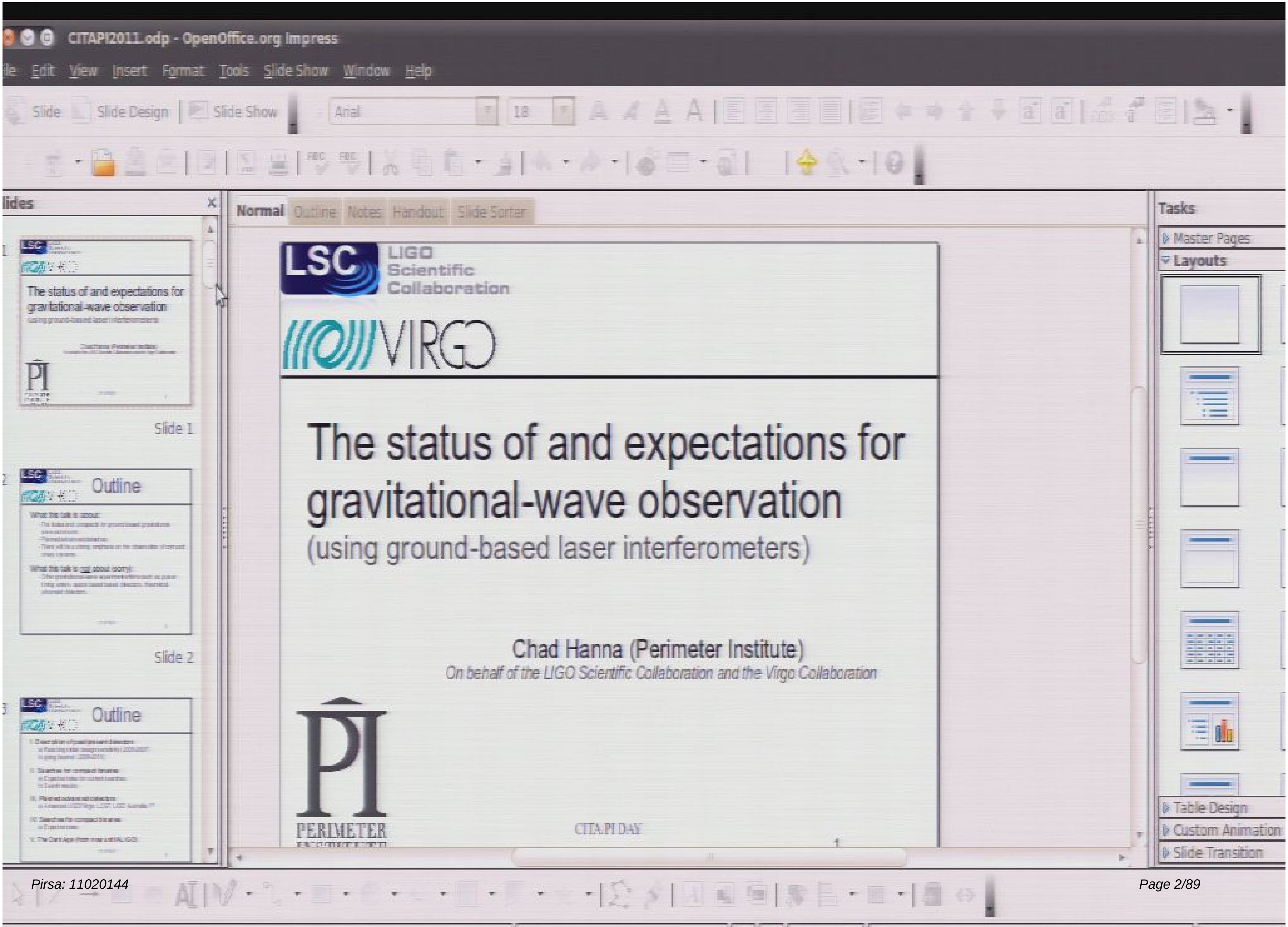
Title: Present status (and near-term expectations) for gravitational-wave observations using ground-based laser interferometers

