SPL waveguide distribution system

Components, configurations, potential problems

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CERN AB/RF
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Waveguide components

- **Waveguides – WR1150**

- 292x146mm
- Cut-off 513MHz, recommended op. freq. 640-960MHz
- Losses 3.7-2.5mdB/m (full height from catalogue)
- Mode tables for full height (left) and half height (right)

harm.	*MODE*	*m*	*n*	*f (MHz)*	*fc(MHz)*	λ_g (m)
1	TE	1	0	704.4	513.2	0.622
2	TE	1	0	1408.8	513.2	0.229
2	TE	2	0	1408.8	1026.3	0.311
2	TE	3	0	1408.8	1539.5	#NUM!
3	TE	1	0	2113.2	513.2	0.146
3	TE	2	0	2113.2	1026.3	0.162
3	TE	3	0	2113.2	1539.5	0.207
3	TE	4	0	2113.2	2052.7	0.597
3	TE	0	1	2113.2	1026.3	0.162
3	TE	1	1	2113.2	1147.5	0.169
3	TM	1	1	2113.2	1147.5	0.169
3	TE	2	1	2113.2	1451.4	0.195
3	TM	2	1	2113.2	1451.4	0.195

harm.	*MODE*	*m*	*n*	*f (MHz)*	*fc(MHz)*	λ_g (m)
1	TE	1	0	704.4	513.2	0.622
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3	TE	4	0	2113.2	2052.7	0.597
3	TE	0	1	2113.2	2052.7	0.597
3	TE	1	1	2113.2	2115.8	#NUM!
3	TM	1	1	2113.2	2115.8	#NUM!
3	TE	2	1	2113.2	2294.9	#NUM!
3	TM	2	1	2113.2	2294.9	#NUM!

Waveguide components

- **Waveguides – WR975**

- 247x124mm
- Cut-off 605MHz, recommended op. freq. 750-1120MHz
- Losses 4.8-3.2mdB/m (full height from catalogue)
- Mode tables for full height (left) and half height (right)

harm.	MODE	m	n	f (MHz)	fc(MHz)	λ_g (m)
1	TE	1	0	704.4	605.3	0.833
2	TE	1	0	1408.8	605.3	0.236
2	TE	2	0	1408.8	1210.5	0.416
2	TE	3	0	1408.8	1815.8	#NUM!
3	TE	1	0	2113.2	605.3	0.148
3	TE	2	0	2113.2	1210.5	0.173
3	TE	3	0	2113.2	1815.8	0.278
3	TE	4	0	2113.2	2421.1	#NUM!
3	TE	0	1	2113.2	1210.5	0.173
3	TE	1	1	2113.2	1353.4	0.185
3	TM	1	1	2113.2	1353.4	0.185
3	TE	2	1	2113.2	1712.0	0.242
3	TM	2	1	2113.2	1712.0	0.242

harm.	MODE	m	n	f (MHz)	fc(MHz)	λ_g (m)
1	TE	1	0	704.4	605.3	0.833
2	TE	1	0	1408.8	605.3	0.236
2	TE	2	0	1408.8	1210.5	0.416
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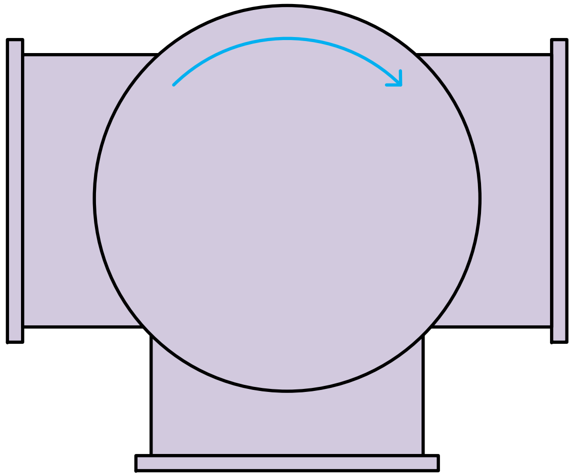
3	TE	2	0	2113.2	1210.5	0.173
3	TE	3	0	2113.2	1815.8	0.278
3	TE	4	0	2113.2	2421.1	#NUM!
3	TE	0	1	2113.2	2421.1	#NUM!
3	TE	1	1	2113.2	2495.6	#NUM!
3	TM	1	1	2113.2	2495.6	#NUM!
3	TE	2	1	2113.2	2706.9	#NUM!
3	TM	2	1	2113.2	2706.9	#NUM!

Waveguide components

- **Circulator**

- Isolation
- Attenuation
- Peak power handling
- RMS power – natural, forced, water cooling

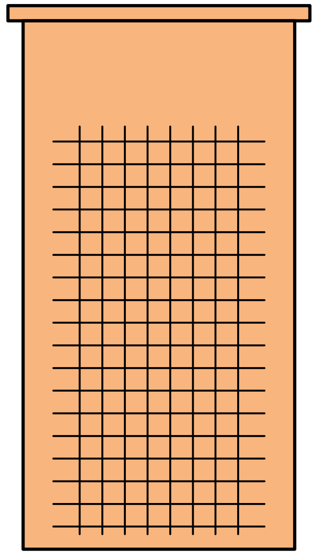


- $1MW_{pk}$ devices should be available from stock

Waveguide components

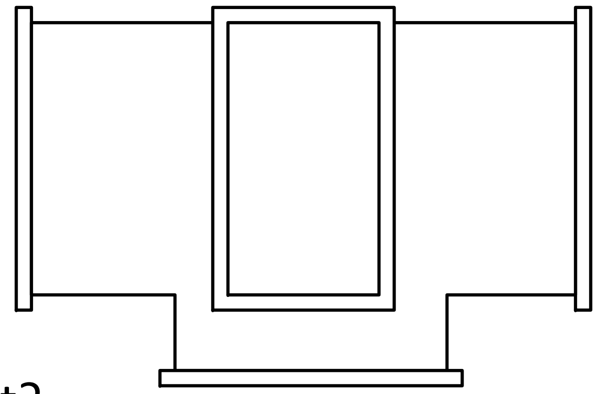
- **Dummy loads**

- “Dry type” preferred
- Physical dimensions depend very much on the RMS power required
- Many suppliers on the market



Waveguide components

- **180° Hybrid (Magic Tee)**

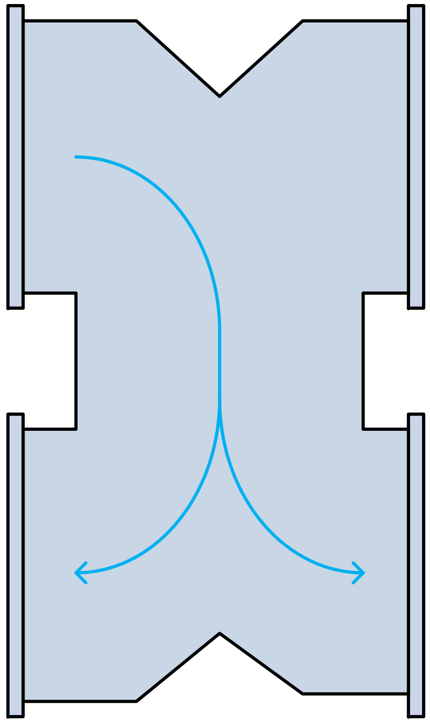


- Lot of experience from LEP
- 4th port must be terminated
- Ports are extending into 3 dimensions
- How good isolation between the ports we can get?

