Questions for Final Discussion

Input from Matthew, Tancredi

General Comments/Questions

- Theory:
  - Rates for topological effects are still (somewhat) up in the air.
  - In the case of the sphaleron, Henry Tye sticks to his guns that the rate may not be suppressed above the sphaleron mass.
  - Gia argues for strong suppression
- Experiment:
  - Signatures for instantons are not clear to me
  - Sphalerons would stick out very clearly.
- Cosmology:
  - The GW connection (Pedro) is interesting
  - But the sphaleron signature there is unclear to me.

I don't have a Dog in this Fight, but …

- Consensus that sphaleron transitions very suppressed
- Challenged by **Tye & Wong** arXiv:1505.03690
- Recall periodic potential, construct Bloch wave solution

$$\left(-\frac{1}{2m}\frac{\partial^2}{\partial Q^2}+V(Q)\right)\Psi(Q) \;=\; E\Psi(Q)$$

$$V(Q) \;\simeq\; 4.75\left(1.31\sin^2(Qm_W)+0.60\sin^4(Qm_W)\right)\ \text{TeV}$$

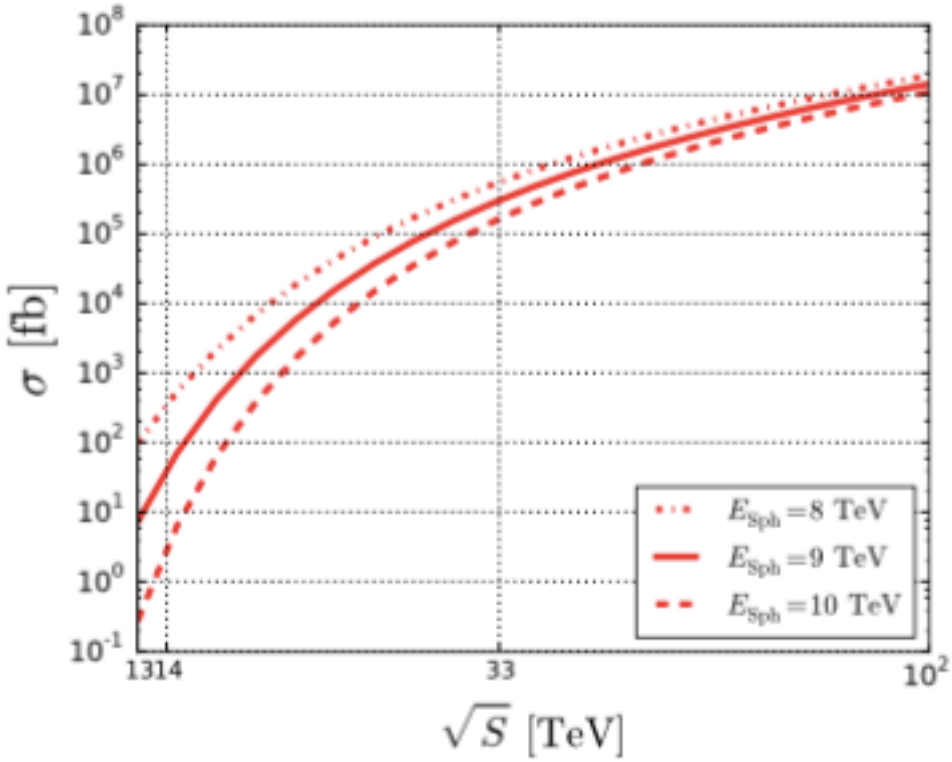
- Henry Tye argues for a "resonant tunnelling" effect
- Unsuppressed transition rate above E_{Sph} ~ 9 TeV

$$\sigma(\Delta n=\pm 1) \;\propto\; \exp\left(c\frac{4\pi}{\alpha_W}S(E)\right) \quad S(E) \;=\; (1-a)\hat{E}+a\hat{E}^2-1 \quad \text{for} \quad 0\le\hat{E}\le 1$$

- S(E) = 0 above E_{Sph}: unknown prefactor *p*

Sphaleron Transitions

- Growth of cross section with energy, if S(E) = 0 above E_{Sph}, *p* constant



- For different sphaleron masses (9 TeV expected)
- Big gain between 13 and 14 TeV (Achim)
- **Normalization *p* unknown**

JE, Sakurai, arXiv:1601.03654

General discussion (Tancredi)

- Uncertainties on QCD instantons and sphalerons cross-section difficult to quantify
  Need more work to make cross-section more reliable.
  We heard that lattice calculation (as in DIS) can help also in pp.
  Experimental limit can guide theory developments.
  → What more can be done ?

