Tracking with GEM Detectors at High Luminosities

The SBS Programme in Hall-A of Jefferson Lab.

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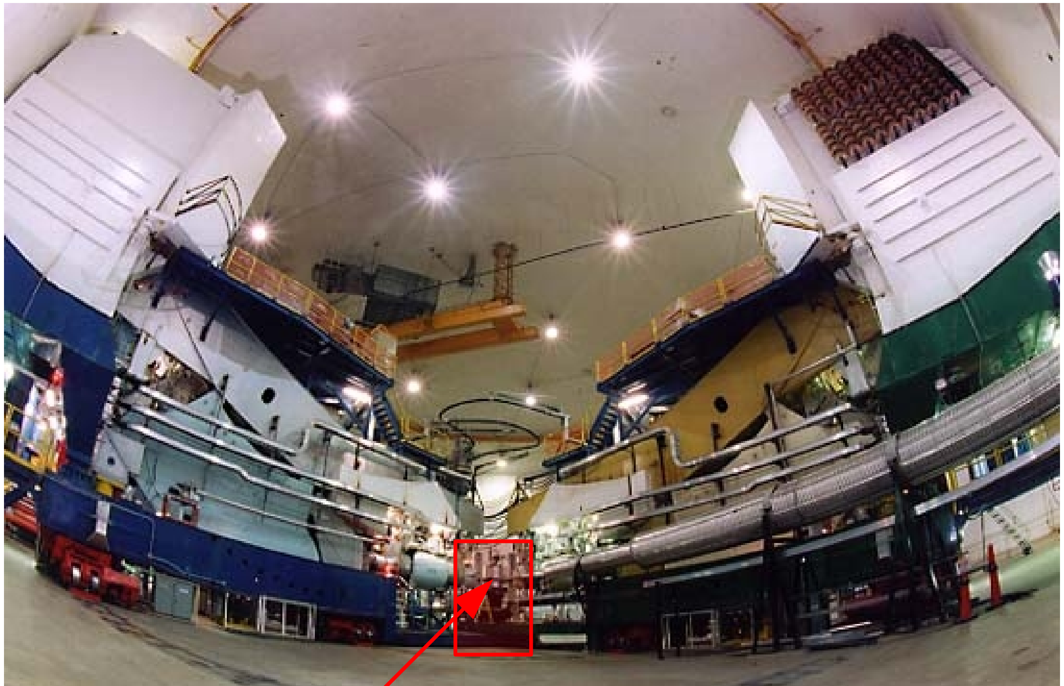
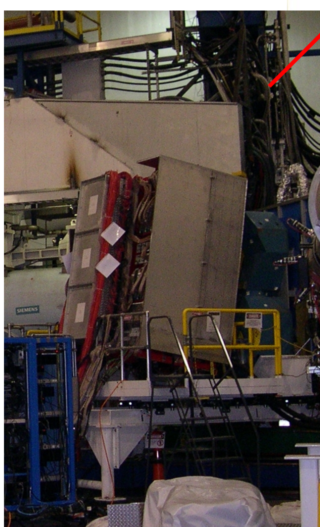
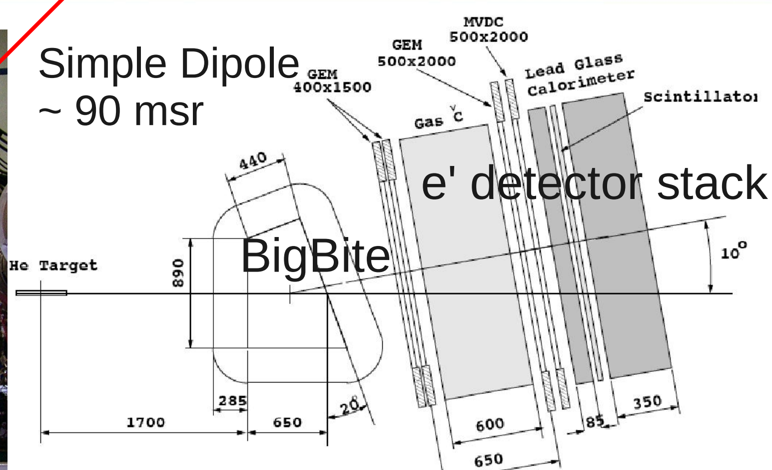
Hall-A of Jefferson Laboratory



- High Resolution Spectrometers (HRS)
  $\delta p/p \sim 10^{-4}$, Modest angle/momentum acceptance
- Large Acceptance Spectrometers:
  $\delta p/p \sim 10^{-2} - 10^{-3}$ larger acceptance in angle and momentum
- BigBite (originally e' detector @ AMPS internal target facility)
  Both Hadron and Electron detectors
  Many new experiments possible.



Simple Dipole
~ 90 msr



Shallow bend angle
detectors view target directly

- CEBAF Accelerator Upgrade
  12 GeV Hall-D
  11 GeV Hall A,B,C
  Glasgow involved in CLAS12 & Hall-A
- 1st Hall-A 11 GeV Beam late 2013
  Continue to use upgraded BigBite
  Extend the concept with big brother...
  Super BigBite Spectrometer (SBS)

http://hallaweb.jlab.org/12GeV/SuperBigBite/

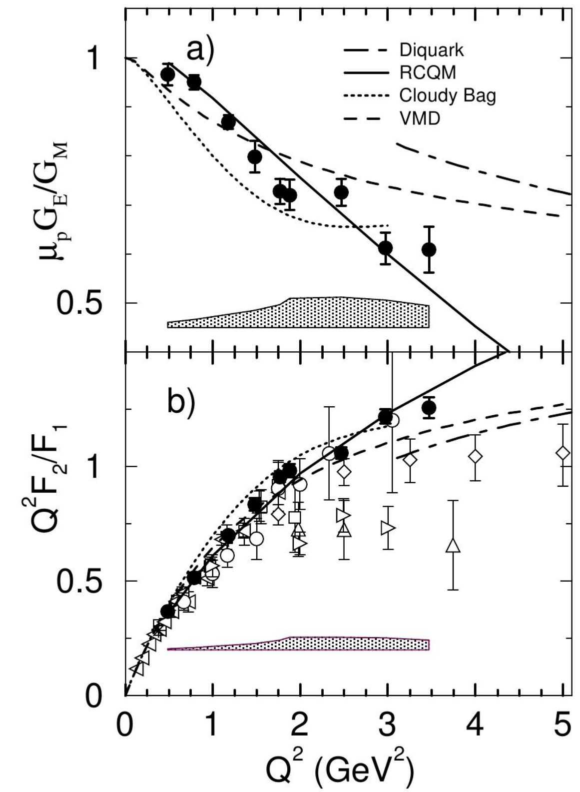
The SBS Programme in Hall-A

Jefferson Lab PAC-35 (2010) Recommendations

Proposal	Spokes-Person	Title	Hall	Days Requested	Days Awarded	PAC Rating
PR12-06-101	G. Huber	Measurement of the charged pion form factor to high Q^2	C	52	52	A
PR12-07-104	G. Gilfoyle	Measurement of the neutron magnetic form factor at high Q^2 using the ratio method on deuterium	B	56	30	A-
PR12-07-108	B. Moffitt	Precision measurement of the proton elastic cross-section at high Q^2	A	31	24	A-
PR12-07-109	L. Pentchev	Large acceptance proton form factor ratio measurements at 13 and 15 $(GeV/c)^2$ using recoil polarization method	A	60	45	A-
PR12-09-003	R. Gothe	Nucleon resonance studies with CLAS12	B	60	40	B+
PR12-09-006	A. Semenov	Neutron electric form factor at Q^2 up to 7 $(GeV/c)^2$ from $^2H(e,e'n)^1H$ via recoil polarimetry	C	66		Unrated
PR12-09-016	B. Wojtsekh-owski	Measurement of the neutron electromagnetic form factor ratio G^n_E/G^n_M at high Q^2	A	58	50	A-
PR12-09-019	B. Wojtsekh-owski	Precision measurement of the neutron magnetic form factor up to Q^2=18 $(GeV/c)^2$ by the ratio method	A	48.5	25	B+

Nucleon Elastic Form Factors
G_{Ep}, G_{Mp}, G_{En}, G_{mn}
Polarised SIDIS
....

M.K. Jones et al., Phys.Rev.Lett., 84 (2000) 1398. Cited 506 times



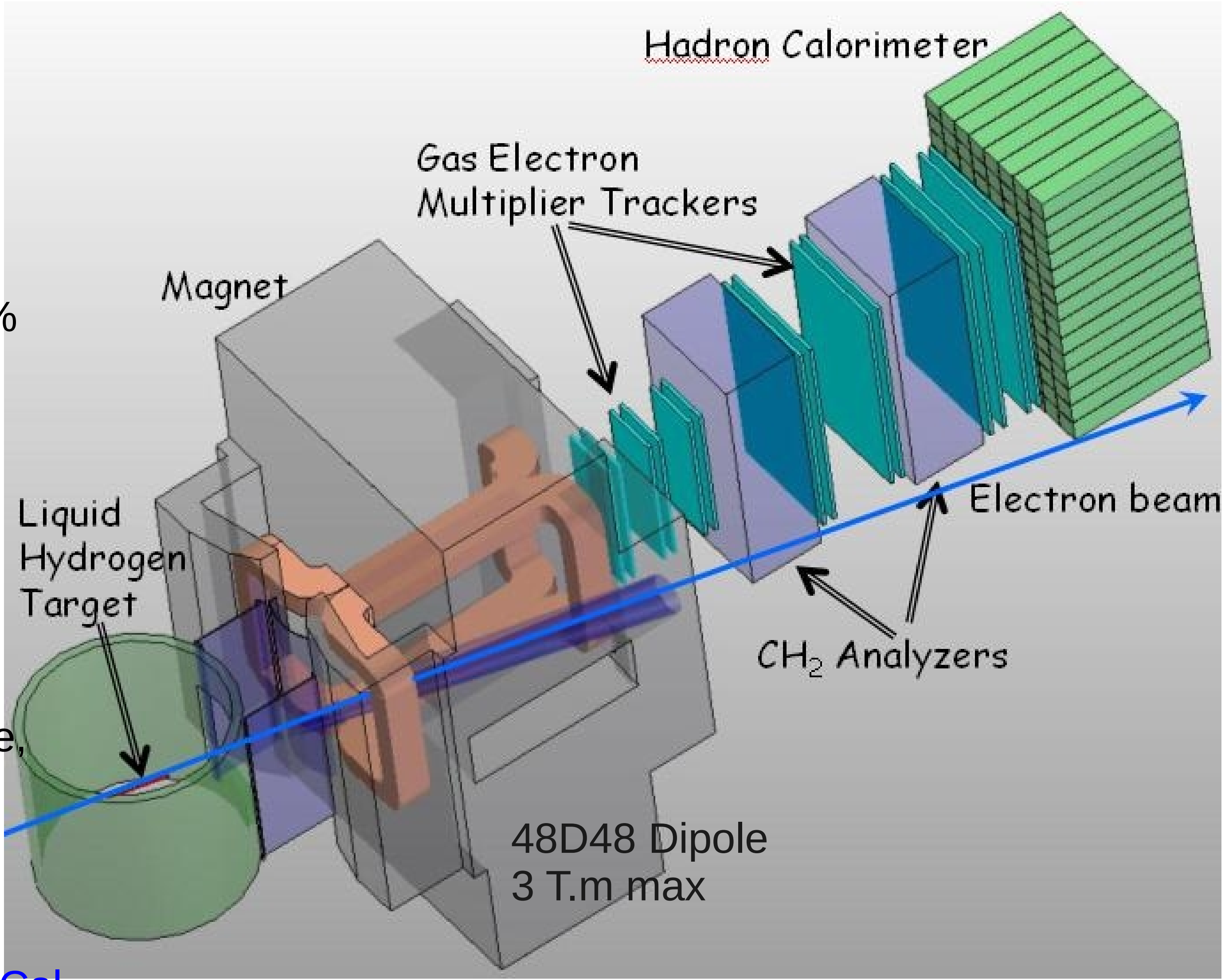
Run at luminosities up to ~10^{39} $s^{-1}cm^{-2}$. Can detectors withstand the counting rates? Expect rates in forward elements ≈ 500 kHz/cm^2, mainly soft photons.