Waveguide components

- **90° Hybrid**

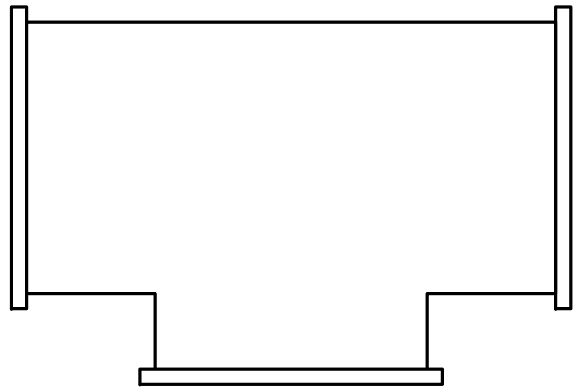
- 4th port must be terminated
- “Planar” 2D construction
- Variable coupling by placing posts inside
- Isolation obtained at DESY >40dB



Waveguide components

- **Tee**

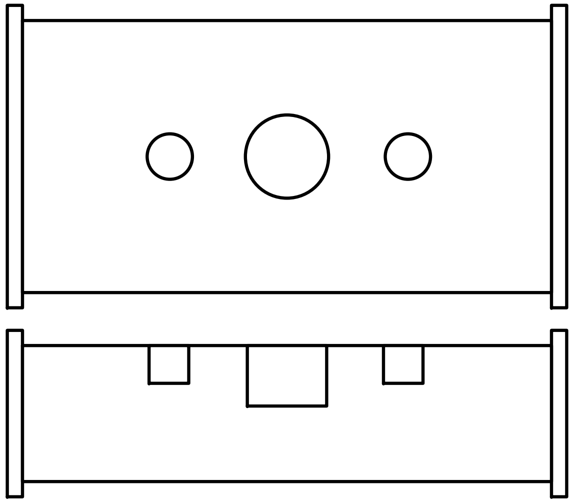
- 3 port device
- “Planar” 2D construction
- Variable coupling by placing posts inside
- No isolation, all reflections are redistributed between the ports



Waveguide components

- **3 Stub tuner**

- Usable as a phase shifter or impedance matching device
- Mechanical control – slow
- If properly designed should be always matched
- Can not block the transmission (to be used as a switch)
- Risk of arcing

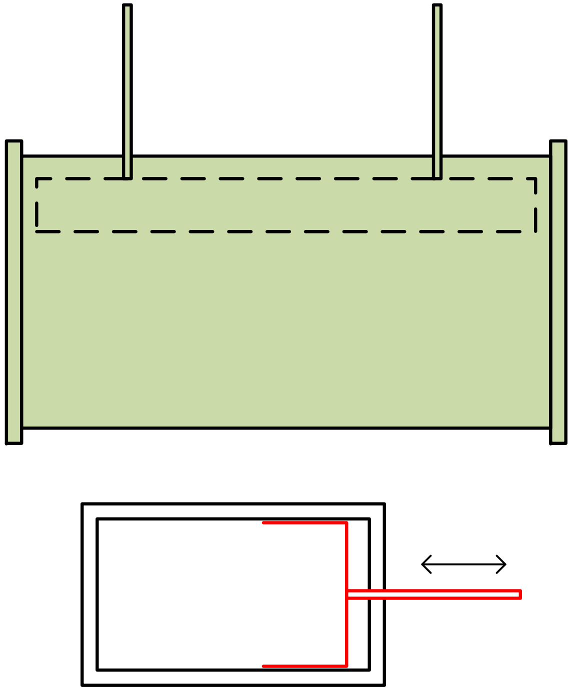


Waveguide components

- **Sliding phase-shifter (DESY design)**

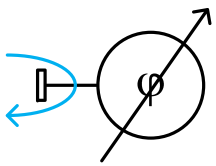
- Mechanical control – slow
- Tuning creates a mismatch (to be analyzed)
- Can be used to block the transmission e.g. to isolate a faulty cavity

- A very good candidate to adjust the static cavity phase

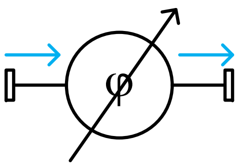


Fast phase shifters

- Needed for fast high power phase/vector modulators
- Usually based on controlled change of propagation velocity a transmission line
- Ferrites, Ferro-electric materials inserted in a coaxial, stripline or waveguide transmission lines
- Transmission type, reflection type
- Typical reaction time requested in SPL ~50us



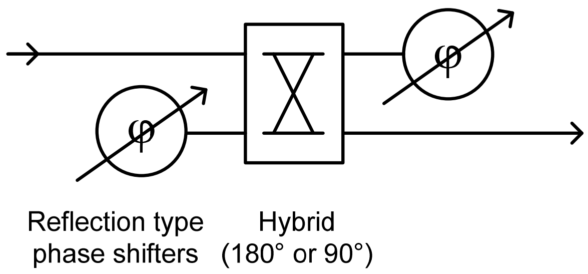
$$S_{11} = \frac{V_1^-}{V_1^+} = e^{-j\varphi}$$

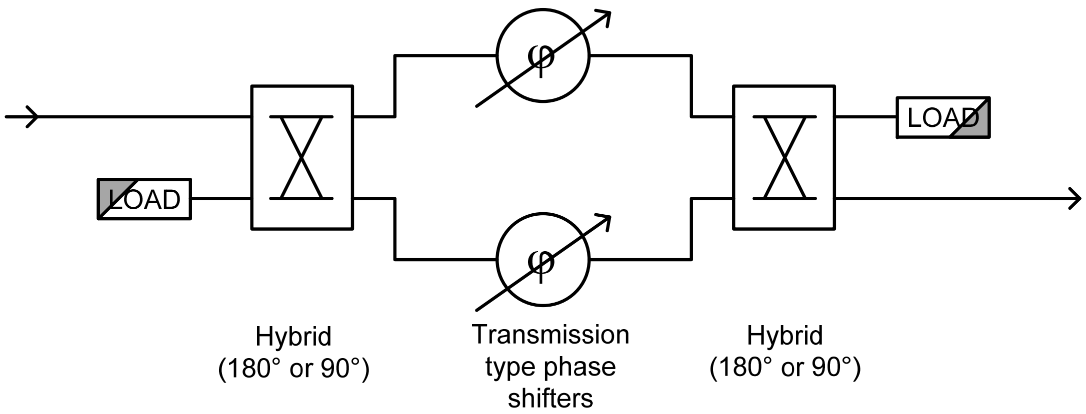


$$S_{21} = \frac{V_2^-}{V_1^+} = e^{-j\varphi}$$

Vector modulators

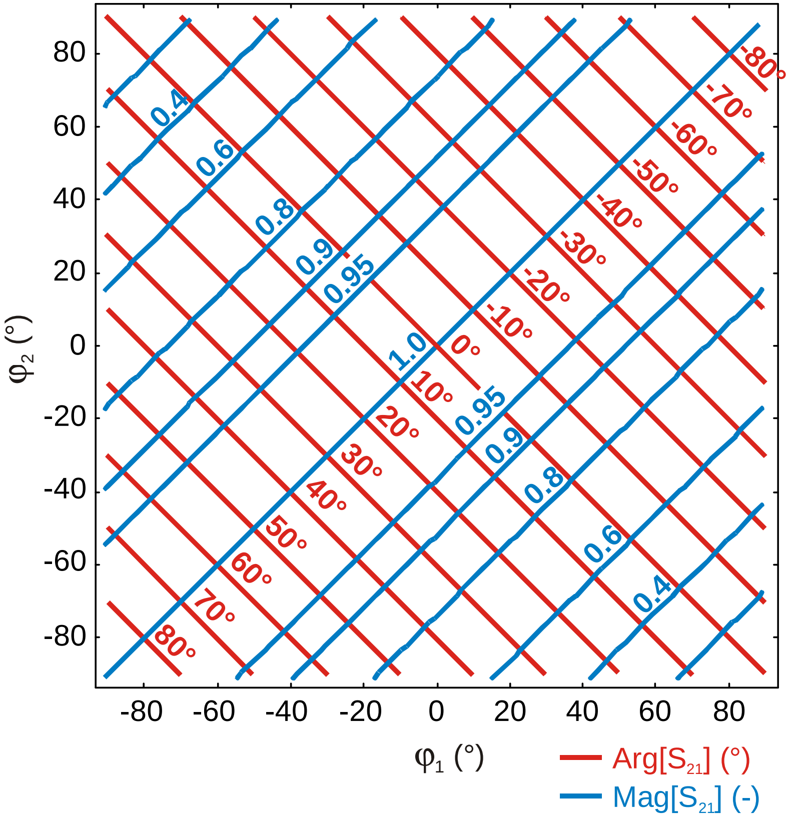
- Typically the incident wave is split into two parts (not necessarily halves)
- The two components are individually phase-shifted
- Finally both combined together again

