Classicalization, a Higgsless alternative

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work (in progress) in collaboration with
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What is classicalization ?

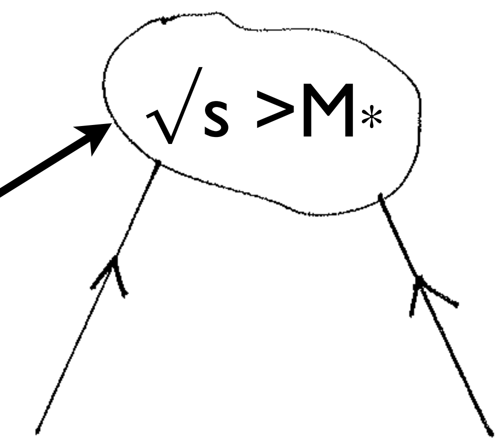
- In QFTs with a cut off (like the Higgsless SM) 2->2 scattering amplitudes blow up at energies near the cut off. Standard (Wilsonian) interpretation => New Physics at these scales.

- Classicalization is an alternative way of unitarizing these amplitudes in some cases. Inspired by black hole physics.

- Take the following simple example of scalar field,

$$\mathcal{L}(\phi) = (\partial_\mu \phi)^2 + \frac{1}{M_*}\phi(\partial_\mu \phi)^2$$

Energy here is like the 'charge' in electrostatics. It generates a classical configuration of ϕ around it.



Dvali, Giudice, Gomez and Kehagias 2010

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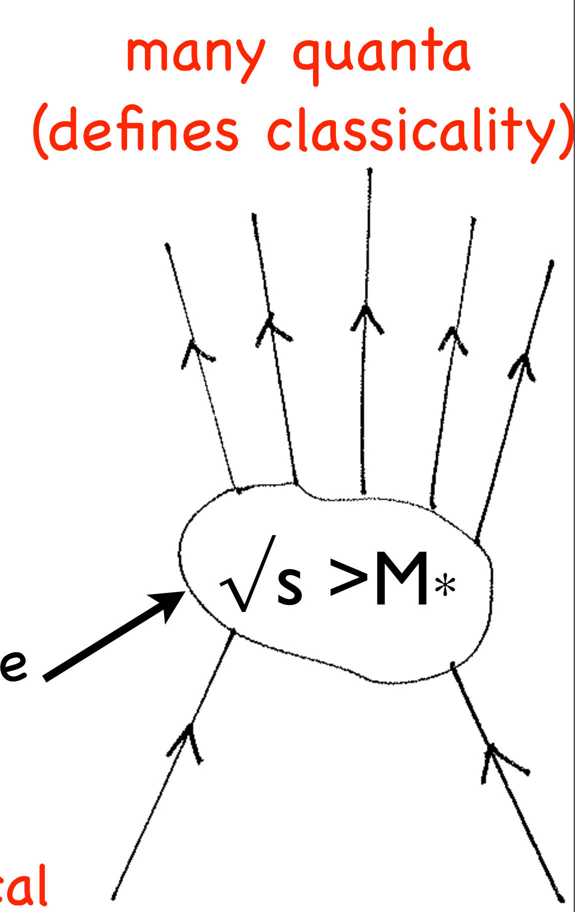

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- 2->2 scattering gets suppressed at high energies. We get instead 2-> Classicalon->many particles.

Unitarizing WW scattering by classicalization

- If there is no Higgs, $W_L W_L \to W_L W_L$ scattering amplitude blows up at around 700 GeV.

- If we add appropriate interactions the longitudinal Ws and Zs can classicalize. Even more minimal than SM! For eg. lets add a classicalizing interaction to Higgsless SM,

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_W^2\, W_\mu W^\mu + \frac{g^4}{4}\,(W_\mu W^\mu)^2$$

- With energy size of classicalon increases (like Black Holes). In theories that exhibit classicalization higher scattering energies does not mean probing shorter distances.

