LHC Collimation Project

Engineering Department

Status of TCLD Collimator Engineering and Design

LHC Collimation Review 2013
31st May 2013

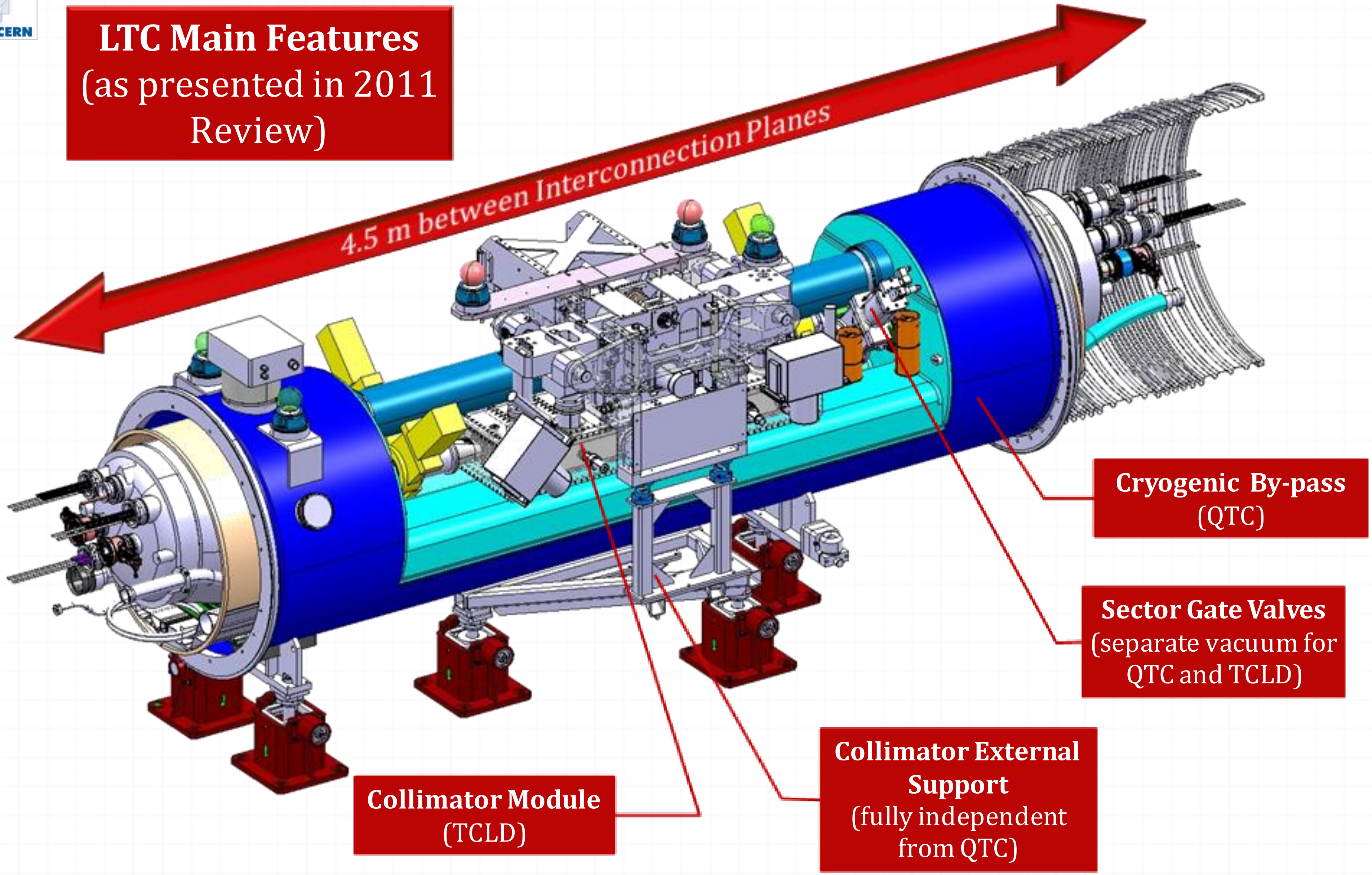
A. Bertarelli (CERN EN-MME)
on behalf of and with input from EN-MME TCLD Team
(M. Timmins, L. Gentini, A. Dallocchio, F. Carra, A. Cherif, D. Ramos, D. Lombard, P. Moyret, N. Mariani, P. Minginette, …) with contributions from many groups (TE-MSC, EN-STI, BE-ABP, TE-VSC..)

Outline

- **DS Collimator Assembly: TCLD and QTC**
  - **Status of QTC (Cryogenic Bypass) Prototype**
- Collimator Module (TCLD)
  - Specification and Present Design
  - Options and Future Outlook
- What's next ...
- Conclusions

DS Collimator Assembly (LTC)

LTC Main Features
(as presented in 2011 Review)



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DS Collimator Assembly (LTC)

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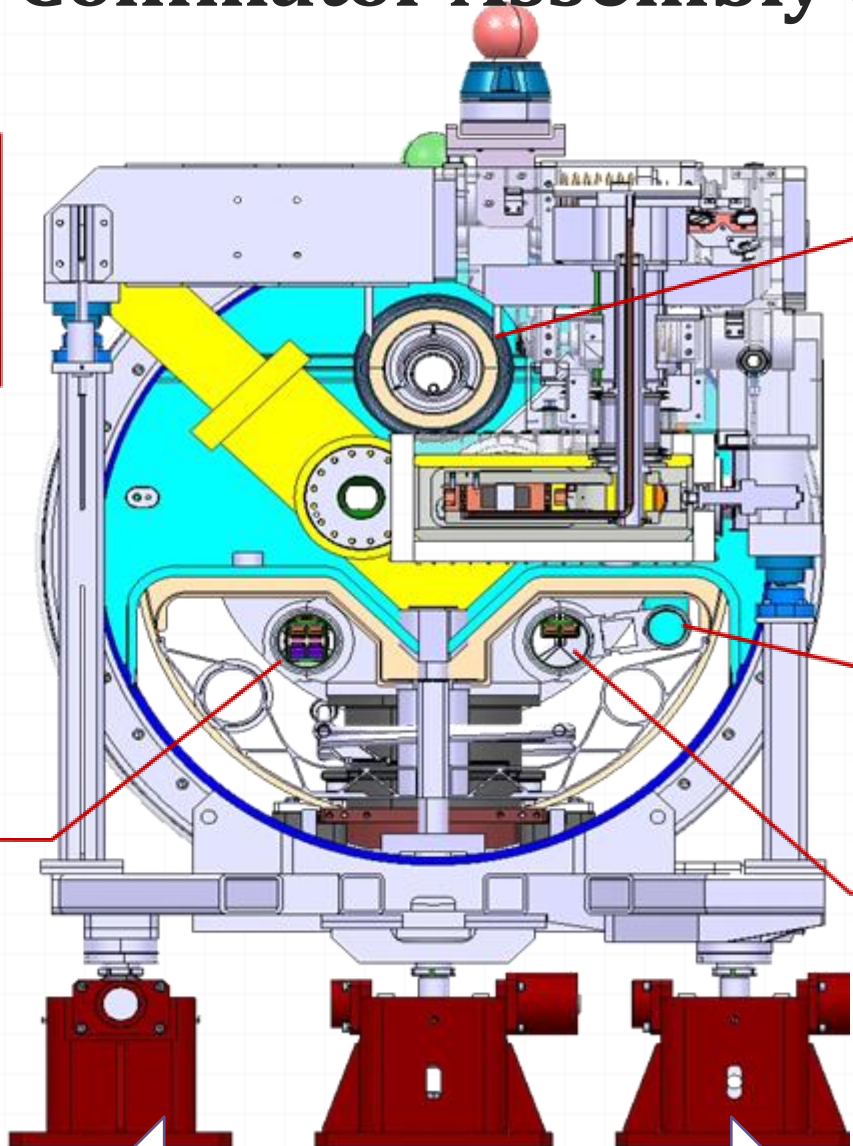
QTC Main Features (for details see **D.D. Ramos** talk 2011 QTC Review)



Heat Exchanger (X-line) going straight through (no bypass)

N-line auxiliary busbars

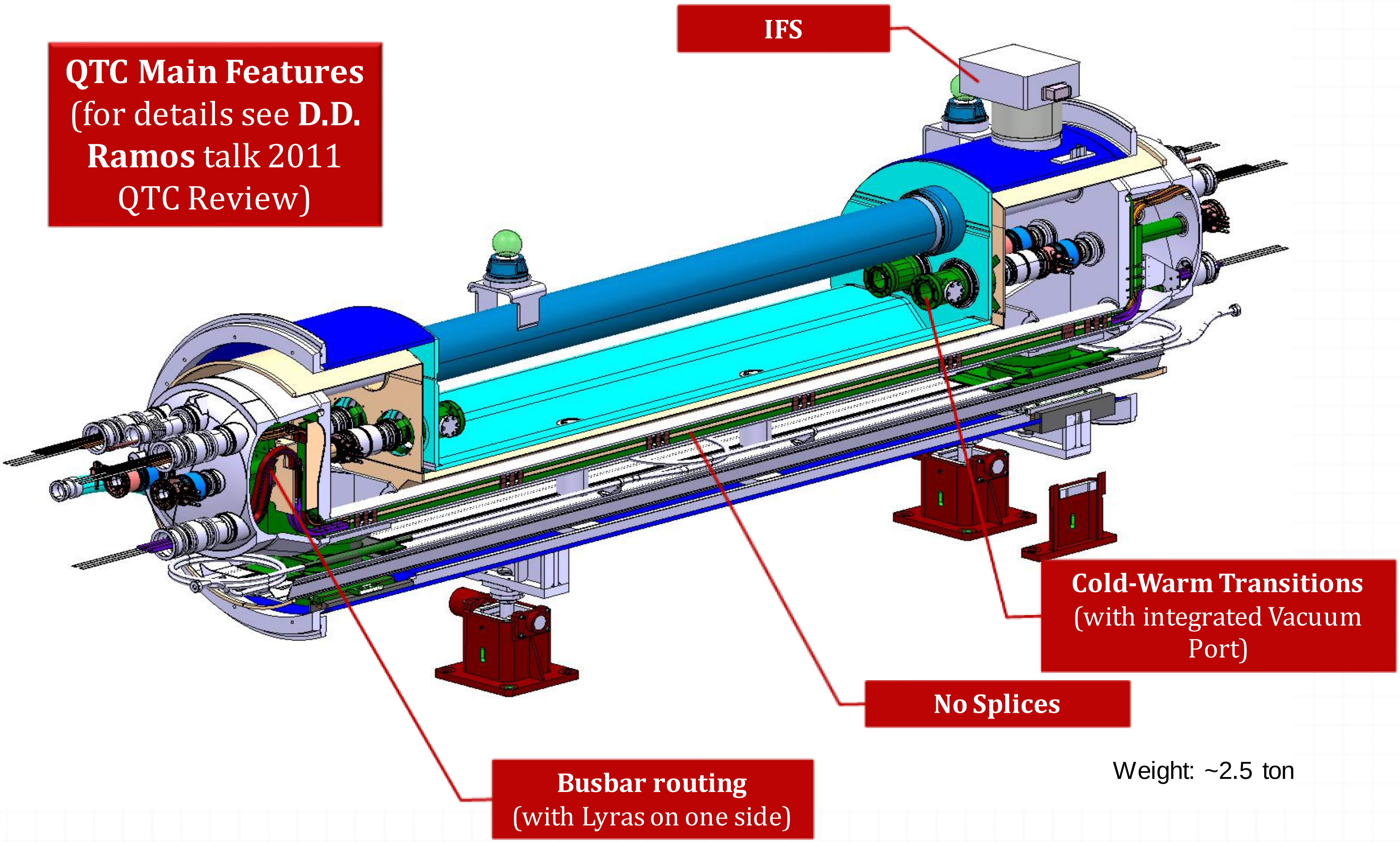
Bypass tube for M1 and M3 busbars

Bypass Tube 2 for M3 busbar

stay in the “shadow” of the arc cryostat

DS Collimator Assembly (LTC)

QTC Main Features
(for details see **D.D. Ramos** talk 2011 QTC Review)



Weight: ~2.5 ton

Back to 2011 Collimation Review ...

LHC Collimation Review 2011, report of the review committee

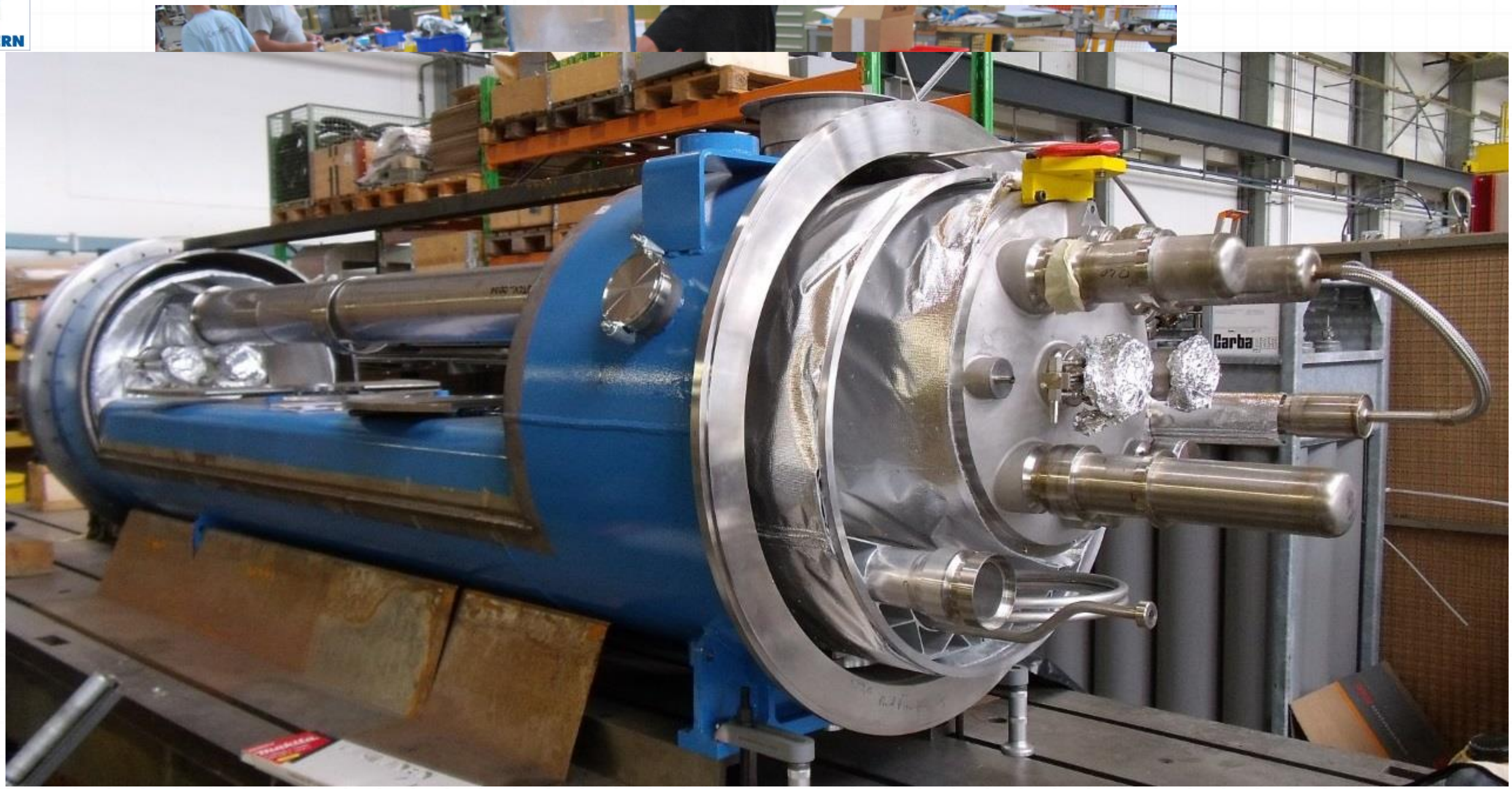
Review committee:

Tiziano Camporesi (CERN), Wolfram Fischer (BNL), Brennan Goddard (CERN), Mike Lamont (CERN), Thomas Markiewicz (SLAC), Nikolai Mokhov (FNAL), Mike Seidel (PSI, chair), Andrzej Siemko (CERN), Johannes Wessels (U. Muenster)

The committee feels nevertheless that the upgrade of collimation in the IR3 and IR7 DS should be carried out in the long term (LS2) as it will allow for increased machine performance. The additional time should be used to complete a proper prototyping of the special cryogenic bypass module. The committee feels that the increased activation of the machine elements in the IR3 and IR7 DS region between LS1 and LS2 should not increase significantly the exposure risks.

- **2011 Collimation Review** recommended the manufacturing of a QTC prototype (without TCLD) and the completion of TCLD design and manufacturing drawing folders.

