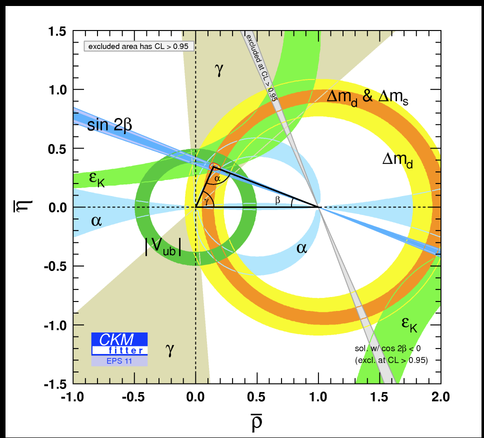
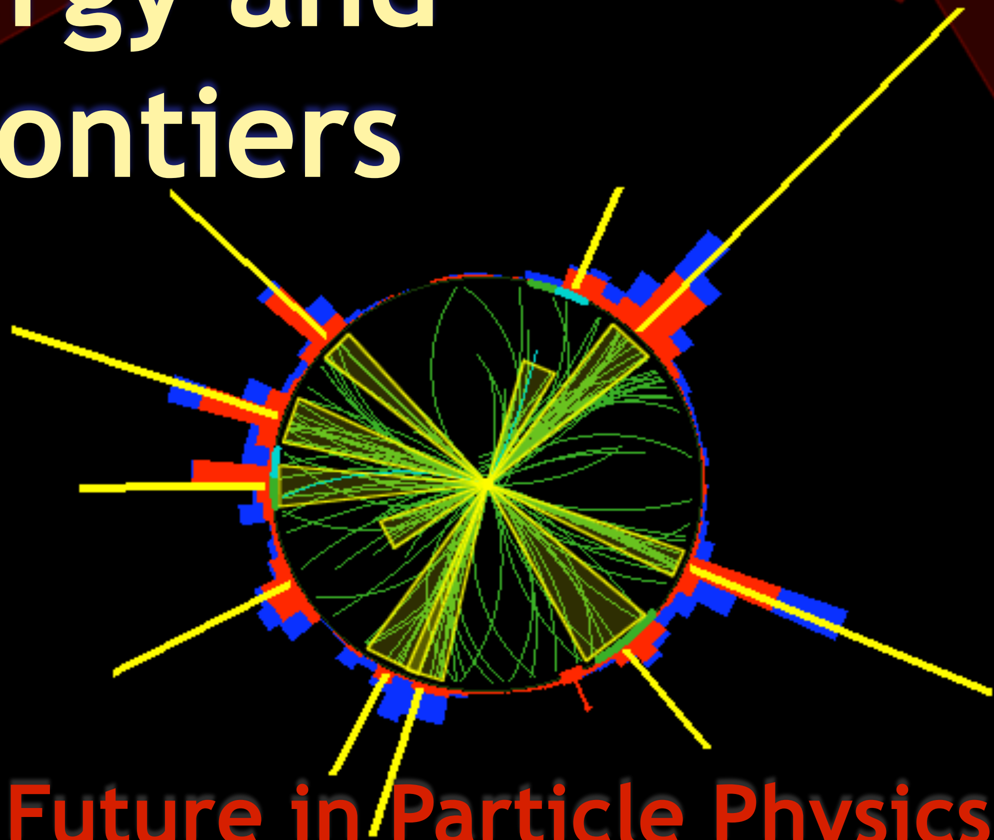
Beyond energy and precision frontiers





Shaping Austria's Future in Particle Physics

Claudia-Elisabeth Wulz

Vienna, 28 Sep. 2011

Important open questions

What is the origin of electroweak symmetry breaking?

Is it the Higgs mechanism?

How must the Standard Model be extended?

Supersymmetry, Grand Unified Theories, …

Can we unify all forces?

Can we include gravity?

Are there extra dimensions?

Are quarks and leptons fundamental particles?

Are there more than three generations?

Why is there asymmetry between matter and antimatter?

What are dark matter and dark energy?

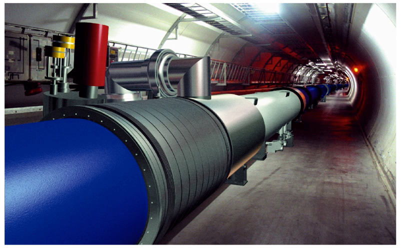
What are the last secrets of neutrinos?

Do we understand dense and hot matter?

Quark-gluon plasma

Facilities to answer the open questions

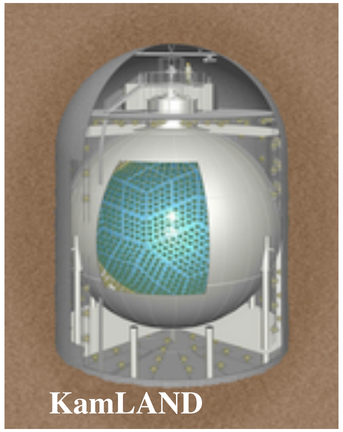
Particle accelerators
e.g. LHC, RHIC, B-factories, ILC

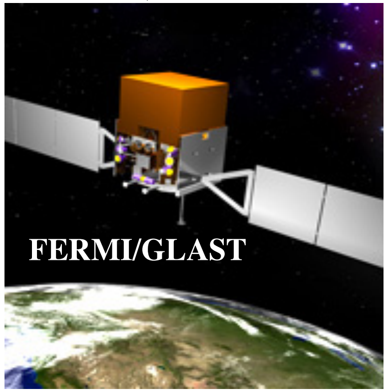


Underground experiments
e.g. Gran Sasso, Kamiokande, SNO, IceCube

Cosmic ray experiments
e.g. Auger

Experiments with reactors or sources
e.g. KamLAND, Double-CHOOZ, Katrin, Atominstitut (ultracold n),





