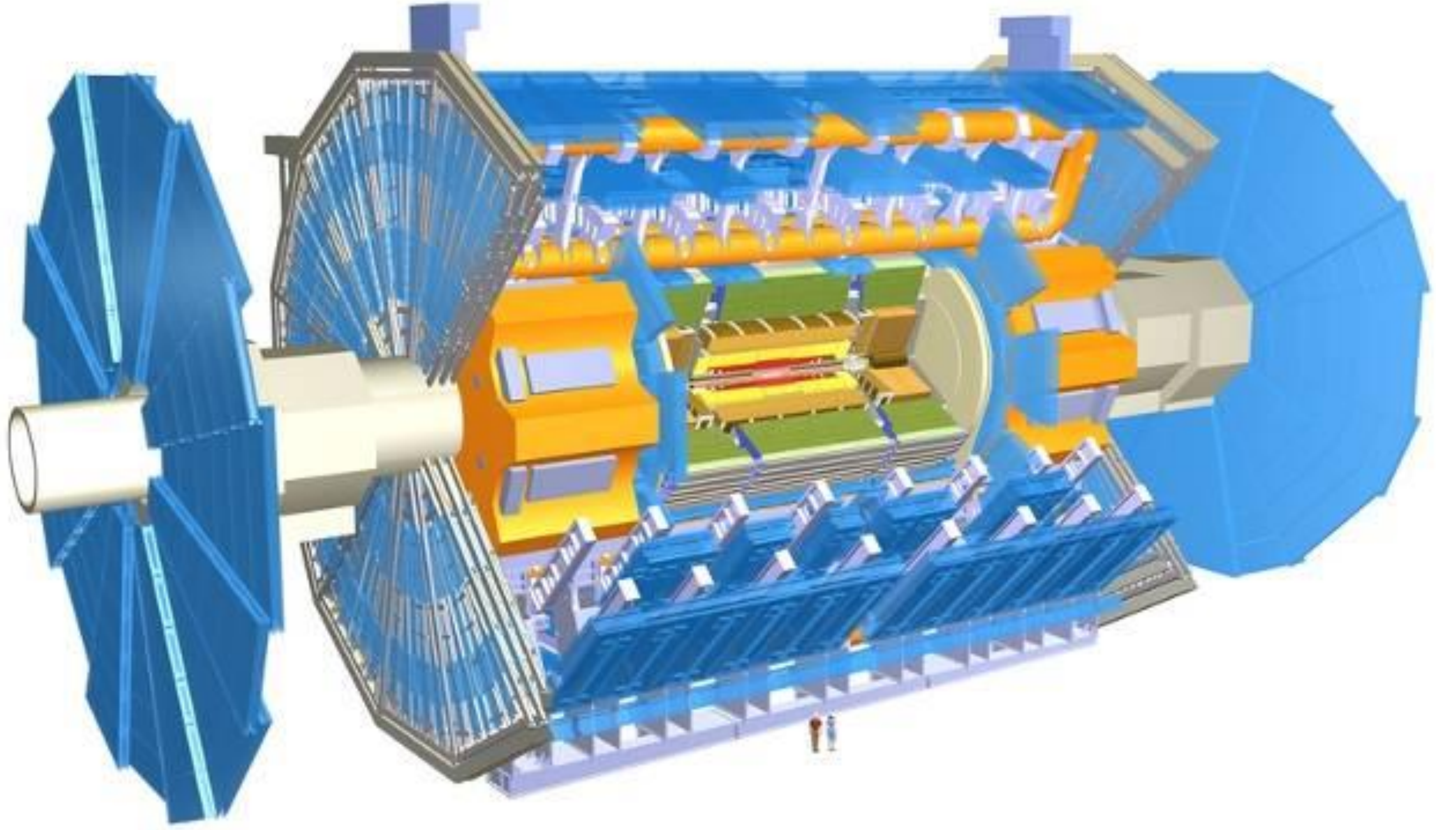
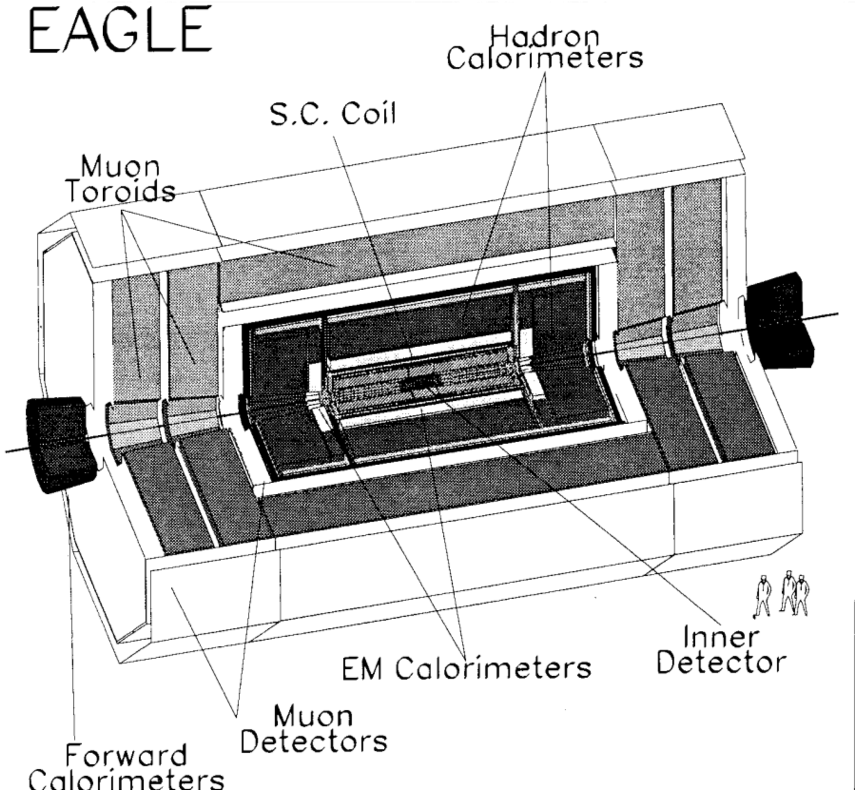
The ATLAS MUON Spectrometer
From first ideas to the H->4ℓ discovery

- The result of a marriage between EAGLE an ASCOT, main divergence on the μ Spectrometer.
- Wrong technology corrected on time.
- It is crucial to understand the physics aspects of the production of every part (talk to the people that really produce the parts).
- It is crucial to have a good detector description to be able to decide on savings.
- Be careful with playing politics and wasting too much time in R&D, move forward with production.
- Do not forget alignment, magnetic field non-uniformity and accessibility of components. One needs to have a good starting point to believe in the Physics results.
- It is critical to have a real candle (Z->$\mu^+\mu^-$, J/ψ->$\mu^+\mu^-$) to understand the details of the detector response.
- The Higgs discovery is for real, how well do we understand the mass scale at less than a ‰ level.
- Conclusions

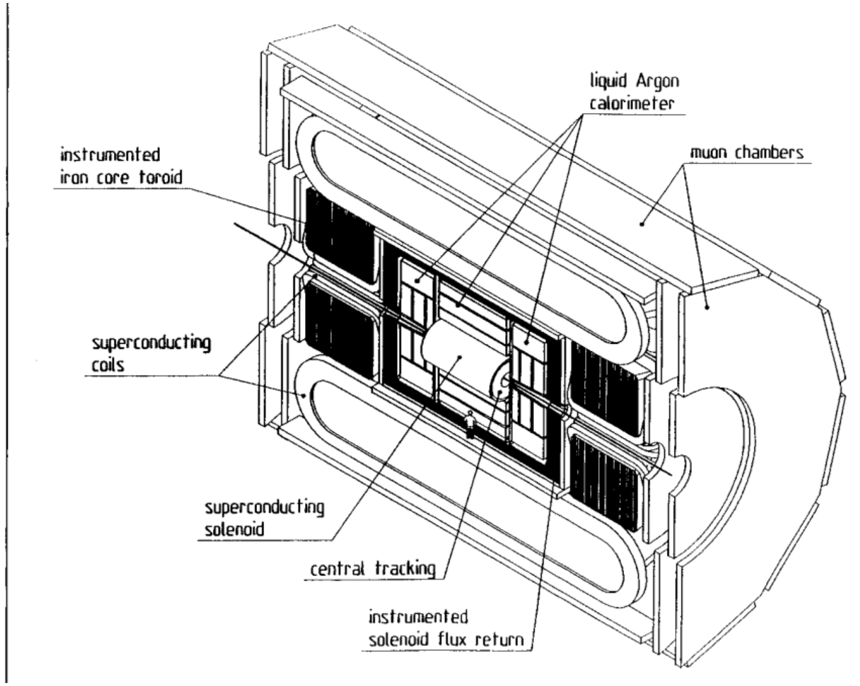
The ATLAS Experiment as it is now



The result of a marriage between EAGLE and ASCOT, main divergence on the μ Spectrometer



ASCOT



- **Iron Toroid** with uniform magnetic field, but due to the Fe material, not a very good momentum resolution at high Pt.

- **Air Toroid** with a non uniform magnetic field (12 coils and 2 Fe Toroid in EC), but with a very good momentum resolution at high Pt. To achieve it, it needs a very precise alignment system and a high control of the magnetic field variations.

End Cap Toroid is critical to keep good μ momentum resolution also at high η

ATLAS Barrel:

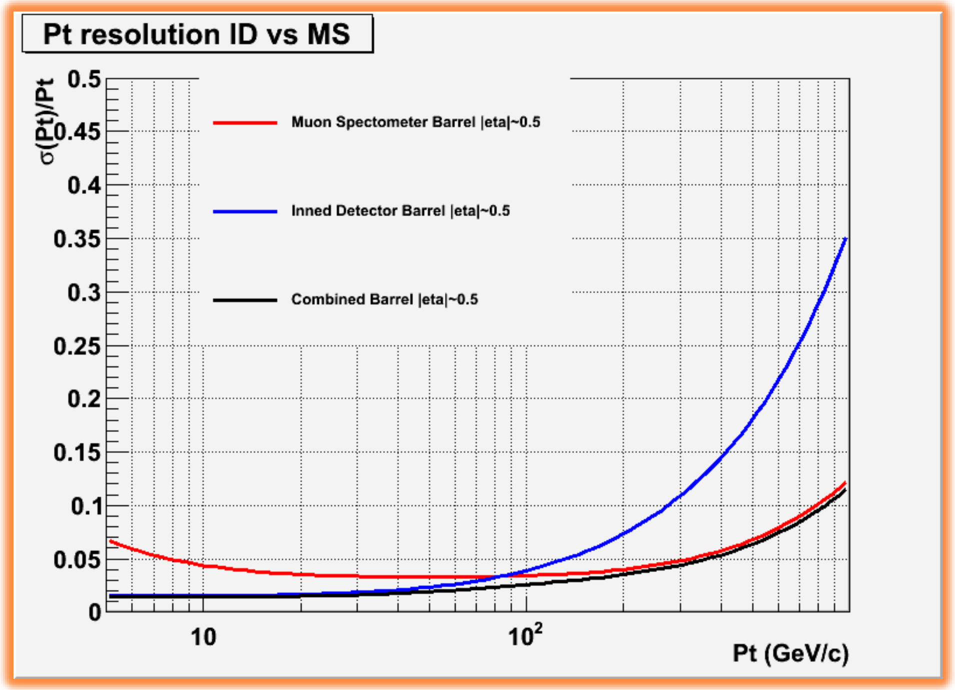
MS needed at very high P_t

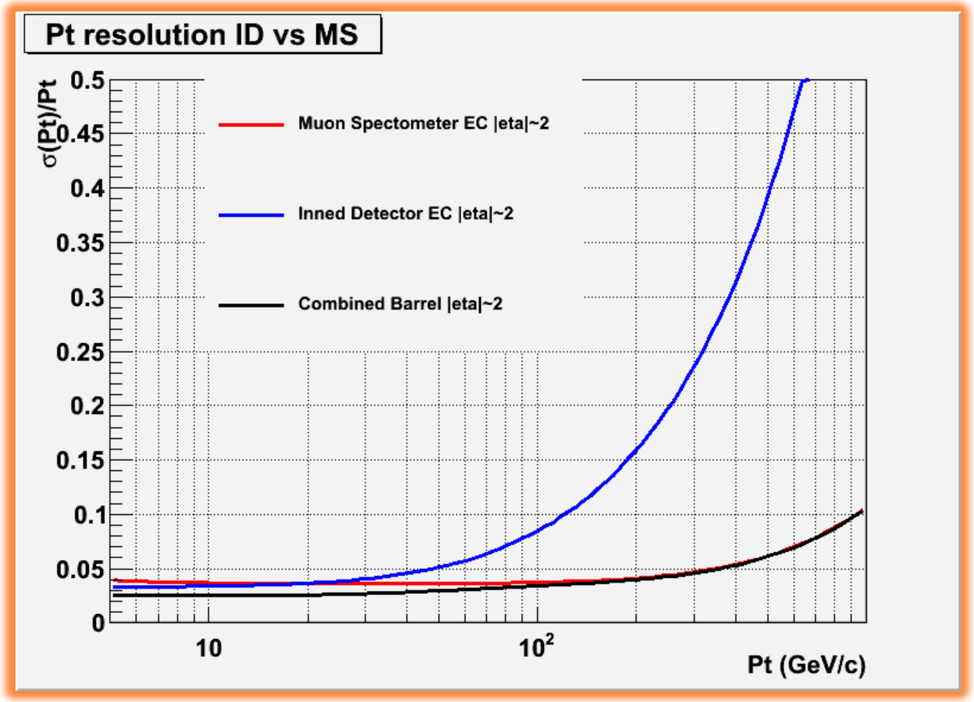
ID better up to P_t~80 GeV

ATLAS Endcap:

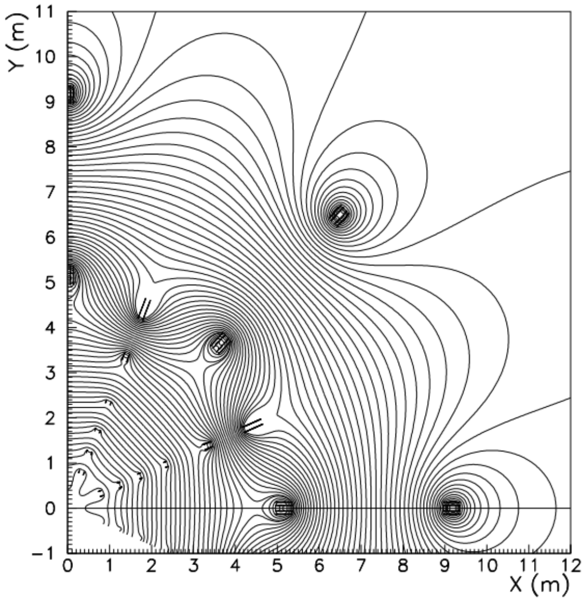
ID better up to P_t~20 GeV

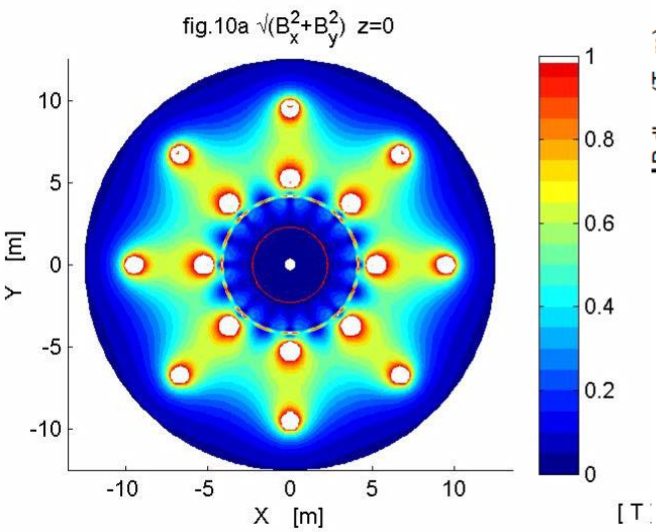
MS as Barrel up to |η|~2.7 thanks *to forward TOROID's*

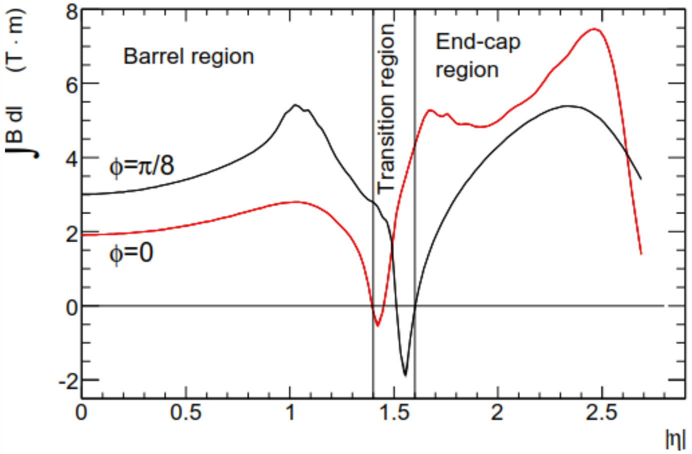




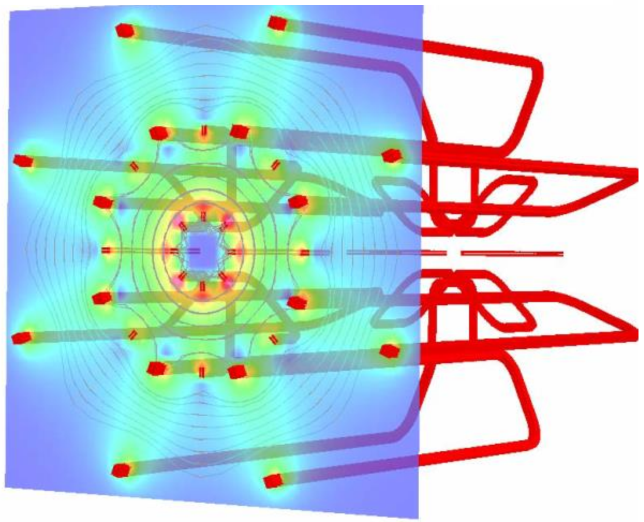
But reducing number of coils (12->8) and interference between EC-Barrel leads to a very complicated magnetic field, that needs to be known to high precision



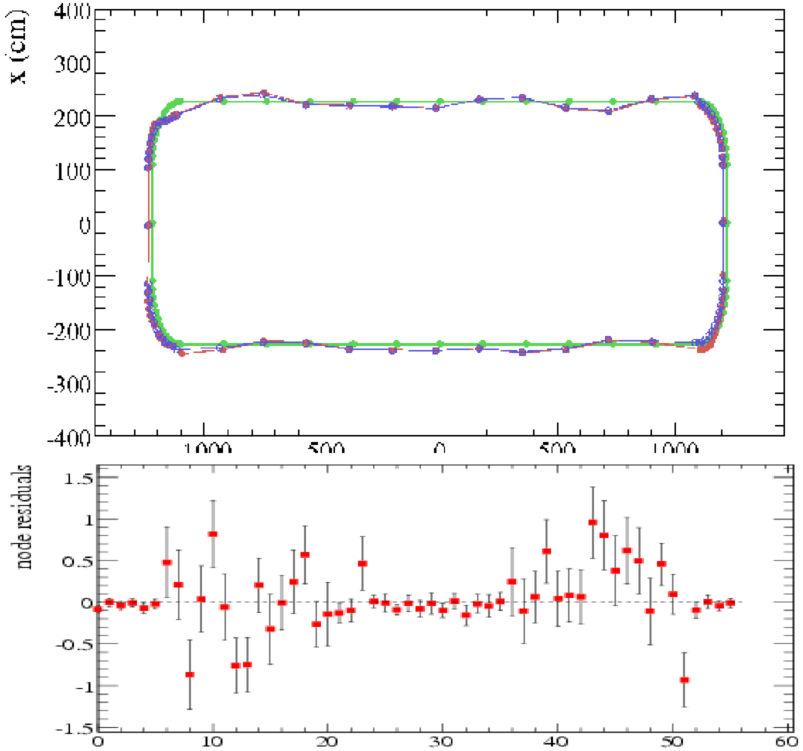




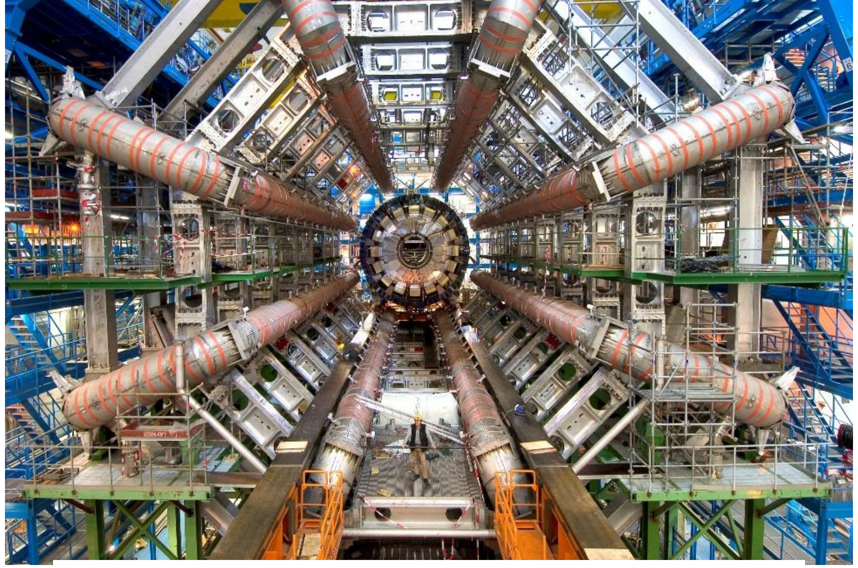
- Need to have a very good (~50μm) alignment system to position magnetic probes and detectors.

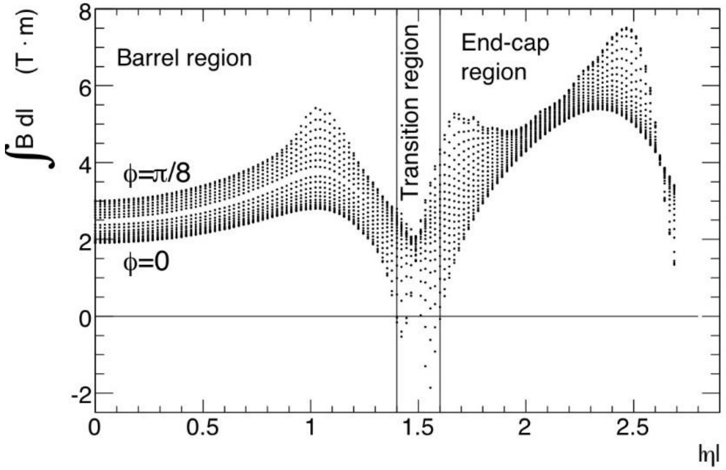


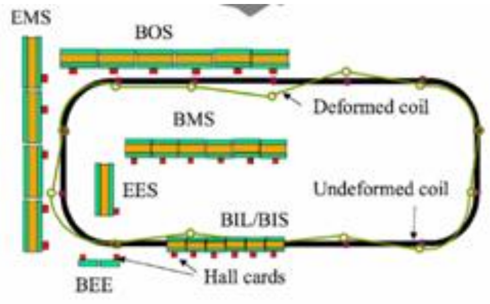
Magnetic Field knowledge

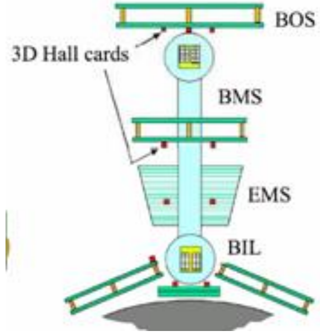


- Magnetic field was measured with probes on chambers to determined where the coils are located to within 1mm.







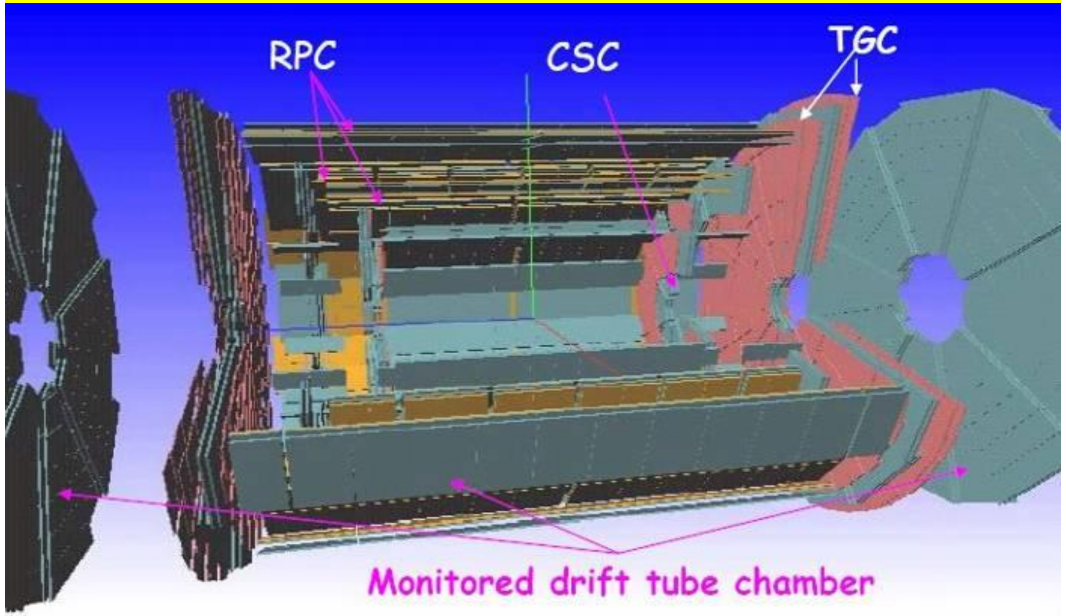


Muon Spectrometer Instrumentation

•High resolution and high acceptance MUON meas.

