The Way to an Optical Design

for the Glasgow Sagnac Speed Meter

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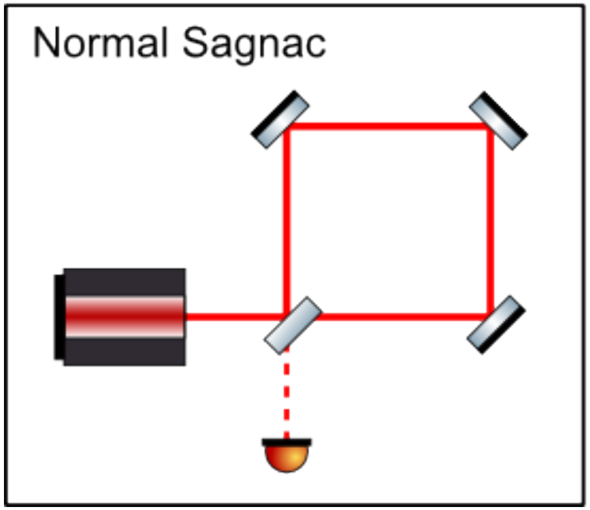
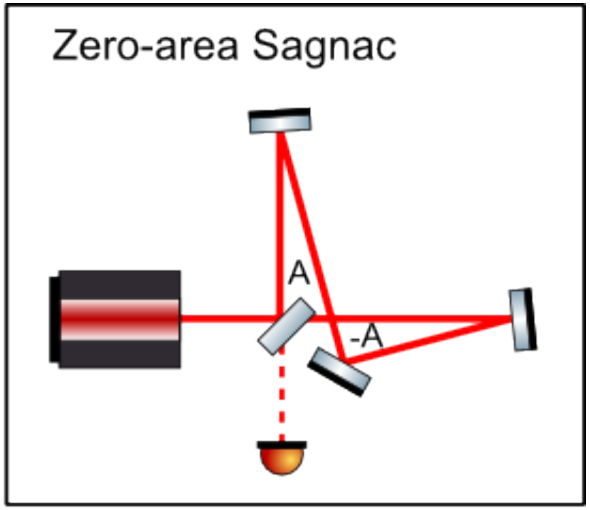
The Sagnac interferometer

- **Sagnac** interferometer used for **rotation measurements**
- By setting up a **zero-area Sagnac** interferometer **rotation signals cancel out**
- This **zero-area Sagnac** interferometer can be used for **sub SQL detection of GW** and fits into L-shape detector facilities

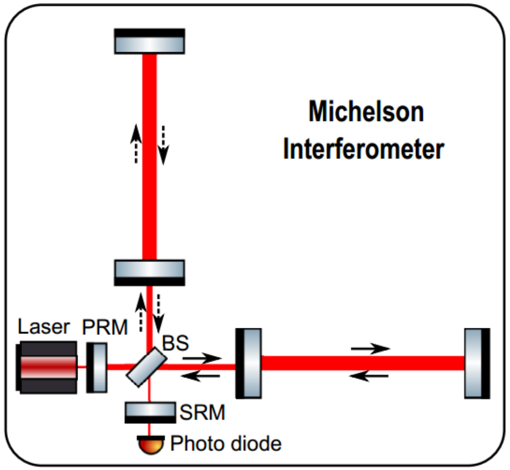




Michelson vs. Sagnac

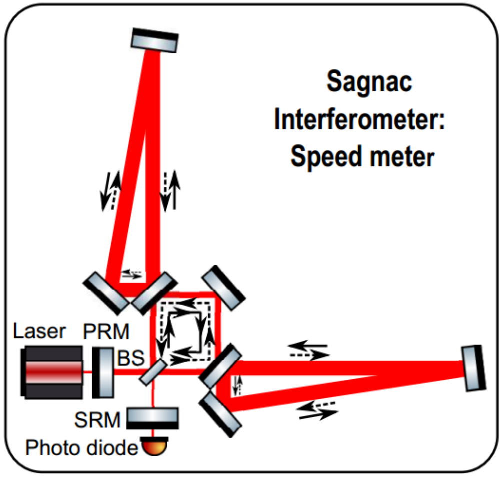
- In a **Michelson** interferometer the **position** of a test mass is **measured continuously**
- That's why it's called **position meter**
- This measurement is **limited** by the **Heisenberg uncertainty principle**

