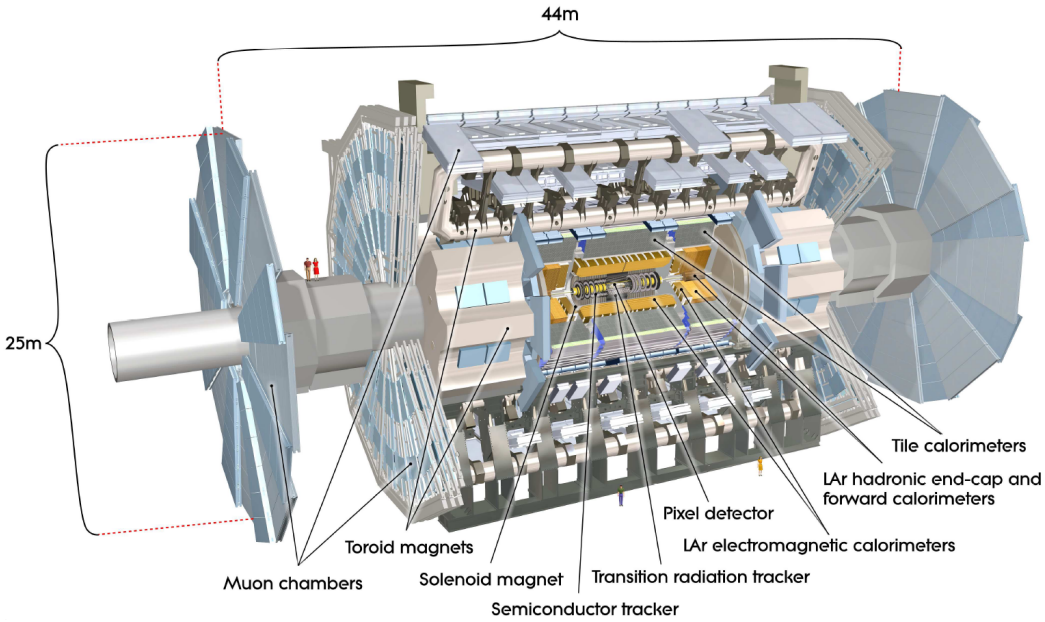
Construction and Test of Full-Size Micromegas Modules for the ATLAS New Small Wheel Upgrade

Jonathan Bortfeldt
on behalf of the ATLAS Muon Collaboration

Ludwig-Maximilians-University Munich, Germany

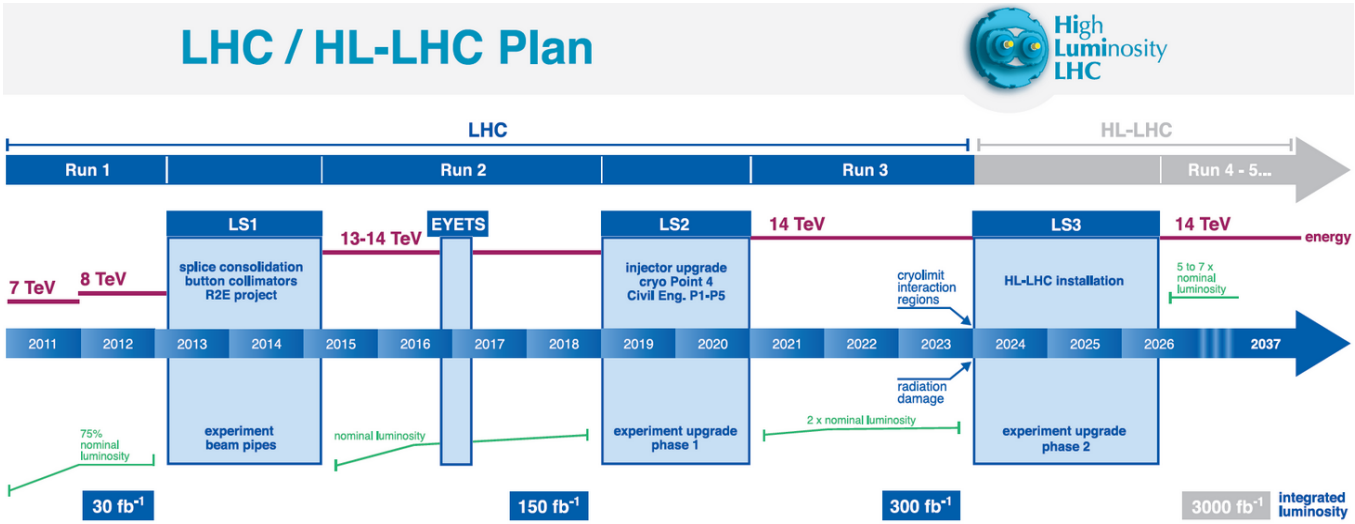
4th International Conference on Micro Pattern Gaseous Detectors
October 12th 2015

ATLAS Detector: Status & Upgrade Plans

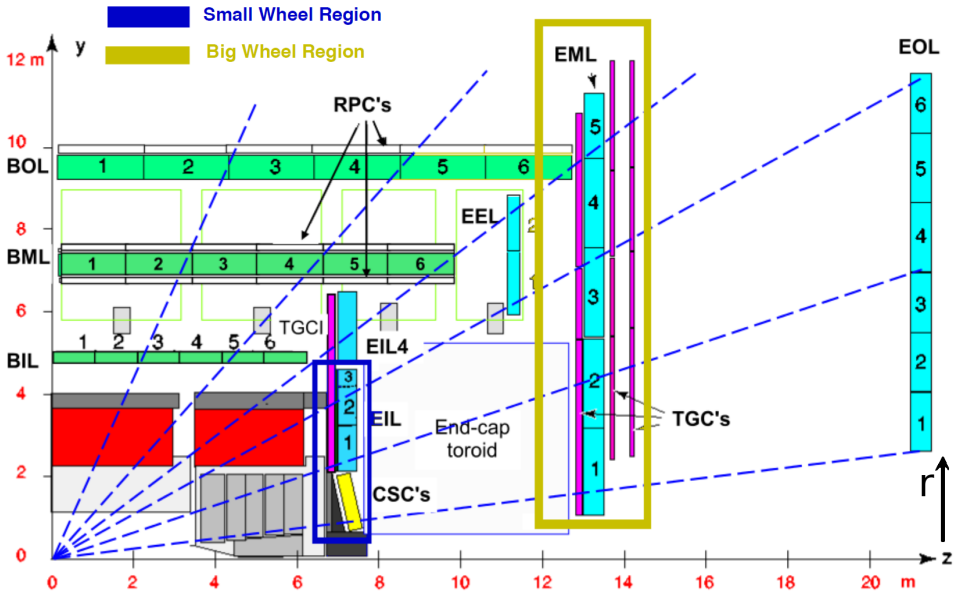


- general purpose detector at LHC/CERN
- pp @ 13 TeV & heavy ions @ 2.76 TeV/u
  → discovery of new particles
  → precision measurements of Standard Model parameters
- this talk: forward muon spectrometer

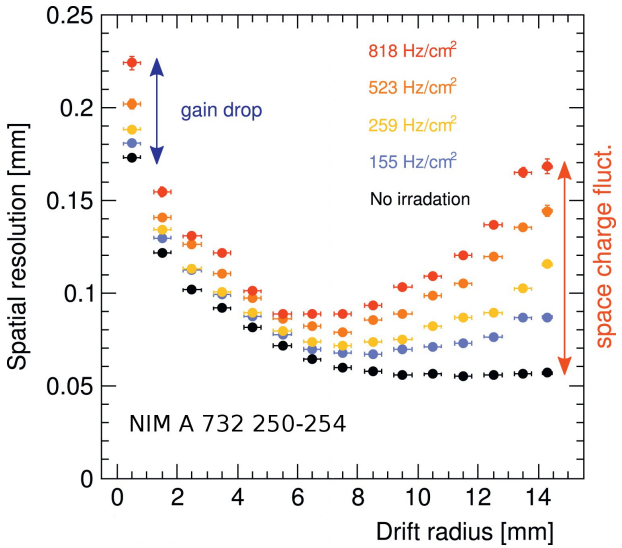
- design:
  $\mathcal{L} = 1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 2021:
  $\mathcal{L} = 2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 2026:
  $\mathcal{L} = 7 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

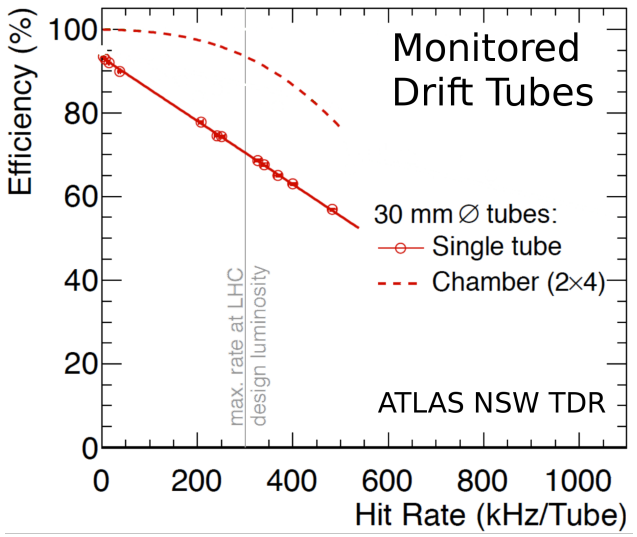


Two New Small Wheels: Motivation



- highest background hit rate in Muon Spectrometer in Small Wheel: innermost endcap
- Cathode Strip Chambers $r < 2\,\mathrm{m}$
- Monitored Drift Tube Chambers $2\,\mathrm{m} < r < 4.3\,\mathrm{m}$
- $\mathcal{L} \gtrsim 5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  $\rightarrow$ excessive hit rates:
  $15\,\mathrm{kHz/cm^2} \sim 4\,\mathrm{MHz/tube}$
  $\rightarrow$ spatial resolution is deteriorated
  $\rightarrow$ efficiency decreases
  $\rightarrow$ trigger bandwidth limit exceeded due to fake triggers





$\rightarrow$ replace with novel high-rate capable detectors

Outline

- New Small Wheel
- Resistive Strip Micromegas

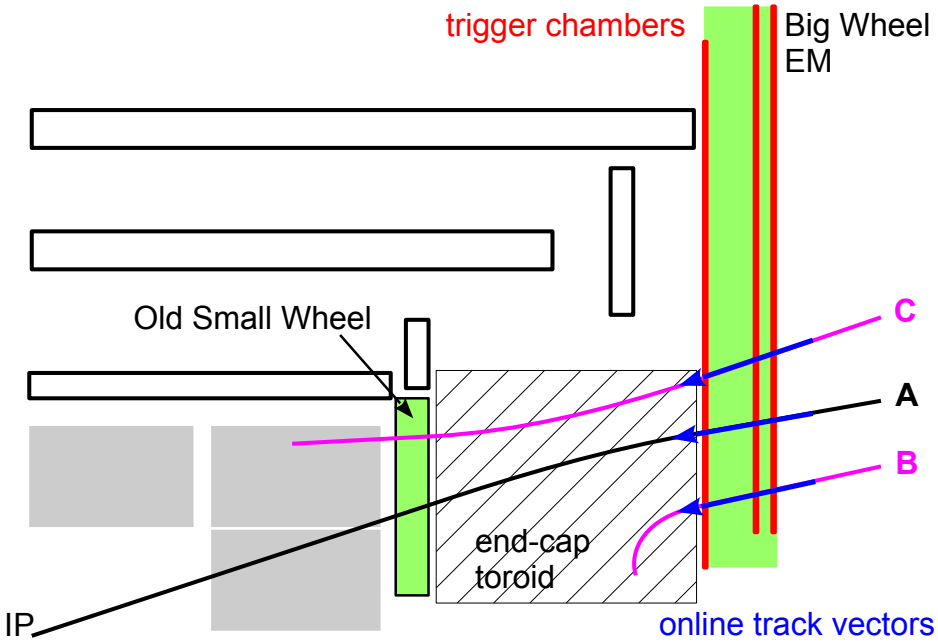
we just received (last week) the first functional readout structures

I will discuss and review:

- Panel Construction
- Quality Control
- Assembly Procedures
- Results from LMU Cosmic Ray Facility with $1\,\mathrm{m}^2$ Micromegas chamber prototype

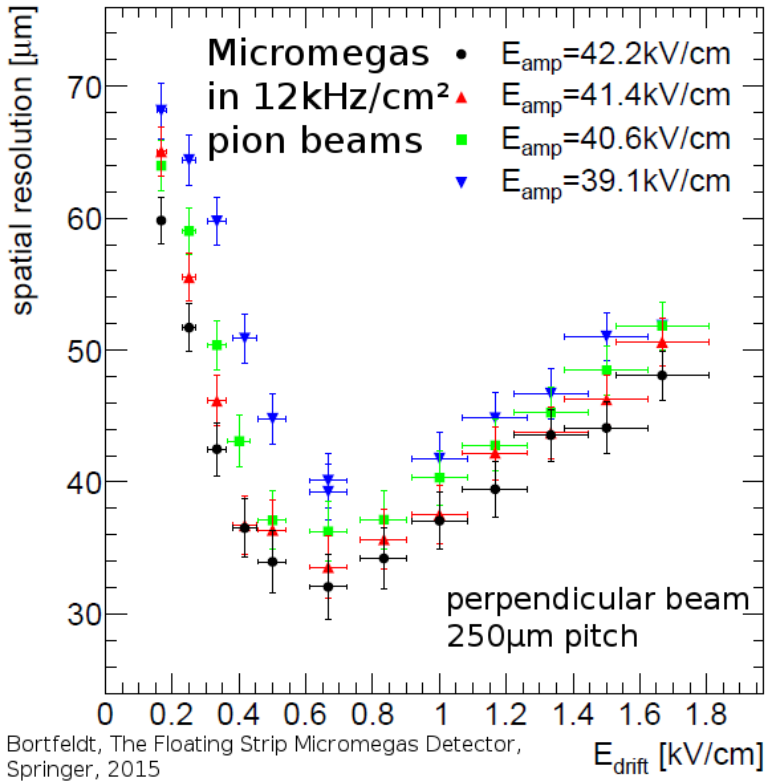
New Small Wheel: Requirements

triggering



- currently: tracks A, B, C create Level 1 trigger

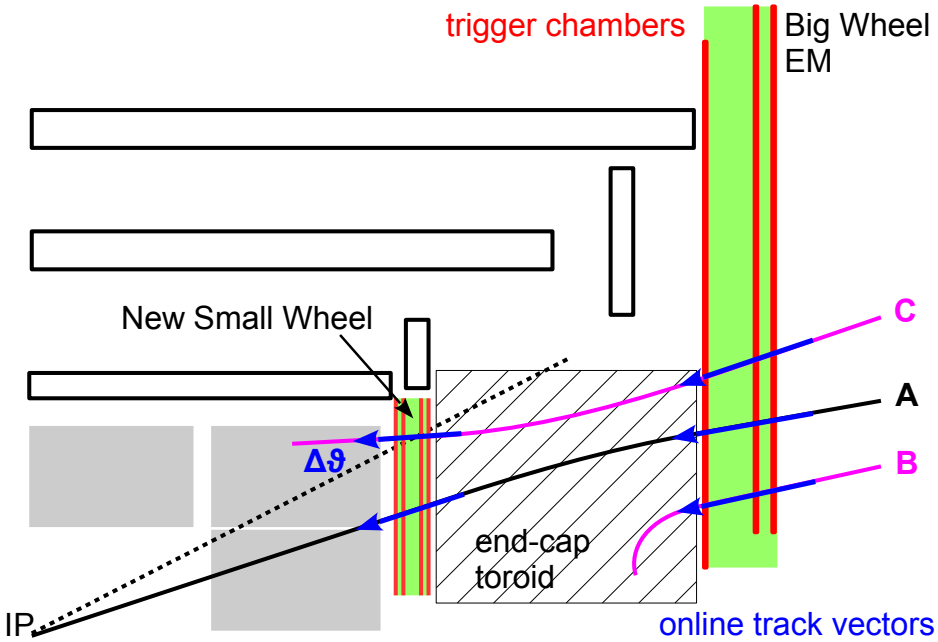
tracking



- Micromegas spatial resolution and efficiency constant in relevant range
- Micromegas can be operated at rates $> 10\,\mathrm{MHz/cm^2}$
  $\rightarrow$ large security margin

