LHCb highlights & prospects

谢跃红，华中师范大学

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Outline

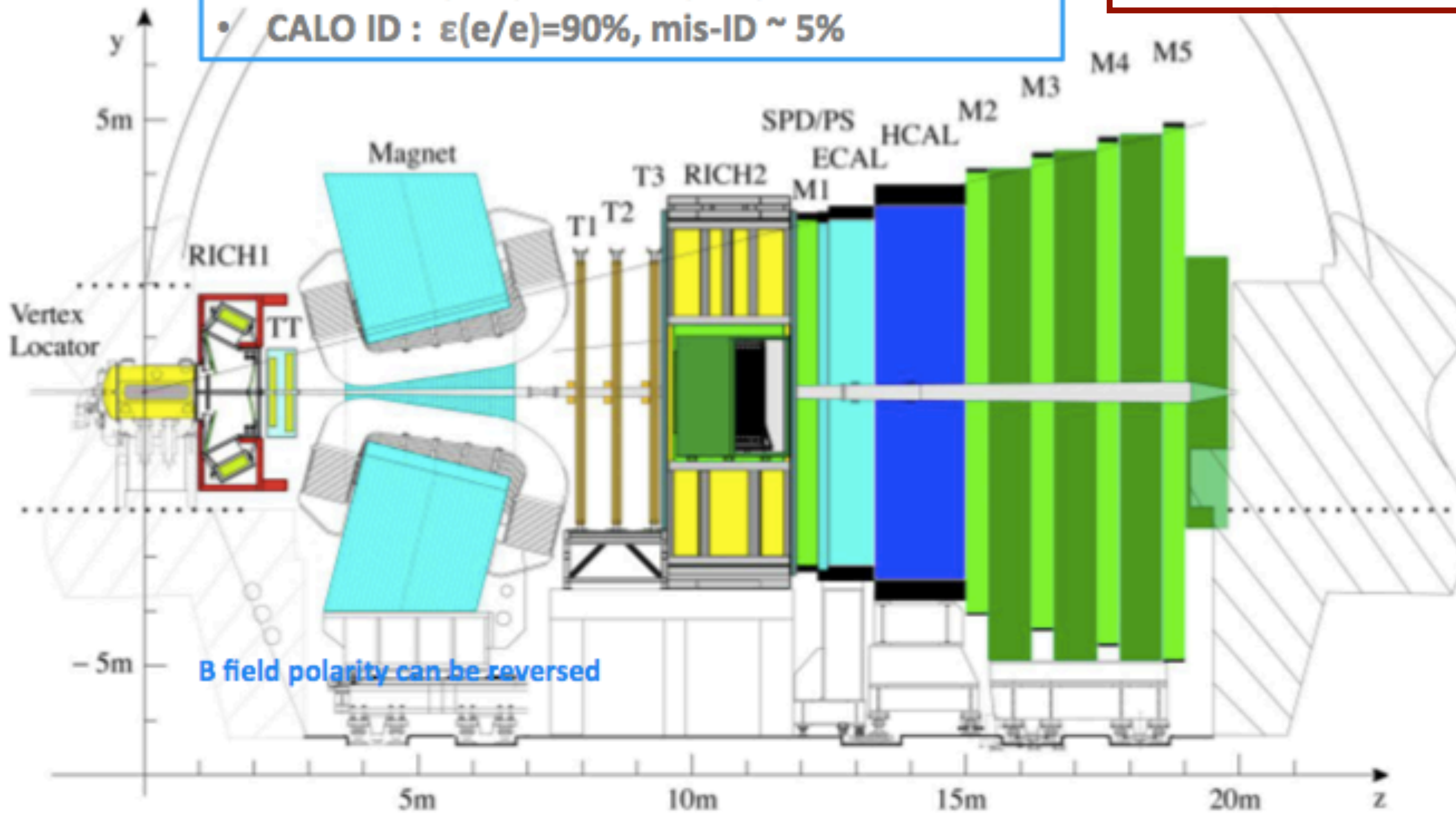
- LHCb experiment
- LHCb highlights
- Upgrade and future prospects
- China@LHCb
- Conclusions

LHCb experiment

A single arm forward detector

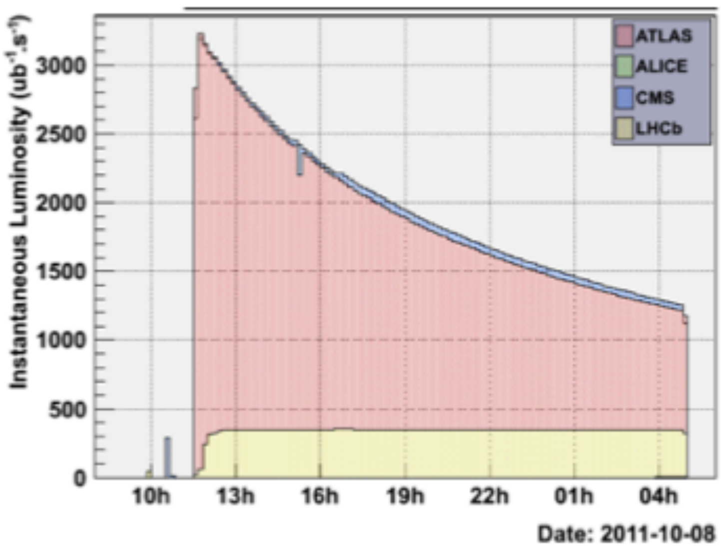
- Decay time resolution Δt: 30-50 fs
- Δp/p = 0.4-0.6%
- Muon ID : ε(μ/μ) = 95%, ε(π/μ) ~ 1%
- RICH ID : ε(K/K) = 95%, ε(K/π) ~ 5%
- CALO ID : ε(e/e)=90%, mis-ID ~ 5%

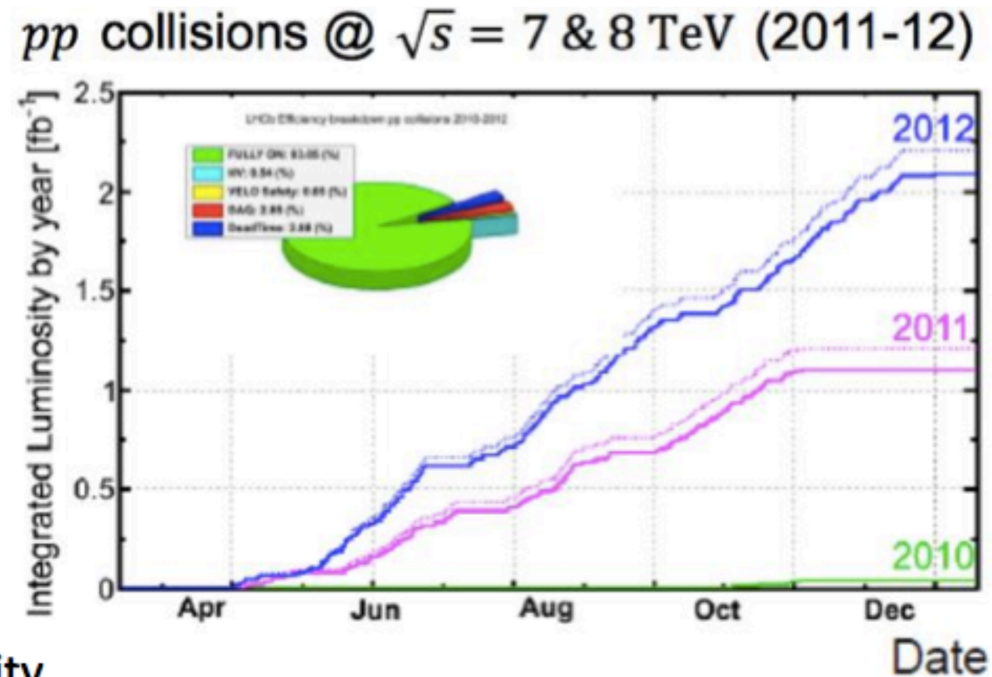
$\sigma(b\bar{b})$~1% σ (pp)
→1.5×10^9 beauty pairs/fill
20 times more charm



Excellent tracking, vertexing and particle identification

RunI data taking





Low and stable instantaneous luminosity

- ☐ $\mathcal{L} \sim 4 \times 10^{32}\ \mathrm{cm}^2\mathrm{s}^{-1}$
- ☐ Factor 2 larger than design luminosity
- ☐ Average pile-up rate ~ 2
- ☐ pp primary vertex reconstructed well

- ➢ Efficient data taking @ LHCb
  - ☐ Efficiency ~ 90 %
- ➢ Results based on 2 magnet configurations

LHCb run-I data

➢ 1 fb^{-1} for 2011 ➢ 2 fb^{-1} for 2012

Major physics program

Beautiful...

Rare Decays
Leptonic, electroweak, radiative decays
Lepton flavour and number violating decays

B decays to Charmonia
Lifetimes, φ_s, $\Delta\Gamma_s$ of B-mesons
Amplitude analyses
华中师大谢跃红任召集人

B decays to Open Charm

Charmless B decays

Semileptonic B decays

QCD, Electroweak and Exotica
t-quark,W, Z production and asymmetries
Search for the exotic particles

B hadrons and Quarkonia
Quarkonia production and properties
Potentially exotic quarkonia (X, Y, Z)
Production and spectroscopy of b-hadrons
清华大学杨振伟任召集人

Charm Physics
Mixing, CP-violation, rare decays of charm
Charm production and spectroscopy

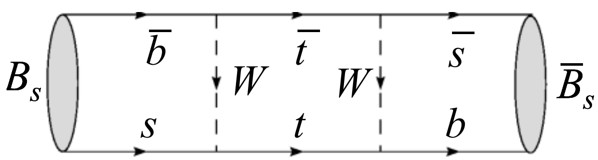
and charming!

LHCb highlights

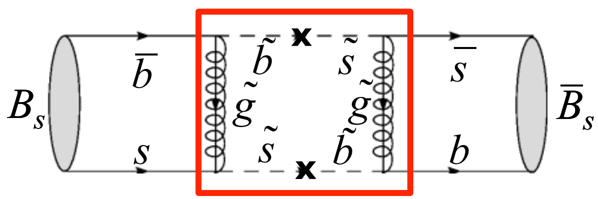
Probes of NP in B mixing

NP in B_s mixing?

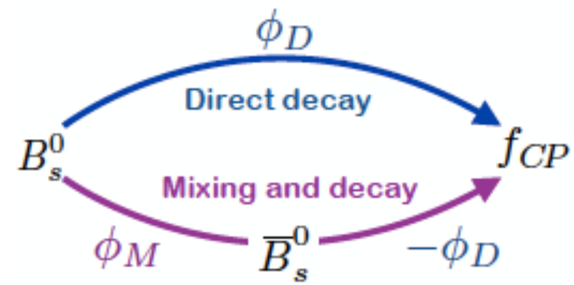
SM contribution



NP contribution



ϕ_s in $B_s \to J/\psi\phi$, $J/\psi\pi^+\pi^-$



$$\phi_s = \phi_M - 2\phi_D$$

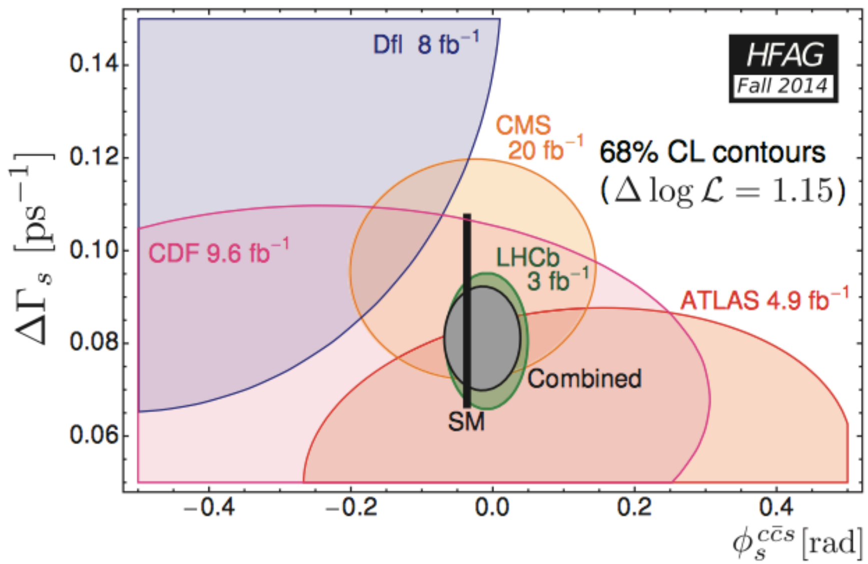
$$A_{CP} \equiv \frac{\Gamma\left(\overline{B}_s^0 \to f\right) - \Gamma\left(B_s^0 \to f\right)}{\Gamma\left(\overline{B}_s^0 \to f\right) + \Gamma\left(B_s^0 \to f\right)} = \eta_f \sin\phi_s \sin(\Delta m_s t)$$

good flavour tagging and time resolution needed

Similar probe for B_d: $\sin 2\beta$ in $B_d \to J/\psi K_S$

ϕ_s result

ϕ_s-$\Delta\Gamma_s$ world average



LHCb: [PRL 114 (2015) 041801]

ϕ_s = -0.058± 0.049± 0.006 rad

SM: (ignore penguin)

ϕ_s = -0.036 ± 0.001 rad

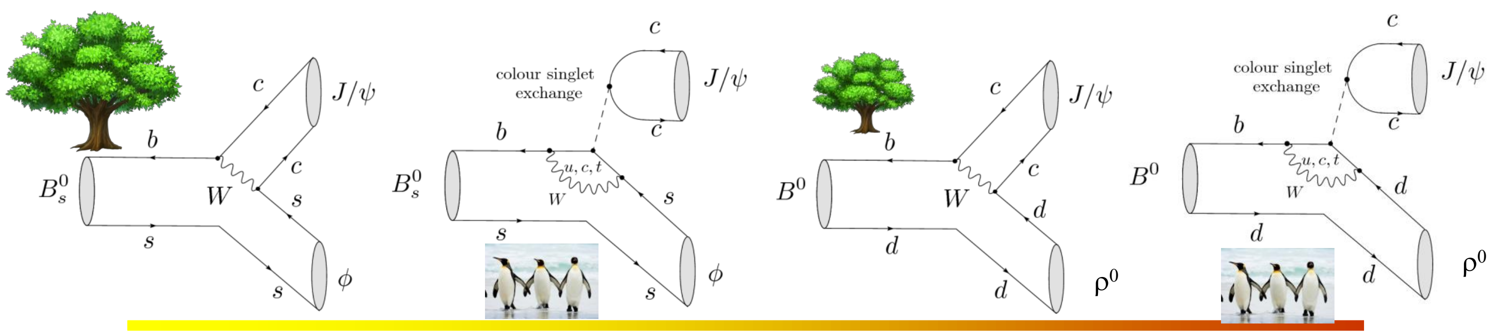
SM-like result. Need improved precision in RUN II to look for sub-leading NP effect

Understanding the effect of penguin contribution in decay becomes crucial

Penguin pollution

Penguin effect controlled using SU(3) flavour symmetry

- SU(3) partners with d↔s



$B_s \to J/\psi\phi$: $b \to c\bar{c}s$

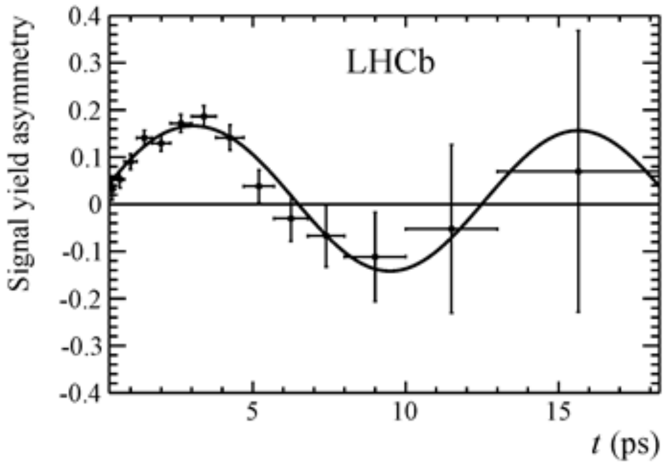
$B_d \to J/\psi\rho$: $b \to c\bar{c}d$

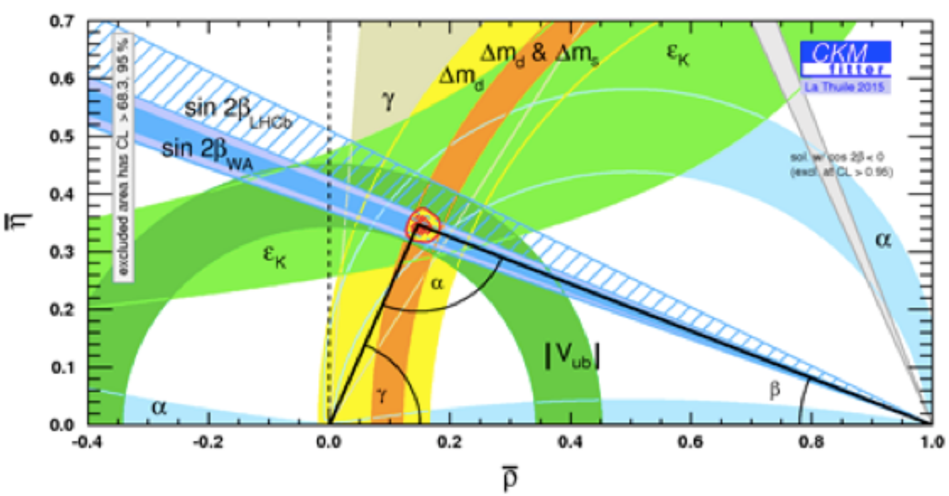
$\Delta 2\beta = \; 2\beta^{J/\psi\,\rho} - 2\beta^{J/\psi\,K^0_S} = -0.9 \pm 9.7^{+2.8}_{-6.3}$ degrees.

