$D \to K^+K^-\pi^+\pi^-$ analysis at BESIII and TORCH testbeam work

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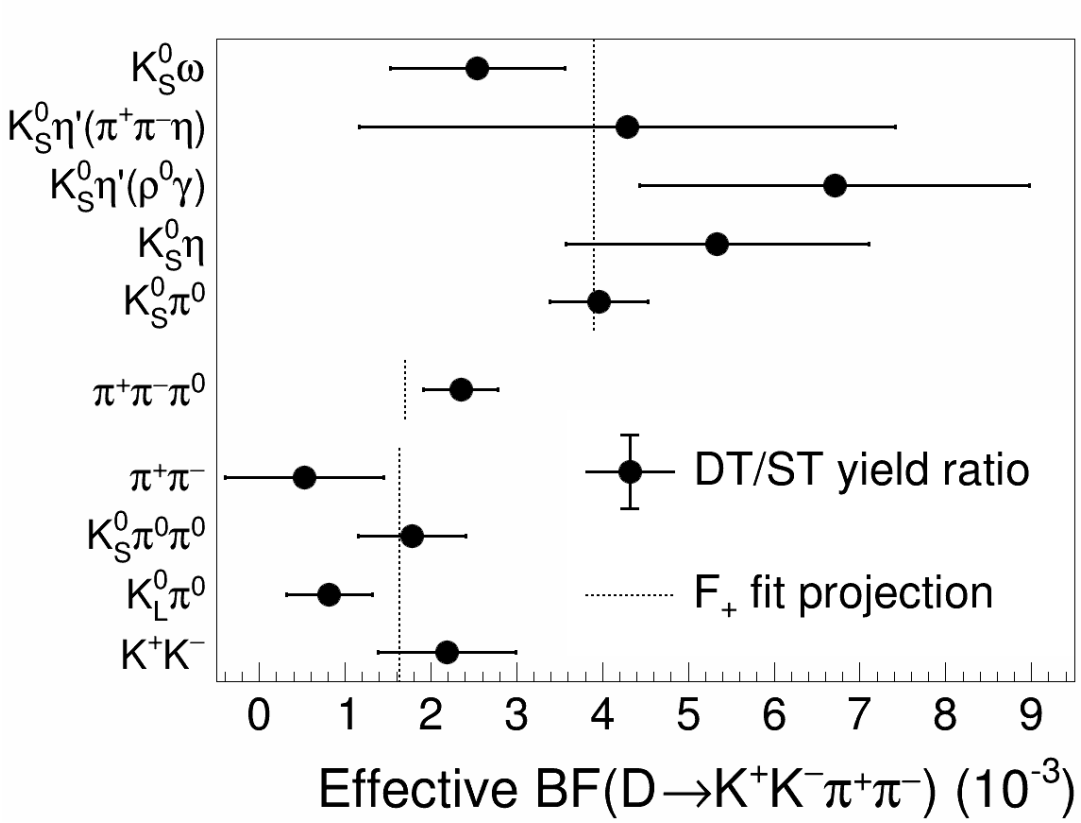
Introduction

I just finished my Confirmation of Status report, and I came up with the following thesis plan:

- ✔ LHCb: Measurement of γ in $B^{\pm} \to [K^+K^-\pi^+\pi^-]_D h^{\pm}$
- ✔ BESIII: Inclusive strong phase analysis of $D^0 \to K^+K^-\pi^+\pi^-$
- ✍ BESIII: Binned strong phase analysis of $D^0 \to K^+K^-\pi^+\pi^-$
  - Plan to work on this in HT23 and TT23
- ✍ TORCH: November 2022 testbeam and PID studies
  - Will hopefully start PID analysis while BESIII analyis is in review

Recap of phase space inclusive measurement



$$\frac{N^{\mathrm{DT}}(KK\pi\pi|f)}{N^{\mathrm{ST}}(f)} \times \frac{\epsilon^{\mathrm{ST}}(f)}{\epsilon^{\mathrm{DT}}(KK\pi\pi|f)} = \mathcal{B}(KK\pi\pi)\Big(1-(2F_+-1)(2F_+^f-1)\Big)$$

Count ST and DT yields and fit, with F_+ and $\mathcal{B}(KK\pi\pi)$ as free parameters

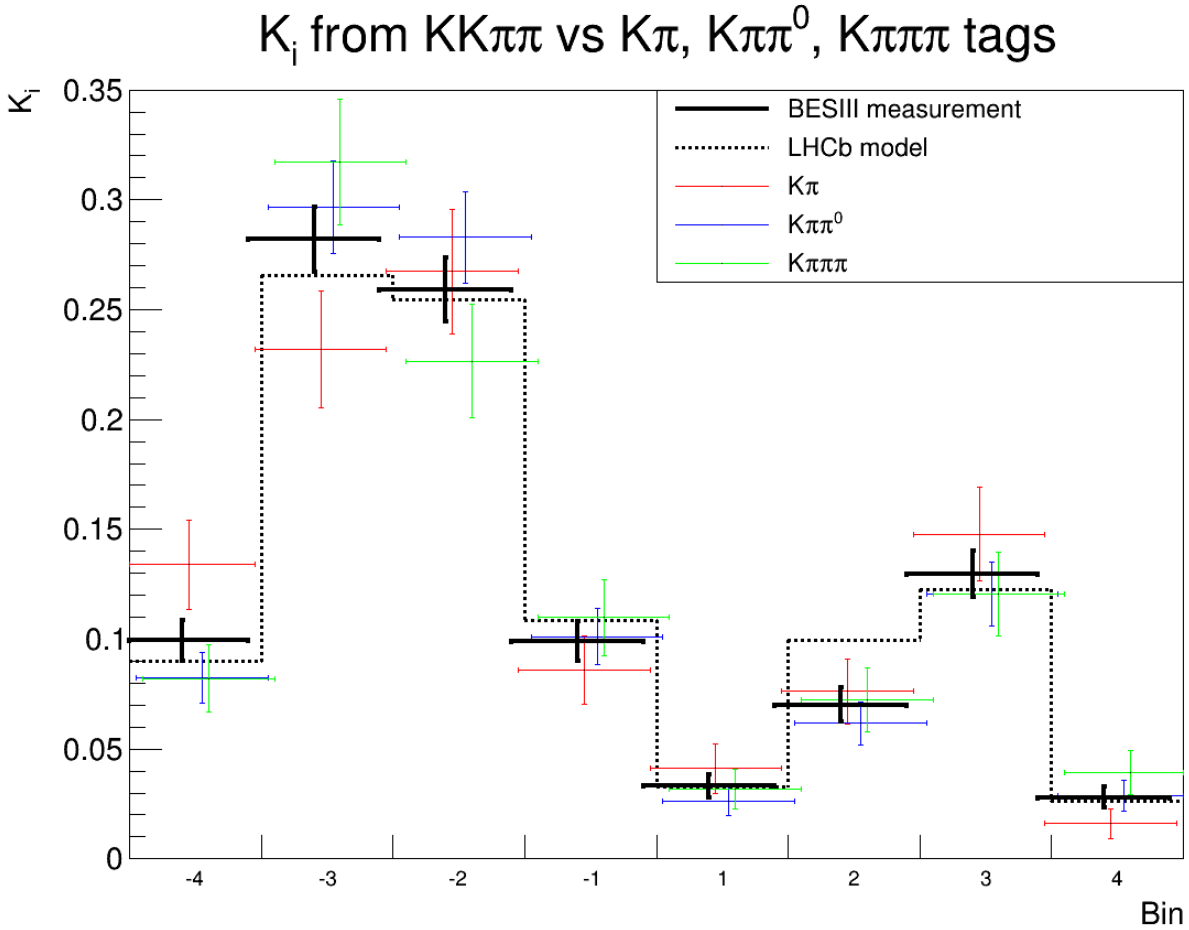
Formalism for binned phase space measurement

