Measurement of $B_s \to \phi \nu\nu$

(at CEPC but also applies to FCC-ee)

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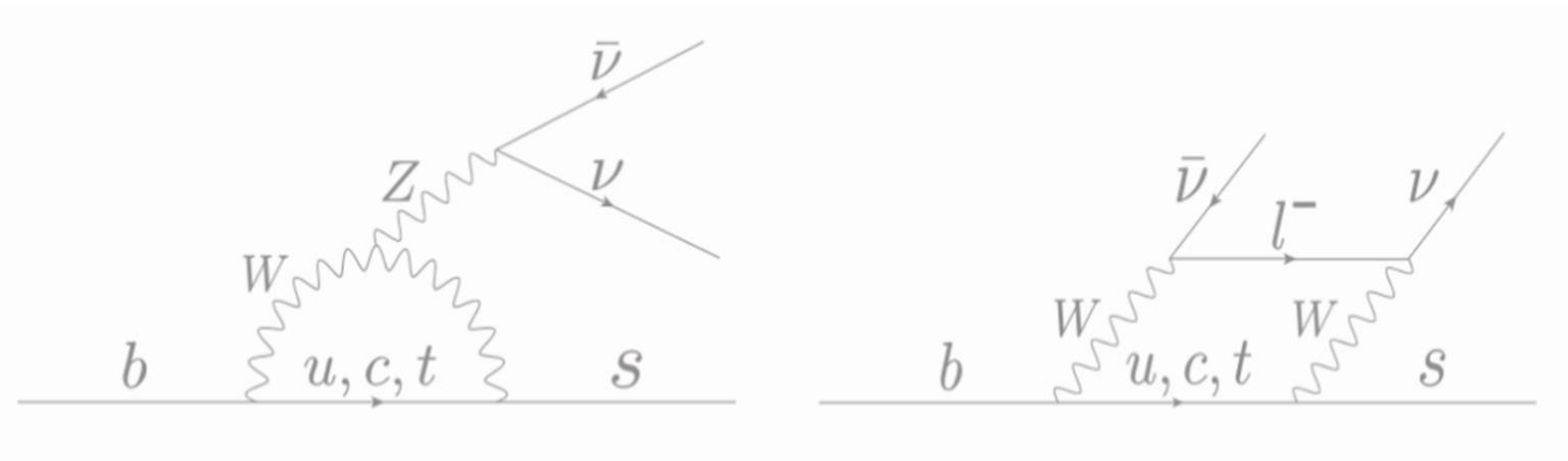
Based on arXiv:2201.07374

With Manqi Ruan, Yudong Wang and Yuexin Wang



May 23, Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022

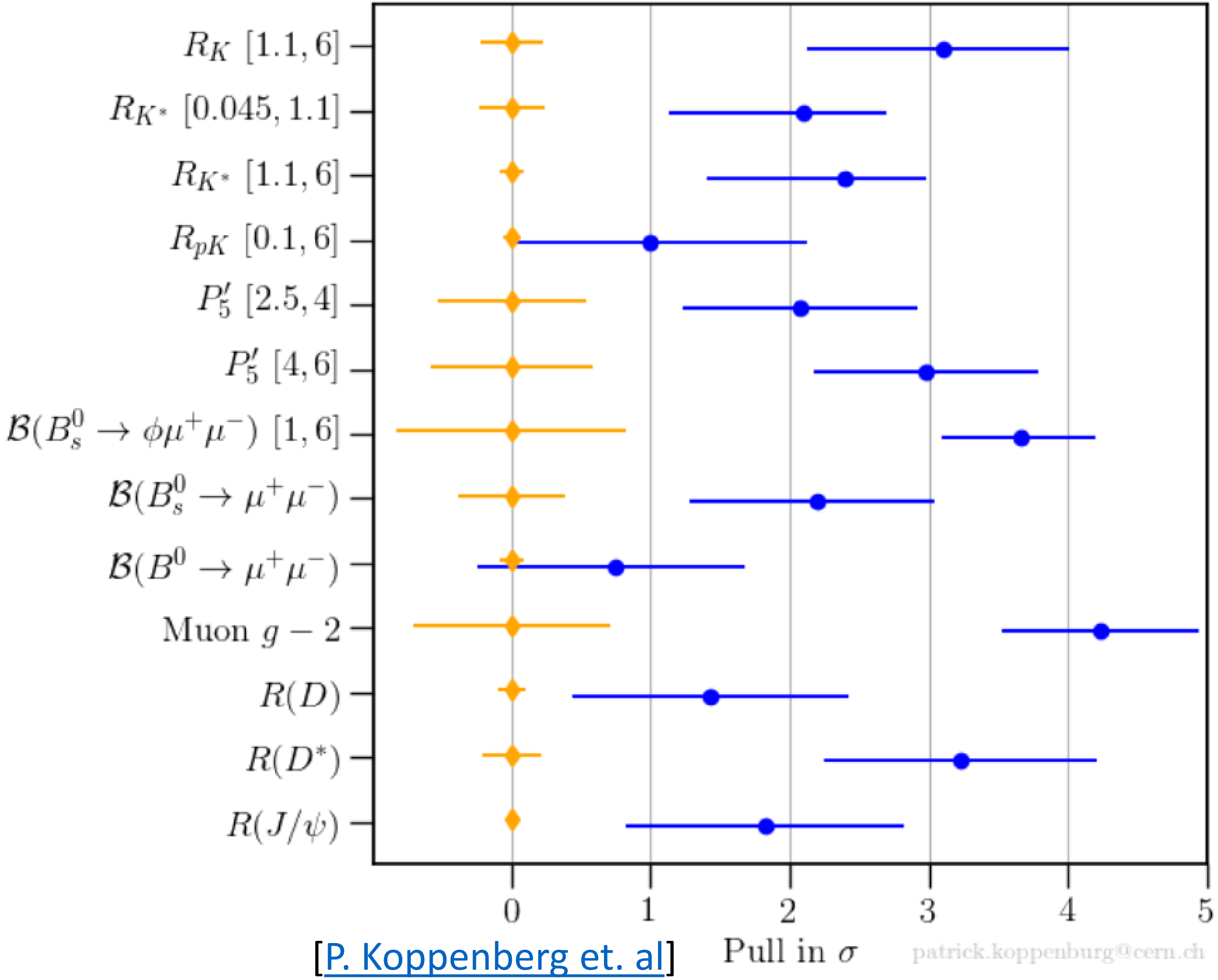
Motivation (I): Flavor Anomalies

A number of recently anomalies in the flavor sector: $R_{K(*)}$, $R_{D(*)}$, $R_{J/\psi}$ … Often indicating lepton flavor universality violation (LFUV).

