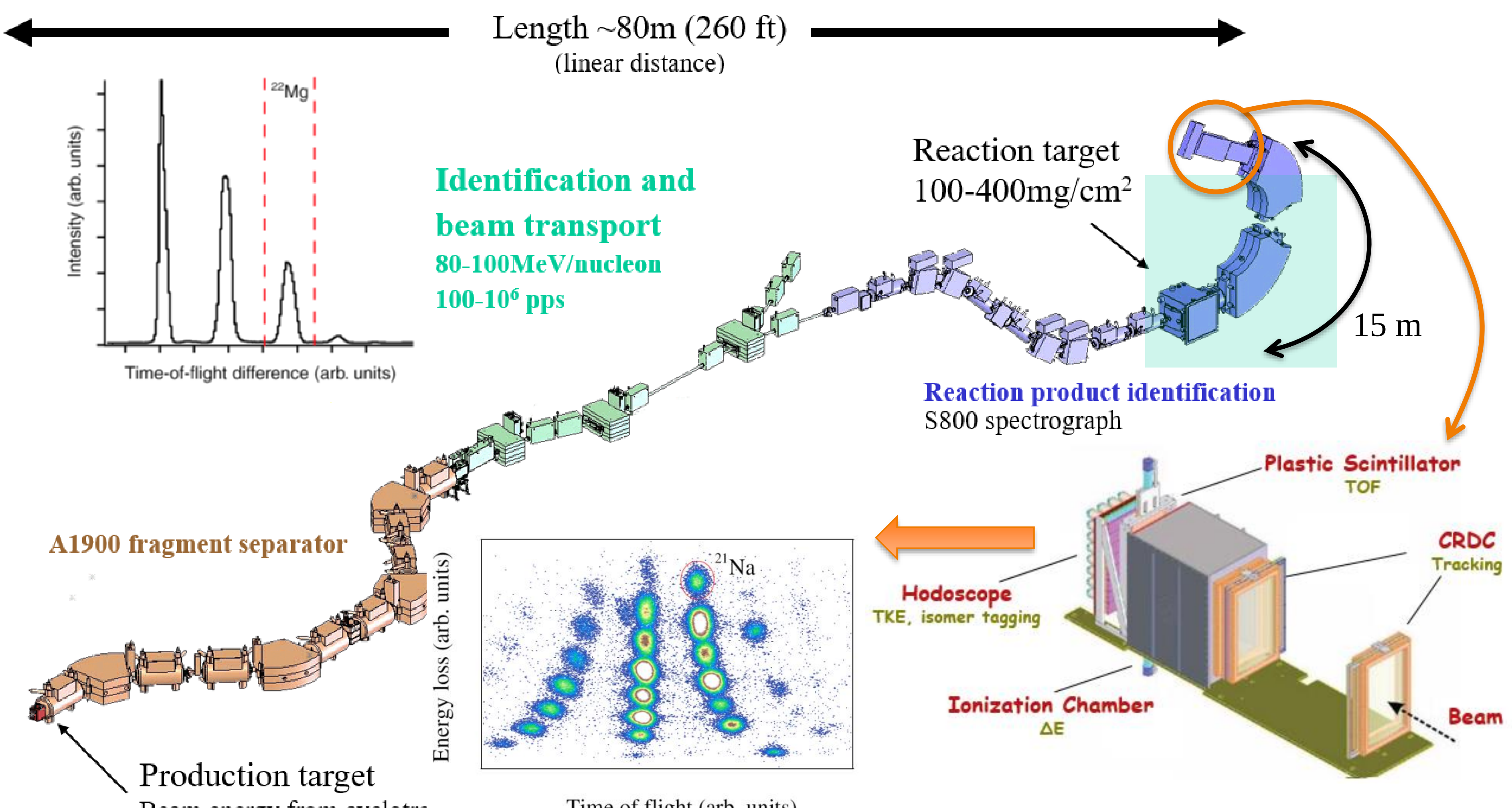
Novel Focal-Plane Detector Concepts for PID at the FRIB S800 Spectrometer

Marco Cortesi
Facility for Rare Isotope Beam (FRIB)
Michigan State University (MSU)

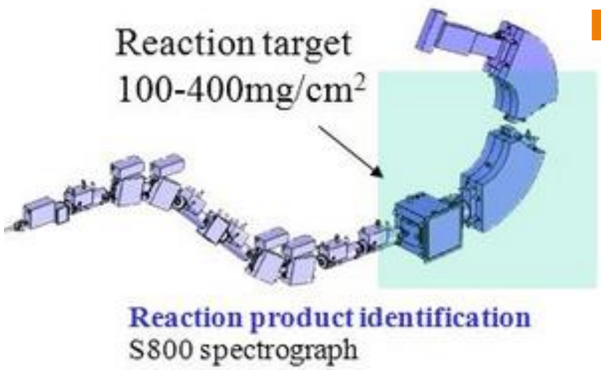
This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Fast-beam experiment with the S800

