Summary WG4

J. Martin Camalich (TH)

CERN

J. Zupan (TH), Alex Cerri - ATLAS, Sandra Malvezzi - CMS, Vladimir Gligorov* - LHCb

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European Research Council
Established by the European Commission

1st of November 2017

LHC schedule

2019 2020	2021 2022 2023	2024 2025 2026	2027 2028 2029	2030 2031	2032 203+
	Run III		Run IV		Run V
LS2		LS3		LS4	
LHCb 40 MHz UPGRADE	$L = 2 \times 10^{33}$	LHCb Consolidation	$L = 2 \times 10^{33}$ 50 fb^{-1}	LHCb Ph II UPGRADE *	$L = 2 \times 10^{34}$ 300 fb^{-1}
ATLAS Phase I Upgr	$L = 2 \times 10^{34}$	ATLAS Phase II UPGRADE	HL-LHC $L = 5 \times 10^{34}$	ATLAS	HL-LHC $L = 5 \times 10^{34}$
CMS Phase I Upgr	300 fb^{-1}	CMS Phase II UPGRADE		CMS	3000 fb^{-1}
Belle II	5 ab^{-1} $L = 8 \times 10^{35}$	50 ab^{-1}			

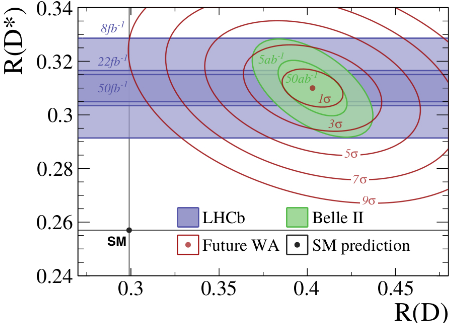
- LHCb expected to collect $\sim 300\ \text{fb}^{-1}$ after phase II upgrade

Prospects for $b \to c\tau\nu$

J. Virto & P. Alvarez (LHCb) & P. Goldenzweig (Belle II) 9.00-10.30 Session TU

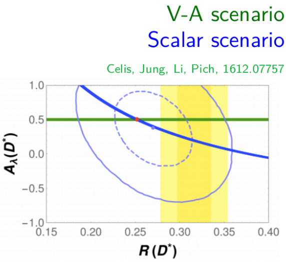
arXiv:1709.10308: J. Albrecht, F. U. Bernlochner, M. Kenzie, S. Reichert, D. M. Straub, A. Tully

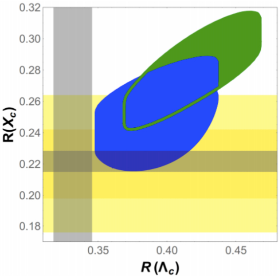
Measurement	SM prediction	Current World Average	Current Uncertainty	Projected Uncertainty[1]				
				Belle II		LHCb		
				5ab^{-1}	50ab^{-1}	8fb^{-1}	22fb^{-1}	50fb^{-1}
				2020	2024	2019	2024	2030
$R(D)$	(0.299 ± 0.003)	$(0.403 \pm 0.040 \pm 0.024)$	11.6%	5.6%	3.2%	-	-	-
$R(D^*)$	(0.257 ± 0.003)	$(0.310 \pm 0.015 \pm 0.008)$	5.5%	3.2%	2.2%	3.6%	2.1%	1.6%



Combined effort of Belle II and LHCb (50 fb^{-1}) should be able to establish NP in $R_{D^{(*)}}$

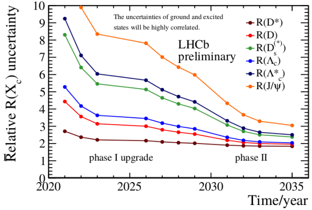
- **New modes** and **kinematic distributions** to distinguish among NP scenarios!





