Review and status of dry vacuum pump technologies and their application in High Energy Physics

Murray Liston

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Abstract

- Dry vacuum pump technologies have been increasingly developed and employed over the last 20 years.
- Primary and secondary dry pump operational mechanisms will be discussed and compared with more traditional oil / fluid based pumps.
- The advantages of dry pumps will be discussed in their specific application to High Energy Physics systems.

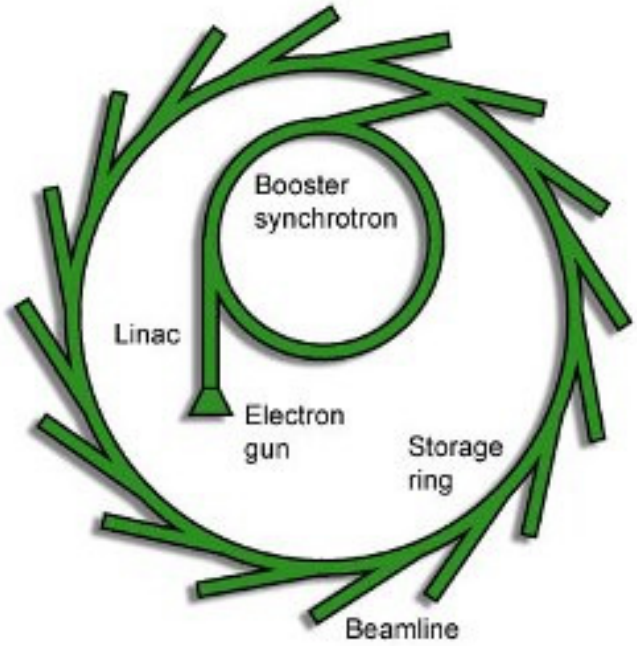
Vacuum in HEP

Image: LHC CERN

Colliders: storage ring, cryogenic cooling lines (superconducting magnets)

Associated general laboratories

Image: Spring-8



Synchrotrons: LINAC, booster, storage ring, beam-lines and cryogenic cooling lines

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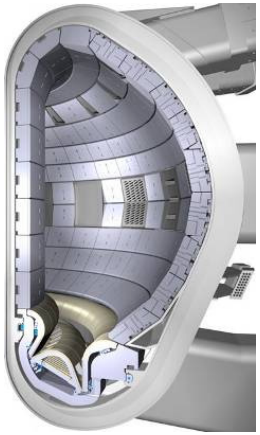
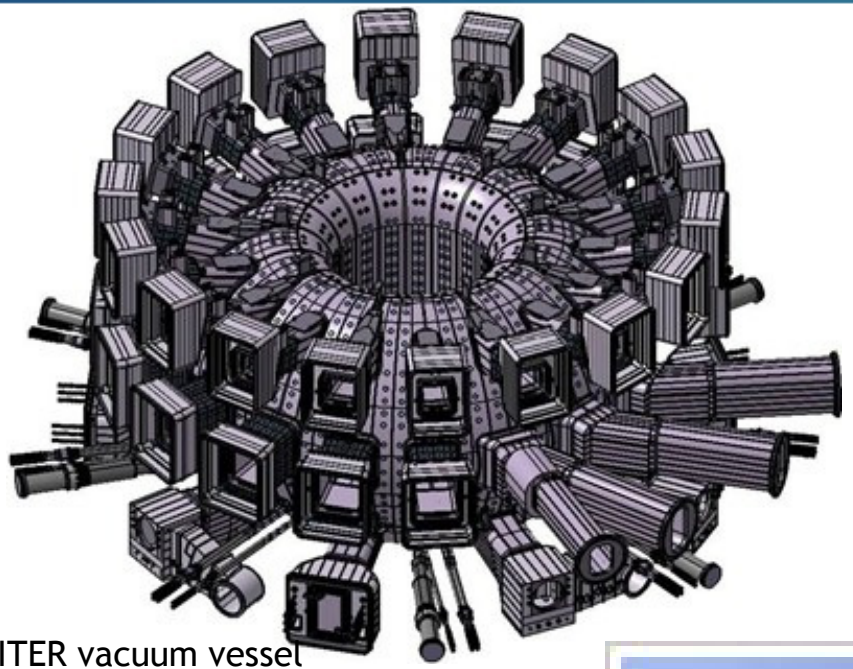
Vacuum in HEP