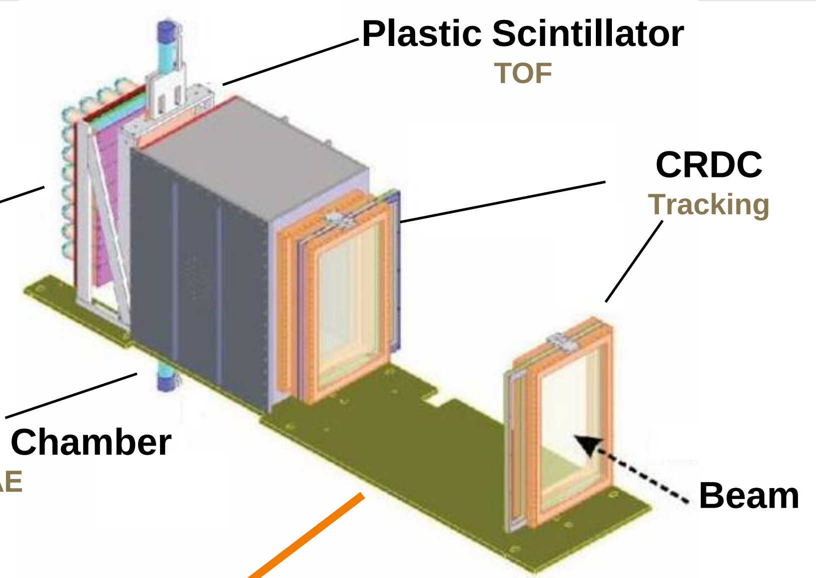


Focal Plane detector system for heavy-ion PID

Current Design of the S800 FP Detector System



Same basic design planned for the HRS



Ionization Chamber (IC):
Z number identification
16 stacked-parallel plate ion chambers (each 1" long).
filled with P10 (300-600 Torr)

- -) *Slow detector → low rate (<5KHz)*
- -) *Low SNR*
- -) *Good resolution only up to Z=50*

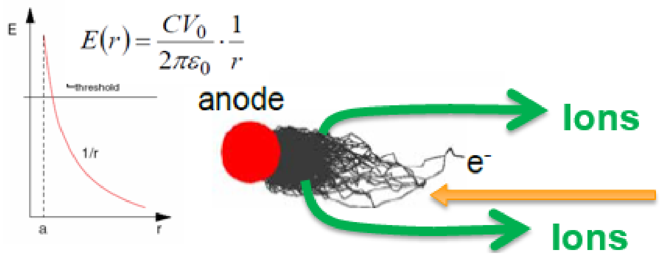
Cathode Readout Drift Chamber (CRDC):
Position and angles
Two CRDCs, 1 m apart, with 30x60 cm² effective area
filled with CF_4/(20%)iC_4H_{10}

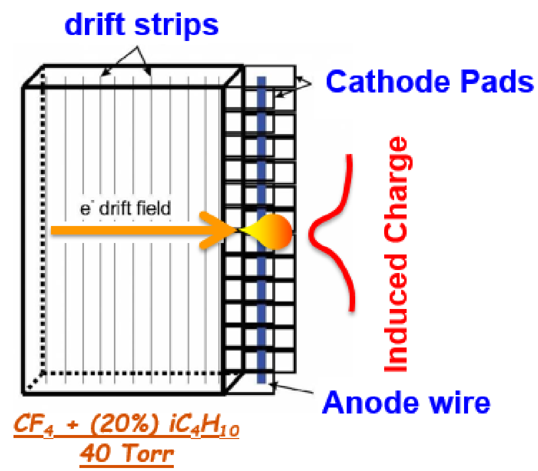
- -) *Slow detector → low rate (<5KHz)*
- -) *Position resolution → <1mm FWHM*
- -) *Aging problems*

Upgrade of the Tracking System

Goal 1: Upgrade the DC gas avalanche readout

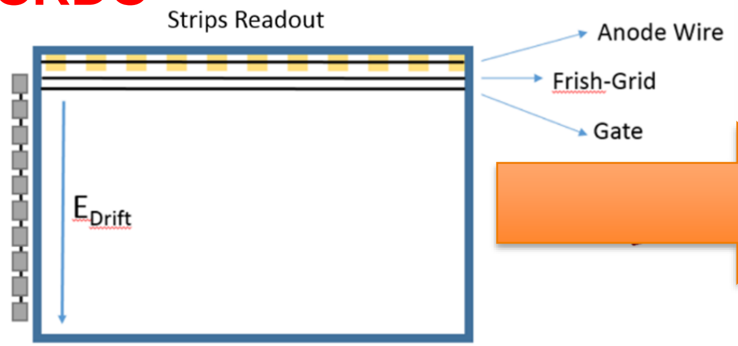
<u>Wire-Based Detector:</u>
"Mechanics", Economic but
Secondary effects → Gain limits
Space charge → Counting-rate limits
Aging → Damage after long-term operation



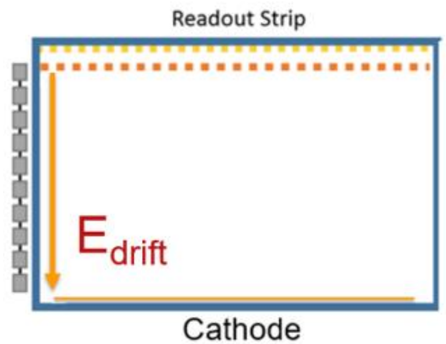


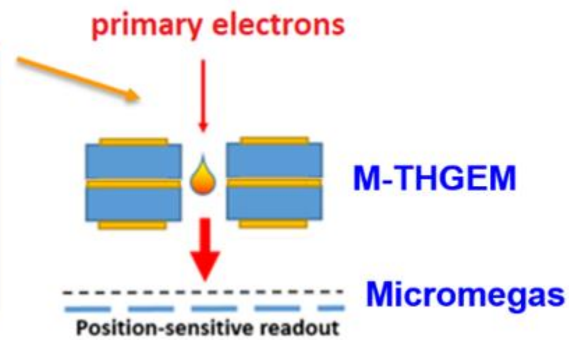
GOAL → Implementation of a new readout based on a hybrid MPGD structure

