Particle Physics Theme SUPA

SUPA Annual General Meeting
St Andrews, 14 May 2014

Paul Soler
University of Glasgow

Particle Physics after Higgs

- After the Nobel Prize in Physics for Peter Higgs and Francois Englert in December 2013 we now live in a post-Higgs era
- This was a triumph for both theoretical and experimental particle physics and captured the imagination of the entire world
- The main goal in particle physics now is to determine whether the Standard Model is sufficient to describe nature and to develop theories that go beyond the Standard Model and carry out experiments to test those theories

P. Higgs (University of Edinburgh)

Dec. 2013

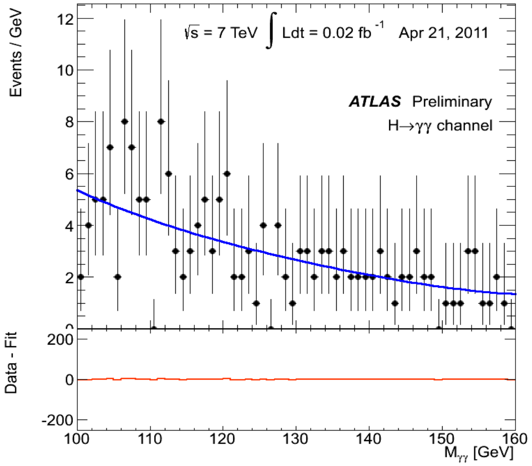
F. Englert (Université Libre de Bruxelles)

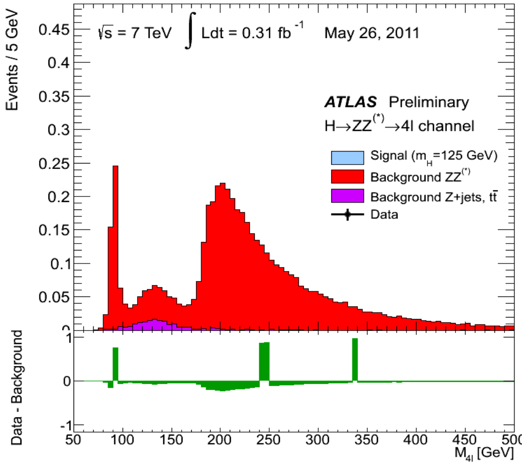
Particle Physics in SUPA

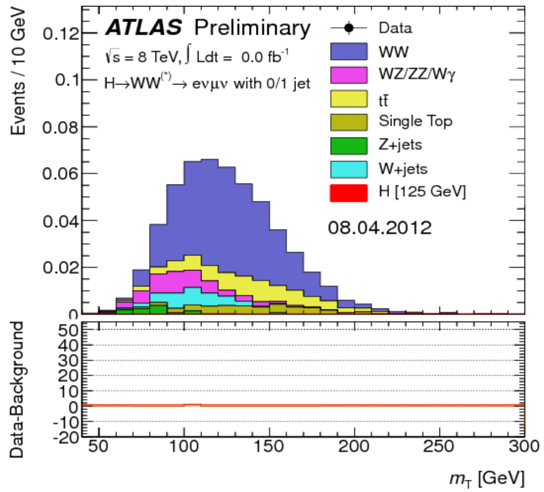
- The Universities of Edinburgh and Glasgow have world-class particle physics groups both in theory and experiment
- Recent areas of strength include:
  - Leading contributions to the construction of the ATLAS and LHCb detectors at CERN
  - Preparations for 13-14 TeV Large Hadron Collider running
  - Discovery of Higgs boson and search for new physics in top quark production at ATLAS
  - World-best measurements of CP violation and discovery of new states in LHCb
  - World leading searches for dark matter
  - Lattice QCD: world's most accurate quark mass and nucleon mass predictions, muon g-2, nucleon form factors, EDM neutron
  - World leading Higgs phenomenology and new physics effects
  - Theoretical analogies between QCD and gravitation
  - Impact of detector research – medical and industrial applications

Highlights ATLAS

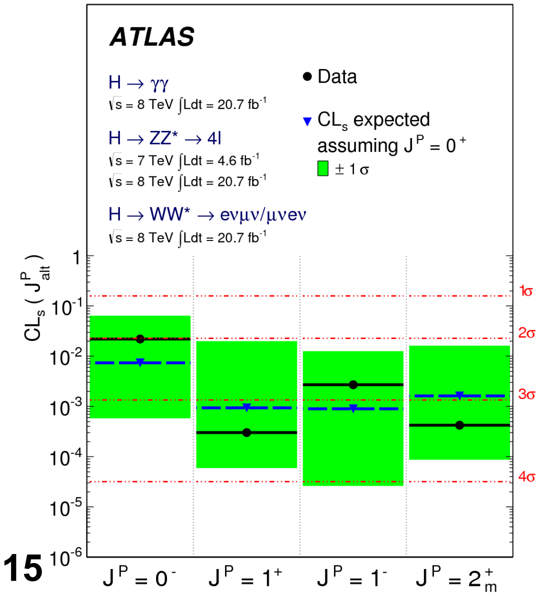
- What are properties of Higgs?







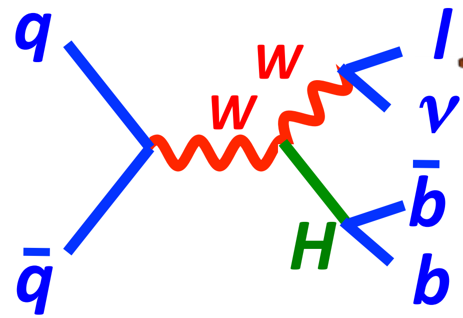
- – Is cross-section consistent with SM?
- – Vector-boson fusion production and couplings
- – Spin: consistent with $J^P=0^+$

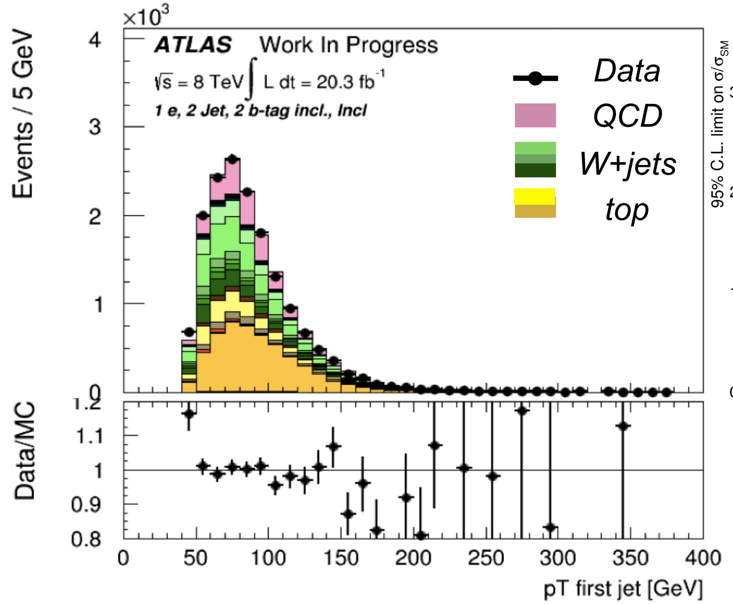


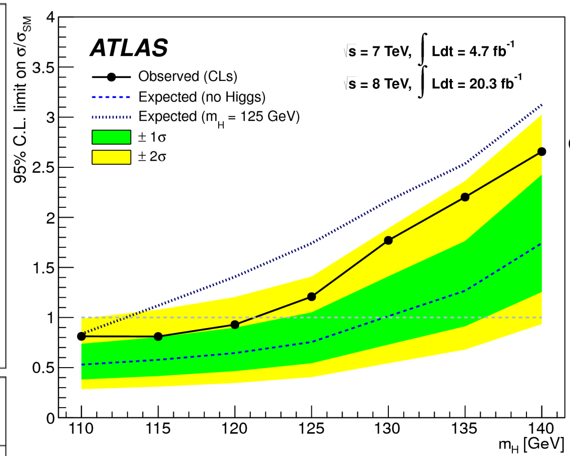
Separation
0^+ vs alternatives

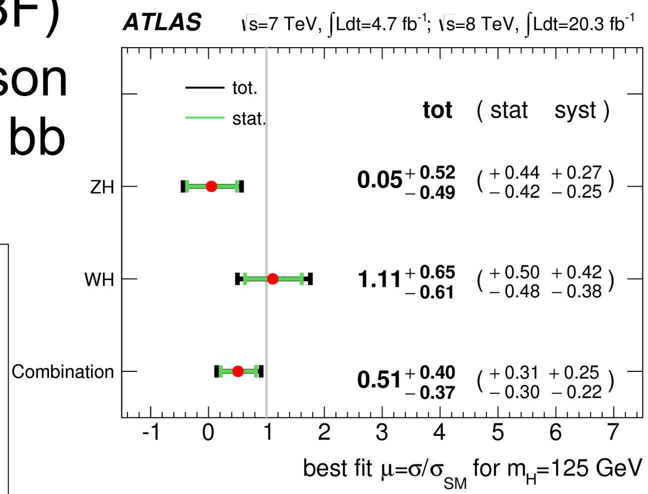
Highlights ATLAS

- Fermionic channels: $pp \rightarrow W\,H(b\bar{b})$
  - Most Higgs searches in bosonic decay channels $(H \rightarrow \gamma\gamma,\quad H \rightarrow ZZ,\quad H \rightarrow WW)$
  - Crucial to verify Higgs coupling to fermions e.g. $H \rightarrow b\bar{b}$ as predicted by the SM (58% BF)
  - H production in association with W (or Z) boson allows triggering and tagging – and decay to bb





