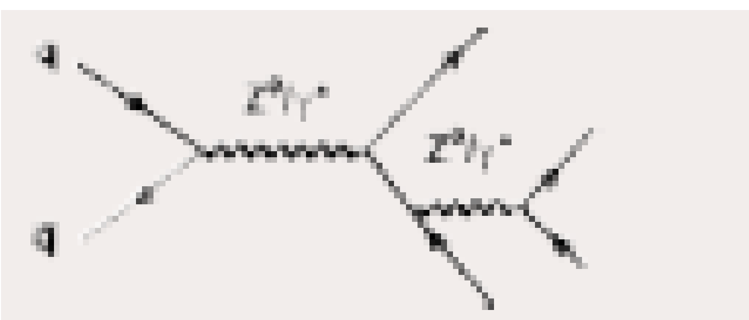
- 2e+2μ; 80% where also triggered by the detectors constructed mainly in Israel.

Adding up the 3 (2e+2μ, 4μ, 4e) final states





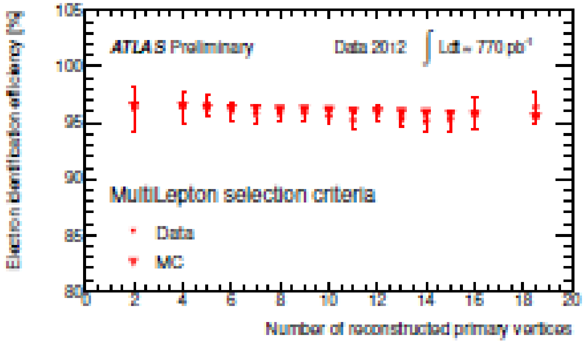
- Also a clear Z peak is seen, from the radiative decay Z->4leptons.

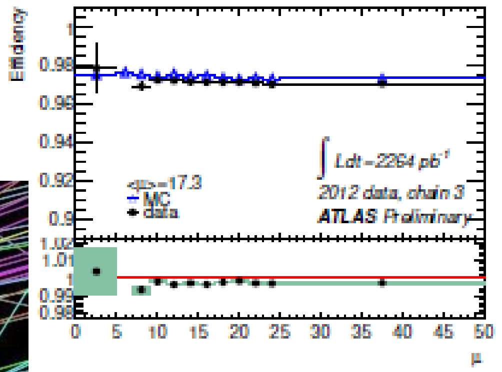


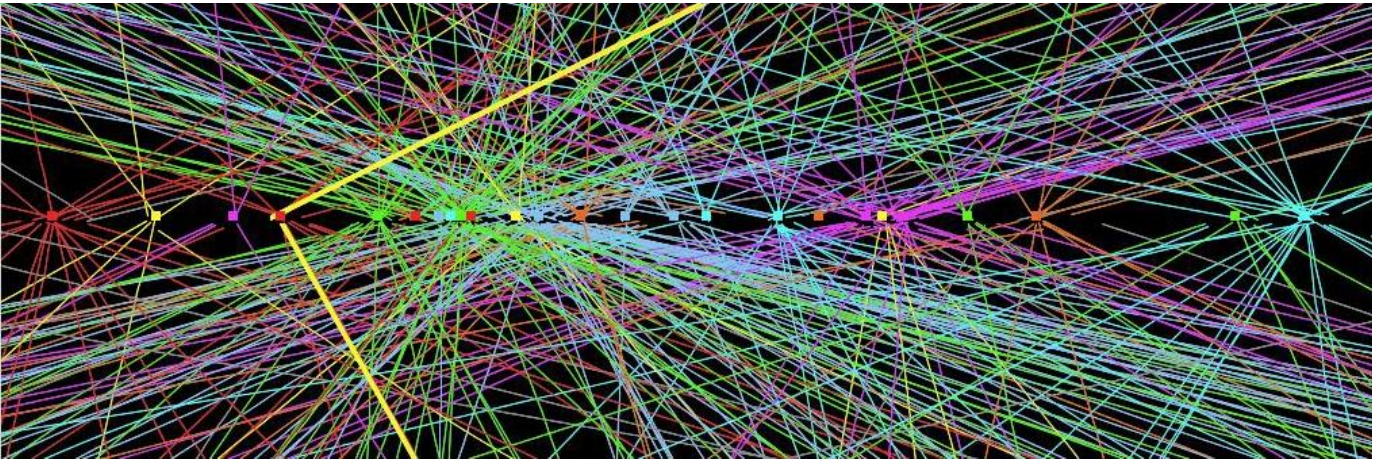
Excess of events at 125GeV

Is this credible with up to 40 interactions occurring at once?

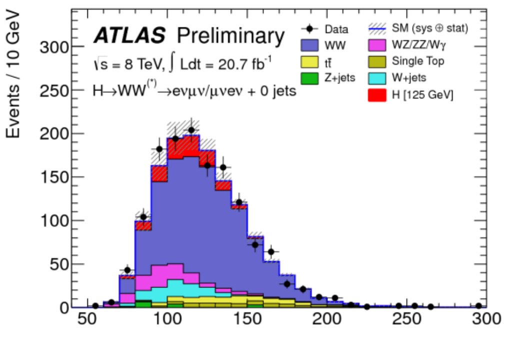
- The lepton reconstruction efficiency is constant with the number of simultaneous interactions, both for e and μ.

