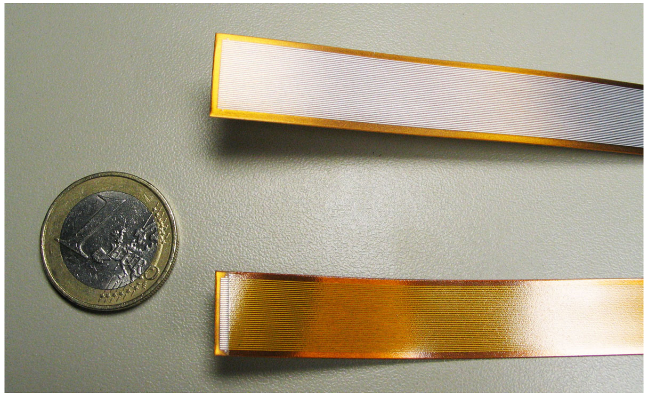
New aluminum microstrips for data transmission in the PANDA Experiment



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Tesi di Laurea Magistrale in Fisica, indirizzo Tecnologie Avanzate
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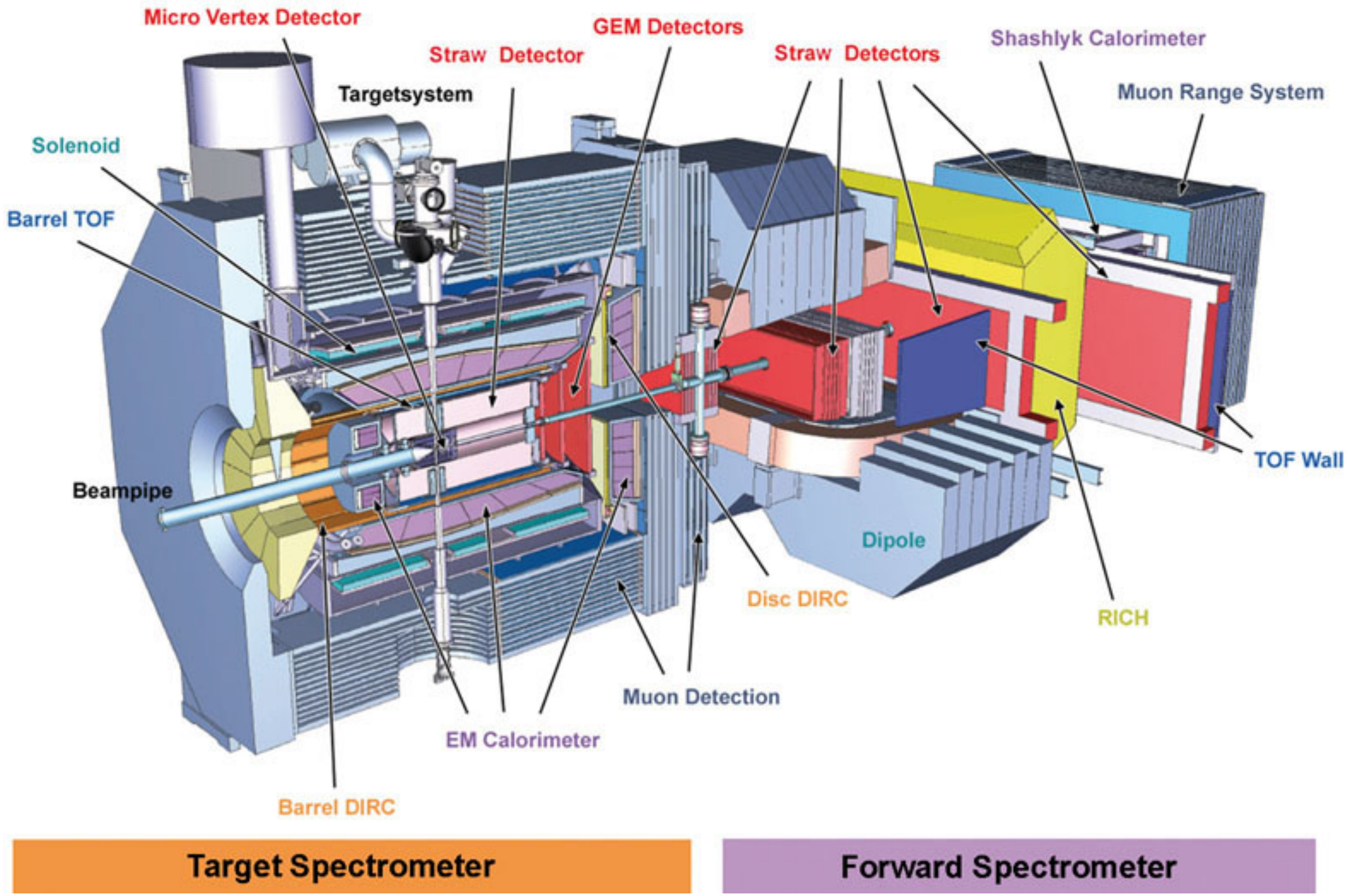
- Conclusions

Introduction

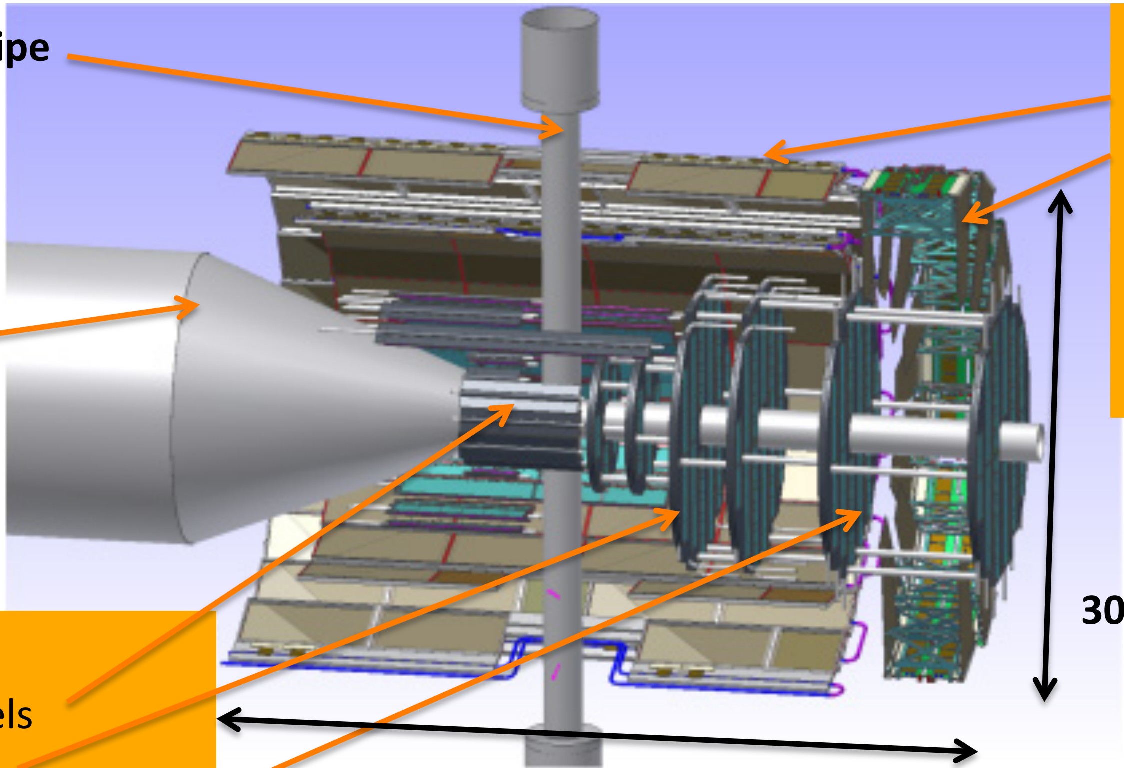
The PANDA Experiment

PANDA (AntiProton ANnihilations at DArmstadt): future fixed target experiment at the FAIR facility at GSI.
Antiproton beam with momentum between 1.5 GeV/c and 15 GeV/c

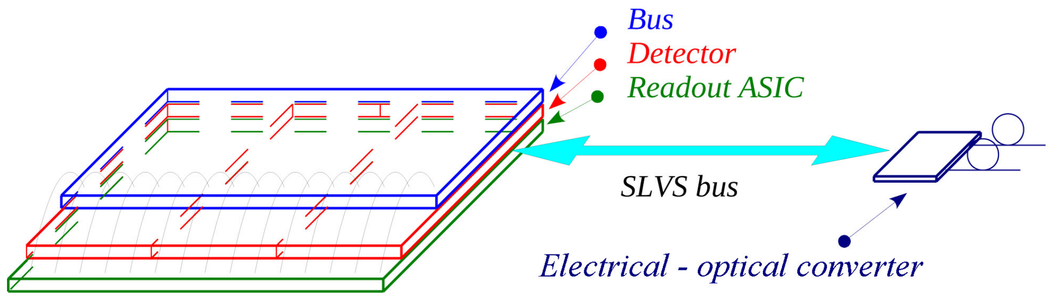


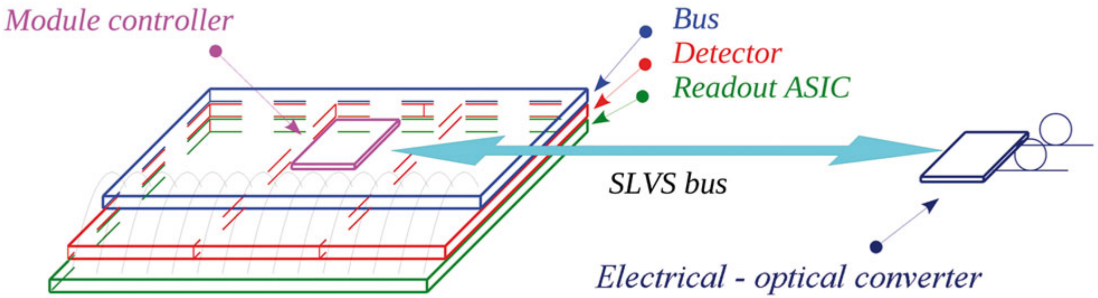
Micro Vertex Detector (MVD)

MVD Layout: 4 barrels surrounding the interaction point and six disks in the forward direction, covered with Double-sided Silicon Strip Detectors and Hybrid Pixel Detectors



Hybrid Pixel Detectors - Readout

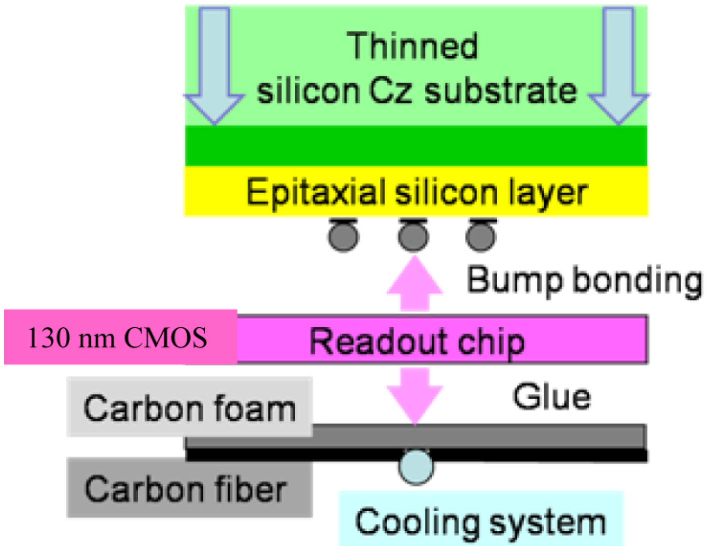




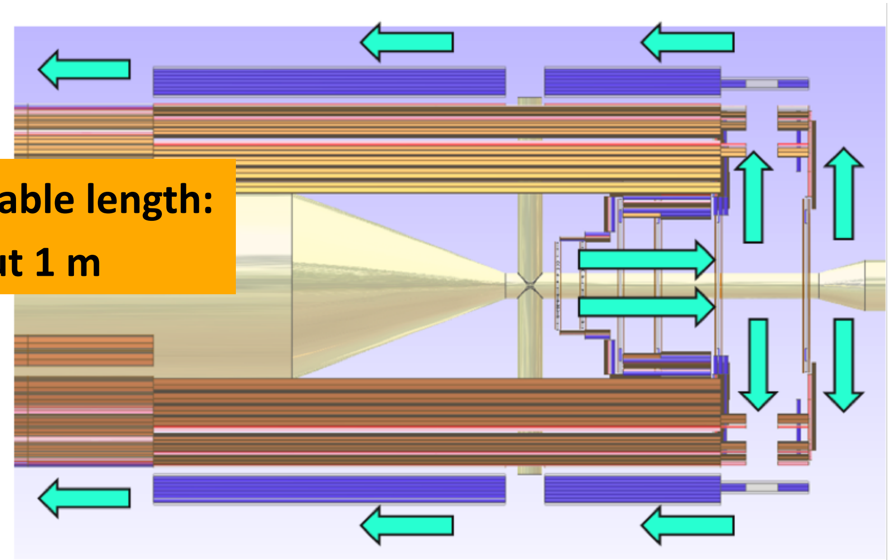
Two solutions:

1. Output directly from ToPix serializer (311.04 Mbit/s).
2. A module controller is added: possible increase of data rate and reduction of lines.

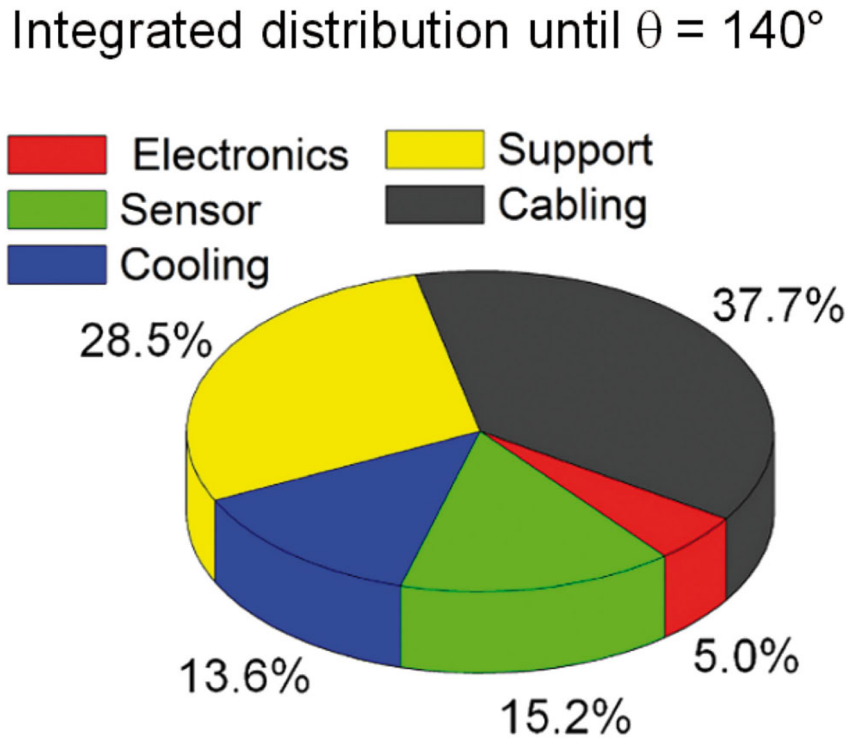
Max. data flow foreseen
(readout chip level):
~450 Mbit/s



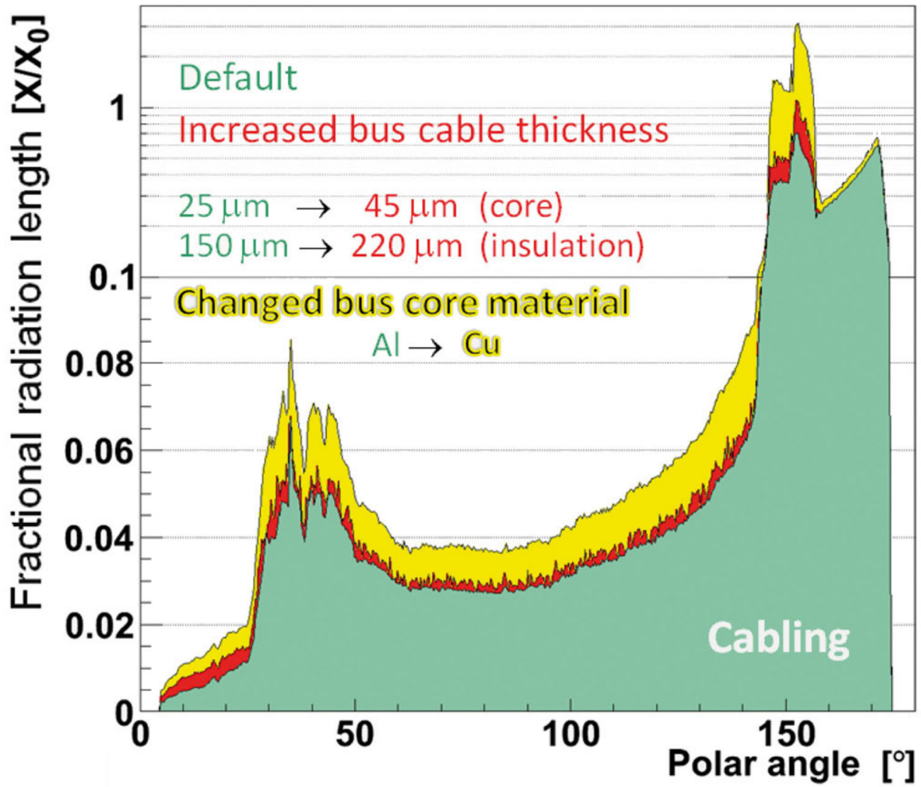
Required cable length:
about 1 m



Radiation Length Studies



The cables contribute to about 38% of the material budget.



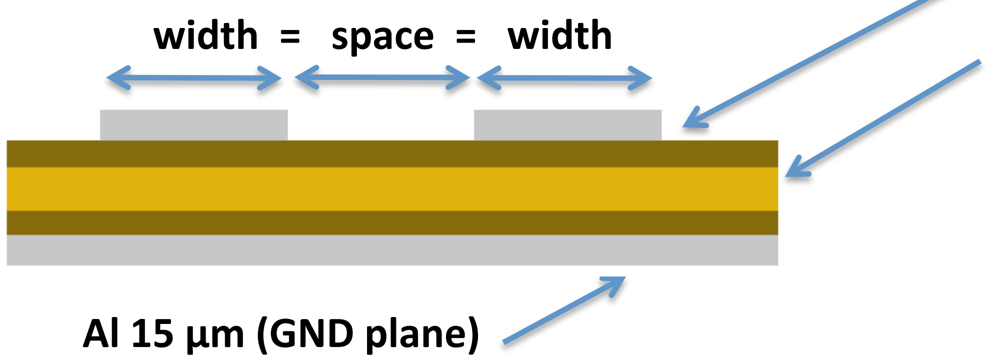
The use of Al instead of Cu could reduce significantly this contribution.

