FAIR Facility for Antiproton and Ion Research

HadronPhysics I3

Study of Strongly Interacting Matter

GSI

GEM-Detector Projects

(GEM-TPC & Planar GEM-Trackers)

p̄anda

Bernd Voss
Helmholtzzentrum für Schwerionenforschung GmbH (GSI)

GSI Detektorlabor

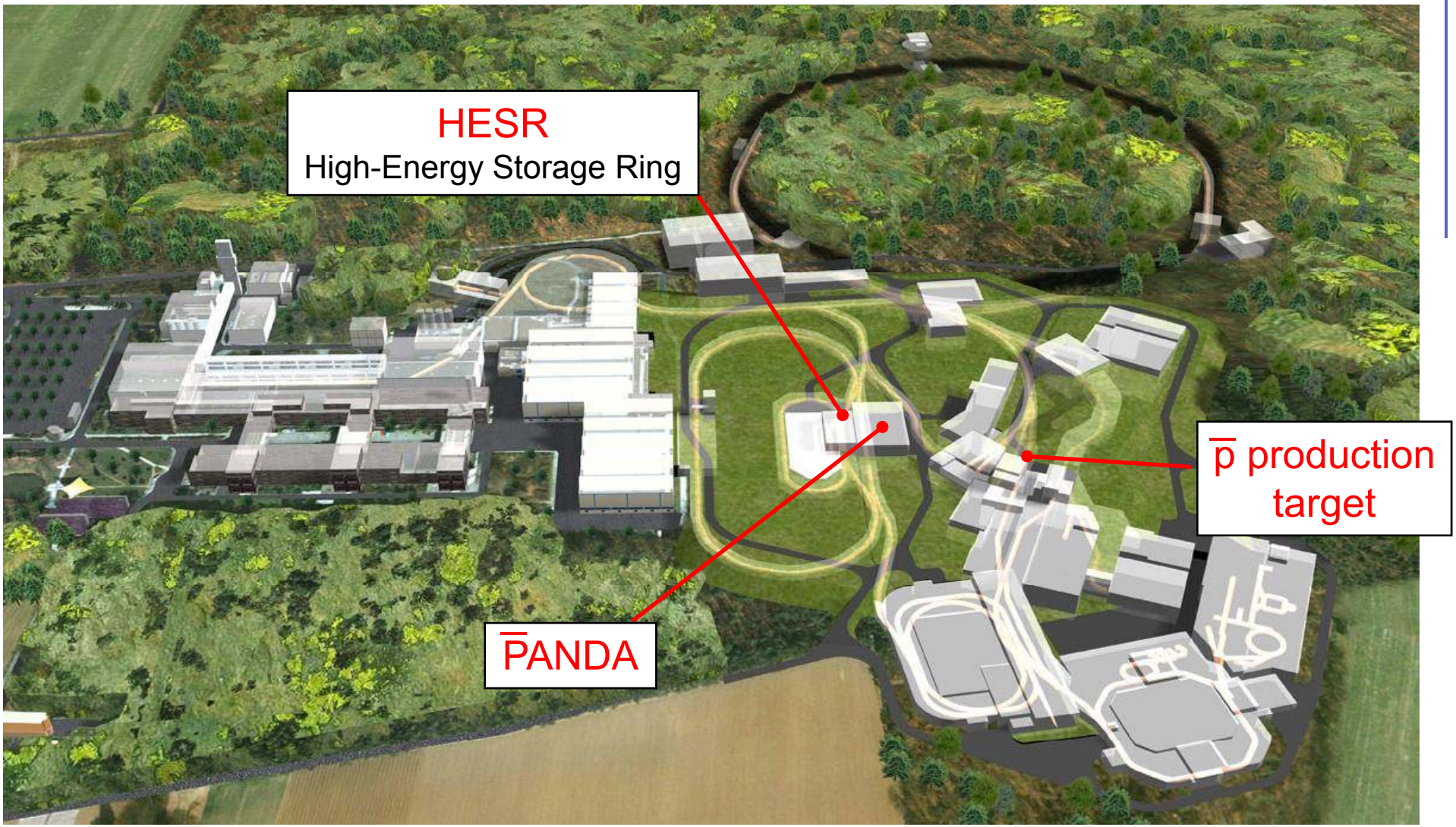
DL

Outline

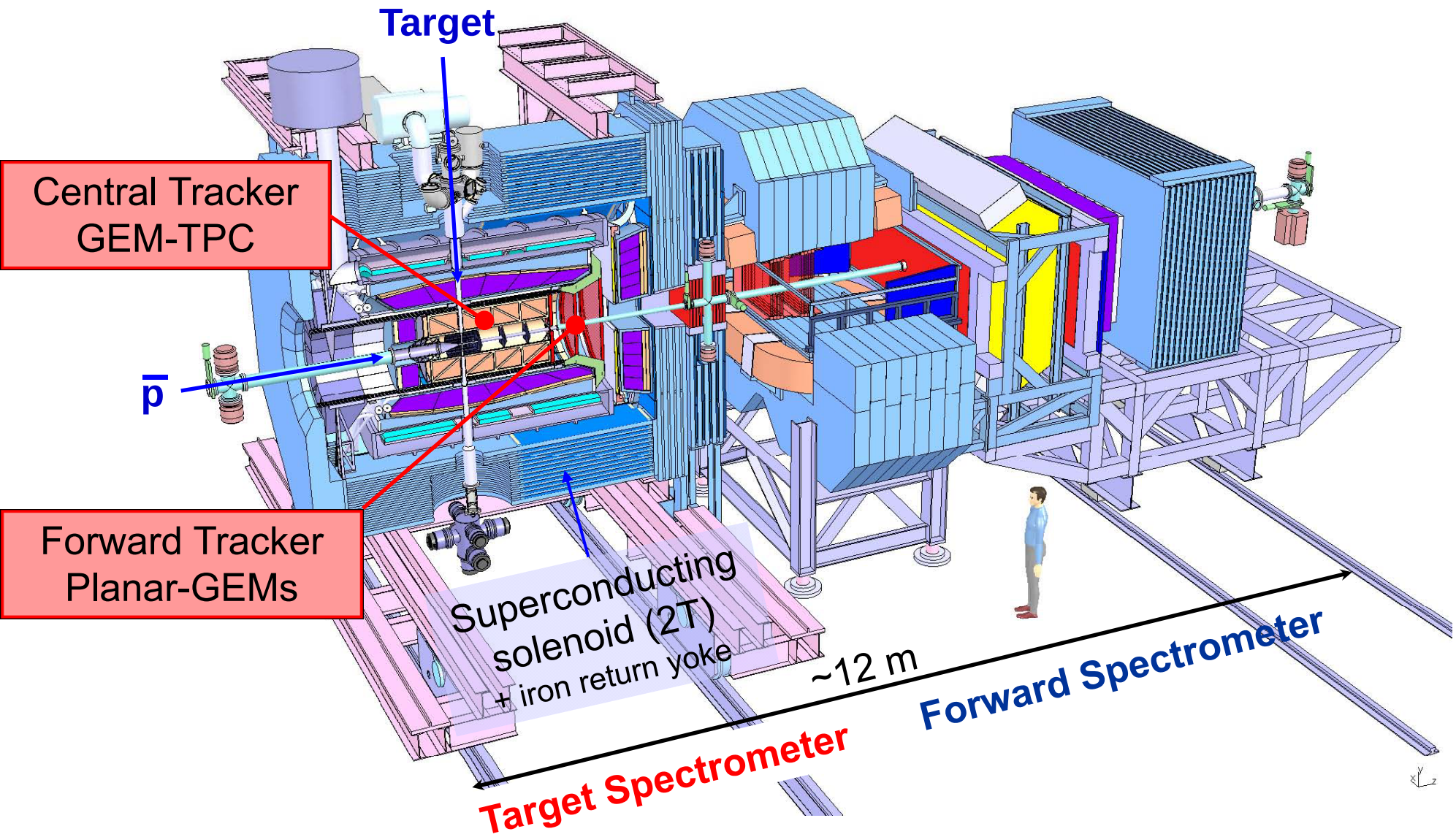
The Experiment	PANDA@FAIR
The Detectors	Tasks, Requirements & Set up
	Basic design & Detector assembly
Simulations	Particle flux & Tracks
Pad Plane	Design & Consequences
Front End Electronic	The XYTER Family
Higher Level Readout	SysCore / Exploder
First Results	Noise figures
The Future	Towards a FAIR-XYTER
Integration	Detector Control System
	Detector Mounting
Road Map	'JointGEM'

The site

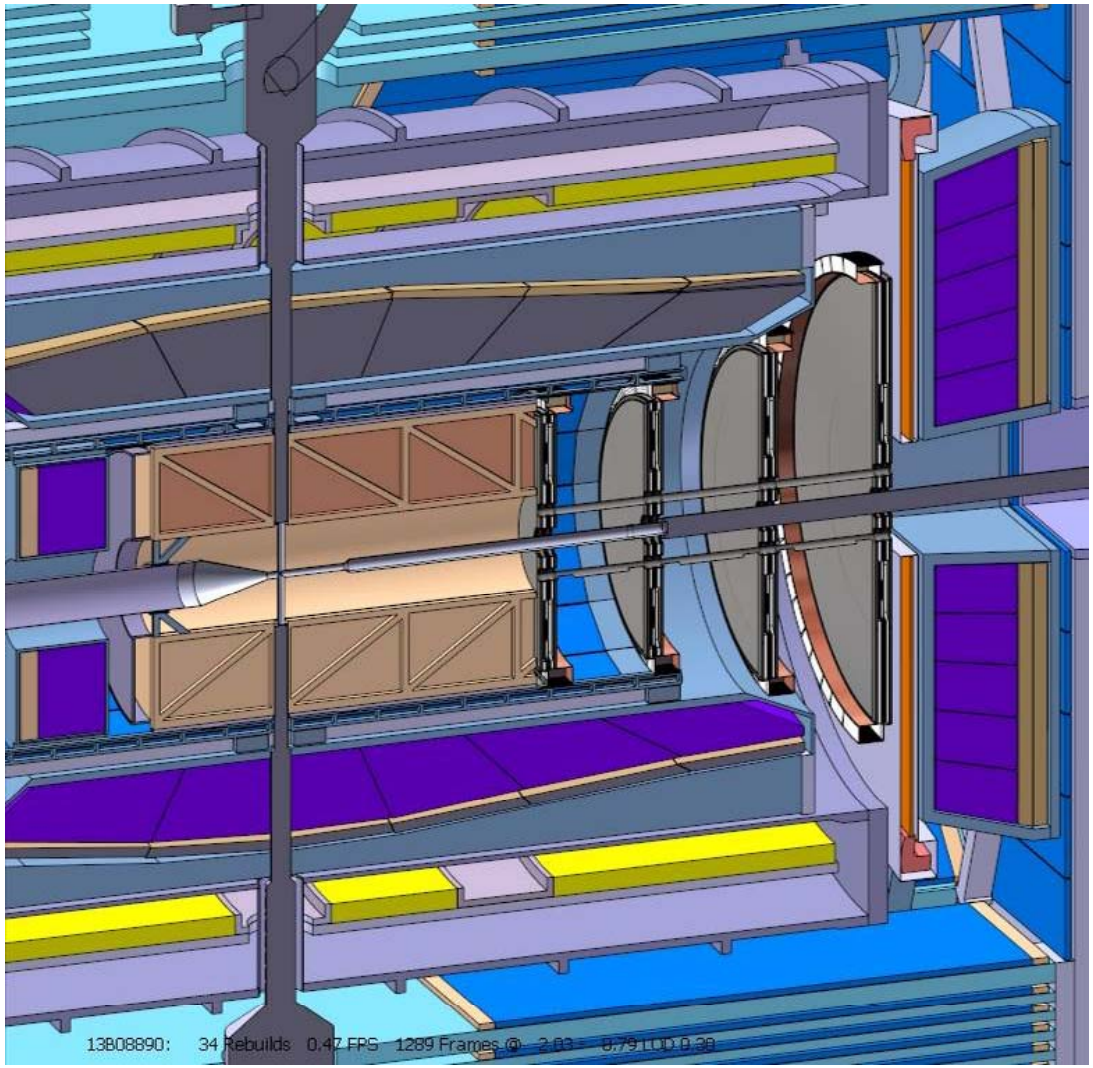
Facility for Antiproton and Ion Research Darmstadt, Germany



Setup Overview



Basic assumptions



Target spectrometer@PANDA 'V833'