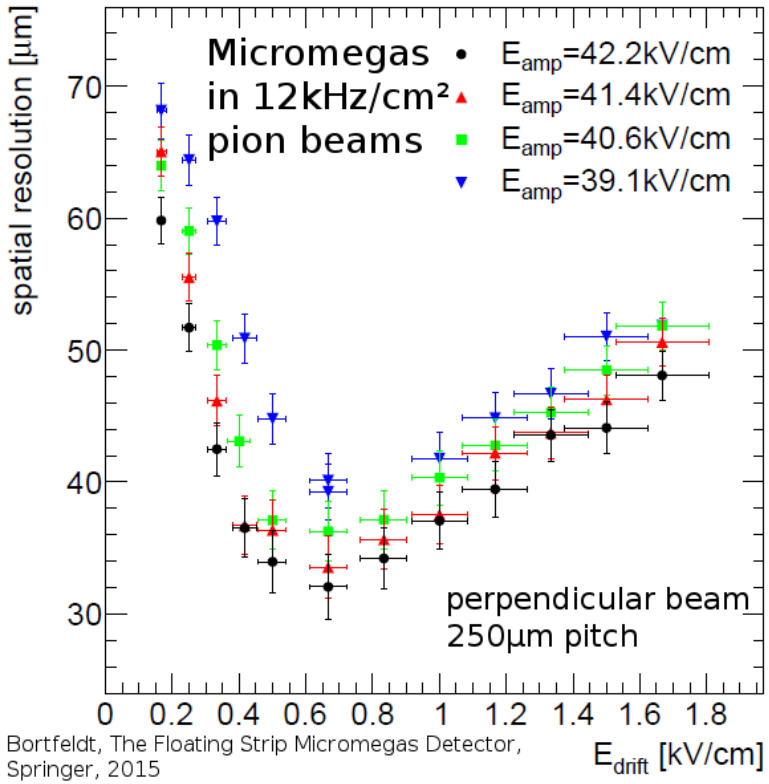
New Small Wheel: Requirements

triggering



- currently: tracks A, B, C create Level 1 trigger
- Small Wheel trigger chambers
  → only track A accepted
  → pointing resolution ∼1 mrad
- significantly reduces fake muon triggers
  → recover low momentum trigger thresholds

tracking



- Micromegas spatial resolution and efficiency constant in relevant range
- Micromegas can be operated at rates
  $> 10\,\mathrm{MHz/cm^2}$
  → large security margin

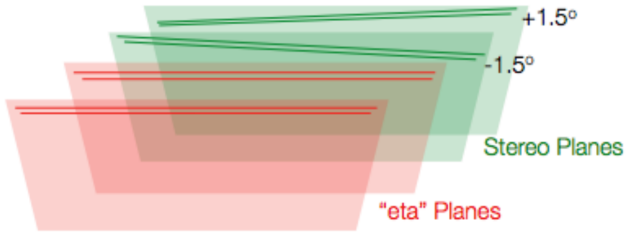
New Small Wheel: Detector Technologies

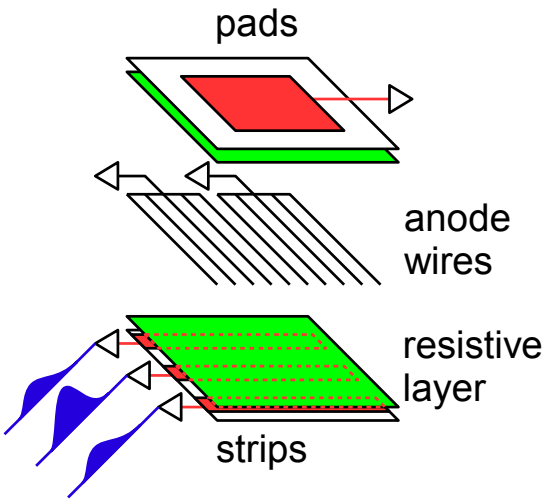
small strip Thin Gap Chambers

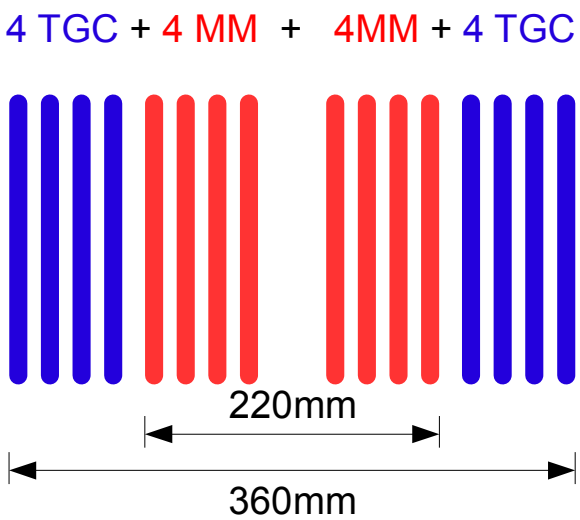
- primary trigger detectors
- excellent timing resolution
  $\rightarrow$ Bunch crossing ID
- good spatial resolution
  $\rightarrow$ online track vectors with < 1 mrad
- pads: region-of-interest
- strips: online track segment
  additional offline track info
- wire groups: coarse azimuthal coordinate

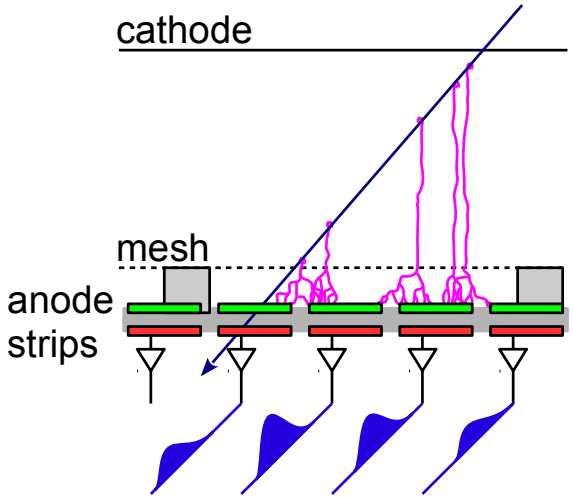
resistive strip Micromegas

- primary tracking detectors
- excellent spatial resolution, independent of track inclination
- good timing resolution
- strips: offline track segment
  additional online track info
- stereo layers: azimuthal coordinate

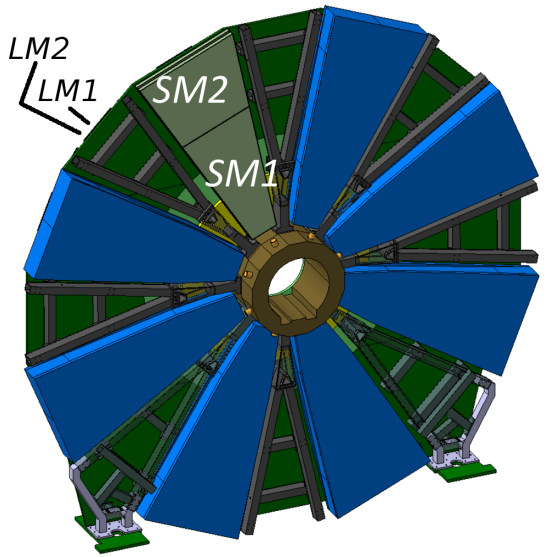




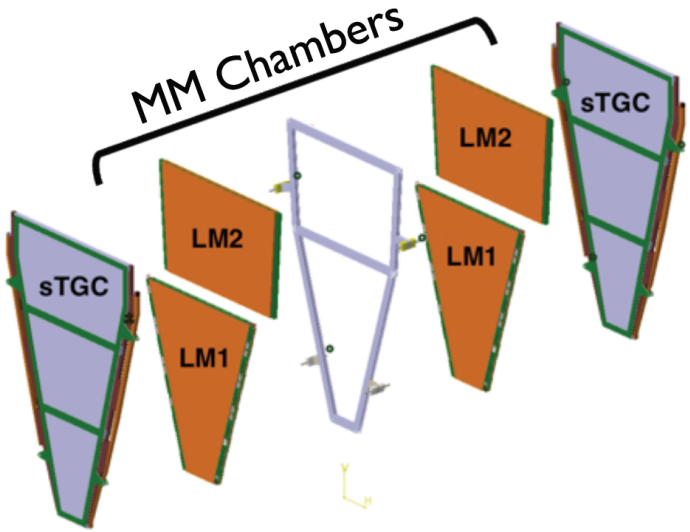


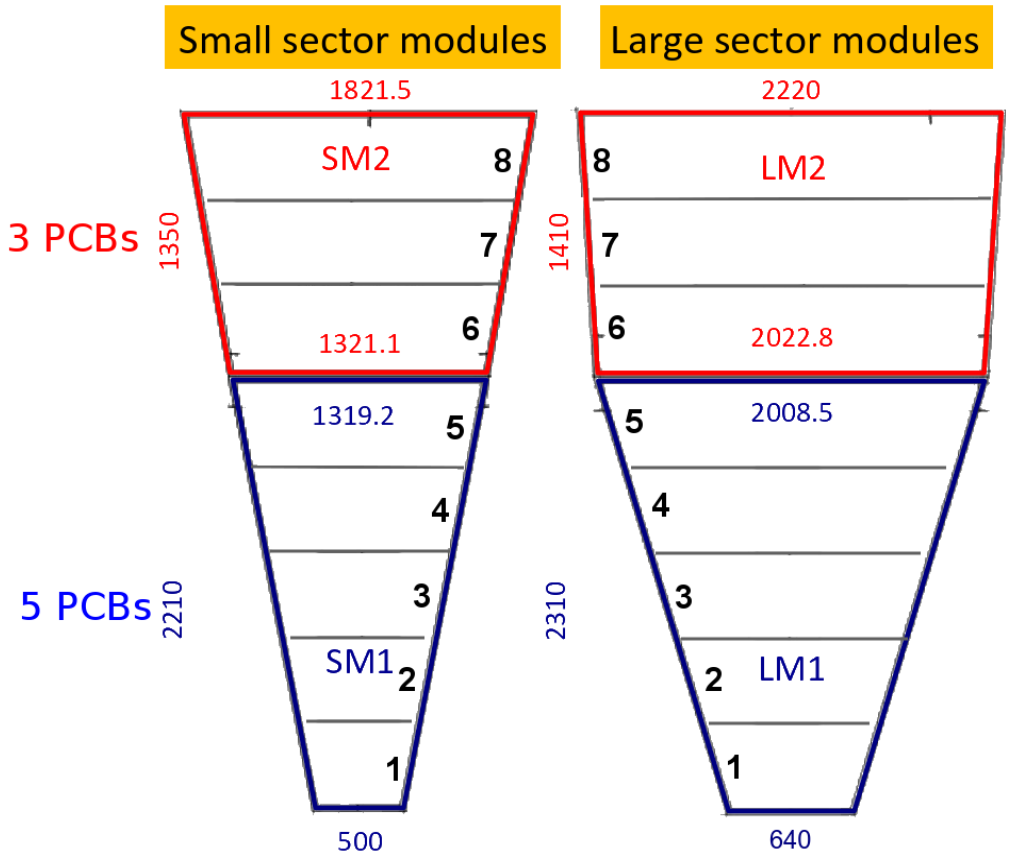


New Small Wheel: Layout



16 sectors: 8 large + 8 small





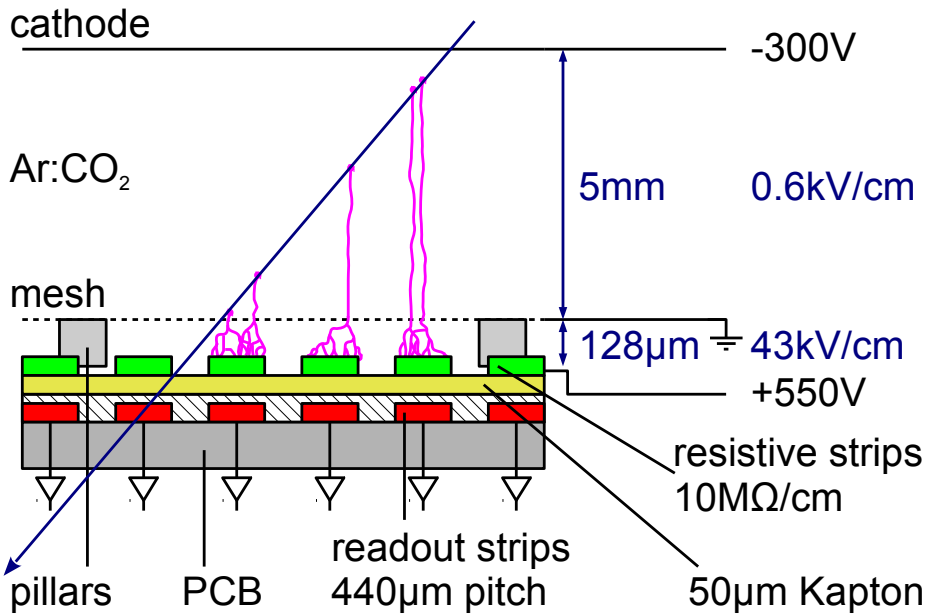
SM1 : Italy INFN (Pavia, Rome, Frascati, Cosenza, Lecce, Napoli)

SM2 : Germany (Munich, Würzburg, Mainz, Freiburg)

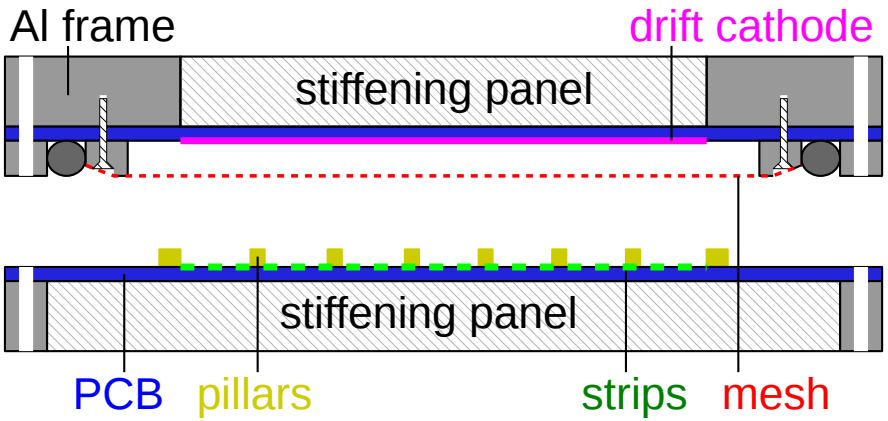
LM1 : France (CEA Saclay)

