Transition Radiation Detector for GlueX

Feasibility studies

S.Furletov, L. Pentchev
Jefferson Lab
GlueX Collaboration Meeting
Oct 9, 2015

Outline

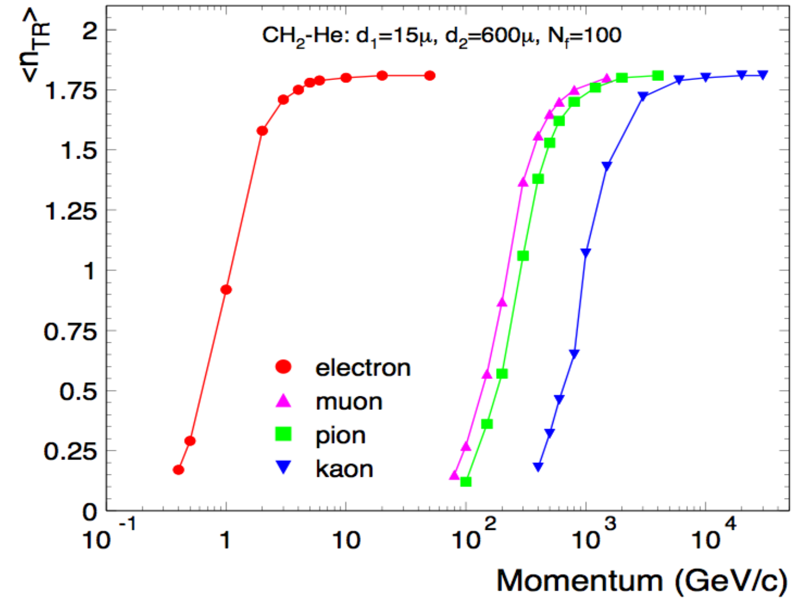
- Motivation
- Introduction to TR
- TRD for GlueX
  - Radiator
  - Detector
  - Gas
- Monte Carlo simulation
- Spare FDC test
- Outlook

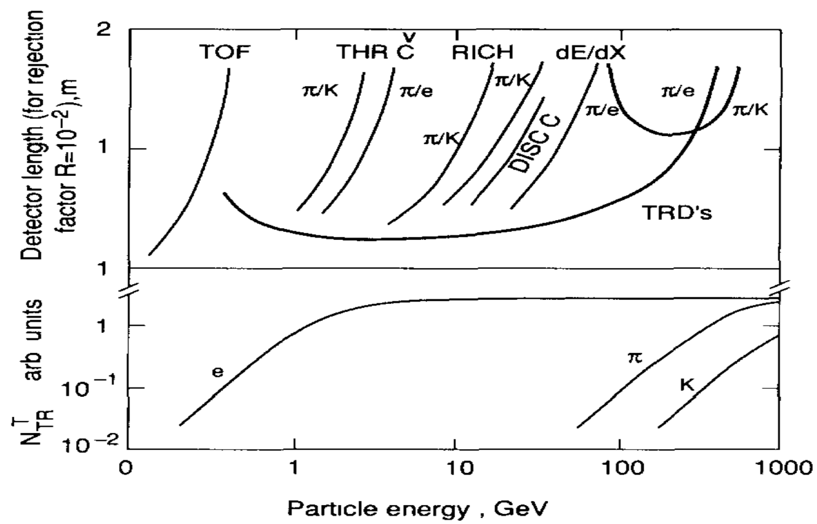
Motivation

Motivation / detector

- Transition Radiation Detectors (TRD) has the attractive features of being able to separate particles by their gamma factor.
- e/π separation in high γ region, where other methods are not working anymore.
- Identification of the charged particle “on the flight”: without scattering, deceleration or absorption.
- Application of TRD in physics experiments:

  ZEUS, H1, HERMES at HERA (DESY), D0, PHENIX, ATLAS, ALICE...
- TRD in space missions – AMS, PAMELA.





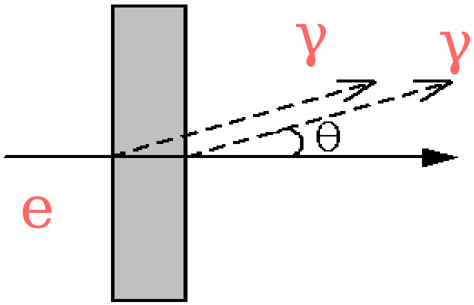
Motivation / physics

- Physics with electron/pion separation:
  - *Charmonium photoproduction (NU Sean, Luke)*
  - *Light vector mesons* (ρ,ω,φ)
- For rare physics TRD can improve hadron rejection by factor 10/100/1000
(*depending on TRD design and implementation*)

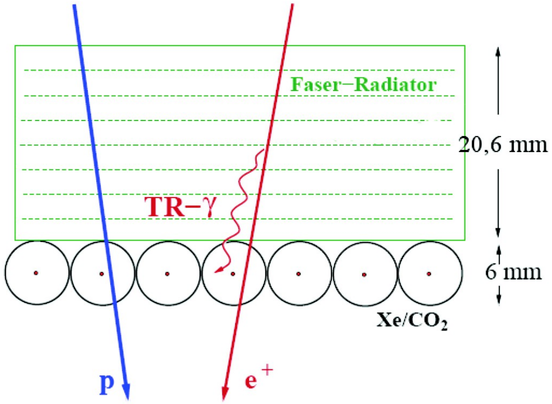
A brief introduction to Transition radiation

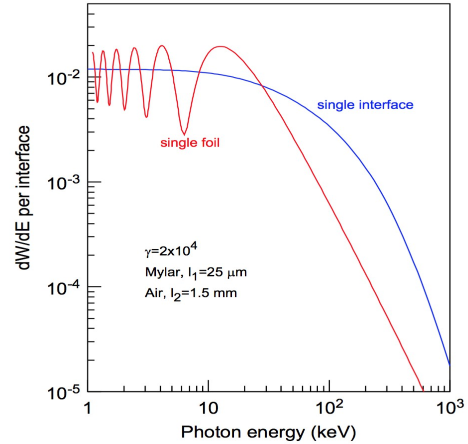
Transition radiation

- Transition radiation is produced by a charged particles when they cross the interface of two media of different dielectric constants.



- Due to electrodynamic nature of TR the probability to emit one photon per boundary is order of $\alpha \sim 1/137$
- Therefore a multilayer dielectric radiators are used to increase the transition radiation yield, typically few hundreds of mylar foils.





From single foil to radiator

- Another possible materials for radiators are polyethylene foam and fibers (fleece)

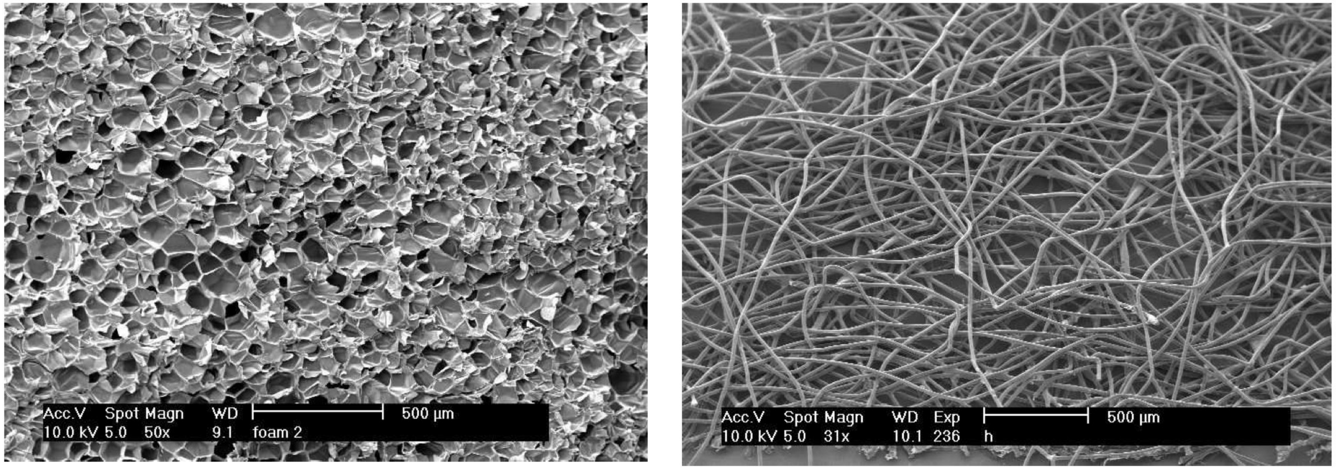
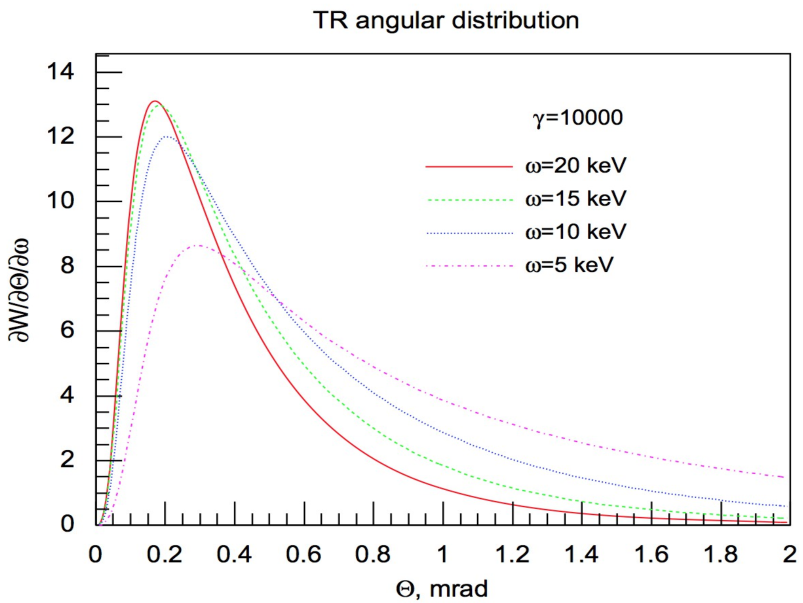