- Are the signatures prediction reliable ?
  In case of ew sphaleron very distinct signature, QCD instanton harder.
  Are the MC tools reliable ?

- Simultaneous production of heavy flavour could be striking signature for QCD instantons.
  Discussed for ep but not so much for pp yet ?

- For an experimental search, we would need to know:
  - Prediction of number of Instanton Decay Partons (Quarks + their flavor, Number of Gluons) in dependence of the Instanton Mass. How reliable can this be done?
  - While the absolute instanton cross-section has apparently large uncertainties, how about the prediction of the instanton-mass dependence of the cross-section. Is this more reliable?
  - Does the argument of Gia, that we should observe first “towers” also apply to QCD Instantons, which do not have a fixed mass

General discussion - special questions (Tancredi)

- In DIS the prediction were given for highly virtual particles at instanton-vertex (Q^2, Q'^2 large) Cross-sections too tiny in pp when asking for hard jet (Valya) ?
- Do we miss a gamma-p component in the ep case (searches and theory prediction)
  - See talk by Achim on using virtual b-quark in photoproduction

More from Tancredi

- The QCD instanton decays isotropically in all quark flavours and gluons. It looks close to soft QCD events. One has an experimental handle exploiting sphericity in the instanton rapidity band and the different quarks flavours.

- A distinct feature is that the chirality is the same for all final state quarks. This is difficult to explore experimentally but might help, in case one sees an enhancement via event shapes, e.g., using Lambdas.

- Did this become clearer this afternoon?

- At HERA we faced the problem of the signature being close to normal events in two ways:
  - 1) we developed tools to systematically compare MC predictions to data. This at the end led to the development of Rivet as we know it today
  - 2) we used MVA techniques to be able to argue on the shape of a discriminator (rather counting events after cuts) hoping to see an increasing signal/background at we go close to the instanton-enhanced region. This was completely new at the time !

