

Work Package 5-a

Advanced Endplate Mechanics ...and... Alignment

Dan Peterson 2010-03-04

The work on advanced mechanics started
construction of the LP1 endplate (and CLEOI, CLEOII, CLEOIII, CLEOc before that)
and with ideas
first presented at Chicago 2008-11-15
also the LCTPC collaboration meetings 2009-04-16 and 2009-09-22 .

The work on alignment started with contributions to the
ILD alignment task force and the ILD LOI in ~ 2009-06.

In short, both will be expanded.

Alignment

At the time of the LOI, we were asked,
“what precision of alignment is required for the tracking?”

We did not know exactly what to do with this; in the end, we set a criteria that (uncorrected) misalignments should not increase the momentum resolution by more than 5%.

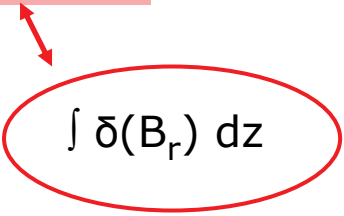
“Toy” Monte Carlos were used to determine a response, where “toy” means that there is no pattern recognition or digitization.

- coherent displacement of the VTX, 2.8 μm ;
- coherent displacement of the SIT, 3.5 μm ;
- coherent displacement of the SET, 6 μm ; and
- coherent displacement of the TPC, 3.6 μm
- internal distortions in the TPC that result in a sagitta in the TPC of 20 μm .

The current questions of alignment will be more complex.

We might answer

what type of distortions can be identified,
what combinations of distortions will lead to ambiguities,
what amount of data is required to make corrections to an acceptable level.


$$\int \delta(B_r) dz$$

FUTURE work will still involve “toy” Monte Carlo’s,
but it will probably require something like Kalman fitting.

Work on “Advanced Endplate Mechanics” is active.

A review of this work is being presented to the USA agencies today, like in 4 hours, by Graham Wilson, representing ILD detector R&D in the USA.

What follows is from the slides prepared for that meeting.

TPC Endplate Development at Cornell

Research toward the development of a TPC endplate for the ILD detector with the goals:

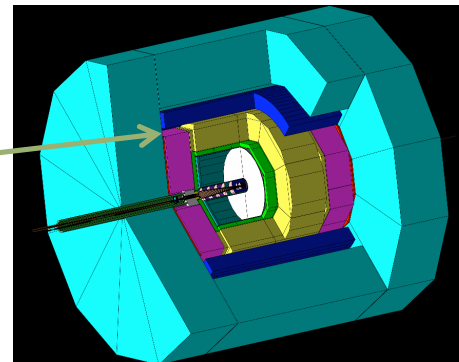
consistent with the implementation
of Micro Pattern Gas Detector (MPGD) readout modules

scattering material $< 0.15 X_0$
to minimize influence on PFA

mechanical alignment and stability of detector elements $\sim 50 \mu\text{m}$
to facilitate calibration of the electric and magnetic distortions.

ILD detector

TPC Endplate



NSF funding for ILD priority R&D

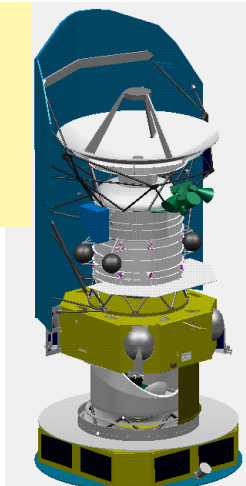
NSF funding for ILD high-priority projects
(collaborative research lead by U. Kansas)

providing personnel support for **design studies** of
ILD TPC endplate (diameter=3.5m), and
limited construction of smaller prototypes for material studies.

LCDRD supplemental funding
(NSF funding, sub-grant from U. Oregon)

supporting **construction** of a next-generation endplate for the
LCTPC-collaboration **LP1 Large Prototype** (diameter=0.77m).

The **design studies** refers to the advanced designs, such as space frames, discussed in the earlier talks.



The **next generation endplate** is for LP1 and is a funded project. It will be useful for detailed study of one particular design. If the LP1 program continues long enough, we can install it.

