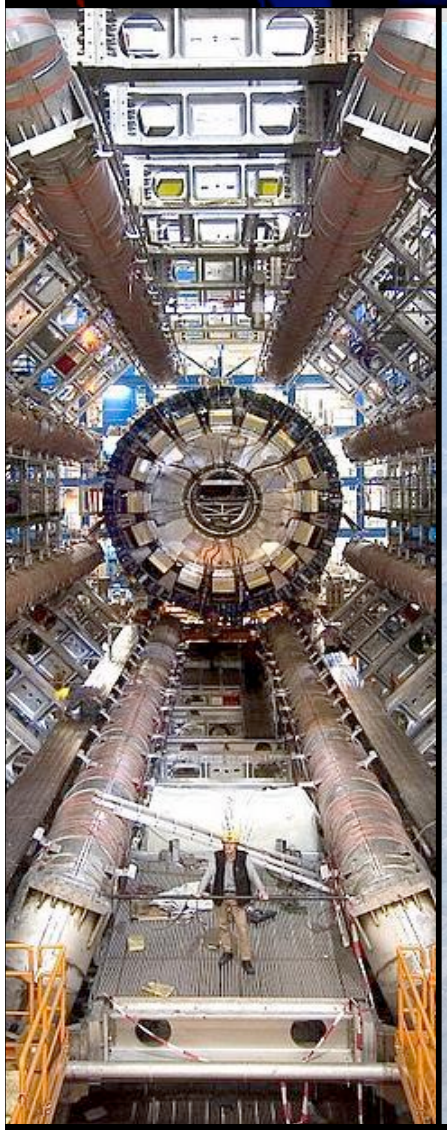
Status of ...



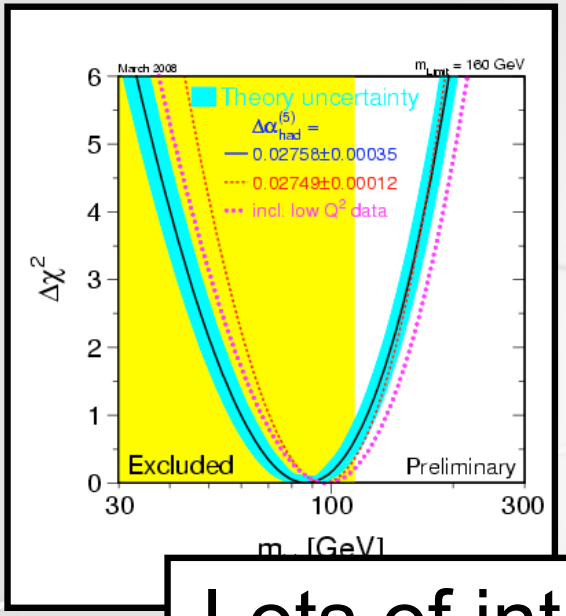
the
LARGE HADRON COLLIDER

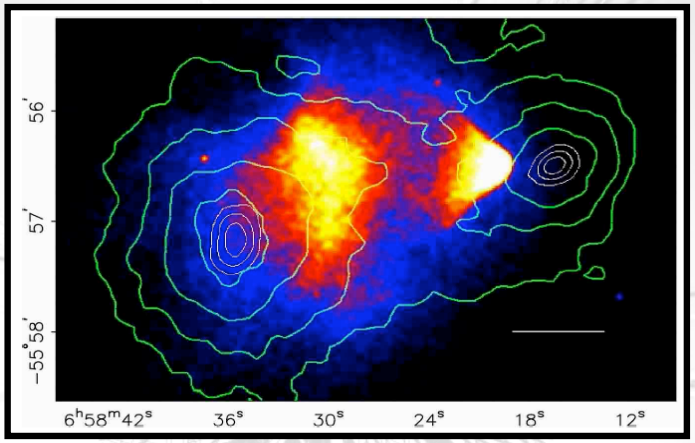
With information from …

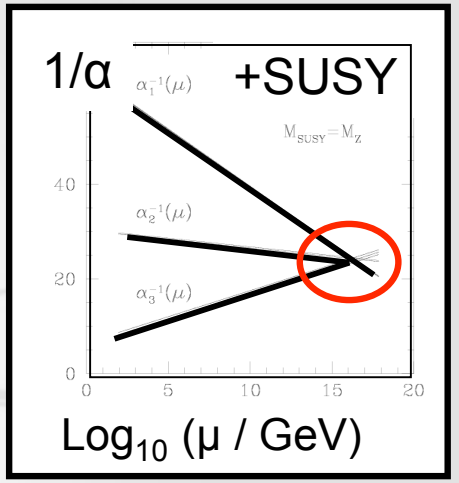
… but also from …

CERN-MOVIE-2008-081.mpg

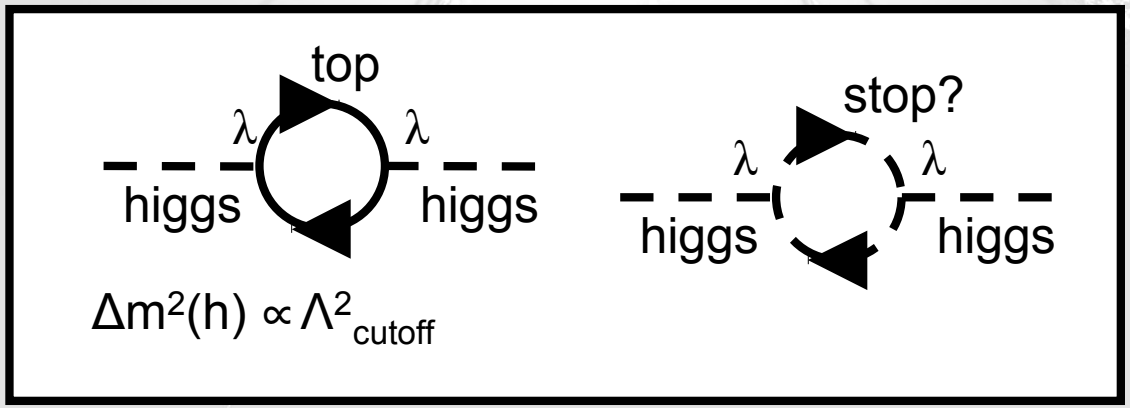
Motivational arguments







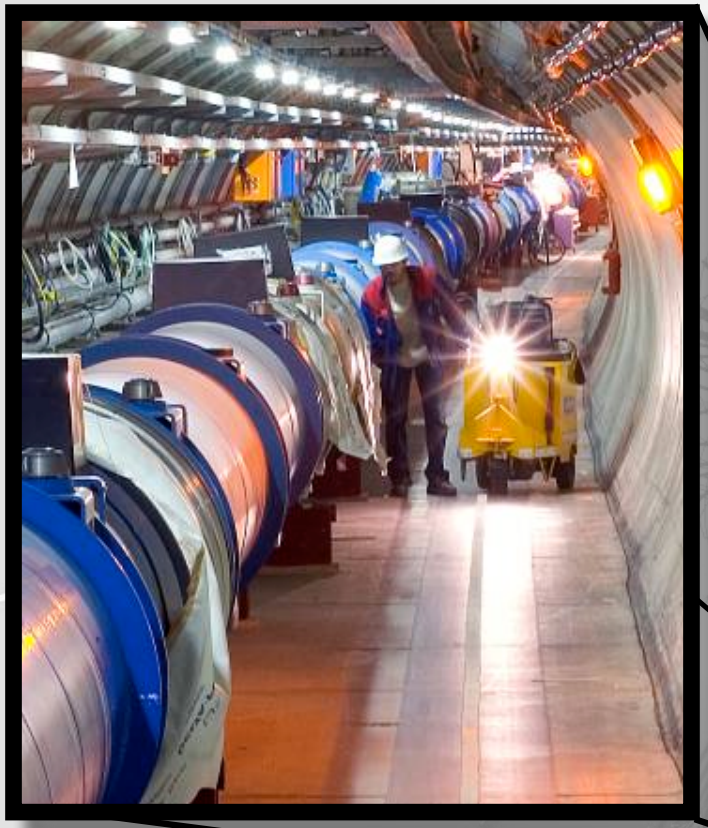
Lots of interesting physics at ~ 1 TeV

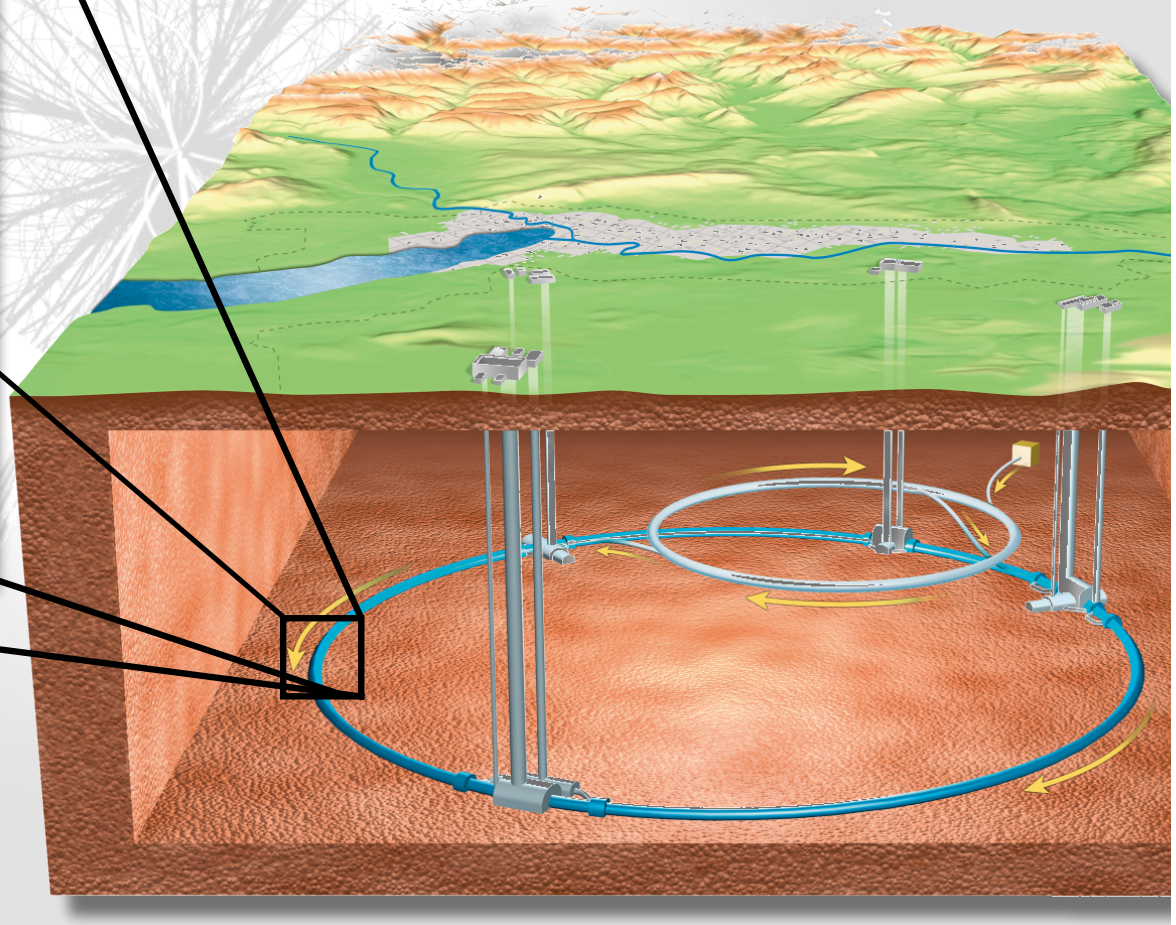


The machine ...

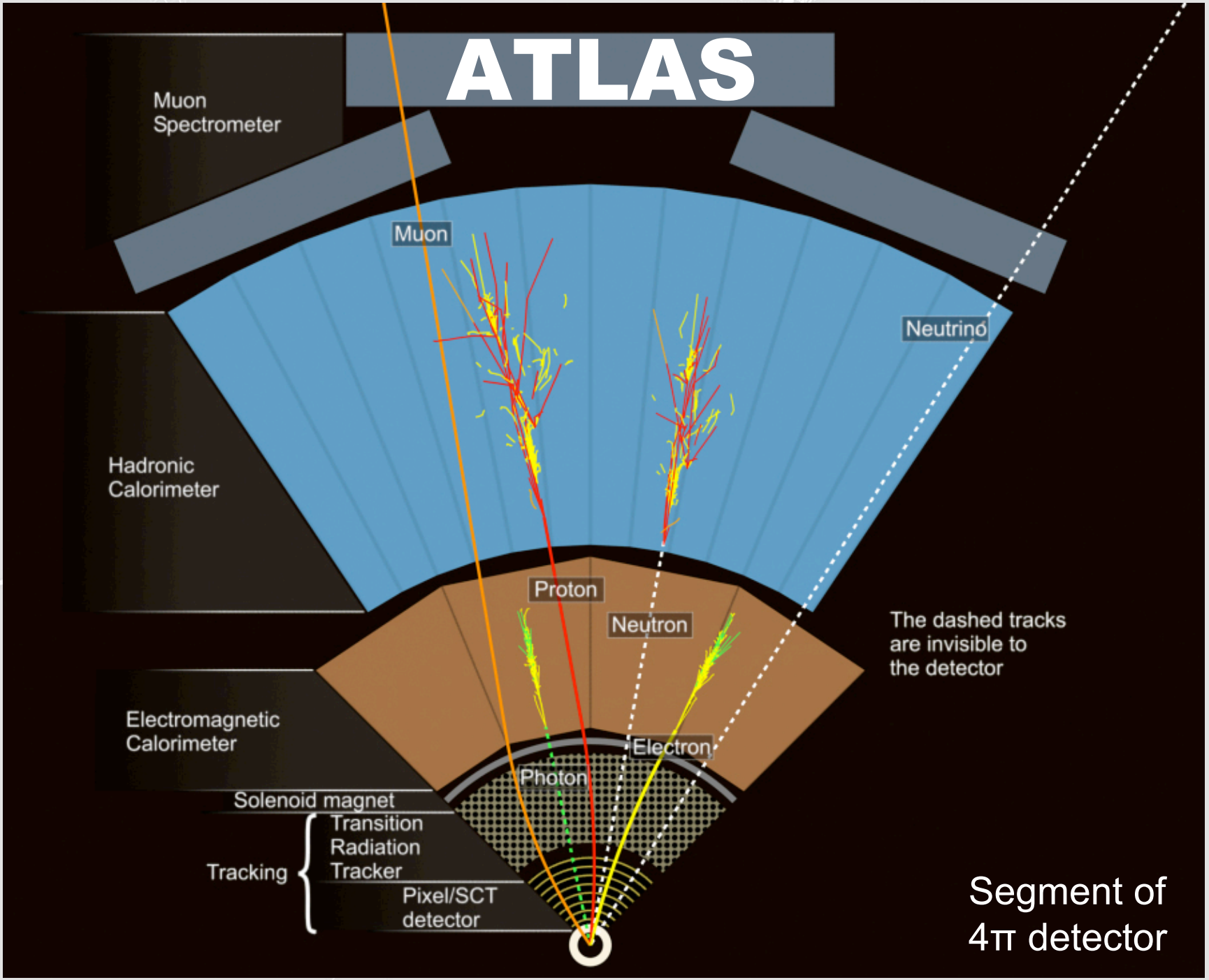
Proton-proton

- **controlled environment**
- **14 TeV**
- **10^9 collisions/s**
- **~decade operation**

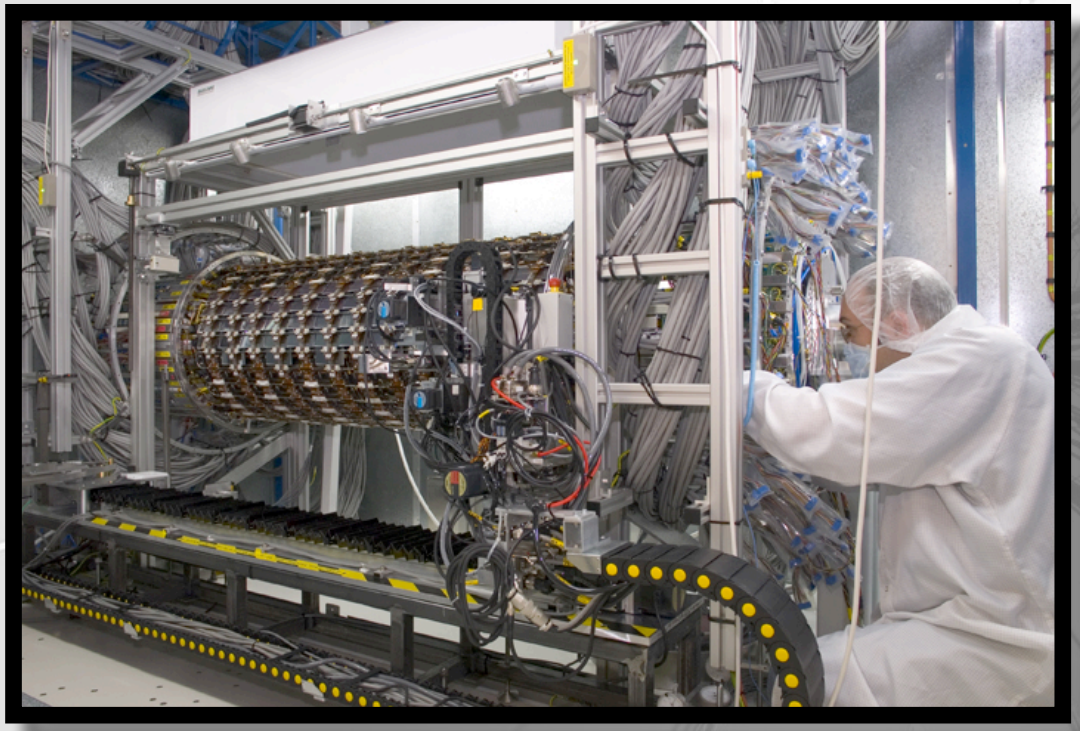


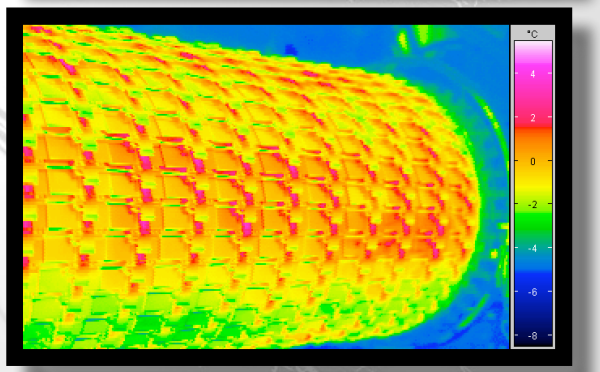


26.659 km circumference
9300 magnets
Four experiments


ATLAS
Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Segment of 4π detector

Local interest ...

