NOVEL FOCAL PLANE DETECTOR CONCEPTS FOR THE NSCL/FRIB S800 SPECTROMETER

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Outline:

1) Introduction (nuclear physicist experiment with RIBs)
2) S800 Spectrometer and Focal-Plane detector system upgrade
3) A new MPGD-based readout for the tracking system
4) A new concept for ΔE/E measurement based on ELOSS detector

Fantastic Nuclei and where to find them

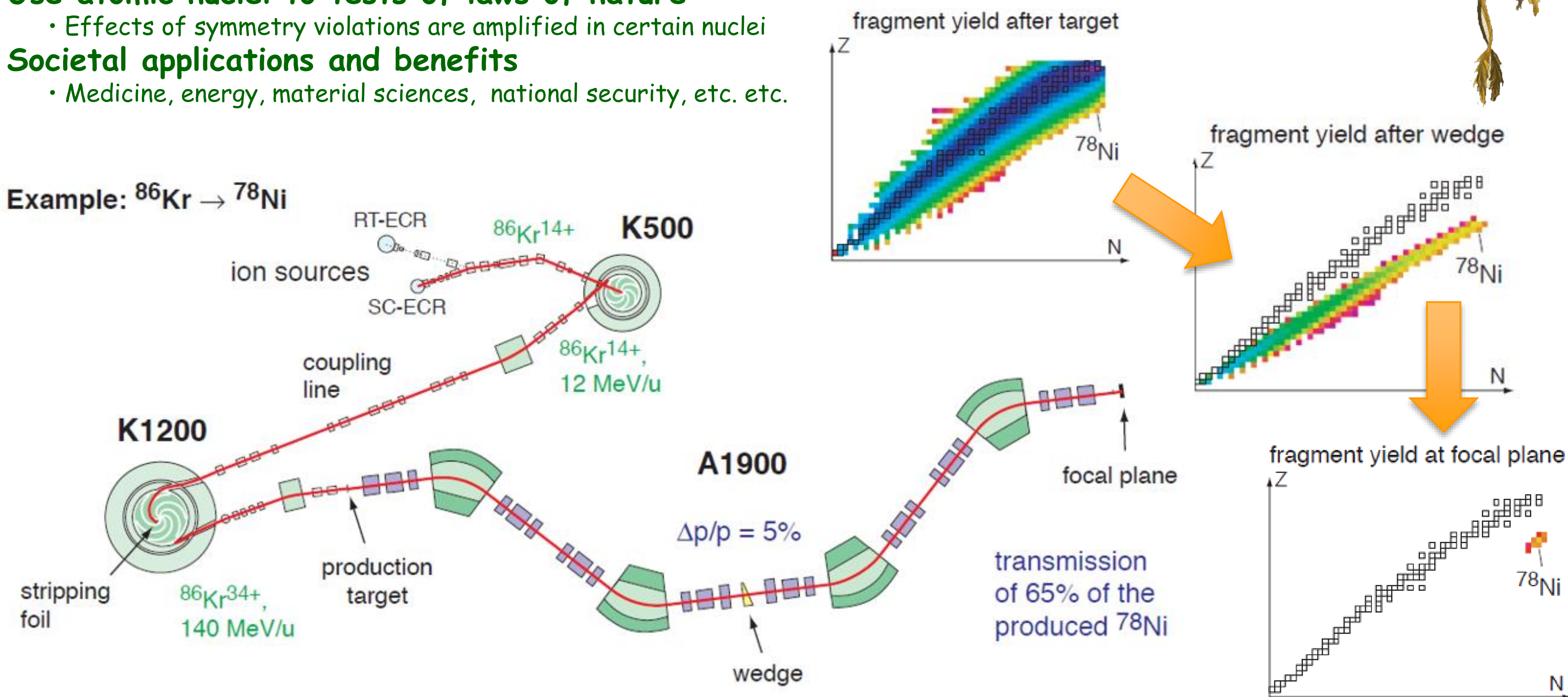
Nuclear Science Challenges addressed by Rare Isotope Beam Physics

Properties of atomic nuclei
- Study of predictive model of nuclei & their interactions, Many-body problem & physics of complex system

Astrophysics: Nuclear Processes in the Cosmos
- Origin of the elements, energy generation in stars, stellar evolution & the resulting compact objects