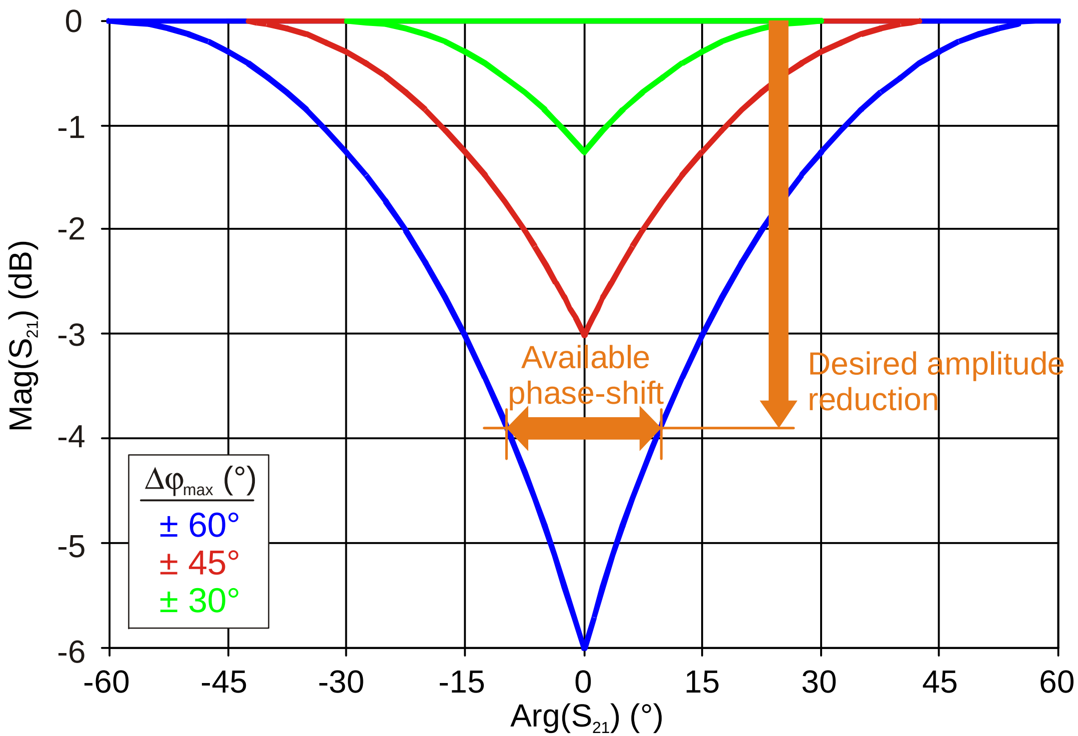




Vector modulators

- Transfer function vs. phase-shift



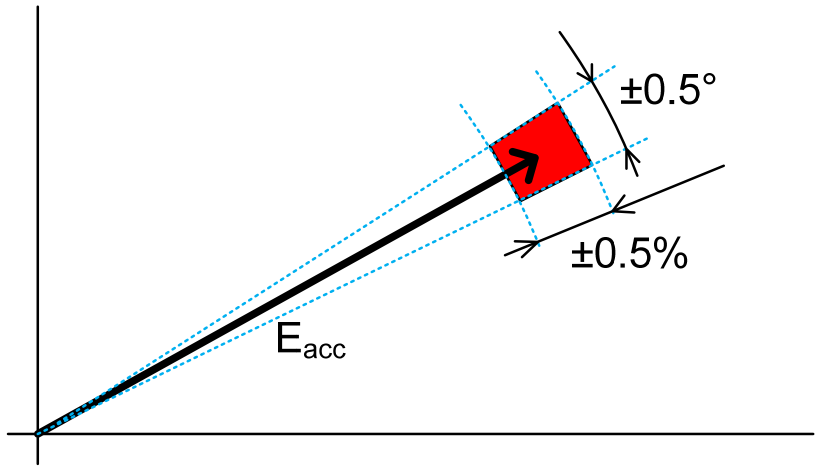


Vector modulators

- A proof of principle at CERN ~2003
  - Reflective type, partially ferrite loaded stripline structure
  - External permanent magnet bias plus tuning coils
  - 352MHz, 250kWpk, 10% duty cycle, <1kHz phase tuning speed
- Coaxial phase-shifters for the Project X
  - Reflective, fully ferrite loaded coaxial line
  - Purely electrical bias and tuning
  - 325MHz, unknown RMS power, most likely very low (~1kW)
  - Very fast response (~10s us)
- Ferrite loaded waveguides
  - Usually bulky to get sufficient tuning range
  - Problems with high RMS power (cooling)

Field quality requirements for the SPL cavities

- Tight tolerances on the field quality ±0.5% amplitude and ±0.5° phase
- For f_c=704MHz, $Q_{ext}=10^6$ BW=704Hz
- When looking to the resonance curve
  - 0.5% amplitude limit is reached when detuned by ~0.05 BW (i.e. 35.2Hz off resonance)
  - 0.5° phase limit is reached when detuned by ~0.004 BW (i.e. 2.8Hz off resonance)



Field quality requirements for the SPL cavities

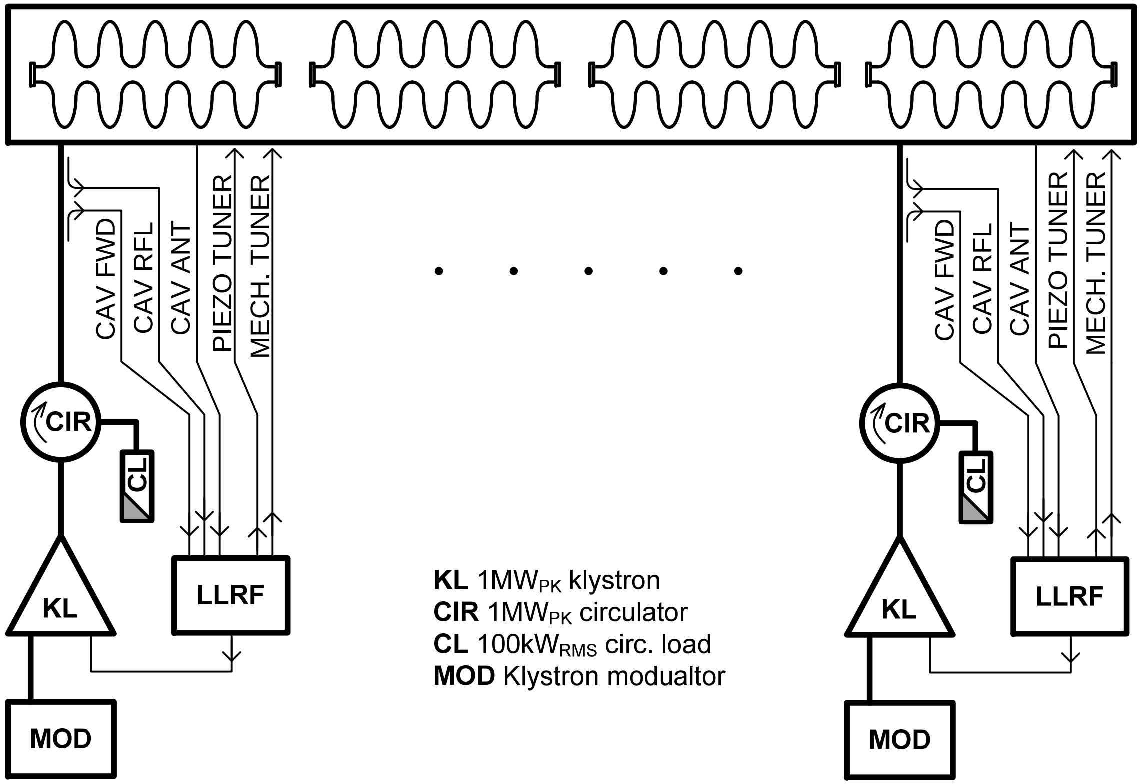
- Lorentz force detuning (LFD) at nominal field: expected ~1 BW
- Compensation of LFD by piezo actuator: expected 10s of Hz
- Piezo compensation can not work in feed-back mode (long delay), only feed-forward techniques
- Microphonics: expected detuning 10s of Hz

