Higgs to dimuon discovery using **quark / gluon tagging** of **ISR**

Nov 27, 2021

SuBin Han

Collaboration with Won Sang Cho, Hyung Do Kim, Dongsub Lee

Intro / Motivation

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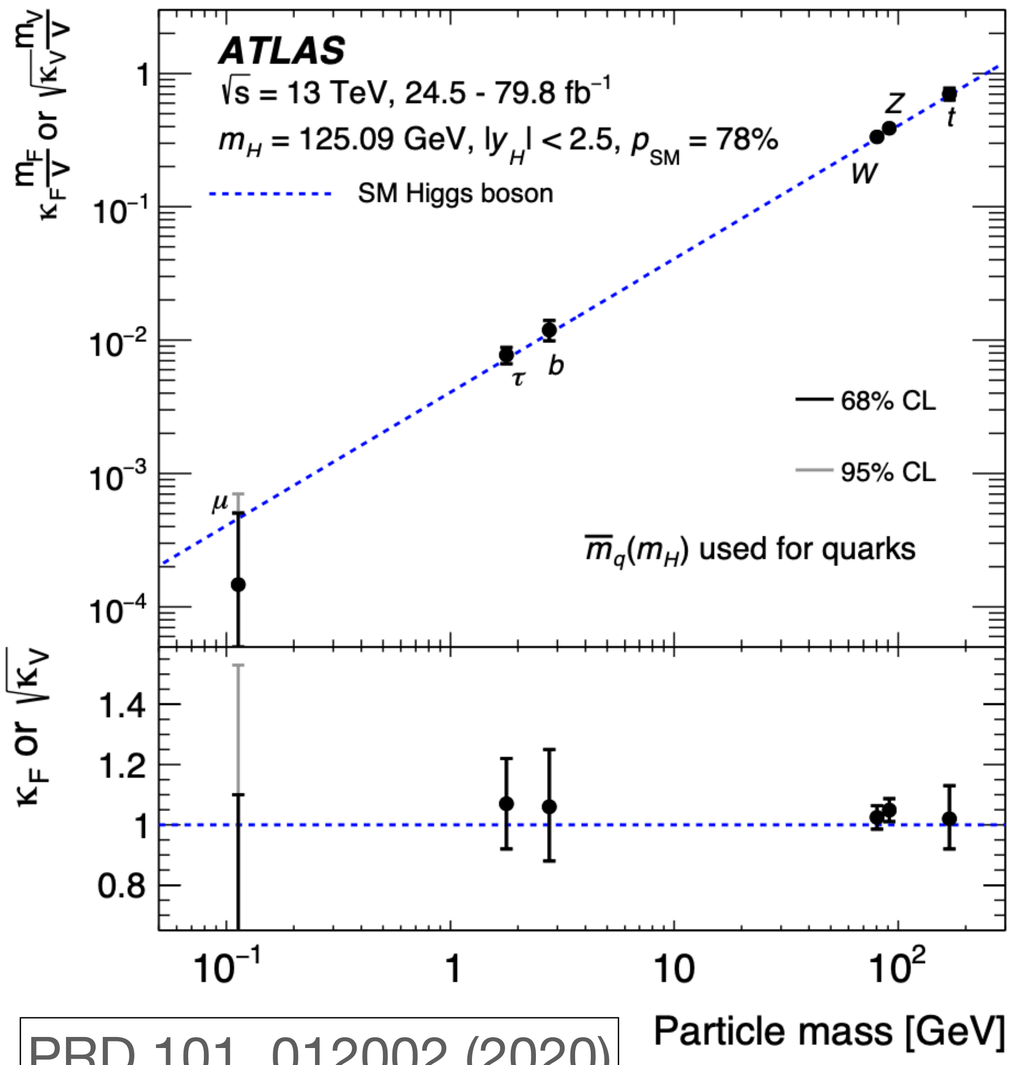

PRD 101, 012002 (2020)

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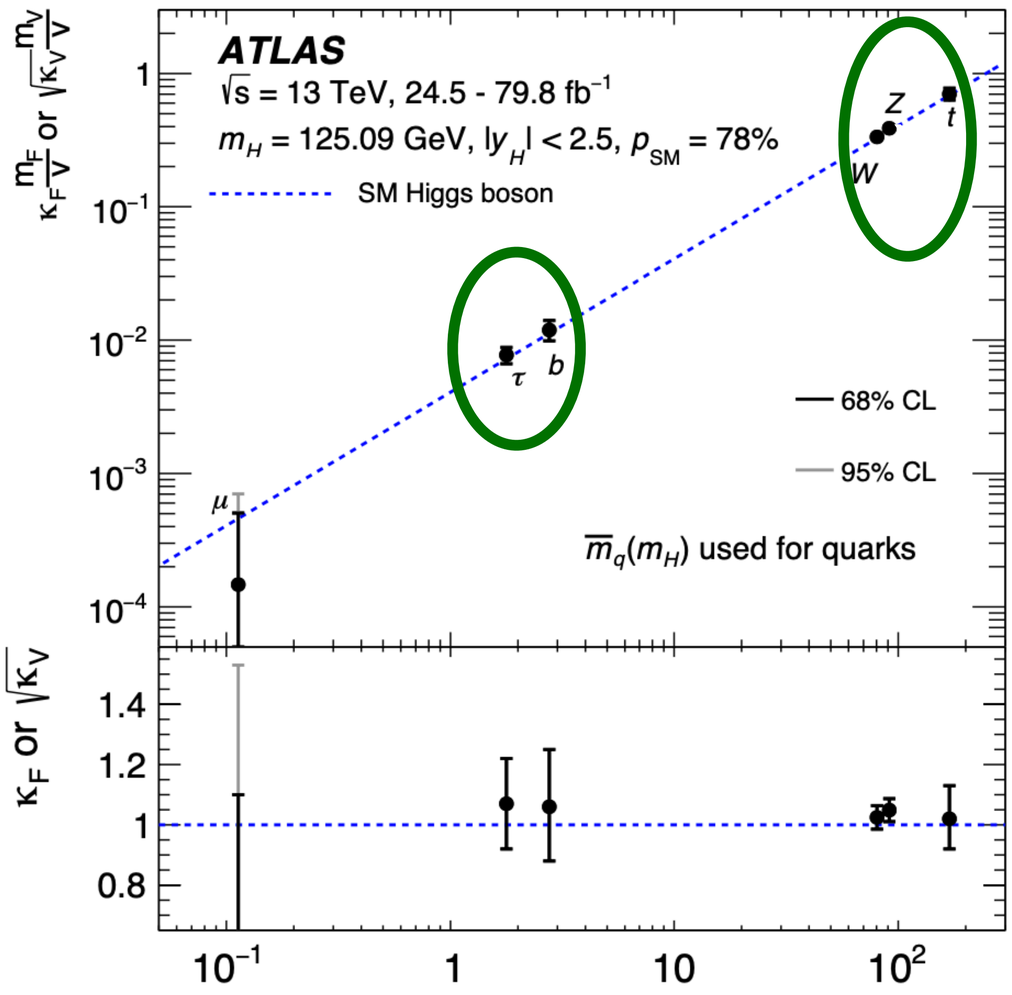

PRD 101, 012002 (2020)

- H $\rightarrow \tau\tau$: 6.4 σ PRD 99(2019) 072001
- H $\rightarrow bb$: 5.6 σ PRL 121(2018) 1218081
- ttH : 5.8σ PLB 784(2018) 173

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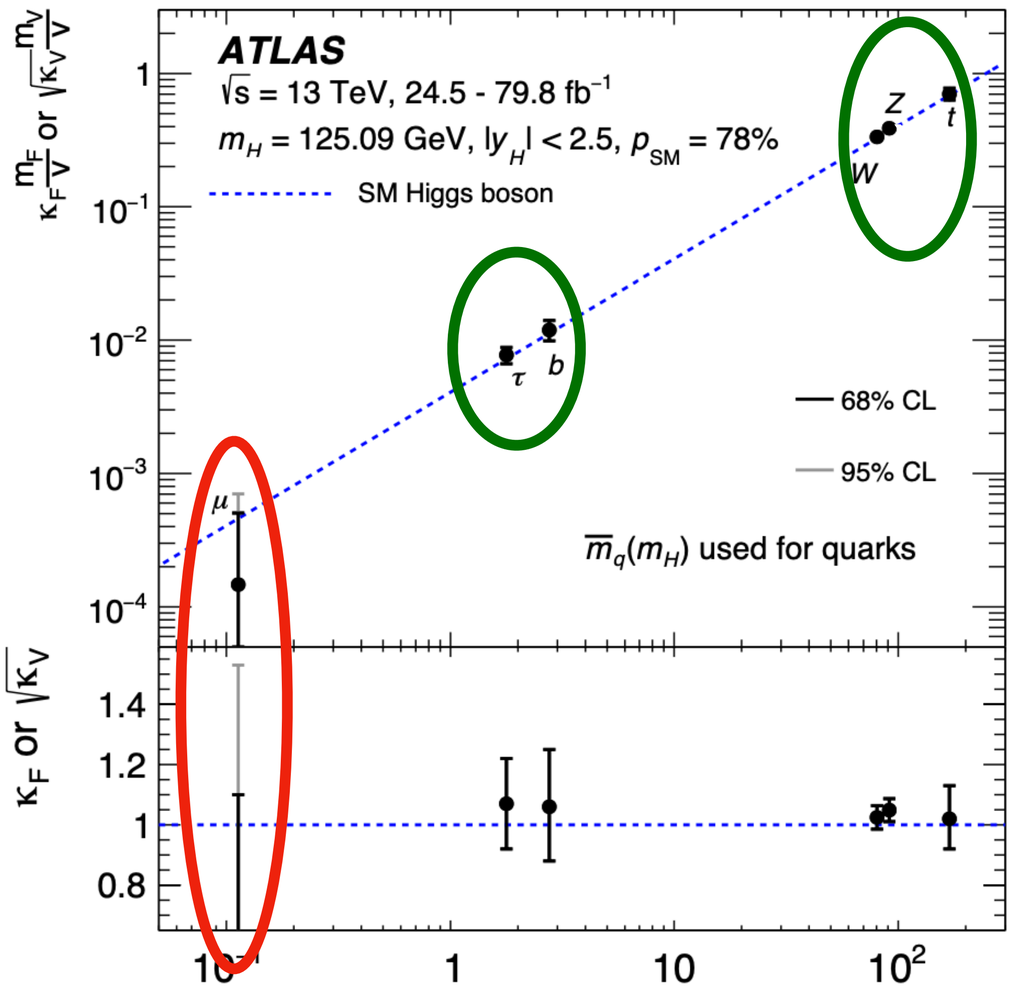

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Higgs ~ 2nd generation fermions

@LHC? : $h \rightarrow \mu\mu$!

