News

CONFERENCE

EPS-HEP 2011: the harvest begins

Impressive results, and so much more to come: this is the general feeling that more than 800 participants took home from the International Europhysics Conference on High-Energy Physics, EPS-HEP 2011, which was held in Grenoble on 21–27 July. After only a year of data-taking, the spectacular performance of the LHC and the amazingly fast data analysis by the experiments have raised current knowledge by a huge notch in searches for new physics.

Those who had hoped that the LHC would reveal supersymmetry early on may have been slightly disappointed, although each extended limit contributes to the correct picture and new physics is guaranteed, as many speakers reminded the audience. CERN's director-general, Rolf Heuer reinforced this point, stating that for the Higgs boson in particular, either finding it or excluding it will be a great discovery.

On the search for the Higgs boson, both the CMS and ATLAS experiments at the LHC have observed small excesses of events in the WW and ZZ channels. Each one is statistically weak but taken together, they become interesting, as each team independently sees a small excess in the low range for the Higgs mass. While this is exactly how a Standard Model Higgs would manifest itself, it is still far too early to tell (p11).

Another big topic of conversation was the report by the CDF collaboration at Fermilab of the first measurement of the rare decay $B_s \to \mu\mu$, appearing possibly stronger than predicted. On the other hand, the CMS and LHCb collaborations at the LHC showed preliminary results, which when combined provide a limit in contradiction with the CDF result (p11). More data will soon clarify what is happening here.

At the press conference, from left to right: Fabio Zwirner, chair of the High Energy Physics Division of EPS; Rolf Heuer, CERN's director-general; Stavros Katsanevas, the deputy director of IN2P3; and Michel Spiro, president of CERN Council. (Image credit: LPSC/Tomas Jezo.)

The session on QCD showed great progress in the field, with updates on parton-distribution functions from the experiments at HERA, DESY, as well as several results from the LHC experiments. These measurements are now challenging the precision of theoretical predictions, and will contribute towards refining the Monte Carlo simulations further. The experiments at Fermilab's Tevatron and at the B-factories also presented improved and impressive limits in all directions in flavour physics, contributing to a clearer theoretical picture.

In neutrino physics, new results came from the T2K and MINOS experiments, giving the first indications of a sizeable mixing angle between the first and third neutrino generations (p6). It was particularly moving to see how Japanese colleagues are recovering after the devastating earthquake and tsunami. Atsuko Suzuki, head of the KEK laboratory, thanked the particle-physics community for its extended support.

An important highlight of the conference was the award of the European Physical Society (EPS) High Energy and Particle Physics Prize to Sheldon Lee Glashow, John Iliopoulos and Luciano Maiani. They received this for their crucial contribution to the theory of flavour, currently embedded in the Standard Model of strong and electroweak interactions, which is still of utmost importance today.

With the first results from significant amounts of data at the LHC, the conference attracted a great deal of interest from the world's press. A press conference was held on 25 July to announce the EPS 2011 high-energy physics prizes, with contributions on the latest results from the LHC, the European strategy for particle physics, and the latest advances in astroparticle physics in Europe.

● A more detailed report will appear in the October issue of the *CERN Courier*.

CERN

LHC passes 2 fb^{-1}

The LHC is enjoying a confluence of twos. On 5 August the total integrated luminosity delivered in 2011 passed 2 fb^{-1}; the peak luminosity has risen to over 2×10^{33} $cm^{-2}s^{-1}$; and fill number 2006 lasted for 26 hours, delivering an integrated luminosity of 100 pb^{-1}.

Following the period of machine development that started at the end of June, the decision was taken to continue running with 50 ns bunch spacing and the maximum of 1380 bunches (*CERN Courier* July/August 2011 p5). Increases in luminosity must come from increasing the number of protons per bunch, or decreasing the transverse beam size at the interaction point. The size of the beams coming from the injectors has now been reduced to the minimum possible, bringing an increase in the peak luminosity of about 50%.

Sommaire en français

News

Neutrinos

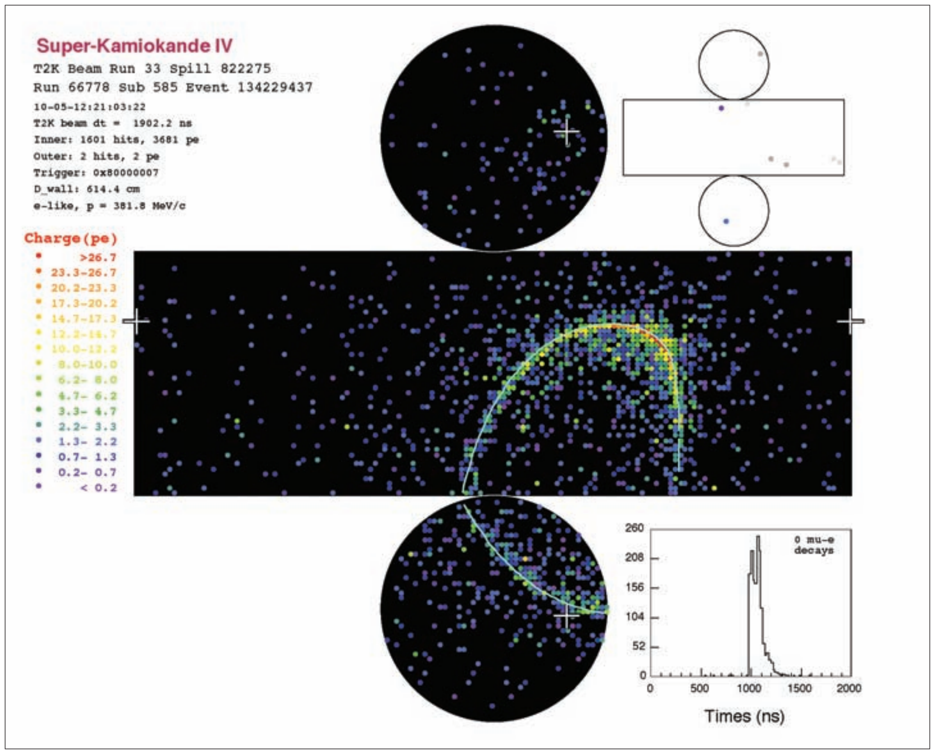
MINOS and T2K glimpse electron-neutrinos

The T2K and MINOS experiments, which are both designed to study neutrino oscillations over long baselines, have reported results from their searches for the appearance of electron-neutrinos in beams of muon-neutrinos produced at distant locations. On 15 June the T2K collaboration announced that it had observed an indication that muon-neutrinos are able to transform into electron-neutrinos over the 295 km baseline of their experiment in Japan. Ten days later, the MINOS collaboration announced its latest results on the same effect. Both experiments find a non-zero value for the neutrino mixing angle θ_{13}. This would be zero if electron- and muon-neutrinos could not transform into each other.

