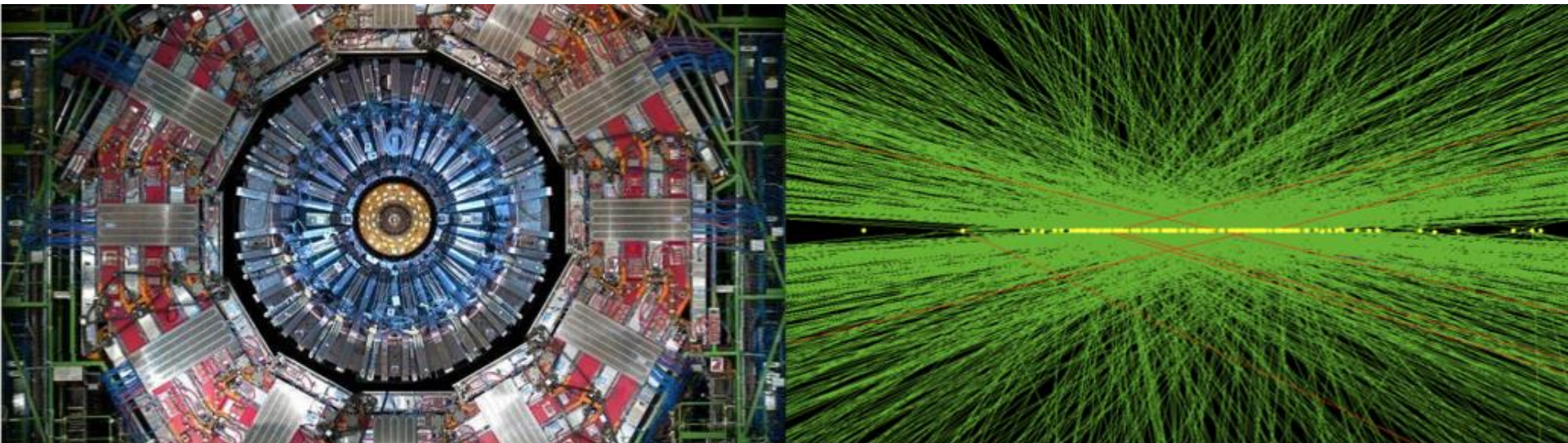
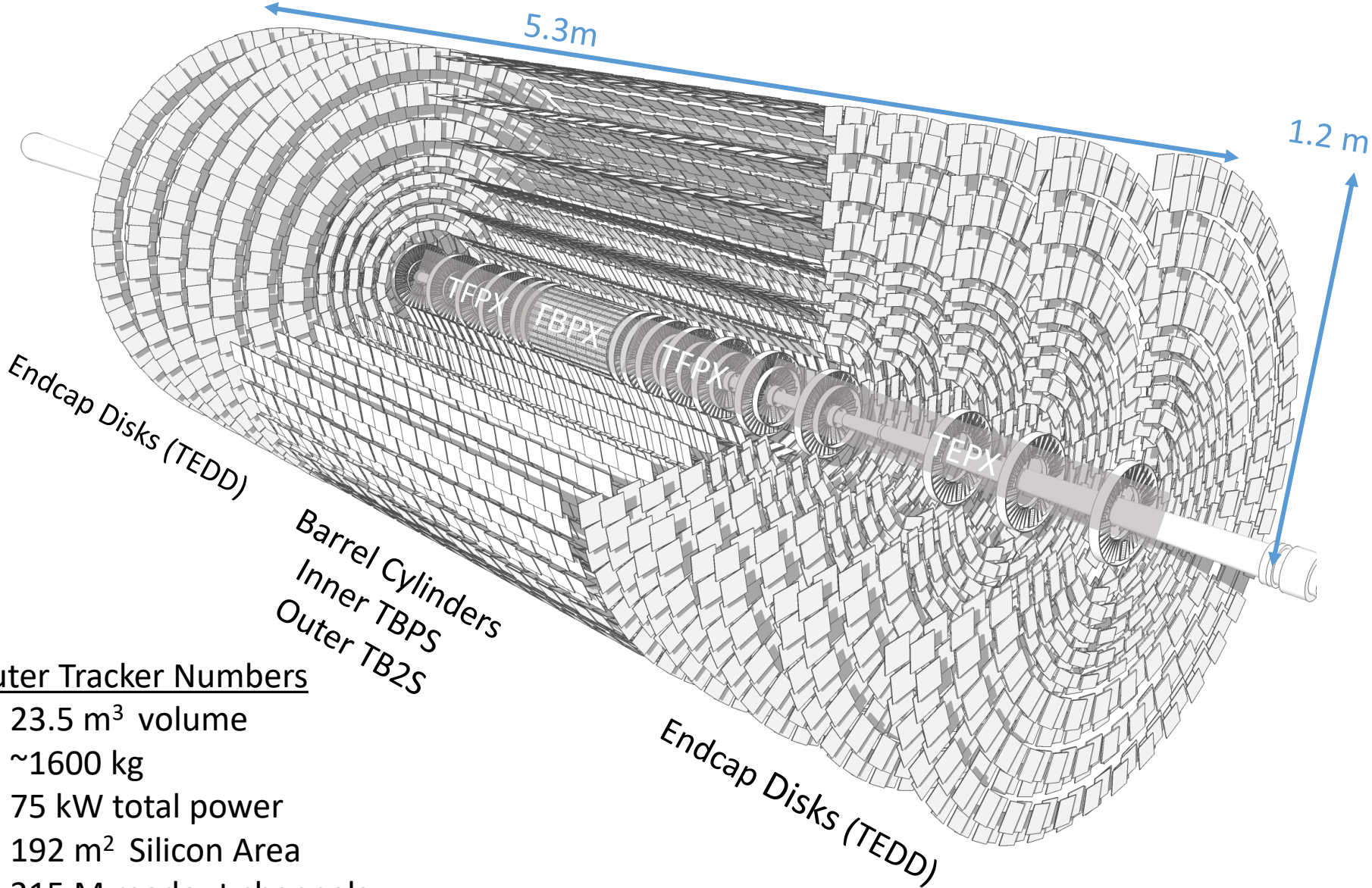




