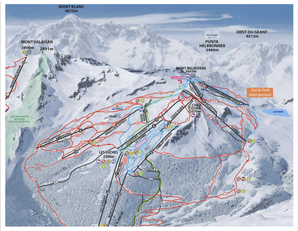
Electroweak physics and long-lived particles at LHCb

Felicia Volle
on behalf of the LHCb Collaboration



21st March 2026

UNIVERSITY OF
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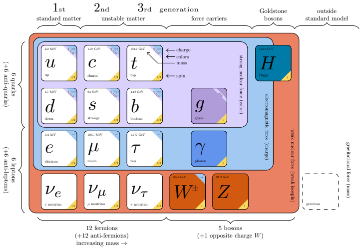
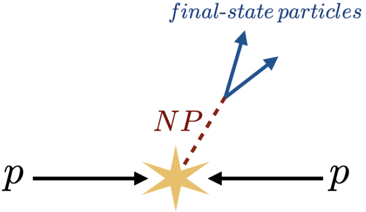
Stress test of the Standard Model of Particle Physics

Electroweak measurements



- Test consistency of Standard Model (SM) observables.

Direct searches for NP

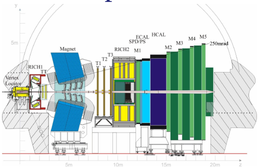


- Search for extension of SM by New Physics (NP) processes.

⇒ Complementarity of both approaches to improve the understanding of our SM.

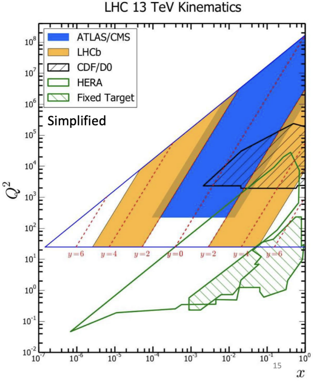
Electroweak measurements at LHCb

LHCb introduction in Christoph's talk.



Int.J.Mod.Phys. A30(2015)1530022

- W & Z production cross-sections at central LHC rapidity probe Bjorken x values of around $10^{-3} - 10^{-2}$.
- LHCb's forward coverage accesses very low (and high) x.
- Complementary PDF coverage outside ATLAS & CMS reach can have strong impact in combinations.



Adapted from arXiv:0808.1847

Z-boson mass measurement

PRL 135 (2025) 161802

At LEP: via beam-energy scans
$\Rightarrow$ precise beam-energy calibration needed.

At LHCb: from final-state kinematics
$\Rightarrow$ detector calibration crucial.

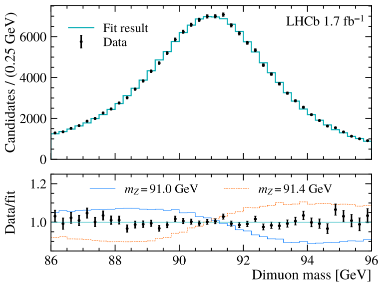
First dedicated m_Z measurement at LHC

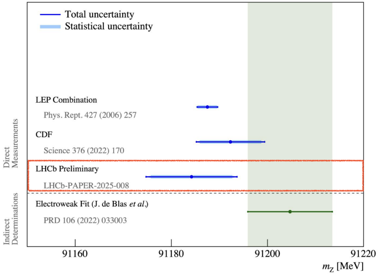
- $Z \to \mu^+\mu^-$ using $1.7\,\text{fb}^{-1}$ at $\sqrt{s} = 13\,\text{TeV}$ (2016).
- Neglecting lepton masses: $m^2 \simeq 2p^+p^-(1-\cos\theta)$; θ well known.

$\hookrightarrow$ Momentum calibration using Z, $\Upsilon(1S)$ (and J/ψ).