Oscillations between the three known flavours of neutrino – electron, muon and tau – are described by a mixing matrix, which can be parameterized in terms of three angles, θ_{12}, θ_{23}, θ_{13}, and a CP-violating phase. Observations of oscillations in solar neutrinos and atmospheric neutrinos have determined θ_{12} and θ_{23}, respectively, leaving θ_{13} still unknown. The new results provide the first indications that this angle is not zero, via values of $\sin^2 2\theta_{13}$.

T2K (Tokai to Kamioka) uses the Super-Kamiokande detector in Kamioka to detect neutrinos produced at the Japan Proton Accelerator Research Complex (J-PARC) situated 295 km away (*CERN Courier* July/August 2008 p19). The new results are from an analysis based on all of the data collected between January 2010 – when the experiment began full operation – and 11 March 2011, when it was interrupted by the enormous earthquake in East Japan. This corresponds to a total of 1.43×10^{20} protons on the neutrino-production target. The collaboration found 88 neutrino events registered in the Super-Kamiokande detector, six of which are clearly identifiable as candidate electron-neutrino events. The expectation would be for 1.5 such events in this data sample if neutrino oscillations do not take place. The observation implies the appearance of electron-neutrinos in the experiment, with a probability of 99.3%. At 90% confidence level (CL), the data are consistent with $0.03 < \sin^2 2\theta_{13} < 0.28$.

The MINOS (Main Injector Neutrino Oscillation Search) in the US sends a muon-neutrino beam 735 km through the Earth from the Main Injector accelerator at Fermilab to a 5000-tonne detector in the Soudan Underground Laboratory in northern Minnesota. In the recently announced analysis, based on 8×10^{20} protons on target, the collaboration found a total of 62 electron neutrino-like events. Only 48 events would be expected if muon-neutrinos do not transform into electron neutrinos.



An event display of one of the six electron-neutrino candidate events recorded by the Super-Kamiokande detector. The coloured circles indicate photomultiplier tubes that were struck by Cherenkov light. (Image credit: T2K.)

The MINOS far detector at the Soudan mine. (Image credit: Fermilab Visual Media Services.)

Compared with T2K, MINOS uses a different method and a different analysis technique to search for electron-neutrino appearance. The MINOS collaboration extracts $2\sin^2\theta_{23}\sin^2 2\theta_{13}$, and finds that it is less than 0.12 at 90% CL, with a best fit of $2\sin^2\theta_{23}\sin^2 2\theta_{13} = 0.04$. This improves on results that the collaboration obtained with smaller data sets in 2009 and 2010. The latest results disfavour $\theta_{13} = 0$ at 89% CL, with a range that is consistent with that measured by T2K.

More work and more data are needed to confirm both these measurements. The T2K experiment collected about 2% of the proposed number of events before the massive earthquake hit in March. Once J-PARC resumes producing muon-neutrinos, which is planned to happen by the end of 2011, the experiment will continue accumulating events. MINOS will continue to collect data until February 2012. In addition, three nuclear-reactor-based neutrino experiments, which use different techniques to measure $\sin^2 2\theta_{13}$, are in the process of starting up.

● Further reading

K Abe *et al.* T2K collaboration 2011 *Phys. Rev. Lett.* **107** 041801.

P Adamson *et al.* MINOS collaboration 2011 arXiv:1108.0015v1 [hep-ex].

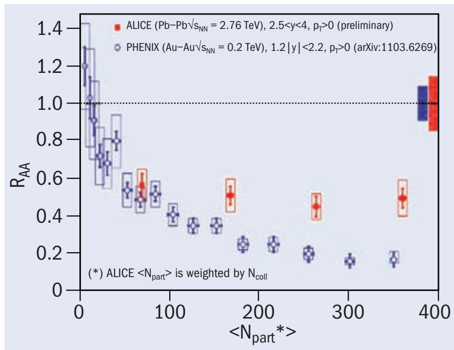
HEAVY IONS

ALICE goes in search of charmonium in the quark–gluon plasma

The ALICE collaboration has measured the nuclear modification (R_{AA}) factor of J/Ψ mesons down to a transverse momentum (p_T) equal to zero, in lead–lead (Pb–Pb) collisions at $\sqrt{s_{NN}}$=2.76 TeV, delivered by the LHC in November 2010. The results, presented at the Quark Matter 2011 conference (p23), hint at the recombination of charm and anticharm quarks in the quark–gluon plasma (QGP) formed in heavy-ion collisions at LHC energies.

The ALICE detector was conceived especially for measurements in heavy-ion collisions and is able to study QGP via comprehensive measurements of hadron abundances and correlations as well as of thermal photons (*CERN Courier* June 2011 p17). At LHC energies, new mechanisms of charmonium production in the QGP could occur. QCD calculations have predicted that a large number of charm quarks, around 50 c-$\bar{c}$ pairs, should be produced per central lead–lead collision at $\sqrt{s_{NN}}$=2.76 TeV. These charm quarks would then coexist with the QGP during its dynamical evolution, like Brownian particles. A number of dynamical transport models predict that c and $\bar{c}$ quarks could then combine in later stages, leading to an enhancement of charmonium production in the most central Pb–Pb collisions.

ALICE detects charmonium down to p_T=0 in two different rapidity domains: |y|<0.9 in the dielectron channel and 2.5<y<4 in the dimuon channel. The detection at low transverse momentum is crucial because the recombination of the charm and anticharm quarks is expected to be the main production mechanism for charmonium at low p_T (p_T<3 GeV/*c*). The different rapidity domains allow for the study of QGP with different charm densities.



Nuclear modification factor for the J/ψ in Pb–Pb collisions at 2.76 TeV as measured by the ALICE collaboration.

