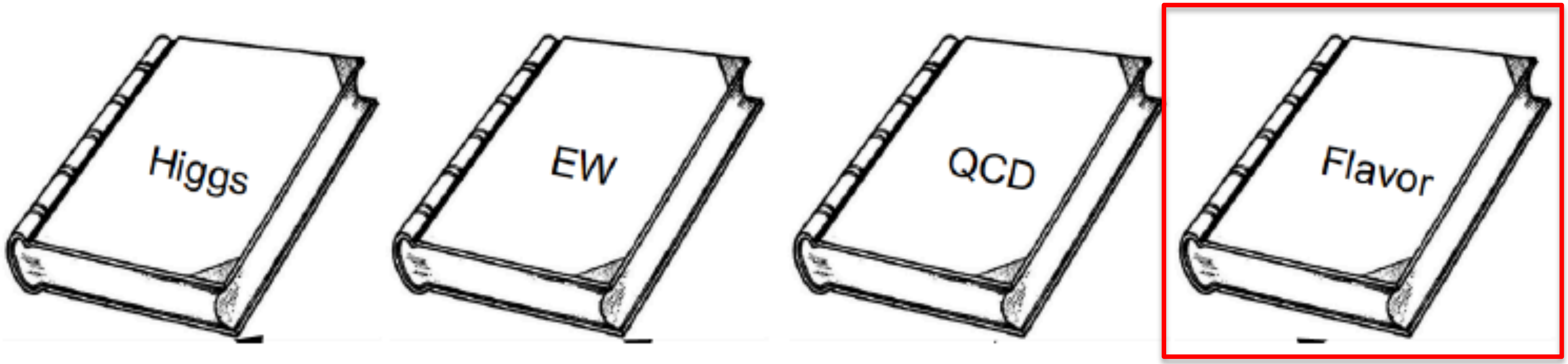
Plan of write-up on Flavor Physics

Hai-Bo Li
Institute of High Energy Physics

From Manqi Ruan

Objectives of this workshop



- To promote the physics study at TDR & to converge to the Physics White Papers by the end of 2020
- Physics white papers:
  - Physics handbooks for new comers: PostDoc/Student
  - Official references for the physics potential
  - Guideline for future detector design/optimization

Call a white paper in last December 2018

Flavor Physics at CEPC

IHEP-Physics-Report-CEPC-2018-12-11-v0.0

Working Group and Conveners

Chapter One: Introduction
Conveners: Hai-Bo Li, Jonathan Rosner

Chapter Two: Leptonic and semileptonic *b*-hadron decays ← Sebastien Descotes-Genon
Conveners: Sebastien Descotes-Genon , Jeorme Charles,
Abner Soffer,Florian Bernlochner, Bob Kowalewski

Chapter Three: *b*-hadronic decays and CP violation ← Abi Soffer, Yu-Kuo Hsiao
Conveners: I.I. Bigi, Chao-Qiang Geng, Abner Soffer,
Yue-Hong Xie

Chapter Four: Rare and forbidden *b*-hadron decays
Conveners: Wolfgang Altmannshofer, Soeren A. Prell,
Emmanuel Stamou

Chapter Five: Charm physics ← Marek Karliner & Jon Rosner, Hai-Yang Cheng
Conveners: Chun-Hui Chen, Hai-Yang Cheng,
Jonathan Rosner

Chapter Six: Exotic hadron and Spectroscopy with heavy flavors ← Marek Karliner & Jon Rosner
Conveners: Marek Karliner, Jonathan Rosner, Wei Wang

Chapter Seven: τ Physics ← Lorenzo Calibbi
Conveners: Emilie Passemar, Emmanuel Stamou,
Lorenzo Calibbi

Chapter Eight: Flavor physics in Z decays ← Lorenzo Calibbi
Conveners: Wolfgang Altmannshofer, Lorenzo Calibbi

Chapter Nine: Two photon and ISR physics with heavy flavors ← Vladimir Bytev
Conveners: S. I. Eidelman, Alexey Zhemchugov,
D. Dedovich, Lian-Tao Wang ??

Chapter Ten: Summary and Conclusion
Conveners: Hai-Bo Li, Manqi Ruan

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Dan Yu & Taifan Zheng

Tentative Schedule

- Nov. 18, 2019: annual CEPC working group meeting at IHEP, Beijing
- Preliminary drafts: December 15, 2019
- The first integration of the white paper: Jan. 15, 2020
- The second integration: May 31, 2020
- Version for publication: July 31, 2020

Flavors Production at different experiments

Particle	@ Tera-Z	@ Belle II		@ LHCb
b hadrons				
B^+	6×10^{10}	3×10^{10}	$(50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S))$	3×10^{13}
B^0	6×10^{10}	3×10^{10}	$(50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S))$	3×10^{13}
B_s	2×10^{10}	3×10^{8}	$(5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S))$	8×10^{12}
b baryons	1×10^{10}			1×10^{13}
Λ_b	1×10^{10}			1×10^{13}
c hadrons				
D^0	2×10^{11}			
D^+	6×10^{10}			
D_s^+	3×10^{10}			
Λ_c^+	2×10^{10}			
τ^+	3×10^{10}	5×10^{10}	$(50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S))$	

From CEPC's CDR using fragmentation ratios from Amhis et al, 17

Heavy quarks @ Z peak

Two key issues: *CP* violation and rare *b*-decays (FCNC)

LHCb sees all species of *b*-particles (and charm in abundance) and is especially good at rare decays with muons and fully charged decay modes. However less efficient for electrons, neutrals, missing energy.

Belle II should explore deeply/widely the B_d and B_u meson systems. Might also runs above the Y(5S) threshold but can't resolve the oscillation and TD CPV of B_s meson, and cannot do Bc and b-baryons.

Highlights: rare decays

FCNC processes: DNA for new physics

Observable	Current sensitivity	Future sensitivity	Tera-Z sensitivity
$\mathrm{BR}(B_s \to ee)$	2.8×10^{-7} (CDF) [438]	$\sim 7 \times 10^{-10}$ (LHCb) [435]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \mu\mu)$	0.7×10^{-9} (LHCb) [437]	$\sim 1.6 \times 10^{-10}$ (LHCb) [435]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \tau\tau)$	5.2×10^{-3} (LHCb) [441]	$\sim 5 \times 10^{-4}$ (LHCb) [435]	$\sim 10^{-5}$
R_K, R_{K^*}	$\sim 10\%$ (LHCb) [443, 444]	$\sim$few% (LHCb/Belle II) [435, 442]	$\sim$few %
$\mathrm{BR}(B \to K^*\tau\tau)$	–	$\sim 10^{-5}$ (Belle II) [442]	$\sim 10^{-8}$
$\mathrm{BR}(B \to K^*\nu\nu)$	4.0×10^{-5} (Belle) [449]	$\sim 10^{-6}$ (Belle II) [442]	$\sim 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	1.0×10^{-3} (LEP) [452]	–	$\sim 10^{-6}$
$\mathrm{BR}(\Lambda_b \to \Lambda\nu\bar{\nu})$	–	–	$\sim 10^{-6}$
$\mathrm{BR}(\tau \to \mu\gamma)$	4.4×10^{-8} (BaBar) [475]	$\sim 10^{-9}$ (Belle II) [442]	$\sim 10^{-9}$
$\mathrm{BR}(\tau \to 3\mu)$	2.1×10^{-8} (Belle) [476]	$\sim$ few $\times 10^{-10}$ (Belle II) [442]	$\sim$ few $\times 10^{-10}$
$\frac{\mathrm{BR}(\tau \to \mu\nu\bar{\nu})}{\mathrm{BR}(\tau \to e\nu\bar{\nu})}$	3.9×10^{-3} (BaBar) [464]	$\sim 10^{-3}$ (Belle II) [442]	$\sim 10^{-4}$
$\mathrm{BR}(Z \to \mu e)$	7.5×10^{-7} (ATLAS) [471]	$\sim 10^{-8}$ (ATLAS/CMS)	$\sim 10^{-9} - 10^{-11}$
$\mathrm{BR}(Z \to \tau e)$	9.8×10^{-6} (LEP) [469]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-11}$
$\mathrm{BR}(Z \to \tau\mu)$	1.2×10^{-5} (LEP) [470]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-10}$

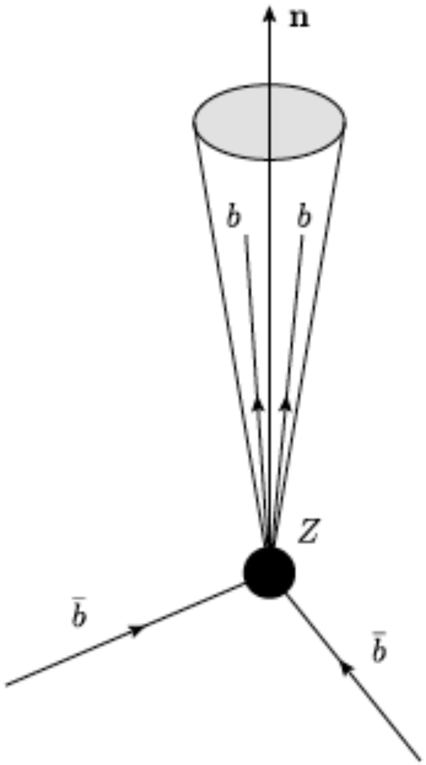
Stable doubly heavy Tetraquark

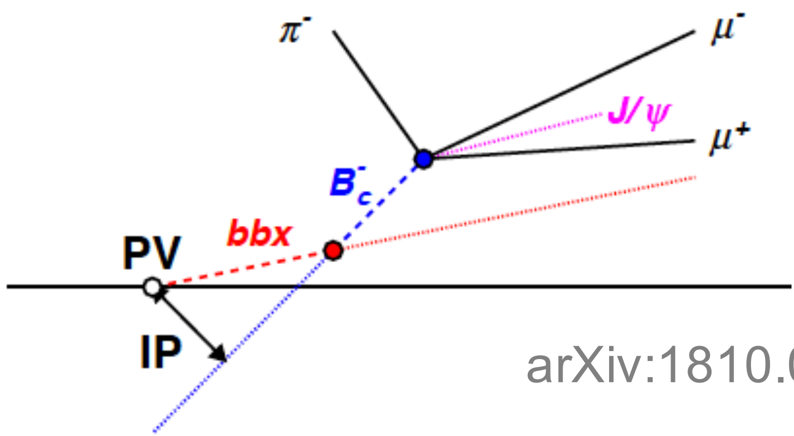
- $bb\bar{q}\bar{q}'$: PLB 782(2018) 412

$$\mathcal{B}(Z \to bb\bar{b}\bar{b}) = (3.6 \pm 1.3) \times 10^{-4}$$ LEP 98

$$\mathcal{B}(Z \to T^{bb}_{\bar{q}\bar{q}'} + \bar{b}\bar{b}) = (1.2^{+1.0}_{-0.3}) \times 10^{-6}$$

$$\tau(T^{bb}_{\bar{q}\bar{q}'}) : \quad 300 - 800 fs$$ PRL 119(2017)20
PRD90(2014) 094007





