The CALICE AHCal:

a high-granular SiPM-on-tile hadronic calorimeter prototype

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On behalf of the CALICE Collaboration

TIPP 2021

Parallel session Calorimeters - 26/05/2021

Calorimeter for ILC

PRISMA+ DETECTOR LAB

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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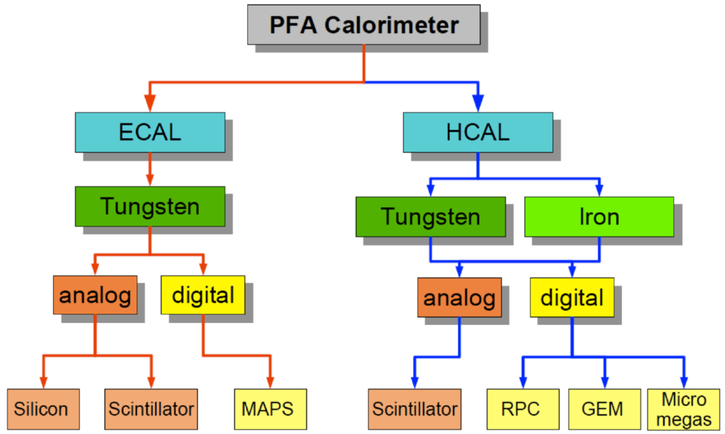
Calorimeters for future colliders

- **CALICE**: development of **calorimeters** for future colliders.
  - Most likely one of ILC / CLIC / CEPC / FCC-ee.

- Target **hadronic calorimetry with a few % resolution**.
  - Not possible using calorimetry alone.
  - Extensive usage of **particle-flow algorithms**.
  - Requires **high granularity**.
- → “Imaging” calorimeter: resolve jet-components.



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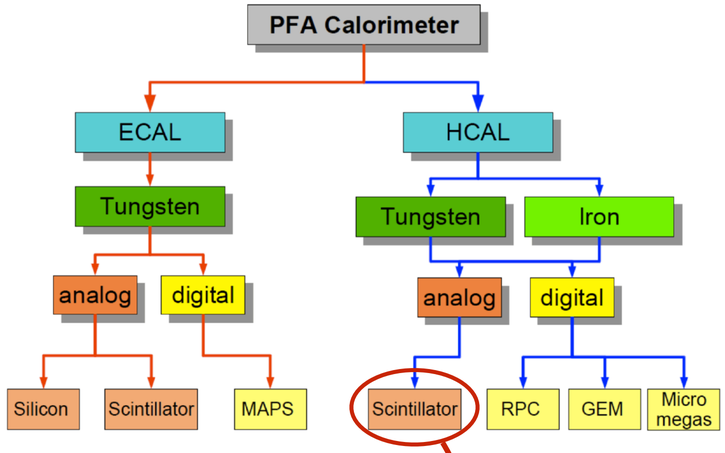
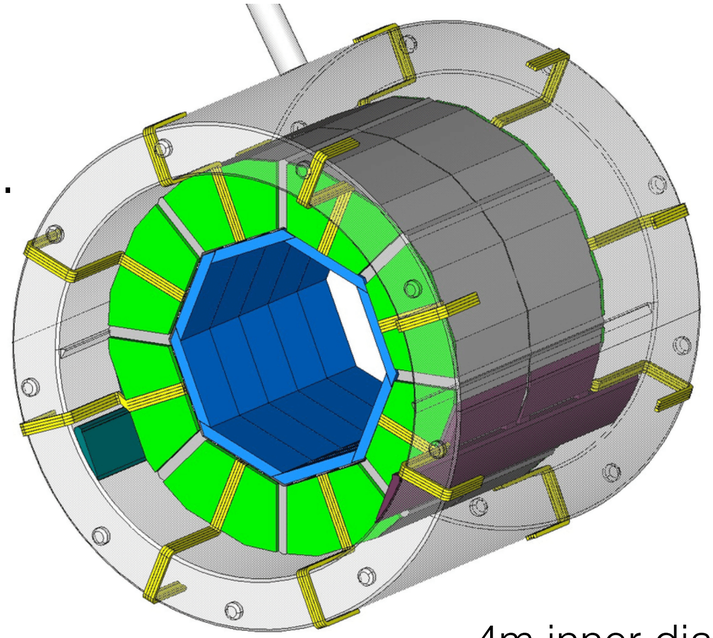
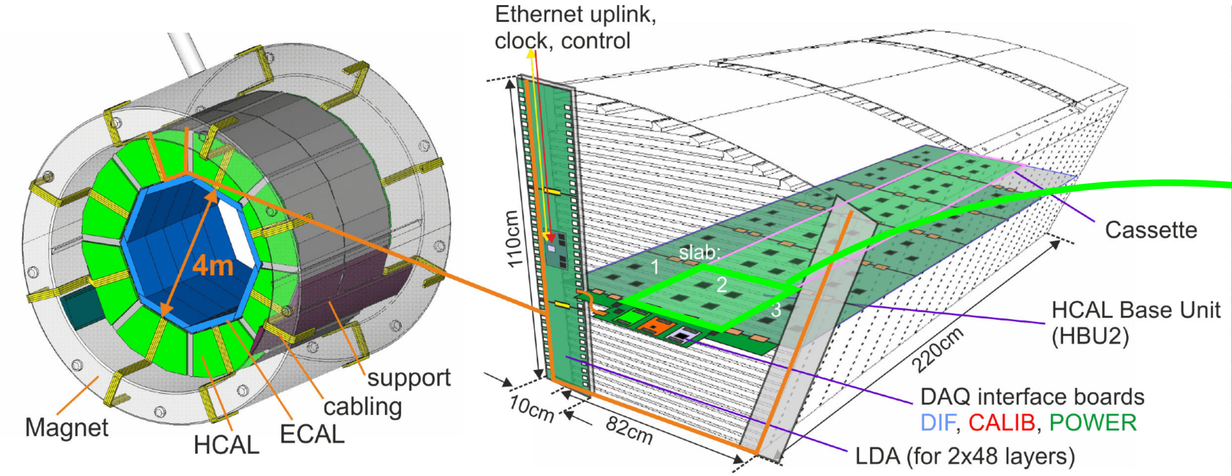
- **AHCal**: **Analogue Hadronic Calorimeter**
  - Plastic scintillator tiles.
  - SiPM readout.
  - Total 8M channels!

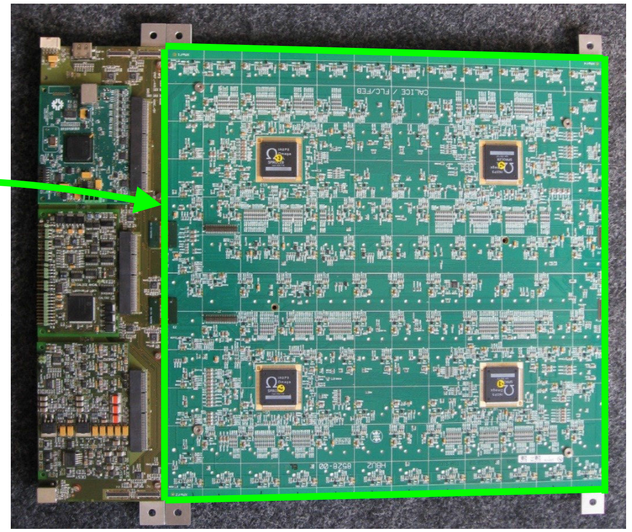




4m inner diameter and length

The Analogue Hadronic Calorimeter





- 1 board = 36x36 cm^2 (144 channels)

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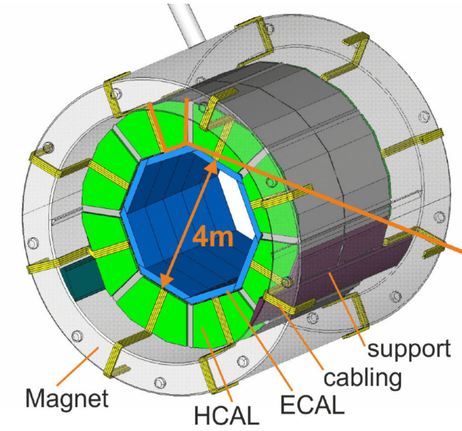
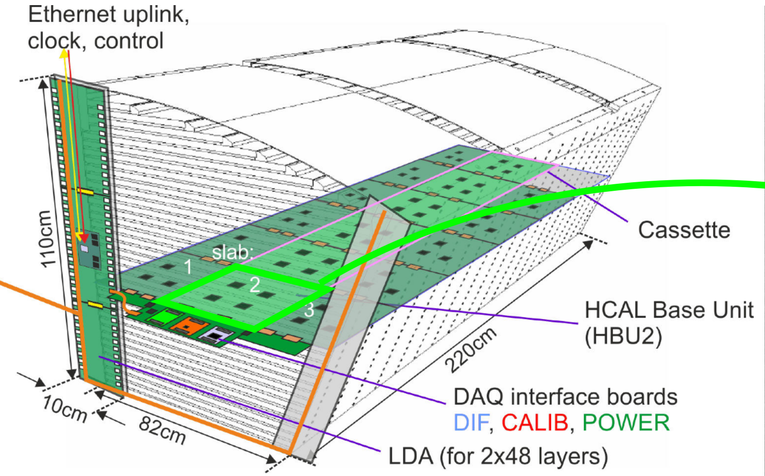
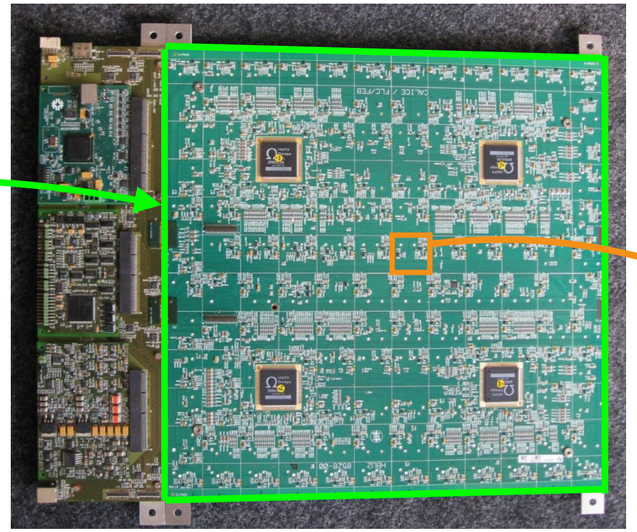
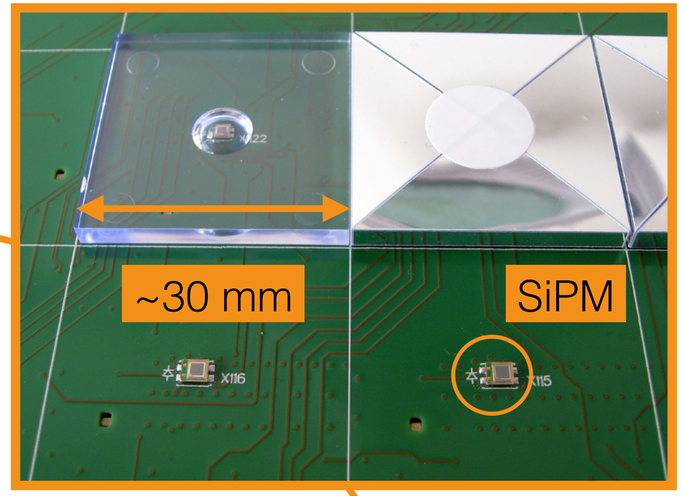




