Study of $B \to D +$ anything at Belle II

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November 18, 2026

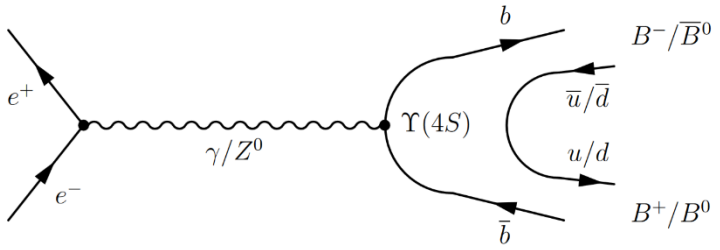


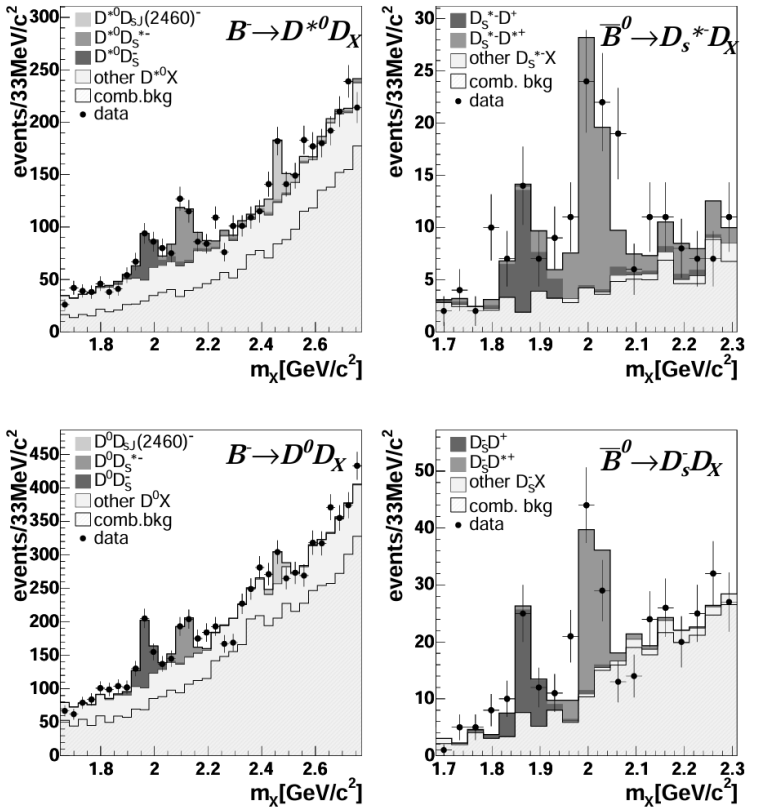
Outline

- Motivation
- Data sets
- Event selection
- Background study
- Data - MC Comparison
- Signal extraction and efficiency
- Summary

Motivation

- Physics goal：
  - We plan to study the states in the recoil mass system X, in B → D + anything decays, and measure the branching fractions of the corresponding B decays.
- FOCUS in BABAR PRD 74, 031103 (2006) : measured $B^- \to D_0 D_s^-$, $D_0 D_s^{*-}$, $D_0 D_{sJ}(2460)^-$ (210 fb^{-1})
  - Previous branching fractions uncertainties: 25-50%
    - $\mathcal{B}(B^- \to D_0 D_s^-) = (0.92 \pm 0.14 \pm 0.18)\%$
    - $\mathcal{B}(B^- \to D_0 D_s^{*-}) = (0.77 \pm 0.15 \pm 0.12)\%$
    - $\mathcal{B}(B^- \to D_0 D_{sJ}(2460)^-) = (0.43 \pm 0.16 \pm 0.13)\%$
- Belle (II) advantage
  - Much larger data + FEI hadronic tag + inclusive recoil-mass method
- Belle II $B^- \to D^0 \rho(770)^-$ measurement already improved precision > 2x with the previous world average --PRD 109, L111103 (2024)
  an important FEI hadronic tag channel





PRD 74, 031103 (2006)

Data sets

- **Software environment:**
  - BASF2 release: light-2609-luna / release-09-00-20
- **Generic MC and Data samples:**
  - **RUN 1 MC16rd and data at $\Upsilon(4S)$ with FEI skim**
  - **GRID (error), partial generic MC downloaded locally for offline analysis**
  - **MC:** /belle/collection/MC/S16_MC16rd-proc16_4S_BB_skim_11180500_v8…
  - **Data:** /belle/collection/Data/S16_proc16_4S_skim_ 11180500 _v8

We should keep the analysis blind. But for training, we looked at a subset of the data to better understand the physics.

Signal MC sample:

- Dedicated MC samples of $B^- \to D^0 D_s^-$ are generated locally to validate the reconstruction procedure.
- In the following study, truth-matched signal candidates are used as the signal MC.

Event selection: Dedicated MC and Selection script

一、粒子重建

```
# ============================================
# Variables
# ============================================
var.addAlias('Lkpi', 'binaryPID(321,211)')
var.addAlias('Lpik', 'binaryPID(211,321)')
# Truth information of the D0 itself.
truth_vars = [
    'mcPDG',
    'mcE',
    'mcP',
    'mcPT',
    'mcPX',
    'mcPY',
    'mcPZ',
    'mcPhi',
    'genParticleID',
    'genMotherPDG',
    'genMotherID',
]
```

$$\frac{\mathcal{L}_K}{\mathcal{L}_K + \mathcal{L}_\pi}$$

```
ma.fillParticleList(
    'pi+:loose',
    cut=track_cut + ' and Lpik > 0.6',
    path=my_path,
)

ma.fillParticleList(
    'K+:loose',
    cut=track_cut + ' and Lkpi > 0.6',
    path=my_path,
)
```

利用binaryPID帮助我们鉴别粒子，变量定义可以从software中查到。其他官方变量都可以这样查到，或者问师兄师姐👍(不知道变量名字的时候)。

binaryPID(*pdgCode1, pdgCode2*) [source]

Returns the binary probability for the first provided mass hypothesis with respect to the second mass hypothesis using all detector components

Event selection: Dedicated MC and Selection script

```
# ============================================================
# 3. Reconstructed final-state particles
# ============================================================

track_cut = (
    'pt > 0.1'
    ' and abs(dz) < 2.0'
    ' and abs(dr) < 0.5'
)

ma.fillParticleList(
    'pi+:loose',
    cut=track_cut + ' and Lpik > 0.6',
    path=my_path,
)

ma.fillParticleList(
    'K+:loose',
    cut=track_cut + ' and Lkpi > 0.6',
    path=my_path,
)
```

确保径迹来自IP并且能飞到CDC

填充末态粒子的函数，使用方法可在software网站查询到：

（其他函数都可以这样查到或者问师兄师姐 👍）

modularAnalysis.fillParticleList(*decayString*, *cut*, *writeOut=False*, *path=None*, *enforceFitHypothesis=False*, *loadPhotonsFromKLM=False*) [source]

Creates Particles of the desired type from the corresponding `mdst` dataobjects, loads them to the StoreArray<Particle> and fills the ParticleList.

```
# ============================================================
# 4. Reconstruct D0 -> K- pi+ and charge conjugate
# ============================================================

ma.reconstructDecay(
    'D0:Kpi -> K-:loose pi+:loose',
    cut='1.7 < M < 2.0',
    chargeConjugation=True,
    path=my_path,
)

ma.matchMCTruth(
    'D0:Kpi',
    path=my_path,
)
```