CRDC



MPGD-DC





New DAQ → replace the obsolete STAR front-end electronics with the GET system

Position-sensitive Micromegas readout

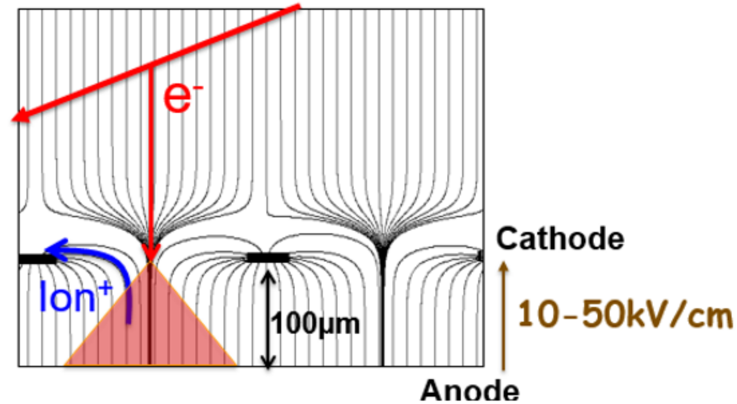
Giomataris et al. NIM A 376 (1996) 29

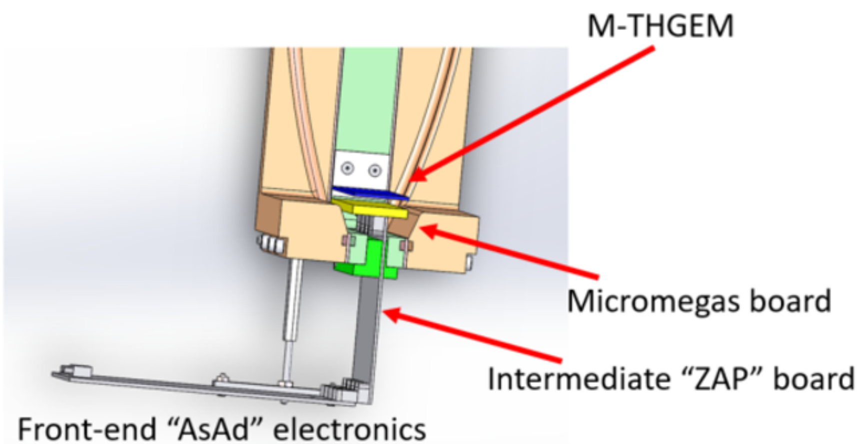
Micromesh Gaseous Chamber:

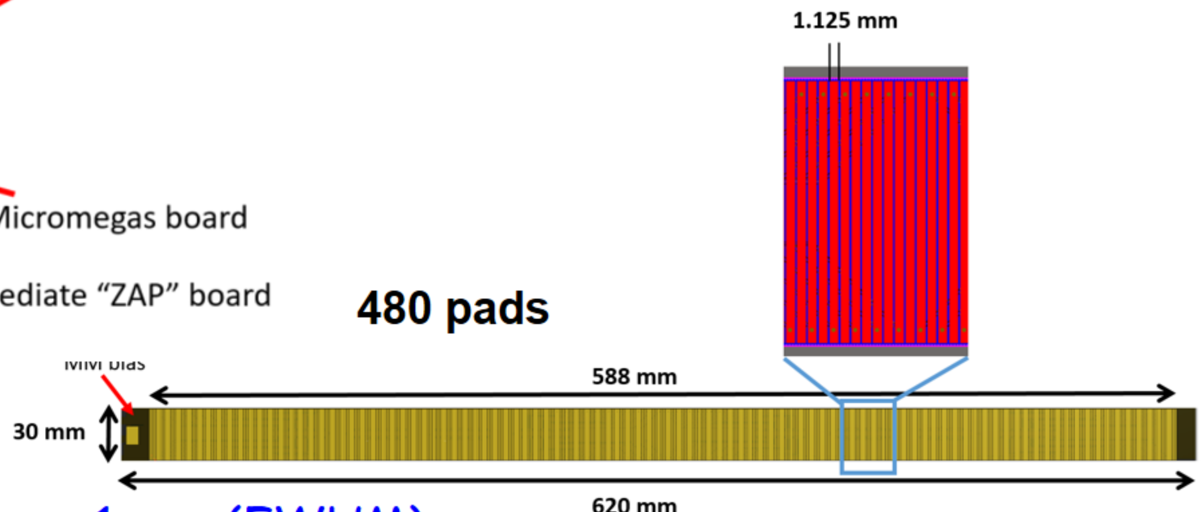
-) a thin mesh supported by 50-100 μm insulating pillars, mounted above readout structure

-) E field similar to parallel plate detector.