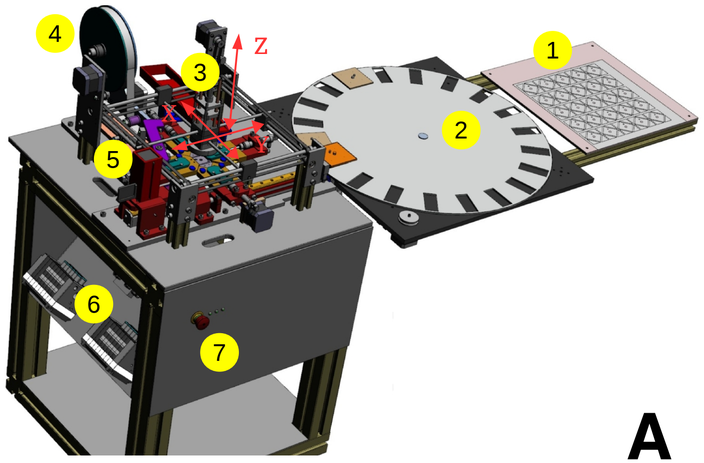




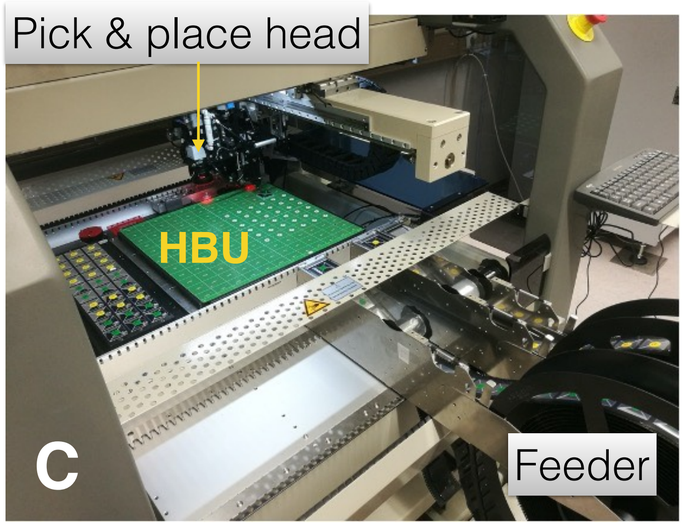
- 1 board = 36x36 cm² (144 channels)

- 1 channel =
  - 1 **SiPM** (Hamamatsu S13360-1325)
  - 1 **scintillator tile** (30 x 30 mm², 3 mm thick), polystyrene.
- Individually wrapped in reflective foil, and glued on PCB.

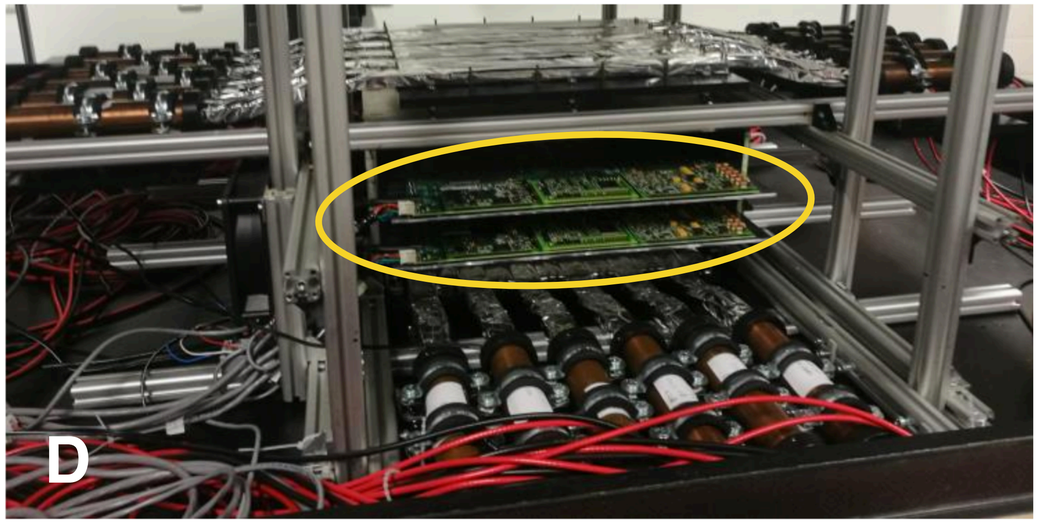
Technological prototype: construction (2017-2018)



A



C

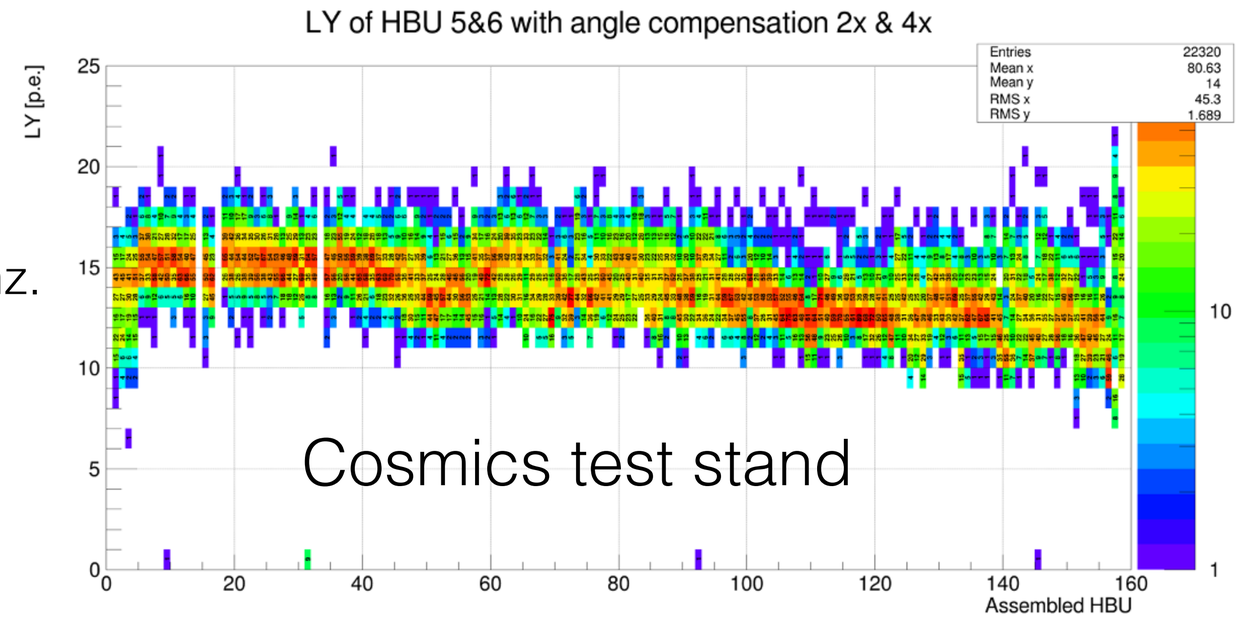


D

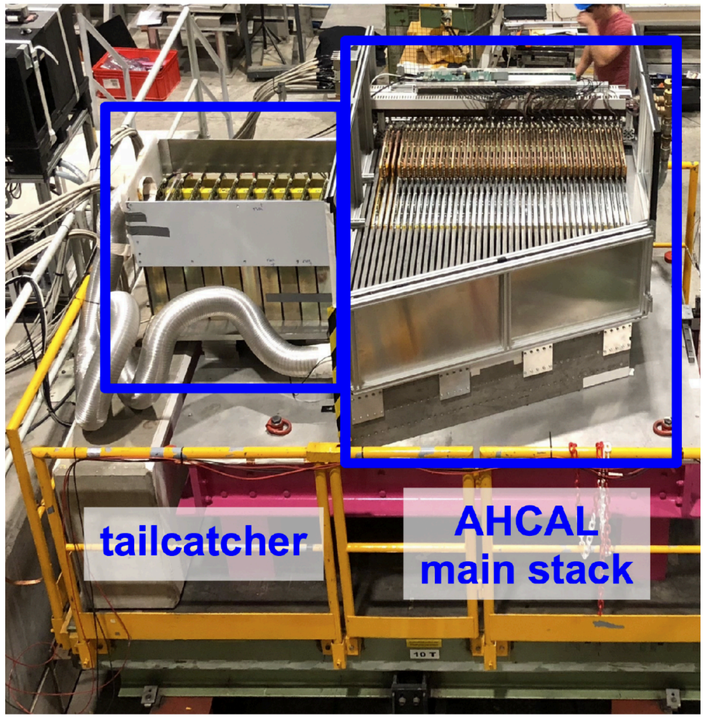
A. Tile produced in Moscow, wrapped in Hamburg
B. SiPM tests in Heidelberg, mounted in DESY.
C. Tile gluing in Mainz.
D. Validation and calibration in cosmics test stand in Mainz.

+ many more institutes…

→ ~22’000 channels (dead channels < 1‰)



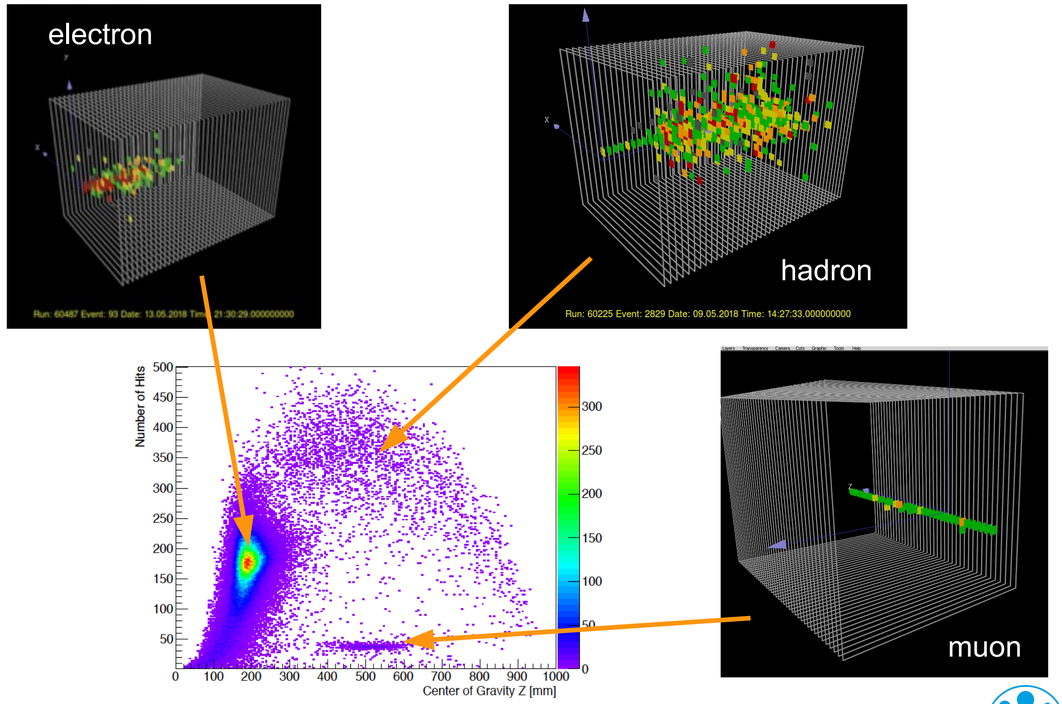
Technological prototype: 2018 TB @ SPS (CERN)



← Beam:

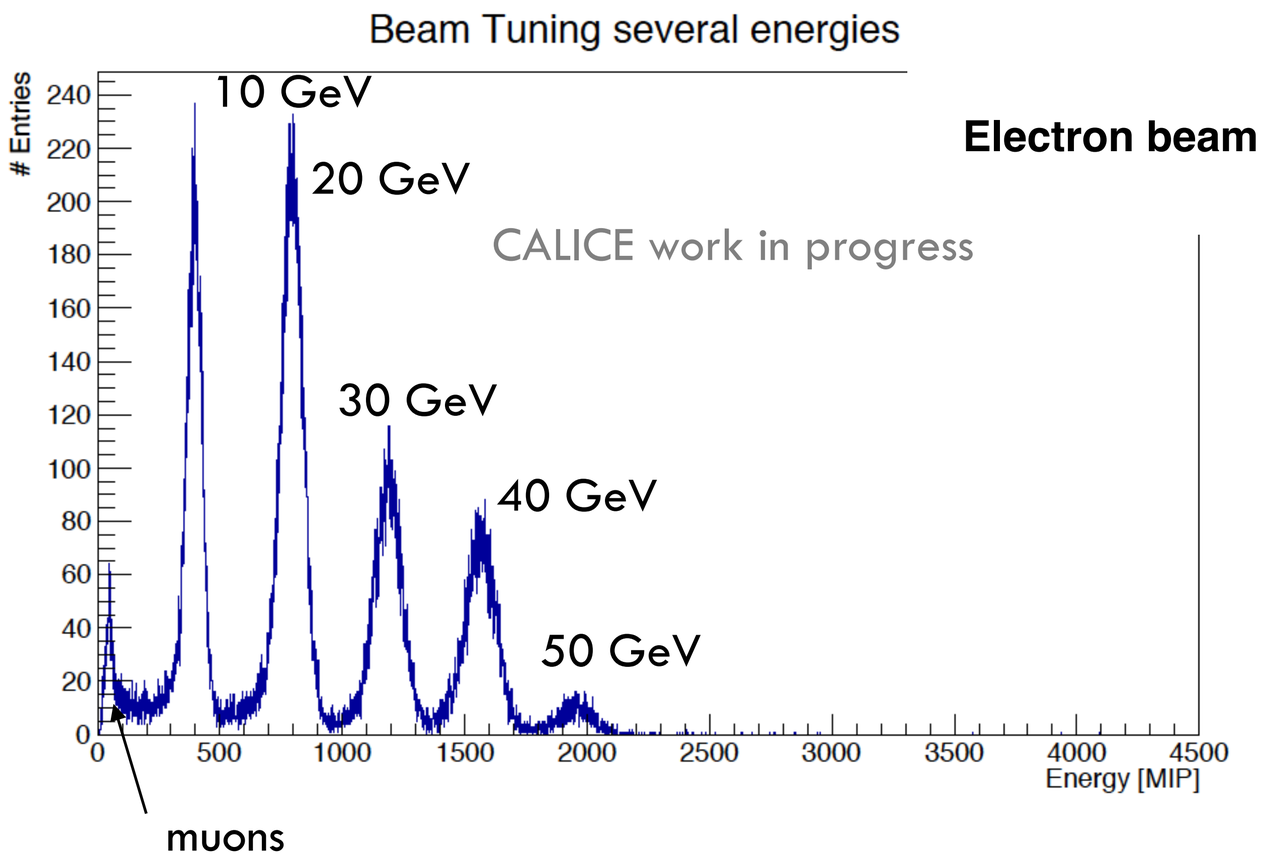
- Muons
- Electrons, 10-200 GeV
- Pions, 10-200 GeV

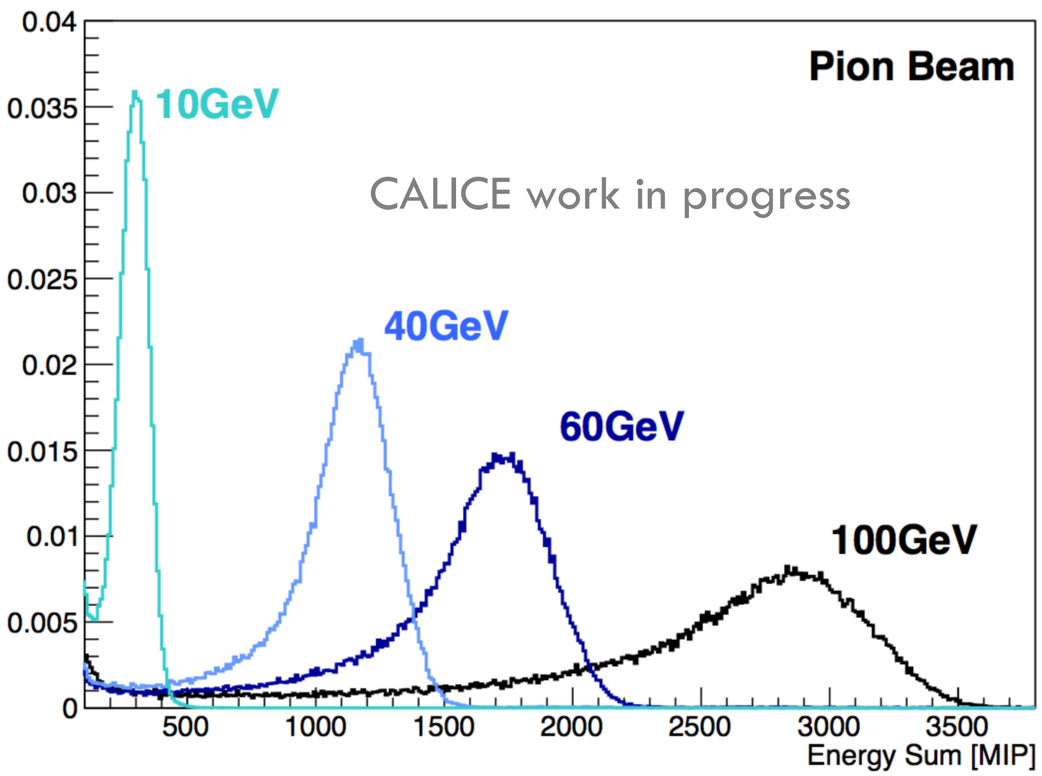
Total: ~100M events



- **3 test-beams @ CERN** with different configurations:
  - **AHCal standalone**: 38 layers (72x72 cm^2: 4 boards each) with 1.7 cm steel absorber = 4λ
  - **AHCal + 8 layers of tail catcher** (CMS HGCal prototype) with 7.4 cm steel absorber.
  - **HGCal + AHCal**.
- Since then, **many more TB @ DESY** with smaller & more dedicated setups.

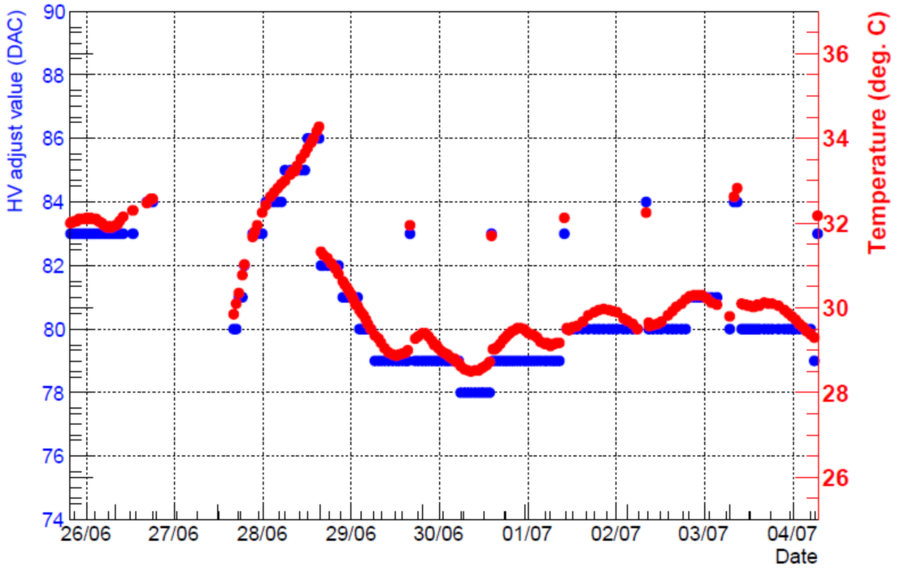
Example result: sum of cell energy

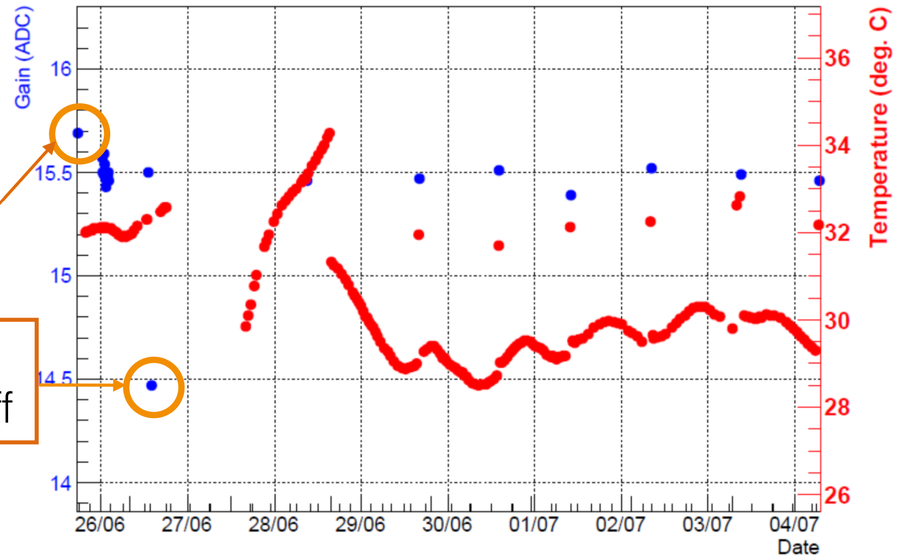




Stable operation!

- **SiPM response is sensitive to temperature**. (gain & photon detection efficiency)
- Can be **stabilised by adapting the bias voltage**.
- "Temperature compensation" used all along data taking.
  - **Gain stays stable**!



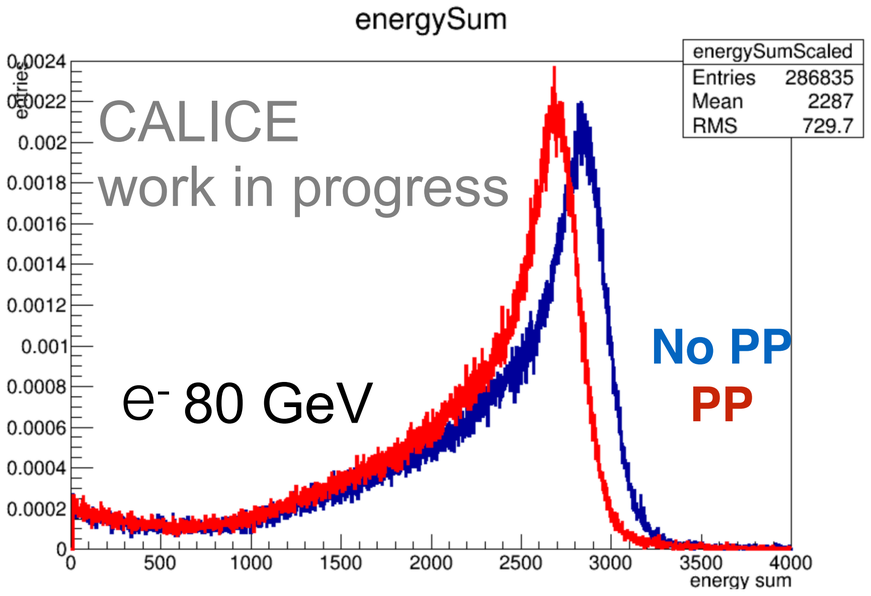


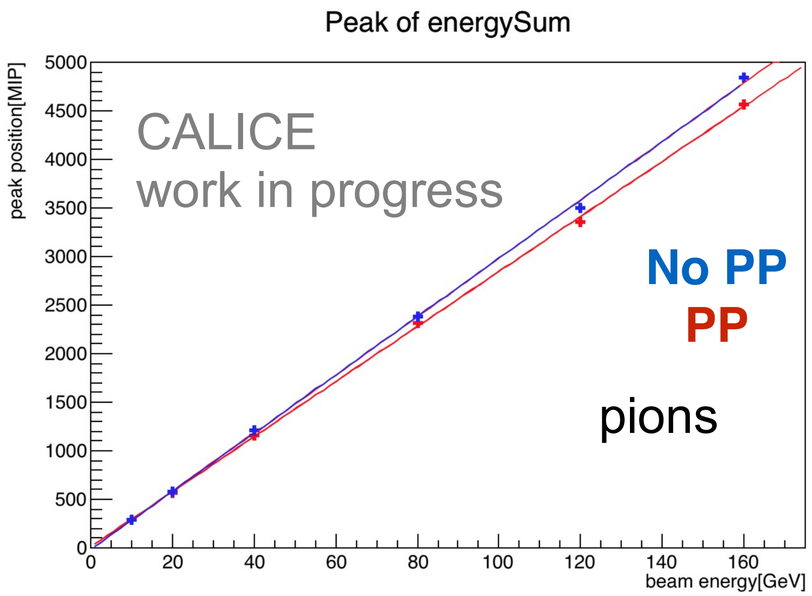
Temperature compensation off

Power-pulsing

- Readout chip:
  - Adapted to ILC beam structure:
    1 ms spill every 200 ms.
  - Low consumption (< ~25 μW)
    using **power pulsing** (0.5% duty cycle).