- Figures of Merit:

  Particle identification

  Momentum resolution $\delta p/p$ (p,θ,z,r)
  - particle momentum p
  - scattering angle θ
  - vertex coordinates z, r
- Basic assumptions:
  - GEM-TPC
    ('short' version: 1,5 m → 1,2 m)
  - GEM-Tracker, 3..4 stations
  - Maximize shape-conformity
    Full angular coverage (φ)
    not possible
  - Radiation hardness 100 krad

GEM-Detectors@PANDA Requirements

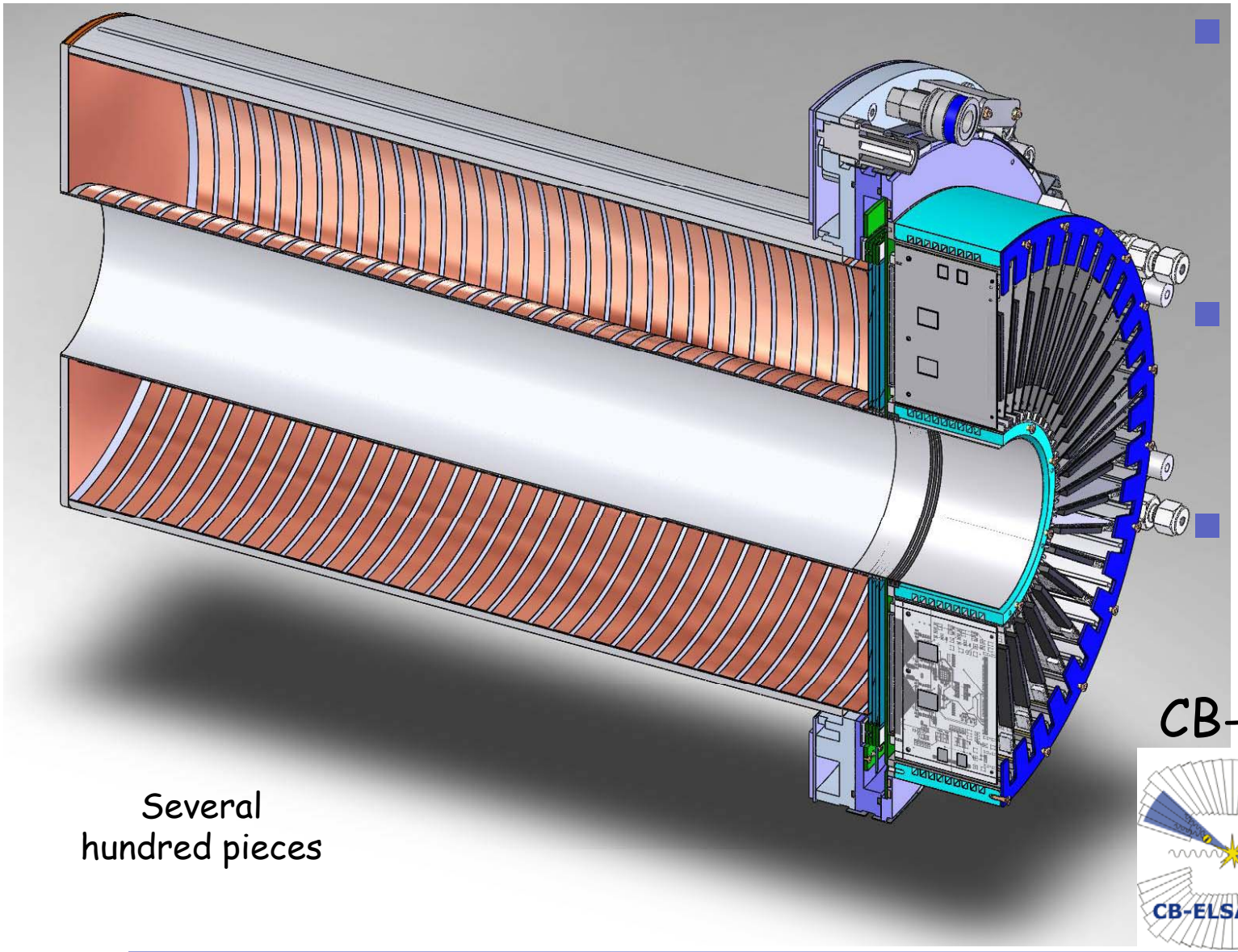
	Planar-GEM Trackers		GEM-TPC	
Figures of merit	Momentum resolution		+ Particle identification	
Resolutions	Position Double track	$\sigma_{r\Phi} \approx 100$ µm ≈ 10 mm, 5°	Secondary vertex	$\sigma_{r\Phi} \approx 150$ µm $\sigma_z \approx 1$ mm
	Momentum $\delta p/p \approx 1$ %			
Solid angle	5..18° (2..26°)		near 4π	
Material budget	0.5 % X_0		1% X_0	
Features	Operation in magnetic field (2T)			
	high granularity, fast signal multi-track resolution suppressed ion-feedback, reduced ***E*** x ***B*** effect			
Challenges	High count rate Low B-Field Low curvature		Continuous operation: Space charge (5 charged tracks/event) Event mixing	

GEM-Detectors@PANDA ...in numbers

Feature			GEM-TPC	GEM-T1	GEM-T2	GEM-T3	GEM-T4
Length (active)		mm	1500	60			
Position from target		mm	-400..1100	810	1170	1530	1890
Radius (active)	inner	mm	150	25..50			
	outer	mm	420	450		560	740
Area		mm^2	0.5	0.6		1	1.7
No. of	GEM foils		3	2 x 3, Single foil		2 x 3, Patched or large-area	
	GEM sectors		300	384		600	1044
	Pad planes		1, single sided	1, double sided			
	Projections		2	4, 2 tracklets			
Readout geometry			Hexagonal pads (x,y)	Cartesian (x,y) Radial strips (r)		Concentric circles (φ) Tilted strips (+60°, -60°)	
Structure size/pitch (resolution driven)			4 mm^2	radial concentric	100..600 µm 400 µm	50 mm < r < 150 mm 150 mm < r < 450 mm	
Max. channel no.			80k	20k		32k	45k
Weight		kg	50	20		30	40
Gas			Ne/CO_2 (90/10)	Ar/CO_2 (80/20)			
Drift time / -velocity			50 µs, 2.8 cm/µs	n x 10 ns			
Cabling		mm^2	10000	10000			

Prototype GEM-TPC

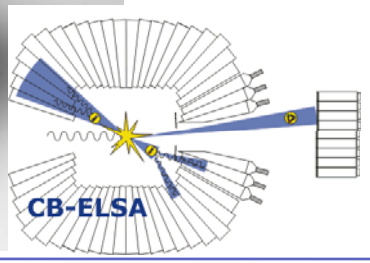
Detector assembly



Several hundred pieces

- Prototype
  - L: 650 mm
    D: 300 mm
  - Modular
- Under construction at GSI-DL
- To be tested 2009 at:

CB-ELSA

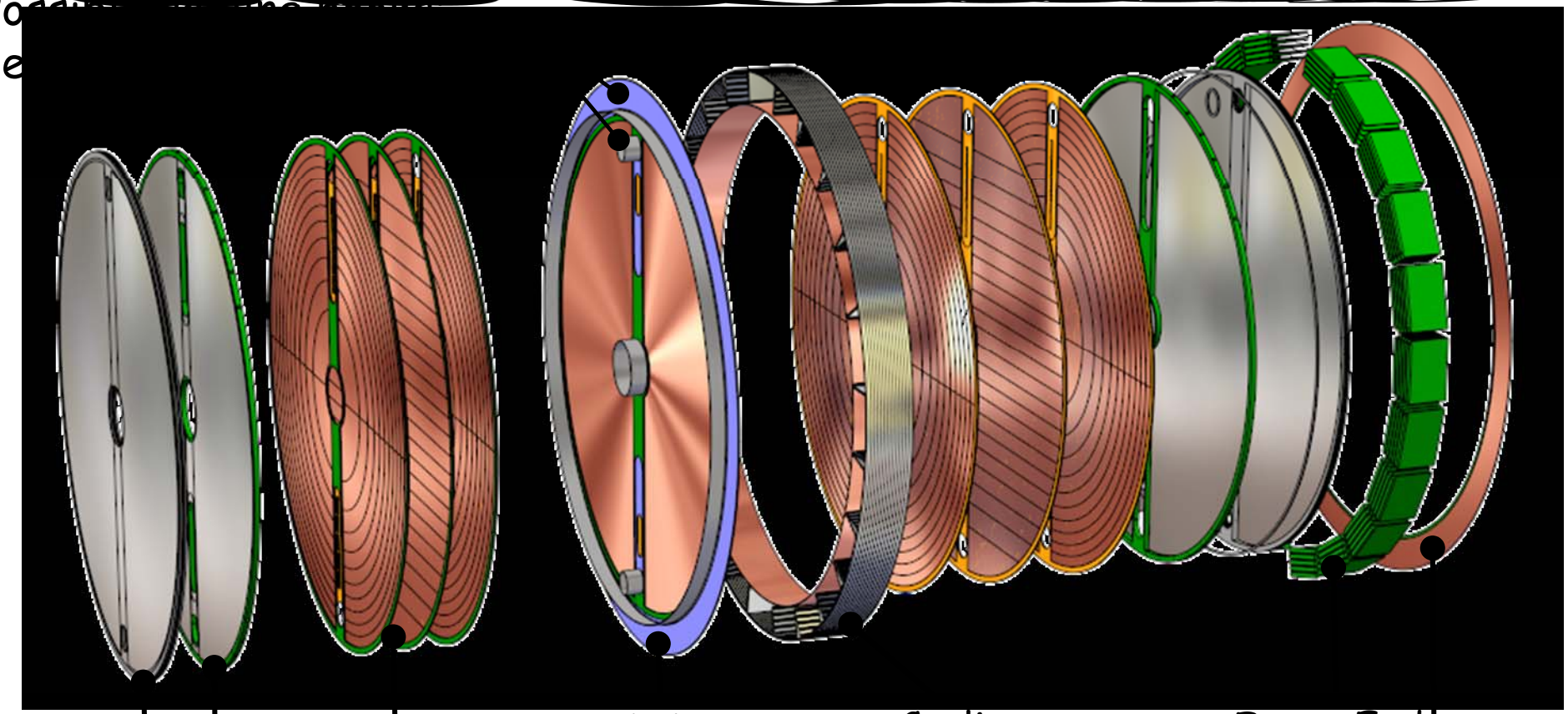


FOPI

Planar GEM-Trackers

Detector assembly

Po[redacted]
ce



Window

Drift electrode

GEM stack

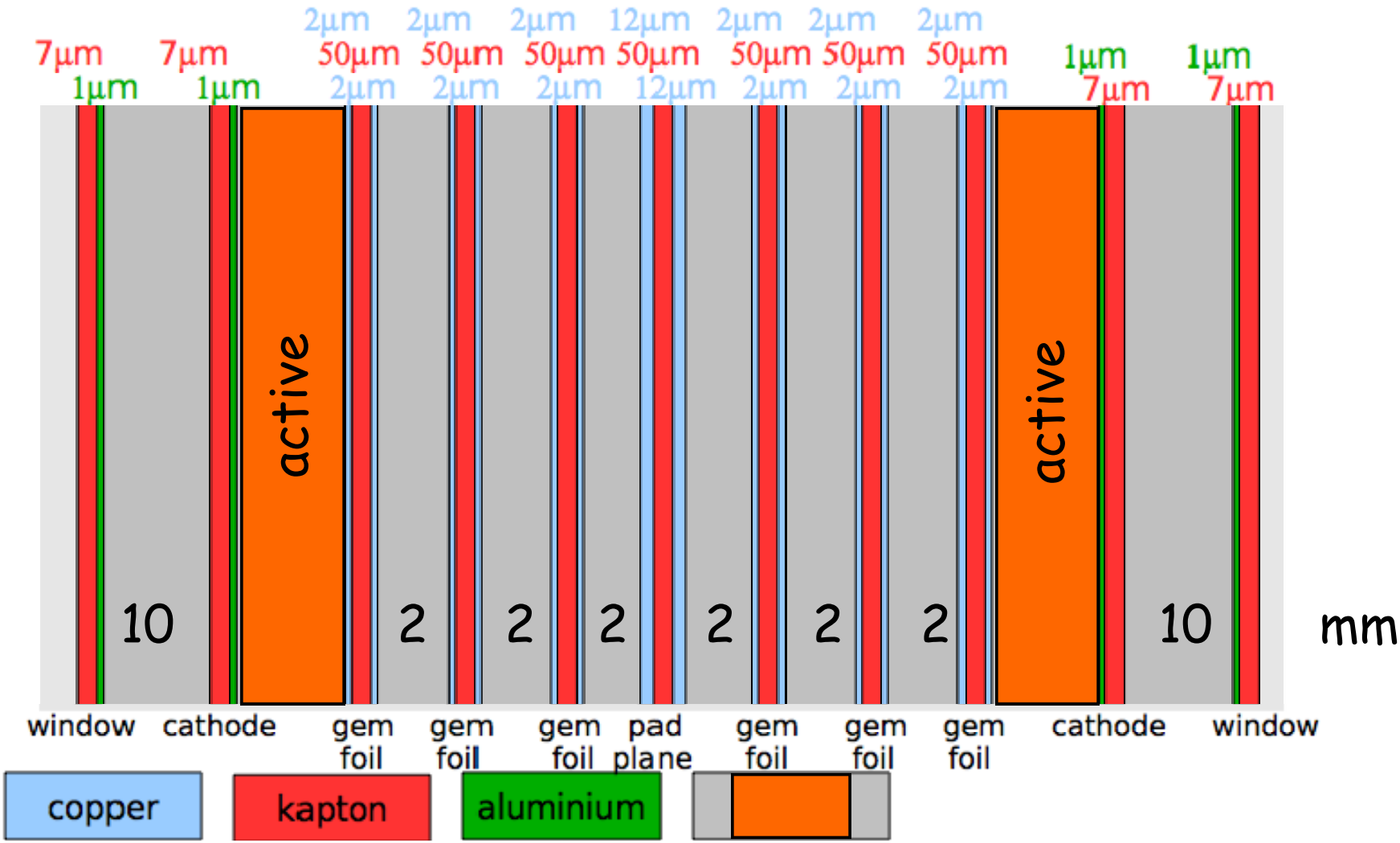
Pad Plane Support & Media-Distribution

Cooling Support & LV- Distribution

Front-End Electronic

Shielding Cover & Read-out Plane

Planar GEM-Trackers Layer stacking



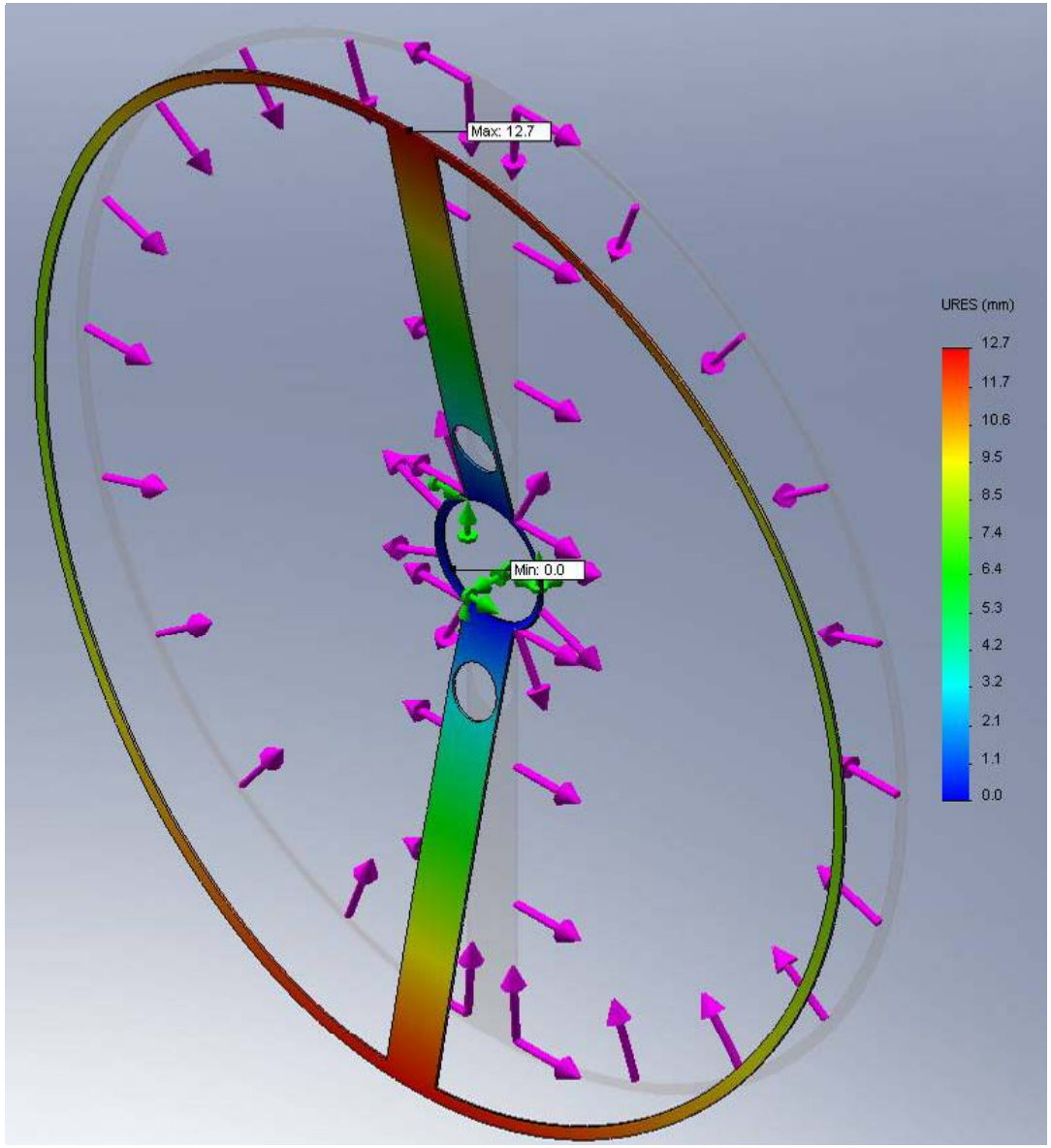
Planar GEM-Trackers …in numbers

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

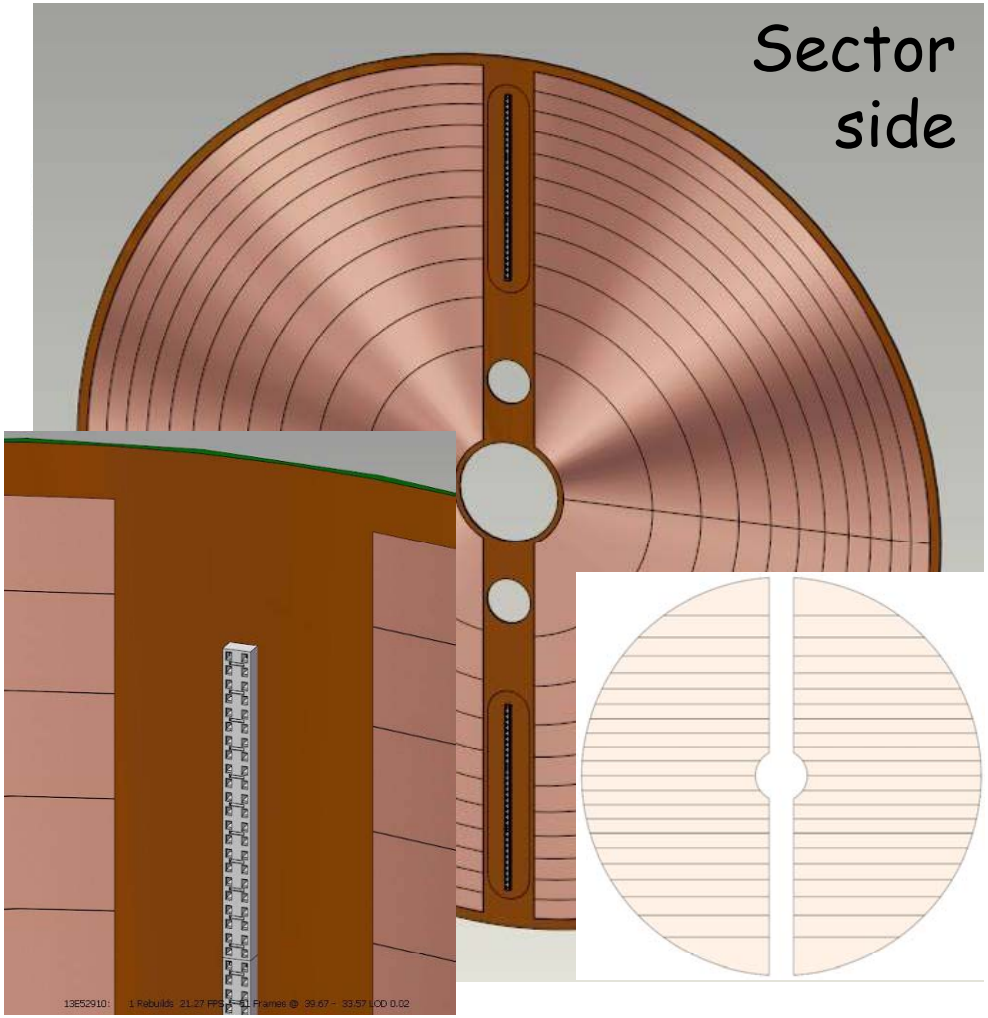
Detector Structure Basic design concepts



Maximum deformation (mm)			
U_x	U_y	U_z	U_{res}
±1,5	± 0,24	12,7	12,7

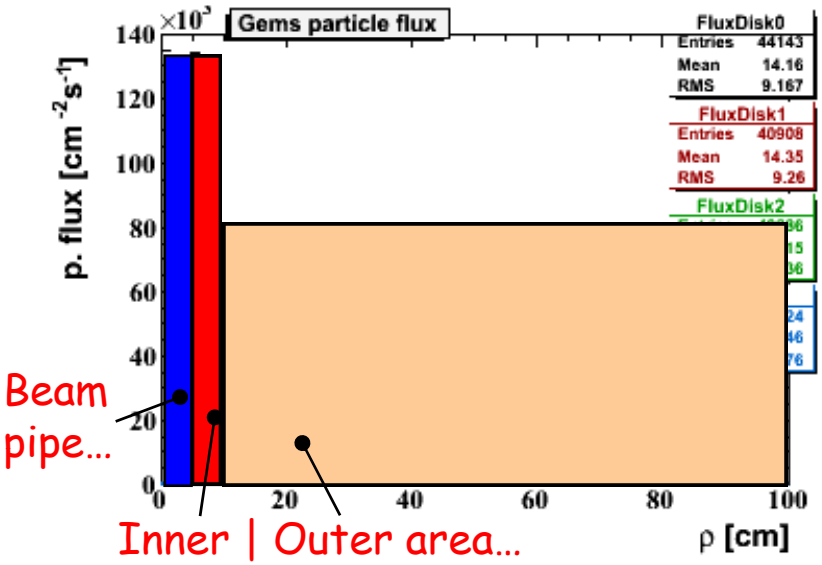
- Design input:
  - ! Minimize material budget
  - ⇨ No mechanical backing structure
  - Symmetric frame layout
- FEM simulation:
  - Planar stretching forces by foils
- Results:
  - Much better than half-disk layout
  - Deformations manageable
  - Still needs some support
    e.g. point-like on outer rim
- Open questions:
  - Sagging of foils
  - ⇨ Spacers
    (e.g. fishing lines opposing foil layer)