• by measuring P (not P (t)) using an Air-Core Toroid,

• with rapidity coverage up to 2.7.

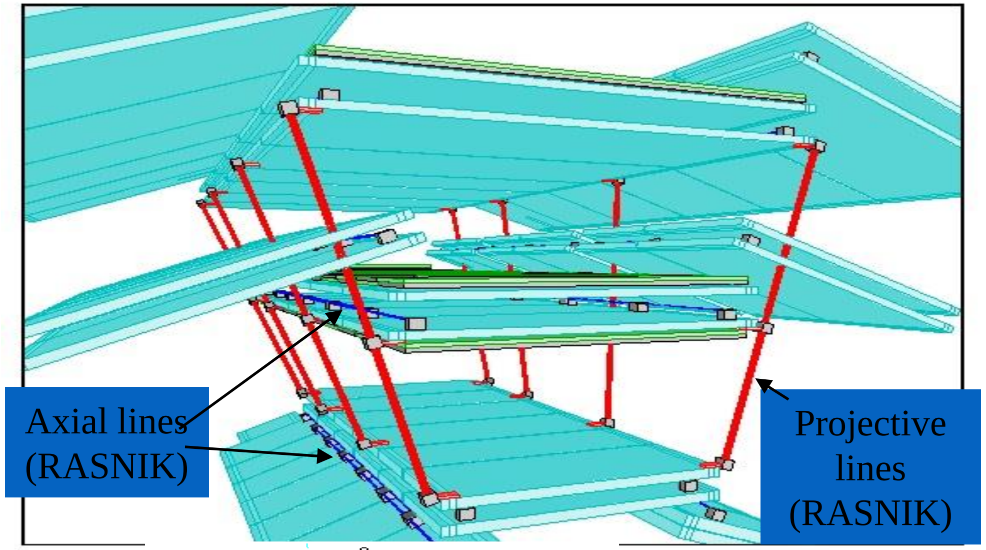


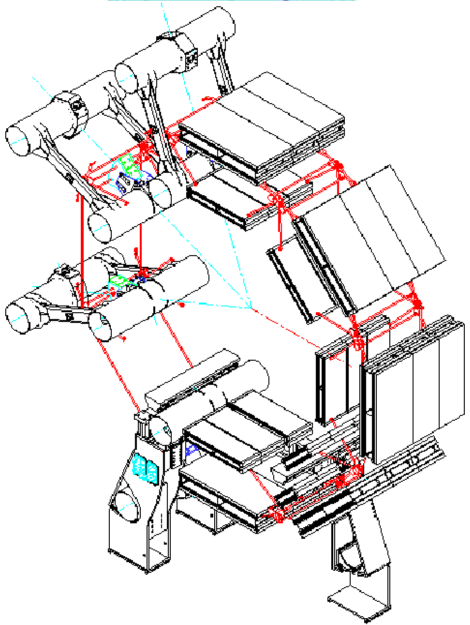
The Muon Spectrometer is instrumented with precision chambers and fast trigger chambers

A crucial component to reach the required accuracy is the sophisticated alignment measurement and monitoring system

- To track MUON's with a precision similar or better than the ID, one needs:
  - Precision detectors, with deformations that can be followed (MDT-CSC)
  - Precise mapping of the magnetic field
  - Alignment system over large distances, to know relative position of tracking chambers to within 30-40 microns.
- To trigger on MUON's, one needs:
  - Fast detectors (RPC-TGC) to provide moderate Pt measurement and Bunch ID.
  - Azimuthal coordinate measurement for both, MUON tracking and to provide corrections to main tracking detectors

MUON Spectrometer



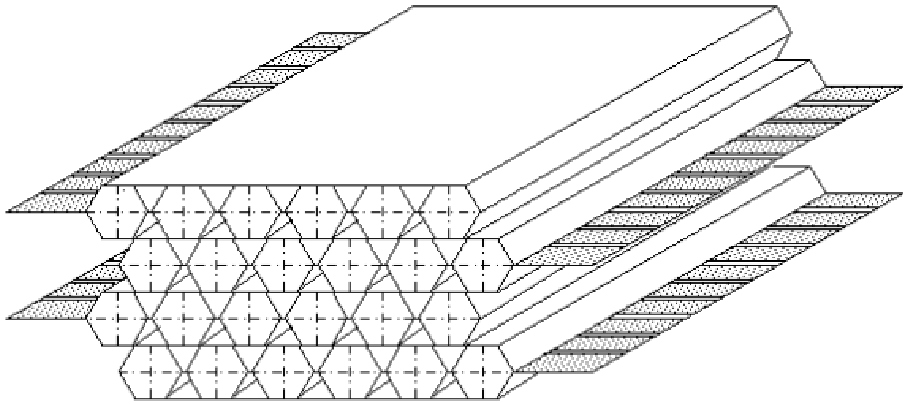


- Intrinsic resolution of chambers+ alignment dominant for P>300GeV/c. With the specs. DP/P~10% at 1TeV. This has impact for high m(H/A) and Z'.
- To achieve it, one needs:
  - Single point measurement with 80 microns precision (shown via chamber scan in tomograph)
  - Parallelism between layers of 2mrad.
  - Follow relative movements between planes to 30-40 microns (through axial and projective alignment; shown in test beam via system test).
  - Known global coordinate to within 0.5mm (reference alignment system)
  - Know the magnetic field map. This requires over 1000 probes, located on chambers. In B0, it has been shown that magnet conductor can be tracked to within 2 mm.

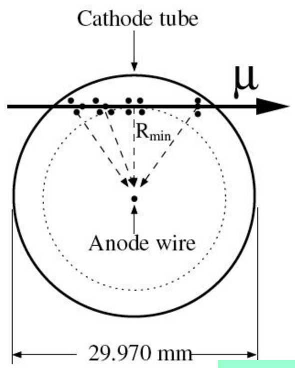
Hard decision at the start of the construction
Move from Honeycomb Strip Chambers to Al tubes with monitored position

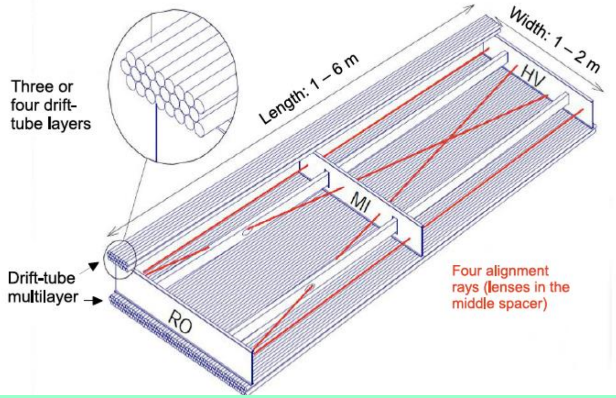
Honeycomb Strip Chambers

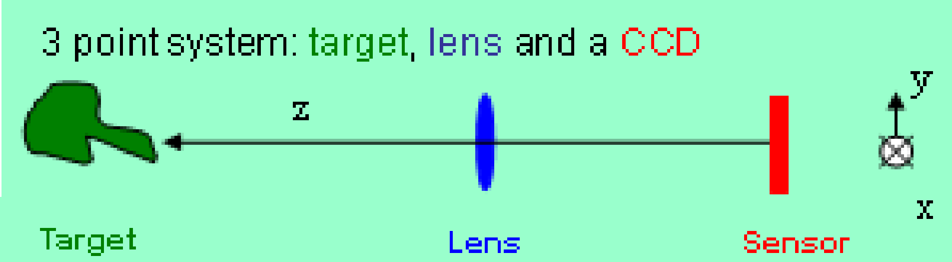
More complicated in the construction and harder to monitor its deformations.

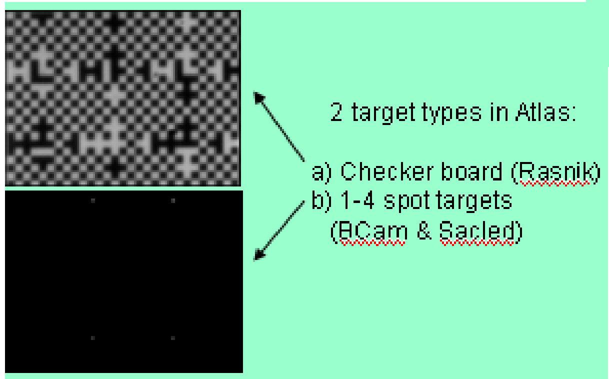


- Final decision: MDT









Some basic issues

- It is crucial to understand the physics aspects of the production of every part (talk to the people that really produce the parts).
  - End-plugs have cracks; do not inject from 2 points.
  - Problems with the quality of the tubes; work together with the firm to get the necessary quality within the same cost.
  - Problems with large leakage current in RPC's; ensure that other groups are involved in fixing the problem.
  - Many problems with noise due to the cabling of the RPC's. Only the experts that understand the full system can solve the problem.
  - Problems with one batch of Optical Fibers, that contained Phosphor, produced by a subcontractor from one of the largest producers.
- But most of the problems were solved by having a group of highly motivated experienced Physicists and technicians that invented new tools/procedures.
  - Precise wire location and automatic assembly of tubes for some sites.
  - Good ground connection achieved by either laser soldering or by simple Russian method (it is important to have experienced physicists involved in all details)
  - Optimize the temperature, humidity and amount of oil in the curing of the RPC's (it is critical to have a real expert in all the aspects, Physics and Chemistry , of every detector).
  - Do not include materials in you amplification region that have not been certified (gas inputs in TGC's).
- But many of these people are not active anymore, and the various Universities/Laboratories have not, in their majority, invest the effort of training new experts.

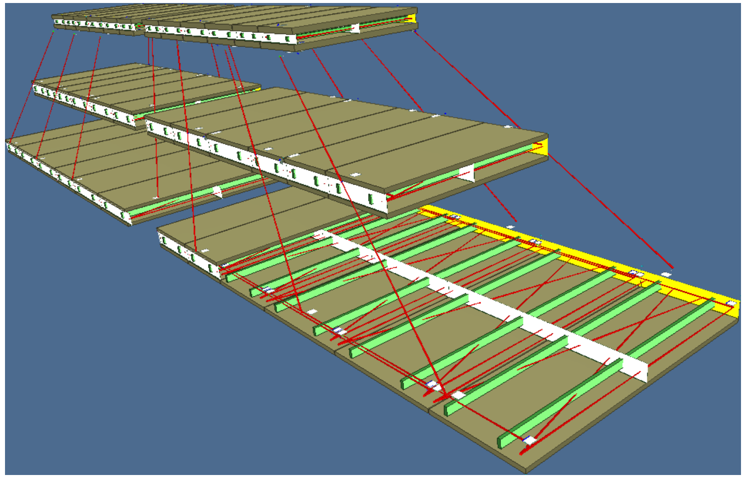
But most of the problems are of financial origin

- No EE chambers; try to save money everywhere to be able to construct them and find a group willing to do it.
- No money to provide the alignment system of non-US deliverables; produce the front-end cards to solve the problem.
- Barrel chamber supports will cost a factor 2 more than in CORE; find a firm that can produce high quality Al profiles and get it for free.
- End-Cap supports cost a factor of 3 more than the CORE estimation; get TC into the game (to get Pakistanis and Russians), find solutions to get the Al profile either free or ½ free and get good manufacturing firms to get the work under the same conditions.
- The US cannot pay for the technical manpower needs for installation and commissioning; get an arrangement to provide Protvino manpower, at a lower cost, and use the money saved on the fiber-optics to cover the Protvino C-C contribution.
- The cost of the power supplies exceeds the original estimates by a large amount; MPI contributes for the missing MDT units and the LV cables are provided by an external source.
- Keep key people at CERN to coordinate the installation and commissioning; use special programs that used to cover help for the Tile, L-Ar and shielding to pay for help in the MUON's.