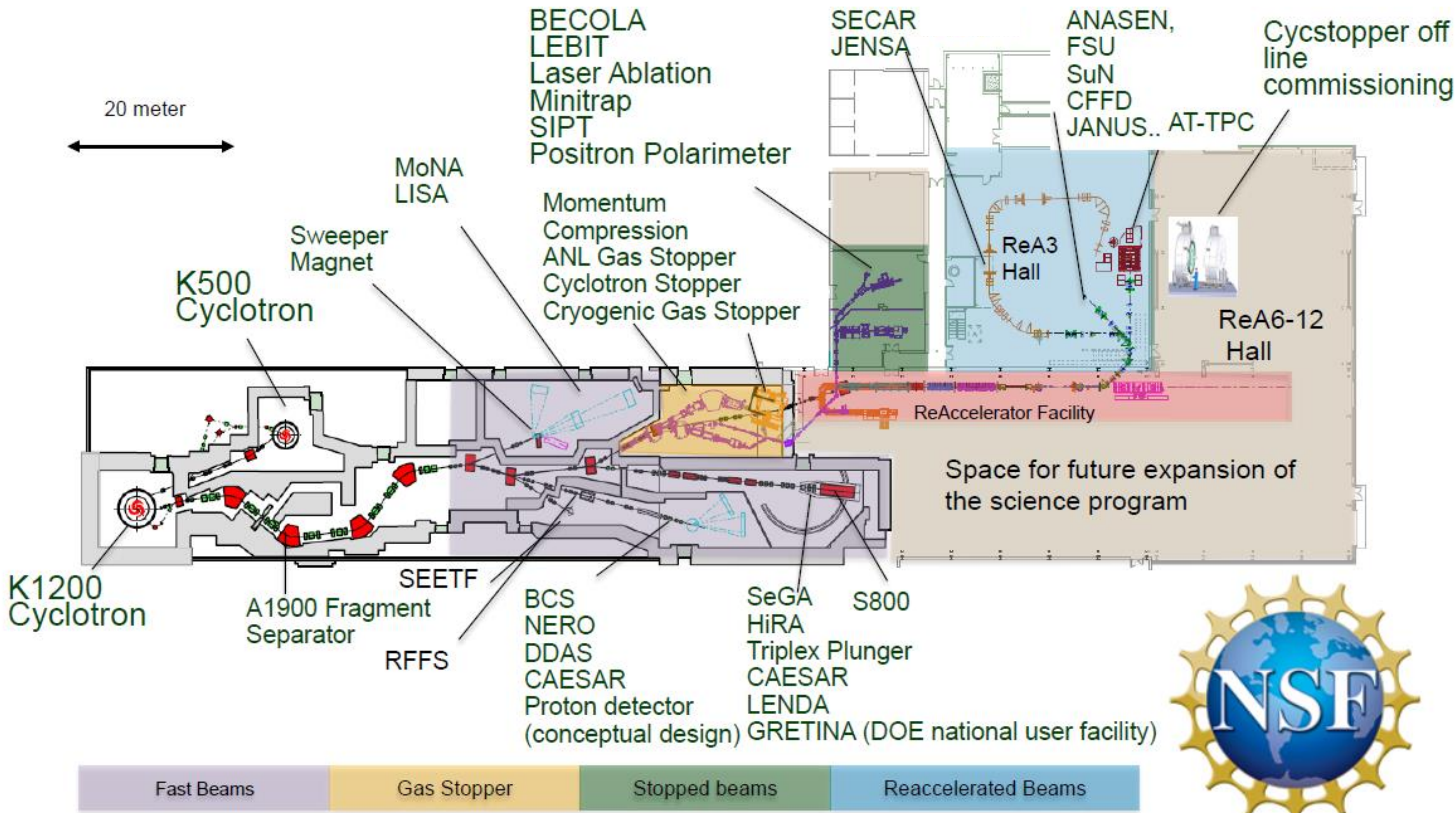
Use atomic nuclei to tests of laws of nature
- Effects of symmetry violations are amplified in certain nuclei

Societal applications and benefits
- Medicine, energy, material sciences, national security, etc. etc.