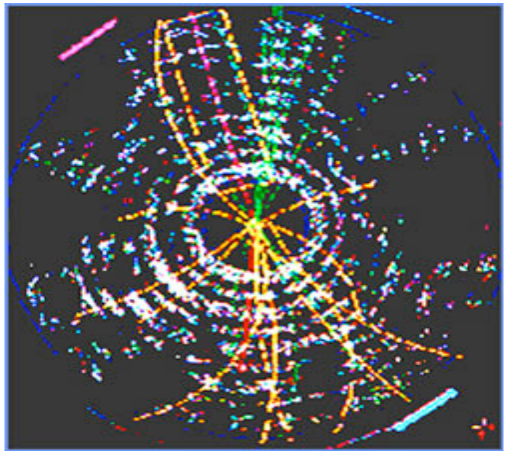
Space probes
e.g. FERMI, Hubble, Planck

Terrestrial Telescopes
e.g. ALMA, VLT, SDSS

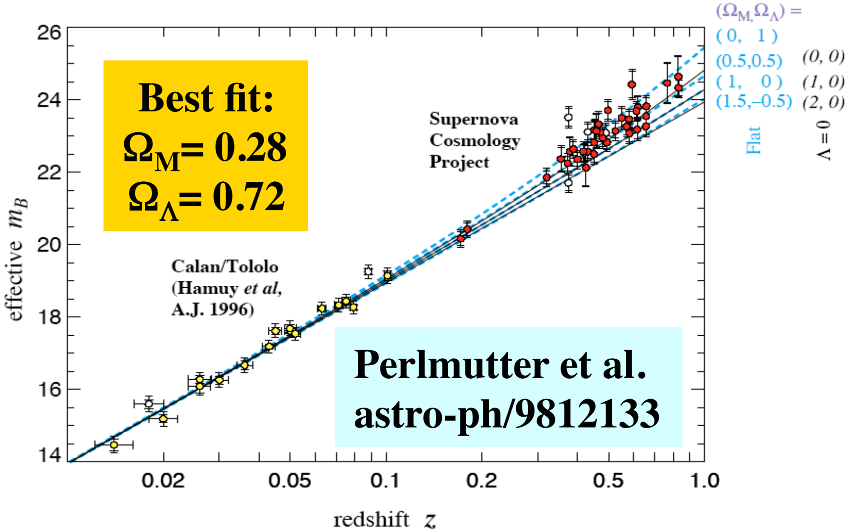
Some past physics highlights


1983: Discovery of the W/Z

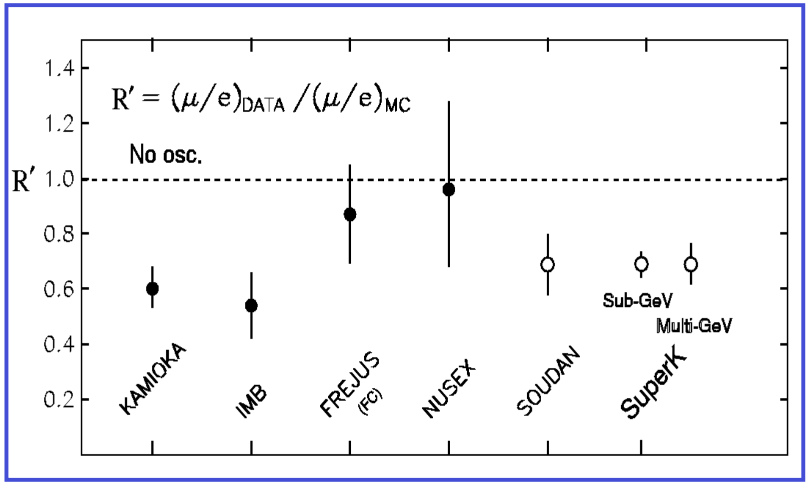
1995: Discovery of the top quark



1998: Discovery of Dark Energy



1990's: Discovery of neutrino oscillations



Status of accelerators

Accelerator	Max. luminosity	Beams	Status/end
LHC (pp)	10^{34} - 10^{35} cm^{-2} s^{-1}	p (3.5-7 TeV) + p (3.5-7 TeV)	running
Tevatron	4.2 x 10^{32} cm^{-2} s^{-1}	p (980 GeV) + $\bar{p}$ (980 GeV)	Sep. 2011
HERA	1.6 x 10^{31} cm^{-2} s^{-1}	e^- (27.5 GeV) + p (920 GeV)	June 2007
LHC (AA)	1 x 10^{27} cm^{-2} s^{-1}	A+A (2.76-5.5 TeV / NN)	running
RHIC	2 x 10^{26} cm^{-2} s^{-1}	A+A (200 GeV / NN)	running
PEP II B	1.2 x 10^{34} $cm^{-2}s^{-1}$	e^- (9 GeV) + e^+ (3.1 GeV)	April 2008
KEK-B	2.1 x 10^{34} $cm^{-2}s^{-1}$	e^- (8 GeV) + e^+ (3.5 GeV)	June 2010
Super KEK-B	0.8 x 10^{36} $cm^{-2}s^{-1}$	e^- (7 GeV) + e^+ (4 GeV)	start 2014?
SuperB	1 x 10^{36} $cm^{-2}s^{-1}$	e^- (7? GeV) + e^+ (4? GeV)	start 2015?

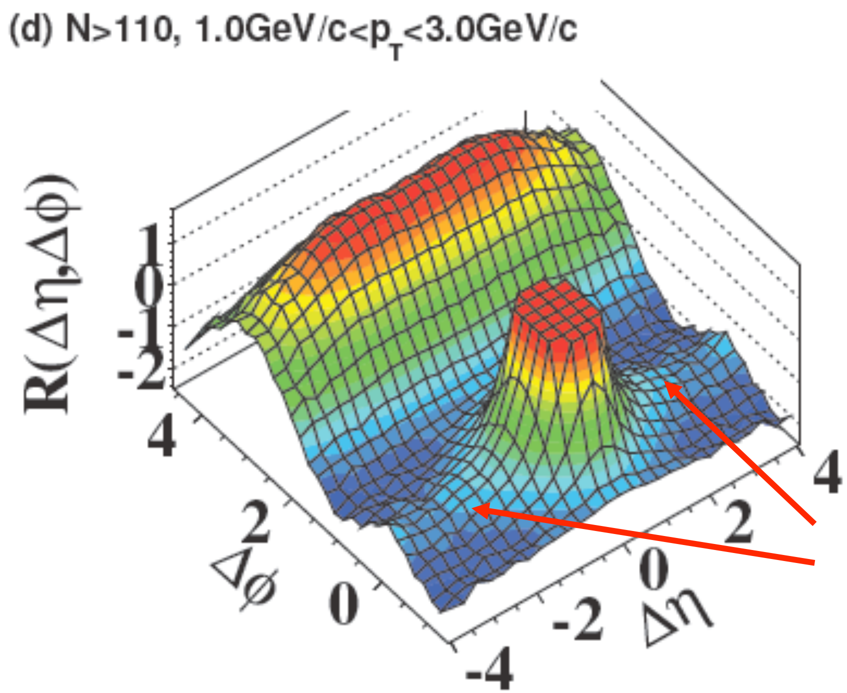
Flagship machines have shut down, LHC is starting up as a discovery machine (and a precision machine …), new B-factories are under way.
We are at a turning point in particle physics!

Near-side long-range correlations

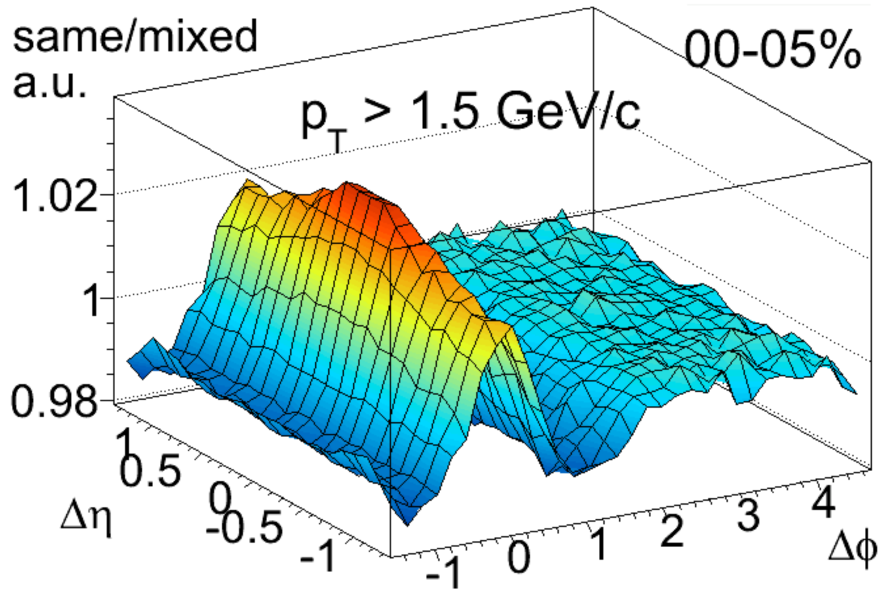
J. High Energy Phys. 09 (2010) 091

First surprise in LHC data!

CMS pp 7 TeV

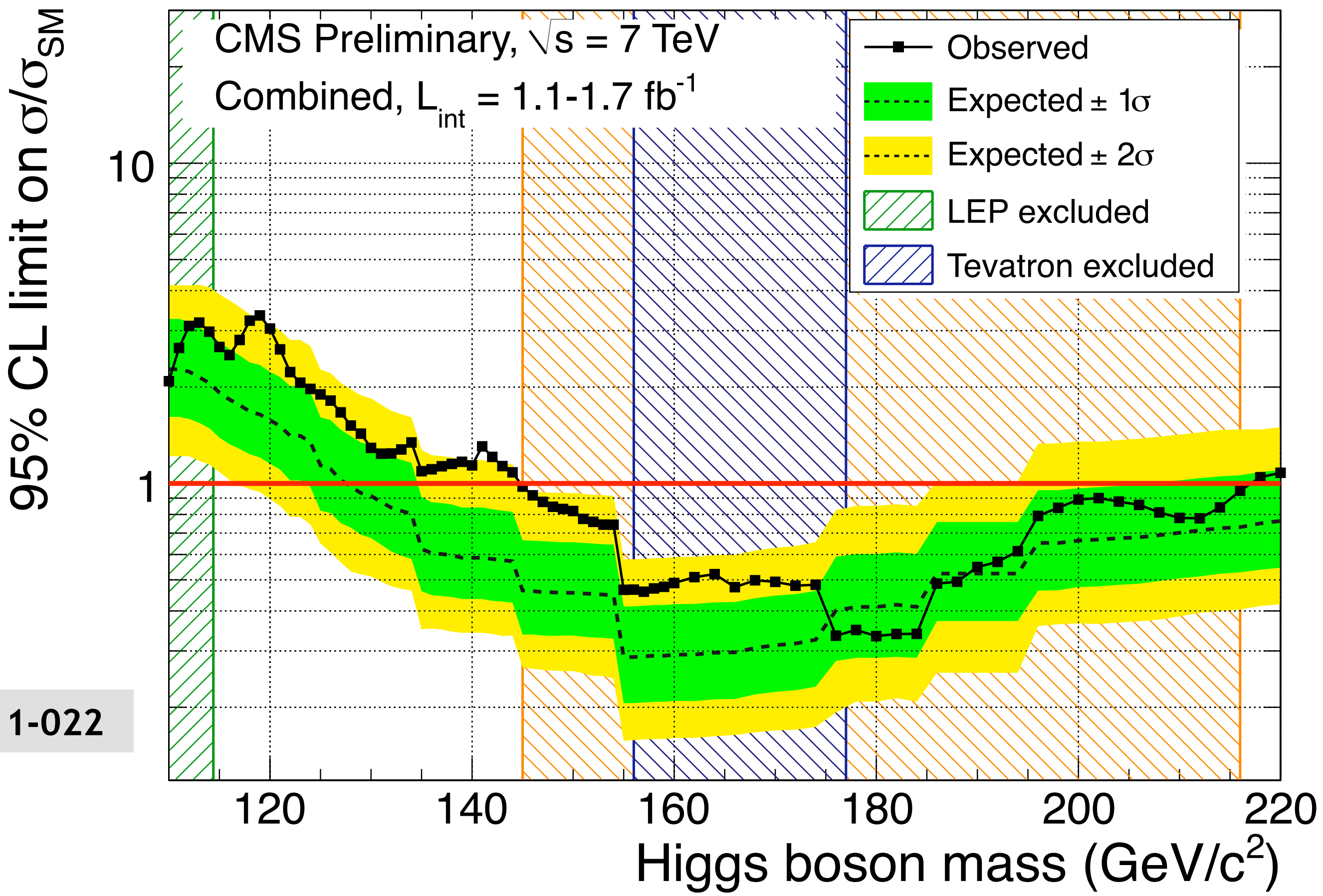


ALICE 2.76 TeV/NN
Central Pb-Pb collisions



Pronounced structure (ridge) in high-multiplicity events for $2.0 < |\Delta\eta| < 4.8$ and $\Delta\phi \approx 0$