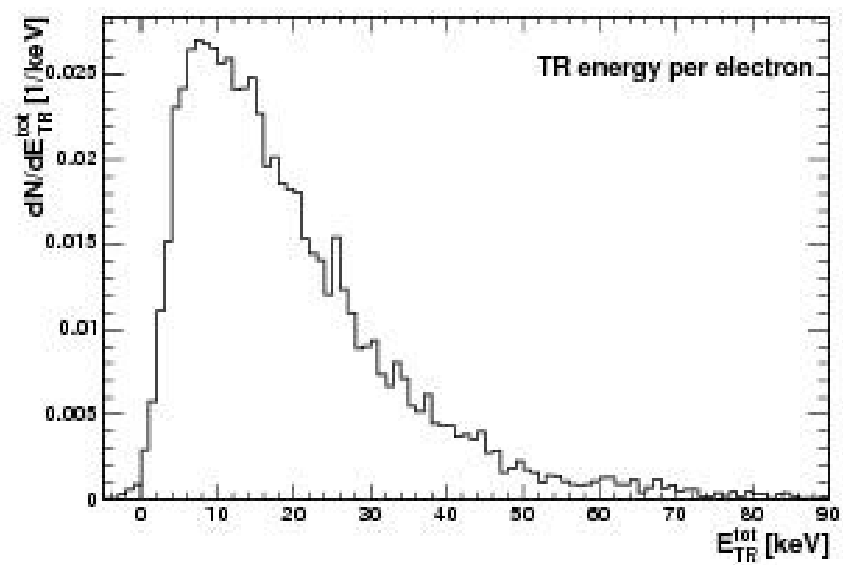
Figure 2: Electron microscope images of a polymethacrylimide foam (Rohacell HF71)(left) and a typical polypropylene fiber radiator (average diameter ≈ 25 μm) (right) [52].

[52] A. Andronic et al. (ALICE collaboration), Nucl. Instr. and Meth. in Phys. Res. A **558**, 516 (2006).

TR features

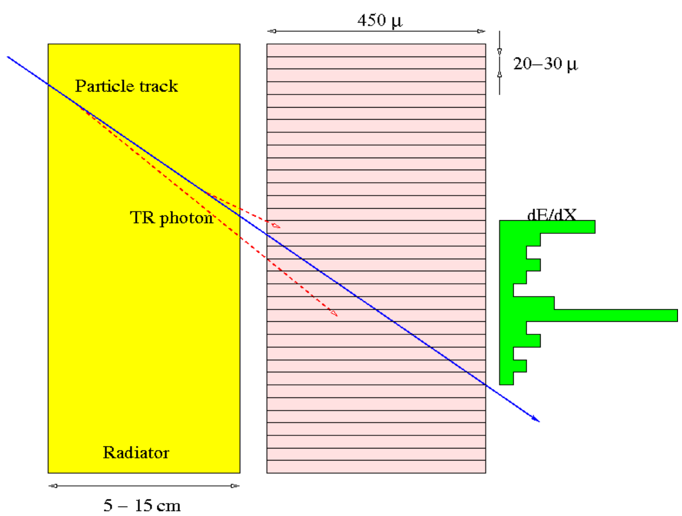
- X-ray TR has remarkable features:
- TR in X-ray region is extremely forward peaked within an angle of 1/γ
- Energy of TR photons are in X-ray region (2 - 40 keV)
- Total TR Energy ETR is proportional to the γ factor of the charged particle

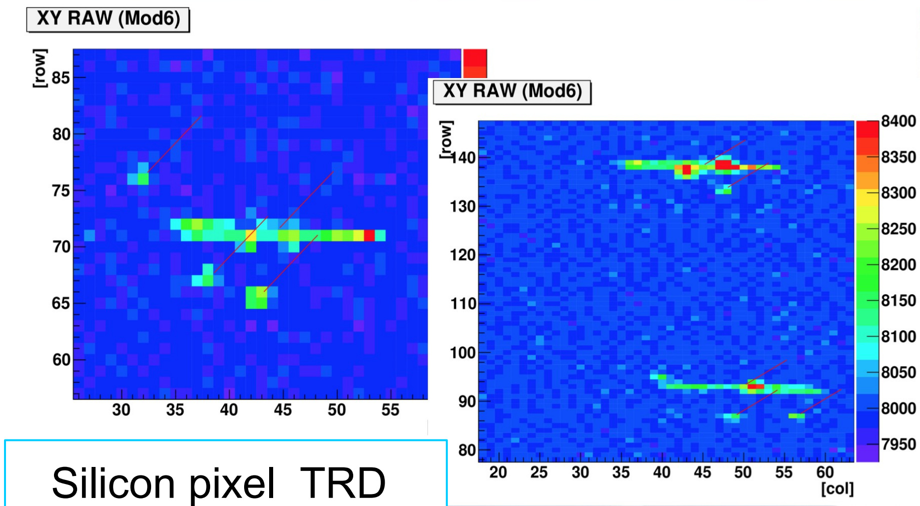




How easy to detect TR ?

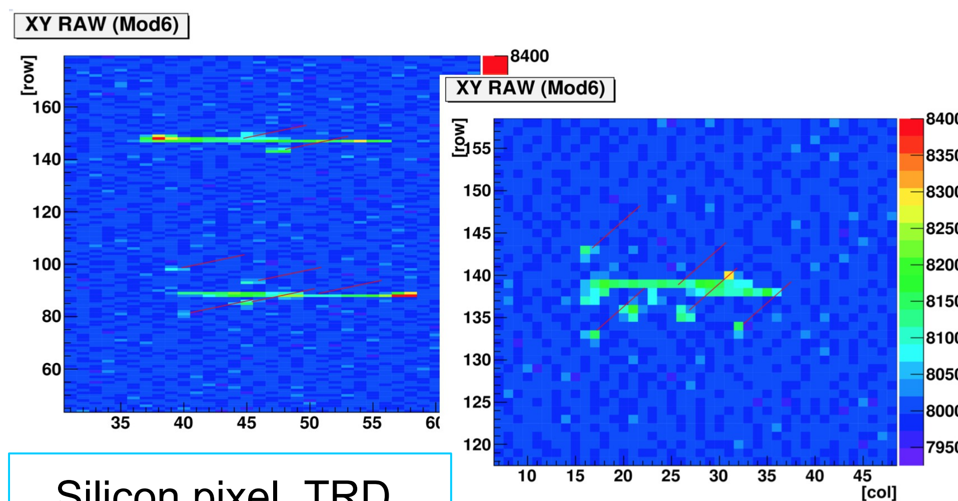
TR detection





Silicon pixel TRD

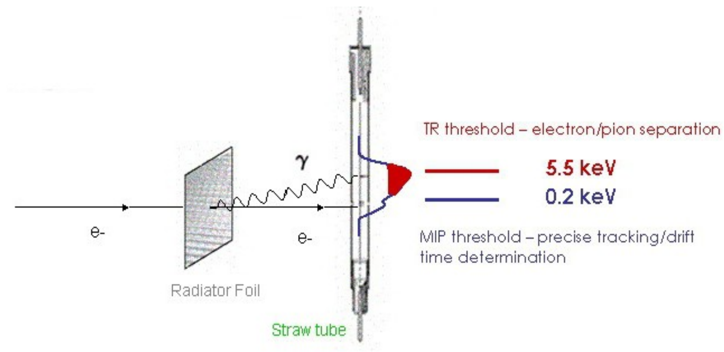
- Silicon pixel detector , 450 μ thick. (pixel size – 20x20μ)
- The electrons energy is 5 GeV (DESY testbeam)
- Radiator thickness 15 cm (fleece)
- TR photons are clearly visible and separated from track by a few pixels !
  - red lines shows the center of found TR clusters