In charged currents, observed deviations of τ, in neutral currents, only μ deviations are observed.

b -> svv type of decays are crucial for LFUV tests [0902.0160, 1409.4557, 1506.02661, 1706.07808, and many more]

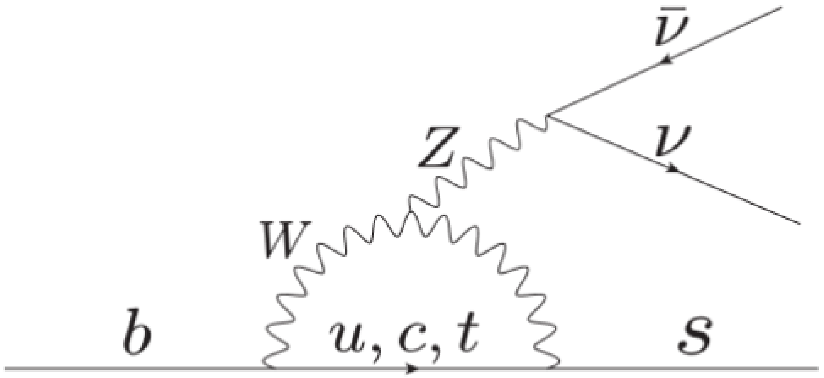
See also Andreas Crivellin's talk

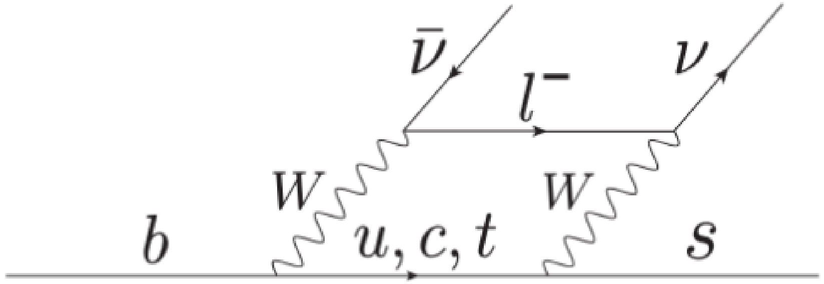


[P. Koppenburg et. al]

Motivation(II): General Perspectives

Imagine testing SM and probing BSM but start with **one-loop electroweak**





$$\mathcal{H}_{\text{eff}} = -\boxed{\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^*} \left(C_L \mathcal{O}_L + C_R \mathcal{O}_R\right) \; + \; \text{h.c.}\,,$$

$$\mathcal{O}_L = \boxed{\frac{e^2}{16\pi^2}} (\bar{s}\gamma_\mu P_L b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu)\,, \qquad \mathcal{O}_R = \boxed{\frac{e^2}{16\pi^2}} (\bar{s}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu)\,.$$

Predictions are also “clean”: neutrinos are non-interactive at low scale, get rid of messy one-loop hadronic/QED corrections.

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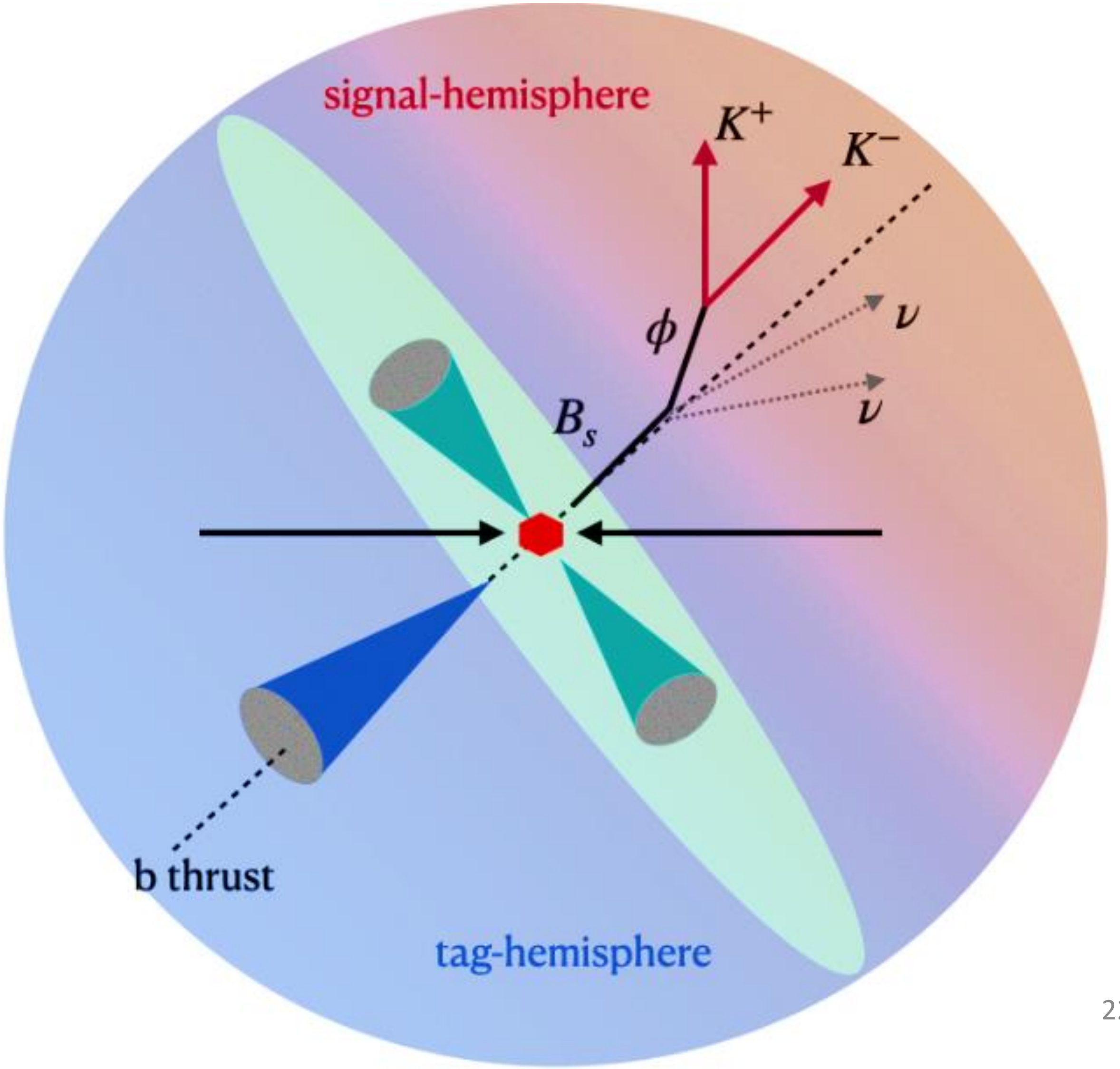
Motivation(III): Z Pole Phenomenology



The current limit (~5.4×10^{-3}) still led by the [LEP result]:

- ➢Significant missing energy: not ideal for hadron colliders.
- ➢Relies on B_s production: limited at B-factories.
- ➢Set a "golden channel" benchmark at the Z pole.

See also [an attempt for B-> K*vv]