- **Different results with and without power pulsing**:
  - Tracked down to different temperature compensation behaviour.
  - **Corrected using dedicated calibrations for power-pulsing mode**.

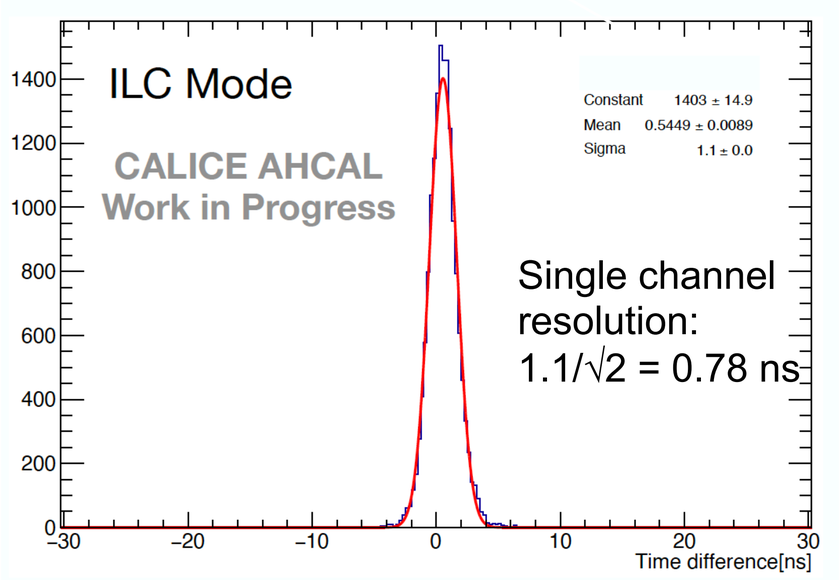


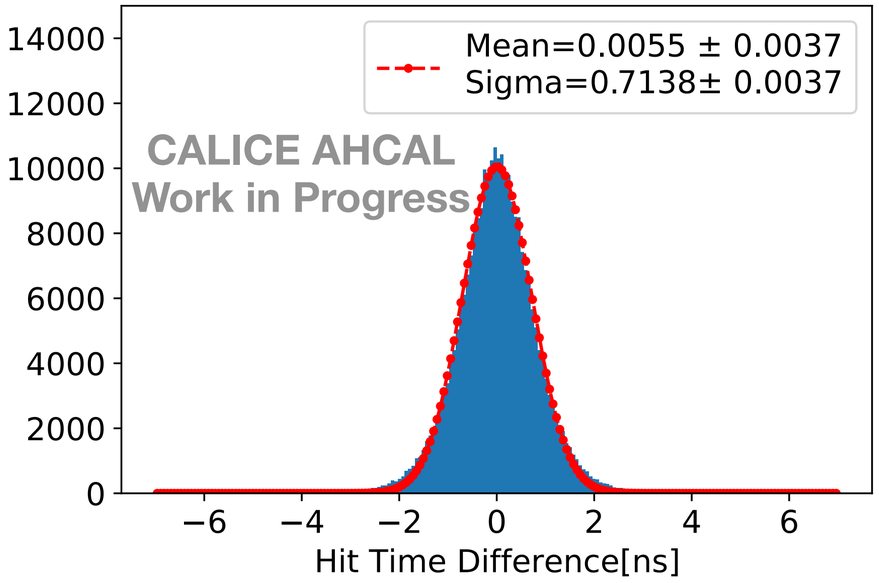


Timing studies

- **Target resolution: ~1 ns**.
- **Dedicated test-beam @ DESY with 5 layers**:
  - Single channel resolution in ILC mode*: **~0.78 ns**.

- Try to separate electronics from intrinsic SiPM-on-tile contributions: dedicated setup with different front-end electronics during test beam at DESY.
  - Measured **intrinsic resolution**: 0.714/√2 = **0.507 ns**.
  - Deduced **front-end electronics contribution**: **~0.6 ns**.





*: Test beam mode: 250 kHz clock (better suited for TB, but worse resolution)

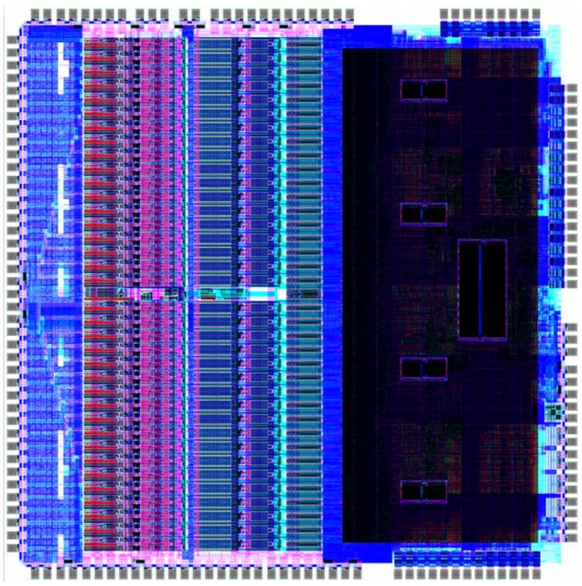
*: "ILC mode": 1 MHz clock

New hardware development:
KLauS ASIC
Megatile scintillators

KLauS ASIC: new readout chip

- Active development of new ASIC (Uni Heidelberg).
  - Version 6 currently under test.
  - Close to final design!
  - Target **~1 ns time resolution**,
  - **Power pulsing**, low power
  - **2 gains**,
  - …

} Same as SPIROCv2

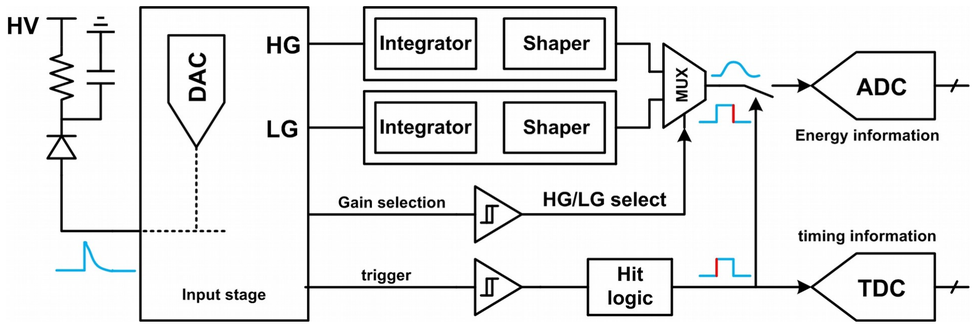


KLauS6 (5x5 mm²)

- More versatile design than SPIROCv2.
  ➞ Allows more flexible beam conditions.

- Same packaging as SPIROCv2.
  ➞ Easy integration into AHCal board.

KLauS Channel



Megatile concept

Technological prototype building: process demonstrated, **but not so simple**…
Can we ease the construction?

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- Build **one single** 36x36 cm^2 **tile**.
- **Cut trenches** and fill with **optical insulation**.
- Pour flowing **glue + TiO_2 mixture** → reflectivity.

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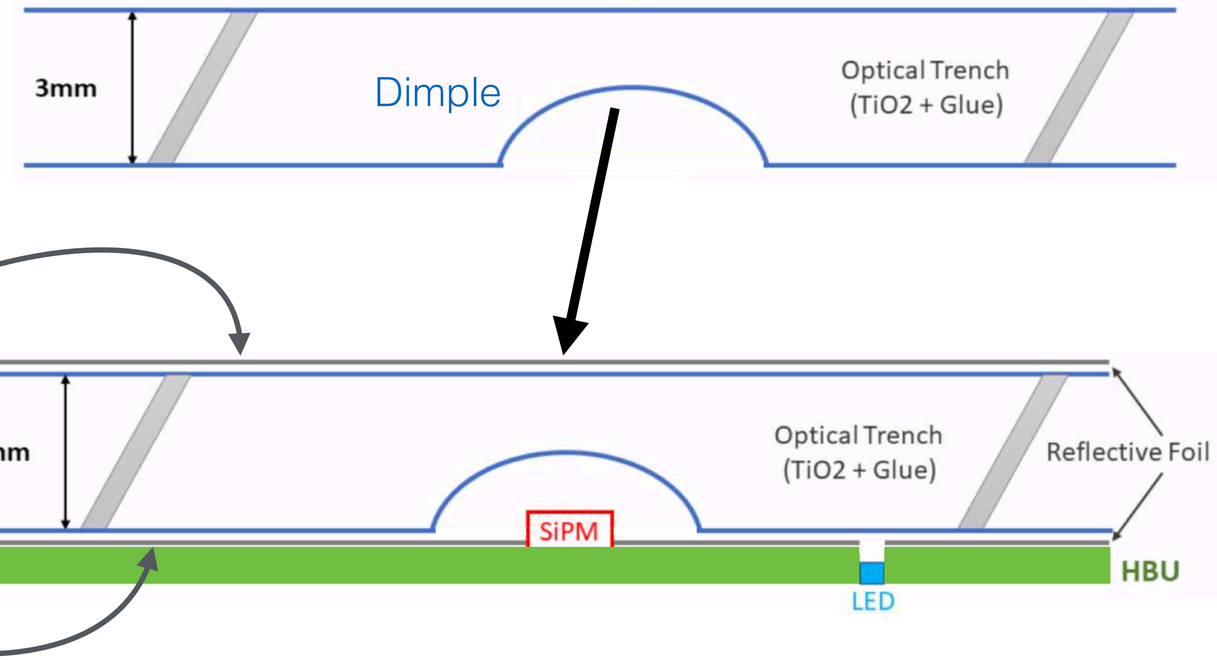
- Put large **reflective foil sheet** directly on board (with laser-cut holes for SiPM)

- **Air gap** (30-100 µm) to ensure total reflection.