- Reflections and isolation in the waveguide system must be also taken into account

A real cavity prototype must be tested and fully characterized in a realistic cryostat to get a reasonable requirements on the Low-Level system and the High Power Vector Modulators

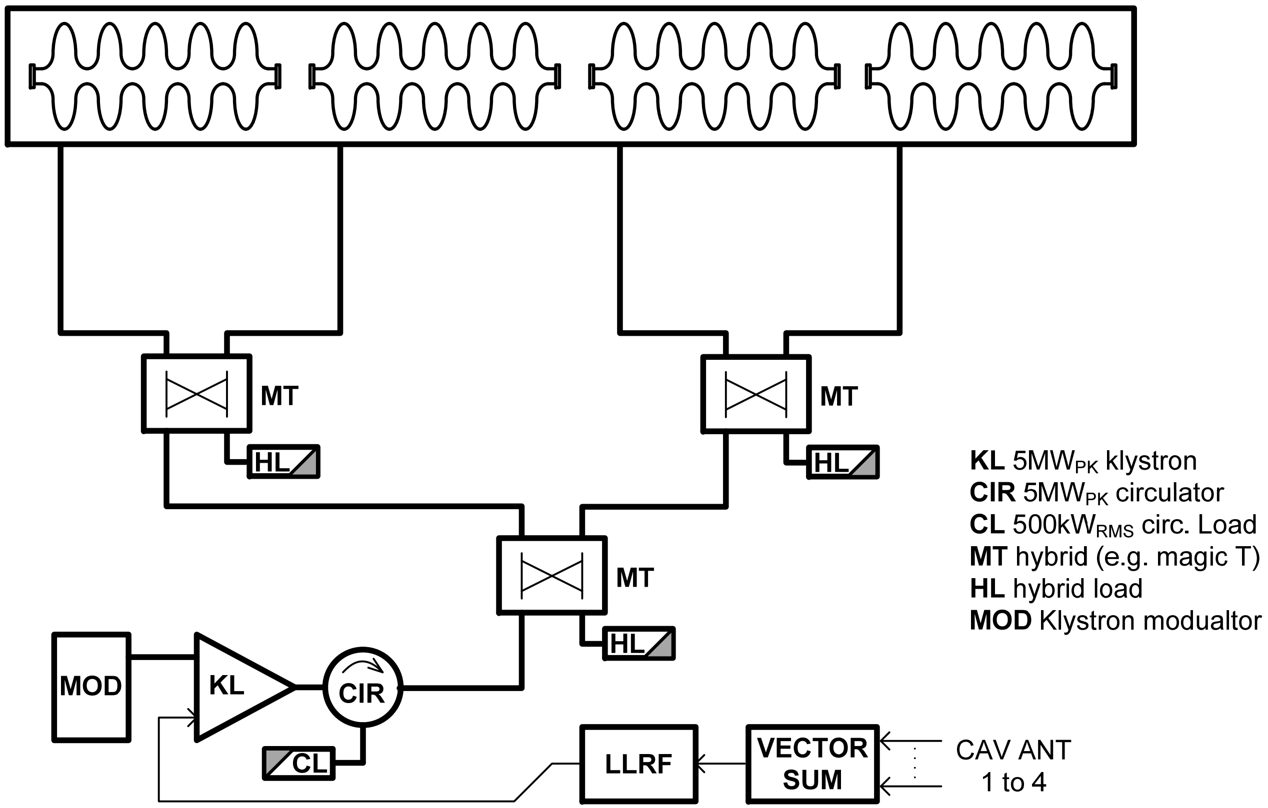
RF distribution scheme ‘candidates’

- One klystron per cavity
  - Optimal from RF controls and Low Level point of view
  - The most expensive, most space demanding variant
  - Life time of the klystrons as consumables



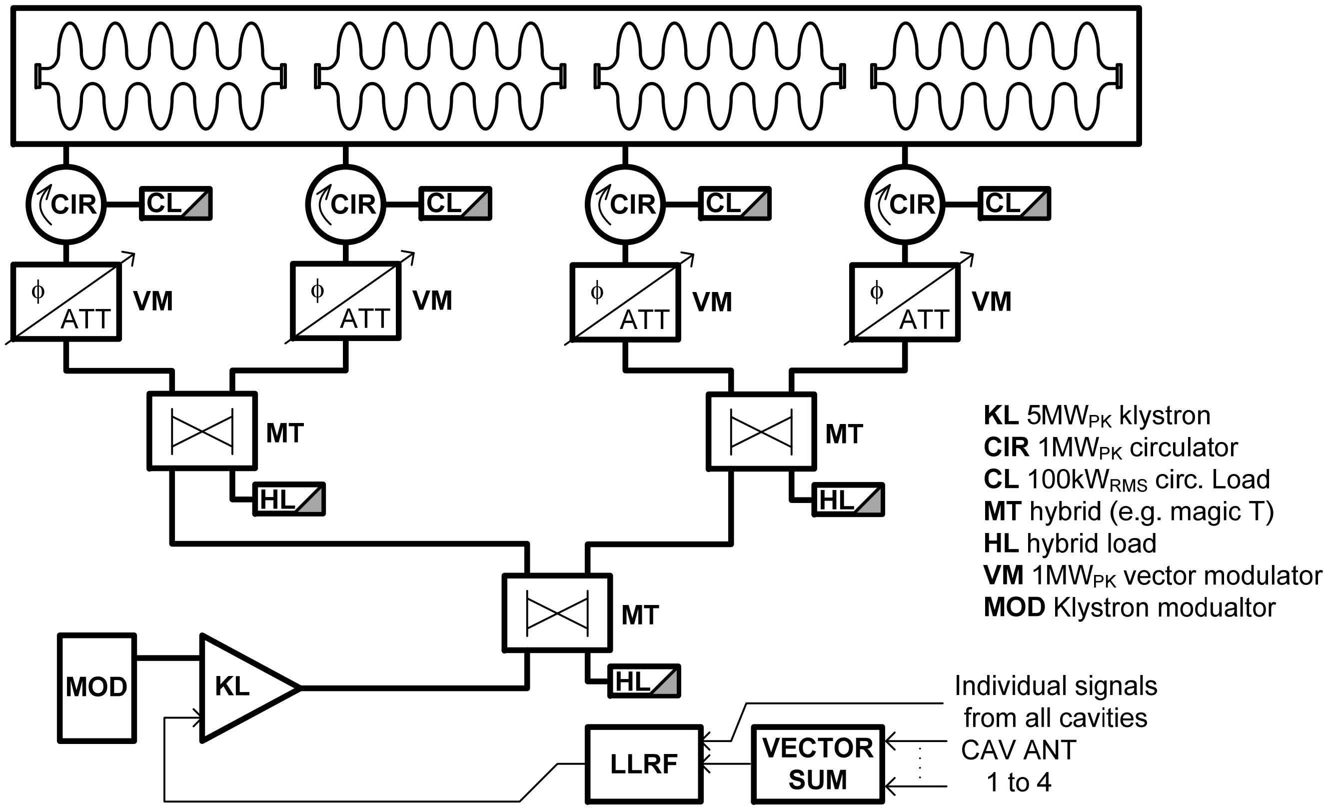
RF distribution scheme ‘candidates’