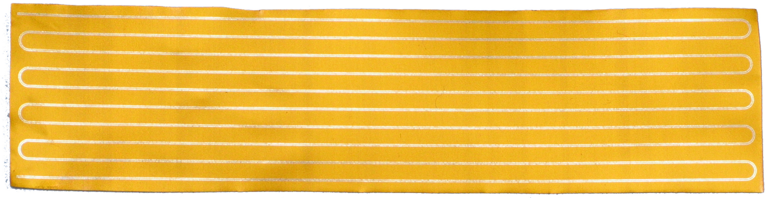
Folded cables

Folded cables prototypes

1. **CERN** (laminated and etched Al on Kapton and glue)

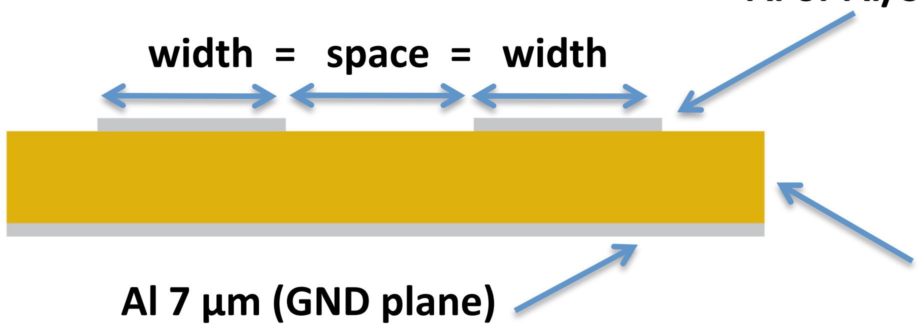
(available widths 100µm, 150 µm, 200 µm)

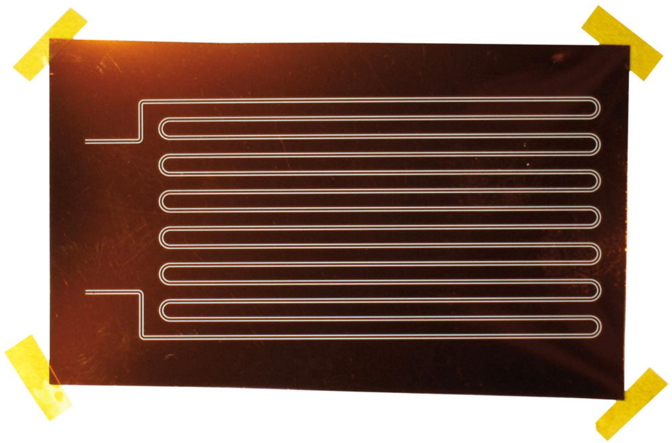




2. **Techfab** (Al or Al/Si (1%) alloy deposition on Kapton); partly unreliable for bonding

(available widths 150µm, 200 µm)





Experimental setup - 1

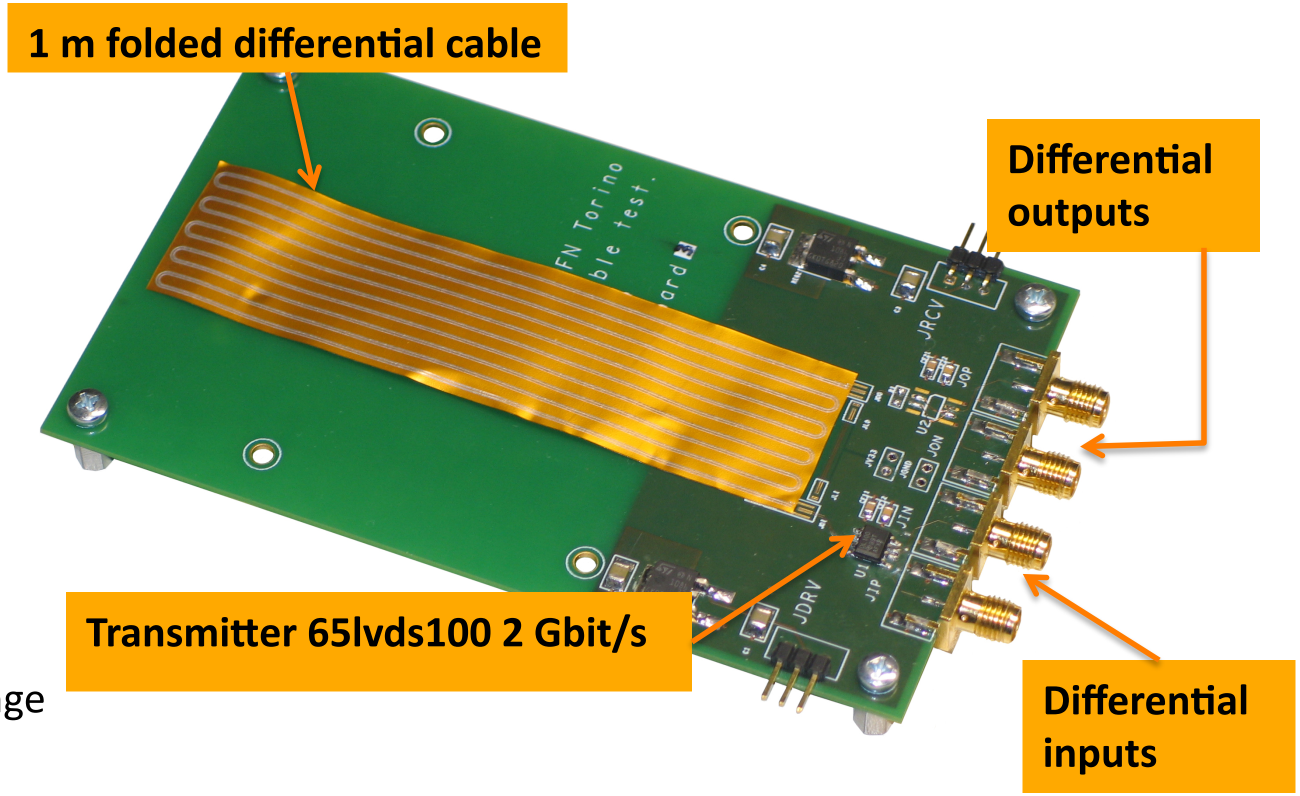
Standard Protocol	Data rate (Mbit/s)
OC3 (Optical Carrier 3x)	155.52
OC12 (Optical Carrier 12x)	622.08
FCx1 (Fiber Channel 1x)	1062.5
GBE (Gigabit Ethernet)	1250
FCx2 (Fiber Channel 2x)	2125 *

* Slightly out of driver operating range

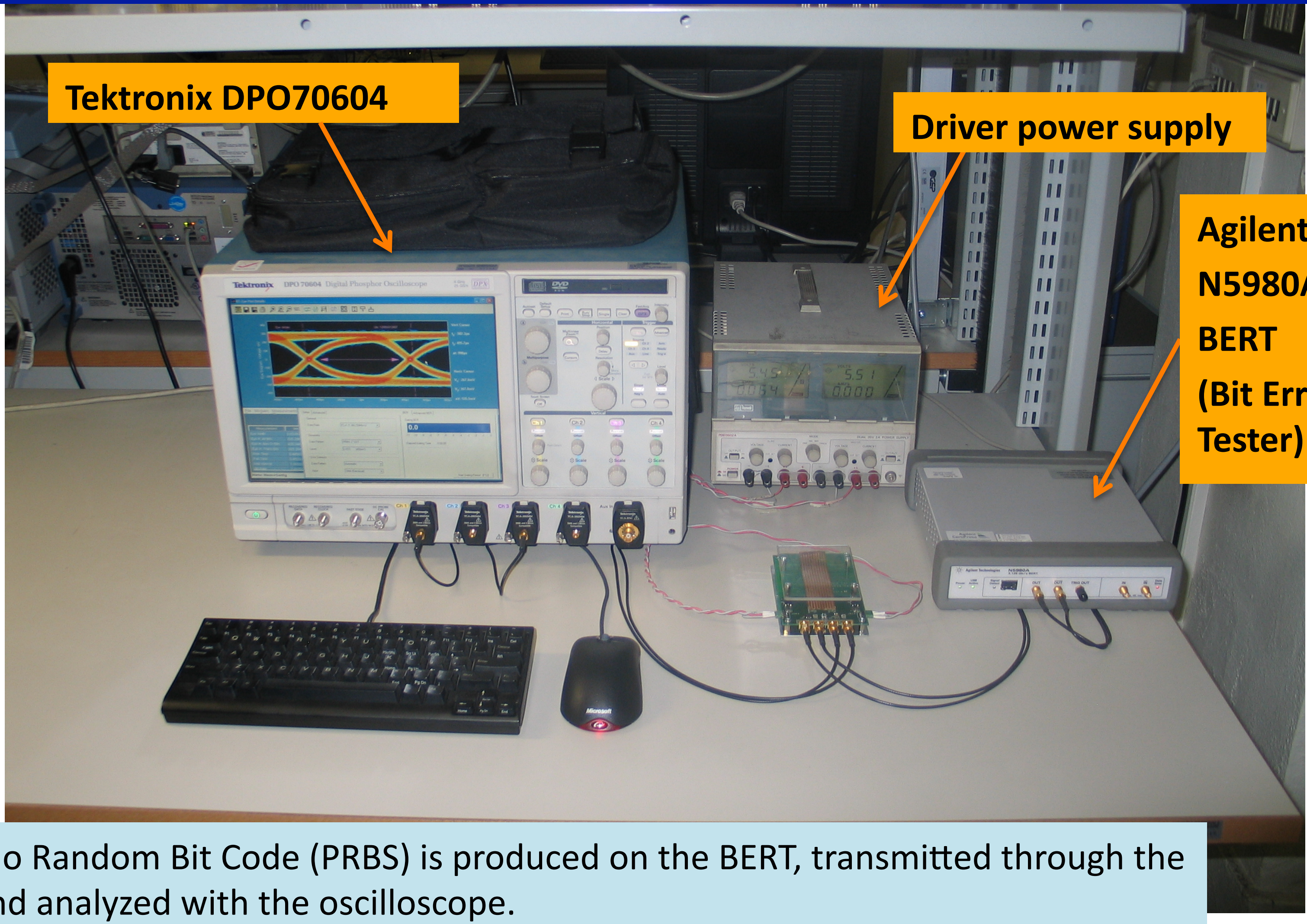
The ground plane of the cable is glued onto the board with conductive epoxy glue; differential lines are connected through wire bonding.

A transmitter on the board reshapes the signal immediately before the cable.

Signals used follow the LVDS standard (Low-Voltage Differential Signaling): common mode 1.25 V, signal swing 350 mV per phase.



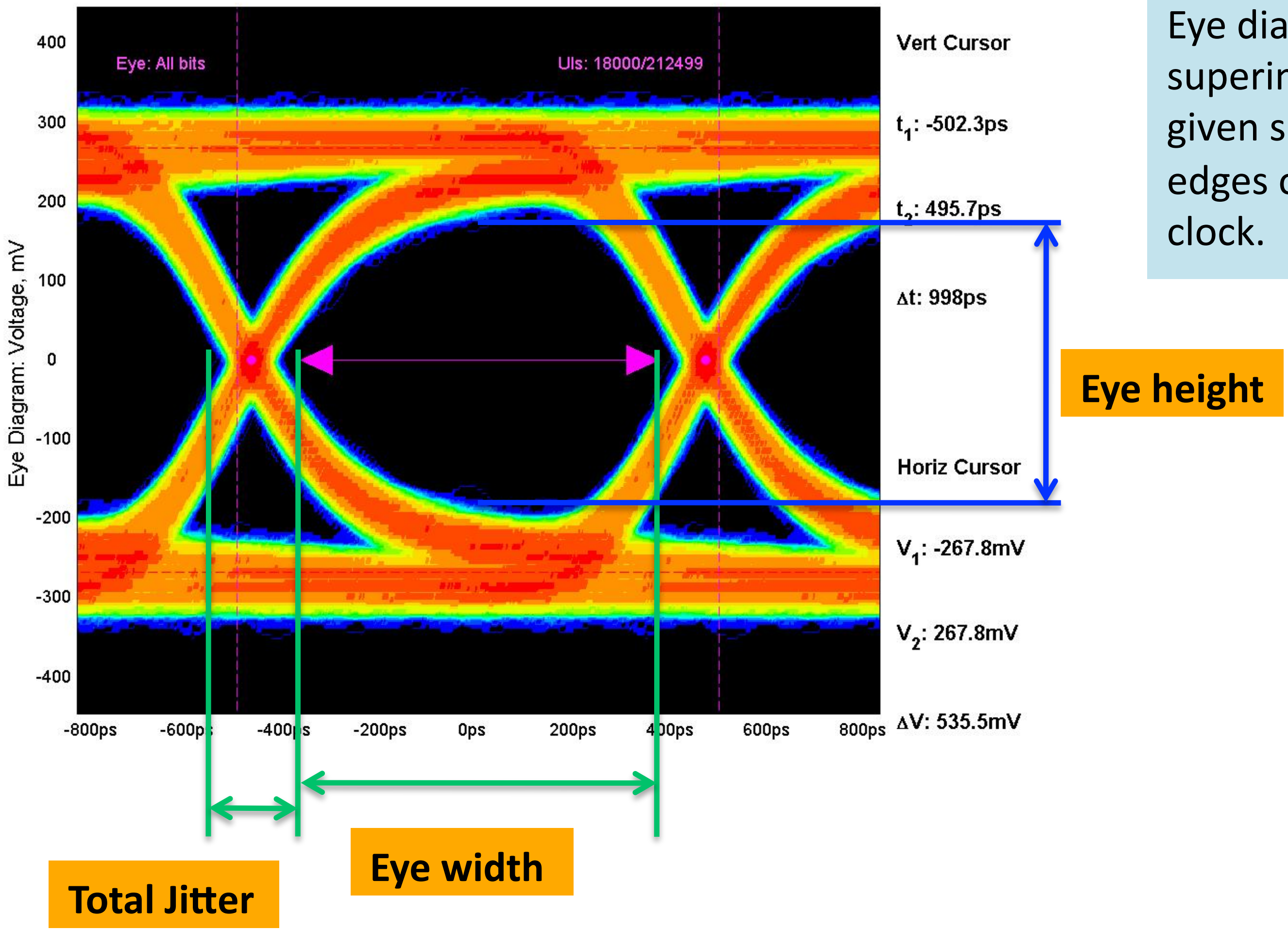
Experimental setup – 2



A Pseudo Random Bit Code (PRBS) is produced on the BERT, transmitted through the cable and analyzed with the oscilloscope.

Available PRBS patterns: 2^7-1, 2^{15}-1, $\underline{2^{23}\text{-}1}$, 2^{31}-1

Eye diagrams



Eye diagrams are obtained superimposing all the bits in a given sequence, triggering on the edges of the (ideal) recovered clock.

These parameters allow to quantitatively evaluate the goodness of a digital transmission line

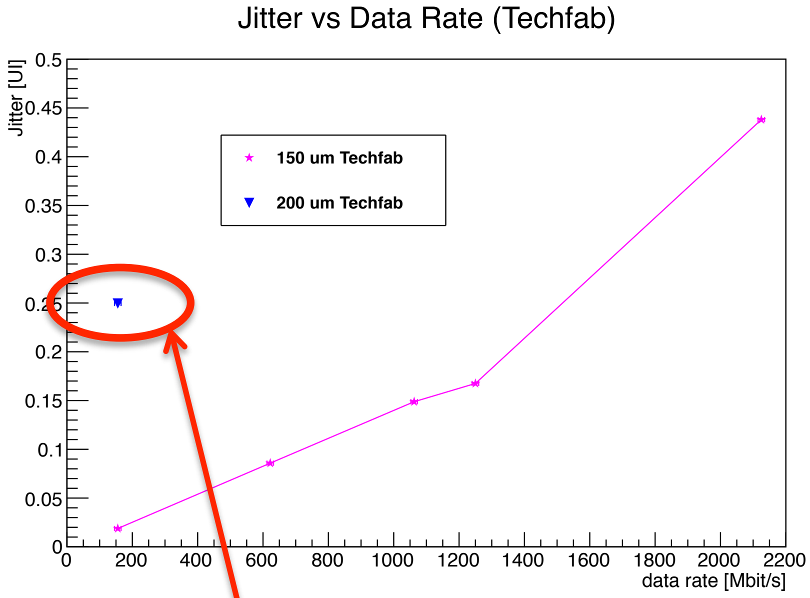
Results - Summary

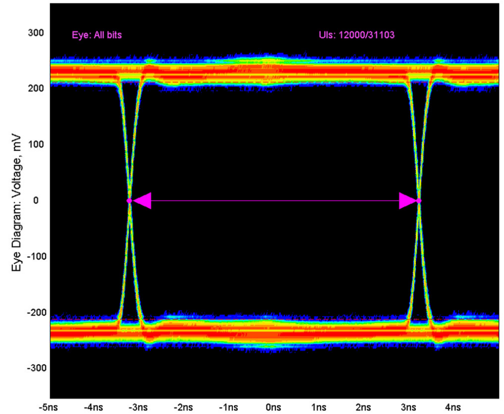
Summary of performed measurements:

- Cable testing:
  - Techfab Al/Si and Al;
  - CERN (9 cables, 3 different widths);
- Comparison with the simulations;
- Irradiation test.

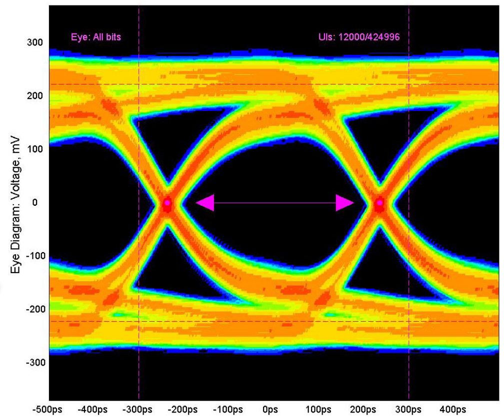
Tested cables:
CERN, width 100 μm (3x)
CERN, width 150 μm (3x)
CERN, width 200 μm (3x)
Techfab, width 150 μm, Al (1x)
Techfab, width 200 μm, Al/Si (1x)

Results – Techfab cables



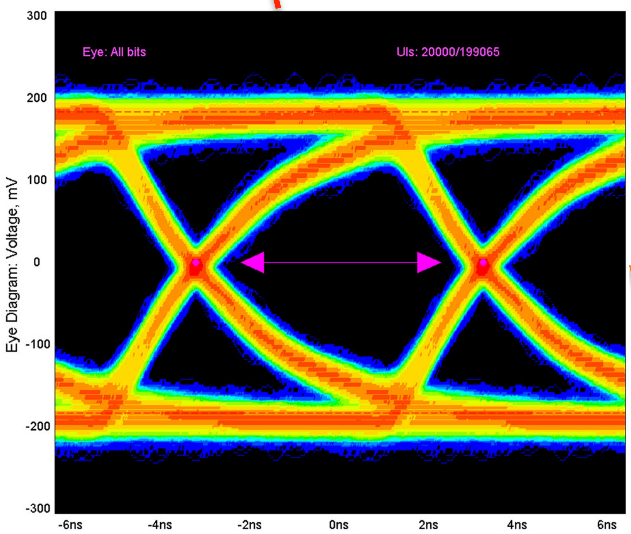


Techfab 150 µm @155.52 MHz



Techfab 150 µm @2125 MHz

Eye is still open

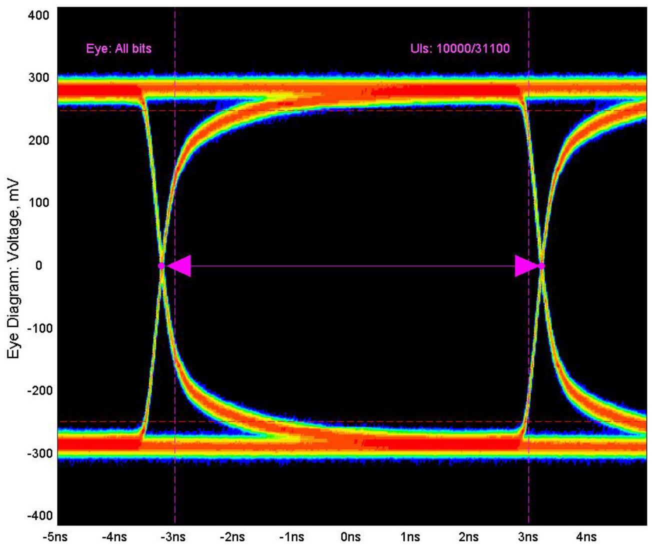


Techfab 200 µm @155.52 MHz

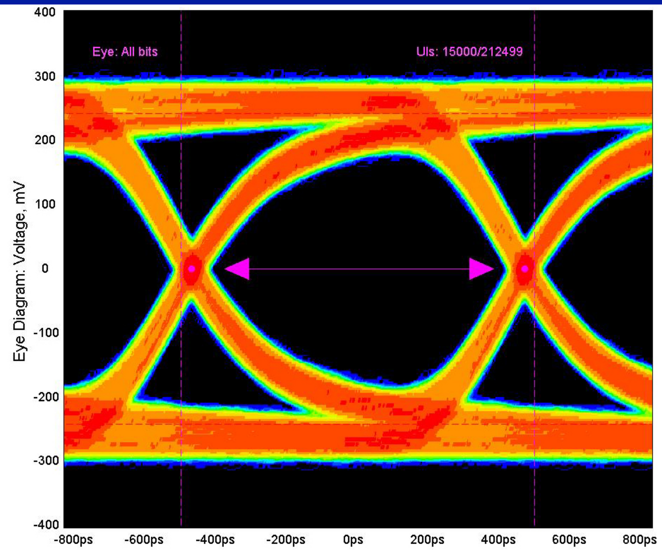
•The 150 µm cable shows a weak and unreliable bonding; the electrical performances are otherwise good.

•The 200 µm with Al/Si deposition featured a more reliable bonding, but a very high resistance (~80Ω) which led to very high jitter values and a closed eye.