QTC Prototype



- **QTC** prototype is almost complete (addition of CWT expected in next weeks …)
- QTC concept is to get final qualification by **cold tests** expected in early **autumn 2013** in SM18 by TE/MSC (additional tooling required, to be designed and manufactured by EN/MME and TE/MSC …)

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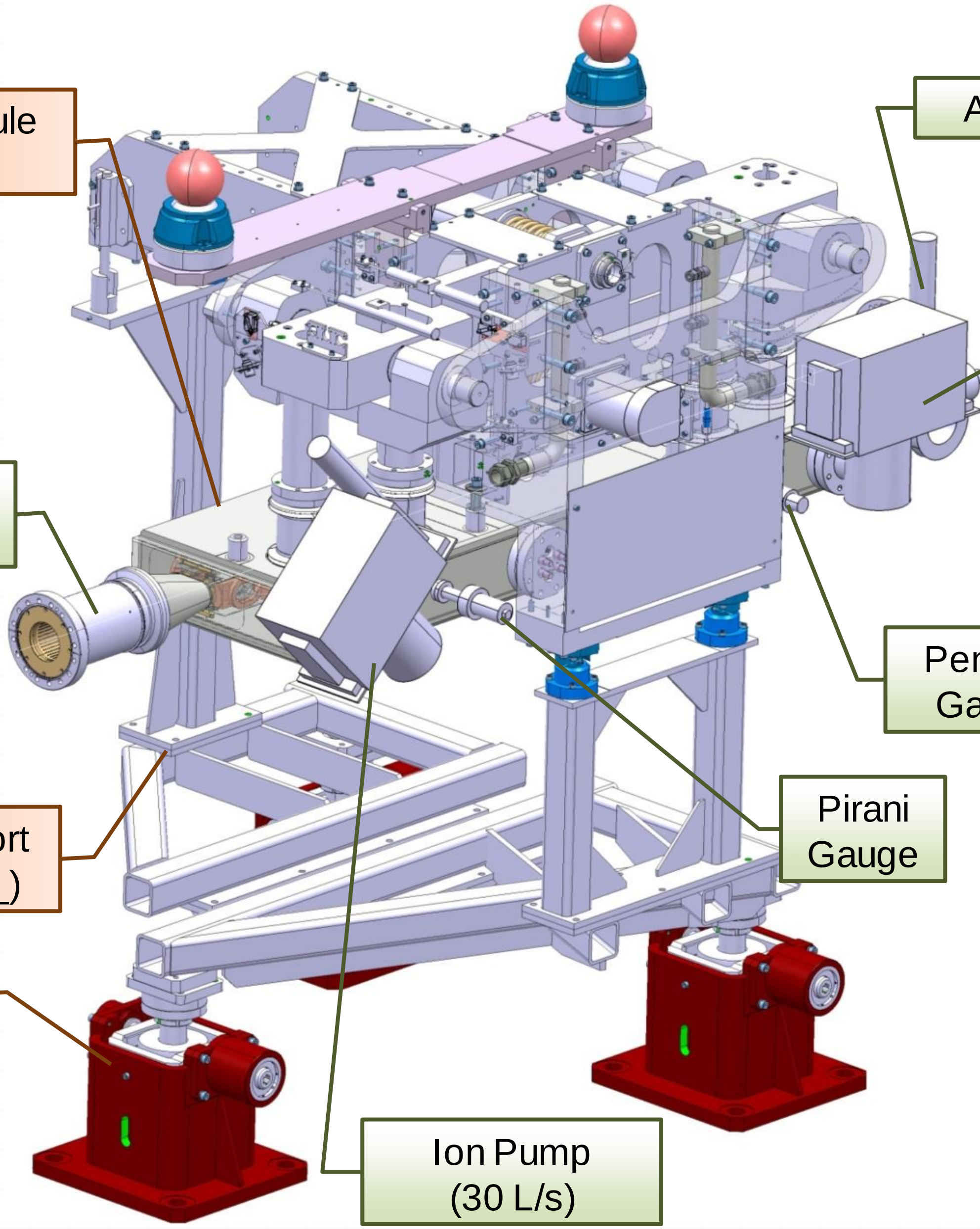
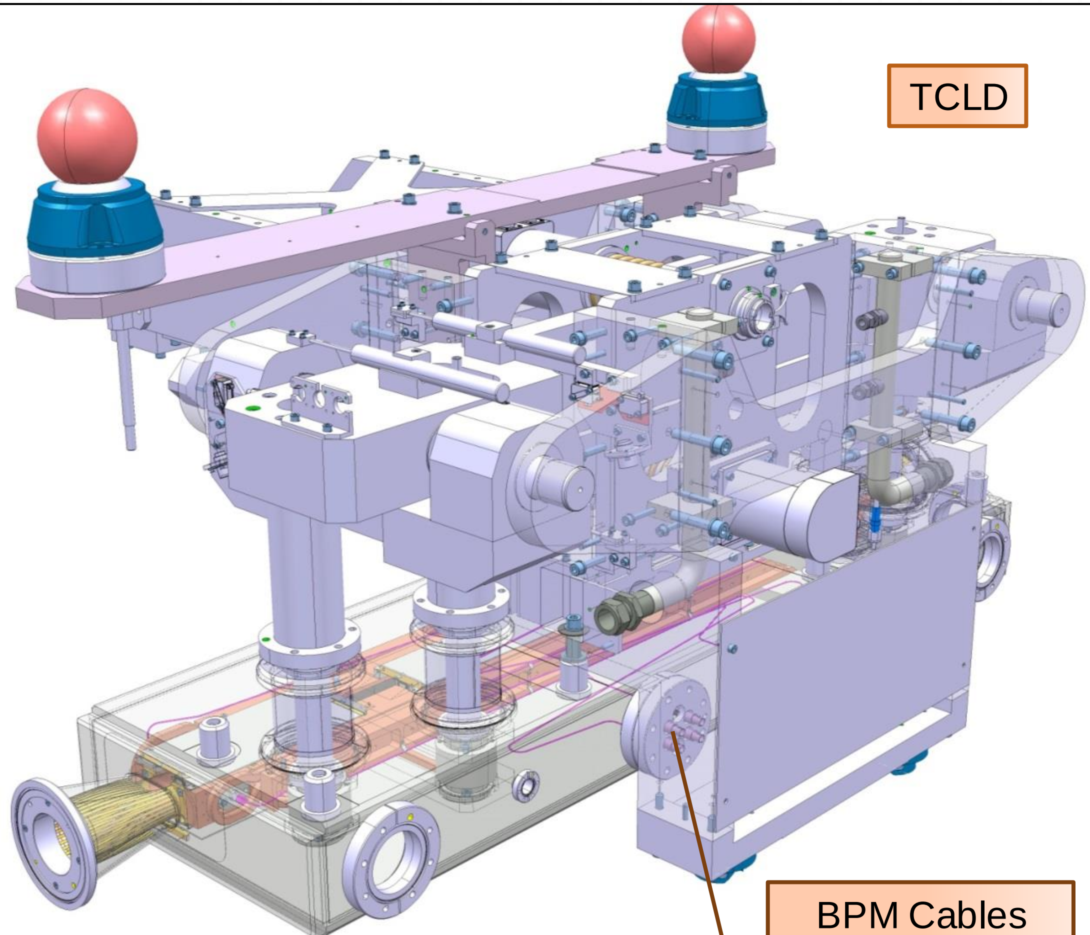
TCLD Layout (as presented in 2011)

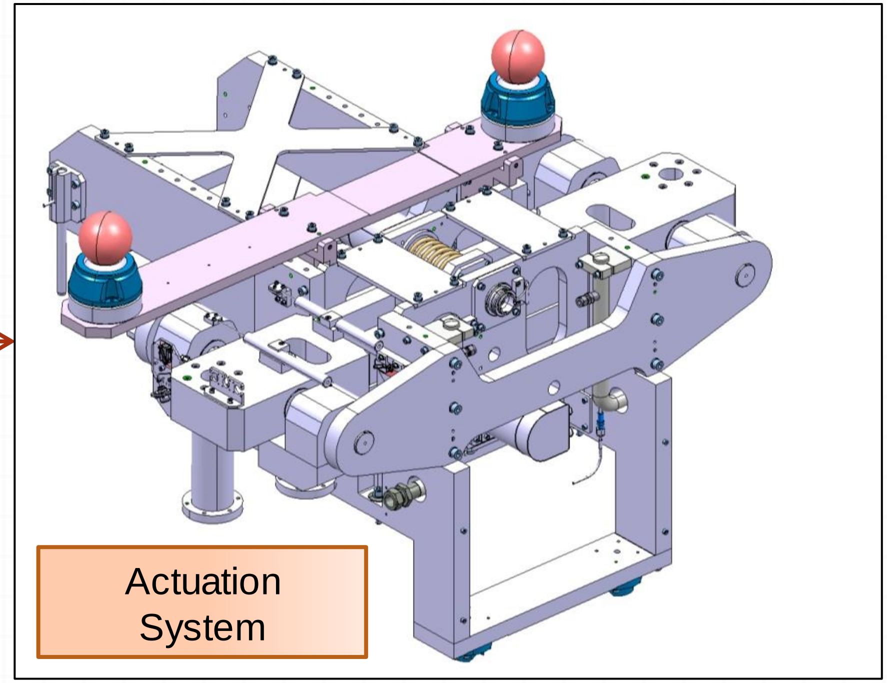


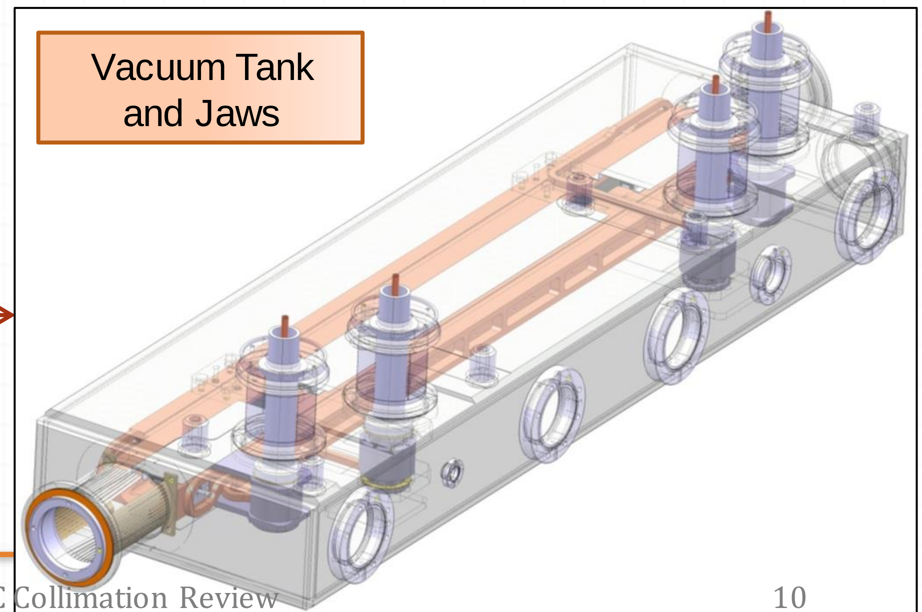
Key Features

- 2 jaws on 1 beam
- TCLD fully independent from QTC
- Pre-aligned TCLD Support for rapid positioning
- Horizontal Orientation
- Hydraulic and electrical manual connections
- On-collimator vacuum equipment

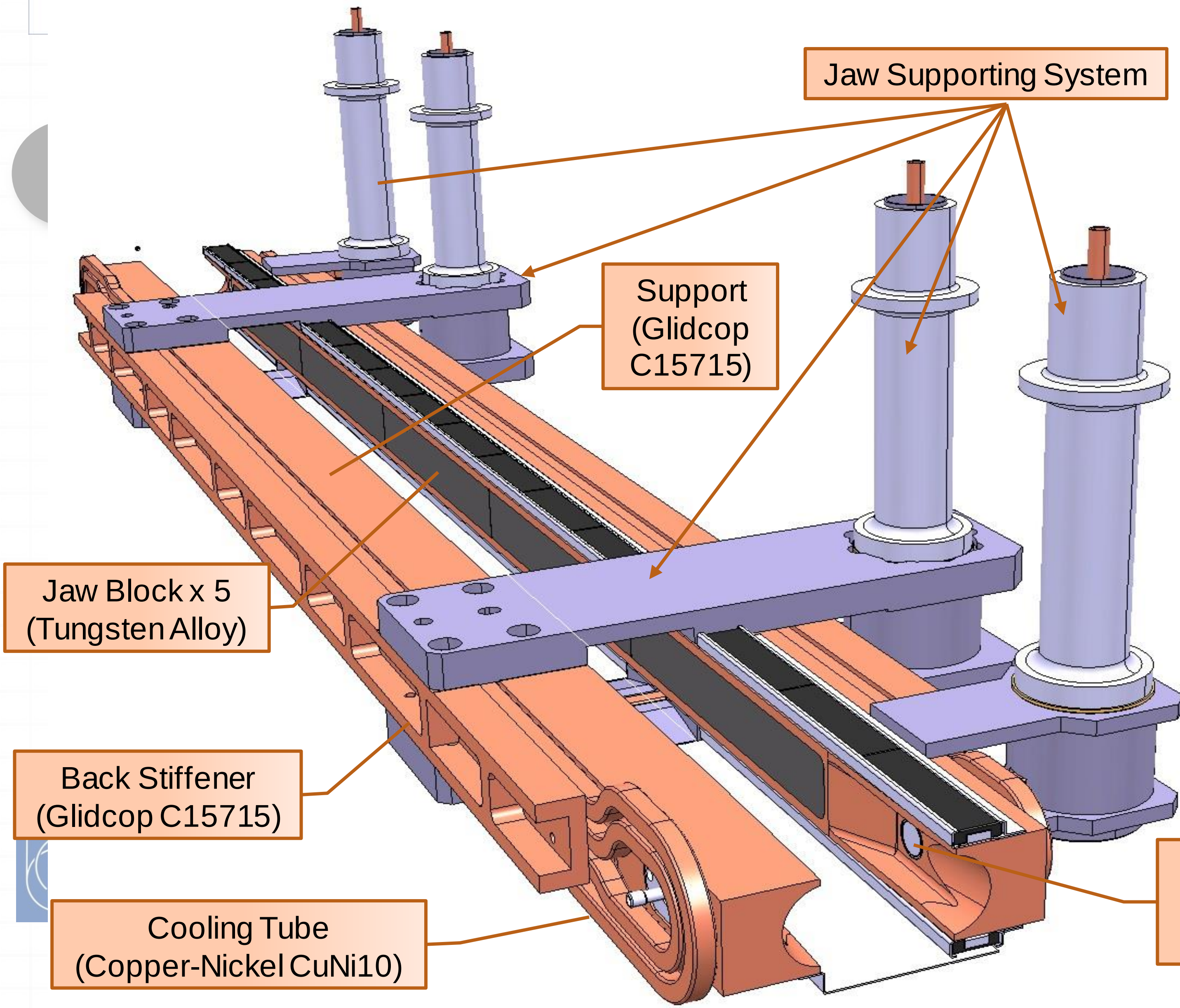
TCLD Product Breakdown







TCLD Jaw Specification and Design (1/2)



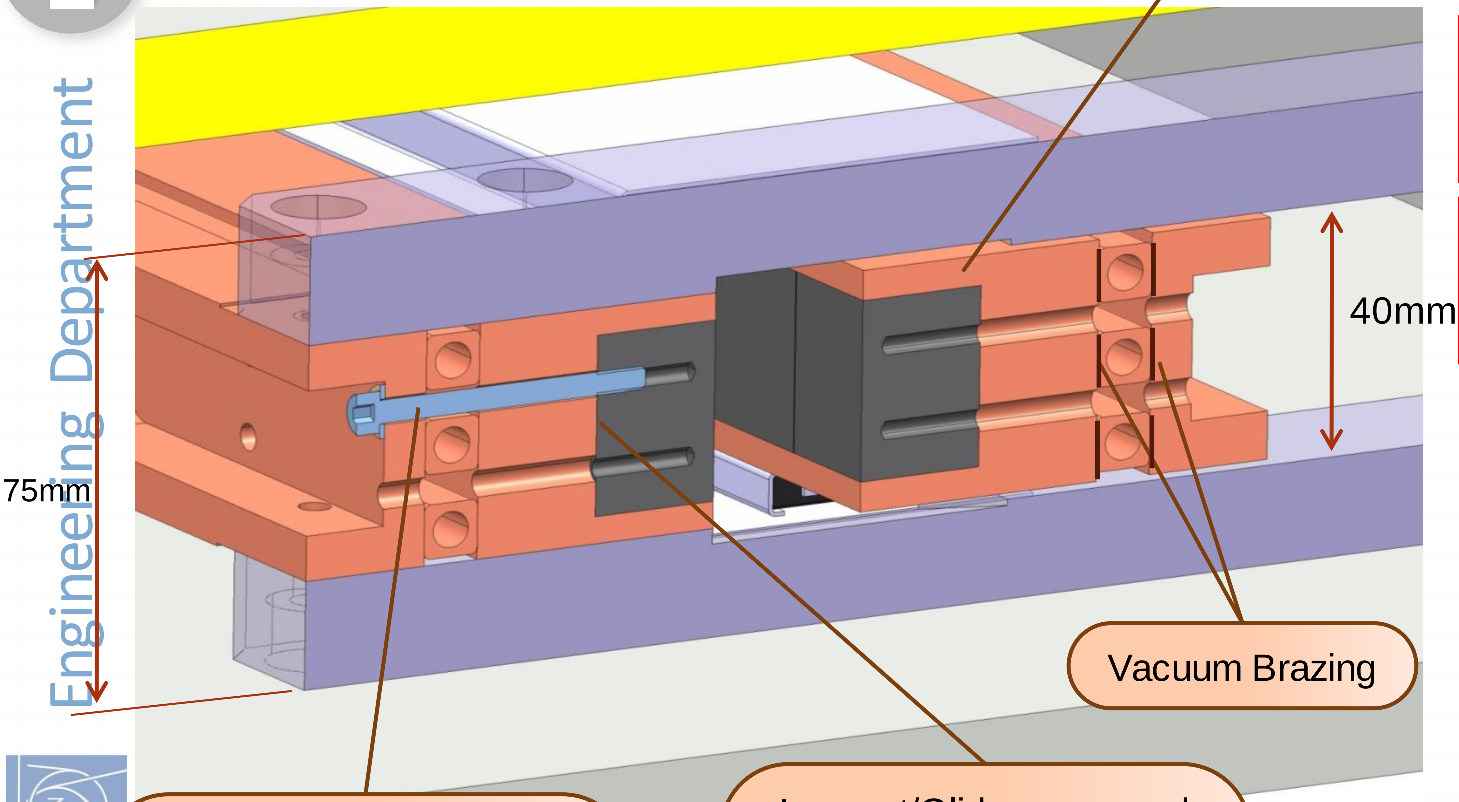
Key Features

- Total length: 1200 mm (including 100m tapering)
- Active length: 1000 mm (5 x 200 mm Blocks)
- Cantilevered jaw supporting system
- Continuous cooling circuit
- BPM pickups: 2 per jaw
- Temperature Diagnostics (2 PT100 per jaw)