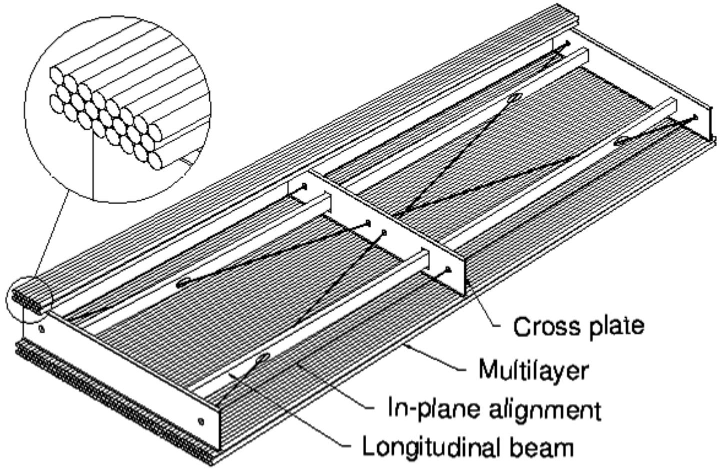
It is crucial to have a good detector description to be able to decide on what to do first

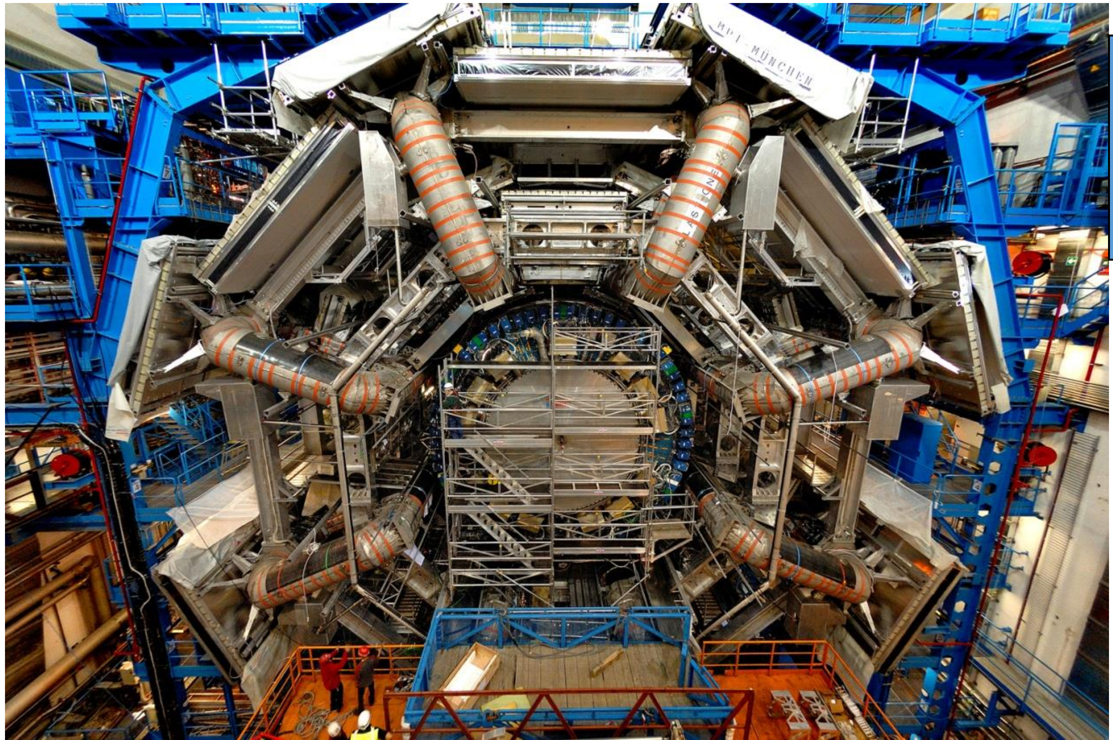
- Having an excellent detector description (first in FORTRAN), allowed to take decisions on where to cut for the initial detector to:
  - Delay the construction of the EE chambers until a group was found to do the job properly (Protvino)
  - Leave enough space at $\eta=0$ to allow for the passage of the ATLAS services and good access to the MUON services.
  - Leave some holes that could not be easily constructed for a later upgrade.
- Having credible responsible successors (Ludo and Christoph have managed to complete the MUON Spectrometer).
- Be careful with playing politics and wasting too much time in R&D, move forward with production. The real problems are found with real detectors, that can generally be corrected for the rest of the production, and not in long meetings, where people repeat the same arguments.

Having a good starting point using the alignment system was crucial to be ready for the large data

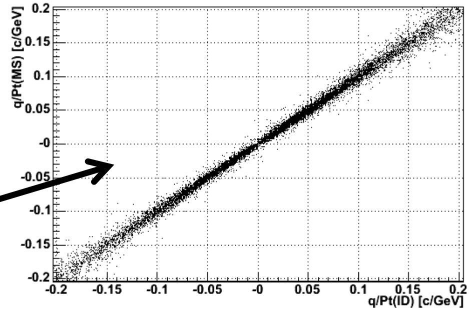


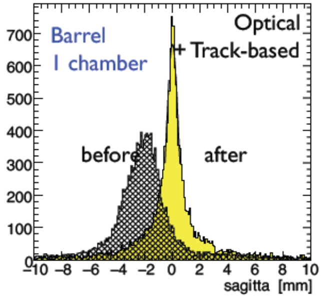
Basic tracking elements are Drift-Tubes, where wired is placed to within 10 microns; tube assembly is placed to within 20 microns, and deformation of the assembly is followed with a local alignment system.

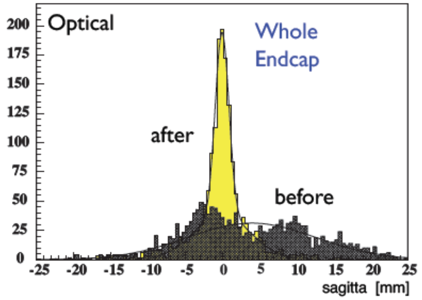




Correlation
Of
Momenta
Measured in ID
And
MUON Spectr.

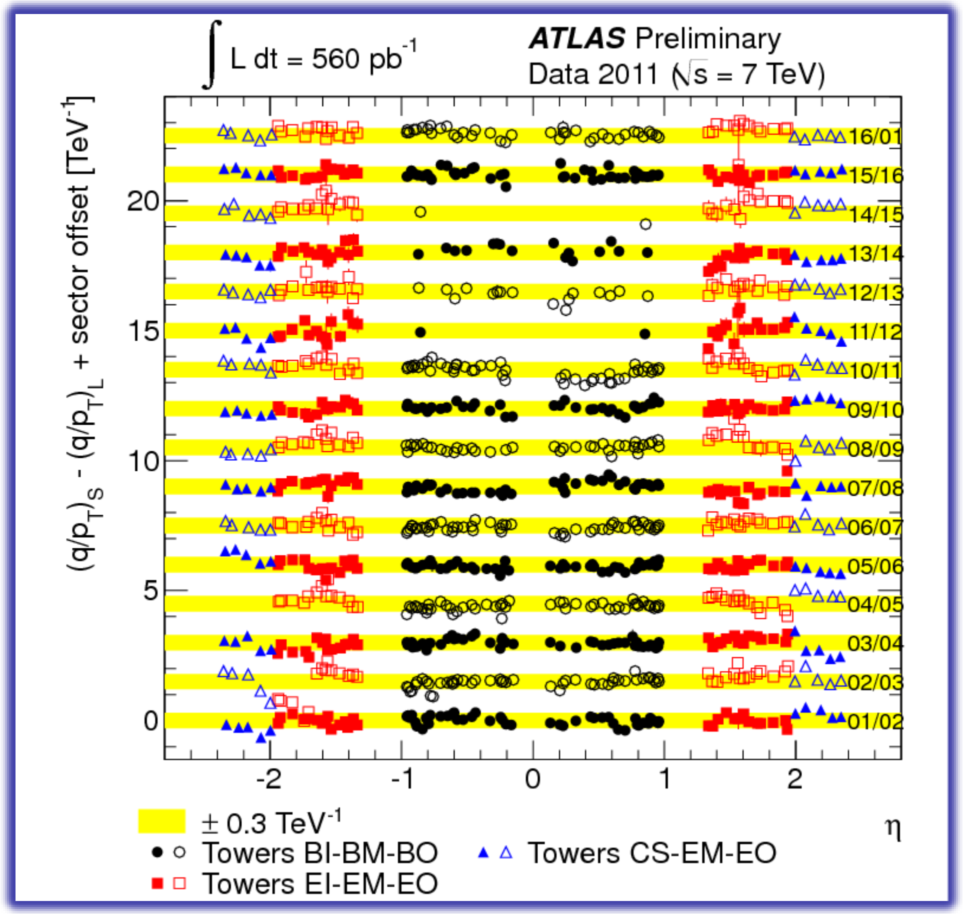






Already in 2011 the resolutions were almost there to ensure that one could clearly identify the Higgs boson in the golden channel H->ZZ*->4ℓ

Muon Resolution at high P



Official numbers 2011

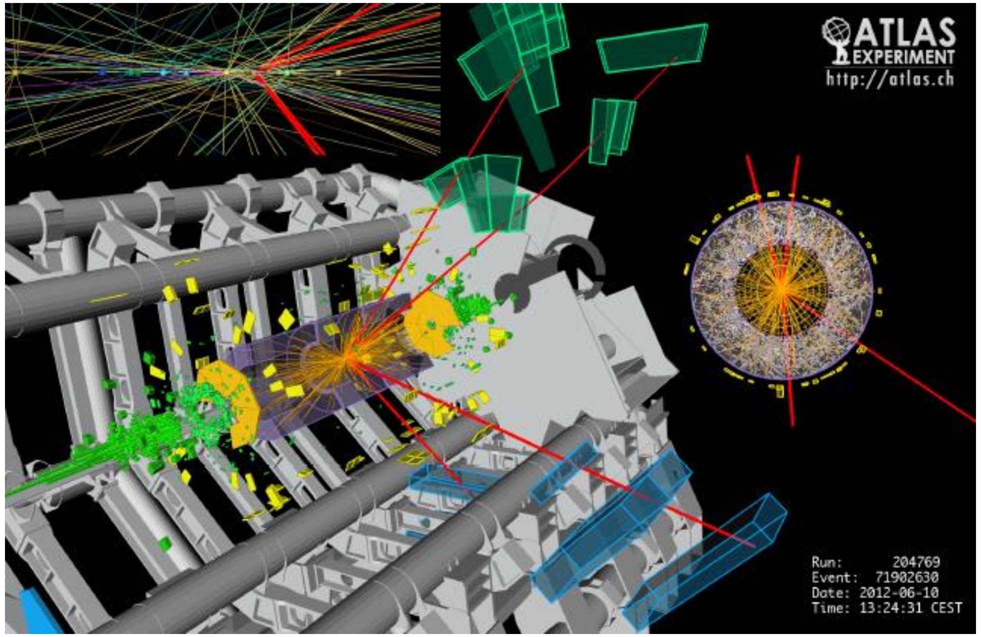
Region	σ_{ali} [TeV^{-1}]
Barrel	0.130 ± 0.05
Endcap MDT	0.174 ± 0.05
Endcap CSC	0.146 ± 0.05

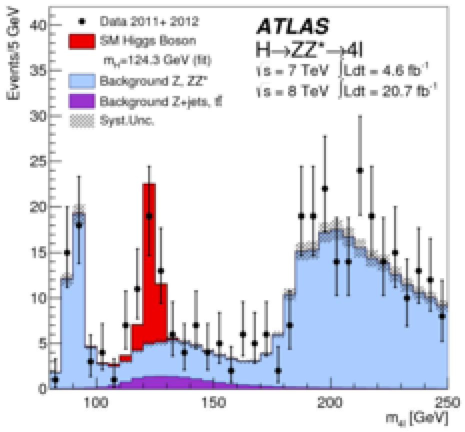
- From these two methods constrains on the alignment contribution to P resolution derived
- difference between the two estimates taken as systematic error
- GOOD enough for high-PT physics