- <u>No change to SiPM:</u>
  - Same electronics boards.
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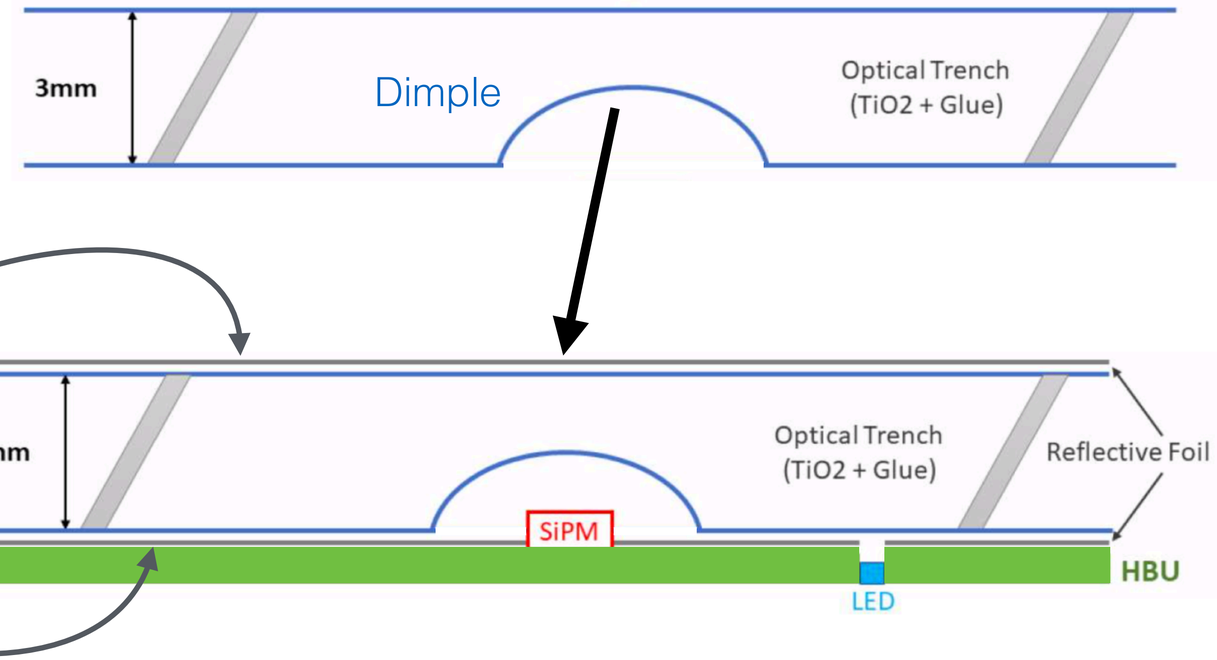

- Put large **reflective foil sheet** directly on board (with laser-cut holes for SiPM)
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- **Easier assembly** 👍
- ~ **No dead area** 👍

- <u>No change to SiPM:</u>
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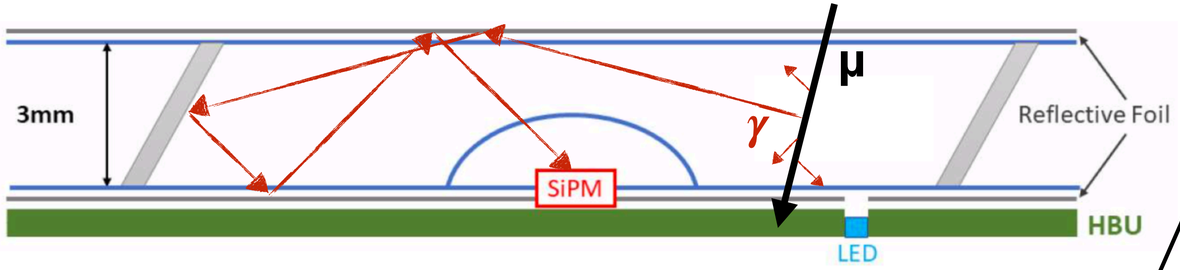
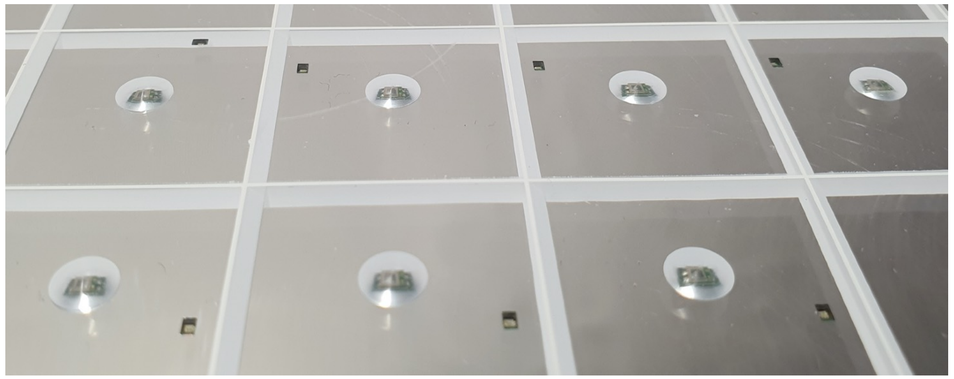
Light yield (LY) and cross-talk (XT) optimisation

- Dimple shape: already optimised for single tiles.
- Trench angle:
  - **Optimised for light yield** using simu.
  - Angle = 30°: minimal dead area.
- ↱ **High light-yield ≈ as single tile** 👍
- **Glue + TiO_2 dependency**.





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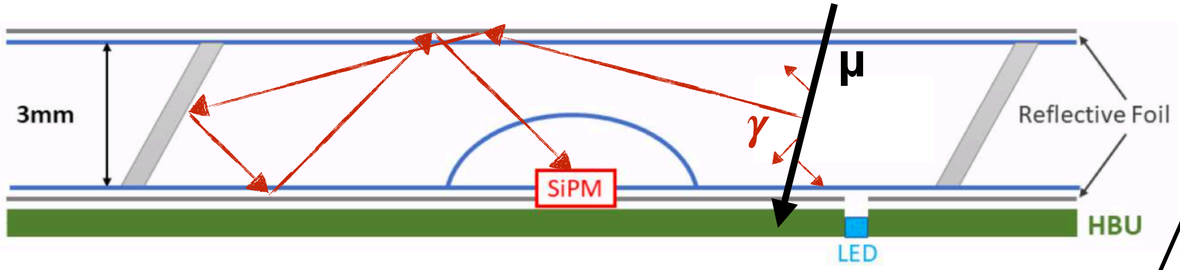
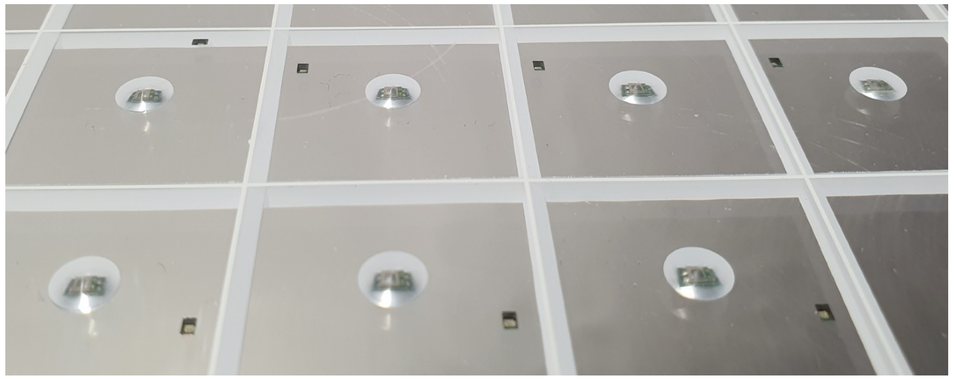
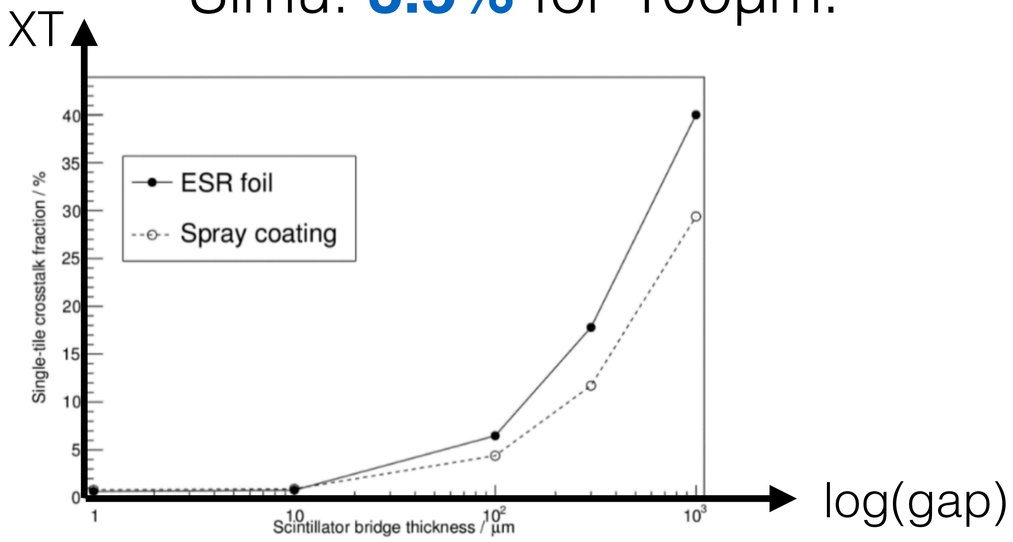
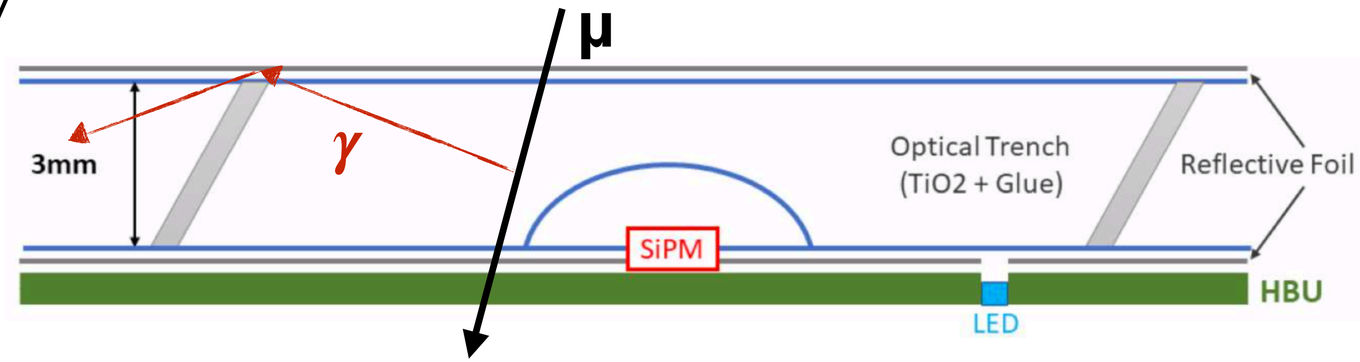




- **Must be careful with air gap**:
  - Too large → optical cross talk.
  - Simu: **3.5%** for 100μm.





Megatile: a promising concept

- **High light-yield ≈ 32 p.e. / MIP**
  ≈ as single wrapped tile 👍 👍
- **Cross-talk**: ≲ **5%**, **OK** (had. showers)

Here in cosmics bench @ Mainz,
but already 3 test-beams @ DESY!