Expect beam late 2013...use mainly well-tried technology

SBS Configured for Recoil-Proton Polarimetry

- High Luminosity: 8 x 10^{38} $cm^{-2}s^{-1}$
- Support high background: 500 kHz/cm^2 (low energy photons mainly)
- Forward angle
- Large acceptance
- Good angular (0.2 mr) and reasonable momentum (0.5% @ 4-8 GeV/c) resolution
- Flexibility: use the same detectors in different experimental setup
- 2 tracker geometries, same base module
  - 1^{st} front, momentum, angle, vertex
  - 2^{nd} polarimeter, asimuthal scattering
- Also GEM in BigBite and BigCal

SBS Configured for Recoil-Proton Polarimetry



Hall-A SBS GEM Collaboration

Hall-A GEM Collaboration

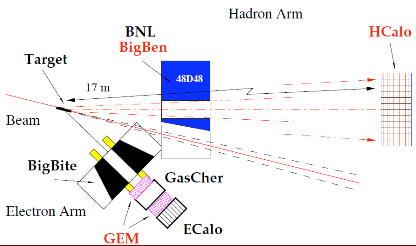
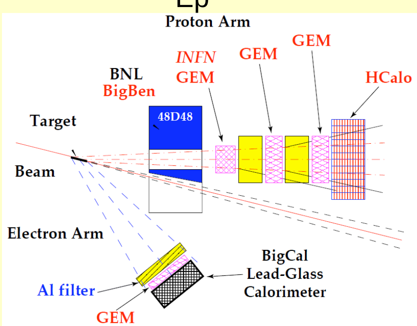
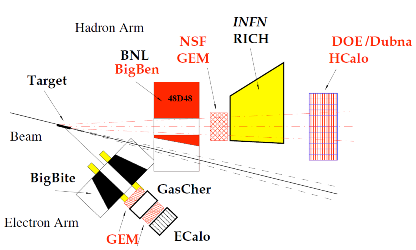
Evaristo Cisbani, INFN Roma (Sanità), Italy
Nilanga Liyanage, University of Virginia, USA

University of Glasgow, Scotland UK
Hall-A, Jefferson Laboratory, USA
Norfolk State University, USA
College of William and Mary, USA

The design and realisation of the GEM trackers for Hall-A makes full use of experience gained at COMPASS.
thanks B. Ketzer for arranging 32 x 32 cm^2 GEM foils

GEM foils and ReadOut Boards (ROB) from CERN Micro Pattern Gas Detectors Group
GEM foils also from Tech-Etch Inc. MA, USA.

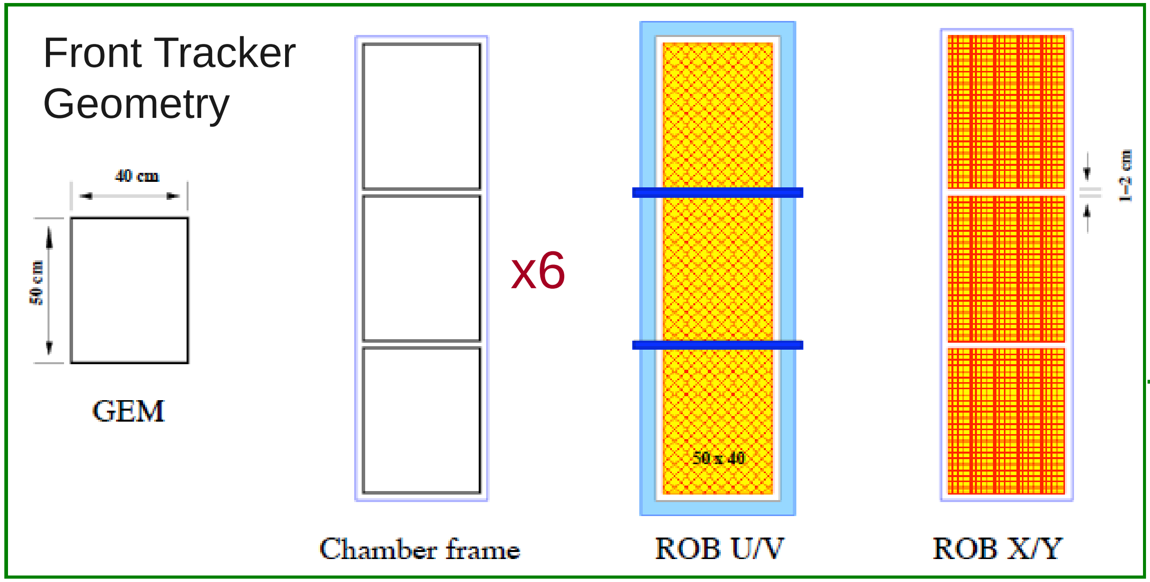
Preliminary Tracking Requirements Hall-A 11 GeV

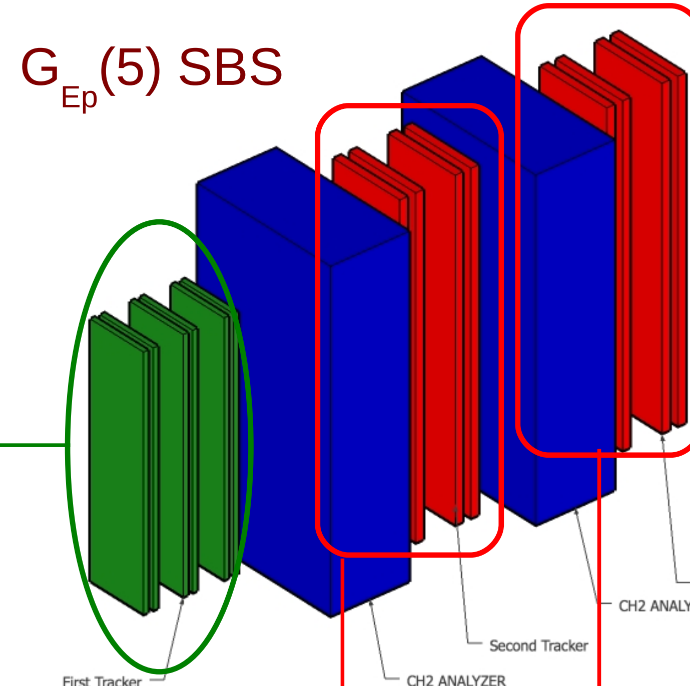
Experiments many more planned	Luminosity ($s^{-1}.cm^{-2}$) *High Rates*	Tracking Area (cm^2) *Large Area*	Resolution		
			Angular (mrad)	Vertex (mm)	Momentum (%)
G_{Mn} or G_{En} 	up to $7\cdot10^{37}$	40 x 150 and 50 x 200	< 1	< 2	0.5%
G_{Ep}(5) 	**up to $8\cdot10^{38}$**	40 x 120, 50 x 200 and 80 x 300	Front <0.7 Pol. ~1.5	~ 1	0.5%
SIDIS 	up to $2\cdot10^{37}$	40 x 120, 40 x 150 and 50 x 200	~ 0.5	~1	< 1%

GEMs OK but tracking in high background-hit environment requires investigation

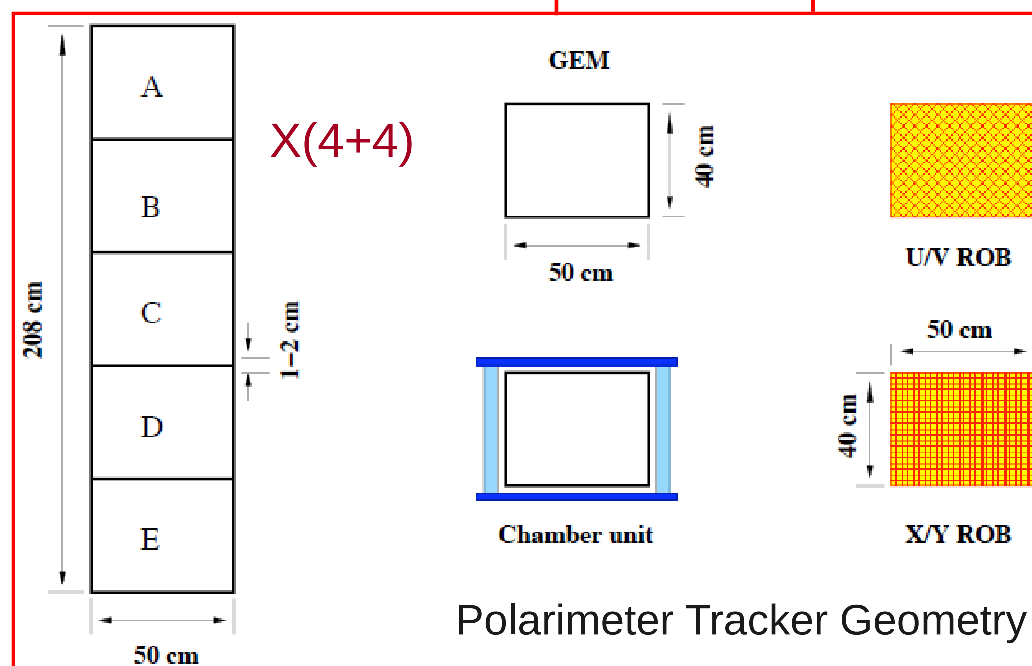
Position Resolution ~ 70 μm required

GEM Tracker Module Configuration for SBS





- Basic 40 x 50 cm^2 building block
- Modules combined to form larger chambers with different sizes
- Electronics along the borders and behind the frame (at 90°) – cyan and blue in drawing
- Aluminium support frame around the chamber (cyan in drawing); dedicated to each chamber configuration