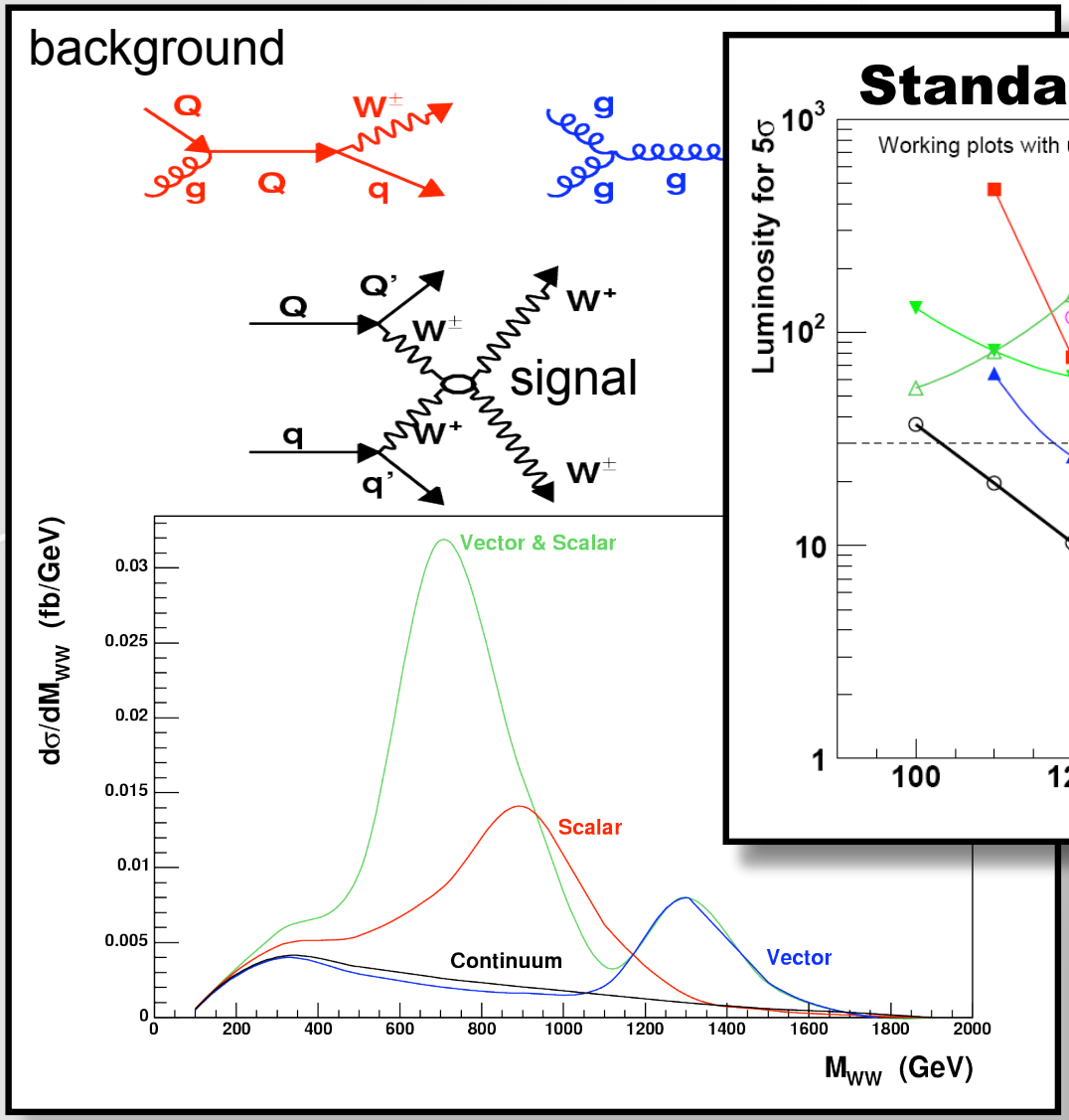


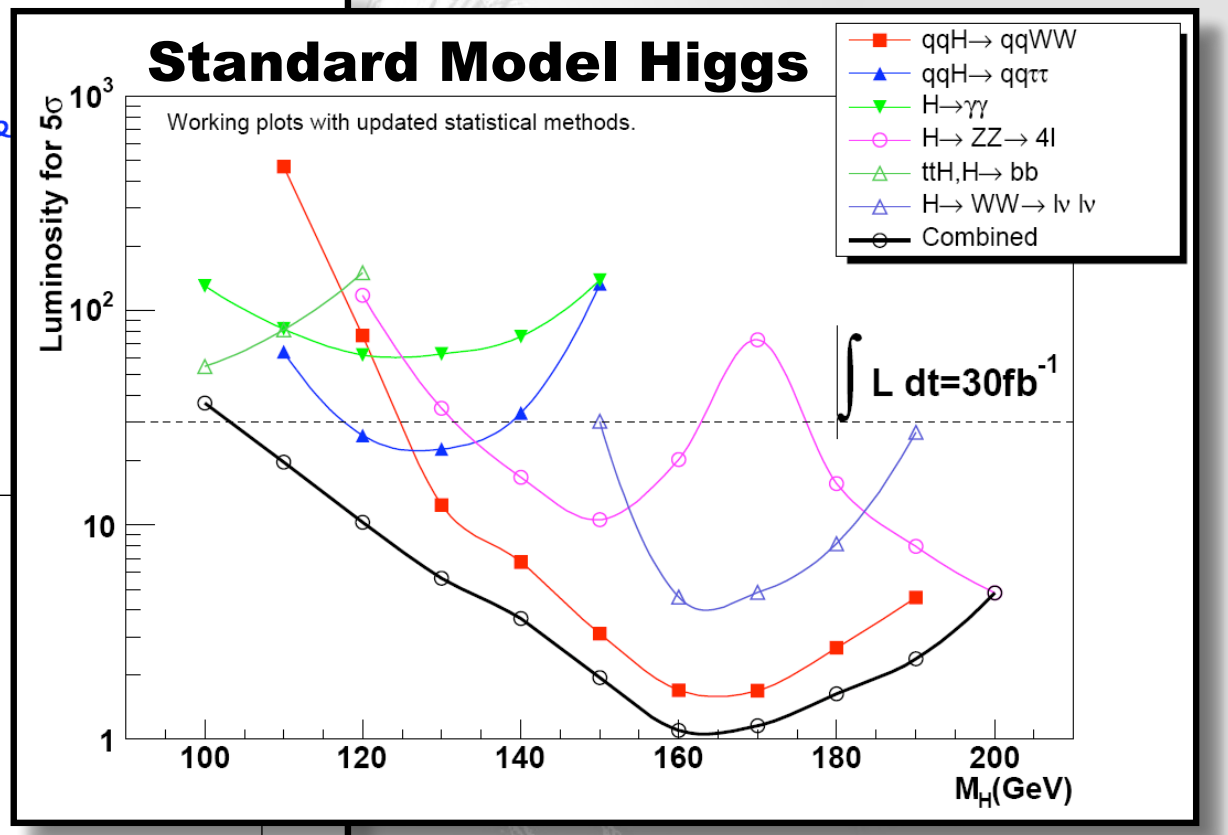


Robotic assembly of precision silicon tracker

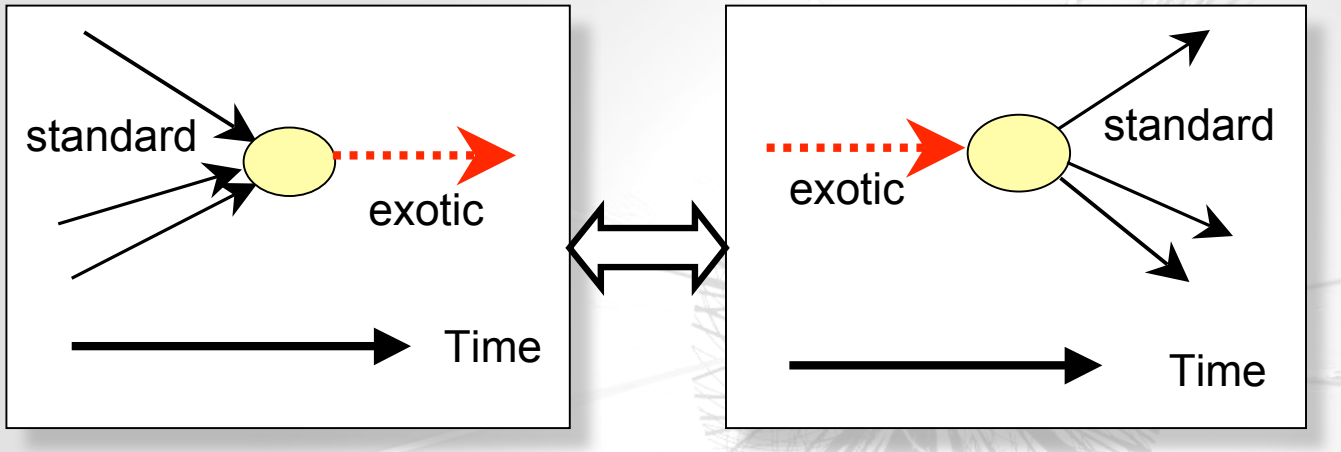
Summer 2004 to Summer 2005

Electroweak symmetry breaking



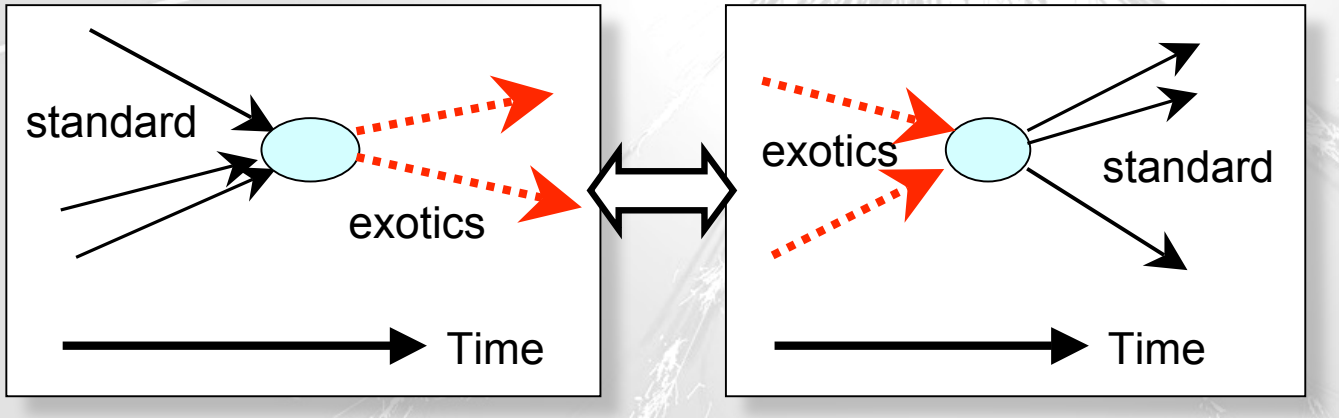


Producing WIMPs?



If exotics can be produced *singly* they can decay

- **No good for Dark Matter candidate**

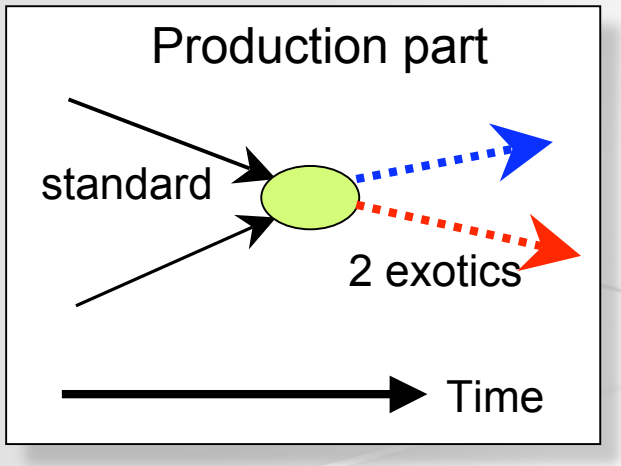


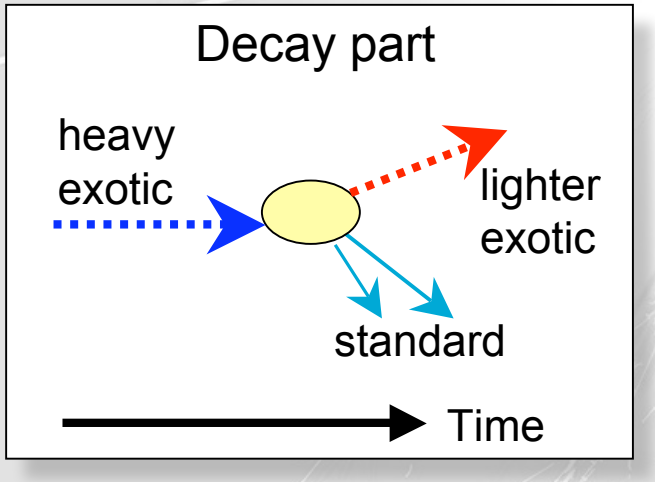
If they can only be *pair*-produced they are stable

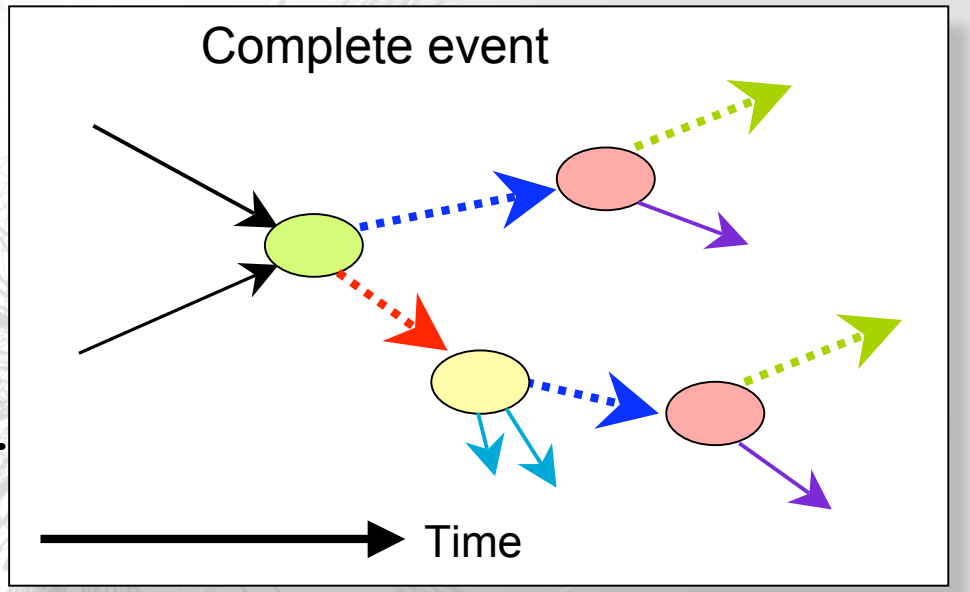
- **Only disappear on collision (rare)**

Require an even number of exotic legs to/from blobs
(Conserved multiplicative quantum number)

“Seeing” WIMPs at the LHC







Events build from blobs with 2 “exotic legs”