按照衰变链，对复合粒子D^0进行重建，并且加入对应的cut条件，再进行truth-match。

函数使用方法同样可以在software网站查到

Event selection: Dedicated MC and Selection script

```
# Reconstructed D0 information, together with its truth.
reco_D0_vars = [
    'PDG',
    'M',
    'E',
    'p',
    'pt',
    'px',
    'py',
    'pz',
    'theta',
    'phi',
    'isSignal',
    'mcErrors',
] + truth_vars

# Reconstructed daughter information, together with its truth.
daughter_reco_vars = [
    'PDG',
    'charge',
    'E',
    'p',
    'pt',
    'px',
    'py',
    'pz',
    'theta',
    'phi',
    'dr',
    'dz',
    'kaonID',
    'pionID',
    'isSignal',
    'mcErrors',
    'Lpik',
    'Lkpi',
] + daughter_truth_vars
```

根据需要确定重建变量

二、保存重建的变量

根据需要保存的复合粒子和末态粒子的变量确定变量列表，可将变量名根据子粒子类型改写名字，便于记忆。

```
reco_vars = (
    reco_D0_vars
    + create_aliases(
        daughter_reco_vars,
        'daughter(0,{variable})',
        'K',
    )
    + create_aliases(
        daughter_reco_vars,
        'daughter(1,{variable})',
        'pi',
    )
)
```

前缀K，便于命名管理

Event selection: Dedicated MC and Selection script

```
# ================================================================
# 5. All reconstructed candidates, including background
# ================================================================

ma.variablesToNtuple(
    'D0:Kpi',
    reco_vars,
    treename='D0_reco',
    filename=OUTPUT_FILE,
    path=my_path,
)


# ================================================================
# Process
# ================================================================

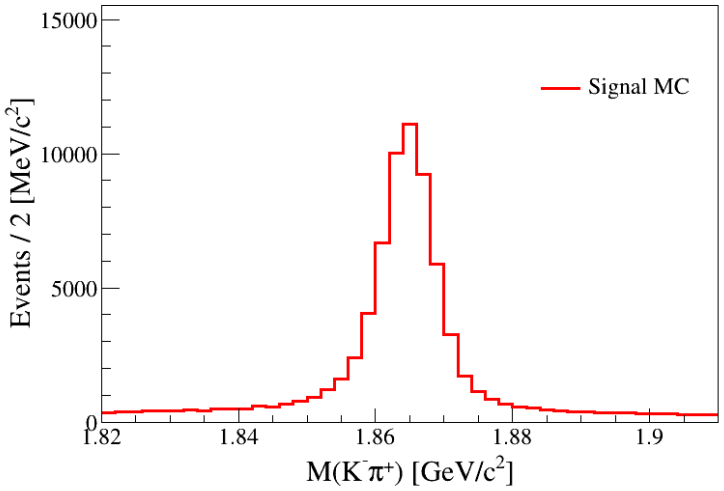
b2.process(my_path)  # 读取整个输入文件
print(b2.statistics)
```

这里将定义好的粒子变量reco_vars存储到D0:Kpi列表中, tree命名为“D0_reco”

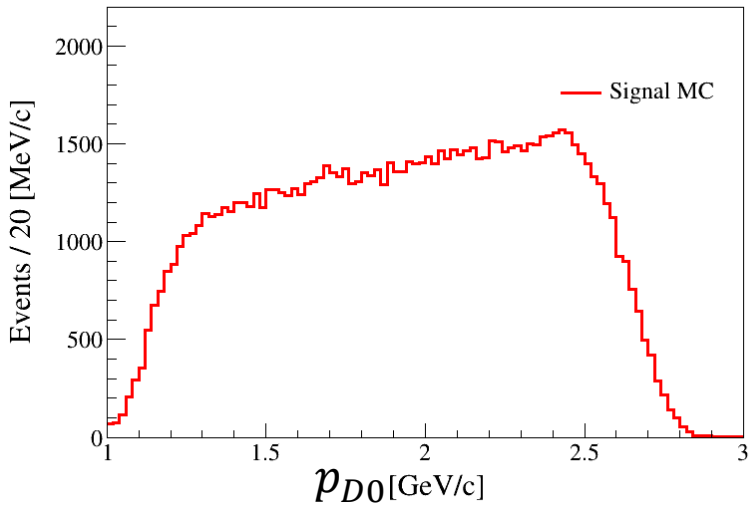
未来研究其它衰变道，我们将用这样的方法自行查阅网站、编写代码、进行分析。

Event selection: Dedicated MC and Selection script

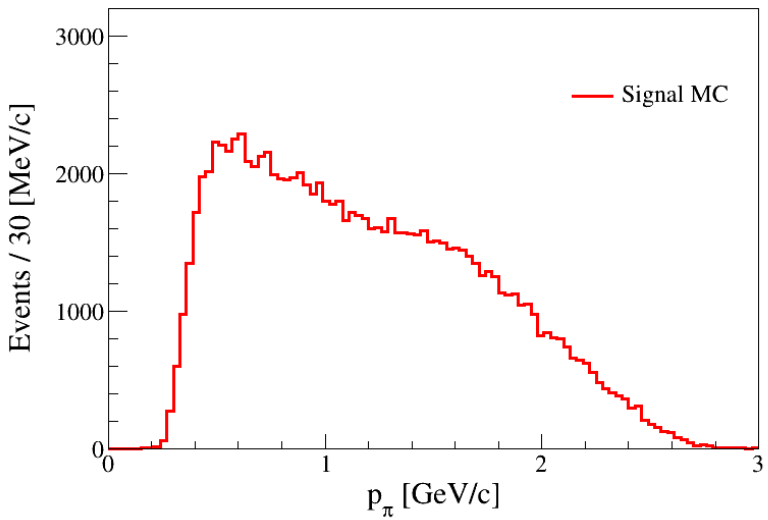
➢ Distributions of Three Key Variables in $B^- \to D^0 D_s^-$



D^0候选者的不变质量



D^0候选者的动量分布



带电pion的动量分布

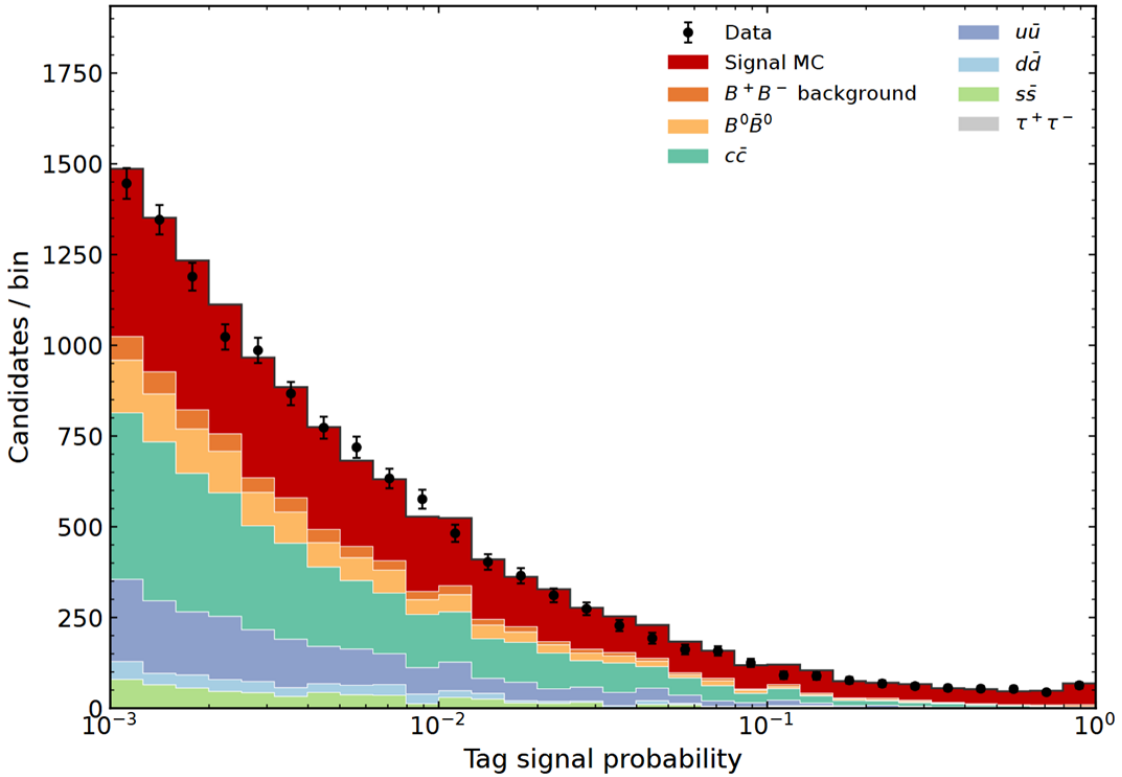
➢ 我们的研究过程是B →D+X，X是anything，我们采用generic MC中truth匹配的signal事件作为signal MC。并且另一侧B使用FEI进行挑选，然后反冲得到X的不变质量分布。