arXiv:1810.06657

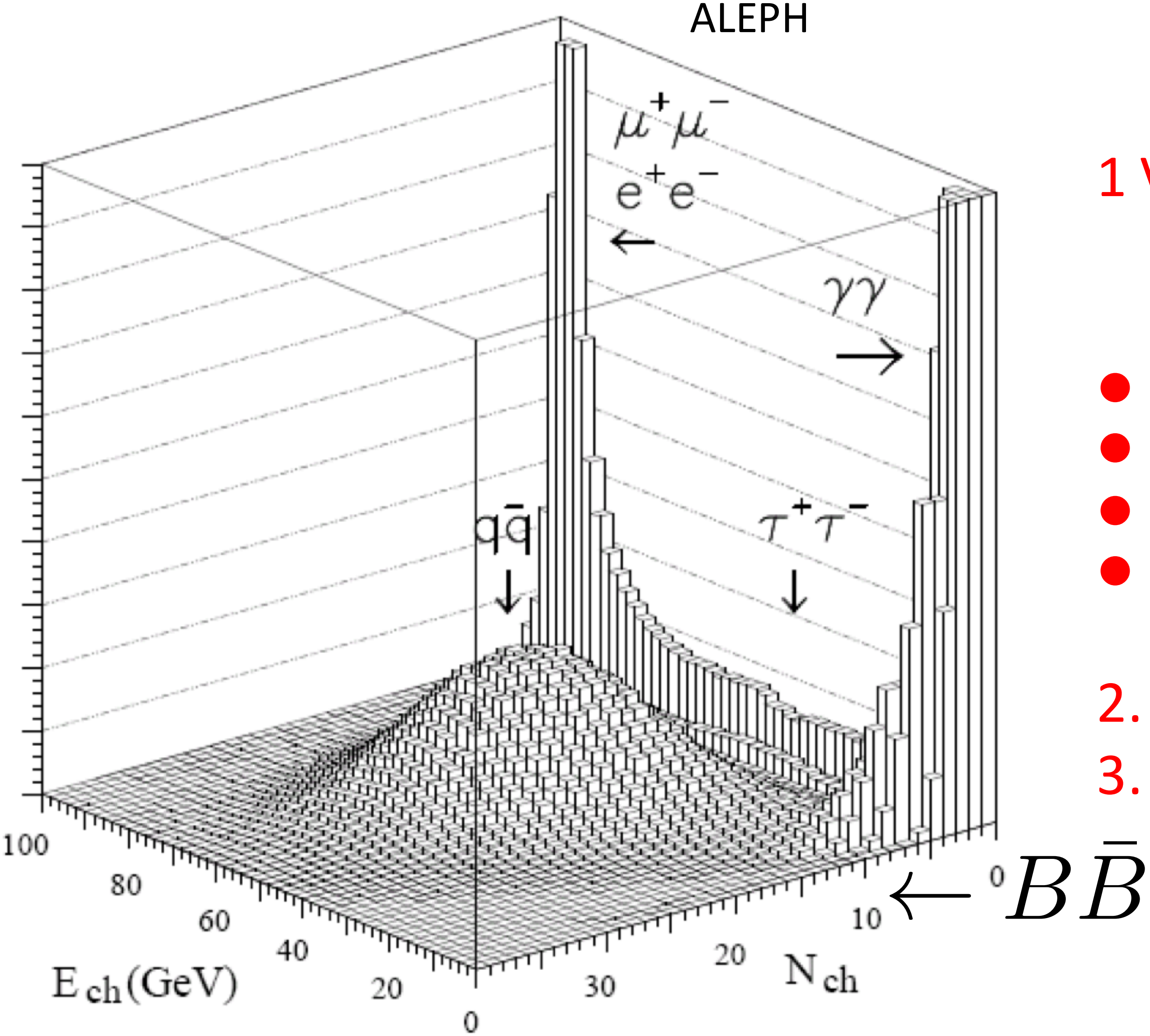
tau lepton at Z peak

Advantage of tau experiment at Z peak:

- Large production cross-section (1.5 nb)
- Strong boost, decay length: 2 mm
- Back-to-back event topology, 80% efficiency
- Background clean
- Good lepton and K_L ID

Disadvantage: K/pi ID is challenge

tau lepton reconstruction @ Z peak



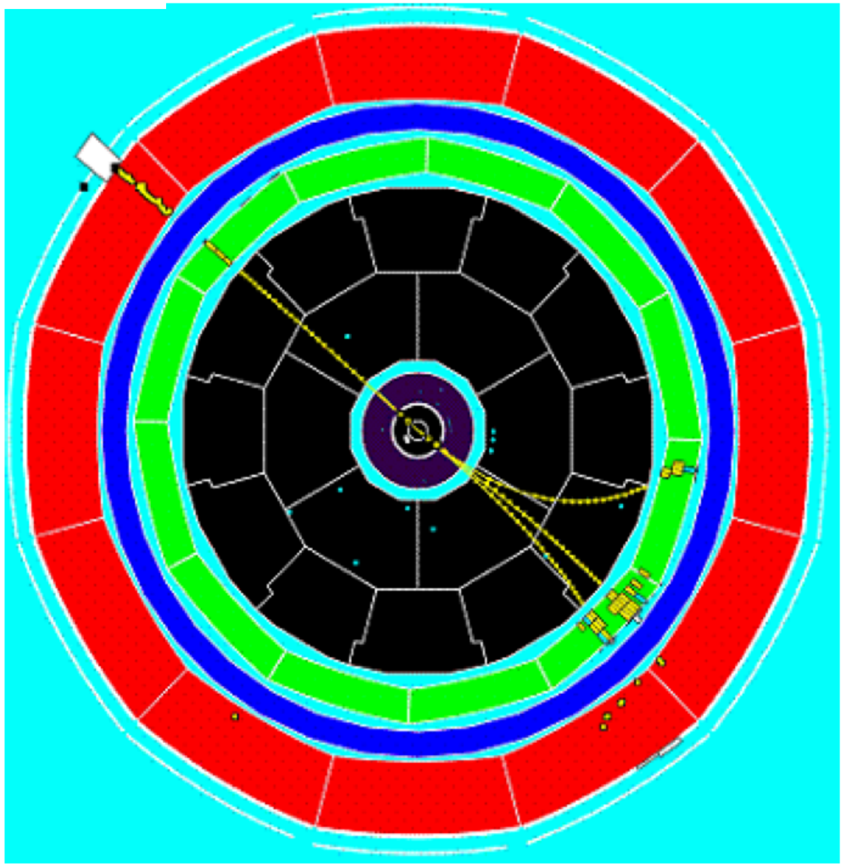
1 Very clean $\tau\tau$ events can be selected with very simple selection criteria.

- Low track multiplicity
- Back-to-back
- Low invariant mass
- Total energy not very small

2. Subtract background
3. Classify all the events

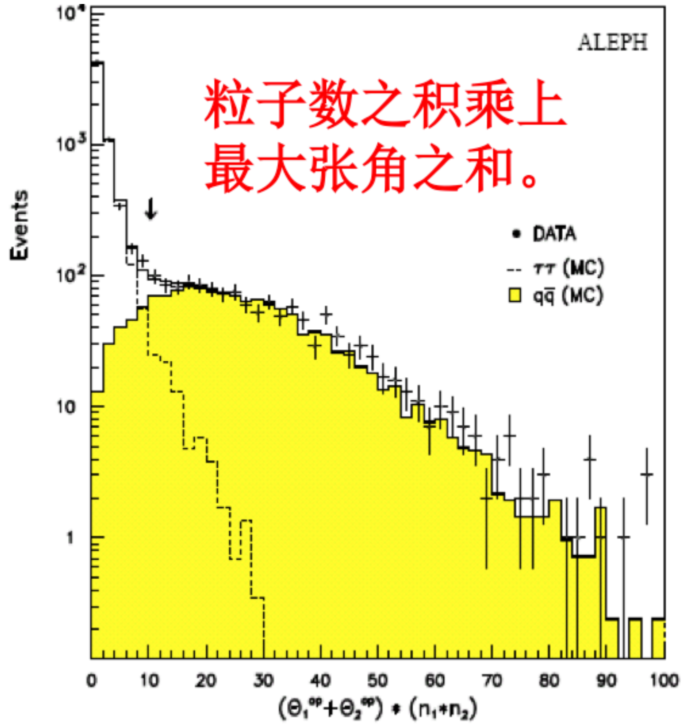
tau lepton reconstruction at Z-peak

ALEPH



Ecm≈91 GeV

Z.Phys.C70:579-608,1996



Physics processes	Efficiency (%)	Contamination (%)
$Z^0 \to \tau^+\tau^-$	78.84 ± 0.13	
Bhabha		0.15 ± 0.03
$Z^0 \to \mu^+\mu^-$		0.07 ± 0.02
$\gamma\gamma \to e^+e^-$		0.07 ± 0.02
$\gamma\gamma \to \mu^+\mu^-$		0.08 ± 0.02
four-fermion		0.14 ± 0.02
cosmic rays		0.02 ± 0.01
$Z^0 \to q\bar{q}$		0.31 ± 0.09

丢失的效率是因几何造成的

Requirement

- For charged tracks
  - Good momentum measurement
  - Good π/K separation (PID for tracks up to 30GeV?)
  - Good vertex: lifetime, background suppression
- For γ/π^0
  - Good geometric coverage
  - Fine granularity with longitudinal readout
  - Good energy resolution and angular resolution
  - Low photon energy threshold: < 200 MeV

Summary

- Understand the experimental precision with 10^{12} *Z:*

  rare decays of tau, *c*- and *b*-hadrons;

  CP violation*;*

  precision tau physics;

- Examine the relevance of a dedicated PID (π / K / p separation) detector.

Thank you!

