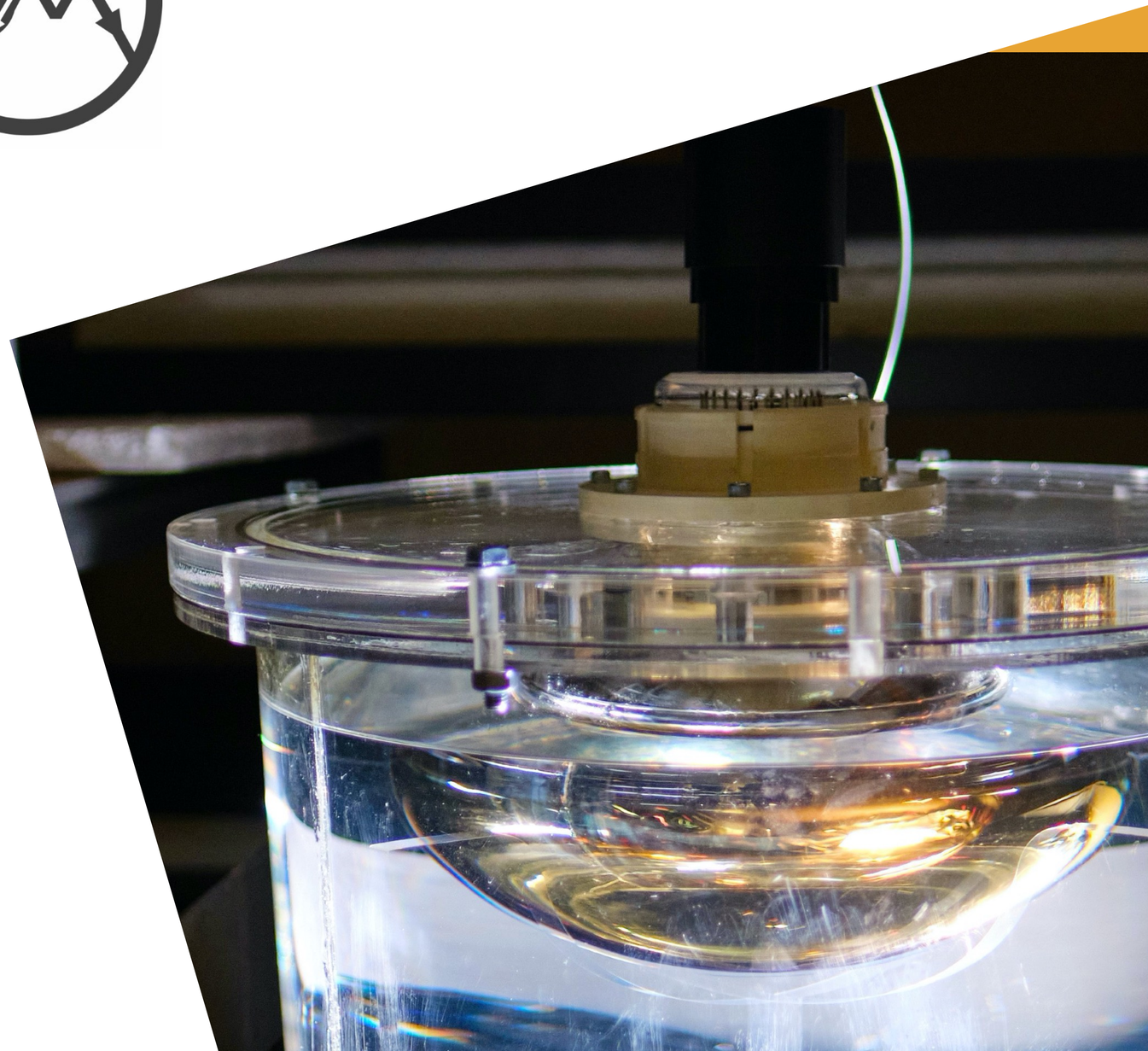
DM Direct Detection

& Collider Searches

Phillip Urquijo
The University of Melbourne

CoE DM Workshop November 2020
Online



Research Teams

- **DM Direct Detection**
  - Post-doc: Federico Scutti
  - PhD: William Dix, Michael Mews
  - MSc: Lachlan Milligan, Owen Stanley

- **Belle II (non-CoE)**
  - Post-doc: Marco Milesi
  - PhD: Daniel Ferlewicz, Marcel Hohmann, Jo-Frederik Krohn, Cate MacQueen
  - MSc: Daniel Marcantonio, Paolo Rochetti, Joey Teoh