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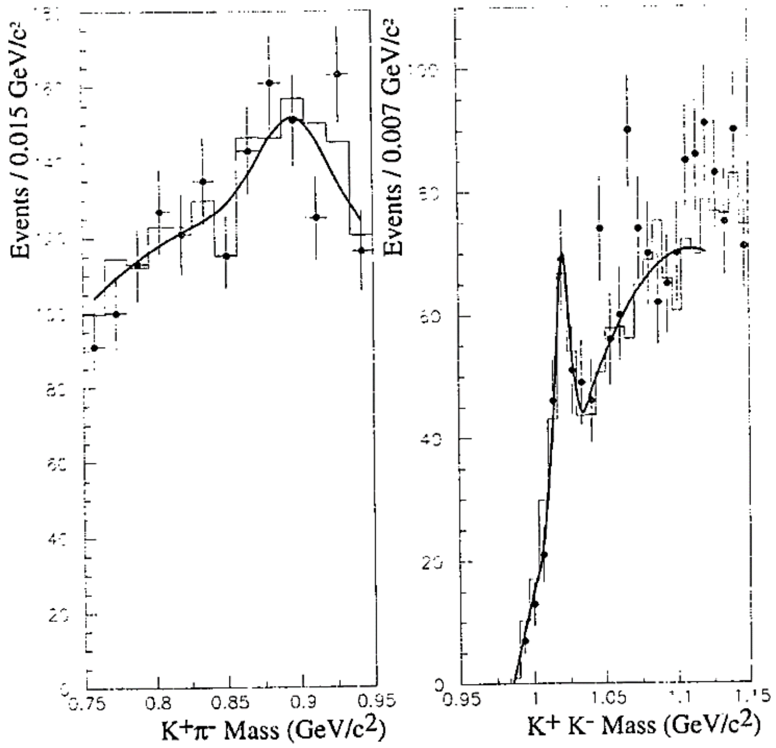
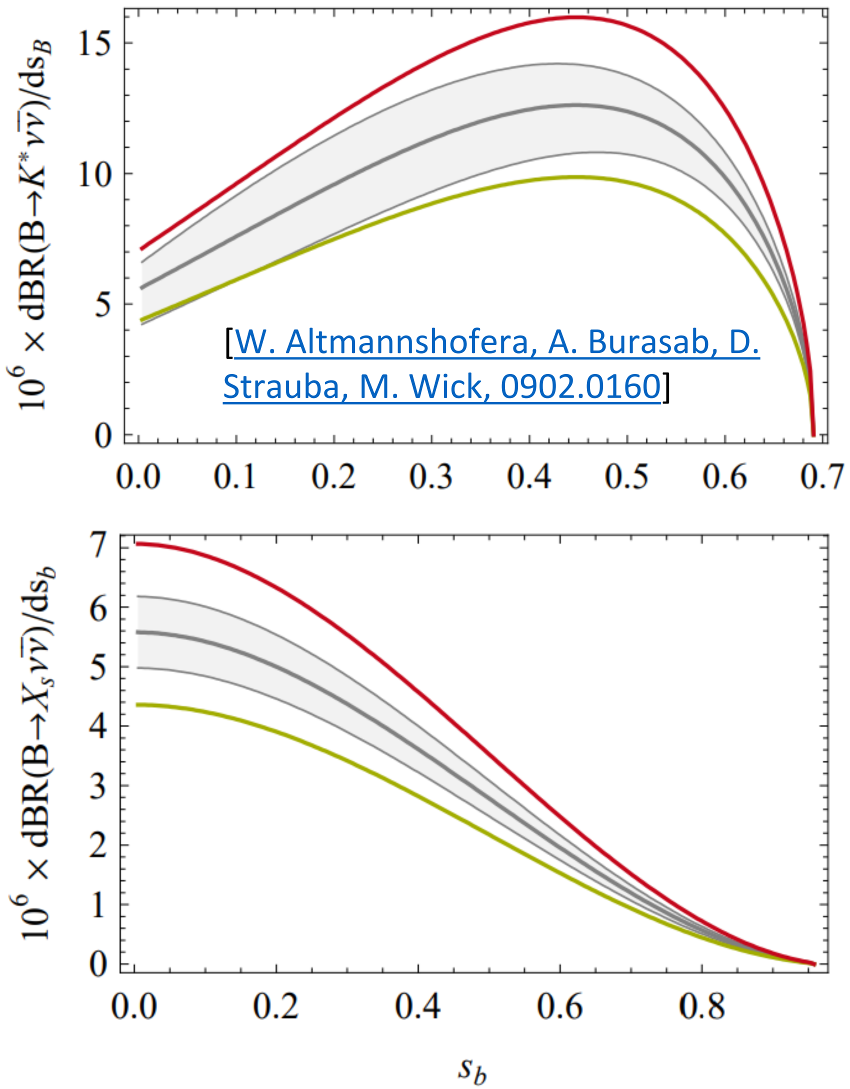
Questions to begin with

Background: would they be significant?
What's their nature?



⬆ The background seems non-negligible in [LEP measurement].

Signal: event rate? Kinematic distribution?



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Quick Answers

Dominant background: $B_{(s)}$->$D_{(s)}$(-> $\phi+X$)+$l\nu$ with the extra lepton/neutrals being soft and untagged.

Signal BR is ~1×10^{-5}, or **3×10^{5} signals** from Tera-Z. Distribution of $q^2 \equiv m^2(\nu\nu)$ calculated from the lattice result [RR. Hogan, Z. Liu, S. Meinel, M Wingate, 1501.00367].

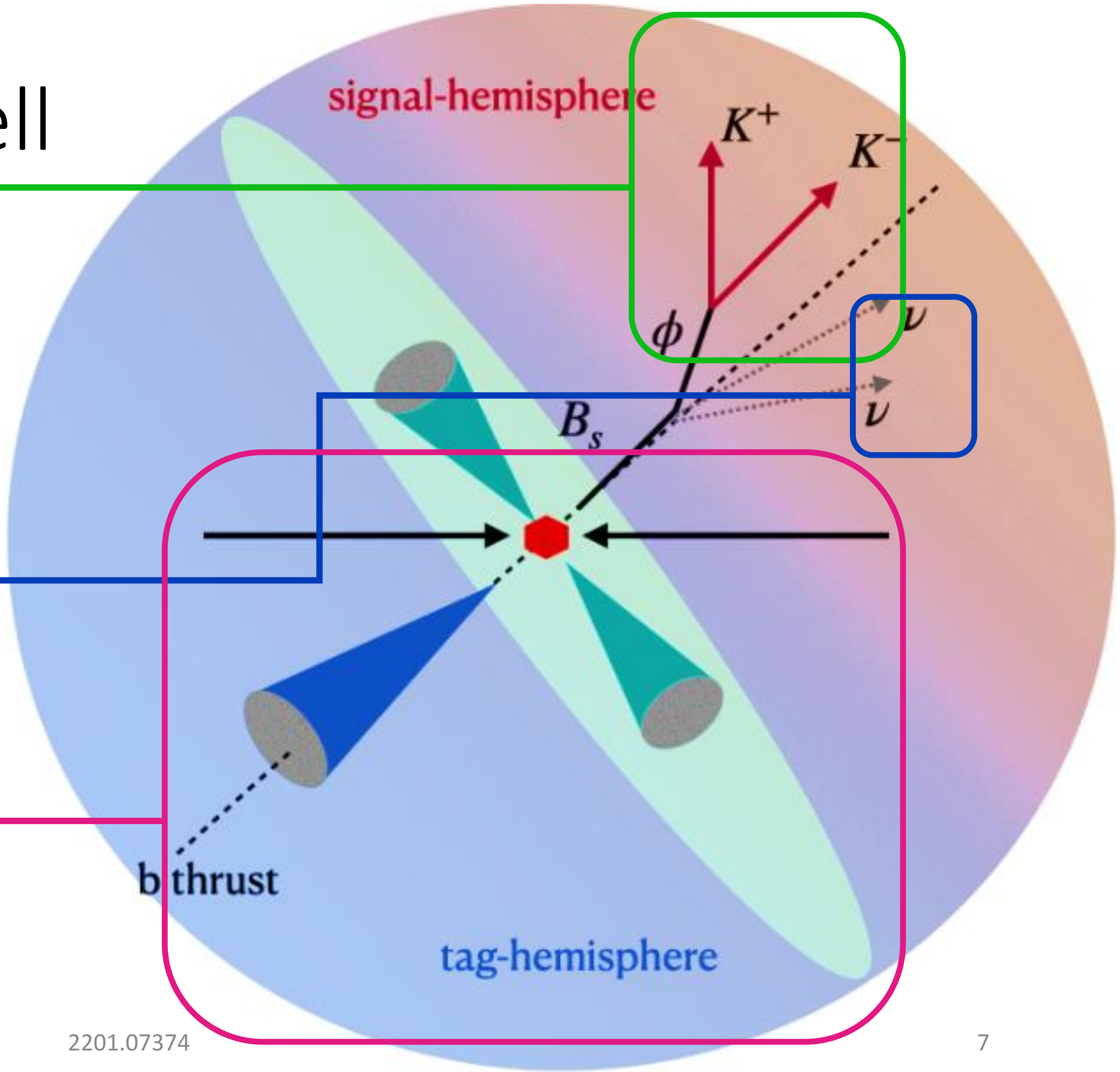
- Lepton identification and event reconstruction is the key.
- To get a reasonable signal-to-background ratio, background rejection must be > **10^{6}**
- Analysis very different from LEP!