Event selection (preliminary)

- **Track and PID**
  - Track: $|dr| < 0.5$cm, $|dz| < 2$cm, pT $>$0.1 GeV/c
  - PID: $\frac{\mathcal{L}(\pi)}{\mathcal{L}(\pi)+\mathcal{L}(k)} > 0.6$ for π; $\frac{\mathcal{L}(k)}{\mathcal{L}(\pi)+\mathcal{L}(k)} > 0.6$ for K
- **Tag side B — FEI**
  - FEI SignalProbability > 0.001
  - Tag B window: M_{bc} > 5.2 GeV/c², $|\Delta E| <$ 0.3 GeV
- **Signal side: $D^0 \to k^-\pi^+$**
  - Build in rest of event.
  - D^0 mass window: $\left|M(k^-\pi^+) - m(D^0)\right| < 0.012\text{GeV/c}^2$
- **Observable:**
  - Recoil mass: $m_x^2 = (P_{\Upsilon(4s)} - P_{B_{tag}} - P_{D_0})^2$

Event selection (preliminary)

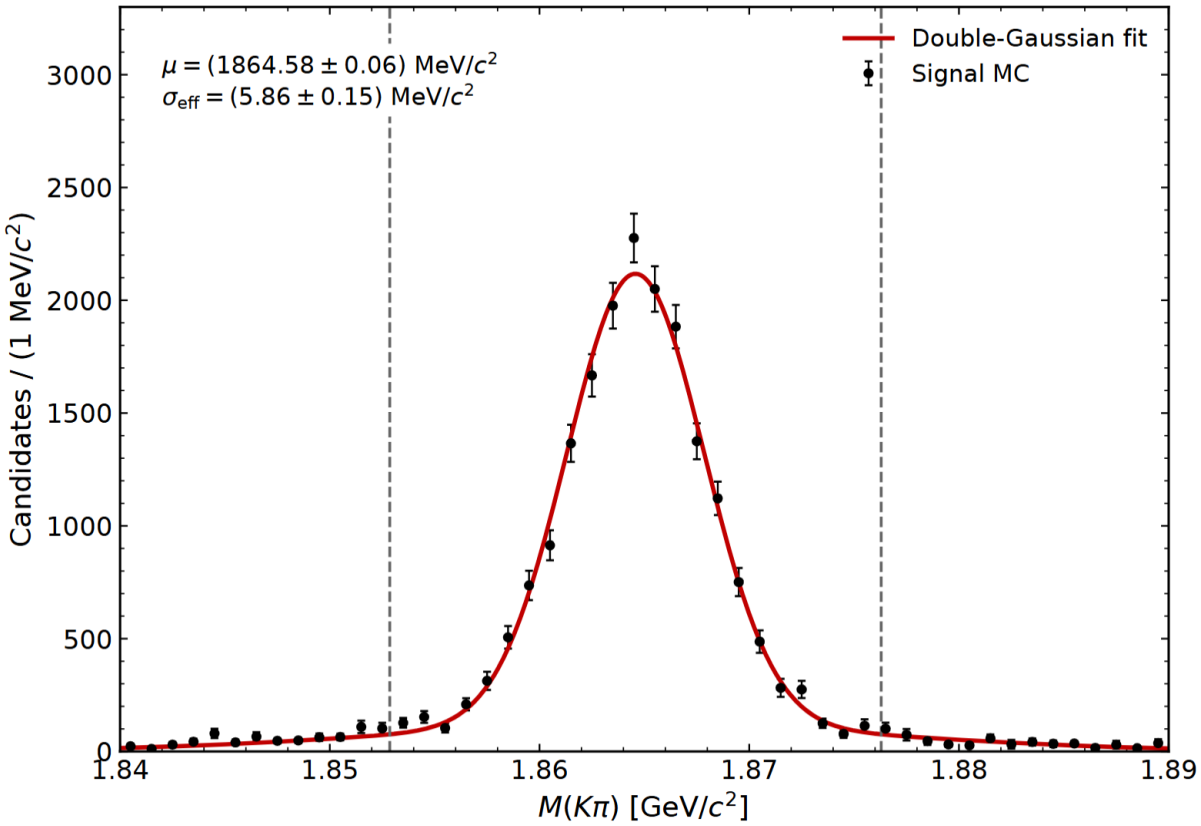
- Signal probability:



we already require the FEI signal probabilityto be above 10^{-3}in our script.

Event selection (preliminary)

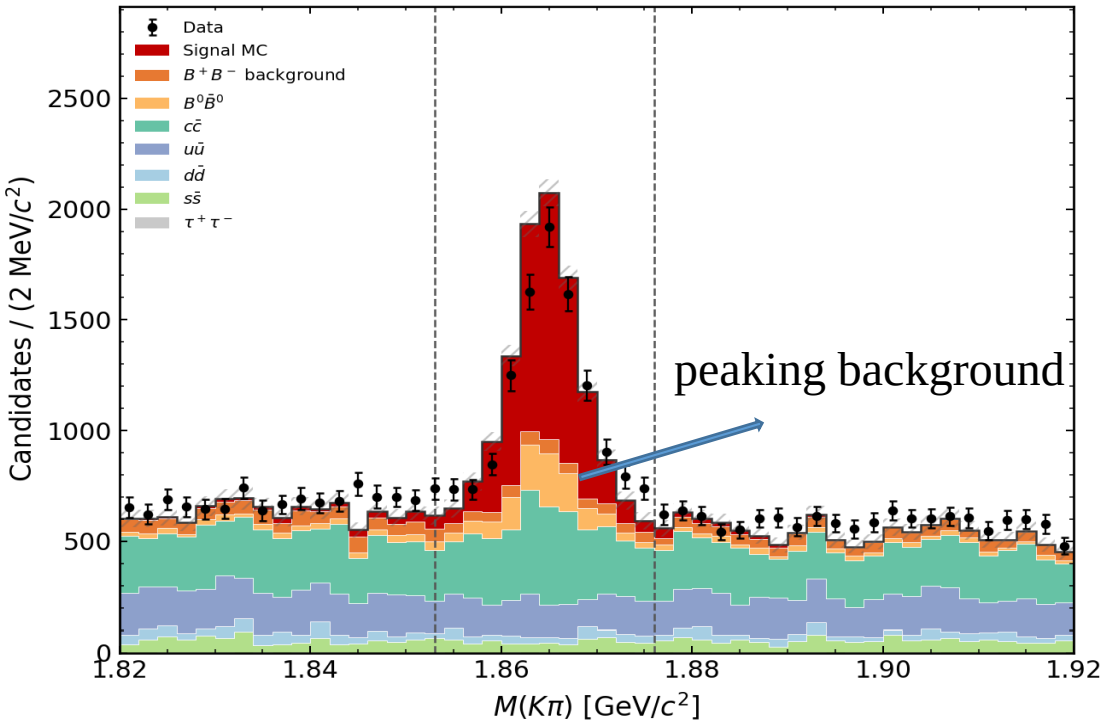
- D^0signal region: [1.853,1.876] Gev/c^2 , covering $\pm 2\sigma$ around the fitted D^0 mass.