Equation for binned analysis is analogous, but more complicated

$$\frac{N_i^{\mathrm{DT}}(KK\pi\pi|f)}{N^{\mathrm{ST}}(f)} \times \frac{\epsilon^{\mathrm{ST}}(f)}{\epsilon^{\mathrm{DT}}(KK\pi\pi|f)} = \mathcal{B}(KK\pi\pi)\left(K_i + K_{-i} - 2\sqrt{K_i K_{-i}}(2F_+^f - 1)c_i\right)$$

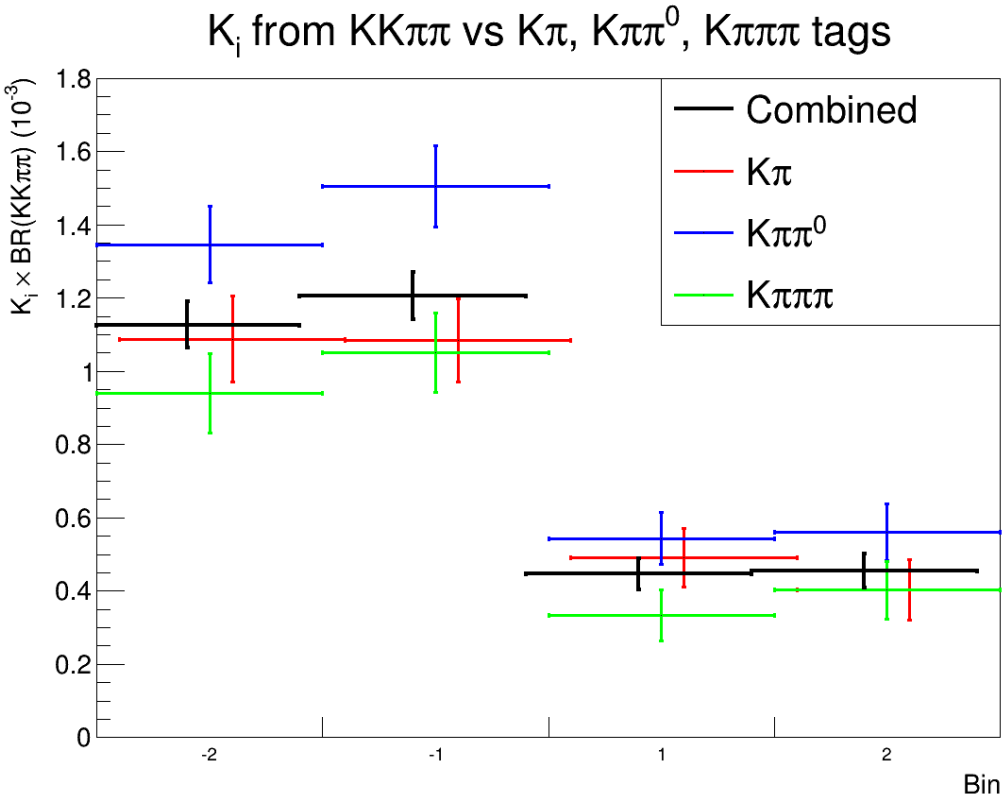
- i labels the phase space bin
- K_i is the fractional bin yield
- c_i is the amplitude averaged cosine of the strong phase
  - For a single bin, $c_i = 2F_+ - 1$
- Binning scheme:
  1. Preliminary studies with $3\,\mathrm{fb}^{-1}$ dataset: 2×2 bins
  2. Analysis for thesis with $8\,\mathrm{fb}^{-1}$ dataset: 2×4 bins
  3. Future analysis with $20\,\mathrm{fb}^{-1}$ dataset: 2×8 bins

Measurement of K_i



- Old plot shown in charm WG last year
- Cross check between BESIII data and LHCb model
- Normalised bin yields show good bin-to-bin agreement

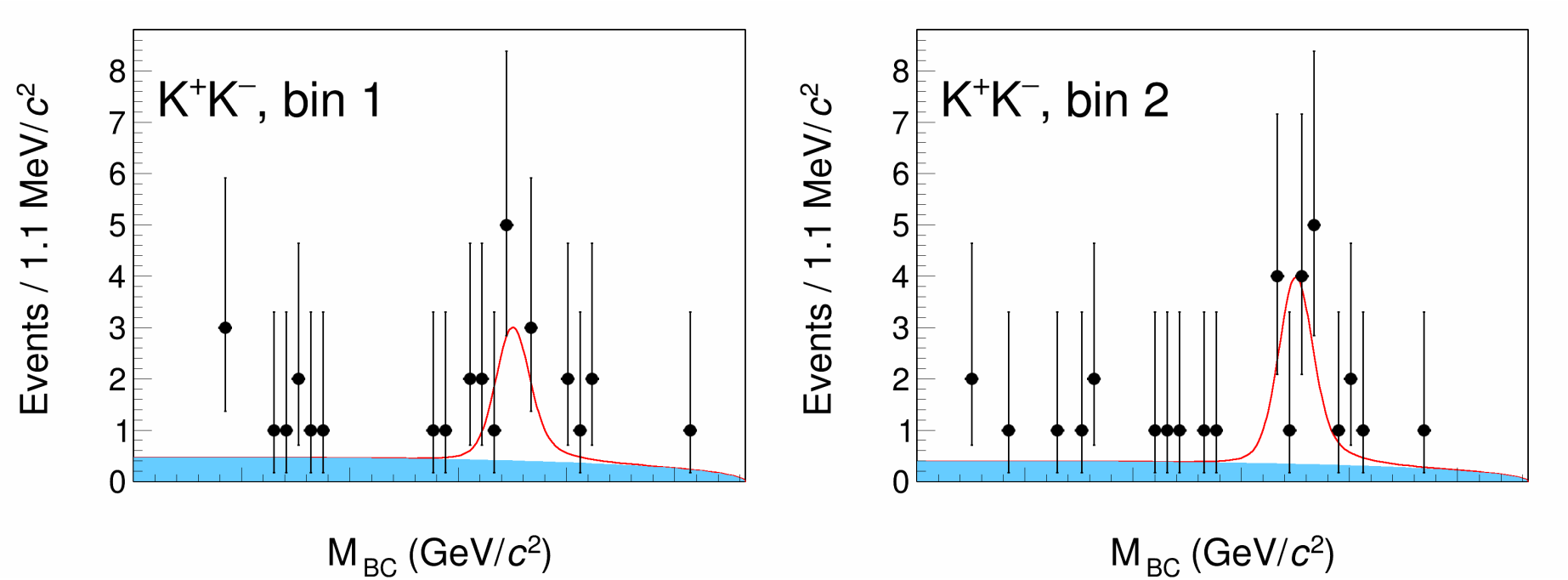
Measurement of K_i



- Redone measurement with reduced 2×2 binning scheme
- This time, I'm looking at the absolute DT to ST yield
- K_i from $K\pi\pi\pi^0$ yields are all larger than $K\pi$ and $K\pi\pi\pi$ tags – systematic effect in π^0 modelling...?
- Not really an issue, just let $\mathcal{B}(KK\pi\pi)$ float in the fit

