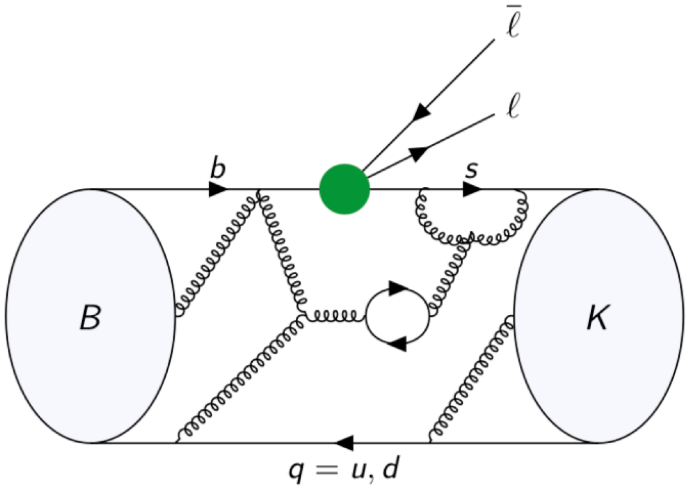
Search for New Physics in the $B \to K \ell^+ \ell^-$ Processes at Belle II

Alejandro Mora

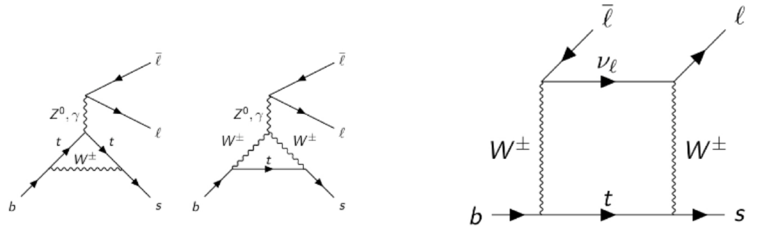
February 20 - 27 of 2019

Moscow, Russia



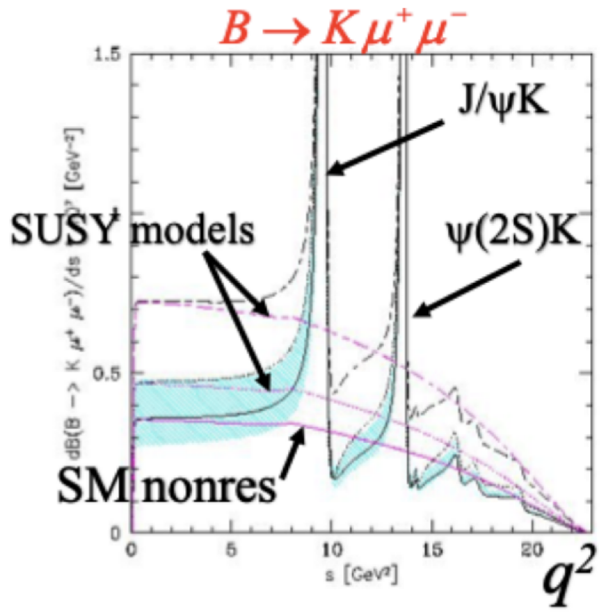
② Search for New Physics in ① the $B \to K\ell^+\ell^-$ Processes ③ at Belle II

The $B \to K \ell^+ \ell^-$ decays



- A flavor changing neutral current $\left(b \to s\ell^+\ell^-\right)$
- Interplay between strong and electroweak interactions
- Forbidden at tree level in the SM. Appears only in diagrams with one or more loops
- $W^\pm$ and t masses are much bigger than B mass, so highly supressed ($\mathcal{B} \sim 10^{-7}$)

NP contributions can be of the same order as SM ones!



J. Walsh [2002] in FPCP-2002, U. Pennsylvania

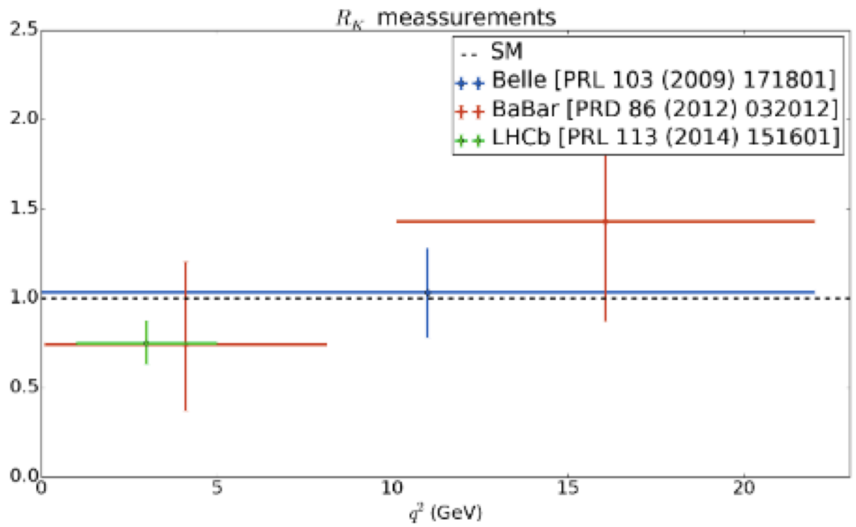
- Solid line + blue bands: SM range ($\pm$35%), Ali et al. form factors [PRD 66 (2002) 034002]
- Dotted line: SUGRA model ($R_7 = -1.2, R_9 = 1.03, R_{10} = 1$)
- Long-short dashed line: SUSY model ($R_7 = -0.83, R_9 = 0.92, R_{10} = 1.61$)
- $R_i = C_i / C_i^{\mathrm{SM}}$

Where to Look for New Physics

DECAY RATE RATIOS

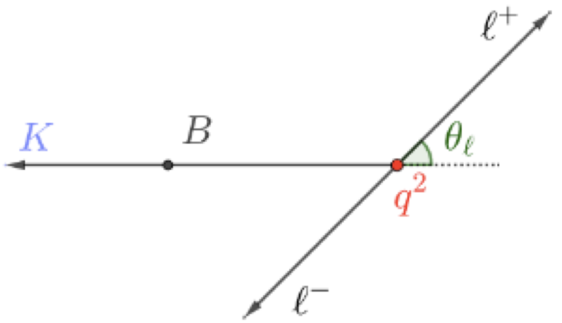
$$R_K = \frac{\Gamma(B \to K\,\mu^+\,\mu^-)}{\Gamma(B \to K\,e^+\,e^-)}$$

$1 \pm \mathcal{O}(10^{-3})$ in the SM!



Where to Look for New Physics

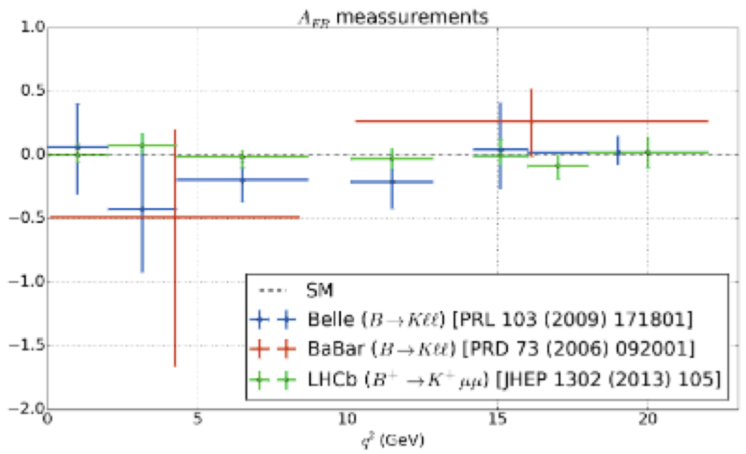
ANGULAR ANALYSIS



$$A^{\ell}_{FB} = \frac{N^{\ell}_{F} - N^{\ell}_{B}}{N^{\ell}_{F} + N^{\ell}_{B}}$$