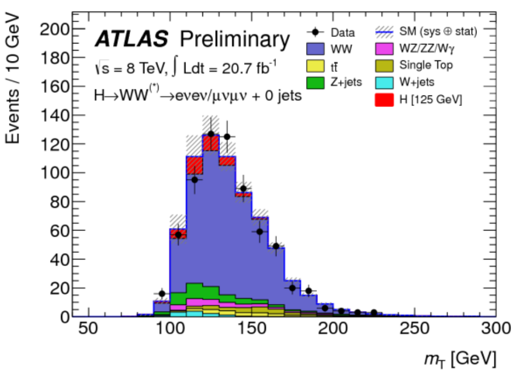


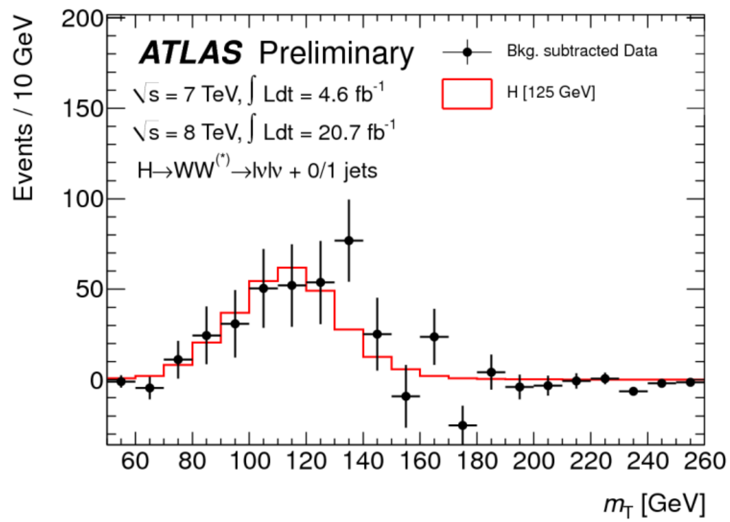


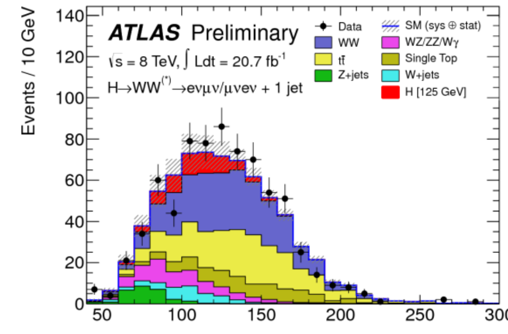


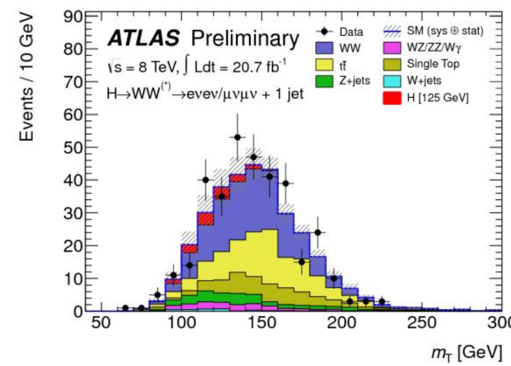
WW->eμ, ee, μμ (+2ν unseen neutrinos)











