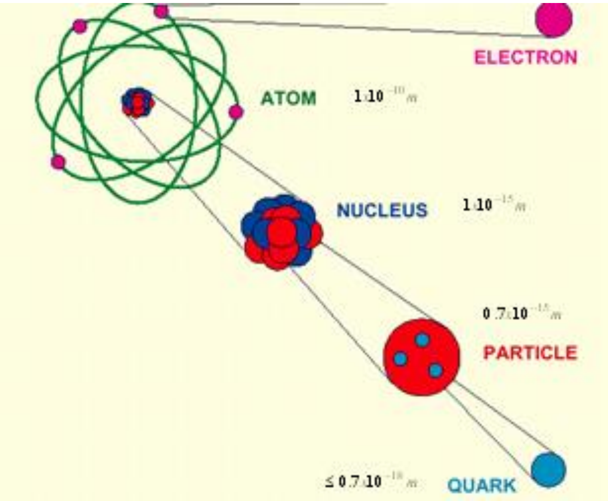
Particle Detectors and their use in the Largest Microscope in the World
The LHC

- Short reminder of Particle Physics basics
- Ways to detect the passage of particles through a media
- How this is done in ATLAS
- Gas detectors and how they operate; possible way to the future
- Pitfalls to avoid in their construction
- How Big-Science can bring people together from different cultures.
- Conclusions

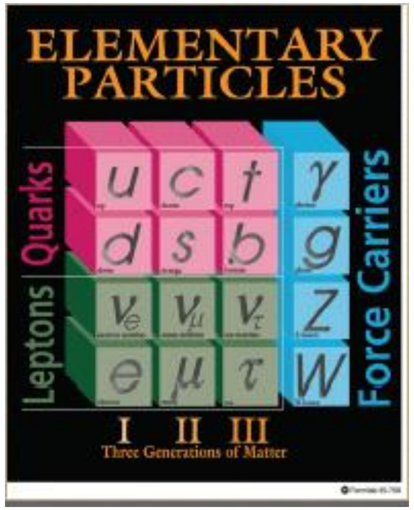
What is matter made off?

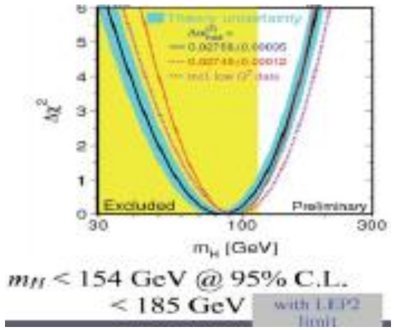


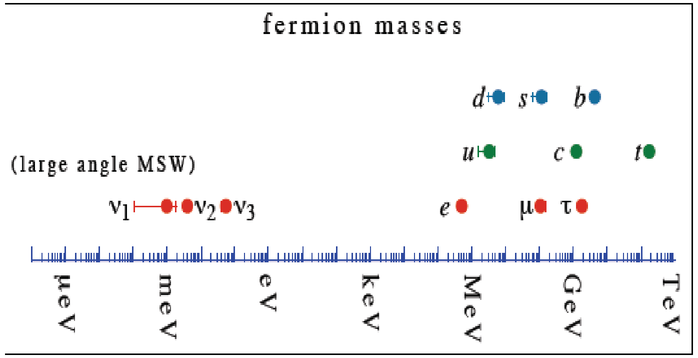
- But if particles have no dimensions, how can they have mass?
- If energy can become pairs of matter and anti-matter, where is the anti-matter?
- Are there other basic particles besides those that we know?

The Standard Model and its problems

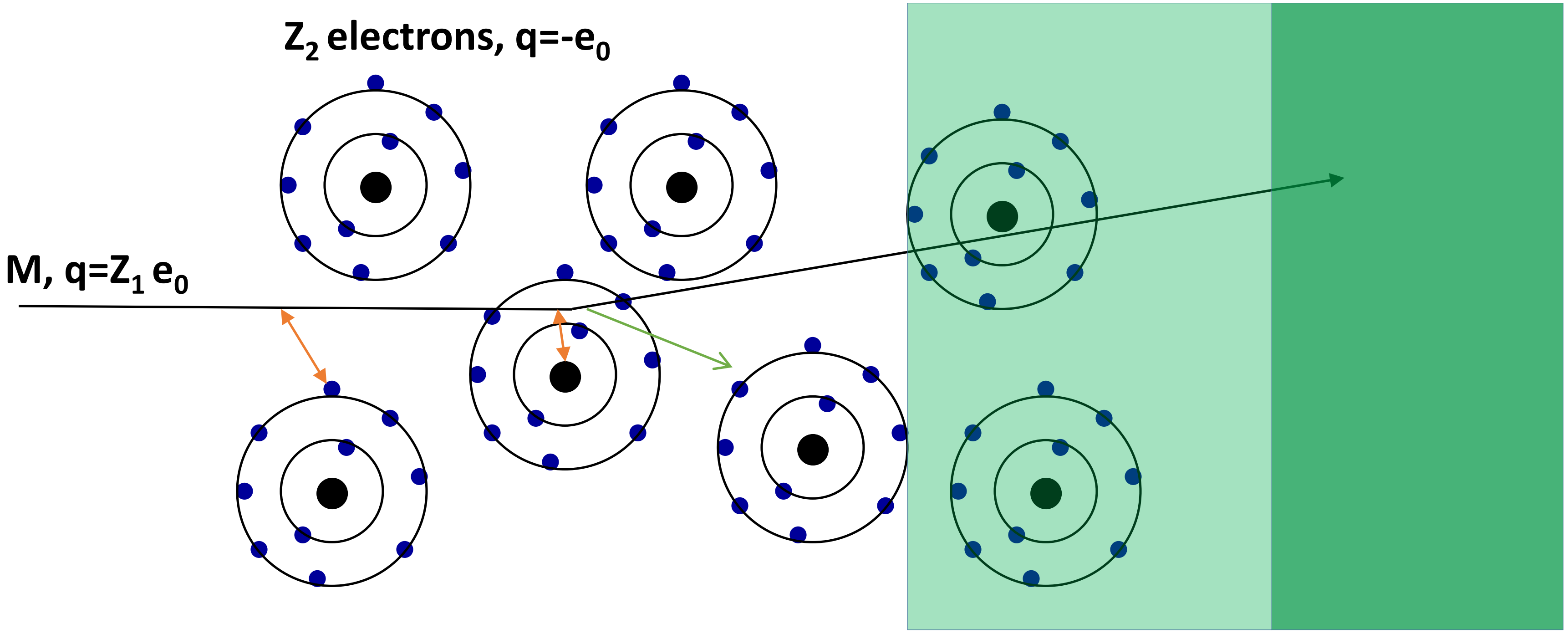
- The SM provides us an excellent description of the basic interactions between quarks and leptons, with tests of Electro-weak radiative corrections at the level of 10E-3.
- There are, however, number of open questions:
  - The Higgs boson(s), responsible for the mechanism of providing mass to all particles, 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.







Electromagnetic Interaction of Particles with Matter



Interaction with the atomic electrons. The incoming particle loses energy and the atoms are excited or ionized.