Critical Features

TCLD Jaw Specification and Design (2/2)

Jaw assembling principles



Key Features

- Block width: 20 mm
- Block height: 30 mm
- Block material: 95%W+3.5%Ni+1.5%Cu (Inermet 180)
- Vacuum Brazing between support, cooling pipe and stiffener
- Water Flow rate: ≤ 5 L/min (3 m/s)
- Water Inlet Pressure 9÷16 bar
- Test pressure 50 bar

Critical Features

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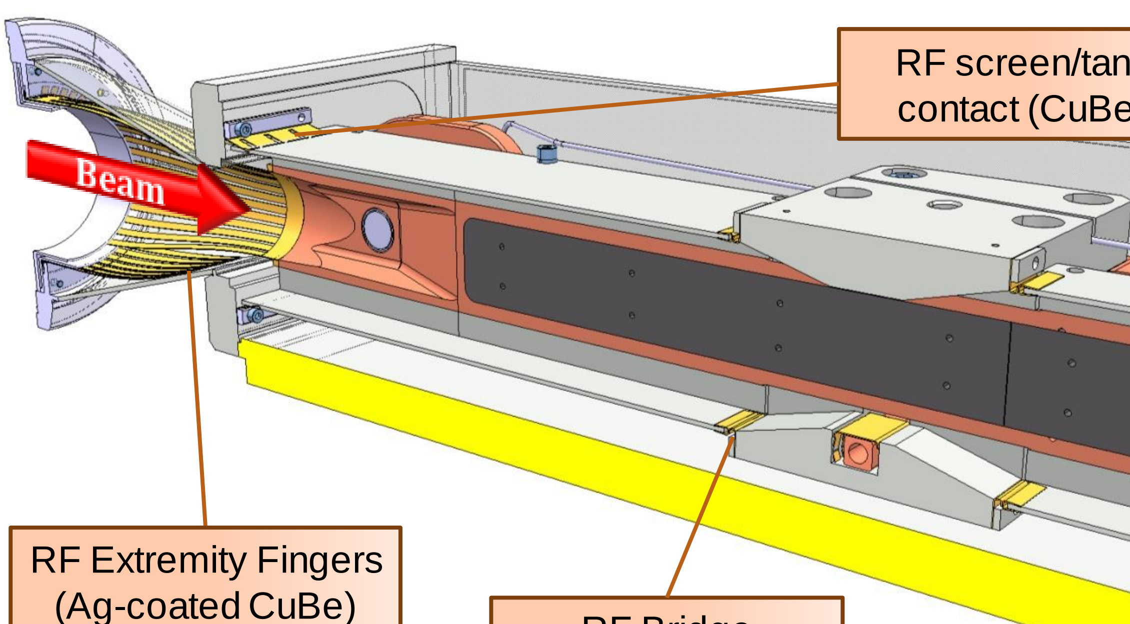
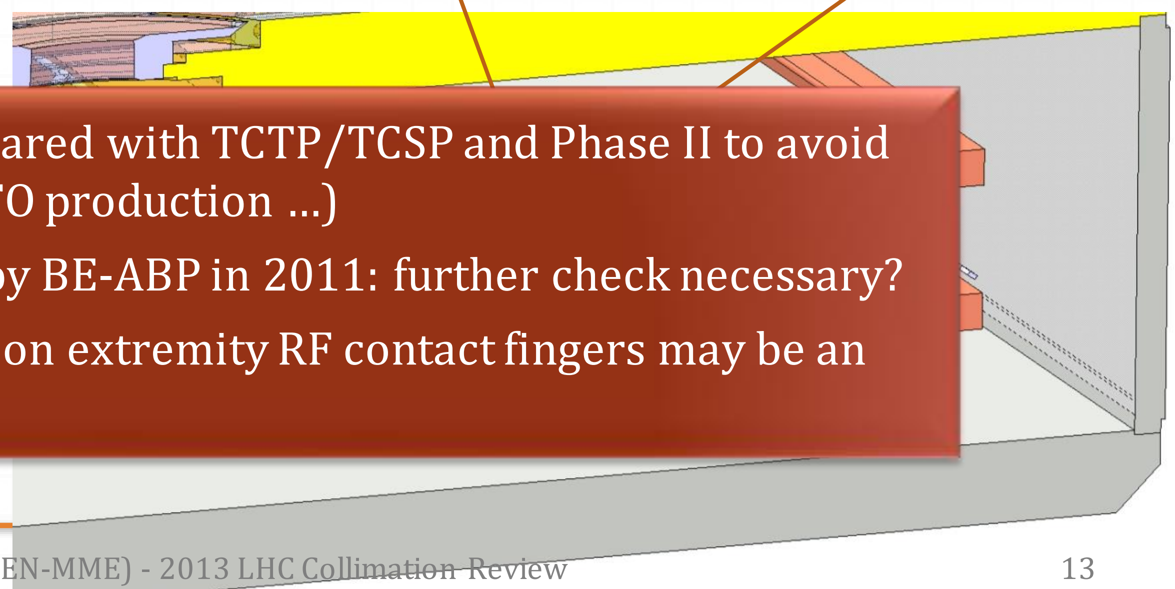
TCLD RF System Specification and Design





Key Features

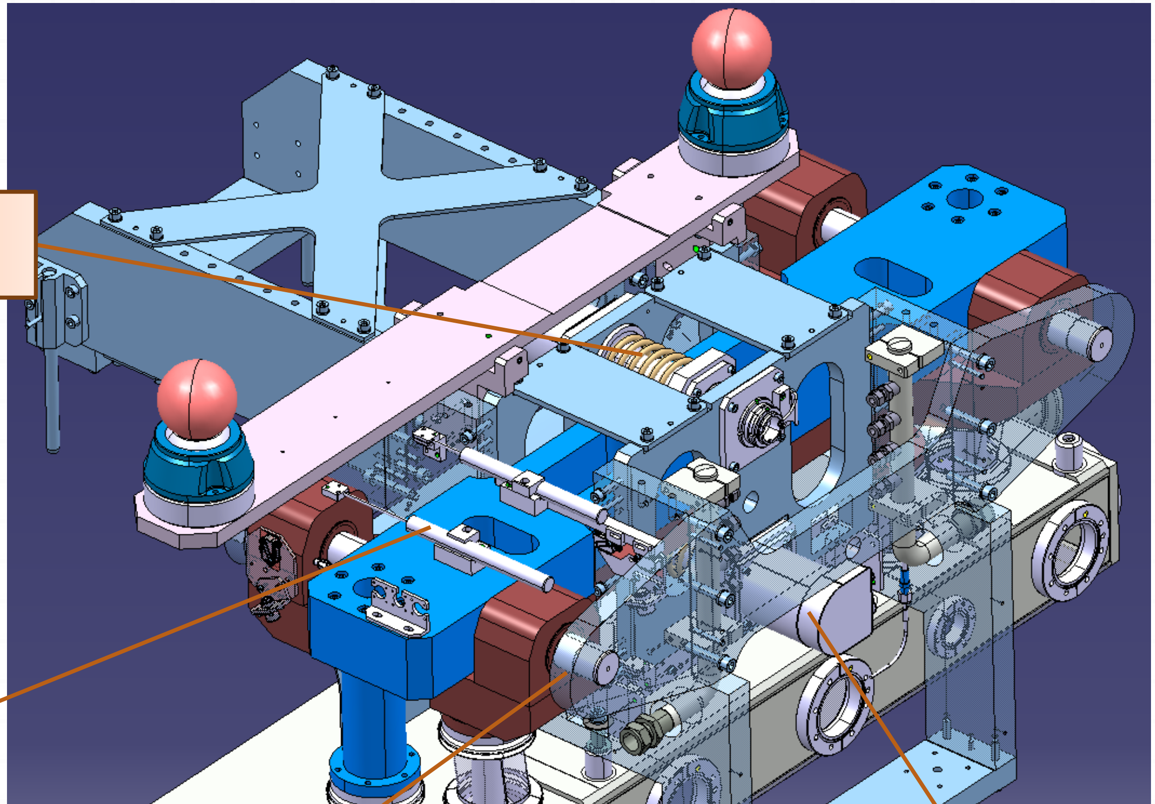
- Contactless RF shielding (Ferrites) with RF Bridge
- Contact Fingers on jaw extremities

Critical Features

- Ferrite-based RF system shared with TCTP/TCSP and Phase II to avoid sliding contacts in UHV (UFO production ...)
- TCLD RF design validated by BE-ABP in 2011: further check necessary?
- Strong shape discontinuity on extremity RF contact fingers may be an issue ....

Engineering

TCLD Actuation System



- Auto-retraction can be limited by motor detent-torque
- It does not work in case of short-circuited motor

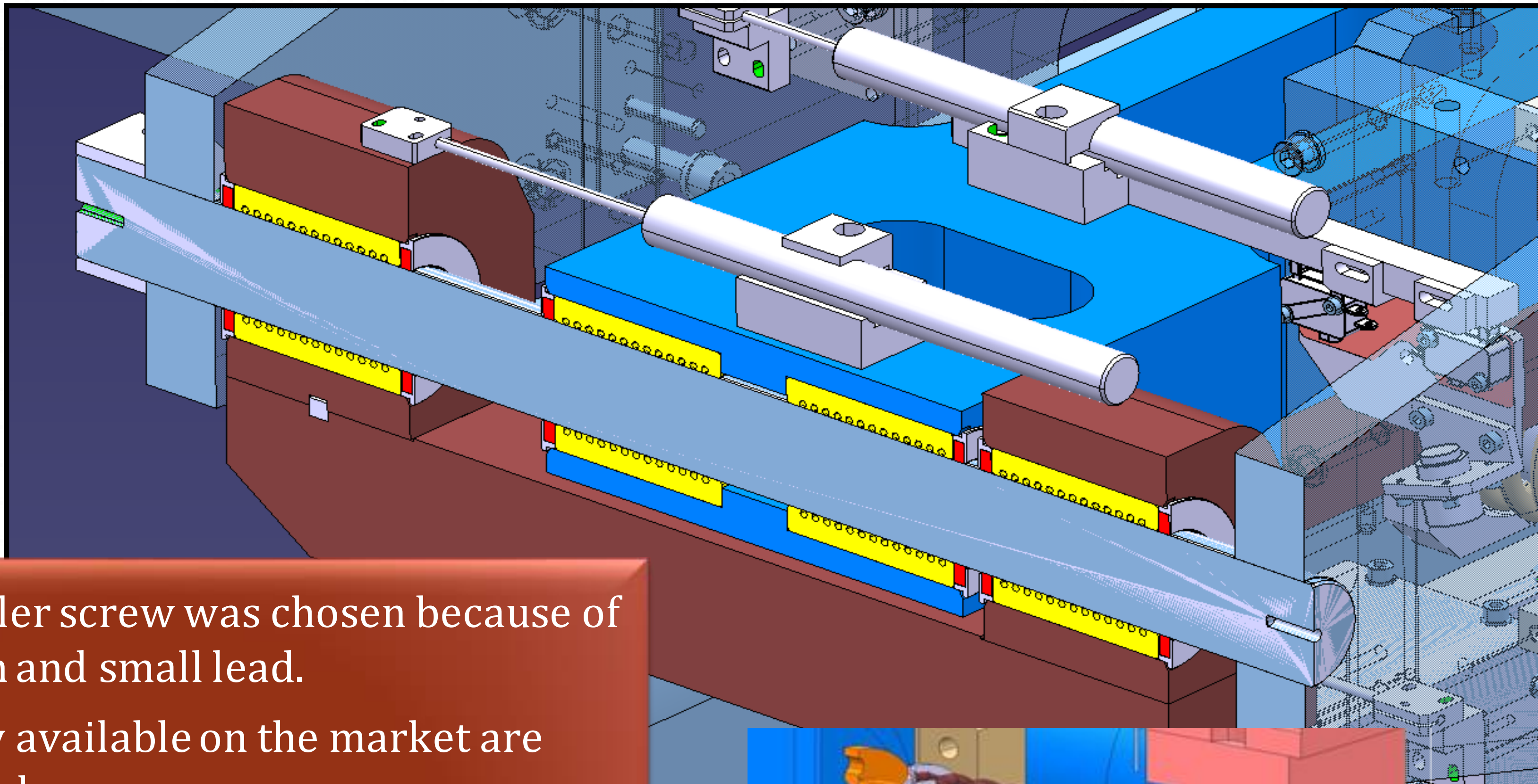
Key Features

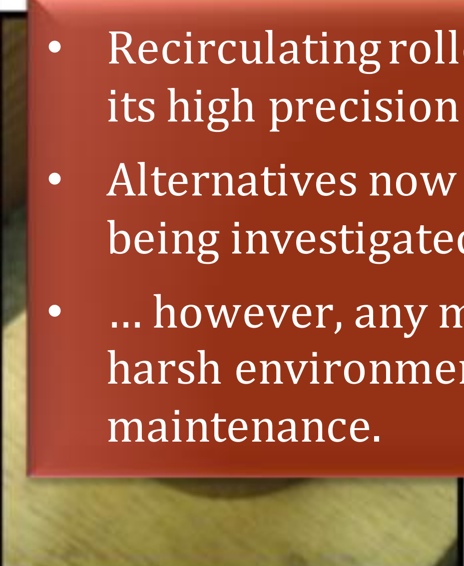
- 1 D.o.F per jaw (1 motor, no angular adjustment)
- Jaw stroke: 25 mm
- Jaw auto-retraction up to ~ 170 mNm (no auto-retraction in case of motor short-circuit)
- Phase 1 Stepping Motors and Electronics

Critical Features

TCLD Actuation System

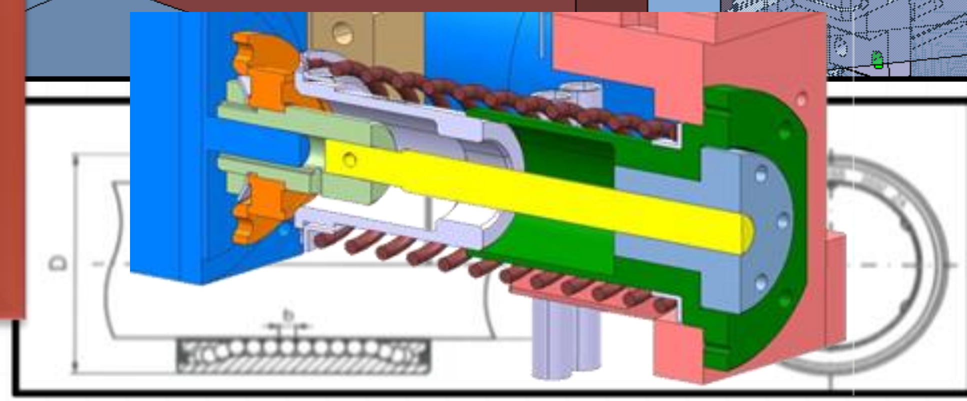
- All-metal sealed Linear Ball Bearings
- Graphite Dry Film Lubricated (DAG 156)
- Graphite Sealing Ring





- Recirculating roller screw was chosen because of its high precision and small lead.
- Alternatives now available on the market are being investigated ...
- ... however, any moving system (particularly in harsh environment) requires regular maintenance.