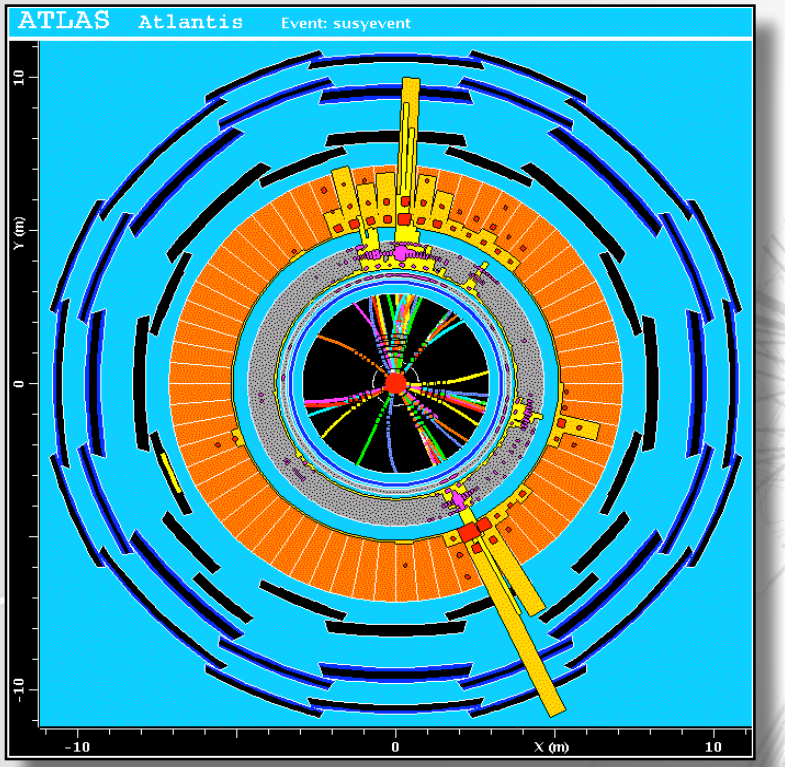
A pair of cascade decays results

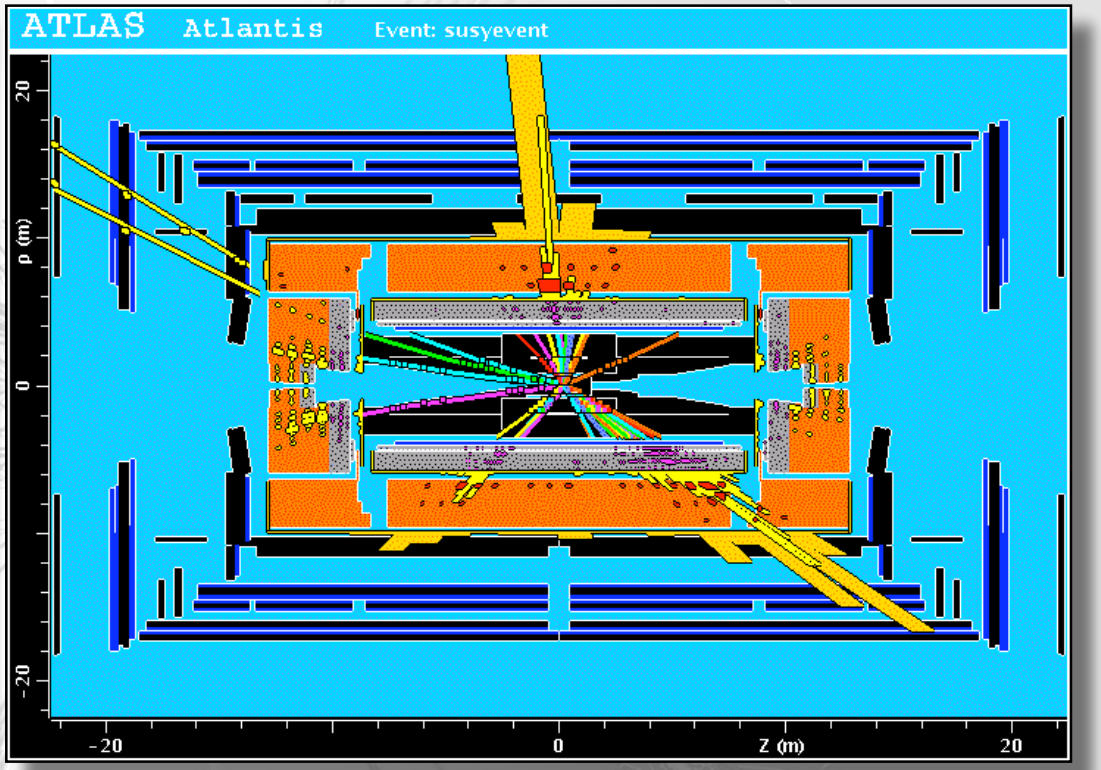
Complicated end result

= exotic

= standard

Simulated SUSY event





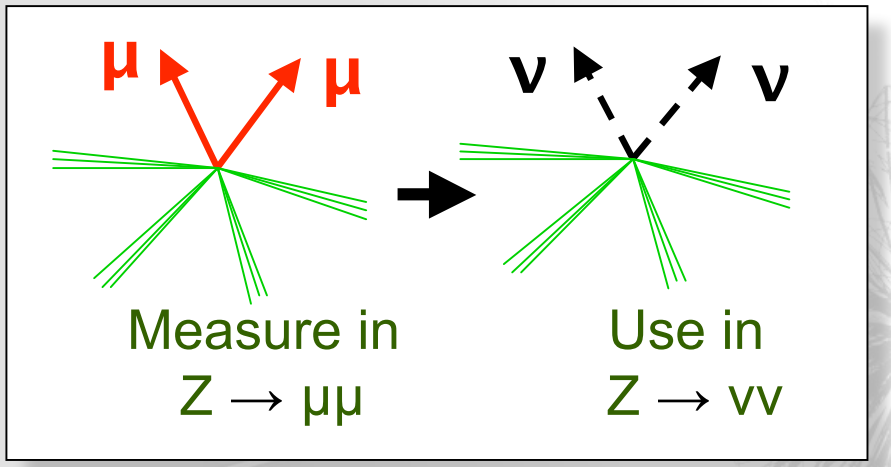
Missing transverse momentum

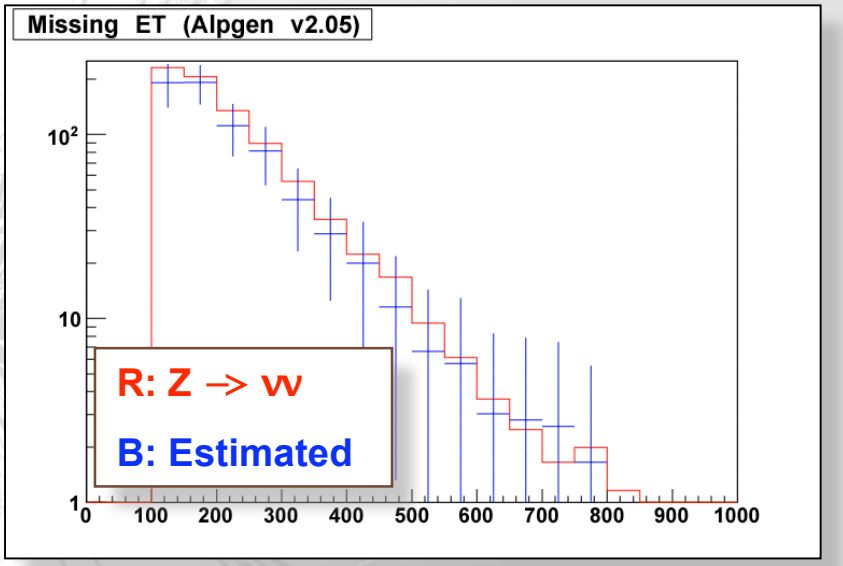
Jets

Heavy quarks

Leptons

Measuring backgrounds





Example: SUSY BG

- Missing energy + jets from Z^0 to neutrinos
- Measure in $Z \rightarrow \mu\mu$
- Use for $Z \rightarrow \nu\nu$

Good match

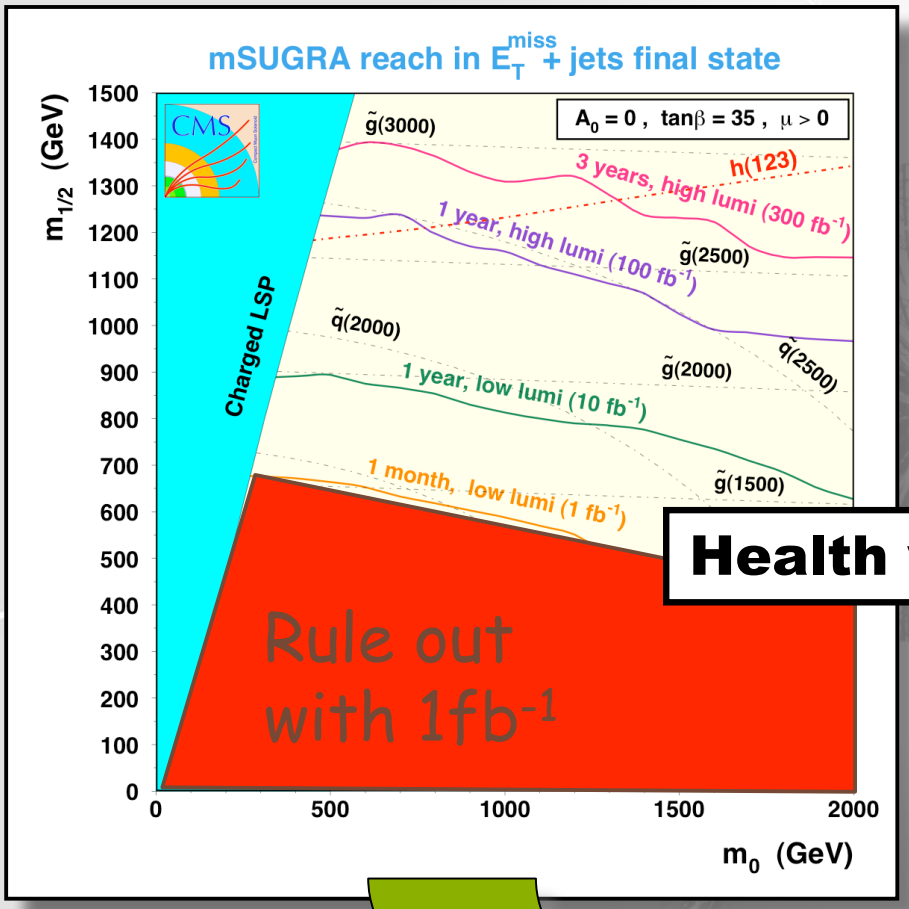
- Useful technique

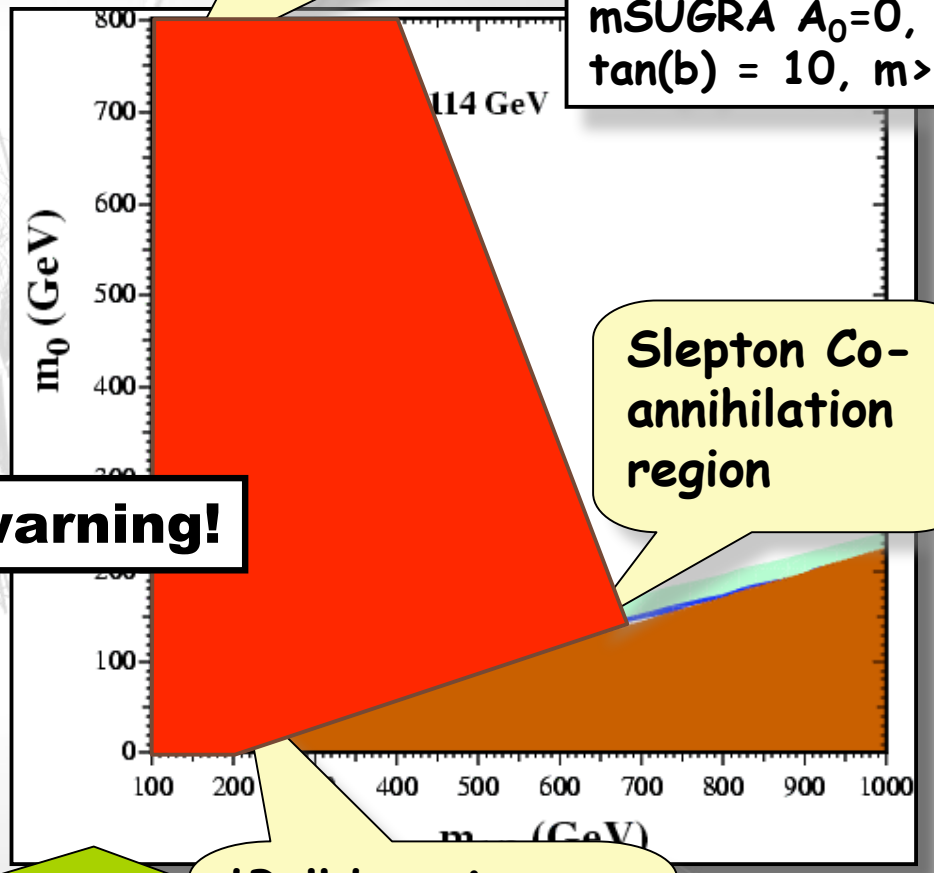
Statistics limited

- Go on to use $W \rightarrow \mu\nu$ to improve

Very many other cross-checks will also be made

Reach in cMSSM?





'Focus point' region: annihilation to gauge bosons

mSUGRA A_0=0, tan(b) = 10, m>0

Slepton Co-annihilation region

Health warning!

'Bulk' region: t-channel slepton exchange

WMAP constraints

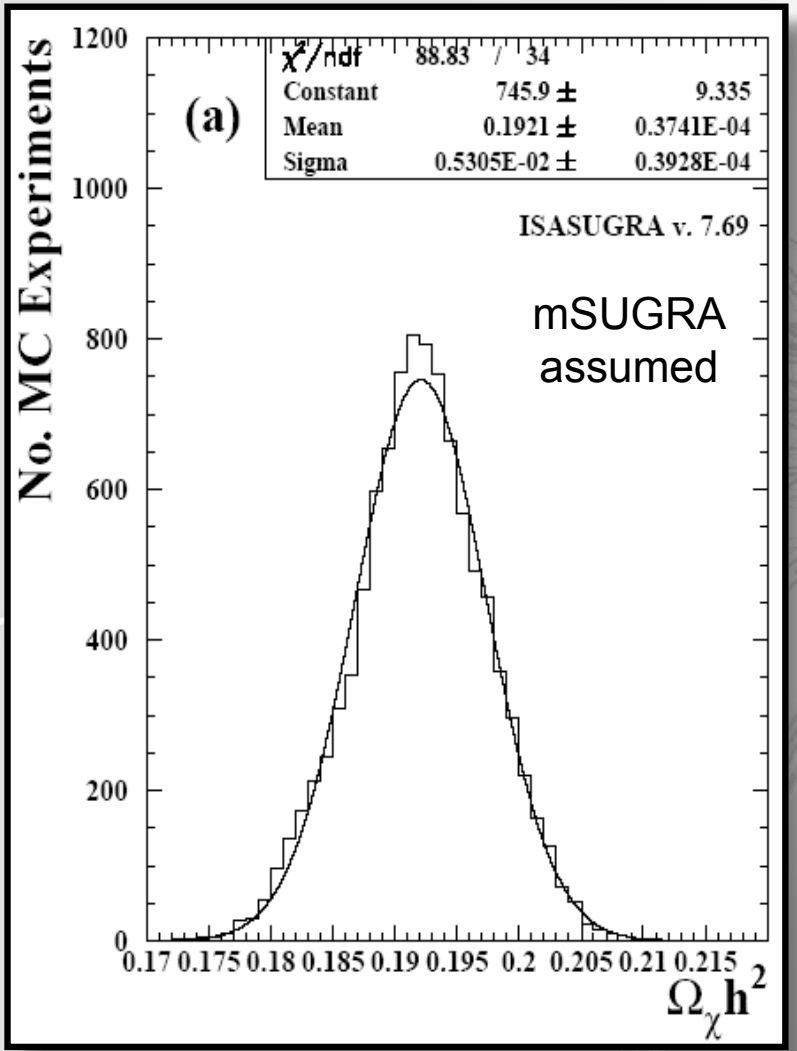
Mapping out the new world

LHC Measurement	SUSY	Extra Dimensions
Masses	Breaking mechanism	Geometry & scale
Spins	Distinguish from Extra Dim.	Distinguish from SUSY
Mixings, Lifetimes	Gauge unification? Dark matter candidate?	

Some measurements make high demands on:

- **Statistics (→ time)**
- **Understanding of detector**
- **Clever experimental techniques**

‘Measure’ relic density?



Use LHC measurements to “predict” **relic density** of observed LSPs

Caveats:

- Cant tell about lifetimes beyond detector (need **direct search**)
- Studies done so far in optimistic case (light sparticles)

To remove mSUGRA assumption need **extra constraints**:

1. All neutralino masses
   - Use as inputs to gaugino & higgsino content of LSP
2. Lightest stau mass
   - Is stau-coannihilation important?
3. Heavy Higgs boson mass
   - Is Higgs co-annihilation important?

