GEM based Transition Radiation detector/ tracker

(July-2019- July 2020)

Yulia Furletova on behalf of GEMTRD eRD22 group

U.S. DEPARTMENT OF ENERGY
JSA
Jefferson Lab
EIC2
EIC Center at Jefferson Lab

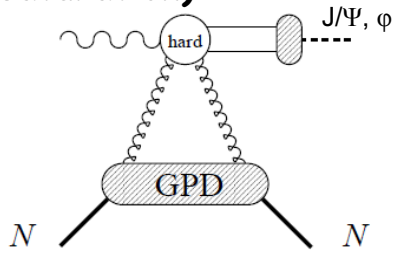
Outline

- Physics motivation
- Intro into TRD
- Test beam setup
- Analysis
- Conclusions

- 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)

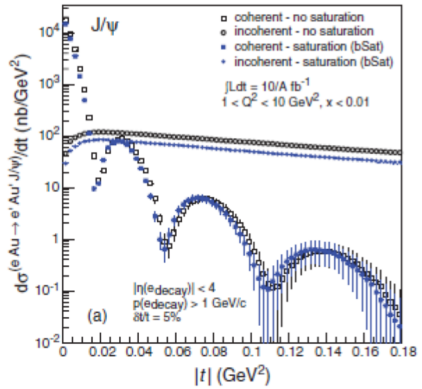
- **GPD and Coherent Exclusive Diffraction (saturation)**

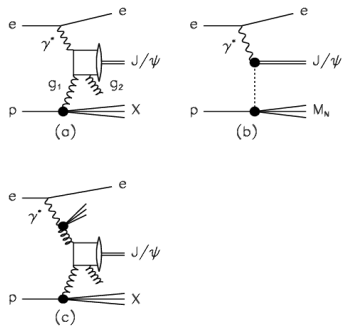


Br (J/ψ->e+e-) ~6%

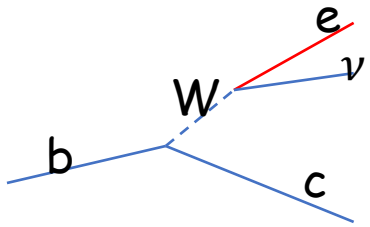
Br (J/ψ->μ+μ-) ~6%

Saturation
Coherent
Exclusive
Diffraction



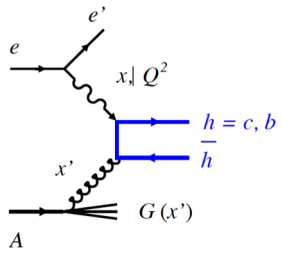


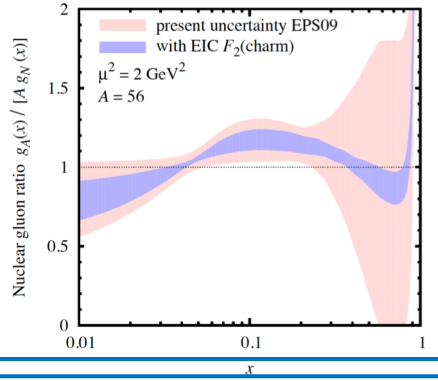
- **Heavy quark tagging**



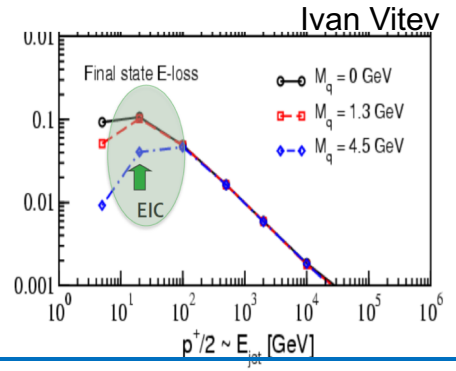
Br ($D^{\pm}$->e+X) ~16%

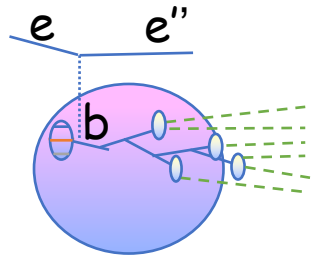
Br ($B^{\pm}$->e+ν+X_c) ~10%



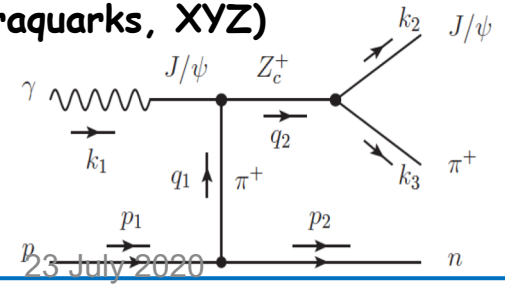


Ivan Vitev

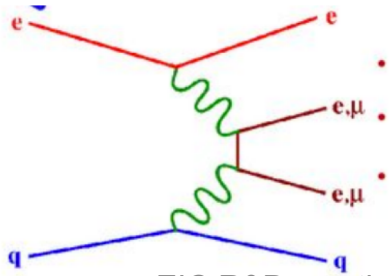




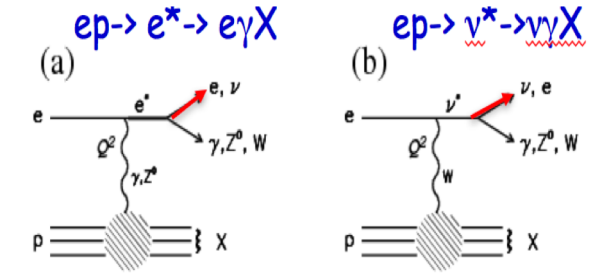
- **Exotic spectroscopy (pentaquarks, tetraquarks, XYZ)**



- **Multi-leptons**



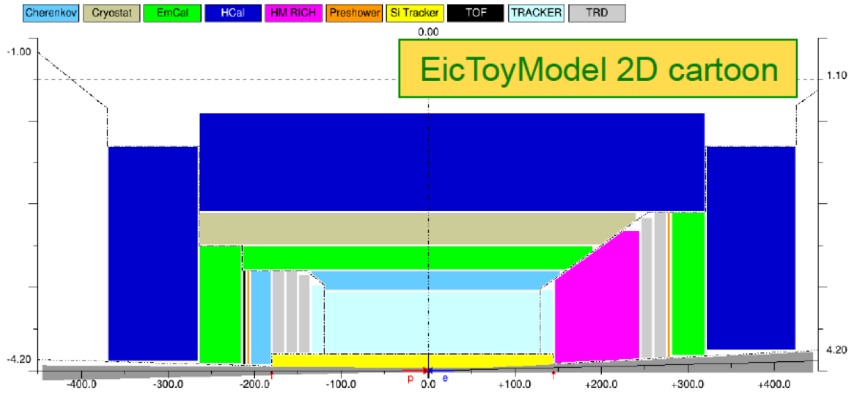
- **Other BSM physics**

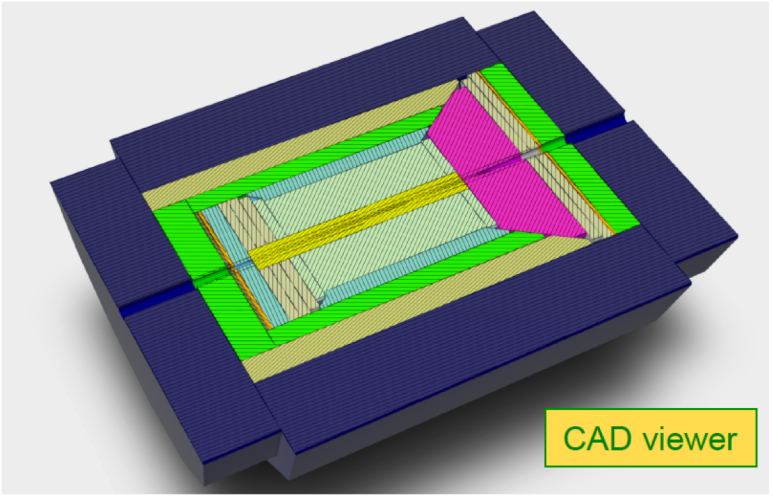


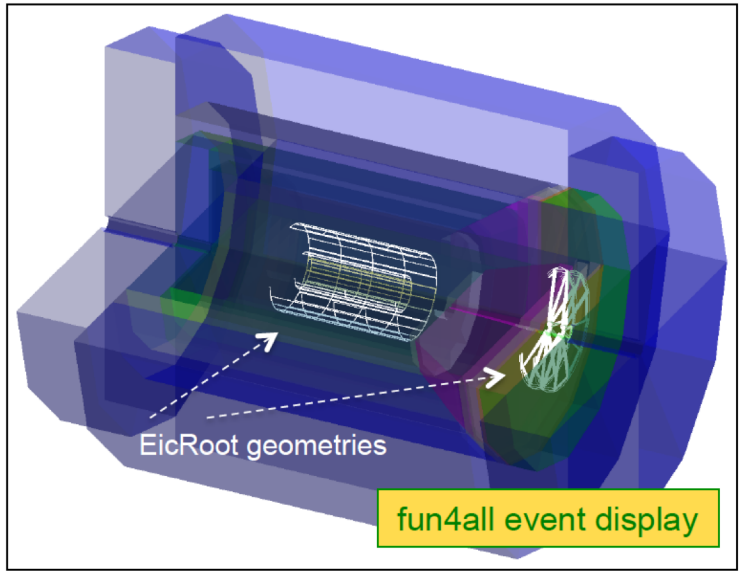
Possible implementation for the EIC

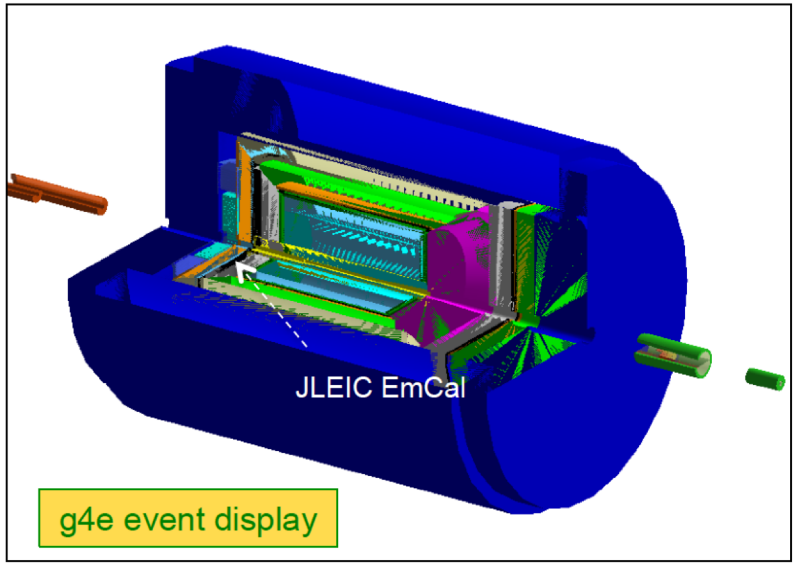
A.Kiselev
(at EICUG Miami meeting)

- The same model in all cases





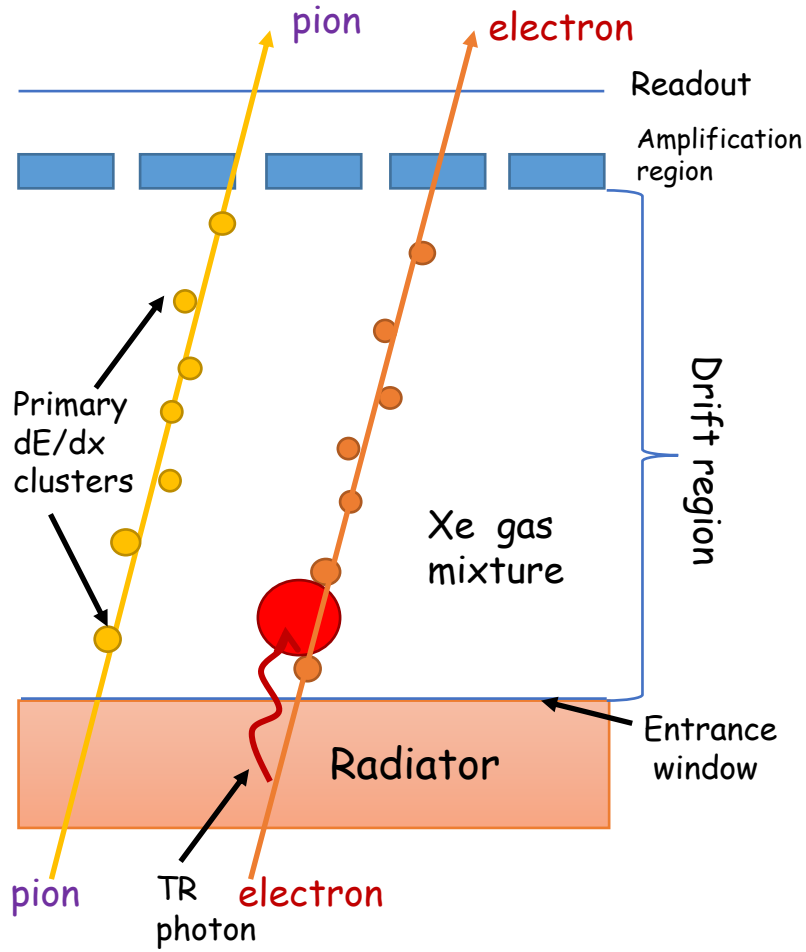




[1]

GEM as Transition Radiation detector and tracker for EIC (eRD22)

- High resolution tracker.
- Low material budget detector
- How to convert GEM tracker to TRD:
  - ✓ Change gas mixture from Argon to Xenon (TRD uses a heavy gas for efficient absorption of X-rays)
  - ✓ Increase drift region up to 2-3 cm (for the same reason).
  - ✓ Add a radiator in the front of each chamber (radiator thickness ~5-10cm)
  - ✓ Number of layers depends on needs: Single layer could provide e/pi rejection at level of 10 with a reasonable electron efficiency (85-95%).



eRD22 goals for FY2020:

1) Measure actual e/pion rejection (with both electron and pion beam)
   - Joint test with DIRC detector (integrated to GlueX framework) for pion run.
   - Fermilab test beam (preparation)

2) Improve the noise level and readout.

3) Test different radiators (low material budget, high yield)

4) Optimize gas-mixture and HV settings to get better rejection.

5) Optimize prototype: field-cage and entrance window

1. Electron hadron rejection

To measure a real e/π rejection factor we need a pion beam!!!

a) In collaboration with eRD6 working towards possible test beam at Fermilab in Spring 2021 (might be delayed due to COVID19)

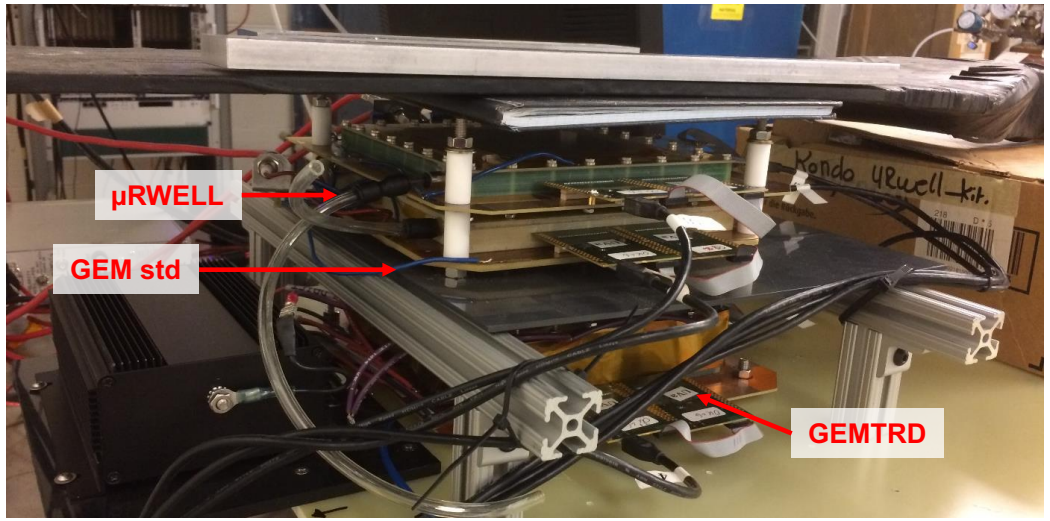
b) use pions from $\rho - meson$ decays (real GlueX/ Hall-D physics !)
Use a commissioning runs (December for DIRC at Glue-X) .

