Thinning

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building on work with Jannik Augscheller

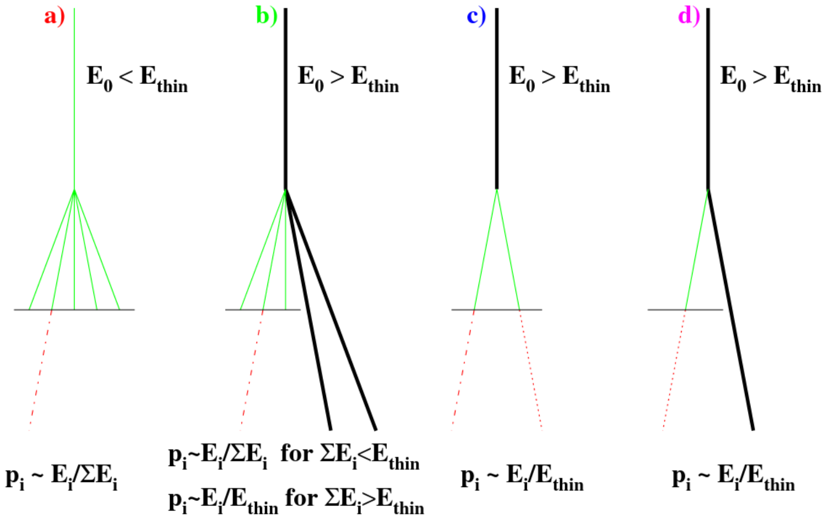
Motivation

- runtime ~ primary energy / energy cut
- track fewer particles
- assign stat. weights, avoid bias
- downside: *artificial fluctuations* (vs. Shower-to-shower fluctuations)
- belongs to *Russian roulette* methods

García-Pareja, Lallena, Salvat 2021

Hillas thinning

- original description ICRC 1981
- threshold energy $E_{th} = \varepsilon\ E_0$ (ε ~ 10^{-5}, 10^{-6}, …)
- in vertices below E_{th}, select **one** out of all secondaries with
  $p_i = E_i / \sum_k E_k$
  $w_i = w_0 / p_i$
- (weighted) energy conserved exactly
- improved further by Hillas (1997), Heck & Knapp (1998)



Hillas 1981; Hillas 1997; Heck, Knapp 1998

Artificial fluctuations

- related to weight distribution (narrower = better)

$$\langle N \rangle = \langle N_\mathrm{t} \rangle \langle w \rangle$$
$$\sigma^2(N) = \langle N_\mathrm{t} \rangle \sigma^2(w) + \langle w \rangle^2 \sigma^2(N_\mathrm{t})$$

- width can be controlled with **weight limitation**
- "optimum weight" $w_{\mathrm{max}} = E_{\mathrm{th}}$ / 1 GeV
- cumbersome with Hillas thinning
  (C7 implementation obscure...)

Hansen, Alvarez-Muñiz, Vázquez 2011; Kobal 2001

Statistical thinning

- keep/discard-test for each secondary independently
- no. of kept particles not fixed
- energy conserved *on average*
- bigger fluctuations (according to Hillas)
- acceptance factor arbitrary

