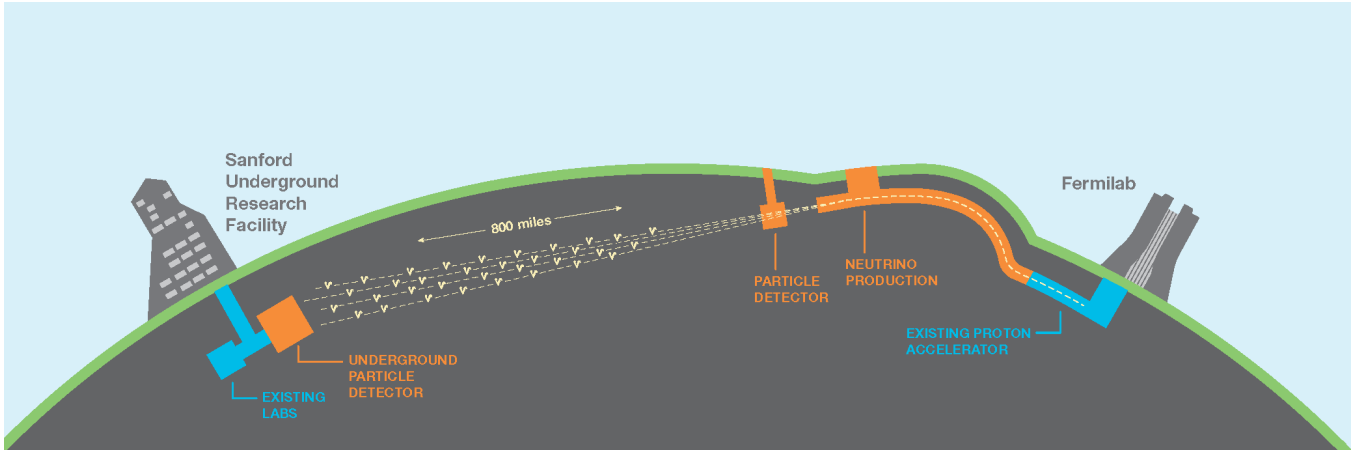

ProtoDUNE-SP: Introduction, Aims and Physics Goals

Mark Thomson

On behalf of the DUNE collaboration

ProtoDUNE-SP DAQ Review, 3rd November 2016

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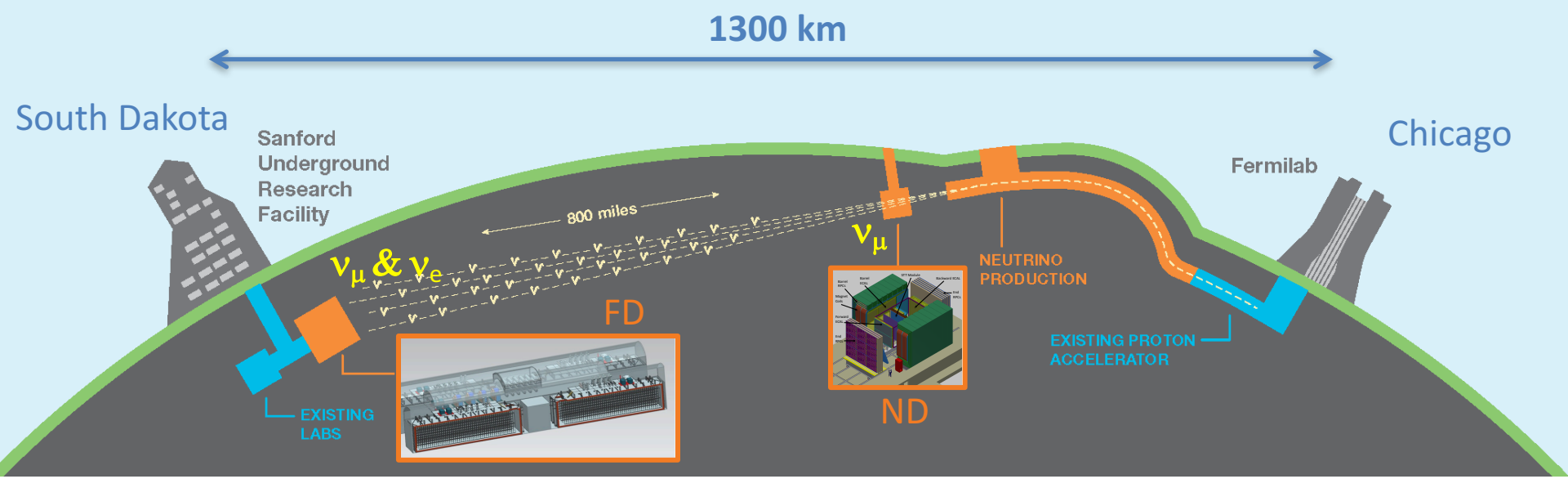
1) Introduction

★LBNF/DUNE will consist of:

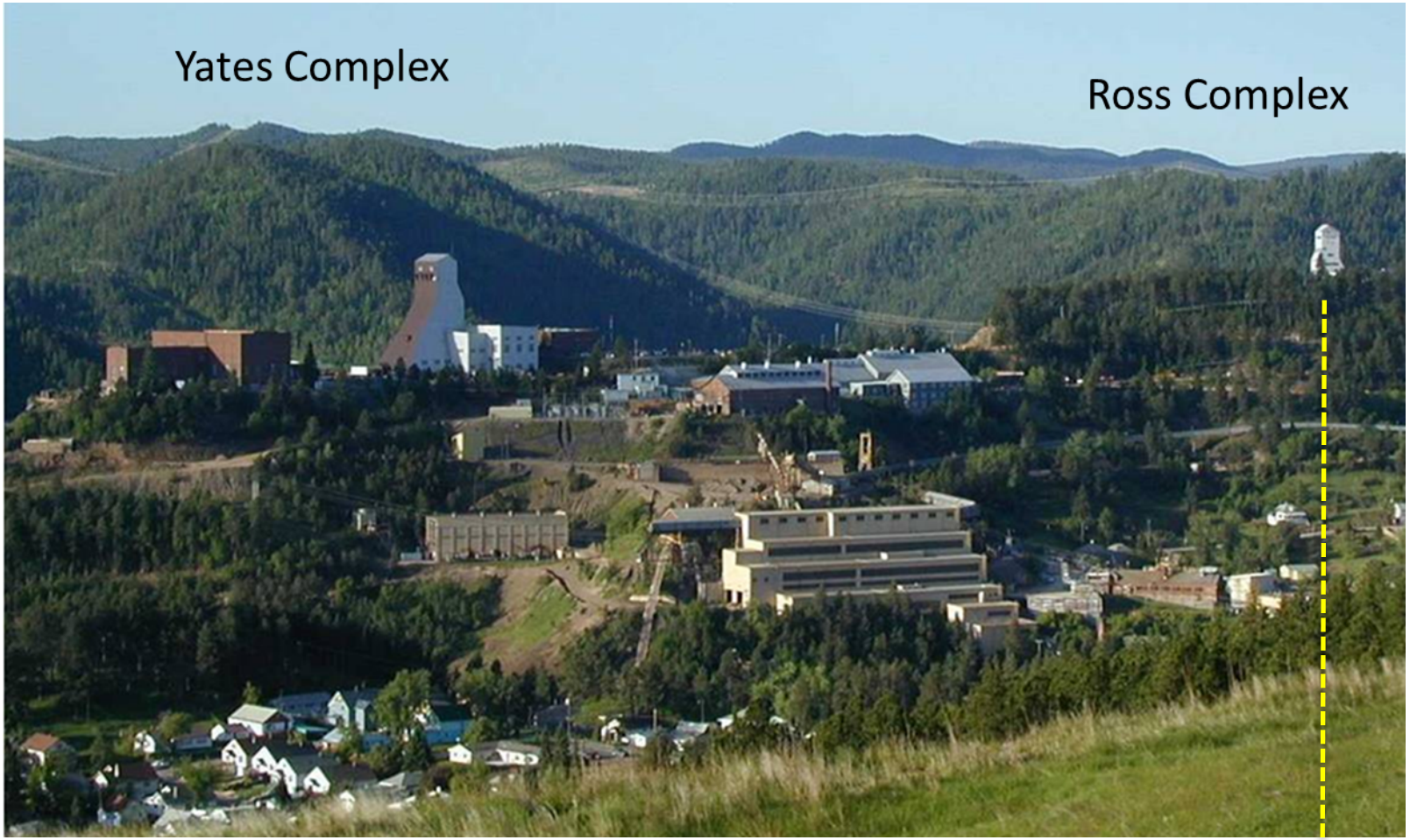
- Muon neutrinos/antineutrinos from high-power proton beam
  - **1.2 MW** from day one (upgradeable)
- Large underground **Liquid Argon Time Projection Chamber**
  - **4 x 17 kton ⇨ fiducial (useable) mass of >40 kton**
- Large near detector to characterize the beam