Scintilation from de-exitation

rare phenomena; Needs high energy

Interaction with the atomic nucleus. The particle is deflected (scattered) causing multiple scattering of the particle in the material. During this scattering a Bremsstrahlung photon can be emitted.

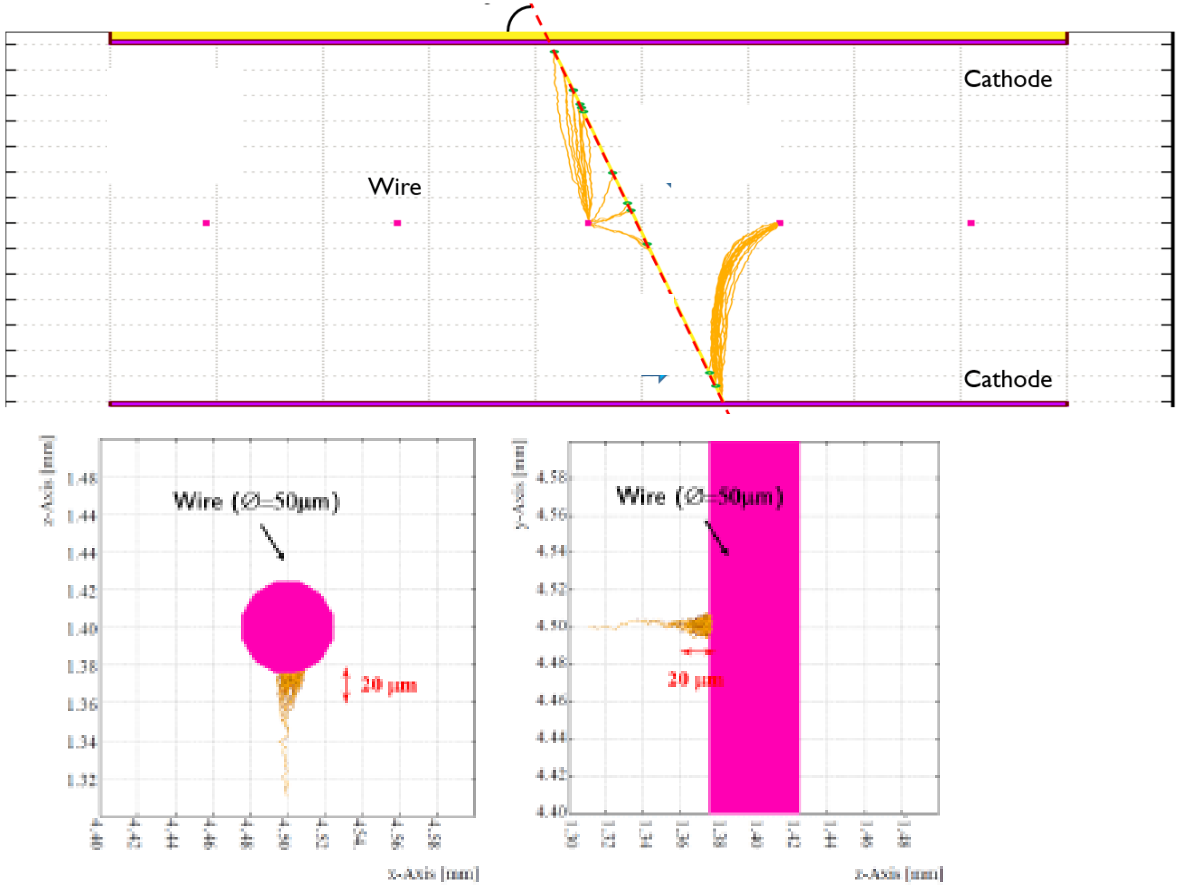
In case the particle's velocity is larger than the velocity of light in the medium, the resulting EM shockwave manifests itself as Cherenkov Radiation. When the particle crosses the boundary between two media, there is a probability of the order of 1% to produced and X ray photon, called Transition radiation.

Ionization is a rare phenomena for MIP's (typically ~10/mm in gas at atmospheric pressure)

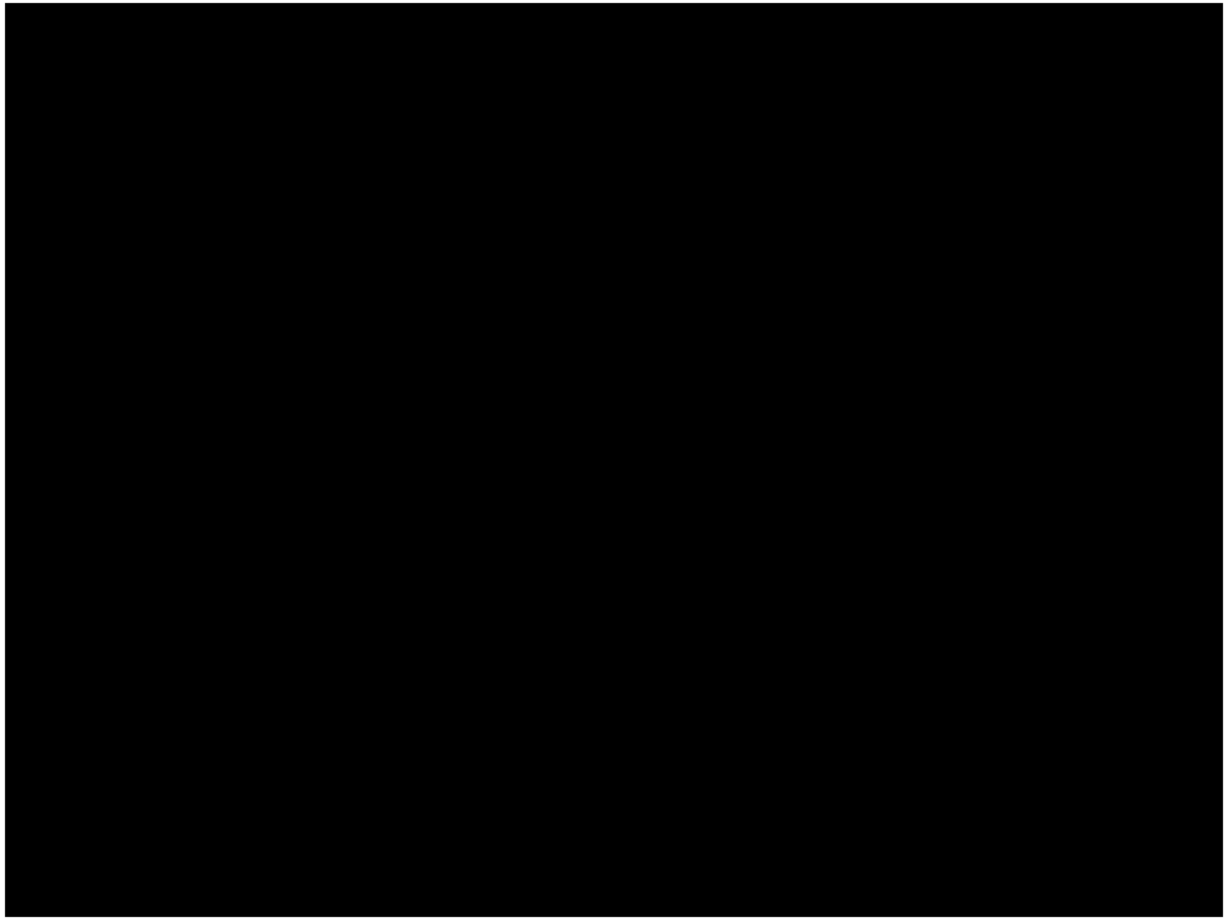
- Need to amplify the signal, if we want to detect a single particle.