L2 Overview: 402.2 Outer Tracker

Steve Nahn and Petra Merkel
HL LHC Risk Workshop - OT
Sept 7th, 2018



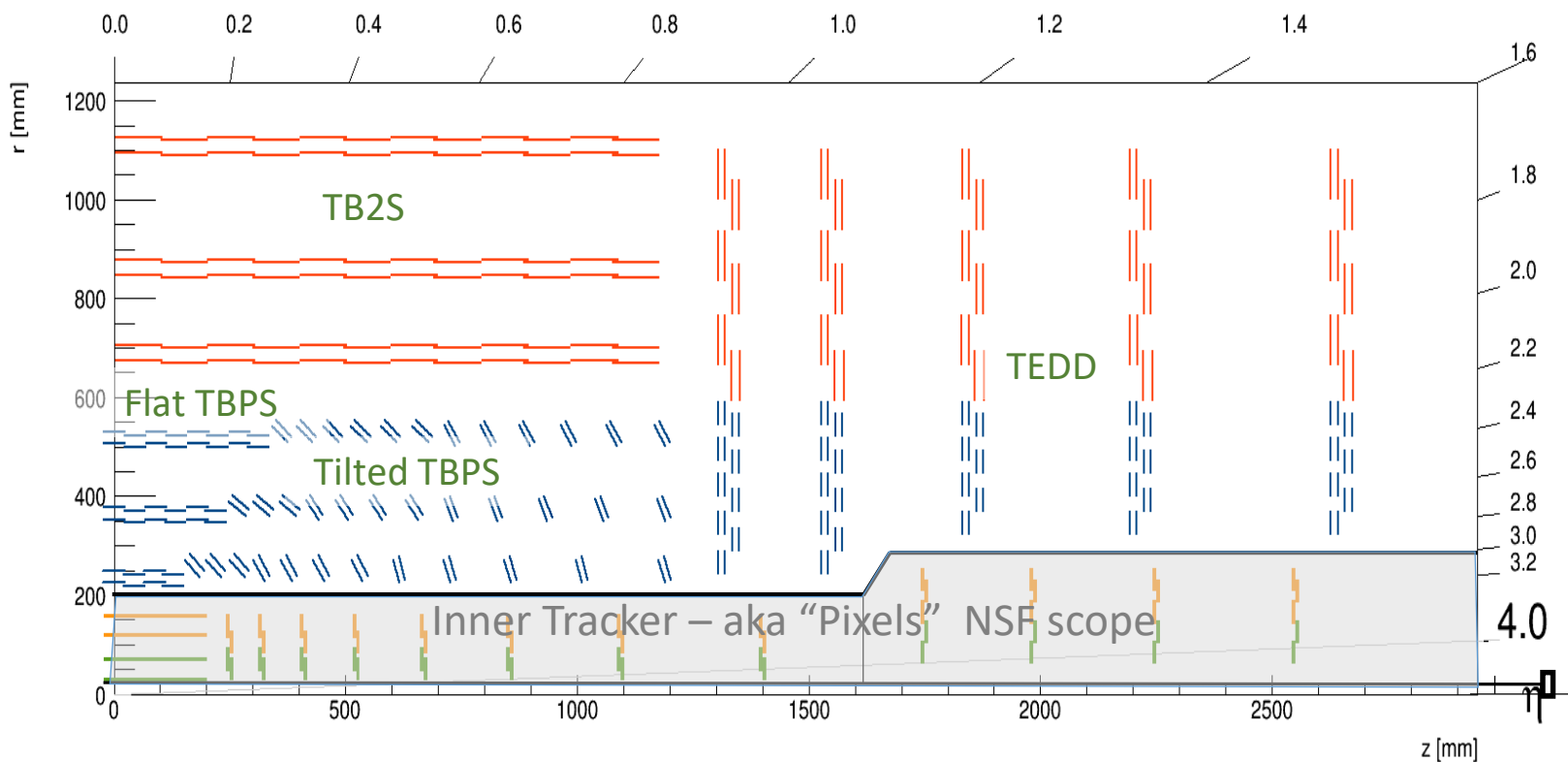


Outer Tracker Numbers

- 23.5 m³ volume
- ~1600 kg