GEM Tracker Channel Accounting

Tracker	Area (cm^2)	Number of Chambers	Readout	Pitch (mm)	Modules/ Chamber	Total Modules	Total Readout Channels
Front Tracker p arm	40 x 150	6	2D 4(x/y) 2(u/v)	0.4	1 × 3	18	49000 + 13500
2^{nd} & 3^{rd} Tracker Polarimeter	50 x 200	4 + 4	2D 2(x/y) 2(u/v)	4 × 0.4	1 × 5	20 + 20	13600 + 13600
Coord. Detector e' arm	80 x 300	2	1D y + y	1.0	2 × 6	24	12000

Total channels 101700

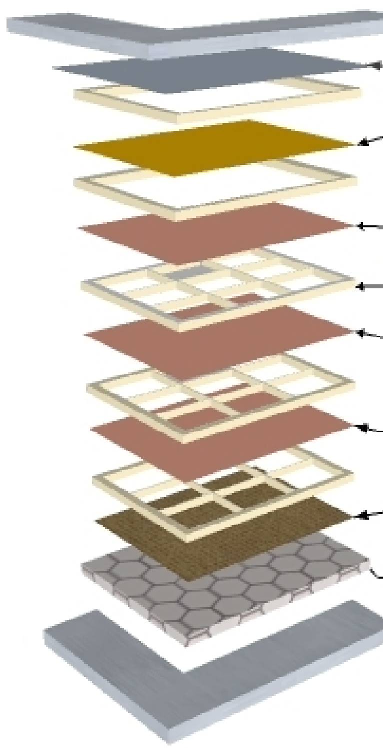
Last 2 Front Tracker modules have strips cut at the middle (half length strips)
....to reduce strip occupancy to facilitate track finding.
2^{nd} and 3^{rd} Trackers for polarimetry have 4 readout strips combined...1.6 mm pitch.

Modular Chamber Construction

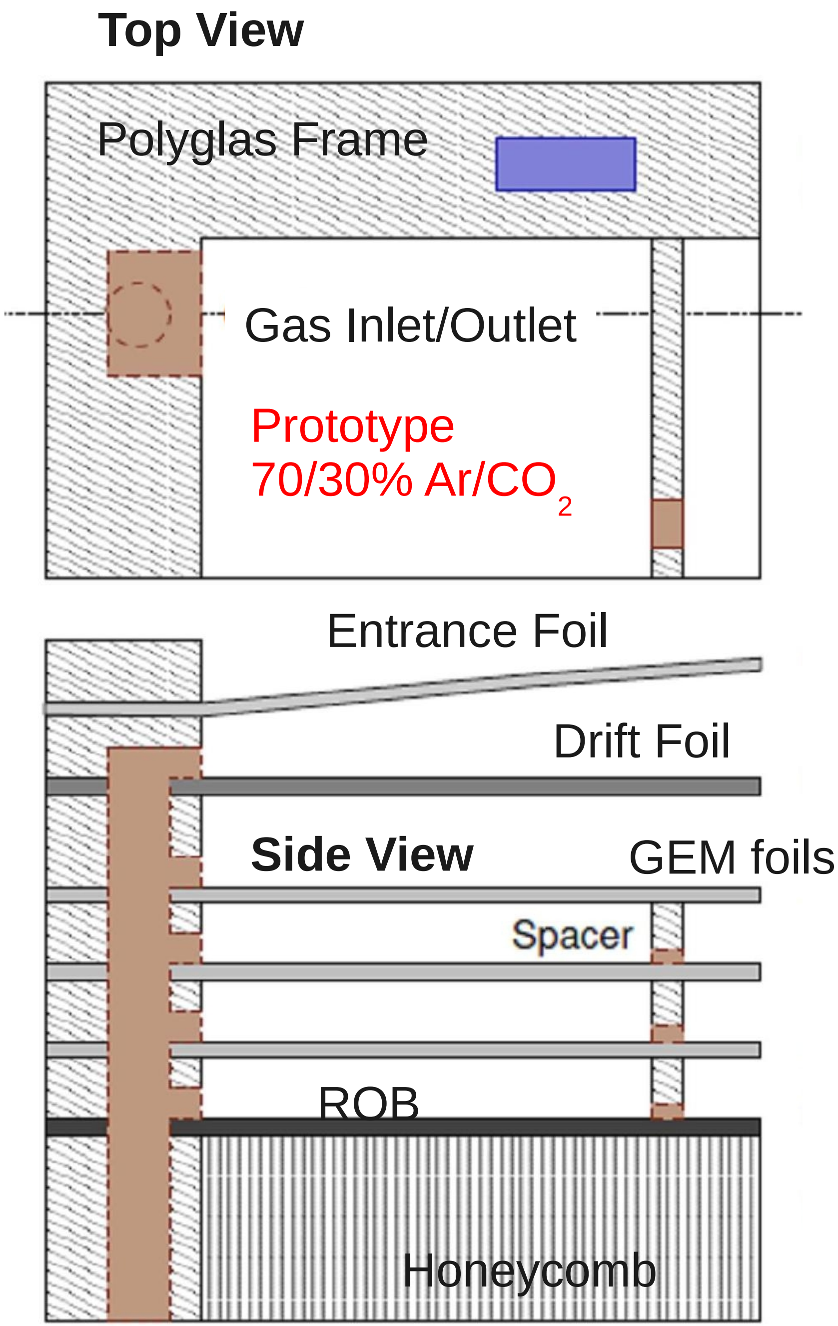
Mechanical Rigidity

Frame width	(mm)	5	6	7	8	9	10
Maximum Sag	(μm)	180	24	21	19	16	12

- Flexible Configuration of Detectors
  to service different experiments
- Use the same base module to build
  different tracker geometries
- Size: 40 x 50 cm^2 active area + 0.8 cm
  frame width. Tensioned 30 kg.
- 3 GEM foils (double mask technology)
- 2D strip ROB 0.4 mm pitch
- Signal amplitude recorded $\rightarrow$
  ~70 µm position resolution
- Either x-y or u-v strip orientation.
- Last 2 chambers front tracker strips in 2 halves
  to reduce occupancy
- Polarimeter chambers 4-strips combined
  1.6 mm pitch
- Coordinate Detector: 1D y readout, 1 mm pitch
  for BigCal e' detector in G_{ep}(5). BigCal $\rightarrow$ x coord.