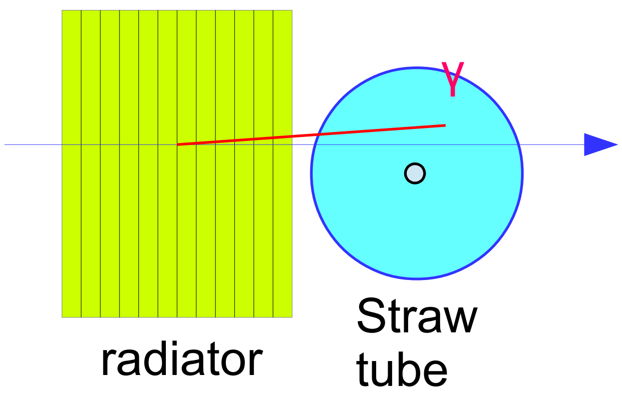


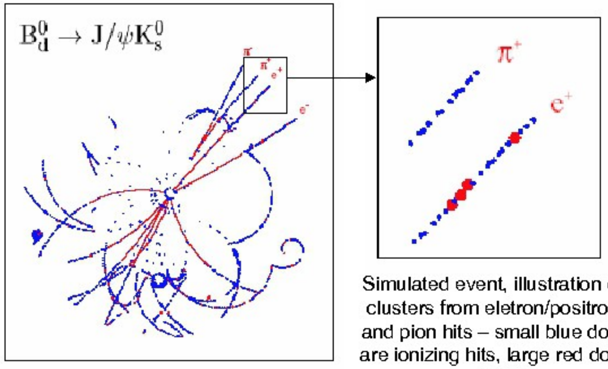
Silicon pixel TRD

TRD principle : ATLAS

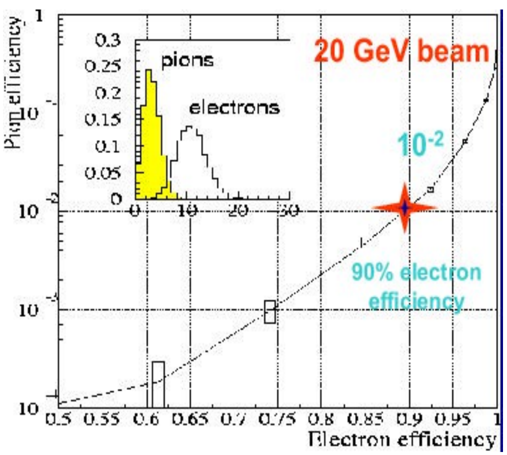
- Typically in high energy physics TRD are used for electron identification and to reject hadron background.
- ATLAS TRT uses proportional gas chambers (straws) filled with Xenon gas mixture:
  - dE/dx +TR, Cluster discrimination by threshold method.







Simulated event, illustration of clusters from eletron/positron and pion hits – small blue dots are ionizing hits, large red dots are TR hits



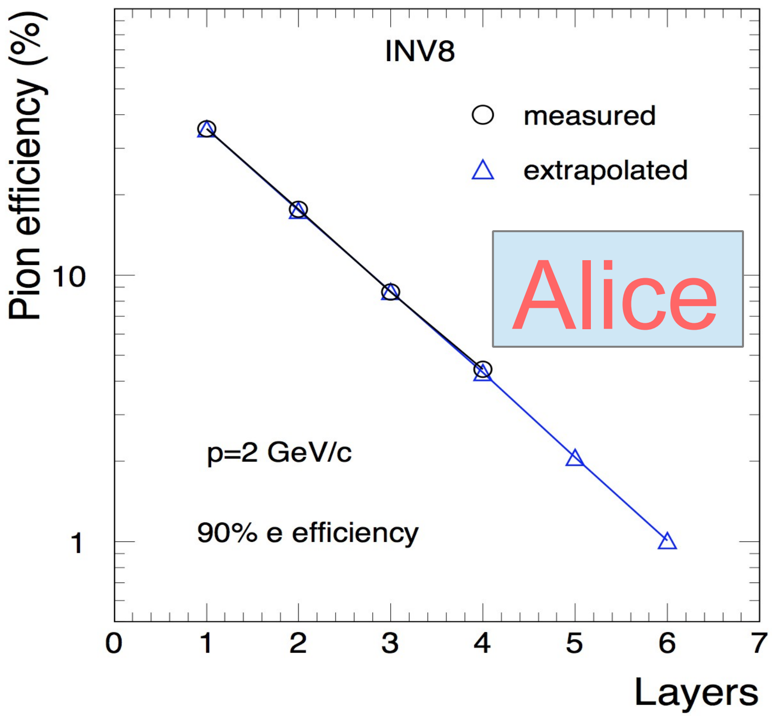
TRD in experiments

Experiment	Radiator (x,cm)	Detector (x,cm)	Area (m^2)	N	L (cm)	N. chan.	Method	π_{rej}
HELIOS	foils (7)	Xe-C_4H_{10} (1.8)	0.5	8	70	1744	N	2000
H1	foils (9.6)	Xe-He-C_2H_6 (6)	1.8	3	60	1728	FADC	10
NA31	foils (21.7)	Xe-He-CH_4 (5)	4.5	4	96	384	Q	70
ZEUS	fibres (7)	Xe-He-CH_4 (2.2)	3	4	40	2112	FADC	100
D0	foils (6.5)	Xe-CH_4 (2.3)	3.7	3	33	1536	FADC	50
NOMAD	foils (8.3)	Xe-CO_2 (1.6)	8.1	9	150	1584	Q	1000
HERMES	fibres (6.4)	Xe-CH_4 (2.54)	4.7	6	60	3072	Q	1400
kTeV	fibres (12)	Xe-CO_2 (2.9)	4.9	8	144	~10 k	Q	250
PAMELA	fibres (1.5)	Xe-CO_2 (0.4)	0.08	9	28	964	Q,N	50
AMS	fibres (2)	Xe-CO_2 (0.6)	1.5	20	55	5248	Q	1000
PHENIX	fibres (5)	Xe-CH_4 (1.8)	~~50~~	~~6~~	~~4~~	~~43 k~~	~~FADC~~	~~~300~~ ?
ATLAS	fo/fi (0.8)	Xe-CF_4-CO_2 (0.4)	31	36	51-108	425 k	N,ToT	100
ALICE	fi/foam (4.8)	Xe-CO_2(3.7)	**126**	6	52	**1.2 mil.**	FADC	200

all radiator material CH_2

What rejection we can expect ?

- Performance of TRD can be parametrized as a function of a detector length.



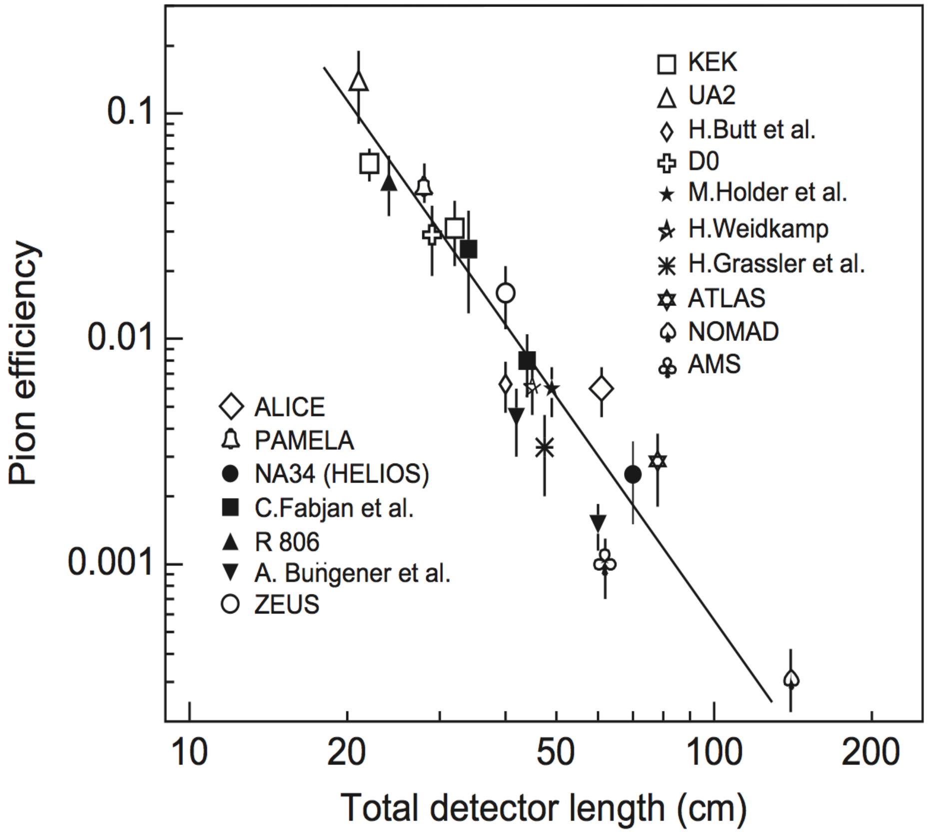
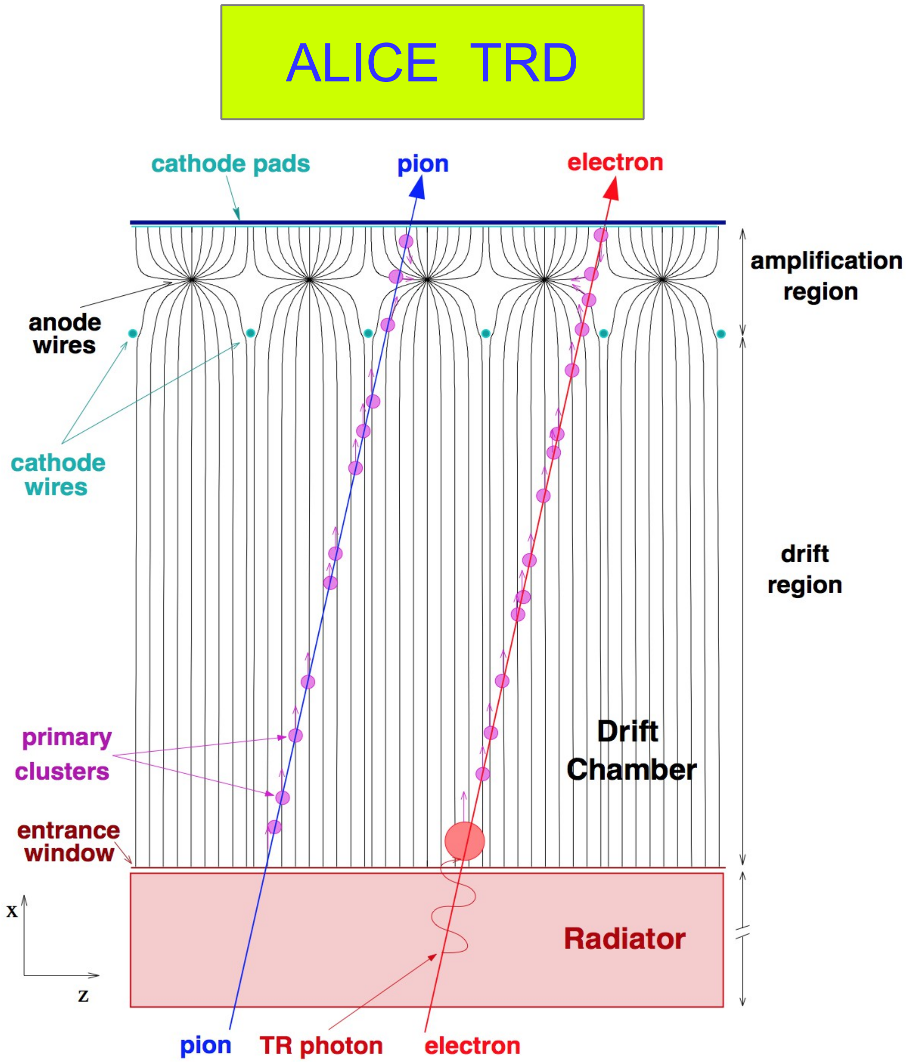


