Research activities in the University of Cambridge HEP group

Nick Barlow

University of Cambridge

CoEPP Workshop

Cairns, 10th July 2013

CoEPP

ARC Centre of Excellence for Particle Physics at the Terascale

UNIVERSITY OF CAMBRIDGE

Disclaimer

- Far too much potential material to do justice to in 25 minutes..
- Content slightly biased by quantity and timing of material I was sent.

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Contents

ATLAS
- SCT
- L1Calo
- Simulation
- SUSY
- Exotics
- Standard Model
- Misc.

ATLAS upgrade
- SCT upgrade

LHCb
- RICH
- Electroweak
- CP violation
- Rare decays

Medical applications

Neutrino physics
- MINOS
- LBNE

ILC detector R&D
- Particle flow

Theory/phenomenology
- BSM physics
- MC generators
- PDFs

Cambridge

Cambridge


Cambridge is here
We are here
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Svalbard (Nor.)
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United States of America
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Norway
Sweden
Finland
Iceland
United Kingdom
Ireland
Denmark
Estonia
Latvia
Belarus
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- Over 18,000 students.
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- Many famous physicists:
  - Newton, Rutherford, Dirac, …

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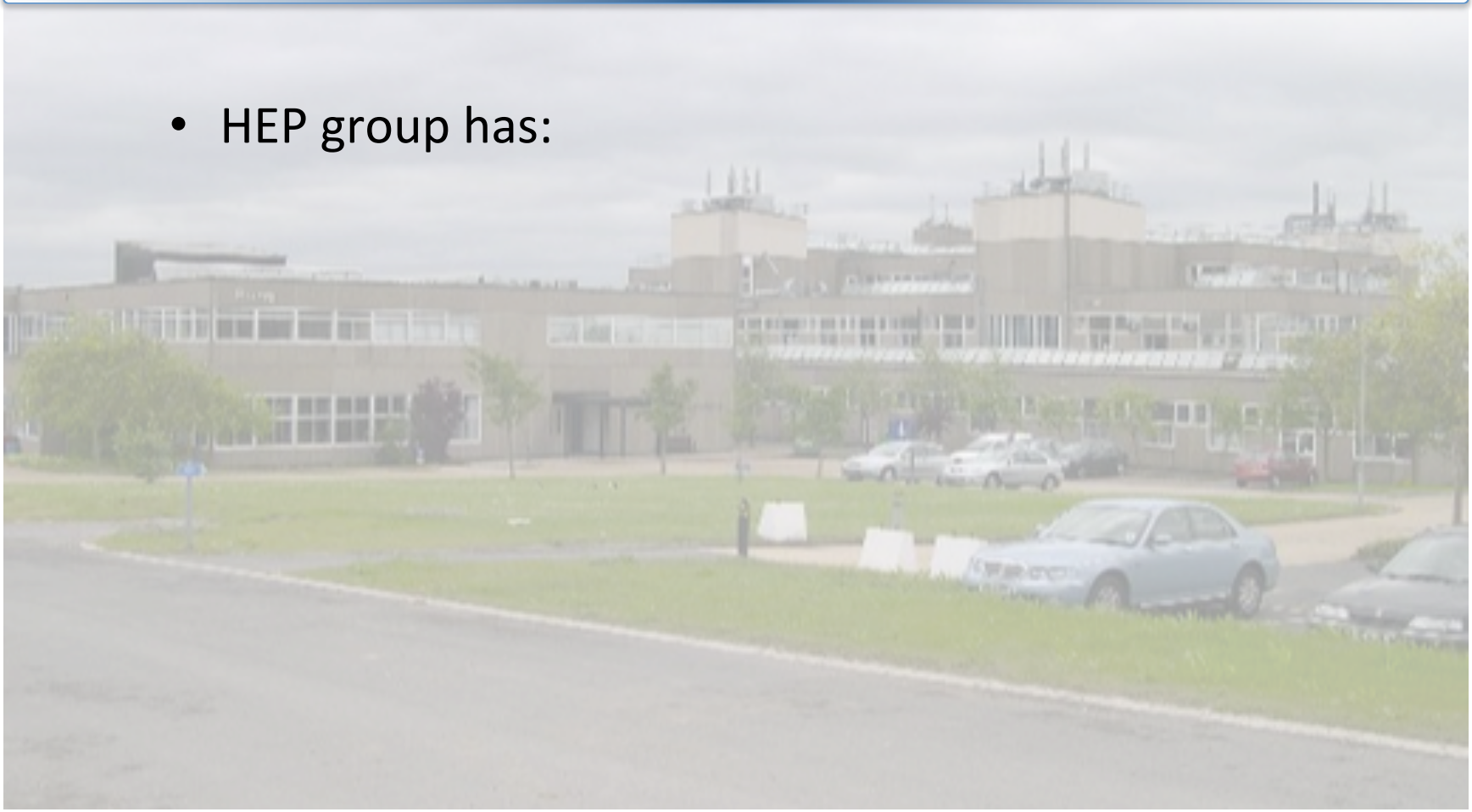
- Physics department is based in the Cavendish Laboratory…..

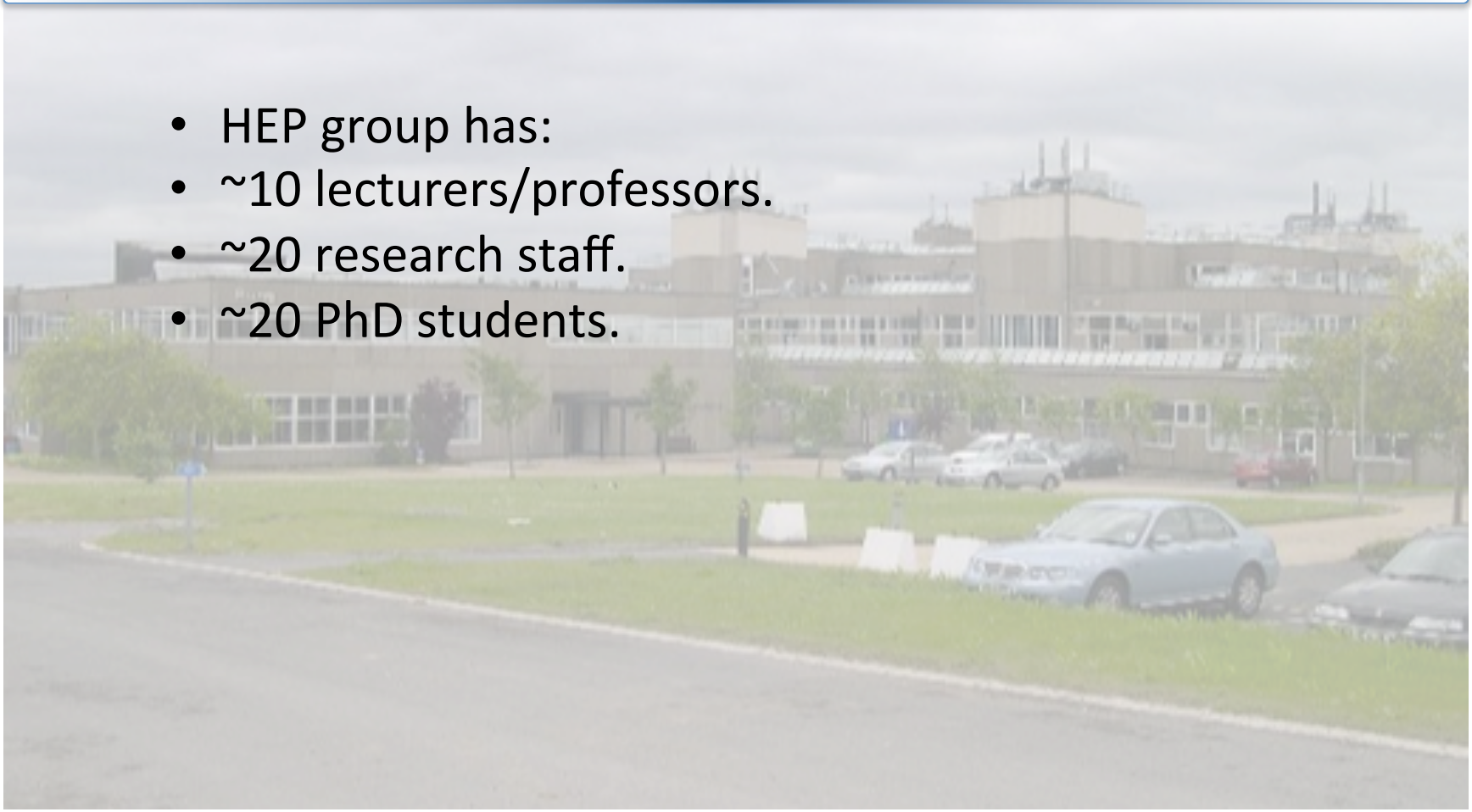
Physics department

Physics department/HEP group



- HEP group has:

Physics department/HEP group



- HEP group has:
- ~10 lecturers/professors.
- ~20 research staff.
- ~20 PhD students.

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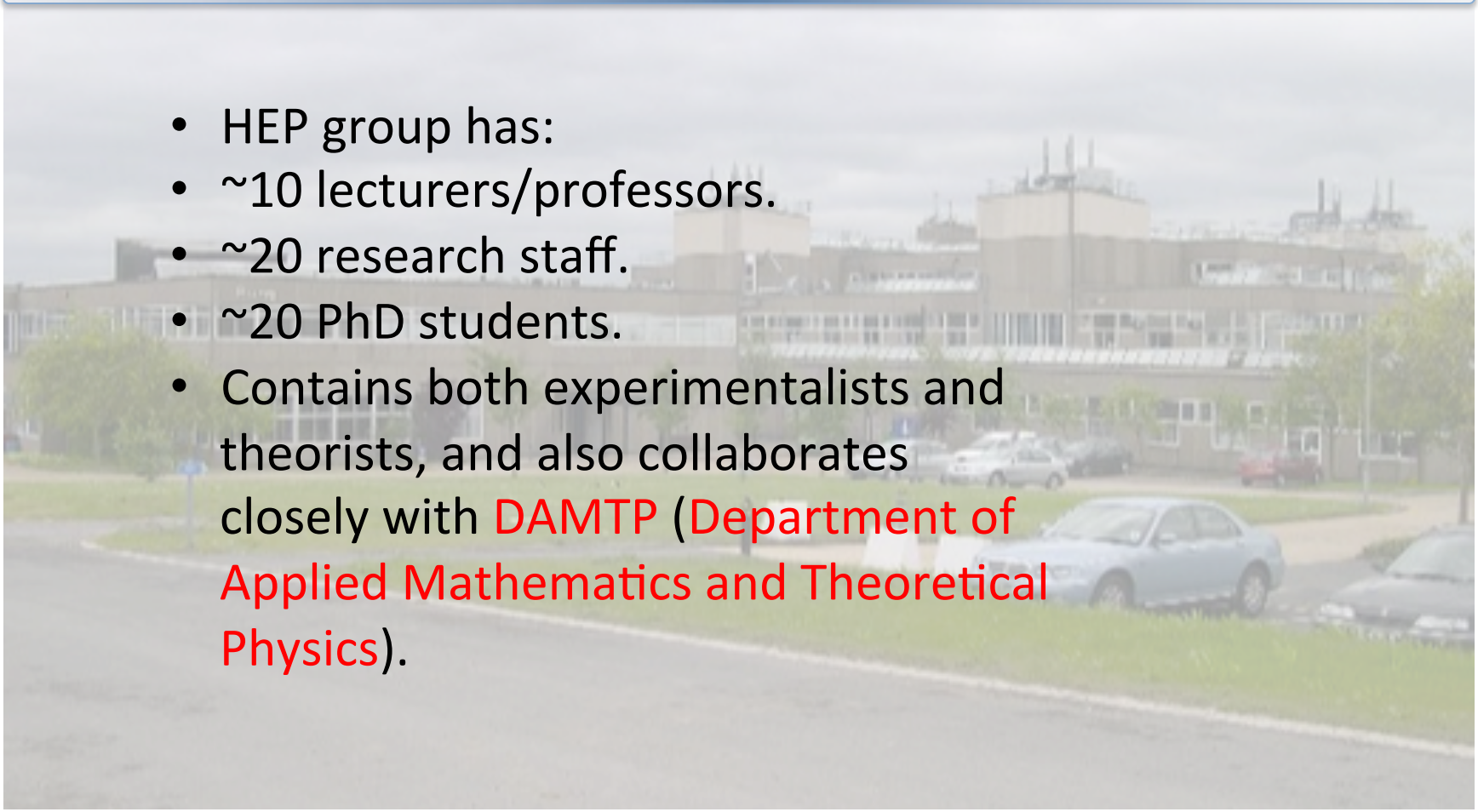

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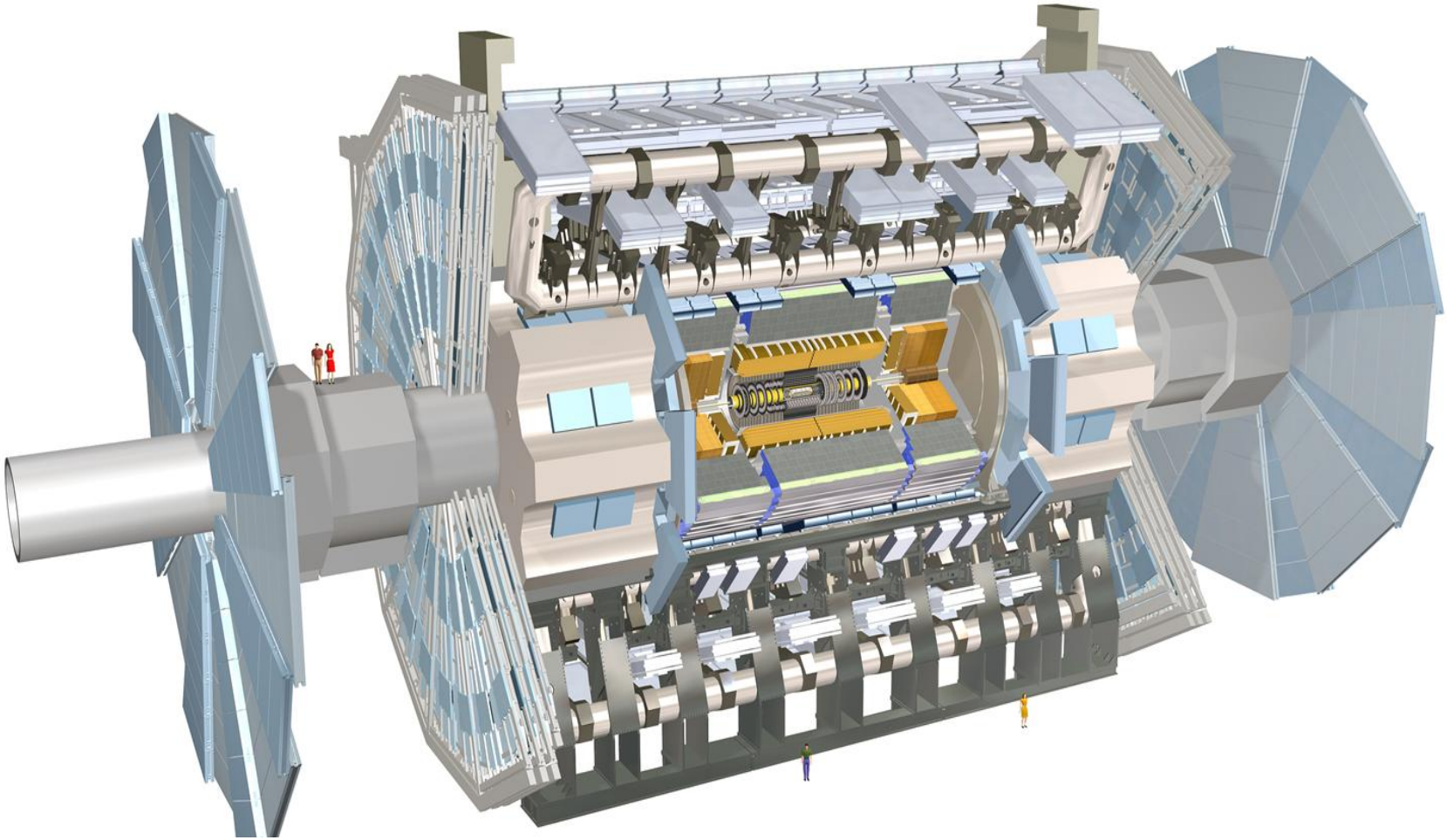
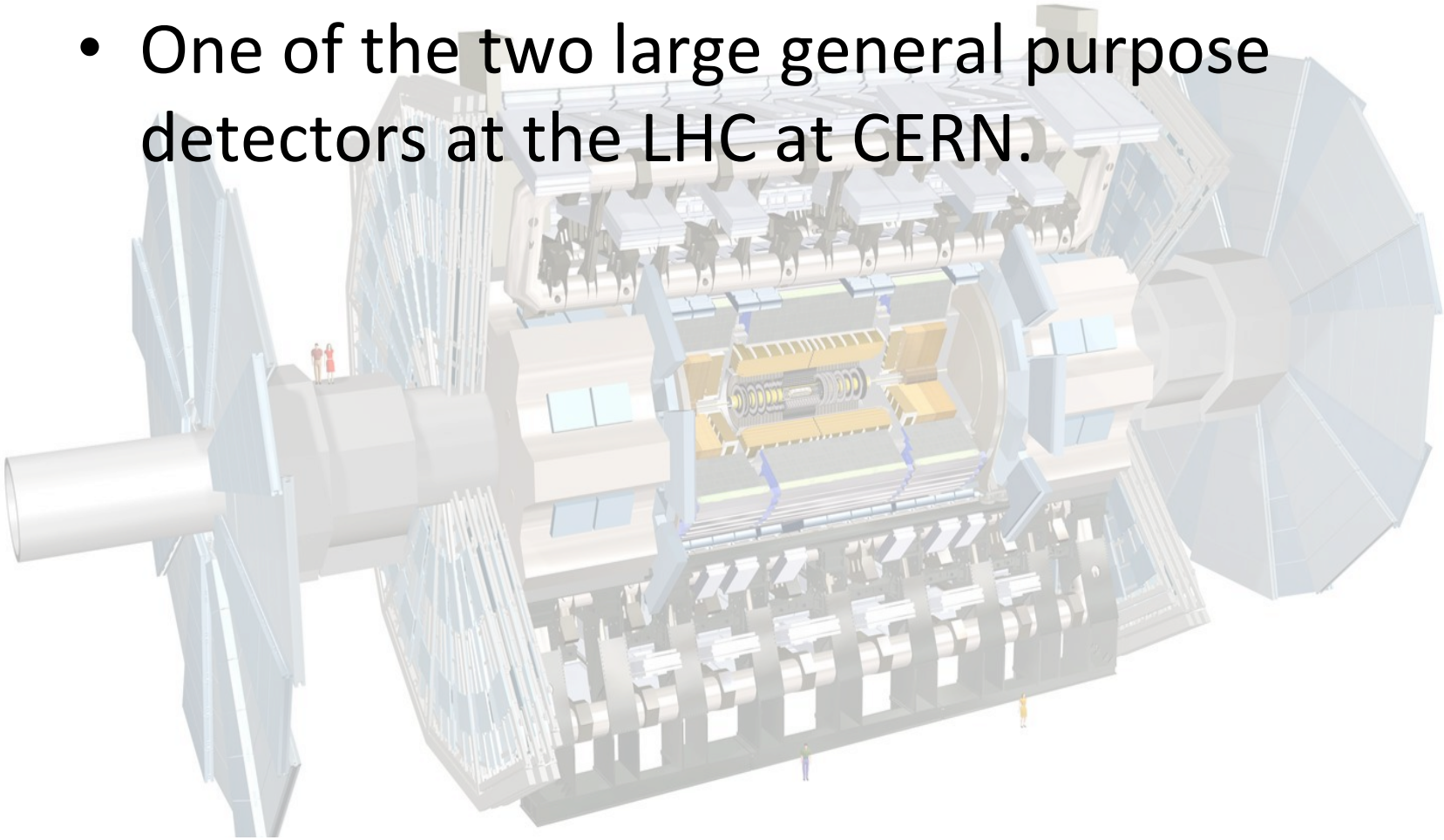
- Contains both experimentalists and theorists, and also collaborates closely with DAMTP (Department of Applied Mathematics and Theoretical Physics).