- 75 kW total power
- 192 m² Silicon Area
- 215 M readout channels

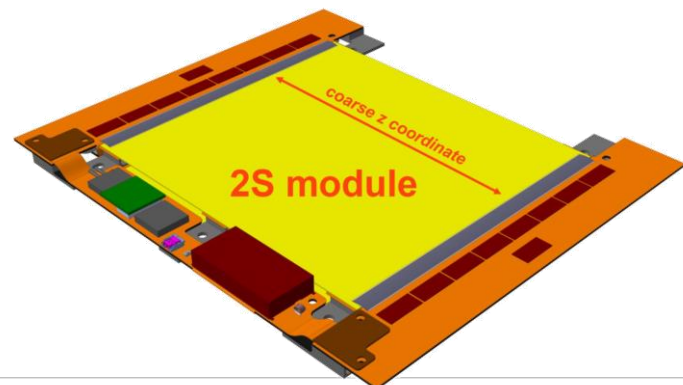
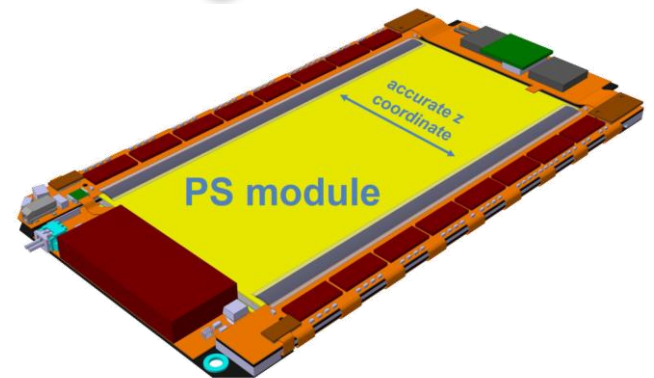
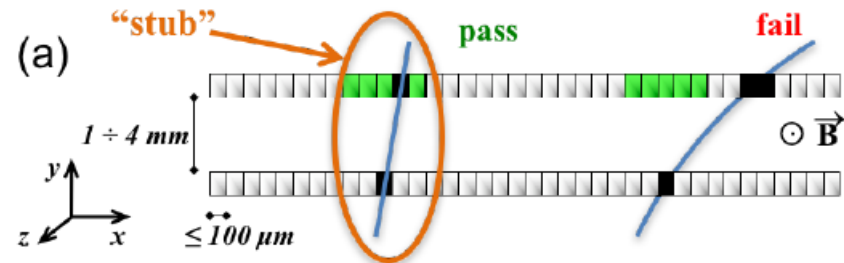
OT Detector Layout

