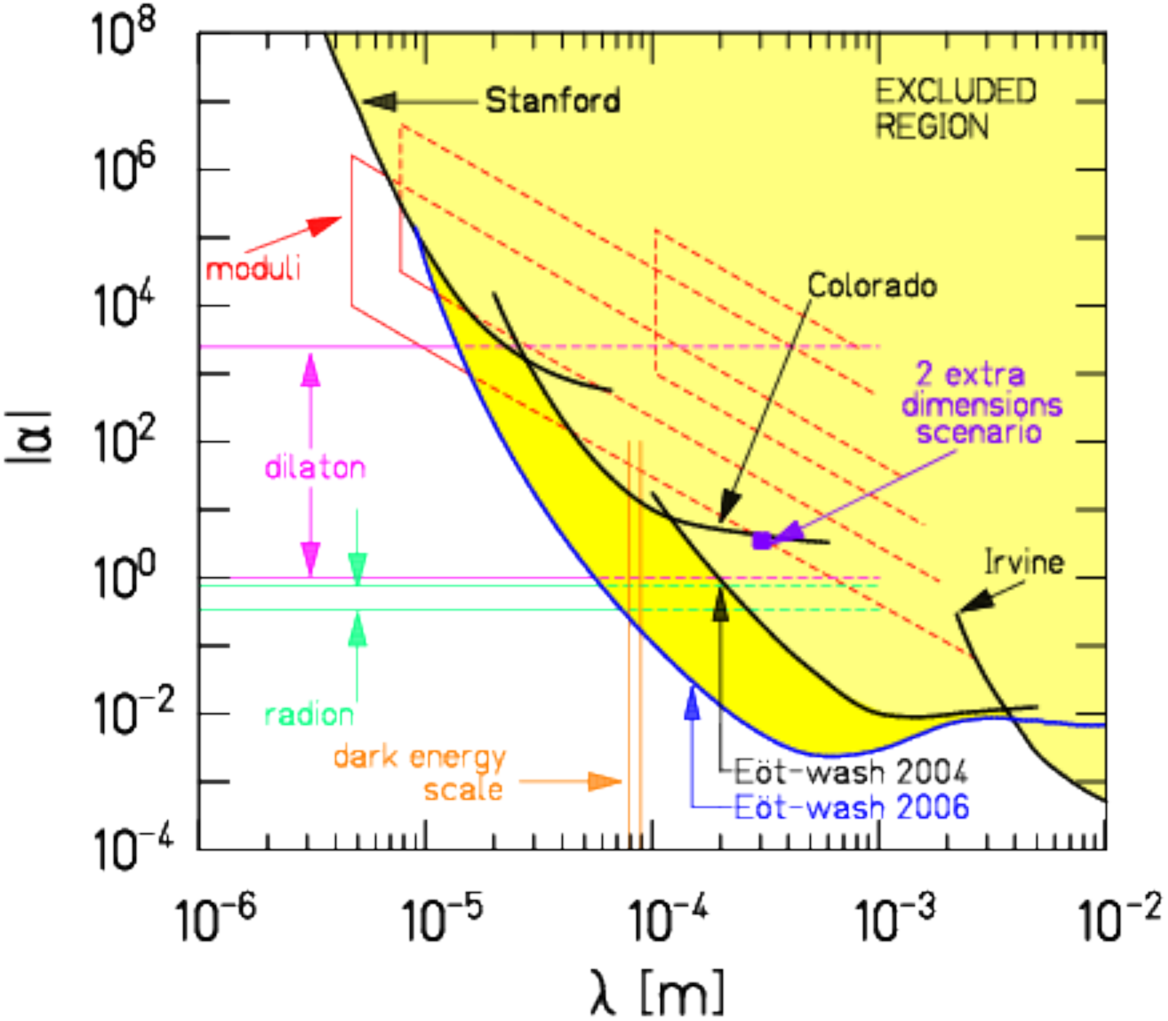
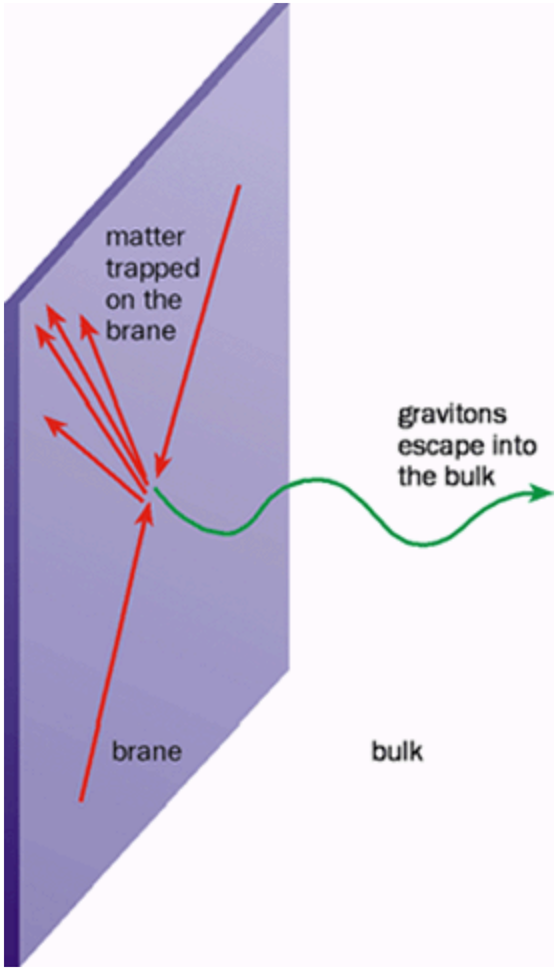
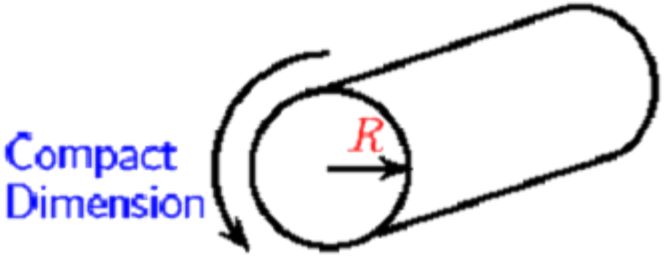
Experimental constraints on deviations from Newton's law