Fit yield of some CP tags

Do simultaneous double tag yield fit of CP tags

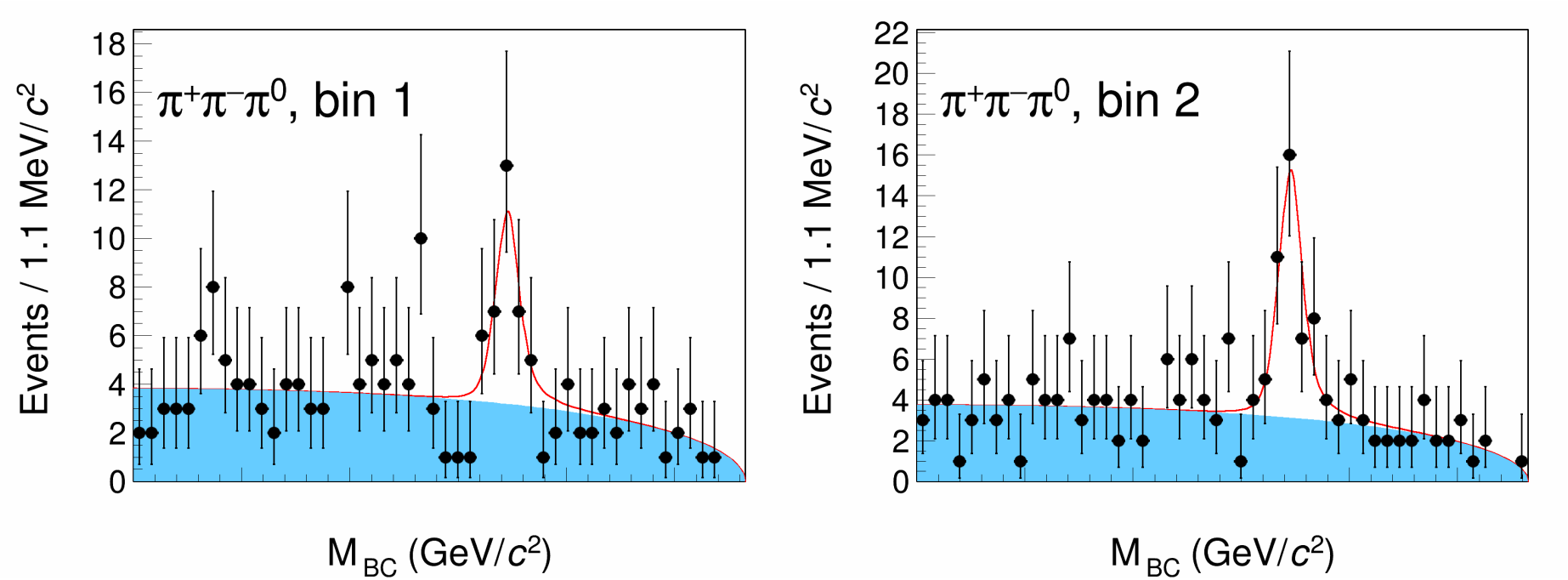


(a) $10.2^{+6.7}_{-3.9}$ **(b)** $14.4^{+4.8}_{-4.1}$

Figure 1: $KK\pi\pi$ vs KK

Fit yield of some CP tags

Do simultaneous double tag yield fit of CP tags

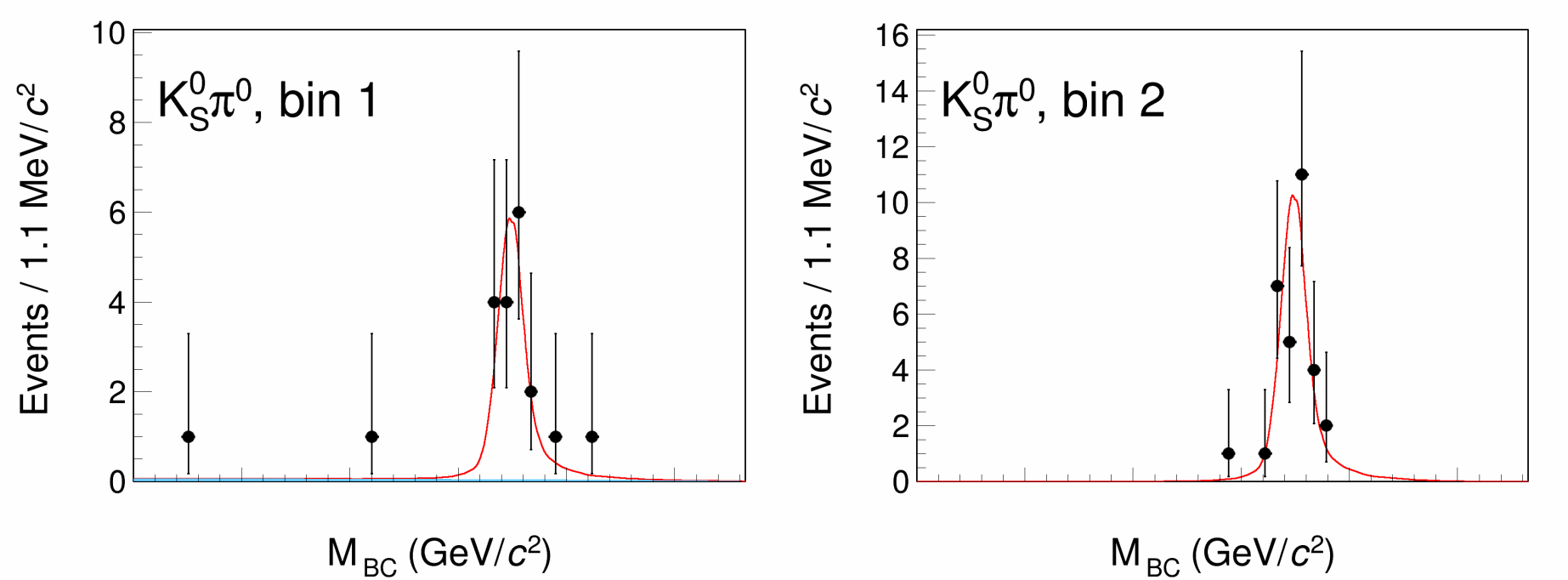


(a) $22.3^{+6.9}_{-6.2}$ **(b)** $34.2^{+8.0}_{-7.3}$

Figure 2: $KK\pi\pi$ vs $\pi\pi\pi^0$

Fit yield of some CP tags

Do simultaneous double tag yield fit of CP tags



(a) $17.6^{+4.6}_{-3.9}$ **(b)** $31.0^{+5.9}_{-5.2}$

Figure 3: $KK\pi\pi$ vs $K_S\pi^0$

Maximum likelihood fit of c_i

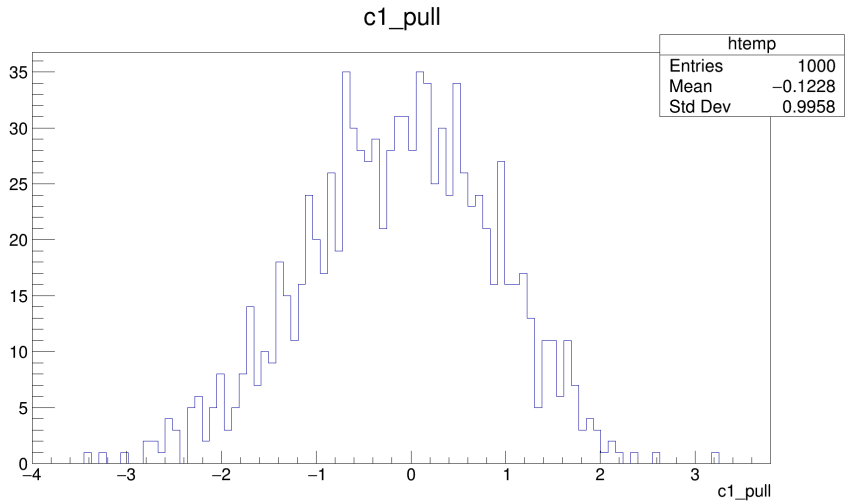
I have also worked on the maximum likelihood fit of c_i (and s_i)