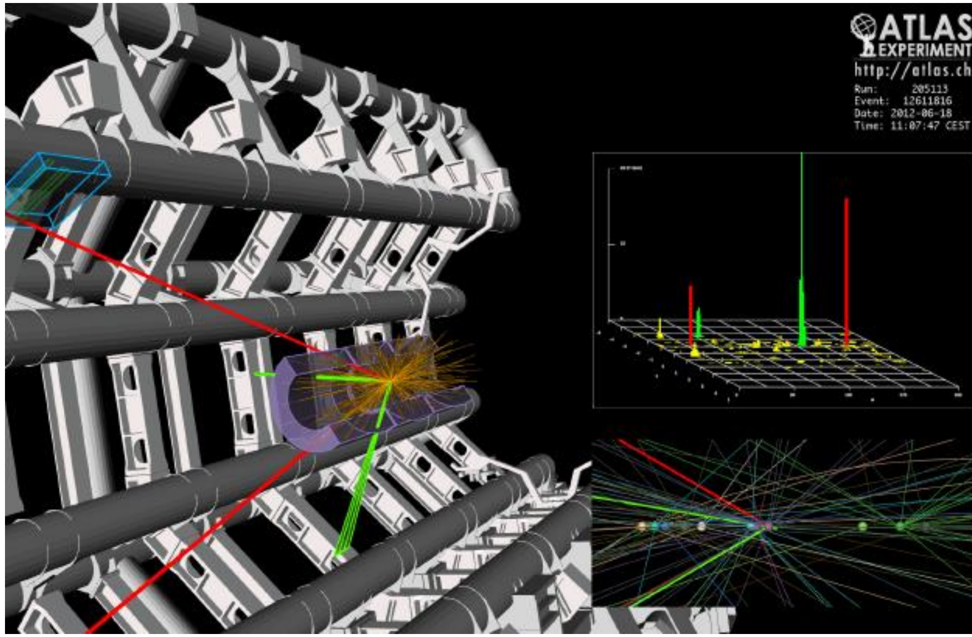
Quite close to design value 40 μm → 0.08 TeV^{-1}:

Very close to achieve the final performance

2011-2012 The Higgs has been discovered



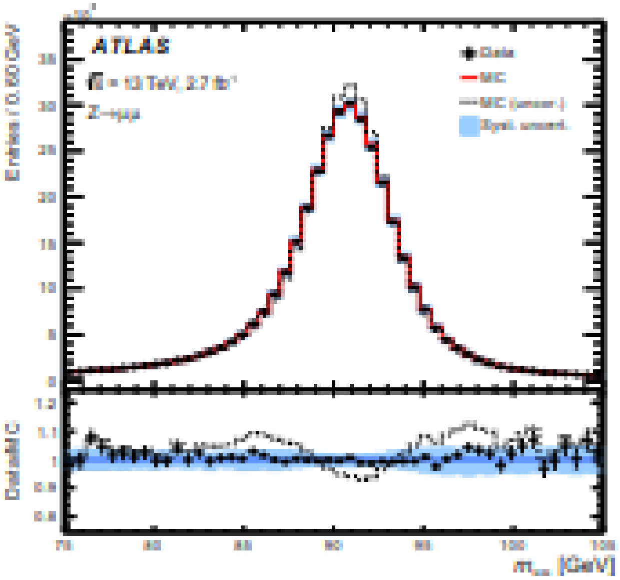


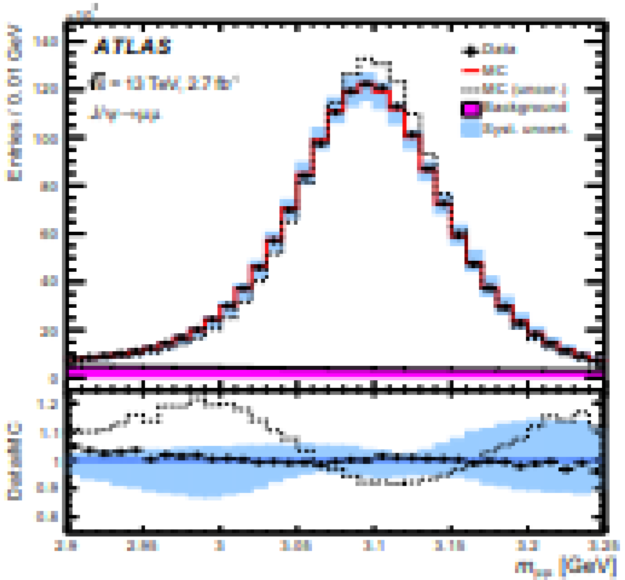


The most important discover in Particle Physics in the last 30 years
The Higgs Brout Englert mechanism provides the mass to point-like particles

The most challenging problem is to obtain a high precision measurement of the Higgs mass

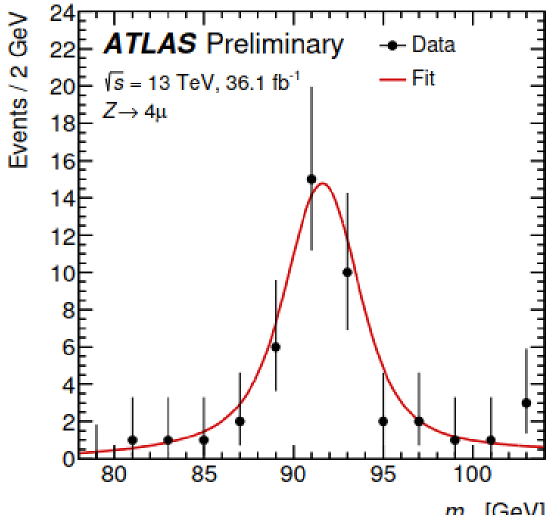
- With the availability of large statistics, both for Run 1 and later for Run 2, an impressive amount of work was performed to map efficiencies, P resolution and scale corrections to the MC, as a function of rapidity, azimuthal angle and momentum, using the candles Z; J/ψ ->$\mu^+\mu$.
- It has been impressive to see that most of the disagreements in the efficiencies could be understood.
- Still there are some unexplained inconsistencies in the uncorrected MC simulation for the large MUON Spectrometer sectors, which are corrected by fudge factors.

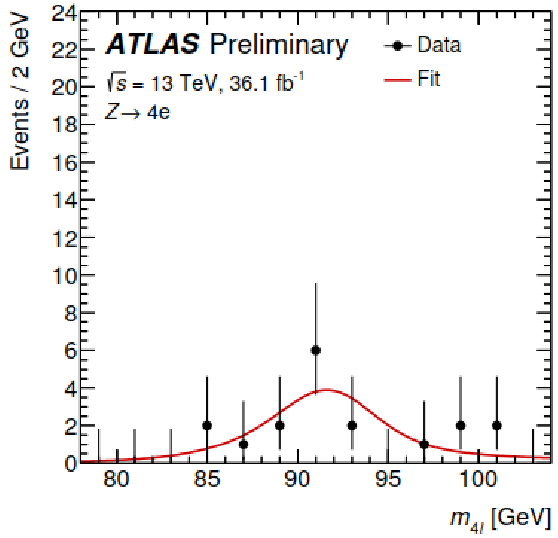




To cross check that you understand the mass scale, look at Z->4ℓ

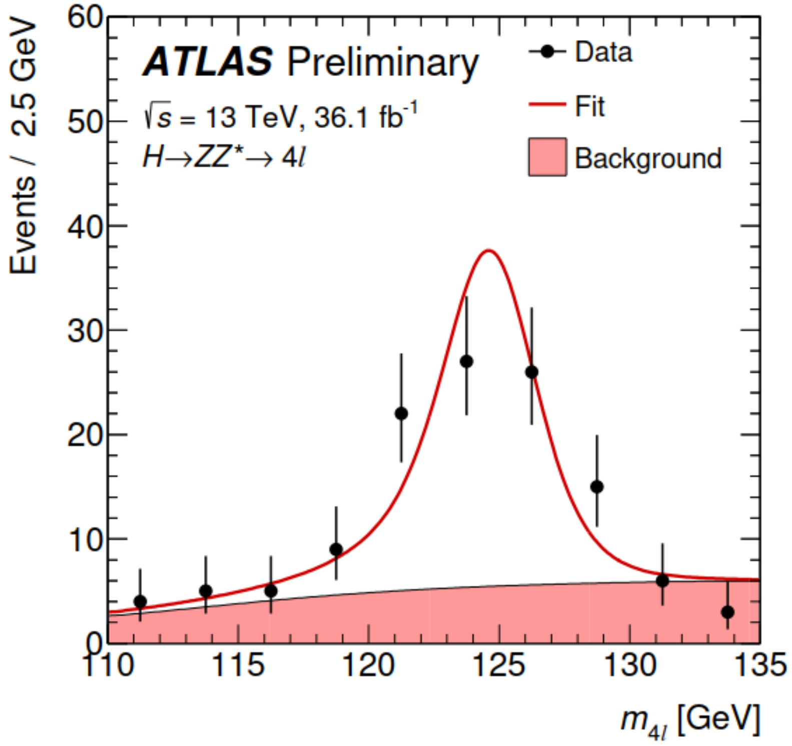
Category	m_Z in simulation [GeV]	m_Z in data [GeV]
4μ	$91.19^{+0.41}_{-0.41}$	$91.46^{+0.42}_{-0.41}$
$4e$	$91.19^{+1.02}_{-1.03}$	$91.75^{+1.08}_{-1.06}$
$2\mu 2e$	$91.18^{+1.11}_{-1.11}$	$91.31^{+1.62}_{-1.33}$
$2e2\mu$	$91.19^{+0.90}_{-0.90}$	$92.49^{+0.91}_{-0.94}$
Combined	$91.19^{+0.34}_{-0.34}$	$91.62^{+0.35}_{-0.35}$





Low statistics, but very consistent

The real H mass measurement from Run2



$$m_H^{ZZ^*} = 124.88 \pm 0.37\ \text{(stat)} \pm 0.05\ \text{(syst) GeV} = 124.88 \pm 0.37\ \text{GeV},$$

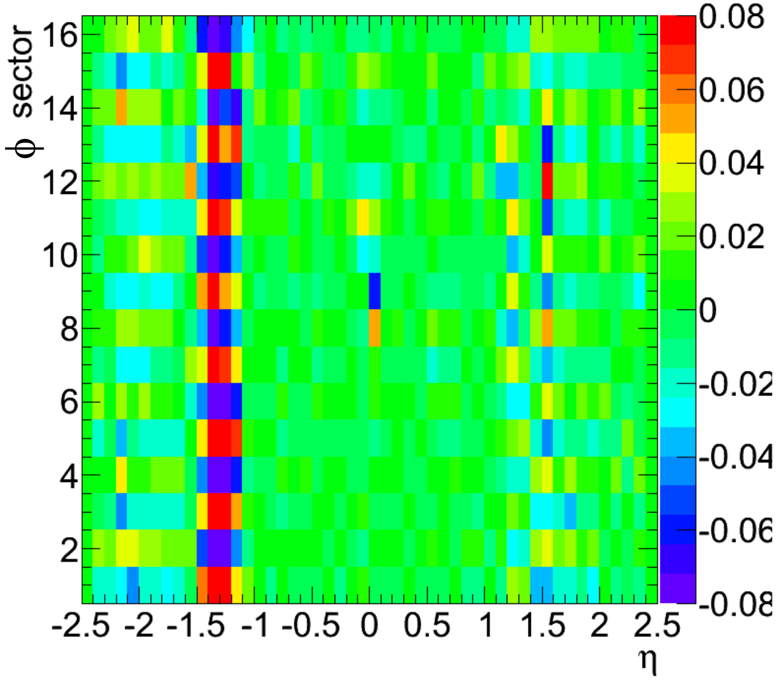
Systematic effect	Uncertainty on $m_H^{ZZ^*}$ [MeV]
Muon momentum scale	40
Electron energy scale	20
Background modelling	10
Simulation statistics	8

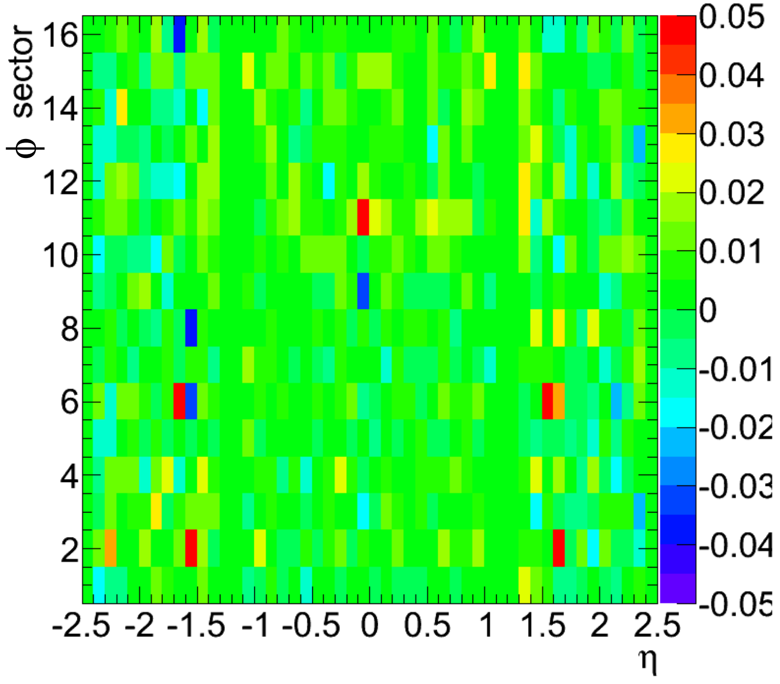
- It is impressive that in such a complex experiment like ATLAS, one is able to keep the systematics to the level of 0.4‰, thanks to a small group of very dedicated and inventive physicists that keep the individual detectors running with ~1% failure rate, the complex magnetic field under control, follow the positioning and deformations of the detectors at the 50µm level and produce the calibrations almost on-line.

