The Planar GEM-Tracker

…current status and future perspectives
(Δ to 12/2015)

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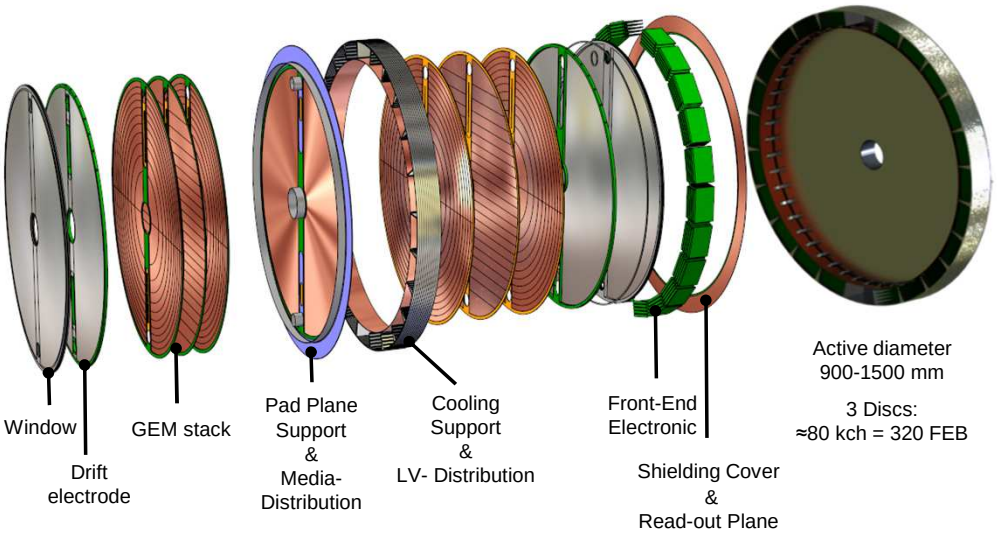
Outline

Recent achievements

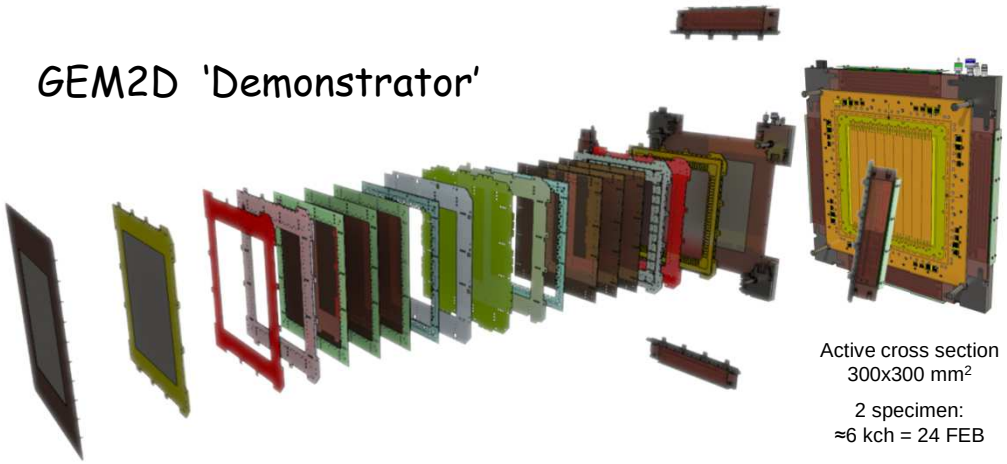
- GEM-Tracker System in PANDARoot & Performance
- GEM-DISCs
- GEM2D Demonstrator
- GEMEX Front-End Readout System Revision

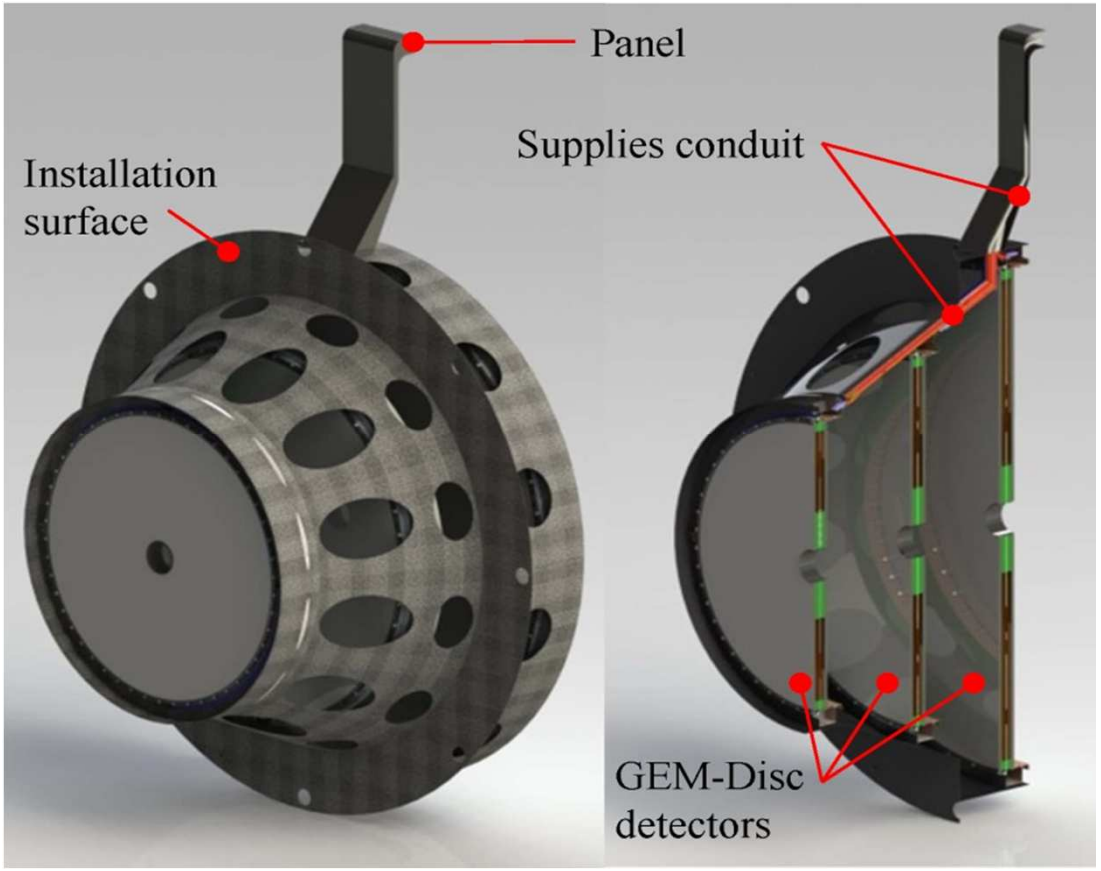
- *Summary Status & Resources*
- *Open Points & Discussions*

GEM-Disc 'Original'



GEM2D 'Demonstrator'





- Shape conformal solution too ambiguous for R&D
- Rectangular shape demonstrator 'GEM2D' chosen in 2012

Integration into PANDA-Root …Material budget

- Material composition (upper limit) used in the simulations:

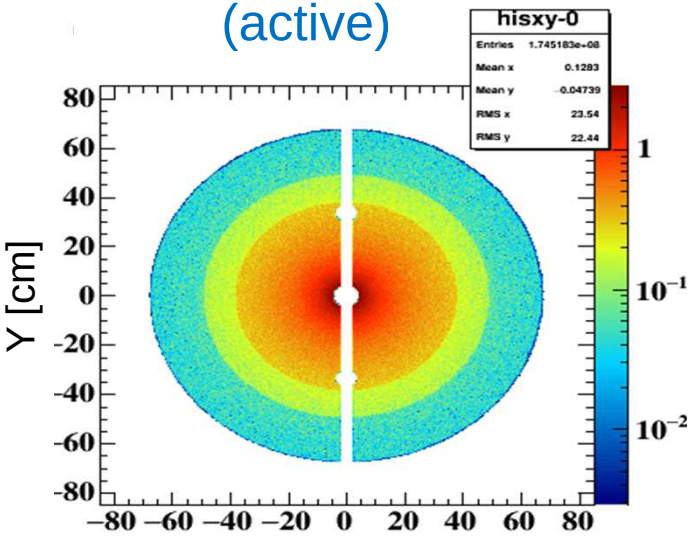
GEM-DISC	Material (kg) Density g/cm³ Sum	Carbon 2.265	Copper 8.96	Aluminum 2.7	Kapton 1.42	Glass Fiber 2.77
1	81.43	2.44	31.93	5.43	0.22	7.03
2	86.12	3.61	66.76	5.81	0.37	9.51
3	94.42	5.54	68.09	6.47	0.69	13.61
Riddle	18.67	X				
Cable Conduit	28.53		X			
System (upper limit)	308.97					

N.Divani (GSI & HIM)

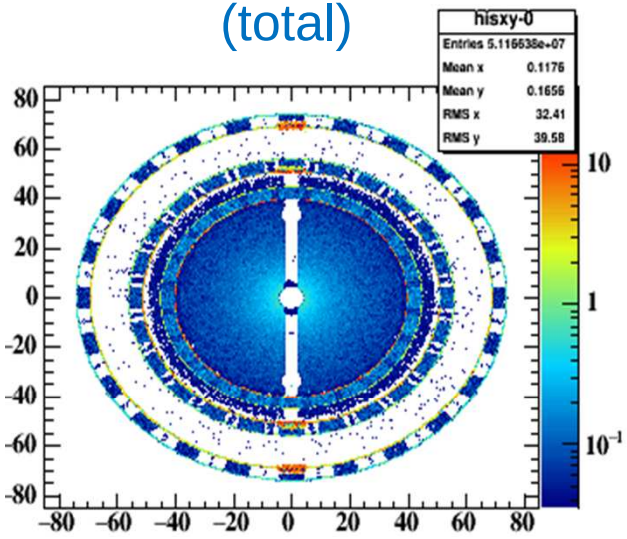
- The full setup ‘active’ and ‘passive’ is implemented
  (except parts of the ‘external’ cable conduit)

Integration into PANDA-Root …Radiation length

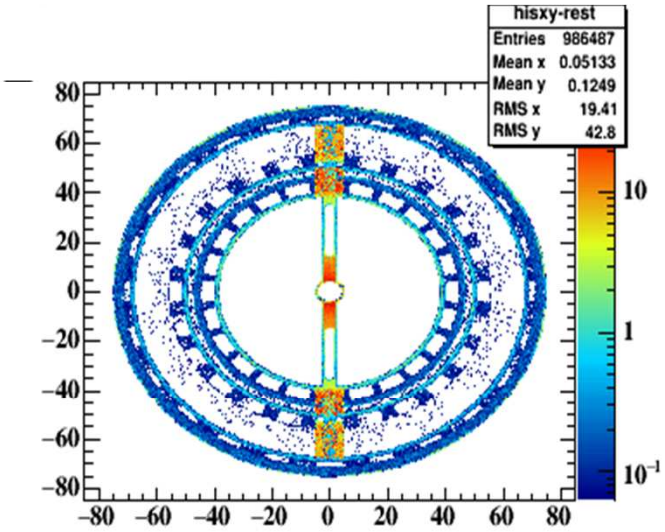
3 GEM-DISCs (active)



