Title: TBA

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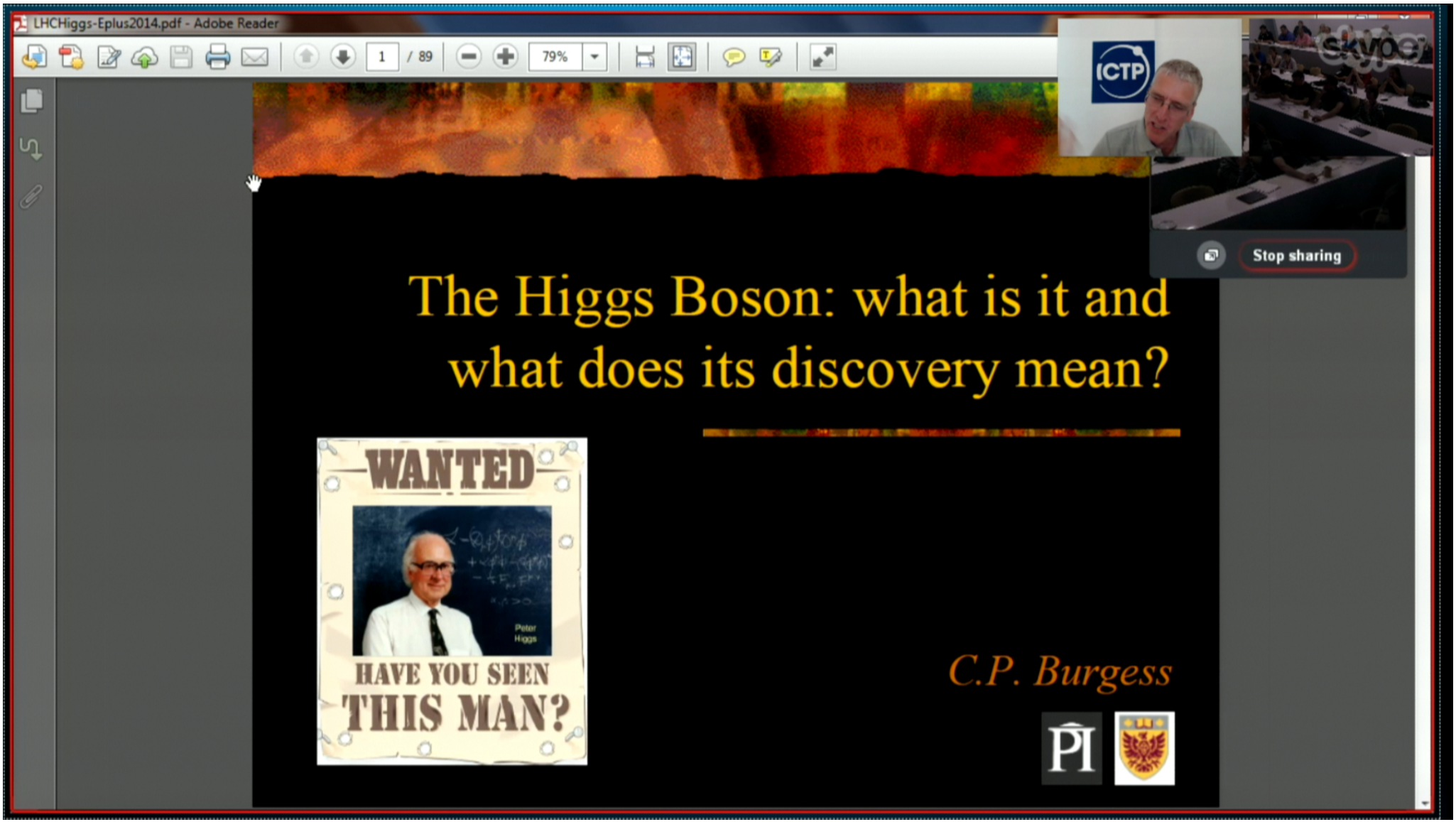
Abstract: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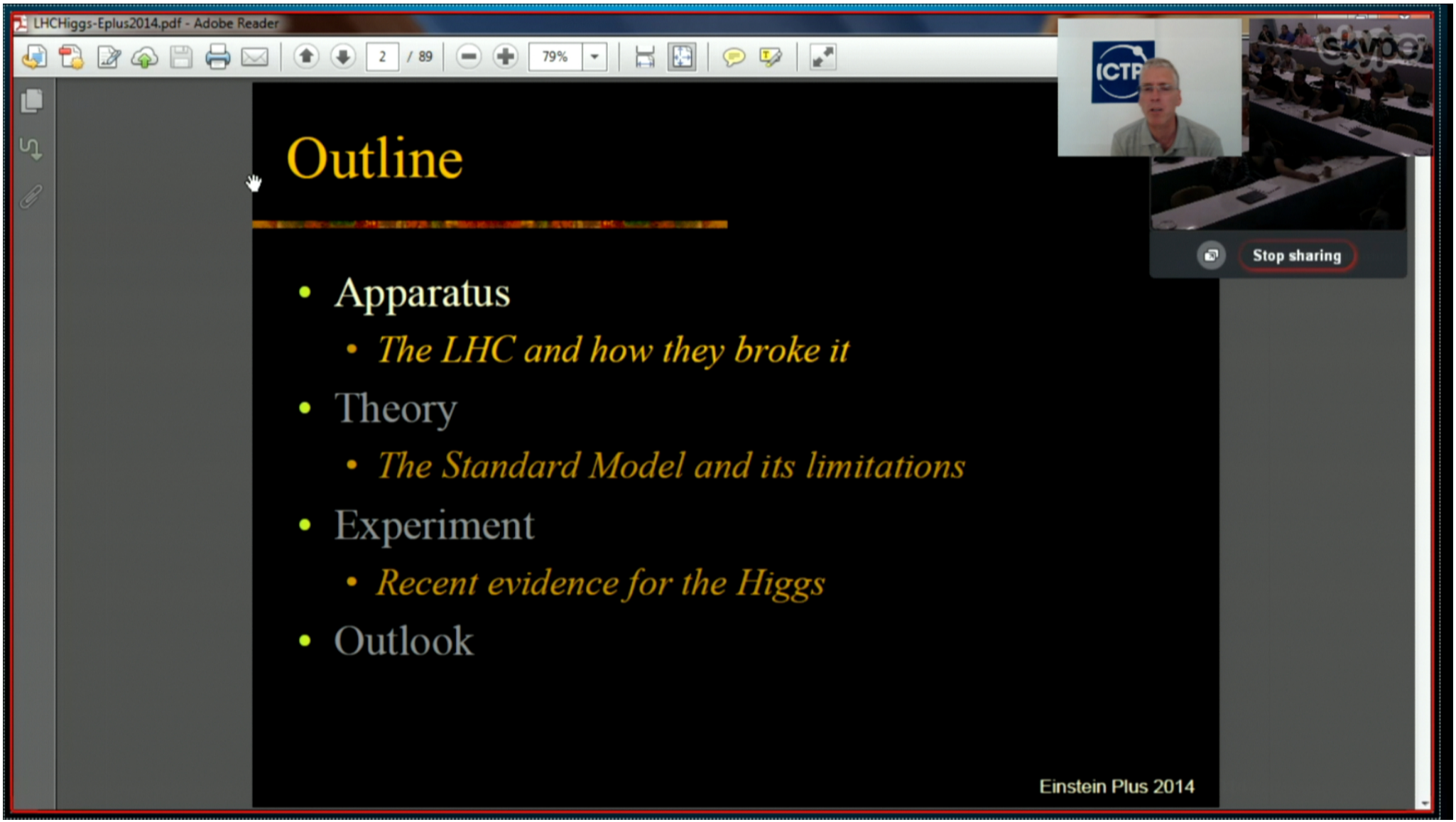
The Higgs Boson: what is it and what does its discovery mean?
WANTED
Peter Higgs
HAVE YOU SEEN THIS MAN?
C.P. Burgess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Outline
Apparatus
The LHC and how they broke it
Theory
The Standard Model and its limitations
Experiment
Recent evidence for the Higgs
Outlook
Einstein Plus 2014
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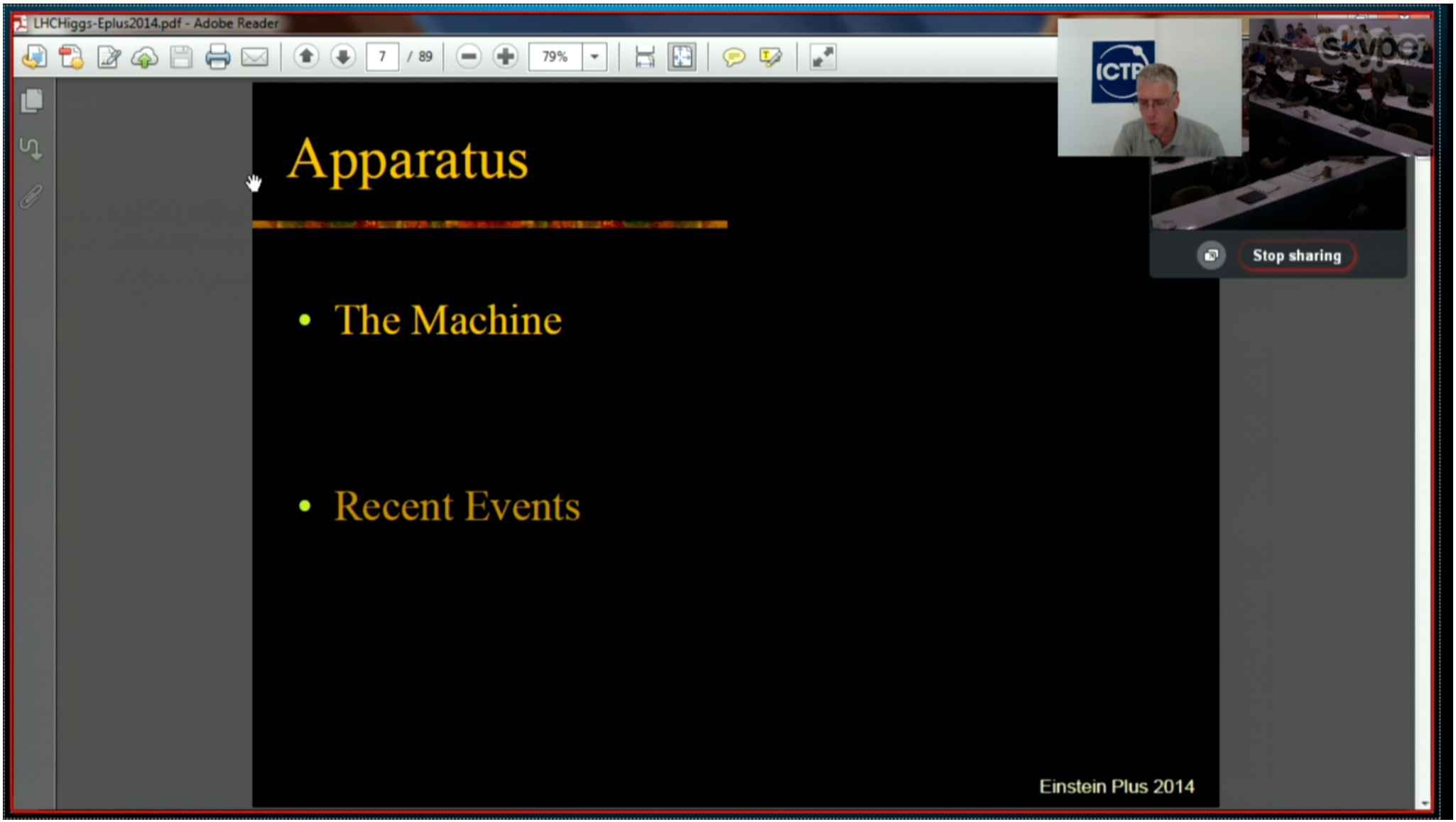
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Apparatus
The Machine
Recent Events
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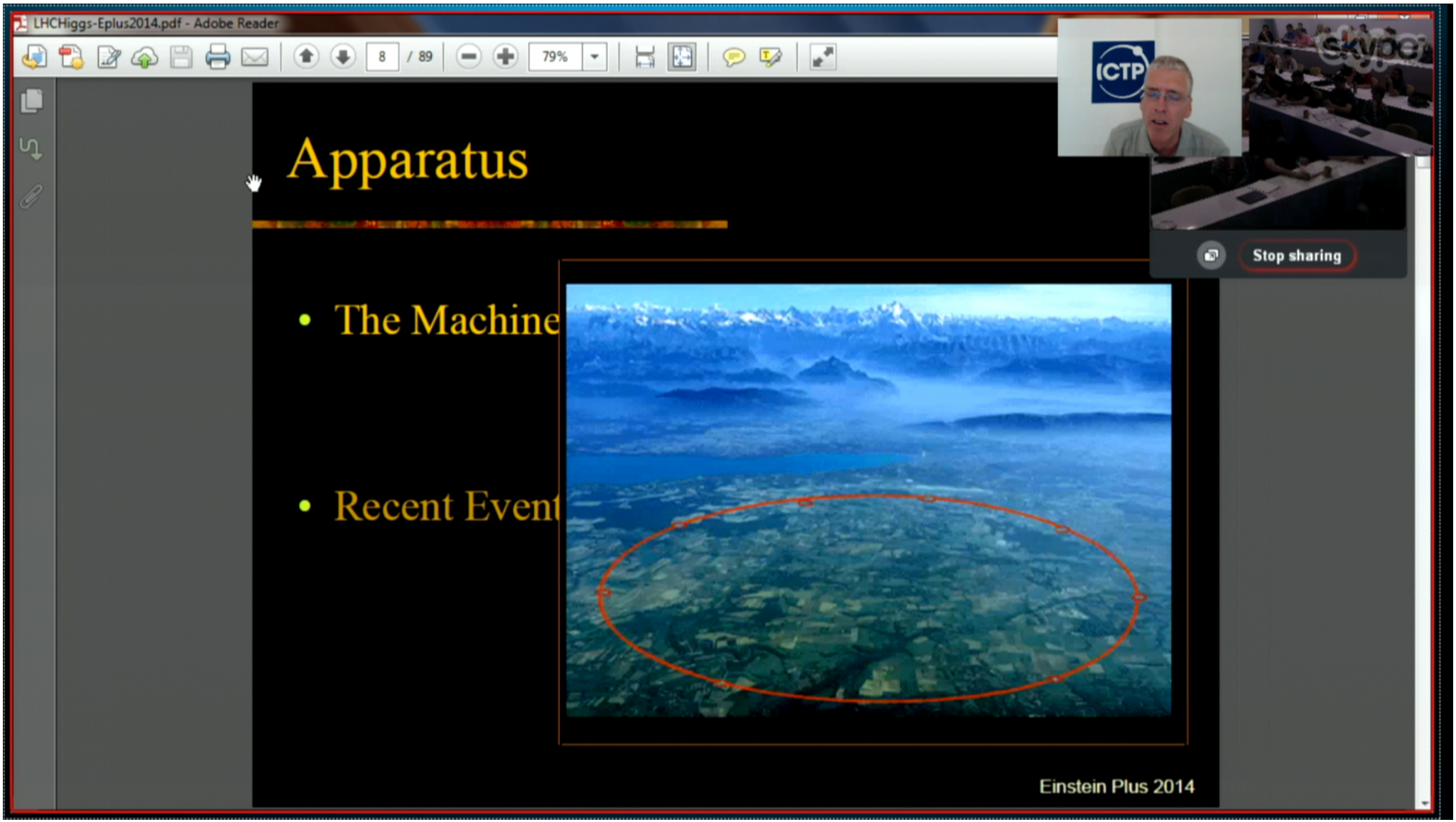
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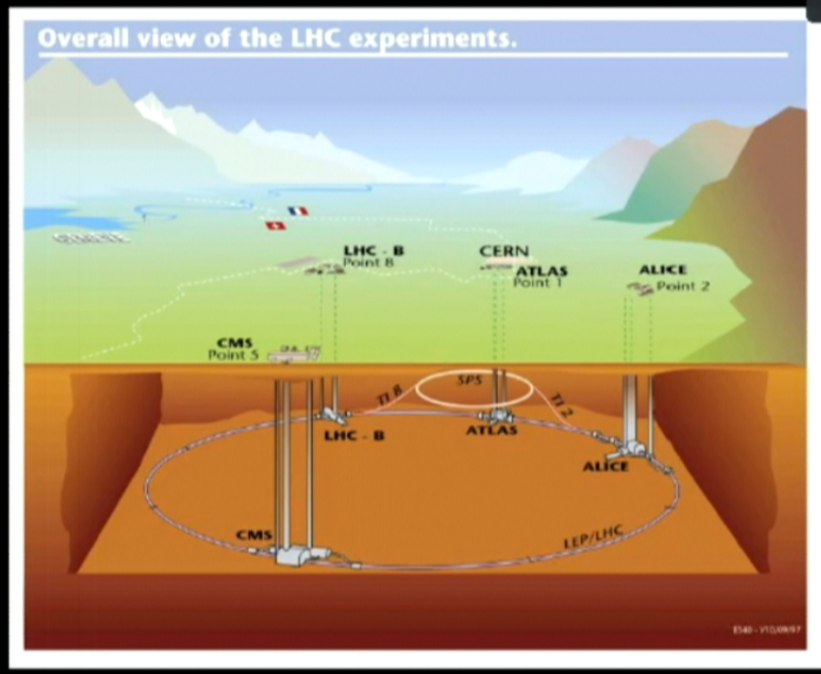
- The Machine
- Recent Event



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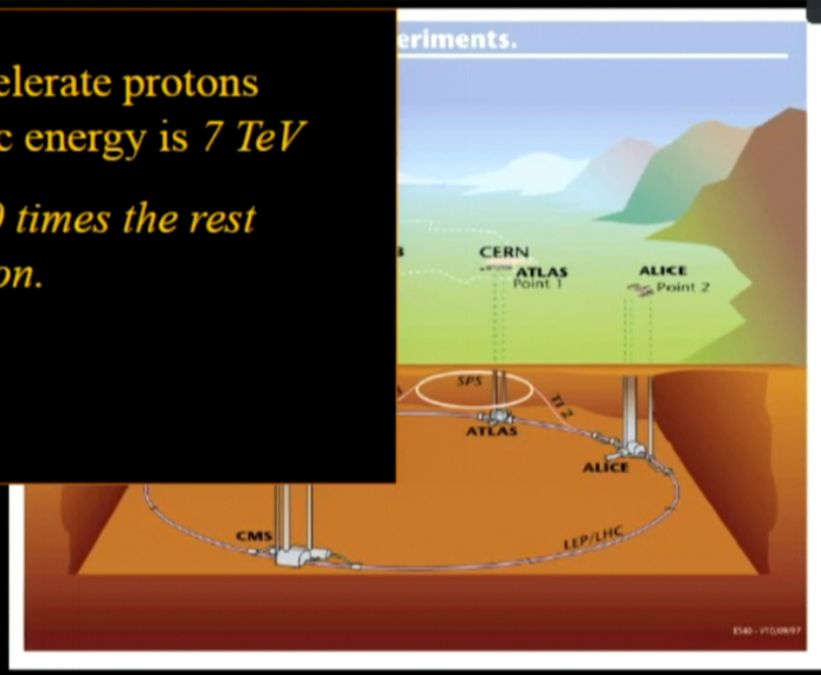
Apparatus