Fusion Energy

$^{2}D + {}^{3}T \longrightarrow {}^{4}He + n + 17.6MeV$





Images: ITER vacuum vessel

Cyclotrons, Heavy ion therapy etc

Gravitational waves…UHV, low vibrations

Image: LIGO

Lasers: ICF (ESP),
Optical (ultra-short and high power)

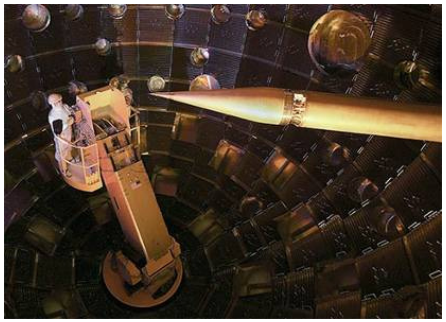


Image: NIF

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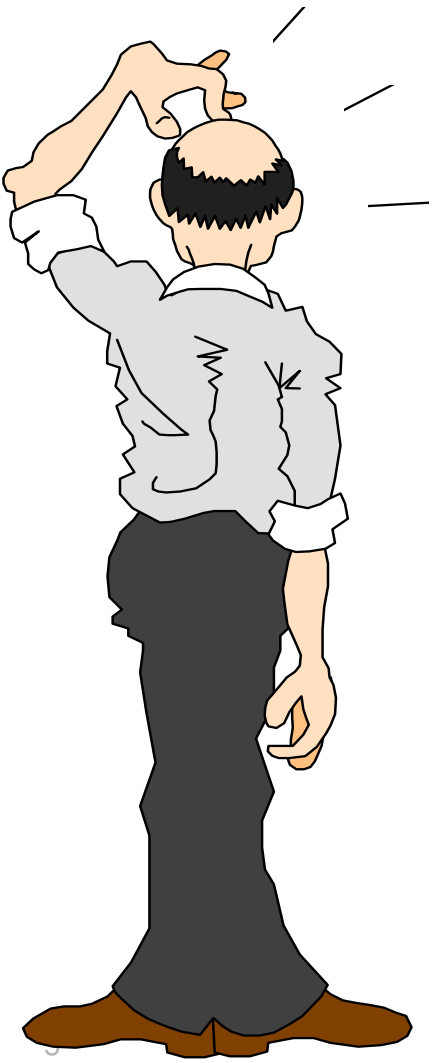
What do users want from vacuum pumping systems?



- Totally clean vacuum
  - with no contamination risk
- Reliability of vacuum pumps
  - “fit and forget”
- Reduced maintenance tasks
  - Simple, fast on site maintenance when needed
- Excellent, repeatable vacuum performance
  - Including pumping of light gases
- Compactness
- Flexibility in control, ease of operation
- Low lifetime cost

Drivers to Dry vacuum pumping in High Energy Physics

- No contamination…clean vacuum…no suck-back risk!
- No oil disposal/exhaust treatment
  - cost, environment
- No oil leaks
- No oil carry-over at high loads and accidents
- Longer Mean Time Before Service and end-user servicing
- 'Process' ability e.g. water vapour (can degrade oil)
- Gas recovery and recirculation
- Radiation load duty

- No accessories
  - e.g. for high gas loads
- No vapours
- Sophisticated controls
- No capacity issues
  - e.g. TMPs vs Sputter Ion Pump
- Safety – H_2, ^2D and ^3T etc
- Vibration
- Noise
- Maintenance to be in phase with scheduled facility shutdown
- **Costs o**f Ownership and Capital Cost

BUT HOW DRY IS "DRY" ??