ATLAS



ATLAS

- One of the two large general purpose detectors at the LHC at CERN.



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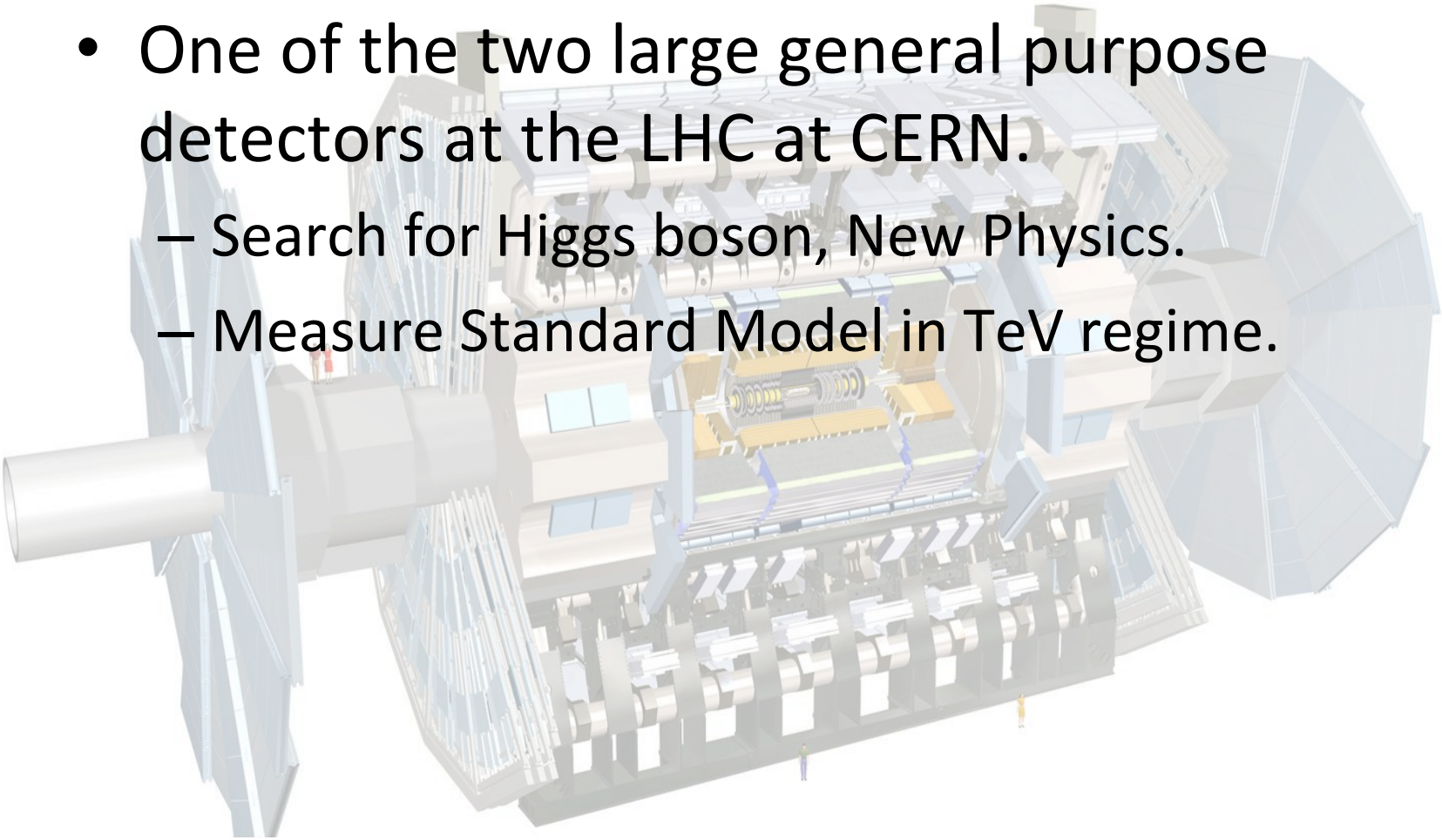

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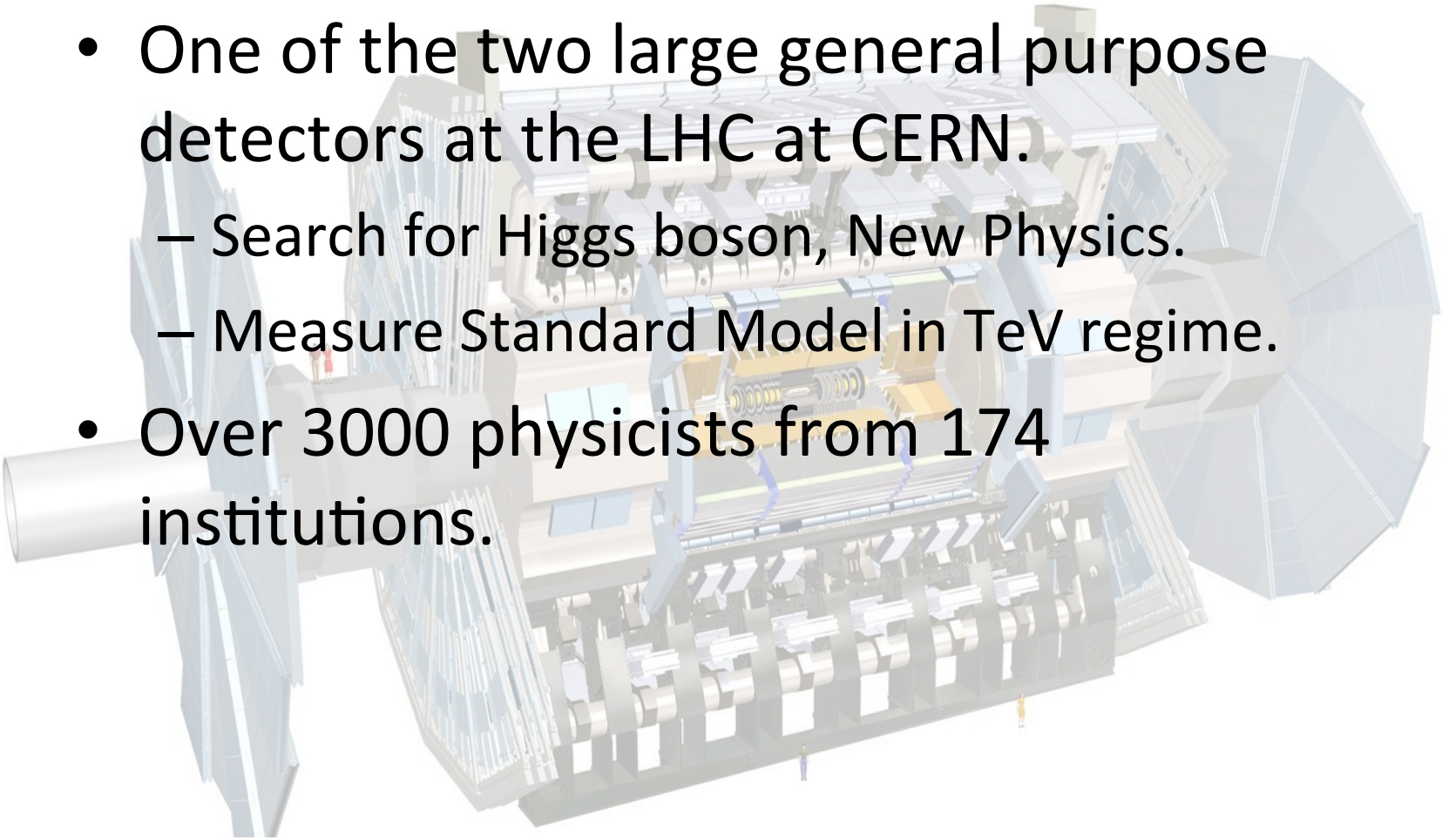

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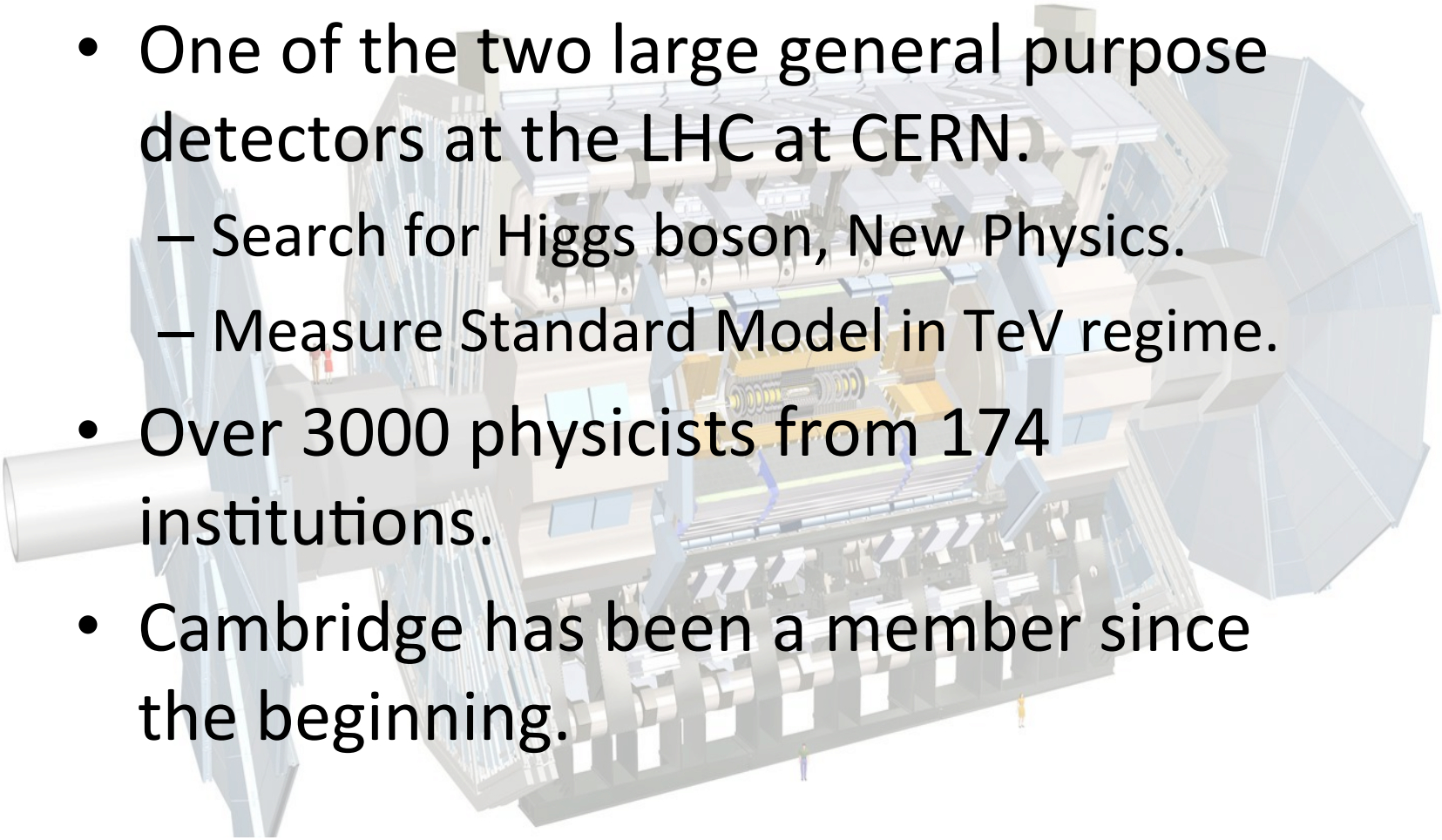
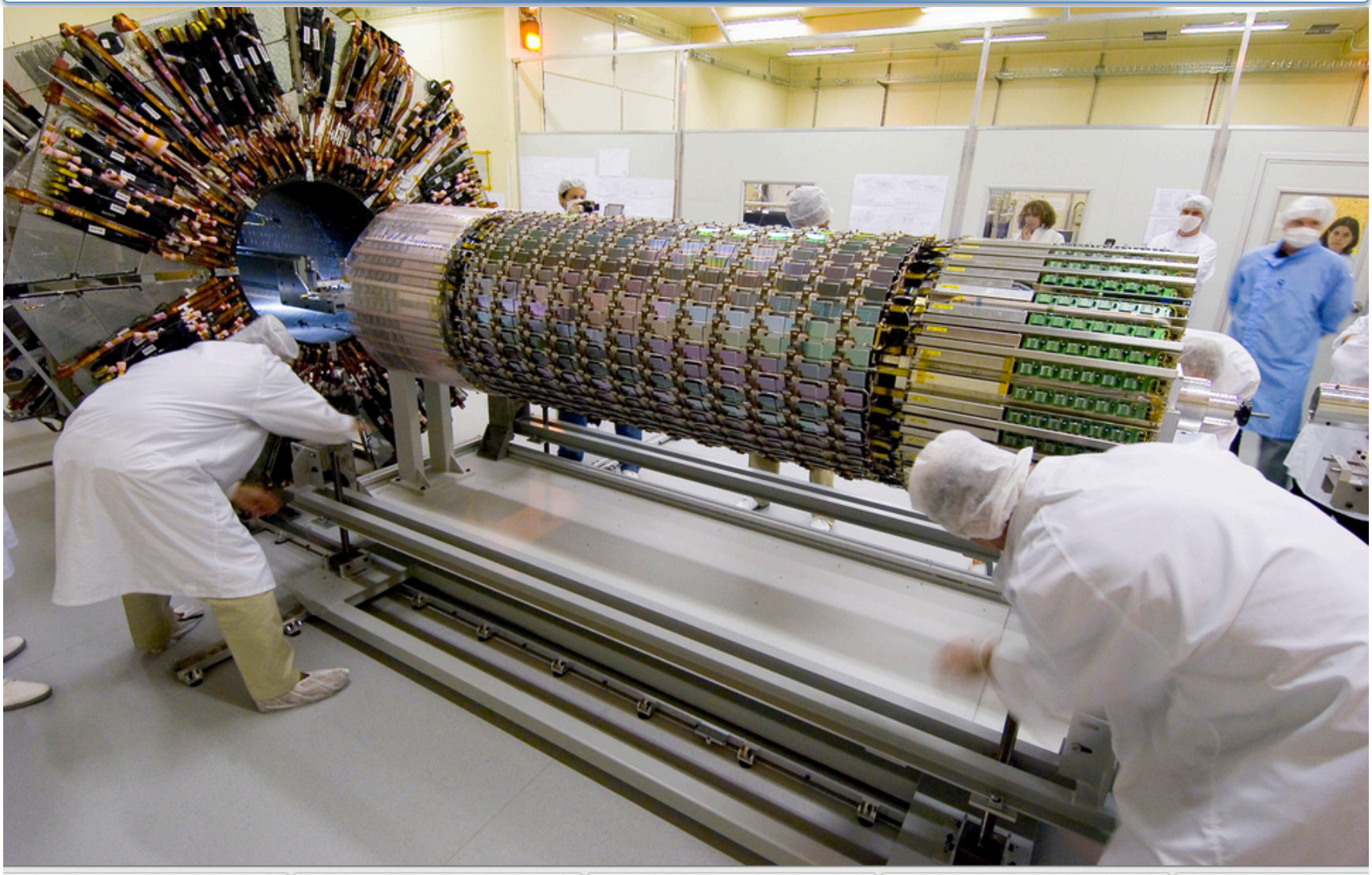
- Cambridge has been a member since the beginning.



ATLAS Semiconductor Tracker (SCT)



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- Silicon strip tracking detector.

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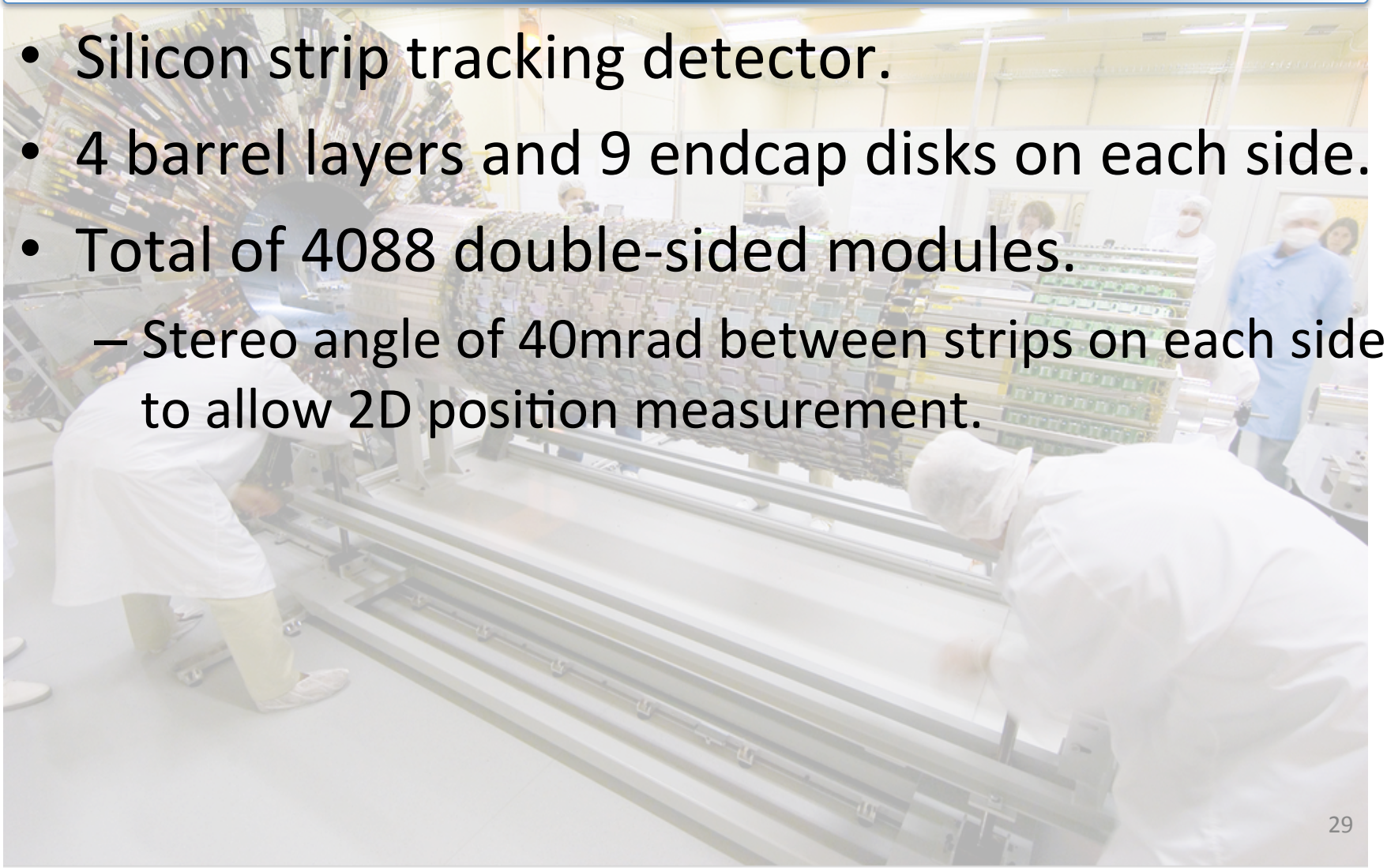