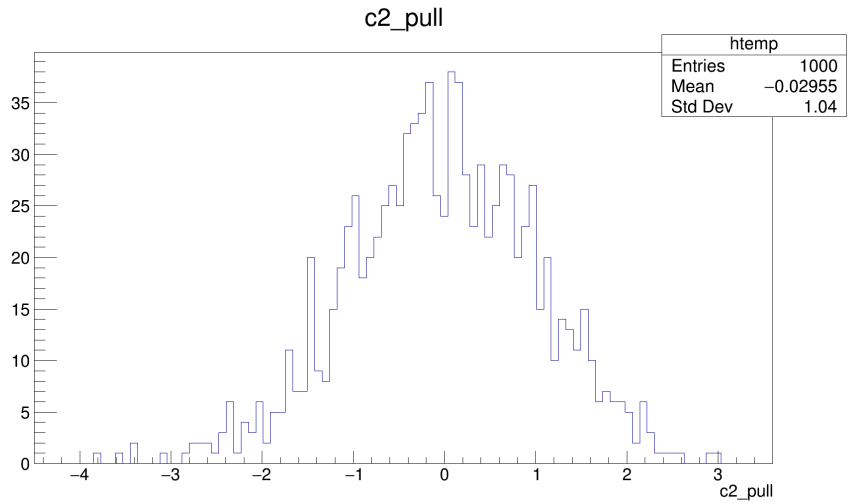
$$\begin{aligned}\mathcal{L} =& [V^{-1}]_{ij}(N_i - \hat{N}_i)(N_j - \hat{N}_j) \\ V_{ij} =& \rho_{ij}\sigma_i(N_i - \hat{N}_i)\sigma_j(N_j - \hat{N}_j) \\ \sigma(N - \hat{N}) =& \sqrt{\sigma_+\sigma_- + (\sigma_+ - \sigma_-)(N - \hat{N})}\end{aligned}$$

- N are the double tag yields measured in data
- $\hat{N}$ are the predicted double tag yields from the value of c_i (and s_i)
- The linear extrapolation of the covariance V is ideal for this analysis because of the asymmetric uncertainties in bins with low yields

Let's do some toys!

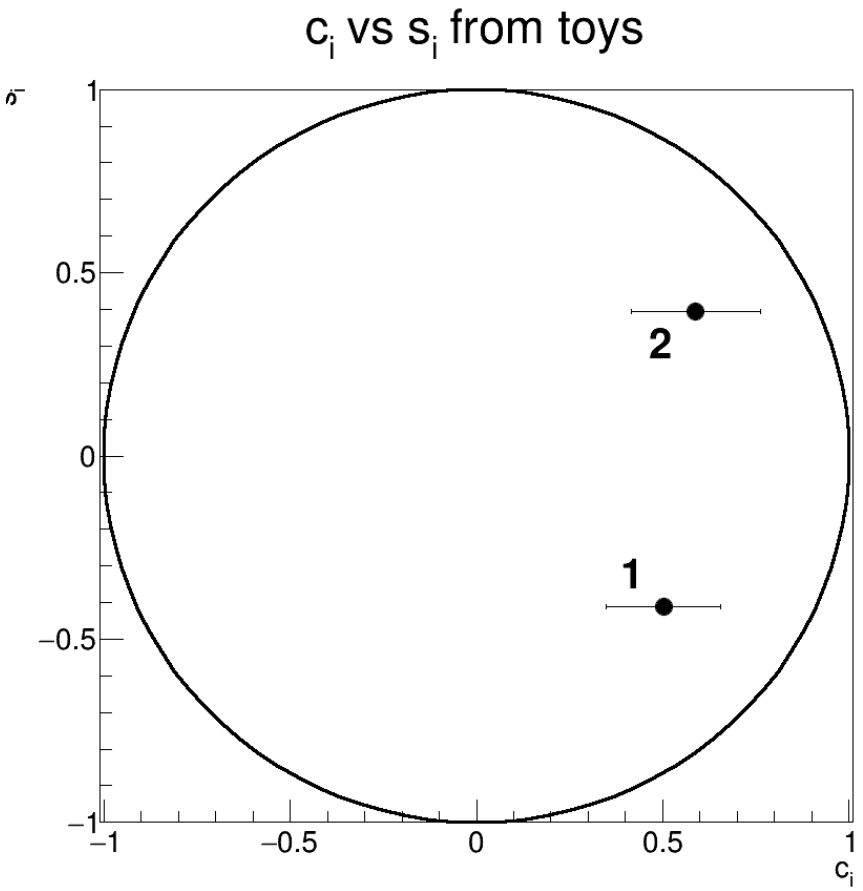
Pulls for fit with KK, $\pi\pi\pi^0$ and $K_S\pi^0$ tags





Bias in c_1 is likely because of low statistics, no bias seen in c_2

Let's do some toys!



- Expect these uncertainties to improve with the full $8\,\text{fb}^{-1}$ dataset
- Will also improve with additional fully and partially reconstructed $KK\pi\pi$ vs CP tags
- Should be sufficient statistics to do a fit with 2×4 bins