- Use solid materials with very low noise electronics.
- Have many ionizing particles (electromagnetic showers).

- **But for large areas, where one has to detect a single charged particle**
  - this can be done by having a strong local electric field, so the electrons from the original ionization get accelerated and start ionizing themselves, creating a multiplicative factor (~10^5 for each original electron from the ionization).

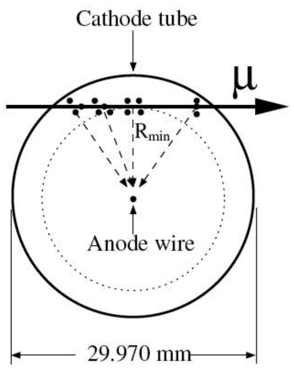


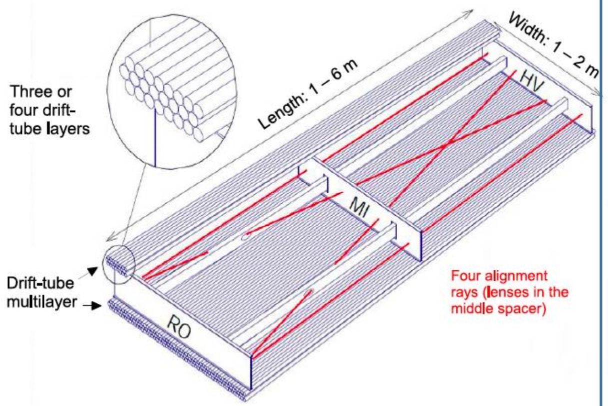
How this is done in ATLAS



Operation of gas detectors

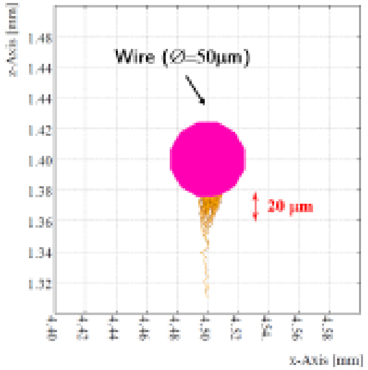
- Ionization and drift

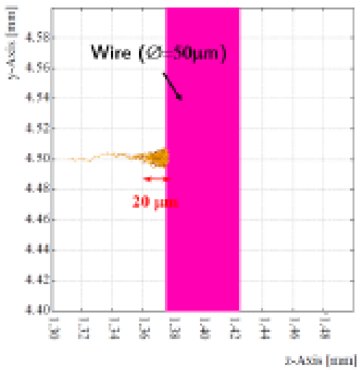




Traversing charge particle ionized gas Molecules
Electrons drift following the weak Electric field towards the anode wire but if produced far away, it can take up 800ns (32 bunch crossings) to reach the wire
Close to the anode wire, the field increases exponentially, and therefore the electron is strongly accelerated and starts ionizing itself.
This leads to a strong multiplication (10^4-10^5) and the local generation of ions.
Increasing the field will lead to sparks

- Amplification





- Retuning ions

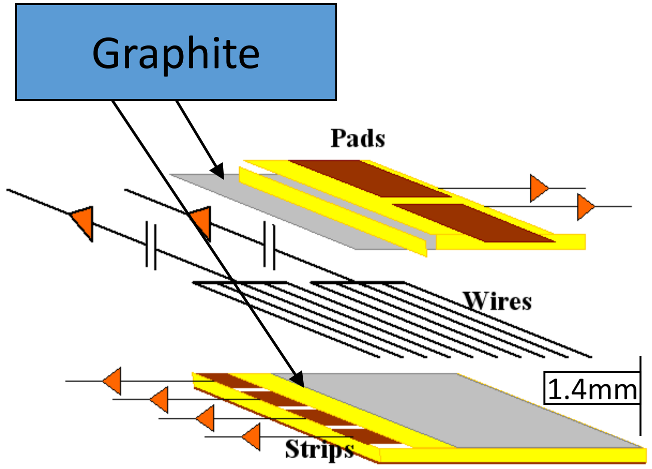
The produced ions are then attracted by the tube ground, but being heavy, they will move slowly (also changing the field, due to their charge), taking ms to reach the walls.

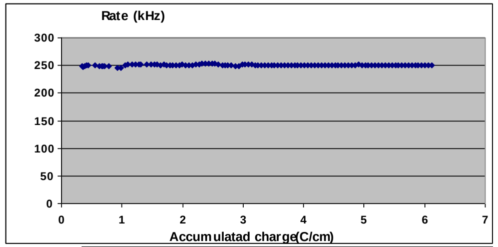
To work at high rates, decrease the drift time to <25ns

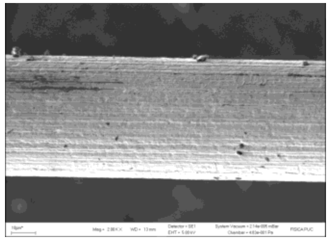
- Decrease the gas gap (less drift-time)
- Increase the field, so electrons from ionization move faster.
- If the field increases too much, also the amplification increases, but this leads to sparks=>try to control damage from sparks by including a high resistance layer.
- At high gas gain, the avalanche is mainly transmitted by photon bremsstrahlung from the accelerated electrons. Most of this photons do not ionize (low energy), but those that ionize need to be absorbed=>use a gas that will absorb them: quenching gas.

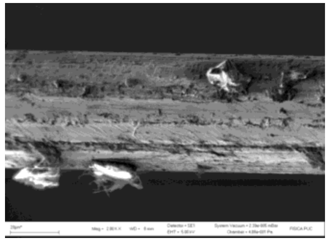
Short Introduction to TGC's

- CSC-like structure, except that anode-to-cathode distance=1.4mm, while anode-to-anode distance=1.8mm.
- Anode wires sandwiched between 2 high resistive layers.
- Readout behind resistive layers (strips, pads) or anodes.
- Operating voltage: 2.9-3.0 KVolts.
- Gas: CO_2-n Pentane (55%-45%): n Pentane increases the ionization, while absorbing the photons in the avalanche.
  - This provides high gain, without sparks.
  - N-Pentane acts also as cleaning agent (no major wire deposits after 6 Coulomb/cm).
  - For a small volume, one can afford to use flammable gas, and take precautions for leaks. C-H3 chains provide a good quencher, and avoids other problems.