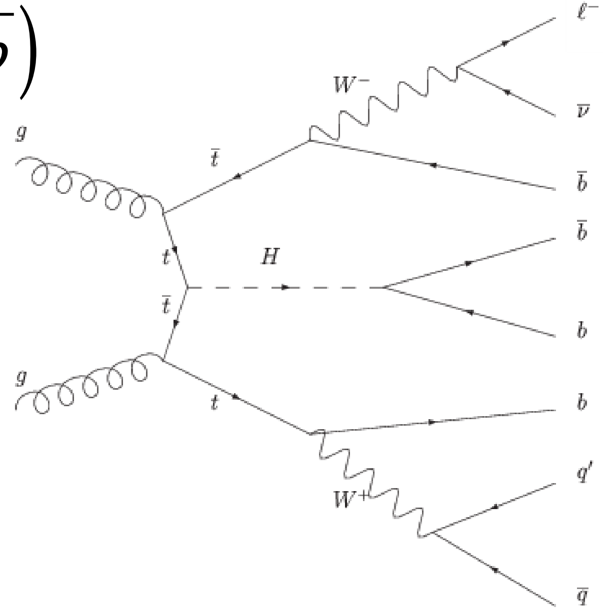


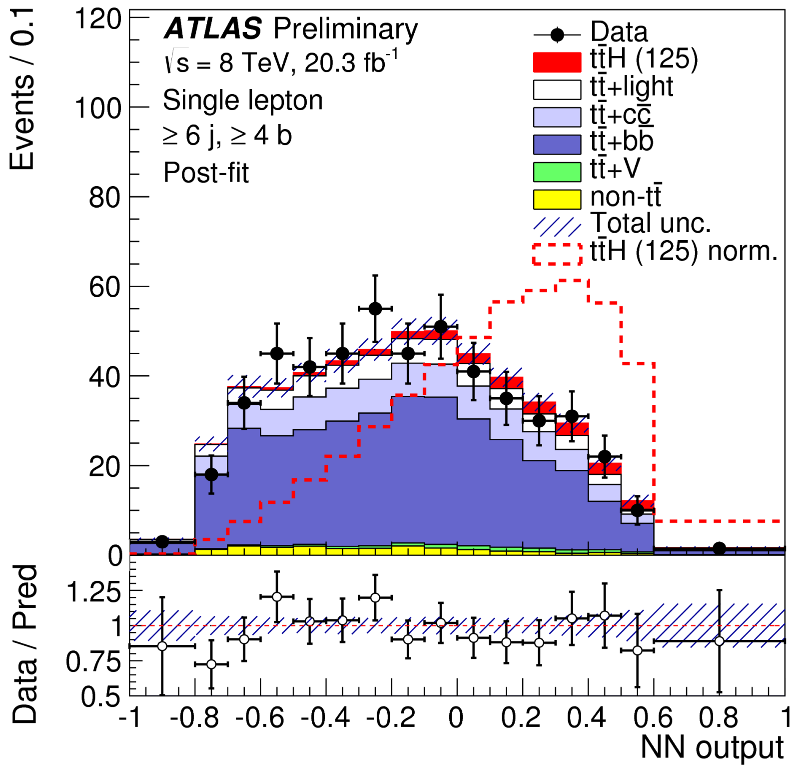


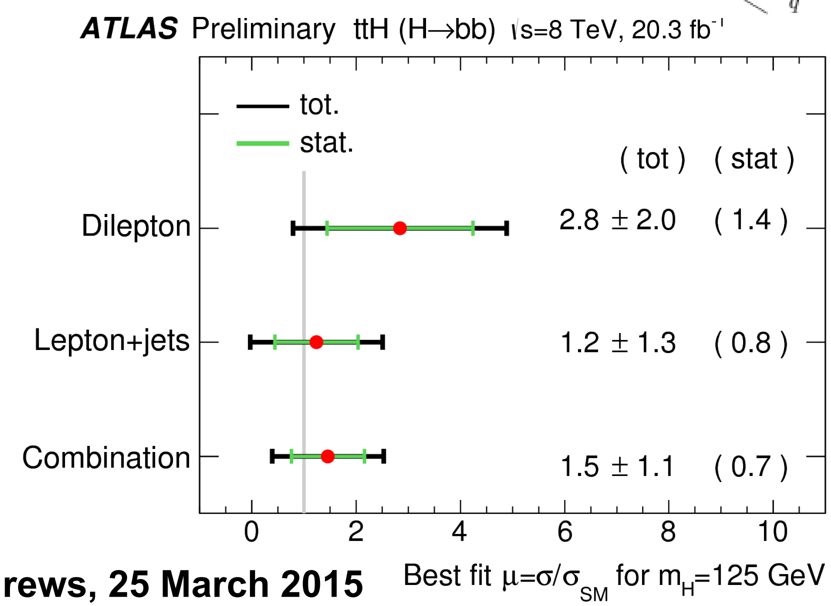
Combination WH and ZH:
JHEP 01 (2015) 069
Signal 1.4σ significance;
weaker than expected
Signal ~0.5 of SM

Highlights ATLAS

- Fermionic channels: $pp \rightarrow t\,\bar{t}\,H(b\bar{b})$
  - Top-Higgs Yukawa coupling
  - Top is heaviest fermion
  - No signal, but close to SM



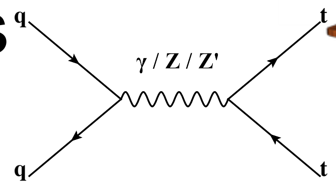


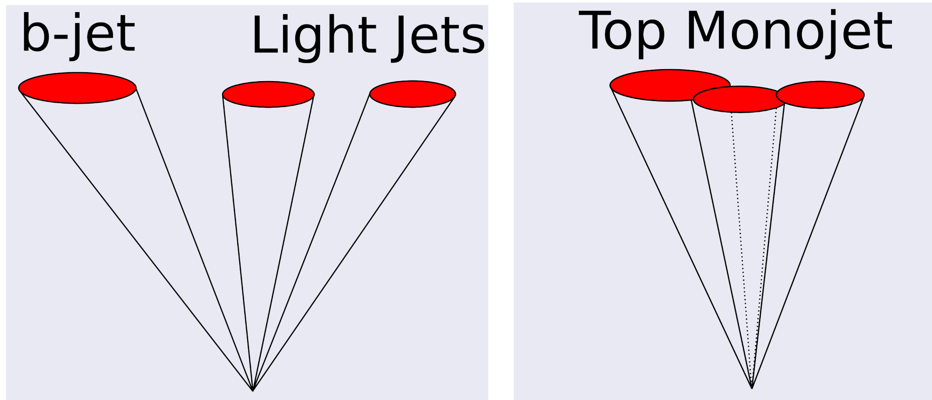


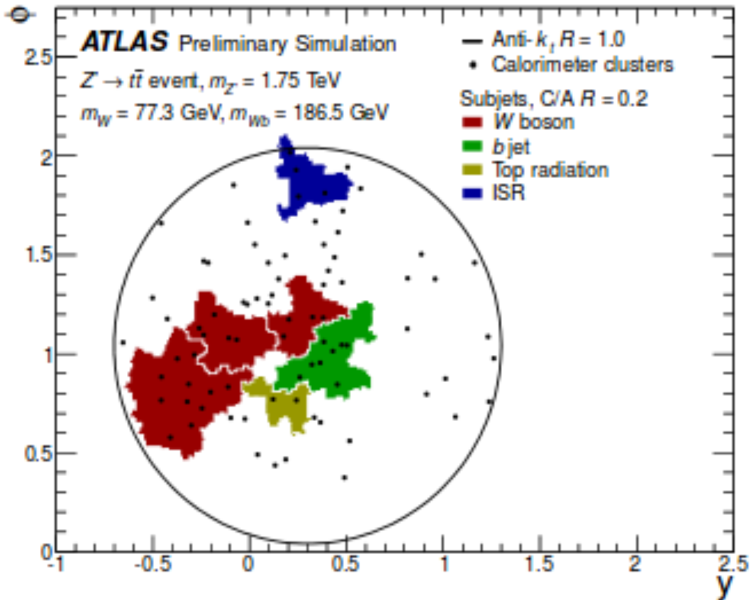
Highlights ATLAS

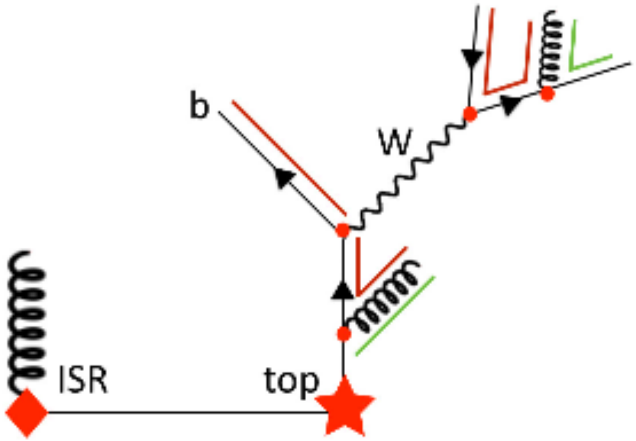
- Top quark production: search new physics
  – Resolved top vs boosted top (important at 13-14 TeV)
  – Boosted topologies: deconstruct shower
  – Make small sub-jets: measure efficiencies