Medium-term goals

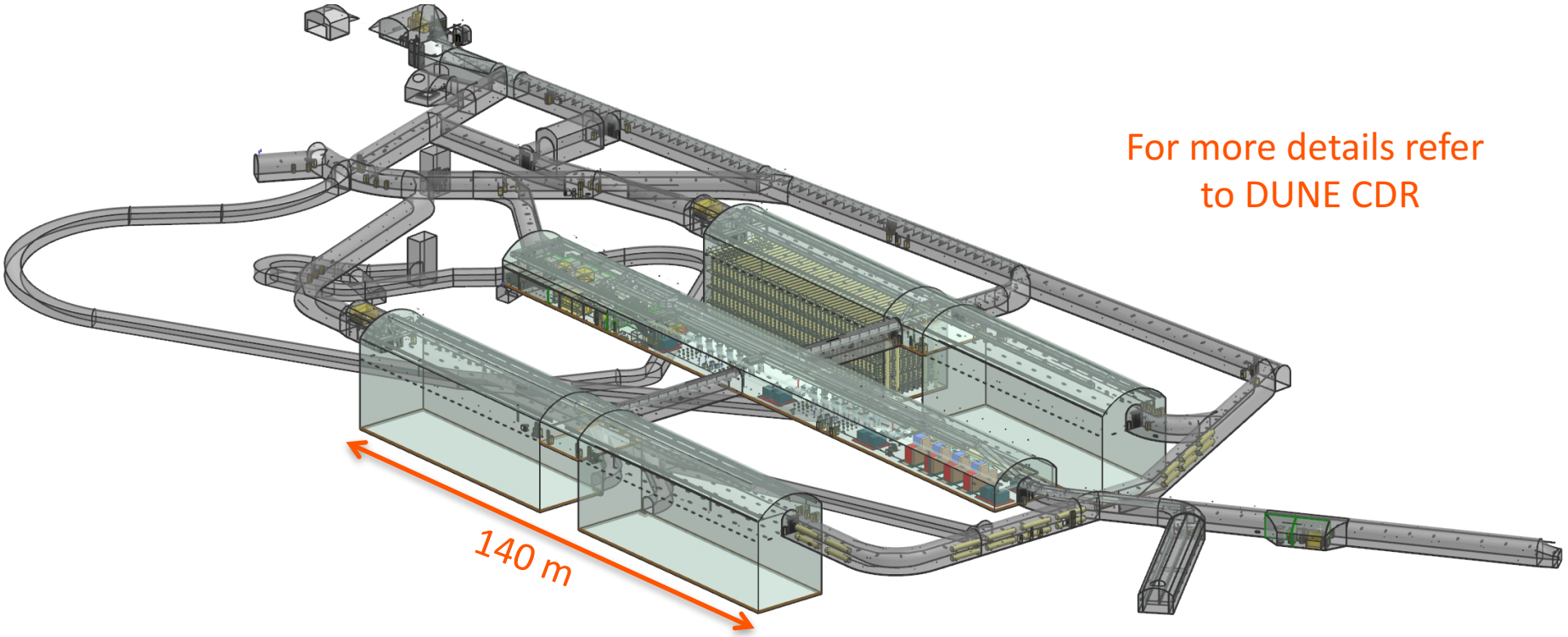
- **DUNE is committed to delivering:**
  - Two large-scale engineering prototype detectors (protoDUNE-SP and protoDUNE-DP) operational at CERN in 2018
  - DUNE TDR for the DOE CD-2 and LBNC Reviews in 2019
  - 20-kt Far Detector fiducial mass ready for beam in 2026
    - Two 10-kt detector modules (not necessarily the same design)
  - Near detector system(s) operational in time for first beam
- **The detailed implementation strategy for 2016 – 2019 was approved by DUNE-EC in June 2016**

Far Detector Strategy



Staged Approach to 40 kt (fiducial)

- **Four chambers hosting four independent 10-kt FD modules**
  - Flexibility for staging & evolution of LAr-TPC technology design
    - Assume four **identical** cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
    - Assume the four 17-kt modules will be similar but **not identical**



For more details refer to DUNE CDR

Staged Approach to 40 kt (fiducial)

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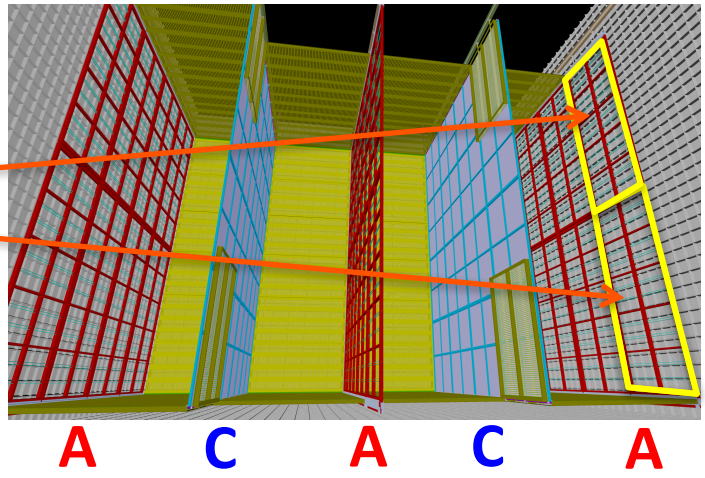
    - Assume four **identical** cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
    - Assume the four 17-kt modules will be similar but **not identical**
- **Collaboration considering two LAr readout technologies**
  - Single-Phase (Ionization read out in the Liquid Ar)
    - Demonstrated by ICARUS & MicroBooNE
    - Basis of first 17-kt detector module
  - Dual-Phase (Ionization amplified and read out in Gas Ar)
    - Pioneered by WA105 (protoDUNE-DP)
    - Option for second and/or subsequent detector modules
- **Large-scale prototypes at CERN are seen as critical**
  - protoDUNE–SP & protoDUNE-DP

Staging strategy

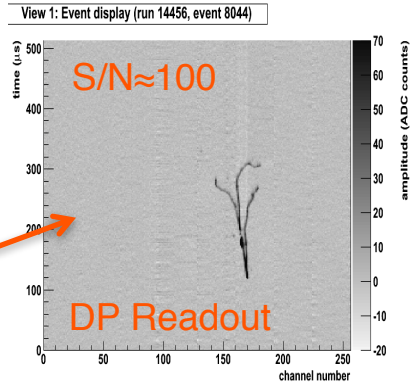
First far detector module:

- **Modular implementation of Single-Phase TPC**
  - Active volume: **12m x 14m x 58m**
  - 150 Anode Plane Assemblies (APA)
    - 6m high x 2.3m wide
  - 200 Cathode Plane Assemblies
    - Cathode @ -180 kV for 3.5m drift



Second & subsequent far detector modules

- Not assumed to be exactly the same, could be:
  - Evolution of single-phase design
  - Dual-phase readout – potential benefits



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Far Detector Development

e.g. single-phase APA/CPA LAr-TPC:

- Design is already well advanced – evolution from ICARUS
- Supported by strong development program at Fermilab
  - 35-t prototype (run ended 03/2016)
    tests of basic design

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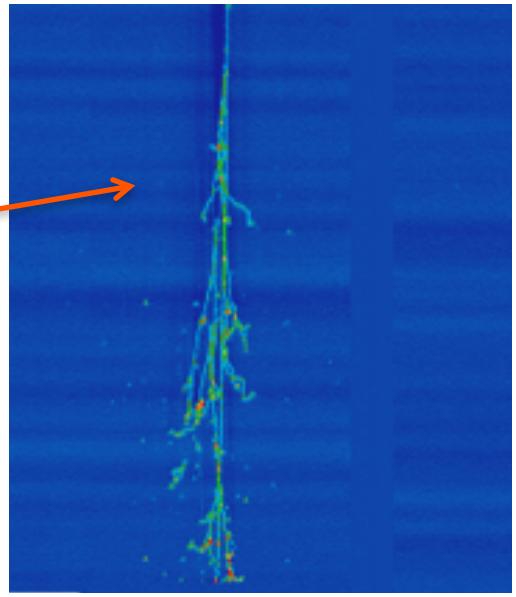

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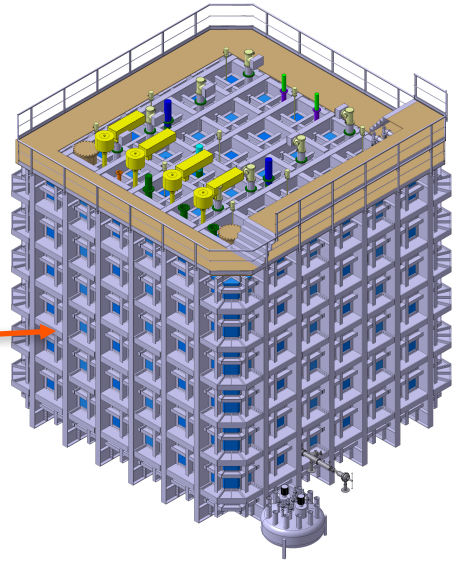
- 2 "Full-scale" prototype**s** (protoDUNEs) at the CERN Neutrino Platform
  - **Single-Phase & Dual-Phase**
  - Engineering prototypes, e.g. **SP**:
    - 6 full-sized drift cells c.f. 150 in the far det.
  - Aiming for operation in 2018



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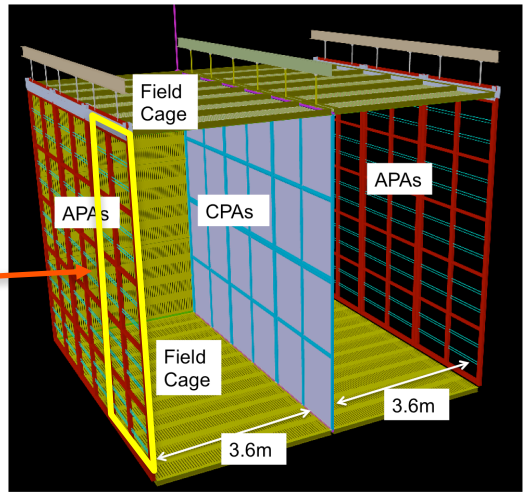