-) $E_{ampl}/E_{drift} > 100$ ➔ high e^- transparency & ion back-flow suppression



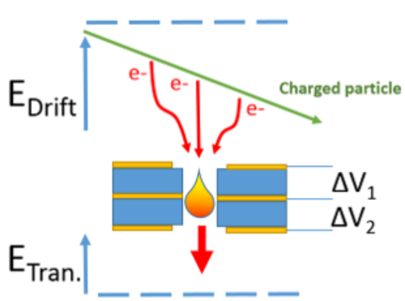




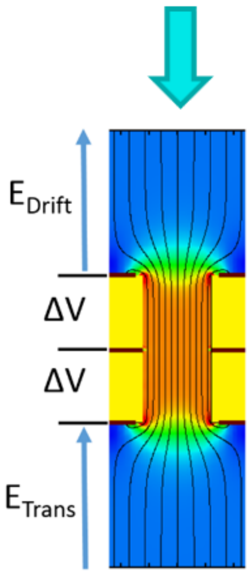
Expected position resolution < 1 mm (FWHM)

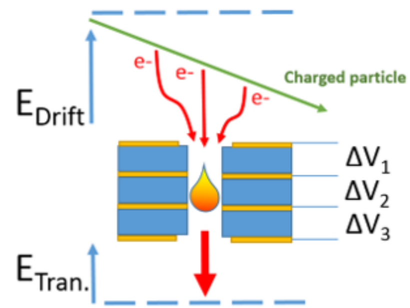
Multi-Layer THGEM (M-THGEM)

Manufactured by multi-layer PCB technique out of FR4/G-10/ceramic substrate

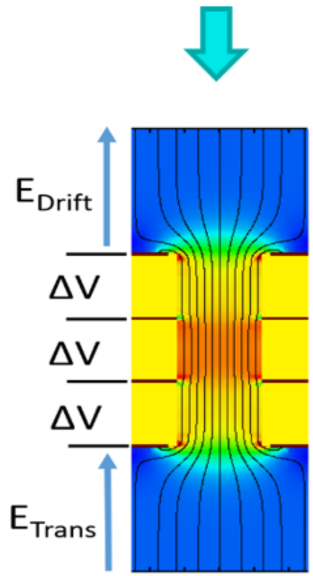


2-Layer M-THGEM



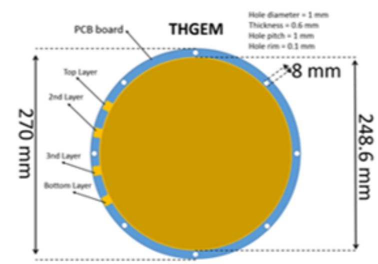


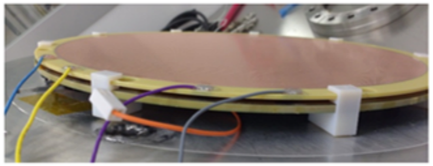
3-Layer M-THGEM



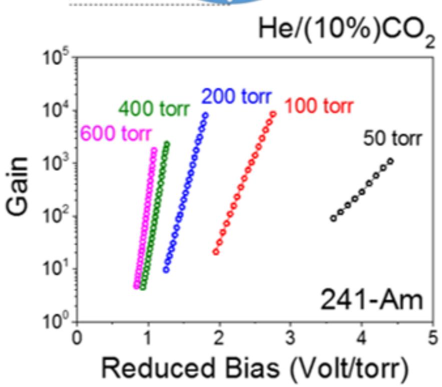
- -) No loss of charge ➔ high gain @ low voltage
- -) Robust avalanche confinement ➔ lower secondary effects
- -) Long avalanche region ➔ high gain @ low pressure
- -) Field geometry stabilized by inner electrodes ➔ reduced charging-up

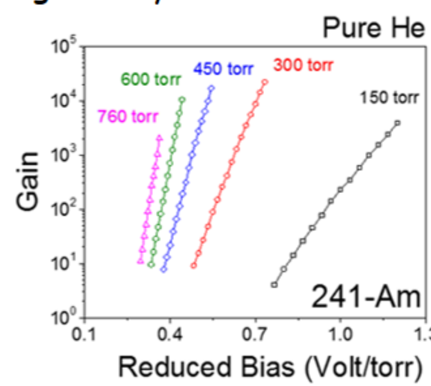
Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)





Single 3-layer M-THGEM



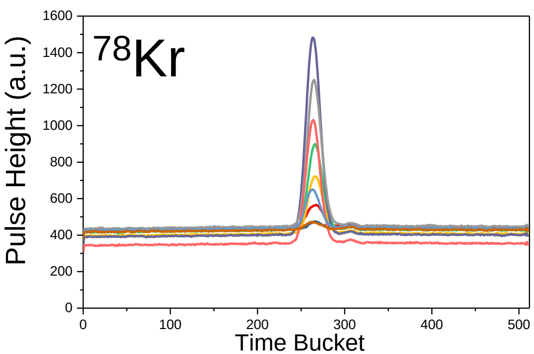


Prototype: Beam Test @ the S800 focal plane

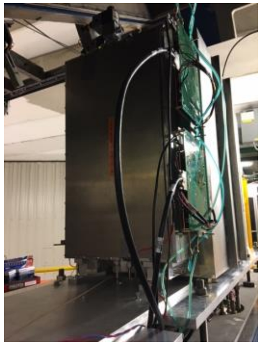
Settings: $^{78}Kr^{36+}$ (150 MeV/u) beam & fragmentation beam cocktail (Z ~ 4 to 36) from ^{86}Kr + Be (2.7 mm)