$\delta_P \approx -\varepsilon\Delta 2\beta$, $|\delta_P| < 0.018$ rad@95%CL

[Phys. Lett. B742 (2015) 38]

sin2β



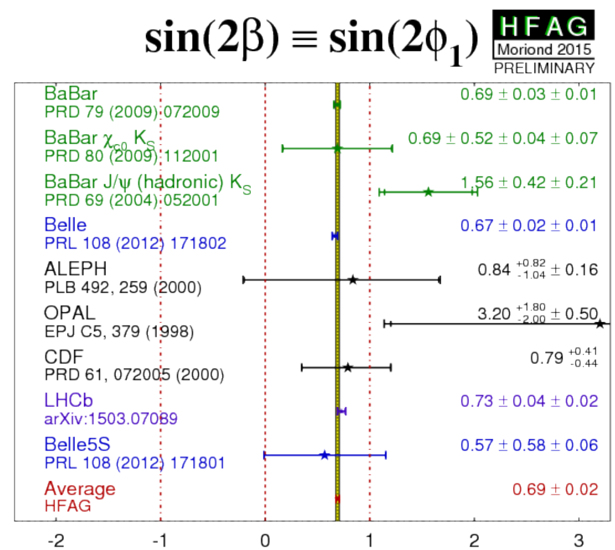


LHCb: [PRL 115 (2015) 031601]

$\sin 2\beta = 0.731 \pm 0.035 \pm 0.020$

Indirect fit in SM:

$\sin 2\beta = 0.771^{+0.017}_{-0.041}$



LHCb precision approaches that of B factories

No tension with SM prediction anymore

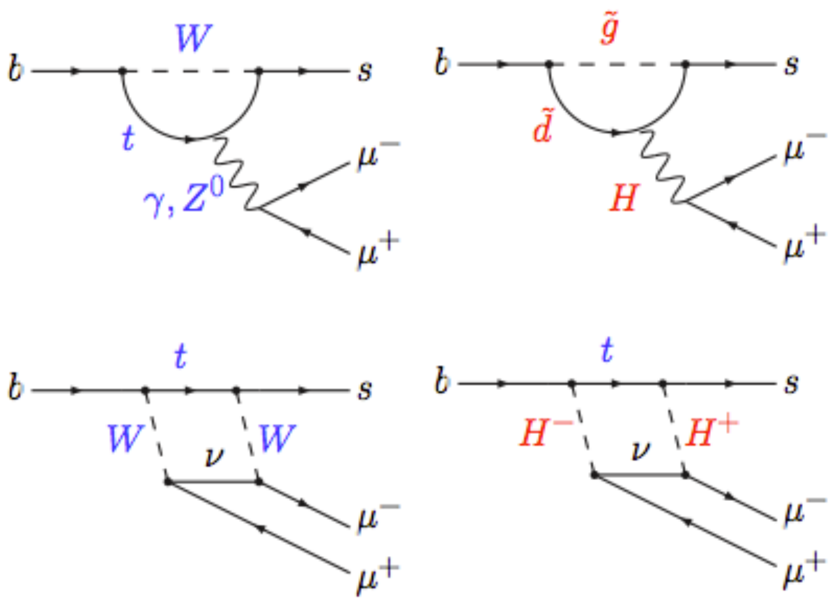
$b \rightarrow s l^+ l^-$ transition

FCNC processes where

SM contribution is suppressed

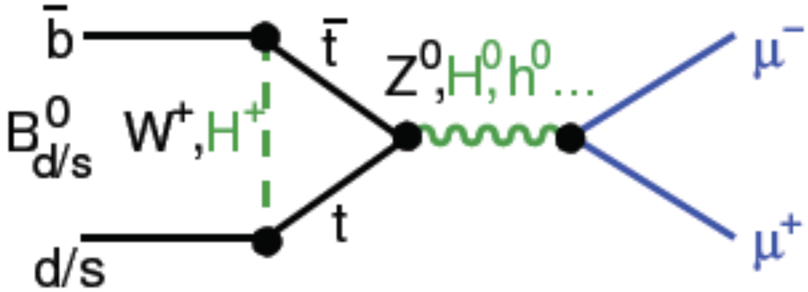
NP effect could be sizeable

$$H = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum (C_i^{SM} + C_i^{NP}) O_i^{SM} + \sum \frac{c}{\Lambda_{NP}} O_{NP}$$



- $B_s \rightarrow \mu^+\mu^-$
- $B \rightarrow K^{*0} \mu^+\mu^-$
- $B^+ \rightarrow K^+ l^+l^-$

$B_{s/d} \to \mu^+\mu^-$

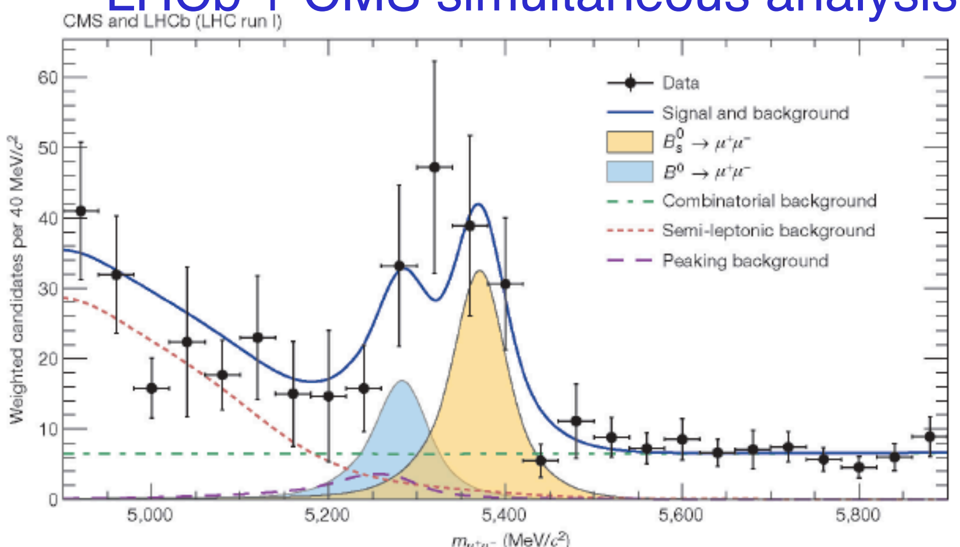


SM prediction

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

Sensitive to NP in scalar sector

LHCb + CMS simultaneous analysis



$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.9\,^{+1.6}_{-1.4}) \times 10^{-10}$$

doi:10.1038/nature14474

$B_s \to \mu^+\mu^-$
first observation
6.2σ significance

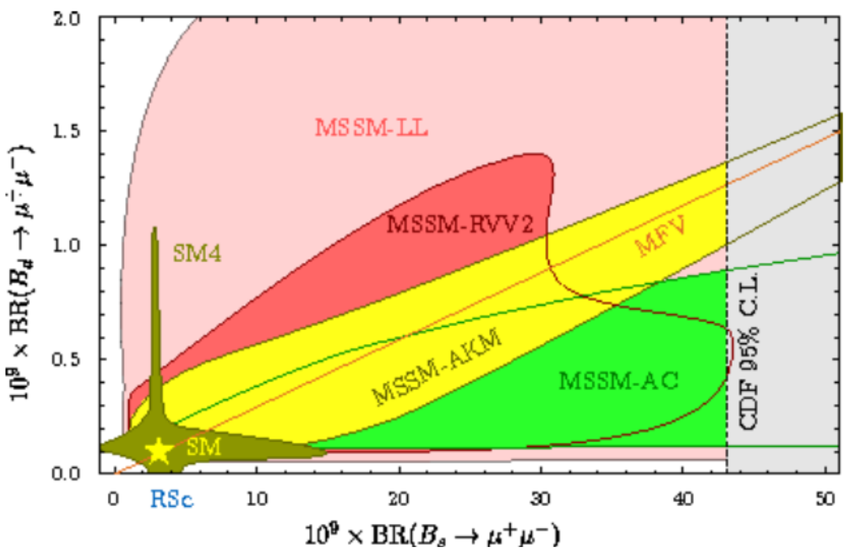
$B_d \to \mu^+\mu^-$
first evidence
3.0σ significance

Consistent with SM within 2.3σ.

NP model killing

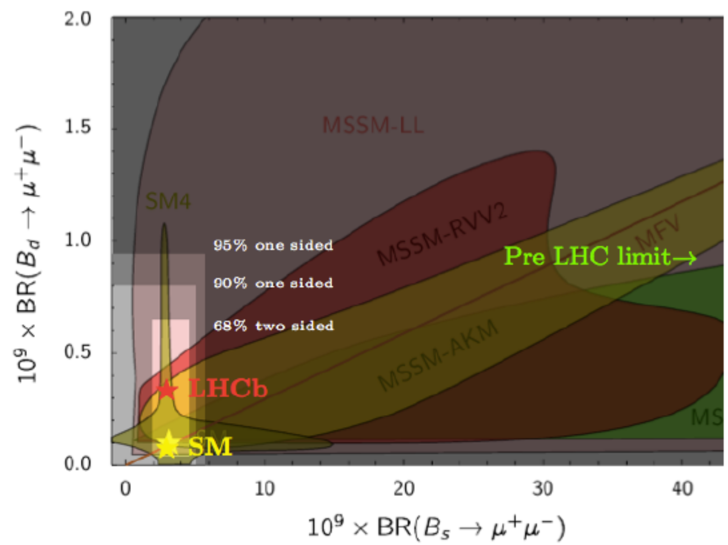
Before the LHC results

[D.Straub arXiv:1205.6094]



After the LHC results

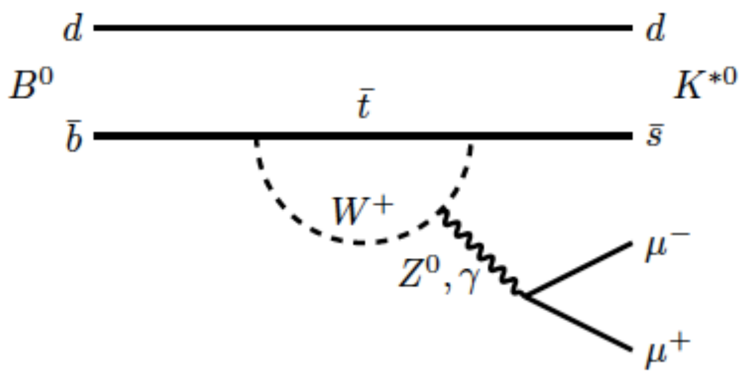
Cartoon of plot from [D.Straub arXiv:1205.6094]

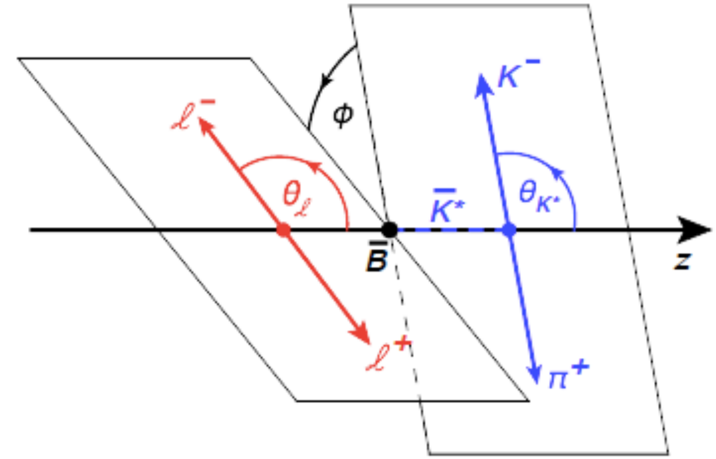


Run II and upgrade goals

- $Br(B_s \to \mu^+\mu^-) / Br(B_d \to \mu^+\mu^-)$ (powerful test of MFV)
- $B_s \to \mu^+\mu^-$ effective lifetime
- CP violation in $B_s \to \mu^+\mu^-$

$B \rightarrow K^{*0}\,\mu^+\mu^-$





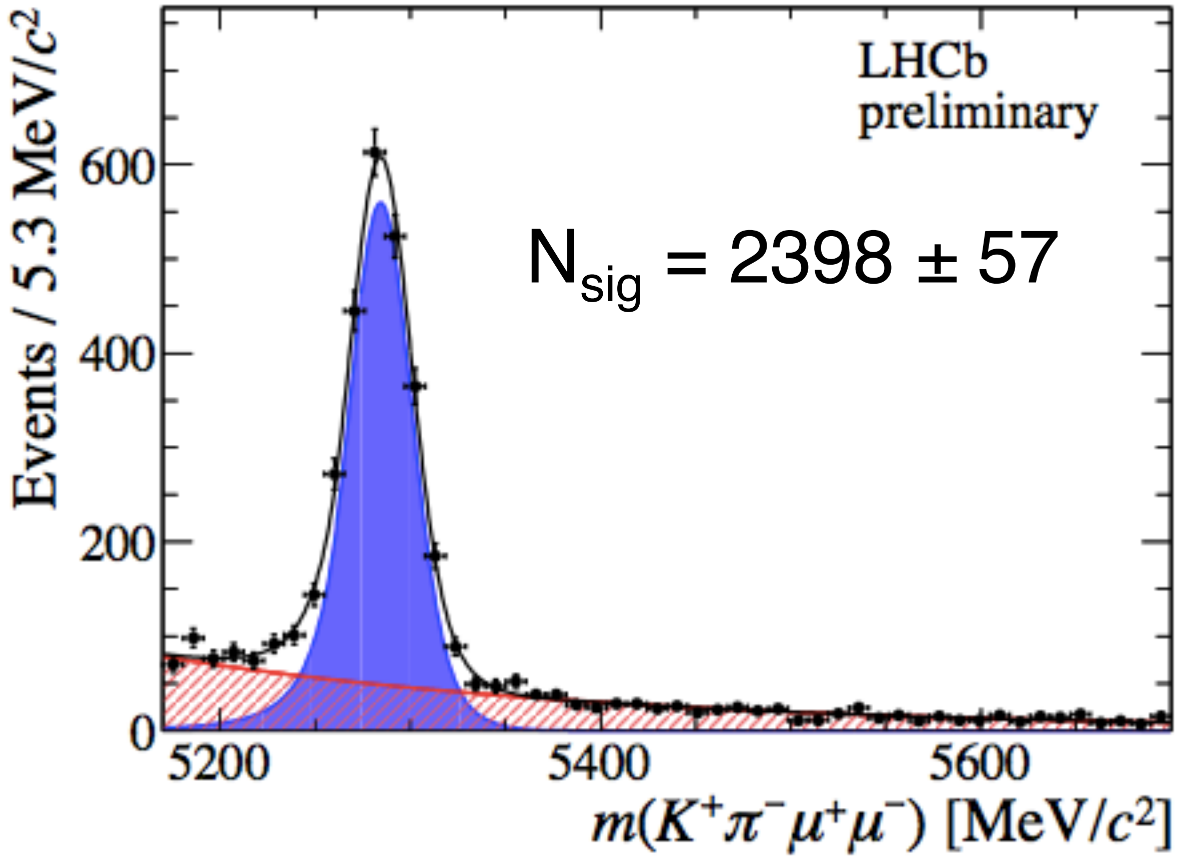
$B^0 \rightarrow K^{*0}\ l^+l^-$ described by three angles (θ_K, θ_l, Φ) and di-muon mass squared, q^2:

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma+\bar{\Gamma})}{d\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \tfrac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Observables: A_{FB}, S_i, F_L