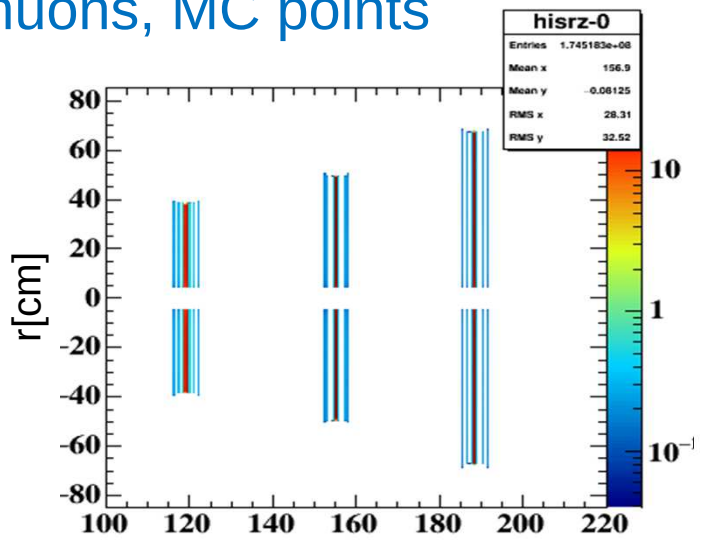
3 GEM-DISCs (total)

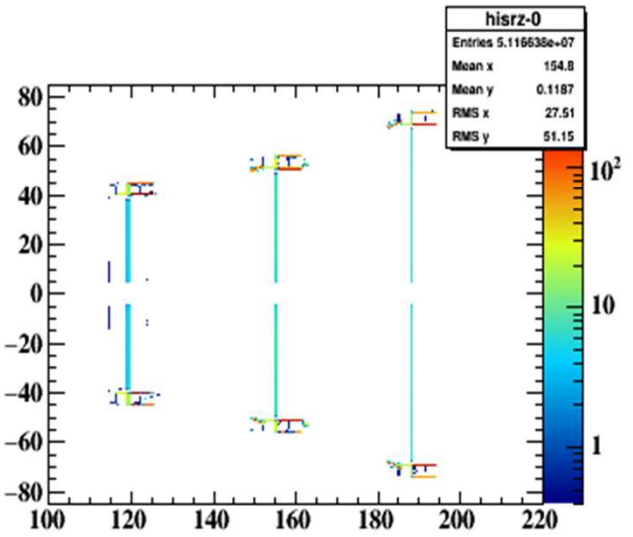


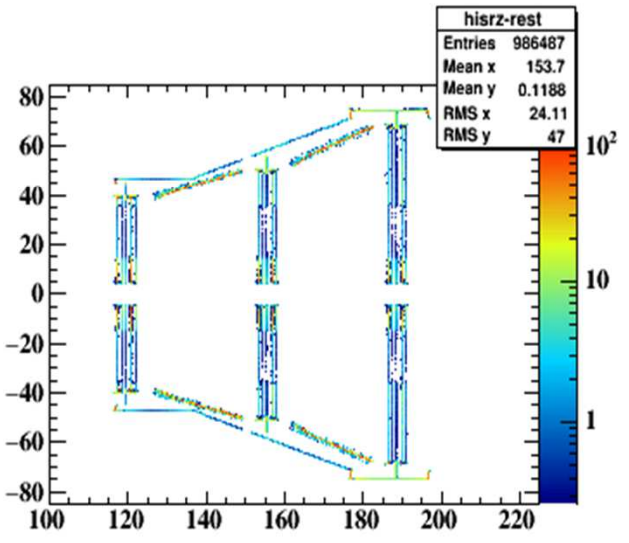
Support & Supplies



muons, MC points







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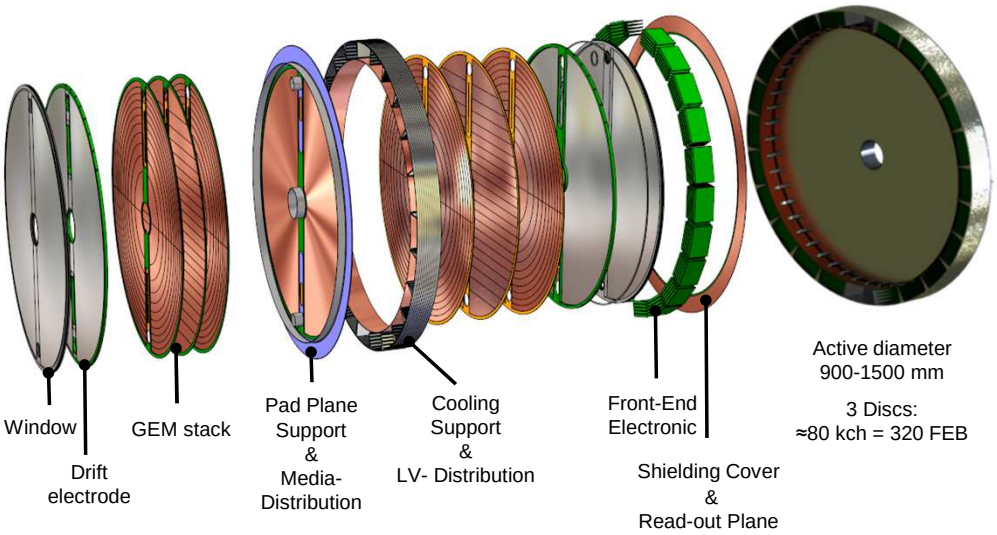
Integration into PANDA-Root …Simulations

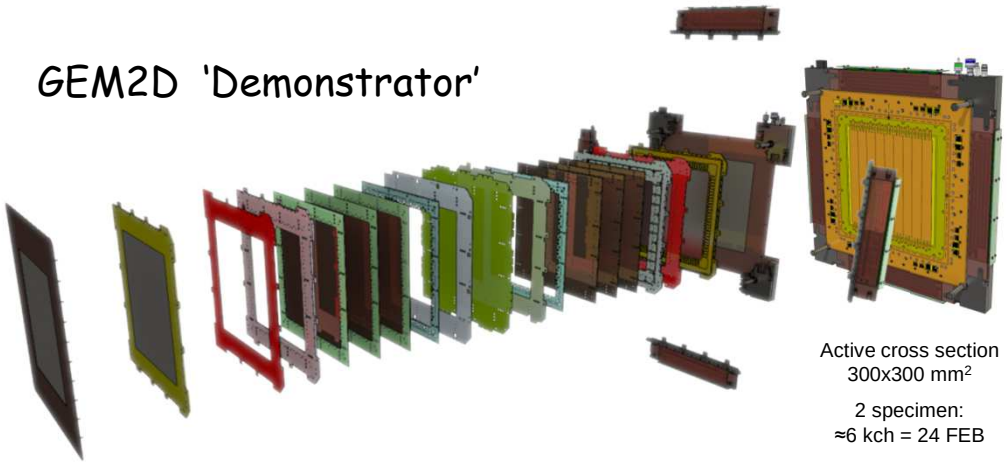
- See talk by Nazila in the tracking session for details

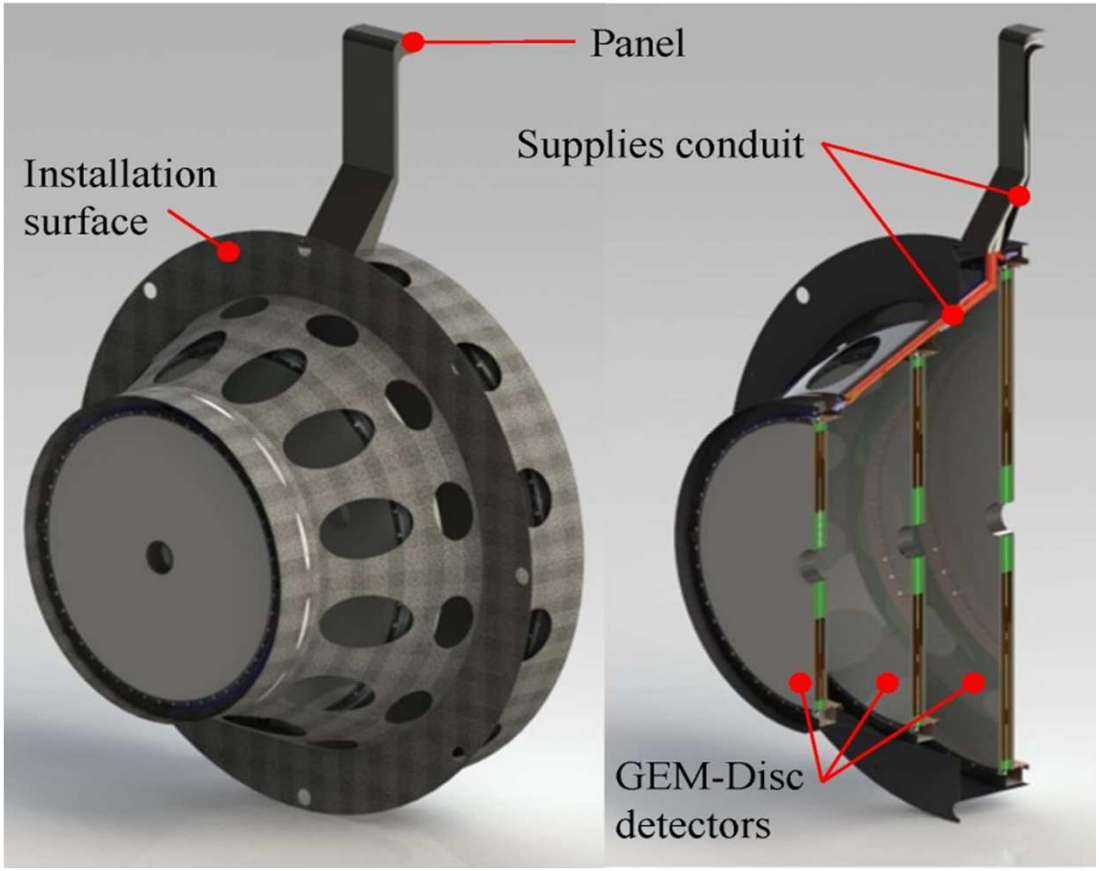
- Simulations show…
  - that 80% of day-1 physics would strongly profit from the GEM-Tracker system
  - that ONLY a FULL GEM-setup is feasible to obtain the physics results
  - the proposed reduction to 1 or 2 GEM-DISCs is NOT favorable

GEM-Disc 'Original'



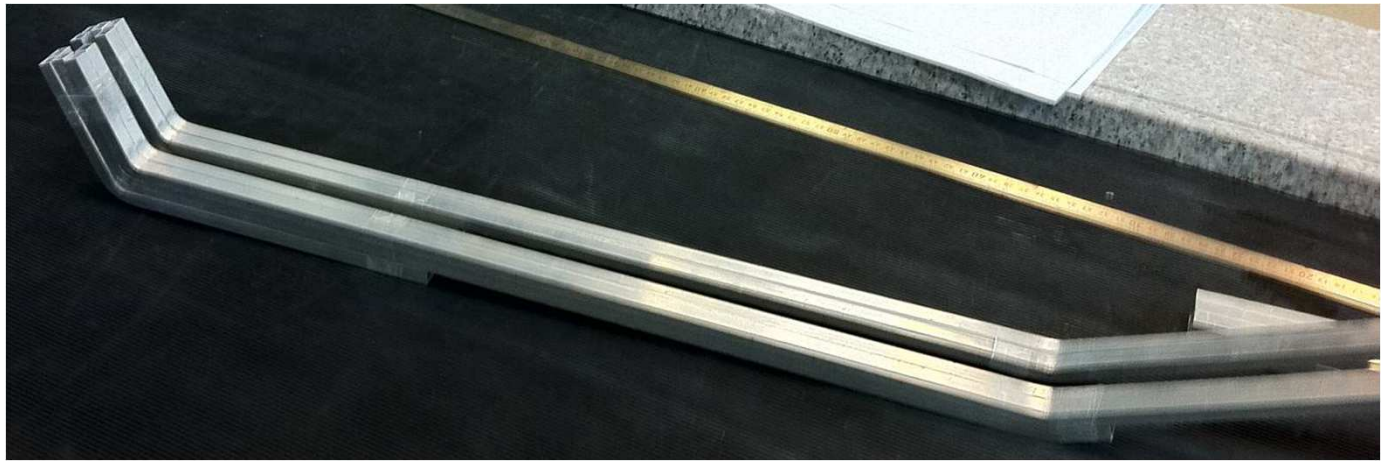
GEM2D 'Demonstrator'