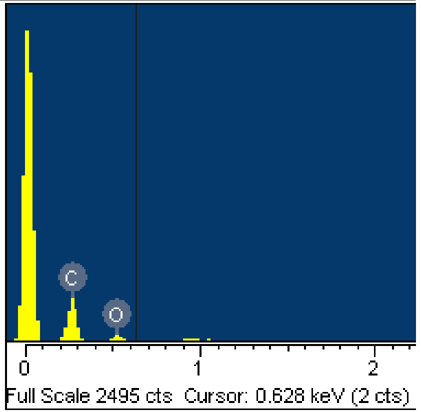








Wires in non-irradiated
And
Irradiated areas

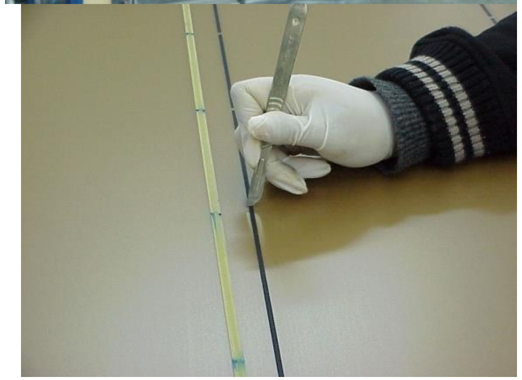


Why resistive coating ?

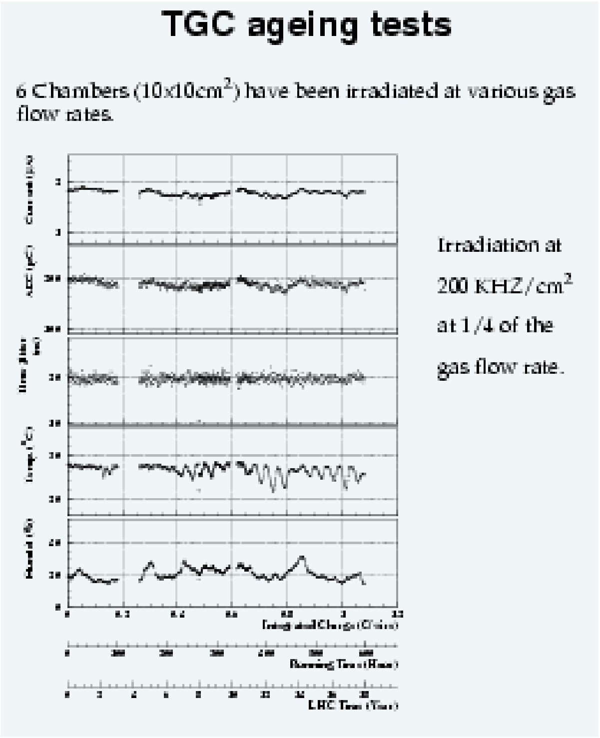
- Having a high resistivity cathode reduces any damage that could be caused by sparking.
- By putting the readout layer behind a thin (100µm-1.4mm) G-10 layer, using standard multi-layer PC procedures, one obtains a smooth cathode surface.
- The transparency of the resistive layer is proportional to R*C (i.e. the surface resistivity X the capacitance to the readout pattern).
  - For low-rates, one can use high-resistivity material and place the readout pattern far from the cathode surface.
  - For high rates, one needs has to reduce the gap between the readout pattern and the cathode to a minimum, to have a low resistivity layer.
- With a highly quenching gas, there are no problems of space-charge limitations (one can have local rates measured in KHz/mm^2), however high rates on a large surface reduces the operating voltage far from the ground contacts, therefore leading to non-uniform gain.
  - Increase the number of ground contacts and make sure that the surface resistivity matches the detector rates.

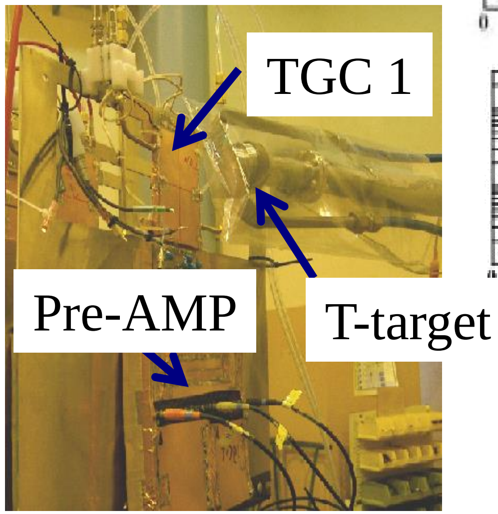
Potential pitfalls

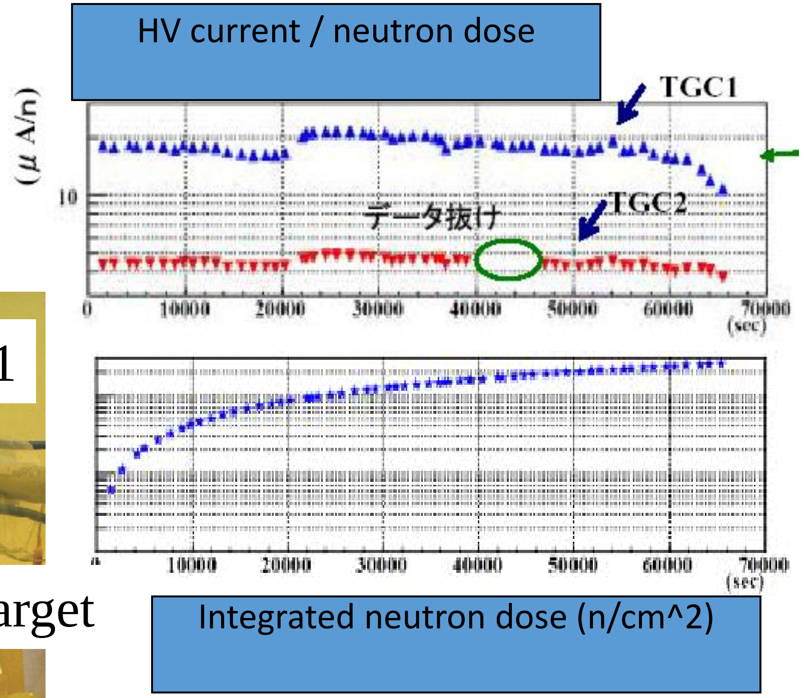
- Quality of the material:
  - The Pre-Preg material on which the resistive coating will be applied has to be smooth, but porous.
  - It is very important that during the mult-layer fabrication (press), the relevant surface has been covered with Tedler paper.
- Conditions for coating:
  - It is very important to control the conditions for applying the coating (low humidity <40%) and well defined temperature. At Weizmann, a special room has been instrumented for this purpose.
- Quality of the coating:
  - The firms that produce the coating material (an admixture of graphite and glue), are not interested in the surface resistivity. Any new batch has to be controlled for the final surface resistivity by using testing samples.
  - During the coating process, some dust particles can be attached. It is crucial to perform a polishing procedure, after the coating material has cured.
  - The coating gun has to be cleaned after each application, to obtain a uniform coating.
- Avoid any contact between glue and the coated surface. This changes the local resistivity.
- Contacts to ground:
  - Various ways of providing contacts to the ground have been tried. Most of them change (conductive glues, Ag compounds, etc) change the conductive properties with time. ATLAS solution: many Cu strips making contact by pressure. Future solution: Cu contact attached by press during multi-layer fabrication.