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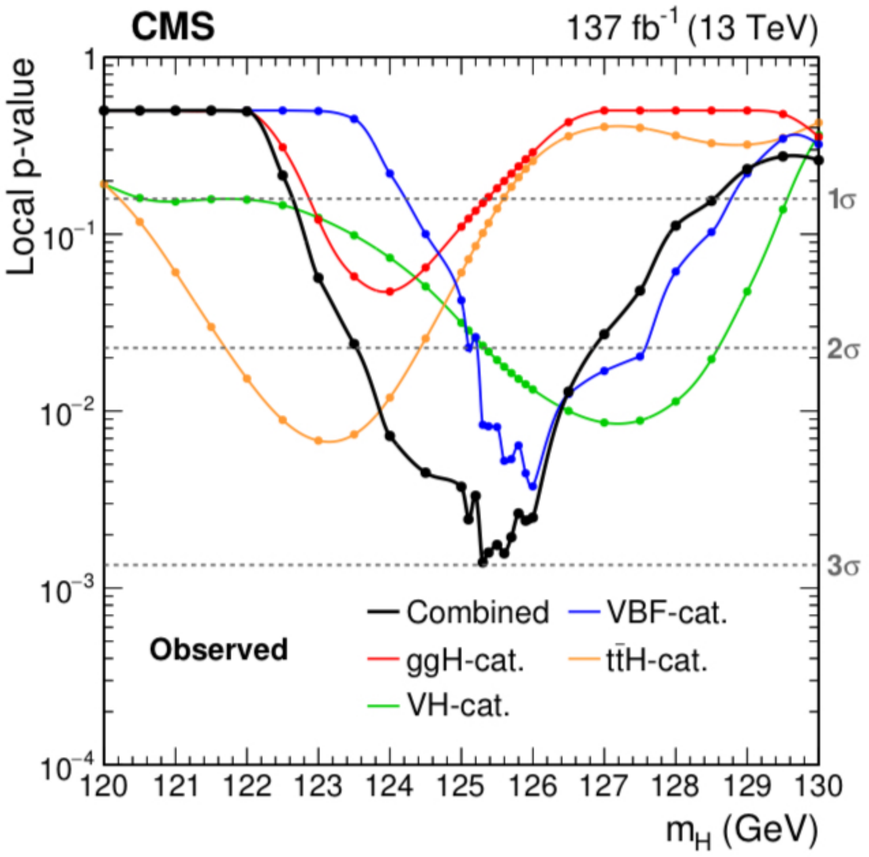

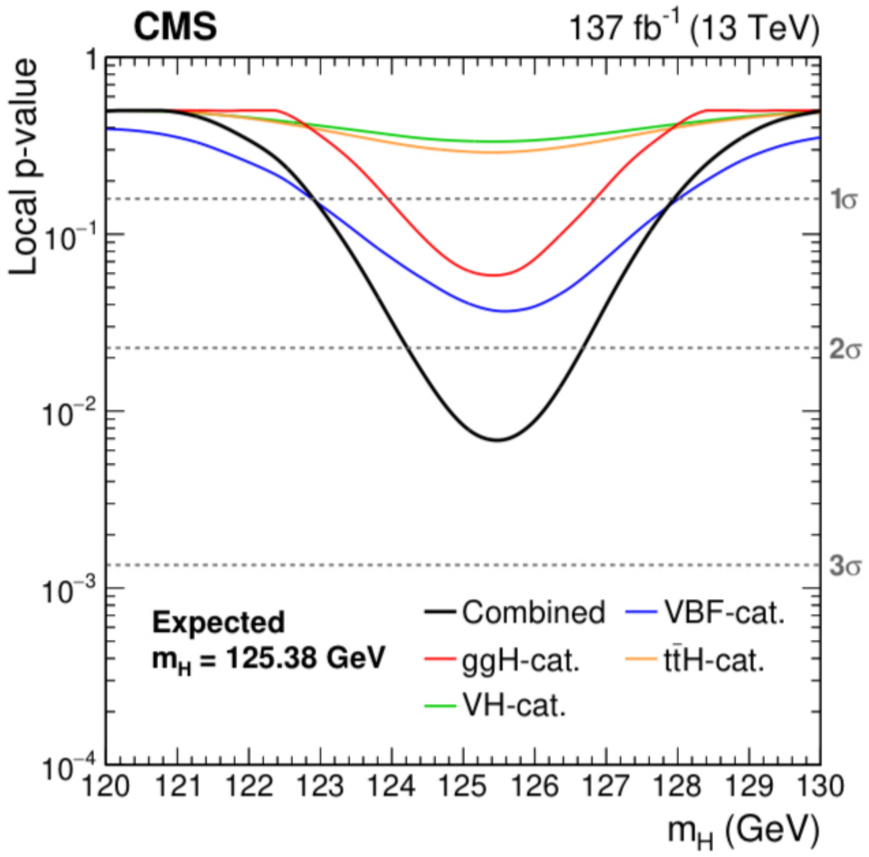

JHEP 01(2021) 148

- CMS : 3.0σ excess (Expected : 2.5σ; VBF ~ 1.8σ / ggH ~ 1.6σ)

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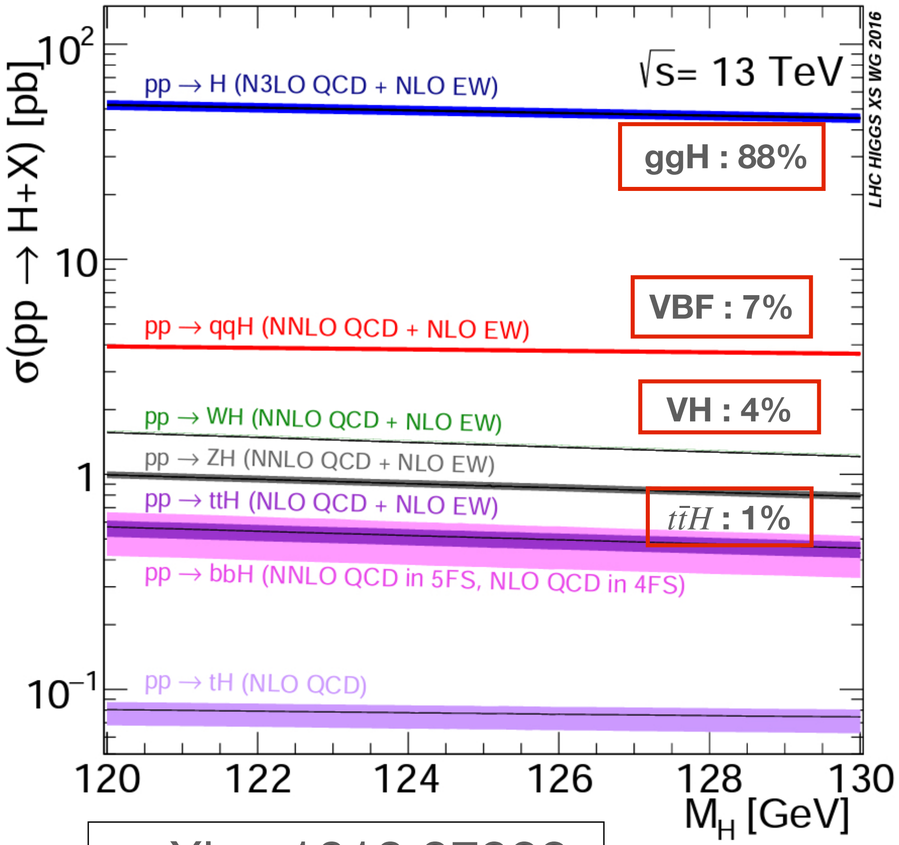
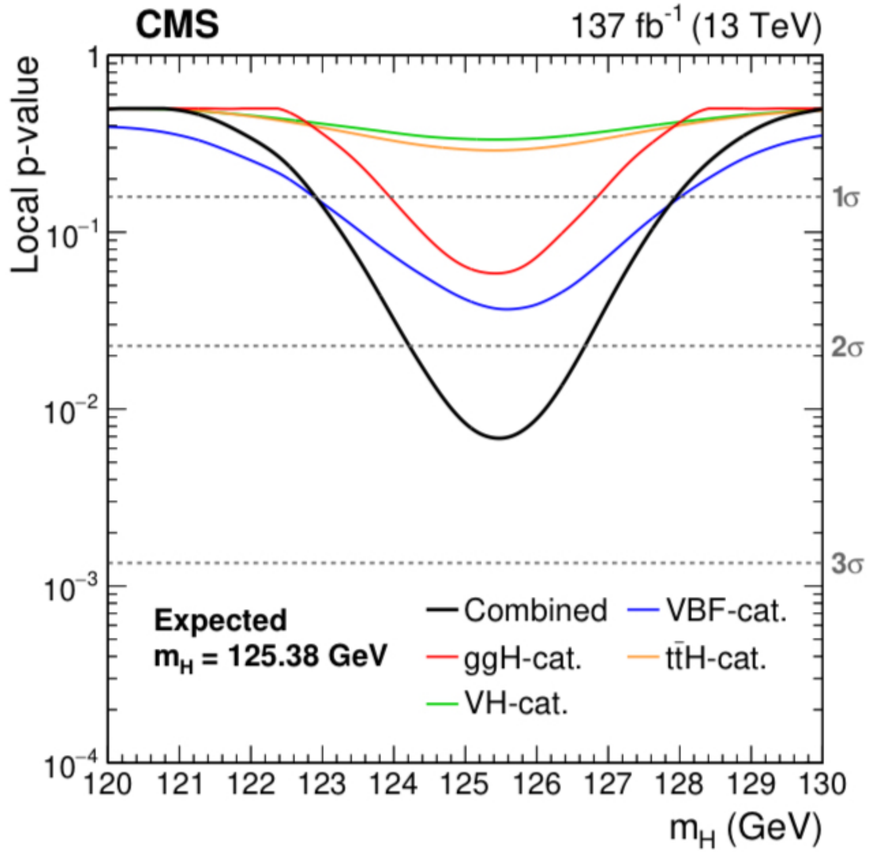


arXiv : 1610.07922



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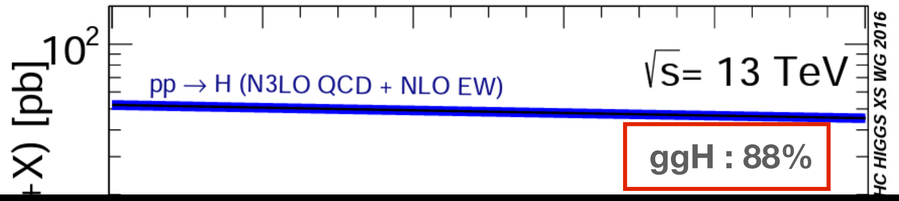
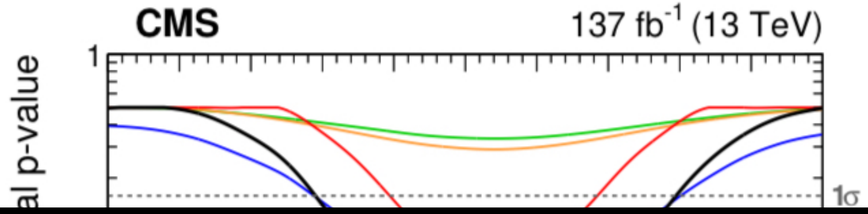
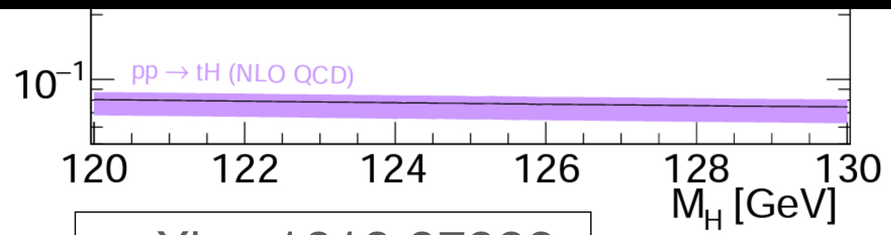