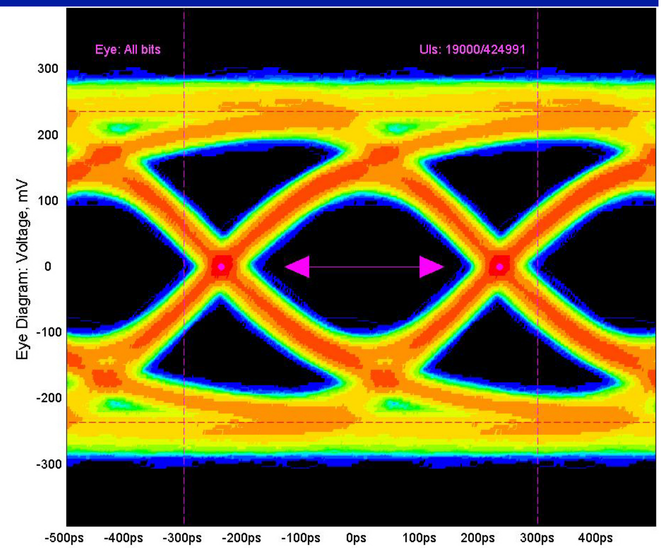
Results – CERN cables



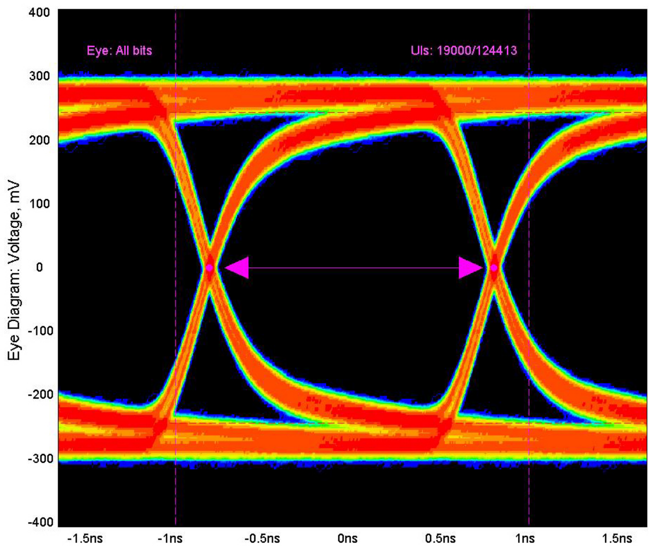
CERN 100 µm @ 155.52 Mbit/s



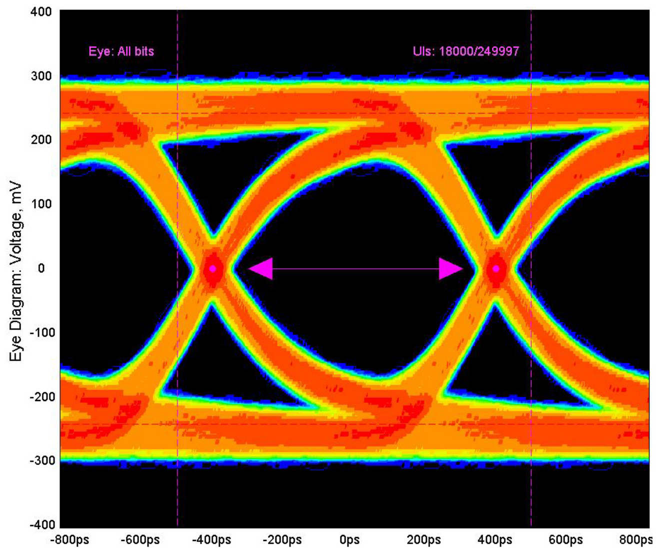
CERN 100 µm @ 1062.5 Mbit/s



CERN 100 µm @ 2125 Mbit/s



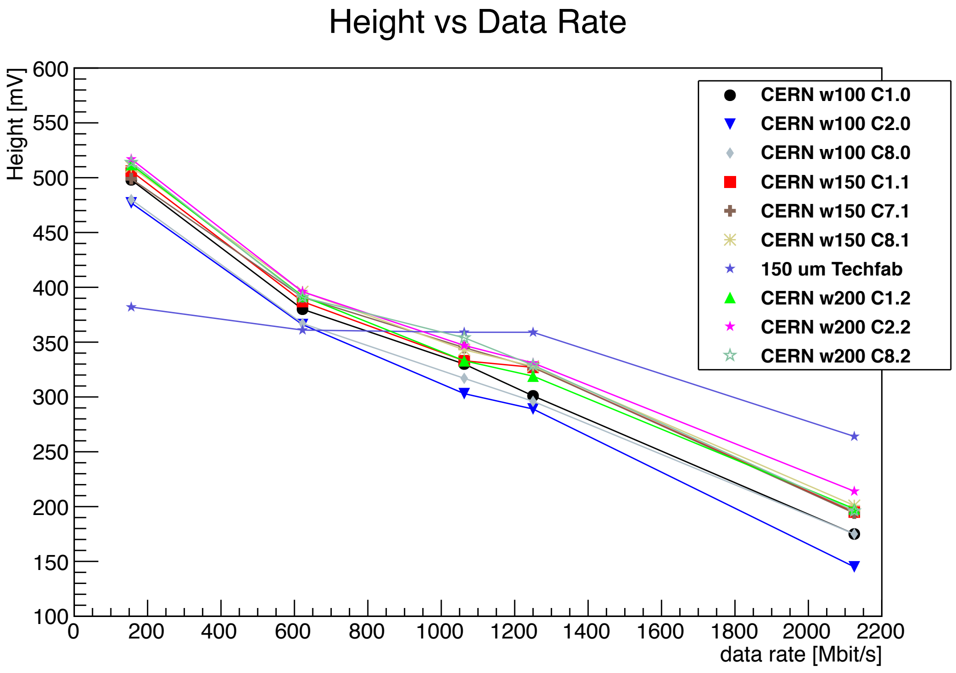
CERN 100 µm @ 622.08 Mbit/s

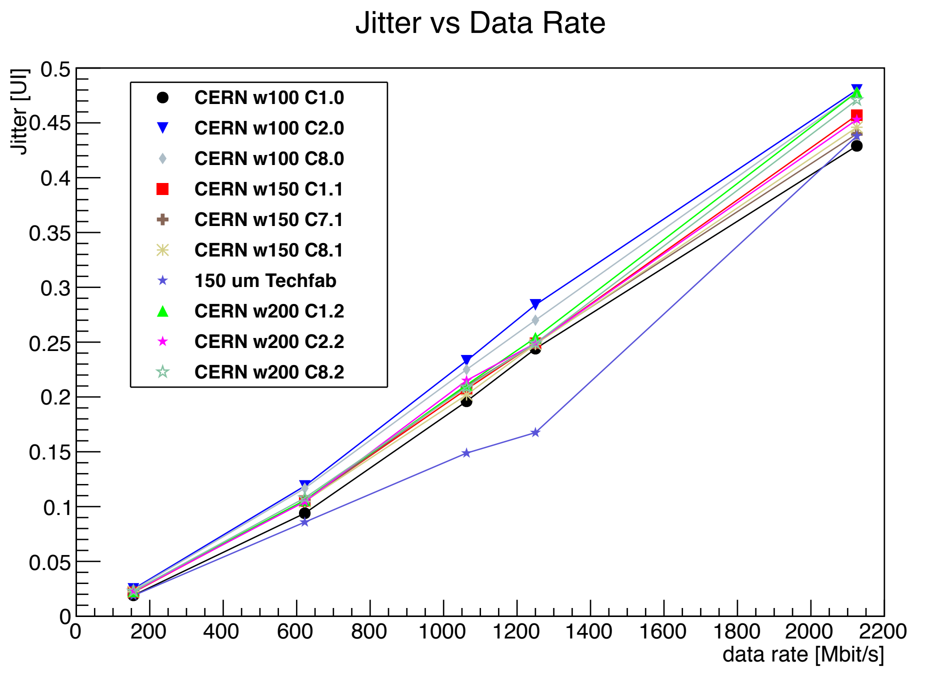


CERN 100 µm @ 1250 Mbit/s

Eye is still open at the maximum frequency, but jitter is above 0.45UI

Results – CERN cables





All the 9 CERN cables tested show similar results and a clear worsening of performances as the frequency increases.

No obvious relationship appears between electrical performances and track width.

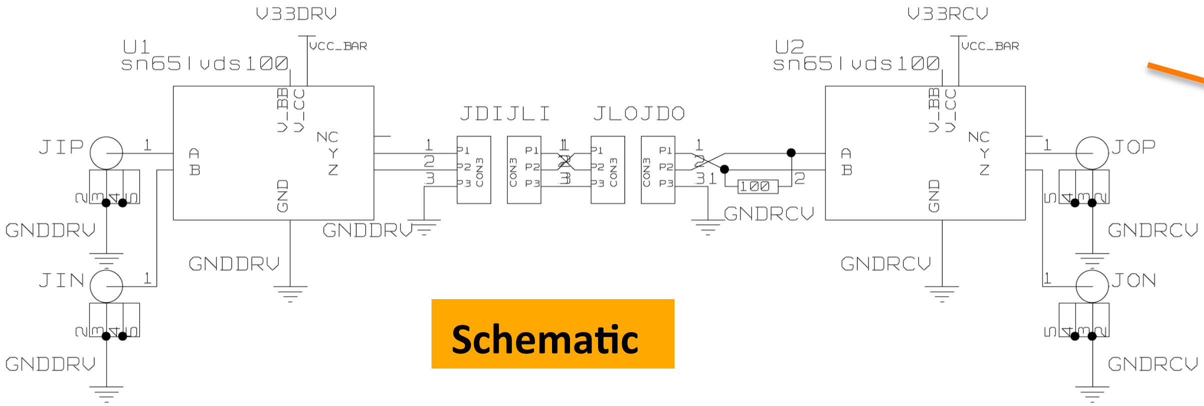
BERT performed on two cables at two data rates (test duration: 5 hours).

errors: 0

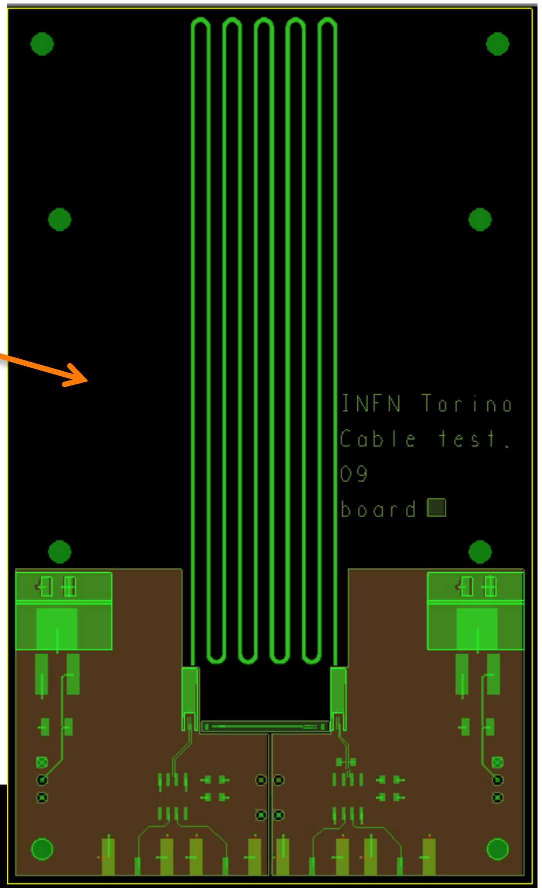
BER < 10^{-13}

Simulations

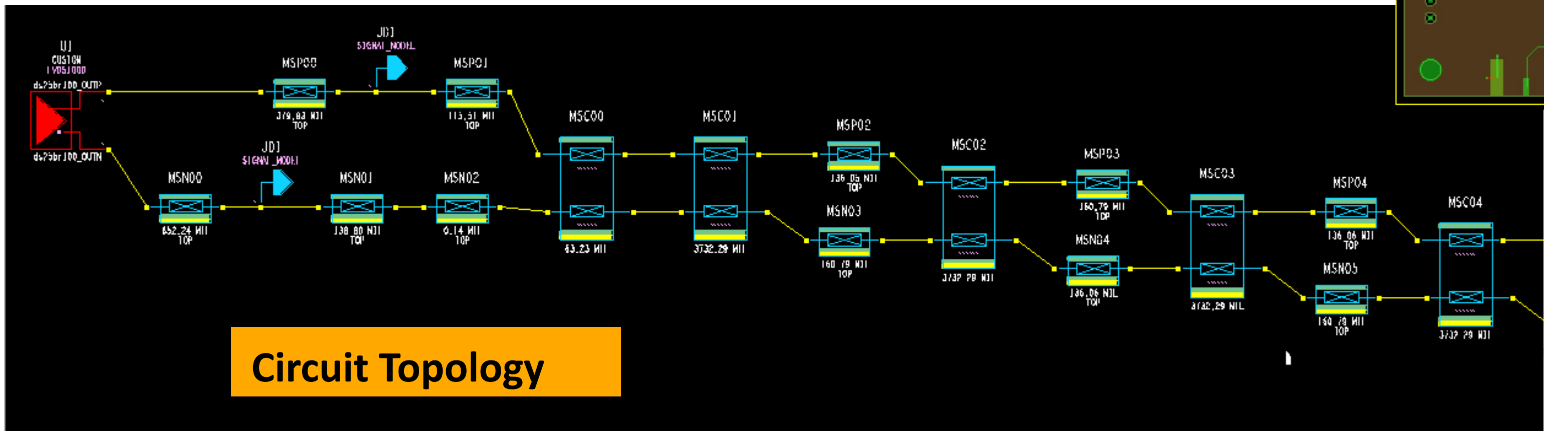
Simulations are performed within the Cadence framework (SigXplorer):



Schematic

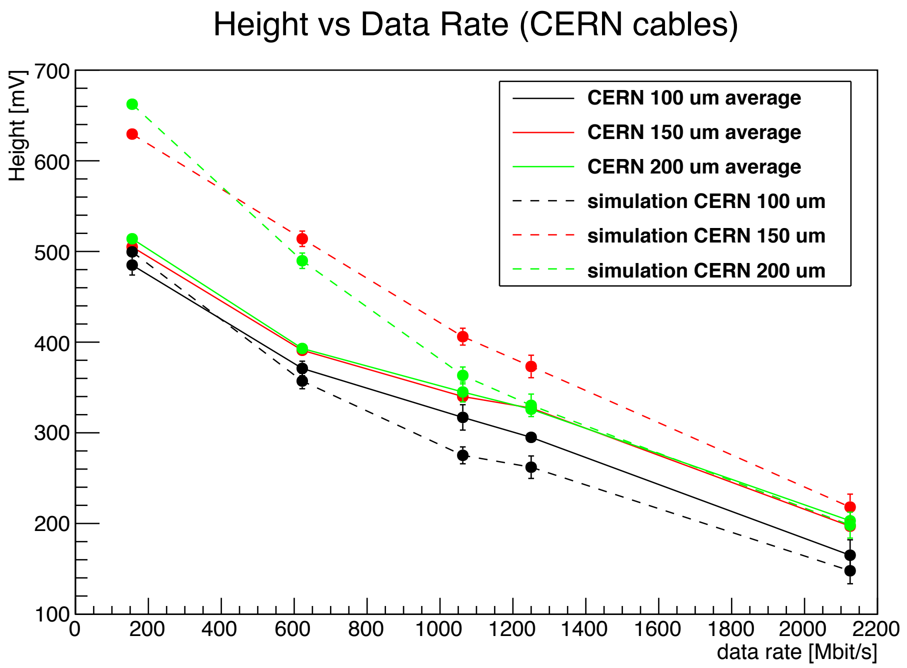


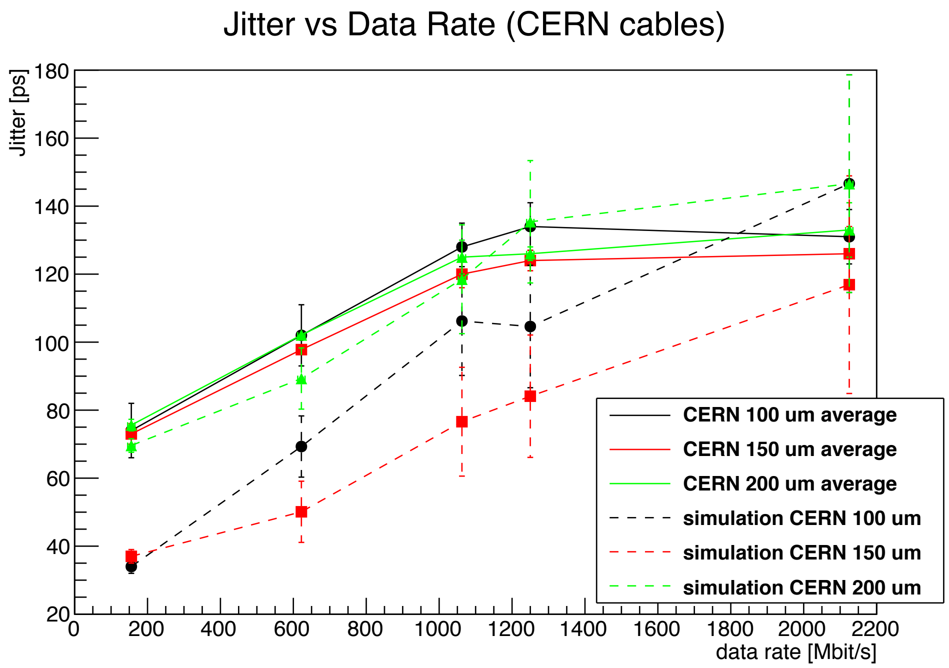
Physical Layout



Circuit Topology

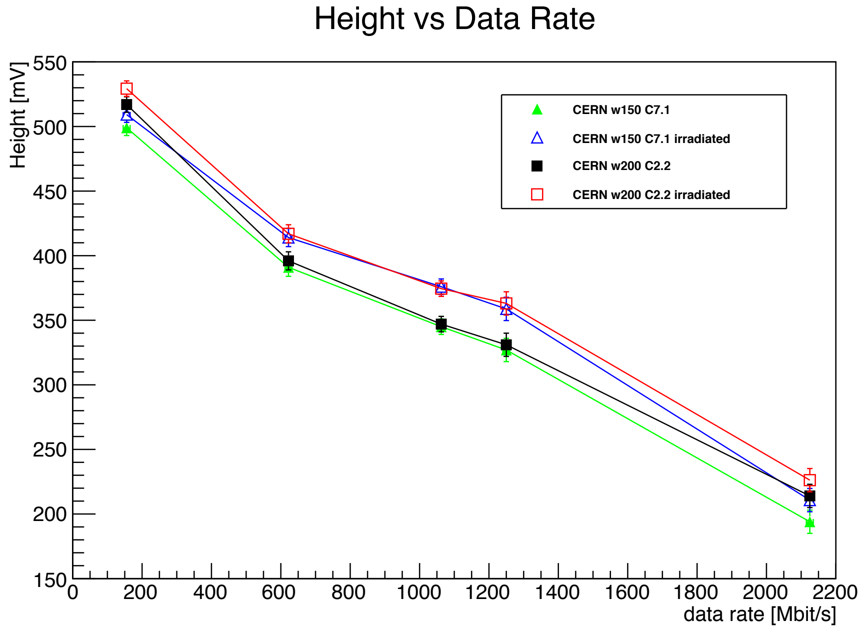
Results of the Simulations

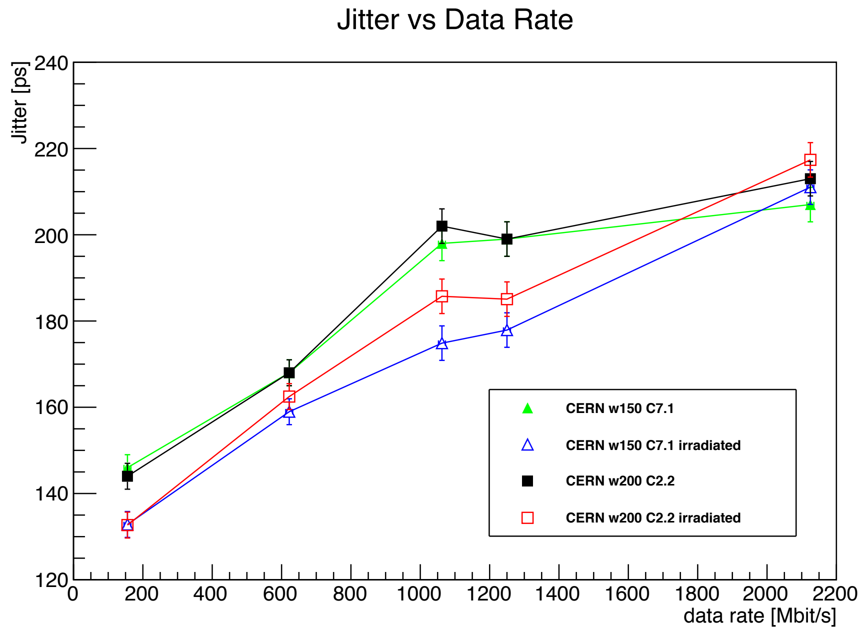




- Bad agreement between simulations and experimental results.
- Simulations have a strong dependence on the pattern, which is very short.
- Unable to simulate correctly the setup without a receiver on the board.

Results – Neutron Irradiation



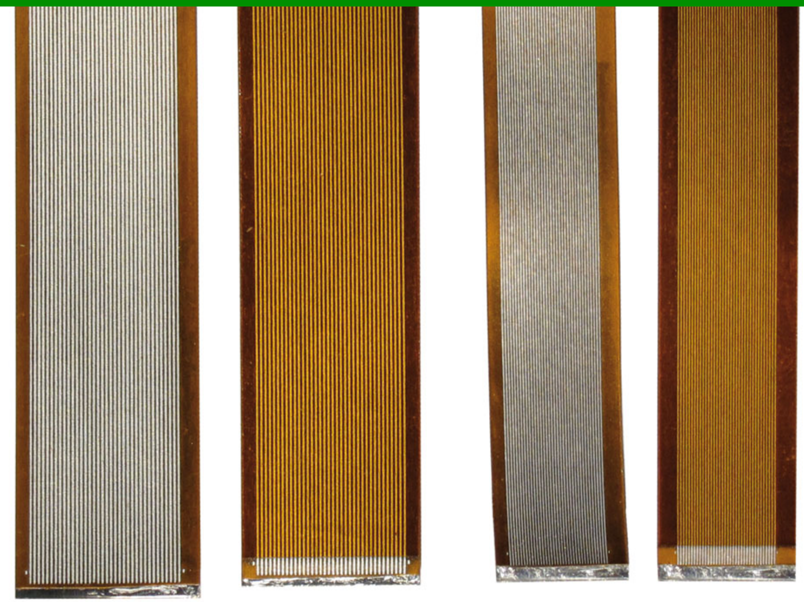


Expected fluence: ~$4 \cdot 10^{14}$ n 1MeV eq /cm^2

- Neutron irradiation at the TRIGA Mark II research reactor at LENA in Pavia: ~1000s irradiation time at a reactor power of 100 kW.
- A slight **improvement** is observed in both eye height and jitter, at most frequencies, for both cables.
- Proton and electron irradiations are planned in Bonn.