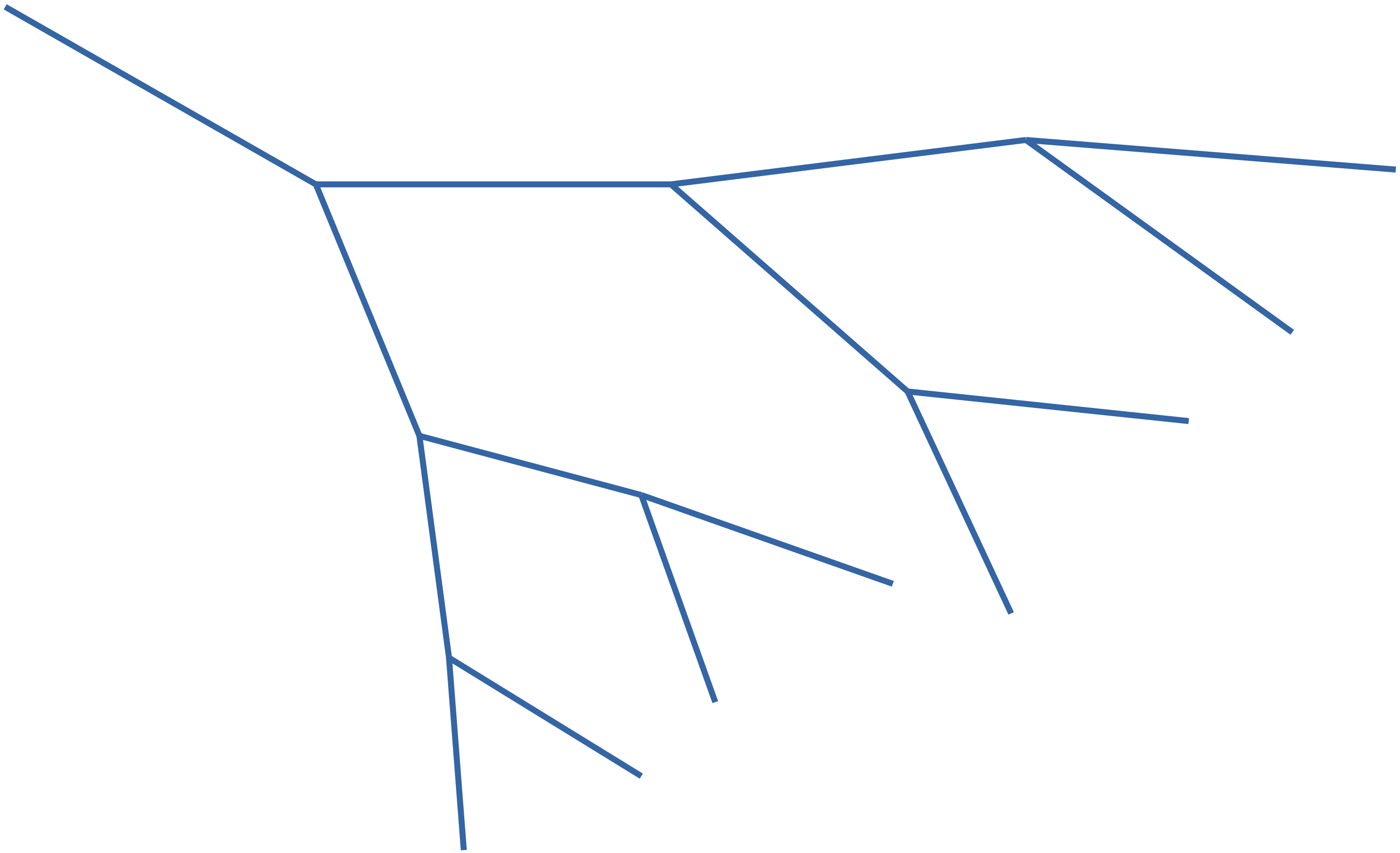
Kobal 2001

C8 implementation

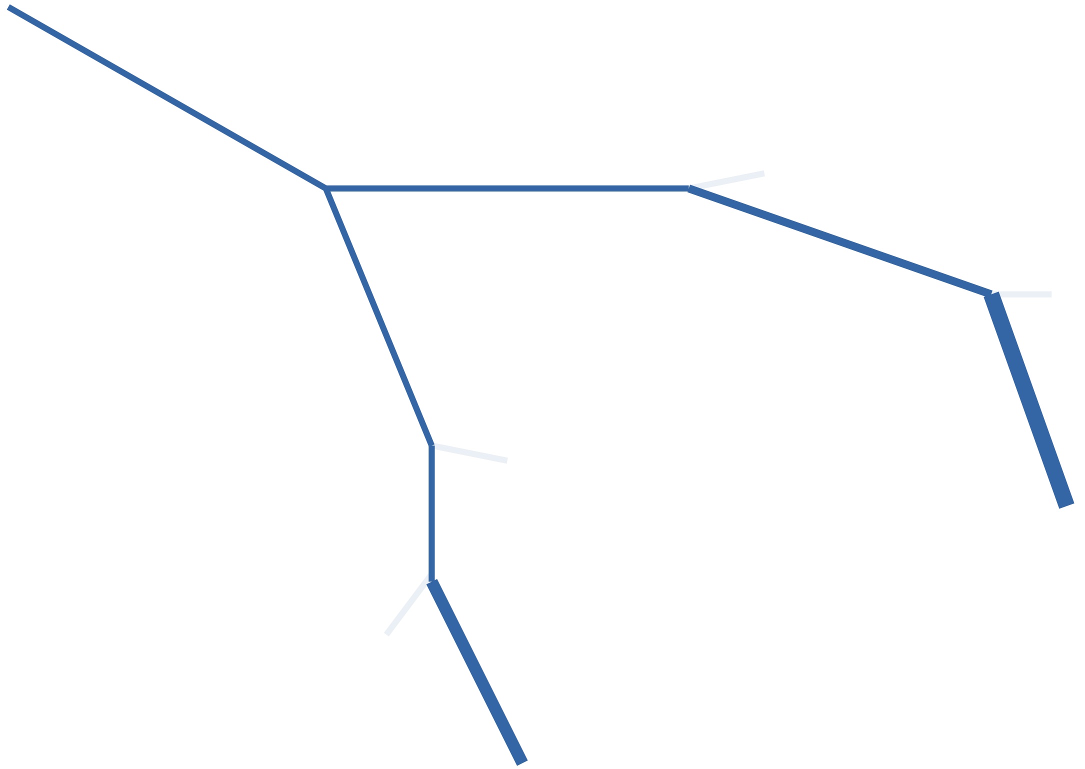
- only EM vertices ($1 \rightarrow 2$ splitting)
- Hillas thinning while no secondary can reach w_{max}
- otherwise stat. thinning for both secondaries with