- to install GEM-TRD setup in front or behind DIRC detector (new mechanical support)
- Integrate GEM-TRD into GlueX DAQ ,
- Integrate GEM-TRD into post-processing analysis (eJANA)

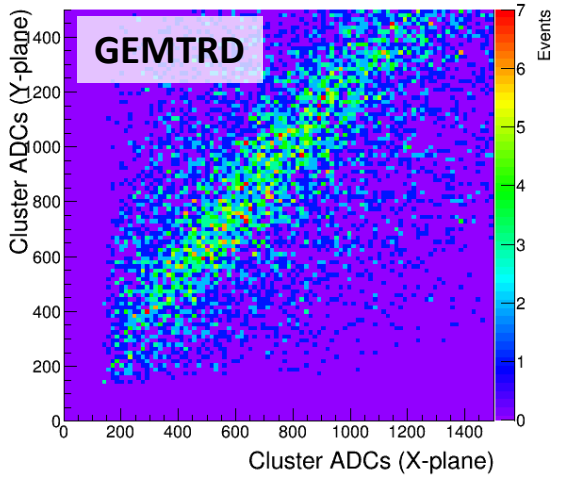
Also:
Have a joint test-beam with EMCAL (eRD1) and mRICH (eRD14) to estimate a Global PID (e/π) performance

UVA cosmic test

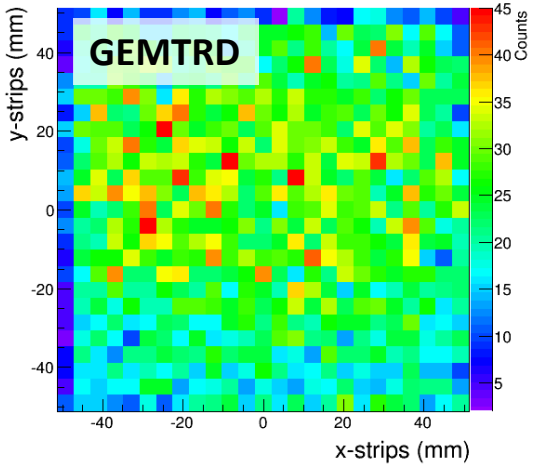
GEMTRD Test in cosmic setup @ UVa

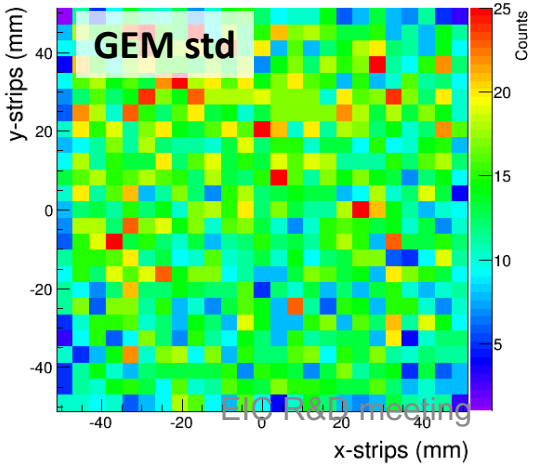


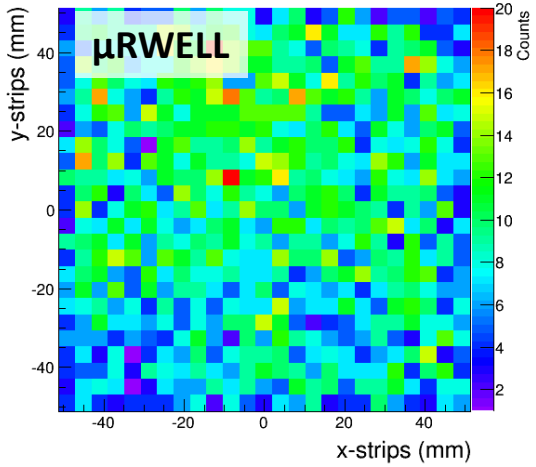
X-Y charge sharing



Reconstructed position hit map

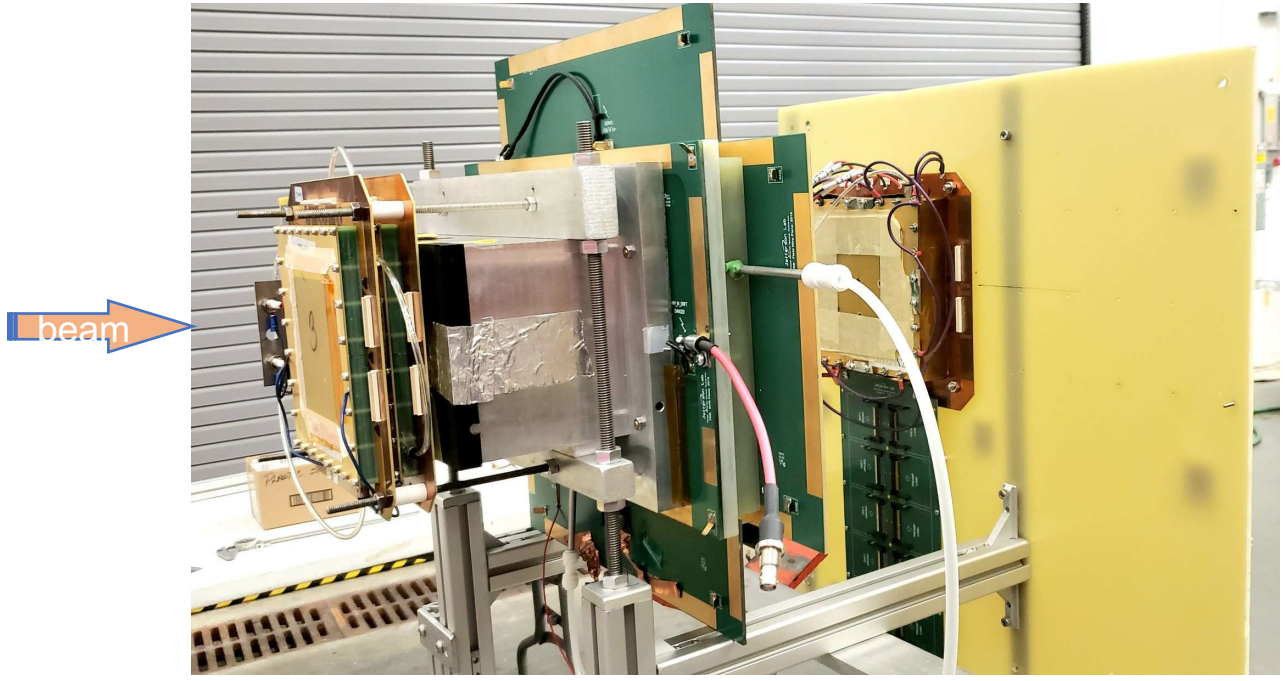


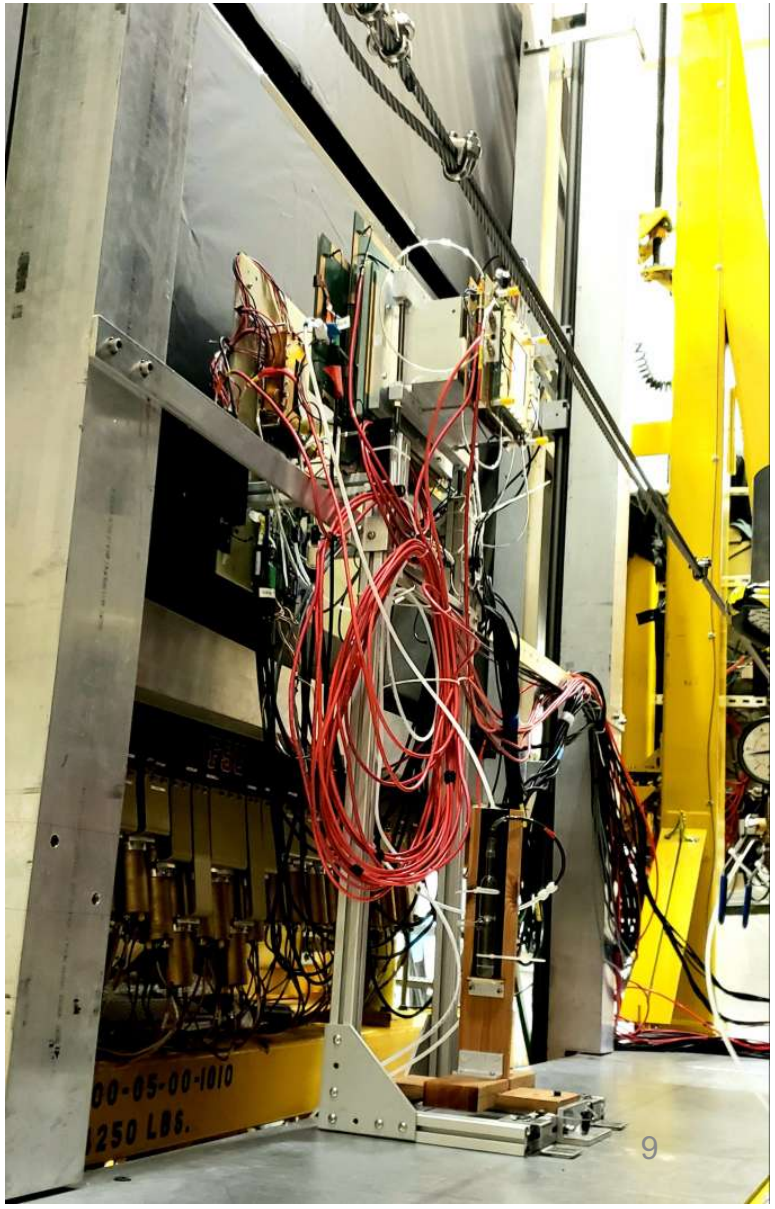




GEMTRD test setup with GlueX

- Motivation:
- To check for real e/pi rejection (detector response on pions)
- Also important for DIRC (precise tracking in front of the detector)



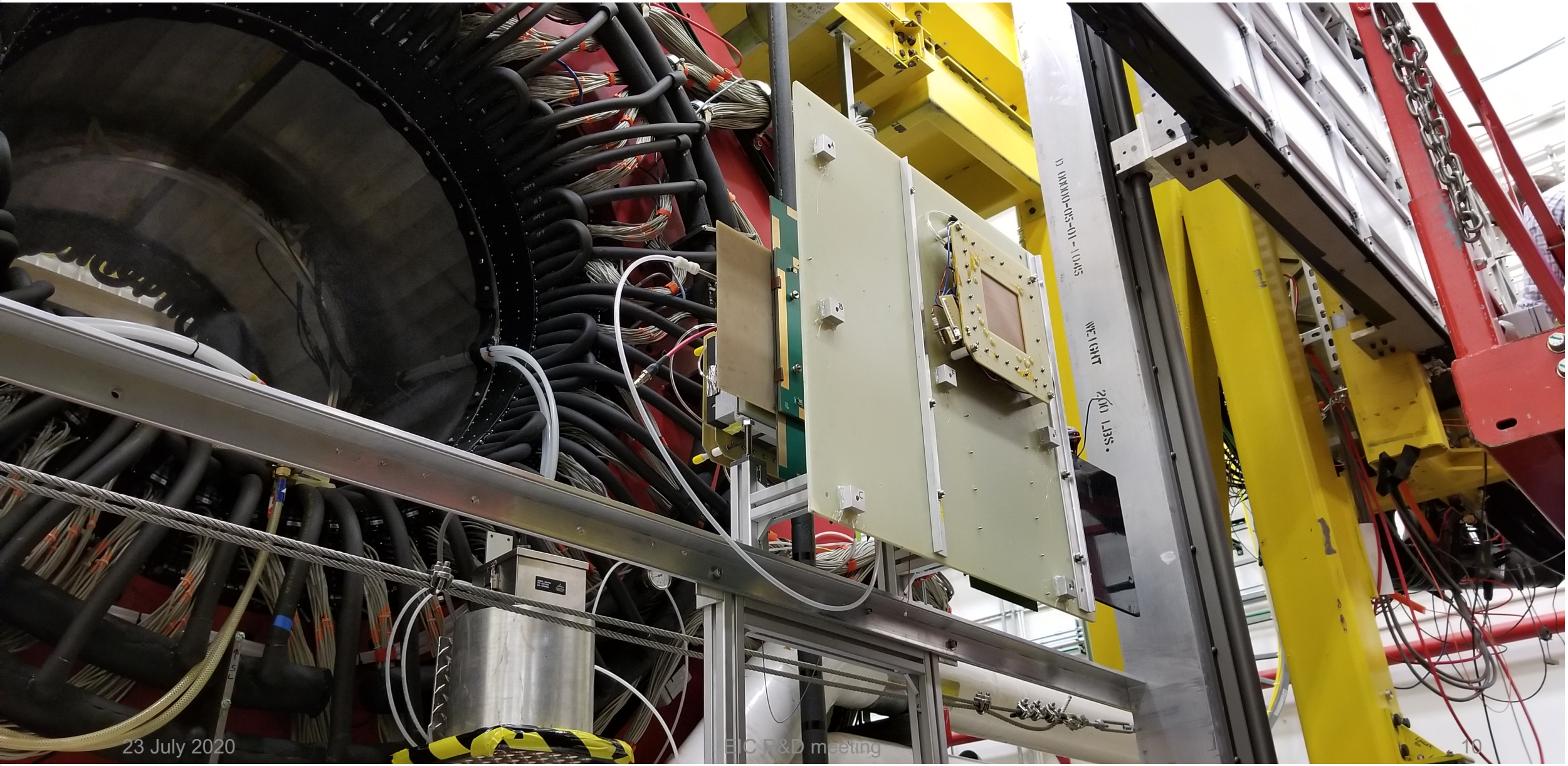


- Setup: 5 tracking detectors

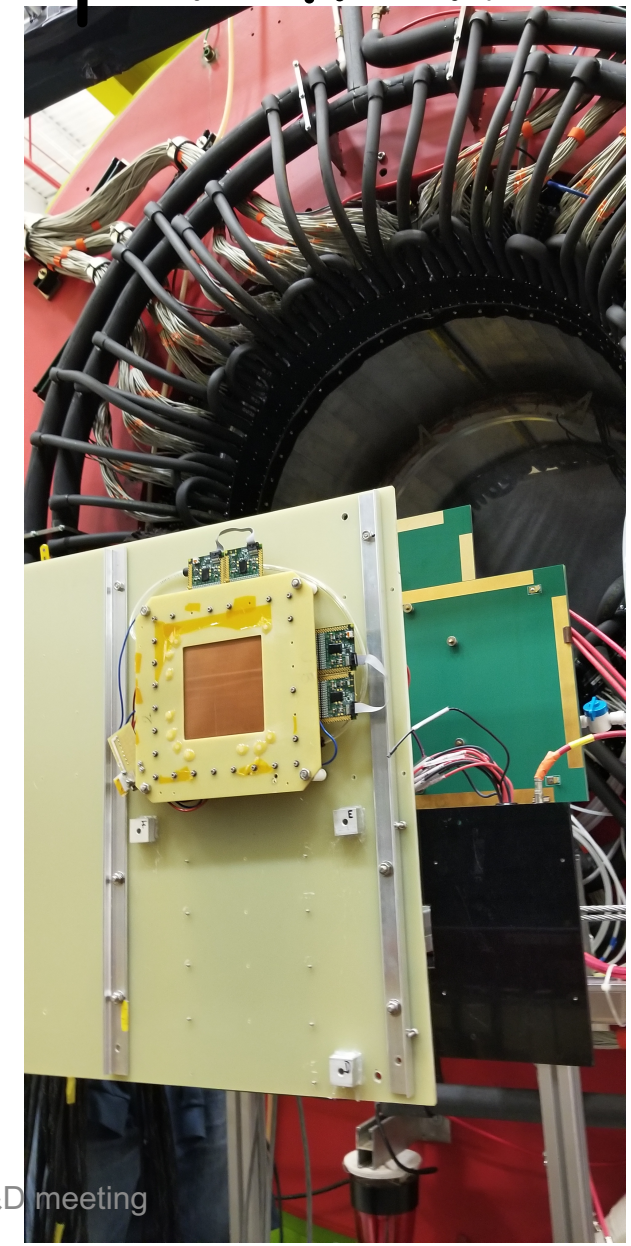
Counting from the target:

-Standard GEM, uRWELL, TRD Multi wire chamber (TRD-MW), GEM-TRD, Standard GEM plane.