Fitted to truth-matched signal events with a double Gaussian to determine the signal window.

Background study

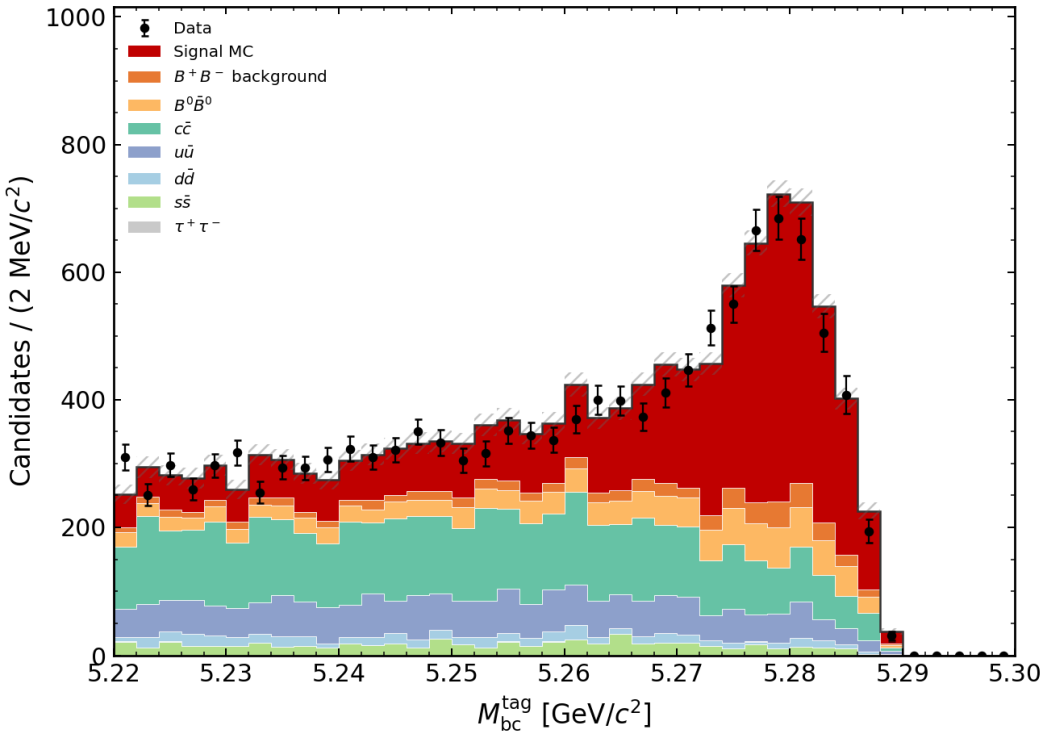
- Distributions of reconstructed D^0

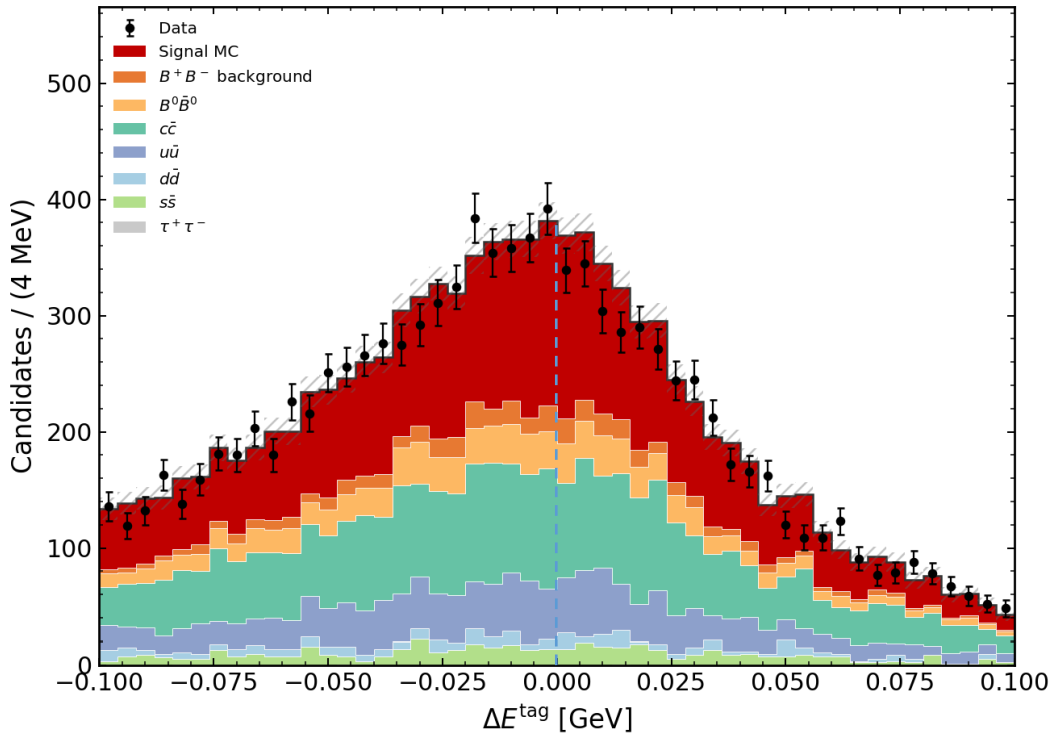


- A potential shift in the D^0 mass peak (maybe limited statistics) and some peaking background. Due to lack of time, the peaking background has not been further investigated.

Data – MC Comparison

- Distributions of Tag B

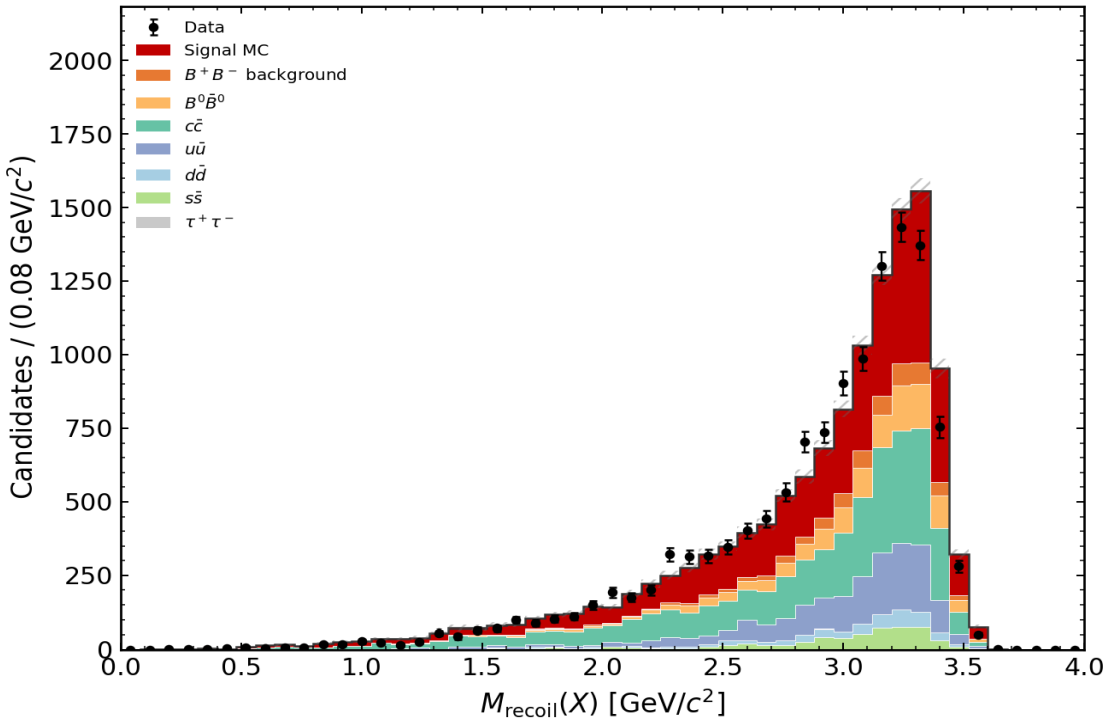




- The distributions $M_{\rm bc}^{\rm tag}$(left) and $\Delta E^{\rm tag}$(right) show a good agreement between data and MC simulation.