N_F: Number of decays with $0 < |\theta_\ell| < \pi/2$

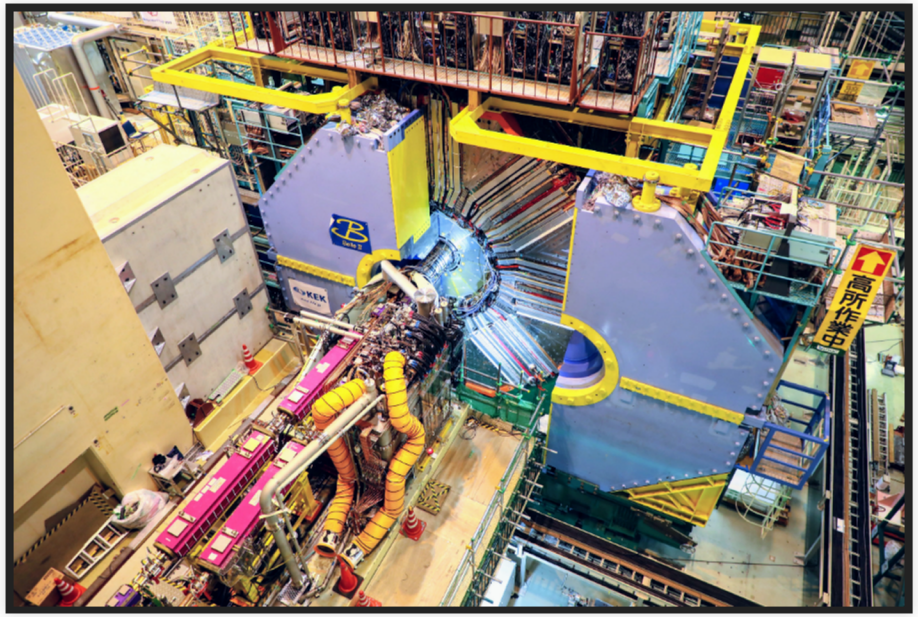
N_B: Number of decays with $\pi > |\theta_\ell| > \pi/2$



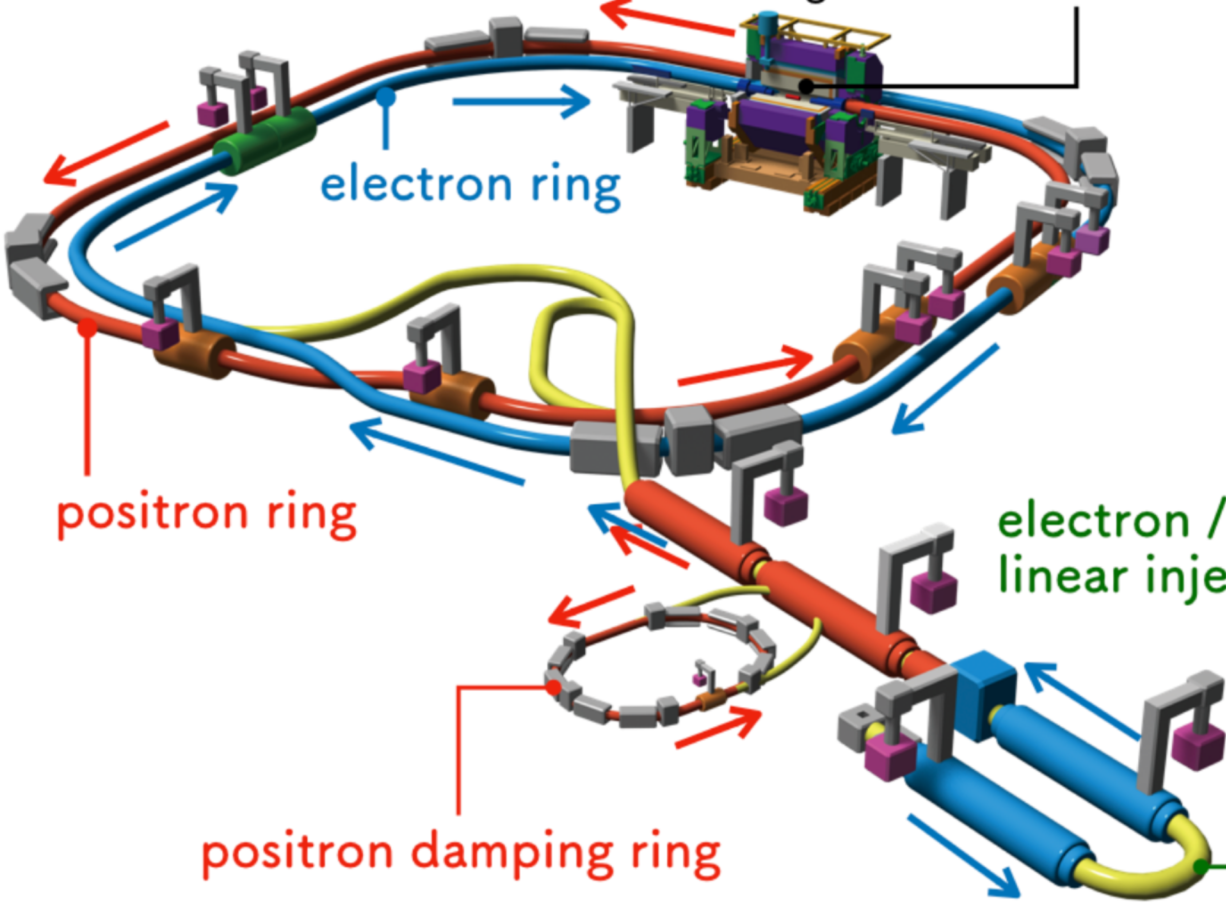
What makes the difference?

THE ACCELERATOR

THE DETECTOR

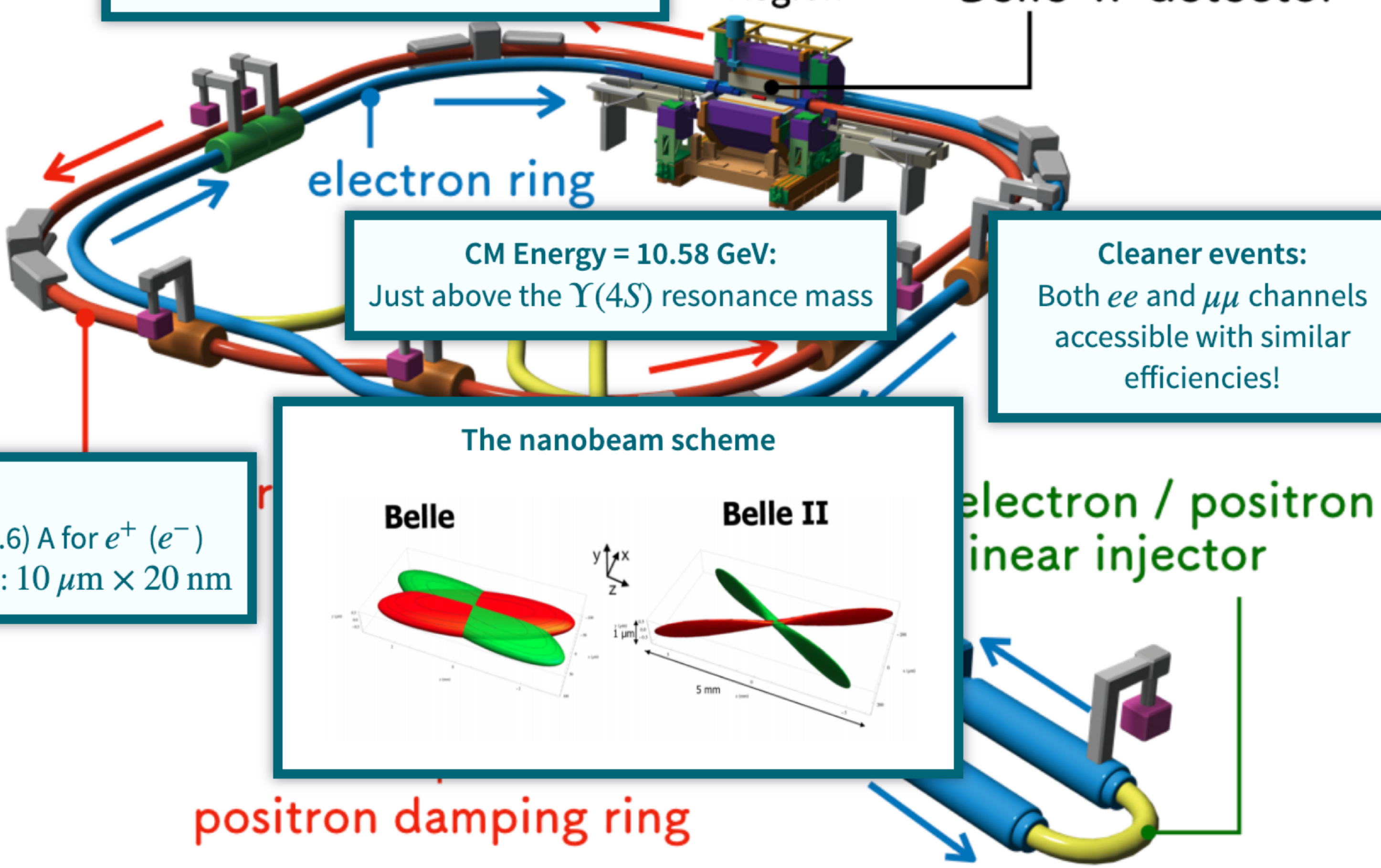


What makes the difference?