(tested on Phase 2 Table for 30000 cycles)



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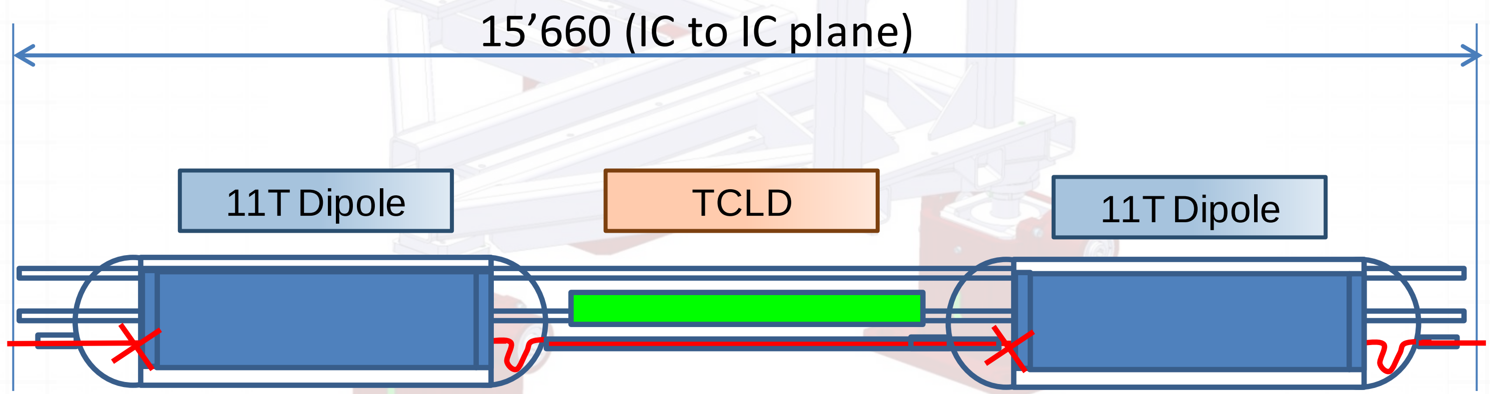
TCLD: Options and Future Outlook

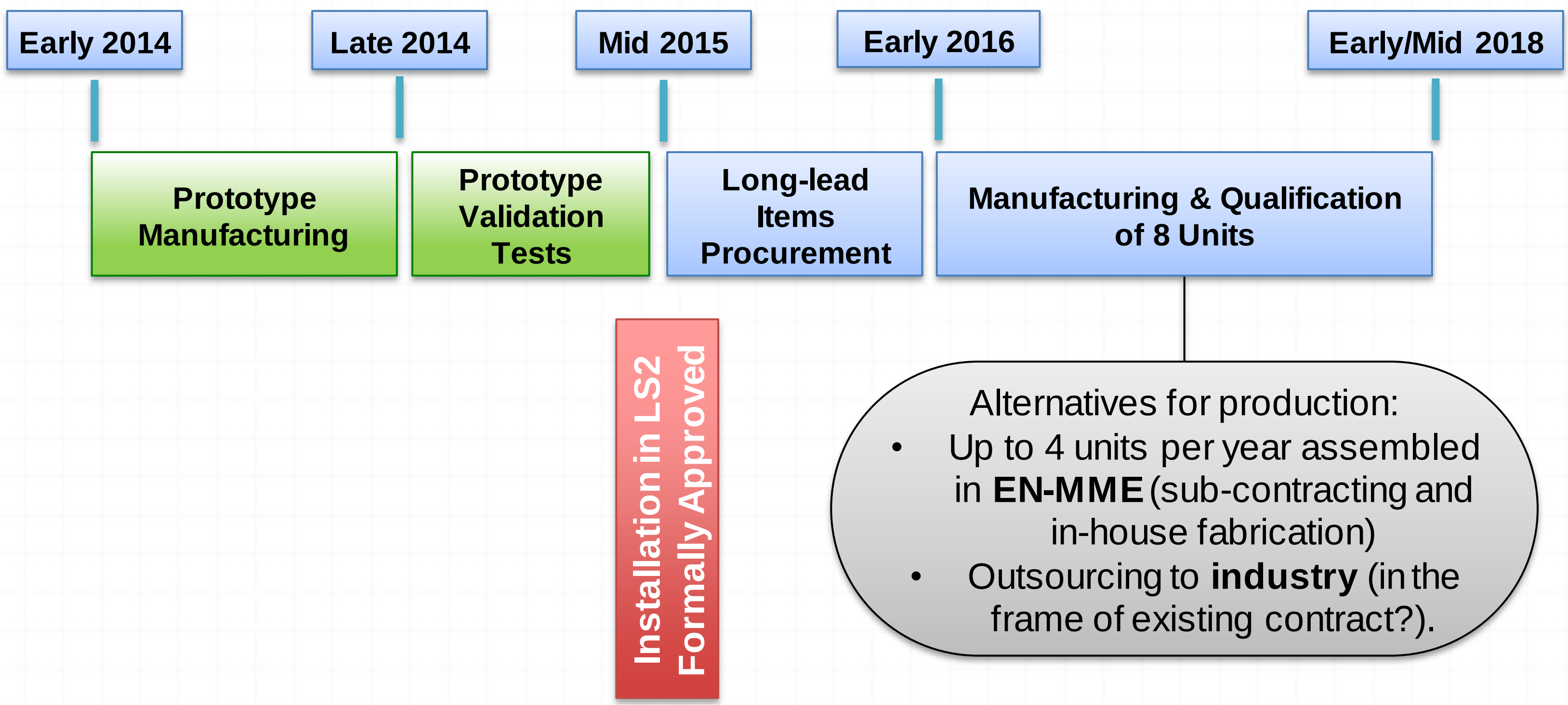
- **Two** main **options** are considered in view of TCLD possible installation, assuming up to **8 TCLD units** are required by **LS2**:

1. **Length of TCLD jaw remains unchanged** (1 m active length, 1.2 total length)
2. **Length of TCLD can and must be reduced** (down to 0.6 m active length?), e.g. to match space allowance permitted by 11 T Dipole design once validated by Physics.



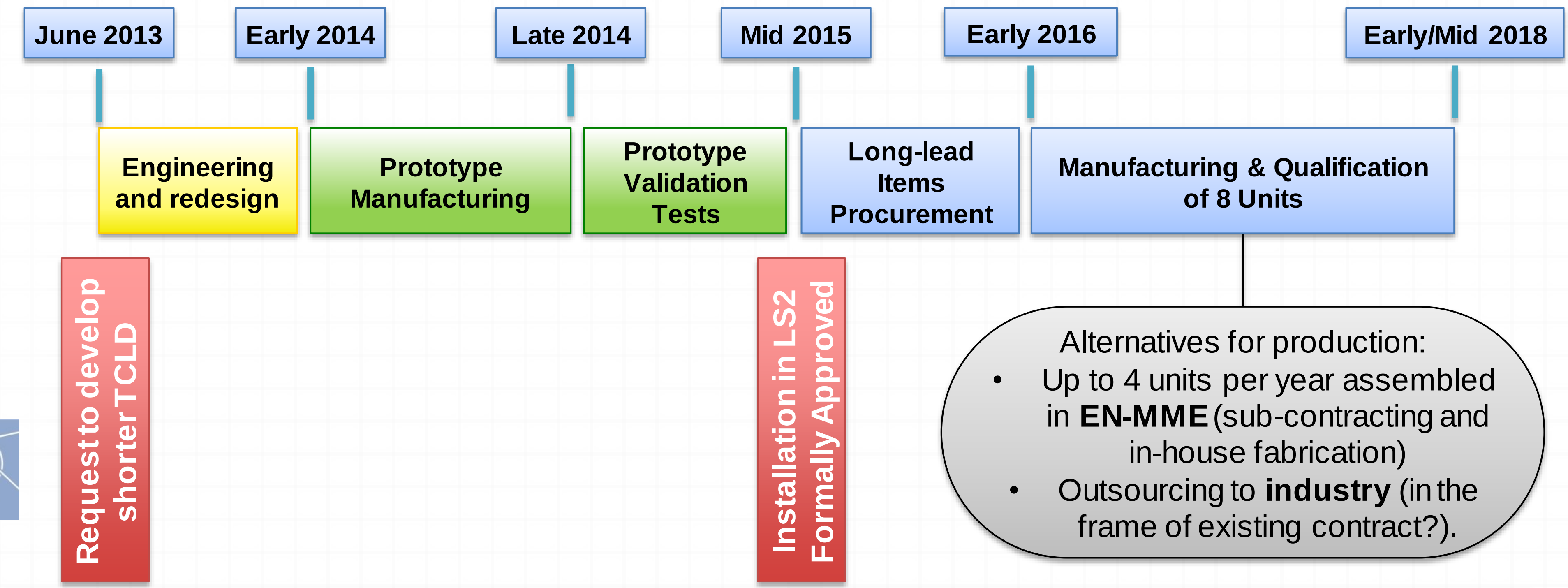
TCLD: Option 1 (1 m jaw length)

- Manufacturing drawing folder exists and needs only limited design work to be completed/validated (mainly on tooling).
- In view of some critical/unknown features in design, it is **proposed to build a full TCLD prototype**.



TCLD: Option 2 (shorter jaw length)

- Present design does not allow to easily shrink jaw length.
- **Substantial redesign required** to reduce jaw length (**e.g. to 0.6 m active length ...**)
- At least **6 additional months for redesign and drafting.** If this is required and allowed by integration, cleaning, physics case, it should be confirmed now!



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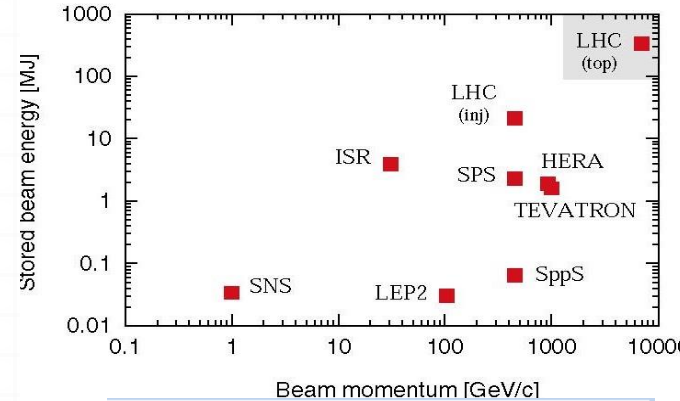
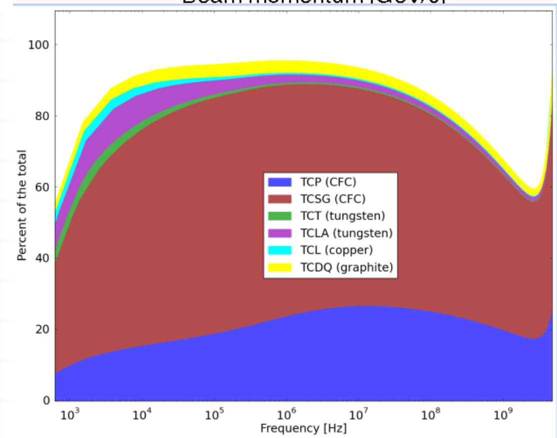
What’s next …

- Collimators and their materials for the HL-LHC era (including TCLD) will be submitted to a number of tougher/additional challenges …
- Maintain Phase I **robustness** in spite of increased nominal/accidental loads.
- Reduce Phase I **impedance** …
- Maintain functionality at **higher operating temperatures** …
- Increase **radiation hardness** …
- Tailor **cleaning efficiency** …
- Maintain/improve **geometrical stability** during CW losses …





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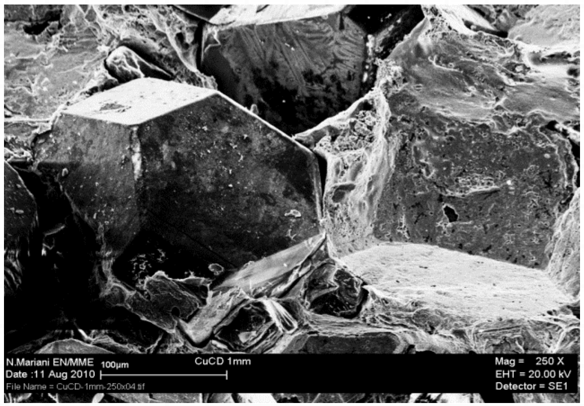
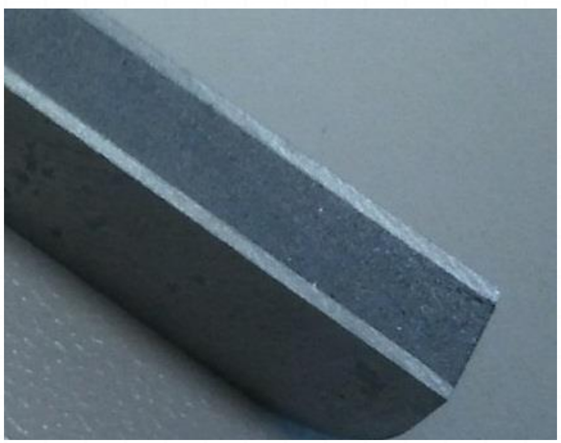
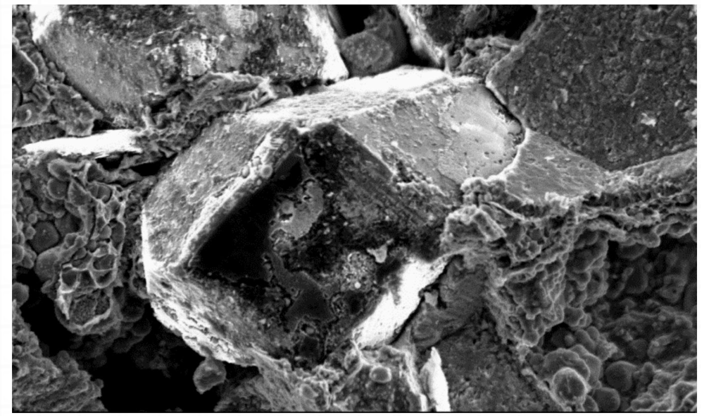
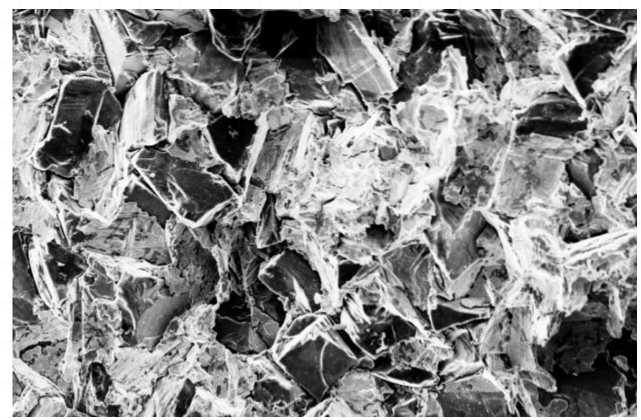
Novel Materials for Collimators

- **Metal Matrix Composites (MMC)** for advanced thermal management materials combine properties of Diamond or Graphite (high ***k,*** low ρ and low ***CTE***) with those of Metals (**strength**, γ, etc.)
- Candidate materials include **Copper-Diamond** (CuCD), **Molybdenum-Copper-Diamond** (**MoCuCD**), **Silver-Diamond** (AgCD), **Molybdenum-Graphite (MoGr)**









Novel materials for Collimators

Material	C-C	Mo	Glidcop ®	Cu-CD	Ag-CD	Mo-Gr all melted
Density [g/cm^3]	1.65	10.22	8.90	~5.4	~6.10	2.8
Atomic Number (Z)	6	42	29	~11.4	~13.9	8.3
T_m [°C]	3650	2623	1083	~1083	~840	~2520
SSNI [kWm2/kg]	24	2.6	2.5	13.1 ÷ 15.3	11.4 ÷ 15.4	83*
TSNI [kJ/kg]	793	55	35	44 ÷ 51	60 ÷ 92	195*
Electrical Conductivity [MS/m]	0.14	19.2	53.8	~12.6	~11.8	1 ÷ 18 **

** Estimated values*
*** with Mo coating*

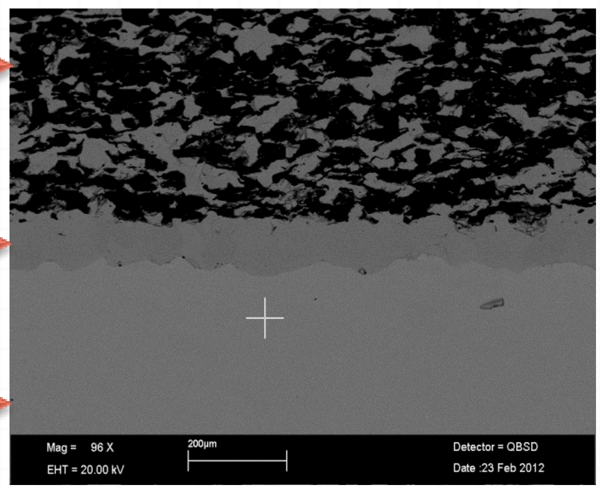
Steady-state Stability Normalized Index: $\frac{k}{\rho\alpha}$