	A	B	C	D	E	F	G	H	I	J	K	L
L	15.223	20.765	21.148	20.154	21.833	21.219	21.186	19.468	20.799	21.524	20.005	15.534
K	21.010	24.744	32.833	30.889	32.759	32.575	33.326	31.828	30.354	32.292	29.243	18.307
J	19.499	30.607	33.137	32.796	34.949	33.749	33.907	32.087	31.232	32.417	29.506	20.434
I	19.982	29.750	32.416	33.635	33.087	34.655	32.719	33.466	31.523	29.975	29.186	20.314
H	19.398	29.878	27.449	37.333	34.279	33.779	34.332	33.890	34.831	32.380	29.963	20.305
G	17.056	28.444	25.276	31.338	34.043	32.897	34.425	34.225	32.313	31.504	29.906	20.768
F	19.619	26.796	30.062	30.926	30.714	32.247	37.278	33.257	32.807	24.485	29.476	19.549
E	18.728	27.746	30.064	30.403	30.019	31.346	33.313	31.395	31.226	31.539	29.188	20.534
D	19.280	28.537	29.976	29.255	30.157	30.876	32.397	30.587	32.128	32.234	31.451	20.621
C	19.886	30.597	32.138	31.719	32.344	33.296	33.484	33.180	32.709	32.496	31.207	19.402
B	18.901	22.853	31.994	32.637	34.072	33.427	31.465	32.574	32.132	32.389	31.560	18.787
A	14.917	20.033	21.582	22.359	21.501	21.441	21.850	22.607	22.138	21.681	21.855	16.347

35
30
25
20
15

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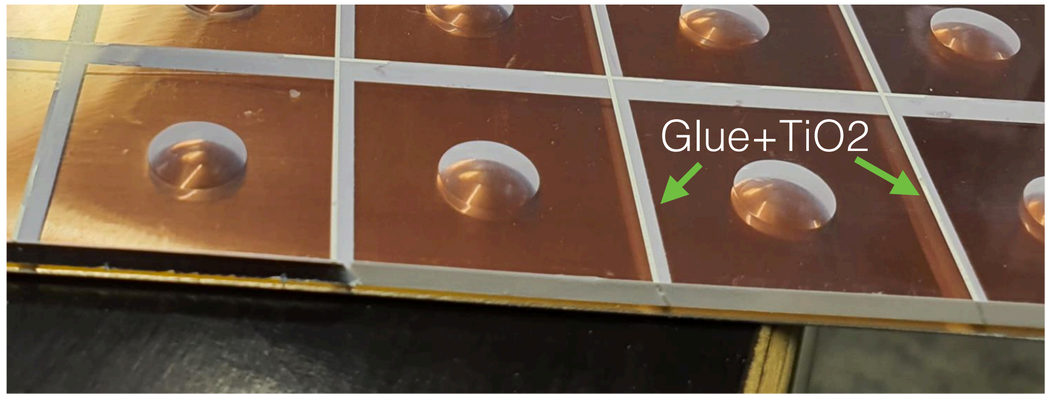
- Air-gap control in test-beam.
- Ensure light-tightness of the edges:



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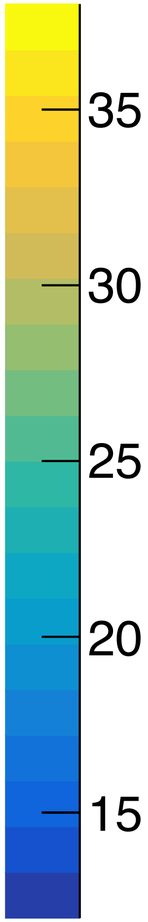

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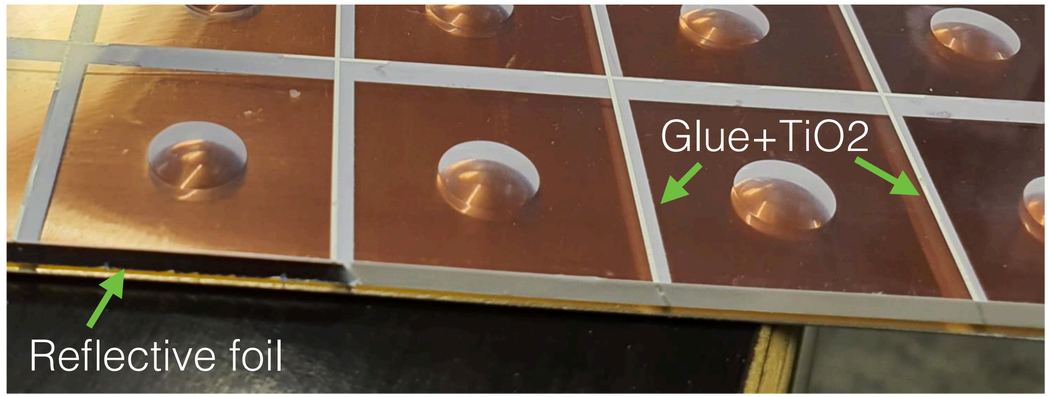
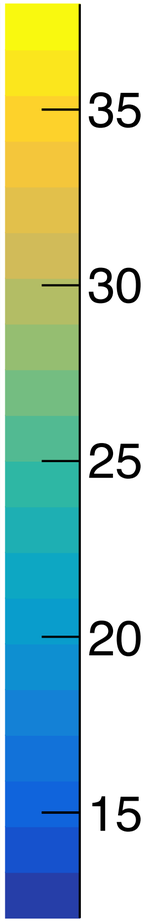


Here in cosmics bench @ Mainz,
but already 3 test-beams @ DESY!

	A	B	C	D	E	F	G	H	I	J	K	L
L	15.223	20.765	21.148	20.154	21.833	21.219	21.186	19.468	20.799	21.524	20.005	15.534
K	21.010	24.744	32.833	30.889	32.759	32.575	33.326	31.828	30.354	32.292	29.243	18.307
J	19.499	30.607	33.137	32.796	34.949	33.749	33.907	32.087	31.232	32.417	29.506	20.434
I	19.982	29.750	32.416	33.635	33.087	34.655	32.719	33.466	31.523	29.975	29.186	20.314
H	19.398	29.878	27.449	37.333	34.279	33.779	34.332	33.890	34.831	32.380	29.963	20.305
G	17.056	28.444	25.276	31.338	34.043	32.897	34.425	34.225	32.313	31.504	29.906	20.768
F	19.619	26.796	30.062	30.926	30.714	32.247	37.278	33.257	32.807	24.485	29.476	19.549
E	18.728	27.746	30.064	30.403	30.019	31.346	33.313	31.395	31.226	31.539	29.188	20.534
D	19.280	28.537	29.976	29.255	30.157	30.876	32.397	30.587	32.128	32.234	31.451	20.621
C	19.886	30.597	32.138	31.719	32.344	33.296	33.484	33.180	32.709	32.496	31.207	19.402
B	18.901	22.853	31.994	32.637	34.072	33.427	31.465	32.574	32.132	32.389	31.560	18.787
A	14.917	20.033	21.582	22.359	21.501	21.441	21.850	22.607	22.138	21.681	21.855	16.347

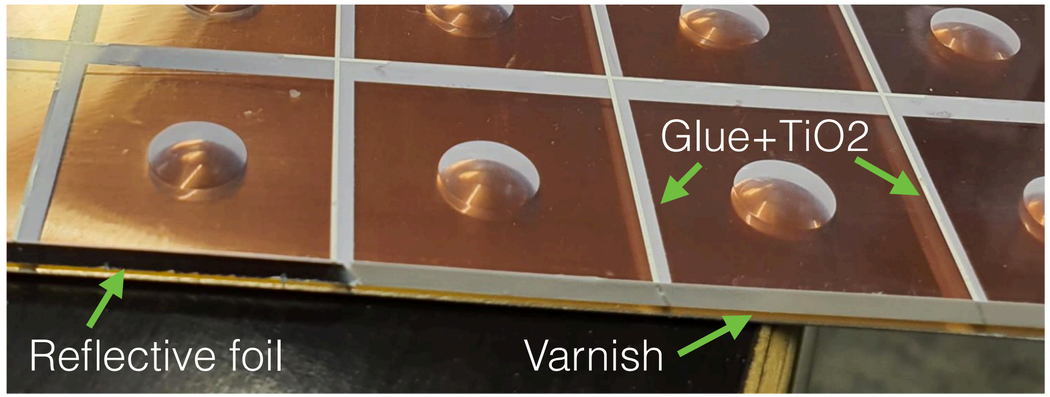


Megatile: a promising concept

- **High light-yield ≈ 32 p.e. / MIP**
  ≈ as single wrapped tile 👍 👍
- **Cross-talk**: ≲ **5%**, **OK** (had. showers)

Still, comes with its own challenges:

- Air-gap control in test-beam.
- Ensure light-tightness of the edges:
  - Using **adhesive reflective foil**, but **not easy and limited improvement**.
  - **Under test**: **use varnish spray**!



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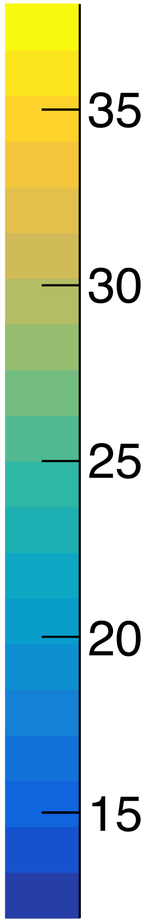
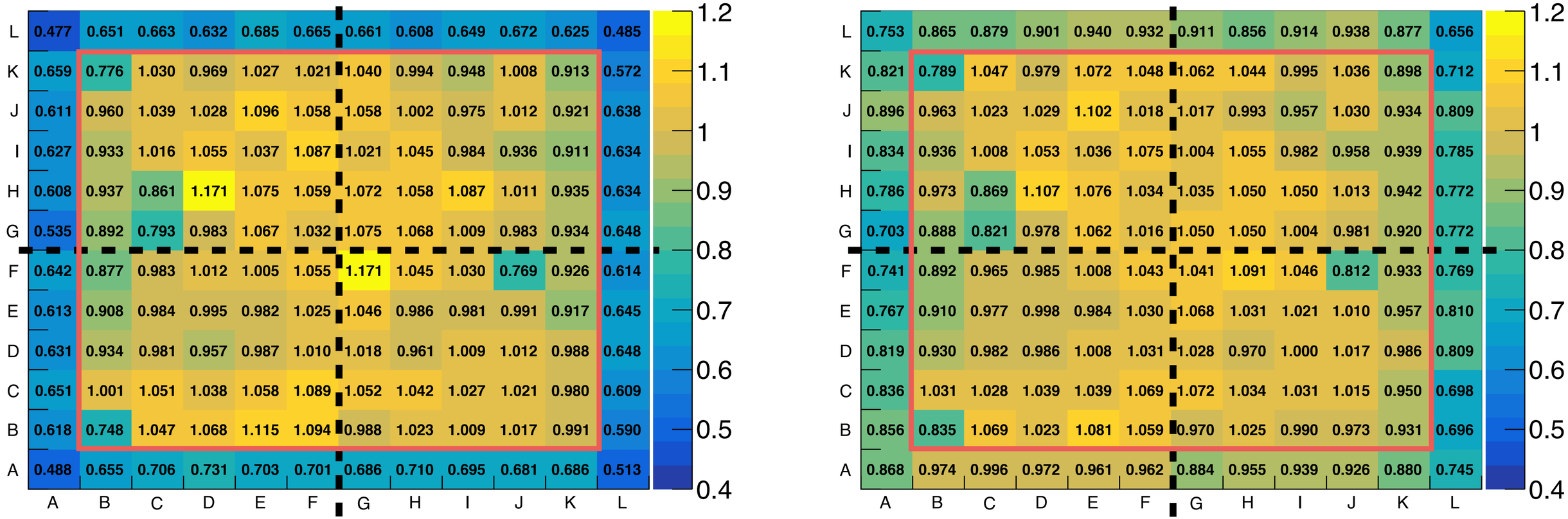