  $[x(t),p(t)] \neq 0$ & $[x(t),x(t')] \neq 0$



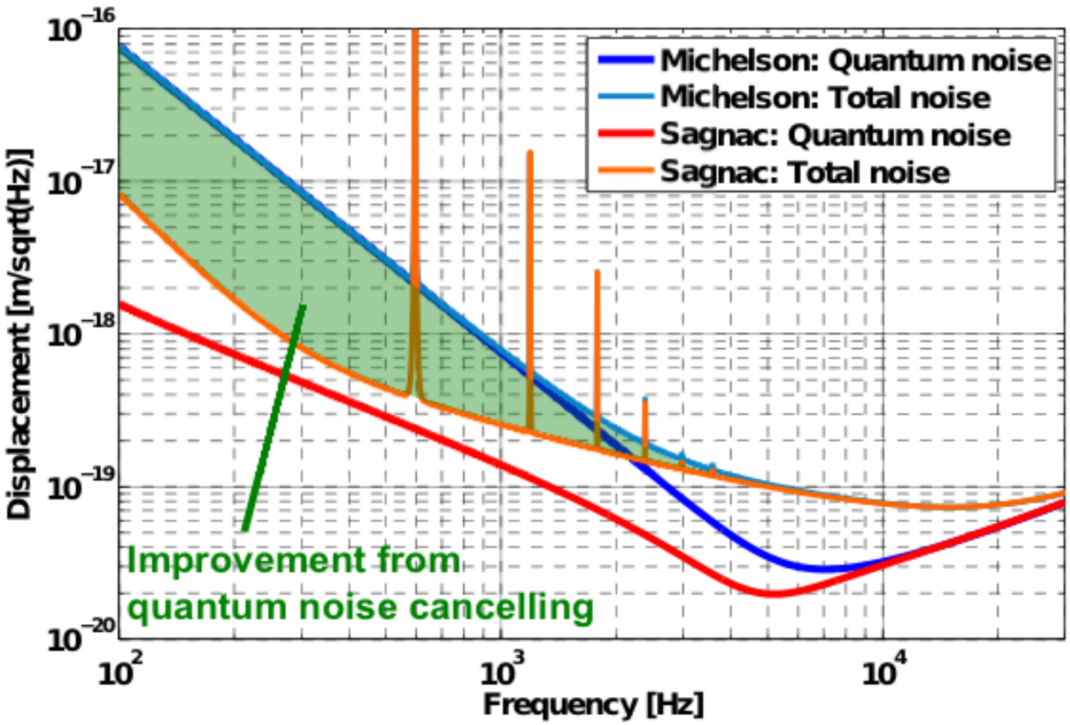
- In a **zero-area Sagnac** interferometer the **speed** of a test mass is **measured**
- That's why it's called **speed meter**
- This measurement is **not limited** by the **Heisenberg uncertainty priciple** (1930 John von Neumann)

  $[p(t),p(t')] = 0$

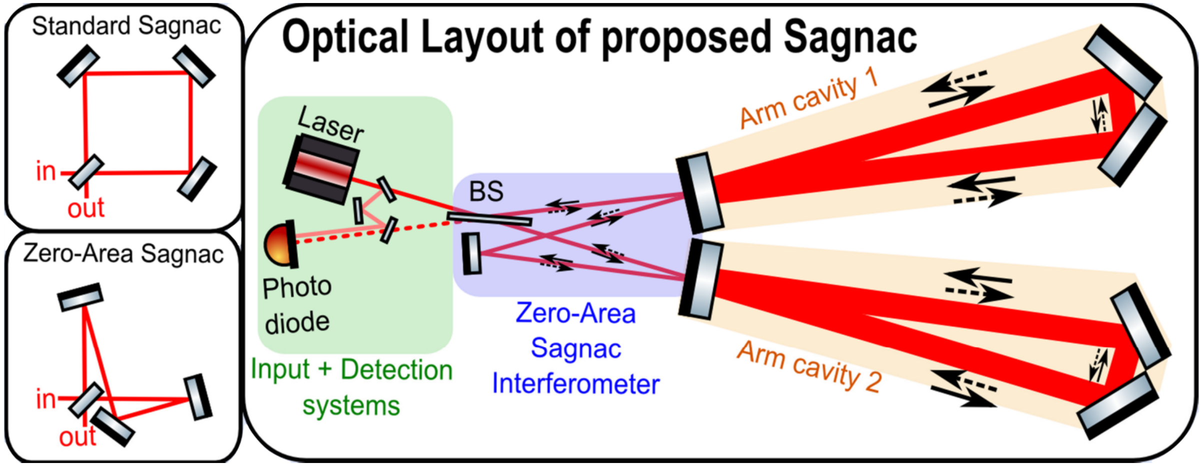


Michelson vs. Sagnac

- Proposed **zero-area Sagnac** interferometer will have a **higher sensitivity** than a Michelson interferometer
- The sensitivity in a frequency range from **100Hz to 1kHz** is proposed to be up to **ten times higher**
- One **goal** of the Glasgow Sagnac speed meter: Below 10^{-18}m/√Hz at 1kHz



Proposed layout



- **Arm-cavities** will have a **finesse of 10000**, they are designed for **1kW** circulating power and a **roundtrip** length of **2.4m**
- Beam radius will be ~1mm at cavity mirrors
- **1/2 inch, 1.6g input mirrors** are suspended by **monolithic** fused silica **suspensions**
- Speed meter will be build on a **sophisticated seismic isolation** system
- **Balanced Homodyne Detection**

Constraints

- Several **constraints** are given for the **transformation** of the **proposed layout** into a more realistic **optical layout**
- **Space** in the **vacuum system** consisting of two tanks with a **diameter of 1m**
- **Input beam** has to be **mode matched** to the **cavities**
- **Cavities** have to be **mode matched** to **each other**
- **Signal beam** and **local oscillator** have to be **mode matched** for perfect **contrast**
- Steering of beams in **all degrees of freedom**

