Title: Fishing for new physics at the LHC

Date: Dec 06, 2016 01:00 PM

URL: http://pirsa.org/16120001

Abstract: I will discuss ways to search for new physics with the LHC heavy ion program and the ATLAS/CMS high level trigger.

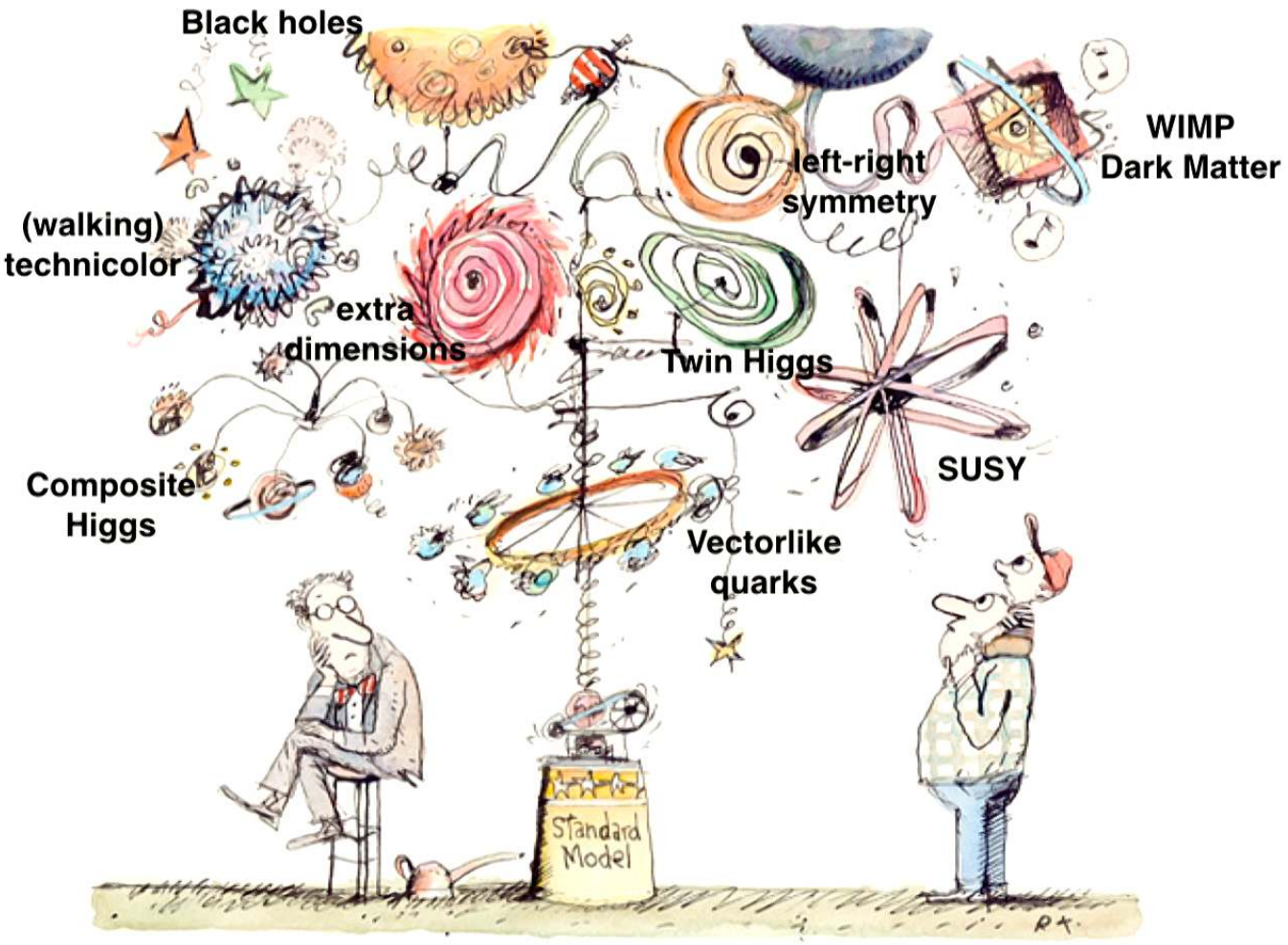
Fishing for new physics at the LHC

"Whale receiving an MRI at CMS"

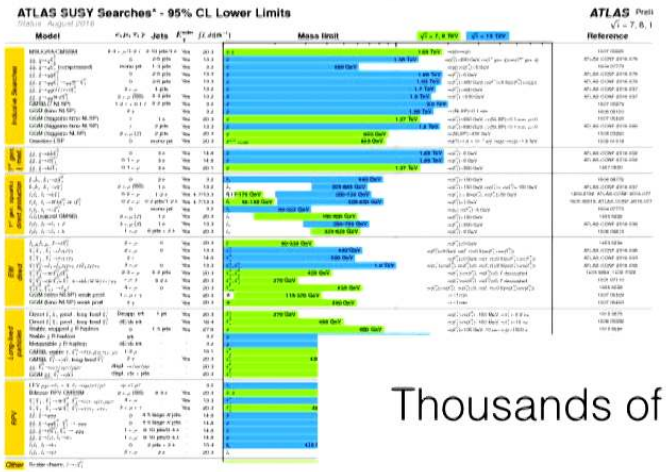
SK, T. Lou, T. Lin, T. Melia
arXiv:1607.06083

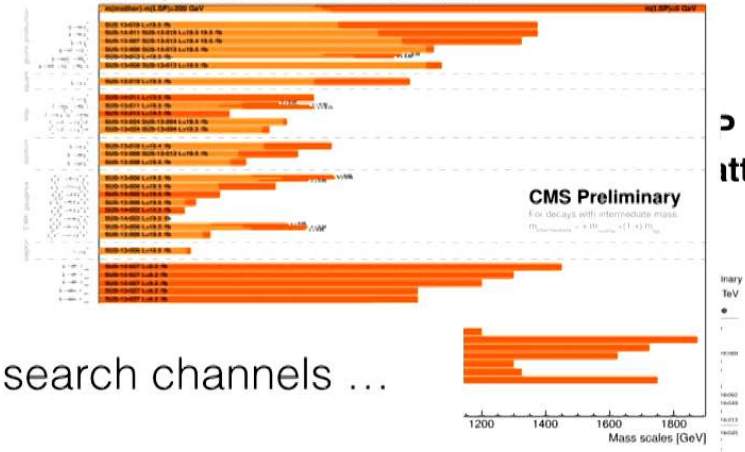
S. Pagan Griso*, SK, M. Papucci, D. Robinson
arXiv:1612.00850
*on ATLAS

Beyond the Standard Model



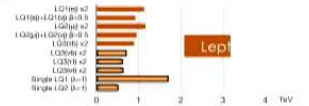
Beyond the Standard Model

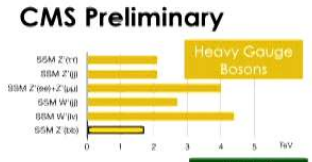


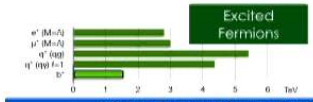


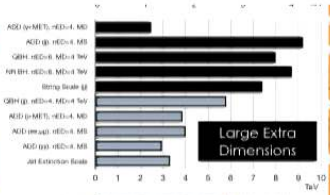
Thousands of search channels …

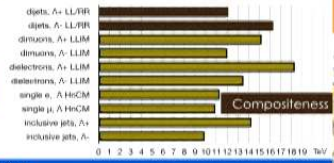
… so far nothing but limits

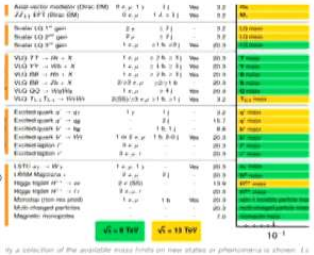


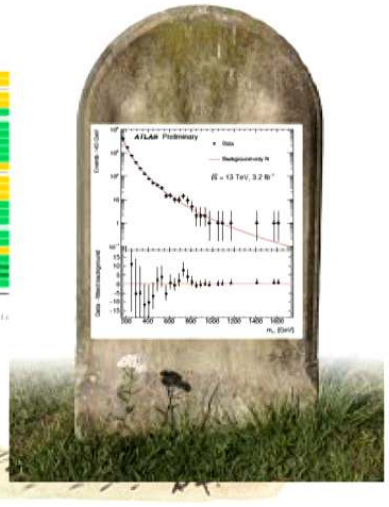












"Keep calm and carry on"

Most of the data still to come

Precision physics

Broaden models

Relaxion, Neutral Naturalness,…

Future / other experiments

100 TeV, intensity frontier, dark matter, …

Signature based approach

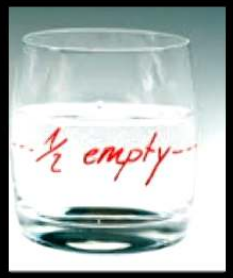
aka "fishing expedition"

Diversify our portfolio

4

Should we go fishing?

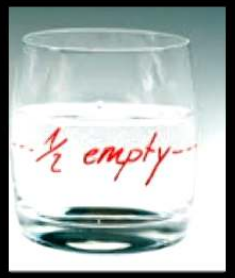
(Minimal theory motivation)



"Probably just another limit…"

Should we go fishing?

(Minimal theory motivation)



Make sure all holes are patched!

(Triggers are crucial)

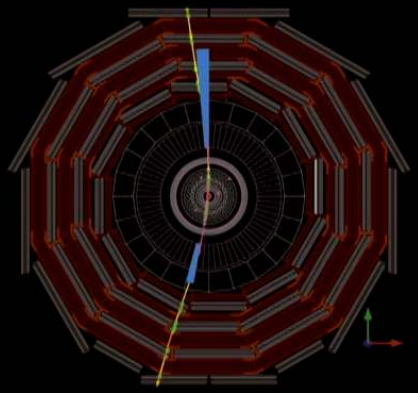
"Probably just another limit…"

Exciting new *experimental* developments!

Two new (unrelated) ideas

Axion-like particles (ALP's)

in heavy ion collisions

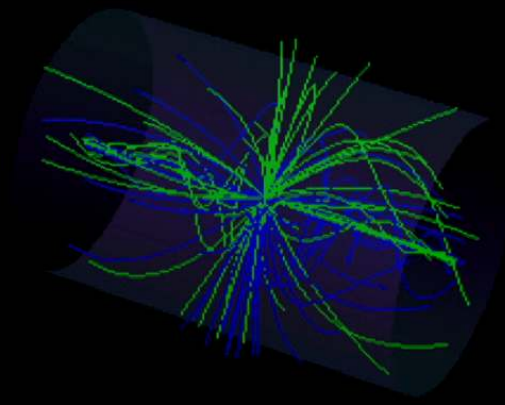


SK, T. Lou, T. Lin, T. Melia
arXiv:1607.06083

A trigger for events with a high

multiplicity of soft tracks

(soft bomb)



S. Pagan Griso, SK, M. Papucci, D. Robinson
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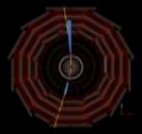
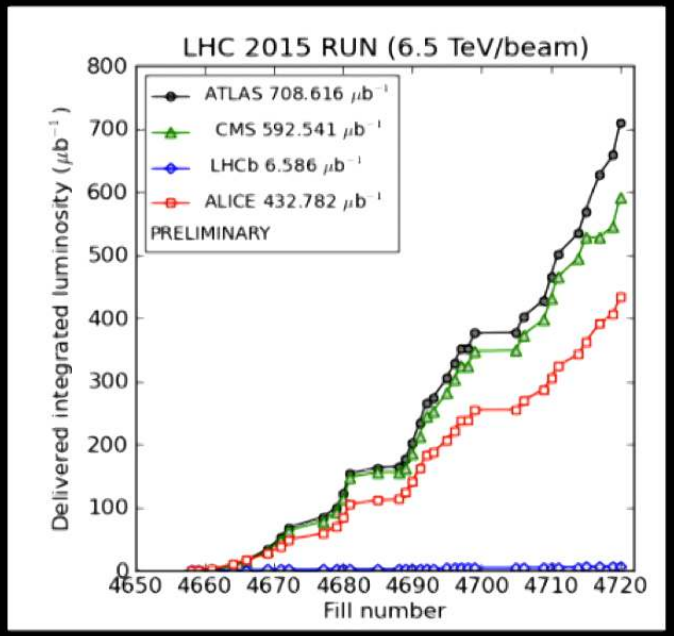
The LHC heavy ion program



Pb-Pb



Heavy ion trivia:
Why is the luminosity so low?