THE UNIVERSITY OF MELBOURNE

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

DM Direct Detection

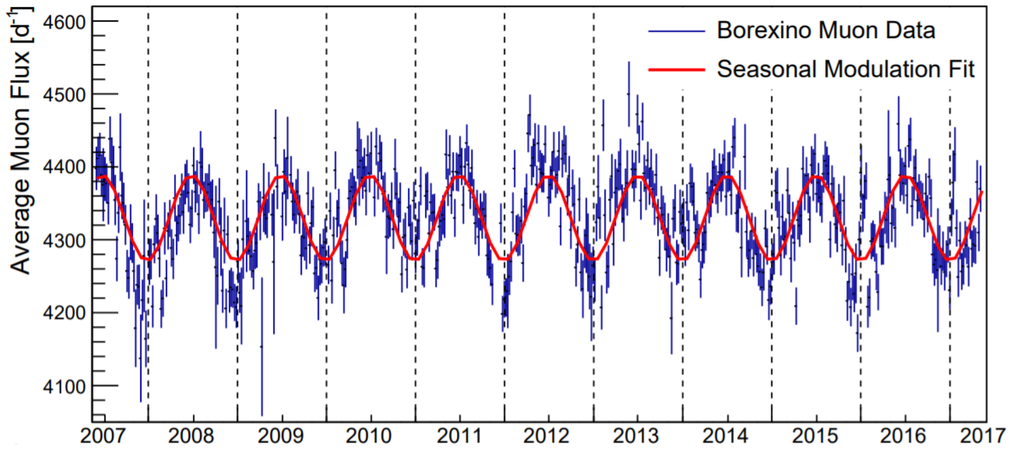
SABRE

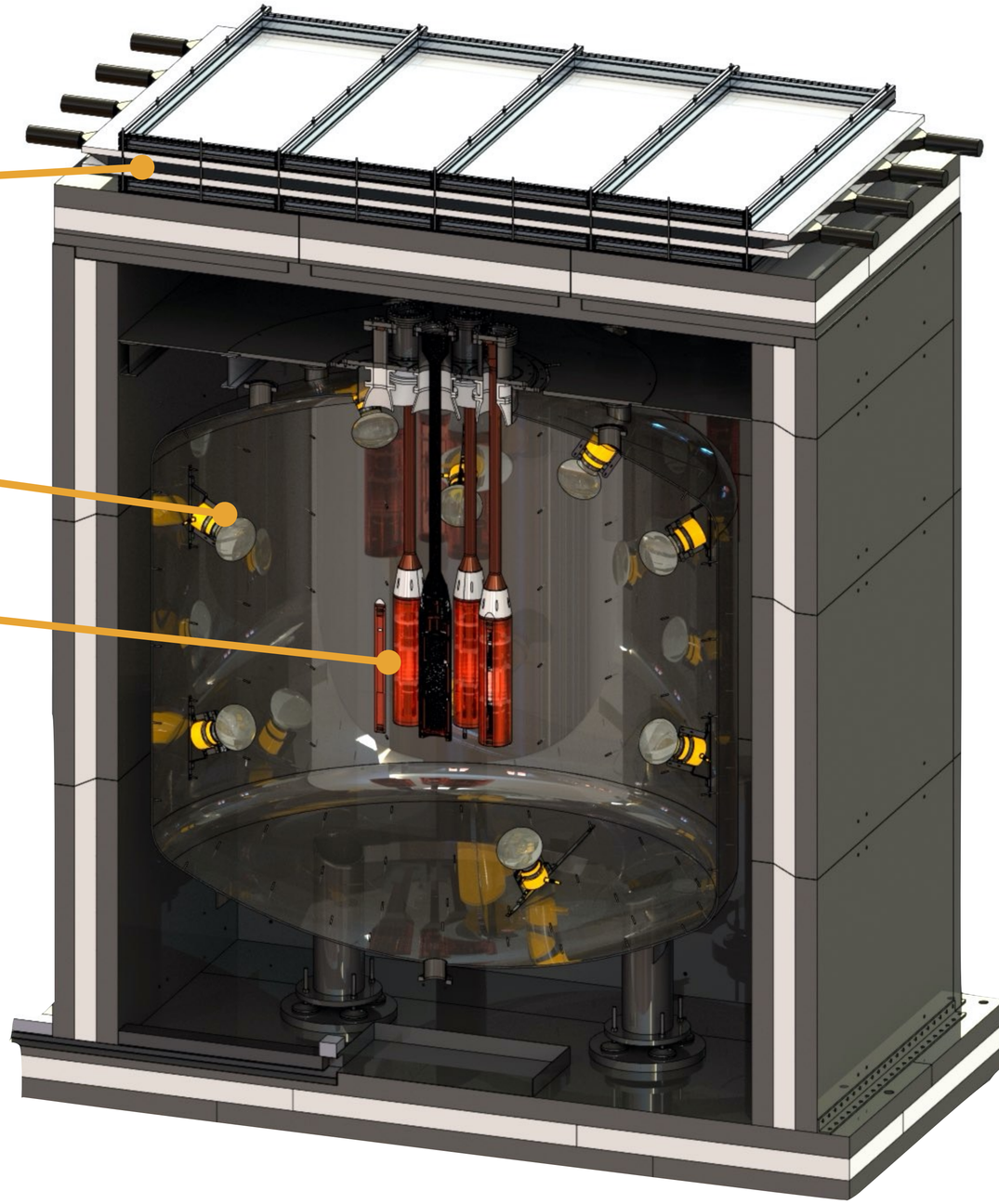
Background Measurements

Software and Computing

SABRE

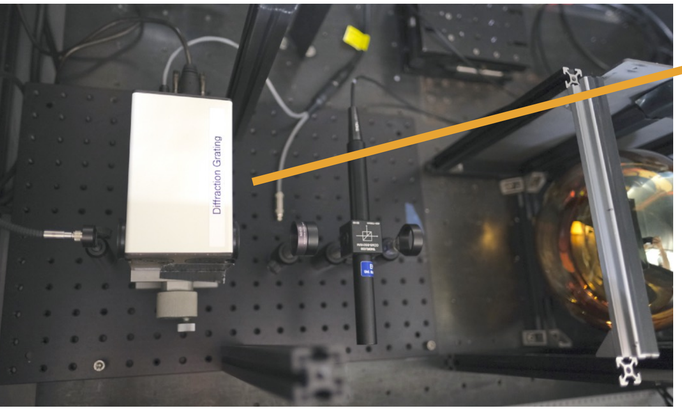
- **ToF Muon System**
  9.6 m^2 x 5 cm EJ200
  R13089 PMT x 16 @ 3.2 GS/s
- **Veto System**
  12t Linear Alkyl Benzene + PPO & Bis-MSB
  Oil-proof base R5912 PMT x 18 @ 500 MS/s
- DM Target Detector
  NaI(Tl) Crystals
  R11065 low radioactivity PMT x ~14 @ 500 MS/s
- Key requirement to understand modulation in background contributions - requires particle ID. e.g. **μ**/γ/n.