- **LHCb** can measure many different channels

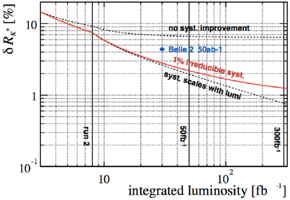
Phase-II will substantially benefit $R(X_c)$ measurements of B_s^0, Λ_b^0, B_c^+ hadrons



- **Homework:** Prospects for kinematic distributions (e.g. D^*/τ polarization)

Prospects for $b \to s\ell\ell$

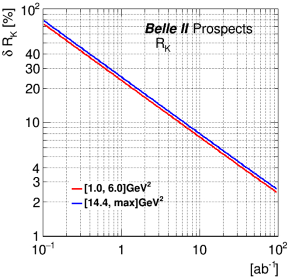
- Bright future for LUV searches in LHCb !

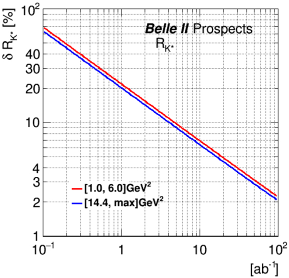


☐ Enough to establish NP (if central values stay put)

☐ Also other ratios measured with high precision, including angular obs

- **Needs to be confirmed by an independent experiment! (Belle II)**





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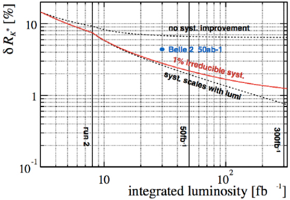

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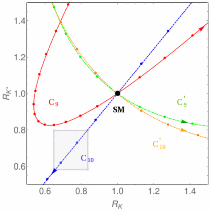
- **Needs to be confirmed by an independent experiment!** P. Řezníček (ATLAS)

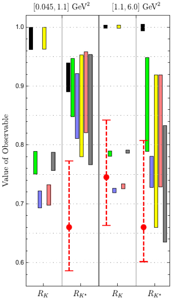
Other Ideas / Analyses

- Channels with electrons in the final states:
  - Rare decays:
    - $B_s \to ee$
    - $B \to K^*ee$ and similar $b \to sll$ transitions
  - LFV decays:
    - $B_s \to e\mu$

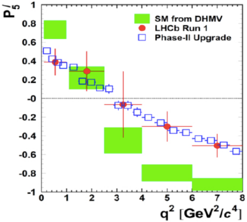
- **Homework:** Prospects for electronic/hadronic modes at ATLAS and CMS S. Sarkar

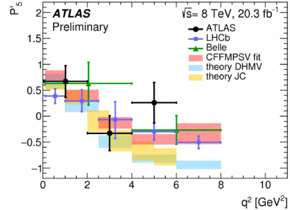
- **Homework:** Look for new observables/measurements!
  - Select type of NP
  - R_{K*} is a **very clean null-test of the SM but a dirty observable in NP!**





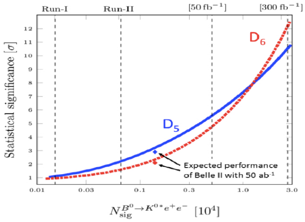
- Brings back issue of **hadronic uncertainties**





- **Homework for theorists:** We have 15 yrs to figure this out (J. Zupan & J. Virto)

- R_{K^*} is a **very clean null-test of the SM but a dirty observable in NP!**



$D_{5,6}$ defined in

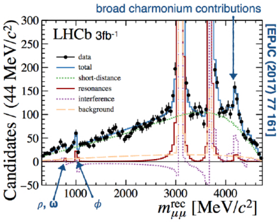
Serra, Coutinho, van Dyk 1610.08761

Expect similar prospects for clean observables Q_i, B_i in

Capdevila, Descotes, Matias, JV 1605.03156

- Tackle head-on hadronic corrections with **semi-empirical models**

  (Paula Alvarez Javier Virto and Luca Silvestrini)



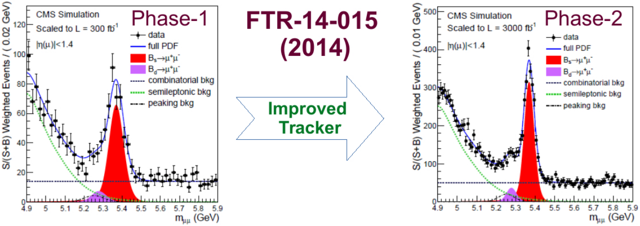
- ... Or **theory** (first-principle calculations–LQCD) ... (Silvestrini's talk)

