Large Size GEM Detectors for 12 GeV Program in Hall A at JLab

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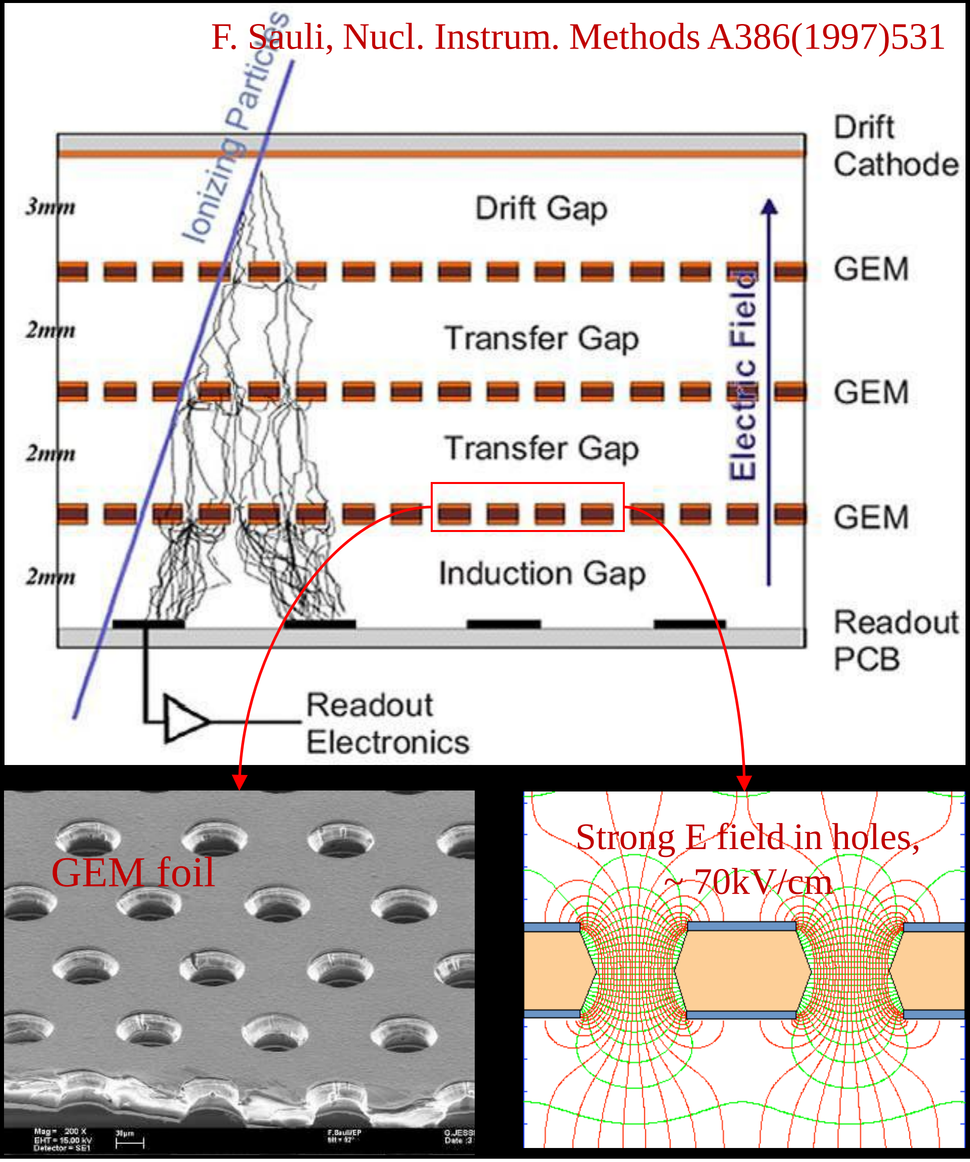
- Gas Electron Multiplier (GEM) Detectors
- GEM Detectors in 12 GeV Programs in Hall A at JLab
- New Developments in Large Area GEM
- Industrial Production Facilities

UNIVERSITY of VIRGINIA

GEM Detectors Principle

- Charged particle ionizes gas in the drift volume
- Primary electrons drift to the GEM holes following the E-field lines
- Electron multiplication the foil because of the strong E-field in the holes.
- Use two to three layers in cascade for a high gain (up to 10^5 in triple GEM)
- Readout board collects charge ➔ Various designs possible ➔ Pads, Strips, 2D patterns Pixel,
- Position resolution depends on gas, geometry, and readout

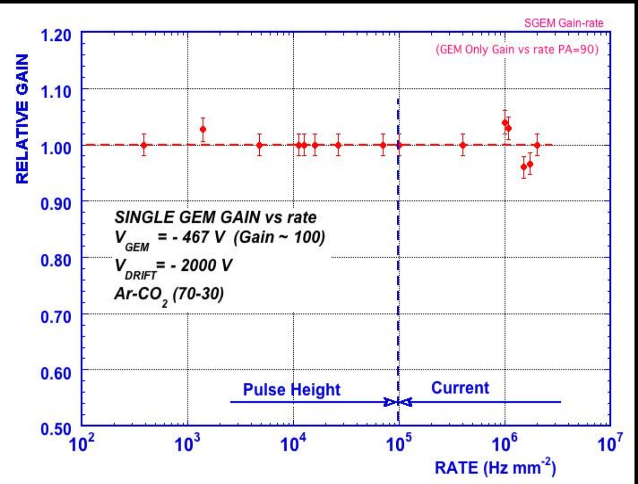


GEM Detectors Performances

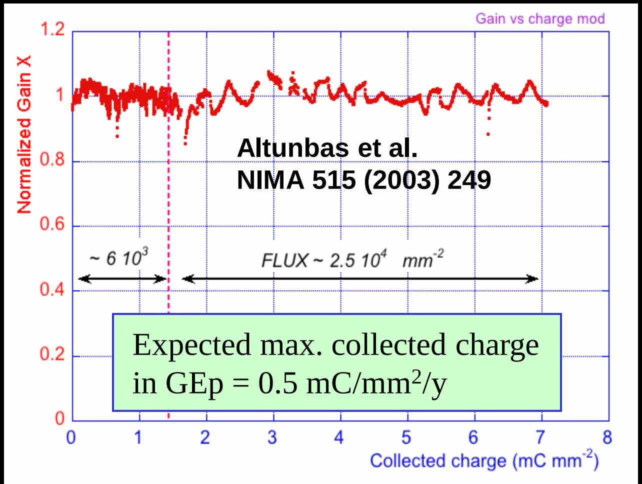
New high luminosity, high precision experiments asking for a new breed of tracking detectors to

- High rate environments (MHz/cm2)
- High position resolutions (< 75 µm)
- Large areas (10s – 100s of m2 with new technological breakthrough)
- Robustness and stability with stacking two or 3 GEM foil (low discharge probability)
- Ex: CMS, Jefferson lab Super-BigBite and SoLID, EIC, ILC…

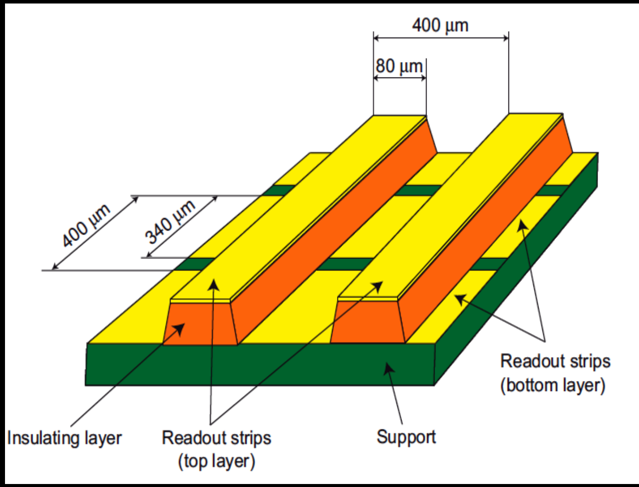
High rate capability



Aging effect



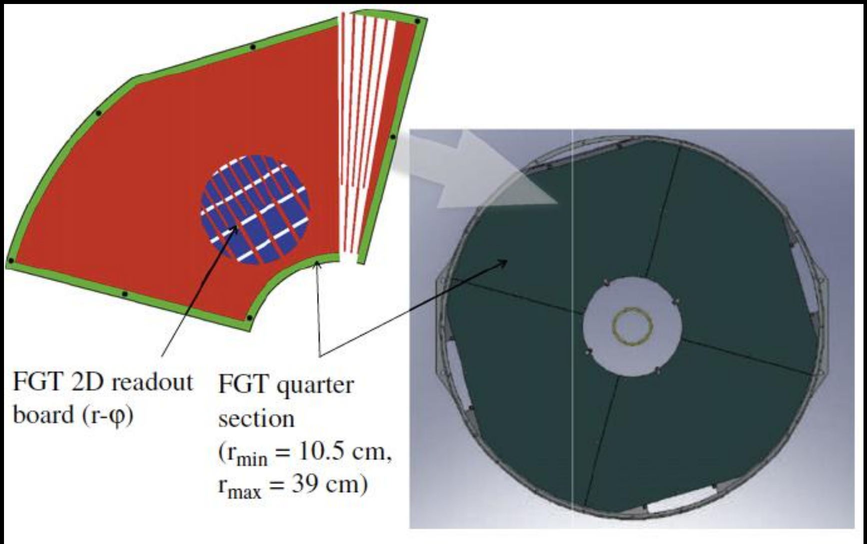
COMPASS 2D readout (~70 µm resolution)



GEMs provide a cost effective solution for high resolution tracking under high rates

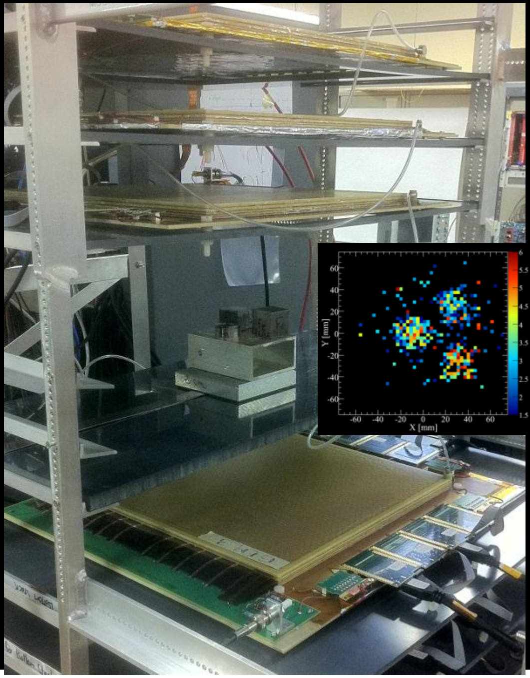
GEM Detectors in Experiments

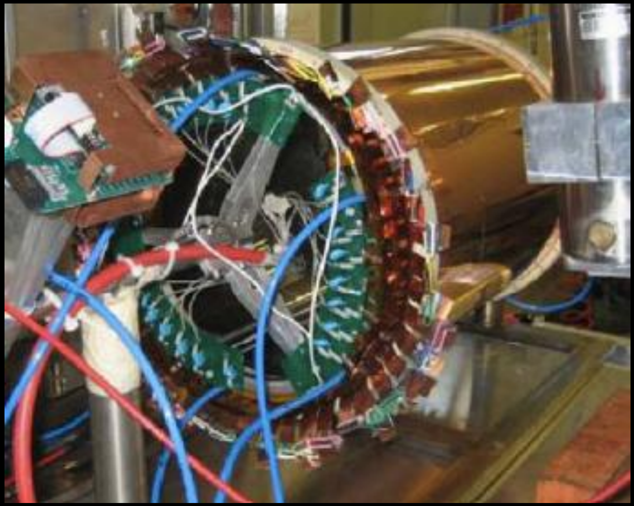
COMPASS: (3-2-2) Triple GEM @ CERN



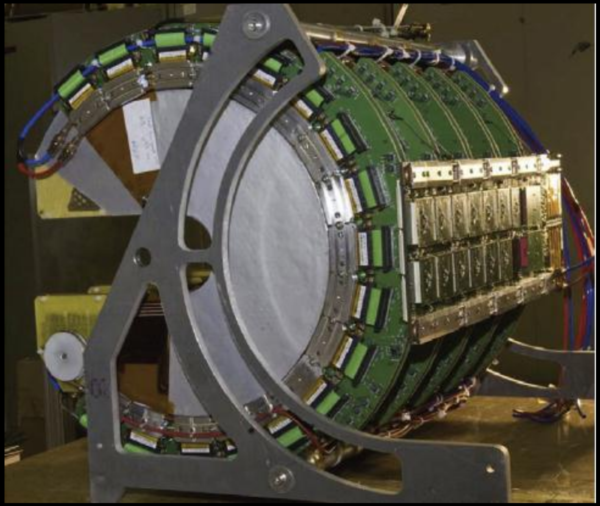
STAR FGT (Forward GEM Tracker): 6 triple-GEM disks