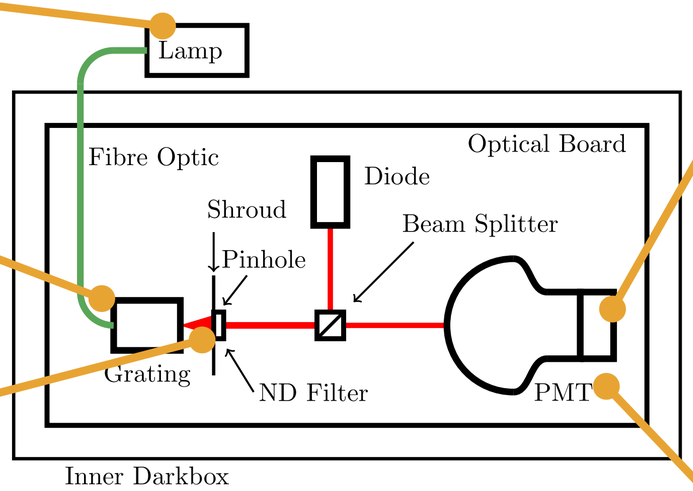


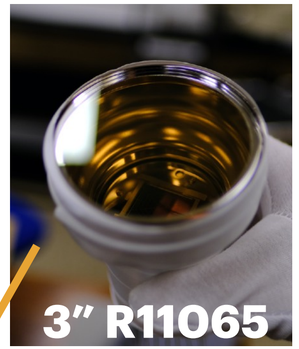


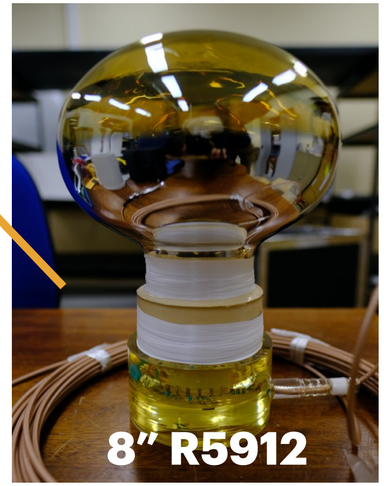
PMT Characterisation

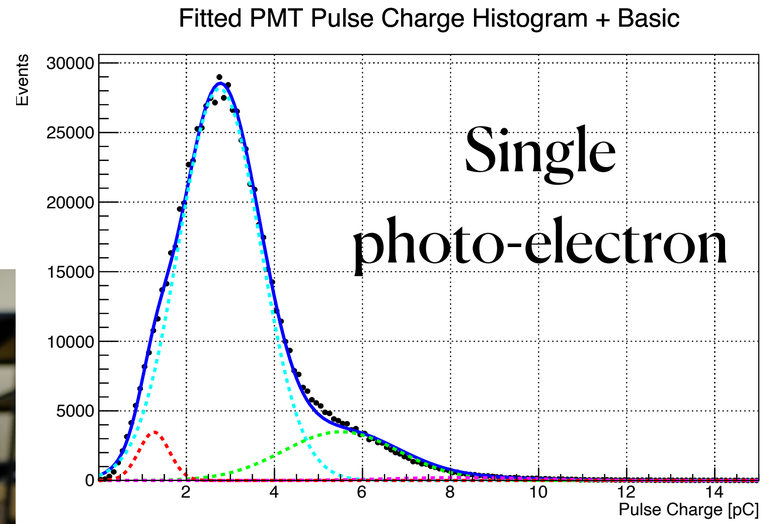
PhD: Bill Dix
MSc: Owen Stanley

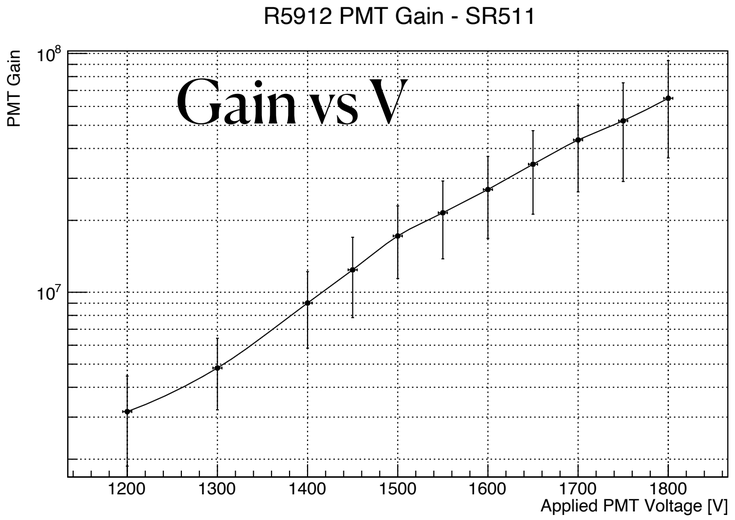












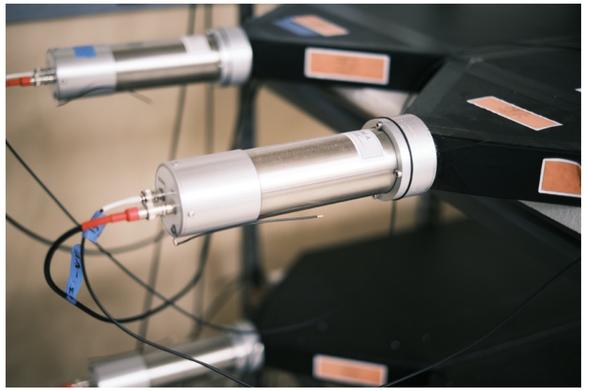
- Measurement of all PMTs: **Quantum Efficiencies**, Photocathode surface scans, Dark current and dark rate (ML suppression algorithm), **Gain**, **Temperature dependence**, spontaneous light emission, after-pulses.
- 8" R5912 - oil-proof assembly, 3" R11065 - low radioactivity metal body. Collaboration with Hamamatsu. Full order after testing procedure finalised.

