Strange tagging at future colliders

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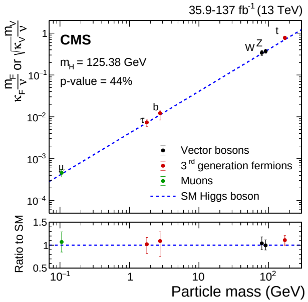
Higgs boson properties

- learned a lot about the Higgs
- Higgs is main source of EWSB
- couples to third generation as expected

Why bother?

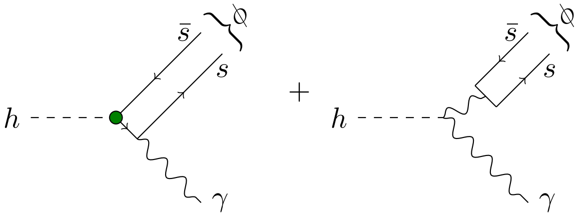
- No understanding of flavor puzzle
- Yukawa modifications could affect only first and second generation

  [E.g. Giudice & Lebedev '08, Bauer *et.al* 15, Ghosh *et.al* '15, Altmannshofer *et.al* '15, Egana-Ugrinovic *et.al* '19]



[CMS: 2009.04363]

Exclusive decay $h \to \phi\gamma$ [Bodwin *et.al* '13, Kagan *et.al* '14]



> Clean decay: BR($\phi(s\bar{s}) \to K^+(u\bar{s}) + K^-(\bar{u}s)) \approx 50\%$

> BUT: BR$(h \to \phi\gamma) \approx 2 \times 10^{-6}$ [König *et.al* '15]

> compare BR$(h \to s\bar{s}) \approx 2 \times 10^{-4}$

> only weak limit at future (hadron) colliders [Kagan *et.al* '14]
estimate: $\mu_{ss} \lesssim \mathcal{O}(10^7)$ @HL-LHC

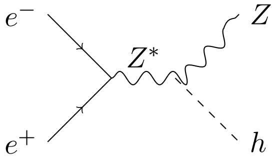
> current limit: BR$(h \to \phi\gamma) < 4.8 \times 10^{-4}$ [ATLAS '17]

Ideas to use differential distributions [see e.g. Bishara *et.al* '16, Soreq *et.al* '16, Yu '16, Carpenter *et.al* '16]

Our brute force method

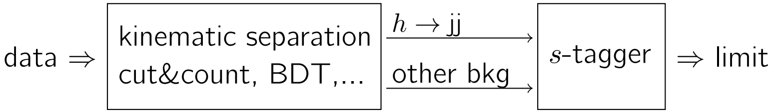
Alternative ansatz:

- FCC-ee will produce 10^6 Higgses via

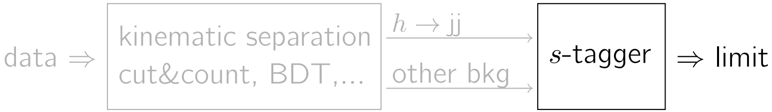


- $\mathcal{O}(200)$ of which decay into strange quarks
- tag strange jets
- Done before in $Z \to s\bar{s}$
  - Measurement of the strange quark forward backward asymmetry around the Z0 peak
    [DELPHI Collaboration, Eur.Phys.J. C14 (2000)]
  - Light quark fragmentation in polarized Z0 decays
    [SLD Collaboration, Nucl.Phys.Proc.Suppl. 96 (2001)]

Setup and assumptions



Setup and assumptions



Part I:

> Clean sample with hadronic Higgses

> We know which jets originate from the Higgs decay

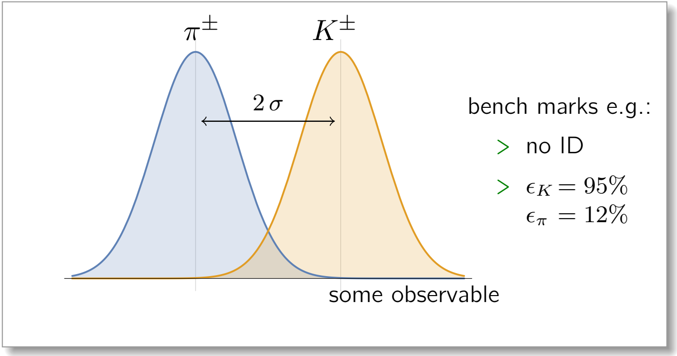
> Generate and shower with `PYTHIA` and `Herwig`