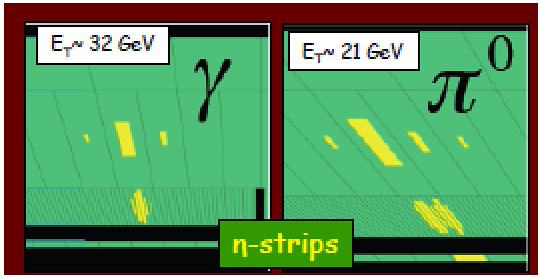
0 jets

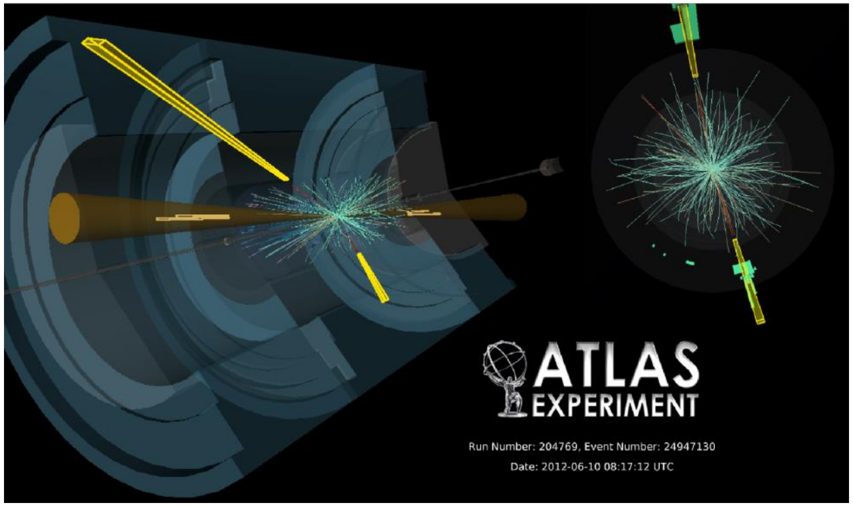
Total after background subtraction

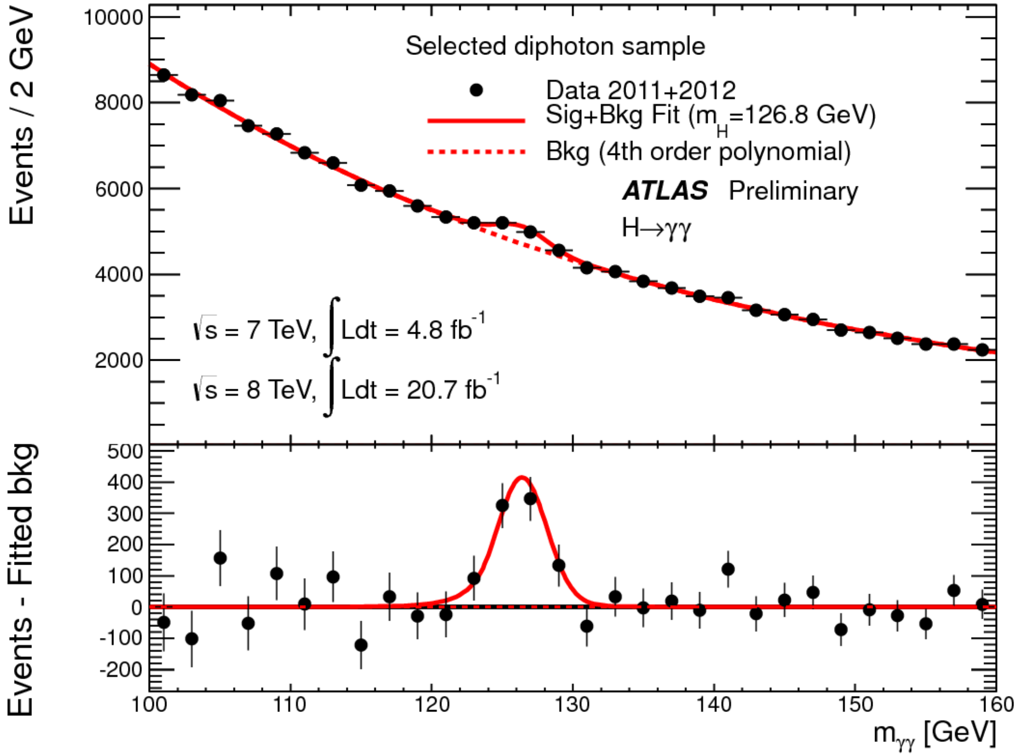
1 jet

- There is an excess of events corresponding to the mass of a Higgs Boson Higgs of ~125GeV.

Two isolated photons final states

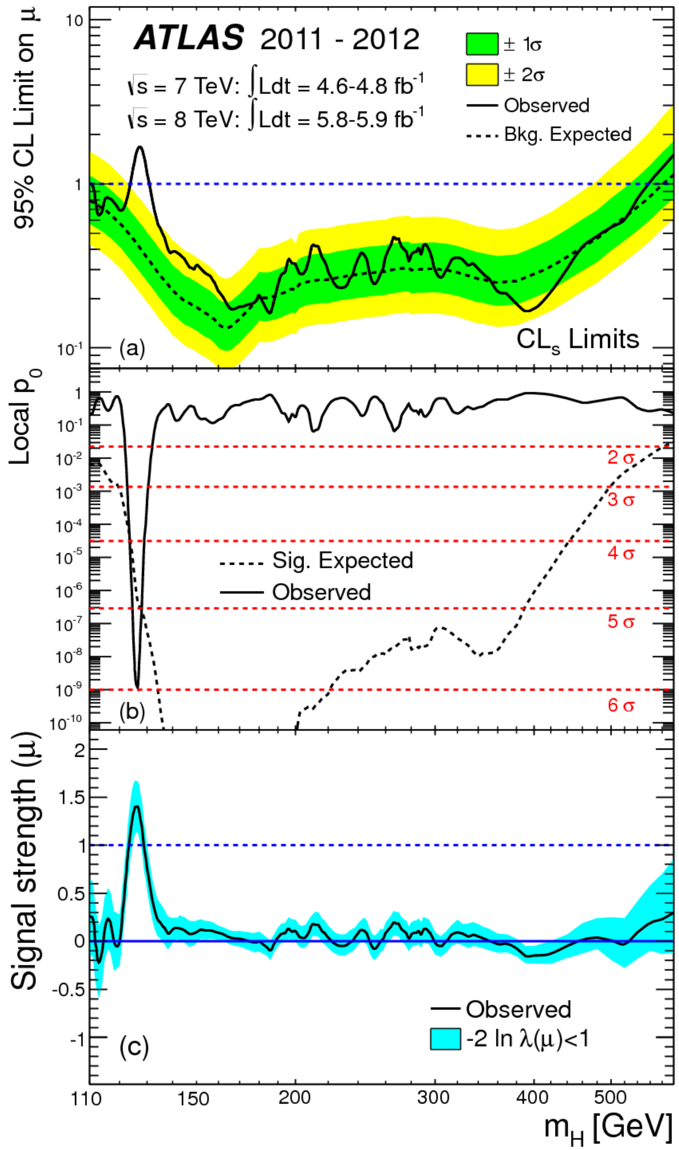






- Due to the excellent energy resolution for each of the photons, combined with the possibility of eliminating 2 nearby photons from π^0 decay, a clear signal is obtained when combining the various cases.