In particular, ALICE has studied the nuclear modification factor, R_{AA}, as a function of collision centrality for J/Ψ mesons. R_{AA} is defined as the ratio of the yield measured in nucleus–nucleus (AA) collisions to that expected on the basis of the proton–proton yield scaled by the number of binary nucleon–nucleon collisions in the nucleus–nucleus reaction. The results from ALICE indicate that the J/Ψ R_{AA} factor appears to show little dependence on centrality (see figure), a trend that is different from that observed at lower energies. The factor for central and mid-central collisions is larger at the LHC than was measured at lower centre-of-mass energy in gold–gold collisions in the PHENIX experiment at the Relativistic Heavy Ion Collider, Brookhaven. In complementary studies, the ATLAS and CMS collaborations at the LHC have measured a smaller J/ΨR_{AA} factor at high p_T (p_T>6.5 GeV/*c*).

These observations contrast with expectations from the dissociation of charmonium through the mechanism of colour-screening in the QGP. They hint instead at the recombination of charm and anticharm quarks in the QGP as the main mechanism for J/Ψ production in central Pb–Pb collisions at LHC energies. ALICE's analysis of J/Ψ production as a function of the p_T and rapidity continues and should shed light on the topic soon.

● Further reading

G Martínez García ALICE collaboration QM2011 Proceedings, arXiv:1106.5889v1.

ANTIMATTER

ASACUSA measures antiproton mass with unprecedented accuracy

The Japanese-European ASACUSA experiment at CERN's Antiproton Decelerator (AD) has reported a new measurement of the antiproton's mass, accurate to about one part in a thousand million. This means that the measurement of the antiproton's mass relative to the electron is now almost as accurate as that of the proton.

To make these measurements, the ASACUSA team first traps antiprotons inside antiprotonic helium, in which the negatively charged antiproton takes the place of an electron and occupies a Rydberg state, keeping it relatively far from the nucleus. The antiprotonic helium atoms thus live long enough to allow the frequencies of atomic transitions to be measured by laser spectroscopy. The frequencies depend on the ratio of the antiproton mass to the electron mass and ASACUSA has already used this technique to achieve record precision (*CERN Courier* July/August 2006 p8).

However, an important source of imprecision comes from Doppler broadening of the resonance observed when the laser is tuned to the transition frequency. The atoms move around, so that those moving towards and away from the laser beam experience slightly different frequencies. In the previous measurement in 2006, the ASACUSA team used just one laser beam, and the achievable accuracy was dominated by this effect. This time they have used two beams moving in opposite directions, with the result that the broadening for the two beams partly cancels out.

The resulting narrow spectral lines allowed the team to measure three transition frequencies with fractional precisions of 2.3–5 parts in 10^9. By comparing the results with three-body QED calculations, they find an antiproton-to-electron mass ratio of 1836.1526736(23), where the error (23) represents one standard deviation. This agrees with the proton-to-electron value, which is known to a similar precision.

● Further reading

Hori *et al.* 2011 *Nature* **475** 484.

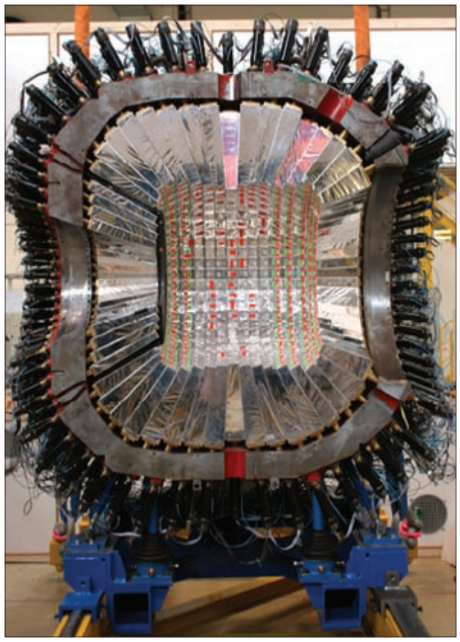
News

New particles

COSY finds evidence for an exotic particle…

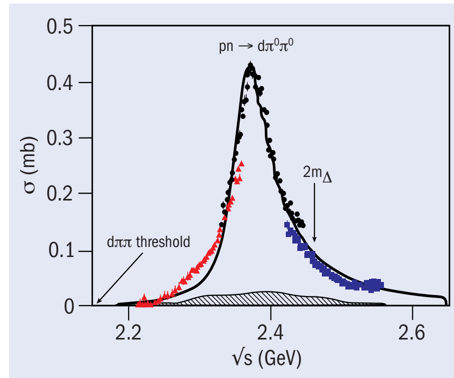
Experiments at the Jülich Cooler Synchrotron, COSY, have found evidence for a new complex state in the two-baryon system, with mass 2.37 GeV and width 70 MeV. The structure, containing six valence quarks, could constitute either an exotic compact particle or a hadronic molecule. The result could cast light on the long-standing question of whether there are eigenstates in the two-baryon system other than the deuteron ground-state. This has awaited an answer since Robert Jaffe first envisaged the possible existence of non-trivial six-quark configurations in QCD in 1977.

The new structure has been observed in high-precision measurements carried out by the WASA-at-COSY collaboration, using the Wide-Angle Shower Apparatus (WASA). The data exhibit a narrow isoscalar resonance-like structure in neutron–proton collisions for events where a deuteron is produced together with a pair of neutral pions. From the differential distributions, the spin-parity of the new system is deduced to be $J^P = 3^+$ and its main decay mode is via formation of a $\Delta\Delta$ system below the nominal threshold of $2m_\Delta$. The collaboration will further test the resonance hypothesis in elastic proton–neutron collisions with a polarized beam; the $J^P = 3^+$ partial waves should be dominated by the new structure, while its contribution to the elastic cross-section should be small.



View into the open central part of the WASA detector. This consists of 1012 CsI(Na) crystals, which surround the superconducting solenoid that contains the mini drift-chamber. The vertical cut-out is for the pellet target system. (Image credit: WASA-at-COSY collaboration, IKP-FZJ.)

The resonance structure also turns out to be intimately connected to the so-called ABC effect, in which the two pions produced in a nuclear fusion process are emitted preferentially in parallel. This 50-year-old puzzle, which is named after the initial letters of the surnames of its first observers A Abashian, N E Booth and K M Crowe, could now find its explanation in the way that such a resonance decays.