Date: Feb 15, 2011 03:00 PM

URL: http://pirsa.org/11020144

Abstract: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LSC LIGO Scientific Collaboration
VIRGO
The status of and expectations for gravitational-wave observation
(using ground-based laser interferometers)
Chad Hanna (Perimeter Institute)
On behalf of the LIGO Scientific Collaboration and the Virgo Collaboration
PI PERIMETER
CITA:PI DAY
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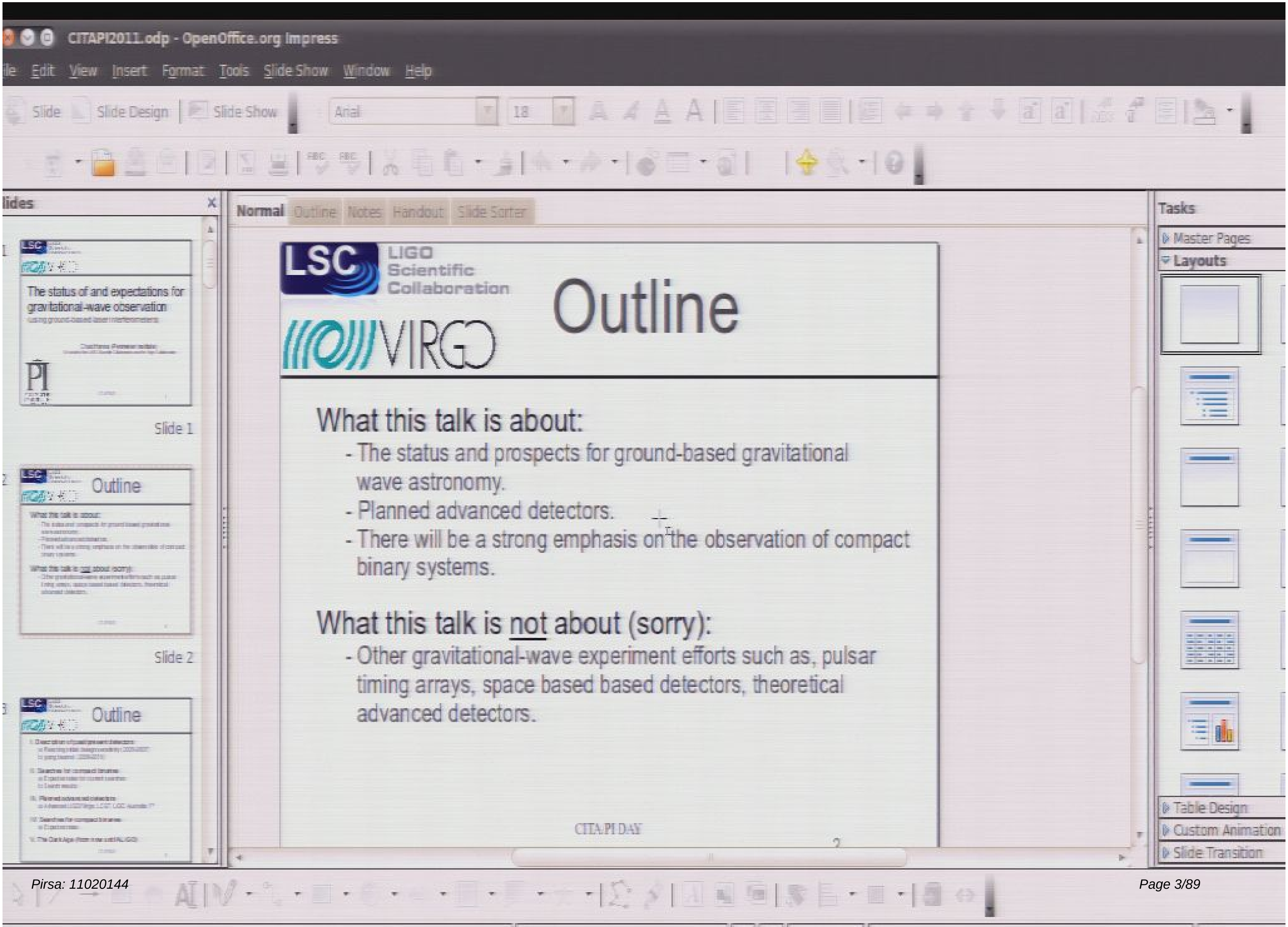
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Outline
LSC LIGO Scientific Collaboration
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What this talk is about:
- The status and prospects for ground-based gravitational wave astronomy.
- Planned advanced detectors.
- There will be a strong emphasis on the observation of compact binary systems.
What this talk is not about (sorry):
- Other gravitational-wave experiment efforts such as, pulsar timing arrays, space based based detectors, theoretical advanced detectors.
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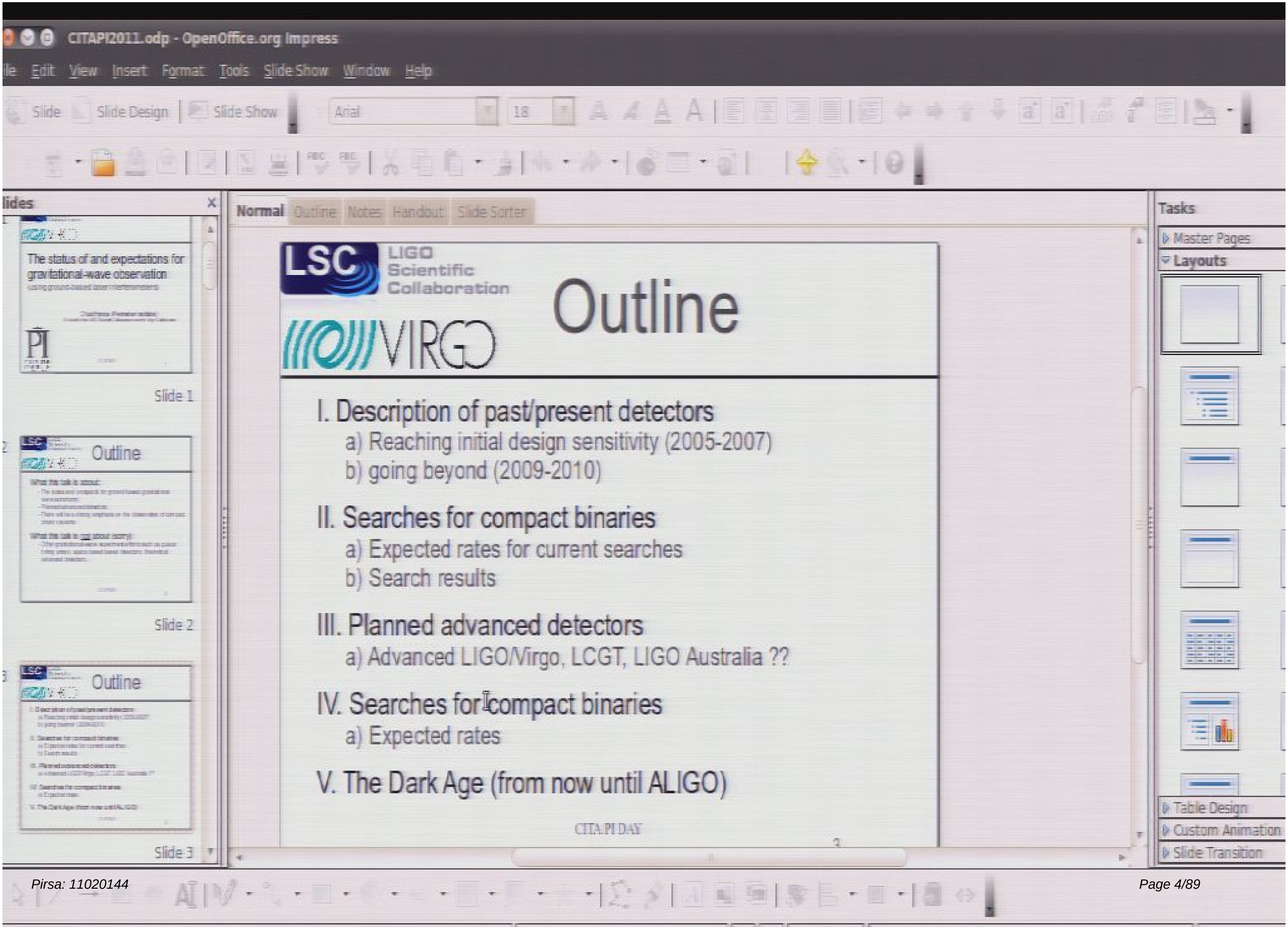
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Outline
I. Description of past/present detectors
a) Reaching initial design sensitivity (2005-2007)
b) going beyond (2009-2010)
II. Searches for compact binaries
a) Expected rates for current searches
b) Search results
III. Planned advanced detectors
a) Advanced LIGO/Virgo, LCGT, LIGO Australia ??
IV. Searches for compact binaries
a) Expected rates
V. The Dark Age (from now until ALIGO)
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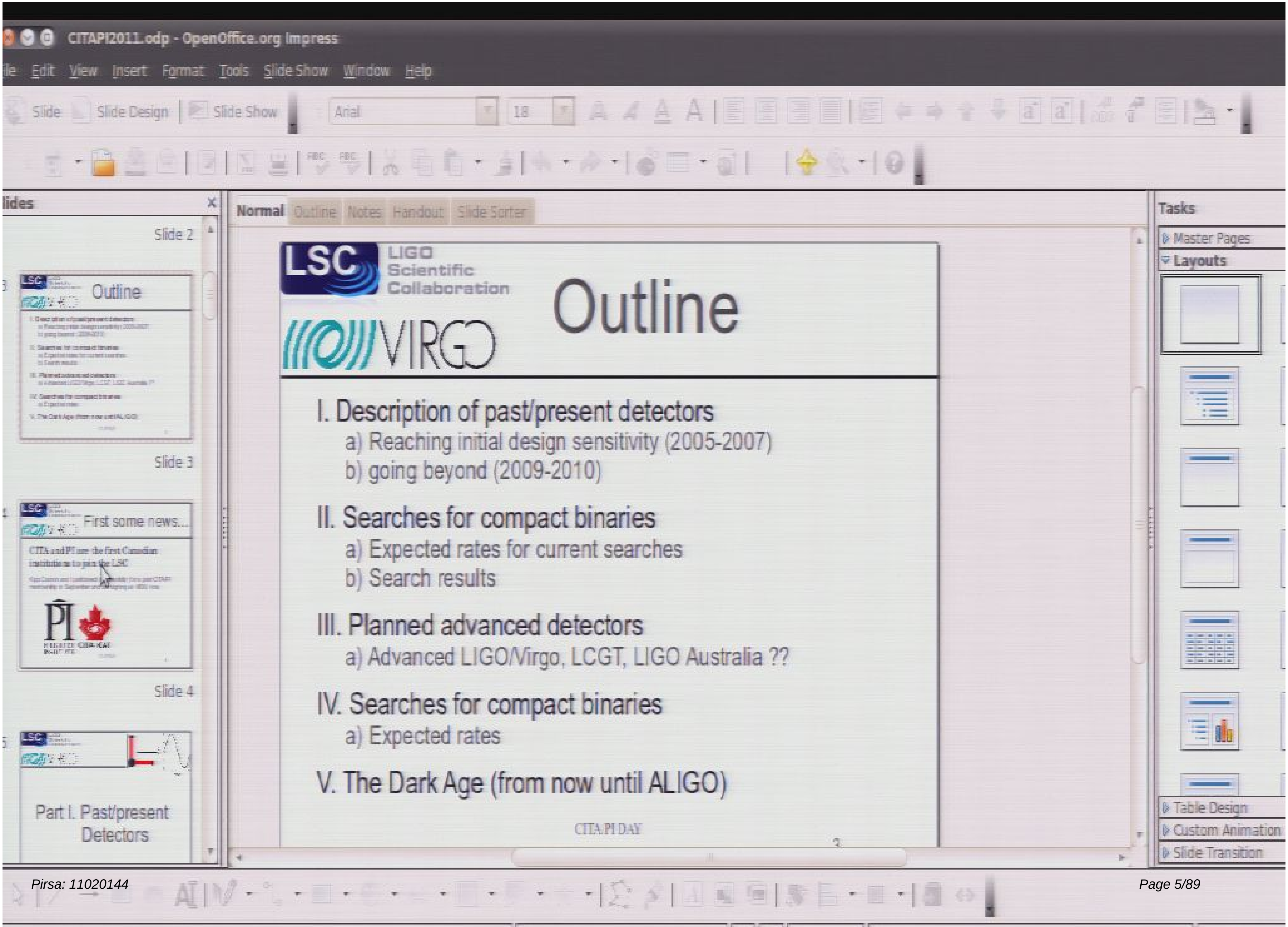
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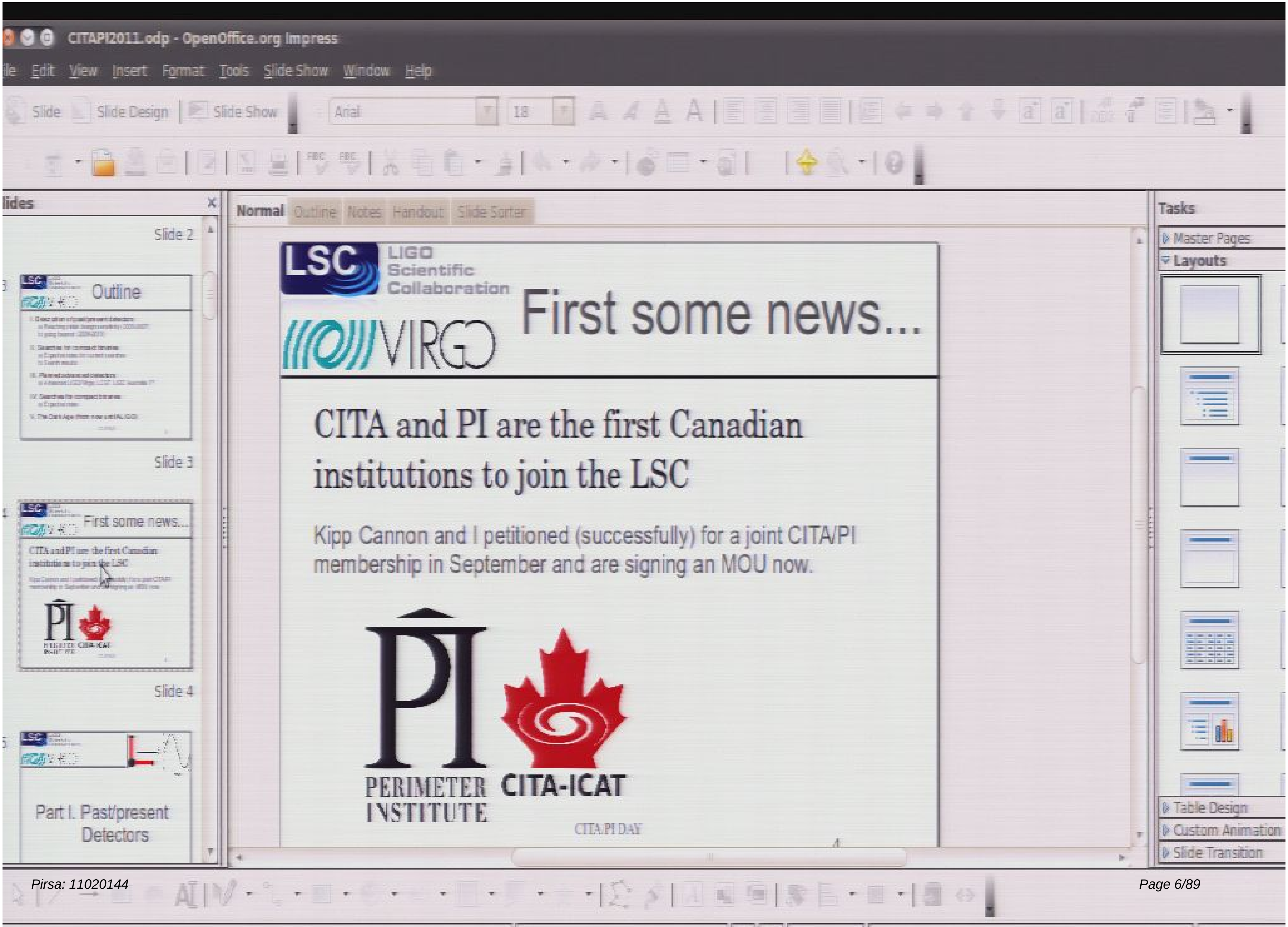
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First some news...
CITA and PI are the first Canadian institutions to join the LSC