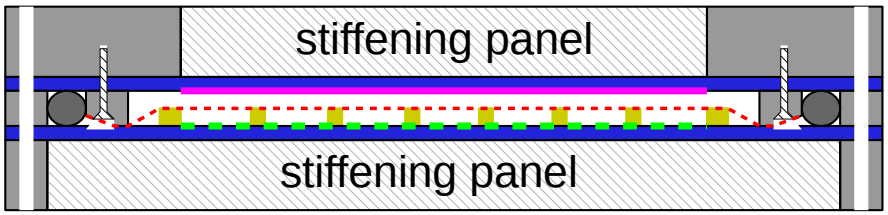
LM2 : Russia (Dubna) & Greece (Thessaloniki), module0: CERN

Resistive Strip Micromegas



- resistive anode strips
  → suppress discharge influence on efficiency
- floating mesh, attached to cathode
  → facilitate cleaning & simplify commissioning
- large active areas: $2.5 \times 1.5\,\mathrm{m}^2$
- detectors based on stiff but light-weight panels
  → cathode on drift panel
  → mesh attached to drift panel
  → readout structure on readout panel





Resistive Strip Readout Board

copper readout strips

- width 300 µm, pitch ∼ 430 µm
- connection to front-end electronics: Zebra-connectors, solderless

resistive strips

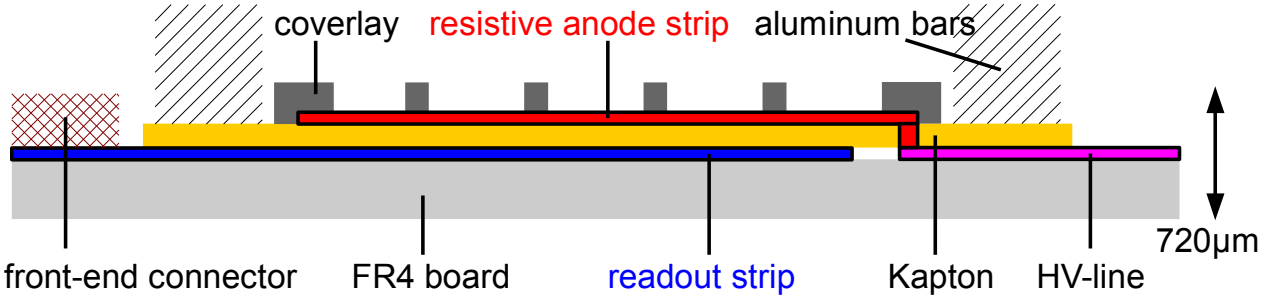
- screen-printed or sputtered on Kapton foil
- width 300 µm, pitch 430 µm
- interconnected every 20 mm

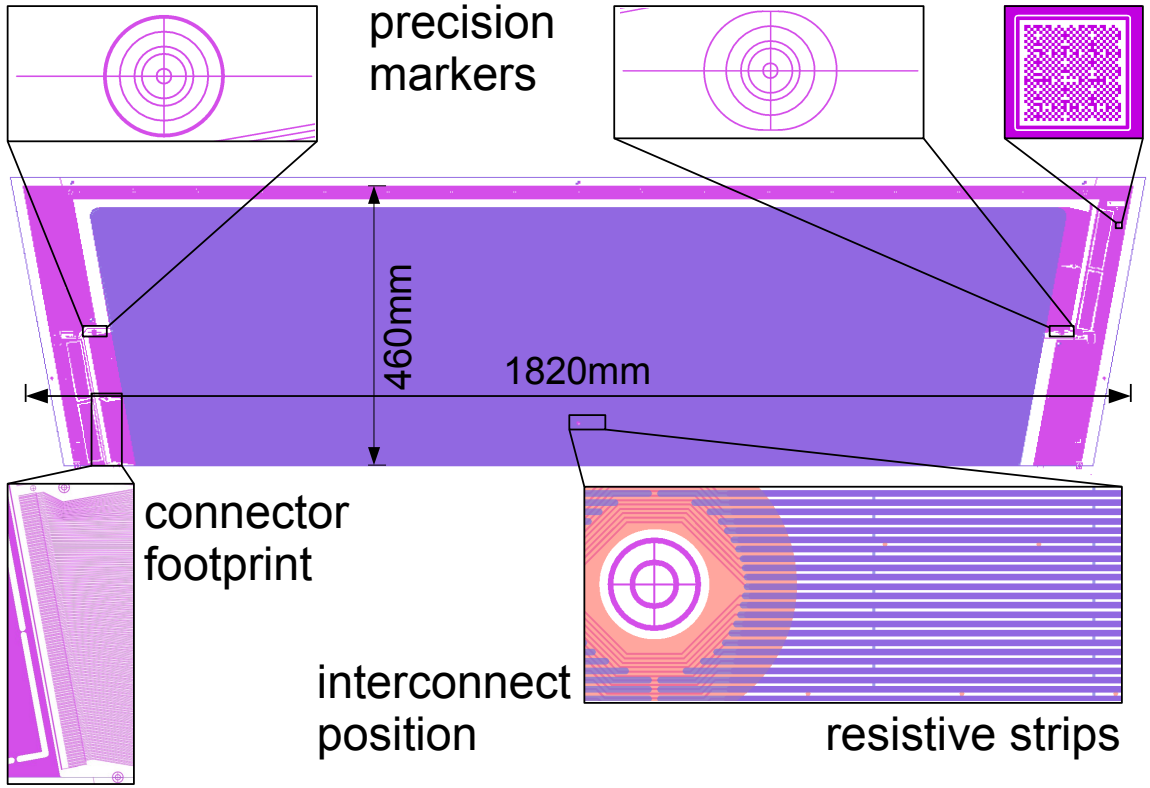
pillars

- 128 µm height, 230 µm diameter
- 7 mm pitch

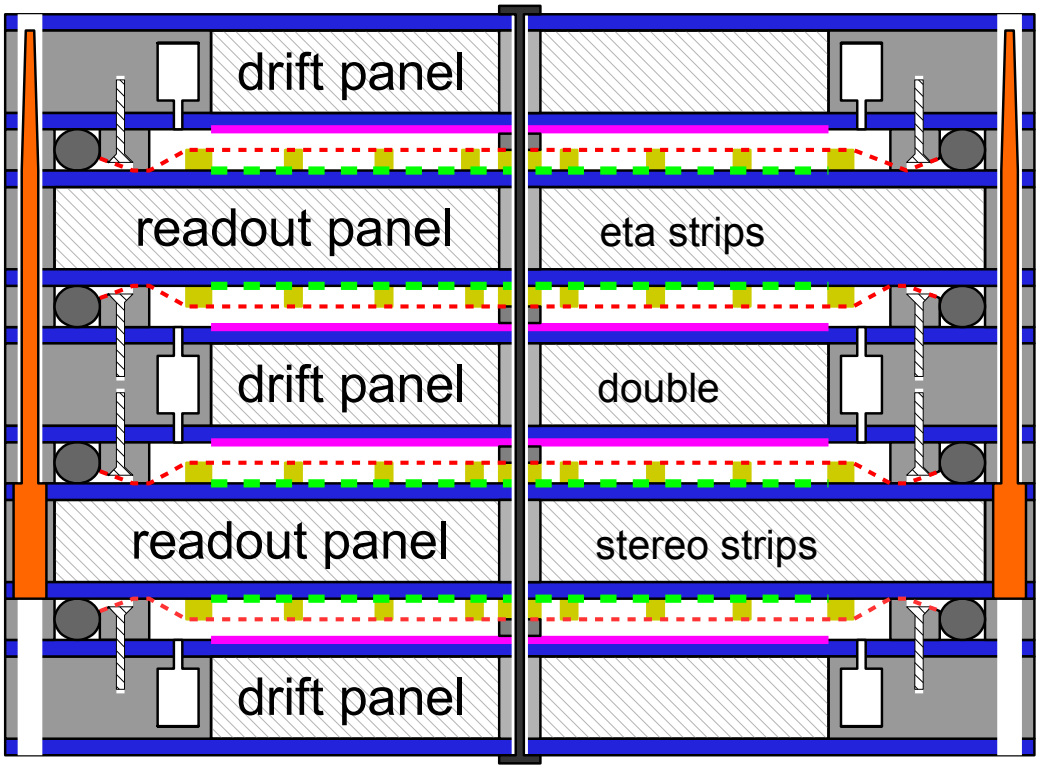
precision markers & rasmasks

- exact w.r.t. strip position → optical alignment of PCBs during construction



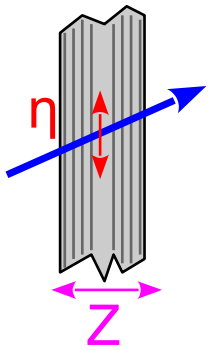


The Task: Single Module



- 2 double readout panels
  → alignment crucial
- 1 double drift cathode panel
- 2 single drift cathode panels

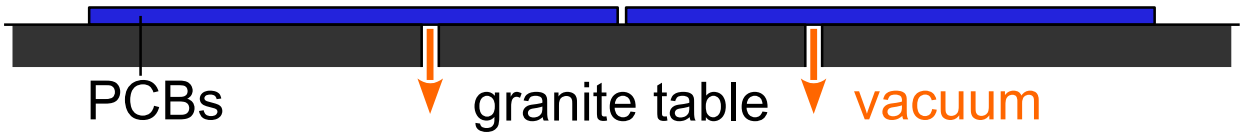
track accuracy:
30 µm in η
80 µm in z



→ absolute position of strips: 35 µm
→ relative alignment of the two readout panels: 18 µm
→ relative alignment of the two sides of a readout panel: 25 µm
→ relative alignment of the readout PCBs of a single side: 25 µm

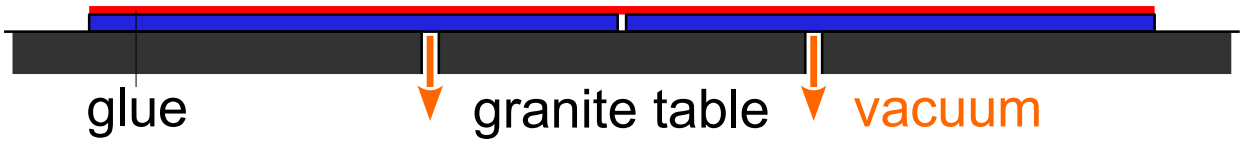
→ readout panel planarity: 37 µm RMS
→ drift panel planarity: 37 µm RMS

Fundamental Idea for Panel Construction



place PCBs on granite table with precise surface and suck
$\rightarrow$ planarity transfers to PCBs

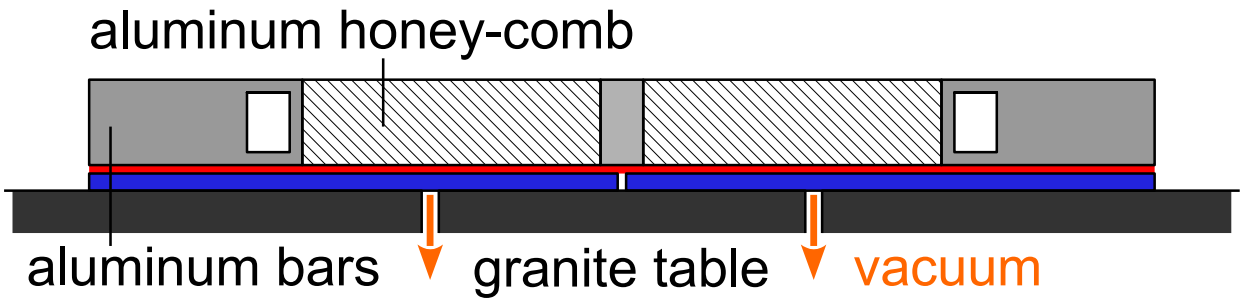
Fundamental Idea for Panel Construction



place PCBs on granite table with precise surface and suck
$\rightarrow$ planarity transfers to PCBs

- apply glue with defined thickness

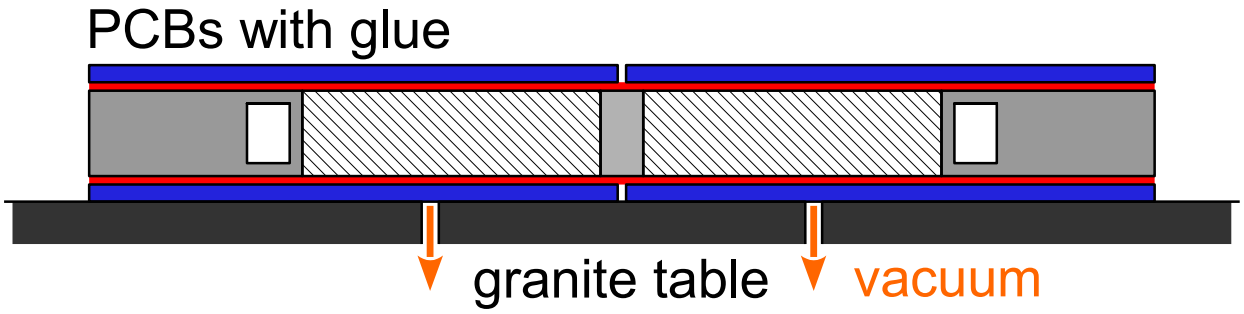
Fundamental Idea for Panel Construction



place PCBs on granite table with precise surface and suck
→ planarity transfers to PCBs

- apply glue with defined thickness
- place aluminum bars and aluminum honey-comb

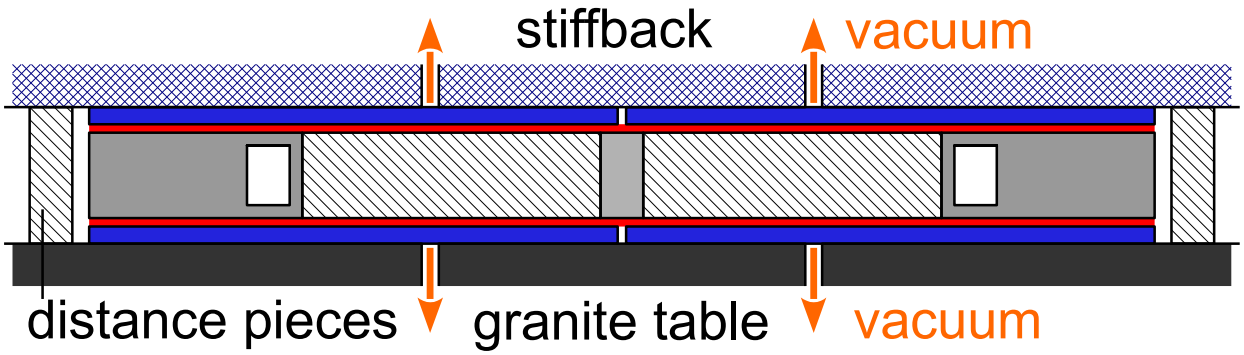
Fundamental Idea for Panel Construction



place PCBs on granite table with precise surface and suck
→ planarity transfers to PCBs

- apply glue with defined thickness
- place aluminum bars and aluminum honey-comb
- place second layer of PCBs with glue already on them