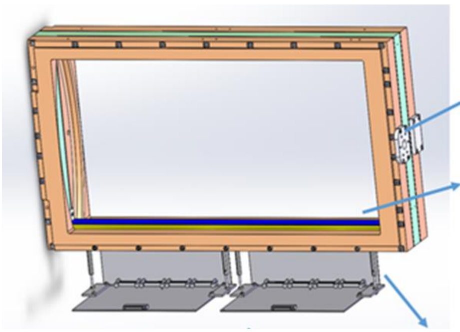
Waveform traces recorded for each "fired" pad

M. Cortesi et al., 2020 JINST 15 P03025



- Number of samples (up to 512 time "buckets")
- Clock "sampling" frequency (time/sample)
- Peaking time; gain
- HITMAKER: baseline + parabolic fit

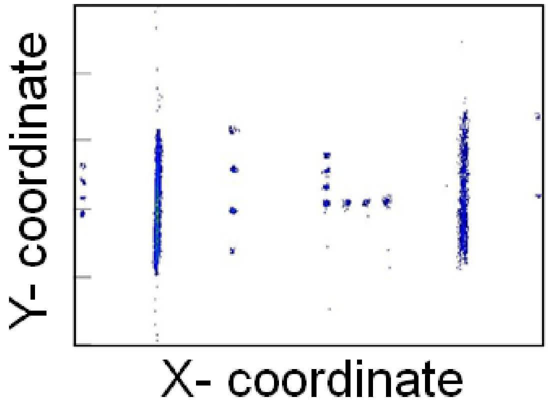


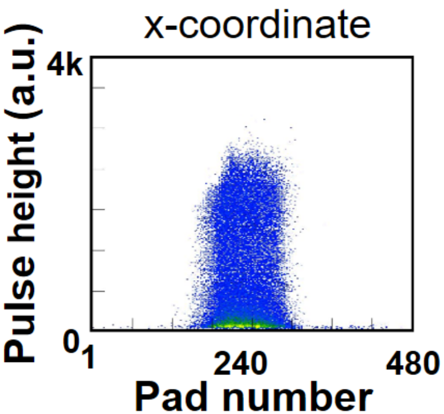


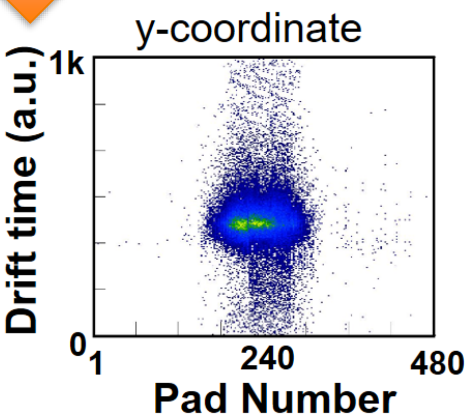
X ➔ charge distribution (center of the gravity)
Y ➔ Arrival time (external trigger)

M. Cortesi et al., 2020 JINST 15 P03025

Position resolution = 0.25 mm (σ)







Summary performance of the new tracking system

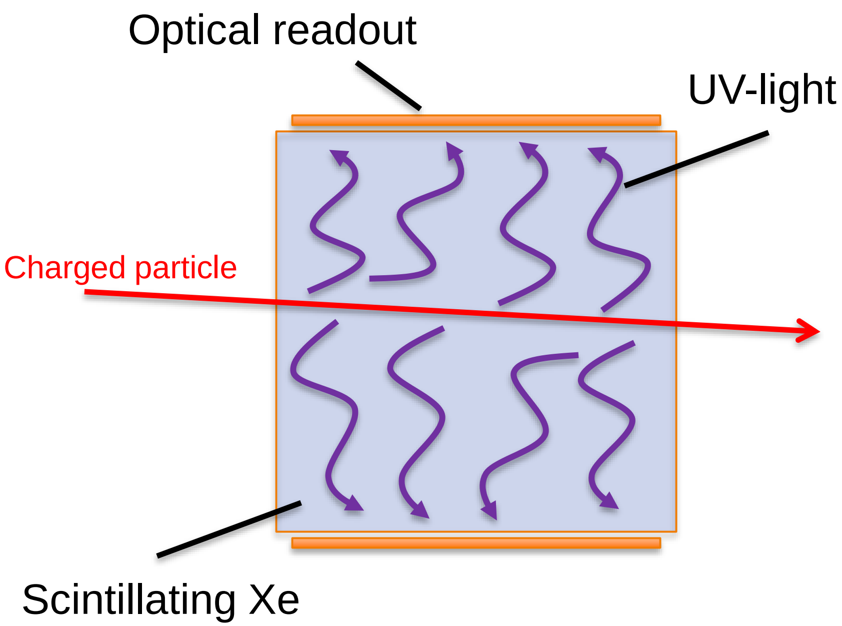
- Simple (construction) and robust, expected lower aging problems
- Better ions-backflow suppression
  - a few % compared to 60-70% of wire-based detector
- High detector gain @ low pressure (MM+THGEM)
- High counting rate (up to 20-30 kHz)
  - faster gas + faster electronics + Multi-hit capability
  - expected DAQ busy time ≈ 20 μs compared to 150 μs (CRDC)
- -) Possibility for active pulse-mode gating (M-THGEM)
  - suppressed non-correlated events
- -) High granularity (all pad are readout individually)
  - Measured position resolution < 0.6 mm (FWHM)