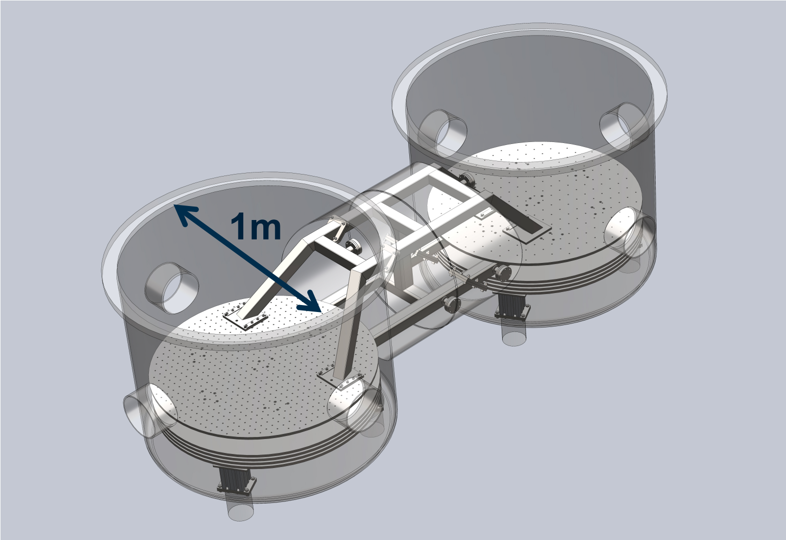
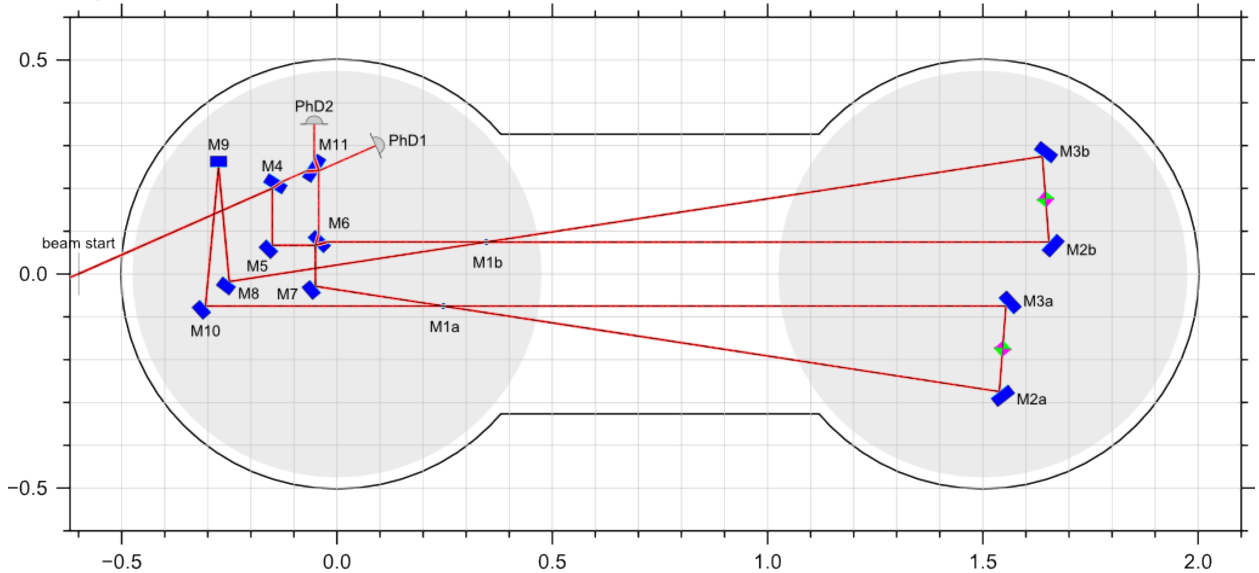


