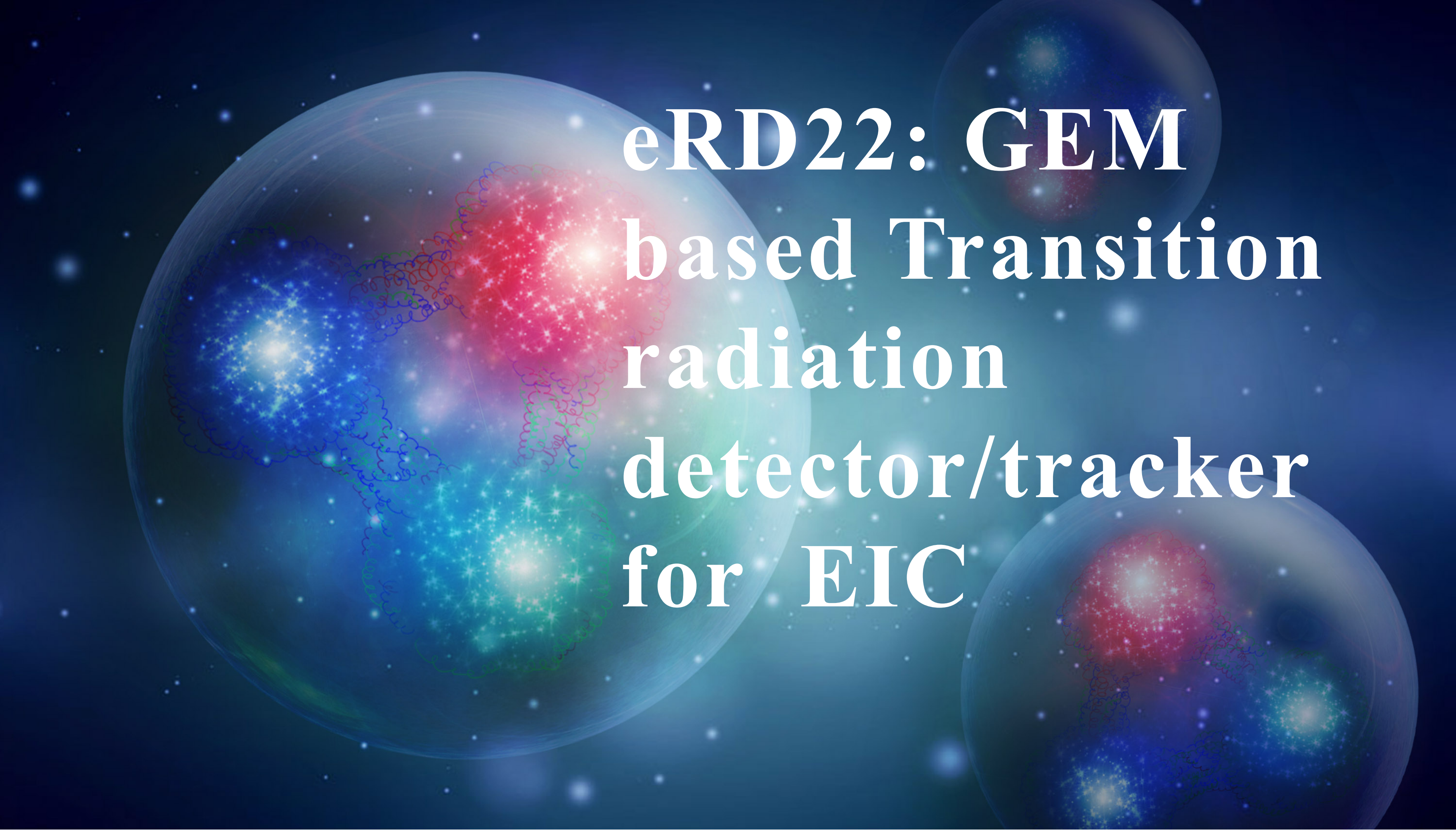


eRD22: GEM based Transition radiation detector/tracker for EIC

Yulia Furletova (JLAB) on behalf of GEM-TRD/T working group

U.S. DEPARTMENT OF ENERGY JSA Jefferson Lab

GEM-TRD/T TEAM:

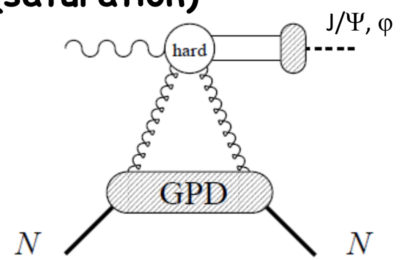
- Jefferson Lab:
  - ✓ Howard Fenker
  - ✓ Yulia Furletova
  - ✓ Sergey Furletov
  - ✓ Lubomir Pentchev
  - ✓ Beni Zihlmann
  - ✓ Chris Stanislav
  - ✓ Fernando Barbosa

- University of Virginia
  - ✓ Kondo Gnanvo
  - ✓ Nilanga K. Liyanage

- Temple University
  - ✓ Matt Posik
  - ✓ Bernd Surrow

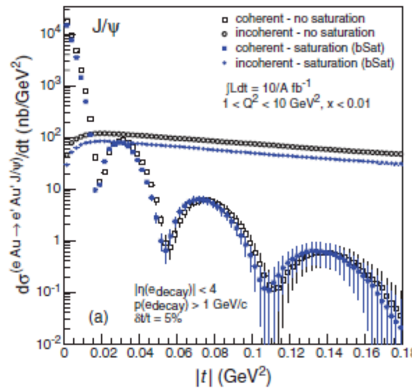
Electron identification (e/hadron separation)

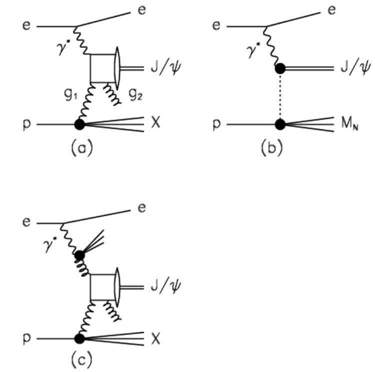
- GPD and
Coherent Exclusive Diffraction (saturation)



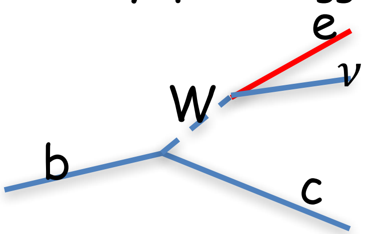
Br ($J/\psi \to e^+e^-$) ~6%

Br ($J/\psi \to \mu^+\mu^-$) ~6%



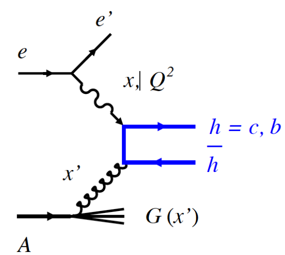


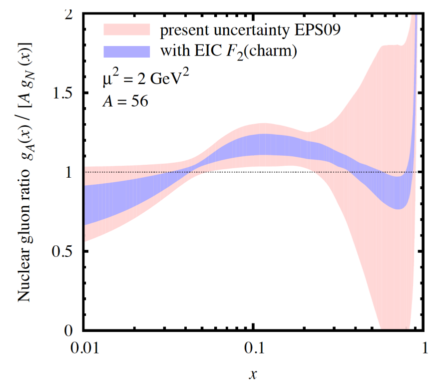
- Heavy quark tagging



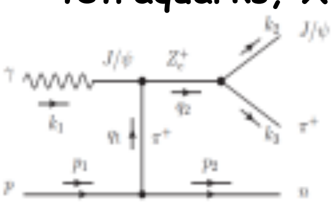
Br ($D^{\pm} \to e+X$) ~16%

Br ($B^{\pm} \to e+\nu+X_c$) ~10%





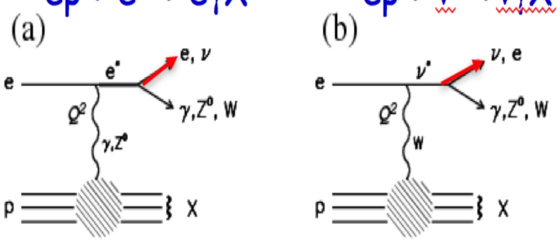
- Exotic spectroscopy (pentaquarks, tetraquarks, XYZ)

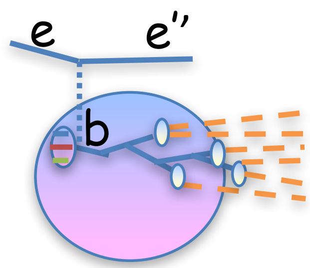


- Other BSM physics

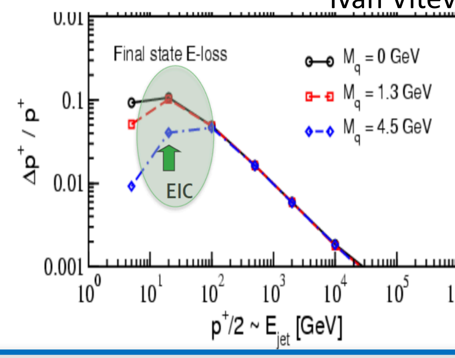
ep-> e*-> eγX

ep-> ν*->νγX





Ivan Vitev

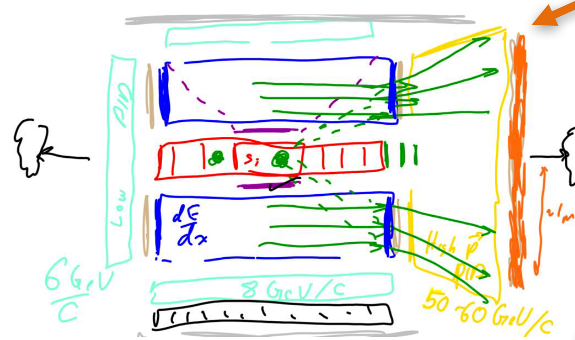


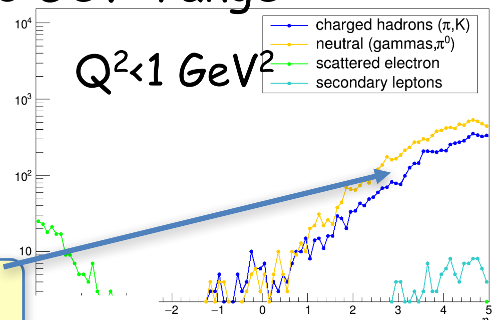
Electron/hadron separation

- The main detector for e/hadron separation is a Calorimeter. Also dE/dx in tracking detectors, as well as Cherenkov detectors could be used in the limited momentum range.
- TRD offers high e/h rejection for electrons in 1-100 GeV range

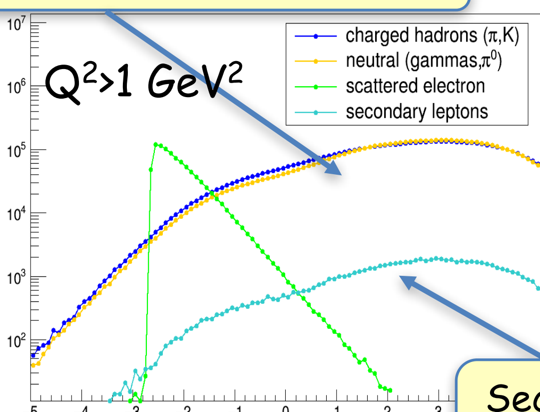
- Hadron end-cap
- between dRICH and EMCAL (extra tracking point)