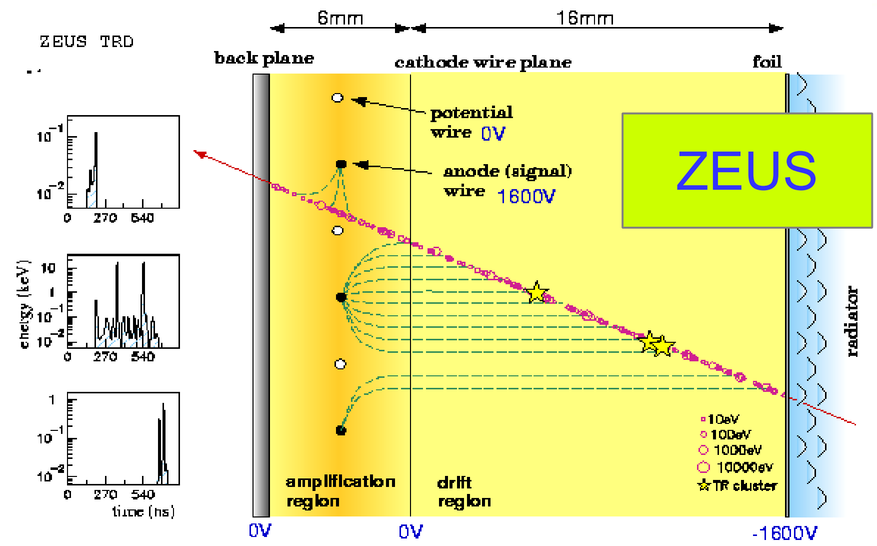
Fig. 11. TRD rejection power as a function of the total length of the detector for various high-energy (astro-)particle experiments (figure from [46]). The line is drawn to guide the eye.

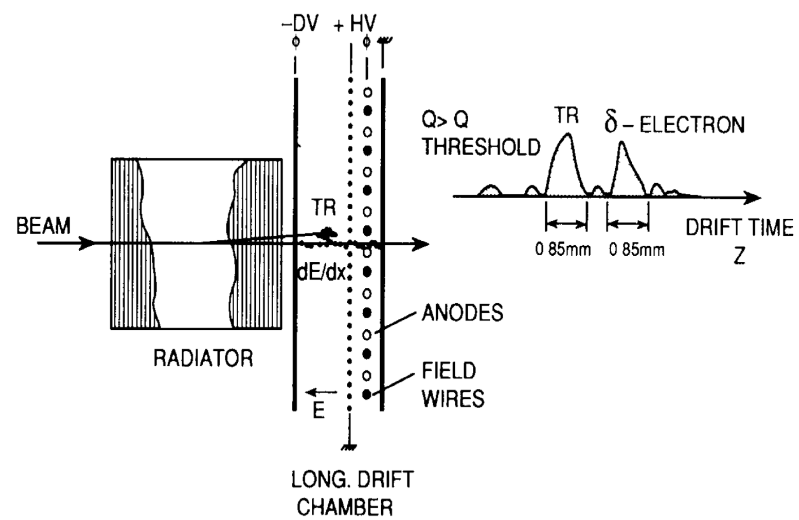
[46] K. Nakamura, et al., Particle Data Group, Journal of Physics G 37 (2010) 075021.

What kind of TRD would be suitable for GlueX ?

TRD with wire chambers







Jefferson Lab

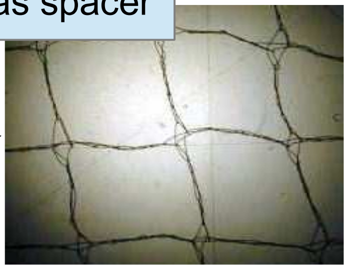
FDC spare module

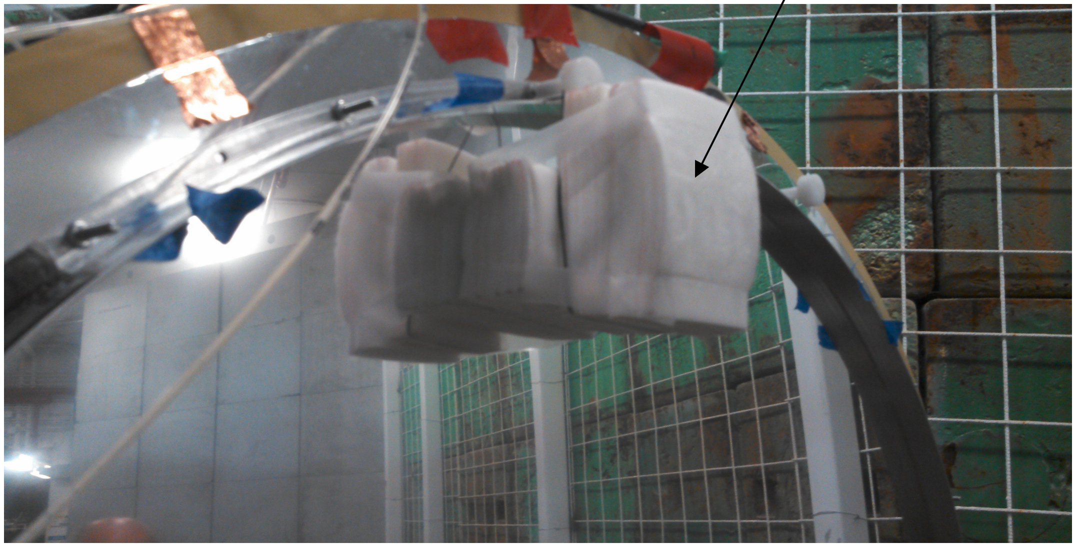
- How to convert FDC to TRD :
  - Change gas mixture from Argon to Xenon
    (TRD uses a heavy gas for efficient absorption of X-rays)
  - Increase drift region up to 2-3 cm (for the same reason).
  - Add a radiator in the front of each chamber
    (radiator thickness 10-15 cm)
- The number of modules (radiator+chamber) depends on required rejection:
  - Single module can provide e/pi rejection at level of 10.
    and 90% electron efficiency.