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A classicalizing interaction which gives classicalons with radii,

(As $W_L^\mu \to \frac{\partial^\mu\phi}{m_W}$, ϕ being the 'goldstone')

$$r_* \sim \frac{\sqrt{s}^{1/3}}{v^{4/3}}.$$

→ the exponent depends on the particular interaction, =1 for black holes

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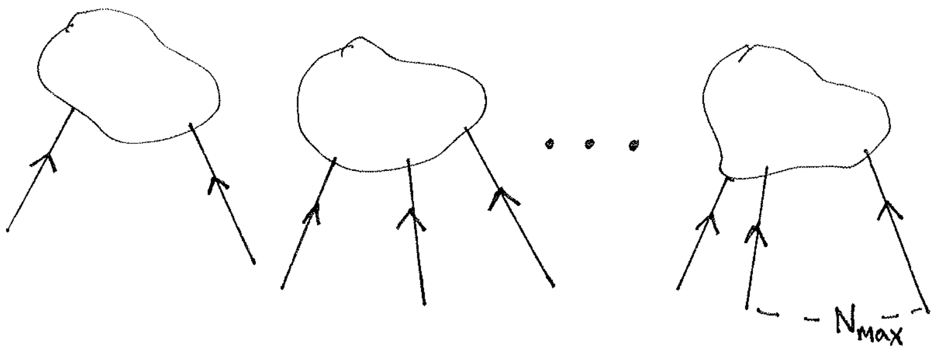
How do we make experimental predictions ?

- The process we can look for in colliders would be:
  Weak Boson Fusion->Classicalon->multiple W/Z
- Cross-section is just the geometric cross-section: $\sigma=\pi r_*^2$.
- Experimentally relevant question: What happens after we produce a classicalon? What is the number of particles classicalon decays to ? What is the energy distribution of the decay products?

unlike black holes, these classicalons would decay only to Ws/Zs

Classicalons have thermodynamic properties!

- Every possible way of localizing the required energy in the classicalon radius r_* must form a classicalon, thus classicalons can be formed from 2,3,4..... N_{max} particles (minimum energy of a particle $1/r_*$ => $N_{max} = \sqrt{s}/(1/r_*) = r_* \sqrt{s}$).



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- Classicalons would rarely decay to 2 particles as there are many more ways of decaying to many particles simply because of combionatrics => 2->2 scatterring suppressed. We see how notion of entropy arises for classicalon.

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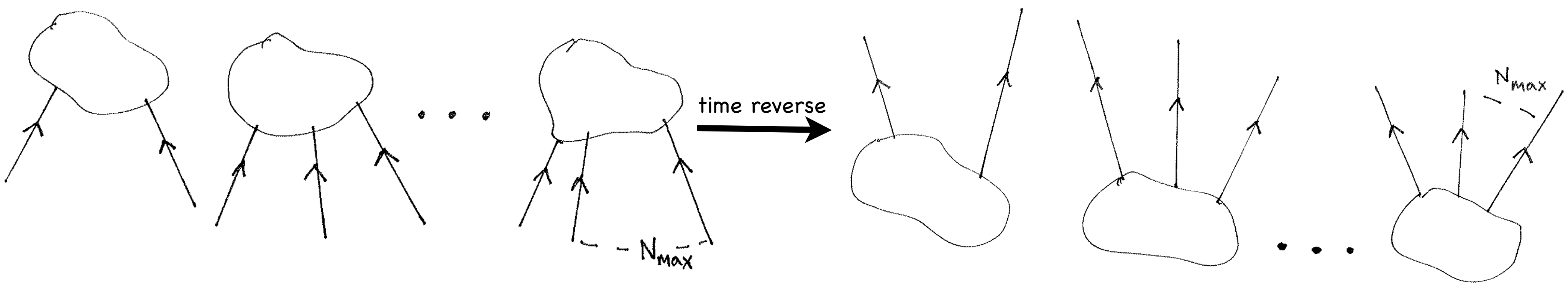

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Classicalons are Bose Einstein systems

- Every possible way of localizing the required energy in the classicalon radius r_* must form a classicalon. How do we compute the number of possible ways?

- We must ensure,
(1) Condition 1: energy conservation, $|\vec{k_1}| + |\vec{k_2}| .... + |\vec{k_N}| = \sqrt{s}$
(2) Condition 2: that all the energy gets localized inside, for eg. scattering plane waves would not localize the energy inside r_*

- All possible ways of choosing the momenta $\mathbf{k}_i$ (without any other restriction) respecting energy conservation gives the Bose-Einstein distribution,

$$N(\omega)d\omega = \frac{g(\omega)d\omega}{e^{\beta\omega} - 1}$$

- We cannot find the temperature ($T = 1/\beta$) and total number of particles without knowing the density of states.