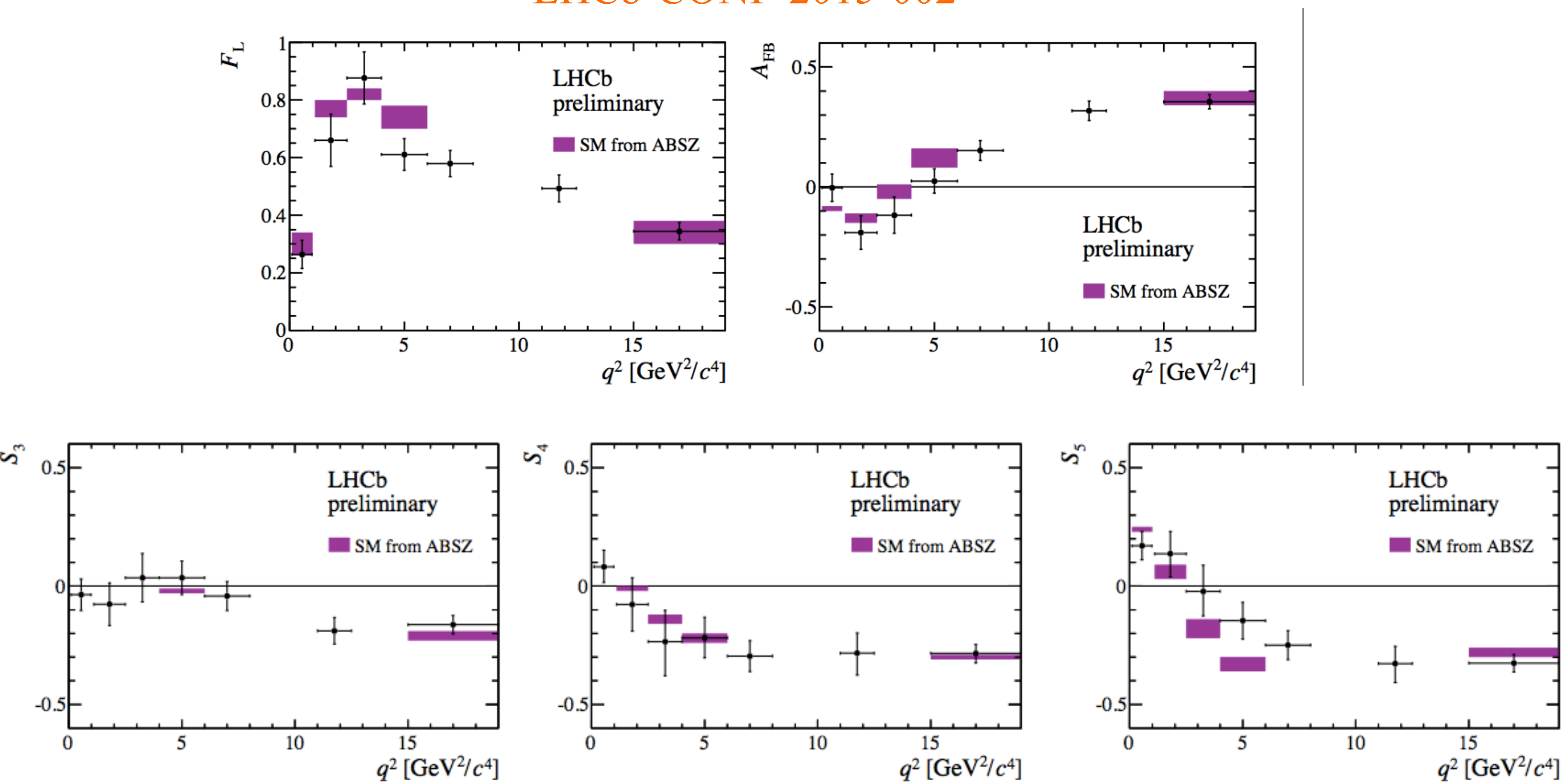
$B \to K^{*0} \mu^+\mu^-$ signal

Update: $1fb^{-1} \to 3fb^{-1}$



$B \to K^{*0}\mu^{+}\mu^{-}$ update

LHCb-CONF-2015-002

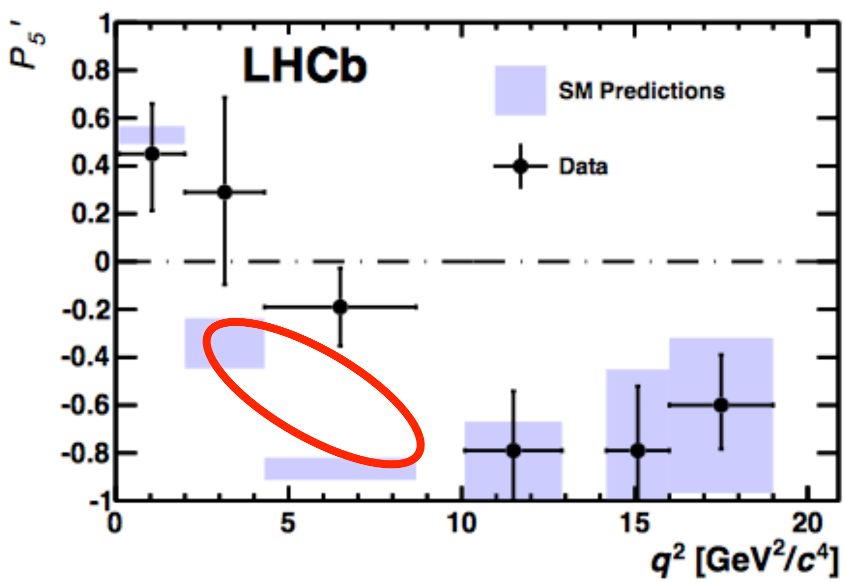


Basically consistent with SM, except S_5 …

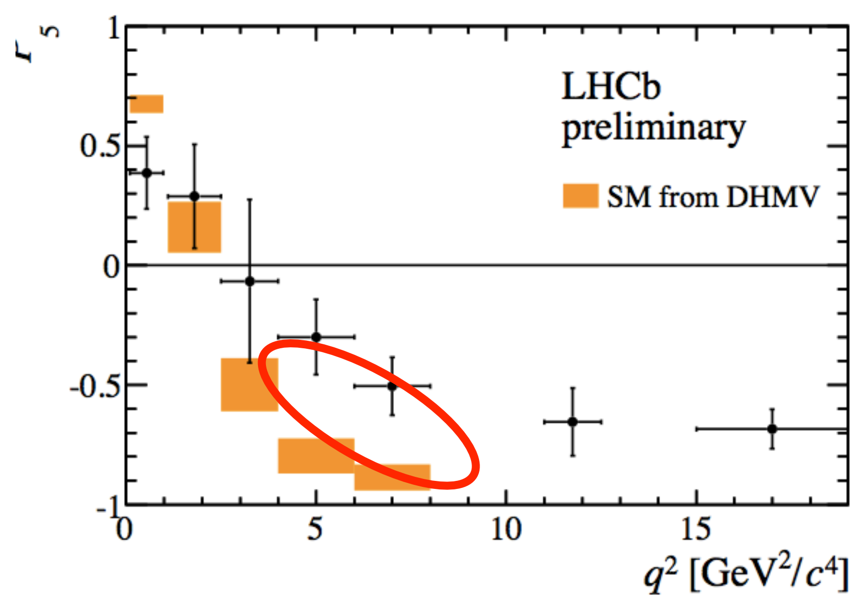
$B \to K^{*0} \mu^+\mu^-$ update: P_5'

theoretically clean variable $$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

$1 fb^{-1}$ PRL 111(2014)191801

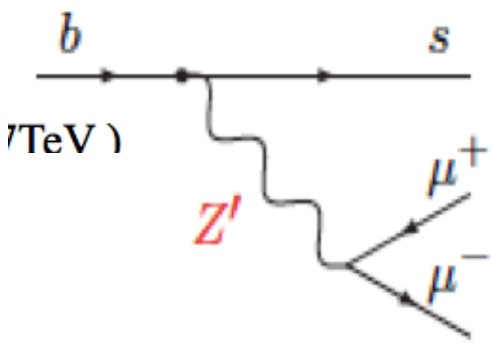


$3 fb^{-1}$ LHCb-CONF-2015-002



Tension with SM prediction confirmed (3.7σ)

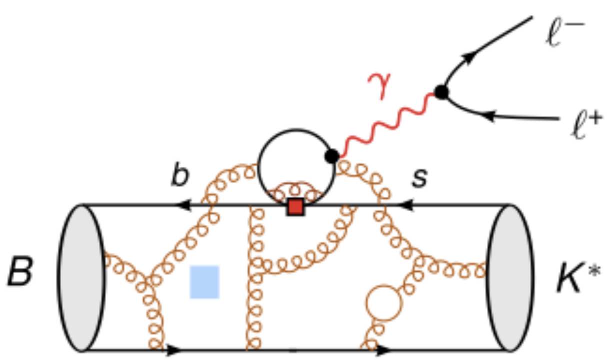
Theoretical interpretation



New physics effect?
e.g. Z'

Gauld et al., JHEP 1401 (2014) 069

or



Unexpected hadronic effect?
e.g. huge charm effects

Altmannshofer, Straub, arXiv:1503.06199

Lepton universality observables may help
→ R_K

R_K

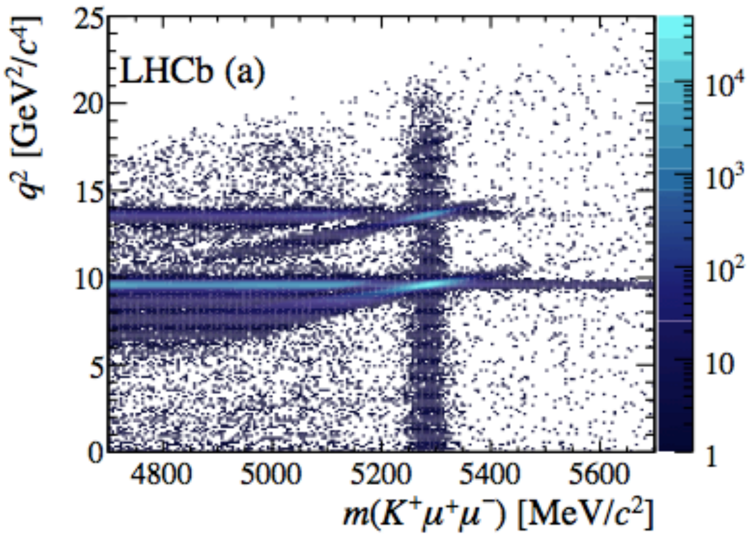
$$R_K = \frac{\Gamma(B^+ \to K^+ \mu^+ \mu^-)}{\Gamma(B^+ \to K^+ e^+ e^-)}$$

SM lepton universality: R_k=1 within $O(10^{-3})$

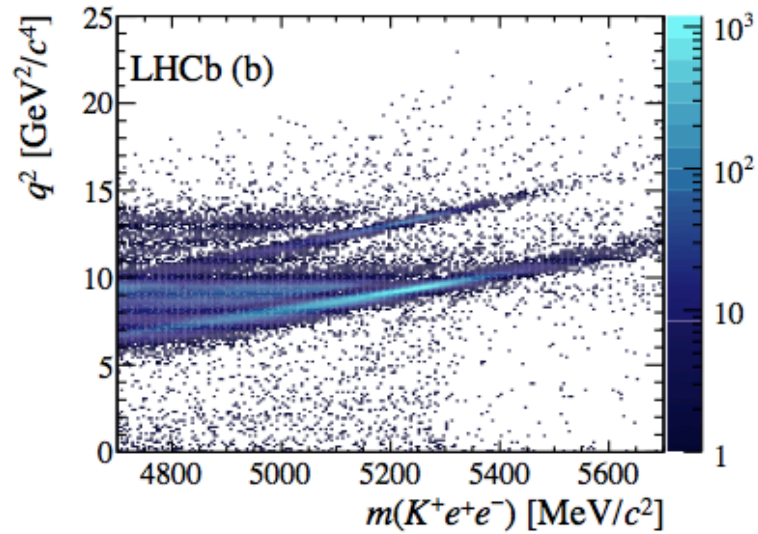
- hardly affected by hadronic uncertainty

Experimental Challenge: bremsstrahlung effect

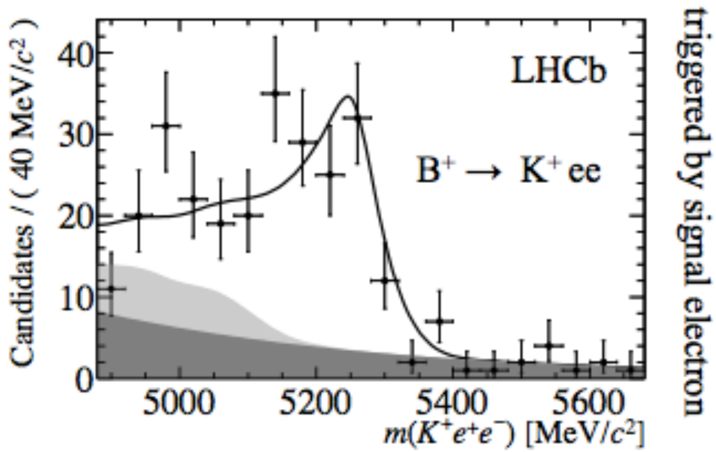
$B^+ \to K^+ \mu\mu$

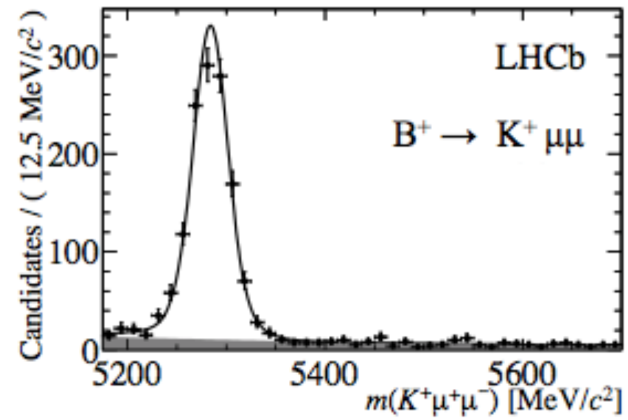


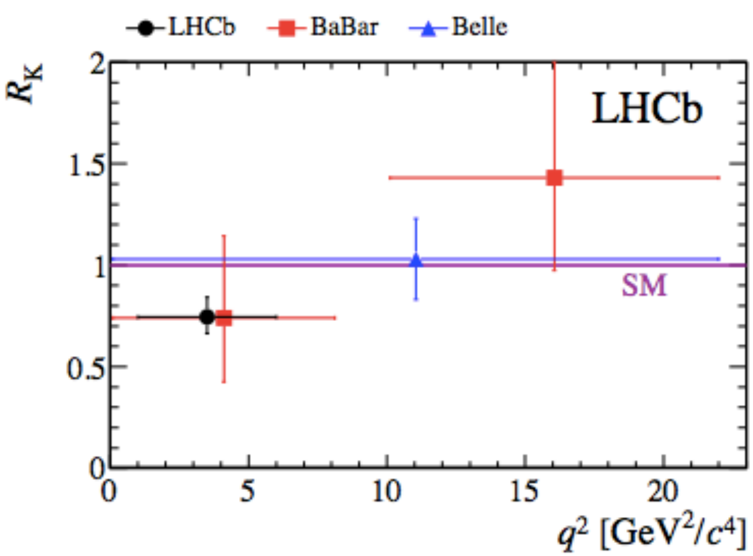
$B^+ \to K^+ ee$



R_K result







Phys. Rev. Lett. 113 (2014) 151601

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

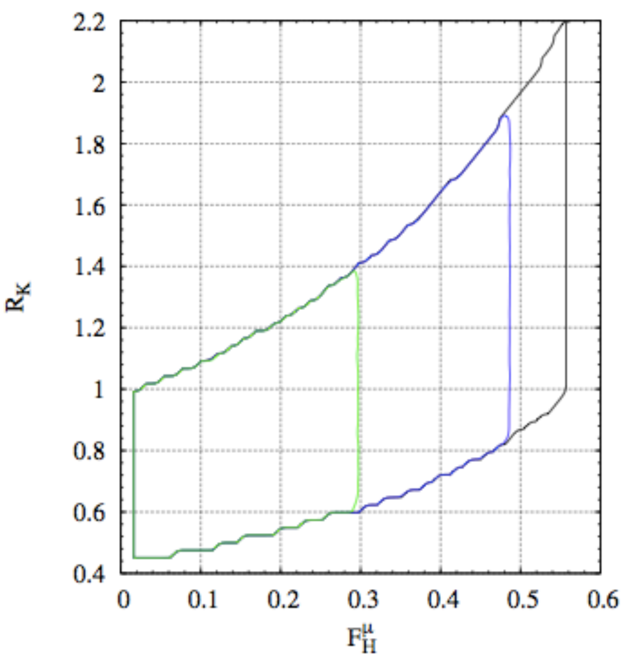
Consistent with SM within 2.6σ

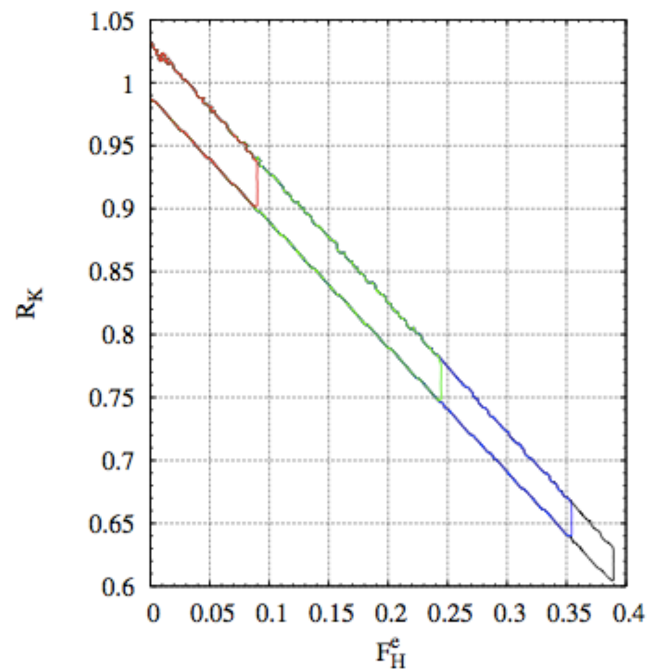
Angular observables in $B^+ \to K^+ l^+ l^-$