Kipp Cannon and I petitioned (successfully) for a joint CITA/PI membership in September and are signing an MOU now.
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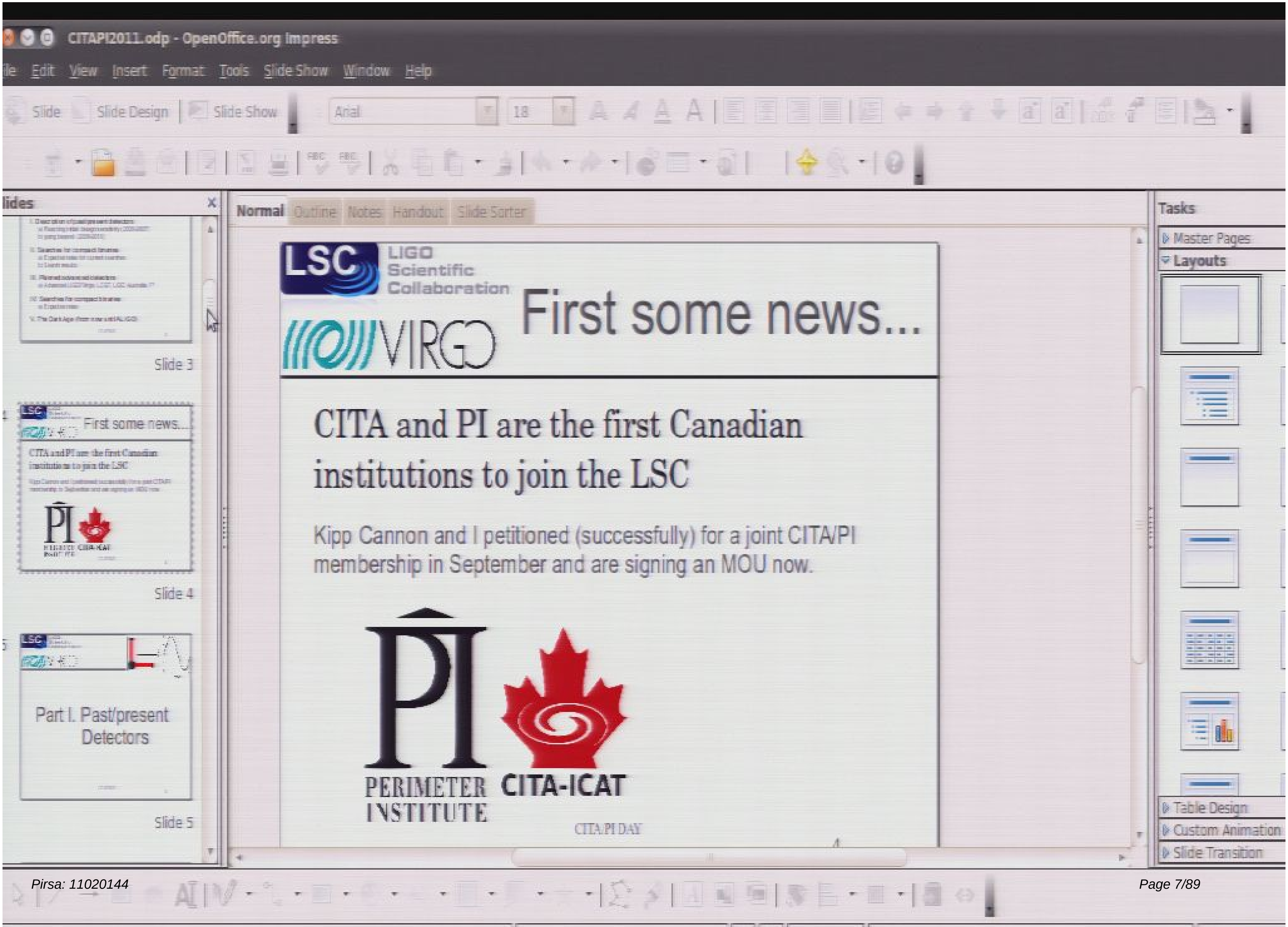
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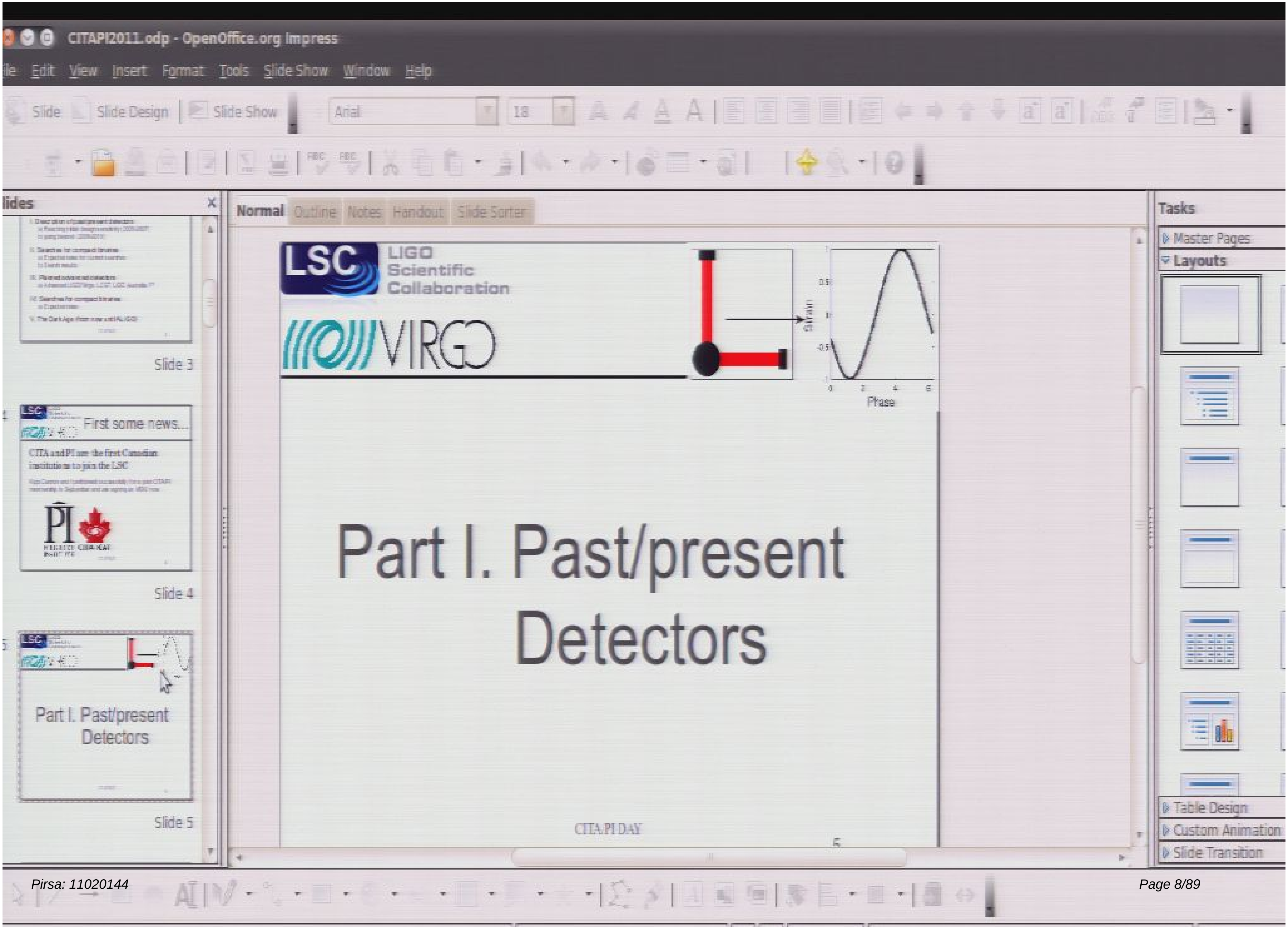
Part I. Past/present Detectors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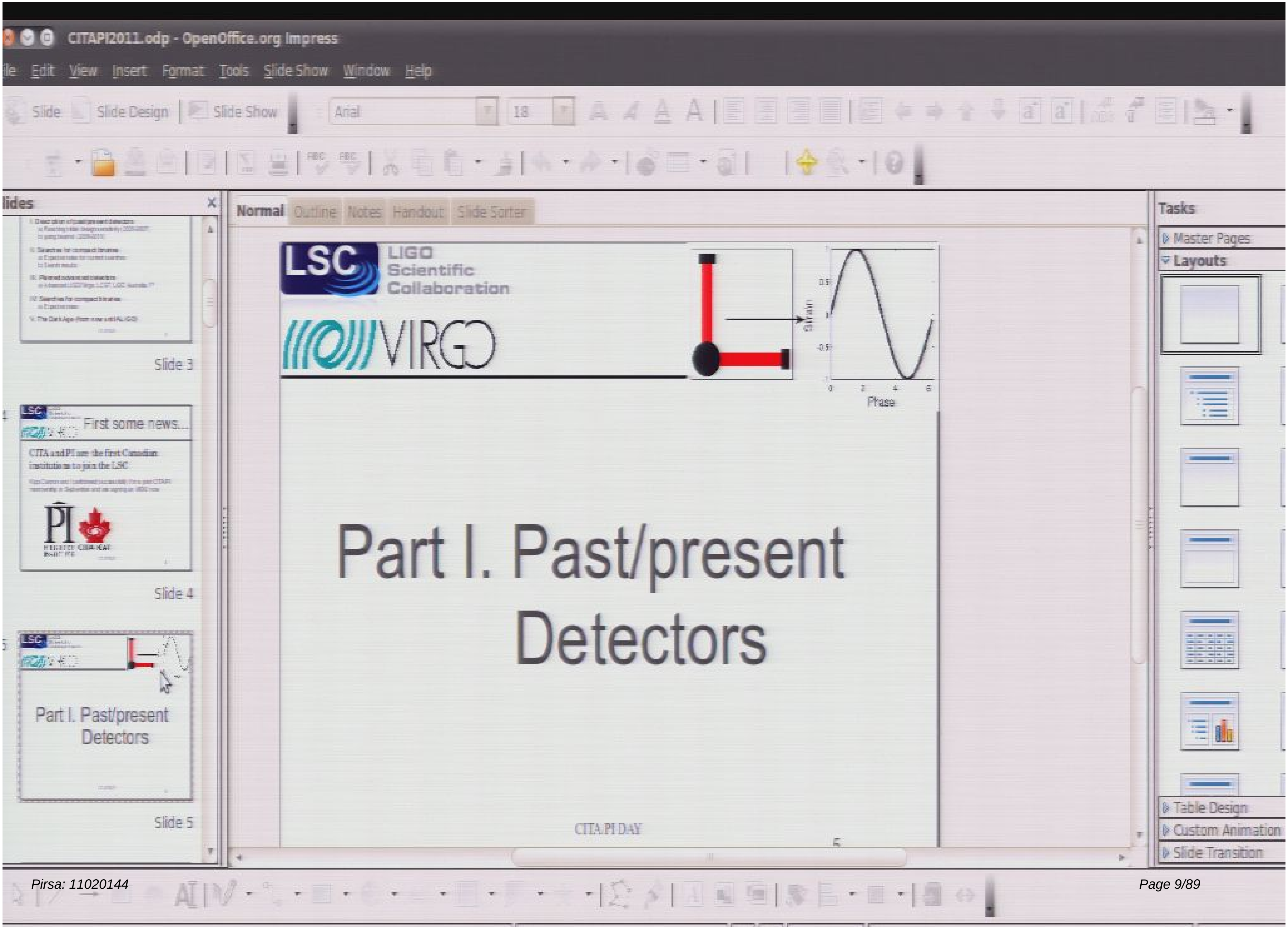
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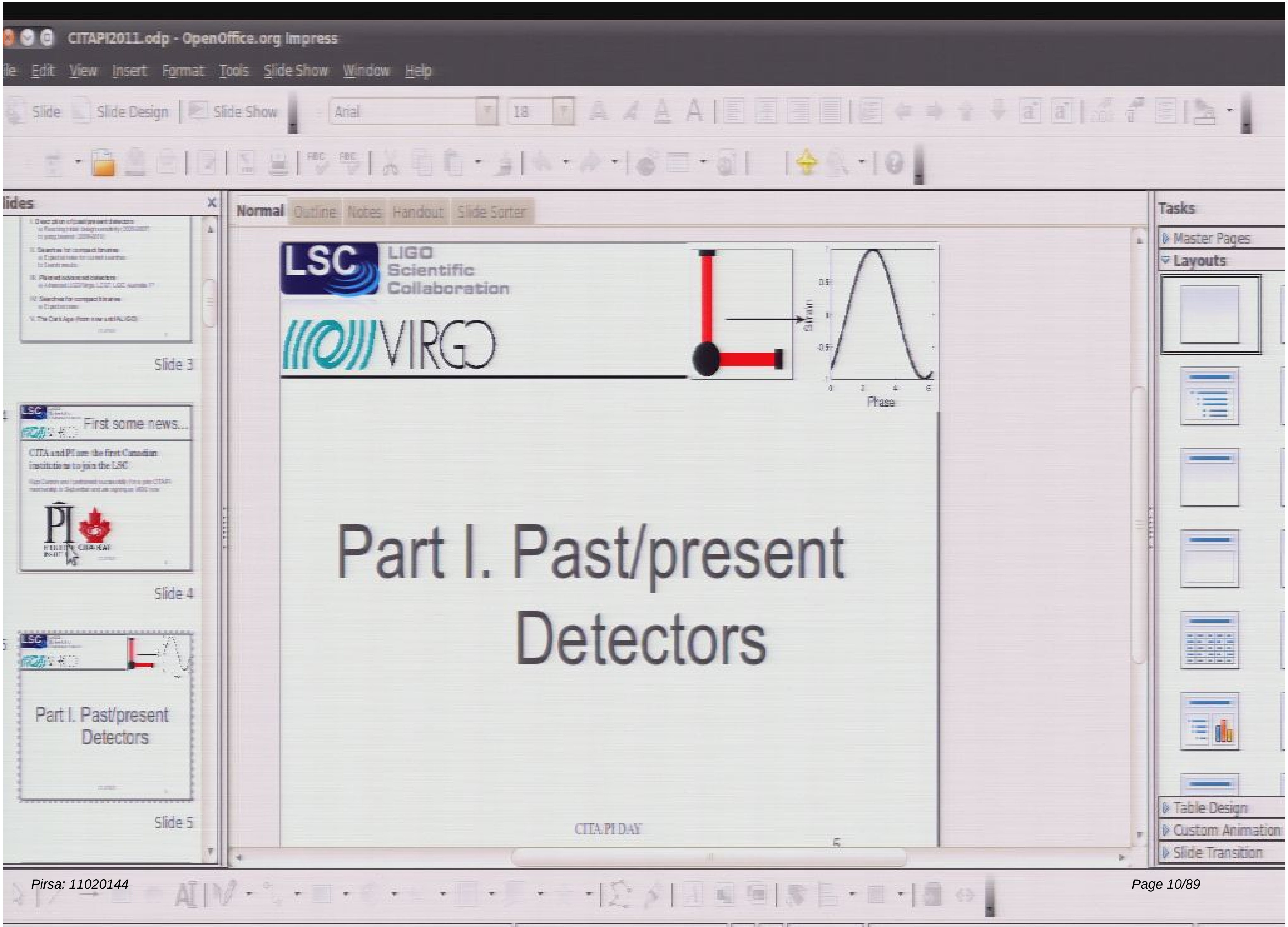
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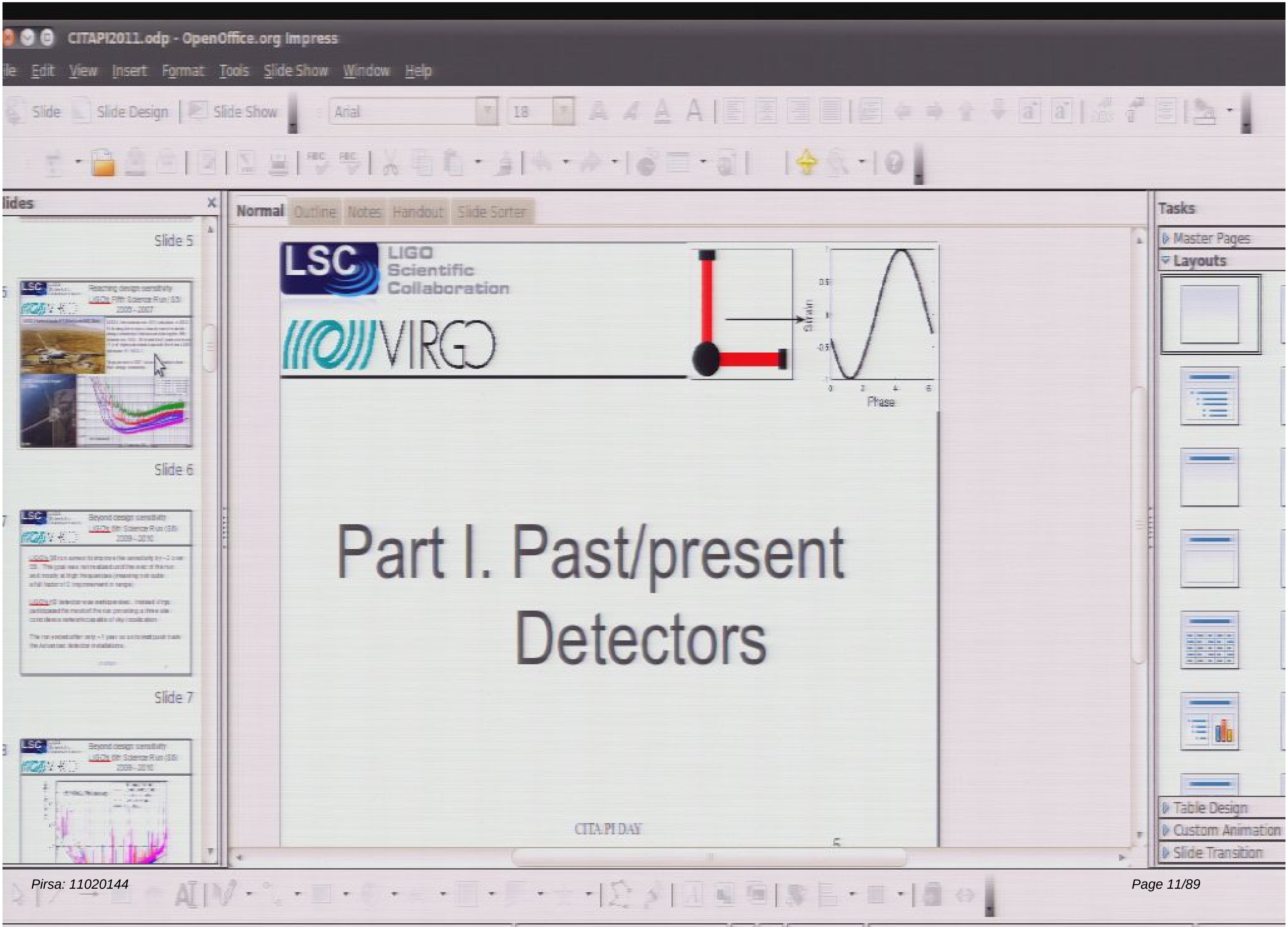
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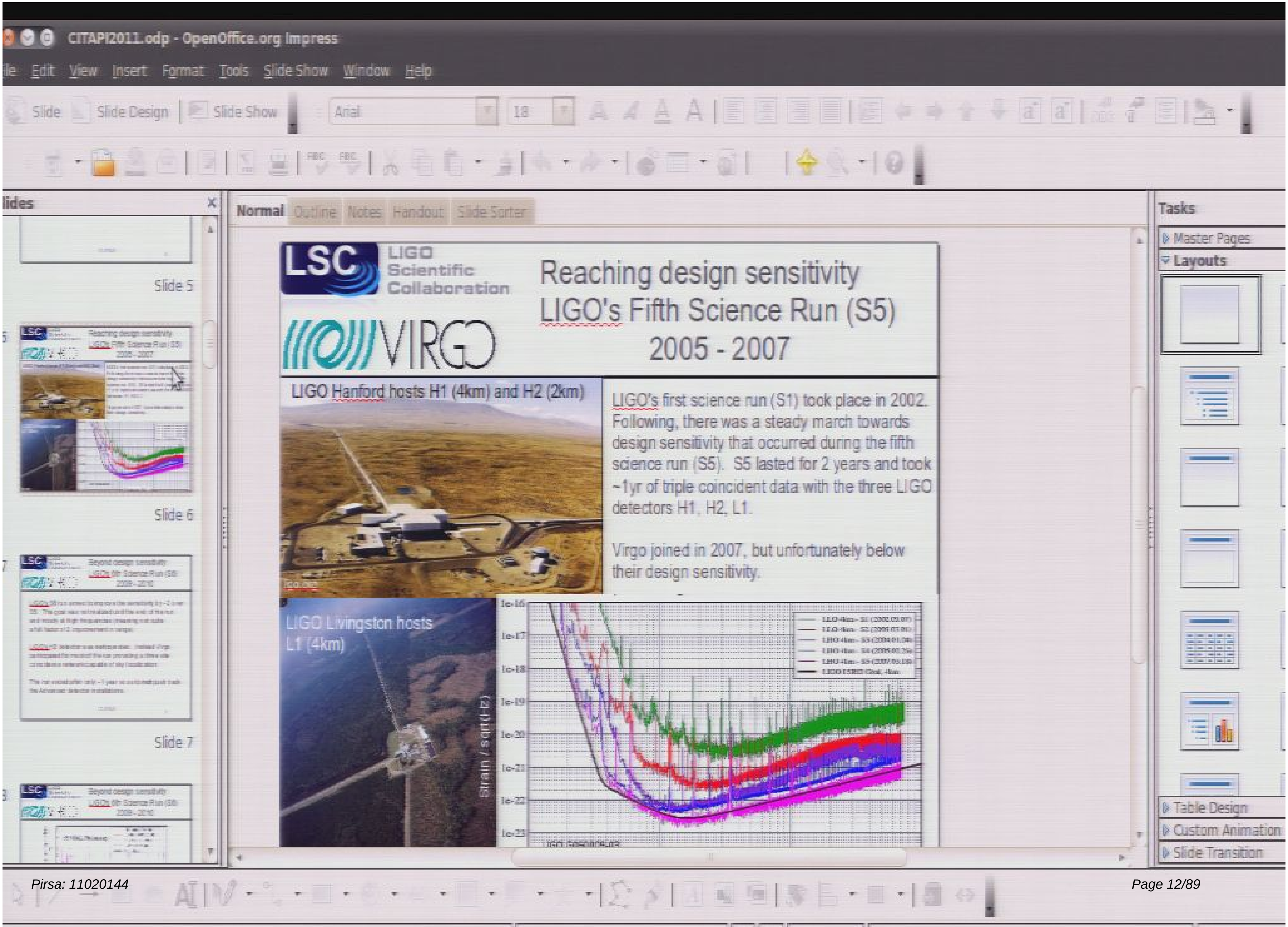
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Reaching design sensitivity
LIGO's Fifth Science Run (S5)
2005 - 2007
LSC
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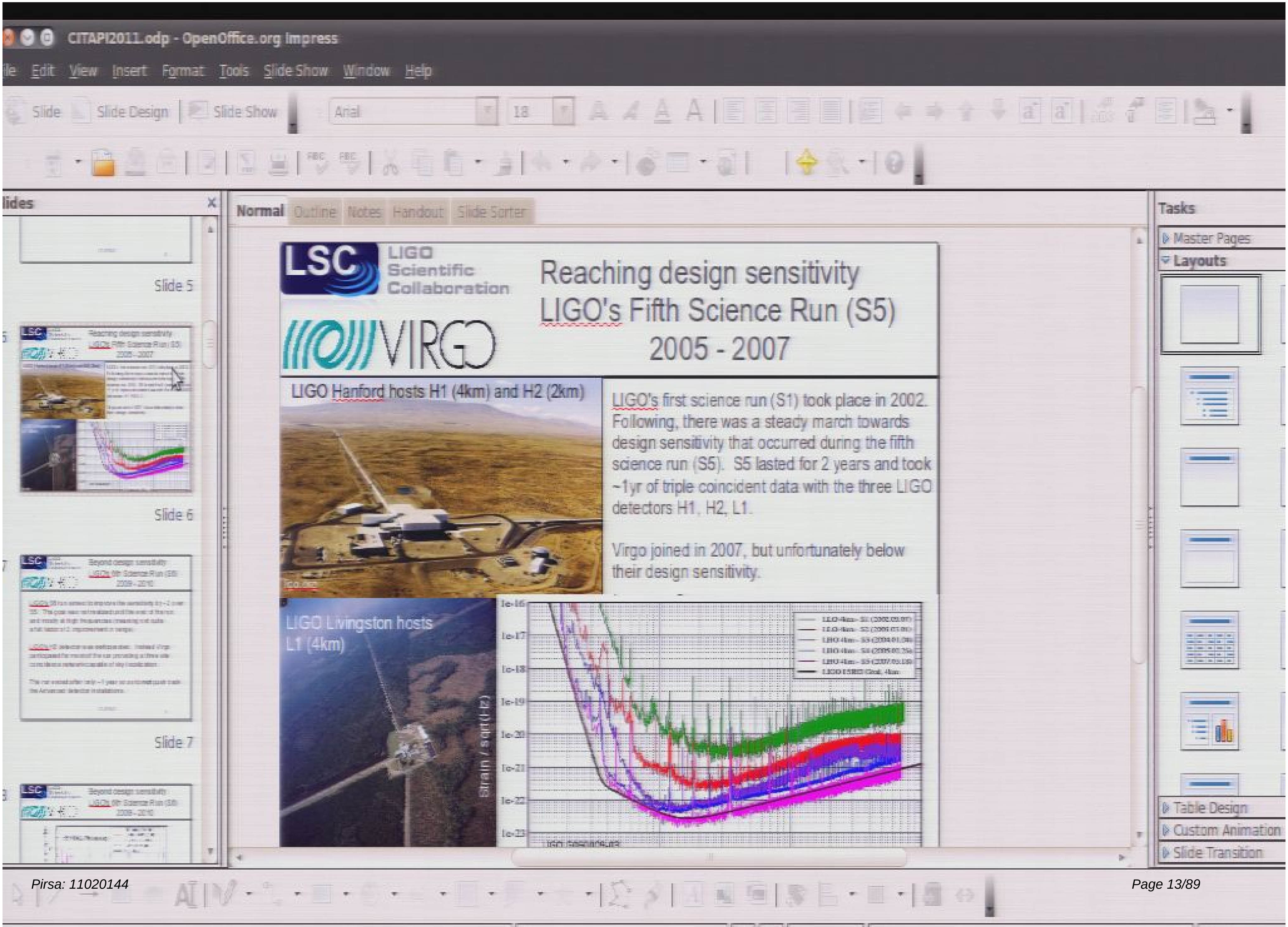
LIGO Hanford hosts H1 (4km) and H2 (2km)
LIGO's first science run (S1) took place in 2002. Following, there was a steady march towards design sensitivity that occurred during the fifth science run (S5). S5 lasted for 2 years and took ~1yr of triple coincident data with the three LIGO detectors H1, H2, L1.
Virgo joined in 2007, but unfortunately below their design sensitivity.
LIGO Livingston hosts L1 (4km)
Strain / sqrt(Hz)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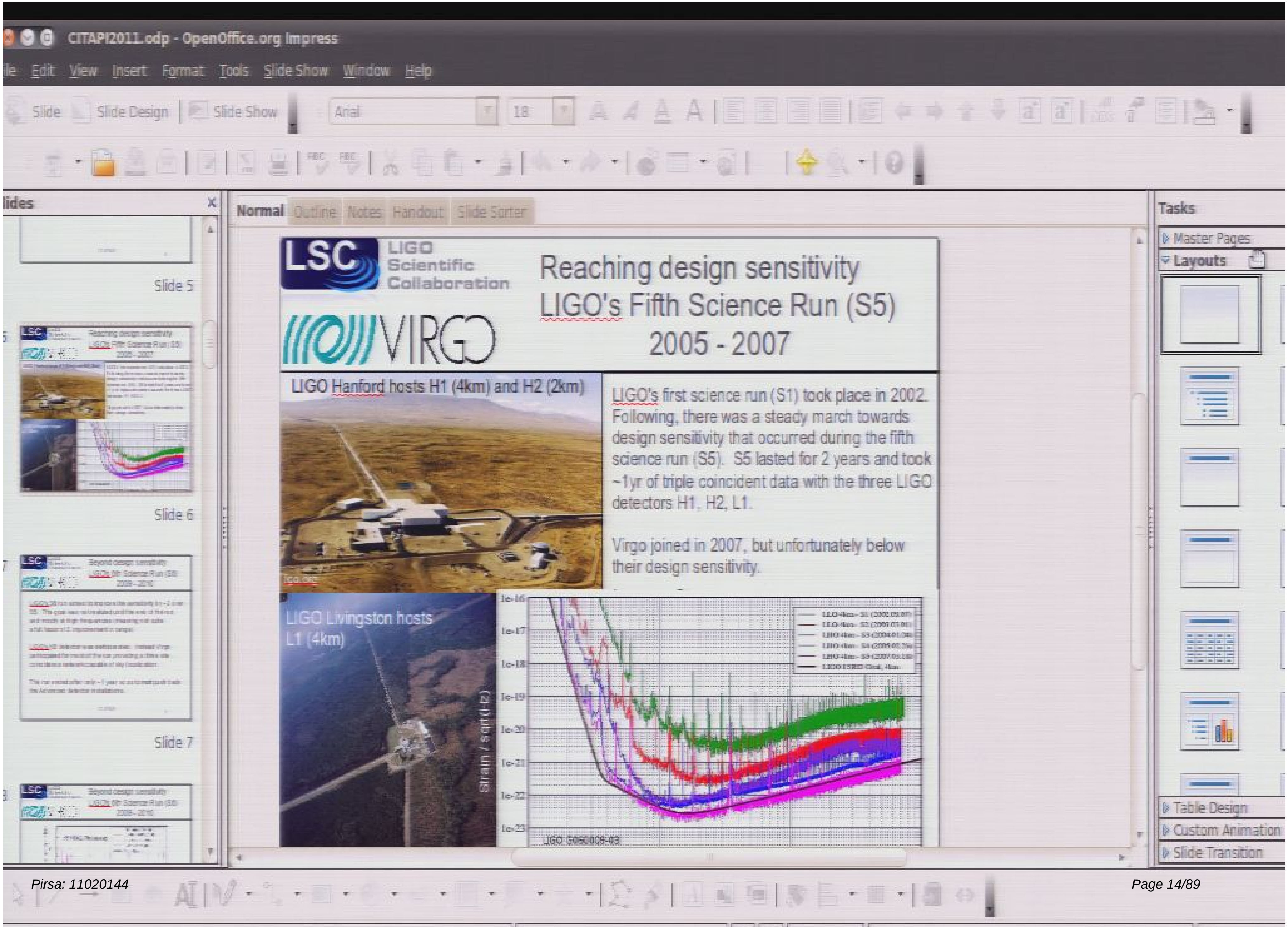
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LIGO G060009-03
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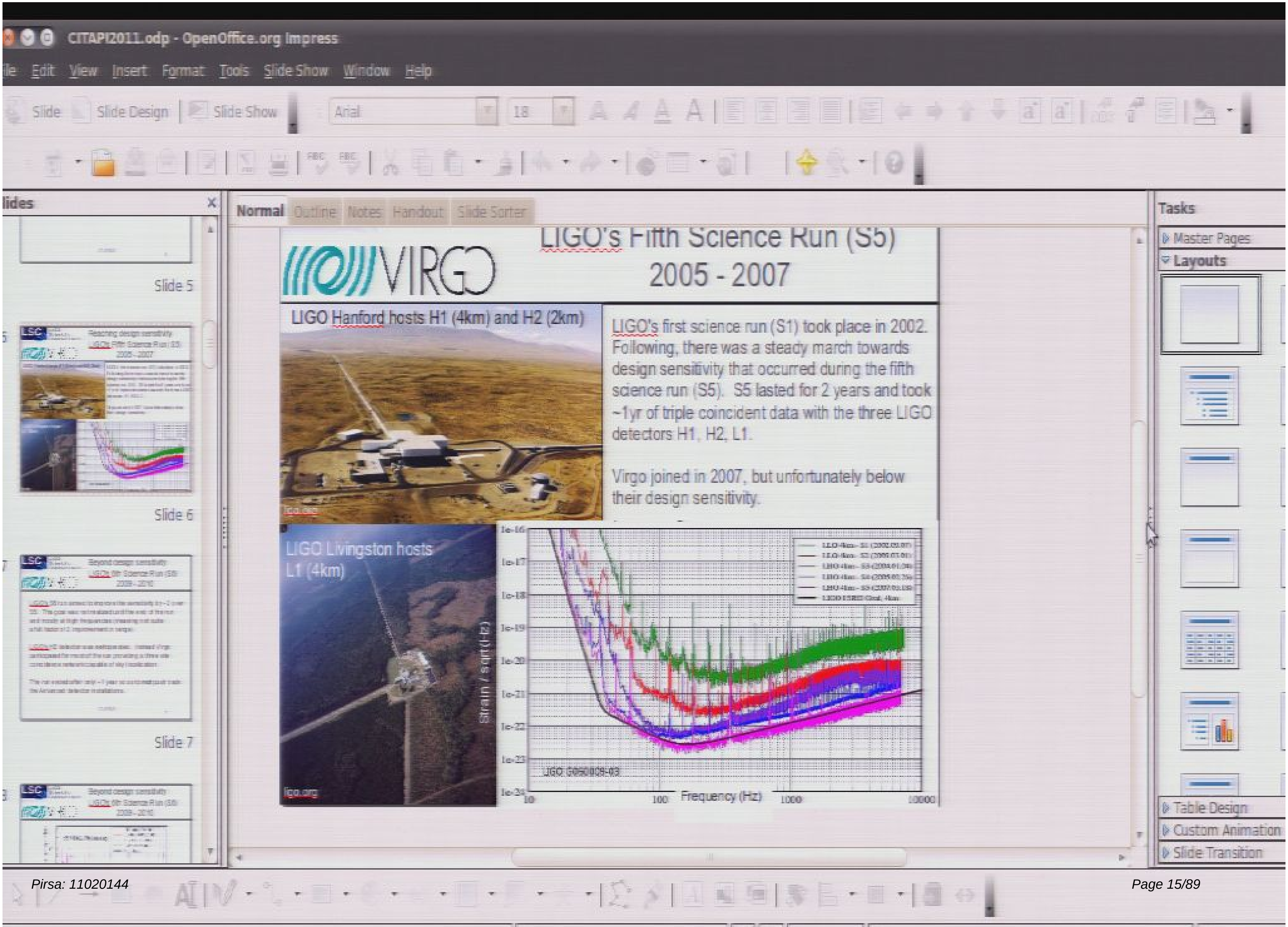
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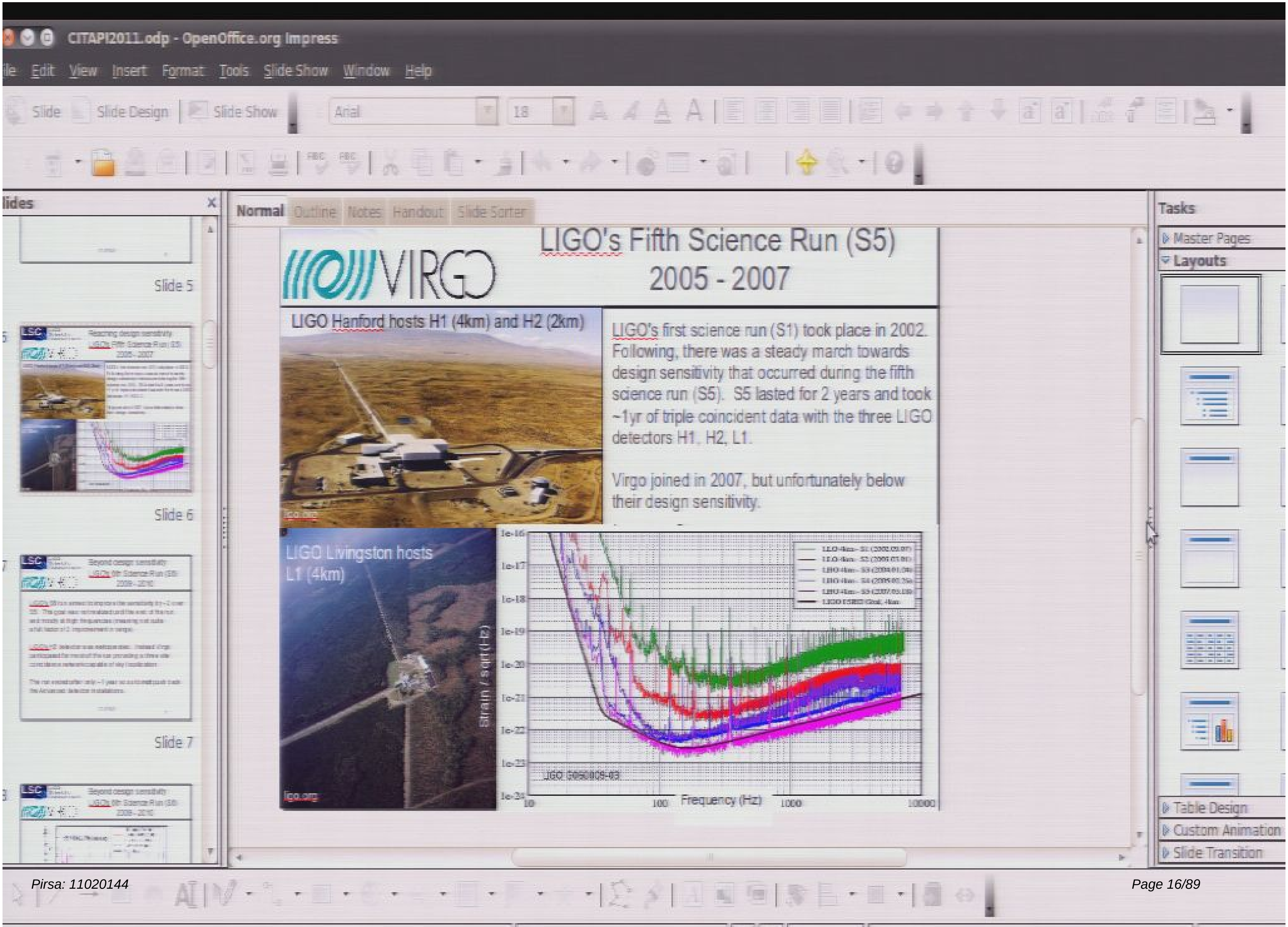
Frequency (Hz)
LIGO-G060009-03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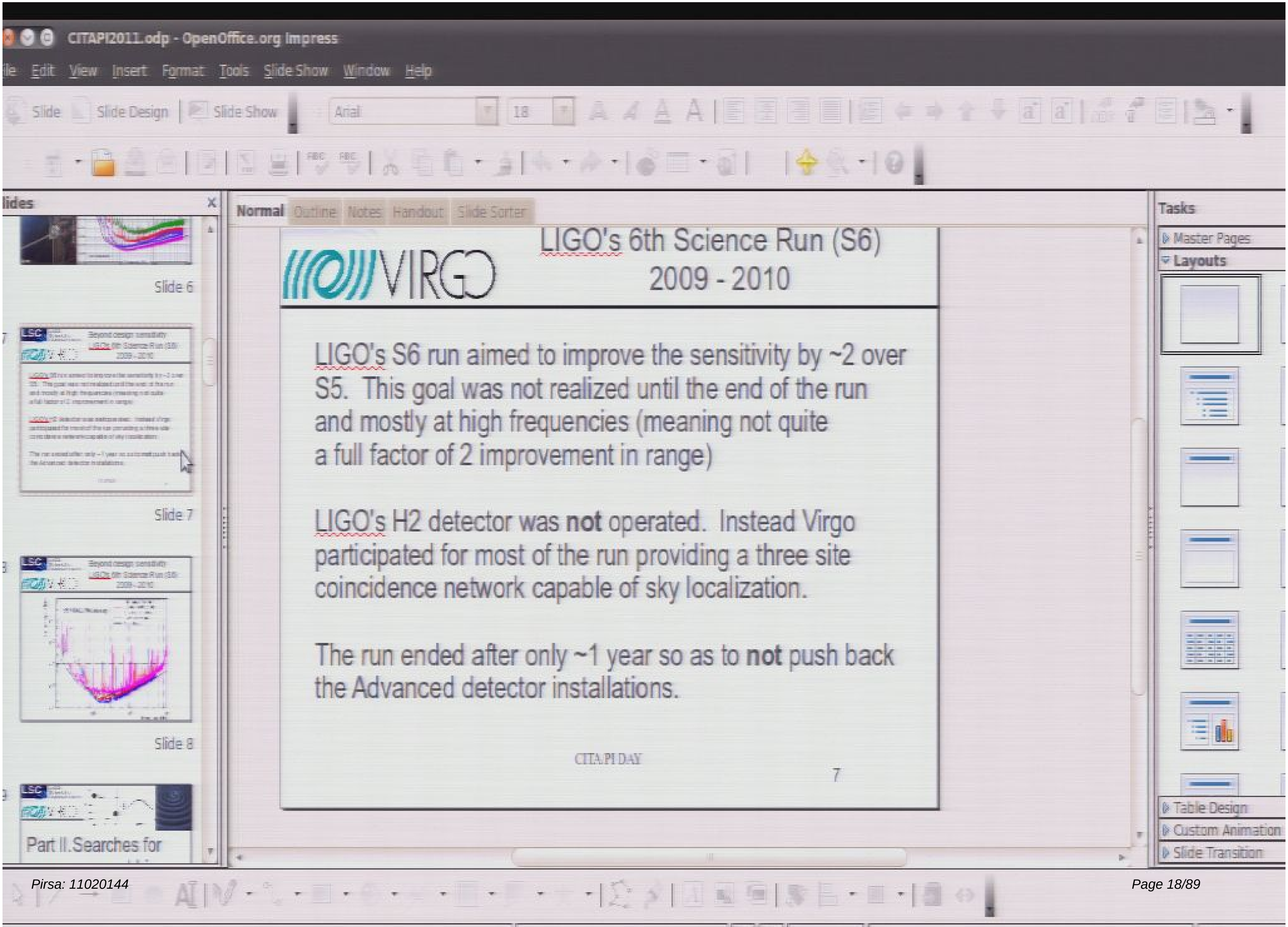
LIGO's 6th Science Run (S6)
2009 - 2010