Parametrisation: $F(r) = \frac{Gm_1m_2}{r^2}(1+\alpha e^{-r/\lambda})$

Extra dimensions

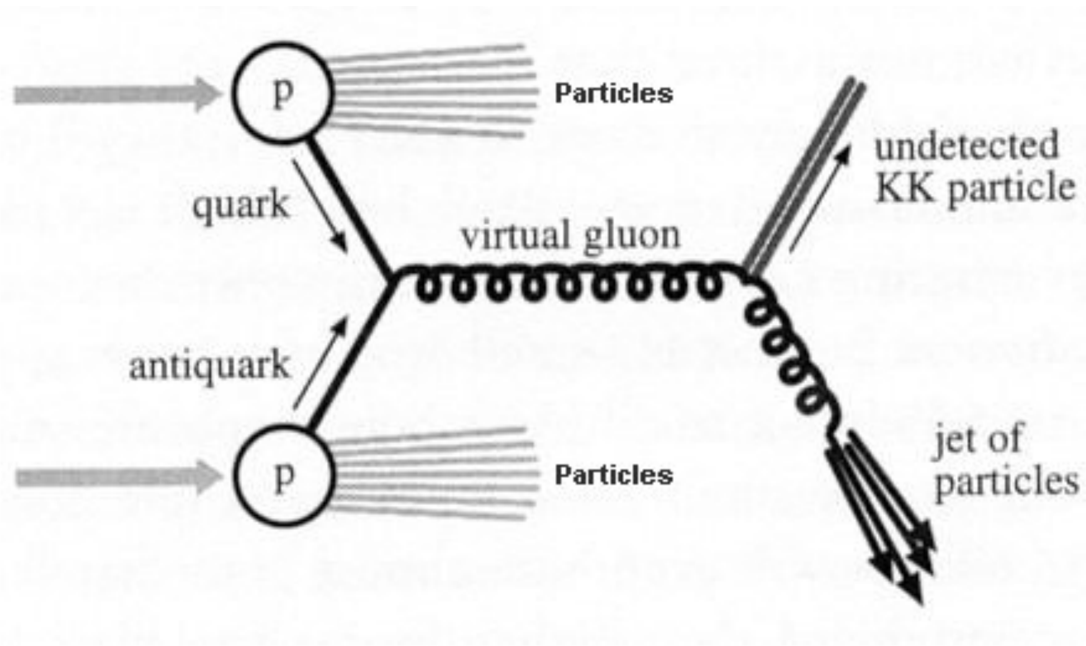




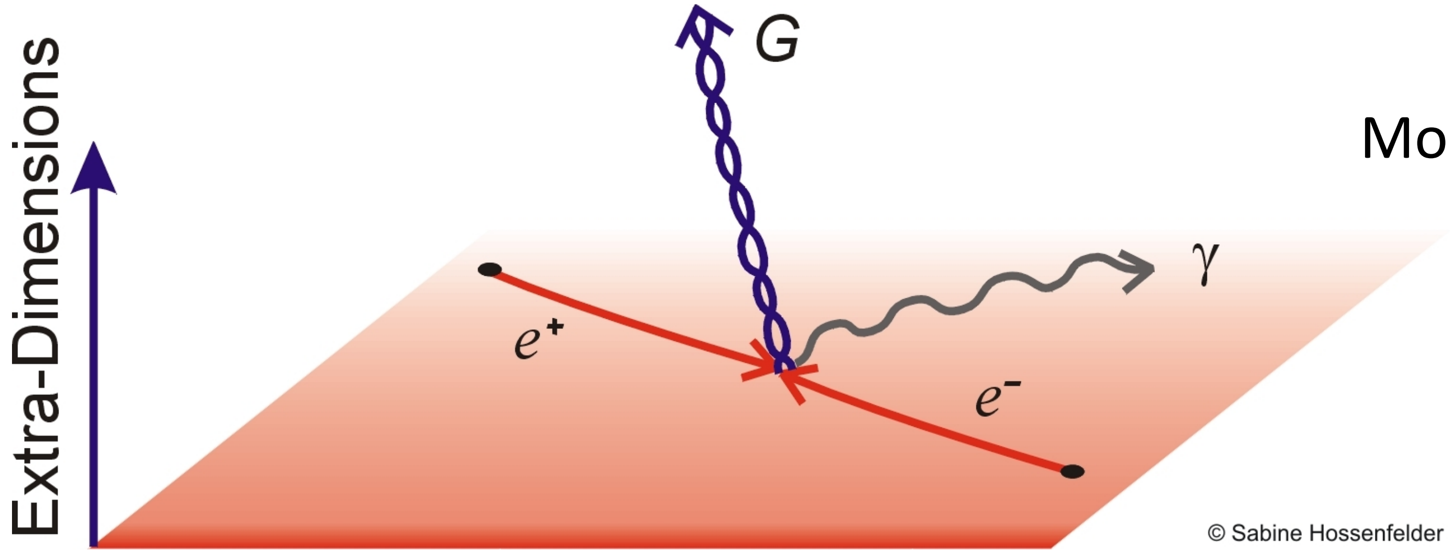
$$\phi(x) = \phi(x + k2\pi R)$$

$$(k = 0, 1, 2, ...)$$

$$p = k/R$$



Monojet



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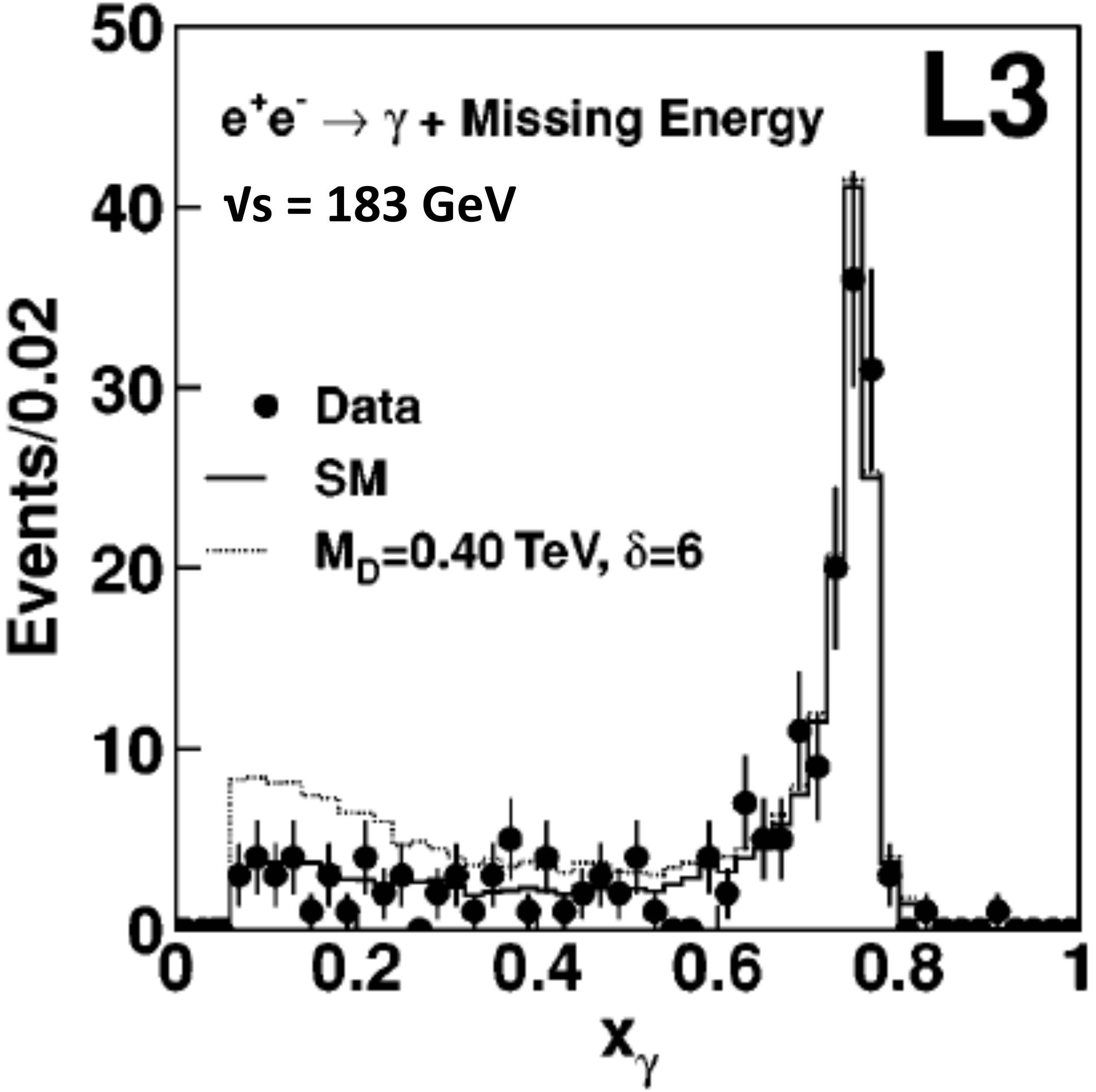
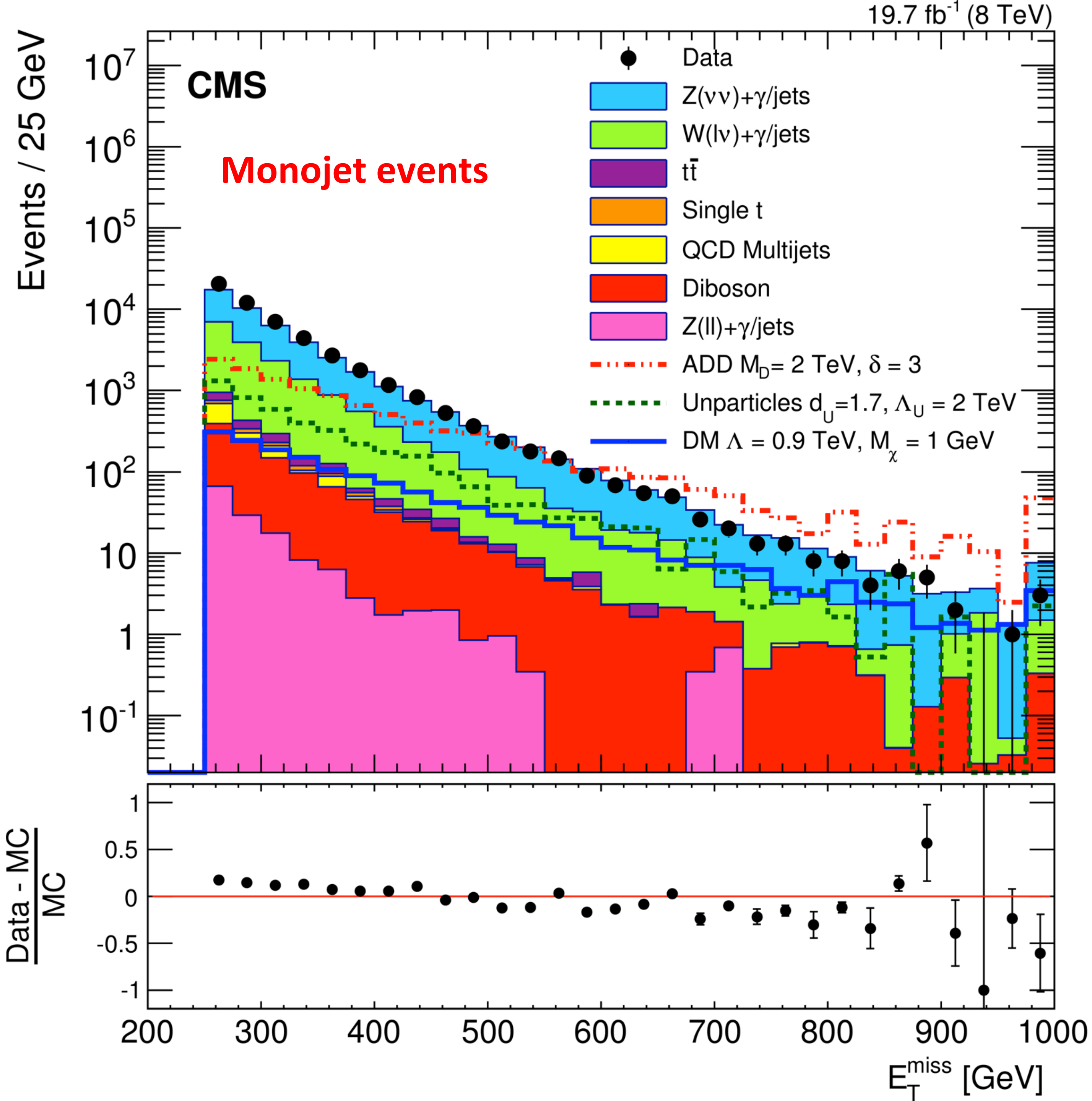
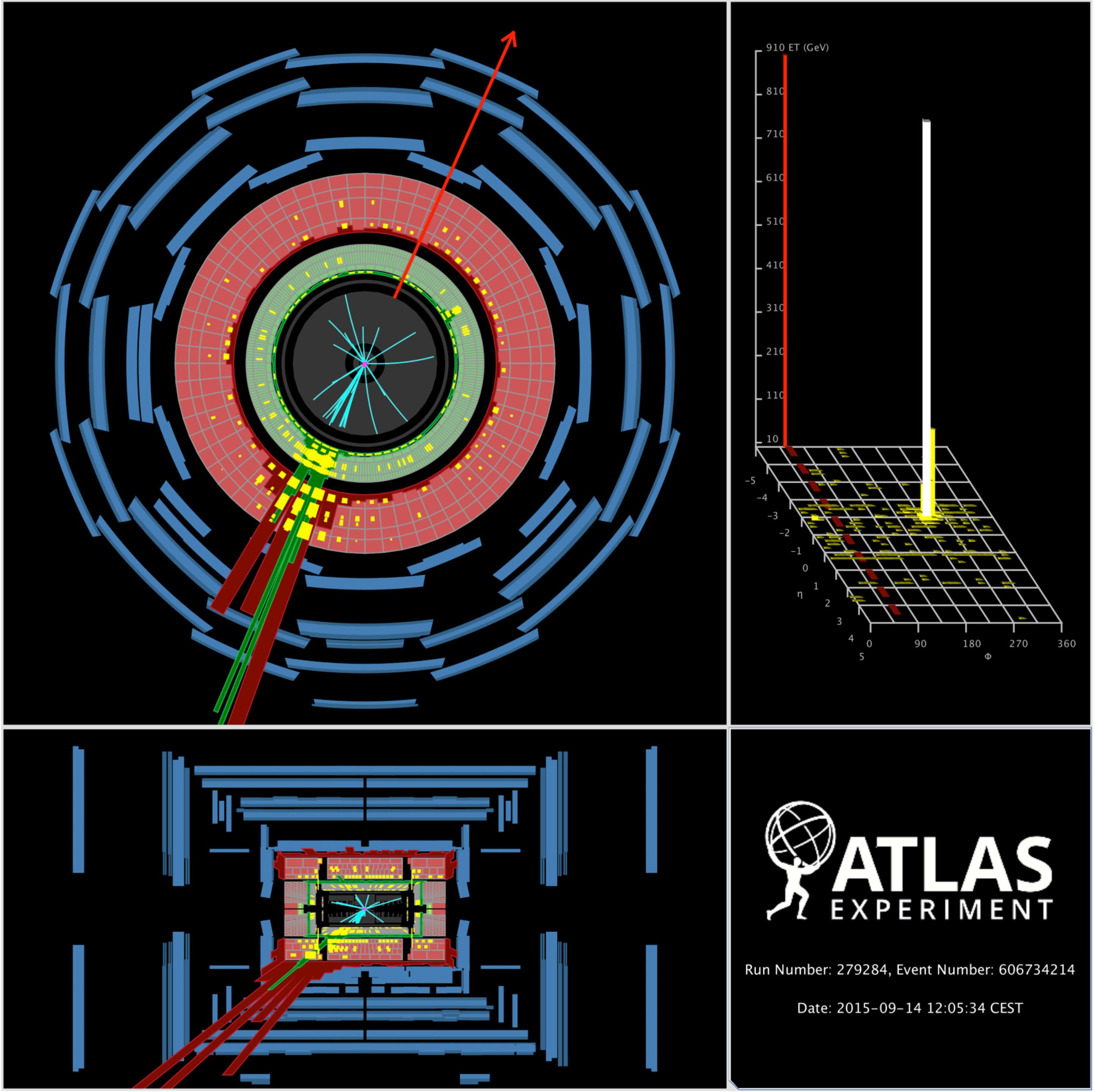
Monophoton



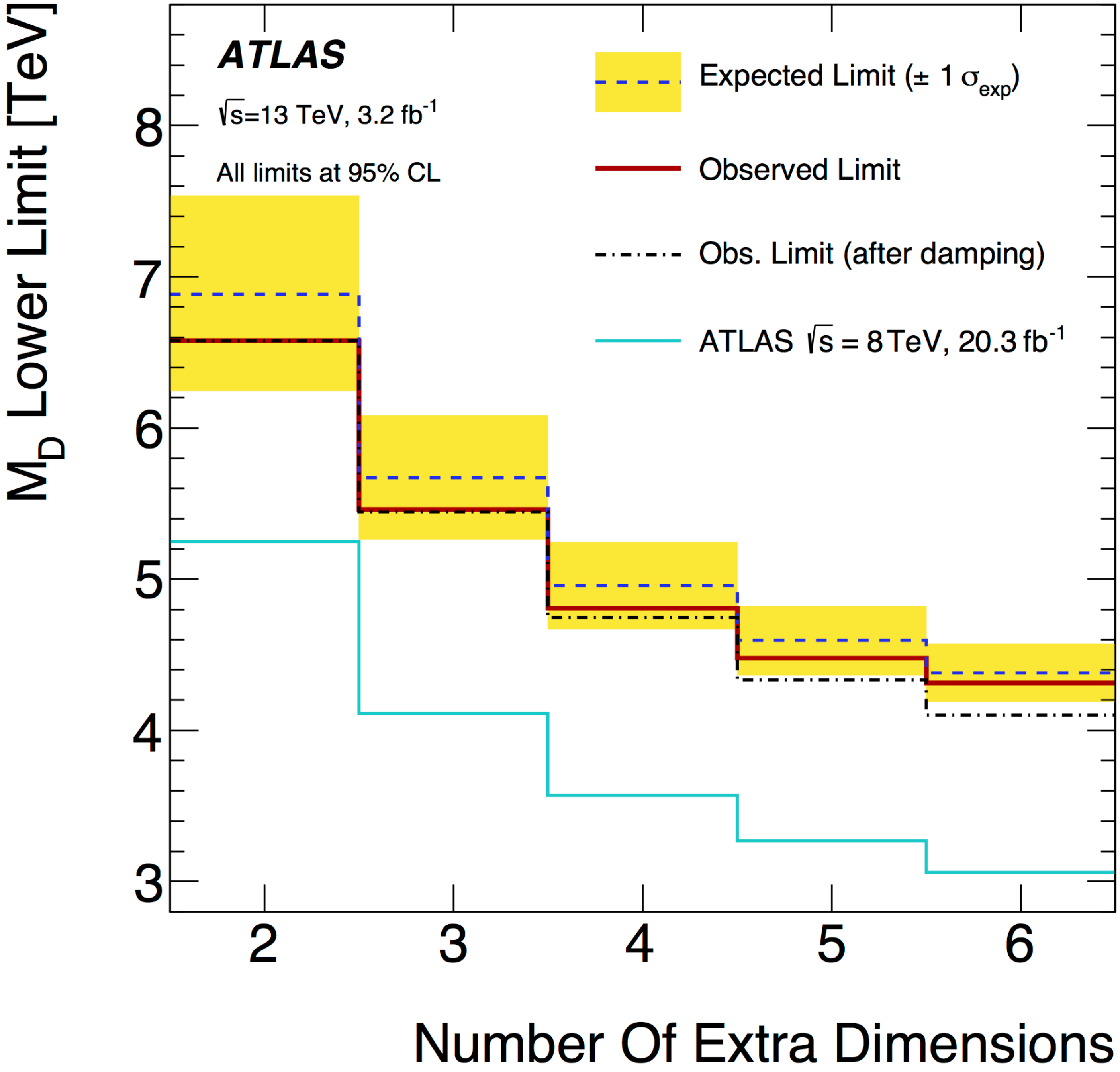
x_γ = fraction of beam energy carried by photon