Radiator

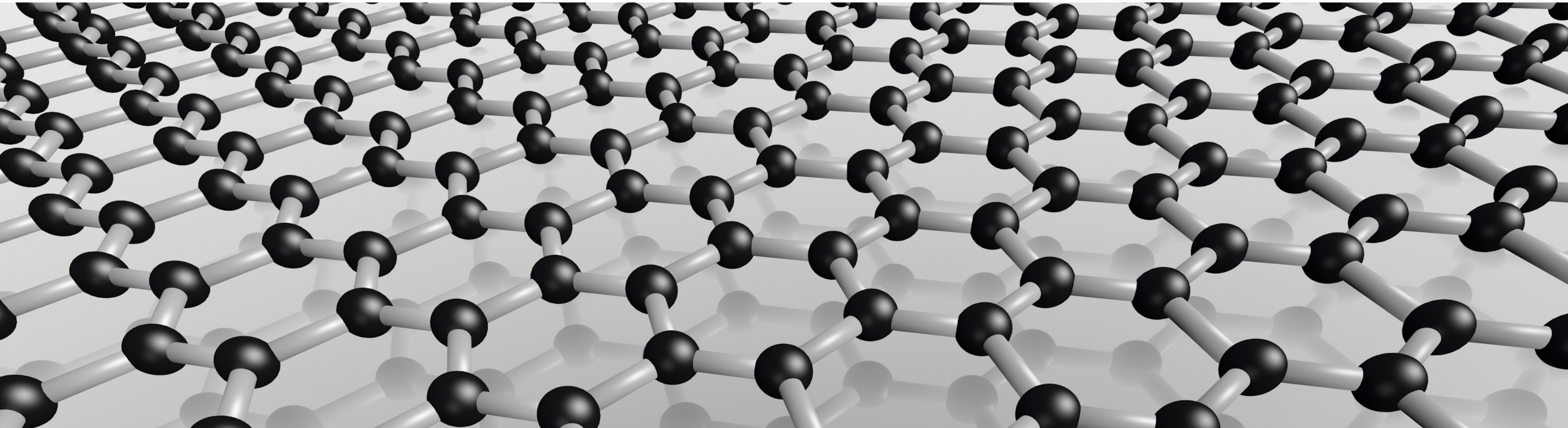
- The theory of transition radiation predicts that the best radiator is a stack of regular foils:
  - 20-30μ mylar foils and 200-300μ air gap.
- ATLAS use foils and spacer between foils to provide air gap.
- ZEUS and many other experiments use fleece radiators.
- Bottom picture shows FDC with fleece radiator in front

Atlas spacer





Graphene radiator ?



Measuring the Lorentz factors of energetic particles with transition radiation

Michael L. Cherry

Department of Physics & Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA

ARTICLE INFO

Available online 1 June 2012

Keywords:
Transition radiation
Energy measurement
Cosmic rays
Graphene

ABSTRACT

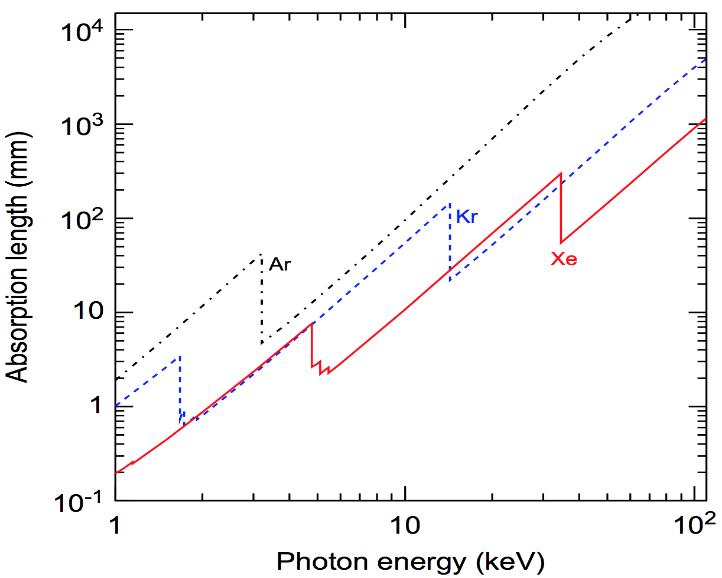
Transition radiation detectors can be used for the measurements of the high energy cosmic ray nuclear composition up to Lorentz factors $\sim 10^5$ if the X-ray yields can be increased beyond those of present designs. The state of the art of current and recently proposed detectors is briefly reviewed, and the considerations are discussed governing the dependence of the transition radiation signal on particle energy. It is shown that the incident particle energy range accessible to transition radiation, and the total intensity produced, can be increased using foils with large plasma frequency. Graphene radiator foils are proposed as a potential high energy radiator.

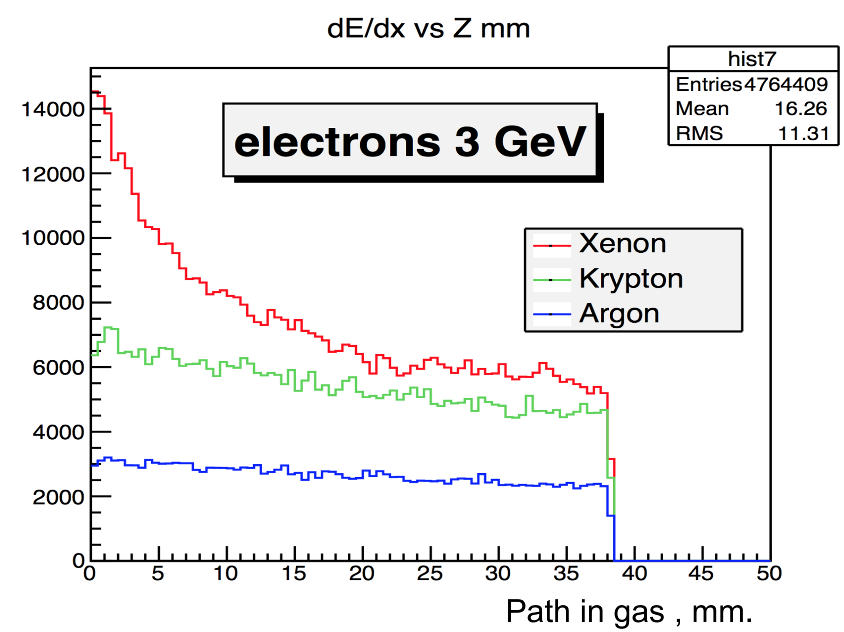
Gas mixture for TRD

Xenon alternative ?

- TRD uses Xenon based gas mixture to absorb TR photons (4 - 20 keV).
- Xenon price is prohibitive to use it just like an Argon: $15 - $20 per liter.
  - needed gas purification system.
- Is there any alternative to Xenon ? Krypton ? Argon ?
  - Bottom-left picture shows absorption length for TR photons
  - Right picture shows dE/dx for Xe, Kr, Ar.

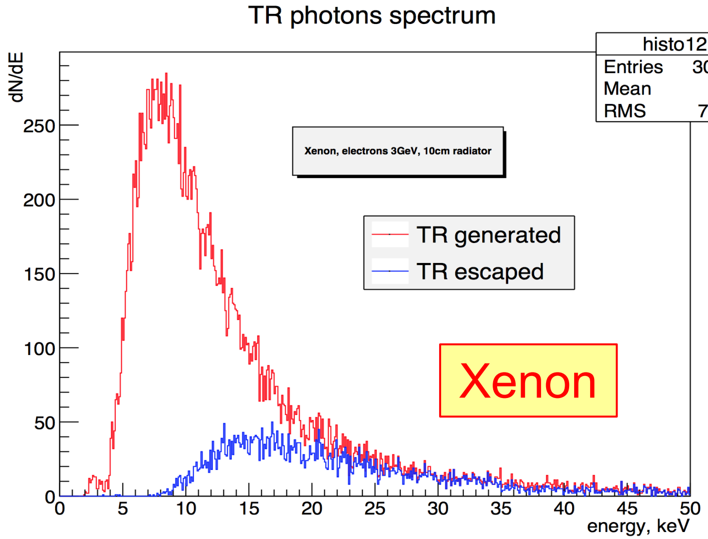
in Physics Research A 666 (2012) 130–147