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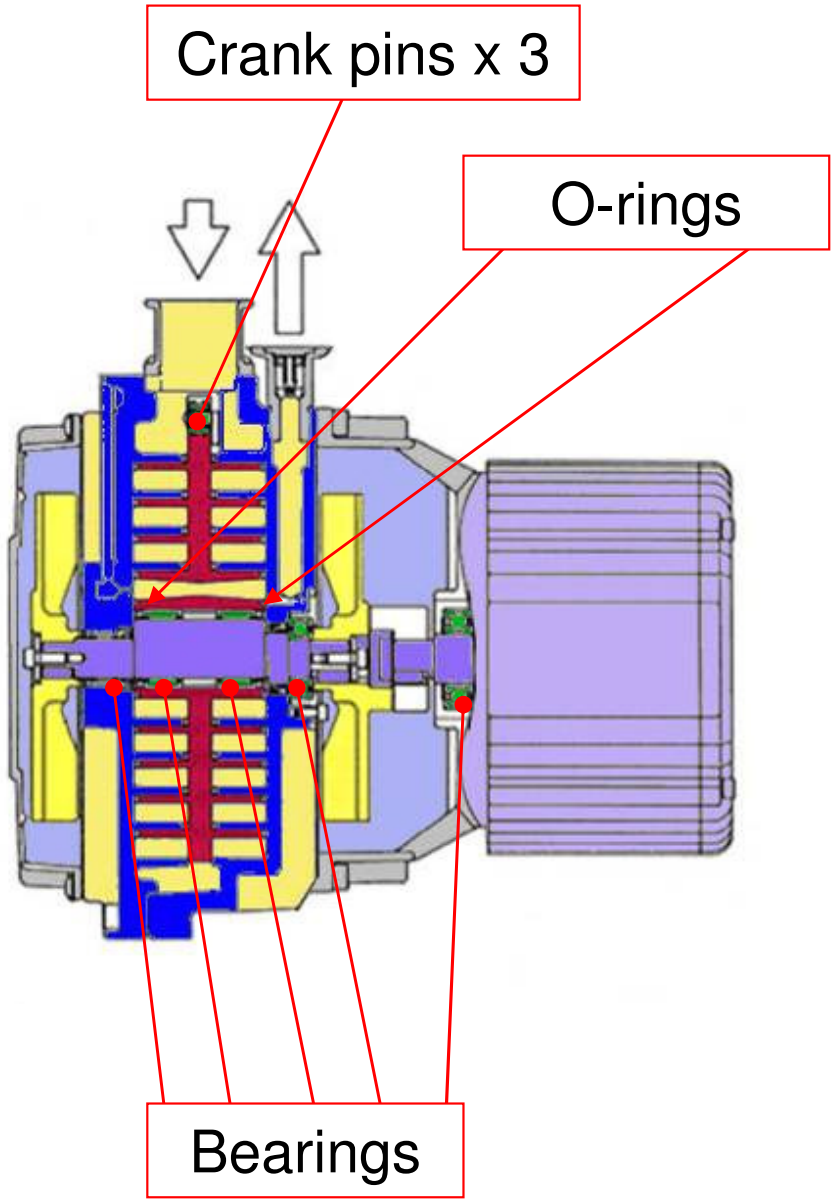
First generation Scroll pumps

- Double sided orbiting scroll within two single sided fixed scrolls
- Crank pins are not isolated from vacuum, need lubrication by vacuum-rated grease (Fomblin® or similar)
- Needle roller bearings also require lubrication
- Lip seals required on shaft to seal the vacuum envelope
- Neglecting maintenance will lead to expensive failures !