More work is in progress

- Probably not all achievable at LHC
- **ILC** would help lots (if in reach)

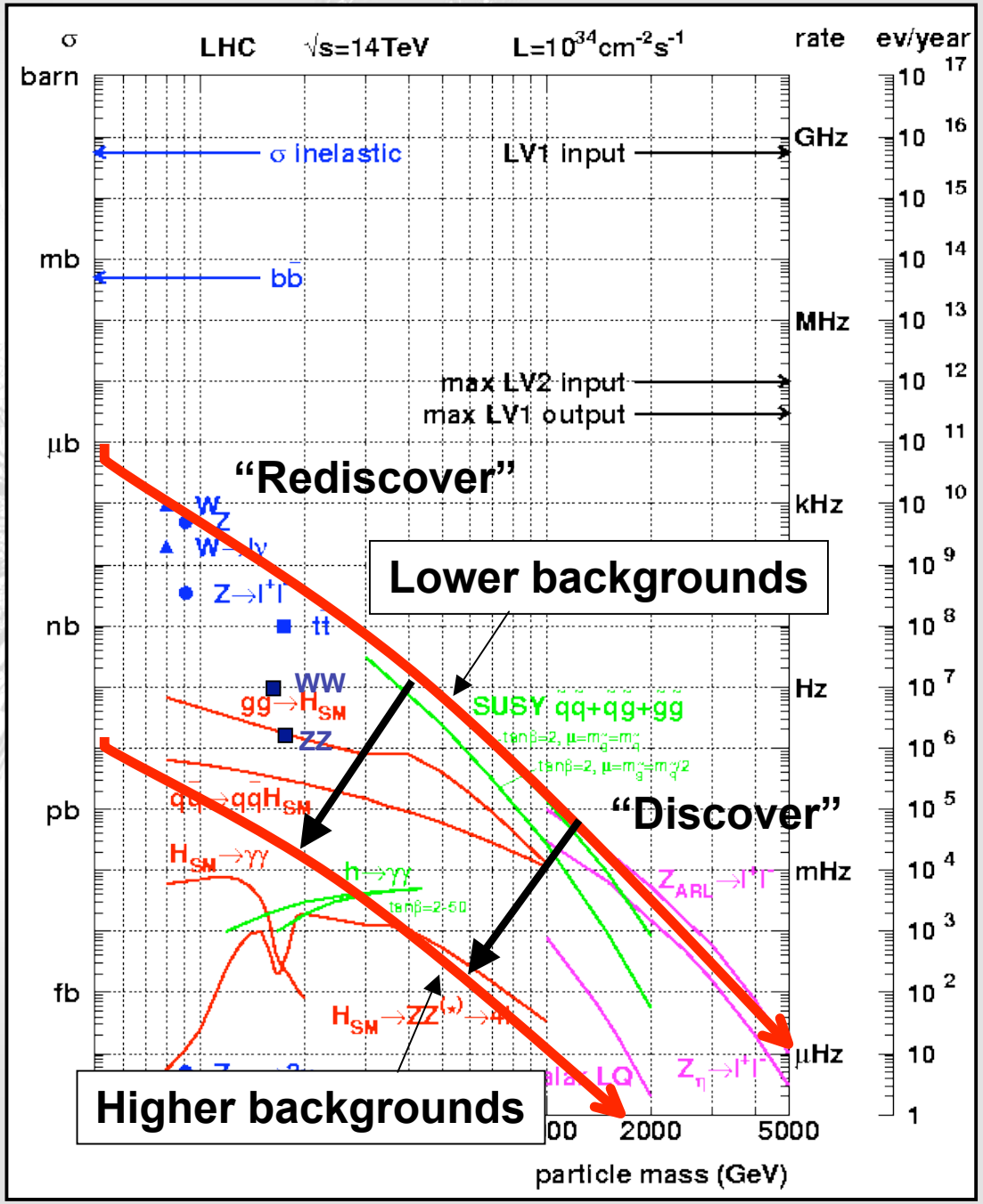
Discoveries?

What can we find "rapidly"?

- Reasonable cross-section
- Low backgrounds
- Easily reconstructed
- Limited detector understanding?

Some things will stick out

Most need more careful analysis



Media interest?

World beater or planet eater? ... experiment will cause black holes some fear could destroy the planet

By PAUL SUTHERLAND
Sun Spaceman

Published: 01 Sep 2008

ADD YOUR COMMENTS

SCIENTISTS are trying to stop the most powerful experiment ever – saying the black holes it will create could destroy the world.

Dubbed by some the Doomsday test, it will be carried out next week in the Large Hadron Collider (LHC), located 300ft underground near the French-Swiss border.

The machine is 17 miles long and cost £4.4billion to create.

When its switch is pulled on September 10, this atom-smasher will become a virtual time machine, revealing what happened when the universe came into existence 14 billion years ago.

New particles of matter are expected to be discovered, new dimensions found beyond the four known, as scientists re-create conditions in the first **BILLIONTHS** of a second after the Big Bang.

Don't panic, there's time to try out every position in the Kama Sutra

WITH just nine days to go until the end of the world, here's what you could get up to before it's too late ...

1. Eat 27 Big Mac meals. Who's counting the calories?

2. Visit all seven continents.

3. Try out all 64 Kama Sutra positions.

4. Watch the entire box sets of Lost, Heroes and Prison Break.

5. Cruise the River Nile.

6. Drive to Switzerland for a ringside seat of doomsday.

Understated commentary continued in popular press...

10th September

> 300 journalists on site

> 3500 press cuttings

LHC on the Google logo

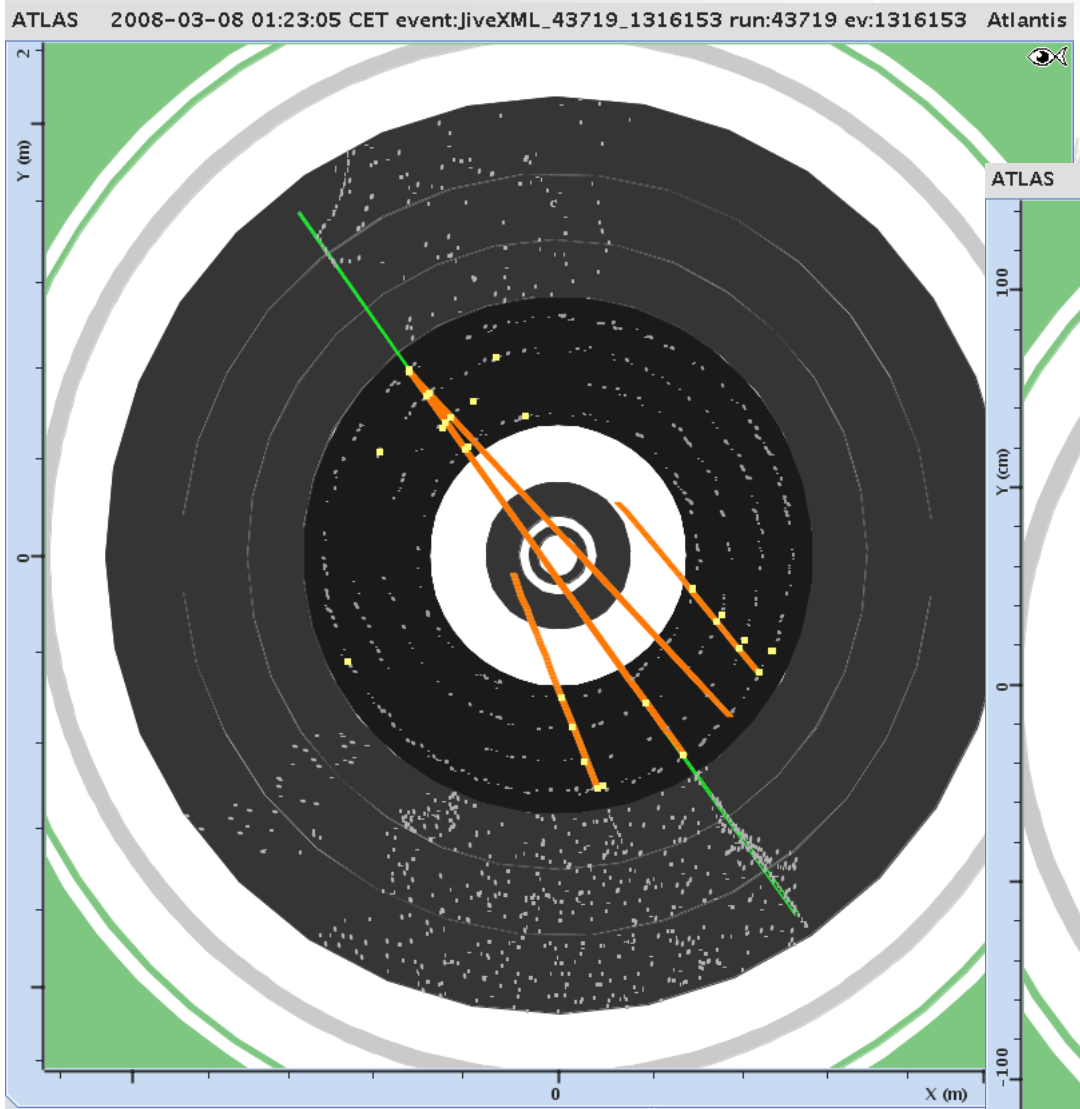
450 television stations picked up broadcast