- Designed to accelerate protons until their kinetic energy is *7 TeV*

  0.94 TeV is 1000 times the rest energy of a proton.



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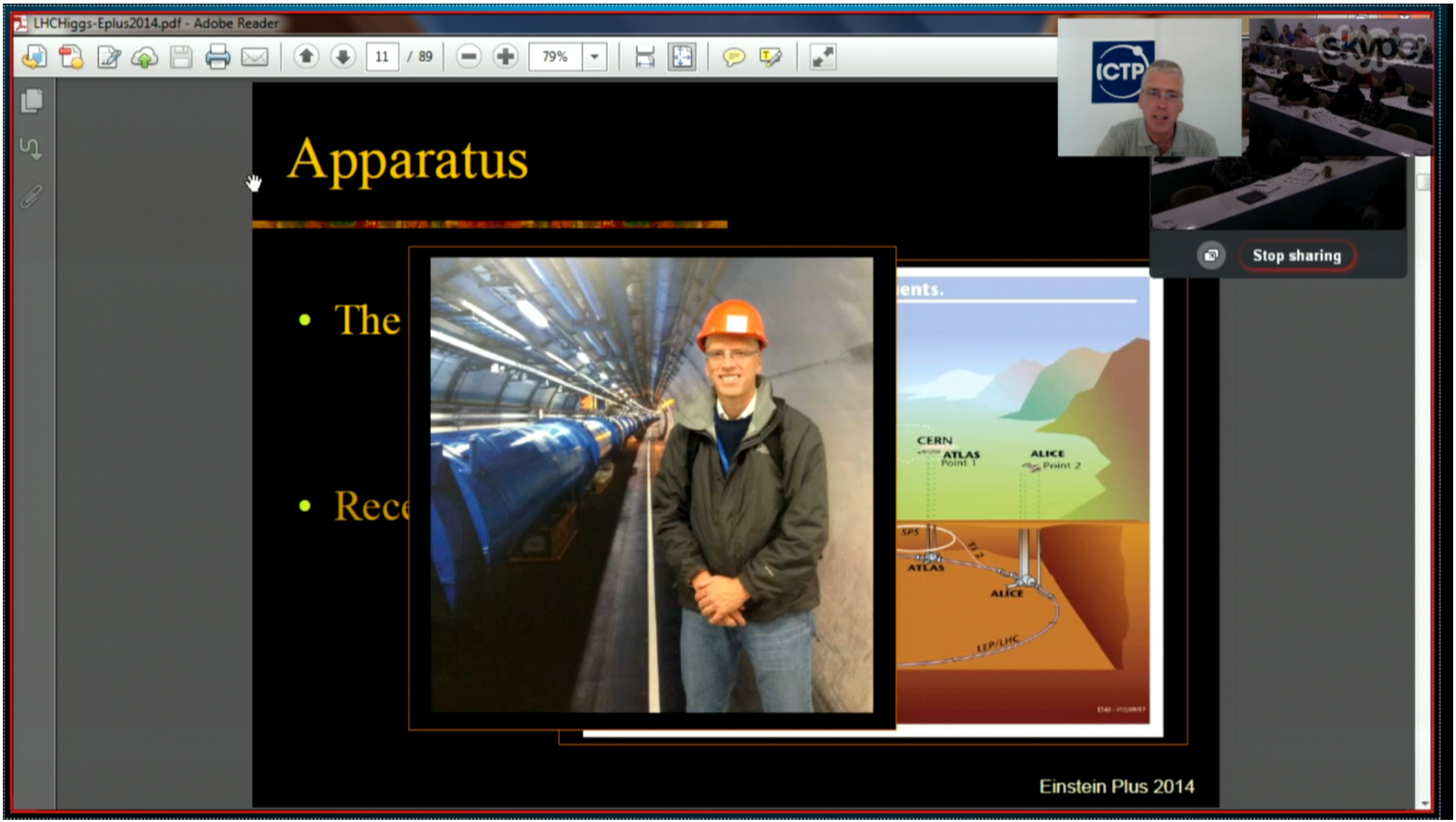
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Apparatus
• The
• Rece
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CERN
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Point 1
ALICE
Point 2
SPS
ATLAS
ALICE
LEP/LHC
Einstein Plus 2014
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skype
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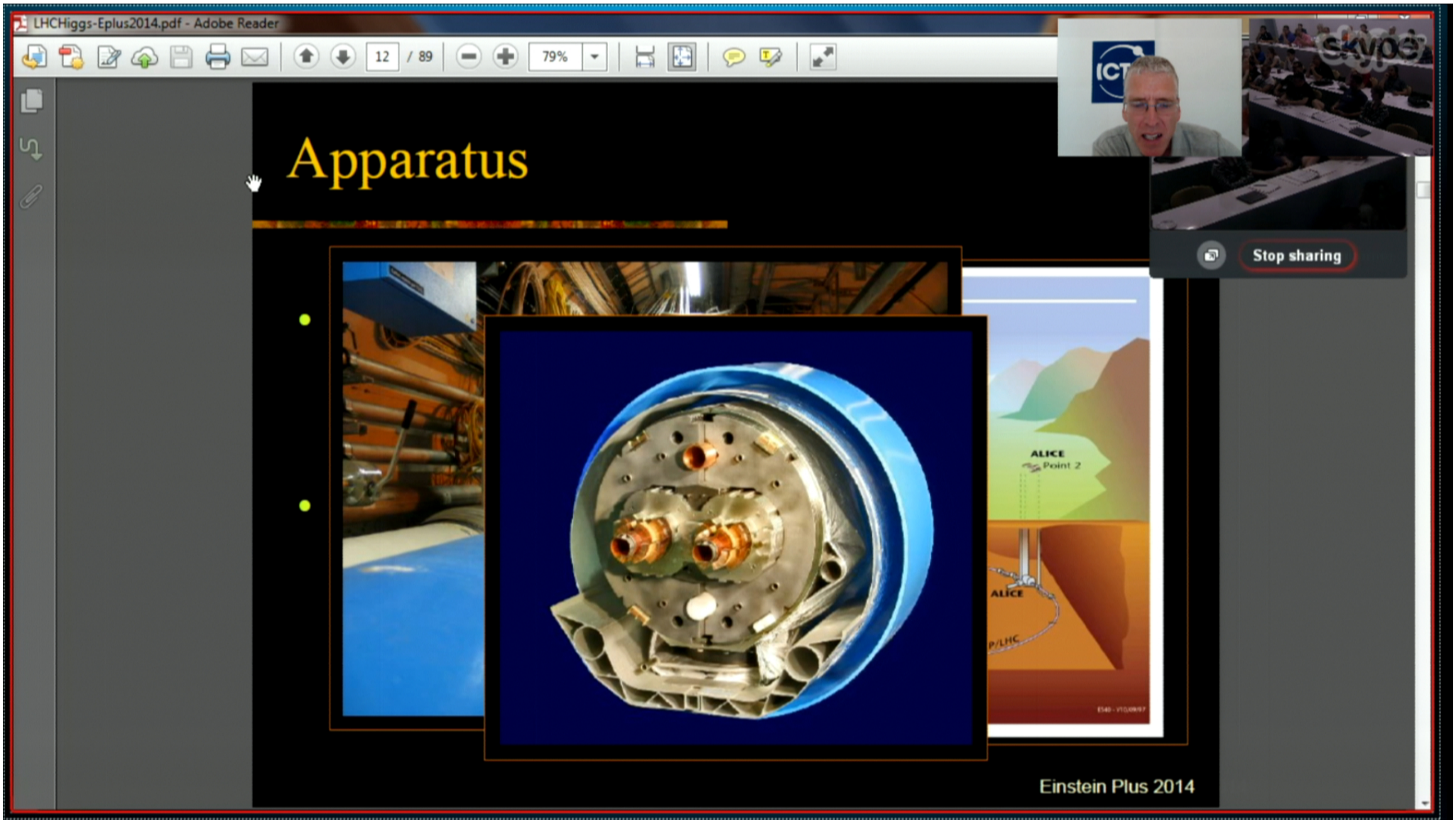
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Apparatus
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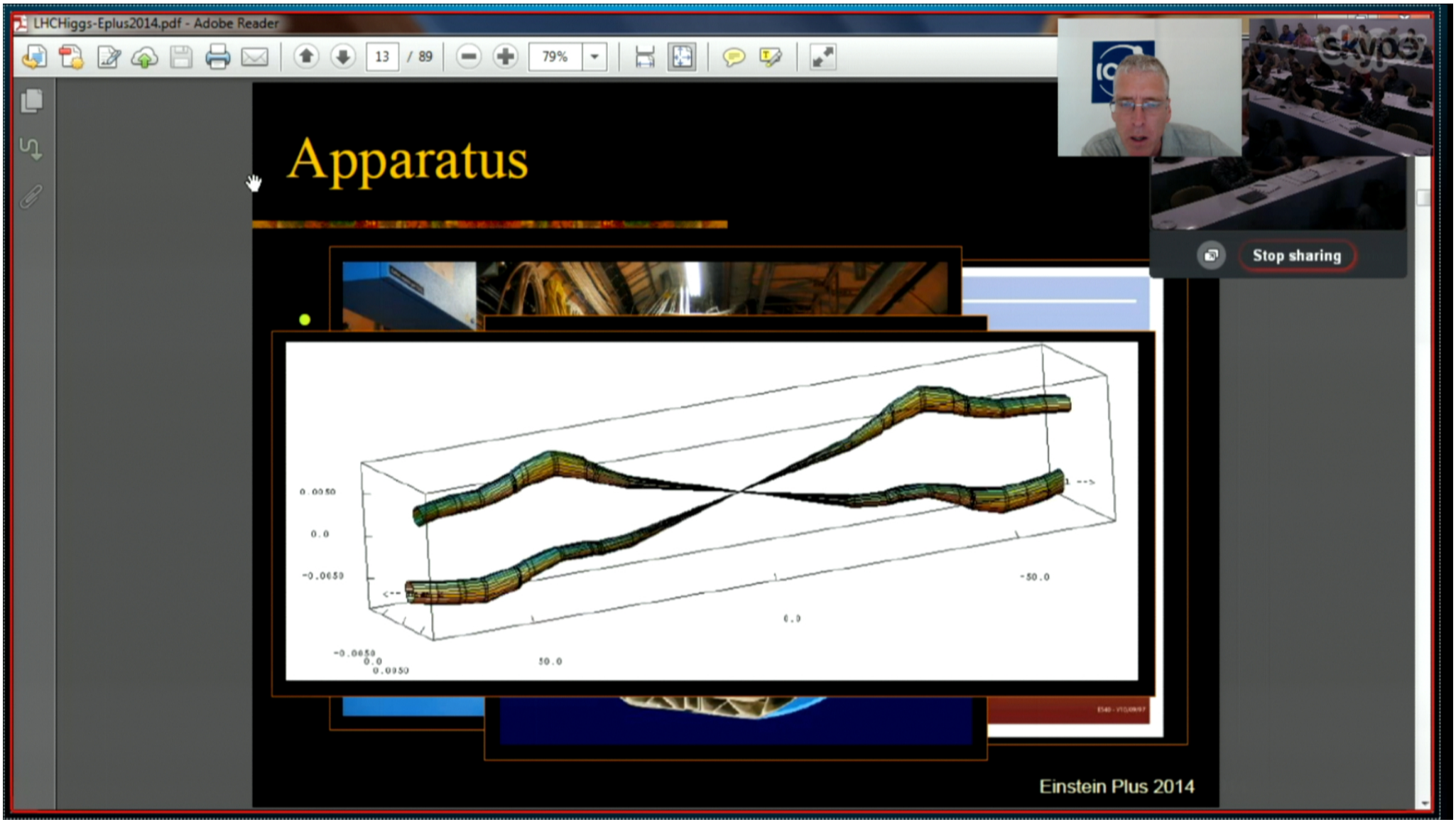
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Apparatus

- The Machine
- Recent Events

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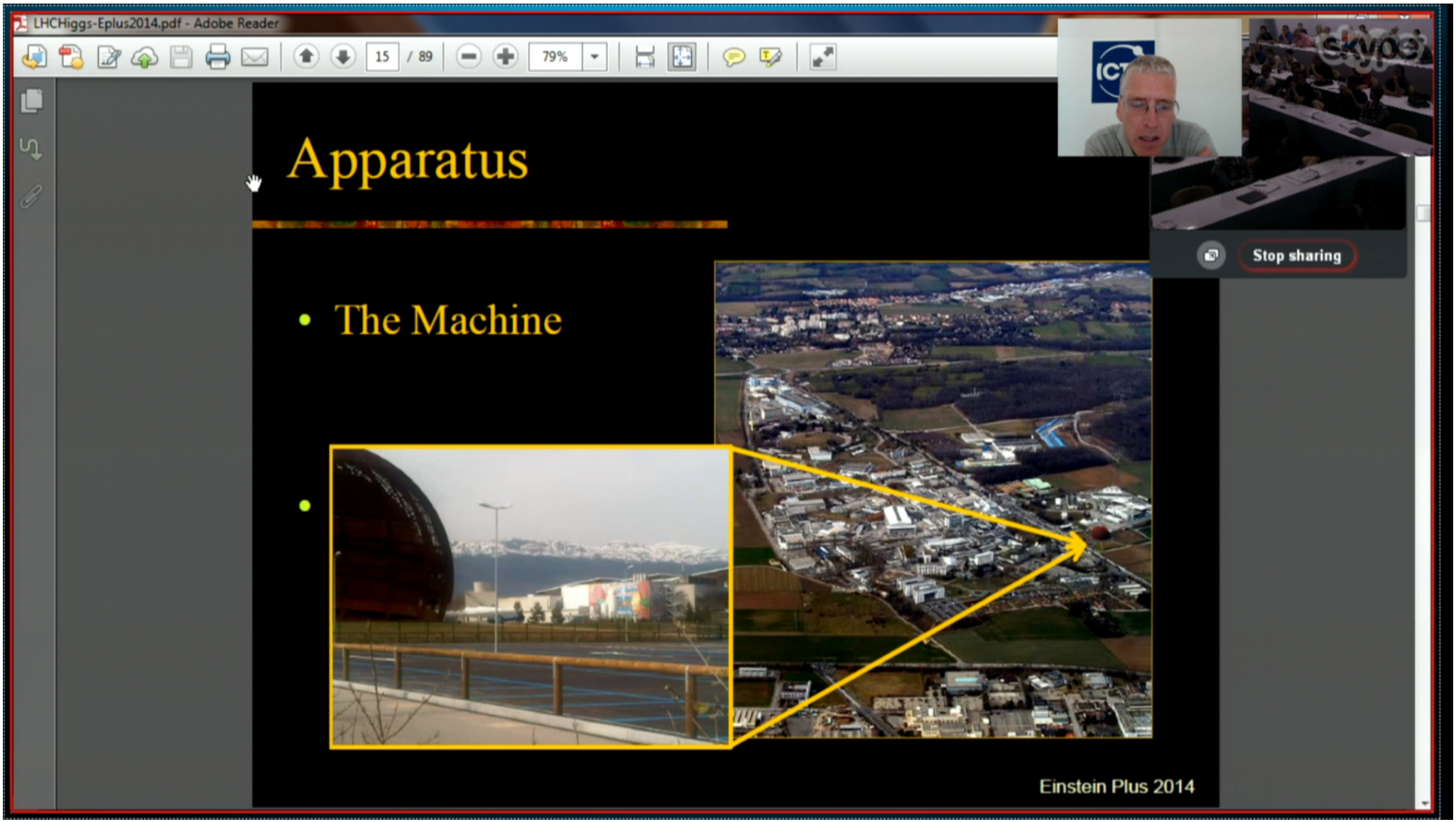
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Apparatus
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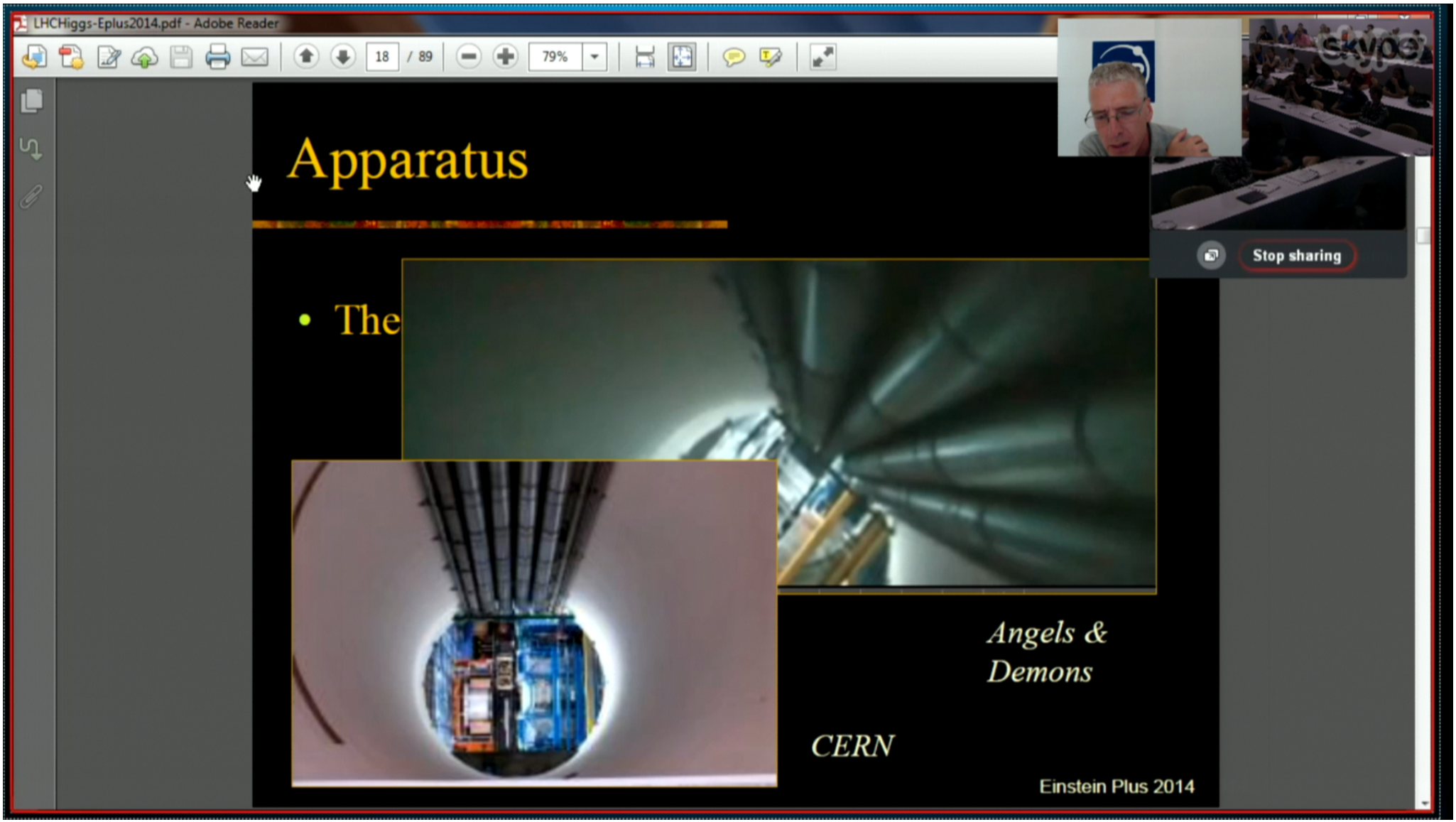
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Apparatus
• The
Angels &
Demons
CERN
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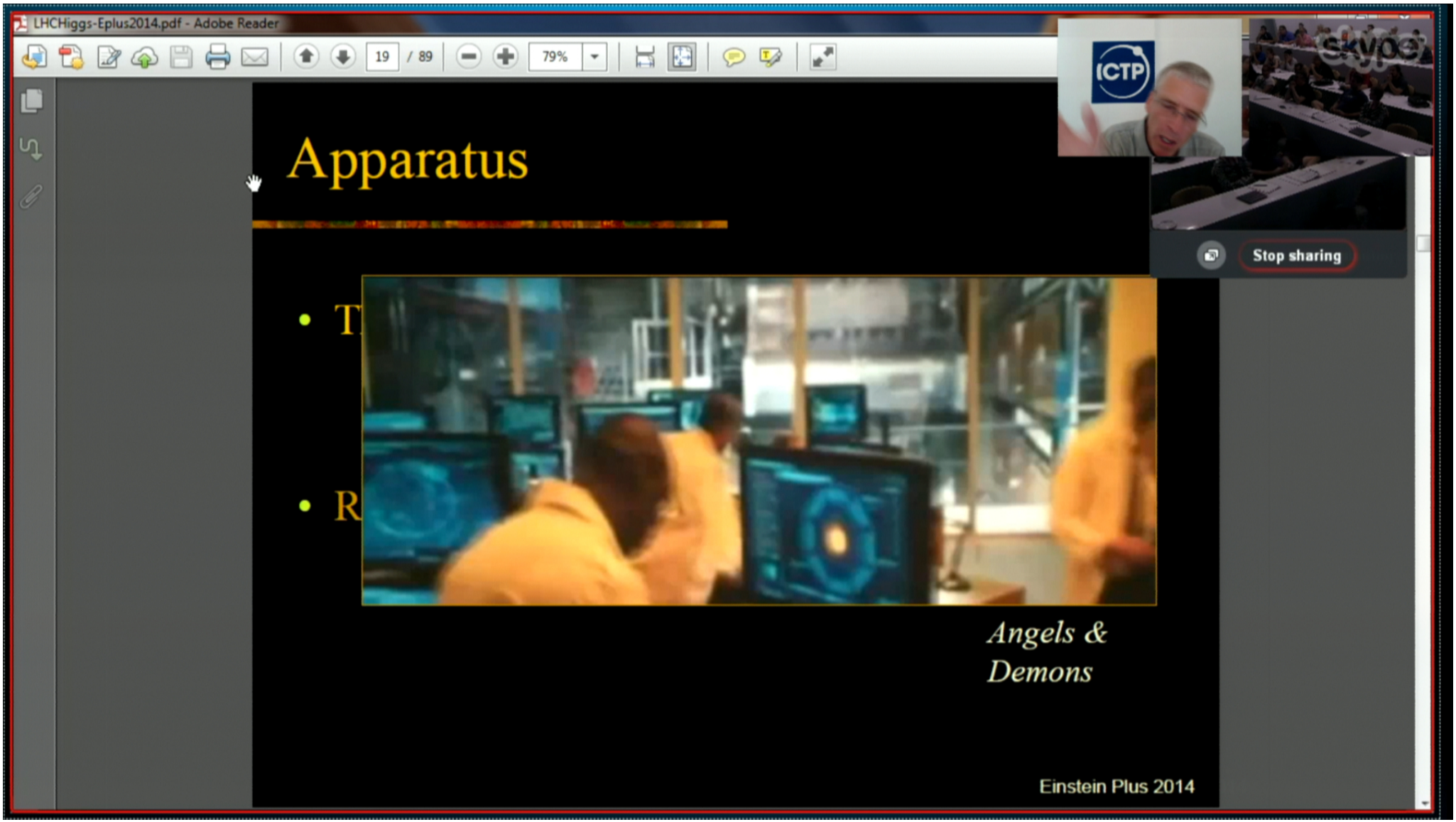
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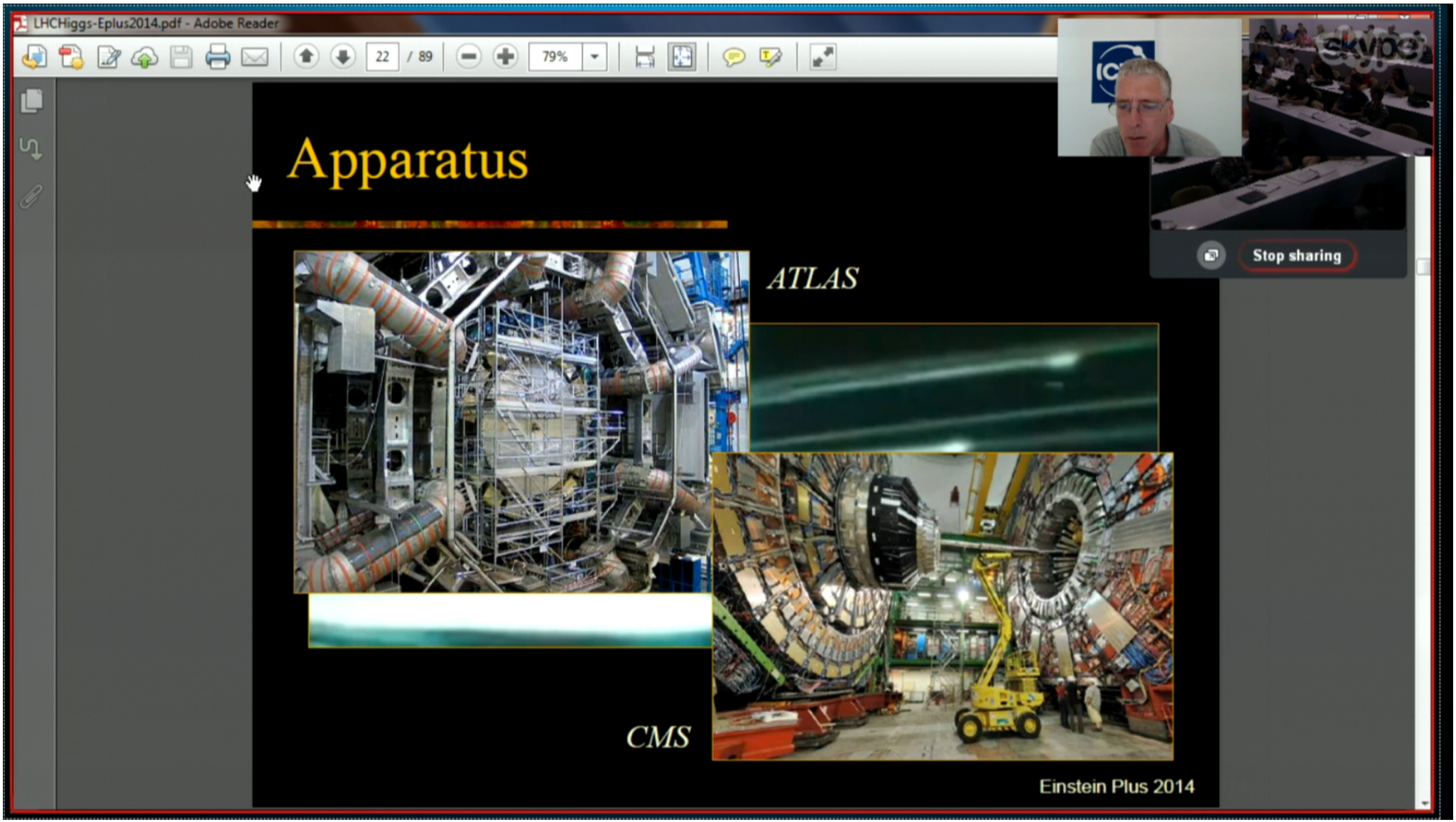
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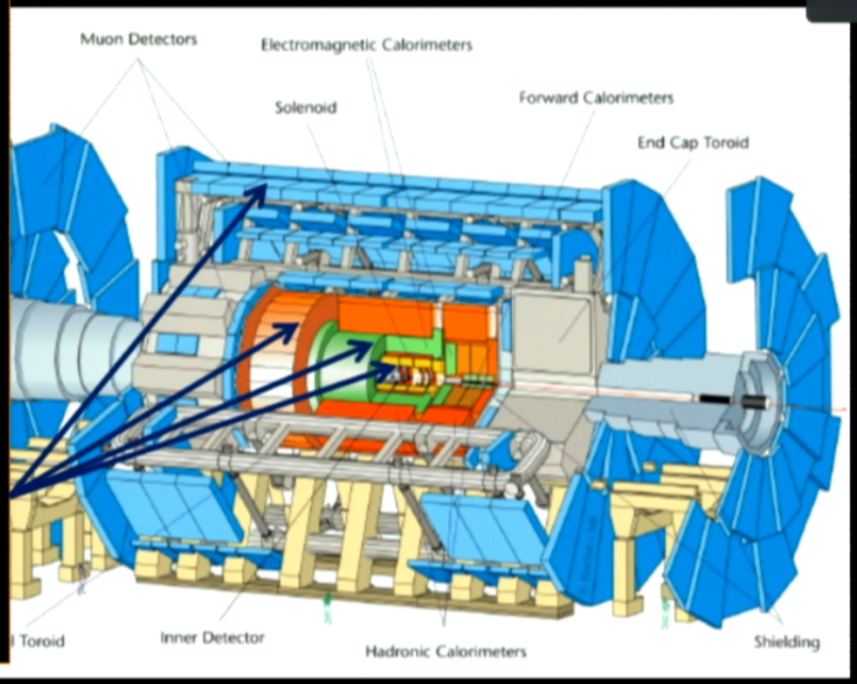
Apparatus