A future physics highlight: Higgs or no Higgs

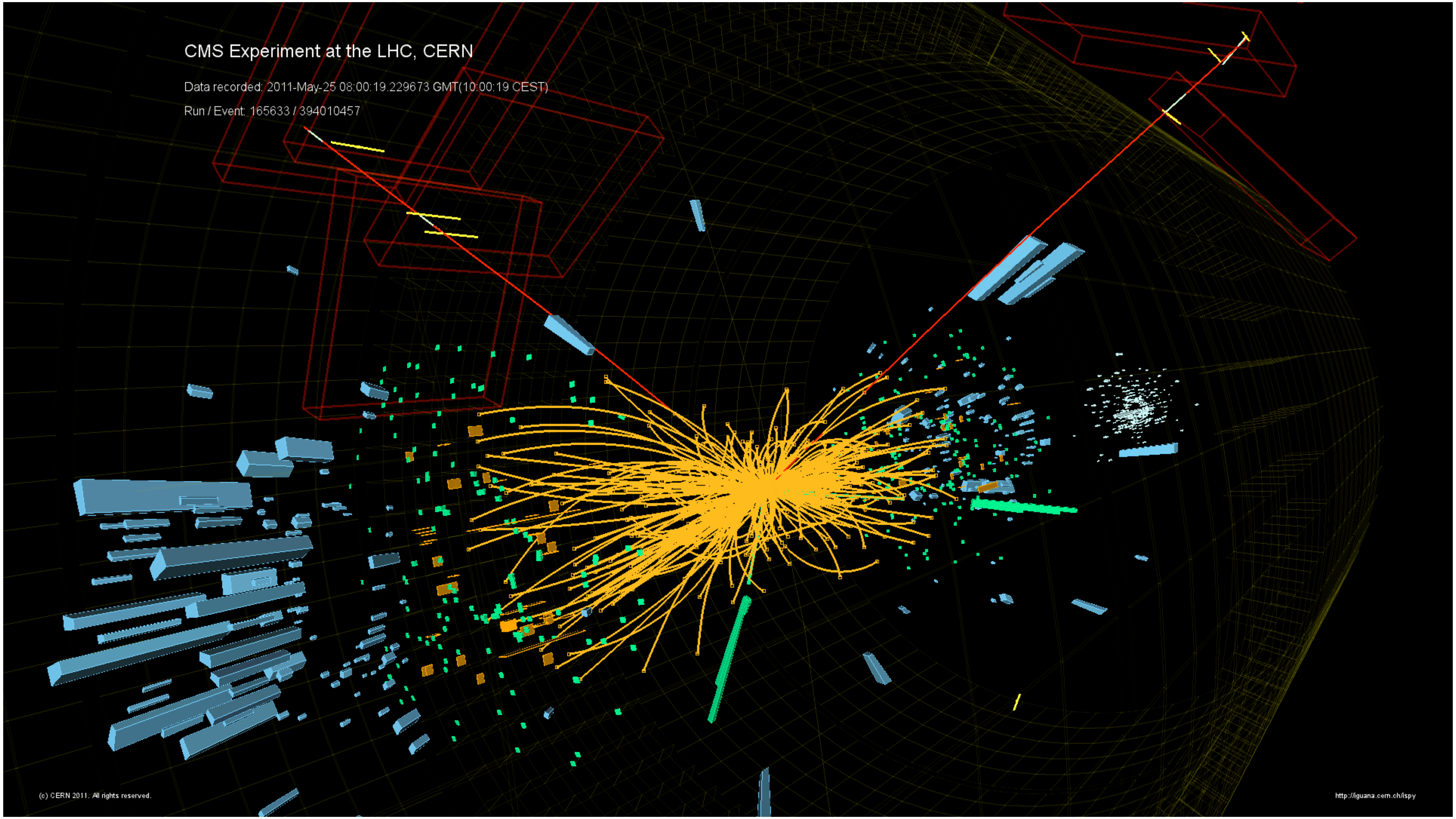


CMS-PAS-HIG-11-022

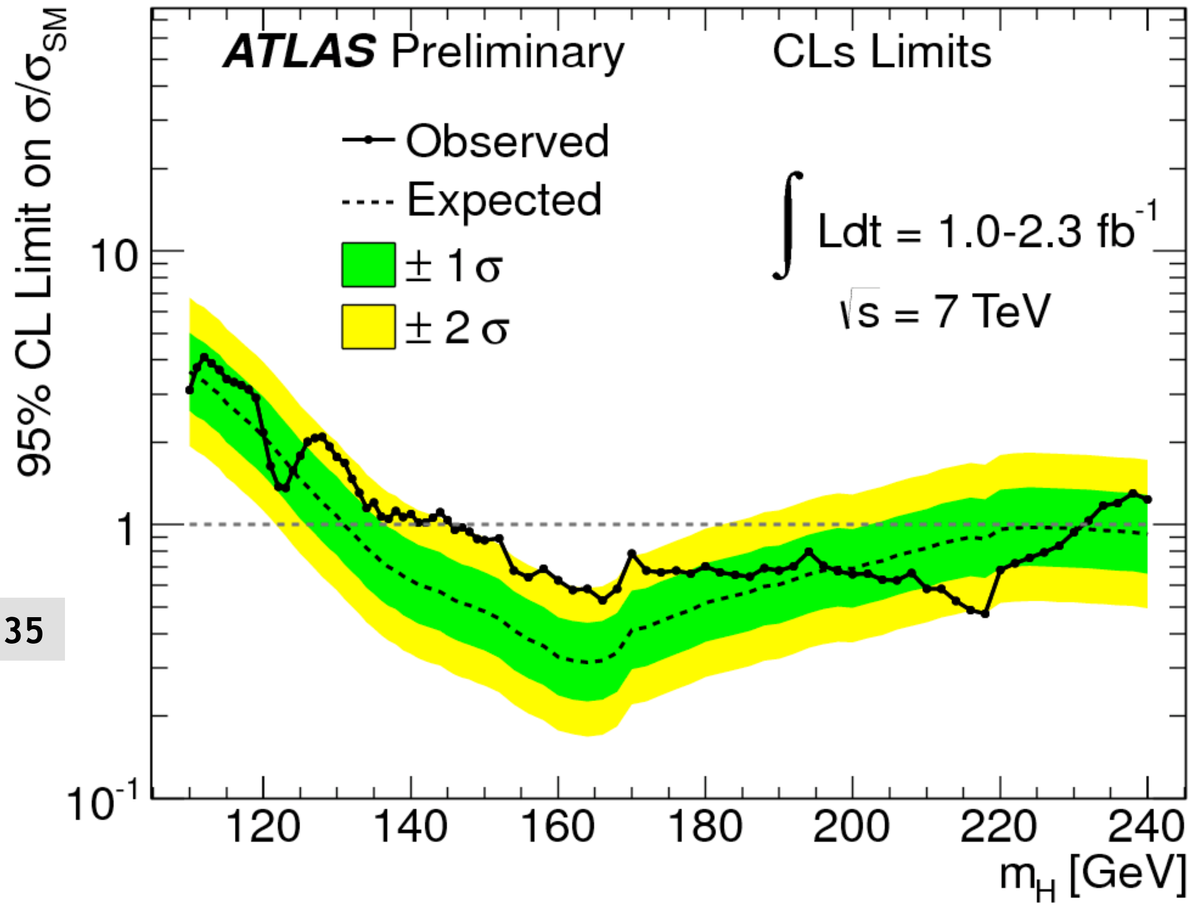
$H \to \gamma\gamma$, $H \to \tau\tau$, $H \to bb$, $H \to WW \to 2\ell 2\nu$, $H \to ZZ \to 4\ell$, $H \to ZZ \to 2\ell 2\tau$, $H \to ZZ \to 2\ell 2\nu$, and $H \to ZZ \to 2\ell 2q$.

The SM Higgs boson is excluded at 95% C.L. in three mass ranges 145-216, 226-288, and 310-400 GeV/c².