19.7 fb^{-1} (8 TeV)
CMS
Monojet events
Data
Z(νν)+γ/jets
W(lν)+γ/jets
$t\bar{t}$
Single t
QCD Multijets
Diboson
Z(ll)+γ/jets
ADD M_D= 2 TeV, δ = 3
Unparticles d_U=1.7, Λ_U = 2 TeV
DM Λ = 0.9 TeV, M_χ = 1 GeV
Events / 25 GeV
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
$\frac{\text{Data - MC}}{\text{MC}}$
1
0.5
0
-0.5
-1
200
300
400
500
600
700
800
900
1000
E_T^{miss} [GeV]

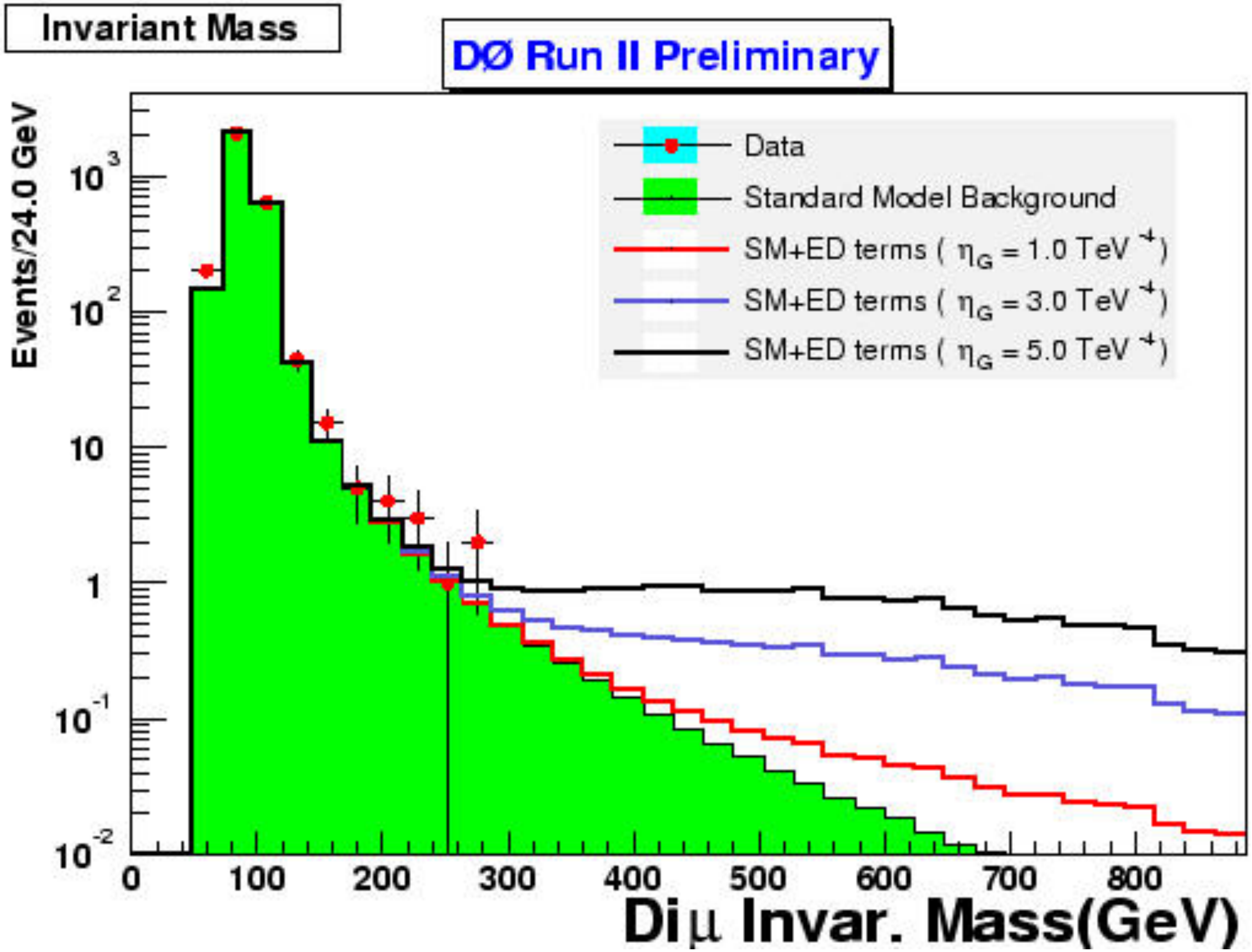


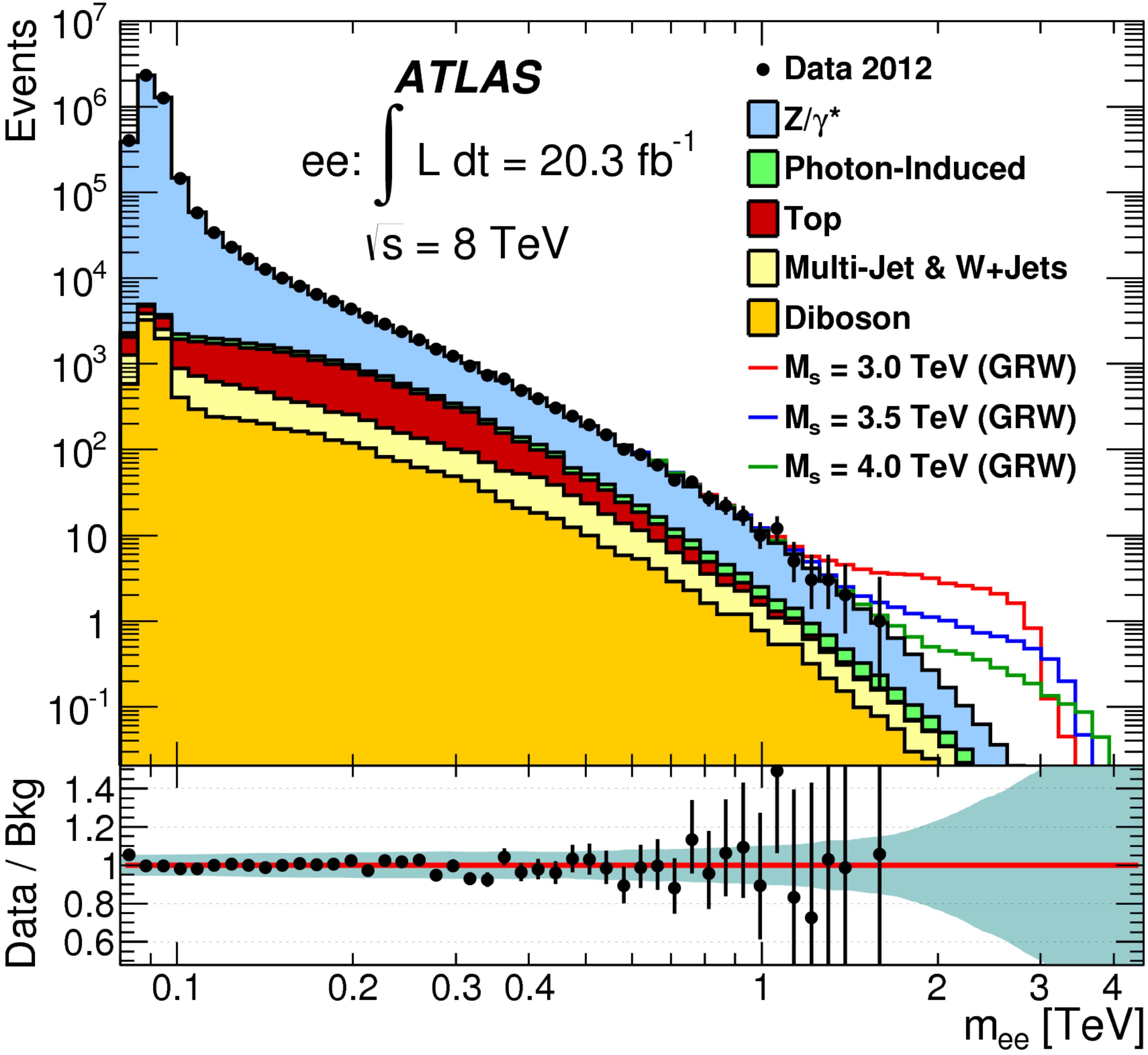
Run Number: 279284, Event Number: 606734214

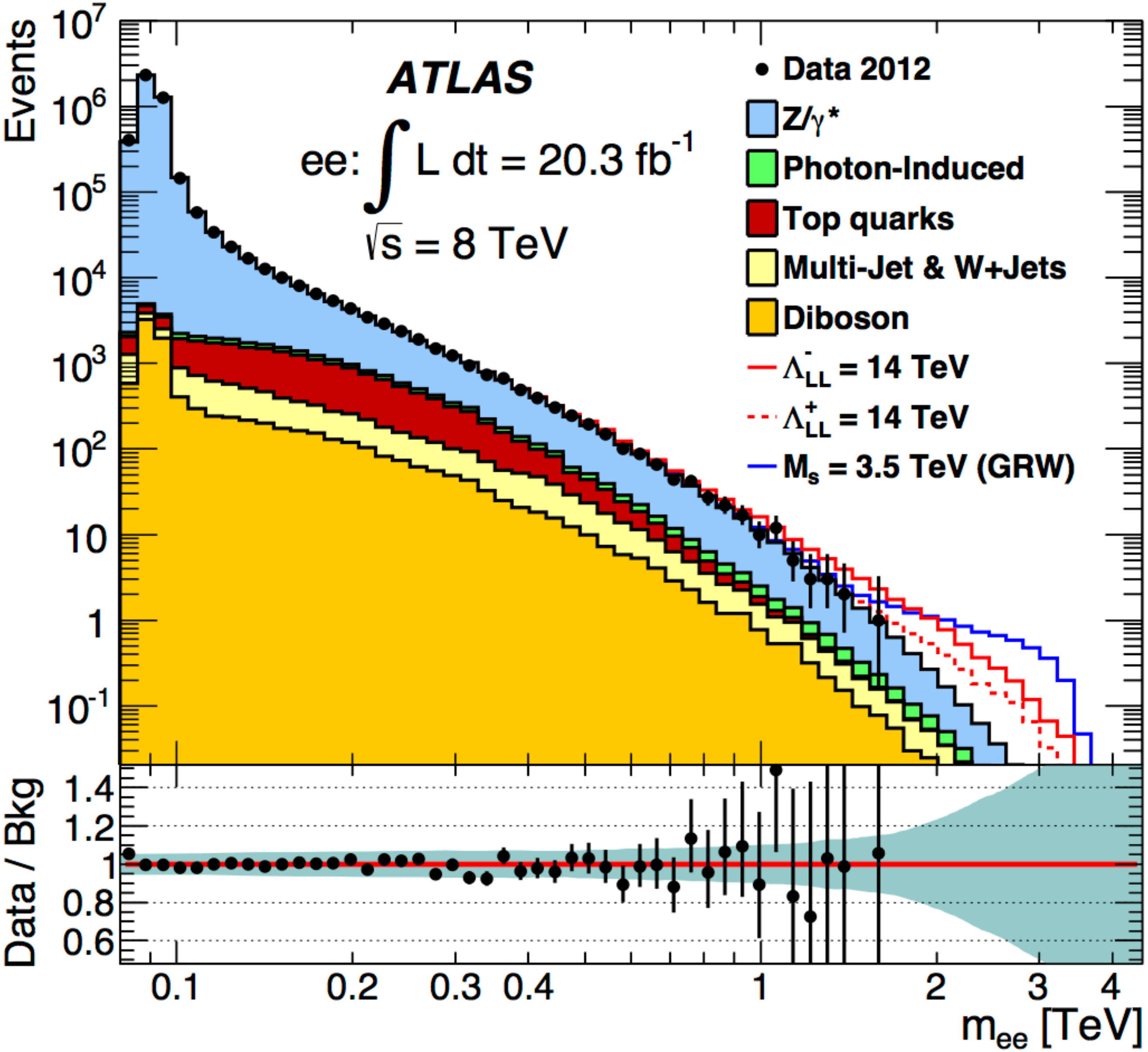
Date: 2015-09-14 12:05:34 CEST


ATLAS
$\sqrt{s}$=13 TeV, 3.2 fb^{-1}
All limits at 95% CL
Expected Limit (± 1 σ_{exp})
Observed Limit
Obs. Limit (after damping)
ATLAS $\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}
M_D Lower Limit [TeV]
3
4
5
6
7
8
2
3
4
5
6
Number Of Extra Dimensions