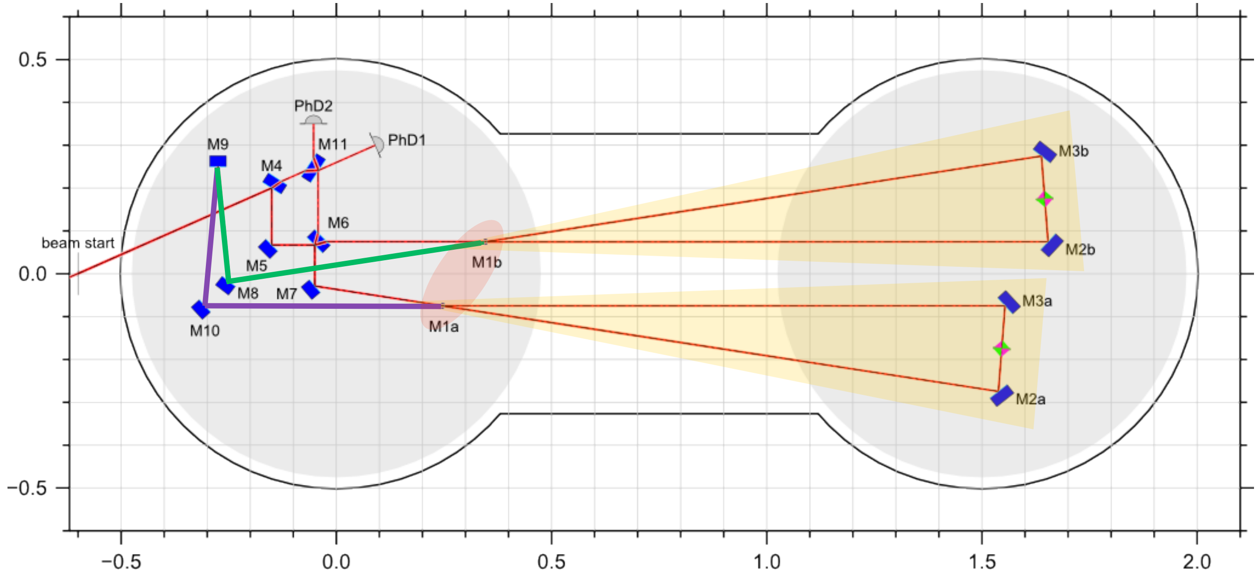
Image: Russel Jones

Optical layout



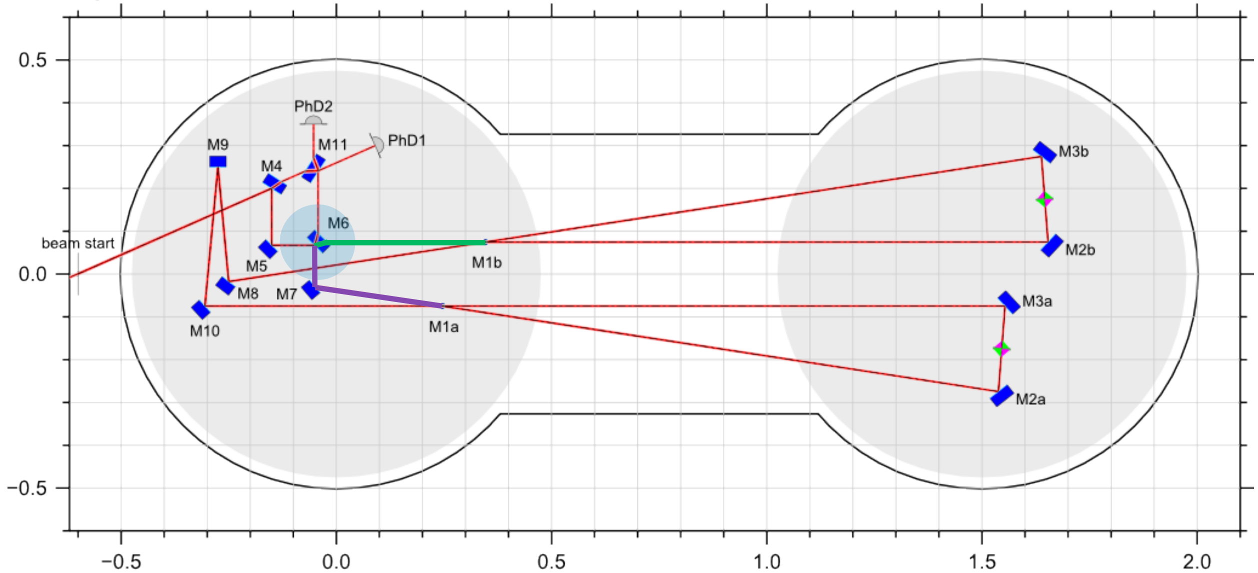
- **Transformation** of the proposed layout into an **OptoCAD** model was done by **Roland Schilling**
- The **input beam** is **mode matched** to the **two cavities**, that are the **heart** of the Glasgow Sagnac speed meter

Optical layout



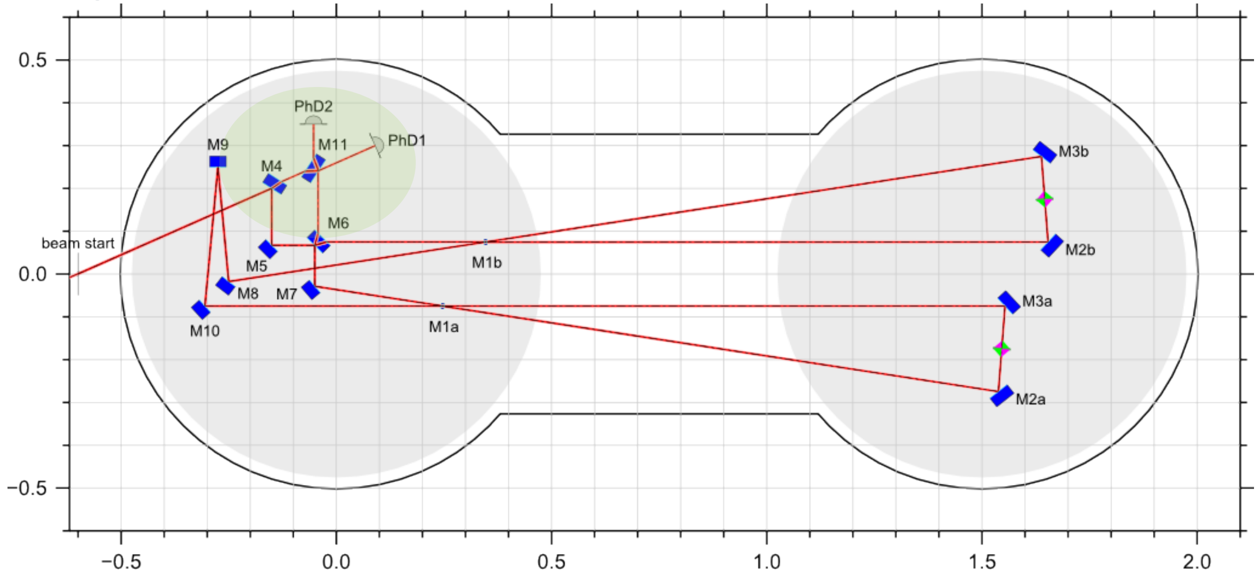
- The design of the **cavities** is the **basis** in the design of zero-area Sagnac
- **Opening angle** of the cavities has **influence** on the **position** of the **curved mirror** and the need of **additional mirrors** between the two cavities
- **Angle of incidence** on the curved mirror needs to be **small** to **avoid astigmatism** of the beam between the cavities