H -> $ee\mu\mu$ candidate



A future physics highlight: Higgs or no Higgs



ATLAS-CONF-2011-135

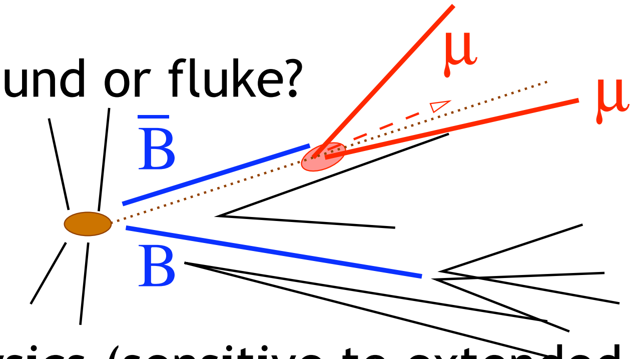
$H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$, $H \rightarrow WW \rightarrow \ell\nu\ell\nu$, $H \rightarrow \gamma\gamma$, $H \rightarrow \tau\tau$, $H \rightarrow WW \rightarrow \ell\nu qq$, $H \rightarrow Z\,Z \rightarrow \ell\ell\nu\nu$, $H \rightarrow Z\,Z \rightarrow \ell\ell qq$, $W\,H \rightarrow \ell\nu bb$ and $ZH \rightarrow \ell\ell bb$.

The Higgs boson mass ranges 149 GeV to 222 GeV and 276 GeV to 470 GeV are excluded at the 95% CL.

Last flashes of excitement from the Tevatron?

W + jet-jet data

Hints for a new particle and new physics?
Technicolor, SUSY, badly modelled background or fluke?



Rate of B_s -> $\mu^+\mu^-$

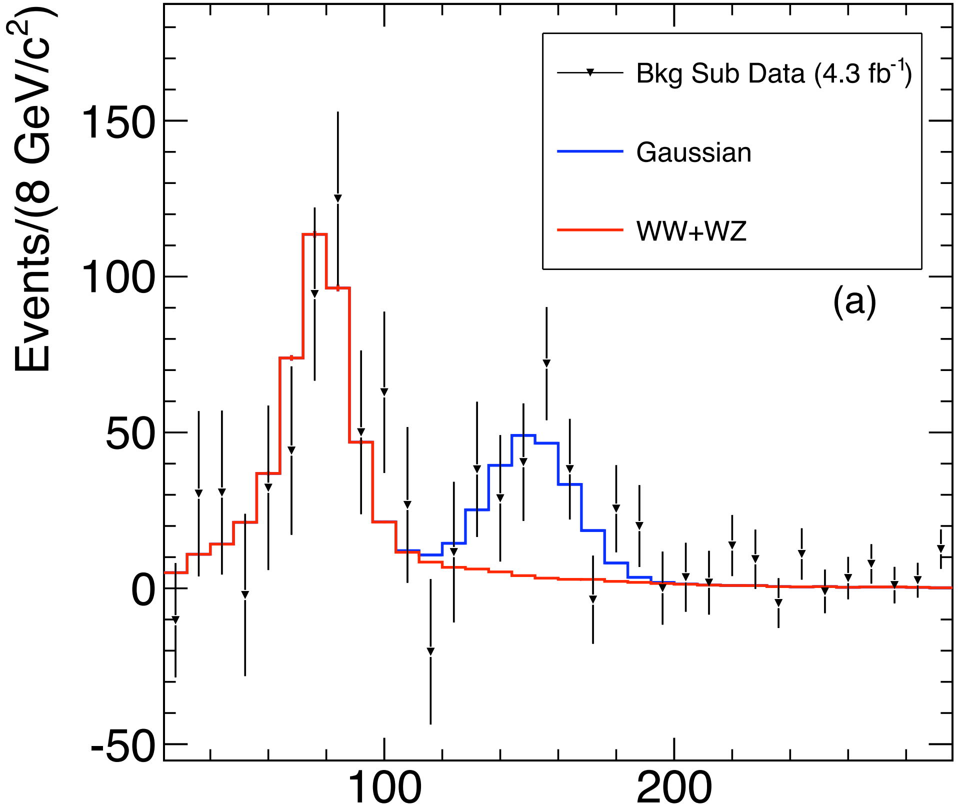
This channel is highly sensitive to New Physics (sensitive to extended Higgs sector, small theoretical uncertainties)

Anomalous like-sign dimuon charge asymmetry A^b_{sl} in semileptonic B decays

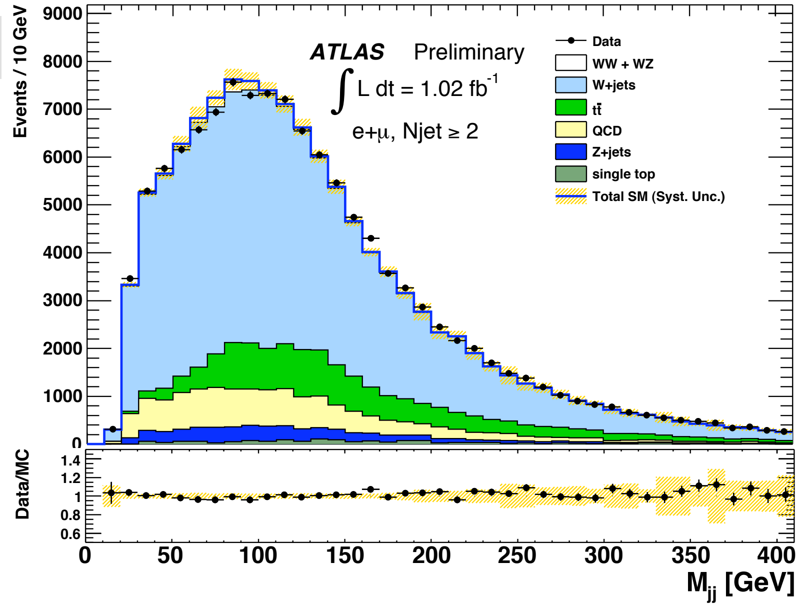
$$\Gamma(B \to \bar{B}) \neq \Gamma(\bar{B} \to B)$$

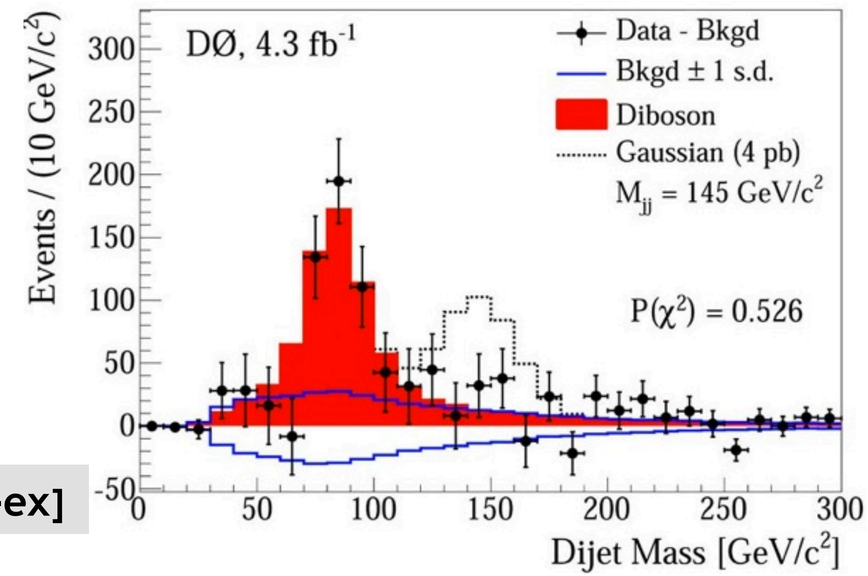
No hints for new particle from D0 and LHC

ATLAS-CONF-2011-097



arXiv: 1104.0699 [hep-ex]





arXiv: 1106.1921 [hep-ex]

CDF result and CMS/LHCb combination for BR(B_s -> $\mu\mu$)

Standard Model value:

$$BR\ (B_s^0 \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

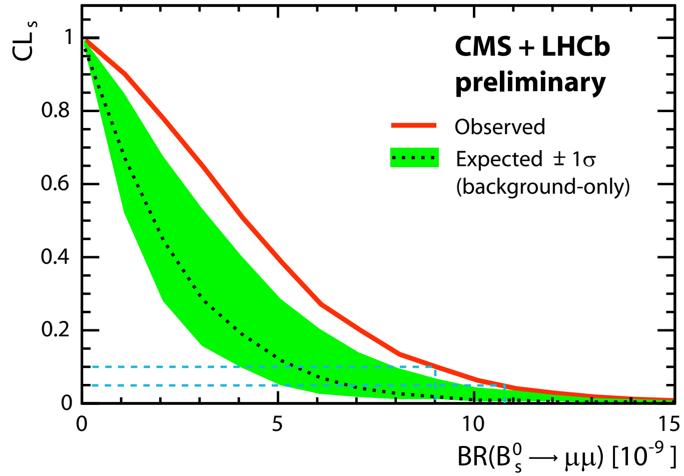
CDF value:

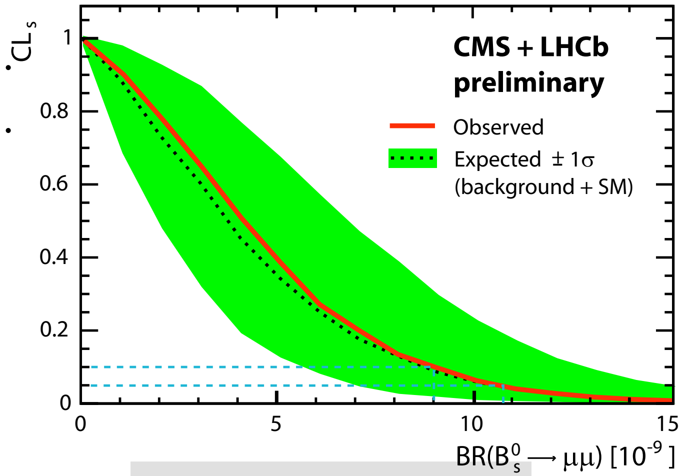
$$BR\ (B_s^0 \rightarrow \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$$

CMS/LHCb combined value:

$$BR\ (B_s^0 \rightarrow \mu^+\mu^-) < 1.08 \times 10^{-8} \text{ at } 95\%\text{C.L.}$$
$$BR\ (B_s^0 \rightarrow \mu^+\mu^-) < 0.90 \times 10^{-8} \text{ at } 90\%\text{C.L.}$$

An enhancement of the BR by more than 3.4 times the SM prediction is excluded at 95% C.L. But there is still room for new physics!





CMS-PAS-BPH-11-019

Anomalous like-sign dimuon charge asymmetry

$$a_{\rm sl}^b \equiv \frac{\Gamma(\bar{B}\to\mu^+X)-\Gamma(B\to\mu^-X)}{\Gamma(\bar{B}\to\mu^+X)+\Gamma(B\to\mu^-X)} = A_{\rm sl}^b$$

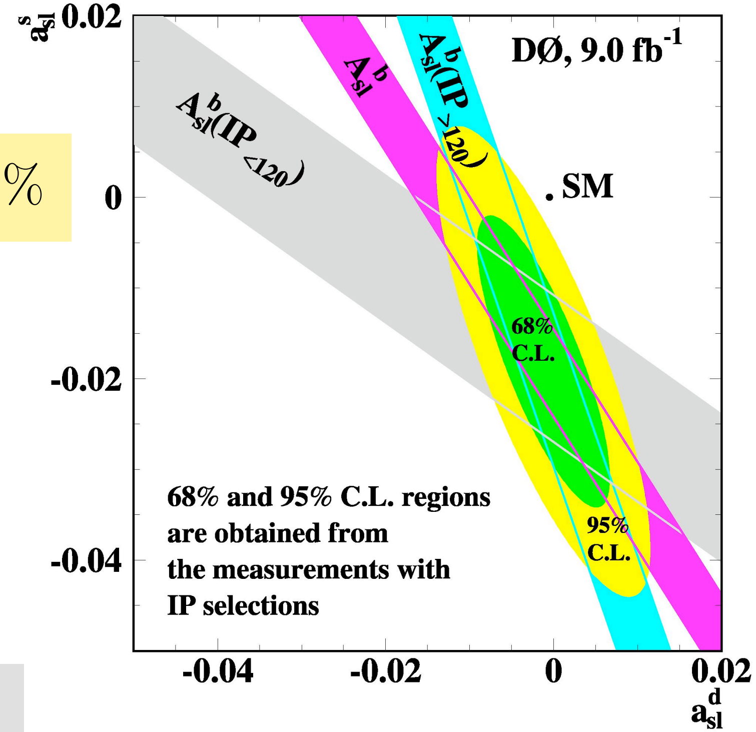
$$A_{\rm sl}^b \equiv \frac{N_b^{++}-N_b^{--}}{N_b^{++}+N_b^{--}}$$

$$A^b_{sl} = (-0.787 \pm 0.172(stat.) \pm 0.093(syst.))\%$$

3.9 σ above CKM expectation in SM

$$A^b_{sl}(SM) = (-0.028^{+0.005}_{-0.006})\%$$

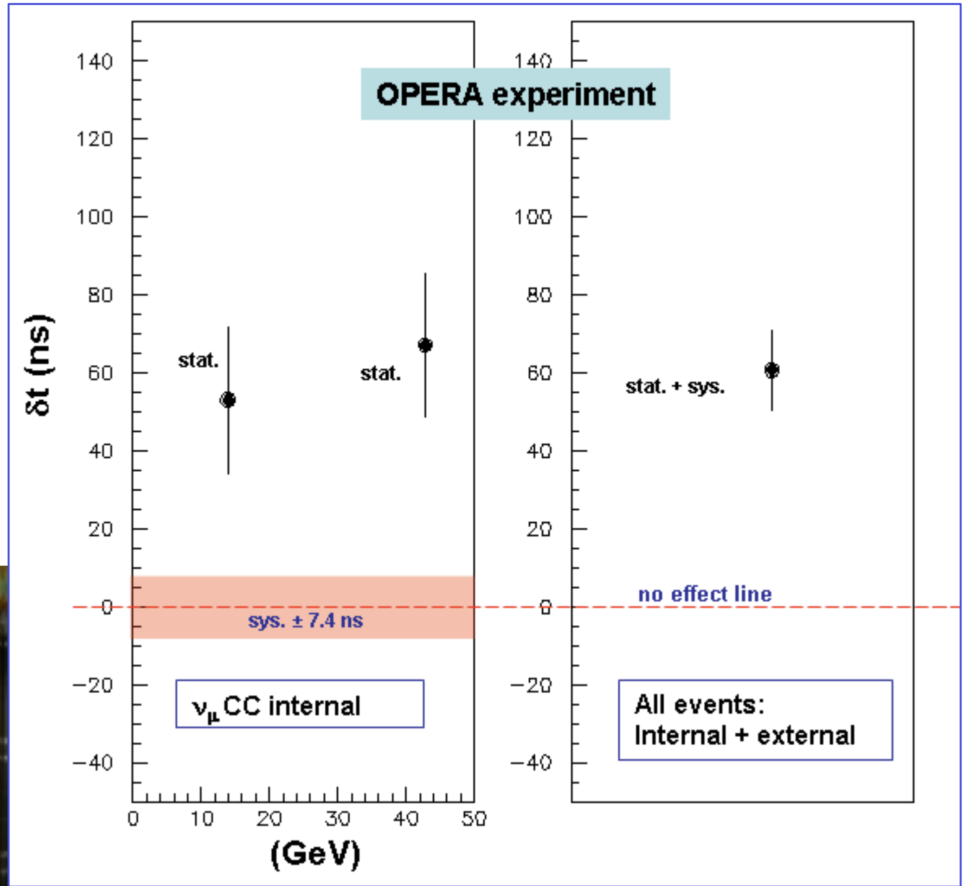
arXiv: 1106.6308 [hep-ex]

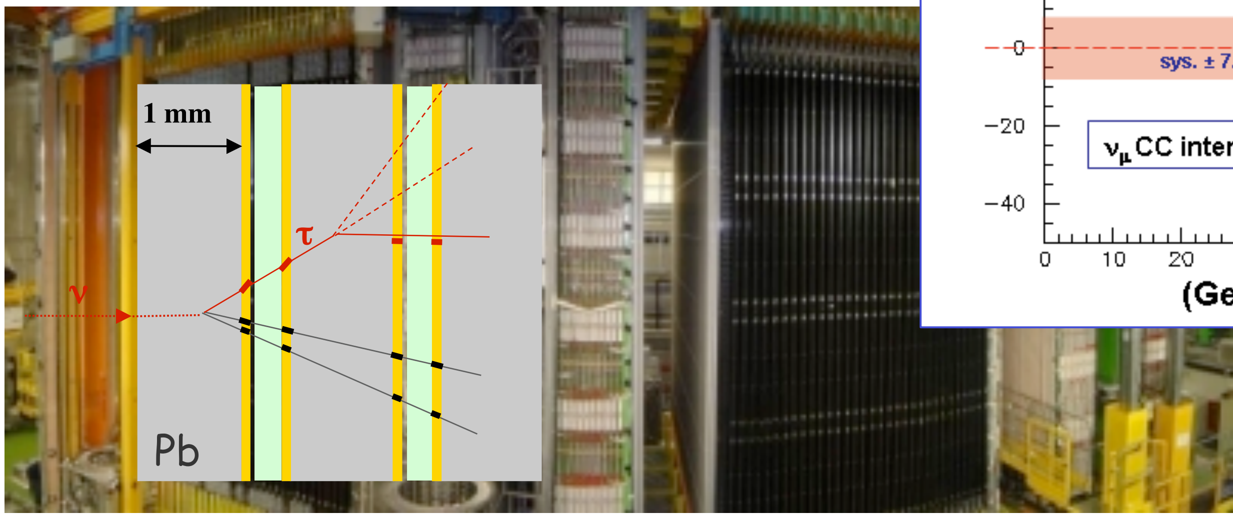


Measurements of $A^o_{\rm sl}$ with different muon IP selections in the $(a^d_{\rm sl}, a^s_{\rm sl})$ plane. The bands represent the ±1 standard deviation uncertainties on each individual measurement. The ellipses represent the 68% and 95% two-dimensional C.L. regions, respectively, of $a^s_{\rm sl}$ and $a^s_{\rm sl}$ values obtained from the measurements with IP selections.