TORCH November 2022 testbeam overview

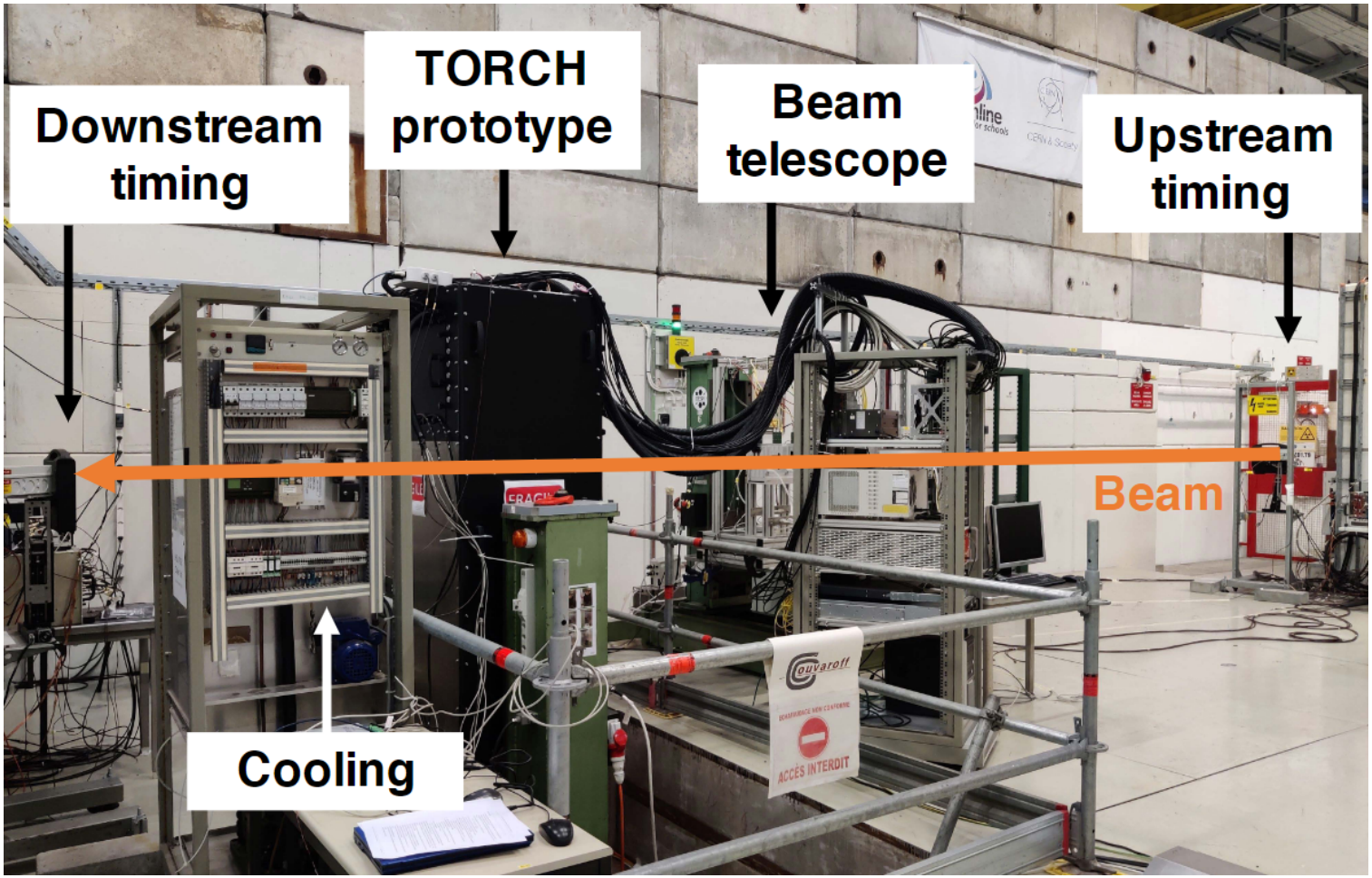


Figure 5: From Jenny's presentation 5th December

31st October – 28th November 2022 at T9 PS Testbeam zone

Brief description of setup

TORCH testbeam relies on the following components:

1. Beam information – provided by the beam physicists at T9
   - Large scintillators S0 and S1 to detect beam
   - Cherenkov counters C0 and C1 to separate pions and protons
2. TORCH – measure timing and Cherenkov angle of emitted photons
3. Trigger – take data when a track hits TORCH
   - Small crossed scintillators at each timing station
4. Timing stations – measure T_0 of the incident track
   - Borosilicate fingers called F1 and F2
5. Beam telescope – measure track incident position (won't cover this)
6. Cooling – should be obvious (won't cover this)