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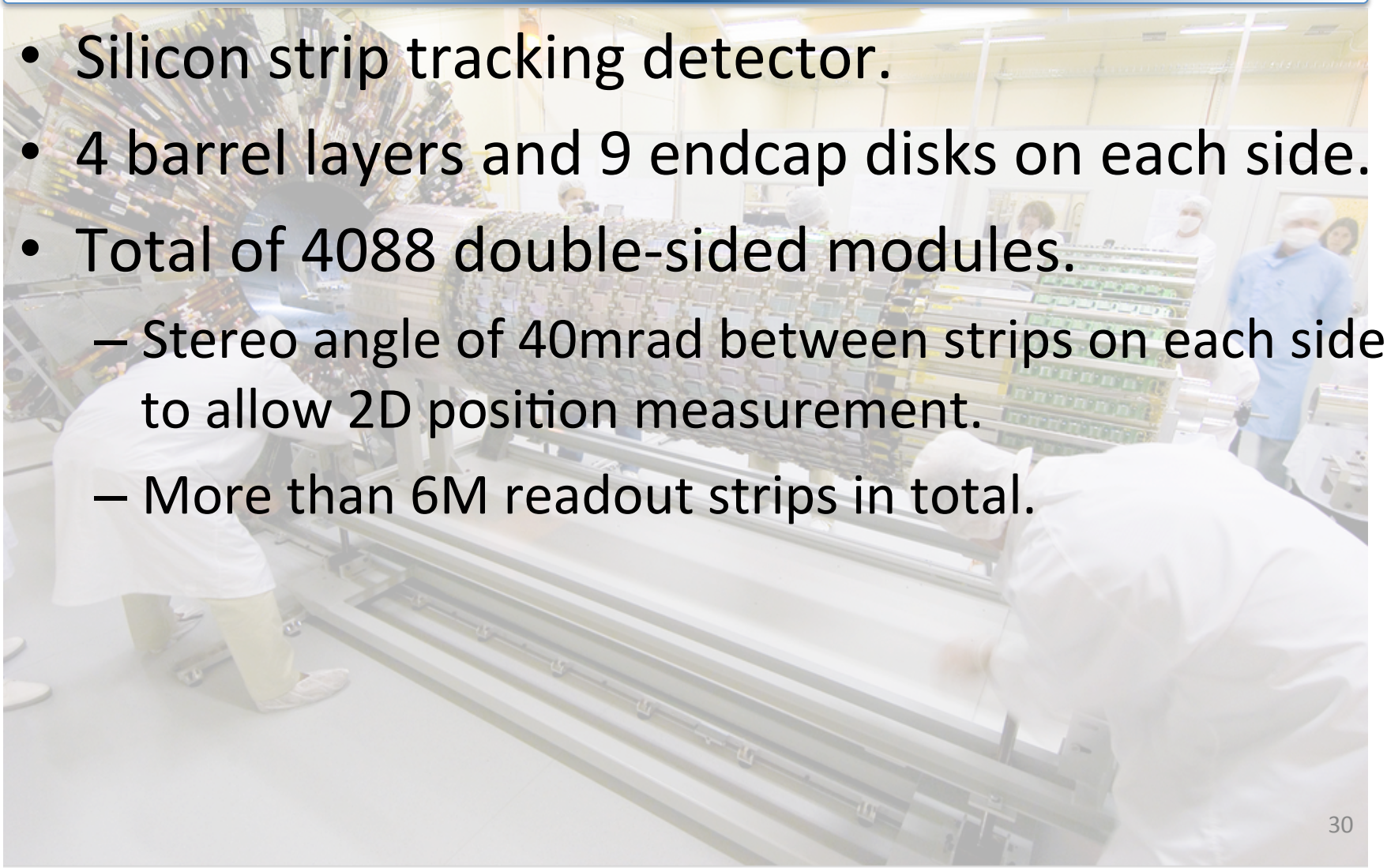

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Major Cambridge involvement in several areas!

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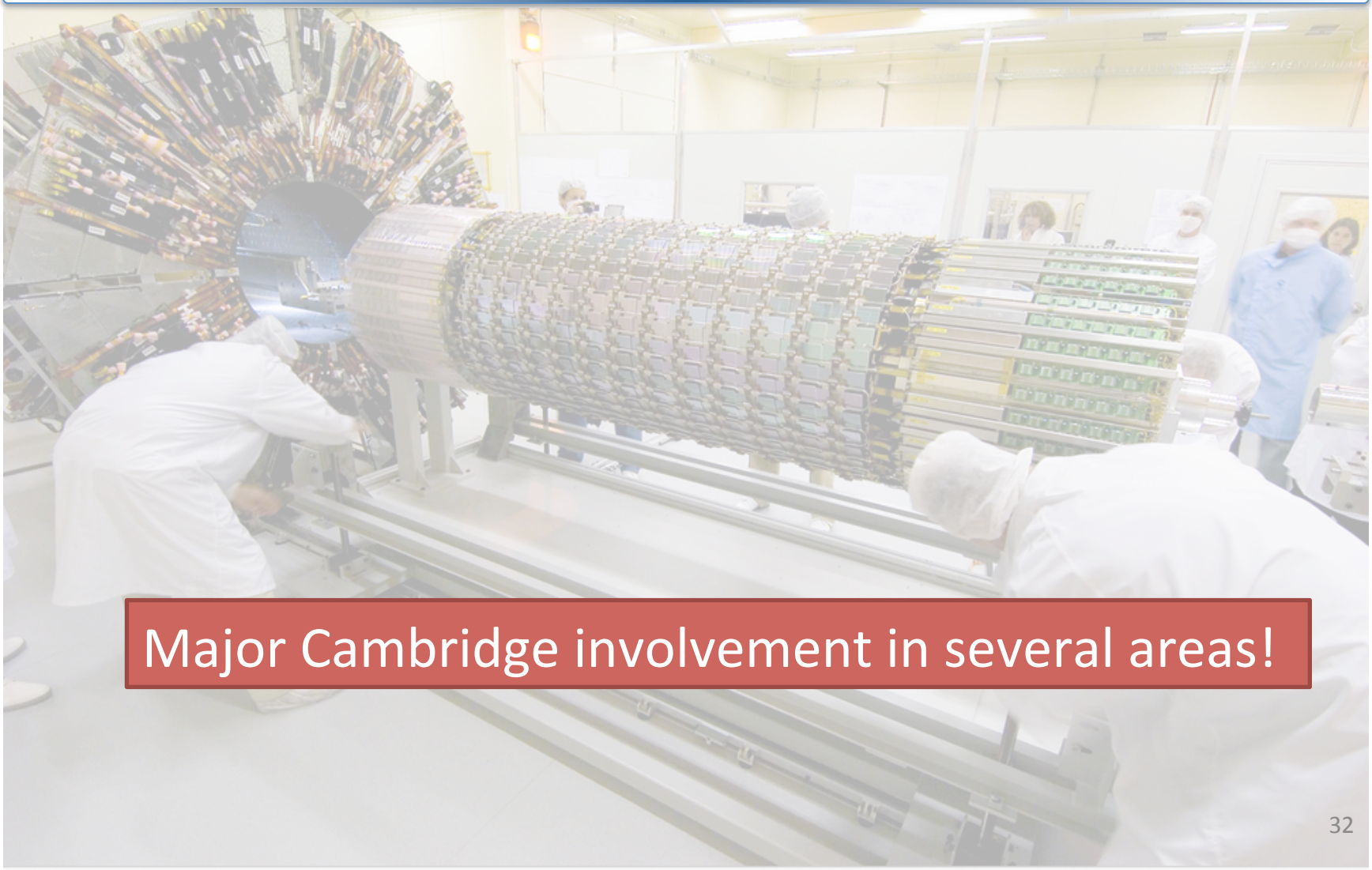

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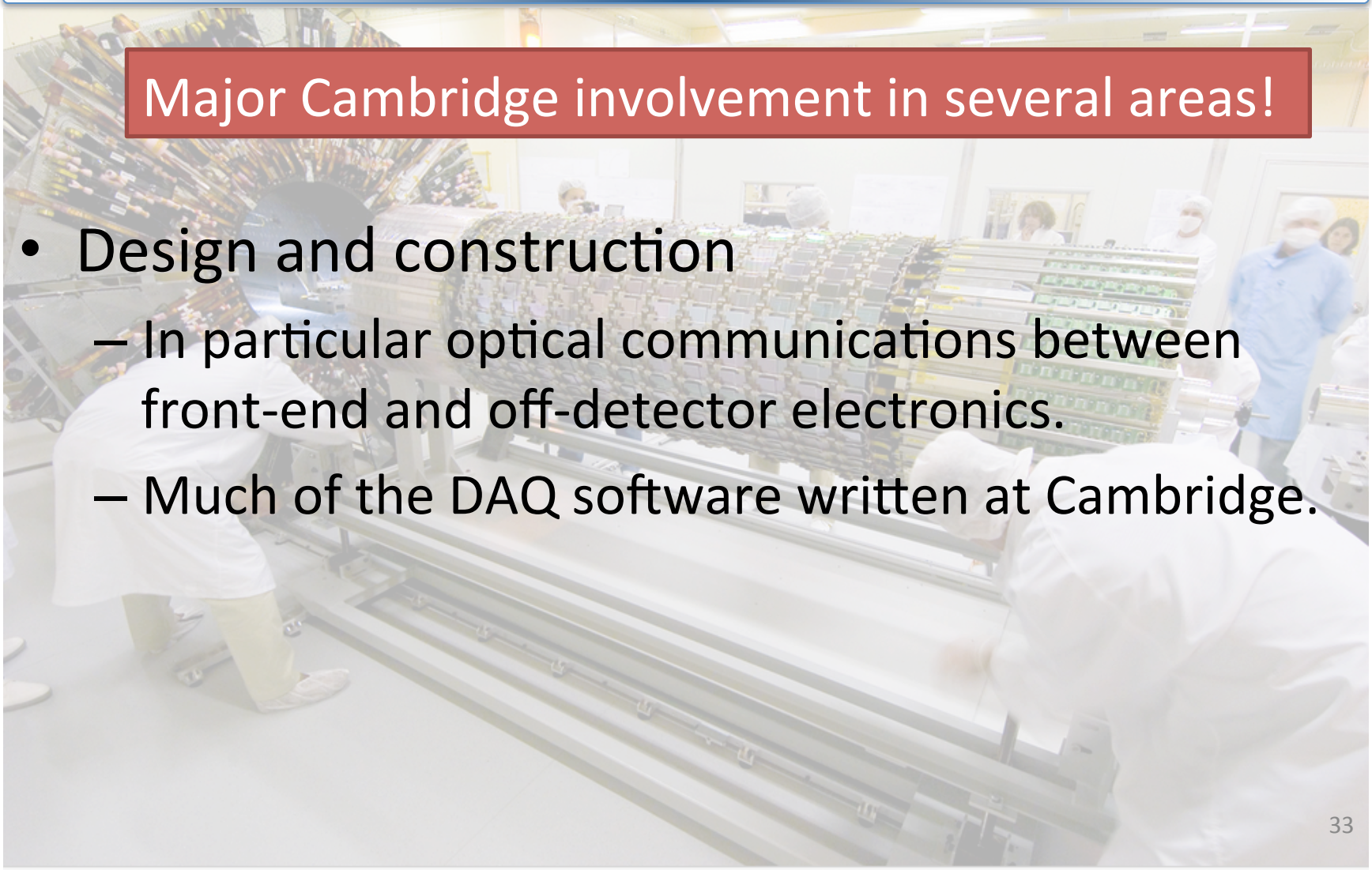
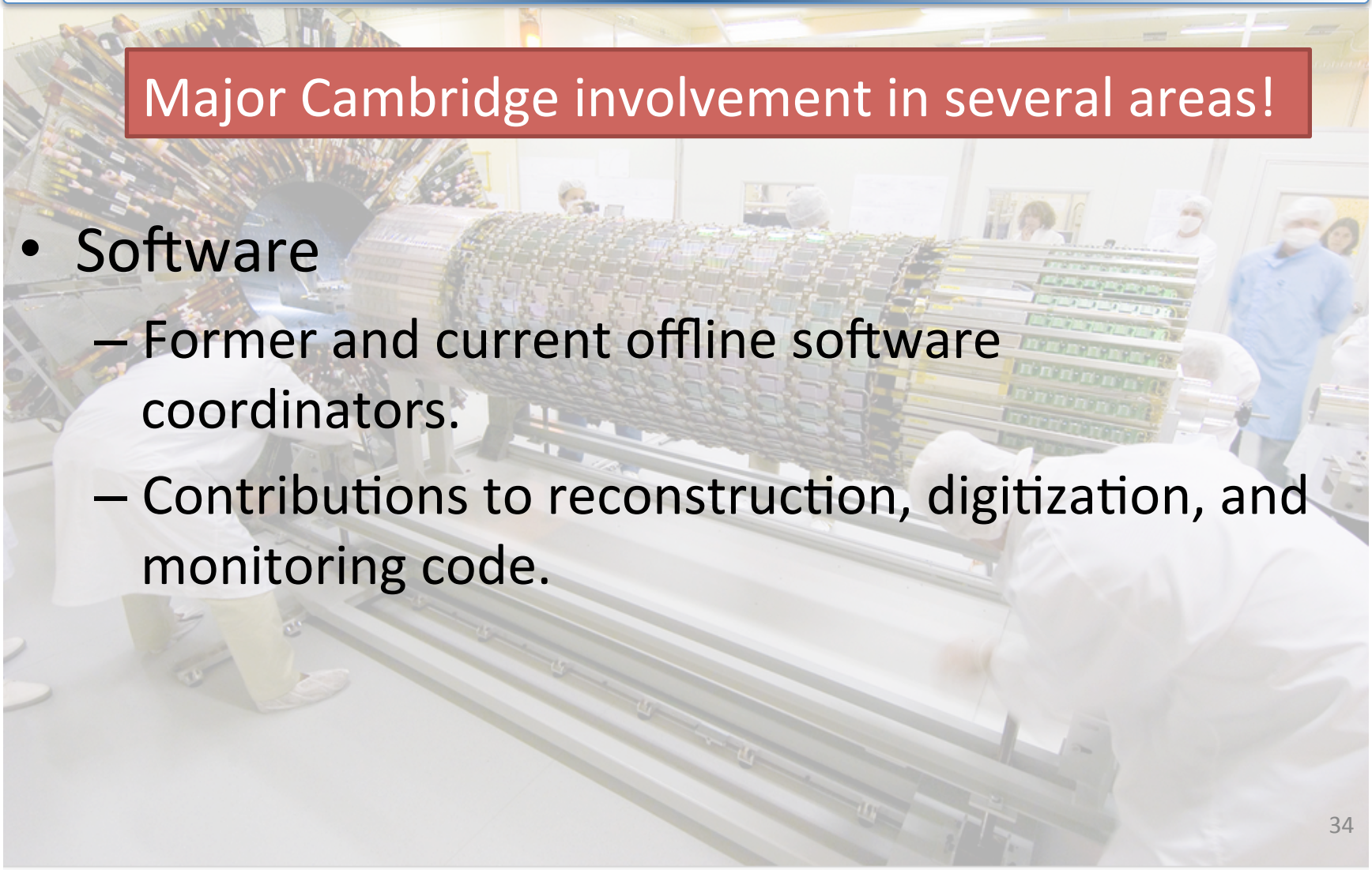


Major Cambridge involvement in several areas!

- Design and construction
  - In particular optical communications between front-end and off-detector electronics.
  - Much of the DAQ software written at Cambridge.

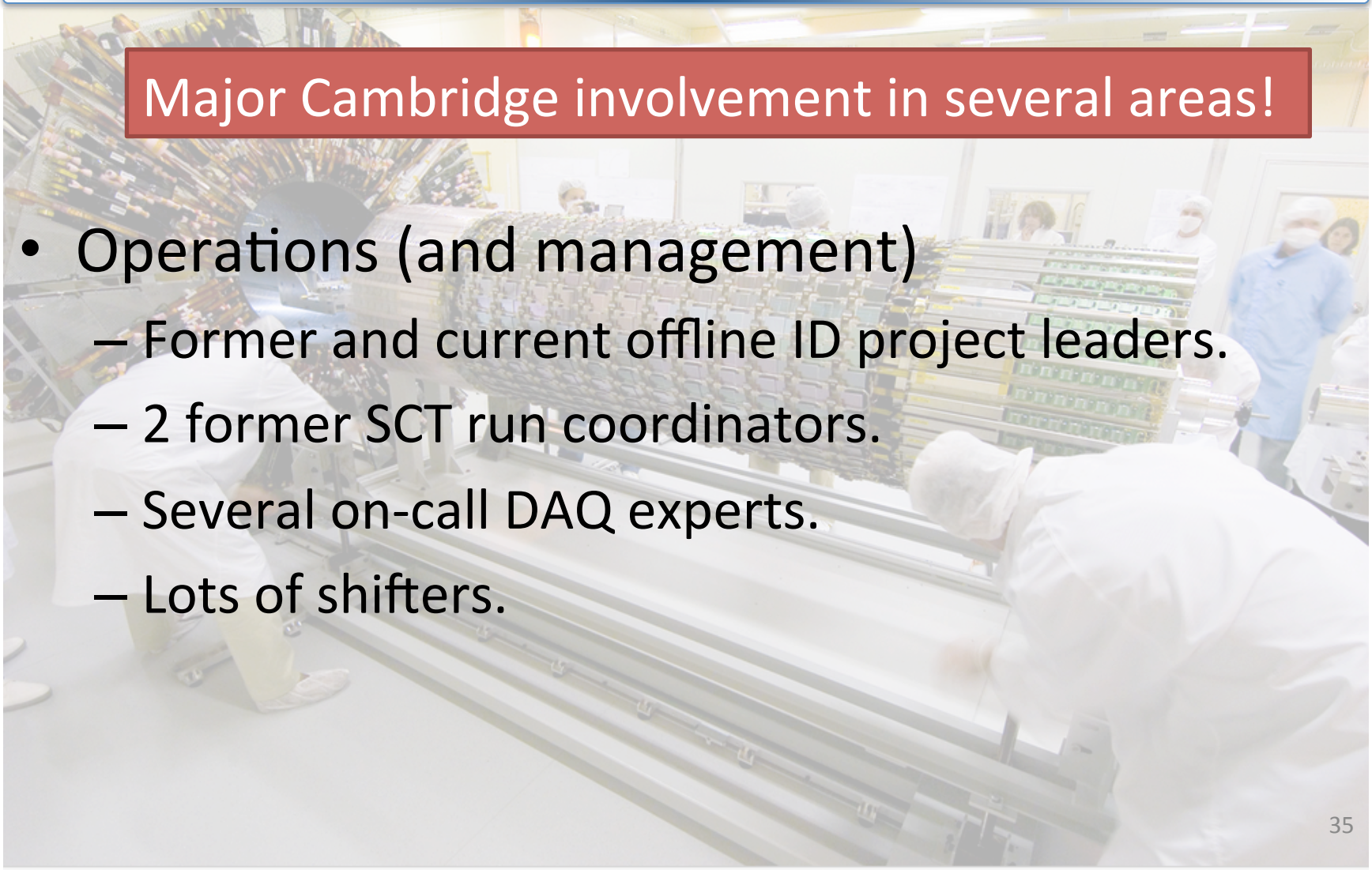
ATLAS Semiconductor Tracker (SCT)



Major Cambridge involvement in several areas!