Straight cables

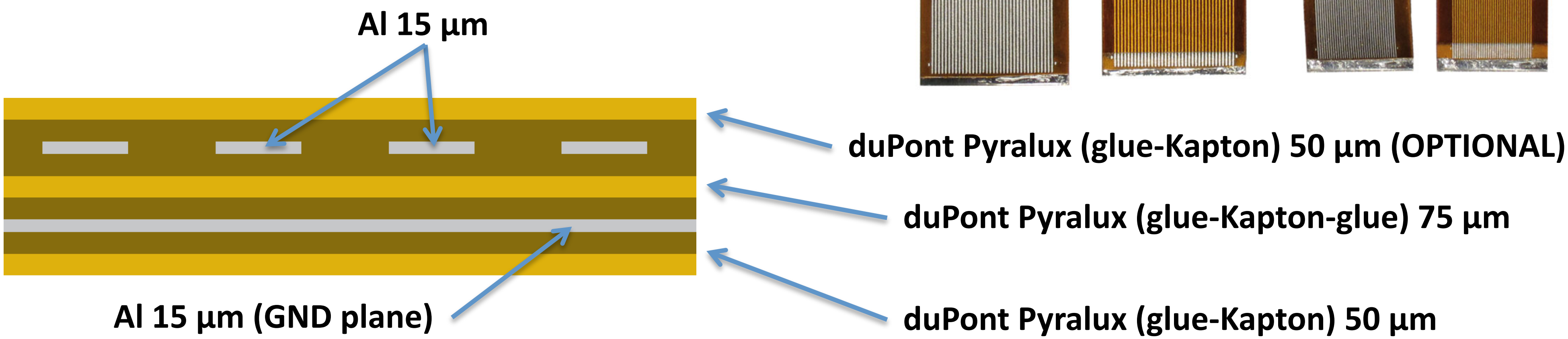
Straight cable Prototypes

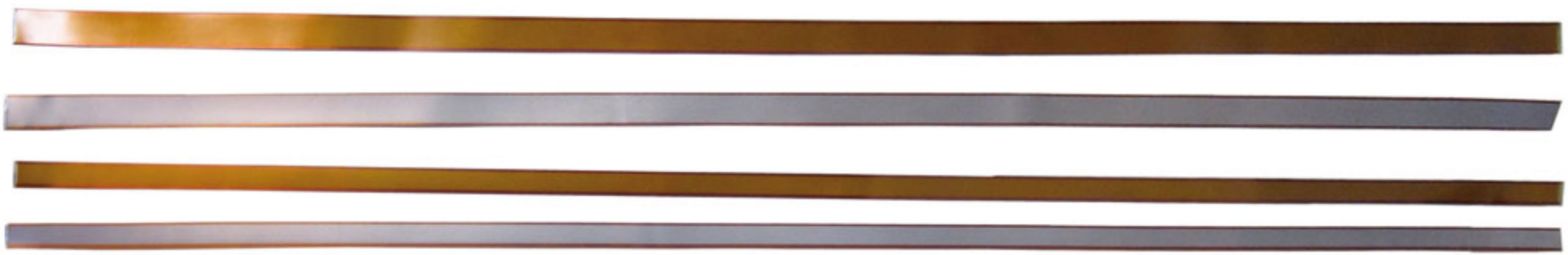


Covered and uncovered cables

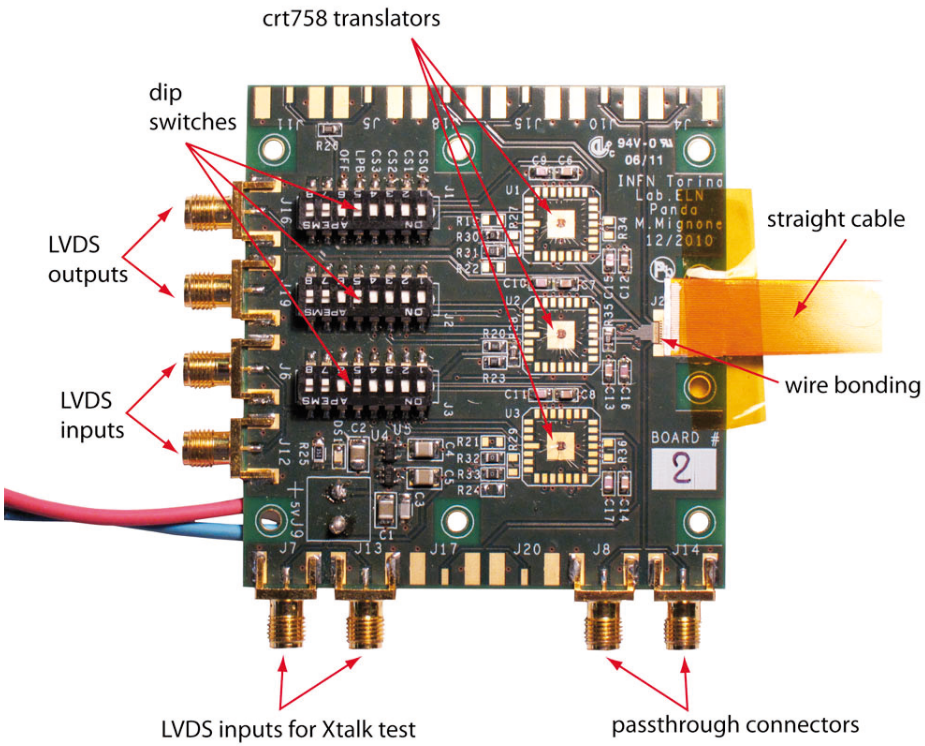
(available widths 100µm, 165 µm)

- **1 m long;**
- **Laminated aluminum technology;**
- **18 differential pairs.**



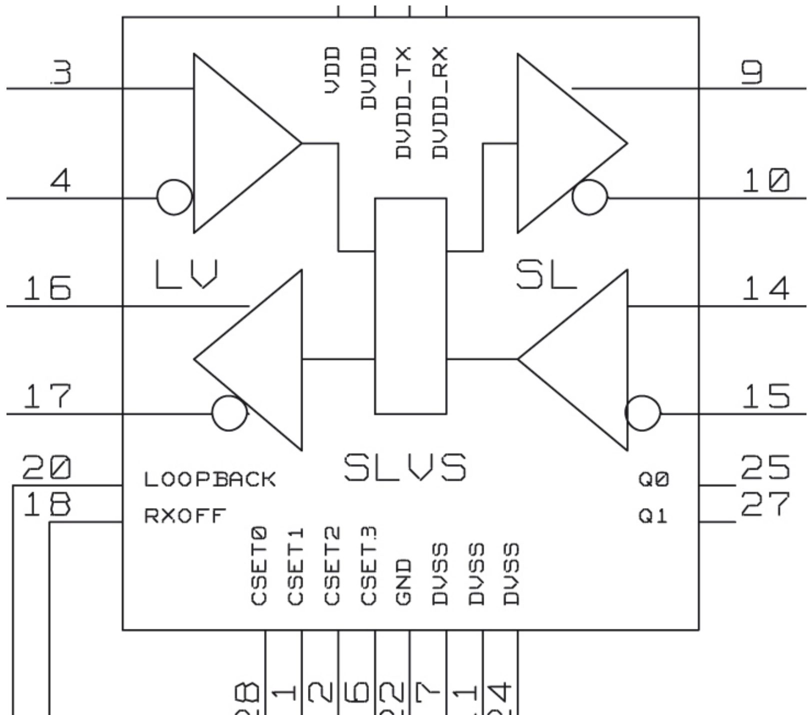


Test board



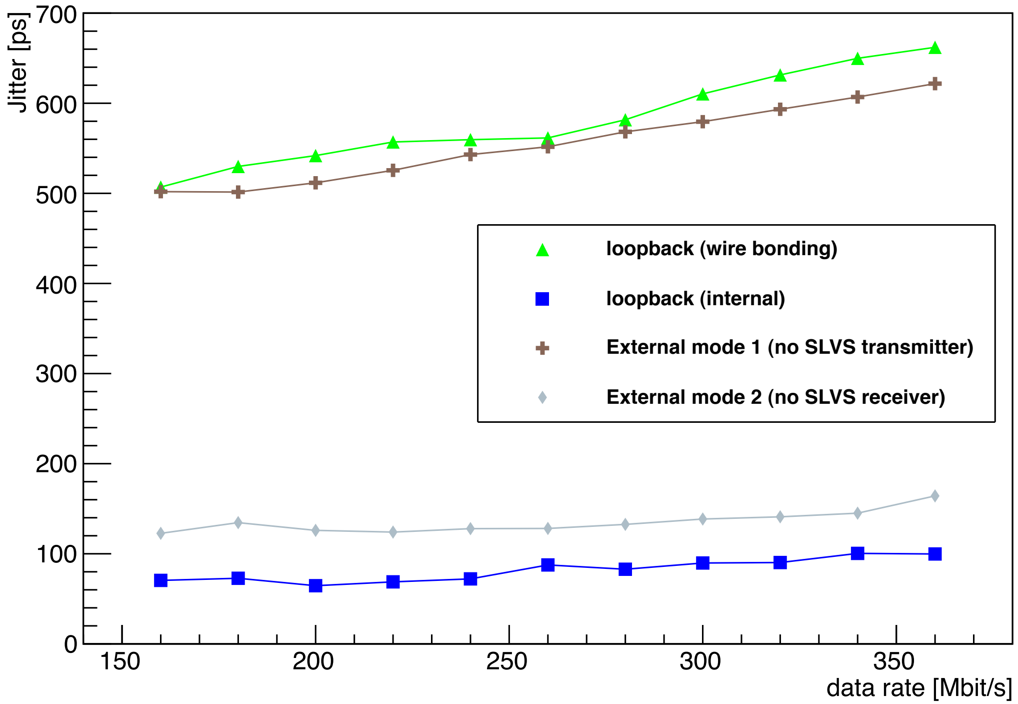
- •Each test board can contain up to three crt758 chips (LVDS-to-SLVS and SLVS-to-LVDS translators).
- •Scalable Low-Voltage Signaling (SLVS) standard: common mode 200 mV, signal swing 200 mV per phase.
- •Optional wire or internal CMOS loopback to test the chips.
- •Dip switches to configure the chips.

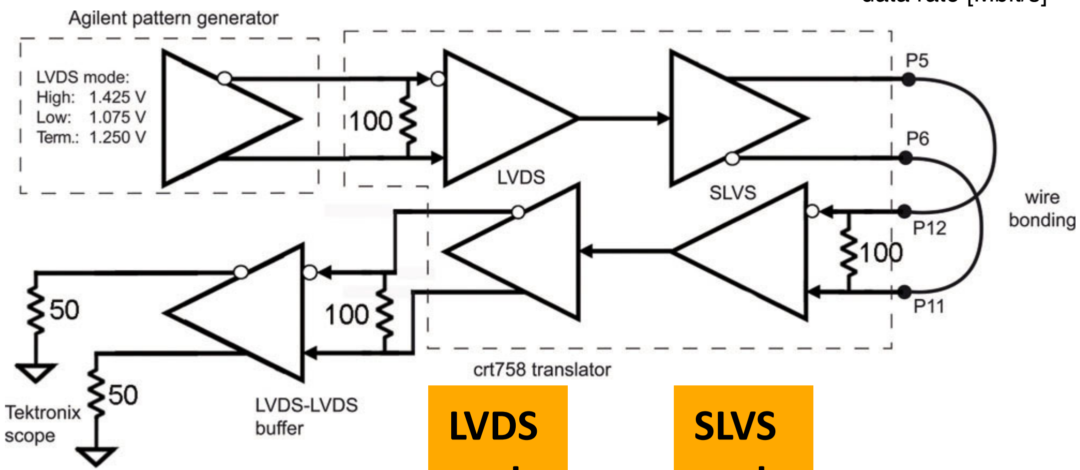
- •Straight cable is connected through wire bonding (both tracks and ground plane).
- •Additional passthrough connectors to bypass the translators.



Transmitter / Receiver tests

Jitter vs Data Rate



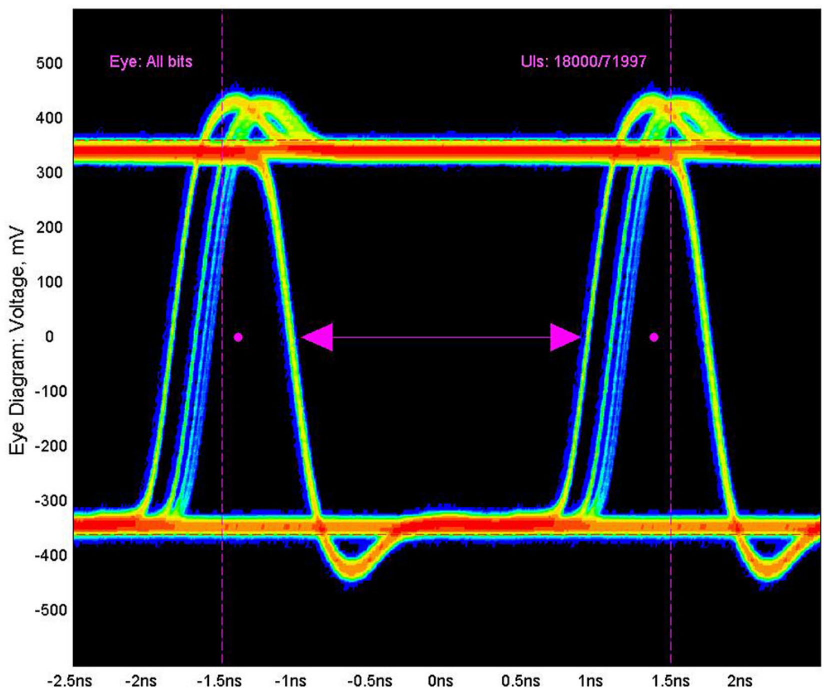


LVDS part

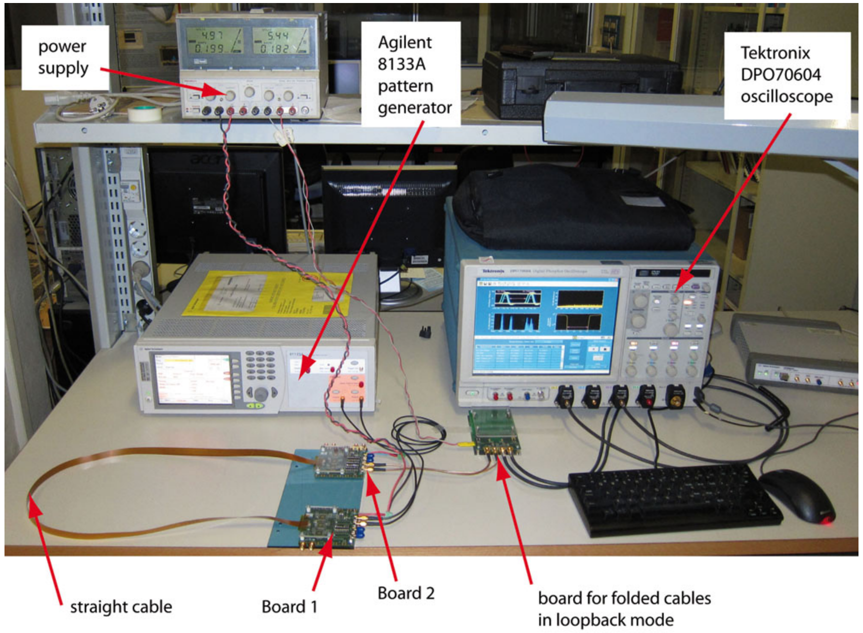
SLVS part

The SLVS Receiver seems the most problematic.

Very large Duty-Cycle Jitter



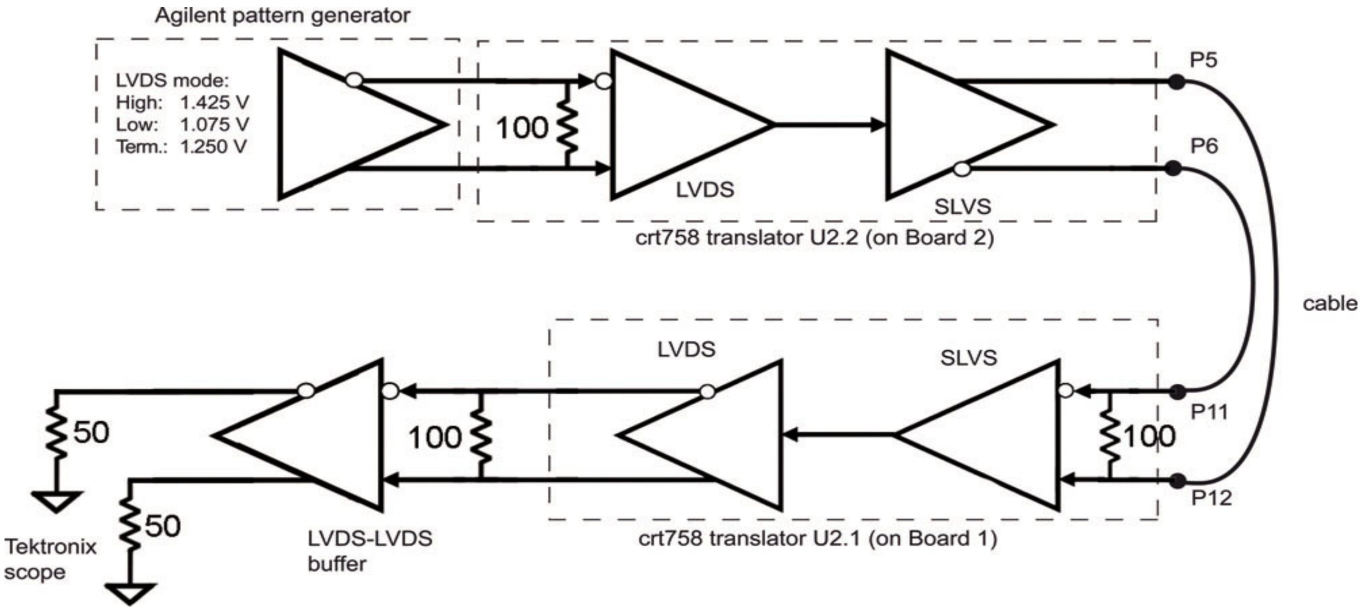
Setup



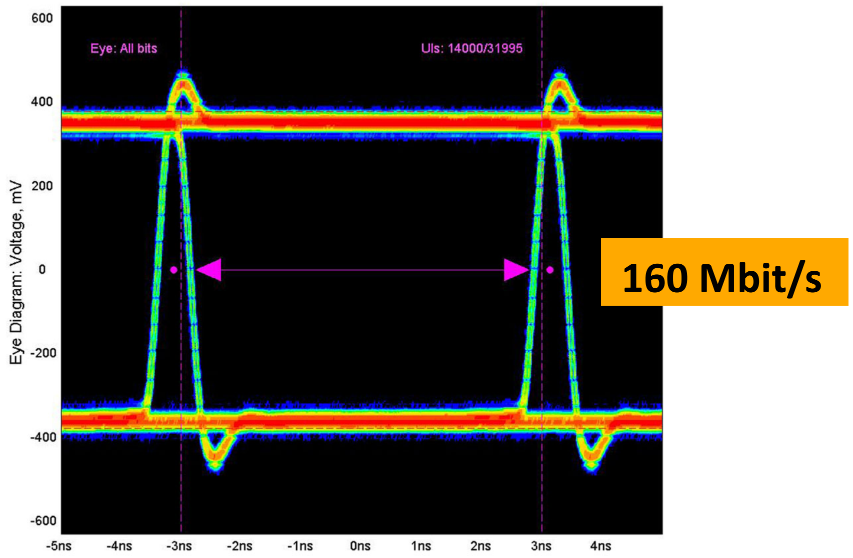
•New pattern generator: more data rates available.

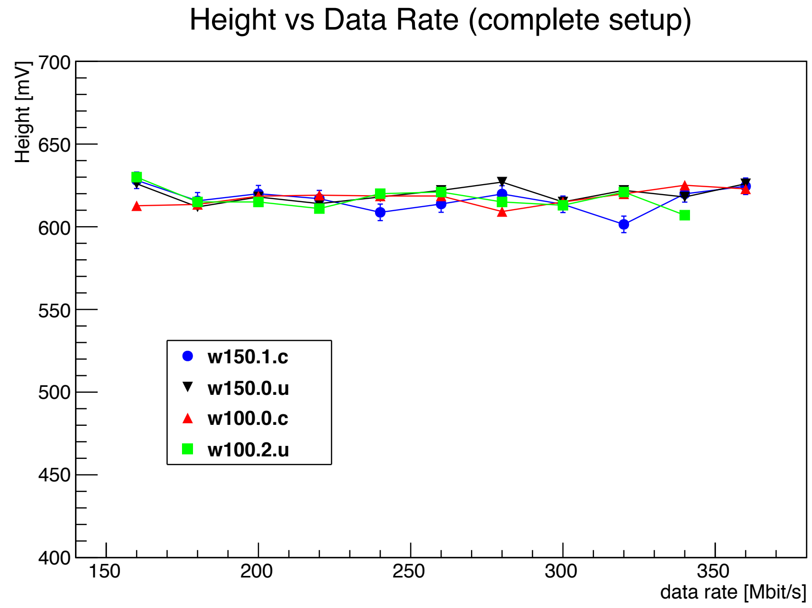
•Two main configurations: "complete" (straight cable and crt758 translators) and cable-only (using passthrough connectors).

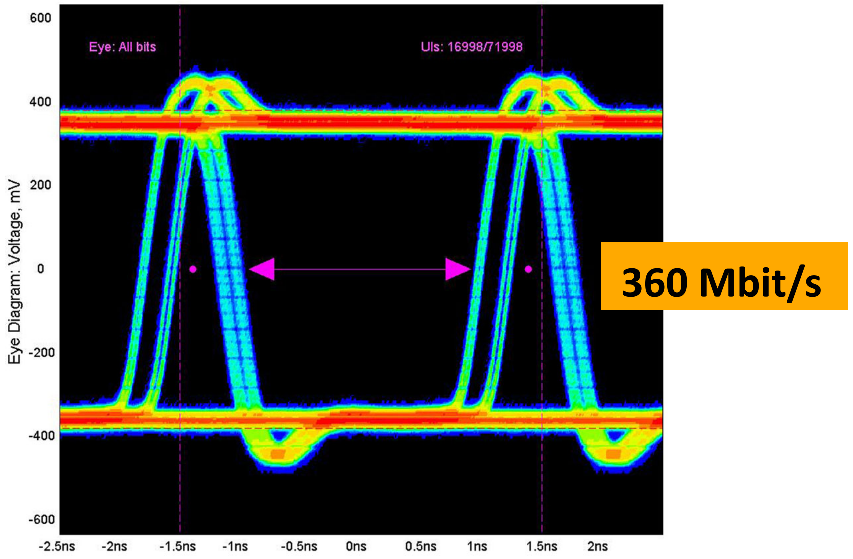
•An LVDS buffer is necessary after the translators for impedance adaptation.