$$p_i = \max(p_i / \textstyle\sum_k E_k \, , \, w_0 / w_{\text{max}})$$

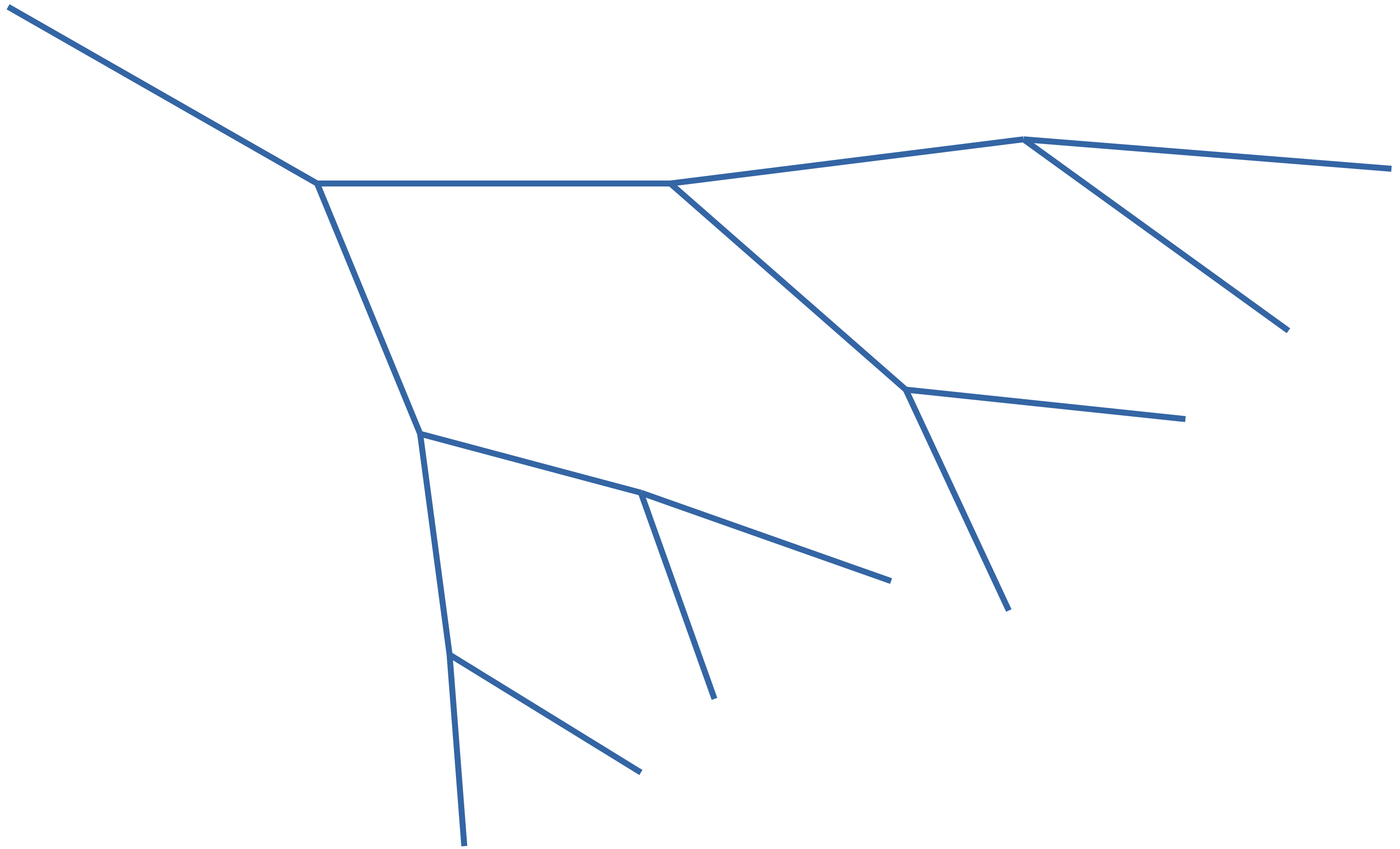