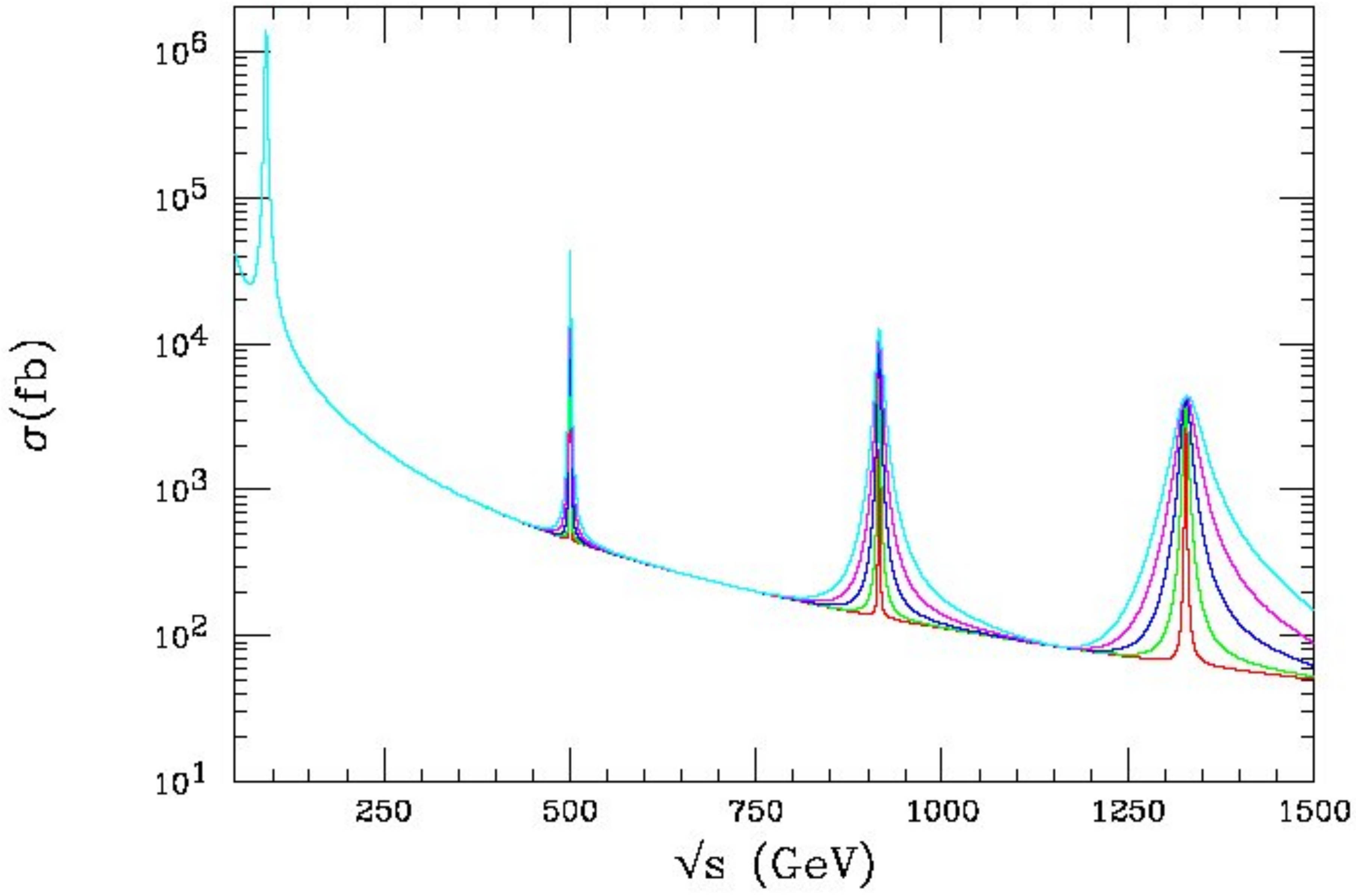
Effects from graviton exchange

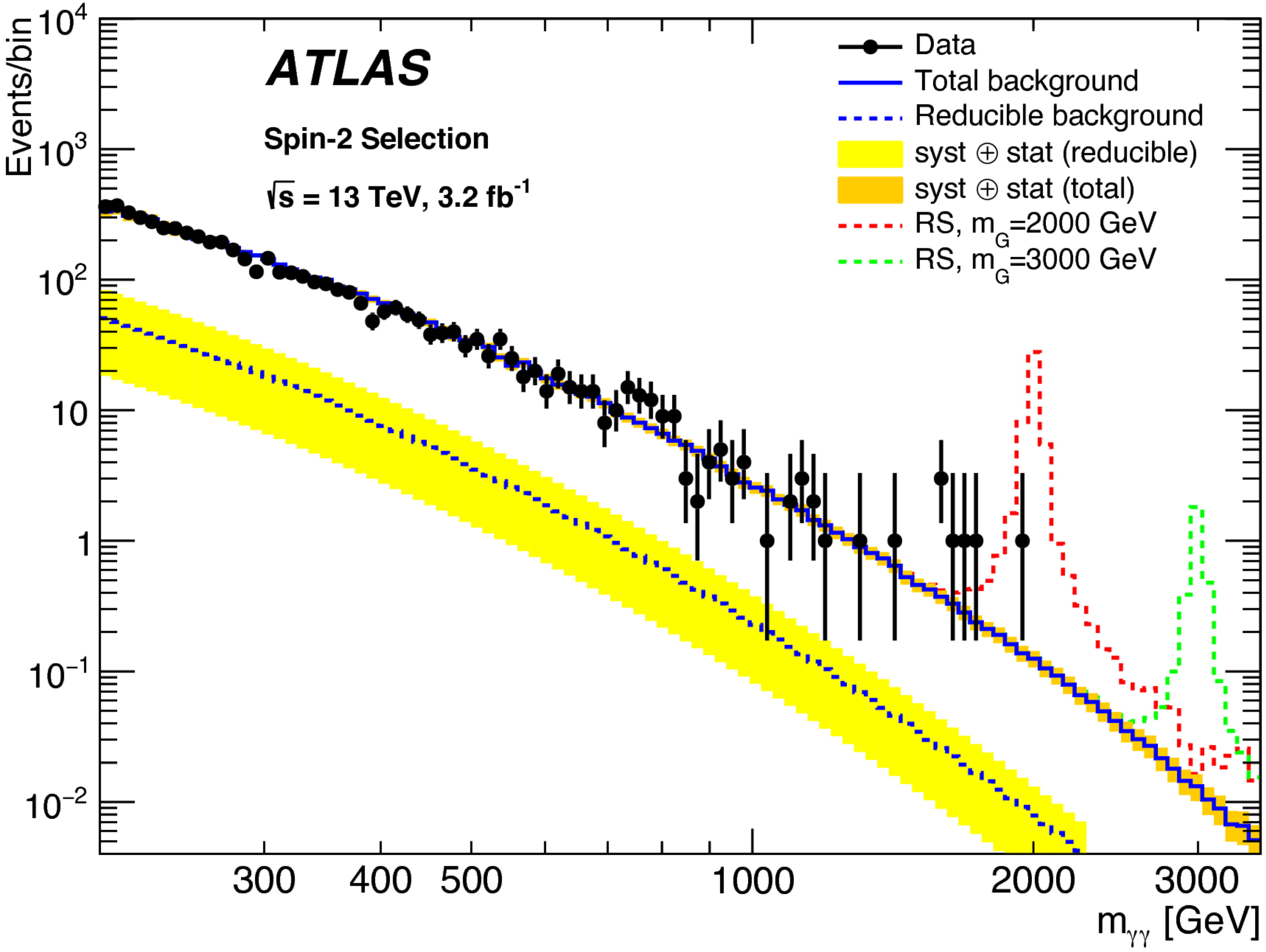


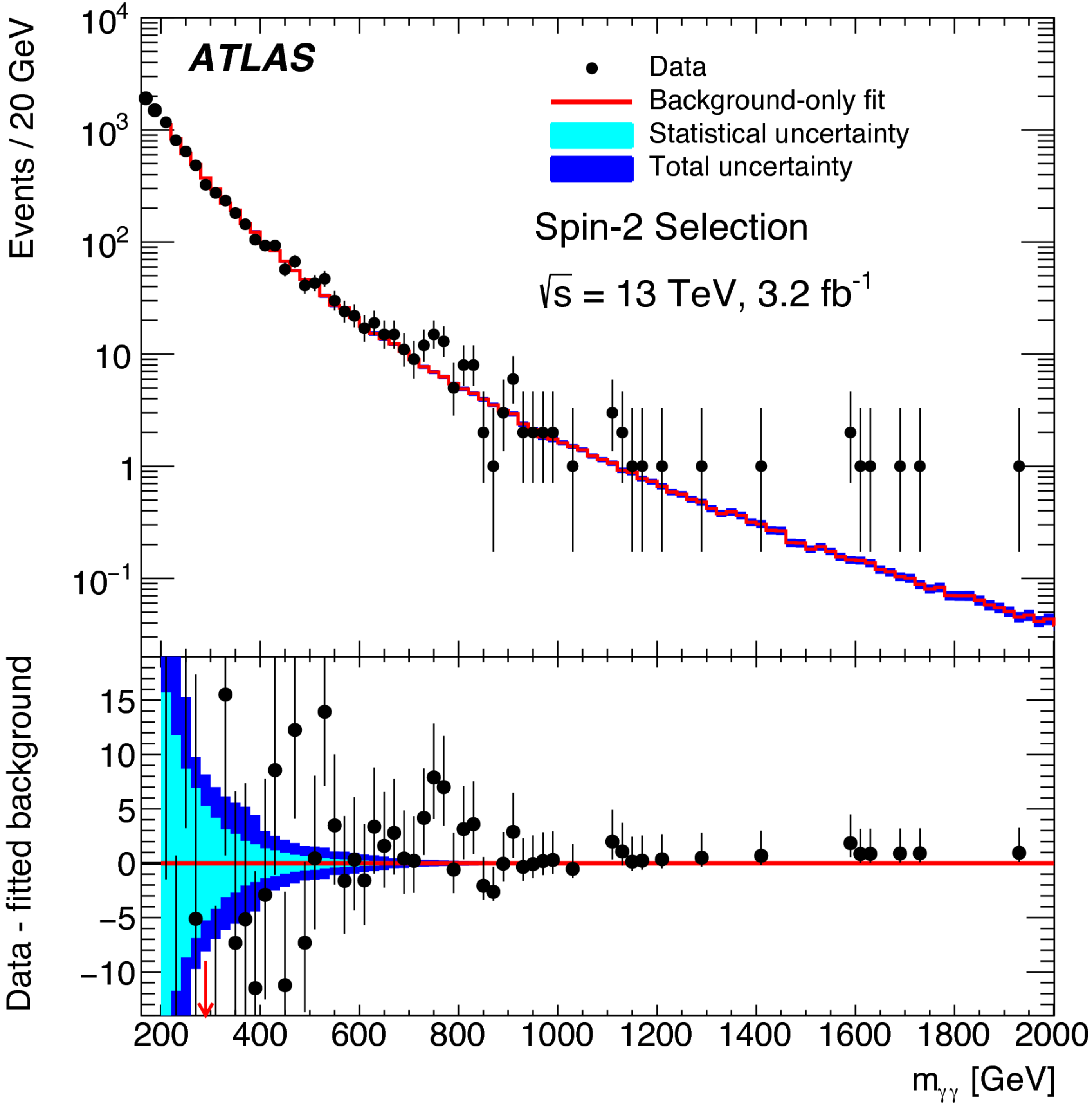

Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
ATLAS
ee: $\int L\,dt = 20.3\ \mathrm{fb}^{-1}$
$\sqrt{s}$ = 8 TeV
● Data 2012
Z/γ^*
Photon-Induced
Top
Multi-Jet & W+Jets
Diboson
M_s = 3.0 TeV (GRW)
M_s = 3.5 TeV (GRW)
M_s = 4.0 TeV (GRW)
Data / Bkg
1.4
1.2
1
0.8
0.6
0.1
0.2
0.3
0.4
1
2
3
4
m_{ee} [TeV]