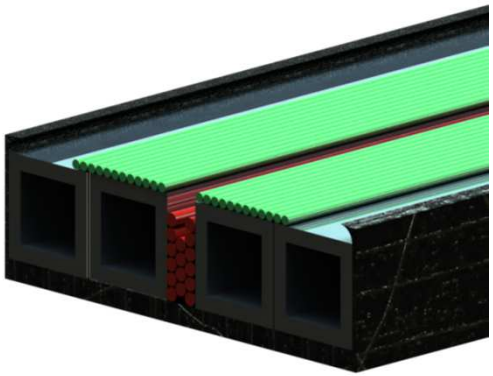




- Shape conformal solution too ambiguous for early-stage R&D
- Rectangular shape demonstrator GEM2D chosen in 2012

Supplies Conduit …the tubes

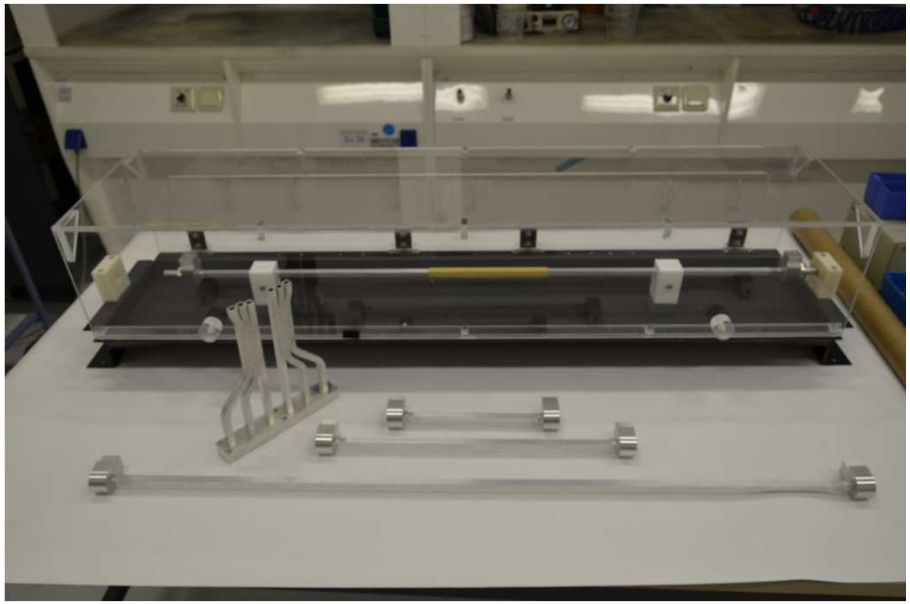


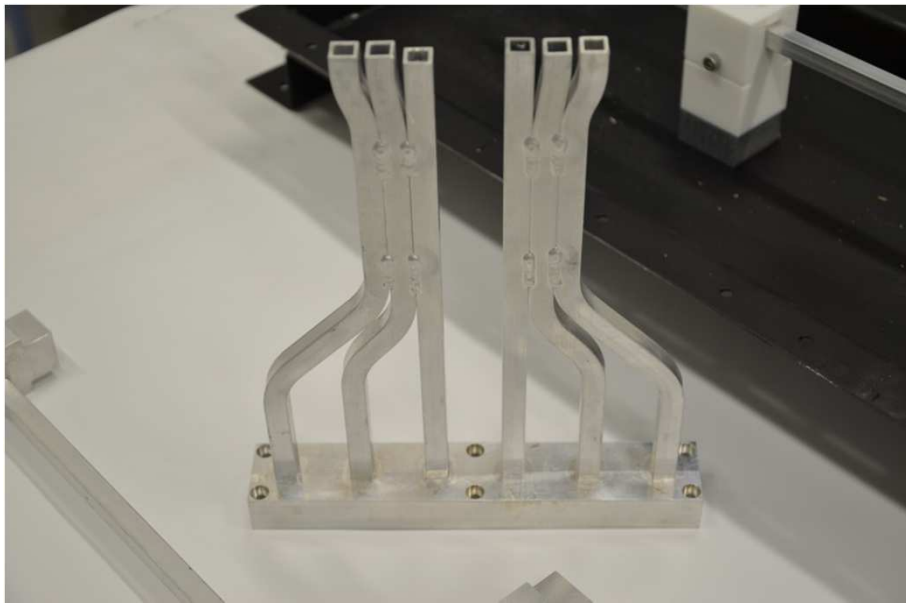


- Al-tubes
  E-beam welded
- Gas/Cooling &
  GND/PWR
- Weight 1-2 kg
- Size 46x52x1000mm^3

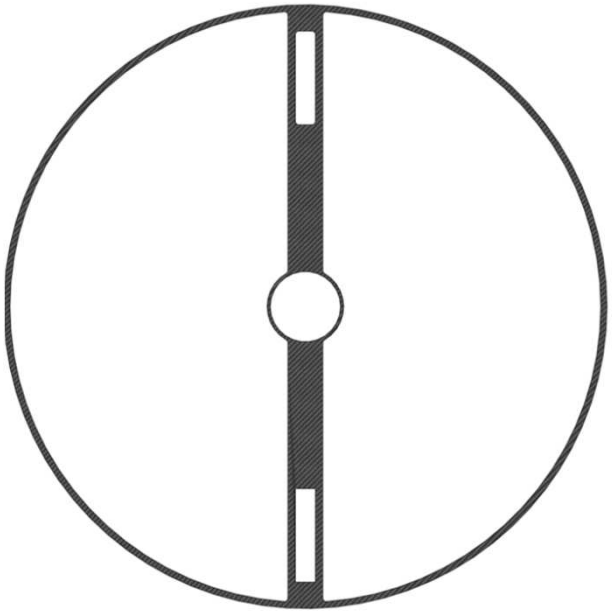
Tests for feasibility (Current / temperature raise) required

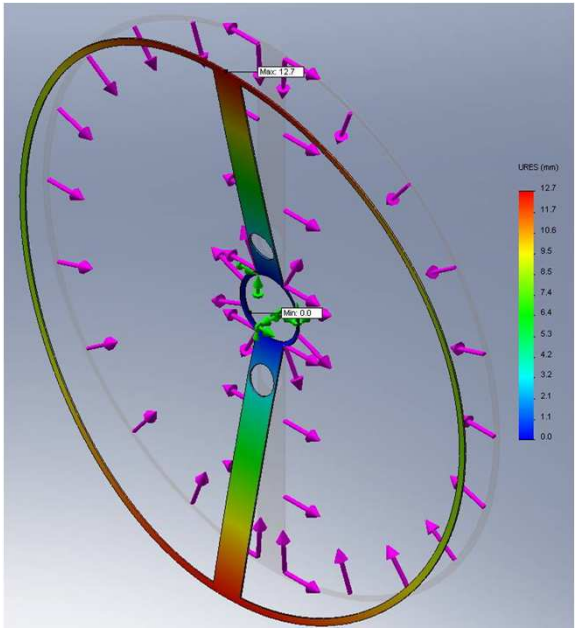
Supplies Conduit …the tubes performance test



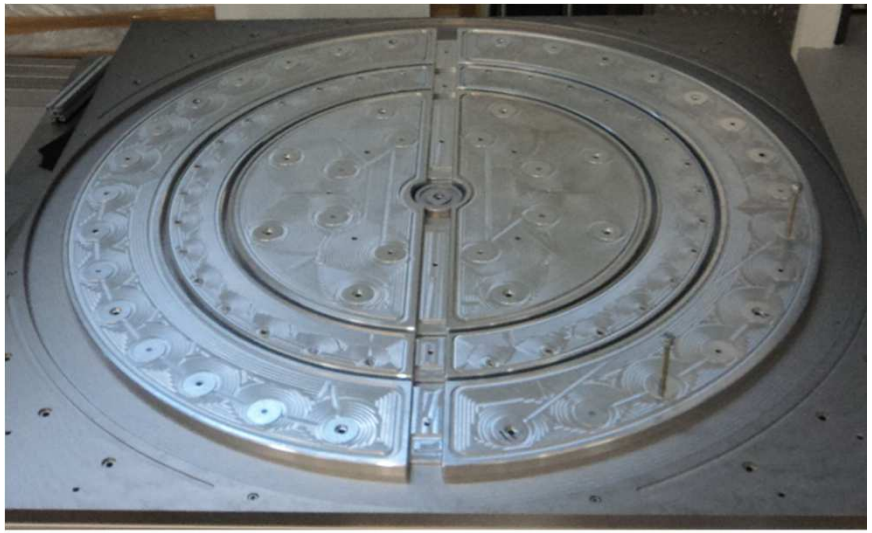


- Test samples operated under realistic conditions (currents) with fluid cooling
- Temperature raise well below the 30°C design goal
- Optimization of the flex-parts pending





Maximum deformation (mm) with planar foil stretching and a 1mm thick frame			
U_x	U_y	U_z	U_{res}
±1,5	± 0,24	12,7	12,7

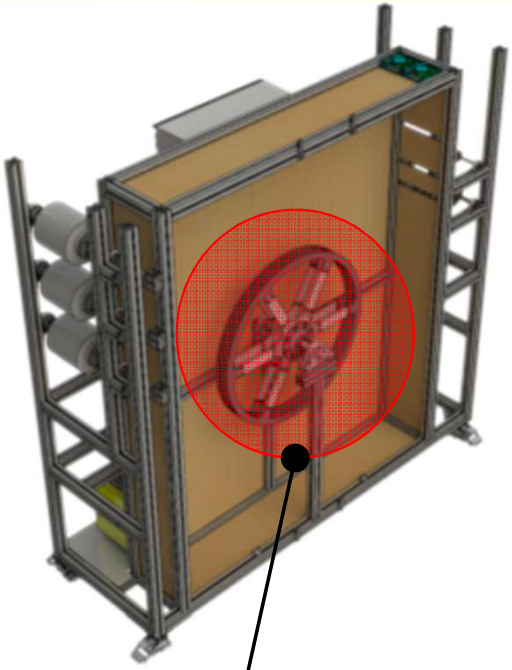


- Needs optimized fiber orientation and resin/matrix composition

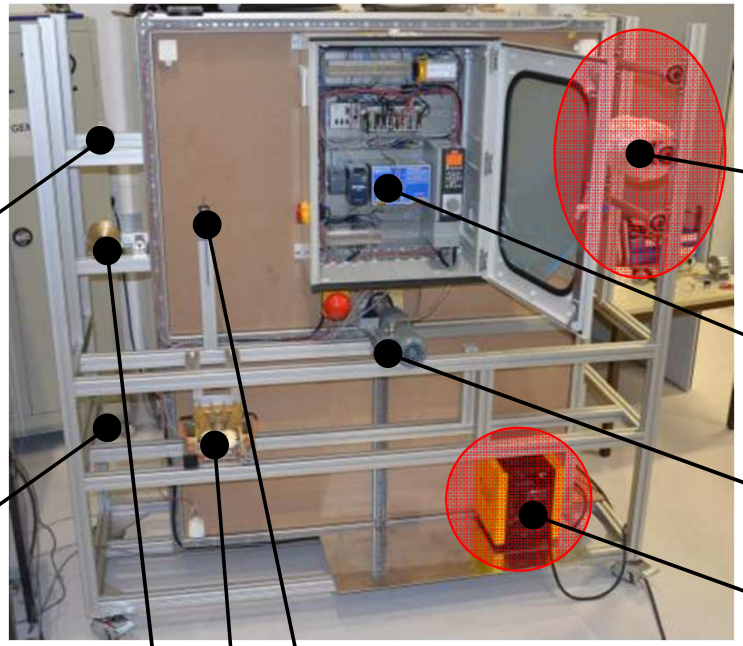
⇨ In-house production of rings
0,5..10 mm thicknesses
various diameters up to 1.5 m