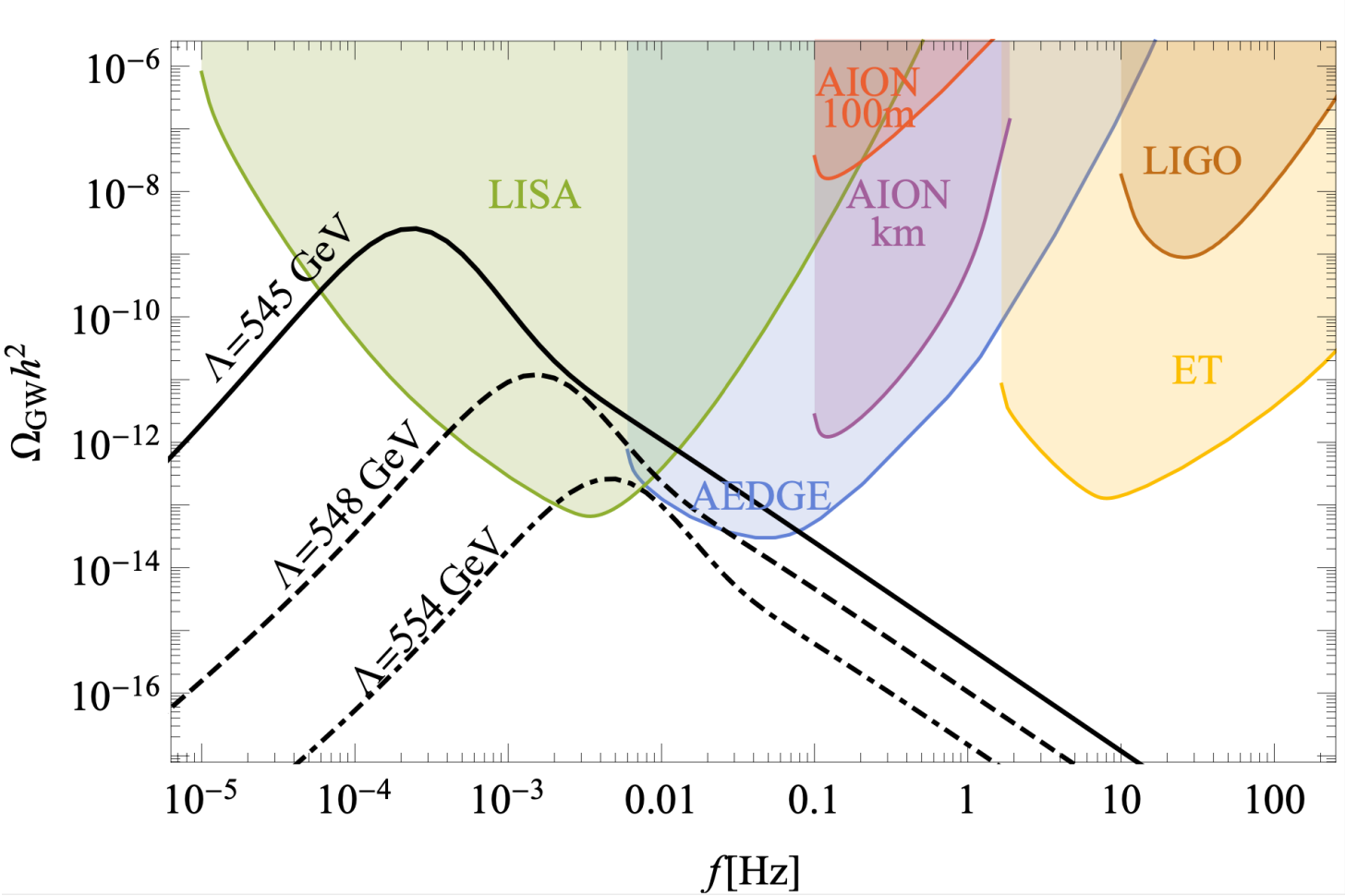
- I am personally sceptical whether the MC generators are good enough to make a discovery.

- Certainly we will be able to set limits.

- However, I think we can probably do more than we think by looking at the data we have (control regions etc).

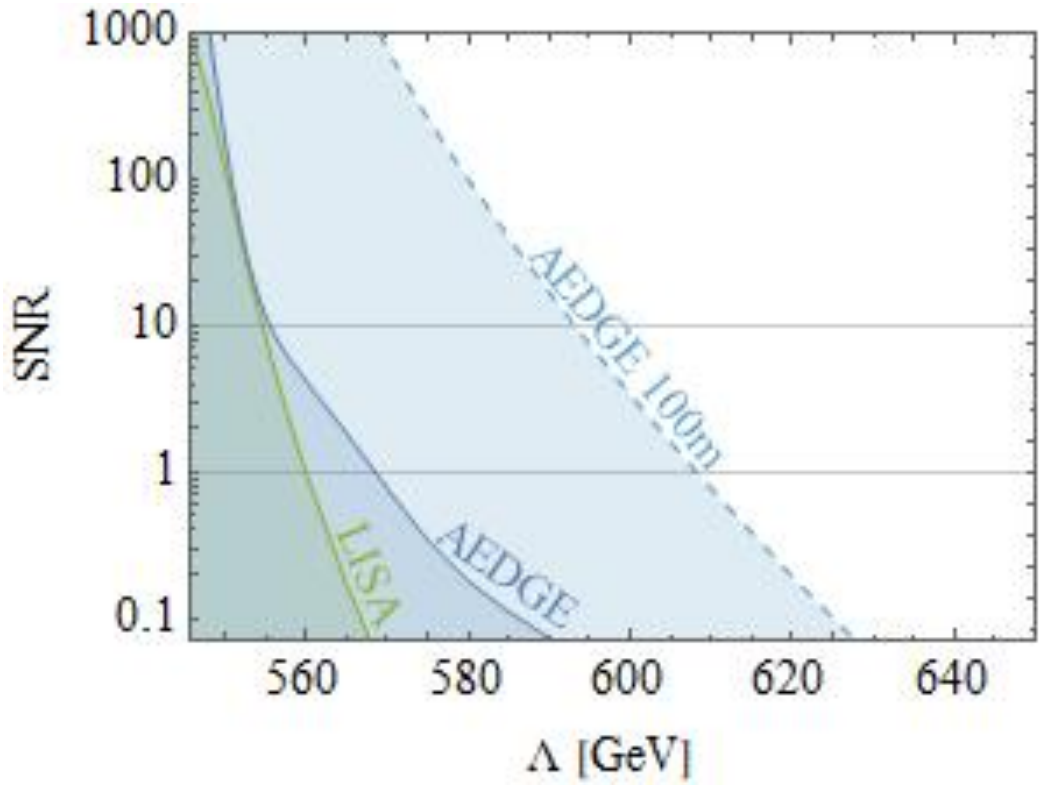
GW Signal in H^6 Model (Pedro)