GEM-TRD/T

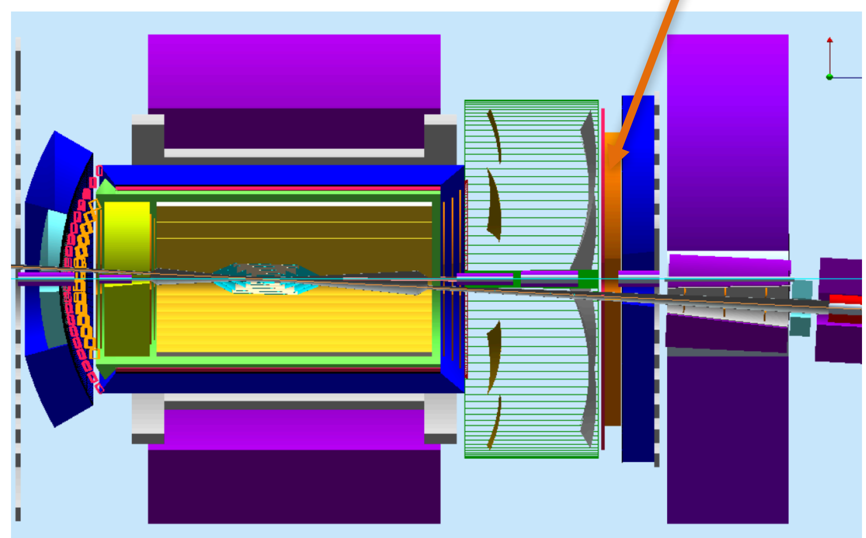




High hadron background

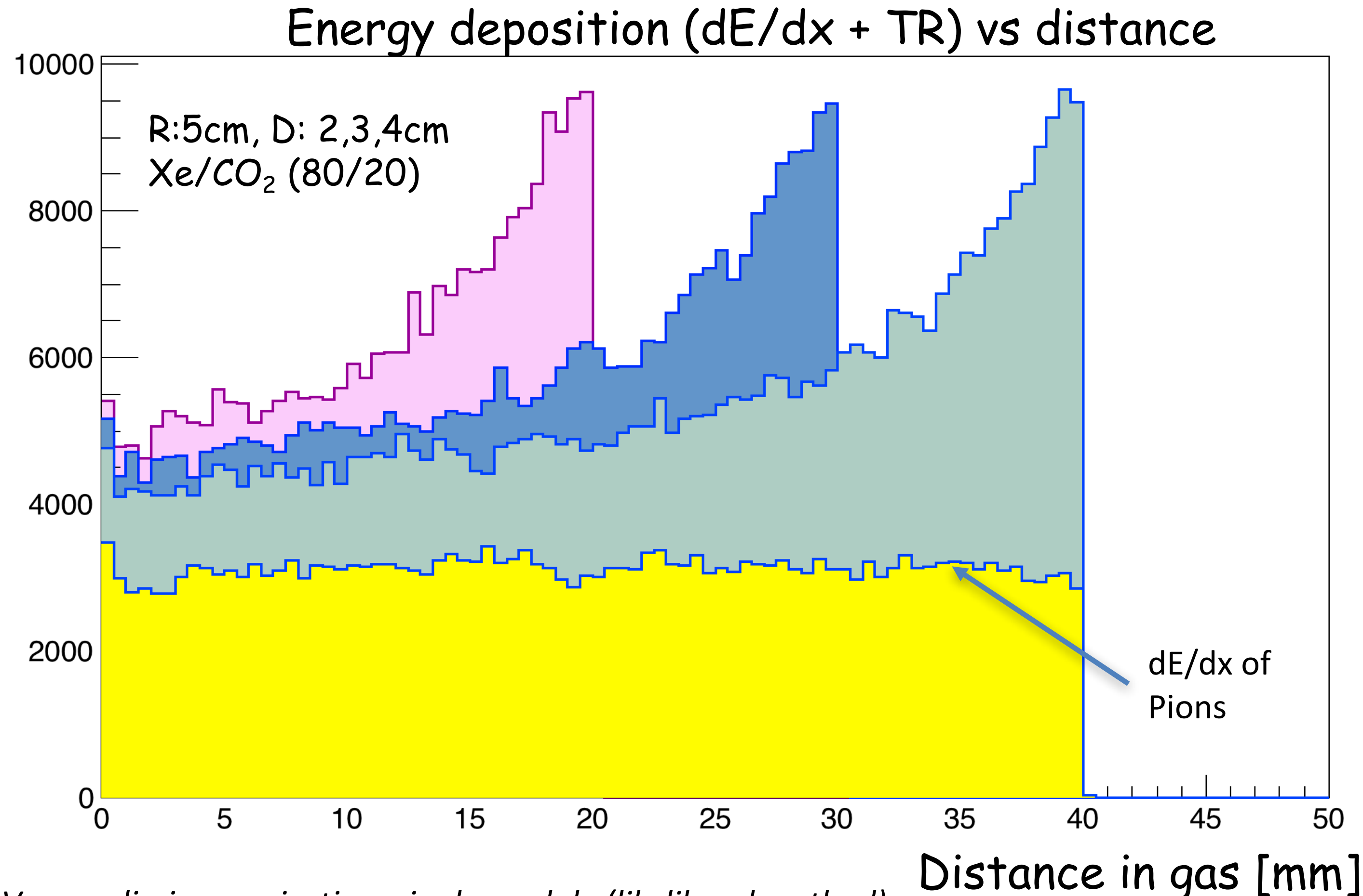


Secondary electrons, pt>100MeV

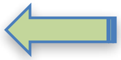


Yulia Furletova

GEANT4: electron and pion comparison



e,π ~3 GeV



Very preliminary rejection, single module (likelihood method)

	90% eff	70% eff
2cm Xe	2.5	12
4cm Xe	4.5	17

Yulia Furletova

GEM-TRD/T prototype

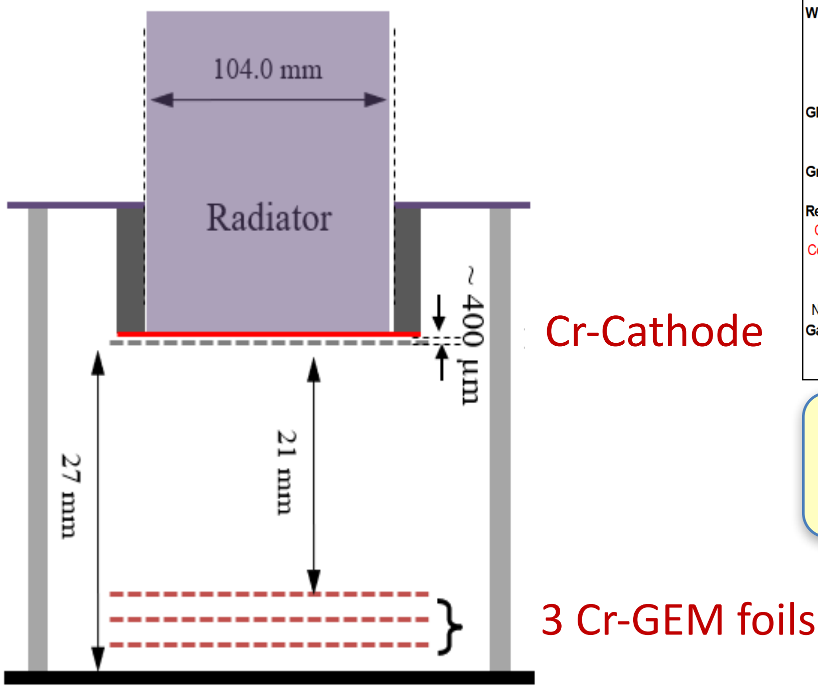
- A standard Cu-GEM-TRD/T prototype is currently under tests
- A new Cr-GEM-TRD/T prototype is under assembly at UVA, will be installed at test beam during the Fall run.

Triple-GEM with standard 5µm Cu-GEM foil

	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	5.2	8.96	14.3	0.8	0.0291	0.0037
Kapton	1	50	1.42	286	0.8	0.0140	0.0057
GEM Foil							
Copper	6	5.2	8.96	14.3	0.8	0.1745	0.0224
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5.2	8.96	14.3	0.2	0.0073	0.0009
Copper-350	1	5.2	8.96	14.3	0.85	0.0309	0.0040
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.473	**0.089**

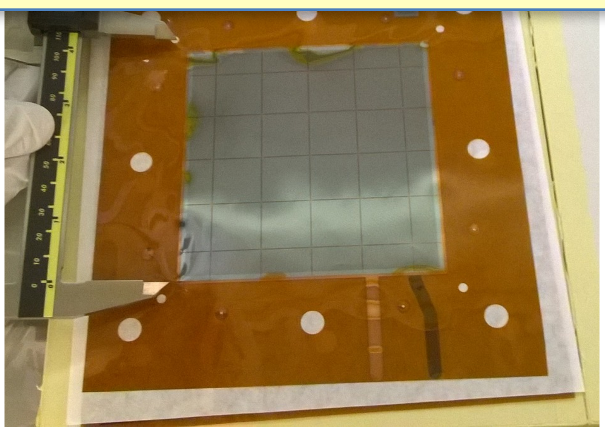
Triple-GEM with Cr-GEM foil

	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0.2	8.96	14.3	0.8	0.0011	0.0001
Kapton	1	50	1.42	286	0.8	0.0140	0.0057
GEM Foil							
Copper	6	0.2	8.96	14.3	0.8	0.0067	0.0009
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0.2	8.96	14.3	0.2	0.0003	0.0000
Copper-350	1	0.2	8.96	14.3	0.85	0.0012	0.0002
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.240	**0.059**

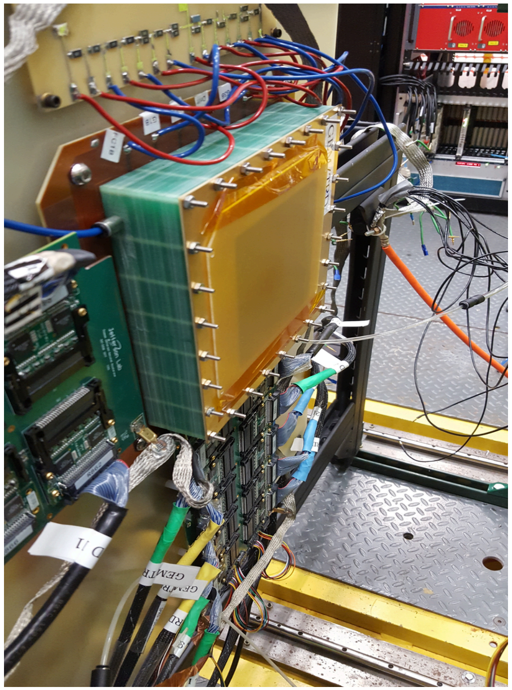


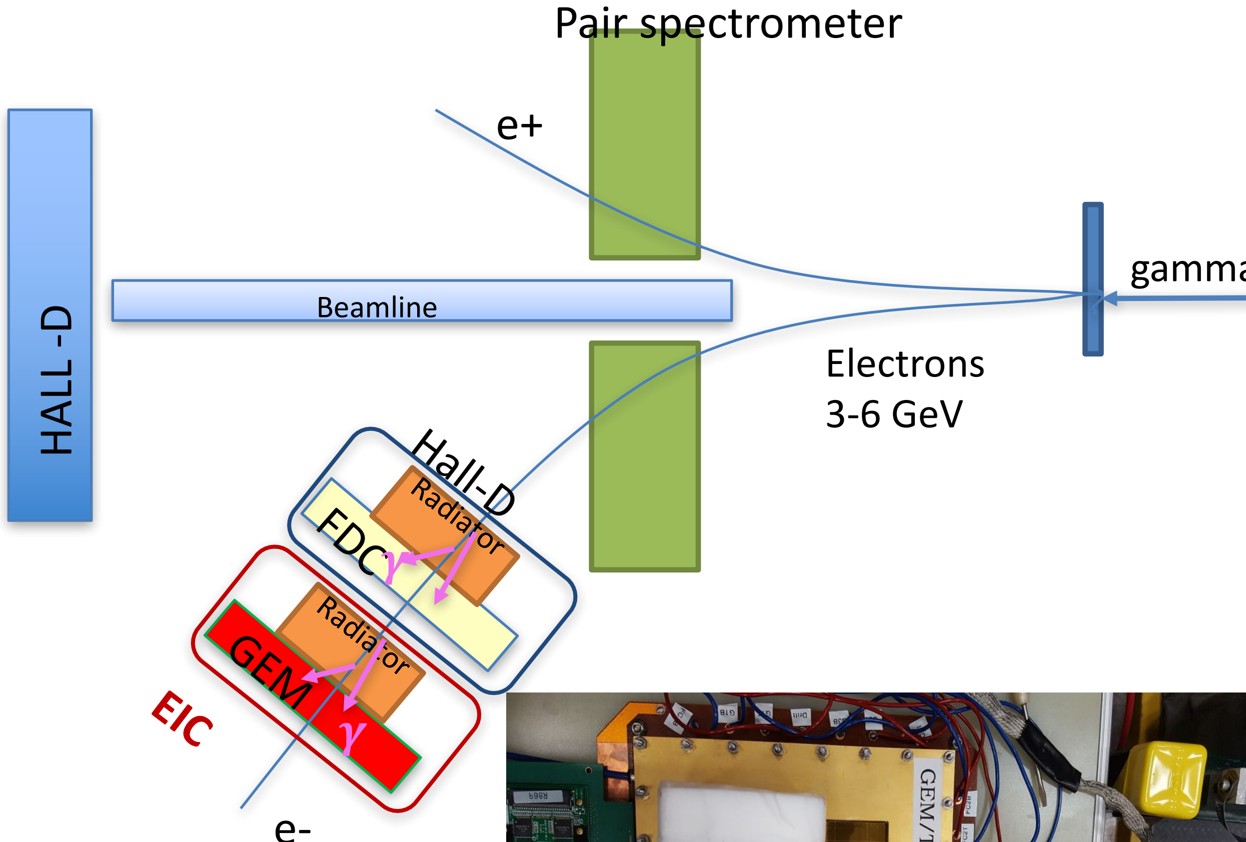
UVa Cr-GEM-TRD

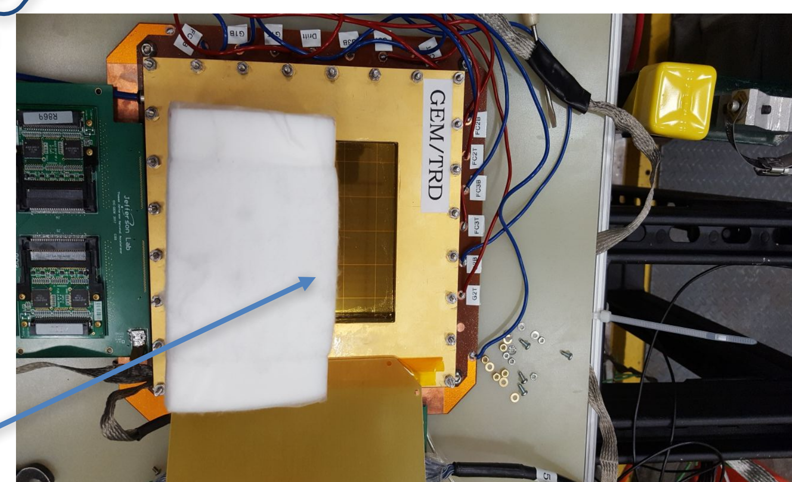
~50% reduction in the amount of material with Cr-GEM



