Faculté de physique et ingénierie Université de Strasbourg

master PSA Physique Subatomique Astroparticules

Hugo CALLONNEC

Development of a new experimental method to simultaneously measure inclusive and exclusive values of the ckm matric element |Vub| in hadronically tagged events with Belle

Supervised by Florian Bernlochner

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BELLE

UNIVERSITÄT BONN

Outline

- Introduction
- Inclusive & Exclusive measurement idea
- Implementation and fitting procedure
- $|V_{ub}|$ calculation and toy generation
- Results
- Conclusion

Scientific context

- The Standard Model is very successful but has limits (CP Violation, dark matter and energy, neutrino masses, matter/antimatter asymmetry, …)

- CKM matrix:

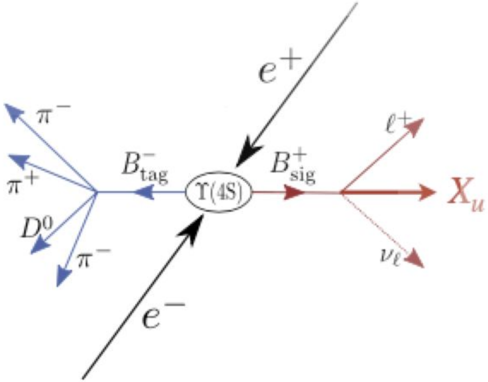
  (Predicted unitary)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_{\text{weak}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{mass}}$$

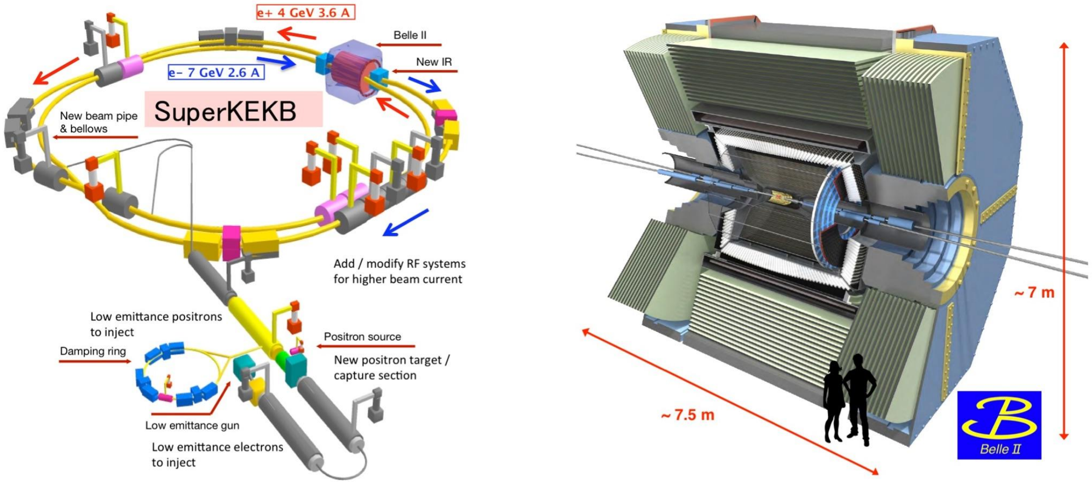
- Need to obtain a precise measurement: B factories

Belle & Belle II experiment

1999-2008: BaBar experiment
1999-2010: Belle experiment
2018- : Belle II experiment



γ(4s) meson decay process



Supe KEKB and Belle II

	KEKB/Belle	SuperKEKB/Belle II
Integrated Luminosity	$1ab^{-1}$	$50ab^{-1}$

Measurement of $|V_{ub}|$ and $|V_{cb}|$

2 differents methods to measure $|V_{ub}|$ and $|V_{cb}|$:

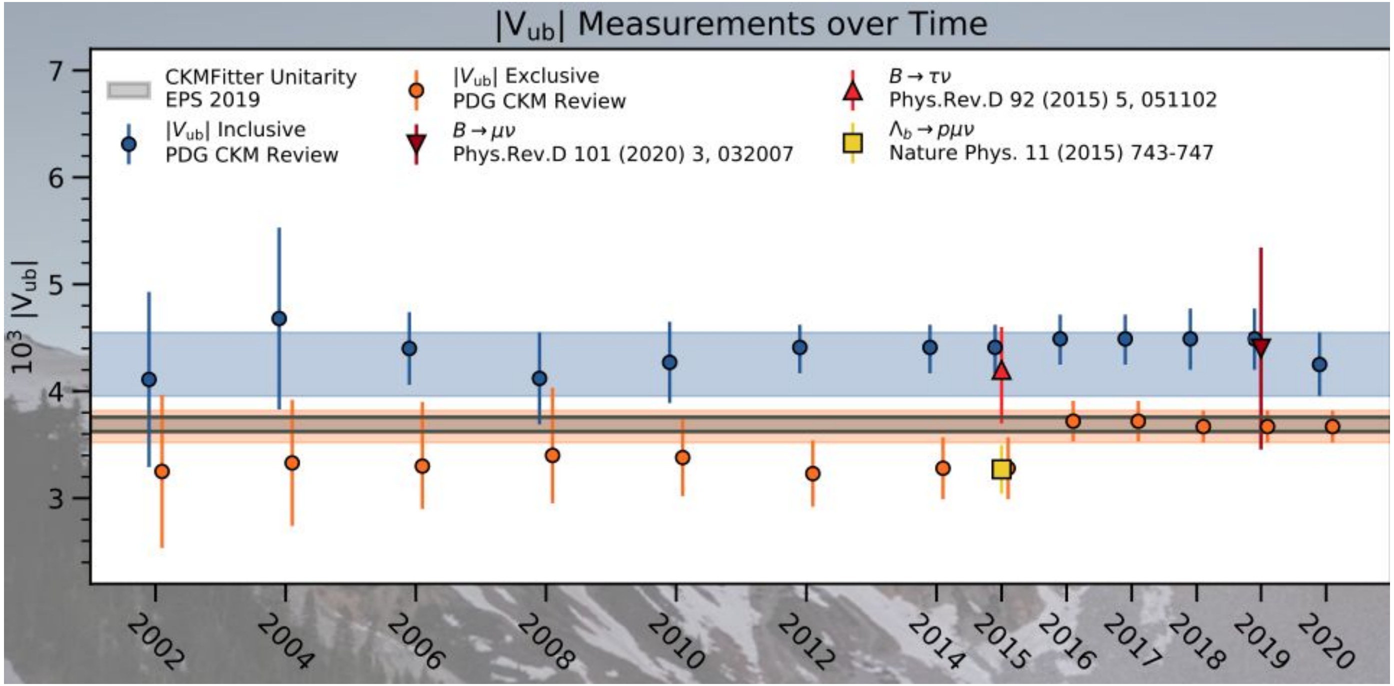
- **<u>Exclusive:</u>**
    - Focus on a single final state as: $B \to \pi^0 l \overline{\nu}_l$ or $B \to \pi^{\pm} l \overline{\nu}_l$
    - Difficulties: low signal yield

- **<u>Inclusive:</u>**
    - Considering all final states containing an up quark: $B \to X_u l \overline{\nu}_l$ (for $|V_{ub}|$) or charm quarks $B \to X_c l \overline{\nu}_l$ (for $|V_{cb}|$)
    - Difficulties: Background contamination

	Belle/Belle II	LHCb
Exclusive measurement	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$
Inclusive measurement	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	Not performed yet

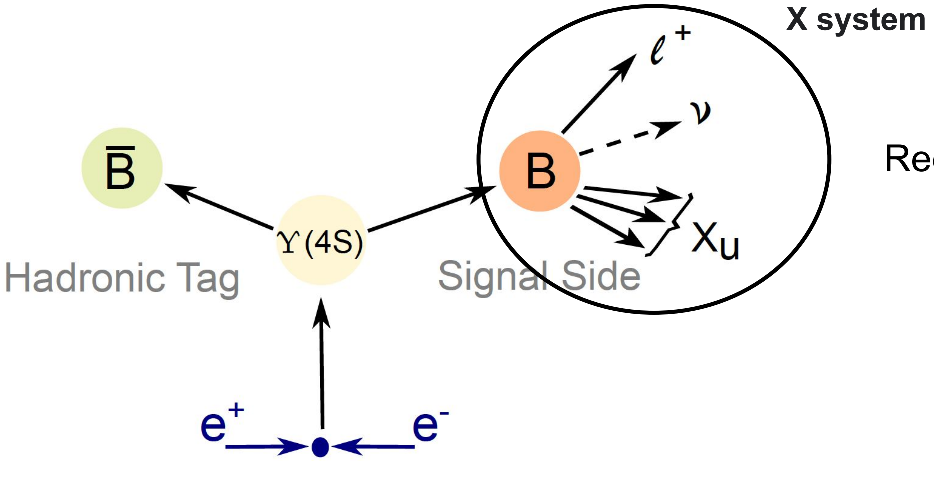
Measurement of $|V_{ub}|$ and $|V_{cb}|$

These two methods exhibit a sizeable tension of respectively 3 and 3.5 standard deviations $|V_{ub}|$ and $|V_{cb}|$:



Inclusive & Exclusive measurement idea

The idea is to measure both exclusive & inclusive $|V_{ub}|$ at the same time:



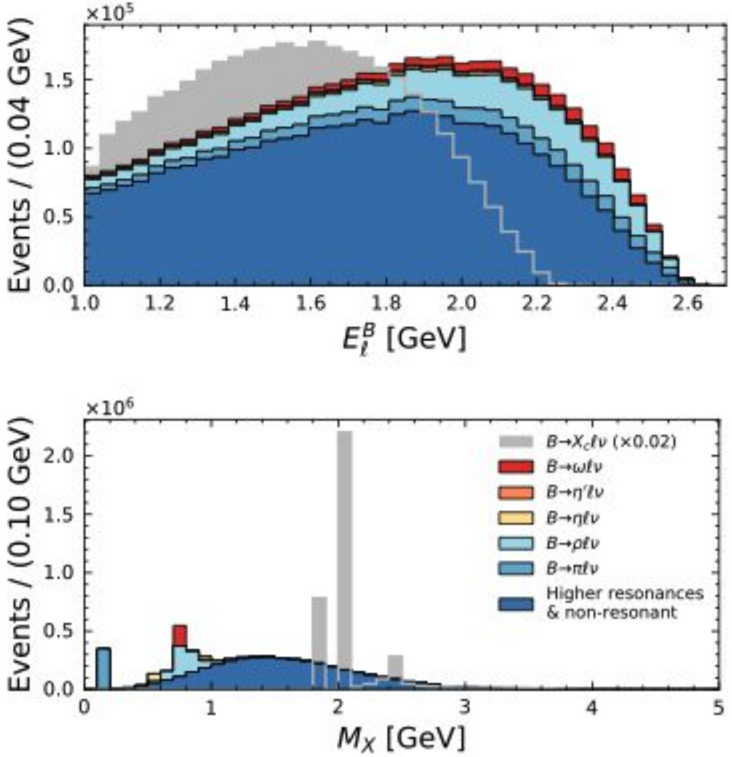
γ(4s) meson decay process

Reconstruction of the X system variables

Suppress Background

Study on 711 fb^{-1} dataset

Background suppression



Generated Mx and lepton energy

Main sources of Background:

- $B \rightarrow X_c l\nu$ decays
- continuum processes

Background suppression performed by Neural Network

Clear **separation** only **possible** in certain **kinematic regions**, e.g. **lepton endpoint** or **low M_X**

System reconstruction

Finally we can reconstruct the kinematics variables of the system:

- The momentum of the X system:

$$p_{\mathrm{X}} = \sum_i \left(\sqrt{m_\pi^2 + |p_{\mathrm{i}}|^2}, p_{\mathrm{i}}\right) + \sum_i (E_i, k_i)$$

- We deduce the mass of the X system:

$$M_{\mathrm{X}} = \sqrt{(p_{\mathrm{X}})^\mu * (p_{\mathrm{X}})_\mu}$$

- Thefour-momentum transfer squared:

$$q^2 = (p_{\mathrm{sig}} - p_{\mathrm{X}})^2$$

Implementation & fitting procedure

From the previous determined variables, we run a binned likelihood fit:

$$\mathcal{L} = \prod_{i}^{\text{bins}} \mathcal{P}(n_i;\nu_i) \text{x} \prod_{k} \mathcal{G}_k$$

$\prod_{k} \mathcal{G}_k$ → nuisance-parameters constraints

Observed events (n_i)   Expected events (ν_i)

Divided into:

- $B \rightarrow$ pi^0 lv
- $B \rightarrow$ pi$^+$ lv
- $B \rightarrow$ Xu lv
- $B \rightarrow$ Xc lv + others background

Where we have: $\nu_i^{\pi^0} = \mu^{\pi^0} \times f_{\pi^0}^i$

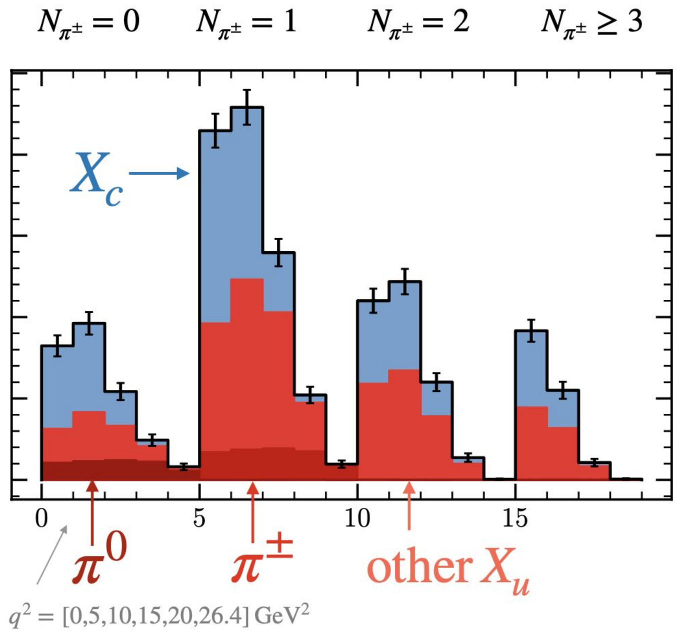
Implementation & fitting procedure

Different fit setup:

	mu size = 3	mu size = 4	mu size = 6	mu size = 9	mu size = 10
pi0	mu0	mu0	mu0	mu0	mu0
pip		mu1			mu1
Xu	mu1	mu2	mu1 ($n_\pi = 0$)	mu1 ($n_\pi = 0$)	mu2 ($n_\pi = 0$)
			mu2 ($n_\pi = 1$)	mu2 ($n_\pi = 1$)	mu3 ($n_\pi = 1$)
			mu3 ($n_\pi = 2$)	mu3 ($n_\pi = 2$)	mu4 ($n_\pi = 2$)
			mu4 ($n_\pi = 3$)	mu4 ($n_\pi = 3$)	mu5 ($n_\pi = 3$)
bkg	mu2	mu3	mu5	mu5 ($n_\pi = 0$)	mu6 ($n_\pi = 0$)
				mu6 ($n_\pi = 1$)	mu7 ($n_\pi = 1$)
				mu7 ($n_\pi = 2$)	mu8 ($n_\pi = 2$)
				mu8 ($n_\pi = 3$)	mu9 ($n_\pi = 3$)

Implementation & fitting procedure

Proof of the concept:



q^2 distribution resulting of an Asimov fit

perfect agreement between predicted and observed data

good separation between variables

Implementation & fitting procedure

Fitting procedure:

Initialisation

Object initialization

Fit Setup

Lattice parameters + number of mus

Fitting part

Chi2 fit

Results

Observed events

Predicted events

fitted data
fitted errors
covariance matrix of fitted parameters

$|V_{ub}|$ exclusive calculation

We start from the formulas:

$$|\mathrm{V_{ub}}|_{\text{exclusive}, \pi^0} = \sqrt{\frac{\mathcal{B}(\mathrm{B} \to \pi^0 l^+ \overline{\nu}_l)}{\tau_\mathrm{B} \Delta\Gamma(\mathrm{B} \to \pi^0 l \;\; \overline{\nu}_l)}}$$

$$|\mathrm{V_{ub}}|_{\text{exclusive}, \pi^\pm} = \sqrt{\frac{\mathcal{B}(\mathrm{B} \to \pi^\pm l^+ \overline{\nu}_l)}{\tau_\mathrm{B} \Delta\Gamma(\mathrm{B} \to \pi^\pm l \cdot \overline{\nu}_l)}}$$

Where:

- $\mathcal{B}(\mathrm{B} \to \pi^0 l \cdot \overline{\nu}_l) = \mathrm{mu}_{\pi^0} \mathrm{x} \mathcal{B}_{\mathrm{MC}}(\mathrm{B} \to \pi^0 l^+ \overline{\nu}_l)$
- $\Delta\Gamma(\mathrm{B} \to \pi^0 l^{\cdot} \bar{\nu}_l)$ is the integral of q^2 distribution
- τ_B is the B meson lifetime

In case we have the same mu for pi^0 and pi^+ we use:

$$|\mathrm{V_{ub}}|_{\text{exclusive}, \pi^\pm} = \sqrt{\frac{\mathcal{B}(\mathrm{B} \to \pi^\pm l^+ \overline{\nu}_l)}{\tau_\mathrm{B} \Delta\Gamma(\mathrm{B} \to \pi^\pm l^+ \overline{\nu}_l)}}$$

$|V_{ub}|$ inclusive calculation

We start from the formula:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u l \ \overline{\nu}_l)}{\tau_B \Delta\Gamma(B \to X_u l \ \overline{\nu}_l)}}$$

$$\Delta\mathcal{B}(B \to X_u l \ \overline{\nu}_l)\Big|_{E_l > 1\text{GeV}}$$

With:

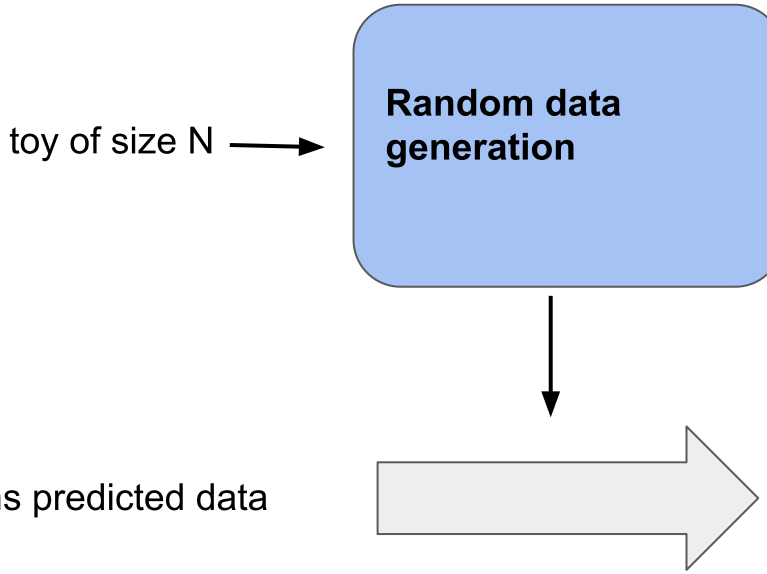
$$\begin{aligned}\Delta\mathcal{B}(B \to X_u l \ \overline{\nu}_l) = \epsilon_{\Delta BF} * (&\text{mu}_{\pi^0} \times \mathcal{B}_{MC}(B \to \pi^0 l \ \overline{\nu}_l) \\ &+\text{mu}_{\pi^\pm} \times \mathcal{B}_{MC}(B \to \pi^\pm l \ \overline{\nu}_l) \\ &+\text{mu}_{X_u} \times \mathcal{B}_{MC}(B \to X_u l \ \overline{\nu}_l)_{\text{correct}})\end{aligned}$$

And:

$$\begin{aligned}\mathcal{B}_{MC}(B \to X_u l \ \overline{\nu}_l)_{\text{correct}} = &\mathcal{B}_{MC}(B \to X_u l \ \overline{\nu}_l) \\ &-\mathcal{B}_{MC}(B \to \pi^0 l \ \overline{\nu}_l) \\ &-\mathcal{B}_{MC}(B \to \pi^\pm l \ \overline{\nu}_l)\end{aligned}$$

Toy generation

Instead of using prediction, we generate random data:



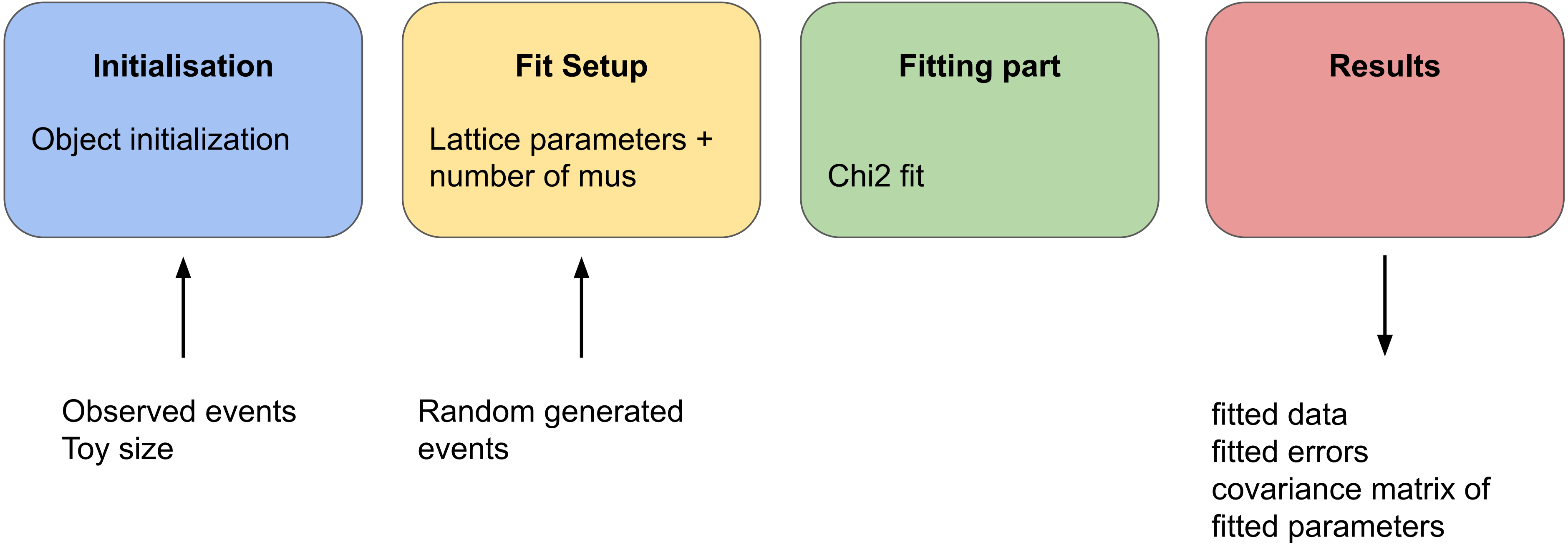
$Item_1$	bin_0	bin_1	...	bin_i
$Item_2$	bin_0	bin_1	...	bin_i
...	...	...	...	bin_i
$Item_N$	bin_0	bin_1	...	bin_i

We define:

$$\text{pull} = \frac{\nu_i - n_i}{\sigma_i}$$

Toy generation

New Fitting procedure:



$|V_{ub}|$ calculation results

Name	Value	Hesse Error
mu_sig_pi0	1.00	0.28
mu_sig_pip	1.00	0.25
mu_sig_Xu	1.00	0.12
mu_bkg	1.00	0.13
b0p	0.407	0.014
b1p	-0.65	0.09
b2p	-0.5	0.4
b3p	0.4	0.7
b00	0.507	0.020
b10	-1.77	0.10
b20	1.3	0.4
b30	4.2	1.0

Case of len(mu) = 4

$$|V_{ub}|_{\text{exclusive, }\pi^0} = (4.20 \pm 0.59) \times 10^{-3}$$

$$|V_{ub}|_{\text{exclusive, }\pi^\pm} = (4.24 \pm 0.52) \times 10^{-3}$$

$$|V_{ub}|_{\text{inclusive}} = (4.40 \pm 0.30) \times 10^{-3}$$

$$\frac{|V_{ub}|_{\text{exclusive, }\pi^0}}{|V_{ub}|_{\text{inclusive}}} = 0.96 \pm 0.14 \quad \frac{|V_{ub}|_{\text{exclusive, }\pi^\pm}}{|V_{ub}|_{\text{inclusive}}} = 0.97 \pm 0.14$$

$$\frac{|V_{ub}|_{\text{exclusive, }\pi^0} + |V_{ub}|_{\text{exclusive, }\pi^\pm}}{|V_{ub}|_{\text{inclusive}}} = 1.92 \pm 0.23$$

$|V_{ub}|$ calculation results

Name	Value	Hesse Error
mu_sig_pi0	1.00	0.22
mu_sig_pip	1.00	0.23
mu_sig_Xu	1.00	0.06
mu_bkg	1.000	0.017
b0p	0.407	0.014
b1p	-0.65	0.09
b2p	-0.5	0.4
b3p	0.4	0.7
b00	0.507	0.019
b10	-1.77	0.10
b20	1.27	0.34
b30	4.2	0.9

Case of len(mu) = 4 (including high Mx)

$$|V_{ub}|_{\text{exclusive, }\pi^0} = (4.20 \pm 0.56) \times 10^{-3}$$

$$|V_{ub}|_{\text{exclusive, }\pi^\pm} = (4.24 \pm 0.51) \times 10^{-3}$$

$$|V_{ub}|_{\text{inclusive}} = (4.40 \pm 0.20) \times 10^{-3}$$

$$\frac{|V_{ub}|_{\text{exclusive, }\pi^0}}{|V_{ub}|_{\text{inclusive}}} = 0.96 \pm 0.13 \quad \frac{|V_{ub}|_{\text{exclusive, }\pi^\pm}}{|V_{ub}|_{\text{inclusive}}} = 0.97 \pm 0.13$$

$$\frac{|V_{ub}|_{\text{exclusive, }\pi^0} + |V_{ub}|_{\text{exclusive, }\pi^\pm}}{|V_{ub}|_{\text{inclusive}}} = 1.92 \pm 0.22$$