Aging Tests

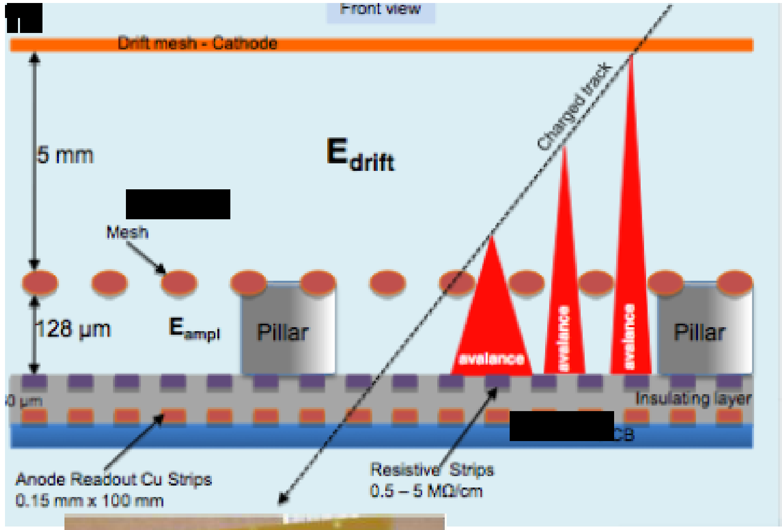


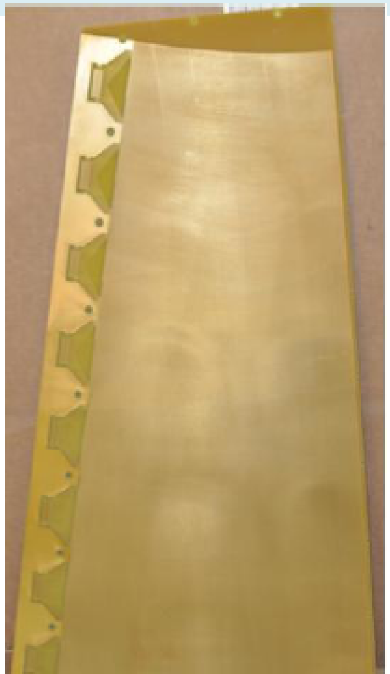




- TGC detectors have been irradiated with Ru for aging test up to 30 LHC years (no deterioration up to 1.3 C/cm.
- They have also been irradiated with n from D-T reaction (14MeV), showing again no deterioration up to 30 LHC years.
- Studies have been published on the measured sensitivity to photons and neutrons as a function of energy.

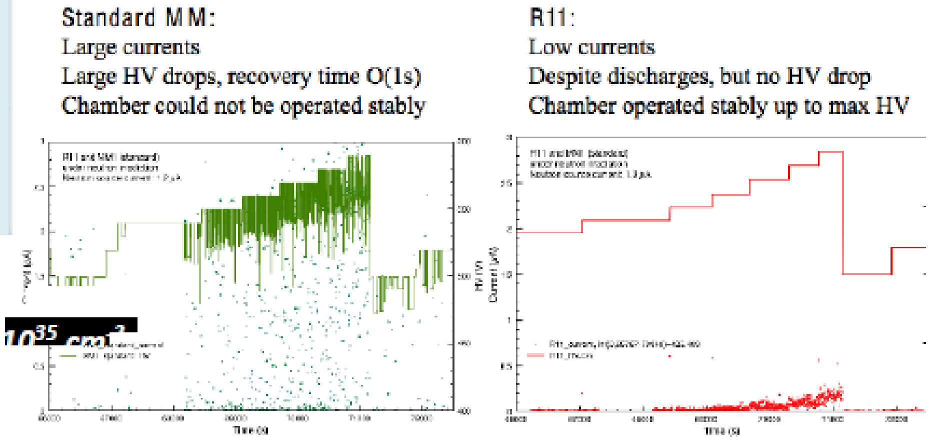
Micromegas: new technology that could be used in the forward region





New structure: resistive anode where the key is to suppress the effects of discharges (has been a great worry with mpgd)

successfully tested with neutrons



big MM in preparation

Plan to go further to multi-plane, full-size proto

Possibility to install in ATLAS cavern for operation experience

World wide collaboration in Science

- CERN: from war to make science together
- From the Holocaust to start working together for science.
- Japan-Israel collaboration and how to share responsibilities.
- How Israelis and Palestinians can work together for Science.
- How Israelis and Pakistanis can work together for Science.
- Bringing South America into the big boys science.
- ATLAS: a conglomerate of different countries, cultures, and IT WORKS!!!
- Conclusions.

CERN: from war to make science together

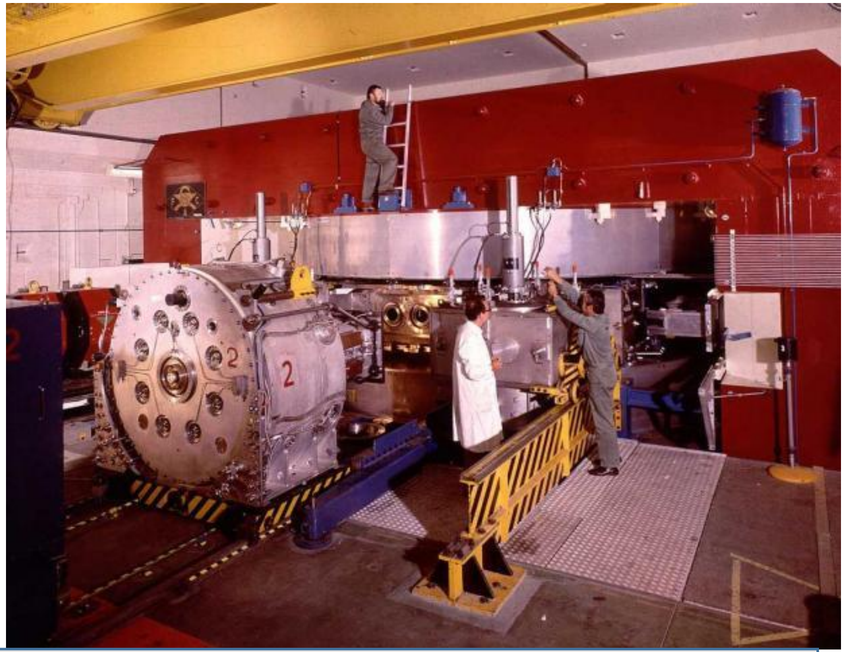
9 December 1949

At the end of the Second World War, European science was no longer world-class. Following the example of international organizations, a handful of visionary scientists imagined creating a European atomic physics laboratory. Raoul Dautry, Pierre Auger and Lew Kowarski in France, Edoardo Amaldi in Italy and Niels Bohr in Denmark were among these pioneers. Such a laboratory would not only unite European scientists but also allow them to share the increasing costs of nuclear physics facilities.
French physicist Louis de Broglie put forward the first official proposal for the creation of a European laboratory at the European Cultural Conference, which opened in Lausanne on 9 December 1949. A further push came at the fifth UNESCO General Conference, held in Florence in June 1950, where American physicist and Nobel laureate Isidor Rabi tabled a resolution authorizing UNESCO to "assist and encourage the formation of regional research laboratories in order to increase international scientific collaboration…"

- And the rest is history….but it was not so easy

Being German at CERN was not easy in the early days

- Although Heisenberg played a very important political role in getting Germany as funding member of CERN, some younger generation German experimentalists were not too happy about his role (Gentner, Bothe).
- CERN open the way for German scientists and Engineers to become integrated into European Science.
- First Germans to come to CERN (and other European institutions) had a very hard time to get accepted after the war.
- Prof. Gentner, through his contacts in Paris during the war (he was in charge in getting the Cyclotron built by Juliot-Curie in operation, and managed to free Joliot-Curie and Langevin), had an important role in helping with this human integration.
- He was the director of the CERN 600MeV Syncrocyclotron, and then Director of Research.