Test Setup at JLAB HALL-D

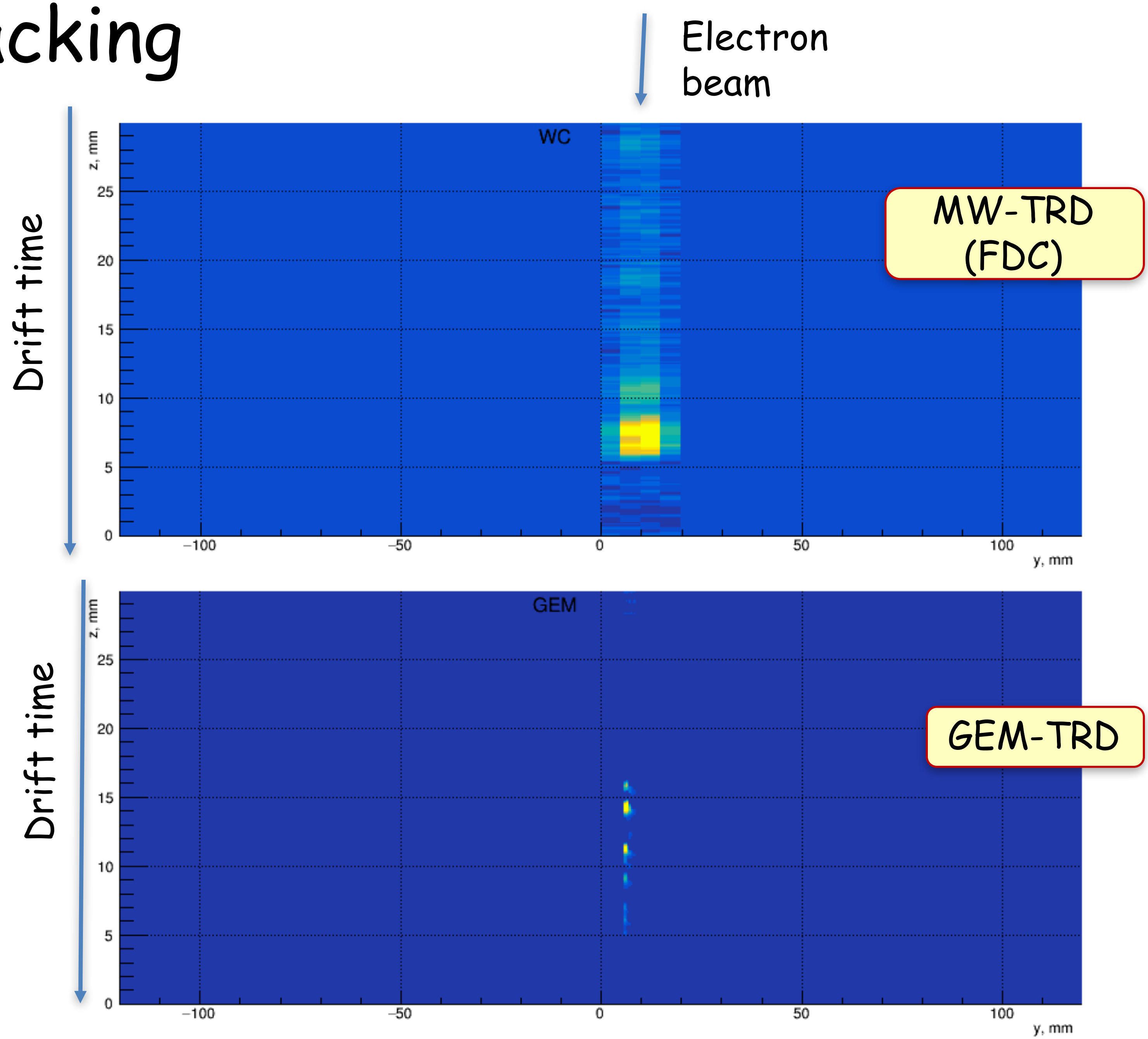






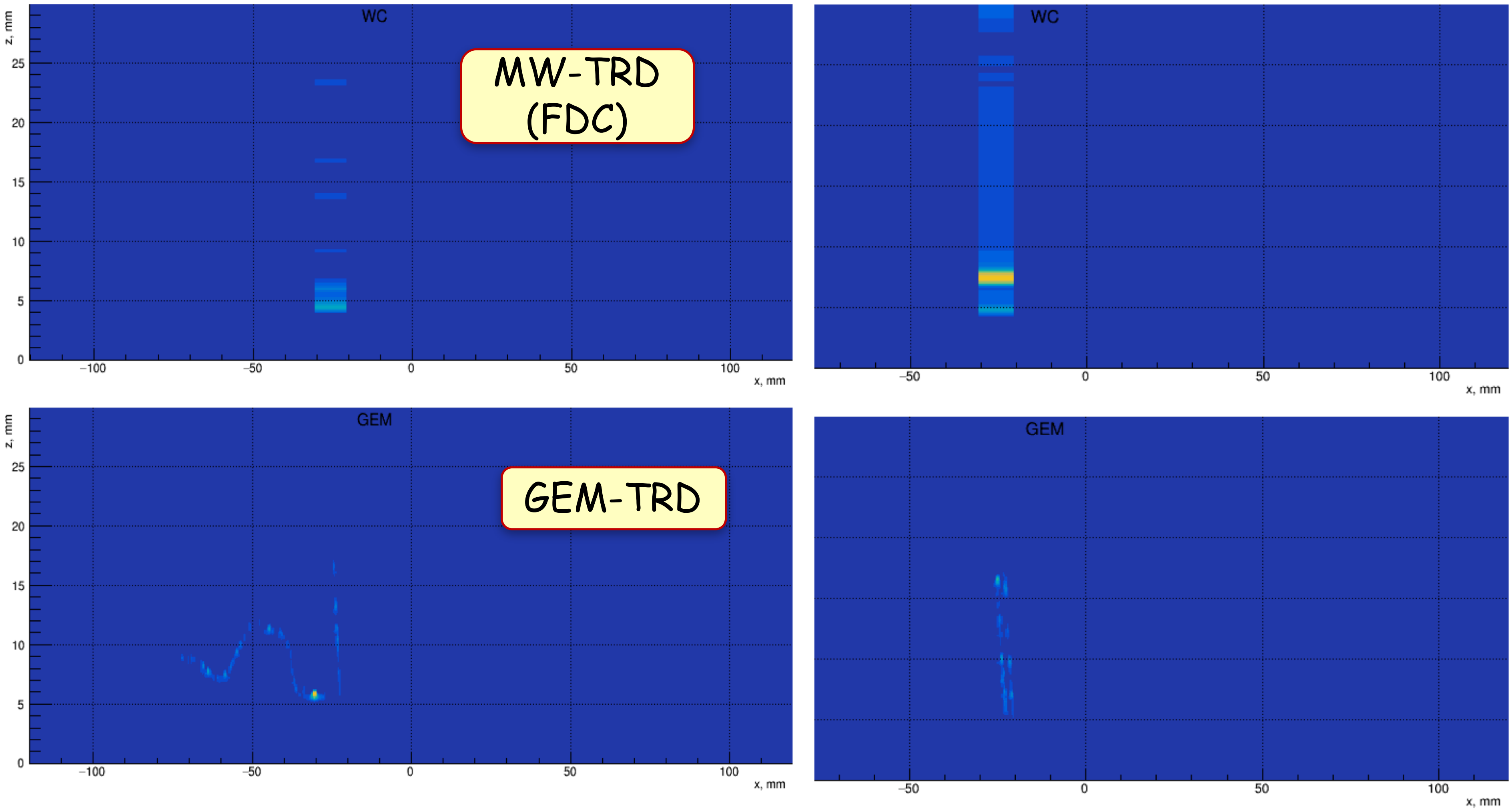
- 3-6 GeV electrons in Hall-D from pair spectrometer
- In parallel with Hall-D MW-TRD (FDC) system
- covered ½ of the sensitive area with radiator

Tracking


Electron beam
Drift time
z, mm
WC
MW-TRD (FDC)
y, mm
Drift time
z, mm
GEM
GEM-TRD
y, mm