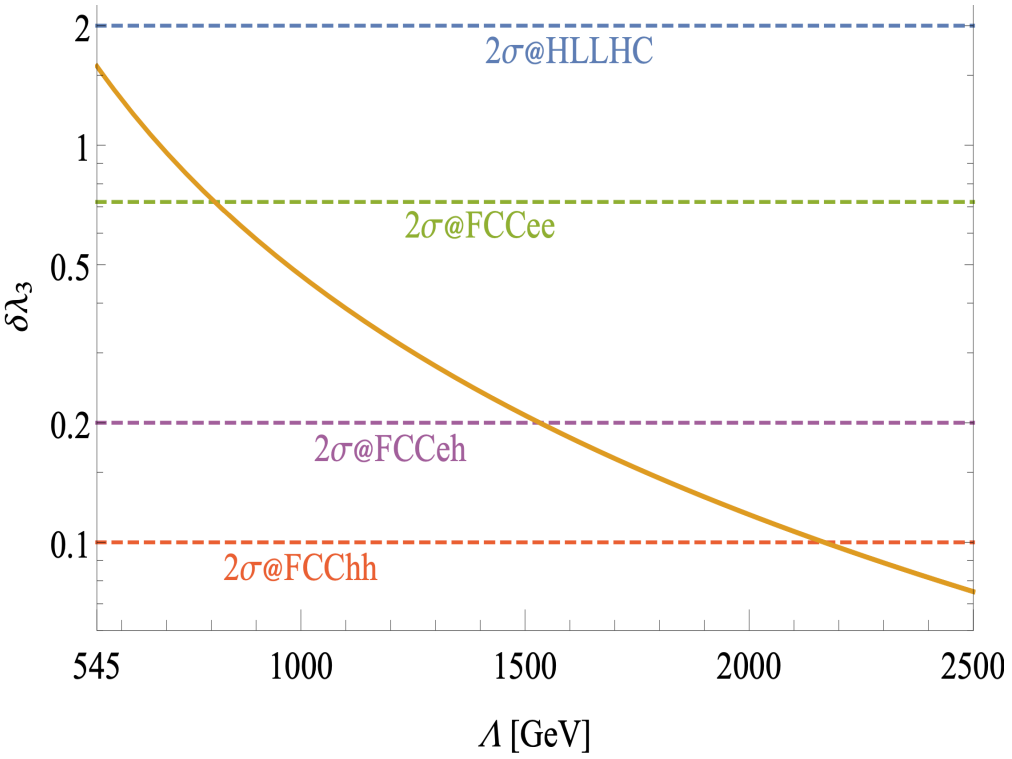
- Strongest signal for which percolation is assured



JE, Lewicki, No & Vaskonen, arXiv:1903.09642

Gravitational Wave Sensitivity to Scale of H^6 Interaction vs Colliders





Gravitational wave sensitivity to Λ, vs future collider sensitivity

Updated from JE, Lewicki & No, arXiv:1809.08242