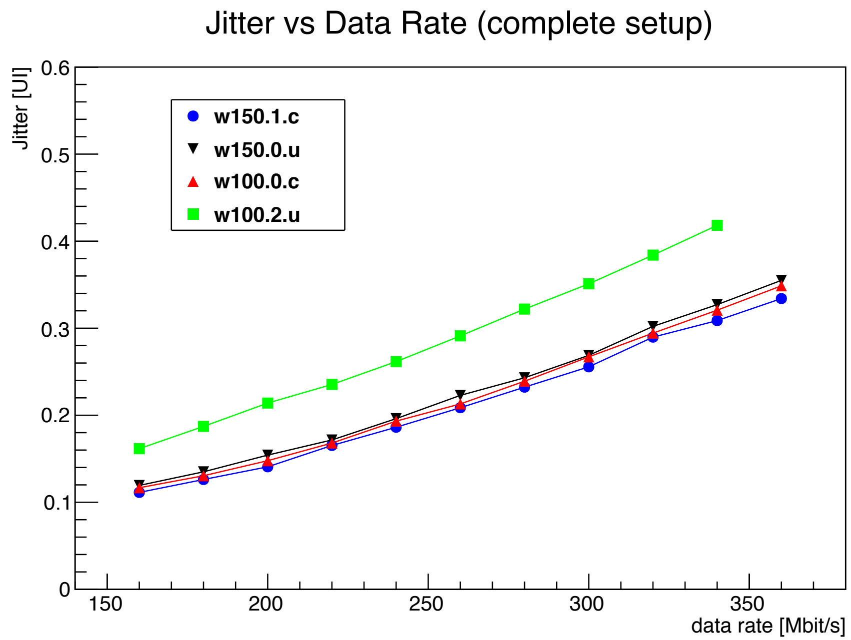


Complete setup

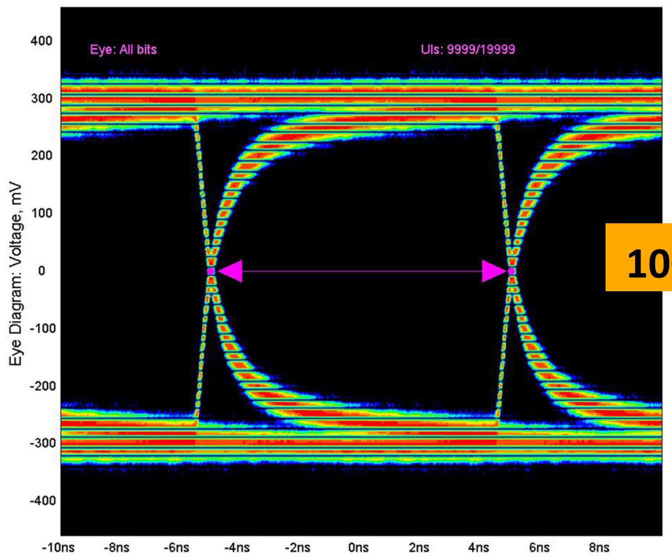




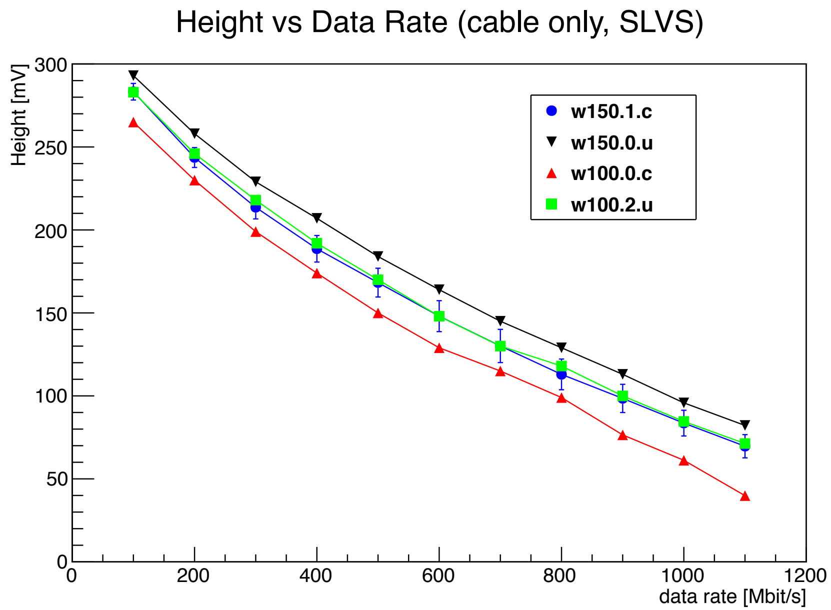


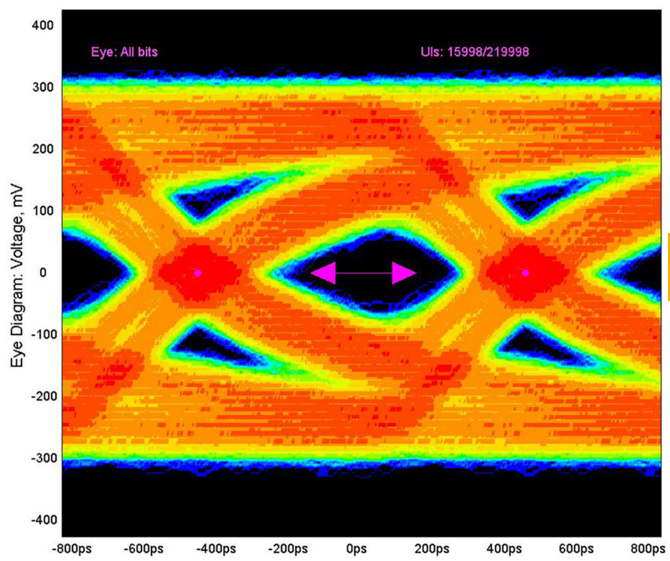


Cable-only setup

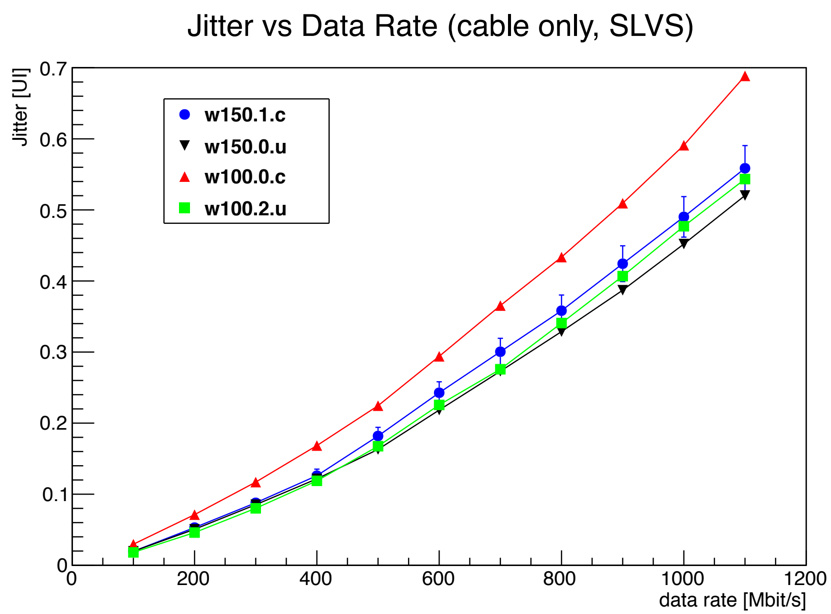


100 Mbit/s

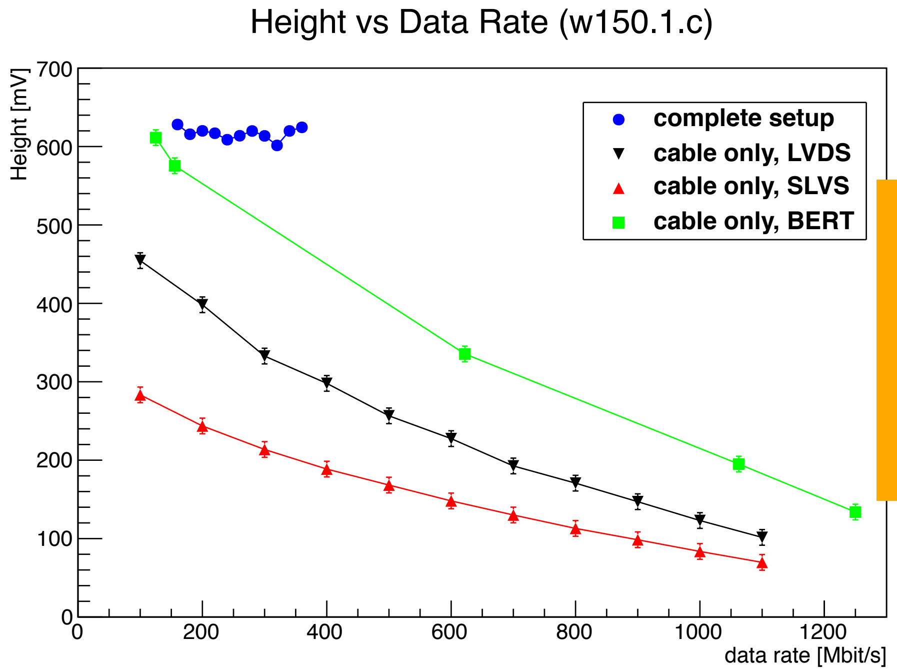




1100 Mbit/s



Straight Cables results



Voltage levels:

BERT: 800 mV

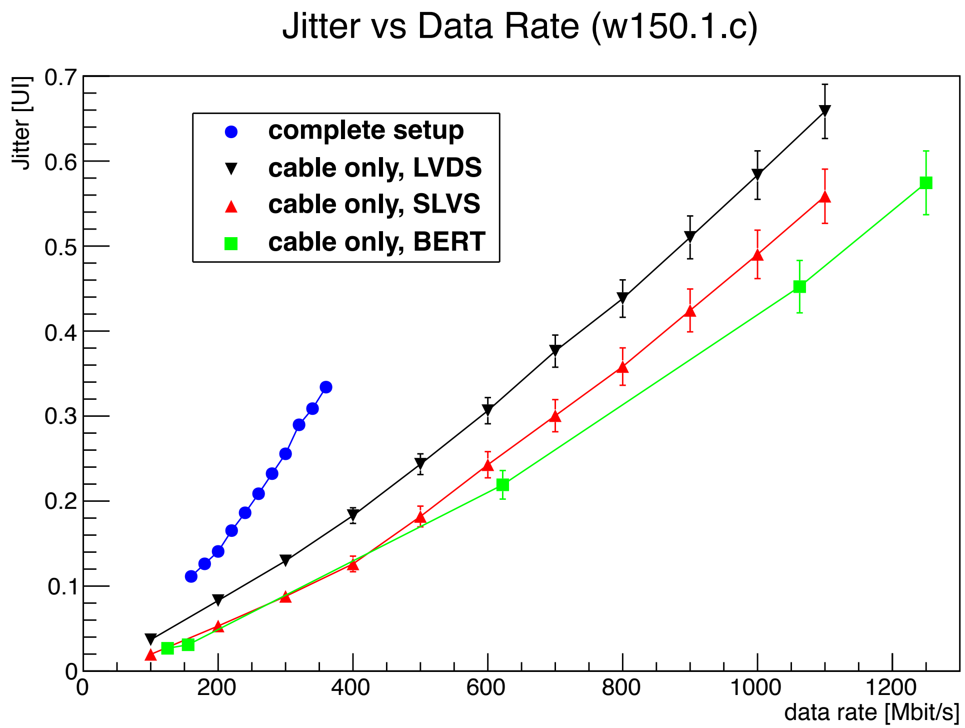
LVDS: 700 mV

SLVS: 400 mV

The differences in the height are explained by the different initial levels.

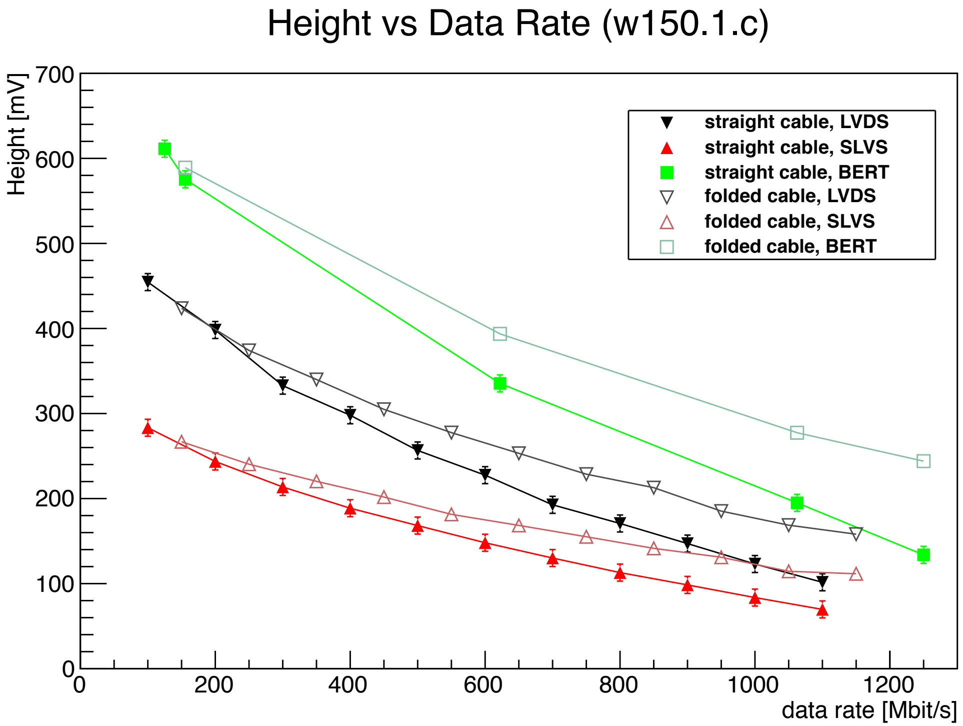
The SLVS-LVDS translators worsen significantly the jitter with respect to the cable-only scenario.

Cable under test: covered, 150 µm

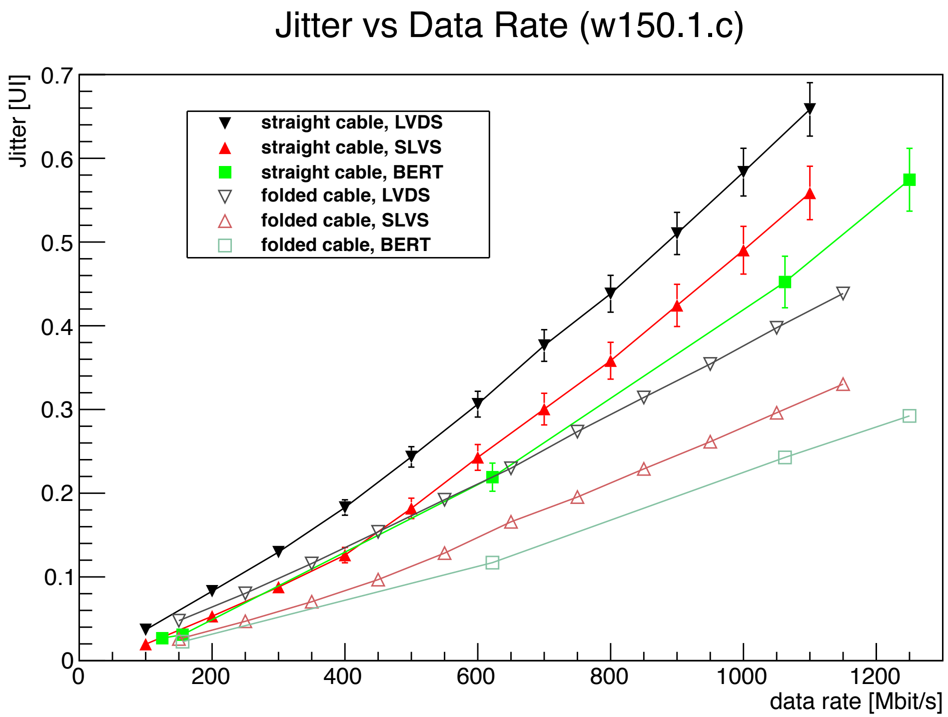


At 300 Mbit/s, the jitter is around 0.3 UI with the translators and around 0.1 – 0.15 UI with the cable alone.

Straight and Folded Cables



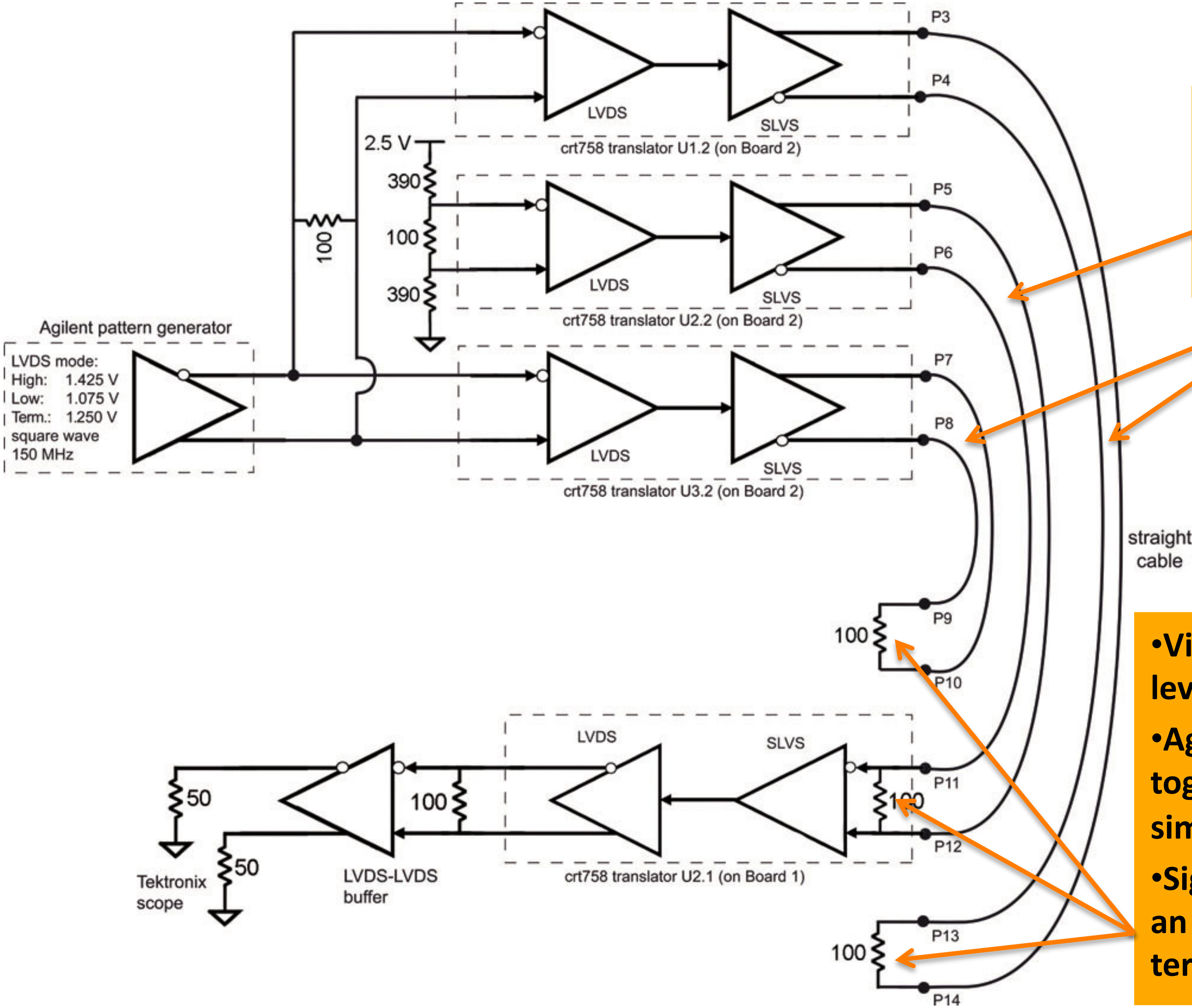
The w150.0.c sample is compared to a folded cable, measured with the same setup.



Performances of folded cables are always better.

Straight cables are suitable for use up to 600 – 800 Mbit/s, while folded cables reach 800 – 1200 Mbit/s .