NP effects in R_K and angular observables are correlated

Gauld et al., JHEP 0712 (2007) 040

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}\cos\theta_l$$



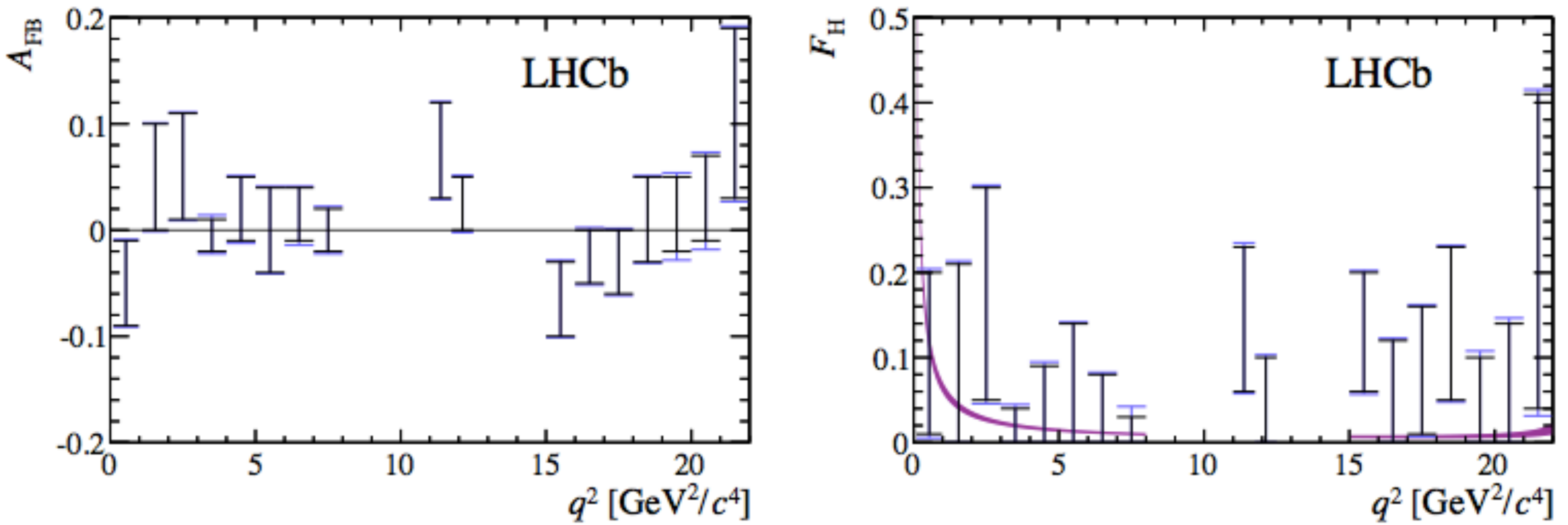


Angular analysis of $B^+ \to K^+\mu^+\mu^-$

1fb^{-1} result Consistent with SM prediction of

$R_K \cong 1$ & $F_H \sim 0$

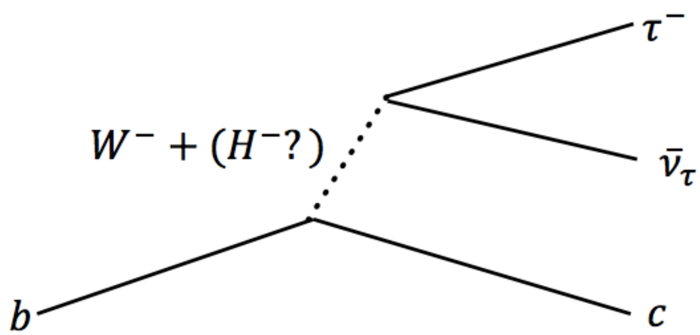
JHEP 1405 (2014) 082



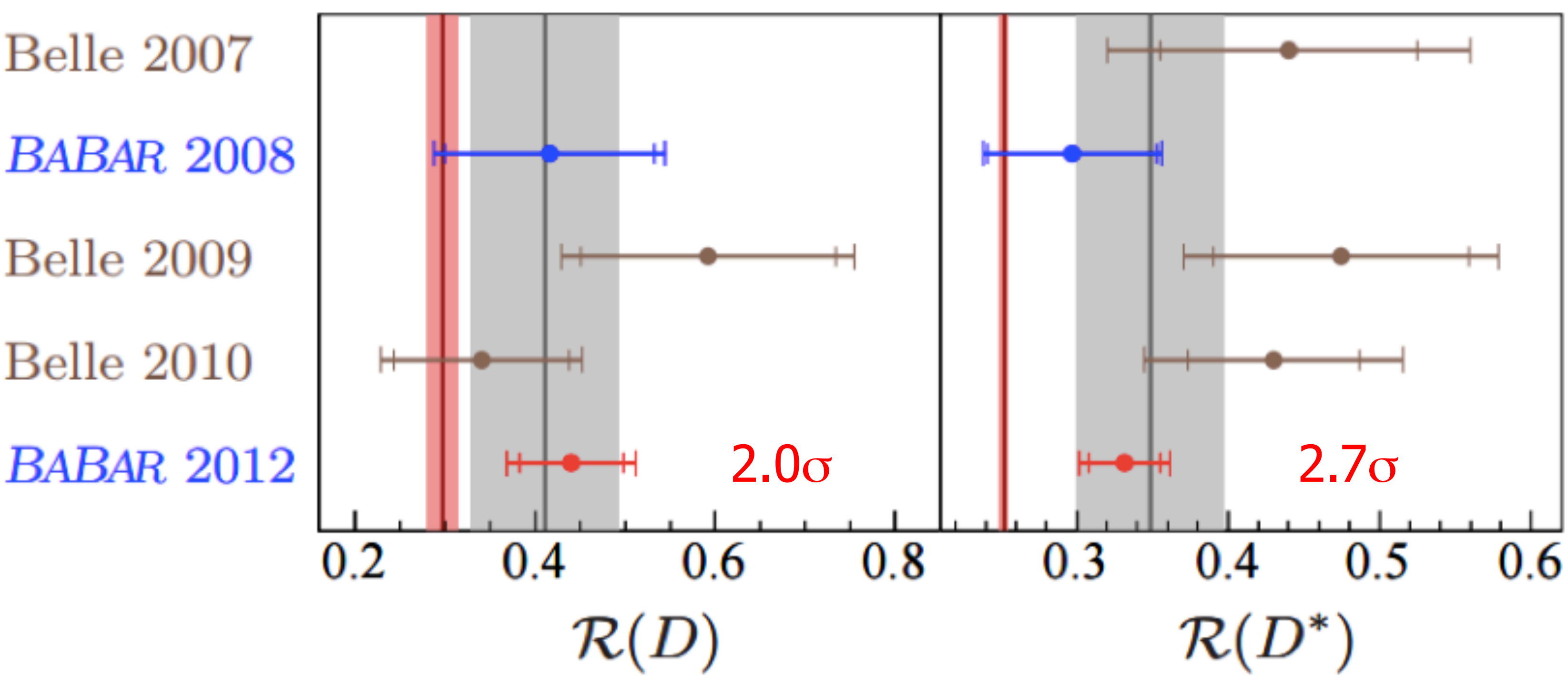
More precise measurement needed

Angular analysis of $B^+ \to K^+e^+e^-$ desirable

$B^0 \to D^{*+}\tau^-\nu$



$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}(\mu \text{ or } e)\nu)}$$



$B^0 \to D^{*+}\tau^-\nu$ partial reconstruction

Leptonic mode: $\tau \to \mu\nu_\tau\bar{\nu}_\mu$

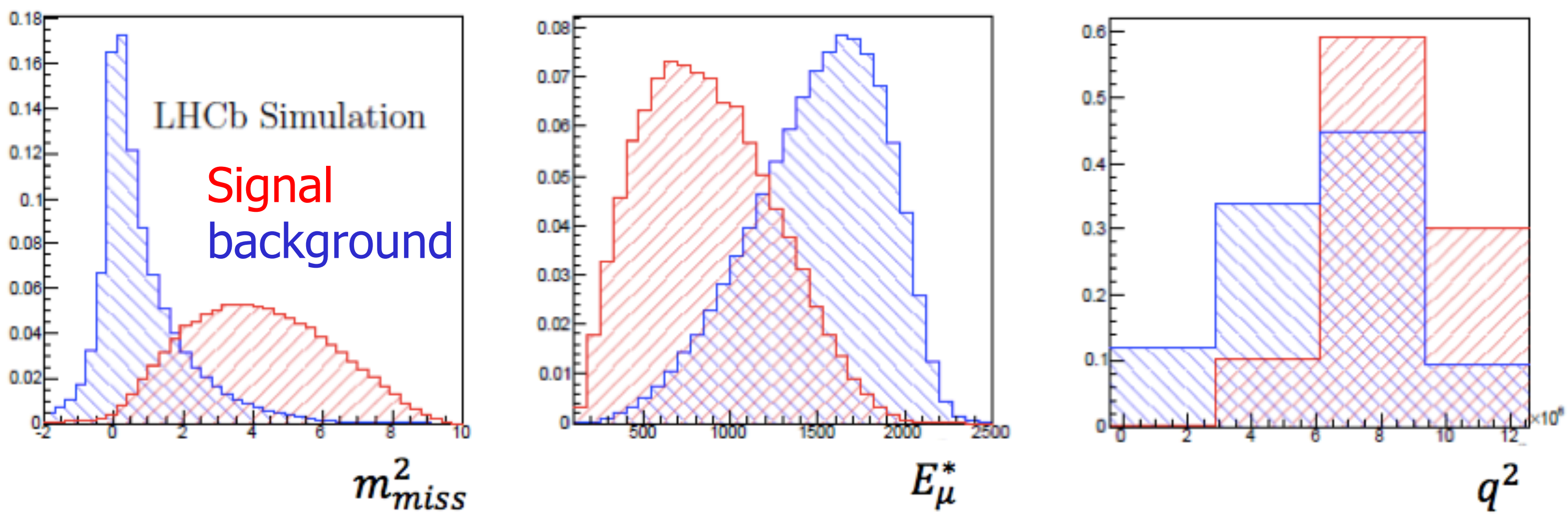
Kinematic variables estimated assuming

$$(p_B)_z = \frac{m_B}{m_{\mathrm{reco}}}(p_{\mathrm{reco}})_z$$

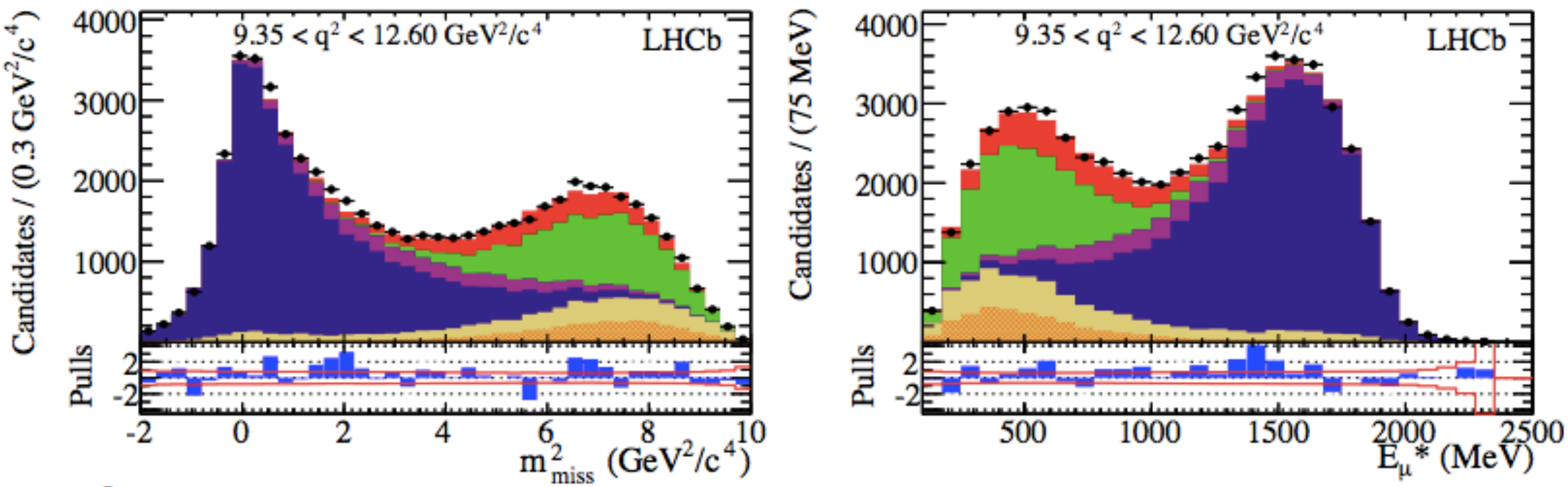
m_{miss}: invariant mass of the invisible pass part

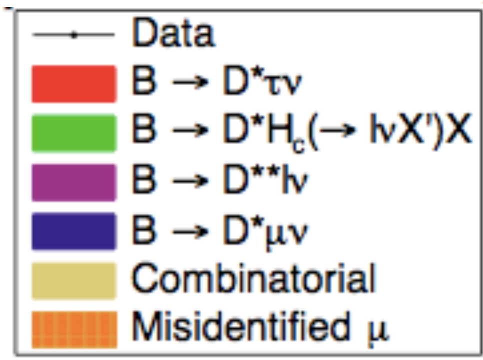
E_μ^*: μ energy in B rest frame

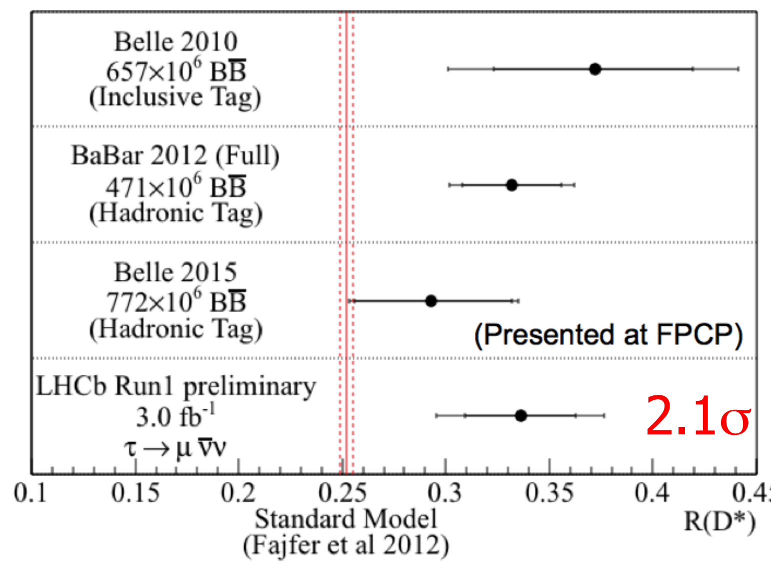
q^2: squared 4-momentum of $\tau\nu$



LHCb R(D∗) result







$$N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu) = 363{,}000 \pm 1600$$

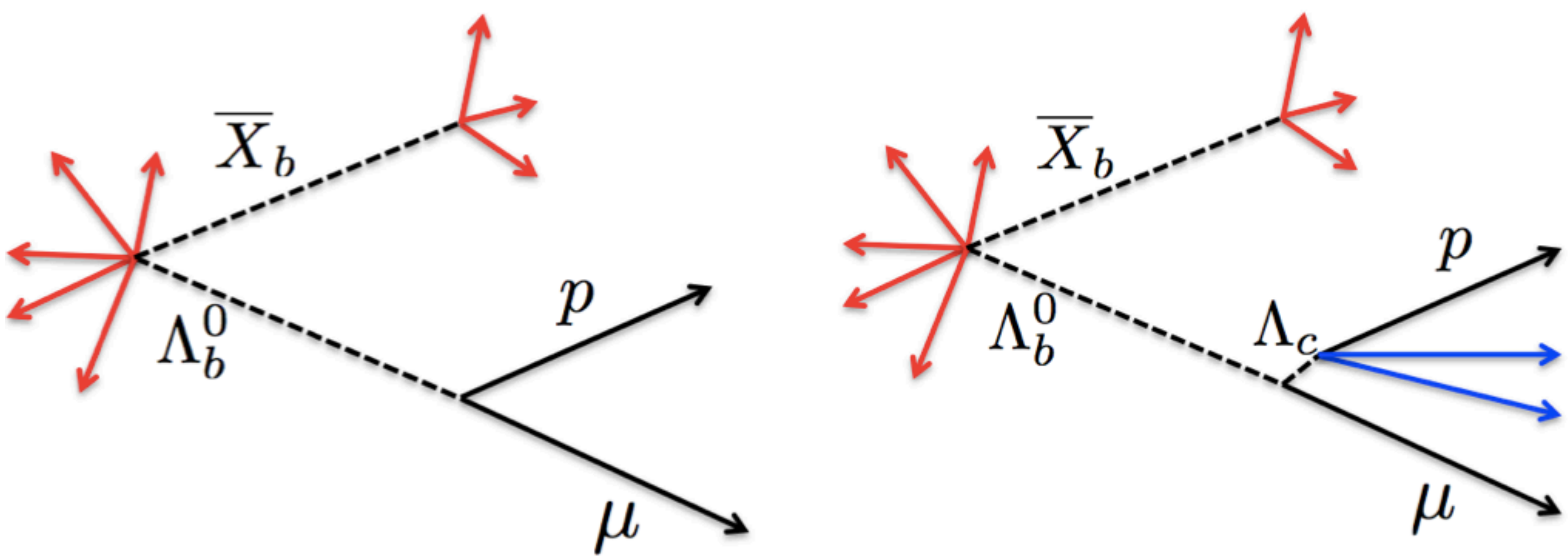
$$R(D^*) = 0.336 \pm 0.027 \pm 0.030$$

This confirms Babar result

V_{ub}

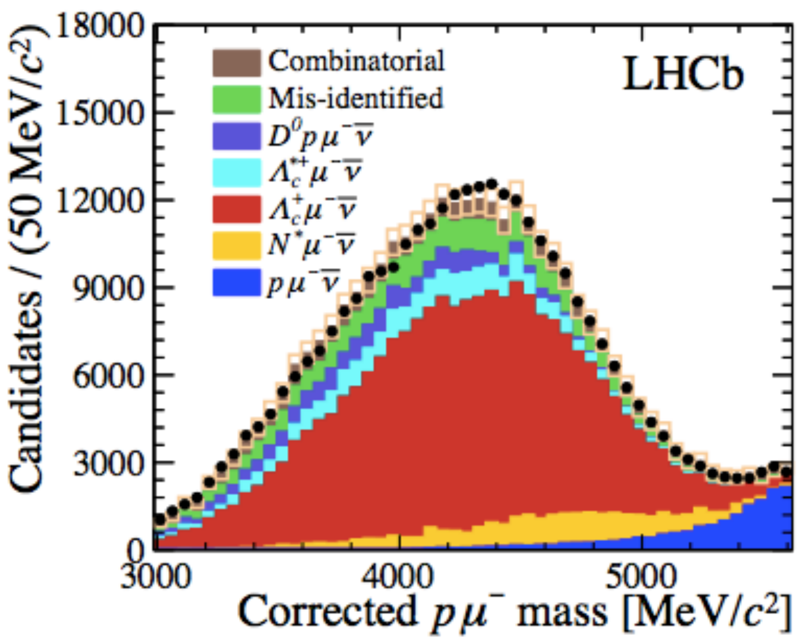
$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,GeV^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,GeV^2}} R_{FF}$$

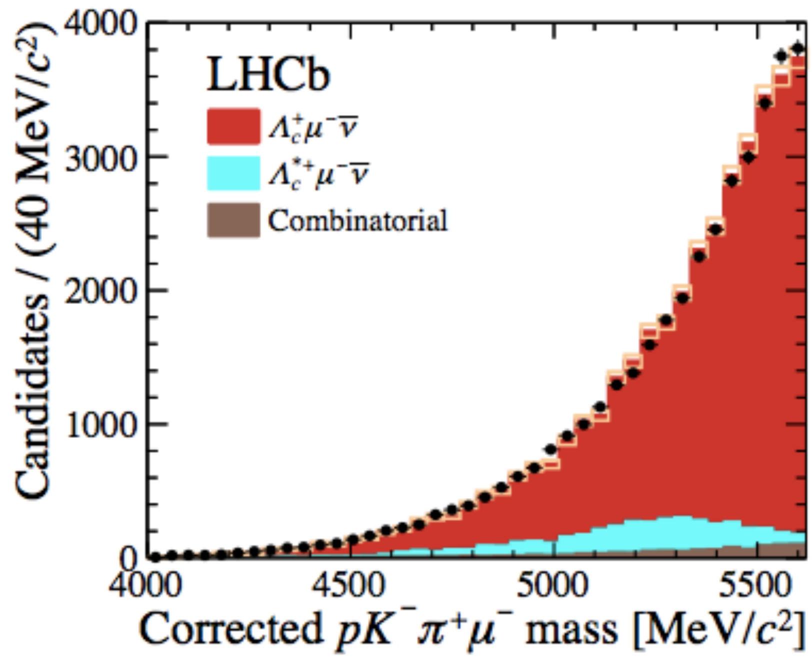
form factor ratio 5% uncertainty on $|V_{ub}|$



