Near Detector Samples in MaCh3

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Why do we need ND samples?

How Do Long-baseline Analyses Work?

$$N(\text{Observables}) = \int \text{Flux}(E_\nu, \text{time}) \times \text{Interaction prob}(E_\nu, \text{final state}) \times \text{Detector Efficiency}(\text{final state}) \times \text{Osc}(E_\nu)$$

- We have a **large number of events (ND + FD)** at DUNE - need to **constrain our systematics**
- How do we do that? **Near Detector! O(100 million), no oscillations!**
- Far detector has **far fewer** events and **oscillations** -> apply systematic constraints

Why is this difficult?

- Systematic model needs to be **complex** - **extrapolating between very precise ND complex ➢ huge FD with different systematic uncertainties**
  - **True energy -> reco energy map** key to extracting true parameter values
- Simplified model will cause **bias/over-constraints**
- Uncertainties are degenerate with each other
- ND data will pin down each systematic -> encountered by **Technical Design Report (TDR) analysis**

Toy Example:

- **Systematic X** applies to **ND and FD events**

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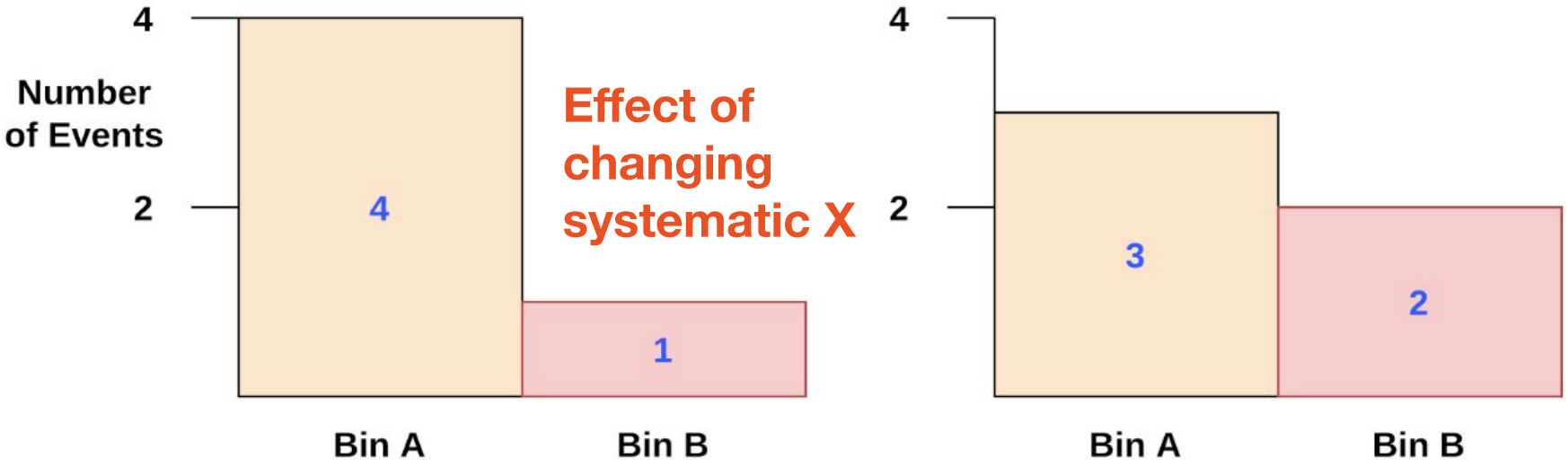

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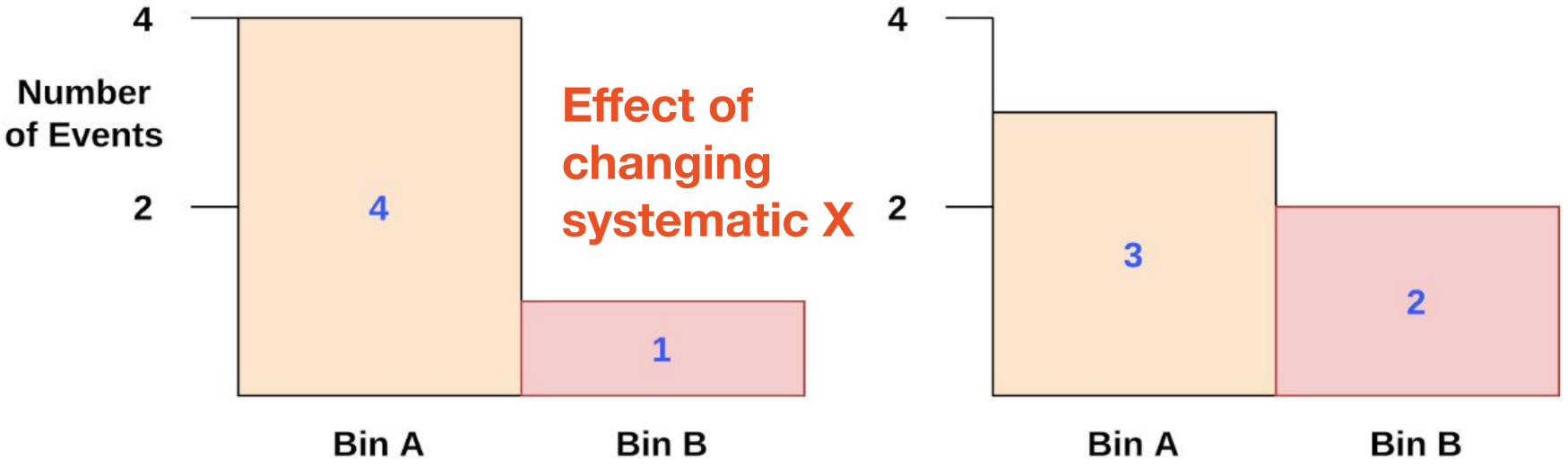