Unthinned



"real" thinning

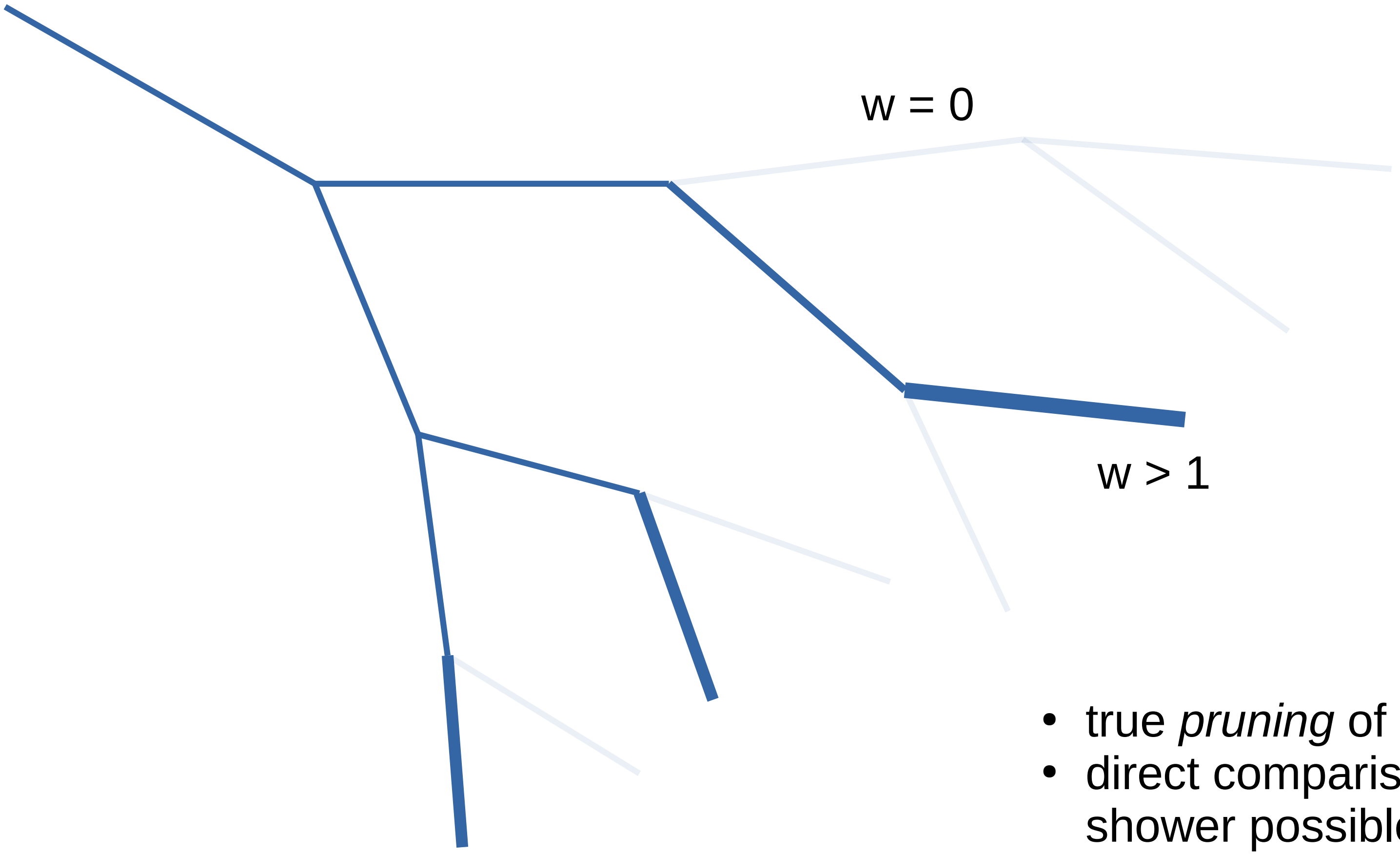


does not correspond to unthinned shower!