- Software
  - Former and current offline software coordinators.
  - Contributions to reconstruction, digitization, and monitoring code.

ATLAS Semiconductor Tracker (SCT)

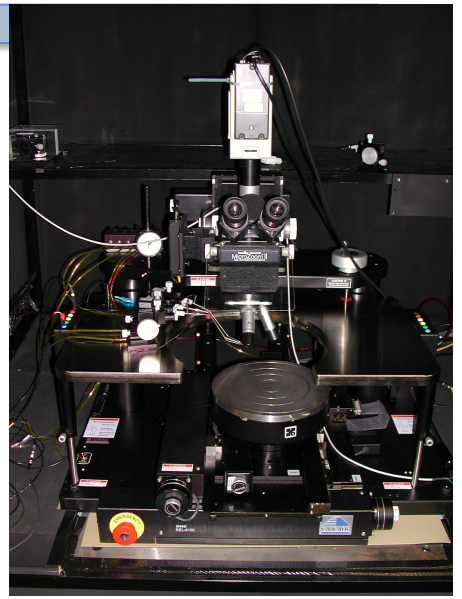


Major Cambridge involvement in several areas!

- Operations (and management)
  - Former and current offline ID project leaders.
  - 2 former SCT run coordinators.
  - Several on-call DAQ experts.
  - Lots of shifters.

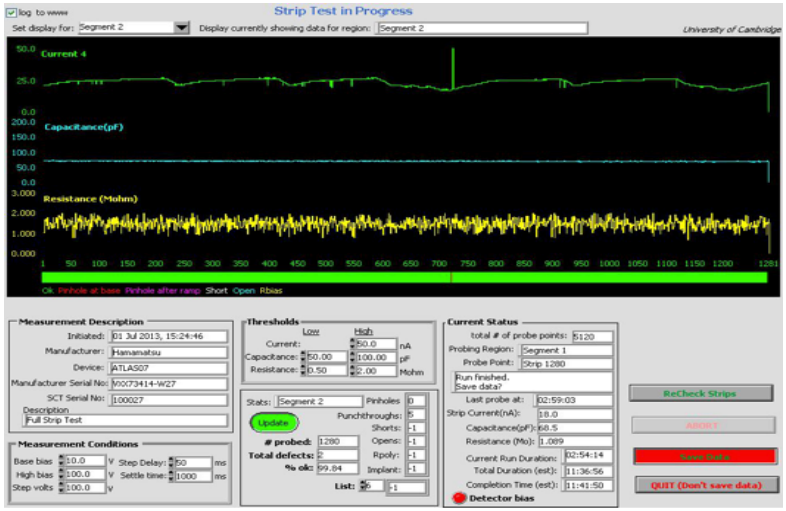
Silicon sensor production

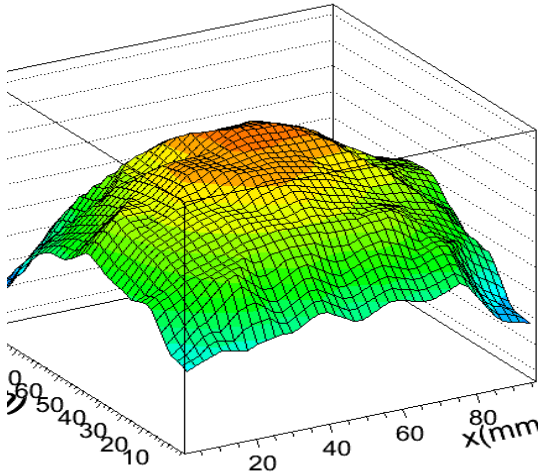
- Silicon sensors:
  - Characterisation
  - Testing
  - QA for upgrade production



ALESSI REL6100
6” semi-automatic probe station and test instrumentation

Labview-based automated sensor test program, including interfacing to prod DB.

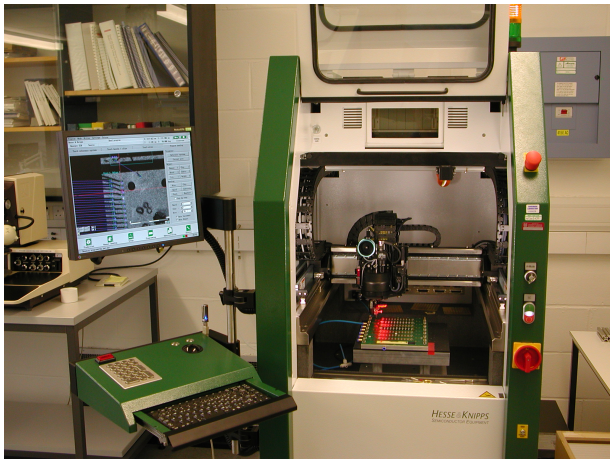




Metrology profile of a module

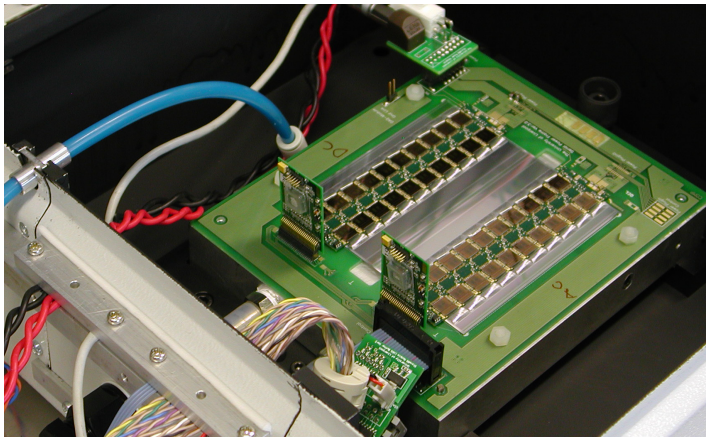
SCT upgrade

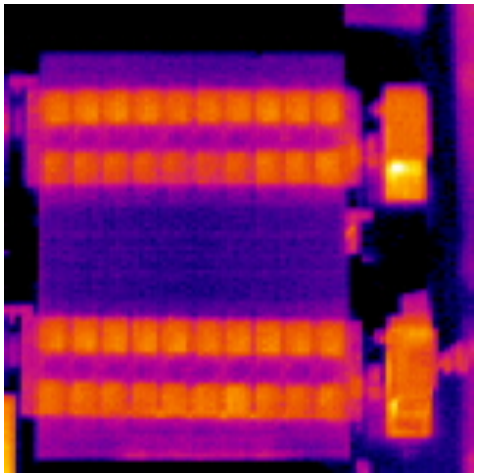
- Cambridge is an upgrade module production site
  - Die bonding, wirebonding
  - Module assembly
  - Metrology
  - Module QA
  - DAQ testing.

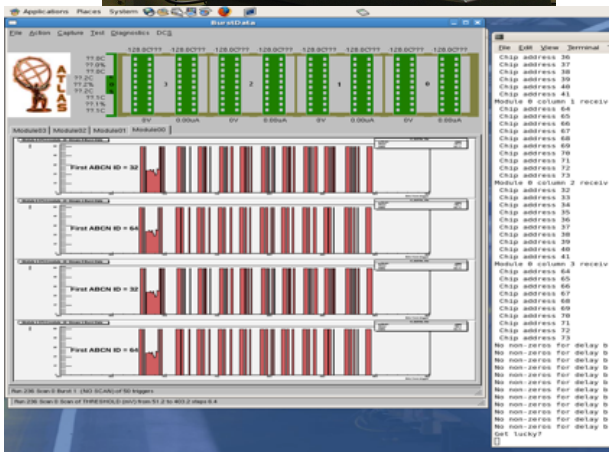


H&K BJ820 automatic wirebonder

Baty Venture 3030 CNC metrology microscope

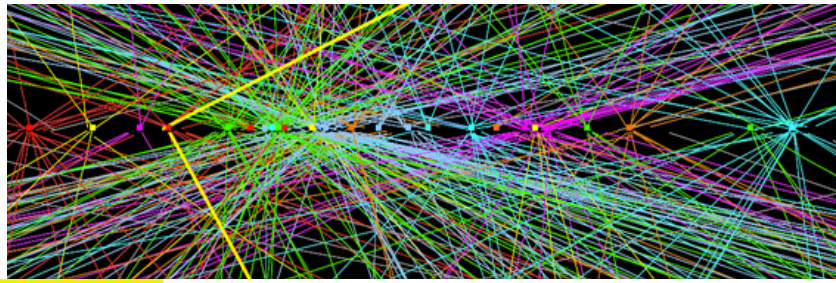


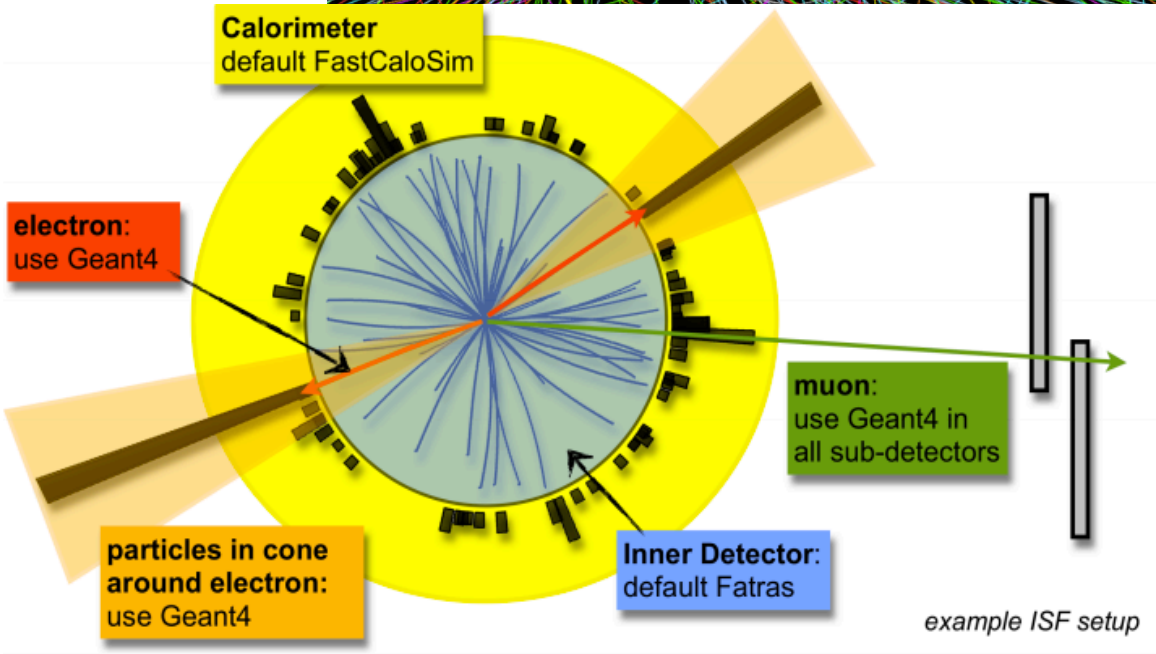




ATLAS simulation

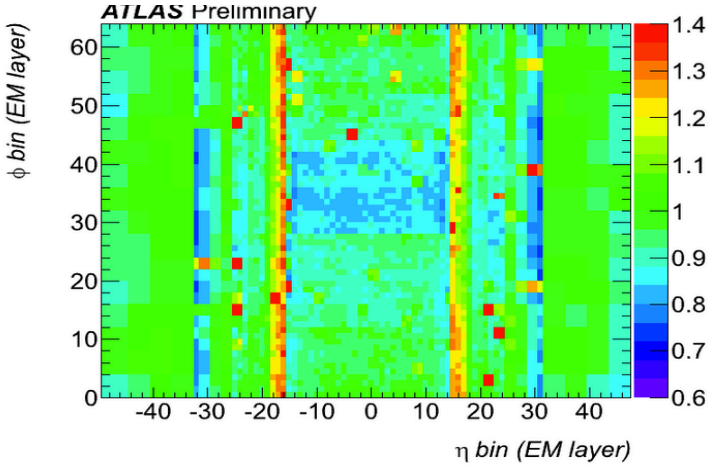
- One member of our group is responsible for simulation and digitization of ATLAS MC.
  - In particular pile-up digitization – using MinBias MC to reproduce effect of multiple pp interactions per bunch-crossing.
- Integrated Simulation Framework (ISF).
  - Flexible combination of fast simulation with full Geant 4 modelling, to give best possible compromise between CPU time and accuracy.

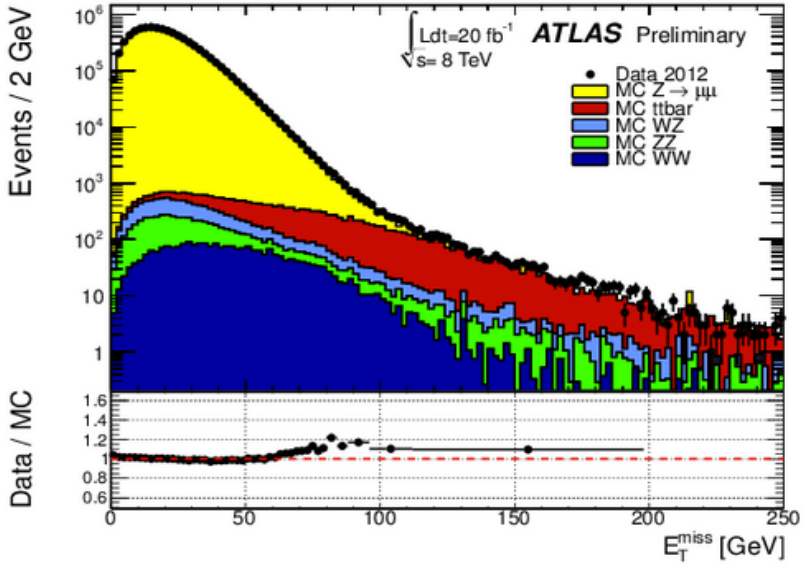




Miscellaneous ATLAS activities

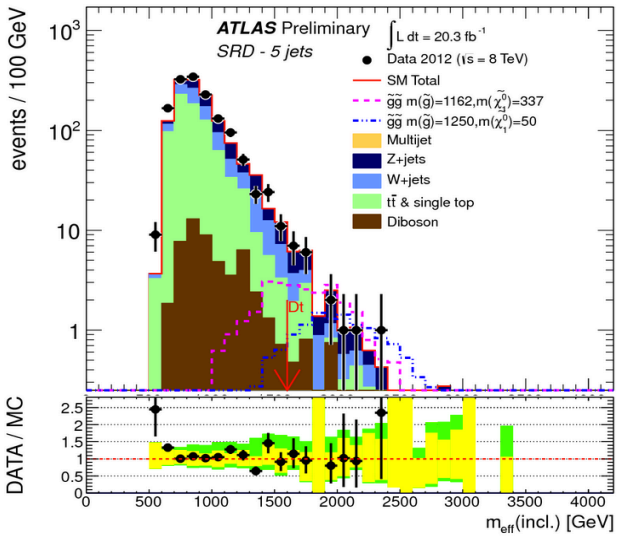
- L1Calo:
  - Calibration activities
  - Trigger shifts.
  - Upgrade studies.
- Data Quality coordinator.
- Prompt Reconstruction coordinator:
  - Responsible for software and operation of reconstruction at Tier-0.
- Missing ET reconstruction:
  - involved with software for propagating uncertainties to MET measurement, and characterizing performance
- Physics Analysis Tools:
  - PileupReweighting tool.
- …

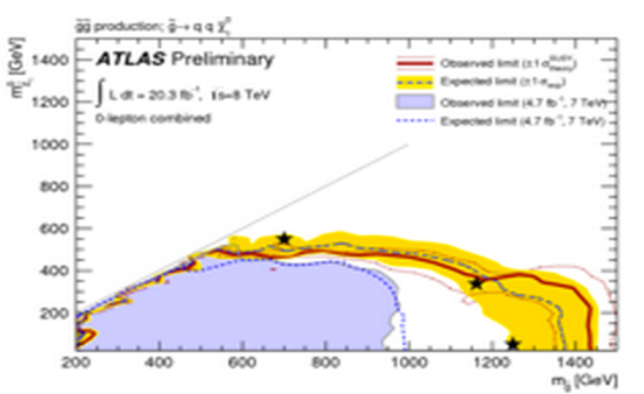


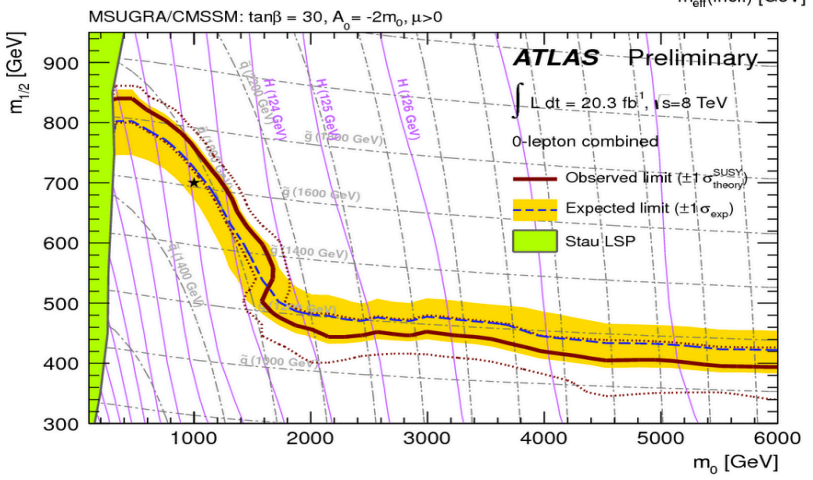


ATLAS physics: SUSY 0-lepton search

- Search for events with high-p_T jets and large missing E_T.
- Latest result on full 2012 dataset (ATLAS-CONF-2013-047)
- One of the most sensitive analyses for many SUSY models.
- Cambridge group involved with signal region optimization, determination of Z->nunu background, and statistial interpretations.