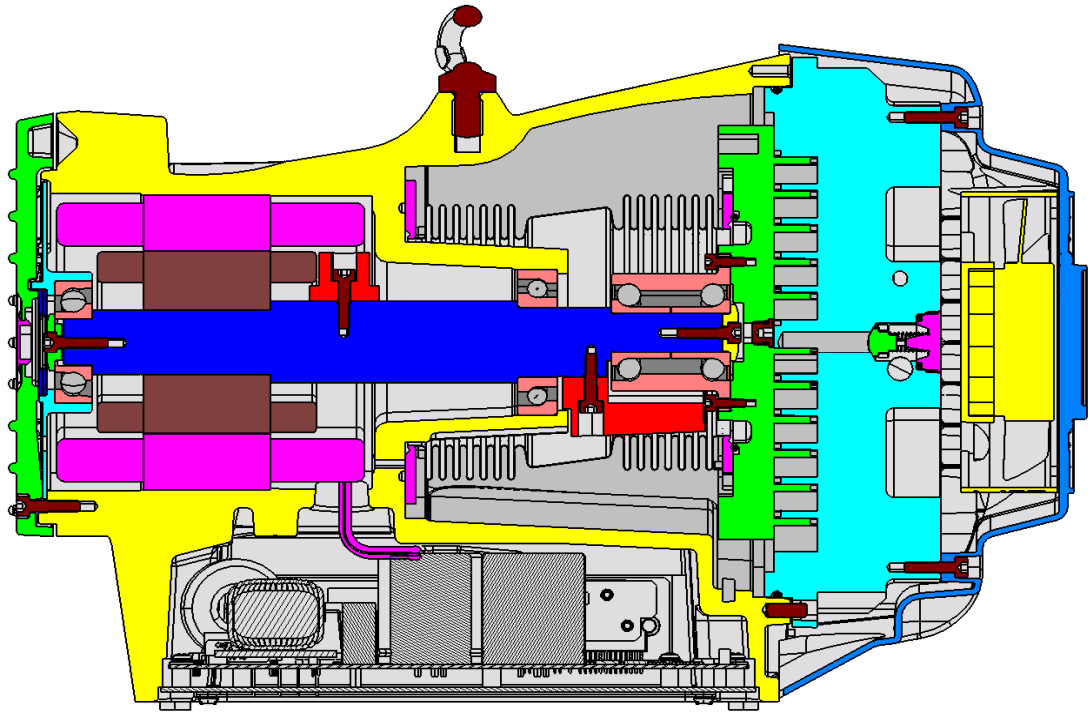
Failure modes of first generation scroll pumps

- Tip seals help to centralise the orbiting scroll
- Tip seal failure leads to axial clashing

- When the grease dries out
  - Crank pin failure can result
  - Timing control is lost
  - Radial clashing occurs

Second generation Scroll pumps

- Single sided scroll, with bearings isolated behind patented stainless steel bellows to eliminate shaft seals and ANY lubricants in vacuum space
- Vacuum levels below 10^{-2} mbar, up to 40 m^3/h
- Totally clean, excellent vapour pumping, ideal for gas recycling / recovery
- Simple maintenance
  - 3 minute tip seal change after >2 years continuous use



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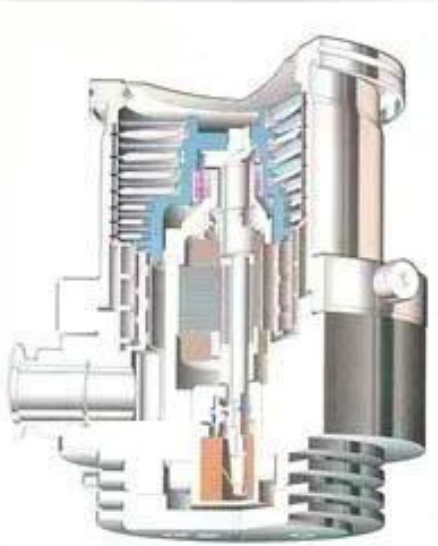
Turbomolecular pumping - considerations

- All turbomolecular pumps require 2 bearings to control axial and radial movement of a rotor at high rotational speed, also to resist high axial loads when venting
- Bearings can be oil- or grease- lubricated ball bearings, passive or active magnetic bearings, or a combination of these
- Ball bearing life is affected by operating temperature and quality of lubrication, as well as any imbalance of the rotor
- Turbo-molecular and Molecular drag stages optimise balance of pumping speed and compression for different gas species
- Users demand long life, simple local bearing servicing, or no maintenance at all…