GEMTRD setup at the GlueX experiment



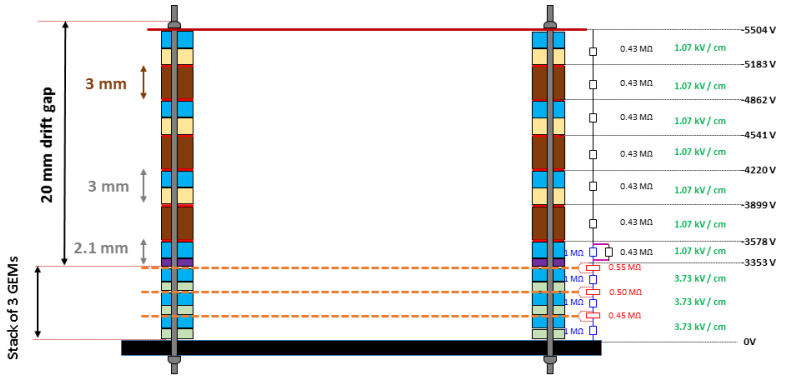
Integration into GlueX experiment



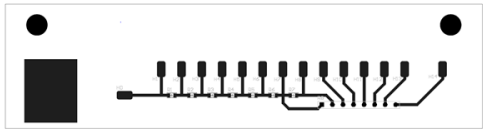
- All 5 modules have been installed in front of the DIRC detector (new mechanical support and alignment)
- All 5 modules have been integrated into GlueX DAQ.
- and integrated into the post-processing analysis (eJANA)

GEM -TRD/T problem during the GlueX test

GEM-TRD/T cross section, 21mm drift volume



Drawing for the resistive divider

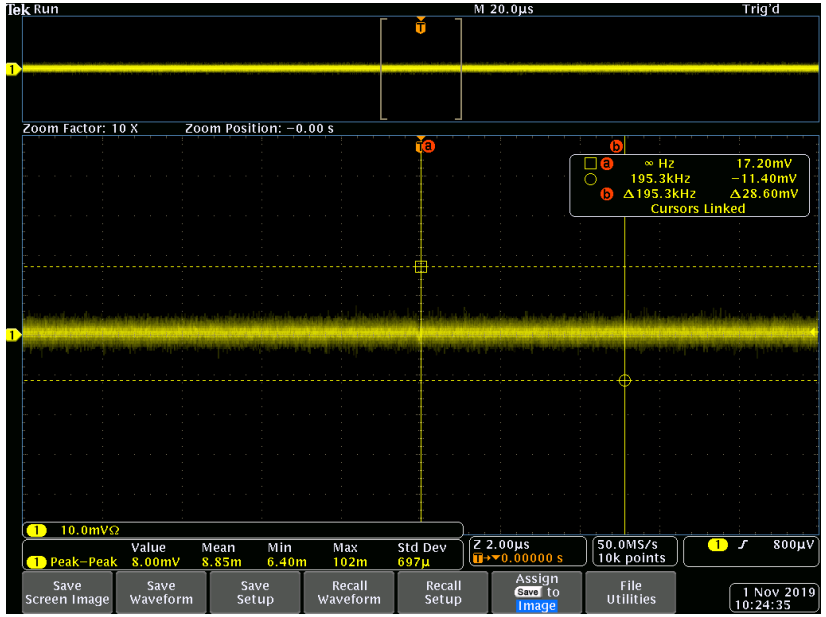


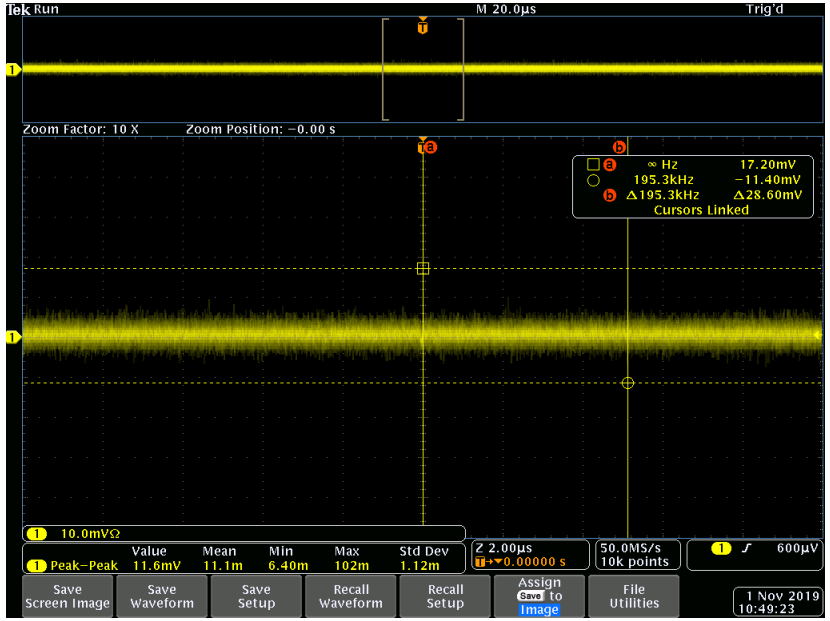
HV 5504 V,
Resistive Divider = 7.404 MΩ,
Max current = 747.3 μA

We have had a set of issues with the prototype during the joint GlueX test beam

- when exposed to the first beam, the prototype quickly develop a discharge-like behavior propagated over all of the FE readout channels which remained for a long period time even after the beam was off.
- We suspected a short in one of the 3 GEM foils
- But before opening, prototype was tested again with cosmic and was working perfectly once again.
- After couple of back and force movements between JLAB and Uva setups, we were able to reproduce the problem with X-ray setup/
- We suspect that one of the G10 frames used for the field cage in the drift volume became prone to charging up in a high particle rate environment and altered the electric field as well as the resulting electric signal of the detector. We proceed to replace this part in the prototype.

2. Improve the noise level and readout.





a) electronics alone with two carrier PCBs, each with 10 preamps, all powered (480 channels): noise 9 mVpp (as previously in the lab) .

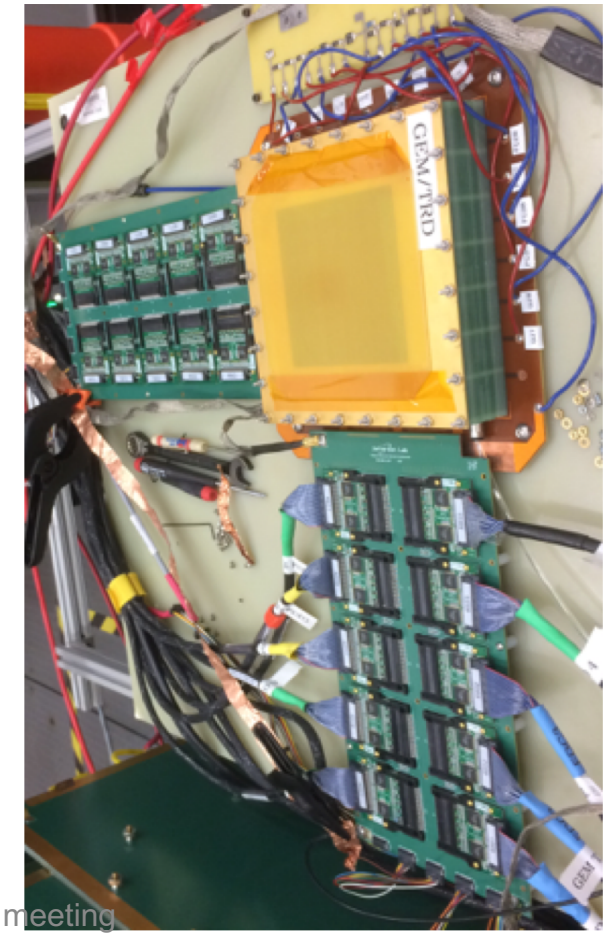
b) one of the carrier boards attached to the detector X coordinate : noise 11 mVpp.

c) two carrier boards attached to the detector X and Y coordinates: The noise increased considerably to 61 mVpp.

Noise and Fe55 test

=> These show that there is coupling on the detector between the X and Y strips. The long strips on the carrier boards, though shielded, may act as antennas

Since the time for installation was very limited, we decided to disconnect the Y coordinate. Fe55 test on X-strips was good!



3. Test of different TR-radiators.

- We continue to search and test different types of radiators
- Goal: to find low material budget, but high TR-yield radiators

- The TR-energy spectrum is very important (minimum of self-absorption)

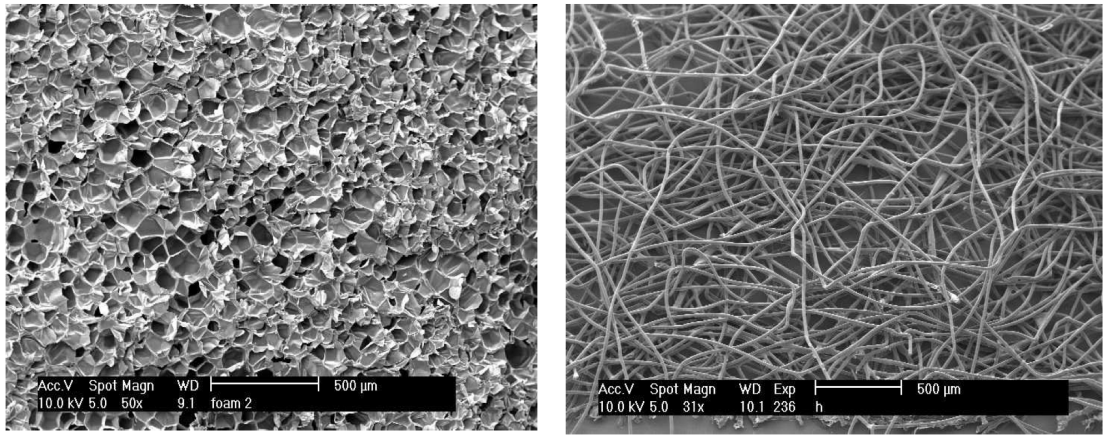
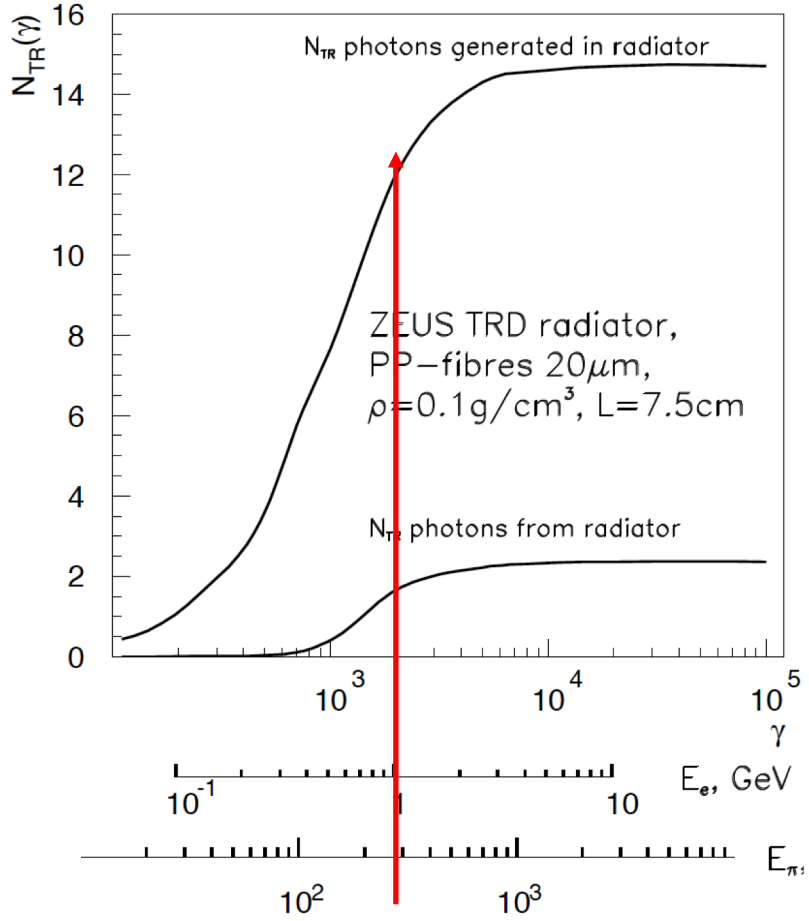


Figure 2: Electron microscope images of a polymethacrylimide foam (Rohacell HF71)(left) and a typical polypropylene fiber radiator (average diameter ≈ 25 μm) (right) [52].

J.Tandler



Only e produce TR photons (E>1GeV)
Pions only start to produce TR at E > 100-150 GeV

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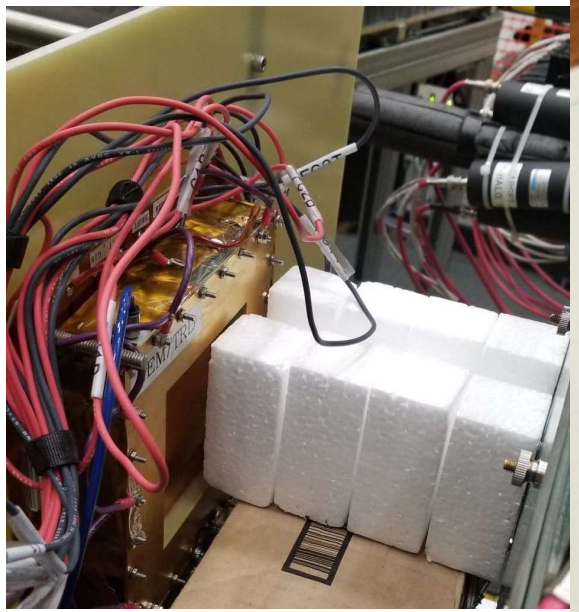
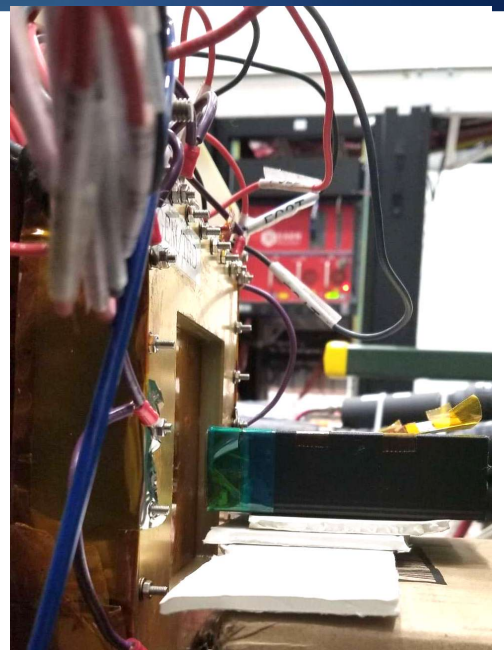
3. Test of different TR-radiators.