- Machinery required
and set up partially
- Design goal of support-free mounting needs justification
- Mold Waiting to be applied
since 08/2011

Tools: winding machinery …slow but precise



Winding & curing volume with small mold (doors removed)



Tension measure-ment

Length measure-ment

Fibers of various types on spools (x3)

Process control

Main drive

Hot-air blower

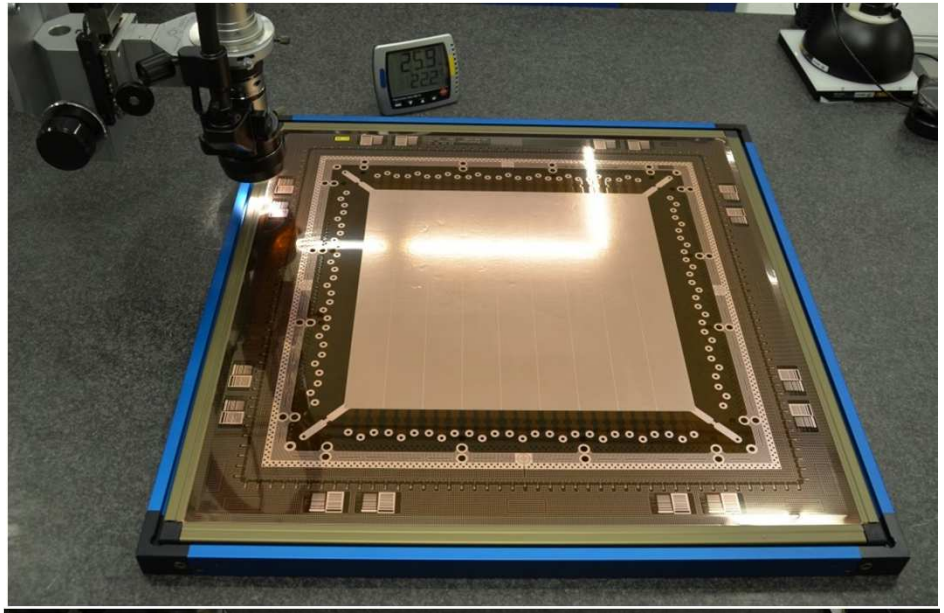
Glue mixer

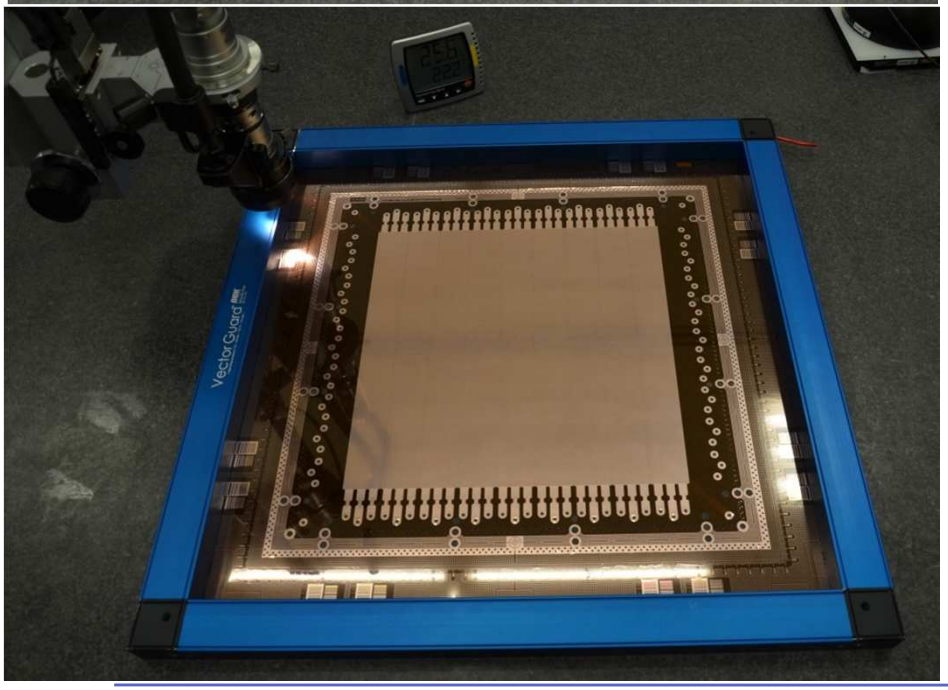
Heated resin bath

Eddy current brake

- High-quality winding of fibers of various (mixed) types
- Set up by 8 students from neighboring universities
- Expected run-up shifted 2016 → Q1/2017

GEM-Foil Quality control

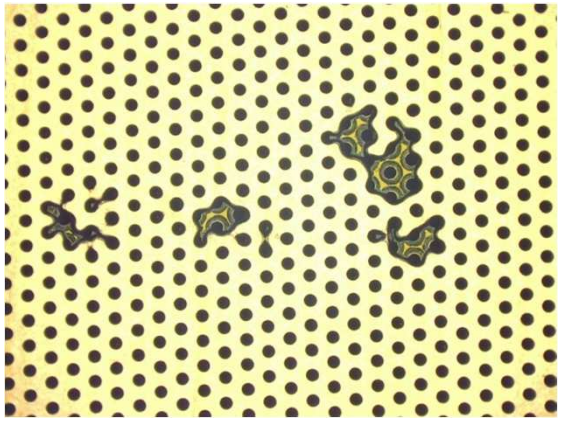


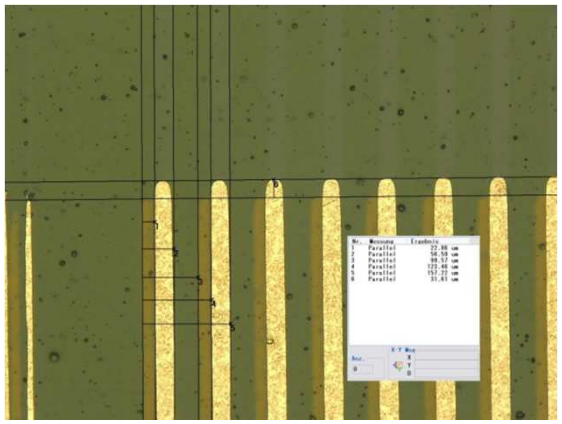


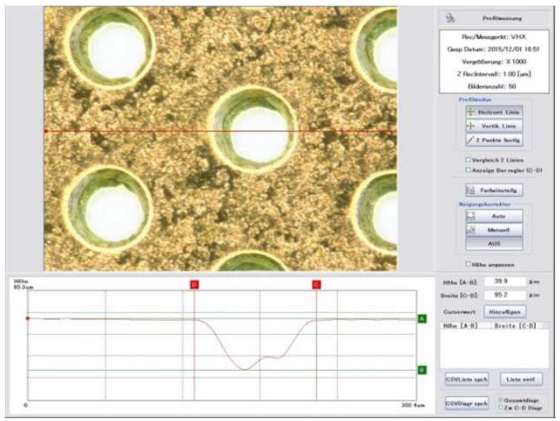
- 2 foils delivered by Techtra as polish inkind realizing GEM2D design 300x300mm^2 active area 9 sectors with identical layout (>1,5 year delivery time)
- Max. 10nA@600V for 12 s in free air at 1amt & ‘normal’ humidity:

  Several shorts in one sector
- Subjective impression of optical homogeneity: OK
- ‘Light’ area < 1 mm^2: OK

GEM-Foil Quality control

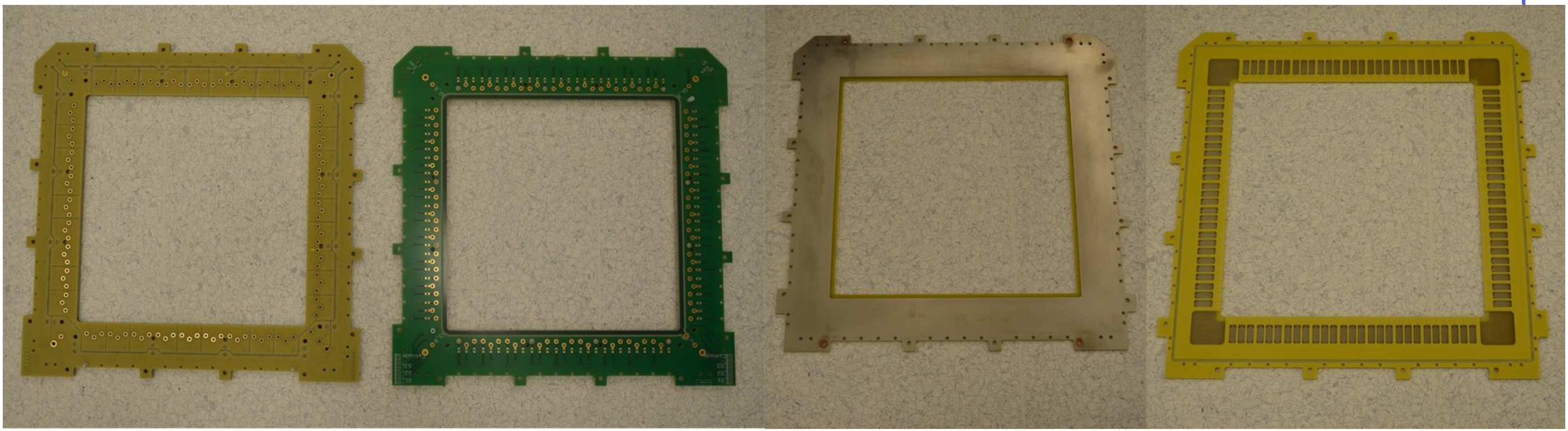


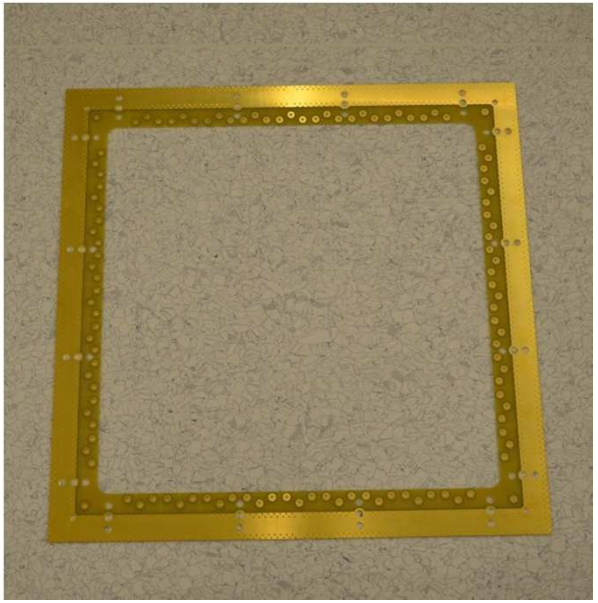




- Optical QA on first specimen revealed unacceptable defects (potential points of failure) & top/bottom misalignment
- Reasons are identified and partially mitigated
- Company needs further support to improve
- Production currently stalled
- Proper in-house QA infrastructure is missing

