Heavy Flavour Physics at SJTU

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2017 SJTU-KIT Collaborative Research Workshop "Particles and the Universe"

LHCb：Tsinghua，GUCAS，CCNU

BelleII：IHEP，Beihang

Particle Theory

3 Professors + 4 Associate Professors + 3 Postdo

Xiao-Gang He

Xiangdong Ji

Hong-Jian He

Wei Wang

Pei-Hong Gu

Jun Gao

Yue Zhao

Outline

- Heavy Flavour Physics
- Theoretical HFP Activities at SJTU
  - Finite Width Problem in B decays
  - Weak Decays of Doubly heavy baryons
- Possible connection to HFP Group at KIT

Fundamental Particles

Quarks


up


charm


top


down


strange


bottom

Leptons


electron


muon

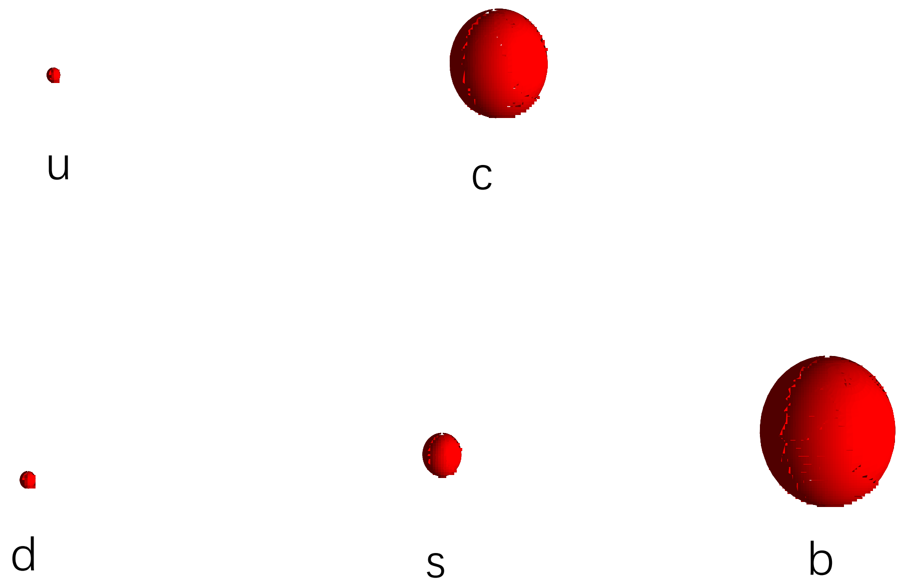

tau


electron neutrino


muon neutrino


tau neutrino

Quark Mass Hierarchy



m_u:2MeV
m_d:5MeV
m_s:95MeV

Light Flavour

m_c:1.3GeV
m_b:4.7GeV

Heavy Flavour

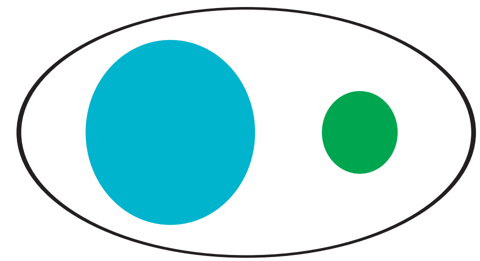
m_t:173GeV

Heavy Flavour Physics: B Physics

- Bound states of b and light quarks

$$\text{mesons}: B^-, B^0, B_s^0$$

$$\text{baryons}: \Lambda_b, \Xi_b^-, \Xi_b^0$$



- Heaviest stable bound states in QCD (>5.2GeV)
- Rich spectrum, many decay channels
- Important source of information about CP violation, CKM parameters and new physics

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Where do we study heavy flavour?

(Super) Flavor Factories

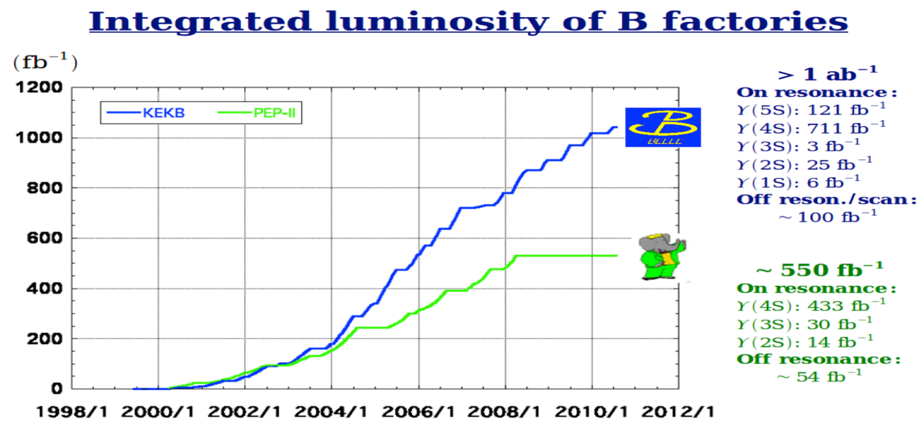
Experiments providing most of analyses today