Data – MC Comparison

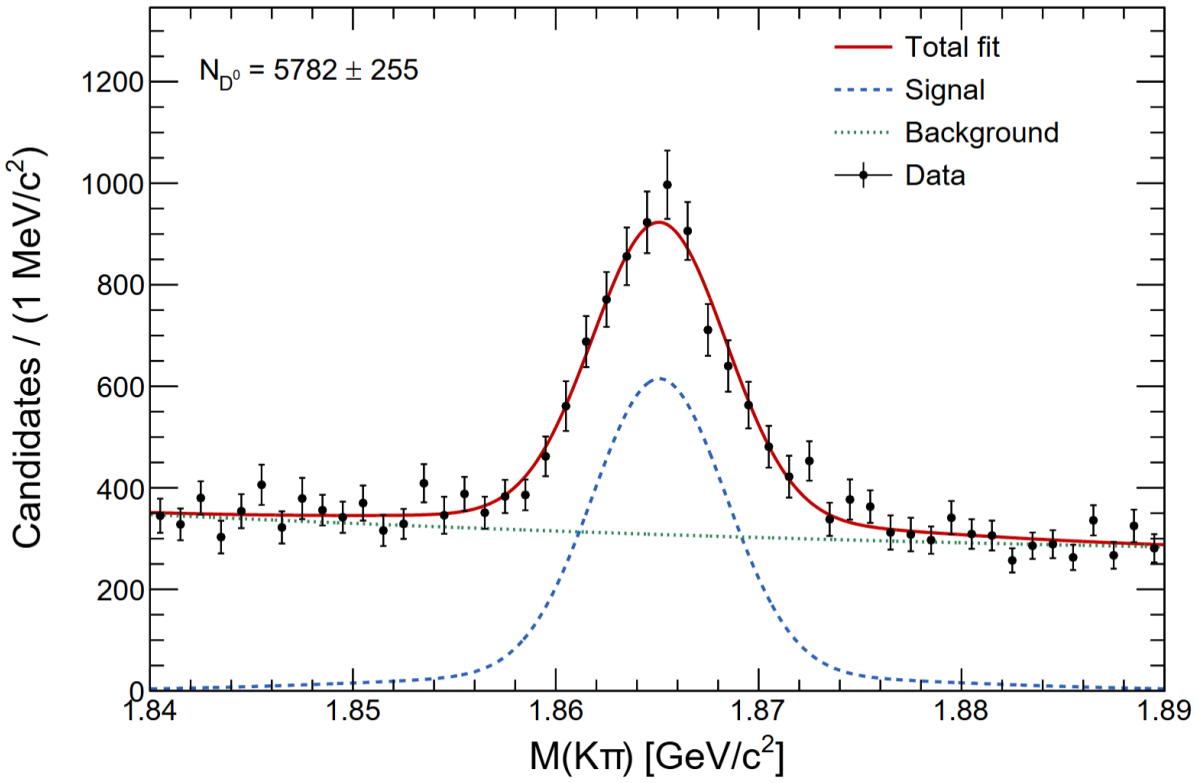
- The distribution of recoiled mass.



- With the current statistics, the D_s^-, D_s^{*-}, and $D_{sJ}(2460)^-$peaks cannot be clearly observed in the recoil-mass spectrum.

Signal extraction and efficiency

- We fit the $M(K\pi)$ distribution to extract the signal yield, using a Gaussian-convolved signal PDF and a Chebyshev polynomial to model the background.



- We have no efficiency estimation due to lack of full signal MC samples.

Summary

- We learned how to generate the signal MC, build the analysis scripts from scratch, use online tools (https://software.belle2.org/, in back-up), and submit GRID jobs.

- Due to the GRID issue, we downloaded FEI-skim data and performed the event selection locally. The limited sample size prevented us from obtaining a preliminary branching-fraction measurement.

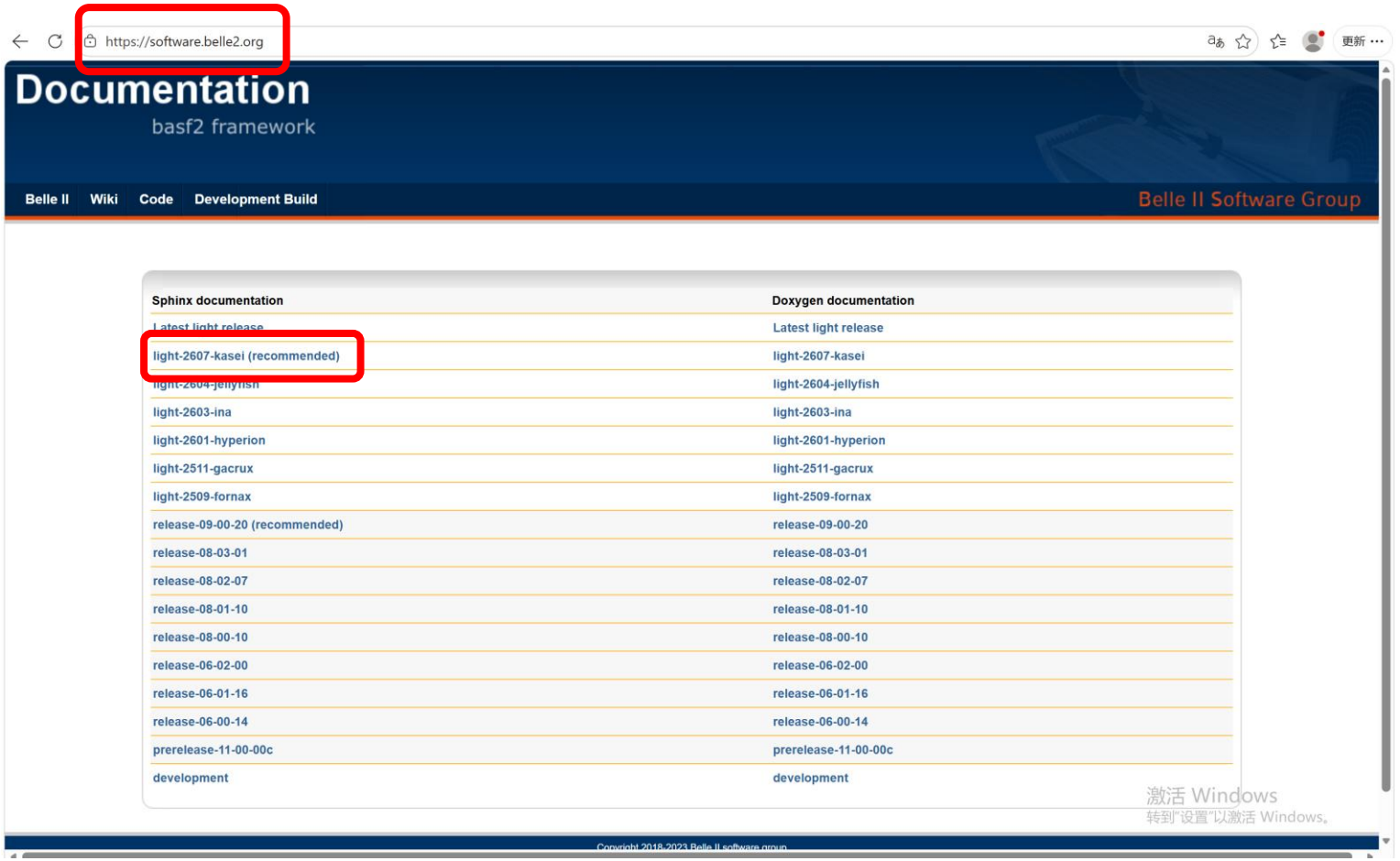
$$\mathcal{B}(B^- \to D^0 X_k) = \frac{N_k^{\text{fit}}}{N_{\text{tag}}\, \varepsilon_k^{\text{eff}}\, \mathcal{B}(D^0 \to K^-\pi^+)}$$