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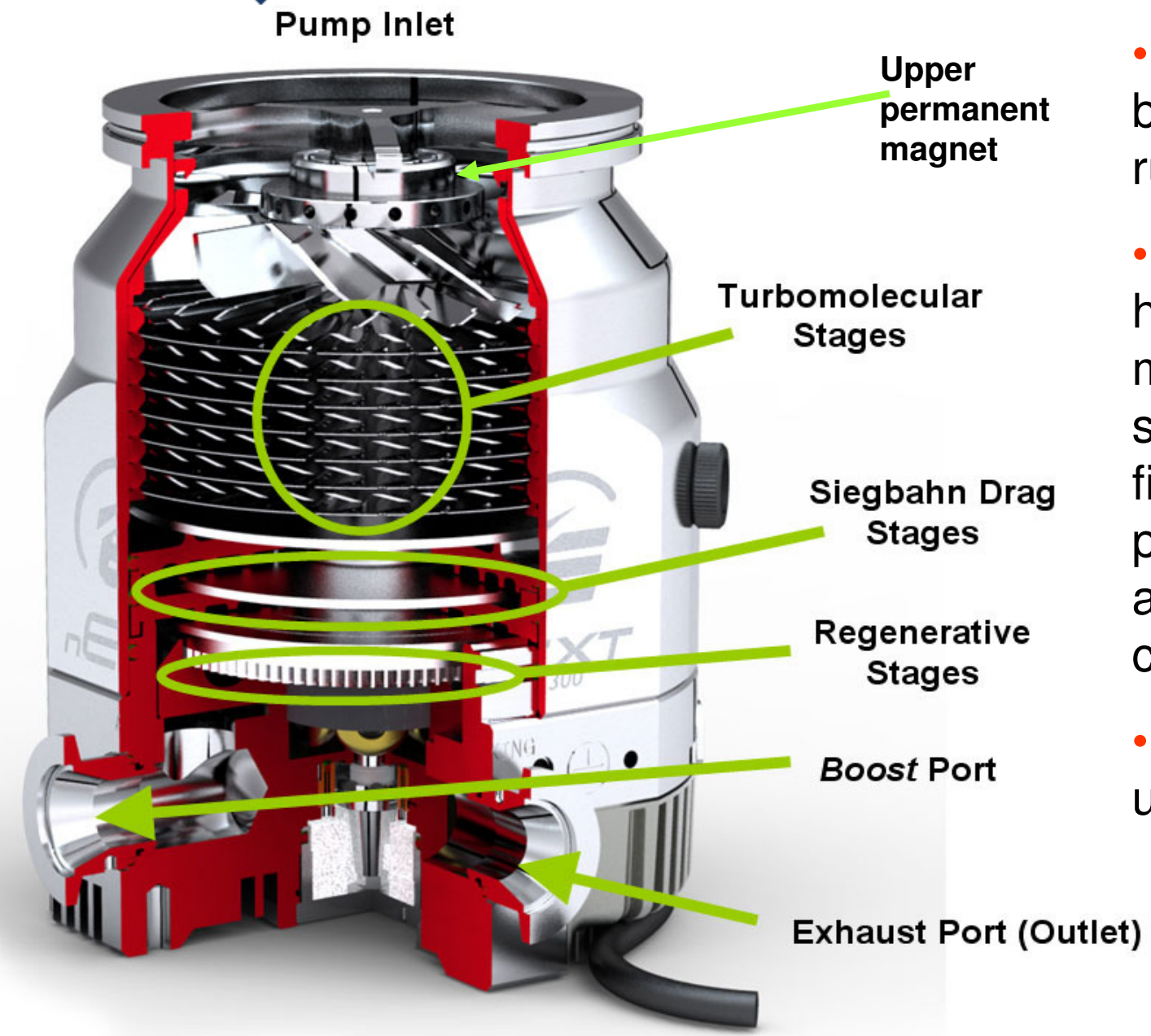
Latest generation turbomolecular pump design



- Oil lubricated ball bearing for cooler running and longer life
- The Siegbahn stage has a rotating disc mounted on the drive shaft and the stator is fixed relative to the pump housing in which a number of spiral channels are formed
- Bearings are end user serviceable
  - no re-balancing