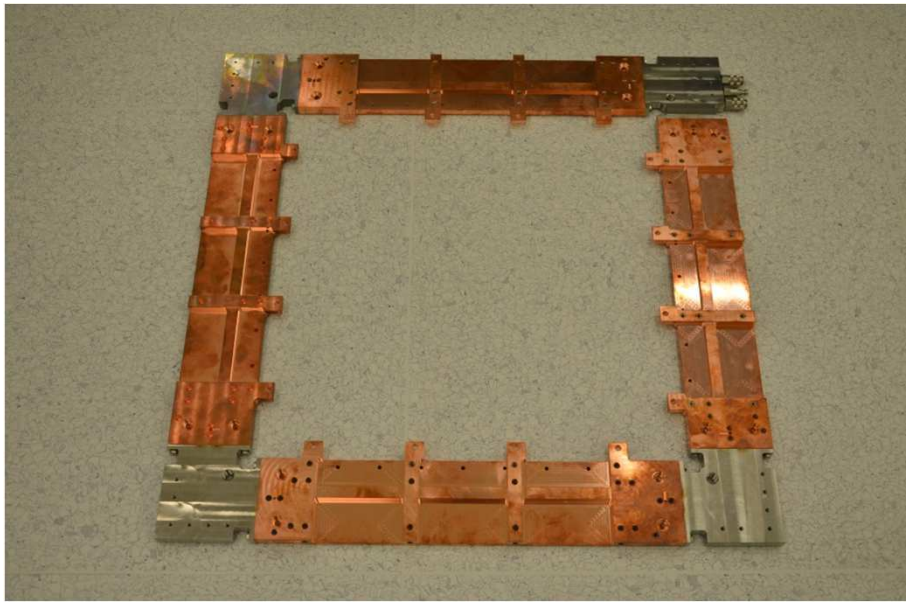
...a lot of Frames

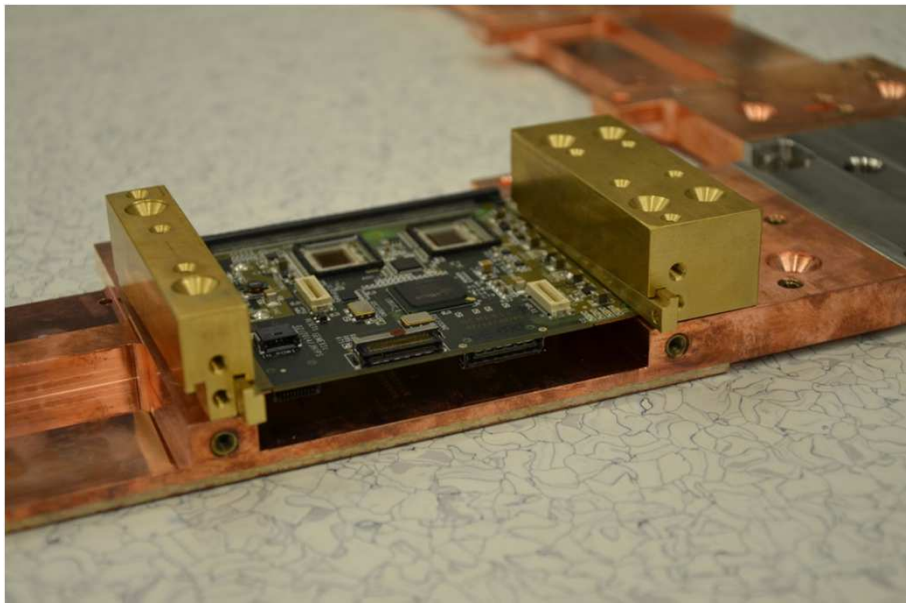




- All frames delivered in 2015
  (shielding, cathode, GEMs, PadPlane stiffener)
  for a set of two GEM2D demonstrator detectors
- Assembly is still pending

Mainframe & Cooling structure

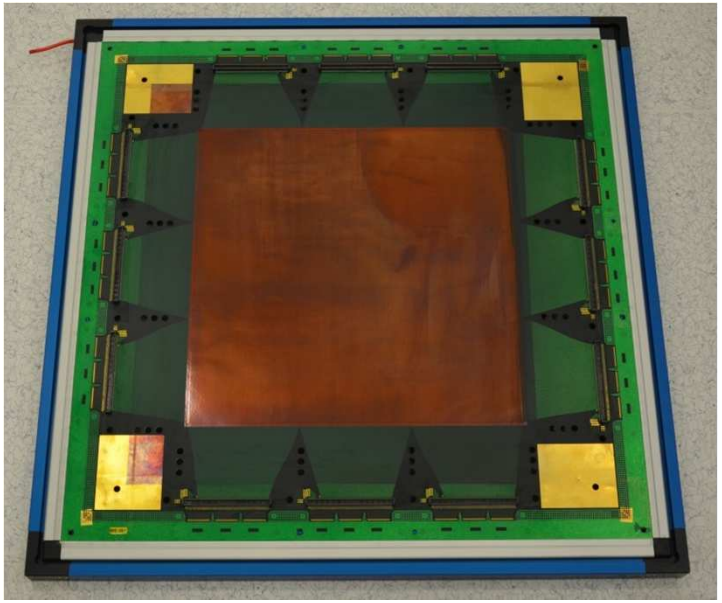


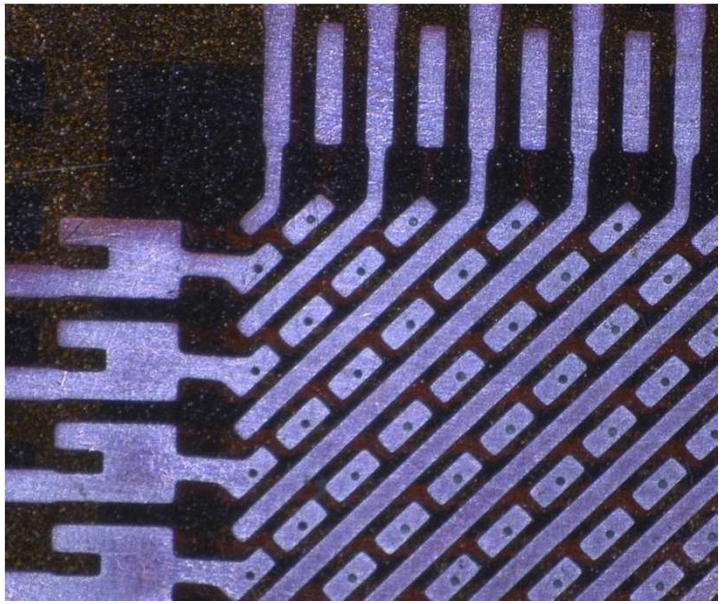


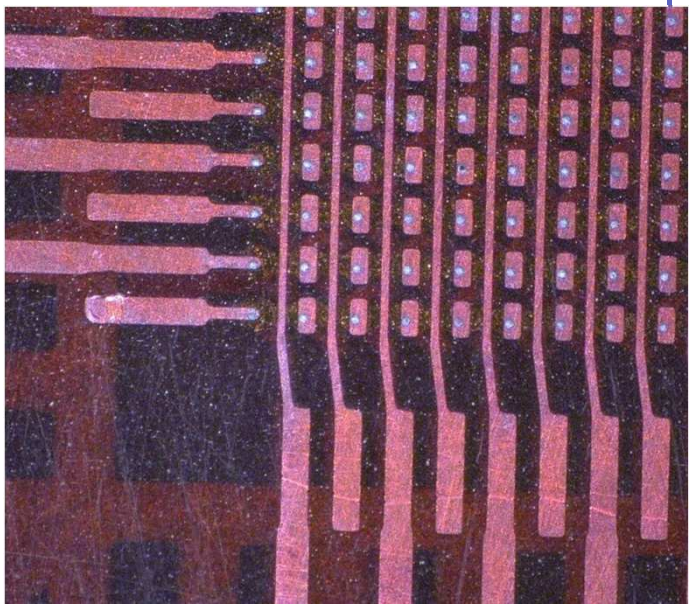
- Cooling ‘main’ structures fabricated at GSI
  (took month’s)
- Successfully tested for leak-tightness under pressure

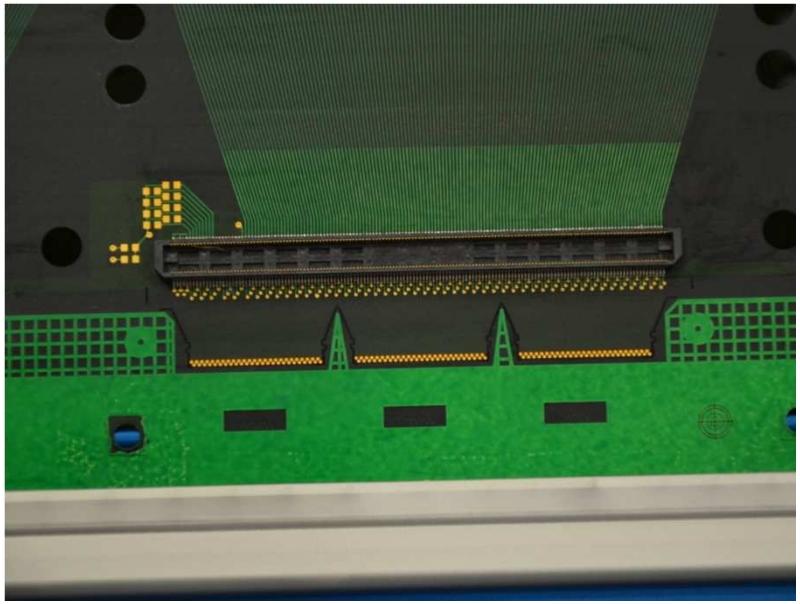
- GEMEX (V1C) readout front-end cards mountable

…PadPlane







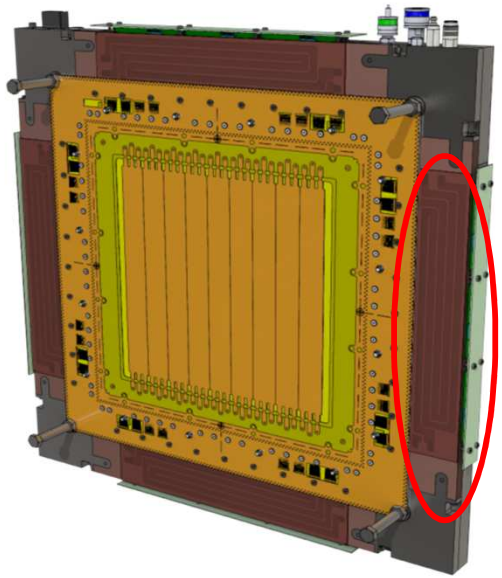


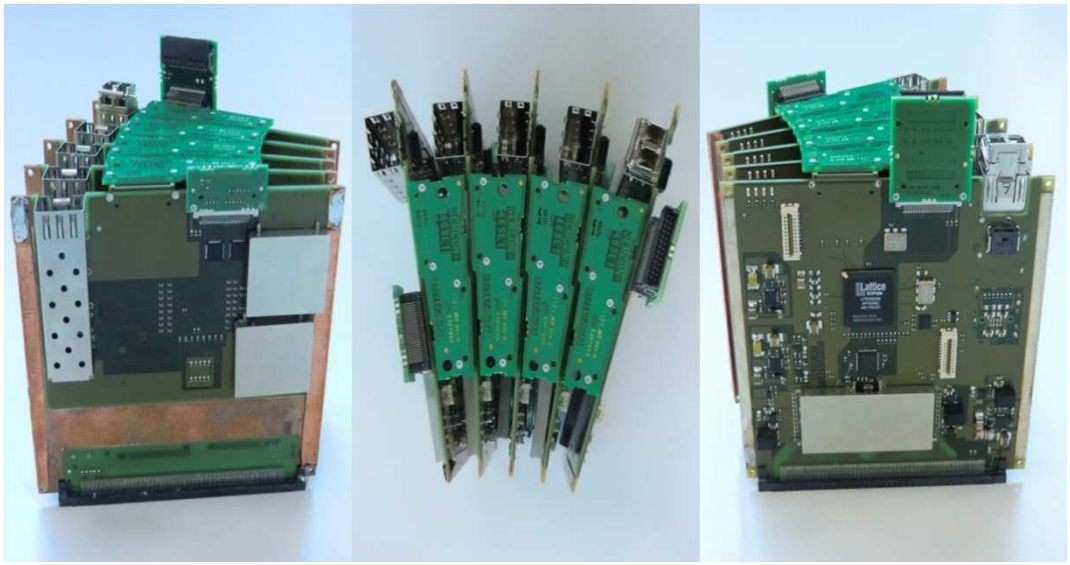
- PadPlane: Cartesian & 45°tilted strips
  - 450/150 µm width/gap, 250 µm thin flex
  - requires 1 Mio µ-vias & <100µm routing
- 2 out of 3 produced & part-mounted by CERN 1 short + 1 cut strip out of 3072 lines
  >1,5 years delivery time
- In-house QA infrastructure is missing