Chamber Material Budget

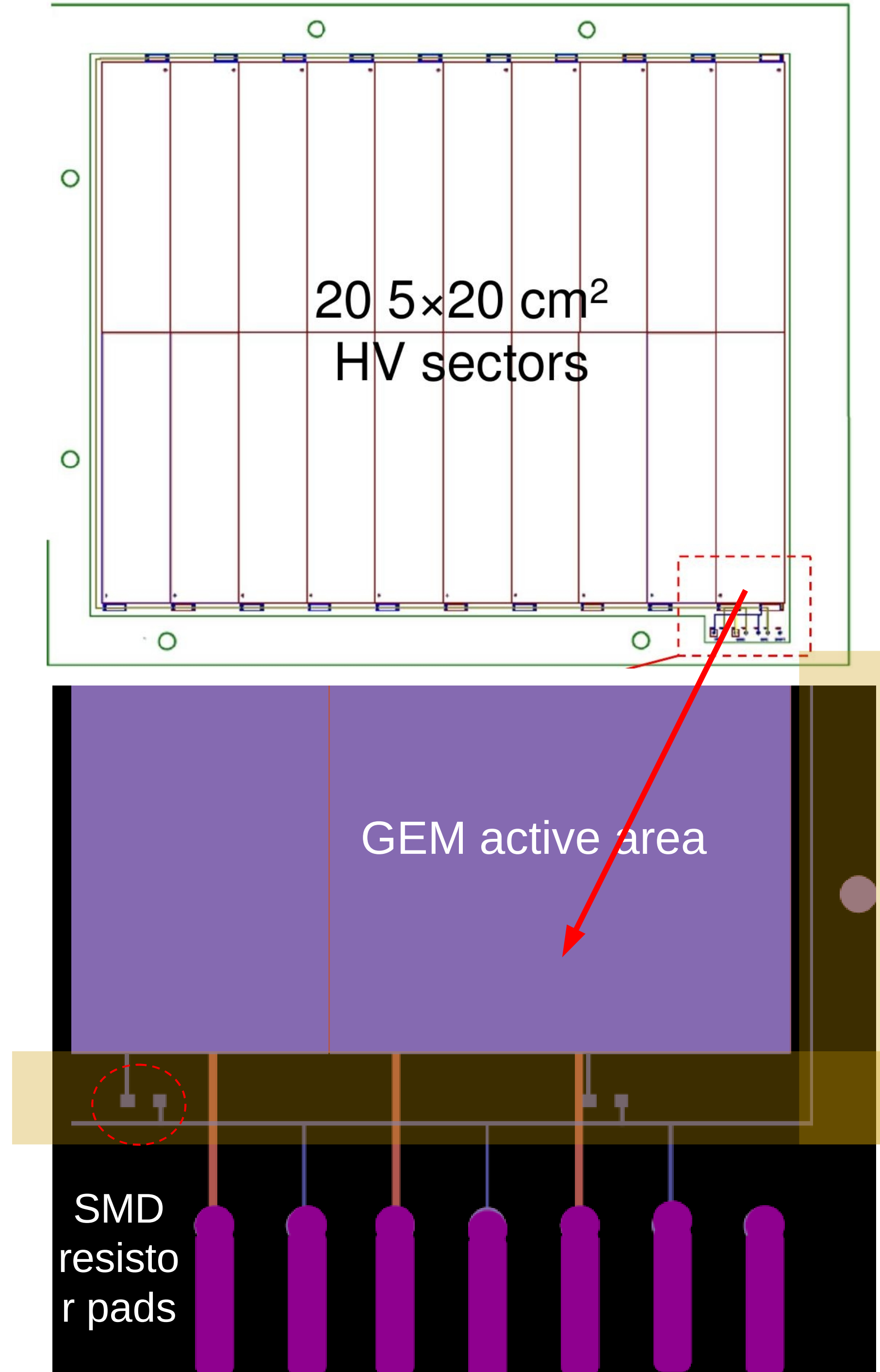


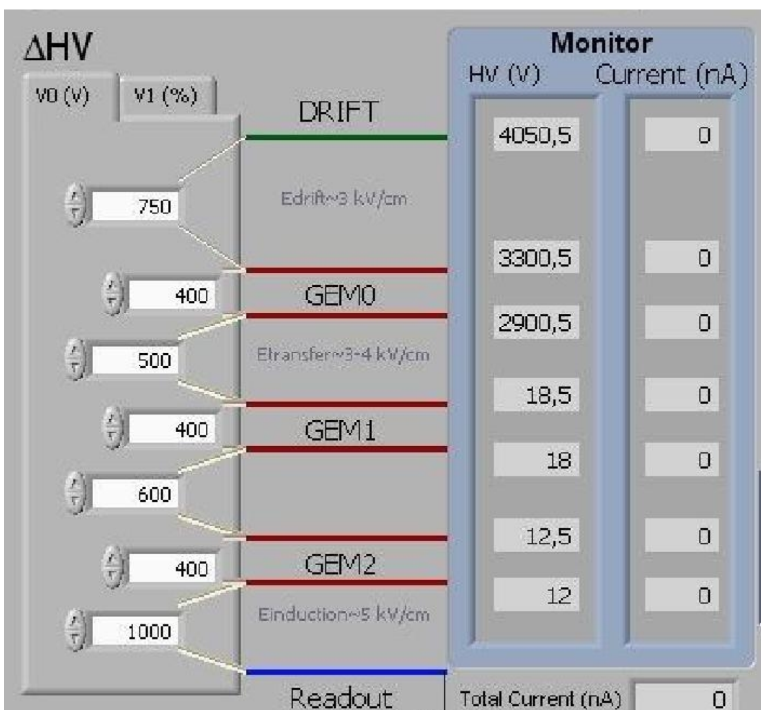
- Based on the COMPASS GEM
- SBS has single honeycomb & smaller thickness of Cu
- Minimise material
- Background (soft-photon conversion)
- Multiple scattering, angular resolution

	Quantity	*Thickness (μm)*	*Density (g/cm3)*	*X0 (mm)*	*Area (%)*	*X0 (%)*
Window						
Mylar	1	10	1.39	287	100	0.3484
Drift						
Copper	1	3	8.96	14.3	100	2.0979
Kapton	1	50	1.42	286	100	1.7483
GEM Foil						
Copper	6	3	8.96	14.3	80	10.0699
Kapton	3	50	1.42	286	80	4.1958
Grid Spacer						
G10	3	2000	1.7	194	0.8	2.4742
Readout						
Copper-80	1	3	8.96	14.3	20	0.4196
Copper-350	1	3	8.96	14.3	75	1.5734
Kapton	1	30	1.42	286	20	0.2098
G10	1	120	1.7	194	100	6.1856
NoFlu glue	1	60	1.5	200	100	3.0000
Honeycomb						
Nomex	1	6000	1	13125	100	4.5714
G10	2	120	1.7	194	100	12.3711
Gas						
(CO2)	1	9000	0.0018	18310	100	4.9153

High Voltage Distribution

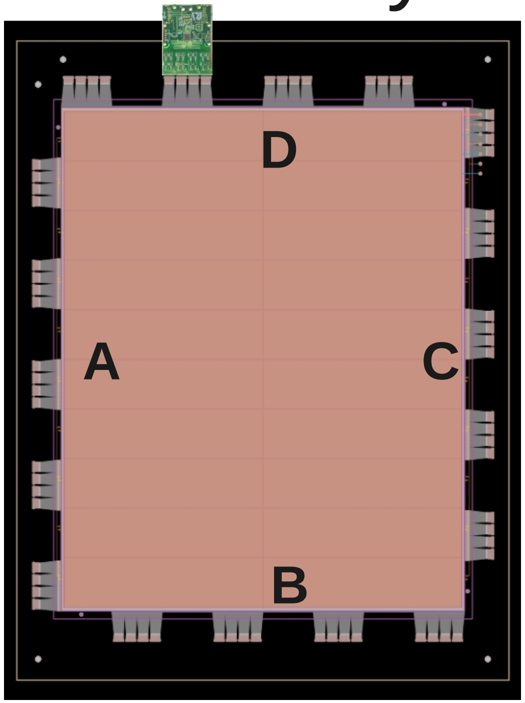
- 7 independent HV channels for each chamber
  Must ramp up/down in phase
- 3 HV identical doublets + 1 for drift (same on all GEM foils); each doublet serves one GEM foil, unused will be cut.
- SMD protection resistors, under the thin frame
- GEM foils stretched at 30 kg tension