Optical layout



- The **optical path length** from the main **beam splitter** to the **two cavities** needs to be **matched** for mode matching in both directions
- Due to **high power** at the main beam splitter, **control** of all **secondary reflections** is needed to avoid stray light that would spoil the sensitivity

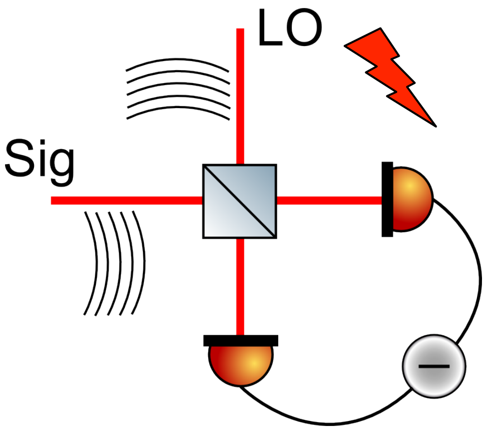
Optical layout

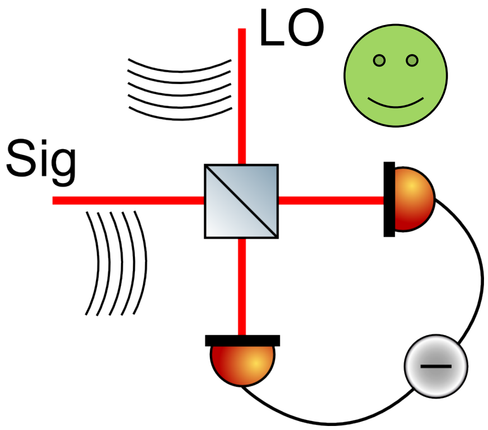


- The **detection system** for the Glasgow Sagnac speed meter is a **Balanced Homodyne Detection**
- At this design stage this is just a very simple sketch of what it could look like
- **Further thoughts needed** for a decent implementation

Balanced Homodyne Detection

- The **Sagnac** speed meter operated **always on a dark fringe**
- A **DC-readout** is **not feasible** for this configuration, since the **Sagnac** interferometer would **compensate for any offset**
- As a result an **external local oscillator** (LO) is **needed** for the readout
- The **local oscillator** beam needs to be **mode matched** to the **signal beam**
- Any **miss match** of size and wavefront curvature results in a **loss of contrast** and thus a **loss of the signal**





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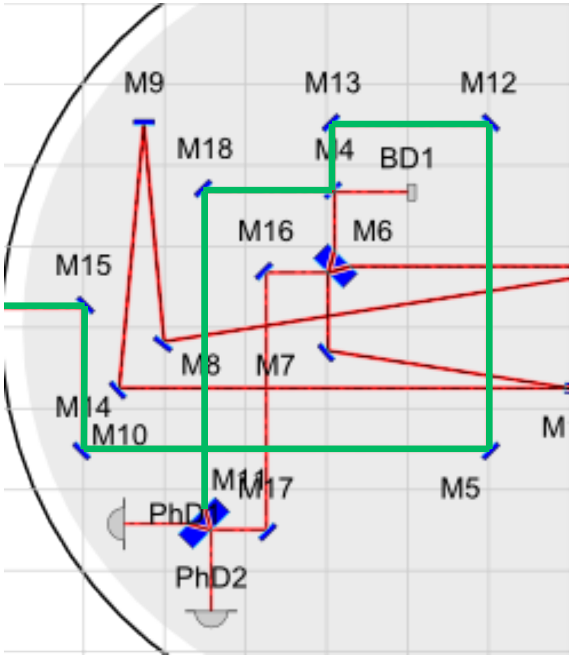
- A **DC-readout** is **not feasible** for this configuration, since the **Sagnac** interferometer would **compensate for any offset**
- As a result an **external local oscillator** (LO) is **needed** for the readout
- **Three** different options:

1. Take the **input beam as LO**
   - **Easy to implement** in the optical layout
   - **Input beam** is **decreasing** in size and thus has an **opposite wavefront curvature** than the signal beam
   - Steering of LO-beam with M18
   - Steering of signal beam with M16 & M17