Partial reconstruction

$$m_{\text{corr}} = \sqrt{m_{h\mu}^2 + p_\perp^2} + p_\perp$$





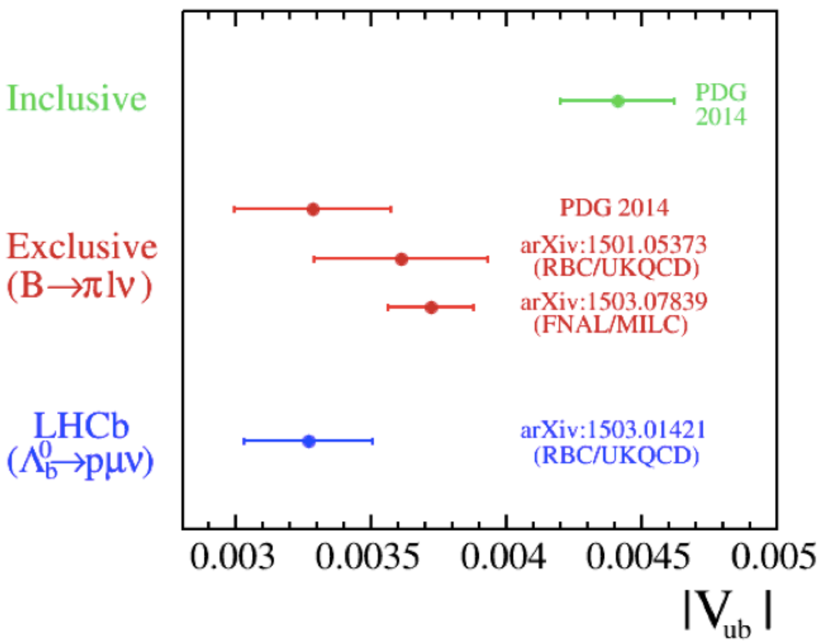
Signal: 17687 ± 733

Normalization: 34255 ± 571

LHCb V_{ub} result

Using PDG exclusive average of $|V_{cb}|$

$$|V_{ub}| = (3.27 \pm 0.15_{\rm exp} \pm 0.17_{theory} \pm 0.06_{|Vcb|}) \times 10^{-3}$$



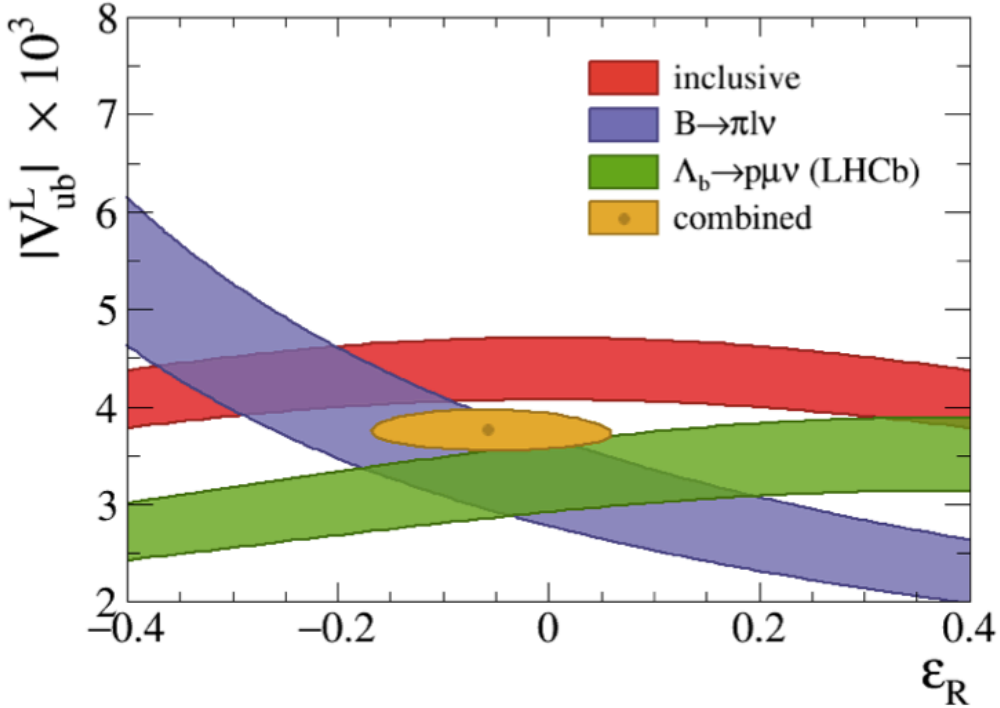
arXiv:1504.01568

Consistent with other exclusive measurements

Can also do $B_s \to K\mu\nu$ and $B_s \to D_s\mu\nu$

Right-handed current?

$$\mathcal{L}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L (\bar{u}\gamma_\mu P_L b + \epsilon_R \bar{u}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu P_L l) + h.c.$$

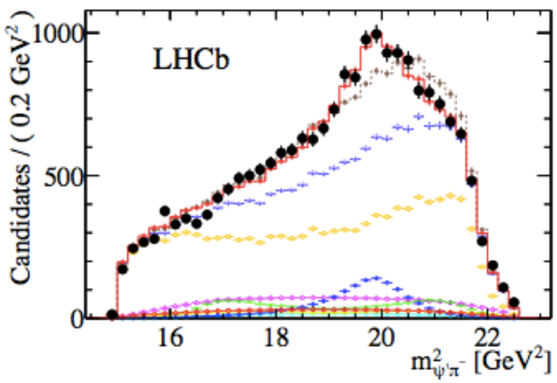


Right-handed current disfavored

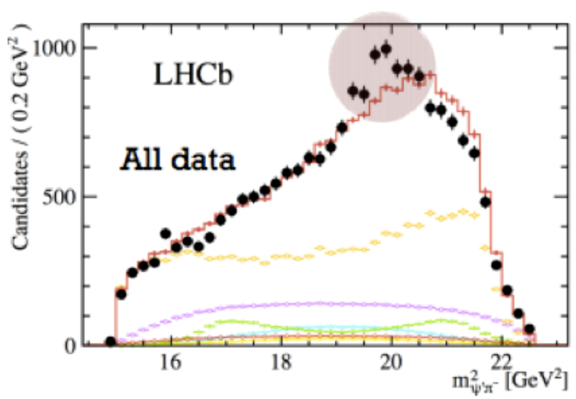
Z(4430)$^-$

- Observed by BELLE but not confirmed by Babar
- LHCb confirmed it (13.9σ), determined $J^P=1^+$

with Z(4430)



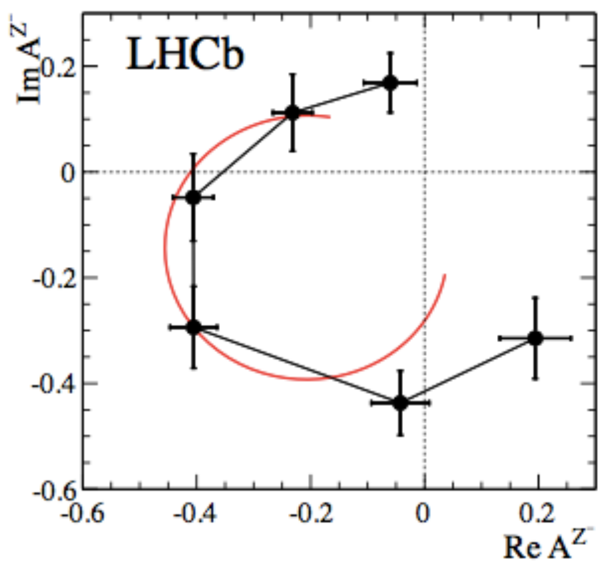
w/o Z(4430)



$B^0 \rightarrow \psi(2S)\ K^+\pi^-$

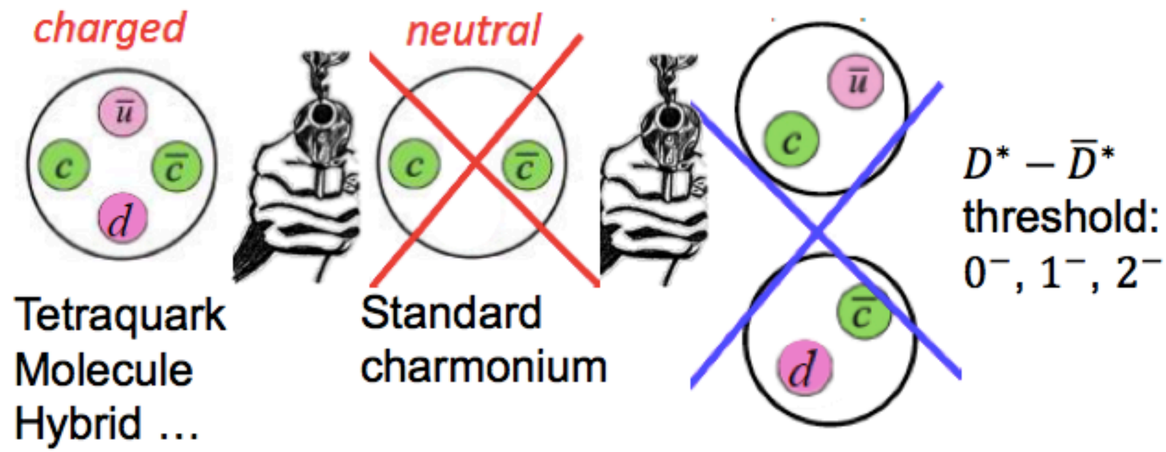
PRL 112, 222002 (2014)

Argand diagram confirming resonance behavior



Z(4430) implication

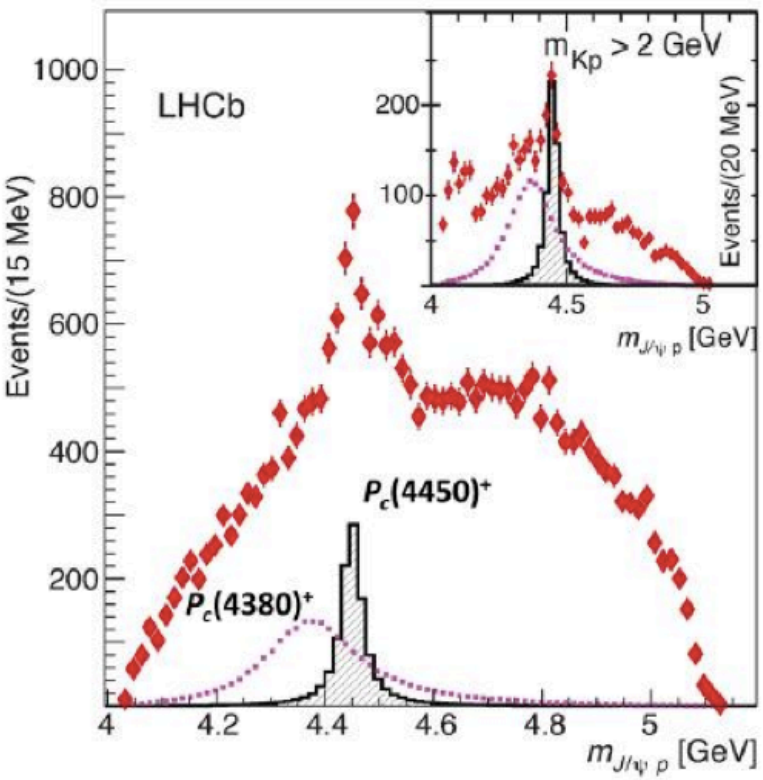
LHCb determined
$J^P = 1^+$

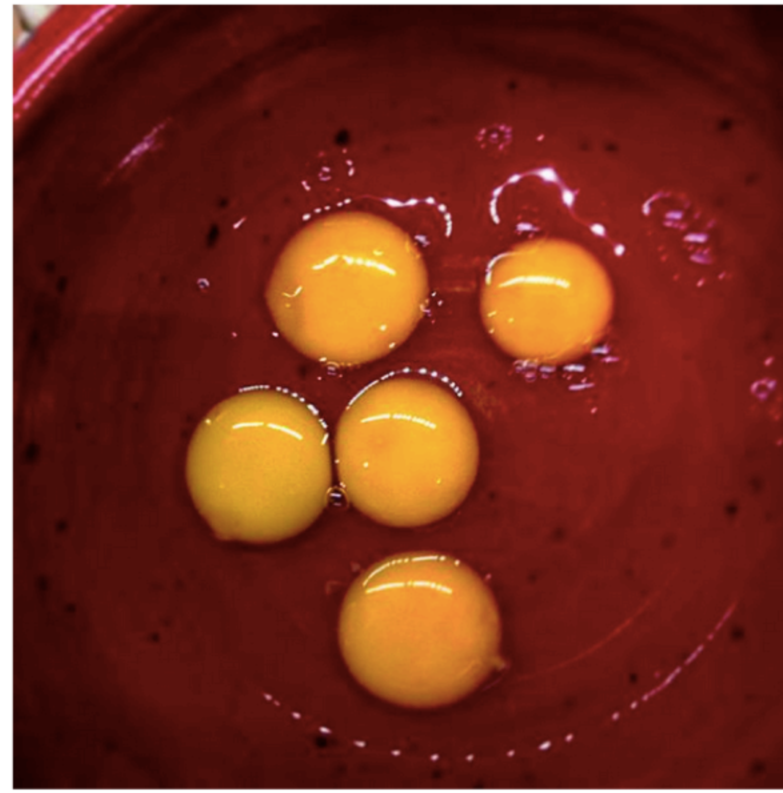


Four quark bound state is a promising explanation of Z(4430).

What about 5 quarks?

We've got some!





$\Lambda_b^0 \to J/\psi p K^-$

请关注张黎明的报告！

Upgrade and future prospects

LHCb time line

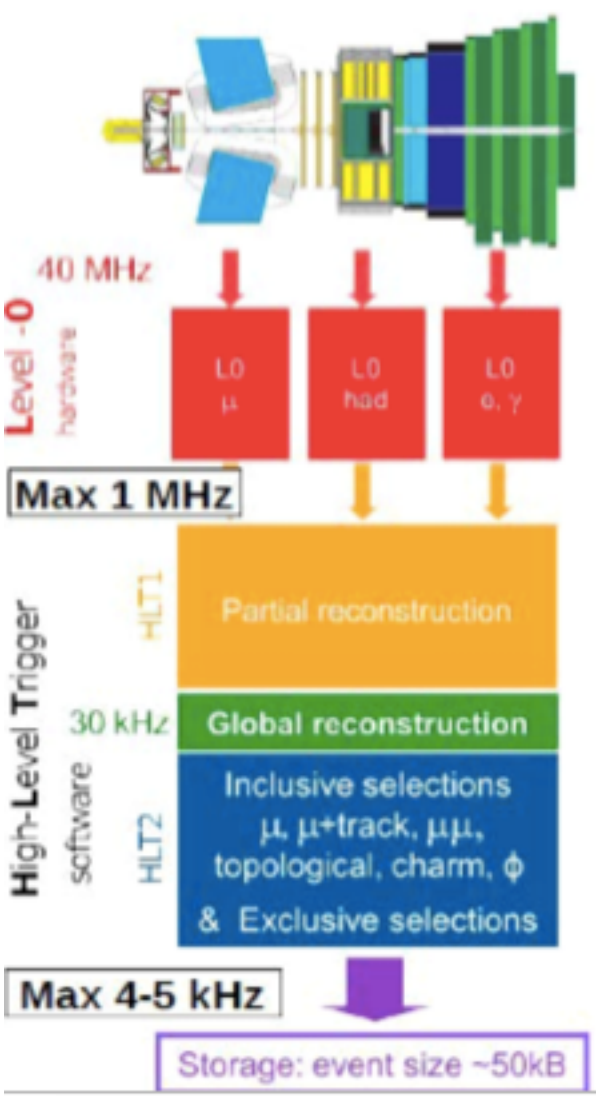
Year	Energy	Int. Lumi.
2010	7 TeV	37 pb^{-1}
2011	2.76TeV	71 pb^{-1}
2011	7 TeV	1.0 fb^{-1}
2012	8 TeV	2.2 fb^{-1}
2013	LHC splice repair	
2014		
2015	13 TeV 25 ns bunch crossing	>5 fb^{-1}
2016		
2017		
2018	LHCb upgrade	
2019	5 fb^{-1}/year	
2020		
2021		
2022	LHC lumi upgrade	
2023		
2024		

- Key challenges: face increases
  - Luminosity
  - Energy
  - Radiation
  - Occupancy

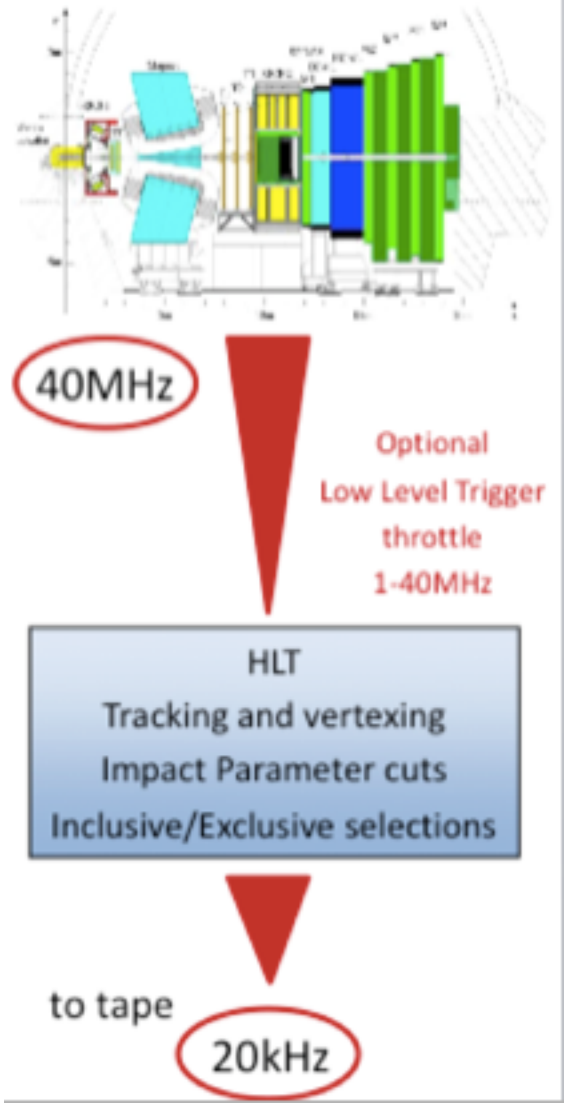
  } New triger, tracking & particle Identification systems
  - Data acquisition
    - take what we are missing so far
  - 2011&12 experience: better projections
- Operate at luminosities up to