Measurement of the energy dependence of the total cross-section for the basic double-pionic fusion reaction to deuterium. The data exhibit a clear resonance-like structure. The solid line shows a fit by a Lorentzian with $m = 2.37$ GeV and $\Gamma = 68$ MeV. The hatched area indicates systematic uncertainties in the measurements.

● Further reading

P Adlarson *et al.* 2011 *Phys. Rev. Lett.* **106** 242302.

…while CDF discovers a heavy relative of the neutron

The CDF collaboration at Fermilab has announced the observation of the Ξ_b^0, the latest entry in the periodic table of baryons. Although Fermilab's Tevatron is not a dedicated bottom-quark factory, the sophisticated particle detectors employed there and large integrated luminosity of proton–antiproton collisions delivered to the experiments have made it a haven for discovering and studying almost all of the known bottom baryons. Experiments there discovered the Σ_b baryons in 2006, observed the Ξ_b^- baryon in 2007 and found the Ω_b in 2009. The lightest bottom baryon, the Λ_b, was discovered at CERN.

The complex decay pattern of the neutral Ξ_b^0 has made the observation of this particle significantly more challenging than that of its charged sibling. Combing through an integrated luminosity of 4.2 fb^{-1} of proton–antiproton collisions produced at a centre-of-mass energy of 1.96 TeV, the CDF collaboration isolated 25 examples in which the particles emerging from a collision revealed the distinctive signature of the Ξ_b^0, through its decay to $\Xi_c^+\pi^-$ and the subsequent decay chain. The analysis established the discovery at a level of 6.8 σ and measured the mass of the Ξ_b^0 as 5787.8 ± 5.0(stat) ± 1.3(syst) MeV/c^2.

CDF also observed a similar number of events for the charged Ξ_b, in the decay $\Xi_b^- \to \Xi_c^0\pi^-$, never previously observed; this served as an independent cross-check of the analysis.

● Further reading

T Aaltonen *et al.* CDF collaboration 2011 arXiv:1107.4015v1 [hep-ex]. Submitted to *Phys. Rev. Lett.*

__Les physiciens des particules du monde entier sont invités__ à apporter leurs contributions aux CERN Courier, en français ou en anglais. Les articles retenus seront publiés dans la langue d'origine. Si vous souhaitez proposer un article, faites part de vos suggestions à la rédaction à l'adresse cern.courier@cern.ch.

CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

Facilities

ELENA prepares a bright future for antimatter research

At its recent session in June, the CERN Council approved the construction of the Extra Low ENergy Antiproton ring (ELENA) – an upgrade of the existing Antiproton Decelerator (AD). ELENA will allow the further deceleration of antiprotons, resulting in an increased number of particles trapped downstream in the experiments. This will give an important boost to antimatter research in the years to come.

The recent successes of the AD experiments are just the latest in a long list of important scientific results with low-energy antiprotons at CERN that started in the 1990s with the Low Energy Antiproton Ring. Over the years, the scientific demand for antiprotons at the AD has continued to grow. There are now four experiments running there (ATRAP, ALPHA, ASACUSA and ACE). A fifth, AEGIS, has been approved and will take beam for the first time at the end of the year; further proposals are also under consideration. The AD is approaching the stage where it can no longer provide the number of antiprotons needed. As antihydrogen studies evolve into antihydrogen spectroscopy and gravitational measurements, the shortage will become even more acute.

The solution is a small ring of magnets that will fit inside the current AD hall – in other words, ELENA, the recently approved upgrade. ELENA will be a 30 m-circumference decelerator that will slow down the 5.3 MeV antiprotons from the AD to an energy of only 100 keV. Receiving slower antiprotons will help the experiments to improve their efficiency in creating antimatter atoms.

Currently, around 99.9% of the antiprotons produced by the AD are lost because of the experiments' use of degrader foils, which are needed to decelerate the particles from the AD ejection energy down to around 5 keV – the energy needed for trapping. ELENA will increase the experiments' efficiency by a factor of 10–100 as well as offer the possibility to accommodate an extra experimental area.

The new ring will be located such that its assembly and commissioning will have a minimal impact on operation of the AD. Indeed, the commissioning of the ELENA ring will take place in parallel with the current research programme, with short periods dedicated to commissioning during the physics run. The layout of the experimental area at the AD will not be significantly modified, but the much lower beam energies involved require the design and construction of completely new electrostatic transfer lines.

The construction of ELENA should begin in 2013 and the first physics injection should follow about three years later. The initial phase of the work will include the installation and commissioning of the ELENA ring while using the existing AD beam lines. The old ejection lines in all of the experimental areas will then be replaced with new electrostatic beam lines that will deliver antiprotons at the design energy of 100 keV. In its final configuration, ELENA will be able to deliver beams almost simultaneously to four experiments, resulting in a vital gain in total beam time.

ILC Global Design Effort publishes milestone report

The International Linear Collider (ILC) Global Design Effort (GDE) has released a major milestone report, *The International Linear Collider: A Technical Progress Report*. As its title suggests, the 162-page report represents the current status of the global R&D that is currently coordinated by the GDE. Coming roughly half way through the ILC Technical Design Phase, it documents the considerable progress that has been made worldwide towards a robust and technically mature design of a 500–1000 GeV electron–positron linear collider. With a stated five-year programme for the technical design phase, the GDE felt it necessary to have a significant mid-term publication milestone that would bridge the gap between the publication of the Reference Design Report (RDR) in 2007 and that of the foreseen Technical Design Report (TDR) in 2012. Because much of the R&D referred to in the report is still ongoing, it necessarily represents a snapshot of the current situation.

The focus of the progress report is on the co-ordinated worldwide "risk-mitigating" R&D that was originally identified at the time of the RDR publication. Although the report is comprehensive in covering nearly all areas of R&D, it has a strong focus on the development of the 1.3 GHz superconducting RF accelerating technology – the heart of the linear collider design. A large fraction of the total resource available has been used to develop the necessary worldwide infrastructure and expert-base in this technology, which includes research into high-gradient superconducting cavities as well as a focus on industrialization and mass-production models for this state-of-the-art technology. A further focus is on the three beam-test facilities: TTF/FLASH at DESY Hamburg, for the superconducting RF linac; the CesrTA facility at Cornell, for damping-ring electron cloud R&D; and ATF/ATF2 at KEK, for final focus optics, instrumentation and beam stabilization. Finally, the report also indicates work towards the ILC TDR baseline design and, in particular, the conventional facilities and siting activities.