- Backgrounds have total fraction of $\mathcal{O}(10^{-3})$.
- χ^2 fit to dimuon mass.

$$m_Z = 91184.2 \pm 8.5(stat) \pm 3.8(syst)\,\text{MeV}$$



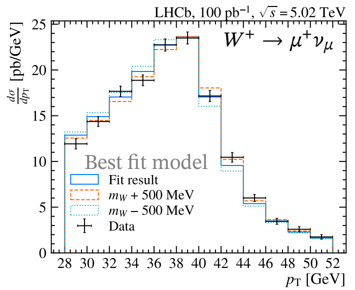


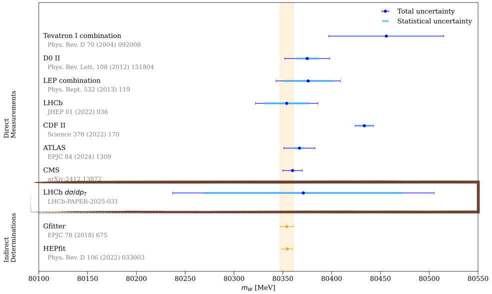
Model-independent m_W measurement

arXiv:2509.18817

- Ensuring long-term reusability of cross-section measurement for evolving models.
- Provide unfolded p_T distribution.
- Unbiased thanks to requiring muon isolation in order to suppress background.
- Validating isolation modelling via $Z \rightarrow \mu^+\mu^-$ decays.
- Proof-of-principle with $100\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 5.02$ TeV (2017).

$$m_W = 80369 \pm 130(exp) \pm 33(th)\ \mathrm{MeV}$$



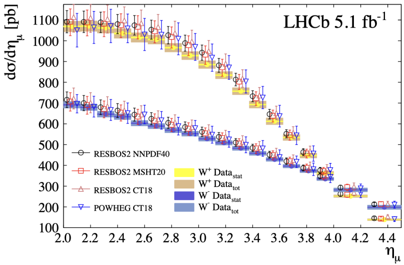


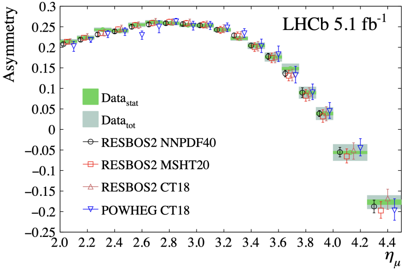
W production cross-section Preliminary LHCb-PAPER-2025-070/71

* $W \to \mu\nu$ decays using 5.1 fb^{-1} at $\sqrt{s} = 13$ TeV (2016-18).
* Momentum correction in data via fit to $Z \to \mu\mu$.
* Template fits including W decays, QCD background, Electroweak processes and heavy flavor processes.
* Maximum-likelihood fit to $p_{\mathrm{T}}(\mu)$ in 36 η_μ bins.

$$\mathcal{A}(\eta_\mu) = \frac{d\sigma_{W^+}/d\eta_{\mu^+} - d\sigma_{W^-}/d\eta_{\mu^-}}{d\sigma_{W^+}/d\eta_{\mu^+} + d\sigma_{W^-}/d\eta_{\mu^-}}$$

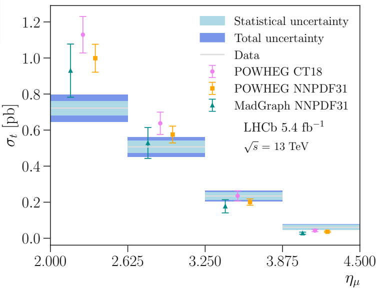
Bonus: Muon charge asymmetry in bins of η_μ.

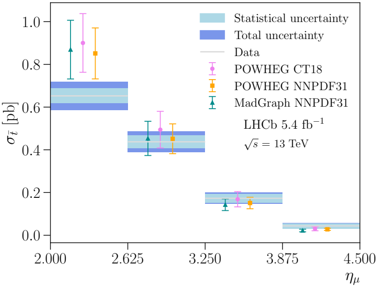


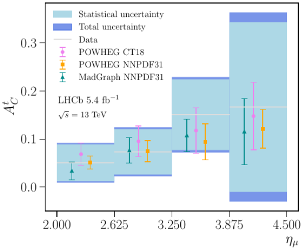


Top quark production cross-section and charge asymmetry **NEW** arXiv:2512.11324

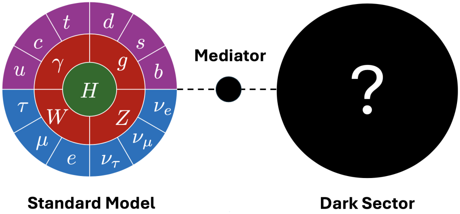
- Forward region enhances sensitivity to charge asymmetry. PRD91(2015)054029
- $5.4\,\text{fb}^{-1}$ at $\sqrt{s} = 13\,\text{TeV}$ (2015-18).
- Differential production cross-section of $t \to W^{+}(\to \mu^{+}\nu_{\mu})b$ decay.
- DeepJet-like algorithm for jet flavour: b-tagging efficiency improves by $11 - 27\%$ per jet, depending on p_{T}.