Transient Thermal Shock Normalized Index: $\frac{R(1-\nu)c_{pv}}{E\alpha\rho}$

Core: 1 MS/m

Carbide layer: 1.5 MS/m

Mo Sheet: 18 MS/m

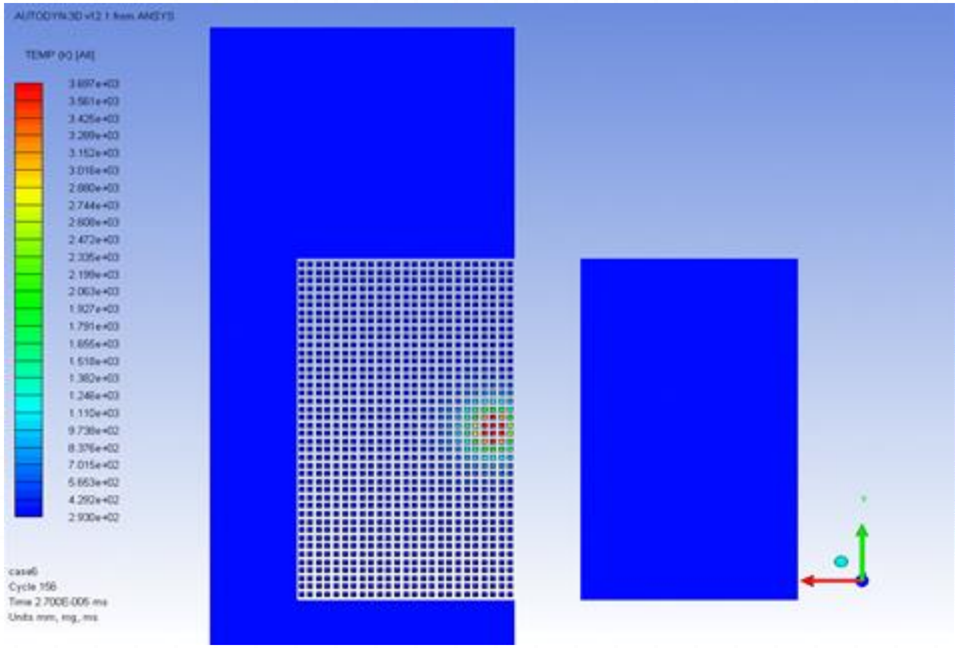


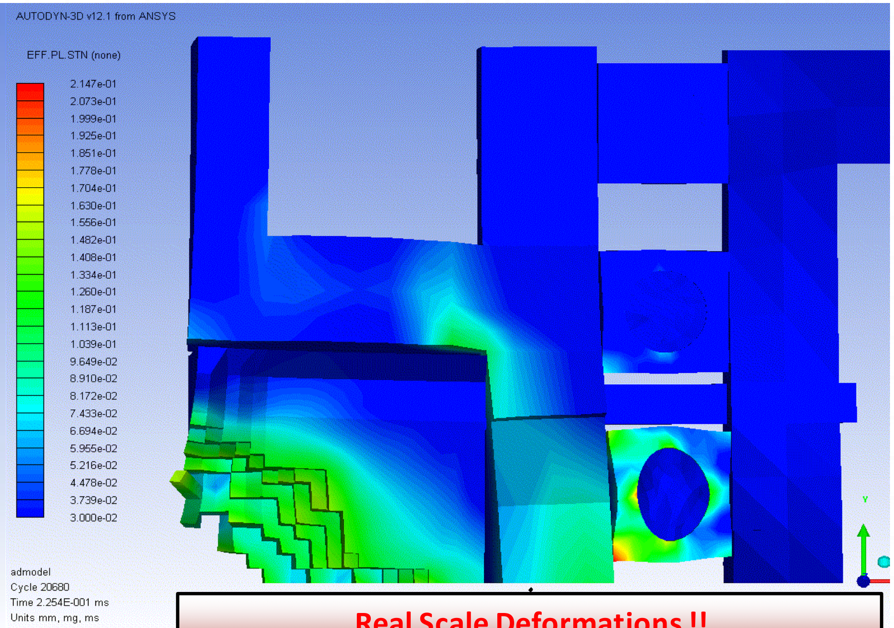
…see N. Mounet's talk: Mo coating to decrease impedance by a factor 10

Example: Accident on TCTA

Simulation of 8 LHC bunches at 5 TeV impacting a Tungsten Jaw

- Probability of **water leakage** due to very severe plastic deformations on pipes.
- Impressive **jaw damage**:
  - Extended eroded and deformed zones.
  - **Projections** of hot and fast solid tungsten bullets (**T≈2000K**, $\mathbf{V_{max} \approx 1\ km/s}$) towards opposite jaw. Slower particles hit tank covers (at velocities just below ballistic limit).
  - Risk of “bonding” the two jaws due to the projected re-solidified material.





Real Scale Deformations !!

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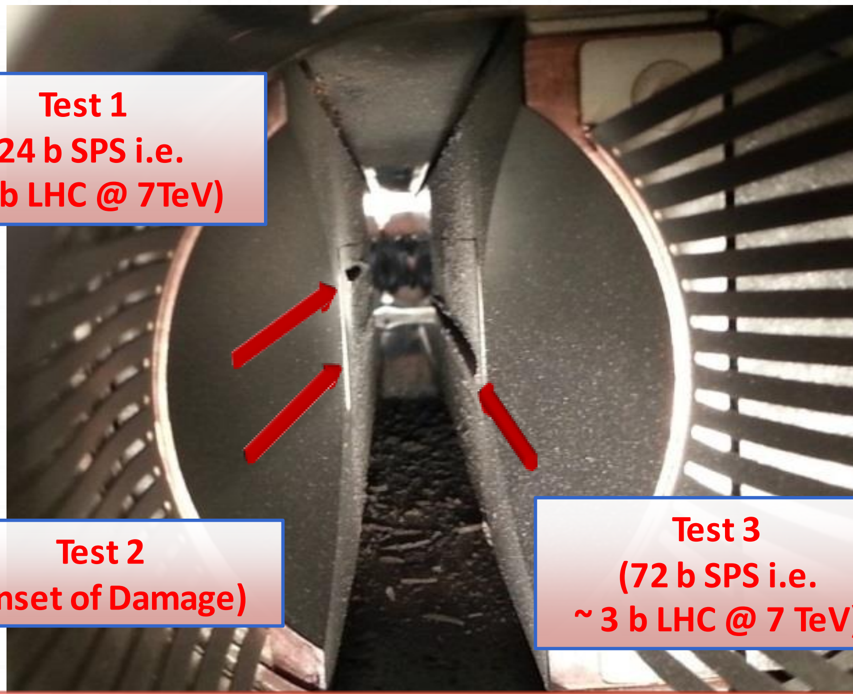
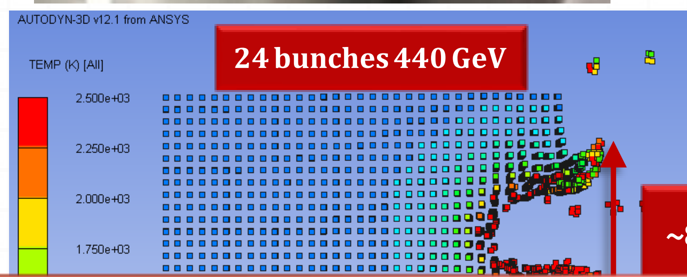
Results of Simulations and Experiments

- Recent experiments (**HRMT-09** and **HRMT-14**) have confirmed that a fraction of a 7 TeV bunch is sufficient to permanently damage Tungsten (Inermet 180)

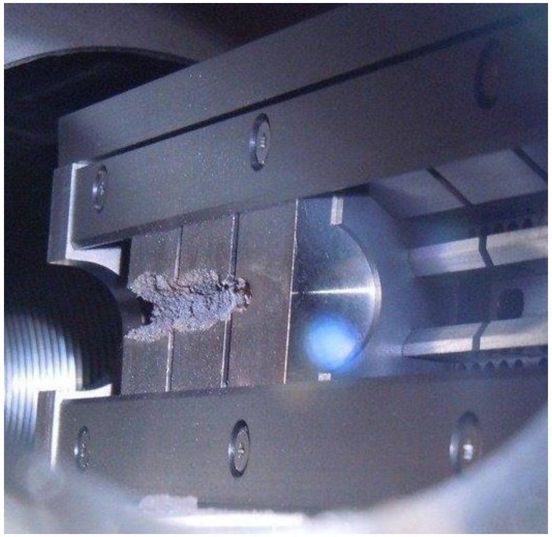




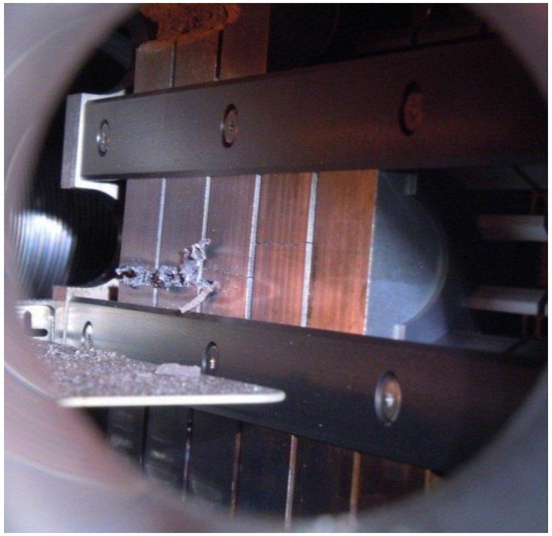
Damage limits at 7 TeV for W jaws presented at MPP Workshop Annecy '13:

- Onset of plastic damage : $5x10^9$ p
- Limit for jaw fragment ejection: $2x10^{10}$ p
- Limit for 5th axis compensation (with fragment ejection): $1x10^{11}$ p

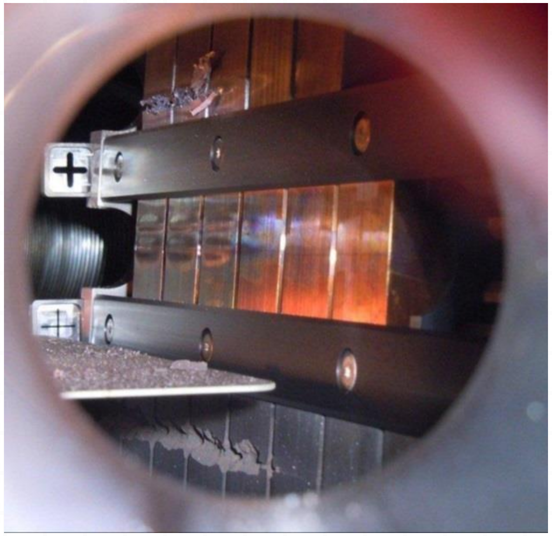
Results of Simulations and Experiments



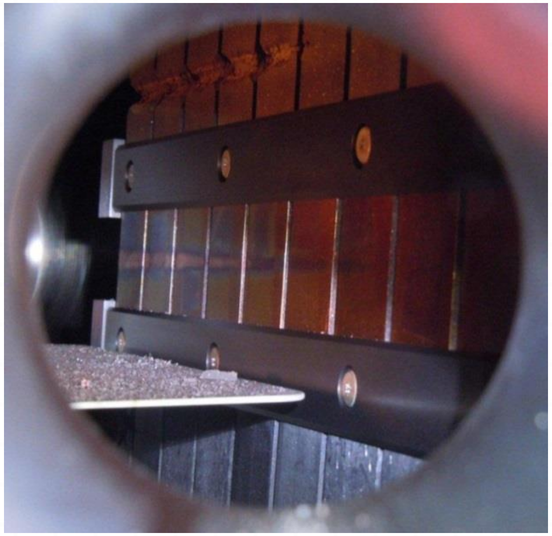
Inermet 180, 72 bunches



Molybdenum, 72 & 144 bunches

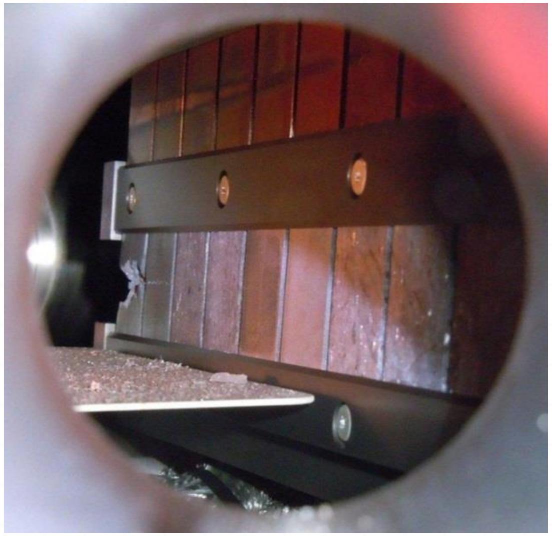


Glidcop, 72 bunches (2 x)



Copper-Diamond
144 bunches

Molybdenum-Copper-Diamond
144 bunches



Molybdenum-Graphite (3 grades)
144 bunches

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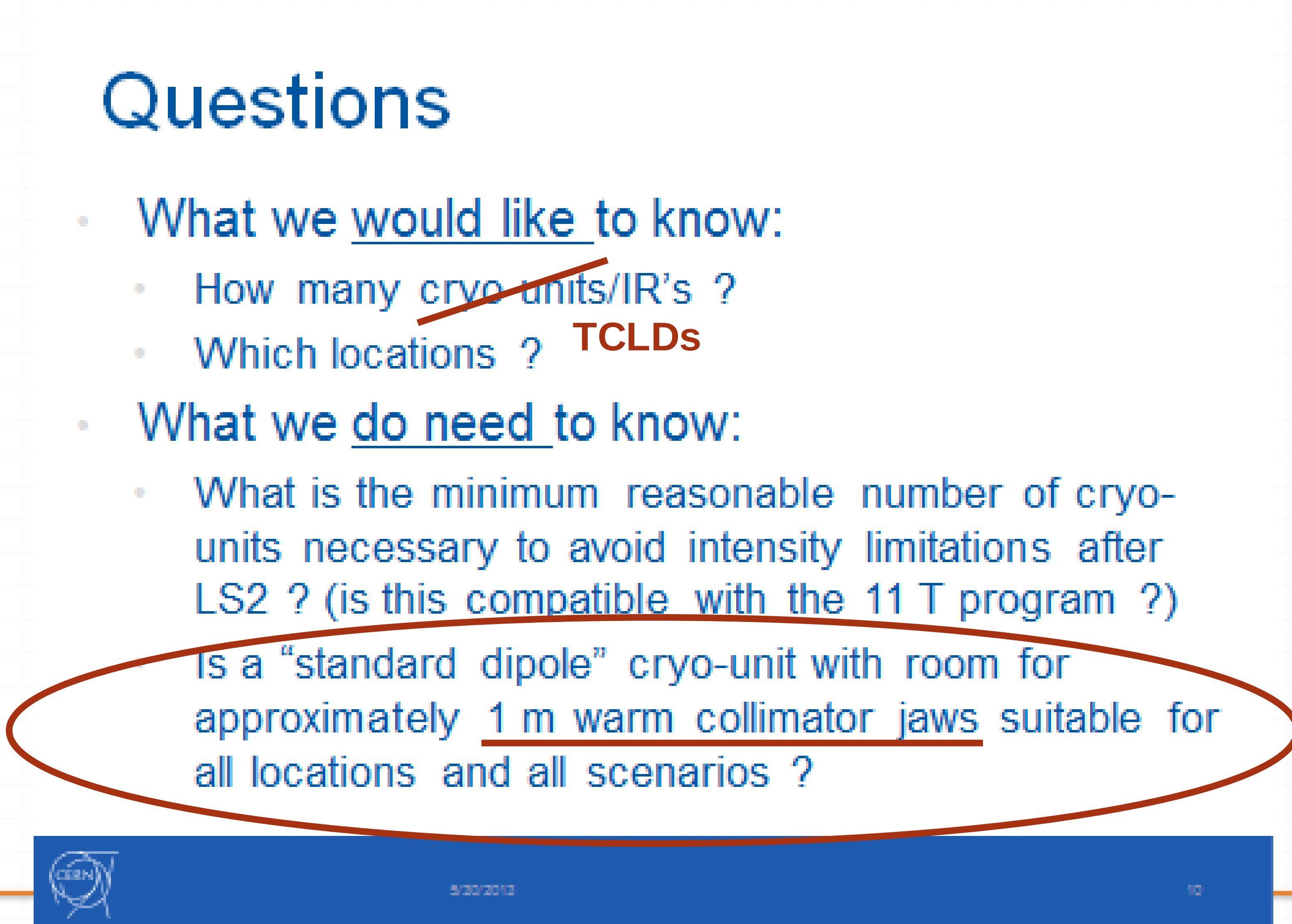
Summary

- **TCLD design is practically complete** and is based on 1 m Tungsten (Inermet 180) Jaw.
- A number of **critical or unknown design features** suggest the manufacturing of a **full TCLD prototype** (as already done for QTC) **in 2014** to anticipate possible issues.
- If jaw length can and must be reduced (down to 0.6 m), an **additional design/drafting effort** is necessary (6+ months): this request should be raised now.
- Assuming a request for 8 units to be installed during LS2, **production can be carried out in 2016/17** either **in house** (with subcontracting) or outsourced **to industry**.
- Recent experiments have confirmed tungsten can be damaged by a fraction of 1 LHC bunch: if simulations anticipate this risk, an engineering / design effort should be launched asap.

Questions

- You may have already seen this slide …

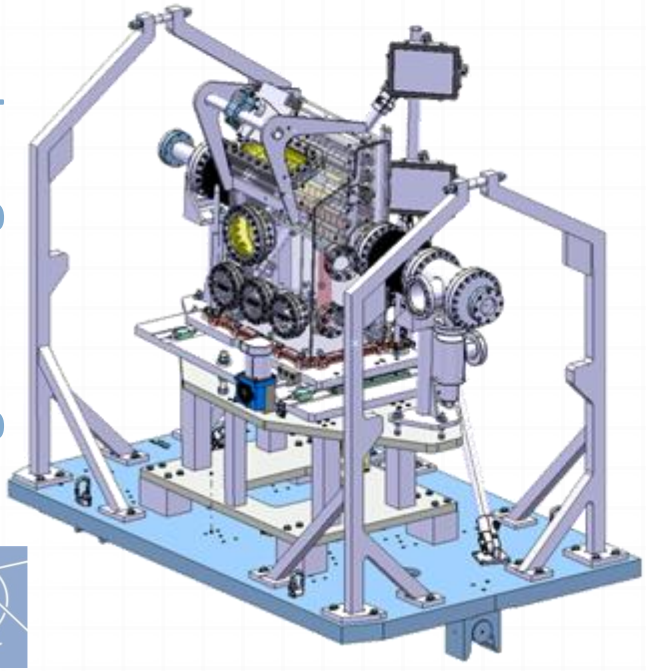


Thank you for your attention!