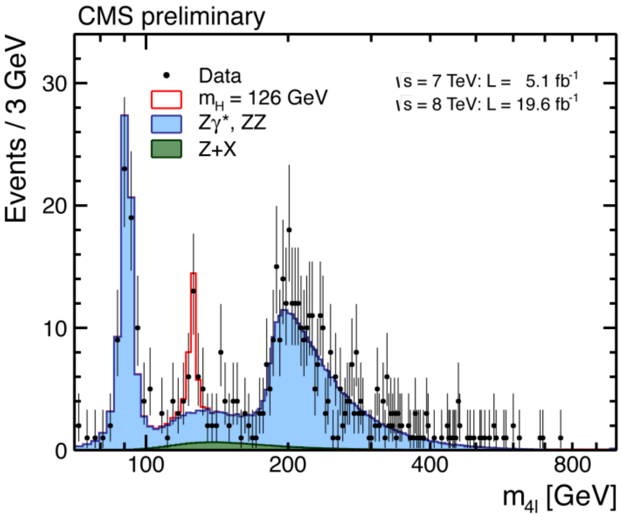
Combining all the channels

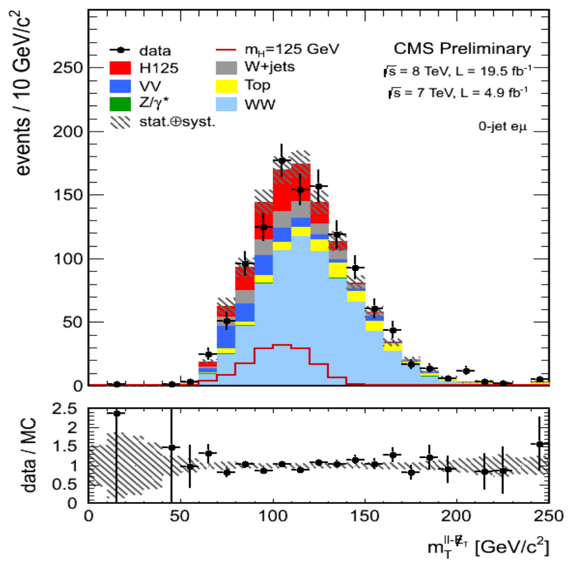


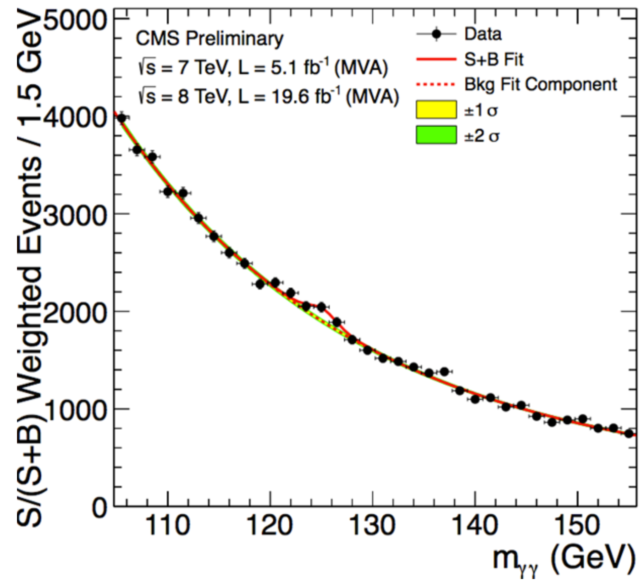
- Probability to exclude the existence of a Higgs Boson.
- Probability of having found a false signal as a function of the mass.
- Comparing the probability of finding the right signal with the expected one.