Muon Tomography @ Florida Tech





Cylindrical GEM Tracker for KLOE @ DAPHNE (Frascati, Italy)



GEM Tracker for LHC TOTEM experiment @ CERN

GEMs in the 12 GeV in Hall A at JLab

Choice of the MPGD technology

System Requirements	Tracking Technology		
	Drift	MPGD	Silicon
High Background Rate (up to): (low energy γ and e) **1 MHz/cm^2**	NO	**MHz/mm^2**	**MHz/mm^2**
High Resolution (down to): **70 μm**	Achievable	**50 μm**	30 μm
Large Area: from 40×150 to 80×300 cm^2	YES	**Doable**	Very Expensive

… and modular: reuse in different geometrical configuration

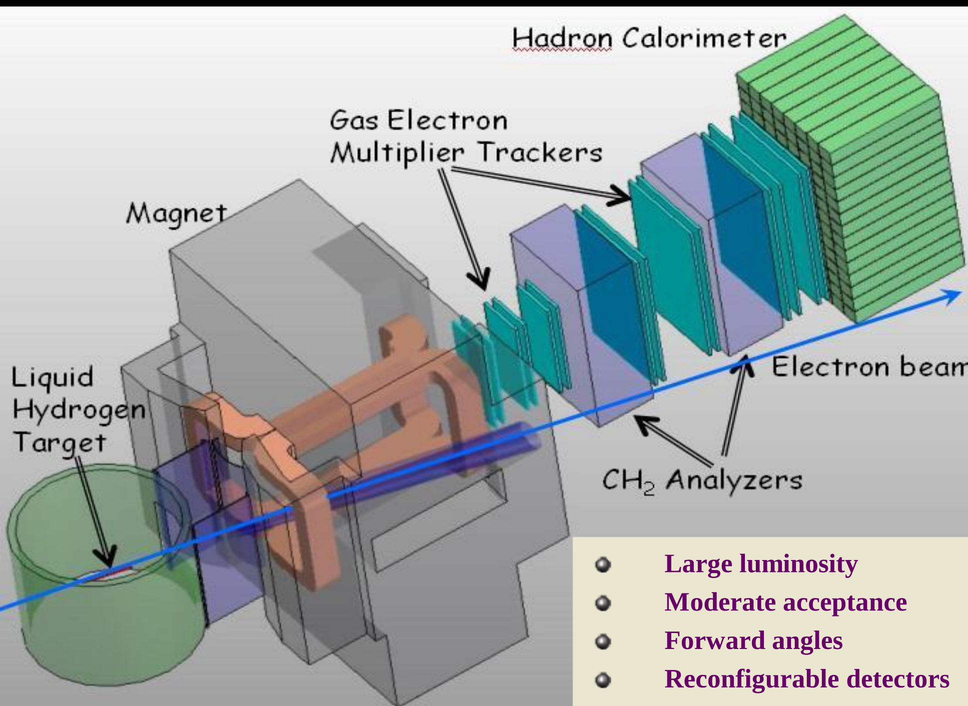
MPGD → **GEM**, **μMs**

GEM ← Flexibility in readout geometry and lower spark rate

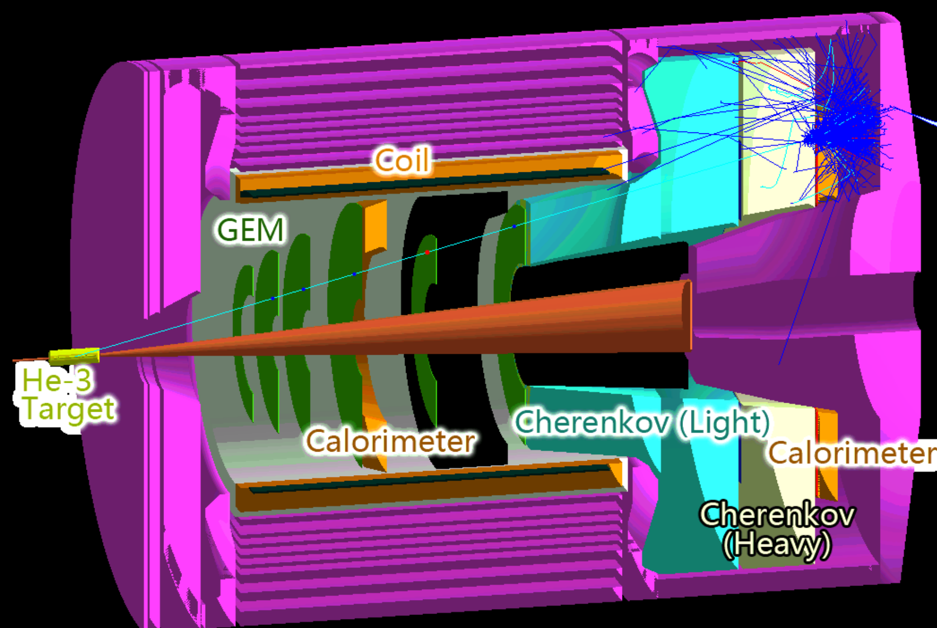
GEMs in the 12 GeV in Hall A at JLab

Large size GEM detectors for two big 12 GeV Experiments in Hall A

Super BigBite Spectrometer @ JLab



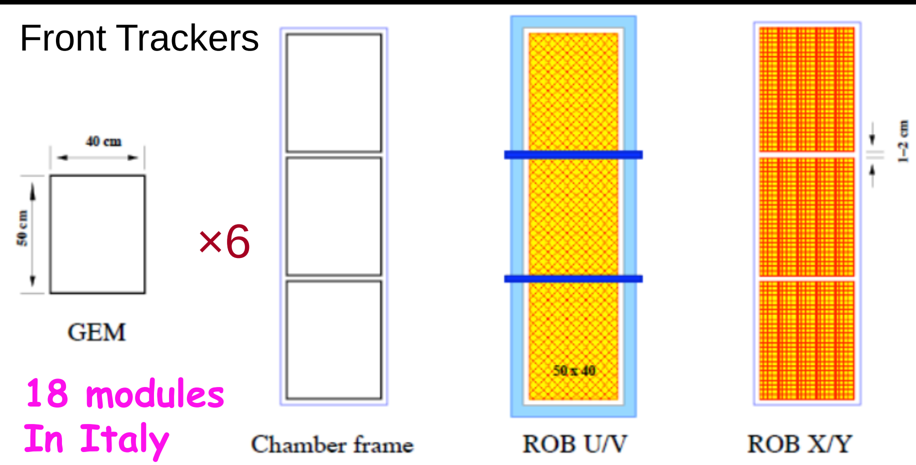
SoLID Spectrometer @ JLab

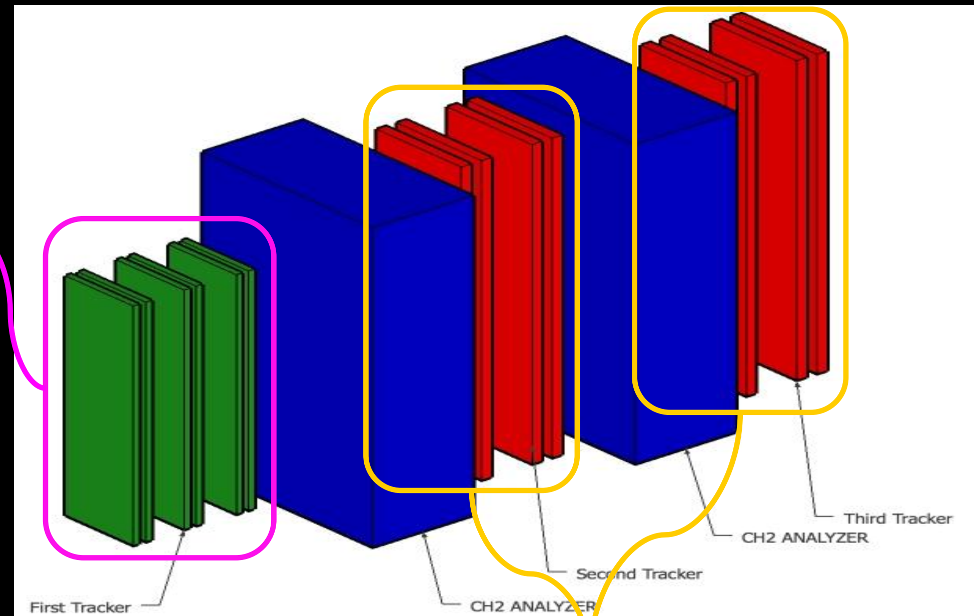


- SBS recently received DOE approval
- Spectrometer for high luminosity experiments to measure nucleon form factors
- SIDIS and DIS

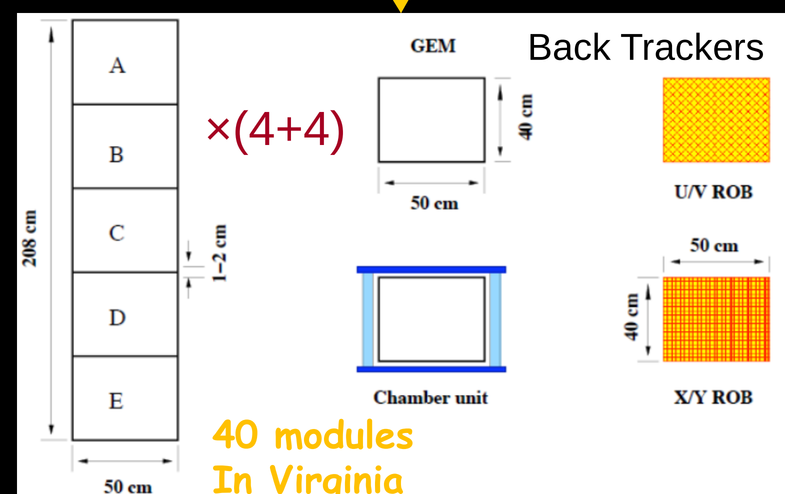
- General Purpose Deep Inelastic Scattering for Parity Violation
- will be used in different configurations for 12GeV PVDIS and SIDIS experiments