What makes the difference?

Different (complementary) to the LHC:
focuses on high intensity, not energies!



CM Energy = 10.58 GeV:
Just above the $\Upsilon(4S)$ resonance mass

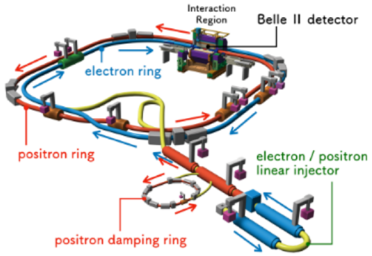
Cleaner events:
Both ee and $\mu\mu$ channels accessible with similar efficiencies!

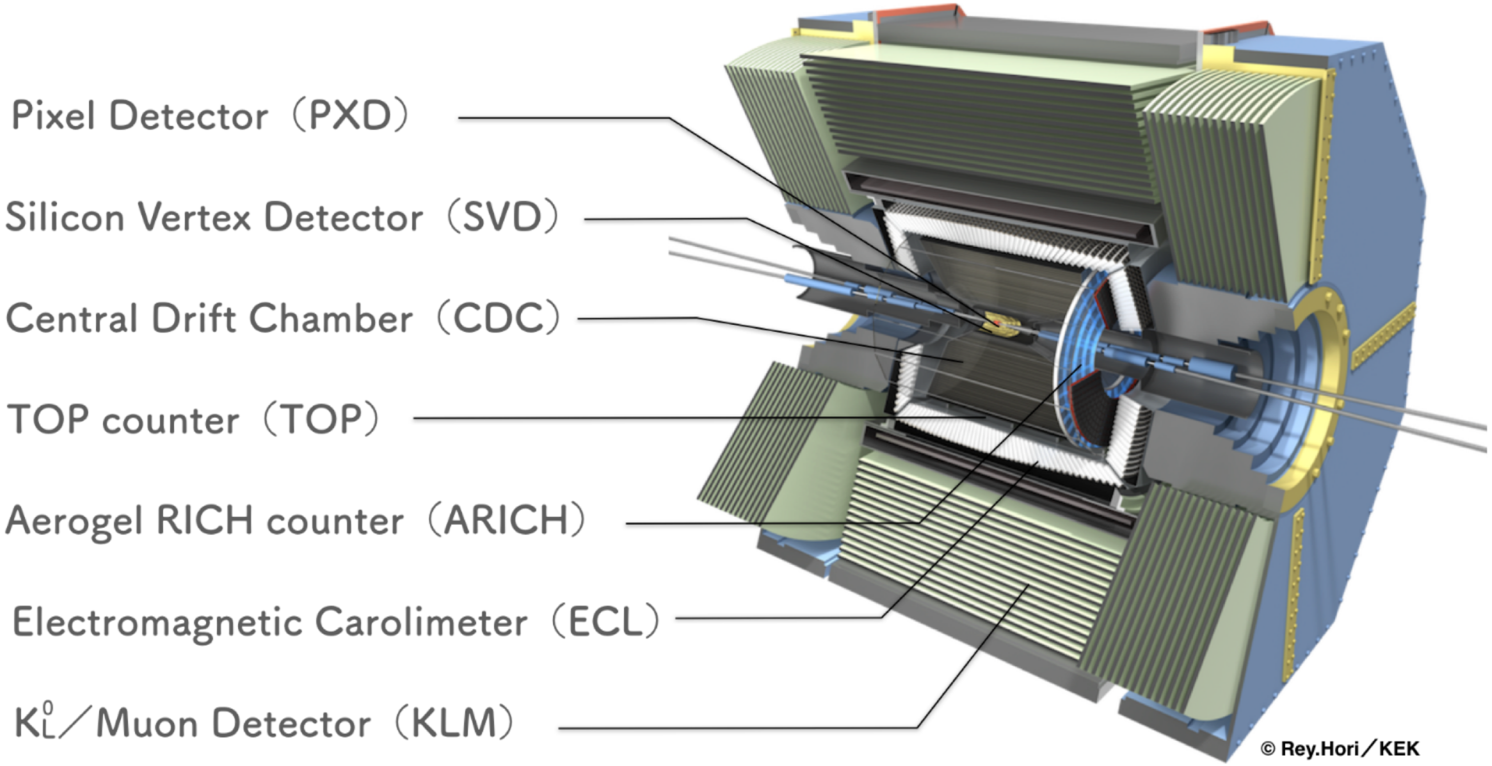
... How?

- Increase currents: 3.6 (2.6) A for e^+ (e^-)
- Reduce beam sizes at IP: $10\ \mu\mathrm{m} \times 20\ \mathrm{nm}$

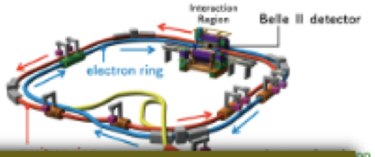
The nanobeam scheme

What makes the difference?





What makes the difference?



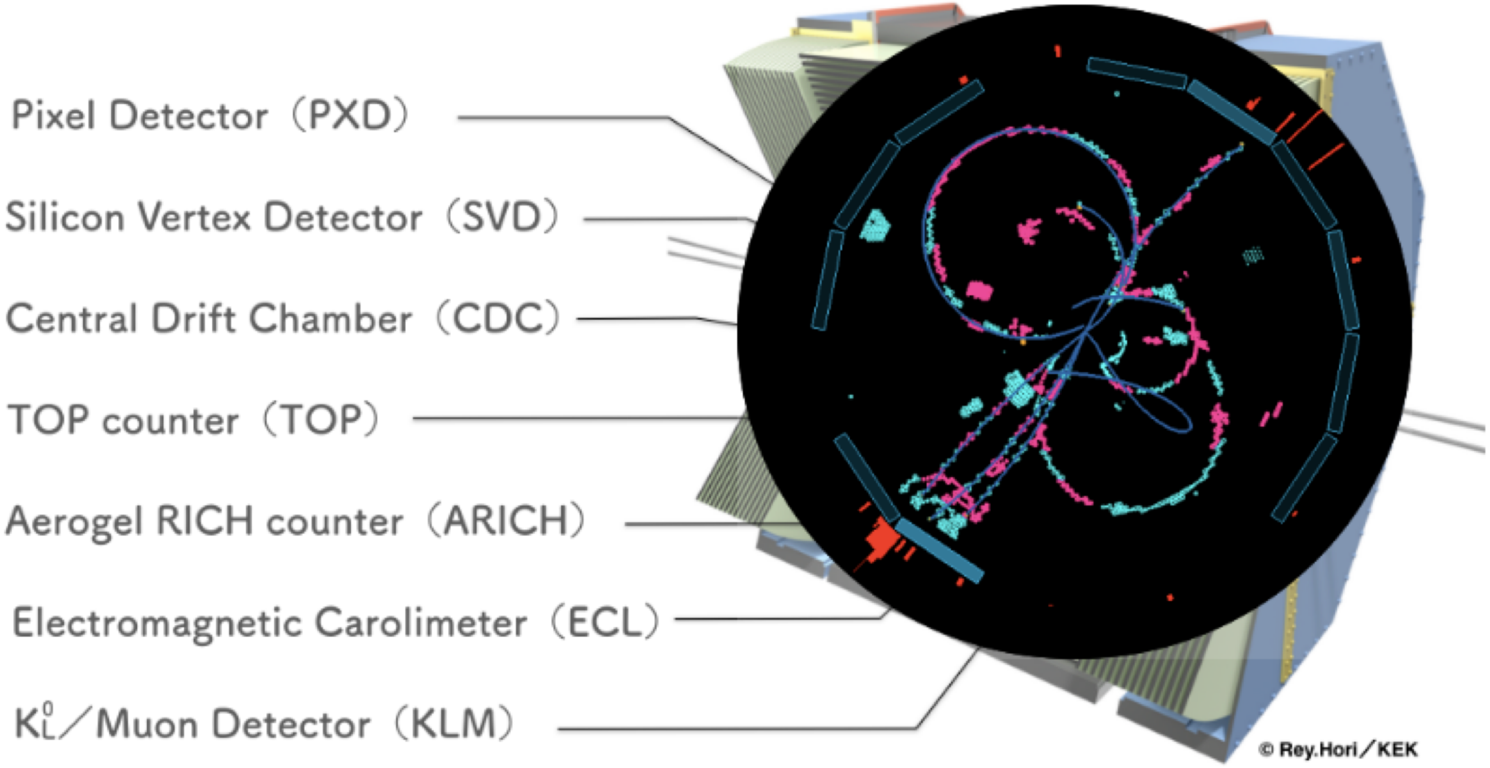
Vertex detectors: primary and secondary vertex reconstruction (K_s^0)