  – New ideas to compute FF on the lattice at small q^2

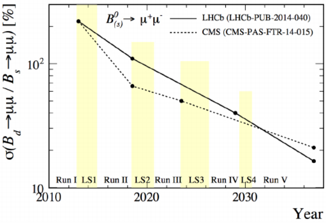
  Martinelli et al., in progress

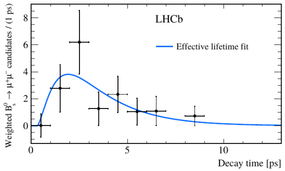
$B_q \to \mu\mu$ discovery channel for NP and "elucidator" of anomalies

- **CMS** can discover $B_d \to \mu\mu$ at $> 5\sigma$ with 3 ab^{-1} (S. Sarkar's talk)



- Healthy competition between **ATLAS**, **CMS** and **LHCb** (P. Alvarez's talk)





[PRL 118, 191801 (2017)]

Recent LHCb measurement: $\tau_{\mu\mu} = 2.04 \pm 0.44 \pm 0.05$ ps

Could reach $\sim$ 2% uncertainty with 300 fb^{-1}

- Also bounds on $B_q \to ee$, $B_q \to \tau\tau$, $B_q \to \mu e$,...

FCNC anomalies beyond $b \to s\ell\ell$

- Search for NP in $b \to d\ell\ell$ at **LHCb**

With 300 fb^{-1}, we will achieve precise measurements of the $\mathcal{B}$'s of $b \to d\ell^+\ell^-$ penguins ($B^+ \to \pi^+\mu\mu$, $B_s^0 \to \overline{K}^{*0}\mu\mu$...)

With 300 fb^{-1} $b \to de^+e^-$ processes will also be important (e.g. expect $O(1000)$ $B^+ \to \pi^+e^+e^-$), so will be able to perform LFU tests with $b \to d$ transitions

- Interplay with $b \to s\nu\nu$ at **Belle II**

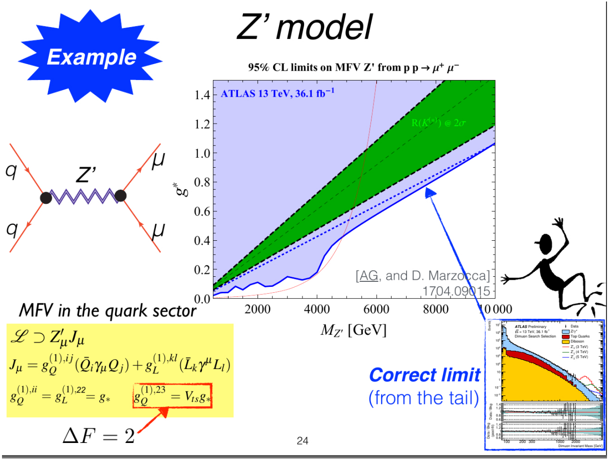
Sensitivities of modes with $\nu\bar{\nu}$ in the final state

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	25%	9.3%
$f_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	–	0.079
$f_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	–	0.077
$\mathcal{B}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5

B2TiP Report (in progress)

The connection of the anomalies with high-p_T searches

- **Great discovery potential!** A. Greljo, You (Flavor, BSM, Higgs joint session)