$$pp \rightarrow t\,\bar{t}$$



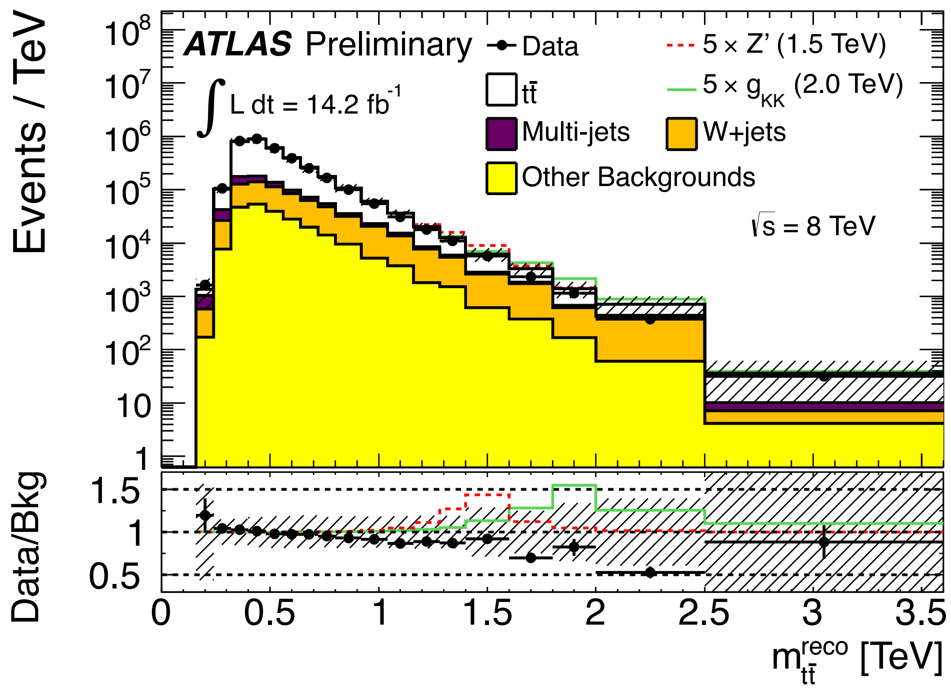


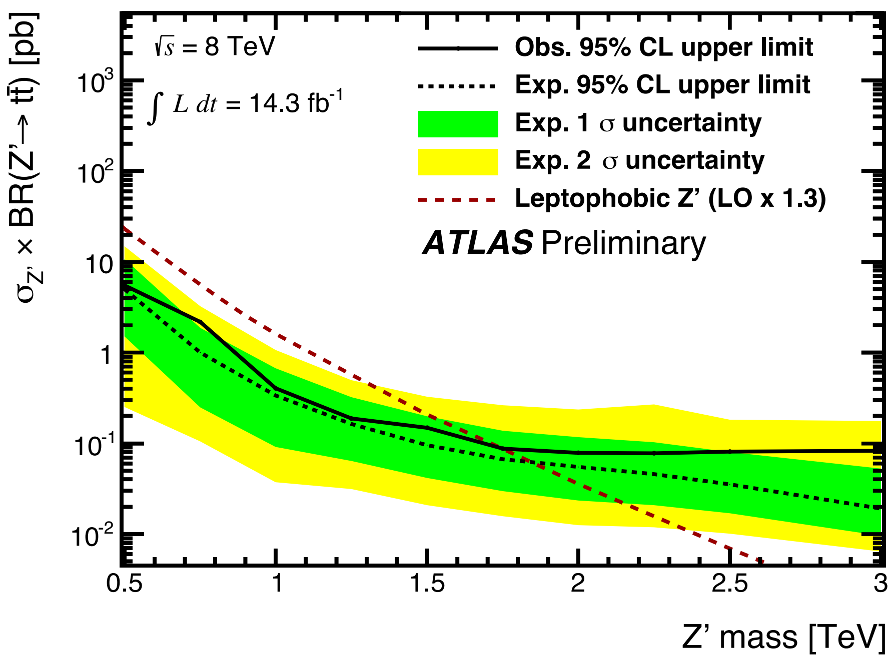




Highlights ATLAS

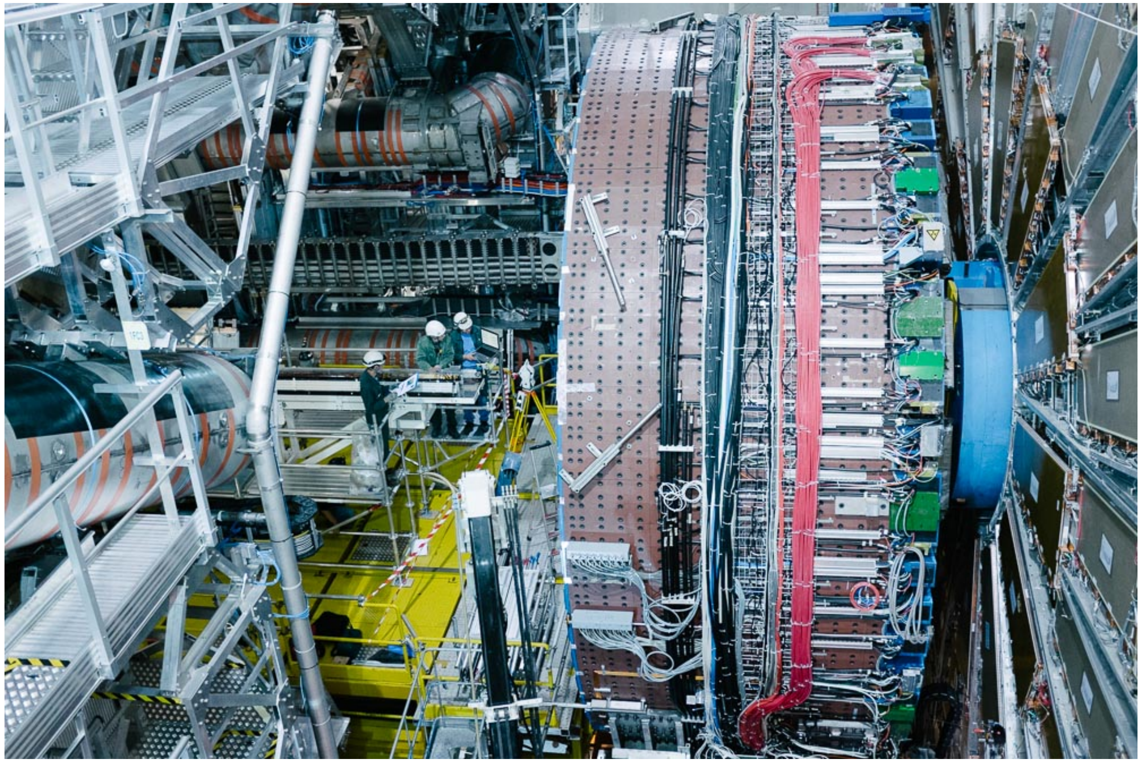
- Top quark production: search new physics
  - Search for resonance peaks in $t\bar{t}$ spectra
  - Results with 7 teV data published PRD 88 (2013) 1, 012004
  - Limits for Z' production at 8 TeV: conference result

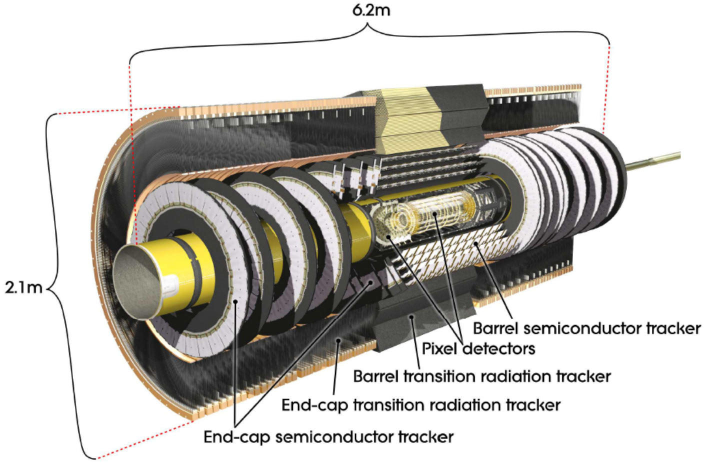




Highlights ATLAS

- Preparation for run 2 (June 2015-July 2018)
- Insertion of B-layer:





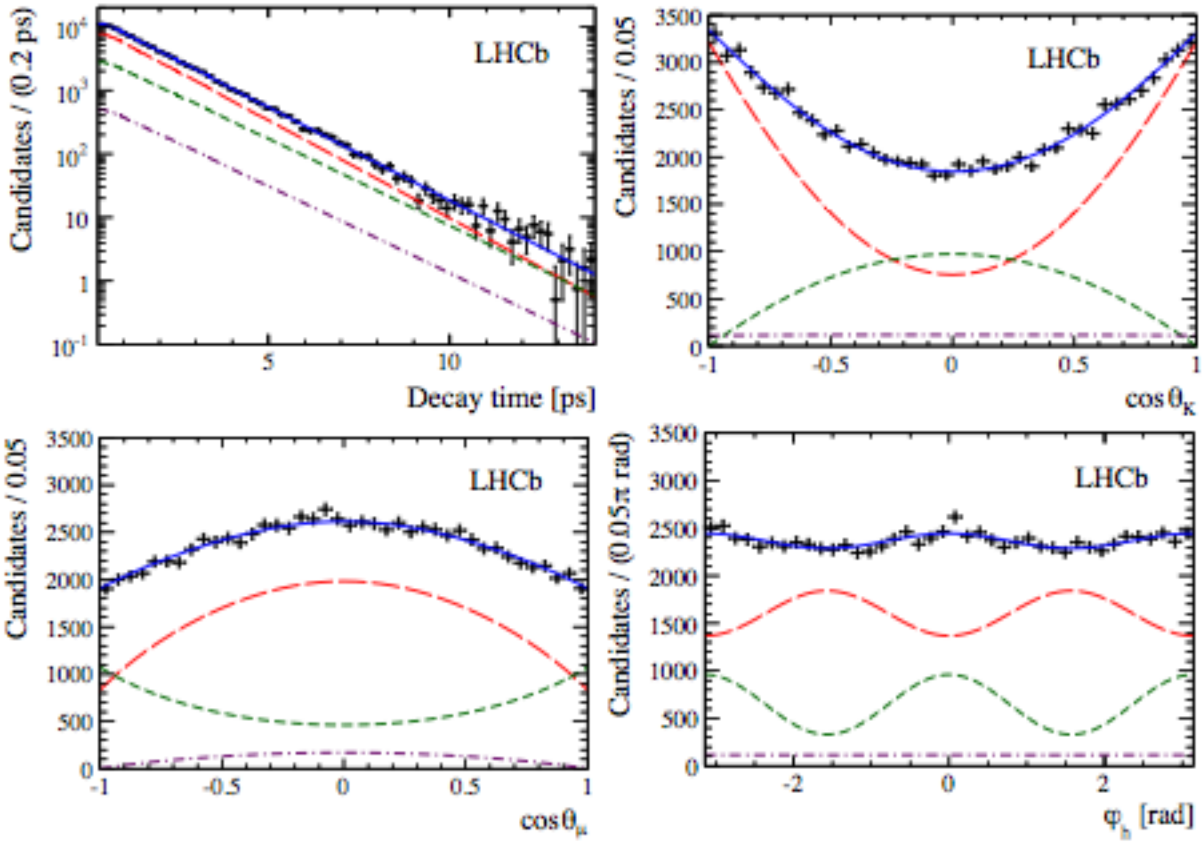
B-layer will improve B-tagging in the 13-14 TeV and high luminosity runs

Highlights LHCb

- CP violation in: $B_s^0 \to J/\psi\, K^+K^-$
  - Determine tiny CP violating phase in B_s^0 decays

$$\phi_s = -0.058 \pm 0.049 \pm 0.006\ rad$$

$$\Delta\Gamma_s = 0.0805 \pm 0.0091 \pm 0.0032\ ps^{-1}$$



World best ϕ_s measurement
Consistent with SM
PRL 114 062004 (2015)

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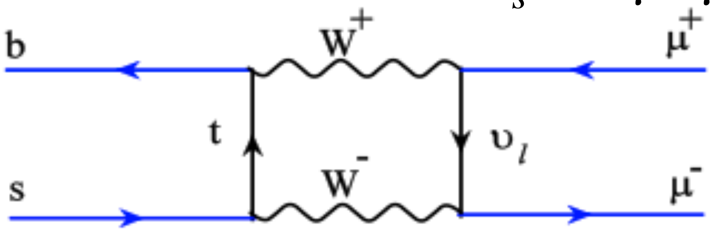
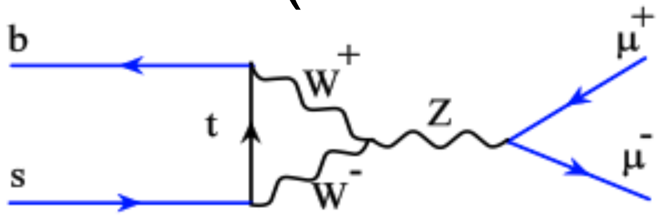
Highlights LHCb

- First evidence for $B_s^0 \to \mu^+\mu^-$ at LHCb (arXiv:1307.5024):



SM box

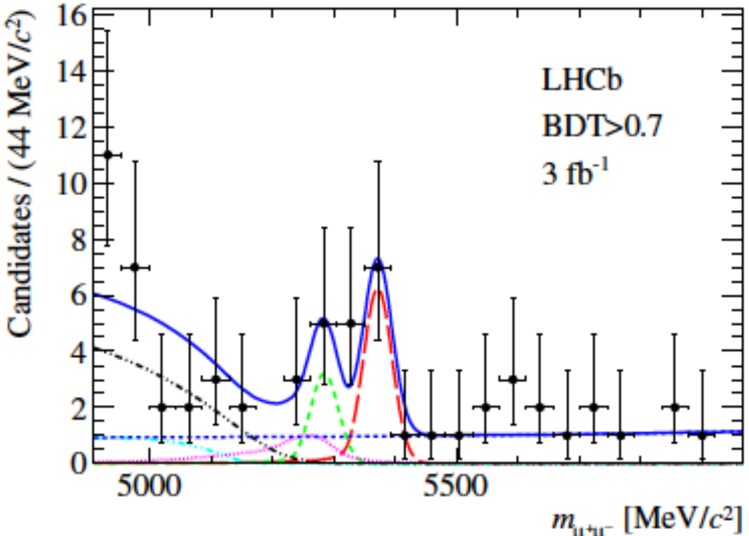


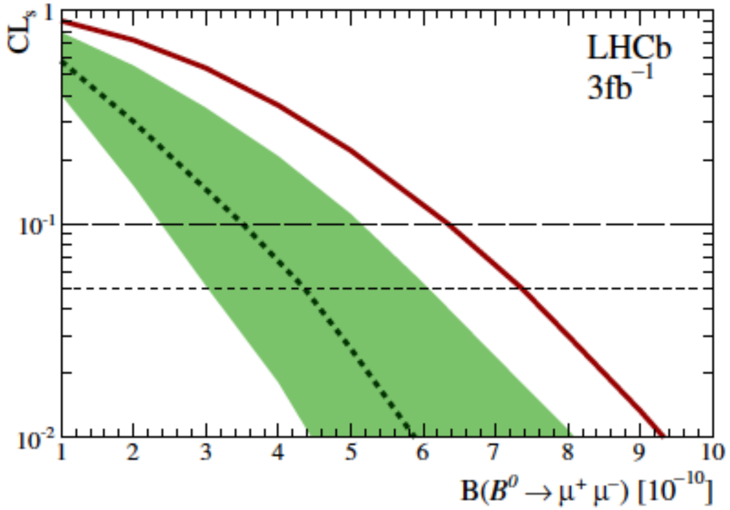
SM Penguin

$$BR(B_s^0 \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}(stat)^{+0.3}_{-0.1}(syst)) \times 10^{-9}$$ (4.0σ)

$$BR(B^0 \to \mu^+\mu^-) < 7.4 \times 10^{-10}\ (95\%\ CL)$$ **PRL 111 (2013) 101805**