Analysis in a Nutshell

Step 1: Find the candidate ϕ

Step 2: Infer the missing momenta correctly

Step 3: Get rid of everything else



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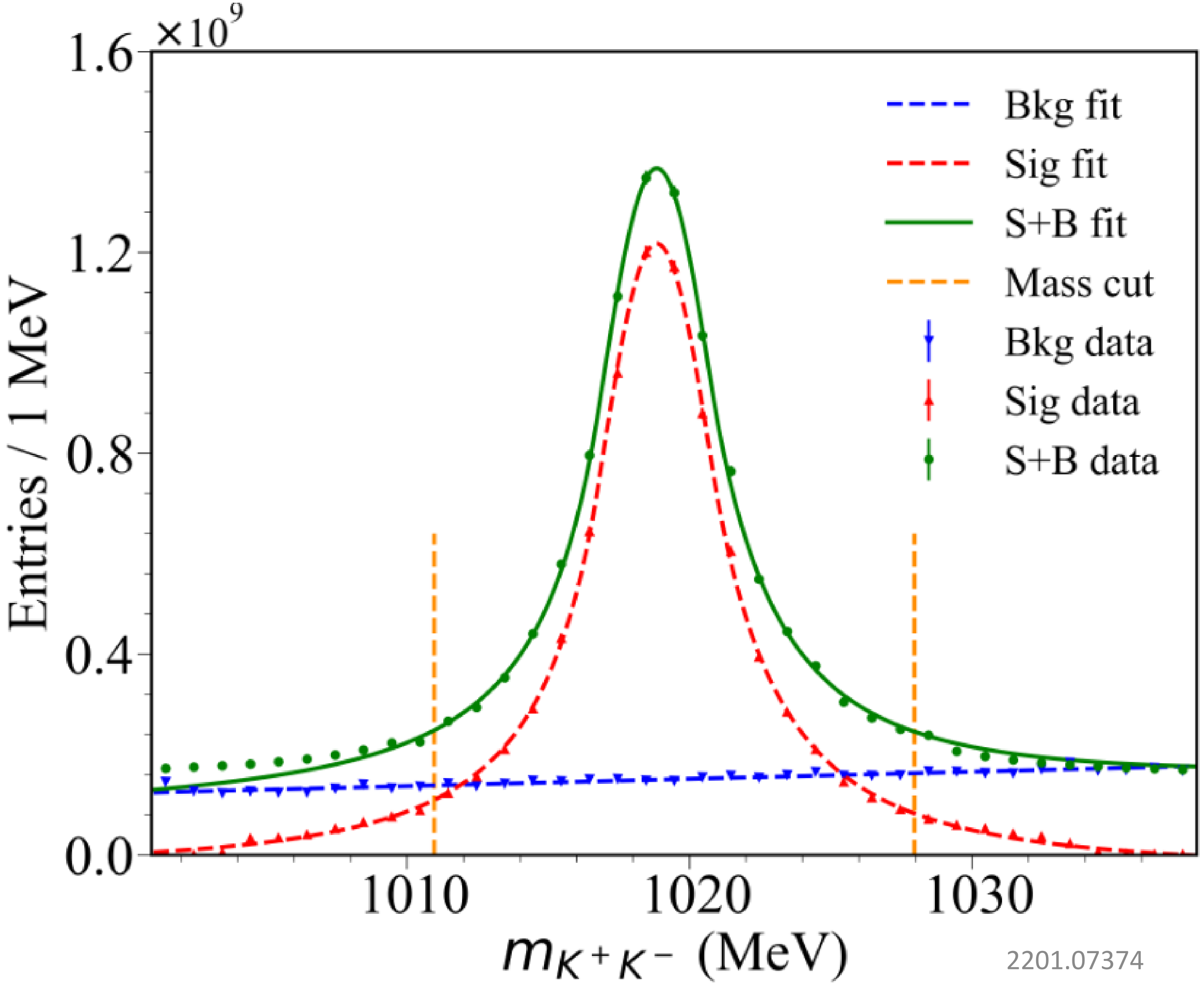
Step1: ϕ reconstruction



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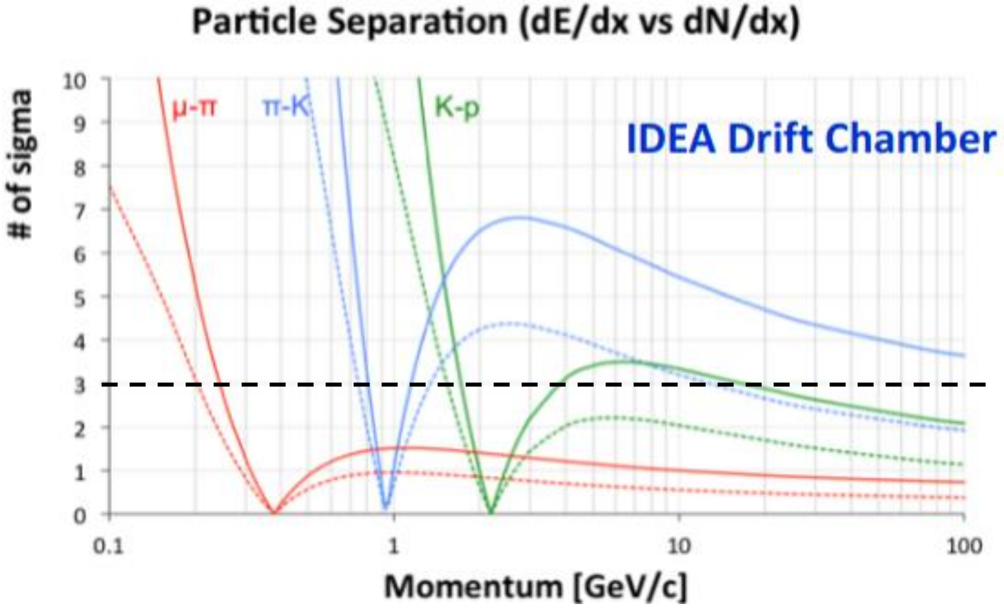
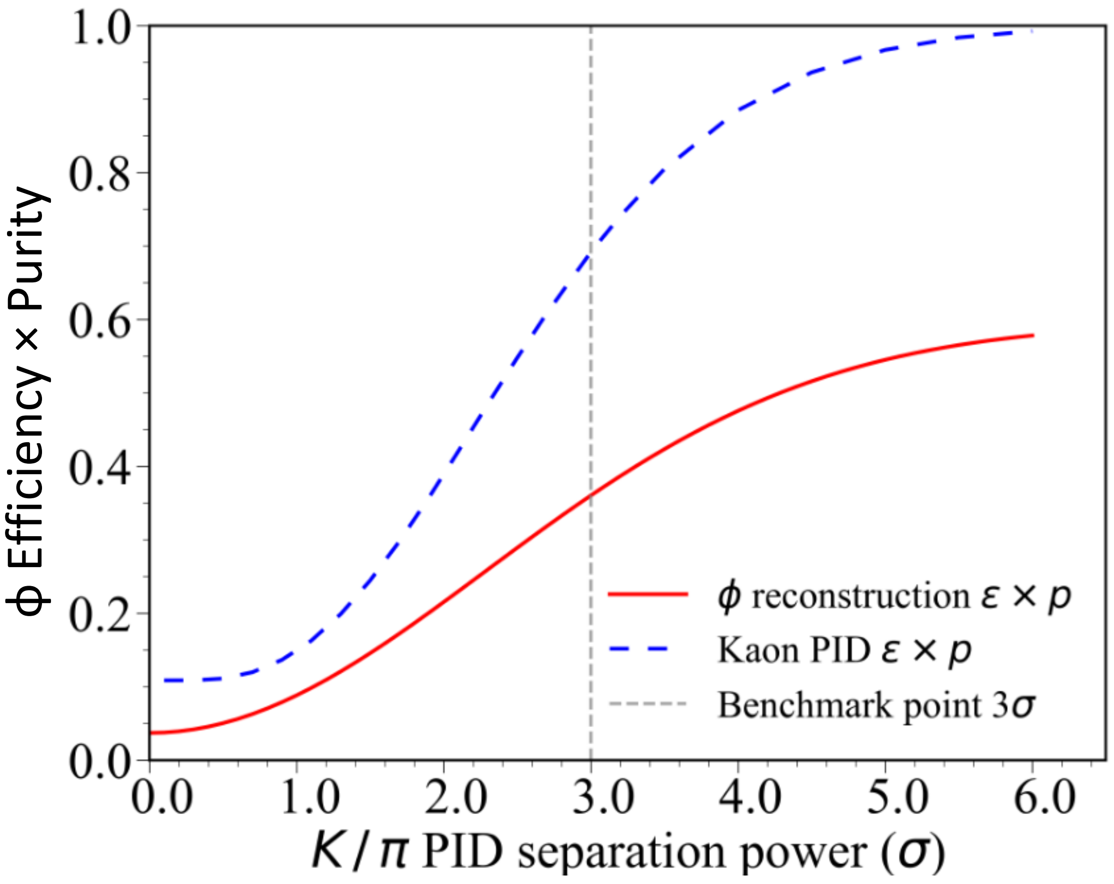
← Brute-force-pairing of K^+K^- together and get the peak. [T. Zheng and J. Wang and Y. Shen, Y.E. Cheung, M. Ruan, EPJC, 2020]