2) ProtoDUNE-SP

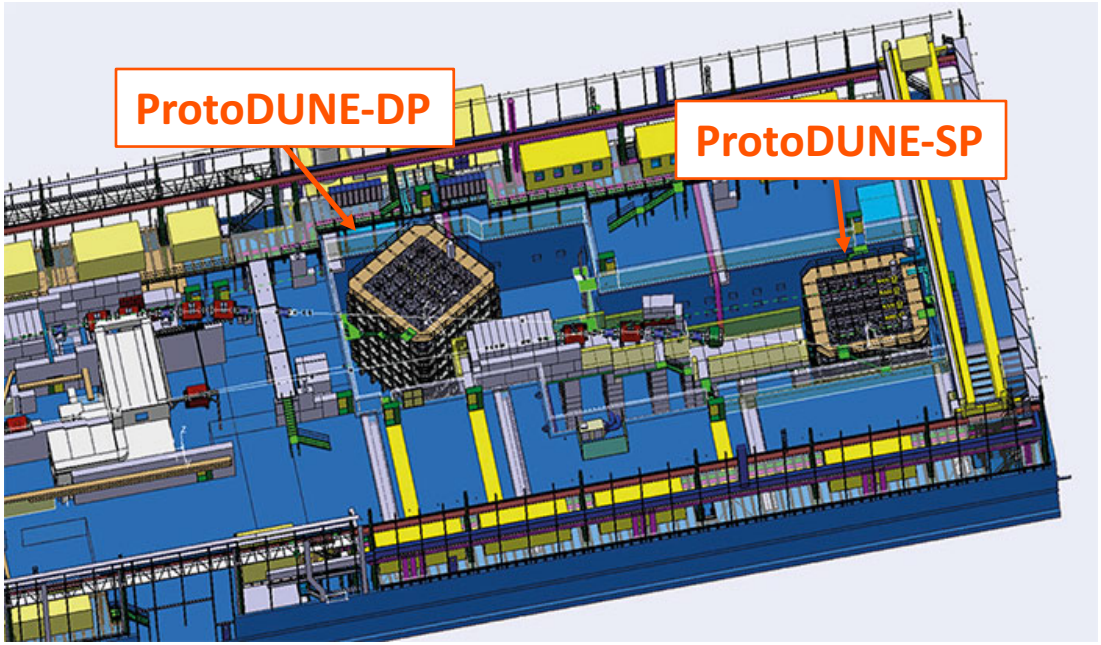
CERN North Area: 27/4/2016

CERN North Area: 5/9/2016

CERN Neutrino Platform

CERN support of international neutrino program

- **Major** CERN infrastructure investment for DUNE:
  - New building: EHN1 extension in the North area
  - Two tertiary charged-particle beam lines
  - Two large (8x8x8 m^3) cryostats & cryogenic systems



Beneficial occupancy

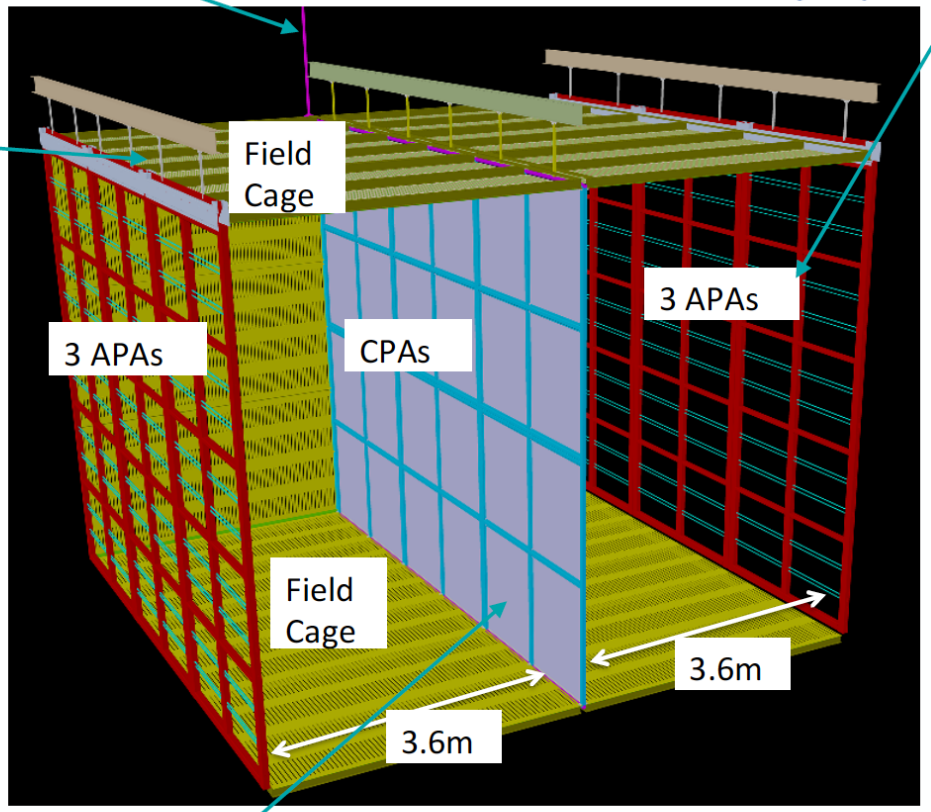
ProtoDUNE-SP Responsibilities

Drift HV system

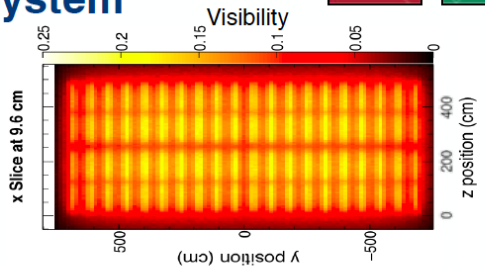
Signal feed-throughs

Anode Plane Assemblies (APA)

Field cage



Photon Detector System



Cold readout electronics

DAQ

Slow control

Cathode Plane Assemblies (CPA)