An object consistent with the Higgs Boson has been discovered

and the other LHC Experiment (CMS) observed a similar effect

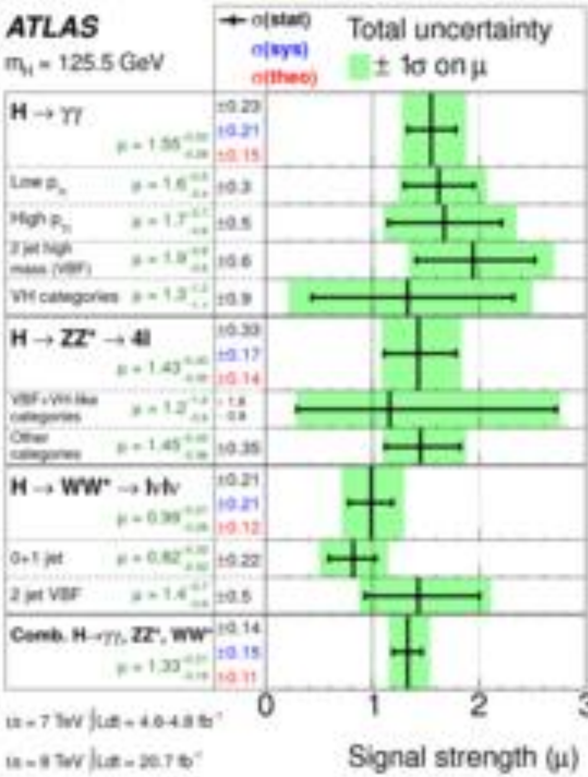


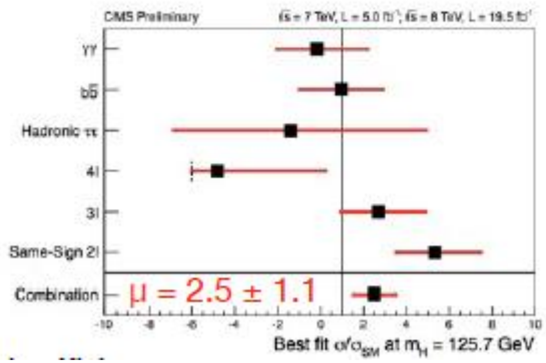




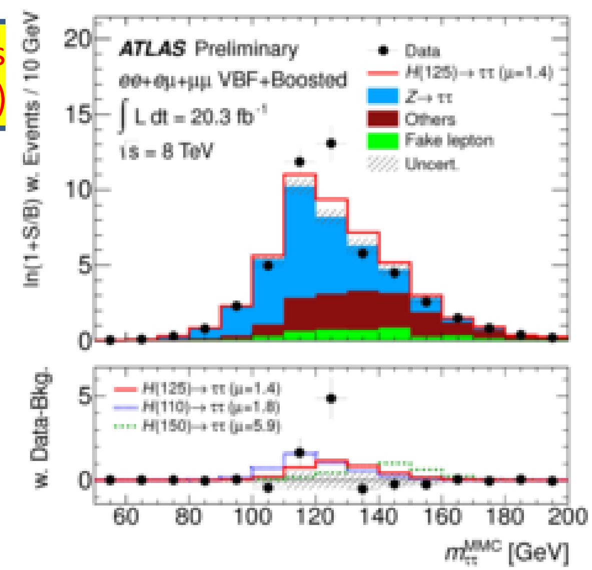
- Is it a Higgs Boson ?

But it also allows to measure the various Higgs couplings to bosons and fermions





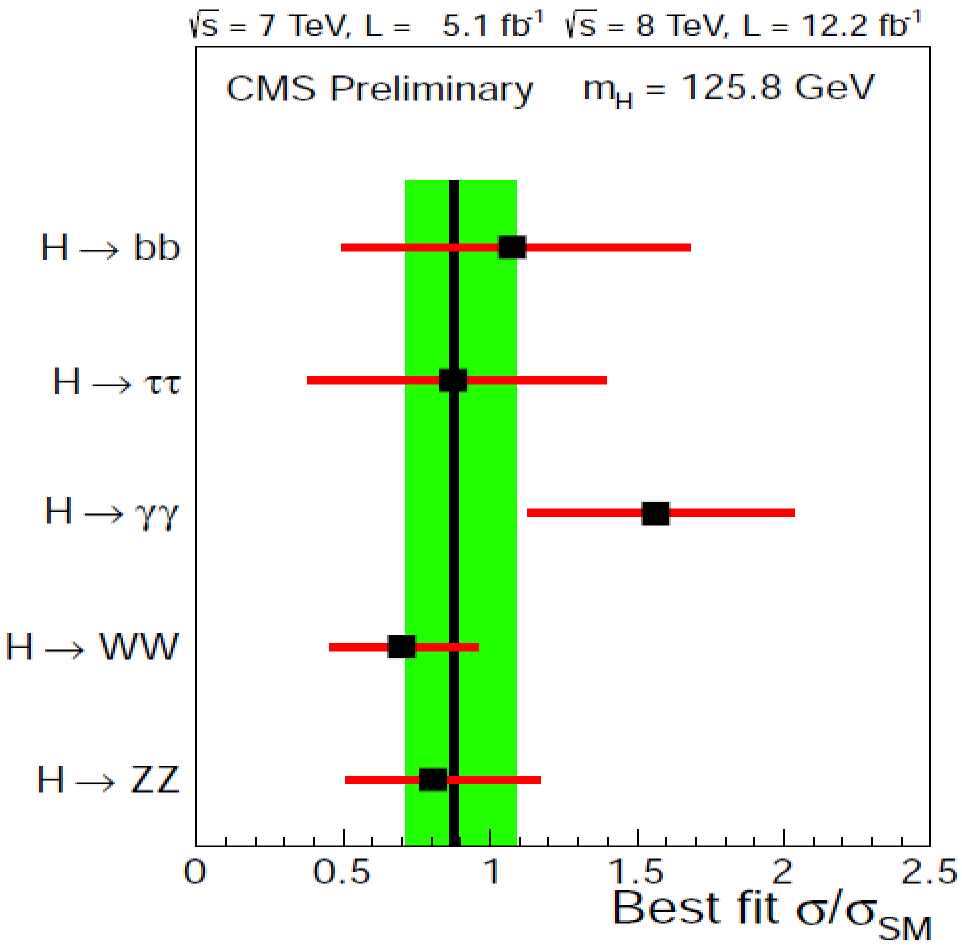
CMS coupling from ttH for various H final states (consistent with SM)