Back up slides

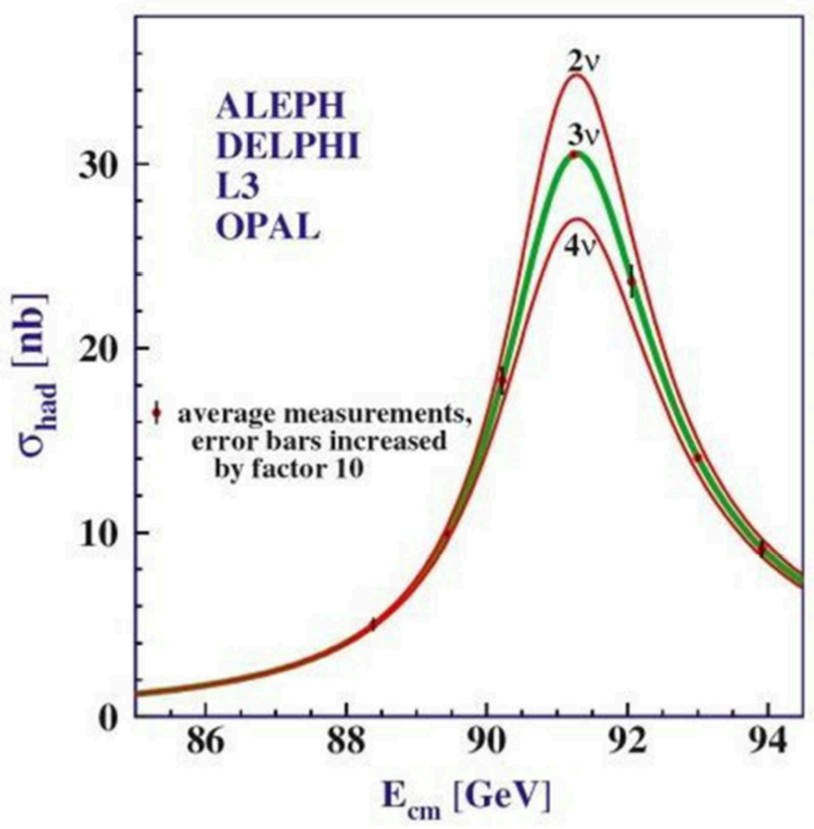
Flavour at the Z: the lepton Physics Case

Direct search: $$n_\nu = (\frac{\Gamma_{inv}}{\Gamma_{lept}})^{meas}/(\frac{\Gamma_{inv}}{\Gamma_{lept}})^{SM}$$

$$n_\nu = 2.9840 \pm 0.0082$$ LEP

0.004 CEPC

Limited by uncertainty due to calculation of Bhabha scattering. Improved by a factor of 2-3 at CEPC



Direct search: one year run at E=105 GeV

$$n_\nu = (\frac{e^+e^- \to \gamma Z_{inv}}{e^+e^- \to \gamma Z_{lept}})^{meas}/(\frac{\Gamma_{inv}}{\Gamma_{lept}})^{SM}$$

$$\Delta n_\nu = \pm 0.0008$$

Blondel, Graverinib, Serrab,
Shaposhnikov arXiv:1411.5230

Flavor at the Z: the lepton physics

A high-luminosity Z factory with 10^{12} Z allows us to search for new physics in the leptonic Z decays:

$$e^+e^- \to Z \to \nu N$$
$$N \to l^+l'^-\nu, q\bar{q}'l, q\bar{q}\nu$$

Blondel, Graverinib, Serrab, Shaposhnikov arXiv:1411.5230

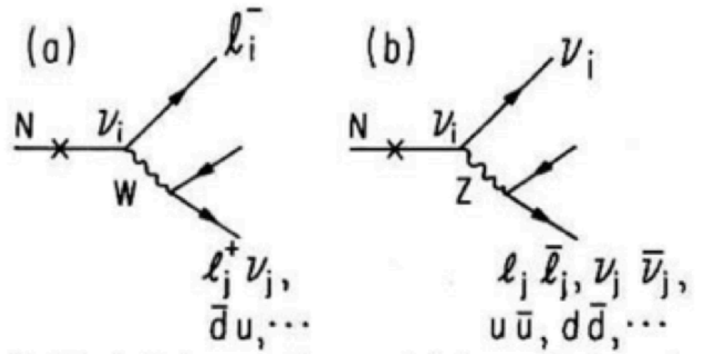


FIG. 2. Typical decays of a neutral heavy lepton via (a) charged current and (b) neutral current. Here the lepton l_i denotes e, μ, or τ.

LNV processes to identify Majorana neutrinos Sensitivity: 10^{-11} at CEPC.

$$e^+e^- \to Z \to NN \to l^+l^+h^-h^- + c.c.$$

Z decays: cLFV

- Lepton Flavor-violating *Z* decays in the SM with lepton mixing are typically:

$$B(Z \to \mu e) \sim B(Z \to \tau e) \sim 10^{-54} \quad B(Z \to \tau\mu) \sim 10^{-60}$$

- Any observation of such a decay would be an indisputable evidence for New Physics.
- Current limits at the level of ~10^{-6} (from LEP and recently ATLAS, *e.g*. DELPHI, Z. Phys. C73 (1997) 243 ATLAS, CERN-PH-EP-2014-195 (2014))
- The CEPC high luminosity *Z* factory would allow to gain up to five orders of magnitude …

A. Abada et al. arXiv:1412.6322

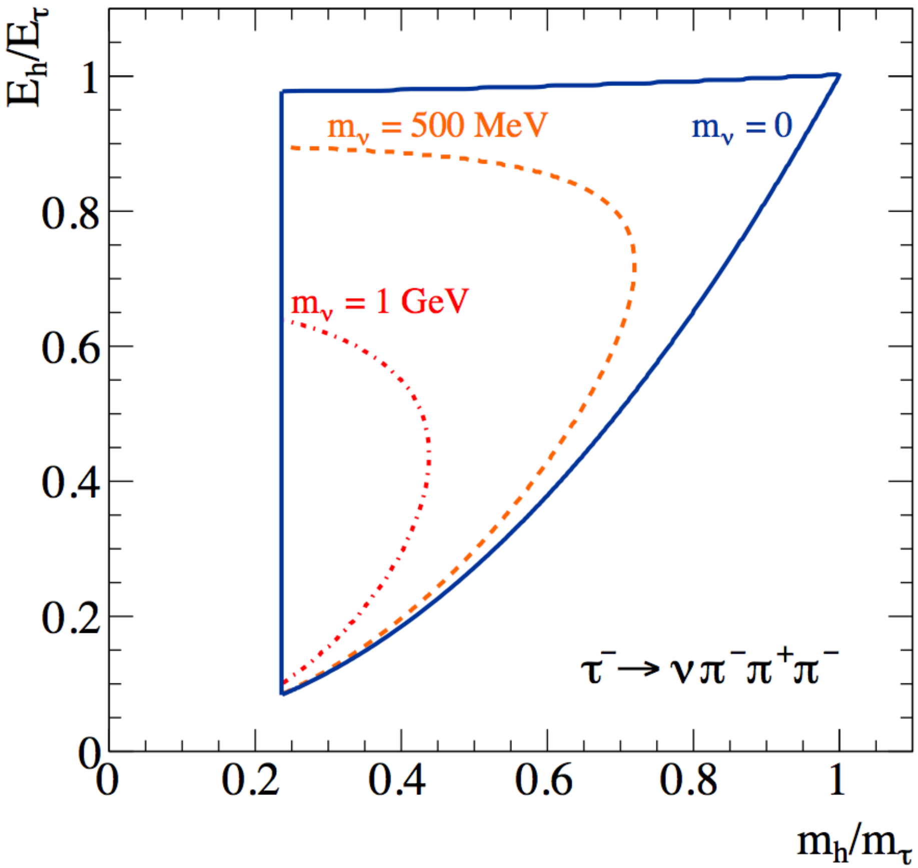
S. Davidson et al. JHEP 1209 (2012) 092

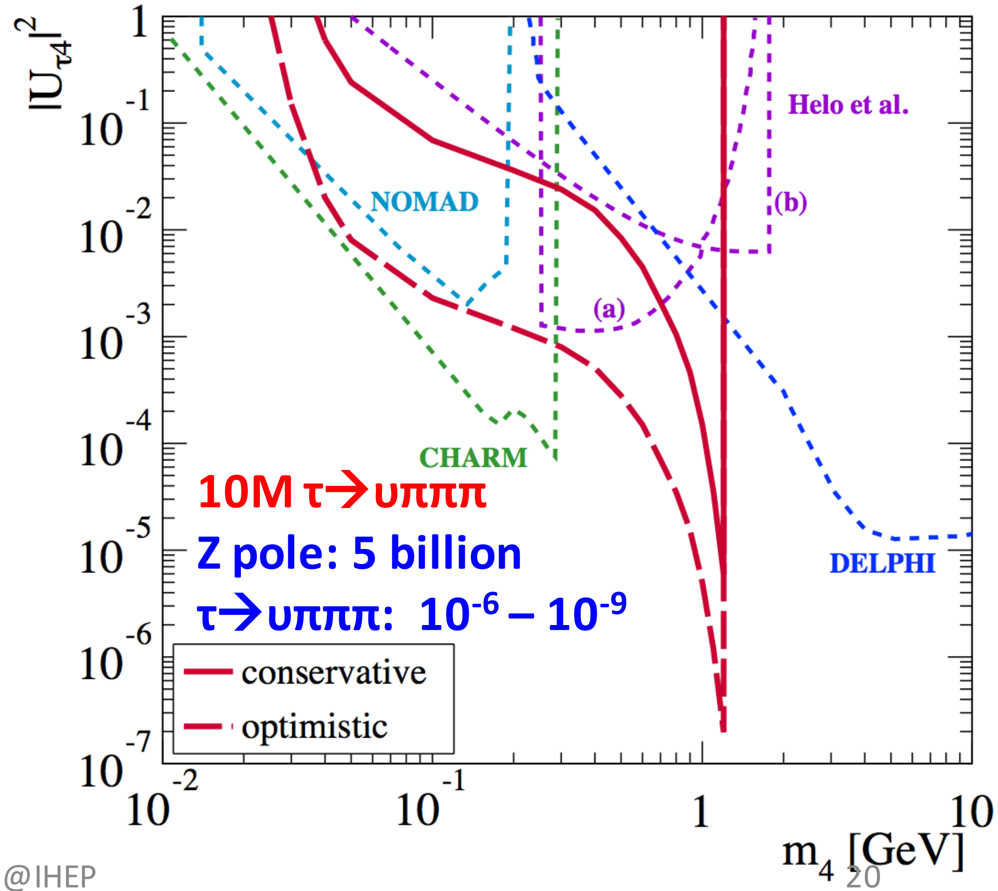
Kinematics of τ decays: heavy neutrinos

arXiv:1412.4785

$e^+e^- \to \tau^+\tau^-$ **at Z pole with known $E_\tau = E_{beam}$**
must understand well the ISR effects

$$\frac{d\Gamma_{tot}(\tau^- \to \nu h^-)}{dm_h dE_h} = \left(1-|U_{\tau 4}|^2\right)\frac{d\Gamma(\tau^- \to \nu h^-)}{dm_h dE_h}\bigg|_{m_\nu=0} + |U_{\tau 4}|^2 \frac{d\Gamma(\tau^- \to \nu h^-)}{dm_h dE_h}\bigg|_{m_\nu=m_4}$$





LNV processes at Z peak

LNV signals of Majorana neutrinos:

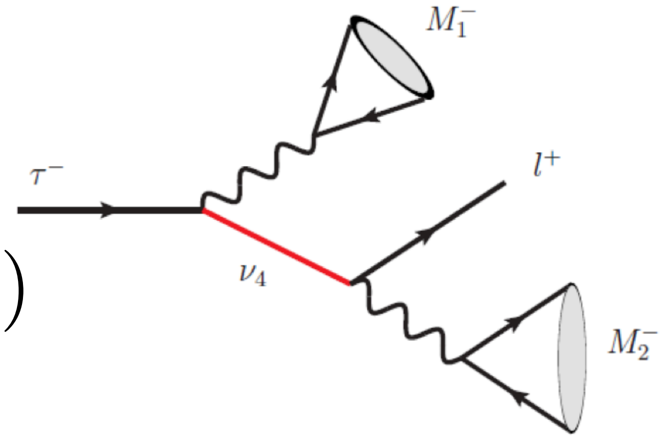
$$B^+/D^+ \rightarrow h^- l^+ l^+ (h = hadron)$$

$$B^0/D^0 \rightarrow h_1^- h_2^- l^+ l^+ (h = hadron)$$

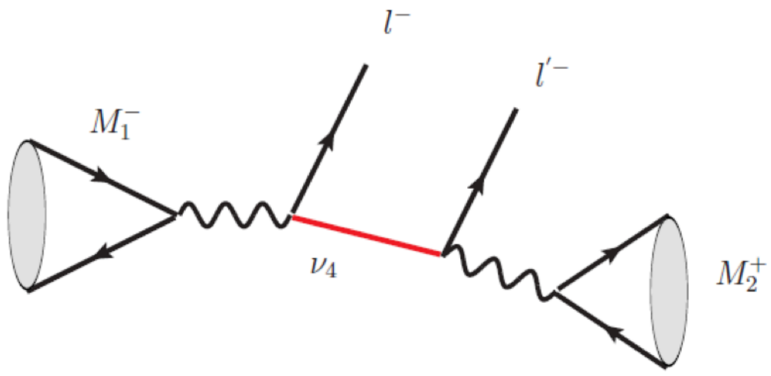
$$Z^0 \rightarrow h_1^- h_2^- l^+ l^+$$

$$\tau^\pm \rightarrow l^\mp h_1^\pm h_2^\pm$$

$$\tau^\pm \rightarrow \nu_\tau l^\pm l^\pm h_1^\mp$$



- Very light neutrinos $\rightarrow \langle m_{ll'} \rangle = \Sigma_i U_{il} U_{l'i} m_i$,
- Very heavy neutrinos $\rightarrow \Sigma_k V_{lk} V_{l'k} / m_k$,
- Resonant neutrinos $\rightarrow \Sigma_k V_{lk} V_{l'k} m_k / \Gamma_N$



Atre, Han, Pascolie and Zhang JHEP 0905,030(2009)

LNV processes at Z peak

LNV signals of Majorana neutrinos:	CEPC	Belle-II
$B^+/D^+ \to h^- l^+ l^+ (h = hadron)$	10^{-10}	10^{-10}
$B^0/D^0 \to h_1^- h_2^- l^+ l^+ (h = hadron)$	10^{-10}	10^{-10}
$Z^0 \to h_1^- h_2^- l^+ l^+$	10^{-11}	
$\tau^\pm \to l^\mp h_1^\pm h_2^\pm$	10^{-10}	10^{-9}
$\tau^\pm \to \nu_\tau l^\pm l^\pm h_1^\mp$	10^{-10}	10^{-9}

- Very light neutrinos $\to \langle m_{ll'} \rangle = \Sigma_i U_{il} U_{l'i} m_i$,
- Very heavy neutrinos $\to \Sigma_k V_{lk} V_{l'k} / m_k$,
- Resonant neutrinos $\to \Sigma_k V_{lk} V_{l'k} m_k / \Gamma_N$

Atre, Han, Pascolie and Zhang JHEP 0905,030(2009)

LNV meson decays: current limits

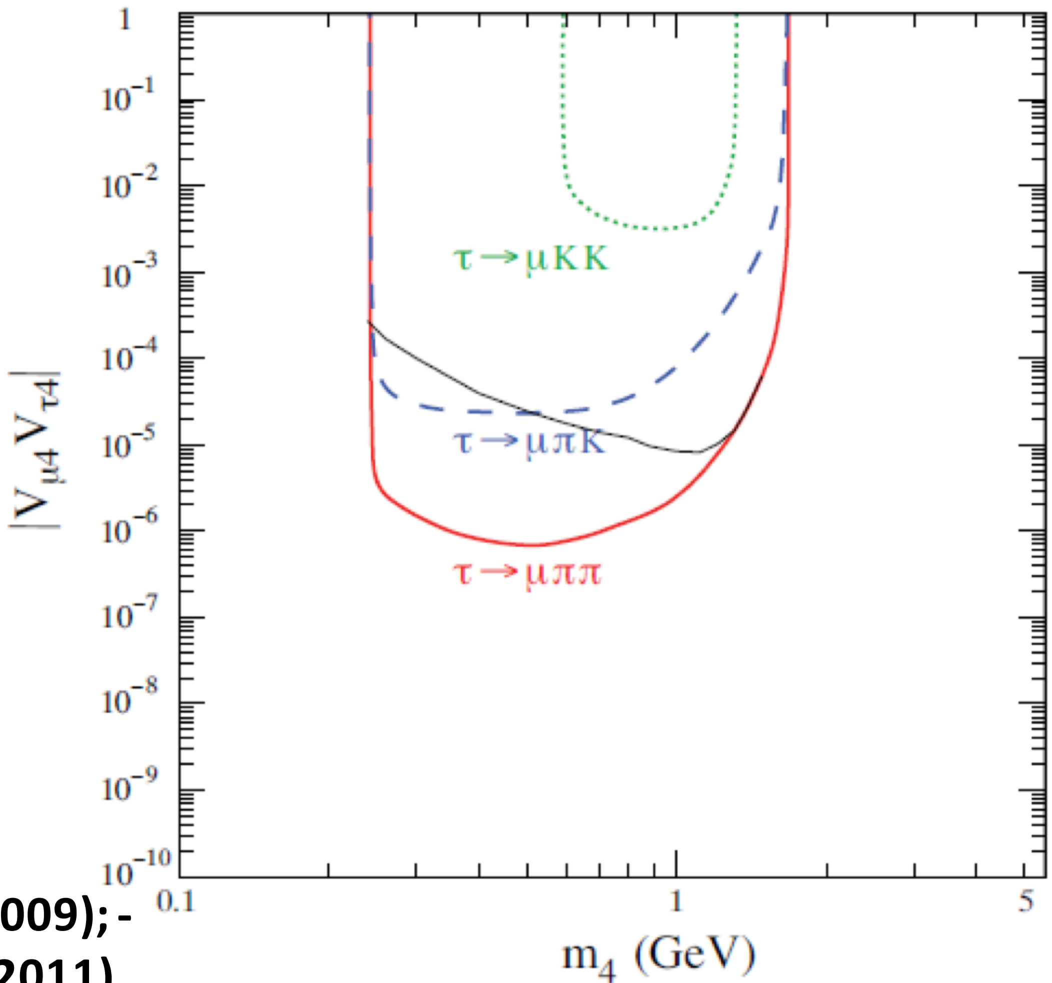
$K^+ \to \pi^- e^+ e^+$	6.4×10^{-10}				
$K^+ \to \pi^- \mu^+ \mu^+$	3.0×10^{-9}		PDG		
$K^+ \to \pi^- e^+ \mu^+$	5.0×10^{-10}				
$D^+ \to \pi^- e^+ e^+$	1.9×10^{-6}		$D_s^+ \to \pi^- e^+ e^+$	4.1×10^{-6}	
$D^+ \to \pi^- \mu^+ \mu^+$	2.0×10^{-6}		$D_s^+ \to \pi^- \mu^+ \mu^+$	14×10^{-6}	
$D^+ \to \pi^- e^+ \mu^+$	2.0×10^{-6}		$D_s^+ \to \pi^- e^+ \mu^+$	8.4×10^{-6}	BABAR1
$D^+ \to K^- e^+ e^+$	0.9×10^{-6}		$D_s^+ \to K^- e^+ e^+$	5.2×10^{-6}	
$D^+ \to K^- \mu^+ \mu^+$	10×10^{-6}		$D_s^+ \to K^- \mu^+ \mu^+$	13×10^{-6}	
$D^+ \to K^- e^+ \mu^+$	1.9×10^{-6}		$D_s^+ \to K^- e^+ \mu^+$	6.1×10^{-6}	
$B^+ \to \pi^- e^+ e^+$	2.3×10^{-8}	BABAR2	$B^+ \to D^- e^+ e^+$	2.6×10^{-6}	Belle
$B^+ \to \pi^- \mu^+ \mu^+$	10.7×10^{-8}	BABAR2	$B^+ \to D^- \mu^+ \mu^+$	1.8×10^{-6}	Belle
	4.0×10^{-9}	$LHCb$		6.9×10^{-7}	LHCb
$B^+ \to \pi^- e^+ \mu^+$	1.3×10^{-6}	BABAR2	$B^+ \to D^- e^+ \mu^+$	1.1×10^{-6}	Belle
$B^+ \to K^- e^+ e^+$	3.0×10^{-8}	BABAR2	$B^+ \to D_s^- \mu^+ \mu^+$	5.8×10^{-7}	LHCb
$B^+ \to K^- \mu^+ \mu^+$	6.7×10^{-8}	BABAR2	$B^+ \to D^{*-} \mu^+ \mu^+$	2.4×10^{-6}	LHCb
$B^+ \to K^- e^+ \mu^+$	2.0×10^{-6}	BABAR2			

BABAR1: J. P. Lees et al, PRD 84, (2011)
BABAR2: J. P. Lees et al, arXiv: 1202.3650
Belle: O. Seon et al, PRD 84 (2011)
LHCb: R. Aaij et al, PRL 104 (2011); arXiv: 1201.5600 LHCb, PRL 112,131802 (2014)

LNV τ data: current limit

Belle: PLB 682, 355 (2010), (90 % C.L.).

	$\mathcal{B}(\times 10^{-8})$
$\tau^- \to e^+\pi^-\pi^-$	8.8
$\tau^- \to e^+\pi^-K^-$	6.7
$\tau^- \to e^+K^-K^-$	6.0
$\tau^- \to \mu^+\pi^-\pi^-$	3.7
$\tau^- \to \mu^+\pi^-K^-$	9.4
$\tau^- \to \mu^+K^-K^-$	9.6



Atre, Han, Pascoli & Zhang, JHEP 0905, (2009); -
Helo, Kovalenko and Schmidt, NPB 853, (2011)

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$D^+ \to K^- \mu^+ \mu^+$	10×10^{-6}	$D_s^+ \to K^- \mu^+ \mu^+$	13×10^{-6}	
$D^+ \to K^- e^+ \mu^+$	1.9×10^{-6}	$D_s^+ \to K^- e^+ \mu^+$	6.1×10^{-6}	
$B^+ \to \pi^- e^+ e^+$	2.3×10^{-8} BABAR2	$B^+ \to D^- e^+ e^+$	2.6×10^{-6} Belle	
$B^+ \to \pi^- \mu^+ \mu^+$	10.7×10^{-8} BABAR2	$B^+ \to D^- \mu^+ \mu^+$	1.8×10^{-6} Belle	
	$4.0 \times 10^{-9} LHCb$		6.9×10^{-7} LHCb	
$B^+ \to \pi^- e^+ \mu^+$	1.3×10^{-6} BABAR2	$B^+ \to D^- e^+ \mu^+$	1.1×10^{-6} Belle	
$B^+ \to K^- e^+ e^+$	3.0×10^{-8} BABAR2	$B^+ \to D_s^- \mu^+ \mu^+$	5.8×10^{-7} LHCb	
$B^+ \to K^- \mu^+ \mu^+$	6.7×10^{-8} BABAR2	$B^+ \to D^{*-} \mu^+ \mu^+$	2.4×10^{-6} LHCb	
$B^+ \to K^- e^+ \mu^+$	2.0×10^{-6} BABAR2			