SBS GEM Trackers



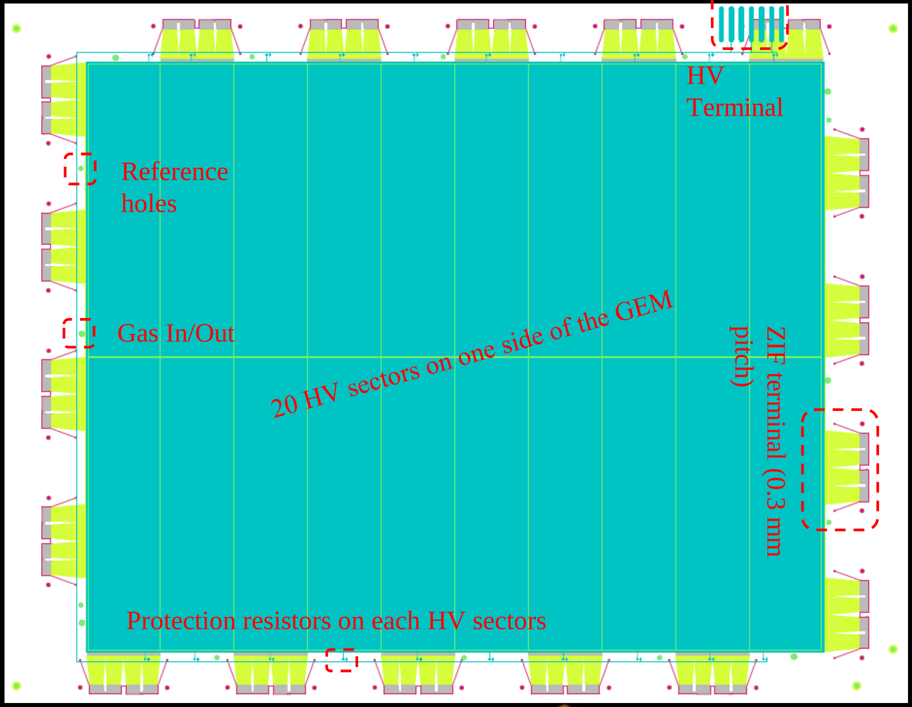


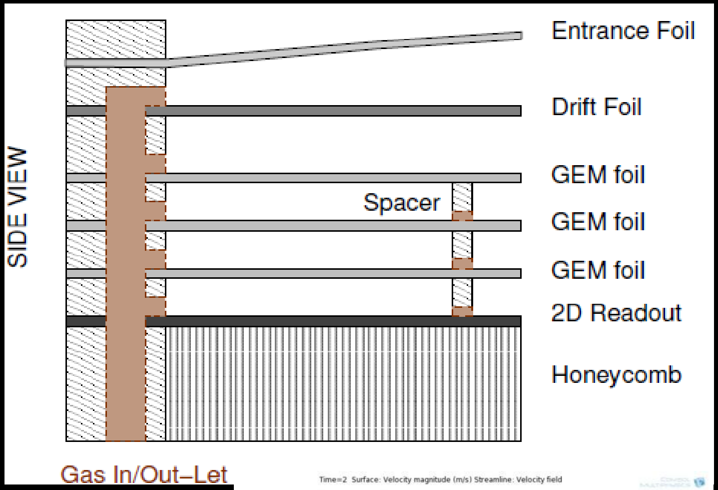
- 50 x 40 cm^2 modules are assembled to form larger chambers with different sizes
- Front Tracker: Six 40 cm x 150 cm^2 GEMs
  - INFN Funding: to be built in Italy (E. Cisbani, Roma, Catania)
- Back Trackers: Eight 50 x 200 cm^2 GEMs
  - 40 to be built in Univ. Of Virginia



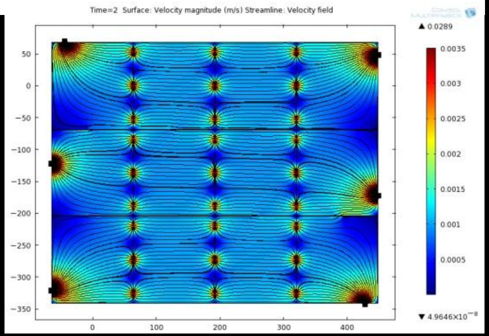
SBS GEM Design

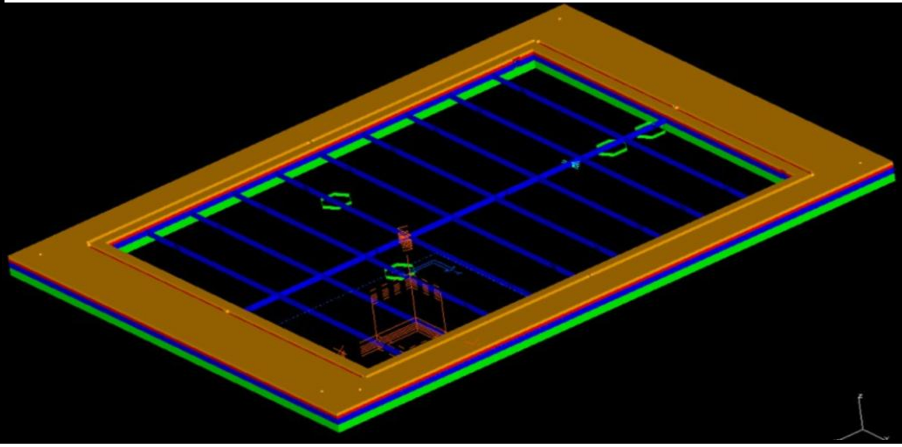
(E. Cisbani, INFN Rome, Italy)





Gas Flow / COMSOL MultiPhysics Simulation

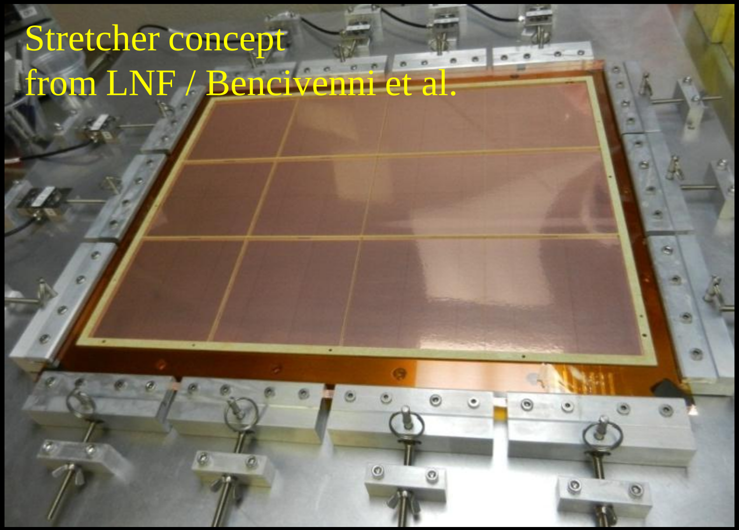


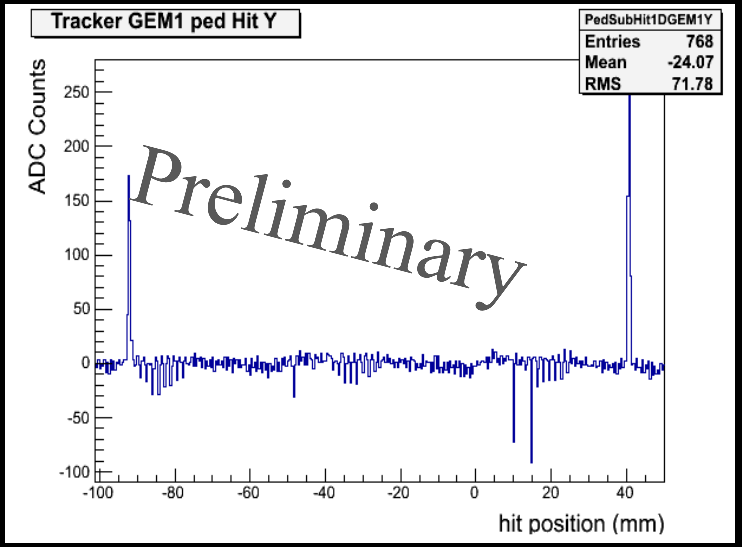


- Large GEM module with small dead area
- Low material budget/Light Structure
- APV25 Electronics (By INFN Italy)
- Modular design & Flexible configuration

SBS GEM UVa Prototype

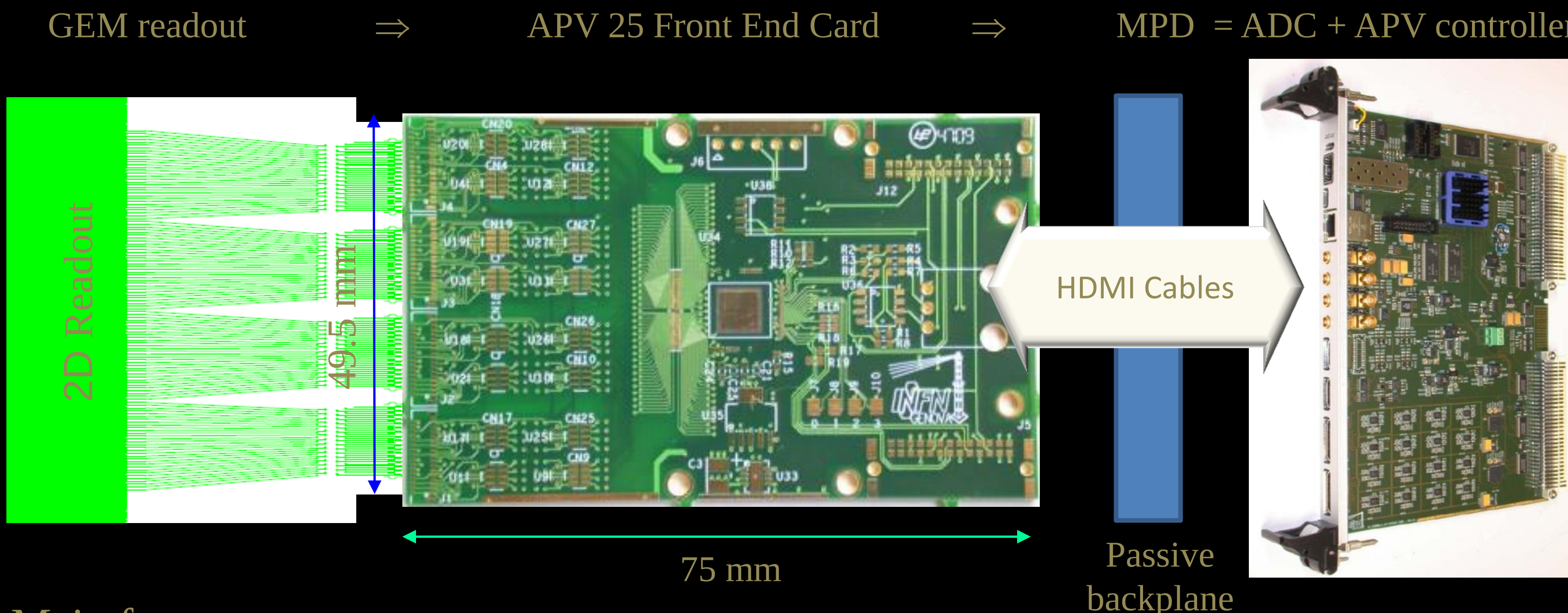
- We just completed the first UVa SBS GEM prototype
  - First prototype by Cisbani (Rome, Italy 2010)
- The prototype is been tested (very preliminary)
  - Cosmic data with APV25/SRS electronics.
- Assembly of the second prototype just started





APV25-MPD Electronics

(E. Cisbani, INFN Rome, Italy)



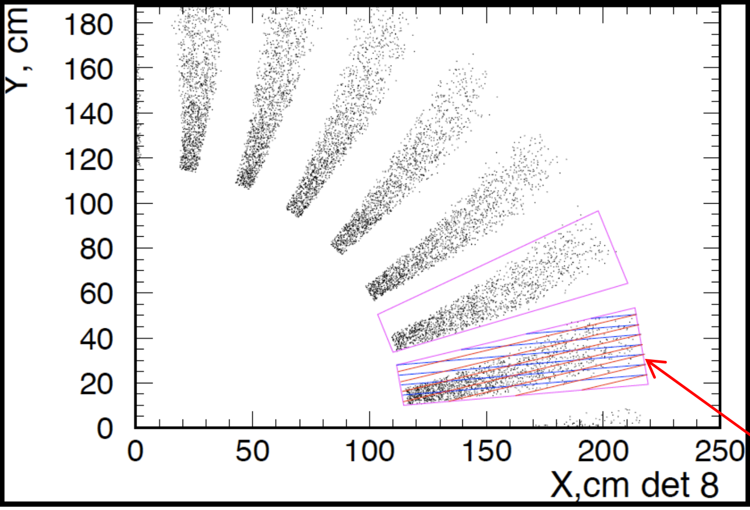
Main features:

- 2 “active” components: Front-End Card and VME64x custom module (MPD=Multi Purpose Digitizer)
- HDMI Copper cables between front-end and VME
- Optional backplane acting as signal bus, electrical shielding, GND distributor and mechanical support
- Developed by INFN, manufactured by a commercial company

SoLID Collaboration

- CO2 gas Cerenkov detector: Temple U.
- Heavy Gas Cerenkov: Temple U.
- EM Calorimeter : W&M, UMass, JLab, Rutgers, Syracuse
- GEM detectors: UVa, Miss State, W&M, Chinese Collaboration (CIAE, Huangshan U, PKU, LZU, Tsinghua, USTC), UKY, Korean Collaboration (Seoul National U)
- Scintillator: Chinese Collaboration, Duke
- MRPC: Tsinghua Univ., Duke
- Electronics: JLab
- DAQ: LANL, UVa and Jlab
- Magnet: JLab and UMass
- Simulation: JLab and Duke

GEM Tracker in PVDIS configuration



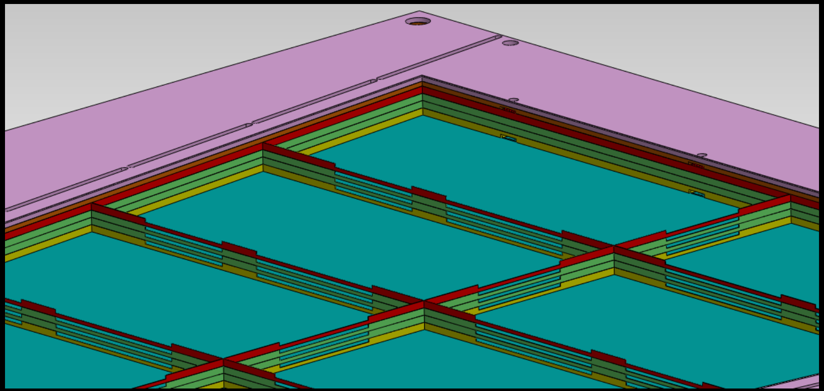
- 4 GEM layers
- 120 GEM modules
- Largest GEM module 100 cm x (20-38) cm
- Total area ~ 23 m2

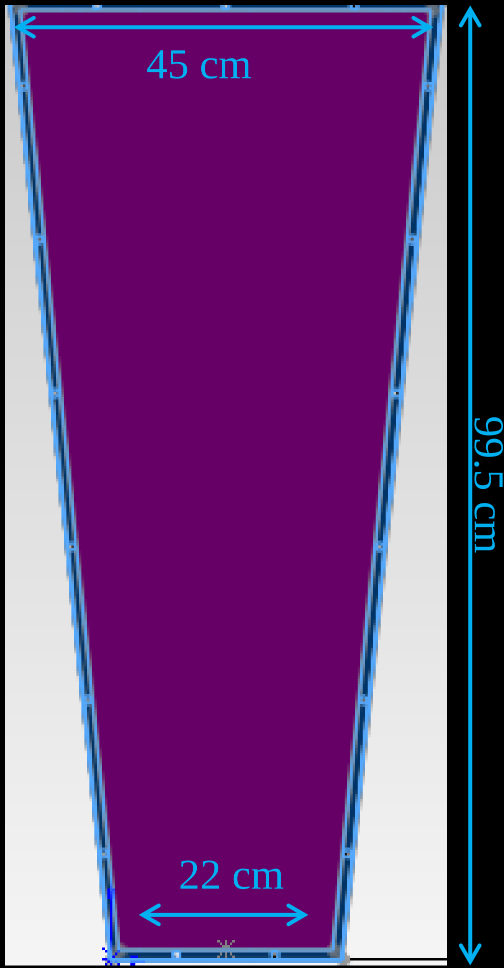
Outline of a GEM Module

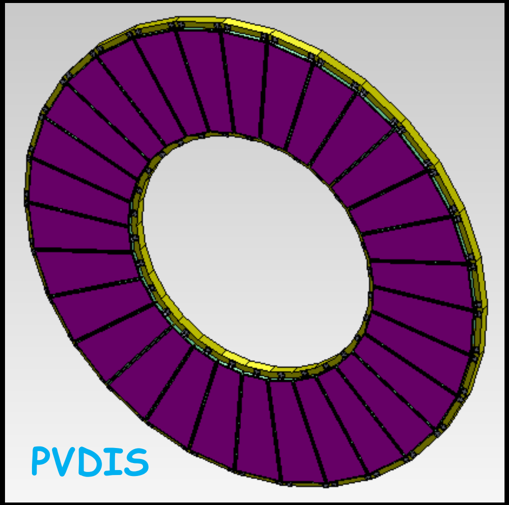
Large Area GEM R&D

Common R&D for various projects

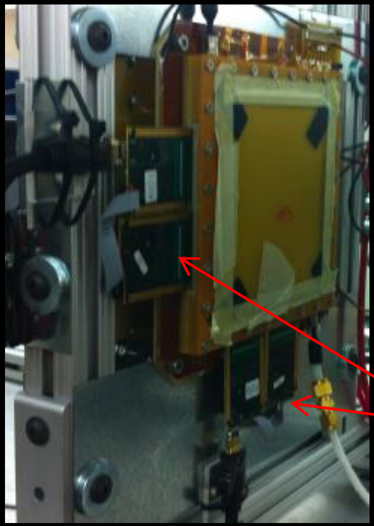
- EIC R&D funding at UVa for a large area GEM for Forward Tracker
- Chamber size very similar to largest SoLID GEM and for CMS high Eta Muon Upgrade
- Seth Saher (UVa undergrad. student) is already working on the design

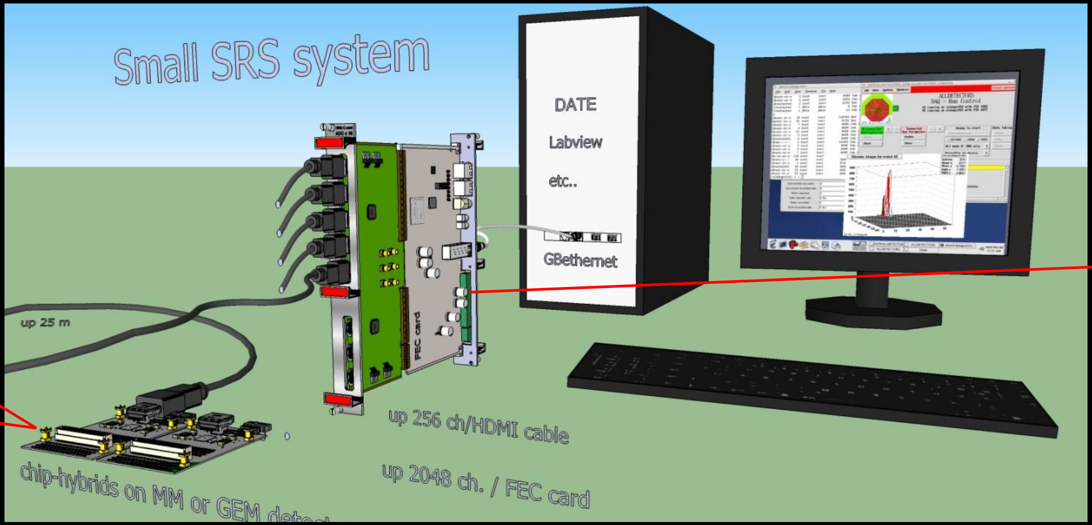






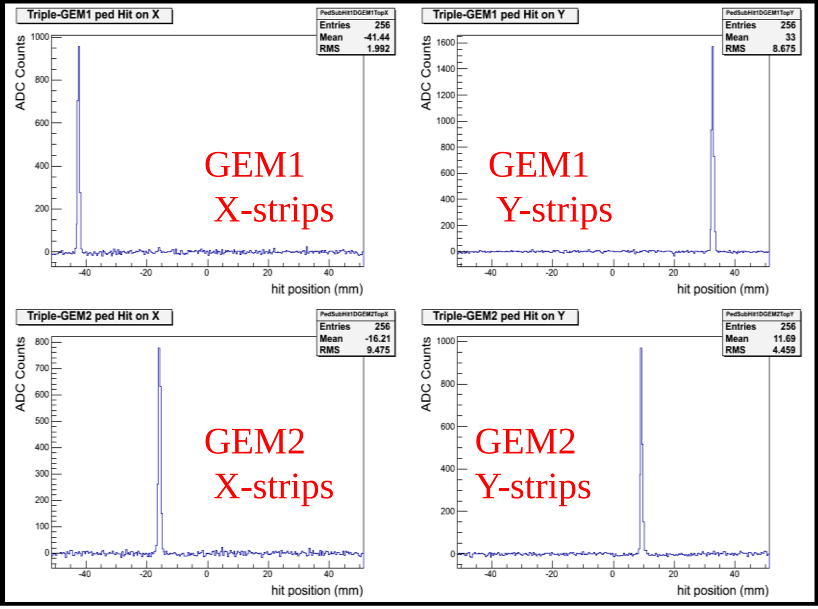
APV25-SRS Electronics





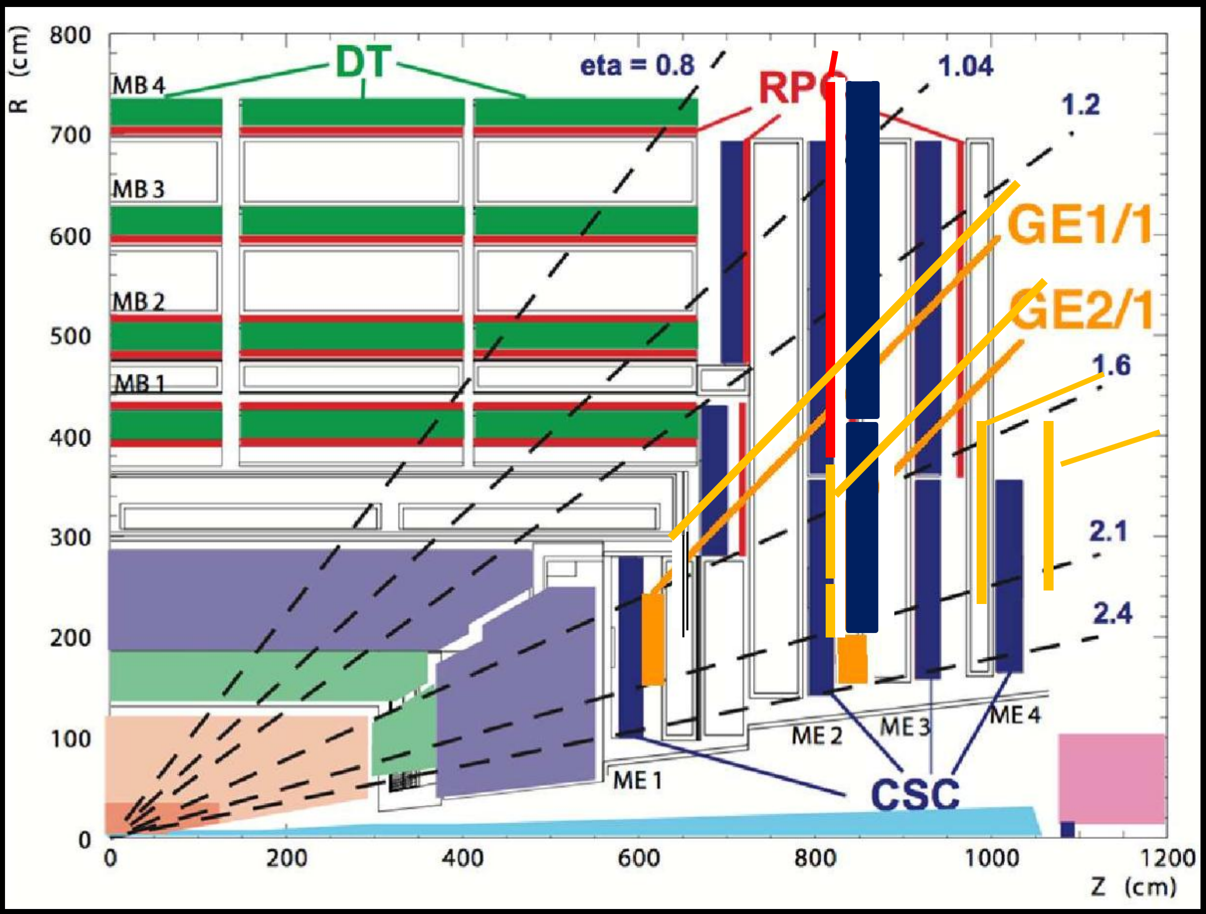
Scalable Readout System (SRS)