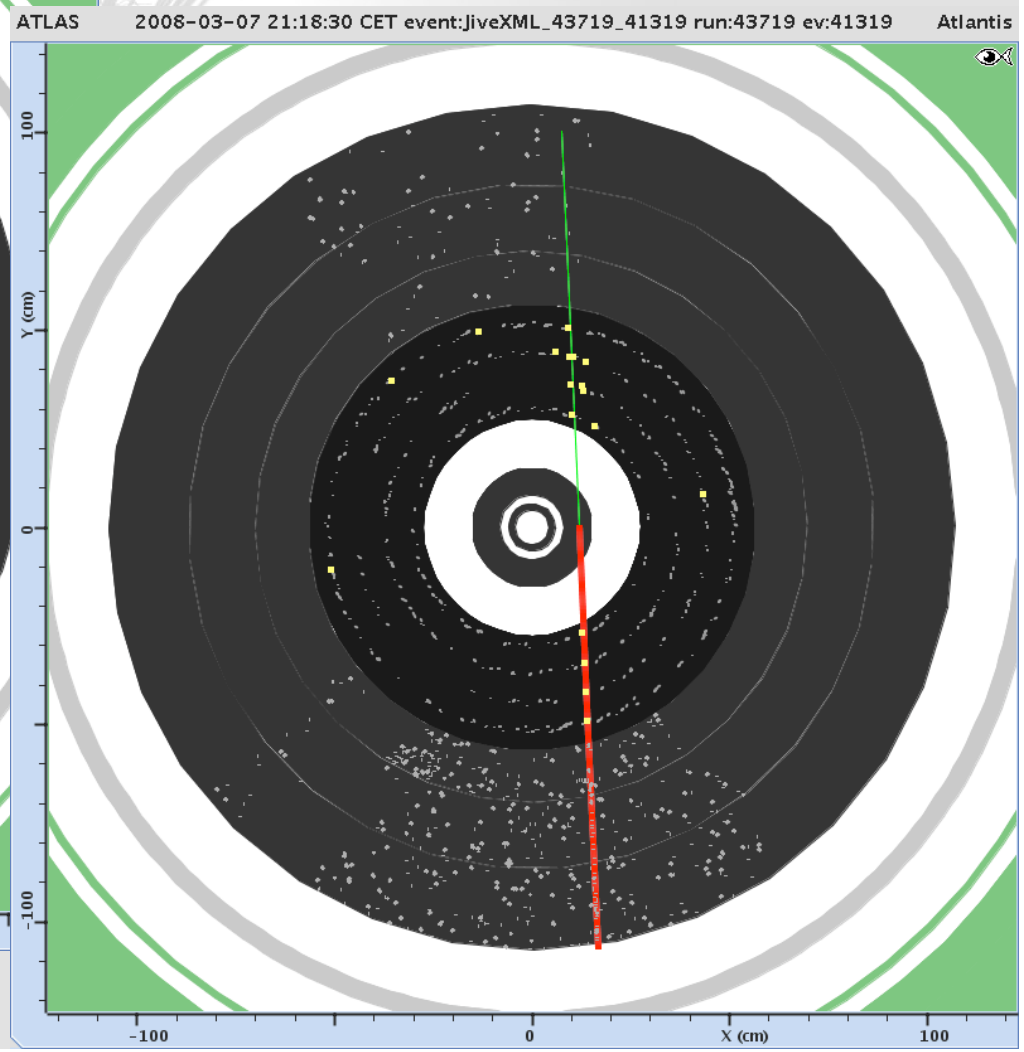
100 million website hits

Lead news story on television news across the world

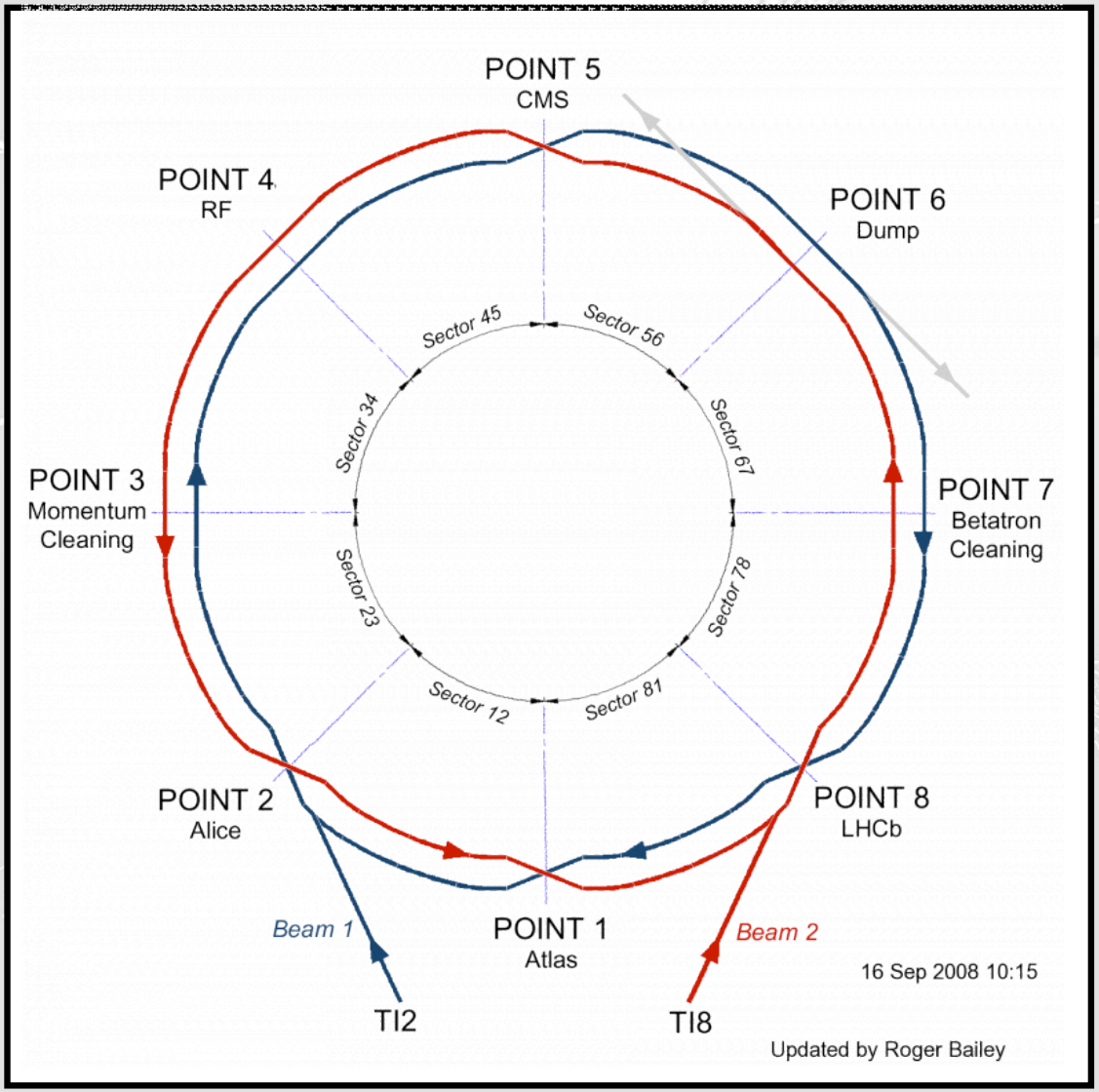
CERN-MOVIE-2008-081.mpg

No beam: cosmic rays

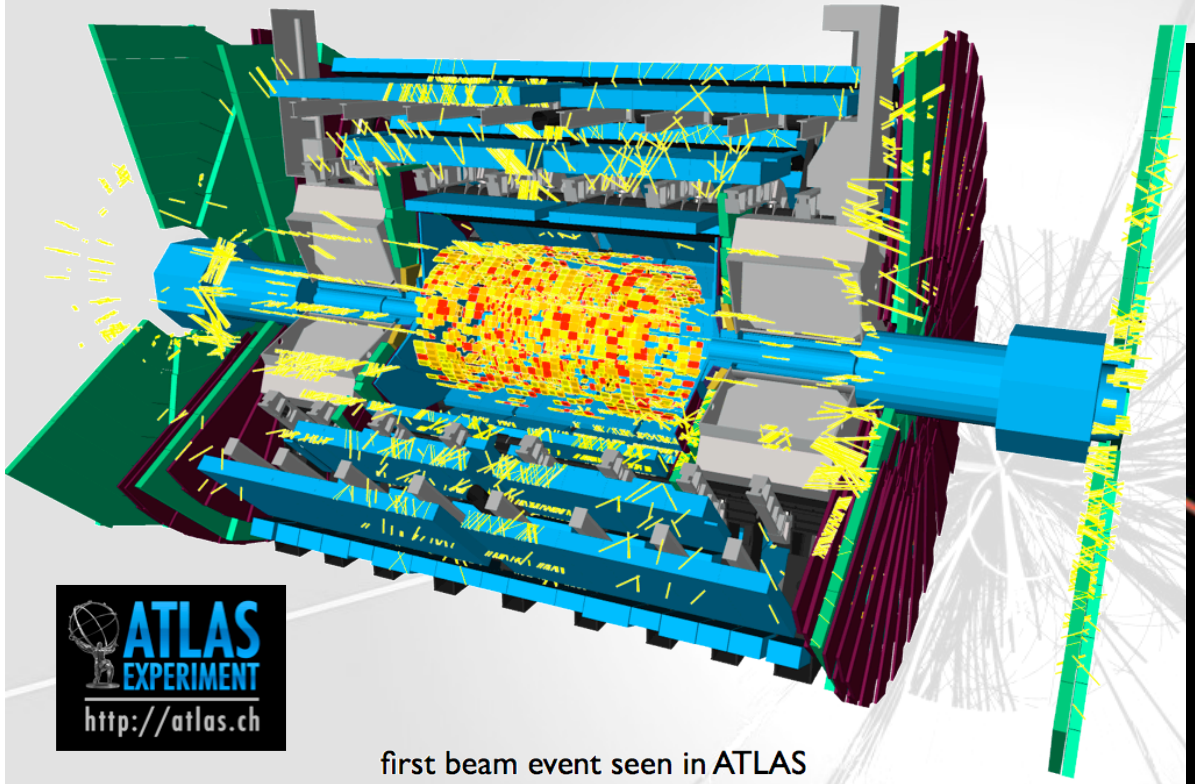




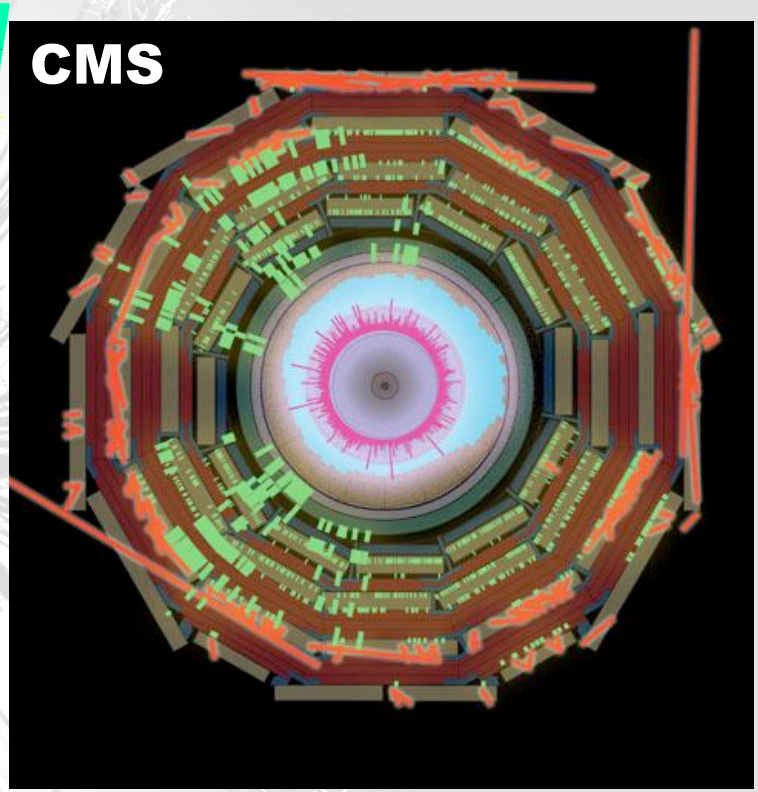
First beam: 10th September 2008

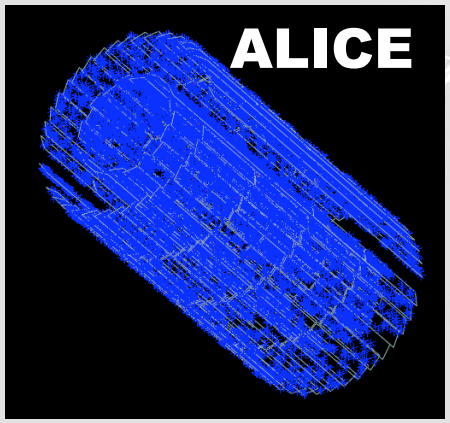


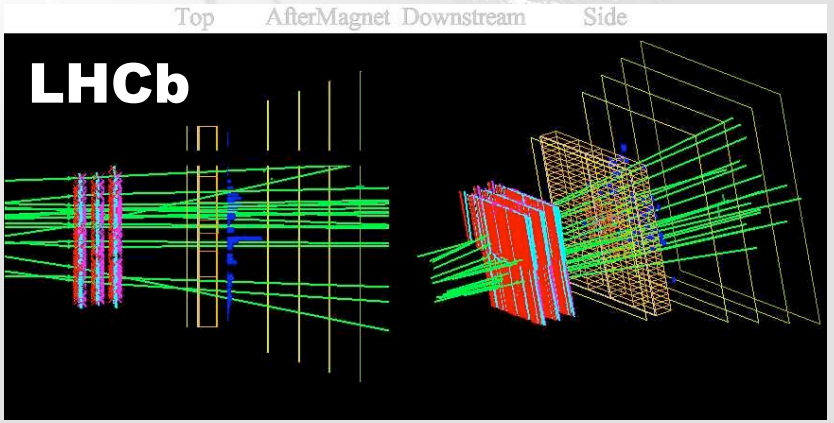
Muon cloud hits detectors

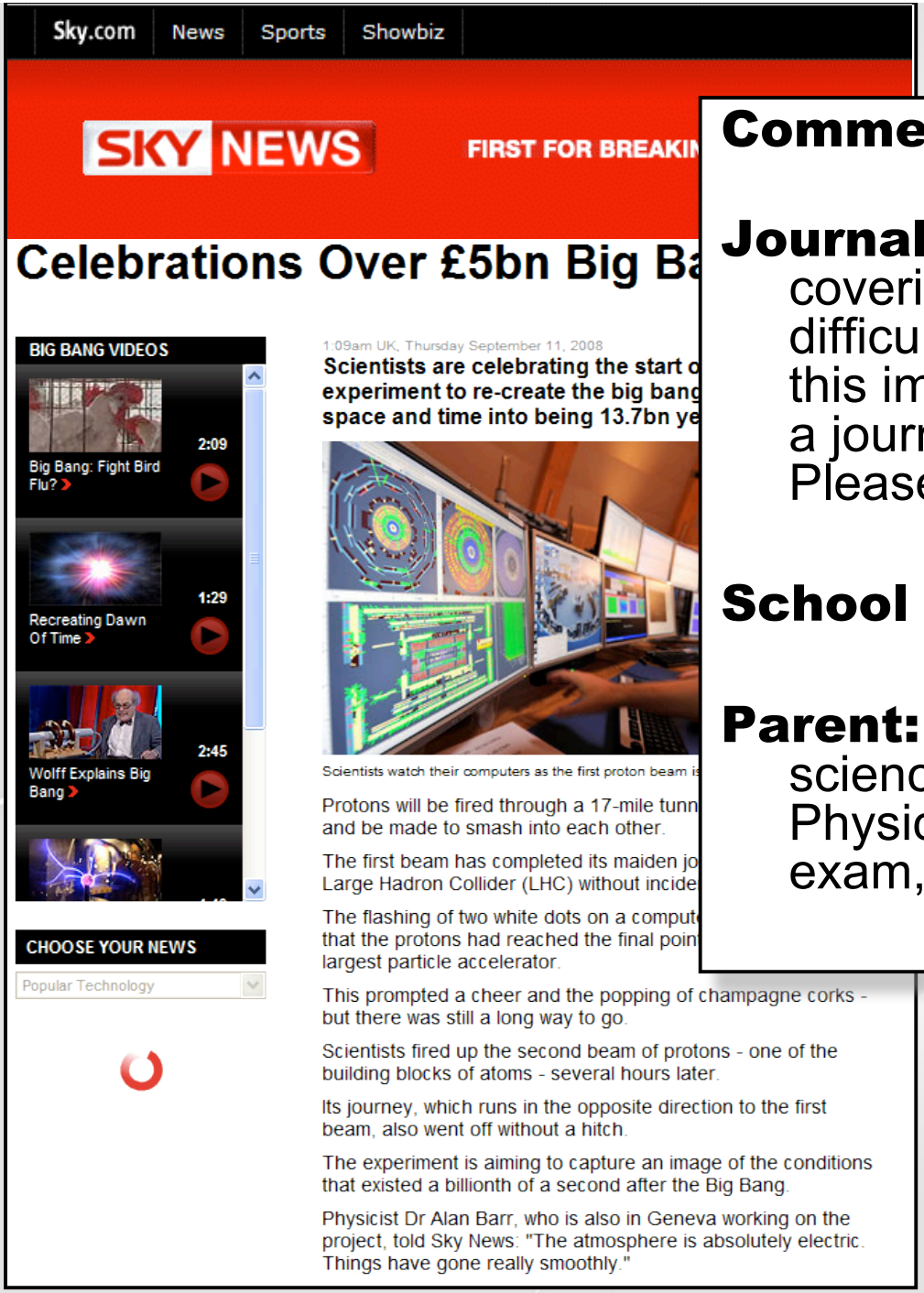


first beam event seen in ATLAS









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10th September

19th Sept

"Teething troubles at the start-up phase are always possible..."

LHC re-start scheduled for 2009

PR10.08
23.09.2008

Geneva, 23 September 2008. Investigations at CERN[1] following a large helium leak into sector 3-4 of the Large Hadron Collider (LHC) tunnel have indicated that the most likely cause of the incident was a faulty electrical connection between two of the accelerator's magnets. Before a full understanding of the incident can be established, however, the sector has to be brought to room temperature and the magnets involved opened up for inspection. This will take three to four weeks. Full details of this investigation will be made available once it is complete.

Warm-up, fix and cool-down needed

Experiments will make the most of it

- **make hardware fixes**
- **finish commissioning with cosmics**

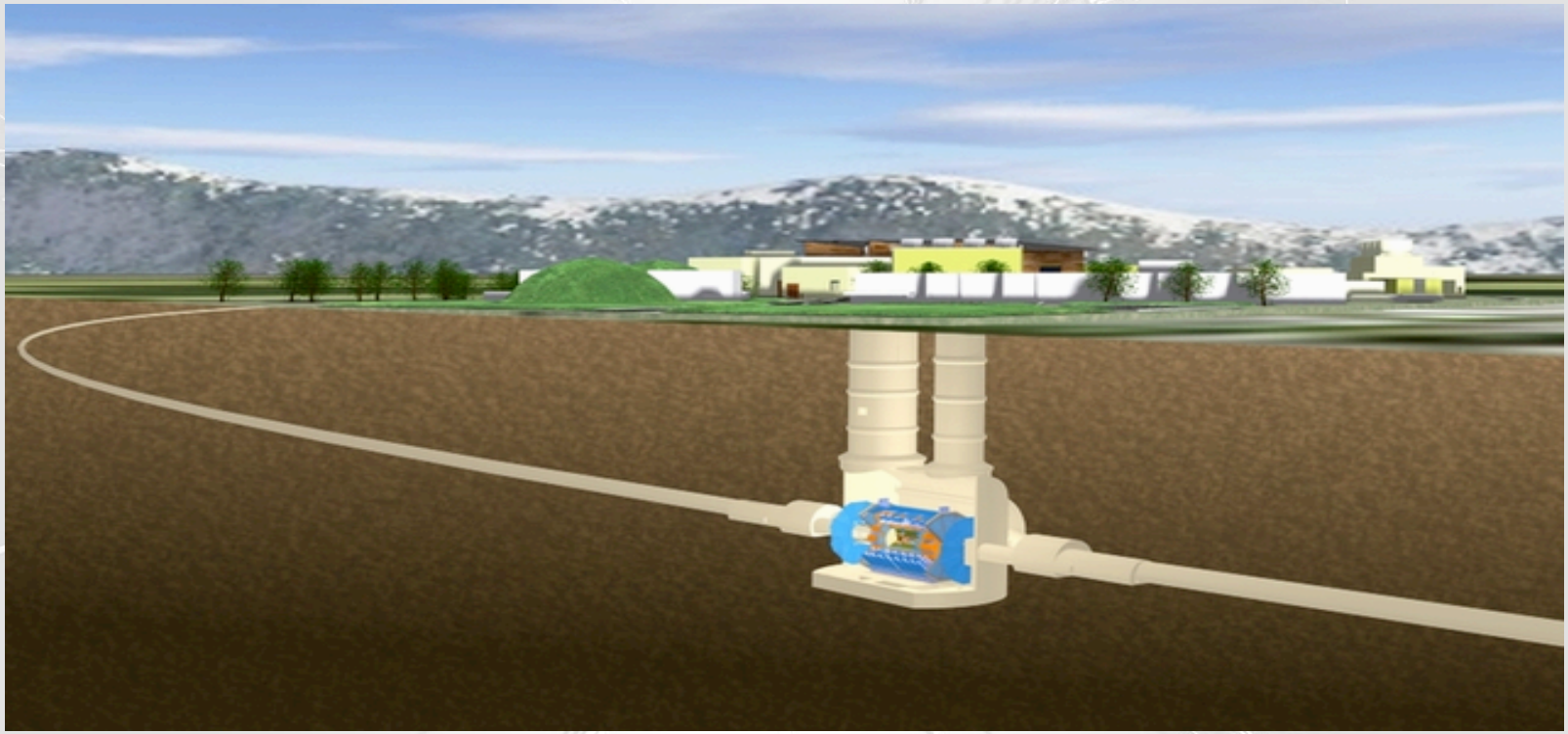
… the beginning …

Physics output will take some time, but benefits seen already…

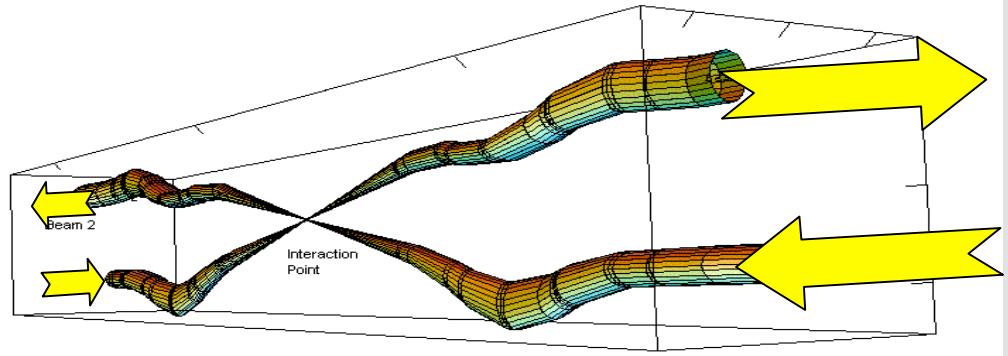
UK Politician:
"**Fundamental science is critical** … it turns out to be a **fantastic investment** … there will be something after the LHC - but that will come as a decision that takes place in light of what people know and in the next generation of technology"

Extras

Collision points



At four places the beams intersect



Relative beam sizes around IP1 (Atlas) in collision

LHC First Beam

Home 18.09.2008

LHC progress report, week 1

Geneva, 18 September 2008. After a spectacular start on 10 September, the
commissioning with beam. To get beams around the ring in both directions on
expectations, and the success continued through the night, with several hund

The next step in the commissioning process is to bring in the radio-frequency
bunched, rather than spreading out around the ring, and will eventually accelerate them to 7 TeV. The RF system
works by 'capturing' the beam, speeding up the slower moving particles and slowing down the faster ones so that
the beam remains bunched into fine threads about 11 cm long. Without it, the beam quickly dissipates and cannot
be used for physics.