"fake" thinning

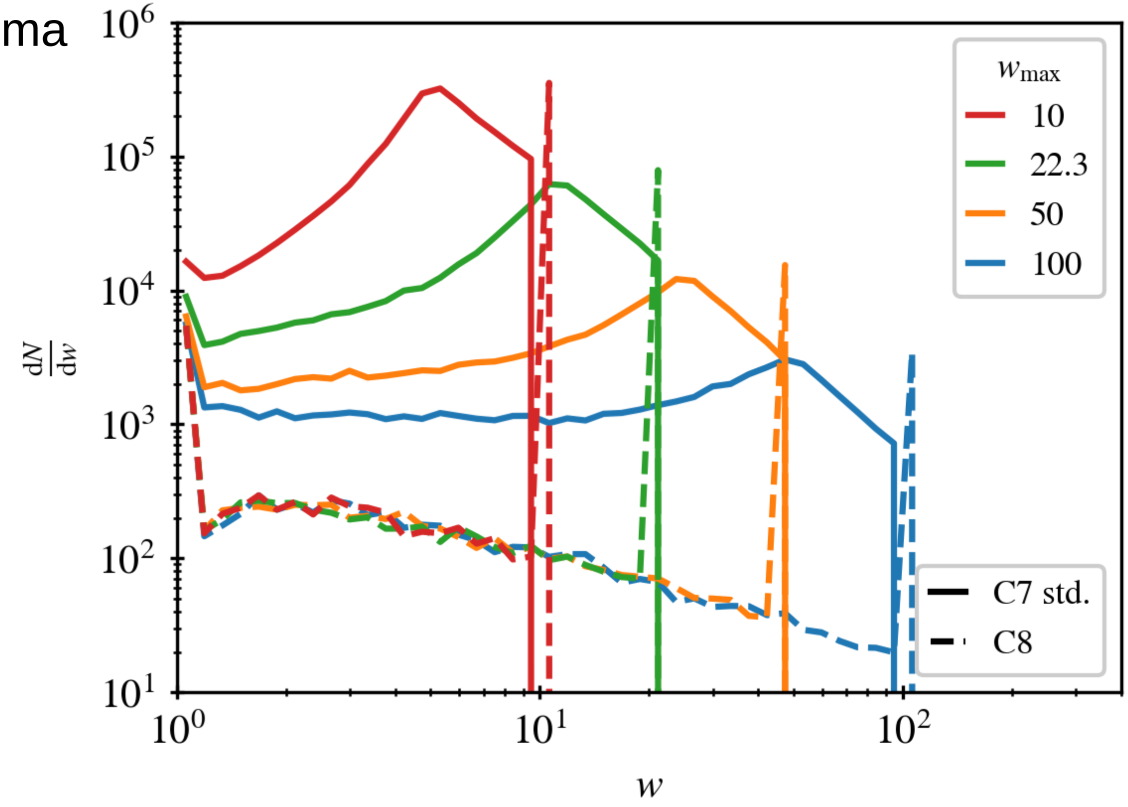
`bin/corsika --multithin`



- true *pruning* of shower
- direct comparison with unthinned shower possible

Weight distribution

vertical 10^{16} eV gamma
$\varepsilon = 10^{-5}$



Backport to C7

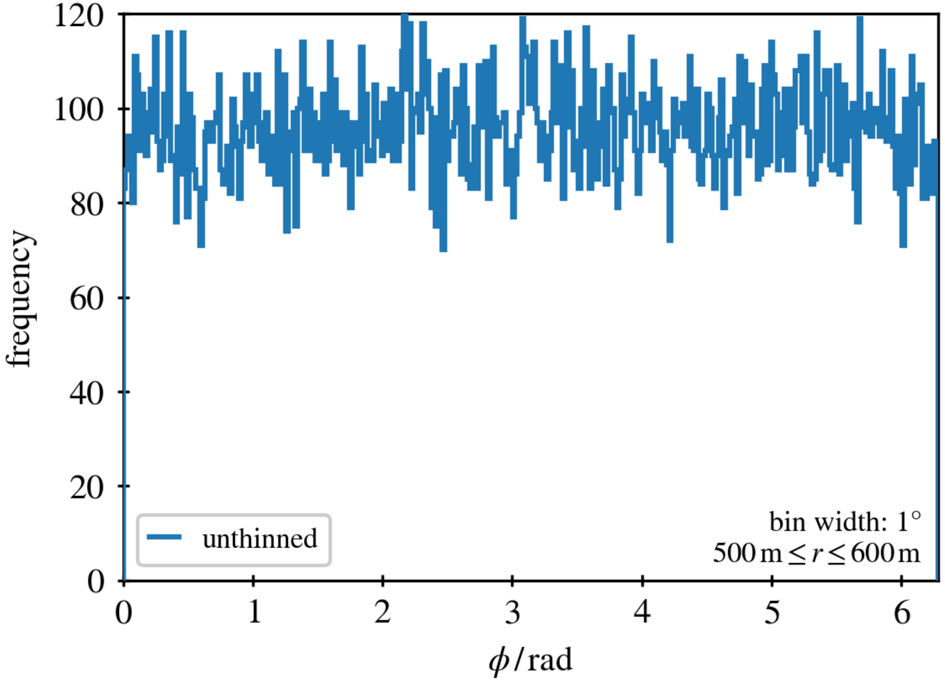
- MR 11, THIN and MULTITHIN
- new coconut option?

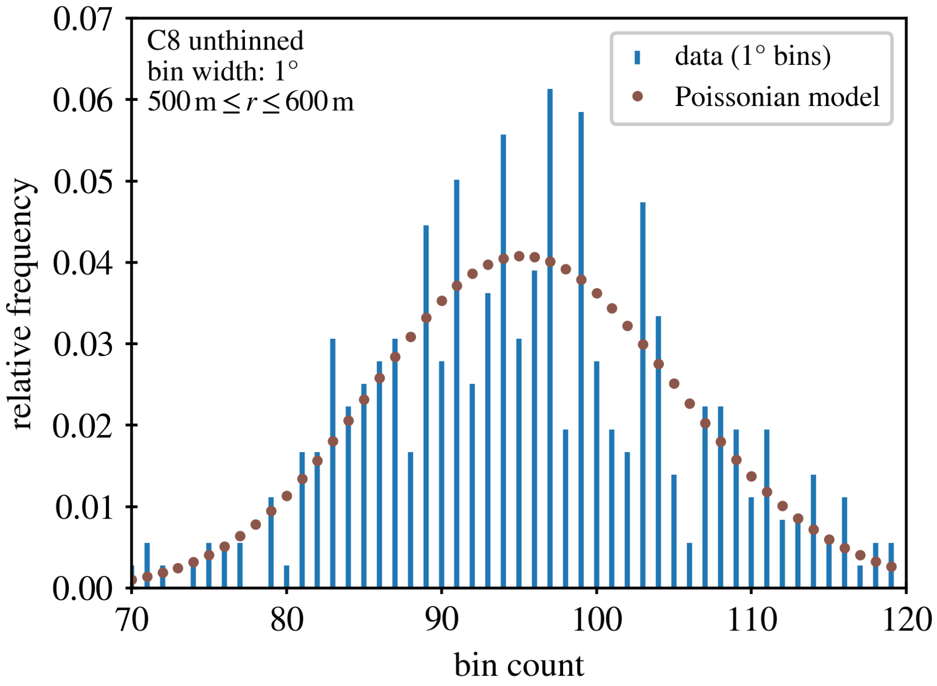
```
    2    FORMAT(' THIN  : EK,E1,IQ1,E2,IQ2=',1P,2E10.3,1X,I2,E10.3,1X,I2)

+ ! weight not updated yet -> equal to parent weight
+       wparnt = wt(np)
+       fmax = wmaxem / wparnt
+       f1 = ek / ekhigh
+       f2 = ek / eklow
+
+       if (ek <= ethinn .and. (f1 >= fmax .or. f2 >= fmax)) then
+ ! do statistical thinning
+         f1 = min(ek / ekhigh, fmax)
+         f2 = min(ek / eklow, fmax)
+         call rmmard(rnd, 2, 2)
+
+ ! consider higher-energy secondary (at NP-1)
+ ! keep with probability p = 1/f1
+         if (rnd(1) * f1 <= 1.) then
+ ! keep, update weight
+           wt(np-1) = wparnt * f1
+         else
+ ! discard, move next particle here
+ ! note: time, weight, etc. of both secondaries are equal, no need to overwrite
+           E(NP-1)  = E(NP)
+           IQ(NP-1) = IQ(NP)
+           U(NP-1)  = U(NP)
+           V(NP-1)  = V(NP)
+           W(NP-1)  = W(NP)
+           NP = NP-1
+         endif
+
+ ! consider lower-energy secondary (at NP)
+ ! keep with probability p = 1/f2
+         if (rnd(2) * f2 <= 1.) then
+ ! keep, update weight
+           wt(np) = wparnt * f2
+         else
+ ! discard
+           NP = NP-1
+         endif
+
+         return
+       endif
+
        CALL RMMARD( RD,1,2 )
```