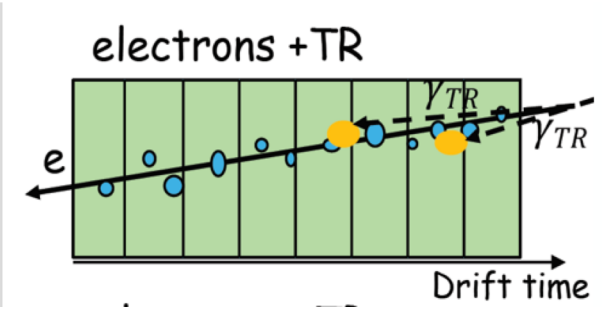
- We continue to search and test different types of radiators
- Goal: to find low material budget, but high TR-yield radiators

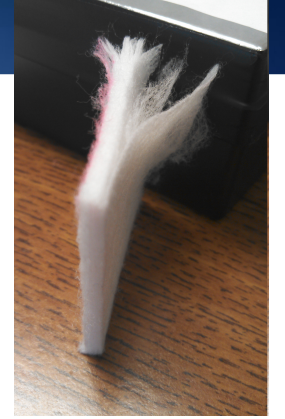


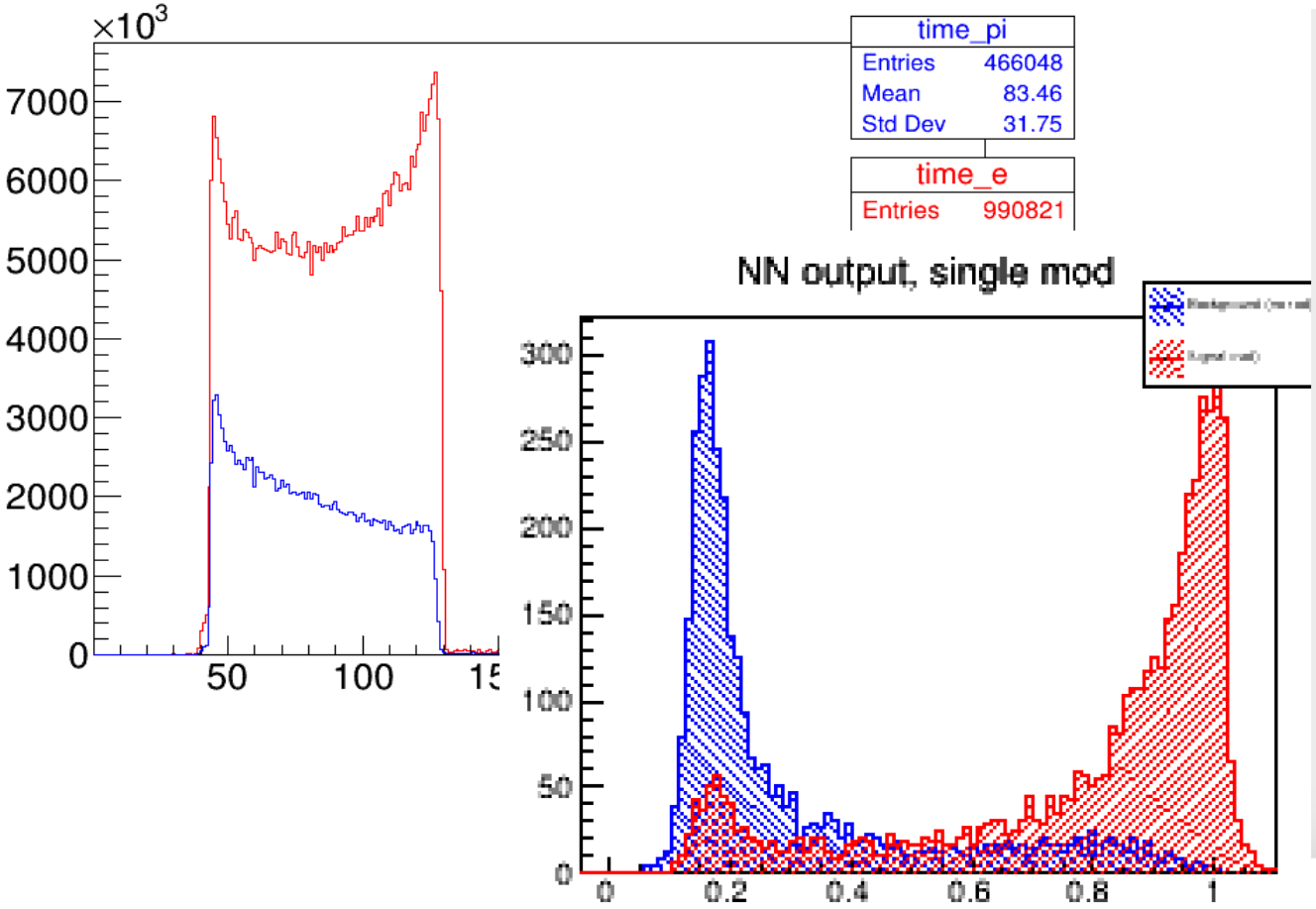


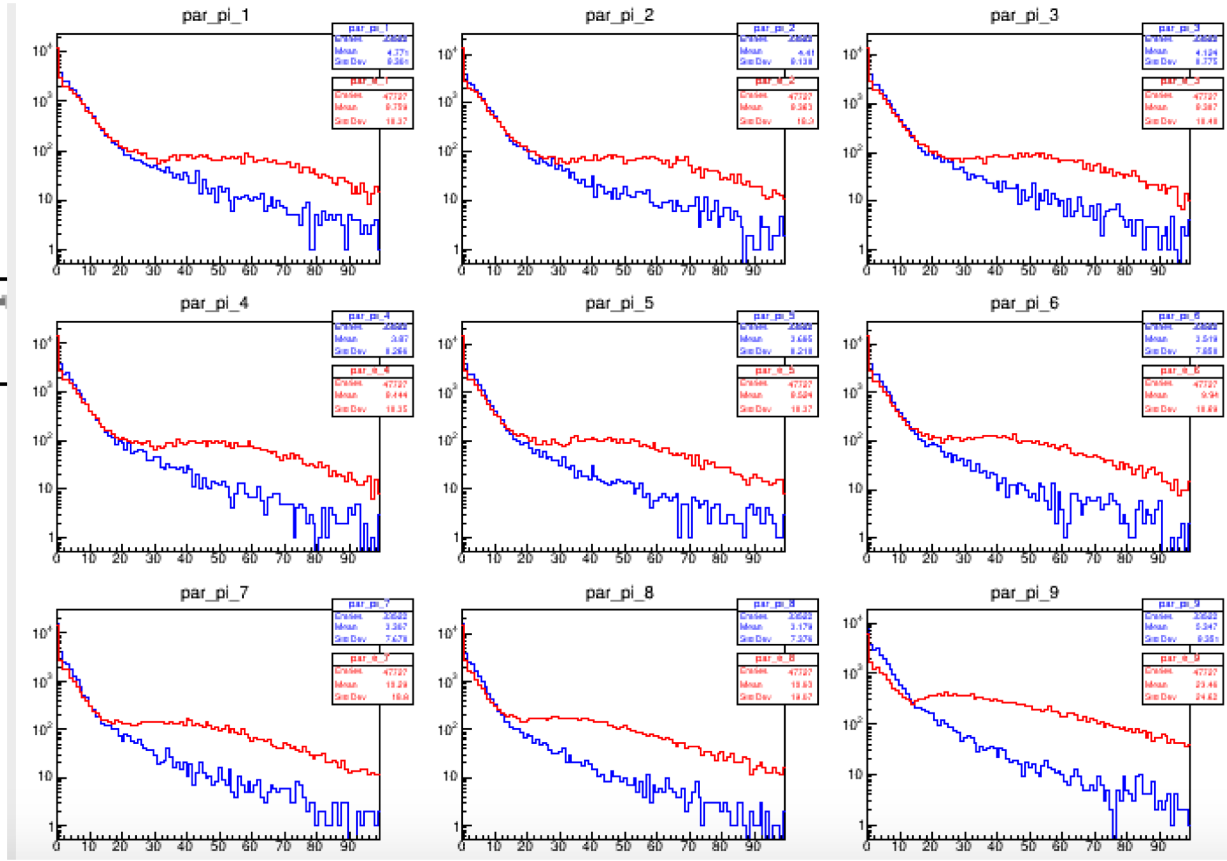
Radiator: Fleece

Beautiful response, High TR-yield, soft and hard TR photon's spectrum



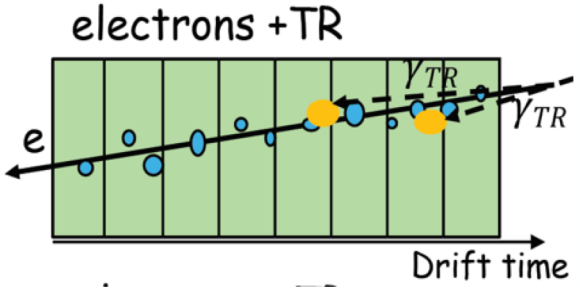


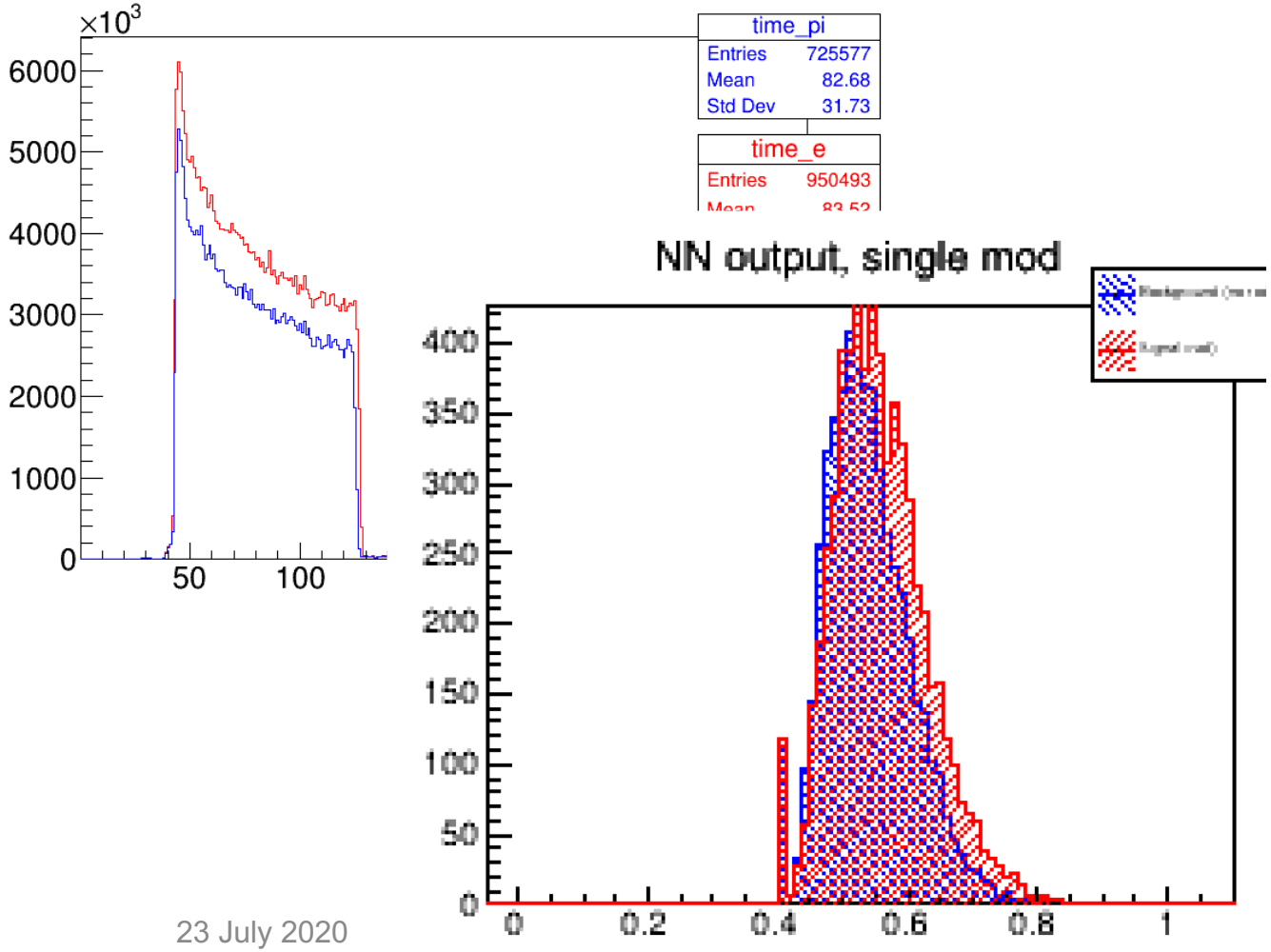


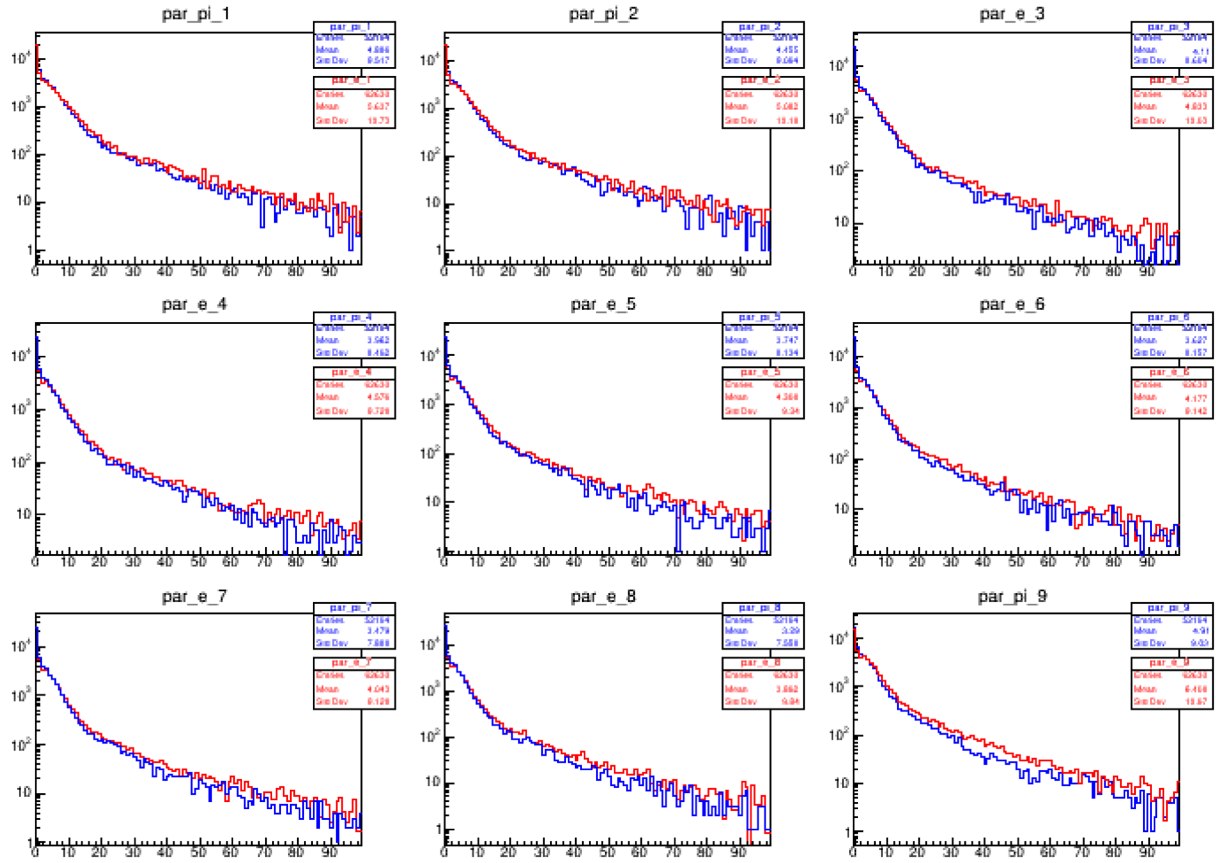


Radiator: Aerogel

No TR yield is seen