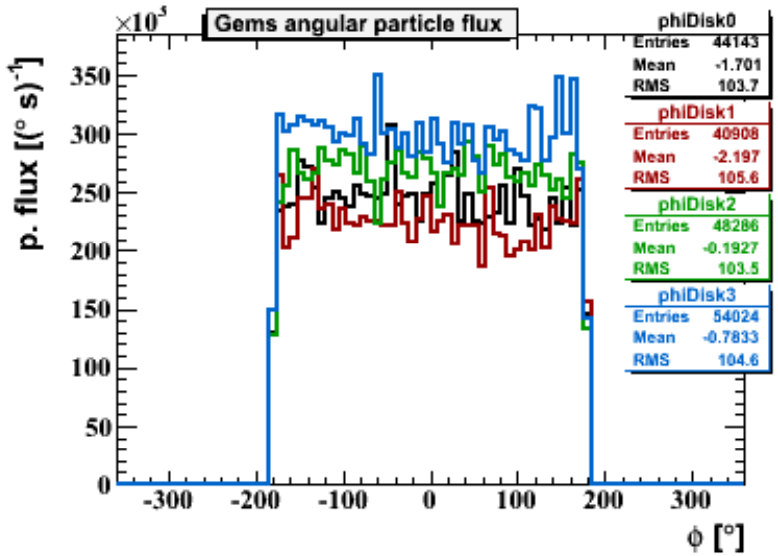
GEM-Foil Sectioning



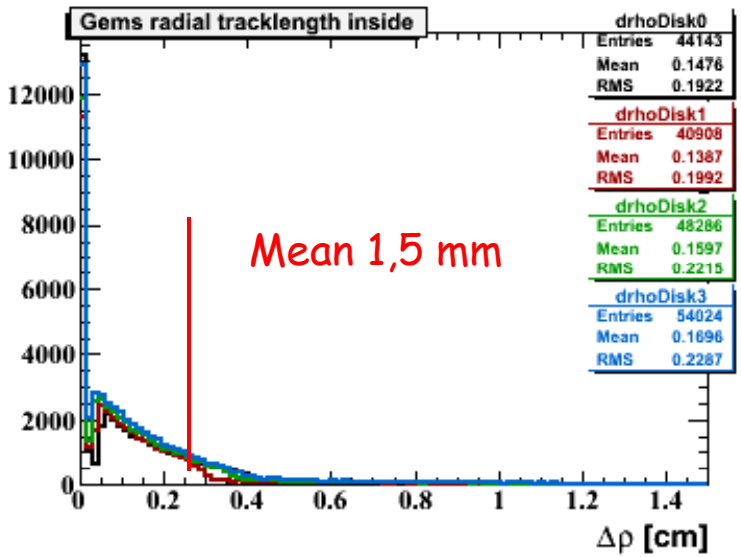
- Discharge prevention
  - Triple GEM setup (per side)
  - Asymmetric gain sharing
  - Segmented foils
- Requirements:
  - ! Max. 10^4 mm^2/Sector
  - ! Avoid dead areas
  - ! Avoid gluing to copper
  - ! Easy contact scenario including series resistors
- Layout:
  - 2x5 µm Copper on 50µm Kapton
  - Inter-sector distance 0,1 mm
  - Combine ¼-circles & strips
  - Contact from window frame (surface) via trough-hole SMD connectors

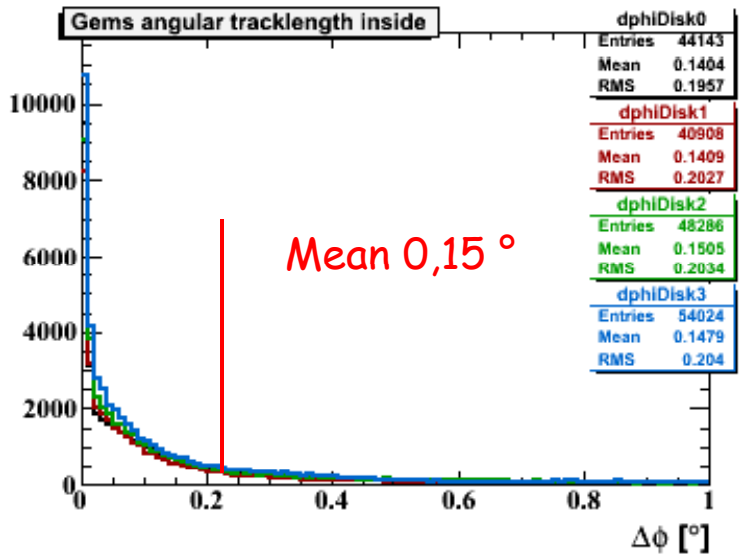
Planar GEM-Trackers Simulation results@15GeV/c





'Standard' physics run $2 \cdot 10^7$ annihilations/s





⇨ Structure size

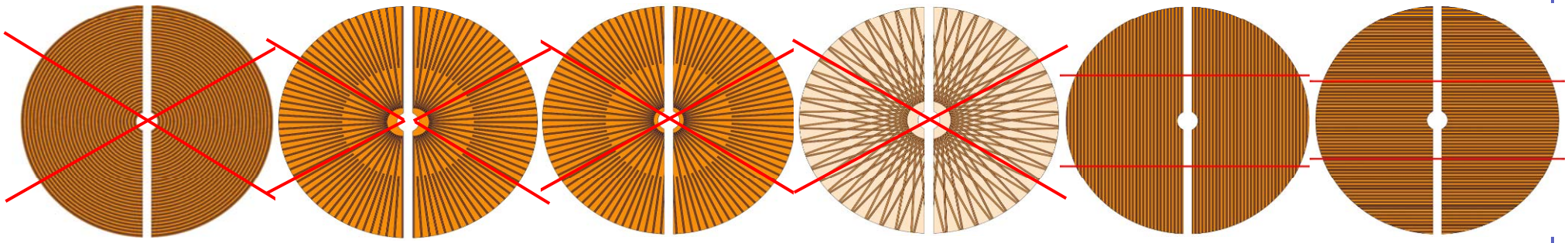
Ralf Kliemt (TU-Dresden) confirmed by Radoslaw Karabowicz (GSI)

Basic design concepts

- Simulation results:
  - HIT-rate 5..50(140)k particles/cm^2/s (r)
  - Track lengths: radial 0,5..8 mm (mean 1,3..1,6 mm)
    angular 0..0,8° (mean 0,15°)
  - Cluster sizes <1 mm (single-cluster HIT to be avoided)
- Purely resolution driven
- Patterning structures under investigation
  - 2D, pitch 400µm, 2 combined on every side
  - Strips
    1. Circular/polar + Radial
    2. Circular/polar + 60° Tilted
    3. Cartesian
  1. Pixels – regular polygon shapes
  2. Hybrid readout structures

PadPlane

Pattern design



GEM	Circular	Radial ‚*acentric*‘	Radial ‚*isocentric*‘	60°Tilted	Cartesian
1/2	5888 (1571)			5880 (2096)	
3	9600 (1571)			9600 (2096)	
4	13440 (1571)			13400 (2096)	

Required for constant resolution, Assumed in simulations

- Problems with Patching (GEM4)
  - Patching process → Dead areas & Increased material budget (Support & Additional routing layers)
  - Signal routing → Cut channels → unequal length, non-uniformity in response

Front-End Electronic General ideas

- Pad Planes
  (3..4 GEM-Ts)

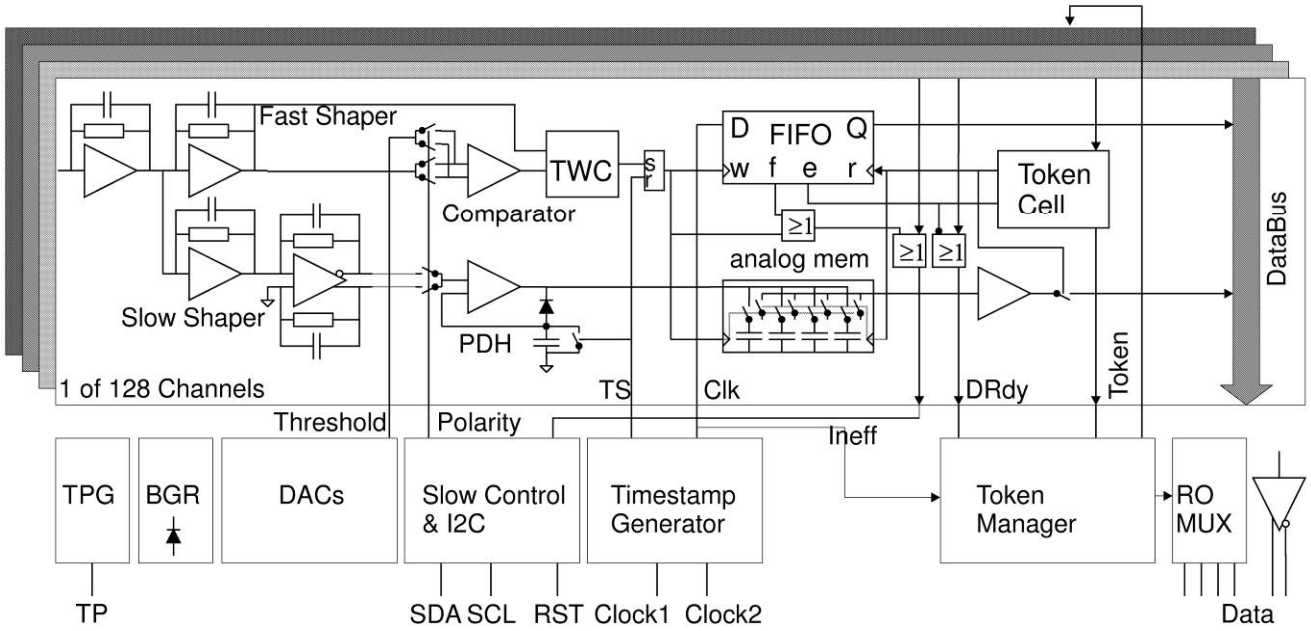
Structure size	Resolution evolution	Channel no.	
0.3..0.5 mm	decreasing	20..26	kch
	constant	96..116	kch
1 mm	constant	80..95	kch

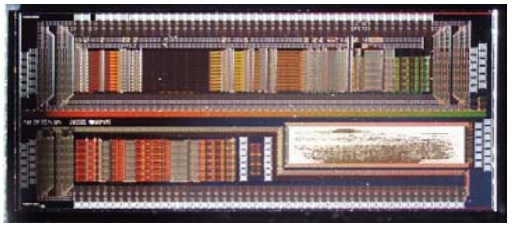
- FEE system (to be used with TPC & Trackers)
  - 'Division bar' not sufficient nor feasible
    Circumferential arrangement FEE-Ring width ≤ 50 mm
    ≈ 7..11% of total detector area
  - (n-)XYTER-based FEB cards 180..900 cards
    (2 ASICs à 128 channels each, 100x65mm^2)

  ➔ overall operating power 21 mW/channel → 2,7 W/chip !

  ➔ ≈ 1..5 kW power/cooling requirements, Axial cooling structure,
  ≈ 30% of weight

Front-End Electronics (n-)XYTER

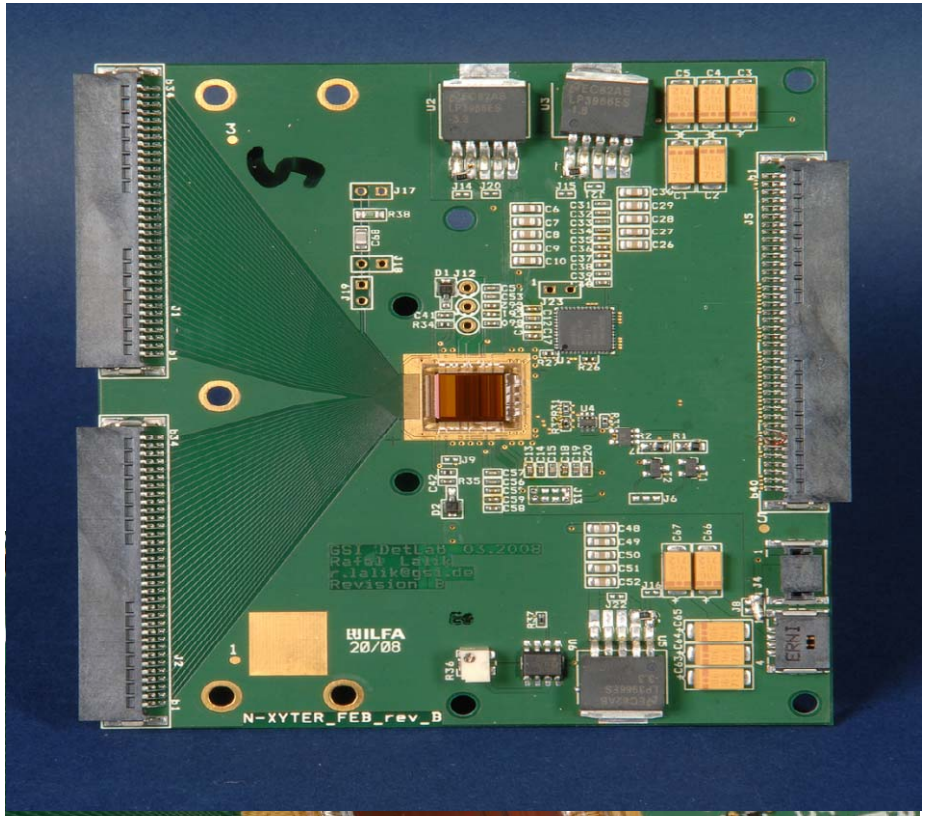


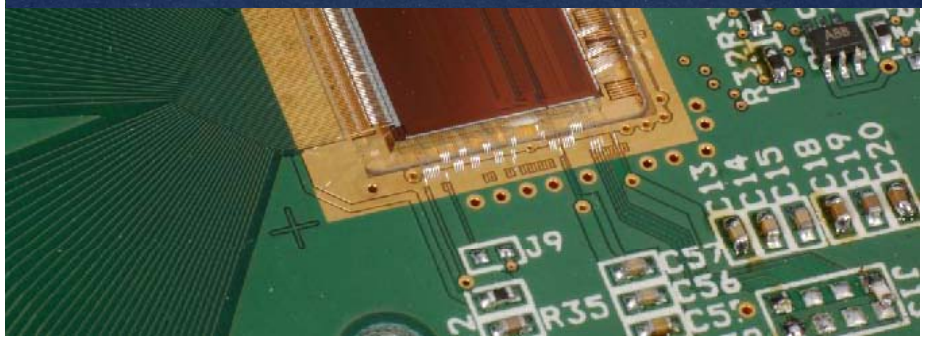


- AMS CMOS 0.35 μm technology
- 128 channels / chip
- Charge-sensitive preamp
- Fast (30ns) & Slow (150ns) Shaper
- Peak detector