Having well defined projects at the edge of technology allows people to concentrate on the end product and to forget about their prejudices.

The CERN 600MeV (1957) and the 28GeV PS (1959) served not only to get German Physicists and Engineers to be integrated into CERN, but also to create a new school of German accelerator experts.

From the Holocaust to start working together for science

- Holocaust in the 50-60's were very present in both Israeli and German minds, but also political elements were part of the problems:
  - The 1952 Luxembourg Agreement on compensations was met with strong opposition in both Israeli and German parliaments:
    - In Israel it was called a "pact with the devil"=>no cultural relations was included as part of the legislation.
    - In Germany, Adenauer had to get the votes of the opposition to pass the legislation.
- But common search for knowledge is stronger that hate=>we are humans with common cultural and scientific interests.

It happened in the CERN cafeteria

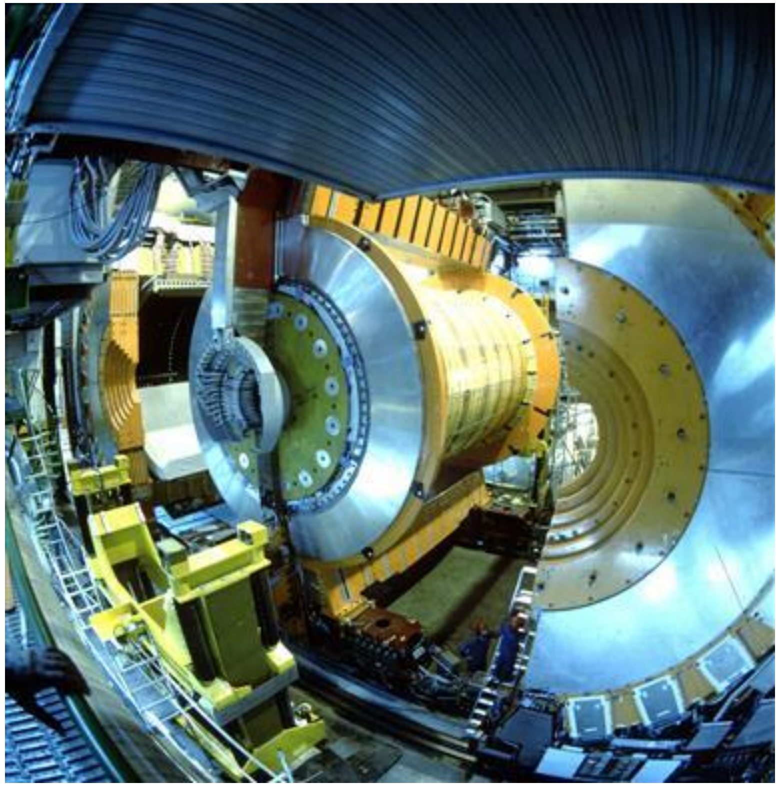
- First real discussion on how to do science together occurred at the CERN cafeteria in 1957:
  - Prof. Gentner (CERN Research Director) & Prof. de Shalit (chair of the Physics Dept., Weizmann Institute) met to discuss possible collaborations between Israeli and German scientists.
  - Main motivation:
    - For German scientists: to regain the respect of the international scientific community.
    - For the Israeli side: scientists must cooperate, even beyond the scope of personal and national tragedies.

Follow up from CERN Cafeteria

- To make it happened, one needs the highest levels: Adenauer and Ben-Gurion:
  - Adenauer was contacted by D. Heineman (co-founder of AEG); quoting Adenauer's memories: "As major of Cologne, I had many friends. Heineman and Prof. Kraus (both Jewish), were the only ones who helped me when I was remove from office".
  - Ben-Gurion was contacted by de Shalit and Aba Eben.
- In December 1959 an official delegation from the MPG, headed by Otto Hahn came for a 10 day visit to the Weizmann Institute and scientific exchange program started in 1962.
- Since 12 May 1965 Germany and Israel have stablished diplomatic relations.
- It took a long time for Israeli scientists to start collaborating with German scientists in common projects. I was the first Israeli to come to DESY to work in a common HEP Experiment and I could not understand how we can do science without each other.

Japan-Israel collaboration and how to share responsibilities

- Japanese and Israeli Physicists worked either together in the same experiment or in opposite ones at DESY.
- Although there was common appreciation, it was through more than 11 years of working together at CERN (OPAL in the LEP ring), that common thrust was achieved and the assurance that each side will keep to its responsibilities.
- This point was crucial for the 2 groups to decide to embark in a common project for the LHC: The ATLAS End Cap μ trigger.



Mutual appreciation and responsibility is a crucial element for the success of a common scientific enterprise

CERN knows how to provide recognition to outside contribution and participation in taking decisions

- The common project worked well, and both sides took their responsibilities.
- CERN first proposed to Israel to become the first paying Observer to the CERN Council.
- Japan followed a few years later with as similar model.
- Contributing states should have a say (even if only during the coffee breaks) on the scientific program of the Institution.

How Israelis and Palestinians can work together for Science

- Although Israel became an Observer State to the CERN Council in 1991, Israeli participation in the CERN Summer Student Program, via its CERN contribution started only in 2002.
- In 2005 it was decided that this contribution could also be used to support Palestinian Summer Students.
- Being CERN a neutral ground, provides both sides an excellent opportunity to work and celebrate together without the feeling of motherhood.

To ensure a fruitful scientific and cultural collaboration, one should avoid the feeling that one side is being patronized.
CERN being a neutral ground, is excellent example to be able to achieve this.