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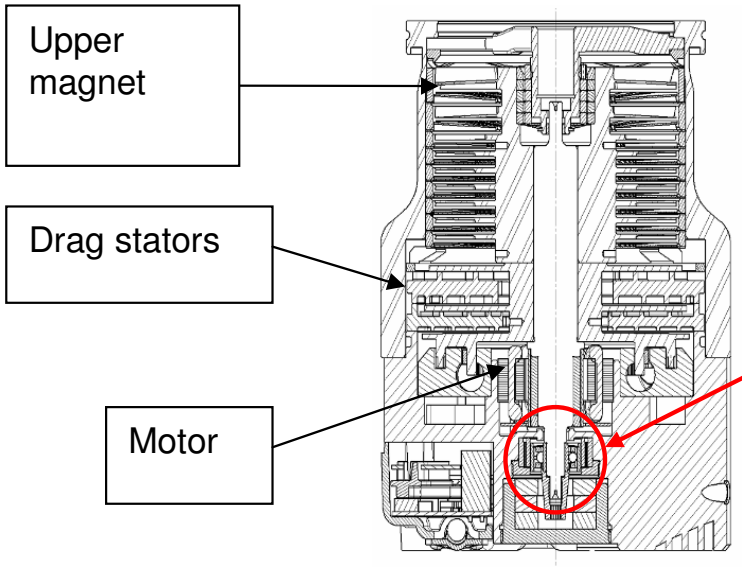
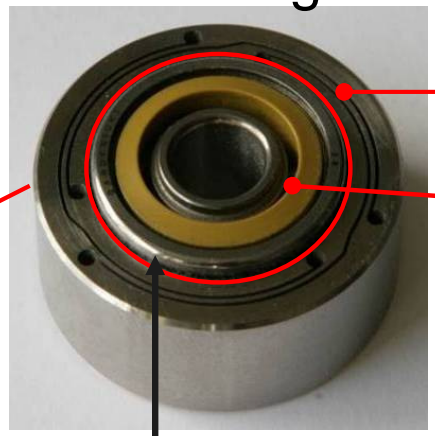
Tolerance of rotor imbalance and easier maintenance

The CMSD relies on arc-shaped spring members which are rectangular section beams





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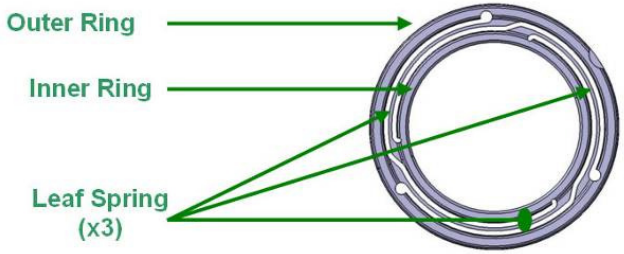
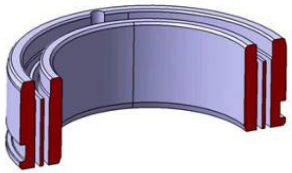
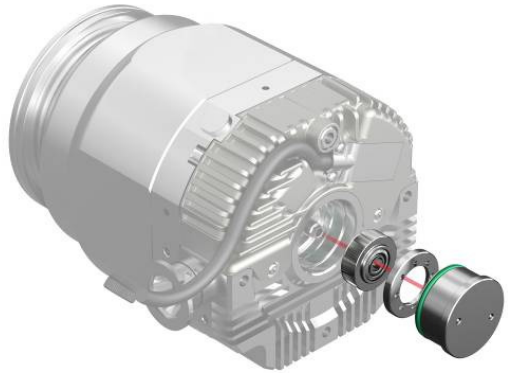