ProtoDUNE-SP Elements

- **ProtoDUNE-SP consists of:**
  - Six APAs (readout wire planes) ~15,000 channels @ 2 MHz
    - Identical to planned first FD module
  - Cathode plane/Field Cage/HV feedthrough
    - Identical to planned first FD module
  - Photon Detection Systems ~240 channels @ 150 MHz
    - Bars embedded in the APAs
    - Possible design for the FD - but still an area of R&D
  - DAQ
    - ATCA-based RCE readout (SLAC) used for DUNE 35-t prototype
    - Not likely to be the exact FD read out system (cost)
    - Also desire to test FELIX readout at ProtoDUNE-SP
    - Decision was to operate in triggered mode (different to far detector)

3) ProtoDUNE-SP: Strategic aims

Strategic view of protoDUNE program

- **Large-scale prototyping/calibration**
  - **Production (delivery of the detector components to CERN):**
    - **stress testing of the production and quality assurance processes** of detector components
    - mitigate the associated risks for the far detector.
  - **Installation:**
    - **test of the interfaces between the detector elements**
    - mitigate the associated risks for the far detector.
  - **Operation (cosmic-ray data):**
    - **validation of the detector designs and performance**
  - **Test beam (data analysis):**
    - **essential detector and physics calibration benchmarks**
    - not necessary for the finalization of the FD.

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Engineering risk mitigation for CD-2

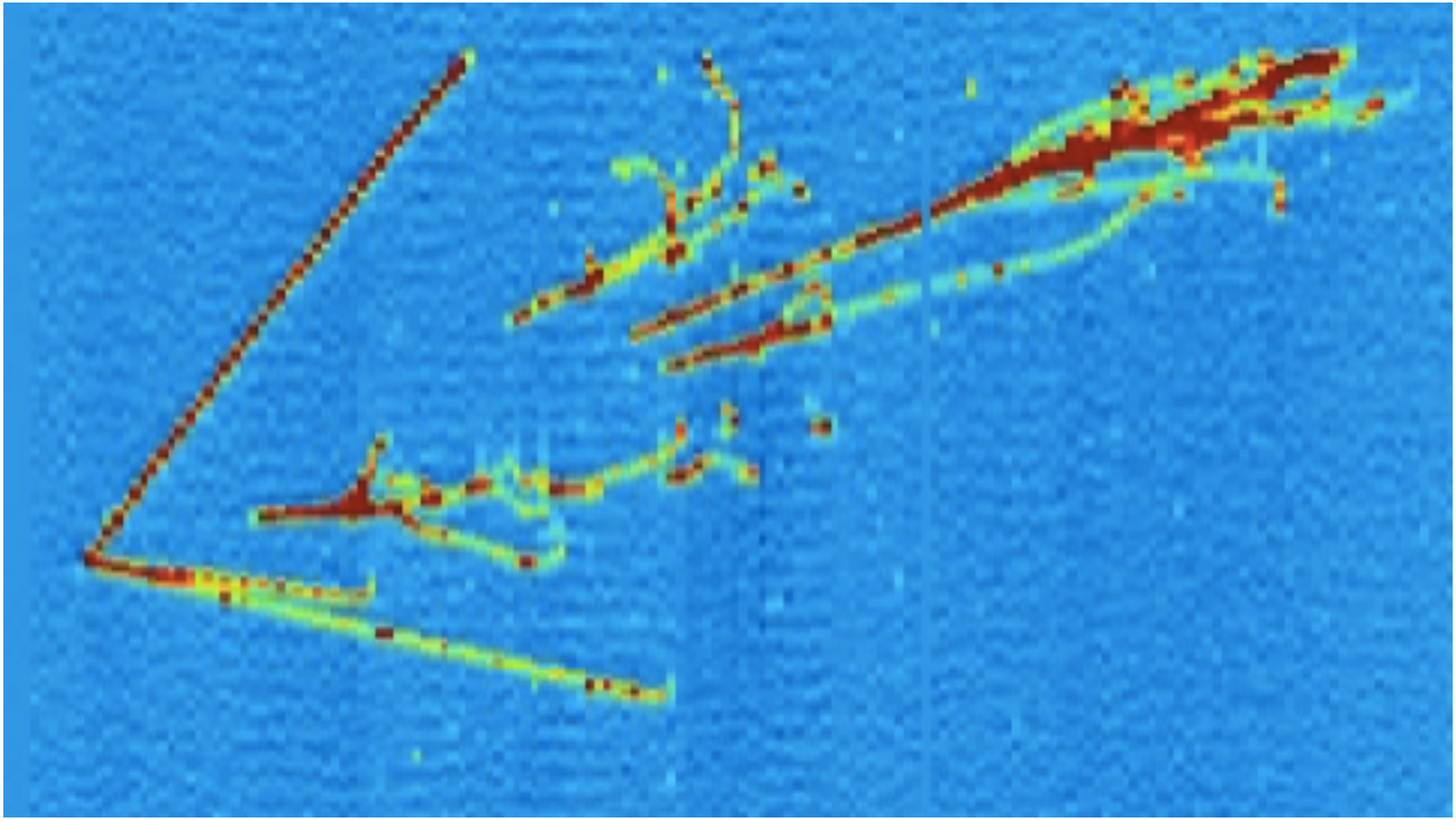
Physics calibration for oscillation analyses