Crosstalk studies

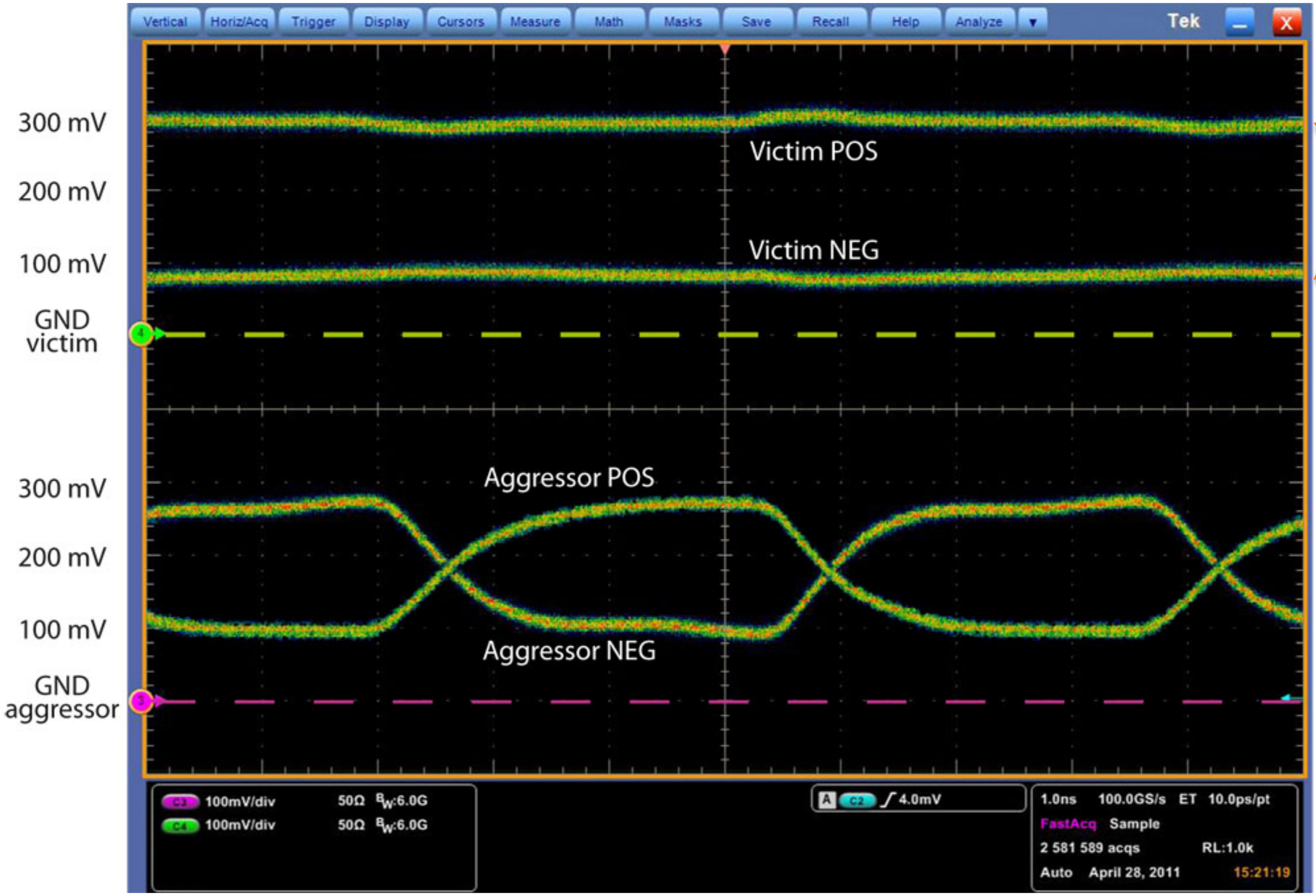


Three adjacent pairs:

- one "victim"
- two "aggressors"

- Victim is polarized at fixed levels;
- Aggressors are connected together and switch simultaneously
- Signals are measured with an active probe on the terminations.

Crosstalk studies



Signals on the victim.

Deviations from the fixed levels are small (about 30 mV).

Deviations are small enough not to induce a change in the logic levels.

Conclusions

Folded Cables:

- CERN laminated cables perform well up to 1.25 Gbit/s and above; no obvious relationship between electrical performances and track width.
- Simulations are substantially unreliable and a prototype characterization is always necessary.
- Good radiation tolerance up to the neutron equivalent fluence expected in PANDA.

Straight Cables:

- The crt758 chips have serious duty-cycle jitter issues, related to the SLVS receiver (also included in ToPix_3 prototype).
- Straight cables can be used successfully to transmit SLVS data, although the translator introduces significant additional jitter.
- The performances of the folded cables seem slightly better than those of the straight cables.
- Crosstalk effects are negligible.

Next Developments:

- Further irradation studies (protons and electrons) on the folded cables at Bonn University.
- Additional crosstalk measurements with Bit Error Rate Test.

Thank you for your attention!

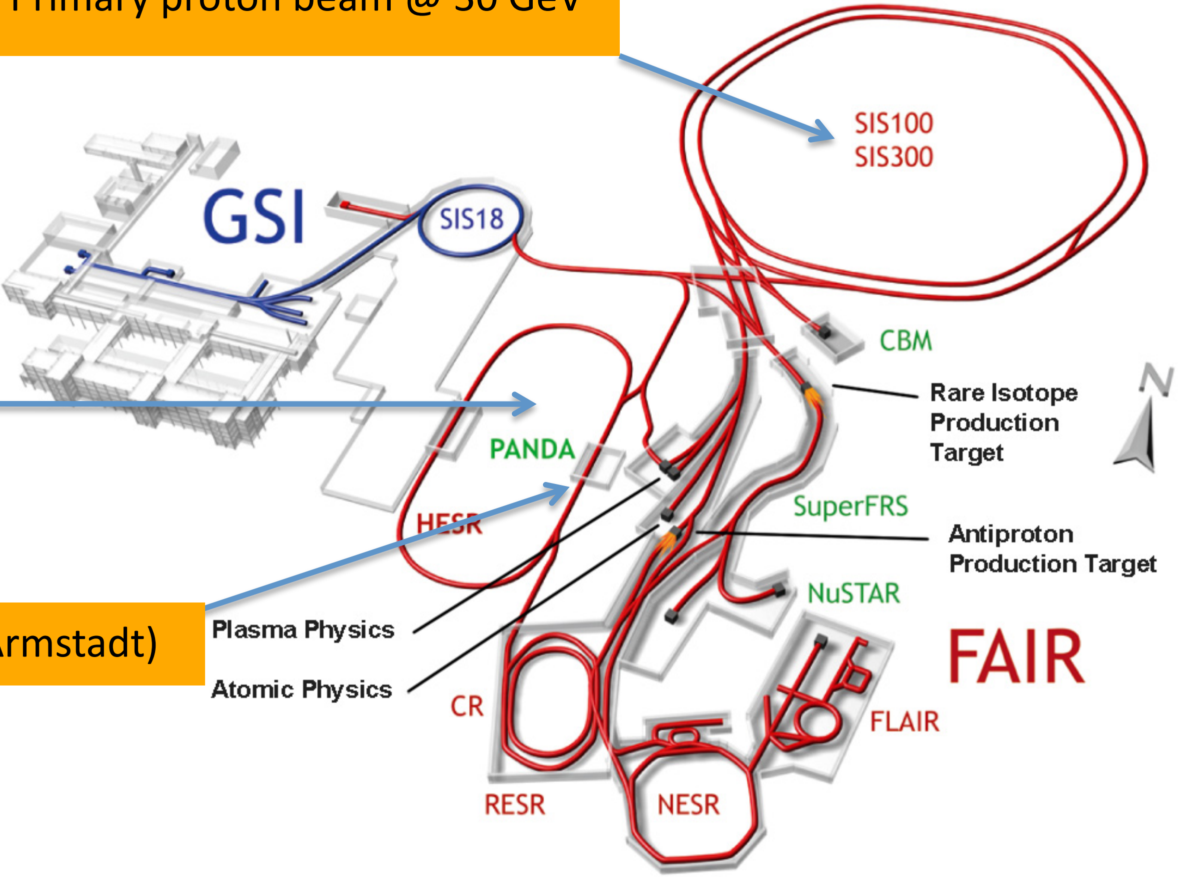
Backup slides

FAIR – Facility for Antiproton and Ion Research

Primary proton beam @ 30 GeV

Storage Ring (HESR):
Antiproton beam with momentum between 1.5 GeV/c and 15 GeV/c

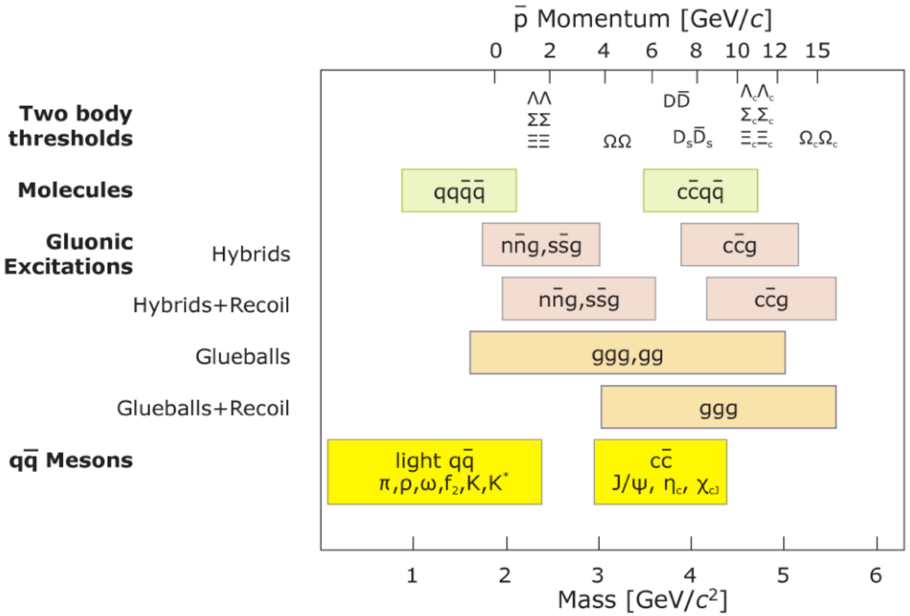
PANDA (Antiproton ANnihilations at DArmstadt)



High Luminosity: L=2·10^{32} cm^{-2} s^{-1}, Δp/p ~10^{-4}

High Resolution: L=2·10^{31} cm^{-2} s^{-1}, **Δp/p ~2·10^{-5}**

The PANDA Experiment



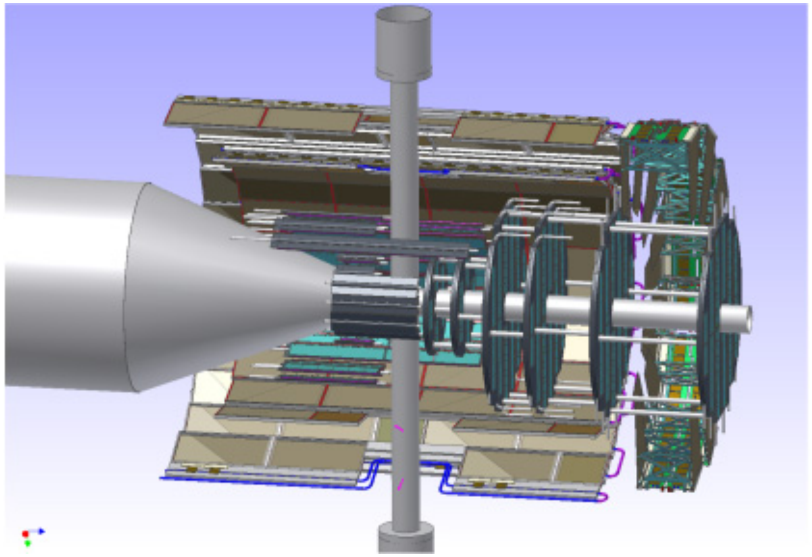
Detector requirements

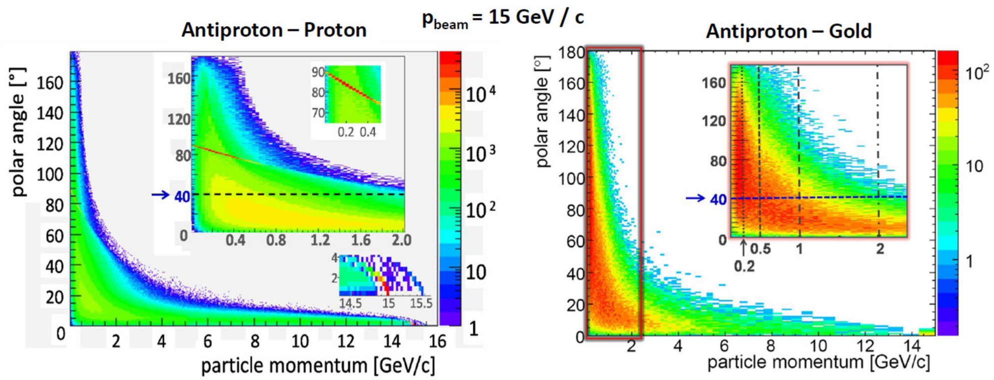
- **Nearly 4π acceptance**
- **Good tracking and charged PID** (100 MeV/c to 8 GeV/c)
- **High rate capability** ($2{\cdot}10^7$ pbar-p annihilations/s)
- **Continuous readout**
- **High primary and secondary vertex resolution**
- **γ detection** between 1 MeV and 10 GeV
- **Good momentum resolution** (~1%)
- **Modular design** (hypernuclear studies)

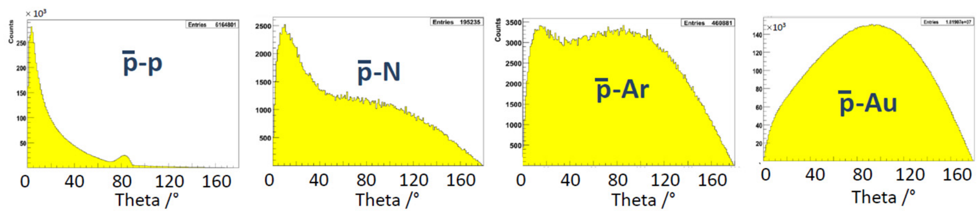
PANDA Physics

- Charmonium spectroscopy
- Search for gluonic excitations (glueballs and hybrids)
- Multi-quark states
- Open charm spectroscopy
- Modification of meson properties in nuclear matter
- Hypernuclear physics
- Nucleon structure (proton time-like form factor, transverse nucleon spin, GPD)

Micro Vertex Detector (MVD)







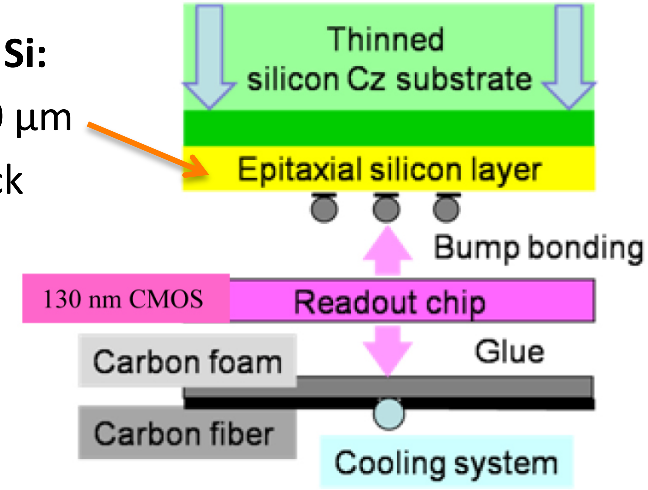
MVD Requirements

- **Good spatial Resolution in z** (better than 100 µm) to resolve secondary vertexes from D mesons decays
- **Good spatial Resolution in r-phi** for momentum measurements
- **Good time Resolution** (better than 6ns) and good readout speed to handle the high rate of $2 \cdot 10^7$ pbar-p annihilations/s
- **Triggerless readout**
- **Limited material budget**: many low momentum particles, starting from few hundreds of MeV/c
- **Measurement of dE/dx** to improve PID
- **Radiation hardness**: expected fluence ~$4 \cdot 10^{14}$ n 1MeV eq /cm^2 (simulating 10 years of pbar-p collisions, 15 GeV/c antiproton momentum, at 50% duty cycle)

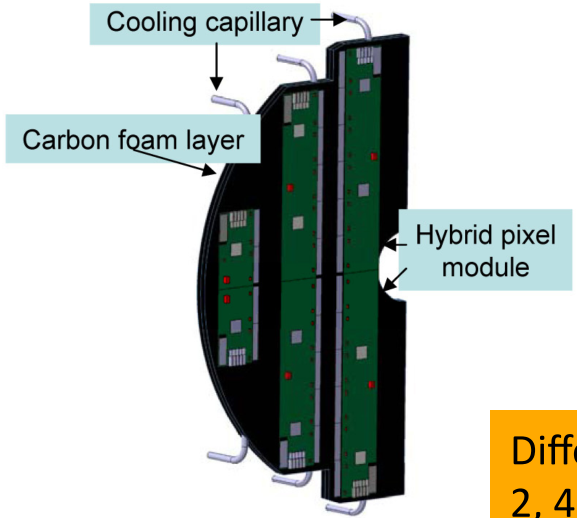
Hybrid Pixel Detectors

epi Si:

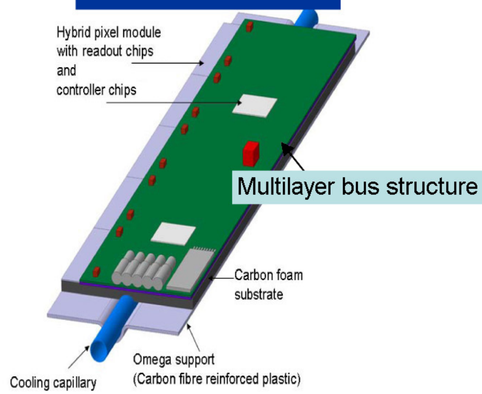
100 µm thick



Pixel half-disk – one side



Pixel Module



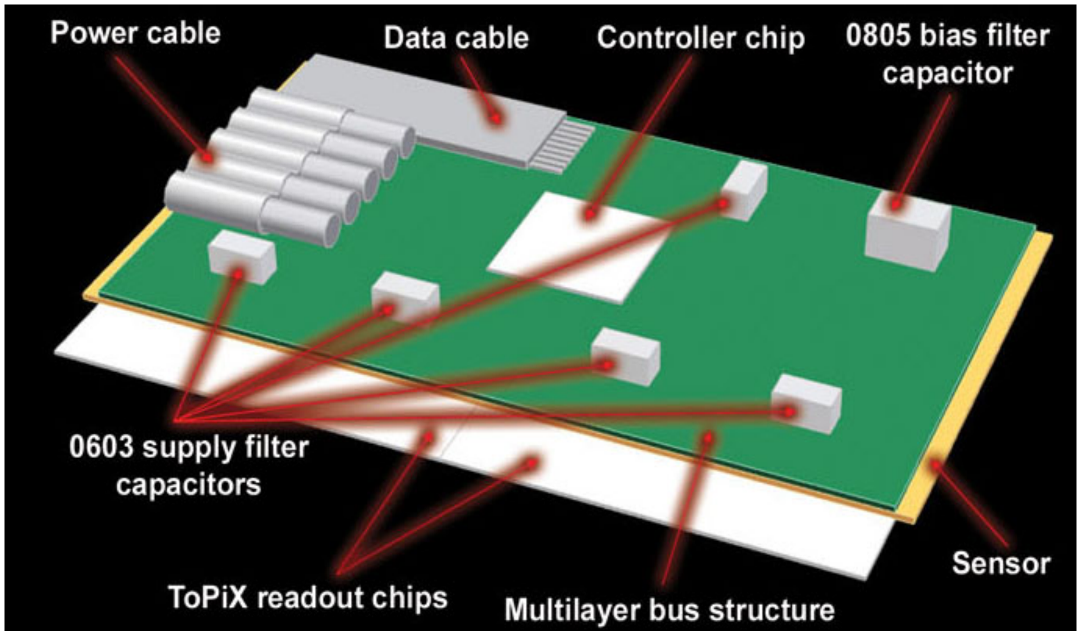
Different module assemblies with 2, 4, 5, 6 readout chips

Pixel cell:

100 µm x 100 µm

ToPix readout chip:

110 x 116 cells (~1.3 cm^2)

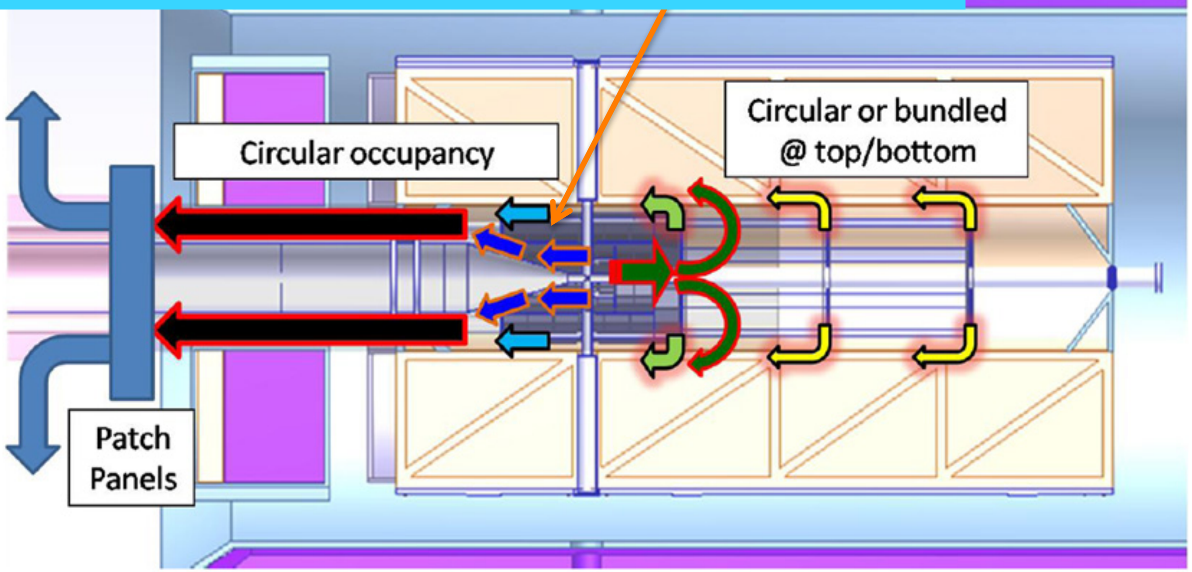


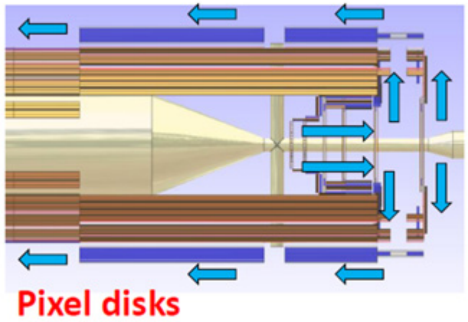
Pixel Readout - routing concept

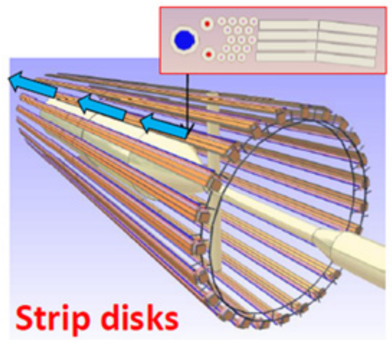
Routing for pixel disks is especially critical – all cables must go in upward direction and then backwards, passing around MVD and thus worsening material budget.