Limits non-SM predictions and puts constraints on SUSY models



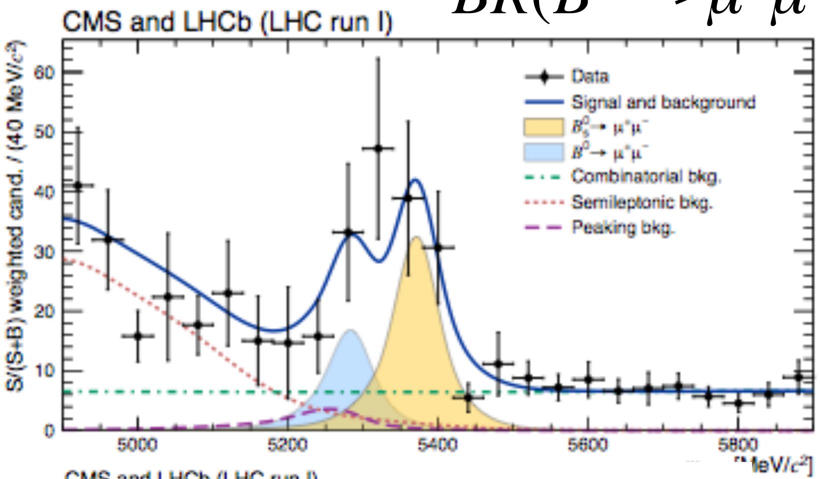


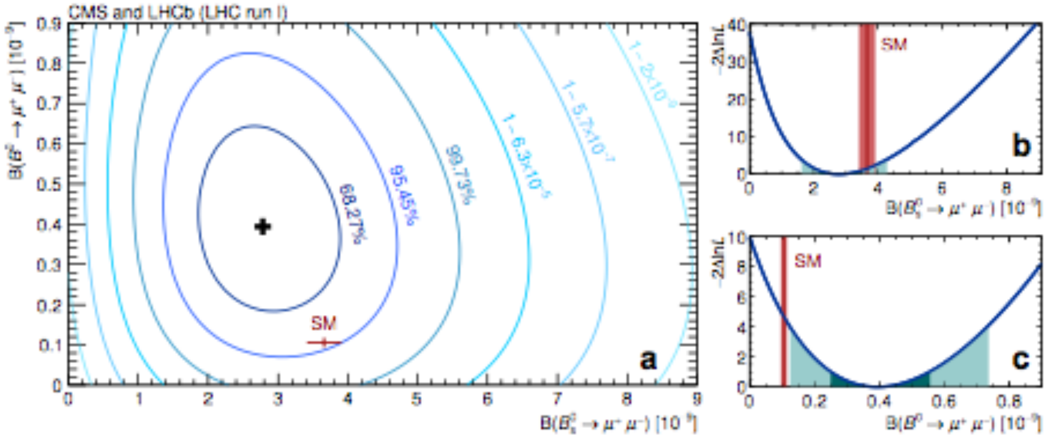
Highlights LHCb

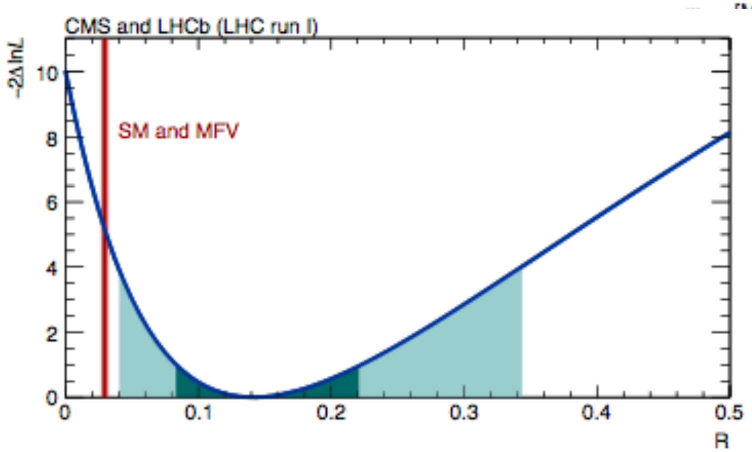
- Combined LHCb and CMS discovery of $B_s^0 \to \mu^+\mu^-$ and first evidence for $B^0 \to \mu^+\mu^-$ (submitted to Nature):

$$BR(B_s^0 \to \mu^+\mu^-) = \left(2.8^{+0.7}_{-0.8}\right)\times 10^{-9} \quad (6.2\sigma)$$

$$BR(B^0 \to \mu^+\mu^-) = \left(3.9^{+1.6}_{-1.4}\right)\times 10^{-10} \quad (3.2\sigma)$$







$$R = \frac{BR(B^0 \to \mu^+\mu^-)}{BR(B_s^0 \to \mu^+\mu^-)} = 0.14^{+0.08}_{-0.06}$$

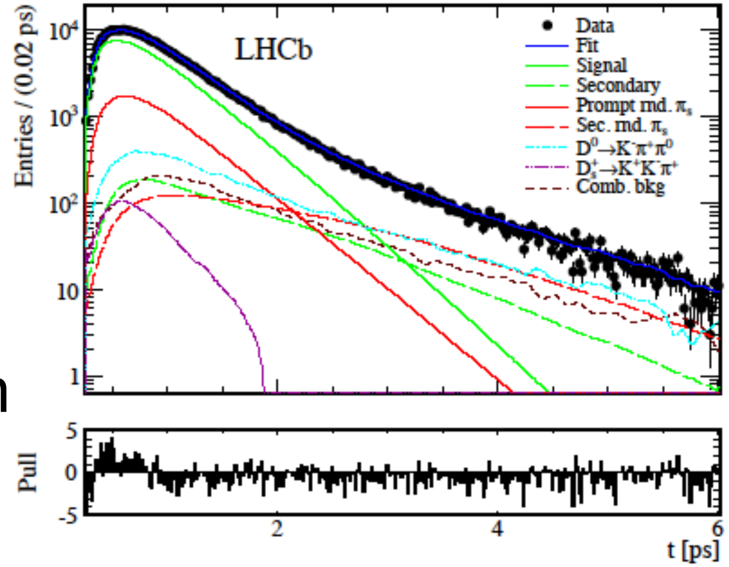
(2.3σ from SM)

Highlights LHCb

- Search for CP violation in charm sector
  - Predicted to be very small in Standard Model
  - Two quantities: y_{CP} and A_Γ

$$y_{CP} \equiv \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D \to K^+K^-)} - 1 \qquad \tau(D^0 \to K^-\pi^+) = 410.2 \pm 0.9\ fs \qquad \tau(D^0 \to K^+K^-) = 408.0 \pm 2.4\ fs$$

$$y_{CP} = (5.5 \pm 6.3 \pm 4.1) \times 10^{-3}$$



  - Best limits on CP violation in charm from 1.0 fb-1 2011 7 TeV data

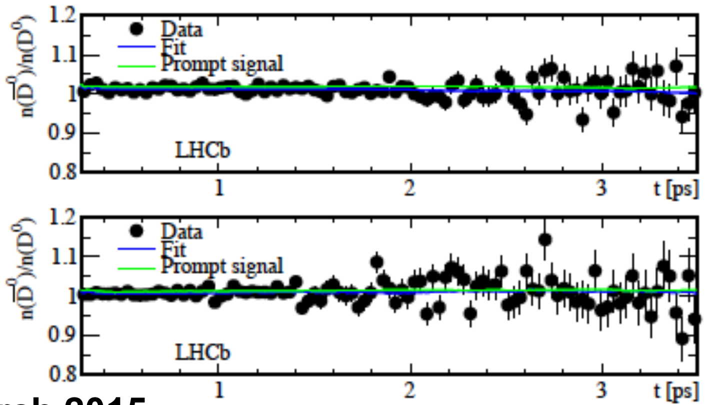
PRL 112 (2014) 041801

$3.11 \times 10^6\ D^0 \to K^-K^+$ events

$1.03 \times 10^6\ D^0 \to \pi^-\pi^+$ events

Tagging: $D^{*+} \to D^0\pi^+$

$$A_\Gamma \equiv \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}} \qquad A_\Gamma(KK) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3} \qquad A_\Gamma(\pi\pi) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

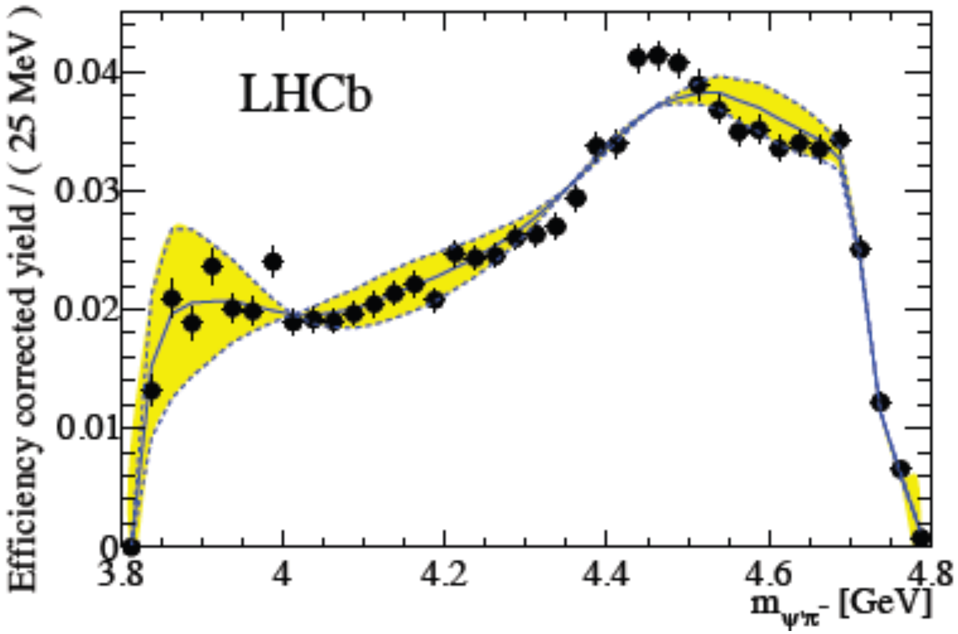


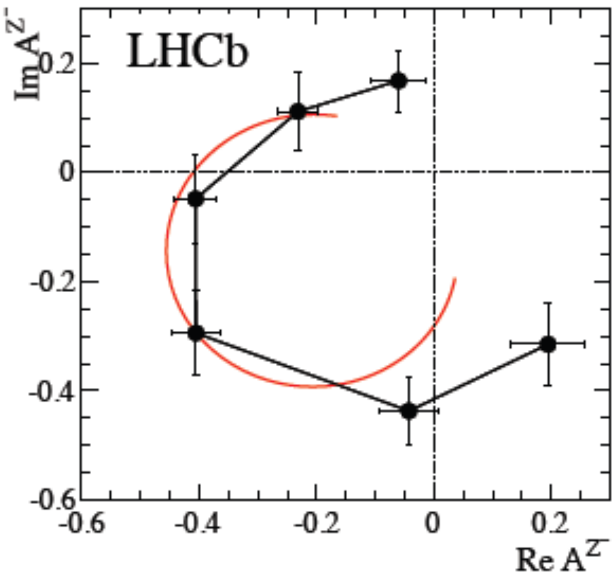
Highlights LHCb

- Establish existence of Z(4430)$^-$: new tetraquark state in $B^0 \to \psi' \pi^- K^+$ with 13.9σ significance

$$m_Z = 4475 \pm 7^{+15}_{-25}\,MeV \quad \Gamma_Z = 172 \pm 13^{+37}_{-34}\,MeV \quad J^P = 1^+ \text{ at } 9\sigma$$

- Established resonant structure:





PRL 112 222002 (2014)