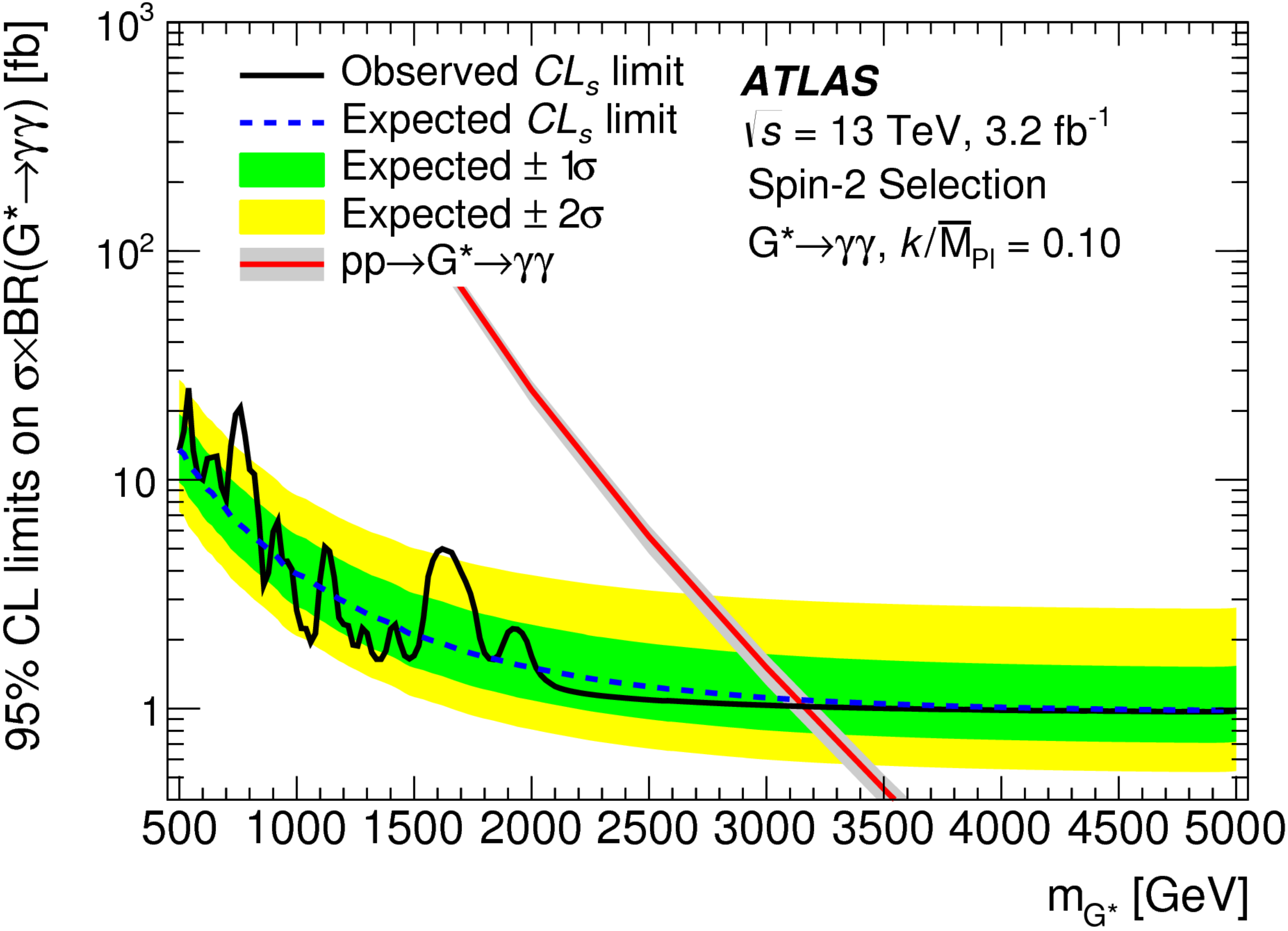

ATLAS
ee: $\int L\,dt = 20.3\ \mathrm{fb}^{-1}$
$\sqrt{s} = 8$ TeV
Data 2012
Z/γ^*
Photon-Induced
Top quarks
Multi-Jet & W+Jets
Diboson
$\Lambda^-_{LL} = 14$ TeV
$\Lambda^+_{LL} = 14$ TeV
$M_s = 3.5$ TeV (GRW)
Events
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
Data / Bkg
1.4
1.2
1
0.8
0.6
0.1
0.2
0.3
0.4
1
2
3
4
m_{ee} [TeV]

KK graviton resonances in Randall Sundrum model



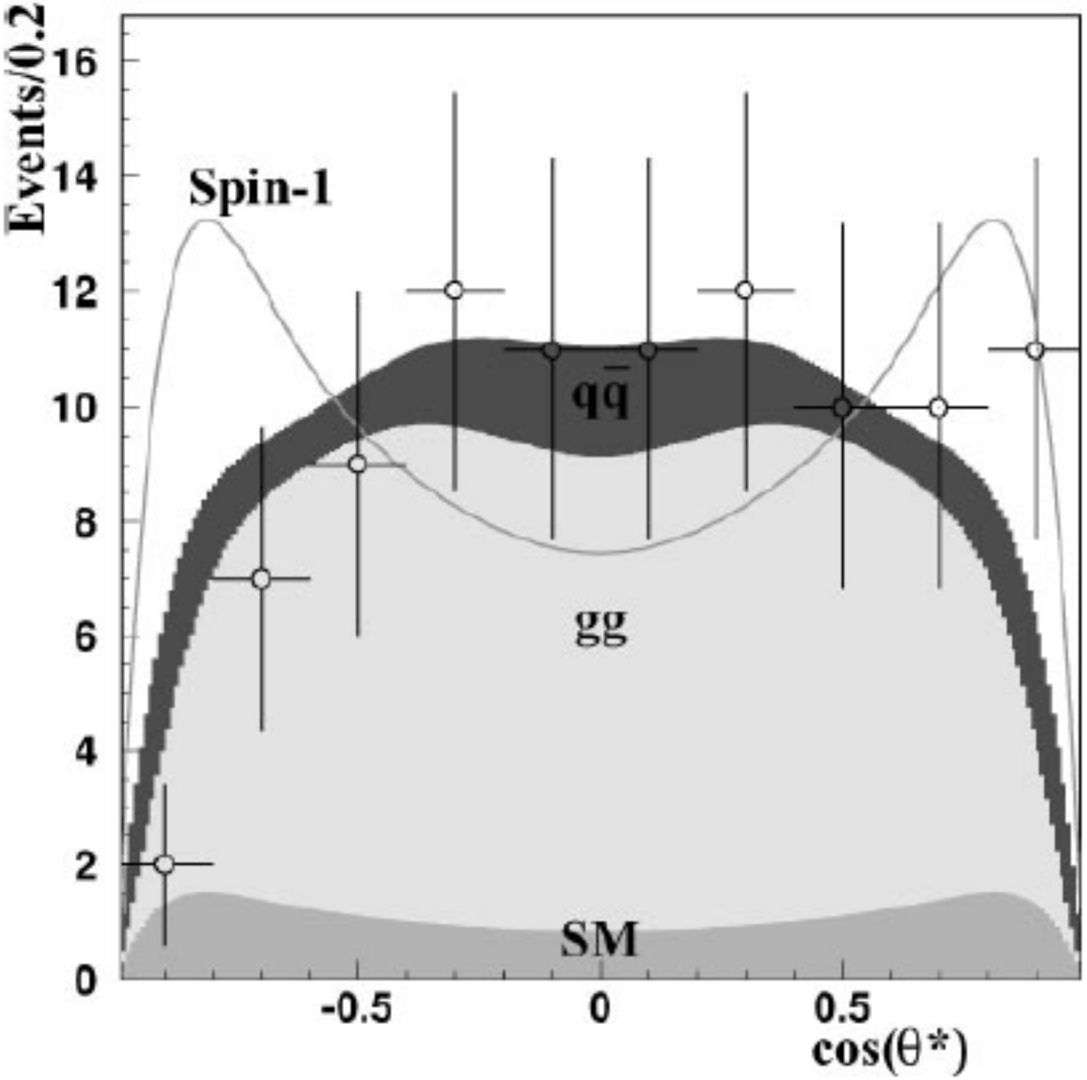

Events/bin
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
ATLAS
Spin-2 Selection
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
Data
Total background
Reducible background
syst ⊕ stat (reducible)
syst ⊕ stat (total)
RS, m_G=2000 GeV
RS, m_G=3000 GeV
300
400
500
1000
2000
3000
$m_{\gamma\gamma}$ [GeV]


ATLAS
Data
Background-only fit
Statistical uncertainty
Total uncertainty
Spin-2 Selection
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
Events / 20 GeV
10^4
10^3
10^2
10
1
10^{-1}
Data - fitted background
15
10
5
0
−5
−10
200
400
600
800
1000
1200
1400
1600
1800
2000
$m_{\gamma\gamma}$ [GeV]

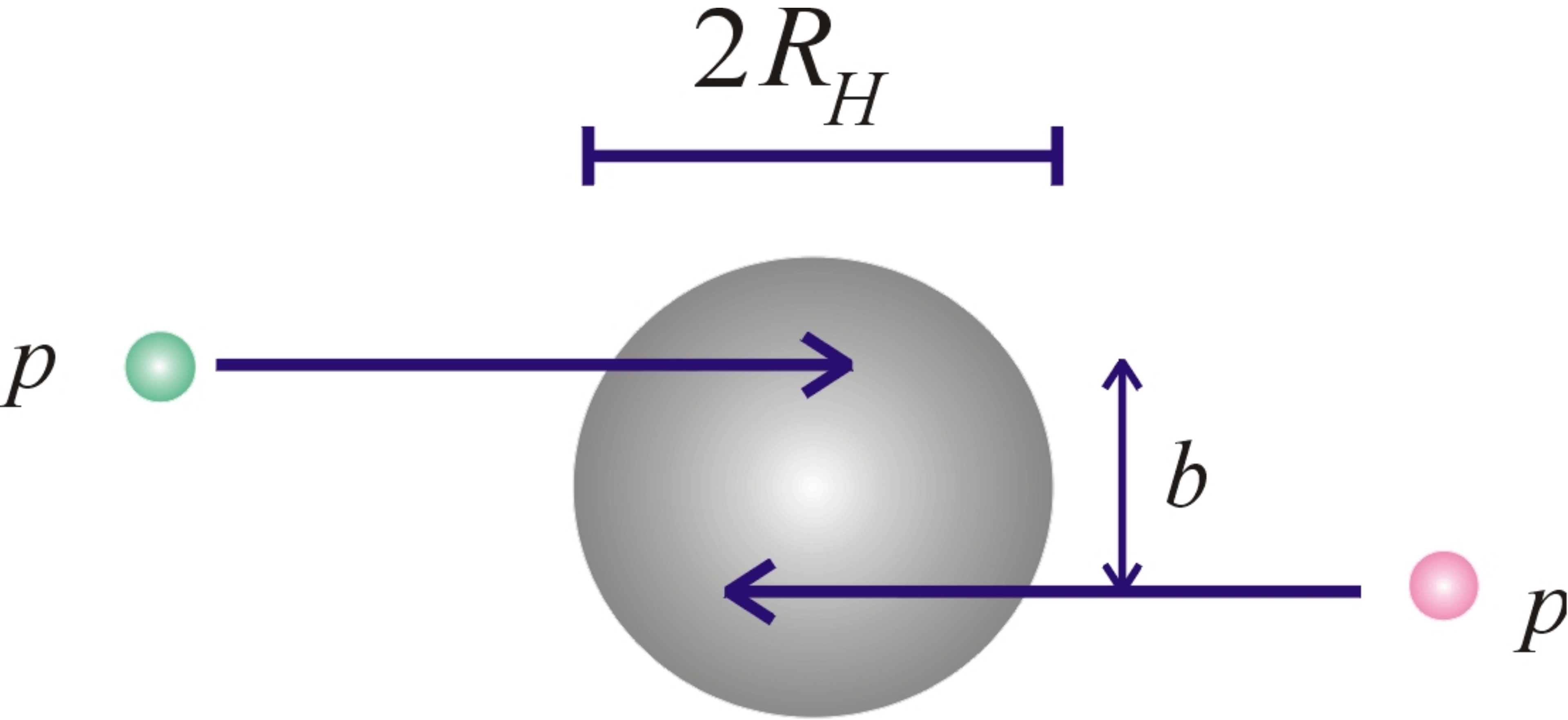


95% CL limits on σ×BR(G*→γγ) [fb]
10^3
10^2
10
1
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
m_{G^*} [GeV]
Observed CL_s limit
Expected CL_s limit
Expected ± 1σ
Expected ± 2σ
pp→G*→γγ
ATLAS
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
Spin-2 Selection
G*→γγ, $k/\overline{M}_{Pl}$ = 0.10