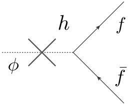


Mediators between the visible and dark sector



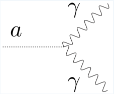
Credits to E.Whiter.

Portal examples:



Higgs portal

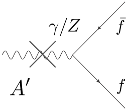
$(\mu S + \lambda S^2)H^\dagger H$



Axion portal

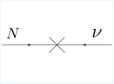
$\frac{a}{f_a} F_{\mu\nu}\widetilde{F}^{\mu\nu}$,

$\frac{a}{f_a} G_{i,\mu\nu}\widetilde{G}^{i,\mu\nu}$



Vector portal

$\varepsilon F_{\mu\nu}F'^{\mu\nu}$ / $\varepsilon B_{\mu\nu}F'^{\mu\nu}$



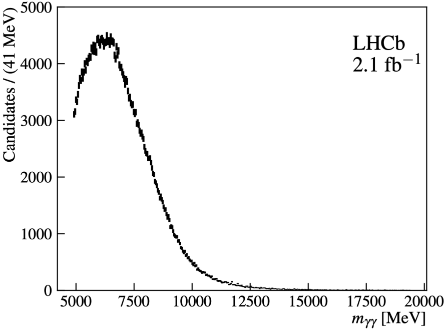
Neutrino portal

$y_N \bar{L} H N$

Search for ALP$\rightarrow \gamma\gamma$

arXiv:2507.14390

- Axion-Like-Particles (ALPs) can solve the strong CP-problem and be a DM candidate.
- Search for ALPs in 2018 dataset.
- Production via gluon-gluon fusion, and decay to photons.
- Covered mass range of $m_{\gamma\gamma} \in [4.9, 19.4]\ \mathrm{GeV}/c^2$.



After electroweak symmetry breaking:

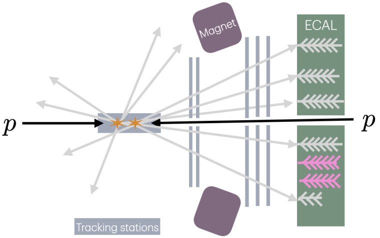
ALP symmetry breaking scale — Coupling to gluons — Coupling to photons — Mass term

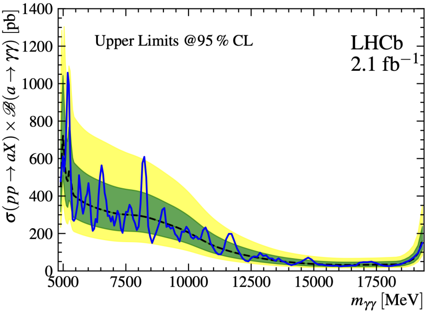
$$\mathcal{L} \supset \frac{a}{4\pi f_a}\left[\alpha_3 c_3 G\tilde{G} + \alpha_2 c_2 W\tilde{W} + \alpha_1 c_1 B\tilde{B}\right] + \frac{1}{2}m_a^2 a^2$$

ALP$\rightarrow \gamma\gamma$ analysis strategy

arXiv:2507.14390

- Candidates built from two calorimeter deposits, identified as γ's from pp collision.
- Candidate required to be in fiducial region $\eta \in [1.8, 5.2]$ and $p_T > 6\,\text{GeV}$
- Multivariate methods against misidentification, and for signal isolation.
- Combinatorial background of γ's and merged $\pi^0 \rightarrow \gamma\gamma$ decays remain and modelled together.



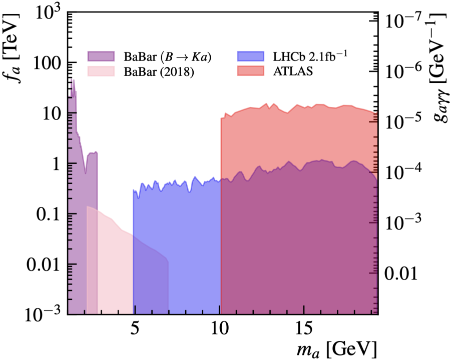


EXTRA:

Search for $B^0_{(s)} \rightarrow \gamma\gamma$ and $\eta_b(1S) \rightarrow \gamma\gamma$.