Research Activities (not all 1st year deliverables)

computer modeling of possible designs of the full-sized ILD endplate

construction of small prototypes to examine detailed properties of constructions methods proposed for the full-sized endplate

compare **Finite Element Analysis** (FEA) predictions with **measured properties** of the **small prototypes** used to understand the properties and provide input to FEA studies of more complex models

construct a **functional low material endplate for the LCTPC LP1** large prototype
(The low material prototype for the LCTPC LP1 large prototype is a complimentary activity that allows detailed study of the properties of one construction technique within a system.
It provides information on the stability beyond that which can be gained from the small prototypes, above)

FEA studies of the complex designs of the **full size endplate**

design and construct **test pieces** for the purpose of identifying **construction problems in the full-sized endplate design**

Work towards a next-generation endplate for the LCTPC LP1 Large Prototype

In 2008, Cornell constructed two endplates for the LCTPC Large Prototype. These were shipped August 2008 and February 2010 and are currently in use.

Endplates included
a system for supporting
MPGD TPC readout modules,
field cage termination for the
uninstrumented areas,
mountings for calibration devices.



The endplate construction was developed to provide the precision required for the ILD;
precision features are **accurate to ~30 microns**,

but not to meet the material limit specified for the ILD TPC;

the bare endplate has mass 18.87 kg over an area of 4657 cm²,
(mass/area) / (aluminum radiation length (24.0 g/cm²)) = **0.169 X₀**.

It is the purpose of this overall study to design an endplate that also meets the material limit.

The majority of effort to date has been in preparing a new computer-aided-design model for the LCTPC LP1 endplate.

The new model is completely **controlled by a spreadsheet** and can be readily evolved into variations of the endplate.

(above) The new model is configured as the **standard LCTPC LP1 endplate**, as constructed except for utility holes. The material (aluminum) is **18.87 kg, 0.169 X₀ (average)**.

Note that much of the material is in the outer flange and that the mass does not include readout modules or electronics.

(below) The new model is configured as a **revised lightened version of the LCTPC LP1 endplate**.

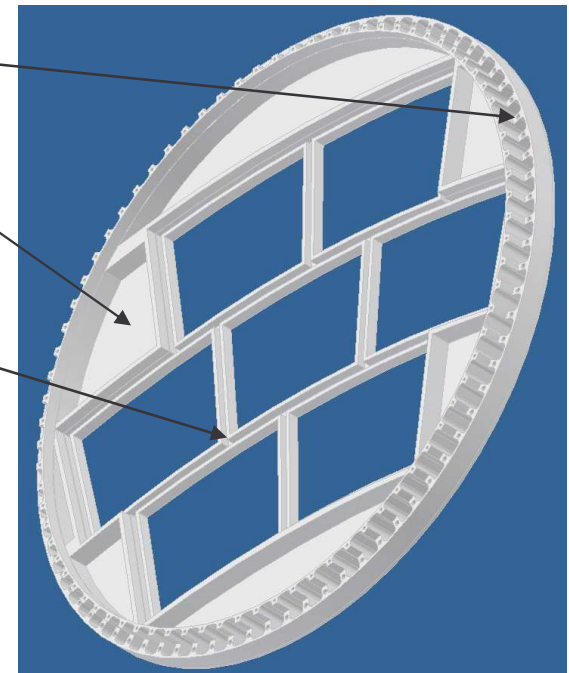
outer stiffening flange: Material is removed between holes.

uninstrumented areas: The endplate has been thinned.
(Note: this is not a design change; these area would be filled with lightweight modules in an ILD TPC endplate.)

module support frame:
Aluminum stiffening of the module support is removed, leaving metal only for the precision surfaces and precision holes

Remaining aluminum is **7.35 kg, 0.066 X₀**.

This is averaged over the full endplate and does not include the modules or electronics. It also does not include the addition of carbon fiber stiffening for the module support, which is discussed in the next slide.)



A new, functional, LCTPC LP1 endplate is being designed with this model.

In the **developing construction plan** for an aluminum/carbon fiber hybrid, the aluminum stiffening in the module support frame is **replaced with carbon fiber**.

Simplifying the construction procedure, the aluminum endplate is used as the principal component of the mold.

Illustrating the process, additional mold parts are temporarily installed on the endplate (fig 1).

The carbon fiber reinforced plastic is cast in the resulting mold (fig 2).