  $L=2*10^{33}\ cm^{-2}\ s^{-1}$ (10x design)
- Expected annual physics yield:
  - Increase x5 in decays with muons
  - Increase at least x10 in hadronic channels
  - Collect ~50 fb^{-1} over 10 years

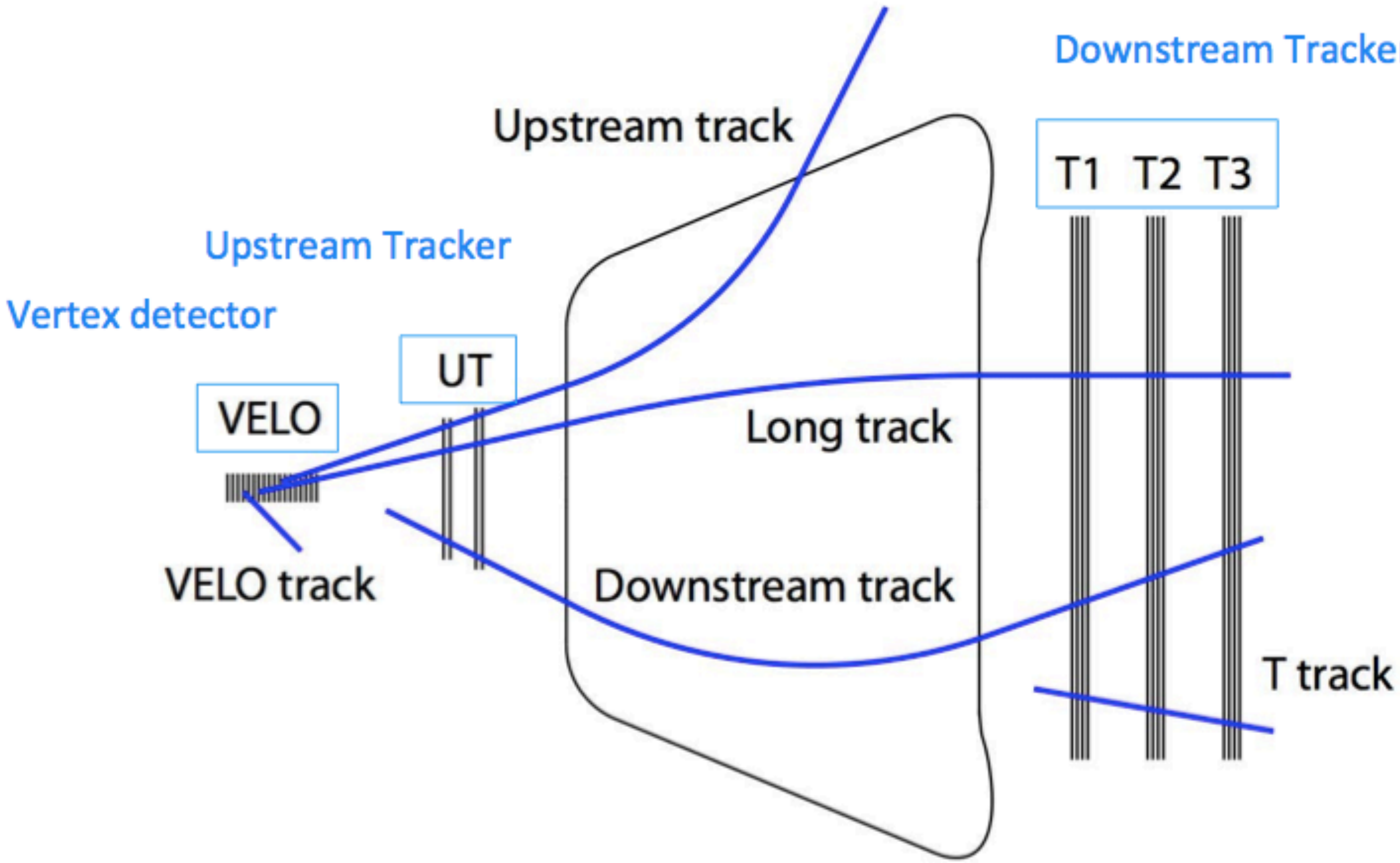
Trigger upgrade



- Full 40MHz readout
  (1MHz for current detector)
- Hardware trigger (L0) becomes optional and tunable
- HLT performs full reconstruction using sub -detector information
- Output increased from 4-5KHz to 20KHz

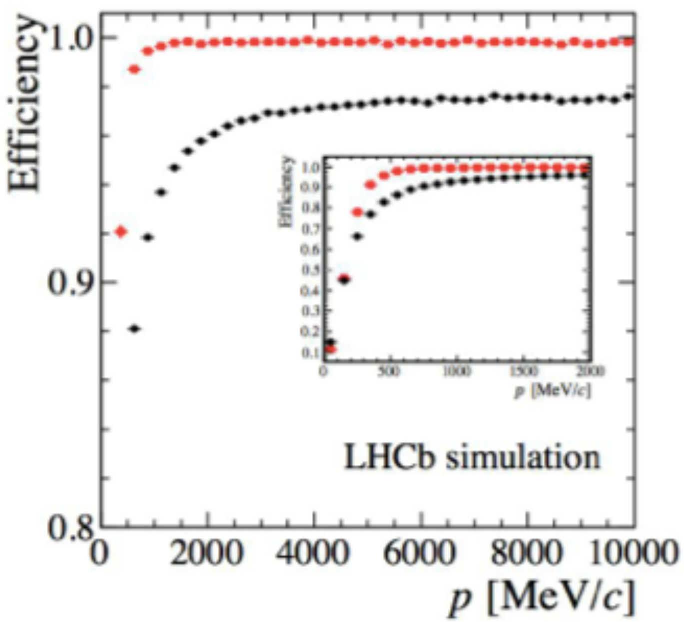


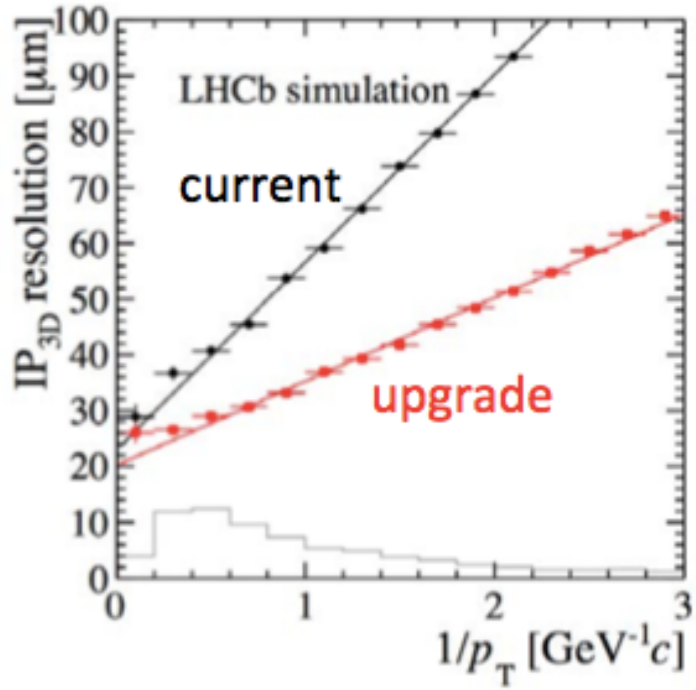
Tracking system



VELO upgrade

- Higher granularity: silicon strips → pixels
- Reduced material
- Enlarged acceptance





Vertexing performance much better

Downstream tracker

Current detector

IT : silicon strips

(50 μm resolution)

OT: straw drift tubes

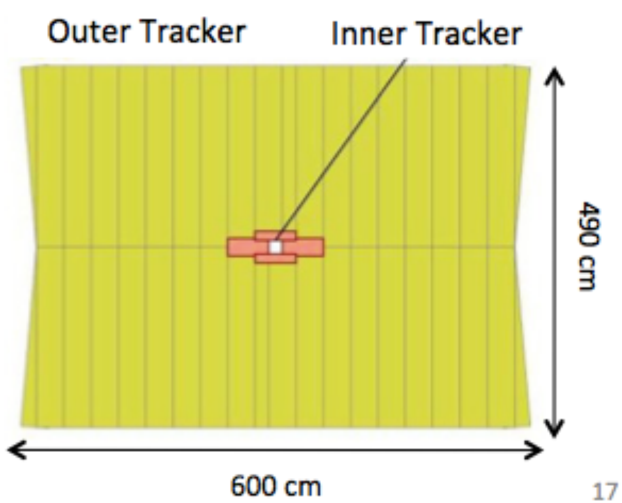
(200 μm resolution)

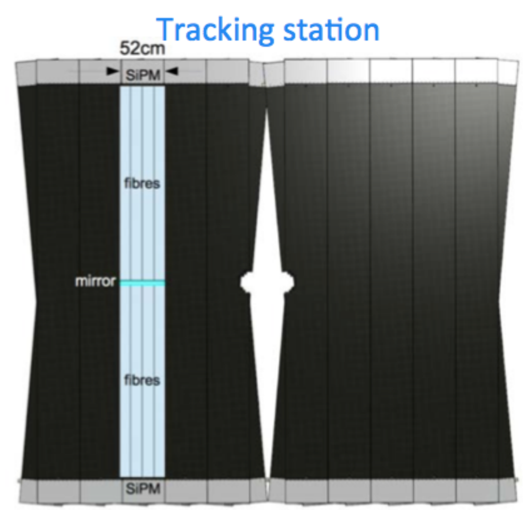
Upgrade: need to handle high occupancy

Scintillating Fibre Tracker

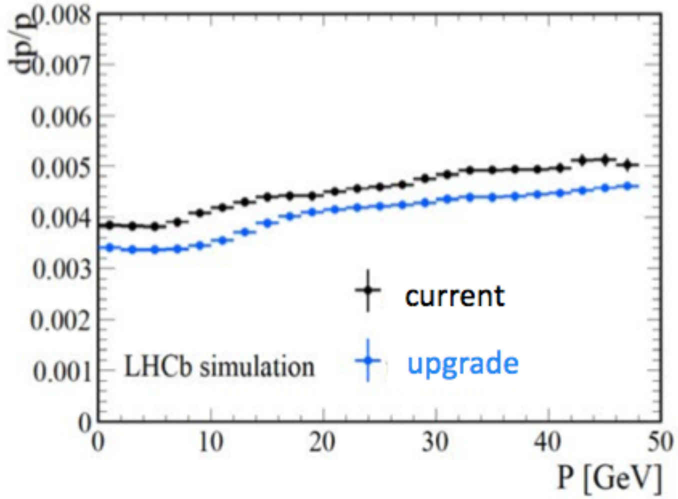
Readout by SiPMT

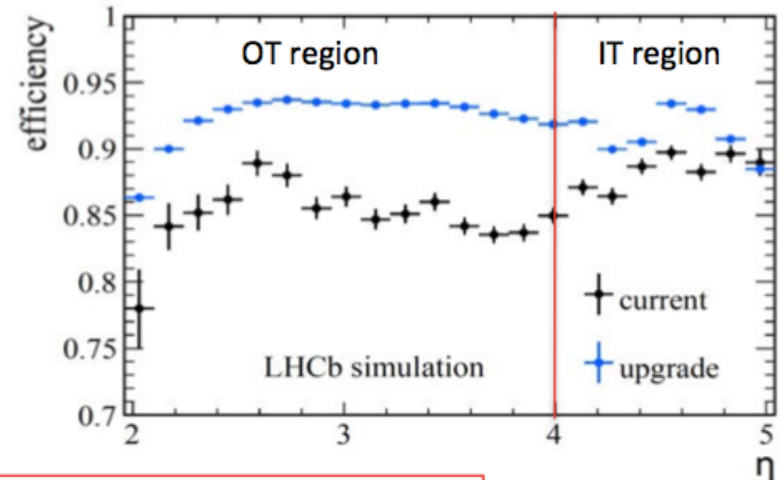
(60-100 μm resolution)





Tracking performance





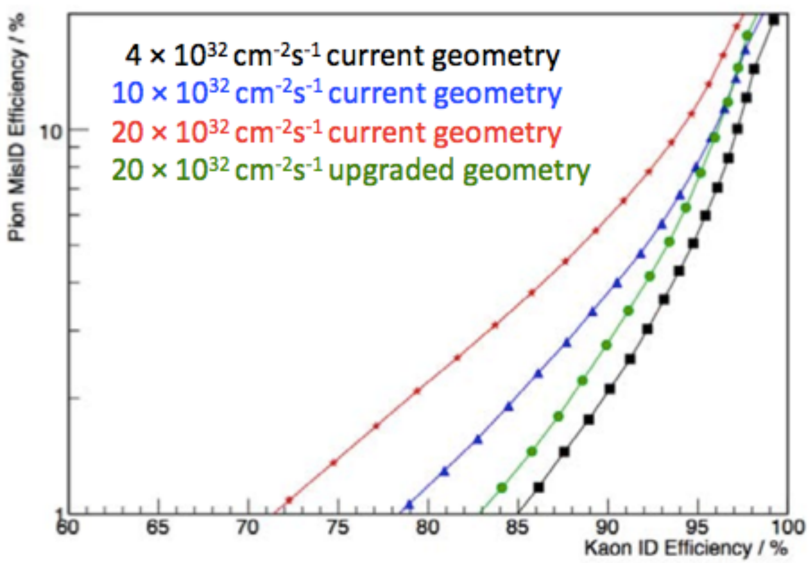
	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	13.1	14.7	25.5
Reconstruction efficiency			
long	90.9	86.9	84.5
long, $p > 5\,\text{GeV}/c$	95.4	92.9	91.5
b-hadron daughters	93.9	91.9	90.6
b-hadron daughters, $p > 5\,\text{GeV}/c$	96.1	95.1	94.2

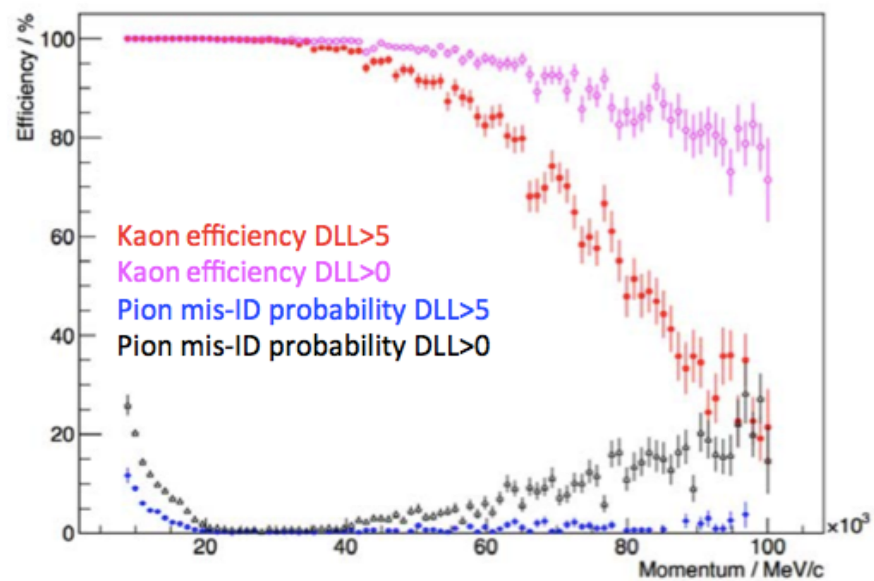
$4. \times 10^{32}$ cm^{-2}s^{-1} 2×10^{33} cm^{-2}s^{-1}

Tracking performance slightly better

RICH upgrade

- Overall structure unchanged
- Replace photon detectors with MaPMTs
- Remove aerogel in RICH1



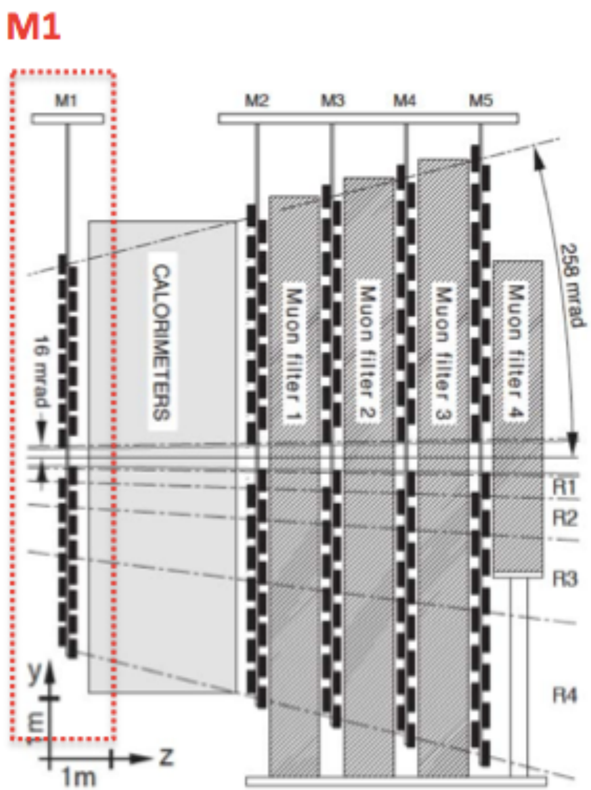


Hadron PID performance close to current one

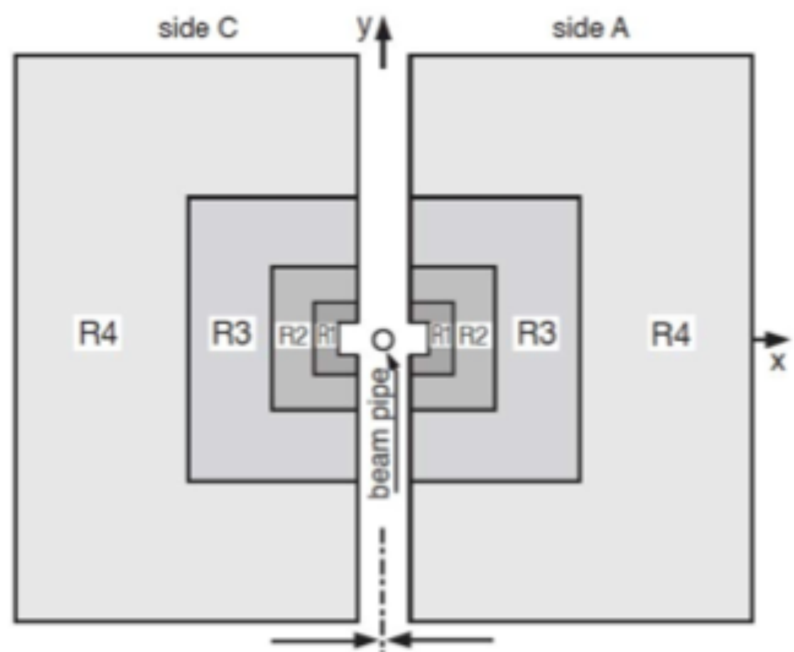
Muon system upgrade

M1 will be removed

Deal with high flux in innermost part of M2

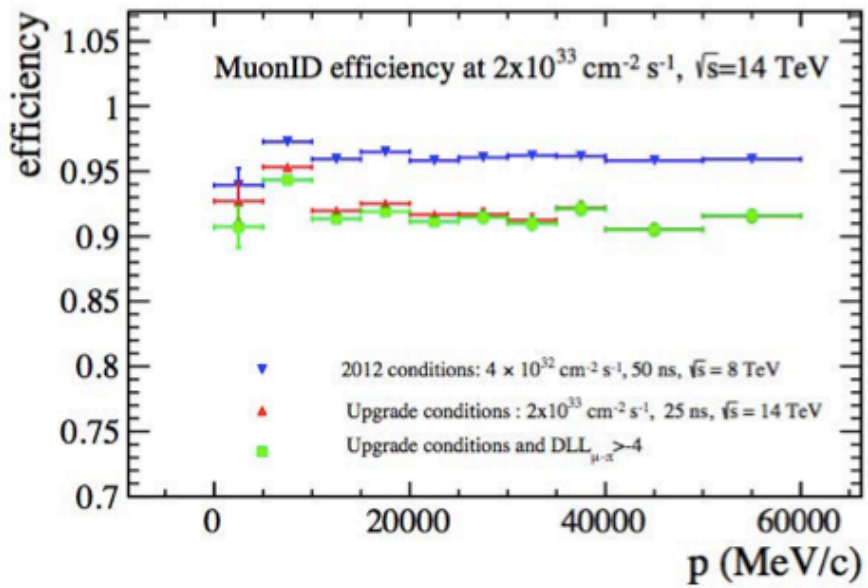


Anode-pad triple-GEM detectors for the R1 regions, MWPCs for the external regions.