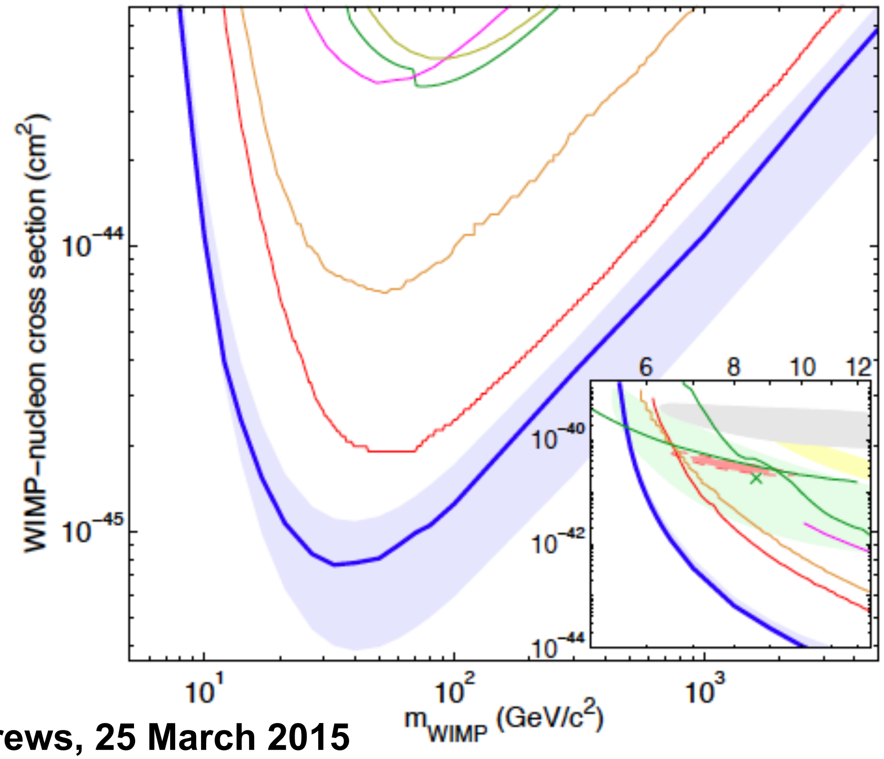
Argand diagram: Z$^-$ amplitude phase vs resonant mass
Demonstrates resonance structure of "tetraquark" $\psi'\pi^- \to c\bar{c}u\bar{d}$

Highlights Dark Matter search

- Astroparticle Physics: interdisciplinary field between particle physics, nuclear physics and astronomy
- First results from LUX dark matter search: most sensitive search for dark matter to date

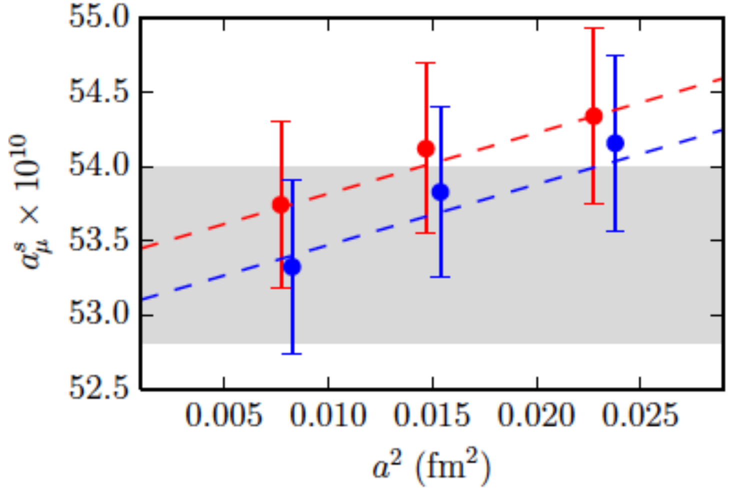
PRL 112 091303 (2014)

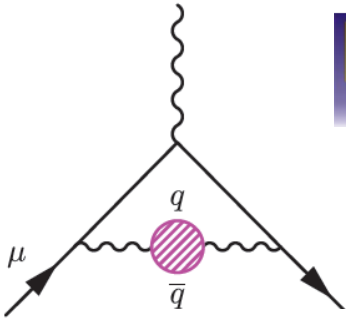
Spin-independent cross-section



Highlights Lattice QCD

- (g-2) for muon shows hints of new physics
  - Better theory needed for new expt (E989@FNAL)
  - New method with s,c quark contributions: 1% accuracy