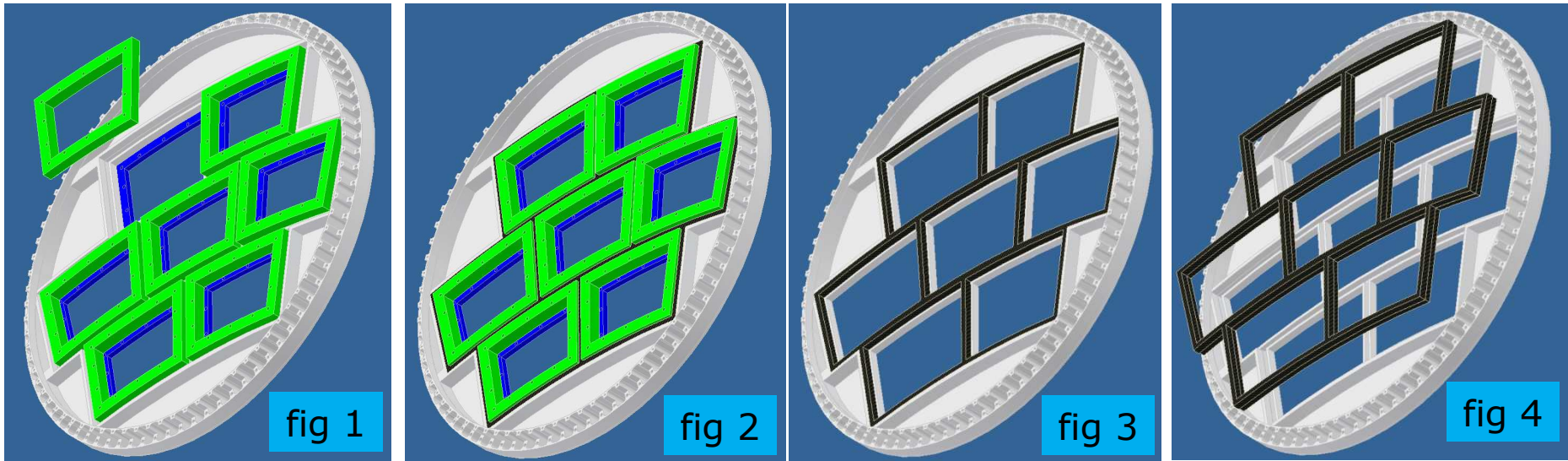
Mold parts are removed leaving the carbon fiber (fig 3).

The aluminum removal is aggressive; half of the carbon fiber stiffening bar is not visible as it protrudes into the machined cavity in the aluminum; (fig 4).

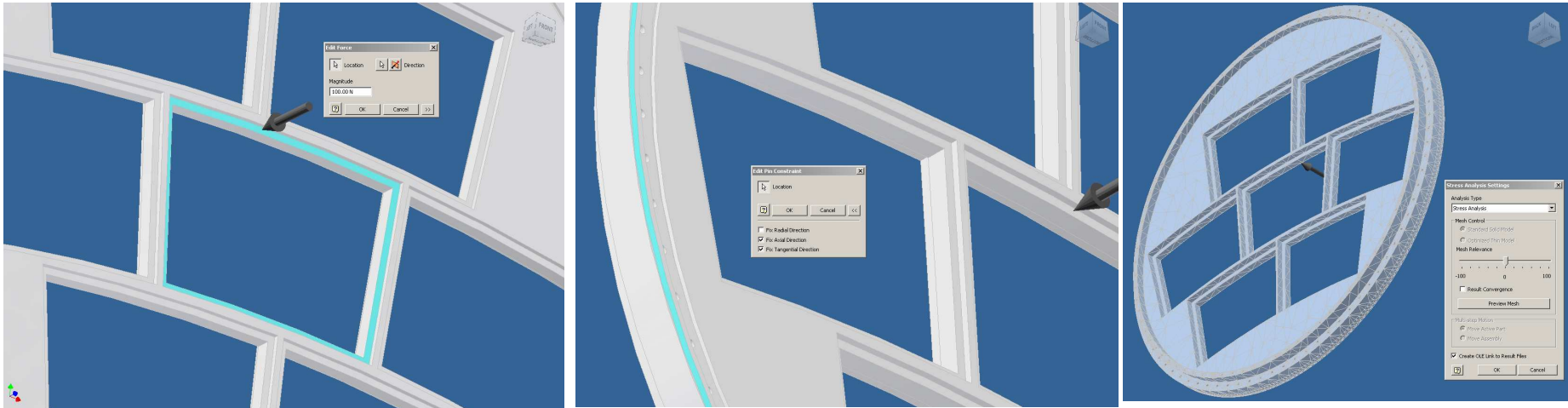
The assembly must then go through a final machining step.