Long-lived particles that can be seen or inferred explicitly:

electrons
photons
protons
neutrons
muons show up here



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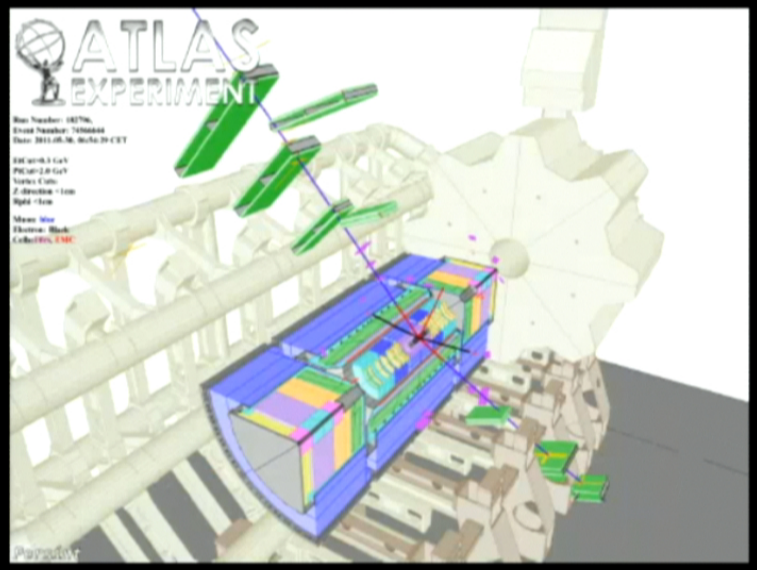
Apparatus



A recorded event with 2 electrons and 2 muons

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Apparatus

- The Machine
- Recent Events

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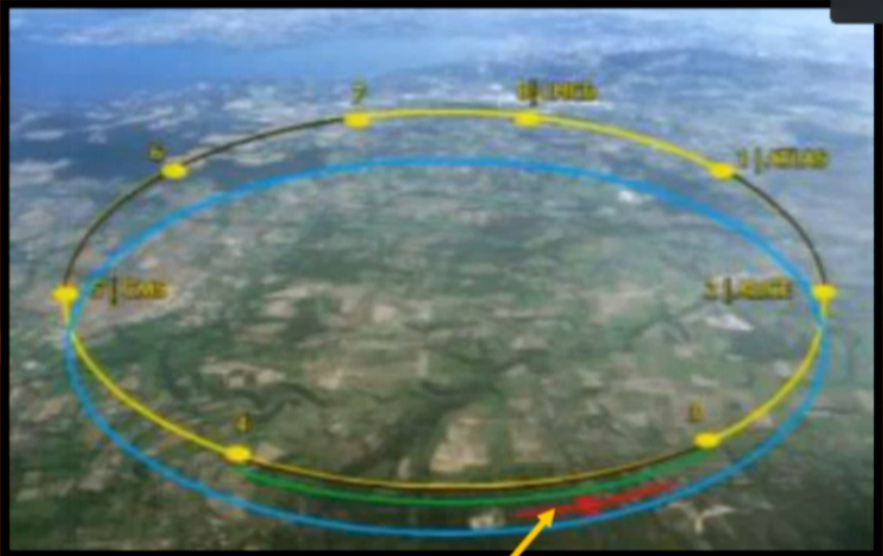
Apparatus

W. Trisch

- The Machine
- Recent Event



The Incident

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Apparatus

W. Trisch

- The Machine
- Recent Event

1200 superconducting magnets

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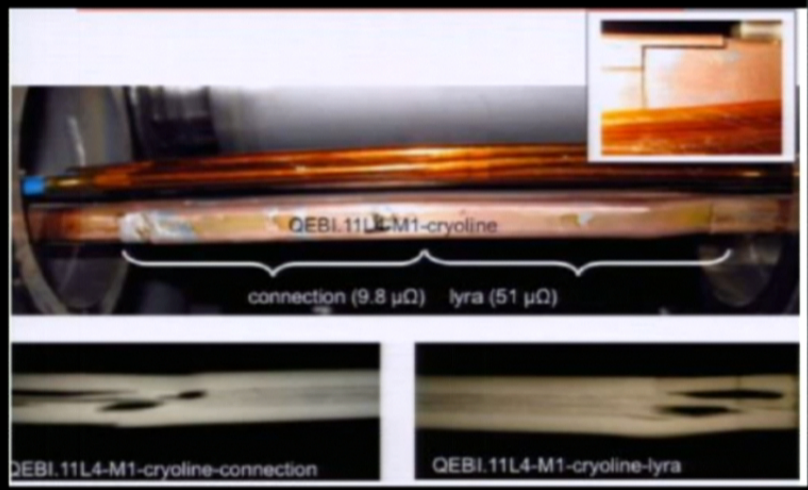
35 / 89 79%

Apparatus

W. Trisch

- The Machine
- Recent Event



dipole interconnect

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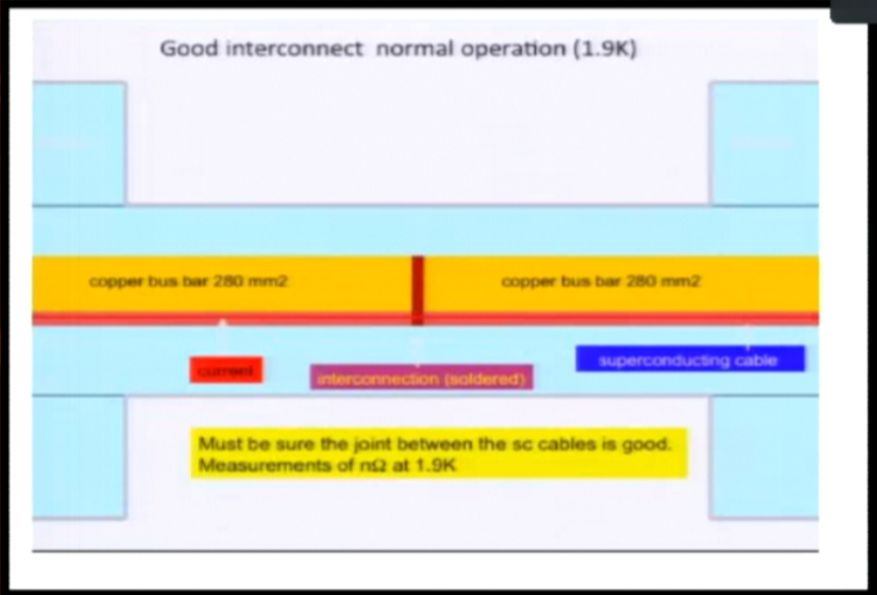
Apparatus

W. Trisch

- The Machine
- Recent Event



schematic connection

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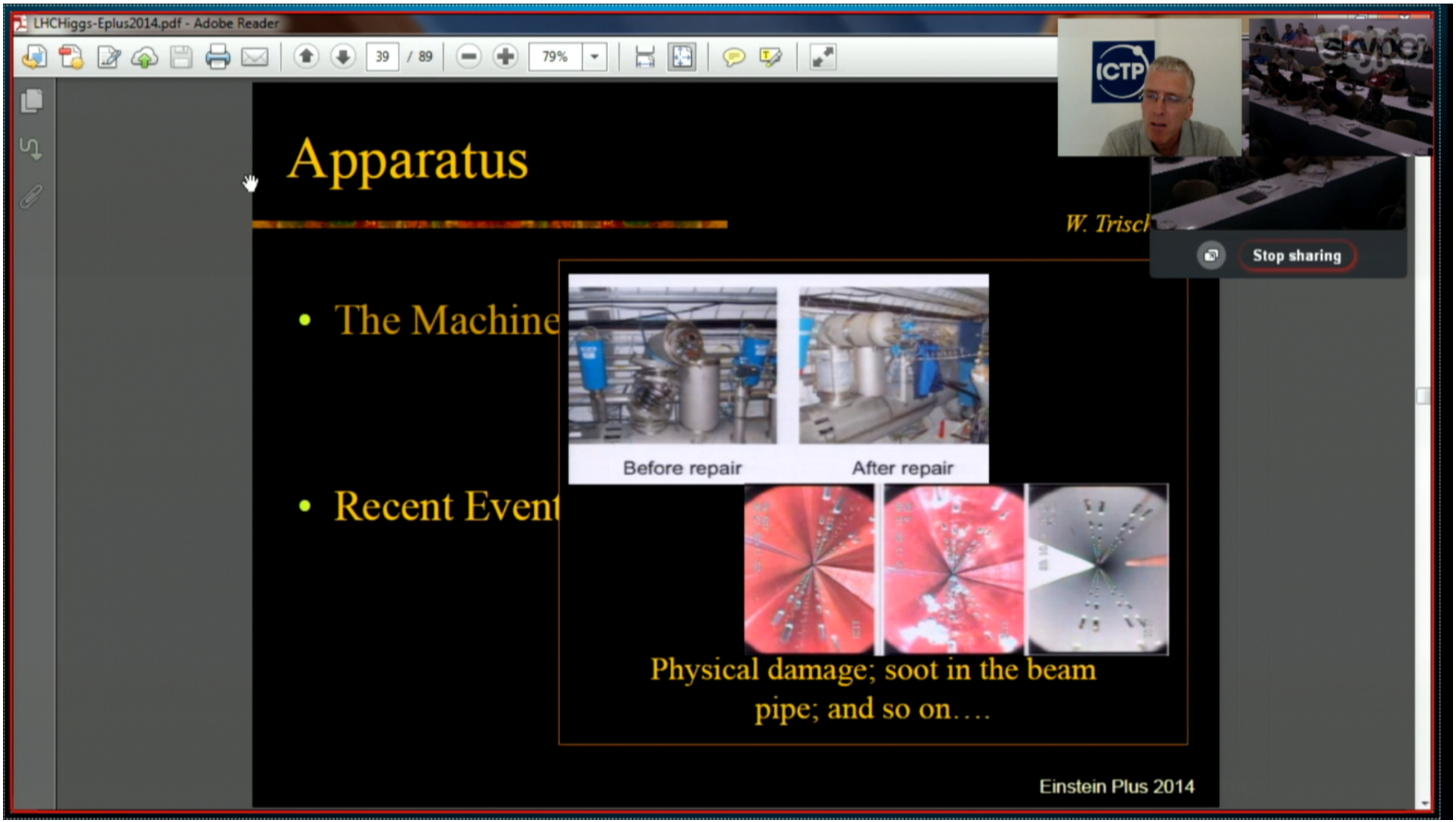
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Apparatus
W. Trisch
The Machine
Recent Event
Before repair
After repair
Physical damage; soot in the beam pipe; and so on….
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Apparatus

W. Trisch

- The Machine
- Recent Event

Replaced 14 quadrupoles and 29 dipoles,
34 interconnections fully repaired

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41 / 89 79%

Apparatus

- The Ma

- Recent

What if there are also problems with the other magnets that did not (yet) fail?

* Time-consuming to warm up and fix
* Can measure resistance to infer which are bad
* Ran at half design energy (7 TeV) since 2009,
* Slightly higher energy before shutdown (8 TeV)
* Fixing magnets until fall this year (2014)
* Restart at design energy (14 TeV)

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42 / 89 79%

Apparatus

- The Machine
- Recent Event

LHC sets new world record

30 November 2009

Scenes of joy in the CERN Control Centre more photos »

Geneva, 30 November 2009. CERN's Large Hadron Collider has today become the world's highest energy particle accelerator, having accelerated its twin beams of protons to an energy of 1.18 TeV in the early hours of the morning. This exceeds the previous world record of 0.98 TeV, which had