ND will work out exact value of systematic X!

Toy Example:

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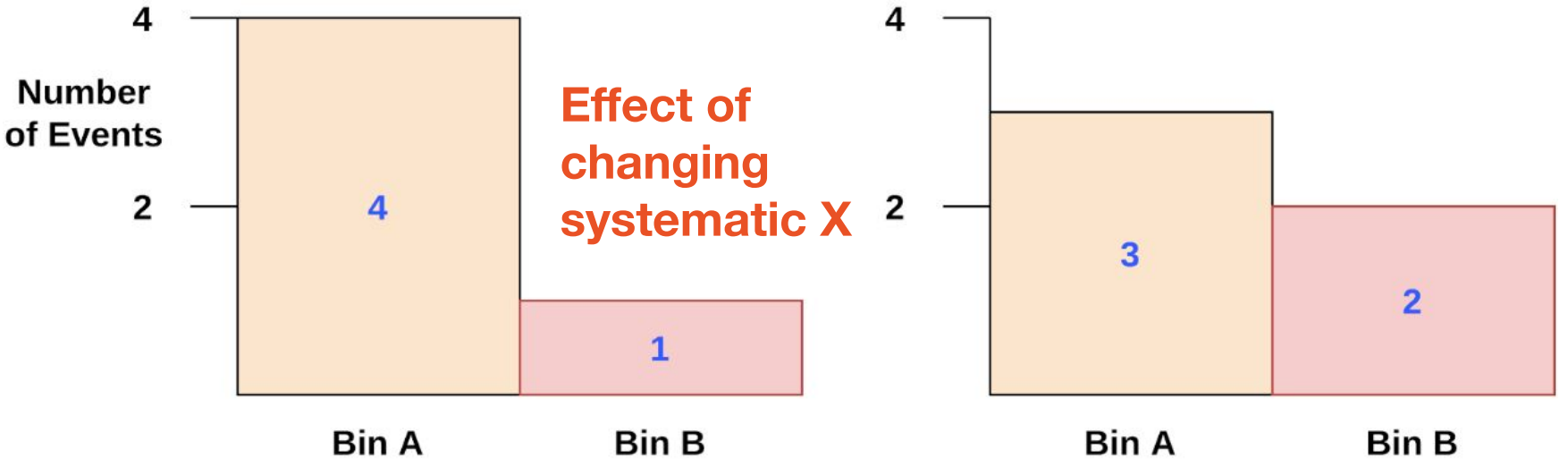


ND will work out exact value of systematic X!