Week 1: Timing with (ancient) NIM modules

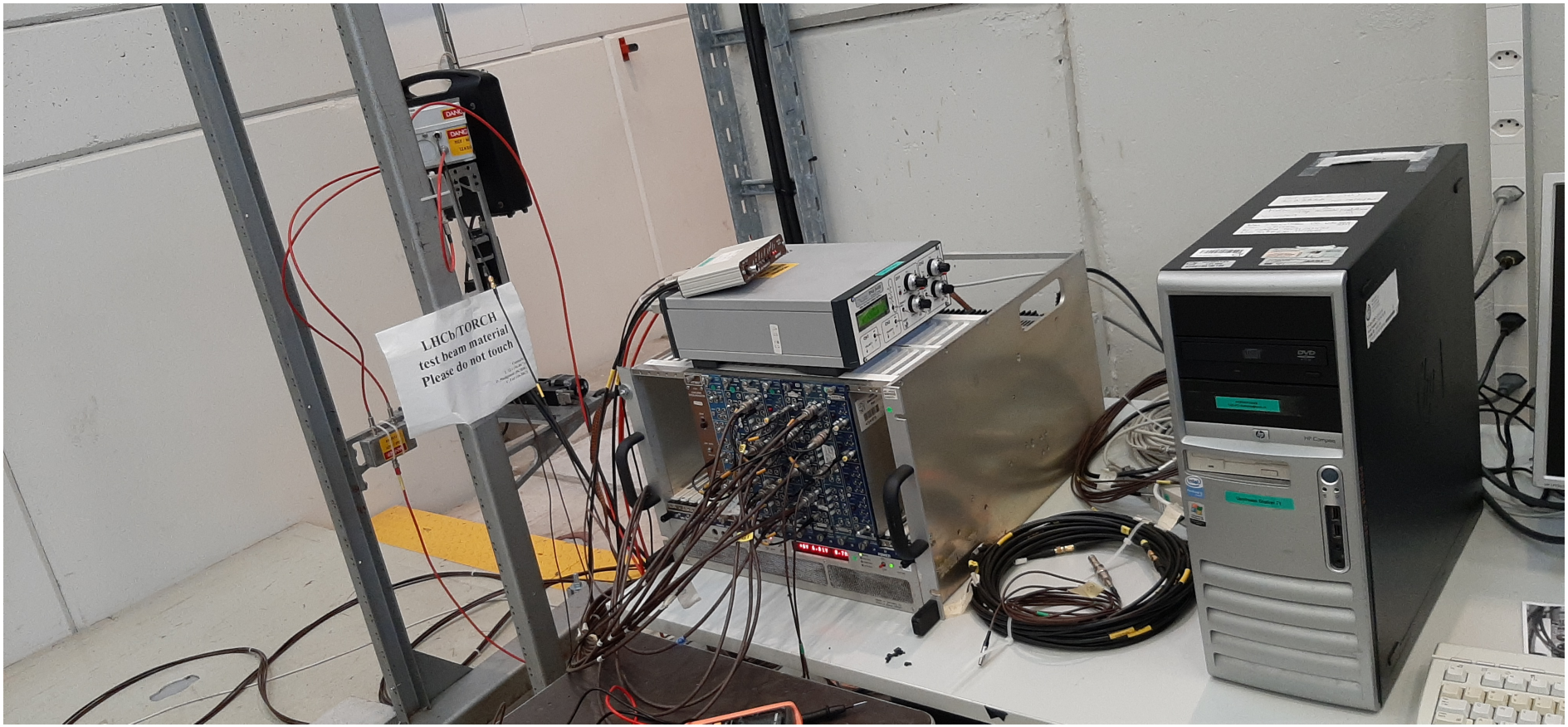


Figure 6: Timing station T1 (upstream) overview

Week 1: Timing with (ancient) NIM modules

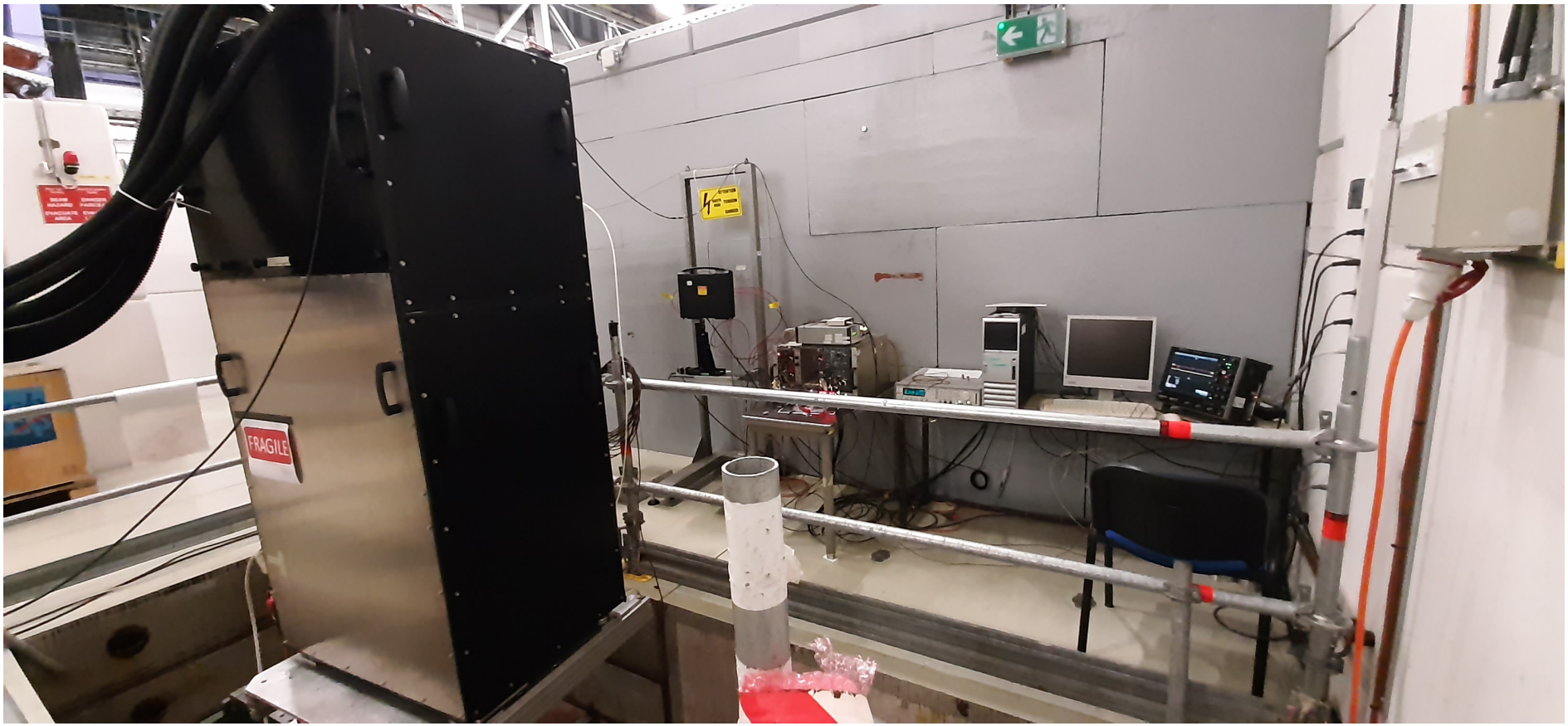


Figure 7: Timing station T2 (downstream) overview

Week 1: Timing with (ancient) NIM modules

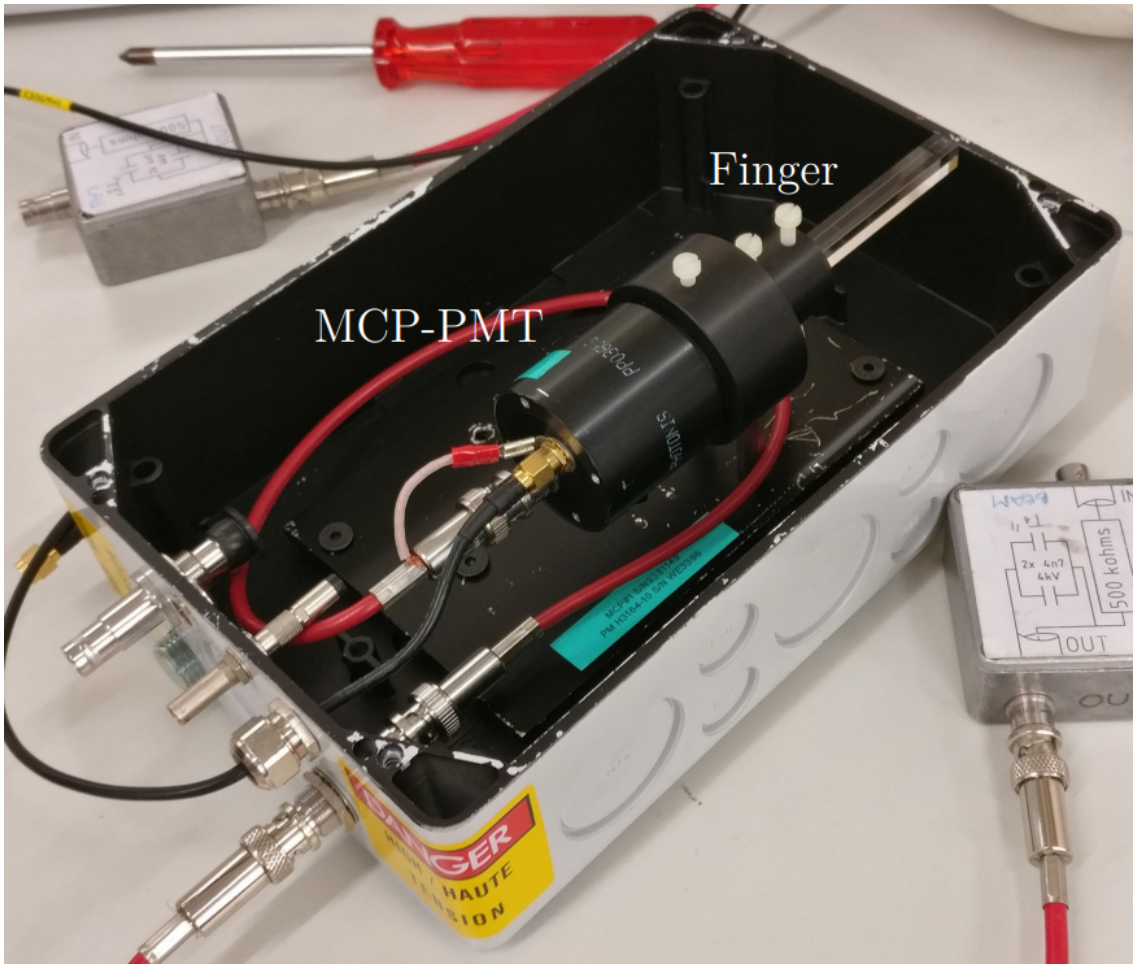


Figure 8: From Thomas Hancock's PhD thesis

Week 1: Timing with (ancient) NIM modules

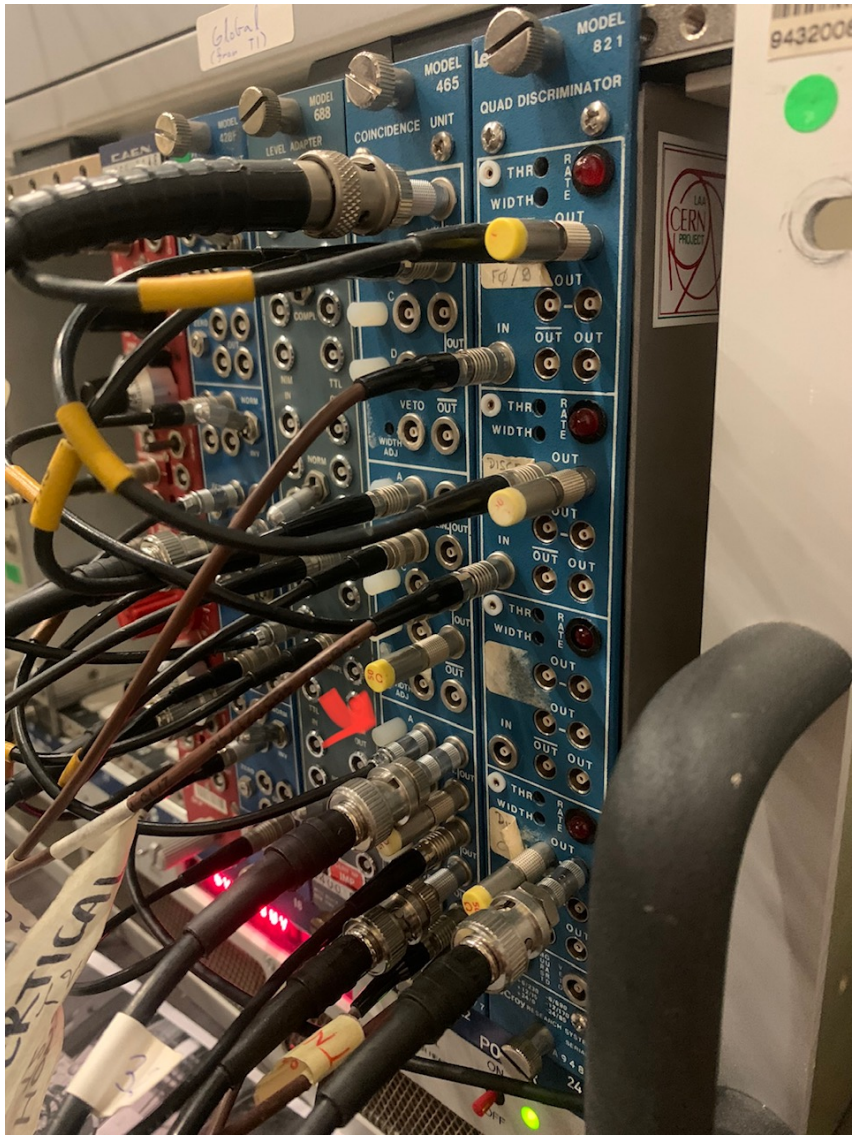


Figure 9: Messy cabling

Week 1: Timing with (ancient) NIM modules

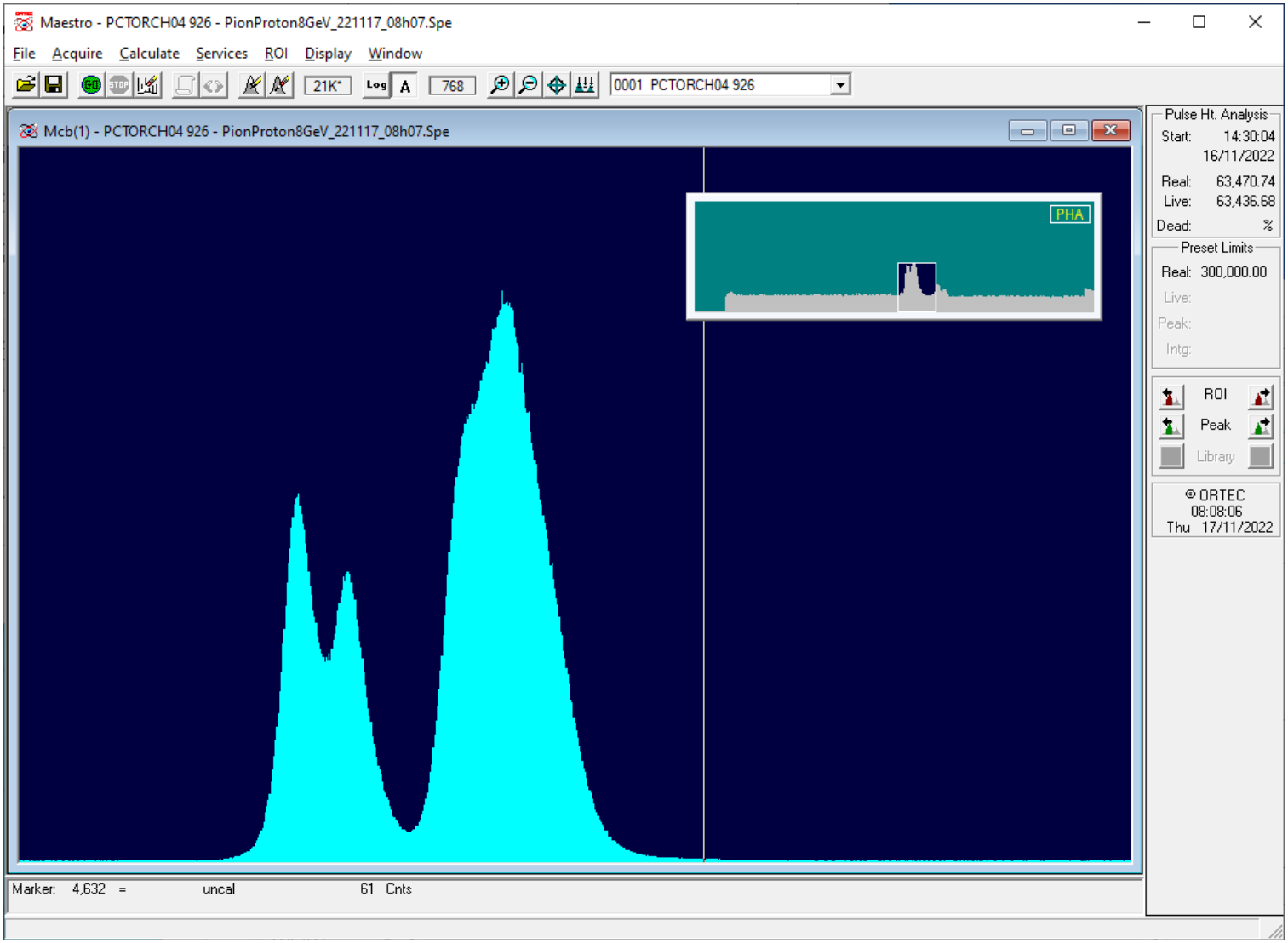


Figure 10: Timing histogram from F1 and F2, with a 6.3 ps bin size

Week 2: TORCH arrives the zone

Figure 11: TORCH was transported horizontally