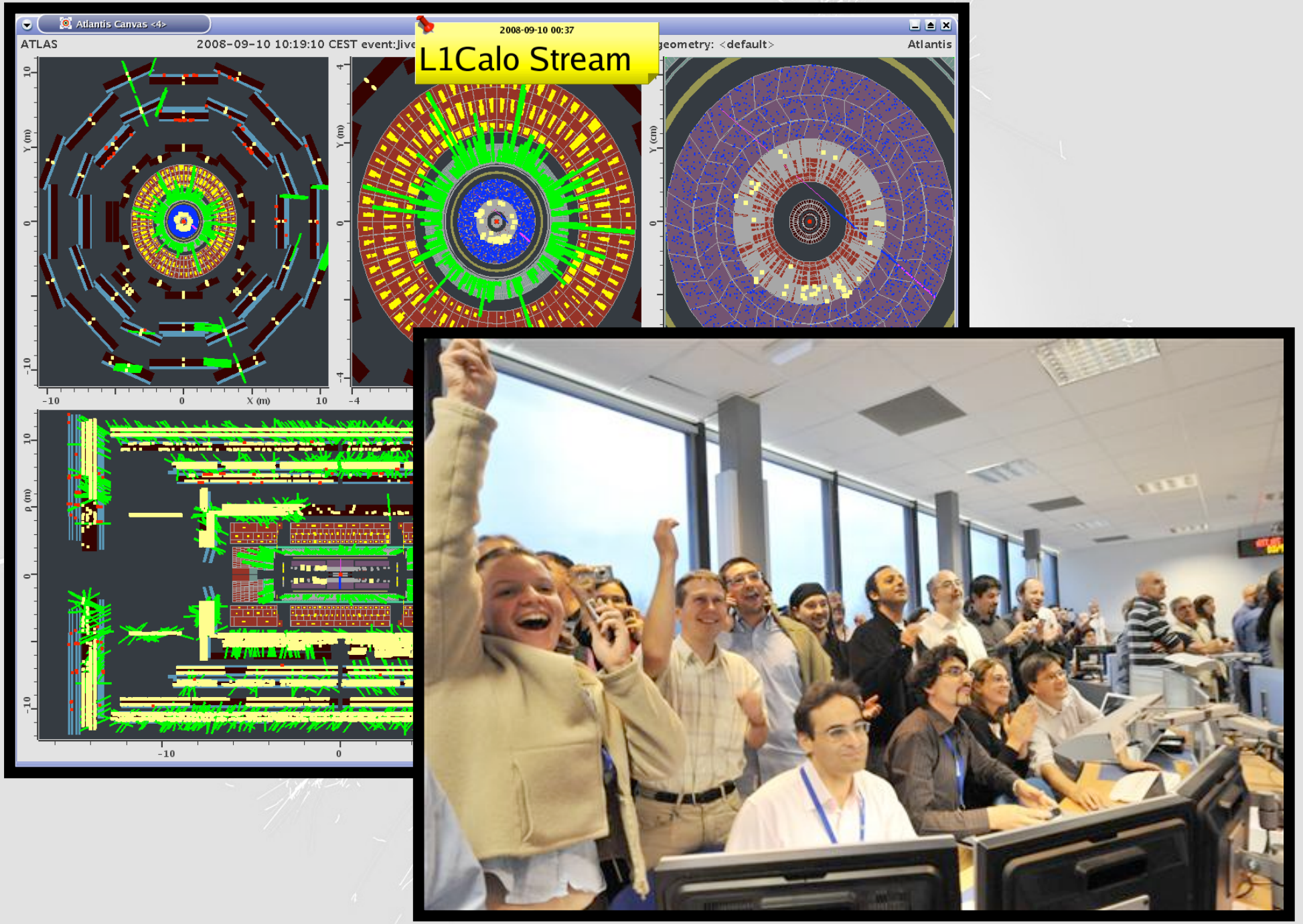
On Thursday night, 11 September, beam two, the anti-clockwise beam, was captured and cir
an hour before being safely extracted from the LHC. The next step is to repeat the process f
that is set to begin this week.

The intervening time has been spent recovering cryogenic conditions after the failure of a power transformer on one of the surface points of the LHC switched off the main compressors of the cryogenics for two sectors of the machine. The transformer, weighing 30 tonnes and with a rating of 12 MVA, was exchanged over the weekend. During this process, the cryogenics system was put into a standby mode with the two sectors kept at around 4.5 K. Since the beginning of the week the cryogenics team have been busy re-cooling the magnets and preparing for operation with beam, which is currently forecast for today. The next stage of the commissioning will be single turn studies using beam one, followed by RF capture and circulating beam in both rings.

The LHC is on course for first collisions in a matter of weeks. Next update 24 September at the latest.

"The LHC is on course for first [900 GeV] collisions in a matter of weeks."

However...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ATLAS
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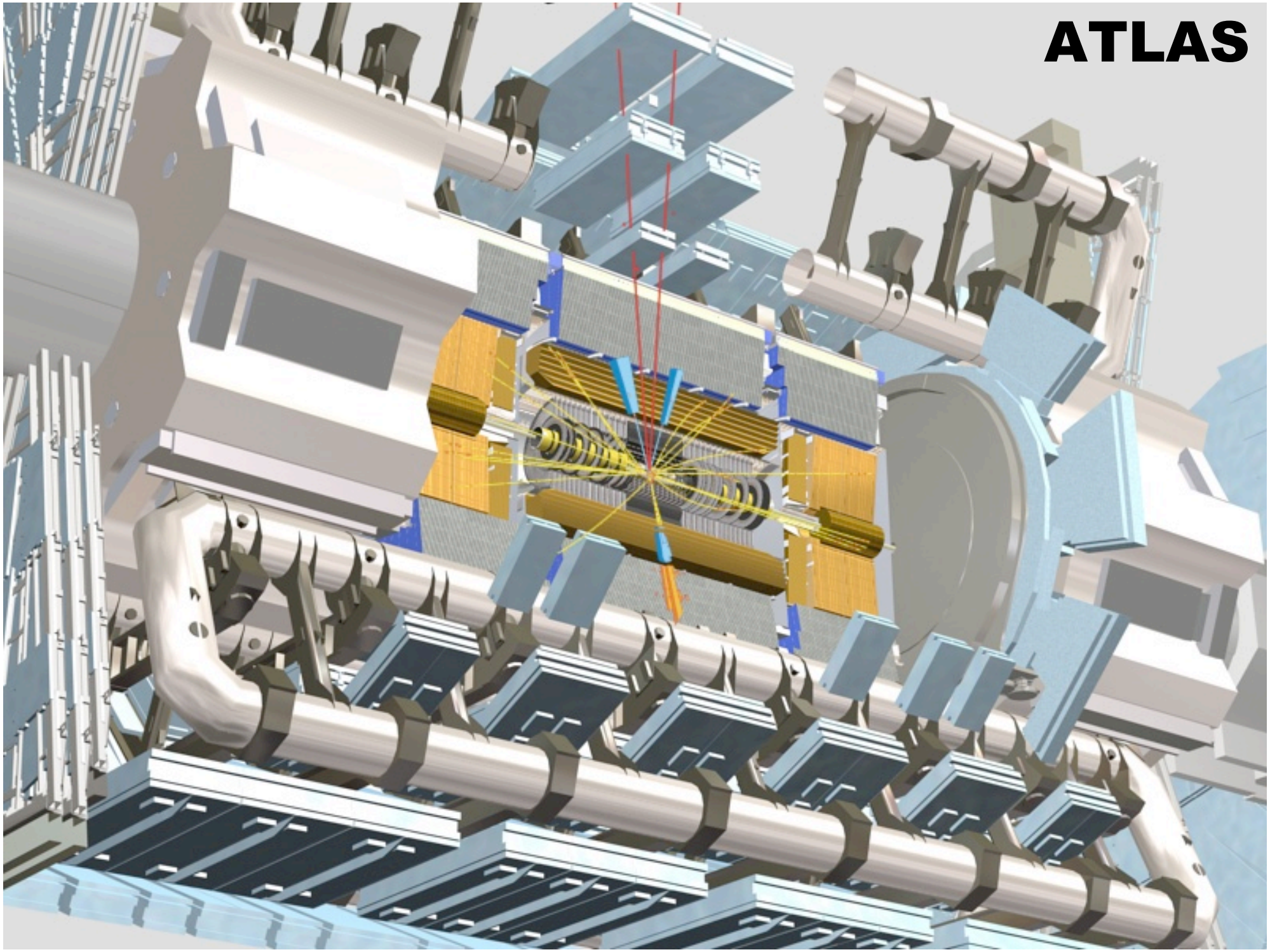
Atlantis
2008-09-10 00:37
L1Calo Stream


ATLAS

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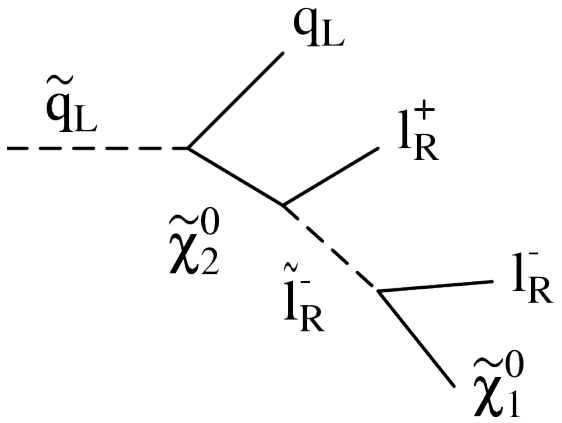
Science as a whole benefits

Constraining masses

Mass constraints

Invariant masses in pairs

- **Missing energy**
- **Kinematic edges**



Frequently-studied decay chain

Observable: Depends on:

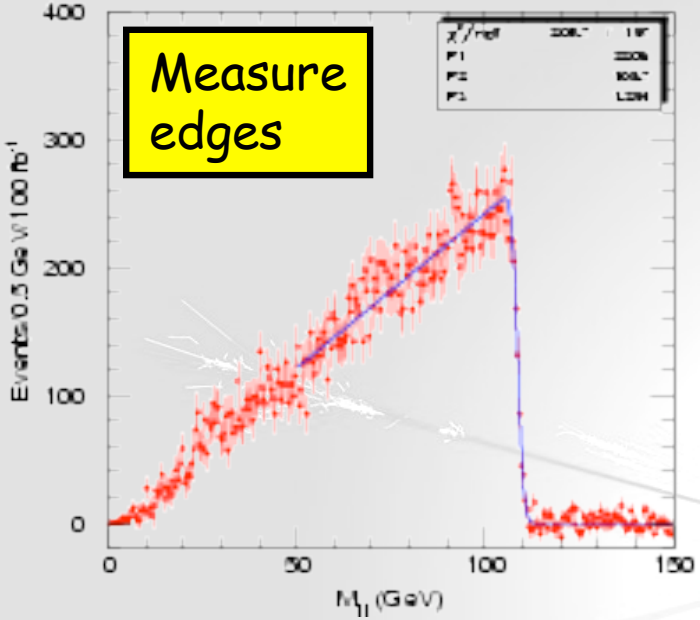
$$m^2(l_1 l_2) = \frac{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}})(m^2_{\tilde{l}} - m^2_{\tilde{\chi}^0_1})}{m^2_{\tilde{l}}} \frac{1 - \cos\theta_{\tilde{\chi}^0_1}}{2},$$

$$m^2(q l_1) = \frac{(m^2_{\tilde{q}} - m^2_{\tilde{\chi}^0_2})(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}})}{m^2_{\tilde{\chi}^0_2}} \frac{1 - \cos\theta_{\tilde{l}}}{2},$$

$$m^2(q l_2) = \frac{1}{4} \frac{(m^2_{\tilde{q}} - m^2_{\tilde{\chi}^0_2})(m^2_{\tilde{l}} - m^2_{\tilde{\chi}^0_1})}{m^2_{\tilde{\chi}^0_2}\, m^2_{\tilde{l}}}$$
$$\times \Big[m^2_{\tilde{\chi}^0_2}(1 + \cos\theta_{\tilde{l}})(1 - \cos\theta_{\tilde{\chi}^0_1}) + m^2_{\tilde{l}}(1 - \cos\theta_{\tilde{l}})(1 + \cos\theta_{\tilde{\chi}^0_1})$$
$$+ 2 m_{\tilde{\chi}^0_2} m_{\tilde{l}} \sin\theta_{\tilde{l}} \sin\theta_{\tilde{\chi}^0_1} \cos\phi_{\tilde{\chi}^0_1} \Big].$$

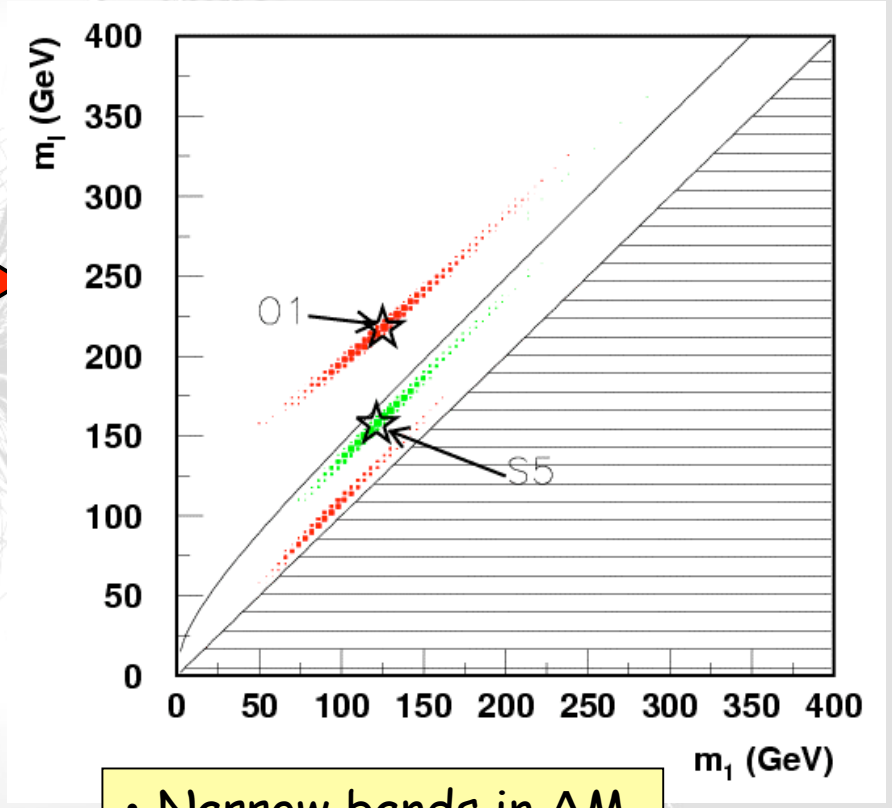
Limits depend on angles between sparticle decays

Mass determination



Variety of edges/variables

Try various masses in equations



- Narrow bands in ΔM
- Wider in mass scale
- Improve using cross-section information

Basic technique

- Measure edges
- Try with different SUSY points
- Find likelihood of fitting data

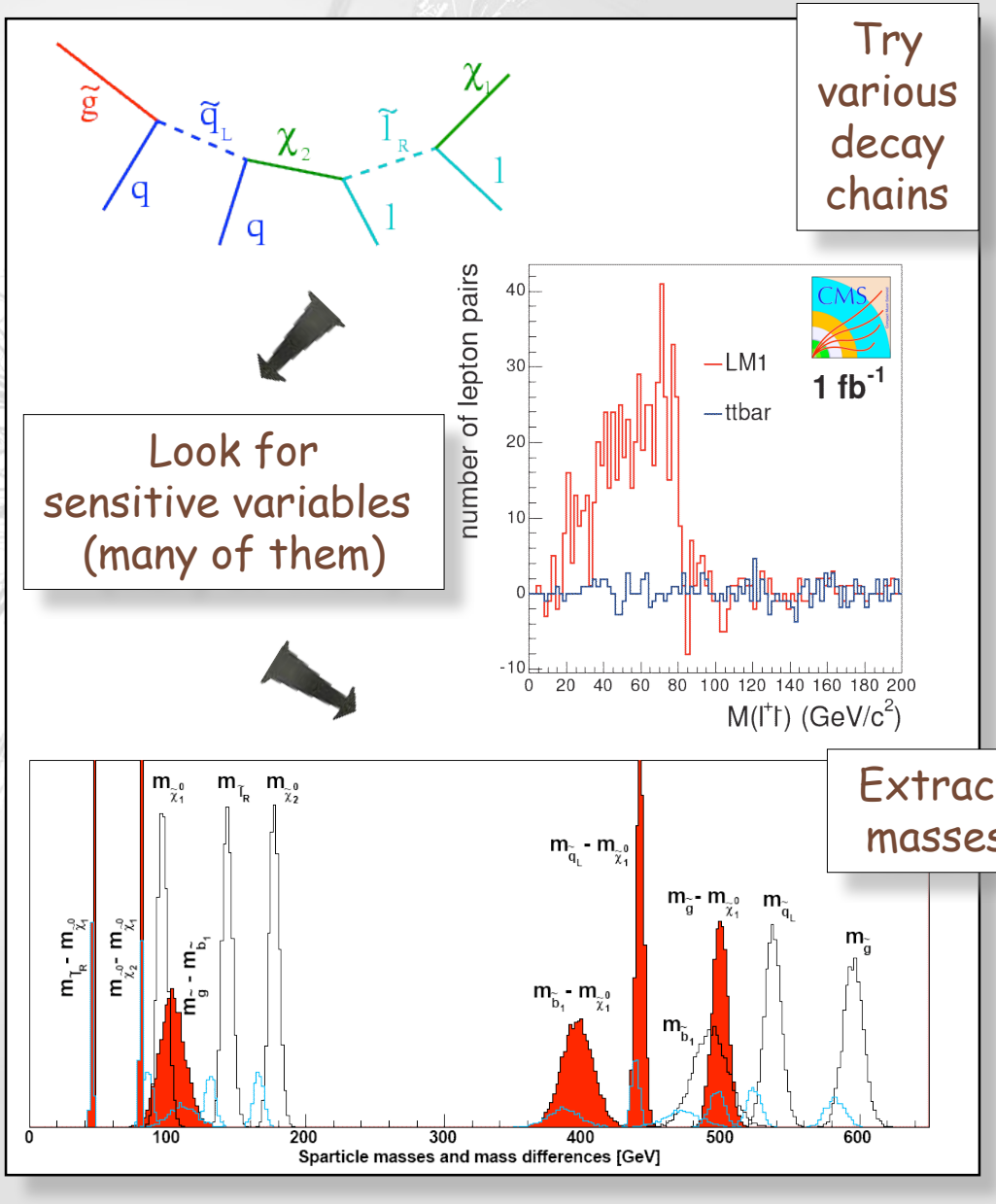
Event-by-event likelihood

- In progress

SUSY mass measurements

Extracting parameters of interest

- Difficult problem
- Lots of competing channels
- Can be difficult to disentangle
- Ambiguities in interpretation
- Lots of effort has been made to find good techniques



SUSY mass measurements:

LHC clearly cannot fully constrain all parameters of mSUGRA

- **However it makes good constraints**
  - **Particularly good at mass differences [$\mathcal{O}$(1%)]**
  - **Not so good at mass scale**
  - **[$\mathcal{O}$(10%) from direct measurements]**
  - **Mass scale possibly best "measured" from cross-sections**
- **Often have >1 interpretation**
  - **What solution to end-point formula is relevant?**
  - **Which neutralino was in this decay chain?**
  - **What was the "chirality" of the slepton " " " ?**
  - **Was it a 2-body or 3-body decay?**

SUSY spin measurements

The defining property of supersymmetry

- Distinguish from e.g. similar-looking Universal Extra Dimensions

Difficult to measure @ LHC

- No polarised beams
- Missing energy
- Indeterminate initial state from pp collision

Nevertheless, we have some very good chances…

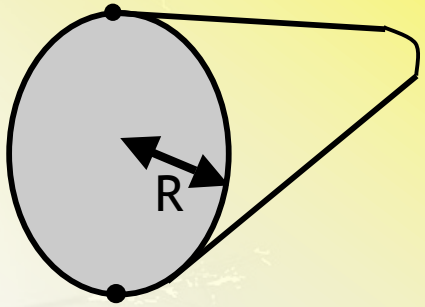
Universal Extra Dimensions

TeV-scale universal extra dimension model

Kaluza-Klein states of SM particles

- **same QN's as SM**
- **$m_n^2 \approx m_0^2 + n^2/R^2$ [+ boundary terms]**
- **KK parity:**
  - **From P conservation in extra dimension**
  - **1st KK mode pair-produced**
  - **Lightest KK state stable, and weakly interacting**

KK tower of masses n=0,1,...