Cross-section : ggH >> VBF

Significance : VBF $\gtrsim$ ggH



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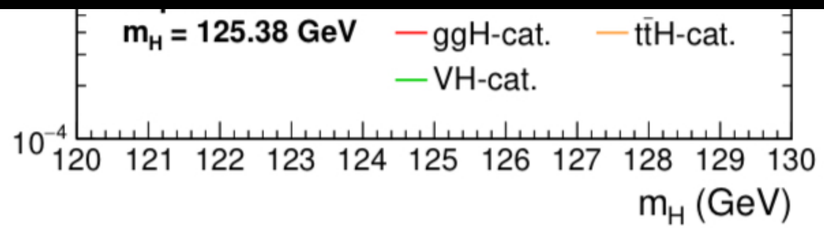

JHEP 01(2021) 148

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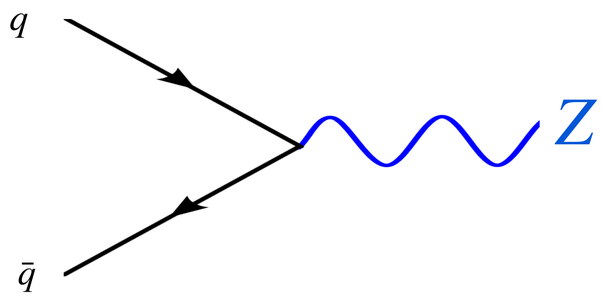

dominant background

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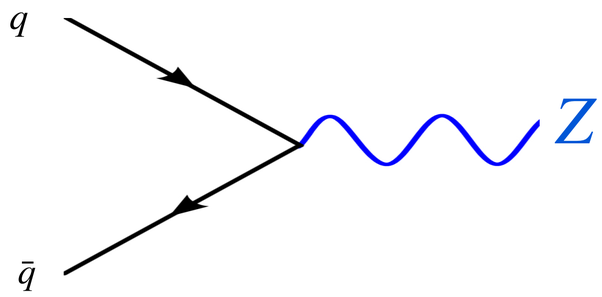

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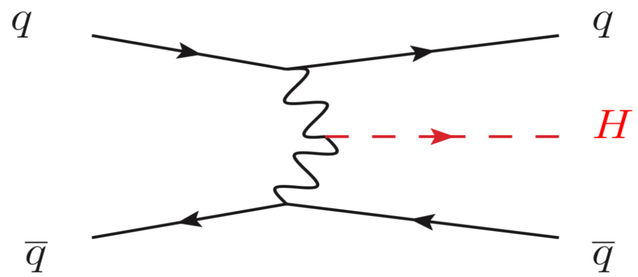

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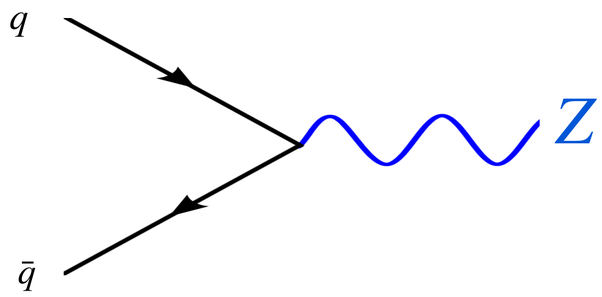

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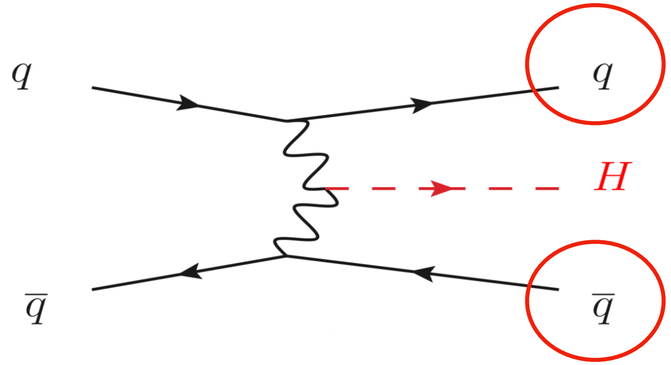

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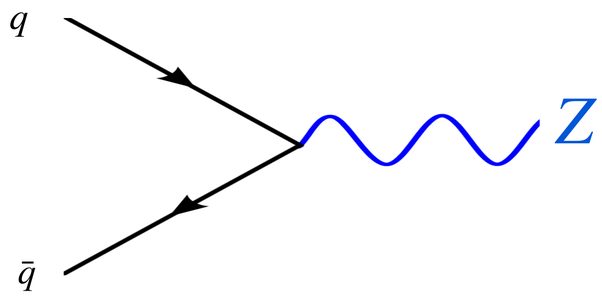

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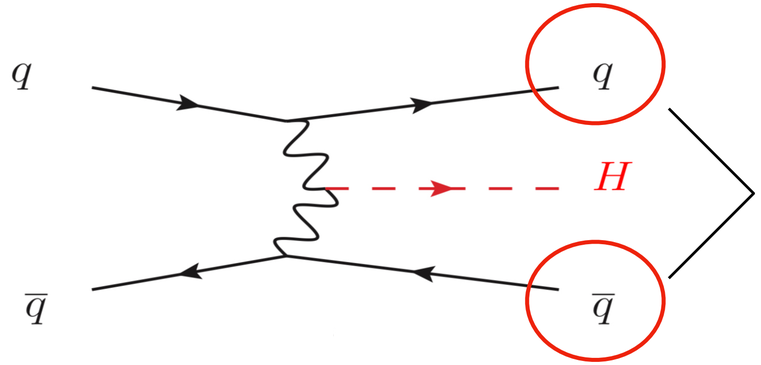

large $\Delta\eta_{jj}$, m_{jj}

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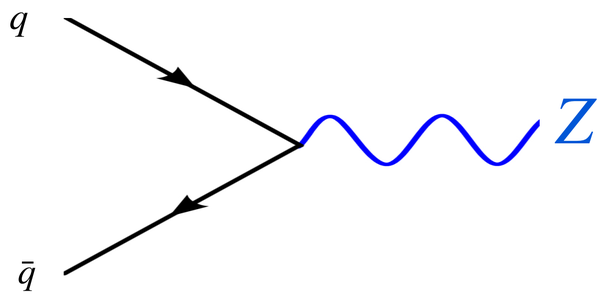

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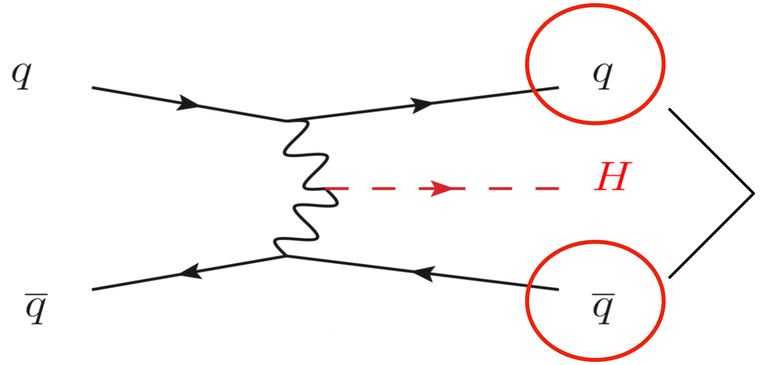

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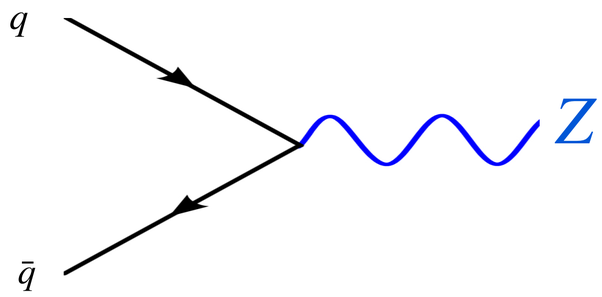

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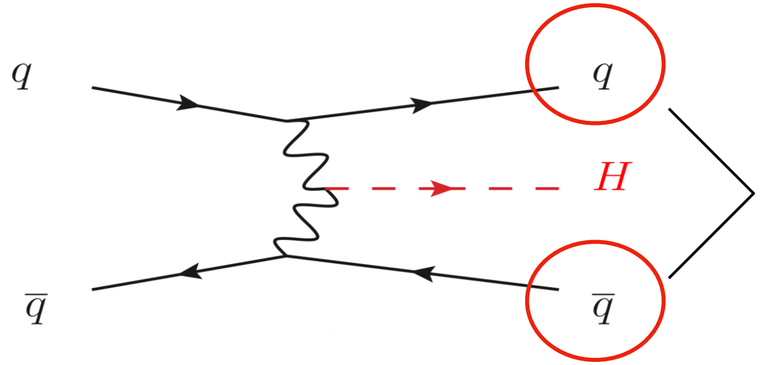

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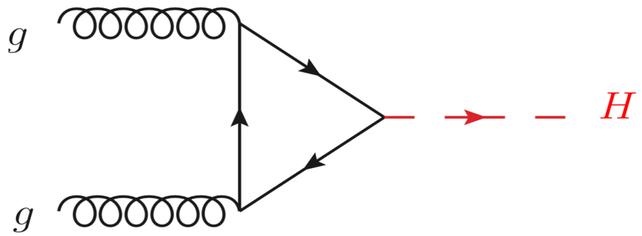
ggH :



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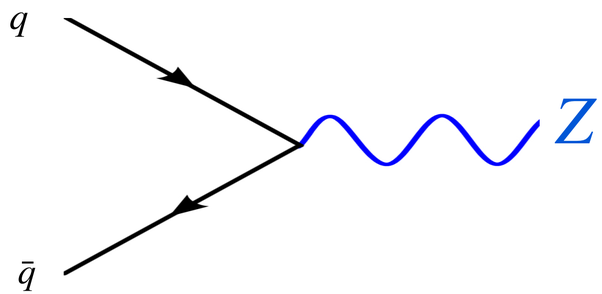

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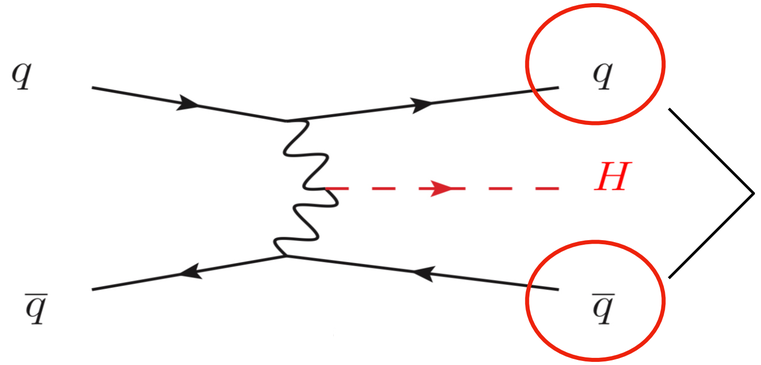

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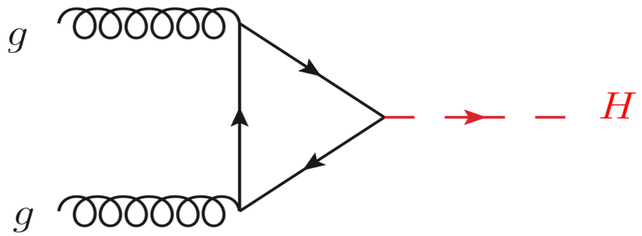

No such handle. But has largest cross-section

Intro / Motivation → Saving ggH !