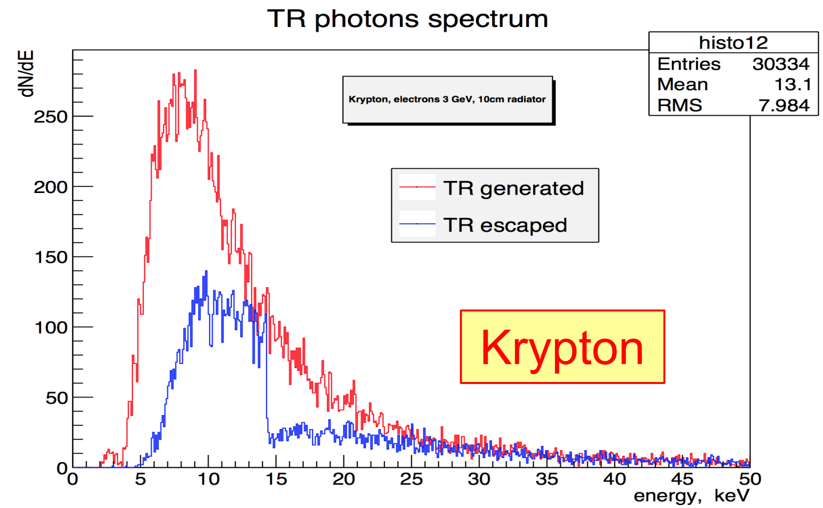


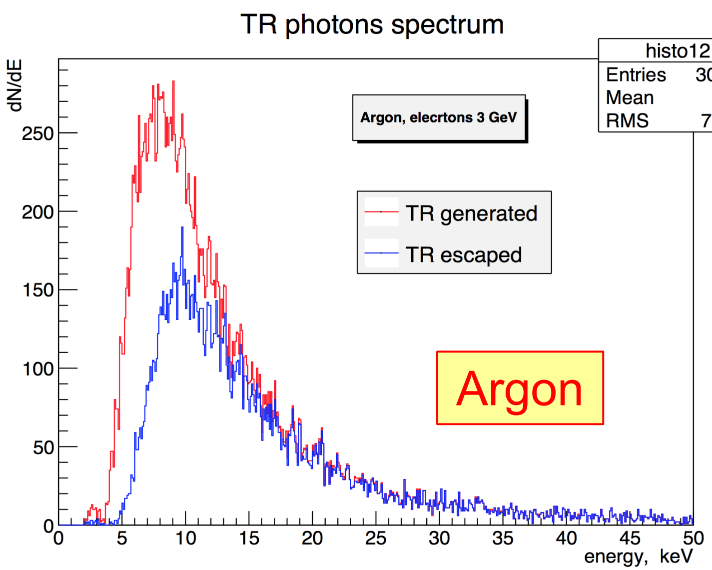


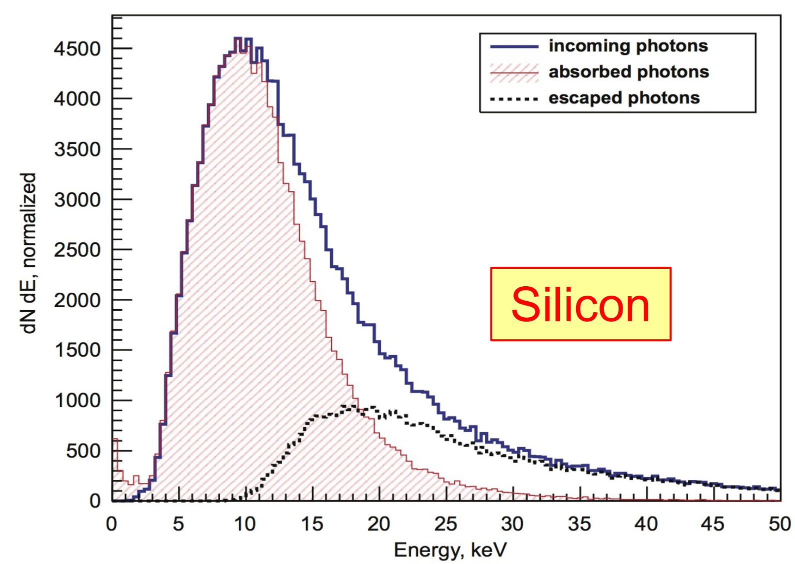
Jefferson Lab

TR absorption

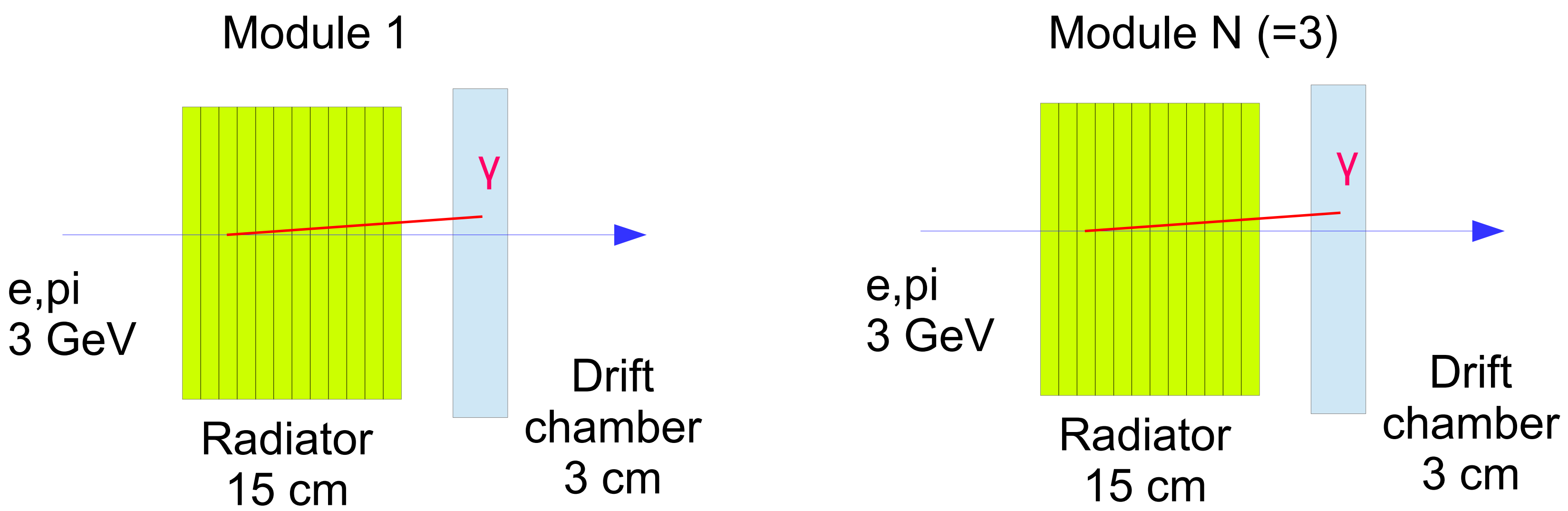






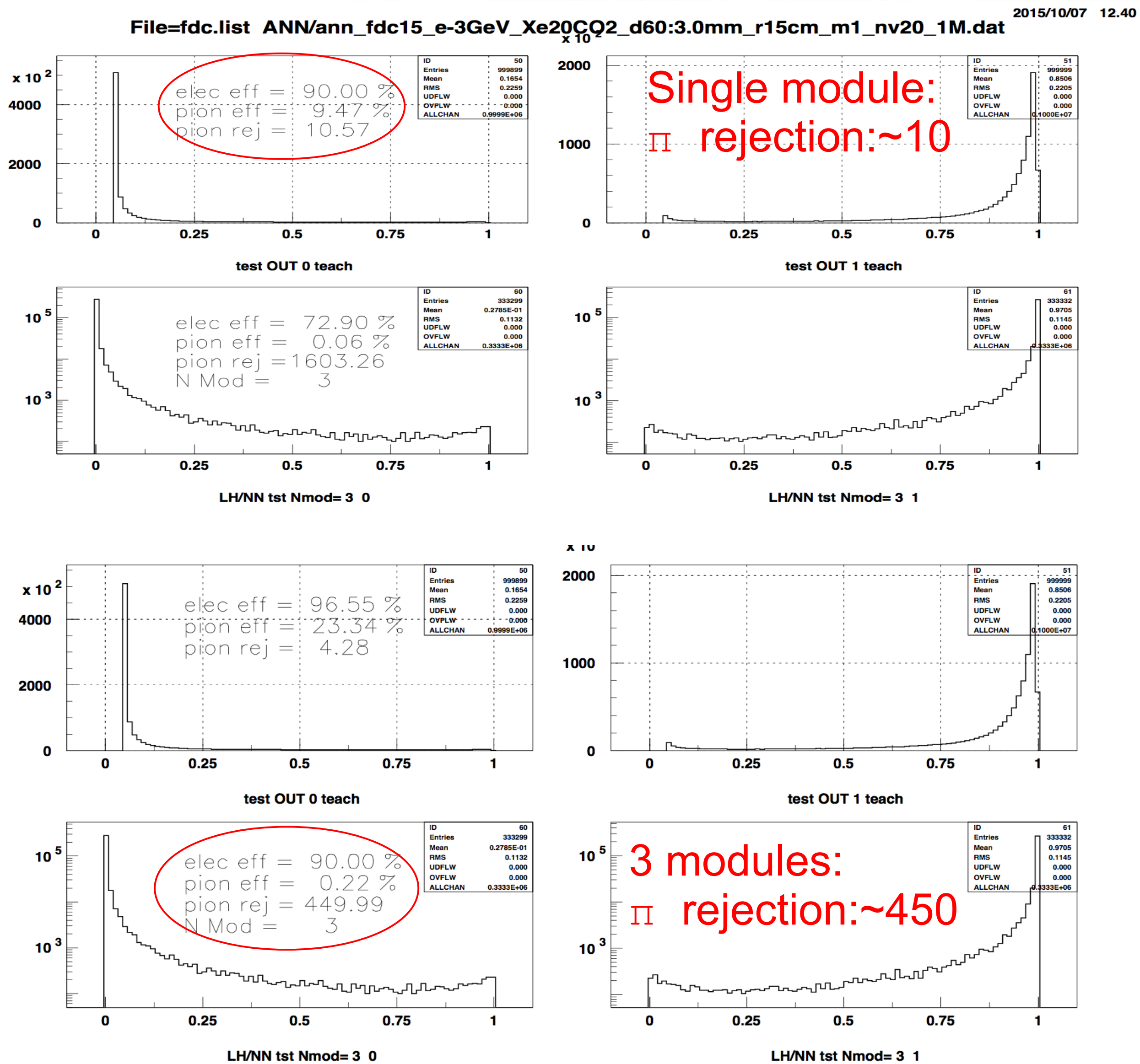


Monte Carlo simulation (Geant4)