Ran for several years at lower energies

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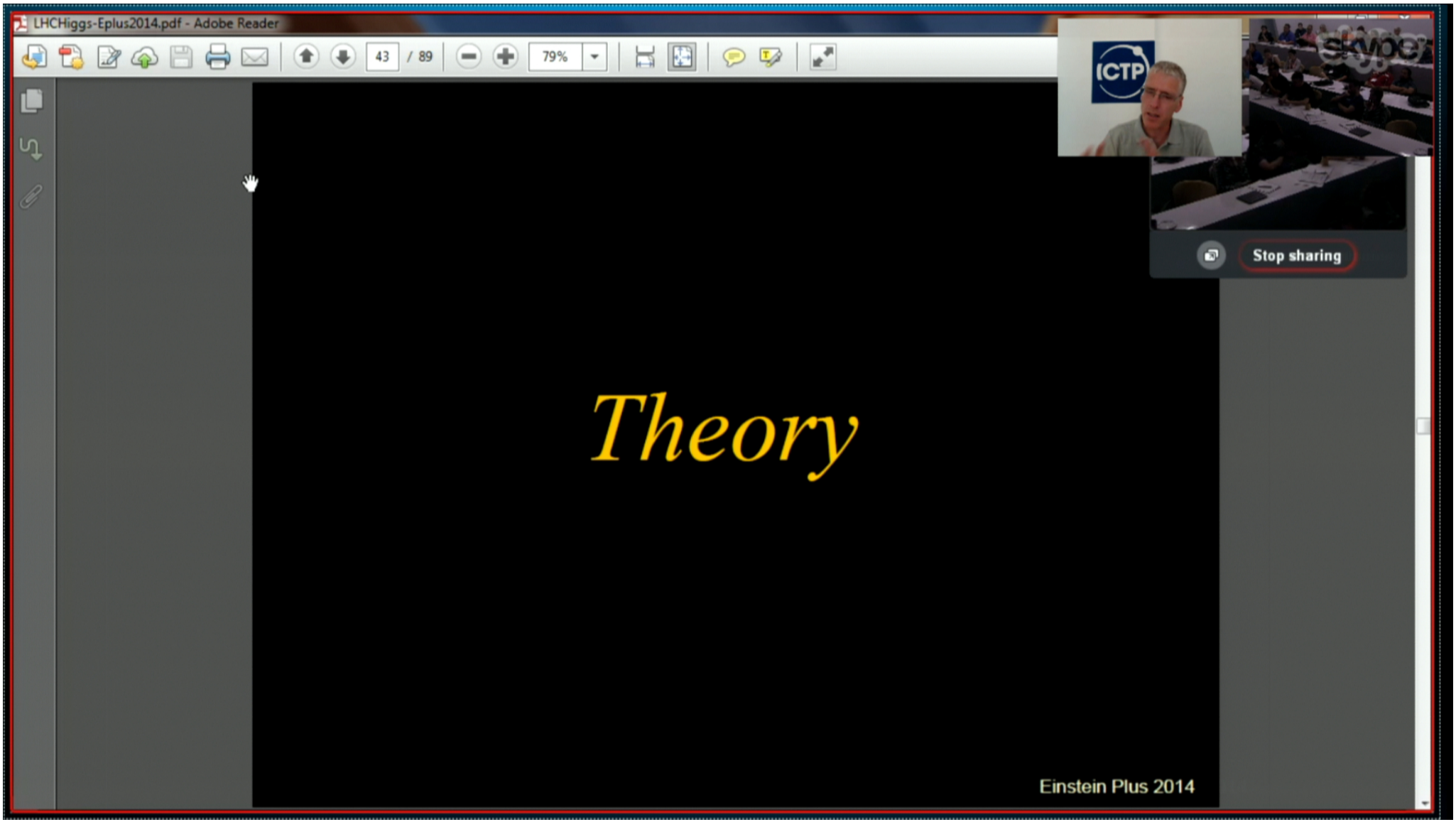
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Theory
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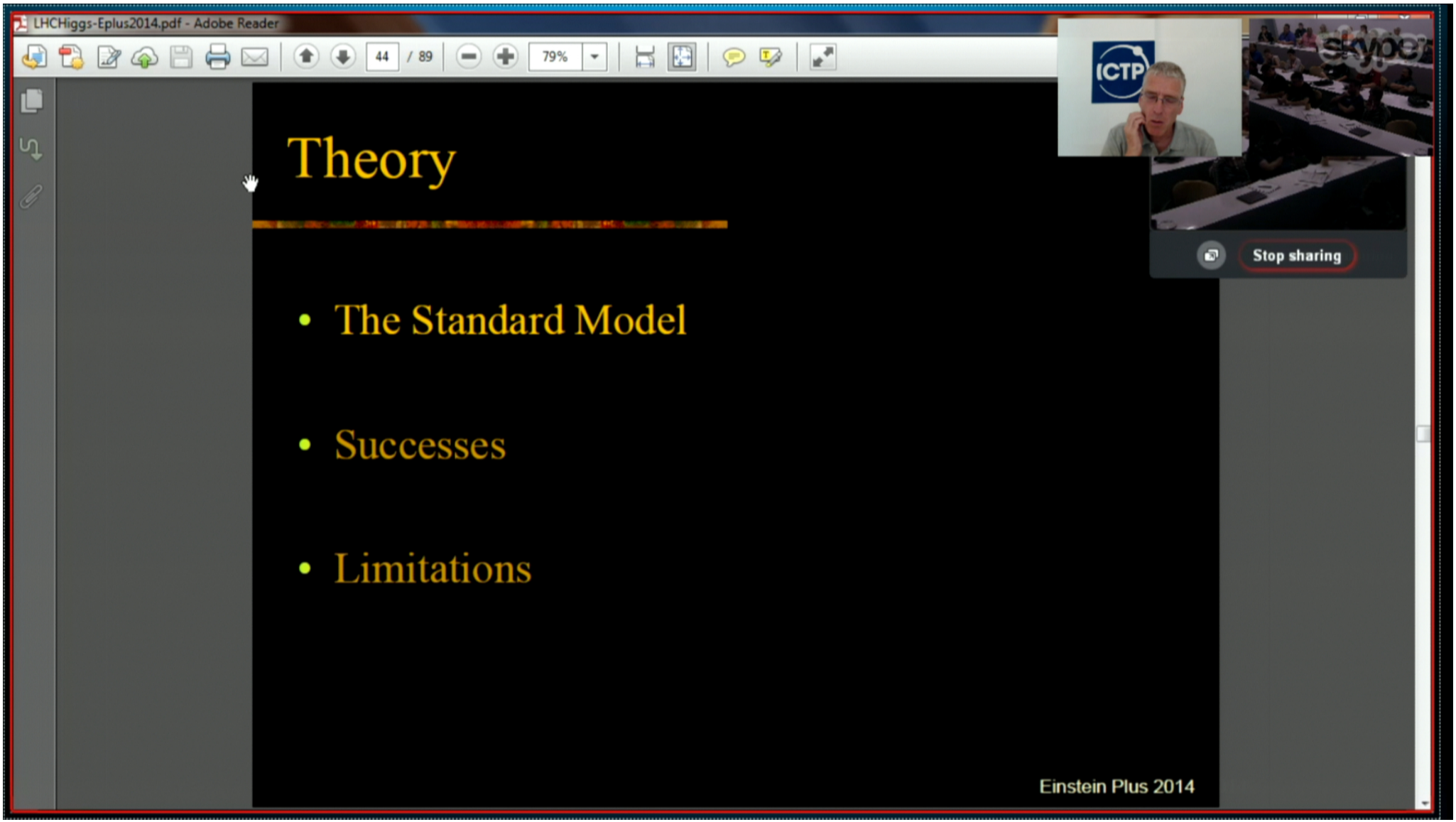
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Theory
The Standard Model
Successes
Limitations
Einstein Plus 2014
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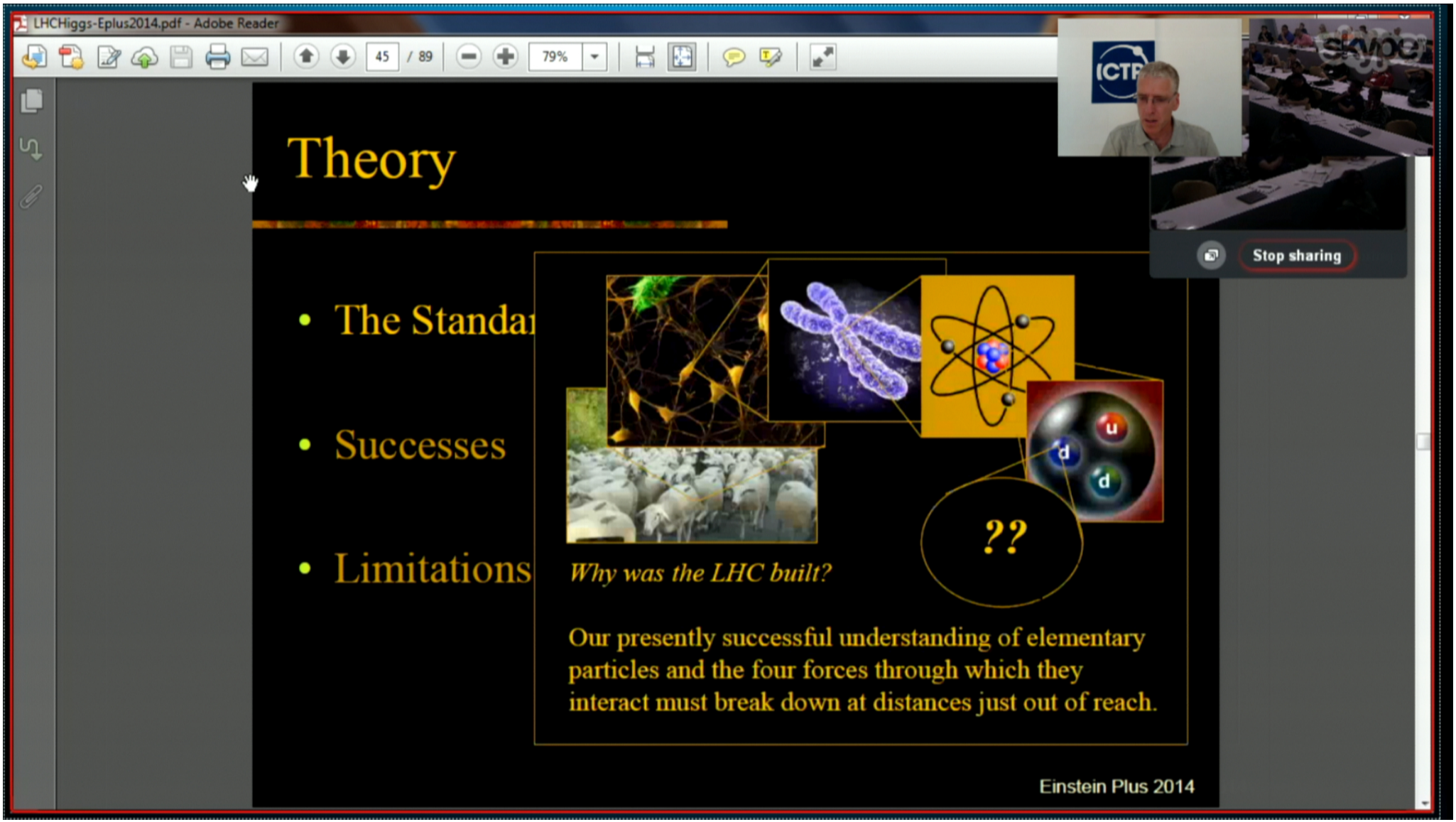
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79%
Theory
• The Standar
• Successes
• Limitations
??
Why was the LHC built?
Our presently successful understanding of elementary particles and the four forces through which they interact must break down at distances just out of reach.
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Theory

- The Standar
- Successes
- Limitations

The Standard Model is the theory which describes the known elementary particles and their interactions.
It describes well all experiments which have been performed to date, with a few recent exceptions.

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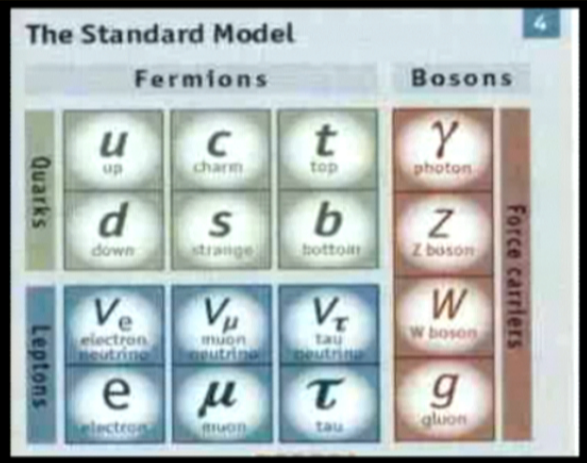
Theory

- The Standard
- Successes
- Limitations



The 12 known constituents of matter and the 4 fundamental forces

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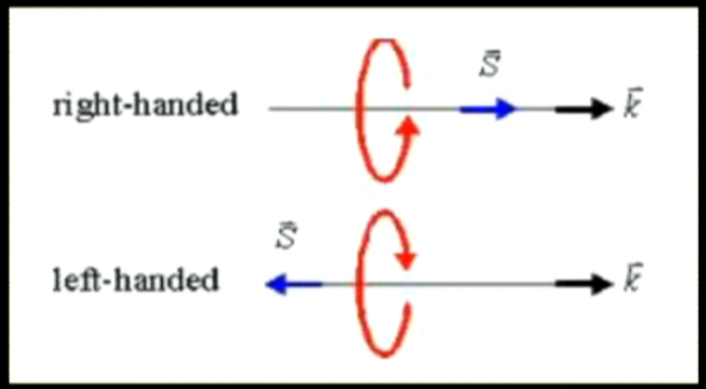
Theory

- The Standard
- Successes
- Limitations



Matter particles come with two spins: left- or right-handed

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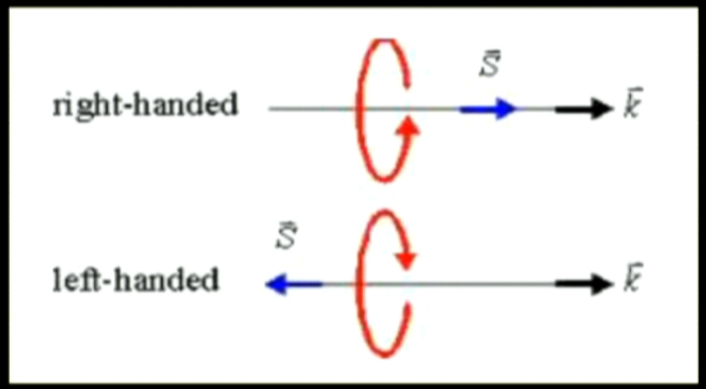
Theory

- The Standard



Matter particles come with two spins: left- or right-handed (like polarizations of light).

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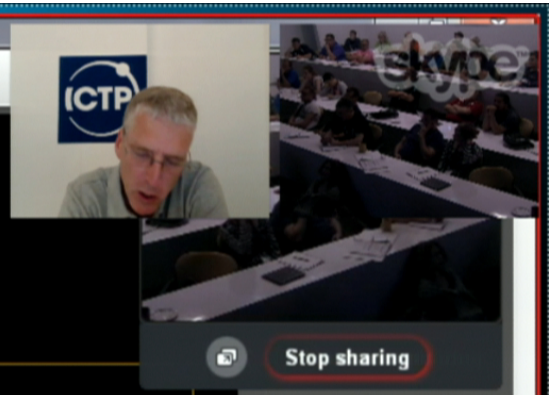

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Theory

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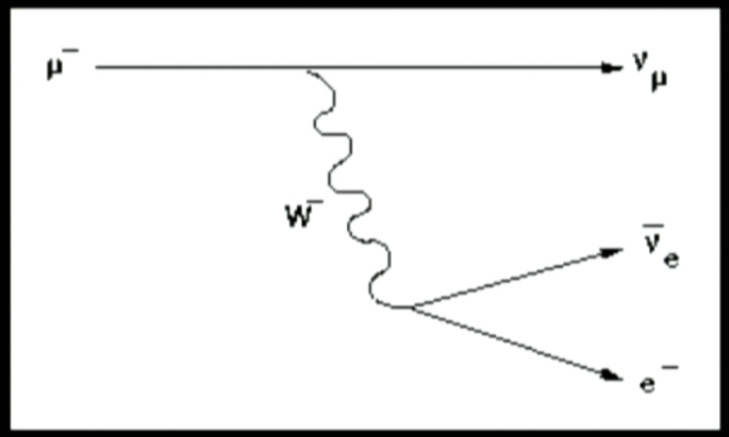
- Successes
- Limitations



The Standard Model incorporates an experimental fact: only *left-handed* particles participate in the weak interactions

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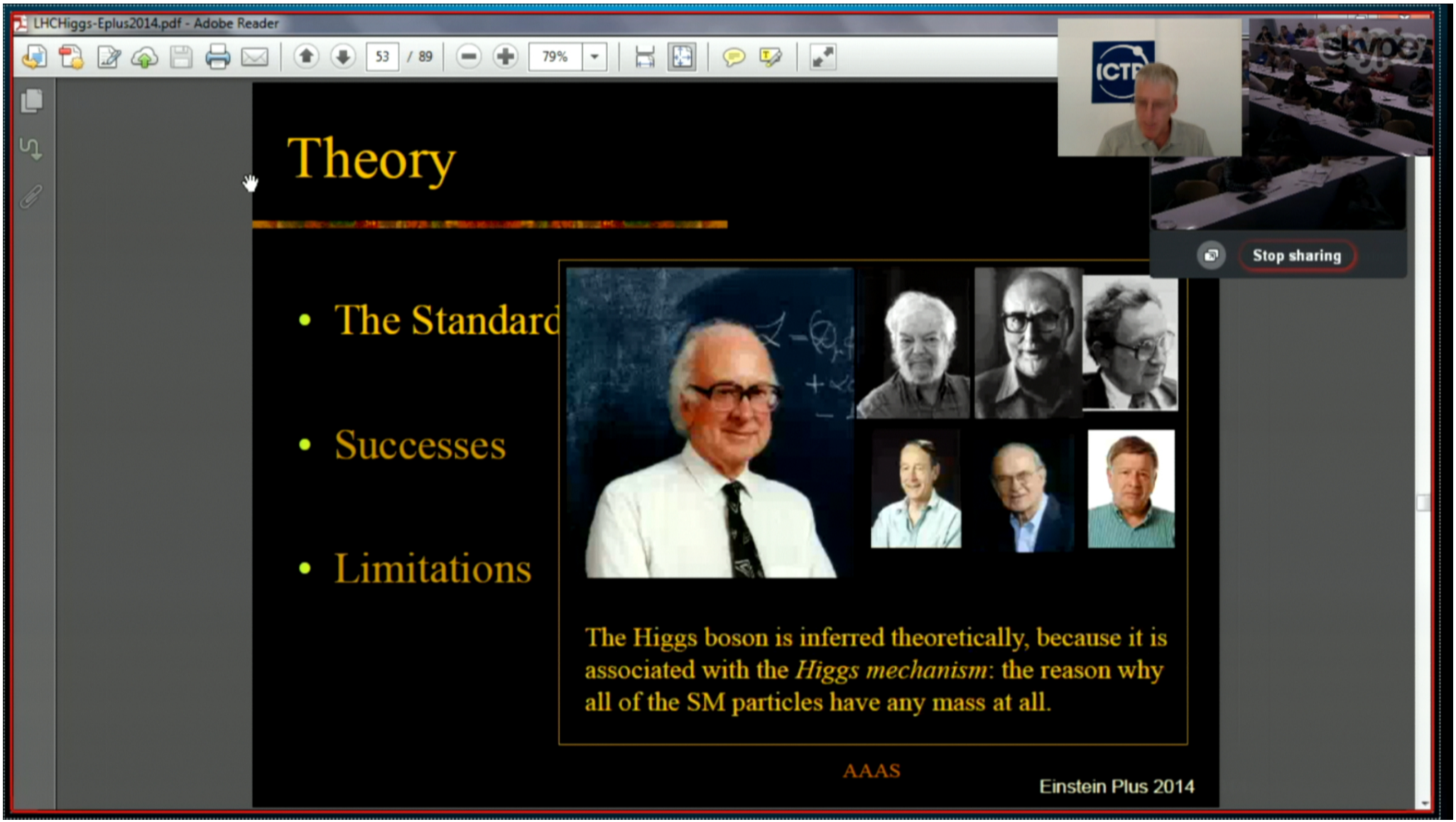
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Theory
• The Standard
• Successes
• Limitations
The Higgs boson is inferred theoretically, because it is associated with the *Higgs mechanism*: the reason why all of the SM particles have any mass at all.
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Theory

- The Standard
- Successes
- Limitations

Although the SM has a symmetry that requires all known particles to be massless, the vacuum has physical properties, which can break this symmetry.

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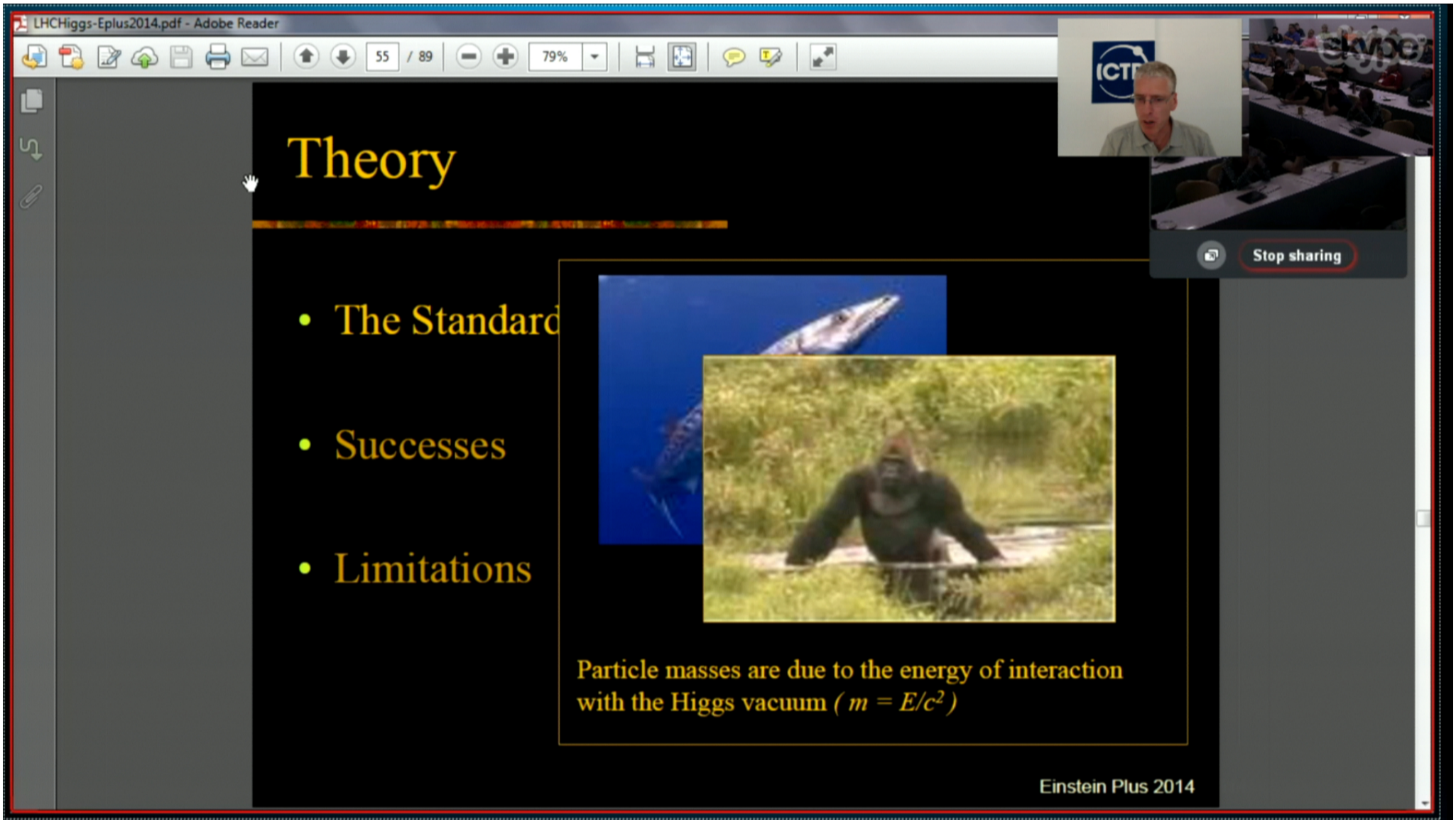
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Theory
The Standard
Successes
Limitations
Particle masses are due to the energy of interaction with the Higgs vacuum ($m = E/c^2$)
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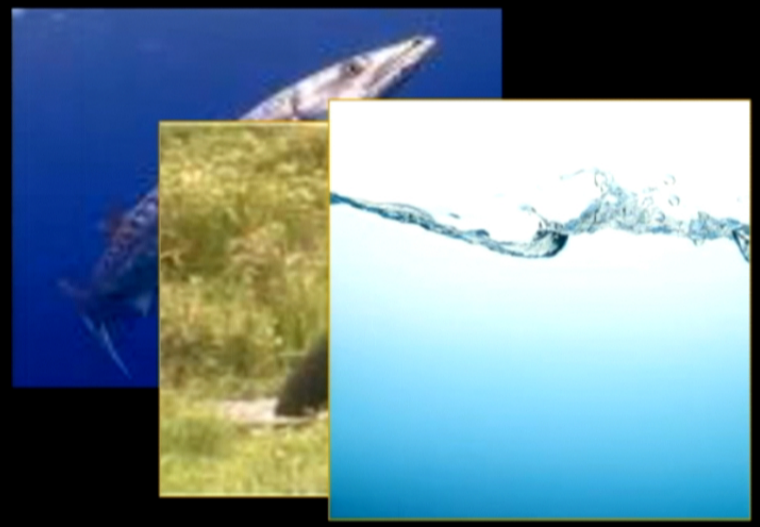
Theory

- The Standard
- Successes
- Limitations



The Higgs *particle* is a wave moving through the Higgs vacuum itself.