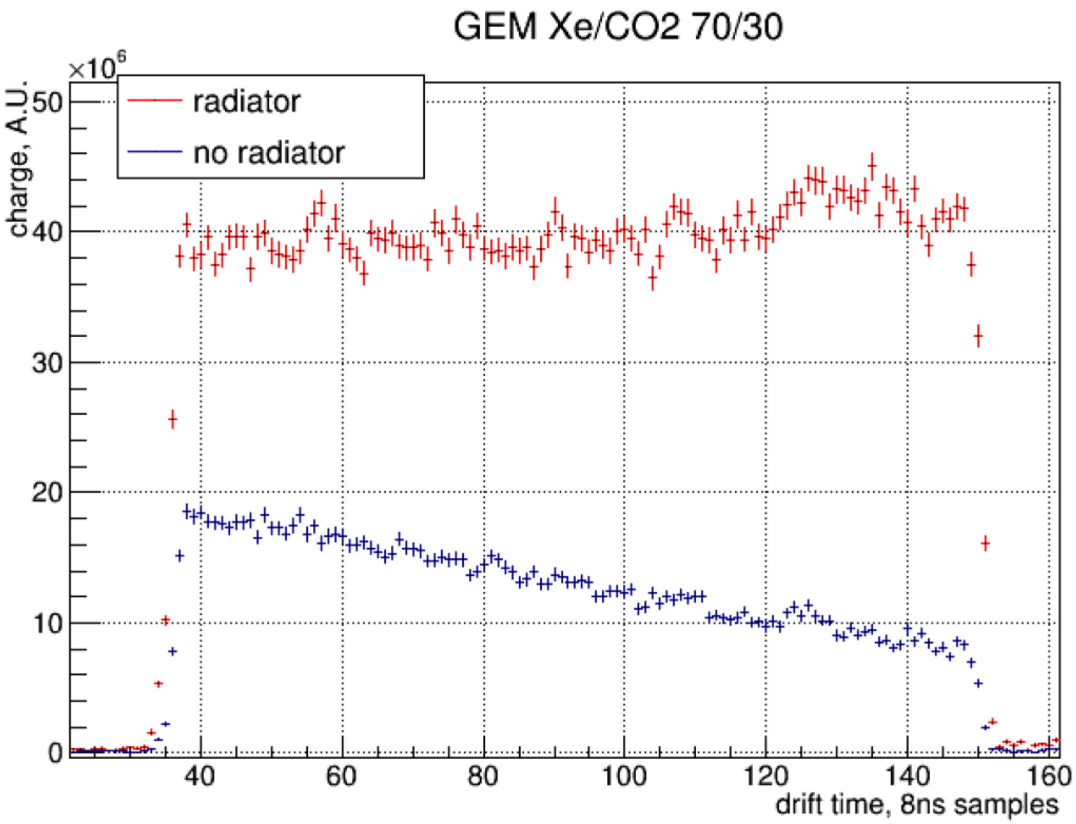
Tracking

Double tracks, delta-electrons,etc



A very first measurements

A very first result during Feb run



- without optimization for gas-gain and drift time

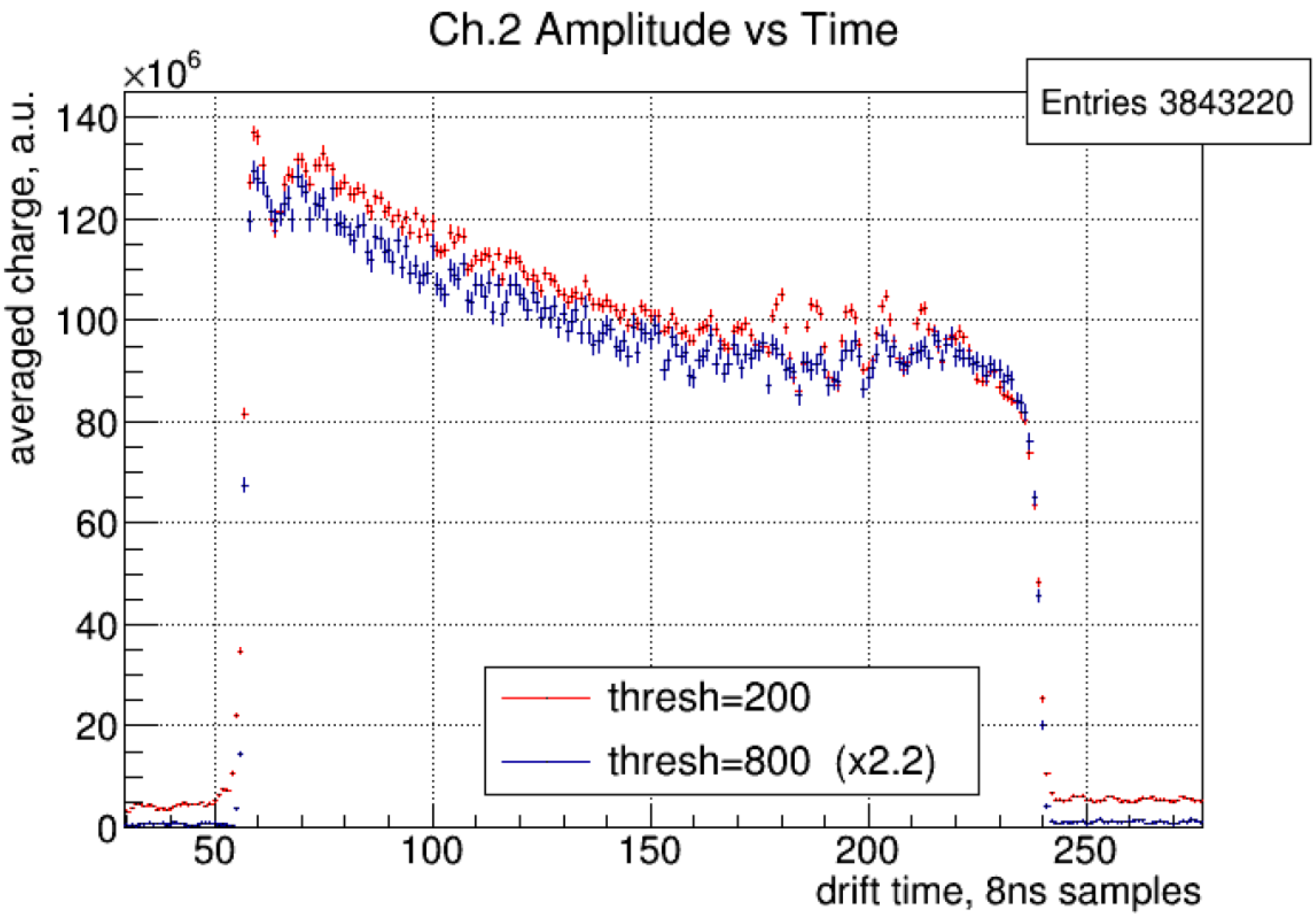
- A slope (without radiator)
- Possible problems:
  - Diffusion
  - HV settings (space charge?)
  - Gas mixture (attachment)

- No possibility to check a quality of gas mixture

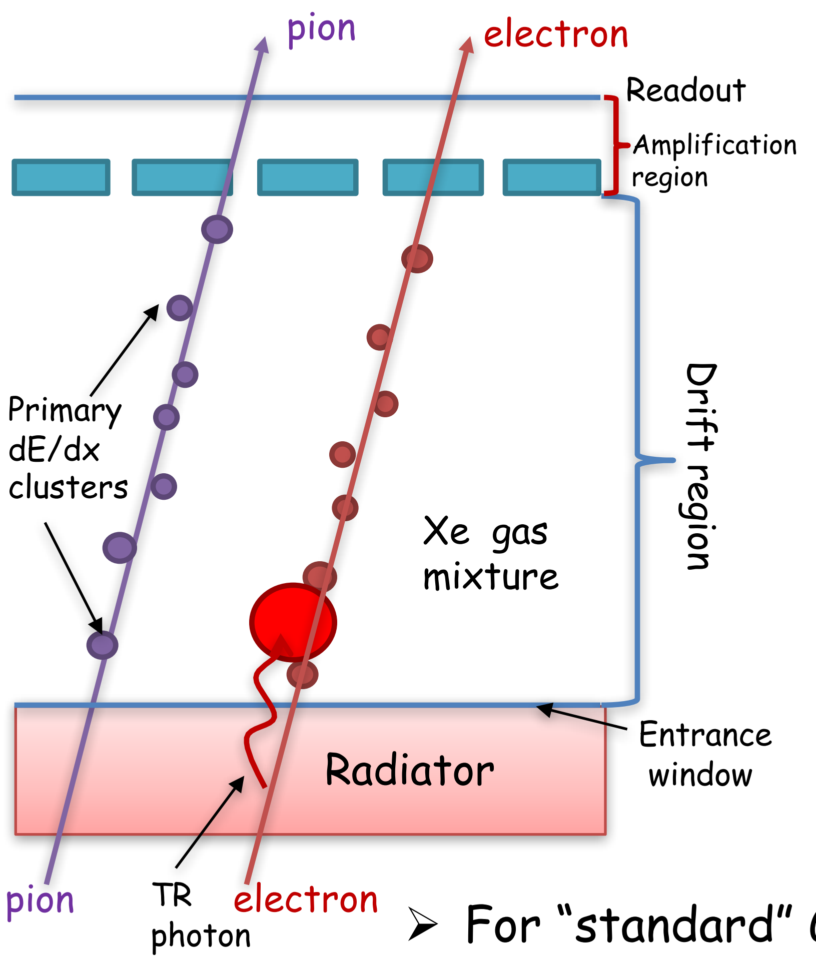
=> Increased a gas flow

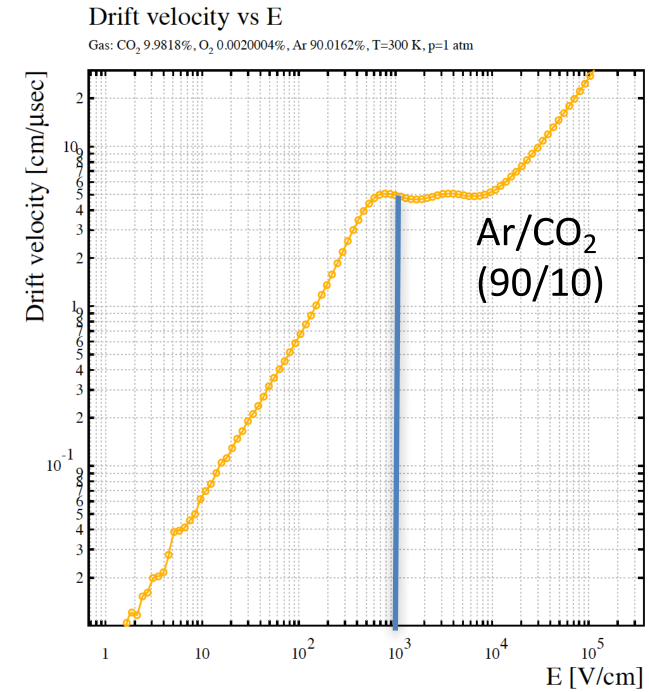
Test beam results

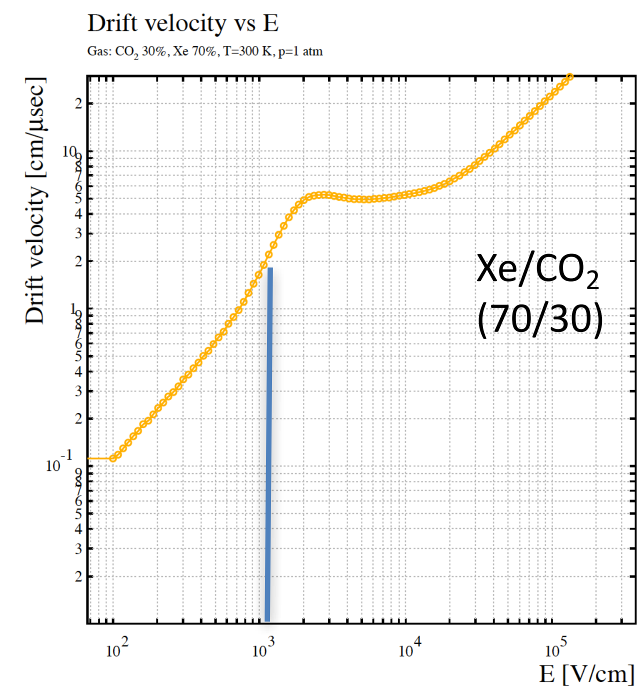
- Effect of diffusion :
  diff. thr for clusters
- No effect on slope



HV divider

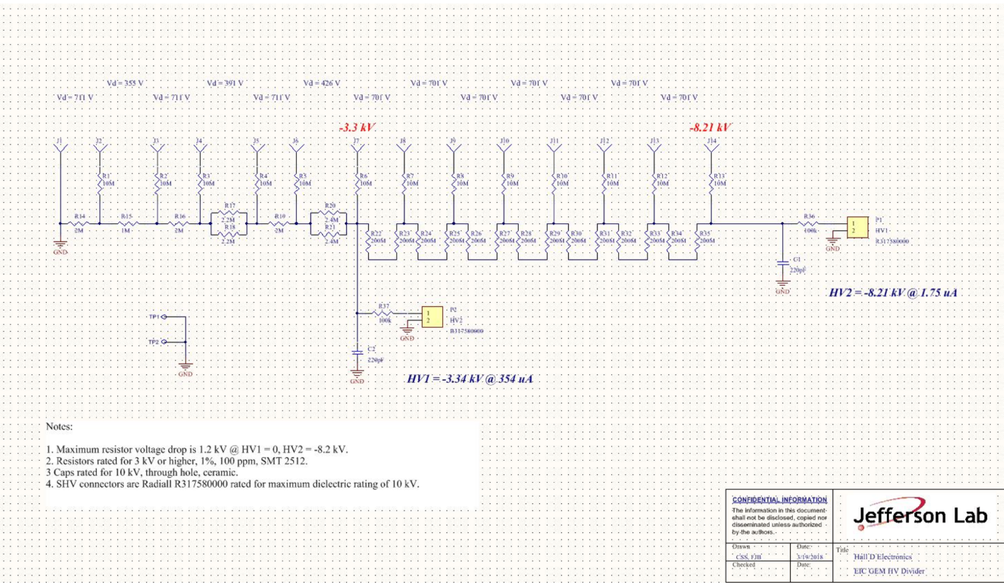


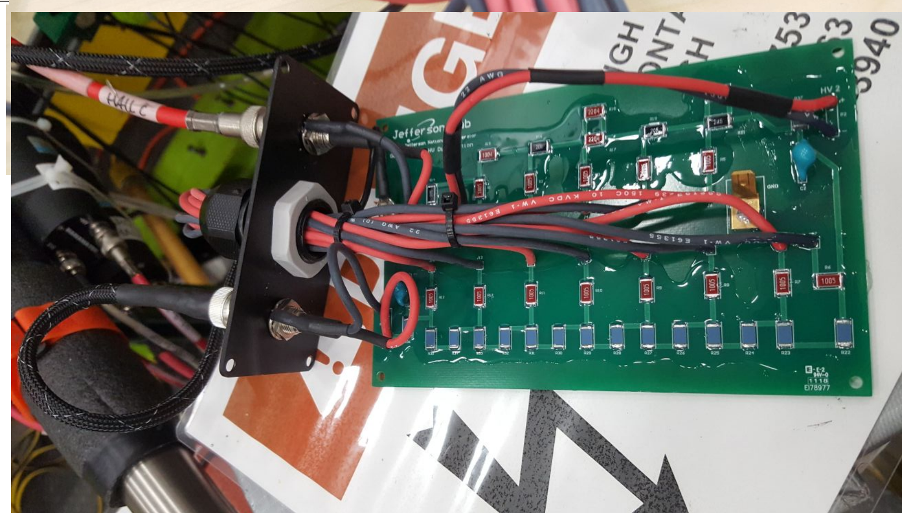




- For "standard" GEM -> single HV setting per module.
- New design of HV divider: independent settings for Drift and Amplification region