LIGO's S6 run aimed to improve the sensitivity by ~2 over S5. This goal was not realized until the end of the run and mostly at high frequencies (meaning not quite a full factor of 2 improvement in range)

LIGO's H2 detector was **not** operated. Instead Virgo participated for most of the run providing a three site coincidence network capable of sky localization.

The run ended after only ~1 year so as to **not** push back the Advanced detector installations.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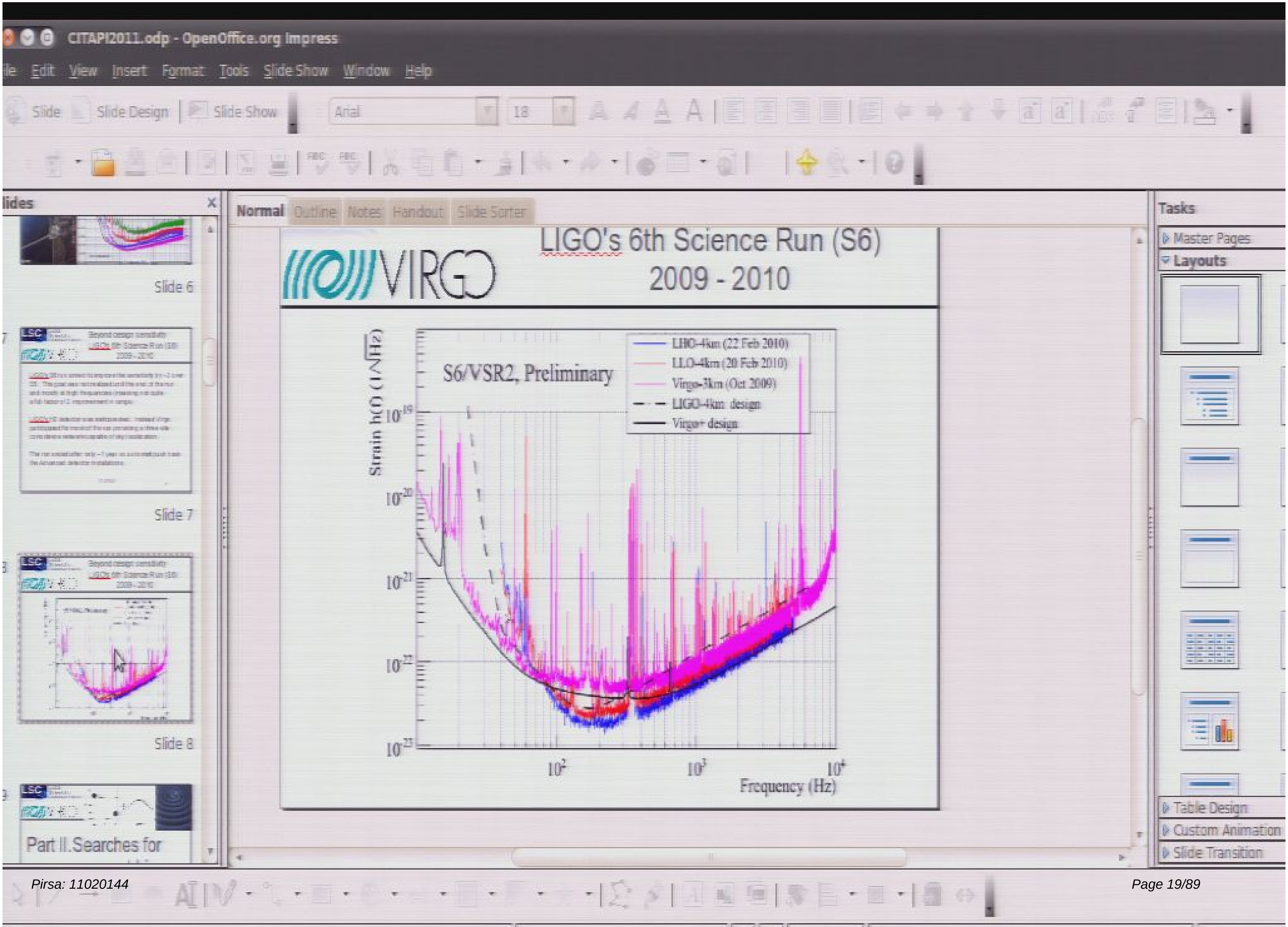
Part II.Searches for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LIGO's 6th Science Run (S6)
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S6/VSR2, Preliminary
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LLO-4km (20 Feb 2010)
Virgo-3km (Oct 2009)
LIGO-4km design
Virgo+ design
Strain h(f) (1/√Hz)
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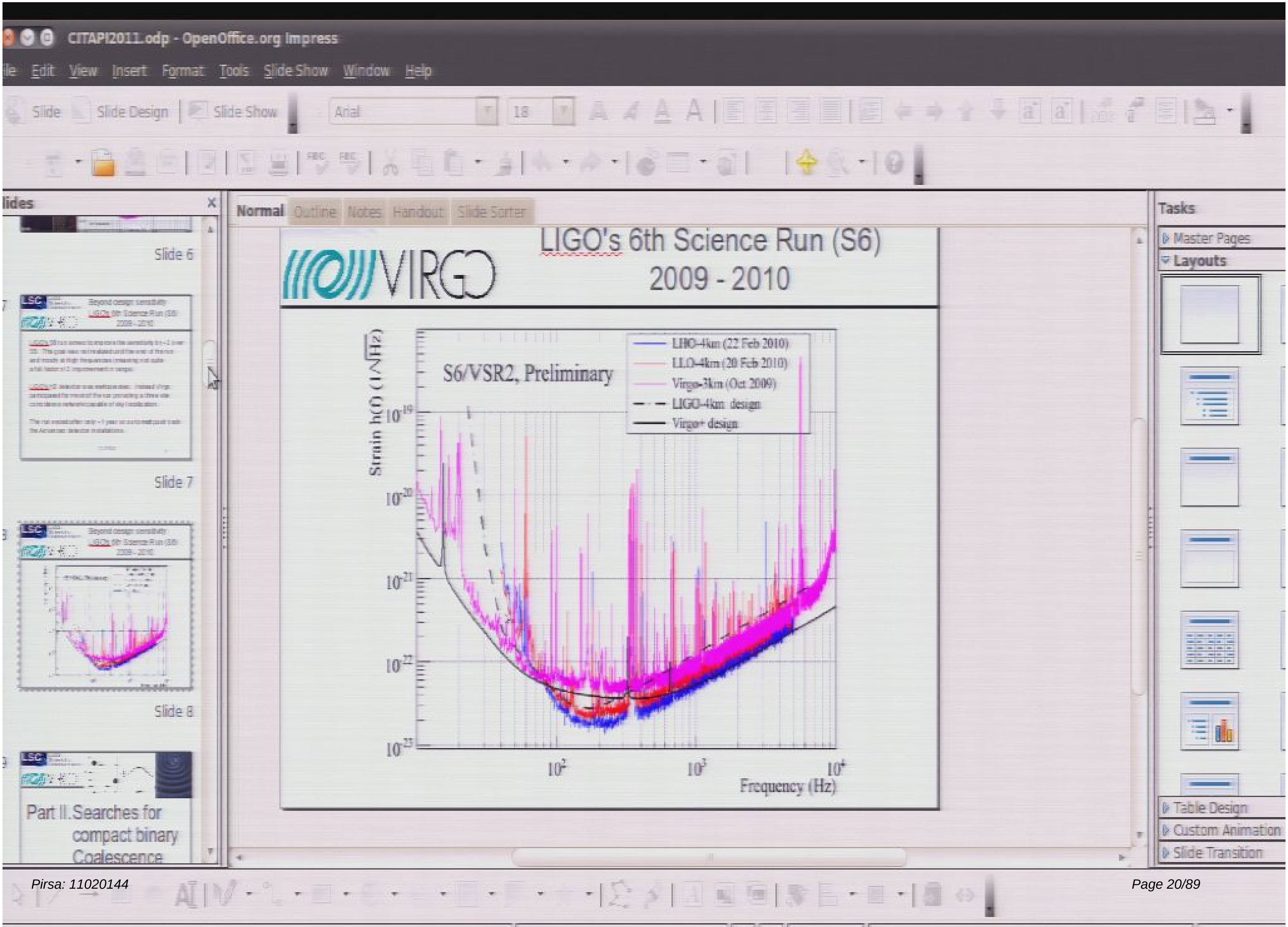
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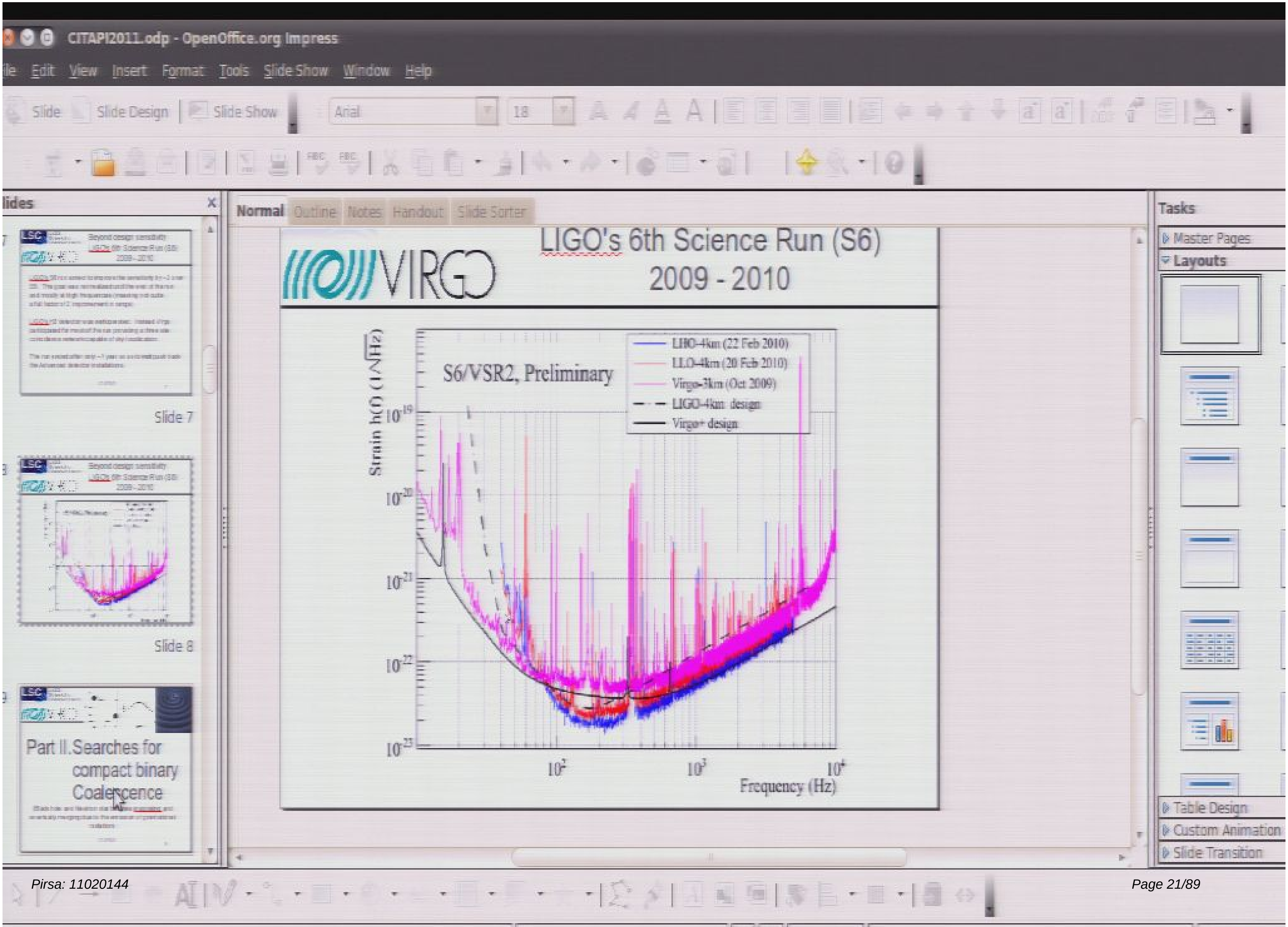
Part II.Searches for compact binary Coalescence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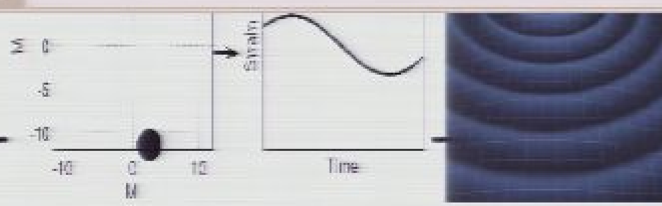
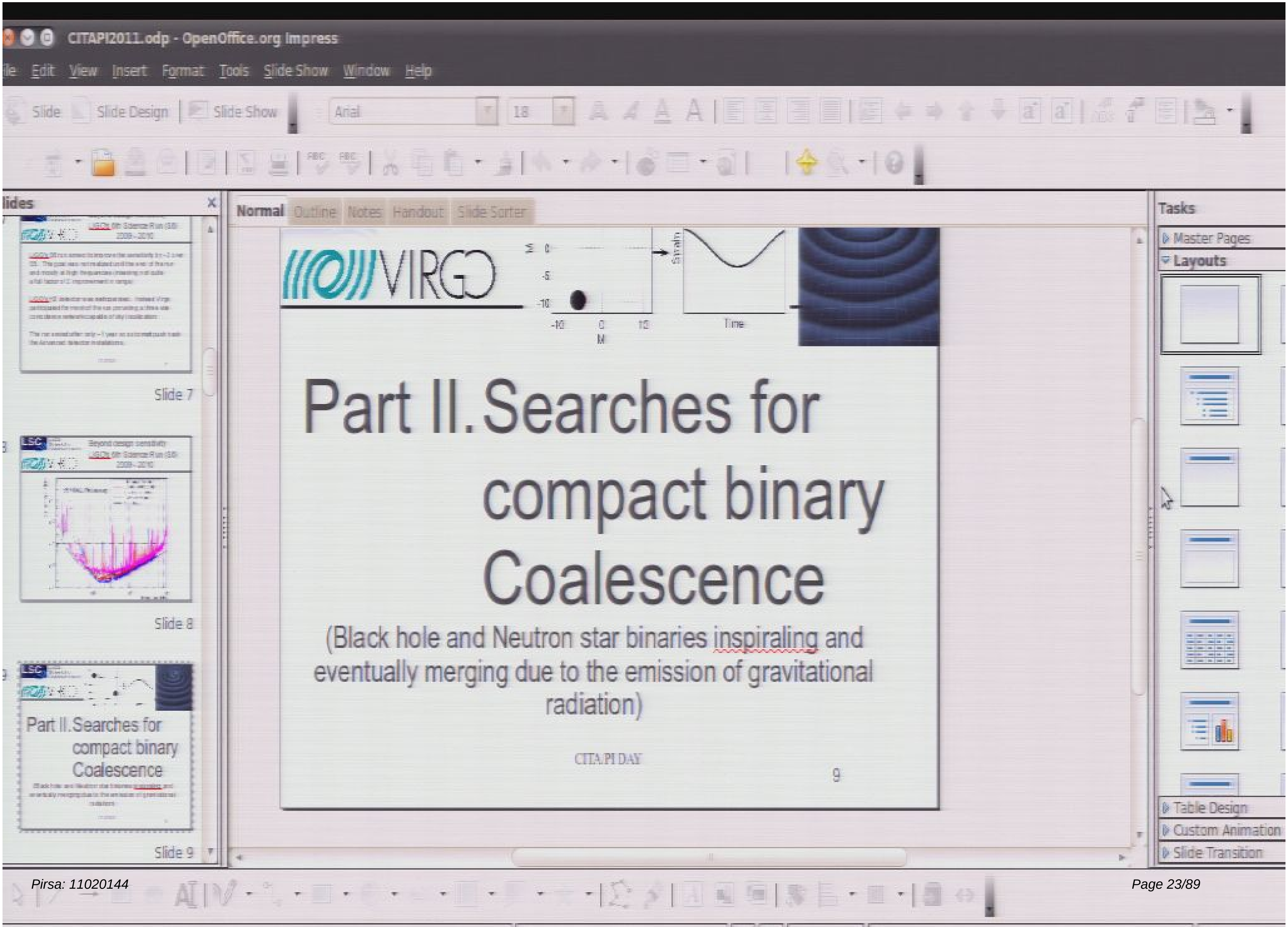


Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)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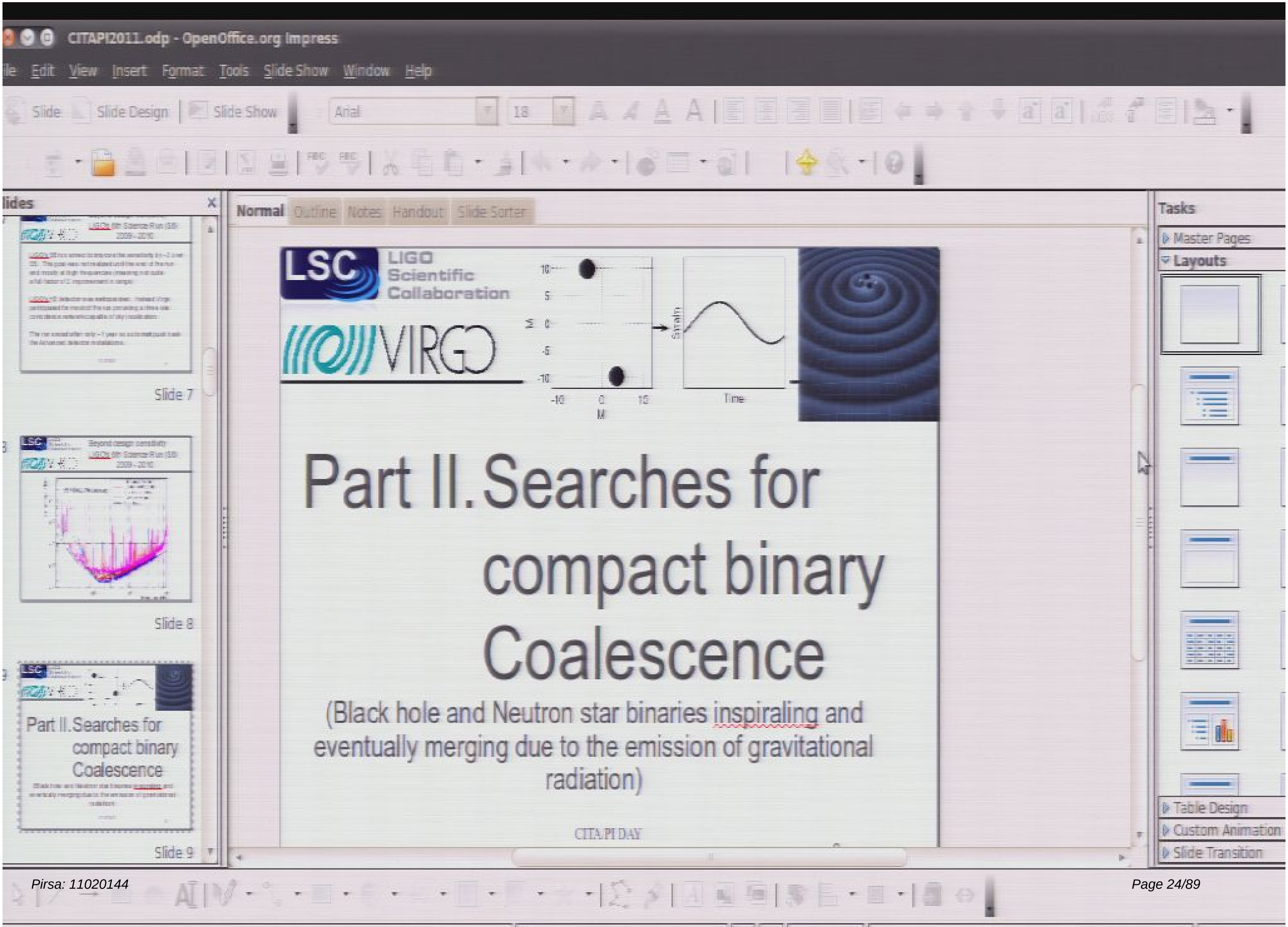
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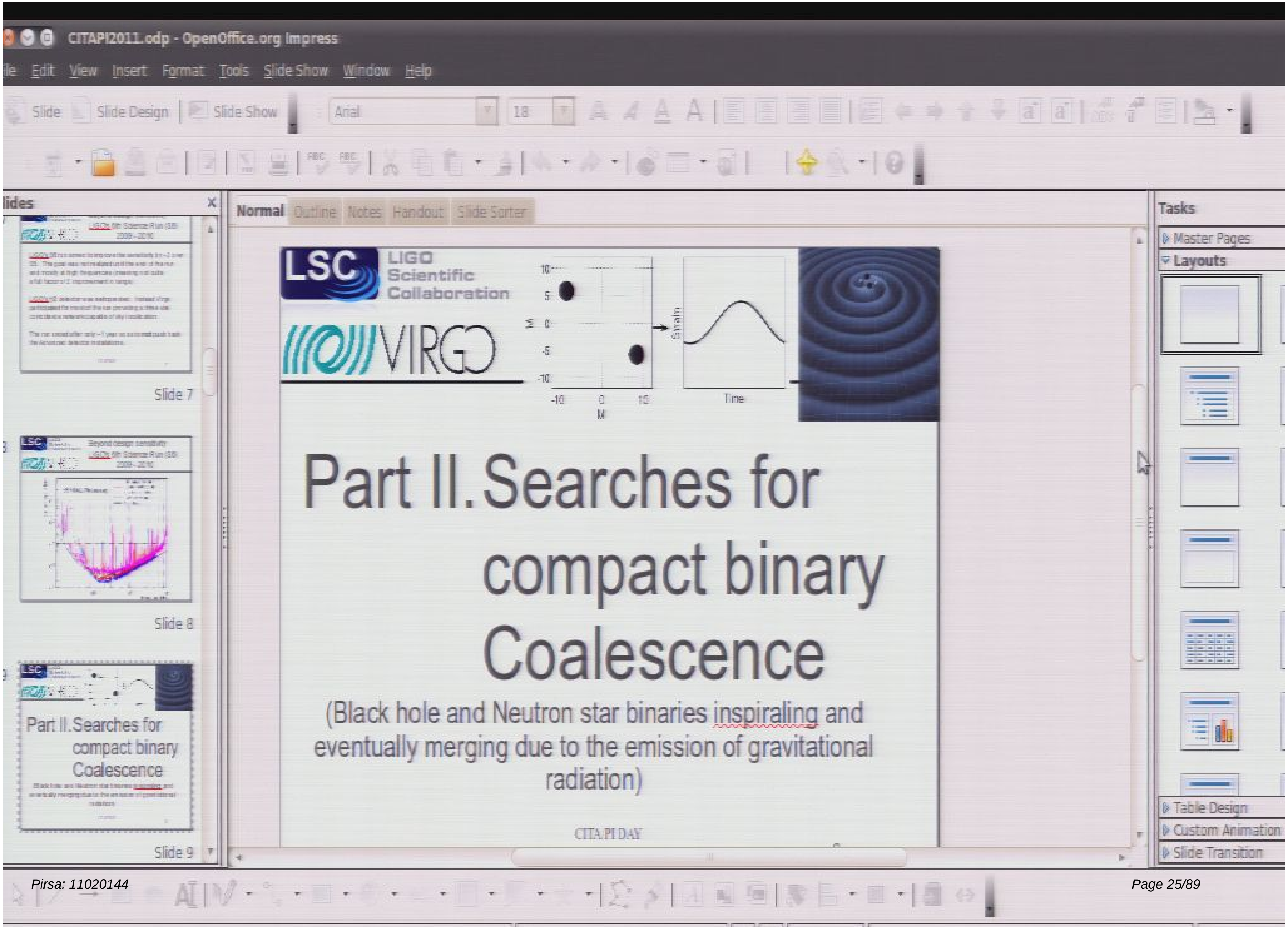
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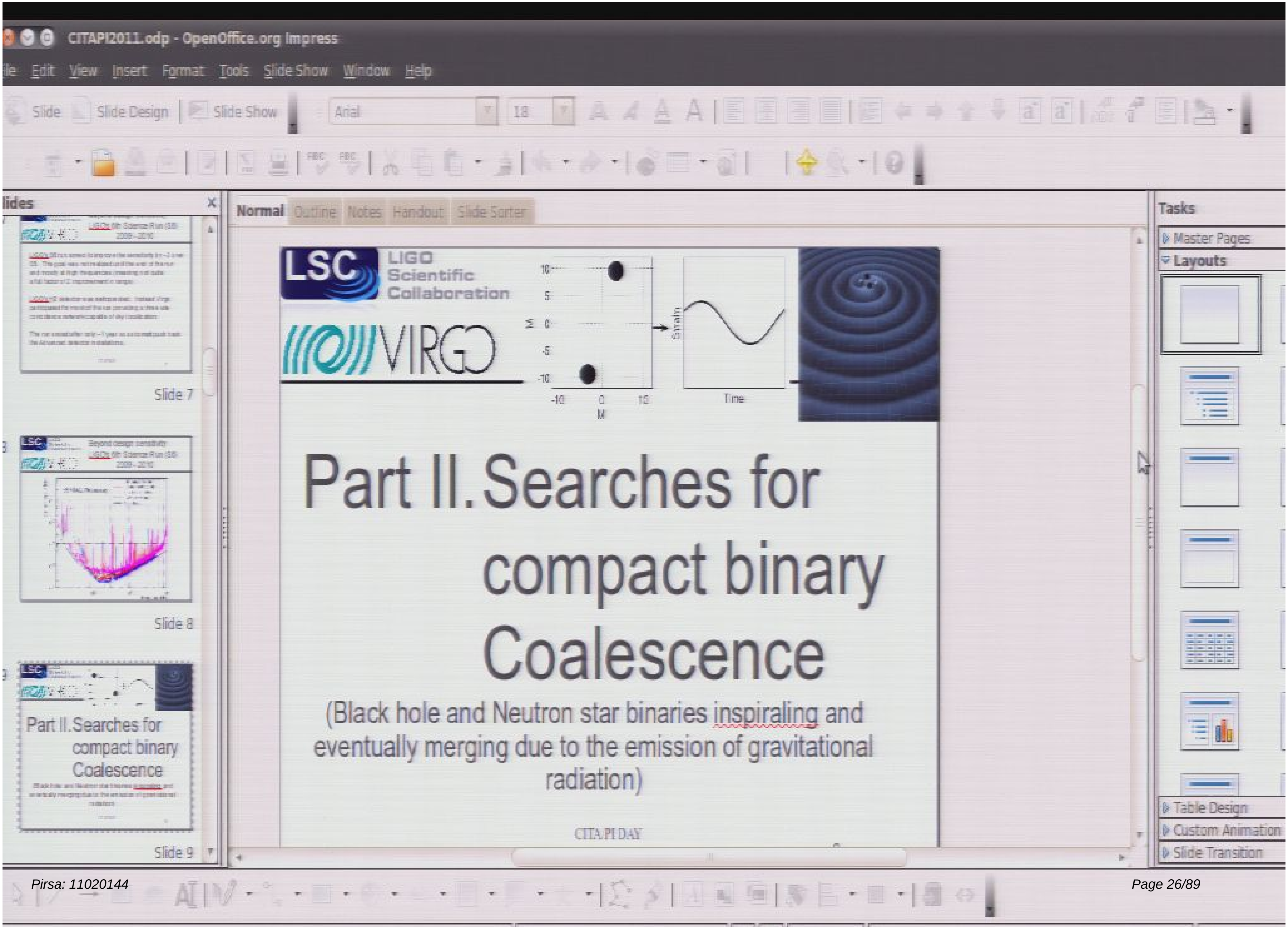
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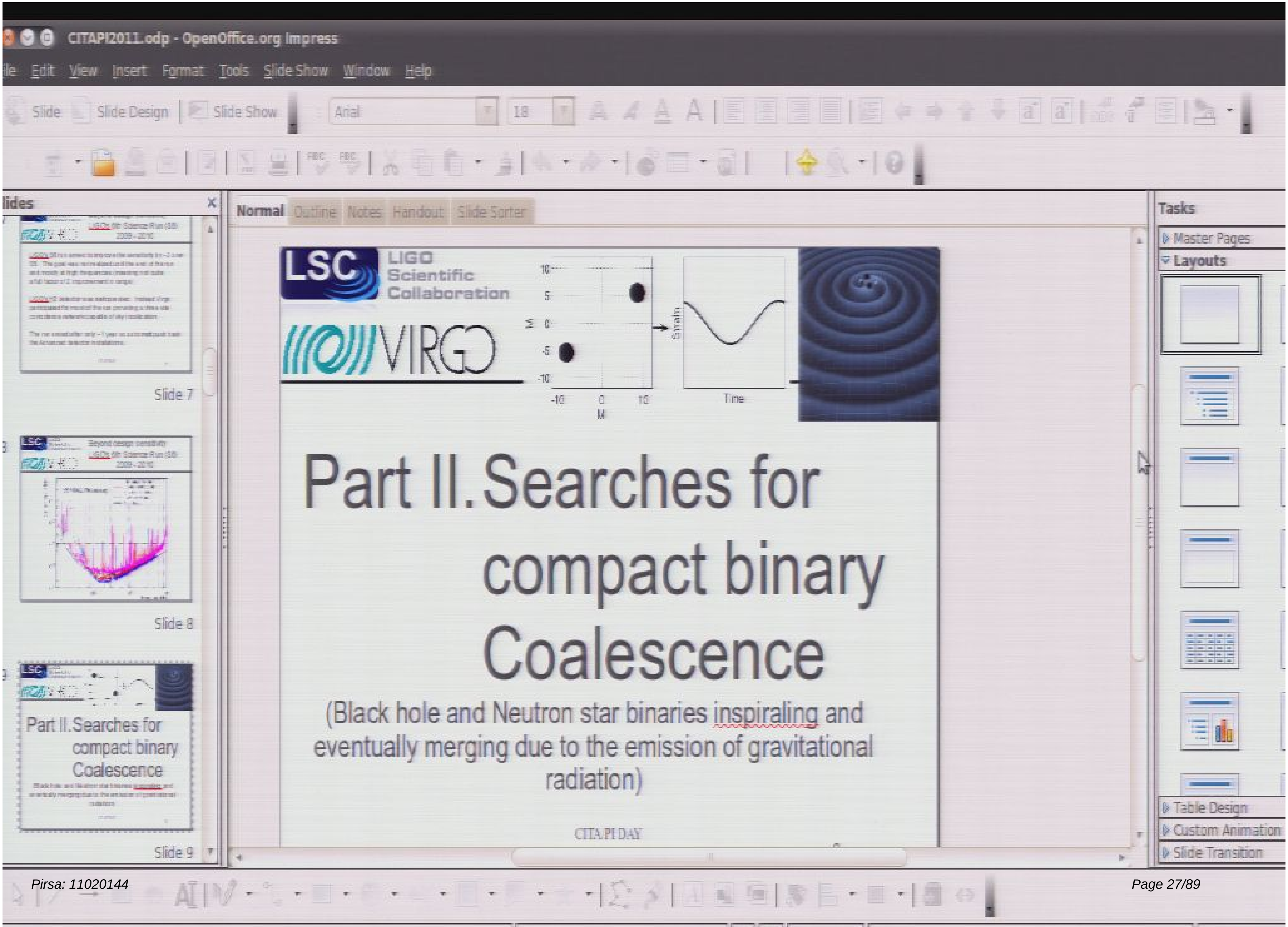
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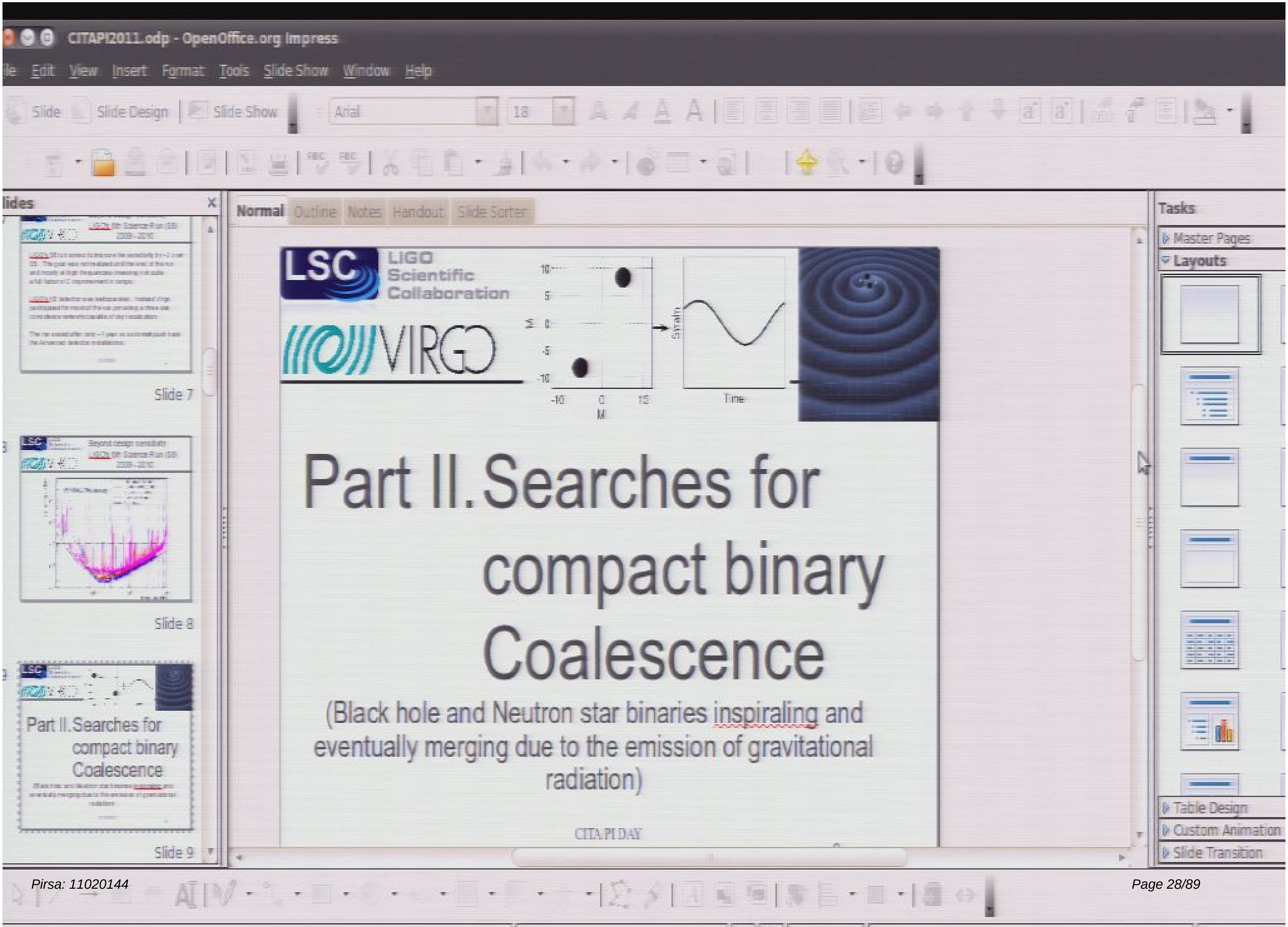
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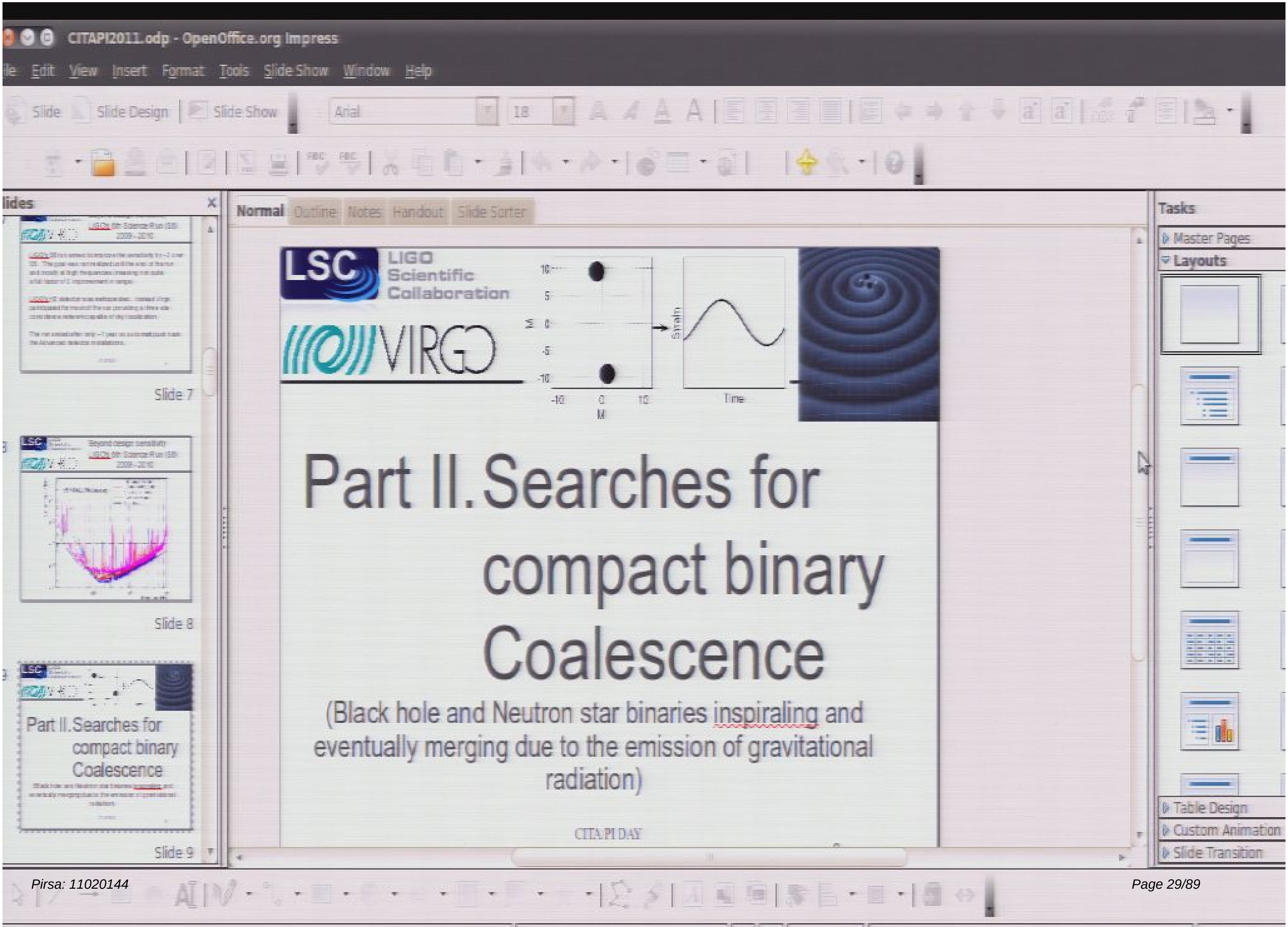
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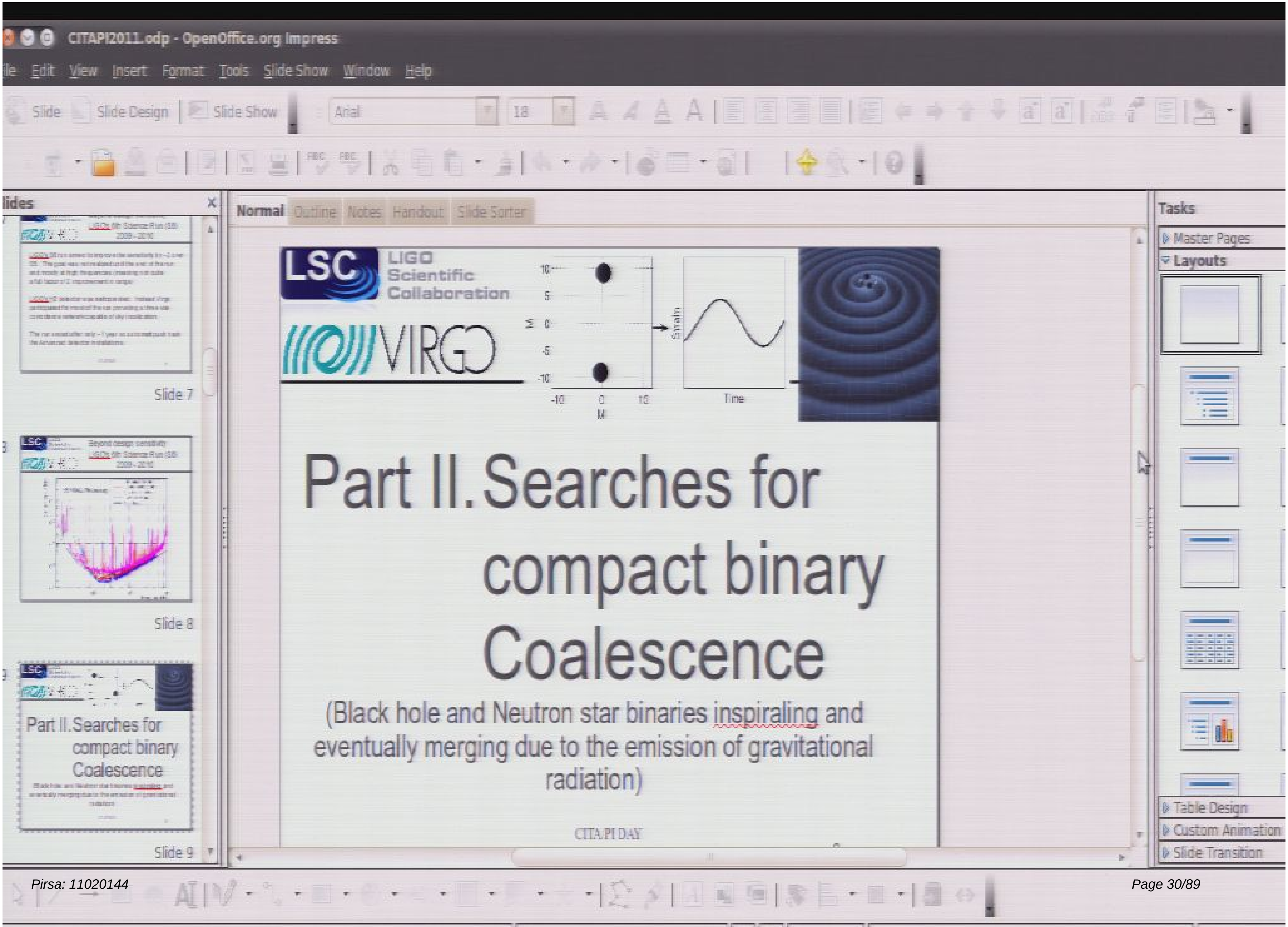

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What did we expect to see?

The optimistic rate estimates put the number of events from NS and BH searches at slightly less than one per year. We are not finished analyzing all of the available data for all types of CBC signals.

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			<0.001[b]	0.01[c]
	IMBH-IMBH			10^{-4}[d]	10^{-3}[e]