> No detector simulation

Kaon reconstruction

Charged kaons:

- stable on detector scales
- tracking efficiency 95%
- Particle ID



Kaon reconstruction

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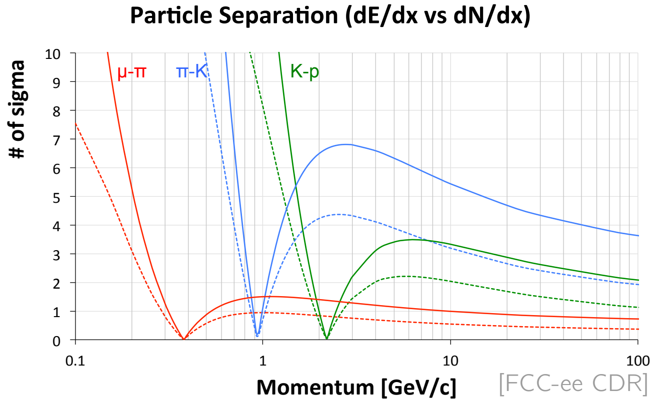
IDEA Drift chamber



[FCC-ee CDR]

e.g.:

%

%

ffer

Kaon reconstruction

Charged kaons:

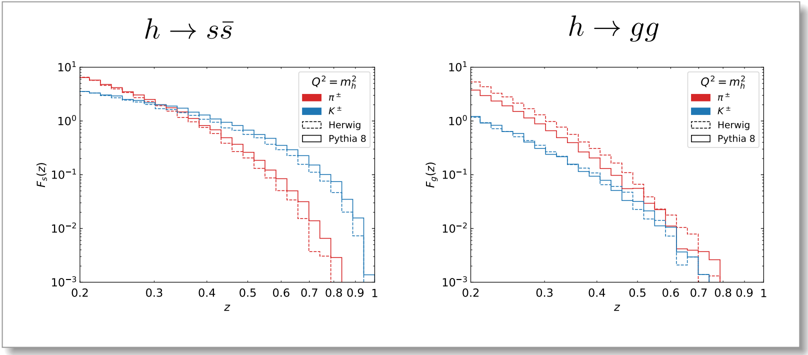
- stable on detector scales
- tracking efficiency 95%
- Particle ID

Neutral kaons:

- Decay length $\sim 80\,\mathrm{cm}$
- Needs to decay to $\pi^{\pm}$ within $5\,\mathrm{mm} < R < 1\,\mathrm{m}$
- reco efficiency 80%

Jet-Flavor

- define flavor of light jet
- strange quarks fragment more likely into hard kaons



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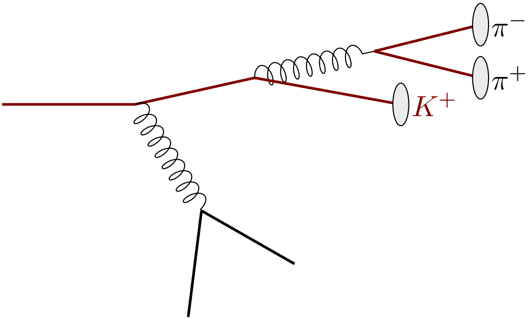

$$J_F = \frac{\sum_{H \in j} \vec{p}_H \cdot \hat{j} R_H}{\sum_{H \in j} \vec{p}_H \cdot \hat{j}} \qquad R_H = \begin{cases} \pm 1 & H = K^{\mp} \\ \pm 1 & H = K_S, \text{ min. } J_F \\ 0 & \text{else} \end{cases}$$