In the hybrid design of the LP1 endplate, 1.58 kg of aluminum is replaced by 1.29 kg of carbon.

The aluminum contribution to the average material $0.014 X_0$ is replaced by $0.006 X_0$ for a total of **$0.072 X_0$** in the hybrid design. (Does not include modules and electronics.)



In preparation for studying the new endplate designs, FEA simulations of the rigidity of the LCTPC LP1 endplate were compared to simple measurements; LP1 is used as a small test structure to calibrate the FEA.



(left) The applied force was 100N (22 lbs) “evenly” distributed over the indicated face on the endplate. This applied force can be easily reproduced on the prototype.

To put this force in context, if 100N is distributed over the full area, 4657 cm², the pressure is 2.1 millibar, ~ the typical overpressure anticipated in the TPC.

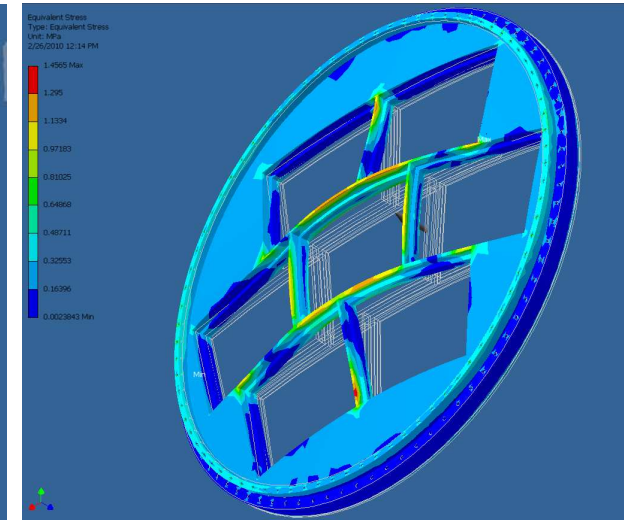
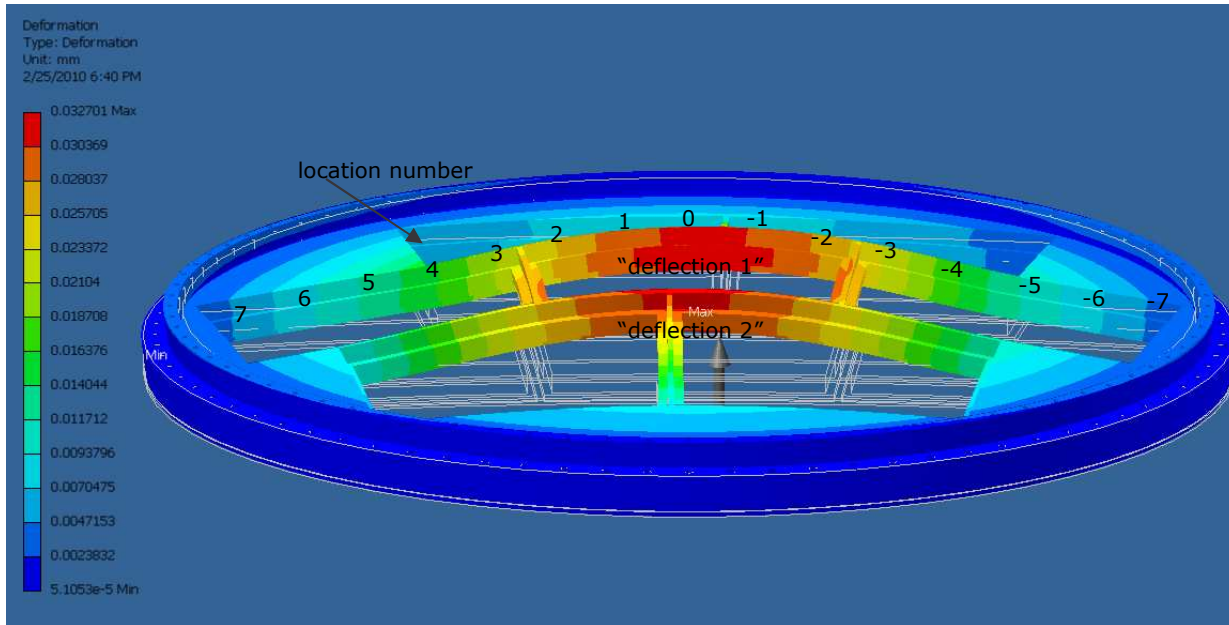
Other significant work has been in studies learning to best duplicate the support with the FEA.