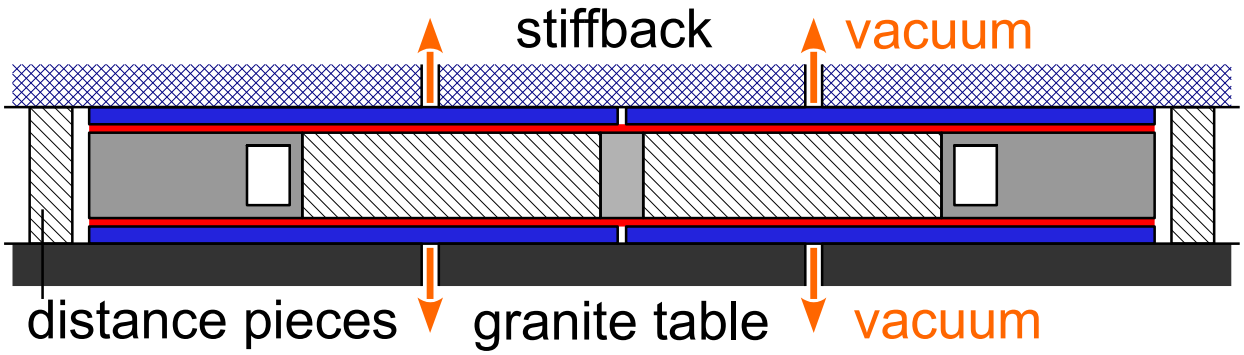
Fundamental Idea for Panel Construction



place PCBs on granite table with precise surface and suck
→ planarity transfers to PCBs

- apply glue with defined thickness
- place aluminum bars and aluminum honey-comb
- place second layer of PCBs with glue already on them
- sucked onto a precise stiffback
  → planarity of second layer
  → parallelicity of both layers

Fundamental Idea for Panel Construction



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- sucked onto a precise stiffback
  → planarity of second layer
  → parallelicity of both layers

two different gluing technologies

- with stiffback
- with vacuum bag i.e. without stiffback

two different drilling concepts

- after gluing
- before gluing

Construction Procedure

1. readout PCBs accurate positioning, first layer
+ glue aluminum bars and honey-comb
+ glue second layer of readout PCBs, accurately positioned

2. drift cathode PCBs, coarse positioning, first layer
+ glue aluminum bars and honey-comb
+ glue second layer of drift cathode PCBs

3. mount mesh frames onto drift panel

4. glue pre-stretched mesh onto drift panel

5. final cleaning

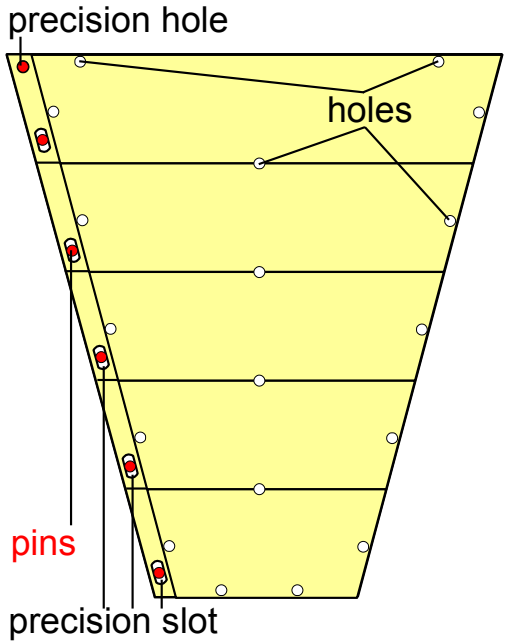
6. assemble, vertically to reduce dust contamination

$\rightarrow$ these procedures will be discussed exemplarily for the Italian (SM1) and the German (SM2) modules. CERN $\leftrightarrow$ Italian, French $\leftrightarrow$ German.

Drift Panel Construction - Rome

main idea:

- holes in PCBs and bars prior to assembly
- alignment via precision holes in PCBs
- simultaneous gluing of both sides
- stack pressed to granite table using vacuum bag
  $\rightarrow$ precision of honey-comb, PCBs and bars needed



- align top PCB on granite table: aluminum bar with precision holes, fixed to table
  $\rightarrow$ precision pins in these holes
  $\rightarrow$ holes & slots in PCB
- align other PCBs relative to top PCB

Drift Panel Construction - Rome

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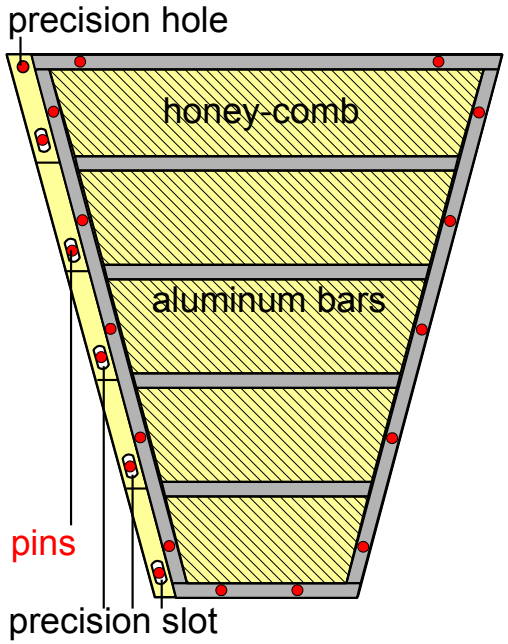

- align top PCB on granite table: aluminum bar with precision holes, fixed to table
  $\rightarrow$ precision pins in these holes
  $\rightarrow$ holes & slots in PCB
- align other PCBs relative to top PCB
- place aluminum bars and honey-comb into the glue
- align with pins in mounting holes

Drift Panel Construction - Rome

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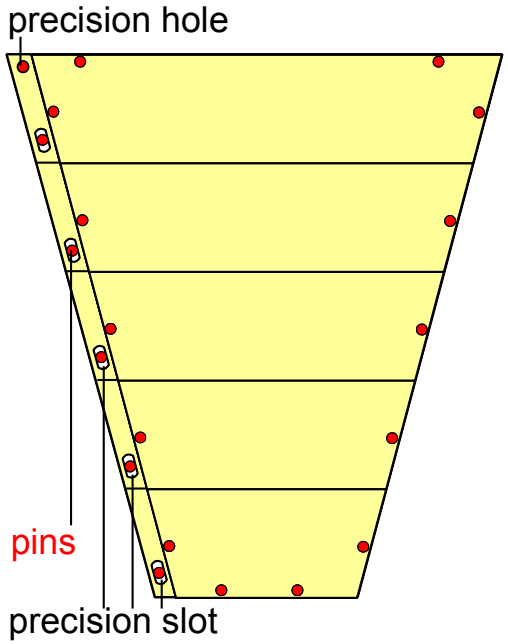

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- align other PCBs relative to top PCB
- place aluminum bars and honey-comb into the glue
- align with pins in mounting holes
- place second layer of PCBs

Drift Panel Construction - Rome

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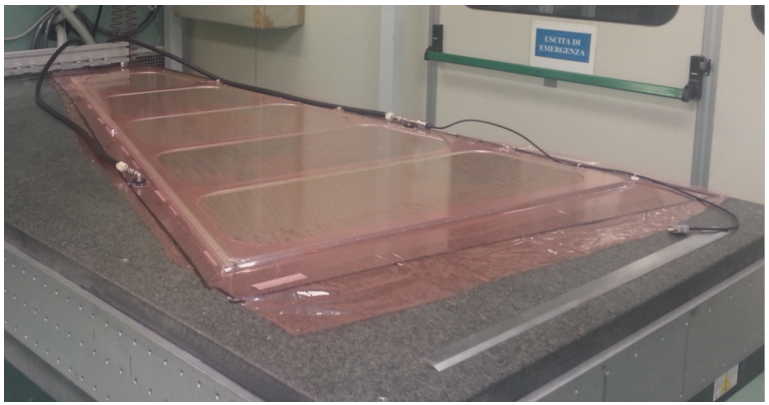
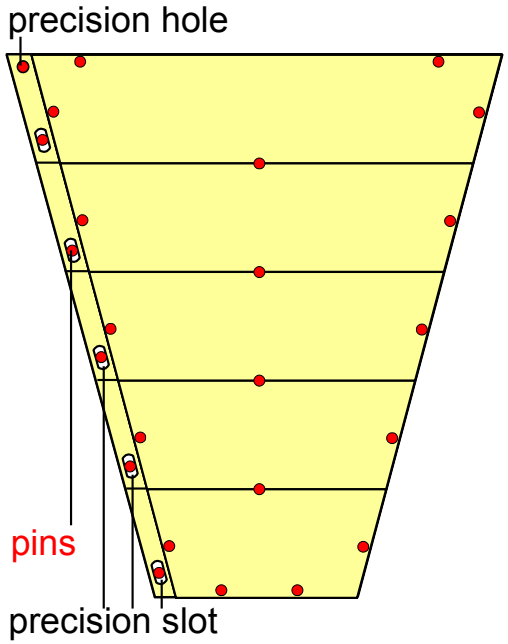
- alignment via precision holes in PCBs
- simultaneous gluing of both sides
- stack pressed to granite table using vacuum bag
  $\rightarrow$ precision of honey-comb, PCBs and bars needed





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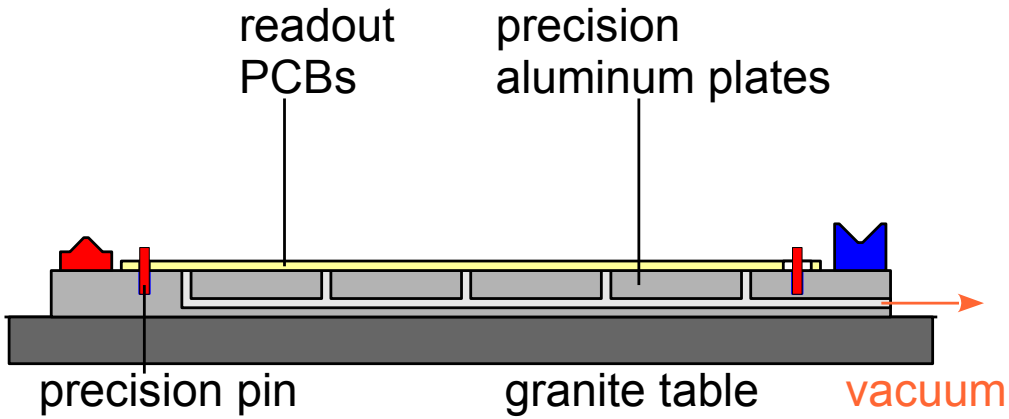
  $\rightarrow$ precision pins in these holes
  $\rightarrow$ holes & slots in PCB
- align other PCBs relative to top PCB
- place aluminum bars and honey-comb into the glue
- align with pins in mounting holes
- place second layer of PCBs
- align inner bars with pins
- place vacuum bag on top and suck stack to table

Readout Panel Construction - Pavia 1/2

main idea:

- holes in PCBs and bars prior to assembly
- alignment via precision holes in PCBs
- simultaneous gluing of both sides
- second layer supported by stiffback
- alignment between layers with precision interlocks



- align PCBs with precision pins in precision hole & slot on precision aluminum plates
- apply vacuum, remove pins and apply glue

Readout Panel Construction - Pavia 1/2

main idea:

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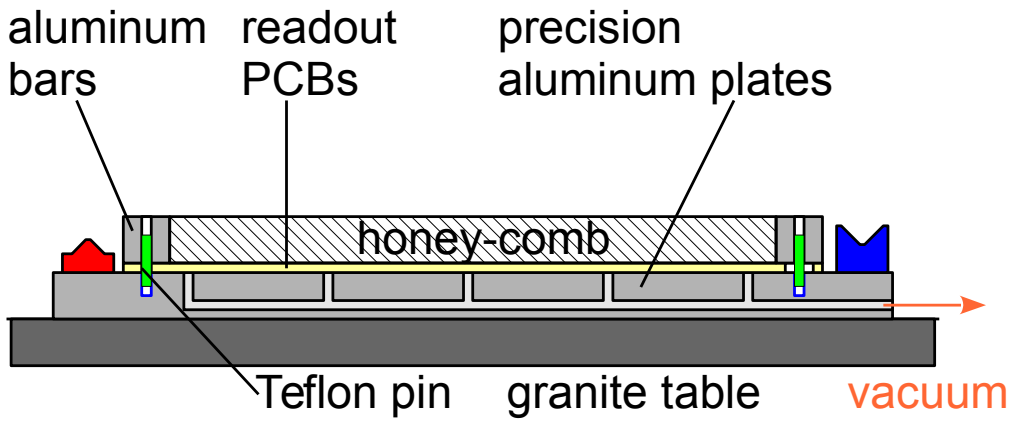
- alignment between layers with precision interlocks



- align PCBs with precision pins in precision hole & slot on precision aluminum plates
- apply vacuum, remove pins and apply glue
- place aluminum bars and honey-comb into the glue
- align with Teflon pins in mounting holes

Readout Panel Construction - Pavia 1/2

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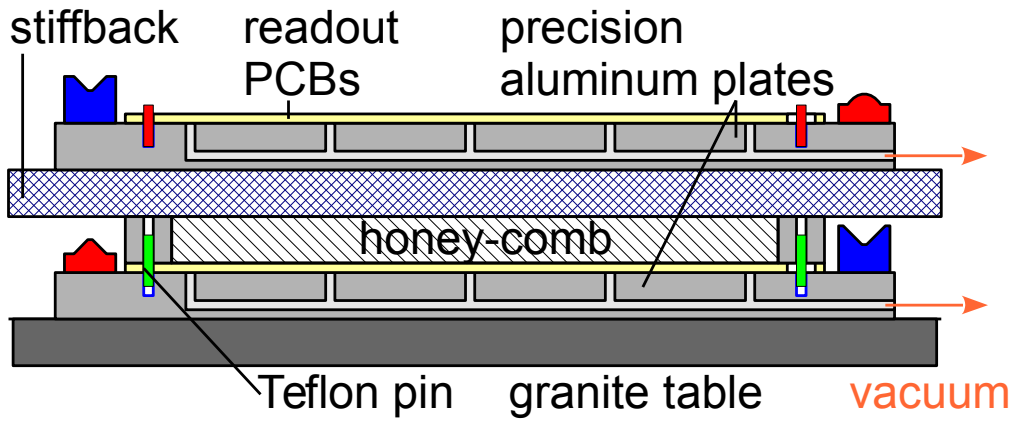

- align PCBs with precision pins in precision hole & slot on precision aluminum plates
- apply vacuum, remove pins and apply glue
- place aluminum bars and honey-comb into the glue
- align with Teflon pins in mounting holes
- place stiffback upsite-down onto the stack
- align second layer PCBs with precision pins on precision aluminum plates on the stiffback
- apply vacuum, remove pins and apply glue

Readout Panel Construction - Pavia 1/2

main idea:

- holes in PCBs and bars prior to assembly
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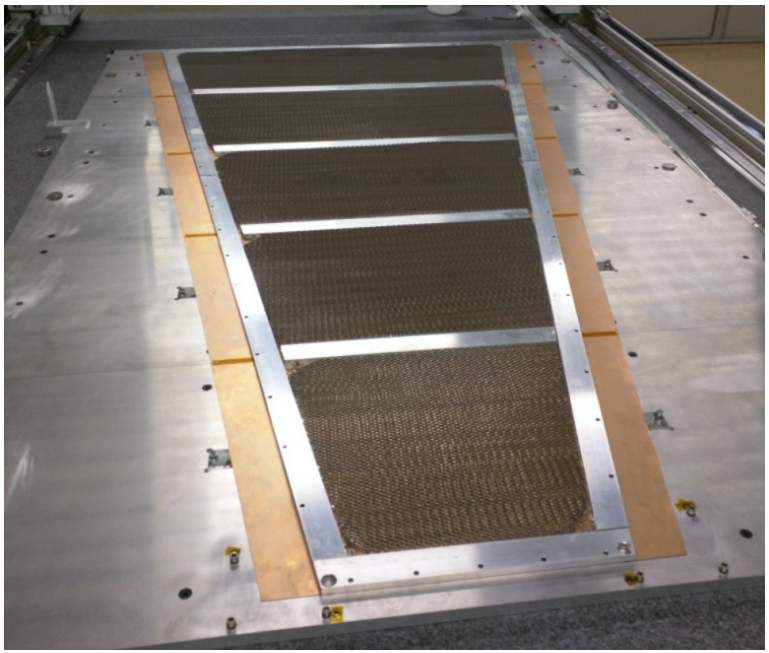
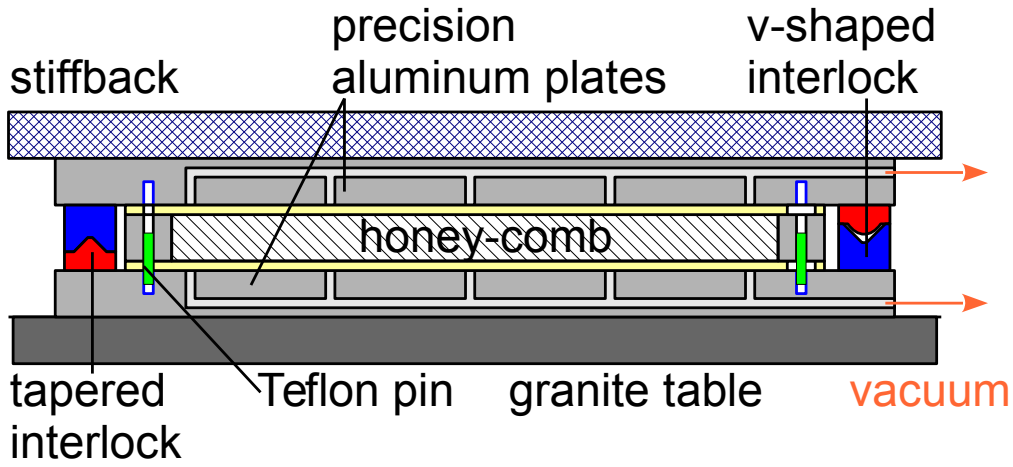
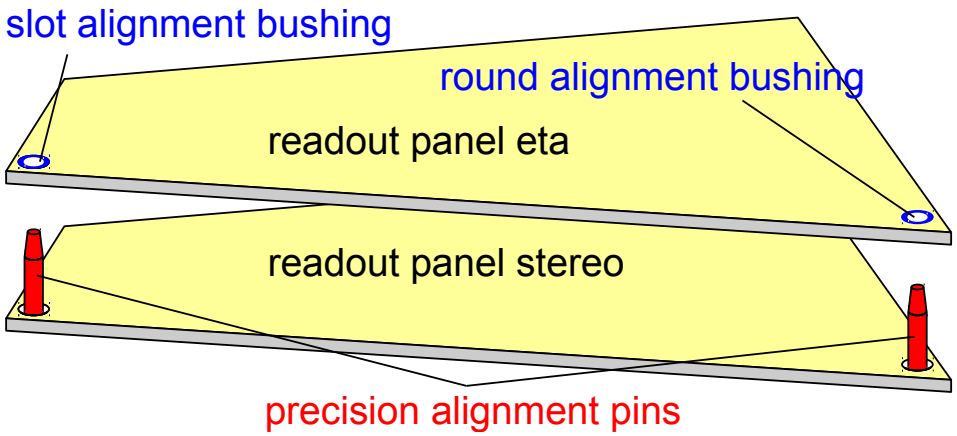


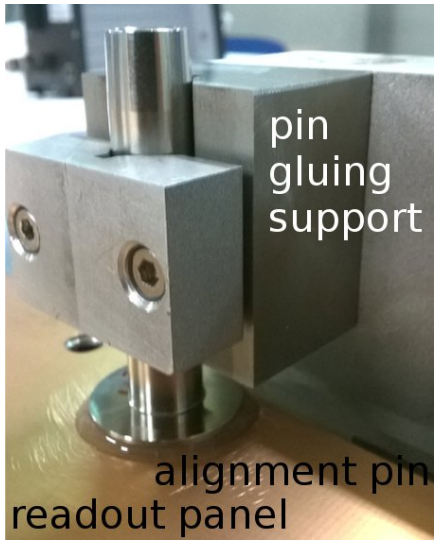


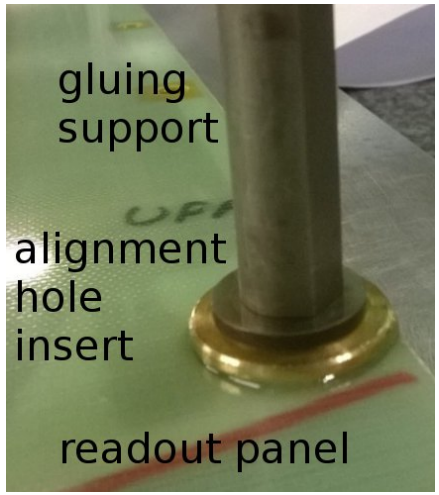
- align PCBs with precision pins in precision hole & slot on precision aluminum plates
- apply vacuum, remove pins and apply glue
- place aluminum bars and honey-comb into the glue
- align with Teflon pins in mounting holes
- place stiffback upsite-down onto the stack
- align second layer PCBs with precision pins on precision aluminum plates on the stiffback
- apply vacuum, remove pins and apply glue
- turn stiffback, alignment of the PCB layers achieved by precision tapered and v-shaped interlocks

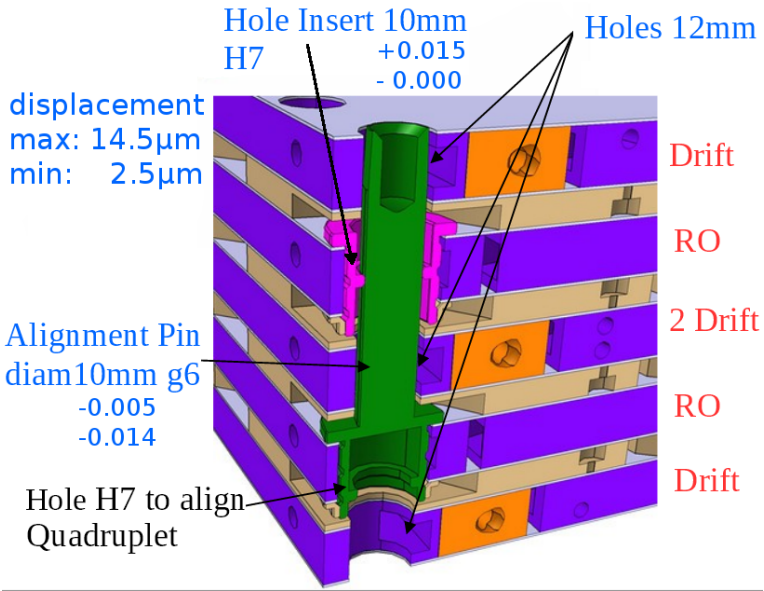
Readout Panel Construction - Pavia 2/2

inter-panel alignment for readout panels:
alignment pins & alignment bushings









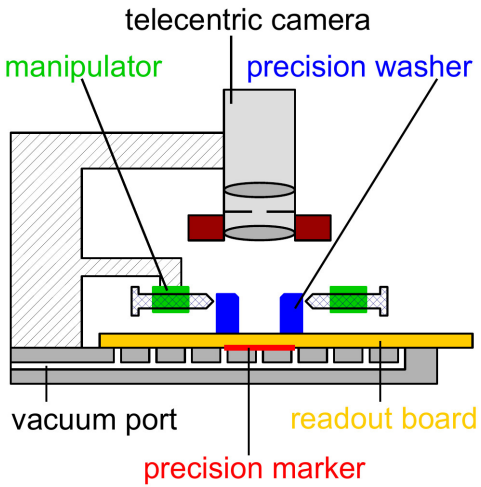
- readout panel on precision aluminum plates
  → gluing support fixed to precision aluminum plates
  → defines position of alignment pins and bushings

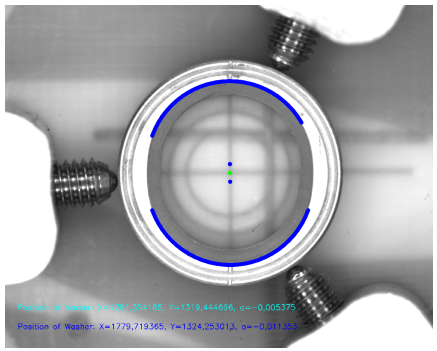
Readout Panel Construction - Munich 1/2

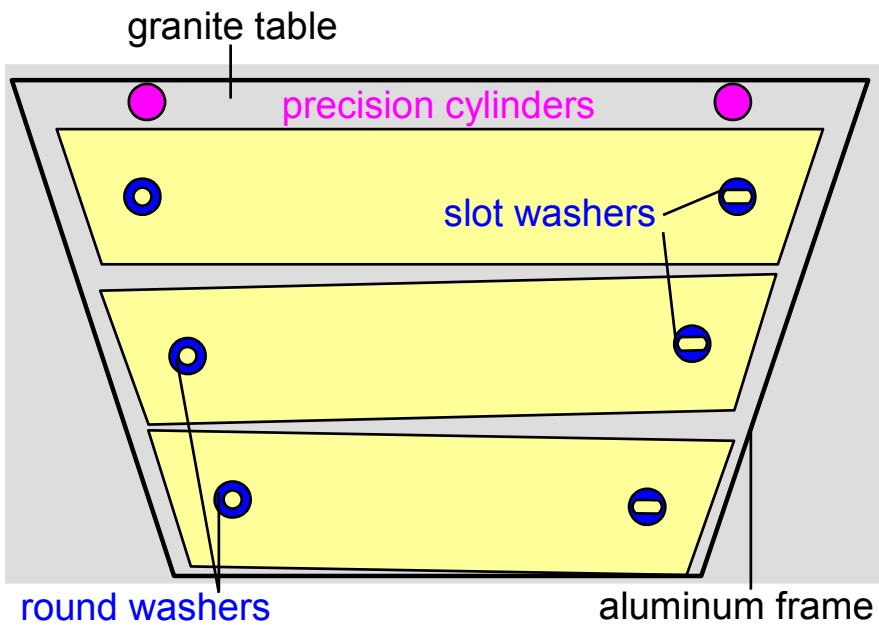
main idea:

- alignment of all components w.r.t. two fixed cylinders
- non-simultaneous gluing of the two sides
- second side supported by stiffback
- drilling, milling & threading after gluing in a single step

- glue two precision washers on each PCB w.r.t. marker, alignment $\lesssim 5\,\mu m$







Readout Panel Construction - Munich 1/2

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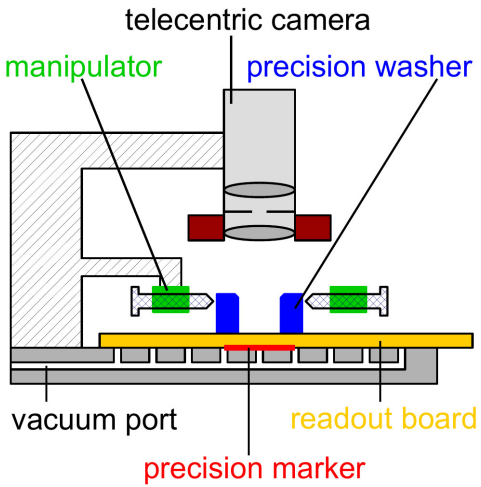
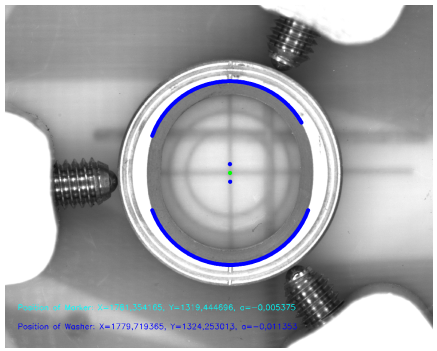
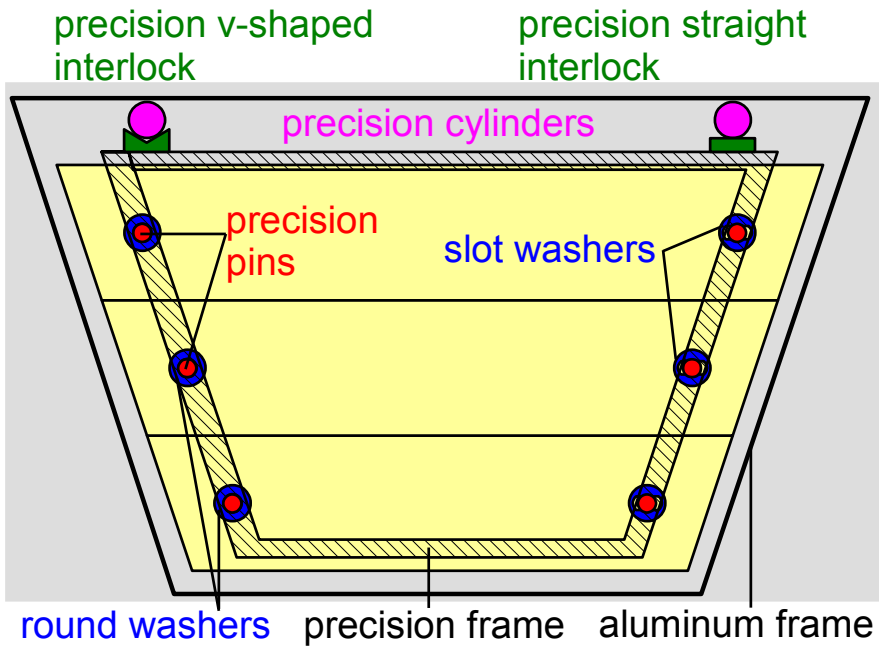
- precise alignment frame: align washers w.r.t. cylinders, apply vacuum, lift frame







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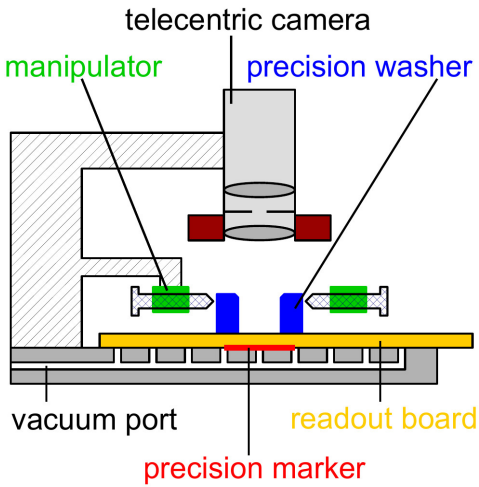