Be careful about fudge factors

- ATLAS physicists work under enormous time pressures to have the right calibration to analyse today the data taken yesterday.
- This leads in many cases to use large or non-understood fudge factors to correct the MC to reproduce the data.
- Although this is acceptable due to time pressure, it is not acceptable that a PhD student is not forced by his advisor to find the physical reason that the experiment needed to use such a fudge factor (provided that the thesis advisor knows the experiment well enough).
- One such example was on the miss position of the ECT

Effect of End-Cap Toroid shift



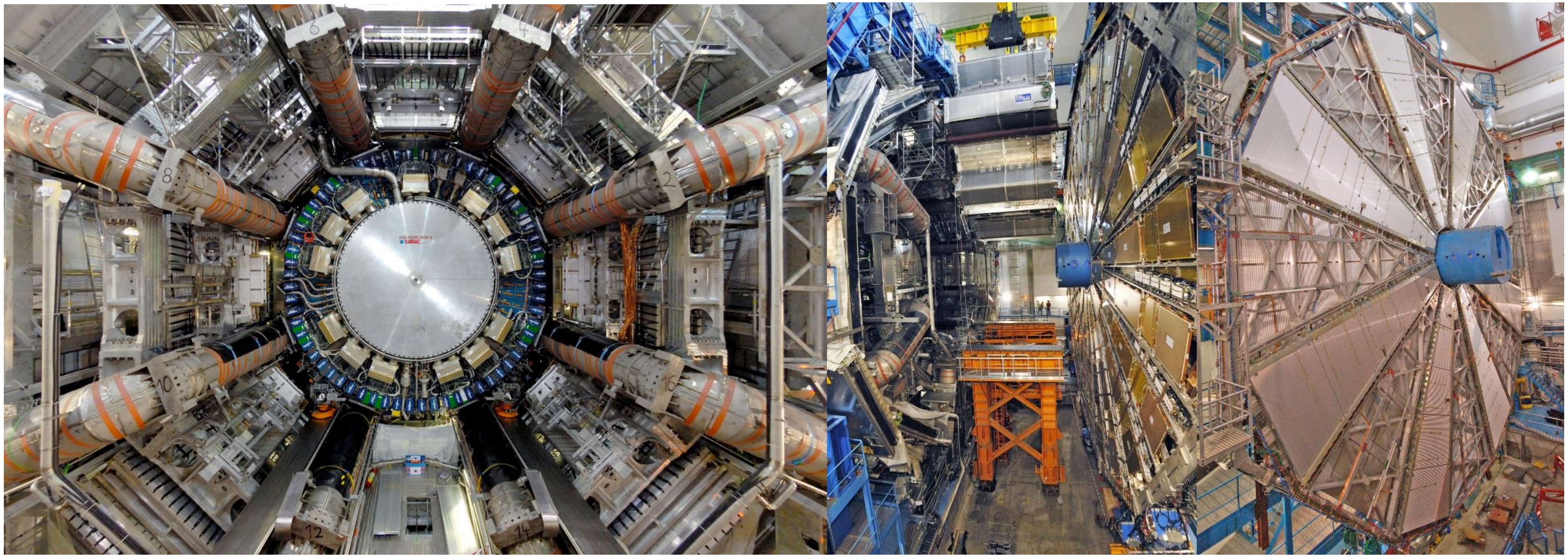


Symmetric Toroid Field Map

Asymmetric Toroid Field Map

- Mean[$(P_{MS}-P_{ID})/P_{ID}$] vs η and ϕ
- Main problem was due to small longitudinal shift of one End-Cap Toroid, which was corrected in analysis.

Conclusions as seen from the MUONs



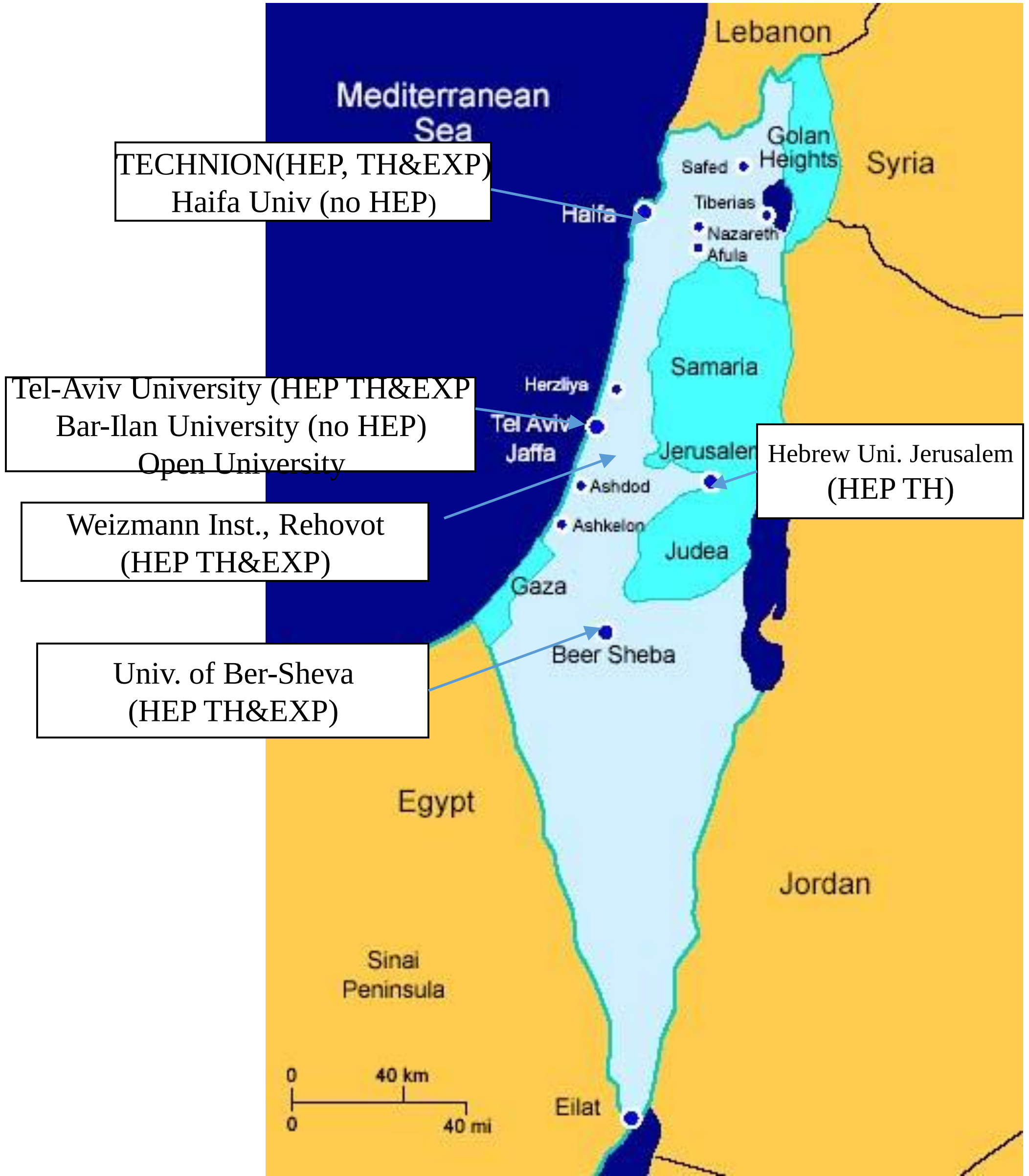
- **I think that we should all feel very proud of having participating in the conception, development construction, commissioning and exploitation of one of the most complex scientific enterprises of mankind.**
- Whenever showing visitors the ATLAS MUON Spectrometer, people have a hard time to believe that the instrumentation constructed by the 49 MUON Institutions around the world fit with each other with mm precision and failure rates in the range of 10^{-2} , providing precise (~100µm) measurements in such a large volume. This is due to a relatively small group of people that feel RESPONSIBLE and have made of **ATLAS the project of almost ½ of their scientific life.**
- **We should all feel proud of what we have accomplished in the last 25 years**

How Israel could become the first non-European Member state of CERN

- Introduction to the Israeli educational system and its influence in the High-Tech revolution
- Israeli relations with CERN

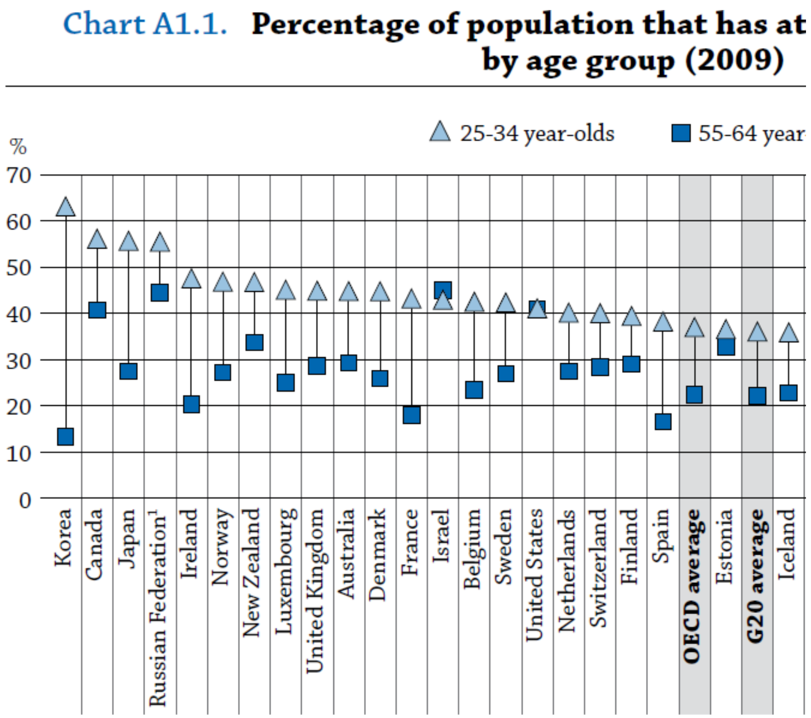
General Comments on Israeli Education and Research

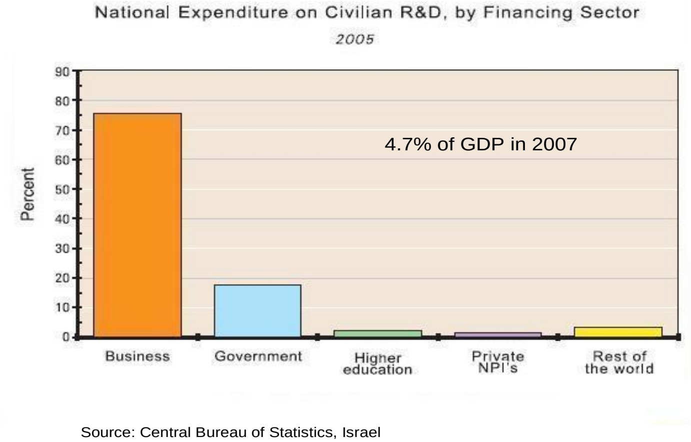
- Israeli Population 8.5 Millions habitants (=CH)
- GDP (PPP)/capita=38K$ (~IT, > GR, <CH=65, CL=24.0)
- Unemployment ~3.7% (not very high due in particular to the high-Tech industry). IT=9.7%, CH=2.4%, CL=7.0%
- 8 Universities (7 with large Research Programs) & 60 Academies/Colleges.
- Average monthly wage (PPP):3.0K$ (IT=3.0K$, GR+2.1K$, CH=5.2K$)
- TECHNION created in 1924 & HU Jerusalem in 1925, Weizmann in 1935 (in 1948: 1,600 students, 90,000 in 1990, >300,000 now)