Week 2: TORCH arrives the zone

Figure 12: A crane and a forklift turns TORCH vertically

Week 2: TORCH arrives the zone

Figure 13: TORCH is ready to be lifted into the zone

Week 2: TORCH arrives the zone

Figure 14: TORCH at its highest point

Week 2: TORCH arrives the zone

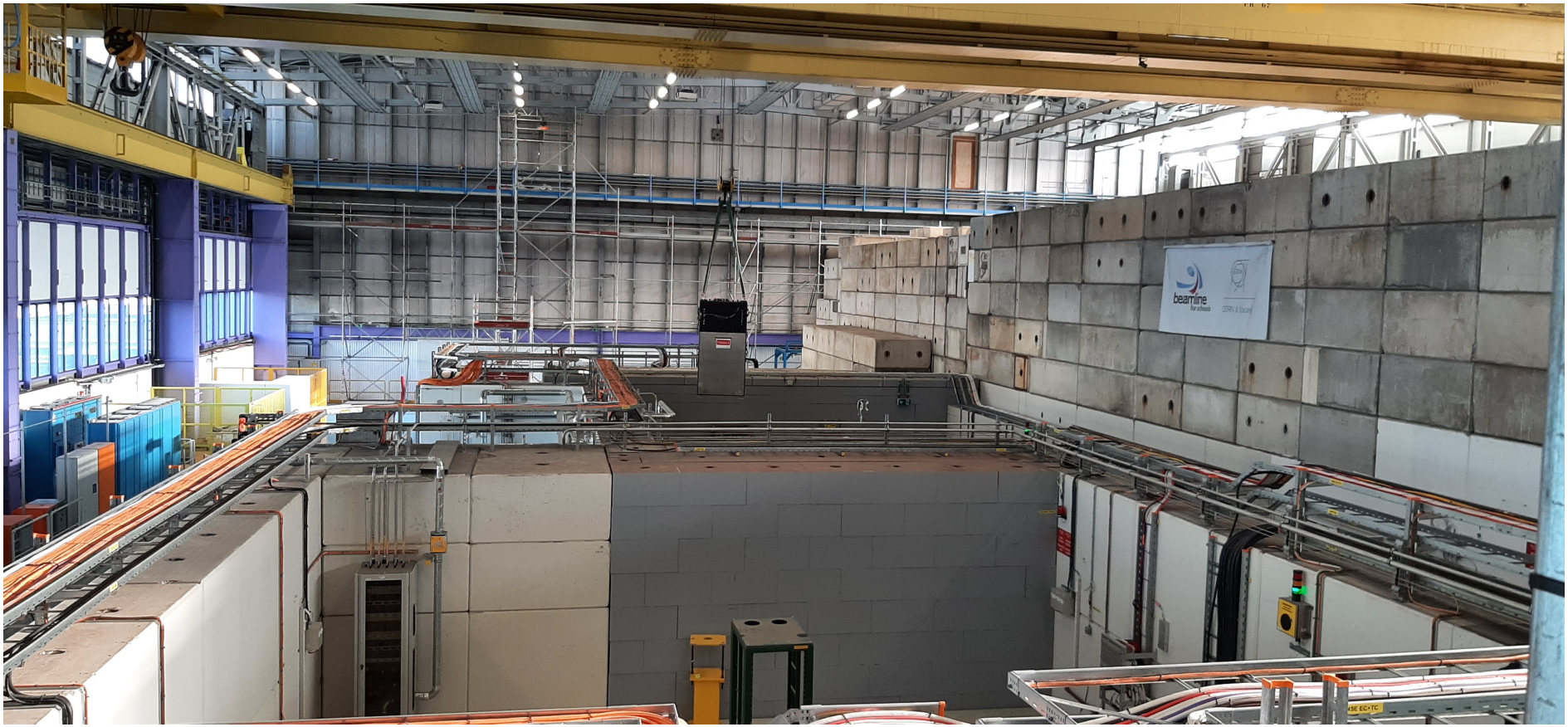


Figure 15: TORCH is then lowered into the zone

Week 2: TORCH arrives the zone

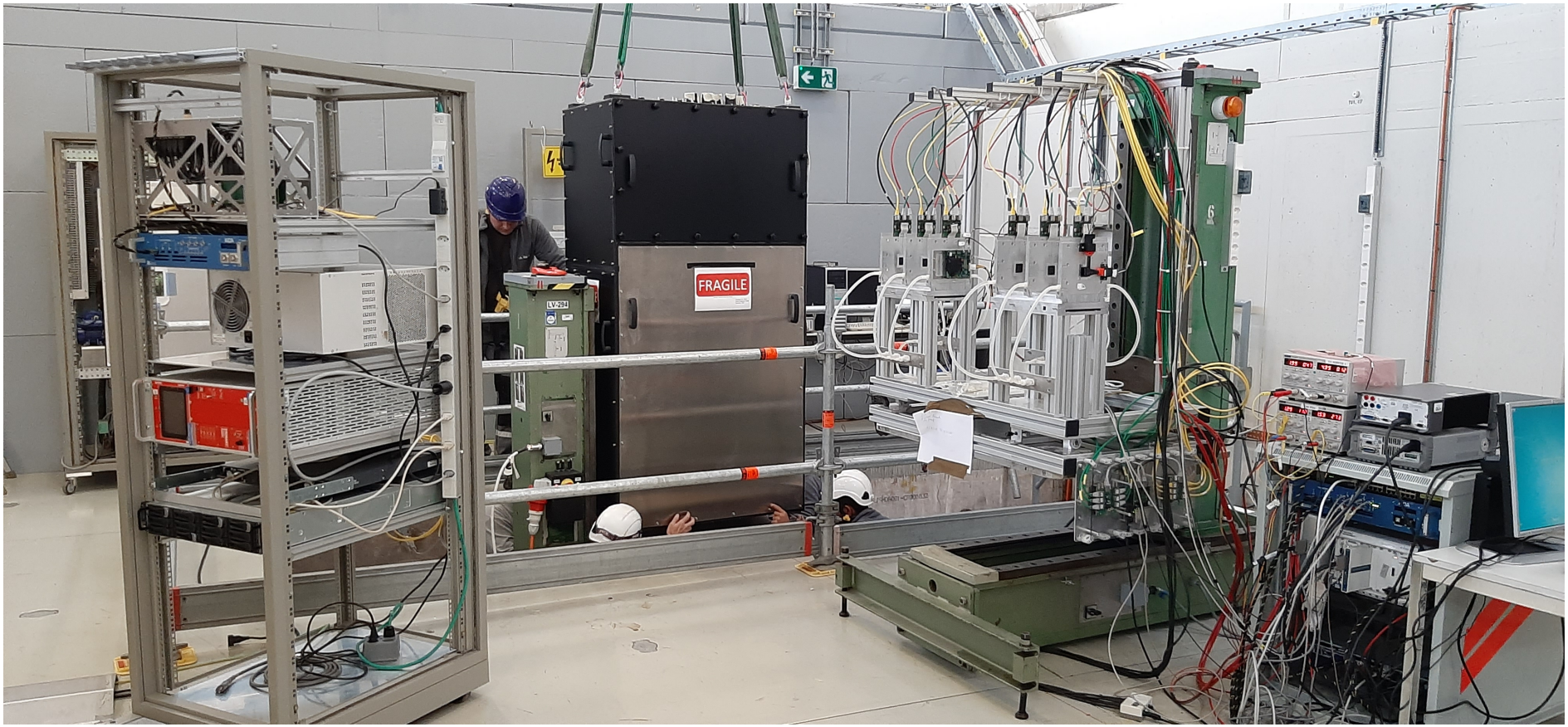


Figure 16: TORCH is safely on the DESY table

Week 2: TORCH arrives the zone

Figure 17: TORCH and the beam telescope, with full cabling and cooling

Week 2: TORCH arrives the zone

Figure 18: DESY table at its highest setting (1 m)

Summary and next steps

- BESIII measurement of c_i and s_i is in the early stages
  - Selection will be almost identical with the recent F_+ measurement
  - Initial toy studies show that c_i fits work
  - Next steps:
    1. Properly calculate bin efficiency/migration by training individual reweighters for each phase space bin
    2. Add selection of partially reconstructed $D \to KK\pi\pi$ vs CP tags
    3. Add the remaining 7 CP tags and $K_{S,L}\pi\pi$ tags
    4. Aim to start charm WG review by end of TT23
- TORCH testbeam done and PID studies will start soon
  - I was involved with setting up trigger and time reference stations
  - Next steps:
    1. Initial studies and cross checks of November 2022 testbeam data
    2. Long term aim is to demonstrate PID separation power directly

Thank you for listening!