And they did celebrate together

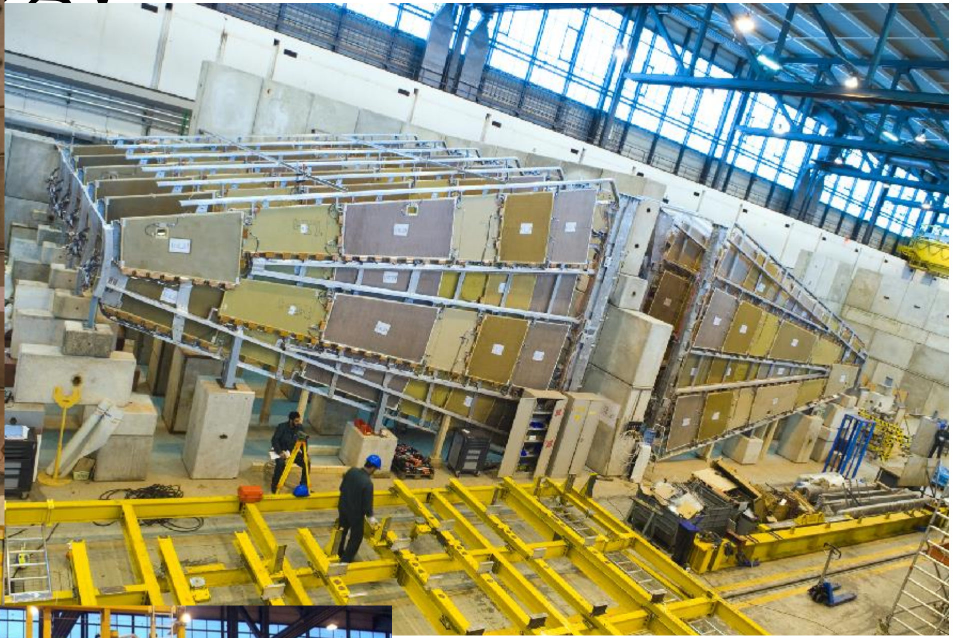
This year, as before, Summer Students from all nationalities organized parties. The decision to organize our own party was taken during the Italian party. Besides showing that the reality is not what you see in the news, we wanted people in Europe to experience a different kind of party. With local music and food such as hummus, labane, pita bread and mahalabie for dessert that we made ourselves, the party was indeed different from all others. The party had more gimmicks such as writing all the signs in English from right to left, or a place where people could practice writing in Arabic and Hebrew, and a screen where we projected animation from Israel and Arab belly dancing

An Israeli-Palestinian Party might sound a bit strange, as people are used to hear of Israel versus Palestine most of the time. That is one of the reasons we, a few Summer Students, decided to throw a joint party on Wednesday, August 22. We wanted to show that despite the disputes between our governments, when it comes down to the people, we can easily get along. In some sense, just like with food for example, our cultures are quite similar.

How Israelis and Pakistanis can work together for Science

- Scientists are used to work together independent of their cultural and religious backgrounds due to their motivation to improve our knowledge.
- It was not at all clear that this could be possible for groups of engineers and technicians, where this motivation is not necessarily present.
- With professor H. Hoorani from Pakistan we decided that it was worth a trial for one of the big projects of the ATLAS Experiment "the ATLAS Big Wheels":
  - The chambers were constructed in Israel, Japan and China
  - The electronics was developed and build in Japan
  - The support structures (precise large Al structures) were designed in Russia and CERN and made in Israel.
  - The jigs and tooling were designed and made in Pakistan
- During 3 year 20 engineers and technicians from Pakistan worked together with 20 Engineers and technicians from Israel to put together the project.

How Israelis and Pakistanis can work together at the edge of technology



They can also have fun together

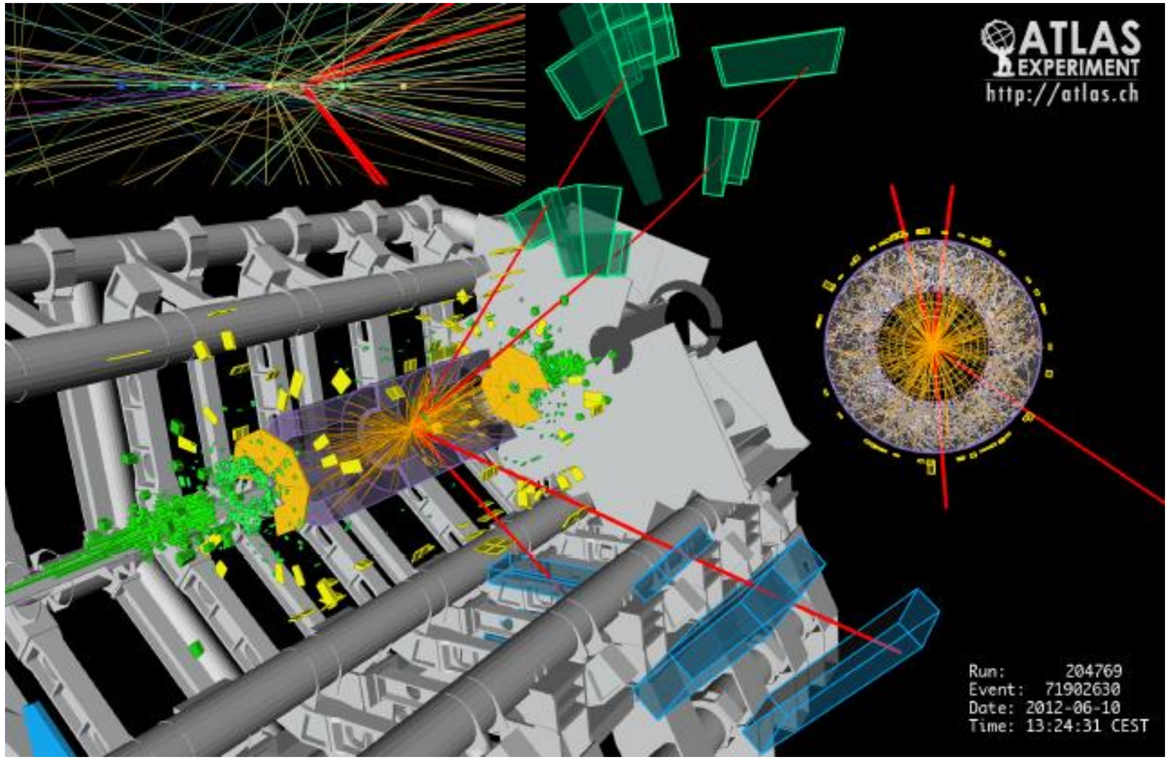
And it also works

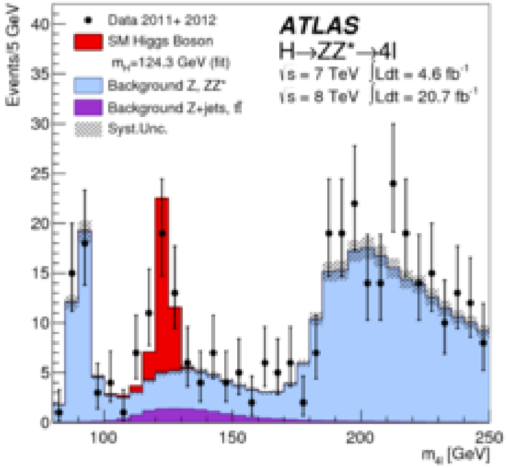
- It is not only the interest in finding the Higgs Boson that makes people work together.
- Having concrete projects at the edge of the technology, leads to new developments.
- CERN provides the possibility to construct such projects, at the edge of technology. This allows people to forget about their mutual prejudices, learn to respect each other and feel proud of their common achievement.