- Divided into 6 barrel layers and 5 endcap disks
 - Barrel has “Flat” section and “Tilted Section”
 - Trigger: Each layer is a sandwich of sensors (next slide)
 - Two flavors of pairs, “PS” and “2S”



OT – Fundamental Unit: Module

- Sensor “sandwich” provides local curvature information for trigger
 - Different spacing in sandwich at different radii to match trigger
- Two types of module
 - **Pixel-Strip (PS):** Strip sensor (PS-s) provide 1D information, Pixelated sensor (PS-p) provide 2D information. Used at lower radius, balance between precision and cost
 - **Strip-Strip (2S):** Strip Sensors (2S) for both slices of sandwich at high radius
- Modules include sensors, ASICs, power and readout hybrids, spacers and mechanical support
 - Sensors and Electronics may differ, Mechanics similar

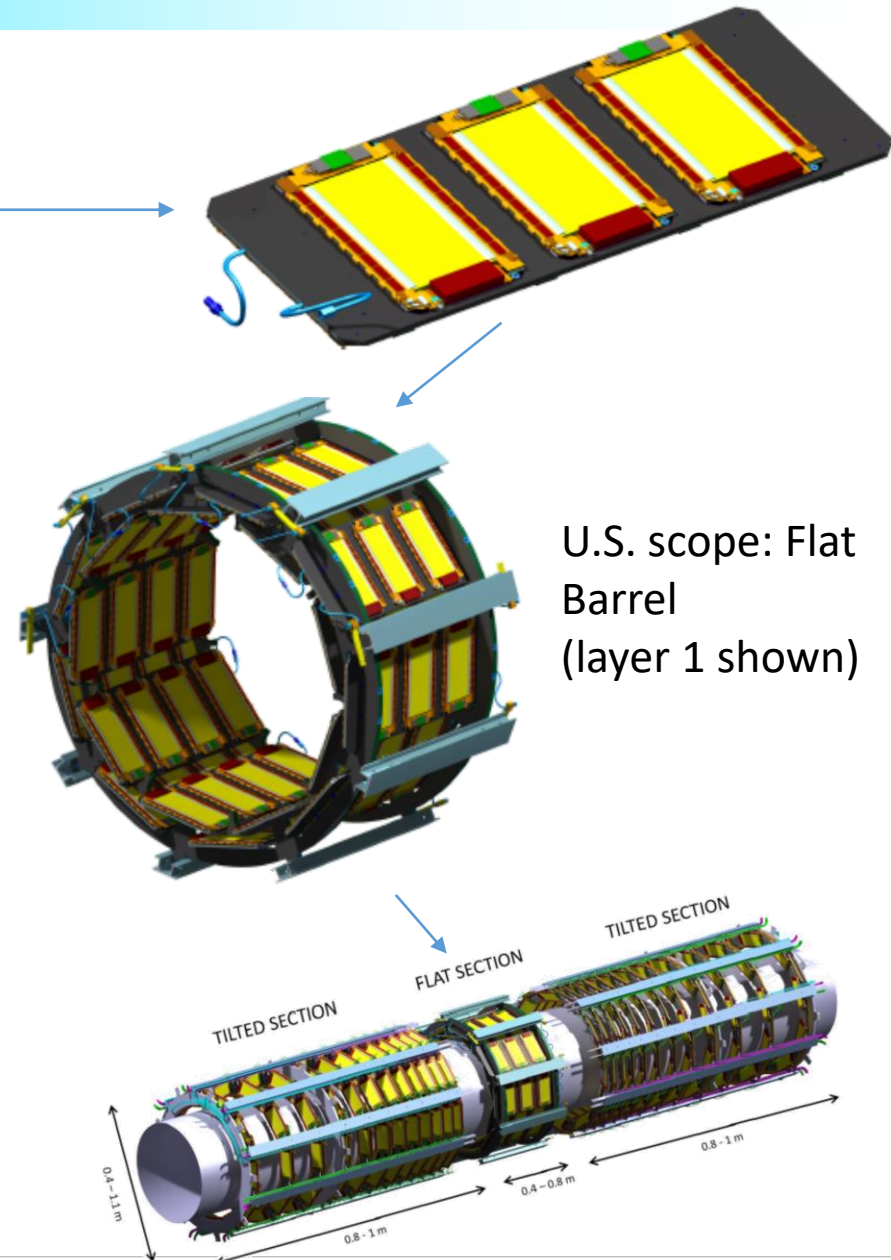


■ Mechanical Structure

- Modules go on Planks
- Planks go on Rings
- Minimize mass: Carbon Fiber
- Dual Phase CO₂ cooling
 - ala FPIX Phase 1

■ Electronics

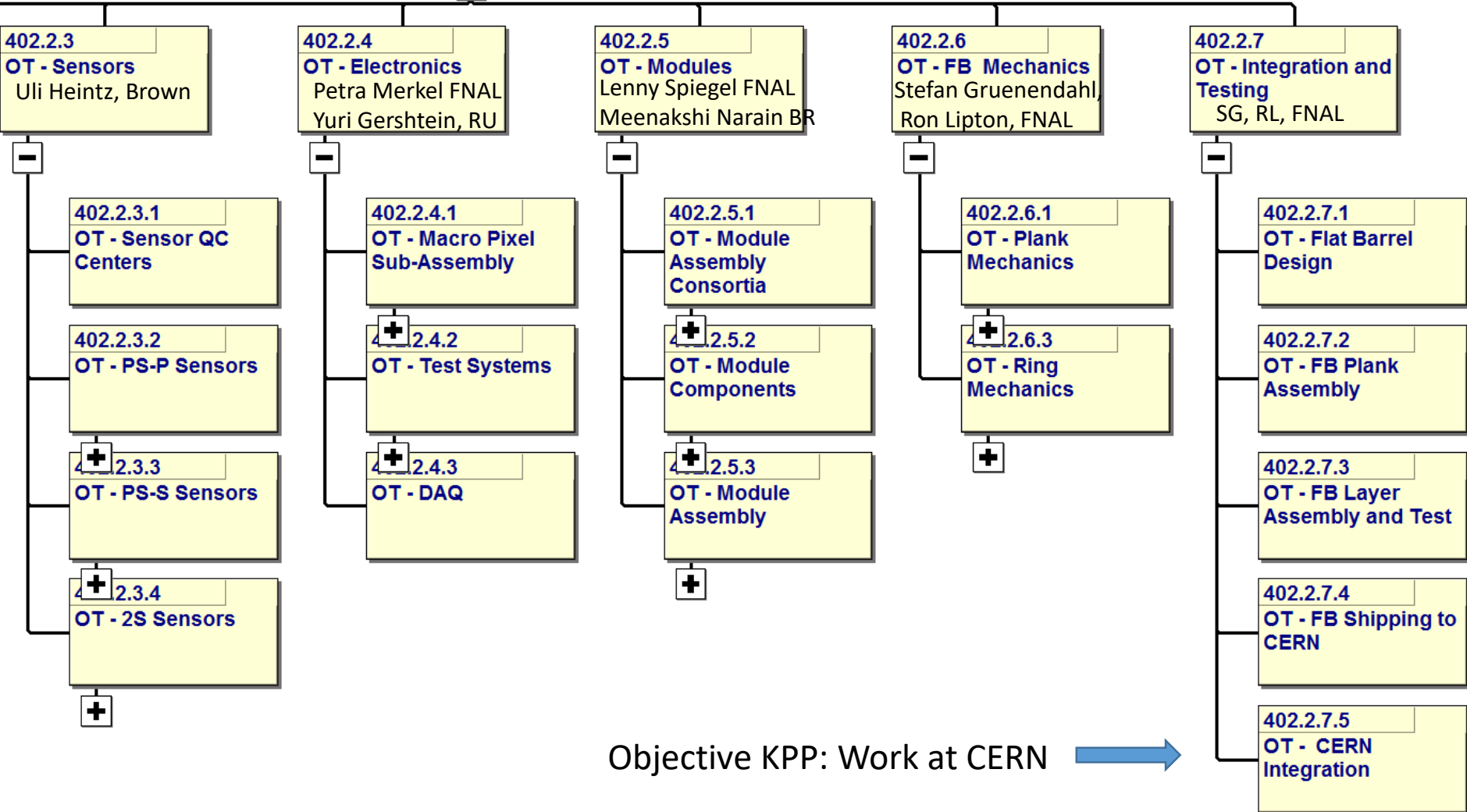
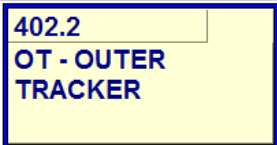
- Test Systems to support component and module QC
- Off-detector Data Acquisition electronics
 - Share of Design and Firmware
 - (Trigger part of 402.07)