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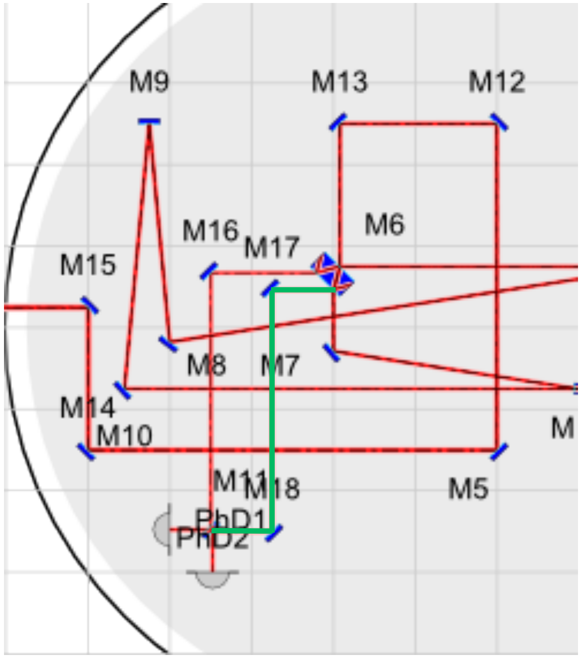
- As a result an **external local oscillator** (LO) is **needed** for the readout
- **Three** different options:

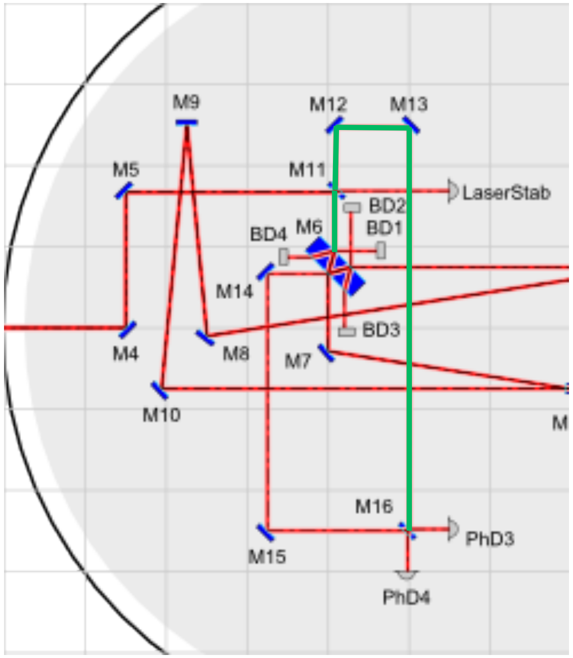
2. Take **AR-reflection as LO**
   - **Separation** of **LO** beam and **signal** beam might be **difficult**
   - **Beams** are **equal** and can be matched at the beam splitter of the BHD
   - Steering of LO-beam with M17 & M18
   - Steering of signal beam with M16



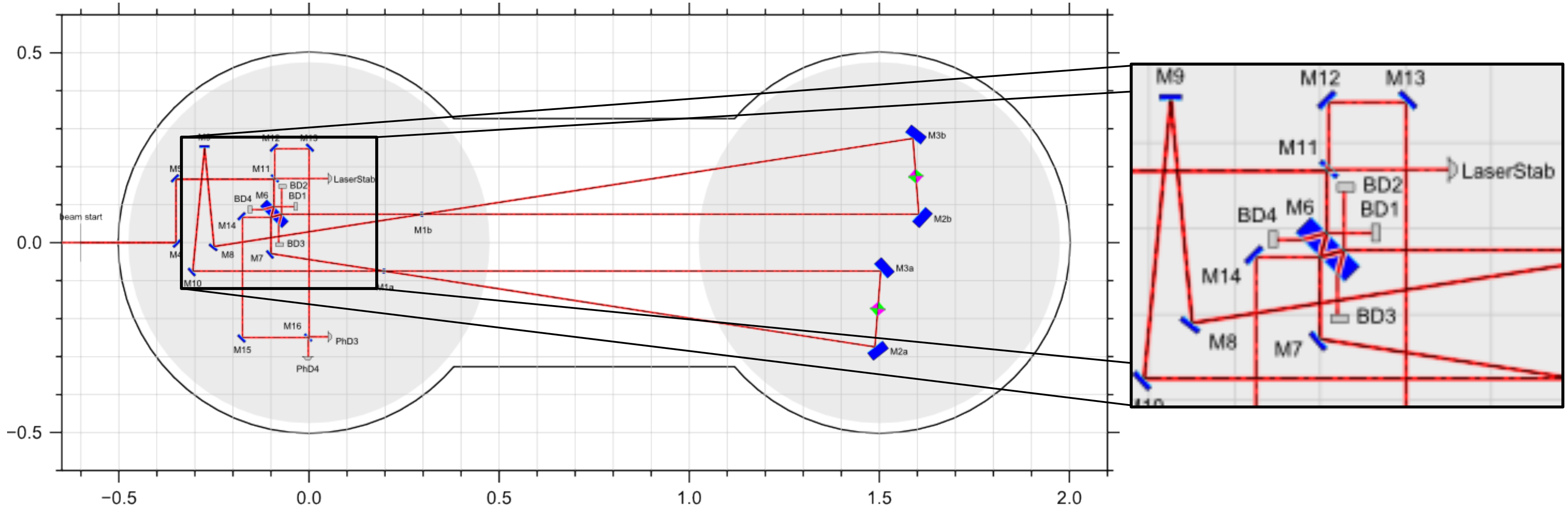
Balanced Homodyne Detection

- The **Sagnac** speed meter operated **always on a dark fringe**
- A **DC-readout** is **not feasible** for this configuration, since the **Sagnac** interferometer would **compensate for any offset**
- As a result an **external local oscillator** (LO) is **needed** for the readout
- **Three** different options:

3. Take the **bright port as LO**
   - **Easy to implement** in the optical layout
   - **Beams** are **equal** and can be matched at the beam splitter of the BHD
   - **Steering** of **LO**-beam with **M12 & M13**
   - **Steering** of **signal** beam with **M14 & M15**
   - All degrees of freedom for both beams

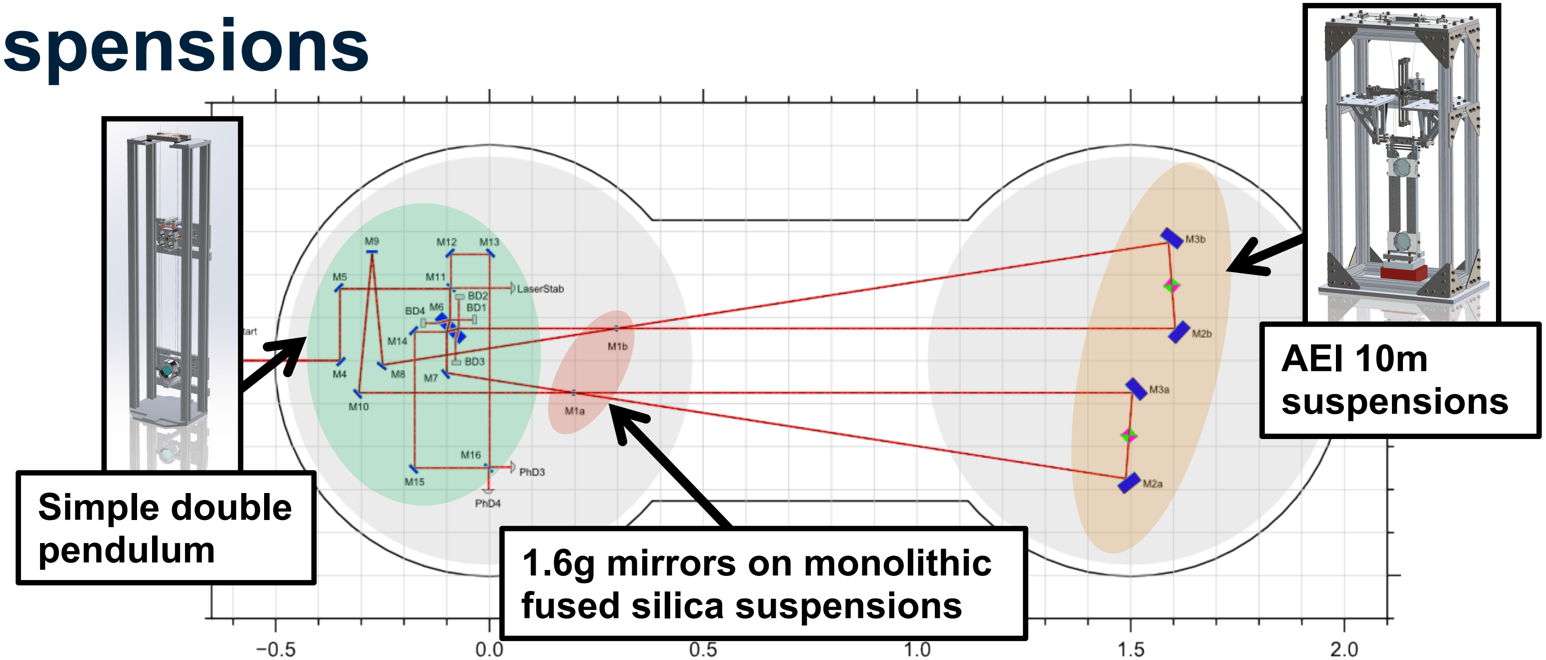


Optical layout version 1.0



- **All components** are now **1inch** mirrors, **except** for the **main beam splitter**. More realistic picture
- The **main beam splitter** has a **radius** of **4.0cm** and a **thickness** of **1inch**
- All **secondary reflections** and **AR-reflections** can be **controlled**