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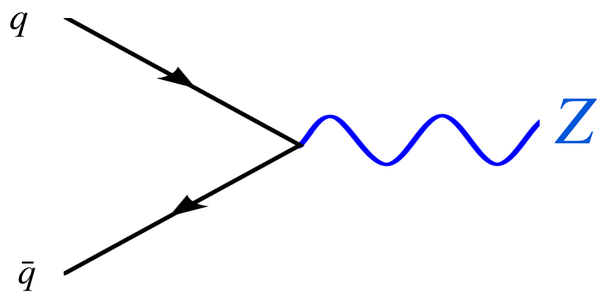

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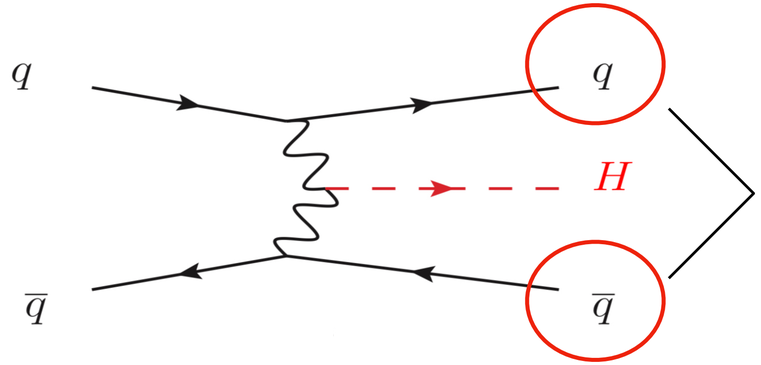

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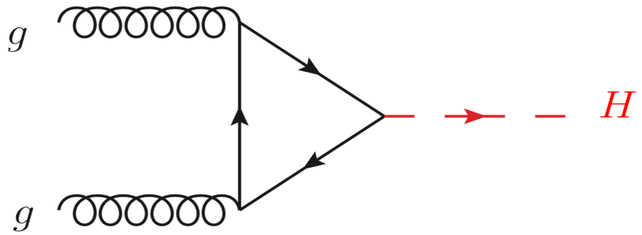

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want to save ggH and exploit it well !

Main Physics : ISR quark / gluon jets 1

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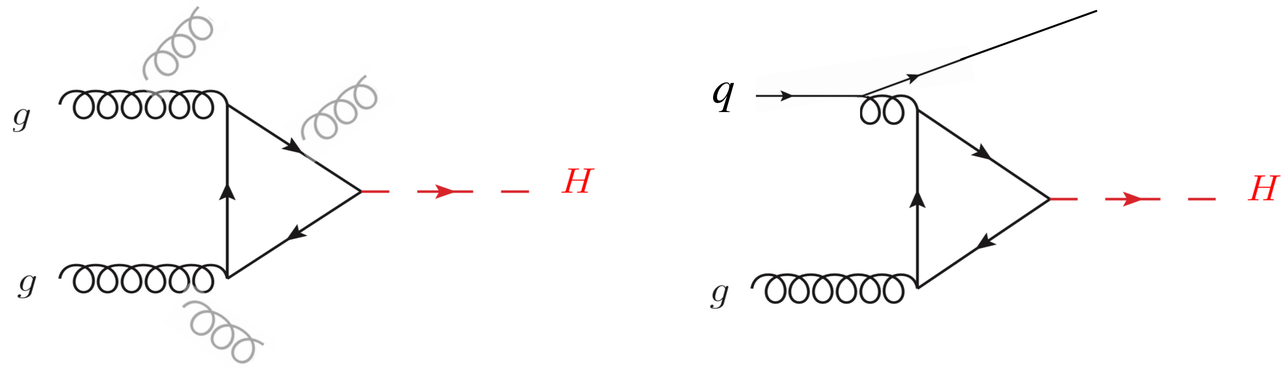
ex) ggH leading jets



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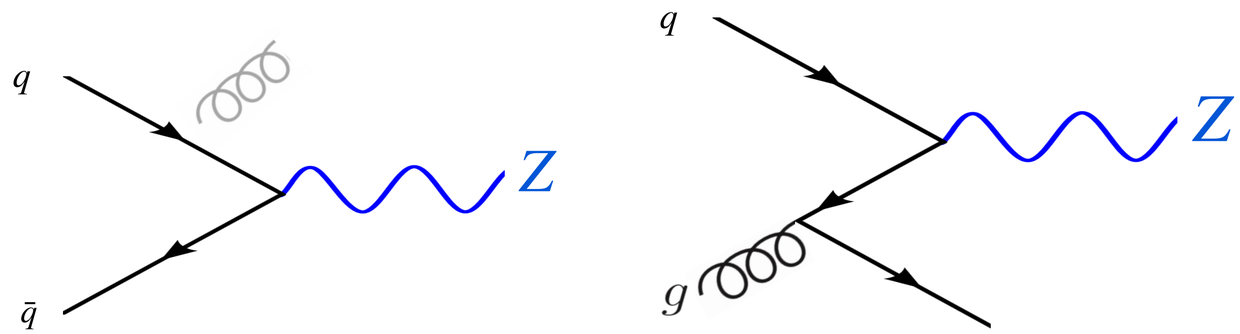

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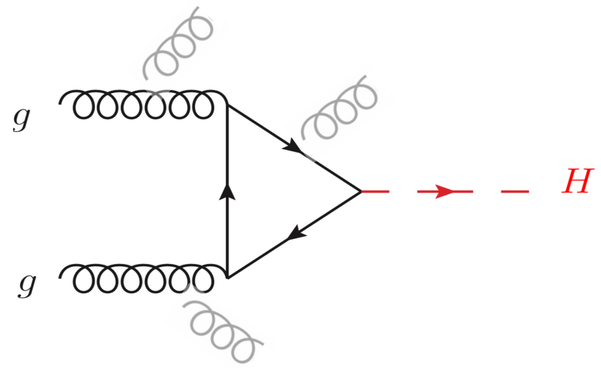

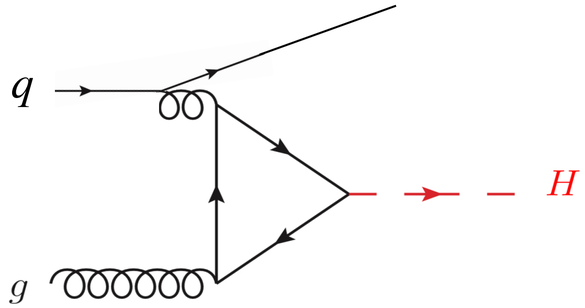

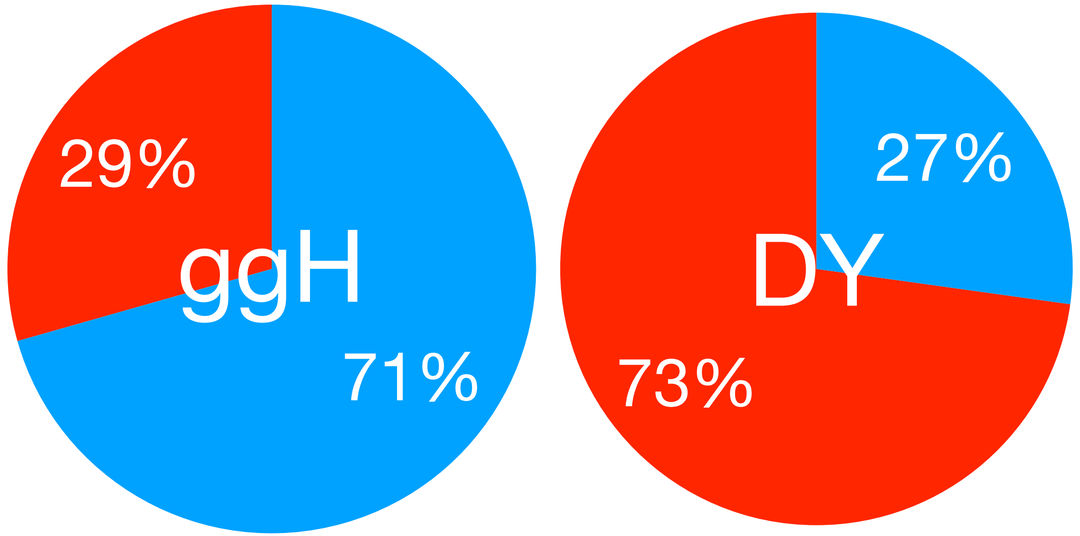

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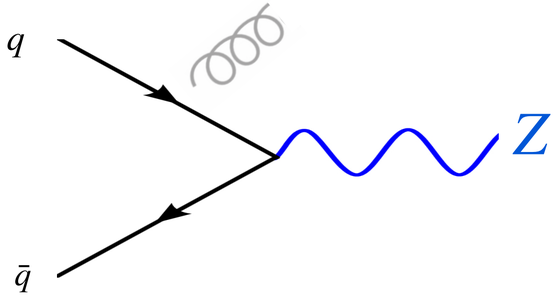

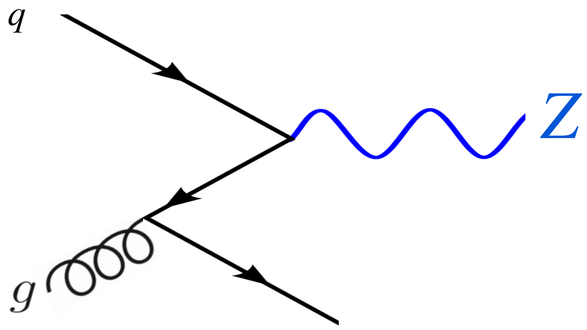

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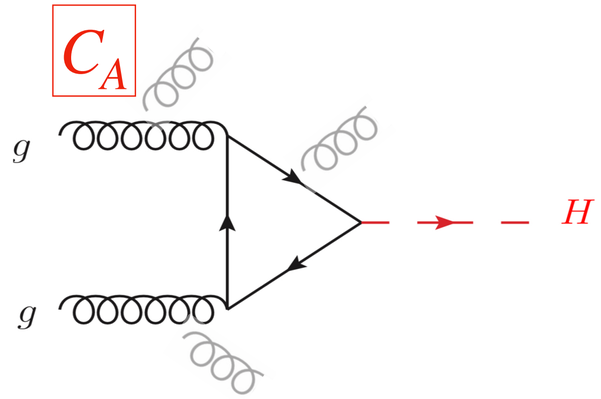