- **Modules (Key Performance Parameter #2)**
 - Deliverable: 2500 PS and 2000 2S working production modules, plus 5% preproduction and 10% spares
 - 952 PS go to Flat Barrel (below), rest to iCMS collaborators
 - Sensors - Procurement (CERN group purchase), QC
 - Electronics
 - Development of Test systems for iCMS, Procurement for U.S. needs
 - Development of Sensor-ASIC assembly: MacroPixel Sub Assembly (MaPSA)
 - Modules
 - Development of assembly sites
 - East Coast and FNAL
 - Module component procurements and QC
 - Assembly of components into modules and QC
- **Flat Barrel Fabrication (Key Performance Parameter #1)**
 - Fabrication of Planks and Rings for the PS Flat Barrel (inner 3 layers)
 - Assembly of (U.S.) PS Modules onto Planks/Rings, QC
- U.S. scope mixes homogeneously with international scope
 - We are independent, but not necessarily the unique supplier
- Threshold KPPs are not tied to LHC schedule and tunnel access
 - Objectives include installation and commissioning activities

Suppressed: 402.2.1 Milestones and 402.2.2 Management



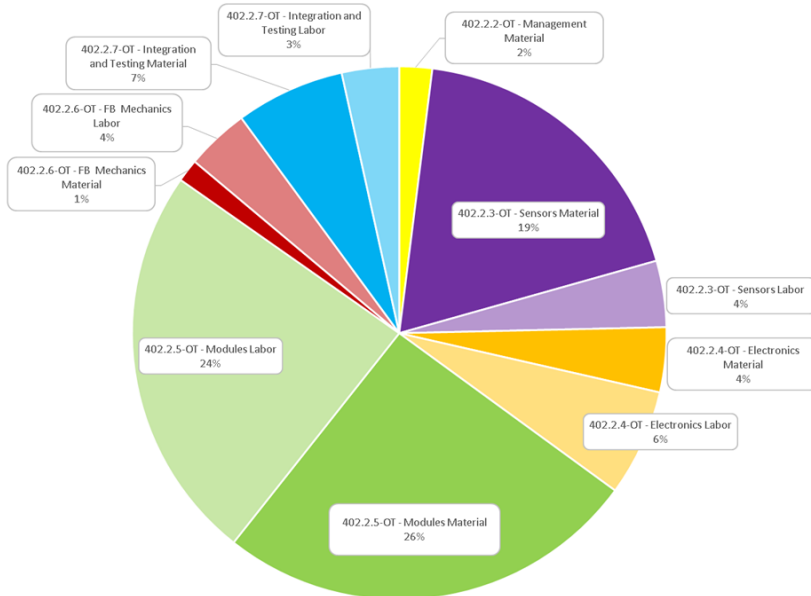
Objective KPP: Work at CERN →



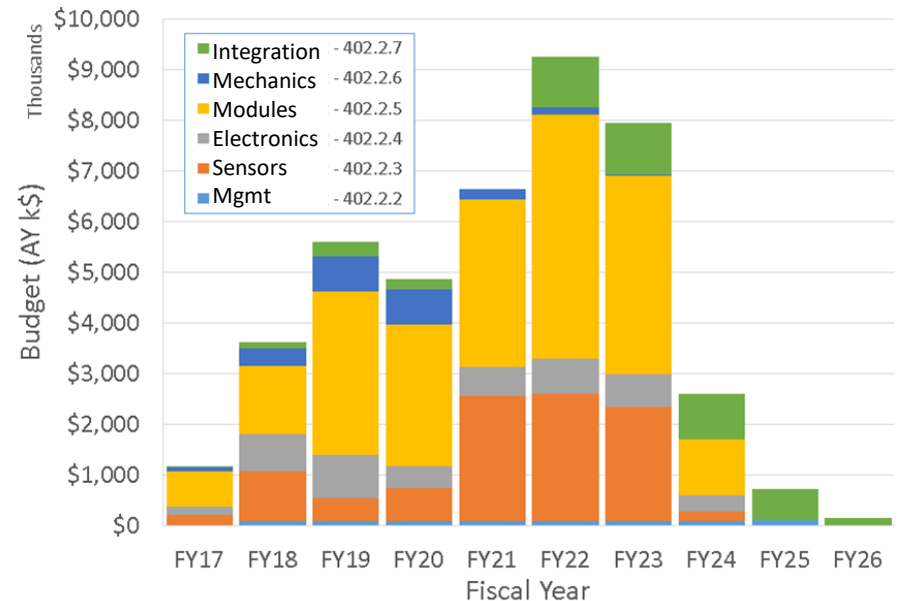
Cost and Cost Profile

WBS	Direct M&S (\$)	Labor (Hours)	FTE	Direct + Indirect + Esc. (\$)	Estimate Uncertainty (\$)	Total Cost (\$)
402.2 OT - OUTER TRACKER	\$21,420,779	340404	192.55	\$42,593,399	\$13,350,307	\$55,943,706