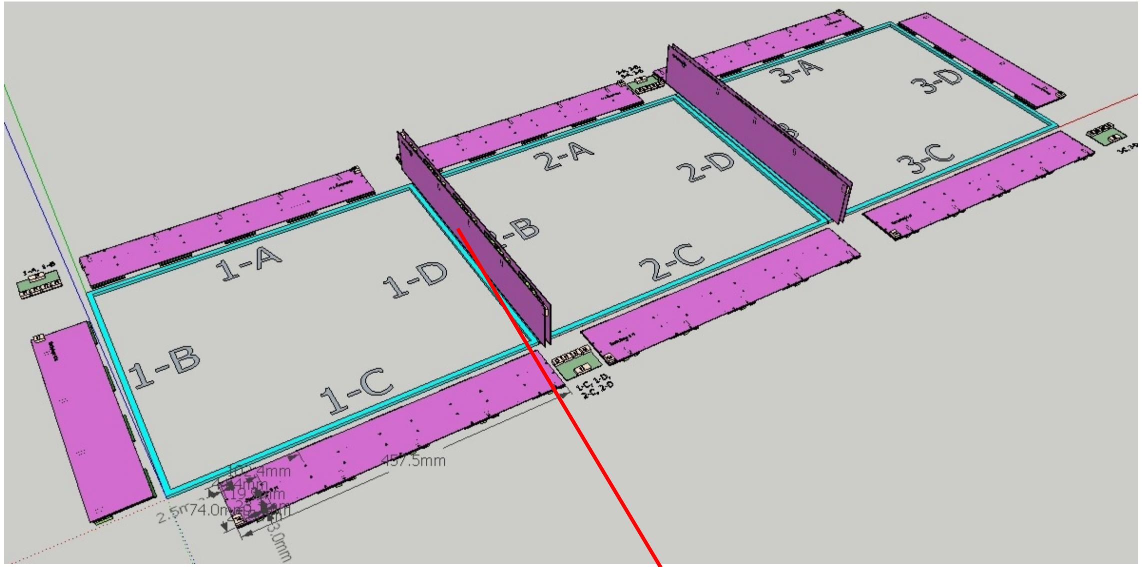


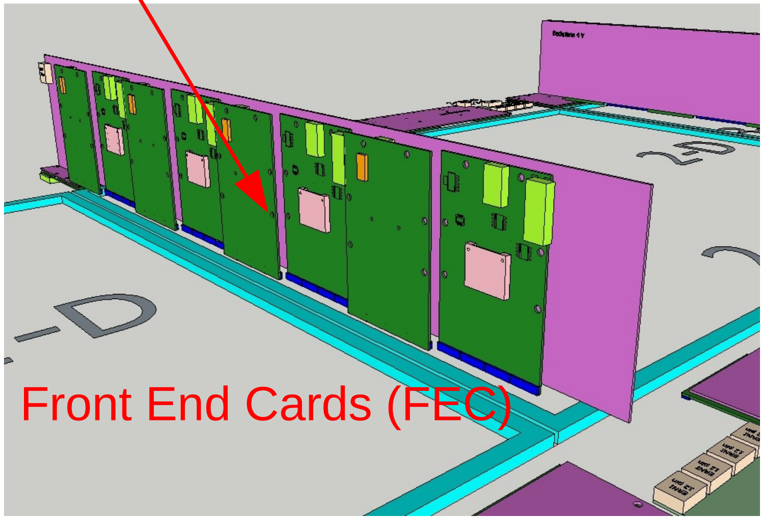


HV supplies developed by Corradi & Murtas at LNF

Layout of Readout Electronics



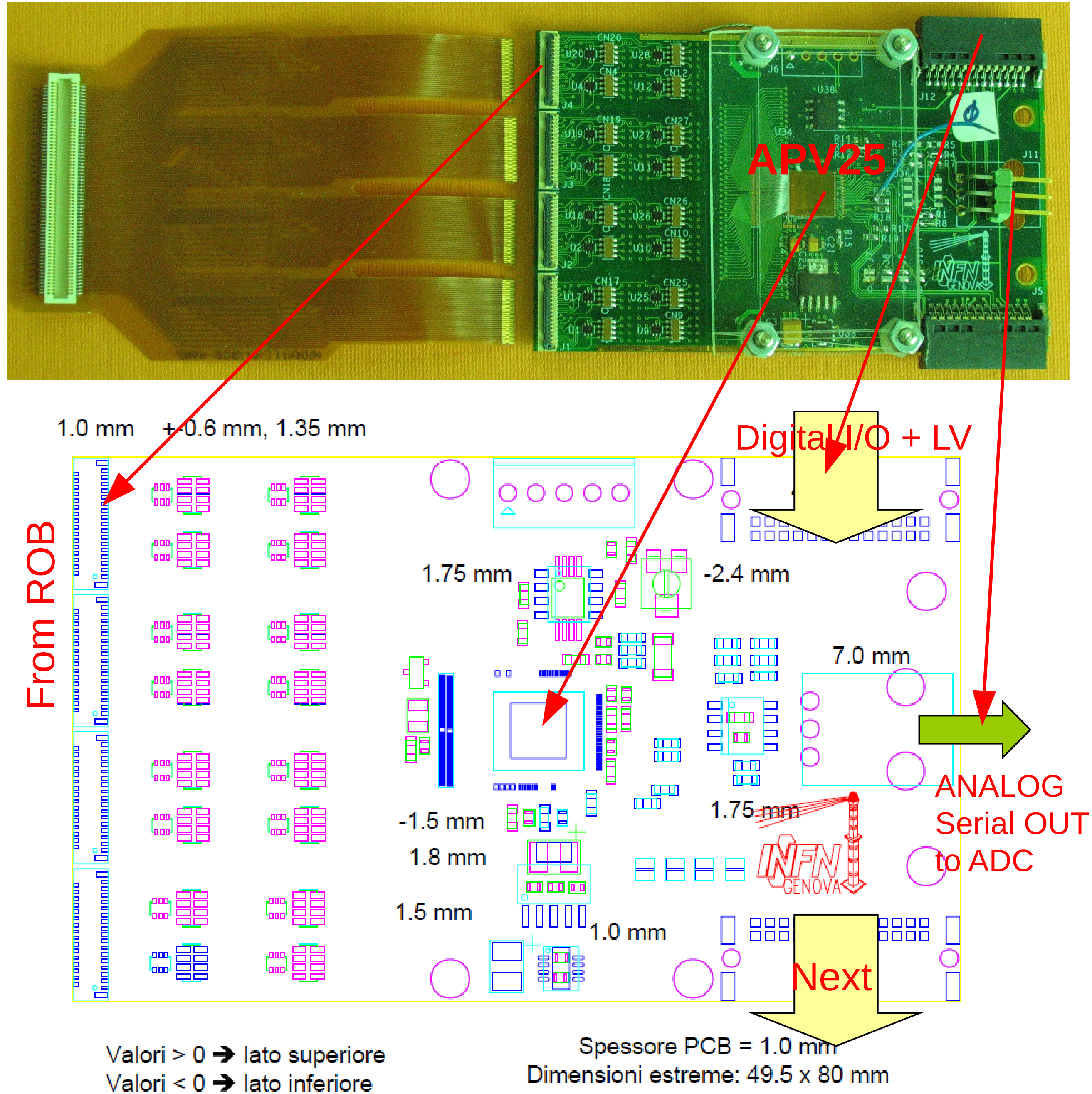




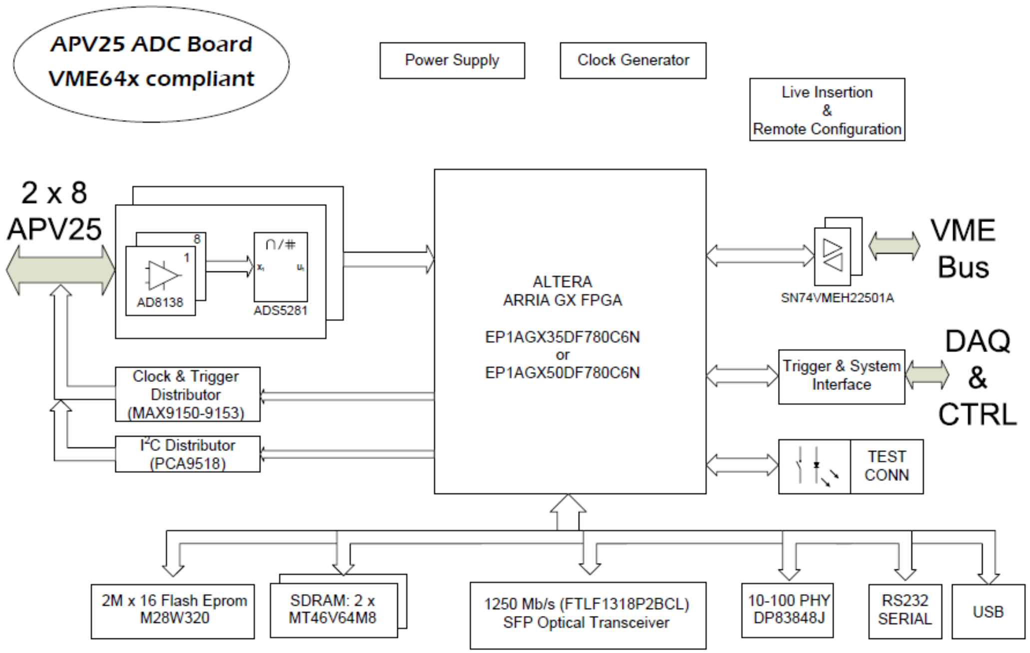
- Cards and modules supported by outer
  carbon-fibre frame
  running round the entire chamber.
- Readout from every side of ROB
  Required for double x-y strip density
  Required for diagonal u-v
  Better mechanical balance
- Extension feeds into ZIF connectors
  No soldering on the readout foil
  Permits safer bending
- Frame width minimum consistent with rigidity to minimise dead area
  Precise machining around the ZIF terminals necessary.

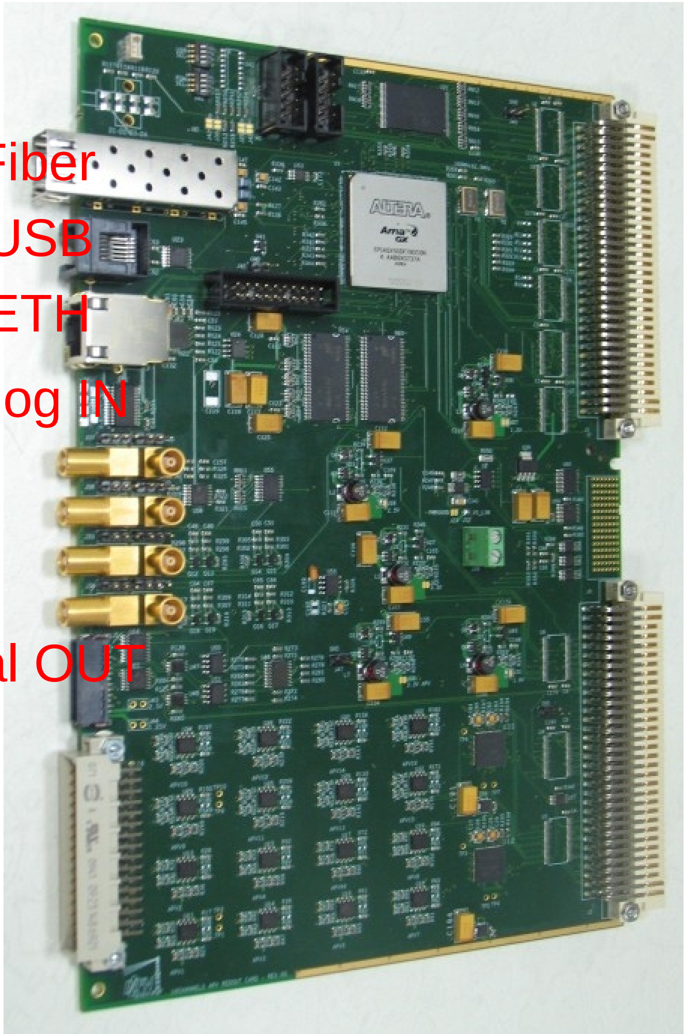
Front End Card (FEC)

- Front End card based on COMPASS original design (private comm. *M.Böhmer, I.Konorov, TUM*)
- Uses APV25 chip. Pipeline ASIC (CMS Si Tracker)
- 128 GEM Channels
- Bus like digital lines (CLOCK, trigger I2C) & Low Voltages
- Single differential line for the serial ANALOG out
- ZIF connectors on the GEM side (no soldering on readout foil); minimize thickness
- 800 FEC needed
- Prototypes under test



VME64x Controller

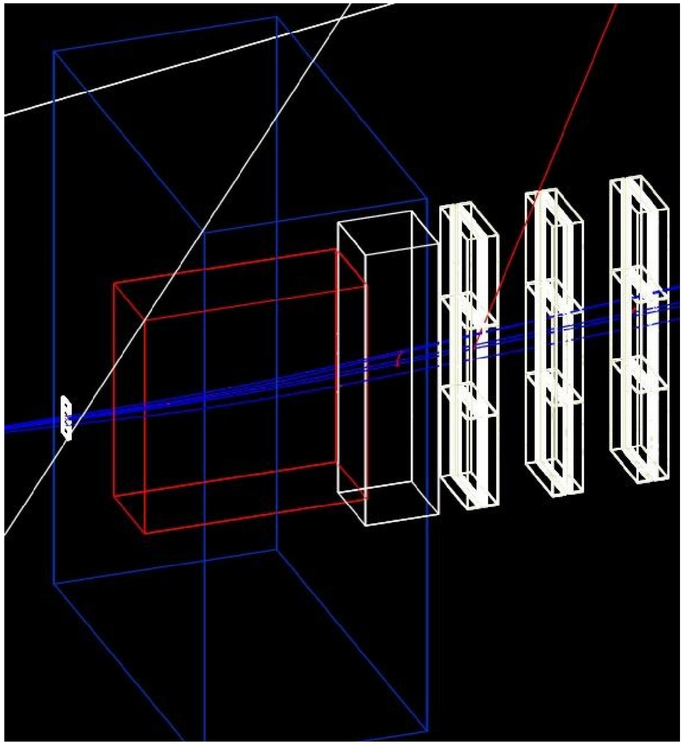


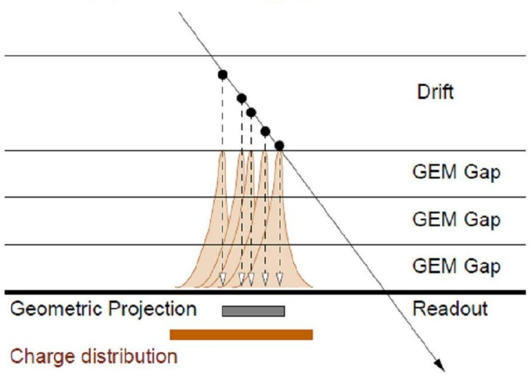


- Hosts digitization of signals from the front end card (FEC).
- Handle all control signals required by FEC (up to **16**)
- 50 modules = 100 k channels
- Compliant JLab/12 VME64x VITA 41 (VXS) standard

  also standard VMEbus
- Detachable ADC module extend FEC-VME64x distance
- 2 x 64 MB SDRAM
- Expected event size ~20 kB, trigger rate < 5 kHz,
- Expected data rate < 100 MB/s (3-sample AVP25 readout?)