- In the future, we plan to produce the full signal MC samples and determine the efficiencies, enabling us to measure the branching fractions.



Thank you for your attention !

Back up



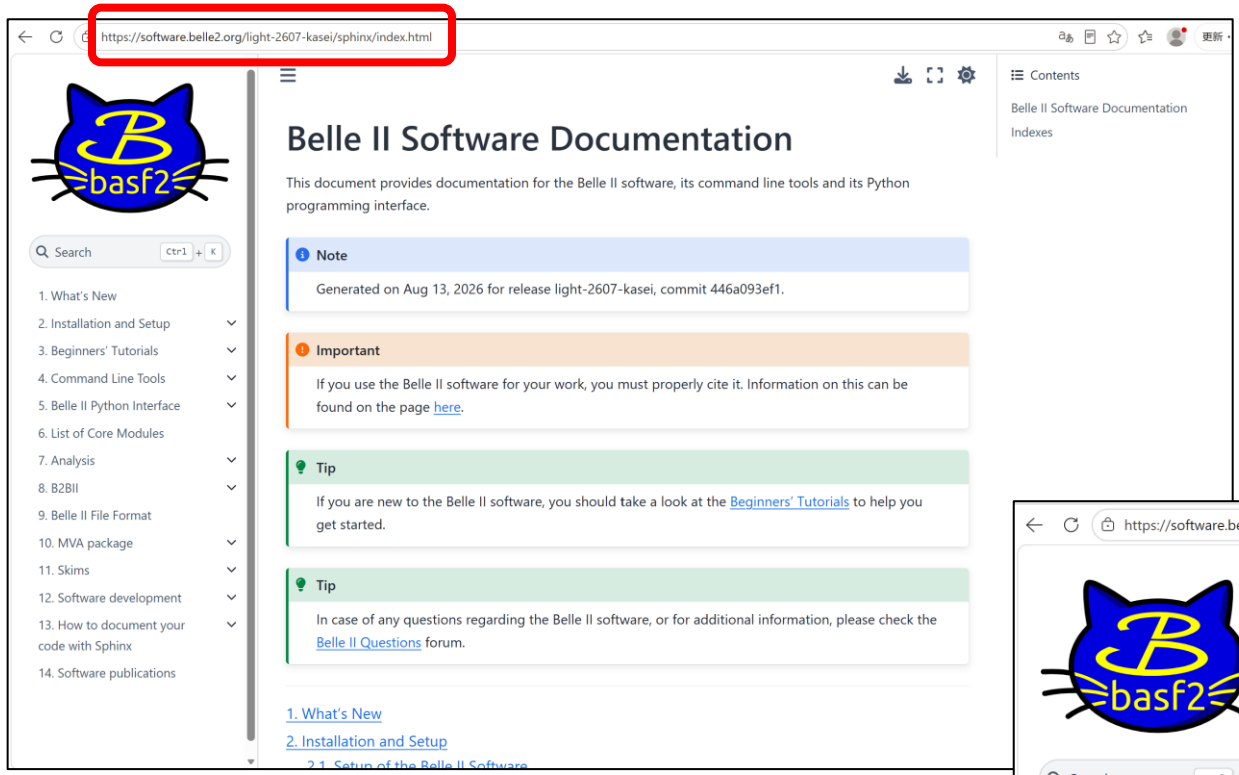
https://software.belle2.org/

可在网页上查找collections路径

（无需连接kek vpn）

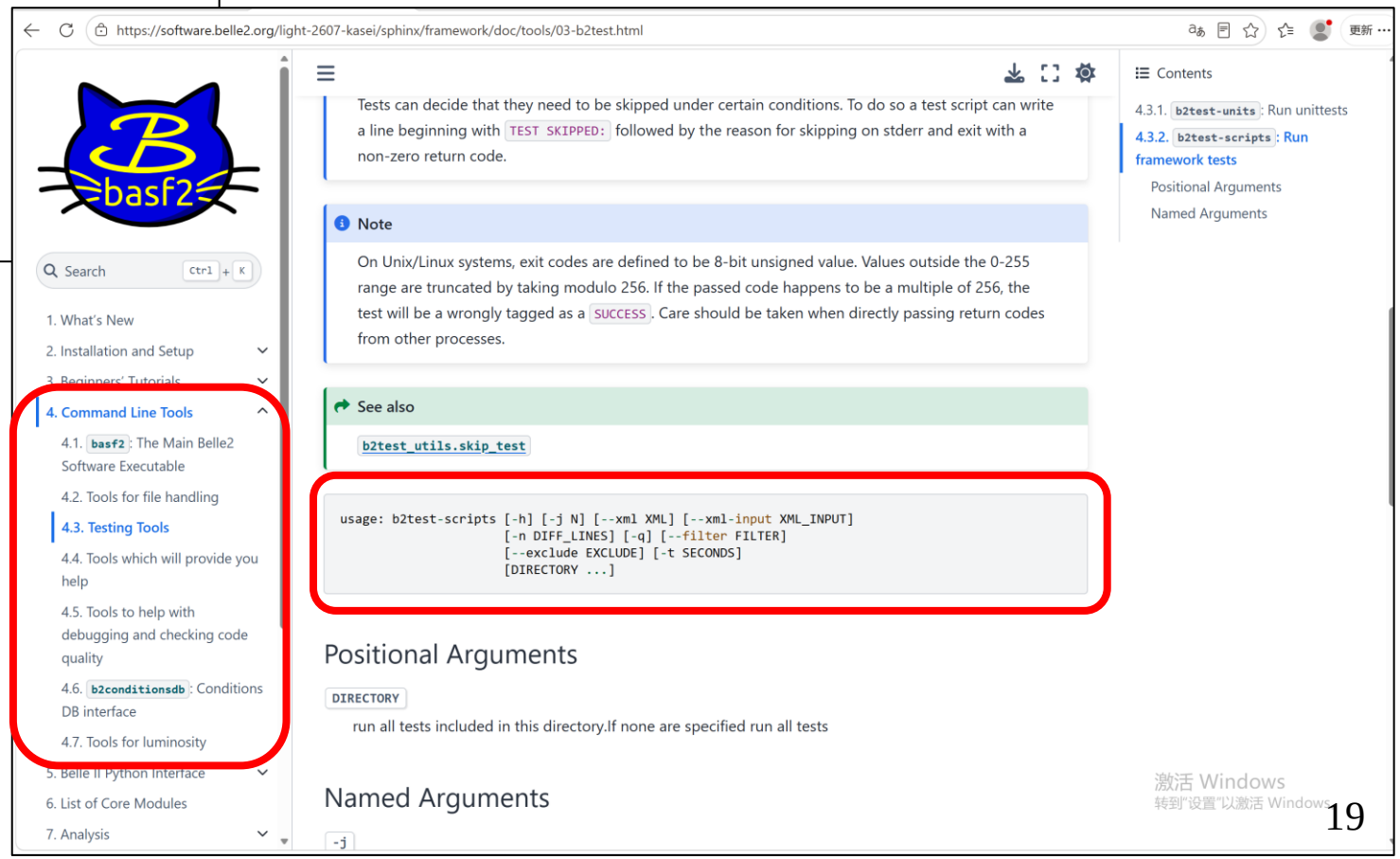
选择最新的 light version 或者 release version

以 light-2607-kasei 为例

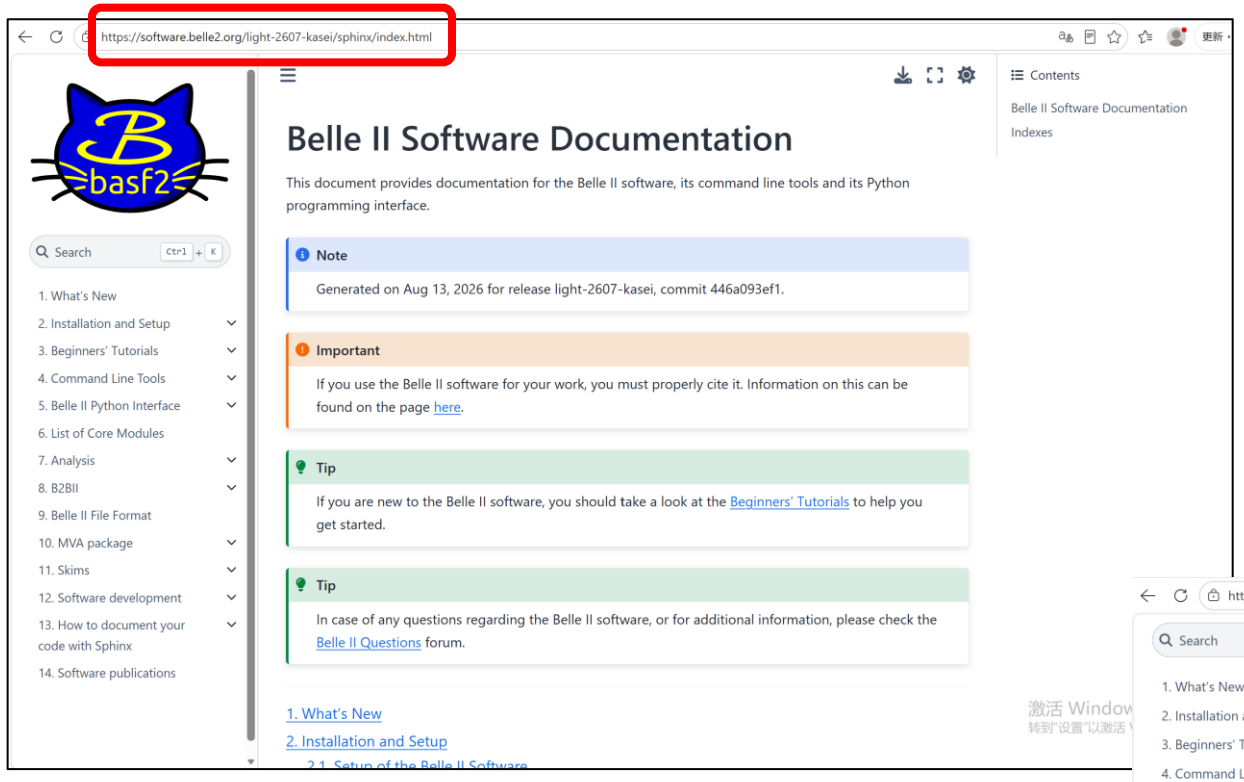


可以直接点击左侧的“Commend Line Tools”