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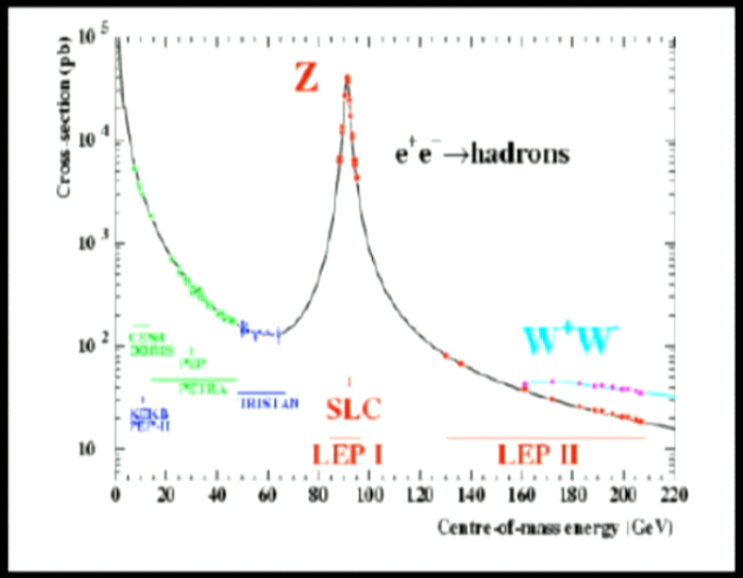
Theory

- The Standard
- Successes
- Limitations



The SM is tested in detail, such as through e^+e^- collisions

A Tonazzo: Moriond 2002

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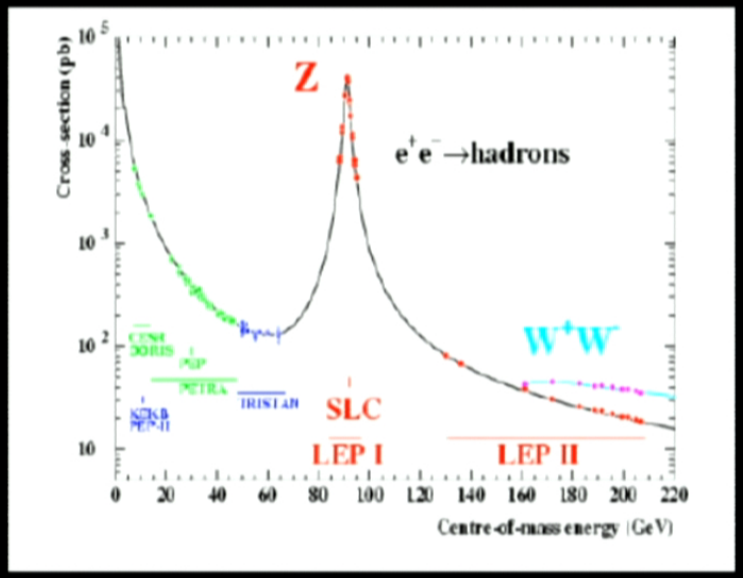
Theory

- The Standard
- Successes
- Limitations



The SM is tested in detail, such as through e^+e^- collisions

A Tonazzo: Moriond 2002

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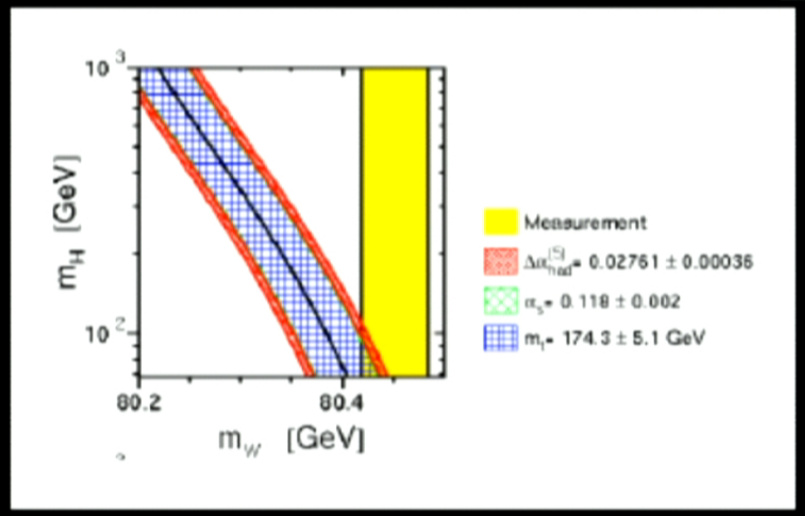
Theory

- The Standard
- Successes
- Limitations



Unknown quantities, like the Higgs mass, are strongly constrained by the accuracy of these tests