Central tracking device: momentum measurement of charged particles

PID systems: K/π separation. Extended to almost 4π

γ and e detection: detection of Bremsstrahlung radiation and higher π/e separation efficiency

μ detection

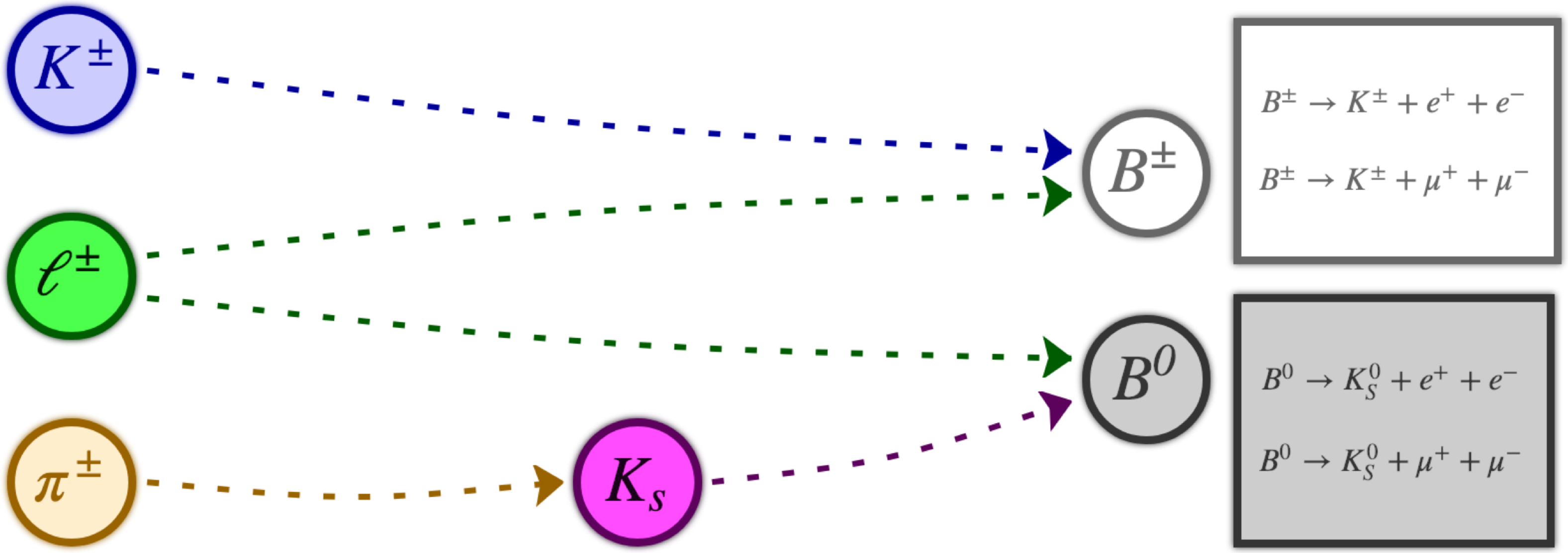


The reconstruction process

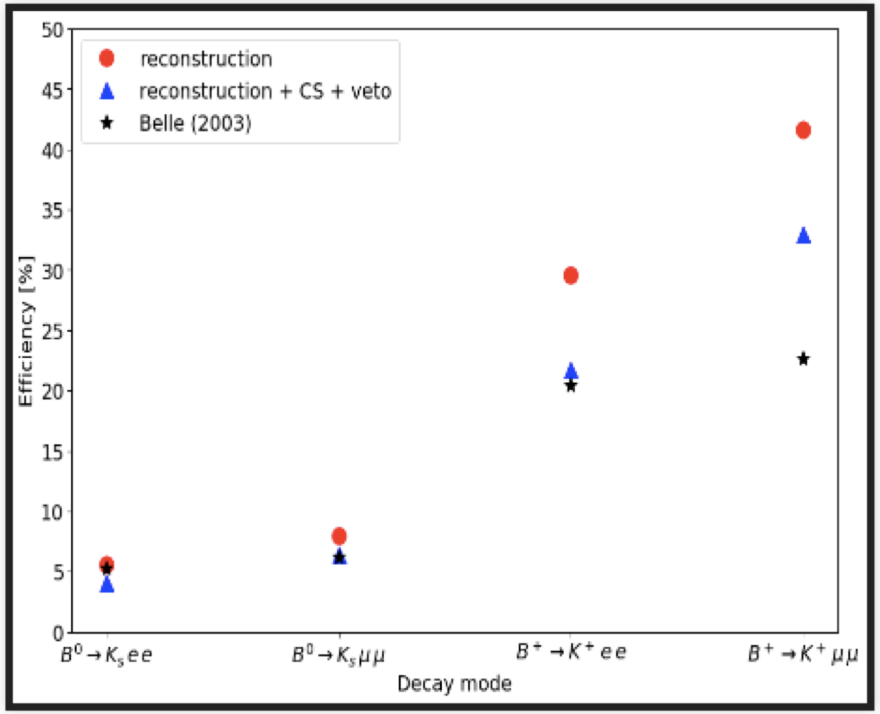
- particle id > 0.1
  (pid $= \mathcal{L}_p / \sum_i \mathcal{L}_i$)
- Good track fit
  ($\chi^2 > 0.001$)
- Near the IP
  ($d_0 < 0.5$ and $|z_0| < 2$)

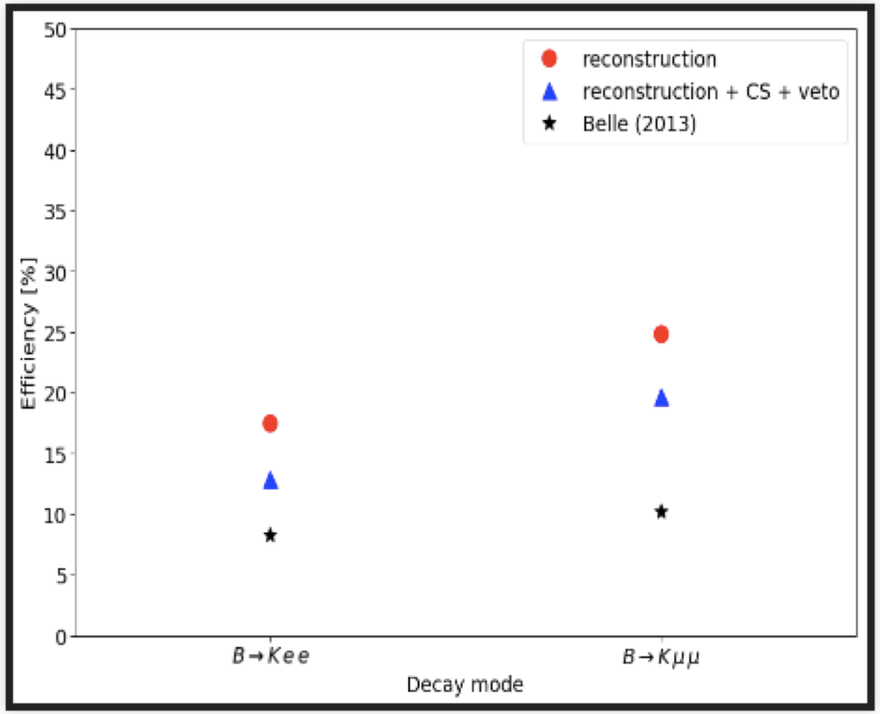
- vertex fit
- cuts in position according to p
- 0.468 GeV $< M <$ 0.528 GeV

- 5.22 GeV < m_{bc} < 5.29 GeV
  $m_{bc} = \sqrt{E_{\text{beam}} - \boldsymbol{p}^2_{B,\text{reco}}}$
- -0.1 GeV < ΔE < 0.05 GeV e ch.
  -0.05 GeV < ΔE < 0.05 GeV μ ch.
  $\Delta E = E_{B,\text{reco}} - E_{\text{beam}}$



Preliminary: MC efficiencies





Conclusions

- The $B \to K\ell\ell$ constitutes an excellent probe for new physics
  - Tests contributions from different NP scenarios
  - Possible to construct observables with low systematic uncertainties
- The Super KEK B-Factory and the Belle II experiment are the perfect environment for this searches
  - World record luminosity
  - Similar efficiencies for both electron and muon channels over the whole q^2 range
  - Current efficiencies similar to those from Belle, with plenty of room for improvement!