3.1 GeV e^+
9 GeV e^-

3.5 GeV e^+
8 GeV e^-

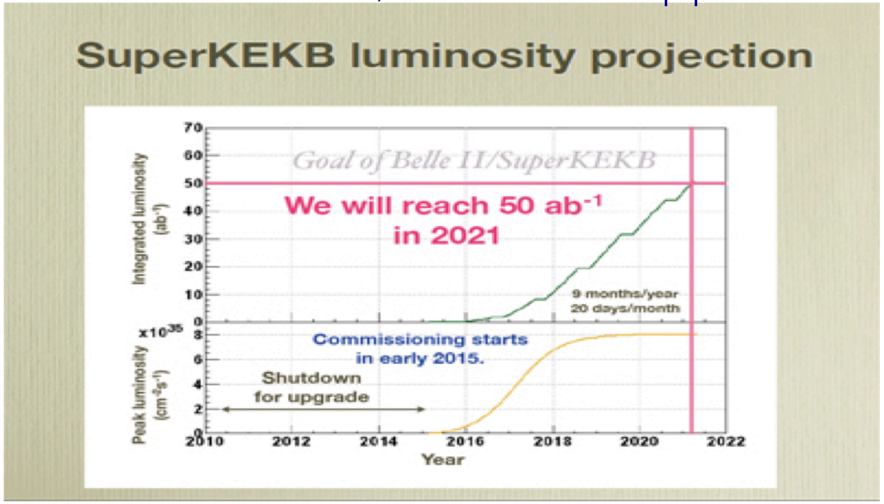
Ongoing Experiments

Planned facilities



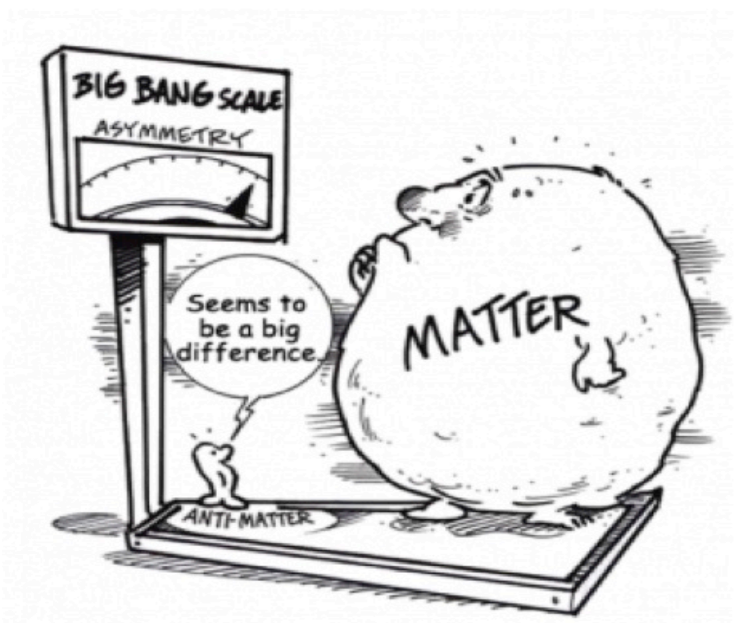
10^9 events, leading to Nobel Prize in 2008

10^{11} events, what will happen?

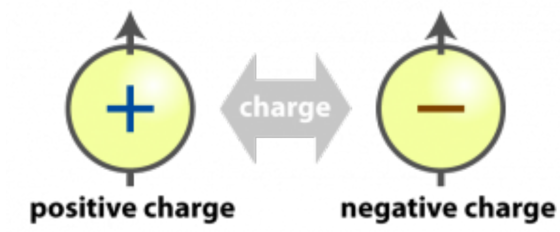


Experimental prospect is very promising!

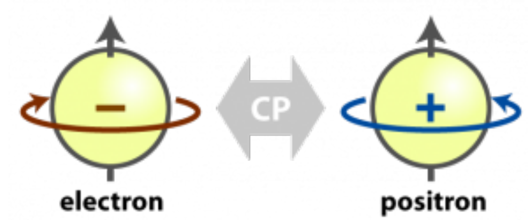
Why HFP?



C:Matter-AntiMatter



CP



One needs C and CP violation in PP.

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CP Asymmetry in Hadron System

- In Kaon system, the CP asymmetry (CPA) can reach roughly 0.2%
- In D decays, CPA at 1% is often argued to be New physics.
- Direct CPA in B decays:

$$A_{cp}(B\rightarrow K^+\pi^-)=(-8.2\pm0.6)\%;\quad A_{cp}(B\rightarrow \pi^+\pi^-) = (31\pm5)\%$$

- In B decays, $\sin(2\beta)$ = 67.2%! Large mixing CPA

B physics→ Ideal Platform to study CPA

Why HFP?

In the past decades, particle physics goes into two directions:

high energy + high precision

- High Energy: LEP, Tevatron, LHC, …

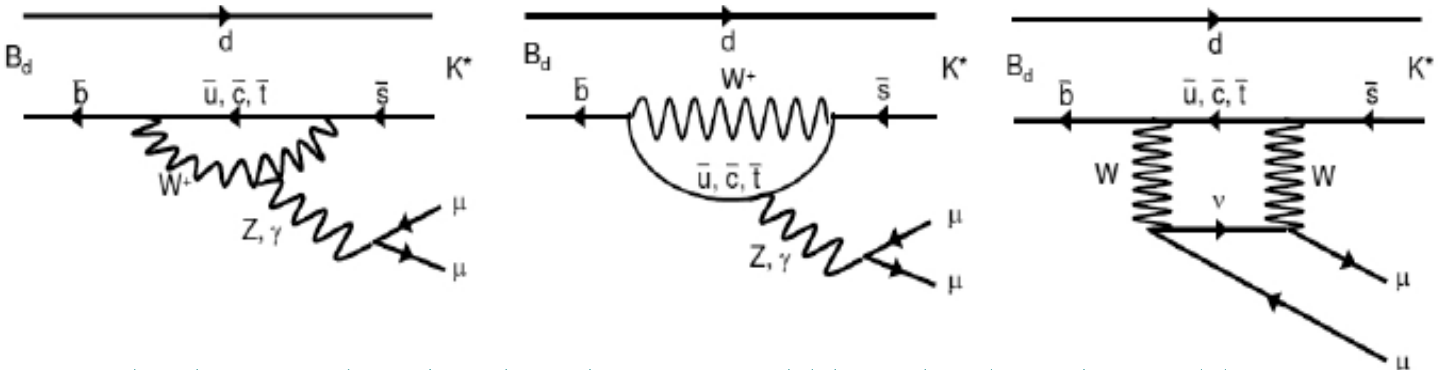
  New particles: W, Z, top, Higgs, …

- High Precision: B factories, BES, LHCb, Belle-II, …

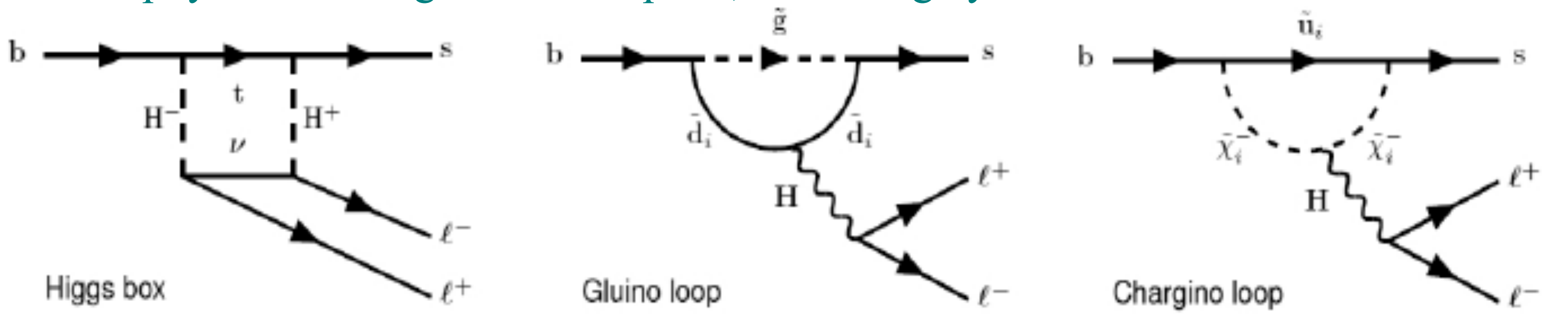
  New phenomena

Why HFP? $B \rightarrow K^* l^+ l^-$: Indirect Search for NP

- Within the SM, these processes proceed via loop diagrams like



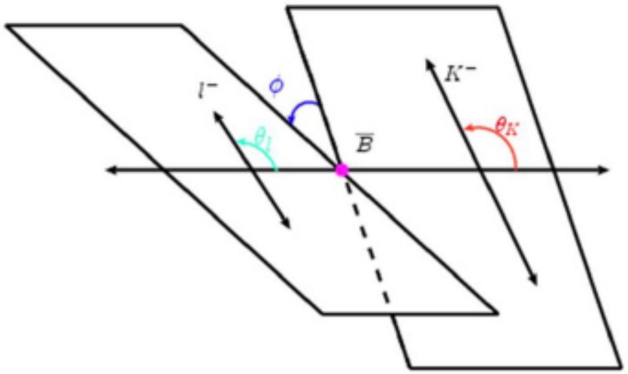
- New physics entering the virtual parts, could largely alter observables

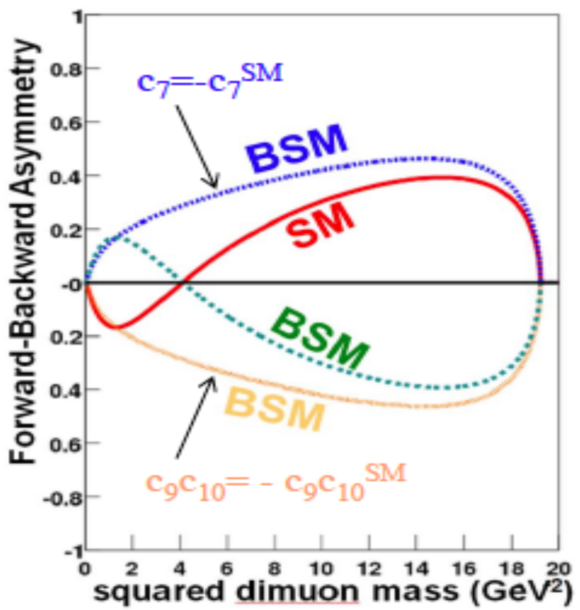


- Effective Hamiltonian: $\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} (C_i^{SM} + \Delta C_i^{NP}) \mathcal{O}_i$

Wilson coeffs. (short-dist. interactions) Operators (long-dist. interactions)

Why HFP: Forward-backward asymmetry





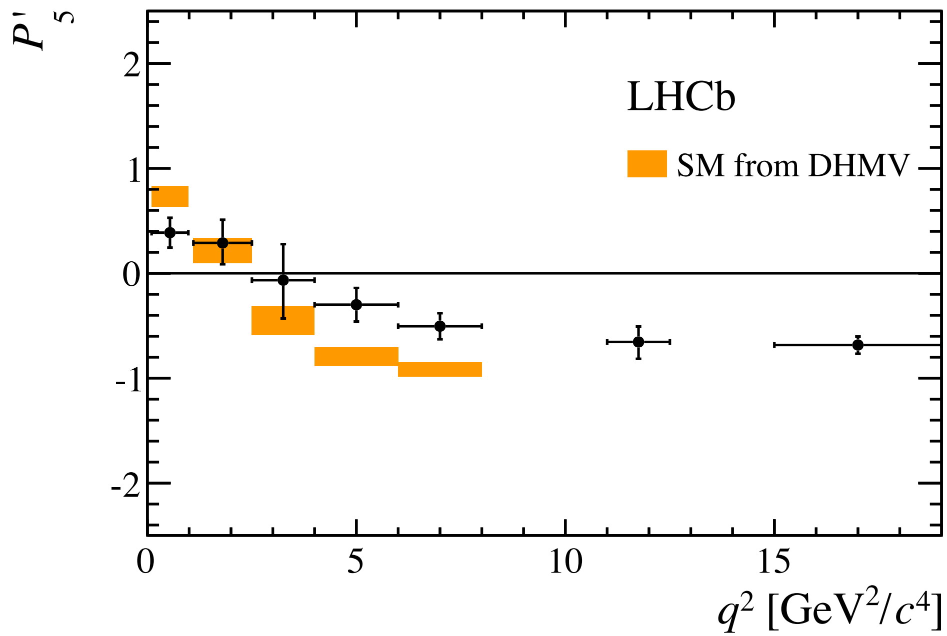
- θ_l: angle of emission between K^{*0} and μ^- in di-lepton rest frame
- θ_{K^*}: angle of emission between K^{*0} and K^- in di-meson rest frame.
- ϕ: angle between the two planes
- q^2: dilepton invariant mass square

$$A_{\rm FB}(q^2) = \frac{P_{\rm F}(q^2) - P_{\rm B}(q^2)}{P_{\rm F}(q^2) + P_{\rm B}(q^2)}$$

A.Ali, et. al, hep-ph/9910221

LHCb: 1512.04442 (3fb^{-1})
ABSZ: 1503.05534

Why HFP: 3.7σ deviations



Form-factor independent observables $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$

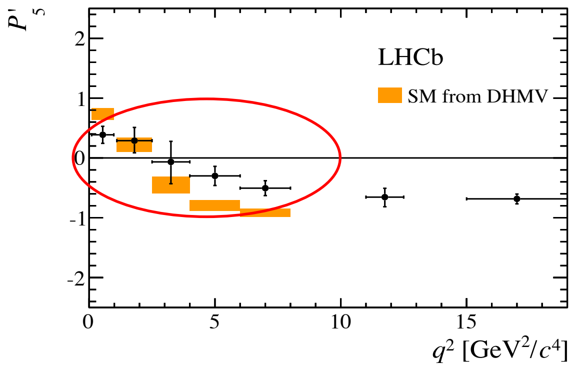
LHCb: 1512.04442
DHMV:1407.8526

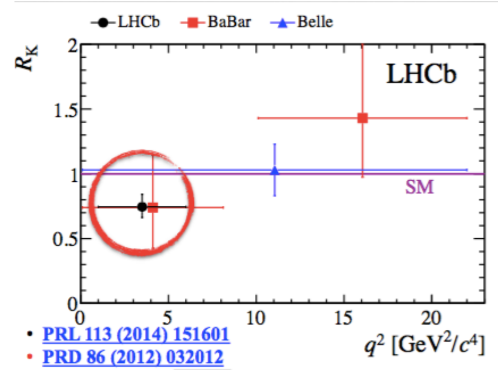
In PP, 5σ deviation is a sign for an important discovery.