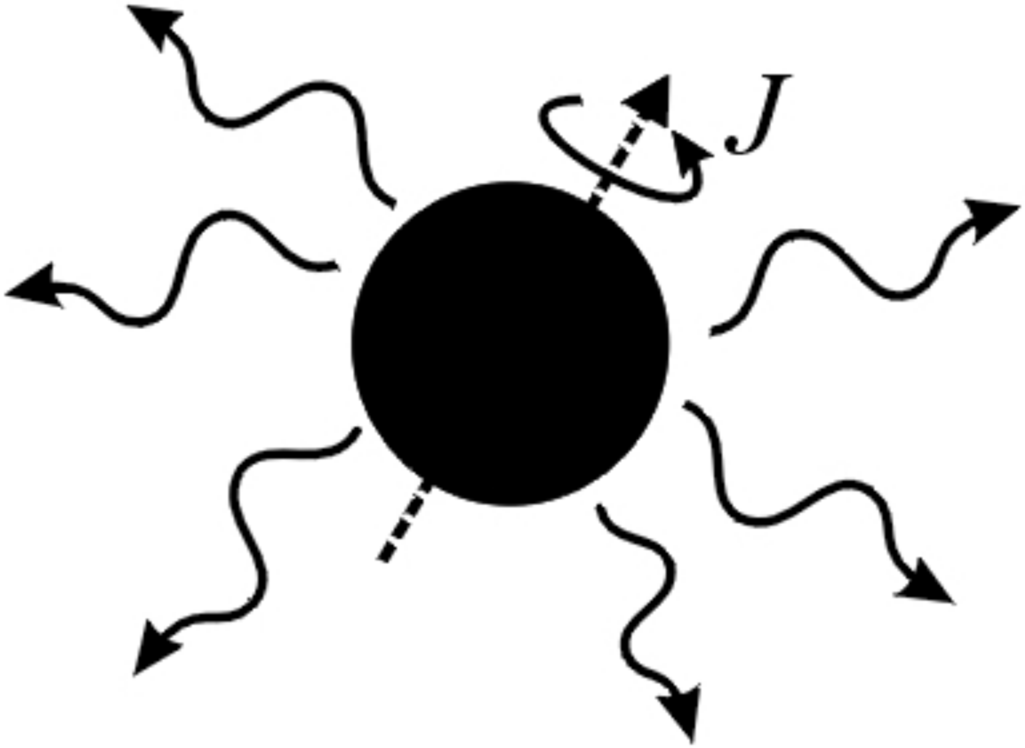
Simulated angular distribution of RS graviton (spin-2), compared to spin-1 bg.