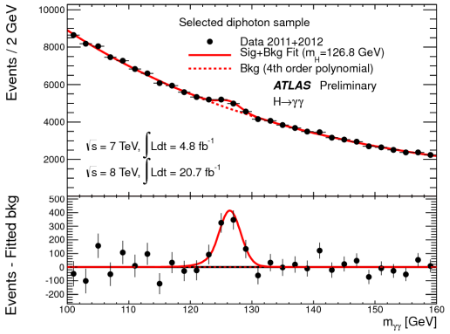
Projects at the edge of technology allow to make new developments

- It is very hard to make new developments without a clear applicable goal.
- CERN, by providing projects for basic research, that are at the edge of the technological possible, allows to improve/develop technologies and test them in a real environment.
- With experiments that include 100M single detector elements that operate with~1% failure, this is tremendous test for developments:
  - In this common work, this included developing new reliable procedures for welding.
  - Develop highly reliable fiber-optics connectors and adapters.
  - Develop highly reliable optical transmitters.
  - Many other software and hardware applications

But from a Physicists point of view, the discovery of the Higgs Particle was the dream becoming a reality





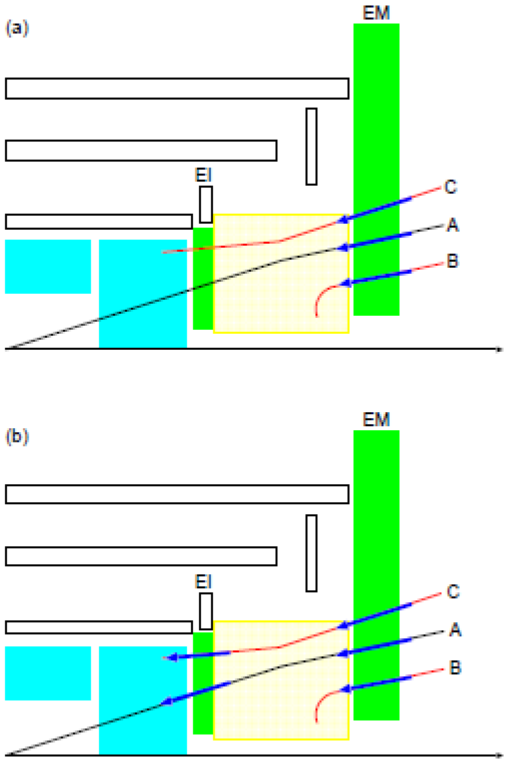


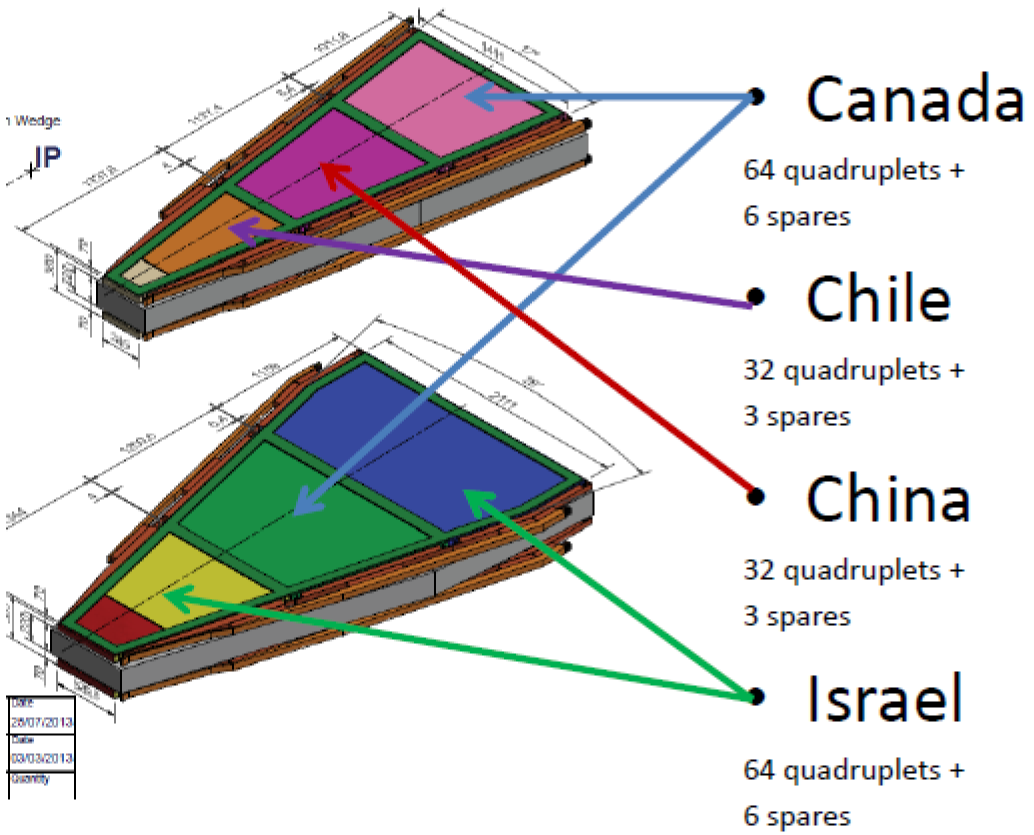
- Quarks and Leptons were shown to be point-like ($<10^{-19}$m), but the acquire their mass through the Brout Englert Higgs mechanism.

Bringing South America into the big boys science

- There are a number of South American groups involved in Experimental Particle Physics.
- These groups have been involved in many experiments at FNAL, BNL and CERN with good success, but mainly based on individual contacts.
- Most of the hardware contributions have been based on electronics developments, or in the construction of scintillator detectors.
- No real effort has been made to collaborate between local groups, to produce a central component of an Experiment.

The Trigger is a crucial part of the LHC Experiments





- By joining forces between the Universidad Federico Santa Maria and the Pontifica Universidad Catolica de Chile; Chile will be able to construct a critical component of the ATLAS Upgrade.

Working together allows to get funding and sharing of responsibilities

- To make an impact in large HEP Experiments, it is crucial for local groups to collaborate in common projects.
- It is only by making a common effort that the groups of a small country can acquire the credibility to be a main player in a crucial component of a large experiment.

Y funciona

El primer detector final para el Nuevo projecto fue contruido en Chile (no en Canada, no en Israel, no en China).

The ATLAS Collaboration

- 3,000 Physicists from around the world working together to make one of the most complex experiments in humankind

Collaboration between people from different cultures allows to make it into a reality

- Many scientist talk about making science together,
- A few DO IT, and it is very satisfying to oneself to see that you have accomplished something that it works.
- In ATLAS, through common work and using know-how from different people, we have been able to make a detector compose of 100,000,000 individual elements operational at the 99% level.

Conclusions

- Having well defined projects at the edge of technology allows people to concentrate on the end product and to forget about their prejudices.
- CERN provides the possibility to materialize such projects, at the edge of technology. This allows people to learn to respect each other and feel proud of their common achievement.
- CERN, by providing projects for basic research, that are at the edge of the technological possible, allows to improve/develop technologies and test them in a real environment
- Mutual appreciation and responsibility is a crucial element for the success of a common scientific enterprise.
- To ensure a fruitful scientific and cultural collaboration, one should avoid the feeling that one side is being patronized. CERN is excellent example on how to achieve this by being in neutral grounds.
- Contributing states should have a say (even if only during the coffee breaks) on the scientific program of the Institution to which they are contributing.
- To make an impact in large HEP Experiments, it is crucial for local groups to collaborate among themselves in common projects.

Conclusions

- The LHC and its experiments have allowed 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.
- Will look in the near future
  - 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.