查找需要的命令行

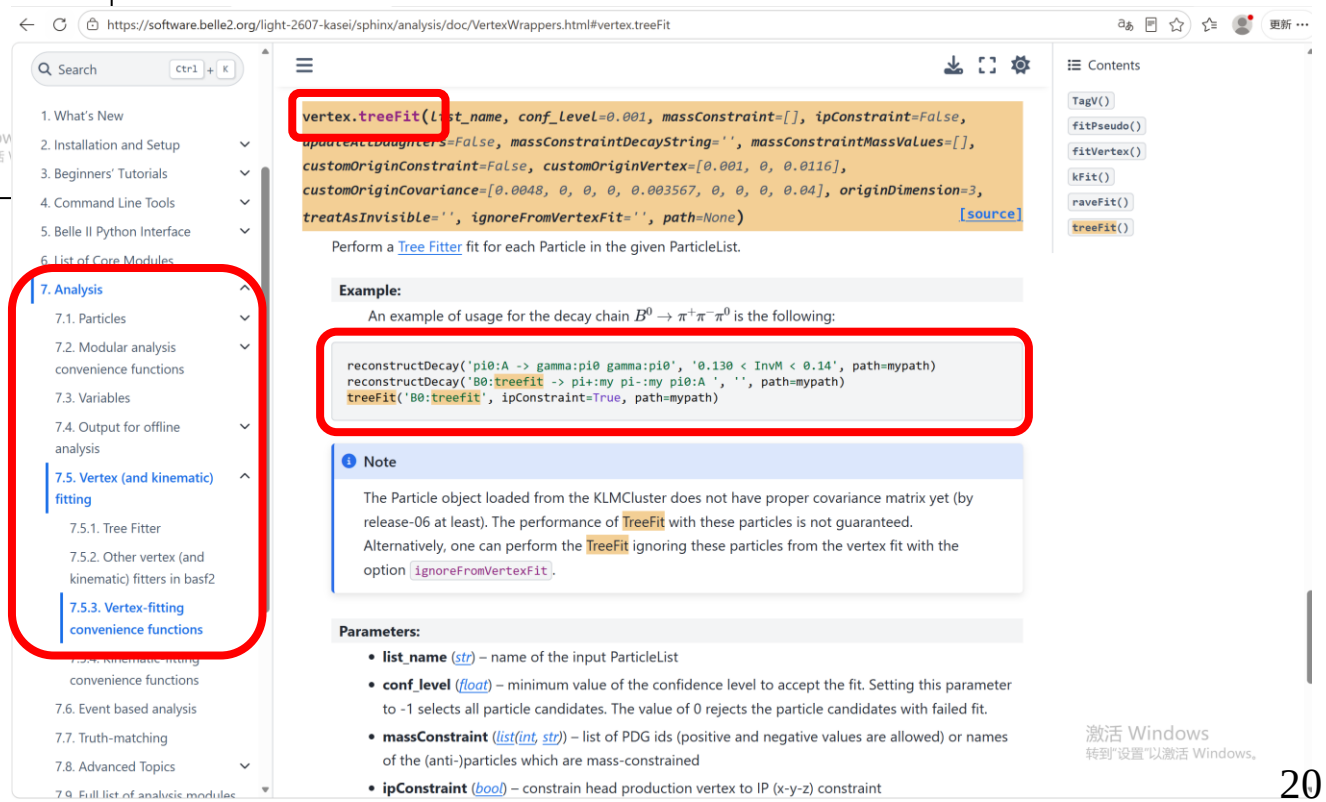


激活 Windows
转到“设置”以激活 Windows。

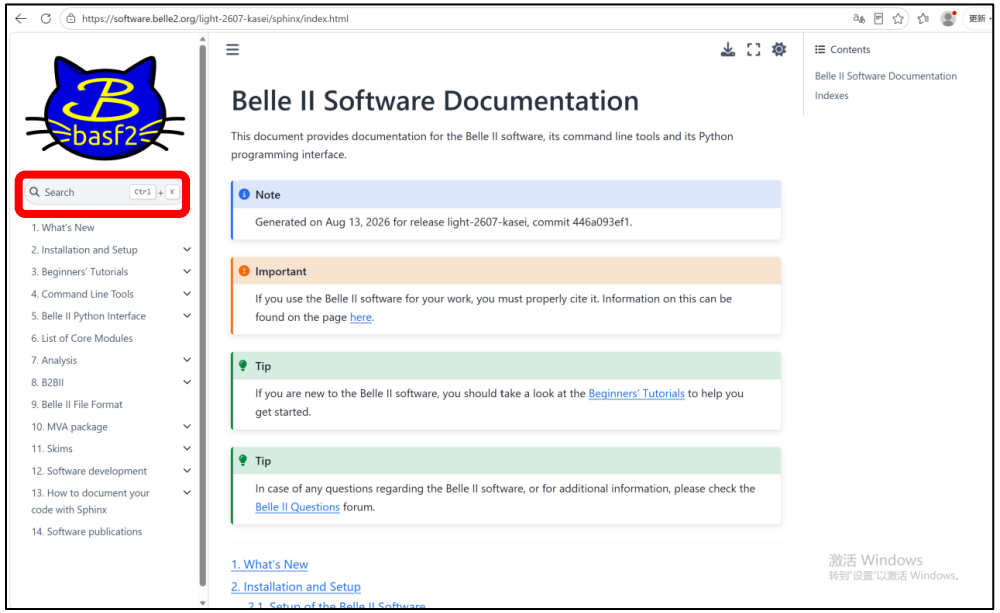


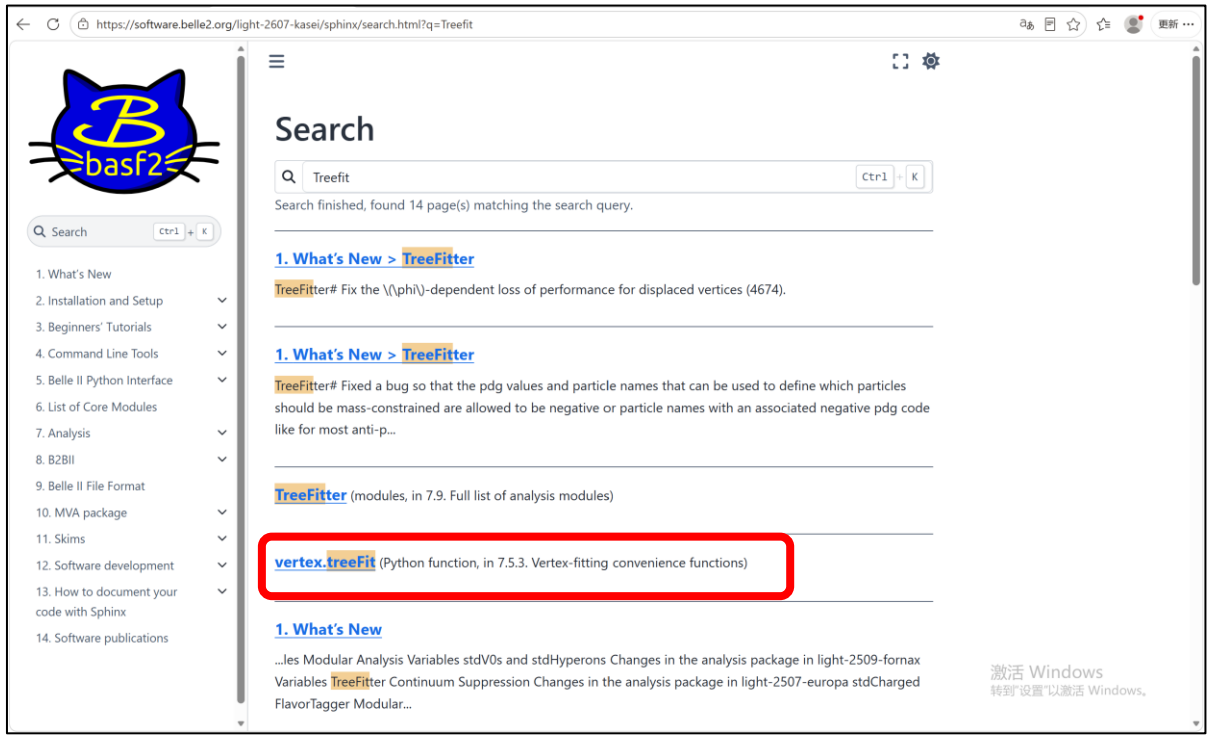
或者点击左侧的目录栏查找需要的知识与信息

以“vertex.treefit”为例



也可以对需要的命令行以及相关信息进行搜索





vertex.treeFit(*list_name*, *conf_level=0.001*, *massConstraint=[]*, *ipConstraint=False*, *updateAllDaughters=False*, *massConstraintDecayString=''*, *massConstraintMassValues=[]*, *customOriginConstraint=False*, *customOriginVertex=[0.001, 0, 0.0116]*, *customOriginCovariance=[0.0048, 0, 0, 0, 0.003567, 0, 0, 0, 0.04]*, *originDimension=3*, *treatAsInvisible=''*, *ignoreFromVertexFit=''*, *path=None*) [source]

Perform a Tree Fitter fit for each Particle in the given ParticleList.

Example:

An example of usage for the decay chain $B^0 \to \pi^+\pi^-\pi^0$ is the following:

```
reconstructDecay('pi0:A -> gamma:pi0 gamma:pi0', '0.130 < InvM < 0.14', path=mypath)
reconstructDecay('B0:treefit -> pi+:my pi-:my pi0:A ', '', path=mypath)
treeFit('B0:treefit', ipConstraint=True, path=mypath)
```

Note