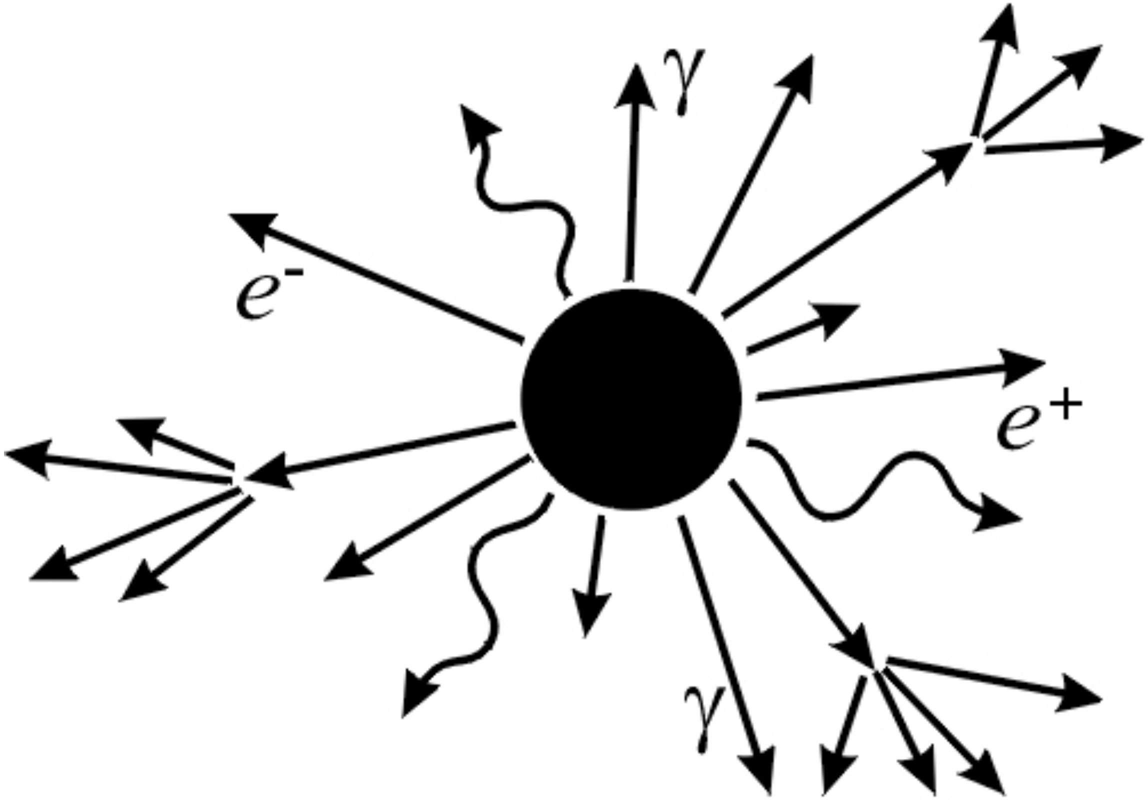
Micro black hole production

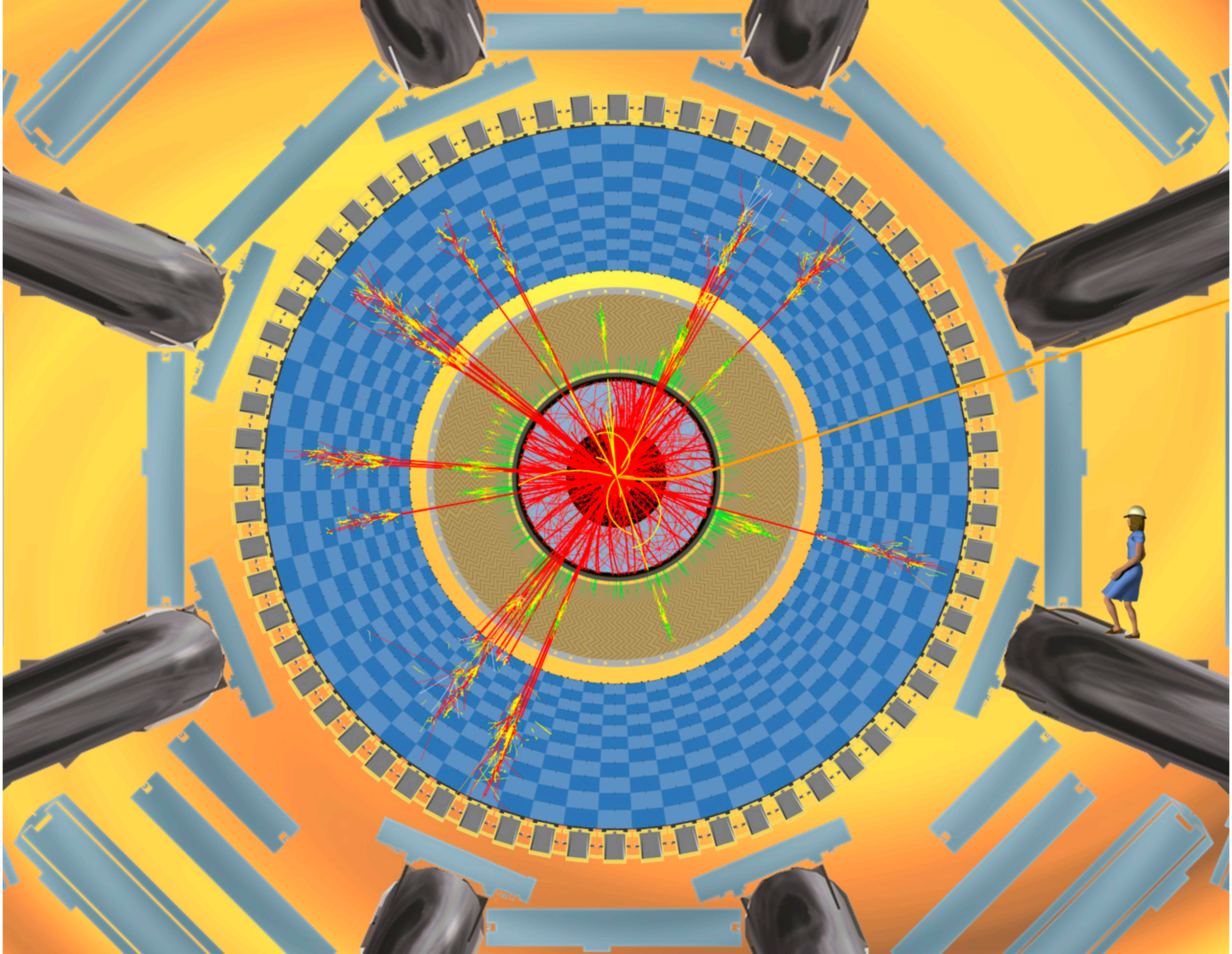


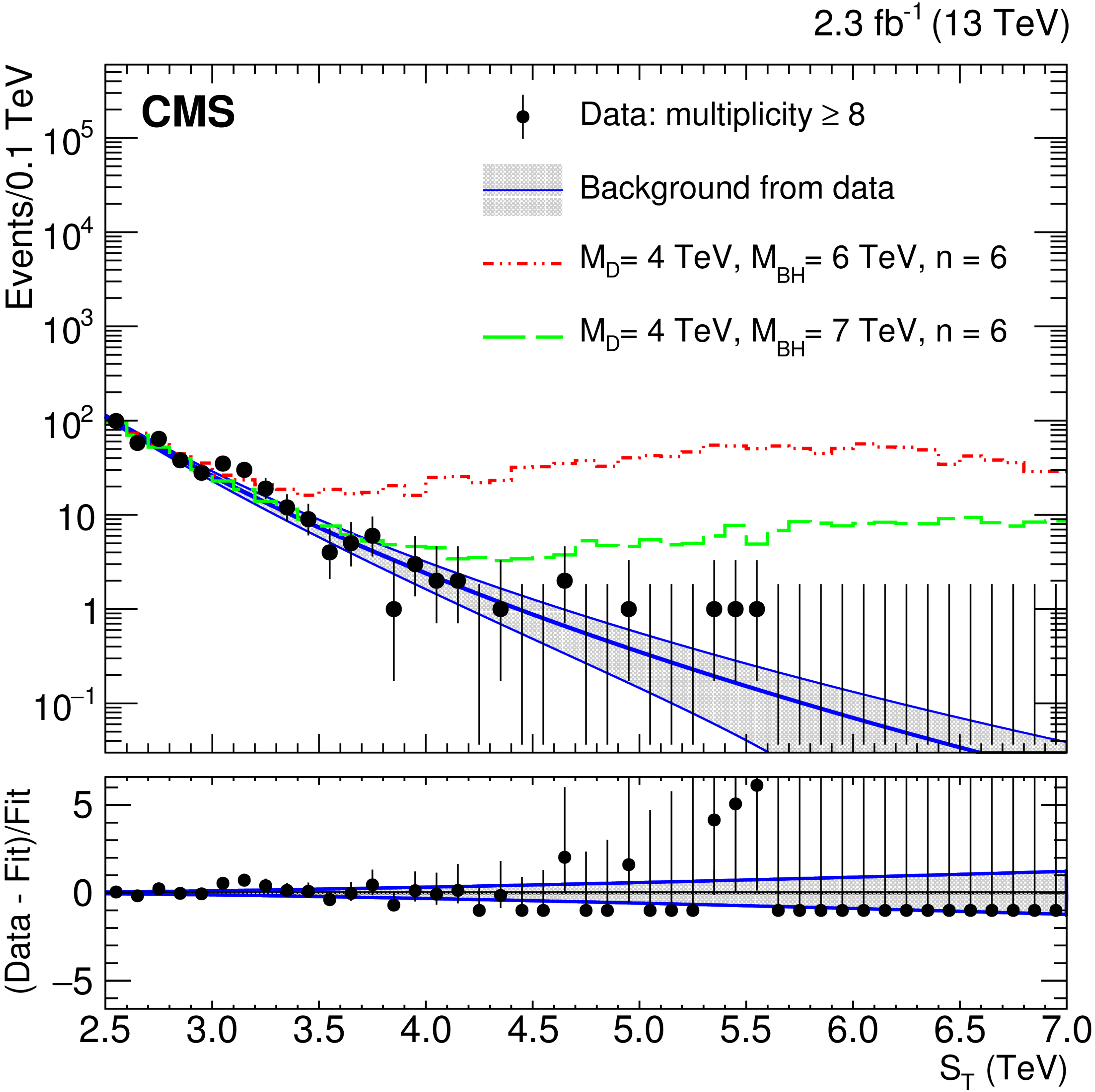
Phase 1 : “spin-down”

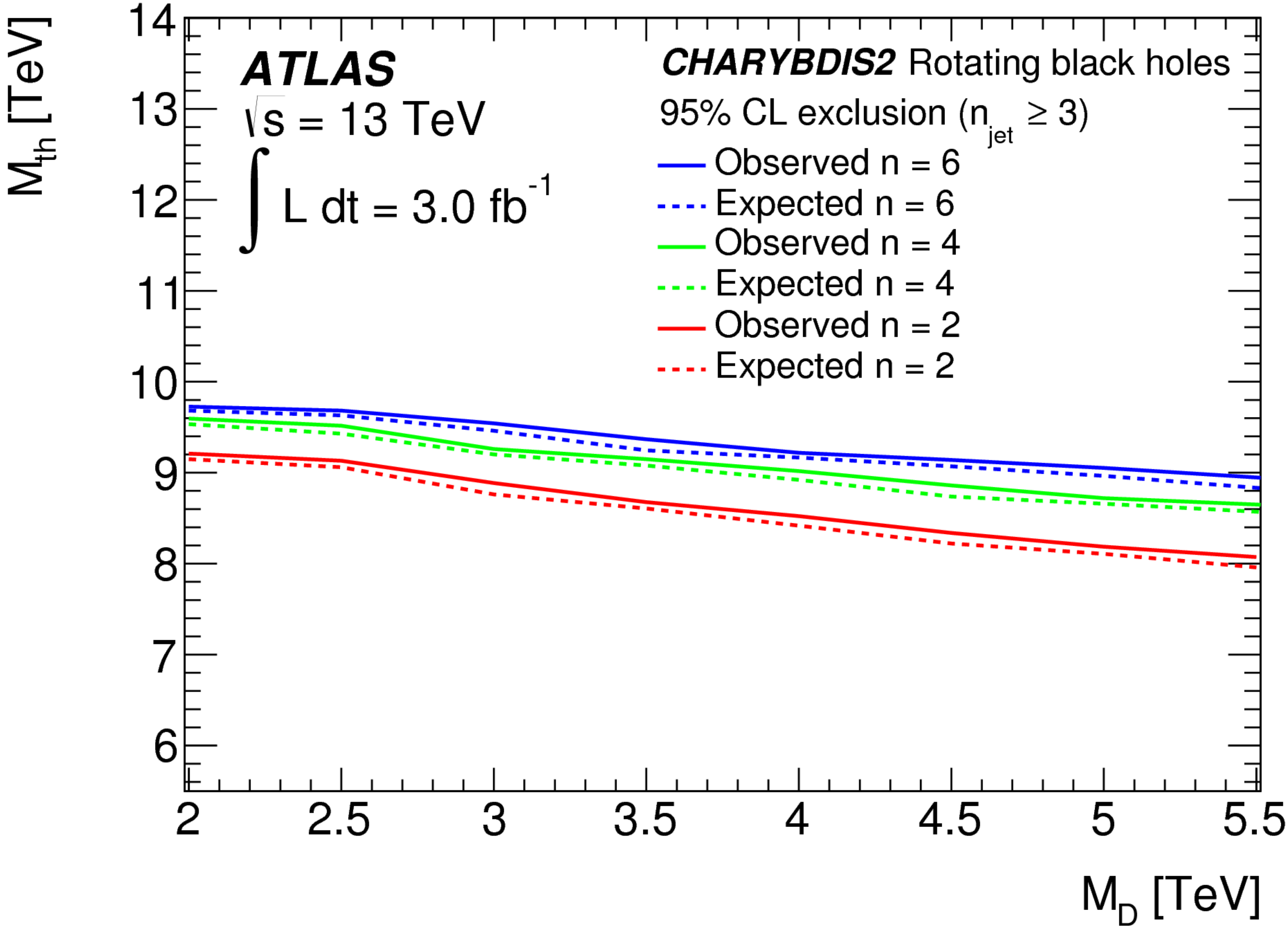


Phase 2: Hawking-radiation and evaporation



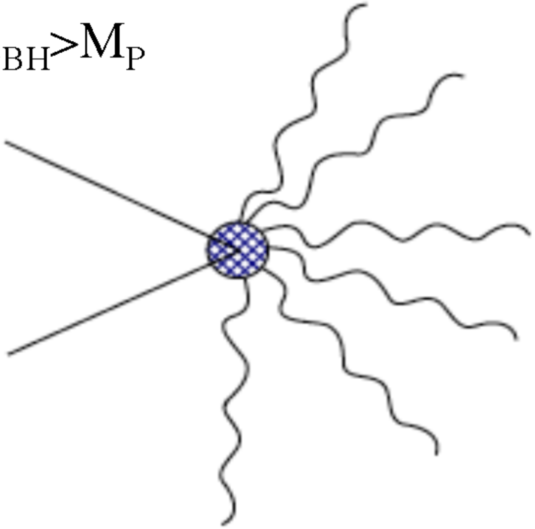



2.3 fb^{-1} (13 TeV)
CMS
Data: multiplicity ≥ 8
Background from data
M_D= 4 TeV, M_{BH}= 6 TeV, n = 6
M_D= 4 TeV, M_{BH}= 7 TeV, n = 6
Events/0.1 TeV
10^5
10^4
10^3
10^2
10
1
10^{-1}
(Data - Fit)/Fit
5
0
−5
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
S_T (TeV)


ATLAS
$\sqrt{s}$ = 13 TeV
$\int L\,dt = 3.0\ \mathrm{fb}^{-1}$
CHARYBDIS2 Rotating black holes
95% CL exclusion ($n_{jet} \geq 3$)
Observed n = 6
Expected n = 6
Observed n = 4
Expected n = 4
Observed n = 2
Expected n = 2
M_{th} [TeV]
M_D [TeV]
6
7
8
9
10
11
12
13
14
2
2.5
3
3.5
4
4.5
5
5.5

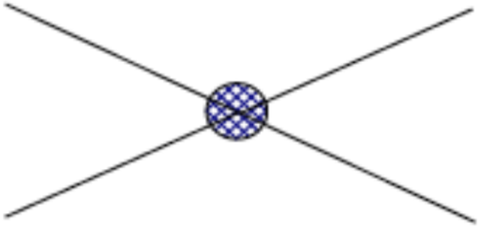
Semi-classical versus quantum non-thermal black hole:

$m_{BH} > M_P$

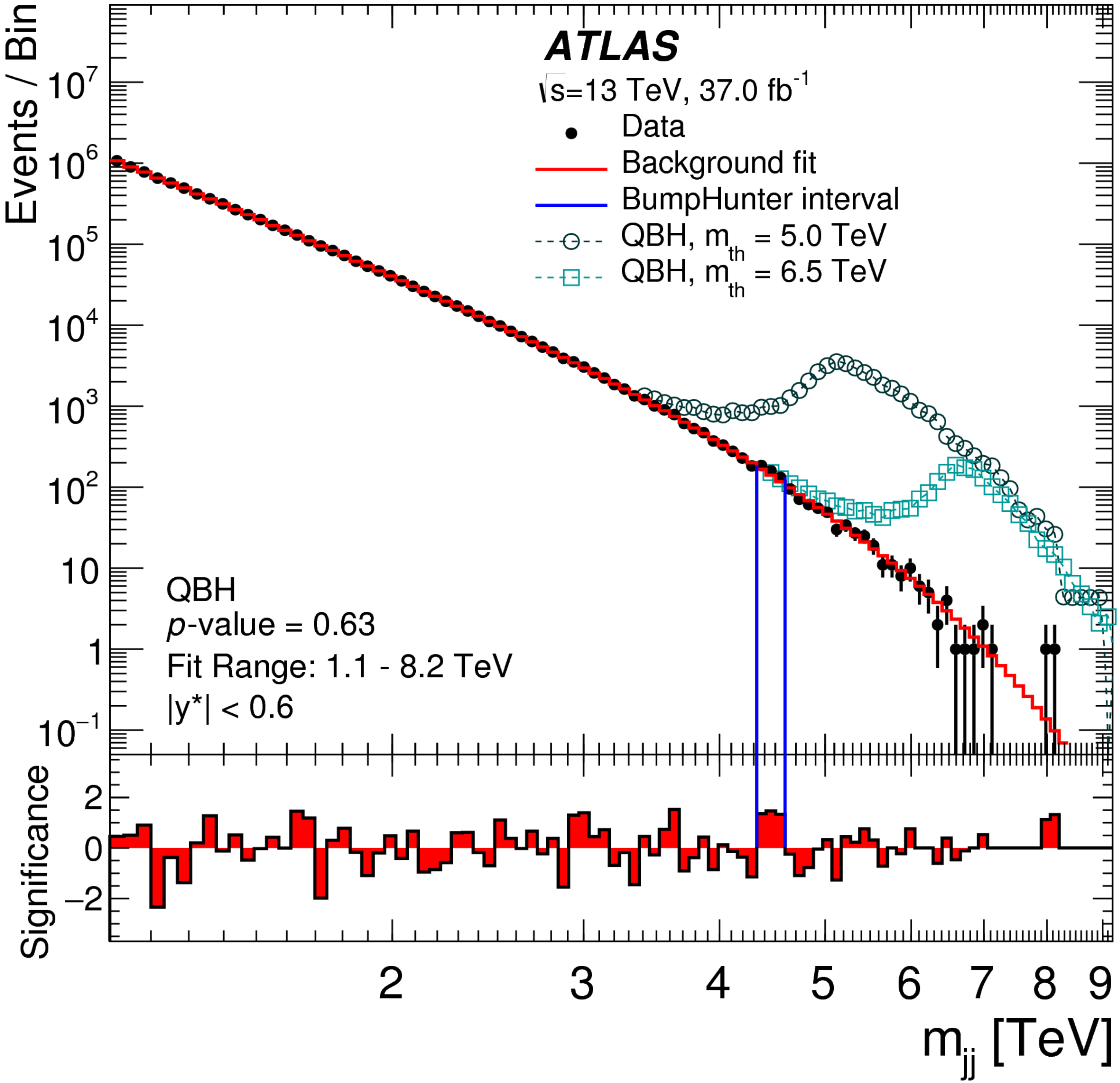


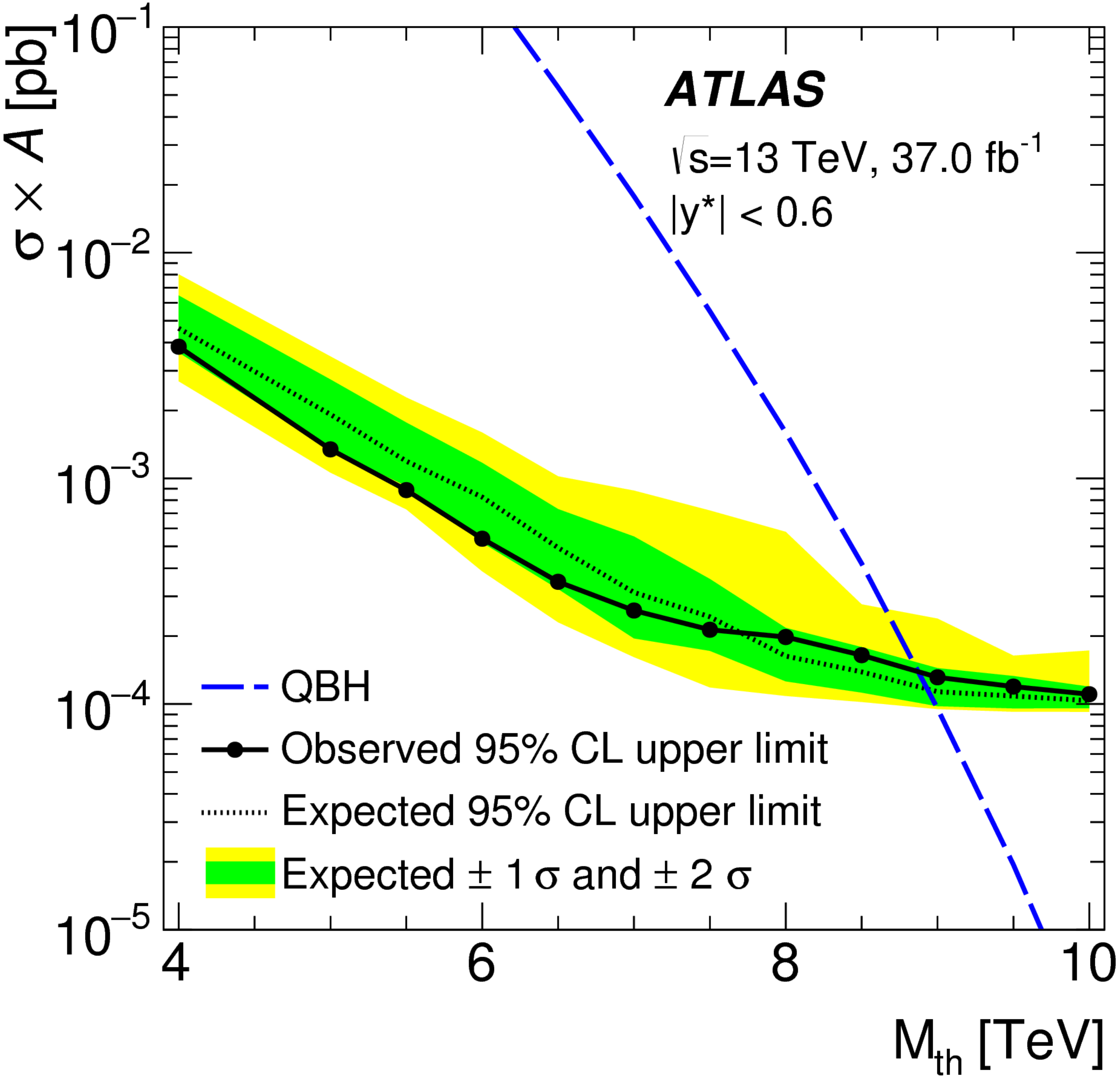
thermal black hole
large entropy

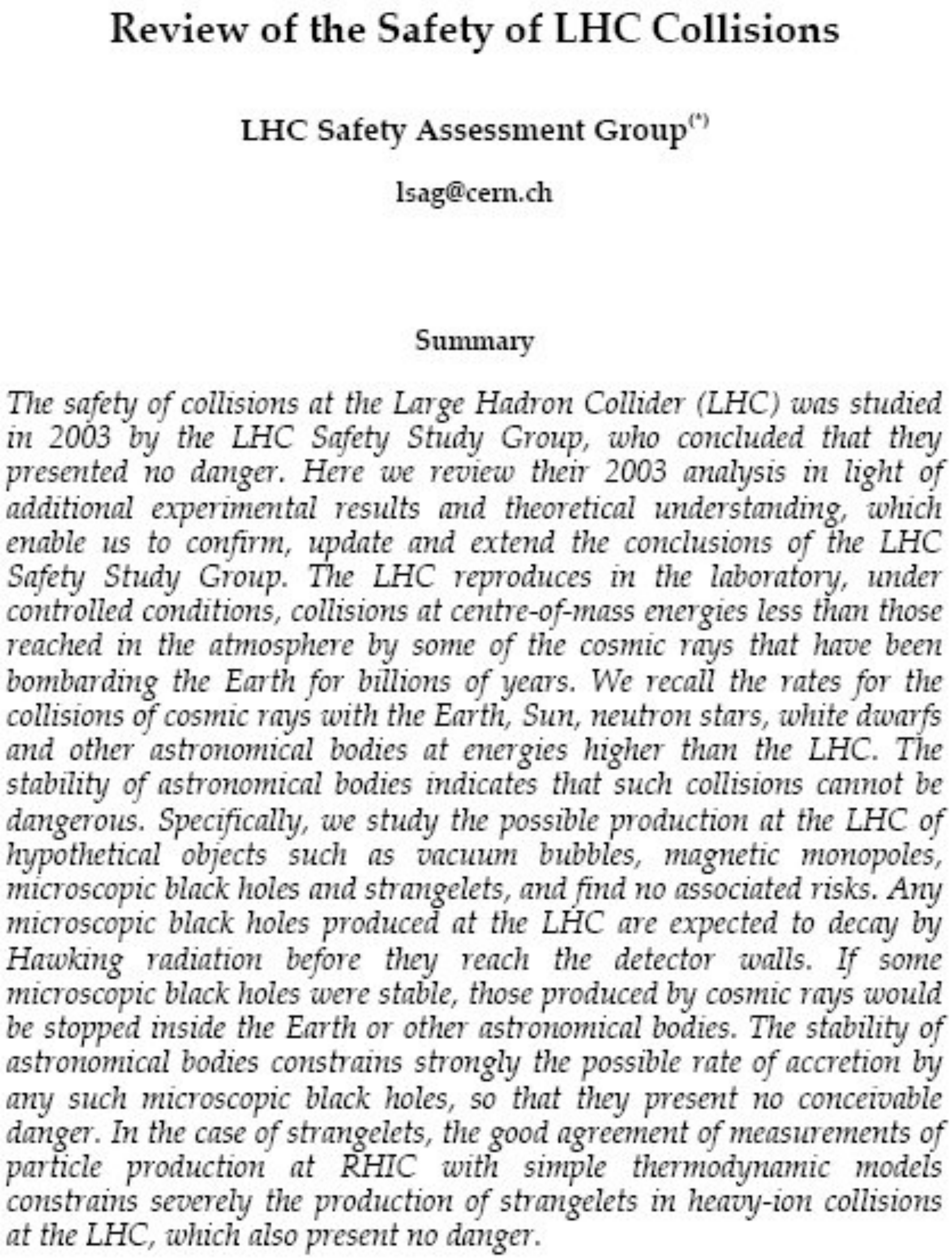
$m_{BH} \sim M_P$



quantum black hole
small entropy


ATLAS
$\sqrt{s}$=13 TeV, 37.0 fb^{-1}
Data
Background fit
BumpHunter interval
QBH, m_{th} = 5.0 TeV
QBH, m_{th} = 6.5 TeV
QBH
p-value = 0.63
Fit Range: 1.1 - 8.2 TeV
$|y^*| < 0.6$
Events / Bin
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
Significance
2
0
−2
2
3
4
5
6
7
8
9
m_{jj} [TeV]


ATLAS
$\sqrt{s}$=13 TeV, 37.0 fb^{-1}
|y*| < 0.6
QBH
Observed 95% CL upper limit
Expected 95% CL upper limit
Expected ± 1 σ and ± 2 σ
$\sigma \times A$ [pb]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
4
6
8
10
M_{th} [TeV]



Review of the Safety of LHC Collisions

LHC Safety Assessment Group(*)

lsag@cern.ch

Summary

The safety of collisions at the Large Hadron Collider (LHC) was studied in 2003 by the LHC Safety Study Group, who concluded that they presented no danger. Here we review their 2003 analysis in light of additional experimental results and theoretical understanding, which enable us to confirm, update and extend the conclusions of the LHC Safety Study Group. The LHC reproduces in the laboratory, under controlled conditions, collisions at centre-of-mass energies less than those reached in the atmosphere by some of the cosmic rays that have been bombarding the Earth for billions of years. We recall the rates for the collisions of cosmic rays with the Earth, Sun, neutron stars, white dwarfs and other astronomical bodies at energies higher than the LHC. The stability of astronomical bodies indicates that such collisions cannot be dangerous. Specifically, we study the possible production at the LHC of hypothetical objects such as vacuum bubbles, magnetic monopoles, microscopic black holes and strangelets, and find no associated risks. Any microscopic black holes produced at the LHC are expected to decay by Hawking radiation before they reach the detector walls. If some microscopic black holes were stable, those produced by cosmic rays would be stopped inside the Earth or other astronomical bodies. The stability of astronomical bodies constrains strongly the possible rate of accretion by any such microscopic black holes, so that they present no conceivable danger. In the case of strangelets, the good agreement of measurements of particle production at RHIC with simple thermodynamic models constrains severely the production of strangelets in heavy-ion collisions at the LHC, which also present no danger.

Therefore, over 3x10^{22} cosmic rays with energies of 10^{17} eV or more, equal to or greater than the LHC energy, have struck the Earth's surface since its formation. This means [6] that Nature has already conducted the equivalent of about a hundred thousand LHC experimental programmes on Earth already – and the planet still exists.

Moreover, our Milky Way galaxy contains about 10^{11} stars with sizes similar to our Sun, and there are about 10^{11} similar galaxies in the visible Universe. Cosmic rays have been hitting all these stars at rates similar to collisions with our own Sun. This means that Nature has already completed about 10^{31} LHC experimental programmes since the beginning of the Universe. Moreover, each second, the Universe is continuing to repeat about 3x10^{13} complete LHC experiments. There is no indication that any of these previous "LHC experiments" has ever had any large-scale consequences. The stars in our galaxy and others still exist, and conventional astrophysics can explain all the astrophysical black holes detected.

As was pointed out 30 years ago by Stephen Hawking [9], it is expected that all black holes are ultimately unstable. This is because of very basic features of quantum theory in curved spaces, such as those surrounding any black hole. The basic reason is very simple: it is a consequence of quantum mechanics that particle-antiparticle pairs must be created near the event horizon surrounding any black hole. Some particles (or antiparticles) disappear into the black hole itself, and the corresponding antiparticles (or particles) must escape as radiation. There is broad consensus among physicists on the reality of Hawking radiation, but so far no experiment has had the sensitivity required to find direct evidence for it.

Independently of the reasoning based on Hawking radiation, if microscopic black holes were to be singly produced by colliding the quarks and gluons inside protons, they would also be able to decay into the same types of particles that produced them [10]. The reason being that in this case they could not carry any conserved quantum number that is not already carried by the original quarks and gluons, and their decay back to the initial state partons would be allowed. For this reason, a microscopic black hole cannot be completely black. In standard quantum physics, the decay rate would be directly related to the production rate, and the expected lifetime would be very short. The case of pair production of black holes carrying new and opposite conserved quantum numbers leads to similar conclusions: only their ground state is guaranteed to be stable, and any further accretion of normal matter in the form of quarks, gluons or leptons would immediately be radiated away. Both this and the existence of Hawking radiation are valid in the extra-dimensional scenarios used to suggest the possible production of microscopic black holes.

In fact, ultra-high-energy cosmic rays hitting dense stars such as white dwarfs and neutron stars would have produced black holes copiously during their lifetimes. Such black holes, even if neutral, would have been stopped by the material inside such dense stars. The rapid accretion due to the large density of these bodies, and to the strong gravitational interactions of these black holes, would have led to the destruction of white dwarfs and neutron stars on time scales that are much shorter than their observed lifetimes [2]. The final stages of their destruction would have released explosively large amounts of energy, that would have been highly visible. The observation of white dwarfs and neutron stars that would have been destroyed in this way tells us that cosmic rays do not produce such black holes, and hence neither will the LHC.

To conclude: in addition to the very general reasoning excluding the possibility that stable black holes exist, and in particular that they could only be neutral, we therefore have very robust empirical evidence either disproving their existence, or excluding any consequence of it.