Why HFP: Anomalies in B decays

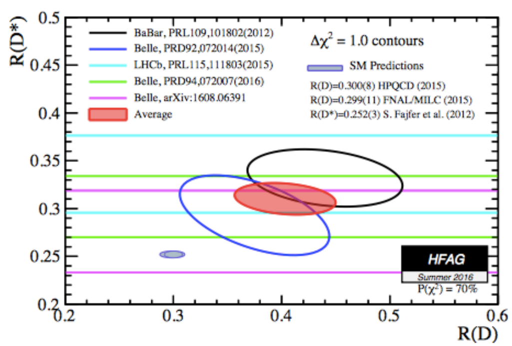
B->D$^{(*)}$ $\tau\nu$， b-> s $\mu\mu$

G. Ciezarek, et.al, Nature 546, 227 (2017)





- PRL 113 (2014) 151601
- PRD 86 (2012) 032012
- PRL 103 (2009) 171801



LHCb Preliminary	low-q^2	central-q^2
$\mathcal{R}_{K^{*0}}$	$0.660\ ^{+\ 0.110}_{-\ 0.070} \pm 0.024$	$0.685\ ^{+\ 0.113}_{-\ 0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]

LHCb arXiv: 1705.05802

In PP, 5σ deviation is a sign for an important discovery.

Why HFP: High Precision

- QCD Radiative corrections
- High Power corrections

$$\alpha_s/\pi \sim 10\% \to (\alpha_s/\pi)^2 \sim 1\%$$

$$\Lambda/m_b \sim 20\% \to (\Lambda/m_b)^2 \sim 4\%$$

- Mismatch between theory and data

$$\Gamma_{K^*}/m_{K^*} \sim 6\% \to (\Gamma_{K^*}/m_{K^*})^2 \sim 1\%$$

1. **Chiral Dynamics and S-wave Contributions in Semileptonic B decays**
   Michael Döring (Bonn U. & Bonn U., HISKP), Ulf-G. Meißner (JCHP, Julich & IAS, Julich & Bonn U. & Bonn U., HISKP), Wei Wang (Bonn U. & Bonn U., HISKP). Jul 3, 2013. 34 pp.
   Published in **JHEP 1310 (2013) 011**
   DOI: 10.1007/JHEP10(2013)011
   e-Print: **arXiv:1307.0947** **[hep-ph]** | **PDF**
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record - Cited by 43 records

Why HFP: Finite Width Problem

K* (50 MeV): B→K*l⁺l⁻ is a four-body process.

Experimental cuts by LHCb:

LHCb-CONF-2015-002

$$m_{K^*} - \delta_m < m_{K\pi} < m_{K^*} + \delta_m \qquad \delta_m = 100\mathrm{MeV}$$

$$\int_{(m_{K^*}-\delta_m)^2}^{(m_{K^*}+\delta_m)^2} dm_{K\pi}^2 |L_{K^*}(m_{K\pi}^2)|^2 = 0.56$$

L denotes the distribution function of Kπ system from K*

Narrow width limit (theoretical results):

$$\int dm_{K\pi}^2 |L_{K^*}(m_{K\pi}^2)|^2 = \mathcal{B}(K^{*+} \to K^0\pi^+) = \frac{2}{3}$$

Why HFP: Finite Width Problem

Experimental cuts by LHCb:

$$m_{K^*} - \delta_m < m_{K\pi} < m_{K^*} + \delta_m \qquad \delta_m = 100\mathrm{MeV}$$

We expect the S-wave:

Doring, Meissner, WW, 1307.0947

$$\int_{(m_{K^*}-\delta_m)^2}^{(m_{K^*}+\delta_m)^2} dm_{K\pi}^2 |L_S(m_{K\pi}^2)|^2 = 0.17$$

It is mandatory to include the S-wave: $B \to (K\pi)_S l^+ l^-$

Why HFP: Finite Width Problem

χPT effective field theory based on the two assumptions

- π's are the Goldstone boson of $SU(3)_L \otimes SU(3)_R \to SU(3)_V$
- *(chiral) power counting* i.e. the theory has a small expansion parameter: $p^2/\ \Lambda^2_{\chi SB}$: $\Lambda_{\chi SB} \sim 4\pi F_\pi \sim 1.2$ GeV

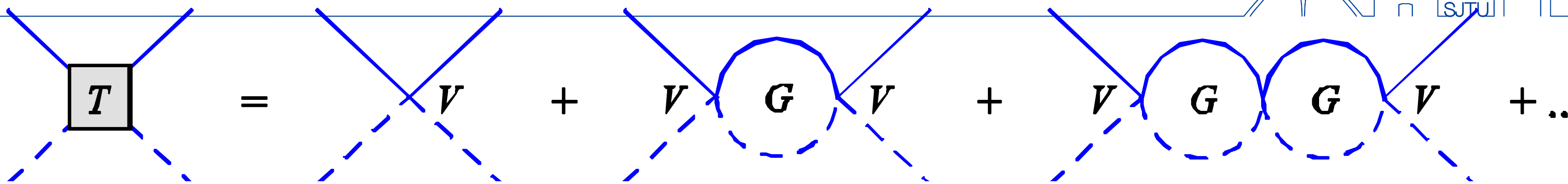
$$\mathcal{L}_{\Delta S=0} = \mathcal{L}^2_{\Delta S=0} + \mathcal{L}^4_{\Delta S=0} + \cdots = \frac{F_\pi{}^2}{4} \overbrace{\langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + U \chi^\dagger \rangle}^{\pi\to l\nu,\ \pi\pi\to\pi\pi,\ K\to\pi..} + \overbrace{\sum_i L_i O_i}^{K\to\pi..} + \cdots$$