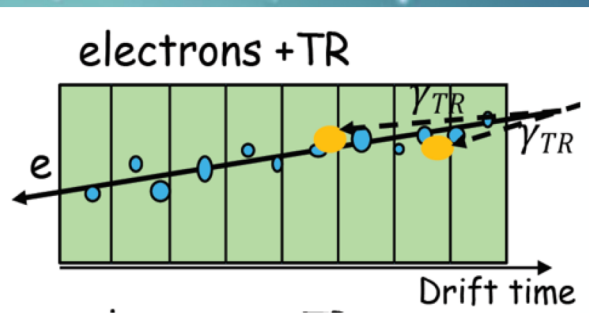


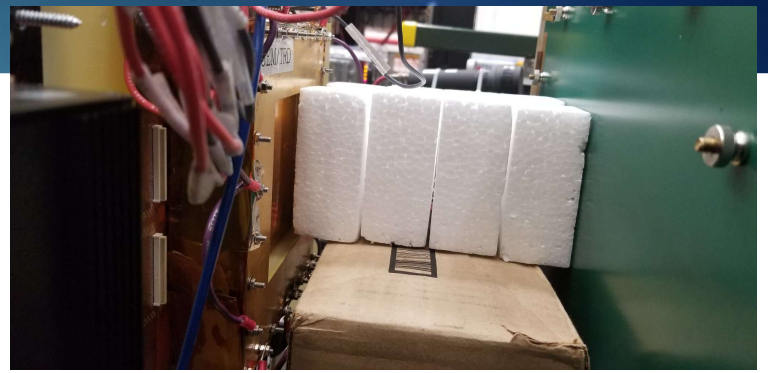


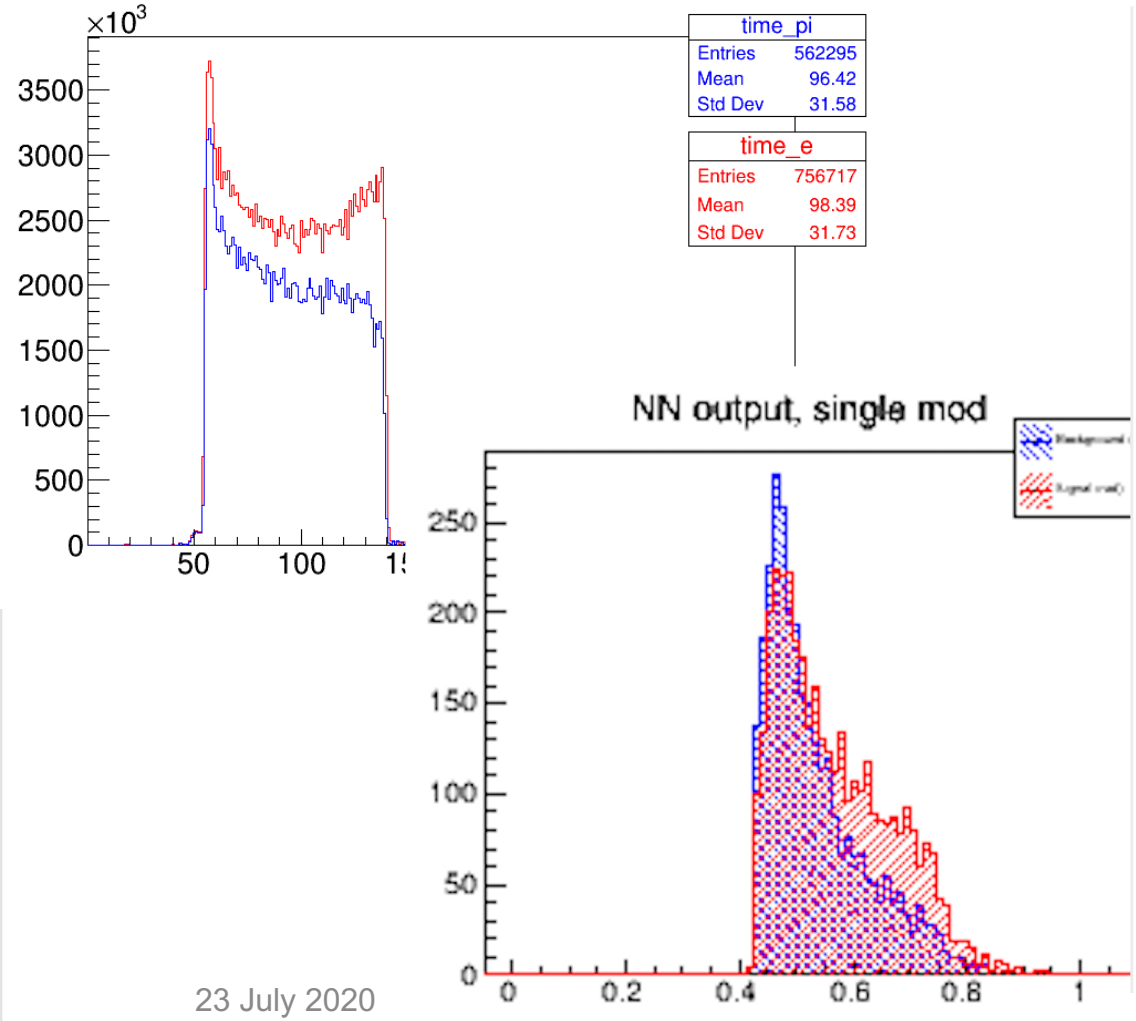


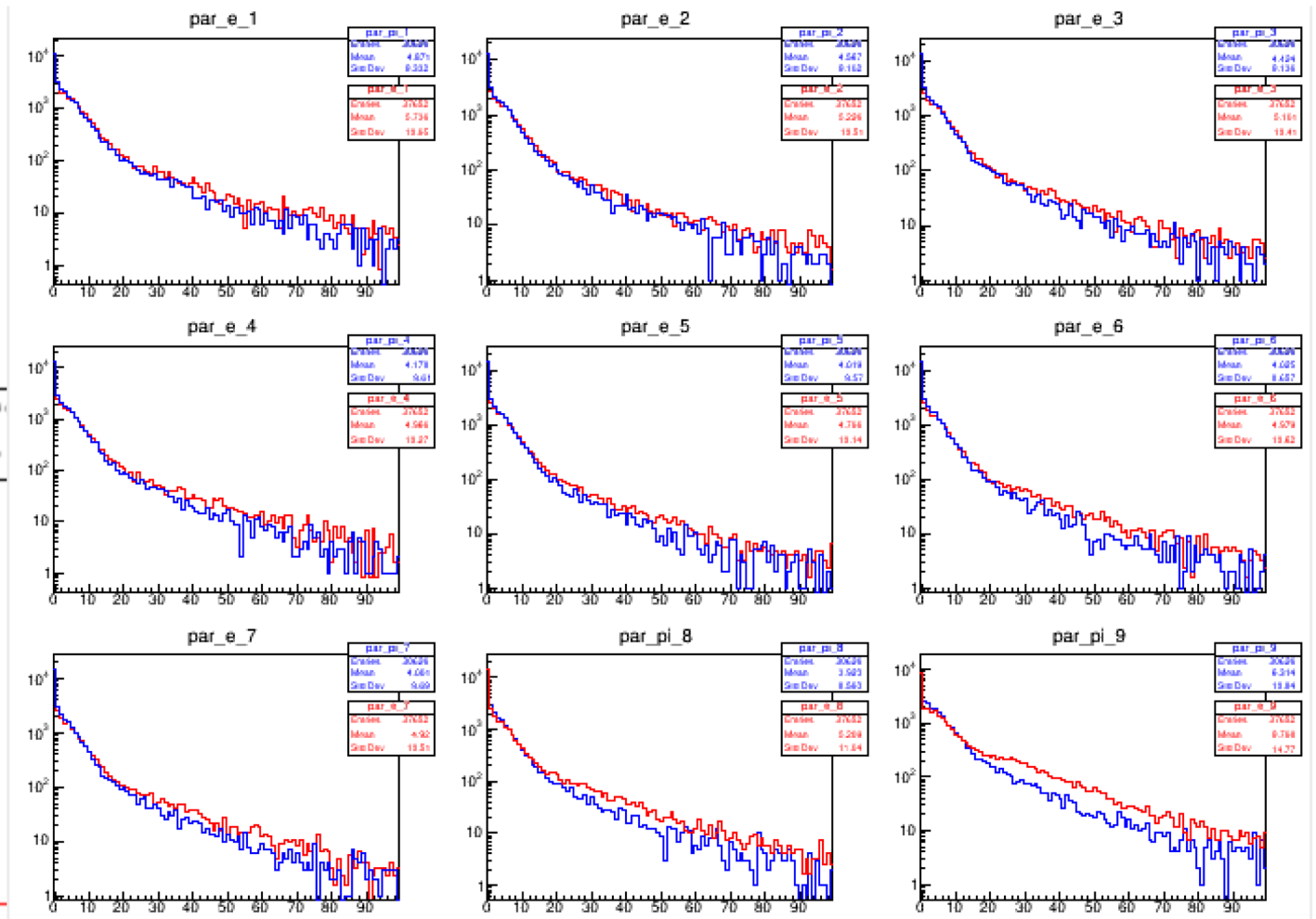
Radiator: Foam

Shows soft spectrum of TR photons (first bins), self-absorption.



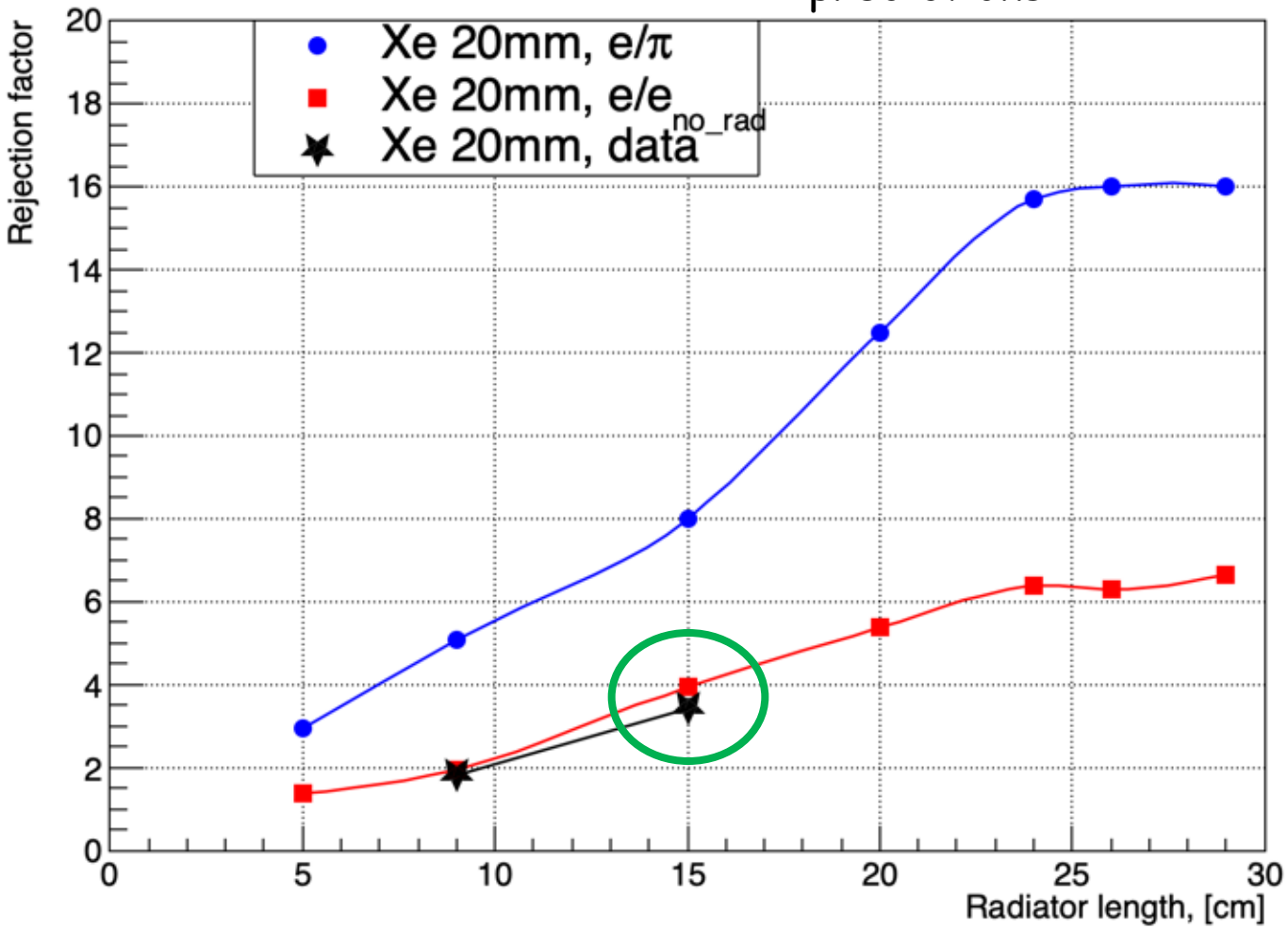






TR-Radiators length

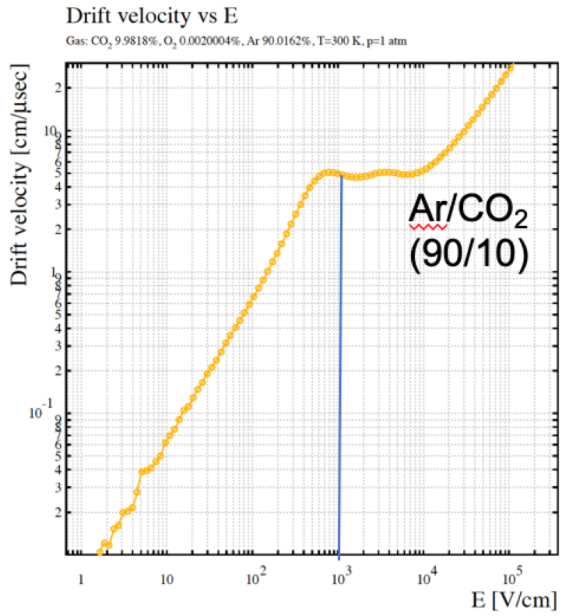
- Few runs with the fleece radiator 9 cm and 15 cm
- Data points are in a good agreement with MC predictions

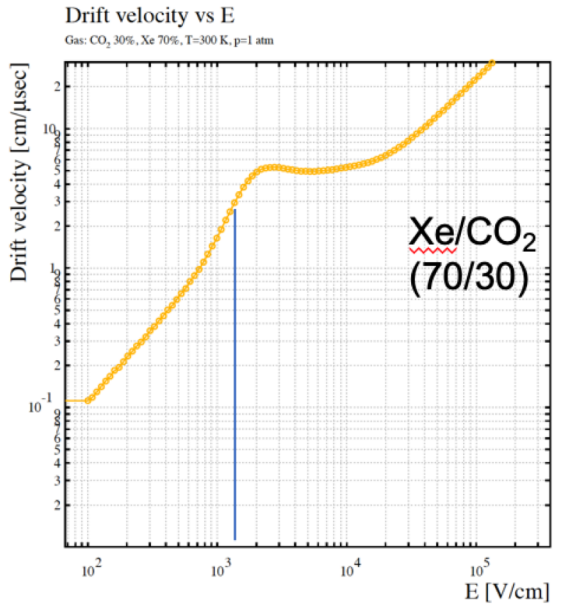


Optimize gas-mixture and HV settings to get better rejection.