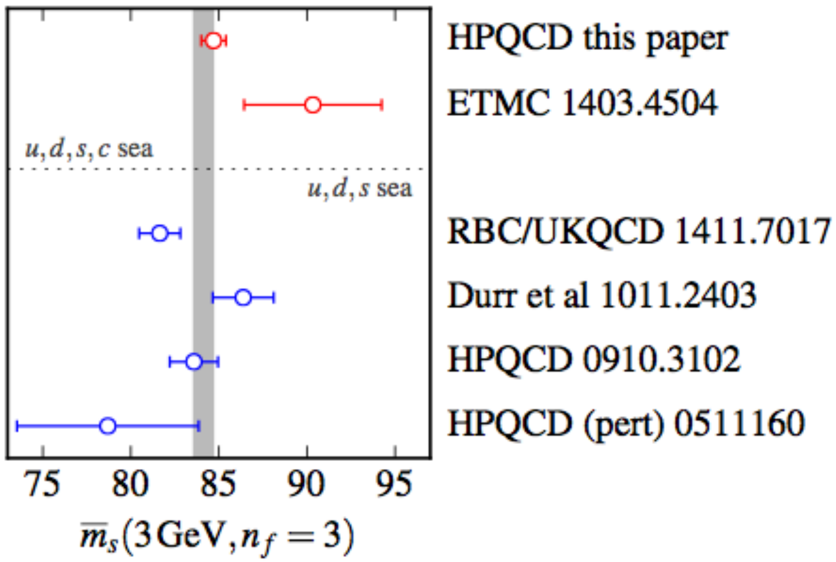


HPQCD

arXiv: 1403.1778

- World's best determination c, s quark masses from lattice QCD

arXiv: 1408.4169 – editor's choice PRD

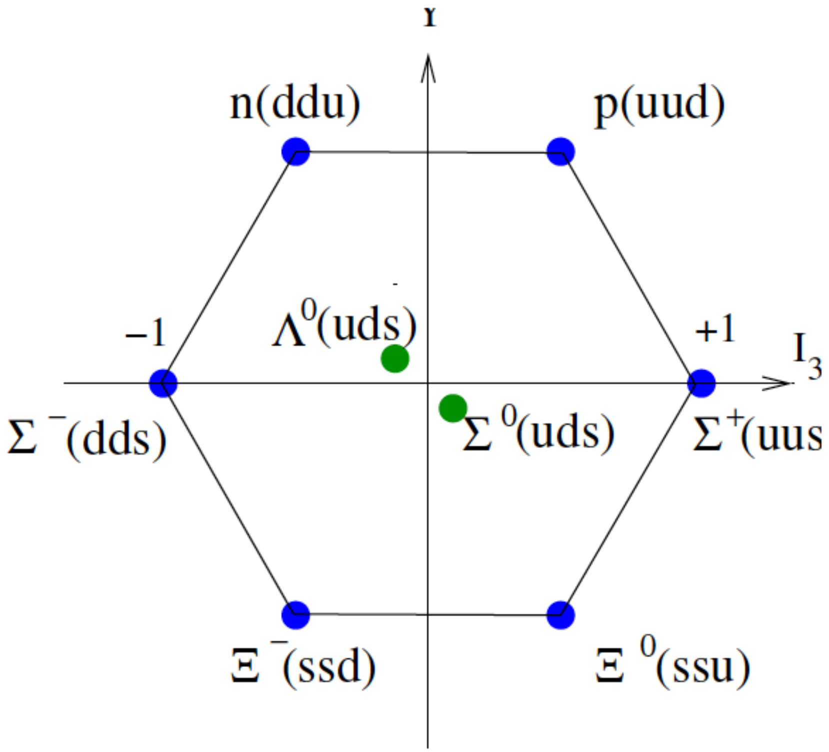


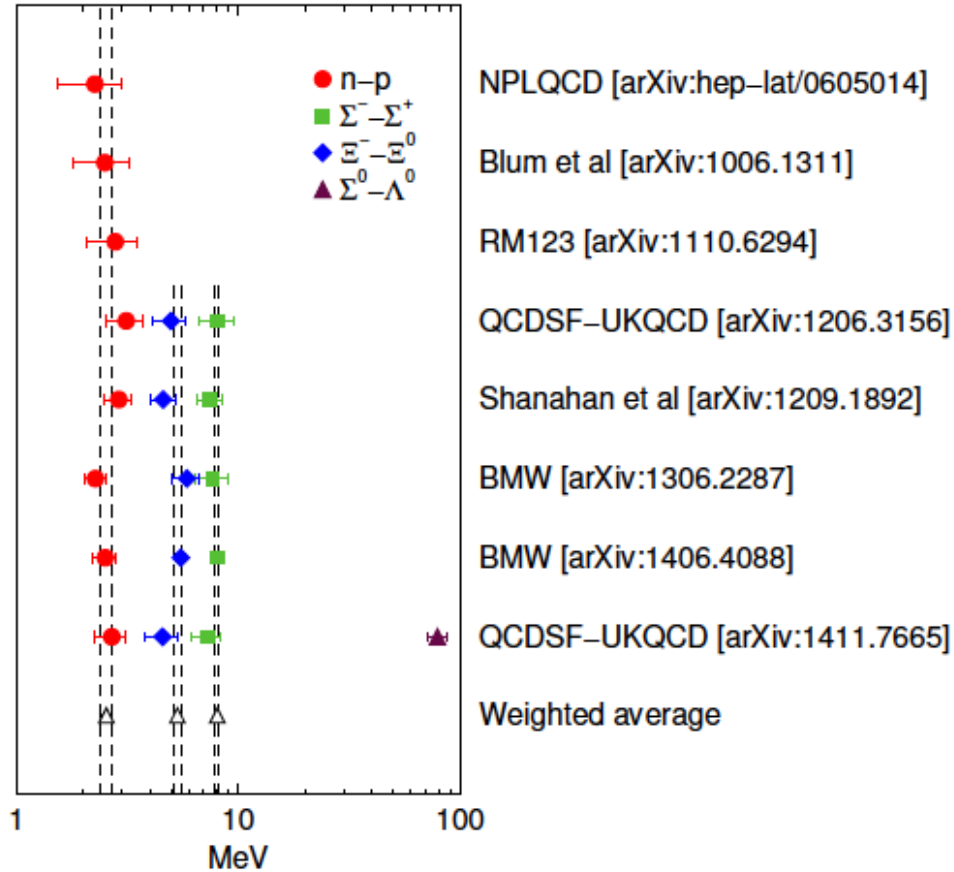
Highlights Lattice QCD

- Baryon mass splittings

arXiv: 1403.1778

  – n-p mass splitting has profound effect on evolution universe
  – QCD contribution to interplay of u-d quark mass difference

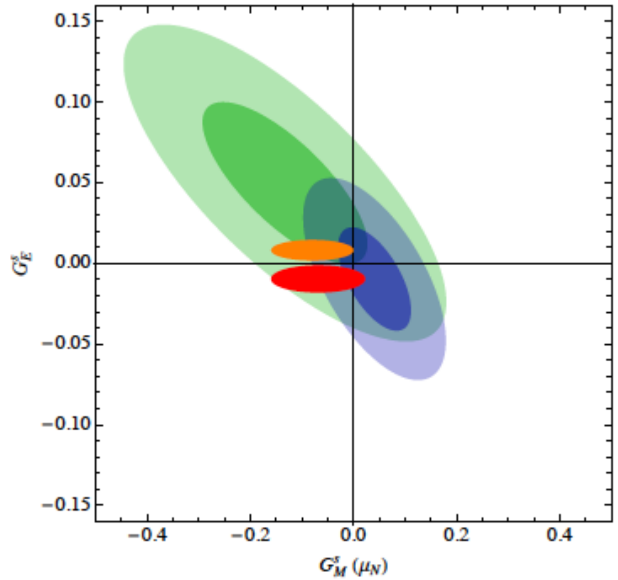




Highlights Lattice QCD

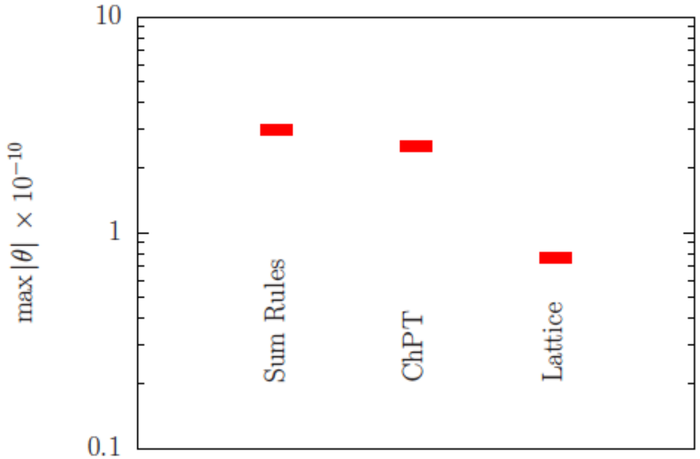
- Strange nucleon form factors
  - Strange quark contribution to nucleo
  - CSSM-QCDSF-UKQCD (orange, red ellipses)
  - Experiments: A4, G0 (green, blue ellipses)

arXiv: 1403.6537



- Electric dipole moment of neutron
  - Probe physics beyond SM
  - QCDSF-UKQCD arXiv: 1502.02295
  - Using experimental result for dipole moment, it constrains CP violating terms in action

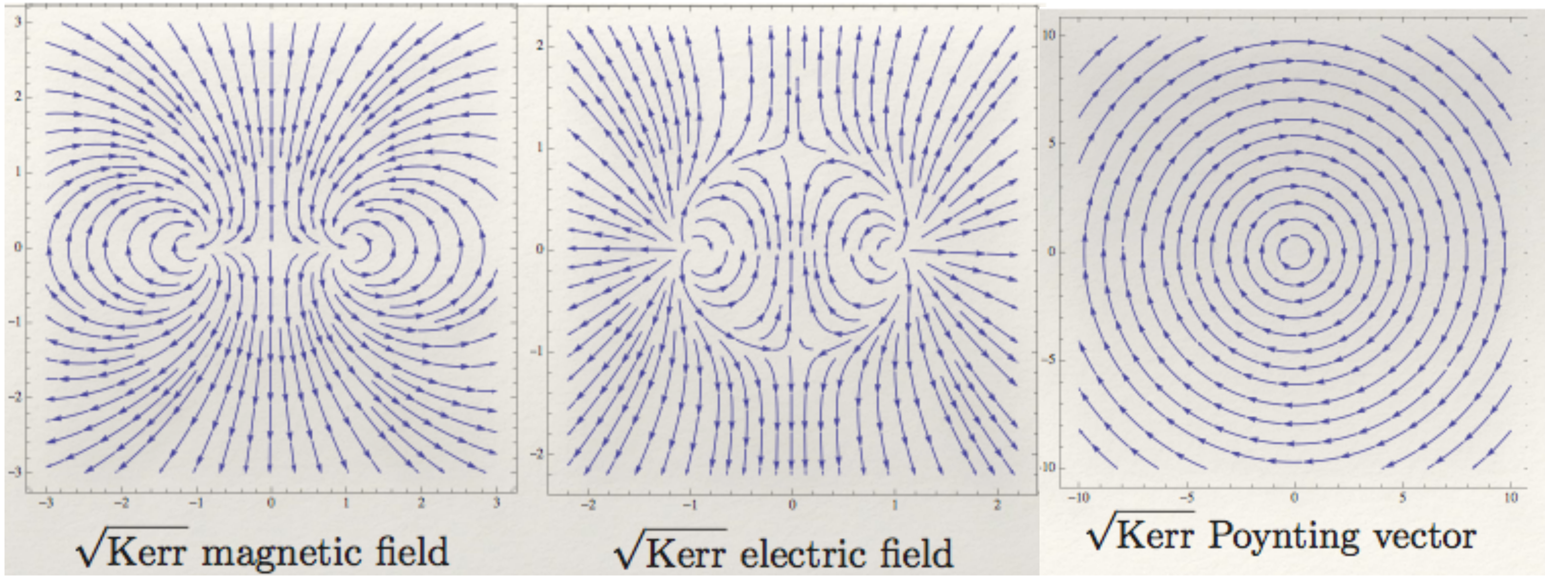
$$|\theta| \leq 7.6 \times 10^{-11}$$



Amplitudes and black holes

- ❑ "BCJ" Conjecture: **arXiv: 1410.0239**
  - Double copy between gauge theory and gravity amplitudes
  - Demonstrated that this relationship extends to non-perturbative solutions of the field equations, not just amplitudes:
    - Example: "square root" of Kerr black hole