All 4 major experiments participate…

…but roughly 10^{-4} times the data

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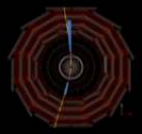
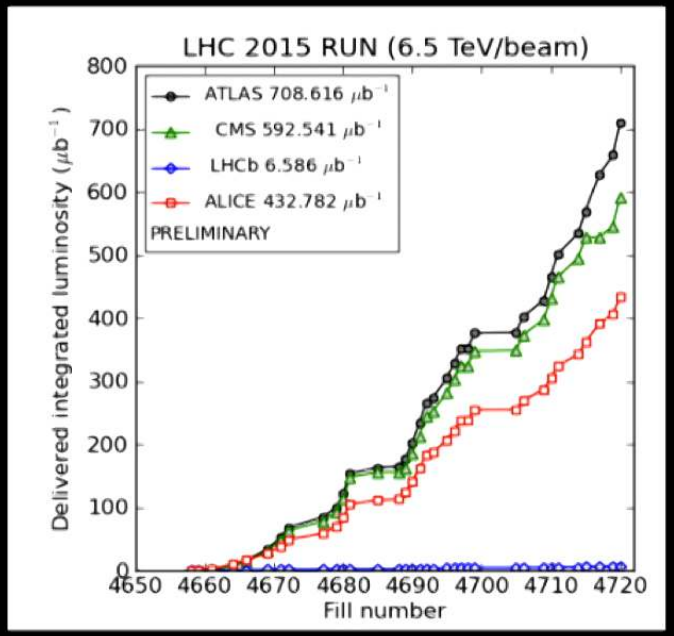
The LHC heavy ion program



Pb-Pb



Heavy ion trivia:
Why is the luminosity so low?

$Pb^{82+}\ Pb^{82+} \rightarrow Pb^{82+}\ Pb^{81+}\ e^{+}$

~ 250 barns

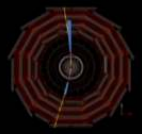
↓

Quenches di-pole magnet ~ 140 m downstream

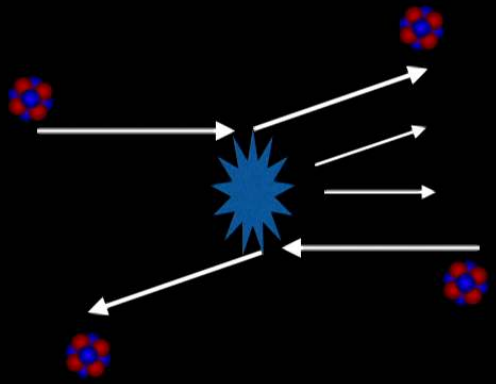
All 4 major experiments participate…

…but roughly 10^{-4} times the data

Ultra-peripheral collisions

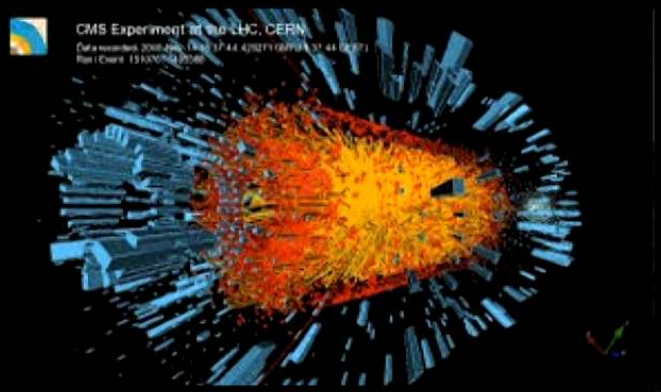


High impact parameter ("grazing") collisions

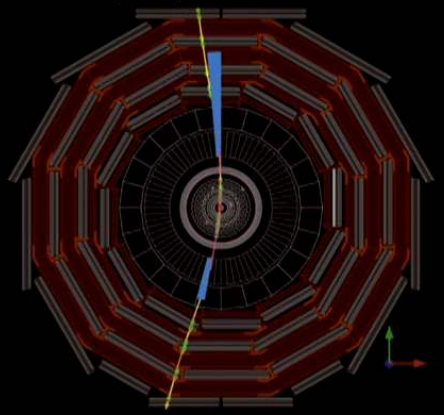


Ions remain intact
Low multiplicity particle production

head-on collision



ultra-peripheral collision



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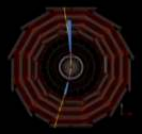
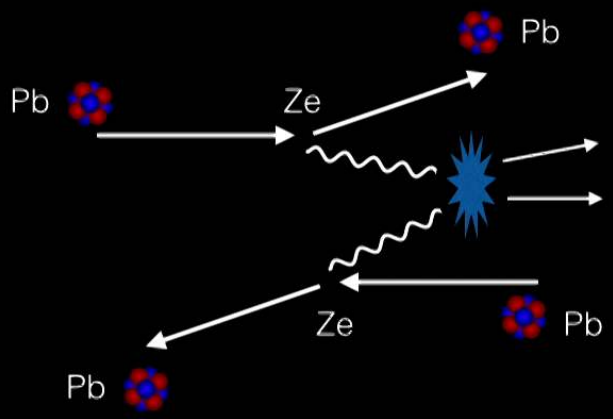
A γ-γ collider



Heavy ion beams are the worlds most powerful flashlight!
(with energy above ~ GeV)

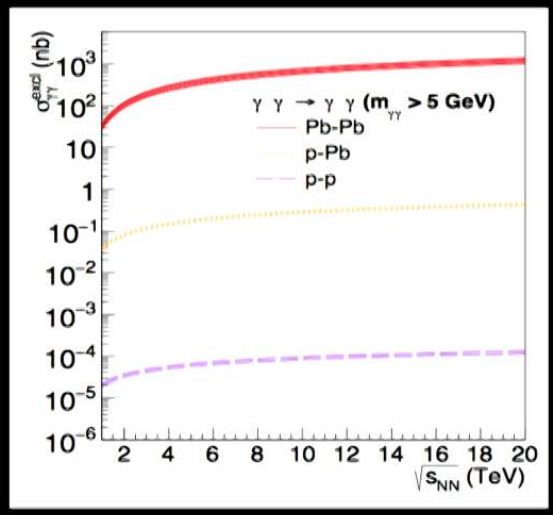


Z=82 for Pb ions

$Z^4 \sim 5 \times 10^7$

$Z^2\ \alpha >> 1$
QED in non-perturbative regime

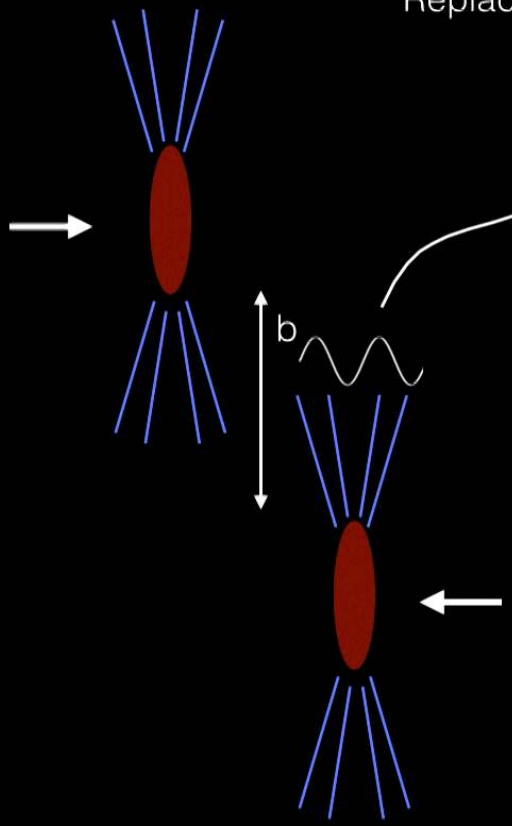
~ 5.5 TeV per nucleon @ LHC
(this is a 1000 TeV collider!)



1305.7142: D. d'Enterria, G. Silveira

Equivalent photon approximation

Replace E, B fields with an equivalent flux of nearly on-shell photons

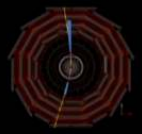


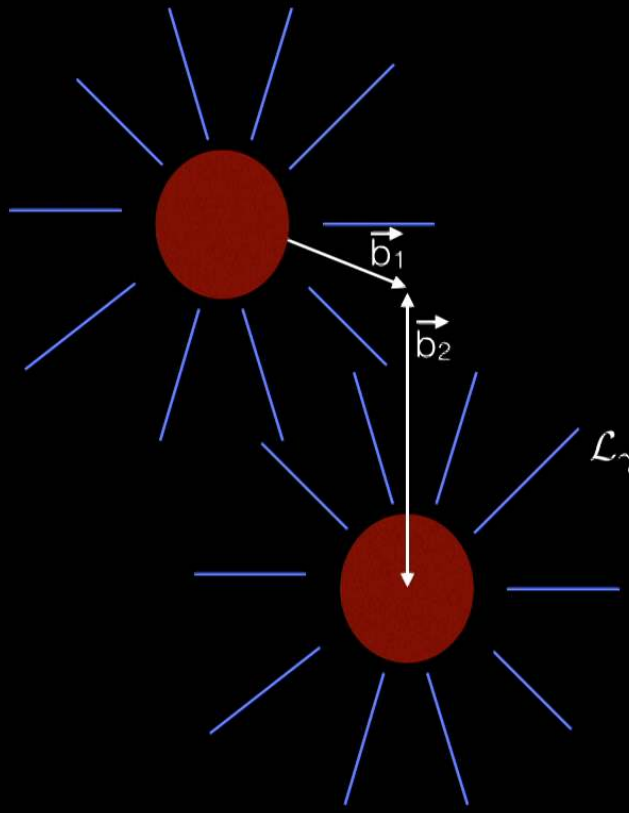
$$\omega_{max} \sim \frac{\gamma}{R}$$

	$b_{min} = 2R$	$\sqrt{s}$	$2\omega_{max}$
p	1.6 fm	13 TeV	1.5 TeV
Pb	14 fm	1050 TeV	160 GeV

Low Björken x: $x \sim 10^{-5}$

Computing the photon flux





Weizsäcker-Williams calculation

$$N_\gamma(\omega, b) = \frac{Z^2\alpha\omega^2}{\pi^2\gamma^2\hbar^2v^2}\left(K_1^2(x) + \frac{1}{\gamma^2}K_0^2(x)\right)$$