A Tonazzo: Moriond 2002

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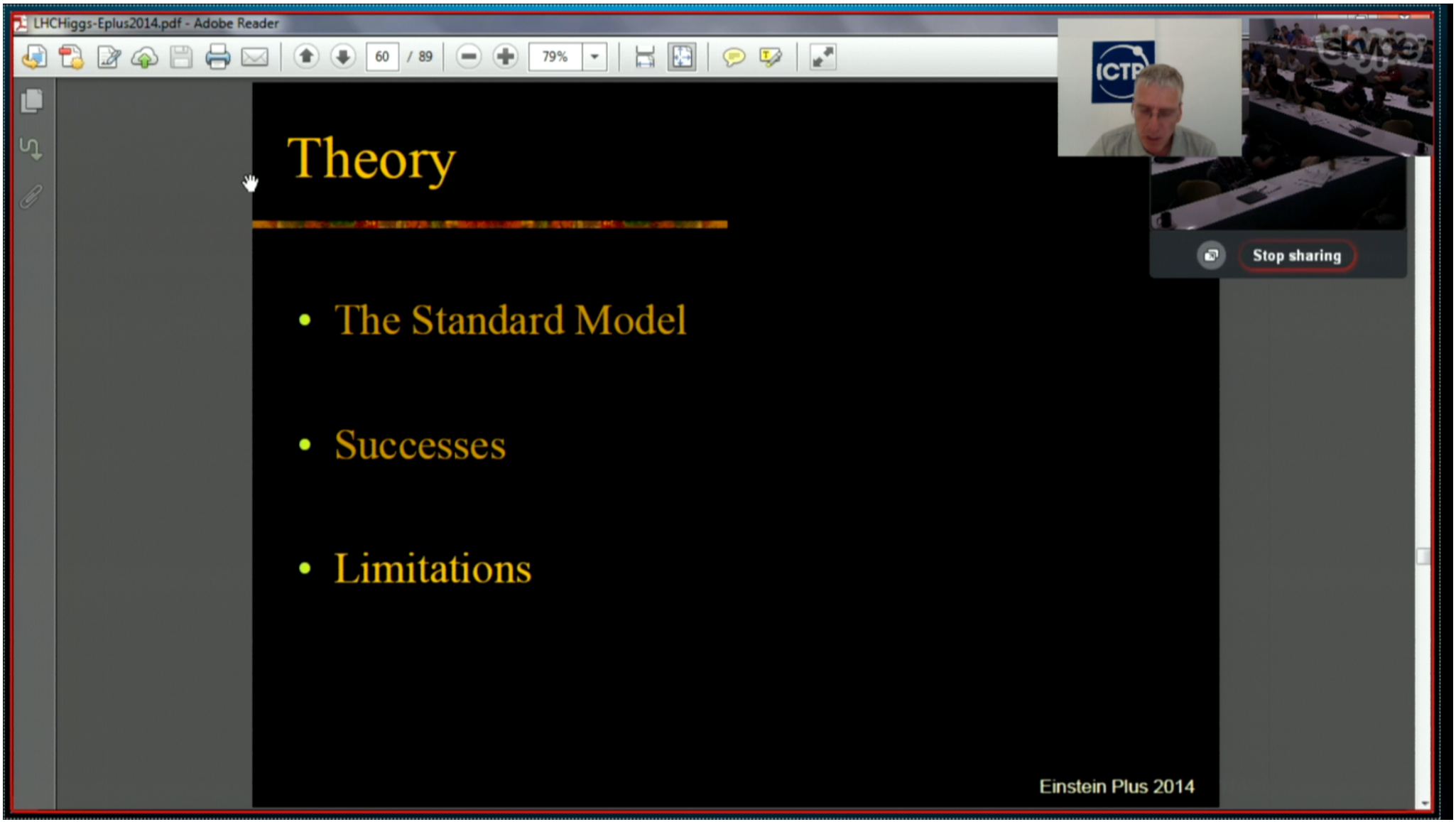
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The Standard Model
Successes
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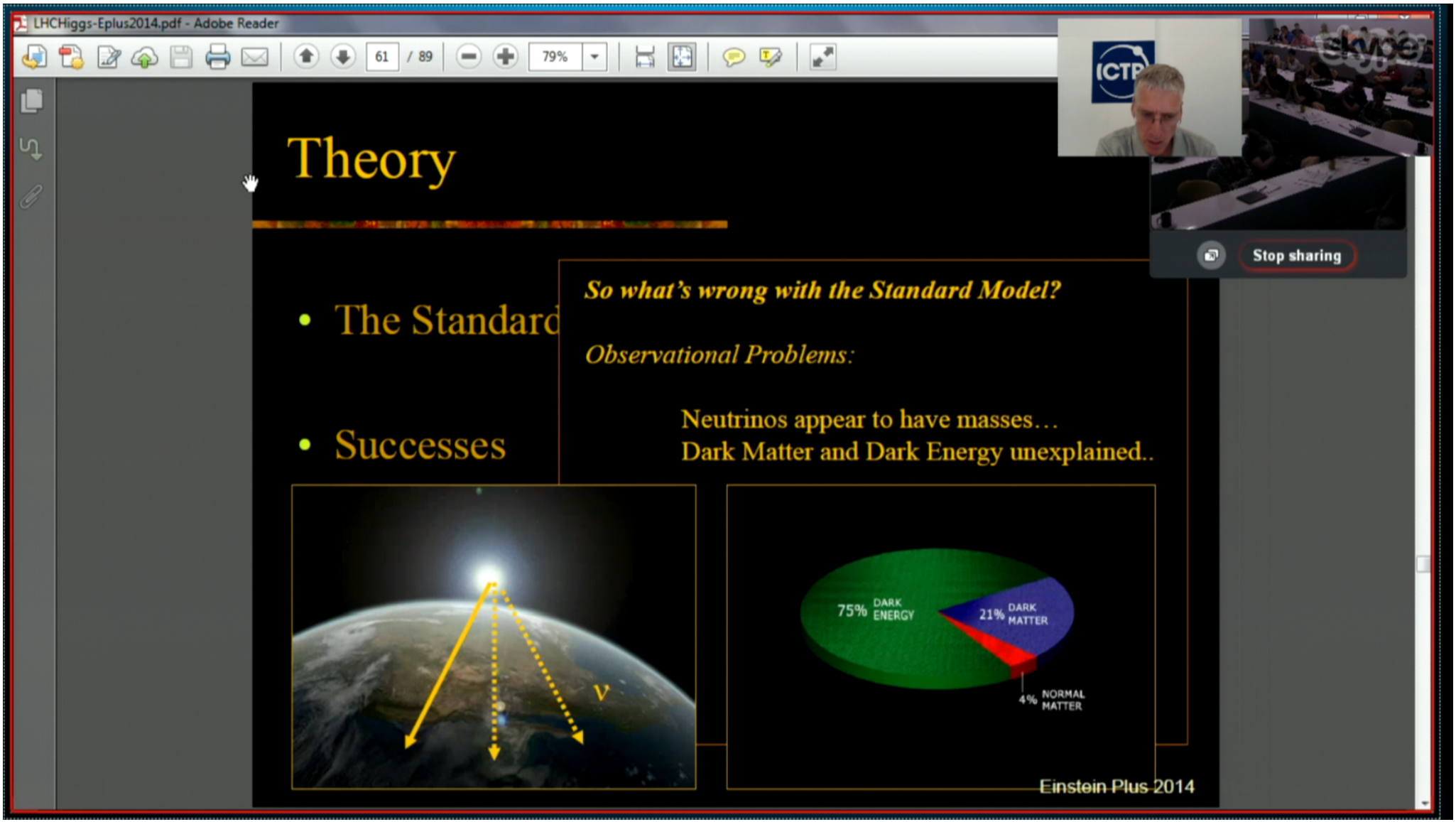
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Theory
• The Standard
• Successes
So what's wrong with the Standard Model?
Observational Problems:
Neutrinos appear to have masses…
Dark Matter and Dark Energy unexplained..
ν
75% DARK ENERGY
21% DARK MATTER
4% NORMAL MATTER
Einstein Plus 2014
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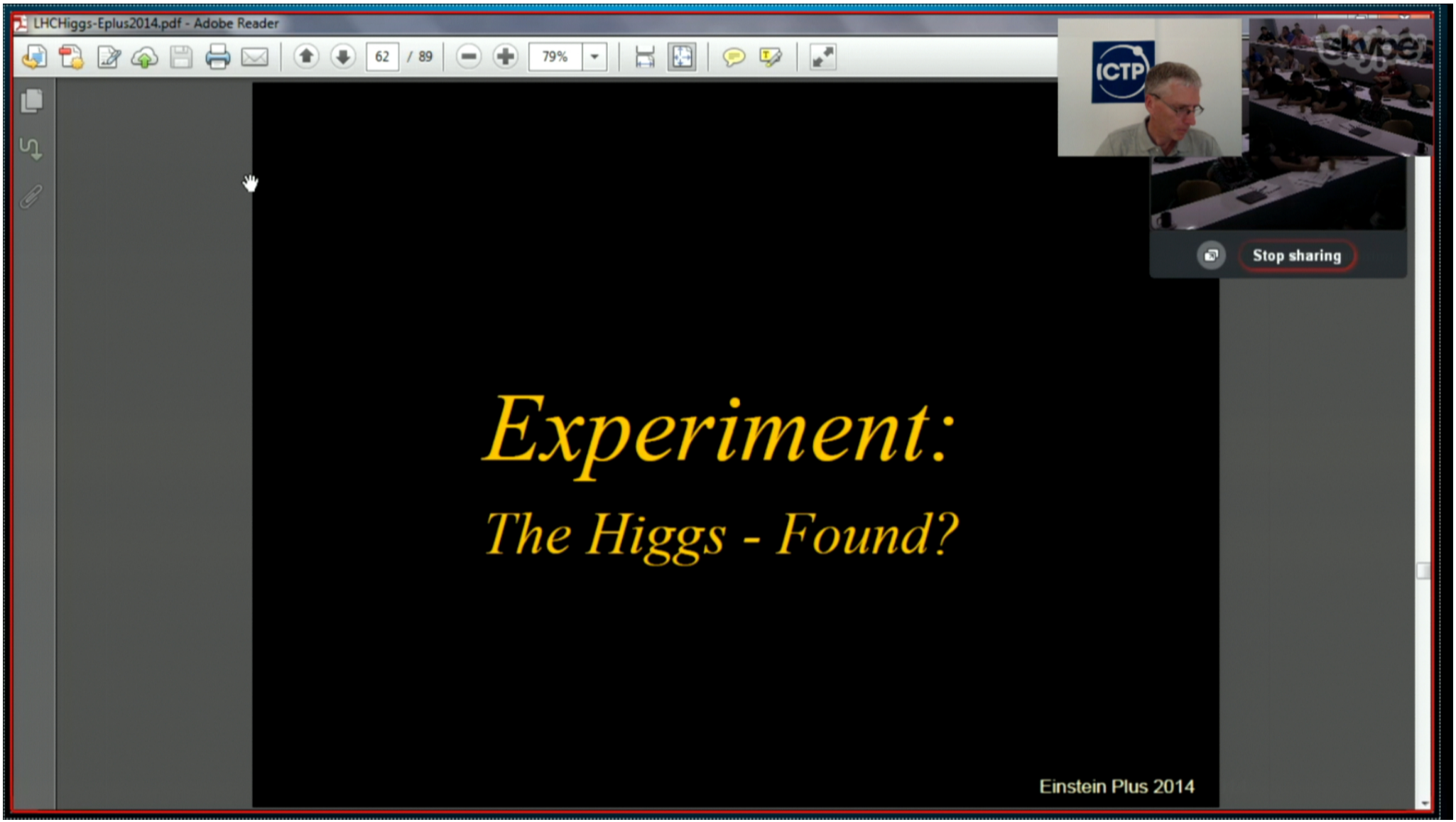
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Experiment:
The Higgs - Found?
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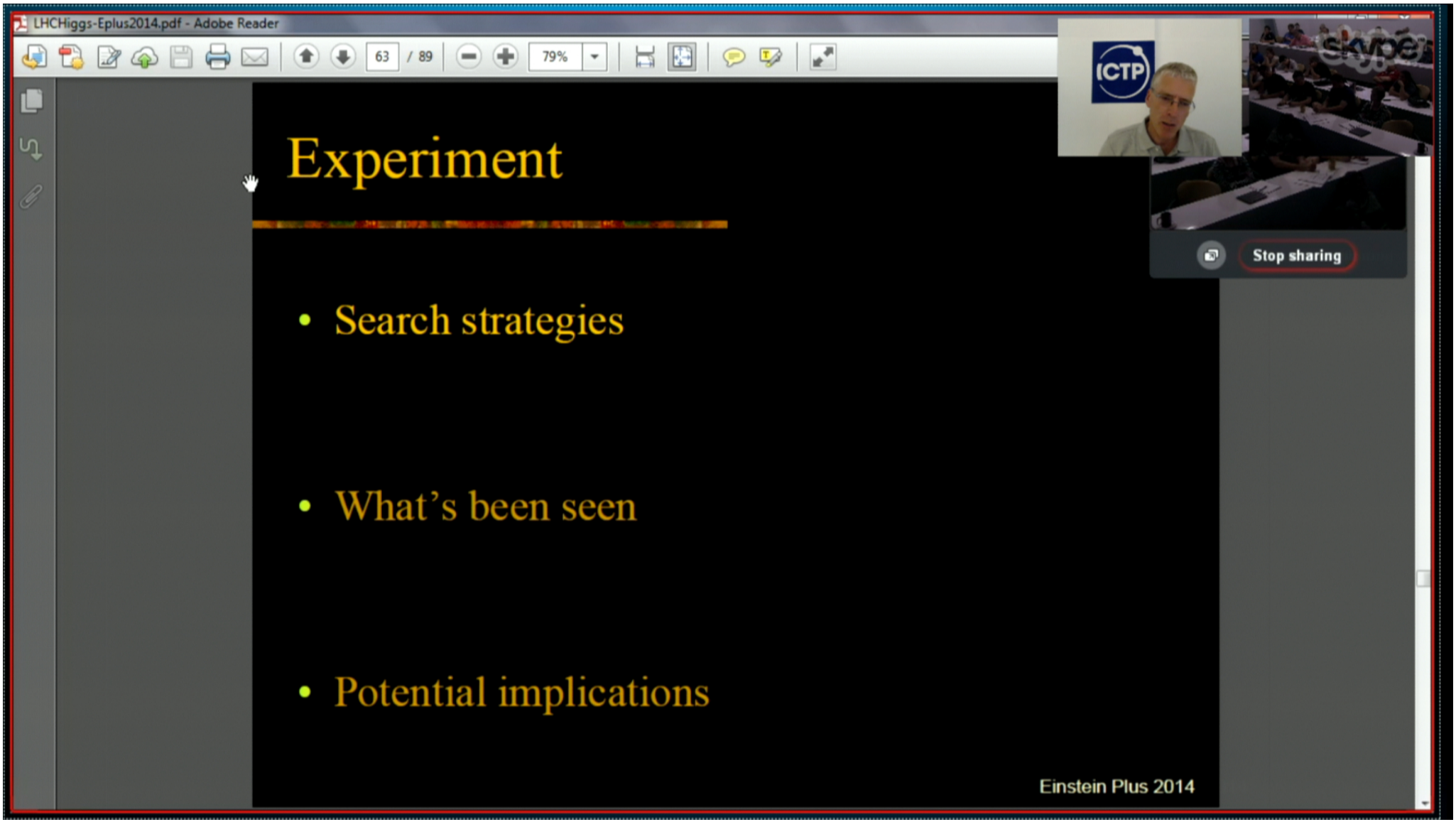
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Experiment
Search strategies
What's been seen
Potential implications
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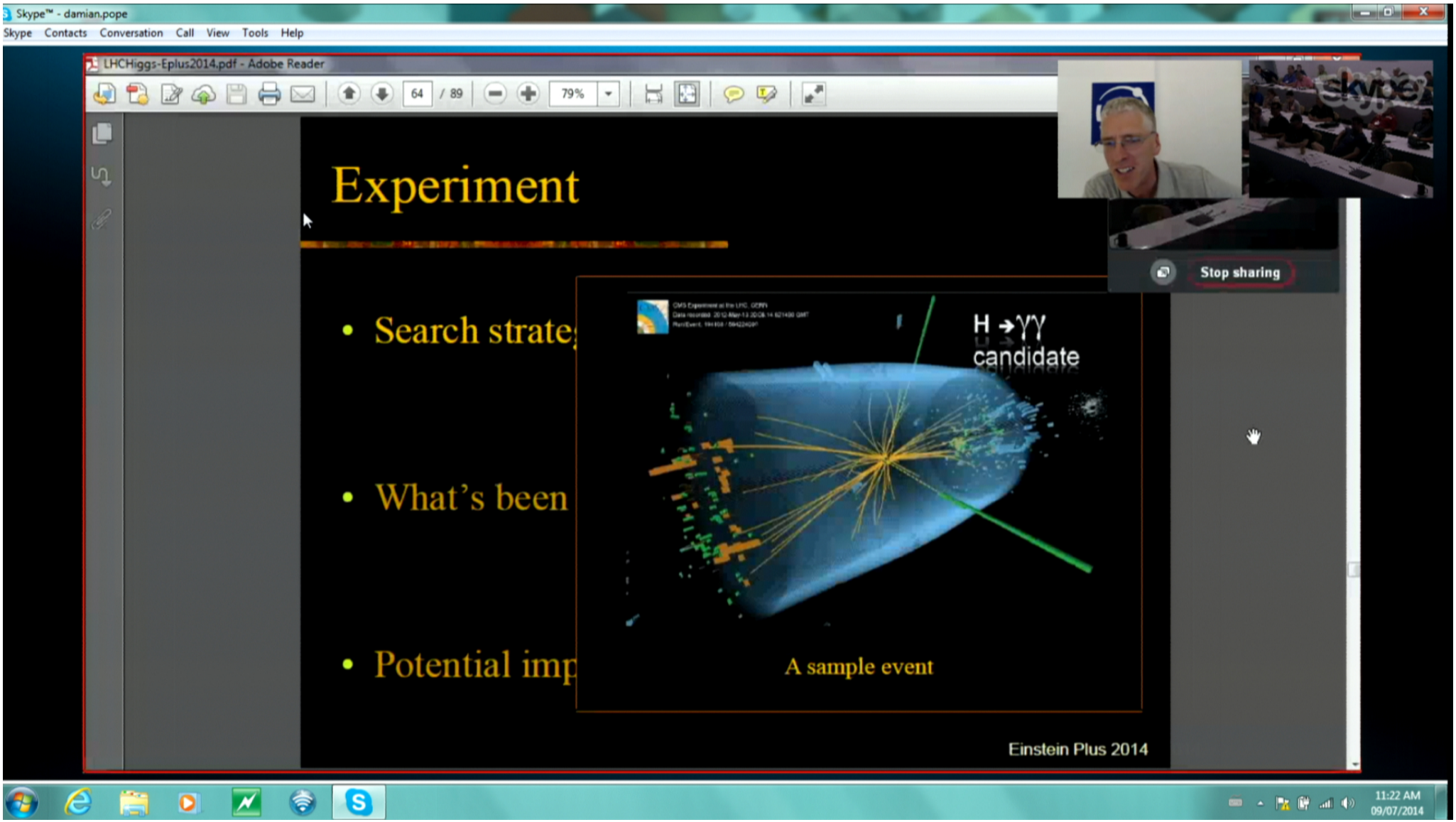
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Experiment
• Search strate
• What's been
• Potential imp
H →γγ
candidate
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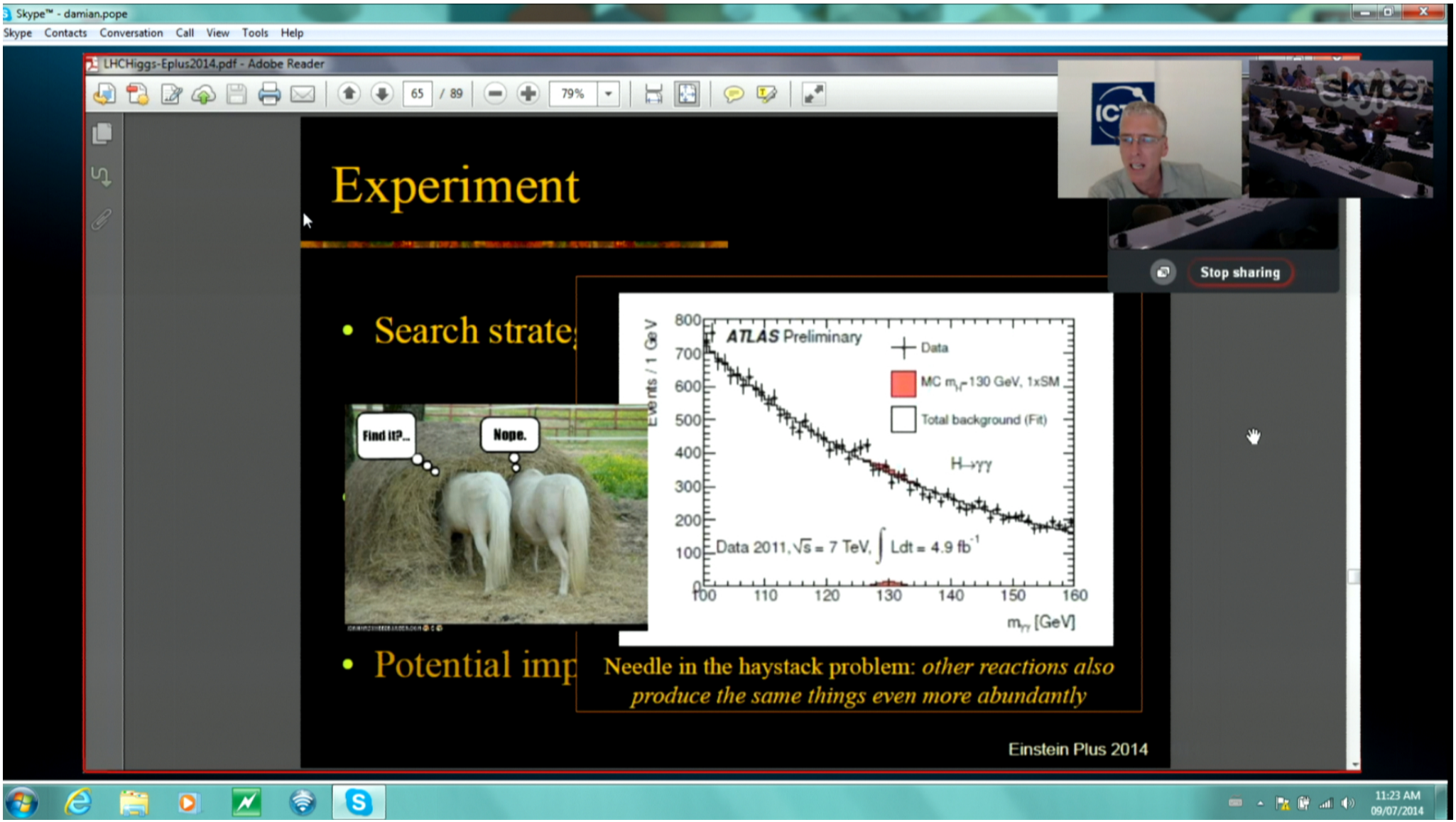
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65 / 89
79%
Experiment
• Search strate
• Potential imp
Find it?...
Nope.
ATLAS Preliminary
Data
MC m_γγ=130 GeV, 1xSM
Total background (Fit)
H→γγ
Data 2011, √s = 7 TeV, ∫ Ldt = 4.9 fb⁻¹
Events / 1 GeV
m_γγ [GeV]
Needle in the haystack problem: other reactions also produce the same things even more abundantly
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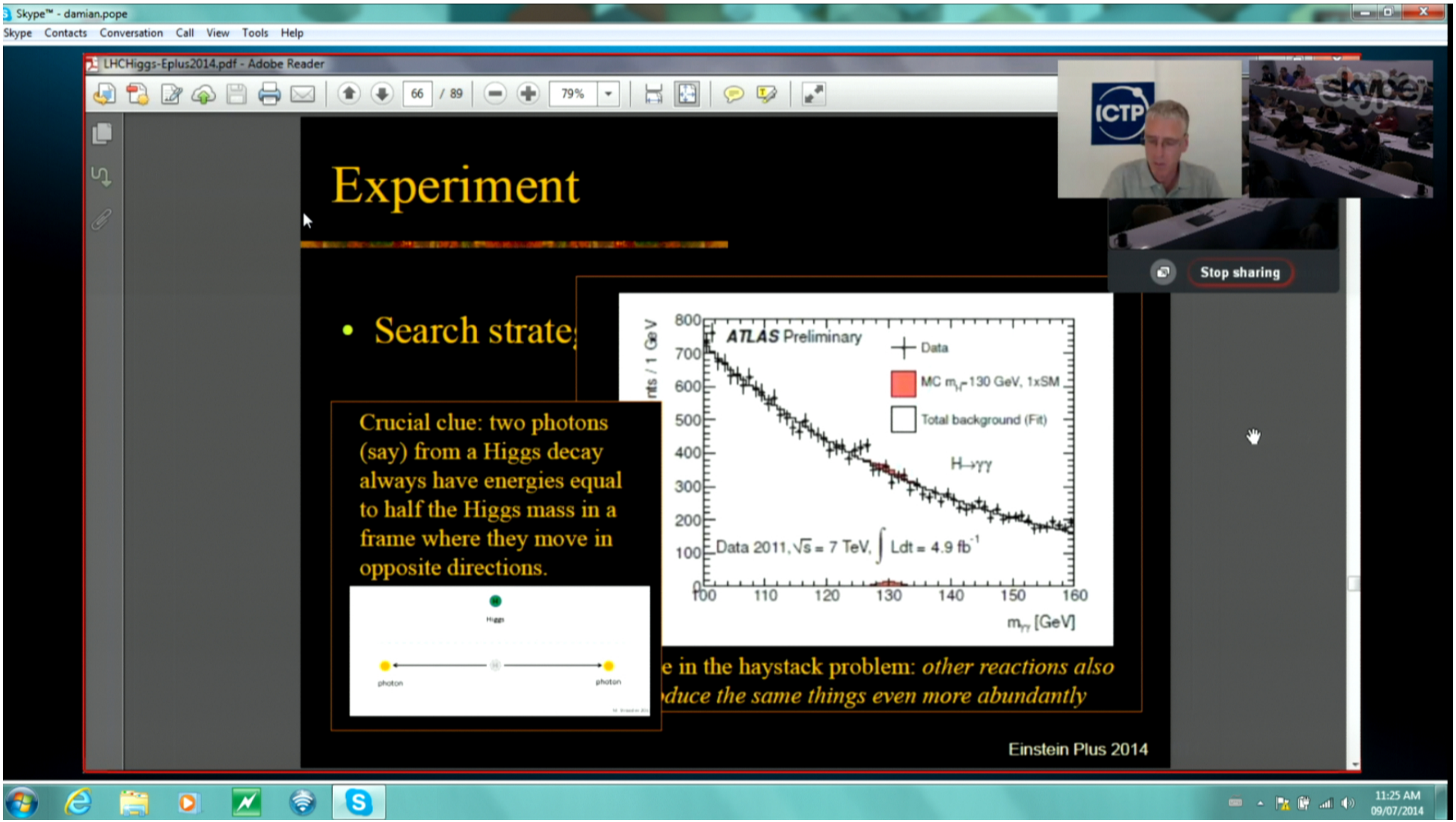
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Experiment
• Search strate
Crucial clue: two photons (say) from a Higgs decay always have energies equal to half the Higgs mass in a frame where they move in opposite directions.
Higgs
photon
photon
ATLAS Preliminary
Data
MC $m_{\gamma\gamma}$=130 GeV, 1xSM
Total background (Fit)
H→γγ
Data 2011, √s = 7 TeV, ∫ Ldt = 4.9 fb⁻¹
$m_{\gamma\gamma}$ [GeV]
e in the haystack problem: other reactions also
duce the same things even more abundantly
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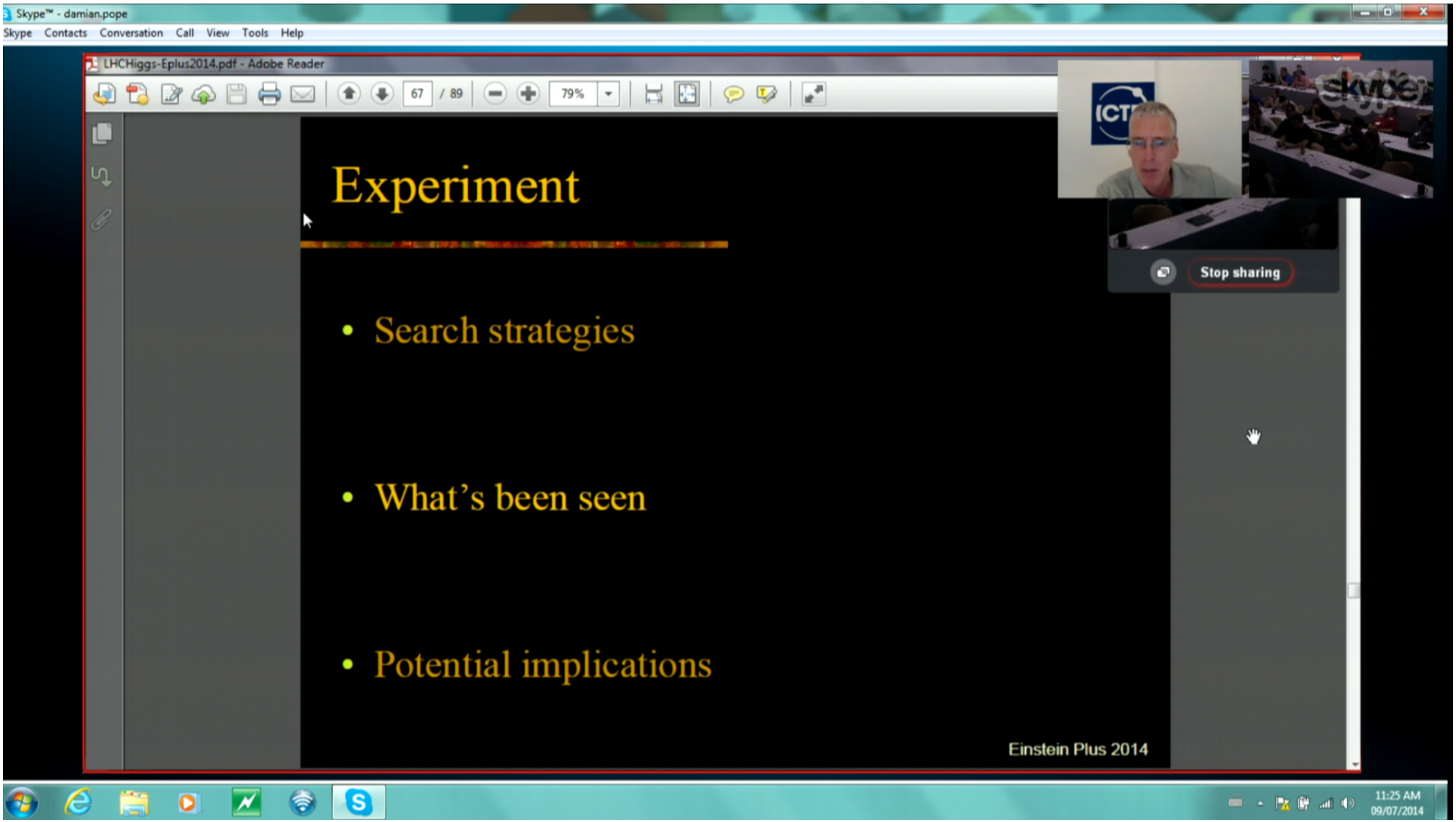
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Experiment
