Short review on photon isolation

Photon19 satellite workshop - Frascati

Marius Höfer

Introduction - I

For any collider process with final state photons, distinguish between:

primary/promt/direct photons

- photons from hard partonic scattering process
- direct component: e.g. QCD-Compton or $q\bar{q}$-annihilation
- fragmentation component: hard $q/g \to \gamma$

secondary photons

- photons emitted during the hadronization process after the actual scattering, from decay of hard hadrons
- huge background

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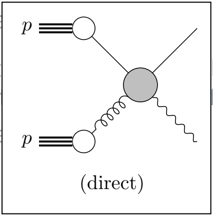
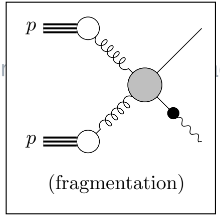


(direct)



(fragmentation)

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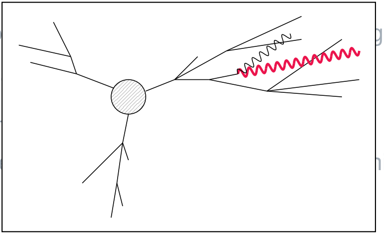

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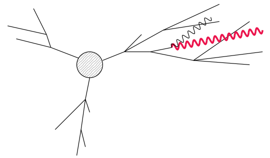
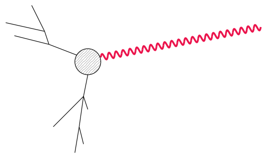
Introduction - II

Idea: look for photons isolated from hardonic radiation


(secondary)


(primary)

Photon Isolation

⇒ "Most of the (transverse) energy in the vicinity of the candidate isolated photon must be carried by the photon itself."

Introduction - II

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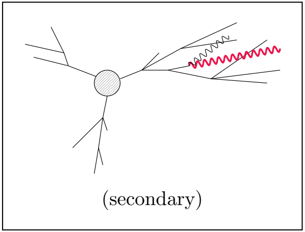

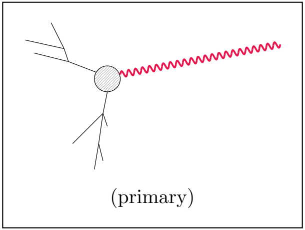

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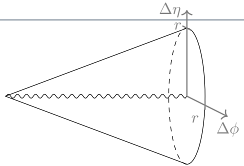
Types of isolation



cone-based isolations

- define cone around photon with $r = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
- restrict allowed hadronic energy inside the cone
- examples:
  - hard cone isolation
  - smooth cone isolation
  - modified versions

other concepts

- based on clustering of particles at parton level
- examples:
  - democratic isolation
  - softdrop isolation

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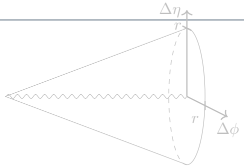

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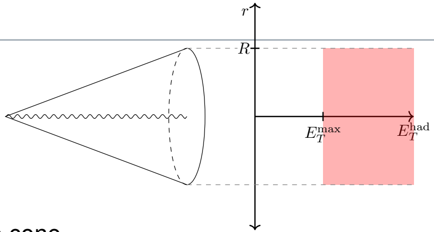


hard cone isolation - I

Idea/Concept

- define cone with fixed R
- integrate all hadronic E_T within the cone
- set upper limit:

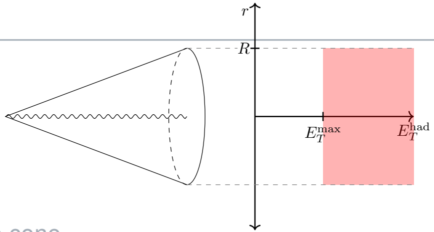
$$E_T^{\text{had}} \leq E_T^{\text{max}}(p_T^\gamma) = \varepsilon p_T^\gamma + E_T^{\text{thres}}$$

technical complications

[Les Houches 2009, 2011, 2015 ...]

- direct component ✓, fragmentation component ✓
- fragmentation functions $D_{i\gamma}$ ($i = g, q, \bar{q}$) are complicated objects
  [M.Gluck et al. 1995; L.Bourhis et al.,hep-ph/9704447]
- $D_{i\gamma}$: $\mathcal{O}(\alpha_{\text{em}})$ or $\mathcal{O}(\alpha_{\text{em}}/\alpha_s)$?
- $E_T^{\text{max}} \to 0$ eliminates fragmentation contribution but is IR unsafe

hard cone isolation - I



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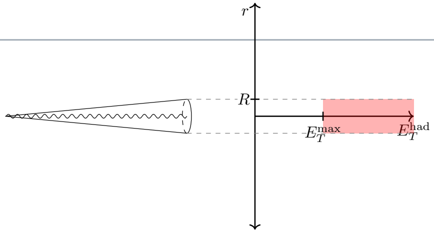
hard cone isolation - II



Problems with narrow cones

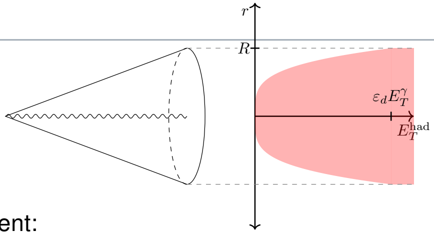
[S.Catani et al.,hep-ph/0204023; Les Houches 2011; S.Catani et al.,1306.6498; S.Catani et al.,1802.02095]

- artificial separation of phase space due to cone

$$\mathrm{d}\sigma^{\mathrm{in}} \sim \ln R\,, \qquad \mathrm{d}\sigma^{\mathrm{out}} \sim \ln \frac{1}{R}$$