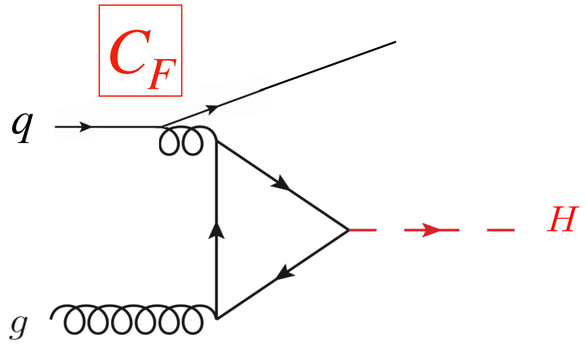

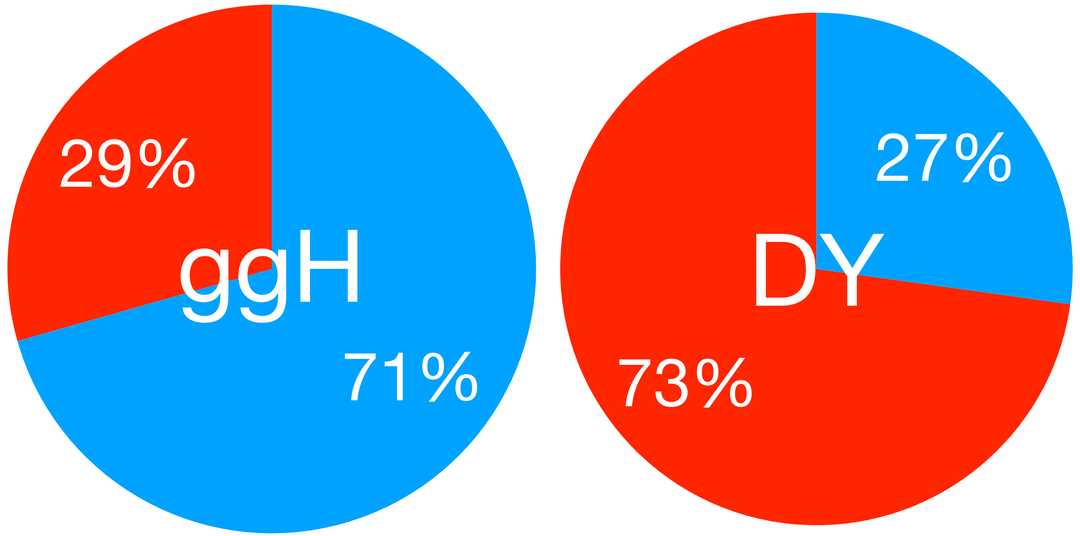

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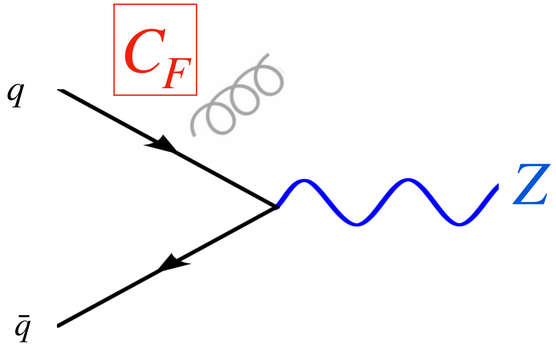

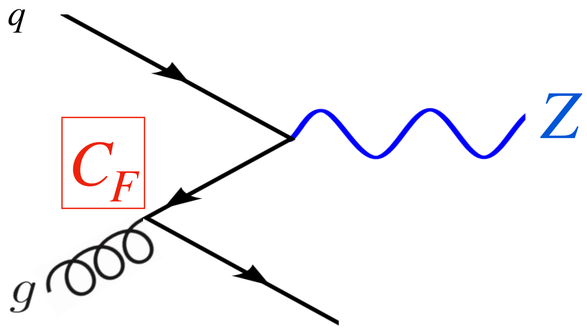

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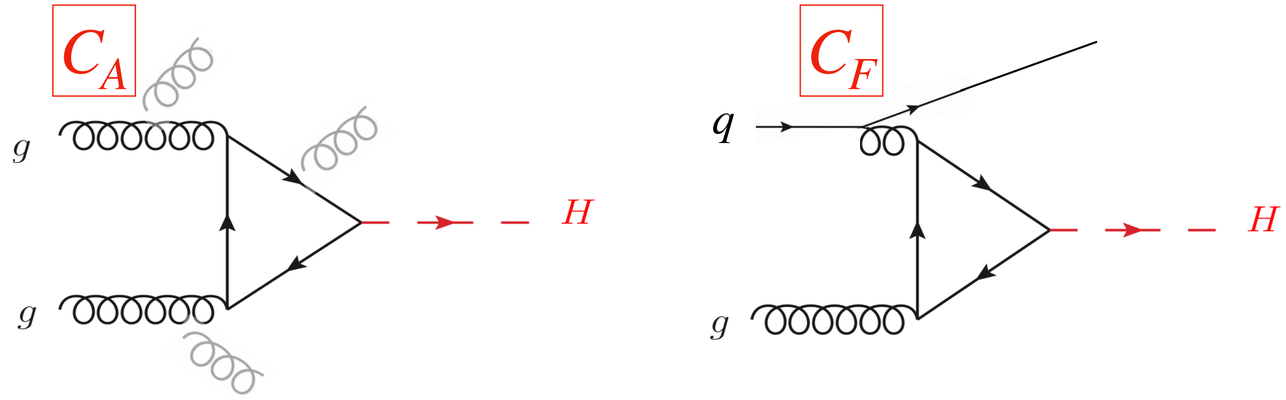

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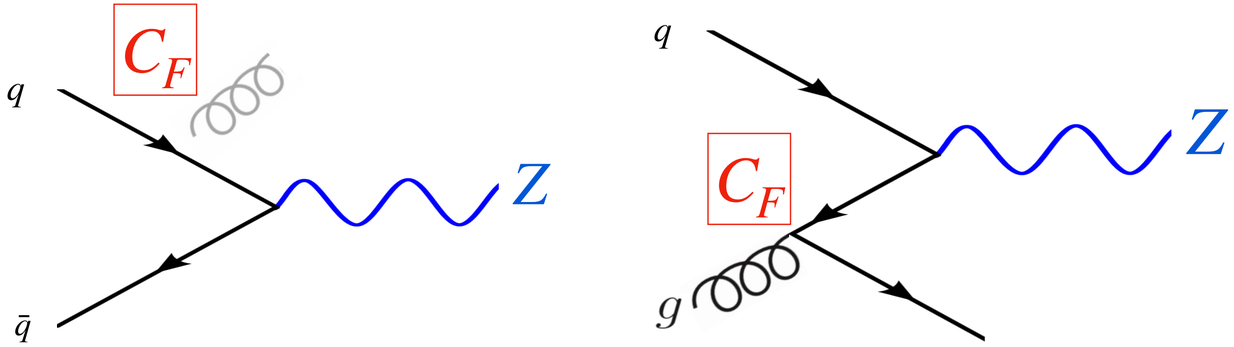

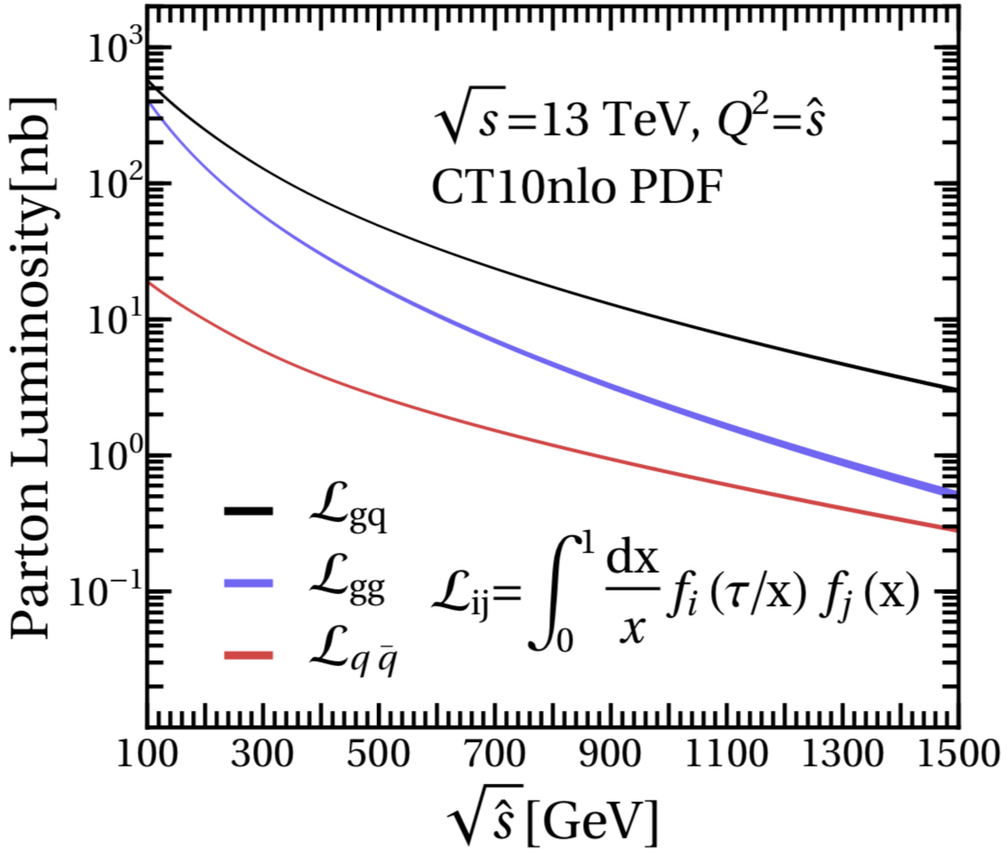

PRD 102, 115007

Main Physics : ISR quark / gluon jets 2

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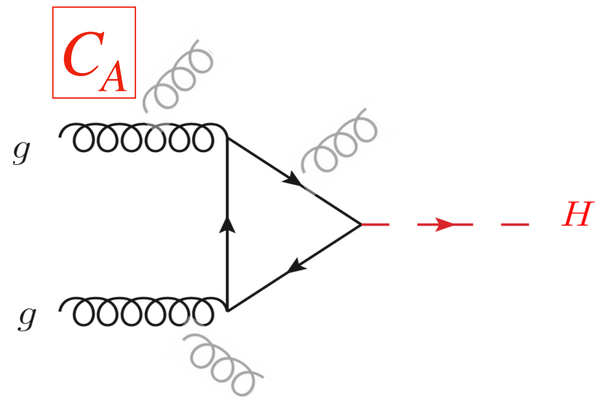

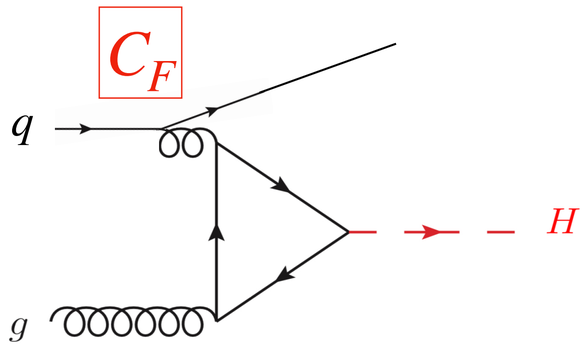

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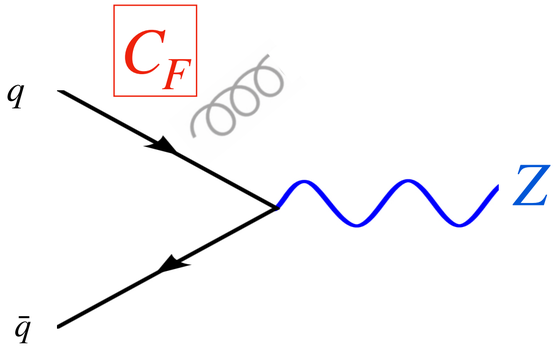
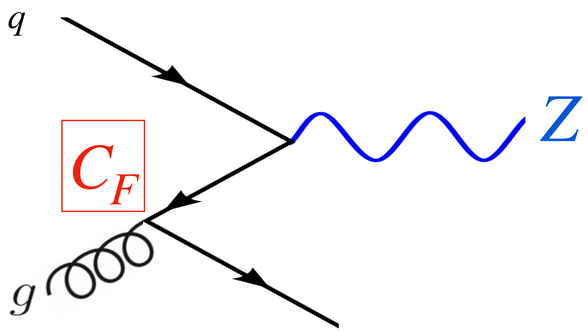
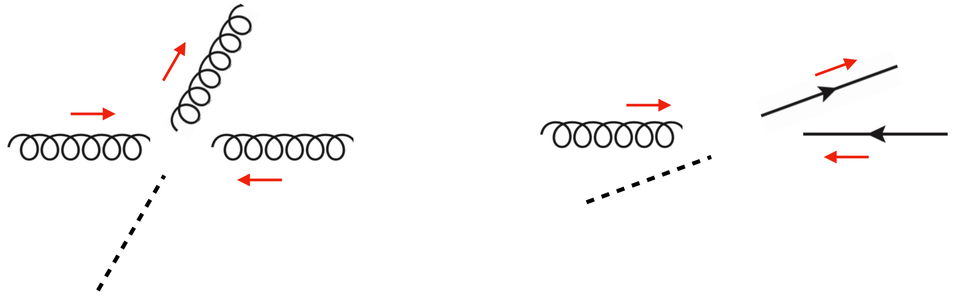