Edge channels

With adhesive reflective foil → With varnish spray

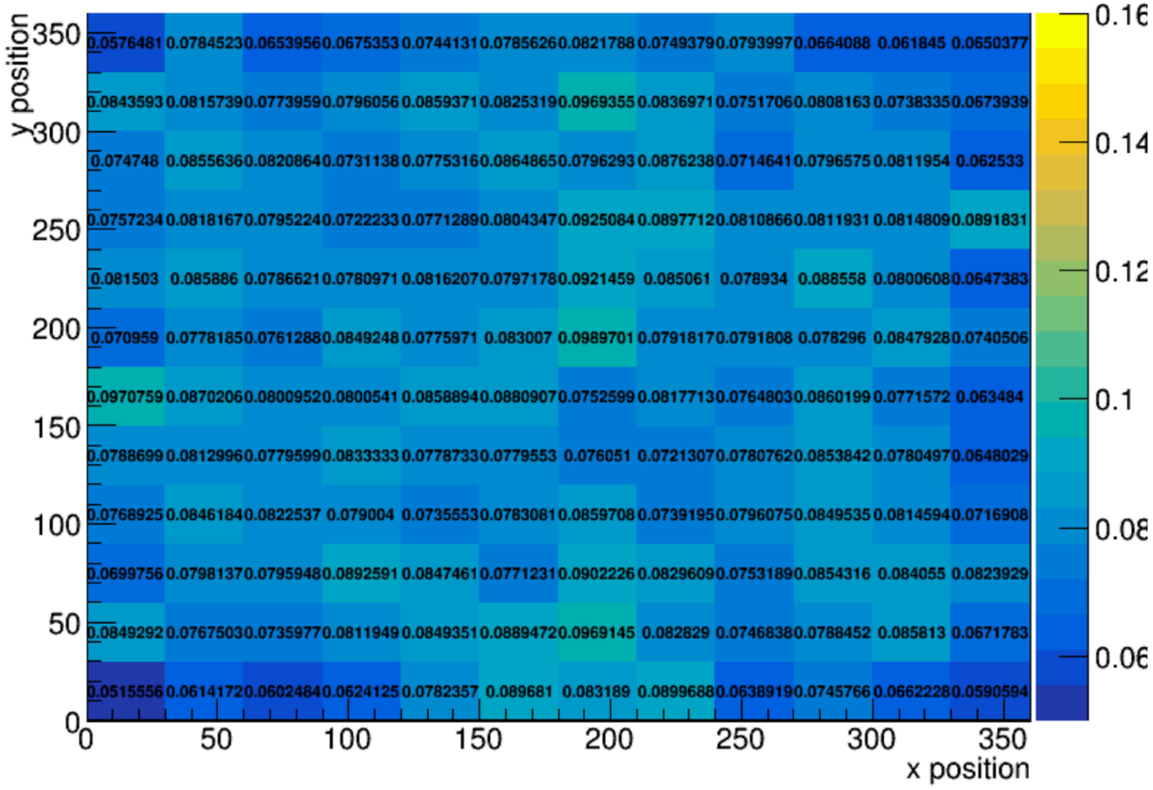


- **Uniformity map**: for each quadrant, **plot LY / <LY in 25 central channels>**.
- **Average ratio** of the 44 **edge channels**: **0.67 → 0.84**.
- Not yet perfect, but already a **>15% improvement**. More studies ongoing!

Cross-talk in cosmics and test-beam

Cosmic test stand:
uniform and low (~7%)

*: older prototype, slightly worse than 5%.



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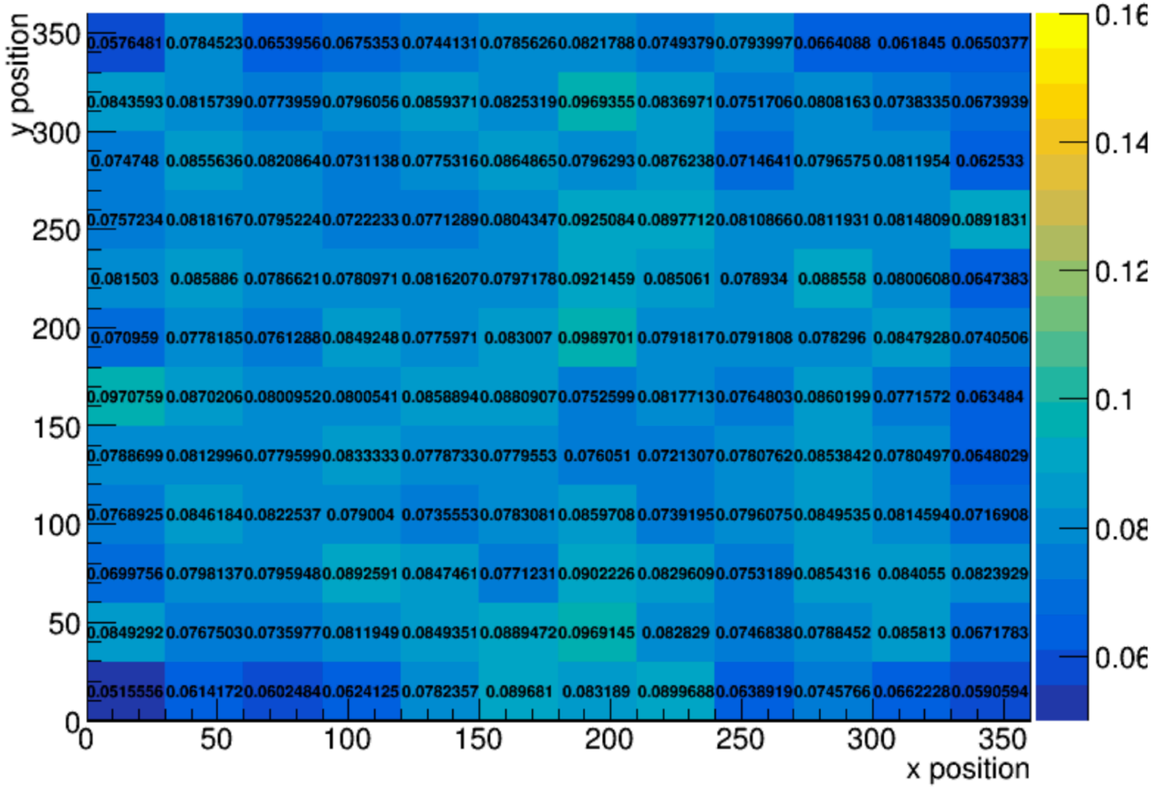
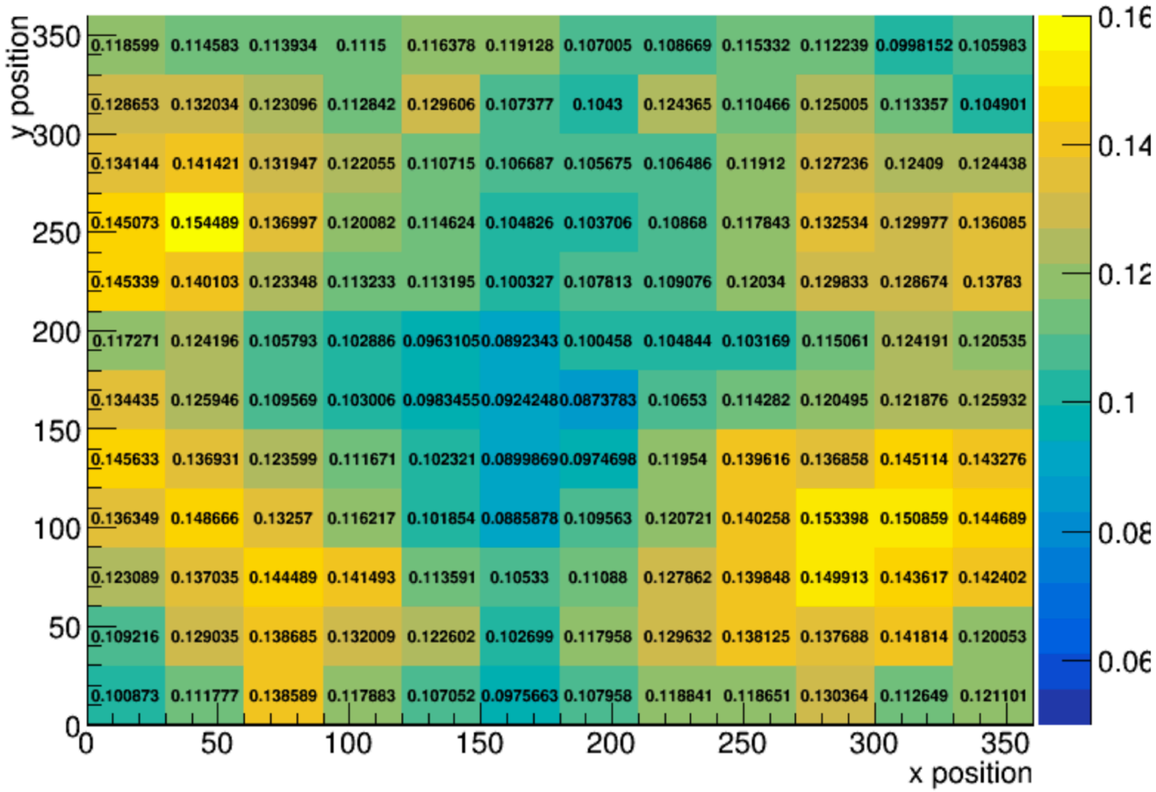
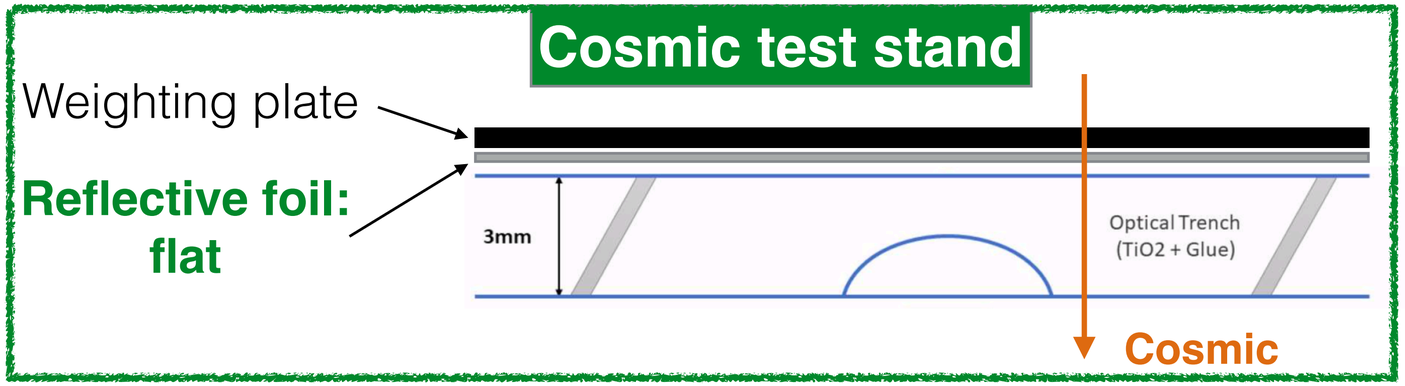


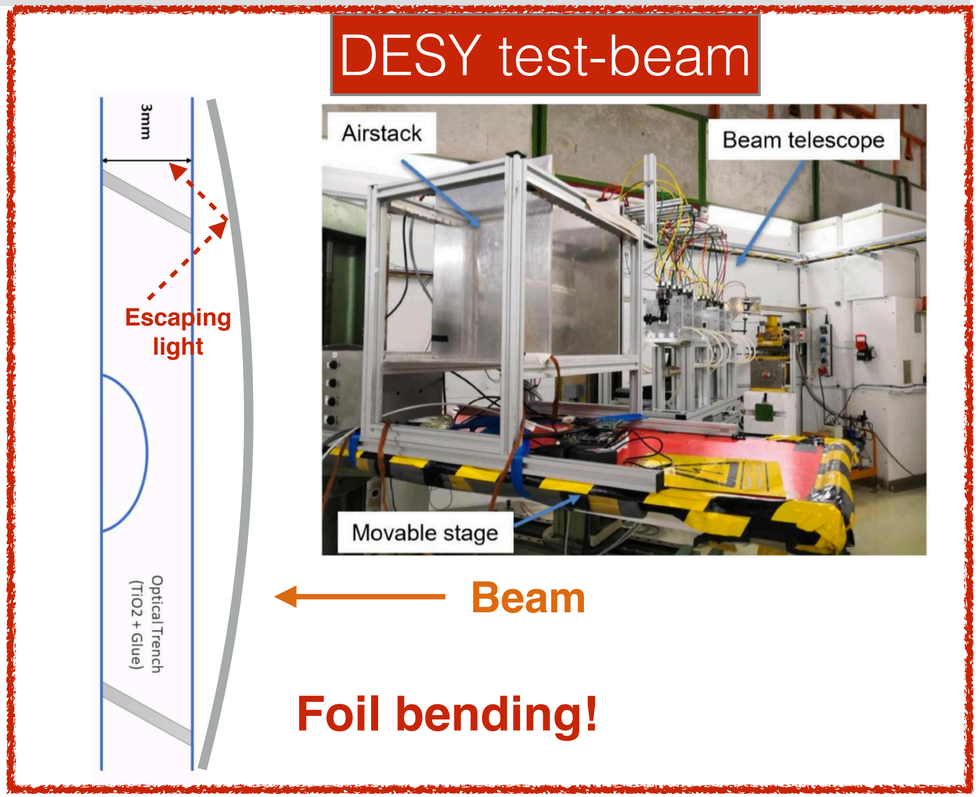
DESY test-beam
large variation, up to 15%



Cross-talk: air-gap control



- Tracked down to **bending foil in test-beam setup**.
- In cosmic test stand, a weighting plate is used to ensure everything is flat.