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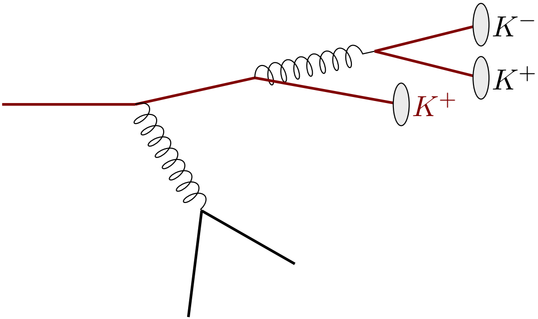

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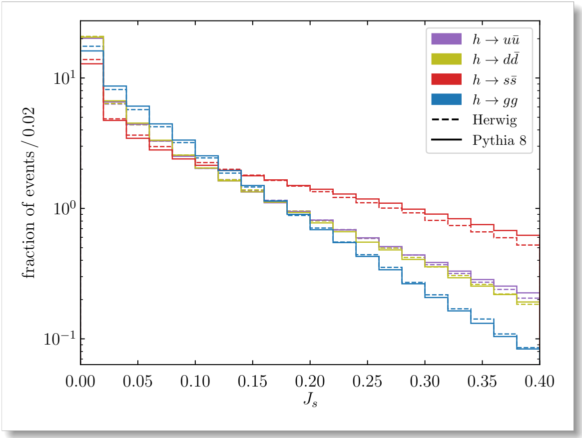
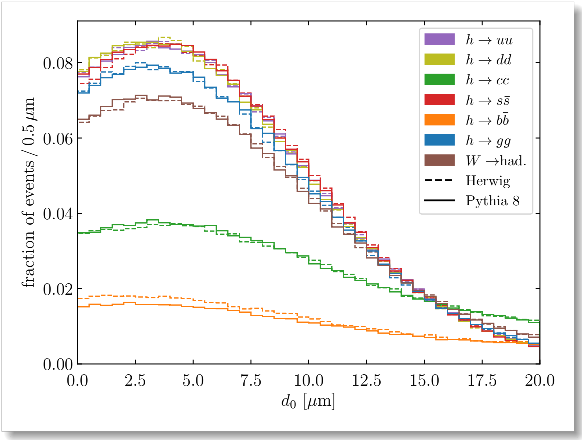
Jet-Flavor

- define flavor of light jet
- strange quarks fragment more likely into hard kaons
- J_s: $R_{K^\pm} = \mp 1$, $R_{K_s} = \pm 1$ minimizing J_s, else 0
- counts collinear hard strange content
- not safe against collinear emission

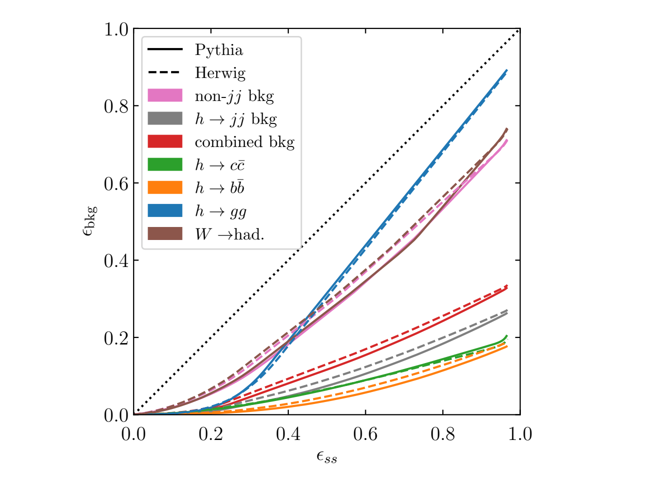


Reject heavy flavor

- Minimalistic approach: Just cut on largest impact parameter
- Require $p_{\text{lab}} > 5$ GeV $\Rightarrow \Delta d_0 \lesssim 10\,\mu$m
- Smear truth values
- Include $5\,\mu$m uncertainty on IP



Signal vs. background efficiencies



Part II: Realistic Collider

Existing studies for $h \to bb, cc, gg$:

- Cut&Count: $m_h = 120\,\text{GeV}$ [Ono *et.al* '12]
- BDT [Talk by Yu Bai @ CEPC meeting]