Strategic view of ProtoDUNE-SP DAQ

- **ProtoDUNE-SP data will validate the LAr-TPC design**
  - Important/essential input to CD-2/3B in October 2019
- **DAQ for ProtoDUNE-SP is not assumed to be same as for Far Detector**
  - Cost
  - Different operating conditions

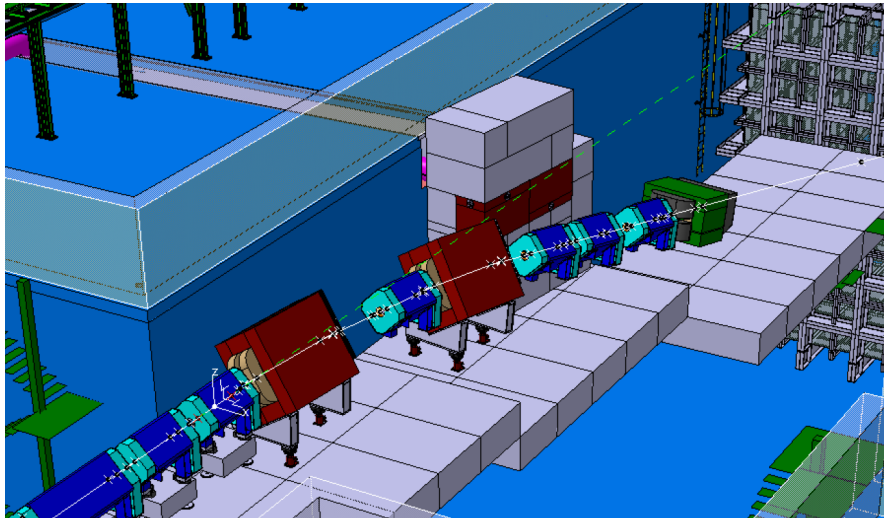
  ⇨ **use tried-and-tested low-risk approach**
- **Adopted SLAC RCE system as baseline for ProtoDUNE-SP**
  - Relatively little hardware development needed
  - Not foreseen as the final system for the far detector due to costs
    - but tests architecture for a possible cost-optimised version
- **Agreed to include R&D DAQ path for FELIX system**
  - FELIX will be used to read out up to 20 FEBs
  - Should be non-invasive, must not compromise/complicate RCE-based data flow

4) DAQ Requirements (Physics)



Want to record

- **Beam triggers**
  - 0.5 GeV – 7 GeV for a variety of particle types
  - A trigger rate of 25 Hz (in spill) is sufficient for anticipated program



- **Cosmic-Ray triggers**
  - For calibrating, understanding detector, e.g. space-charge effects
- **Beam information**
  - PID systems, etc.

DAQ Requirements from Physics

- **Run plan**
  - 6M beam triggers in 3-month period prior to LS2 shutdown
  - Anticipate cosmic-only running in 2019
  - Running beyond 2019 (if any) to be discussed with CERN management
- **Constraints**
  - Data links out of ENH1
  - Cost of disk/tape
- **Considerations led to an agreed "DAQ scenario"**

Parameter	Value
Trigger rate	25 Hz
Spill duration	4.8 s
SPS Cycle	22.5 s
Readout time window	5 ms
# of APAs to be read out	6
Single readout size (per trigger)	230.4 MB
Lossless compression factor	4
Instantaneous data rate (in-spill)	1440 MB s^{-1}
Average data rate	576 MB s^{-1}
3-Day buffer depth	300 TB

Physics Measurements

- **ProtoDUNE-SP measurements have three main goals**
  - **Validate** detector design/performance
    - e.g. establish S/N, argon purity, …
    - Can be achieved with cosmic-ray data
    - Needed in time of TDR reviews (LBNC and DOE CD-2/3B)
  - **Calibrate** detector response to known charged-particles in energy range relevant to DUNE FD neutrino interactions (0.5 – 5 GeV)
    - e.g. understanding calorimetric measurements in LAr
    - Requires beam data
    - Needed for ultimate physics program
  - **Measurement** of particle interactions in argon to provide data to improve modeling in the simulation
    - e.g. measurement of pion interaction cross sections/processes.
    - Requires beam data
    - Needed for ultimate physics program

Preliminary Run Plan

- **Assumptions**
  - **Trigger rate (in spill) = 25 Hz**
  - **Duty cycle = 0.2** two 4.8 s spills per 48 s SPS super cycle
  - Electron triggers in hadron beam pre-scaled to 0.5 Hz
  - Both +ve and –ve beam operation
  - **Operational efficiency (detector + beam availability) = 50 %**

P (GeV/c)	# of Spills	# of e^+	# of K^+	# of μ^+	# of p	# of π^+	Total # of Events	Beam Time (days)
1	70K	84K	≈ 0	70K	689K	625K	1.5M	19.4 days
2	16K	19K	9K	36K	336K	572K	1.0M	4.4 days
3	13K	16K	26K	17K	181K	540K	780K	3.6 days
4	11K	13K	19K	16K	107K	510K	660K	3.1 days
5	11K	13K	29K	13K	96K	510K	660K	3.1 days
6	11K	13K	36K	12K	94K	510K	660K	3.1 days
7	11K	13K	42K	8K	87K	510K	660K	3.1 days
Total	143K	171K	161K	172K	1.6M	3.8M	5.9M	39.7 days