… additional “entertainment” follows

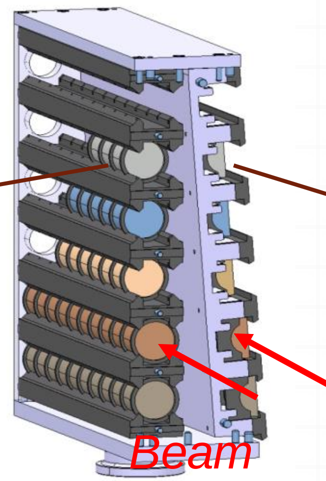
HRMT14: Experiment Goals and Setup

- **Benchmark** advanced numerical simulations and **material constitutive models** through extensive acquisition system.
- Characterize **existing** and **novel materials** currently under development for Phase II Collimators: Inermet180, Molybdenum, Glidcop, MoCuCD, CuCD, MoGR.
- **Collect**, mostly in real time, **experimental data** from different acquisition devices (Strain Gauges, Laser Doppler Vibrometer, High Speed video Camera, Temperature and Vacuum probes).



Medium Intensity (Type 1 samples):

- Strain measurements on sample outer surface;
- Radial velocity measurements (LDV);
- Temperature measurements;
- Sound measurements.



High Intensity (Type 2 samples):

- Strain measurements on sample outer surface;
- Fast speed camera to capture fragment front formation and propagation;
- Temperature measurements;
- Sound measurements.

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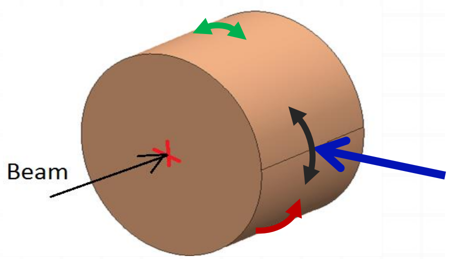
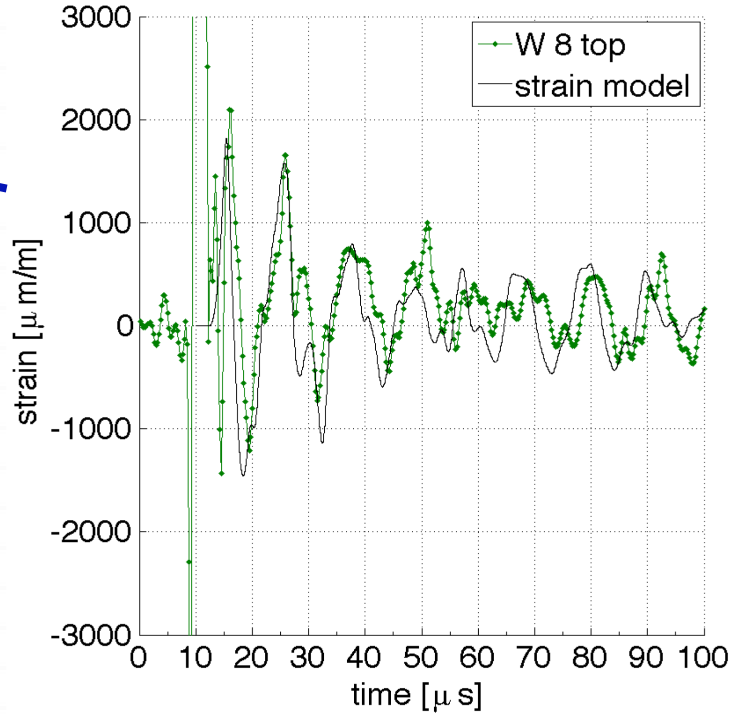
HRMT14: Medium Intensity Tests

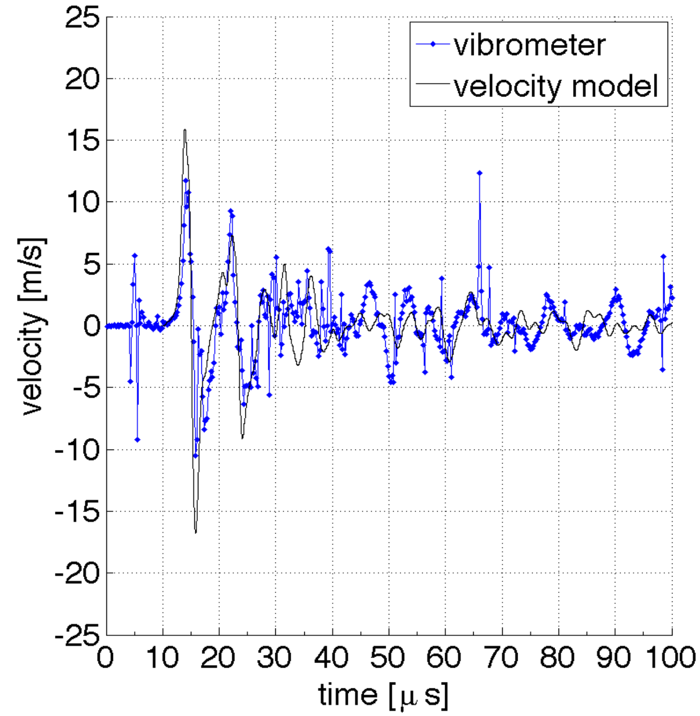
- Extensive numerical analysis (**Autodyn**), based on FLUKA calculations to determine **stress waves**, **strains and displacements**.
- Comparison of simulated **Hoop and Longitudinal Strains and Radial velocity** with measured values on sample outer surface.



Inermet180
24 b (scraped)

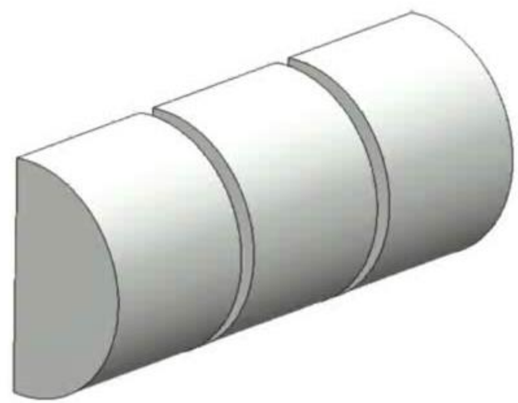
Total intensity:
2.7e12 p
σ ≅ 1.4 mm





HRTM14: High Intensity Tests

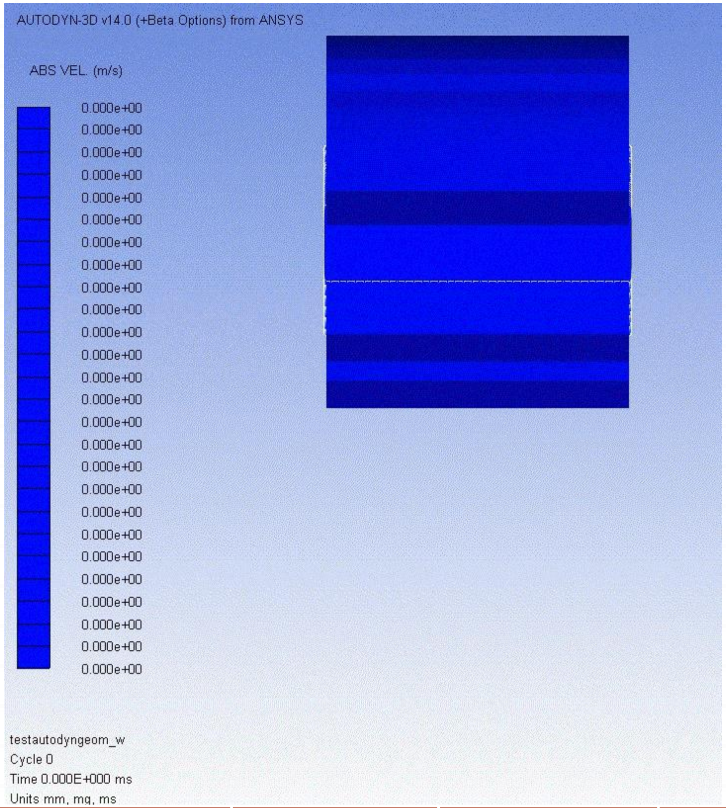
Inermet samples as seen from viewport and camera

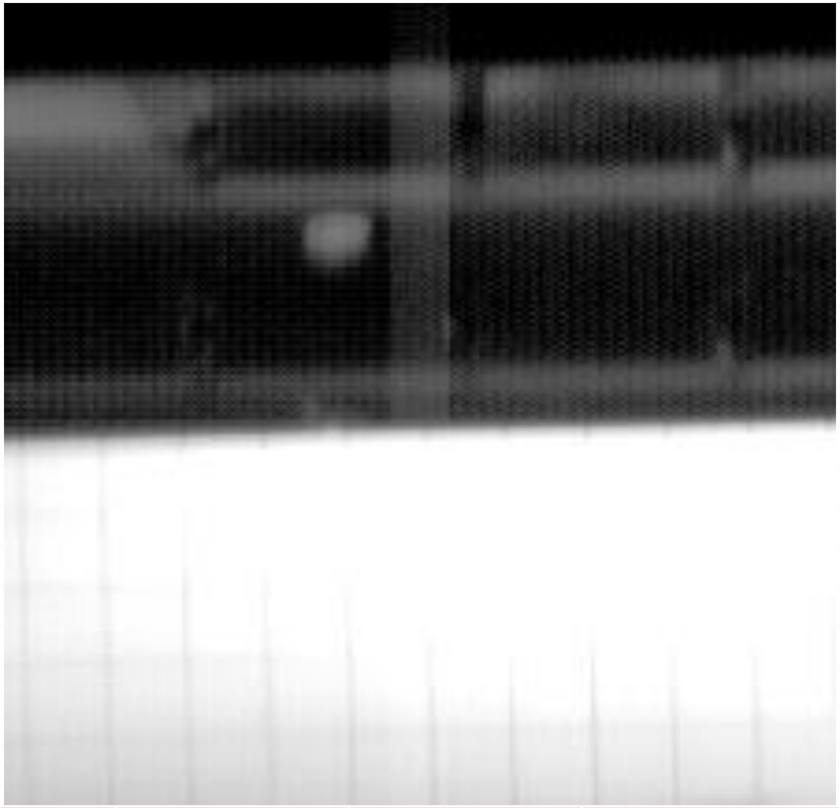


HRMT14: High Intensity Tests

Inermet : comparison Autodyn (SPH) between simulation and experiment

Beam



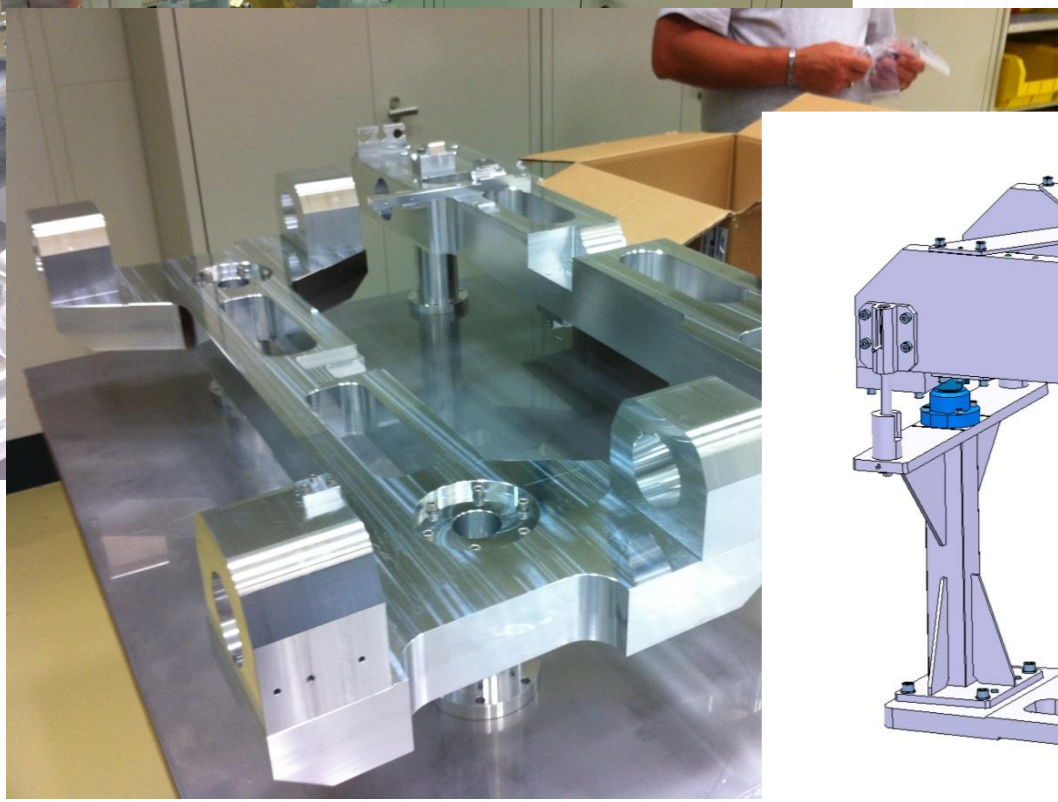


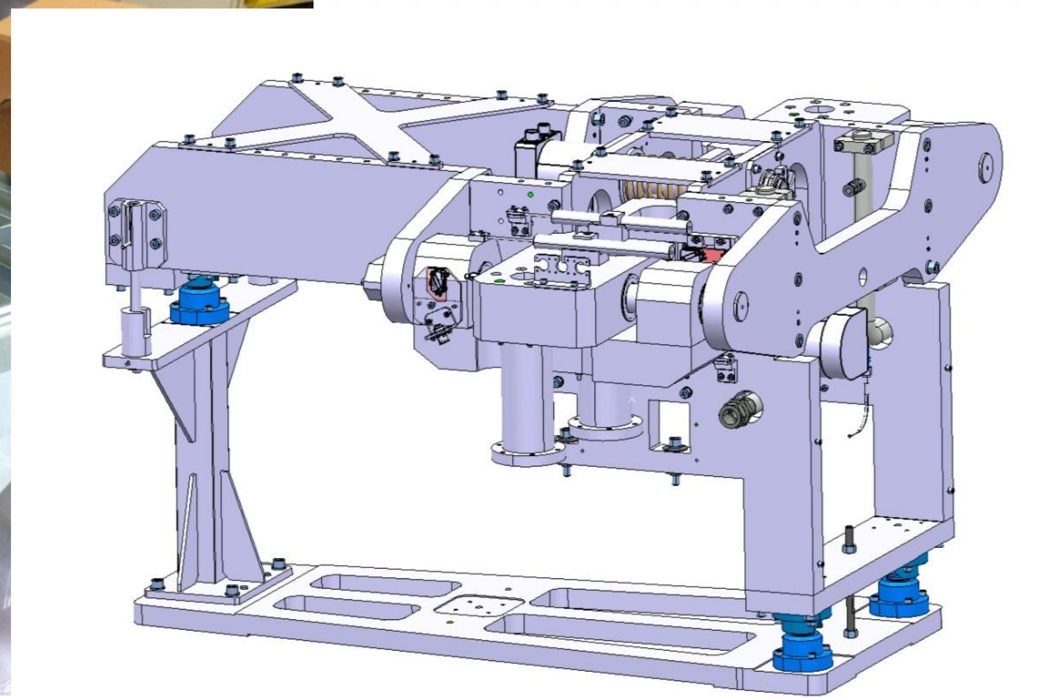
Case	Bunches	p/bunch	Total Intensity	Beam Sigma	Specimen Slot	Velocity
Simulation	60	1.5e11	9.0e12 p	2.5 mm	9	**316 m/s**
Experiment	72	1.26e11	9.0e12 p	1.9 mm	8 (partly 9)	**~275 m/s**

Engineering Department

TCLD Actuation System

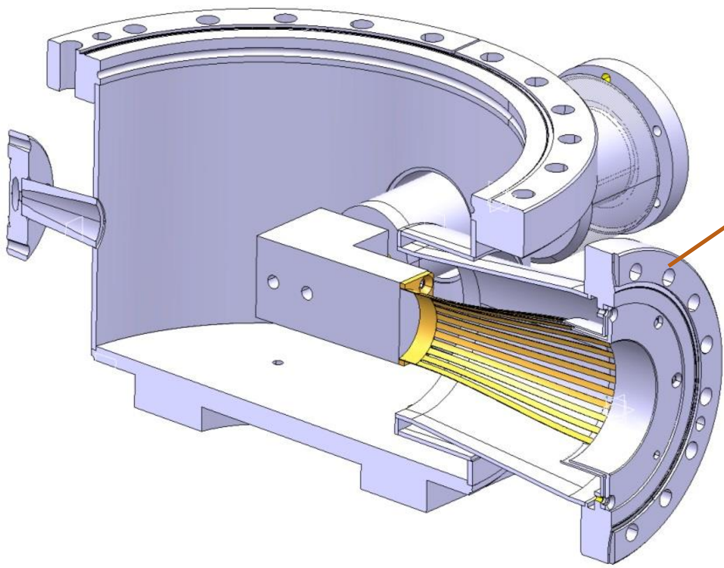
- Components for an Actuation System Set already available
- Actuation system can be cycle-tested with an ad-hoc test bench.