• Search strategies
• What's been seen
• Potential implications
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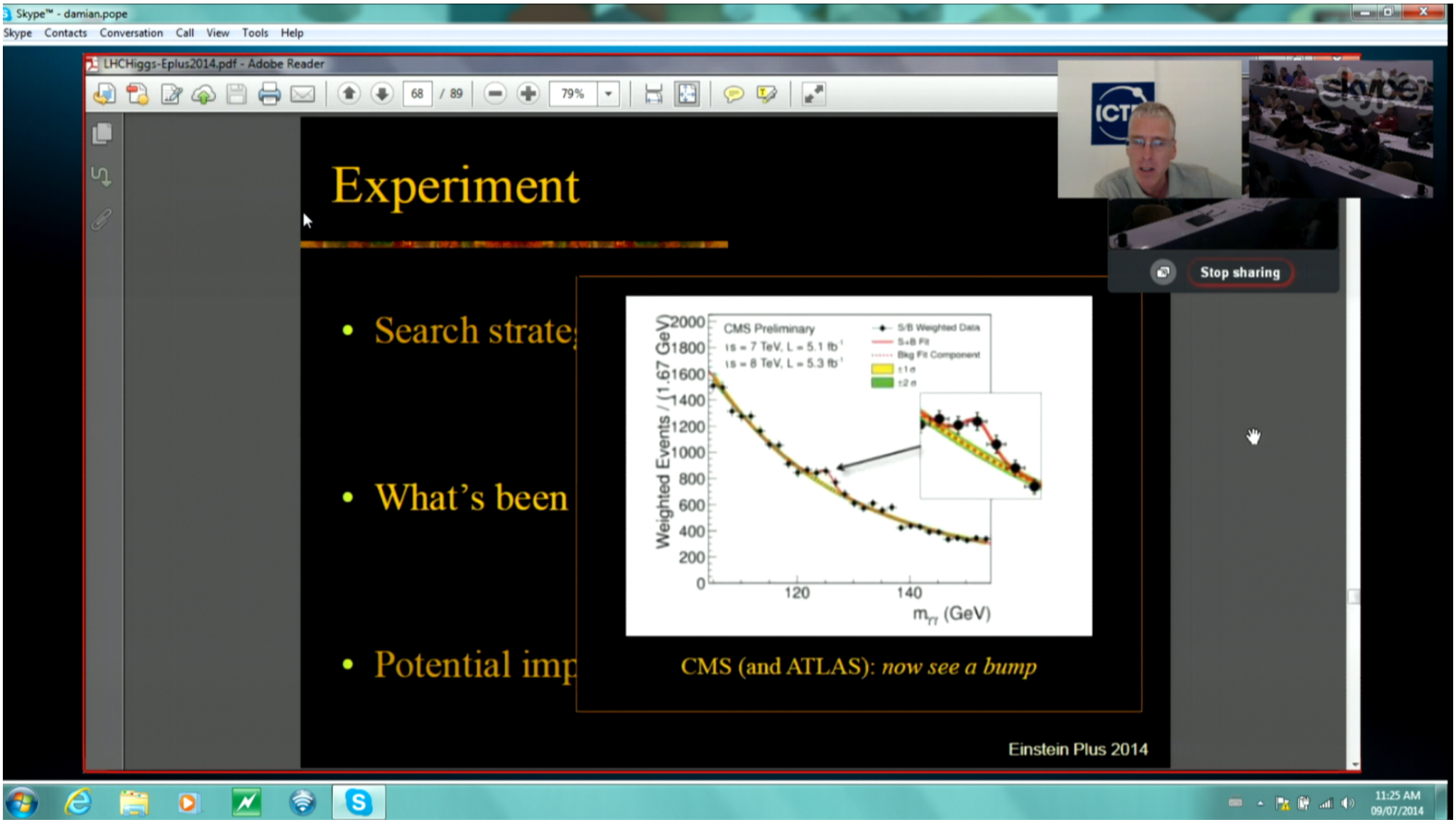
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Experiment
• Search strate
• What's been
• Potential imp
CMS Preliminary
√s = 7 TeV, L = 5.1 fb⁻¹
√s = 8 TeV, L = 5.3 fb⁻¹
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
m_γγ (GeV)
CMS (and ATLAS): now see a bump
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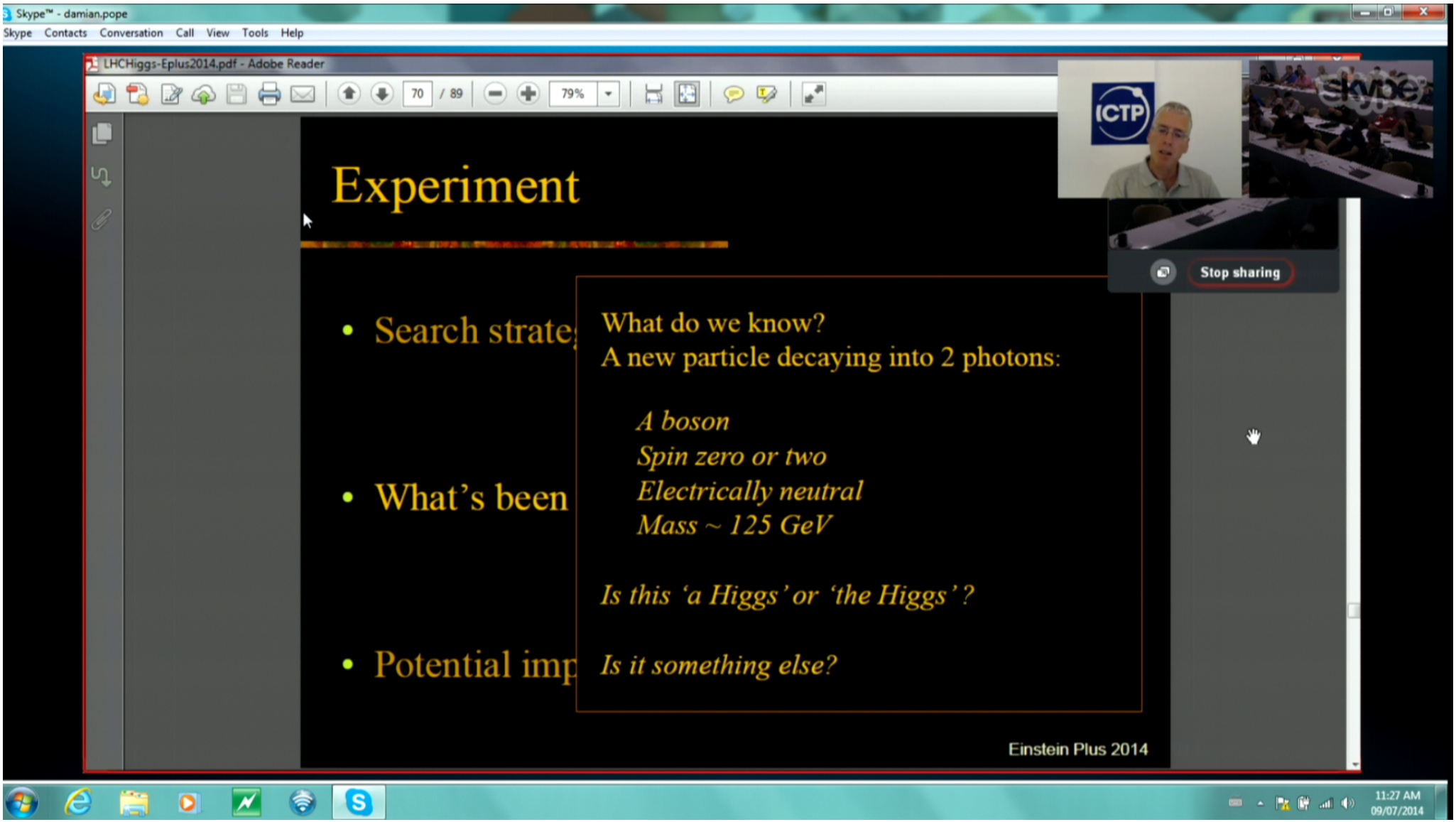
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79%
Experiment
• Search strate
• What's been
• Potential imp
What do we know?
A new particle decaying into 2 photons:
A boson
Spin zero or two
Electrically neutral
Mass ~ 125 GeV
Is this 'a Higgs' or 'the Higgs'?
Is it something else?
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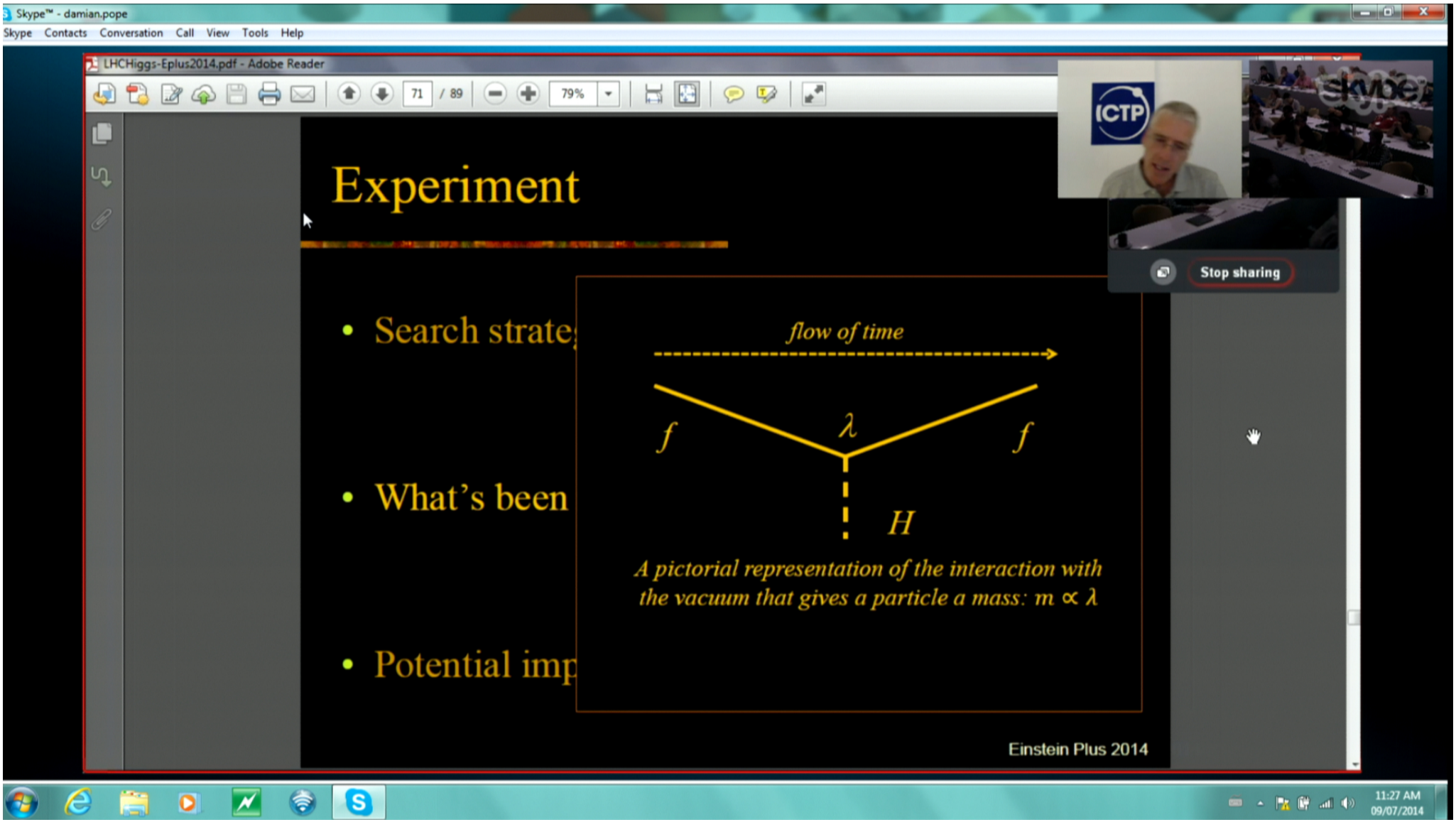
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71 / 89
79%
Experiment
• Search strate
• What's been
• Potential imp
flow of time
f
λ
f
H
A pictorial representation of the interaction with the vacuum that gives a particle a mass: m ∝ λ
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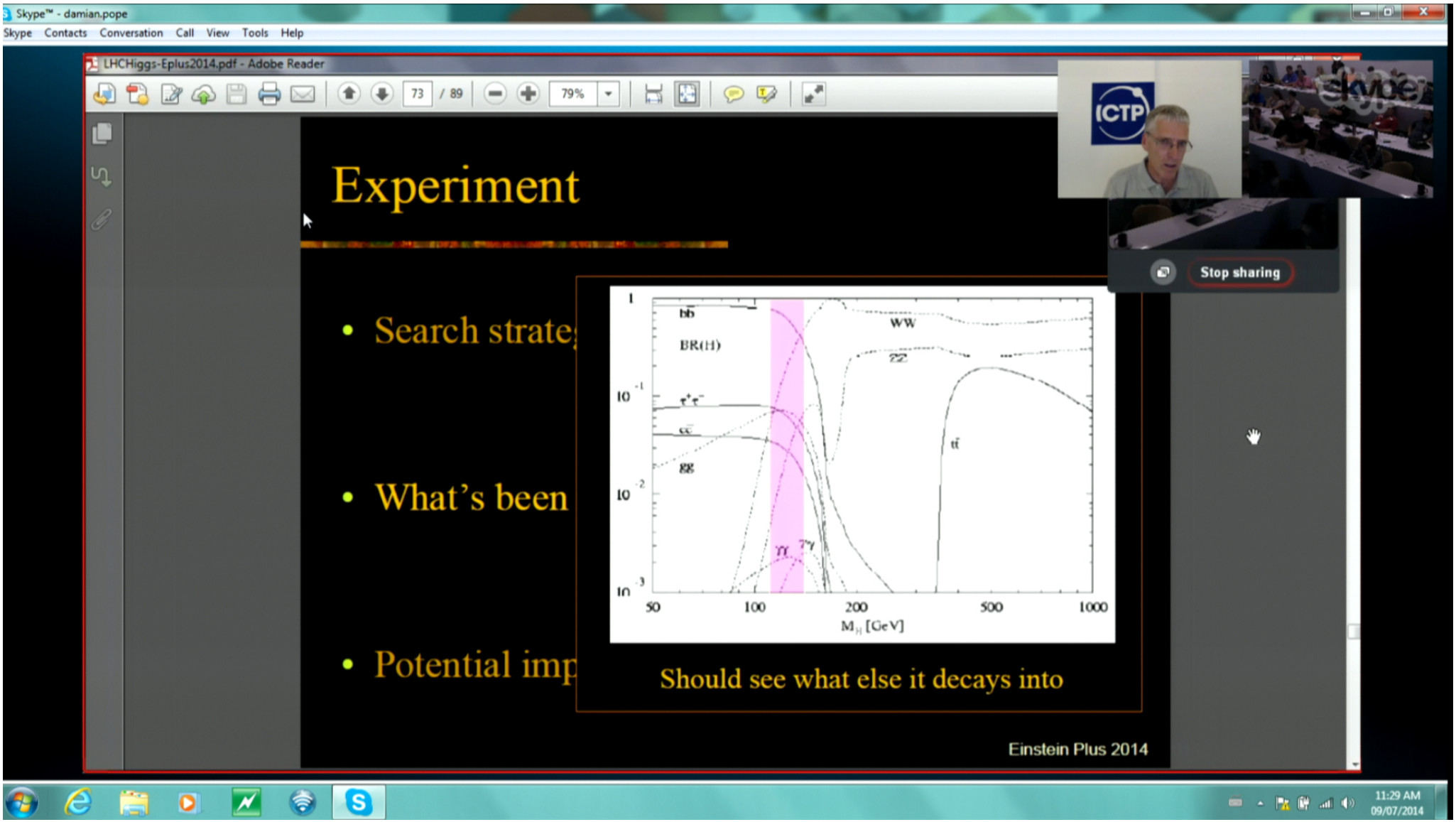
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73 / 89
79%
Experiment
• Search strate
• What's been
• Potential imp
bb
BR(H)
WW
ZZ
$\tau^+\tau^-$
$c\bar{c}$
gg
$t\bar{t}$
$\gamma\gamma$
$Z\gamma$
1
10^{-1}
10^{-2}
10^{-3}
50
100
200
500
1000
M_H [GeV]
Should see what else it decays into
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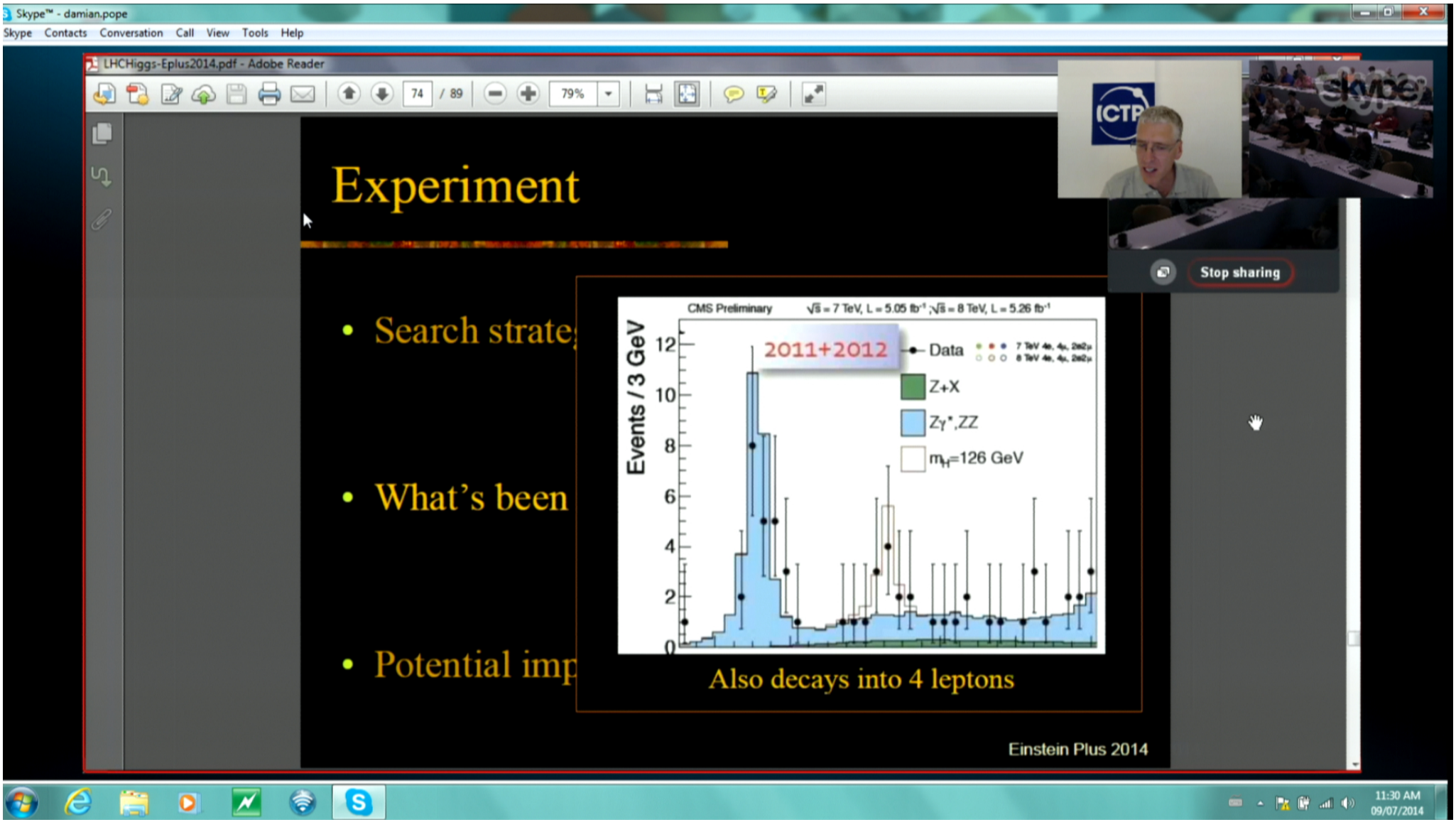
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79%
Experiment
• Search strate
• What's been
• Potential imp
CMS Preliminary
√s = 7 TeV, L = 5.05 fb⁻¹ ;√s = 8 TeV, L = 5.26 fb⁻¹
2011+2012
Data
Z+X
Zγ*,ZZ
m_H=126 GeV
Events / 3 GeV
Also decays into 4 leptons
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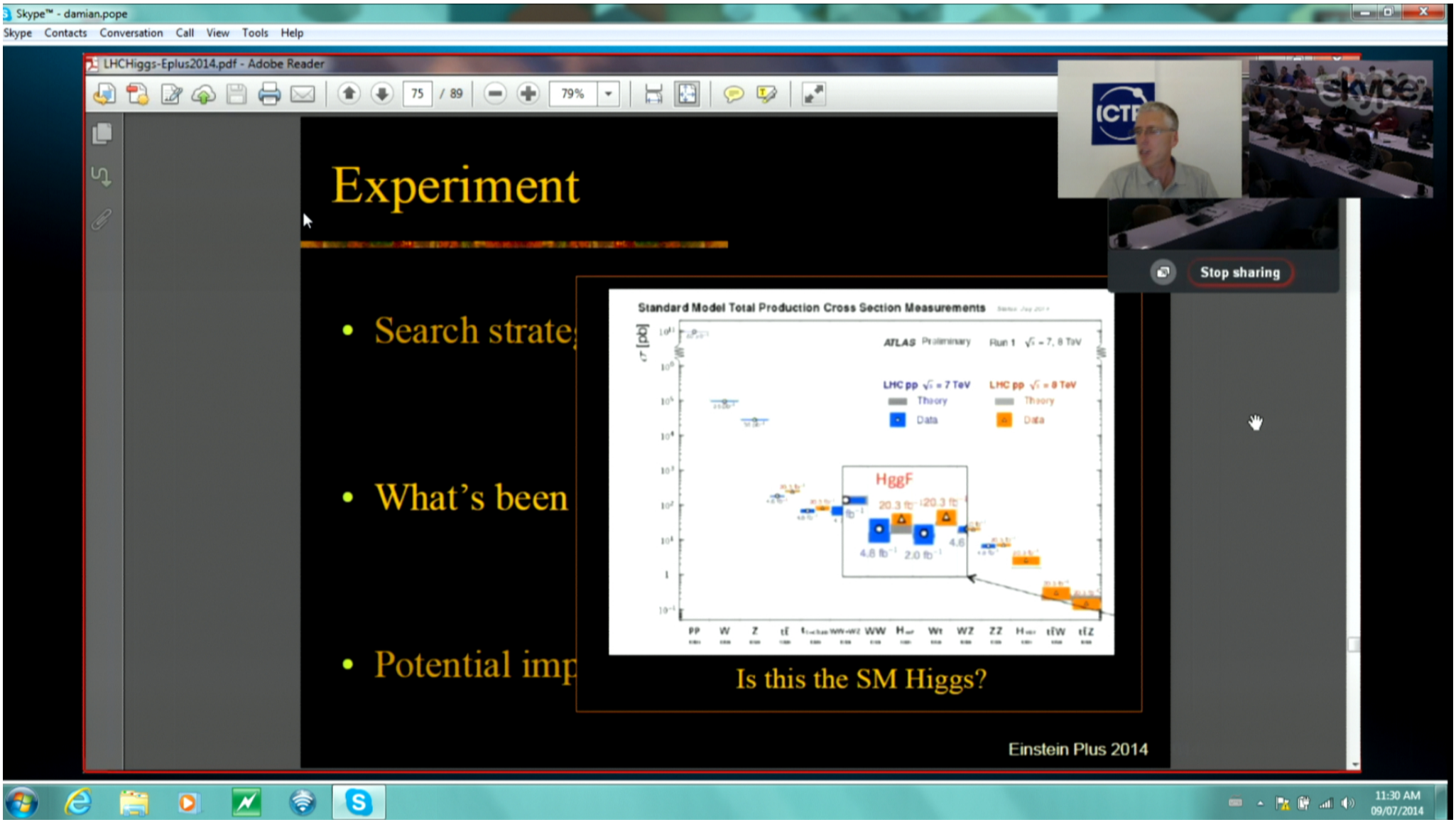
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Experiment
• Search strate
• What's been
• Potential imp
Standard Model Total Production Cross Section Measurements
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
LHC pp √s = 7 TeV
Theory
Data
LHC pp √s = 8 TeV
Theory
Data
HggF
Is this the SM Higgs?
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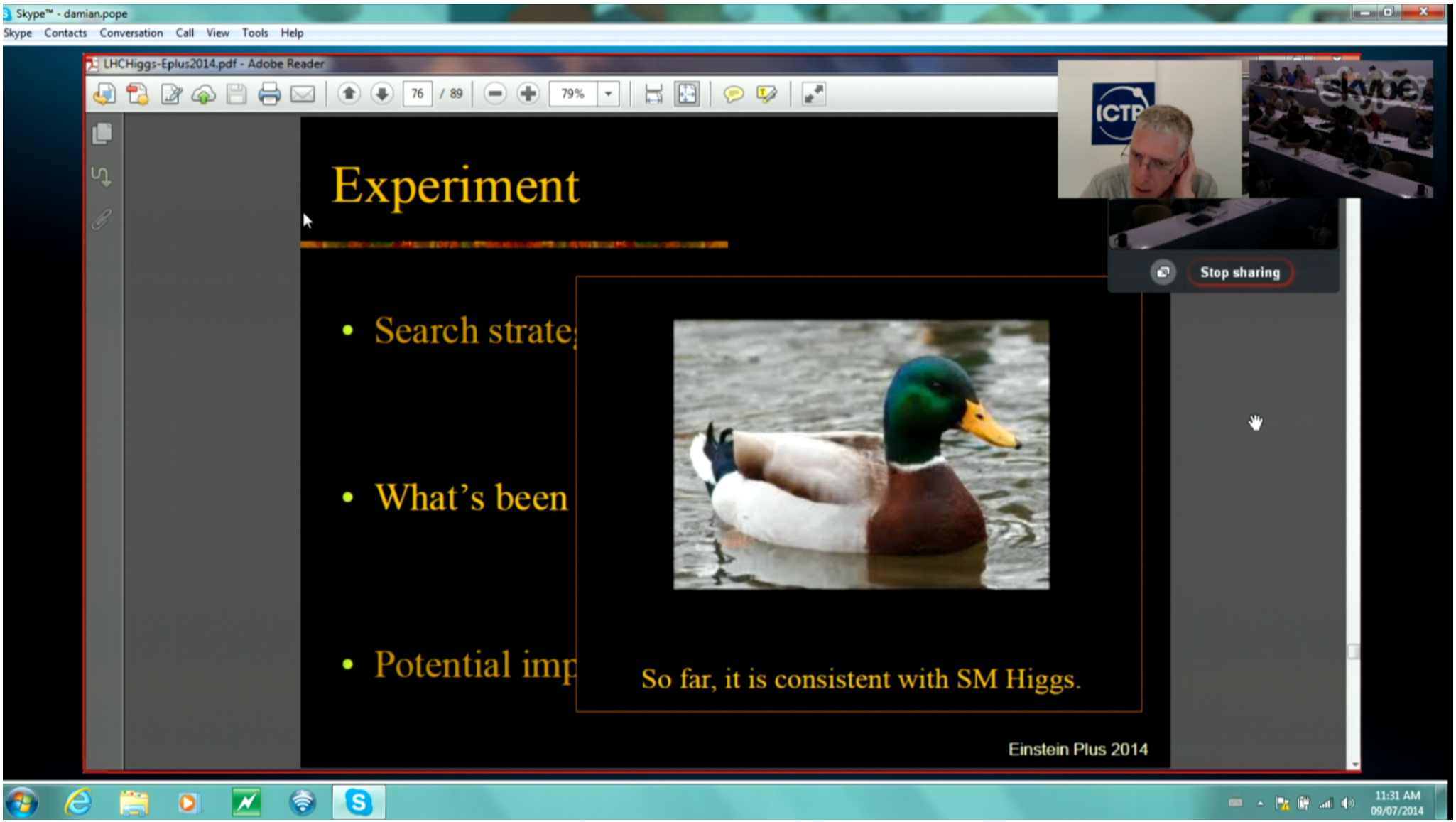