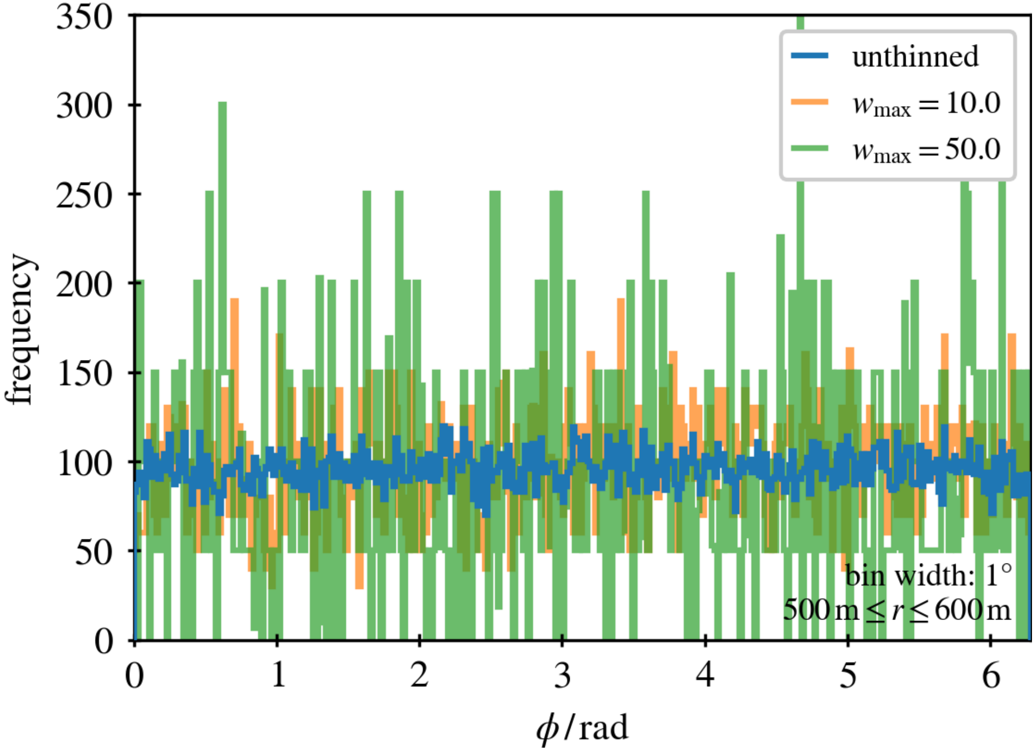
(Artificial) fluctuations

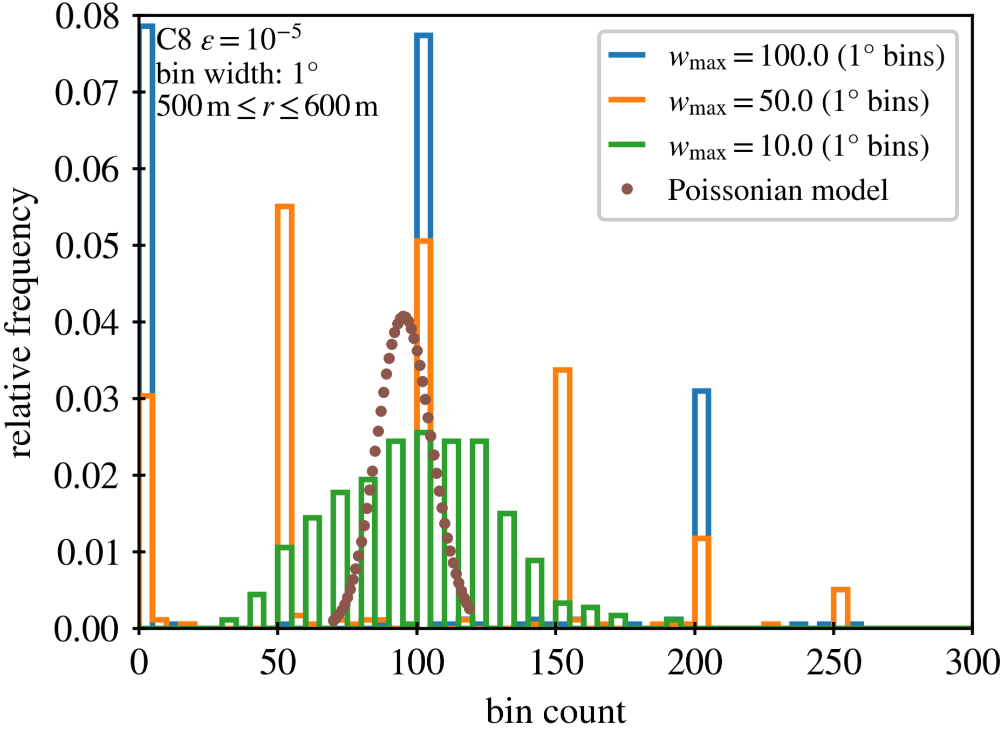
- here: azimuthal (bin-to-bin) fluctuations