- Time-stamping with 1 ns resolution
- Data driven, autonomous hit detection
- Token ring readout @ 32 MHz
  de-randomizing, sparcifying
- Expected noise:
  370 e-@10pF, 550e-@20pF

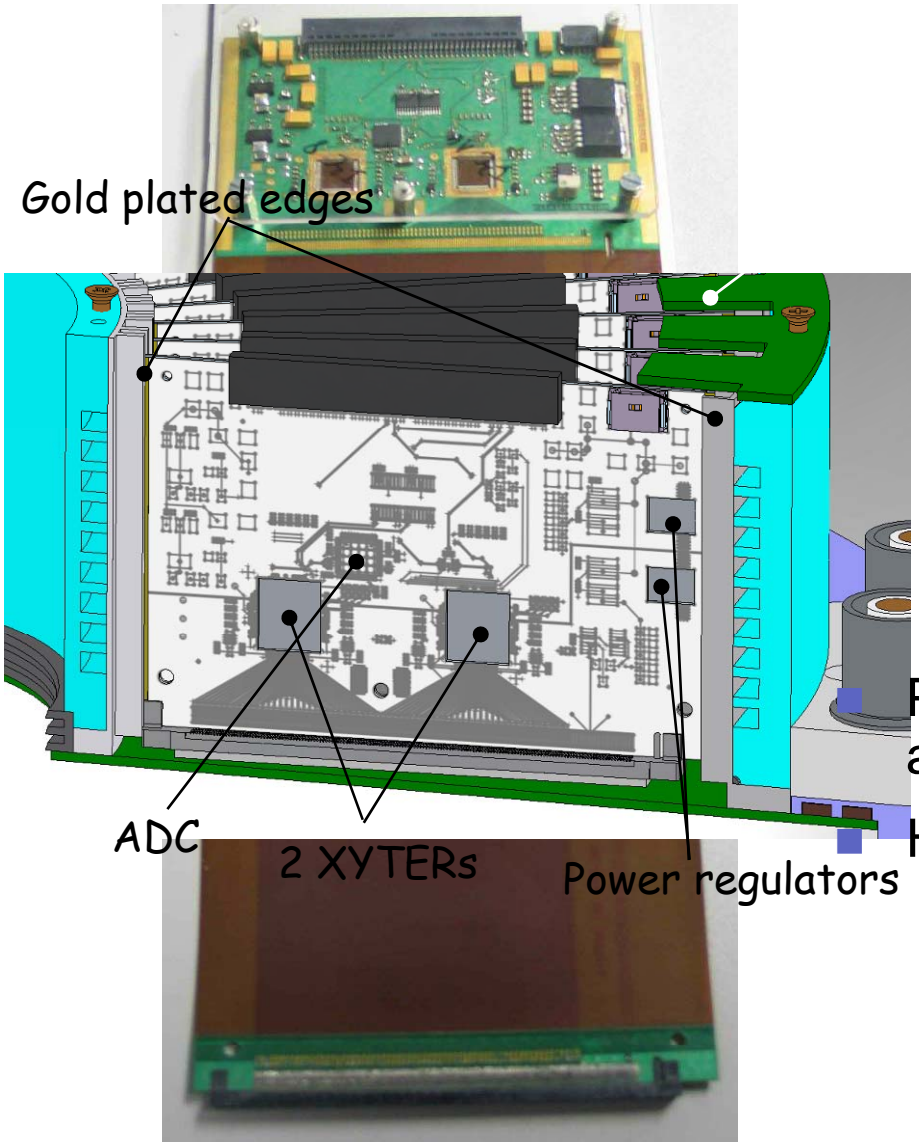
Front-End Electronics XYTER testing board





- Simple hybrid PCB with
  - signal fan-in
  - ADC
  - interconnect to DAQ chain (SysCore / KIP, Exploder / GSI)
  - CBM beam time September 2008: whole signal chain operative
- ‘Chip-In-Board’
  - avoids space eating vias
  - allows pitch adaptation:
    - 50,7 µm on chip
    - 101,4 µm on PCB (two levels)
    - 10 Rev. C boards, fully functional

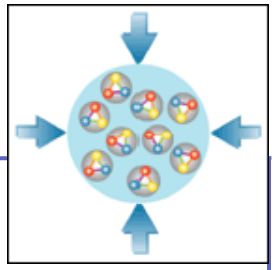
Front-End Electronics XYTER TPC Prototype board

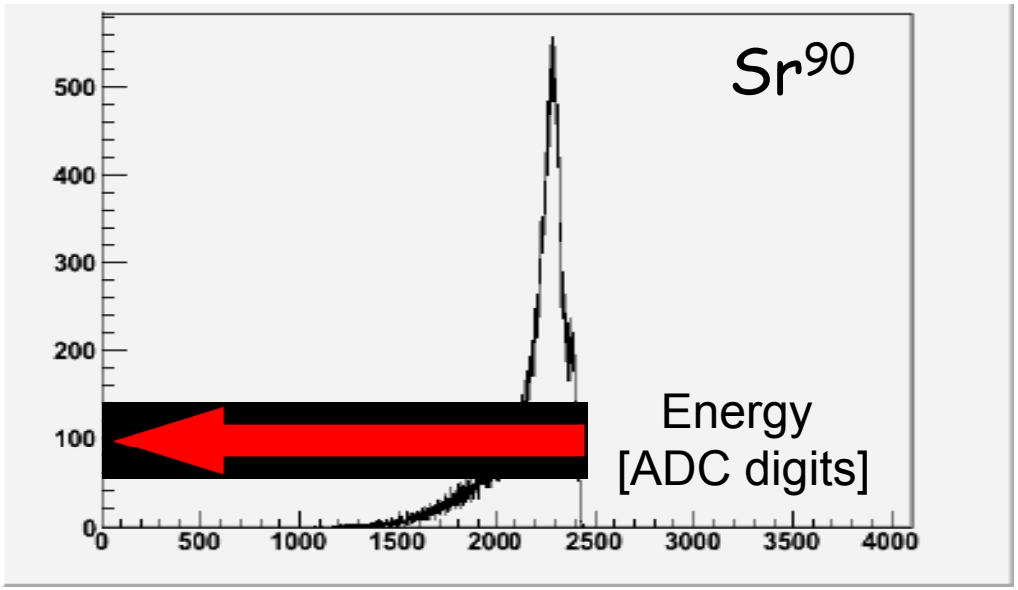


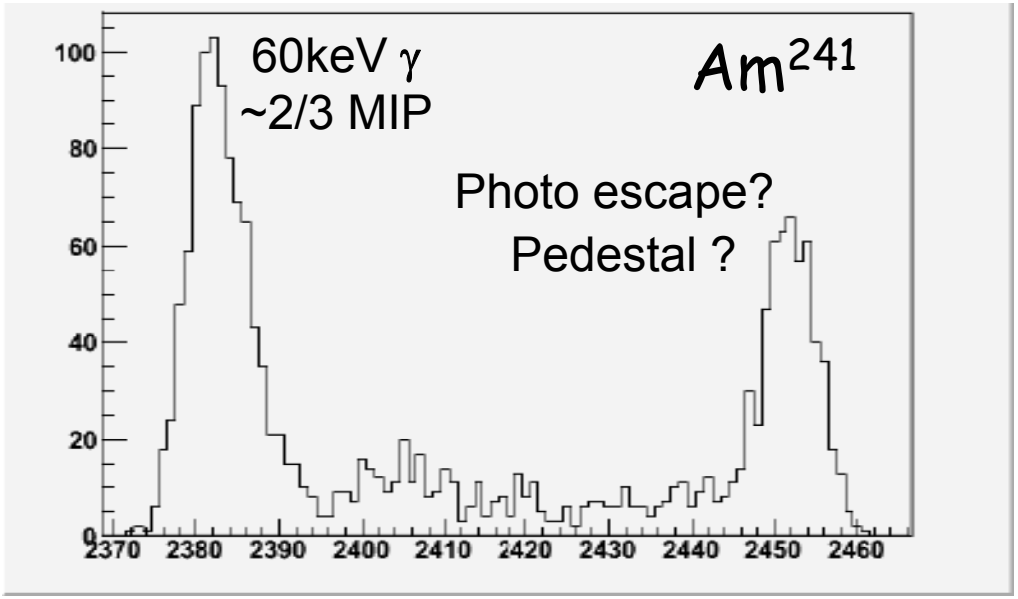
42	4-layer PCBs for PANDA TPC prototype
2	XYTER chips / card chip-in board glued to aluminium backing step-down & staggered bonding
2 x 128	channels / card
300	pins / connector
~350	Watt power dissipation passive heat pipe system cooling liquid HFE-7100 (3M)

- PCB lab-tested
  awaiting in-beam test (@CB-ELSA)
- Higher integration level (1:1):
  - SysCore Boards (KIP Heidelberg)
  - Exploder+… (GSI-EE, MBS)
  - Others …?

Experimental data Energy-Output (preliminary)