Radius of extra dimension ~ TeV^{-1}

S_1/Z_2

First KK level looks a *lot* like SUSY

BUT same spin as SM

Cheng, Matchev

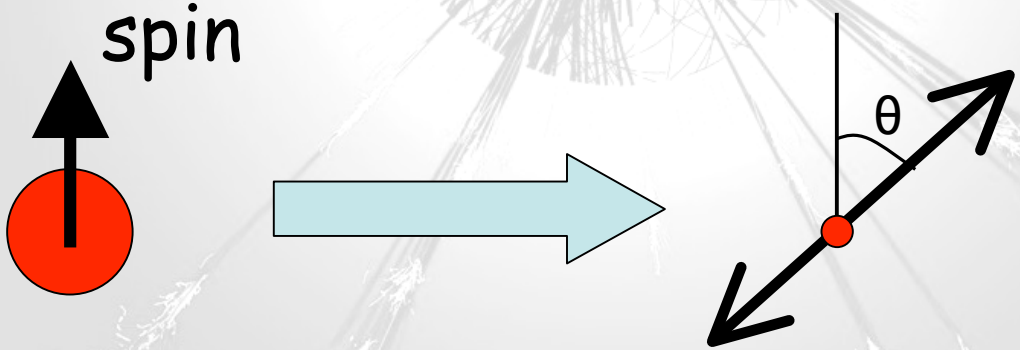
hep-ph/0205314

Dubbed "Bosonic Supersymmetry"

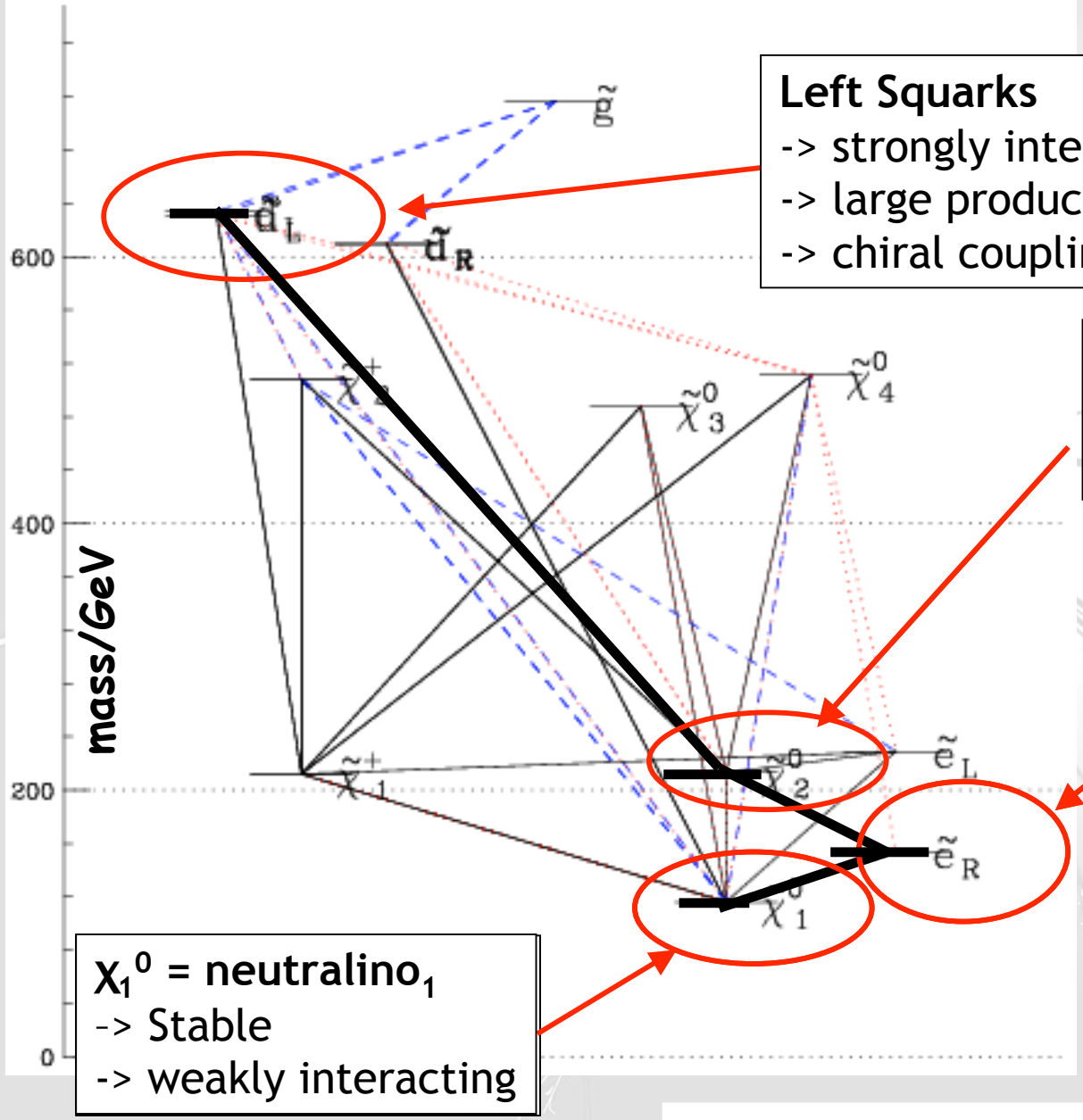
Measuring spins of particles

Basic recipe:

- **Produce polarised particle**
- **Look at angular distributions in its decay**



Revisit "Typical" sparticle spectrum



Left Squarks
-> strongly interacting
-> large production
-> chiral couplings

LHC point 5

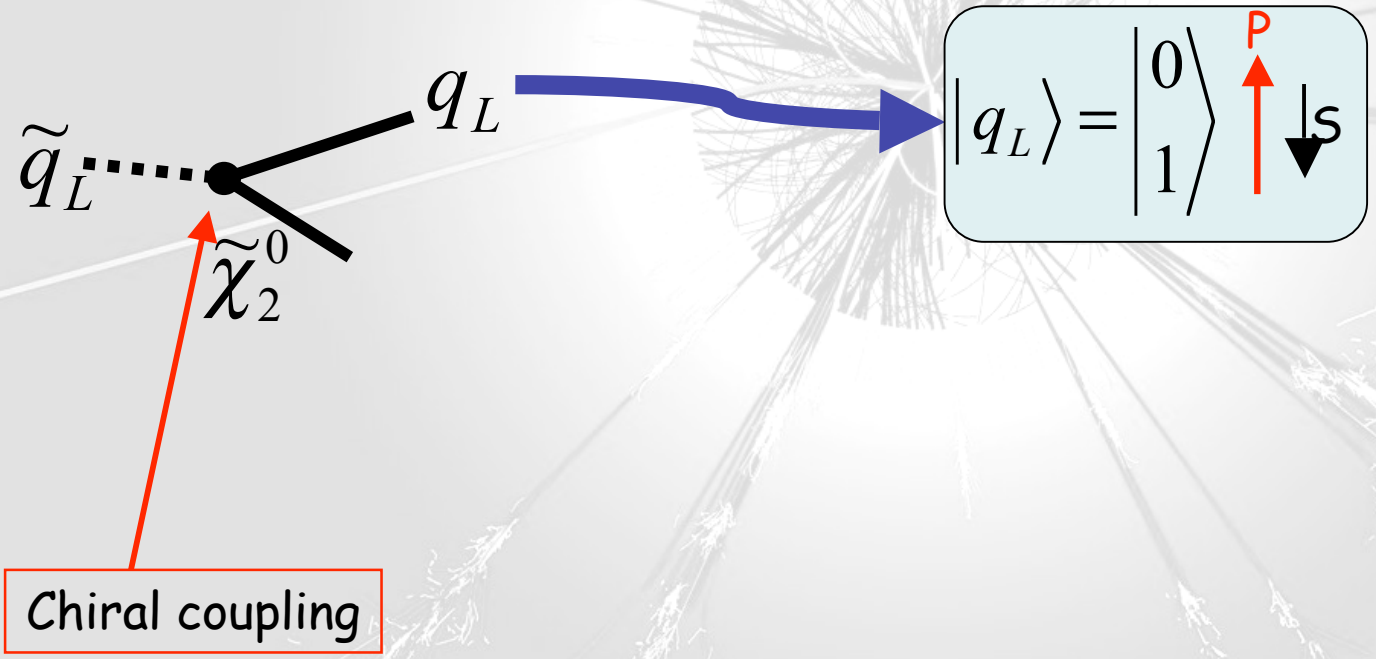
χ_2^0 = neutralino$_2$
-> (mostly) partner of SM W^0

Right slepton
(selectron or smuon)
-> Production/decay produce lepton
-> chiral couplings

χ_1^0 = neutralino$_1$
-> Stable
-> weakly interacting

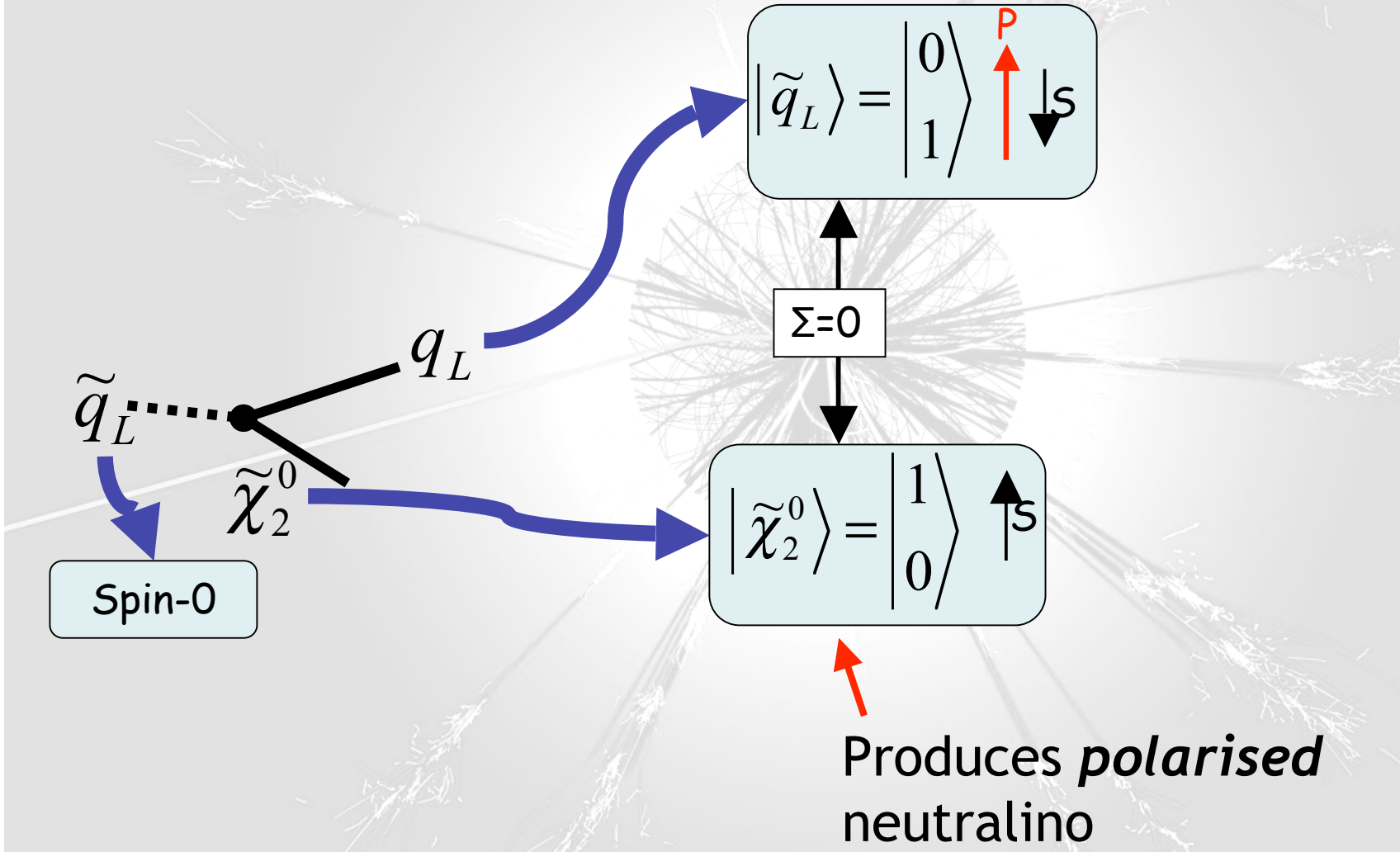
Some sparticles omitted

Spin projection factors



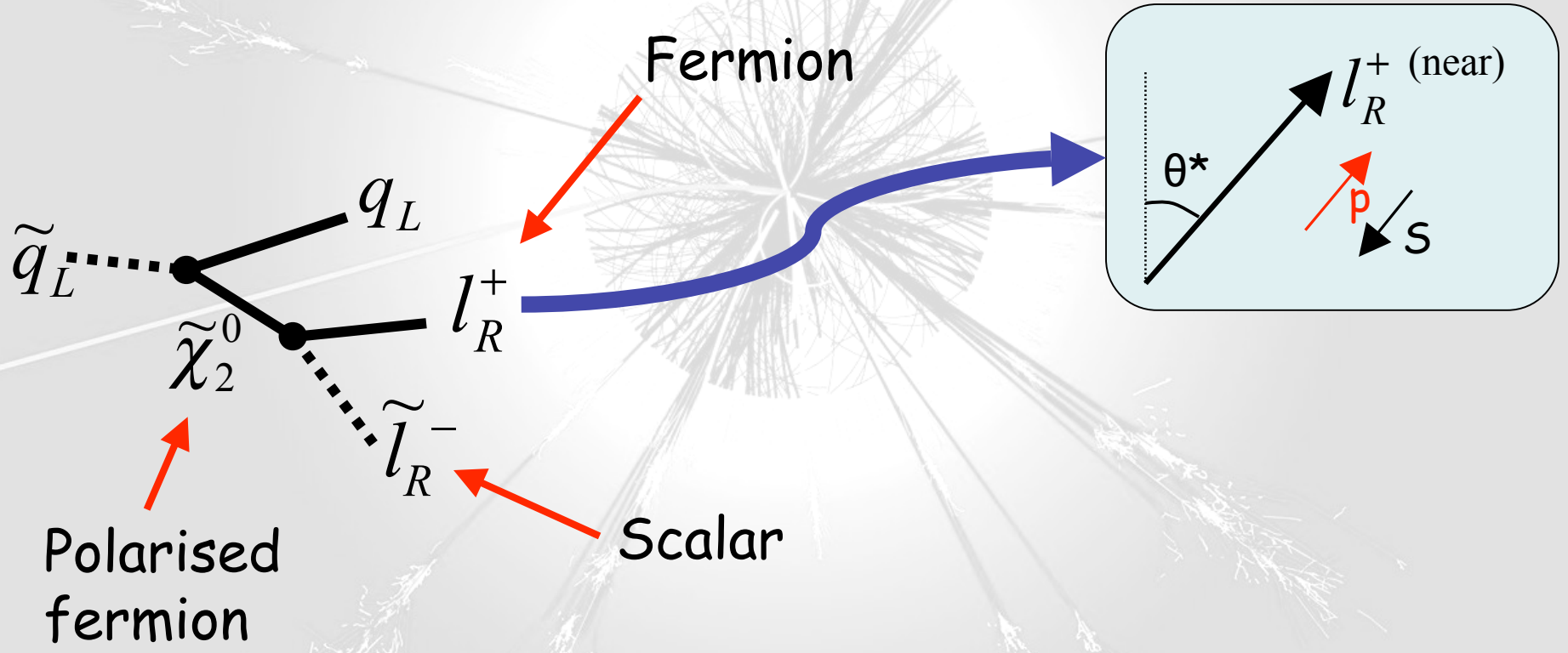
Approximate SM particles as massless
-> okay since m « p