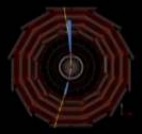
with $x \equiv \omega b/\gamma v\hbar$

Photon-photon luminosity

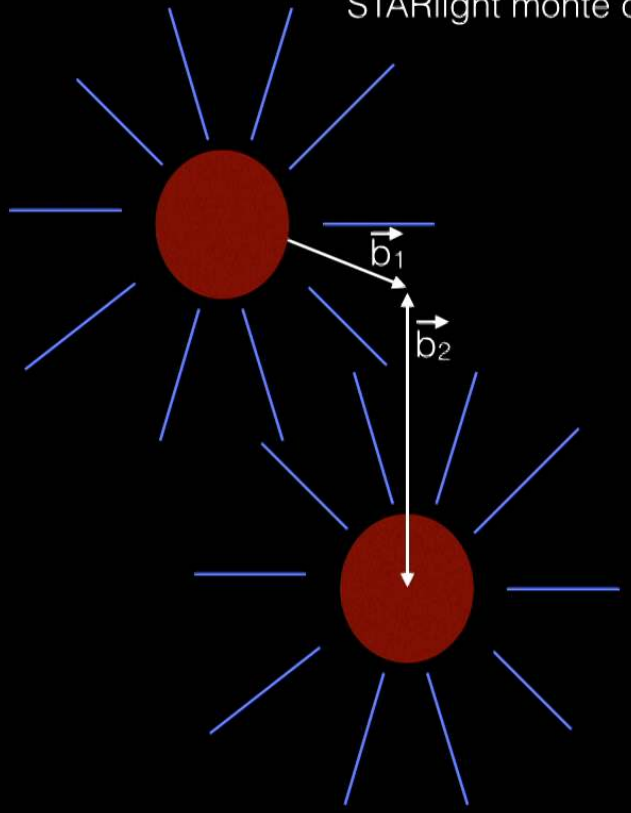
$$\mathcal{L}_{\gamma\gamma}(\hat{s}) = \frac{1}{\hat{s}}\int d^2b_{1,2}\, d\omega_{1,2}\, N_\gamma(\omega_1, b_1)\, N_\gamma(\omega_2, b_2) \times F(|b_1 - b_2|)\,\delta(\hat{s} - 4\omega_1\omega_2)$$

nuclear form factor

Computing the photon flux



STARlight monte carlo (S. Klein et. al., 1607.03838)

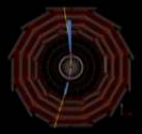


from latest STARlight manual

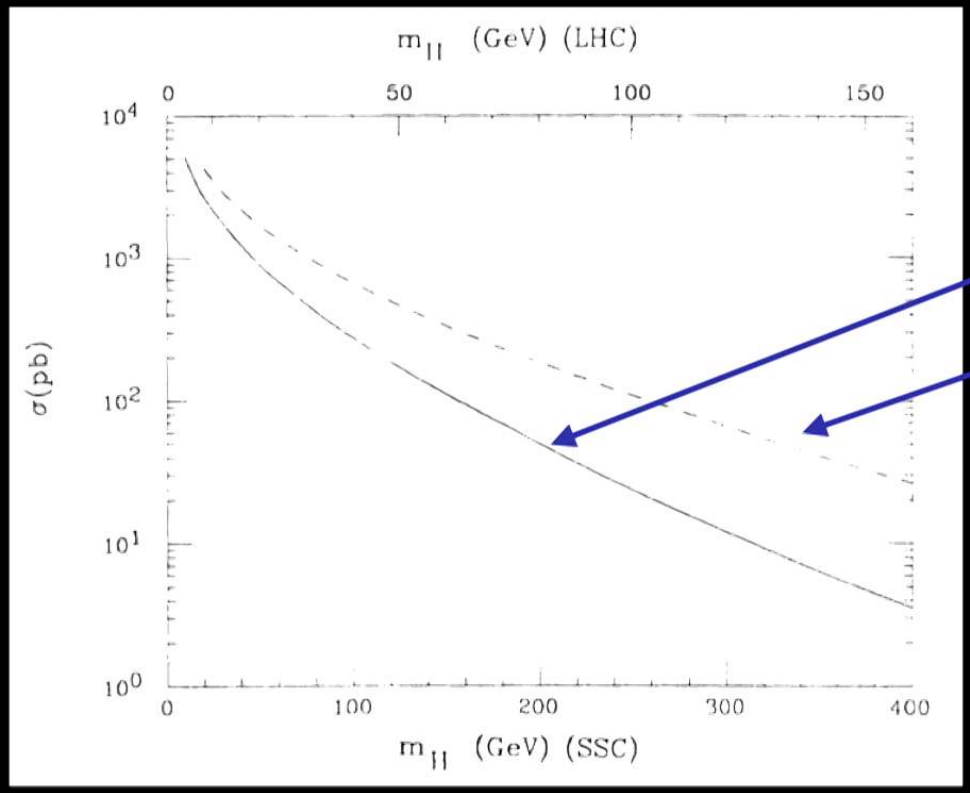
```
--------------------------------------------------------------------------------
Channels of Interest:

2-Photon Channels
Currently supported 2-photon (prod. mode = 1) channel options:
      jetset id        particle
   ---------------------------------
      221         eta
      331         eta-prime
      441         eta-c
      9010221     f0(975)
      225         f2(1270)
      115         a2(1320)
      335         f2(1525)
      33          rho0 pair
      11          e+/e- pair
      13          mu+/mu- pair
      15          tau+/tau- pair
      88          axion-like particle (ALP)

Process 88 refers to the single production of a hypothetical axion-like
particle (ALP), which decays to a pair of photons. The ALP mass has to be
specified by the user through the parameter AXION_MASS. The narrow width
approximation is assumed here, with a fixed axion decay constant of
\Lambda=1 TeV. (See equation (1) of arXiv:1607.06083 for the appropriate
```

Pb-Pb Luminosity
now: ~ 1 nb^{-1}
HL-LHC: ~ 10 nb^{-1}

Applications



Higgs production in photon fusion



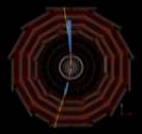
with form factor

no form factor

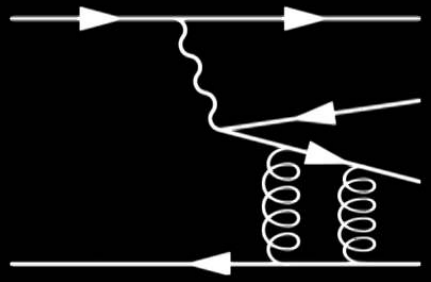
Unfortunately, this rate is too low…

B. Cahn, D. Jackson (1990)

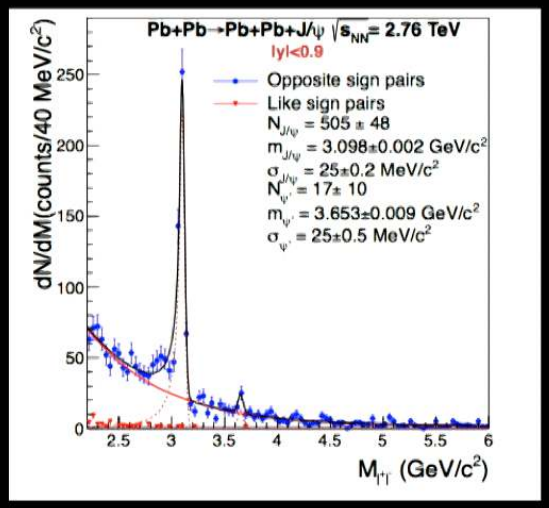
Applications



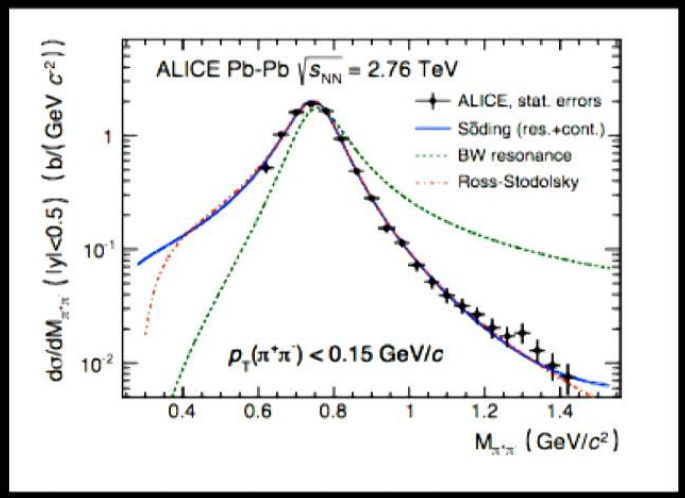
Exclusive meson production



J/Ψ production



ρ⁰ production



(Similar results from CMS and ATLAS)

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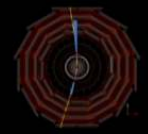
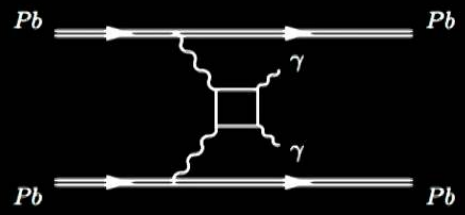
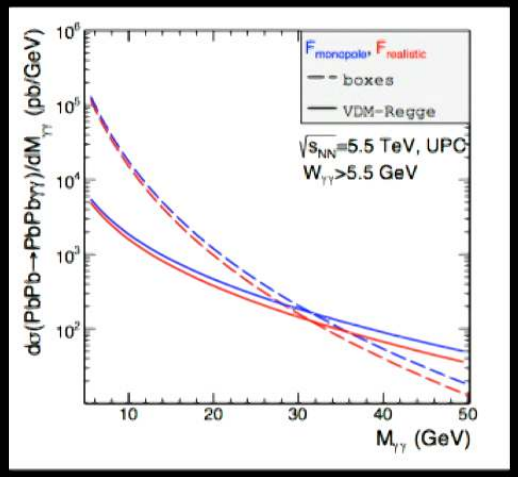
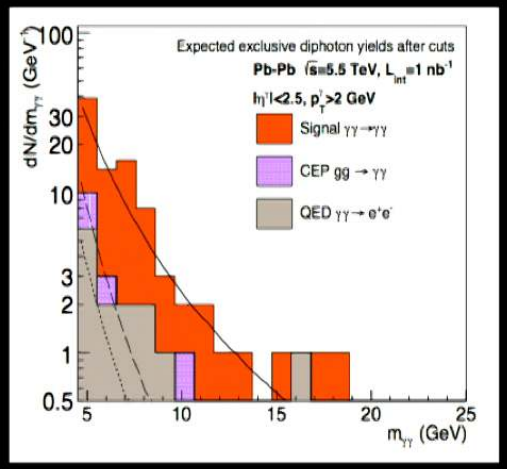
Applications