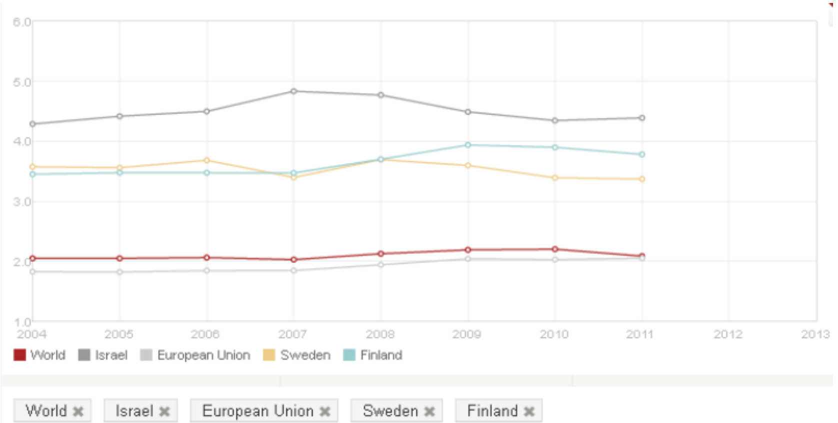


General Comments on Israeli Education and Research

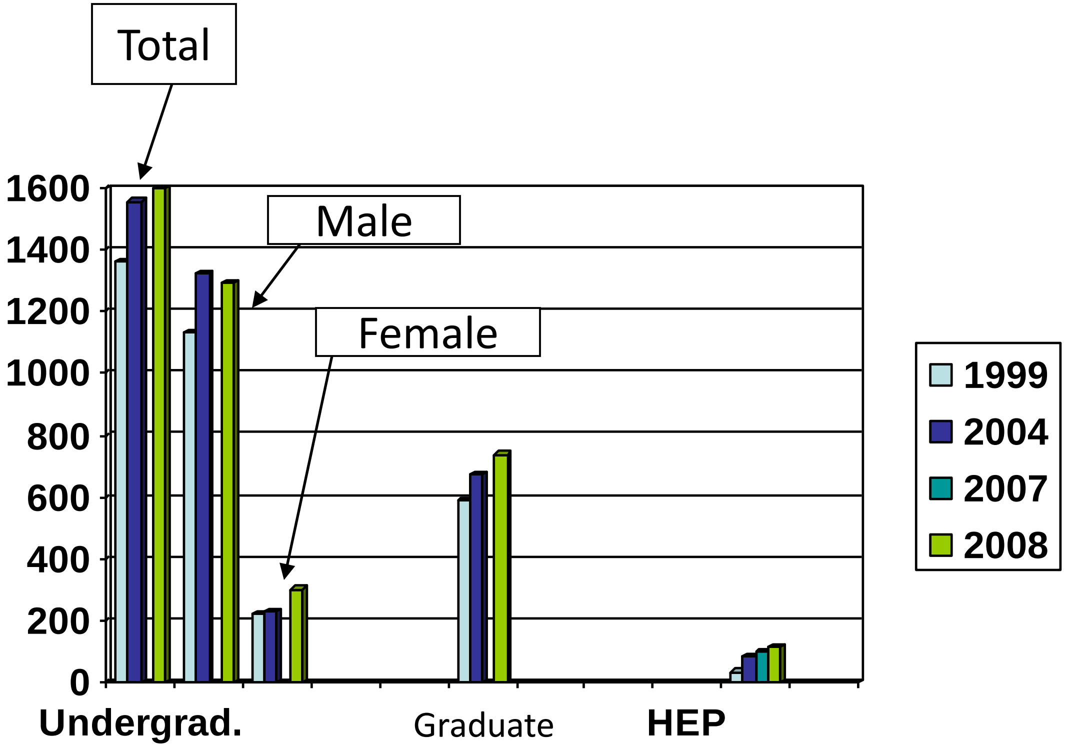
- Education has always been a priority in Israel and the first two Universities were established 24 years before the existence of the State of Israel.
- **47% of the age group 55-64 years old have 16+ years of education (mainly due to the Russian immigration) , while the same % is also for the youngers.**
- 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 the last few years.**





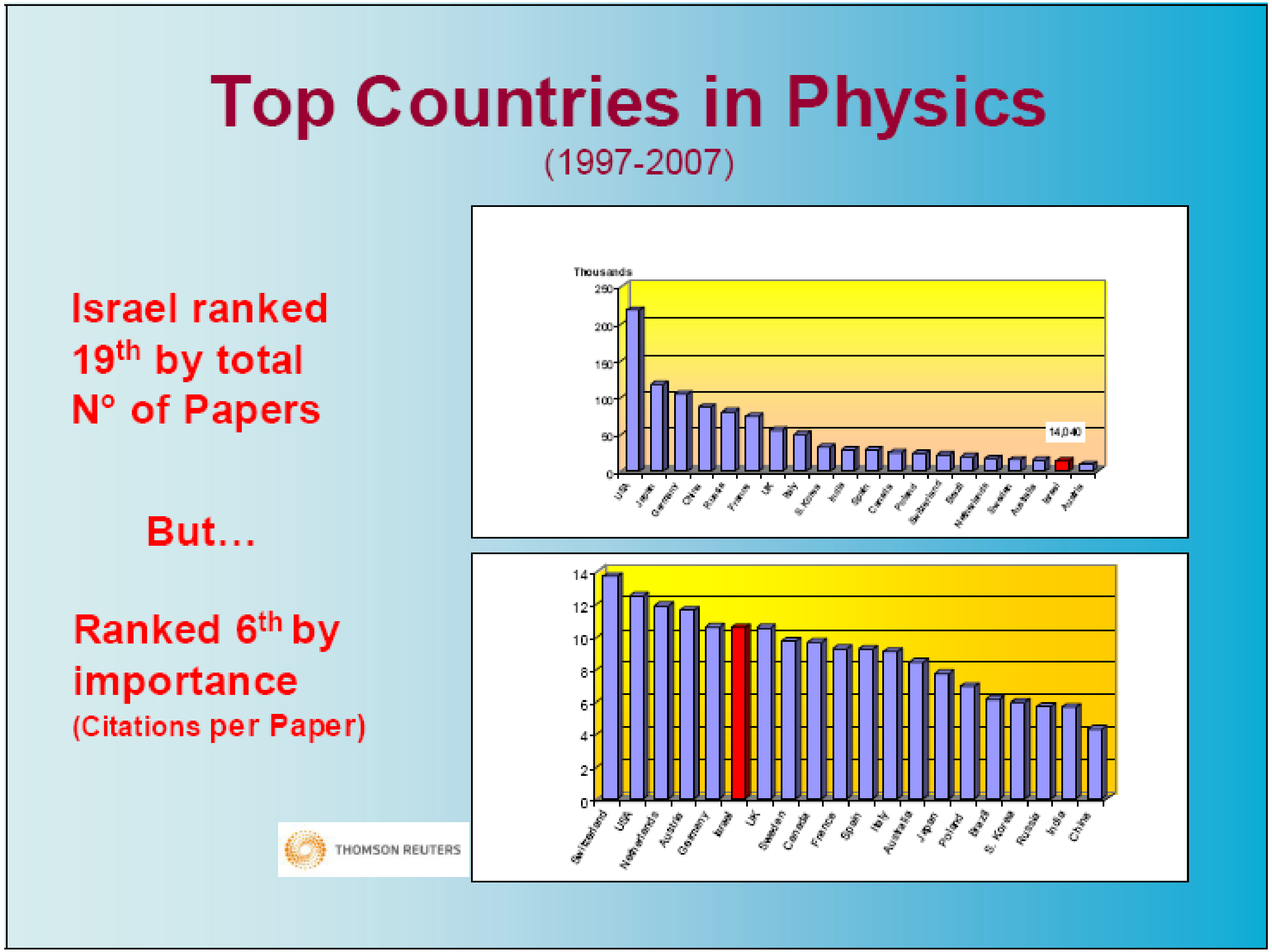


Physics Students in Israel

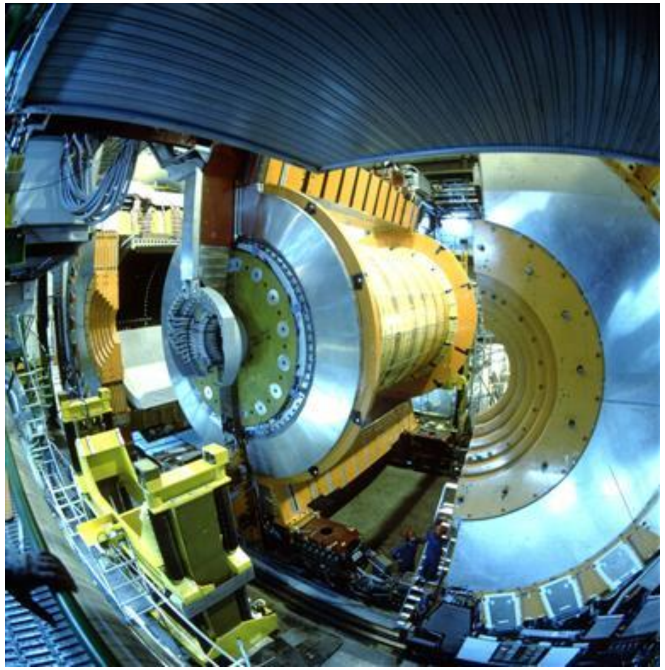


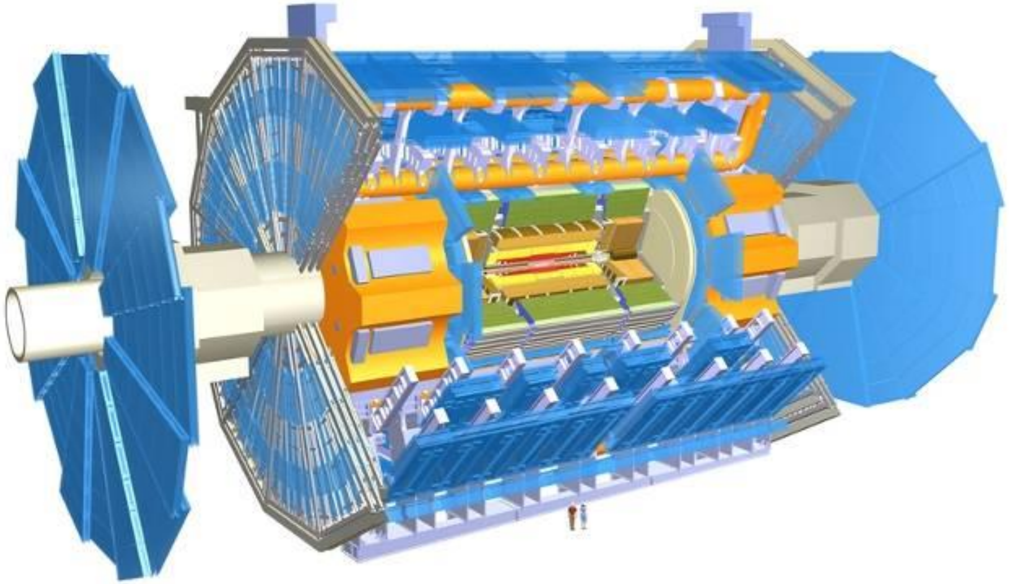
- Although there was a general drop of Physics Students in the late 90’s, this trend has changed considerably, mainly due to the immigration from Science minded Students from Russia as well as the High-Tech boom.

Including in Physics



But also major contributions to the CERN Experiments





- New detectors for the OPAL Experiment in the 90’s, and 6,000m² of crucial detectors for the Higgs discovery in the 2010’s
- Scientific Coordinator and Higgs Conveners in the 90’s
- Responsible for the largest Project of the ATLAS Experiment (The MUON Spectrometer)
- Higgs Convener and New Physics Convener in ATLAS

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.

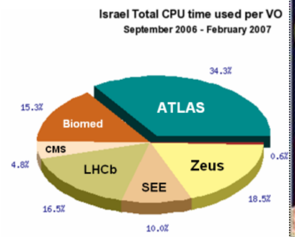
Relations with CERN before applying for membership

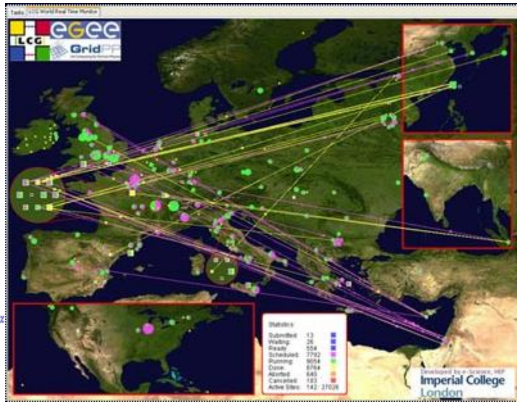
- Cash contribution support a number of programs:
  - 1) Fellows and Associates Program:
    - The regular fellowship program was expanded to include Israeli Fellows, competing on equal footing as their European colleagues, as well as CASS.
  - 2) Industrial Associates program:
    - engineers from Israeli 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.
  - 3) Doctoral Technical and Summer Students programs:
    - 37 Summer Students in the last 17 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).