GEMEX FEB

Targeted detector systems

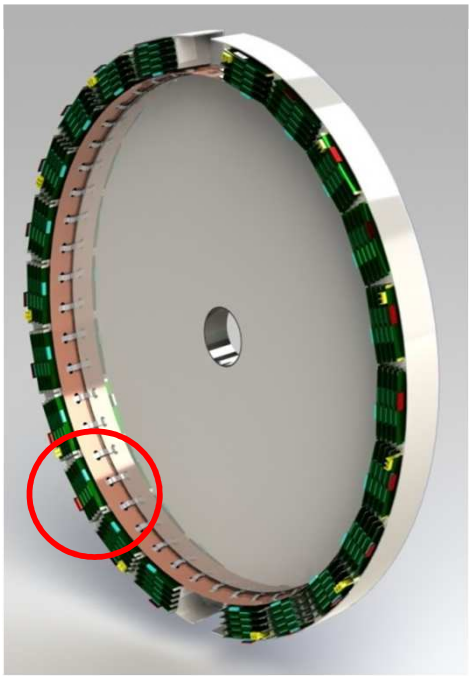
Medium-sized
Square-shaped
GEM2D
demonstrator
(3 kch)

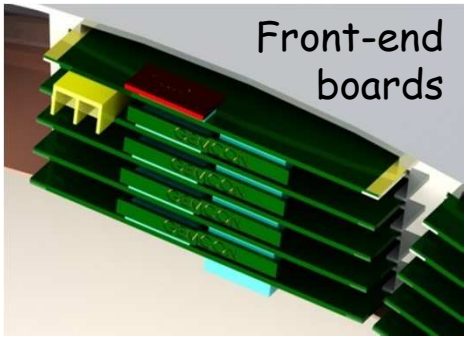




- High-density front-end boards with local intelligence
- 6 (80) kch, 24 (320) FEBs operated in groups with common supply, control, optical link
- Development at GSI
  synergies with other FAIR projects (SuperFRS, BioMat, ACC…)

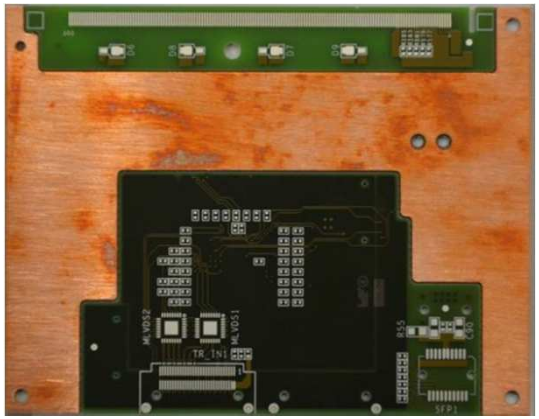
Large-sized
Circular-shaped
GEM-Disc detector
(20..45 kch)



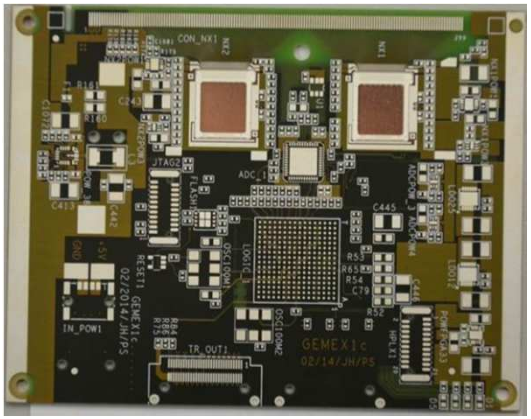


GEMEX 2.0 …a change in paradigm

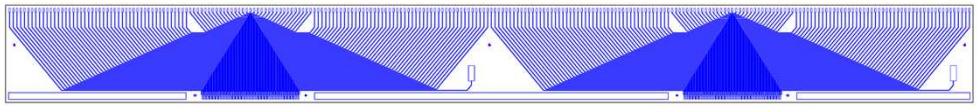
Back-



Front-side view

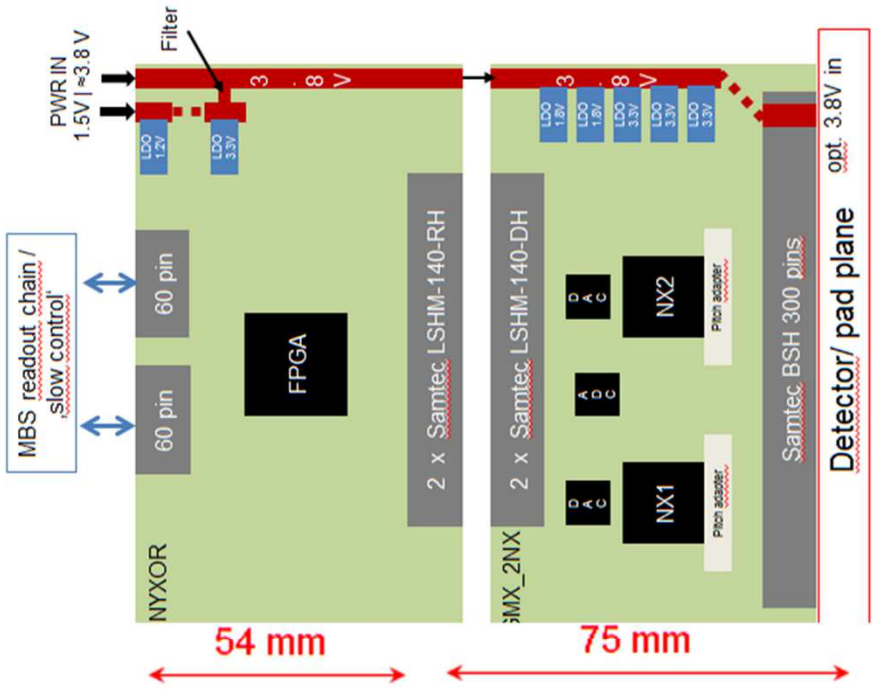


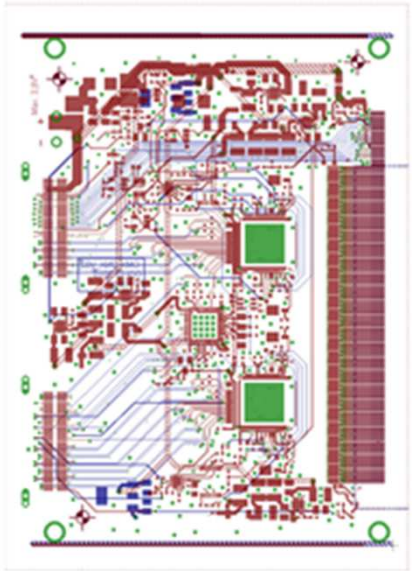
- Revision1C failed in 2014
  - Too low yield due to (50→100)µm bonding structures on PCB
  - Too high noise values during beam-tests at GSI (powering scheme)



- Change of concept:
  - Easier debugging & maintenance (interfaces accessible)
  - Make use of pitch adapters
  - Analog/digital parts split/modular
  - Timing scheme adaptable (self-triggered, white (grey) rabbit, SODA, …)

GEMEX 2.X





- XILINX Spartan 6 FPGA-based board (offering more building blocks)
- Successful in-beam application of the system performed in 06/07 2016 at GSI
- Some flaws found & addressed
- Revision pending
- Way to large, still ‘triggered’, synchronization (SODA) missing
- Engineers left the DL group
- So far only marginal support by EE

Work Packages / Status / Risks (1)

Item	Task / Workpackage	Work done…	to be performed…	Next Mile-stone	Potential Risk	Mitigation
1	**Simulation & Analysis (PANDA physics)**	Occupancy & hit-rates, detector response, general scenario (matter distribution) Resolutions & efficiencies for selected benchmark channels.	TDR contribution. Simulation of relevant physics channels (forward peaked), mass resolutions, efficiencies etc.	TDR	No qualified personnel available after 06/2017.	Train students already available. Extend contracts.
2	**Simulation & Analysis (Detector physics, GEM-functionality)**	Crude, integral detector response simulated successfully.	Clusterization & digitization	TDR	No qualified personnel available	Train students already available
4	**Mechanical Infrastructure: Support structure –** **Exo-skeleton (Riddle & Plug)** **Cable conduit (Devils head)**	First specimen of 'Riddle' done. 'Plug' conceptual studies done. Proof-of-principle studies performed successfully. Competent vendor found.	Update actual designs. Realize Riddle & Plug, Devils-head. Eventually find vendor.	TDR	No qualified vendor. No budget (90k), additional supervision efforts.	DIY with lots of 'infantry' & space
5	**Mechanical Infrastructure: Support structure –** **Detector-internal structures (Frames, Housing, Strong back etc.)**	Conceptual design of general build-up and planes/layer stacking/functional separation. Winding machinery designed and prototype built. Proof-of-principle studies performed successfully (LV, Gas).	Update designs, refine technologies, put in operation winding machinery, build & verify specimen, validate processes	Validation & Verification	Complete mechanical failure in parts requiring conceptual redesign.	
6	**Infrastructure for GEM & PP QA / Investigation (Development & Qualification).** **'TestBox' for optical inspection**	Conceptual design done, Multi-functional Test-Stand designed and built, GEM designs in first specimen in house	Find vendor for 'special' parts (microscopic system, GEMs) in order to perform QA ,	Realization of sub-systems	No qualified vendor for GEMs, money-wise contribution by NCBJ cut down, no external QA applicable	None !!! applicable
7	**Infrastructure: Cosmics test stand**	Not started				Set up an appropriate system

Work Packages / Status / Risks (1)

Item	Task / Workpackage	Work done…	to be performed…	Next Mile-stone	Potential Risk	Mitigation
8	**Thin large-area GEM foils (production & QA)**	Conceptual design for the GEM-DISCs done. Design for the GEM2D demonstrator finished, first specimen delivered.	Continue qualifying the designated vendor (TECHTRA). Start series production for the GEM2D demonstrator. Continue with GEM-QA.	GEM2D assembly	Low-quality of foils. Failure to produce large-area foils with the designated vendor.	Ask CERN for production (low probability to be successful due to capacity problems though)
9	**Large-area read-out structures (micro-patterned Pad-Plane ‚PP')**	Conceptual design for the GEM-DISCs done. Design for the GEM2D demonstrator finished, first specimen delivered	Continue qualifying the designated vendor (CERN). Continue with PP-QA. Integrate in GEM2D detector. Start designing the GEM-DISC PP.	GEM2D assembly	Low-quality of devices. Failure to produce large-area structures with the designated vendor.	None !!! applicable
10	**Mounting Support & -structures**	Conceptual design done. Partially 1st trial set up done.	Redesign & update required. Setup and tests with the real detector system.	(Riddle)		
11	**ASIC and FEE Adaptation and optimization** **Read-out, DAQ & DCS**	Proof of principle system based on n-XYTER (GEMEX) under construction. 1st batch tested with promising results.	Design and built radiation hard FEE in parallel to application of non-rad-hard 1st-day electronics. Check other options for the ASIC (e.g.VMMx).	GEMEX full-system test	No qualified personnel available. No rad-hard read-out available.	Find alternative FEE potentially available by the time of realization.
12	**Demonstrator (GEM2D) development and tests.**	Design done, Parts delivered except GEMs. Assembly and tests pending (lab & beam).	Assembly, full test cycles, application in beam.	GEM2D assembly	No qualified personnel to prepare the detector and perform the tests. No suitable analysis procedures developed (WP 1 & 2).	Add qualified personnel. Start with MC and analysis procedures in due time (depend also on availability of the FEE).