TCLD RF System Specification and Design

Proposed tooling to cycle and qualify RF Contact Fingers

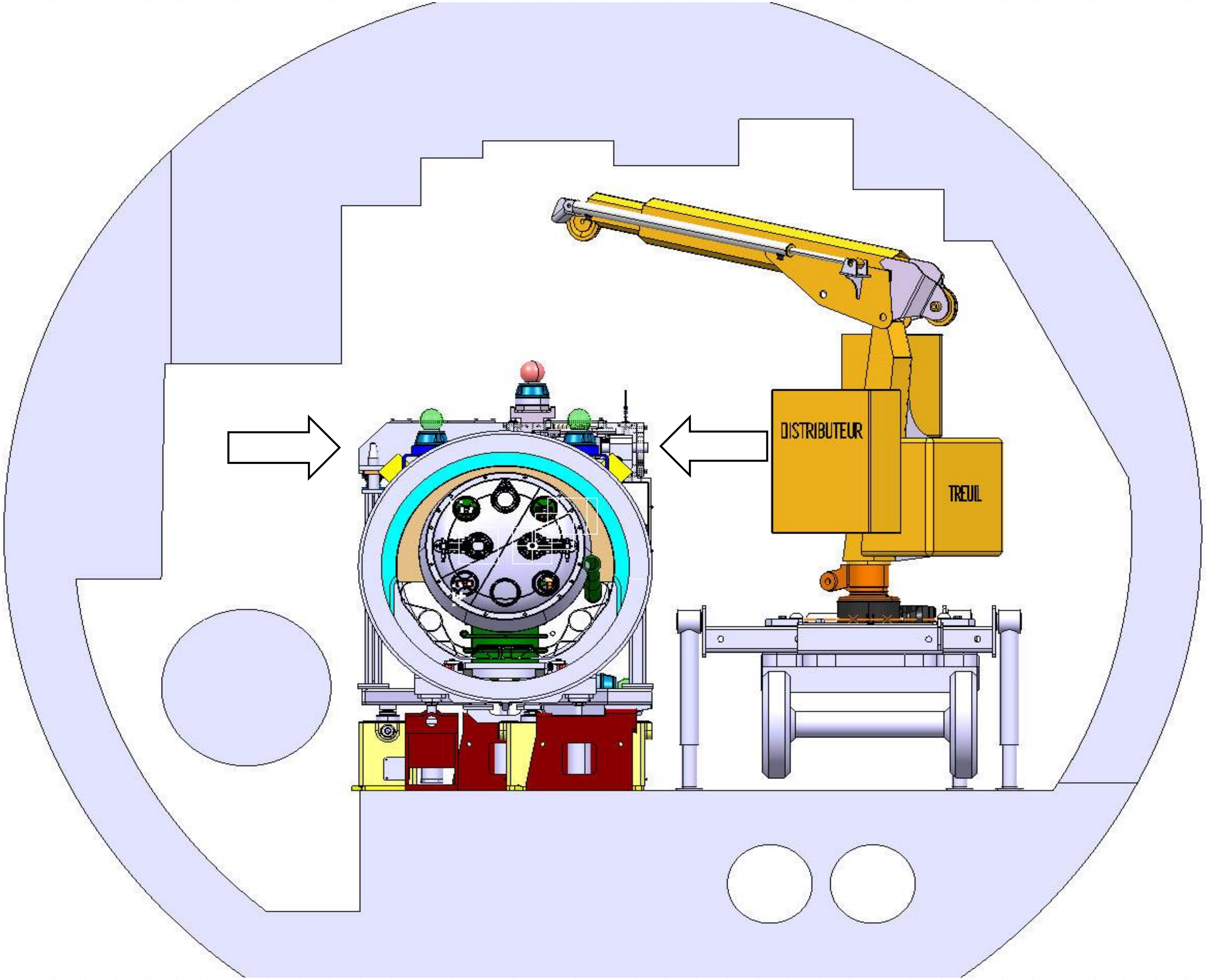


TCLD RF Impedance simulations, H. Day (BE-ABP), May 2011

Summary

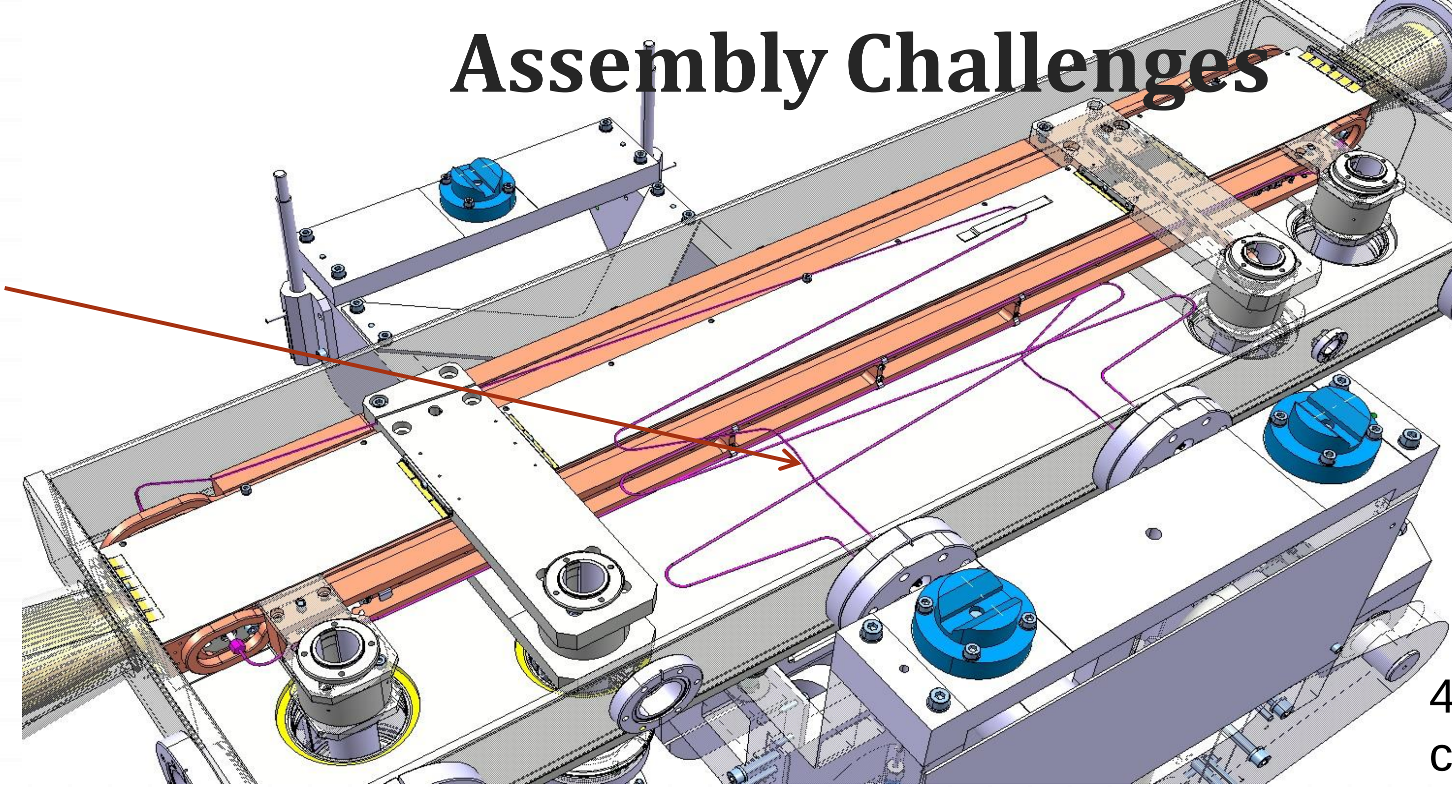
- Electromagnetic simulations of the DS Collimator have been carried out giving the impedance and EM field profiles
- The impedance is significantly below the design impedance budget of the LHC, indicating that the designs should not contribute to any significant increase in the impedance of the LHC
- EM field simulations show that the current impedance reduction techniques (RF clips, tapering, RF fingers) are effective in reducing the geometric impedances by masking cavities and transitions