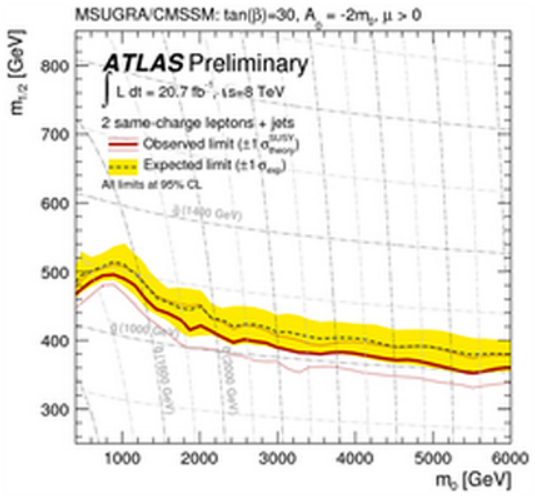


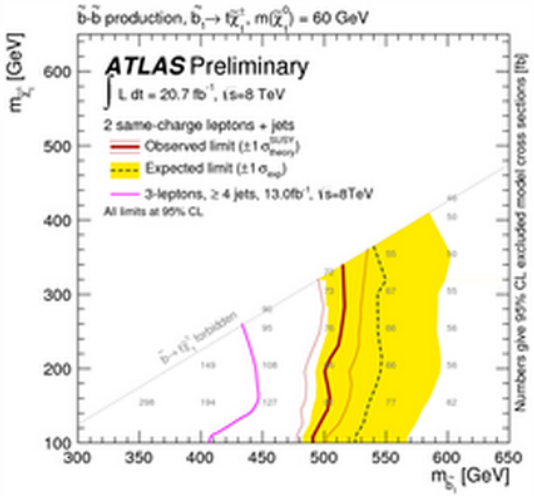
ATLAS physics: SUSY searches with same-sign dileptons and b-jets

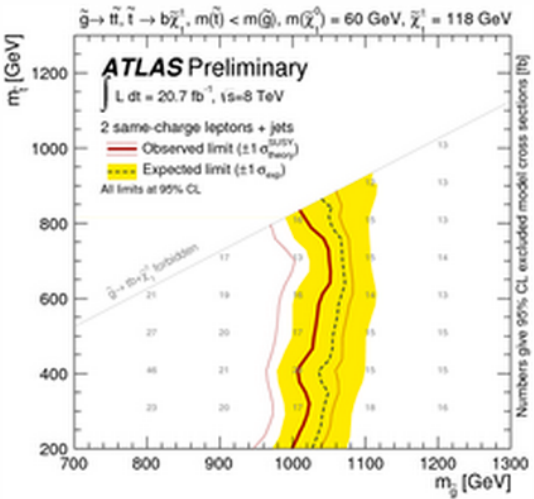
- CONF note already published on full 2012 dataset

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-007/

  - Paper is in progress.
- Very versatile analysis – wide variety of interpretations…
  - mSUGRA, direct sbottom, gluino-stop, RPV, …



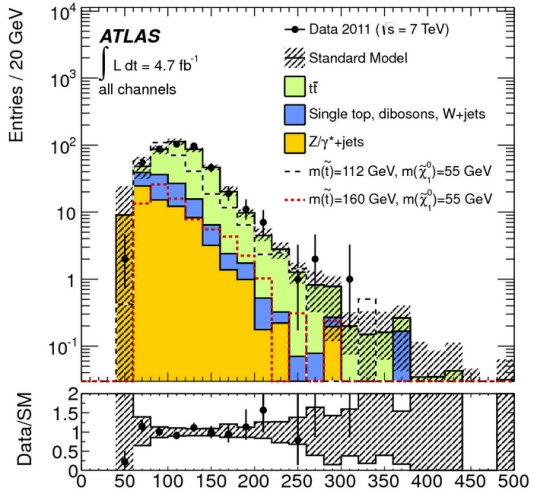




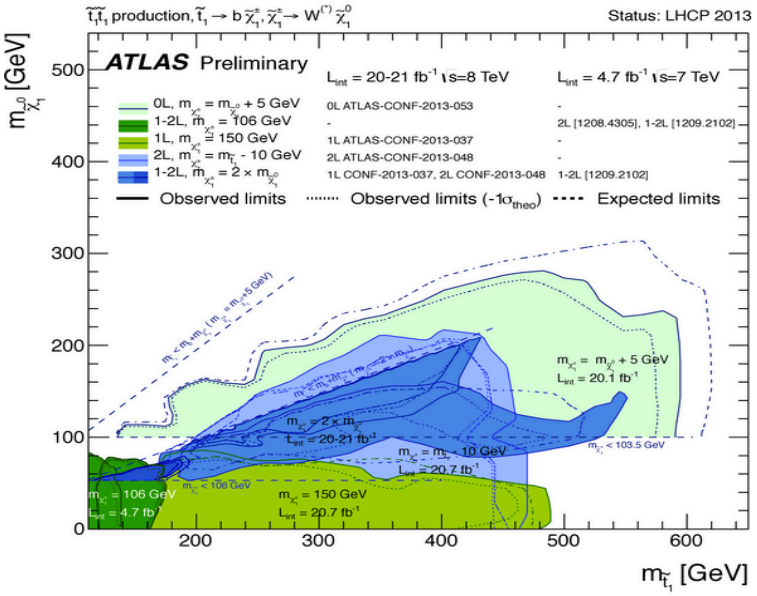
ATLAS physics: SUSY stop search

- Collaboration with Martin White (and others)

- Search for stop decays to
  b+chargino
  in 2-lepton final state.
  - Aimed at models with small mass difference between chargino and neutralino.
- Analysis on 2011 data



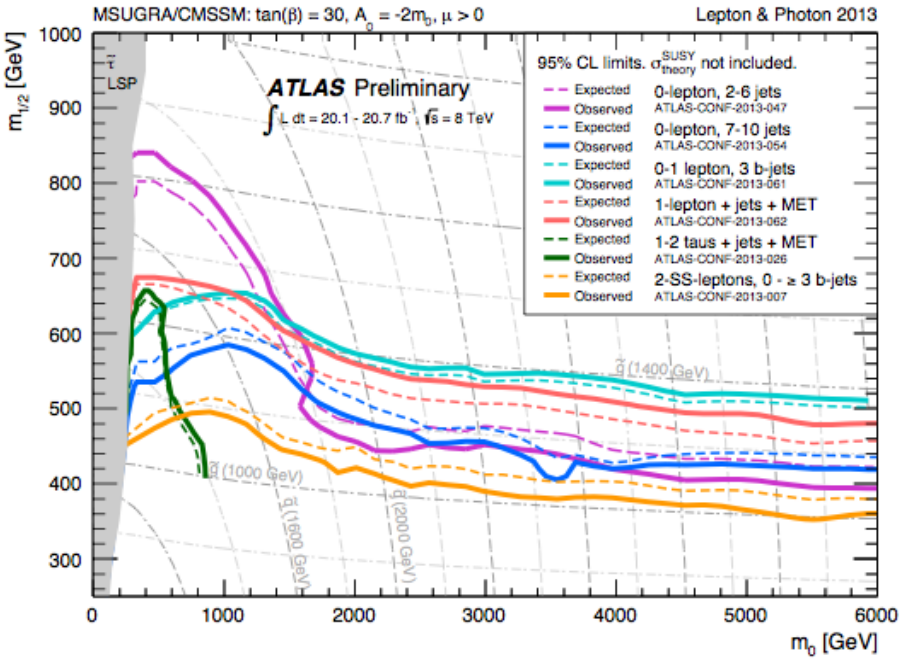
EPJC 72:2237 (2012)



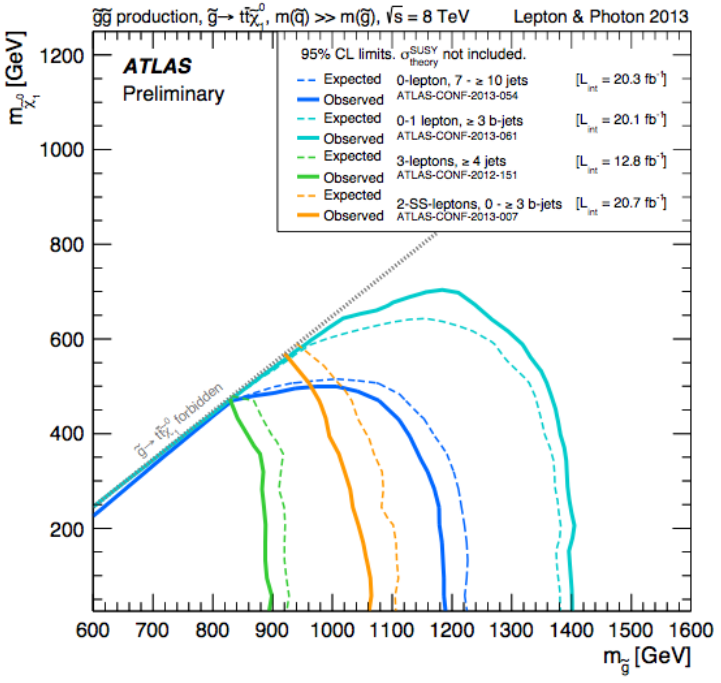
- Update on full 2012 dataset available imminently (aiming for EPS).

ATLAS physics – SUSY exclusions

mSUGRA



Gtt



ATLAS physics: RPV and Long-Lived SUSY (1)

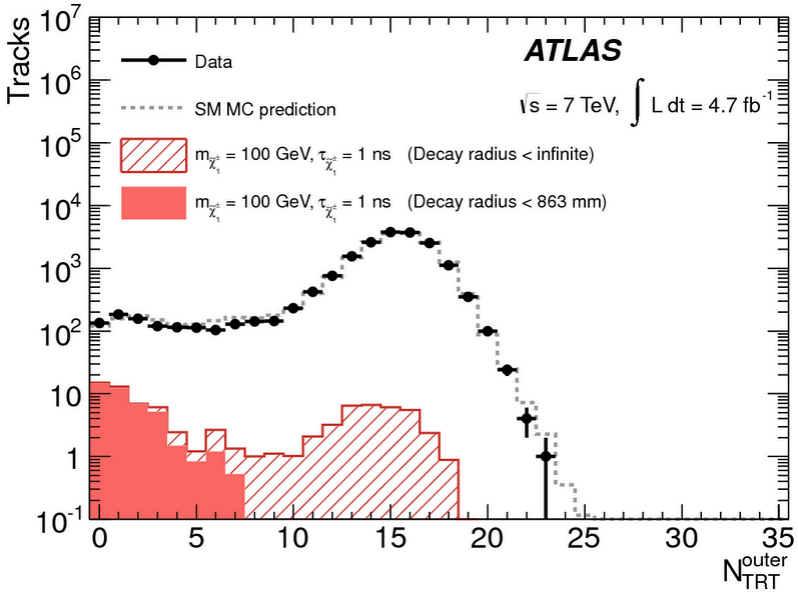
- Most collider SUSY searches assume R-Parity conservation.
  - Stable, neutral LSP is a good dark matter candidate.
- However, no a priori reason why R-Parity could not be violated – can introduce RPV terms in superpotential:

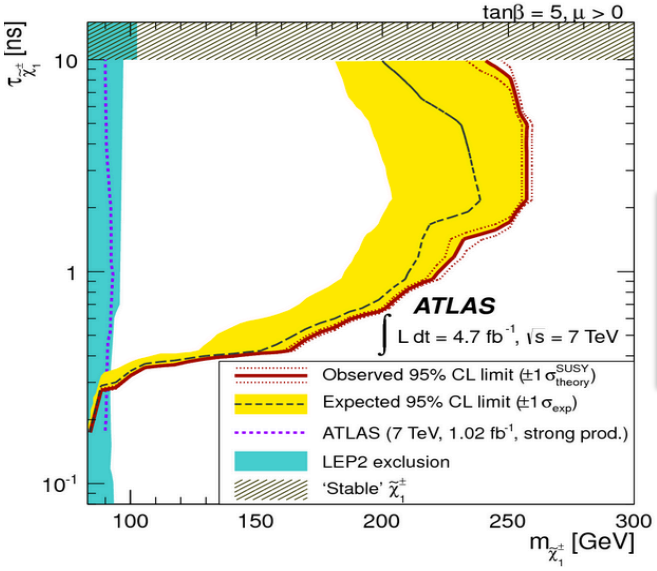
$$\lambda_{ijk} L^i L^j \overline{E}^k + \lambda'_{ijk} L^i Q^j \overline{D}^k + \lambda''_{ijk} \overline{U}^i \overline{D}^j \overline{D}^k + \epsilon_i L_i H_2$$

  - Some constraints from e.g. proton decay, but lots of parameter space left to explore!!
- Several New Physics (inc. SUSY) scenarios can give rise to new, heavy, long-lived particles, if they have:
  - Small couplings (e.g. RPV SUSY)
  - Highly off-shell particles in decay chain (e.g. split SUSY)
  - Very small mass splittings in decay chain (e.g. Anomaly Mediated SUSY Breaking (AMSB)).
- Member of the group is currently co-convener of ATLAS RPV/LL SUSY group.

ATLAS physics: RPV and Long-Lived SUSY (2)

- Cambridge group currently involved in
  - RPV SUSY displaced vertex search (see Nitesh's talk)
  - AMSB disappearing tracks search:
    - Search for direct chargino production in events with ISR jet (use Jet +MET to trigger).
    - Chargino and neutralino are highly degenerate – chargino can decay inside the tracker volume to neutralino and soft pion (not reconstructed) – disappearing track.

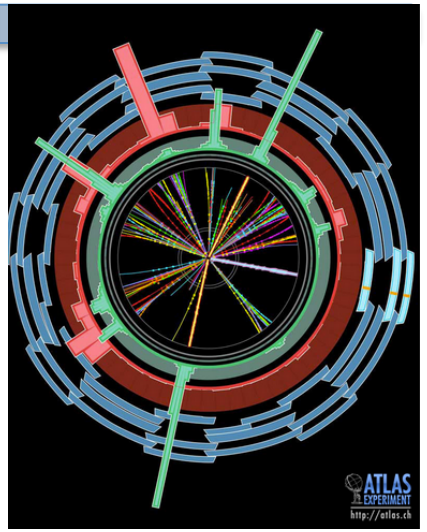




JHEP 01 (2013) 131
Update with 8TeV data is imminent.

ATLAS physics: Exotics searches

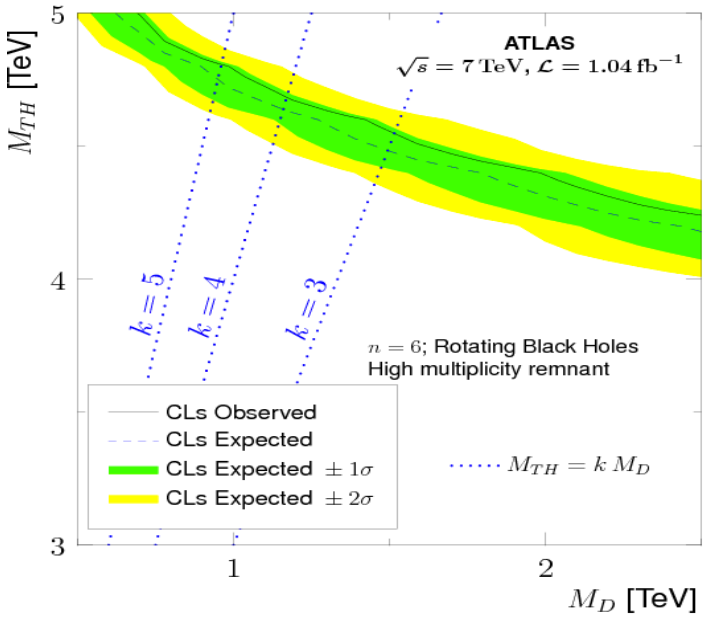
- Microscopic black holes could be produced at LHC in theories with extra spatial dimensions.
- In semi-classical approximation, decays will be "democratic" (particles produced according to degrees of freedom).



- ATLAS analysis on 2011 dataset published in PLB

  arXiv:1204.4646

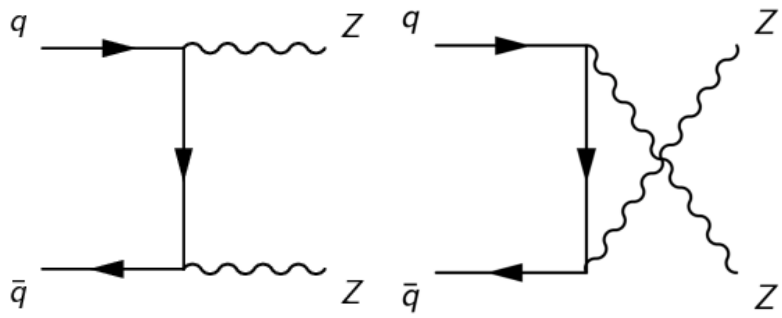
- Update on full 2012 dataset (20.3fb^{-1}) in preparation.



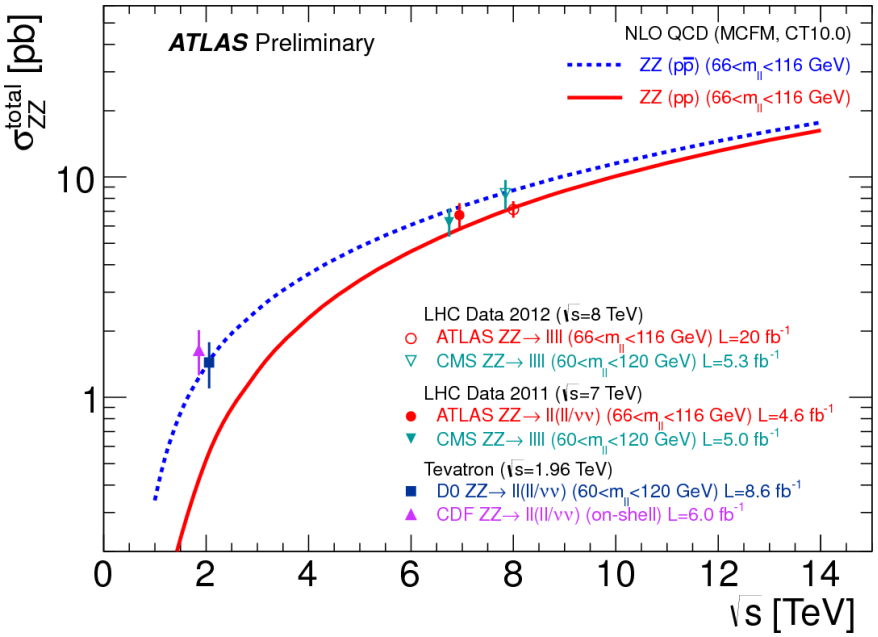
Diboson Physics in ATLAS

- Diboson studies constitute a precision test of the Standard Model, as well as an opportunity to look for signs of New Physics
- Focus on measuring Standard Model processes with two-boson intermediate states

  (*Wg, Zg, WW, WZ, ZZ*)
- Analyses consist of a measurement of the cross-section (fiducial and total cross-section) and searches for anomalous triple gauge couplings.



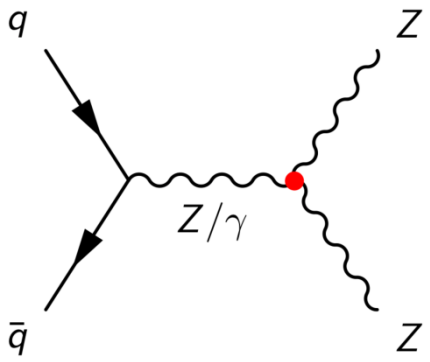
ATLAS-CONF-2013-020



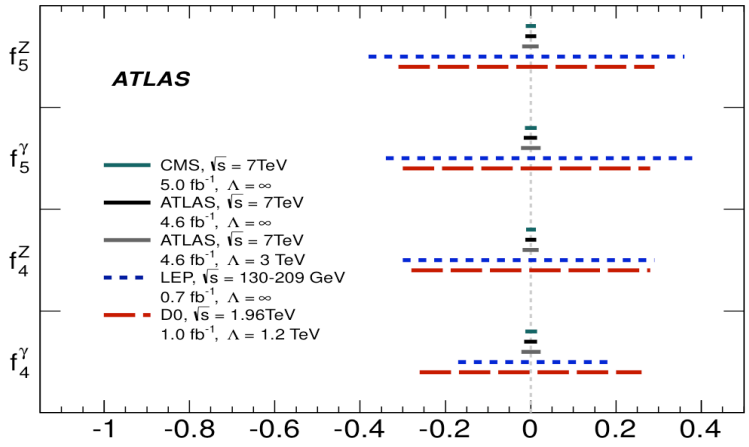
Diboson Physics in ATLAS

- Standard Model Lagrangian determines gauge boson self couplings.
- Anomalous couplings would enhance diboson production rate and alter event kinematics.
- Search for couplings of the form

  WWZ, WWg, ZZZ, ZZg
- Set limits using kinematic distributions sensitive to anomalous couplings, e.g. p_T^Z.