The technical progress report will serve as a solid base for the production of the final report on the technical design phase R&D, which will be part of the TDR. Some 350 authors from more than 40 institutes around the globe have contributed to its successful publication. Now attention is already turning to producing the TDR – work that will formally start at the joint ILC-CLIC workshop being held in Granada in September.

● The report, which is available online at www.linearcollider.org/interim-report, is the first of two volumes; a second volume, to be released soon by the ILC Research Directorate, will focus on the ILC scientific case and on the design of the detectors associated with the collider.

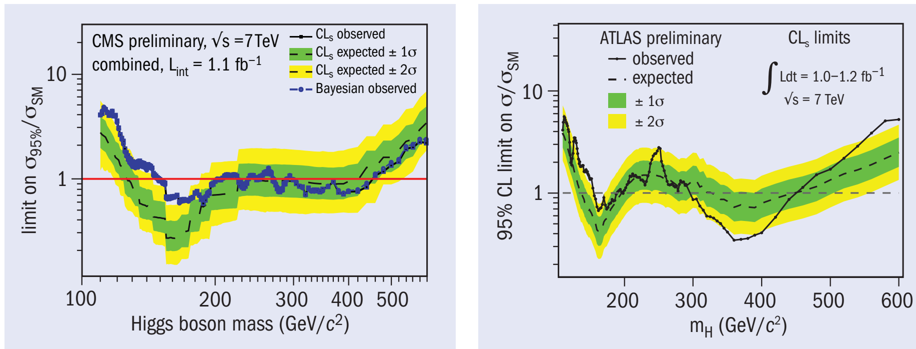
LHC EXPERIMENTS

The LHC homes in on the Higgs

EPS-HEP 2011

In this issue, news from the LHC experiments focuses on a few highlights at the first big summer conference.

HEP 2011



Experimental limits from the LHC on Standard Model Higgs production in the mass range 100–600 GeV. The solid curves (labelled CL_s observed) reflect the observed experimental limits, parameterized in units of the theoretically predicted cross-section (vertical axis) for the production of Higgs of each possible mass value (horizontal axis). All mass ranges for which the solid curve dips below the horizontal line at the value of $\sigma_{95\%}/\sigma_{SM} = 1$ are excluded. The dashed curve shows the expected sensitivity to the Higgs boson, based on simulations. The green and yellow bands correspond to the 68% and 95% excursions, respectively, of the expected limits.

The outstanding performance of the LHC enabled the ATLAS and CMS collaborations to report remarkable progress in the hunt for the Higgs boson at EPS-HEP 2011. With an integrated luminosity of more than 1 fb^{-1} each – the original luminosity goal for all of 2011 – the experiments have been able to extend significantly the exclusion region for the Standard Model Higgs boson and to achieve impressive advances in extending sensitivity in other mass ranges.

In the Standard Model, the Higgs boson endows other particles and itself with mass. At the same time, the dominant decay mode of the Higgs depends on the value of its mass. Consequently, a comprehensive search for the Higgs must look in numerous decay modes.

At the conference, each collaboration reported results on several possible Higgs decay modes. These results were based on the full sample of data recorded by the end of June; the ability to search for so many decay modes so promptly reflected the efficiency of the experiments and the dedication of the collaborations. The most generally promising decay modes, such as $H\rightarrow\gamma\gamma$, $H\rightarrow W^+W^-$, and $H\rightarrow Z^0Z^0$, were well covered by both experiments, while early results on $H\rightarrow\tau^+\tau^-$ from CMS and on $H\rightarrow b\bar{b}$ from ATLAS were also produced. In each experiment the results of these searches can be combined to optimize sensitivity across the range of possible Higgs boson masses.

The CMS and ATLAS Higgs limits presented at the conference are summarized by the solid curves in the two figures. These plots show the result of combining the limits from all of the analysed decay modes in each experiment in terms of the range of possible Standard Model Higgs mass that can be excluded with 95% confidence.

The two experiments presented similar exclusion ranges. They have now excluded mass ranges for the Higgs boson from 150 to 200 GeV and 300 to 450 GeV; they have also established expected limits within 50% of the Standard Model prediction for the region in between. Moreover, they are homing in on both the low mass region (around 115–150 GeV), which is preferred by electroweak measurements, and the high mass region above about 450 GeV. Throughout these regions, the experiments have already achieved sensitivities, reflected by the dashed curves, within a factor of 2–3 of the Standard Model cross-section.

While it is still early in the hunt for the Higgs, but the ATLAS and CMS data also show some excesses that participants at the conference found tantalizing. For instance, both experiments currently see a small excess of candidate events at a mass of roughly 140 GeV. However, given the large range of masses and modes investigated by the two experiments and the as yet limited statistics, the limits observed do sometimes fluctuate from the limits that are expected. In addition, although the two detectors are independent, the results can be somewhat correlated because their background estimates make use of the same theoretical predictions.

Even as the LHC provides the experiments with more data, the painstaking process of combining the limits of the two experiments is currently underway. A combination with the experiments at Fermilab's Tevatron, whose searches are particularly complementary in the low mass region, will also eventually be done.

Will the Higgs boson be discovered soon, or will the Standard Model Higgs boson be excluded as more data are accumulated? The answer at present is "watch this space".

● Further reading

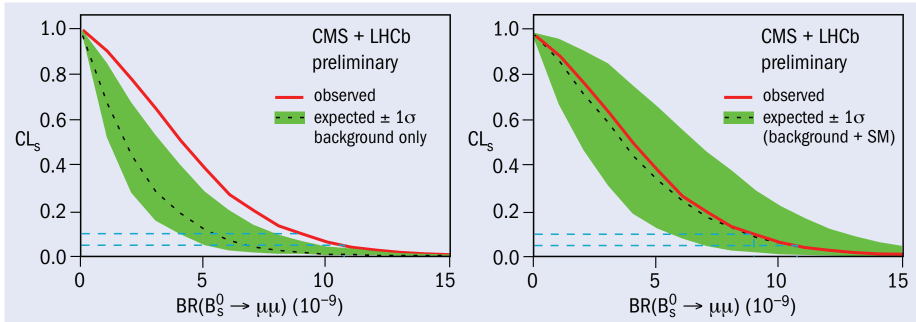
CMS collaboration 2011 CMS-HIG-11-011.
ATLAS collaboration 2011 ATLAS-CONF-2011-112.