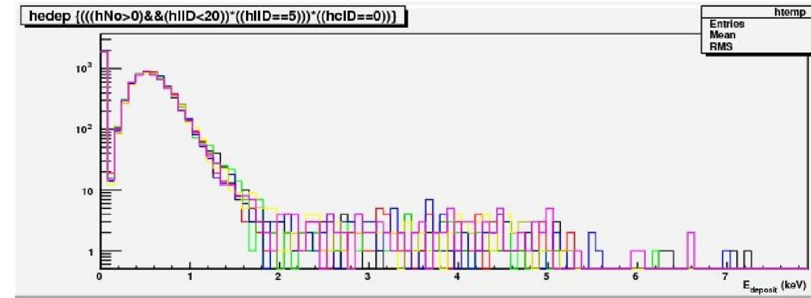
Monte Carlo Simulations

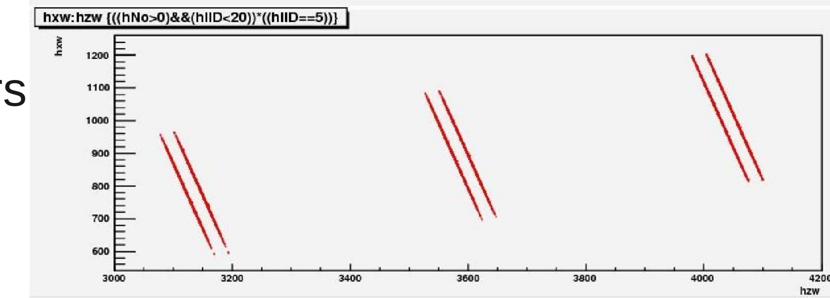


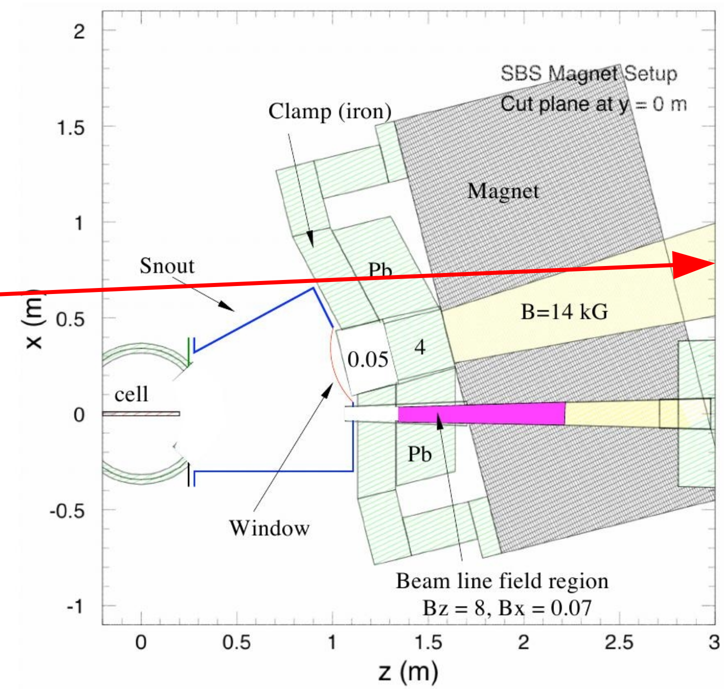


- **Geant-4 GEM**
- Model ionisation process
- Track reconstruction algorithms
- G4 Other Detectors

- Beam induced background in target and vicinity
- Impact on rates, GEM-strip occupancy and track reconstruction efficiency?
- After the dipole the most serious source of background is soft photons...
- 500 - 1000 kHz/cm^2 in front trackers.







Occupancy Levels in Chambers

$G_{Ep}(5)$ Experiment..highest design luminosity so far: 8 x 10^{38} $s^{-1}.cm^{-2}$

Tracker	Area of interest for tracking, cm^2	Rate, kHz/cm^2	Strip pitch, mm	Strip occupancy, %	Number of pseudo-tracks per event	Number of strip planes
First	0.20 x 18	400	0.4	13.5	1.65×10^{-2}	12
Second	$2\pi\ 0.35^2$	130	1.6	7.4	8.7×10^{-6}	8
Third	$\pi\ 4.8^2$	64	1.6	3.6	5.2×10^{-4}	8
BigCal	$\pi\ 1.2^2$	173	1	2.4	2.8×10^{-2}	2

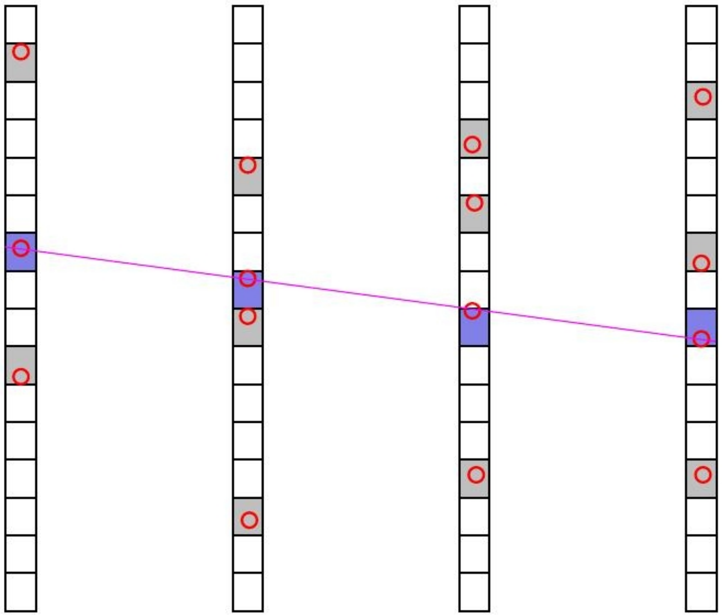
- SBS @ 14°, BigCal e' @ 39°.
- Rate predictions: DINREG, P. Degtiarenko, JLab. Model region around target in some detail. Similar simulations give good predictions for current 6 GeV experiments
- Occupancy I = trS, t = integration time, r = rate, S = strip area.
  t =3 x 25 ns front tracker, 2 x 25 ns 2nd & 3rd. tracker.
  S assumes strip width + 0.4 mm (extent of e' cloud at ROB)
- Elastic kinematic correlation required to distinguish real tracks from large number of background hits.
- Hit position in electron arm: vertical coordinate GEM, horizontal BigCAL... target length dominates horizontal uncertainty, so GEM not useful here
- Elastic proton kinematic range on front tracker from ±3σ cut around e' hit position
- Reconstruct proton track in FT consistent with e' track
- Reconstruct track in 3rd aided by coordinate info from rear hadron calorimeter
- Reconstruct track in 2nd using already reconstructed tracks in FT and 3rd

Track Reconstruction Software (O.Hansen Hall-A) Tree-Search Algorithm

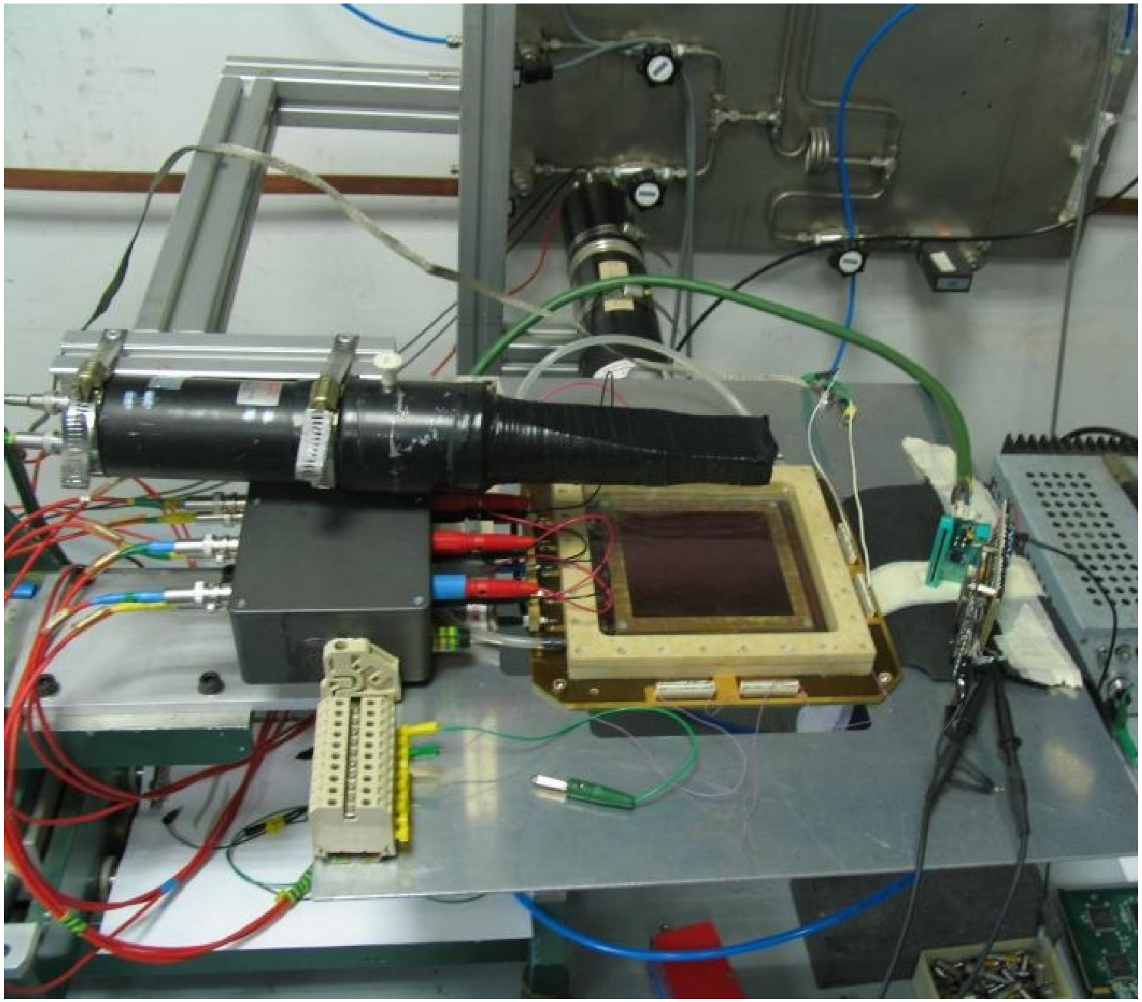
- Proposed Dell'Orso et al., NIM A287, 436 (1990)
- Recursive template matching
- Computationally fast and efficient in memory use
- Proven at HERMES for various MWDC
- Used Qweak for HDC and VDCs
- Used in Hall-A BigBite MWDCs, Gen, SIDIS SSA
- Appears suitable for SBS front tracking