New HV divider

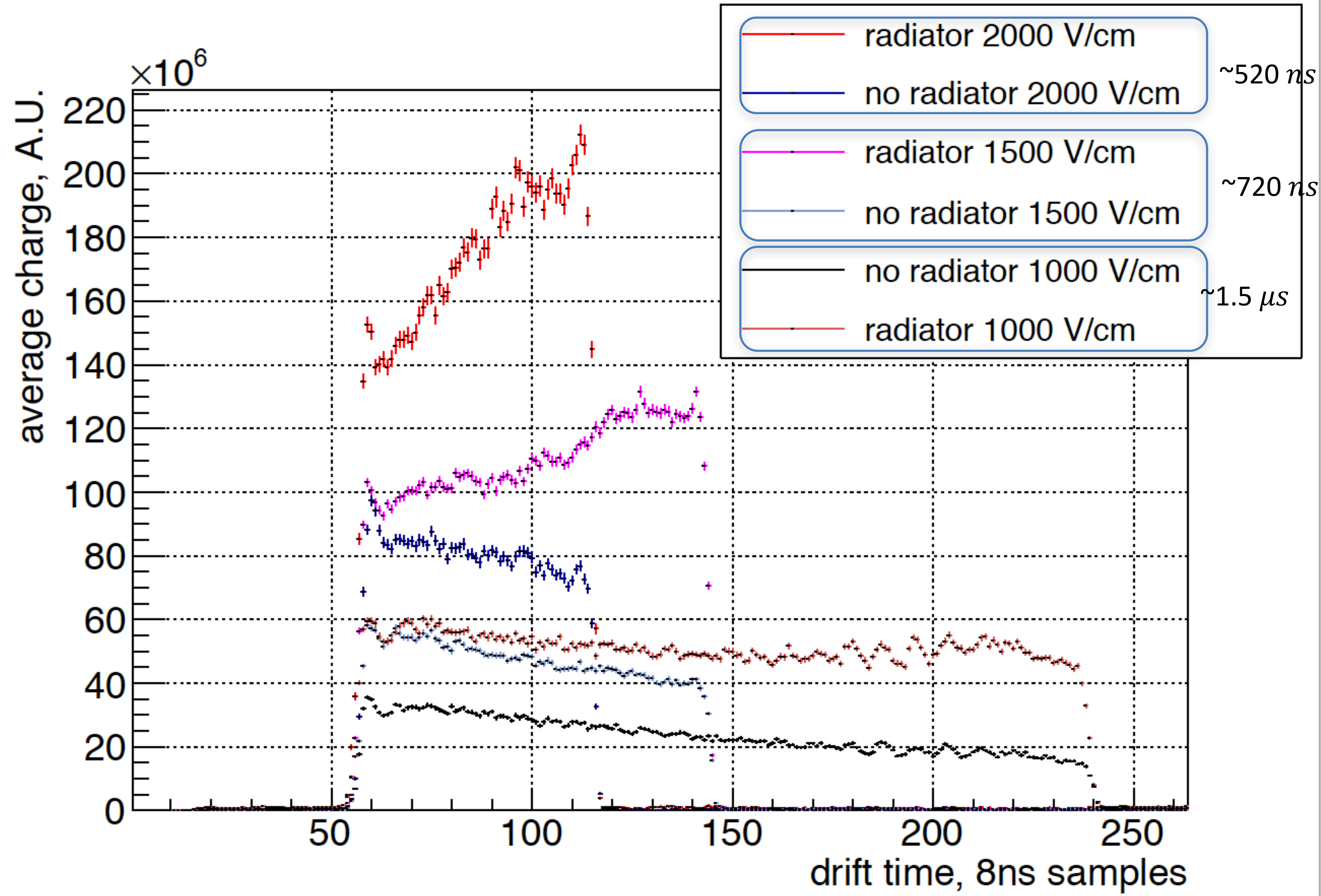




HV1 (amplification): -3.3kV
HV2 (drift): -8.21kV

Test beam results

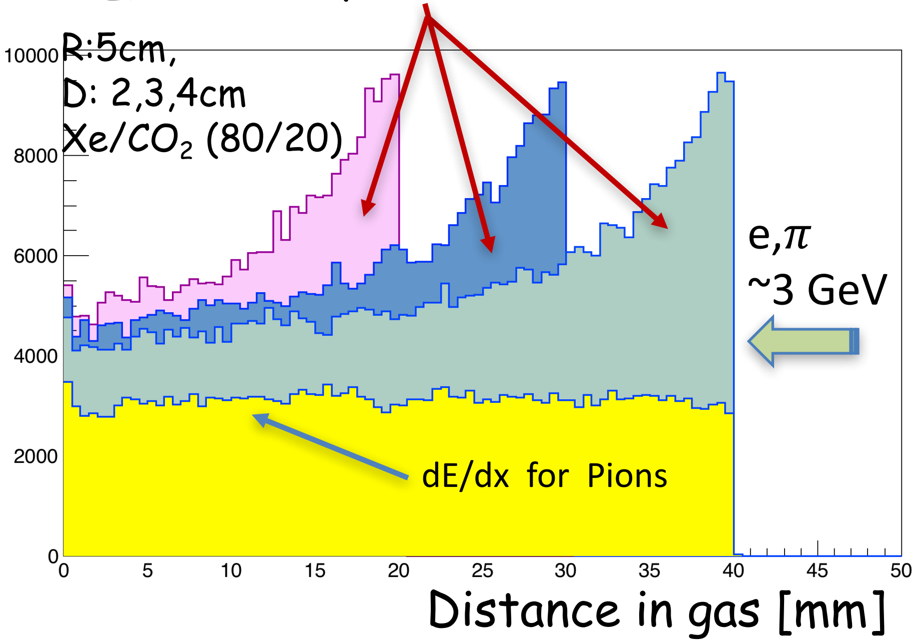
➢ HV adjustments (drift only)



Energy deposition (dE/dx + TR) vs distance

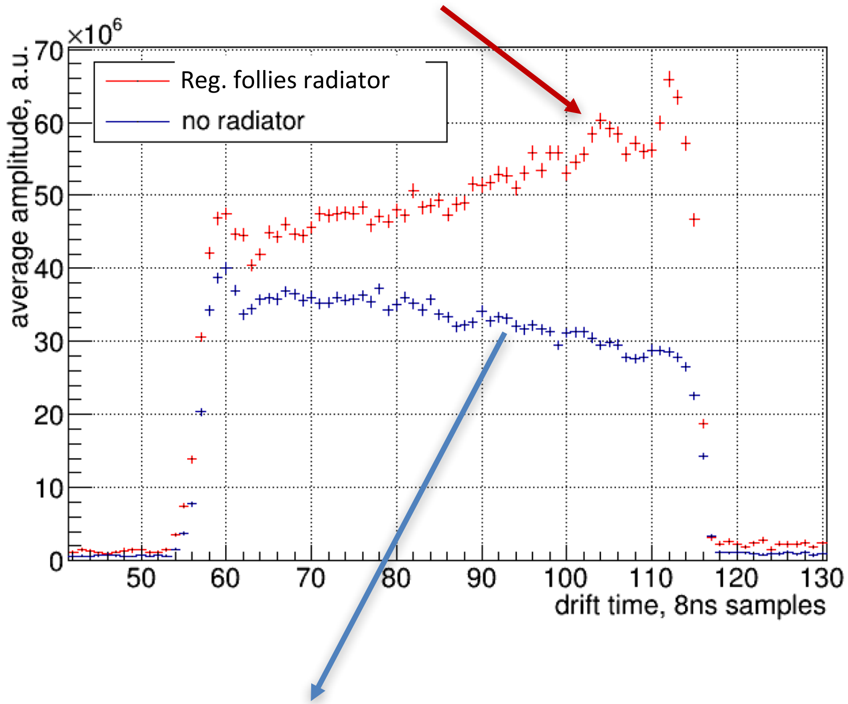
GEANT4 simulation

- dE/dx + TR for electrons



Measured data

- Clearly see TR-photons, but



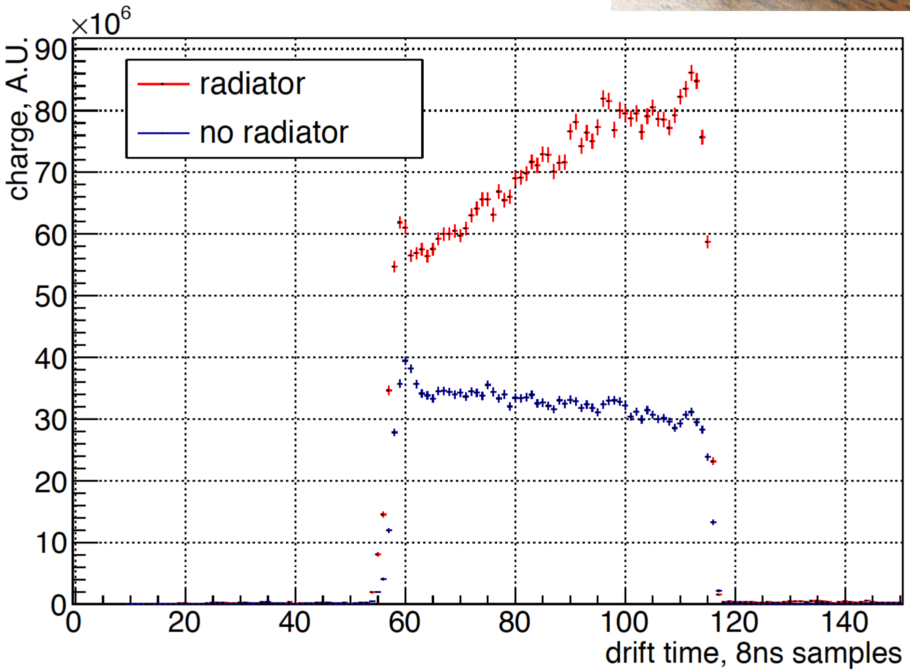
- Slope in dE/dx, possible problems:
  - Bad gas mixture
  - Wrong HV settings (?)
  - Diffusion (x)
  - Space charge

Radiators

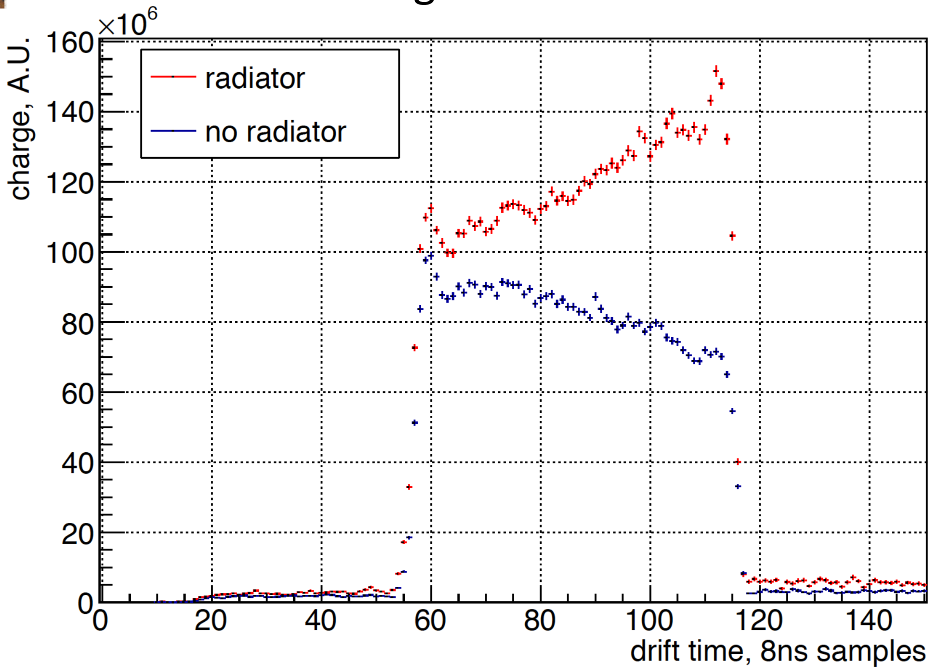
Fleece radiator:
Random oriented
Polypropylene fivers (20μm)

Regular foils:
~200 polypropylene foils (~13 μm thick)
with spacers (~180μm) made from nylon net