Light-by-Light scattering



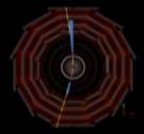




1601.07001: M. Kłusek-Gawenda, P. Lebiedowicz, A. Szczurek

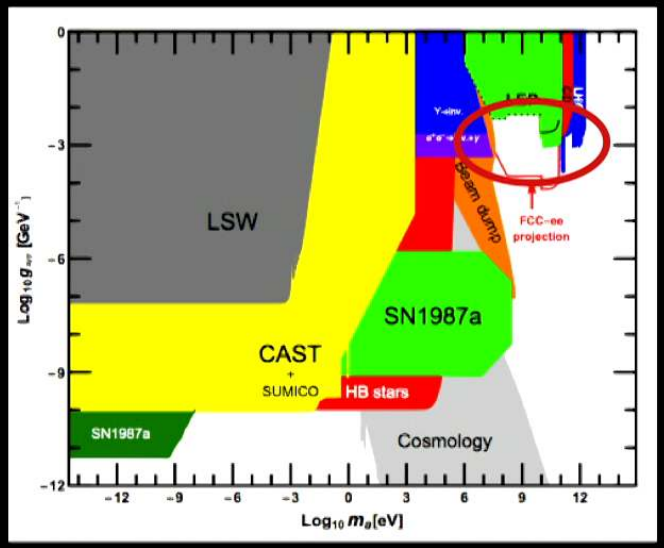
1305.7142: D. d'Enterria, G. Silveira

ALP's in ultra-pheripheral collisions

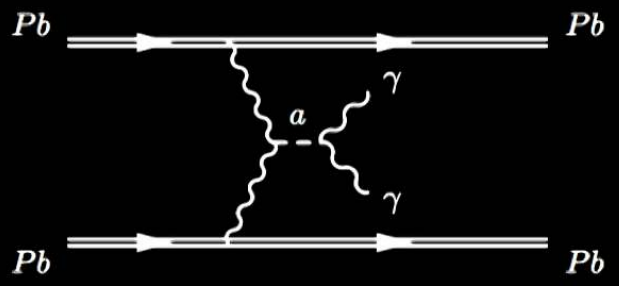


SK, T. Lou, T. Lin, T. Melia: arXiv:1607.06083

$$\frac{1}{2}(\partial a)^2 - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}\frac{a}{\Lambda}F\widetilde{F}$$



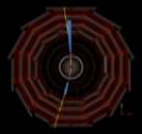
J. Jaeckel, M. Spannowsky: 1601.07001



1 GeV - 100 GeV range

see also
A. B. Balantekin, et.al. Phys. Rev. Lett. 55, 461 (1985)
A. Natale, Mod. Phys. Lett. A, 09, 2075 (1994)

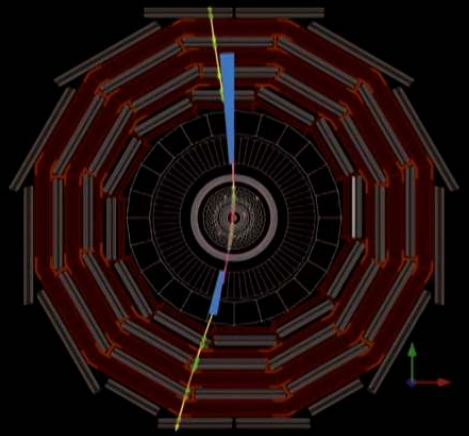
Triggers



CMS has two dedicated UPC triggers

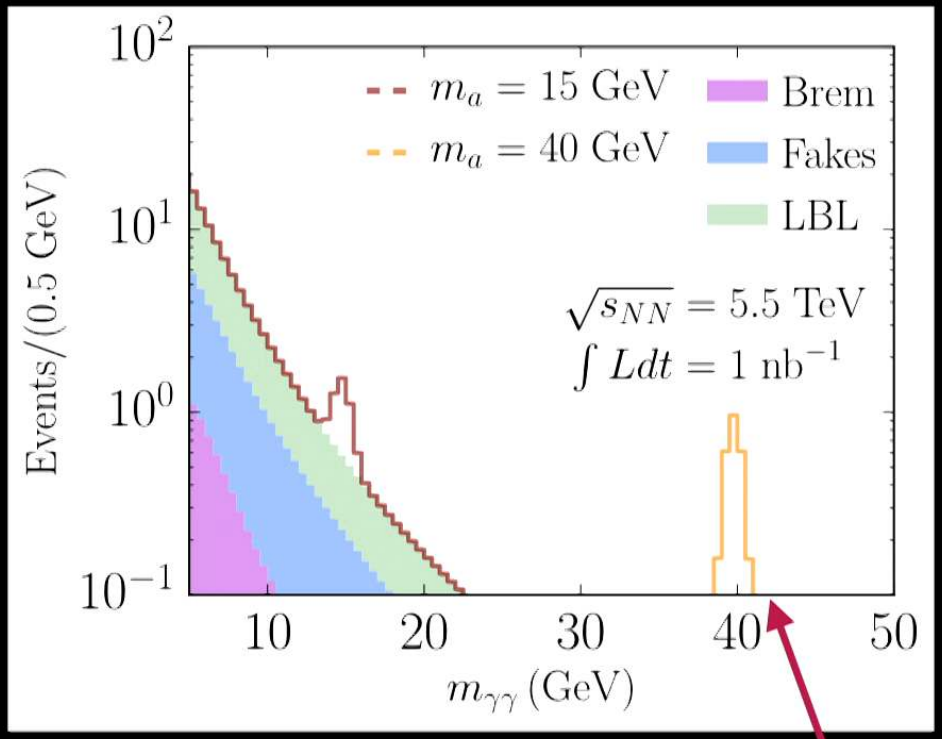
2 photons with $E\gamma > 2$ GeV
or
1 photon with $E\gamma > 5$ GeV

Veto activity in at least one of the forward calorimeters



Events as clean as LEP but with LHC-grade detectors!

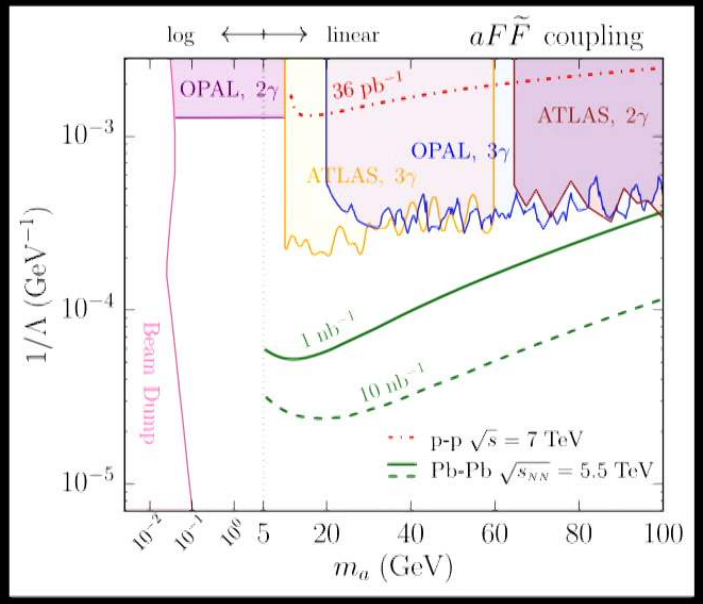
Results

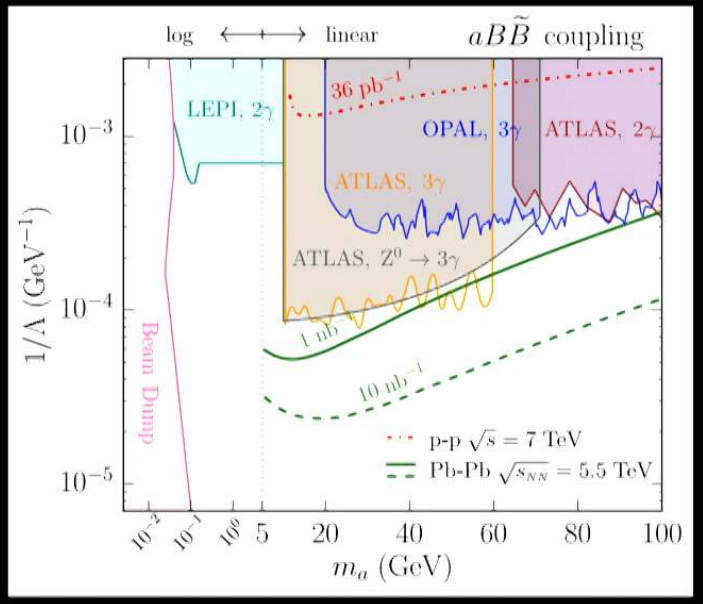


Background free!

Light-by-light:
Z. Bern, A. De Freitas, L. J. Dixon, A. Ghinculov, and H. L. Wong (2001)

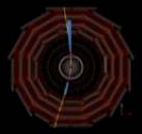
Results





Most other limits are also new recastings

Hot off the press



Light-by-light scattering in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV with the ATLAS detector at the LHC

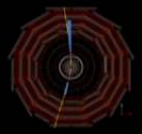
The ATLAS Collaboration

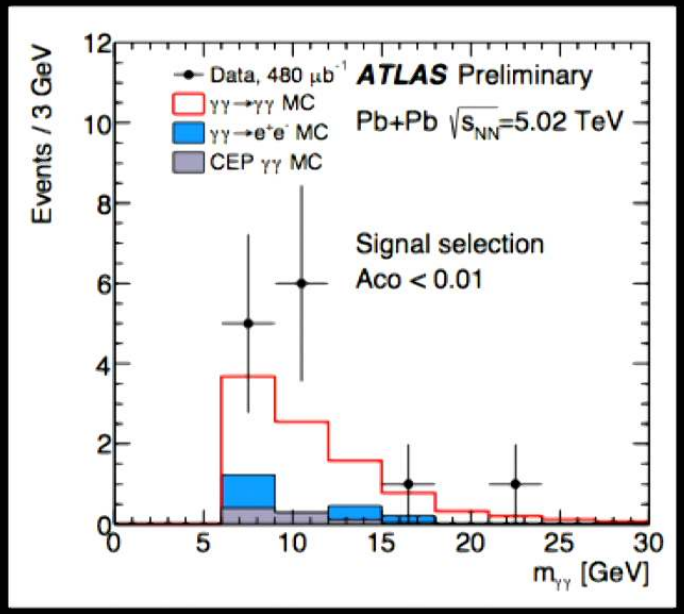
Abstract

This note reports evidence for light-by-light scattering, using 480 μb^{-1} of Pb+Pb collision data at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV recorded by the ATLAS experiment at the LHC. After background subtraction and analysis corrections, the cross section of $\gamma\gamma \rightarrow \gamma\gamma$ process for photon transverse momentum, $E_{\mathrm{T}} > 3$ GeV, photon pseudorapidity, $|\eta| < 2.4$, diphoton invariant mass greater than 6 GeV, diphoton transverse momentum lower than 2 GeV and diphoton acoplanarity below 0.01, has been measured to be 70 ± 20 (stat.) $\pm$ 17 (syst.) nb, which is in agreement with the SM prediction of 49 ± 10 nb.