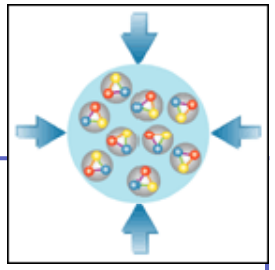


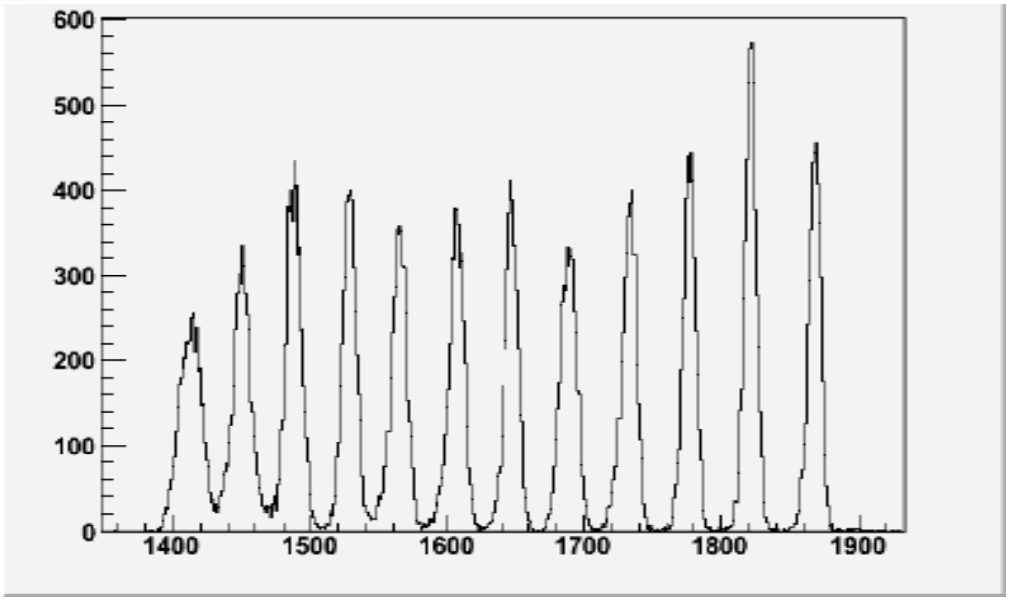


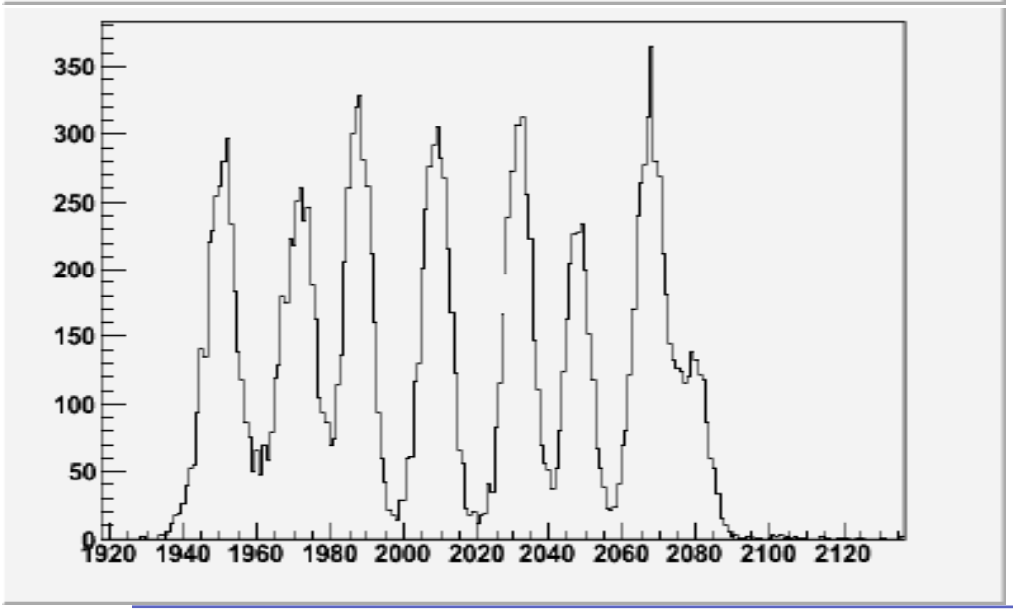


- Si Detector
  - 300µm strip-pitch
  - DC coupled
  - 40V
- Pulse-height spectra on one strip
  - 'as is, on the table'
- Enhanced low-energy part: δ-electrons & other scattering

Experimental data Energy-Output (preliminary)







- Pulse-height spectra
  - with internal test pulse
  - C_{det} not determined (5-10 pF)
- Peak-to-peak distance ~5560e-
- σ ~425e- (370e-expected)

⇨ Analog read out chain operative

⇨ Temperature coefficient spoils the effort

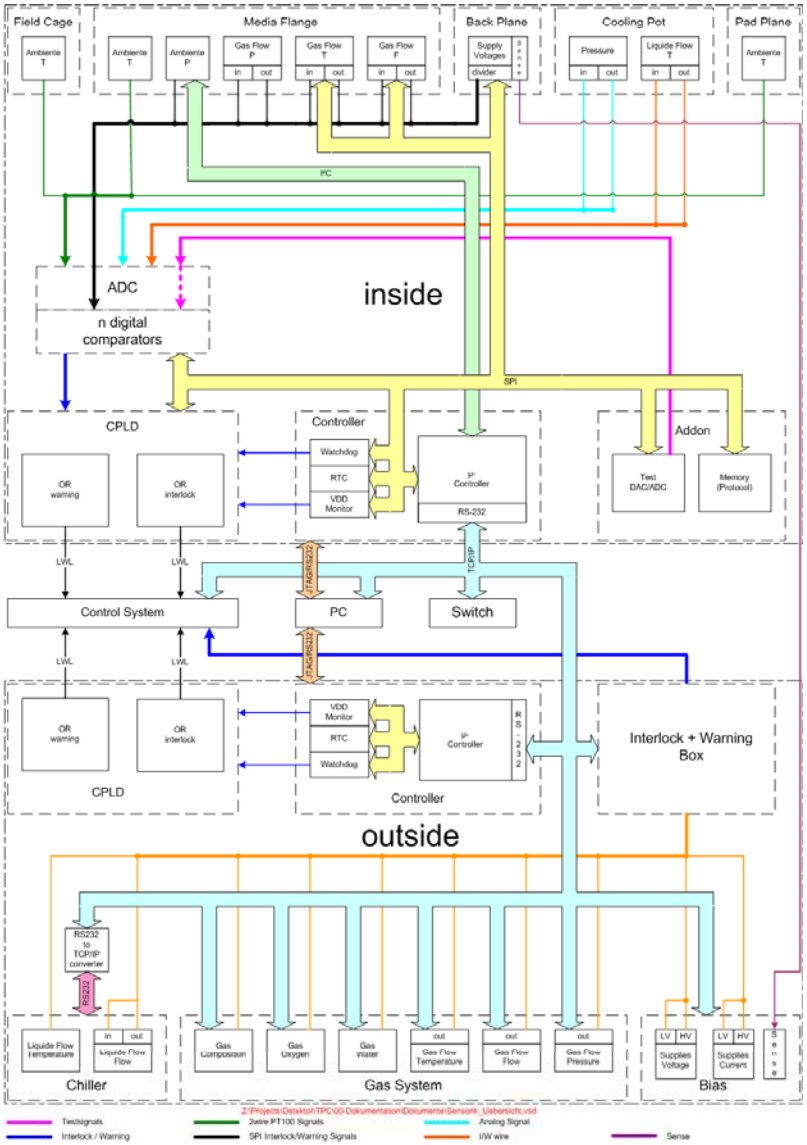
Front-End Electronics n-XYTER Engineering Run

- Preparations by Hans Kristian Soltveit (Physikalisches Institut Heidelberg)
- Several thousand chips@110k€
- Issues addressed:
  - Temperature coefficients on three amplifiers
  - Pad arrangement, input-ESD-pads, LVDS in/out arrangements
  - Shielding (in particular mono stable cross-talk)
  - Choice of process
  - Epoch marker output
- Time line (03/2009):
  - Current: Extensive corner analysis on new schematics
  - End of April: Finalize schematics & Review on modifications
  - May & June: Layout modifications
  - End of June: Submission readiness review & Successive submission to AMS

The Future: FAIR-XYTER ...for gaseous detectors

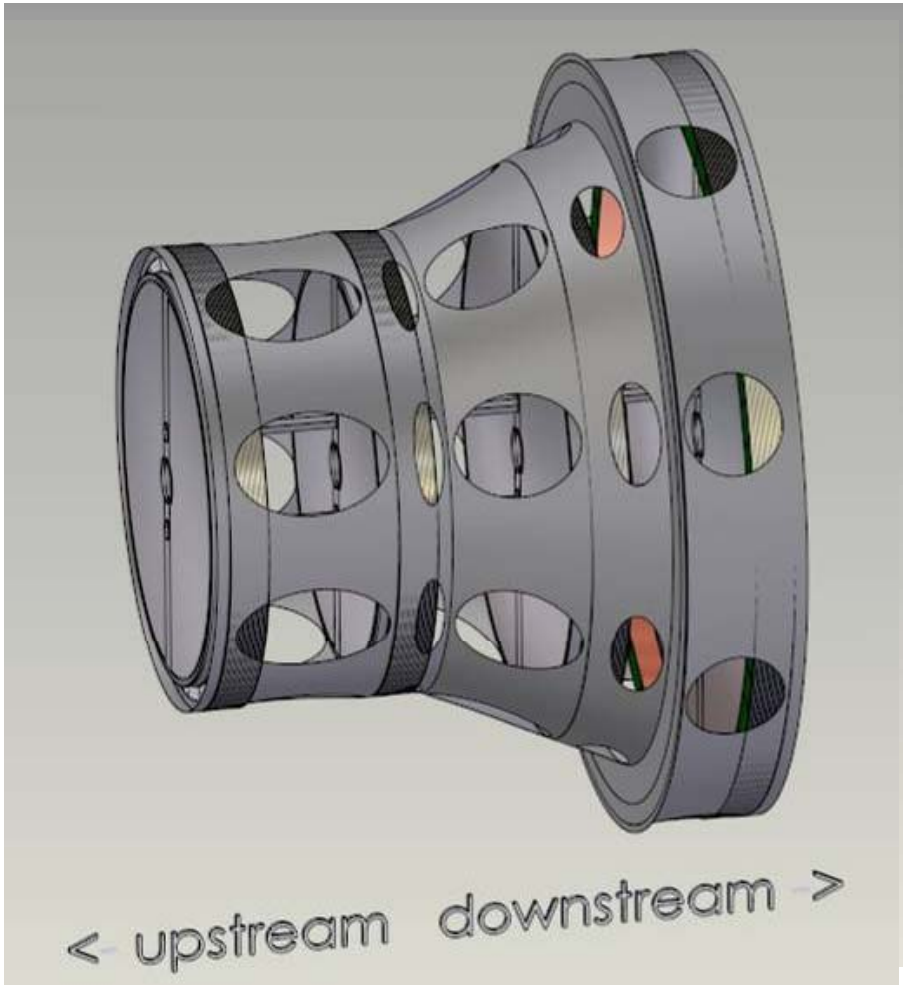
	GEM-Tracker	GEM-TPC	Others
Channels/chip	32-128		64-128
Power limit/channel	10mW		
Noise limit	500e$^-$@5pF		500e$^-$@5pF, 900e$^-$@25pF
Max. rad dose	100 krad		
Avg. det. capacity		7 pF	7..150 pF
Max. det. capacity	2...150 pF	7 pF	
Rate/channel	4..11/200kHz	250 kHz	250 kHz
Ampl.	94 ke	25 ke	> 25 ke
Signal distribution	Landau		
Measured feature	Spatial resolution	+ Hit-time	
Signal shape		30..40ns	
Max. possible signal	200ke = average*2	750ke=average*30	1000ke, 3000ke, Dual range
ADC res./ampl.		7 bit, 5 ke	8-9 bit linear, 4 ke
Time resolution	10ns/hit	4ns/hit	4ns
Special tasks	Spark protection	+ baseline restoration	+forced neighbor readout

Detector Control & Monitoring Structure



- Current concept:
  - Modular, expandable, flexible
  - Same structure for all GEM-Detectors
  - Hierarchical interlocking
  - Failsafe operation
  - Hard- & software limits
- Integration into PANDA-DCS database started
  - Identified 45 parameters so far

Detector-Mounting ‘Riddle’ design



- Optimize position determination
  → Maximize inter-detector distances
- Equalize weighting of information
  → Balance inter-detector distances
- Maximize shape-conformity
- Symmetrise the loads, moments and thicknesses
  - Minimize mounting and adjustment efforts
  - + Simple & stiff support structures

  → Multi-conical shape of the supports (‘Matroschka’ principle)

  → Shell structure (0.5..1mm CRP)

  → 50µm sag

GEM-Projects Road map

FP7-JRA WP24 (605 k€ granted)

GEM-TPC, GEM-Tracker	2009				2010				2011				2012			
Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Precursor-Prototype design / fabrication / test																
Development of thin large area GEM foils																
Development of large read-out structures																
ASIC (and FEE) adaptation and optimization																
Quality control and calibration																
Material research																
TPC field-cage study and optimization																
Light-weight frames and support structures																
Read-out and DAQ																
Detector assembly and integration																

PANDA Time horizon: 2016..2018

GEM-Projects: TPC[1] & Tracker[2]
GSI crew-members & tasks

Jörg Hehner[1]	Aging tests
Andreas Heinz[1]	PadPlane, GEMs, sensors, WebInfo
Markus Henske[1]	Material tests, sensors, infrastructure, purchase
Radoslaw Karabowicz[2]	Root-Simulations
Volker Kleipa[1]	Front-End Electronics (XYTER)
Jochen Kunkel[1,2]	Mechanics, drawings, simulations, assembly
Rafal Lalik[1]	Front-End Electronics (XYTER)
Christian Schmidt[1]	Front-End Electronics (XYTER)
Sandra Schwab[1]	Part production, tooling , FOPI environment
Daniel Soyk[1]	FEM-Simulations
Eduard Traut[1]	GEM generals
Ufuk Tuey[1]	General mechanics, drawings
Bernd Voss[1,2]	‚**All** & nothing', ideas & concepts, project & logistics
Jan Voss[1]	General mechanics, material tests
Joachim Weinert[1]	Part production, tooling