Spin projection factors



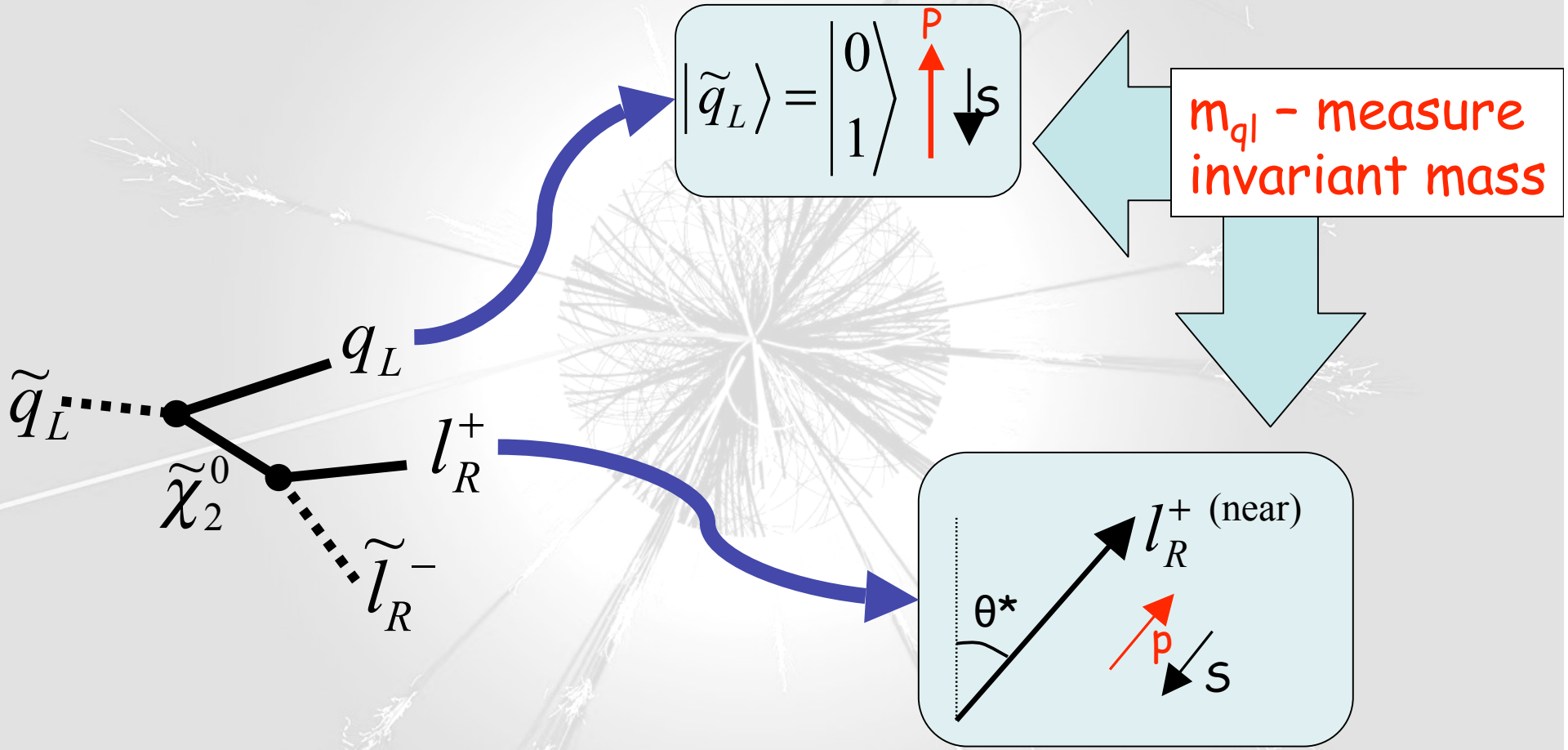
Approximate SM particles as massless
-> okay since m « p

Spin projection factors



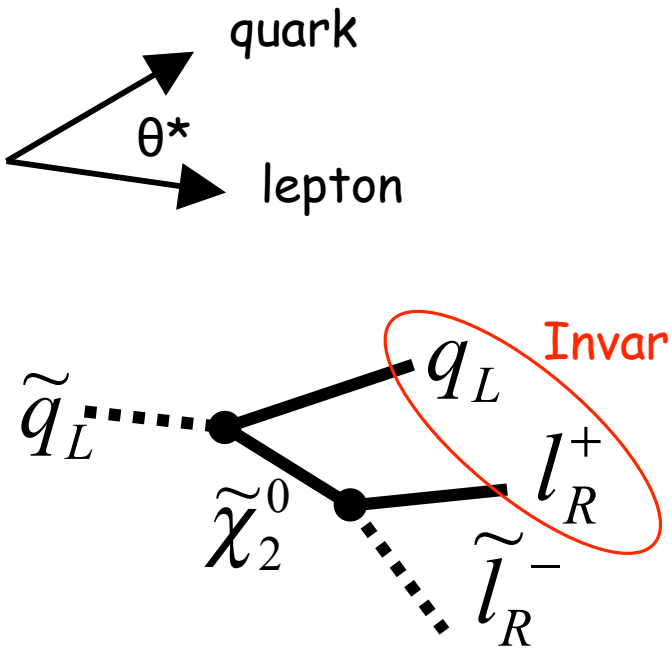
Approximate SM particles as massless
-> okay since m « p

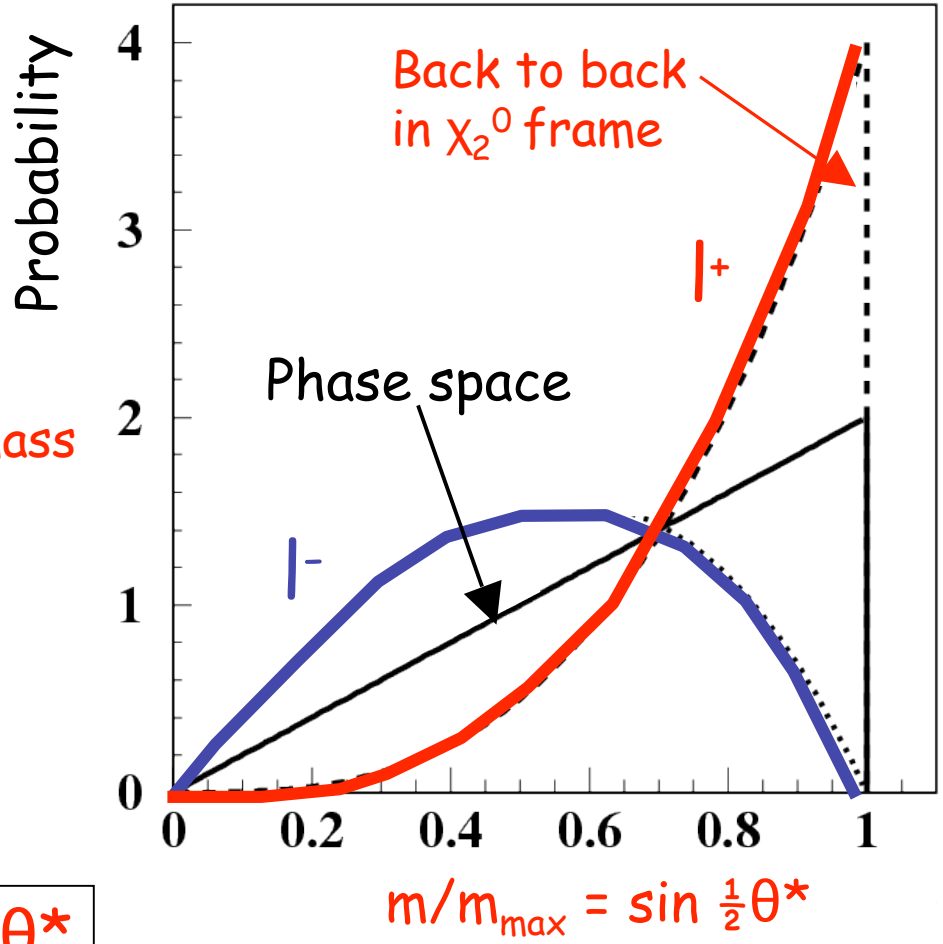
Spin projection factors



Approximate SM particles as massless
-> okay since m « p

$l^{near}q$ invariant mass





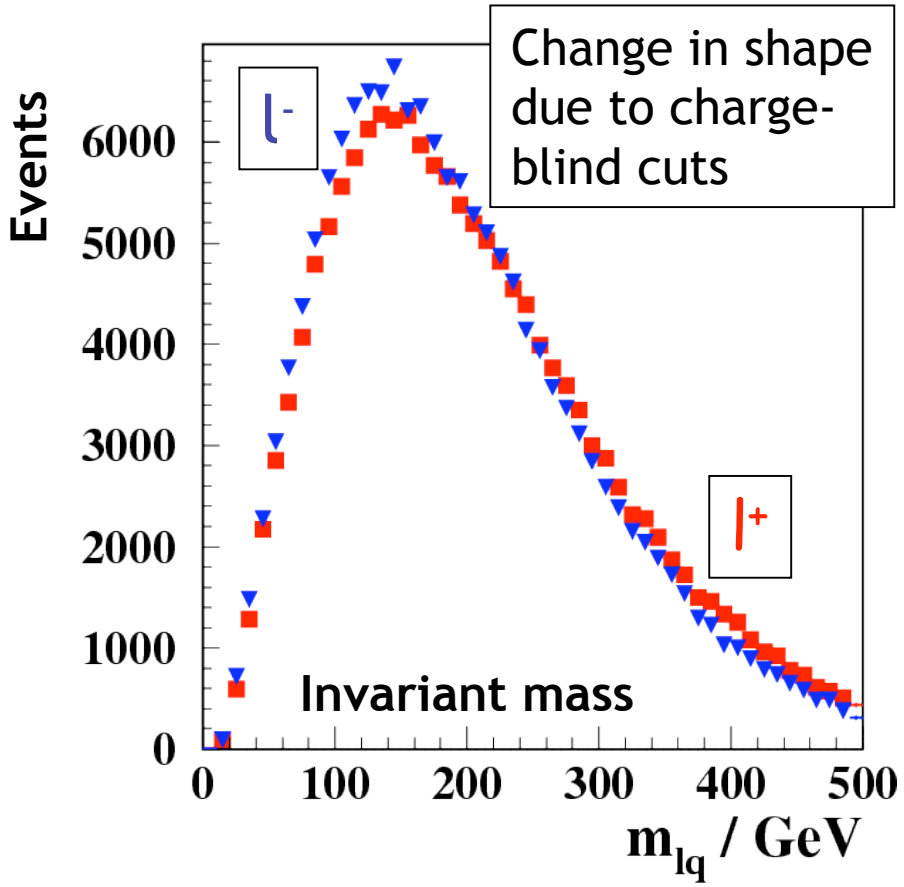
Phase space -> factor of $\sin \frac{1}{2}\theta^*$

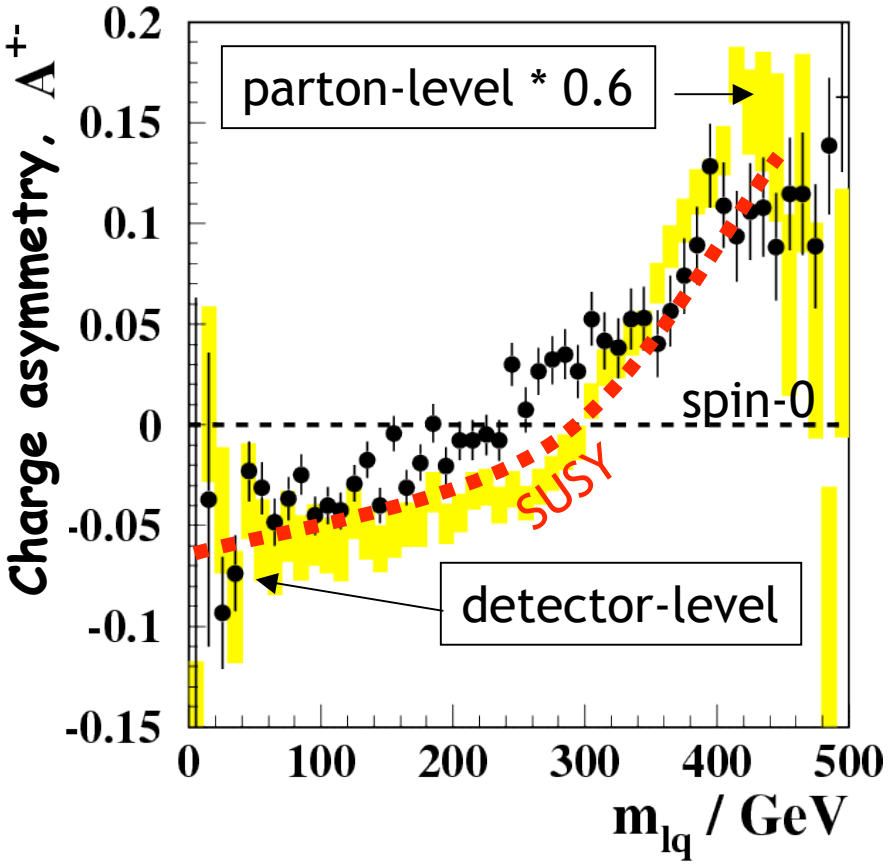
Spin projection factor in $|M|^2$:

l^+q -> $\sin^2 \frac{1}{2}\theta^*$

l^-q -> $\cos^2 \frac{1}{2}\theta^*$

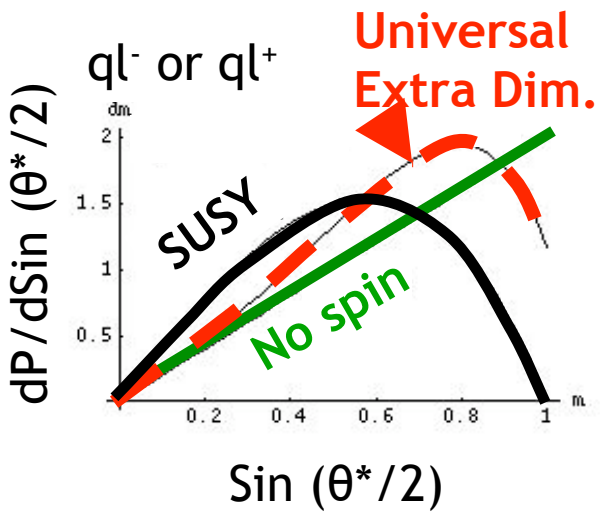
After detector simulation

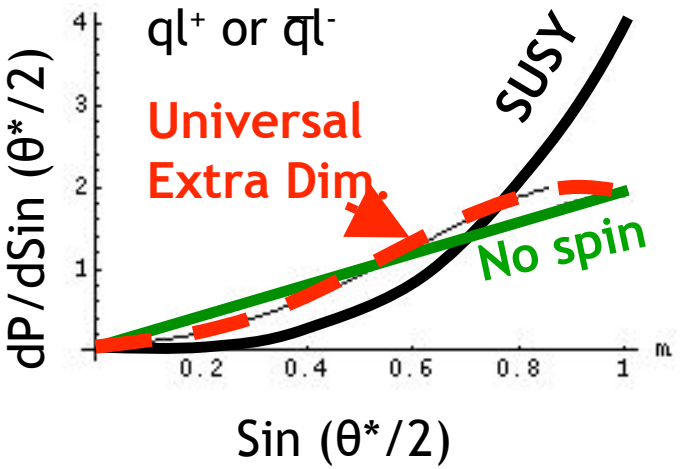


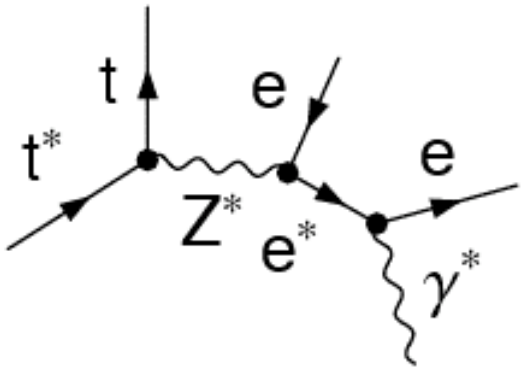


-> Charge asymmetry survives detector simulation
-> Same shape as parton level (but with BG and smearing)

Distinguishing between models







As expected, UED differs from all-scalar (no-spin) and from SUSY

Smillie et al.