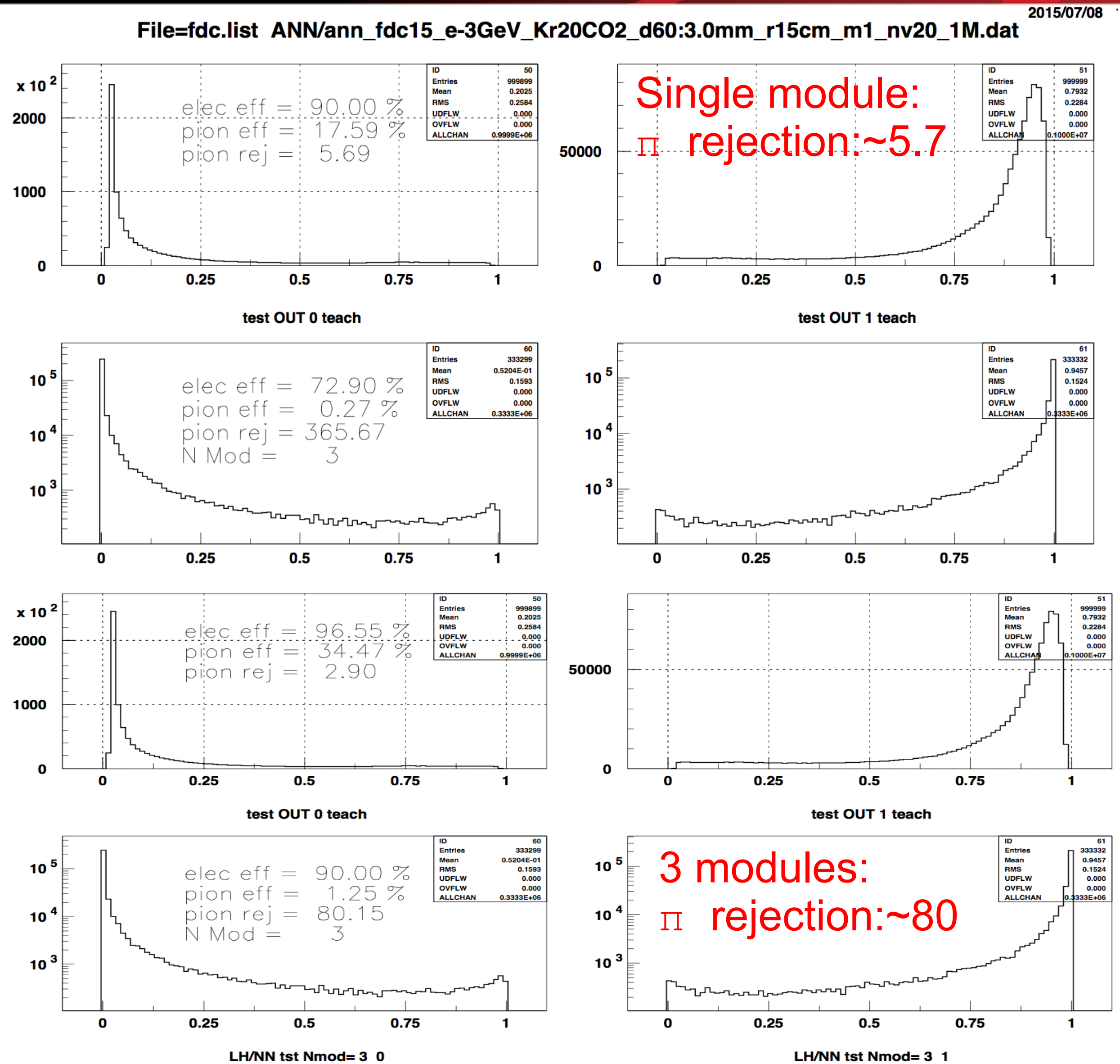


e/pi rejection with Xenon

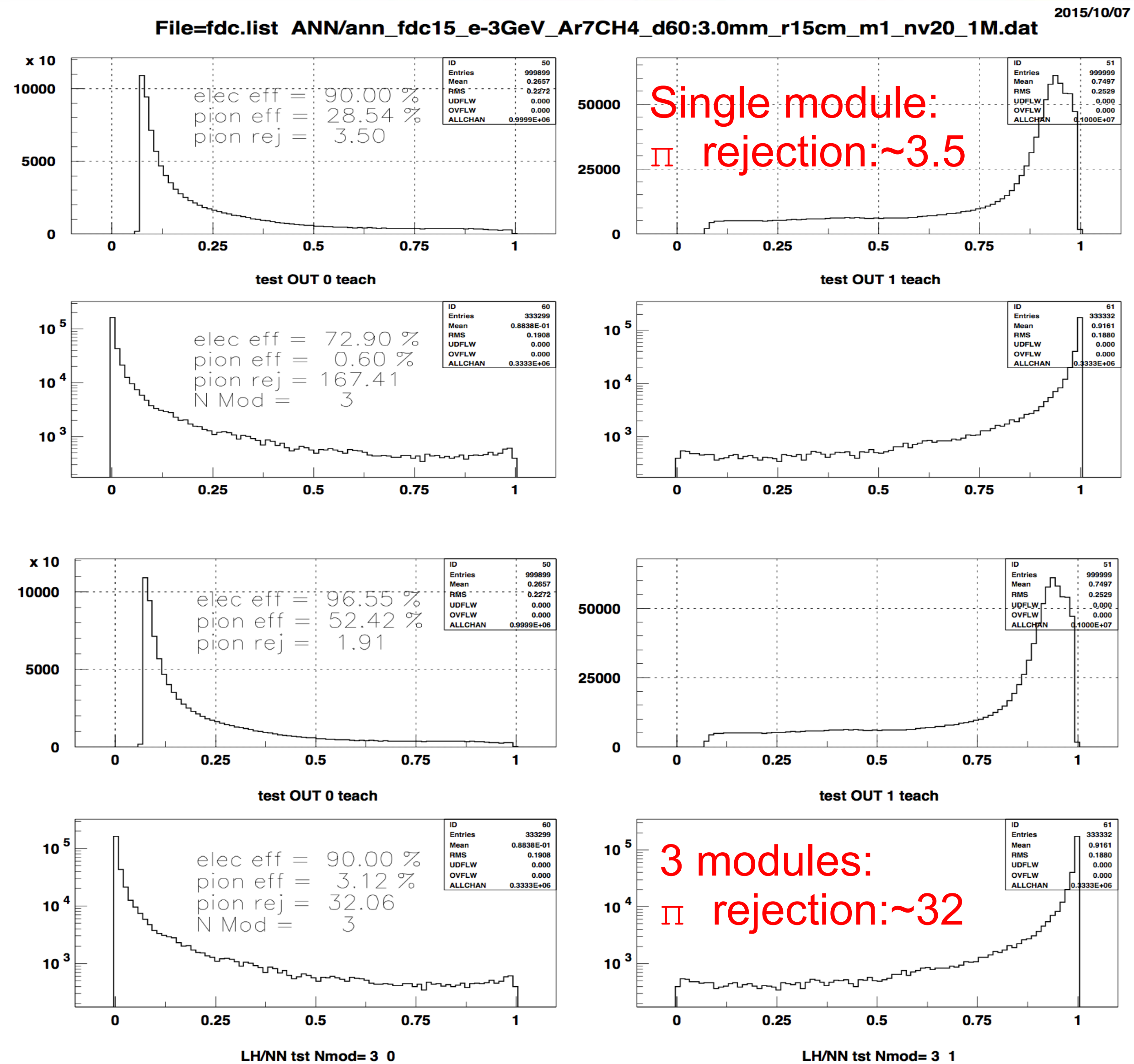
- e,pi 3 GeV
- 15cm fleece radiator
- Xenon 3 cm
- use Neural Network
- FADC readout
- 90% electron efficiency



e/pi rejection with Krypton



e/pi rejection with Argon



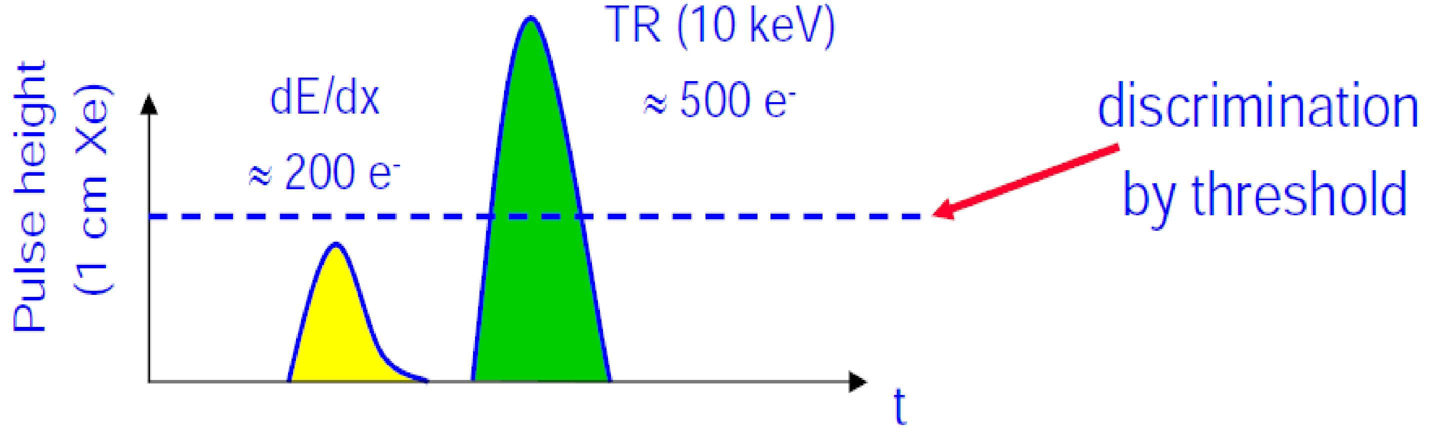
e,pi rejection

electron efficiency	90%		72%
N mod	1 module	3 modules	3 modules
Xenon	10	450	1600
Krypton	5.7	80	360
Argon	3.5	32	160