Upgrade of the Energy-Loss System

This material is based upon work supported by the National Science Foundation under grant no. 2017986

Goal: Upgrade of the dE/E Concept ➔ ELOSS

Energy-Loss Optical Scintillation System ELOSS



Operational principle:

-) Large volume filled with high-scintillation yield gas (Xe)
-) Excitation created along the track of a charged particle that crosses the volume
-) De-excitation with emission of intense, prompt scintillation light
**) Optionally: stimulated emission of electro-luminesce light*
-) The light readout by array of photodetectors that surround the detector effective volume

-) dE/E based on Xe scintillation light detection

-) High scintillation yield ➔ 28 photons/keV - 70% of NaI(Tl)
-) Fast process ➔ scintillation photons emitted within a few ten ns
-) Homogeneous medium, no radiation damage
-) Compact and flexible geometry
-) Increase resolution ➔ stimulated electroluminescence
-) Scintillation light detection based on well-developed technology
➔ single-electron sensitivity with 30% quantum efficiency
➔ time resolution < 200 ps
-) Easy purification and high efficiency gas recovery technique
-) Readout decoupled from the sensitive medium ➔ high SNR

-) Optical readout configurations

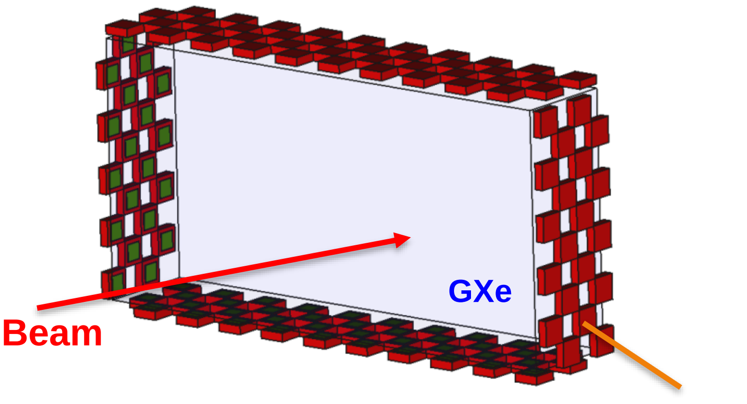
-) Array of Hamamatsu PMTs model R8520-406

-) Commercially-available DAQ

-) Based on MDPP-32 for PMT-based readout

Optical Readout: Hamamatsu R8520 PMT

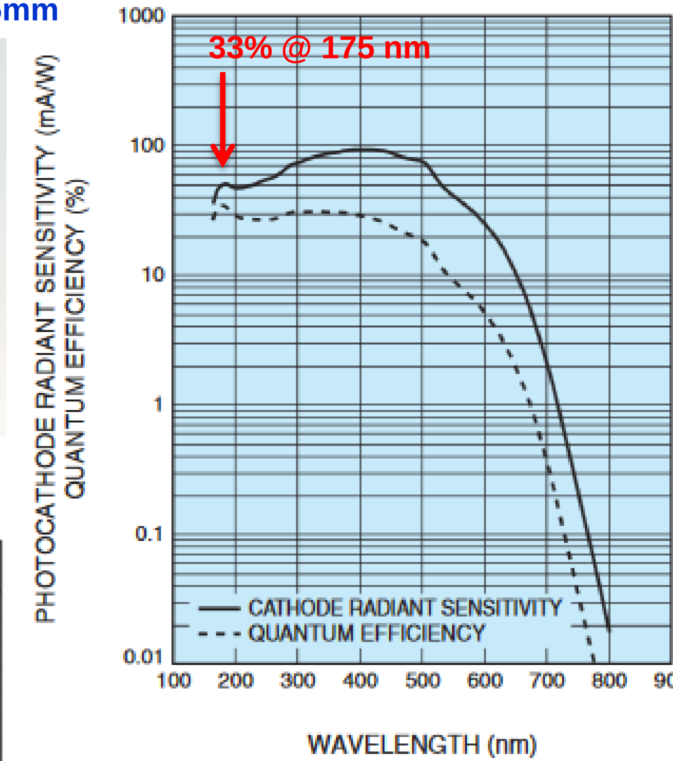
- Geometry: array of Hamamatsu PMTs (model R8520-406)



120 PMTs R8520

Filling factor F_F = 23.3%
Detector effective length = 120 mm
QE x F_F x Length = 8.4 mm