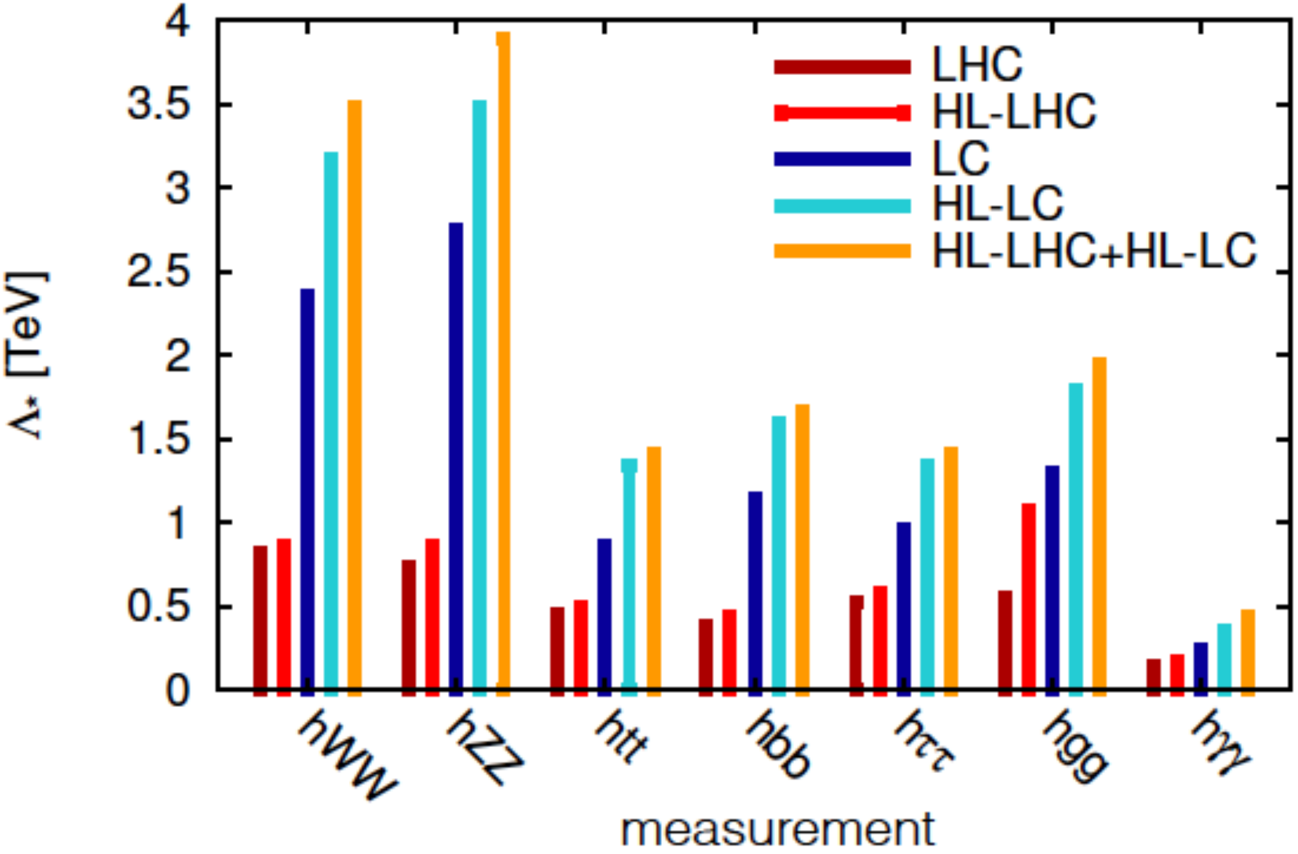
      Ricardo Monteiro (Oxford), Donal O'Connell (Edinburgh), Chris White (Glasgow)



Highlights Phenomenology

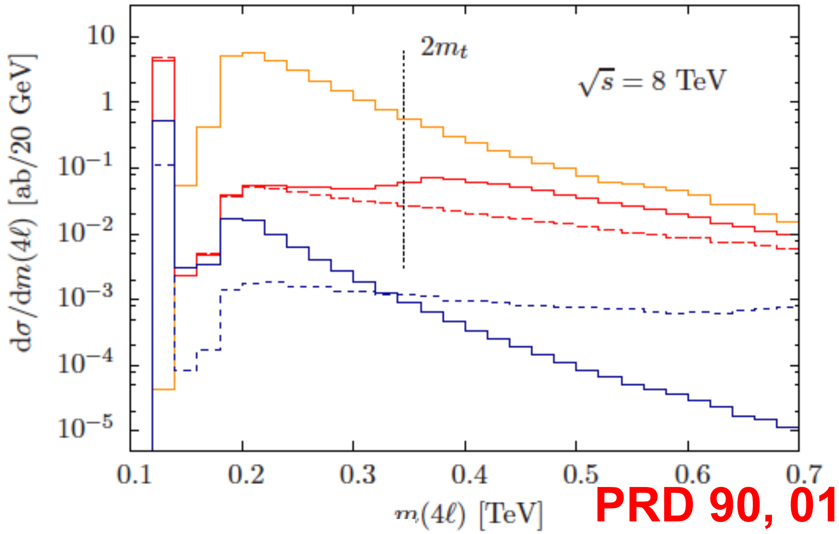
- Studies of impact of new phenomena beyond the SM from detailed Higgs coupling measurements:
  - New physics scale

C. Englert et al. (selected by J. Phys. G Nuc. & Part. highlights of 2014)



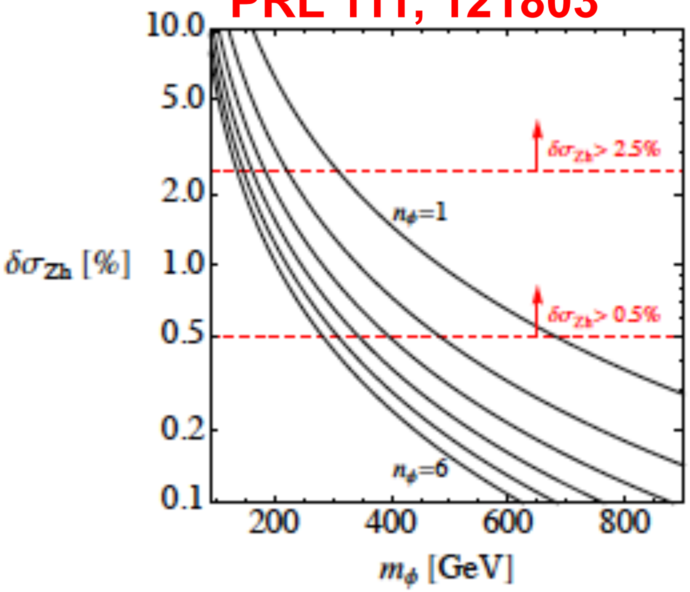
Highlights Phenomenology

- Novel ways to study the electroweak scale hierarchy problem and Higgs coupling properties at present and future collider experiments

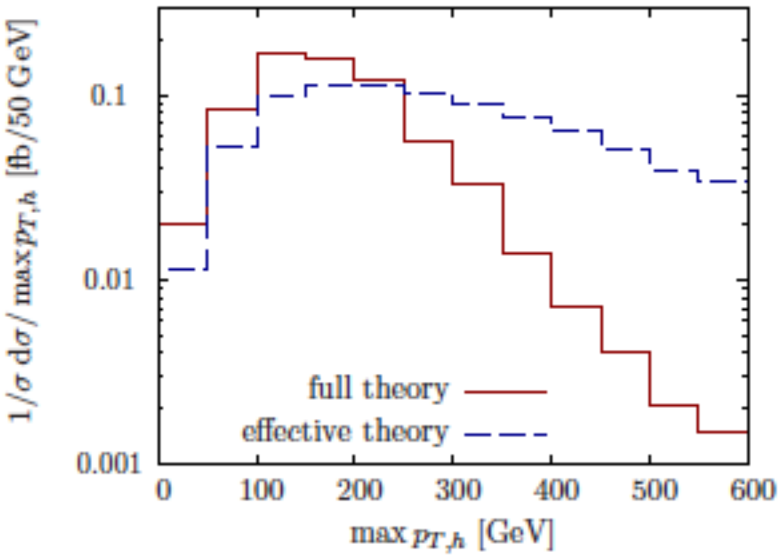


PRD 90, 013010
Editor's choice

PRL 111, 121803



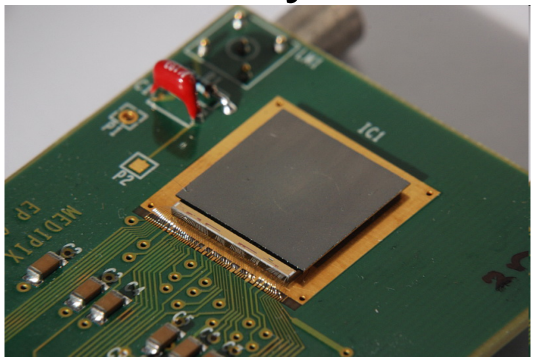
PRL 112, 013013

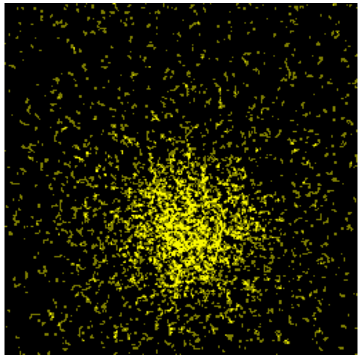


Research highlight Nature Physics

Knowledge Exchange

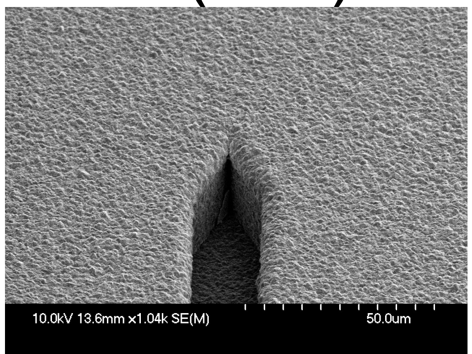
- Dima Maneuski: STFC Enterprise Fellow
  - Medipix dosimetry for radiopharmaceutical production (^{18}F-FDG system at Gartnavel Hospital cyclotron)





100 times more sensitive than conventional dosimeters

  - Other: Cyclotron Research Centre (Liege), wakefield acceleration (Strathclyde), electron backscatter diffraction
- STFC Innovation Partnership Scheme (IPS) – R Bates
  - Manufacture test probes using nanofabrication techniques
  - Seeded by SUPA innovation award



Conclusions

- Achievements in 2014-15 include:
  - ATLAS: SM Higgs being slowly confirmed
  - LHCb: rare decays and CP violation confirm SM, set strict SUSY limits
  - Dark matter: LUX most sensitive search
  - Lattice QCD: sub-percent accuracies
  - Theory: powerful relationship between QCD “field theory” and gravitation (new calculational tools)
  - Phenomenology: Higgs data sets new limits to beyond SM physics and new ways to interpret LHC data
  - Impact: Medipix KE success story and industrial partnerships