- **Homework?** “No-lose theorems” for anomaly-related NP at HL/HE-LHC

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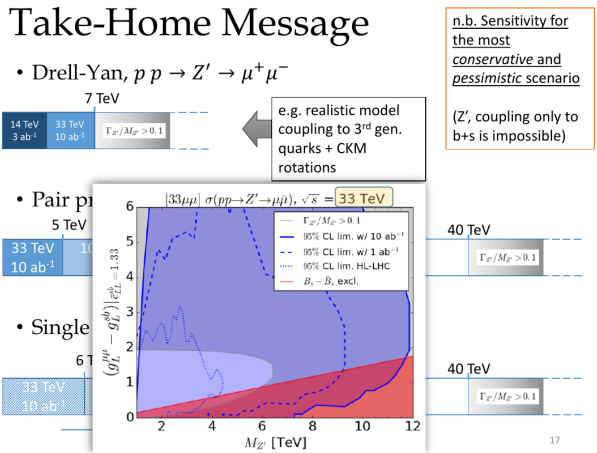
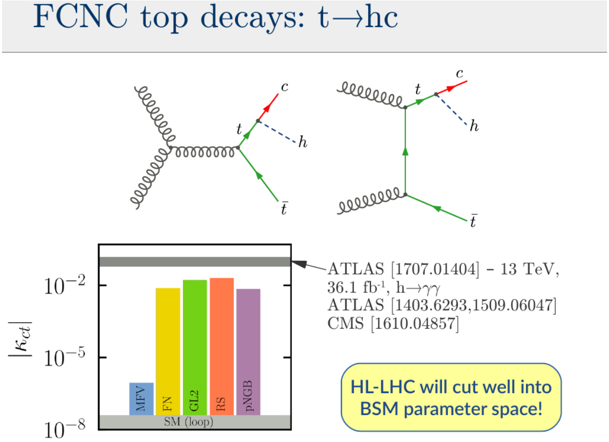


- **Homework?** “No-lose theorems” for anomaly-related NP at HL/HE-LHC

On the connection of flavor to Higgs (and top)

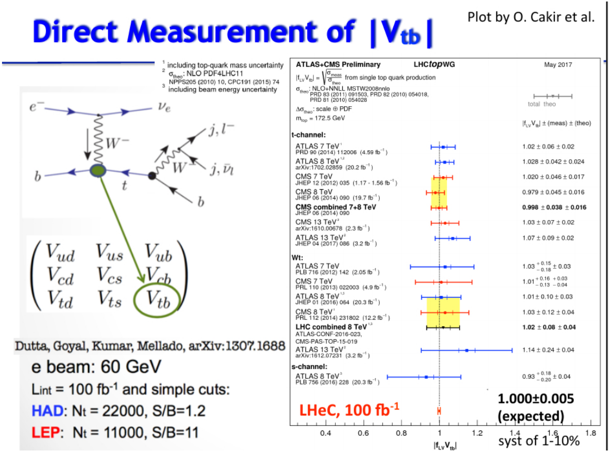
Fady Bishara, Oscar Augusto



Homework: Incorporate flavor aspects of top physics in WG4

On the flavor aspects of LHeC

Uta Klein, Max Klein



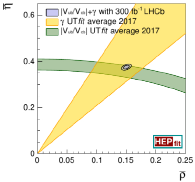
- Interesting interplay with flavor
  - High precision measurement of V_{tb} (and V_{ts}?)
  - Complementarity with NP searches at HL-LHC

Classic program on CKM metrology

- **Overconstrain CKM:** Tree (SM) vs. loop processes (NP) L. Silvestrini & F. Dordei
  - Prospects of **LHCb** for γ (300 fb^{-1})

Sample	$\sigma_{\rm stat}(\gamma)^\circ$
Run 1	8
Run 2	4
Upgrade	~ 1
Phase-2 upgrade	<0.5

  - Impact on Unitarity fits in $(\bar{\rho},\ \bar{\eta})$



  - $\delta\bar{\rho} = \pm\, 0.003$ (now $\pm\, 0.029$)
  - $\delta\bar{\eta} = \pm\, 0.005$ (now $\pm\, 0.029$)

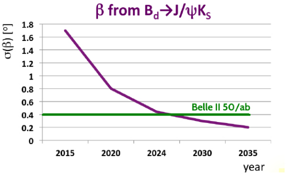
  - Belle II expects $\sigma(\gamma) \sim 2^o$

- Impact of **LHCb** phase II also in CKM loop processes: $\sin 2\beta$
  - Current precision

$$S \equiv \sin 2\beta = 0.691 \pm 0.017$$

[HFLAV Summer 2017]

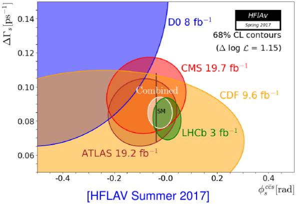
  - Prospecs at LHCb only
    $\sigma(\sin 2\beta) \sim 0.005$



[LHCb Upgrade II Expression of interest]

[B physics experiments comparison]