- Portable readout system developed by RD51 Collaboration (CERN)
- Successfully tested with APV25 chip (many users and experiments)
- APV25 cards, 1 ADC board, 1 Data Concentrator board
- Data transferred through Gb Ethernet via UDP (ALICE DAQ)
- Common platform for different chips (Bettle, VFAT, VMM1)

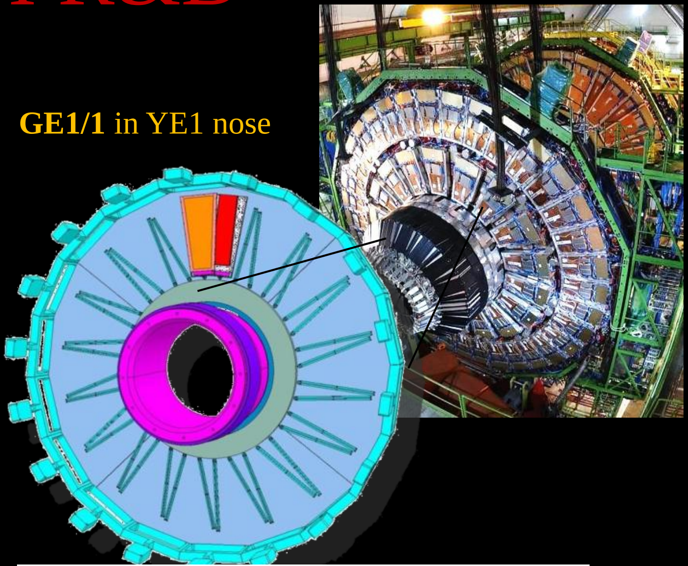


Large area CMS GEM R&D

The currently un-instrumented high-η RPC region of the muon endcaps presents an opportunity for instrumentation with a detector technology that could **sustain the radiation environment long-term** and be suitable for operation at the LHC and its future upgrades into Phase II: **GEM Detectors**



GE1/1 in YE1 nose

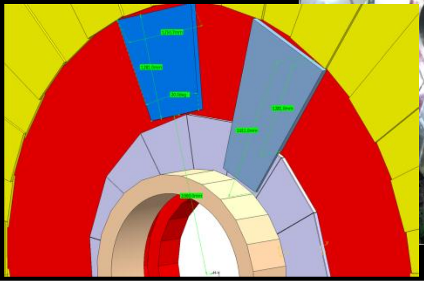


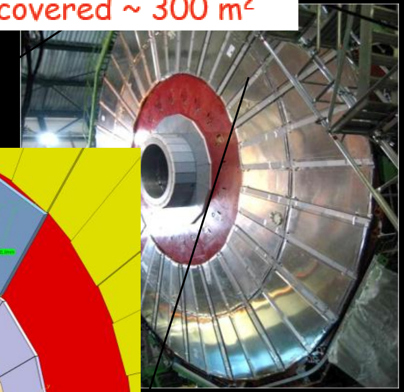
GEM s for triggering and tracking

- Proposal to cover the 1.6 < |η| < 2.4 region with GEMs.
- GEMs for
- 240 GEM chambers

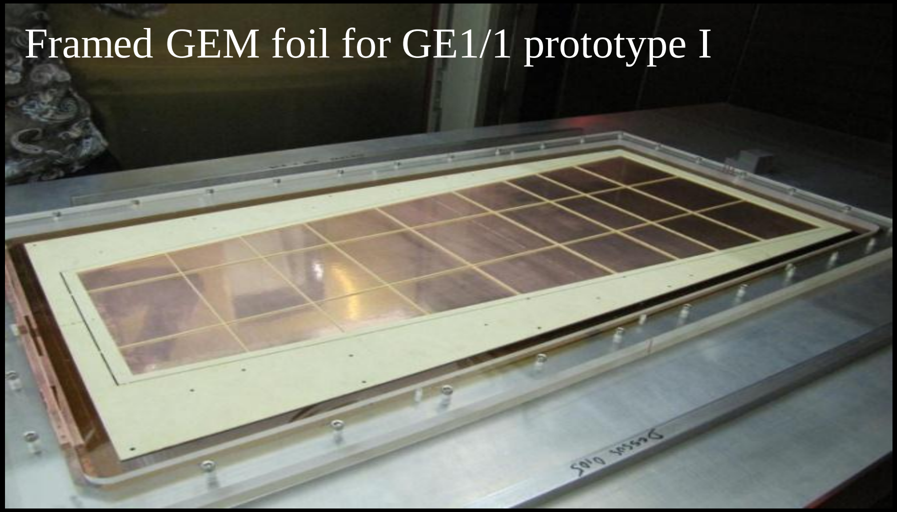
Total active area covered ~ 300 m^2

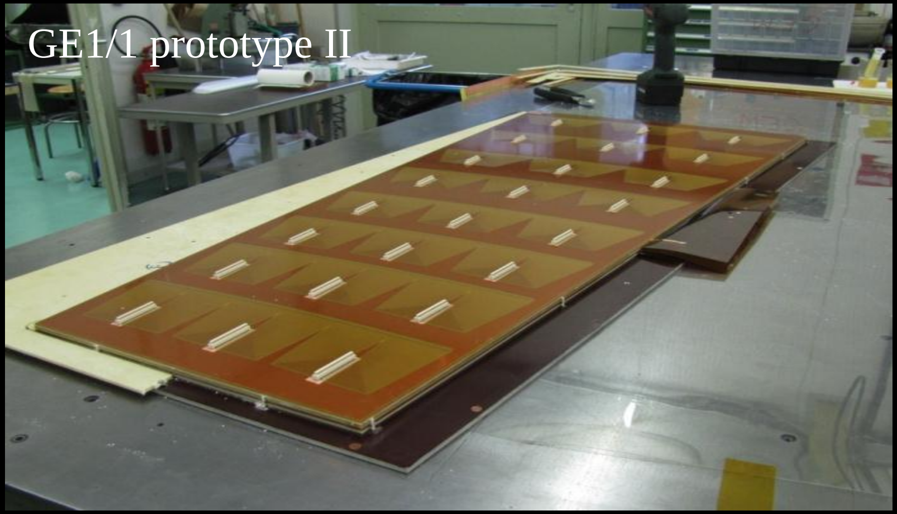
GE2/1 on back of YE1





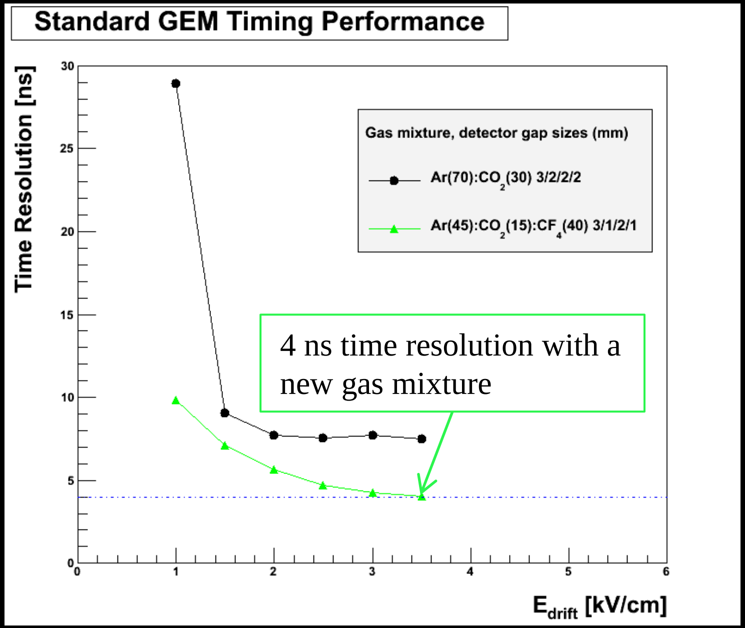
Large area CMS GEM R&D





Extensive R&D by CMS Collaboration over many years:

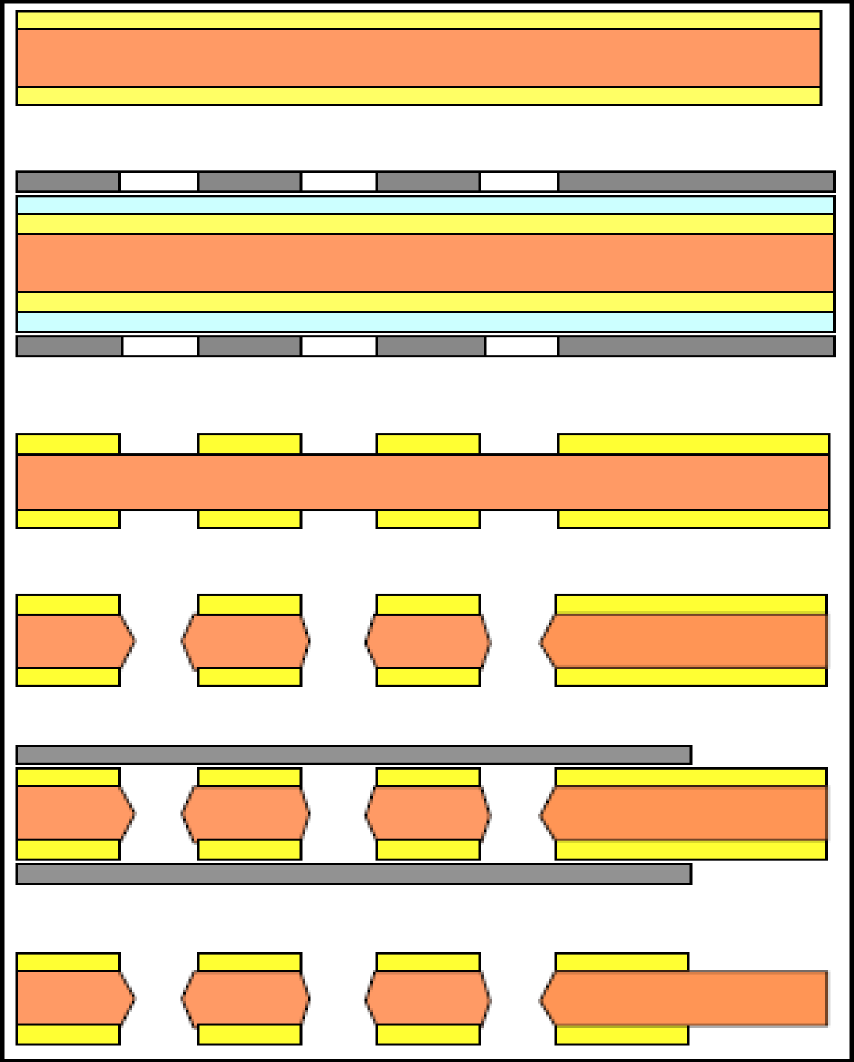
- New Geometry (3-1-2-1) triple GEM with Ar/CO2/CF4 to achieve 4 ns timing resolution
- Participate in the development with RD51 Collaboration of the single mask technique for large area GEM
- NS2 technique for faster and spacer free GEM assembly
- Contributing in the development of the VFAT/SRS Electronics



New Developments: Double Mask Technique

Before:

- Starting with 50 µm Kapton, 5 µm Cu both sides
- Photoresist coating deposition,
- First masking,
- exposure to UV light
- Metal etching,
- Kapton etching
- Second masking
- Metal etching and cleaning

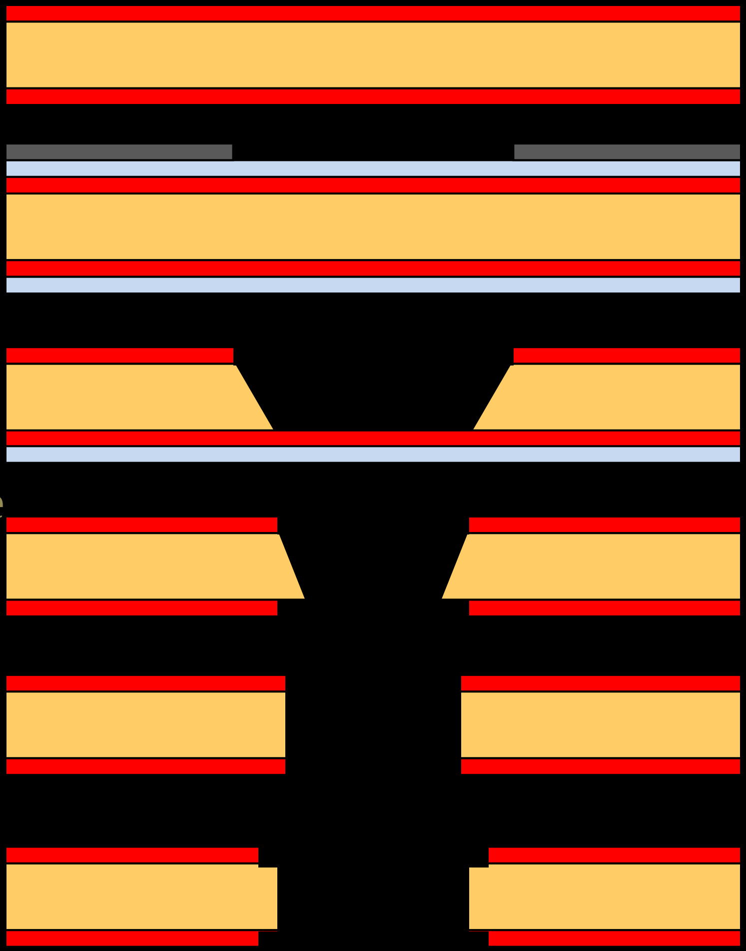


Double mask technique and raw Kapton roll width (~ 550 mm) ➔ Maximum size of 40 × 40 cm^2 active area for GEM detectors

New Developments: Single Mask Technique

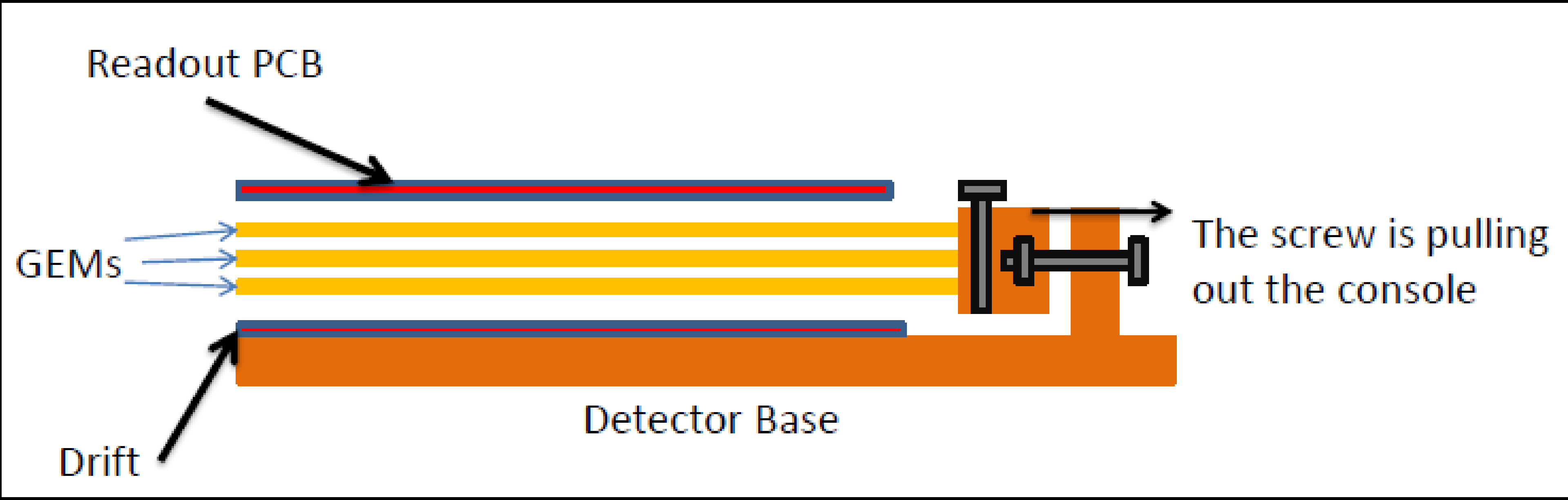
Now:

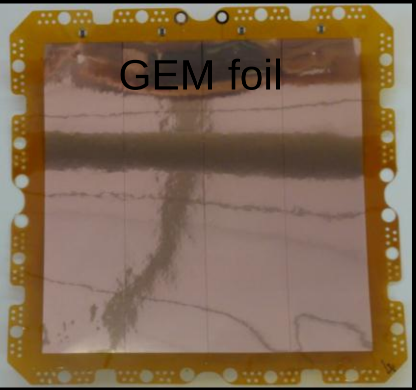
- Starting with 50 µm Kapton, 5 µm Cu both sides
- Photoresist coating deposition, single mask
- Hole opened with metal and Kapton etching, bottom side metal etching, with top side metal is preserved with cathodic protection technique
- Kapton etching ➔ cylindrical or bi-conical shaped hole
- Further metal etching to form a small rim and eventually to reduce the copper thickness

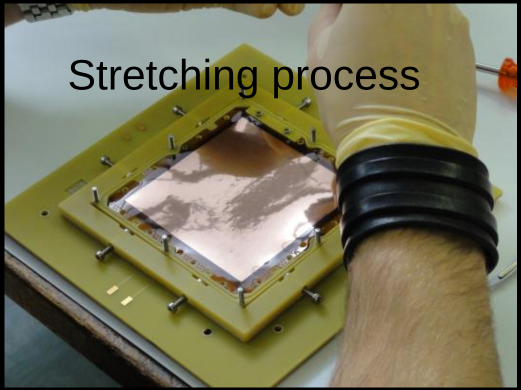


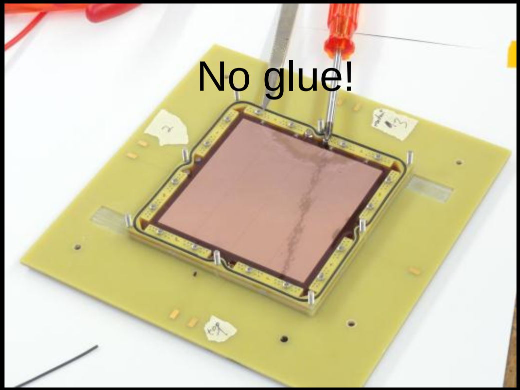
Single mask technique and wider Kapton roll (~ 615 mm) ➔ Can go up to 200 × 50 cm^2 active area for GEM detectors

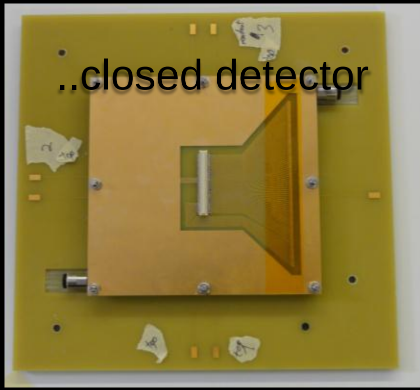
New Developments: No Stretch No Spacer





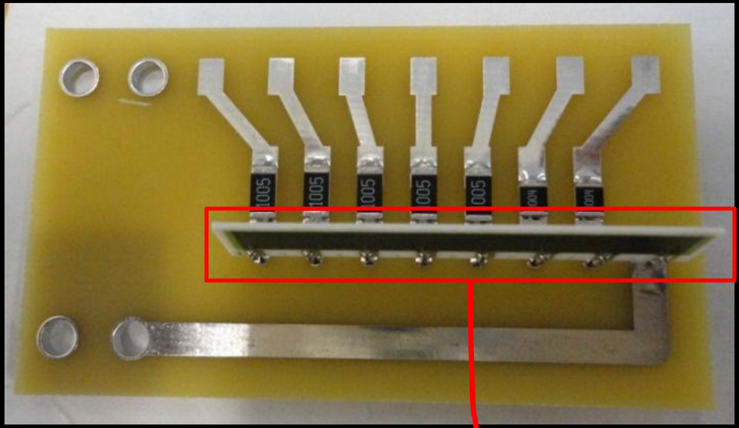


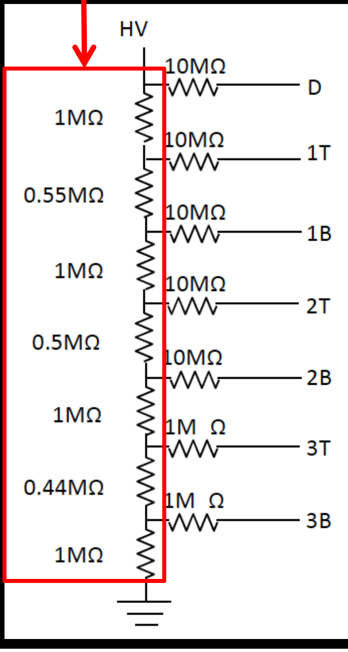




New Developments: compact HV Divider

- Gains, spark rates etc. well studied for this combination of resistors.
- Nominal operation = 4.1 kV (Test at 4.3 kV)
- If there a spark in the bottom GEM, ΔV for other GEMs increase by only about 6 V. A spark in the other foils has negligible effect.





Voltages, fields and gains in typical operating conditions

Electrode	Voltage (V)	Field (kV/cm)	ΔV (V)	Gain
Drift	−4100	2.49		
GEM1 TOP	−3353		410	50
GEM1 BOT	−2943	3.73		
GEM2 TOP	−2196		374	23
GEM2 BOT	−1822	3.73		
GEM3 TOP	−1075		328	8.5
GEM3 BOT	−747	3.73		
PCB	0		TOT 1112	9775

GEM Production: @ CERN

The Goal is to setup a production line being able to face most of the future requests for large GEM productions (from 1 piece to few hundreds, size up to 2m x 0.6m)

2011

- Up to 15 GEMs 1m x 0.5m / month technician
- Cost : around 1200 CHF/GEM
- 150 GEM/ year

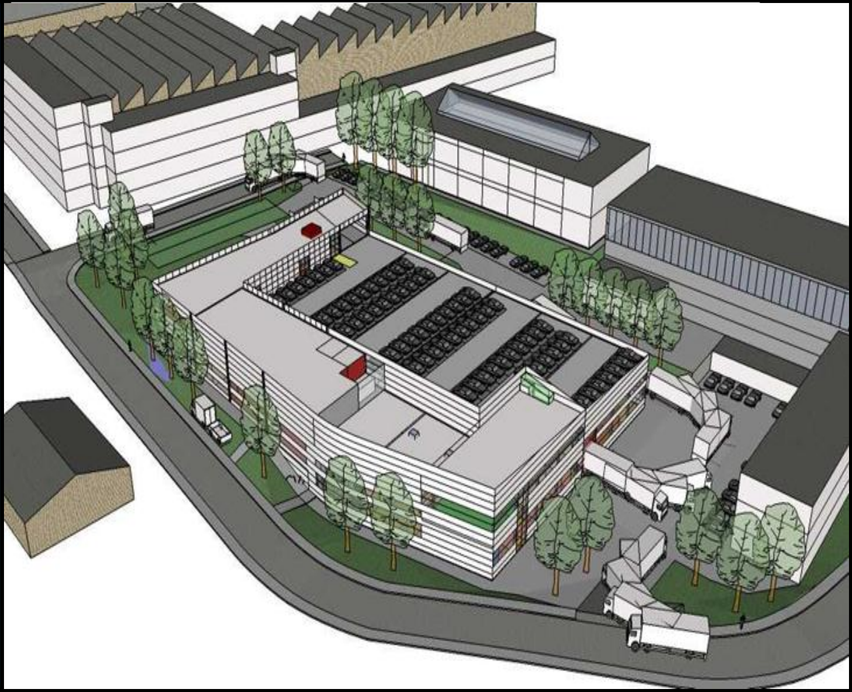
2012

- Up to 24 GEMs 1m x 0.5m / month technician
- Cost: around 900 - 1000 CHF/GEM (Compass GEM 700 CHF)
- 240 GEM/year