BACKUP

Measurements

$$R_K:$$

Belle: $1.03 \pm 0.19(\text{stat}) \pm 0.06(\text{sys})$ (full range)	[PRL 103 (2009) 171801]
BaBar: $1.00^{+0.31}_{-0.25}(\text{stat}) \pm 0.07(\text{sys})$ (full range)	[PRD 86 (2012) 032012]
LHCb: $0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.04(\text{sys})$ $(1 < q^2 < 6\text{GeV}^2)$	[PRL 113 (2014) 151601]

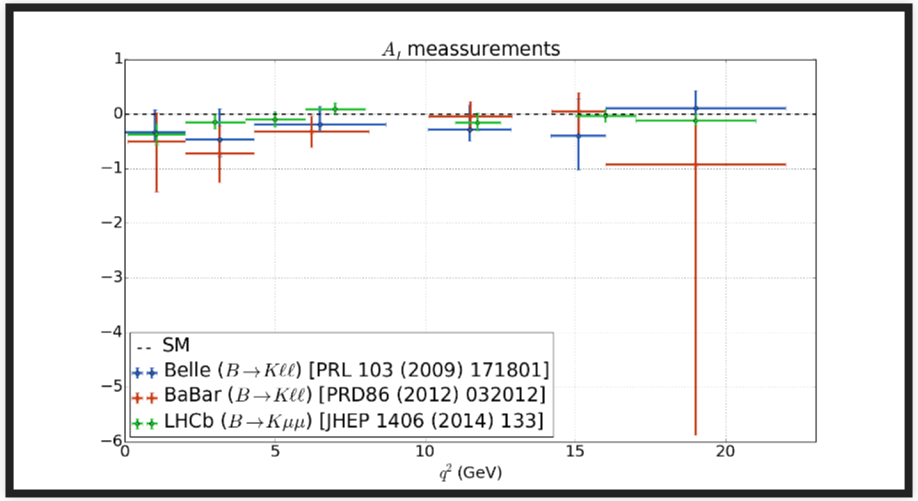
$$A_{FB}:$$

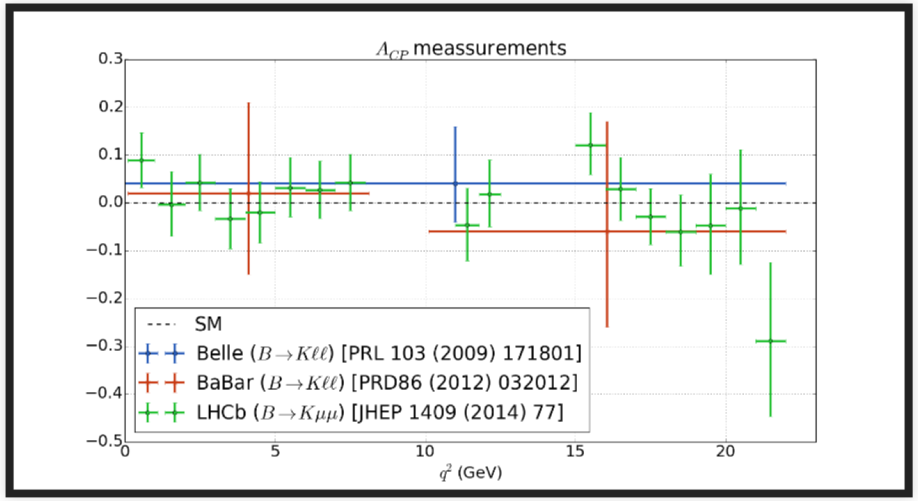
Belle: $0.10 \pm 0.14(\text{stat}) \pm 0.01(\text{sys})$ $(B^+ \to K^+\ell^+\ell^-)$	[PRL 96 (2006) 251801]
BaBar: $0.15^{+0.21}_{-0.23}(\text{stat}) \pm 0.08(\text{sys})$ (all channels)	[PRD 73 (2006) 092001]
LHCb: $0.02^{+0.05}_{-0.03}(\text{stat})^{+0.02}_{-0.01}(\text{sys})$ $(B^+ \to K^+\mu\mu)$	[JHEP 1302 (2013) 105]

Other observables

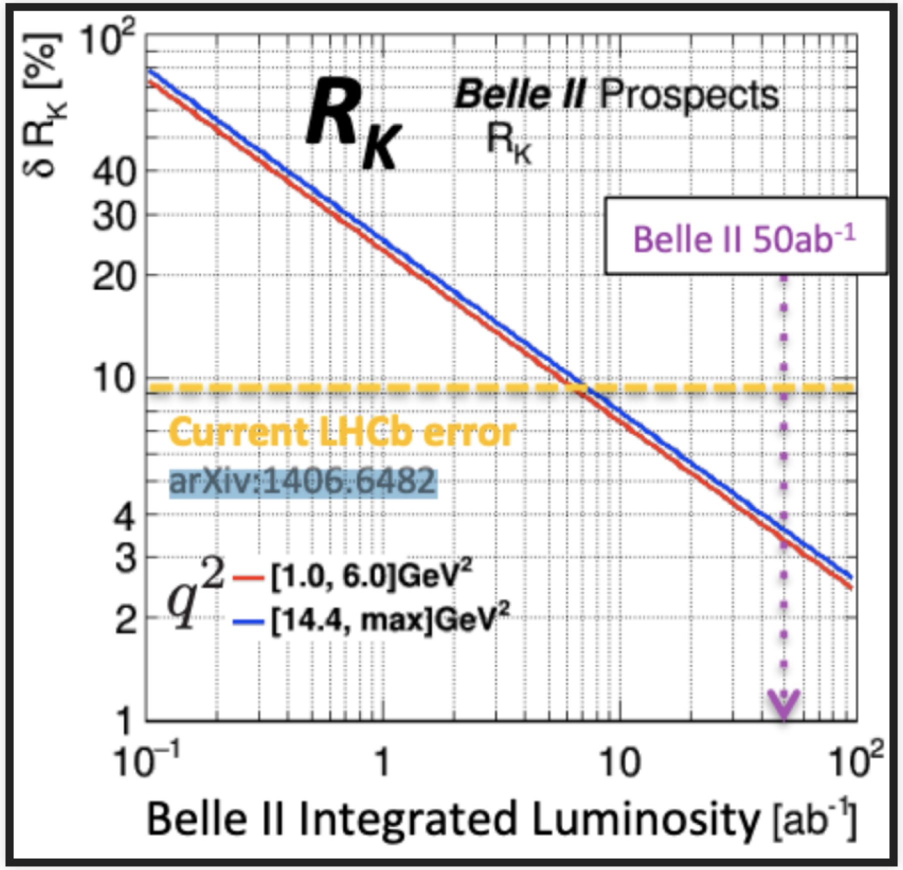
$$A_I^\ell = \frac{\mathcal{B}(B^0\to K^0\ell\ell)-\mathcal{B}(B^+\to K^+\ell\ell)}{\mathcal{B}(B^0\to K^0\ell\ell)+\mathcal{B}(B^+\to K^+\ell\ell)}$$

$$A_{CP}^\ell = \frac{\mathcal{B}(\overline{B}\to\overline{K}\ell\ell)-\mathcal{B}(B\to K\ell\ell)}{\mathcal{B}(\overline{B}\to\overline{K}\ell\ell)+\mathcal{B}(B\to K\ell\ell)}$$





Effect of luminosity in δR_K



Similar events in Belle and LHCb

$$B^- \to D^0\left(K^-\pi^+\right) + \tau^-\left(e^-\overline{\nu}_e\nu_\tau\right) + \overline{\nu}_\tau$$

$$\overline{B^0} \to D^{*+}\left(D^0\left[K^-\pi^+\right]\pi^+\right) + \tau^-\left(\mu^-\overline{\nu}_\mu\nu_\tau\right) + \overline{\nu}_\tau$$