CPV interference phases: $\phi_s = -2arg(V_{ts}V_{tb}^*/V_{cb}V_{cs}^*)$



[HFLAV Summer 2017]

LHCb:

- $J/\psi\phi$ [PRL114, 041801 (2015)]
- $J/\psi K^+K^-$ [arXiv:1704.08217 (2017)]
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- $\psi(2S)\phi$ [Phys. Lett. B762 (2016) 253-262]
- $D_s^+D_s^-$ [PRL113, 211801 (2014)]

CMS:

- $J/\psi\phi$ [Phys. Lett. B 757 (2016) 97]

ATLAS:

- $J/\psi\phi$ [JHEP 08 (2016) 147]

$\phi_s = -21 \pm 31$ mrad

[HFLAV Summer 2017]

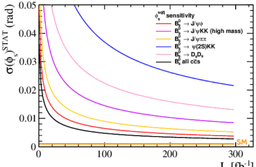
$\phi_s^{SM} = -37.6^{+0.7}_{-0.8}$ mrad

[CKM Fitter]

- **Metrology important for anomalies:** Bounds on LQ and Z' models from mixing!
- Lot of room for improvement! Interplay between **LHCb**, **ATLAS** and **CMS**

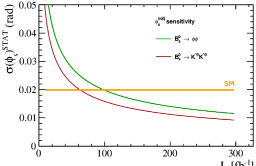
  Dordei (LHCb), Řezníček (ATLAS), Sarkar (CMS)

ϕ_s from $b \to c\bar{c}s$ transitions



[LHCb Upgrade II Expression of interest]

ϕ_s from $b \to s\bar{q}q$ transitions



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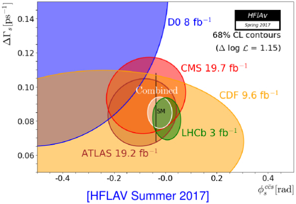

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  Dordei (LHCb), Řezníček (ATLAS), Sarkar (CMS)

	2011	2012	2015-17		2019-21	2023-30+
Detector	current	current	IBL		IBL	ITK
Average interactions per BX $<\mu>$	6-12	21	60		60	200
Luminosity, fb^{-1}	4.9	20	100		250	3 000
Di-μ trigger p_T thresholds, GeV	4 - 4(6)	4 - 6	6 - 6	11 - 11	11 - 11	11 - 11
Signal events per fb^{-1}	4 400	4 320	3 280	460	460	330
Signal events	22 000	86 400	327 900	45 500	114 000	810 000
Total events in analysis	130 000	550 000	1 874 000	284 000	758 000	6 461 000
MC $\sigma(\phi_s)$ (stat.), rad	0.25	0.12	0.054	0.10	0.064	0.022

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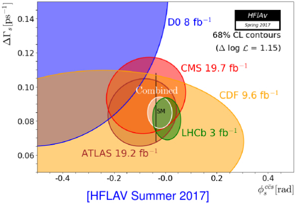

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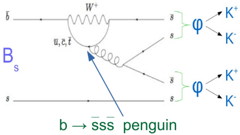
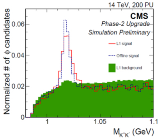


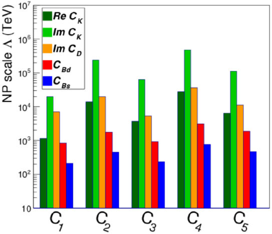


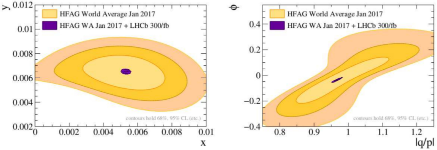
  - **Homework:** Potential for full-fledged flavor program at ATLAS, CMS?