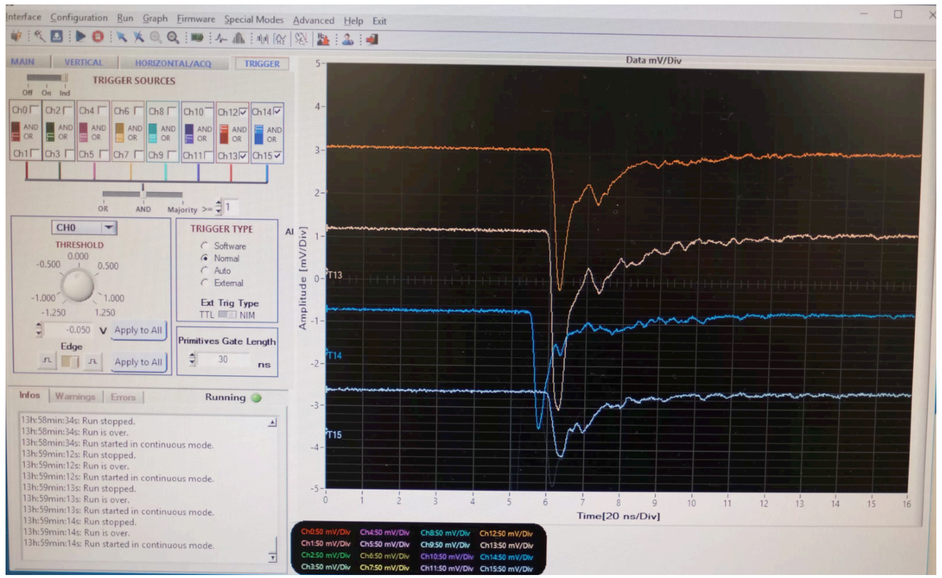
Muon Survey & Veto

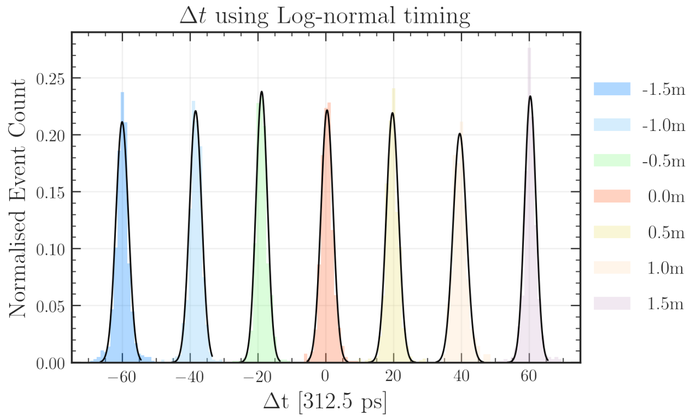
DP190103123 w/ A. Duffy

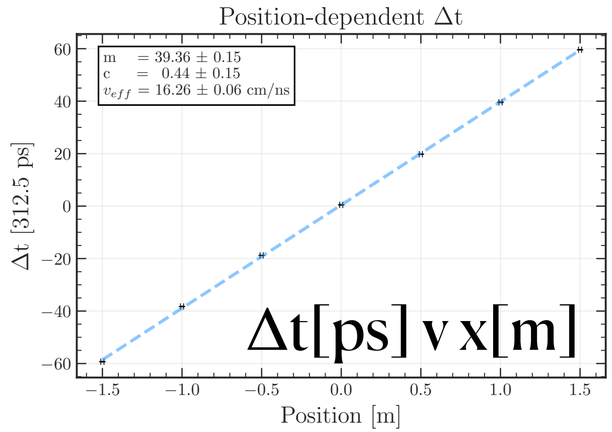
PhD: Michael Mews
PD: Federico Scutti

- **SALEM** (Scintillating array for locating energetic muons). (3m x 0.4m EJ200) x 8 modules. 2-PMT readout ToF-type system with ~5cm μ position resolution.
  - Stage 1: 2 layer configuration for μ flux vs. direction at SUPL (1025 m) + Small muon setup (3-layer 0.18 m^2) for studies at other depths (<800 m). **Systems ~ready for deployment.**
  - Stage 2: SABRE μ Veto and location sensitive particle ID layer.



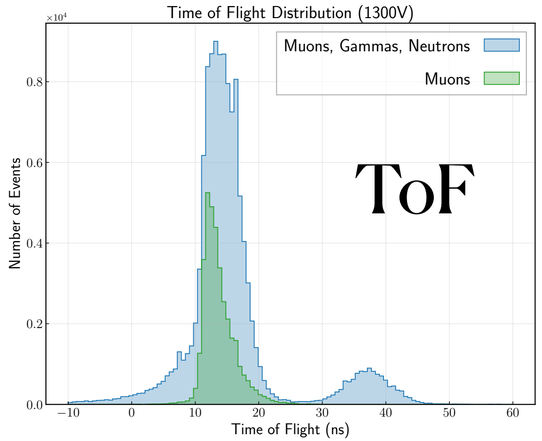


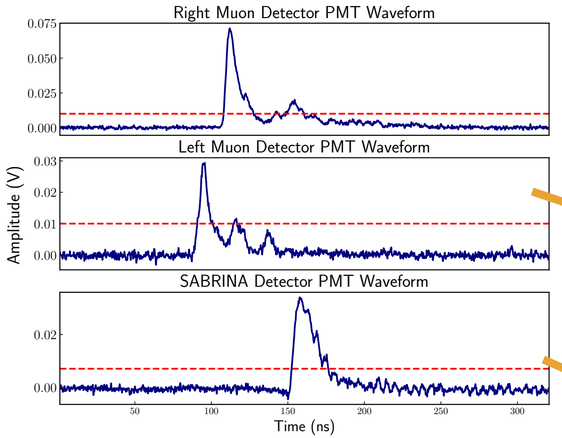


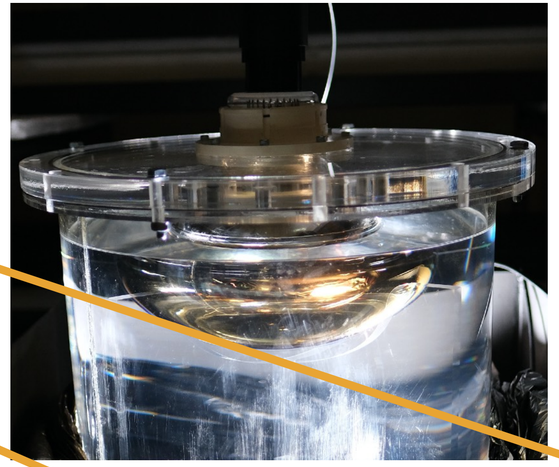


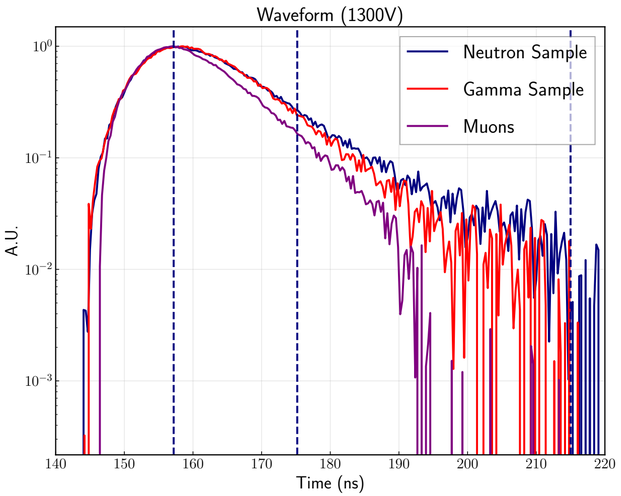
Particle Identification in Organic Scintillator Veto

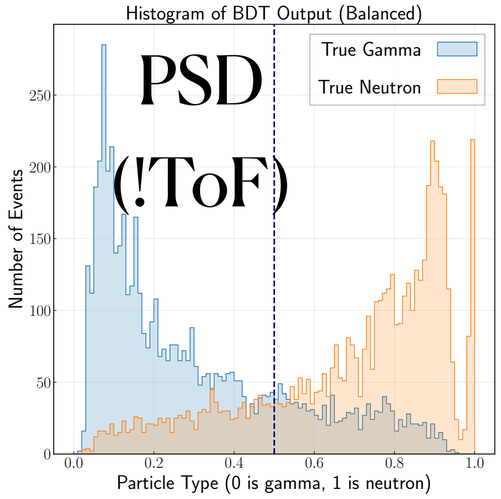
MSc: Lachlan Milligan

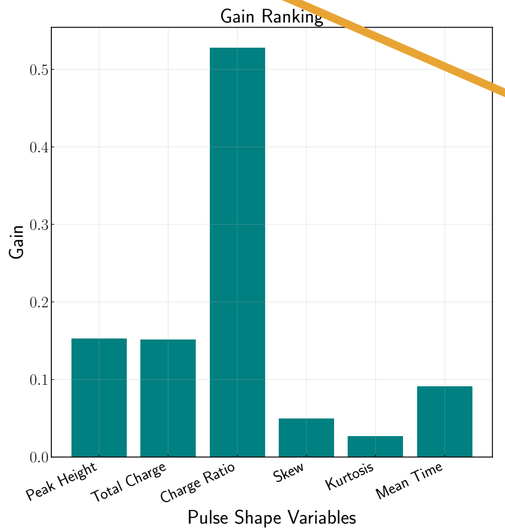












- SABRINA (Little SABRE Veto System).
  - R&D for n/γ/μ separation based on waveform **pulse shape discrimination** and **time of flight** (σ = 1 ns).
- New approach to identify (modulating) background composition with the veto systems.