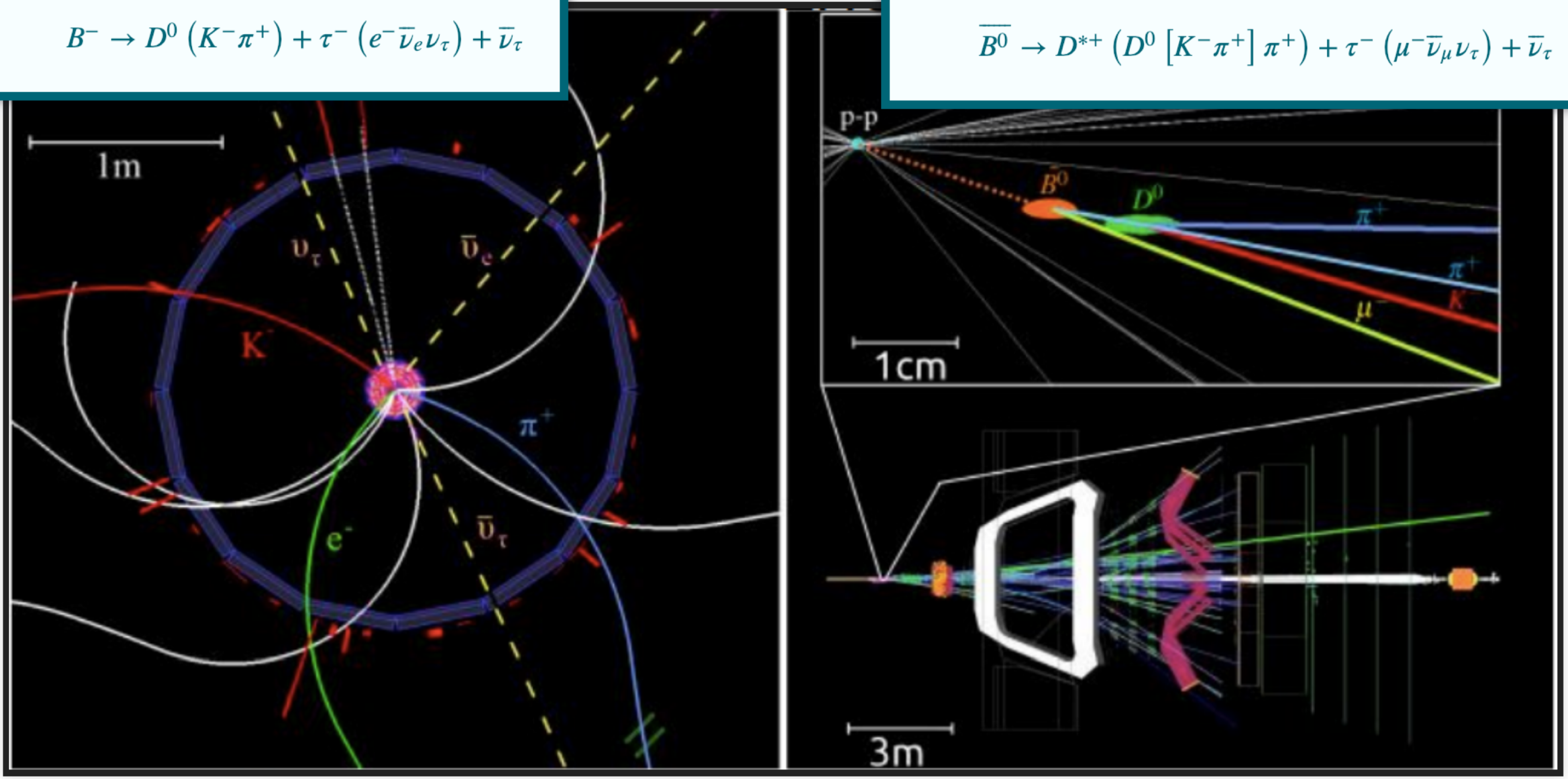


Image courtesy of T. Browder in *Second international workshop "Particles, Gravitation and the Universe"*, 2018, Hanoi

First events topologies

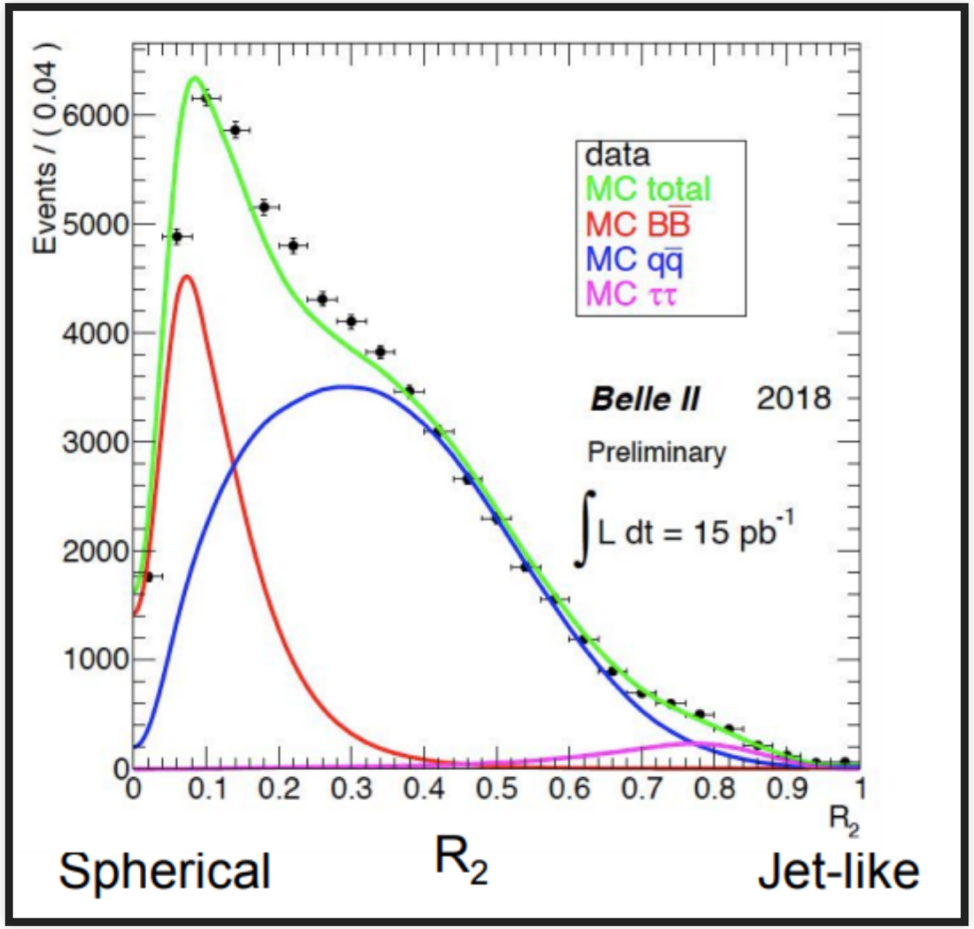
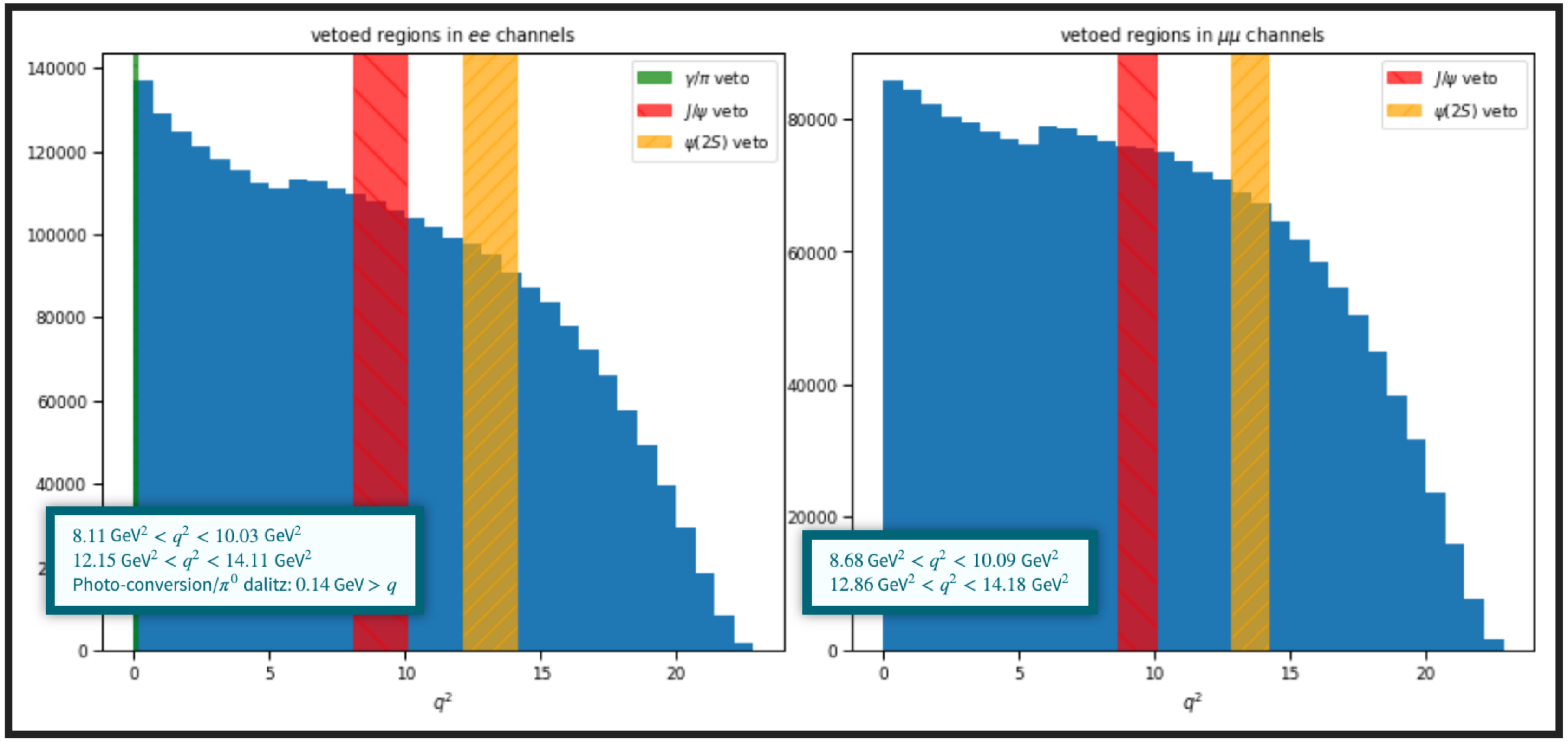