Dimension 30mm x 30mm
Effec. Area 20.5mm x 20.5mm

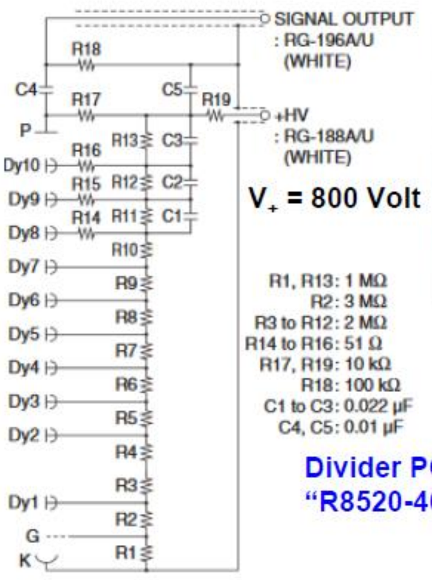


Parameter		R8520-406			R8520-506			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
Cathode sensitivity	Luminous (2856 K)	80	100	—	80	100	—	µA/lm
	Blue sensitivity index (CS 5-58)	—	11.0	—	—	9.5	—	—
	Radiant at 420 nm	—	100	—	—	80	—	mA/W
	Quantum efficiency at 175 nm	—	30	—	—	3	—	%
	Quantum efficiency at 420 nm	—	25	—	—	25	—	%
Anode sensitivity	Luminous (2856 K)	40	100	—	40	100	—	A/W
	Gain	—	1×10^6	—	—	1×10^6	—	—
Anode dark current (After 30 minute storage in darkness)		—	2	20	—	2	20	nA
Time response	Anode pulse rise time	—	1.8	—	—	1.8	—	ns
	Electron transit time	—	12.4	—	—	12.4	—	ns
	Transit time spread (FWHM)	—	0.8	—	—	0.8	—	ns
Pulse linearity (2 % deviation)		—	30	—	—	30	—	mA

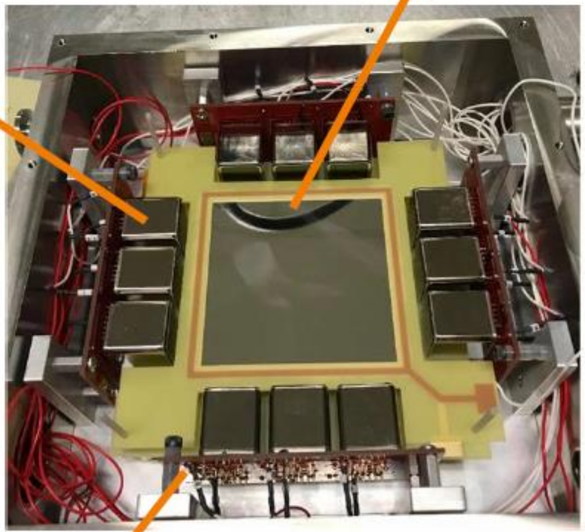
ELOSS prototype: performance evaluation

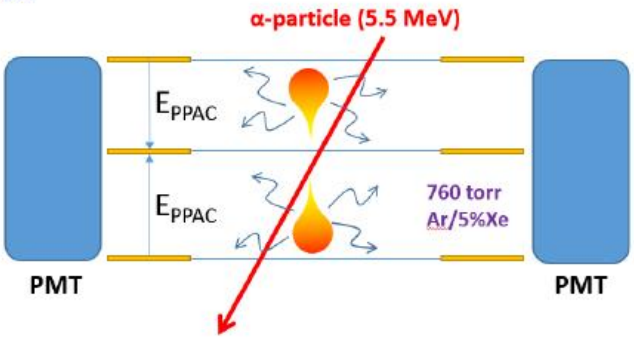
Hamamatsu PMT Model R8520-406

PPAC cathode electrode used as mirror & electron-stimulated electroluminescence emission



V_+ = 800 Volt

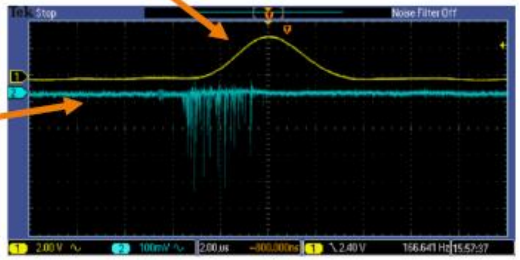




Divider PCB with pick-up signal "R8520-406 Datasheet"

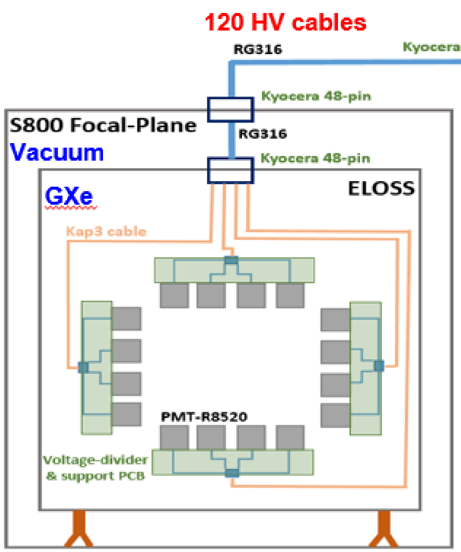
PPAC Anode
Charge-Premp

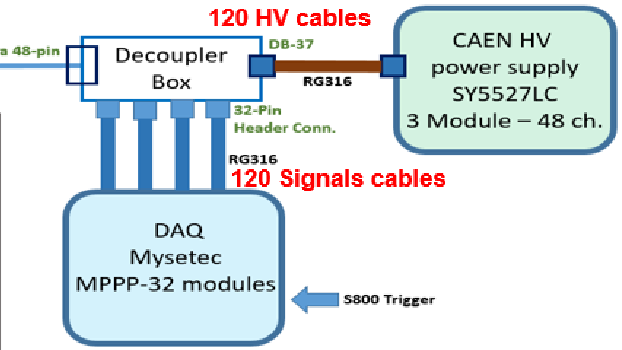
Ar/5%Xe (1 atm)