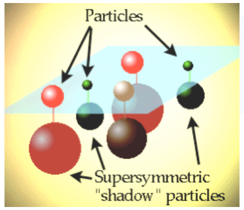
A phantom of the OPERA?

Can neutrinos travel faster than light?

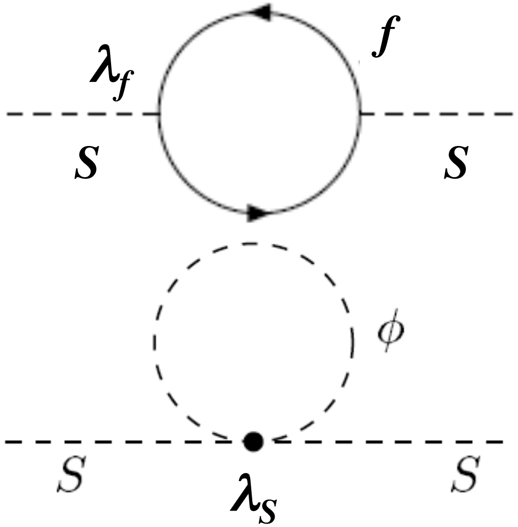




arXiv: 1109.4897 [hep-ex]



Supersymmetry

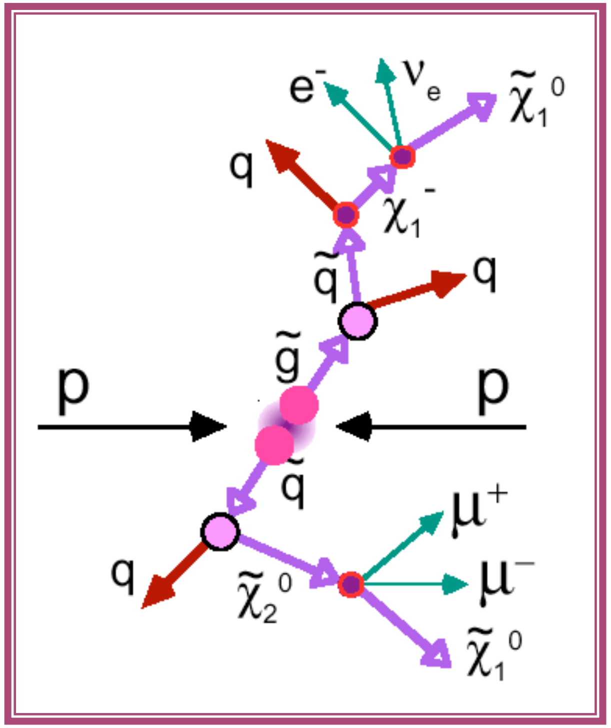


$$\Delta m_S^2 = -\frac{\lambda_f^2}{8\pi^2}[\Lambda_{UV}^2 - m_f^2 \ln \frac{\Lambda_{UV}^2}{m_f^2}] + \ldots$$

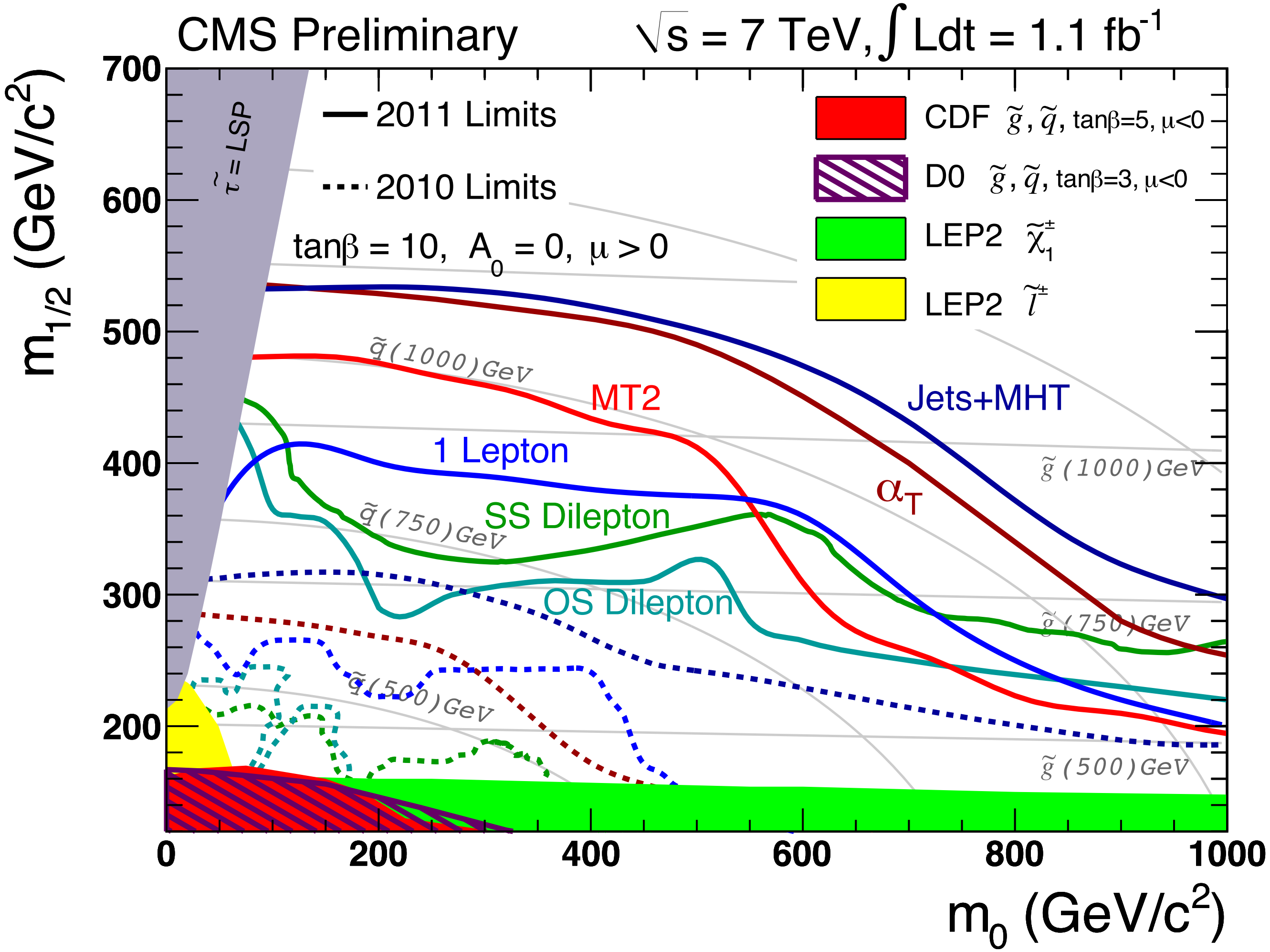
$$\Delta m_S'^2 = +\frac{\lambda_S^2}{8\pi^2}[\Lambda_{UV}^2 - m_\phi^2 \ln \frac{\Lambda_{UV}^2}{m_\phi^2}] + \ldots$$

Initial searches are performed with a number of inclusive final states. Signatures can contain jets, missing transverse energy, leptons or photons.

Example of squark-gluino cascade event



Observed limits from SUSY searches in the CMSSM



A large region of the phase space is already excluded …
but SUSY is not dead yet!

Exploration of further SUSY models

Reminder: the minimal supersymmetric Standard Model (MSSM) has 105 parameters -> difficult to explore.
We can study benchmark MSSM models with fewer parameters, and NMSSM's as well as R-parity [$R = (-1)^{2S+L+3B}$] violating scenarios. New and sometimes more unusual experimental signatures will arise.

Examples:

CMSSM (constrained MSSM): $m_{1/2}$, m_0, A_0, $\tan\beta$, $\mathrm{sign}(\mu)$

mSUGRA (minimal supergravity model): $m_{1/2}$, m_0, A_0, $\mathrm{sign}(\mu)$

NUHM (non-universal Higgs mass models):
$m_{1/2}$, m_0, m_H (or m_{Hu}, m_{Hd}), A_0, $\tan\beta$, $\mathrm{sign}(\mu)$

mGMSB (minimal gauge-mediated SUSY breaking):
$M_{messenger}$, Λ (visible sector soft SUSY breaking scale), $\tan\beta$, $c_{gravitino}$, $N_{messenger}$

RPV MSSM (R-parity violating): $m_{1/2}$, m_0, A_0, $\tan\beta$, $\mathrm{sign}(\mu)$, Λ

Examples of new signatures

mGMSB:

The NLSP plays an important role since cascade decay chains of sparticles typically end in the NLSP. This is often a stau, which decays to tau and gravitino or neutralino, which can decay to a photon and a gravitino (missing energy in the detector).