- Must from the same vertex
- Must in the hemisphere with lower total energy
- Gaussian approximation of PID

Interlude of Particle Identification (PID)



↑ The progress in dE(N)/dx, time-of-flight, RICH detection lead to > 3σ separation between K and π.



→: If the PID power is low, real ϕ would be overwhelmed by π fakes, satiates after 4-5 σ

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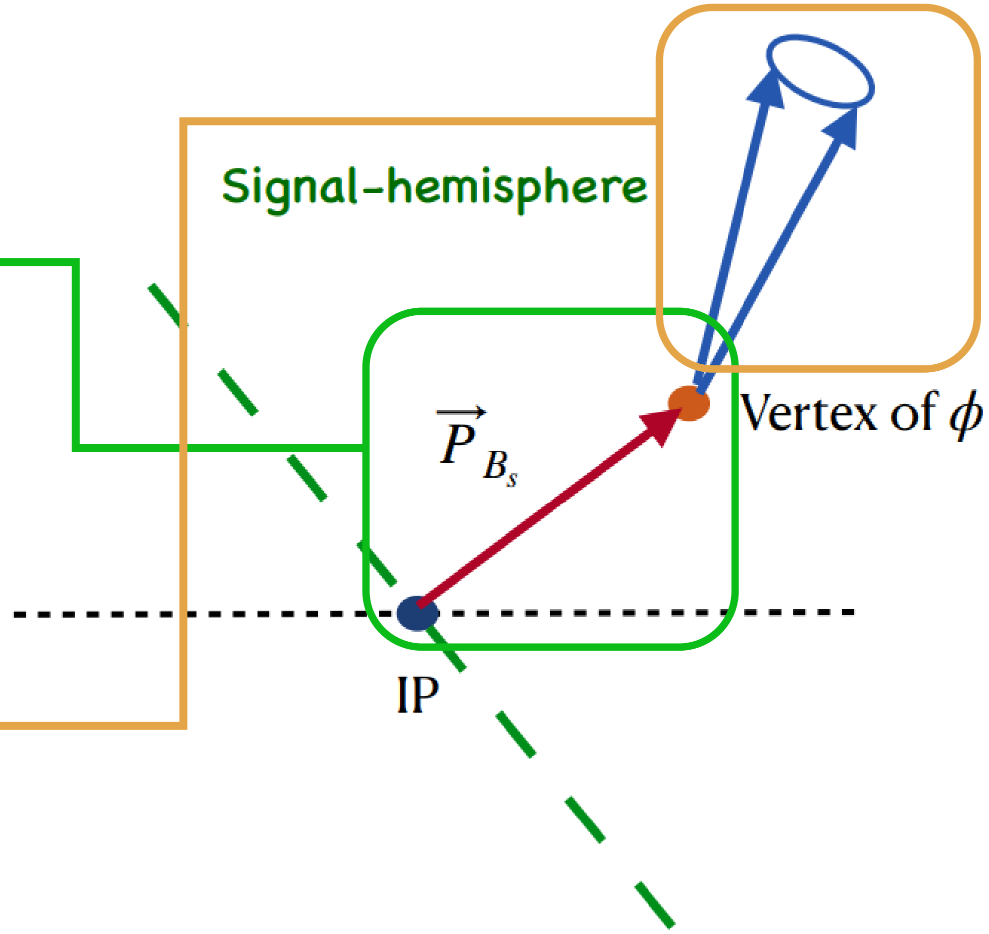
Full reconstruction

Step 1: The momentum direction of B_s is determined by the displacement between the primary vertex (PV) and secondary vetex (SV)



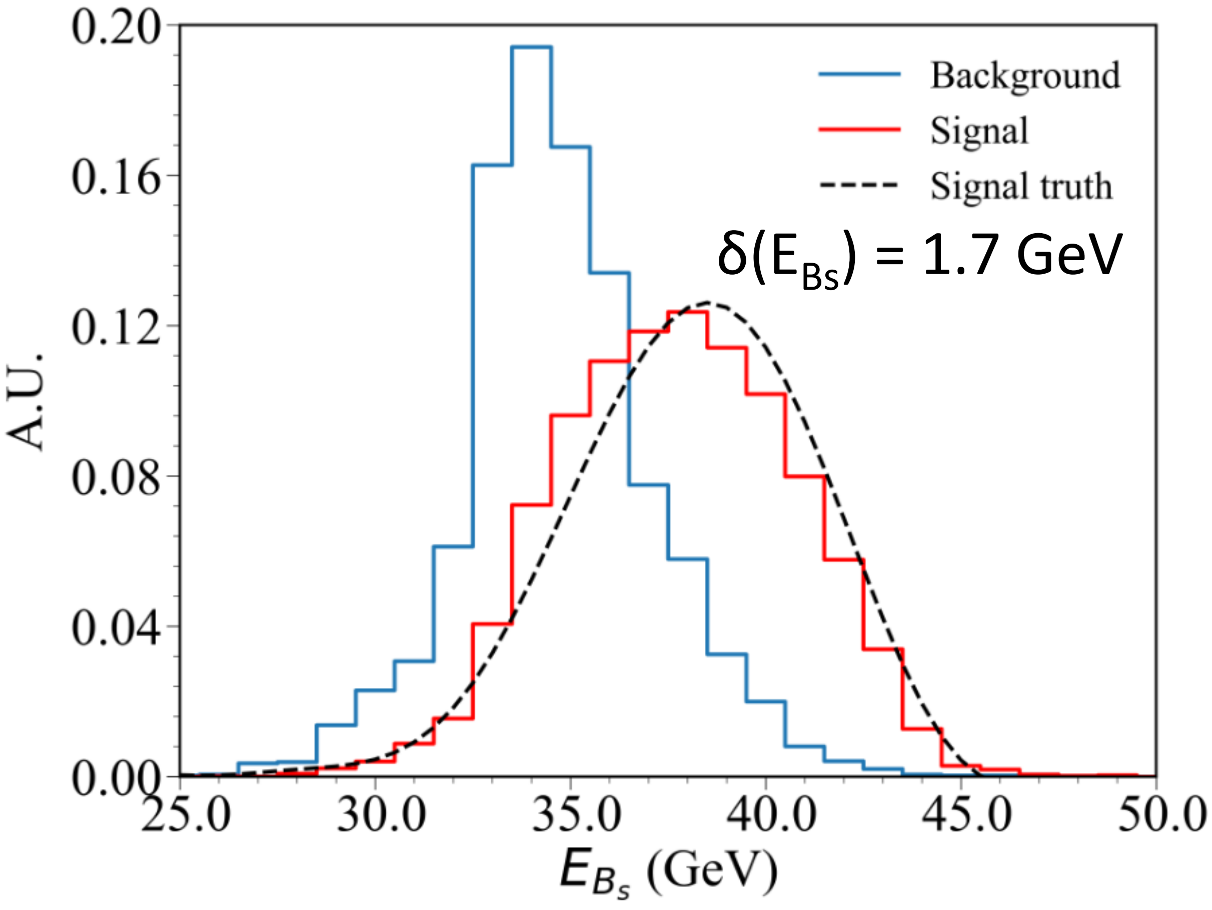
Step 2: Infer the total invisible energy using momentum conservation