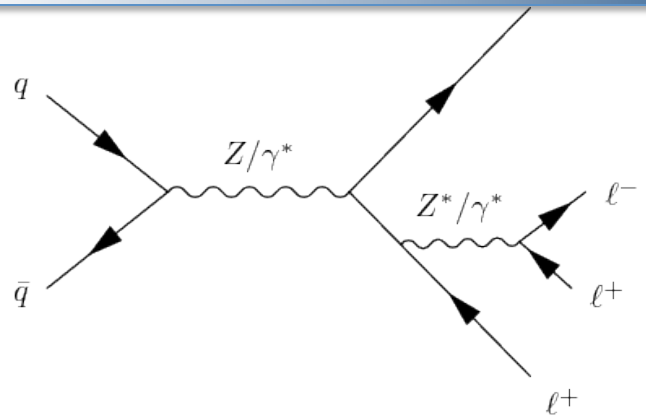


ZZZ, ZZγ vertices forbidden in SM.
Parametrize vertex using four couplings:
$f_4^Z, f_5^Z, f_4^\gamma, f_5^\gamma$



JHEP(2013)128

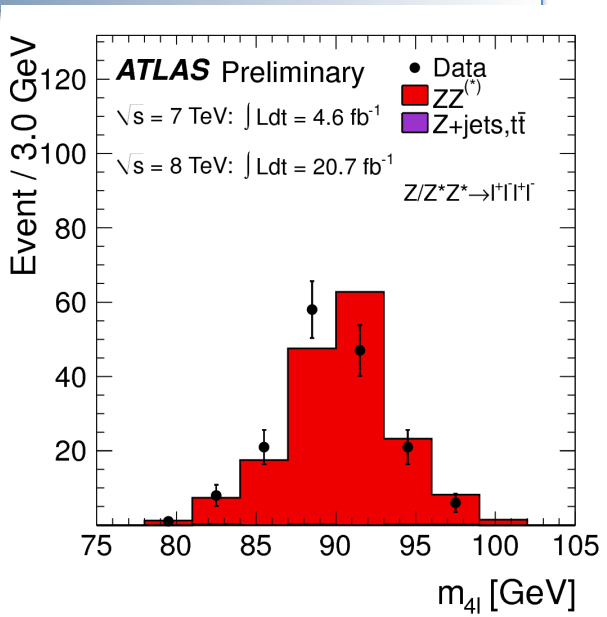
ATLAS physics: single Z -> 4 leptons

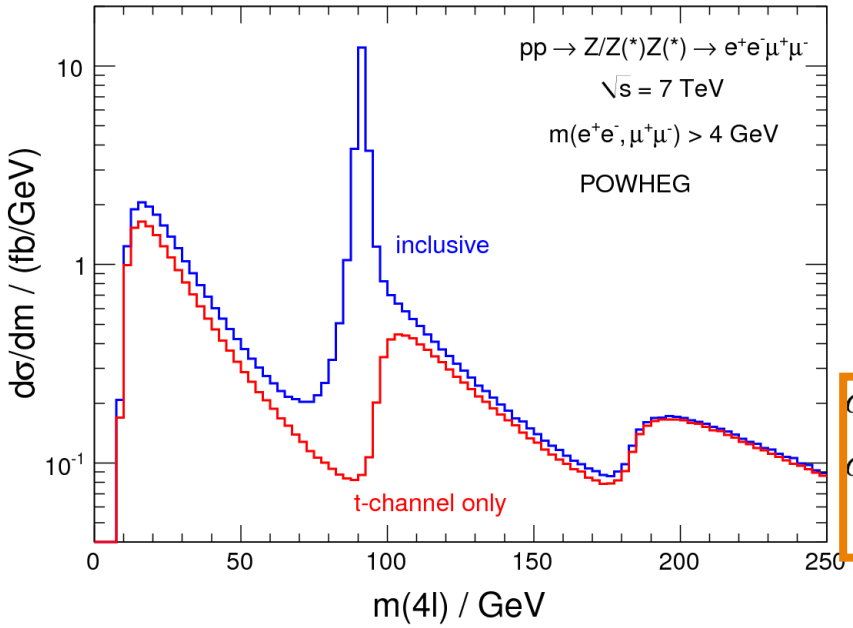


Looking for Z peak in 4-lepton invariant mass spectrum.

Almost background-free.

Cross-check for Higgs mass measurements.





Phase Space:

$$76 < M_{4\ell} < 106\ GeV$$

$$M_{\ell^+\ell^-} \geq 4\ GeV$$

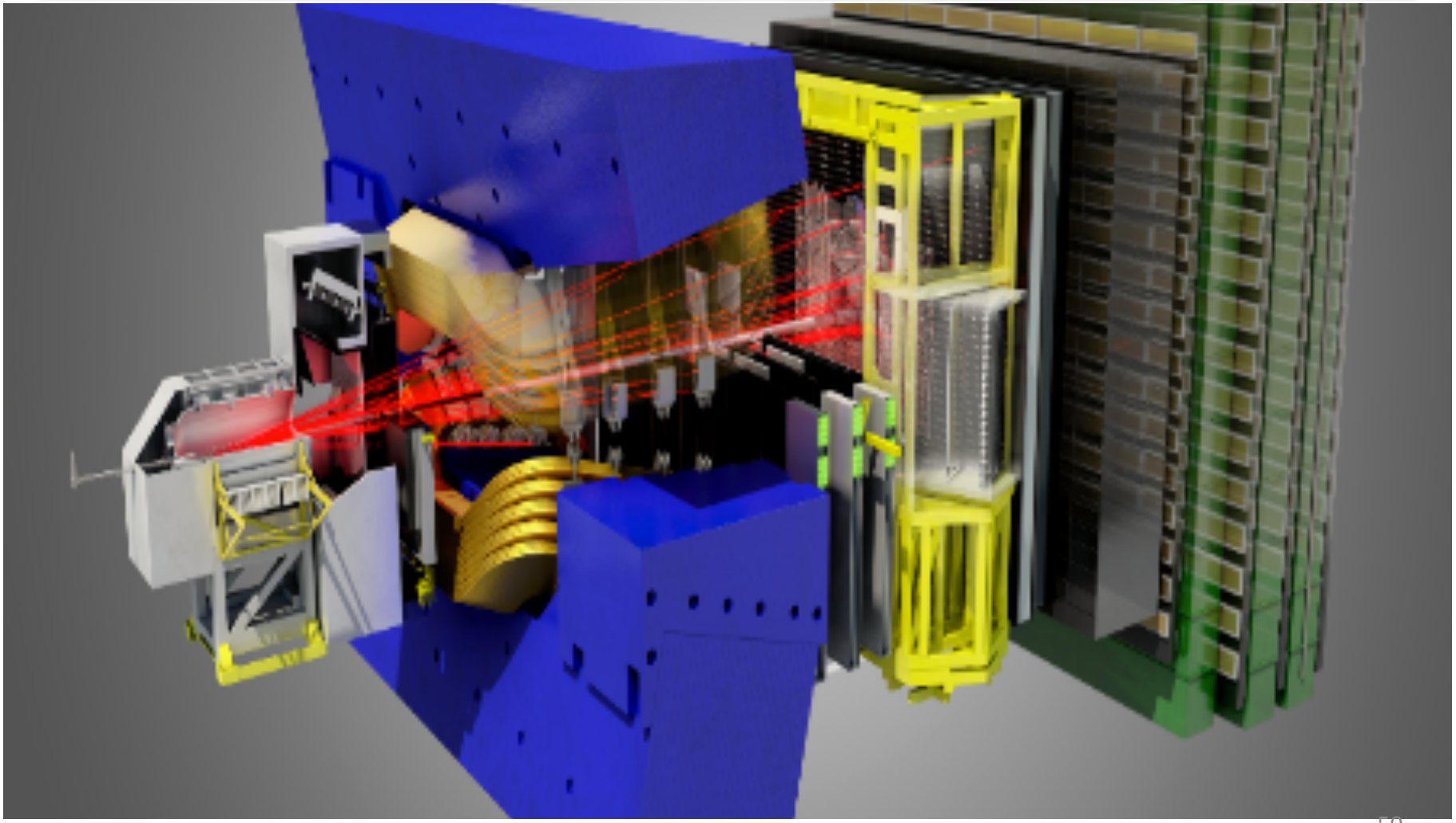
$$\sigma(4\ell) = 114 \pm 27\ (\text{stat}) \pm 7\ (\text{syst}) \pm 2\ (\text{lumi})\ \text{fb at } \mathbf{7\ TeV}$$

$$\sigma(4\ell) = 150 \pm 13\ (\text{stat}) \pm 7\ (\text{syst}) \pm 5\ (\text{lumi})\ \text{fb at } \mathbf{8\ TeV}$$

$$BR(Z \to 4\ell) = (4.2 \pm 0.4) \times 10^{-6}$$

ATLAS-CONF-2013-055

LHCb



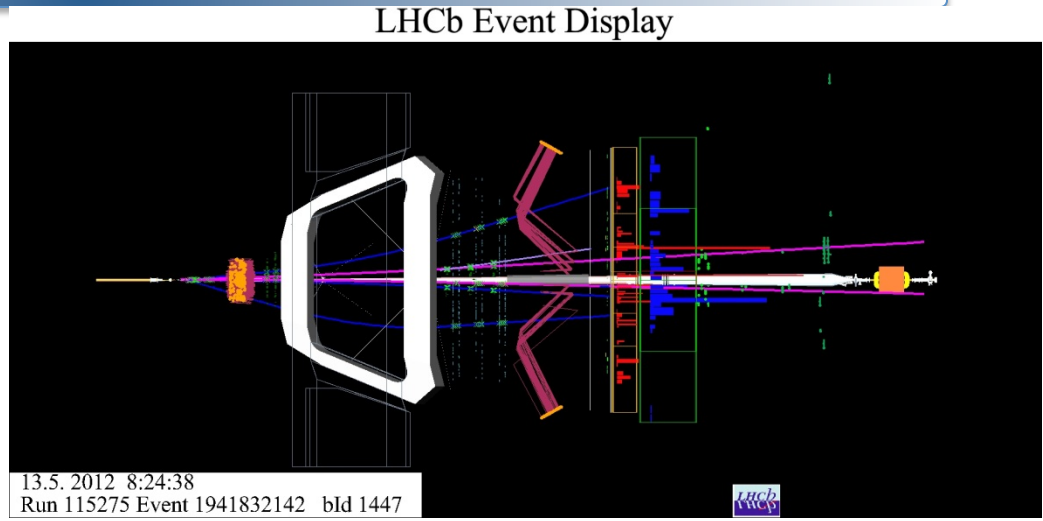
LHCb

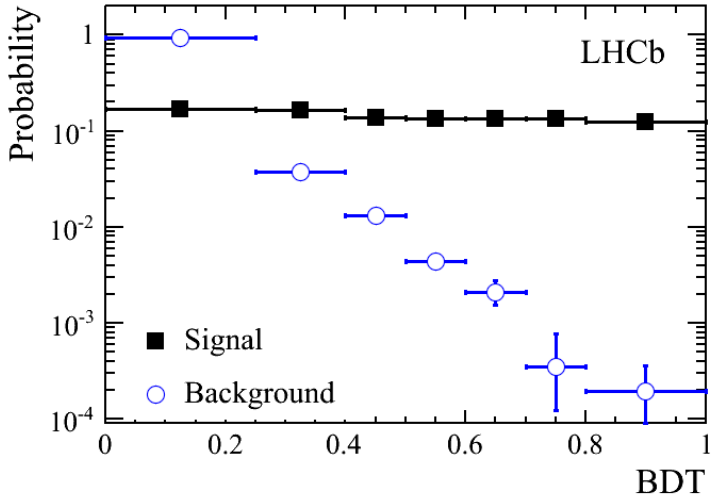
- Forward arm spectrometer
  - Covers pseudorapidity region $1.9<\eta<4.9$.
  - Designed to look for New Physics in B decays (complementary to ATLAS and CMS).
  - 13micron vertex resolution in azimuthal plane.
  - Excellent particle ID via RICH (lots of Cambridge involvement!).
  - Luminosity levelling allows operation in a low pile-up environment.
    - $3fb^{-1}$ recorded.

LHCb physics: $B_s \rightarrow \mu^+\mu^-$

- $B_s \rightarrow \mu^+\mu^-$ is FCNC decay that proceeds via penguin or box diagrams.
- Helicity suppressed, so small SM branching fraction

  $(3.54 \pm 0.30) \times 10^{-9}$.
- Sensitive to new physics in scalar, pseudoscalar sectors, and extended Higgs models.
- Analysis uses 1.0fb^{-1} 2011 data and 1.1fb^{-1} 2012 data. (PRL 110 021801).
- Signal/background discrimination performed using BDT.
  - Take signal shapes from B_S to pipi or KK.
  - Background shapes from mass sidebands





LHCb physics: $B_s \rightarrow \mu^+\mu^-$

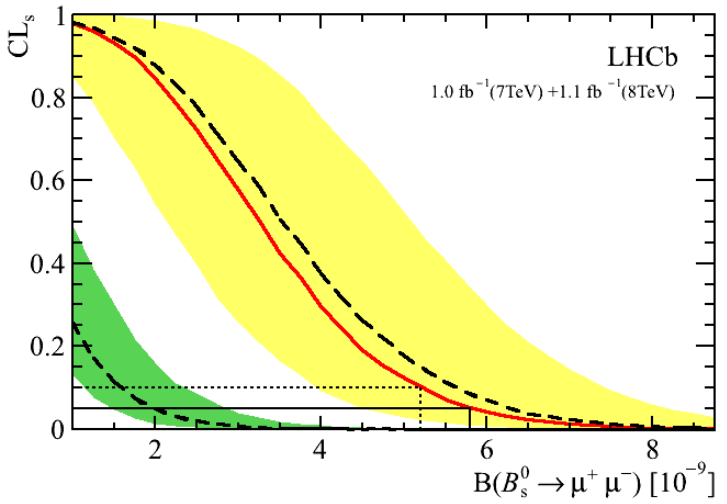
- Compatibility with background-only hypothesis:

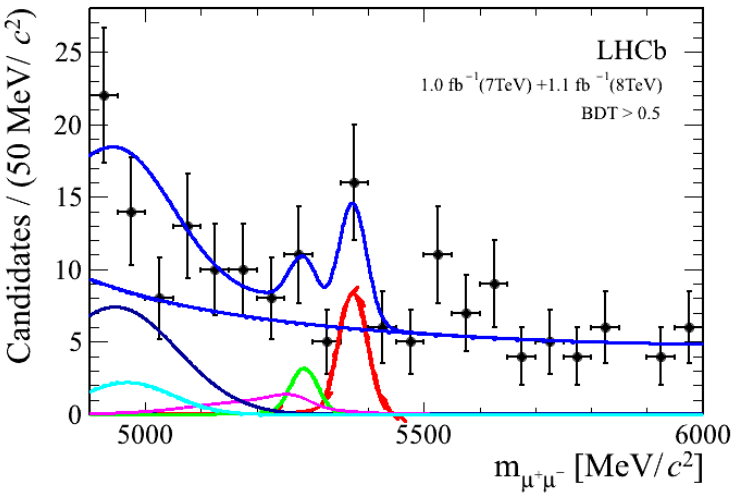
  p-value=5×10^{-4}.

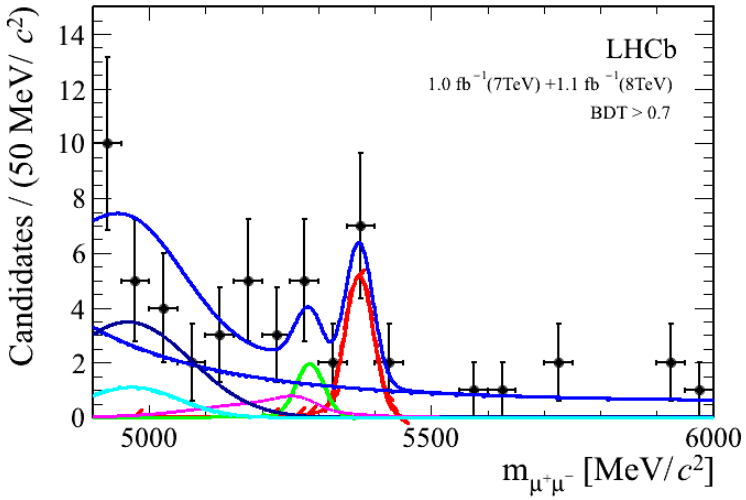
- 3.5σ excess of signal candidates

➔first evidence of $B_s \rightarrow \mu^+\mu^-$ decays!

BR=$(3.2^{+1.4}_{-1.2}(\text{stat})\ ^{+0.5}_{-0.3}(\text{syst}))\times10^{-9}$

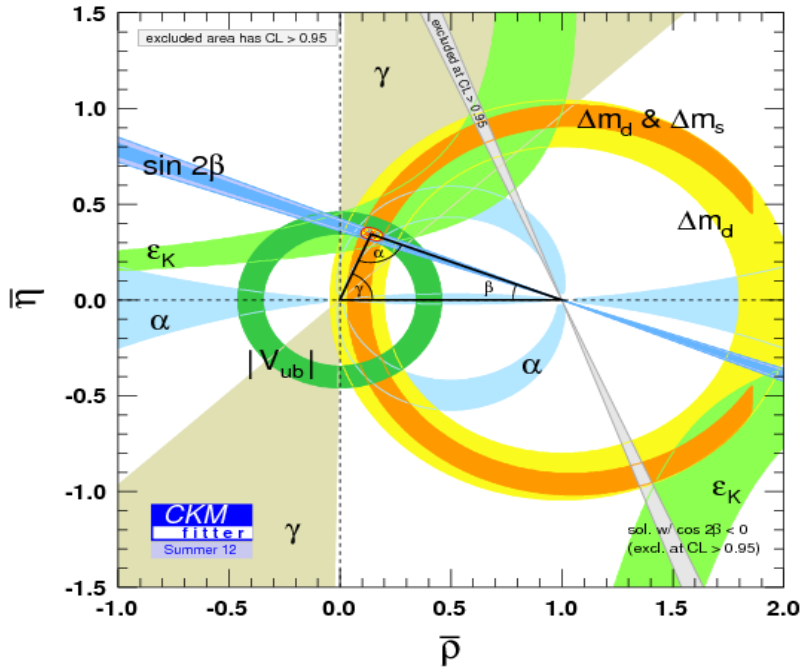






LHCb physics: measurement of CKM angle γ

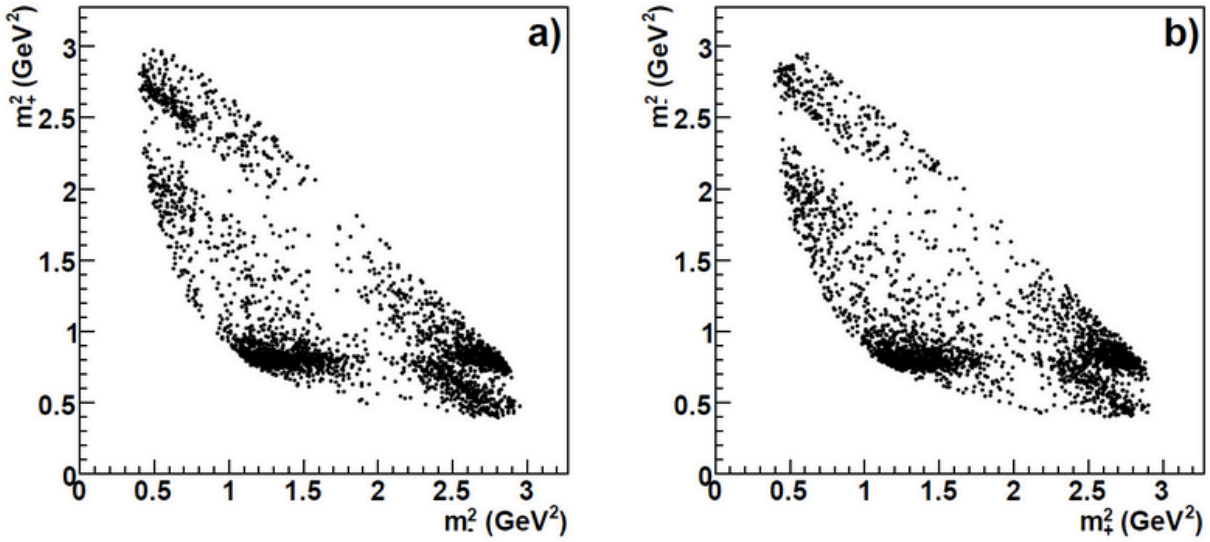
- Unitarity Triangle describes CP violation in S.M.
- Least-well-constrained angle is γ
- Can be measured directly using tree-level $B^{\pm} \rightarrow D^0/\bar{D}^0 K^{\pm}$ and $B^0 \rightarrow D^0/\bar{D}^0 K^{*0}$ decays, with D^0 and $\bar{D}^0$ decaying to the same final state $K_S \pi^+ \pi^-$.
  - Interference leads to sensitivity to γ, which is weak phase difference between V_{ub} and V_{cb}.