CMS and LHCb pull together in search for rare decay

The first major conference since the LHC started to deliver significant luminosities provided the opportunity for the experiments to begin to work together on certain results. CMS and LHCb joined forces in just this way in their search for the decay $B_s\rightarrow\mu^+\mu^-$. This rare decay mode is suppressed in the Standard Model, which predicts a branching ratio of $(3.2\pm0.2)\times10^{-9}$. It has recently gained much attention, with a preliminary measurement from the CDF experiment at Fermilab indicating a possible excess of events over the Standard Model expectation.

Now LHCb and CMS have combined

their results based on 0.34 fb^{-1} and 1.14 fb^{-1} of proton–proton collisions, respectively, at a centre-of-mass energy of 7 TeV. The observed candidates in both experiments are consistent with the expectation from the sum of backgrounds and Standard Model signal. The combination results in an upper limit on the branching ratio for $B_s \rightarrow \mu^+\mu^-$ of less than 1.1×10^{-8} at 95% confidence level (CL), which improves on the limits obtained by the separate experiments and represents the best existing limit on this decay. Enhancement of the branching ratio by more than 3.4 times the Standard Model prediction is excluded at 95% CL. However, there remains room for a contribution from new physics, so the experiments will press ahead with this search, as the data flood in from the LHC.

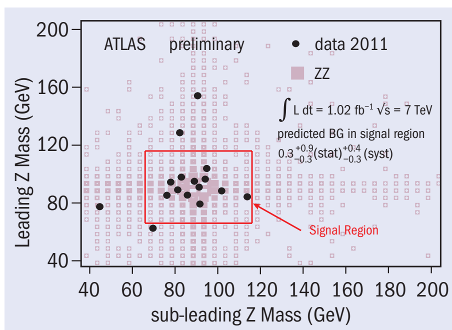


Left: the observed (solid curve) and expected for background-only (dotted curve) CL_s values as a function of the branching ratio for ($B_s^0 \rightarrow \mu^+\mu^-$). The green shaded area contains the ±1σ interval of possible results compatible with the expected value, when only background is observed; the 90% and 95% CL observed limits are illustrated by the dashed lines. Right: the same, but adding the Standard Model signal to the background for the calculation of the expected value.

ATLAS takes a closer look at dibosons

A wealth of physics results from ATLAS emerged at EPS-HEP 2011, ranging from detailed measurements of strong and electroweak processes to a spectrum of searches for new physical processes using the full 2011 dataset collected up until the end of June, and comprising up to 1.2 fb^{-1} of analysed data. As with the Higgs searches, constraints on other new processes now probe mass ranges that have substantially increased with respect to 2010 data alone, but no evidence has yet appeared for physics beyond the Standard Model. Several measurements also benefited by including the 2011 data, such as measurements of the cross-section for the production of pairs of top quarks with a precision of 8%, and a more than 7σ observation of electroweak production of single top quarks.

The collected integrated luminosity has now brought processes involving the dibosons WW, WZ and ZZ under the microscope at ATLAS. Diboson production at the LHC is of great interest because it tests the fundamental gauge structure of



The masses of the leading (higher transverse momentum) Z candidate versus the mass of the sub-leading Z candidate in events with two oppositely-charged same-flavour lepton pairs. The solid circles show events observed in ATLAS data, while the prediction from simulation is shown as pink boxes.

the Standard Model. The production of the pairs involves boson self-couplings that are precisely predicted by the Standard Model, so any deviation from the expected values would be an indication of new physics.

Of the three dibosons, the production of ZZ pairs is particularly rare. The Z bosons were observed in ATLAS via their decays to electrons or muons, giving a very clean signature of four isolated leptons with high transverse momentum. Electrons were identified from a cluster in the fine-granularity ATLAS electromagnetic calorimeter, muons from a track in the muon spectrometer, in each case matched to a track measured in the high-precision inner detector. In events with four leptons, pairs of oppositely-charged electrons or muons were combined to form Z candidates.

The figure shows a plot of the mass of one electron or muon pair against the mass of the second pair. The ZZ signal is clearly seen as a cluster of events around the Z boson mass, 91 GeV, for both pairs. ATLAS thus sees 12 events that are consistent with ZZ production, with an expected background of 0.3 events, and measures a cross-section of 8.4^{+27}_{-24} pb compared with the Standard Model prediction of 6.5 pb.

ATLAS has also measured cross-sections for WW and WZ production, again using leptonic final states. All values are in agreement with Standard Model expectations, and the WZ and ZZ measurements have been used to constrain gauge boson self-couplings. These constraints are comparable with, and in some cases tighter than, those from measurements at the Large Electron–Positron collider at CERN and at Fermilab's Tevatron.

Further reading

ATLAS collaboration 2011 ATLAS-CONF-2011-099 (WZ).
ATLAS collaboration 2011 ATLAS-CONF-2011-107 (ZZ).
ATLAS collaboration 2011 ATLAS-CONF-2011-110 (WW).

CMS in search of new physics

The CMS collaboration contributed more than 30 new or updated physics analyses at EPS-HEP 2011. The most eagerly awaited results probably concerned searches for the Higgs boson as well as for new physics beyond the Standard Model. A highly anticipated search is the one for supersymmetry (SUSY), and the corresponding search for the production of new heavy supersymmetry particles. If SUSY exists in nature at the tera-electron-volt scale, it could solve many of the outstanding issues in particle physics, such as the gauge hierarchy problem. It could also deliver a natural candidate particle to explain the high density of dark matter in the universe.

The CMS collaboration released several new analyses at EPS-HEP 2011 on the search for SUSY, based on the full data sample of about 1 fb^{-1} at 7 TeV in the centre-of-mass, collected by the end of June 2011 and analysed in time for the conference. These analyses search for a variety of characteristic event final-state topologies: e.g. events with a large missing transverse momentum plus either only jets, or leptons and jets. Techniques already used to analyse the 2010 data sample, based on 30 times less data, were further refined and used with the 2011 data.