Rare Isotope Beam Physics -> Projectile Fragmentation

Pre-FRIB Science Opportunities at NSCL
with Fast, Stopped, Reaccelerated Beams



Major US Project: Facility for Rare Isotope Beams (FRIB)

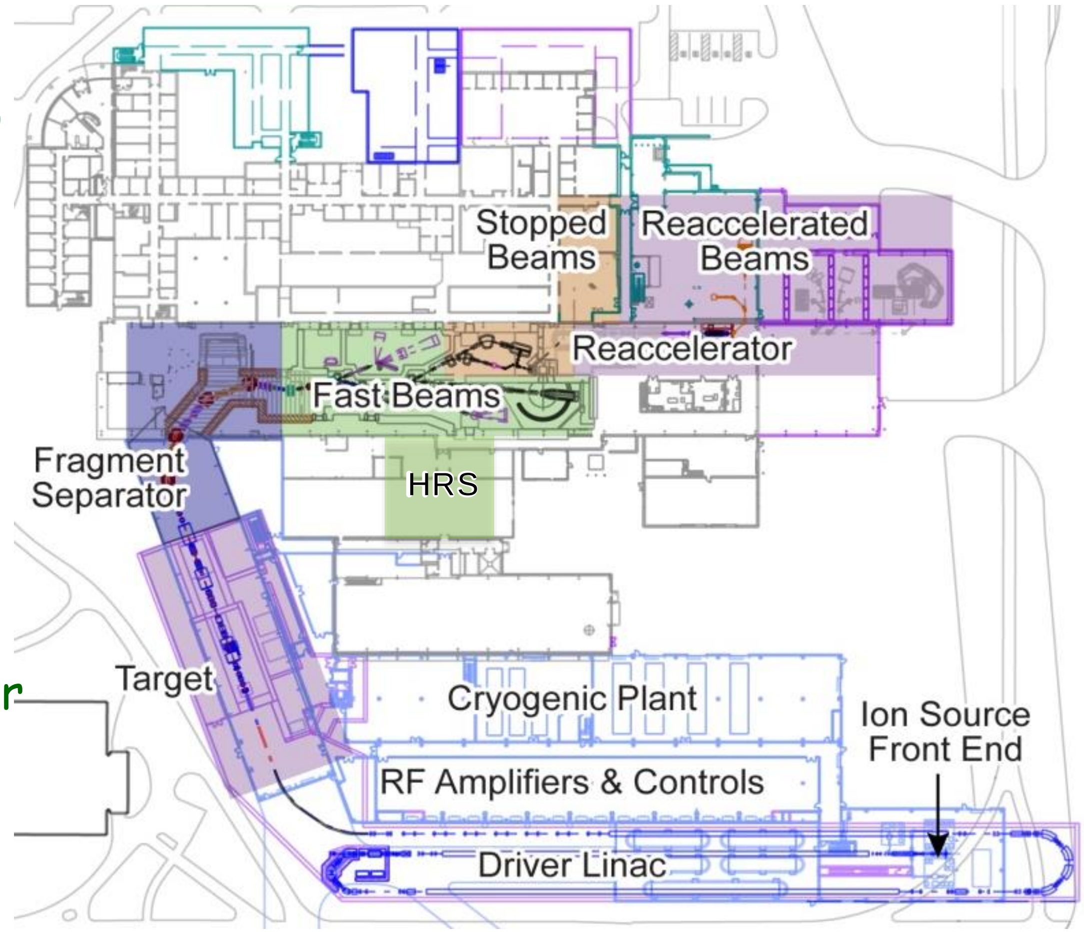
-) Funded with financial assistance from DOE Office of Science (DOE-SC) with cost share and contributions from Michigan State University (MSU) & State of Michigan.

-) Key features is 200 MeV/u
400 kW beam power (5×10^{13} $^{238}U/s$)
Tremendous discovery potential:
80% coverage Z < 82