(center) While the real endplate is supported by blocks on a table, in the model, a constraint is placed on a small surface. The constraint is axial (reacting to the force) and tangential. Radial constraints, and constraints of flat surfaces, are avoided; as implemented in the simple FEA, these constraints are applied to macroscopic surfaces, are equivalent to “fixed supports” and lead to non-physical applied torques.

(right) The mesh size was studied to ensure that it does not compromise the result.

The results of the FEA are shown below.

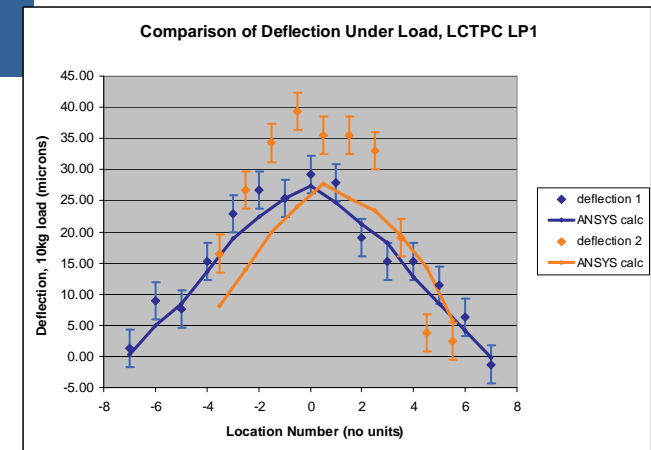
(left) Predicted maximum deformation is **33 μm** . (right) Predicted maximum stress is **1.46 MPa** (aluminum 6061-T6 yield is **241 MPa**).



(left) **Measured** values of the deflection of the LP1 endplate are compared to the FEA results:

measurements along the module support indicated as "deflection 1" are within $5 \mu\text{m}$,

measurements along the module support indicated as "deflection 2" are not as close and differ by about 40%.



(It is possible to explain this discrepancy with an unevenly applied load.)

The average of the measurements agrees with the FEA at the level of about 20%.