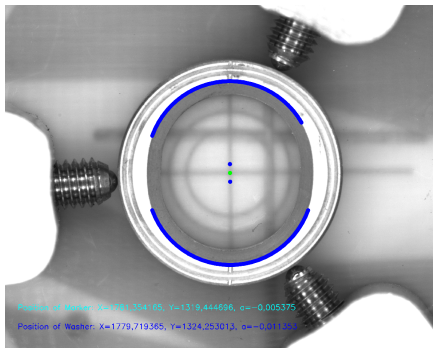

- glue two precision washers on each PCB w.r.t. marker, alignment $\lesssim 5\,\mu m$
- precise alignment frame: align washers w.r.t. cylinders, apply vacuum, lift frame
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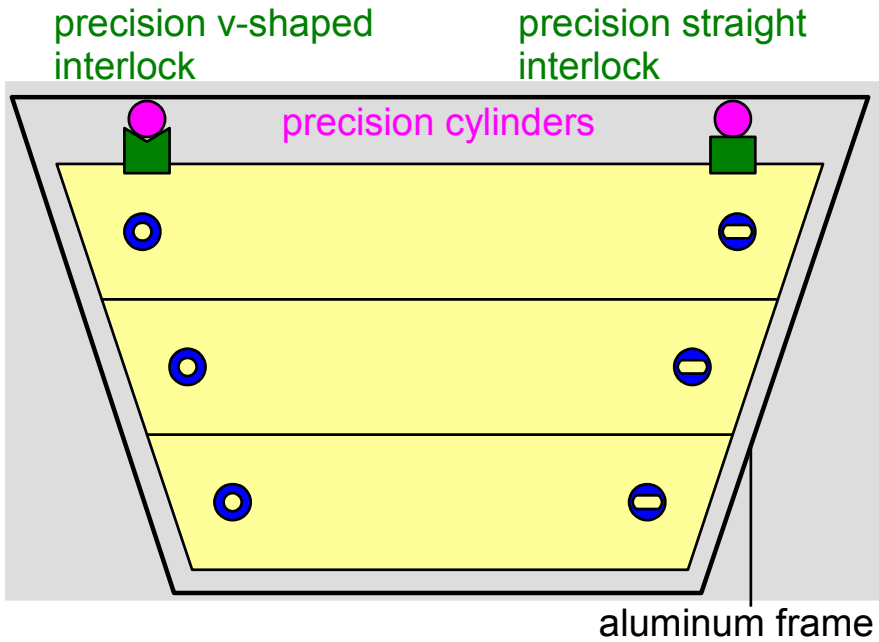

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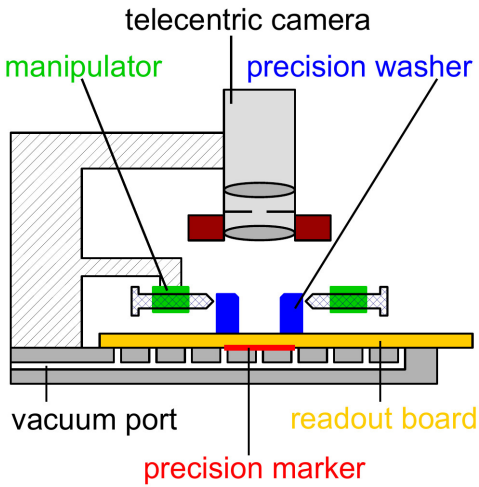

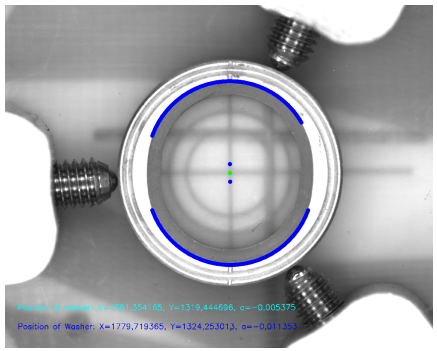

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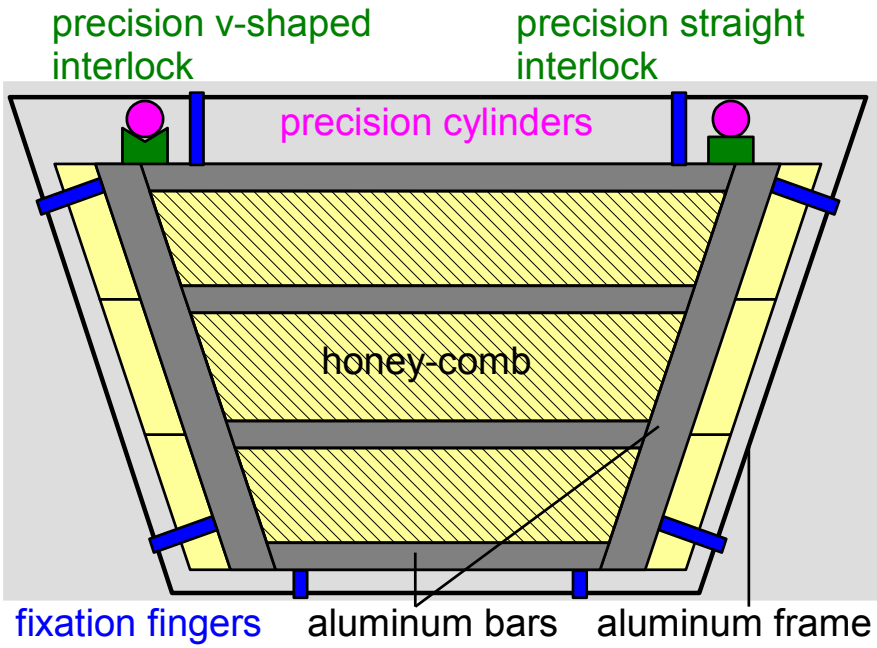
- place aluminum bars and honey-comb into glue
- glue curing, then lift semi-panel off the table



Readout Panel Construction - Munich 1/2

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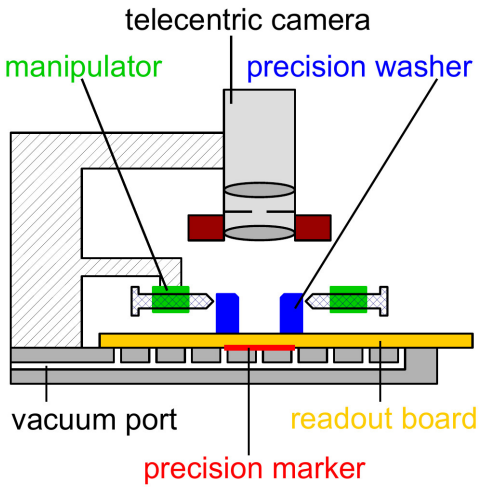

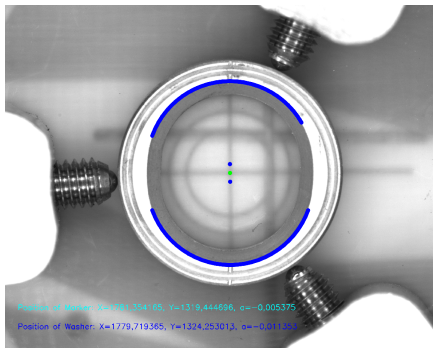

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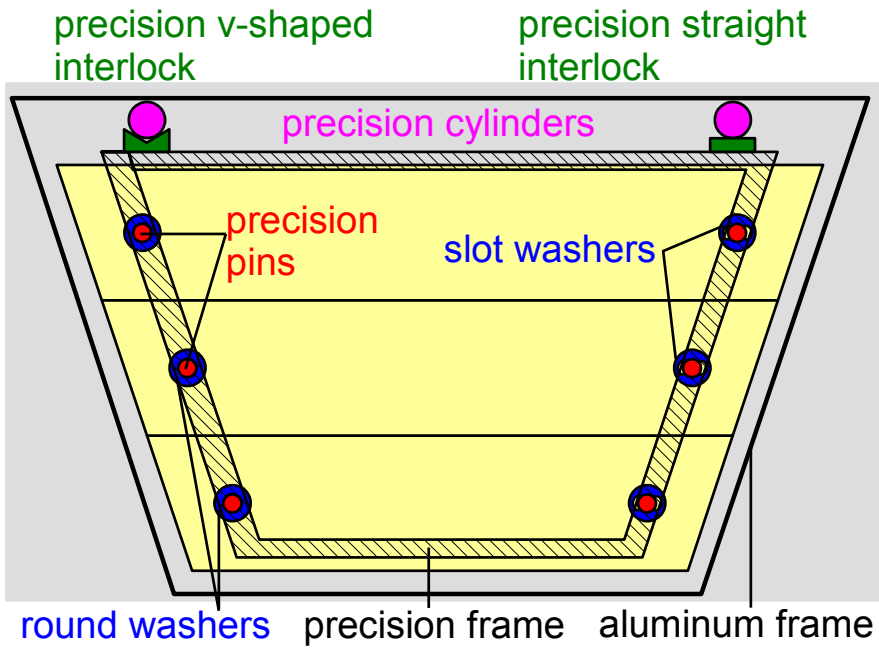
- glue two precision surfaces on top PCB w.r.t. cylinders, apply glue
- place aluminum bars and honey-comb into glue
- glue curing, then lift semi-panel off the table
- align second layer PCBs, apply vacuum & glue



Readout Panel Construction - Munich 1/2

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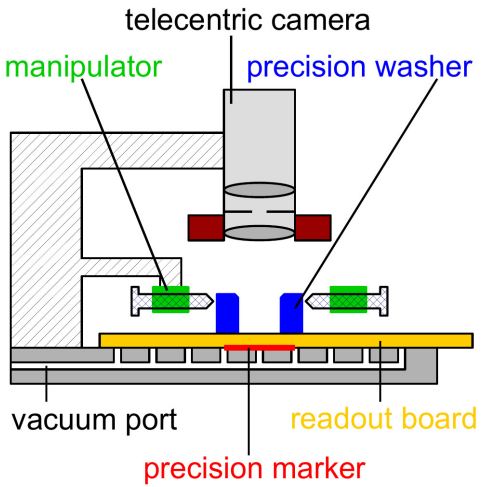
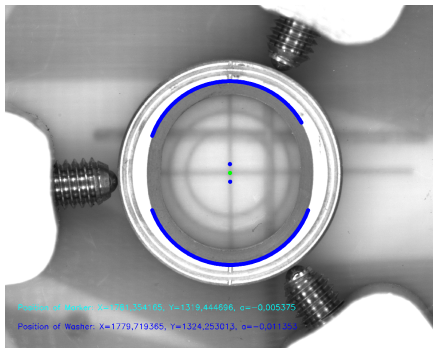
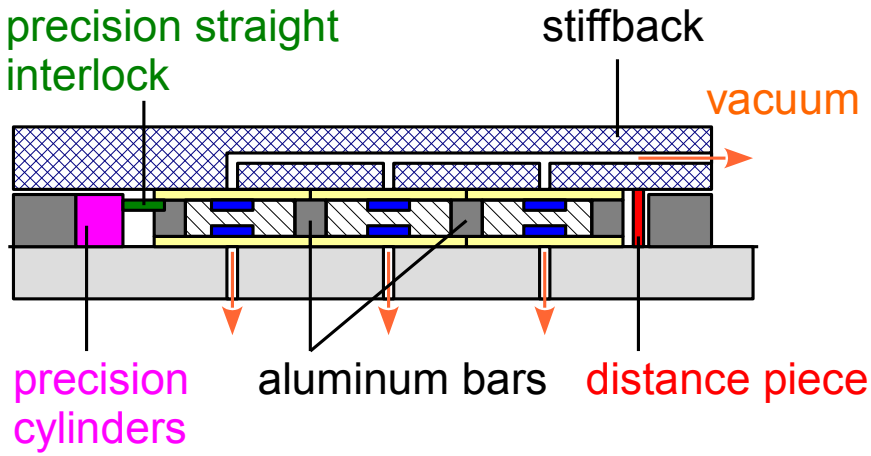
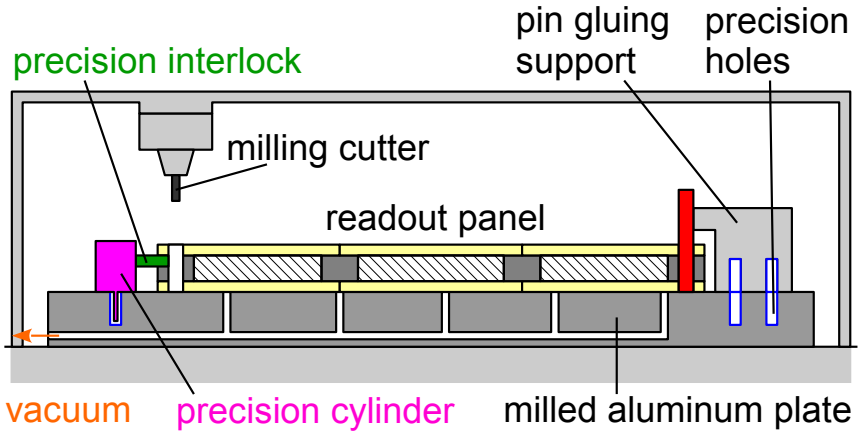




- glue two precision washers on each PCB w.r.t. marker, alignment $\lesssim 5\,\mu m$
- precise alignment frame: align washers w.r.t. cylinders, apply vacuum, lift frame
- glue two precision surfaces on top PCB w.r.t. cylinders, apply glue
- place aluminum bars and honey-comb into glue
- glue curing, then lift semi-panel off the table
- align second layer PCBs, apply vacuum & glue
- suck semi-panel to stiffback, place onto second layer
- align semi-panel with precision surfaces w.r.t. cylinders

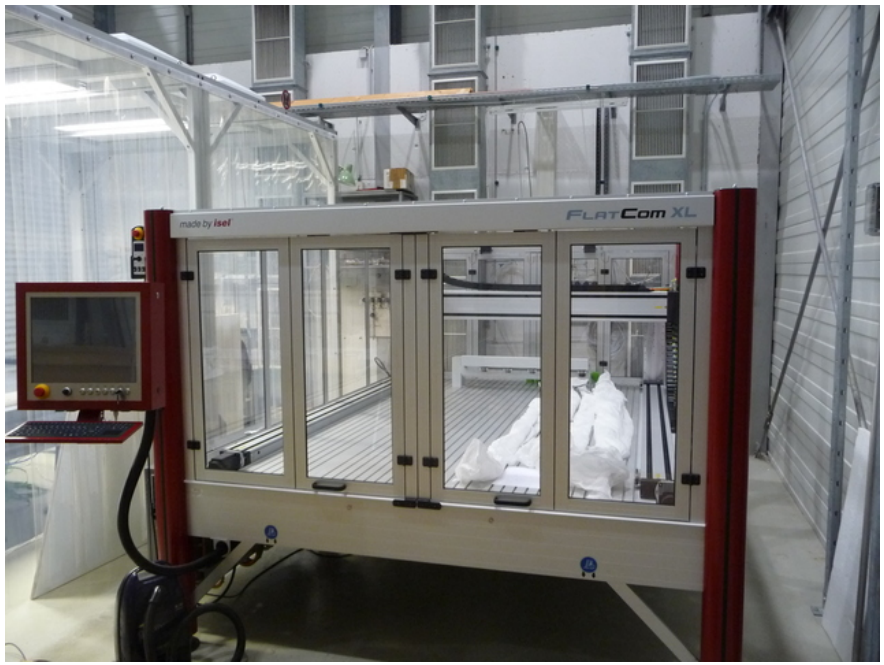


Readout Panel Construction - Munich 2/2



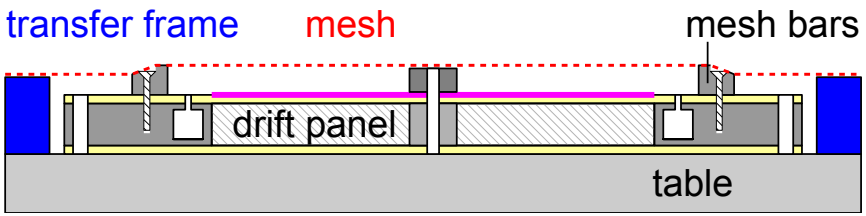
milling, drilling & threading

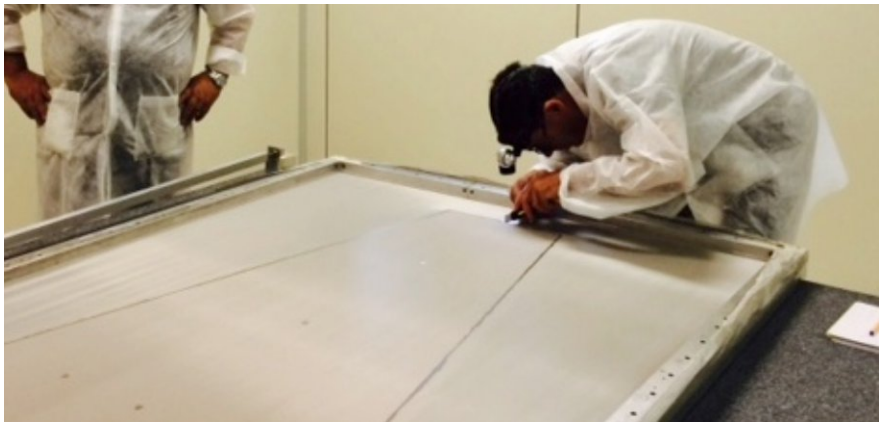
- large CNC portal milling machine
  $\rightarrow$ mill precision holes in one step
- alignment on machine table w.r.t. fixed precision cylinders
- precision holes in machine table
  $\rightarrow$ align pin/bushing gluing support