402.2.2 OT - Management	\$658,000	40664	23.00	\$844,022	\$84,402	\$928,424
402.2.3 OT - Sensors	\$7,582,541	30447	17.23	\$9,651,654	\$2,672,348	\$12,324,001
402.2.4 OT - Electronics	\$1,436,802	30484	17.24	\$4,427,137	\$1,361,562	\$5,788,698
402.2.5 OT - Modules	\$8,990,428	204978	115.94	\$21,172,433	\$6,615,628	\$27,788,061
402.2.6 OT - FB Mechanics	\$433,000	20031	11.33	\$2,212,199	\$1,024,739	\$3,236,938
402.2.7 OT - Integration and Testing	\$2,320,008	13800	7.81	\$4,285,955	\$1,591,629	\$5,877,583

402.2-OT-WBS L3 Base Budget Breakdown (DOE)
BAC = \$42.59M (AY\$)



402.2-OT-Base Budget Profile (DOE)-WBS L3 Subprojects
BAC = \$42.59M (AY\$)





OT Cost Drivers > \$1.5M

CMS Driver	Labor (FTE-years)	Labor (M\$)	M&S (M\$)	Labor + M&S (M\$)	Estimate Uncertainty (M\$)	Total (M\$)
OT.5 - Produce and test modules	51.7	8.1	1.5	9.7	2.9	12.6
OT.3 - Procure Sensors	0.0	0.0	6.9	6.9	2.0	8.9
OT.5 - Module mechanics	2.1	0.3	2.9	3.1	1.3	4.5
OT.5 - Procure hybrids	0.0	0.0	3.3	3.3	1.0	4.3
OT.5 - Establish / maintain module assembly site (East Coast)	4.9	0.8	1.8	2.6	0.7	3.3
OT.6 - Plank and Ring mechanics	11.1	1.6	0.6	2.2	1.0	3.2
OT - Outer Tracker integration and commissioning	0.0	0.0	2.5	2.5	0.7	3.2
OT.7 - Flat Barrel design, assembly and test	5.5	1.4	0.3	1.7	0.8	2.5
OT.4 - DAQ development	8.4	1.5	0.1	1.6	0.4	2.0
OT.4 - MaPSA purchase and testing	2.2	0.1	1.2	1.3	0.6	1.9
OT.3 - Sensor prototyping, production and testing	14.5	1.4	0.1	1.5	0.4	1.9