RPV MSSM:

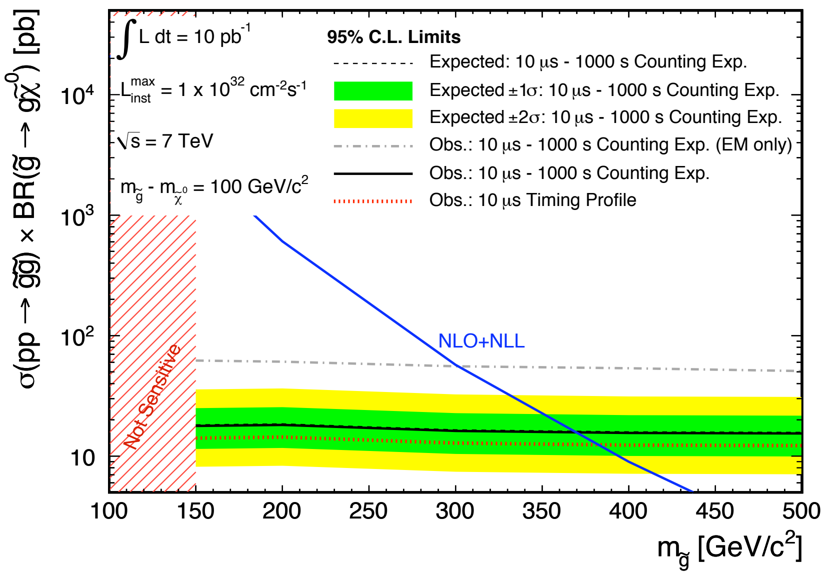
Lepton number violation or baryon number violation is allowed, the proton is still stable. The LSP (not necessarily a neutralino) decays to Standard Model particles. For a neutralino LSP the signatures are the same as for R-parity conserving models, except that there is no missing energy. IF the RPV coupling is very small, decays are delayed, leading to displaced vertices. For stau LSP there are taus in the final state.

Long-lived, stopped gluinos

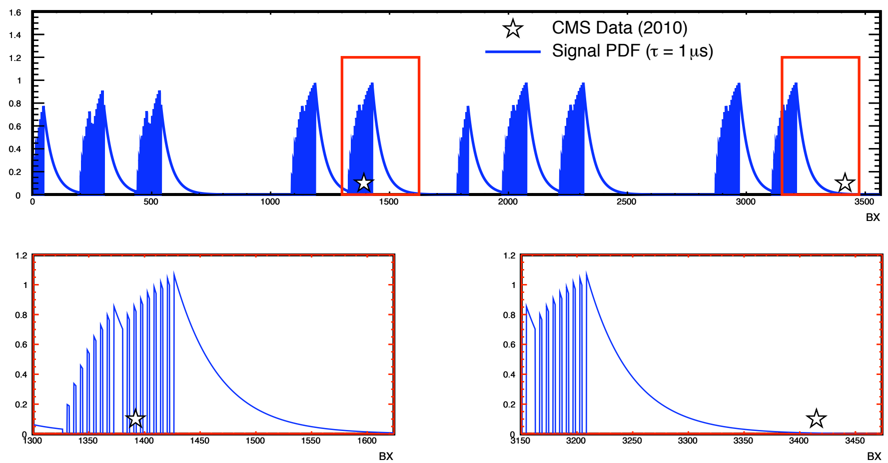
hep-ex 1011.5861, Phys. Rev. Lett. 106, 011801 (2011)

Look for decays in time intervals with no pp collisions, using calorimeter triggers. Long-lived gluinos would hadronize into "R-hadrons" $(\tilde{g}g, \tilde{g}q\bar{q}, \tilde{g}qqq)$

Assumption: $\mathrm{BR}(\tilde{g} \to g\tilde{\chi}_1^0) = 100\%$



In-orbit positions of 2 events, with exponential decay profile for 1 μs lifetime hypothesis overlaid

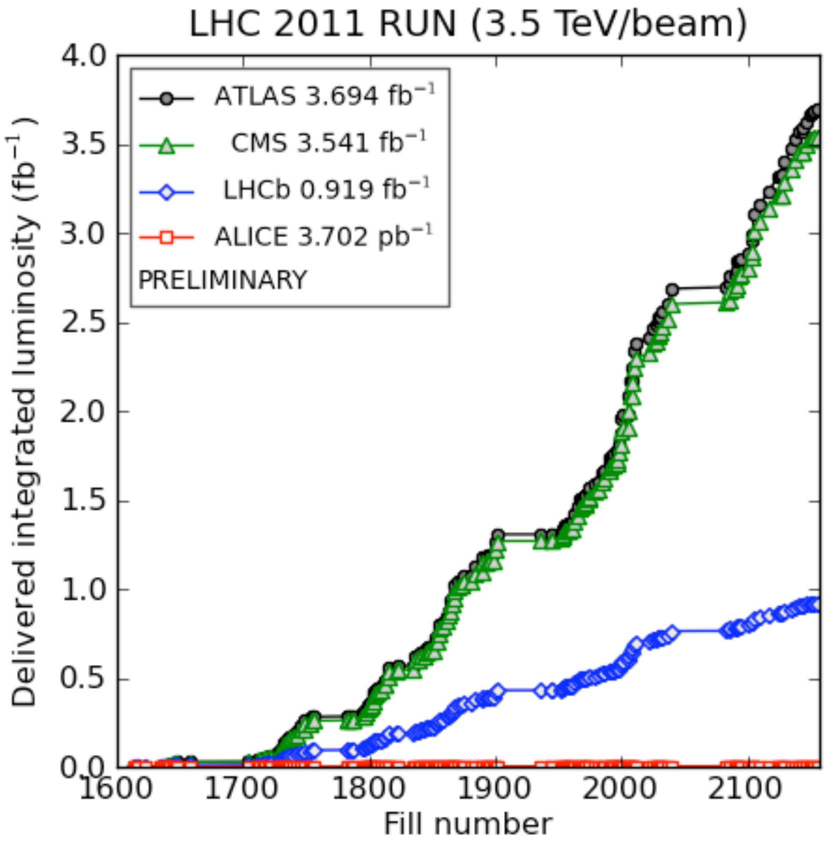


Gluino mass limit:

$m(\tilde{g}) > 370\ \mathrm{GeV}$

for lifetimes between 10 μs to 1000 s

Experiments must keep up with machines



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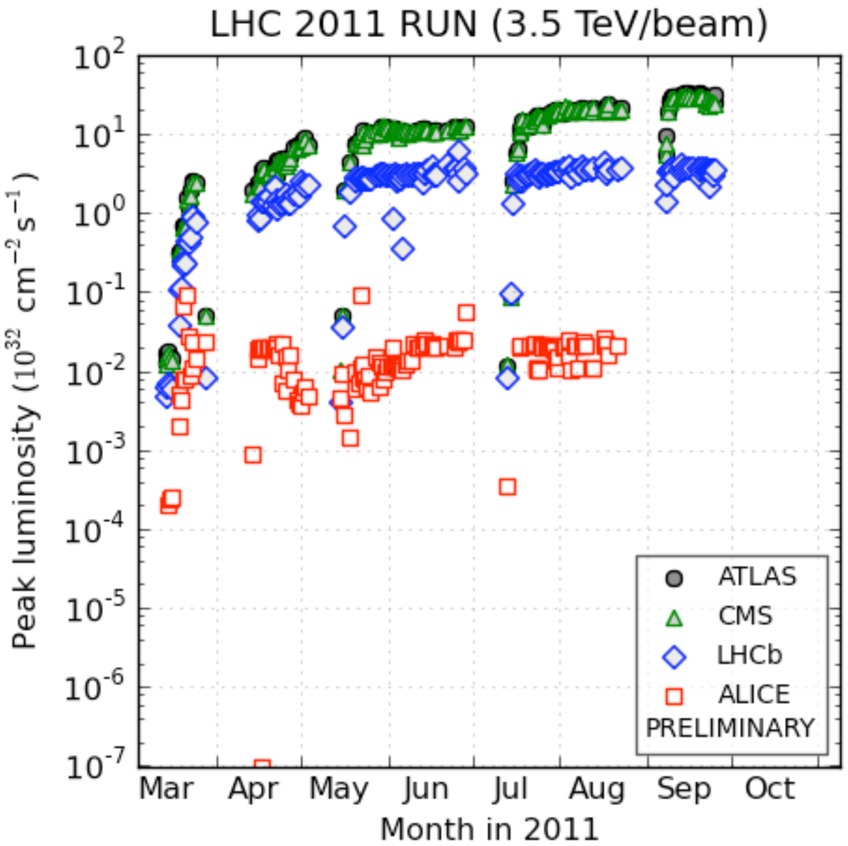
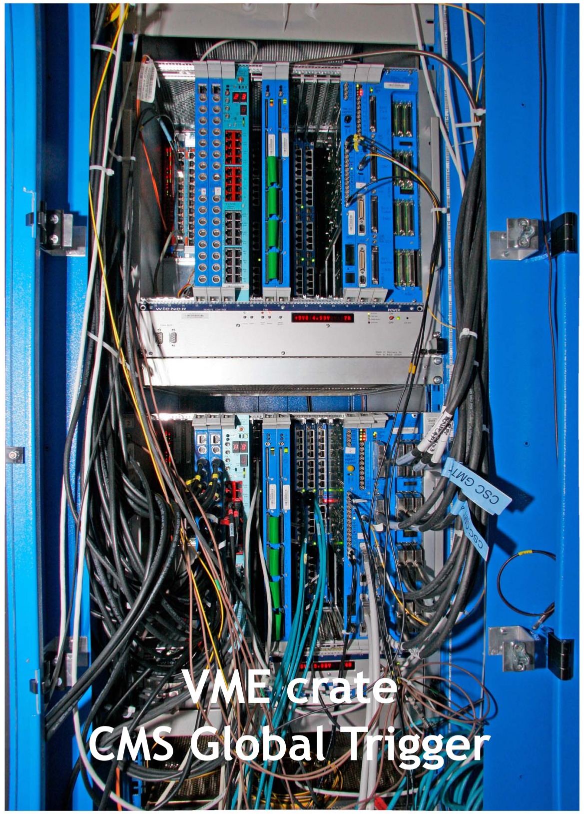