Mesh Stretching, Cleaning and Gluing

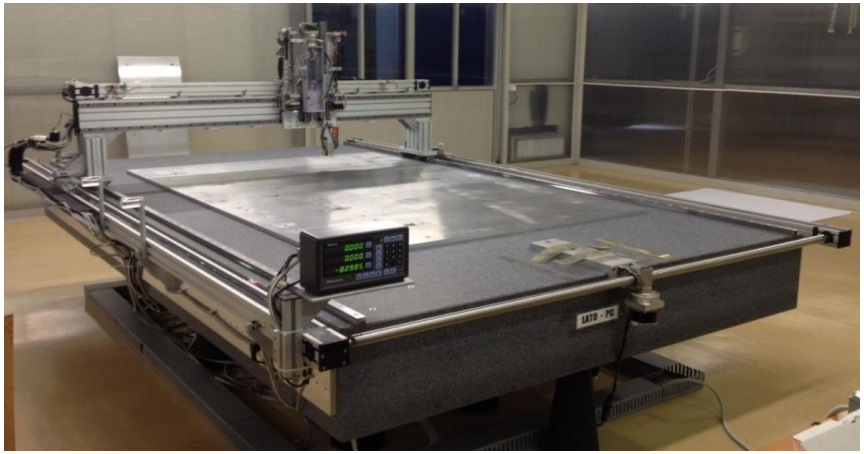
- woven stainless steel mesh (250 lines/inch, 30 µm wire diameter) stretch with pneumatic or mechanic clamps
- glue on transfer frame
- clean with solvent, brushes and high-pressure water
  (same cleaning procedure for panels)
- glue onto drift panel





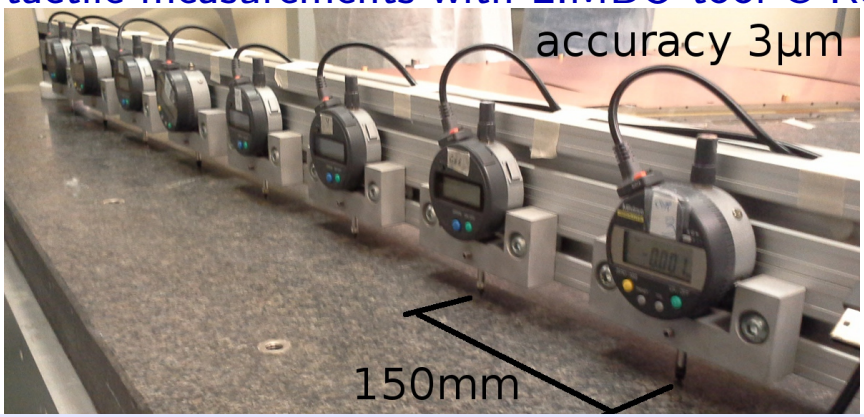
Panel Planarity Measurement Systems

tactile measurements with coordinate measurement system @ Pavia

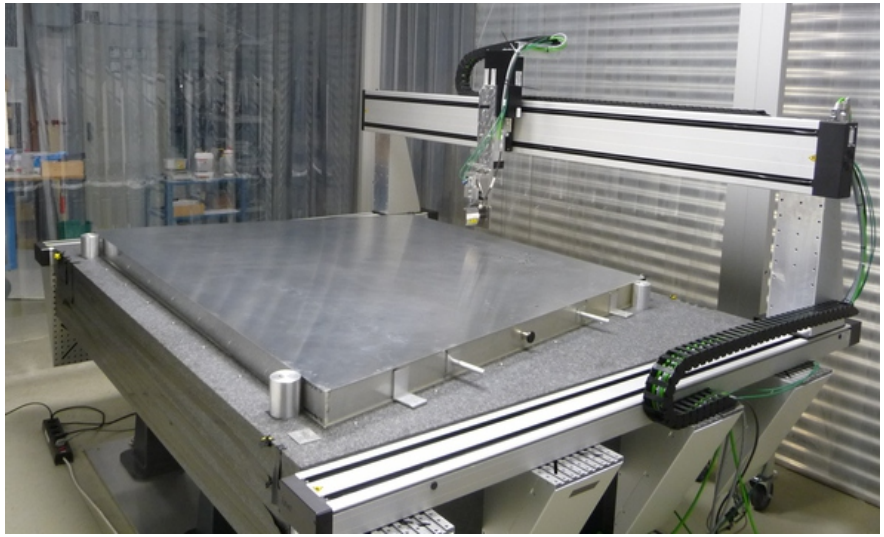


- indicator + optical line on a portal CMM
- granite table tolerance 9 µm
- repeatability 6 µm

tactile measurements with LIMBO tool @ Rome



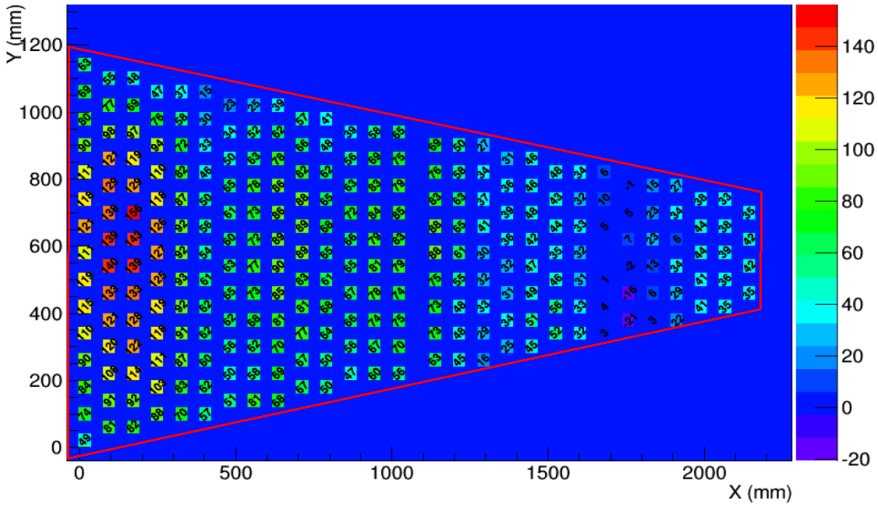
optical measurements with coordinate measurement system @ Munich



- laser distance sensor on a portal CMM
- granite table tolerance 6 µm
- accuracy 8 µm
- CMM cross-check with interferometer

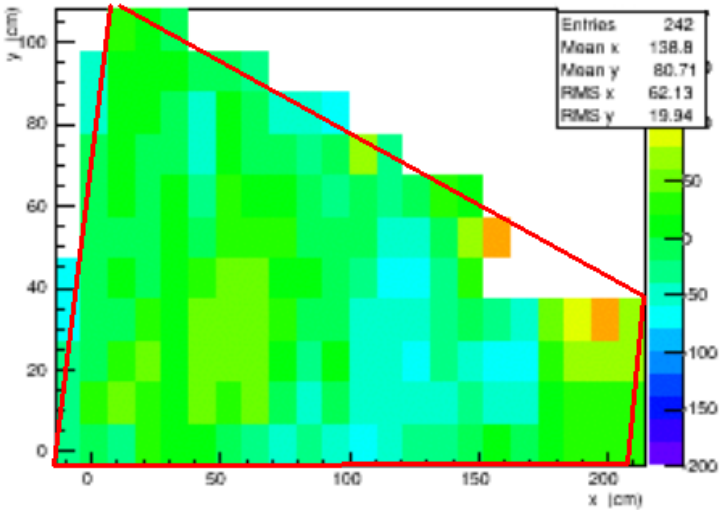
Panel Planarity Measurement Results

dummy readout panel @ Pavia



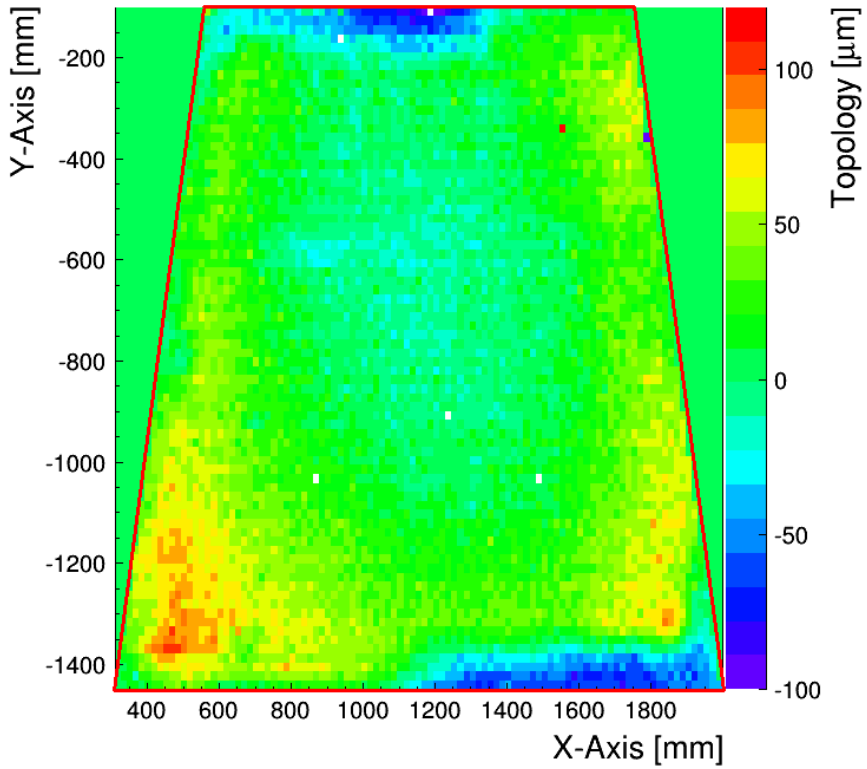
RMS 33 µm, min-max 200 µm

drift panel @ Rome



RMS 39 µm, min-max 200 µm

dummy readout panel @ Munich



- RMS 29 µm, min-max 190 µm
- upper deformation due to misplacement of distance piece between table and stiffback
  → solved for module0 production

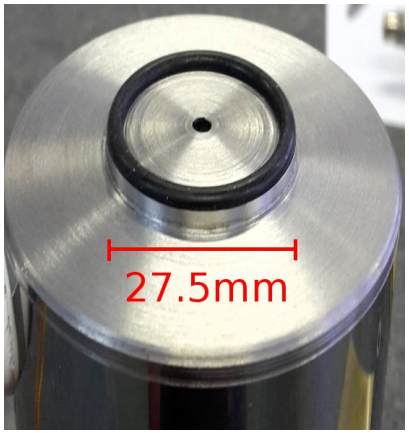
→ all panels are within specification!

Gas Tightness of Panels

"... should not loose more than 10^{-5} gas volumes per minute."

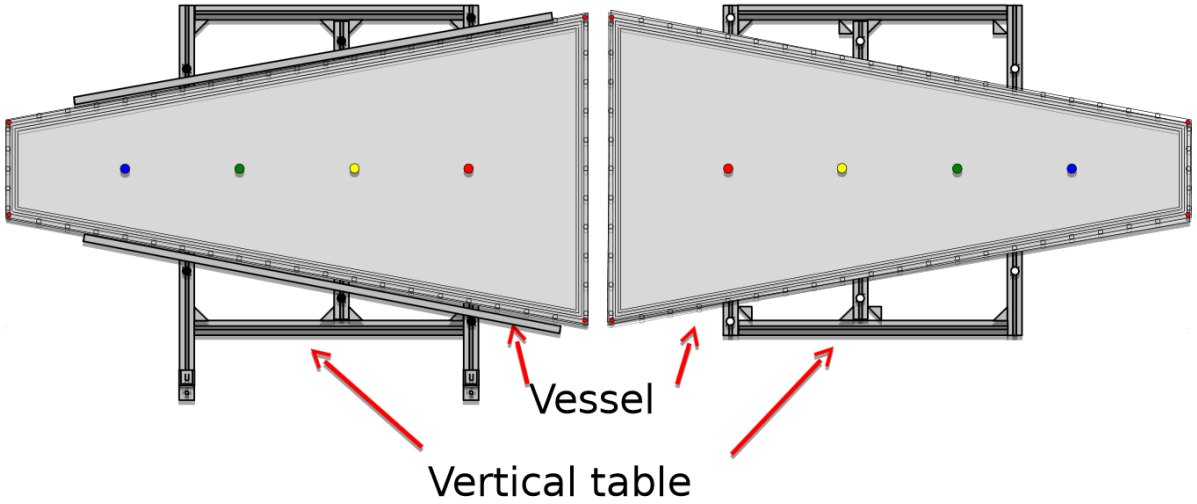
local tests

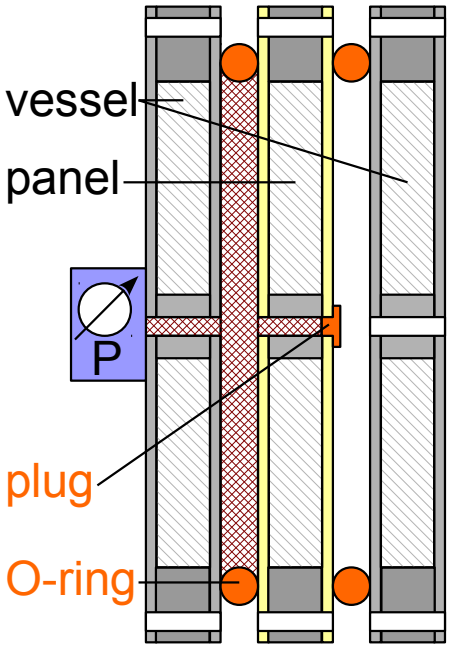
- gaps between neighboring PCBs
- "weight" tightness tester
  $\rightarrow$ tight if $\Delta P < 0.5\,\text{mbar}$ in $\Delta t \geq 8\,\text{s}$



global tests

- vessel, enclosing complete panel
  $\rightarrow$ tight if $\Delta P < 0.5\,\text{mbar}$ in $\Delta t \geq 7\,\text{h}$