DAQ, Software and Computing

PD: Federico Scutti + group

Pyrate offline software documentation

FS MM Created by Federico Scutti
Last updated Nov 20, 2020 • 27 min read • Analytics

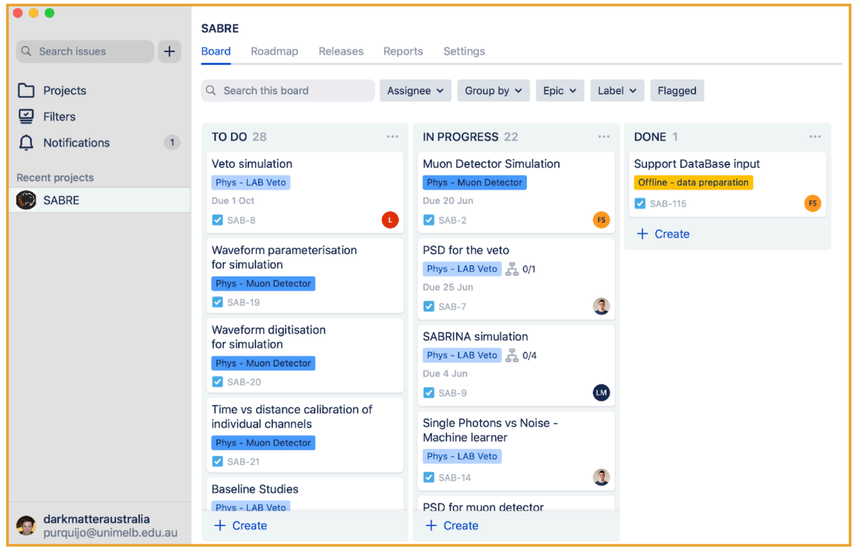
Use cases

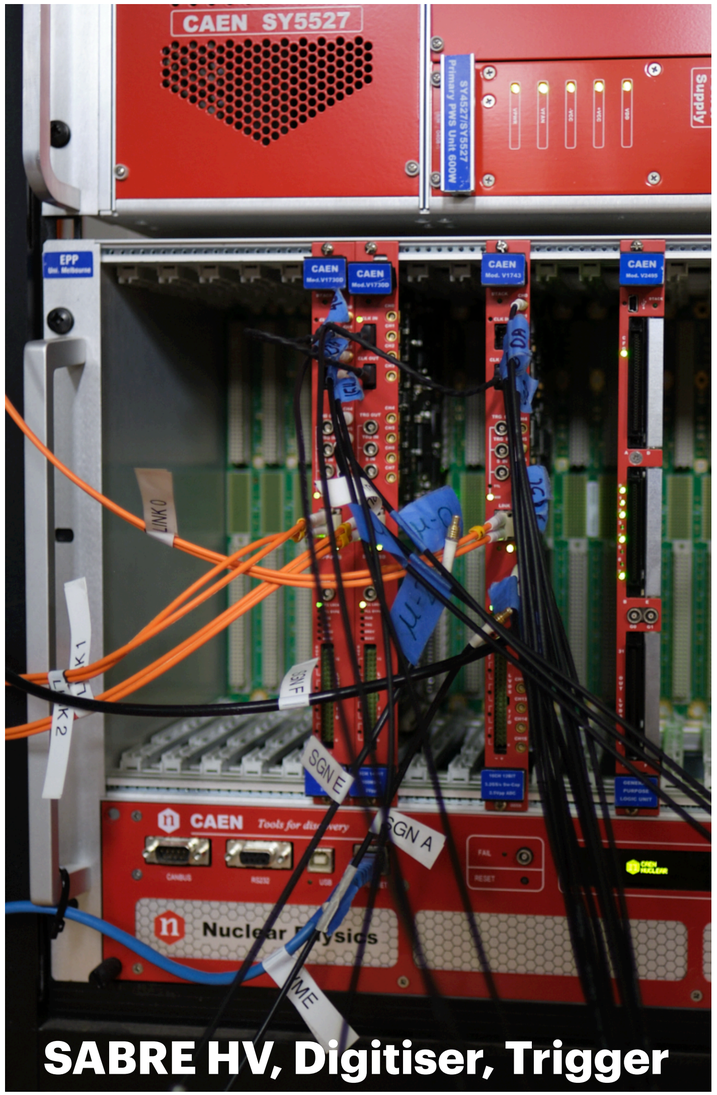
Pyrate is a software package developed for the following use cases:

- Data transformation from format X to Y.
- Event reconstruction: computing and transforming variables, e.g. waveform digitisation, energy calibration, global event variables, detector variables etc.
- Data analysis: applying a set of selection criteria and weights to input data/simulation and display some plots.

The software has been written in python 3.8.3 and contains configuration files in yaml. Files have been formatted with black. Memory consumption monitoring is performed using memory_profiler. Currently, it features the following set of dependencies:

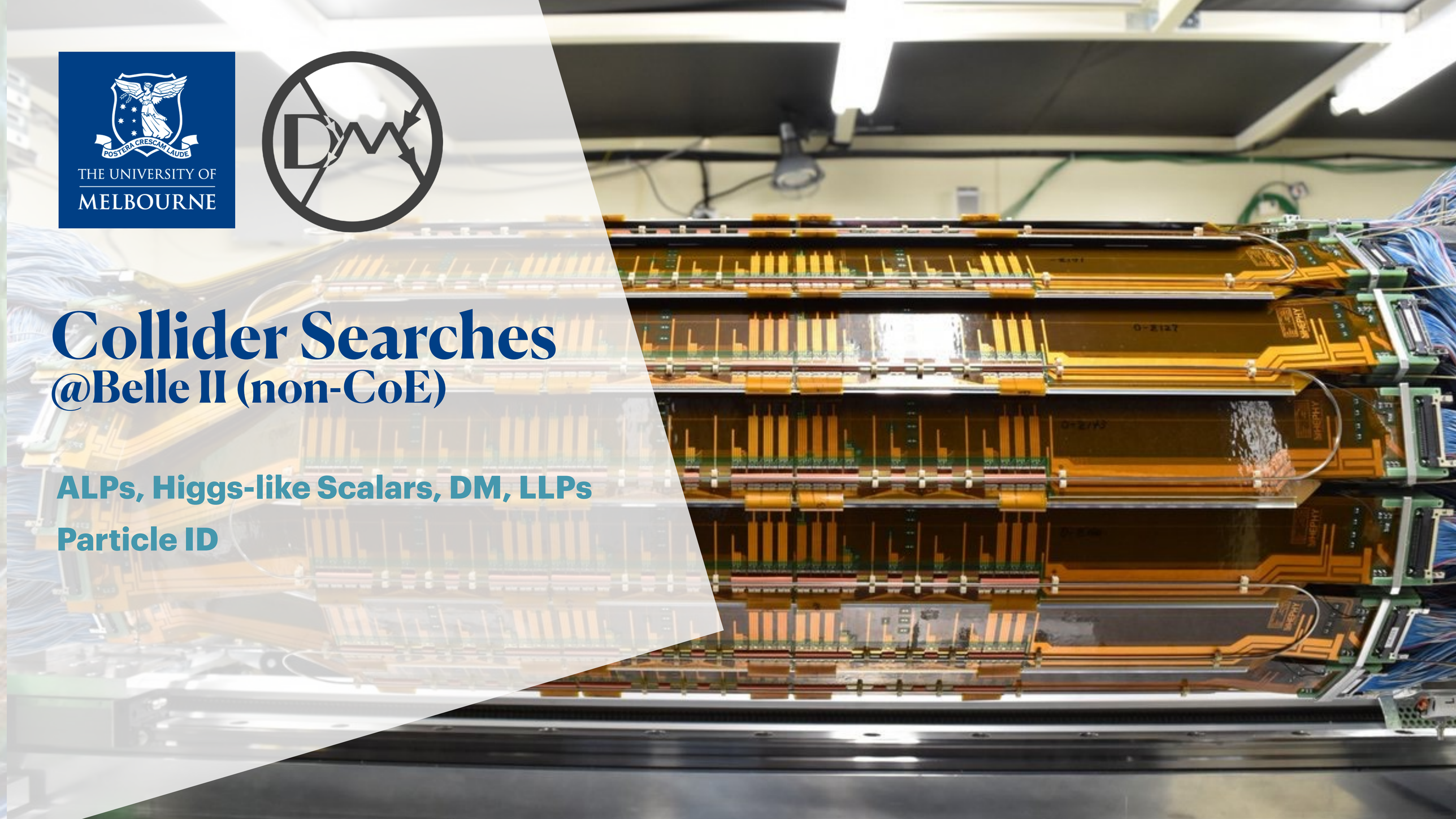
- ROOT 6.22/01 which can be installed in this way. (or see here if you get stuck)
- pyYAML.
- colorama.
- tqdm.