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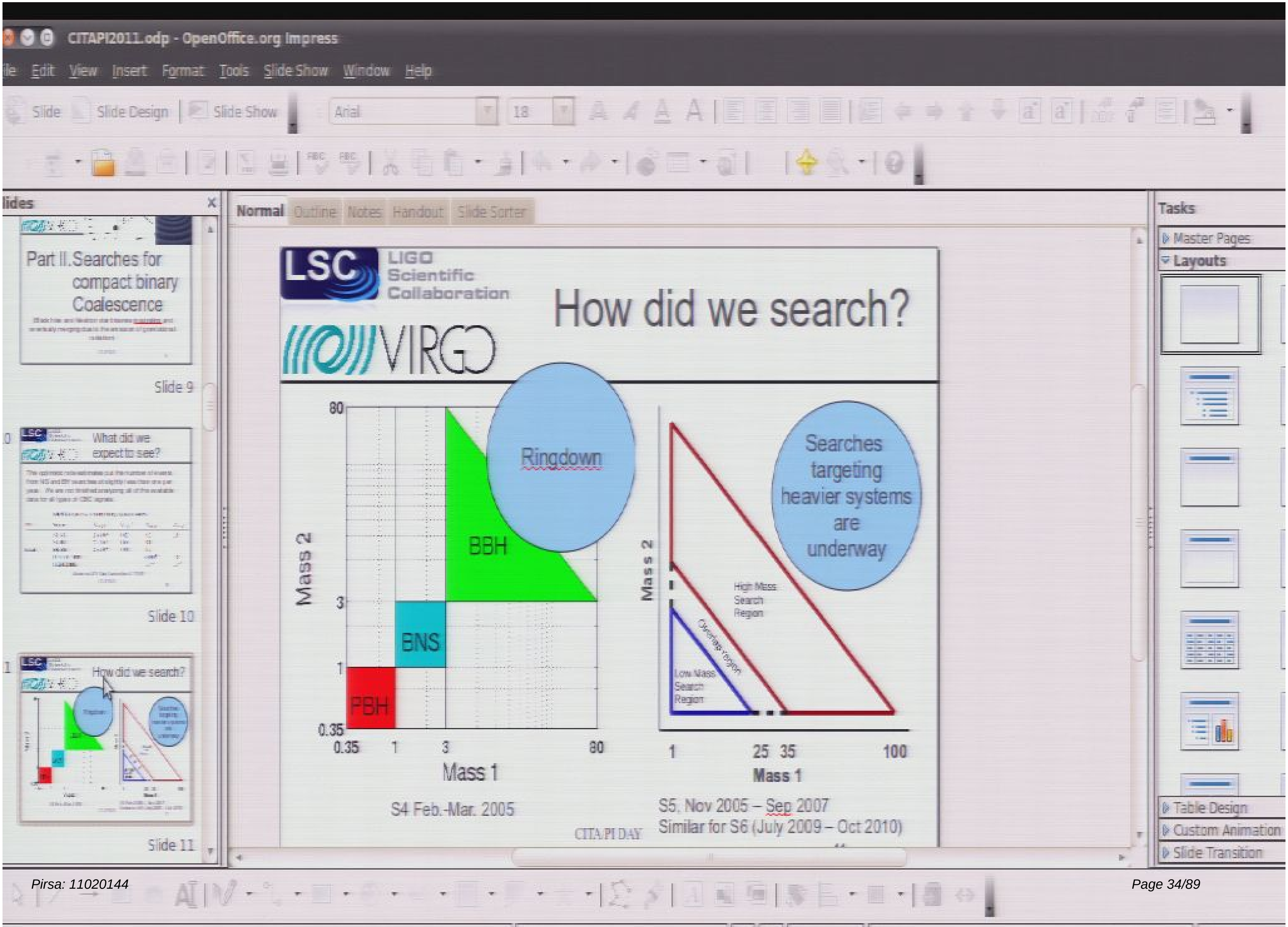
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VIRGO
How did we search?
Ringdown
BBH
BNS
PBH
Mass 2
Mass 1
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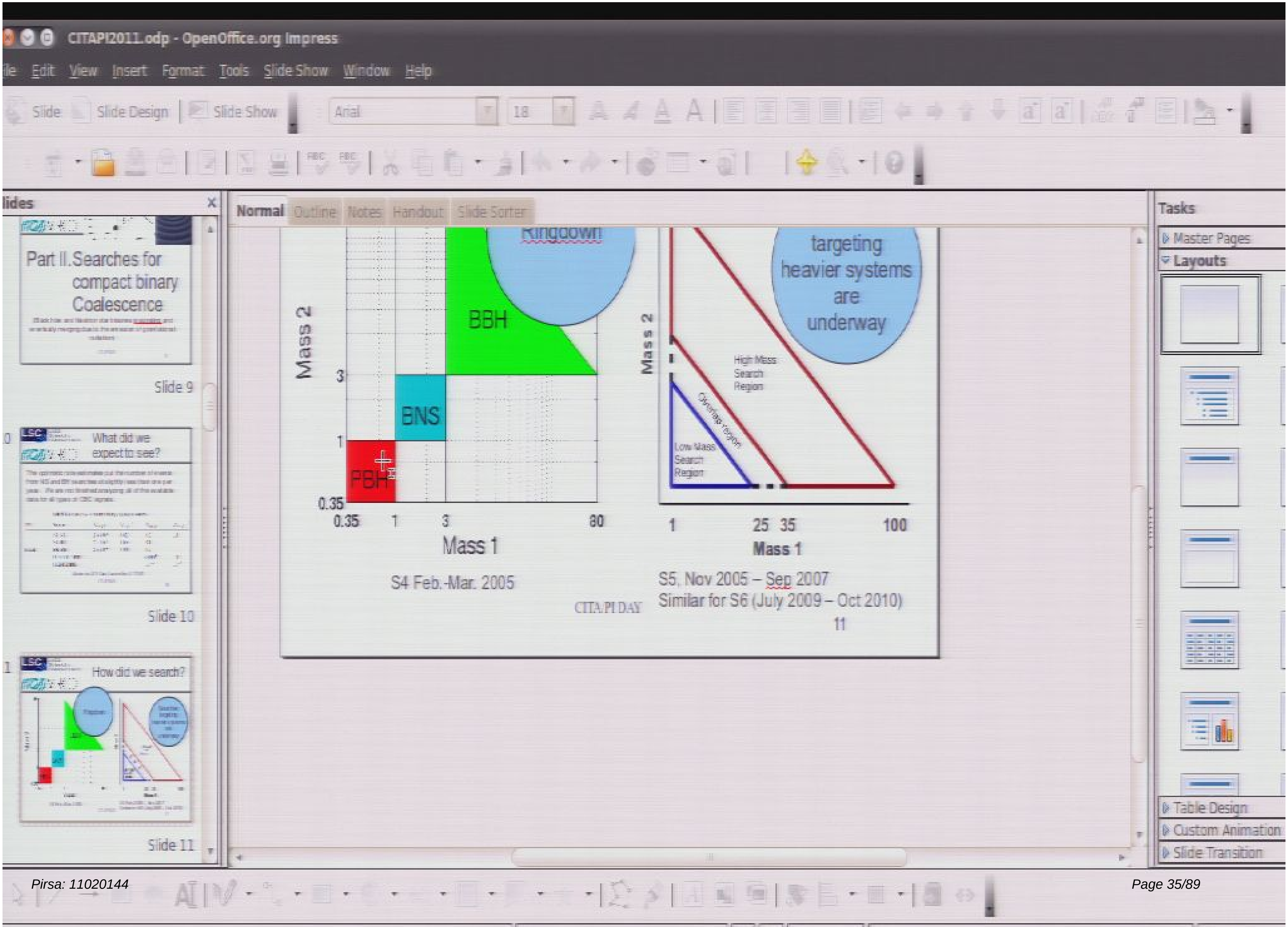
0.35
S4 Feb.-Mar. 2005
Searches targeting heavier systems are underway
High Mass Search Region
Overlap region
Low Mass Search Region
1
25 35
100
S5, Nov 2005 – Sep 2007
Similar for S6 (July 2009 – Oct 2010)
CITA/PI DAY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Ringdown
targeting heavier systems are underway
BBH
BNS
PBH
Mass 2
Mass 1
0.35
1
3
80
S4 Feb.-Mar. 2005
High Mass Search Region
Overlap region
Low Mass Search Region
1
25
35
100
S5, Nov 2005 – Sep 2007
Similar for S6 (July 2009 – Oct 2010)
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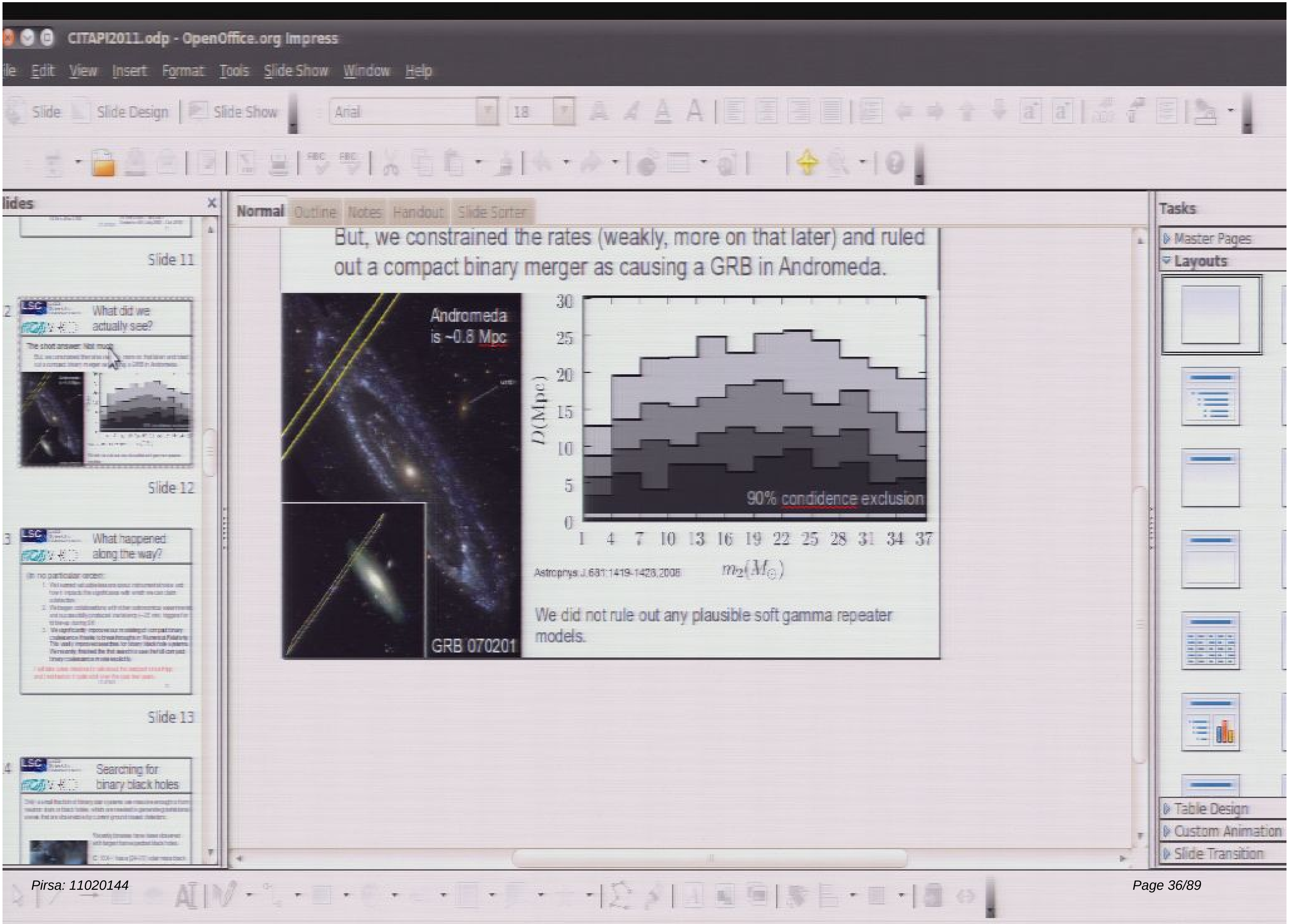
Part II. Searches for compact binary Coalescence
What did we expect to see?
How did we search?
Slide 9
Slide 10
Slide 11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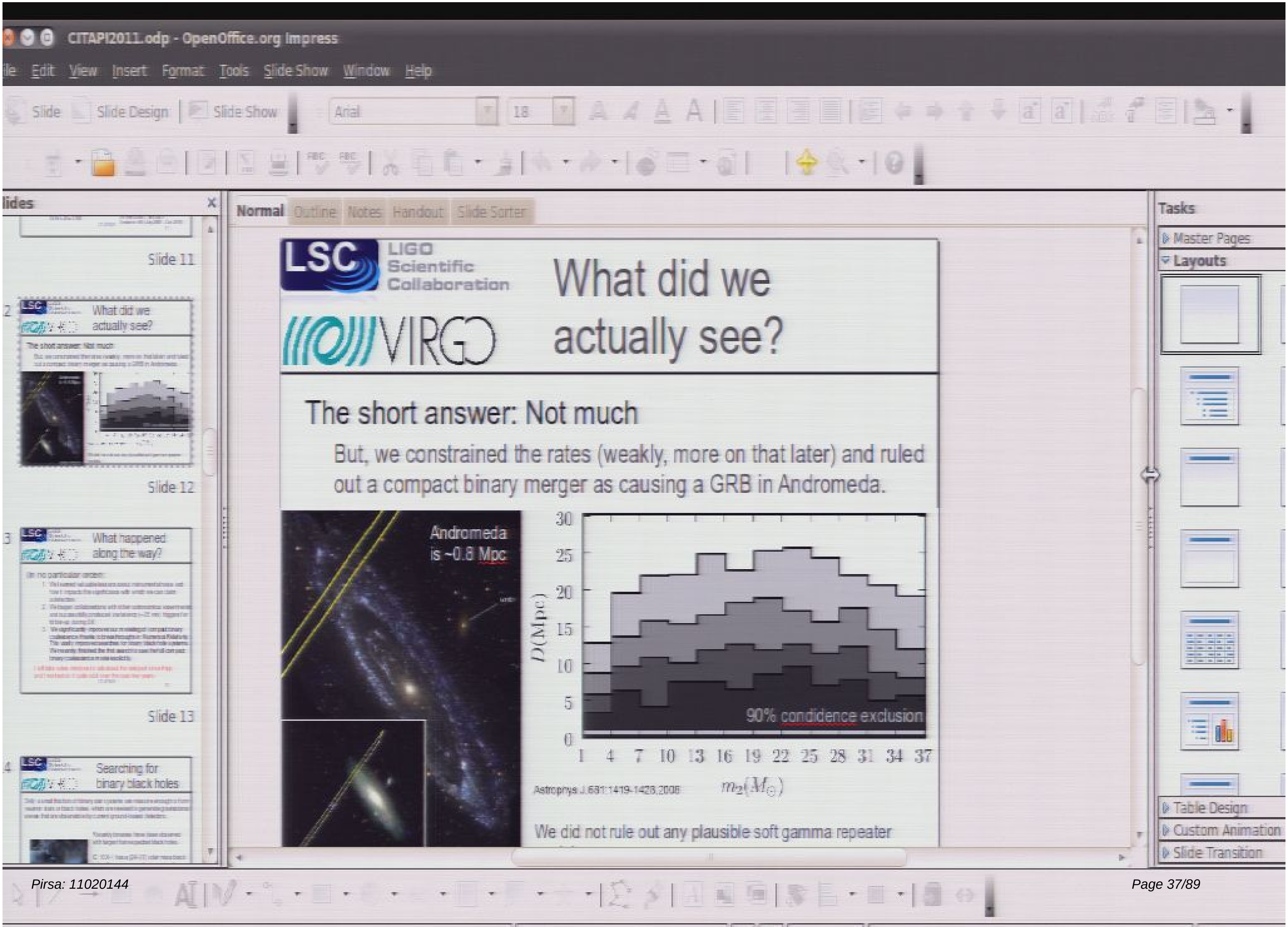
But, we constrained the rates (weakly, more on that later) and ruled out a compact binary merger as causing a GRB in Andromeda.
Andromeda is ~0.8 Mpc
GRB 070201
D(Mpc)
90% condidence exclusion
$m_2 (M_\odot)$
Astrophys.J.681:1419-1428,2008
We did not rule out any plausible soft gamma repeater models.
Slide 11
What did we actually see?
Slide 12
What happened along the way?
Slide 13
Searching for binary black holes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LSC LIGO Scientific Collaboration
VIRGO
What did we actually see?
The short answer: Not much
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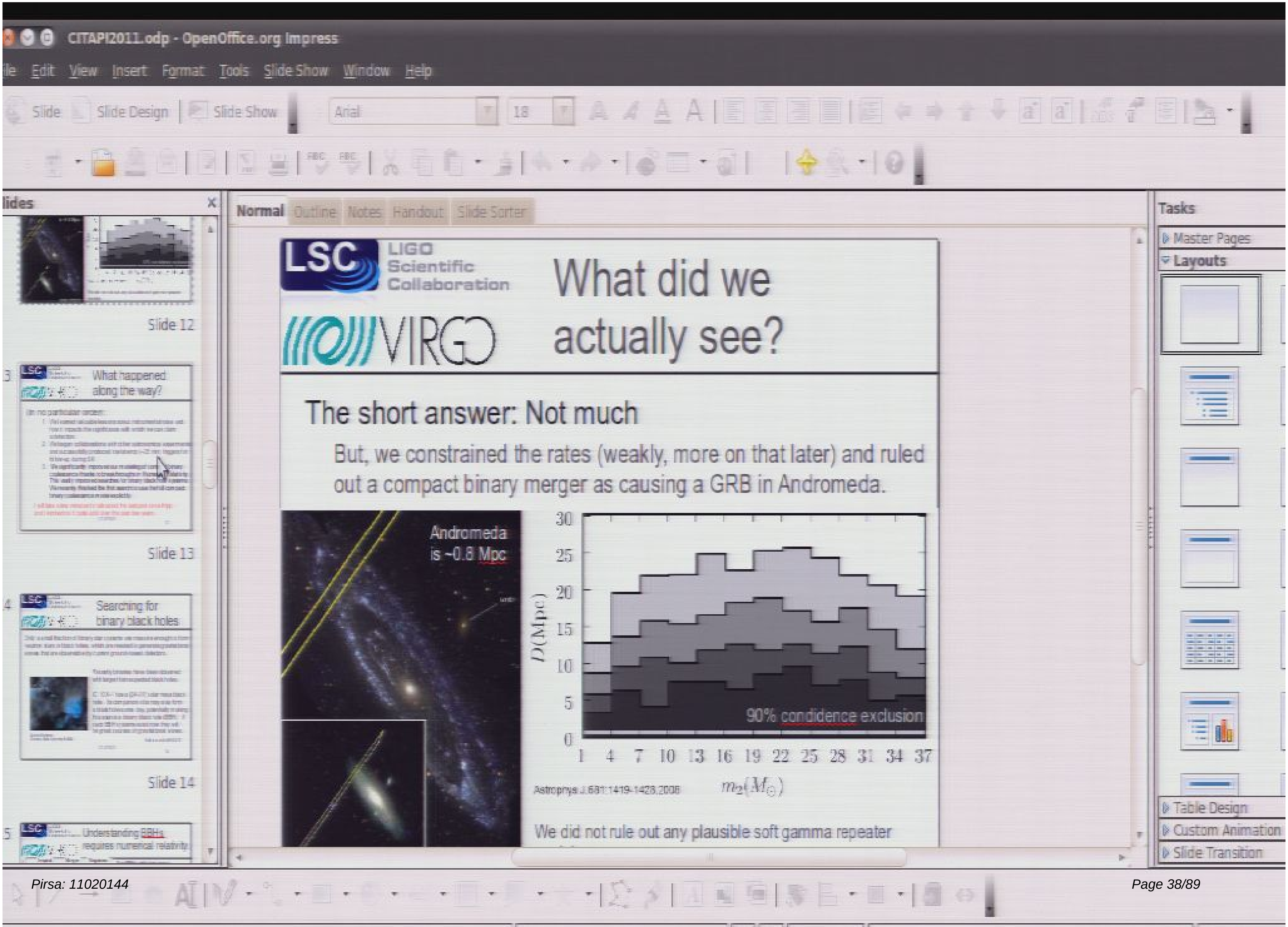
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What happened along the way?
Searching for binary black holes
Understanding BBHs requires numerical relativity
Slide 12
Slide 13
Slide 14
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Slide Transition

What happened along the way?

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(in no particular order):

1. We learned valuable lessons about instrumental noise and how it impacts the significance with which we can claim a detection.
2. We began collaborations with other astronomical experiments and successfully produced low latency (~25 min) triggers for follow-up during S6
3. We significantly improved our modeling of compact binary coalescence thanks to breakthroughs in Numerical Relativity. This vastly improved searches for binary black hole systems. We recently finished the first search to use the full compact binary coalescence model explicitly.

I will take a few minutes to talk about the last part since Kipp and I worked on it quite a bit over the past few years.

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13

What happened along the way?

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Searching for binary black holes

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Only a small fraction of binary star systems are massive enough to form neutron stars or black holes, which are needed to generate gravitational waves that are observable by current ground-based detectors.

Aurore Simonnet
Sonoma State University/NASA

Recently binaries have been observed with larger than expected black holes.

IC 10 X-1 has a [24-31] solar mass black hole. Its companion star may also form a black hole some day, potentially making this source a binary black hole (BBH). If such BBH systems exist now they will be great sources of gravitational waves.

Bulik et al. arXiv:0803.3516

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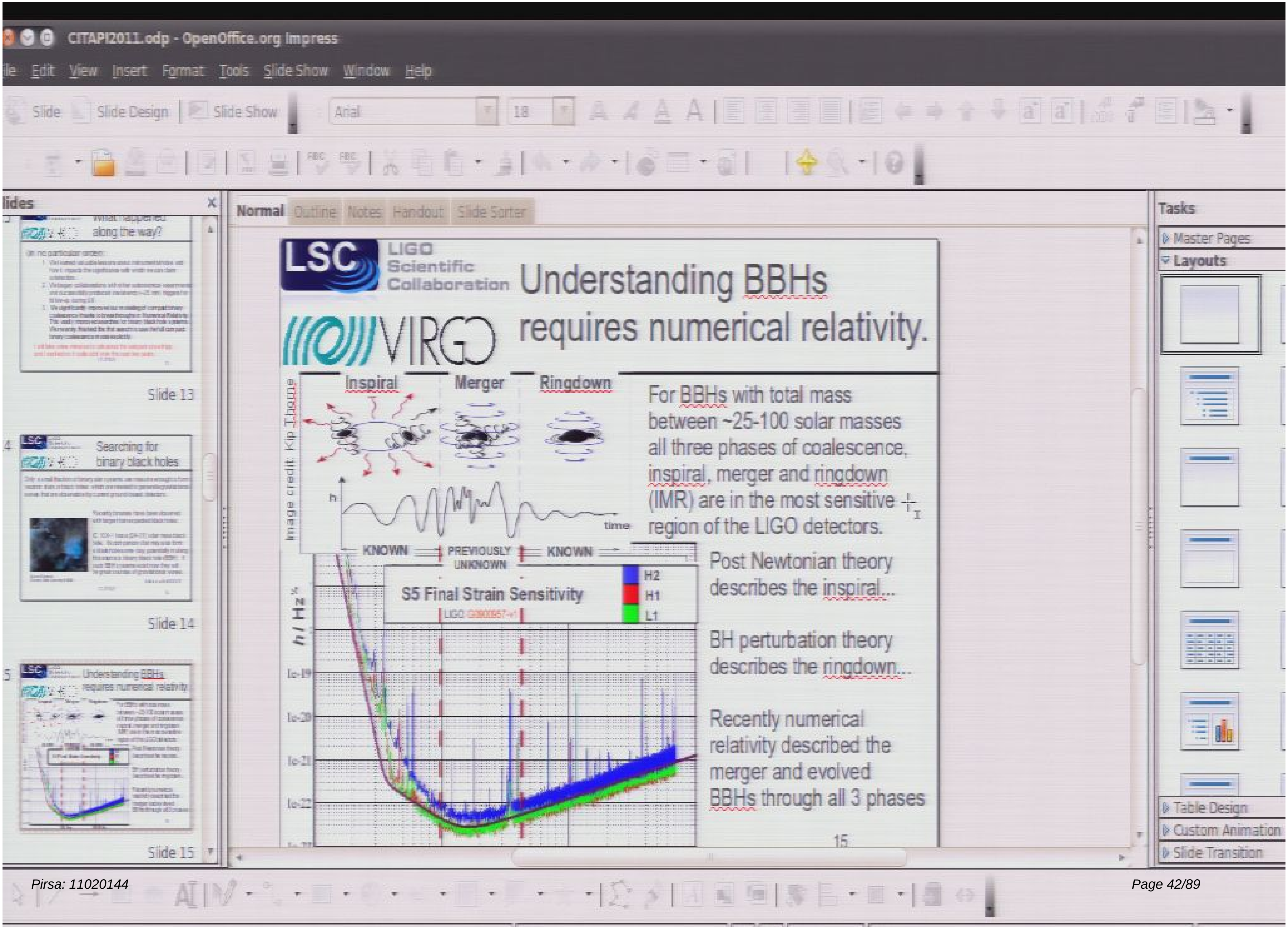
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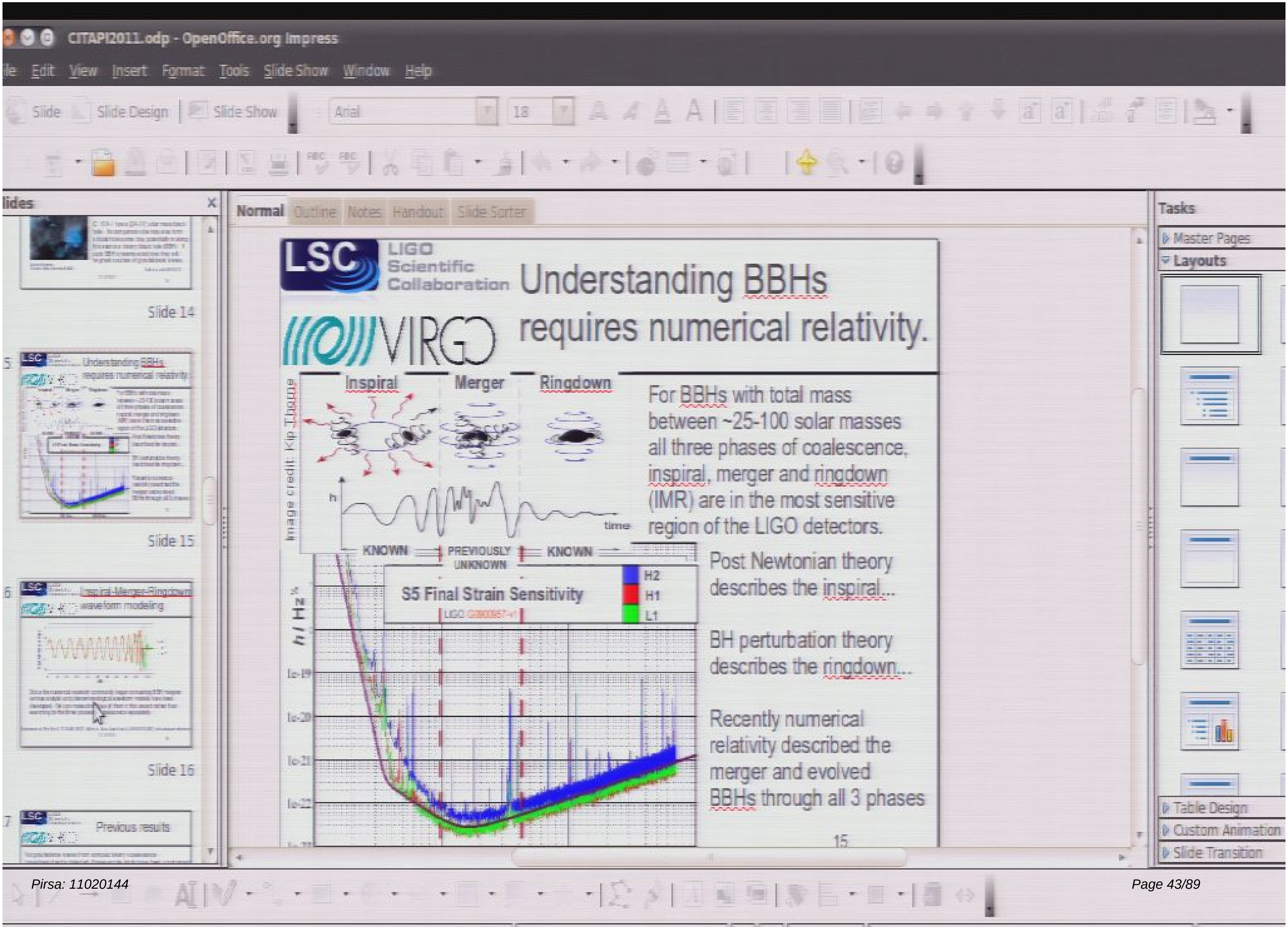
Understanding BBHs requires numerical relativity.
Inspiral
Merger
Ringdown
Image credit: Kip Thorne
h
time
KNOWN
PREVIOUSLY UNKNOWN
KNOWN
S5 Final Strain Sensitivity
H2
H1
L1
For BBHs with total mass between ~25-100 solar masses all three phases of coalescence, inspiral, merger and ringdown (IMR) are in the most sensitive region of the LIGO detectors.
Post Newtonian theory describes the inspiral...
BH perturbation theory describes the ringdown...
Recently numerical relativity described the merger and evolved BBHs through all 3 phases
15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Previous results
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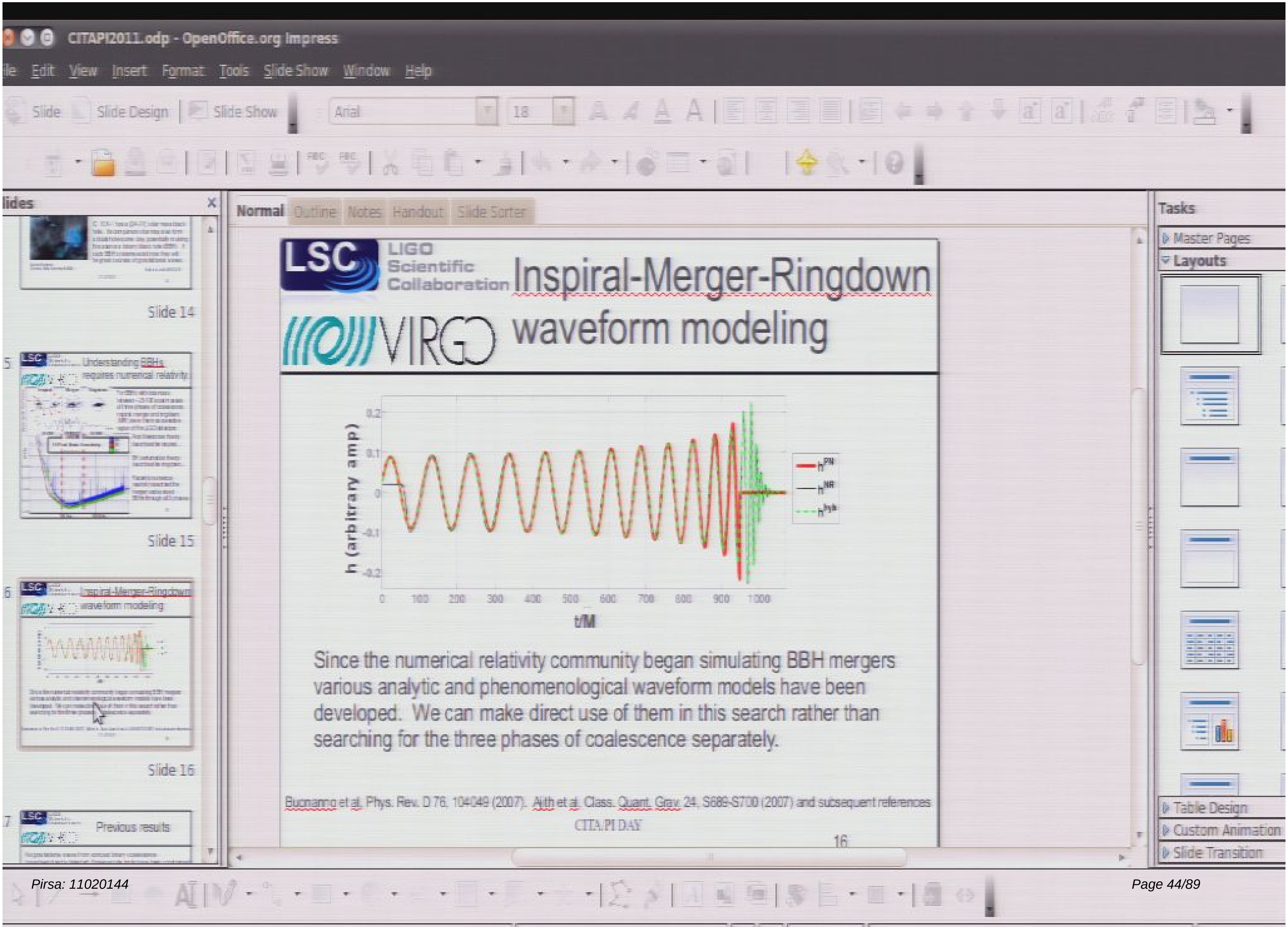
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Inspiral-Merger-Ringdown waveform modeling
h (arbitrary amp)
t/M
h^{PN}
h^{NR}
h^{hyb}
Since the numerical relativity community began simulating BBH mergers various analytic and phenomenological waveform models have been developed. We can make direct use of them in this search rather than searching for the three phases of coalescence separately.
Buonanno et al. Phys. Rev. D 76, 104049 (2007). Ajith et al. Class. Quant. Grav. 24, S689-S700 (2007) and subsequent references
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Slide 14
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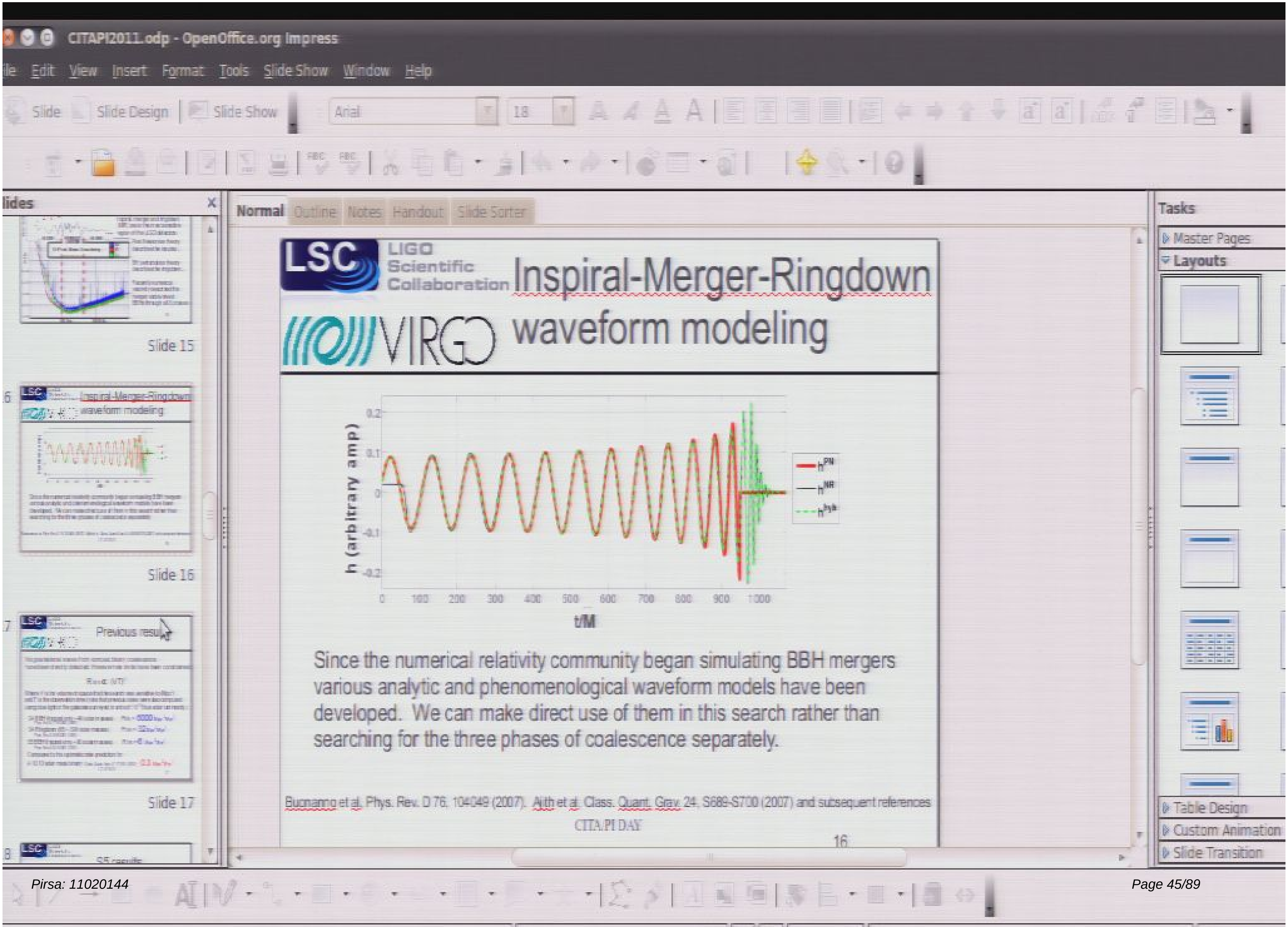
Slide 16
Understanding BBHs requires numerical relativity
Previous results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LSC LIGO Scientific Collaboration
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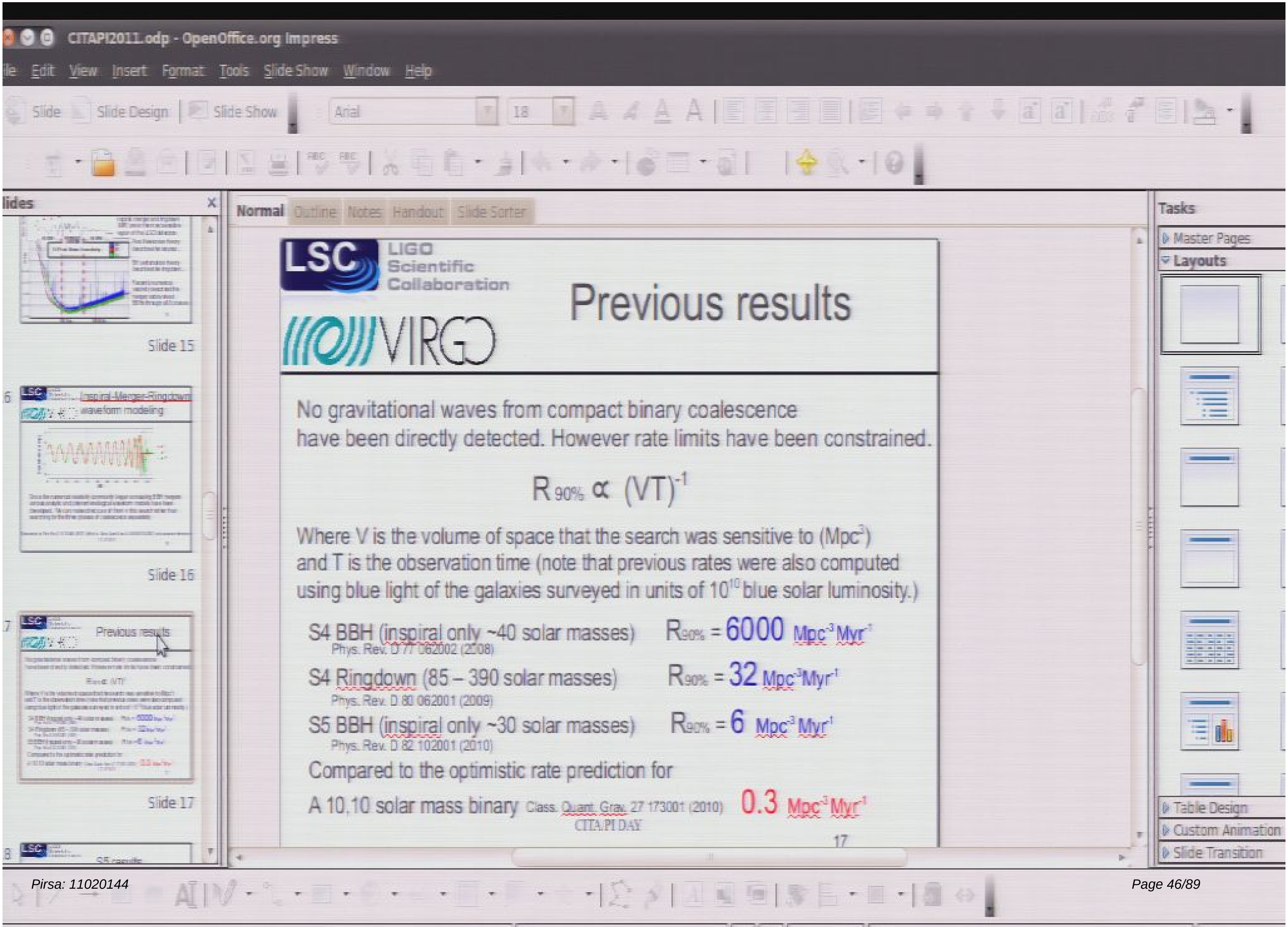
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LSC LIGO Scientific Collaboration
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Previous results
No gravitational waves from compact binary coalescence
have been directly detected. However rate limits have been constrained.
$R_{90\%} \propto (VT)^{-1}$
Where V is the volume of space that the search was sensitive to (Mpc^3)
and T is the observation time (note that previous rates were also computed
using blue light of the galaxies surveyed in units of 10^{10} blue solar luminosity.)
S4 BBH (inspiral only ~40 solar masses) $R_{90\%}$ = 6000 $Mpc^{-3}Myr^{-1}$
Phys. Rev. D 77 062002 (2008)
S4 Ringdown (85 – 390 solar masses) $R_{90\%}$ = 32 $Mpc^{-3}Myr^{-1}$
Phys. Rev. D 80 062001 (2009)
S5 BBH (inspiral only ~30 solar masses) $R_{90\%}$ = 6 $Mpc^{-3}Myr^{-1}$
Phys. Rev. D 82 102001 (2010)
Compared to the optimistic rate prediction for
A 10,10 solar mass binary Class. Quant. Grav. 27 173001 (2010) 0.3 $Mpc^{-3}Myr^{-1}$
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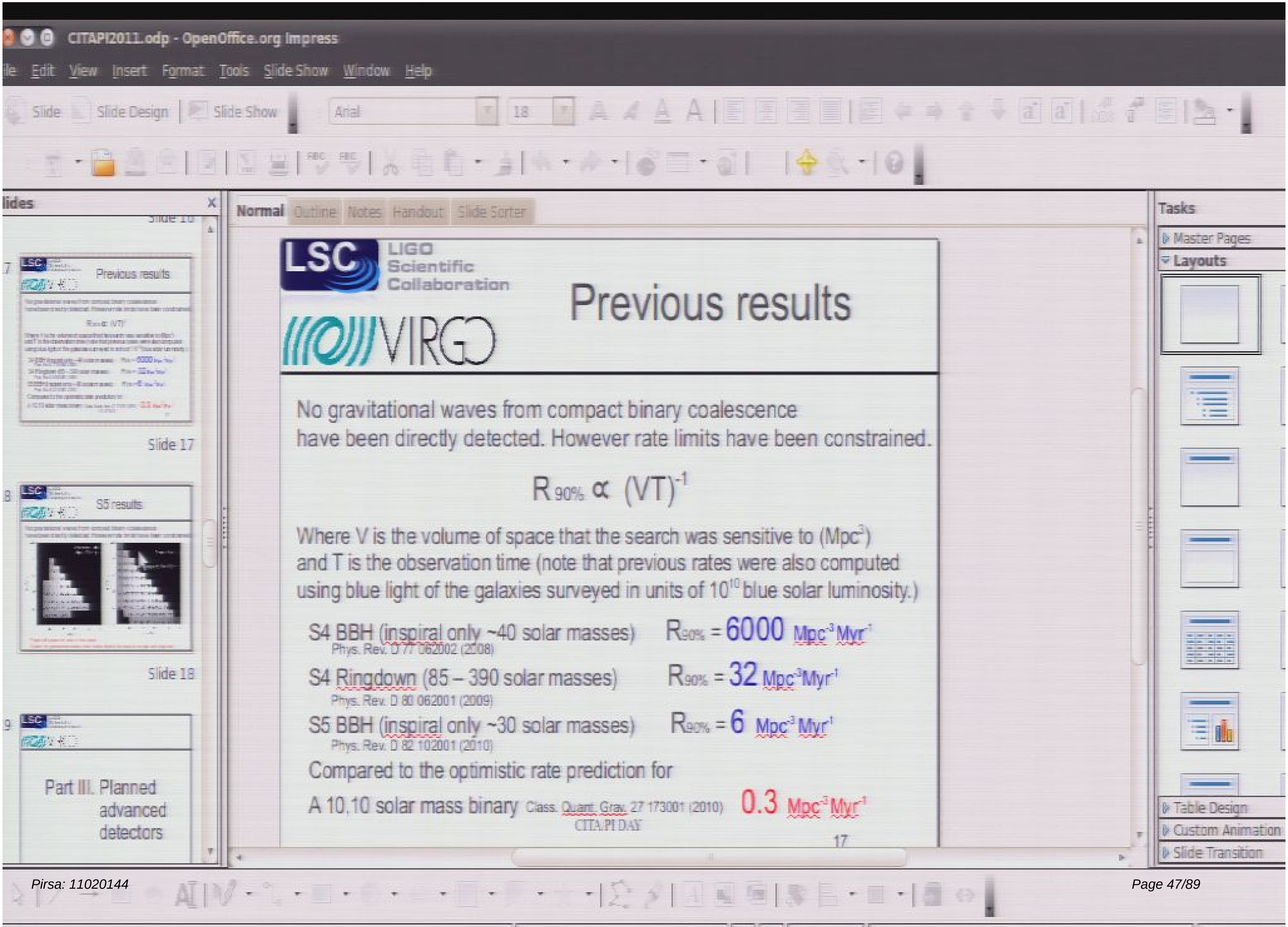
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VIRGO
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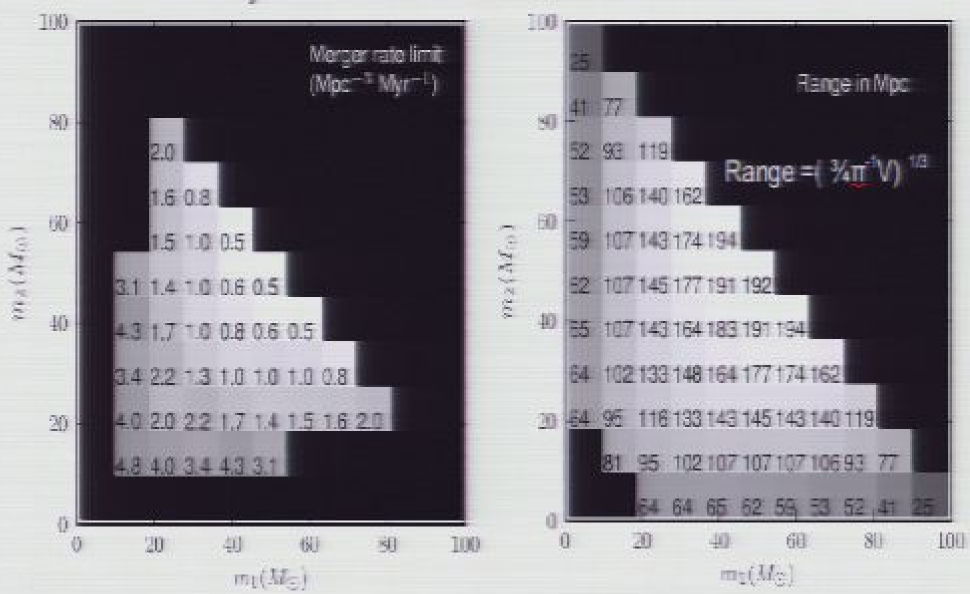
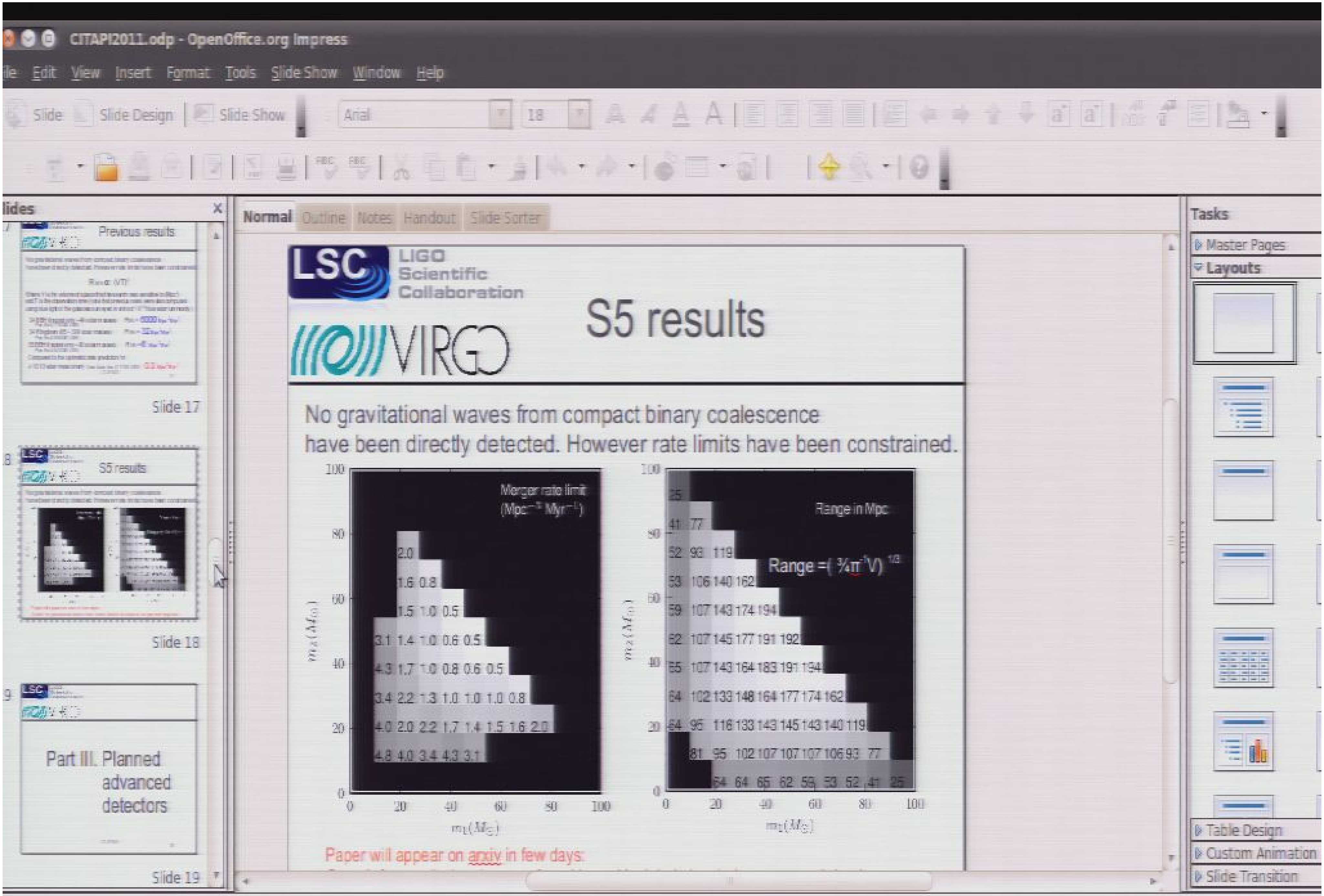
Slide 17
Slide 18
Part III. Planned advanced detectors