Results of the ALP→ $\gamma\gamma$ search

arXiv:2507.14390



Upper limits at 95% CL:

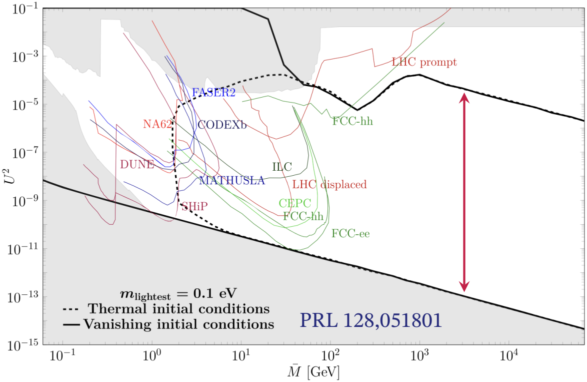
- f_a vs. m_a (left) using $c_1 = c_2 = c_3 = 10$.
- $\mathcal{B}(B^0 \to \gamma\gamma) < 0.83 \times 10^{-5}$.
- $\mathcal{B}(B^0_s \to \gamma\gamma) < 2.68 \times 10^{-5}$.
- $\sigma(pp \to \eta_b(1S)(\gamma\gamma)X) < 765$pb.

Best limits on f_a in $m_a \in [4.9, 10]$ GeV.

First measurement of purely neutral final-state at LHCb.

Heavy Neutral Leptons (HNLs)

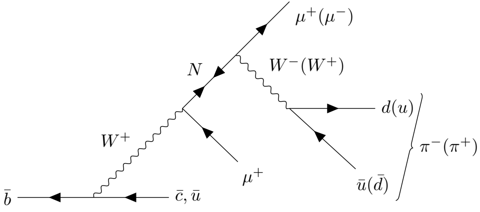
- Right-handed counter parts of the SM neutrinos, ν_ℓ.
- Mixing with ν_ℓ.
  - ν_ℓ mass suppression.
  - Coupling to ν_ℓ via $|U_{\ell N}|^2$.
- Theoretical constraints from matter-antimatter asymmetry and ν_ℓ oscillation without fine-tuning.

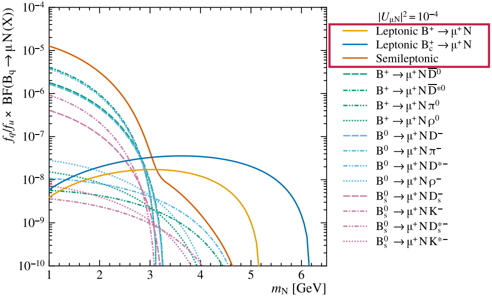


HNL search in B-decays

NEW arXiv:2512.14551

- $\mathcal{L} = 5.04\,\text{fb}^{-1}$ at $\sqrt{s} = 13\,\text{TeV}$ (2016-18).
- Multitude of decay modes:
  - $B^+_{(c)} \to \mu^+ N$,
  - $B \to \mu^+ N X$.
- N mass in $[1.6, 5.5]$ GeV.
- $\text{FD}_z(N) \lesssim / \gtrsim 20\,\text{mm}$.