From last month

Light-by-light scattering



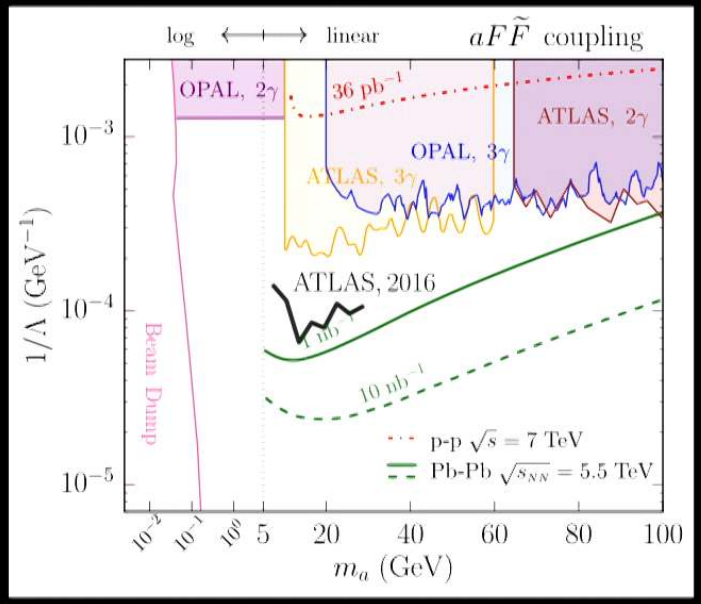


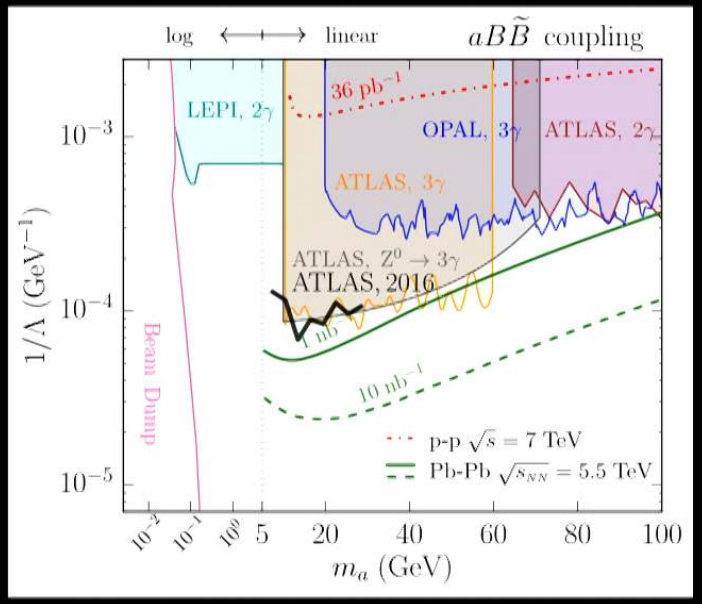
Standard Model discovered at 4.4 σ !

$$\mu = 1.4 \pm 0.6$$

Limits on ALPs?

Limits on ALP's

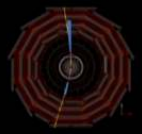




Heavy ions set the world's best limit between 6 and 30 GeV*

*Assuming no events observed above 30 GeV, the limit extends to 100 GeV.

Future directions



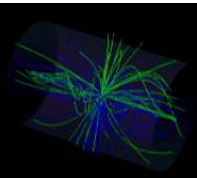
Eagerly waiting for CMS!

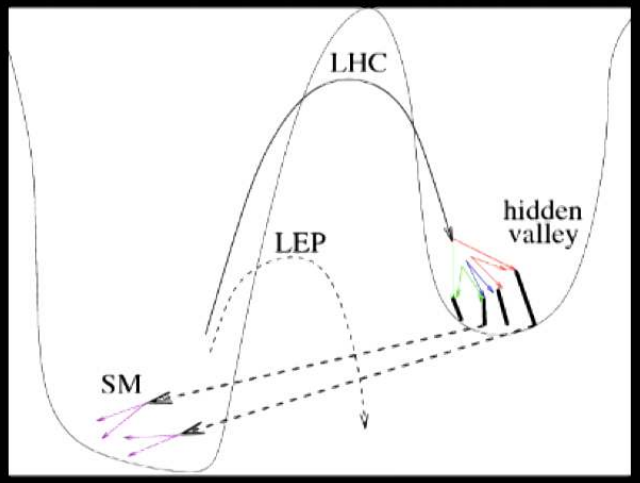
- Dark photons
- Leptophobic Z'
- Fractionally charged particles
- …

The detectors are exquisite & events are very clean
(a role for LHCb and/or ALICE?)

Ultra-peripheral collisions may be a tool at the intensity frontier

Hidden valleys





- High multiplicity of final states, often displaced
- Applications in Neutral Naturalness, dark matter, …

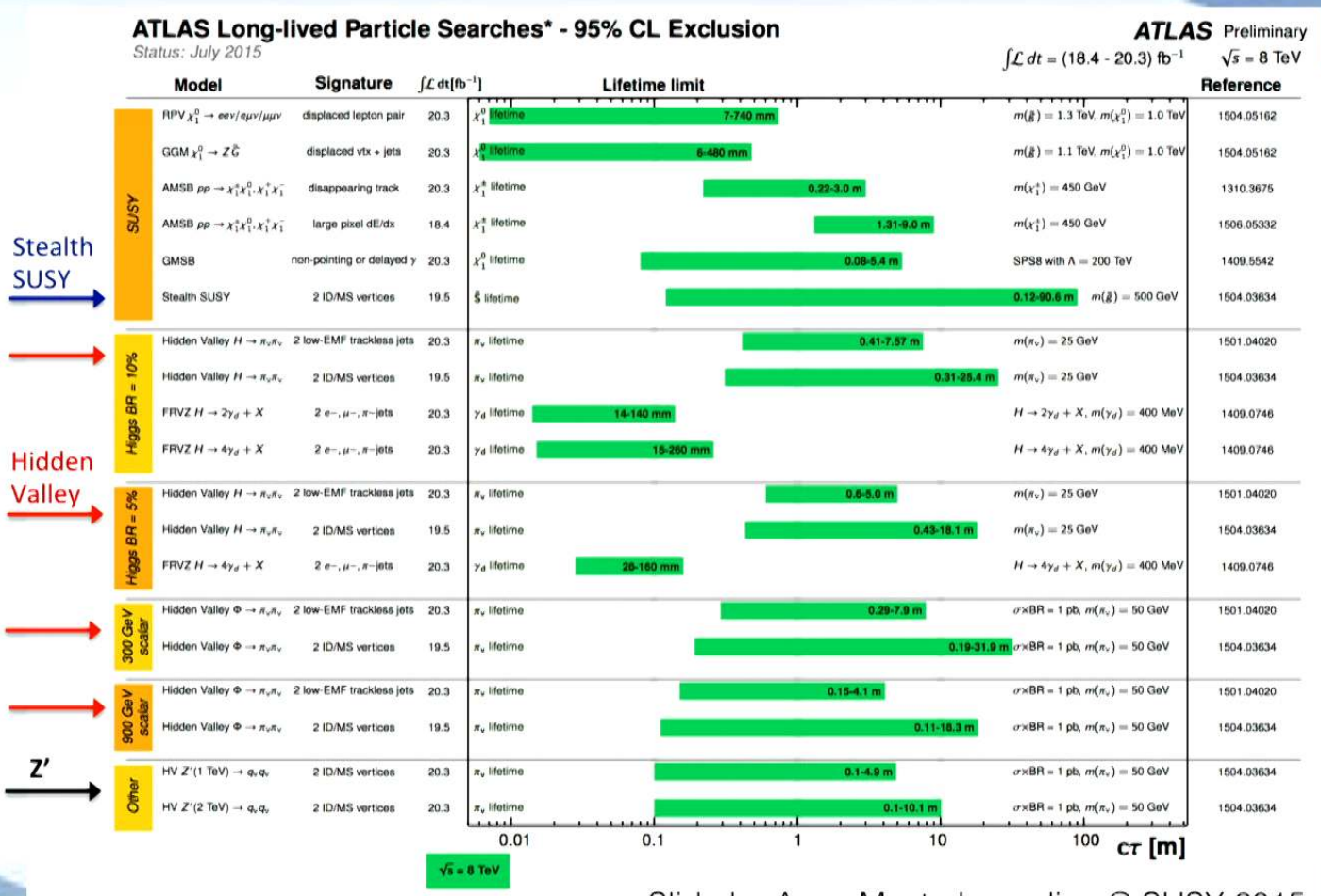
Needs special triggers

M. Strassler, K. Zurek : 0604261, 0605193, 0607160

25

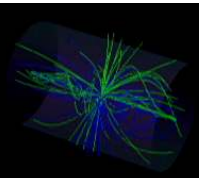
…

Status of HV-LLP searches in Atlas after LHC Run 1



Slide by Anna Mastroberardino @ SUSY 2015

“Soft bomb” or “Fireworks”

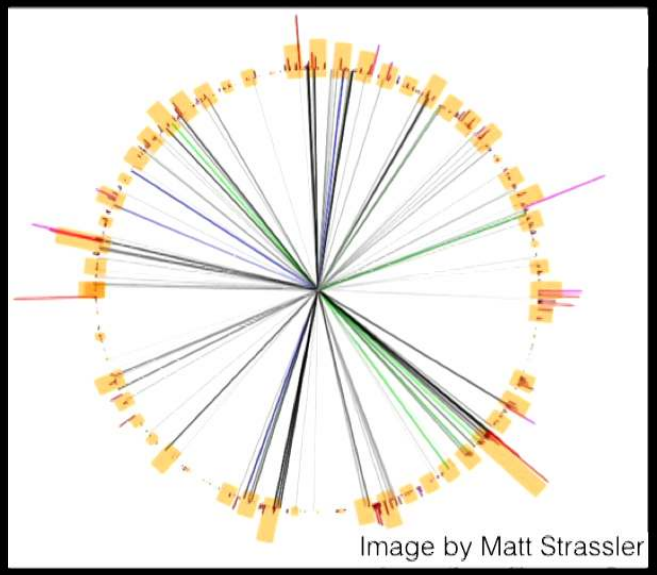


Hidden valley with $g^2N \gg 1$

↓

Non-perturbative parton shower

1. Large multiplicity of soft particles
2. Spherical event shape
3. Multiplicity scales linear with energy

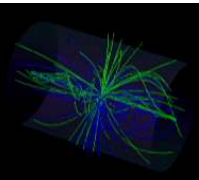


Existing trigger strategies fail

M. Strassler: 0801.0629
Y. Hatta, T. Matsuo: 0804.4733
D. Hofman, J. Maldacena: 0803.1467

27

Additional Assumptions



1. Neglect fluctuations away from sphericity — No jets

2. Assume Maxwell-Boltzmann distribution:

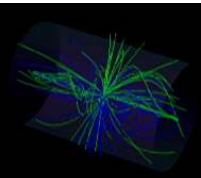
$$f(\mathbf{p}) \sim \frac{\mathbf{p}^2}{m^2} e^{-\sqrt{m^2+\mathbf{p}^2}/T}$$

Y. Hatta, T. Matsuo: 0807.0098

with $m = 1\ \mathrm{GeV}, \quad T = 0.5\ \mathrm{GeV}$ — No hard leptons

3. All hidden sector particles decay prompt — No MET

Additional Assumptions



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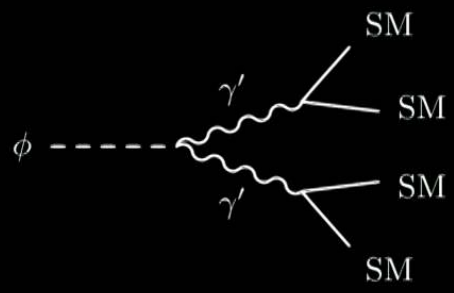
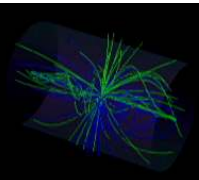
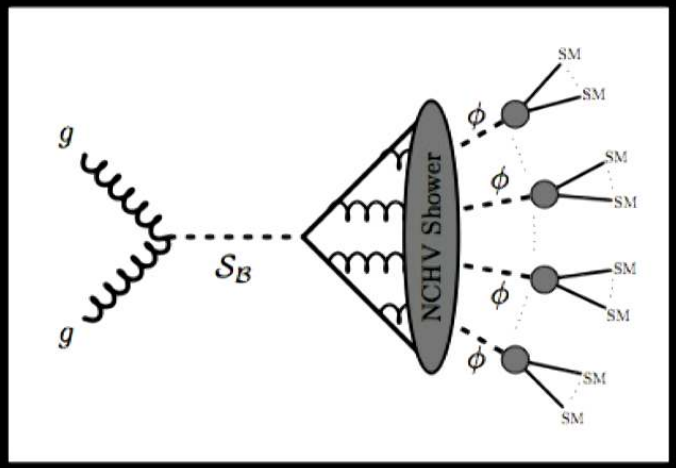