- ATLAS coupling measurements to bosons, consistent with the SM

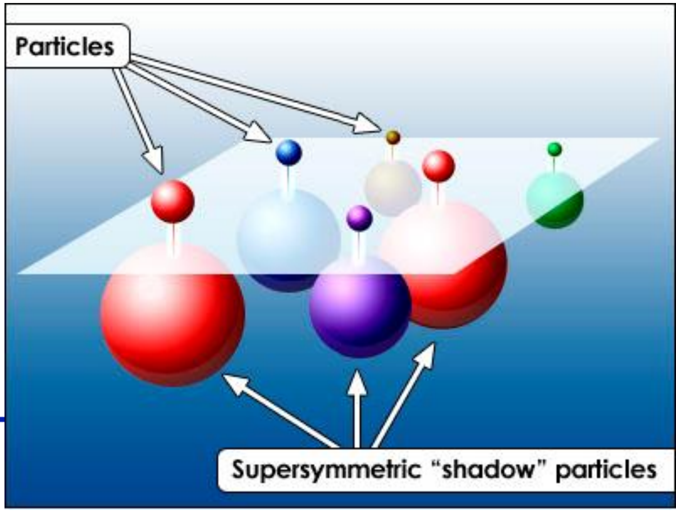
- H->ττ from ATLAS obtained by weighting the events ln(1+S/B).

And also CMS is consistend with the SM

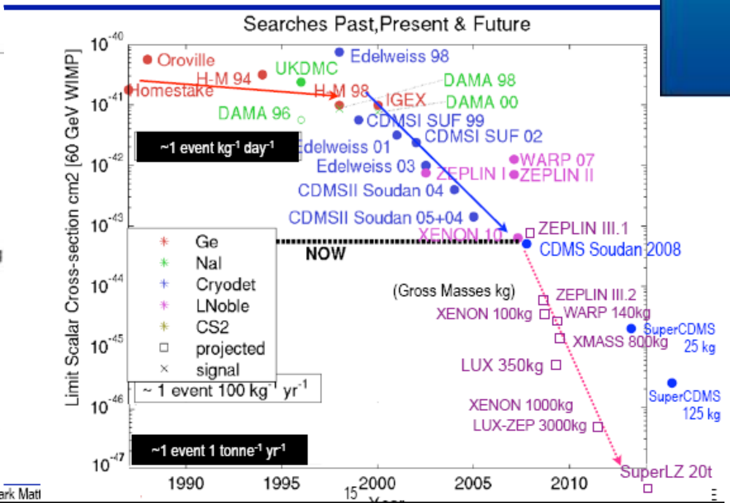


Other mysteries to be solved

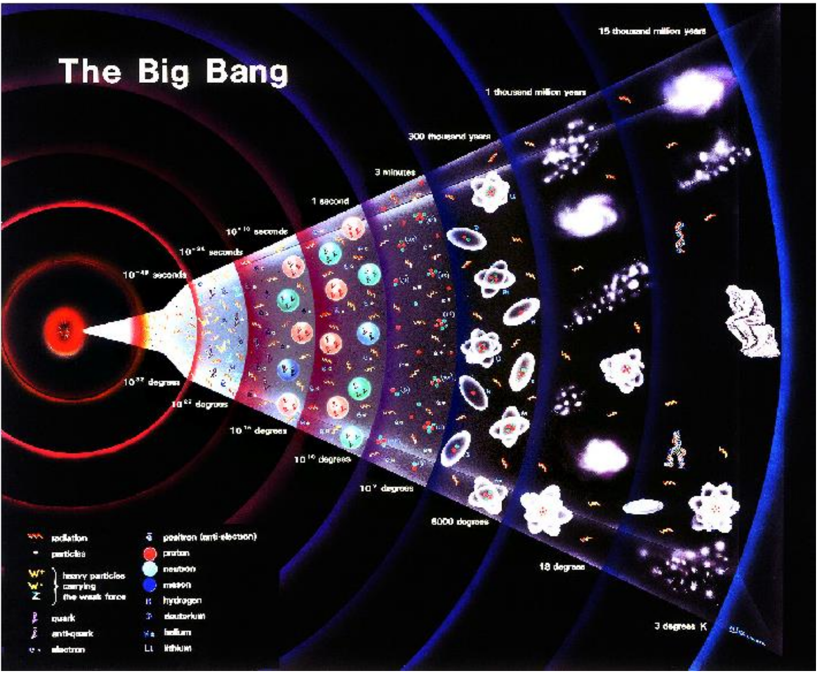
- We do not understand our Universe.
- We know that our Universe is made of only 4% of regular matter, but another 30% is made of a different kind of matter (maybe Super-symmetric particles). The LHC will open a large window (up to 3TeV in mass) to find this kind of matter.
- This search is complementary to the future, more sensitive, series of underground experiments looking for dark matter interactions.