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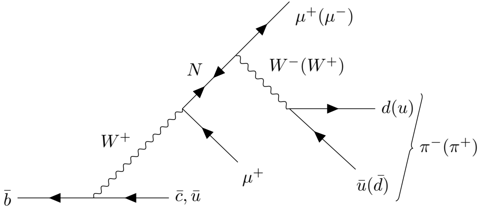
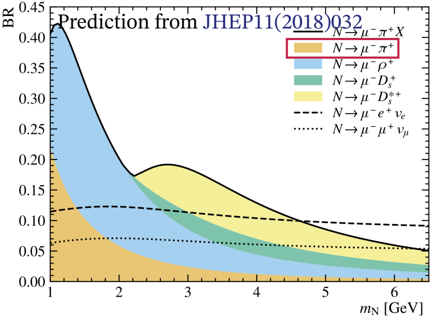
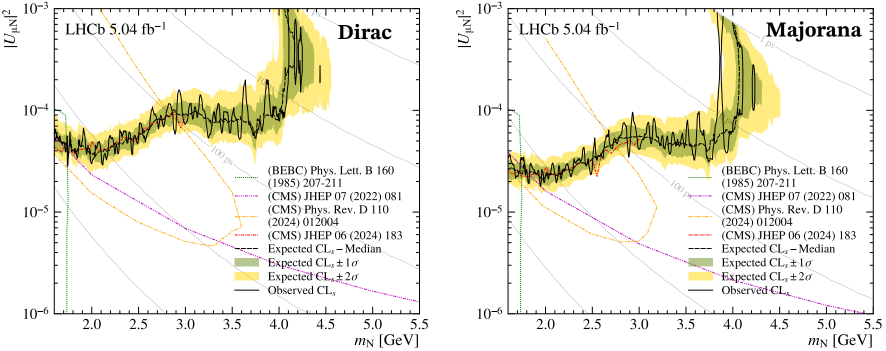
  - $B^+_{(c)} \to \mu^+ N$,
  - $B \to \mu^+ N X$.
- N mass in $[1.6, 5.5]$ GeV.
- $\text{FD}_z(N) \lesssim / \gtrsim 20\,\text{mm}$.
- Focus on $N \to \mu^\pm \pi^\mp$ decay.
- $\mu^\pm\mu^\pm$ (μSS) & $\mu^\pm\mu^\mp$ (μOS).
  - Dirac-like HNL $\hat{=}\mu$OS.
  - Majorana-like HNL $\hat{=}\mu\text{SS} + \mu\text{OS}$.
- Bump hunt simultaneously in all reconstruction categories.





Results of HNLs in *B*-decays

NEW arXiv:2512.14551

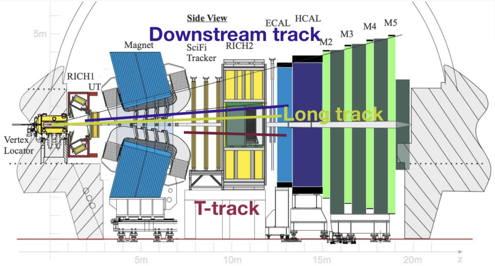


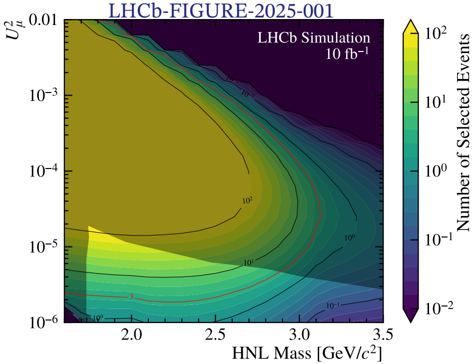
Order of magnitude improvement with respect to LHCb's Run 1 result.

How to improve?

- Upgrade I of LHCb detector: example of capability of fully software based trigger.
- Use large Run 3 dataset: collected 2.5×Run 1+2 dataset at $\sqrt{s} = 13.6\,\text{TeV}$ and pile-up increase of factor ~ 5.
- T-tracks: $\text{FD}(z) \in [2.5, 8]\text{m}$.
- Extend to $N \to \mu^- \pi^+ X$, $N \to \mu^- e^+ \nu_e$ & $N \to \mu^- \mu^+ \nu_\mu$.

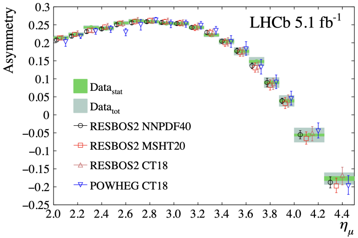
Suggests promising prospects for HNL searches.

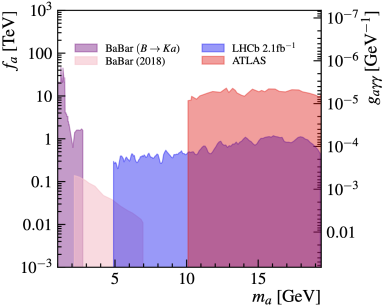




Conclusion

- LHCb provide stringent probes of electroweak precision measurements and NP searches.
- Improvement of b-tagging efficiencies using new DeepJet-like algorithm will impact large range of analyses.
- New analysis strategies are explored, as for example the model-independent m_W extraction and the exploitation of fully neutral final-state.
- New tracking strategies can enhance sensitivity of long-lived particles.