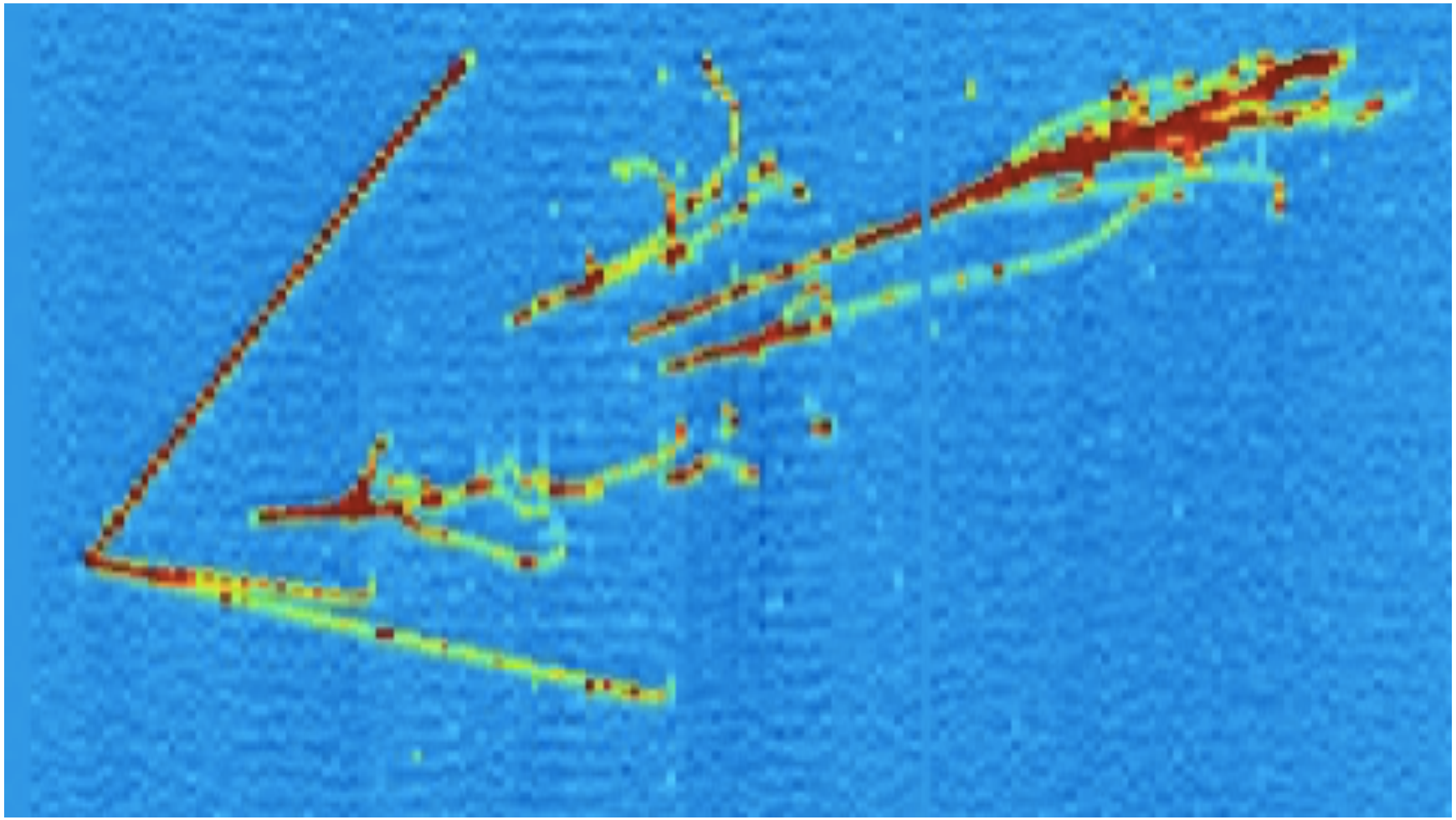
Hadron beam (+ve)

Momentum Bins (GeV/c)	# of Spills per Bin	# e^+ per Bin	Beam Time per Bin (days)
0.5, 06, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7	5000	300K	1.4

High-purity electron beam (+ve)

- **Can be achieved (+ve and -ve) in a 120 day run period**

5) Summary



Summary

- **ProtoDUNE-SP is an essential part of the DUNE plan**
  - **Engineering Validation**
  - **Physics Calibration**

- **Data volumes are large**
  - **Continuous TPC readout at 2 MHz** (for 5ms around trigger)
  - **PDS readout at 150 MHz**

- **Adopted a tested relatively low-risk solution**
  - **SLAC RCE system + FELIX R&D stream**
  - **25 Hz trigger rate** (in spill)

- **DUNE has assembled a strong and experienced DAQ team**
  - **We are confident that we can deliver on schedule**