Additional Assumptions



4. Only decays to electrons and muons (for simplicity)

5. Production through gluon fusion



Benchmark points

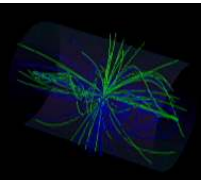
$m_{S_B} = 750$ GeV

$m_{S_B} = 400$ GeV

$m_{S_B} = 125$ GeV

(exotic Higgs decay)

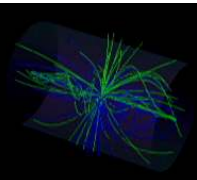
Triggers at ATLAS



Level 1 (L1) (hardware)
total: 100 kHz
Calorimeters, muon chambers
Combine raw objects
Example: 3μ: 15 GeV 7 kHz

Trigger tables at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults

Strategy



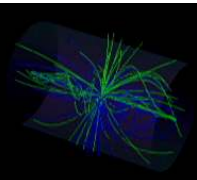
1. L1 trigger

Many “loopers” in the B-field

↓

Trigger on ISR jet and / or MET (Ecal)

Strategy



1. L1 trigger

   Many “loopers” in the B-field

   ↓

   Trigger on ISR jet and / or MET (Ecal)

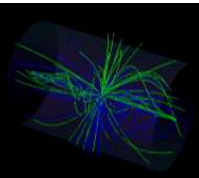
2. HLT

   Inner tracker available, but limited tracking

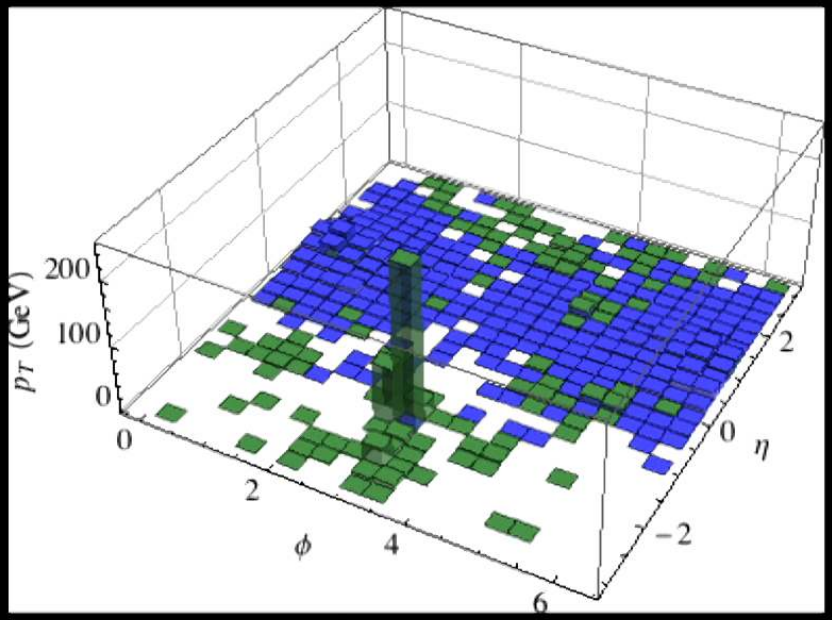
   ↓

   trigger on overdensity of hits

Truth level



Example event display

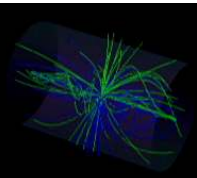


Blue: leptons

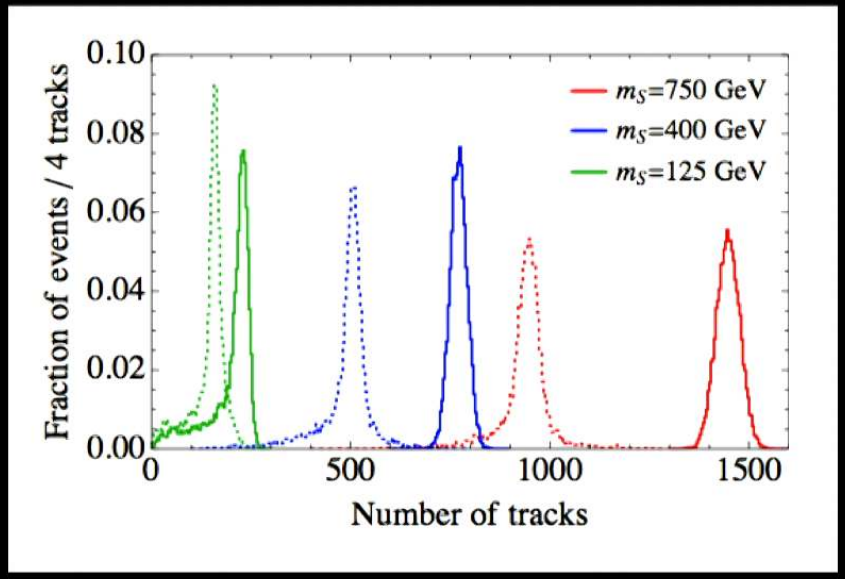
Green: hadrons

ISR Jet recoils against a cloud of soft leptons

Track multiplicity



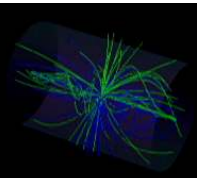
tracks / GeV

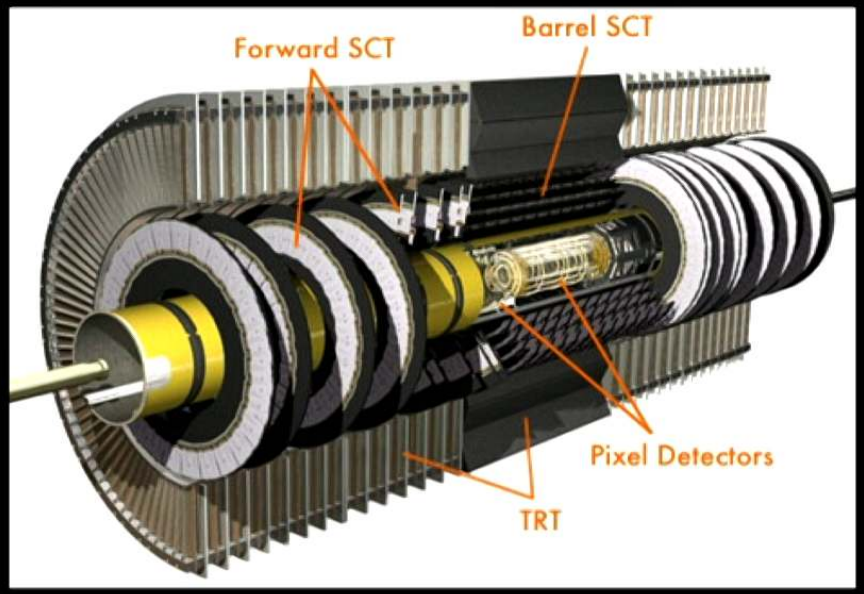


tracks / GeV is model dependent

roughly half of the tracks within tracker acceptance

The ATLAS inner detector



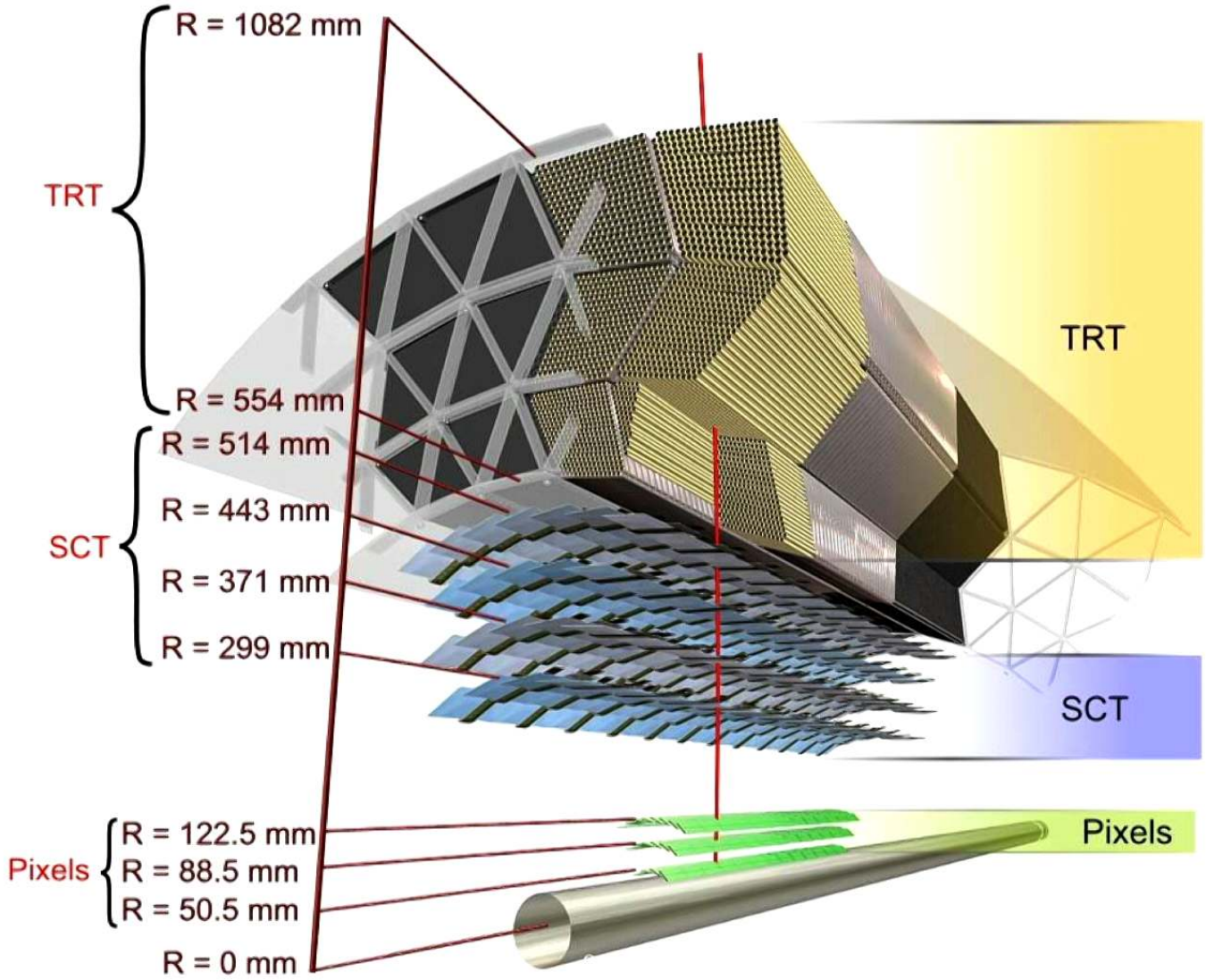


Accounted for
- Bremsstrahlung (electrons only)
- Energy loss

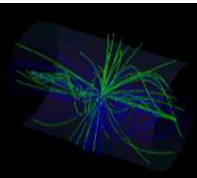
Neglected
- Pixel clustering

components included in simulation

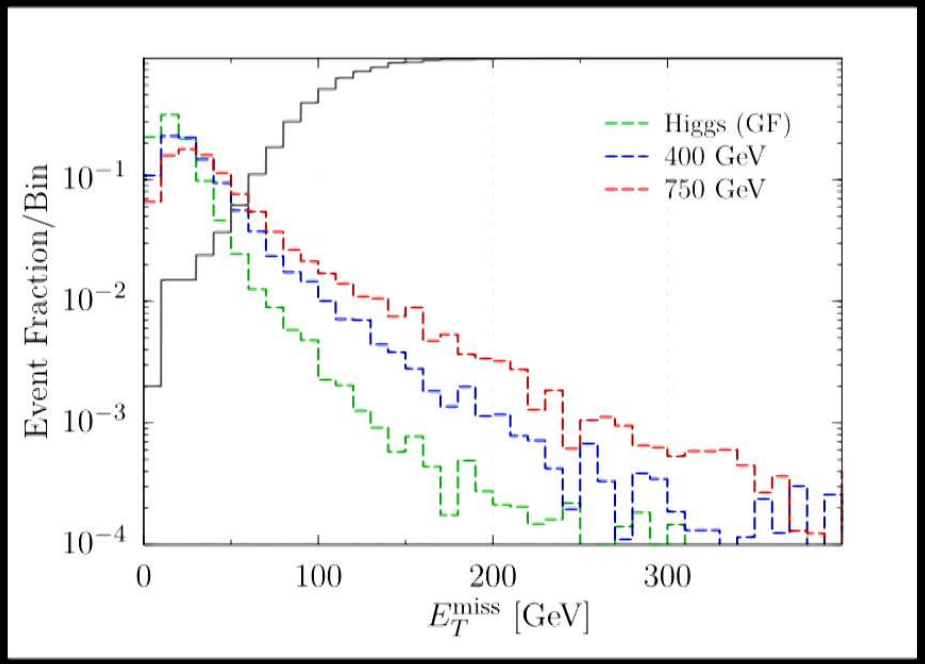
0. pipe
1. IBL
2. pixel barrel 1
3. pixel barrel 2
4. pixel barrel 3
5. pixel wheel 1
6. pixel wheel 2
7. pixel wheel 3
8. services
9. SCT barrel 1
10. SCT barrel 2
11. SCT barrel 3
12. SCT barrel 4
13. SCT wheel 1
14. SCT wheel 2
15. SCT wheel 3
16. SCT wheel 4
17. SCT wheel 5
18. SCT wheel 6
19. SCT wheel 7
20. SCT wheel 8
21. SCT wheel 9
22. TRT barrel 1
23. TRT barrel 2
24. TRT barrel 3
25. TRT barrel 4
26. TRT wheel 1
27. TRT wheel 2