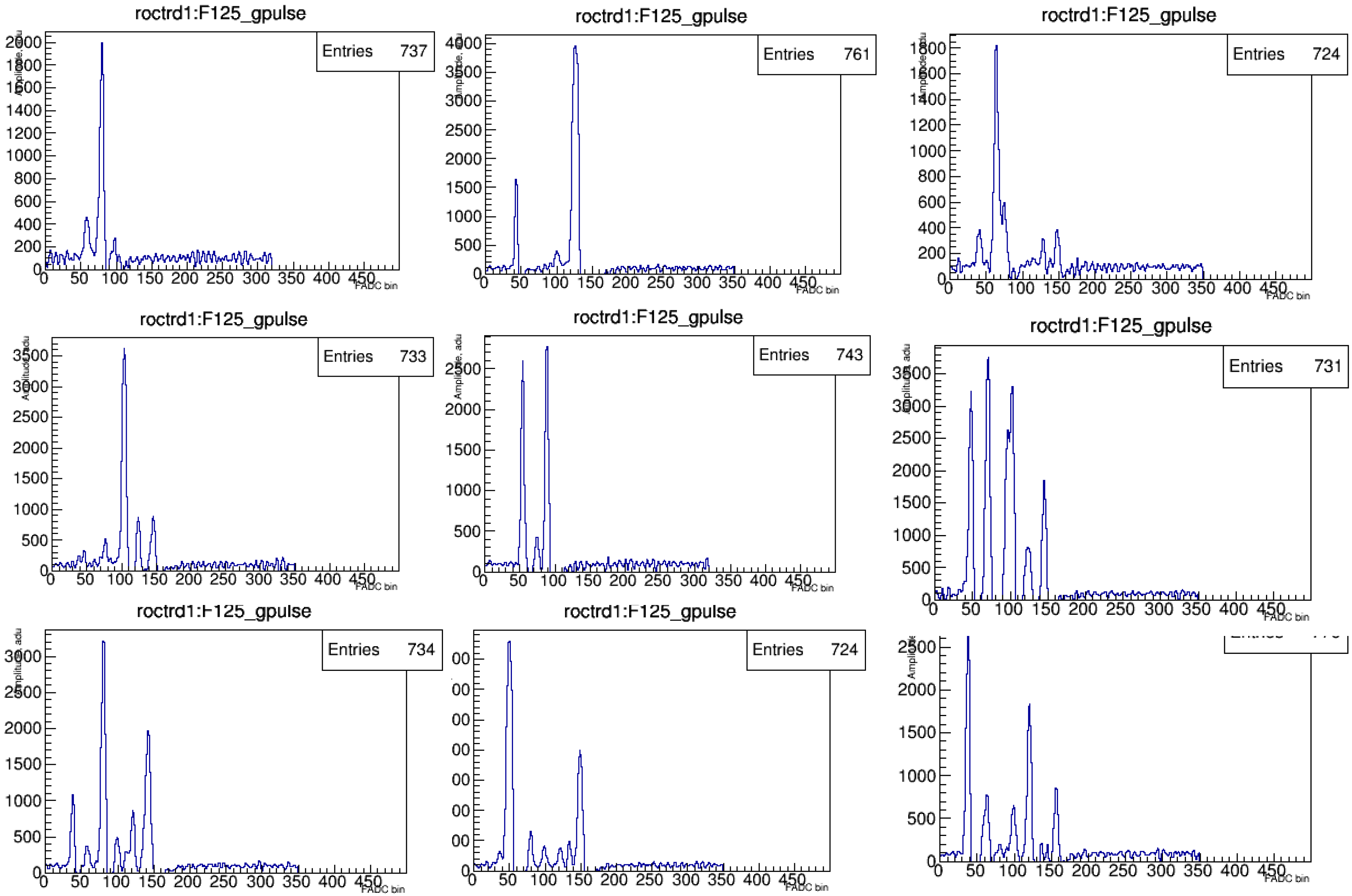
Fleece



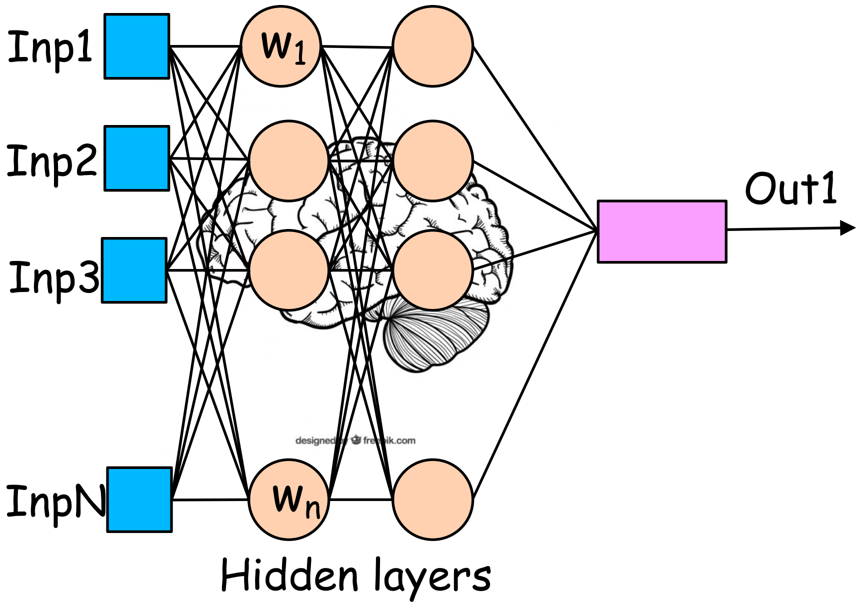
Regular foils



GEM-TRD/T signals (as seen in FADC125)



TR identification: Machine learning technique

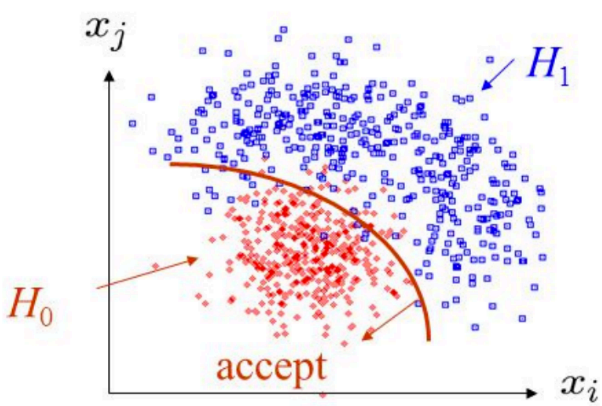


Inspired by biological brain models, Artificial Neural Networks are mathematical algorithms which are widely used various applications in particle physics : for example, pattern recognition, selection, forecasting, classification, etc.

Many variables can be used to disentangle signal and background events.

ANN find the weights (w_i) which solve our classification problem.

ANNs are trained on signal and background using MC sample and then applied all "knowledge" to the data or an other sample.



The learning rate can be gradually decreased during the training (# epoch)

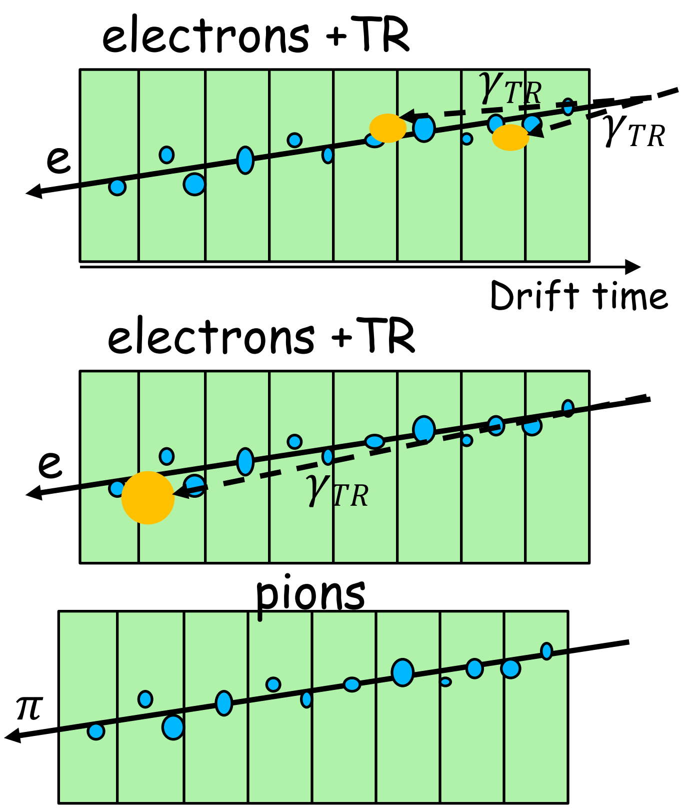
This technique could be applied for everything: track finding, event selection, trigger

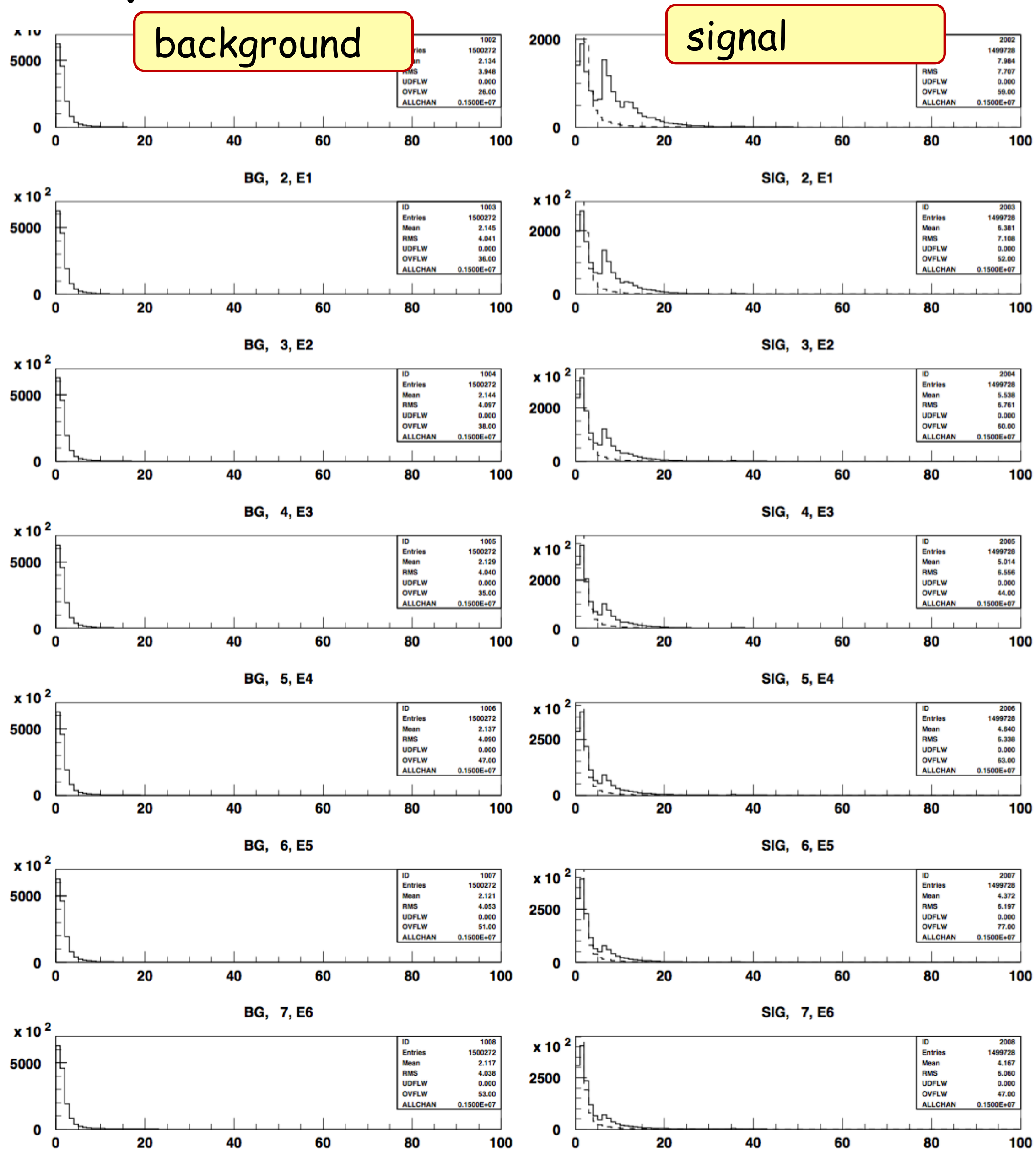
TR identification: Artificial Neural Network

Input variables:

Total or per slice or per cluster (we use 27var)