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



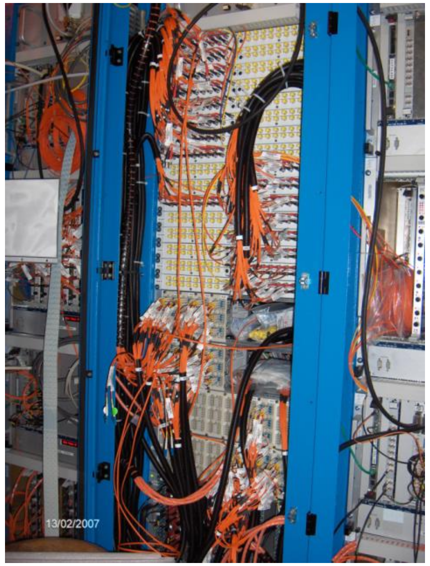


Relations with CERN

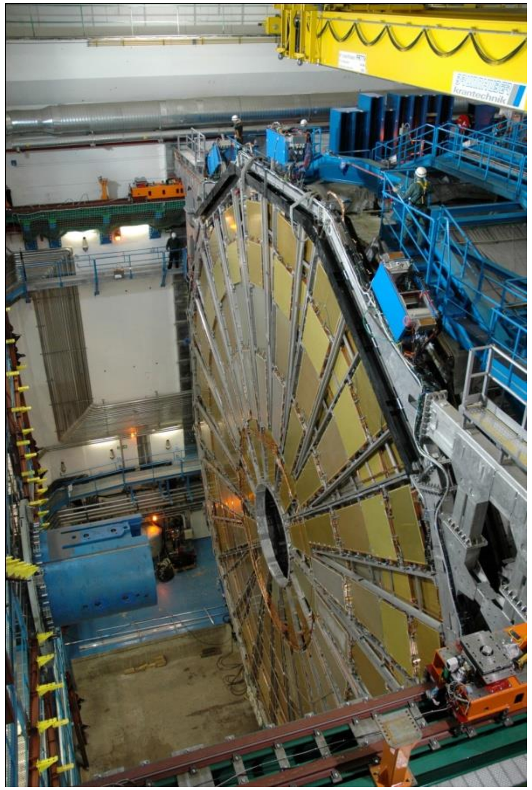
- In-kind Contributions:
  - Although at the start of the program there was good contact and interest from the Machine side, later on most of the purchasing was done by the experiments, including network equipment. Examples of such contracts are:
    - Optical transmission equipment for the synchronization 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)

R&D and Industrial Contracts with CERN

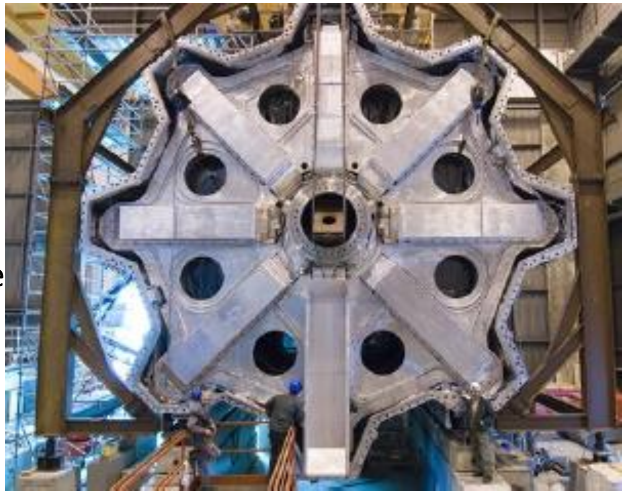
- Transmission elements: Fiber optics and converters.
- Very strong contacts with FIBERNET (small firm (150 employees) with a lot of flexibility and network connections to other firms. This allowed to produce various custom products for 3 experiments, for a total of 3.6 MCHF:
  - Large number of halogen-free multi-fiber bundles and patch-cords
  - Development of custom made patch-panels and fiber supports.
  - Development of single to multimode optical panels, using connections to another R&D firm (COLORCHIP)
  - Development of special high density connectors for Si detectors (ALICE)
  - Development with a cable firm (Superior) of special LV cables.
- The firm got an special recognition (prize) from 3 of the LHC experiments for their excellent work. They are, however, not included in most of the general CERN contracts for infrastructure.
- Typically, only 5% of the firms involved with CERN get such a recognition.



R&D and Industrial Contracts with CERN



- Al welding and precision mechanics:
  - Due to the work with the Military and Aircraft Industry, firms are used to high quality requirements; this includes their sub-contractors (this is important, since the large firms have very high overheads).
  - Experience, combined with NETWORKING have been a critical element in obtaining excellent results in Orbital Welding (UNIWELD Ltd) for the Heat Shields of the EC Toroids. According to the firm, the experience that they have gained with the CERN project has been important for jumping into other contracts.
  - High quality welding (usually complemented by penetration tests), combined with precision machining (2 of the firms: MARESCO and TAL Technologies got also a CERN award), as well as measurement equipment, have been crucial to the success of the various projects.
  - Very high quality extrusion facilities, mainly motivated by the fabrication of complicated Al profiles for antennas have been important in the production of various profiles used in the ATLAS experiment (EXTAL)



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

Trying to improve the situation

- March 2013
  - Workshop on Technology transfer at Weizmann
  - Participating 20 Physicists working on developments for the upgrades and representatives from various High-Tech Industries in Israel
  - Very good contacts achieved, and some common projects

- Israeli Industrial exhibit at CERN.
  - 11 firms participated
  - 150 relevant visitors

This actions brought some improvements

Table 3: 2014 Industrial return per order and contract range for supplies of various amounts
(Excluding visiting research teams and collaborations)

	Commitments by amount of the order/contract (rounded kCHF)										
	≤ 10 kCHF		10+ to 50 kCHF		50+ to 200 kCHF		200+ to 750 kCHF		> 750 kCHF		
	Amount	Ind.Ret.	Amount	Ind.Ret.	Amount	Ind.Ret.	Amount	Ind.Ret.	Amount	Ind.Ret.	Total
Austria	458	0.55	612	0.68	655	0.62	42	0.07	1 175	0.56	2 980
Belgium	686	0.64	606	0.42	1 916	1.15	1 063	0.75	265	0.07	4 487
Bulgaria	174	1.41	107	1.74	301	1.51	507	5.44			1 079
Switzerland	10 884	7.57	7 540	6.12	6 275	3.65	4 561	5.52	15 585	2.12	44 595
Czech Republic	441	1.11	581	1.38	265	0.54	646	1.30	97	0.06	2 031
Germany	5 141	0.88	5 776	0.70	6 415	0.67	9 526	0.88	11 086	0.40	38 845
Denmark	931	0.78	1 116	1.87	1 806	1.21	400	0.54			5 191
Spain	615	0.18	2 511	0.60	9 082	1.50	6 960	1.51	10 257	0.64	24 844
Finland	485	0.85	475	0.64	508	0.50	56	0.08	200	0.14	1 607
France	10 176	1.71	7 636	1.26	8 847	0.61	7 311	0.85	47 548	3.00	78 758
United Kingdom	1 420	0.34	2 588	0.43	2 688	0.42	6 680	0.81	6 585	0.32	20 147
Greece	200	0.53	515	0.47	517	0.67					1 050
Hungary	107	0.43	45	0.17	38	0.10	56	0.28	5 240	3.50	5 535
Israel	116	0.29	246	0.51			780	1.29			1 131
Italy	1 616	0.37	2 201	0.46	5 656	0.67	4 502	1.06	26 202	1.85	40 158
Netherlands	641	0.36	1 065	0.57	2 057	0.64	336	0.14	4 107	0.61	8 198
Norway	148	0.35	400	0.40	788	0.66	413	0.51	101	0.05	1 866
Poland	347	0.34	556	0.52	3 561	1.47	1 086	1.40	1 653	0.42	6 857
Portugal	181	0.56	104	0.22			117	0.33	1 458	0.82	1 860
Romania	72	0.26	165	0.57	421	1.26	[illegible]		5	0.01	666
Serbia	126	3.65	53	1.38	55	1.36					236
Sweden	266	0.27	554	0.52	1 500	1.08	1 156	0.85	1 525	0.34	4 500
Slovakia	158	0.40	131	0.60	5	0.01	58	0.36	254	0.38	601
Sub-Total	36 196		38 650		41 528		50 877		129 608		289 088
USA	2 008		2 648		3 750		1 405		11 427		21 934
Other States	1 710		2 280		2 536		781		7 585		14 670
Sub-Total	3 808		5 128		6 286		2 184		18 812		36 204
Total	38 841		40 757		47 823		53 061		148 721		329 348

- Total purchases in Israeli Industry during 2014:1.841MCHF+1.131MCHF=2.972MCHF.
- This represents 22.7% of the total Israeli contribution in 2014 and exceeds the 17% participation of the Ministry of Economy.
- Further actions are still needed to improve further, other countries have a full office dealing with helping their Industries to participate in CERN tenders.

Table 4: Payments and Outstanding commitments in 2014
on behalf of Visiting Research Teams and Collaborations[1]

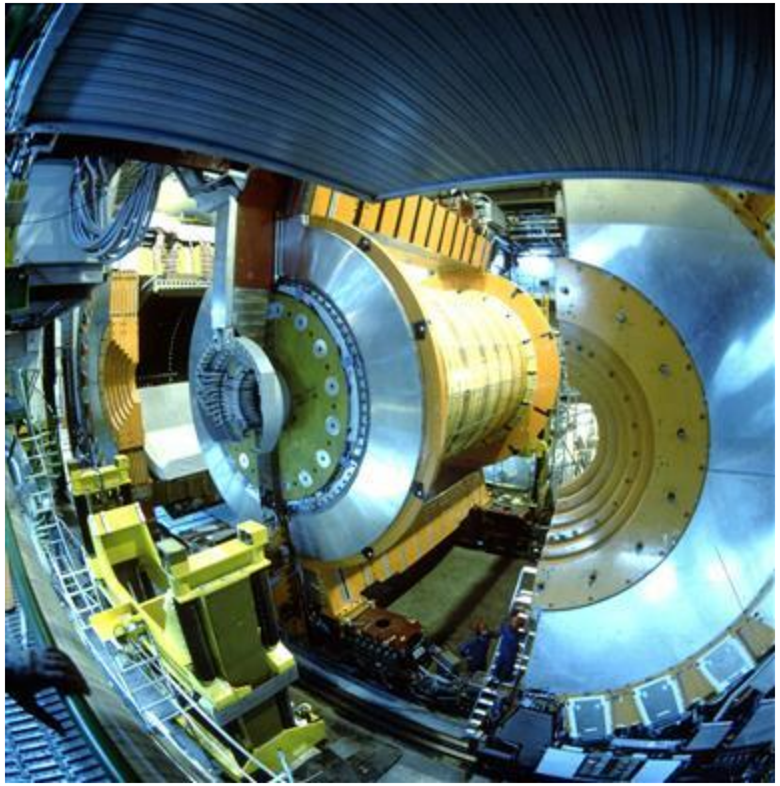
Country of origin	LHC Experiments[2] (rounded kCHF)	Others (rounded kCHF)	Grand Total (rounded kCHF)
Austria	413	458	872
Belgium	300	364	663
Bulgaria	224	190	413
Switzerland	3 901	3 658	7 559
Czech Republic	118	221	339
Germany	12 458	2 847	15 305
Denmark	16	6	22
Spain	882	115	997
Finland	63	335	399
France	3 645	1 549	5 194
United Kingdom	1 813	2 935	4 748
Greece	17	45	63
Hungary	36	51	87
Israel	1 841	123	1 964
Italy	1 809	1 547	3 356
Netherlands	921	642	1 563
Norway	1 068	503	1 571
Poland	3 876	272	4 148
Portugal	25	74	99
Romania	1	4	4
Serbia			
Sweden	54	150	204
Slovakia	111	237	347
Sub-Total	33 593	16 325	49 918
Other States	4 131	7 265	11 396
Total	37 724	23 590	61 314

Educational aspects

- Israeli High School and University Students:
  - Israeli teachers
    - 1 in 2011
    - 2 in 2012
    - 4 in 2013
    - 40 in 2014
  - High school groups from Israel spending 1 week at CERN
    - 20 Students in 2012
    - 110 Students in 2013
    - 140 Students in 2014, 2015, 2016
    - 200 Students/year since 2017, but almost impossible to find Israeli's to teach them.
  - Israeli BSc Physics & Engineering Students
    - 37 Summer Students (+7 Palestinian Students) since 2003.
  - Israel MSc and PhD students involved in ATLAS; 25

But the main contribution came through a large part of the OPAL Experiment Construction

- 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

If you have a partner that you can trust, you dare to go into a large common adventure

- 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.
- The visible contribution of the MUON End-Cap Trigger System of ATLAS, was a major point in convincing the other 20 Member States of CERN, to accept a non-European 21 State.

Conclusions

- Due to an enormous effort of some very dedicated scientists, one has been able to achieve in the ATLAS MUON Spectrometer an incredible performance on a very large volume, that has allowed to reach a systematic error on the Higgs mass measurement of 0.4‰ (i.e. knowing the position of the detectors at the 0.1mm level and of the magnets at the 1mm level).
- It took more than 20 years for the Israeli HEP community to show that they could be consider as fully integrated into the European HEP community, and although politically not easy, be able to be the first non-European Member State of CERN.