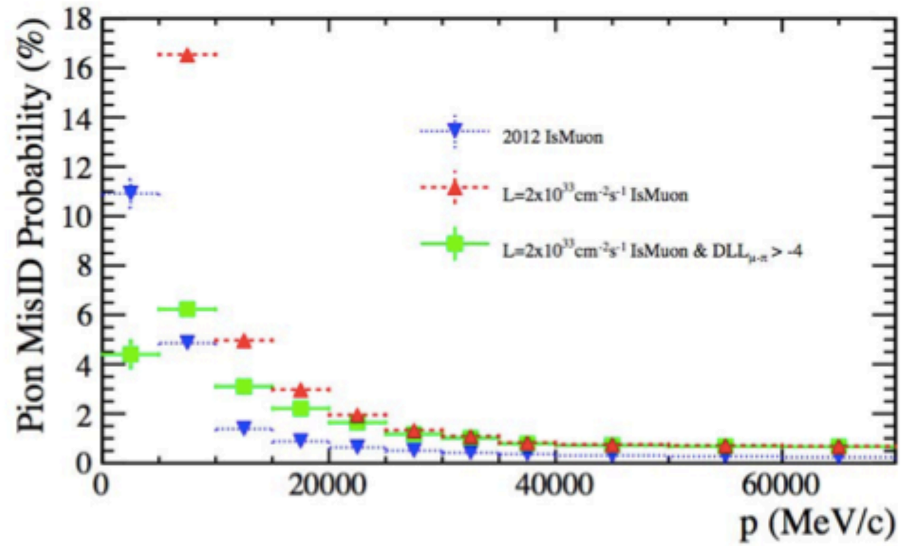


Muon performance

Efficiency



Pion MisID



Excellent muon-id performance retained

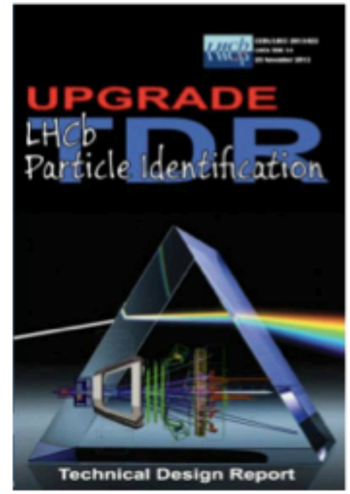
μ efficiency above 90%

$\pi \rightarrow \mu$ mis-identification rate below 5%

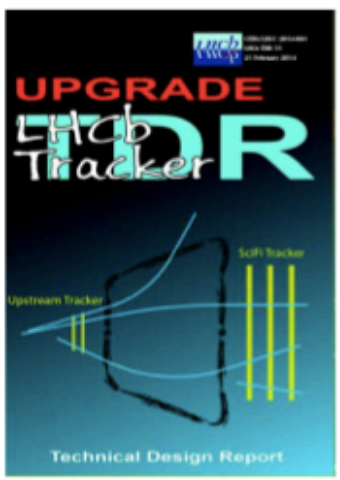
Upgrade TDRs

CERN-LHCC-2011-001

CERN-LHCC-2012-007



CERN-LHCC-2013-001



CERN-LHCC-2013-021

CERN-LHCC-2014-001

CERN-LHCC-2014-016

Physics potential of upgrade

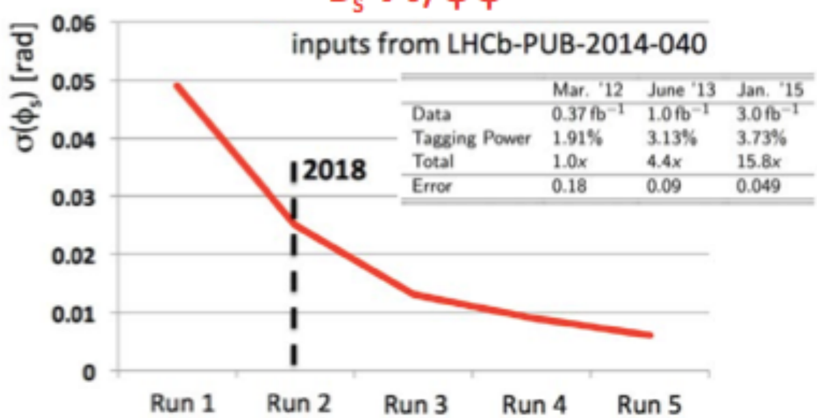
Type	Observable	LHC Run 1	LHCb 2018	LHCb upgrade	Theory
B_s^0 mixing	$\phi_s(B_s^0 \to J/\psi\,\phi)$ (rad)	0.049	0.025	**0.009**	~ 0.003
	$\phi_s(B_s^0 \to J/\psi\, f_0(980))$ (rad)	0.068	0.035	**0.012**	~ 0.01
	$A_{sl}(B_s^0)$ (10^{-3})	2.8	1.4	**0.5**	0.03
Gluonic penguin	$\phi_s^{\rm eff}(B_s^0 \to \phi\phi)$ (rad)	0.15	0.10	**0.018**	0.02
	$\phi_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$ (rad)	0.19	0.13	**0.023**	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$ (rad)	0.30	0.20	**0.036**	0.02
Right-handed currents	$\phi_s^{\rm eff}(B_s^0 \to \phi\gamma)$ (rad)	0.20	0.13	**0.025**	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5%	3.2%	**0.6%**	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.04	0.020	**0.007**	0.02
	$q_0^2\, A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	10%	5%	**1.9%**	$\sim 7\%$
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.09	0.05	**0.017**	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	14%	7%	**2.4%**	$\sim 10\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ (10^{-9})	1.0	0.5	**0.19**	0.3
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	220%	110%	**40%**	$\sim 5\%$
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	7°	4°	**0.9°**	negligible
	$\gamma(B_s^0 \to D_s^{\mp}K^{\pm})$	17°	11°	**2.0°**	negligible
	$\beta(B^0 \to J/\psi\, K_S^0)$	1.7°	0.8°	**0.31°**	negligible
Charm CP violation	$A_\Gamma(D^0 \to K^+K^-)$ (10^{-4})	3.4	2.2	**0.4**	–
	ΔA_{CP} (10^{-3})	0.8	0.5	**0.1**	–

- Before the upgrade (8 fb^{-1})
- After the upgrade (50 fb^{-1})
- Theory uncertainty (as far as we know today)

The extrapolations assume:
- Precisions scale as √L.
- Gain ×2 on fully hadronic decays removing L0 trigger.
- HLT and analysis performance as in Run I
- Backgrounds as in Run I.

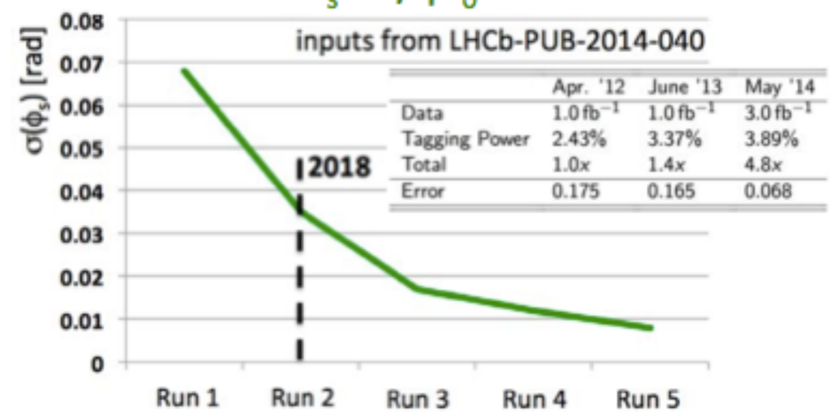
Key CP measurements

$B_s \to J/\psi\phi$



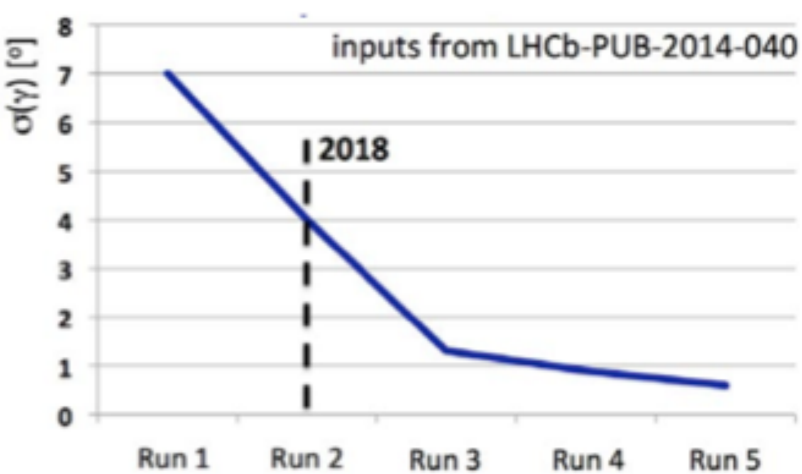
	Mar. '12	June '13	Jan. '15
Data	0.37 fb^{-1}	1.0 fb^{-1}	3.0 fb^{-1}
Tagging Power	1.91%	3.13%	3.73%
Total	1.0x	4.4x	15.8x
Error	0.18	0.09	0.049

$B_s \to J/\psi f_0$

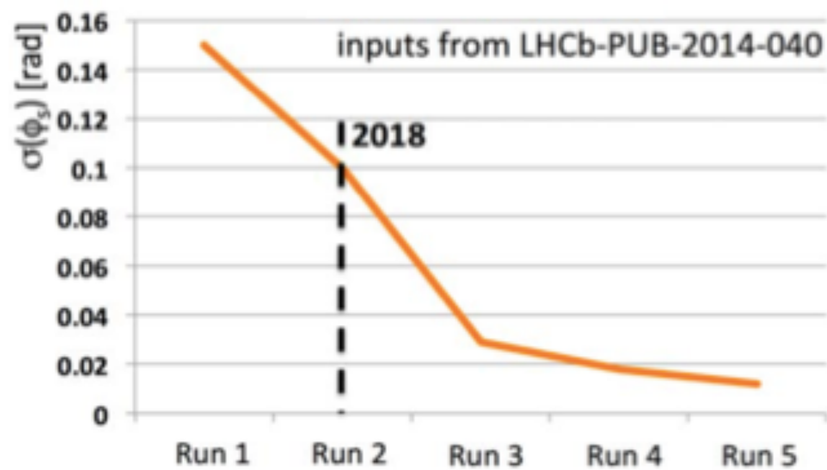


	Apr. '12	June '13	May '14
Data	1.0 fb^{-1}	1.0 fb^{-1}	3.0 fb^{-1}
Tagging Power	2.43%	3.37%	3.89%
Total	1.0x	1.4x	4.8x
Error	0.175	0.165	0.068

γ measurement



$B_s \to \phi\phi$



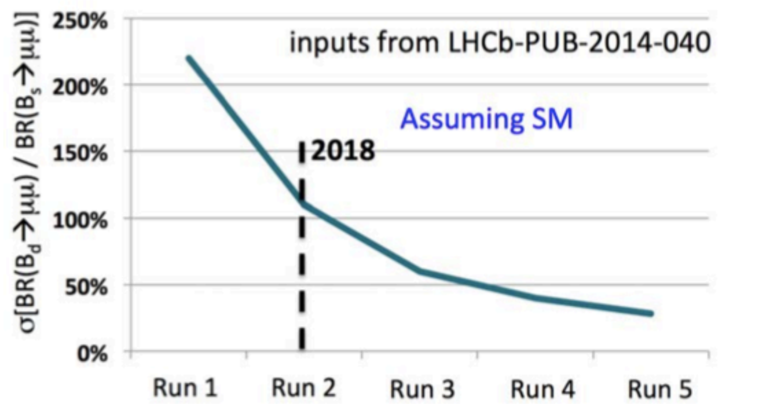
Rare decays

$B_{s/d} \to \mu^+\mu^-$

LHCb

$$\mathcal{B}\left(B_s \to \mu^+\mu^-\right) = 2.9^{+1.1}_{-1.0} \times 10^{-9}$$

$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\right) < 7.4 \times 10^{-10} \quad 95\%\, C.L.$$



Lots of new opportunities

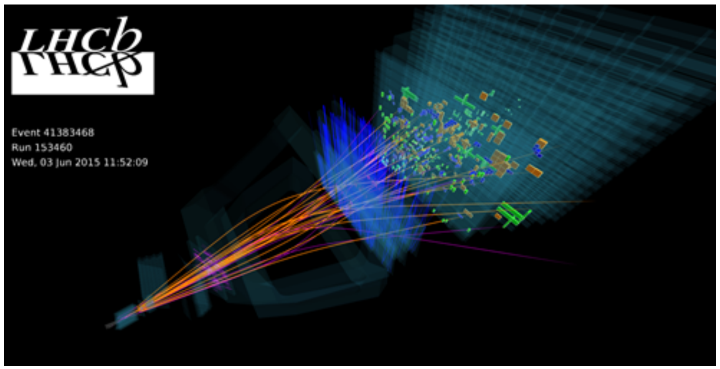
- CP violation in $B_s \to \mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$
- Precise measurement of $B_s \to \phi\gamma$ lifetime
- Precise $B^+ \to K^+l^+l^-$ angular analysis

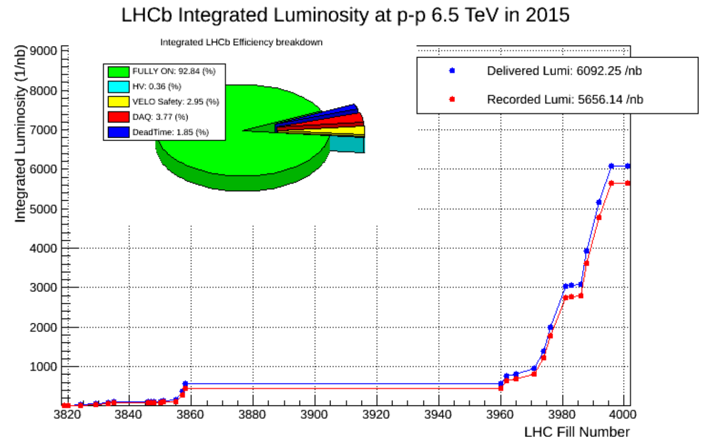
The plan

LHC era			HL-LHC era	
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2020-22)	Run 4 (2025-28)	Run 5+ (2030+)
3 fb^{-1}	8 fb^{-1}	23 fb^{-1}	46 fb^{-1}	100 fb^{-1}