SABRE HV, Digitiser, Trigger

- Low thresholds w/ waveform sampling: **> ~ 100 TB per year raw data**.
- Analysis Software framework: **PyRATE** (SABRE).
- Collaboration tools: Confluence, JIRA, Bitbucket, Slack.
- Computing: DAQ, DB, UniMelb Compute & Storage.



Collider Searches
@Belle II (non-CoE)

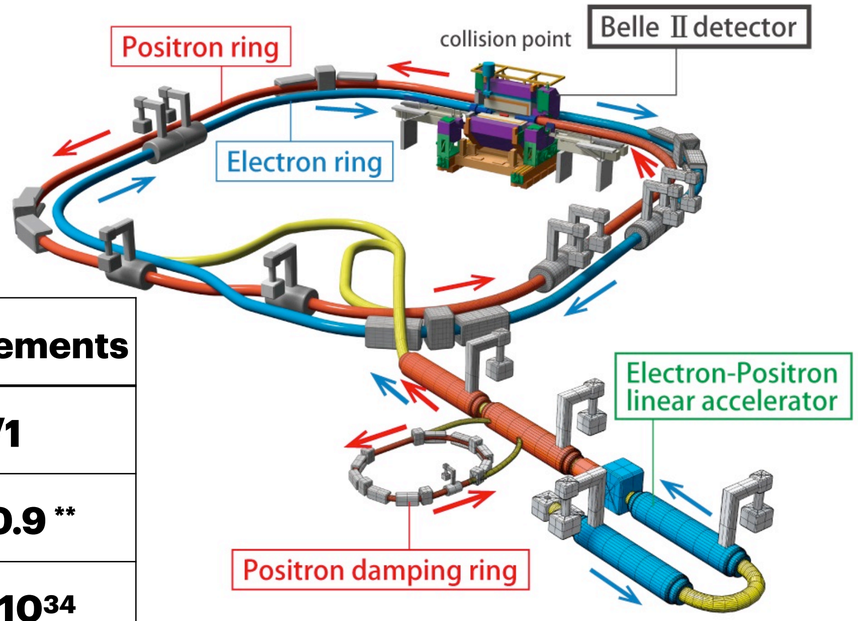
ALPs, Higgs-like Scalars, DM, LLPs

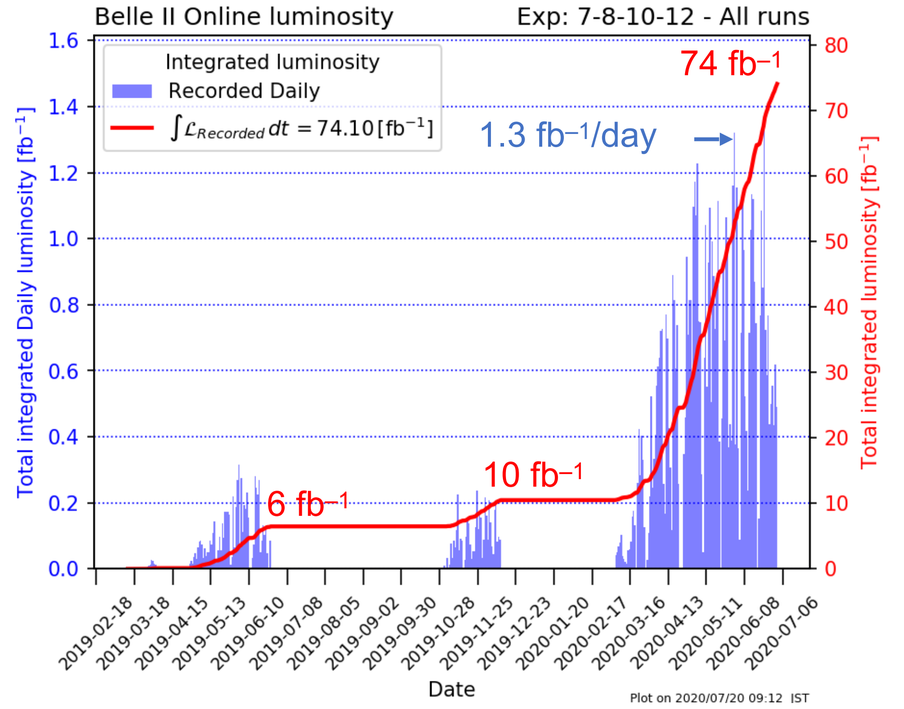
Particle ID

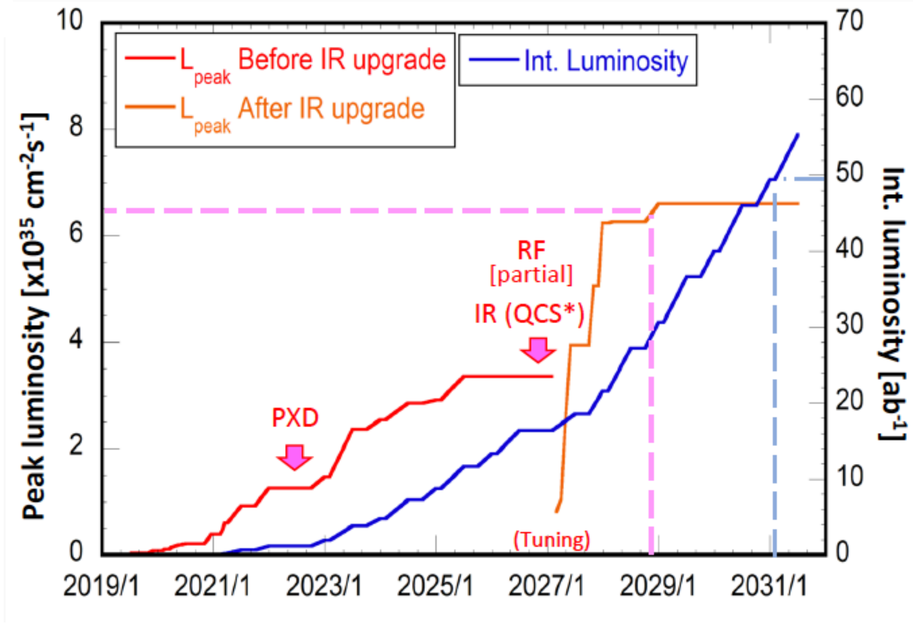
Belle II @ SuperKEKB

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

	KEKB	SuperKEKB	**Achievements**
β^*_y(mm)	5.9/5.9	0.3/0.27	**1/1**
I_{beam}(A)	1.19/1.65	2.6/3.6	**0.7/0.9** **
L($cm^{-2}s^{-1}$)	2.11x10^{34}	80x10^{34}	**2.4x10^{34}**







- Luminosity exceeded previous world record, and ramping up.