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$\tau^- \to e^+K^-K^-$	6.0
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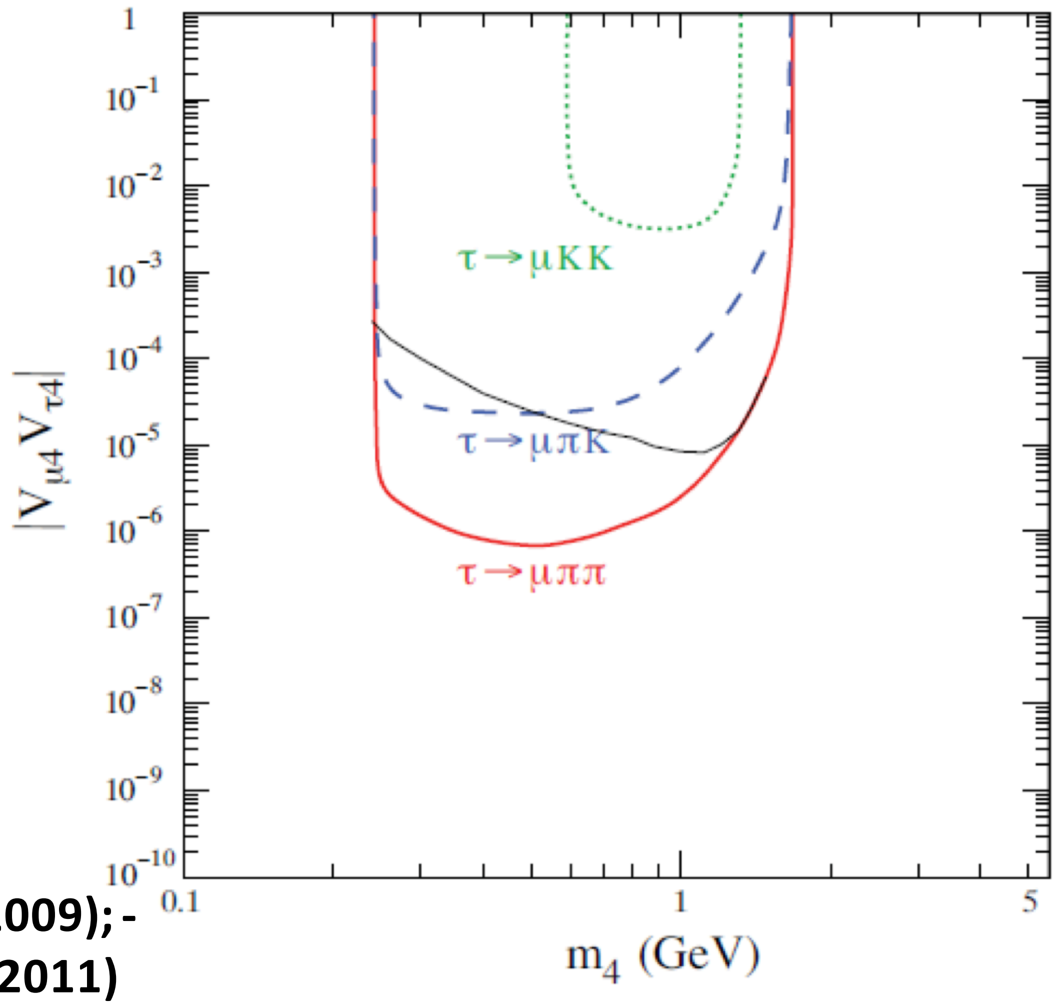
$\tau^- \to \mu^+\pi^-K^-$	9.4
$\tau^- \to \mu^+K^-K^-$	9.6



Atre, Han, Pascoli & Zhang, JHEP 0905, (2009); -
Helo, Kovalenko and Schmidt, NPB 853, (2011)

tau lepton at Z peak

Advantage of tau experiment at Z peak:

- Large production cross-section (1.5 nb)
- Strong boost, decay length: 2 mm
- Back-to-back event topology, 80% efficiency
- Clean background
- Good lepton and K_L ID

Disadvantage: K/pi ID is challenge

Tau lepton at Belle-II

- Low cross section and back-to-back
- Relatively short decay length : 0.25 mm
- High background from qqbar and B decays
- Good pi/K PID and Ks reconstruction
- Limited K_L reconstruction
- Low efficiency for high multiplicity

tau lepton reconstruction at Belle

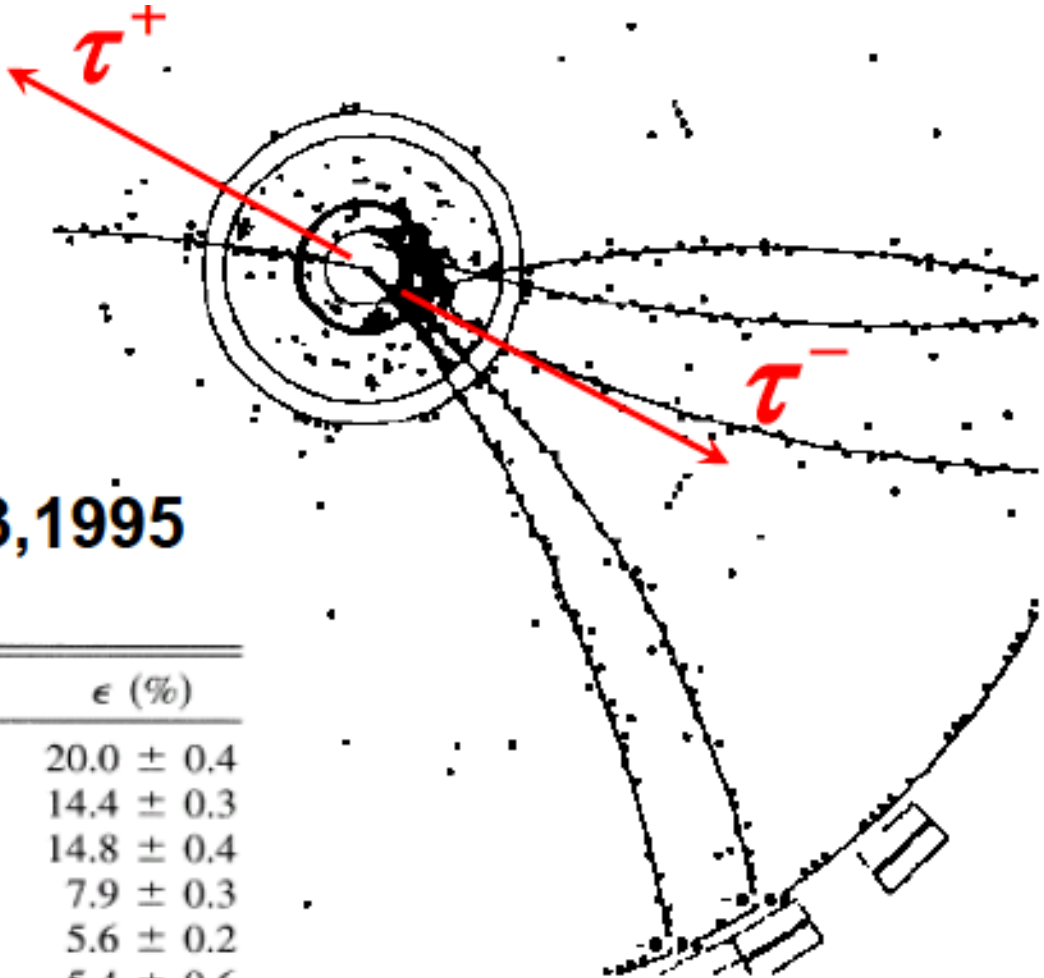
Ecm～10.6 GeV

Tau 对之间任意粒子的夹角均大于**90°**。

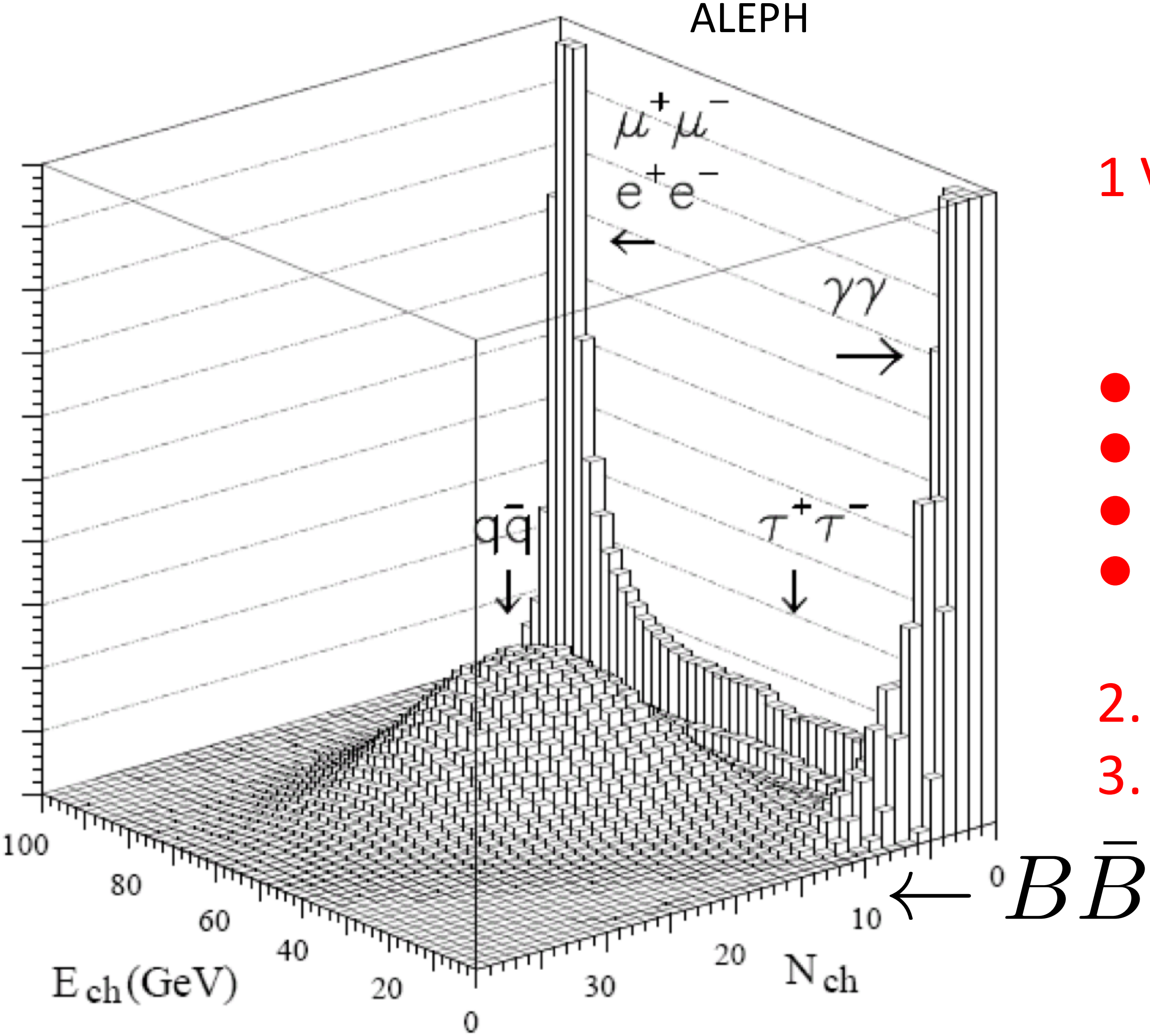
CLEO

Phys.Rev.Lett.75:3809-3813,1995

Sample	N_d	f_b^{τ} (%)	$f_b^{q\bar{q}}$ (%)	ϵ (%)
e-$3h$	18815	7.5 ± 0.2	0.2 ± 0.2	20.0 ± 0.4
μ-$3h$	13985	12.8 ± 0.2	0.3 ± 0.3	14.4 ± 0.3
$3h$-$3h$	4877	16.8 ± 1.3	6.5 ± 1.3	14.8 ± 0.4
e-$3h\pi^0$	3227	4.5 ± 0.4	0.3 ± 0.3	7.9 ± 0.3
μ-$3h\pi^0$	2335	10.3 ± 0.4	0.7 ± 0.7	5.6 ± 0.2
$3h$-$3h\pi^0$	1681	13.6 ± 0.6	12.3 ± 1.4	5.4 ± 0.6