Fantastic chiral prediction $A_{\pi\pi} \sim (s - m_\pi^2)/F_\pi{}^2$ Weinberg, Colangelo *et al*

$$\mathcal{L}_{\Delta S=1} = \mathcal{L}^2_{\Delta S=1} + \mathcal{L}^4_{\Delta S=1} + \cdots = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K\to 2\pi/3\pi} + \underbrace{G_8 F^2 \sum_i N_i W_i}_{K^+\to\pi^+\gamma\gamma,\, K\to\pi l^+ l^-} + \cdots$$

⚠ ChiPT limited to low energies

Unitarized Approach

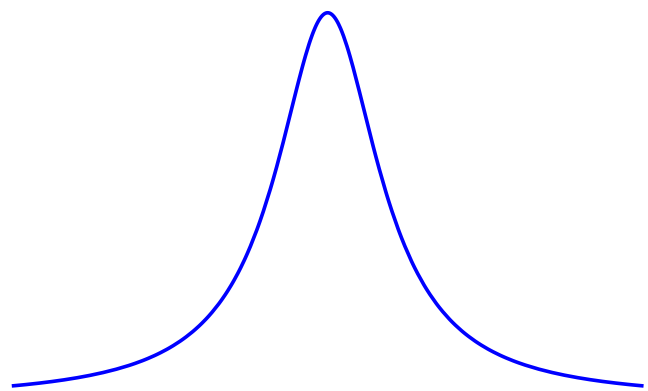


Summing all order contributions:

$$V + VGV + VGVGV + \ldots = \frac{V}{1 - GV}$$

1-GV＝0

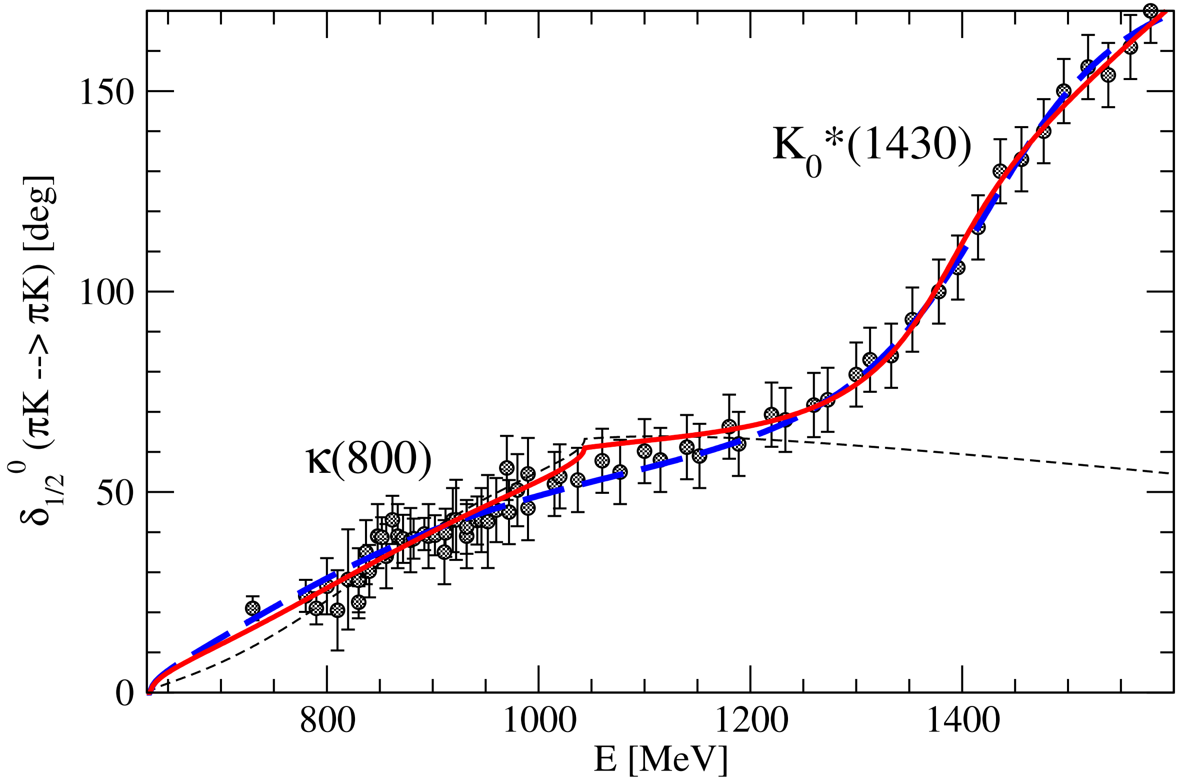
s=s$_0$



Above Threshold：pole corresponds to resonance

→ Hadron Molecule

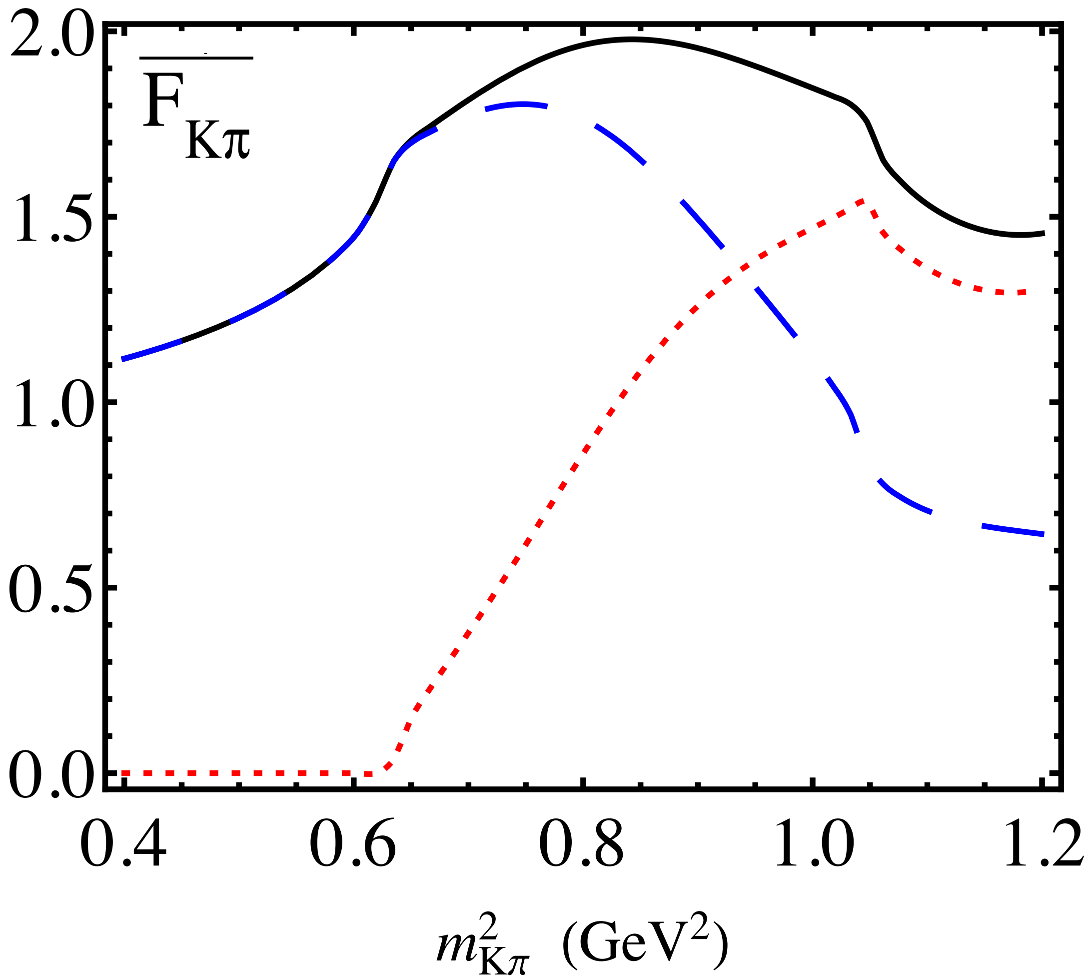
Unitarized χPT and phase shift



M.Döring,U.-G.Meißner,WW,1307.0947

Phase Shift

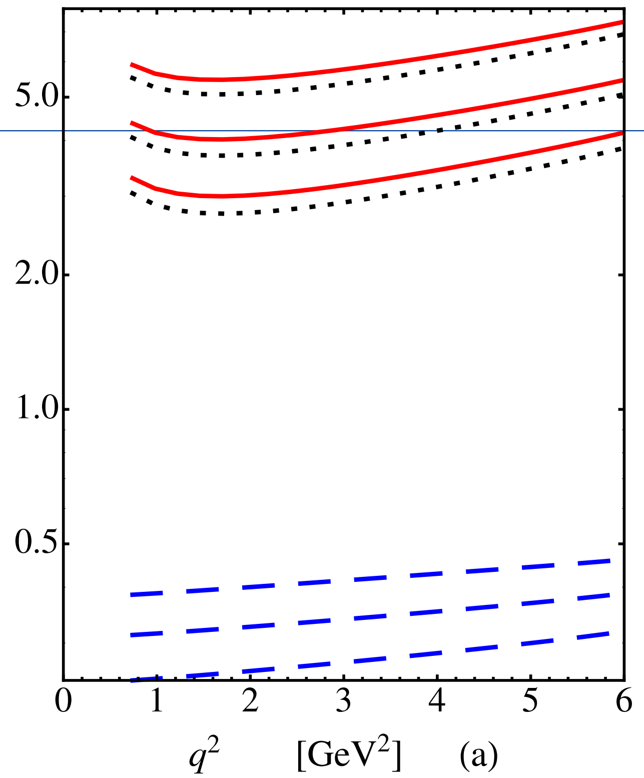
Scalar form factors in χPT



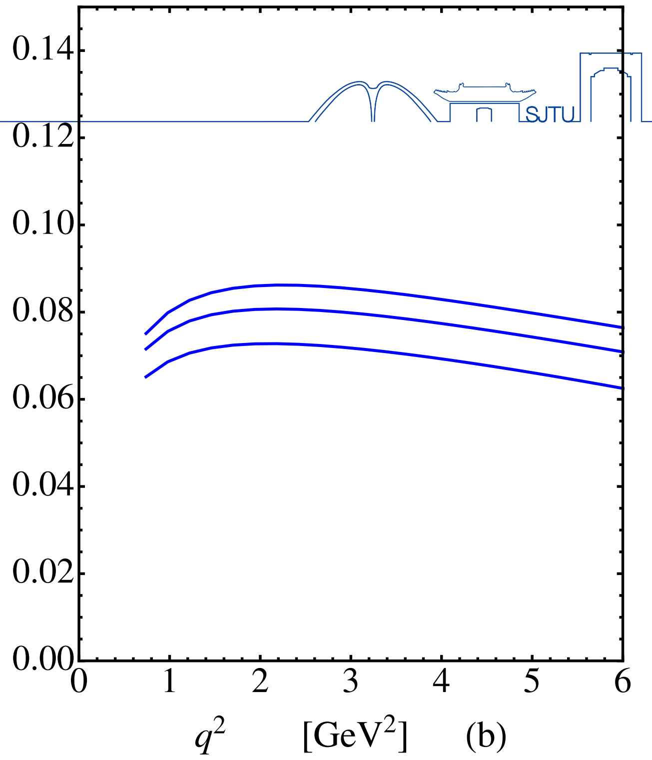
twice-subtracted Omnes solution matched onto χPT