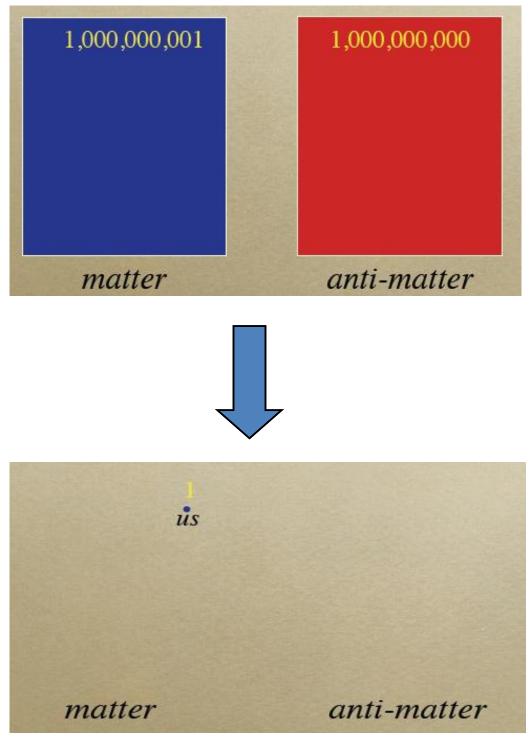


DM Direct Search Progress Over Time (2008)



Looking at the basic interactions gives us information about the earliest moments of the beginning of the Universe

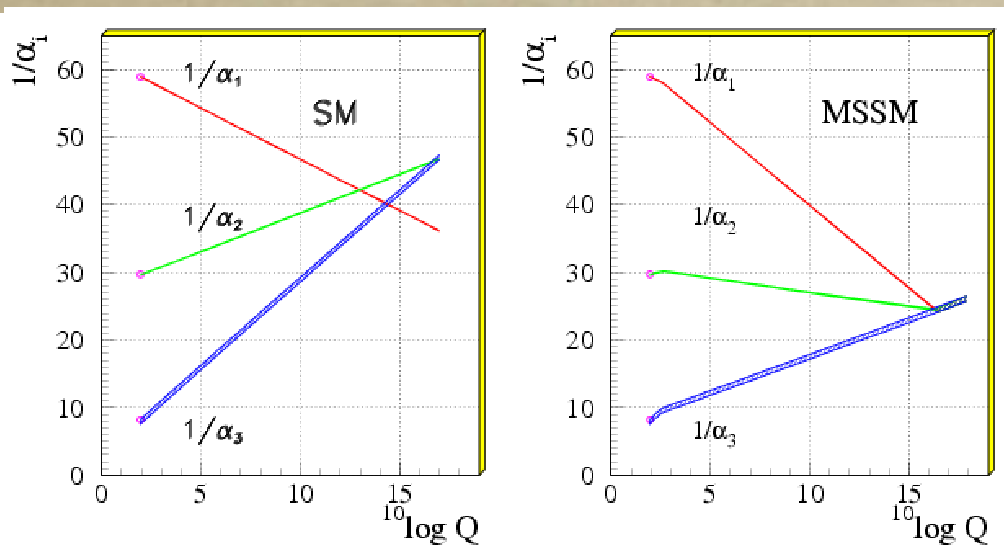




- The Weak force (responsible for radioactivity, i.e. n->P+e+ν) gives a mechanism to produce more matter than anti-matter.
- Similarly to the beginning of the Universe, at the LHC energies, the weak interactions play a major role.
- Heavy quarks (b->c+μ (e)+ν) through non-time-reversal, can give us a hint in to this mechanism to produce a small excess of matter.

Why are our expectations so high at the LHC collision energies

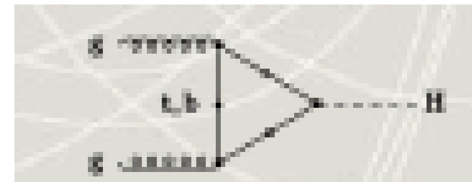
- ~1900 *reached atomic scale* $10^{-8}\text{cm} \approx \alpha/m_e$
- ~1970 *reached strong scale* $10^{-13}\text{cm} \approx M e^{-2\pi/\alpha s b0}$
- ~2010 *will reach weak scale* $10^{-17}\text{cm} = \text{TeV}^{-1}$



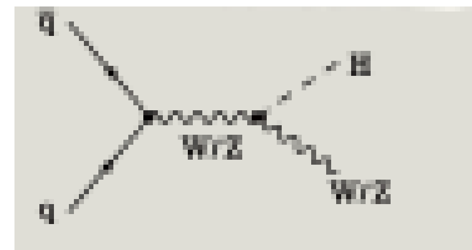
- Having a new phenomena at the TeV scale, would allow for a unification of the various forces at higher energy.
- If new phenomena at 1TeV=>2 LHC years; if 3 TeV=> 10LHC years

This is just the start, we need to do much more to get hints of what is behind…

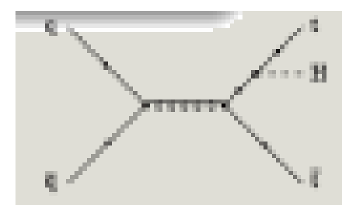
- Most of the present H observations are based on production by Gluons (+/-14% systematic errors).