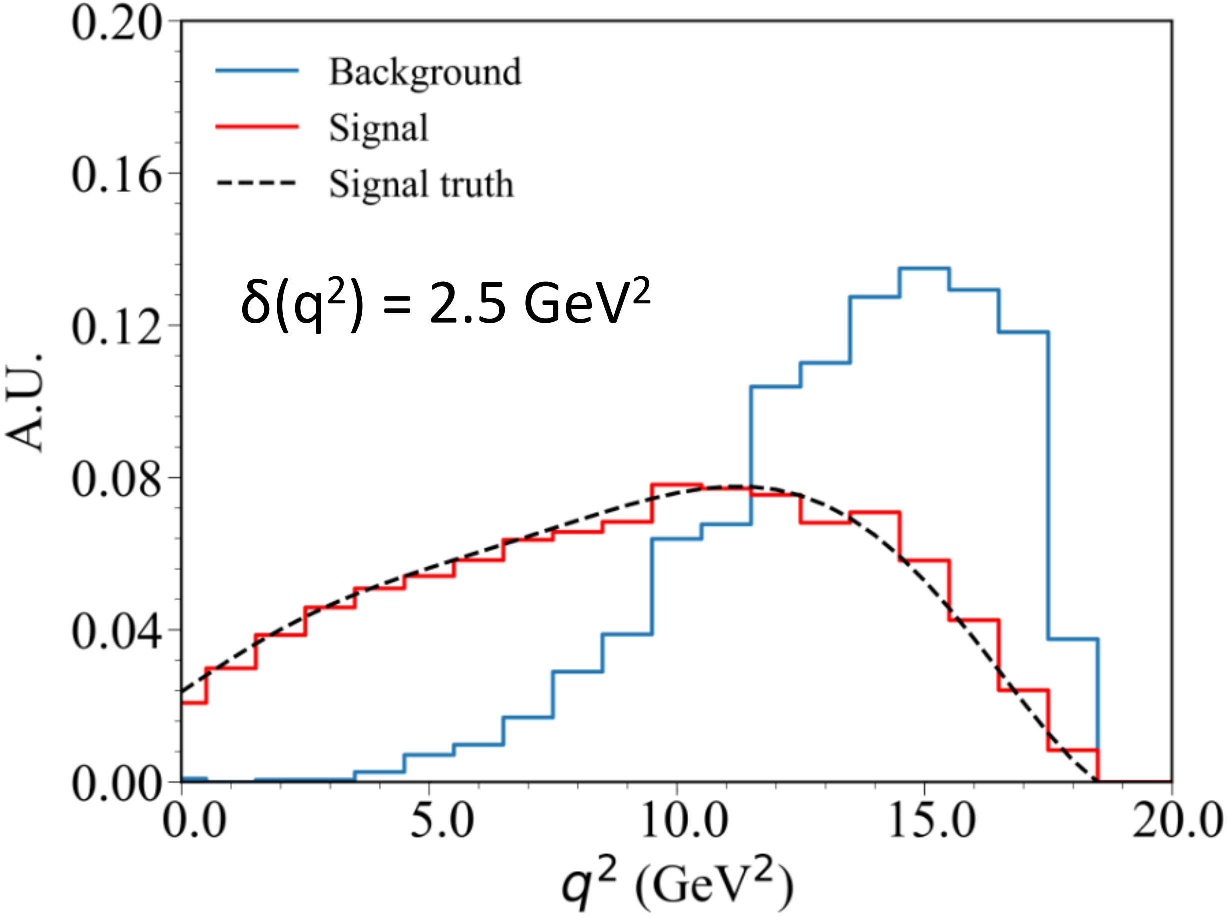
See also Anson Kwok's talk this afternoon

$$E_{B_s}^{(i)} = \frac{s + (M_{\rm sig}^{(i-1)})^2 - M_{\rm tag}^2}{2\sqrt{s}} - E_{\rm sig} + E_\phi \,,$$

$$(q^2)^{(i)} = (p_{B_s}^{(i-1)} - p_\phi)^2 \,,$$

Step 3: Reconstruct the B_s energy and thus q^2





Reconstruction errors comes from various (sometimes non-Gaussian) noises: detector resolution, untagged particles, extra neutrino(s), electron ISR …

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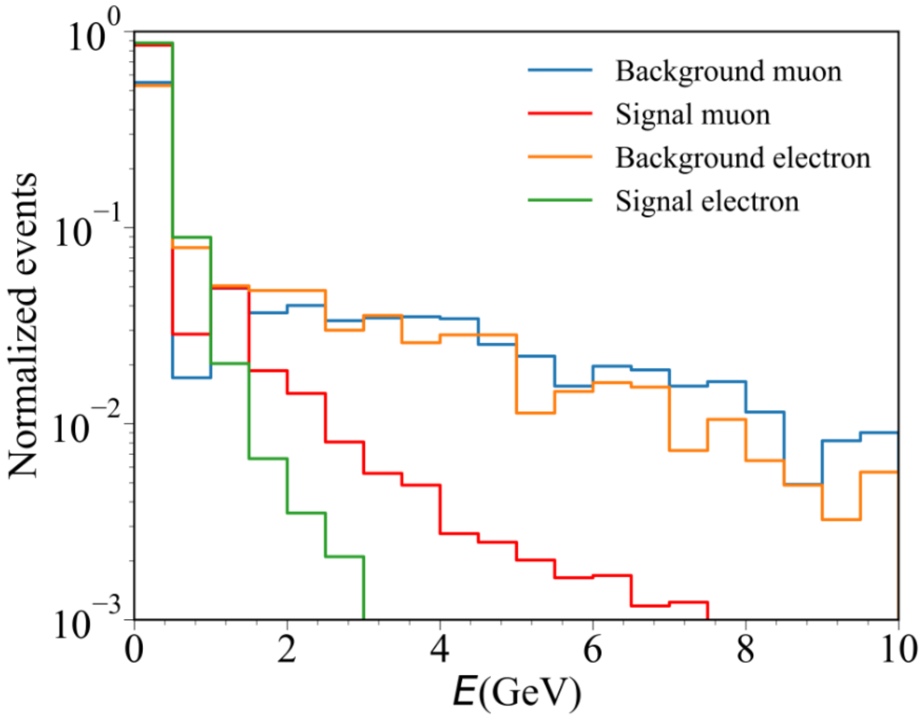
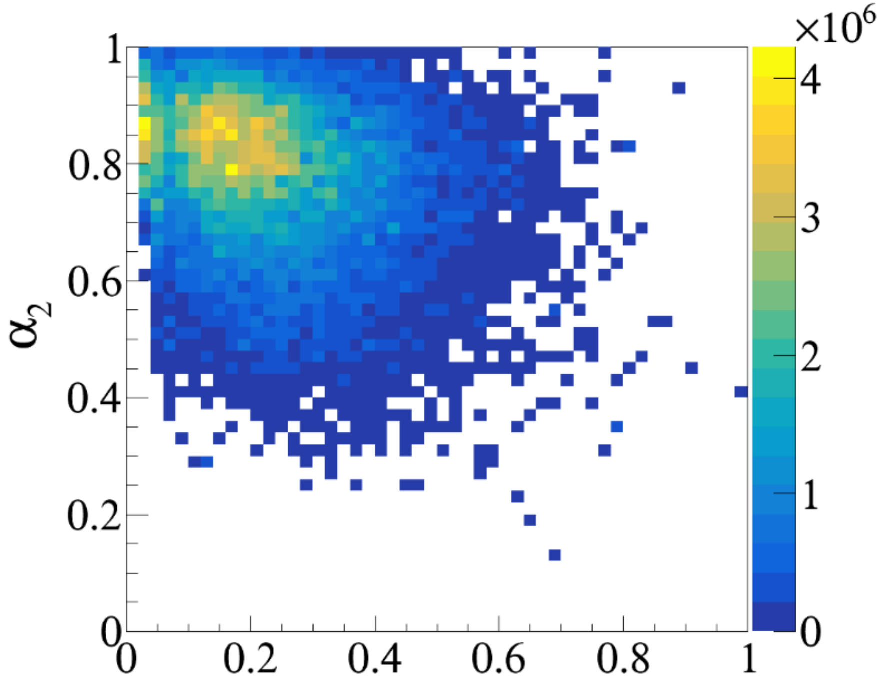
Useful Features:

↓: Major backgrounds: *B->D(-> ϕ+X)+lv*, leading lepton energy in the signal hemisphere is useful

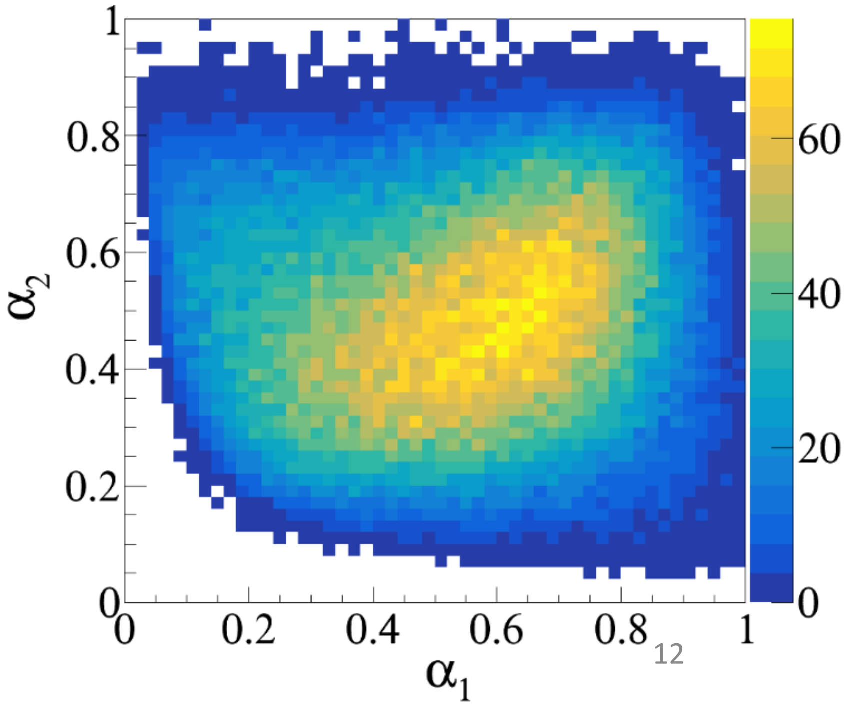


Ratio between ϕ energy and the visible energy (α1) and visible vs. beam energy (α2)



→: Background

⤵: Signal



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Results

Cuts	$B_s \to \phi\nu\bar{\nu}$	$u\bar{u}+d\bar{d}+s\bar{s}$	$c\bar{c}$	$b\bar{b}$	total bkg	$\sqrt{S+B}/S$ (%)
CEPC events ($10^{12}Z$)	3.03×10^5	4.28×10^{11}	1.20×10^{11}	1.51×10^{11}	6.99×10^{11}	276
$N_{\phi(\to K^+K^-)}>0$	8.09×10^4	1.09×10^{10}	4.04×10^9	6.08×10^9	2.10×10^{10}	179
[a] "Signal" ϕ	5.38×10^4	2.52×10^8	4.09×10^8	1.69×10^9	2.35×10^9	90.9
Energy asymmetry > 8 GeV	4.74×10^4	6.25×10^7	9.76×10^7	4.93×10^8	6.53×10^8	53.9
$E^N_{B_s}>28$ GeV	4.06×10^4	4.25×10^6	9.59×10^6	5.00×10^7	6.38×10^7	19.7
$\alpha<1.1$	3.03×10^4	2.41×10^6	3.10×10^6	8.47×10^6	1.40×10^7	12.4
b-tag > 0.6	2.33×10^4	$<2.0\times10^4$	2.95×10^5	5.97×10^6	6.27×10^6	10.77
E_μ and $E_e<1.2$ GeV	2.10×10^4	-	5.85×10^4	2.10×10^6	2.16×10^6	7.03
$\theta^{miss}_\phi>0.1$ rad	1.77×10^4	-	2.75×10^4	1.38×10^6	1.41×10^6	6.75
$q^2<14.0$ GeV^2	1.34×10^4	-	2.02×10^4	6.04×10^5	6.24×10^5	5.96
BDTG response> 0.89	0.75×10^4	-	$<1\times10^2$	1.03×10^4	1.03×10^4	1.78
Efficiency	2.40%	-	-	6.82×10^{-8}	1.47×10^{-8}	-