Work Packages / Status / Risks (3)

Item	Task / Workpackage	Work done…	to be performed…	Next Mile-stone	Potential Risk	Mitigation
13	**TDR writing**	Preparatory work done while writing CT-TDR (GEM-TPC)	Collect input & write.	M3	Risk of delays, esp. in QA issues	Start as early as reasonably possible (9 month 'lead-in' time for FAIR to decide).
14	**Prototype (close to final)**	Conceptual design done.	Everything else up to here (see above)	M8	Added risks due to larger area for GEMs and PadPlane parts.	Start qualification procedures / develop algorithms, set up appropriate infrastructure.
15	**System Tests in laboratory and in beam.**		Set up & operate various production- & test-stands		No qualified personnel to prepare and perform the tests. No suitable analysis procedures developed (WP 1 & 2).	Add qualified personnel.
16	**Final detector production, assembly and integration**	Conceptual design done.	Everything else up to here (see above)	M9	Space for assembly not assured so far.	Start negotiations and allocation in due time (Q4/2017)

Summary

Overall…

- At all time we found the solutions required or are on the way technically and with respect to simulation it just takes time
- So far there is no major problem with the ‘detector’ budget but rather with ‘infrastructure’ and the way we spend it
- No show-stopper to be faced so far, nevertheless…
  - The project isn't driving full throttle, support up to now is moderate
    We are behind schedule by at least ≈2,5 years
  - TDR writing can start only if general problems are solved
  - We may catch up, but only if there will be more support, faster decisions, more enthusiasm

GEM-Tracker (54) 'Alumni' members & tasks

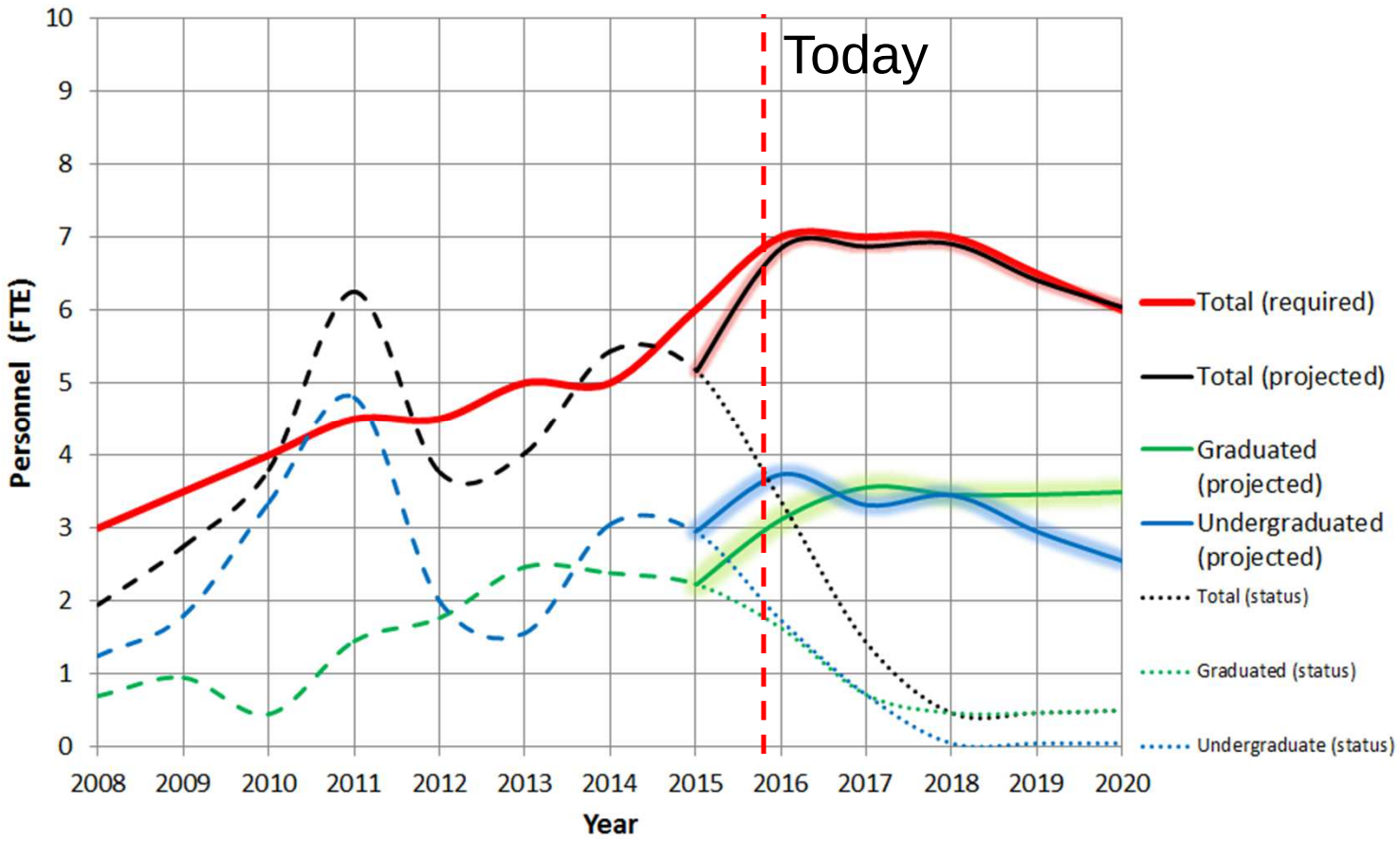
GSI

Yannick	Ahouannou		GEM-Frame Wickelvorrichtung
Dirk	Auer		Moulds, FEM simulations
Rahul	Arora		GEM Generals
James	Bailey		GEM-QA
Farsane	Baraki		Electronics, Testumgebung
Olga	Bertini	(HIM)	Phys.-Simulations (setup-wise, PANDARoot)
Maher	Bouzayene		GEM-Frame winding
Patrick	Breckner		Electronics Part Mounting
Philipp	Castorph		T-Sensors
Armstrong	Djoumessi		FEE, Testing
Nico	Donaera		Electronics
Lukas	Dritschler		GEM-QA, Prozessteurung
Mouhssine	El Hayani		GEM-Frame Wickelvorrichtung
Mohamed	El Khallali		GEM-QA
Sebastian	Fesissow		General supplies
Atif	Fouad		GEM-Frame Wickelvorrichtung
Mario	Gagulic		GEM-stretching
Siavash	Ghasemzadeh-Asl		FEE, Testing
Daniel	Glaab		GEM-Frame
Andrii	Gromliuk		Design (GEM2D), Det.-Simulations, Electronics
Andreas	Heinz		PadPlanes, GEM generals, Sensors, WebInfo
Markus	Henske		Sensors, Cooling, Purchase
Houssem	Jmour		GEM-Frame winding
Isidore	Kameni		GEM-QA, Prozesseinrichtungen
Ingo	Kaufeld		General mechanics
Can	Kaya		Supplies Conduit, set-up & functional tests
Volker	Kleipa		Analog electronics
Eugen	Kramer		Electronics
Jochen	Kunkel		General mechanics, drawings, assembly
Mathias	Lieb		Electronics
Mohamed	Maataga		GEM-Frame Wickelvorrichtung
Dima	Melnichuk	(NCBJ)	Det.-Simulations (GEM/PadPlane, Garfield)
Witali	Merker		Electronics
Yves Moriaz	Ngassa Tchangang		GEM-Frame, Process realization
Robin	Molatta		Electronics, Sensors
Milad	Nuri		Supplies Conduit, set-up & functional tests
Rouven	Plewe		GEM-Design
André	Remers		Riddle, Moulds (outer)
Bodowin	Renner		Electronics
Jörg	Reuss		Riddle-mould, Handyman
Nami	Saito	(HIM)	GEM-QA, data analysis
Sarah	Schütz		Support & Insertion tool
Marco	Seibert		Electronics
Ivan Fernando	Soriano Osornio		Electronics, Partmounting
Daniel	Soyk		Detector Simulations
Clavel Janvon	Tchatcho Bitchou		Electronics
Eldrige	Tchoua Yamedji		GEM-Disc Moulds, Fasteners
Jessica	Tischer		Support
Eduard	Traut		GEM generals, Moulds (outer & inner)
Elena	Traut		Cabling & Infrastructure
Mirabelle	Tsadjeu Tsamo		Electronics
Jan	Voss		General mechanics, GEM generals
Tobias	Weick		Moulds

GEM-Tracker (10) 'Active' crew members & tasks

Name	Affiliation	Task	%	Type
Christoph Cäsar		Front-end electronics, Testing	5	PostDoc
Nazila Divani Vreis	HIM	Phys.-Simulations (setup-wise, PANDARoot)	100	PhD
André Ehret*	HIM	General mechanics & FEM simulations, Supplies, Conduit, GEM(-QA, Framing, Processing)	100	Eng
Andrea Neeb		Relief person, gofer	10	Student
Sandra Schwab		CAM	5	Tec
Carmen Simons		Bonding	5	Tec
Bernd Voss		Project, ‚All & nothing'	25	PI
Joachim Weinert		CAM	5	Tec
Takehiko Saito	HIM	Project		PI
Bogdan Zwieglinski	NCBJ	Project		PI
	&… the GSI-DL & central infrastructure (mainly mechanical & electronics workshop) * to be employed >10/2016			

Personnel evolution: Trending & Request



'Unhealthy 'Ratio under-/graduate
2:1 (in FTE)
5:1 (in 'hands')

Personnel engaged so far	#
Semi-skilled	5
Student Trainee	43
Bachelor	17
Master	4
PhD	3
PostDoc	2
Staff Engineer	7
Staff Physicist	1
Total persons engaged	65
Total pieces of work	66

2008-2015: 'low-budget' concept – reduced staff supplemented with students as 'multipliers' – worked reasonably well

2016-2018: drop-outs and reduction of trained personnel while facing increasing work load

→ requires compensation by 3 qualified FTE right away

‚graduate' = qualified
(staff, engineers, PhD, Master)

‚undergraduate' = semi-skilled
(Bachelor students, student trainees)

Vulnerable spots

- We suffer from a substantial drain in permanent man-power in the past 5 years, partially due to unspeakable hic-ups in the whole project
- Man-power in specialized engineering & ‘hands-on’ work is required
- Enforcement would be well appreciated in the fields of… (e.g.)
  - Mechanical design (here we seem to be on a good track)
  - Operation of lab-infrastructure
  - (Data Acquisition) & Analysis
  - Cooling
  - Detector Control System