$|V_{ub}|$ calculation results

Case of len(mu) = 3

Name	Value	Hesse Error
mu_sig_pi	1.00	0.21
mu_sig_Xu	1.00	0.11
mu_bkg	1.00	0.12
b0p	0.407	0.014
b1p	-0.65	0.09
b2p	-0.5	0.4
b3p	0.4	0.7
b00	0.507	0.020
b10	-1.77	0.10
b20	1.3	0.4
b30	4.2	1.0

$$|V_{ub}|_{exclusive} = (4.24 \pm 0.45) \times 10^{-3}$$

$$|V_{ub}|_{inclusive} = (4.28 \pm 0.29) \times 10^{-3}$$

$$\frac{|V_{ub}|_{exclusive}}{|V_{ub}|_{inclusive}} = 0.99 \pm 0.12$$

$|V_{ub}|$ calculation results

Case of len(mu) = 3 (including high Mx)

Name	Value	Hesse Error
mu_sig_pi	1.00	0.17
mu_sig_Xu	1.00	0.06
mu_bkg	1.000	0.017
b0p	0.407	0.014
b1p	-0.65	0.09
b2p	-0.5	0.4
b3p	0.4	0.7
b00	0.507	0.019
b10	-1.77	0.10
b20	1.27	0.34
b30	4.2	0.9

$$|V_{ub}|_{\text{exclusive}} = (4.24 \pm 0.44) \times 10^{-3}$$

$$|V_{ub}|_{\text{inclusive}} = (4.28 \pm 0.20) \times 10^{-3}$$

$$\frac{|V_{ub}|_{\text{exclusive}}}{|V_{ub}|_{\text{inclusive}}} = 0.99 \pm 0.11$$

Toy generation results

Case of len(mu) = 3

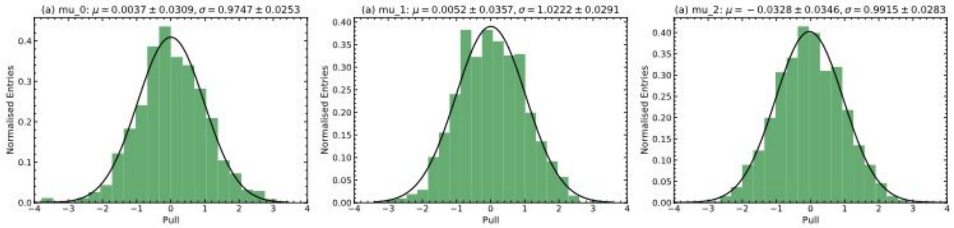


Figure 4.1: Mu of size 3 pull distribution
This toy has a number of events of 1000

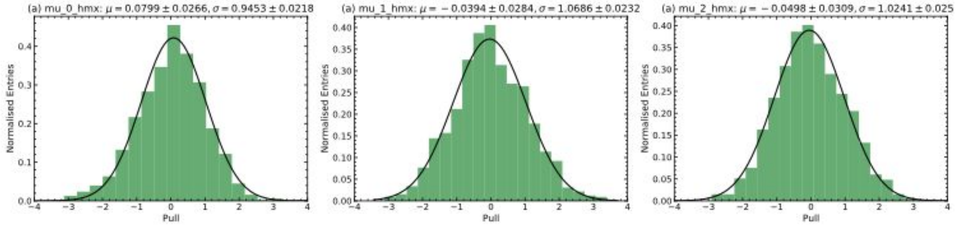


Figure 4.2: Mu of size 3 pull distribution (including high Mx)
This toy has a number of events of 1000

Toy generation results

Case of len(mu) = 4

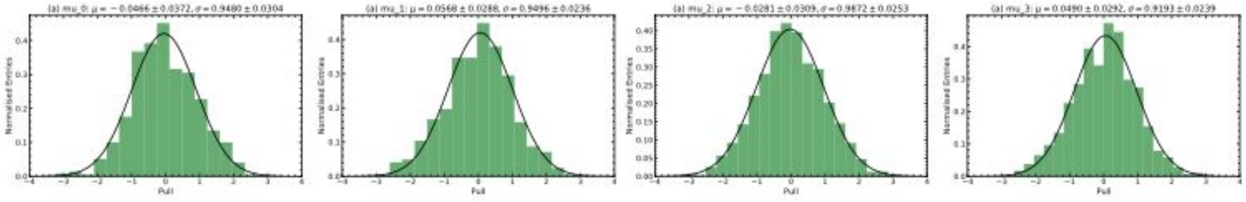


Figure 4.3: Mu of size 4 pull distribution
This toy has a number of events of 1000