Charm physics in the HL era

Joachim Brod

- LHCb will measure hundreds of billions of charm decays after Phase I (II)
- D-$\bar{D}$ mixing paradigmatic example





[LHCb report CERN-LHCC-2017-003]

- w. 300/fb expect $\delta x \sim 5\ 10^{-5}$, $\delta y \sim 3\ 10^{-5}$, $\delta|q/p| \sim 3\ 10^{-3}$, $\delta\phi \sim 1°$, $\delta A_\Gamma \sim 10^{-5}$
- get $\delta\Phi_{M12} \sim 0.1°$ and $\delta\Phi_{\Gamma 12} \sim 0.4°$

L. Silvestrini

- **GIM very efficient:** Opportunities for null-tests of the SM in the *up*-quark sector

Strangeness in the HL-LHC era G. D'Ambrosio

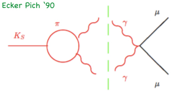
- LHCb is a strangeness factory: expt's and th's working on this

  Rare n Strange 2017: strange physics at LHCb

  Diego Martinez Santos Marc Olivier Bettler Xabier Cid Vidal

- Demonstrated physics case with measurement of best world bound on $K_s \to \mu\mu$!

Ecker Pich '90



No CP conserving Short Distance due to Furry Theorem

Gaillard Lee

LD 5×10^{-12} 20% TH err

Short Distance		
SM	$10^{-5} \lvert \Im (V_{ts}^* V_{td}) \rvert^2 \sim 10^{-13}$	
NP	10^{-11}	allowed

VALUE (10^{-9})	CL%		DOCUMENT ID		TECN
< 9	90	1	AAIJ	2013G	LHCB
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 0.032 \times 10^4$	90		GJESDAL	1973	ASPK
$< 0.7 \times 10^4$	90		HYAMS	1969B	OSPK

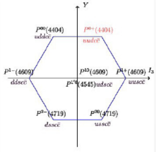
[1] AAIJ 2013G uses 1.0 fb^{-1} of pp collisions at $\sqrt{s}$ = 7 TeV. They obtained B($K_S^0 \to \mu^+\mu^-$) $< 11 \times 10^{-9}$ at 95% C.L.

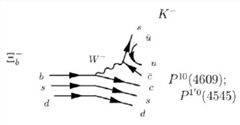
- Many new-physics and SM opportunities in **kaon** and **hyperon** decays
- **Homework:** tau decays as a separate subtopic?

Spectroscopy in the HL-LHC era: Experiment M. Pappagallo

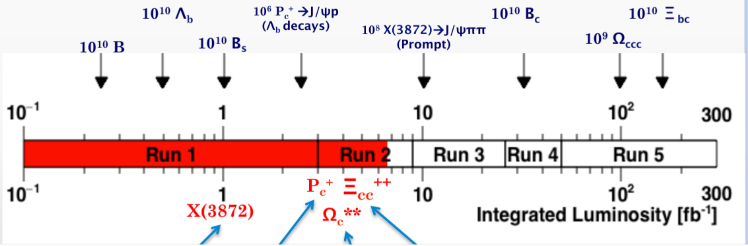
- **LHCb** expects $\times 400$ ($\times 200$) yields in hadronic (dimuon) final states
- Potential for e.g. clarification of nature of pentaquark

[E. Santopinto et al.: PRD 96 (2017) 014014]





- Great interest into spectroscopy
- The observation of the two pentaquarks is the most cited LHCb paper
- The large data set collected in the HL-LHC era, together with an upgraded detector, will boost sensitivity in searches for heavy states with small production cross sections and/or small decay rates



Spectroscopy in the HL-LHC era: Theory A. Polosa

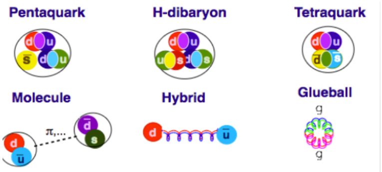
- Theoretical interpretation of X, Y, Z states
  (emphasizes limitations to understand nonperturbative phenomena!)