- One klystron feeding four cavities
  - No individual control of fields inside the cavities – proved to get a control instability
  - One “big” high power circulator
  - Least expensive



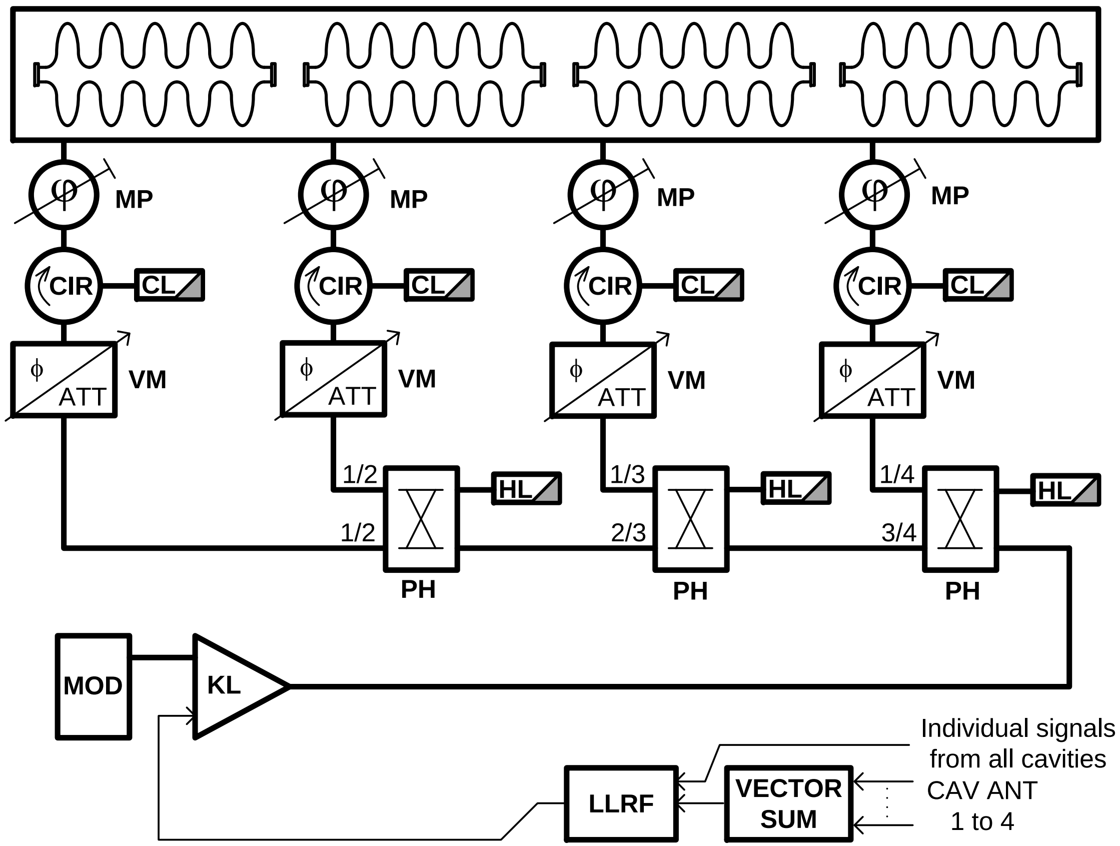
RF distribution scheme 'candidates'

- One klystron feeding four cavities
  - Individual control of each cavity – a fast high power vector modulator required
  - Smaller circulator for each cavity
  - A detailed analysis of controllability by the Low-Level RF people required
  - Cost to be evaluated, only one consumable, extra power for individual control needed



RF distribution scheme ‘candidates’

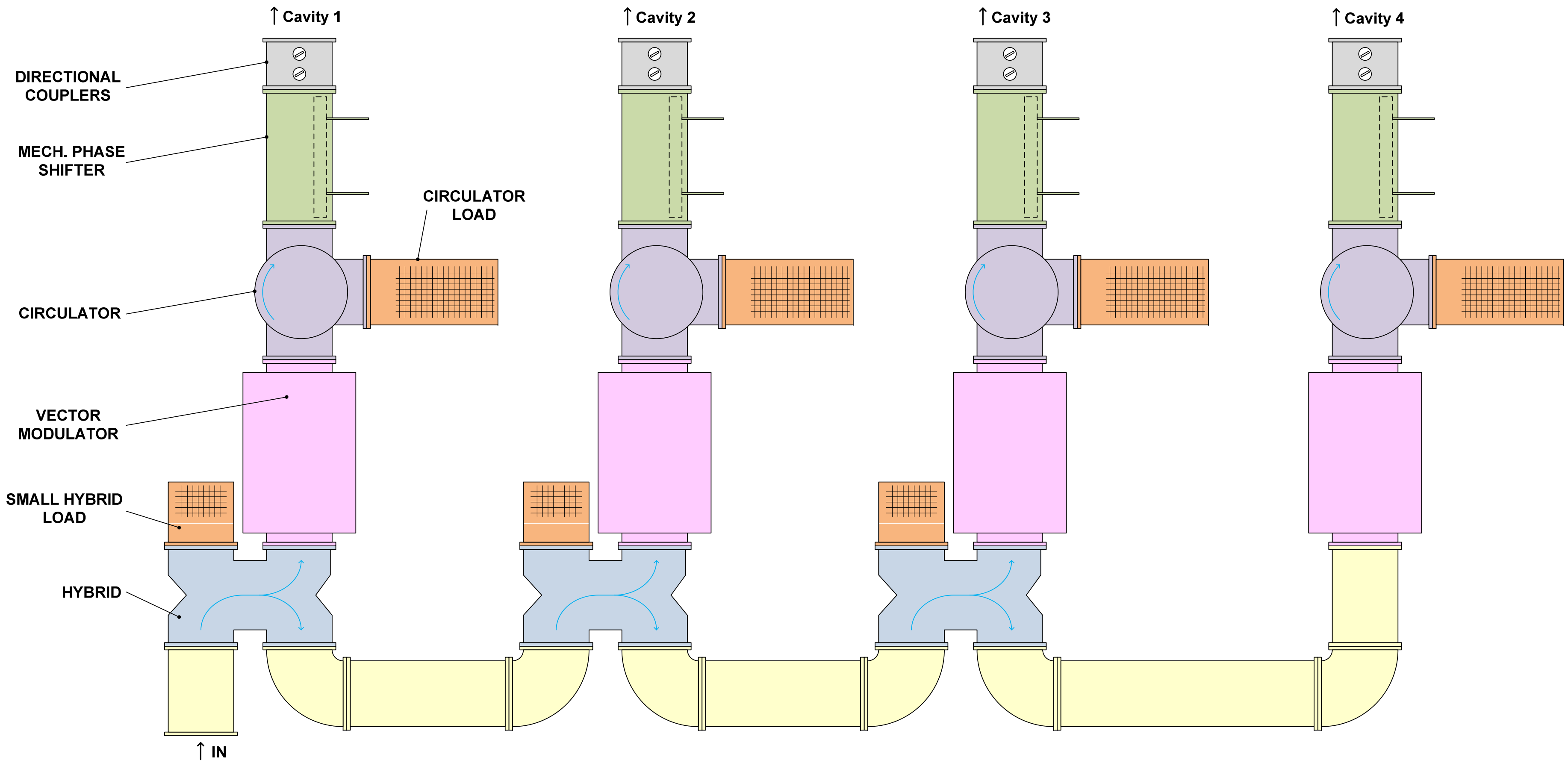
- If 1 klystron/4 cavities this would be a preferred layout
  - Linear distribution using less space consuming “planar” hybrids with individually adjusted coupling
  - Vector modulators for fast phase/amplitude field control
  - Mech. phase shifters for cavity phasing or isolation