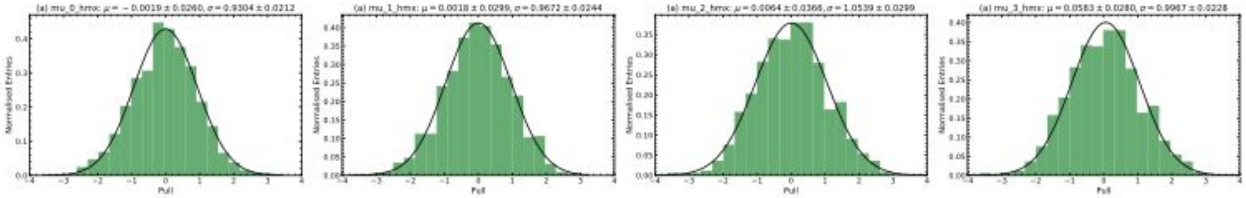


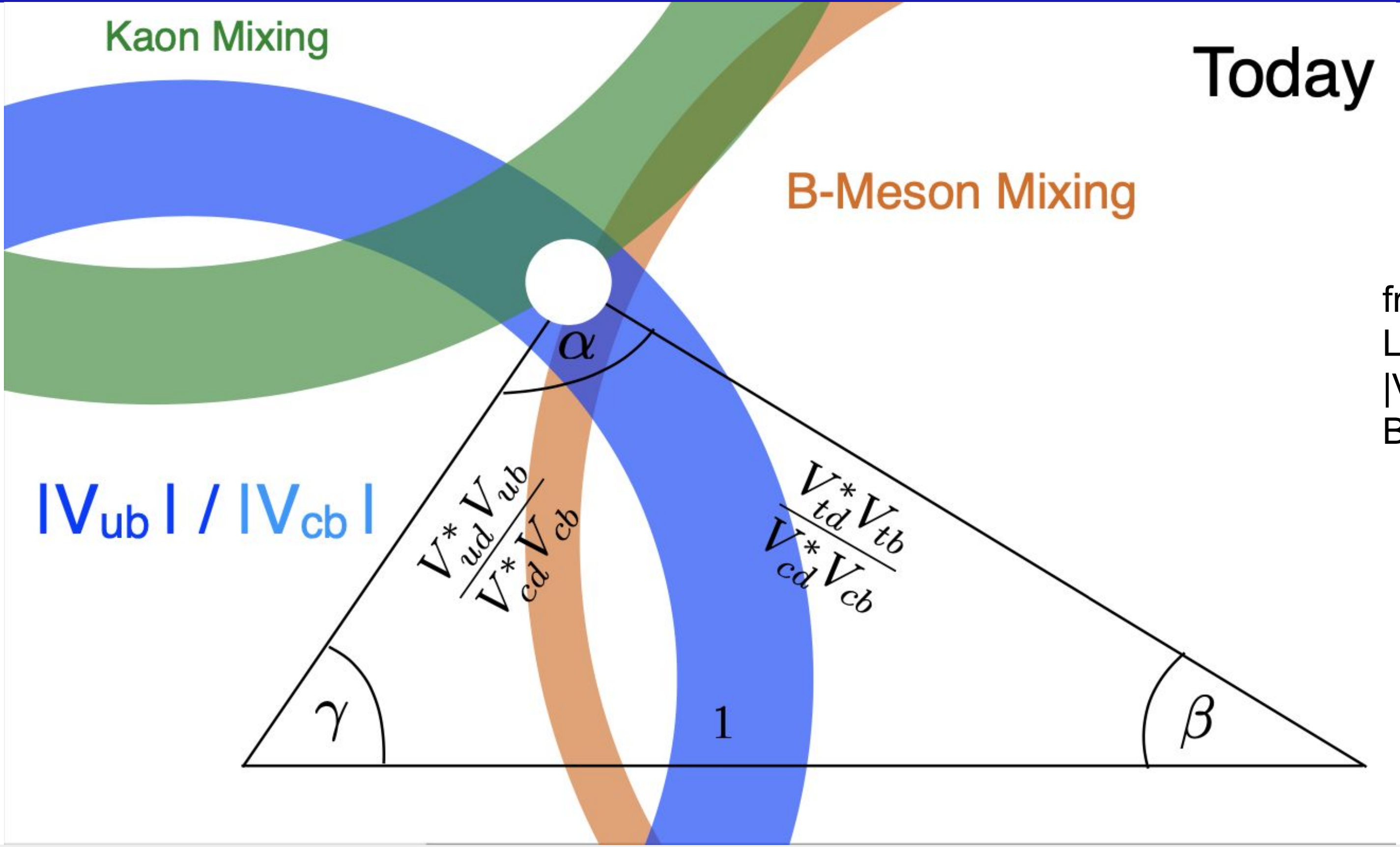
Figure 4.4: Mu of size 4 pull distribution (including high Mx)
This toy has a number of events of 1000

Conclusion

- **$|V_{ub}|$ calculation:**
  - Coherent with previous calculations
  - Need to be perform with other sizes of mu
- **Toy generation:**
  - Implementation of toys is working
  - Still biased