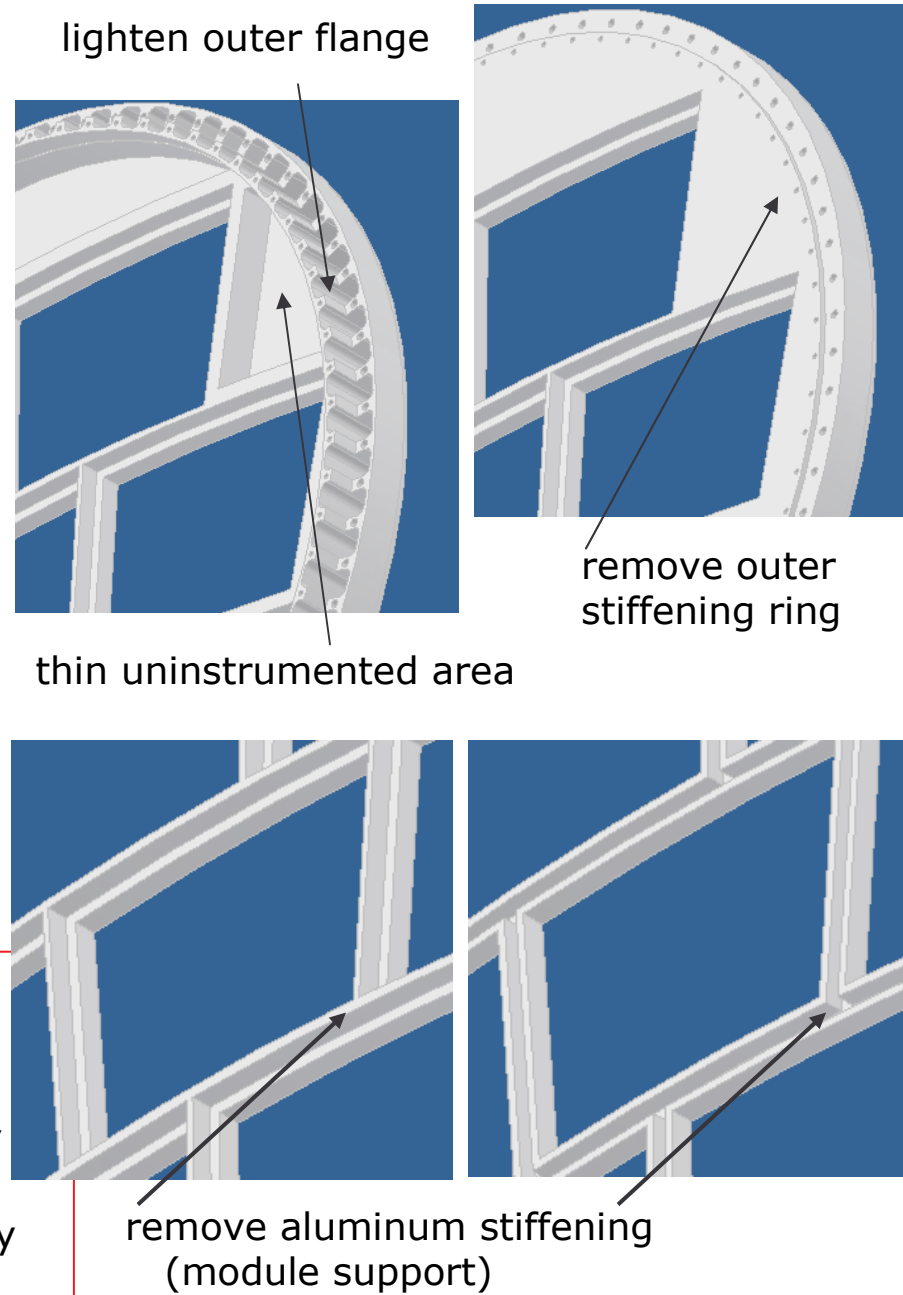
ANSYS calculations have been run to study the effects of lightening various parts of the endplate. This is characterized by the maximum deflection under the 100N (22 lbs) load.

	max. deflection	mass
LCTPC LP1 (standard)	33 μm	18.87 kg
(1) thin uninstrumented area	51 μm	11.63 kg

further simulations, starting with the baseline (1) "thin uninstrumented area"		
	Δ max. deflection	Δ mass
(1)+(2) lighten outer flange	17 μm	-2.70 kg
(1)+(3) remove outer stiffening ring	15 μm	-0.88 kg
(1)+(2)+(3)	29 μm	-3.11 kg
(1)+(4) remove aluminum stiffening (module support)	81 μm	-1.58 kg
(1)+(2)+(4)	117 μm	-4.28 kg

- "lighten outer flange" has a effect similar to "remove outer stiffening ring" with a greater mass saving .

- "remove aluminum stiffening (module support)" causes a significant change in stiffness. The replacement with carbon fiber will be necessary to maintain the stiffness.



Conclusions and Near-future Activity

When comparing results from FEA simulations with measurements, average results are within 20%. This is typical of other observations of ANSYS and is **sufficient for the relative measurements made in this study.**

In the design study for a hybrid aluminum/carbon fiber LCTPC LP1 endplate, the **design of lightening the outer flange** area with pocketing is more effective than removing the outer stiffening ring.

Methods will be developed to study the **transverse stiffness of the module supports**, which is more closely related to the endplate mechanical stability, and alignment stability, with both aluminum or carbon fiber stiffening in the module support.

There is a significant loss in stiffness when removing the aluminum stiffening for the module support. **Prototypes of simple beams, with the cross section of the module support**, will be made in aluminum and in aluminum/carbon fiber hybrid, to understand the stiffness that can be restored in the hybrid design.

Space-frame designs will be started in the next month, including LP1 and ILD. These are more complicated mathematically; the spreadsheet-driven model procedure will facilitate these designs.

The space-frame model will likely be made not as a single "part" but as an "assembly" of "parts". The simple FEA that is being employed does not accept assemblies. **Techniques** will be developed to **convert the assembly to a unified part**, or **building mechanically equivalent parts**.

Discussions with vendors for construction of a new endplate will start this month.

We will **decide on which technology** (aluminum/carbon fiber hybrid, or space frame) to further develop for a new LCTPC LP1 endplate.