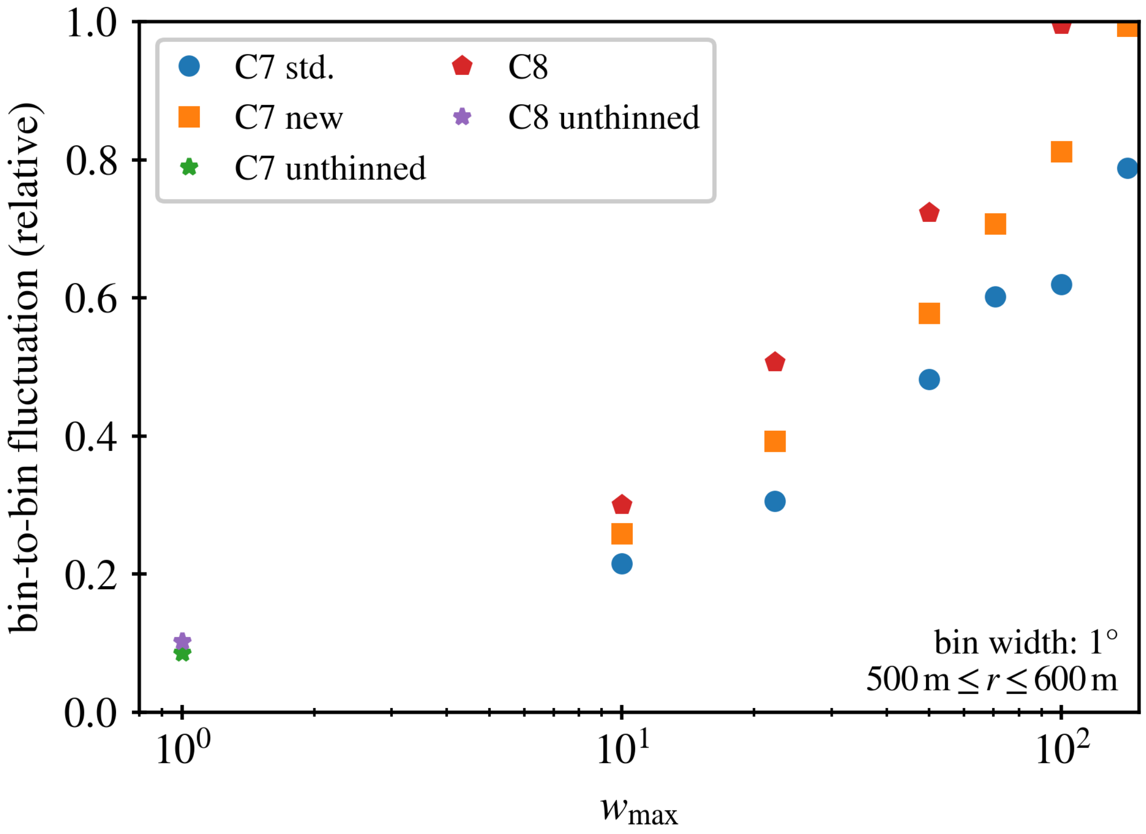


With thinning





Performance comparison



impact on runtime
not checked yet!

Conclusions

- Thinning works
- unbiased, check with `--multithin`
- narrow weight distribution possible
- Performance? New optimum weight prescription?
- Paper?