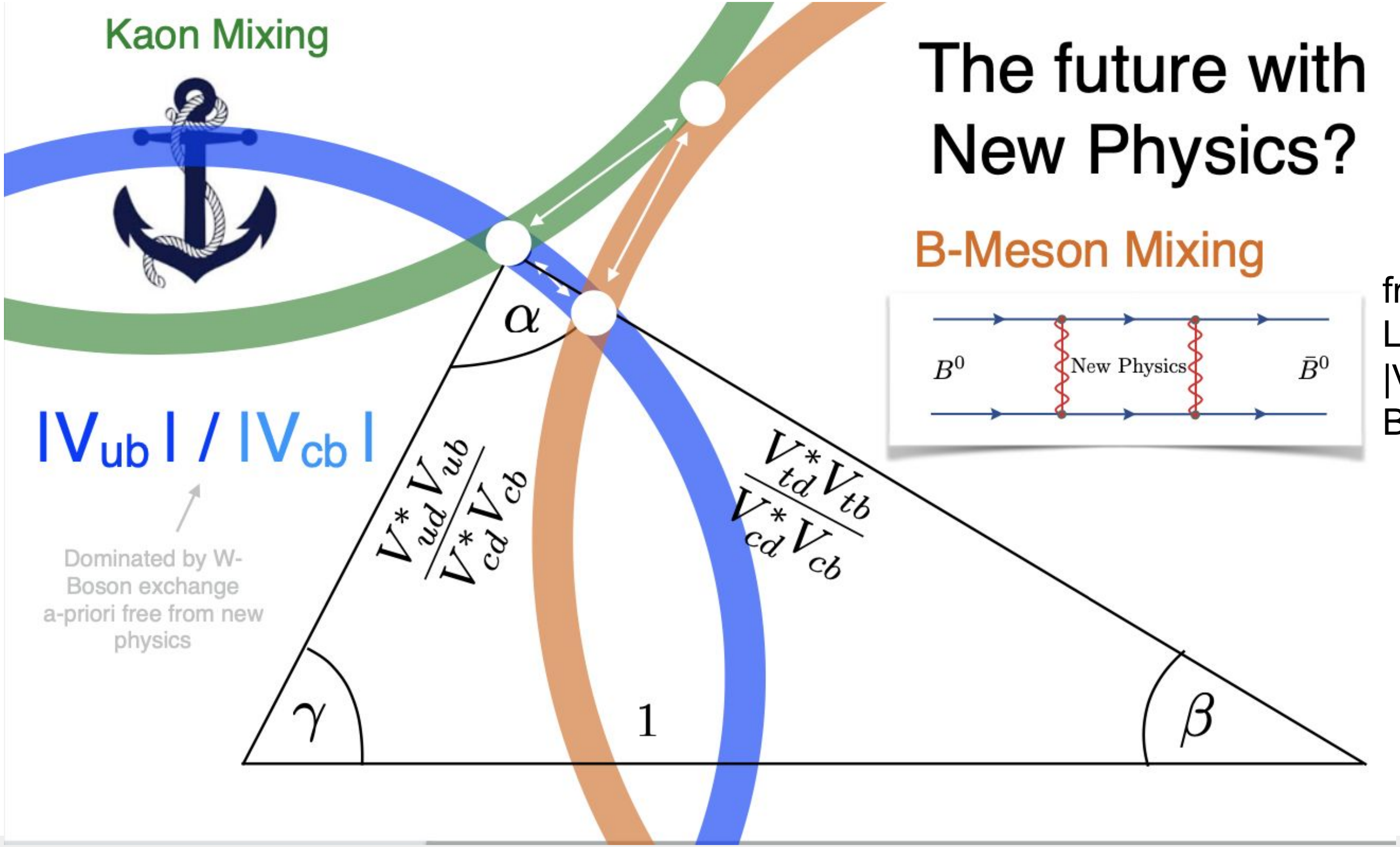
Thank you for your attention

Backup slides



from
Latest developments on |Vub| and |Vcb| by Florian Bernlochner

Backup slides



from
Latest developments on |Vub| and |Vcb| by Florian Bernlochner

Backup slides

$\mathcal{B}$	Value B^+	Value B^0
$B \to X_u \ell^+ \nu_\ell$		
$B \to \pi \ell^+ \nu_\ell$	$(7.8 \pm 0.3) \times 10^{-5}$	$(1.5 \pm 0.06) \times 10^{-4}$
$B \to \eta \ell^+ \nu_\ell$	$(3.9 \pm 0.5) \times 10^{-5}$	-
$B \to \eta' \ell^+ \nu_\ell$	$(2.3 \pm 0.8) \times 10^{-5}$	-
$B \to \omega \ell^+ \nu_\ell$	$(1.2 \pm 0.1) \times 10^{-4}$	-
$B \to \rho \ell^+ \nu_\ell$	$(1.6 \pm 0.1) \times 10^{-4}$	$(2.9 \pm 0.2) \times 10^{-4}$
$B \to X_u \ell^+ \nu_\ell$	$(2.2 \pm 0.3) \times 10^{-3}$	$(2.0 \pm 0.3) \times 10^{-3}$

Backup slides

$$|V_{ub}|\ (\text{BLNP}) = \left(4.01 \pm 0.08^{+0.15}_{-0.16}{}^{+0.18}_{-0.19}\right) \times 10^{-3},$$

$$|V_{ub}|\ (\text{DGE}) = \left(4.12^{+0.08}_{-0.09} \pm 0.16^{+0.11}_{-0.12}\right) \times 10^{-3},$$

$$|V_{ub}|\ (\text{GGOU}) = \left(4.11^{+0.08}_{-0.09} \pm 0.16^{+0.08}_{-0.09}\right) \times 10^{-3},$$

$$|V_{ub}|\ (\text{ADFR}) = \left(4.01 \pm 0.08^{+0.15}_{-0.16} \pm 0.18\right) \times 10^{-3}.$$