S5 results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.



Paper will appear on arxiv in few days: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S5 results
No gravitational waves from compact binary coalescence
have been directly detected. However rate limits have been constrained.
Merger rate limit
(Mpc^{-3} Myr^{-1})
Range in Mpc
Range =(¾π^{-1}V) $^{1/3}$
$m_2(M_\odot)$
$m_1(M_\odot)$
Paper will appear on arxiv in few days.
Previous results
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S5 results
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Part III. Planned advanced detectors
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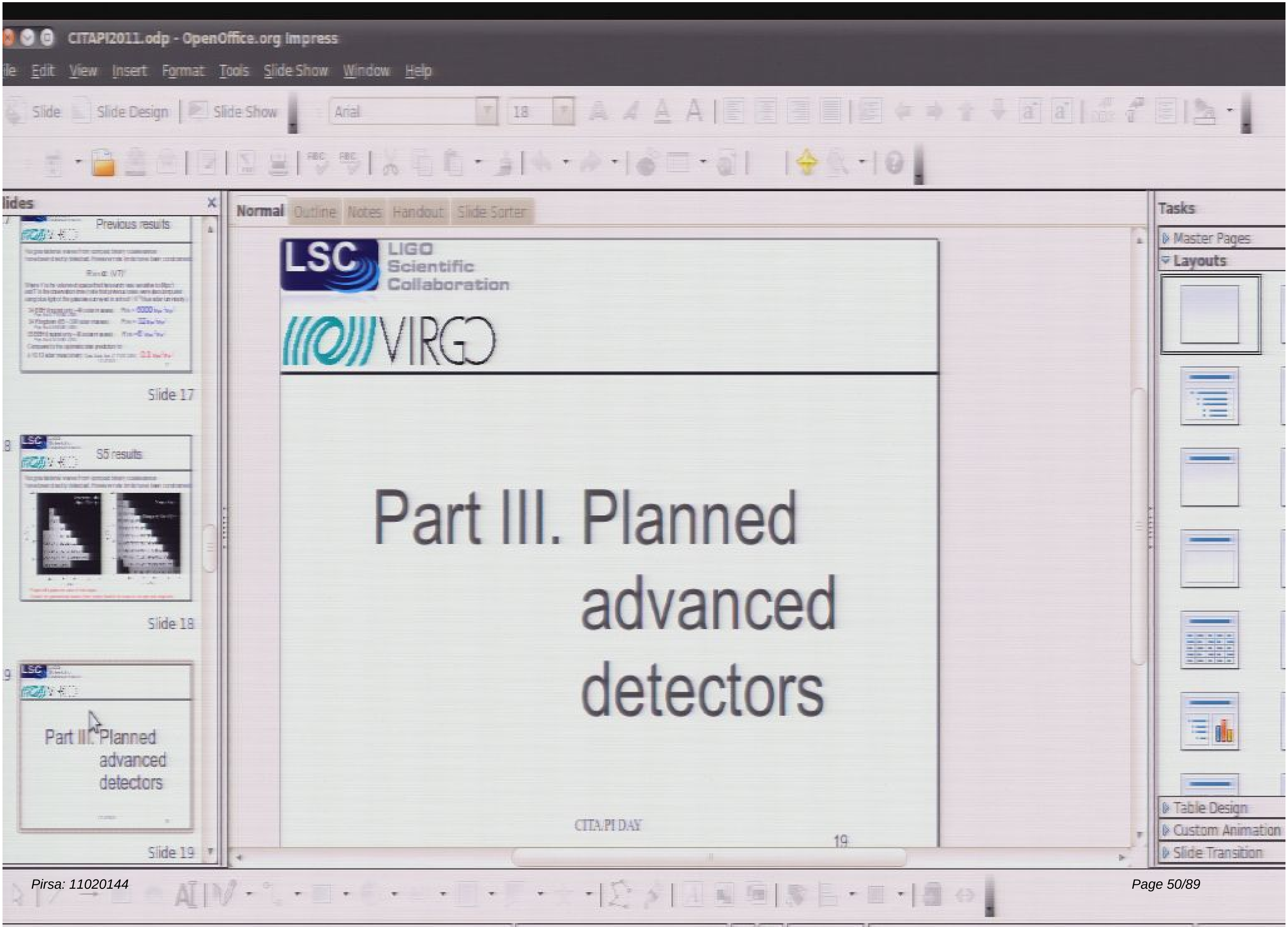
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Part III. Planned advanced detectors
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S5 results
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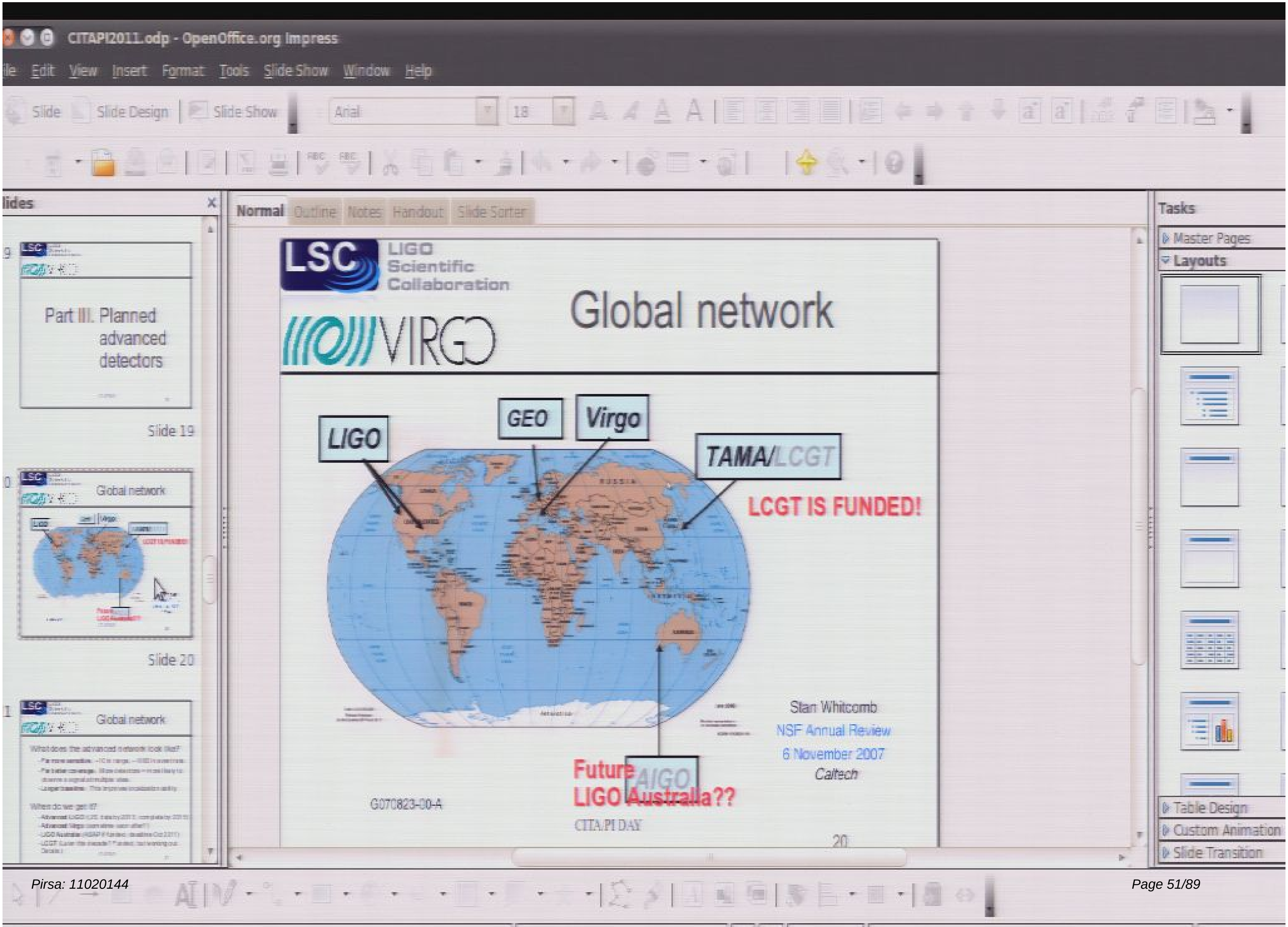
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VIRGO
Global network
LIGO
GEO
Virgo
TAMA/LCGT
LCGT IS FUNDED!
Future
LIGO Australia??
AIGO
Stan Whitcomb
NSF Annual Review
6 November 2007
Caltech
G070823-00-A
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Part III. Planned advanced detectors
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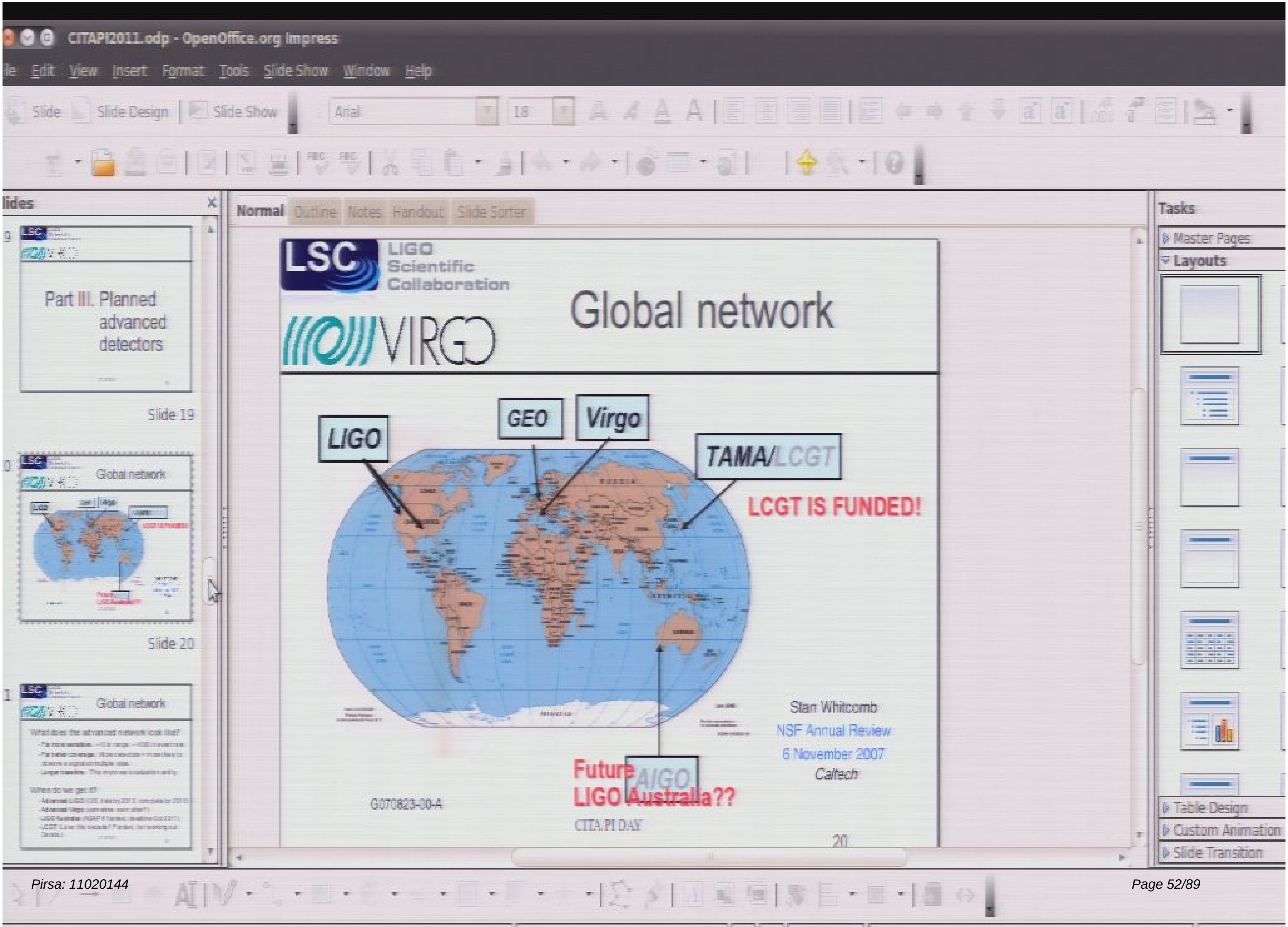
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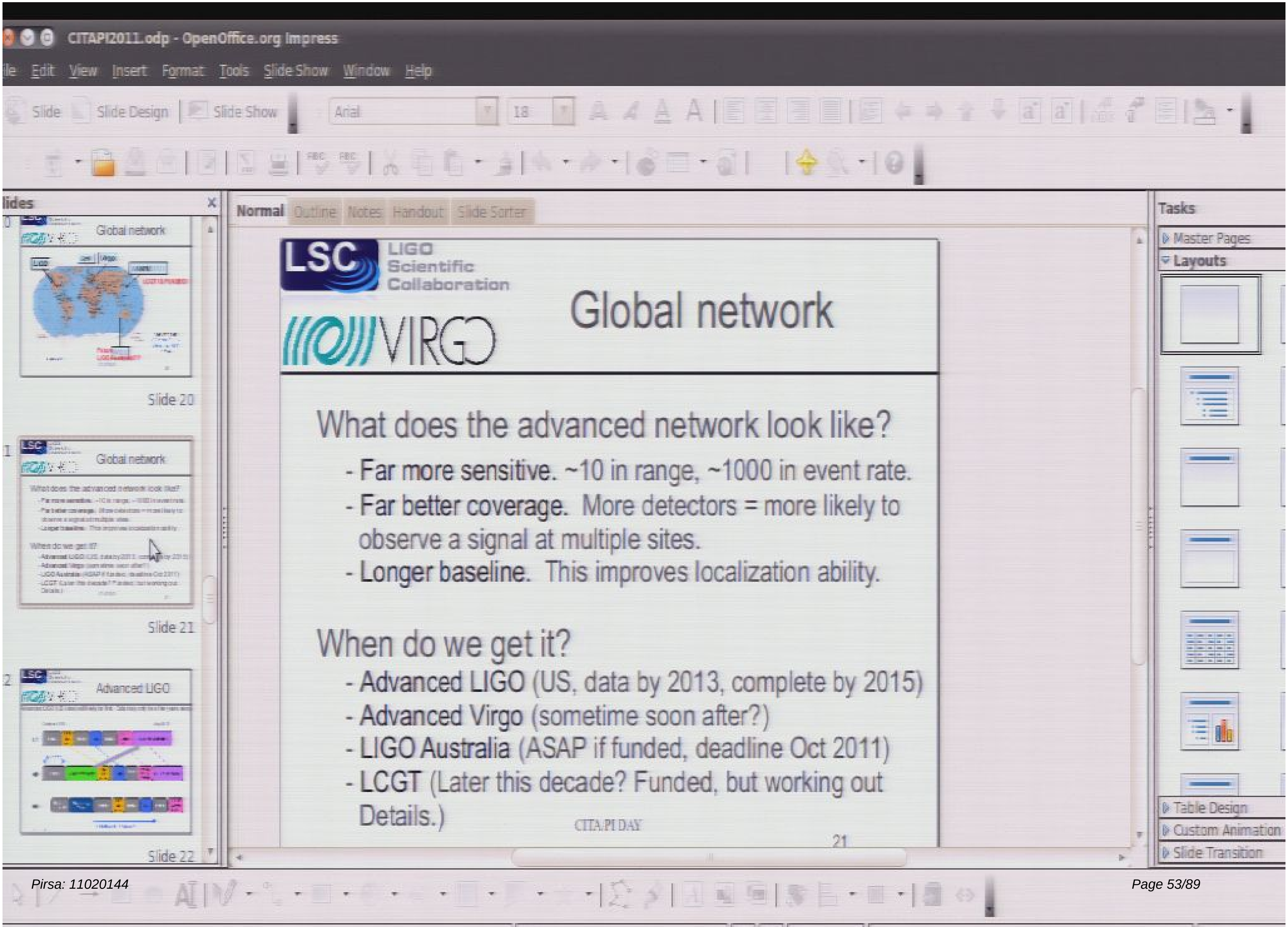
Global network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Global network
What does the advanced network look like?
- Far more sensitive. ~10 in range, ~1000 in event rate.
- Far better coverage. More detectors = more likely to observe a signal at multiple sites.
- Longer baseline. This improves localization ability.
When do we get it?
- Advanced LIGO (US, data by 2013, complete by 2015)
- Advanced Virgo (sometime soon after?)
- LIGO Australia (ASAP if funded, deadline Oct 2011)
- LCGT (Later this decade? Funded, but working out Details.)
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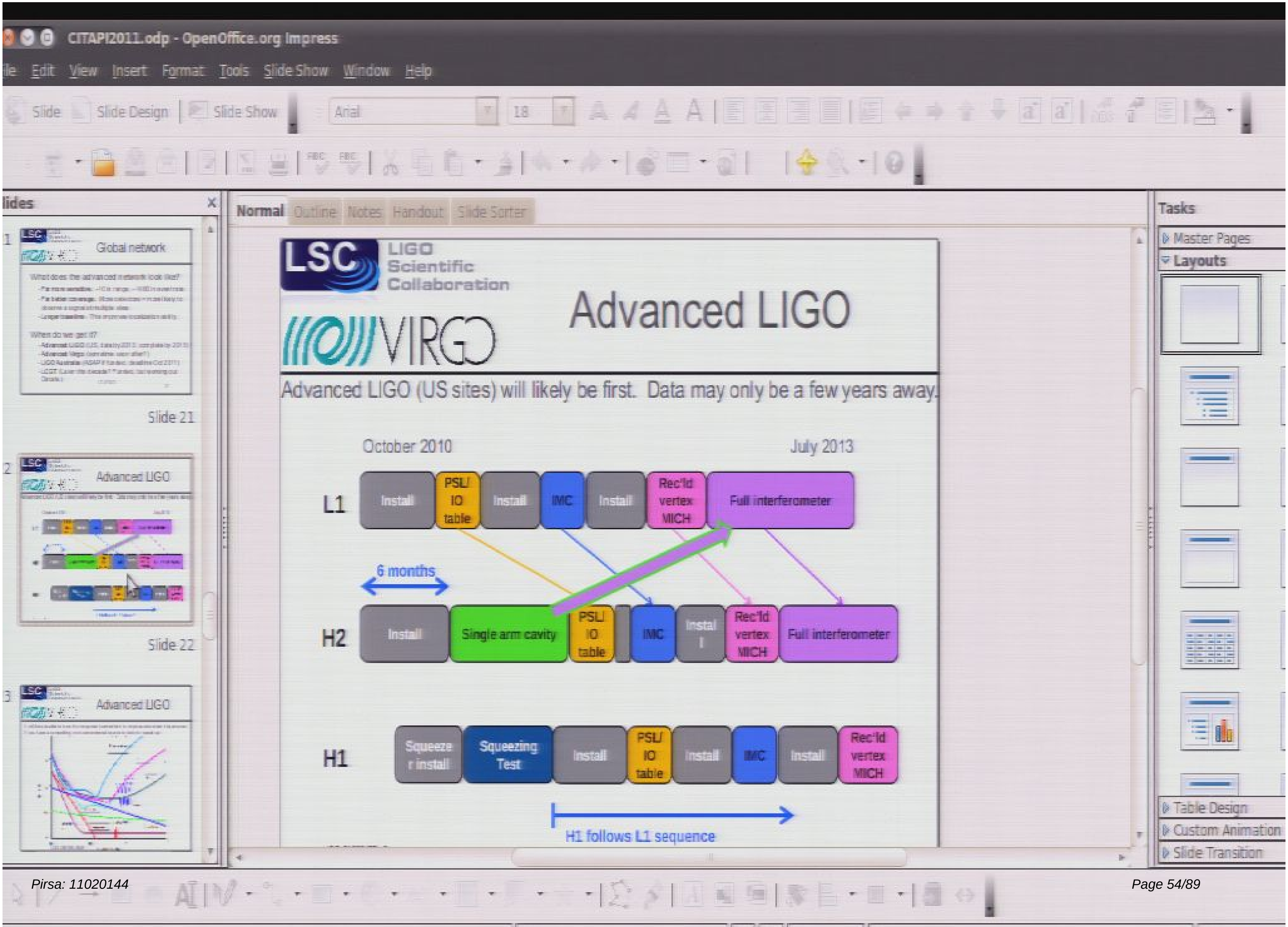
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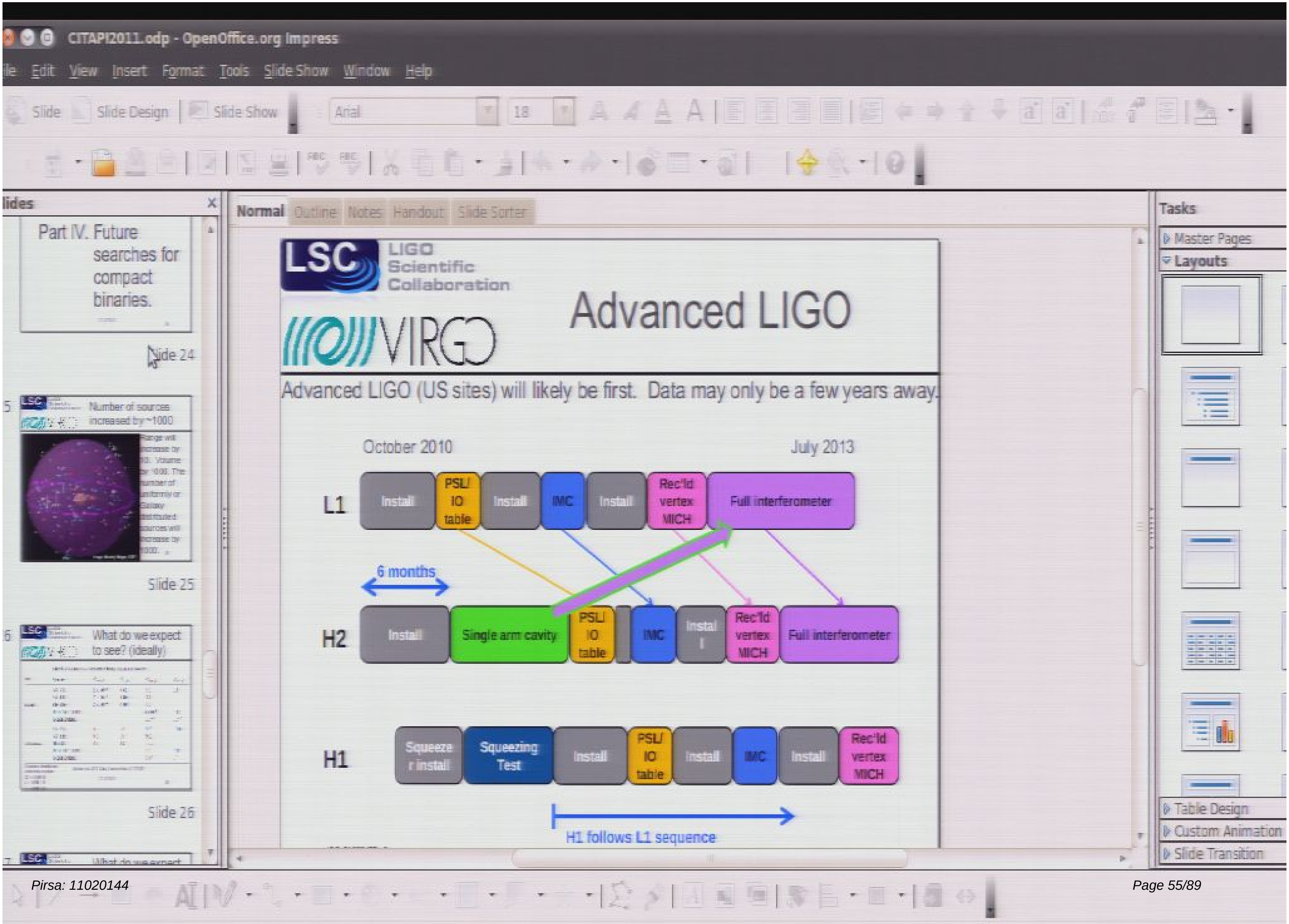
Advanced LIGO
Advanced LIGO (US sites) will likely be first. Data may only be a few years away.
October 2010
July 2013
L1
Install
PSL/ IO table
Install
IMC
Install
Rec'ld vertex MICH
Full interferometer
6 months
H2
Install
Single arm cavity
PSL/ IO table
IMC
Instal l
Rec'ld vertex MICH
Full interferometer
H1
Squeezer install
Squeezing Test
Install
PSL/ IO table
Install
IMC
Install
Rec'ld vertex MICH
H1 follows L1 sequence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6 months
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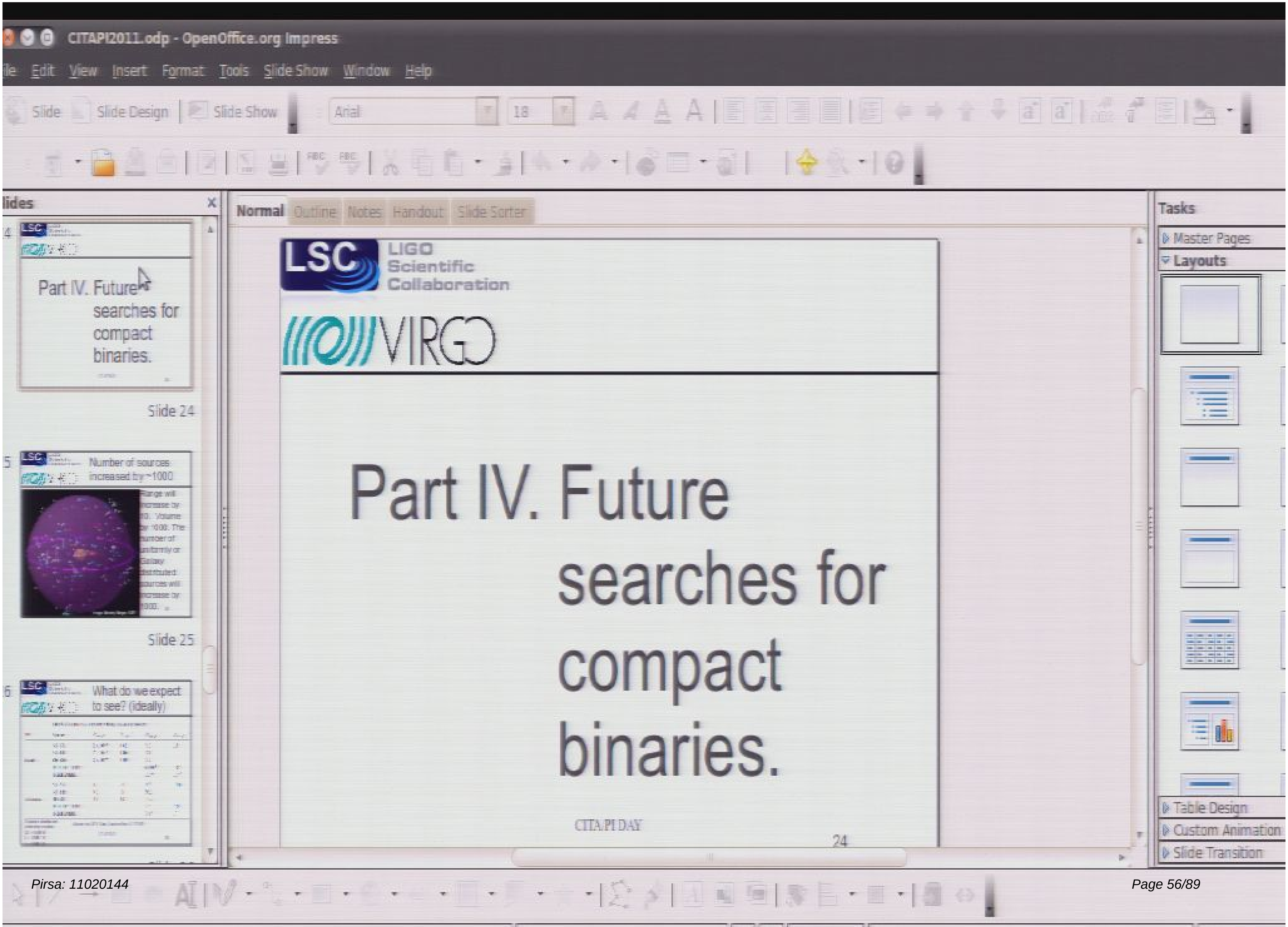
Single arm cavity
PSL/ IO table
IMC
Instal l
Rec'ld vertex MICH
Full interferometer
H1
Squeeze r install
Squeezing Test
Install
PSL/ IO table
Install
IMC
Install
Rec'ld vertex MICH
H1 follows L1 sequence
Part IV. Future searches for compact binaries.
Slide 24
Slide 25
Slide 26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Part IV. Future searches for compact binaries.
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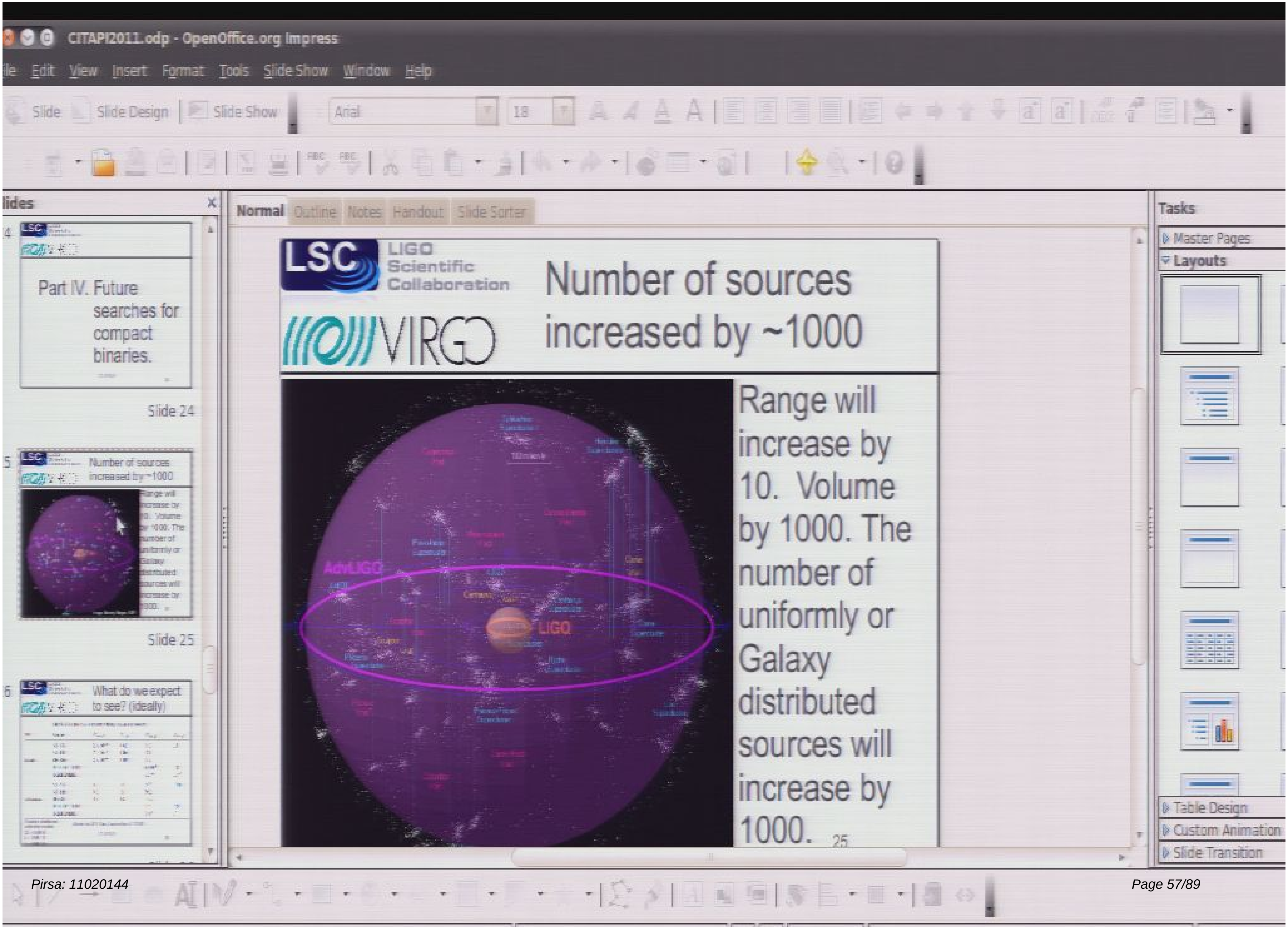
24
Slide 24
Number of sources increased by ~1000
Slide 25
What do we expect to see? (ideally)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Normal Outline Notes Handout Slide Sorter
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Part IV. Future searches for compact binaries.
Slide 24
Number of sources increased by ~1000
Slide 25
What do we expect to see? (ideally)
LSC LIGO Scientific Collaboration
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Number of sources increased by ~1000
AdvLIGO
LIGO
Range will increase by 10. Volume by 1000. The number of uniformly or Galaxy distributed sources will increase by 1000.
25

What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
Initial	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			<0.001[b]	0.01[c]
	IMBH-IMBH			10^{-4}[d]	10^{-3}[e]
Advanced	NS–NS	0.4	40	400	1000
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Sources distributed uniformly implies
32 > SNR 8
4 > SNR 16

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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Table 5. Detection rates for compact binary coalescence sources.

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J Abadie et al 2010 Class. Quantum Grav. 27 173001

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VIRGO

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Sources distributed uniformly implies
32 > SNR 8
4 > SNR 16
1 > SNR 25

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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4 > SNR 16
1 > SNR 25

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What do we expect to see? (Realistically)

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It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

40 events → 5 events, all near threshold
Can we make confident detection(s) early?
YES! But it will require a lot of work...

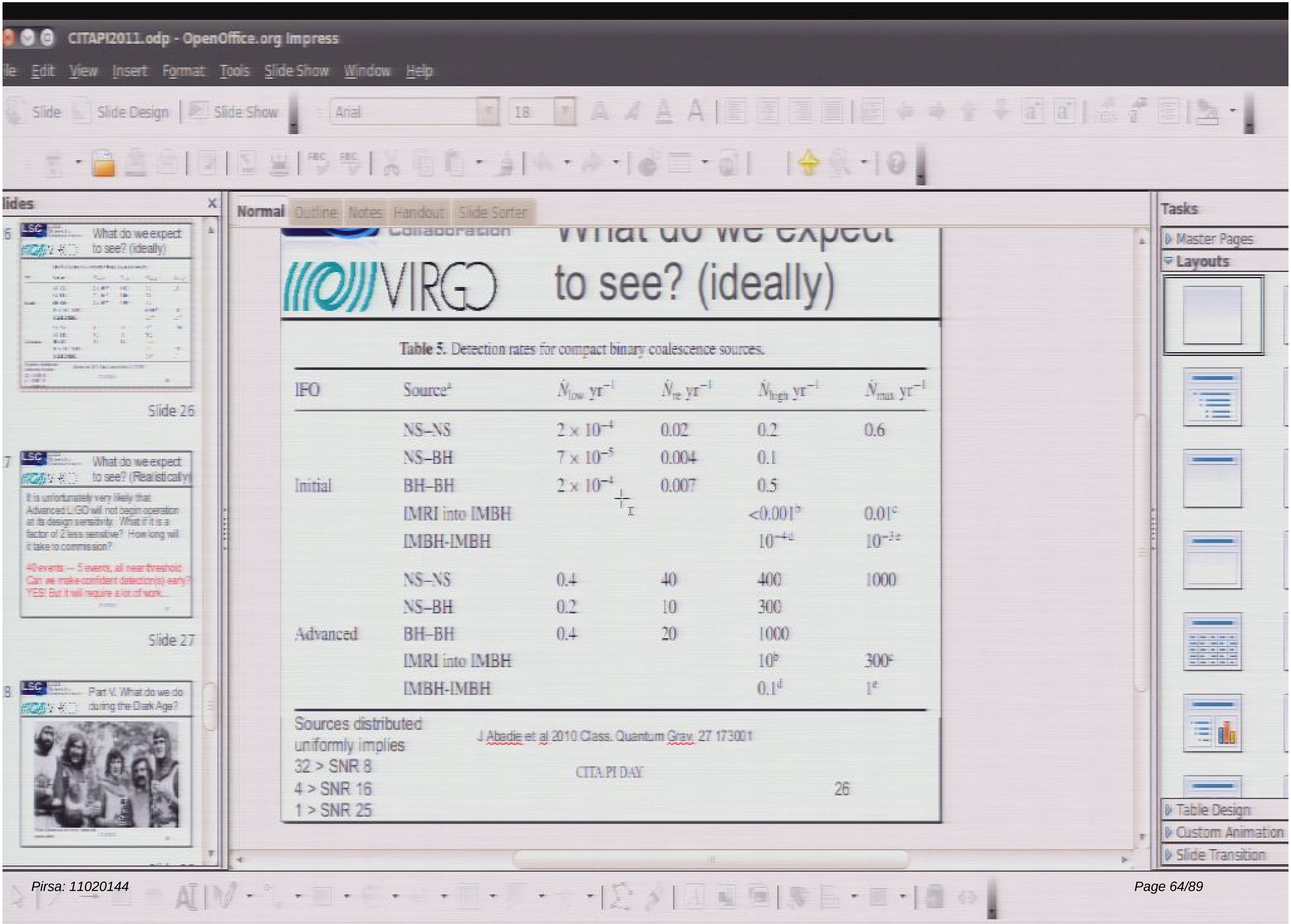

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			$<0.001^{b}$	0.01^{c}
	IMBH-IMBH			10^{-4d}	10^{-3e}
	NS–NS	0.4	40	400	1000
	NS–BH	0.2	10	300	
Advanced	BH–BH	0.4	20	1000	
	IMRI into IMBH			10^{b}	300^{c}
	IMBH-IMBH			0.1^{d}	1^{e}

Sources distributed uniformly implies
32 > SNR 8
4 > SNR 16
1 > SNR 25

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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What do we expect to see? (Realistically)

It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

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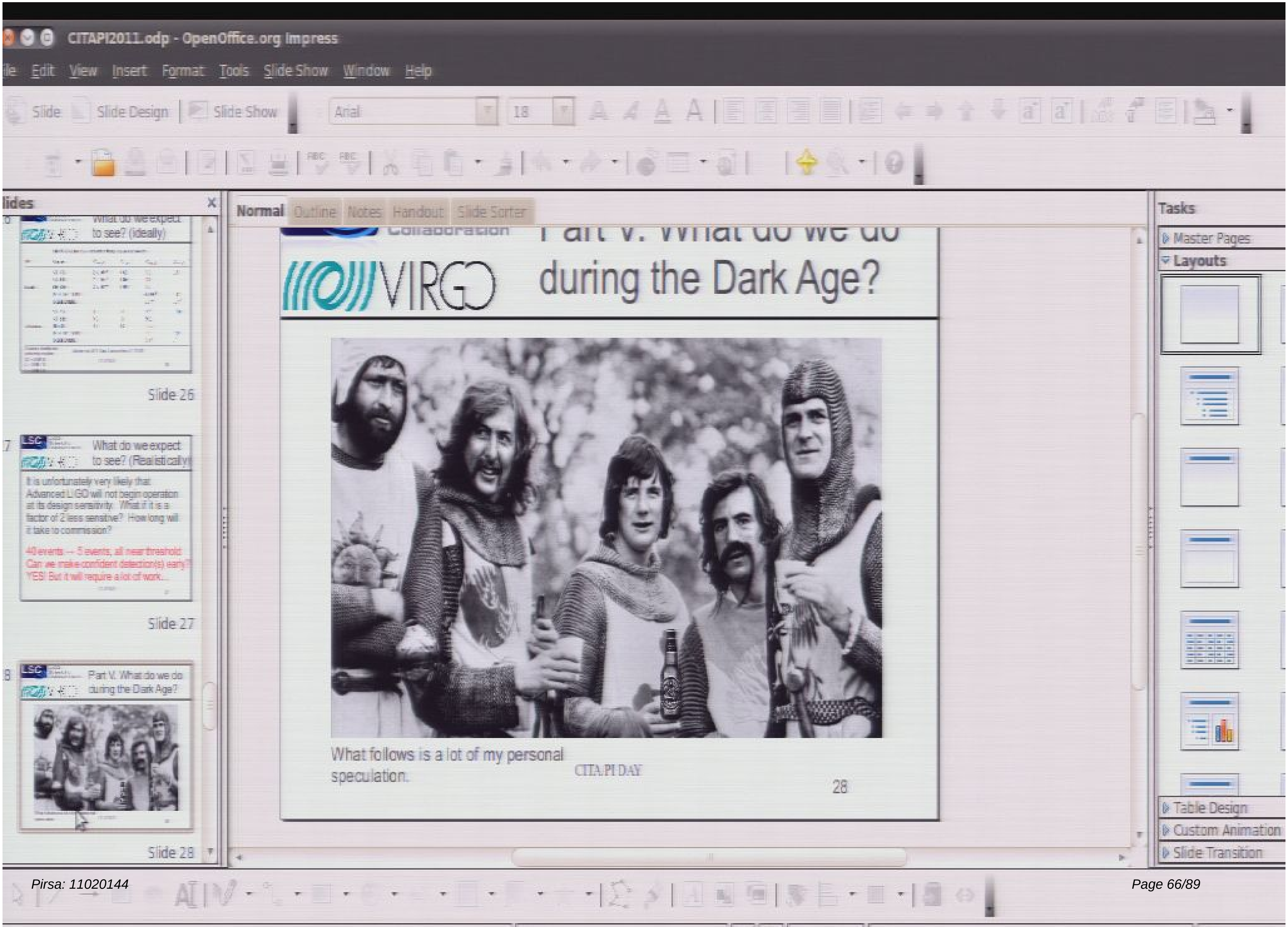
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Part V. What do we do during the Dark Age?
VIRGO
What follows is a lot of my personal speculation.
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Slide 26
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Slide 27
Slide 28

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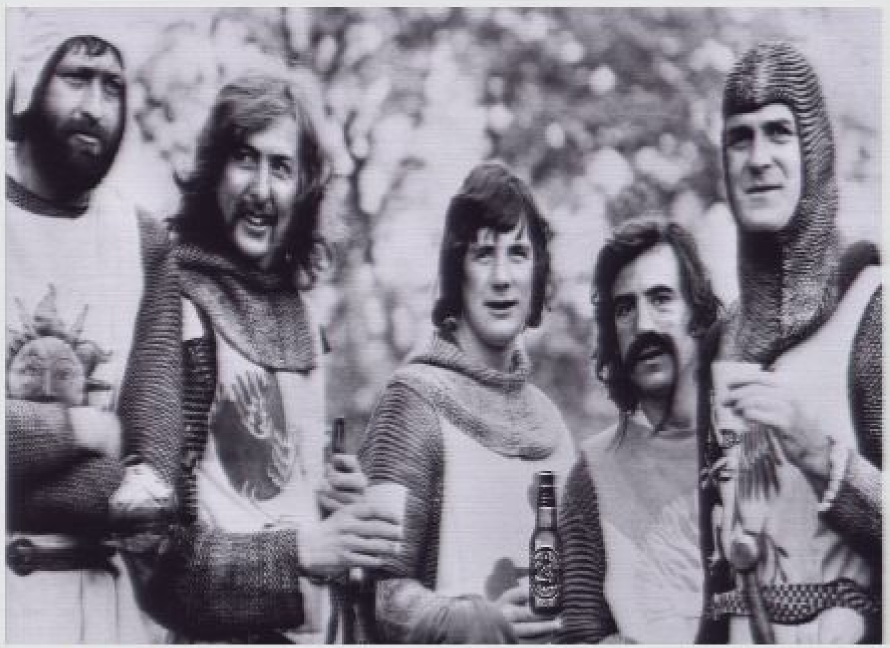
Part V. What do we do during the Dark Age?