Cables about 1 m long are needed to reach the optical transceivers.

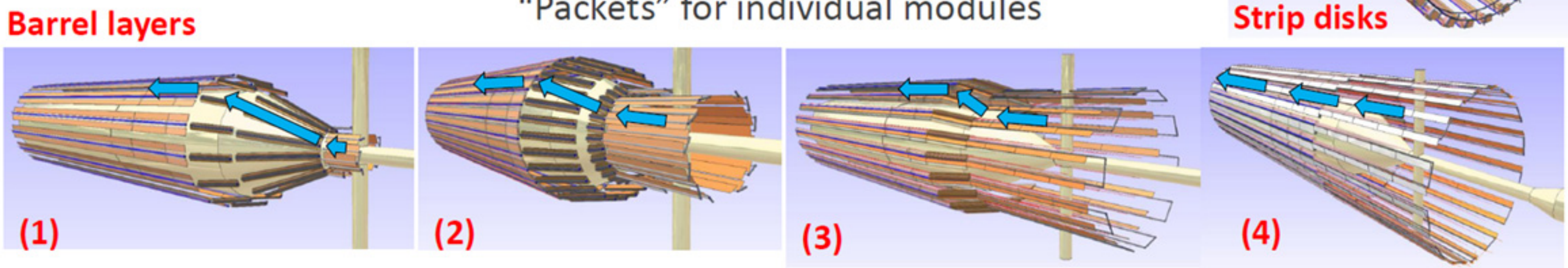
Max. data flow foreseen (readout chip level):
~450 Mbit/s in disks and ~390 Mbit/s in barrels



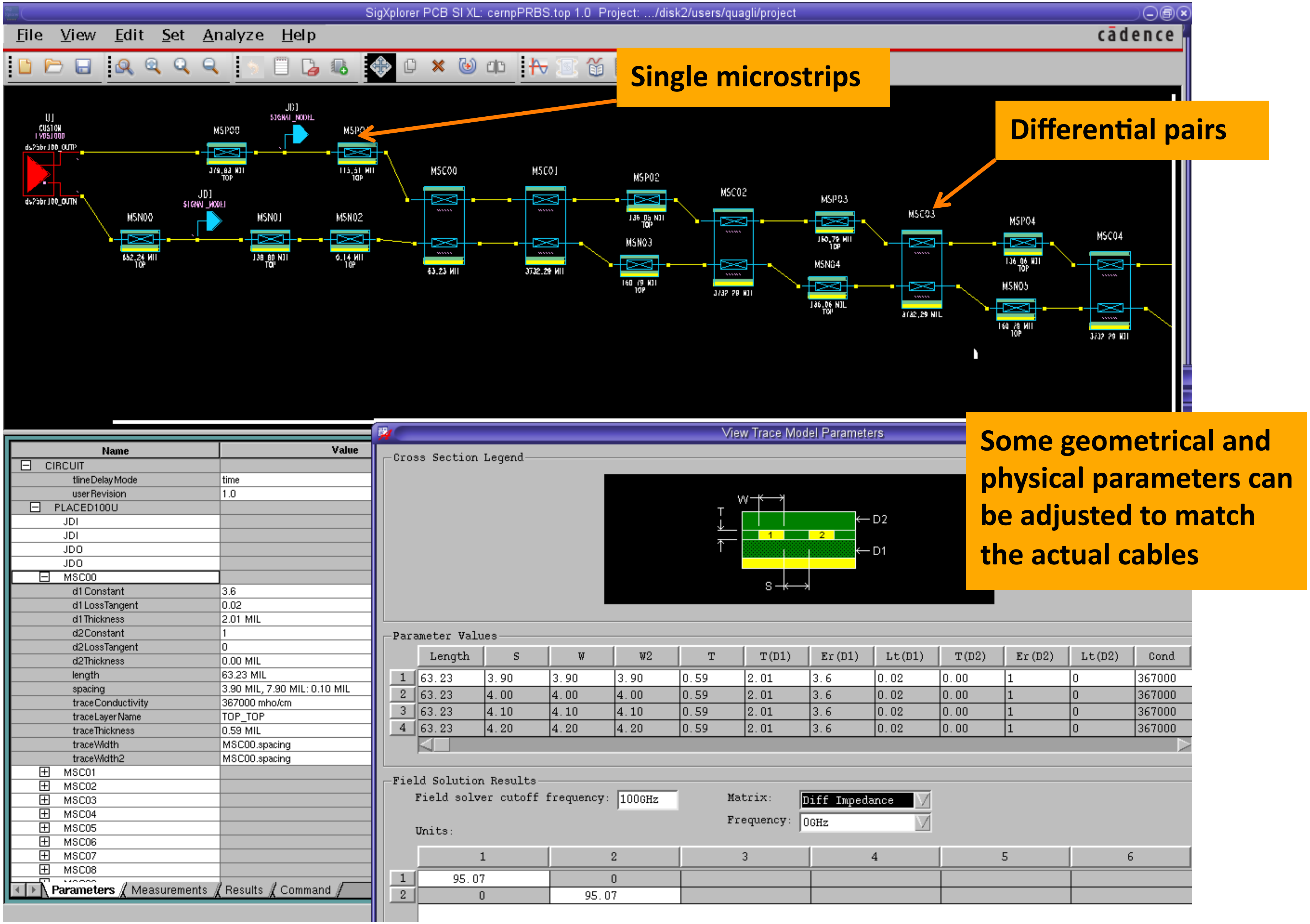




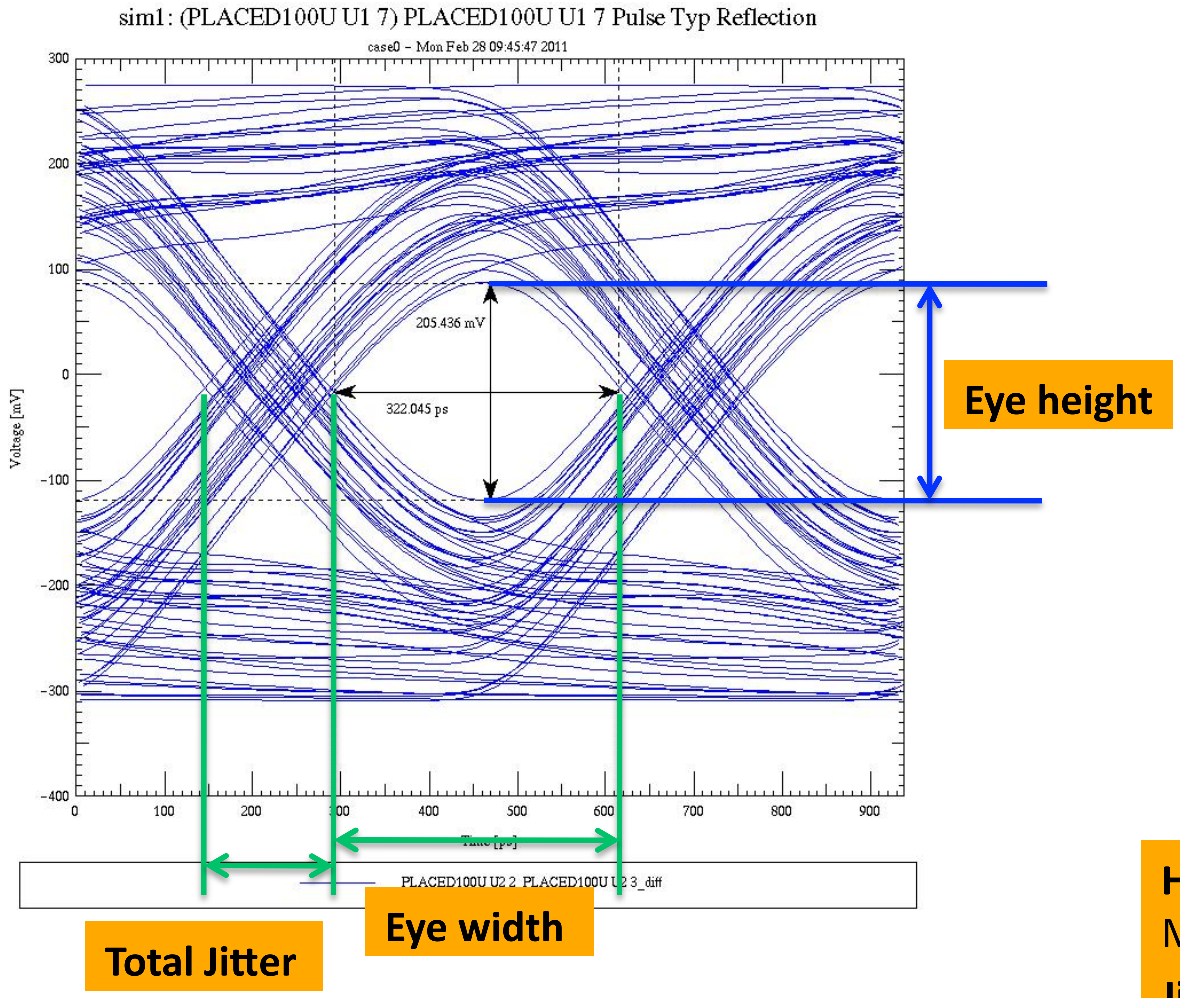
“Packets” for individual modules



Simulations - 2



Simulations - 3



Reflection simulations are performed at the same frequencies used in the experimental setup.

The pattern used was a 2^7-1 PRBS (obtained externally with a Mathematica script).

The uncertainty in the results was evaluated repeating 30 times one simulation, reshuffling each time the pattern using a different seed.

Height:
Mean = 221 mV, **Sigma = 14 mV (6.5 %)**
Jitter:
Mean = 156 ps, **Sigma = 23 ps (15 %)**
(150 µm cable @ 2125 MHz)

Next Developments

With current setup:

•Further irradiation studies with electrons.

•BER (Bit Error Rate) measurements.

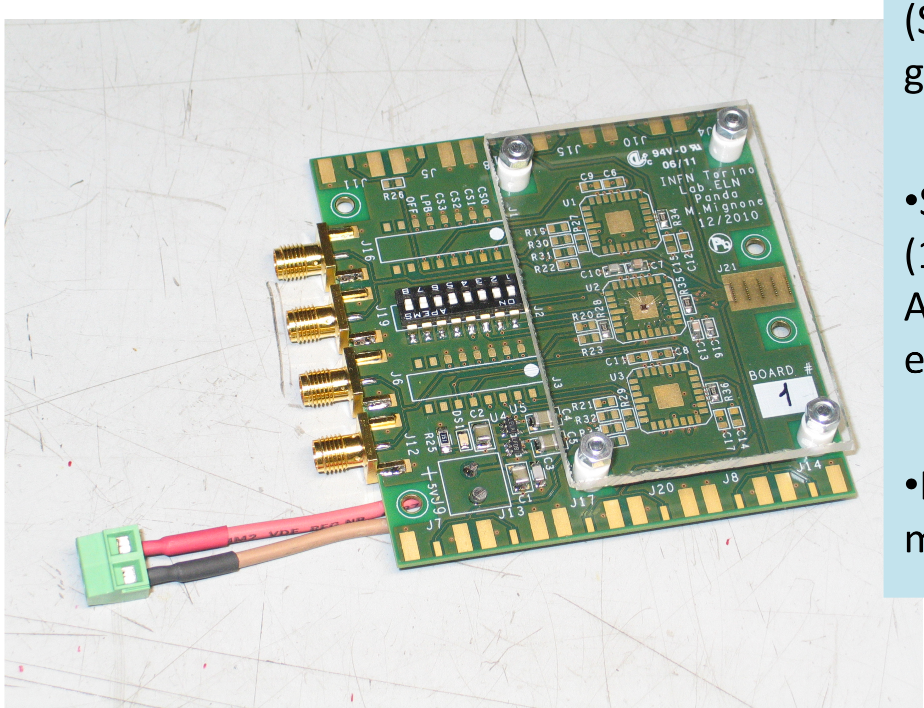
New setup:

•A new setup will be available for testing; it will comprise:

•Test board with up to three driver/receiver SLVS chips (Scalable Low-Voltage Signaling: common mode 200 mV, gnal swing 200 mV per phase).

•Straight cables (1 m long), with 18 differential couples (100 µm or 150µm wide) in laminated Al on Pyralux. Available with and without a cover layer of Kapton for enhanced robustness.

•Having many lines on the same cable, crosstalk measurements are also possible.



Results - 2

Evaluation of measurement error (100 µm cable @ 622.08 MHz):

1. 15 repetitions of a single measurement **on the same day.**

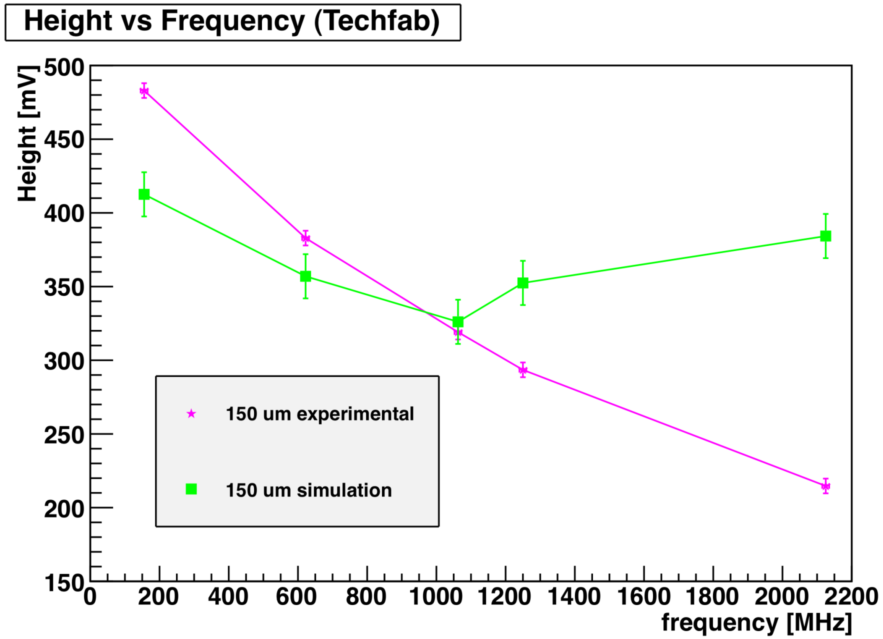
Height:	mean = 371 mV, **sigma = 3 mV (0.9 %)**
Jitter:	mean = 199.7 ps, **sigma = 1.2 ps (0.6 %)**

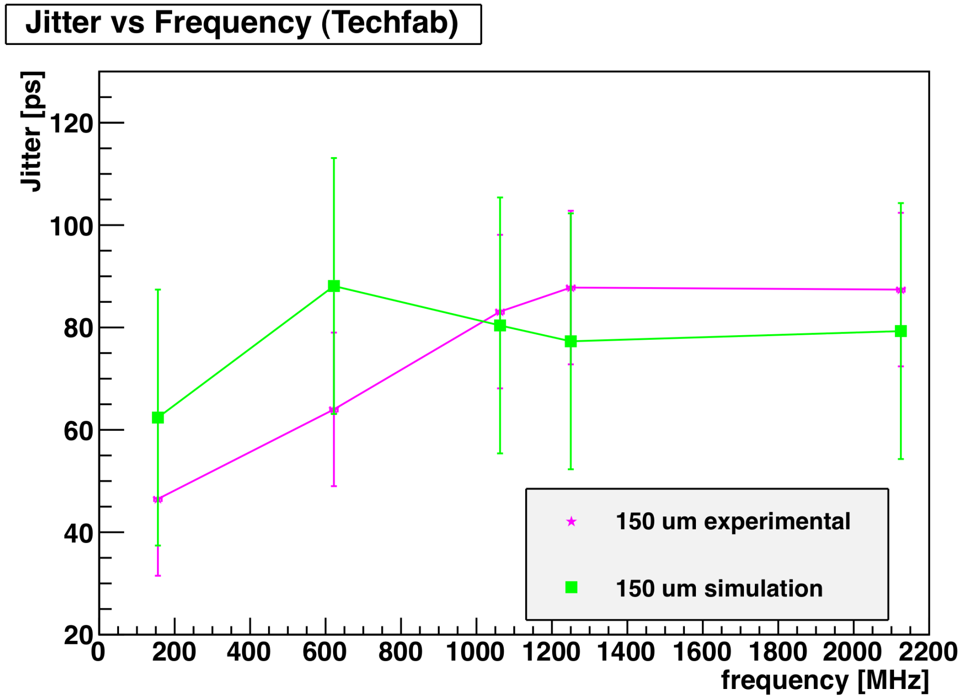
2. 15 repetitions of a single measurement **on various days and times.**

Height:	mean = 367 mV, **sigma = 4 mV (1.2 %)**
Jitter:	mean = 192 ps, **sigma = 15 ps (8 %)**

When taking into account environmental variations, **jitter** is a much less precise measurement than **eye height**.

Results - 4

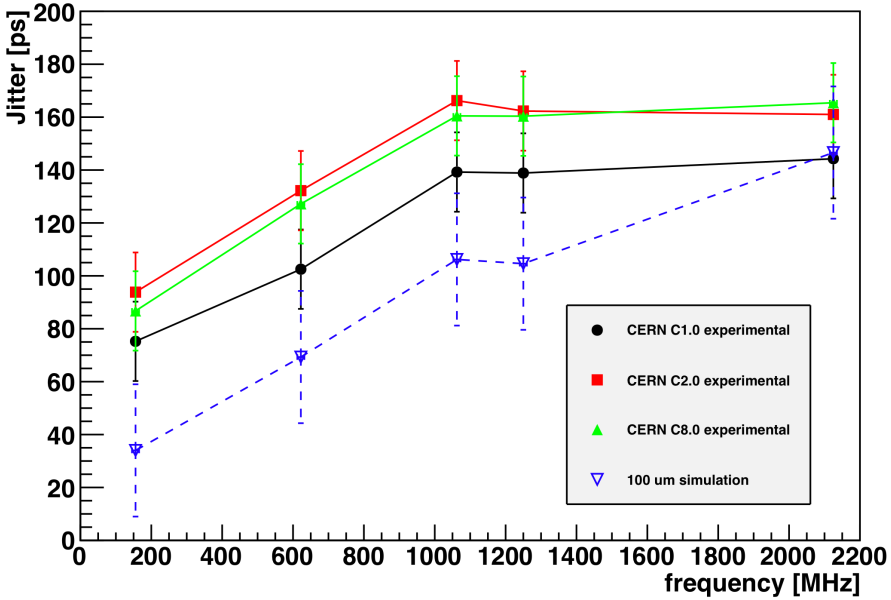




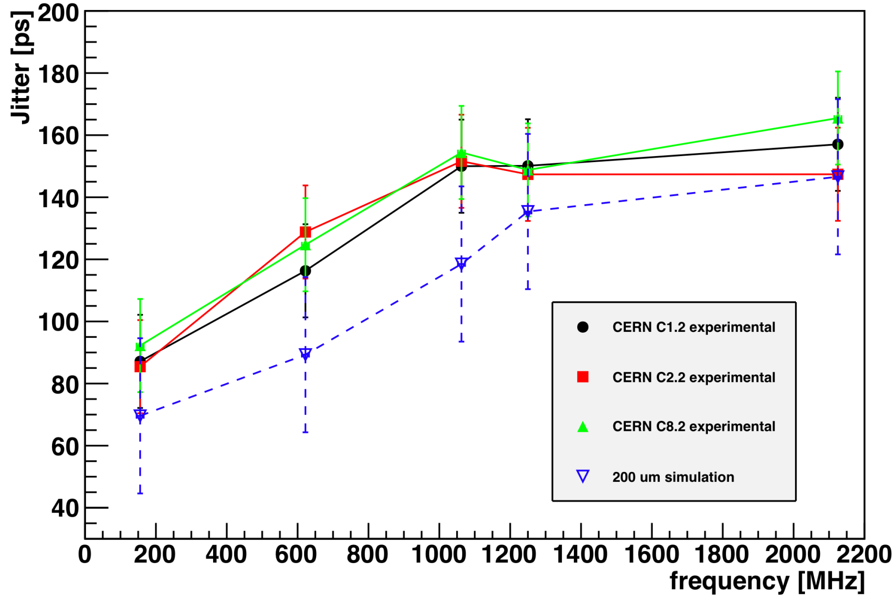
Agreement between simulation and experimental data is good for jitter, but not for height (especially at high frequencies). May be due to difference between the transmitter used (the one inside the BERT and not the one on this specific board) and its model.