- Large M&S Procurements

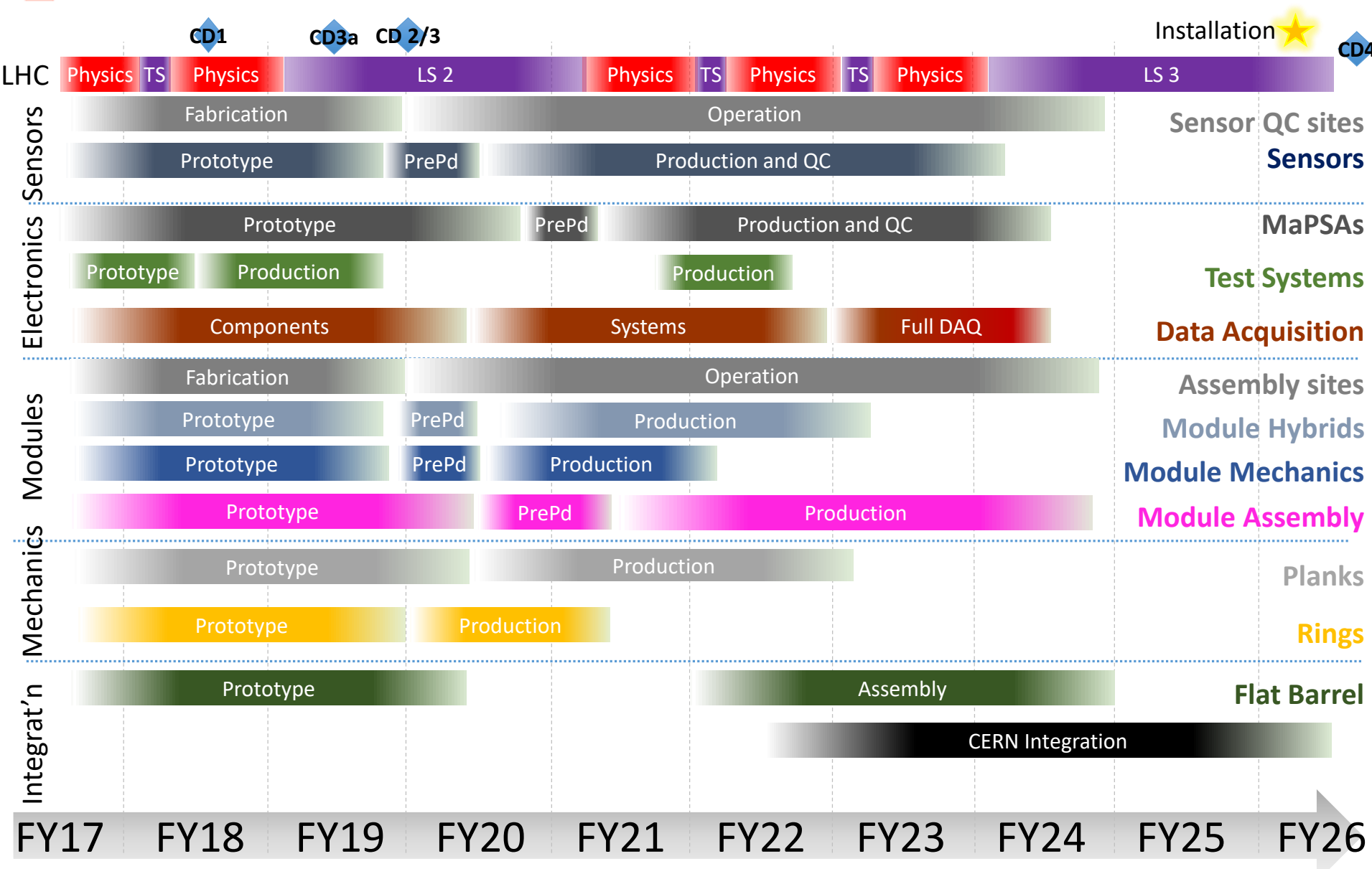
- Sensors, Hybrids, Al-CF mechanics, MaPSA = \$13.6M BAC out of \$24.8M
 - Investigating less expensive mechanics solutions, lower cost/higher risk Bump Bonding vendors

- Substantial Labor Costs

- Manual Module Assembly – \$8.1M
 - Investigating options for automatization
 - Significant Engineering effort – \$5.9M
 - DAQ firmware, Engineering for Mechanical Substructure and Integration, Sensor testing



OT Cartoon Schedule



Outer Tracker Float

- Flat Barrel delivery has 11 months to CMS request date
 - +5 months to installation
 - 3.1 years to CD4
- Module completion has 7 months to CMS request date
 - +10 months to installation
 - 3.1 years to CD4
- Prototyping effort and completion of Vendor inquiries will inform durations between now and CD-2 Baseline