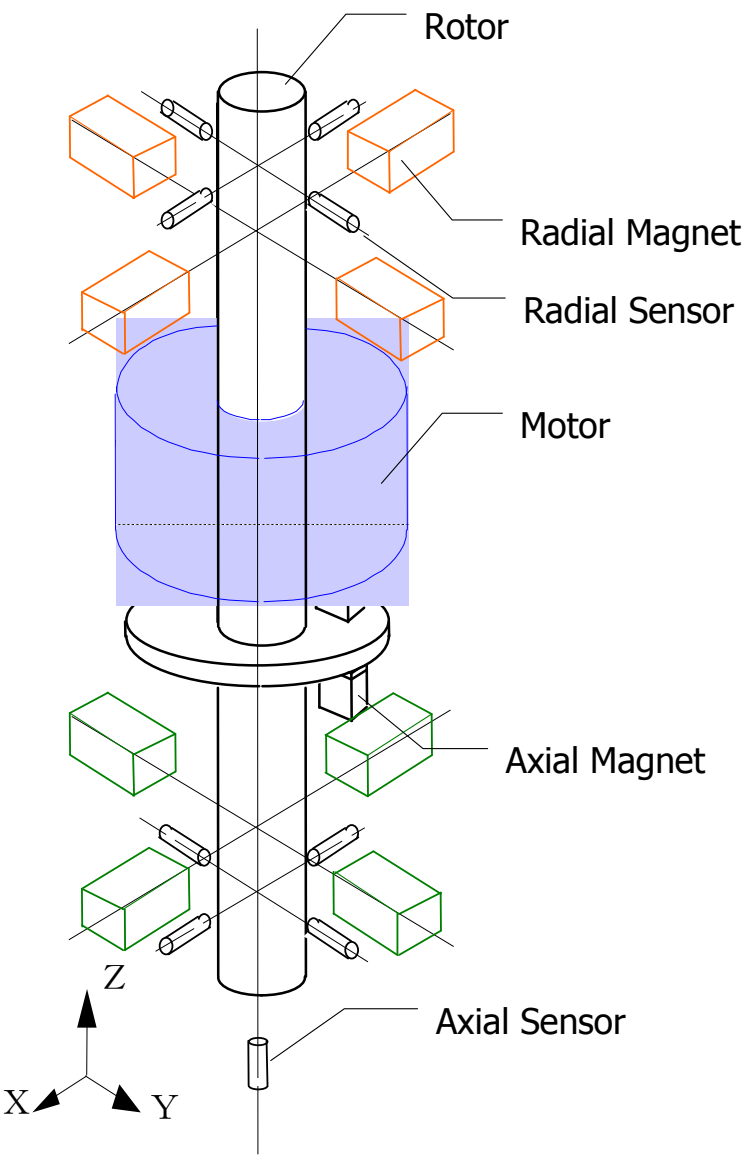
CMSD allows end-user service and frees up space for Siegbahn and Regenerative drag stages

Magnetic levitation turbomolecular pumps

Although nEXT pumps are unique and do not need rebalancing, for higher capacity pumps “Maglev” bearings are used 300 to 4500 l/s

- Completely clean
- No process contamination of, or by, bearings
- Can align TMPs in series and no drying out of bearing
- No bearing wear (or effect of temperature, shock loading, rapid vent, chemical or particulate attack)
- Any orientation
- Zero maintenance
- Low magnetic field and high field resistance
- Ultra low vibration
- Ultra low noise
- UHV versions
- Radiation resistance to >1e8 rads
- Low power requirement

Magnetic Bearings vs Ball Bearings



Magnetic bearing

Bearing Type	Magnetic Bearing	Ball Bearing
Bearing Life	✓	⊘
	permanent	2-3 years
Periodic exchange parts	✓	⊘
	No	Yes (bearing)
Grease / Oil	✓	⊘
	Not used	Used
Noise/ Vibration	✓	⊘
	Low vibration	Vibration
Mounting	✓	⊘
	Free	Restricted
Transport	✓	✓
	Free	Free

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Summary

- High Energy Physics requirements for vacuum technology continue to provide new challenges for engineers
- Customer demands are for higher levels of cleanliness, and lower requirements for control and maintenance
- The vacuum industry will continue to develop new technological solutions and meet the needs of tomorrow's users

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