Appendix

LHCb detector in Run 3

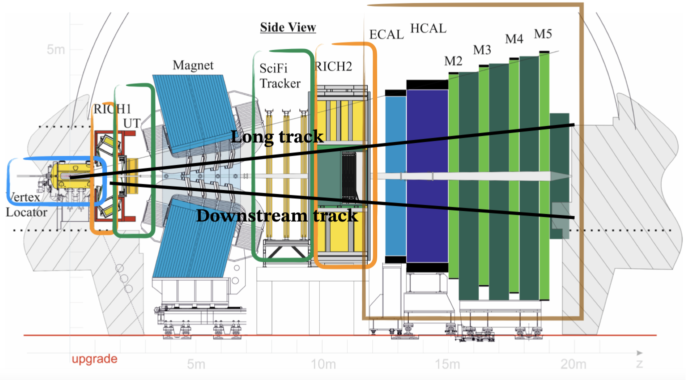
Increased instantaneous luminosity (pile-up ≈ 6).

New Vertex detector

New Particle Identification detector

New tracking system

New read-out



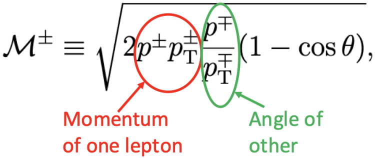
Removal of hardware trigger ⇒ Fully software-based trigger.

- Reconstruction of **all charged** particles.
- Potential for trigger on tracks starting outside of vertex detector ("downstream") ⇒ Advantageous for **long-lived** particles.

Momentum calibration for m_Z measurement

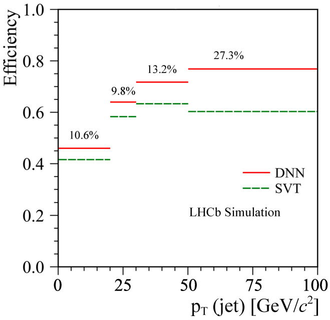
- Charge-dependent curvature bias originating from tracker misalignment.
- Correct data via pseudomass using $Z \to \mu^+\mu^-$ decays without assumption on mass.
- Extraction of relative shift of $\mathcal{M}^+$ to $\mathcal{M}^-$.
- Z resolution improves by $\mathcal{O}(20\%)$.

$$\mathcal{M}^{\pm} \equiv \sqrt{2p^{\pm}p_{\mathrm{T}}^{\pm}\frac{p^{\mp}}{p_{\mathrm{T}}^{\mp}}(1-\cos\theta)},$$

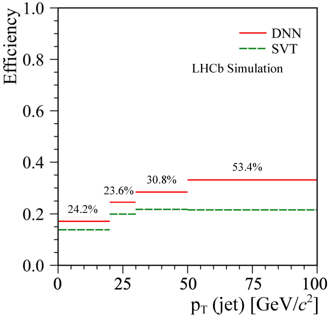


- $\Upsilon \to \mu^+\mu^-$ decays for further momentum scale calibration, including Time-varying momentum scale in data, and simulation corrections of η/ϕ variations and momentum smearing.

DeepJet-like algorithm



- Around 400 jet observables, related to jet constituents and jet substructure.
- Multiclass DNN providing b-, c- and light-jet probability.
- Significant improvement of b- (top) and c-tagging efficiency (bottom) with respect of secondary vertex tagging.
- Applied to inclusive search [including improvement of jet-energy resolution] for $H \to b\bar{b}$ and $H \to c\bar{c}$ in 2016 dataset and extrapolation to future prospects in arXiv:2601.16802.



	σ_{UP}/σ_{SM} 2016, 1.6 fb^{-1}	σ_{UP}/σ_{SM} Runs 1-4, 50 fb^{-1}	σ_{UP}/σ_{SM} Runs 1-5, 300 fb^{-1}
$H \to b\bar{b}$	11.1	1.1	0.38
$H \to c\bar{c}$	1834	141	45