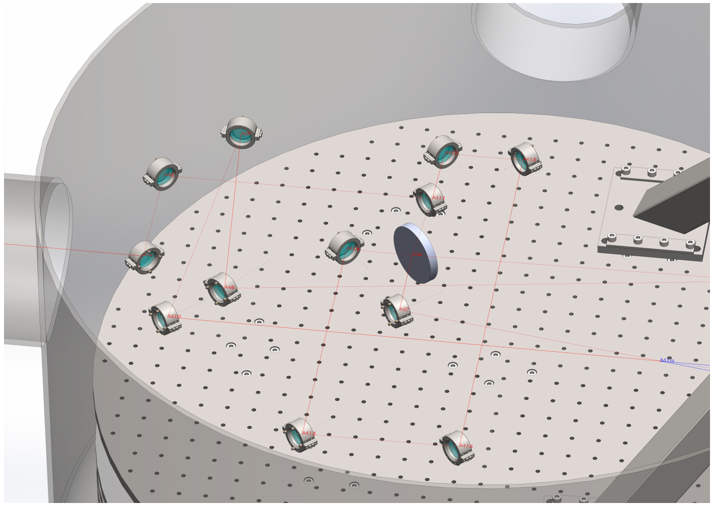
Suspensions

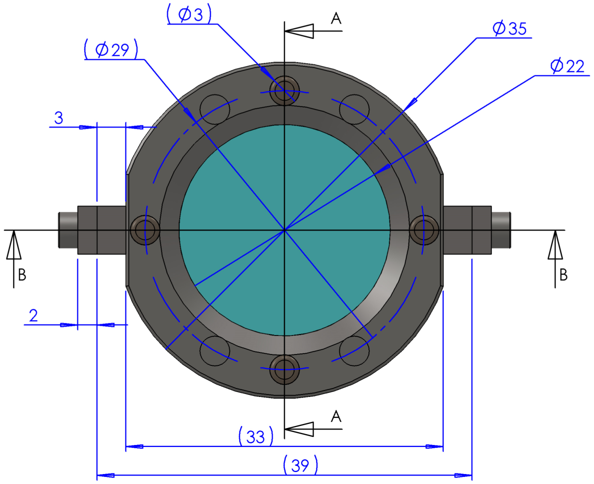


- **Large cavity mirrors** will be suspended from **AEI 10m suspensions**
- **1.6g input mirrors** will be suspended from **monolithic fused silica suspensions**
- **Other components** (1inch mirrors) will be suspended from **simple double pendulum** stages

Suspensions

- Next **important step** is to **design** the **auxiliary suspensions**
- A **very compact design** for the double pendulum is **needed**, since there will be **more than 10** suspensions in the left tank
- As a **first idea** we are planning to use a **5mm thick steel ring** to encage the 1inch mirrors, which results in a **total mass** of **~73g**

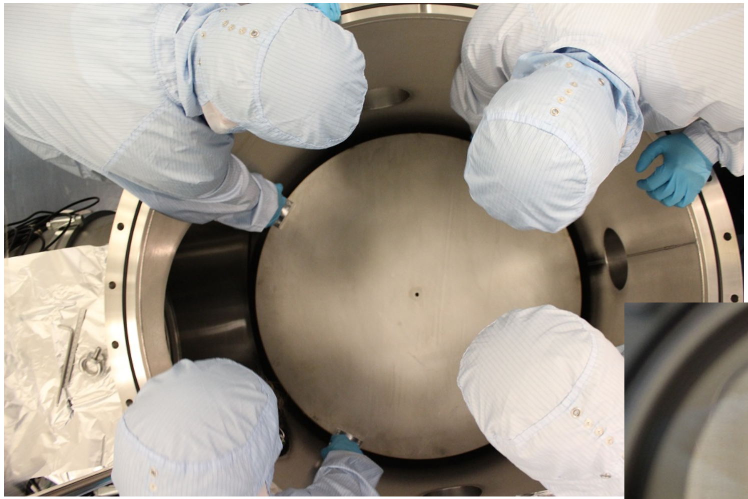


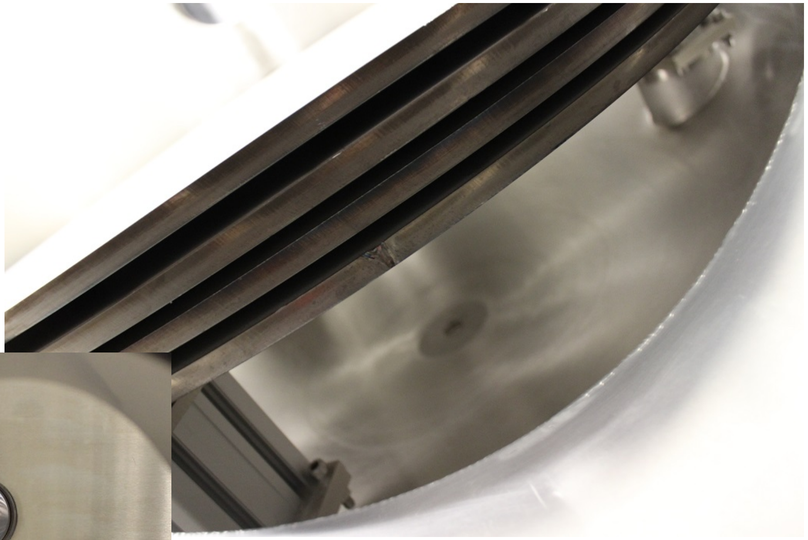


Images: Russel Jones

Installation of seismic pre-isolation

- **Installation** of the seismic pre-isolation stacks **completed last week**
- One **stack** consists of **four steel plates** with an outer diameter of **90cm** and a weight of **60kg** each with viton rubber in between





THANK YOU FOR LISTENING!