Backup

PANDA GEM-Tracker Benchmarking

Benchmark channels

pp	pA	Channel	Final state	Related to MVD	Related to CT	Related to FT	Arguments / Aims
→		$(n)\pi^+\pi^-$	$(n)\pi^+\pi^-$		X		
→		$\psi(3770) \rightarrow D^+ D^-$	2K 4π	X	X		Secondary vertex tagging capability Special consideration of the slow π coming from the D* decays K, π tracking and momentum measurement
→		$\psi(4040) \rightarrow D^{*+}D^{*-}$		X	X		
→		ΛΛ	$p\pi^-p\pi^{+-}$	X	X	X	Λ reconstruction, partly only with CT (~15%) → tests vertexing capabilities of CT Incorporates also cascade decays outside MVD
→		ΞΞ	pp 4π	X	X	X	
→		$\eta_c \rightarrow \Phi\Phi$	4K		X		PID studies and V^0 reconstruction with CT
	→	J/ΨX	2l X	X	X		High p_T lepton tracks in multi-track environment → CT important for momentum measurement nd tracking
→		pp	pp	X	X	X	important for FT background studies for CT and MVD

Planar GEM-DISCs …in numbers

Feature		Param./ Total	GEM1	GEM2	GEM3
Position from target		(mm)	1170	1530	1890
Outer (active) radius		(mm)	450	560	740
No. of	GEM foils	3 x (2x3)	Single foil	Patched or large-area	
	GEM sectors	2028	384	600	1044
	pad planes	3	1, double sided		
	projections	12	4		
Simulation result		HIT-rate	5..140 k particles/cm^2/s (r)		
		Track Length	radial 1..4 mm mean 2,2..2,4 mm angular 0..0,8° mean 0,2°		
Readout geometry		4 options	Cartesian (x,y) Radial strips	Concentric circles Tilted strips (+60°,-60°)	
Structure pitch (resolution driven)		Radial Concentric	400..800 µm 400 µm	50 mm < r < 150 mm 150 mm < r < 450 mm	
Channel no.			10k (20k)	11k (32k)	15k (45k)
Weight (kg)			20	30	40

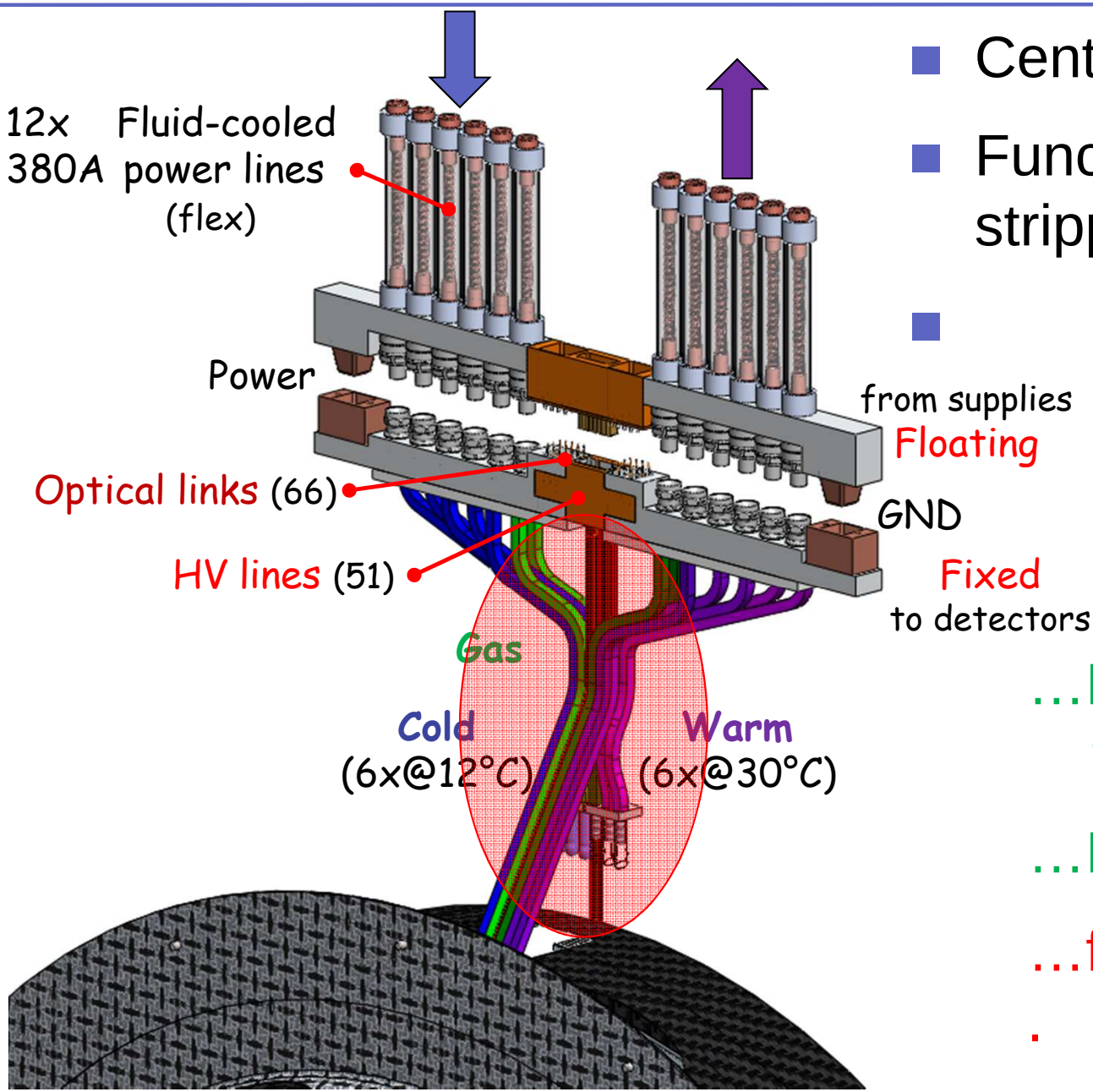
Planar GEM-Trackers …in numbers

For the set of four (in%)	Active	Absorber (no backing)	Supply	Support	Front-End
Weight Contribution	0,5	4	≈ 33	≈ 34	≈ 28
Radiation Length design goal	0,093	1,405	n.ev.*)		
Radiation Length status quo technique	0,093	3,485			

*) ‚n.ev' = not evaluated so far

⇨ Requested 0,5% X_0 per detector achievable

Supplies conduit Internal panel



- Centrally locked interface
- Functionalities (protection, shield, etc.) stripped & grouped
- Rectangular Al-tubes
  Standard & customized plugs

…panels with housing removed

…Fabrication of various test samples started

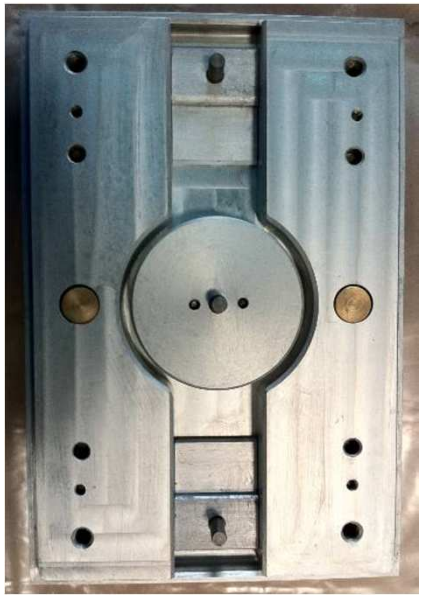
…Feasibility tests performed

…further pathway through
. PANDA TS still to be routed

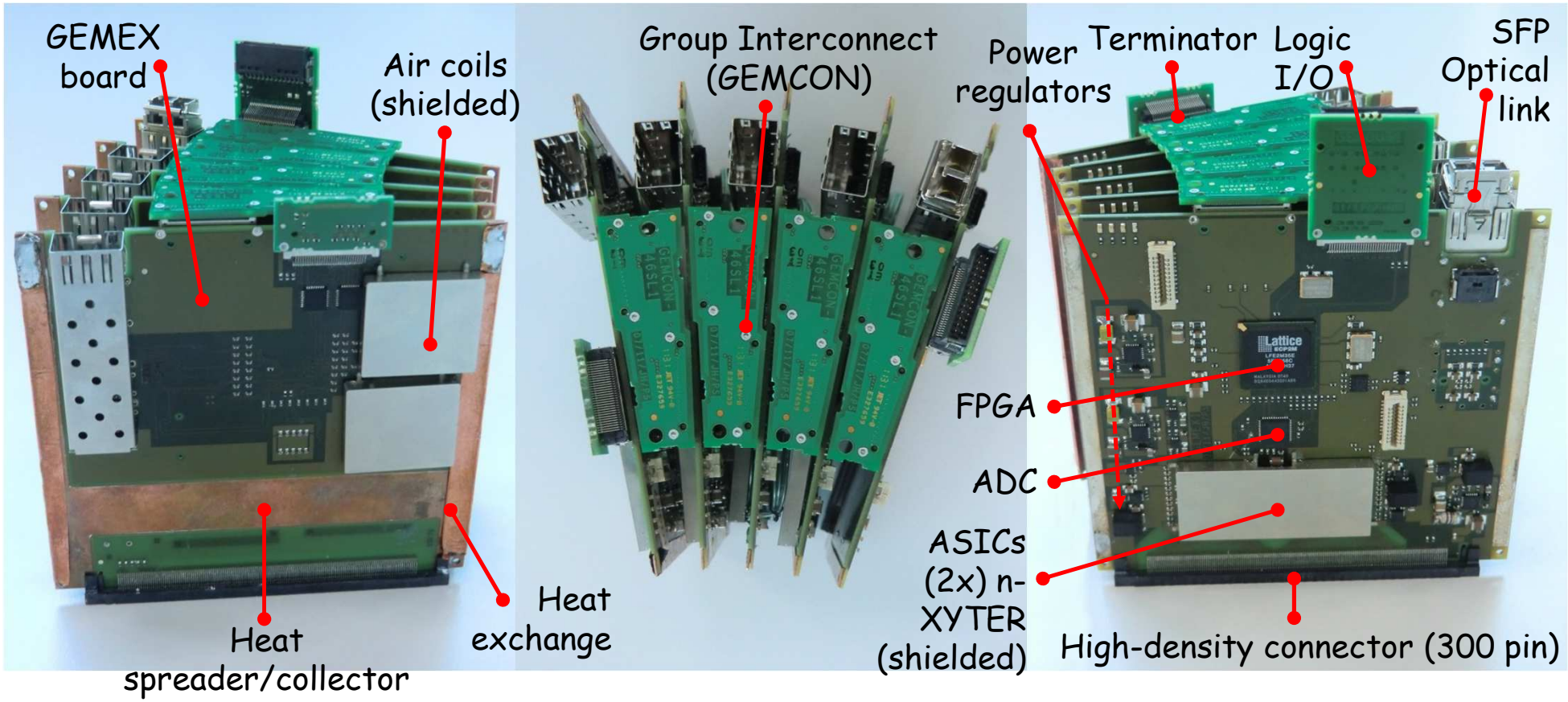
Tools: planar mould large scale puzzle

- Very precise 100 µm
- Various thicknesses 0,5..10 mm
- Various diameters 900..1500 mm
- Quite costly ~10 k€

- Waiting to be applied since 08/2011



GEMEX FEB Realization (V1.0)



- 104 mm x 95 mm x 26 mm
- Groups of up to 16 cards
- 1 SFP (2Gb/s) per group