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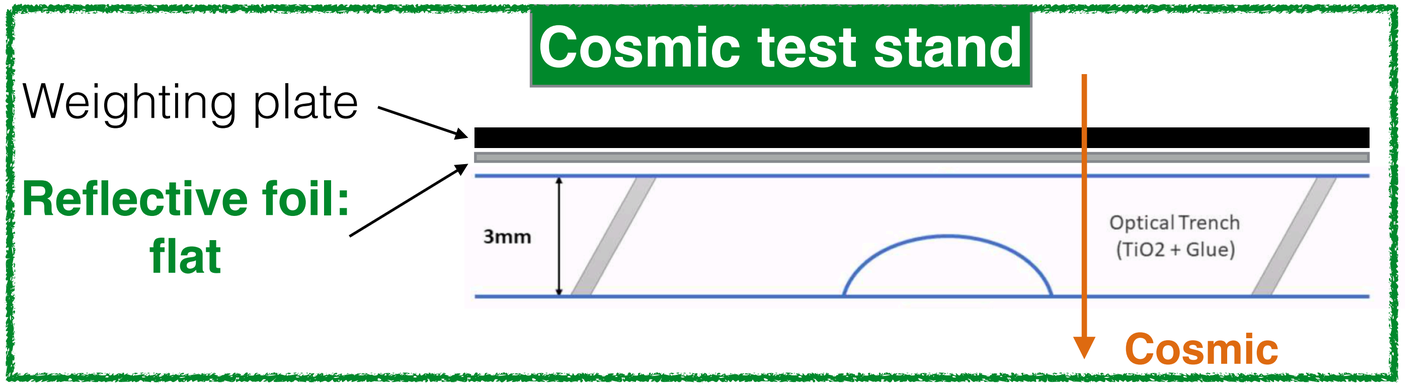
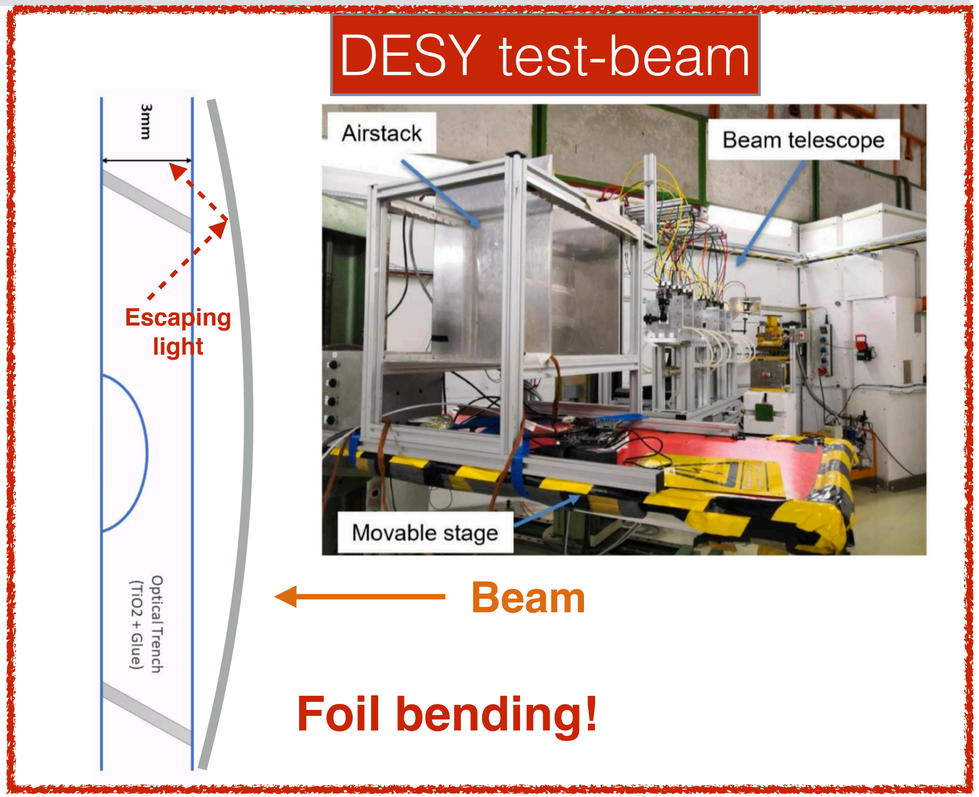
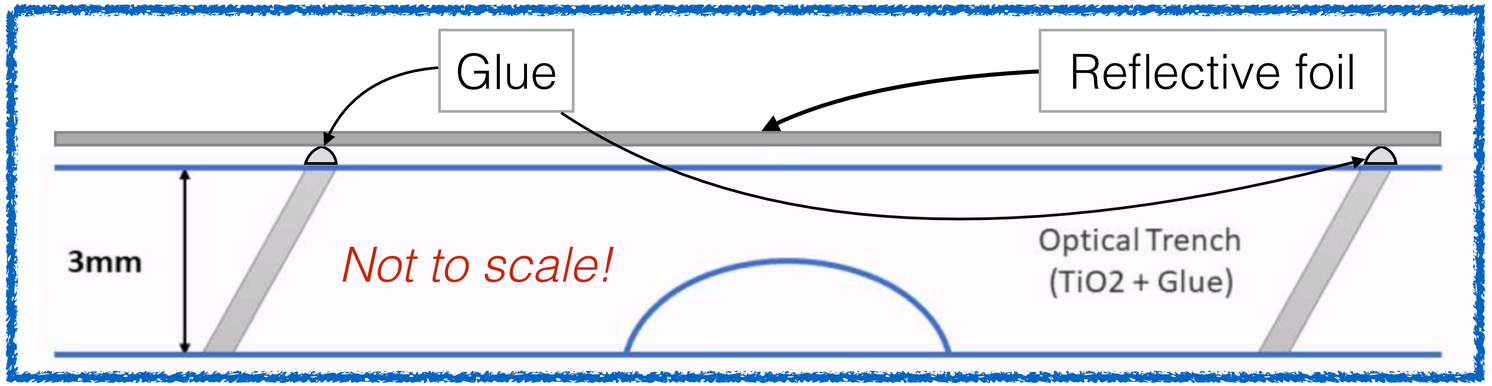




- Tracked down to **bending foil in test-beam setup**.
- In cosmic test stand, a weighting plate is used to ensure everything is flat.
- Idea: **glue the foil directly to the megatile**.
- Tested in last test-beam, updated version for next one!



Conclusion

- **Successful building and commissioning of the technological prototype with ~22'000 channels**.
- Multiple **very fruitful test-beam** @ CERN-SPS in 2018, **many ongoing analyses**.
  - **Very stable operation**, thanks to temperature compensation.
  - Unexpected **power-pulsing dependence observed and understood**.

- Test-beams @ DESY with smaller setups for dedicated studies.
  - For example: **timing resolution ~ 0.724 ns, better than 1 ns target**!

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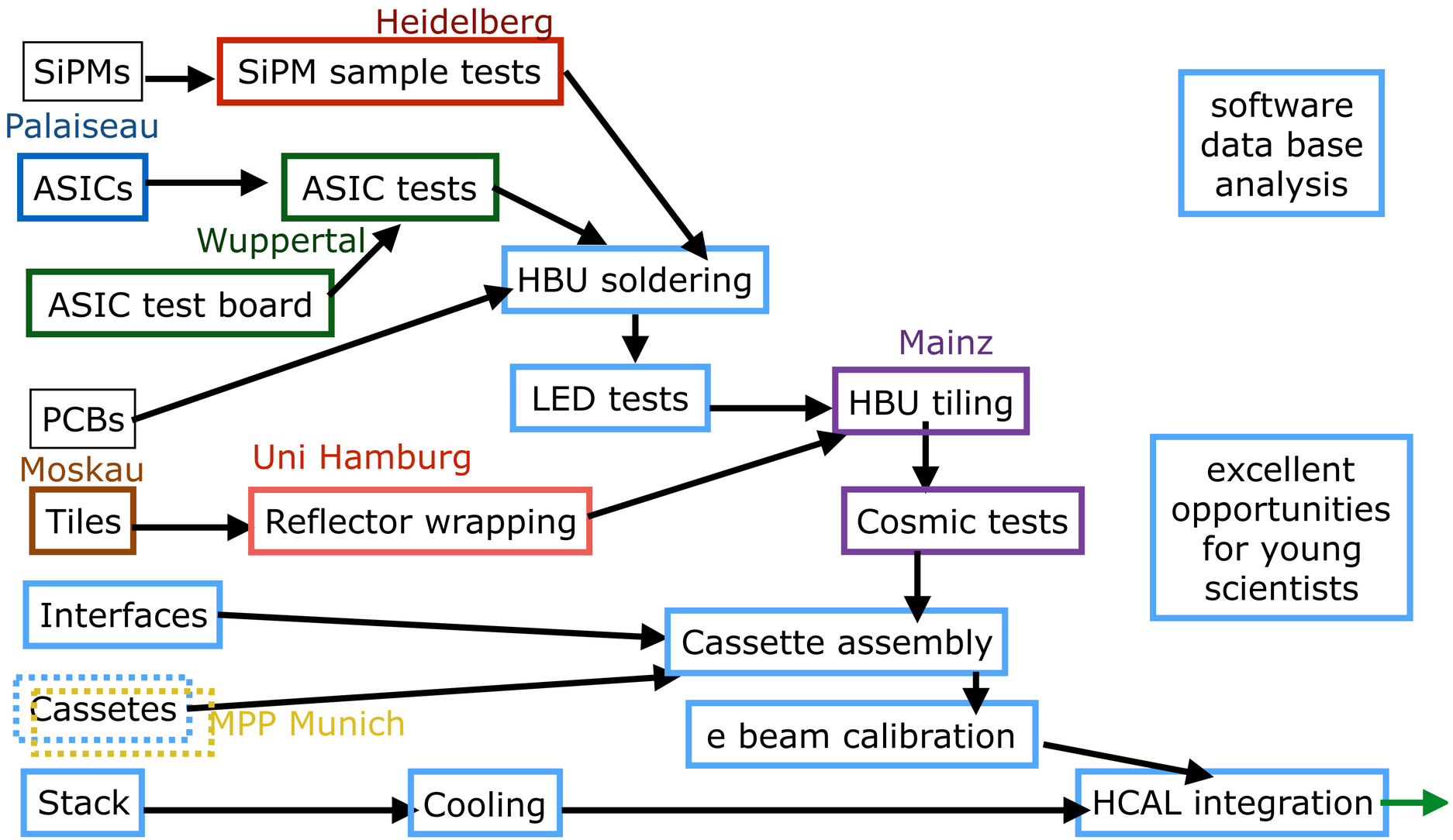
Not mentioned:
- KLauS read-out chip…
- Simulation and particle ID…

Stay tuned for more results!

Thanks for your attention!

BACKUP


Heidelberg
SiPMs
SiPM sample tests
Palaiseau
ASICs
ASIC tests
Wuppertal
ASIC test board
HBU soldering
PCBs
LED tests
Mainz
HBU tiling
Moskau
Uni Hamburg
Tiles
Reflector wrapping
Cosmic tests
Interfaces
Cassette assembly
Cassetes
MPP Munich
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Stack
Cooling
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software
data base
analysis
excellent
opportunities
for young
scientists