28. TRT wheel 3
29. TRT wheel 4
30. ECAL barrel
31. ECAL wheel


R = 1082 mm
TRT
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
TRT
SCT
Pixels
R = 122.5 mm
R = 88.5 mm
R = 50.5 mm
Pixels
R = 0 mm

Level 1 trigger



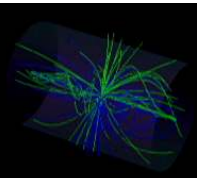
MET
(as seen by the ECAL)



L1 MET ~ 5% -10%

efficient

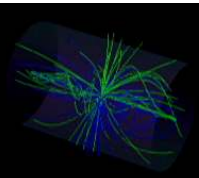
Level 1 trigger



Summary

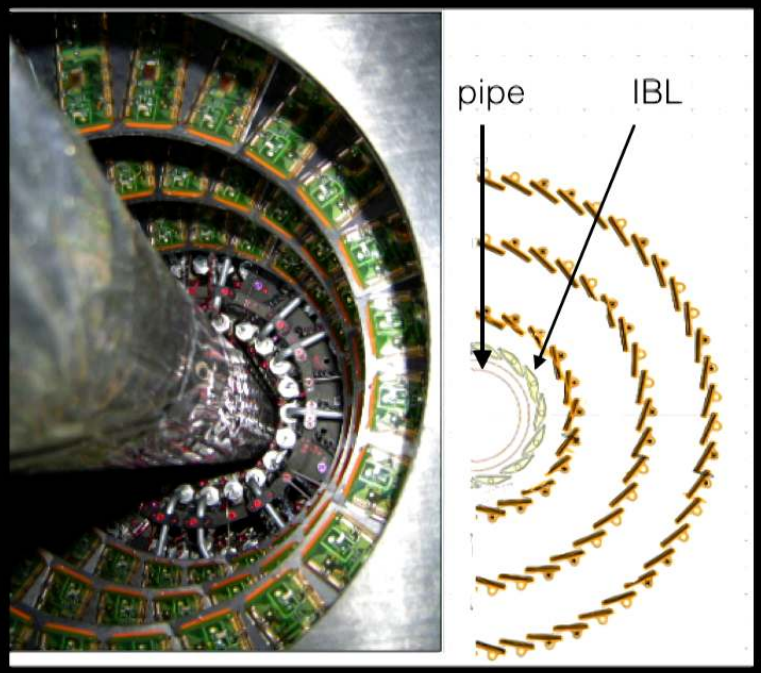
	Higgs (VH)	Higgs (VBF)	Higgs (GF)	400 GeV (GF)	750 GeV (GF)
1j ($p_T > 100$ GeV)	0.057 ± 0.002	0.107 ± 0.003	0.034 ± 0.001	0.104 ± 0.002	0.169 ± 0.002
3j ($p_T > 40$ GeV)	0.026 ± 0.001	0.045 ± 0.002	$< 1\%$	$< 1\%$	0.019 ± 0.001
4j ($p_T > 20$ GeV)	0.019 ± 0.001	0.034 ± 0.002	$< 1\%$	0.016 ± 0.001	0.052 ± 0.002
$E_T^{\text{miss}} > 50$ GeV	0.088 ± 0.002	0.063 ± 0.001	0.030 ± 0.001	0.077 ± 0.001	0.136 ± 0.002
$1\gamma/e$ ($E_T > 20$ GeV)	0.045 ± 0.002	0.011 ± 0.001	$< 1\%$	$< 1\%$	$< 1\%$
1μ ($p_T > 20$ GeV)	0.073 ± 0.002	0.011 ± 0.001	$< 1\%$	$< 1\%$	$< 1\%$
Combined	0.224 ± 0.003	0.162 ± 0.003	0.055 ± 0.001	0.140 ± 0.002	0.217 ± 0.002
$\sigma_{pp \to h+X} \times \epsilon_{\text{comb}}$ (pb)	0.50	0.60	2.39	–	–

High level trigger



Focus on Insertable B-layer (IBL) because:

1. Catch as many soft tracks as possible
2. Less diffusion of the hits



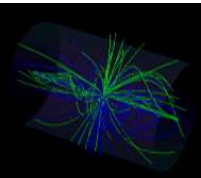
Installed in May 2014

- 31 mm radius
- 50 x 250 μm^2 pixels
- 64 cm long in z-direction

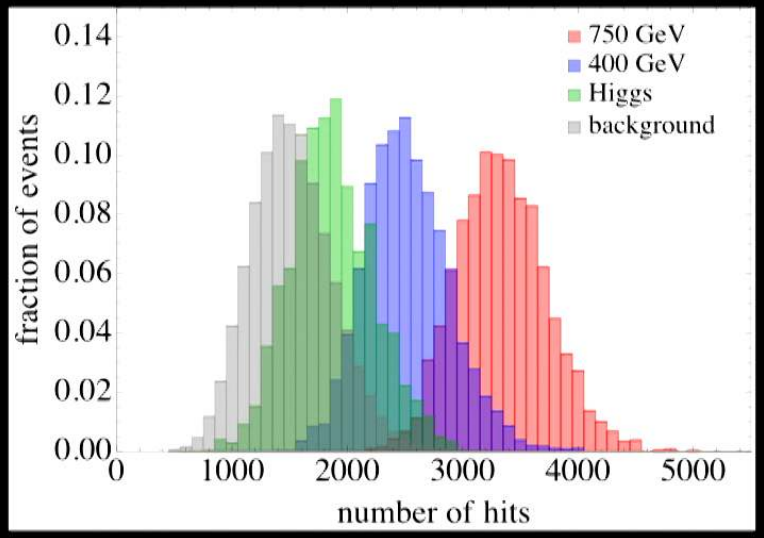
  (-2.5 $\lesssim \eta \lesssim$ 2.5)

40

High level trigger



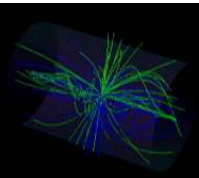
Hit multiplicity on the IBL



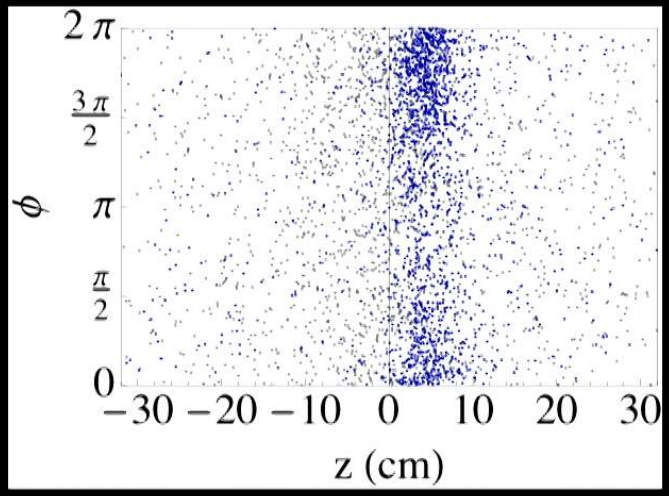
hits from pile-up is non-poissonian

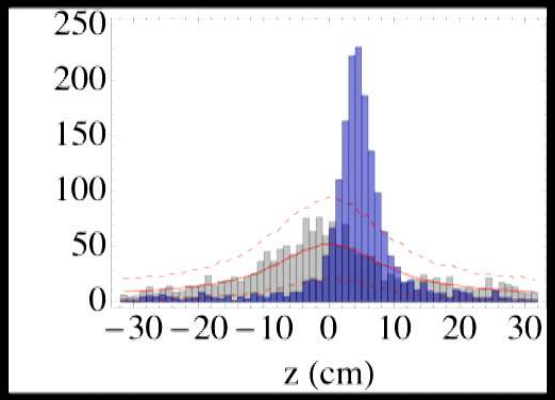
Decent separation just from counting

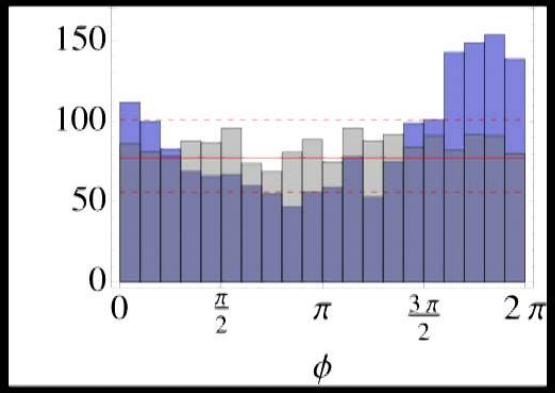
High level trigger



Example event on the IBL





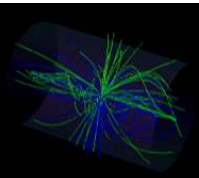


Gray: pile-up

Blue: soft bomb

Variance in signal hits is much smaller

High level trigger



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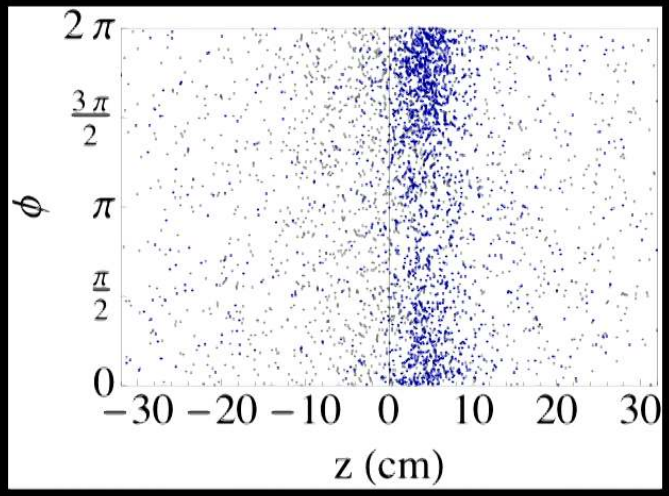