Results - 5

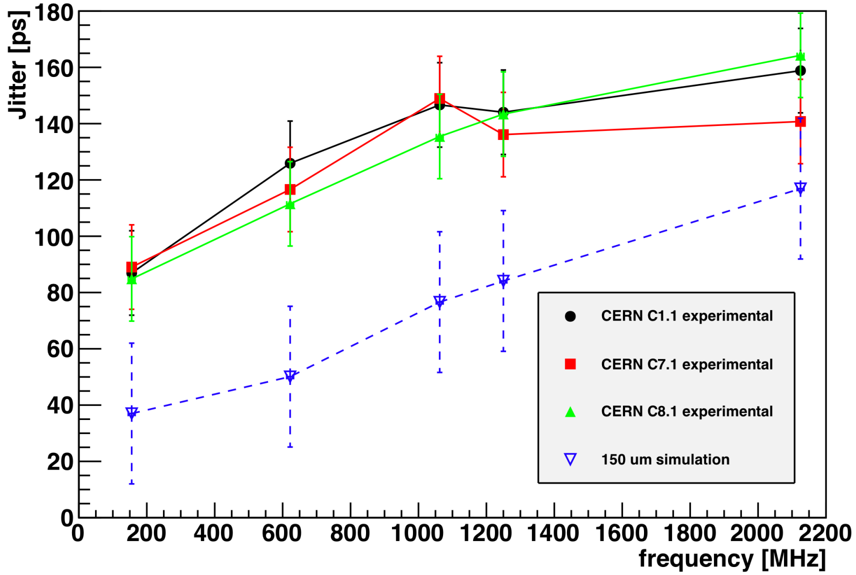
Jitter vs Frequency (track width 100 um)



Jitter vs Frequency (track width 200 um)

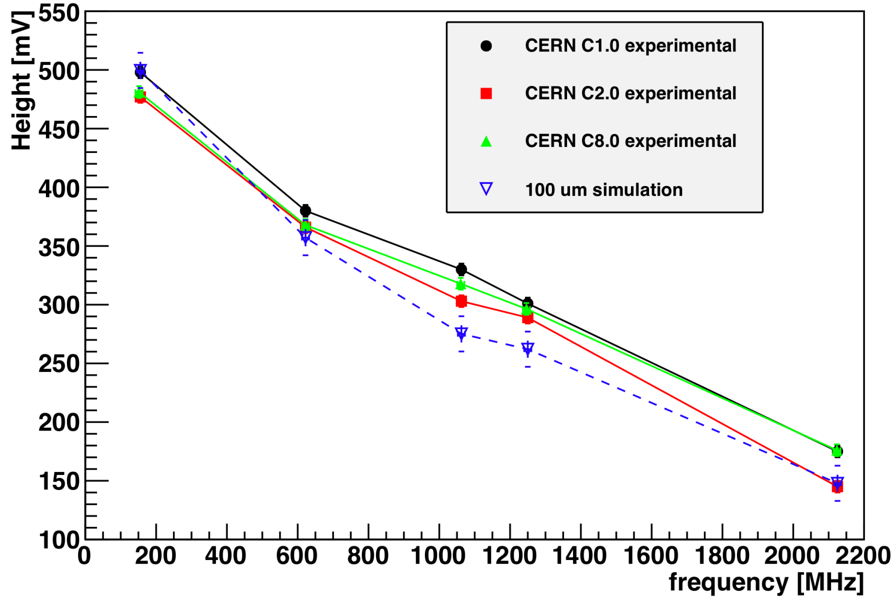


Jitter vs Frequency (track width 150 um)

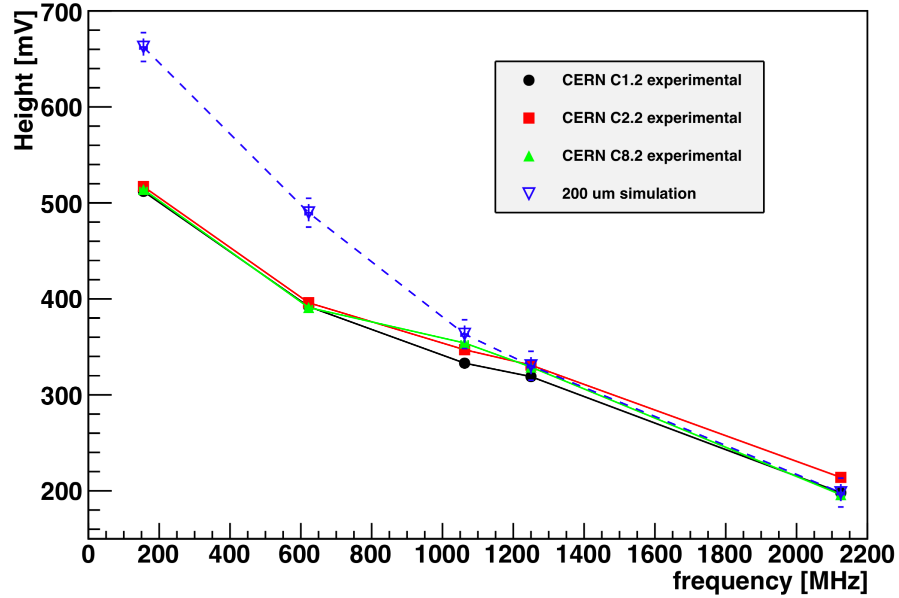


Results - 6

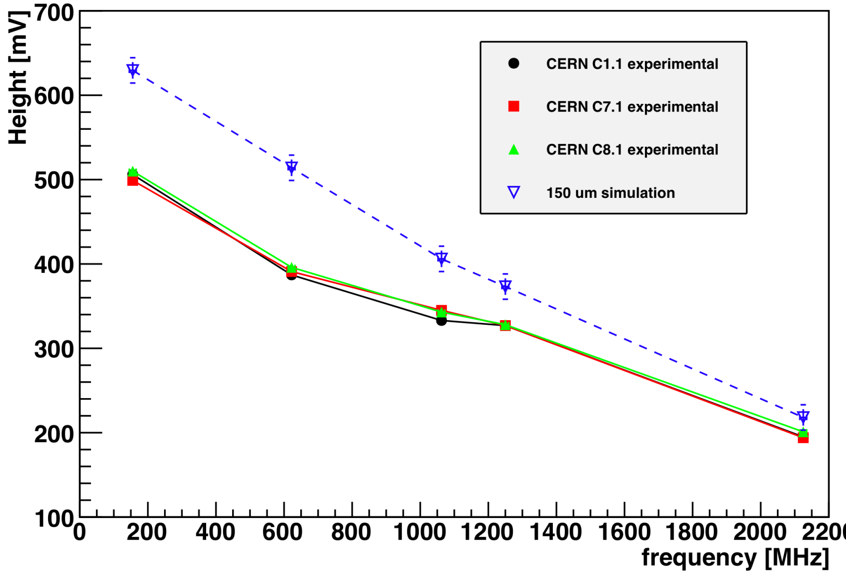
Height vs Frequency (track width 100 um)



Height vs Frequency (track width 200 um)

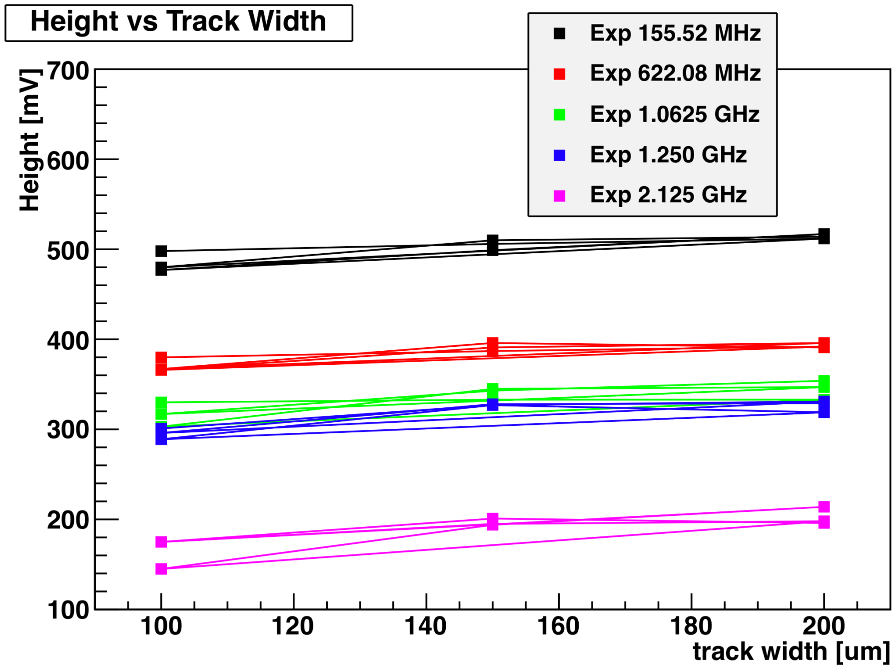


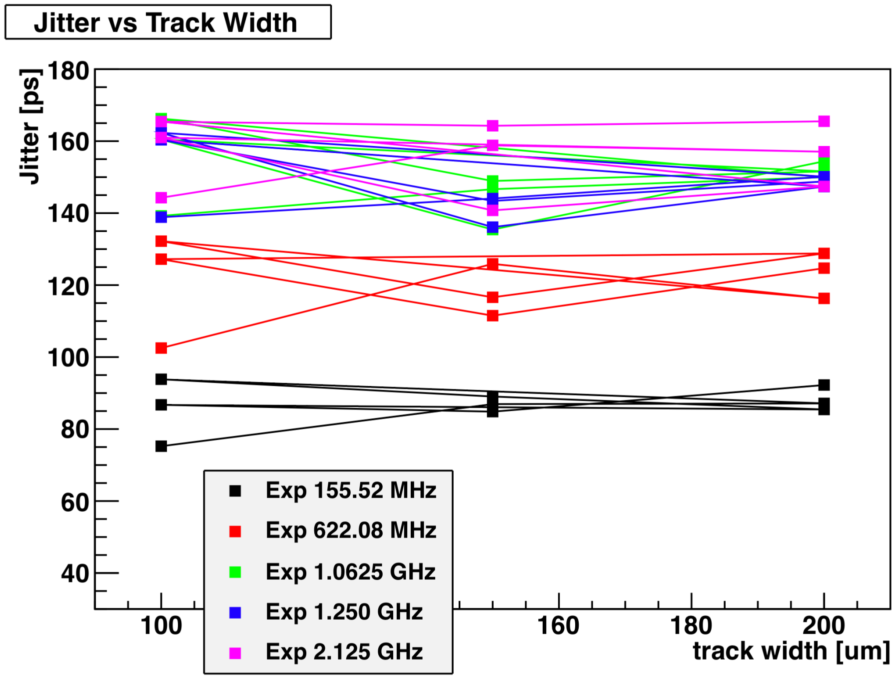
Height vs Frequency (track width 150 um)



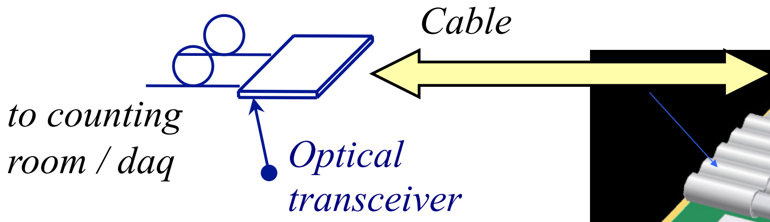
Results - 9

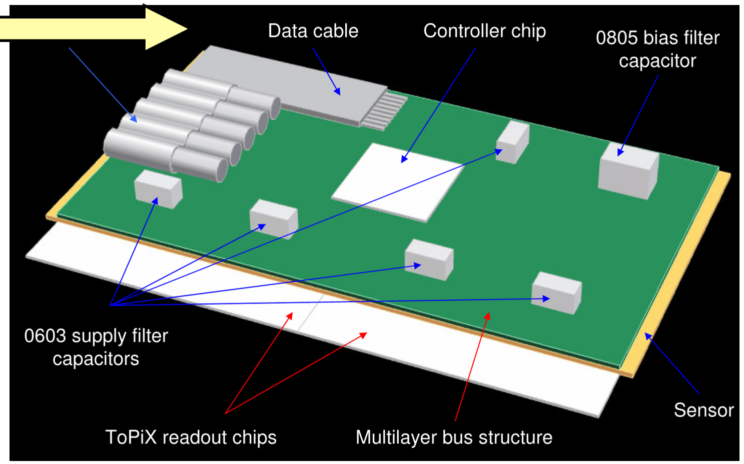
Data from the previous slide are plotted against track width instead of frequency.



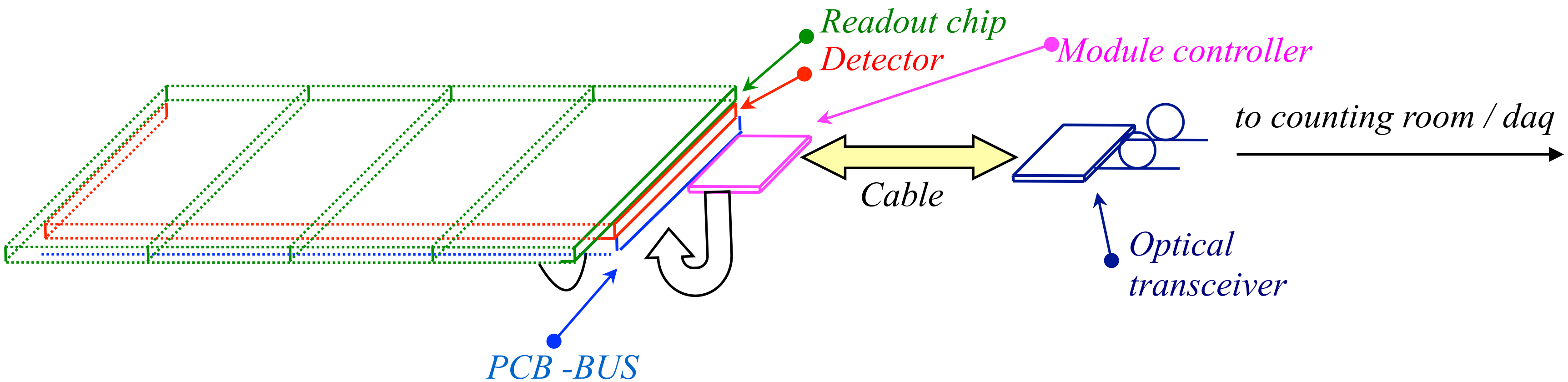


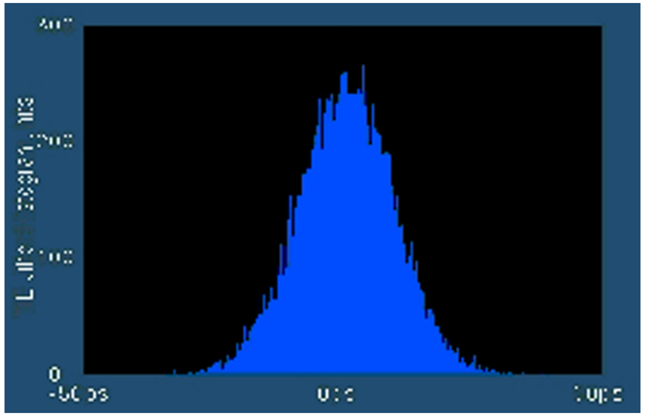
Increasing the track width, the height slightly improves, while no clear trend can be found for jitter.

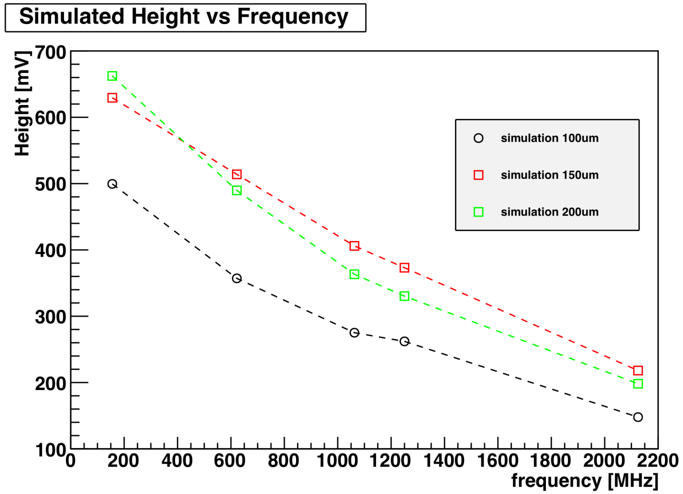


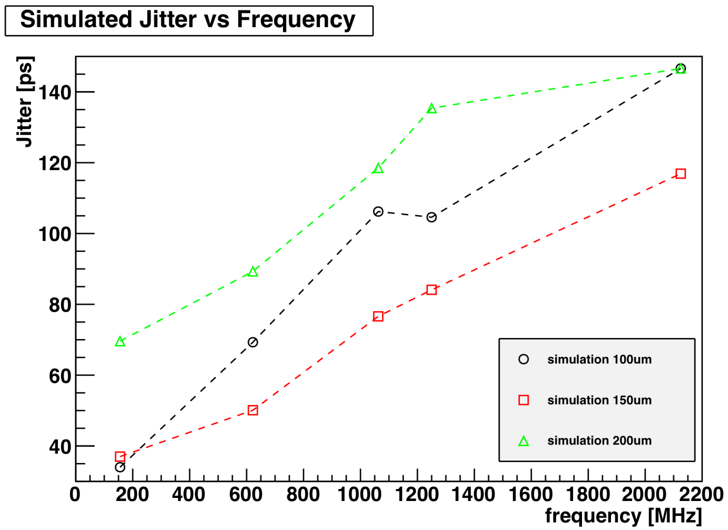


Different assemblies with 2, 4, 5, 6 readout chips






Simulated Height vs Frequency
Height [mV]
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
frequency [MHz]
simulation 100um
simulation 150um
simulation 200um


Simulated Jitter vs Frequency
Jitter [ps]
140
120
100
80
60
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
frequency [MHz]
simulation 100um
simulation 150um
simulation 200um

$$Z_{diff} = 2Z_0(1 - 0.48e^{-0.96\frac{d}{h}})$$

Note that:

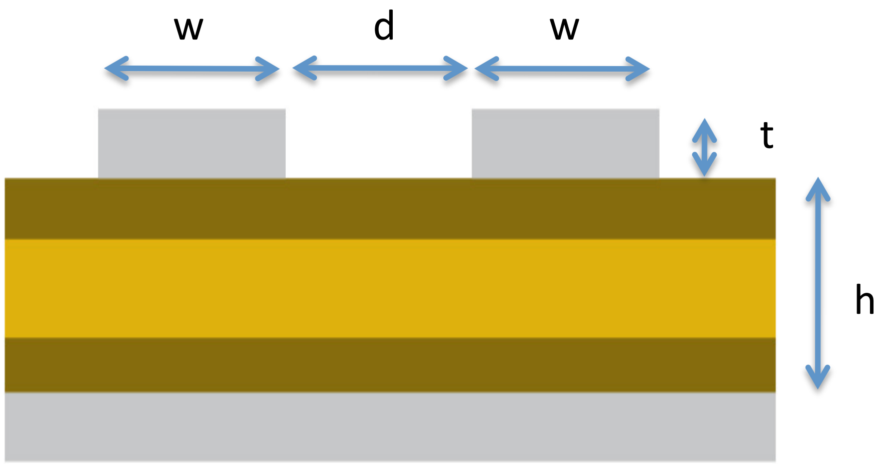
Z_{diff} depends on the ratio d/h:

- Increasing d increases Z_{diff}
- Increasing h decreases Z_{diff}

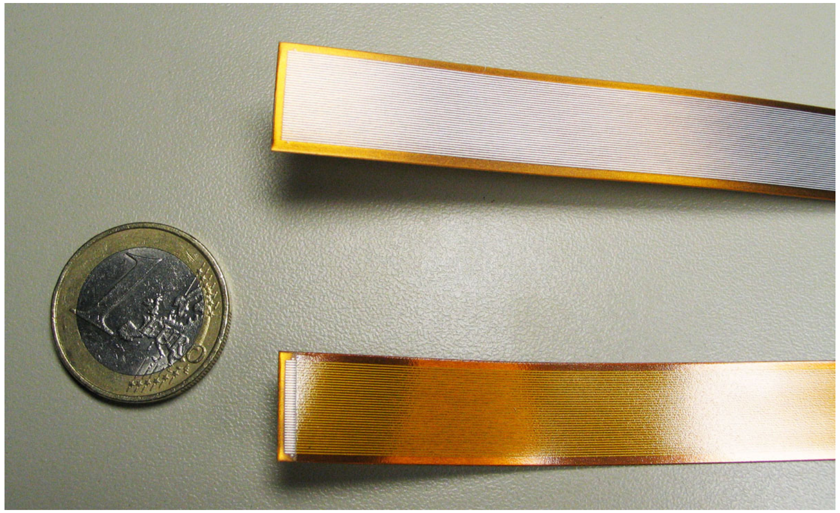
$$Z_0 = \frac{60}{\sqrt{0.475\varepsilon_r + 0.67}} \ln\left(\frac{4h}{0.535w + 0.669t}\right)$$

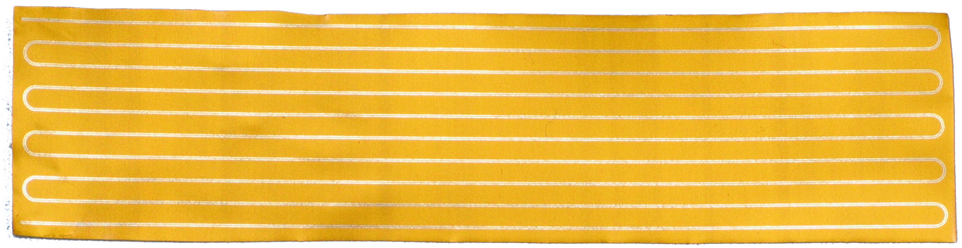
Note that:

- Increasing w decreases Z_0.
- Increasing h increases Z_0.
- Increasing t decreases Z_0, although it has small effect on Z_0.



Low mass cables for the pixel modules of the PANDA MVD





T. Quagli
HISKP, 2011 June 28th