Imaginary part
Real part
Magnitude

S-wave contributions in B➔Kπl⁺l⁻



Decay widths:
Red: total
Black: P-wave
Blue:S-wave



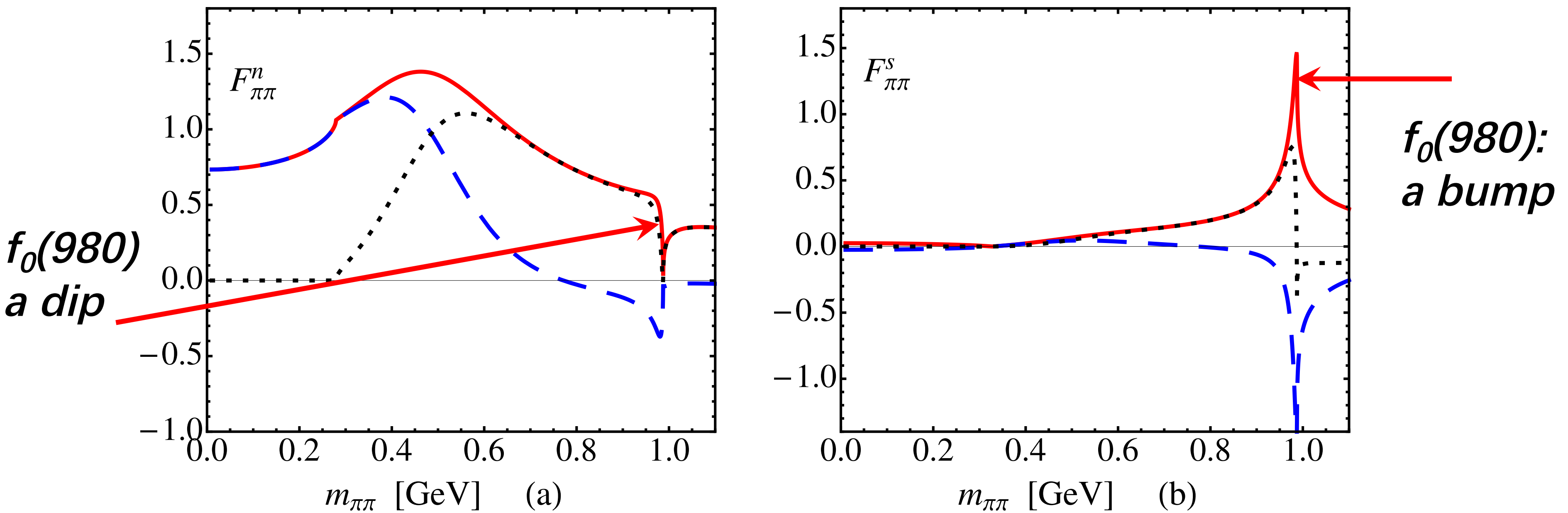
S-wave fraction

M.Döring,U.G.Meißner,WW,1307.0947

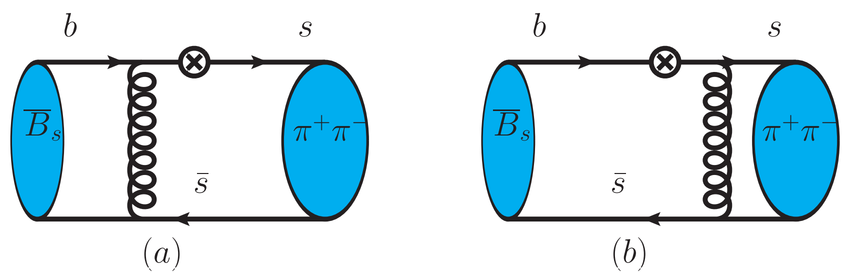
$$F_S = 0.101 \pm 0.017 \pm 0.009$$

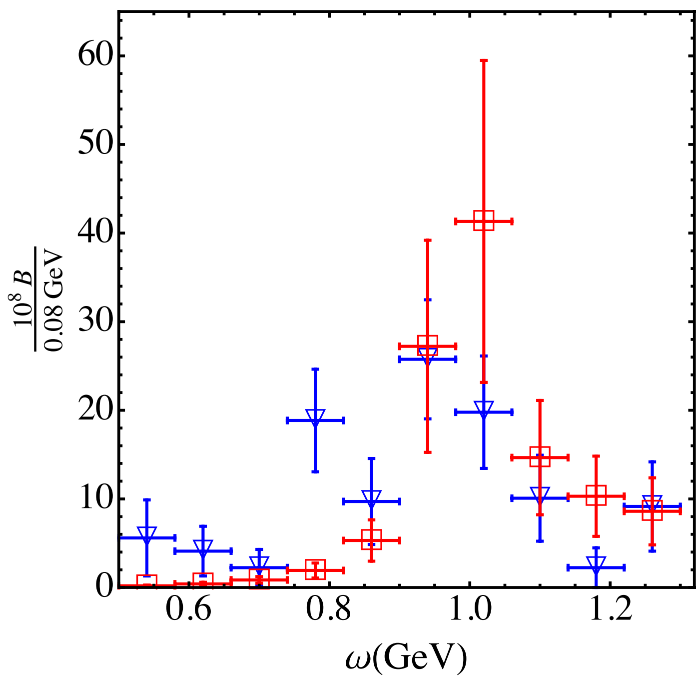
LHCb:1606.04731

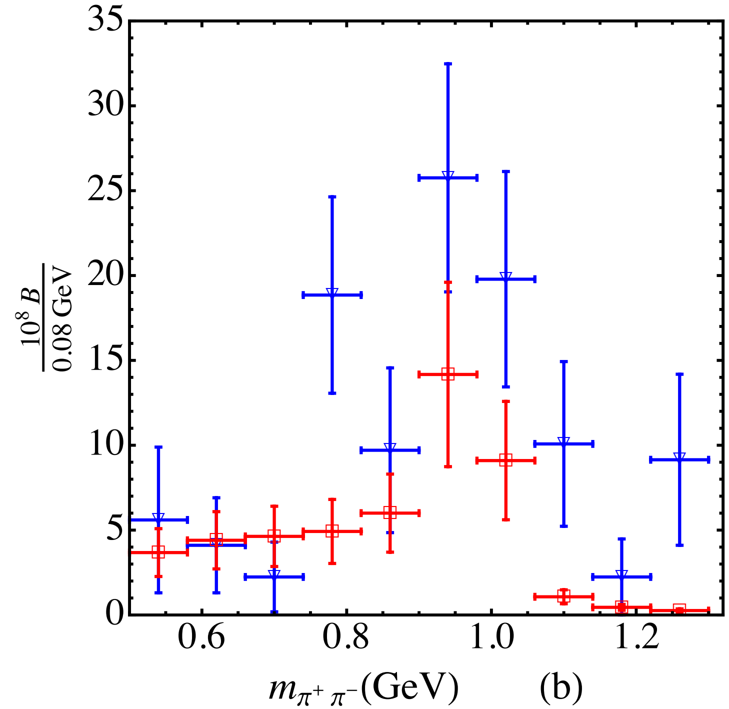
Scalar form factors in χPT



$B_s \to \pi^+\pi^-\mu^+\mu^-$







LHCb:1412.6433

LCSR+χPT： WW,R.Zhu,1502.15104

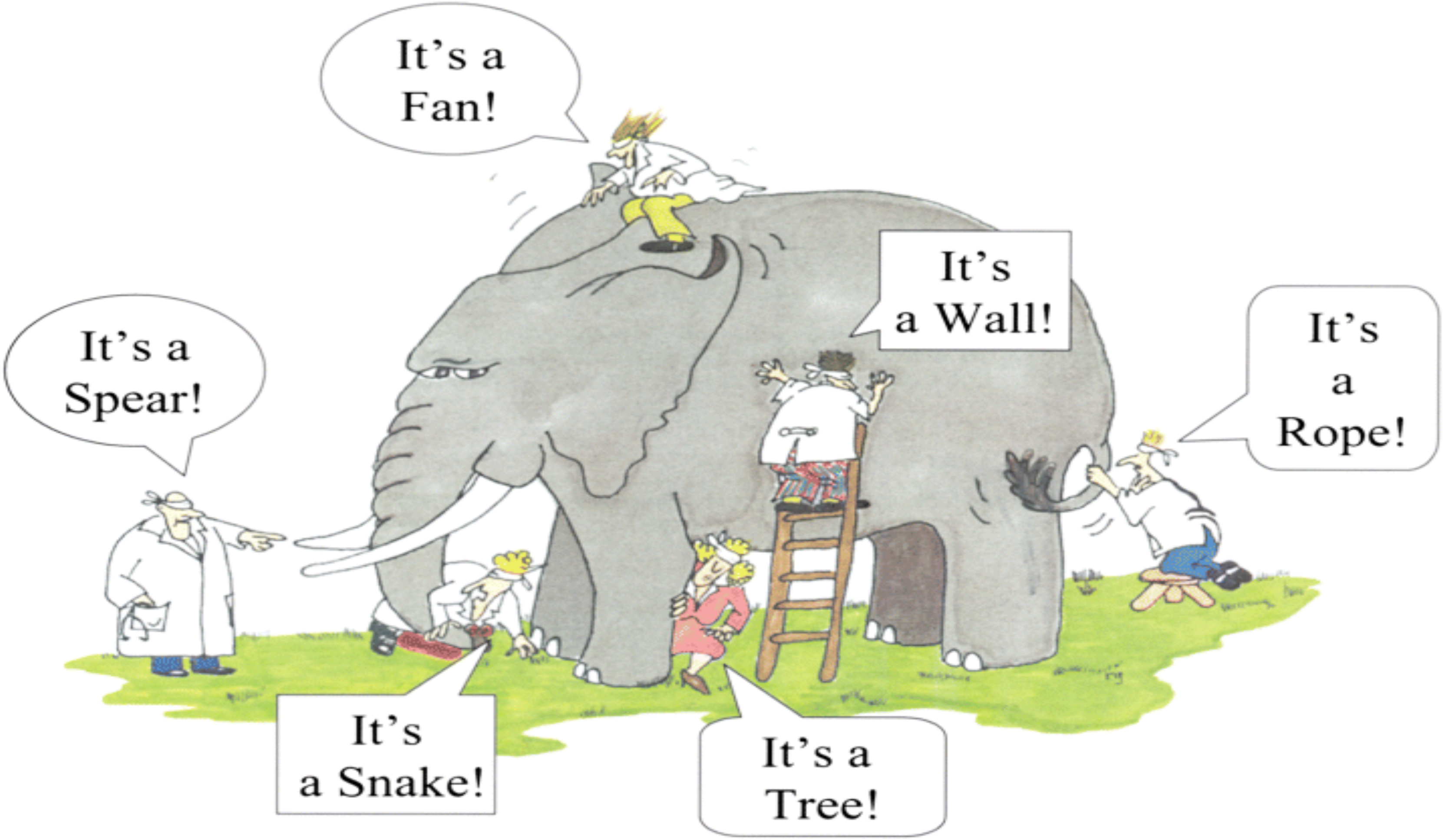
PQCD: Wang, Li, WW, Lu,1502.15104


It's
a
Rope!

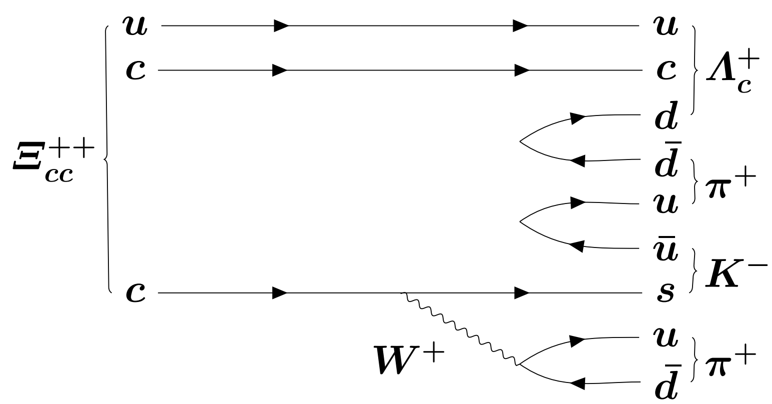

It's a
Spear!


It's
a
Rope!

We have only started to study the heavy flavour physics···and we need to look from every angle



Weak decays of doubly heavy baryons



1. **Observation of the doubly charmed baryon Ξ_{cc}^{++}**
LHCb Collaboration (Roel Aaij (CERN) *et al.*). Jul 5, 2017. 19 pp.