- <dE/dx>
- Number of clusters
- Timing …

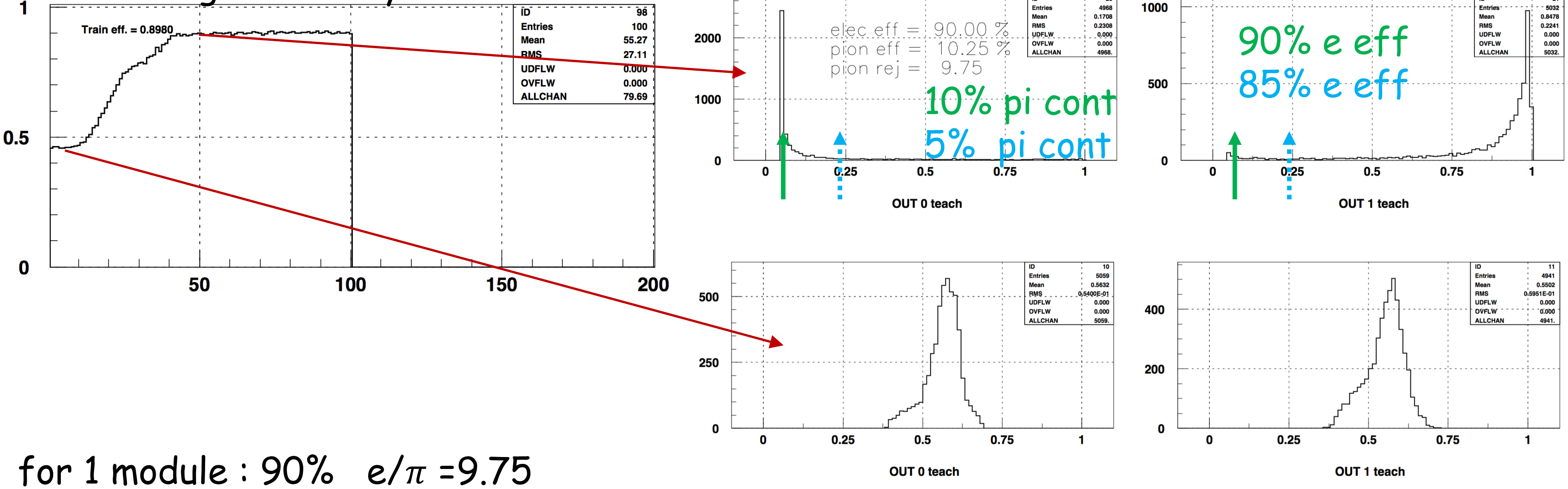




TR identification: Neural Network

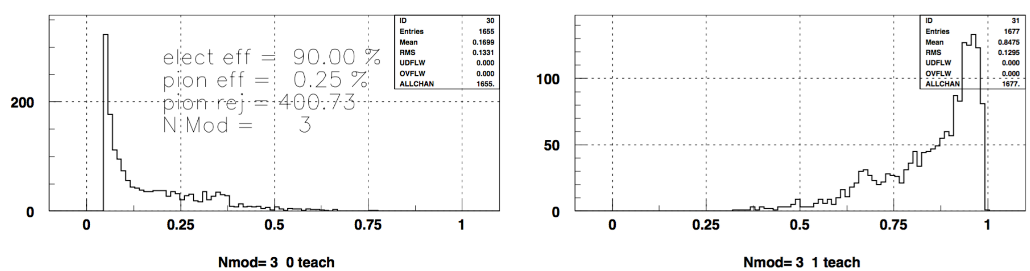
Training efficiency

efficiency for 1 module



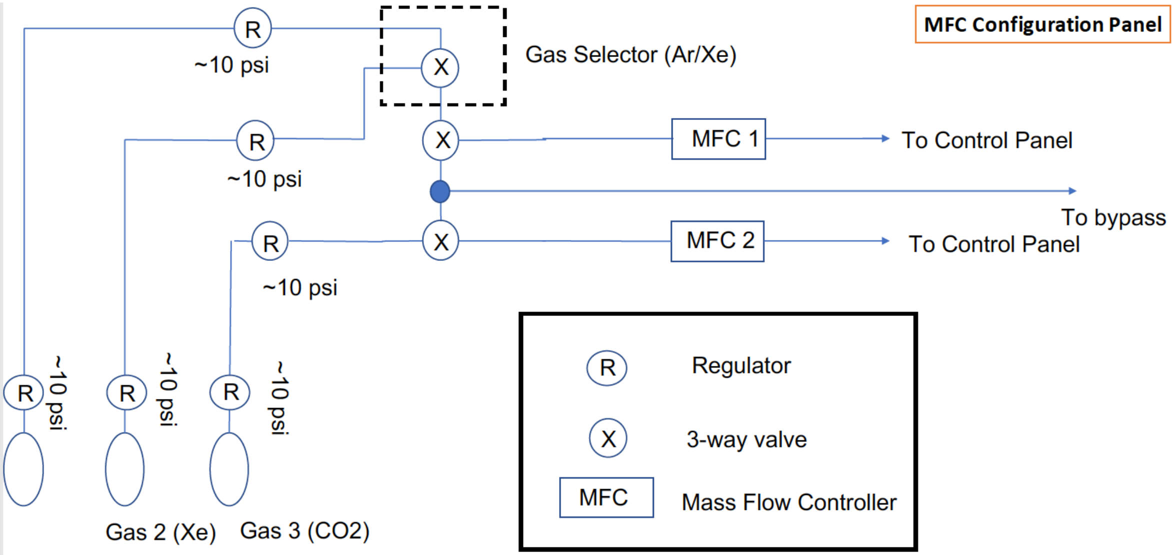
for 1 module : 90% e/π =9.75
But for 3 modules:
e/pi =10x10x10 = 1000
but e efficiency: 0.9x0.9x0.9=73%

efficiency for 3 modules

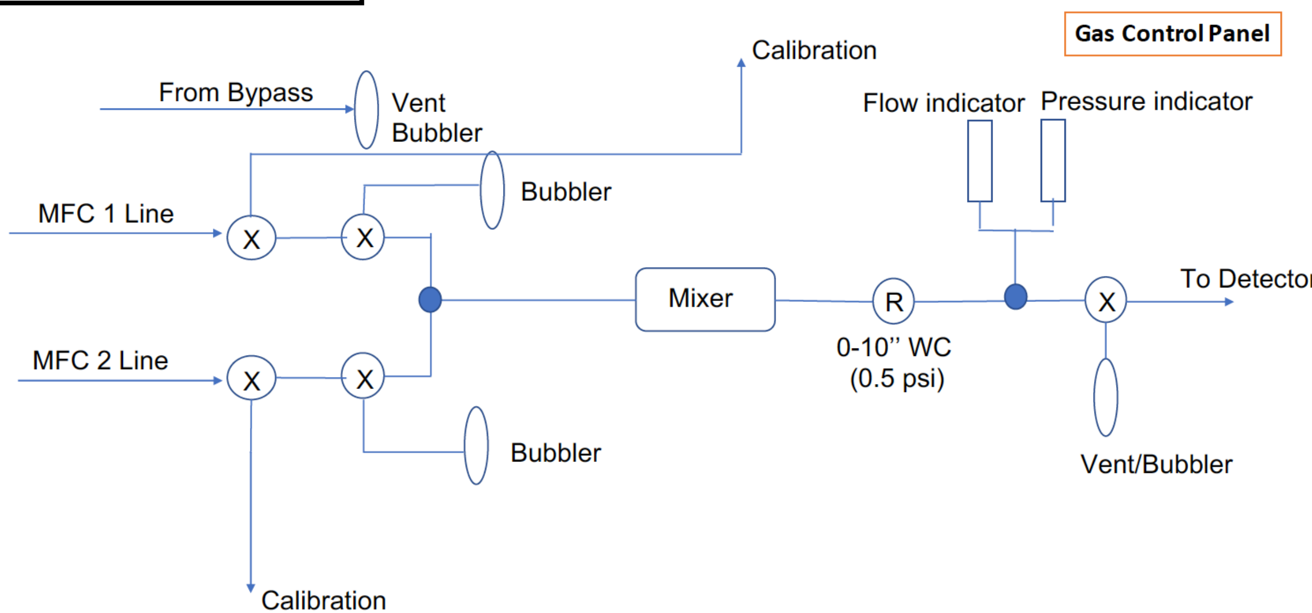


Efficiency for 3 modules:
e efficiency 90%
but e/π ~ 400.

GAS system

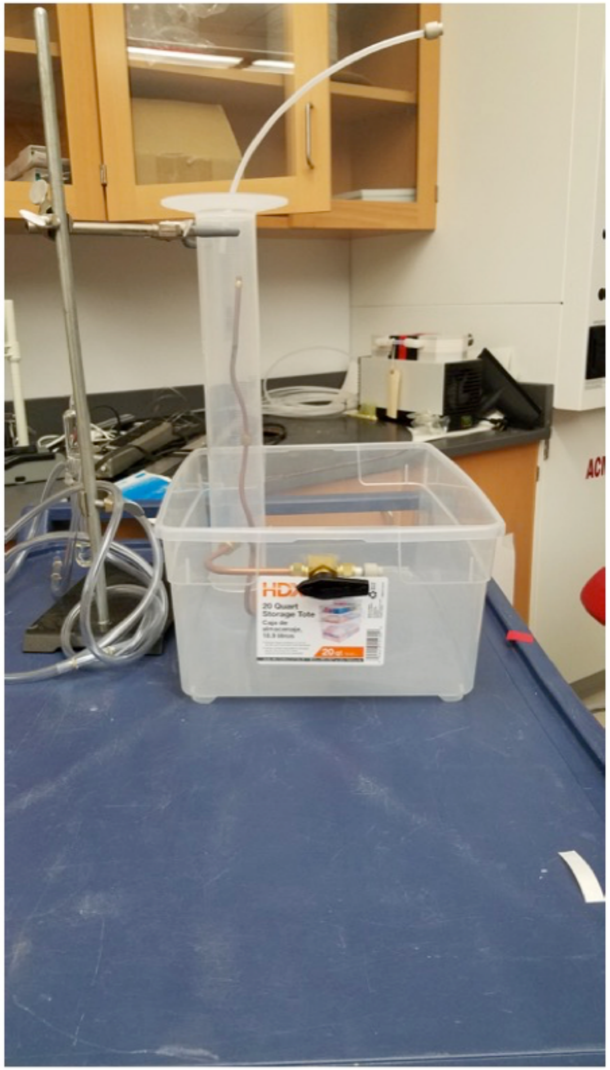


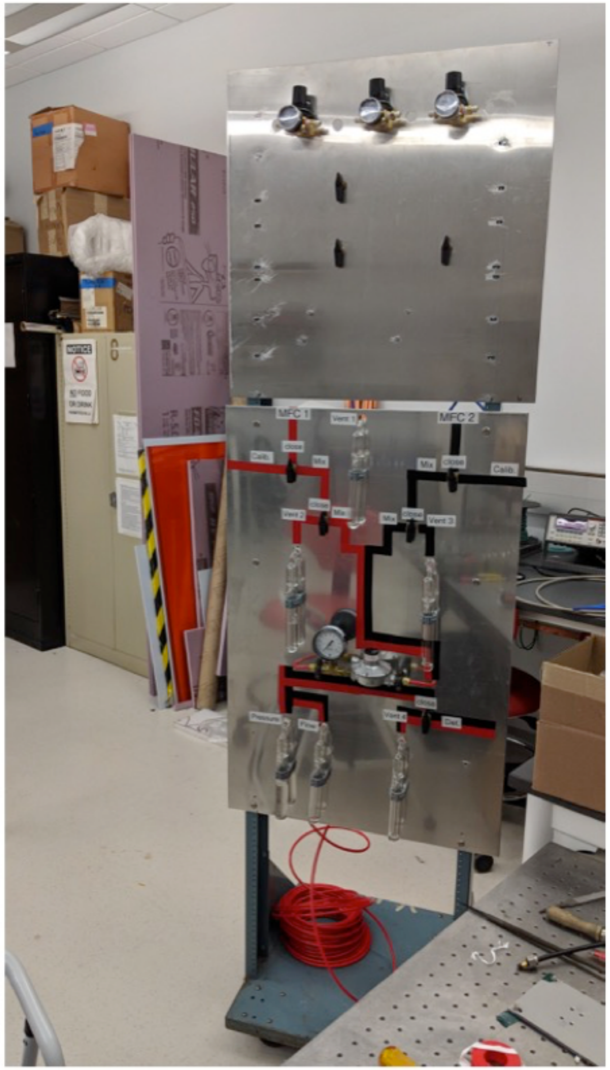
- Without a re-circulation and a purification system (too early stage of R&D)
- Mixing system to mix custom gas concentrations
- Flow controller, CO_2 controller



Yulia Furletova

GAS system at Temple U.





Yulia Furletova

Achievements:

- We performed a GEANT4 simulation of TRD setup with GEM detector (gas and radiator volumes) for a single layer operation and estimated e/pi rejection factor.
- We built and tested a new GEM based TRD prototype and optimized its performance (new HV divider, different drift filed voltages, gas gain, etc)
- Front-end electronic / DAQ :
  - Test new DAQ with Flash ADCs (fADC125)
- Using the existing facility at JLAB Hall-D perform a test beam measurements with different TR-radiators
- We have a lots of data to analyze!
- New gas-mixing system is ready to use.