tau lepton reconstruction @ Z peak



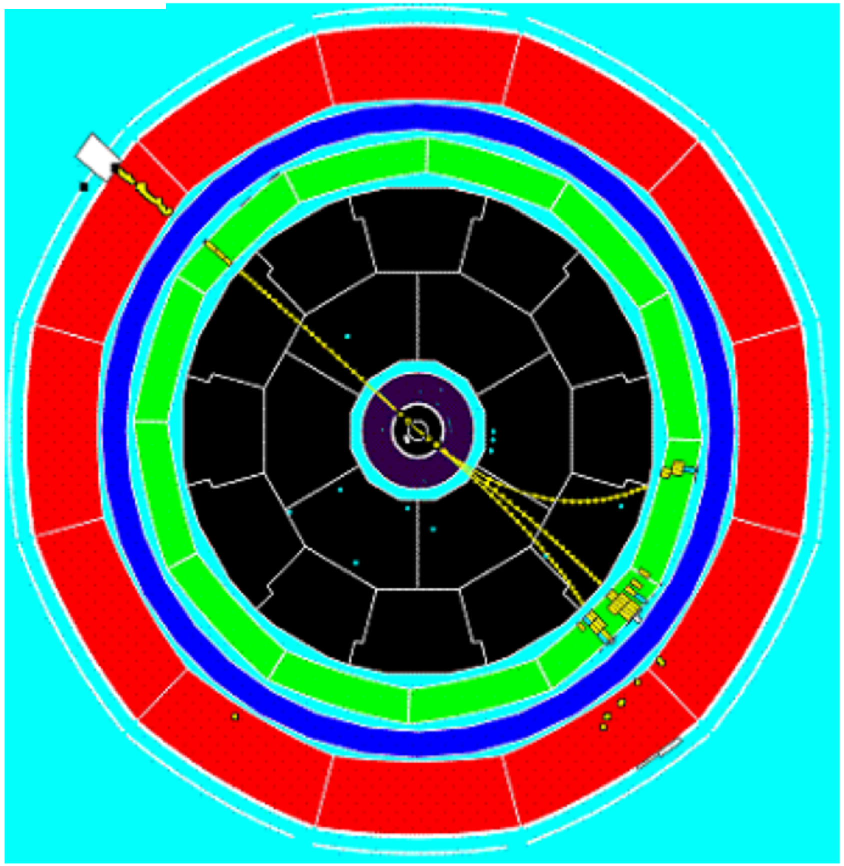
1 Very clean $\tau\tau$ events can be selected with very simple selection criteria.

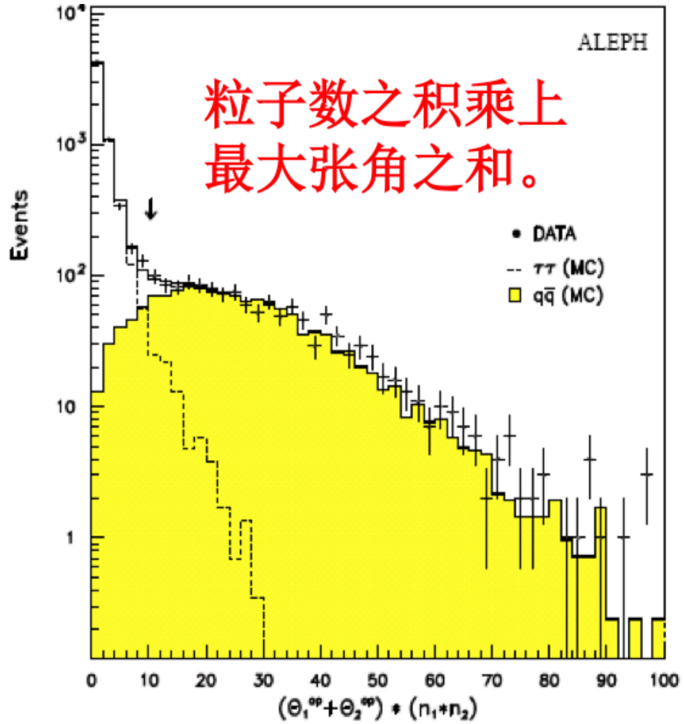
- Low track multiplicity
- Back-to-back
- Low invariant mass
- Total energy not very small

2. Subtract background
3. Classify all the events

tau lepton reconstruction at Z-peak

ALEPH





Ecm≈91 GeV

Z.Phys.C70:579-608,1996

Physics processes	Efficiency (%)	Contamination (%)
$Z^0 \to \tau^+\tau^-$	78.84 ± 0.13	
Bhabha		0.15 ± 0.03
$Z^0 \to \mu^+\mu^-$		0.07 ± 0.02
$\gamma\gamma \to e^+e^-$		0.07 ± 0.02
$\gamma\gamma \to \mu^+\mu^-$		0.08 ± 0.02
four-fermion		0.14 ± 0.02
cosmic rays		0.02 ± 0.01
$Z^0 \to q\bar{q}$		0.31 ± 0.09

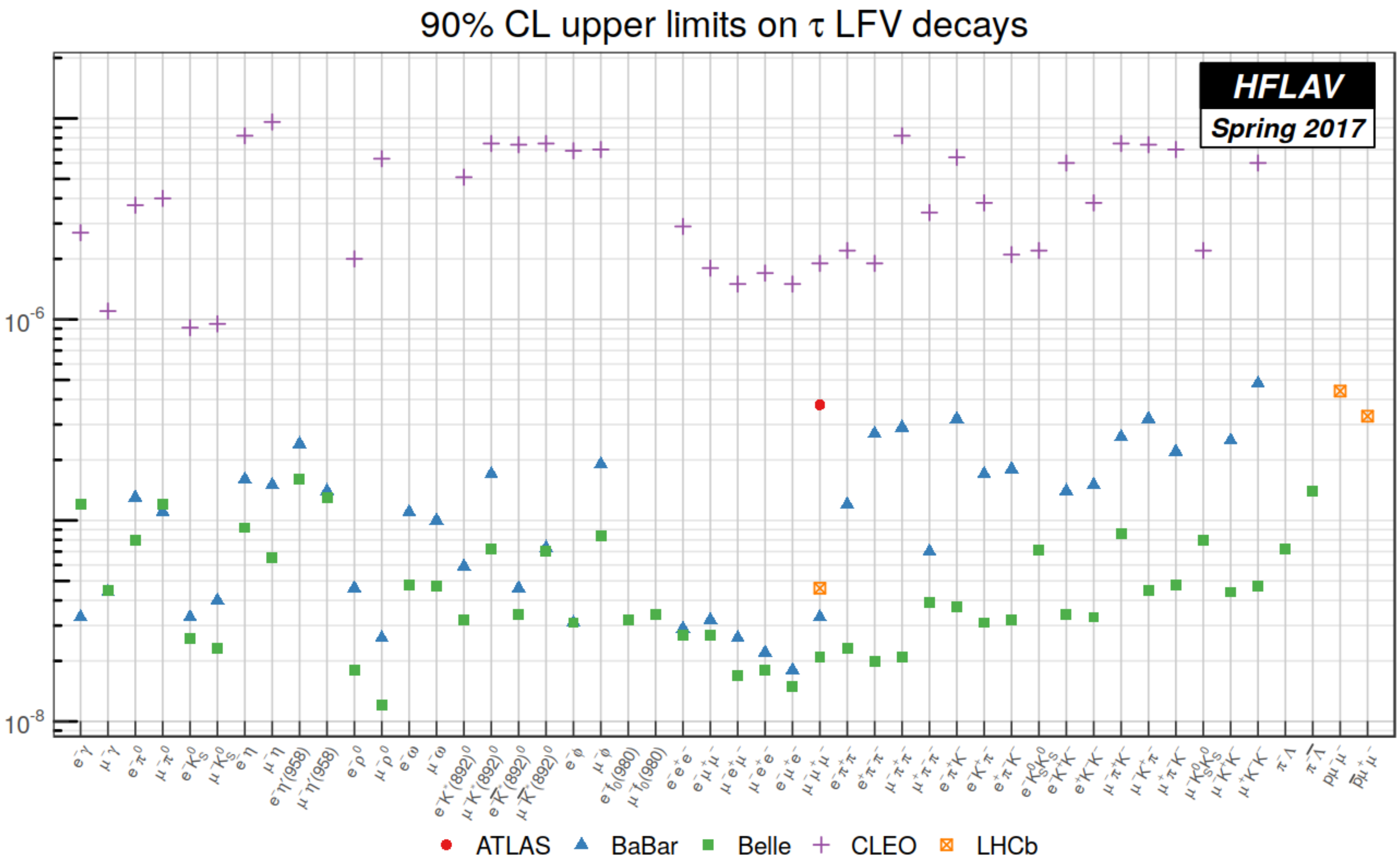
丢失的效率是因几何造成的

List of tau physics @ Z peak

- High precision tau decays rates (uncertainty: 10^{-5})
- Vus, tau life time, tau coupling, αQCD etc.
- Rare: cLFV, LNV …
- CPV in tau production and decay (10^{-4})
- Anomalous magnetic moment of the tau: ~10^{-6} -10^{-7}
- Electric Dipole Moment of the tau: Re(d_{tau}) ~ 10^{-19} e cm
- Weak Dipole Moments of the tau (Z and W coupling)

cLFV in tau decays

6×10^{10} τ pairs on Z pole at CEPC → reach at 10^{-9}-10^{-10}



Heavy quarks @ Z peak

Two key issues: *CP* violation and rare *b*-decays (FCNC)

LHCb sees all species of *b*-particles (and charm in abundance) and is especially good at rare decays with muons and fully charged decay modes. However less efficient for electrons, neutrals, missing energy, hadronic multibody decays.