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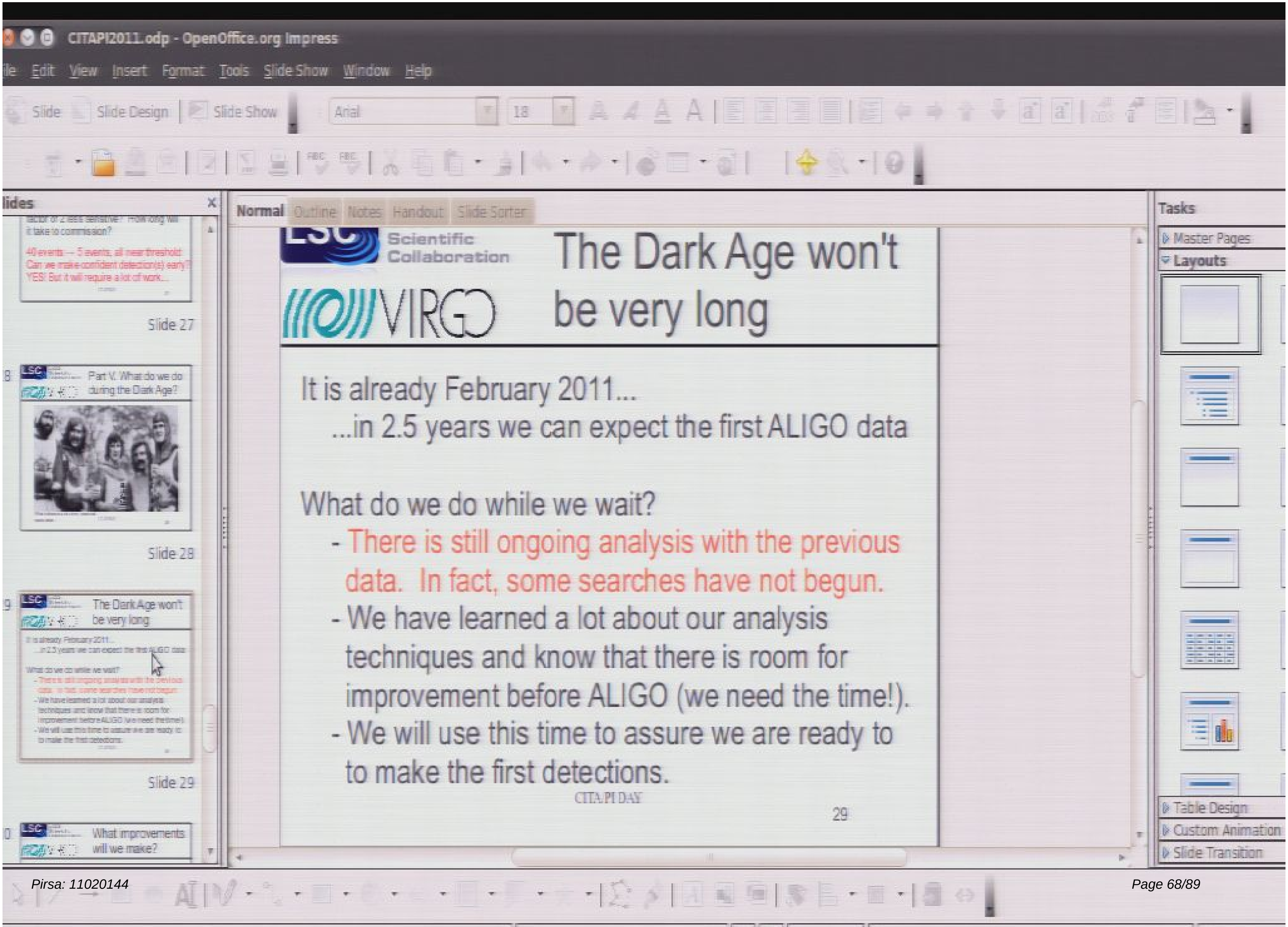
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The Dark Age won't be very long
It is already February 2011...
...in 2.5 years we can expect the first ALIGO data
What do we do while we wait?
- There is still ongoing analysis with the previous data. In fact, some searches have not begun.
- We have learned a lot about our analysis techniques and know that there is room for improvement before ALIGO (we need the time!).
- We will use this time to assure we are ready to to make the first detections.
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Slide 28
Slide 29
Part V. What do we do during the Dark Age?
What improvements will we make?
Tasks
Master Pages
Layouts
Table Design
Custom Animation
Slide Transition

What improvements will we make?

Improving our confidence in detections

- The first events will be near threshold (statistically)
- We have to be able to pin down the false-alarm probability (FAP).

How can we improve our confidence?

- Improved detector characterization schemes. We need to know when the detector is misbehaving.
- Improved background estimation, understanding how instrumental glitches effect the analysis.
- EM coincidence.

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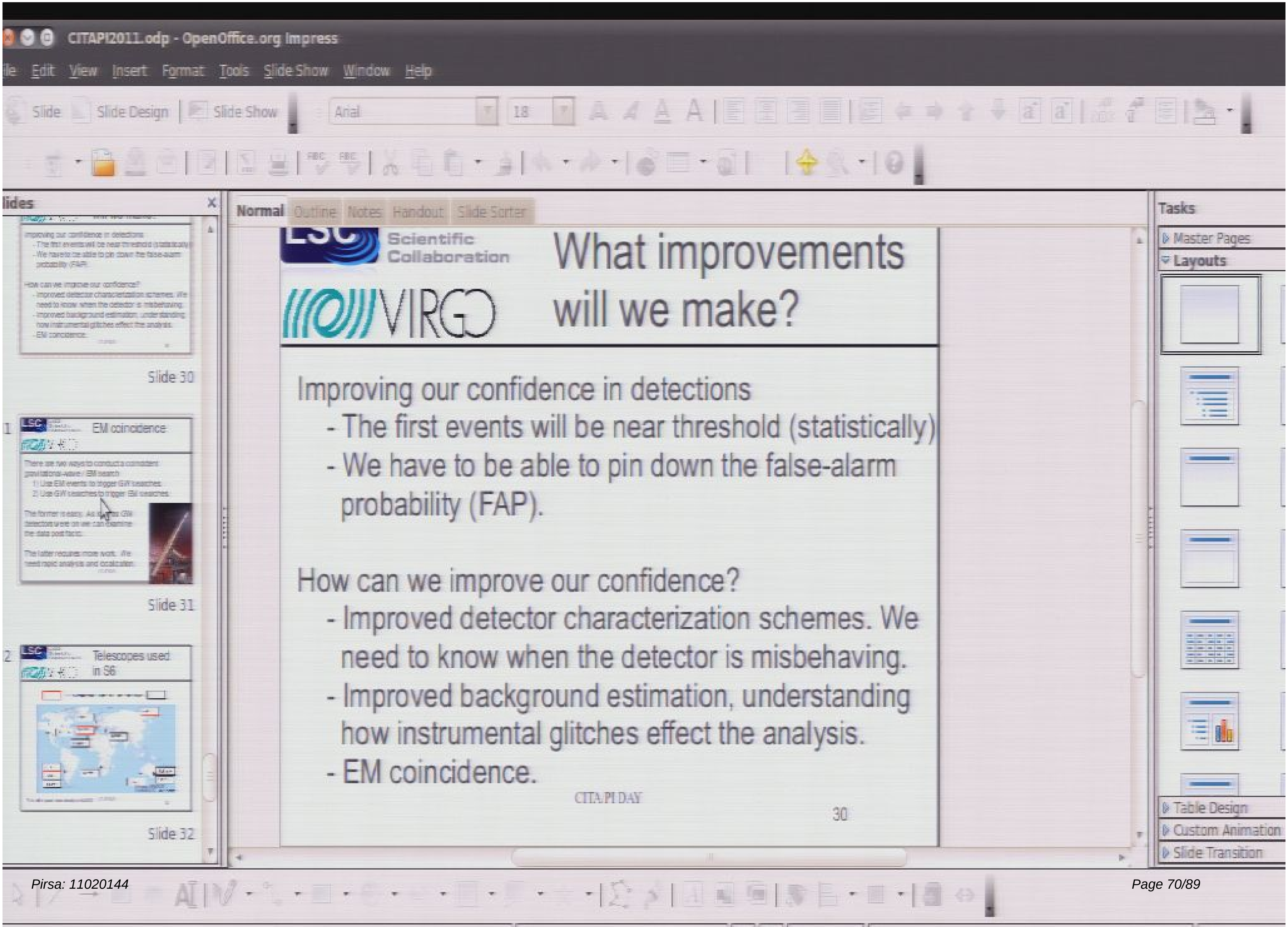
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EM coincidence
Slide 31
Telescopes used in S6
Slide 32
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EM coincidence

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There are two ways to conduct a coincident gravitational-wave / EM search

1) Use EM events to trigger GW searches.
2) Use GW searches to trigger EM searches.

The former is easy. As long as GW detectors were on we can examine the data post facto.

The latter requires more work. We need rapid analysis and localization.

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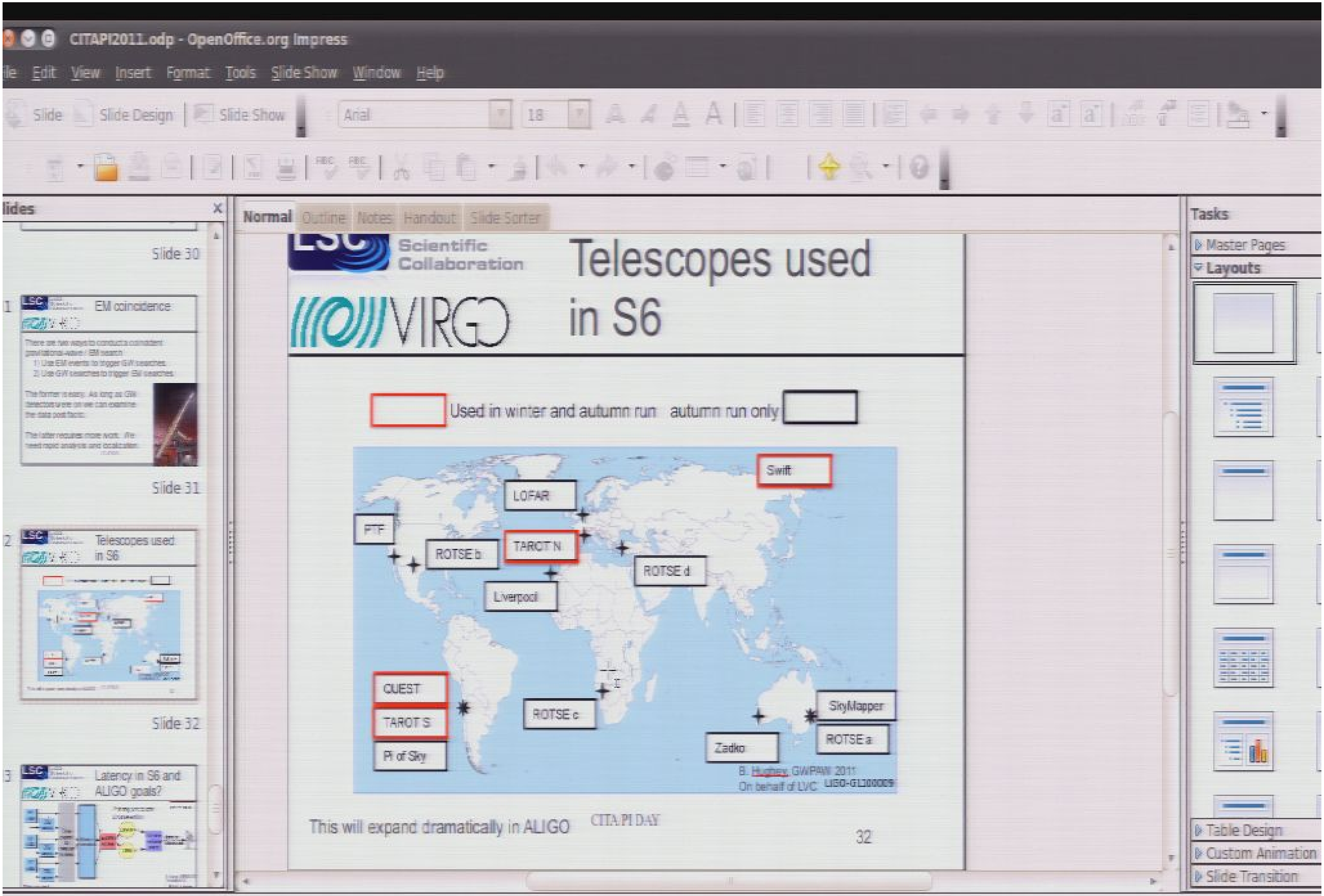
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Telescopes used in S6
LSC Scientific Collaboration
VIRGO
Used in winter and autumn run
autumn run only
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LOFAR
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ROTSE b
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TAROT S
Pi of Sky
ROTSE c
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ROTSE a
B. Hughey, GWPAW 2011
On behalf of LVC
LIGO-G1100009
This will expand dramatically in ALIGO
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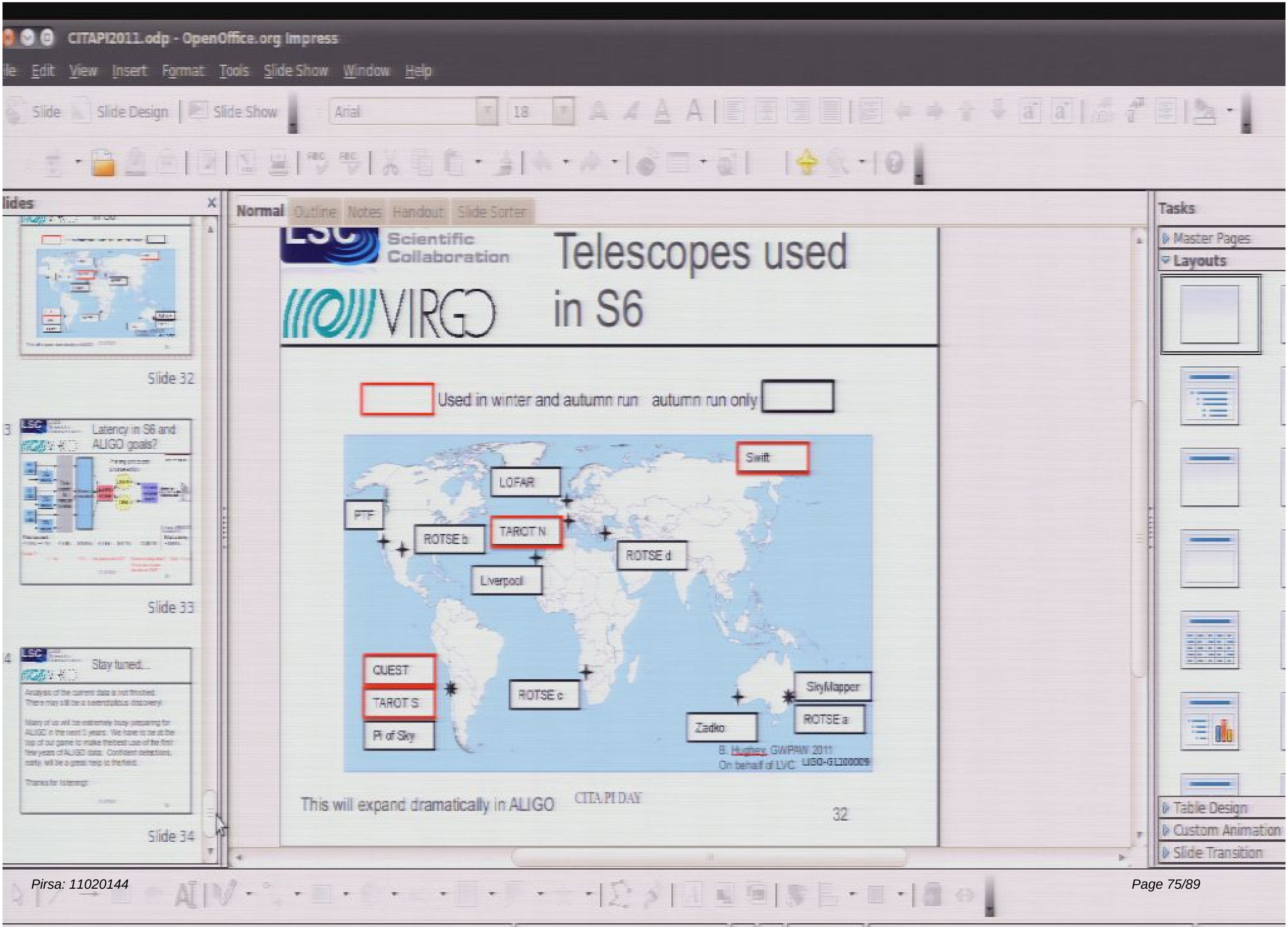
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Latency in S6 and ALIGO goals?
Stay tuned...
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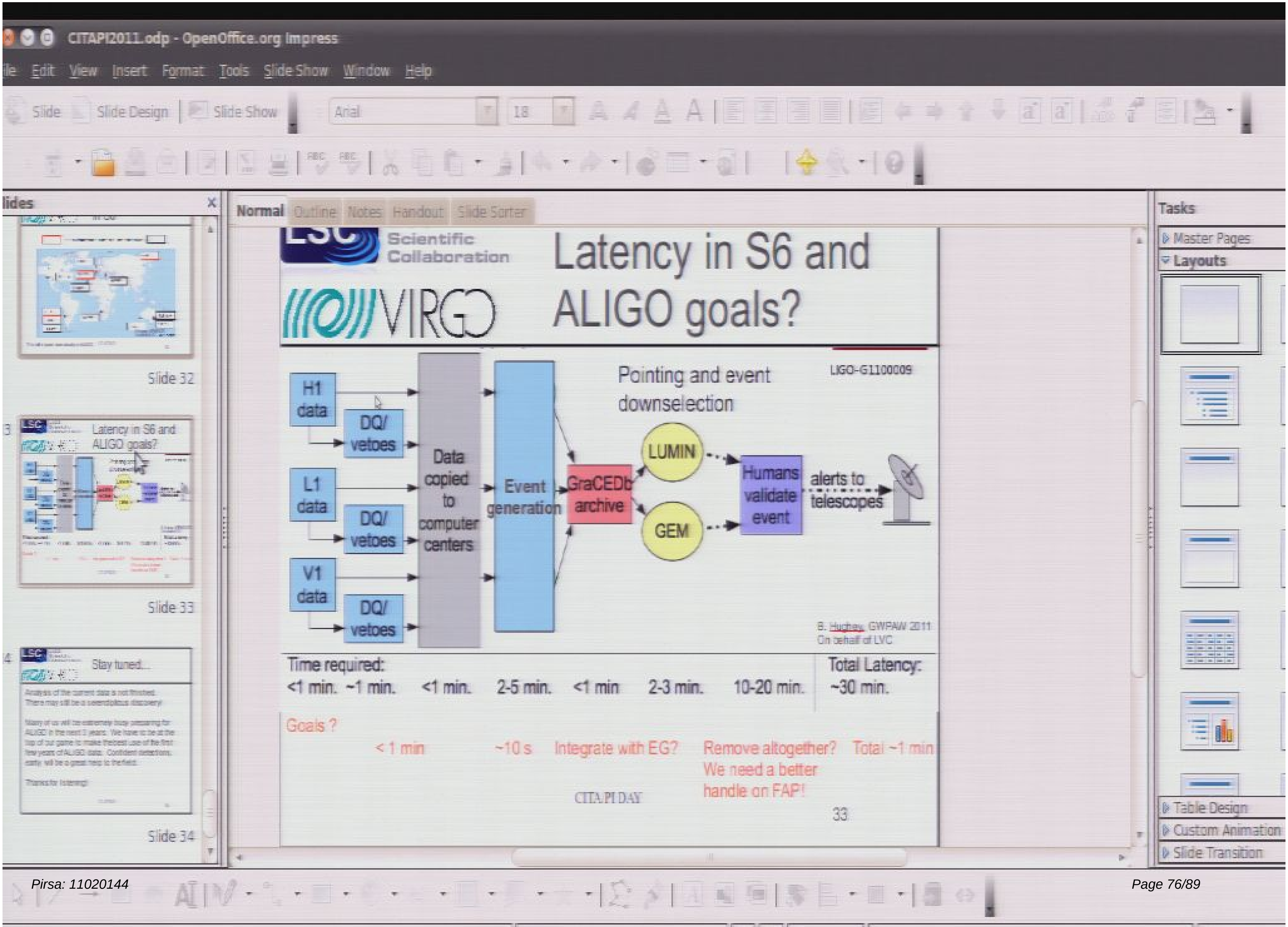
Slide 34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VIRGO
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LIGO-G1100009
Pointing and event downselection
H1 data
L1 data
V1 data
DQ/ vetoes
DQ/ vetoes
DQ/ vetoes
Data copied to computer centers
Event generation
GraCEDb archive
LUMIN
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Humans validate event
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B. Hughey, GWPAW 2011
On behalf of LVC
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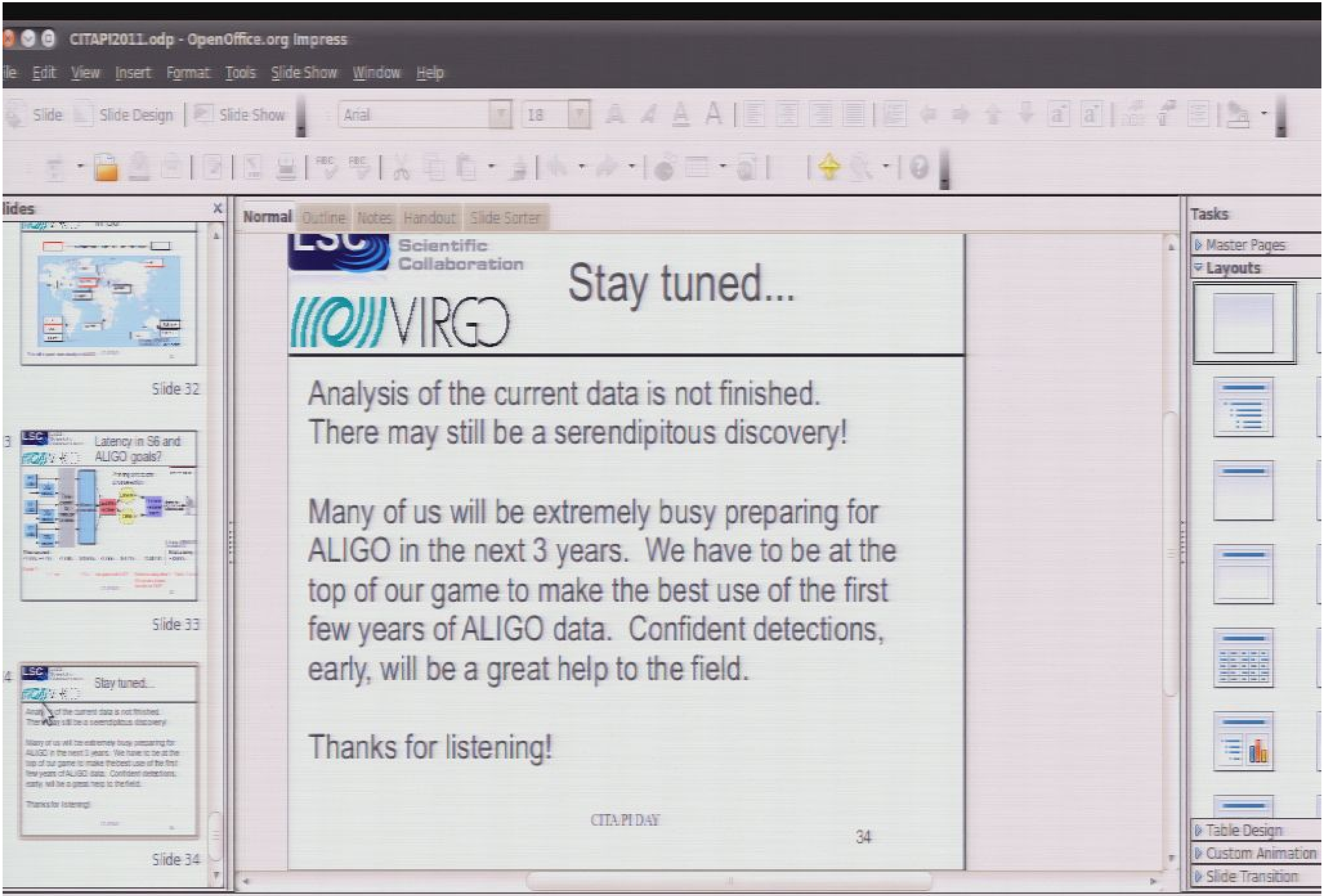
33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Analysis of the current data is not finished.
There may still be a serendipitous discovery!
Many of us will be extremely busy preparing for ALIGO in the next 3 years. We have to be at the top of our game to make the best use of the first few years of ALIGO data. Confident detections, early, will be a great help to the field.
Thanks for listening!
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Slide 32
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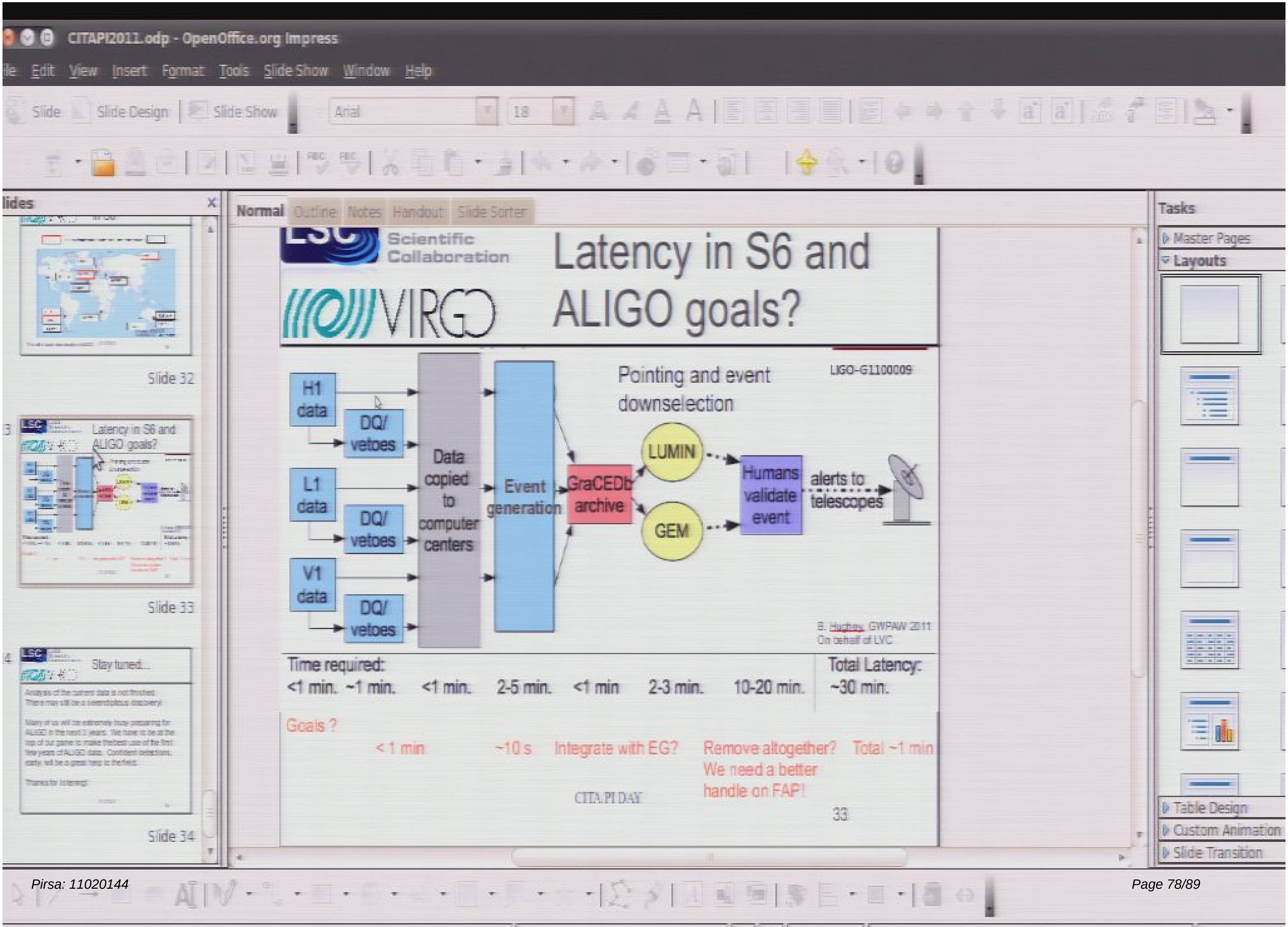
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No Signal
VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

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No Signal
VGA-1


No Signal
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