What we **cann't do at the moment**:

We do not have available readout electronics to equip more then one module (all electronics was borrowed from JLAB Hall-D, ~$50/channel) =>

- We will not be able to do a test at Fermilab or CERN with e and π beams to estimate a real performance and to perform a joint test beam setup with tracker, calorimeter and Cherenkov detectors.
- We will not be able to test TRD with 2 modules (second module could absorb TR photons escaped from the first module).

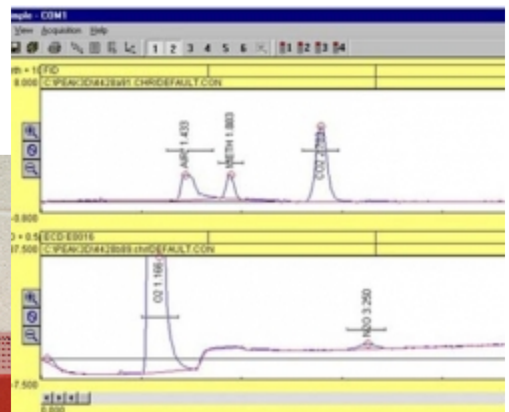
What we will do within next few months

- Test Module with different (%) gas mixtures: gas system is ready (Xe gas price went up from $10/liter to $26/liter)
- Test Cr module: new prototype is ready and under a test at UVA
- Continue with test beam data analysis
- Planning to present our results at conferences and prepare a publication

In addition to our original FY18 proposal (budget request for FY19)

We have identified a several issues and studies which should be pursued in addition to those in our original plans as important steps towards the realization of a new generation of transition radiation detectors as a part of the EIC project.

1. **Gas system**: gas analyzer to begin quantifying and monitoring contaminations and to measure the concentrations of the Xe and CO_2 gasses.
   -> split a cost with Hall-D ca. $7k (40%)



SRI 8610C

In addition (budget request for FY19)

We have identified a several issues and studies which should be pursued in addition to those in our original plans as important steps towards the realization of a new generation of transition radiation detectors as a part of the EIC project:

- In collaboration with readout consortium:

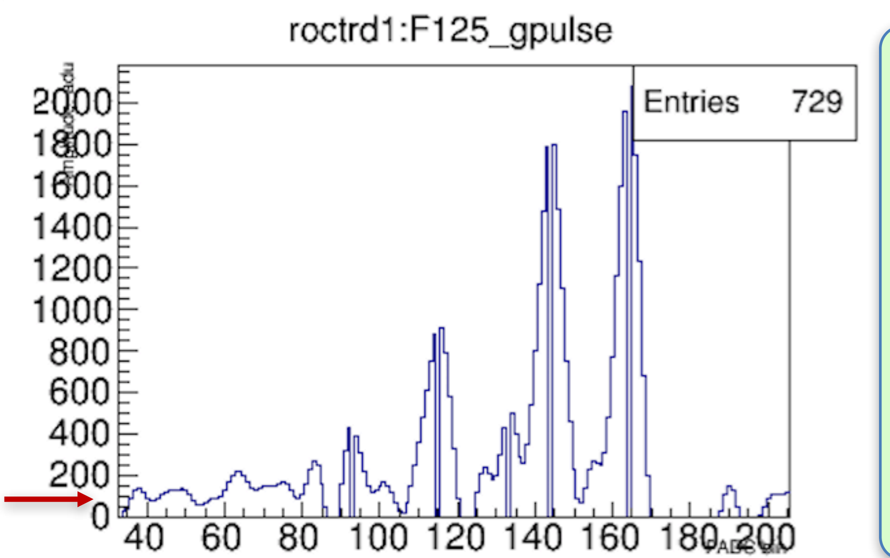
2. On-line particle identification: to move a part of an off-line reconstruction software into on-line (FPGA evaluation board ~$7k)

Step1.
-> Optimize software on computer,
-> Compare with other likelihood methods
-> adopt this technique for a possible use within the FPGA
Step2. Need FPGA (VIRTEX or ..)
Step3. Code algorithm for FPGA

3. Readout hardware: find a cheaper solution/replacement of FlashADC125 (cheaper then $50/channel): FADC125 have a timing resolution of 8ns/bin, and covers a whole drift time range >1μs . APV25, VMM3, DREAM or SAMPA does not provide necessary coverage or timing resolution.

CEA-Saclay has an interest in ASIC developments for EIC and in particular for GEM-TRD/T
We are looking forward to collaborate!

Readout hardware: find a cheaper solution/replacement of FlashADC125 (<<$50/channel): FADC125 have a timing resolution of 8ns/bin, and covers a whole drift time range >1μs .



FADC 125MHz == 8ns/bin
Preamp peaking time: 3-4 bins ~ 20-30ns
need better
Problems: undershooting (base at 100ADU),
loosing signal =>
need better shaper and
need also baseline restorer
Need: dE/dx, Cluster counting + timing
Coverage ~ 1μs

Available electronics for GEM

- -APV25: too few bins, coverage ×
- -VMM3 : 200ns/bin ×
- -SAMPA: 10-20 MHz only × but…

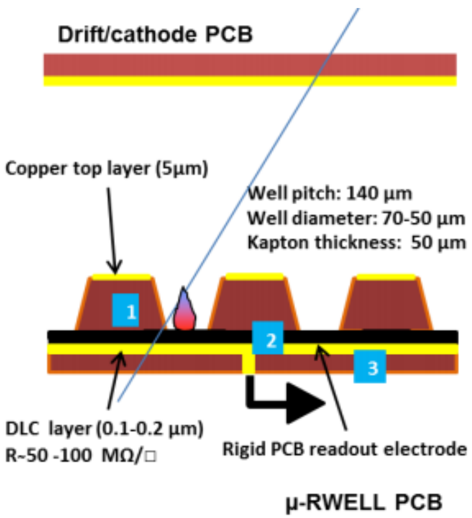
lots of good features inside SAMPA:

- 32channels/chip 30$/chip => 1$/channel v
- Shaper/preamps v
- Baseline restorer v
  (similar to ASDBLR/ATLAS)
- DSP: Zero suppression, thresholds v
- ASICs : could implement later any PID algorithms v

In addition (budget request for FY19)

4. Detector prototype: following the EIC R&D (tracking consortium eRD6) effort on new technology such as μRWELL detectors, we are planning to work in parallel with the consortium toward an optimization of the detector for TRD/Tracking application. ($15k)

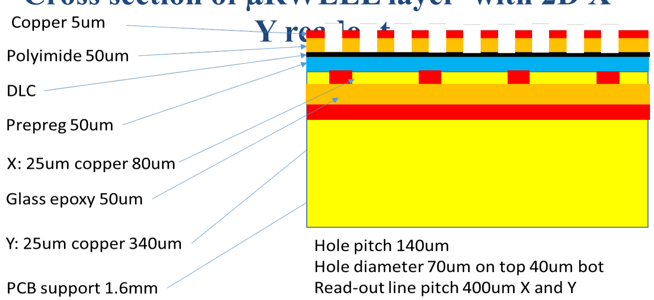
- μRWELL combines the advantages of both GEM and Micromegas
  - Like Micromegas → single amplification stage, thin structure, low material
  - Like GEM → Simple and single structure
  - Unlike GEM and Micromegas → no stretching needed for detector assembly
- The μRWELL PCB is realized by coupling
  - A suitable WELL patterned Kapton foil as amplification stage
  - A resistive stage for the discharge suppression and current evacuation
  - A standard readout PCB

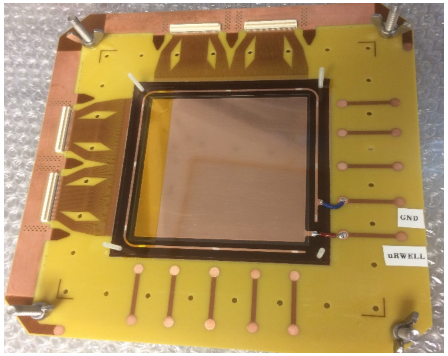


G. Bencivenni et al., 2015_JINST_10_P02008

UVa Prototype: μRWELL with 2D X-Y readout

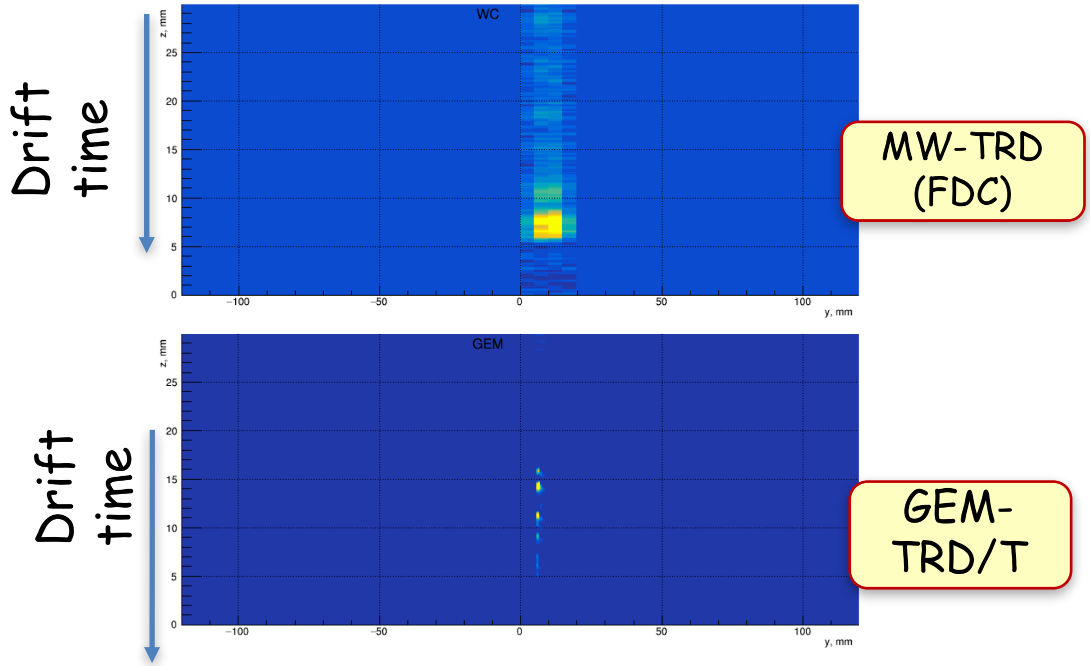
Cross section of μRWELL layer with 2D X-Y re





In addition (plans for FY19)

5. **Tracking:** evaluate the performance of our prototype as a tracker (space point resolution, Xe vs Ar etc)   (no cost)



6. **Radiator optimization:** we need to identify and test promising new radiator materials to optimize the yield of TR-photons (no cost)

30

The table 1 below summarizes the Temple University budget request for FY19.

Table 1: **Temple University-Gas System** FY19 request.

	Request	**-20%**	**-40%**
Gas supplies	$700	$400	$0
Travel	$3,000	$2,000	$2,000
Overhead (58.5%)	$2,165	$1,404	$1,170
Total	**$5,865**	**$3,804**	**$3,170**

Table 4: **A total eRD22** FY19 request.

	Request	**-20%**	**-40%**
JLAB	$27,300	$12,300	$4,100
UVA	$23,075	$ 11,460	$ 4,845
Temple U	$5,865	$ 3,804	$ 3,170
Total	**$56,240**	**$ 27,564**	**$12,115**

The table 2 below summarizes the Jefferson Lab budget request for FY19.

Table 2: **JLAB: FPGA and Gas Analyzer** FY19 request.

	Request	**-20%**	**-40%**
FPGA evaluation board	$7,000	$0	$0
Gas analyzer (% with Hall-D)	$8,000 (50%)	$ 5,000 (30%)	$ 0
Travel	$5,000	$4,000	$3,000
Overhead (36.5%)	$7,300	$3,300	$1,100
Total	**$27,300**	**$12,300**	**$4,100**

The table 4 below summarizes the University of Virginia budget request for FY19.

Table 3: **UVA prototyping** FY19 request.

	Request	**-20%**	**-40%**
μRWELL prototype	$5,000	$0	$0
Gas/Field cage	$5,000	$ 0	$ 0
HV power supply	$5,000	$ 5,000	$ 0
Travel	$5,000	$4,000	$3,000
Overhead (61.5%)	$3075	$2460	$1845
Total	**$23,075**	**$ 11,460**	**$4,845**

Summary

- Electron identification is very important for EIC physics. Due to a large hadron background expected in the forward (Hadron-endcap) region, a high granularity tracker combined with TRD functionality could provide additional electron identification - GEM-TRD/T
- GEANT4 simulation of GEM-TRD has been performed
- Test beam measurements has been performed
- Test beam analysis are ongoing
- Looking forward to a collaboration with tracking and readout consortiums!

Thank you!

Backup