Image courtesy of T. Browder in *Second international workshop "Particles, Gravitation and the Universe"*, 2018, Hanoi

Physics Backgrounds

Charmonium decays: $B \to K + J/\psi(\ell^+\ell^-)$ and $B \to K + \psi(2S)(\ell^+\ell^-)$

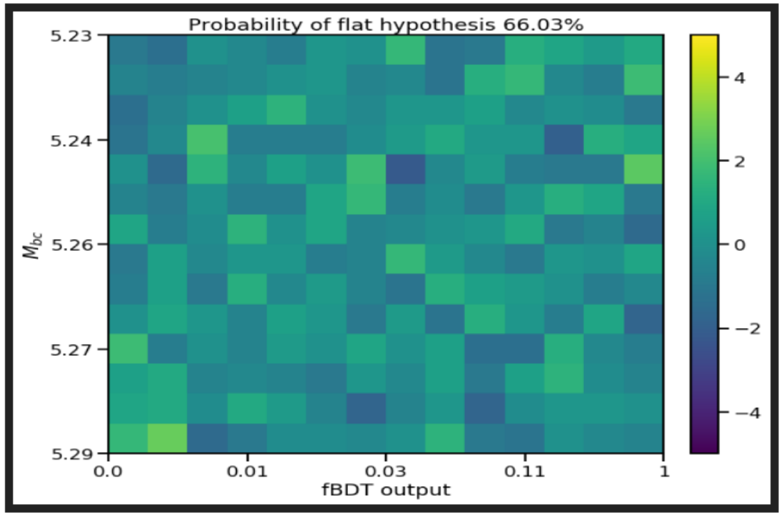
Solution: veto regions

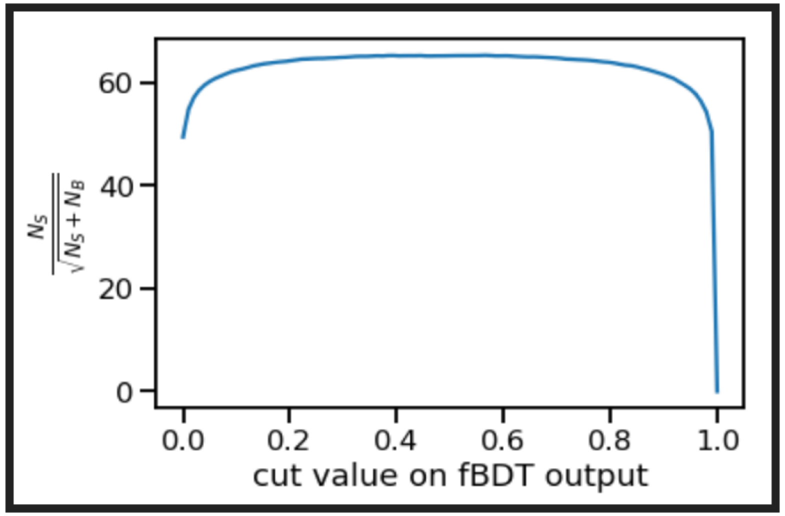


Physics Backgrounds

Continuum events: $ee \to qq$

Solution: MVA classifier





Background rejected: 91.66%. Signal kept: 92.88%
(on testing dataset)

MVA specs

fastBDT

Training/testing samples with 1:1 signal to background ratio

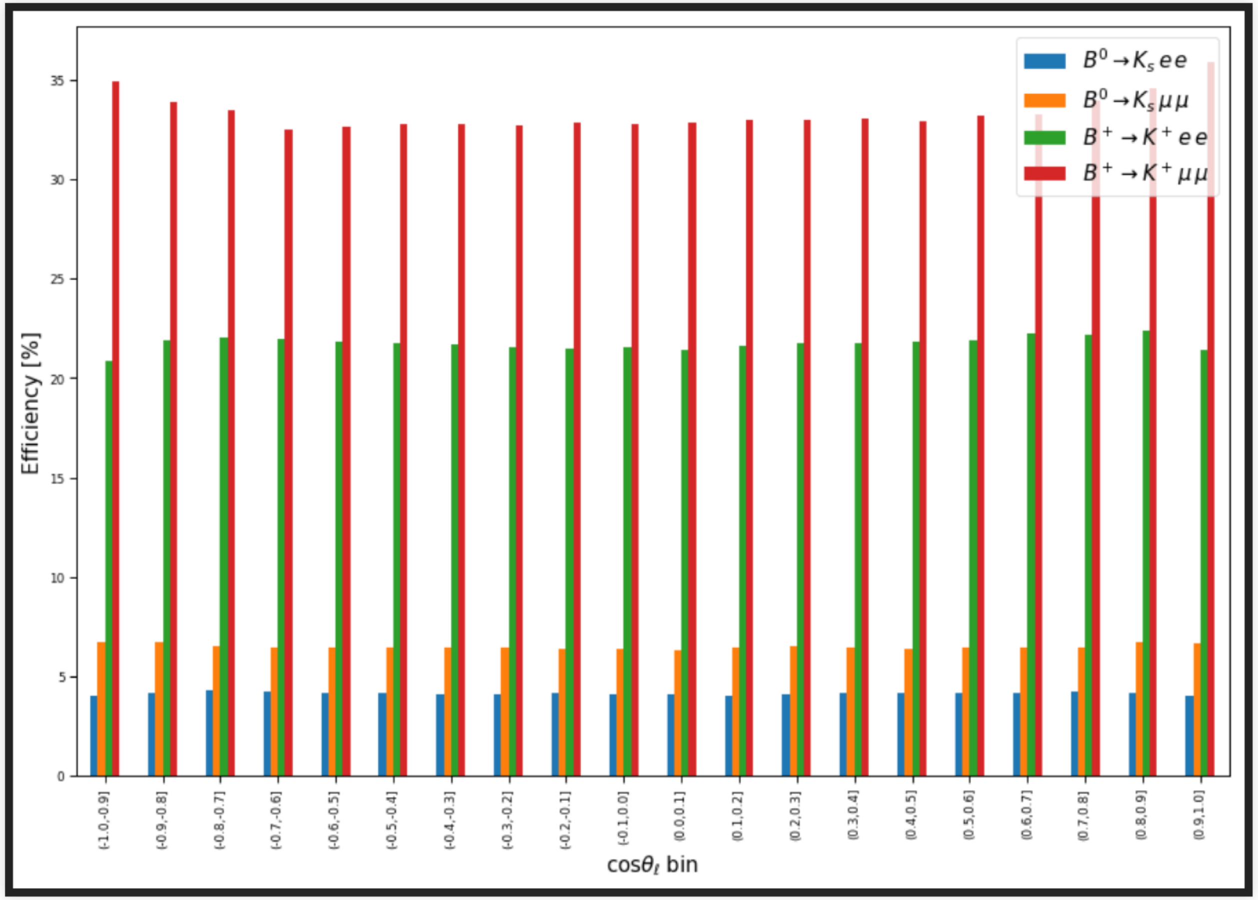
48572 examples after reconstruction cuts (80% of data for training, 20% for testing)

18 variables

- KSFWM (13)
- Cosine of the angle between signal thrust and beam axis (1)
- Cosine of the angle between signal thrust and ROE thrust (1)
- R2 (1)
- Magnitude of the ROE and the signal thrust axis (2)