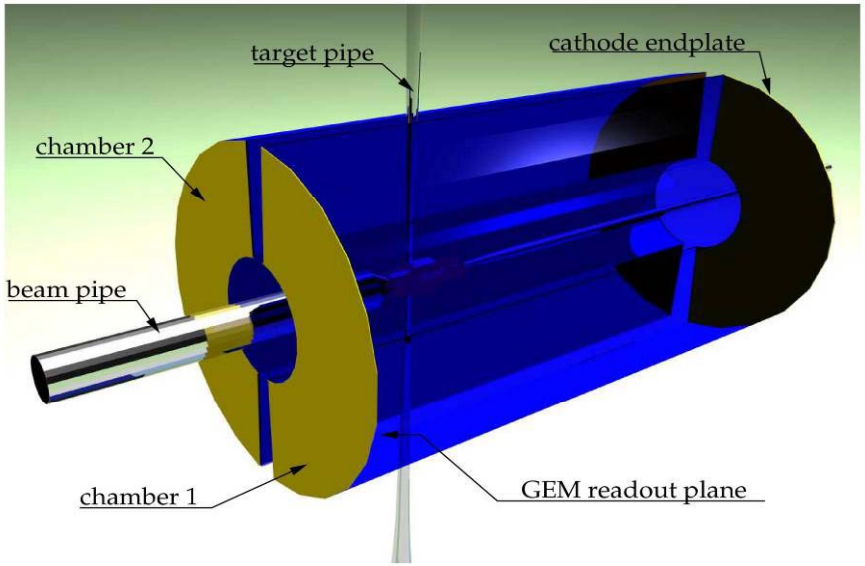
Backup slides

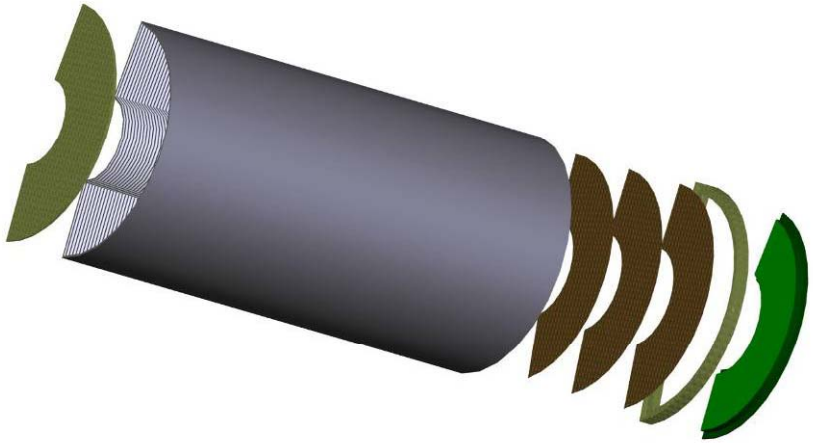
Physics goal

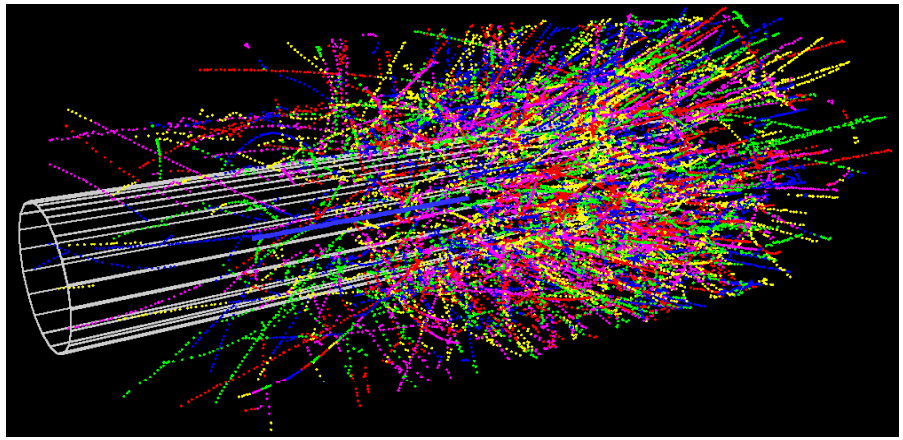
- **Precision spectroscopy: mass, width, branching ratios**
  - Charmonium
  - Gluonic excitations above 2 GeV/c^2
- **Charmed meson** properties in nuclear medium
- **Double hypernuclei** production and spectroscopy
- **Electromagnetic processes**
  - Time-like electromagnetic form factors
  - Generalized parton distributions
  - Transverse spin distribution in nucleons
- Open charm physics
  - Spectroscopy
  - Rare decays
  - CP violation in charm sector

TPC Layout @ PANDA

Basic Properties





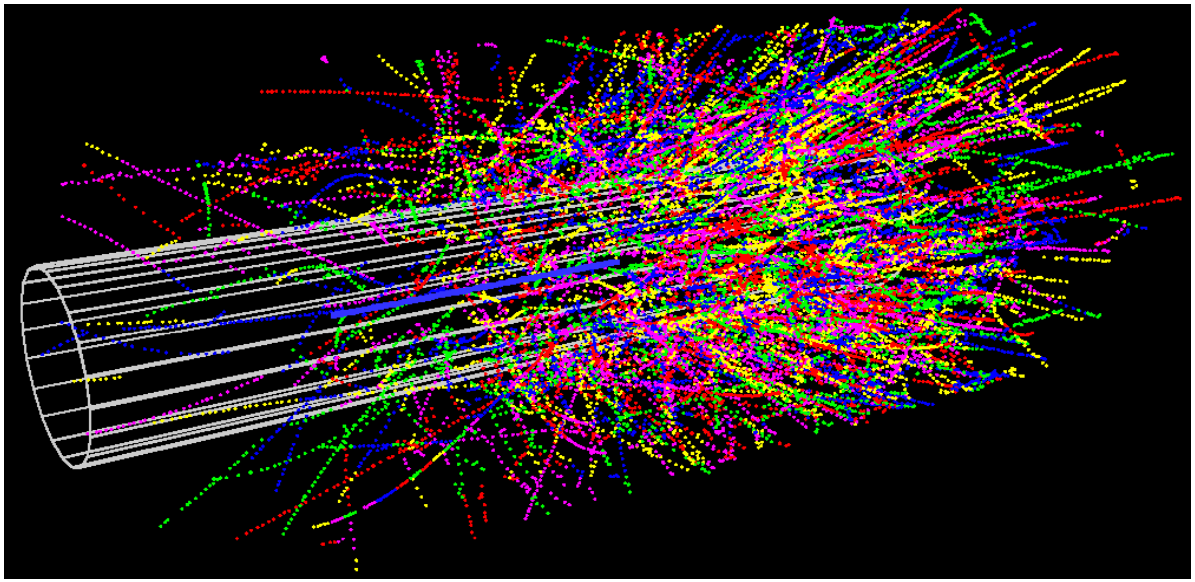


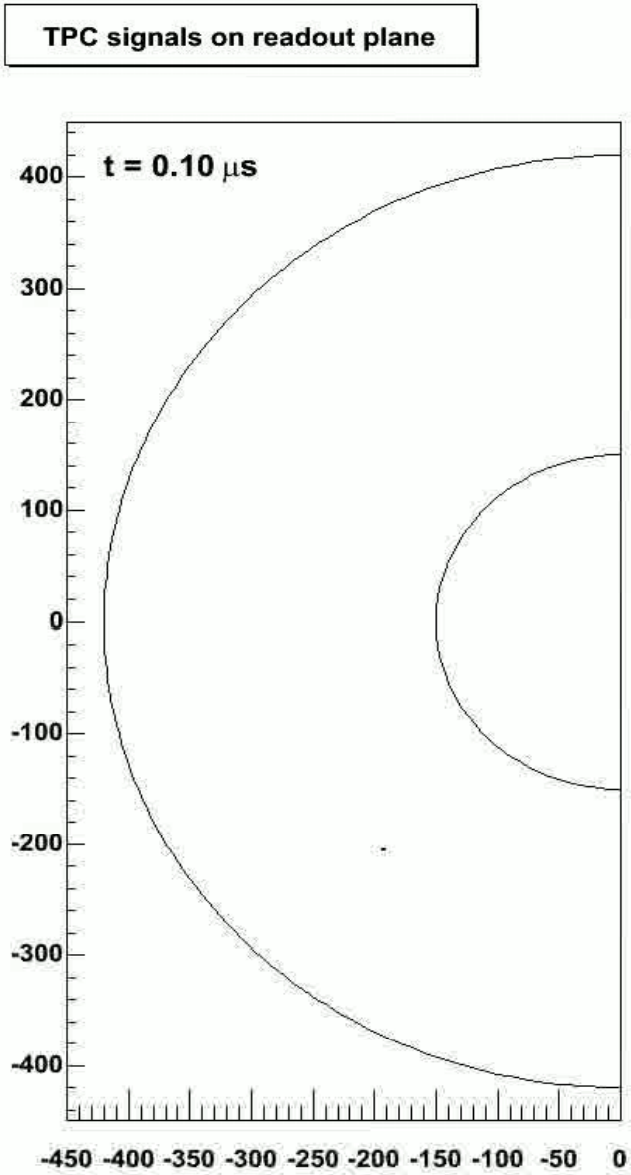
Event Mixing

- $2 \cdot 10^7$ annihilations / s
- 5 charged tracks / event
- v_D=3 cm/μs, L=150 cm ⇨ t_D^{max}=50 μs

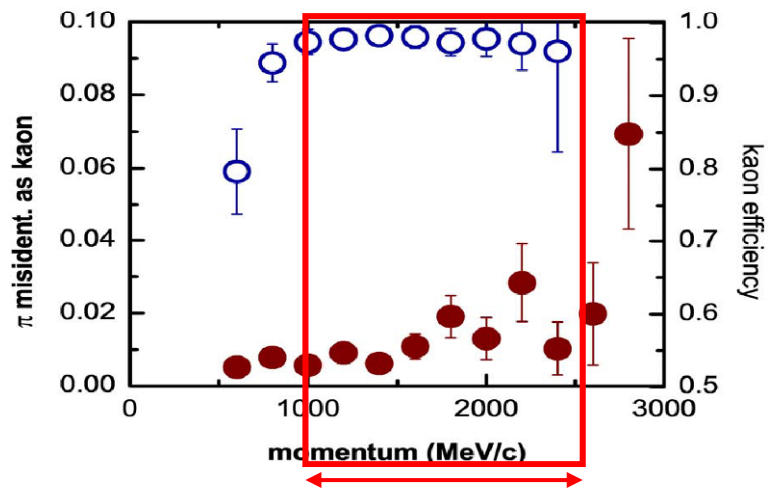
⇨ 5000 tracks superimposed in one TPC "picture"