- Provides a clean SM "benchmark" measurement of γ, against which we can compare other measurements that may also be sensitive to New Physics.

LHCb physics: measurement of CKM angle γ

- Fit Dalitz plots of D decays
  - Difference between D^0 and $\overline{D}^0$ can provide measurement of γ.

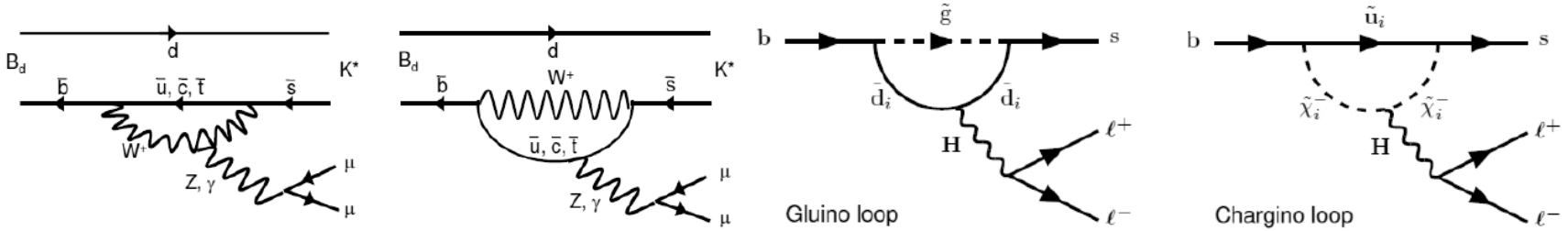


- Combine measurements of different B->DK modes to obtain γ=(67± 12)°.
  - Best measurement from a single experiment.

    arXiv:1305.2050

LHCb physics: CP asymmetry in $B^0 \rightarrow K^{*0}\ \mu^+\mu^-$

- $B^0 \rightarrow K^{*0}\ \mu^+\mu^-$ is a FCNC, proceeds via loop diagrams in the SM.
  - Therefore, New Physics can enter at same level.



- Can investigate using variables such as the partial rate of the decay, the dimuon forward/backward asymmetry, the CP asymmetry, in terms of the dimuon invariant mass squared q^2.

$A_{CP} = (\Gamma(B^0 \rightarrow K^{*0}\ \mu^+\mu^-) - \Gamma(\overline{B}^0 \rightarrow \overline{K}^{*0}\ \mu^+\mu^-))/(\Gamma(B^0 \rightarrow K^{*0}\ \mu^+\mu^-) + \Gamma(\overline{B}^0 \rightarrow \overline{K}^{*0}\ \mu^+\mu^-))$

- Analysis performed on $1fb^{-1}$ LHCb data.
- B->J/psi K* used as a control channel.
  - Perform simultaneous fit to both B->J/psiK* and B->K*mumu in bins of q^2.
- Average of results taken over both magnet polarizations taken, to reduce detector effects.

LHCb physics: CP asymmetry in $B^0 \rightarrow K^{*0}\,\mu^+\mu^-$

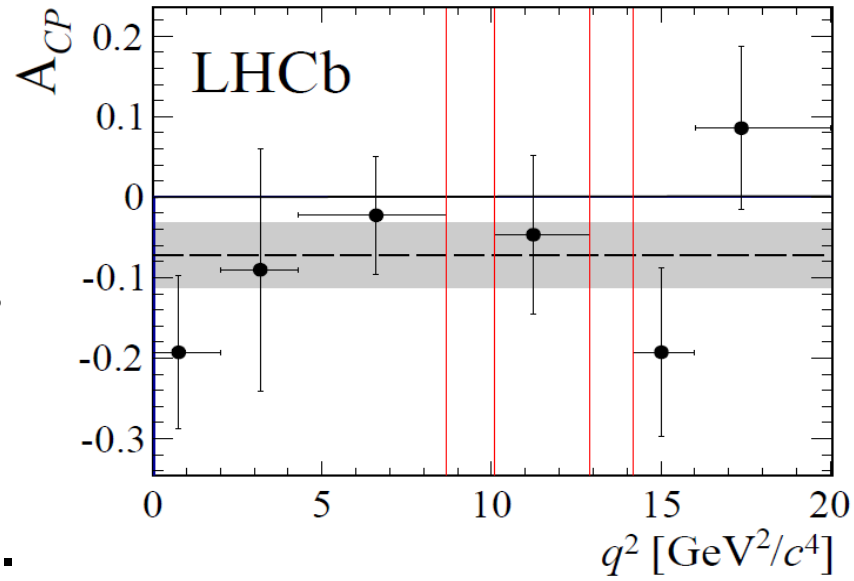
- The integrated value of A_{CP} across the q^2 range is:

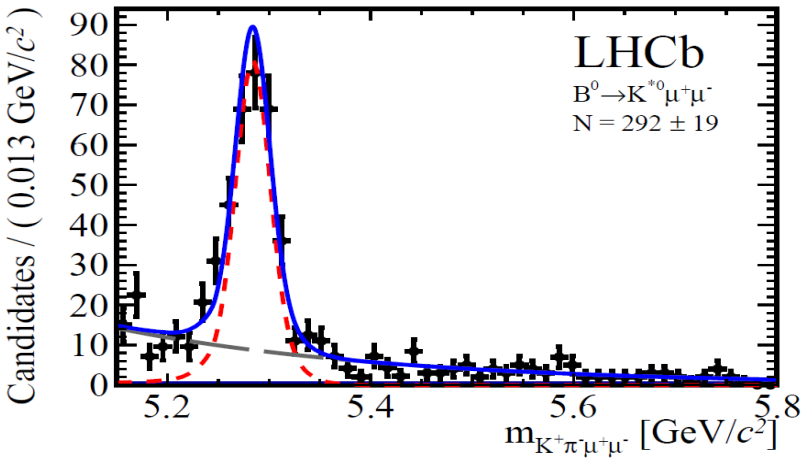
  $A_{CP} = -0.072 \pm 0.040 \pm 0.005$

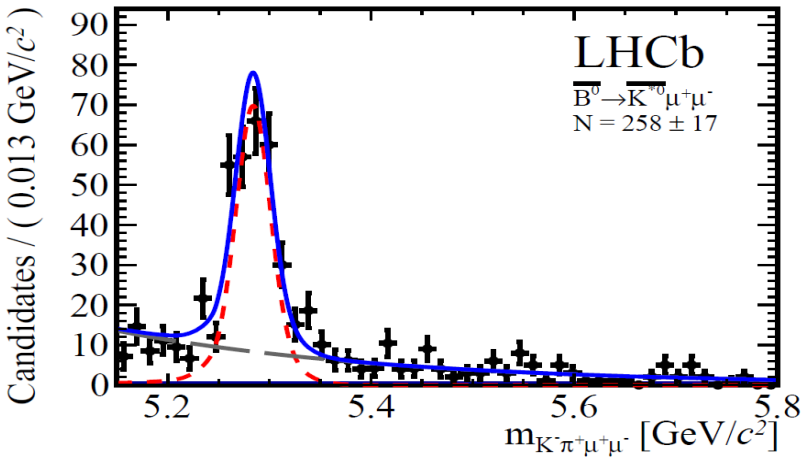
- World's most precise measurement.

  (PRL 110 031801)

- Currently being updated with 2012 data, and for $B^0 \rightarrow K^0\,\mu^+\mu^-$ channel.

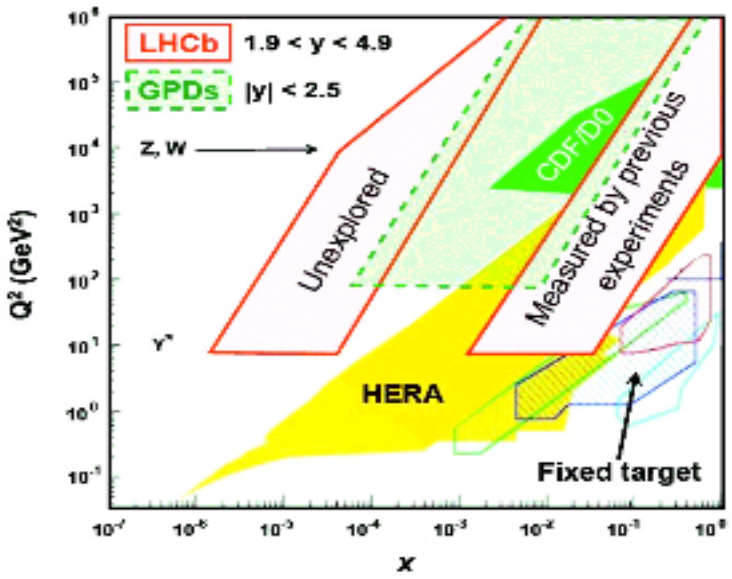


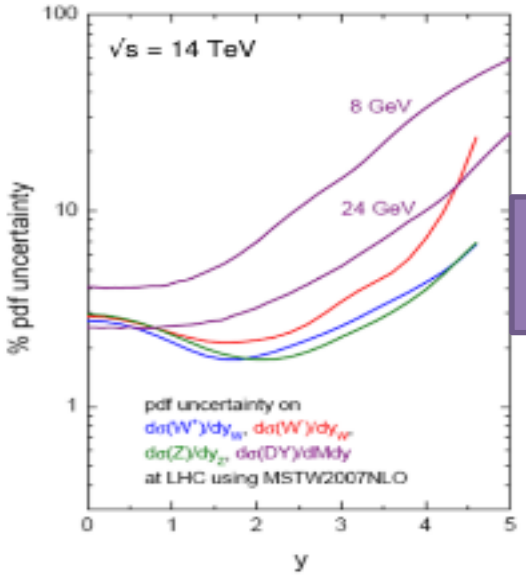




LHCb physics: Z cross-section

- In region covered by LHCb, we see events boosted in forwards direction.
  - One parton has high x, one has low x.
  - Low x PDF is not well constrained by previous measurements.
  - Current predictions of cross-sections in LHCb acceptance suffer from large PDF uncertainties.
  - Use LHCb data to constrain PDFs.



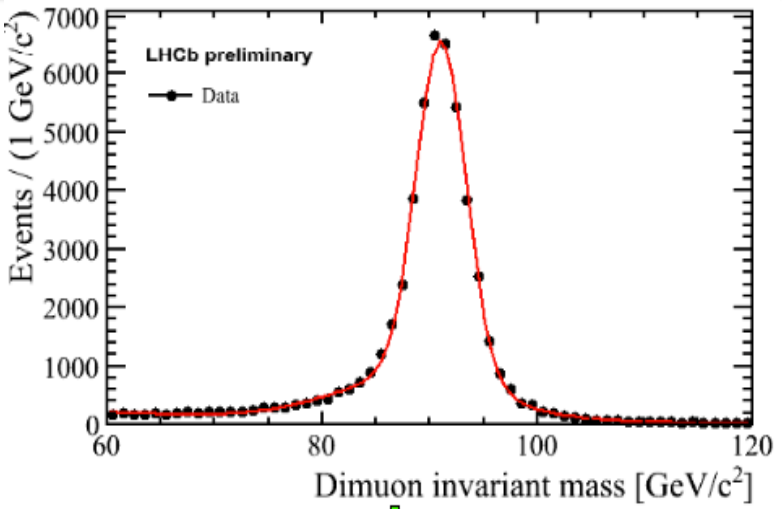


Plots from Thorne et. al. arXiv:0808.1847

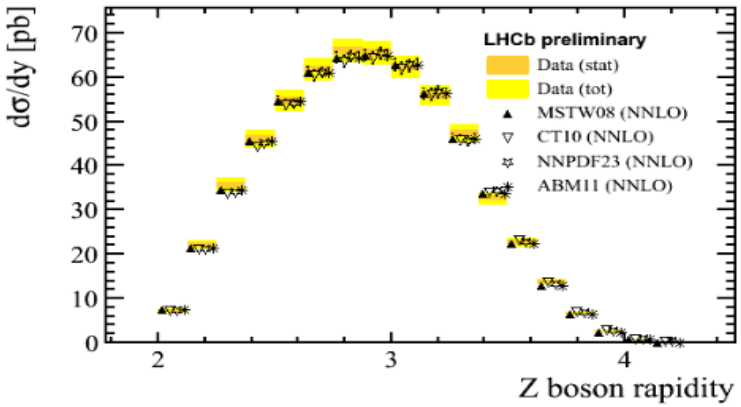
LHCb physics: Z cross-section

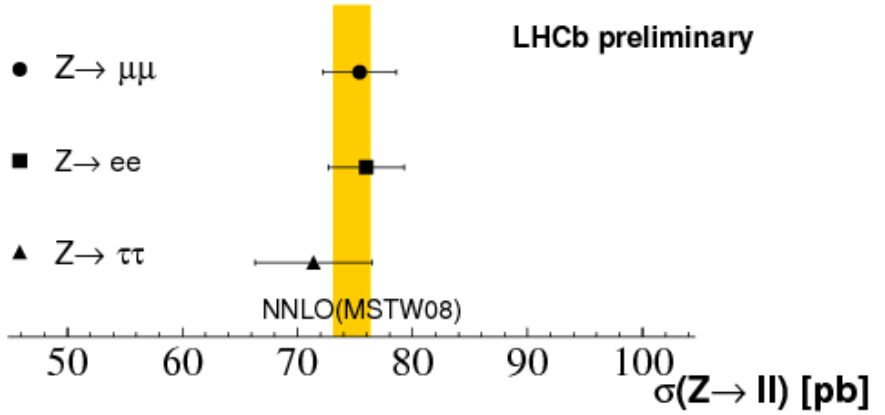
- Look at Z➔μμ
  LHCb-CONF-2013-007
- Good agreement with SM and other LHCb results,

(e.g. JHEP 01 (2013) 111,
JHEP 02 (2013) 106,
JHEP 06 (2012) 058).



- Liasing with PDF fitting groups to maximise usefulness of results.





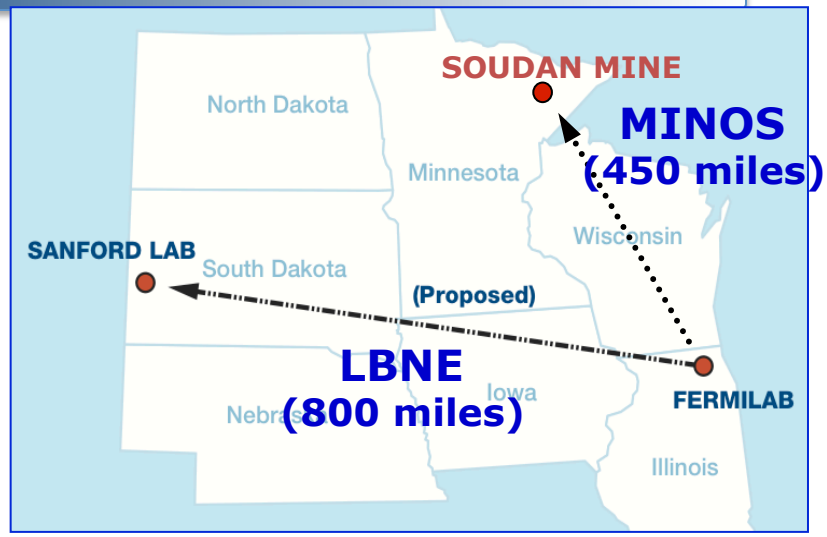
Neutrino physics

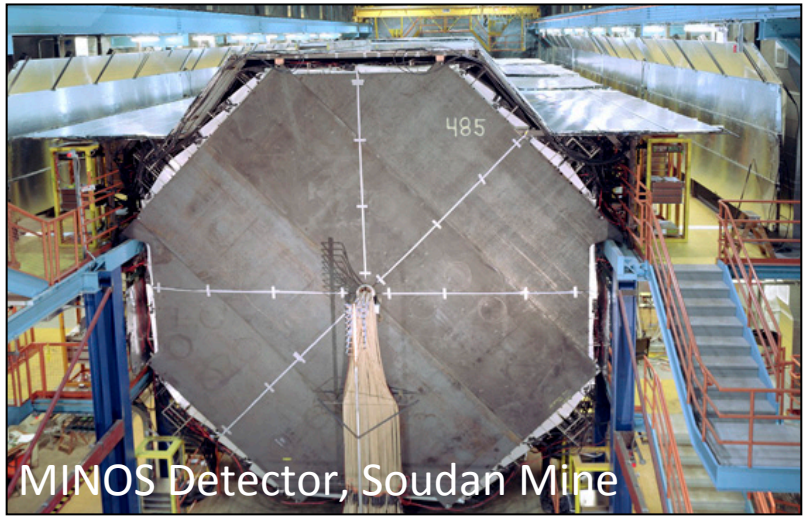
Neutrino physics research at Cambridge

The Cambridge group has collaborated on neutrino physics research at Fermilab for the past decade.

(1) MINOS Experiment
- Operational since 2005.
- World-leading results on neutrino oscillation physics, with many leading roles taken by Cambridge group.
- Currently transitioning to next phase, MINOS+.

(2) LBNE Experiment
- Future long-baseline neutrino experiment, with significant physics capabilities.
- Cambridge heavily involved in technical design effort.