- Conversion of software to handle GEM as opposed to MWDC under way
- No (MWDC) L/R ambiguity handling
- Weighted averaging strip signals
- Exploit amplitude & time correlations
- Works better with several redundant planes

Successive Approximation Method

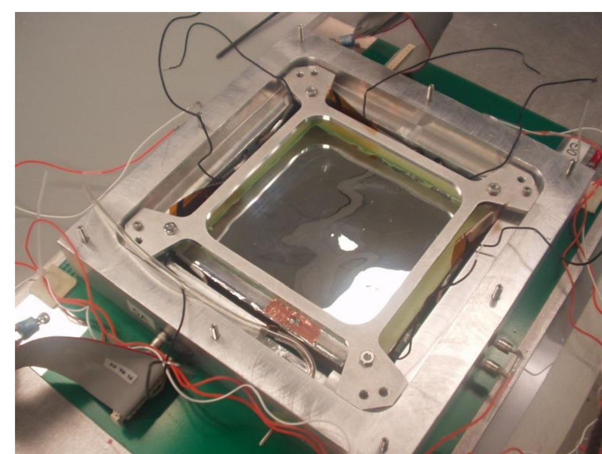


Tests of Prototype GEMs



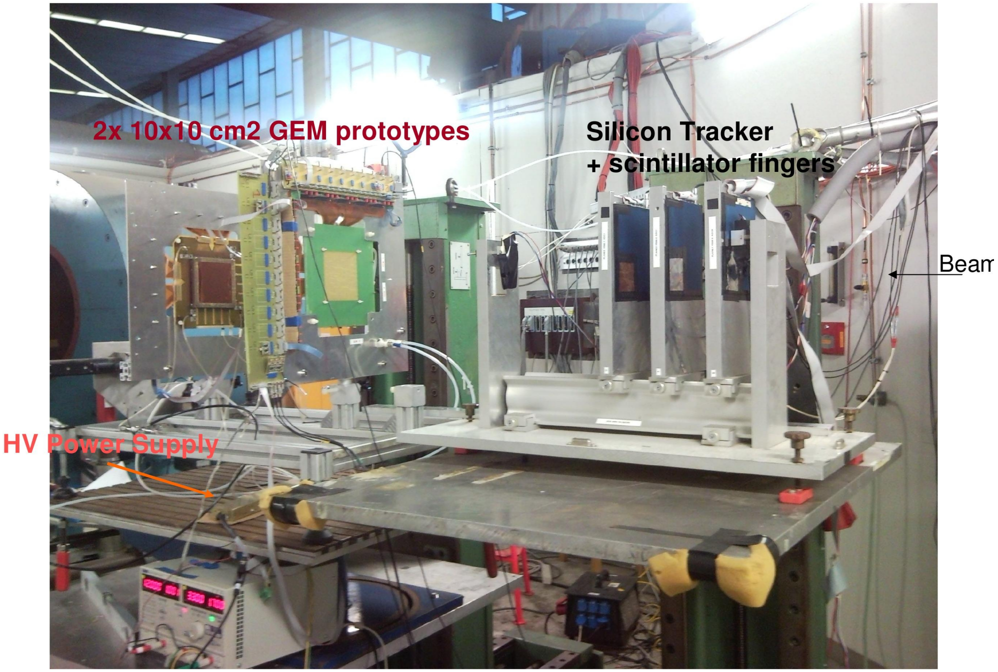
- Tests with 3 GeV beam @ DESY
- Parasitic tests in Hall-A (e,e'x)
- So far 10 x 10 cm^2 prototype with Gassiplex readout.

- Plan similar tests this year of 40 x 50 cm^2 GEM module
- Study behaviour in high rate environment
- Commission FEC (AVP25)
- Test cluster analysis and fitting
- Study tracking performance at high multiplicity
- Require sufficient “redundant” planes



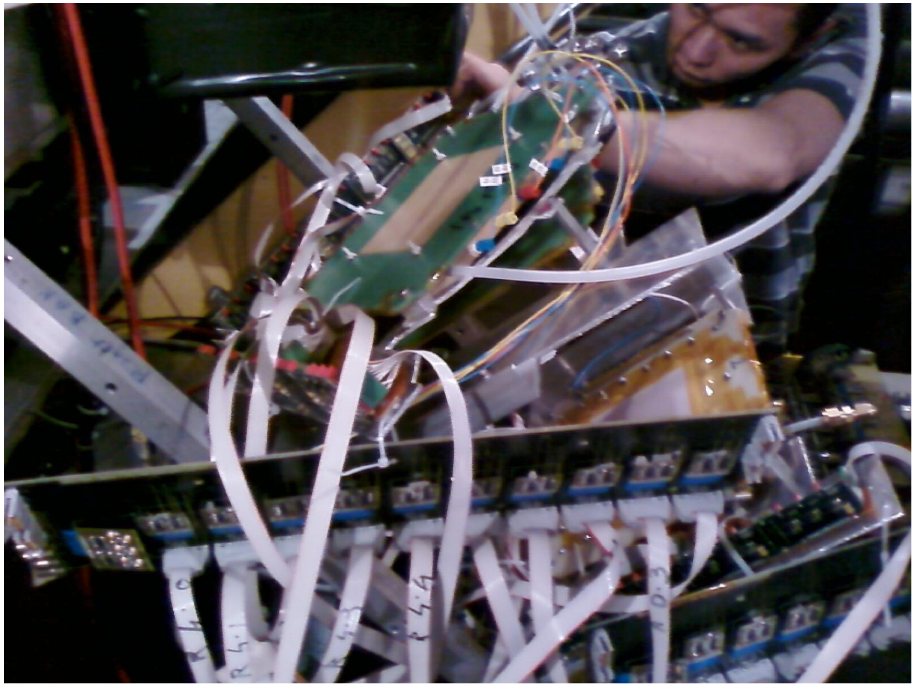
GEM Beam Tests

DESY



- DESY-II Test area
  low intensity e^- beam 1 – 6 GeV
- 2 10 x 10 cm^2 2D prototypes
  with Gassiplex readout
- Characterise small chamber
- Prepare for 40x50 cm^2 module test
  expected 2010
- Behaviour of full-size module
- Fine-tune design/construction
- Test APV25 based FEC

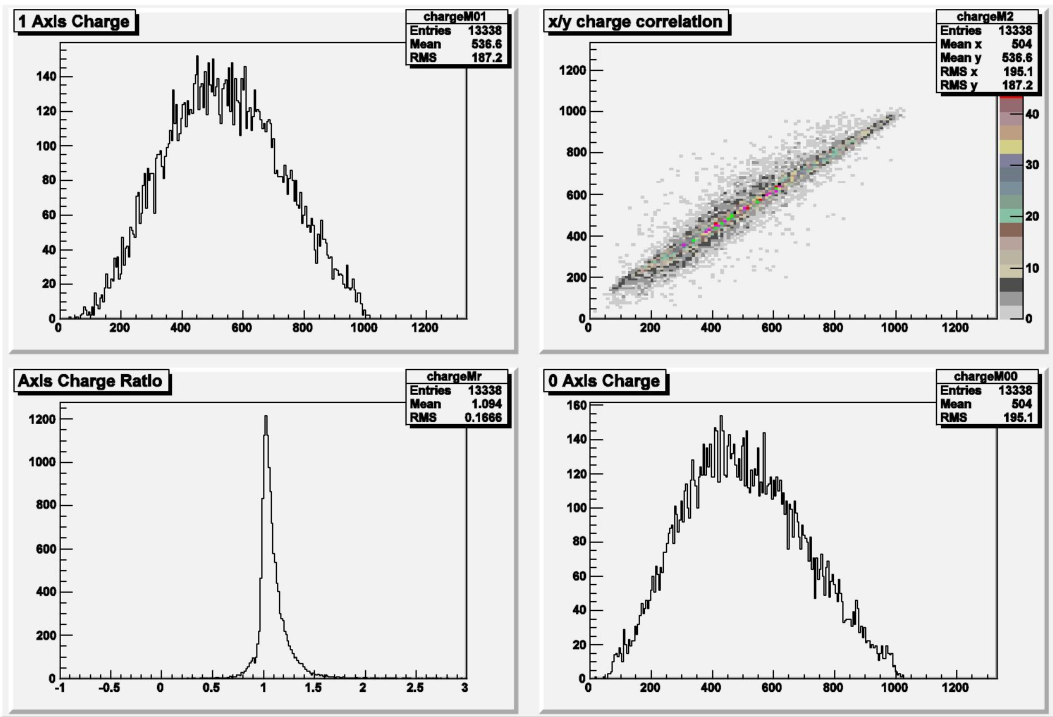
Hall-A



- 4 10 x 10 cm^2 GEM behind the VDCs
  of hall A HRS
- PREX $^{208}Pb(e,e')$ experiment...6 GeV,
  high luminosity
- Good correlation; tracks projected from
  VDC and GEM tracks.
- Preliminary resolution (from residuals)
  ~ 60 microns.
- Continue Autumn 2010 5-chamber
  telescope with APV-25 readout