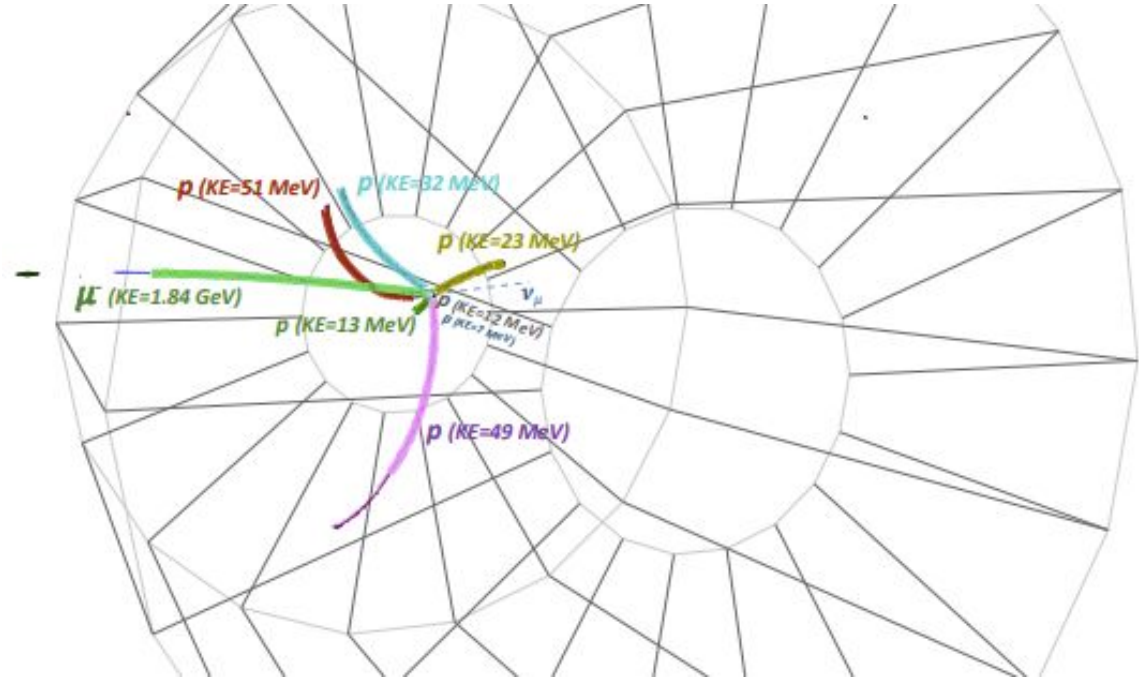
- Add **systematic Y** which **only affects ND** also **shifts events from A->B** = **degeneracy**
- Now ND **can't work out value of systematic X**

Why add ND-GAr Samples?

- ND-GAr is designed to **reconstruct low-energy final states that ND-LAr would miss**

- Adding these samples will help **constrain interaction systematics** that currently **dominate uncertainty** in LBL experiments
    - Also **at low energies** these models have **significant shape differences** that ND-GAr can reconstruct

- And now we need to get these samples into an analysis to **prove the effect it has on interaction uncertainties**



So what do we need to do this?

- Realistically **simulated** and **reconstructed** events
  - There's no point if our samples don't reflect the performance of ND-GAr

- Accurate detector systematics for **BOTH ND-LAr and ND-GAr**
  - Realistic **uncertainties on reconstructed energy** for both detectors so we can see the effect of ND-GAr
  - Sophisticated enough that **degeneracies prevent ND data from pinning them down**

- We need a **sophisticated cross-section model**
  - Complex enough that there are **degeneracies that ND-LAr can't constraint that ND-GAr can**

How do the samples get implemented in MaCh3?

CAF Formatting and Selection Cuts

- CAF files need to be formatted before being read into MaCh3
- Split CAFs by:
  - FHC/RHC
  - True oscillation channel (e.g. numu -> numu)
- Sample selection can be done within MaCh3
  - Events outside cut can also be removed prior to save on loading memory
- CAFs also need to be POT normalised before applying a given exposure

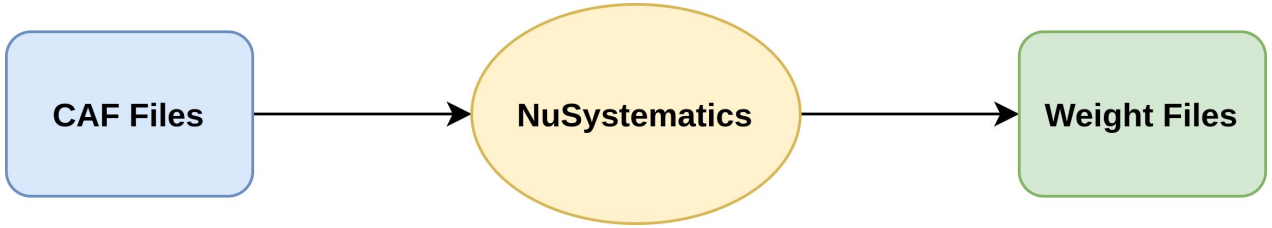
Flux Systematic Implementation

- DUNE flux systematics are implemented as normalisation parameters directly from an xml configuration file
    - Kinematic ranges and events can be specified

```
<parameter name="b_0" nom="1" prior="1" lb="-9999" ub="9999" error="0.125273361158" renorm="0" type="norm" detid="1" stepscale="0.3">
  <correlation par="b_0">1.0</correlation>
  <correlation par="b_1">0.907000866856</correlation>
  <correlation par="b_2">0.771384178567</correlation>
  <correlation par="b_3">0.668384954479</correlation>
  <correlation par="b_4">0.614799452504</correlation>
  <correlation par="b_5">0.561344023656</correlation>
  <correlation par="b_6">0.487473466558</correlation>
  <correlation par="b_7">0.415728929742</correlation>
  <correlation par="b_8">0.369395794412</correlation>
  <correlation par="b_9">0.332358668703</correlation>
  <correlation par="b_10">0.302496952533</correlation>
  <correlation par="b_11">0.334619054654</correlation>
  <correlation par="b_12">0.383126438258</correlation>
  <correlation par="b_13">0.353606585102</correlation>
```