Belle II should explore deeply/widely the B_d and B_u meson systems. Might also runs above the Υ(5S) threshold but can't resolve the oscillation and TD CPV of B_s meson, and cannot do Bc and b baryons.

Heavy quarks @ Z peak

b-hadron productions at CEPC and Belle-II

b-hadron species	Fraction in decays of $Z^0 \to b\bar{b}$	Number of b-hadron at Z^0 peak	Fraction in $\Upsilon(4S)/(5S)$ decays	Number of b-hadron at $\Upsilon(4S)/(5S)$
B^0	0.404 ± 0.009	22.0×10^{10}	0.486 ± 0.006 ($\Upsilon(4S)$)	4.9×10^{10}
B^+	0.404 ± 0.009	22.0×10^{10}	0.514 ± 0.006 ($\Upsilon(4S)$)	5.1×10^{10}
B_s	0.103 ± 0.009	5.4×10^{10}	0.201 ± 0.030 ($\Upsilon(5S)$)	0.6×10^{10}
b baryons	0.089 ± 0.015	4.8×10^{10}	–	–

- The production rate of Bc meson is small, $10^6 - 10^7$ Bc mesons are expected from NRQCD

- In the first class of Λ_b decays one gets $p\pi^-$, $p\pi^-\pi^0$, pK^-K^0, ΛK^-, $p\pi^-\pi^+\pi^-$, $p\pi^-K^+K^-$, $p\pi^-\bar{K}^0K^0$, etc.

  In the second class one probes pK^-, $pK^-\pi^0$, $pK_S\pi^-$, ΛK^+K^- etc.

- Ξ_b^- decays lead to $\Lambda^0\pi^-$, $\Lambda^0\pi^-\pi^0$ etc. and Λ^0K^-, $\Lambda^0K^-\pi^0$, $\Lambda^0\bar{K}^0\pi^-$ etc.

  For Ξ_b^0 decays one probes FS about $\Sigma^+\pi^-$, $\Lambda^0\pi^+\pi^-$ etc. and Σ^+K^-, $\Lambda^0\pi^+K^-$ etc.

- For obvious reasons we list only first class of Ω_b^-, namely $\Xi^0\pi^-$, Ω^-K^0.

Heavy quarks @ Z peak

Likely unique to CEPC:

1) Any leptonic or semileptonic decay mode involving *Bs, Bc* or *b*-baryon, including electrons and taus.
2) Any decay mode involving *Bs, Bc* or *b*-baryon with neutrals.
3) Multibody (means 4 and more) hadronic *b*-hadron decays.

$$B_s \to \phi\tau\tau \qquad B_s \to \eta\mu\mu$$

$$B_s \to \eta'\tau\tau \qquad B_s \to \eta'\mu\mu$$

$$B^0 \to K^{(*)}\tau\tau \qquad B^0 \to \pi^0\mu\mu$$

$$B^0 \to \pi^0\tau\tau \qquad B^0 \to \eta\mu\mu$$

$$B^+ \to K^{+(*)}\tau\tau \qquad B \to h\nu\bar{\nu}$$

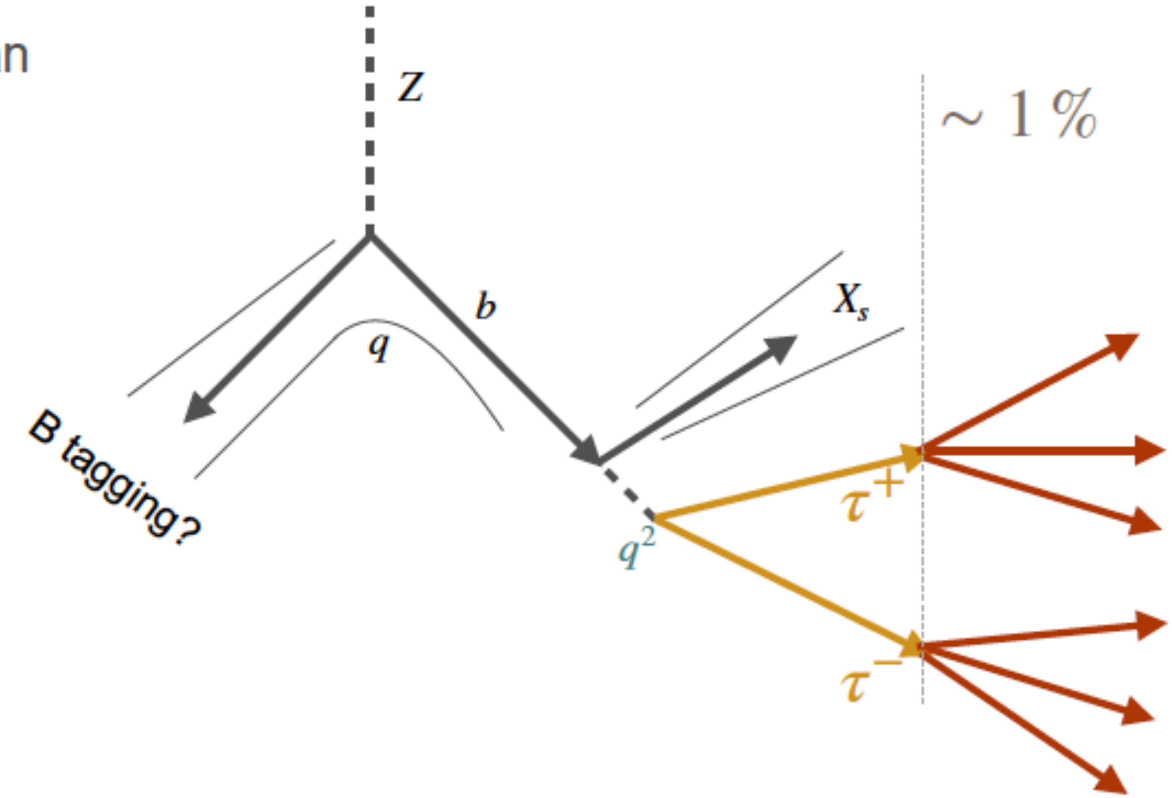
B/Bs → (K*) tau tau

Reconstruction Methods

Talk by Simon Wehle

Inclusive

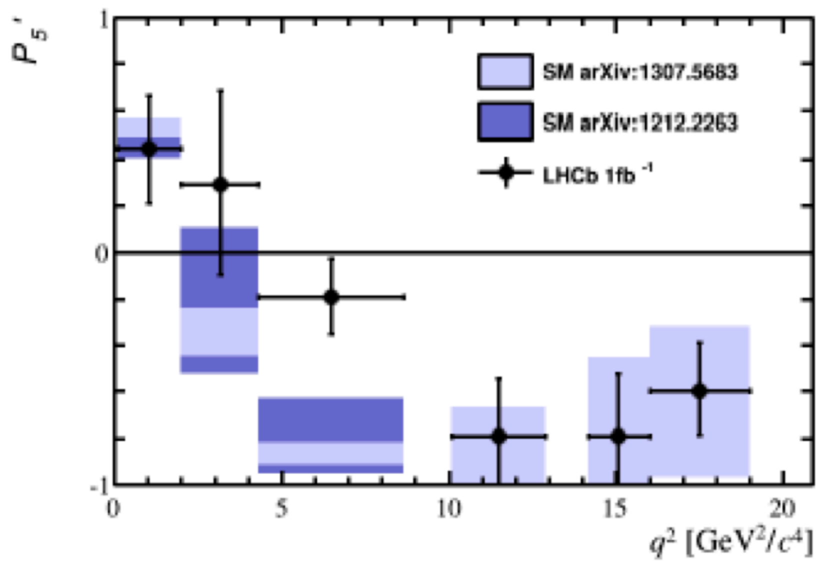
- Inclusive decays offer very clean theoretical observables
- Important benchmarks:
  - Kaon identification
  - Ks finding
- Possible problems
  - difficult to estimate spectator



Flavors at the *Z*: EW penguins

	$3\,\text{fb}^{-1}$ (7+8 TeV)	2015	CEPC	LHCb Upgrade
$B^0 \to K^{*0}\mu^+\mu^-$	$2.6\text{k}^\dagger$	$1.4 - 2.1\text{k}$	20k	34 k
$B^+ \to K^+\mu^+\mu^-$	4746 ± 81	$2.6 - 3.9\text{k}$	10k	61.6 k
$B^+ \to \pi^+\mu^+\mu^-$	100	$50 - 80$	1000	1280
$B^+ \to K^+e^+e^-$ $(1 < q^2 < 6)$	256^{+25}_{-23}	$140 - 210$	10k	3320

†with enlarged q^2 windows for $3\,\text{fb}^{-1}$ analysis



LHCb update and CEPC will improve it by a factor of 3-4 after 2028. Theoretical uncertainty is in the same level.

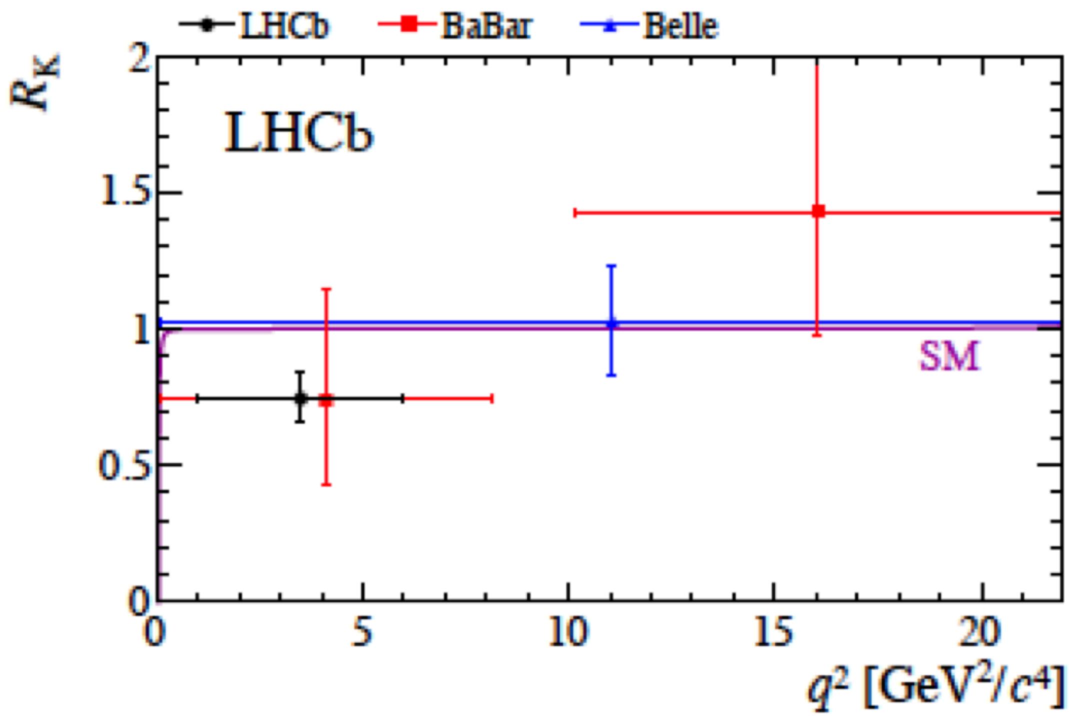
At CEPC we can search for:

$B_s \to \eta\mu\mu$	$B_s \to \phi\tau\tau$
$B_s \to \eta'\mu\mu$	$B_s \to \eta'\tau\tau$
$B^0 \to \pi^0\mu\mu$	$B^0 \to K^{(*)}\tau\tau$
$B^0 \to \eta\mu\mu$	$B^0 \to \pi^0\tau\tau$
$B \to h\nu\bar{\nu}$	$B^+ \to K^{+(*)}\tau\tau$

Flavor at the Z: EW penguins

Lepton universality

$$R_K = \frac{\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)}{\mathrm{BR}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}(stat) \pm 0.036(syst)$$



LHCb, PRL 113 (2014) 151601
Belle, PRL 103 (2009) 171801
Babar, PRD 86 (2012) 032012

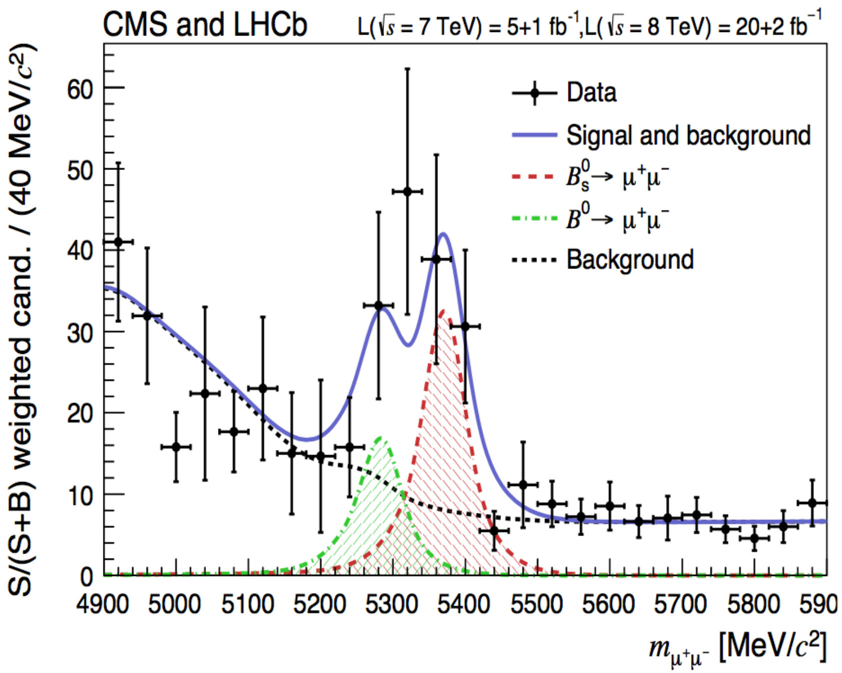
Consistent with SM within 2.6 σ

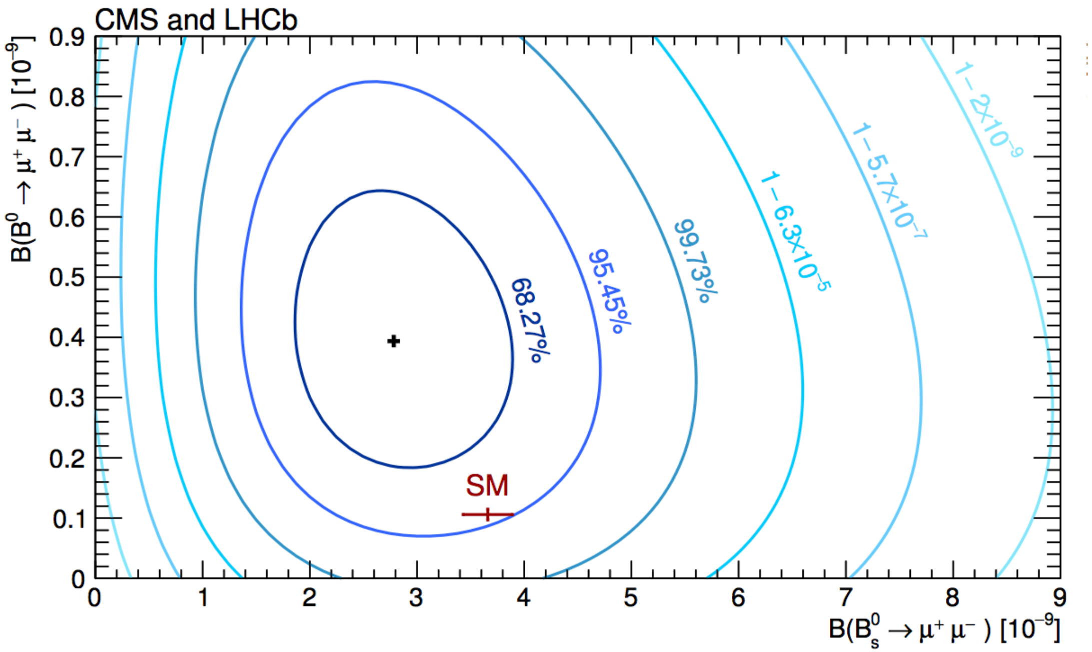
R_K is theoretical extremely clean:

$R_K = 1 + O(10^{-4})$

CEPC reach: (2-4) %

Flavors at the Z: EW & Higgs penguins





LHCb and CMS, arXiv:1411.4413

$$B(B^0 \to \mu\mu) = (3.94^{+1.58+0.31}_{-1.41-0.24}) \times 10^{-10} (3.2\sigma)$$

$$B(B_s \to \mu\mu) = (2.79^{+0.66+0.26}_{-0.60-0.19}) \times 10^{-10} (6.2\sigma)$$

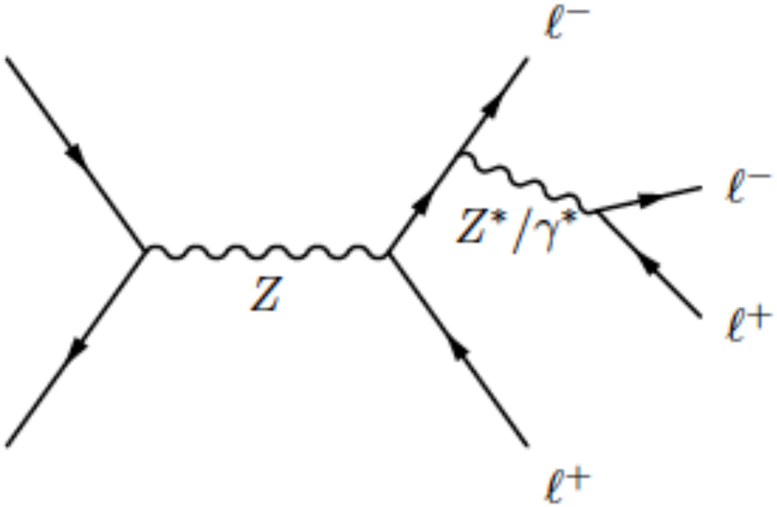
$$B(B^0 \to \mu\mu) = (1.06 \pm 0.09) \times 10^{-10}$$

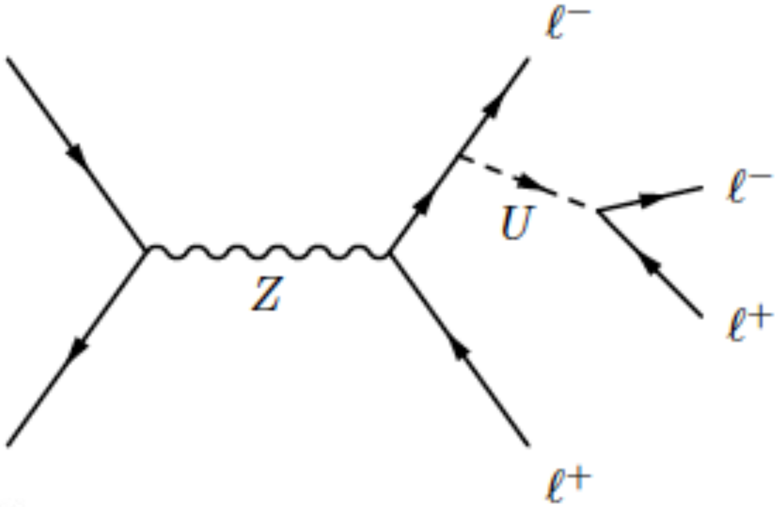
$$B(B_s \to \mu\mu) = (3.66 \pm 0.23) \times 10^{-10}$$

Theory: Bobeth et al.
PRL 112(2014)101801

Probe New physics in Z four-body decays

Example: $Z \to b\bar{b}l^+l^-, \;\; l^+l^-l'^+l'^-$





$Z \to l^+l^-l^+l^-$

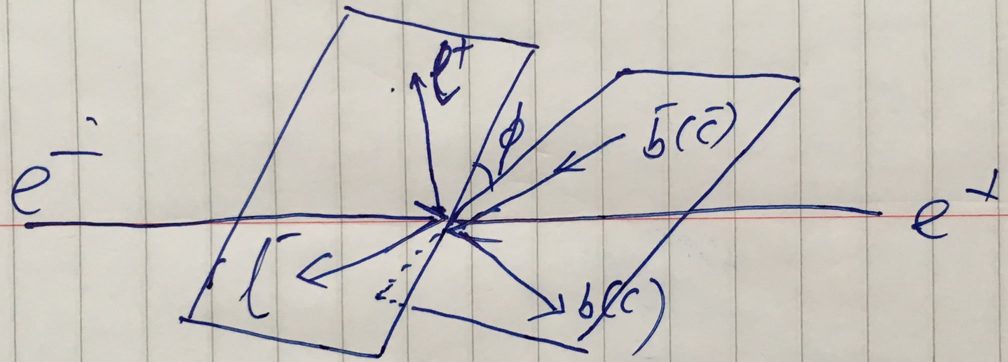
U could be scalar or vector boson

arXiv:1805.05791

CPV in Z decays

$$\mathcal{B}(Z \to b\bar{b}l^+l^-) \approx 10^{-5} - 10^{-6}$$

$Z \to b\bar{b}\, l^+ l^-$, $\quad Z \to l'^+ l'^- l^+ l^+$



T odd: $(\vec{P}_{\bar{b}} \times \vec{P}_b)\cdot \vec{P}_{l^-}$, $\quad (\vec{P}_{l^+} \times \vec{P}_{l^-})\cdot \vec{P}_b$

$$A = \frac{N(\cos\phi \cdot \sin\phi > 0) - N(\cos\phi \cdot \sin\phi < 0)}{N(\cos\phi \cdot \sin\phi > 0) + N(\cos\phi \cdot \sin\phi < 0)}.$$