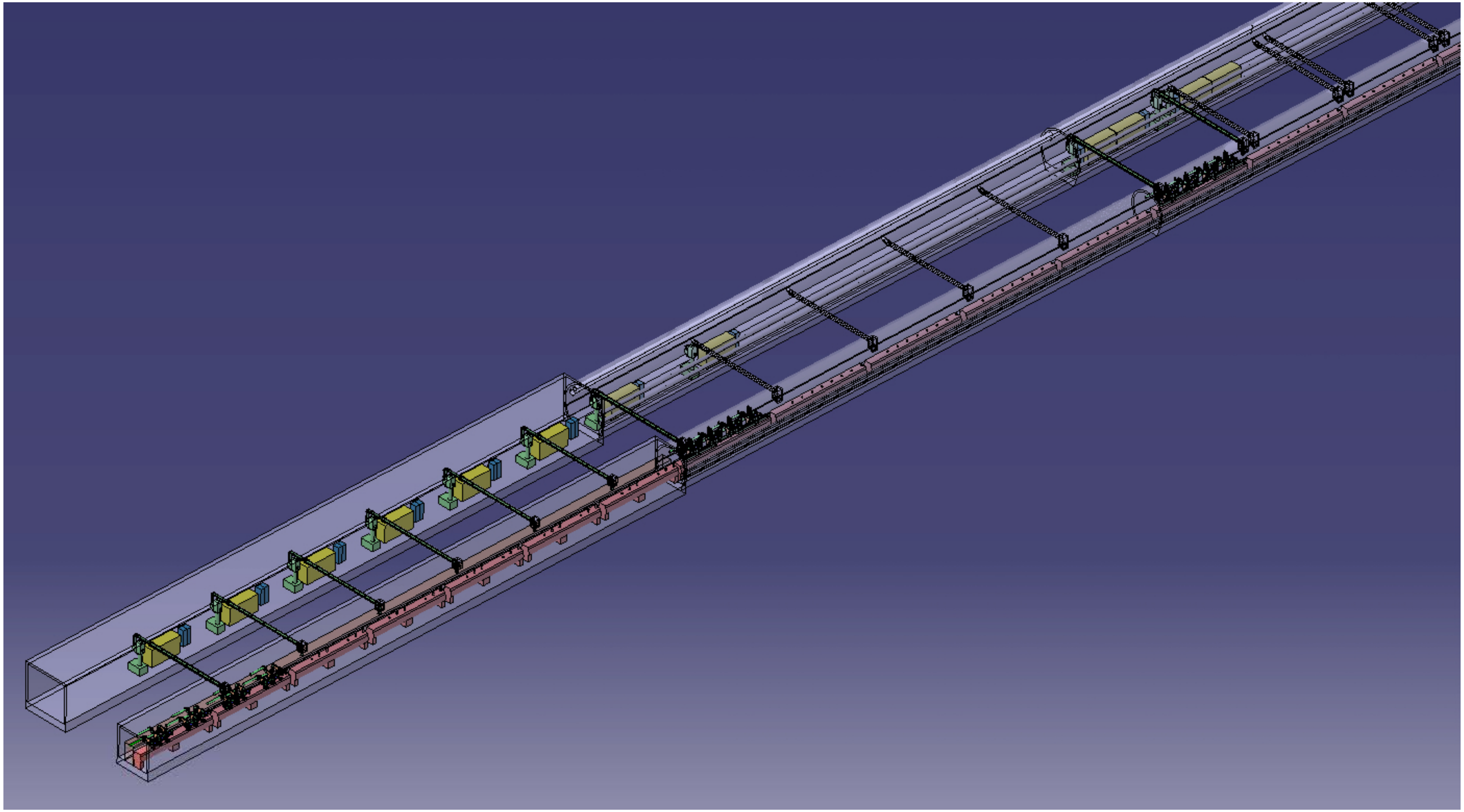
KL 5MW$_{PK}$ klystron
CIR 1MW$_{PK}$ circulator
CL 100kW$_{RMS}$ circ. Load
PH hybrid (e.g. planar 90°)
HL hybrid load
VM 1MW$_{PK}$ vector modulator
MP Mech. phase-shifter/switch
MOD Klystron modualtor

RF distribution scheme 'candidates'

- Example of an integration. In reality all 3 dimensions must be used to use the available tunnel volume efficiently



Tunnel integration proposal (J.M. Lacroix, TS/MME)



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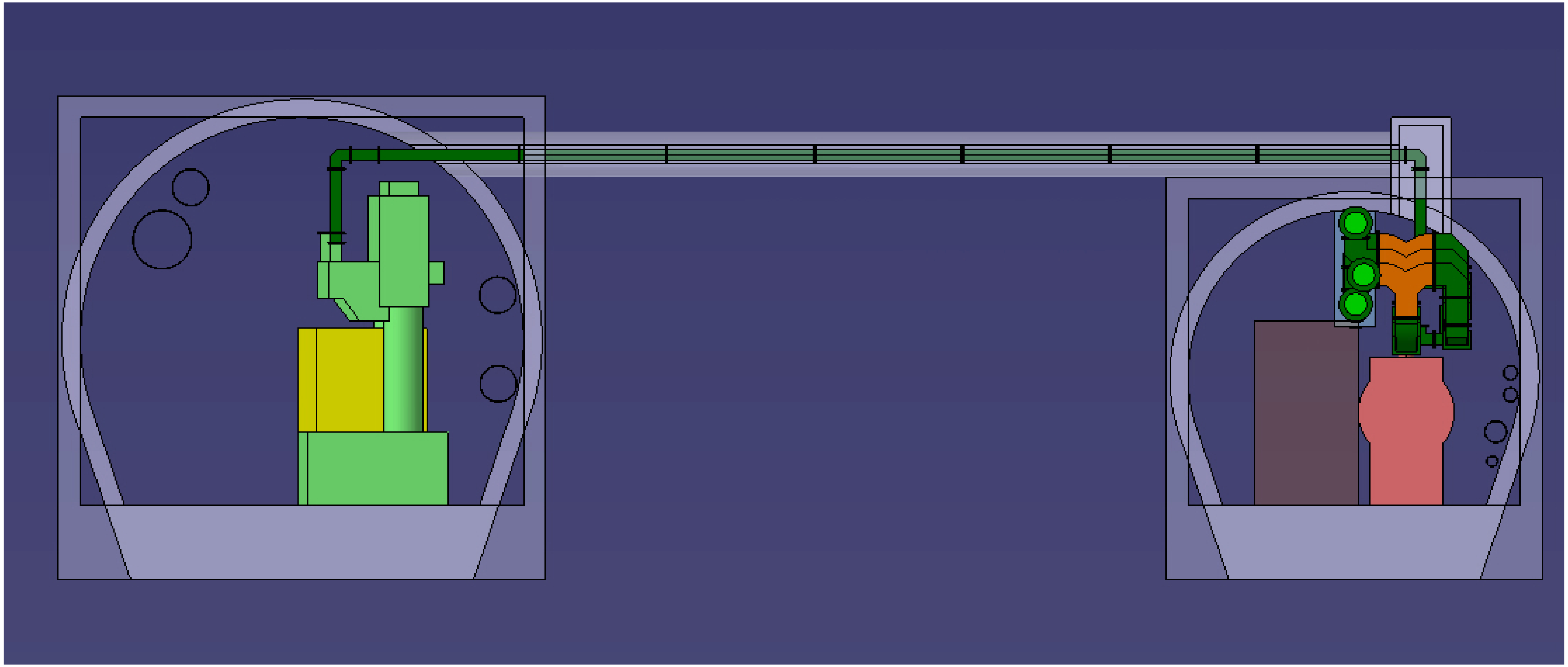