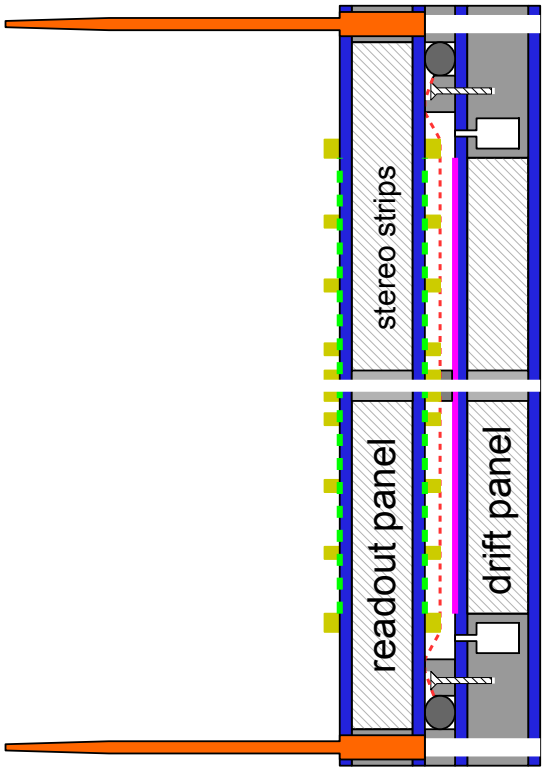


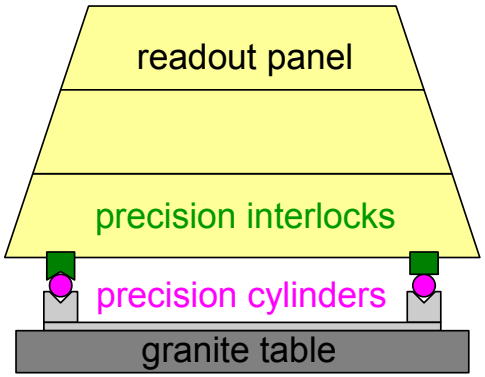
Quadruplet Assembly

main idea:

- vertical assembly in clean room
  → avoid dust contamination
- coarse alignment of the drift panels
- alignment of the two readout panels critical
  → alignment pins in precision bushings
  → alternative: precision interfaces on rails
- stepwise assembly with high-voltage tests

- fix drift panel to assembly support
- mount first readout panel (mounting hole accuracy)





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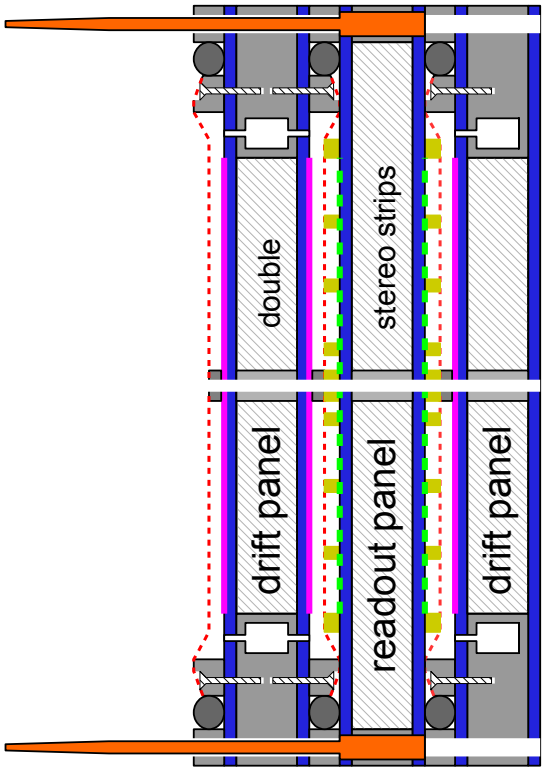

- fix drift panel to assembly support
- mount first readout panel (mounting hole accuracy)
- mount double drift panel (mounting hole accuracy)

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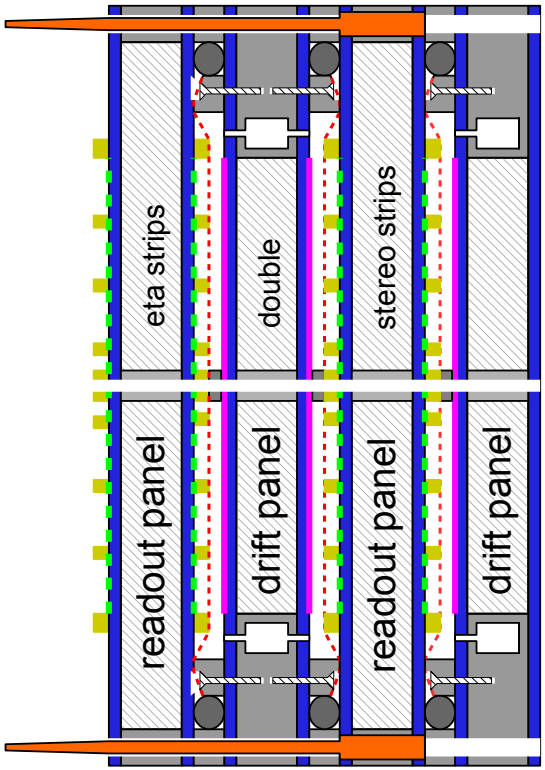

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- mount double drift panel (mounting hole accuracy)
- mount second readout panel w.r.t. precision pins in first readout panel

Quadruplet Assembly

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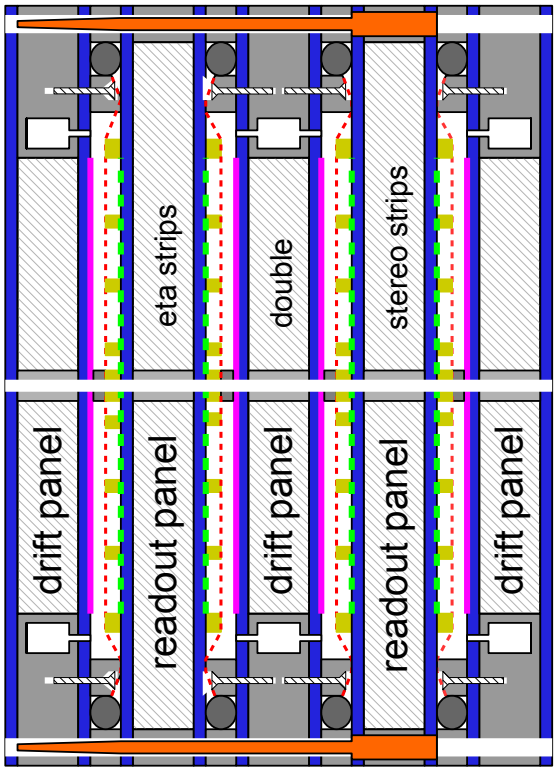
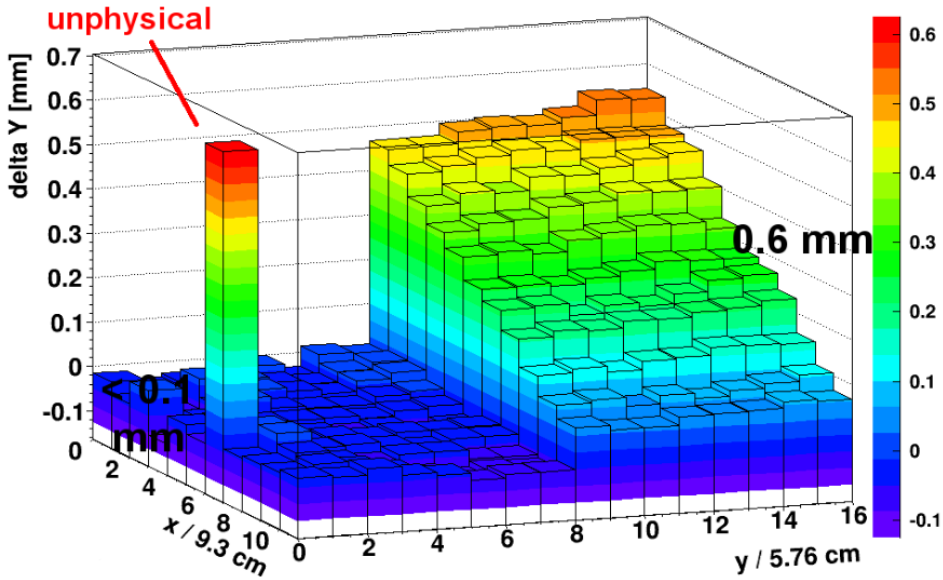


- fix drift panel to assembly support
- mount first readout panel (mounting hole accuracy)
- mount double drift panel (mounting hole accuracy)
- mount second readout panel w.r.t. precision pins in first readout panel
- mount last drift panel, mount interconnections

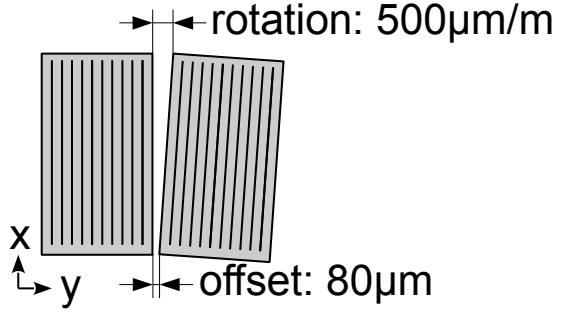
LMU Cosmic Ray Measurement Facility

difference between predicted and measured hits



- two ATLAS-BOS monitored drift tube chambers as precise track reference
- scintillator hodoscope as coarse complementary track reference
- 9 m^2 active area, $-30°$ to $+30°$ acceptance

- measurements with 1 m^2 floating-mesh Micromegas chamber prototype
- readout plane consisting of two PCBs, no precision alignment used!



→ position & deformations of readout PCBs measurable with $\mathcal{O}(20)$ µm accuracy

Summary

- New Small Wheels for the ATLAS Forward Muon Spectrometer
- small-strip Thin Gap Chambers (main trigger) & resistive strip Micromegas chambers (main tracker)
- task: construction of Micromegas quadruplets with 30 µm spatial resolution in precision direction
- panel construction
  $\rightarrow$ desired planarity reached
- inter-plane alignment with precision pins & bushings or precision interlocks
- quality control procedures defined
- assembly methods developed
- Cosmic Ray Facility ready

module0s will be built during the next months with the desired precision
facilities are ready
procedures defined

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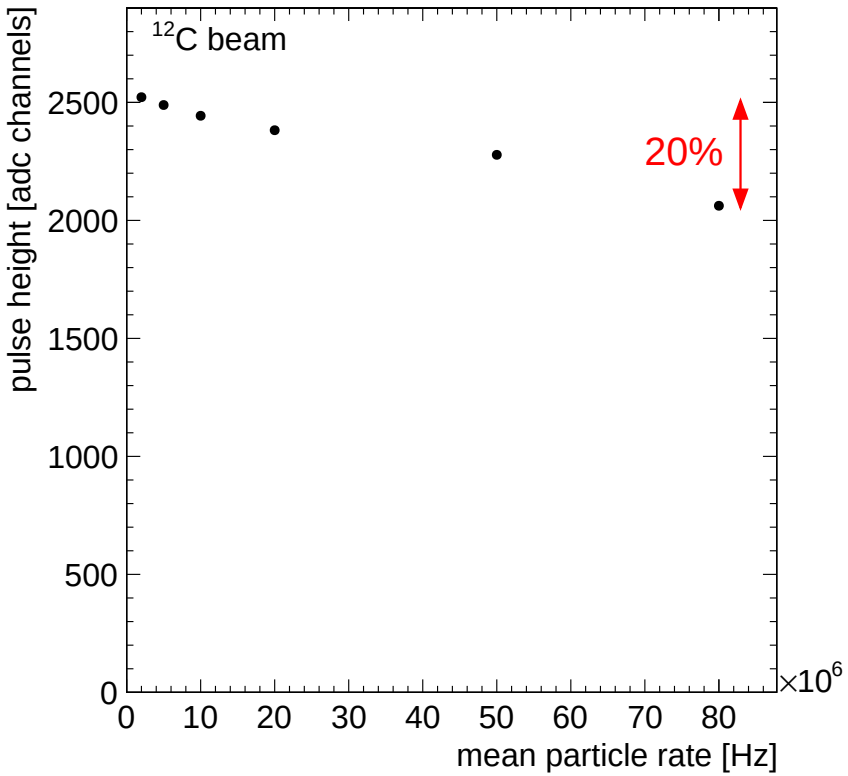
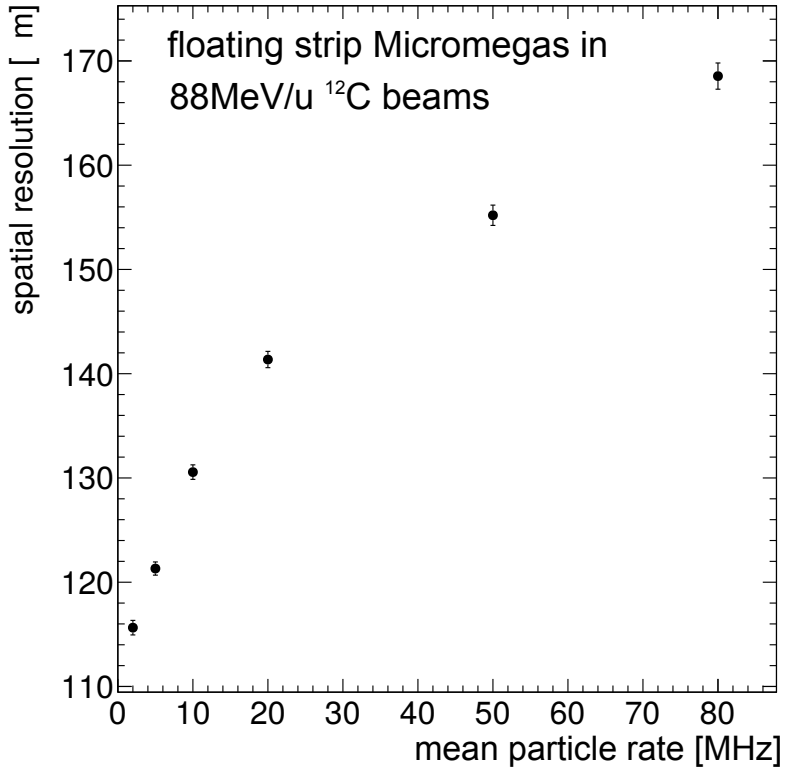
Thank you!

backup

Pulse Height & Spatial Resolution for 88 MeV/u Carbon Ions





- measured in $6.4 \times 6.4\,\mathrm{cm}^2$ floating strip Micromegas
- up to 80 MHz single particle tracks visible but not all of them separable
- only 20% reduction @ 80 MHz

- highest rates: slight distortion of hit position by hits on adjacent strips
- limited by multiple scattering

$\rightarrow$ tracking of carbon ions at highest rates possible