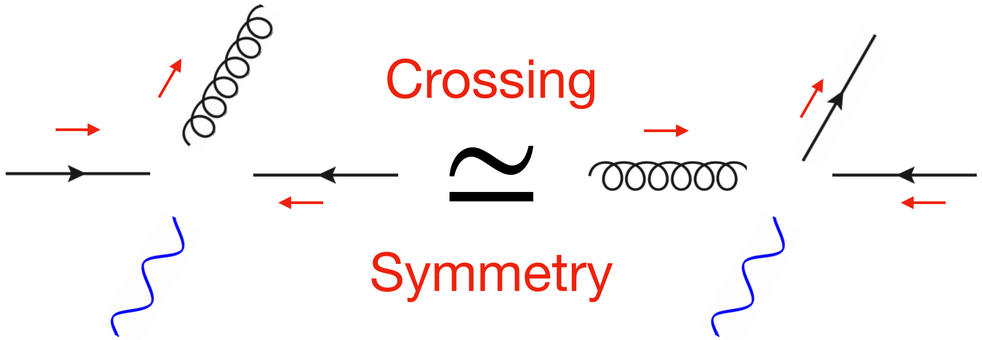


Effectively,

Helicity

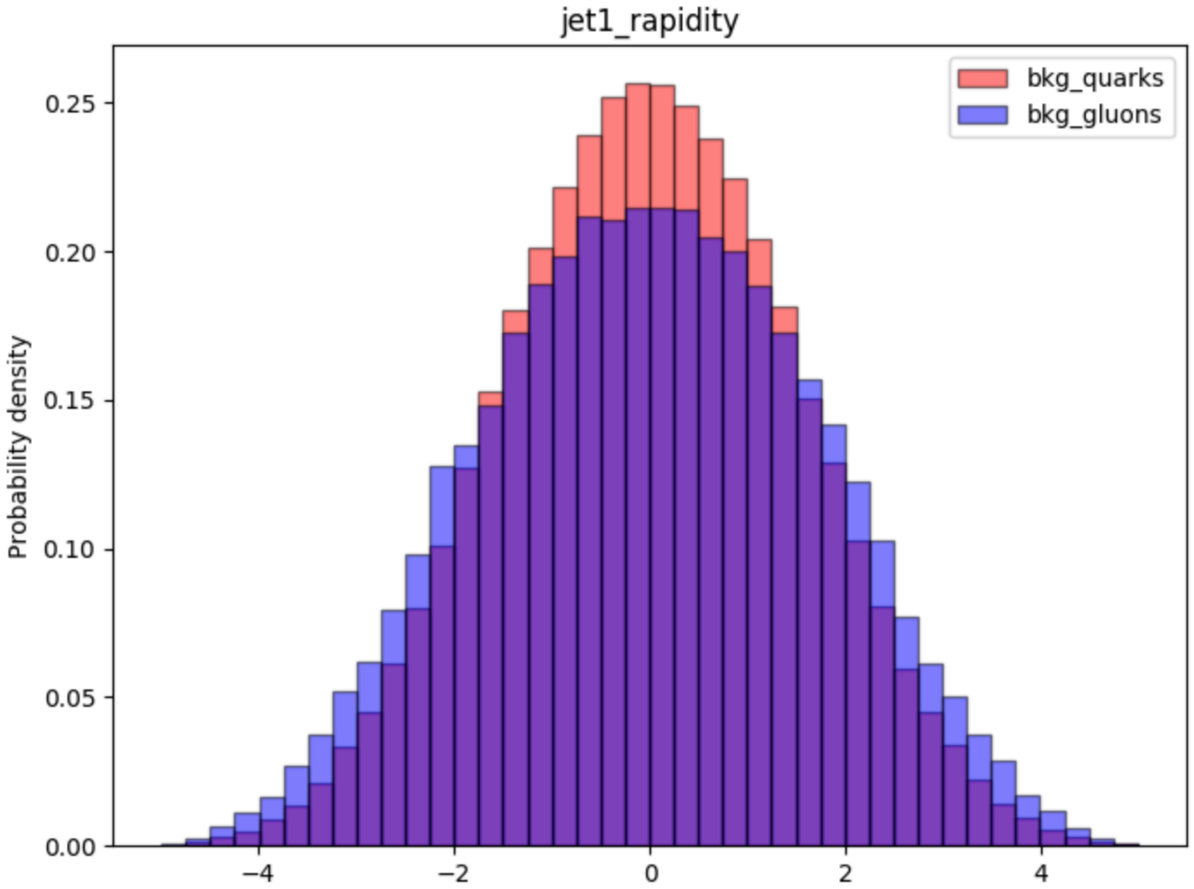


Central gluon (low η) Forward quark (high η)

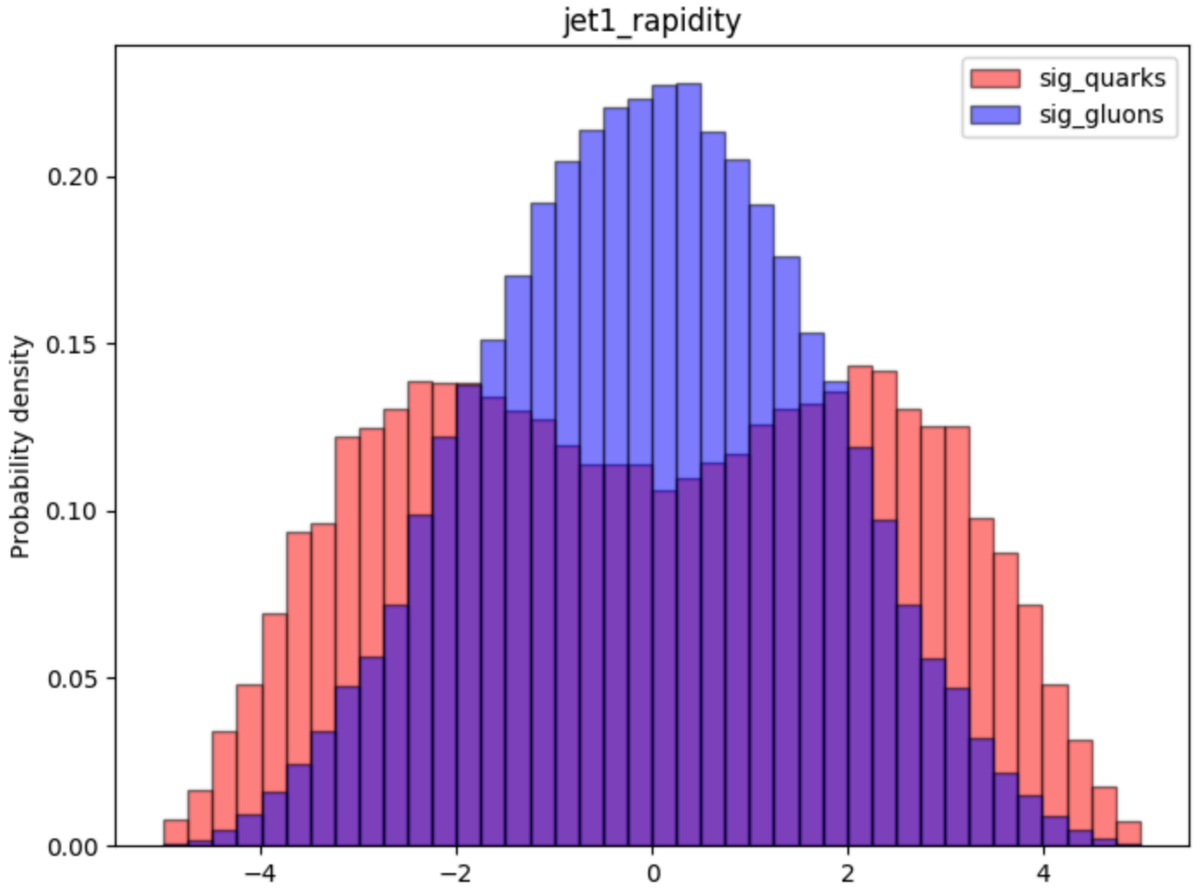


Backup; kinematic consideration

DY



ggH



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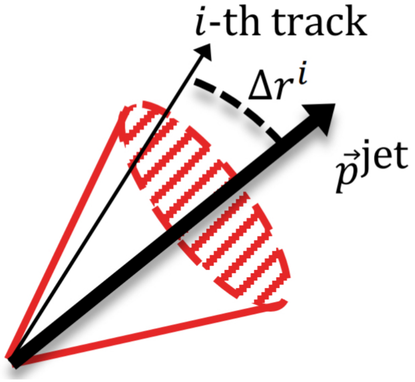
Ex) Girth $\equiv$ $\Sigma_{i \in jet}\left(\frac{p_T^i}{p_T^{jet}} \Delta r^i\right)$



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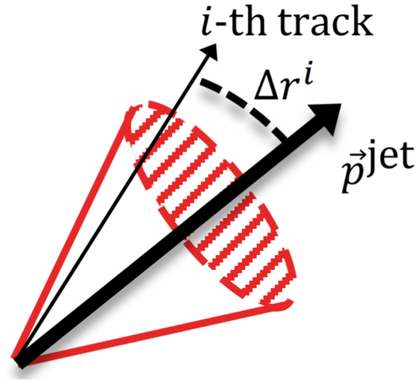

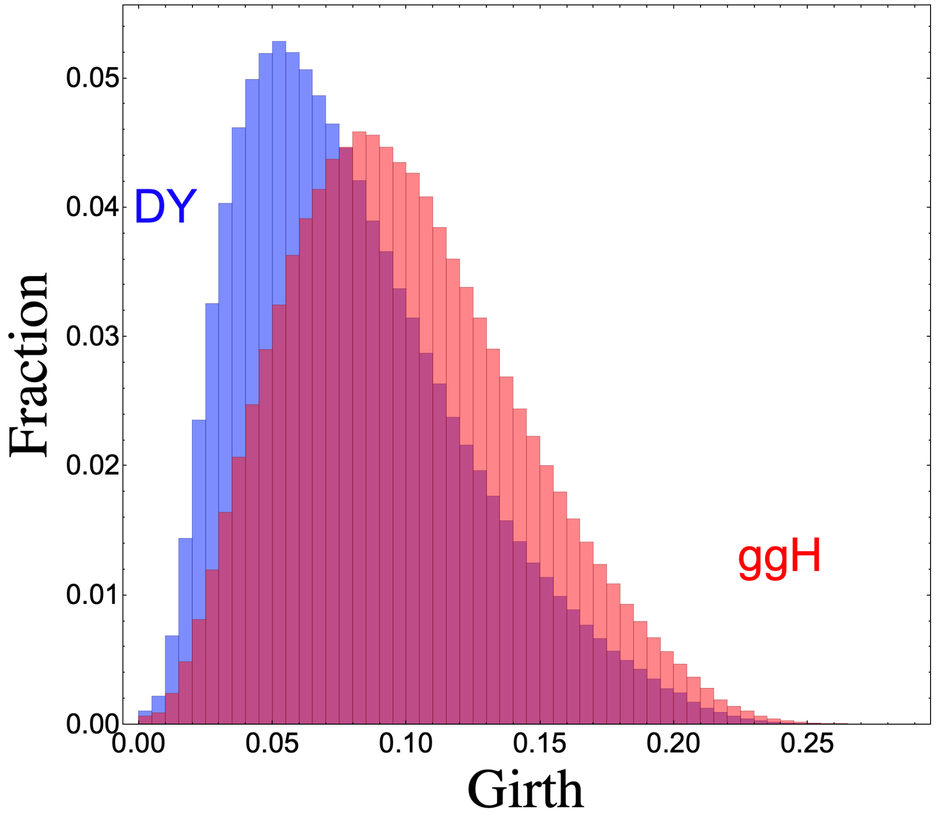

Main Physics : Jet-substructure variables

- Gluon jet : broader than quark jet

  → jet-substructure variables

  : Girth, EEC, track multiplicity, ...