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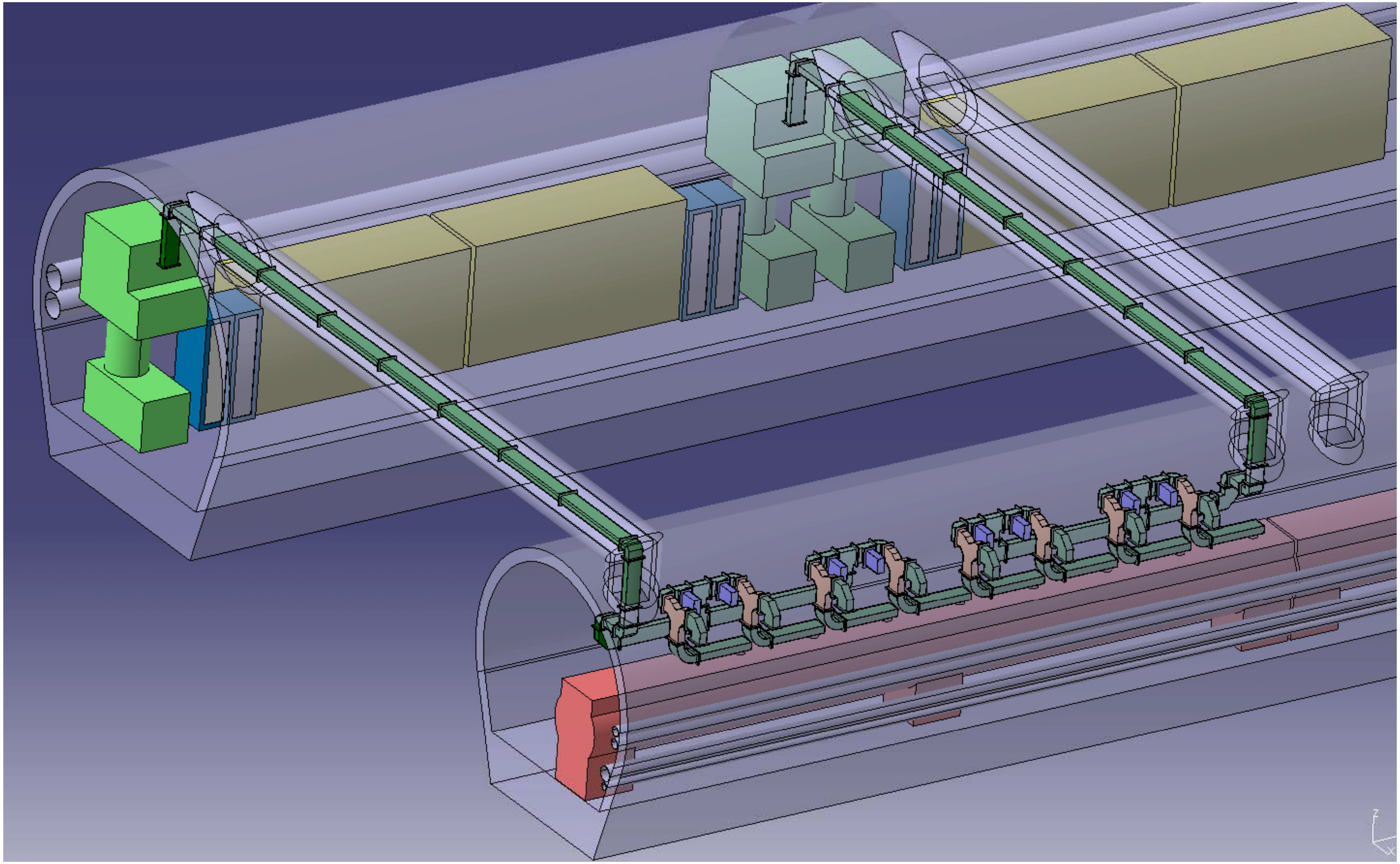

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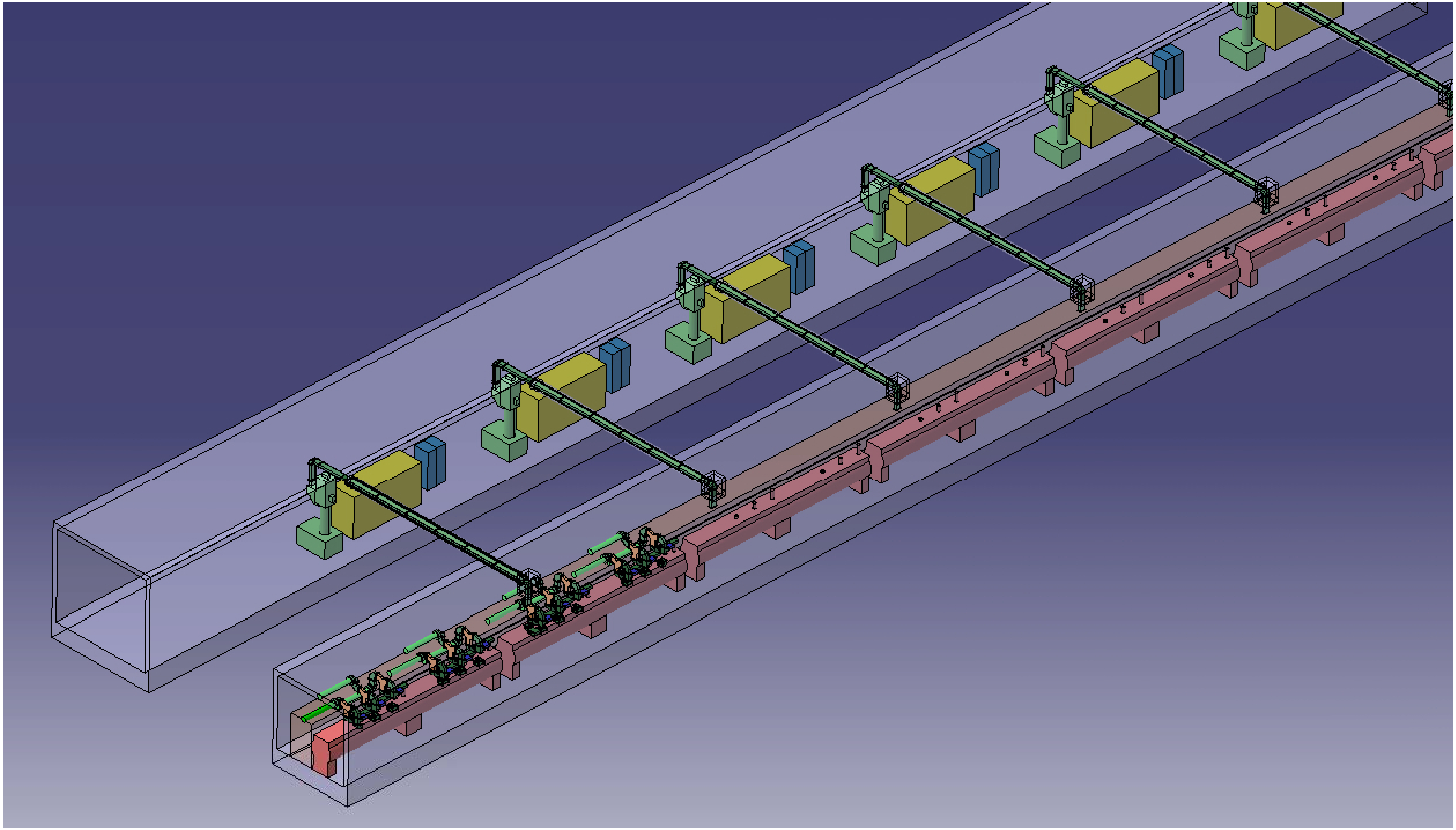