The Particle object loaded from the KLMCluster does not have proper covariance matrix yet (by release-06 at least). The performance of TreeFit with these particles is not guaranteed. Alternatively, one can perform the TreeFit ignoring these particles from the vertex fit with the option `ignoreFromVertexFit`.

Parameters:

- **list_name** (*str*) – name of the input ParticleList
- **conf_level** (*float*) – minimum value of the confidence level to accept the fit. Setting this parameter to -1 selects all particle candidates. The value of 0 rejects the particle candidates with failed fit.
- **massConstraint** (*list(int, str)*) – list of PDG ids (positive and negative values are allowed) or names of the (anti-)particles which are mass-constrained
- **ipConstraint** (*bool*) – constrain head production vertex to IP (x-y-z) constraint

表格

粒子	PDG 质量	备注
D_s^-	**1968.34 ± 0.07 MeV/c²**	基态 $c\bar{s}$ 赝标介子
D_s^{*-}	**2112.2 ± 0.4 MeV/c²**	矢量介子，$D_s^{*-} \to D_s^-\gamma$
$D_{sJ}(2460)^-$	**2459.5 ± 0.6 MeV/c²**	即 $D_{s1}(2460)^-$，$c\bar{s}$ 的 $J^P = 1^+$ P 波激发态

D_s^- 在 $1.968\ \text{GeV}$，　D_s^{*-} 在 $2.112\ \text{GeV}$，　$D_{sJ}(2460)^-$ 在 $2.460\ \text{GeV}$

$$\boxed{M_{\text{bc}} = \sqrt{E_{\text{beam}}^{*2} - |\vec{p}_B^{\,*}|^2}} \qquad \boxed{\Delta E = E_B^* - E_{\text{beam}}^*}$$