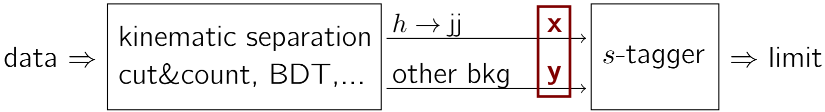
Assumptions:

- $h\nu\nu$ final state (don't consider $h\ell\ell$ or hqq)
- Non-$h \to jj$ flavor composition as in C&C study:
  60% $\nu\ell qq$
  20% $\nu\nu qq$
  10% qq

flavor	W	bb	uu	dd	cc	ss	gg
relative abundance [%]	66	6	7	6	7	6	0

- ϵ_{qq} from $h \to qq$
- ϵ_W from $ee \to WW$

Results

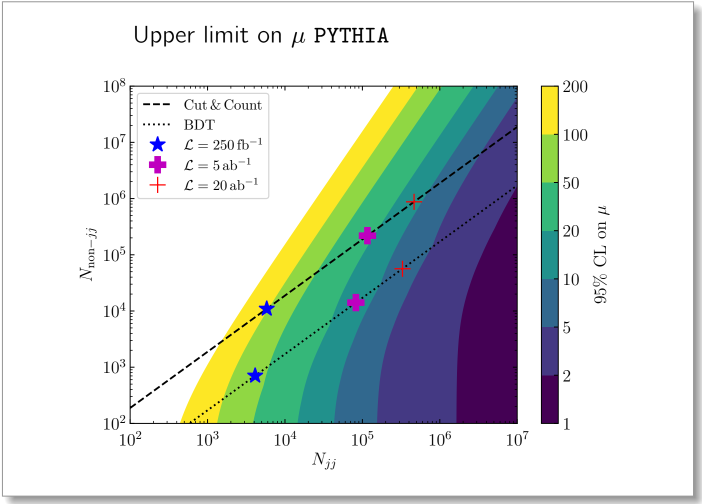


x-Axis: $N_{jj} = \mathcal{L}\sigma_h BR_{jj}\epsilon_{jj}$

y-Axis: $N_{\text{non-}jj} = \mathcal{L}\sum_{i\in\text{non-}jj}\epsilon_i$

For each point (x,y) find best cut values to minimize upper limit

Results



Upper limit on μ PYTHIA
Cut & Count
BDT
$\mathcal{L} = 250\,\text{fb}^{-1}$
$\mathcal{L} = 5\,\text{ab}^{-1}$
$\mathcal{L} = 20\,\text{ab}^{-1}$
$N_{\text{non}-jj}$
N_{jj}
10^2
10^3
10^4
10^5
10^6
10^7
10^8
95% CL on μ
200
100
50
20
10
5
2
1

Conclusion

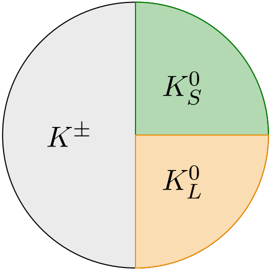
- s-tagger in the context of $h \to s\bar{s}$
- proof-of-concept, can be improved
- validation possible with large data sets of WW and Z
- with $10\ \mathrm{ab}^{-1}$ (FCC-ee): $\mu_s \lesssim 20$
- compare with HL-LHC: $\mu_s \lesssim 10^7$
- applicable to other searches with s-jets (up to some modifications)

Thank You

BACKUP

Strange hadronization

In which kaons can a s quark hadronize?



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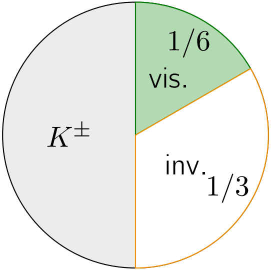

Impact parameter resolution

$$\Delta d_0 = \sqrt{\Delta_{\mathsf{IP}}^2 + (5\,\mu\mathrm{m})^2 + \left(\frac{10}{p\sin^{3/2}\theta}\right)^2}$$