The results are remarkable, testing regions in the parameter space of SUSY theory where the squarks and gluinos (the supersymmetric partners of quarks and gluons) can be as heavy as 1 TeV. Unfortunately there is no sign so far of the production of SUSY particles. With these latest results, CMS has substantially reduced the phase space where SUSY can hide, particularly in the so-called constrained models such as the Constrained Minimal Supersymmetric extension of the Standard Model (CMSSM). Figure 1 illustrates the impressive reach of the CMS analyses with respect to other experiments in the plane of the universal scalar and gaugino masses at the GUT scale (m_0 and $m_{1/2}$, respectively) of the CMSSM.

The collaboration has also released its first paper based on the 2011 dataset of 1 fb^{-1}, namely on the search for very high mass resonances in events that have at least two jets with a large transverse momentum in the final state. Jets are observed in the detectors as sprays of particles ejected from the interaction point in a given direction – that is, the direction of the original parton produced in the hard scattering of the collision, or in the decay of a heavy new particle. Examples of possible heavy new particles that can be

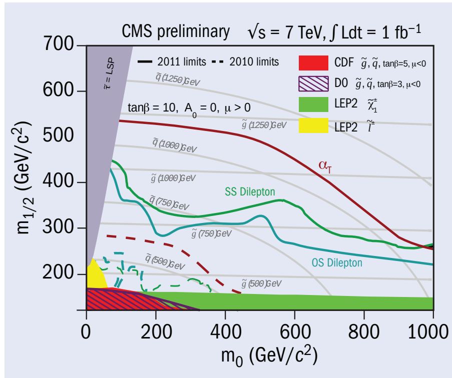


Fig. 1. Results of the search for supersymmetry by CMS: the area below the curves is excluded by the measurements. Results are shown for different analyses. Exclusion limits obtained from previous experiments are presented as filled areas in the plot. Grey lines indicate constant squark and gluino masses.

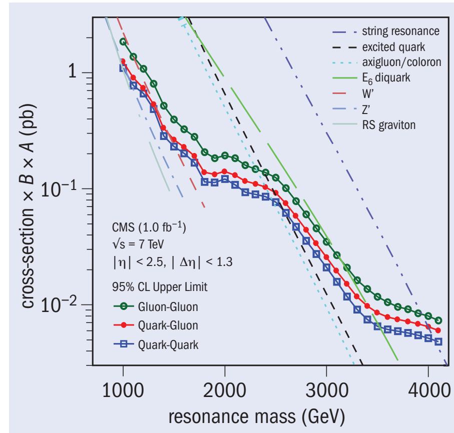


Fig. 2. Results of the search for di-jet resonances by CMS are shown for 95% CL upper limits on the cross-section times acceptance for di-jet resonances produced in gluon–gluon, gluon–quark and quark–quark scattering, compared to predictions of the production for various new particles.

studied in such di-jet invariant mass analyses are new gauge bosons, graviton resonances, string resonances, and more exotic objects that couple via the strong force, such as axigluons or colour octet states. Each one of these particles is predicted in one or more models for new physics beyond the Standard Model.

CMS has now examined the di-jet mass for mass values up to 4 TeV. No significant sign of di-jet resonances has been found and, as figure 2 shows, various other new particles have now been excluded in the range of 1–4 TeV, depending on the model and particle species.

The search for SUSY and other new physics signatures at the LHC is in a very early stage – an important increase in luminosity is expected before the end of 2012. These first data are beginning to disfavour the simplest and more constrained models, but the range of possibilities that need to be explored further is vast. As David Gross said in the concluding remarks at the conference: "Nobody promised it would be easy."

Further reading

CMS-SUS-11-003 and arXiv:1107.4771.

LHCb brings precision to bear on B physics

The LHCb experiment has been designed to focus on B physics, which offers a rich hunting ground for new physics as the large numbers of B hadrons produced at the LHC allow the detailed study of rare processes. Two results presented at EPS-HEP 2011 show how quickly the experiment has been able to access this kind of physics. In one case, LHCb has made the first 5σ observation of a CP asymmetry at the LHC, in the mode $B^0 \to K\pi$; in the other, the collaboration has made the most precise measurement to date of the forward-backward asymmetry of the rare decay $B^0 \to K^{*0}\mu^+\mu^-$, which is very sensitive to new physics.

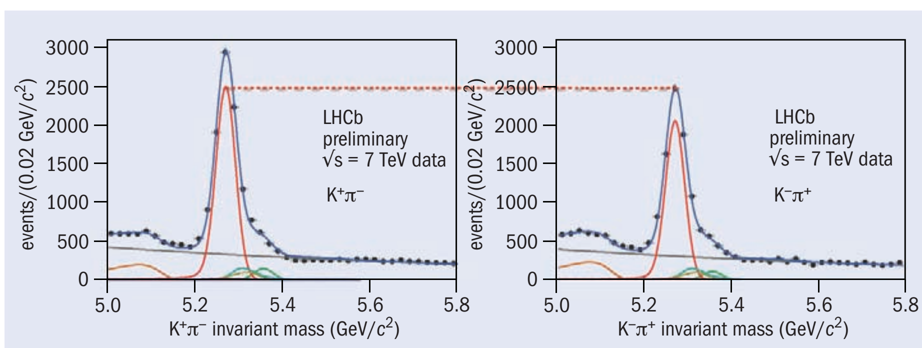


Fig. 1. Invariant mass plots showing signals for $B^0 \to K^+\pi^-$ (left) and $\bar{B}^0 \to K^-\pi^+$ (right) illustrating the clear asymmetry in the raw rates, corresponding to 5σ CP asymmetry .

The CP asymmetry for the $B^0 \to K\pi$ decay is defined as $A_{CP}(B^0 \to K\pi) = [\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)] / [\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)]$. As figure 1 shows, the asymmetry is clearly visible in the raw invariant mass distribution measured by LHCb for a data sample corresponding to 320 pb^{-1} of integrated luminosity – i.e. most of the data taken up to the LHC's technical stop in June, just a month prior to the conference. However, to correct for any asymmetry in the production of the B^0 and $\bar{B}^0$ and in the detection of the different final states, the collaboration uses control channels, such as $B^0 \to J/\Psi K^{*0}$ and

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$D^{*+} \rightarrow D^0\pi^+$; they also compare results taken with opposite polarities of the detector's magnetic field. The corrections are typically at the percent level and yield a corrected asymmetry of $A_{CP} = -0.088 \pm 0.011 \pm 0.008$.