- First 2 papers produced on **dark sector physics (Z', a')**. First flavour papers to come in 2021.
- Longer timeline than original - **detector upgrade program** under development. (Now on program advisory for upgrades to particle reconstruction and identification).

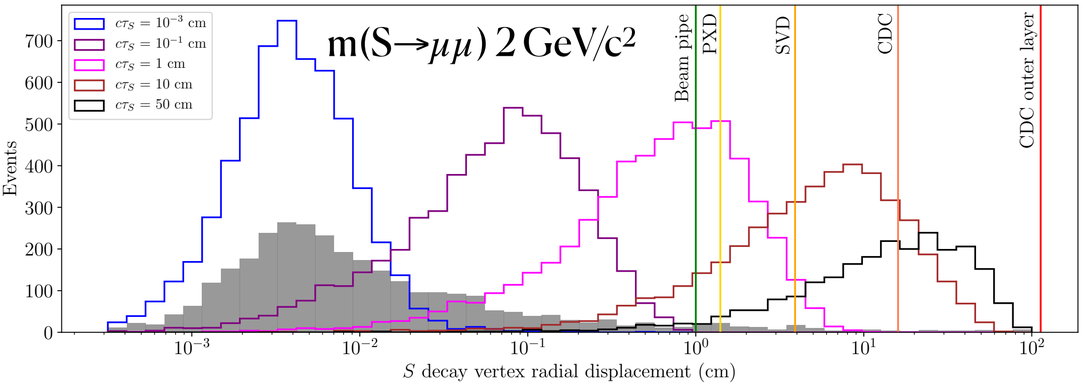
Dark sector searches

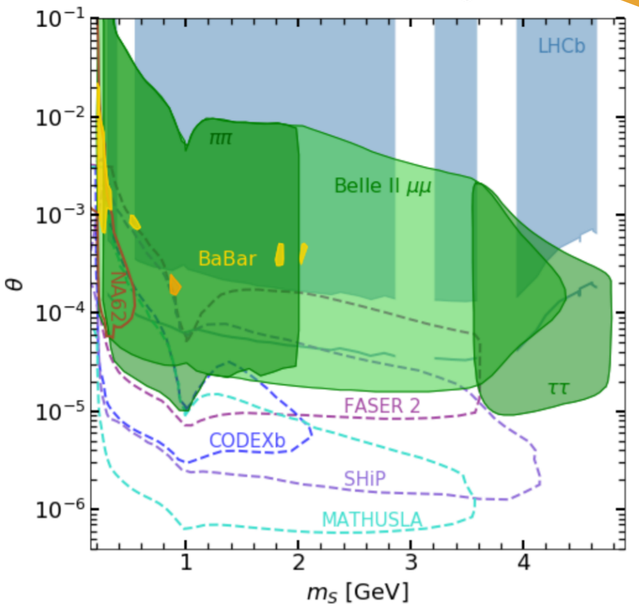
DP210101900 w/ A. Thamm

PhD: Cate MacQueen
MSc: Daniel Marcantonio

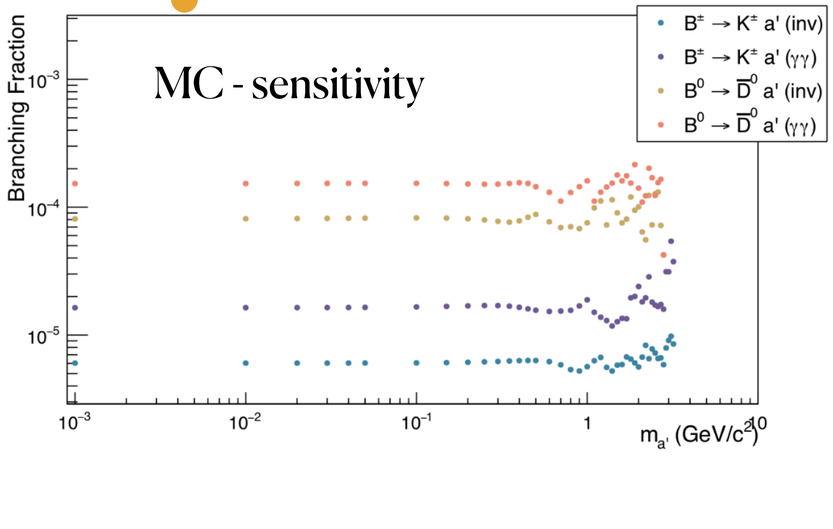
- Vector portal $\epsilon F_Y^{\mu\nu} F'_{\mu\nu}$ $(dark\ photon\ A')$, $\sum_l \theta g' \bar{l} \gamma^\mu Z'_\mu l$ $(dark\ Z')$
- Axion portal $\frac{G_{agg}}{4} a G_{\mu\nu} \tilde{G}^{\mu\nu} + \frac{G_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$ $(axion, alps)$
- Scalar portal $\lambda H^2 S^2 + \mu H^2 S$ $(dark\ Higgs)$