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Experiment
• Search strate
• What's been
• Potential imp
So far, it is consistent with SM Higgs.
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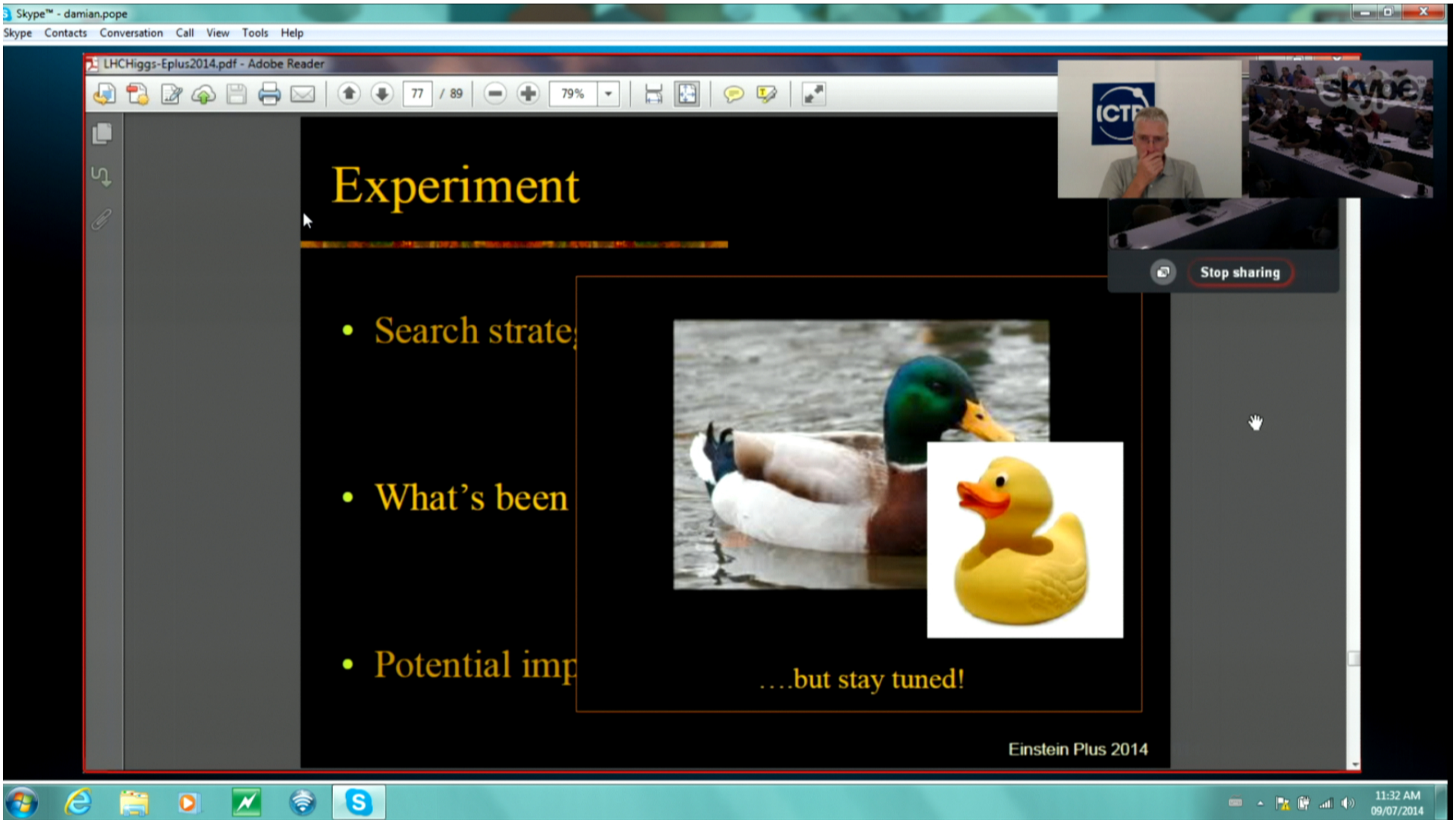
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Experiment
• Search strate
• What's been
• Potential imp
….but stay tuned!
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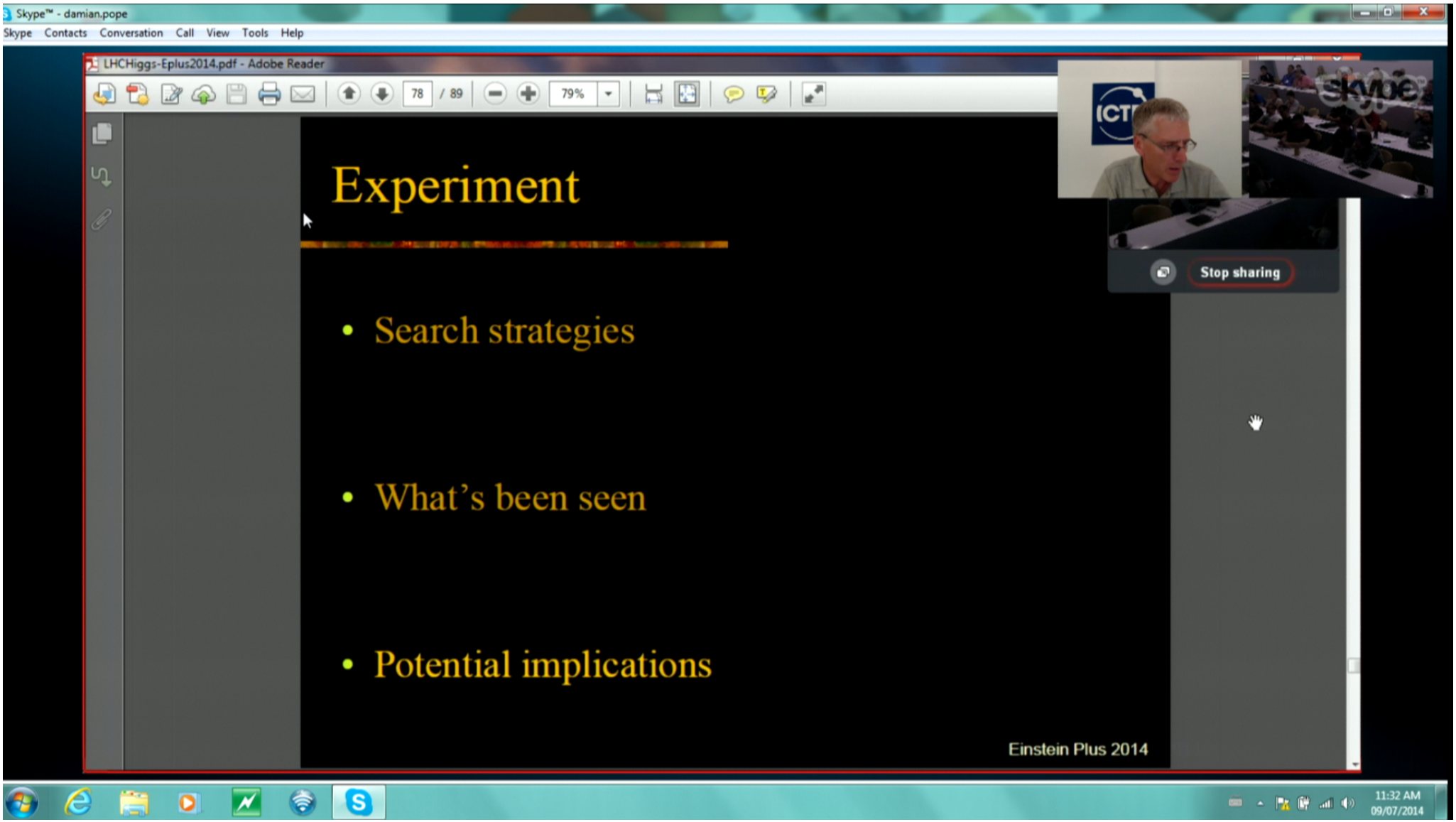
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Experiment
• Search strategies
• What's been seen
• Potential implications
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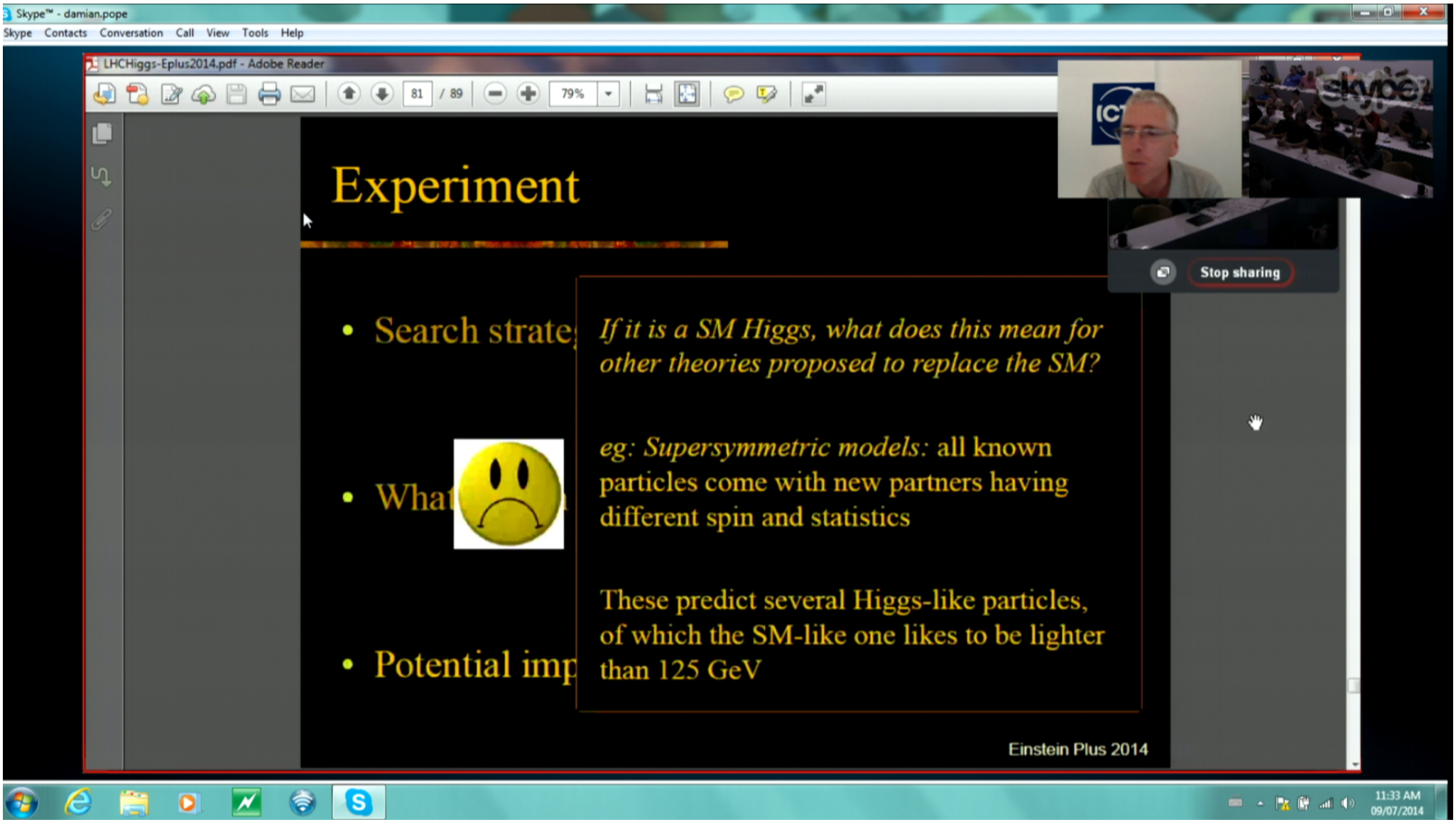
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Experiment
• Search strate
• What
• Potential imp
If it is a SM Higgs, what does this mean for other theories proposed to replace the SM?
eg: Supersymmetric models: all known particles come with new partners having different spin and statistics
These predict several Higgs-like particles, of which the SM-like one likes to be lighter than 125 GeV
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Experiment
SUSY 2013
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The only stop
seen at LHC so far
CERN
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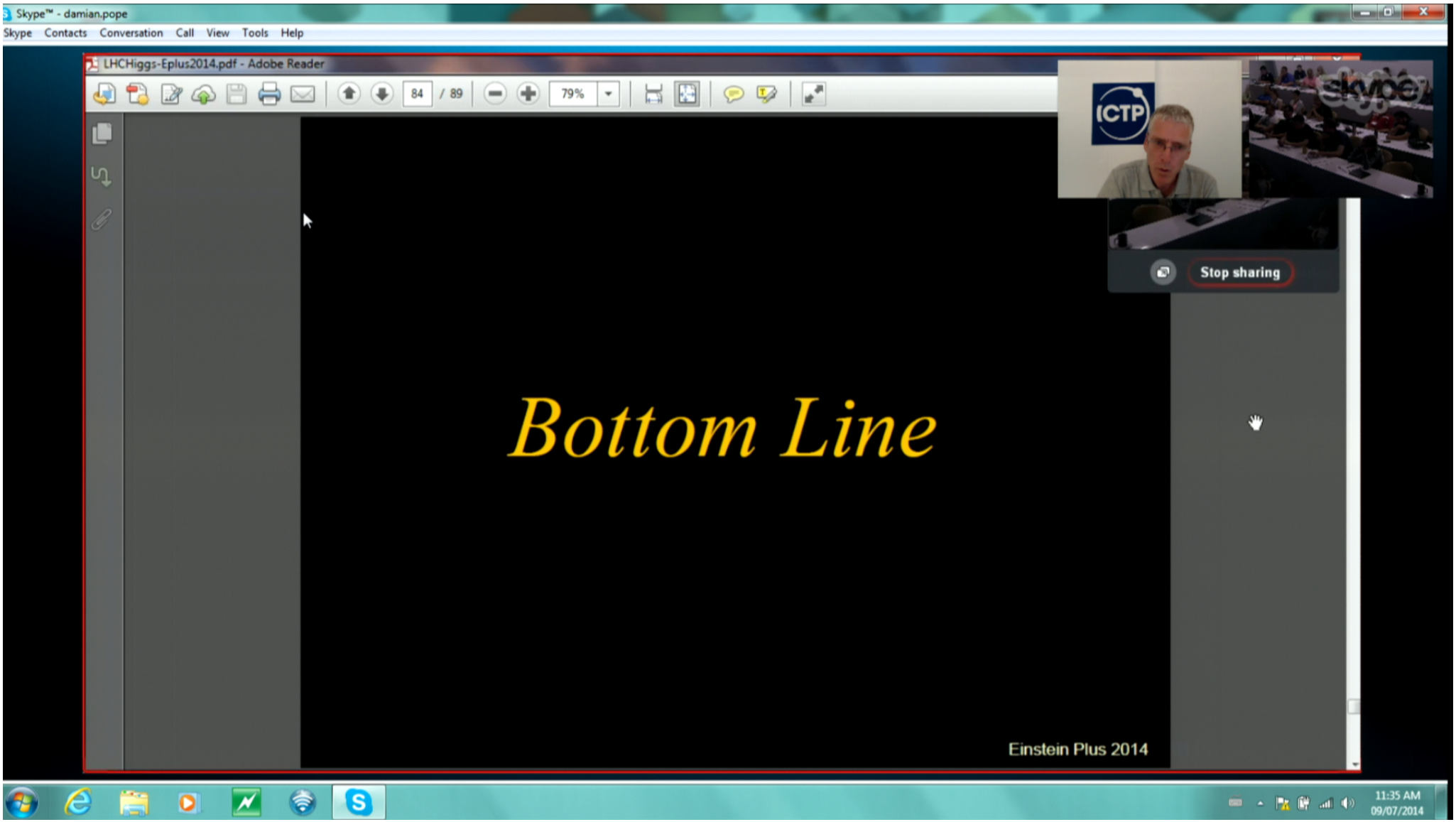
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Bottom Line
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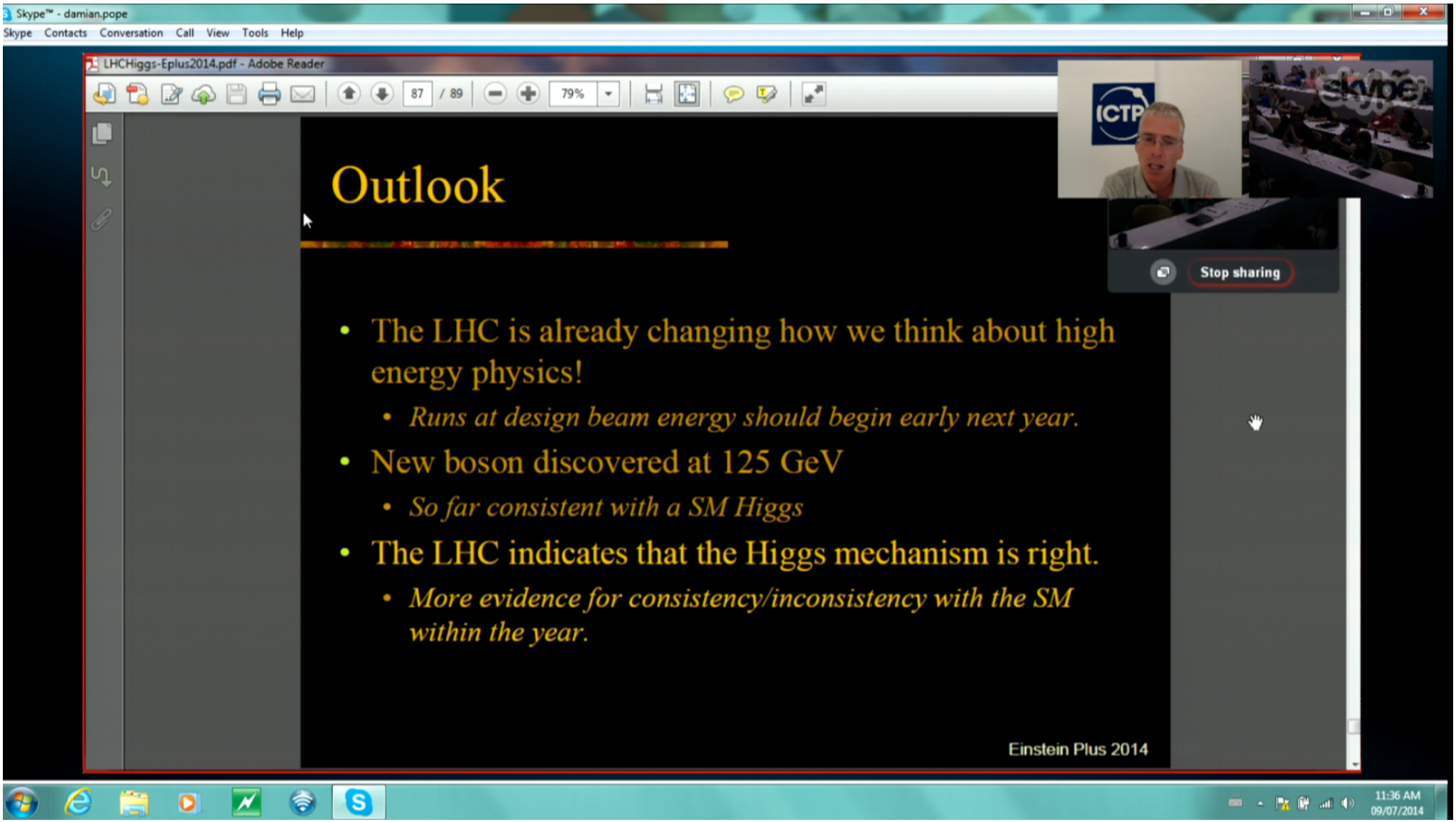
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Outlook
The LHC is already changing how we think about high energy physics!
Runs at design beam energy should begin early next year.
New boson discovered at 125 GeV
So far consistent with a SM Higgs
The LHC indicates that the Higgs mechanism is right.
More evidence for consistency/inconsistency with the SM within the year.
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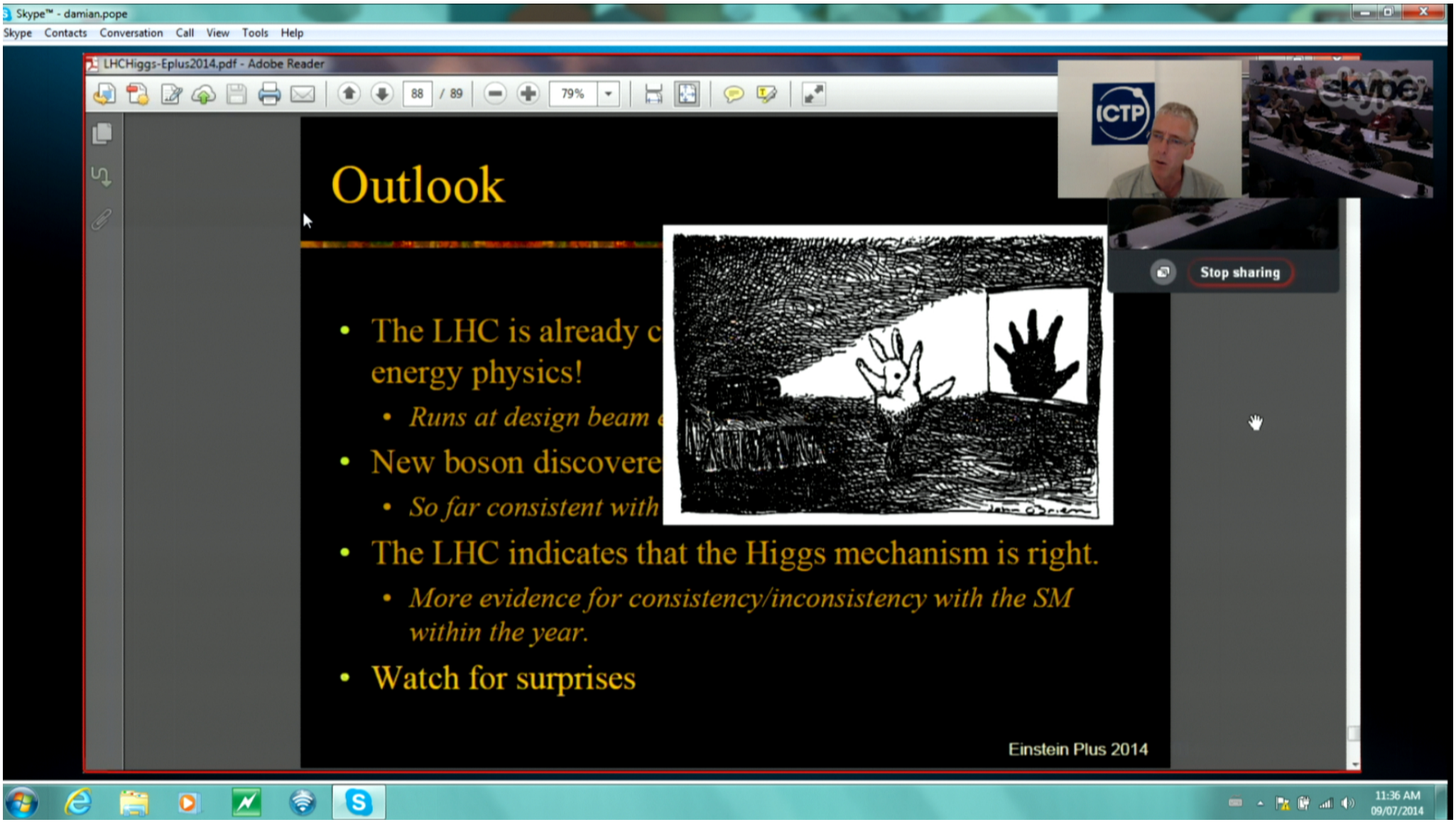
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79%
Outlook
• The LHC is already c
energy physics!
• Runs at design beam e
• New boson discovere
• So far consistent with
• The LHC indicates that the Higgs mechanism is right.
• More evidence for consistency/inconsistency with the SM within the year.
• Watch for surprises
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