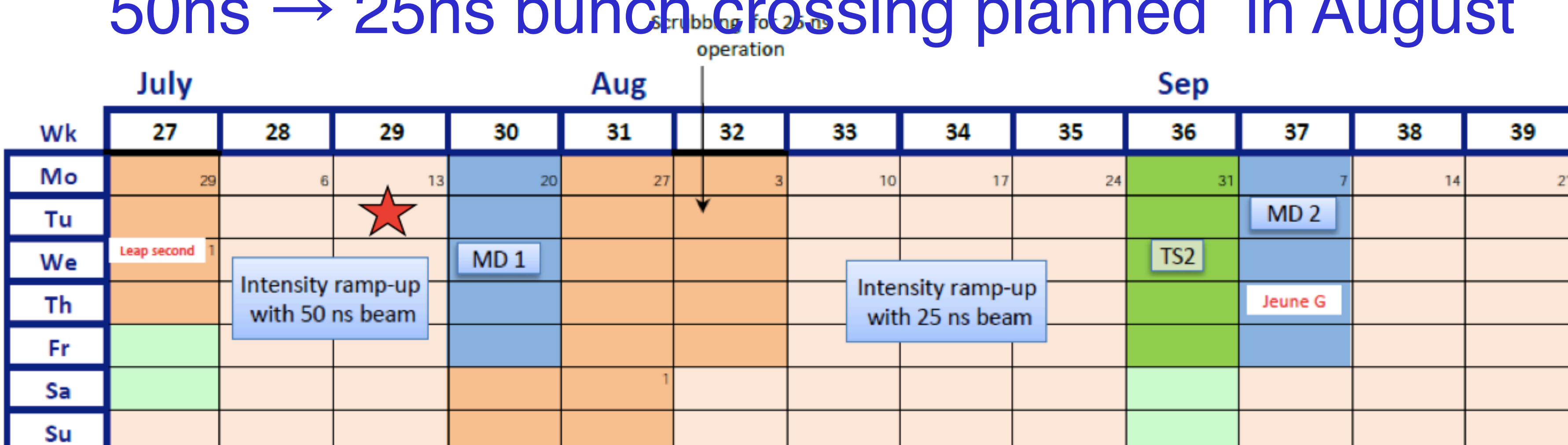
Where we are now

Physics run at 13 TeV started on 3 June 2015

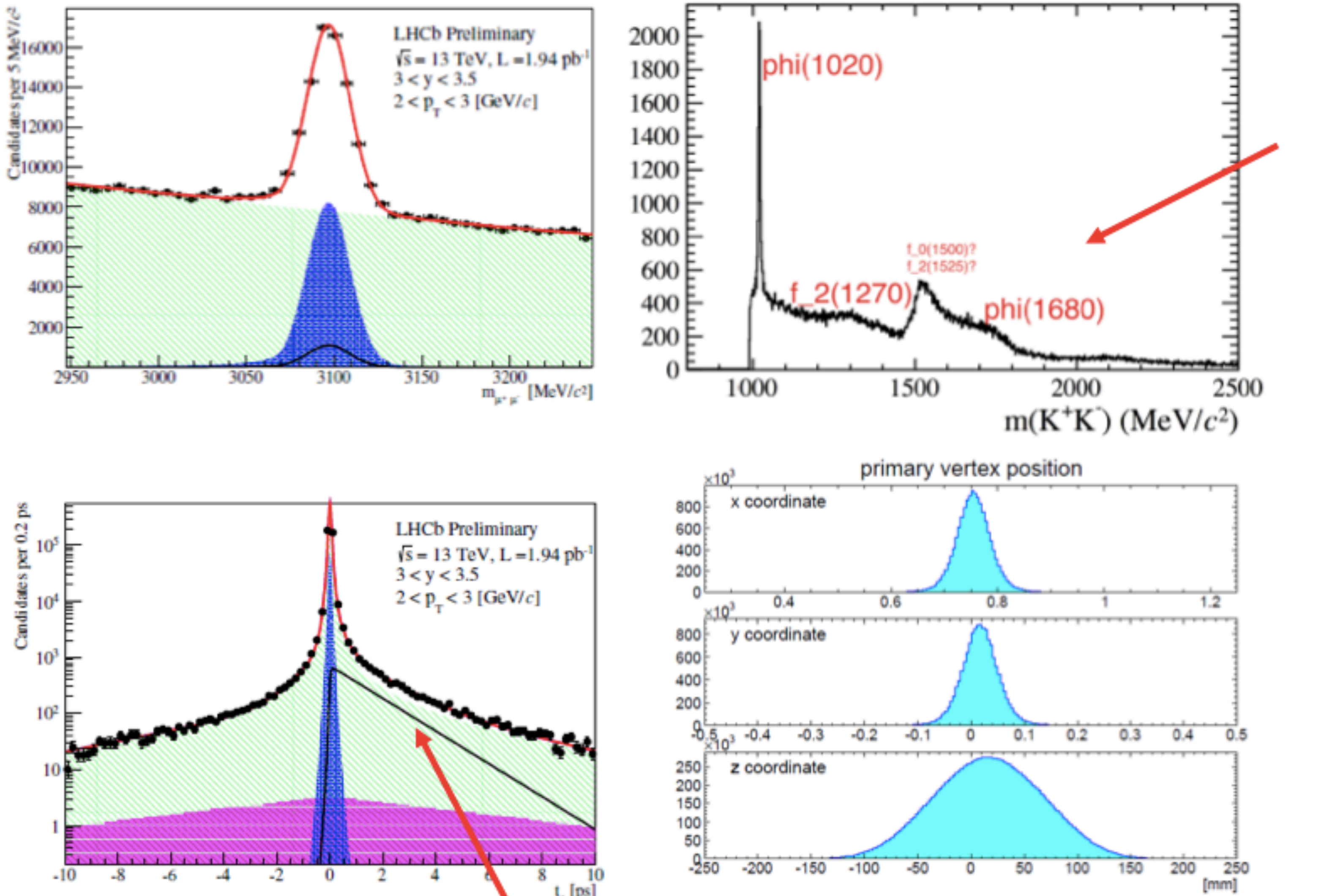




50ns → 25ns bunch crossing planned in August



Some mass peaks in Run II



b hadrons

China@LHCb

China@LHCb

Over 1100 members，68 institutes，16 countries

中国单位（17 members）

清华大学，华中师范大学，中国科学院大学

主要研究方向和代表性成果

CP violation & new physics search: ϕ_s measurement

Hadron production & exotic states: pentaquark discovery, B_c physics

显著度

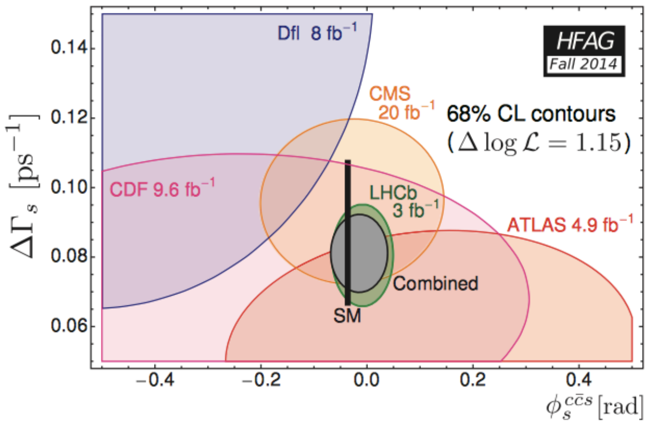
中国组成员担任两个物理工作组召集人

探测器升级

中国组将参加对Scintillating Fiber Tracker 的升级，主要从事：相关电子学部件的设计、生产和检测，寻迹软件的开发

中国组重要成果：ϕ_s精确测量

ϕ_s-$\Delta\Gamma_s$ world average



B$_s$混合角的世界最精确测量

严格限制了新物理的藏身之处

科学通报 2015年 第60卷 第4期

科学新闻

《中国科学》杂志社
SCIENCE CHINA PRESS

LHCb关于正反物质性质差异的研究取得新进展

现行理论认为，宇宙大爆炸产生了几乎等量的物质和反物质．由于物质和反物质在微观性质上存在一定的差异(物理学上称为“电荷共轭-宇称对称性破缺”，简称CP破坏)，宇宙经过长时间的演化，形成我们今天观测到的由正物质组成的世界．

欧洲大型强子对撞机(LHC)是目前世界上最大、能量最高的粒子加速器．大型强子对撞机底夸克实验(LHCb)是LHC上的4个主要探测器之一，它的主要物理目标是测量在b和c强子中的CP破坏和稀有衰变现象．最近，LHCb实验利用2011~2012年期间采集的数据对B_s介子混合角ϕ_s进行了世界最精确的测量(图1)，这标志着对正反物质性质差异的研究取得重要进展．作为该课题组的负责人之一，华中师范大学谢跃红教授与课题组中其他数十名科研人员共同完成了相关的理论研究和数据分析，相关研究结果于2015年2月在*Physical Review Letter*杂志上发表．

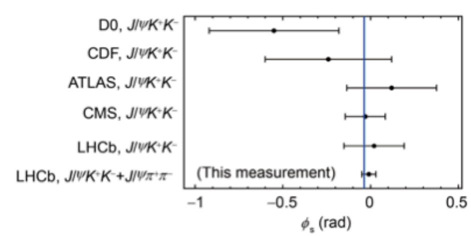
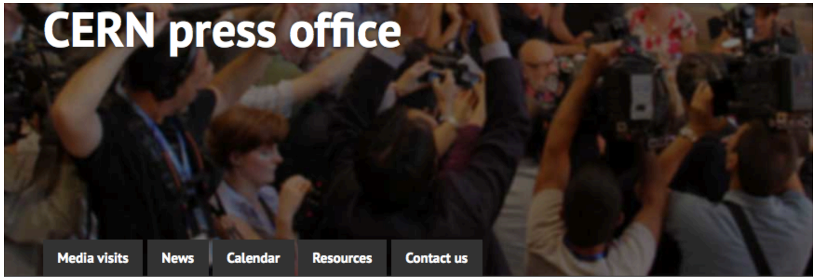


图 1 (网络版彩色)LHCb与其他实验的ϕ_s测量结果的比较．竖直线为标准模型预言值

值．CDF, D0, ATLAS, CMS等高能实验都利用这个过程对ϕ_s进行了测量，但测量精度相当有限．谢跃红等人曾利用2011年的LHCb数据得到了精度约为0.1 rad的ϕ_s测量结果．

中国组重要成果：五夸克态的发现



Latest news

CERN's LHCb experiment reports observation of exotic pentaquark particles

清华大学所在国际合作组取得新突破

五夸克态，确实存在！

2015年07月15日07:17　来源：人民网-人民日报　手机看新闻

打印　网摘　纠错　商城　分享　推荐　人民微博　关注　字号

原标题：五夸克态，确实存在！

本报北京7月14日电 （赵婀娜、丁乐）14日，欧洲核子研究中心大型强子对撞机上的LHCb实验组宣布：在实验中观测到由五夸克组成的重子态，首次确认五夸克态的存在。这项研究由清华大学和美国雪城大学的研究人员，以及LHCb国际合作组成员共同完成。

Conclusions

- Many excellent new results from LHCb
  - Discovery: pentaquark states!
  - Precision measurements: CPV, rare decays
  - Unexpected: semileptonic results
- Basic picture is SM-like, with a few puzzles to be understood: P_5', R_K, $R(D^*)$
  - Improving measurement precision
  - Better control of hadronic uncertainties
- LHCb Run-II and upgrade will be crucial & exciting
- China is playing a increasingly important and visible role at LHCb

Backup slides

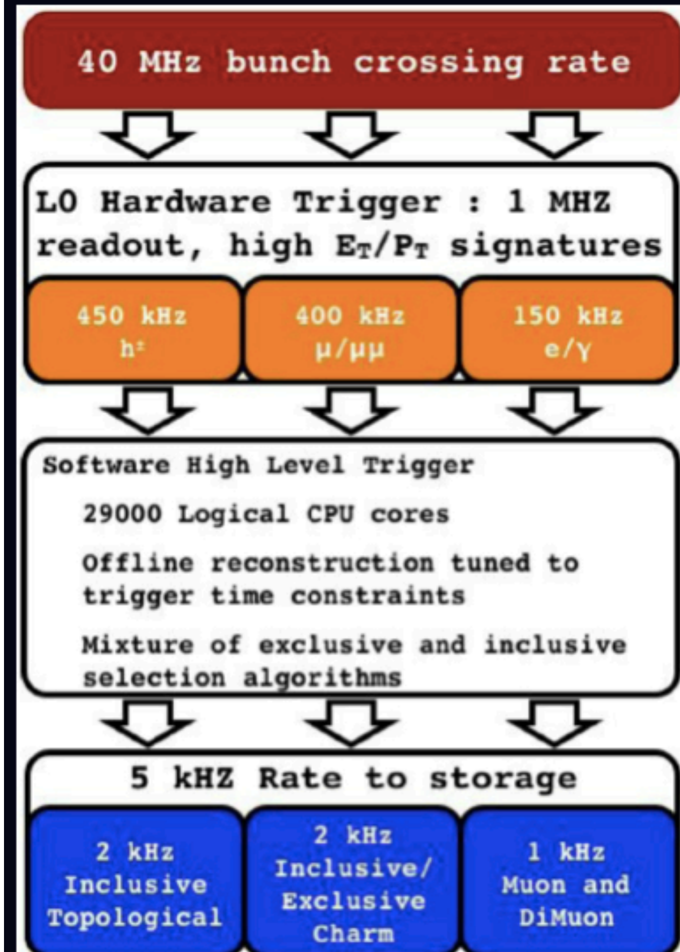
LHCb升级与SuperB比较

Observable class of observables)	SM prediction	Ultimate th. error	Present result	Future (S)LHCb	Future SuperB	Future Other
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	input	$0.1\%_{(\mathrm{Latt})}$	0.2252 ± 0.0009	-	-	
$\lvert V_{cb}\rvert$ $[\times 10^{-3}]$ $[B \to X_c\ell\nu]$	input	1%	40.9 ± 1.1	-	$1\%_{\mathrm{excl}}, 0.5\%_{\mathrm{incl}}$	
$\lvert V_{ub}\rvert$ $[\times 10^{-3}][B \to \pi\ell\nu]$	input	$5\%_{(\mathrm{Latt})}$	4.15 ± 0.49	-	$3\%_{\mathrm{excl}}, 2\%_{\mathrm{incl.}}$	
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	0.9°	1.5°	
$S_{B_d \to \psi K}$	2β	$\lesssim 0.01$	0.671 ± 0.023	0.0035	0.0025	
$S_{B_s \to \psi\phi, \psi f_0(980)}$	$2\beta_s$	$\lesssim 0.01$	-0.002 ± 0.087	0.008	-	
$S_{[B_s \to \phi\phi]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.03	-	
$S_{[B_s \to K^{*0}\bar{K}^{*0}]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.02	-	
$S_{[B_d \to \phi K^0]}$	$2\beta^{eff}$	$\lesssim 0.05$	-	0.03	0.02	
$S_{[B_d \to K_S^0\pi^0\gamma]}$	0	$\lesssim 0.05$	-0.15 ± 0.20	-	0.02	
$S_{[B_s \to \phi\gamma]}$	0	$\lesssim 0.05$	-	0.02	-	
$A_{\mathrm{CP}}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	-	0.004	
$A_{\mathrm{CP}}(b \to (s+d)\gamma)$	$\sim 10^{-6}$	-	-0.060 ± 0.060	-	0.02	
$A_{\mathrm{SL}}^d[\times 10^{-3}]$	-0.5	0.1	-5.8 ± 3.4	0.2	4	
$A_{\mathrm{SL}}^s[\times 10^{-3}]$	2.0×10^{-2}	$< 10^{-2}$	-2.4 ± 6.3	0.2	~ 0.6	
$\mathcal{B}(B \to \tau\nu)[\times 10^{-4}]$	1	$5\%_{\mathrm{Latt}}$	(1.14 ± 0.23)	-	$4-5\%$	
$\mathcal{B}(B \to \mu\nu)[\times 10^{-7}]$	4	$5\%_{\mathrm{Latt}}$	< 13	-	$2-3\%$	
$\mathcal{B}(B \to D\tau\nu)[\times 10^{-2}]$	1.02 ± 0.17	$5\%_{\mathrm{Latt}}$	1.02 ± 0.17	[under study]	2%	
$\mathcal{B}(B \to D^*\tau\nu)[\times 10^{-2}]$	1.76 ± 0.18	$5\%_{\mathrm{Latt}}$	1.76 ± 0.17	[under study]	2%	
$\mathcal{B}(B_s \to \mu^+\mu^-)[\times 10^{-9}]$	3.2	$5\%_{\mathrm{Latt}}$	< 4.2	0.15	-	
$R(B_{s,d} \to \mu^+\mu^-)$	0.29	$\sim 5\%$	-	$\sim 35\%$	-	
$q_0(A^{FB}_{B \to K^*\mu^+\mu^-})[\mathrm{GeV}^2]$	4.26 ± 0.34			2%	[under study]	
$A_{\mathrm{T}}^{(2)}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.04	[under study]	
$A_{\mathrm{CP}}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.5%	1%	
$B \to K\nu\bar{\nu}[\times 10^{-6}]$	4	$10\%_{\mathrm{Latt}}$	< 16	-	0.7	
$\lvert q/p\rvert_{D-\mathrm{mixing}}$	1	$< 10^{-3}$	0.91 ± 0.17	$O(1\%)$	2.7%	
ϕ_D	$\lesssim 0.1\%$		–	$O(1^\circ)$	1.4°	
$a_{\mathrm{CP}}^{\mathrm{dir}}(\pi\pi)(\%)$	$\lesssim 0.3$		0.20 ± 0.22	0.015	[under study]	
$a_{\mathrm{CP}}^{\mathrm{dir}}(KK)(\%)$	$\lesssim 0.3$		-0.23 ± 0.17	0.010	[under study]	
$a_{\mathrm{CP}}^{\mathrm{dir}}(\pi\pi\gamma, KK\gamma)$	$\lesssim 0.3\%$			[under study]	[under study]	
$\mathcal{B}(\tau \to \mu\gamma)[\times 10^{-9}]$	0		< 44	-	2.4	
$\mathcal{B}(\tau \to 3\mu)[\times 10^{-10}]$	0		$< 210(90\%\ \mathrm{CL})$	1-80	2	
$\mathcal{B}(\mu \to e\gamma)[\times 10^{-12}]$	0		$< 2.4(90\%\ \mathrm{CL})$			~ 0.1 MEG; ~ 0.01 PSI-future; ~ 0.01 Project X
$\mathcal{B}(\mu N \to eN)(Tl)$	0		$< 4.3 \times 10^{-12}$			10^{-18} PRISM
$\mathcal{B}(\mu N \to eN)(Al)$	0		-			10^{-16} COMET, Mu2e
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})[\times 10^{-11}]$	8.5	8%	$17.3^{+11.5}_{-10.5}$			$\sim 10\%$ NA62; $\sim 5\%$ ORKA; $\sim 2\%$ Project X
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})[\times 10^{-11}]$	2.4	10%	< 2600			$\sim 100\%$ KOTO; $\sim 5\%$ Project X
$\mathcal{B}(K_L \to \pi^0 e^+e^-)_{SD}$	1.4×10^{-11}	30%	$< 28 \times 10^{-11}$			$\sim 10\%$ Project X

LHCb升级后在B_s介子的CP破坏和稀有衰变的研究中普遍具有优良性能

SuperB具有对含中微子模态的衰变、辐射衰变、V_{ub}的较强研究能力

Trigger



- Level-0 Trigger: hardware
  - ➢ use calorimeters and muon system
  - ➢ select high-p_T particles
    - ✓ $p_T(\mu) > O(1)$ GeV/c
    - ✓ $p_T(h,e,\gamma) > O(3)$ GeV/c
- High-Level Trigger: software
  - ➢ HLT1: add VELO information
    - ✓ impact parameter and lifetime
  - ➢ HLT2: global event reconstruction
    - ✓ exclusive & inclusive selections

Trigger efficiency: ~90% for dimuon events
~30% for multibody hadronic final states