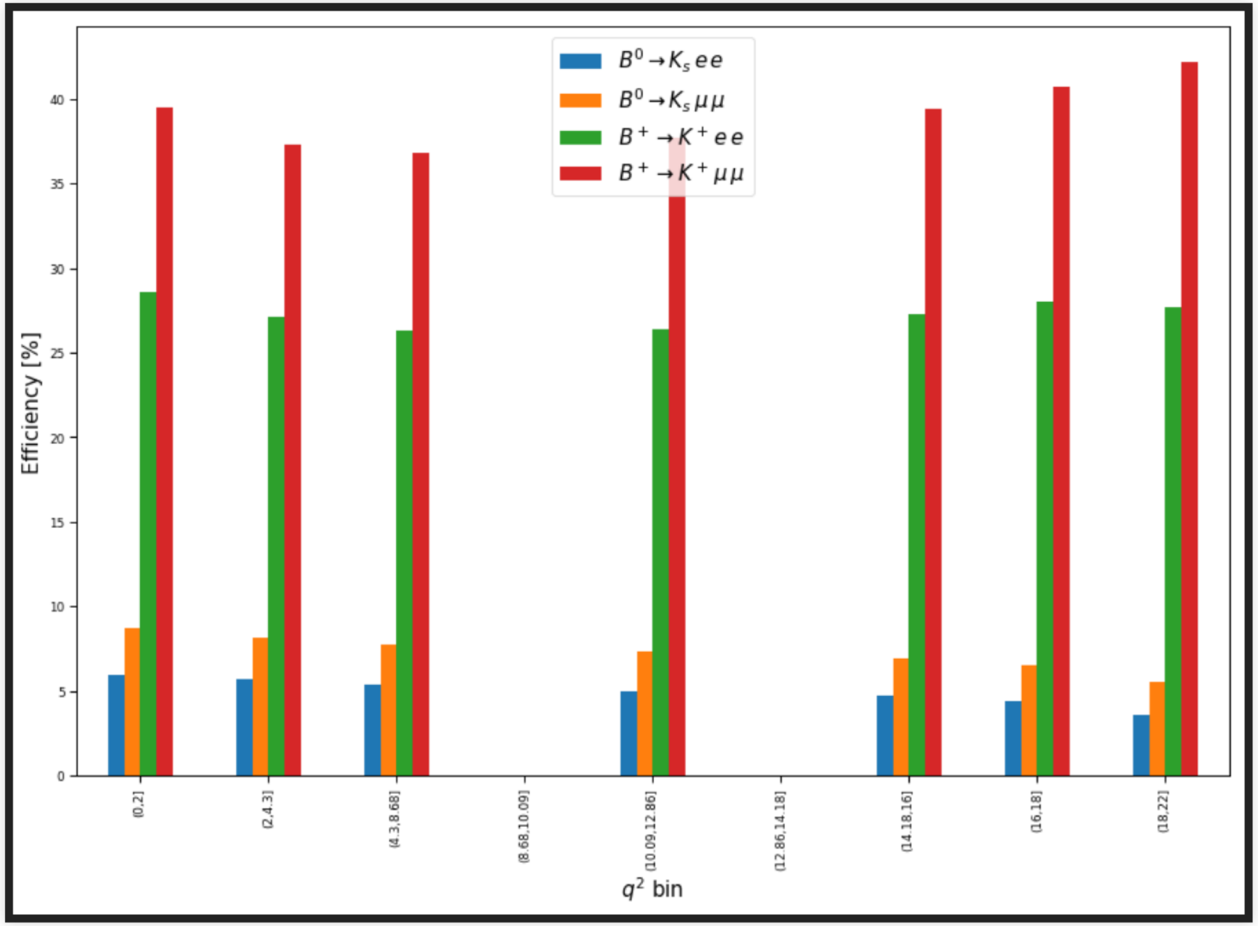
Preliminar: efficiencies

Angular

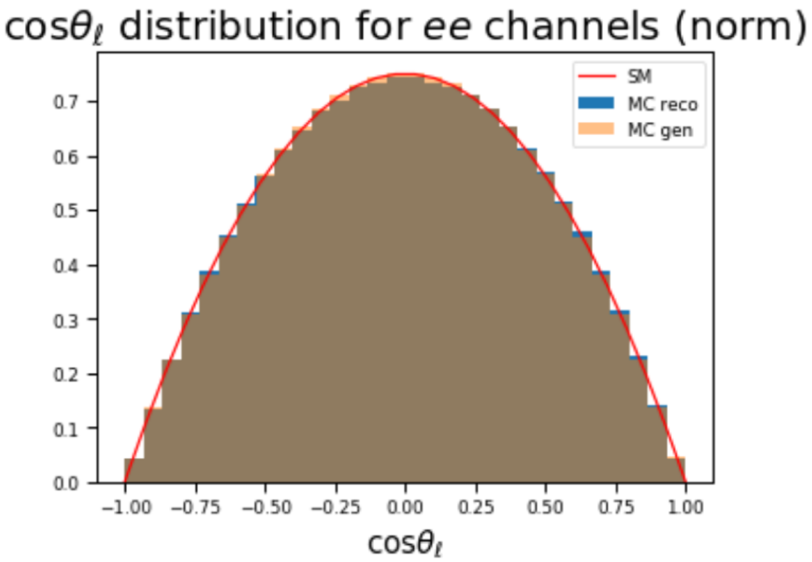


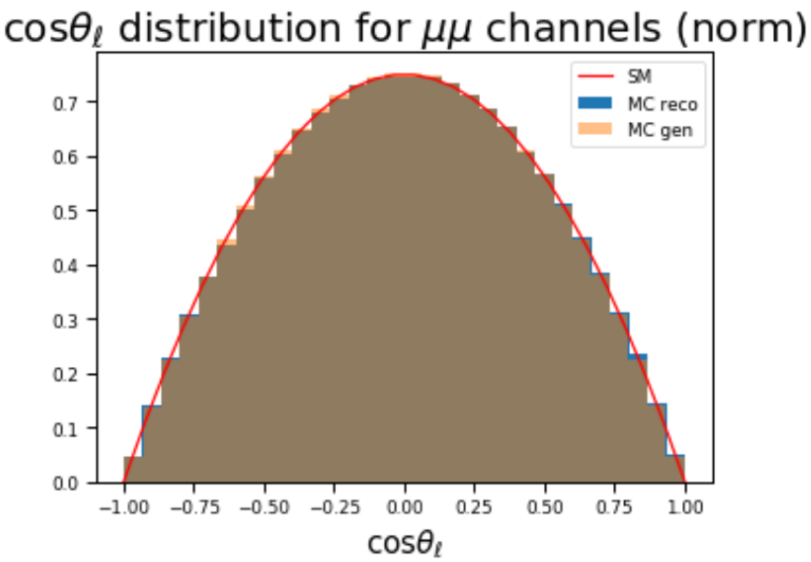
Preliminar: efficiencies

In q^2 bins

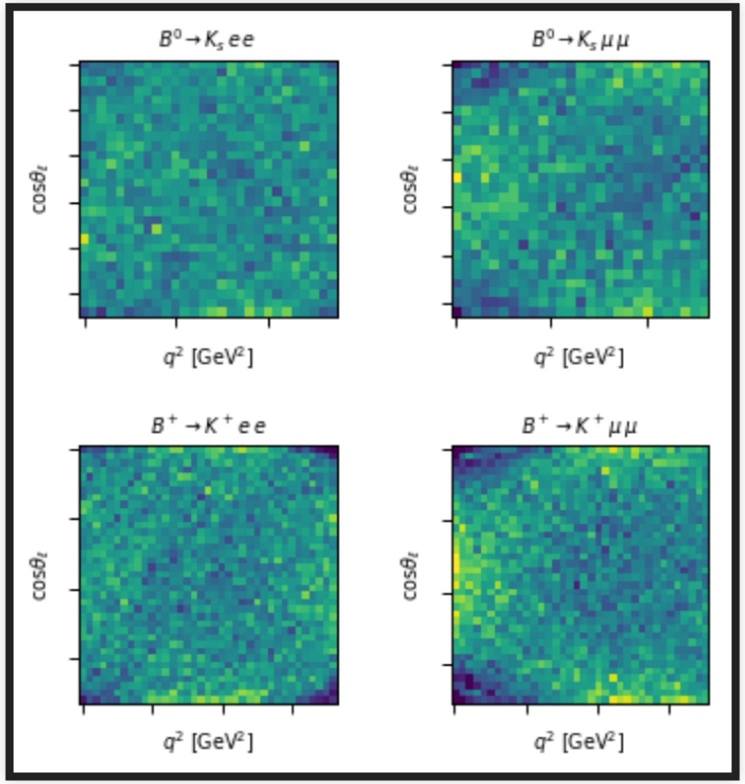


Angular distributions





Correlations between q^2 and $\cos\theta_\ell$



Preliminar: sources of background from generic B^0 decays ($1.2\ \mathrm{ab}^{-1}$)