Inclusive b-jet tagging removes most non-Z->bb backgrounds

Finaly, background rejection reaches O(10^7), leaving an S/B ≈ 1

Relative sensitivity: **O(2%)**

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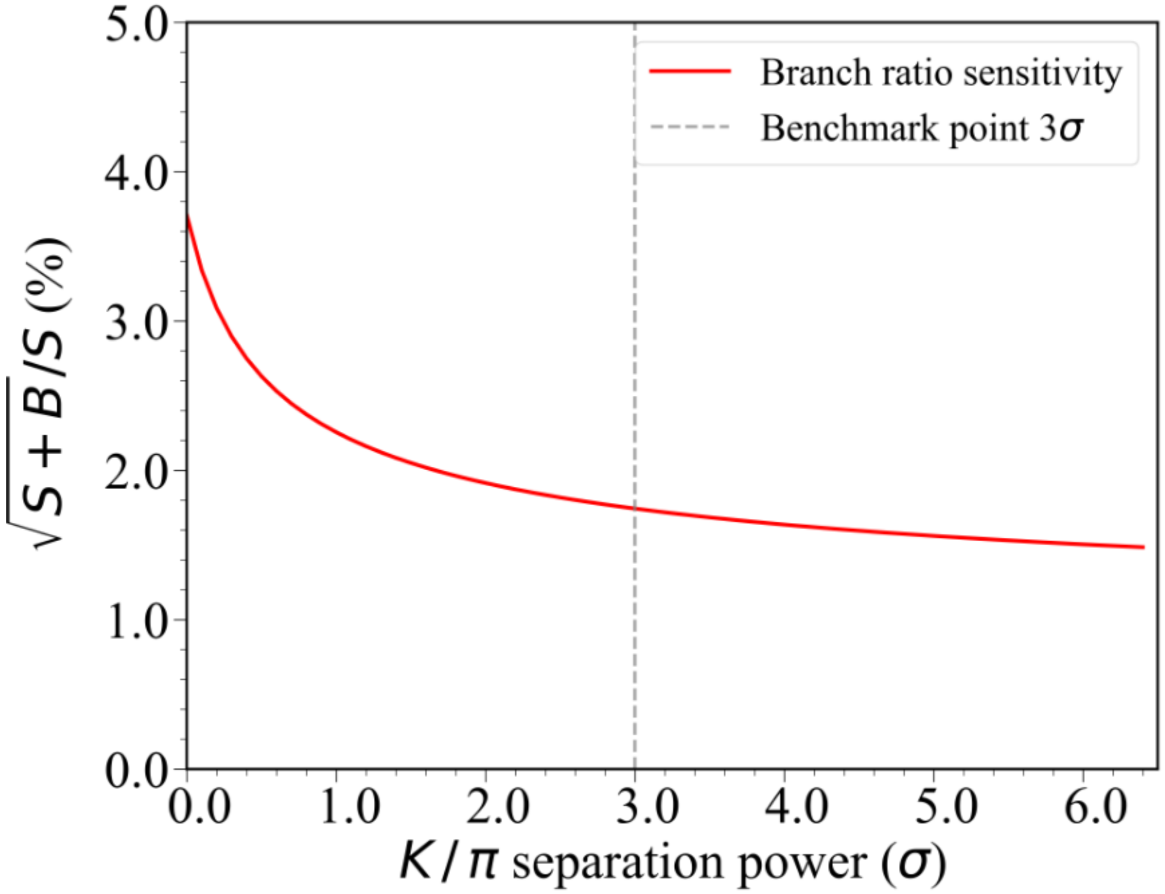
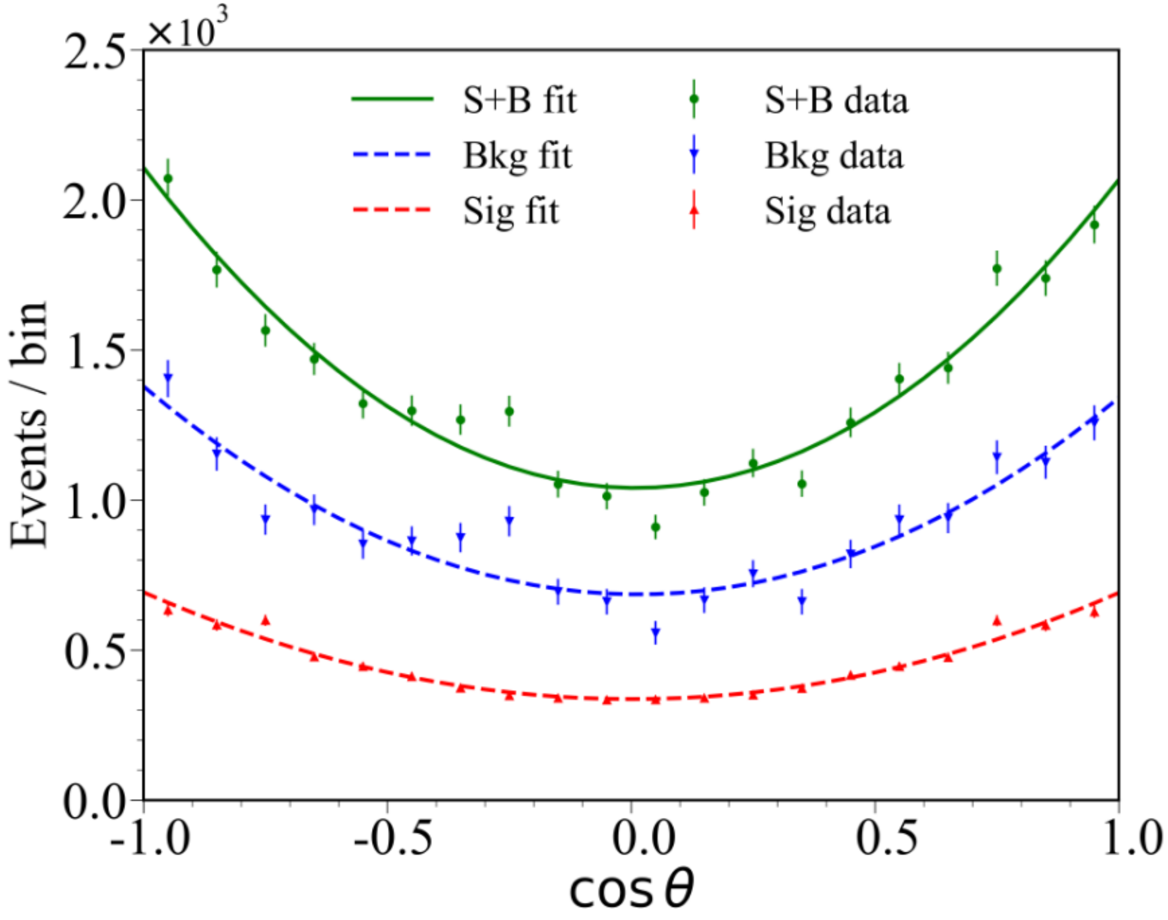
Results (II)

$\boxed{\downarrow}$: Many other handles stop sensitivity drops when PID is not ideal





$\boxed{\uparrow}$: Reconstructed angles between K and B_s, can be used to measure the polarization of ϕ.

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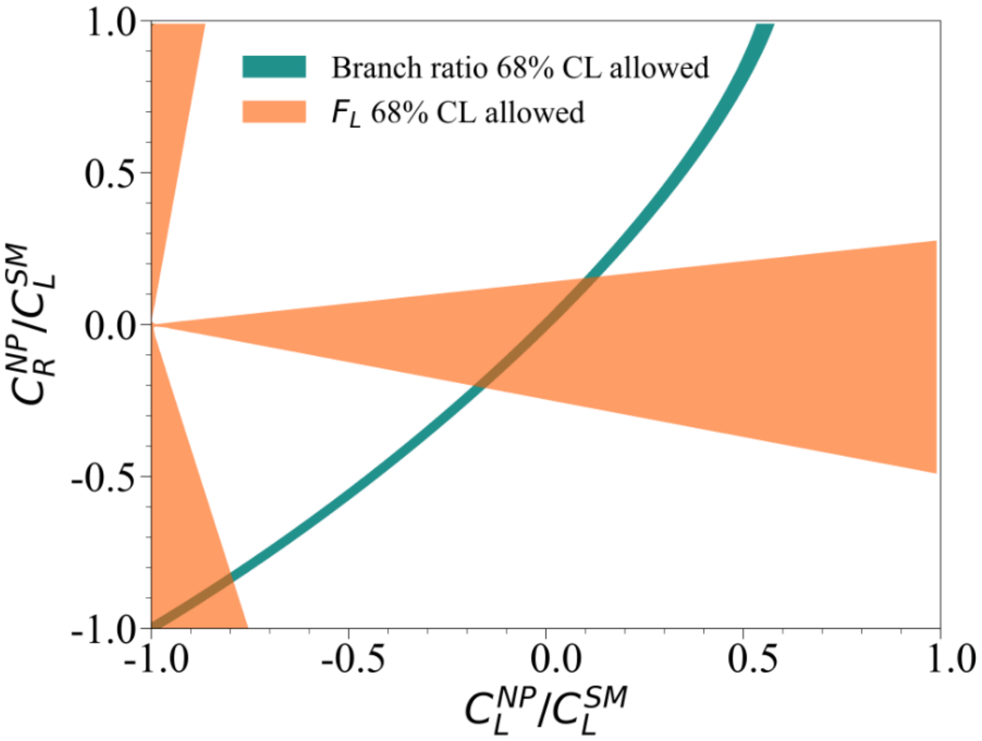
Summary and Outlook



- Set up an benchmark for future collider flavor phenomenology.
- Relative precision of O(1%) is achievable at Tera-Z (with full detector simulation!). Compare with Belle II (~10% of B->K*vv)
- Both BR and polarization are useful in constraining new physics. Best when combined with pesudoscalar transitions.
- Arguably the best channel? B->K*vv affected by the large width of K*, phenomenology of B->Kvv unknown.
- Also useful for light BSM states (e.g.) B_s -> ϕ+ALP, a bump in the q^2 distribution.

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