Sphaleron transitions in scattering

Stimulated by work of Tye & Wong*,

Ellis & Sakurai** published detailed plots of observables of $\Delta N_{\rm CS} = \pm 1$ processes in pp scattering, e.g.

$$q + q \quad \to \quad \bar{q} + 3\bar{q} + 3\bar{q} + 3\bar{\ell} + X$$

$\sigma = 7.3$ fb for $E_{\rm cm} = 13$ TeV (41 fb at 14 TeV)

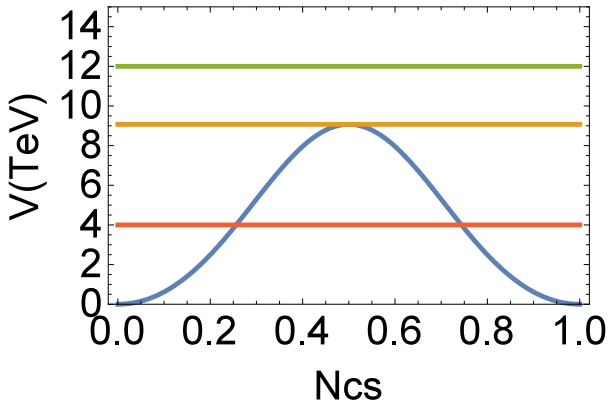
on the other hand, received wisdom from earlier work by many:

substantial exponential suppression at parton level extends beyond sphaleron energy $\simeq 9$ TeV

*PRD92(2015)045005
**JHEP04(2016)086

Δ(fermionnumber) = $\Delta N_{\rm CS}$

potential energy in Bose fields *versus* $N_{\rm CS}$



integer $N_{\rm CS}$ gauge-equivalent

$V = E_{\rm sph} \simeq 9$ TeV at $N_{\rm CS} = 0.5$

$E < E_{\rm sph}$: tunneling through the barrier

$E \gg E_{\rm sph}$: coasting freely over the barrier?

sphaleron transition, $\Delta N_{\rm CS} = \pm 1$, involves large fields of order $m_W/\sqrt{\alpha_{\rm W}}$ in extended region of order $1/m_W$

semi-classical $\leftrightarrow$ many quanta

scattering process:

$|2 \text{ bosons}\rangle \xrightarrow{(1)} |\text{sphaleron transition}\rangle \xrightarrow{(2)} |$ many W's & H's$\rangle$

probability (1) exponentially suppressed even at $E > E_{\rm sph}$

probability (2) unsuppressed

inclusive fermion-fermion scattering*

$$\widehat{\sigma} \approx \frac{1}{m_W^2}\left(\frac{2\pi}{\alpha_W}\right)^{7/2} \exp\left[-\frac{4\pi}{\alpha_W} F\left(\frac{\sqrt{\widehat{s}}}{4\pi m_W/\alpha_W}\right)\right]$$

$$\approx 5.3 \times 10^3 \text{ mb } \exp\left[-370\, F\left(\frac{\sqrt{\widehat{s}}}{30 \text{ TeV}}\right)\right]$$

Holy Grail function

$$F(\epsilon) = 1 - \frac{3^{4/3}}{2}\epsilon^{4/3} + \frac{3}{2}\epsilon^2 + \cdots$$

first few terms cannot be trusted for $\epsilon = \mathcal{O}(1)$

*Ringwald JHEP10(2003)008 *and references here in*

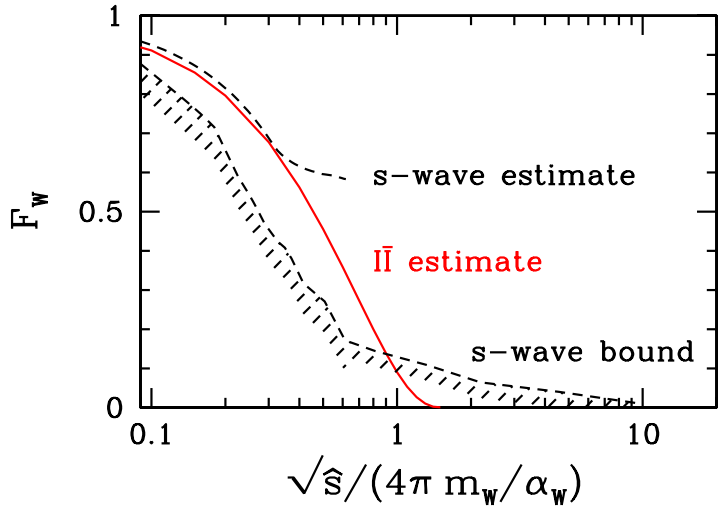
next two plots from Ringwald *op. cit.*

red: Khoze & Ringwald, instantons

black: Bezrukov *et. al.*[*], semiclassical, s-wave

plot of F:

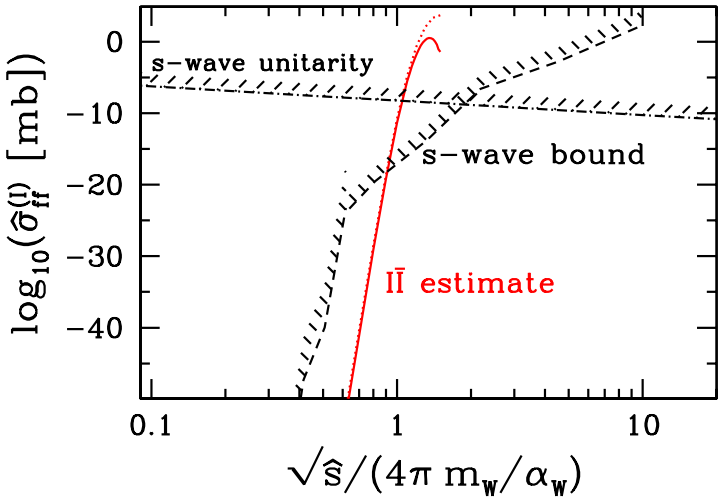
[*]Bezrukov, Levkov, Rebbi, Rubakov, Tinyakov, PRD68(2003)036005


1
0.5
0
F_W
0.1
1
10
$\sqrt{\hat{s}}/(4\pi\, m_W/\alpha_W)$
s−wave estimate
$I\bar{I}$ estimate
s−wave bound

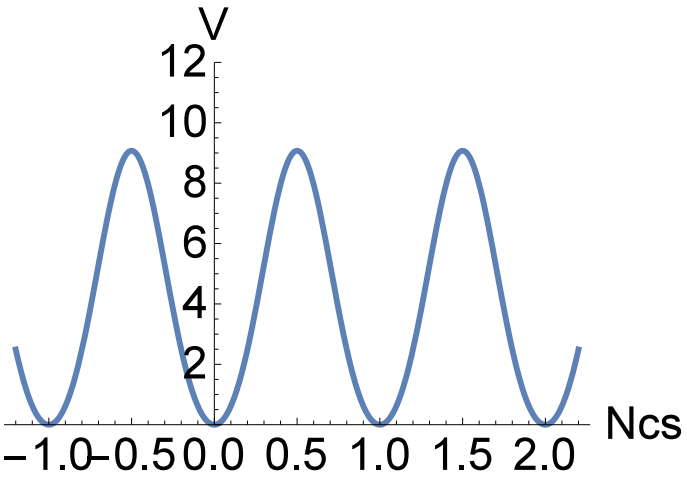
s-wave and total cross section including prefactor

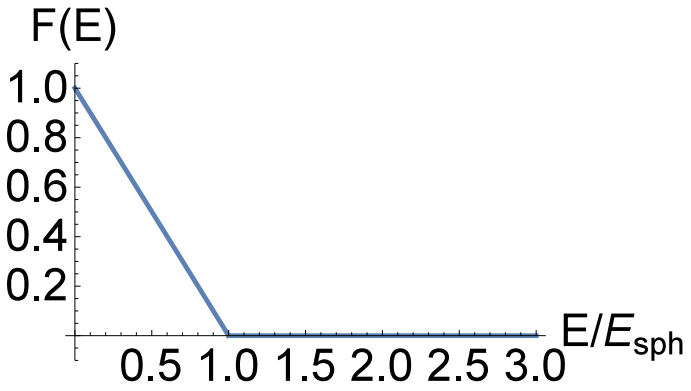
e.g. $(2\pi/\alpha_{\mathrm{W}})^{7/2} \simeq 8.7 \times 10^{7}$

plot:


0
−10
−20
−30
−40
s−wave unitarity
s−wave bound
$l\bar{l}$ estimate
0.1
1
10
$\log_{10}(\hat{\sigma}^{(l)}_{ff})$ [mb])
$\sqrt{\hat{s}}/(4\pi\, m_W/\alpha_W)$

Tye & Wong: infinite extent in N_{CS}, similarities with periodic potential experienced by electrons in metal





exponential suppression ends when $E \gtrsim E_{\text{sph}}$

critique Bachas & Tomares*

- model with one degree of freedom (N_{CS}) does not capture exponential suppression (1)

- infinite domain of N_{CS} ignores gauge equivalence of integer N_{CS} – real domain is compact, like a circle

*JHEP1605(2016)143