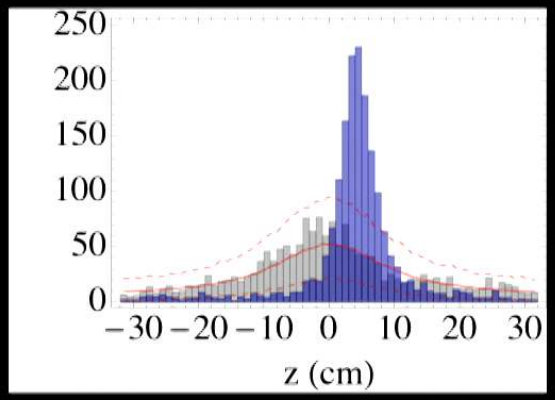

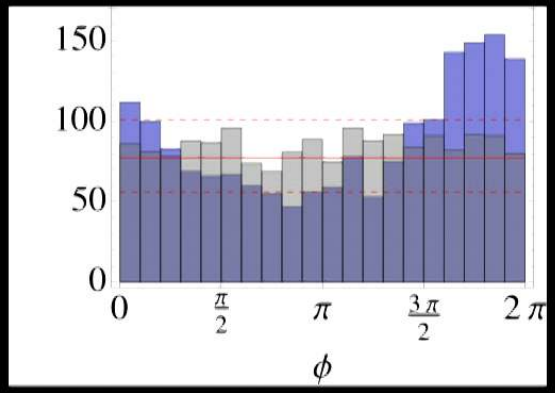

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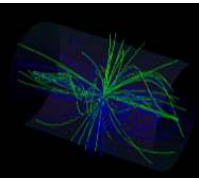
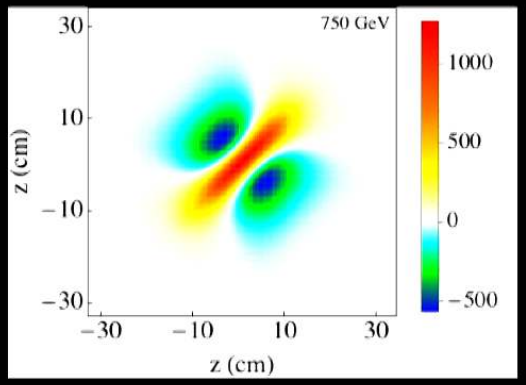
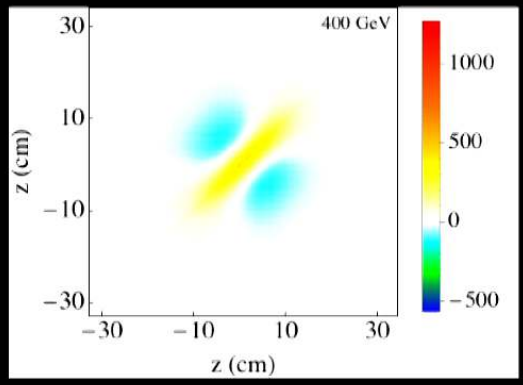


Covariance

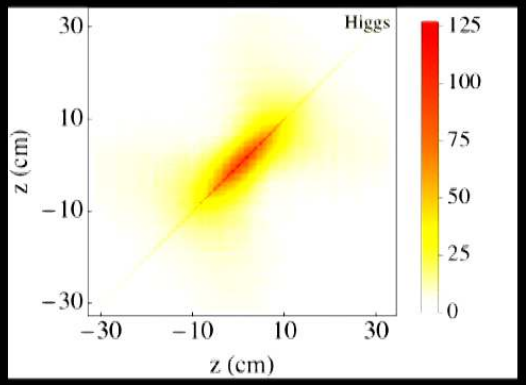
750 GeV



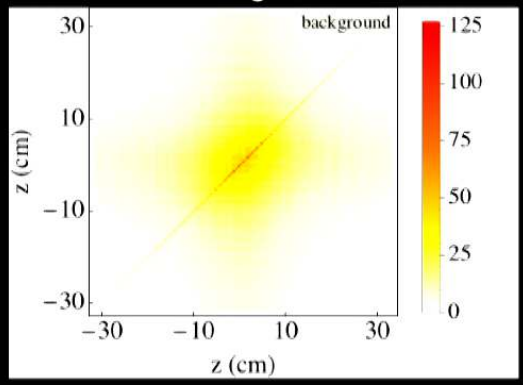
400 GeV



125 GeV



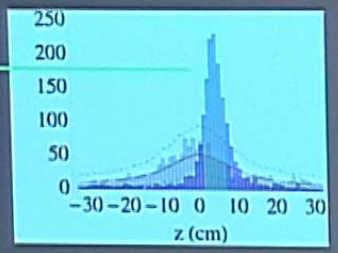
Background

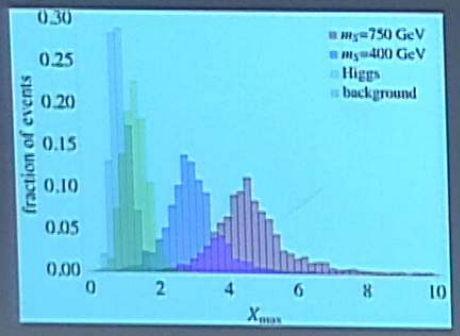


High level trigger

Model independent discriminant

$$X_{max} = \frac{\text{observed}}{\text{expected background}}$$



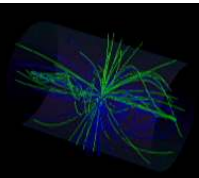


Background rejection

	10^{-3}
750	1.00
400	0.93
125	0.06

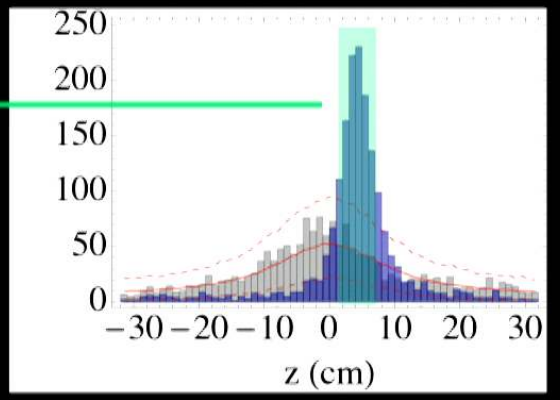
45

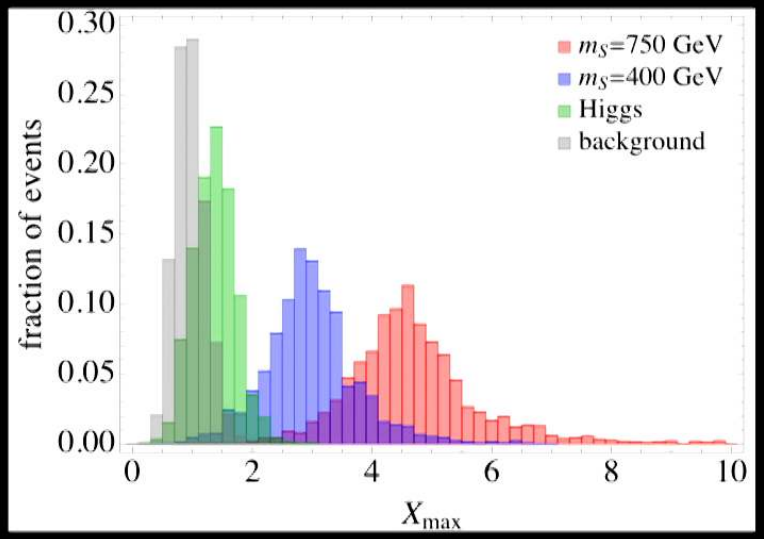
High level trigger



Model independent discriminant

$$X_{max} = \frac{\text{observed}}{\text{expected background}}$$

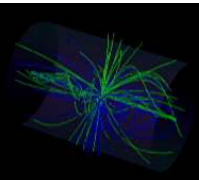




Background rejection

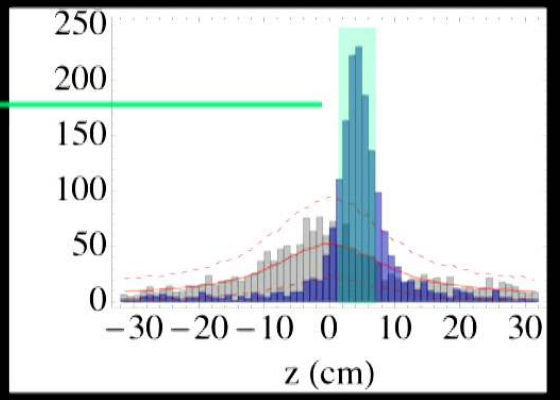
	10^{-3}
750	1.00
400	0.93
125	0.06

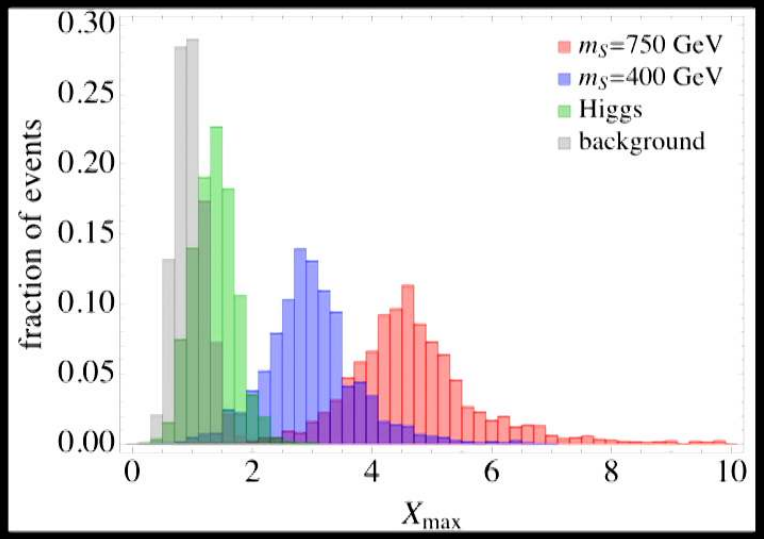
High level trigger



Model independent discriminant

$$X_{max} = \frac{\text{observed}}{\text{expected background}}$$

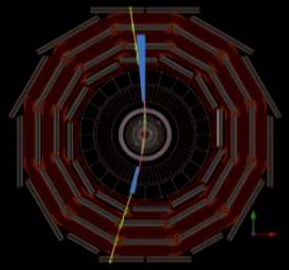




Background rejection

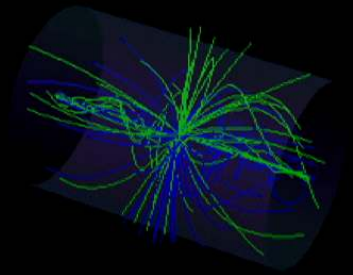
	10^{-3}
750	1.00
400	0.93
125	0.06

Conclusions



heavy ion beams are awesome $\gamma\gamma$ colliders

→ Limits on ALP's



Trigger on "soft bombs" by looking at hits, rather than tracks

(L1 is the bottleneck)