- The test was performed with the standard fleece radiator (15 cm)
- Our HV divider allows to vary drift and gain voltages independently.
- Varied the gain voltages from 3200V to 3600V (gain setting to optimize efficiency for low-energy clusters and not to overshoot high energy clusters.
- we kept the drift field at 1500V/cm. This drift field corresponds to a drift time ca. 720 ns or to a drift velocity ca, 3 cm/μs (note that Xe mixture HV settings differs from Ar mixture settings).

Best runs:
a) Run 1350. HV 3450V, Rejection 3.4
b) Run 1346. HV 3500V, Rejection 3.0
c) Run 1345. HV 3400V, Rejection 2.9



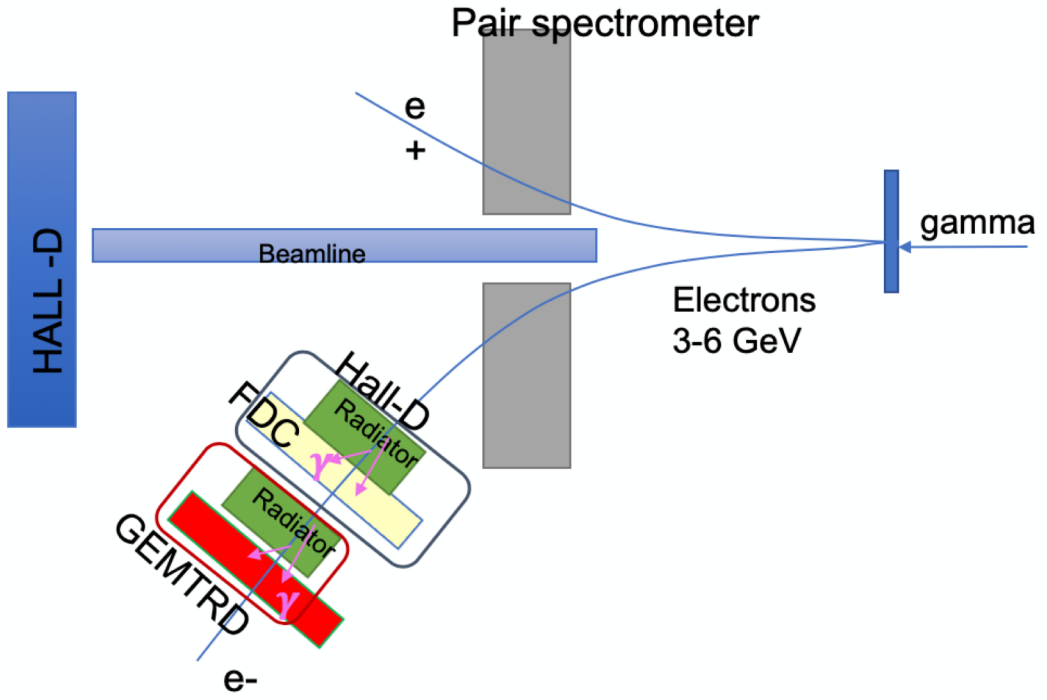


COVID19

Due to the lab and facilities closures we were not able to finish a test with different radiators and gas mixtures, and also to perform the planned joint beam test with the EMCAL and mRICH to get global PID estimates.

At the moment all hardware related activities are postponed

Planning to resume as soon as possible (setup is ready)



Proposal for FY21 – prototype with a new readout

1) Improve noise level:

Current design is based on COMPASS readout made of X and Y strips of pitch size of 400µm.

Readout: APV25 -> GAS-II + fADC 125

high noise seems directly linked to the strip capacitance from the two X and Y layers

a new concept of pad readout PCB as anode readout for MPGD technologies

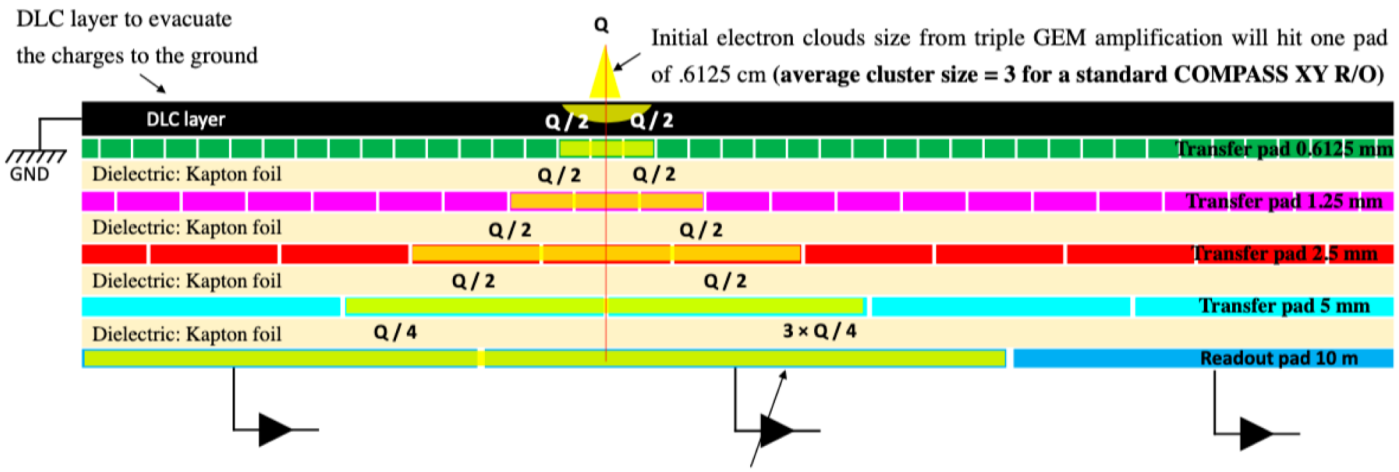


Figure 13: Principle of capacitive-coupling large-pads anode readout for MPGDs.

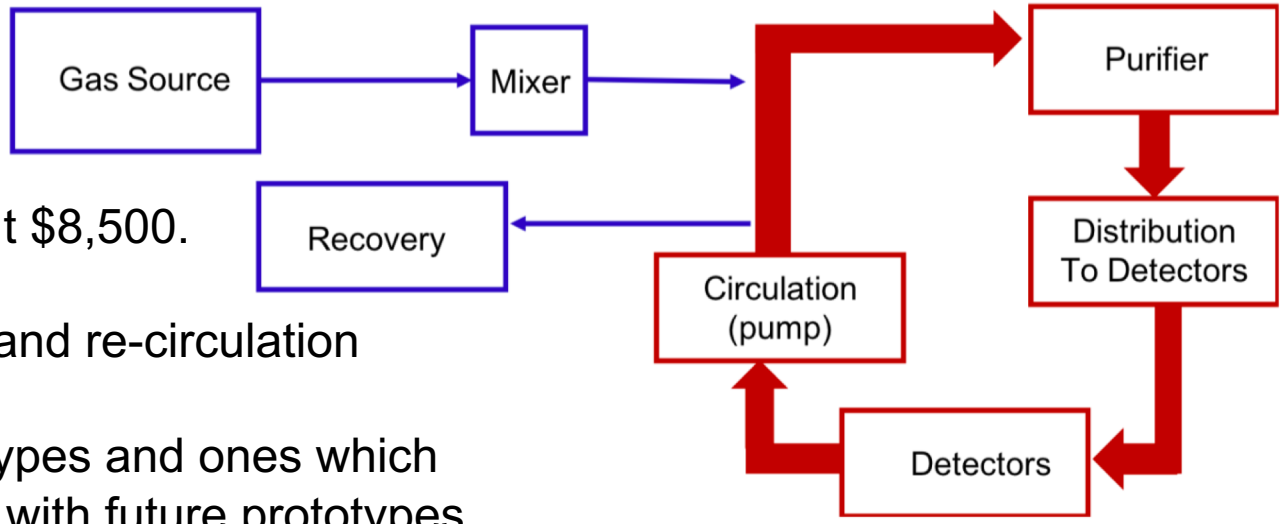
Proposal for FY21 - Noise level

characterize the detector noise performance

It is important to minimize the trace capacitance by developing a dedicated readout setup with ASICs mounted directly on PCBs and connected as close as possible to the strips (240 X by240 Y). This may require a stack of PCBs per readout plane given the low ASIC channel density.

For newly developed GEM readout design (Large-Pad Readout) by shielding strip planes or using a strip-stitch technique it might be possible to minimize inter-strip capacitance between planes. We would like to characterize the noise performance of such design too.

Proposal for FY21 - Begin design of Xe re-circulation system:



the price of Xe small portable bottle of Xe costs about $8,500.

We plan to begin designing a small Xe gas cleaning and re-circulation system for our GEM TRD prototypes:

- easily applicable to multiple GEM TRD prototypes and ones which move beyond 10 cm×10 cm to ensure its use with future prototypes and tests.
- compliment our current gas mixer and analyzer modules with additional modules needed to purify, distribute, circulate, and recover the gas.
- we plan to build off the knowledge and expertise of the ATLAS experiment at CERN (TRD/T detector)
- We are in the contact with CERN experts and plan to visit CERN to see and learn about the ATLAS TRT gas system which would be greatly beneficial and directly applicable to our GEM TRD detector.

Proposal for FY21 – Test beam measurements

- Joint test beam mRICH and EMCAL which didn't happened due to COVID-19 quarantine. Goal: impact of the tracker resolution on the performance of EMCAL and mRICH detectors, as well as to estimate the global PID performance.

- Test of different radiators

- Test of different gas mixtures percentages and optimize the detector performance

- Possible pion beam test at Fermilab (in collaboration with eRD6)

This test is very preliminary, and will depend on beam availability and restrictions due to COVID19, progress with paper work needed to run the setup at the test beam, as well as a gas or gas-system restriction

ML FPGA for GEMTRD and other subdetectors => proposal for the JLAB LDRD

Proposal for FY21 – Test beam measurements

Table 4: **A total eRD22** FY21 request.

	Request	**-20%**	**-40%**
JLAB	$17,233	$10,789	$8,631
UVA	$13,075	$ 10,460	$ 7,845
Temple U	$7,925	$ 0	$ 0
Total	**$38,233**	**$ 21,249**	**$16,476**

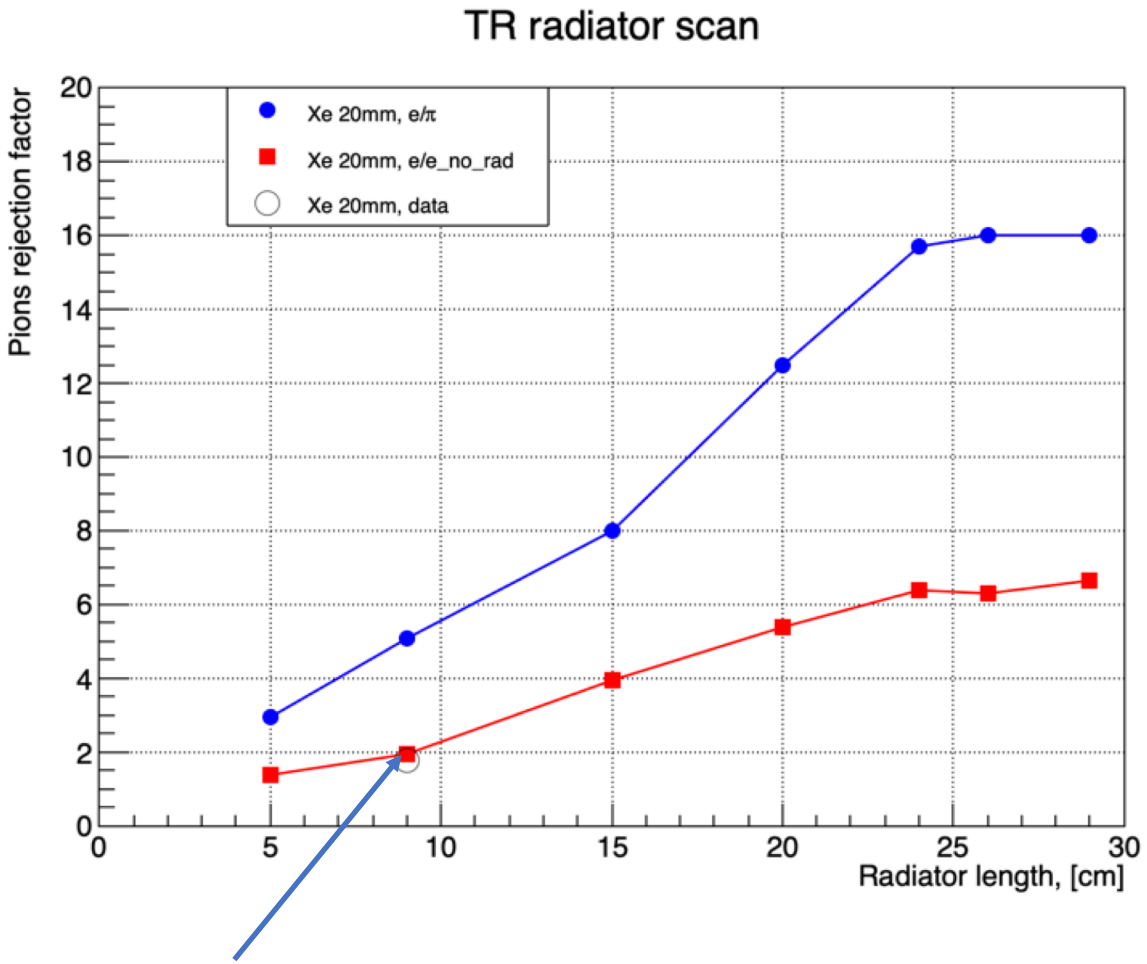
Conclusion

A new Transition Radiation detector based on GEM technology
https://doi.org/10.1016/j.nima.2019.162356