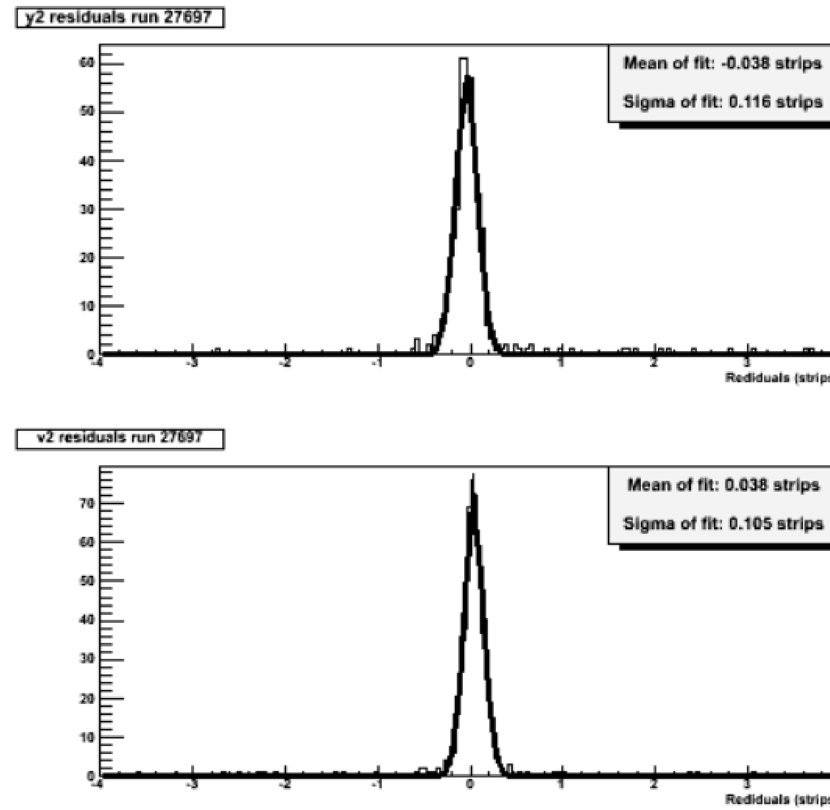
Beam Test Analysis

DESY



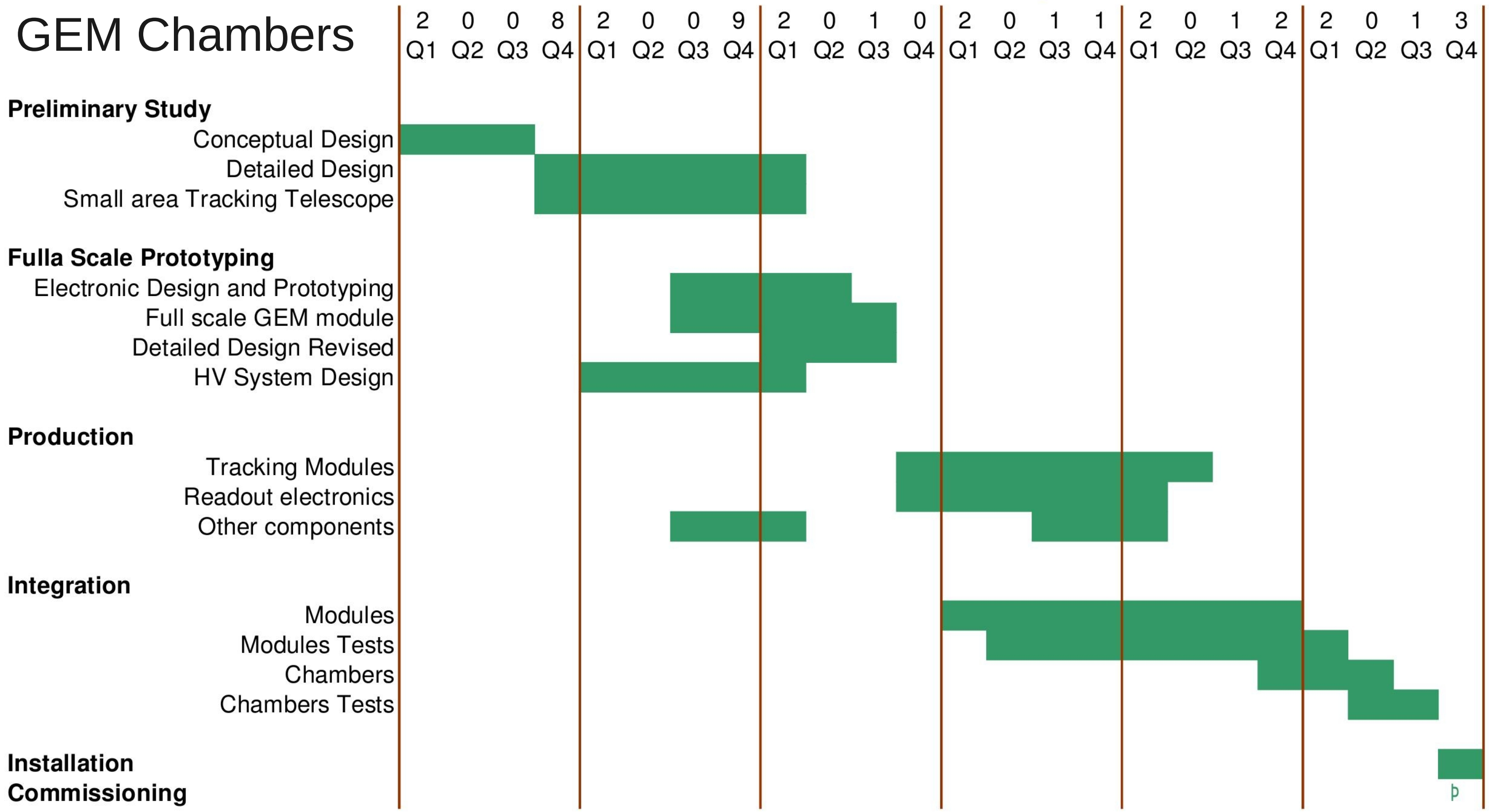
- 10 x 10 cm^2 prototype
- Amplitude correlation between x and y strips
- Useful in rejecting non-track accidentals

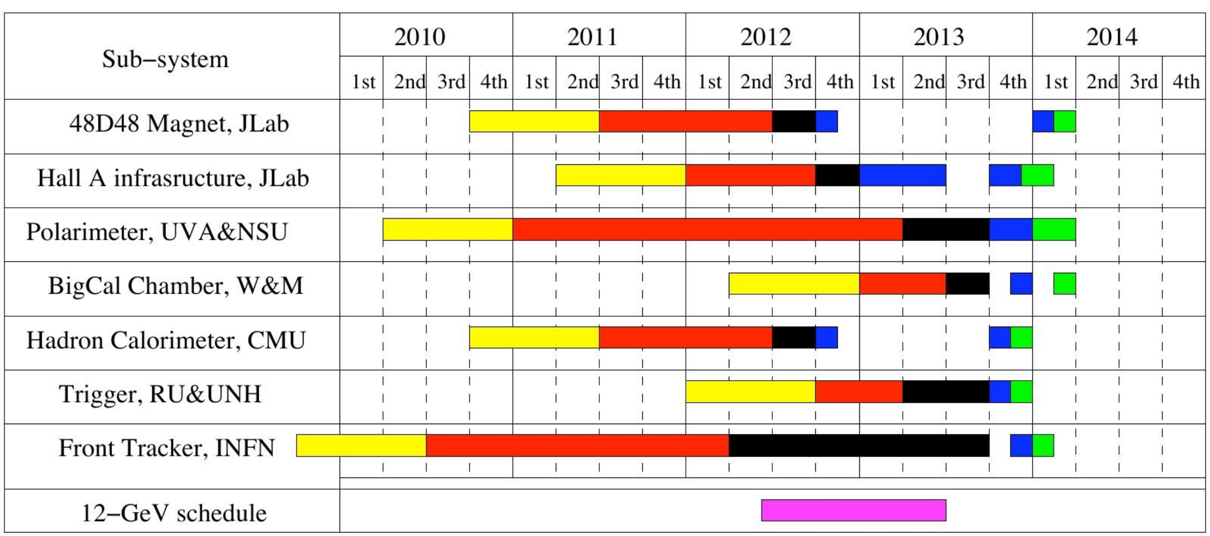
Hall-A



- 10 x 10 cm^2 prototype
- Strip pitch of 400 mm
- Correlated with HRS VDC track reconstruction
- Obtain a position resolution of ~ 60 mm

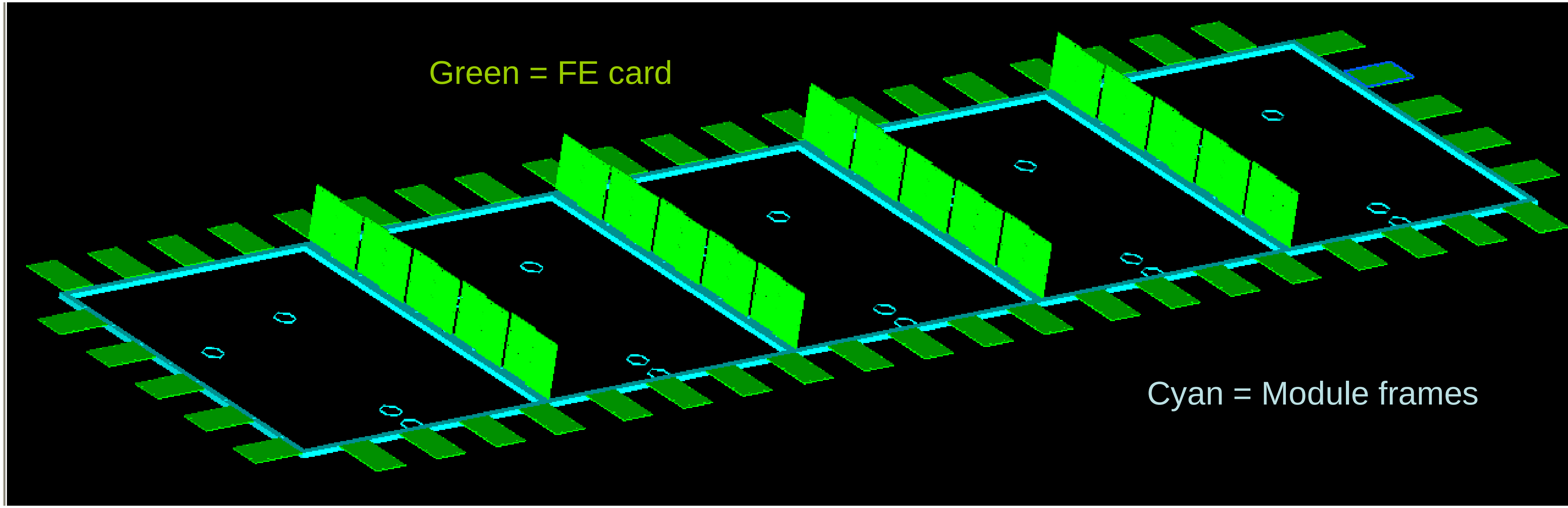
Time Lines





Overall SBS Time Lines
Design
Construction
Testing
Installation
Commissioning
CEBAF down for upgrade

Backup: Electronics layout and outer support



Cards and modules are supported by an outer aluminum frame which runs all around the chamber.

Optimization is in progress.