This result is a world best, with a significance of more than 5σ, and is in good agreement with the existing world average of $A_{CP}(B^0 \rightarrow K\pi) = -0.098 +0.012 -0.011$. It is an important landmark for LHCb. The many CP asymmetries in B decays can be sensitive to physics beyond the Standard Model and form an important part of the physics programme for the experiment.

In a second study, LHCb has observed the decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$. This is a rare mode involving a flavour-changing neutral current; it proceeds via a $b \rightarrow s$ transition through a loop diagram, with a branching ratio of order 10^{-6}. New physics processes can therefore enter at the same level as the Standard Model processes, making the decay a sensitive probe of contributions from new physics. The partial rate as a function of the di-muon invariant mass squared (q^2) and the di-muon forward-backward asymmetry (A_{FB}) can both be affected in many new physics scenarios. Existing measurements of A_{FB} vs q^2, which are shown on the left side of figure 2, have all tended to be rather higher than the expectation from the Standard Model, hinting at possible new physics, although the individual statistical significance is small.

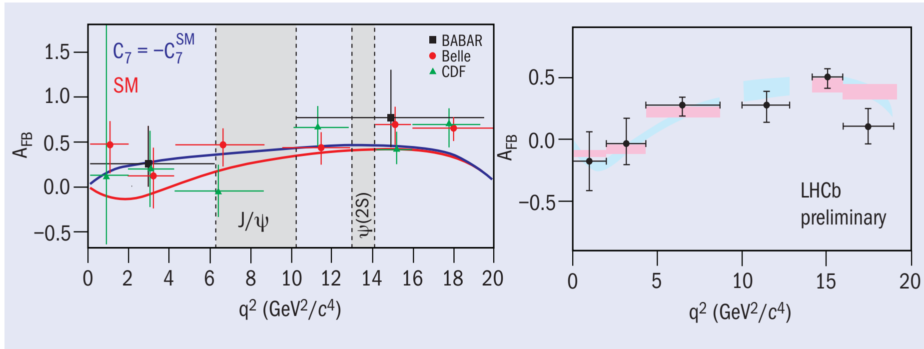

Fig. 2. A_{FB} vs q^2 for the muons from $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decays. Left: for all previous measurements compared to Standard Model (SM) and beyond SM. Right: new result from LHCb, giving the most precise results, consistent with SM prediction (shaded bands).

LHCb has already collected over 300 events for $B^0 \rightarrow K^{*0}\mu^+\mu^-$, with a signal-to-background ratio above three. This is the largest sample of such decays in the world, and is even cleaner than the samples used by the B factories. The right side of figure 2 shows the distribution of A_{FB} vs q^2 for these events, which is in good agreement with the Standard Model expectation (shown by the shaded bands). The collaboration plans to continue to study this channel in finer detail, with measurements that include more angular variables, and expects to achieve high sensitivity to any small deviation from the Standard Model.

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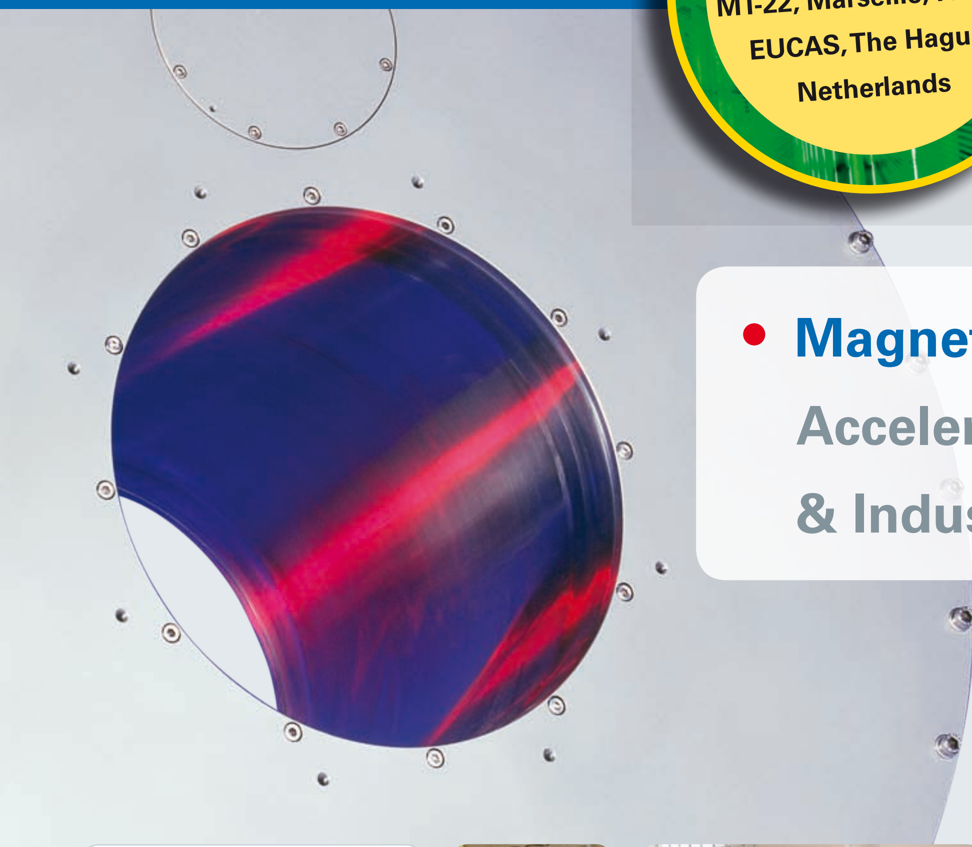

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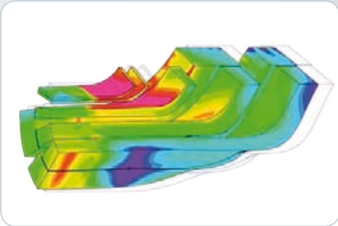






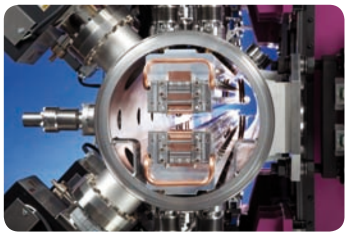

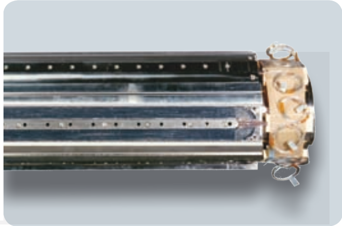

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