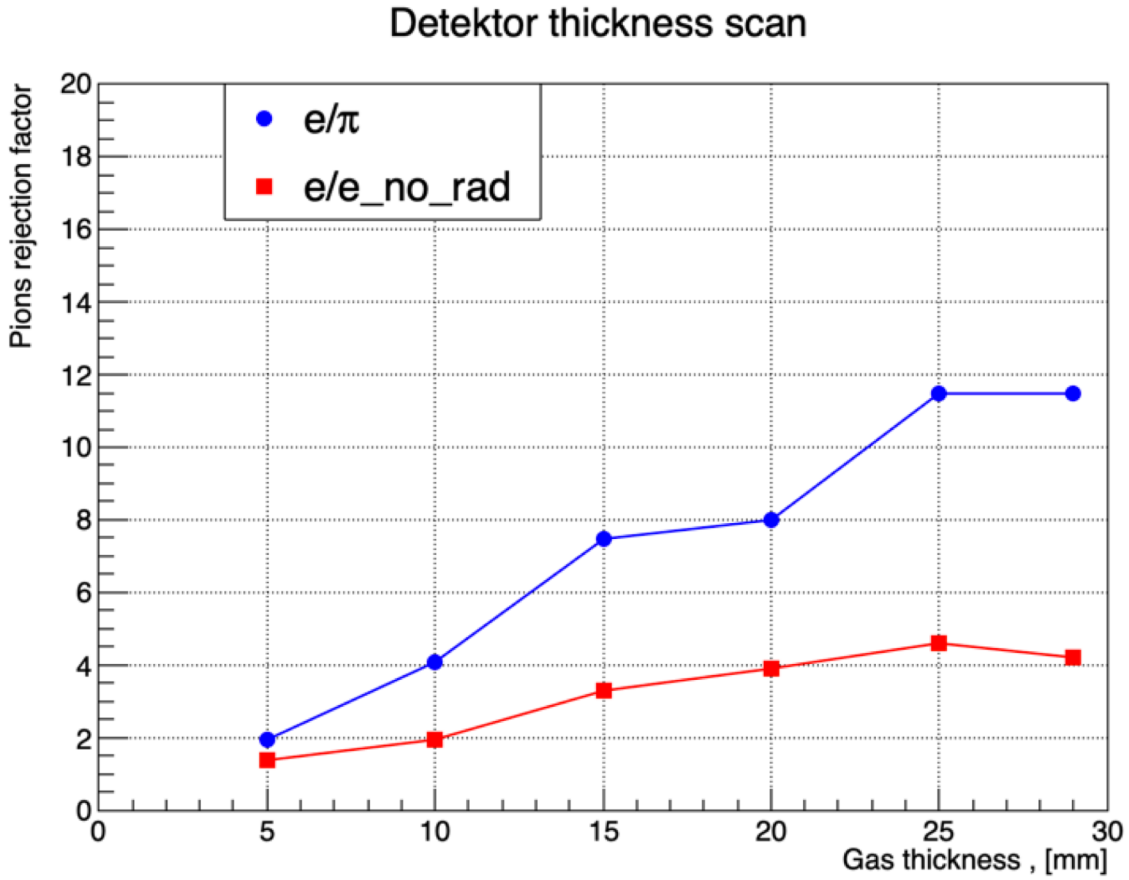
Backup

Backup

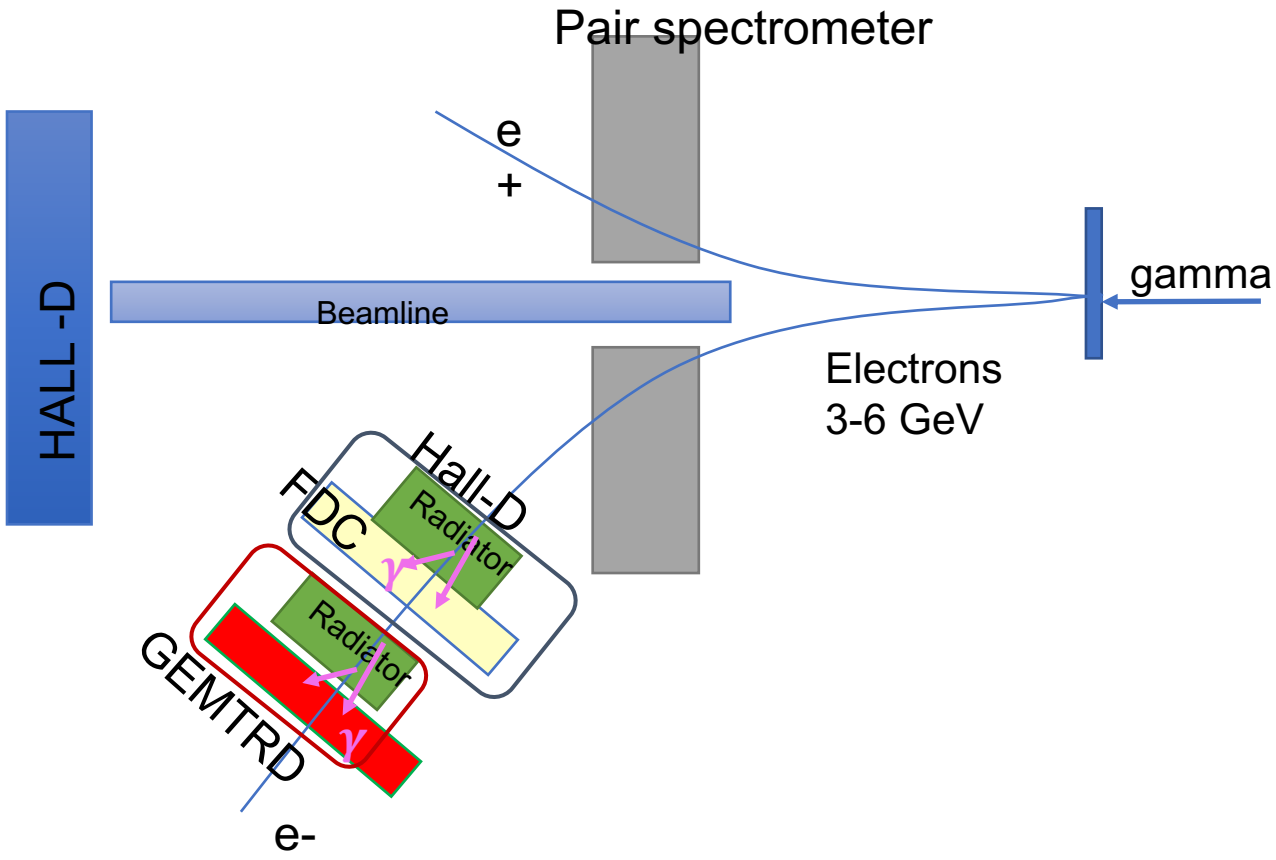
e/π rejection (MC and Data)

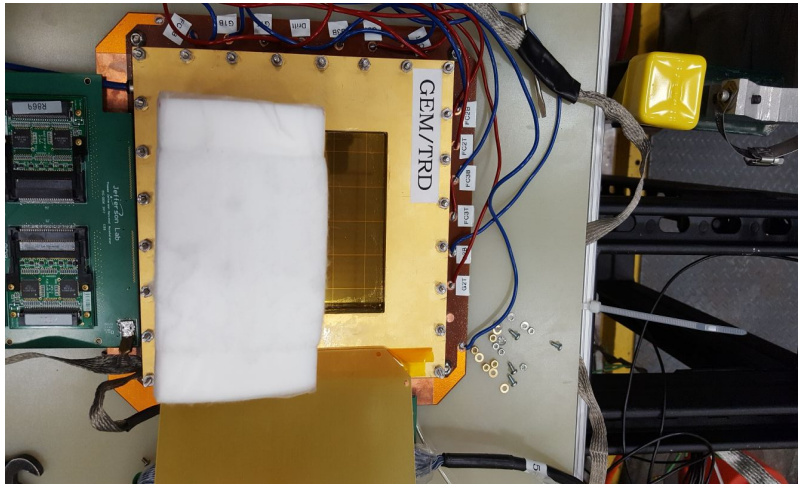


DATA point



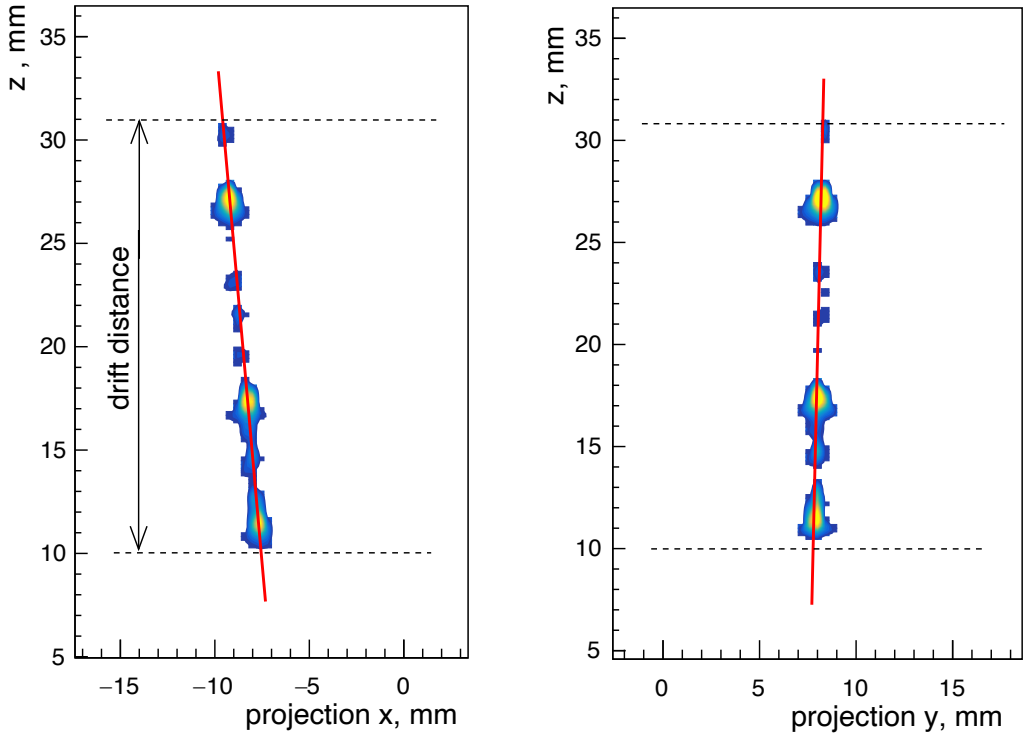
Test Setup at JLAB HALL-D





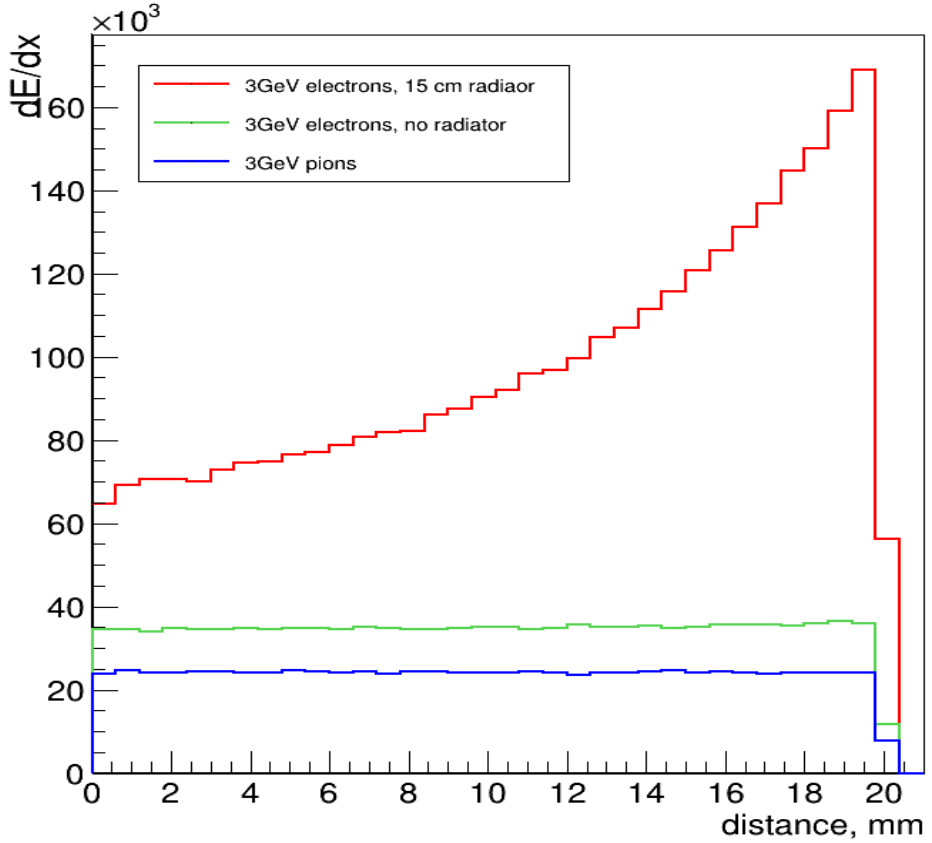
- 3-6 GeV electrons in Hall-D from pair spectrometer
- In parallel with Hall-D MW-TRD (FDC) system
- covered $\frac{1}{2}$ of the sensitive area with radiator (mimicking pion beam)
- Test with Ar/CO_2 and Xe/CO_2 mixtures
- Different radiators