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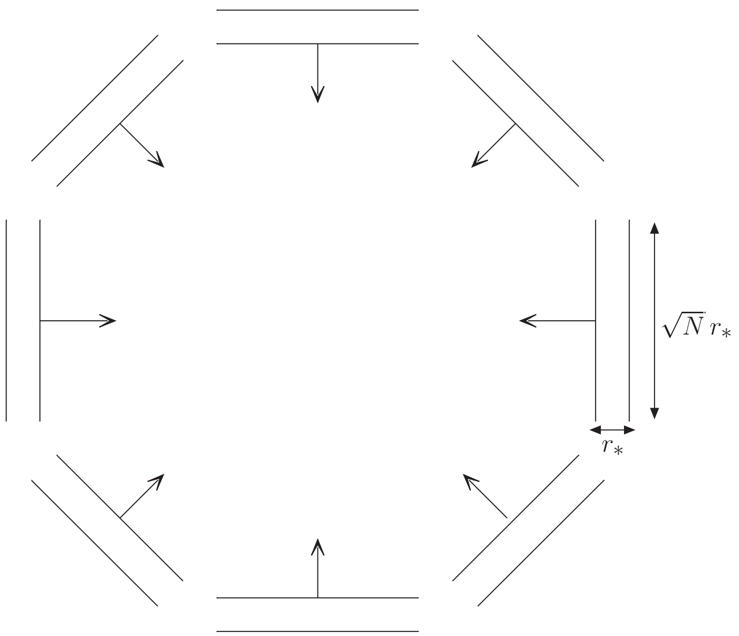
The Density of states

- In order to localize all the energy in the classicalon radius wavepackets must have size at most r* in the longitudinal direction.

- The wavepackets can be much longer in the transverse direction, of size $\sqrt{N}$ r*. This leads to a Φ~1/r field outside the classicalon radius r*. Most of the energy is still inside the classicalon radius r*.



- For such wavepackets density of states function is:

$$g_\omega d\omega = \frac{1}{8\pi^3}(2r_*)d\omega \times L^2(4\pi\omega^2) = \frac{Nr_*^3\omega^2}{\pi^2}d\omega$$

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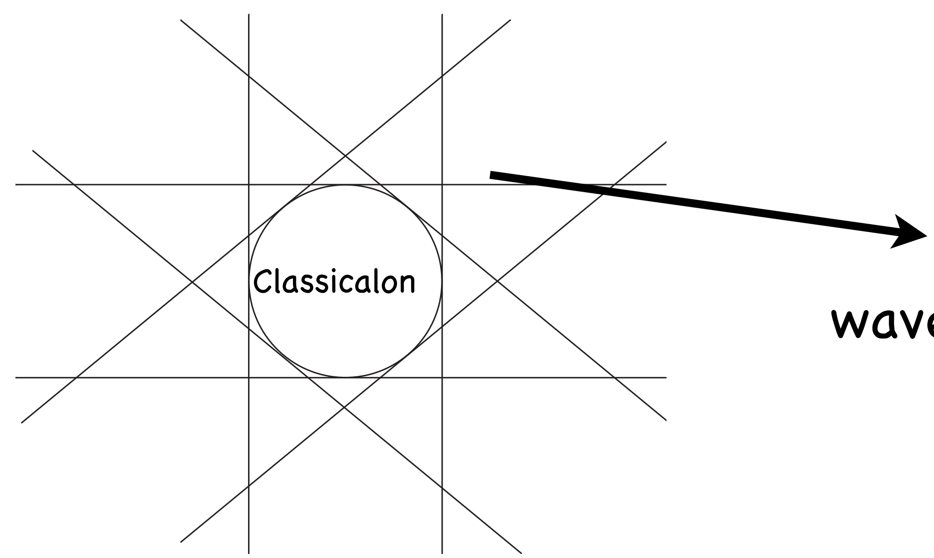

Outside r_* the wavepackets superpose to give $\Phi \sim 1/r$

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crucial difference from blackbody radiation

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Temperature, decay multiplicity and entropy

- With this density of states function and the distribution function we obtain the temperature, number of decay particles and entropy.

$$\frac{N_* r_*^3}{\pi^2} \int_{\omega=\pi/r_*} \frac{\omega^2 d\omega}{e^{\beta\omega}-1} = N_*$$
$$\frac{N_* r_*^3}{\pi^2} \int_{\omega=\pi/r_*} \frac{\omega^3 d\omega}{e^{\beta\omega}-1} = \sqrt{s},$$

$$\beta \sim r_* \Rightarrow T \sim \frac{1}{r_*}$$

$$N_* \sim \sqrt{s} r_*$$

$$S \sim N_*$$

- For the black hole case we recover the well known proportionality of the entropy with the area.

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For these classicalons $N_* \sim (\sqrt{s})^{(4/3)}$ whereas for black holes, $N_* \sim (\sqrt{s})^2$.