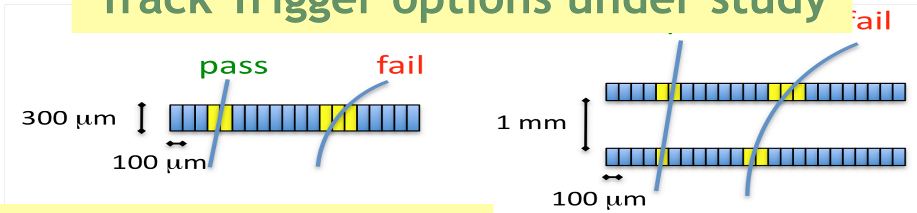
(generated 2011-09-26 01:16 including fill 2155)

Challenge for detectors (pile-up, occupancies) as well as trigger and data acquisition systems (trigger rates, storage limits), data analysis (selection, processing, batch jobs). Upgrade program of the LHC foresees a factor 10 luminosity increase. For Super KEK-B the increase will be a factor 40!

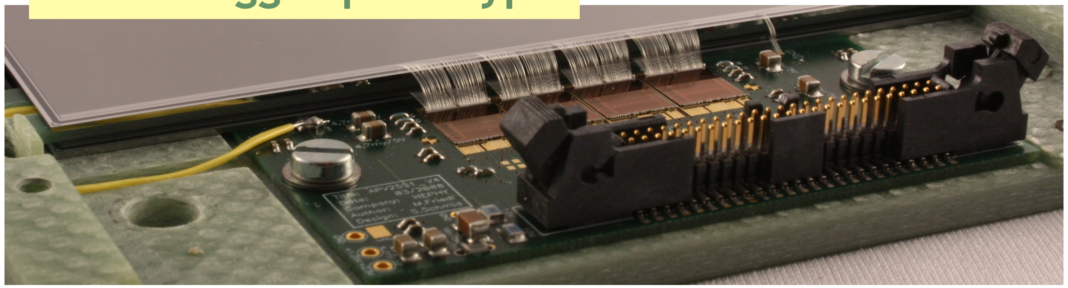
Detector and trigger upgrade examples



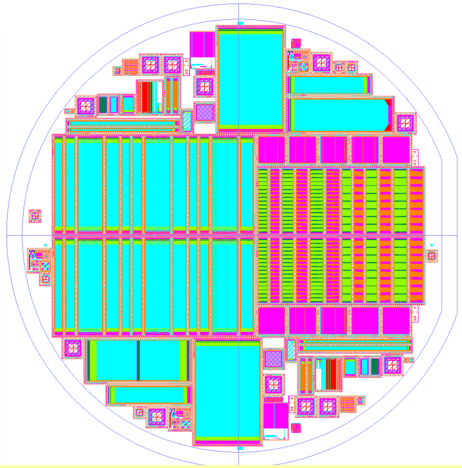
Track Trigger options under study



Track trigger prototype



µTCA crate



Si sensor development

Austrian involvement in particle physics

Accelerator-based physics

CERN: ATLAS, CMS, ASACUSA
KEK/JAEA: BELLE, BELLE-2, J-PARC E15 & E17
FAIR: FLAIR, PANDA
DAFNE: Siddharta

Non-accelerator-based physics

LNGS: VIP
Atominstitut: precision experiments with ultracold neutrons

Astroparticle physics

FERMI (formerly GLAST)
HESS
Cosmic Ray Observatory Innsbruck

Detector and accelerator R&D

RD42, LHC phase 2 upgrade, ILC, detectors for astro- and particle physics
medAUSTRON

Particle physics theory and phenomenology

SUSY, QCD, QFT, chiral perturbation theory, neutrino physics, quantum mechanics, gravitational physics

Plans for research at HEPHY

Experiments CMS and Belle

Continue and finish ongoing analyses

inclusive SUSY/BSM studies and studies with leptons,
simplified models,
QCD (quarkonia),
V_{ub} and V_{cb}

Define new analysis topics

more model-specific SUSY scenarios, NMSSM,
other Beyond the Standard Model topics (W', Z', extra dimensions, but also exotica),
precision measurements in the B system

Widen participation

incorporate theorists (from HEPHY and elsewhere) formally in work,
invite SMI physicists,
identify collaboration possibilities for HEPHY physicists,
maybe approach ATLAS colleagues in Innsbruck

Plans for research at HEPHY

Theory

revisit research topics in view of new results,
guidance of experimentalists,
reinforce group,
hire a top expert in „new physics“

“Physics centre”

set up a coordination group to explore synergies in particular with the group of Prof. Abele in the field of precision physics,
organize academic training activities to facilitate collaboration,
make plans for common research and publications

New opportunities

stay open for anything (neutrino experiments, ...)

HEPHY Institut für Hochenergiephysik

Plans for technology development

Upgrade of CMS and BELLE

silicon detector development,
trigger development,
electronics development,
algorithm development

Computing

secure operation and upgrade of Grid Tier-2 centre,
strengthen computing group,
improve user support

Partners

industry (Siemens, Infineon, Wien Strom, …),
medAustron

For most of these activities participation of SMI should be possible and their implementation discussed. HEPHY should also engage in related projects of SMI.

Teaching and personnel handling

Courses and projects:

offer courses on modern particle and astroparticle physics,
projects including possibilities to work at CERN, in Japan, etc.,
offer projects as a pack with SMI and Atominstitut,
participate in development of curricula for physics studies

Incentives:

provide a mentor for each diploma and doctoral student,
organize seminars and other events specially for students,
identify and offer prizes,
provide career advice and make career plan for personnel,
provide academic and complementary skills training,
(writing, giving talks, leadership, working with the media, …)

Fund raising and outreach

Fund raising:

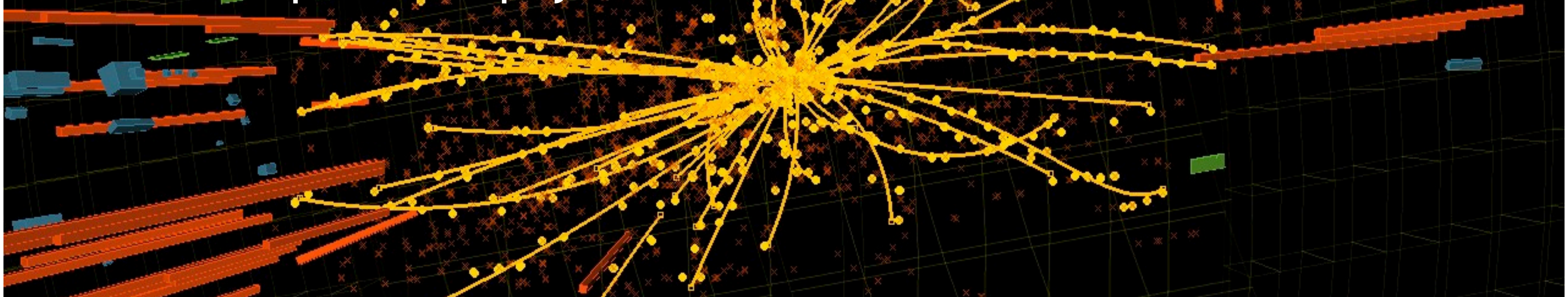
explore a large range of possibilities (ministries of science, education and technology), science funding agencies (FWF, FFG), European Union, local governments, universities, specific grants for women, industrial collaborations, sponsors

Outreach for the public and for scientists:

outreach is already quite exemplary at HEPHY,
continue the tradition,
but concentrate on events where participation is large (but keep things like the "Begabtenakademie"),
continue to organize and initiate conferences and workshops

Conclusions

- We are at a turning point in particle physics.
- The time is ideal to set the foundations for a new, unique institution combining frontier and precision physics.



- The work will be challenging but immensely gratifying if successful.
- Thank you for the invitation!