New Machine procurement and installation(2011) and new building(2013)

- UV exposure unit moving from 2m x 0.6m → 2.2m x 1.4m
- GEM alcohol resist stripping
- GEM electro etch moving from 1m x 0.6m→ 2.2m x 0.6m; 10 baths compacted
- GEM polyimide etch moving from 1m x 0.6m → 2.2m x 0.6m; 10→ 30 GEM/day roll to roll compatible no tooling needed

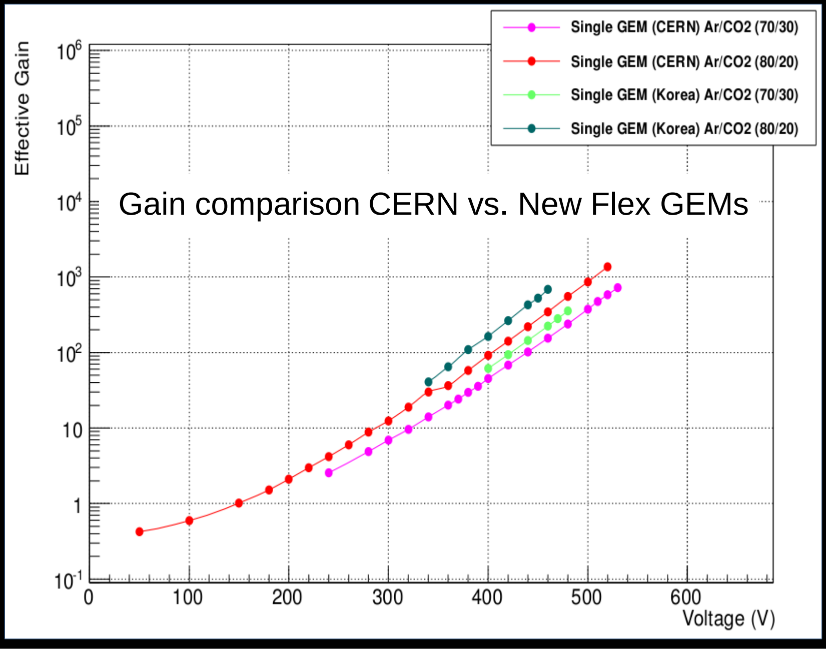
- 40 m^2 room reserved for MPGD assembly
- All the machines for large size detectors production are in the layout
- Area 900 m2 → 1400m2 with optimized layout
- Most of the baths will be replaced by compact machines
- Rooms are reserved for new processes (laser and plasma)



GEM Foils Production: Industrial Production

New Flex, Seoul, S. Korea

- Technology transfer from CERN to New Flex for single mask GEM production
- Already able to produce small (10 × 10 cm^2) GEM foils
  - 10 foils produced with very good results
- Gradually trying larger area GEM foils
- GEM license agreement signed by NewFlex in March 2012



GEM Foils Production: Industrial Production

Industrialization progress: TechEtch (-> GEMs)

- Already producing GEM foils
- Contact refreshed by Rui in January 2012
- Declared interest to upgrade to GEM single mask process -> CERN to explain procedure
- Concerning large sizes ($0.5x1.2m^2$) they cannot yet deal with long foils (polyimide etching)
- They are seeking collaboration with MIT for R&D money for large single mask project
- Waiting for their feedback on status of this project

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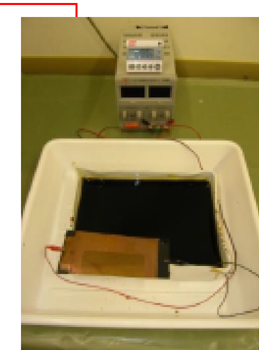
GEM Foils Production: Industrial Production

Industrialization progress: Techtra (-> GEMs)



- January 2012 => visit to Techtra for discussing new facilities for GEM foil production
- February 2012 => Techtra decision to upgrade to larger machines (target 65x220cm^2)
  => identified new 200m^2 location in Technology Park (cut into 3 rooms)
  => started experiencing single mask technology
- April 2012 => CERN technical consultation to help in machine range selection
- May 2012 => Techtra met WISE to discuss purchasing polyamide etching machine
  => Purchasing of second hand machines -> Techtra visiting companies to check machine suitability
  => Requested quotation for microscope adapted to large GEMs (2m x 1m)

- Ready to be operative in upgraded configuration: probably not before end 2012

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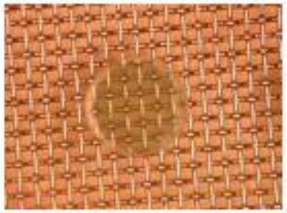
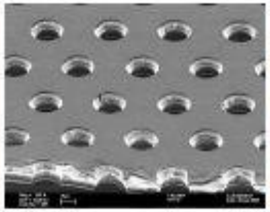
The RD51 Collaboration at CERN

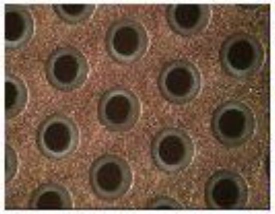
The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. **The main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.**

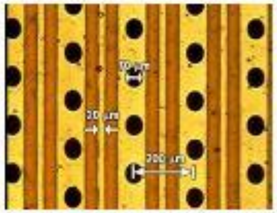
The invention of Micro-Pattern Gas Detectors (MPGD), in particular the Gas Electron Multiplier (GEM), the Micro-Mesh Gaseous Structure (Micromegas), and more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operational stability and radiation hardness. In some applications, requiring very large-area coverage with moderate spatial resolutions, more coarse Macro-patterned detectors, e.g. Thick-GEMs (THGEM) or patterned resistive-plate devices could offer an interesting and economic solution. The design of the new micro-pattern devices appears suitable for industrial production. In addition, the availability of highly integrated amplification and readout electronics allows for the design of gas-detector systems with channel densities comparable to that of modern silicon detectors. Modern wafer post-processing allows for the integration of gas-amplification structures directly on top of a pixelized readout chip. Thanks to these recent developments, particle detection through the *ionization of gas* has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators.

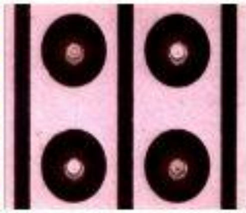
The RD51 collaboration involves ~ 450 authors, 75 Universities and Research Laboratories from 25 countries in Europe, America, Asia and Africa. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration established common goals, like experimental and simulation tools, characterization concepts and methods, common infrastructures at test beams and irradiation facilities, and methods and infrastructures for MPGD production.

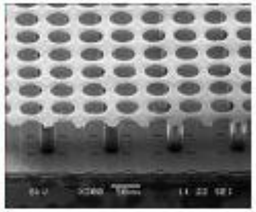

MicroMegas


GEM


THGEM


MHSP


microPIC


Ingrid

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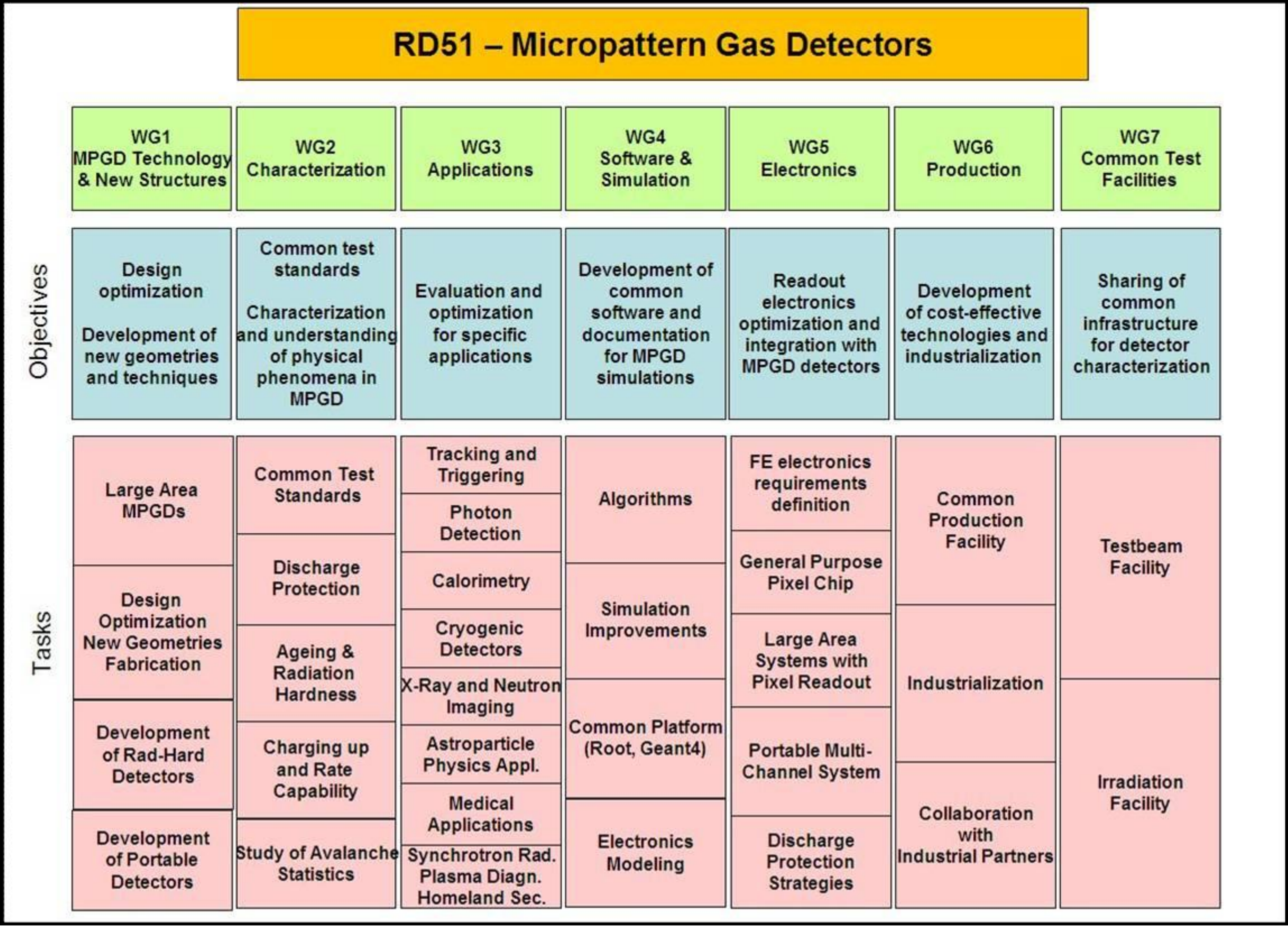