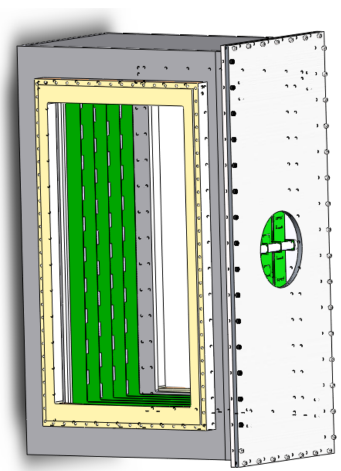
PMT-Light
Fast-Premp
(Electroluminescence)

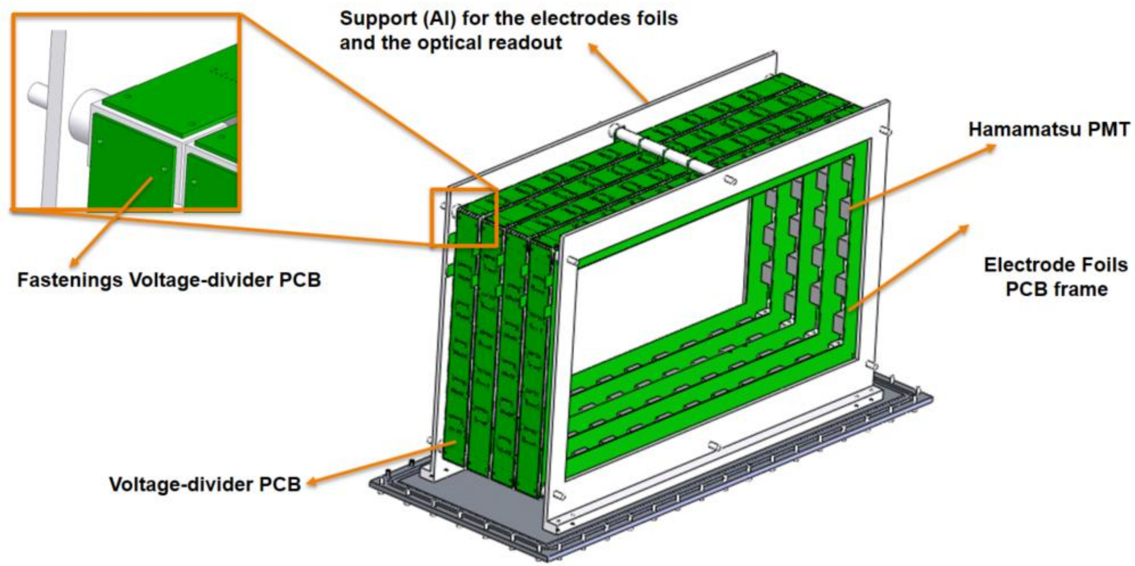
Mechanical design: in progress



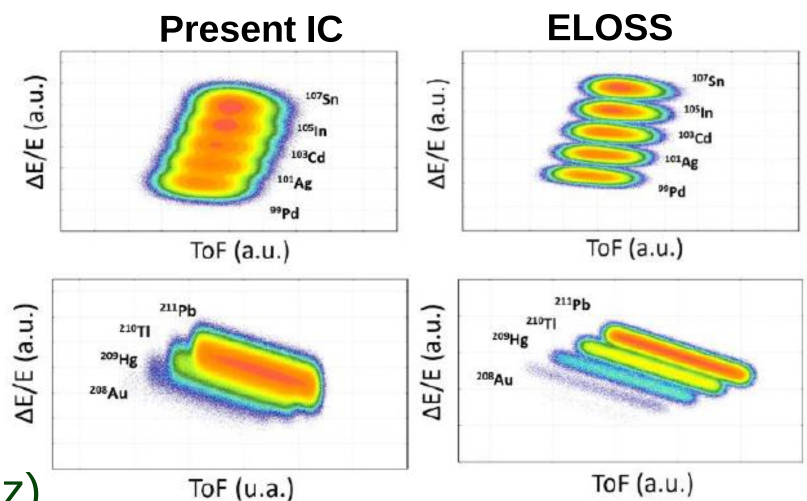


The mechanical support structure hold the ELOSS inner electrode frames as well as the PMT voltage-divider PCB.
The two supporting frames are made of Aluminum and the spacers/rods are made of low outgassing material,
either Macor (glass ceramic) or PEEK





Summary expected ELOSS performance



Lise++ calculation

<u>**Compared to conventional IC:**</u>

- A (“3 times”) better resolving power
- Sensitivity to high-Z particles (above Z = 50)
- Larger dynamic range

  -) optional: change the pressure of the filling gas
- Higher rate capability (up to a few hundred of KHz)

  -) Xe emission is emitted within a few ten of ns
- Good time resolution (< 300 psec) – not possible with IC
- Localization capability (a few mm) – not possible with IC

This material is based upon work supported by the National Science Foundation under grant no. 2017986