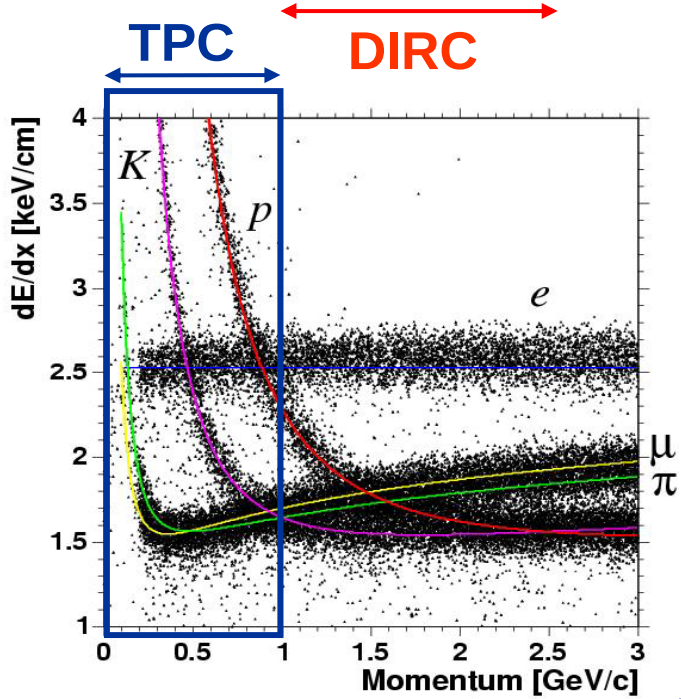
⇨ tracks mixed in time





PID Performance



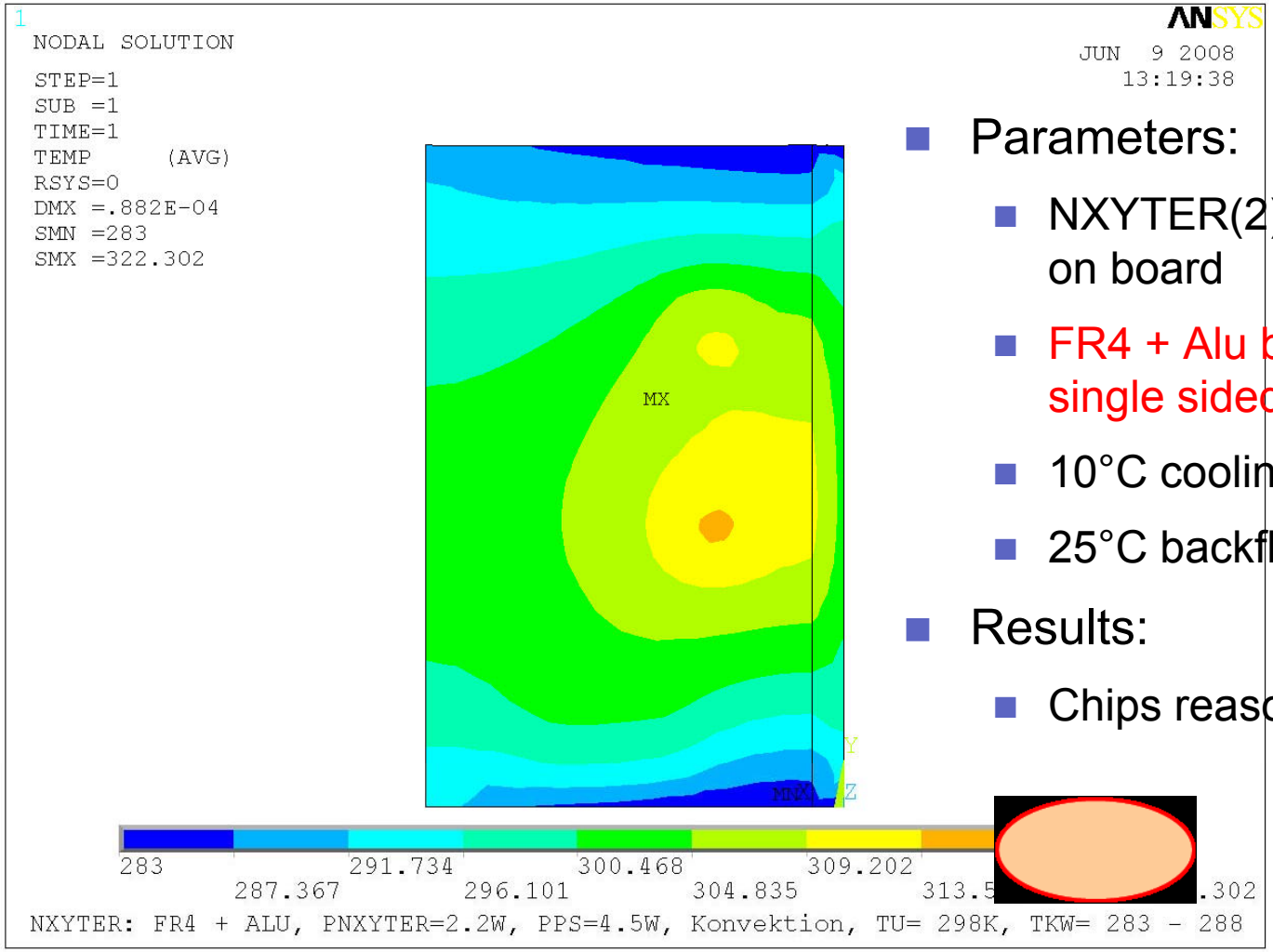


PID Processes:

- Cherenkov radiation: above 1 GeV
  - ⇨ radiators: **quartz**, aerogel, C_4F_{10}
- Specific energy loss: below 1 GeV
  - ⇨ best accuracy with **TPC**
- Time of flight
- EMC for e and γ

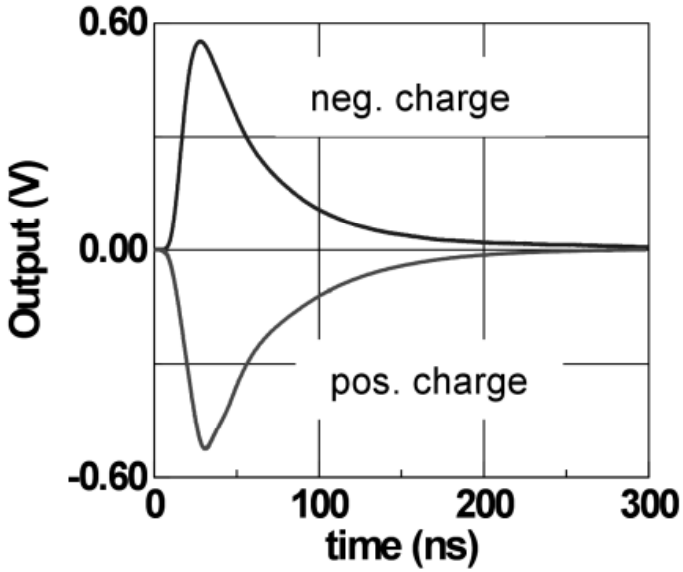
Cooling Motivation

Simulations

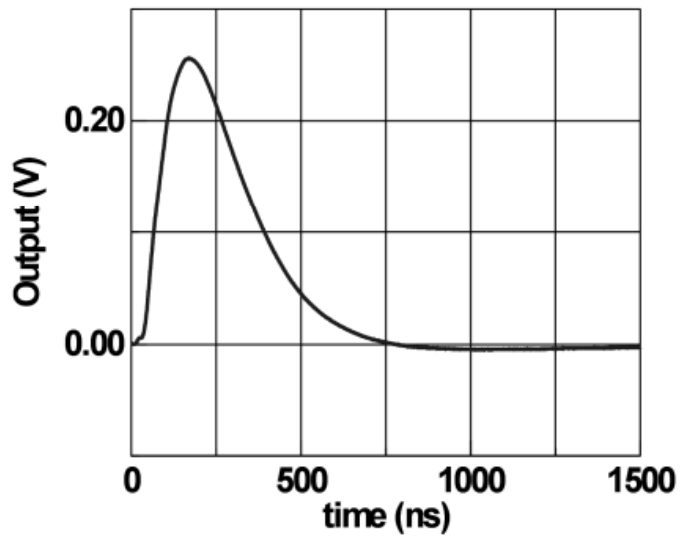


- Parameters:
  - NXYTER(2) + ADC + voltage regulators on board
  - FR4 + Alu backing, single sided mounting
  - 10°C cooling media temperature
  - 25°C backflow temperature
- Results:
  - Chips reasonably cool

Analogue Pulses, Peaking Time, Front-End Noise



a)



b)

	FAST channel	SLOW channel
ENC	26.9 e/pF + 200 e	12.7 e/pF + 233 e
peaking time[a] (1% to 99%)	18.5 ns	139 ns

Engineered for 30 pF, giving 1000 e 600 e

power consumption: 12.8 mW per channel; OK for neutrons!

System Integration Issue Global Timing

- SysCore generates 48 to 64 bit data elements:
  - n-XYTER provides
    - 14 bit time stamp @ 1ns resolution
    - 7 bit channel number
  - FEB provides
    - 10 bit peak height
  - SysCore adds
    - chip number
    - epoch counter
    - some diagnostic
  - SysCore provides data FIFO

Relate local time stamps to global events:

Feed a global epoch marker or event strobe into SysCore

- The serialized event number with successive time stamp could be fed into auxiliary inputs.
  - This event header would be added to the data elements
  - Such synch scheme should be fine up to about 50 kHz event rate

Test Setup Complex Multi-layer Data Chain

- Detector
- n-XYTER-FEB
  - n-XYTER
    - FEB and Bonding Technology
    - Documentation (Manual)
- ADC
- Interconnect
- SysCore / Exploder
  - Firmware
  - Embedded software
  - Soft configuration
- Ethernet-Interconnect
- PC and DAQ
  - KNUT
  - GUI
  - DAQ System

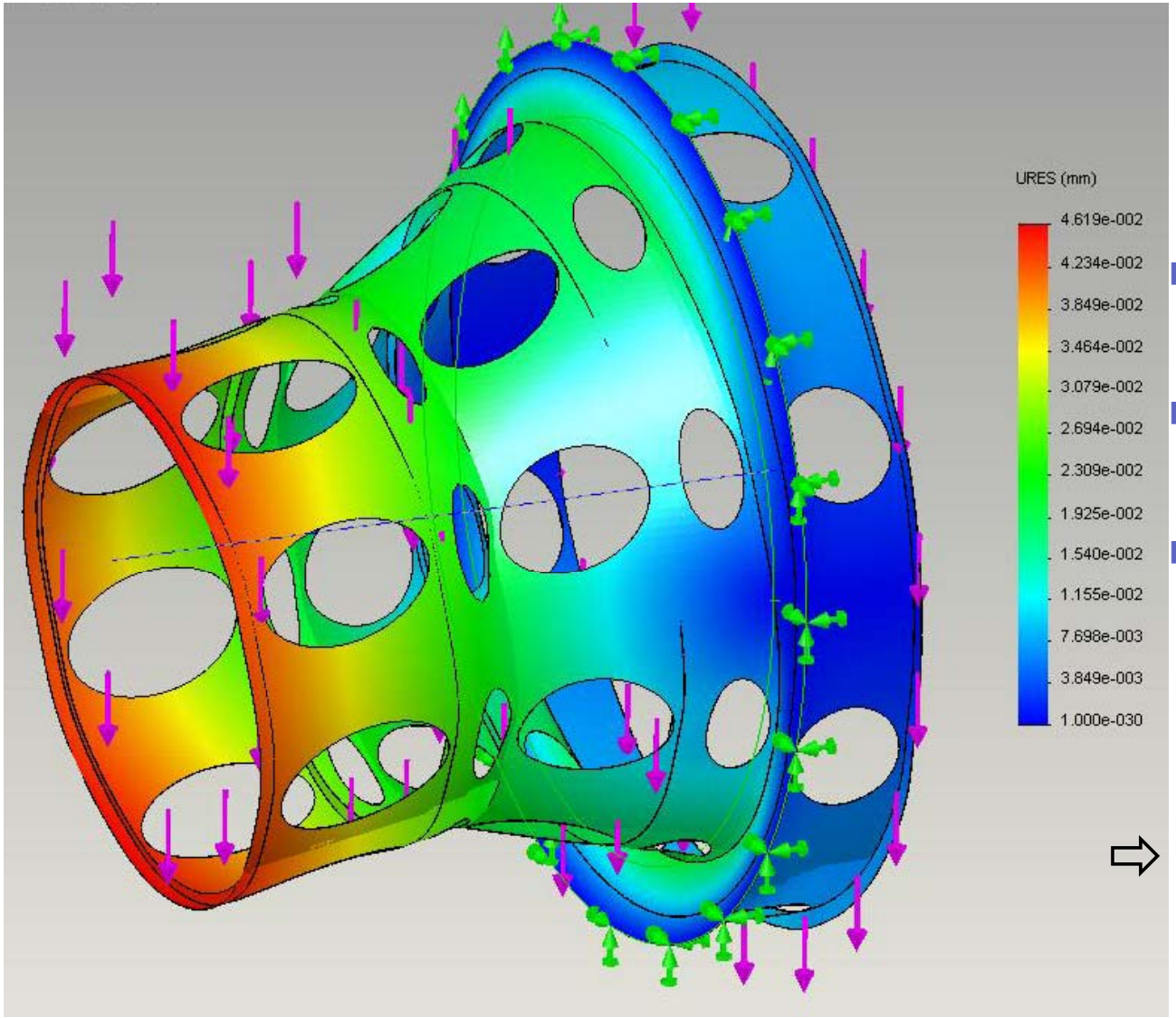
<u>Ongoing</u>:

Realize software design freeze to be packaged

<u>Still missing</u>:

Diagnostic toolbox for system analysis
to make successful deployment in other labs feasible

The 'Riddle' Deformation under load



- Conservative assumptions
  worst-case material constants
- Max. deformation quite small
- Local reinforcement still possible

⇨ Reasonable concept