Summary

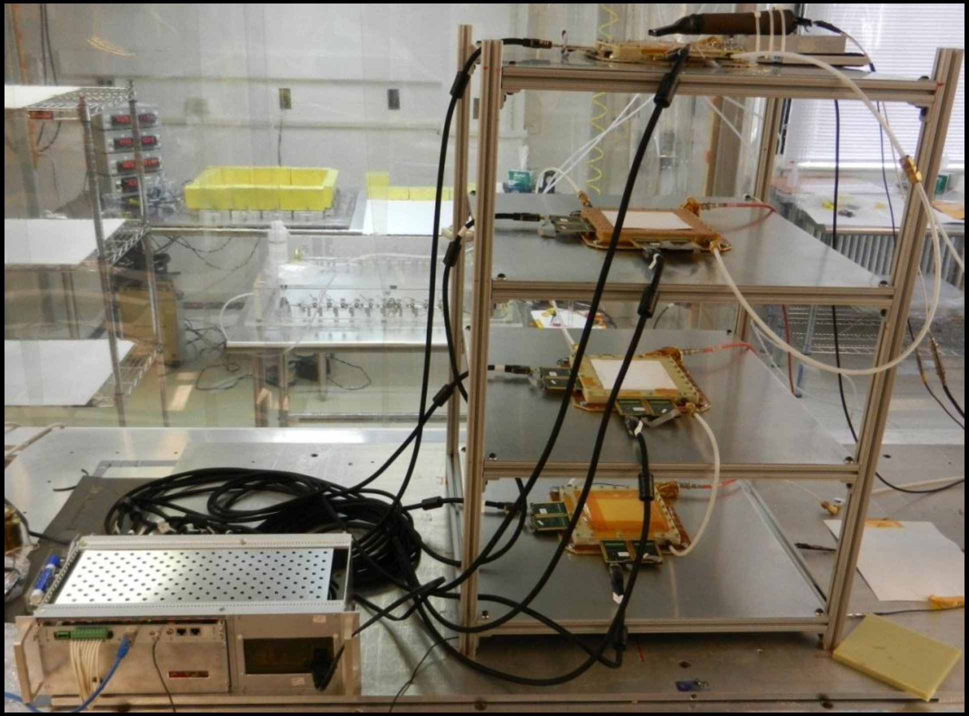
- GEM detectors to play a big role in Hall A Spectrometers for JLab 12 GeV
  - Large area GEM no longer an issue
- Univ. of Virginia and INFN Roma to build the SBS Tracker GEMs
  - One prototype built at UVa, taking data right now
- Big collaboration with many Chinese institutes for the SoLID GEM project
  - Would benefit from the latest development from RD51 Collaboration at CERN
  - Common design and protoying with major proposals for HEP or Nuclear Physics experiments involving GEM (CMS, EIC …)
- We are looking forward for a fruitful collaboration
  - Willing to welcome graduate students (or undergrad. Student) for a couple of month at UVa to get some training in our Clean Room on assembly of large area GEM chamber

GEM Team @ Univ. of Virginia

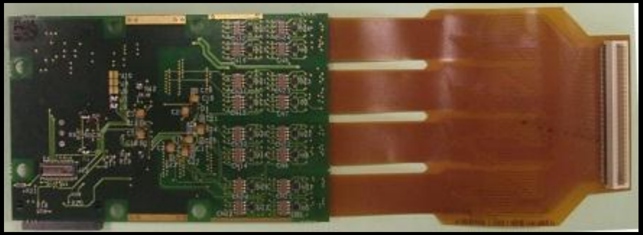
- Senior Research Scientist:
  - Prof. Nilanga Liyanage
  - Dr Vladimir Nelyubin
- Research Scientist:
  - Dr Kondo Gnanvo
- Graduate Students:
  - Kiadtisak Saenboonruang
    - small GEM tracker, analysis, SBS prototype assembly
- Undergraduate Students
  - Taylor Sholtz
    - Drawings for the stretcher and new GEM design
  - Seth Saher
    - Design for SoLID large GEM prototype

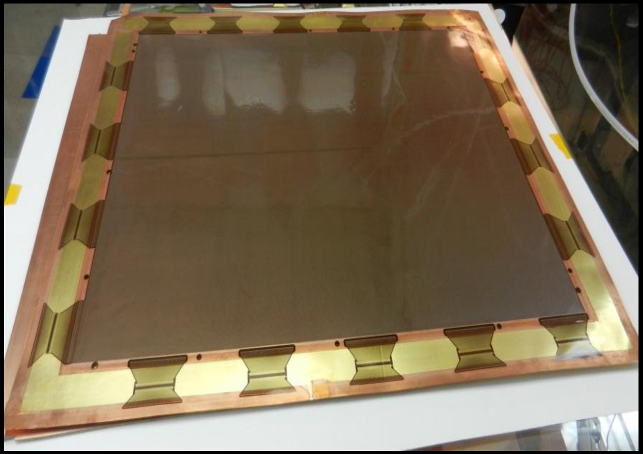
Backup

GEM & SRS Electronics @ UVa



Flexible adapter from Panasonic to APV25-MPD Electronics





Trackers setup with 4 GEMs

- APV25 SRS Electronics 2048 channels
- Position resolution of our chambers
- Setup will be used to characterize the large SBS GEM prototype

APV25 Readout time

- Buffer length 192 samples : 4.8 us Look back 160 samples
- 32 samples reserved for event readout
- ➔ Look back 160 samples ➔ 4 us

- APV readout time :

t_APV = 141 x number_of_sample / 40 MHz

t_APV (1 sample) = 3.7 us.

Max rate APV front end :

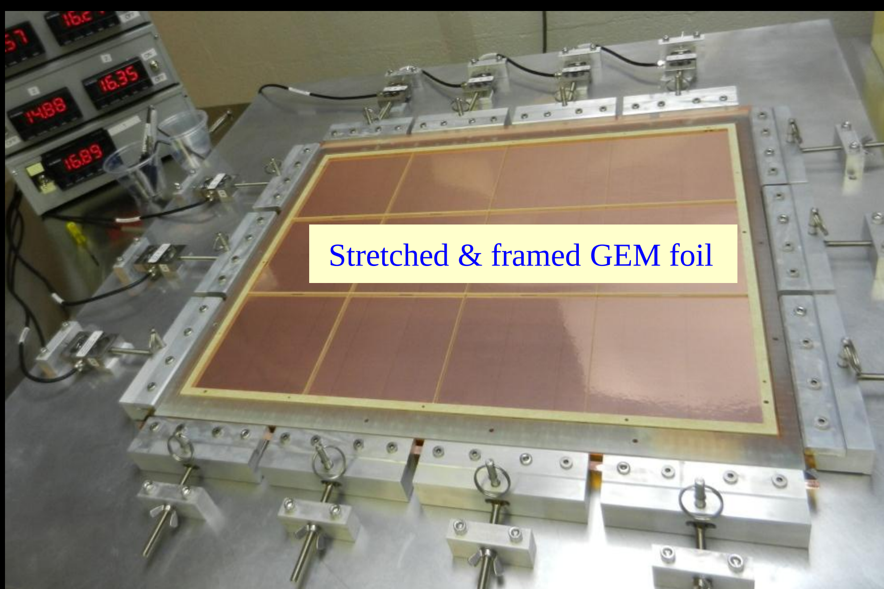
270 KHz in 1 sample mode

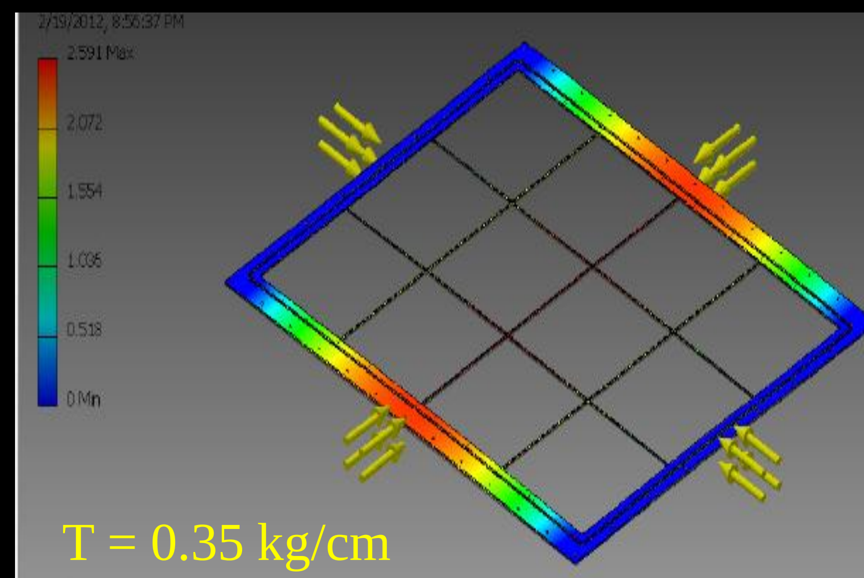
90 KHz in 3 samples mode

Will be triggered by coincidence trigger around 50 KHz

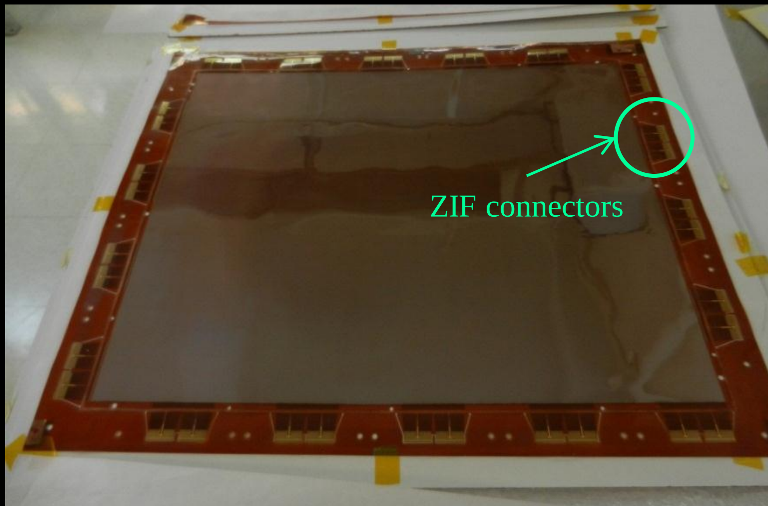
The GEM Foil Stretcher

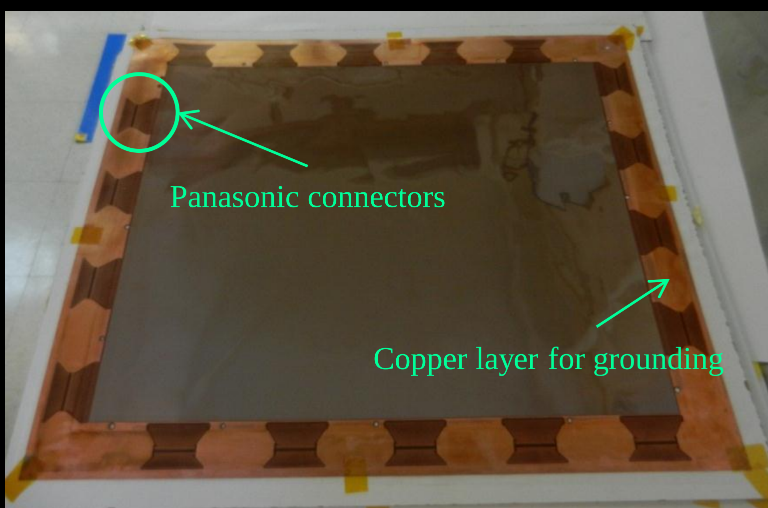
- UVa Stretcher device upgraded from Benciveni (LNF. Italy) and Cisbani (Roma, Italy)
- Improvement ➔ Foil is stretched in less than 30 min
- 7 Load cells with max tension of 23 kg over 13 cm
- Various tension test on mock foils at 0.25kg/cm, 0.35kg/cm, 0.75kg/cm
- Monitoring displays of the measured tension





X/Y strips readout board





- COMPASS readouts
  - (1280 top strips, 1024 lower strips)
- 2 different designs for the connectors
  - One original board design with ZIF connectors (E. Cisbani, Roma, Italy)
  - Two modified design with Panasonic connectors and additional copper grounding (K. Gnanvo, UVa)