FDC spare packet tests

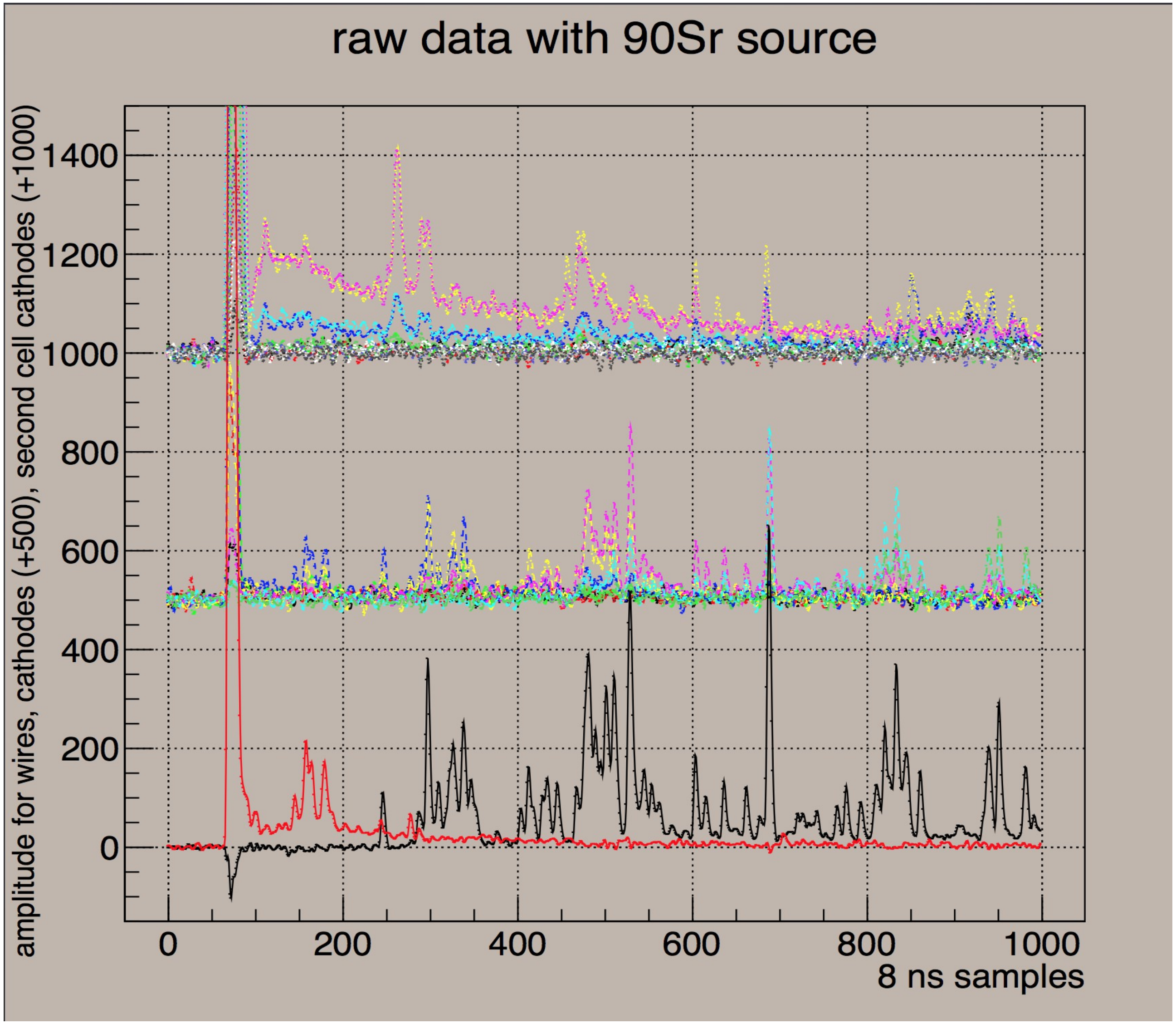
TR detection methods

1) Cluster counting method
2) Total energy deposition
3) dE/dx along track (FADC)



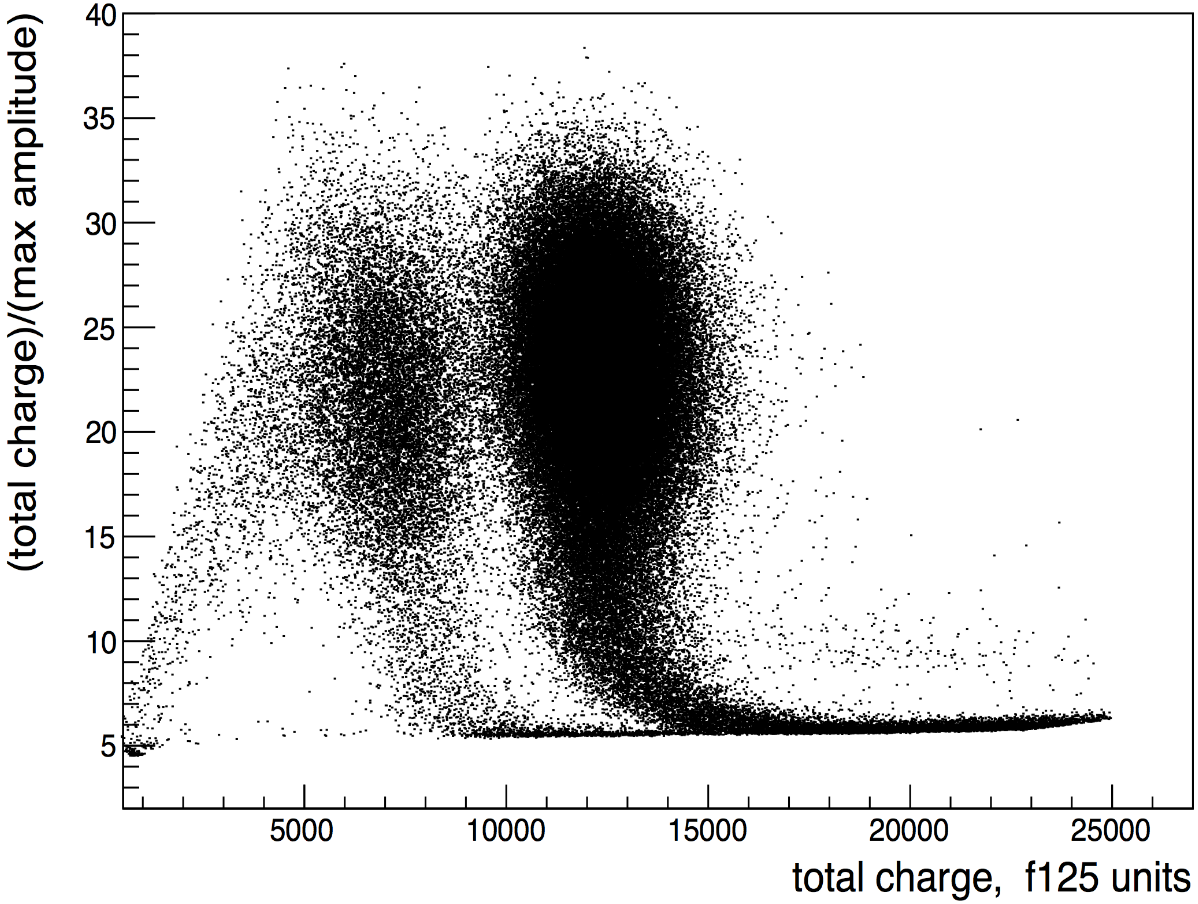
^{90}Sr FDC test

- Efficiency along 9μsec drift region
- Diffusion depends on gas mixure



^{55}Fe FDC test

- Check enegy resolution for X-rays: 8-15%



Outlook

- Test FDC spare module in Hall D
  - start with Argon
- Next step would be test with Xenon
-
-
-

Backup slides

backup