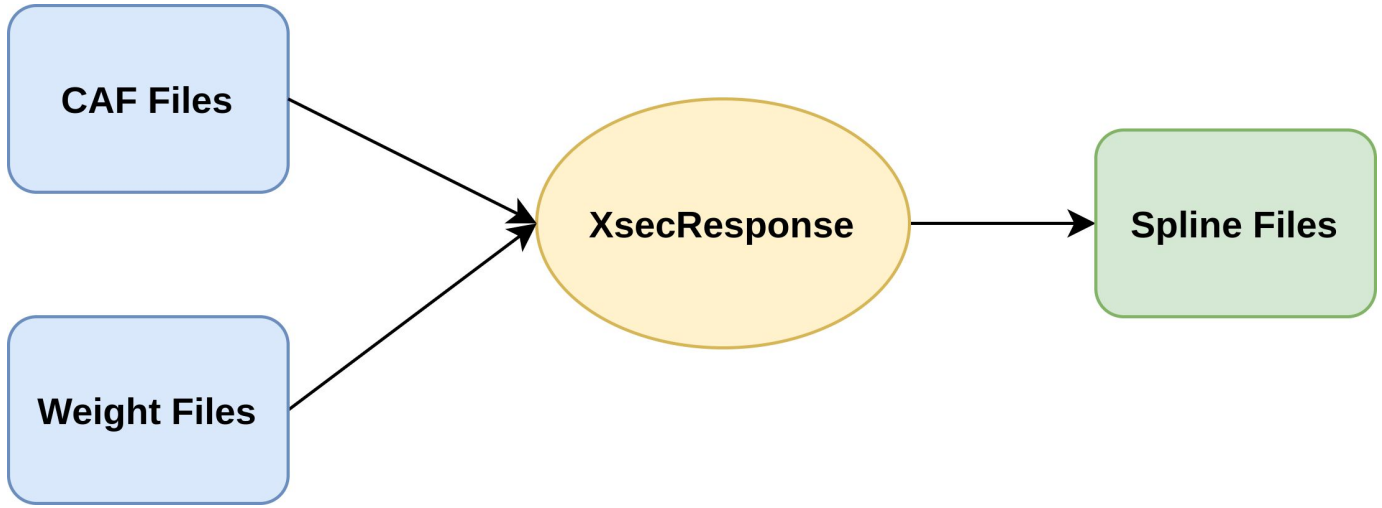
Xsec Systematic Implementation: NuSystematics

- NuSystematics interacts with GENIE to return systematic weights for a given event
- DUNE TDR analysis uses event-by-event weights from CAFs to produce binned response functions during the fit
    - NuSystematics is interfaced with LarSoft files to produce CAF files with weights
- MaCh3 requires response functions independent from data mtuples for reweighting information
    - Weight files are generated using CAF files with GenieEvent records without need for Larsoft



Xsec Systematic Implementation: XsecResponse

- XsecResponse is a T2K program which produces spline files from mtuples and systematic weights files
- Repurposed for DUNE CAFs and weights and added to the DUNE Github organisation
- DUNE weight files are interfaced with XsecResponse program to produce spline files in MaCh3 format



Detector Systematic Implementation

- Detector systematics could be implemented as **shift parameters**

- Change the value of reconstructed event variables during the fit -> if they cross a bin boundary then move them into the new bin
    - Binning variables and any event information that affects the binning variables need to be stored

- Can also be implemented as **spline** or **normalisation parameters**

```
if (sr->isFD) {
  if (sr->RecoHadEnNue < 0.) sr->RecoHadEnNue = 0.;
  if (sr->Ev_reco_nue < 0.) sr->Ev_reco_nue = 0.;
  sr->Ev_reco_numu  += scale * sr->RecoHadEnNumu;
  sr->Ev_reco_nue   += scale * sr->RecoHadEnNue;
```

Summary

- We need LBL studies with ND-GAr samples to prove its ability to constrain our interaction systematic model

- To do that we need:
  - Fully simulated and reconstructed samples
  - Sophisticated cross-section and systematic models for both ND-LAr and ND-GAr

- A lot of work has gone into MaCh3 to make adding samples easy and putting together the pipeline for producing systematic inputs
  - Time to use them!

Back up