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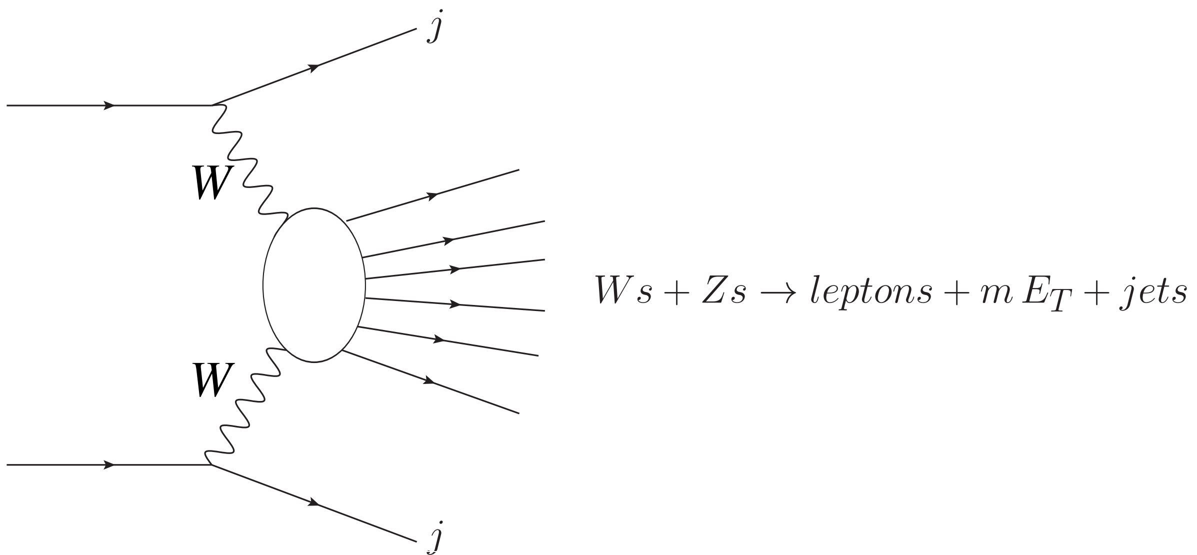
Classicalons at LHC

- The final LHC signature would be multiple Ws/Zs ->leptons+jets+mE $_T$.



- We use the effective W/Z approximation and convolute the geometric cross-section $\pi r_*^{\,2}$ with the W/Z-boson luminosity function to get the final cross-section :

$$\sigma = \int_{\tau_{min}}^{1} d\tau \pi r_*(\hat{s})^2 \int_{\tau'}^{1} \frac{d\tau'}{\tau'} \int_{\tau'}^{1} \frac{dx}{x} f_i(x,q^2) f_j(\tau'/x,q^2) \frac{dL}{d\xi}$$

- We find the total number of Ws/Zs a classicalon would decay to by solving for β and N_* the equations,

$$\gamma N_* r_*^3 \int \frac{\omega\sqrt{\omega^2 - m^2} d\omega}{e^{\beta\omega} - 1} = N_*$$

$$\gamma N_* r_*^3 \int \frac{\omega\sqrt{\omega^2 - m^2} d\omega}{e^{\beta\omega} - 1} = \sqrt{s},$$

Results

$\sqrt{\hat{s}_{min}}$ (GeV)	Multiplicity	Total Cross-section (fb) W^+W^+, W^+W^-, W^-W^-	Signal l^+l^+(fb)	$3l$(fb)	$3l^+$(fb)	Background l^+l^+(fb)
600	4	57, 56, 14	4.3	4.6	0.5	1.4
740	5	35, 33, 7.8	2.7	4.6	0.4	0.3
870	6	23, 22, 4.8	2.6	4.2	0.4	<0.3
1000	7	16, 14, 3.1	2.2	3.4	0.8	-
1130	8	11, 10, 2.0	1.5	2.4	0.6	

(preliminary)

(at 14 TeV with Λ= 500 GeV)

- For Λ= v = 246 GeV these classicalons can be seen even with 7 TeV LHC energy:

  2 same sign leptons (multiplicity 5): 3.6 fb

  3 same sign leptons (multiplicity 5): 0.5 fb

Results

2 same sign leptons

3 same sign leptons !
hardly any background

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Summary

- Classicalization can unitarize WW scattering in the absence of the Higgs.
- Classicalons have thermodynamic properties like temperature and entropy and their decay products will have a Bose-Einstein distribution.
- Prospects for finding these classicalons are good at the LHC. Might even see them in the 7 TeV run.