Long lived particles
220 MeV/c² - 4.8 GeV/c²





<1 MeV/c² - 4.8 GeV/c²
LLP, invisible or γγ

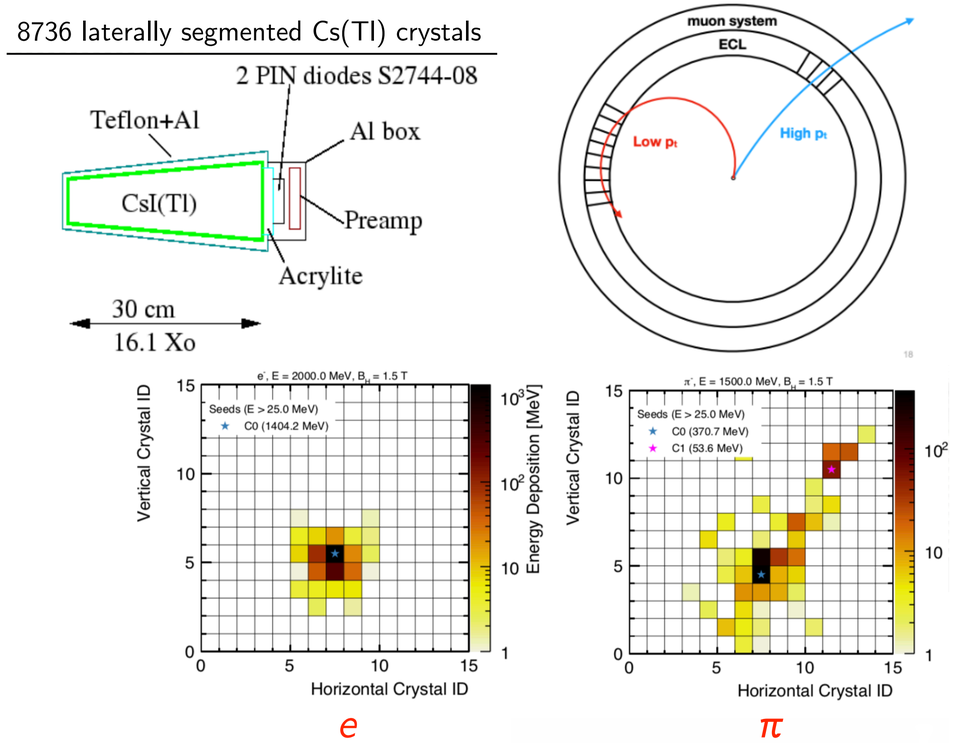


- Our searches: Photon couplings, Dark matter, Dark Photons, **Long lived particles**
- **B→K$^{(*)}$S**/a′ (**Loop**) & **B→D$^{(*)}$S**/a′ (**Tree**) (*S/a′*→ γγ, **χχ**, $f^+ f^-$), **ee→A′γ** (*A′*→χχ, $f^+ f^-$)

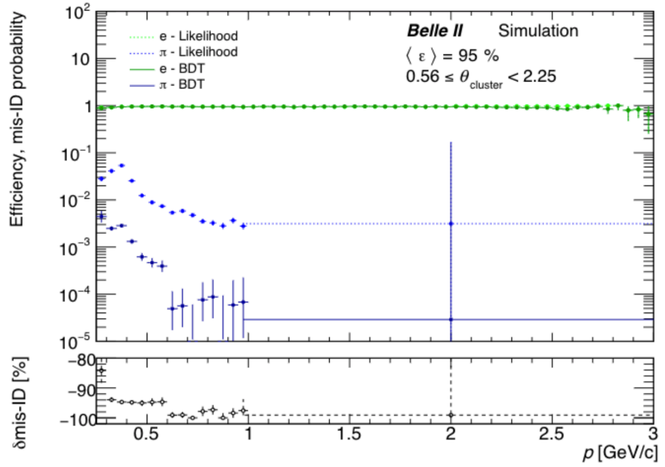
Particle Identification

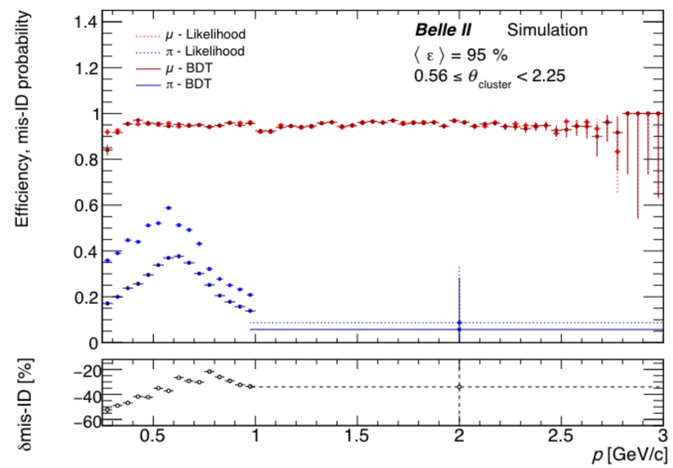
DP190101991

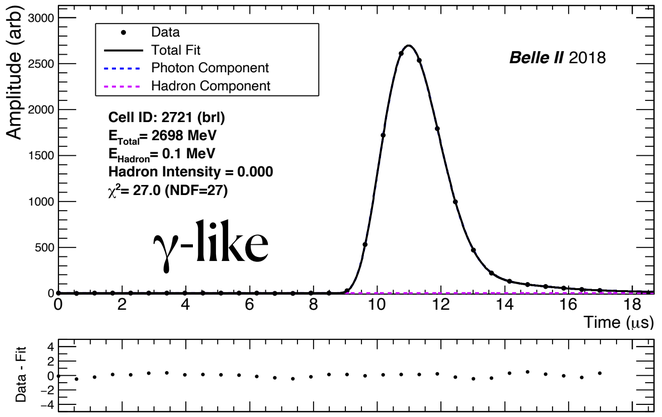
MSc: Joey Teoh; PhD: Daniel Ferlewicz, Cate MacQueen; PD: Marco Milesi

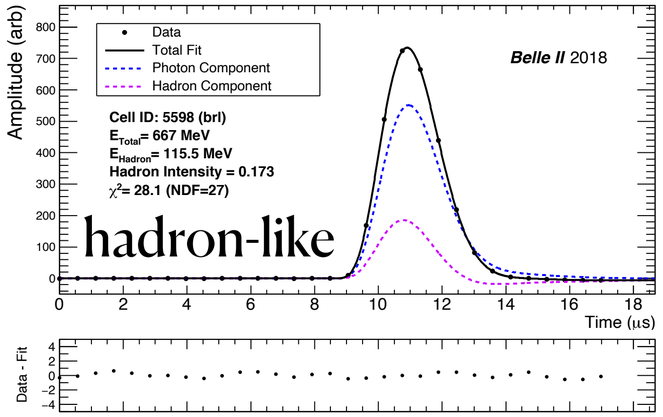


e *π*









- BDT based full detector particle ID (CDC dE/dx, TOP, ARICH, ECL, KLM). **Focus on CsI(Tl)** crystal calorimeter inputs including shower shape, longitudinal information, and **PSD (new, under testing)**.
- Manage lepton ID and systematic uncertainty measurements for all analyses with leptons.

Conclusion

- SABRE
- Background
- Belle II
- Particle ID R&D