LHCB-PAPER-2017-018, CERN-EP-2017-156
e-Print: **arXiv:1707.01621 [hep-ex] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service; Link to conference slides; Interactions.org article
Detailed record - Cited by 27 records

Connections with HFP theory Group

Institut für Theoretische Teilchenphysik

Prof. Dr. Ulrich Nierste

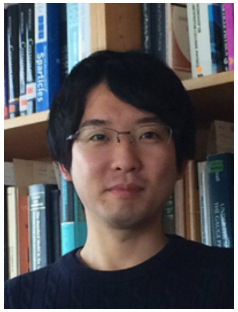
Prof. Dr. Matthias Steinhauser

Robert Ziegler

Institut für Kernphysik

Prof. Dr. Monika Blanke

Dr. Teppei Kitahara



Conclusion

- Heavy Flavour Physics
  - Finite Width Problem in B decays
  - Weak decays of Doubly heavy baryons
- Possible connections with HFP Group at KIT

Thank you very much for your attention

Vielen Dank!

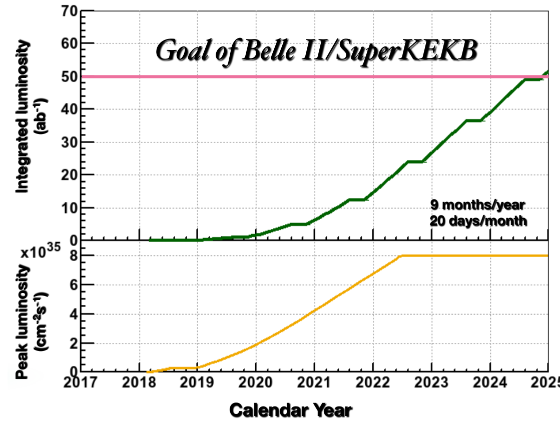
Experimental Prospect

Belle-II

Expected data sample @ full luminosity

Channel	Belle	BaBar	Belle II (per year)*
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

* assuming 100% running at each energy



LHCb