Handling

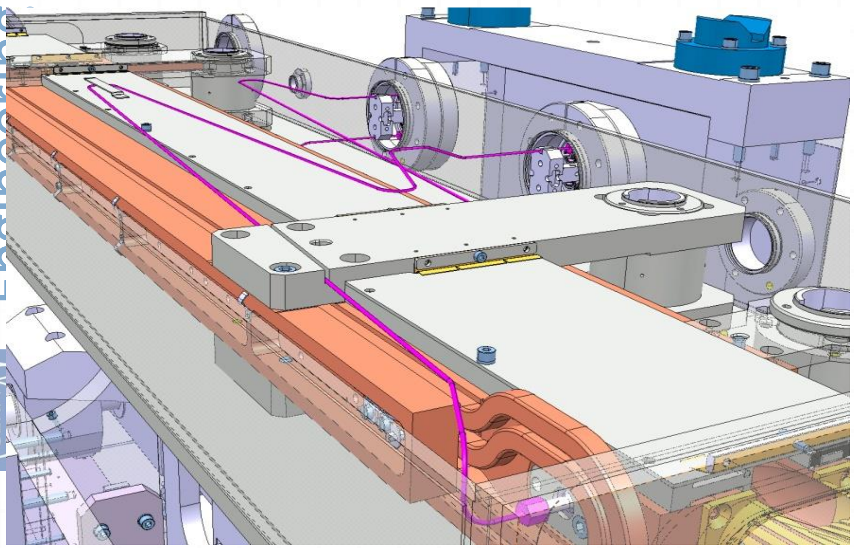


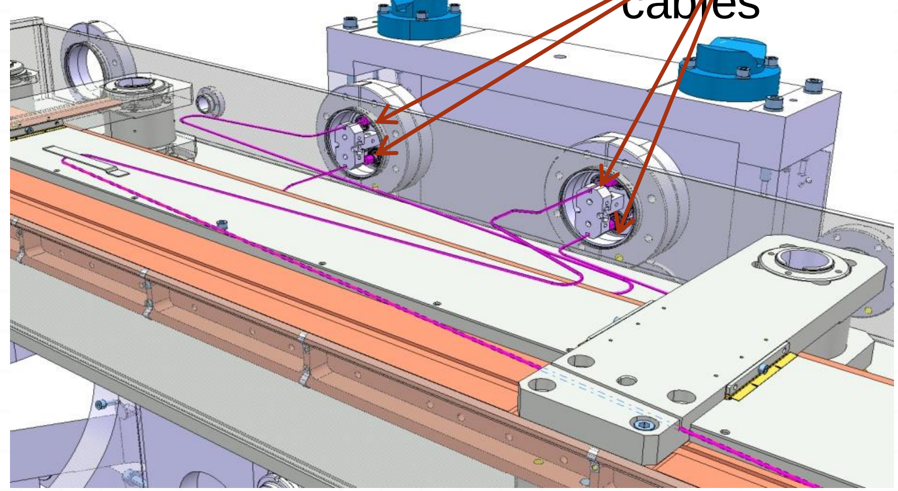
Assembly Challenges

Cable rooting



4 feadthrough connections on tank cables

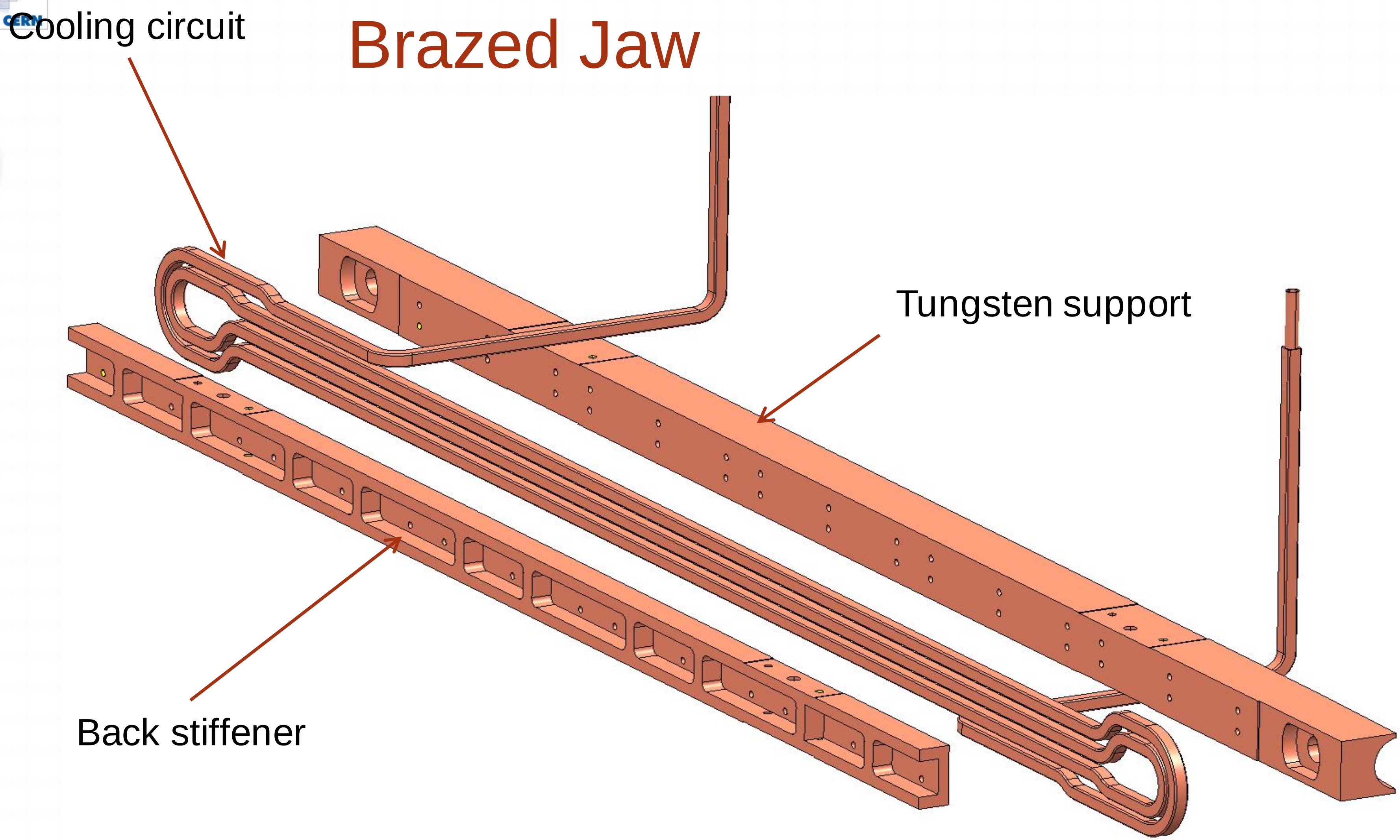




EN Engineering Department

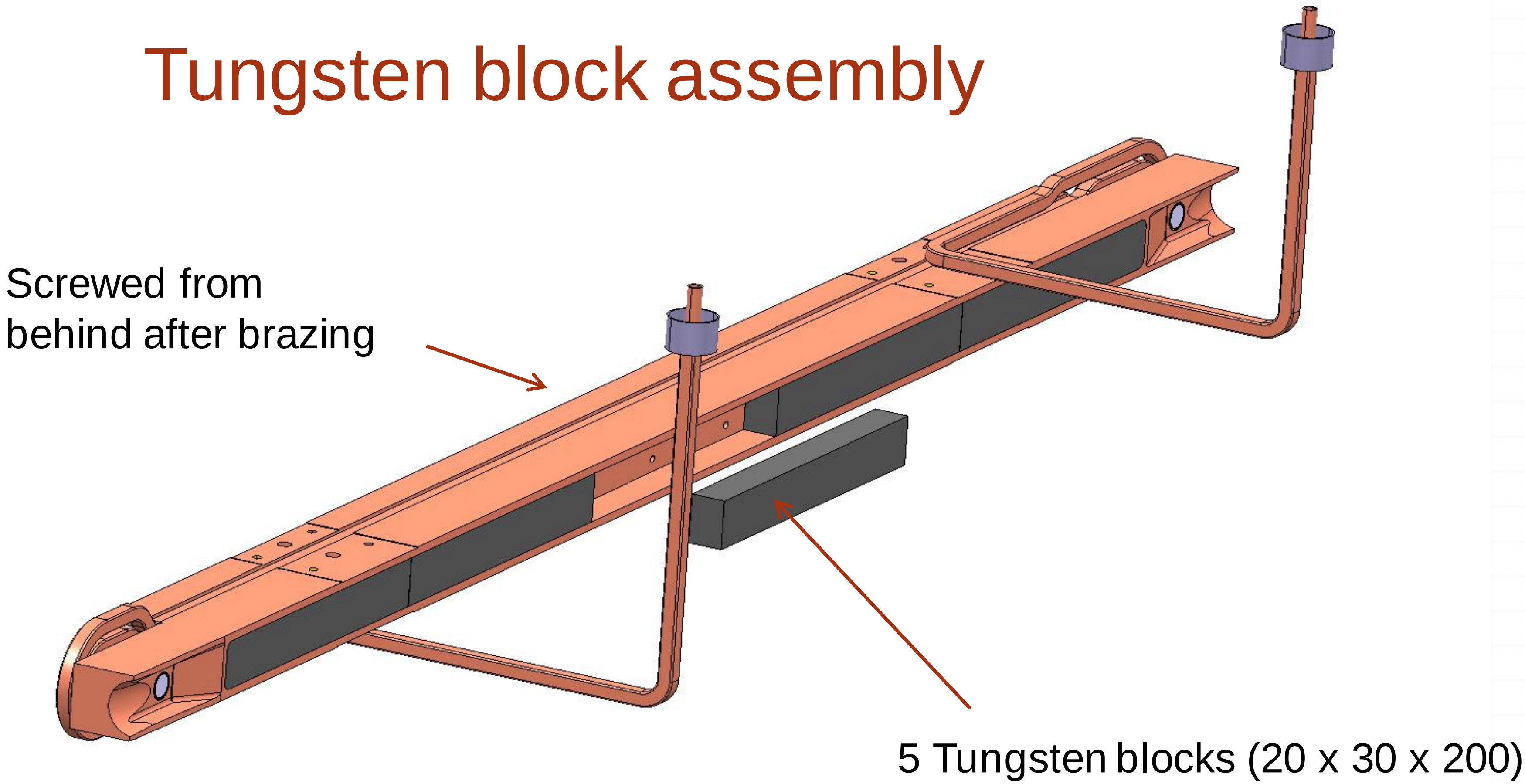
Assembly Challenges

Brazed Jaw

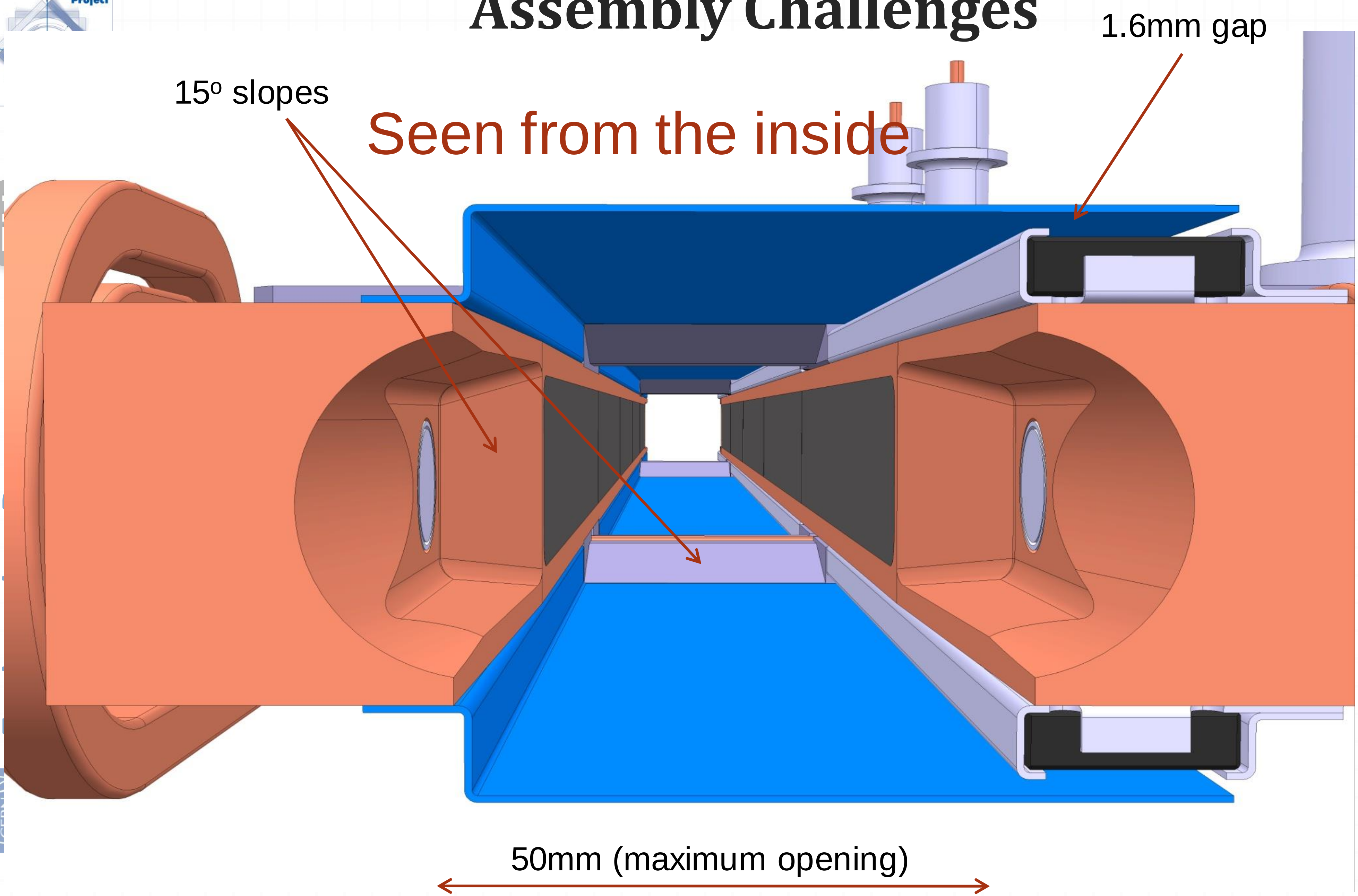


Assembly Challenges

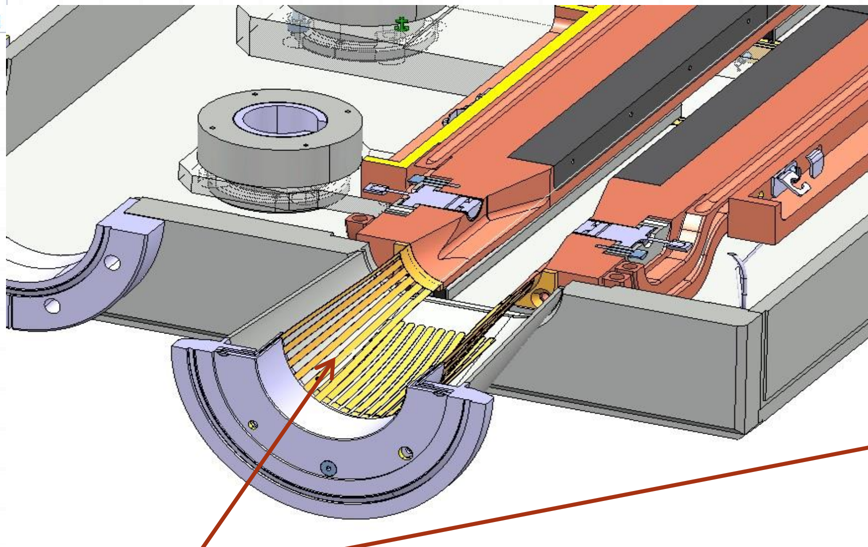
Tungsten block assembly

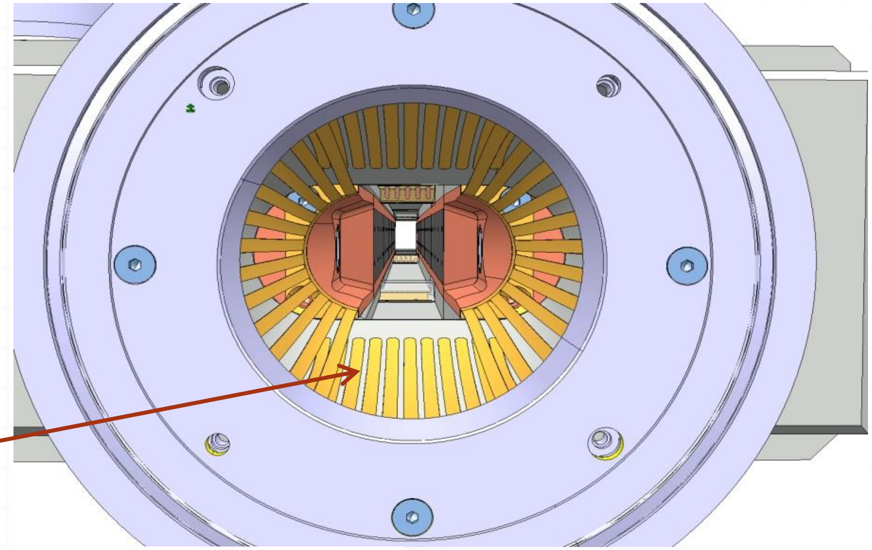


Assembly Challenges



RF CONFIGURATION FOR TCLD COLLIMATOR – extra illustrations

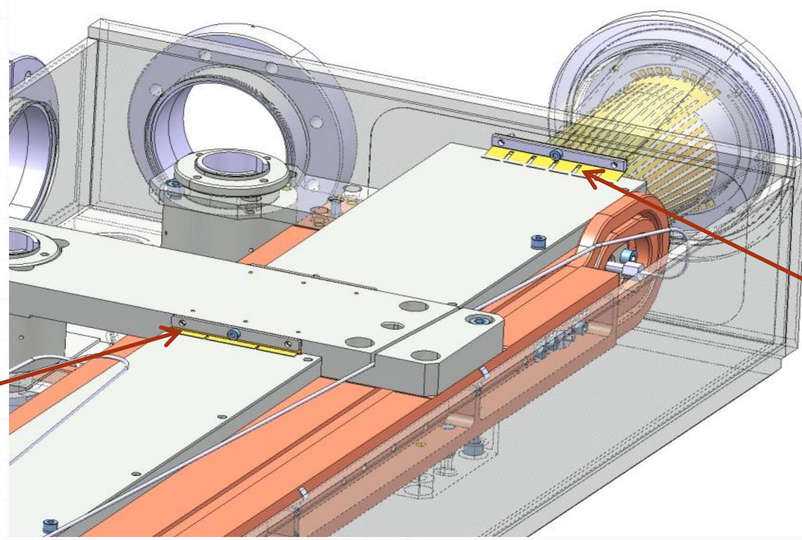




RF extremity fingers

Horizontal fixed contact

Vertical mobile contact



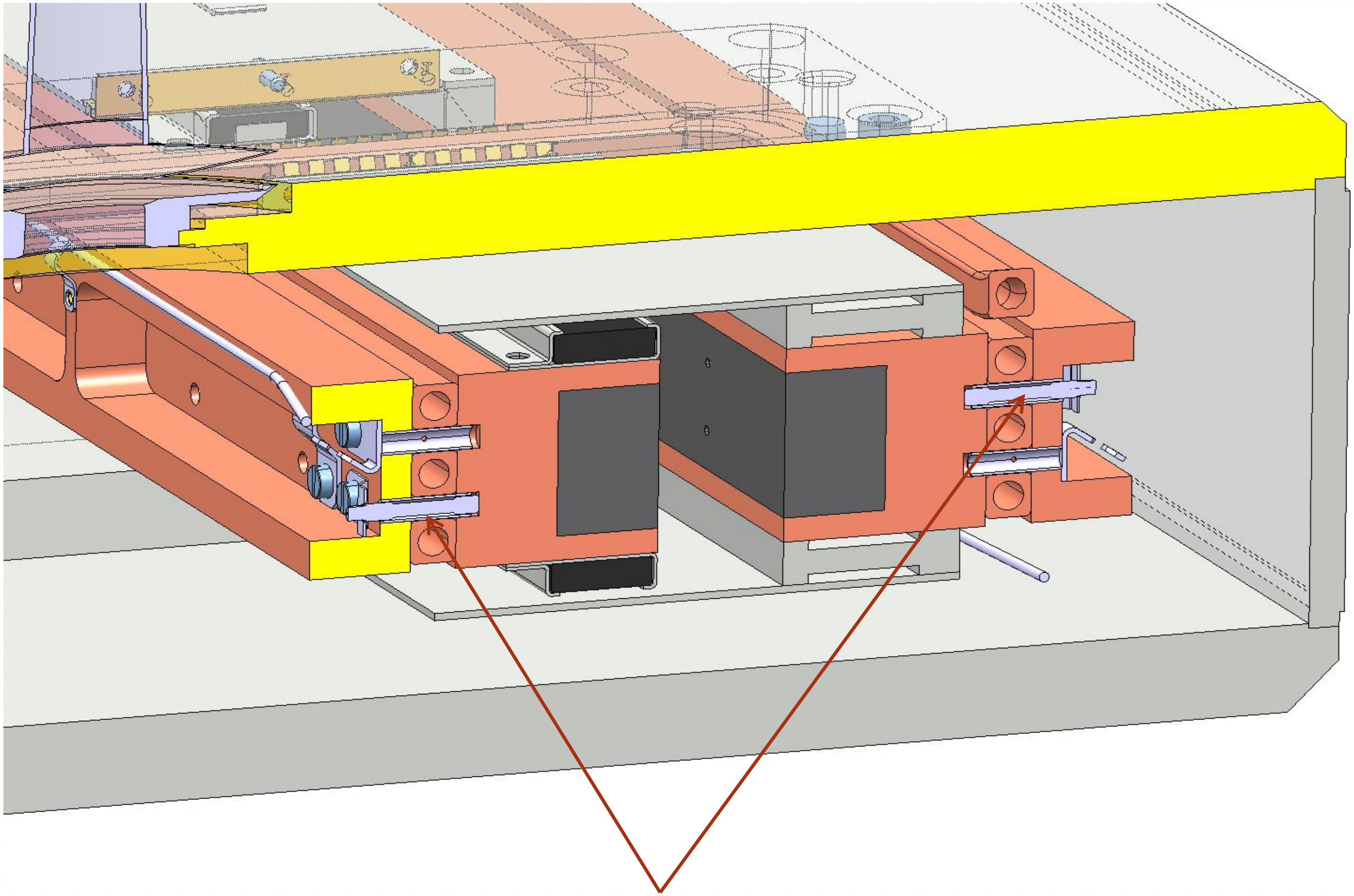
RF screen contacts

RF screen/tank contact

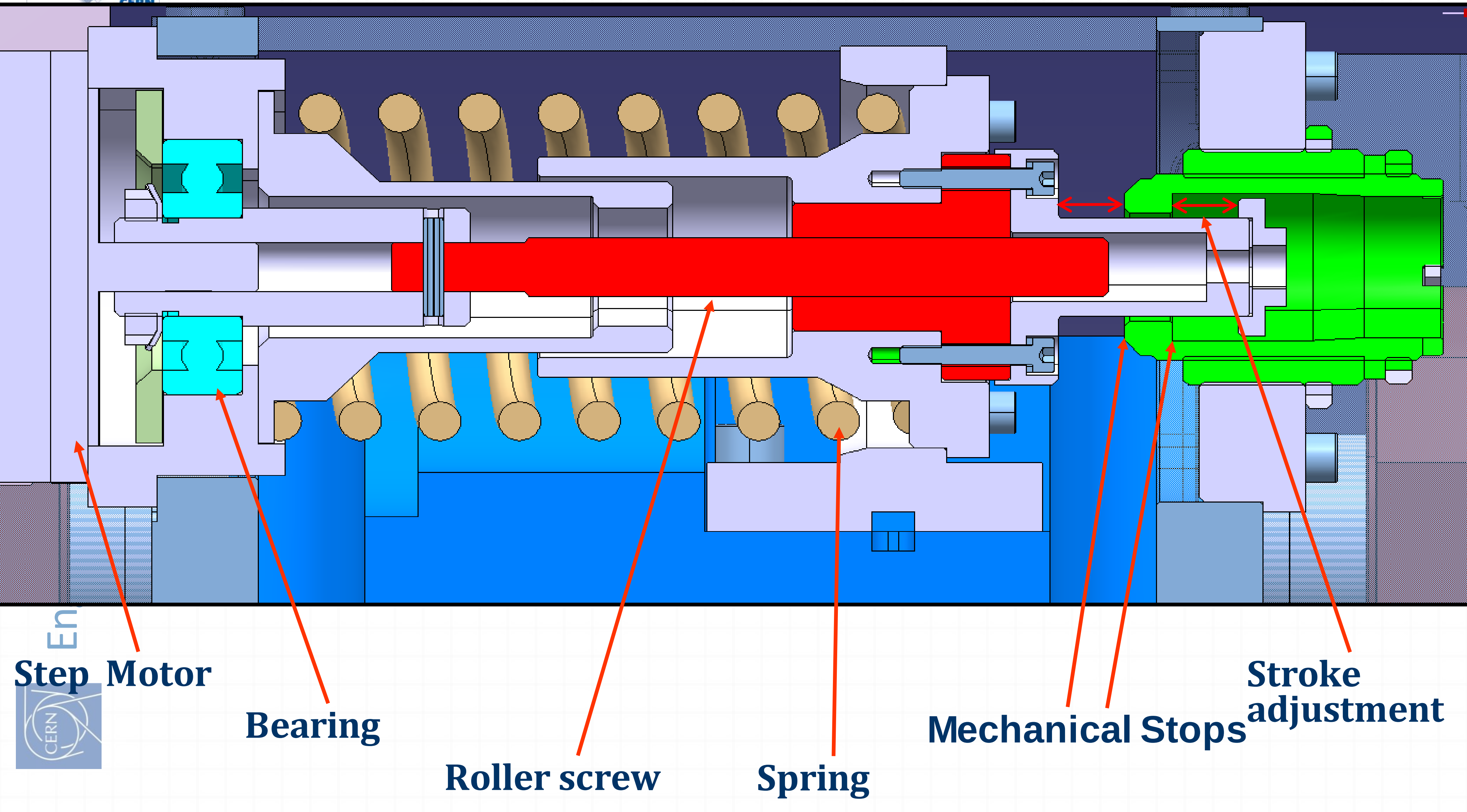
LHC Collimation Project CERN

EN Engineering Department

TEMP. PROBE CONFIGURATION



4 Temperature probes (1at each jaw extremity)


Step Motor
Bearing
Roller screw
Spring
Mechanical Stops
Stroke adjustment