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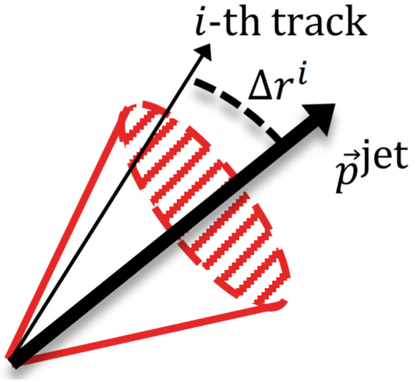

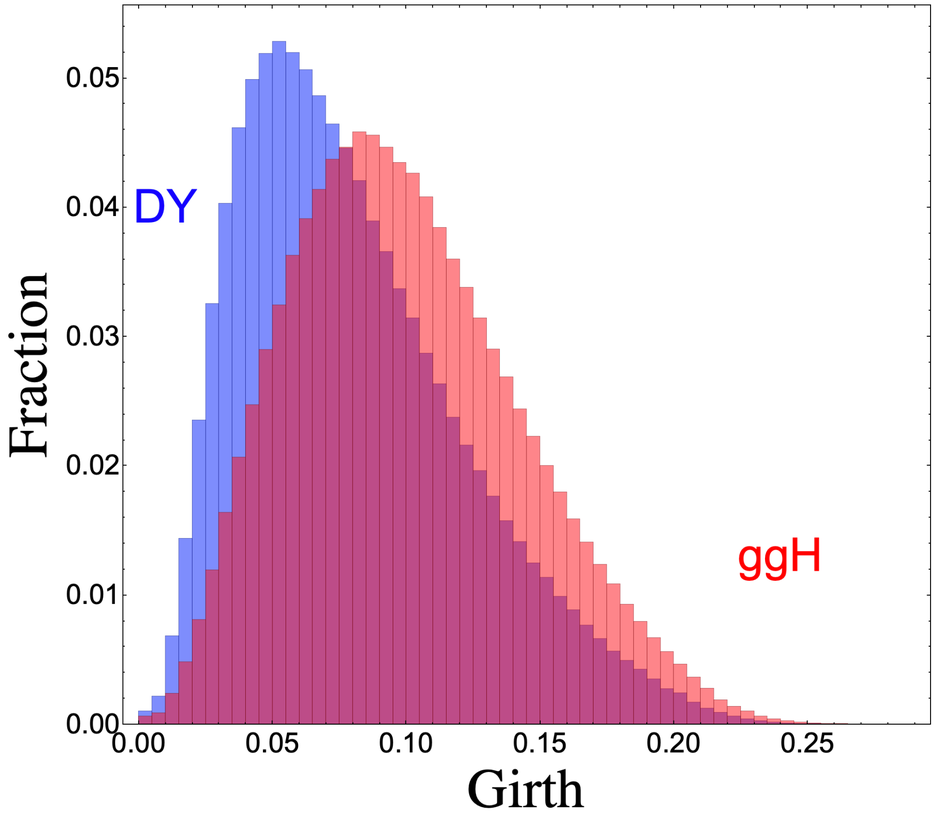

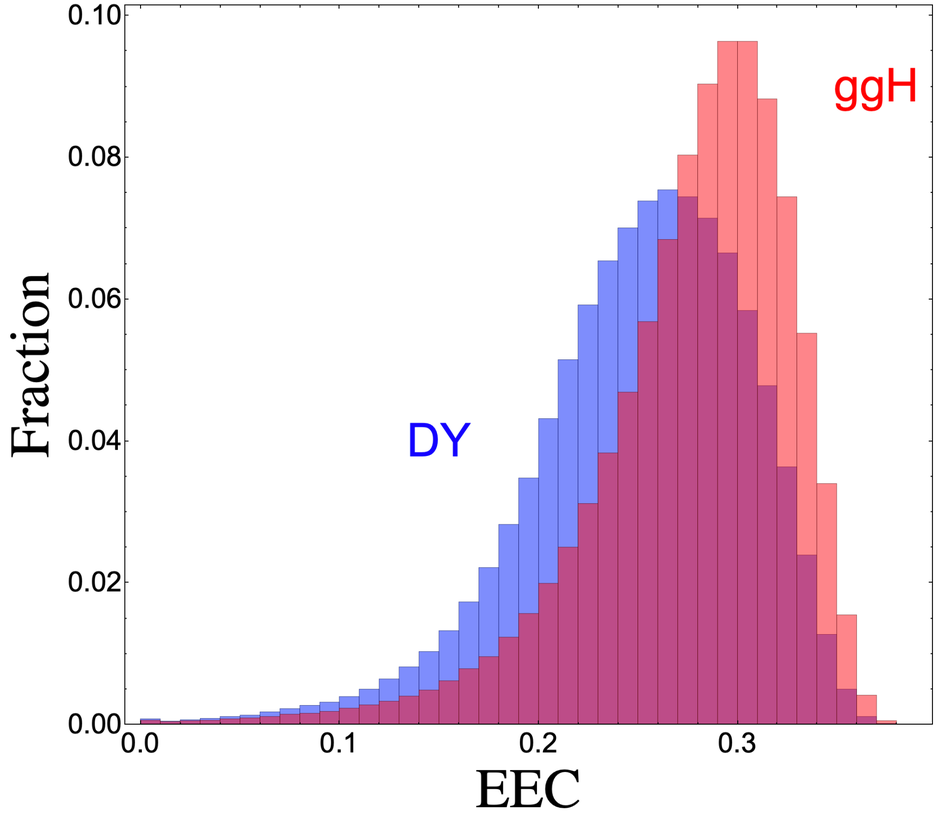

Multi-Variate Analysis (MVA)

Benchmark : CMS result (JHEP 01(2021) 148)

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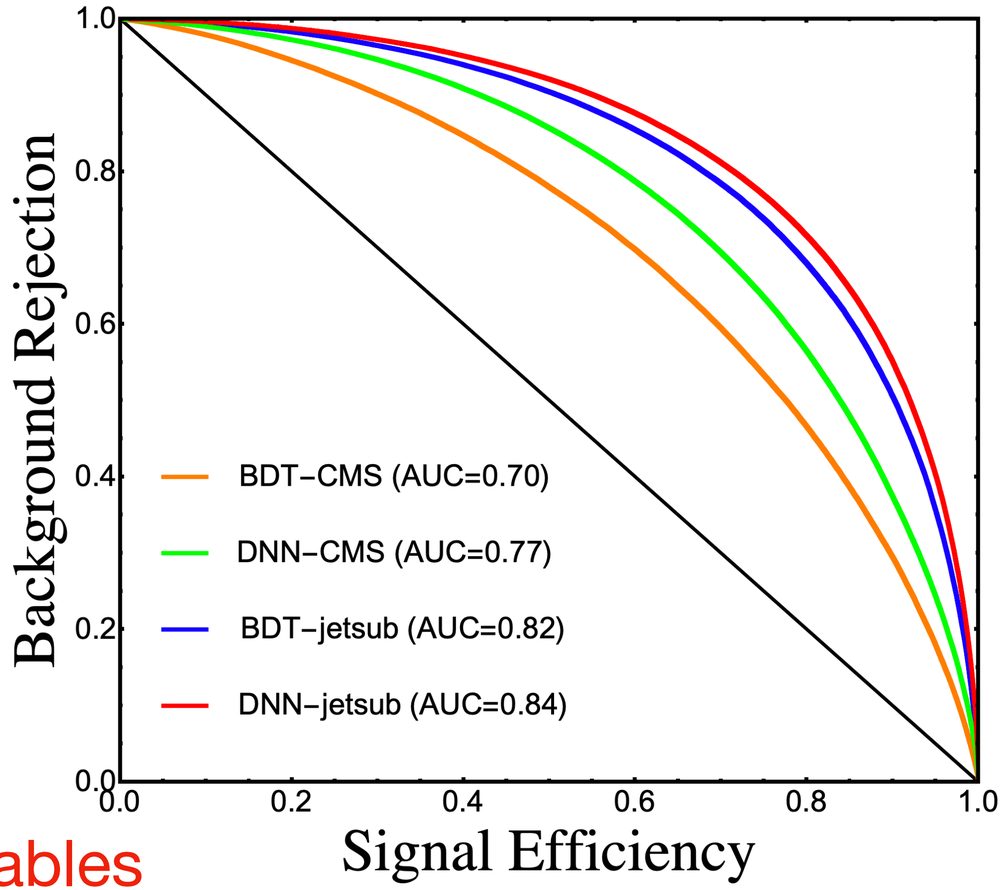
ROC curve



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Statistical Analysis

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- Uniformly binned template of $m_{\mu\mu}$
  w/ sub-categorization using MVA scores.
  $\rightarrow$ Profile likelihood ratio test

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- Test statistics :

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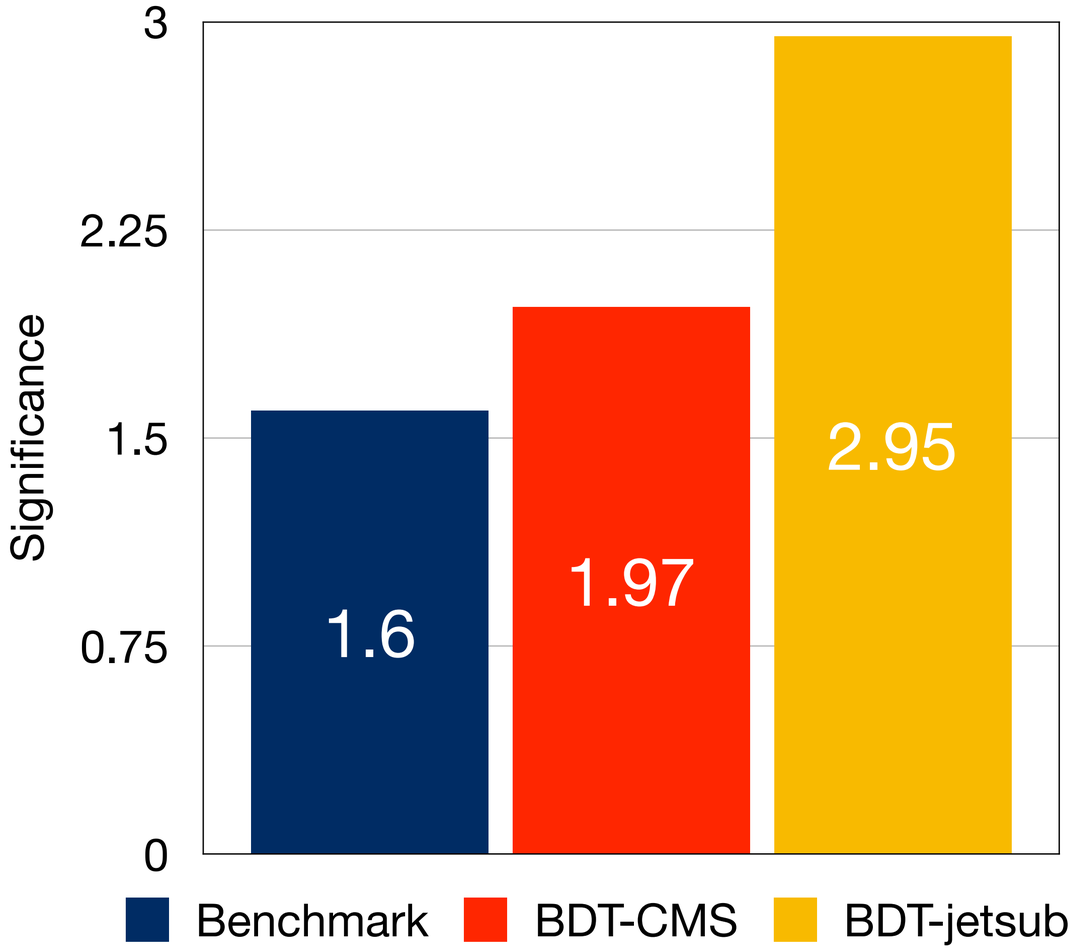