DURING THE LAST FEW YEARS THE FOLLOWING CHARGED 1^{+-} STATES HAVE BEEN DISCOVERED

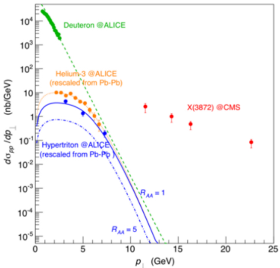
$Z_c^{\pm,0}(3900)$, $Z_c^{\pm,0}(4020)$, $Z_b^{\pm,0}(10610)$, $Z_b^{\pm,0}(10650)$

WITH MASS VALUES **ABOVE** THE CORRESPONDING MESON-MESON THRESHOLDS:

$\delta =$	$+7.8$	$+6.7$	$+2.7$	$+1.8$	MeV
	$\bar{D}^0 D^{*+}$	$\bar{D}^{*0} D^{*+}$	$\bar{B}^0 B^{*+}$	$\bar{B}^{*0} B^{*+}$	

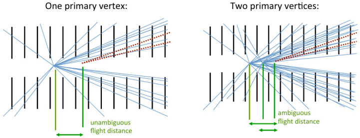


- ► Empirical discrimination at colliders!

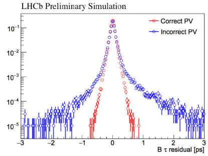


- LHCb timing tracker impact Mark Richard James Williams

- 5 → 55 visible interactions/crossing



Incorrect PV association ⇒ incorrect decay time measurement

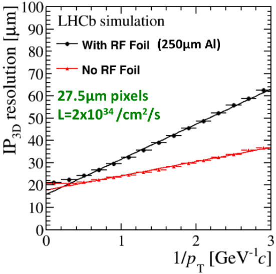


Important for much of core LHCb programme:

- Lifetime measurements
- Precision mixing analyses
- Time-dependent CP violation

Effect will be even stronger for partially-reconstructed decays (e.g. semileptonics) where spatial pointing is distorted, but time is not

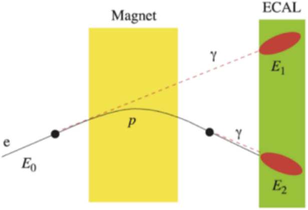
- Ideas to remove the RF foil in LHCb Greg Max Ciezarek



- VELO resolution key for controlling backgrounds
- RF foil key limiting factor for VELO resolution
- We want to run without RF foil!
  - For equal background, 25% gain in effective luminosity for semileptonic decays
  - 30% reduction in wrong PV association
- Studies ongoing
  - We'd like to thank CERN RF and Vacuum groups

LHCb calorimetry impact Preema Rennee Pais

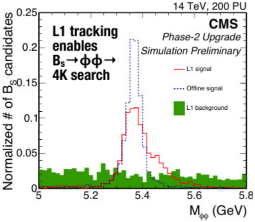
- Electron reconstruction:
  - Challenging due to bremsstrahlung; momentum and mass resolution degraded
  - Recover by adding ECAL clusters to extrapolated upstream electron track
    - Limited by calorimeter acceptance, energy threshold ($E_T > 75$ MeV)



- Innermost ECAL modules must be replaced during LS3
  - Excellent opportunity to test upgraded module designs before Upgrade II (LS4)
  - Increased granularity, spatial resolution, addition of timing info?

- Increased PU conditions ~ 200 calls for improvements in detectors and trigger
- Tracker and trigger improvements in ATLAS Julie Hart Kirk
  - Trigger upgrade – TDR in preparation.
  - For Bphysics:
    - Upgrades to muon trigger and addition of hardware tracking should allow thresholds to be kept at a level that B-physics measurements will continue to be part of the ATLAS physics programme (See talk by Pavel Reznicek).
    - Hardware tracking also allows exclusive reconstruction without need for CPU intensive full detector tracking.
- Tracker and trigger improvements in CMS Louise Skinnari

- Of particular relevance to flavor physics
  - New inner pixel + outer tracker system
    - *Higher granularity & improved momentum resolutions*
    - *Capability of tracking @ 40 MHz => can enable signatures otherwise unattainable*
  - Improvements also from...
    - *Upgraded muon system => reduced trigger rates & extended η acceptance*
    - *Potential to benefit from precision timing (under study)?*



Summary of Homework

1. Prospects for kinematic distributions (e.g. D^*/τ polarization)
2. Prospects for electronic/hadronic modes at ATLAS and CMS
3. Incorporate flavor aspects of top physics in WG4
4. “No-lose theorems” for anomaly-related NP at HL/HE-LHC
5. Potential for full-fledged flavor program at ATLAS, CMS? (hadronic and electronic decay modes?)
6. tau decays as a separate subtopic?