  - without isolation: exact cancellation
  - with isolation: residual $\ln R$-dependence
- $R \lesssim 0.1$: resummation necessary
- typical cone sizes ($0.3 \lesssim R \lesssim 0.5$): effect negligible

smooth cone isolation



Idea/Concept

[S.Frixione,hep-ph/9801442]

- make isolation condition r-dependent:

$$E_T^{\mathrm{had}}(r) \leq E_T^{\mathrm{max}}(p_T^\gamma, r) = \varepsilon p_T^\gamma \left(\frac{1-\cos r}{1-\cos R} \right)^n \qquad \forall r \leq R$$

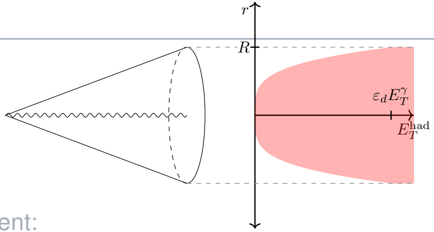
- $E_T^{\mathrm{max}}(p_T^\gamma, r) \underset{r\to 0}{\longrightarrow} 0$: direct comp. ✓, frag. comp. ✗
- IR safe

tight isolation parameters

[Les Houches 2013, 2015; S.Catani et al.,1802.02095]

- Problem: smooth profile cannot be implemented in experiment
- mimic experimental isolation with tight isolation parameters

smooth cone isolation



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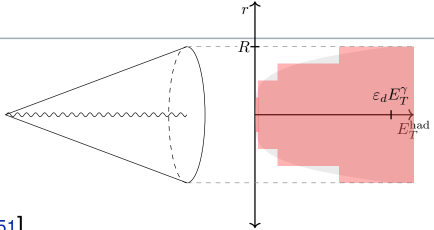
modified versions



discretized smooth cone isolation

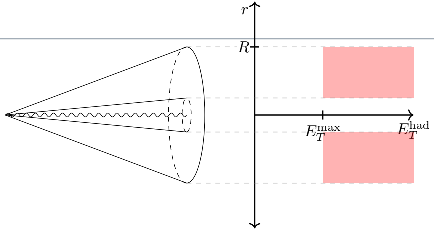
[Les Houches 2009, 2011; C.Frye et al.,1510.08451]

- fit smooth energy profile function $E_T^{max}(p_T^\gamma, r)$ to detector cells $\rightarrow$ concentric hard cones
- need finite E_T^{max} in innermost cone $\rightarrow$ fragmentation contribution
- parameters have to be chosen carefully

hollow cone isolation

hybrid cone isolation

modified versions



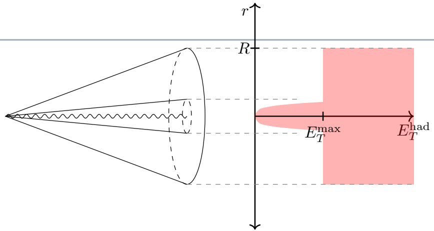
discretized smooth cone isolation

hollow cone isolation

[Les Houches 2011; S.Catani et al.,1306.6498]

- within hard cone (R) define smaller cone ($r < R$) in which weaker or no bounds on E_T^{had} are applied
- mimics experimental difficulty to deal with em shower in detector
- suffers from large logs , $\ln r$, like narrow cones → resummation

hybrid cone isolation



modified versions

discretized smooth cone isolation

hollow cone isolation

hybrid cone isolation

[F.Siegert,1611.07226; X.Chen et al.,1904.01044]

- within hard cone (R) define smaller smooth cone ($r^2 \ll R^2$), which eliminates the fragmentation contribution
- outer hard cone describes experimental isolation exactly
- dependence on isolation parameters can be determined correctly, no uncertainty from tuning of isolation parameters

democratic isolation

[N.Glover, A.Morgan 1994]
[ALEPH 1995]
[A.Gehrmann-De Ridder et al.,hep-ph/9705305]

- used during in LEP era
- treat photon candidates and partons democratically in jet algorithm:

$$\text{if} \quad z = \frac{E_{\text{EM}}}{E_{\text{EM}} + E_{\text{HAD}}} > z_{\text{cut}} \quad \Rightarrow \quad \text{"photon-jet "} = \text{ isolated photon}$$

- idea similar to hard cone isolation, different notion of "photon-vicinity"
- direct component ✓, fragmentation component ✓
- unfeasible for LHC due to huge event rate

softdrop isolation

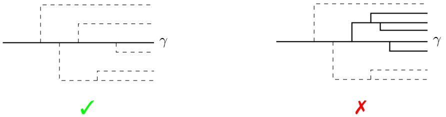
[Z.Hall,J.Thaler,1805.11622]

– based on soft-drop declustering [A.Larkoski et al., 1402.2657]

$$\frac{\min\left(p_T^1, p_T^2\right)}{p_T^1 + p_T^2} \geq z_{\mathrm{cut}} \left(\frac{R_{12}}{R_0}\right)^{\beta}$$

– if jet **fails** soft-drop at all stages $\rightarrow$ left with one hard constituent

– if remaining hard constituent is photon $\rightarrow$ isolated photon



(a) (b)

from [Z.Hall,J.Thaler,1805.11622]

– direct component ✓, fragmentation component ✗

– equivalent to smooth cone at leading non-trivial order in small R-limit

Summary

two main classes of photon isolation

- cone based
- clustering based

cone based isolations differ in distribution of allowed hadronic energy

- fixed upper limit
- smooth energy profile
- combinations and modifications of both

different approached preferred by experiment and theory

- mostly used in experiment: hard cone
- mostly used in theory: smooth cone

Summary

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Thank you!

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