Summary

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ggH has largest cross-section but has less contribution to $h \to \mu\mu$ than VBF

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$h \to \mu\mu$ significance can be enhanced

by exploiting ggH channel more efficiently,

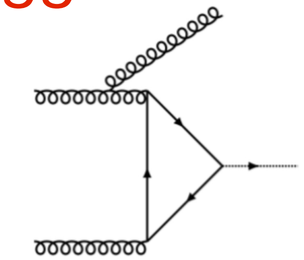
by quark / gluon tagging of ISR jet,

by including jet-substructure variables

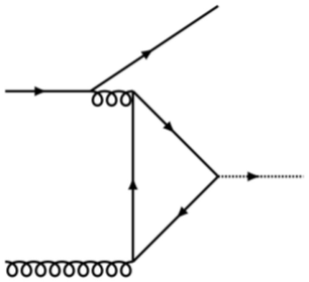
Thanks

Backup; Roguh Estimation of Quark/Gluon ratio

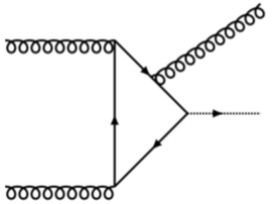
ggH



$\propto 2C_A\mathcal{L}_{gg}$



$\propto C_F\mathcal{L}_{gq}$

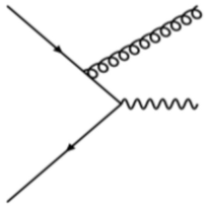


$\propto 3C_F\mathcal{L}_{gg}$

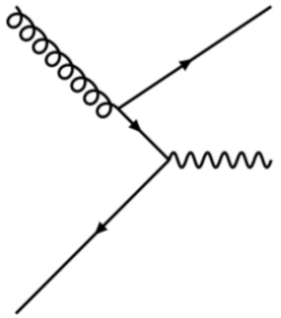
$$\frac{\sigma_g}{\sigma_q} \propto \frac{(2C_A + 3C_F)\mathcal{L}_{gg}}{C_F\mathcal{L}_{gq}}$$

$$\simeq 7\frac{\mathcal{L}_{gg}}{\mathcal{L}_{gq}} \ (\sim 3\text{-}4)$$

DY



$\propto 2C_F\mathcal{L}_{qq}$



$\propto C_F\mathcal{L}_{gq}$

$$\frac{\sigma_g}{\sigma_q} \propto \frac{2C_F\mathcal{L}_{gg}}{C_F\mathcal{L}_{gq}} \sim \frac{1}{7} - \frac{1}{10}$$

+ next order gluon jets through glue-glue
→ quark triangle loop diagram

Backup; CMS variables

- 4 Dimuon system

  $p_T^{\mu\mu}$, $y^{\mu\mu}$

  ϕ_{CS}, cos θ_{CS} : azimuthal and polar angle in Collins-Soper rest frame.

- 4 Each muon

  η^{μ} , $\frac{p_T^{\mu}}{m^{\mu\mu}}$

- 3 (+2) Each jet

  p_T^{j} , η^{j}

  $\Delta R(\mu\mu, j_1)$: distance between the leading jet and dimuon in $\eta - \phi$ space

- 3 Dijet system

  m^{jj} : dijet invariant mass

  $\Delta\eta^{jj}$

  $\Delta\phi^{jj}$

- 5 Dimuon ~ jets

  $\Delta\eta(\mu\mu, j_1)$, $\Delta\eta(\mu\mu, j_2)$

  $\Delta\phi(\mu\mu, j_1)$,$\Delta\phi(\mu\mu, j_2)$

  $z_* = \frac{y^{\mu\mu} - (y^{j_1} + y^{j_2})/2}{|y^{j_1} - y^{j_2}|}$: Zepenfeld variable

Backup; jet-substructure variables

$$\text{girth } G = \frac{1}{p_T^{jet}} \sum_{i \in \{\text{const.}\}} p_T^i |\Delta \vec{r}_i|$$

$$\text{broadening } B = \frac{1}{\sum_i |\vec{p}^{\,i}|} \sum |\vec{p}^{\,i} \times \hat{p}^{\text{jet}}|$$

$$= \frac{1}{\sum_i |\vec{p}^{\,i}|} \sum |\vec{k}_T^{\,i}|$$

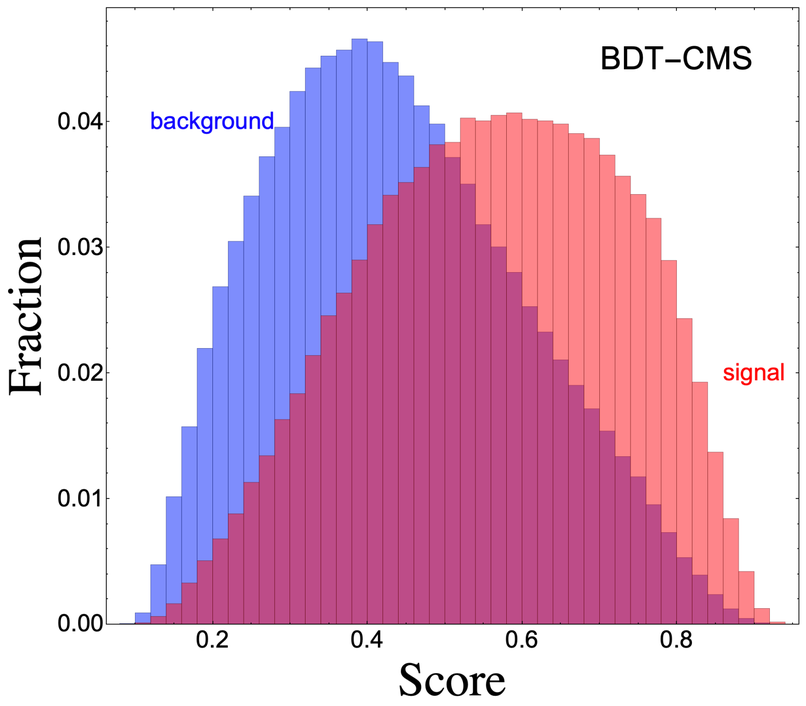
$$\text{EEC } C_1^\beta = \frac{1}{(\sum_i p_T^i)^2} \sum_{i<j} p_T^i p_T^j (\Delta R_{ij})^\beta$$

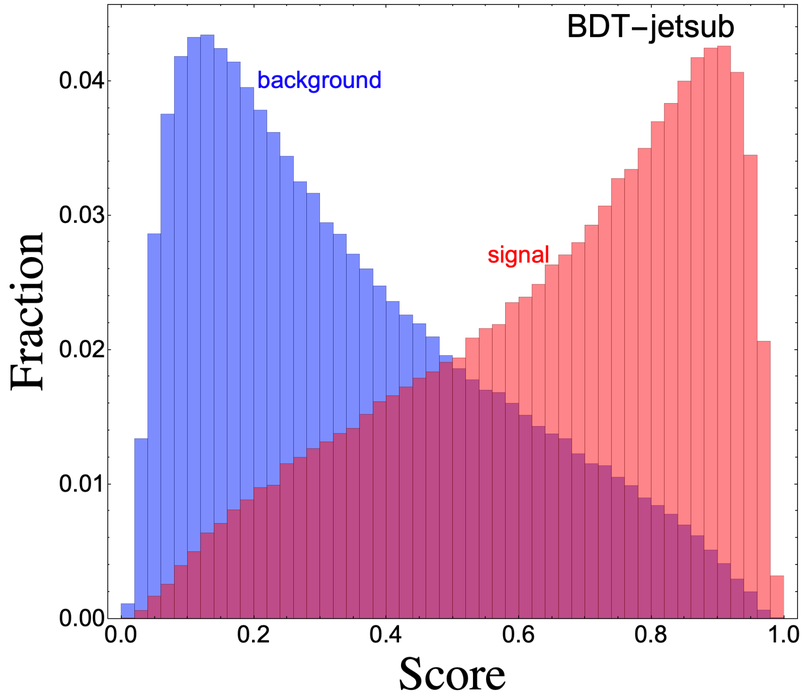
$$\text{RMS-}p_T \sqrt{< p_T^2 >} = \frac{1}{p_T^{\text{jet}}} \sqrt{\frac{1}{n_{\text{tk}}} \sum_i (p_T^i)^2}$$

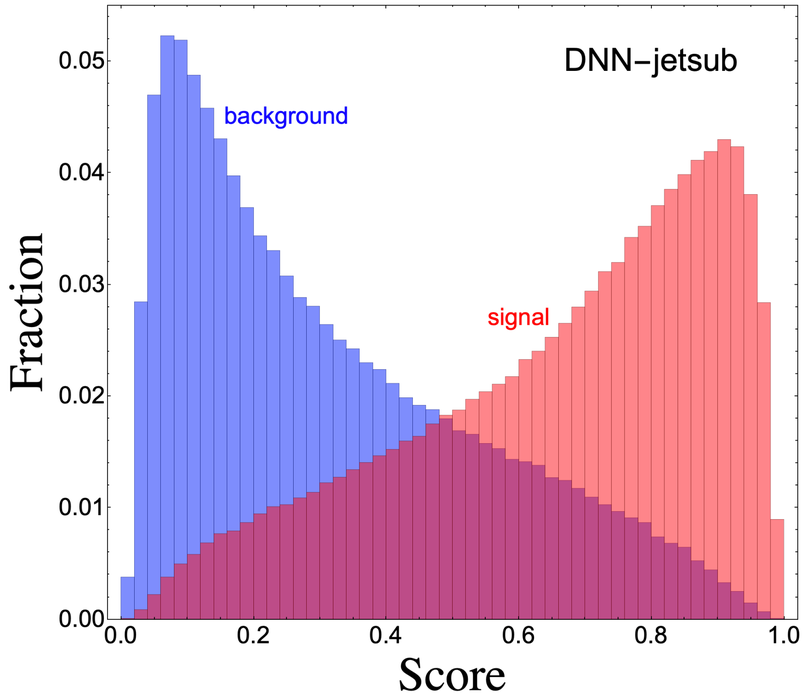
$$\text{Pull-vector } \vec{v}_p = \frac{1}{p_T^{\text{jet}}} \sum_i p_T^i |\Delta \vec{r}^{\,i}| \Delta \vec{r}^{\,i}$$

Backup; Multi-Variate Analysis (MVA)

Score Plots







Backup; Mutual information