GEMTRD tracking



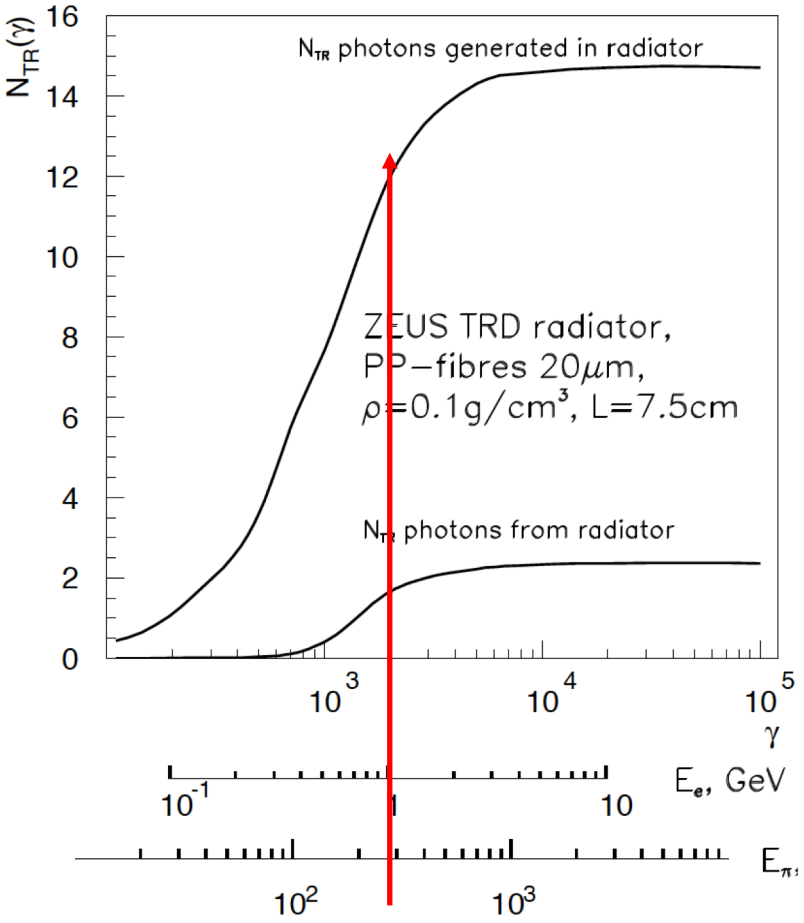
GEANT4: electron and pion comparison

Energy deposition (dE/dx + TR) vs distance



e,π ~3 GeV

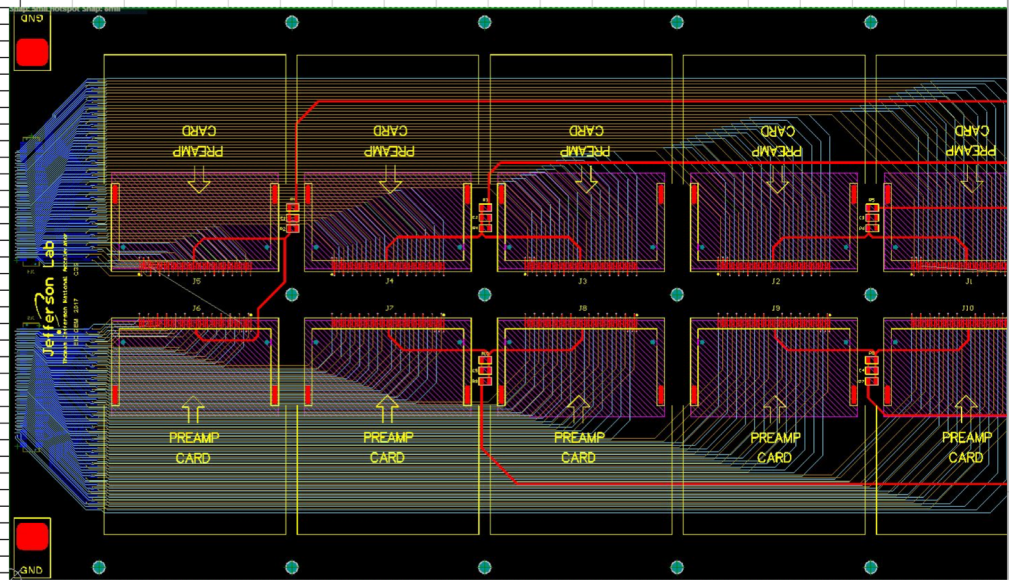
J.Tandler

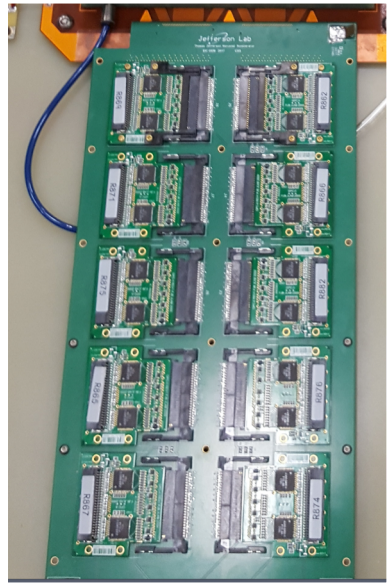


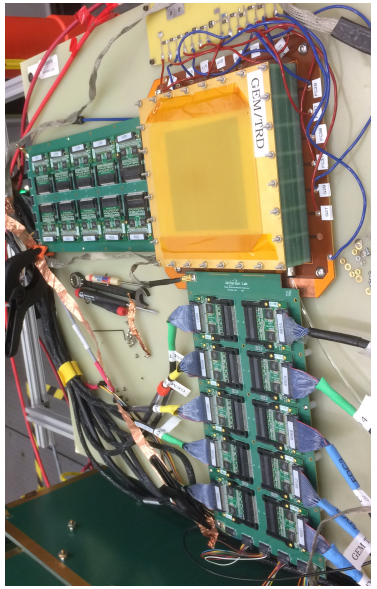
Only e produce TR photons (E>1GeV)
Pions only start to produce TR at E > 100-150 GeV

New interface board

J15	Channel	Pre-Amp	Pre-Amp Pin
1	GND		
2	CH121	J6	50
3	CH122	J6	49
4	CH123	J6	48
5	CH124	J6	47
6	CH125	J6	46
7	CH126	J6	45
8	CH127	J6	44
9	CH128	J6	43
10	CH129	J6	42
11	CH130	J6	41
12	CH131	J6	40
13	CH132	J6	39
14	CH133	J6	37
15	CH134	J6	36
16	CH135	J6	35
17	CH136	J6	34
18	CH137	J6	33
19	CH138	J6	32
20	CH139	J6	31
21	CH140	J6	30
22	CH141	J6	29
23	CH142	J6	28
24	CH143	J6	27
25	CH144	J6	26
26	CH145	J7	50
27	CH146	J7	49
28	CH147	J7	48
29	CH148	J7	47
30	CH149	J7	46
31	CH150	J7	45
32	CH151	J7	44
33	CH152	J7	43
34	CH153	J7	42
35	CH154	J7	41

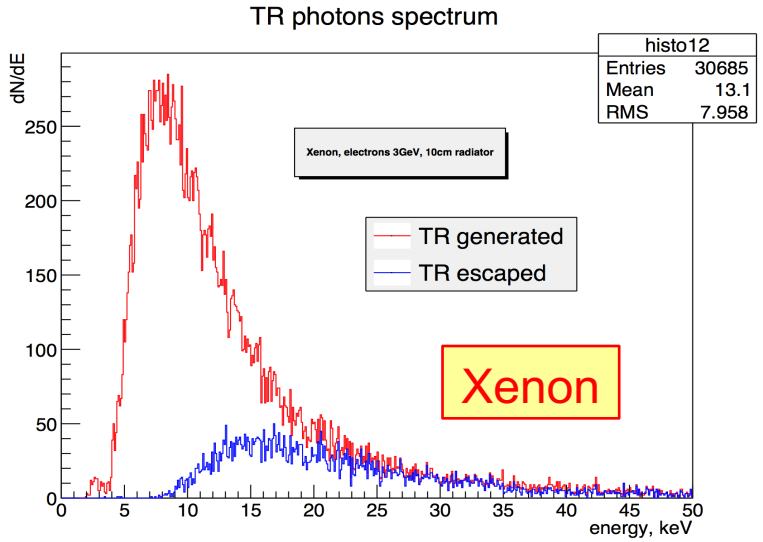


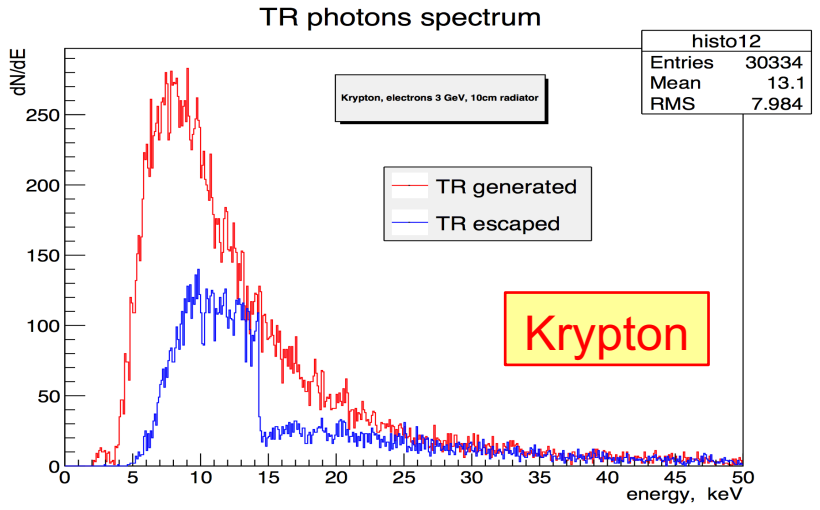


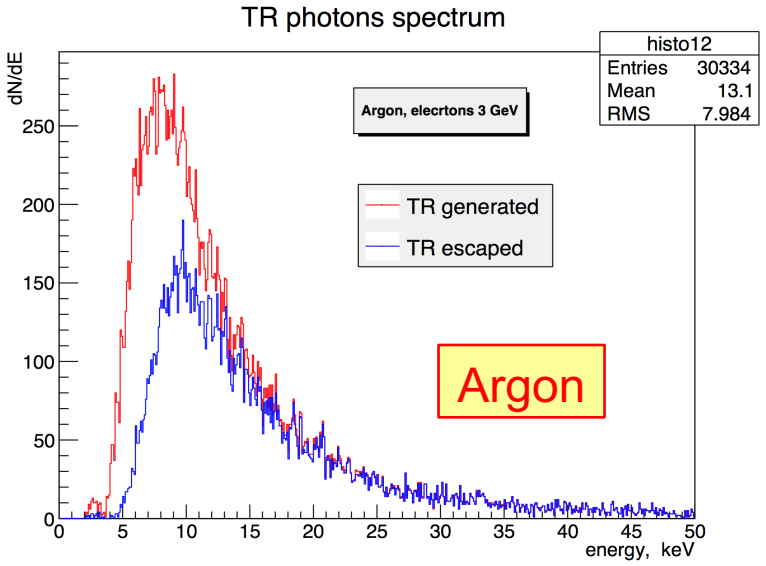


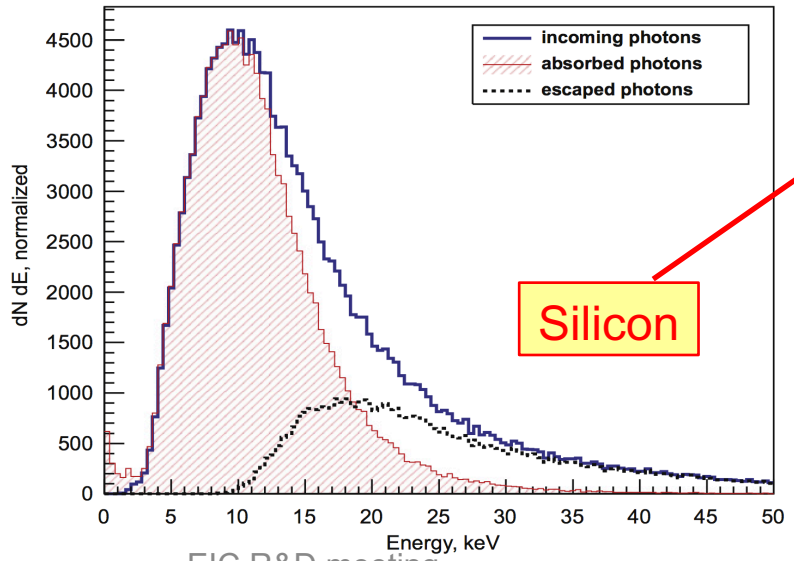
- compatible with JLAB Flash-ADC system
- Each board holds 10 preamplifiers, each preamplifier connects to 24 GEM strips resulting on a readout of 240 GEM strips per each readout board or X/Y coordinate.
- A pre-amplifier has GAS-II ASIC chips (3 chips per each preamplifier card) and provides 2.6 mV/fC amplification. A preamplifier has a peaking time of 10 ns. It consumes 50 mWatt/channel and has a noise <0.3 fC. The dynamic range of preamplifiers (where it is linear) is about 200 fC.
- Covers up to 2.4 (32) μs of a drift time.

TR absorption





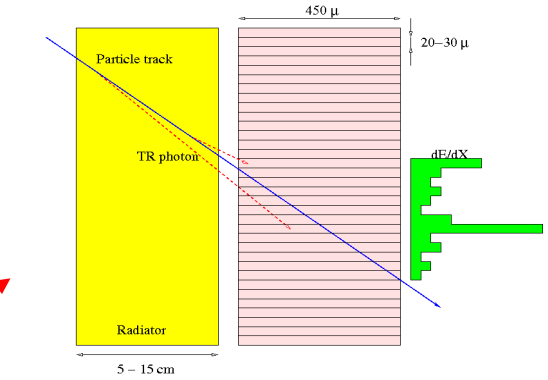


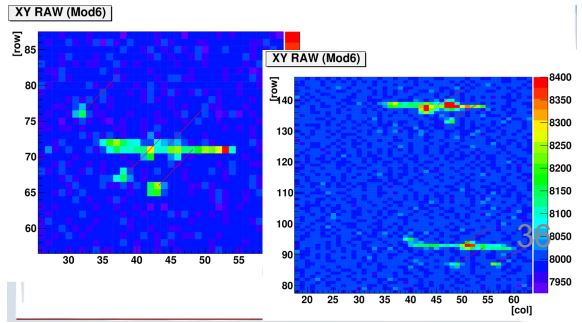


New transition radiation detection technique based on DEPFET silicon pixel matrices

https://doi.org/10.1016/j.nima.2010.06.342

JuliaFurletova, SergeyFurletov



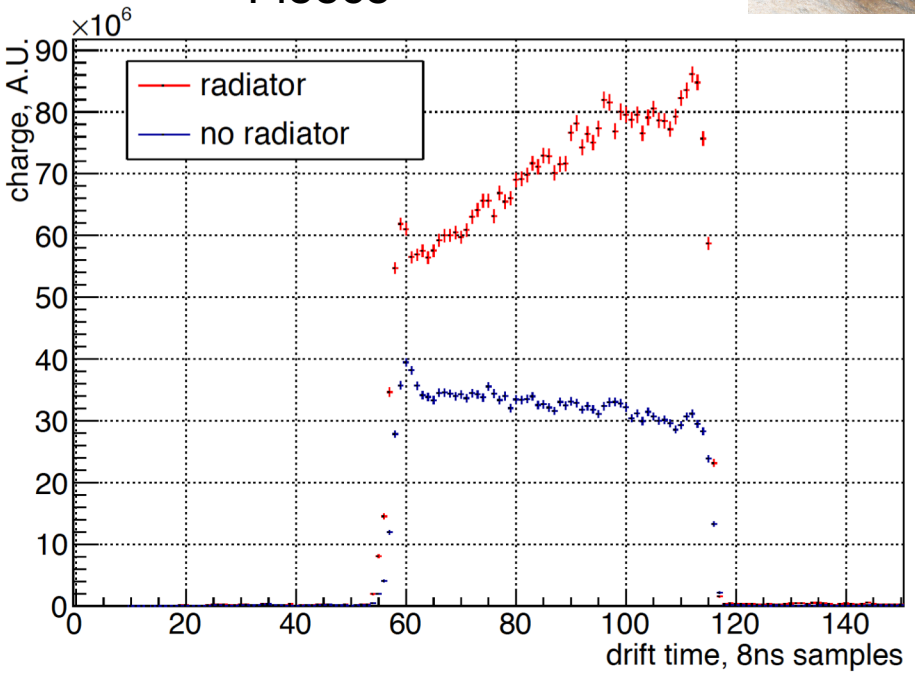


Charge as a function of drift distance

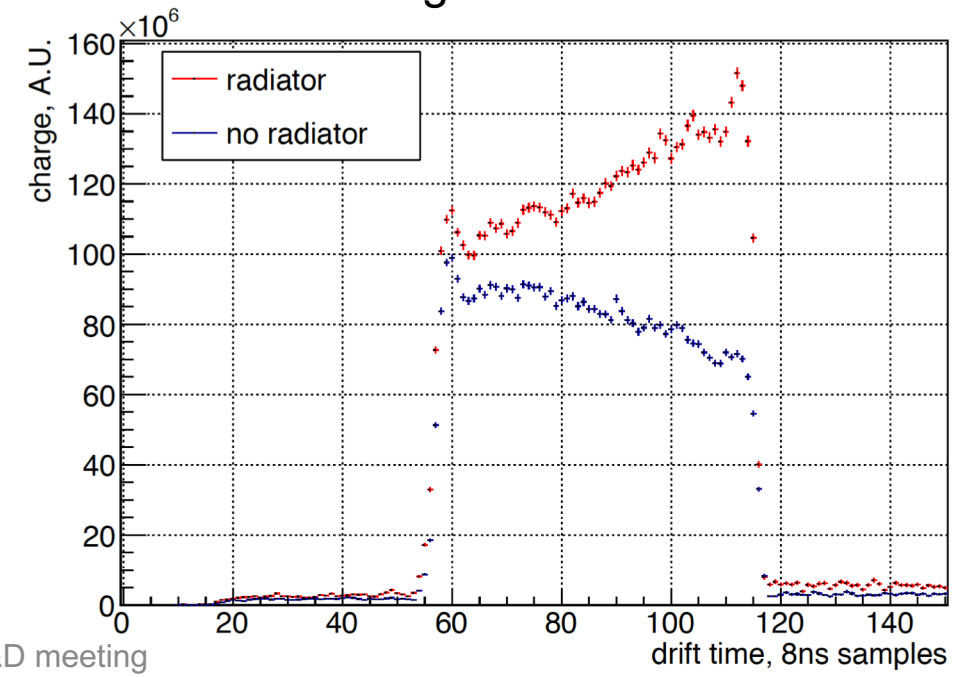
Fleece radiator:
Random oriented
Polypropylene fivers ($20\mu m$)

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

Fleece



Regular foils



Conclusions

- Very challenging!