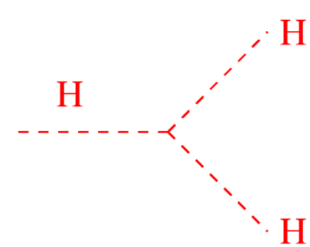
- Need to look at real Yukawa couplings, on a well defined production mode. This is the base of the future upgrades (with a strong Israeli participation to ensure single lepton trigger) of the LHC experiments for the High Luminosity program.



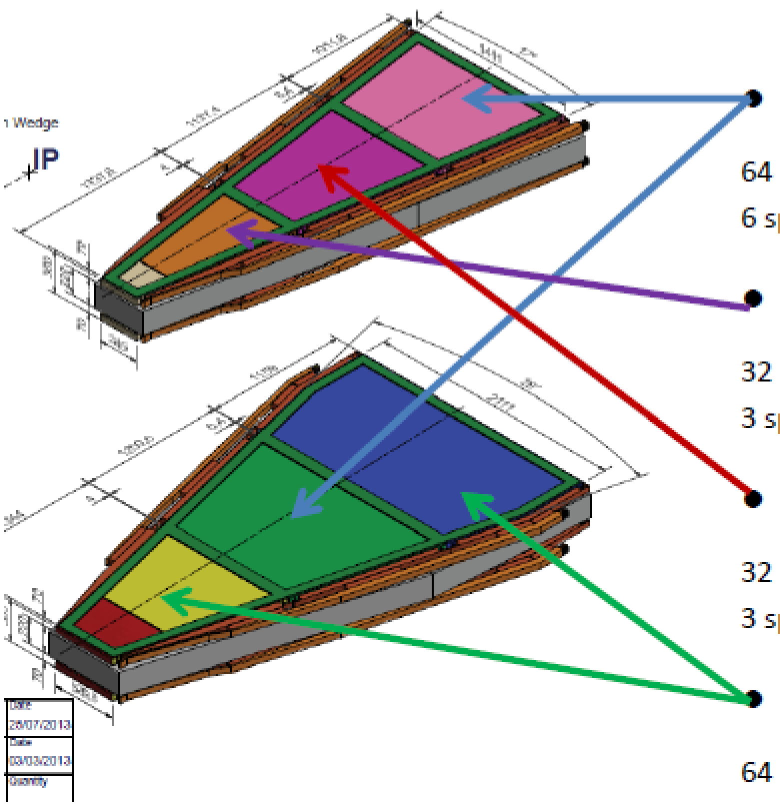
- Need to look at the coupling to UP-like quarks, which is possible at the LHC with the increase energy and Luminosity.



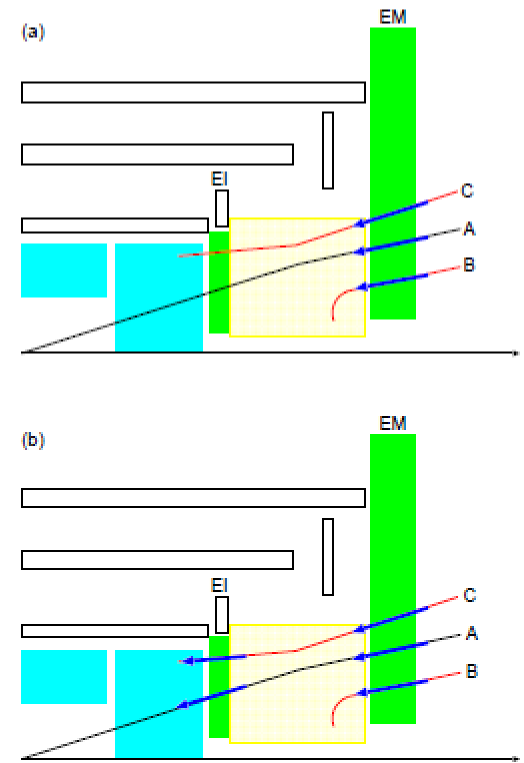
- Need to look at the Higgs self coupling, which will only be possible (within 30%) with very high Luminosity (3Abarns^{-1}) with the LHC upgrade.



And again here, the Israeli contribution in close collaboration with Chile will play a major role



- **Canada**
  64 quadruplets +
  6 spares
- **Chile**
  32 quadruplets +
  3 spares
- **China**
  32 quadruplets +
  3 spares
- **Israel**
  64 quadruplets +
  6 spares



First time that critical detectors for a large experiment will be constructed in South America

Conclusions

- Israel has shown that good education and high level scientific research are crucial inputs to develop High-Tech.
- The Israeli contribution to the CERN experiments, although small, plays a very important role.
- The LHC and its experiments will allow to clarify very important questions on our Universe:
  - The origin of mass , via the discovery of the Higgs Boson has just been found. This is the most important discovery in Particle Physics in the last 30 years.
  - The possibility of finding dark matter, that makes most of the Universe (still no signs of it , but we have only explored 1/3 of the range)
  - The possibility of understanding the asymmetry between matter and anti-matter in the Universe (making progress, but I did not show results)
  - Finding new phenomena (higher dimensions, mini- black holes, etc.
- The next 10 years promise to be very interesting to our understanding of the Universe.