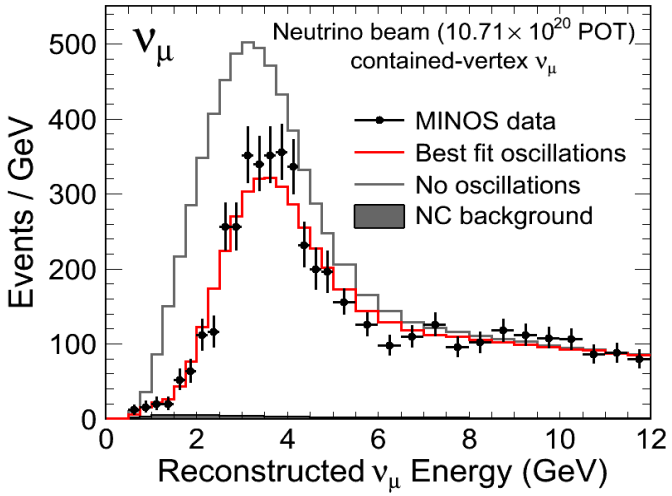


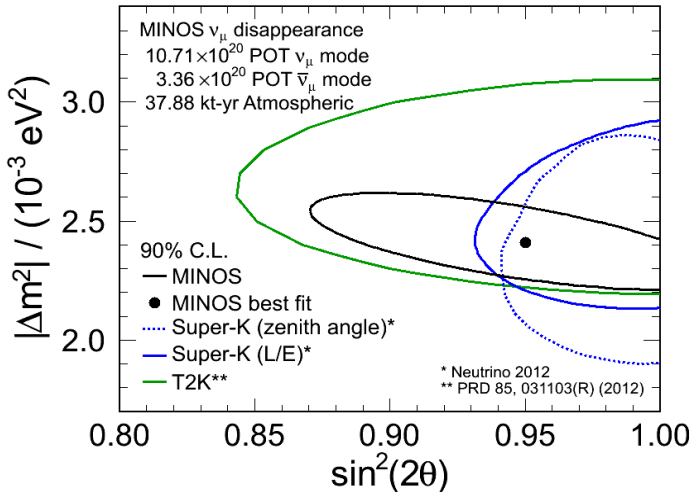


MINOS Detector, Soudan Mine

The MINOS experiment

PRL 110, 251801 (2013)





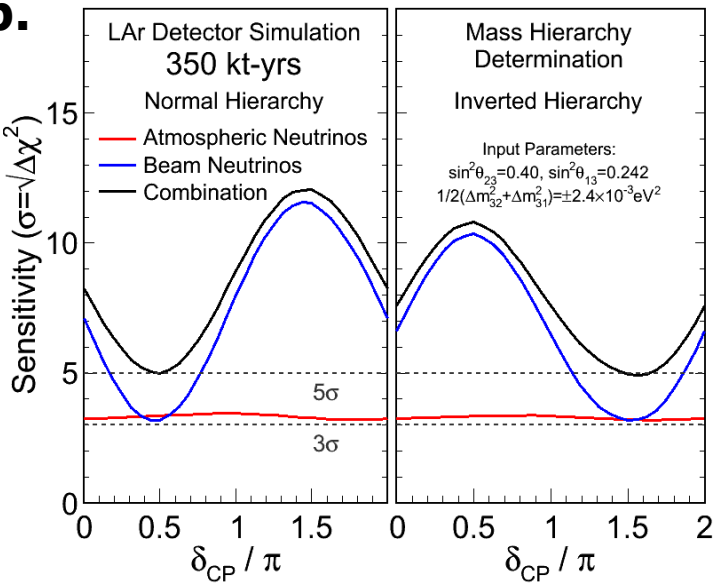
- **MINOS has performed precision oscillation measurements using an accelerator ν_μ beam.**
  - Neutrinos are produced by NuMI facility at Fermilab and travel 450 miles through earth to 5 kiloton MINOS detector.
  - MINOS also measures oscillations in atmospheric neutrinos.
- **MINOS recently published final results on ν_μ, $\bar{\nu}_\mu$ disappearance and ν_e, $\bar{\nu}_e$ appearance.**

  ν_μ: Phys. Rev. Lett. **110**, 251801 (2013)

  ν_e: Phys. Rev. Lett. **110**, 171801 (2013)
- **Cambridge played leading role in ν_μ disappearance analysis.**
  - Combined analysis of accelerator and atmospheric neutrinos.

The LBNE experiment

- **LBNE is a future long-baseline neutrino experiment to be operated from Fermilab.**
  - Project currently entering technical design phase.
- **Compelling physics case:**
  - Neutrino oscillations:
    - ◇ Determination of neutrino mass hierarchy.
    - ◇ First measurements of CP-violating phase.
  - Underground physics:
    - ◇ Proton decay searches
    - ◇ Supernova neutrinos.



A Blake & H Gallagher (ISOUPS conference, 2013).

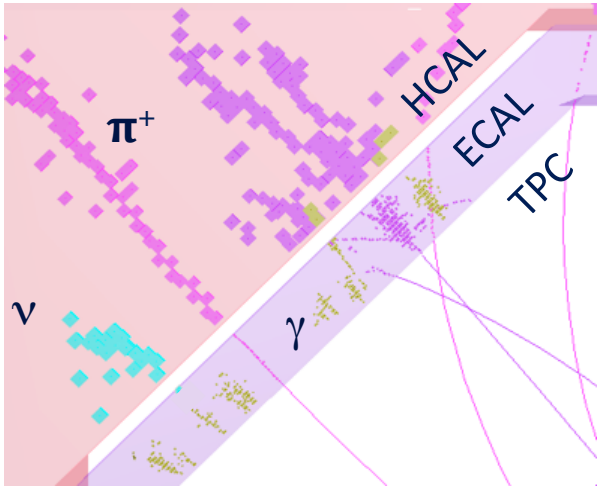
- **The LBNE detector will employ Liquid Argon technology.**
  - Can image neutrino interactions with unprecedented resolution.
- **Cambridge is collaborating in Fermilab R&D and design effort.**
  - Development of fully automated LAr neutrino event reconstruction

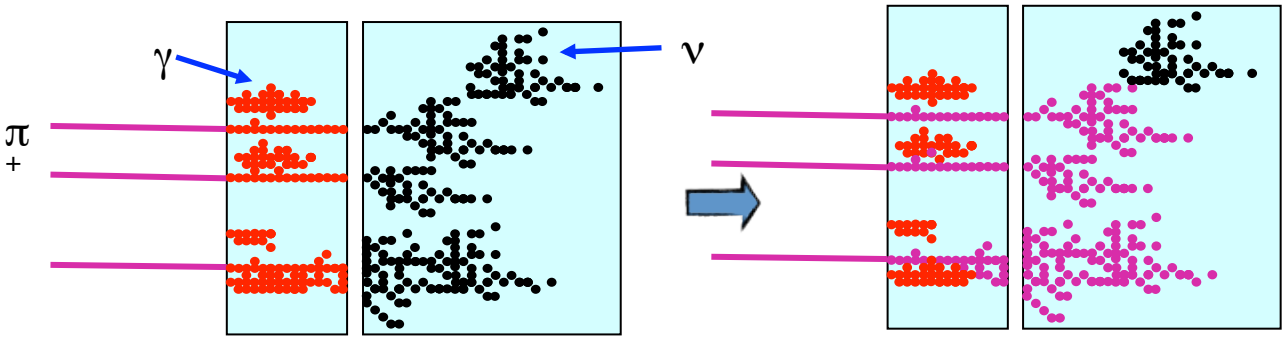
ILC detector calorimetry

- Strong physics case for next large accelerator facility to be a high-energy linear e+e- collider.
- Precision studies, complementary to (HL)LHC.
- Will require excellent calorimeter performance!
  - Sufficient resolution to be able to distinguish hadronicaly decaying W and Z.
- Cambridge joined CALICE collaboration in 2002.
  - R&D projects for high resolution ILC calorimeter.
- Pandora-PFA algorithm developed at Cambridge.

Pandora particle flow calorimetry

- In a typical jet: 60% of energy is carried by charged hadrons, 30% by photons, 10% from neutral hadrons (n and K_L).
- Traditional calorimetry: measure all components of jet energy in ECAL/HCAL.
  - About 70% of energy measured in HCAL,
    $\sigma_E/E = 60\%/\sqrt{E}$
- Particle flow calorimetry: use fine-granularity calorimeter and sophisticated algorithm to trace paths of individual particles through detector.





$E_{JET} = E_{ECAL} + E_{HCAL}$

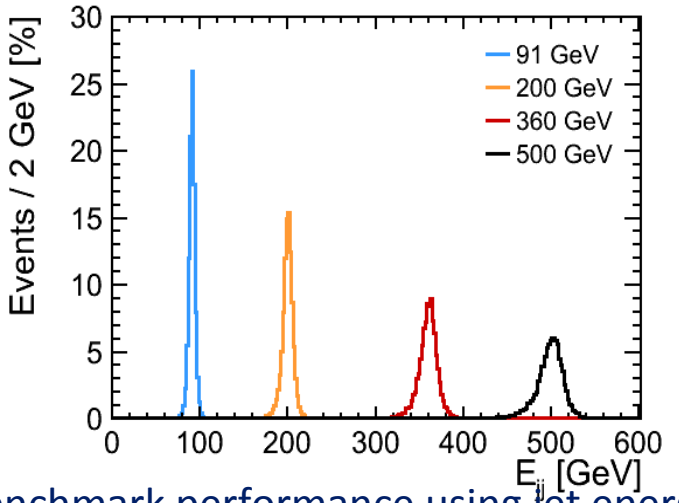
$E_{JET} = E_{TRACK} + E_{\gamma} + E_n$

Particle flow improvement

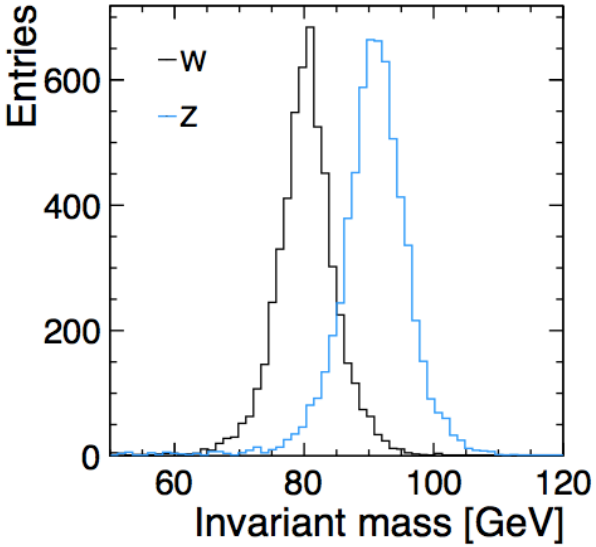
- Charged particle momenta measured in tracker.
- Photon energies measured in ECAL
- Only 10% of energy measured in HCAL

Pandora Particle Flow performance

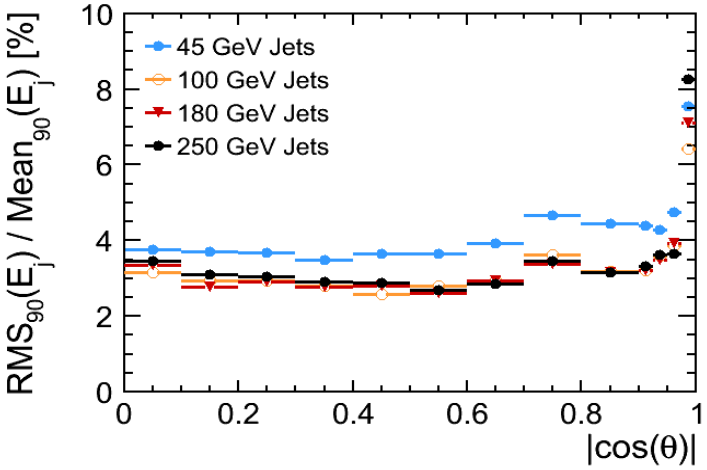
- Pandora PFA is state-of-the-art particle flow for ILC/CLIC
- Uses over 50 pattern recognition algorithms to meet ILC target of $\sigma_E/E \leq 3.5\%$.
- Documented in:
  - NIMA 611: 25-40 (2009)
  - NIMA 700: 153-162 (2013)
  - CLIC conceptual design report
  - ILC detailed baseline design document



Benchmark performance using jet energy resolution in Z decays to light quarks:

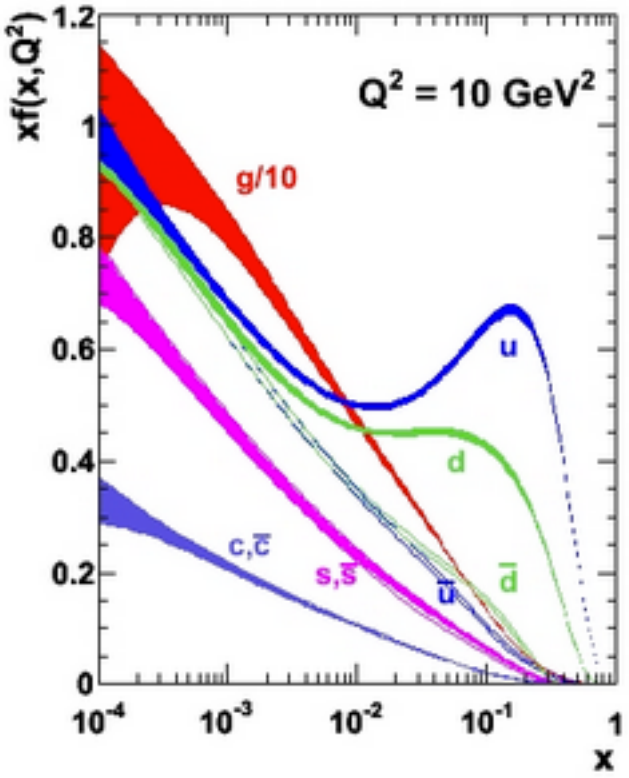


- W/Z separation possible via dijet invariant mass
- Compare distributions from e+e→WW(lqnunu) with those from e+e→ZZ(qqnunu)



Theory/phenomenology (1)

- Monte Carlo simulations.
  - Members of the group involved with development of Herwig, MC@NLO, Charybdis
- Parton Distribution Functions.
  - Part of the MSTW collaboration, involved in determining PDFs from all available data, and using NNLO perturbative QCD, and providing them for use e.g. at LHC.

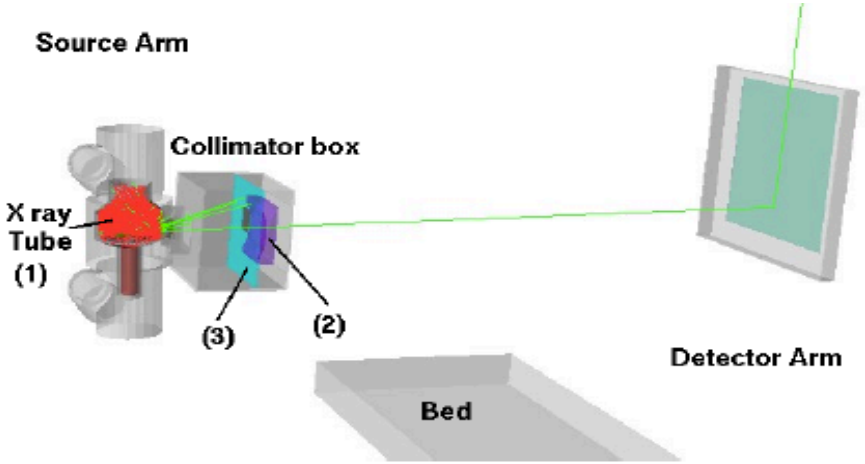


Theory/phenomenology (2)

- Physics beyond the Standard Model
  - Extensive work on search strategies for New Physics at colliders.
    - SUSY, extra dimensions, black holes.
  - Charybdis2 event generator for black holes:
    - arXiv:0904.0979
    - Recently updated to include bulk RS models
  - SoftSusy spectrum generator (collaboration with CoEPP)
  - Weekly Cambridge SUSY meeting, involves both Cavendish HEP group, DAMTP, and experimentalists.

Geant 4 simulation of medical X-ray scanner

(http://www.ghost-project.org/, collaboration with Department of Oncology.)



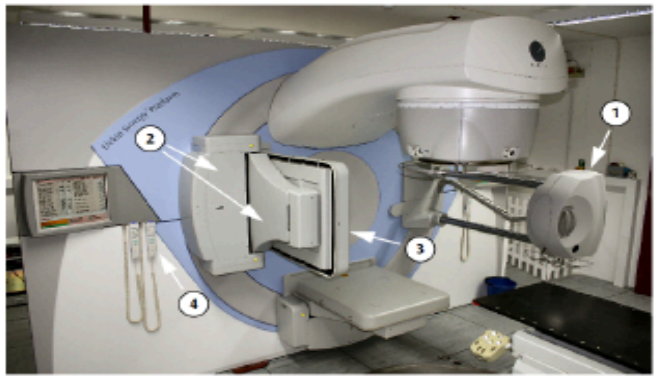


Figure 2.2 *Typical treatment room*

(1) kV source
(2) kV detector arm
(3) kV detector panel
(4) XVI handheld controller

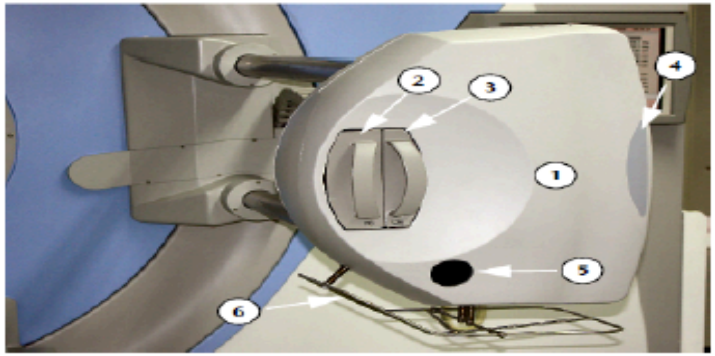


Figure 3.1 *Front view of the kV source arm*

(1) kV source
(2) Filter cassette
(3) Collimator cassette
(4) Handle
(5) Locking push button
(6) kV touchguard frame

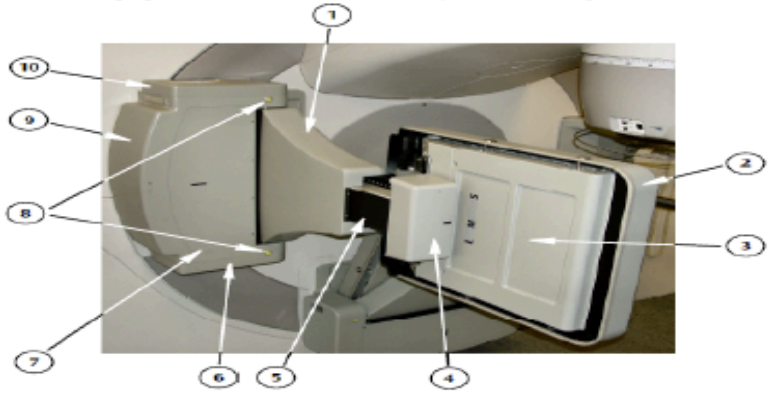


Figure 3.11 *kV detector arm and structures*

(1) Shoulder
(2) Detector touchguard
(3) Cradle assembly
(4) Middle arm touchguard
(5) Middle arm
(6) B-side cover (DCB)
(7) Front cover
(8) Manual brake release buttons
(9) Base assembly
(10) A-side cover (ACB)

Conclusions

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