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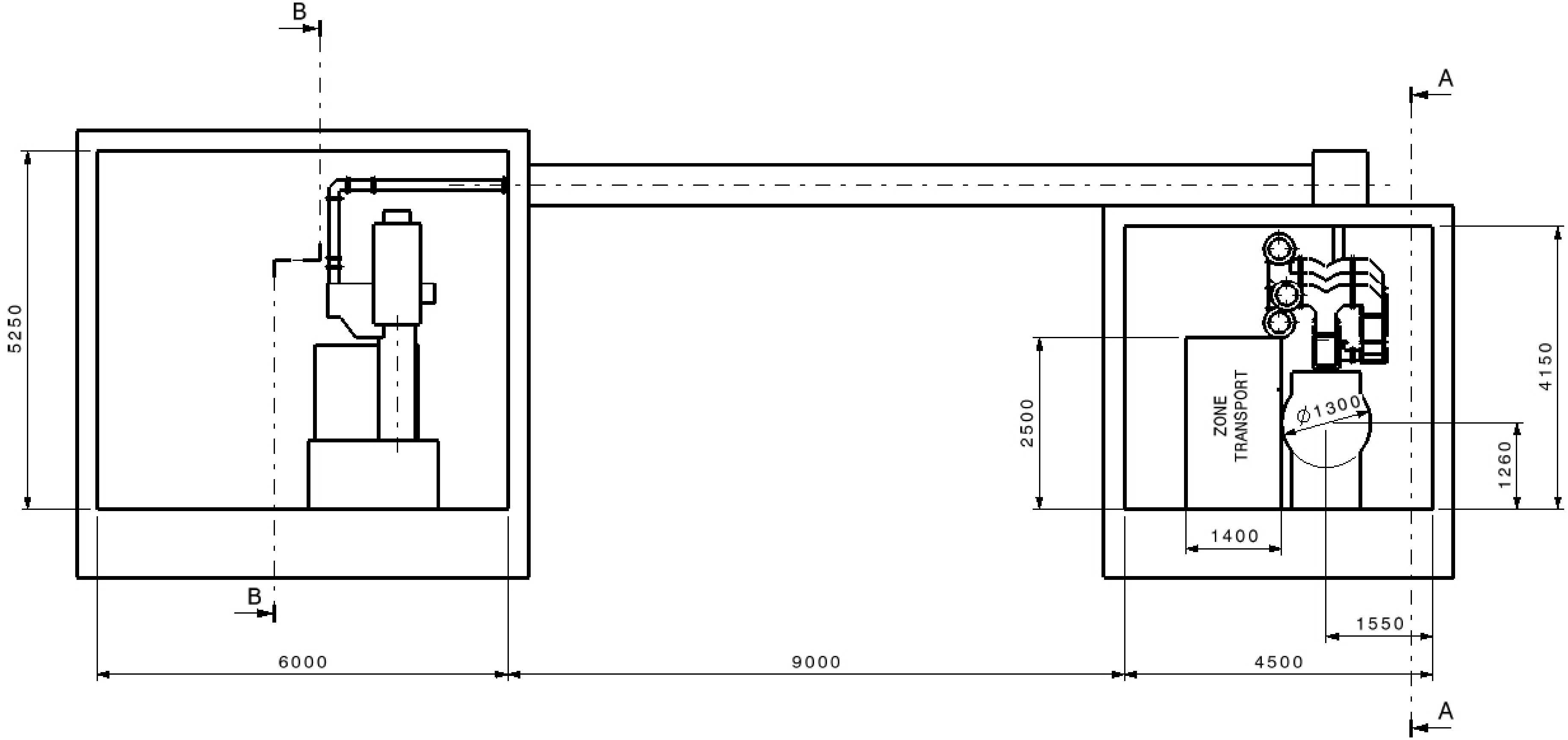

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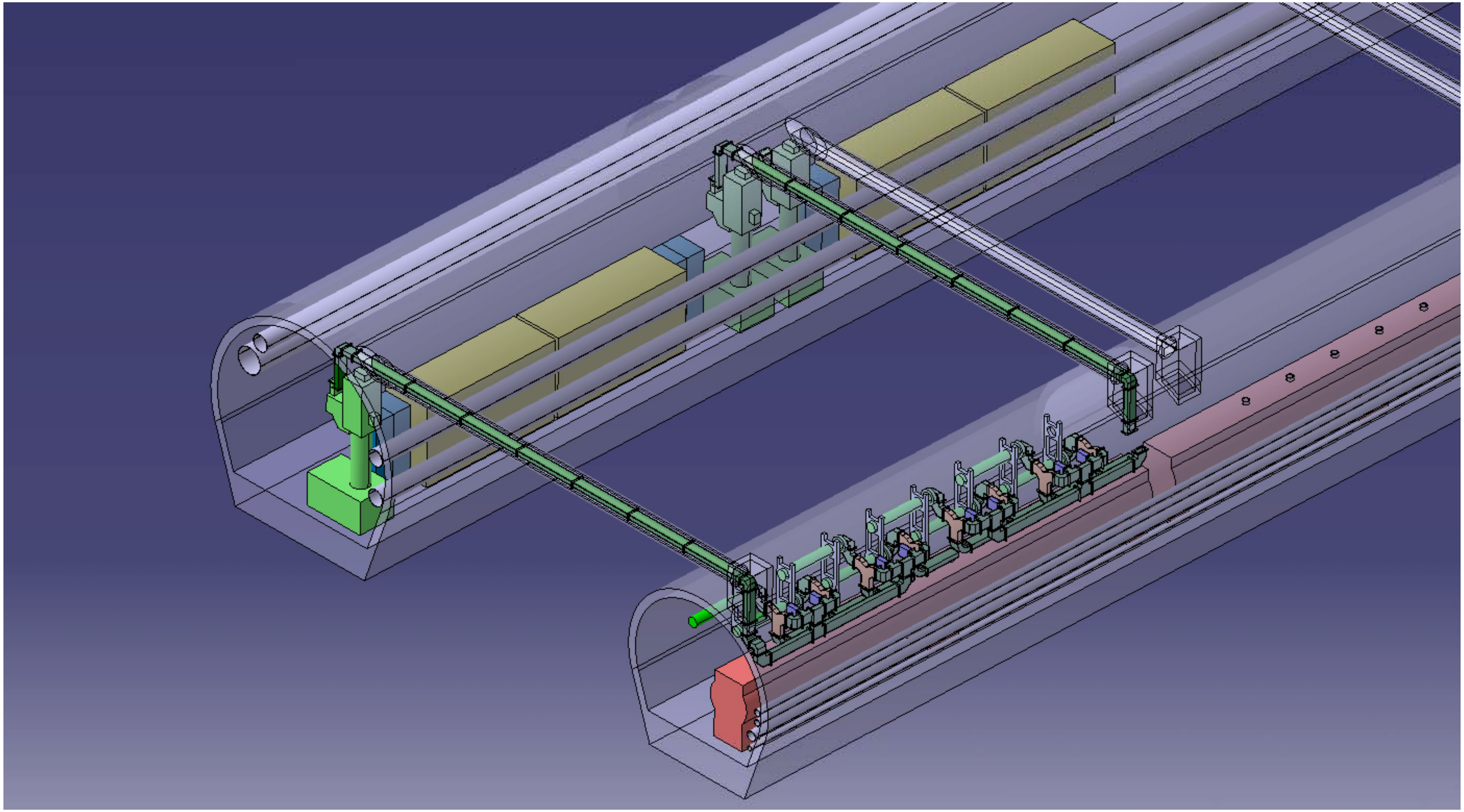

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