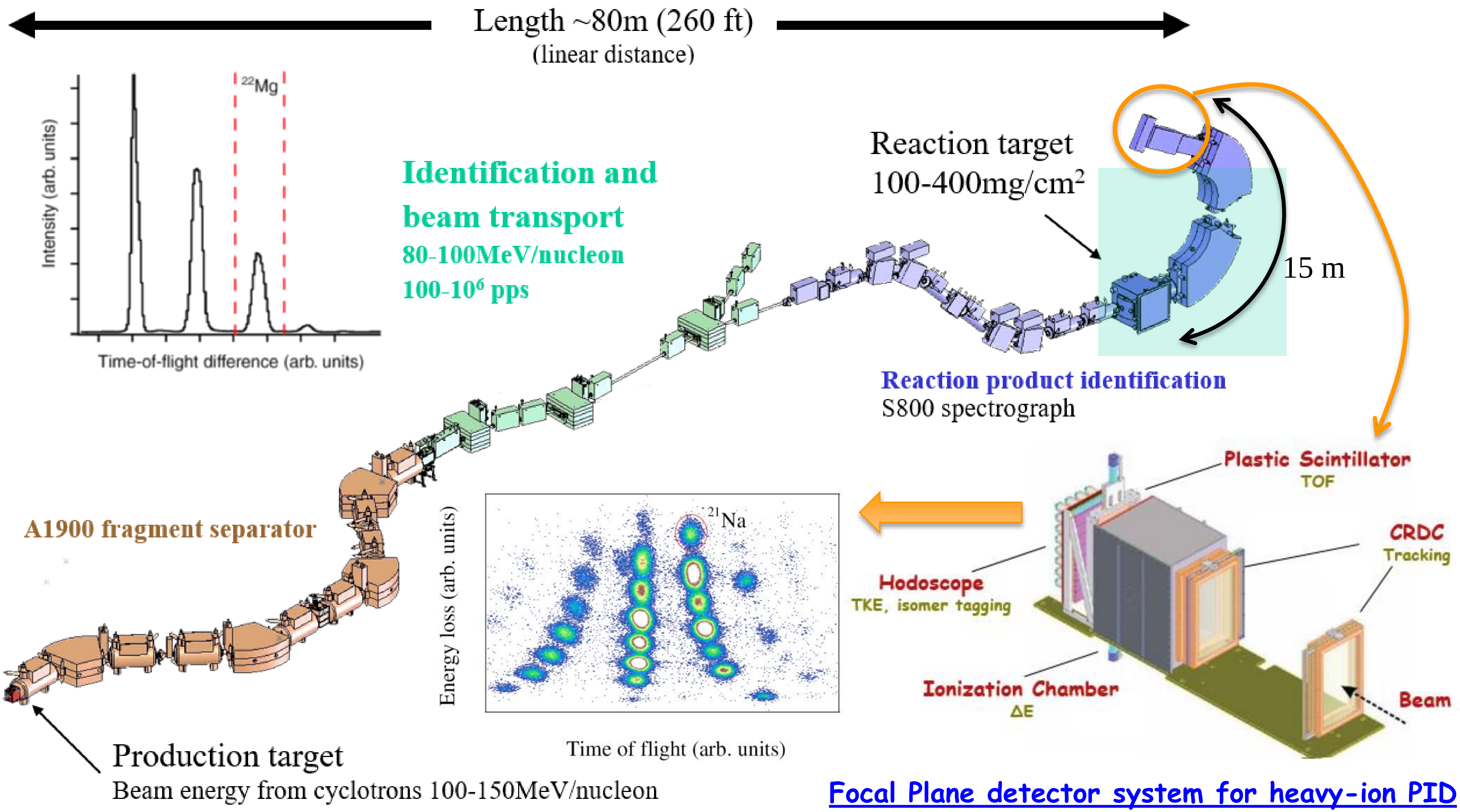
-) Separation of isotopes in-flight

-) Science program requires range of energies: Fast, Stopped, & reaccelerated beams

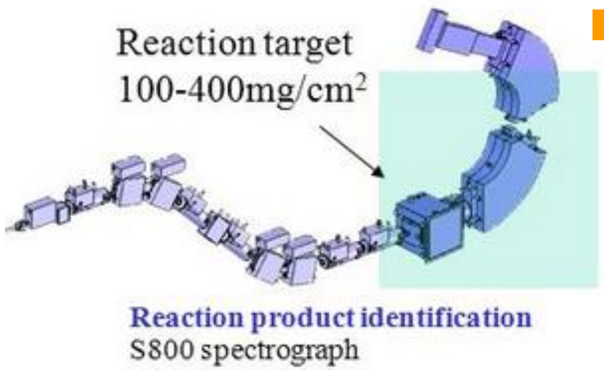
-) Upgradable to 400 MeV/u & multi-user



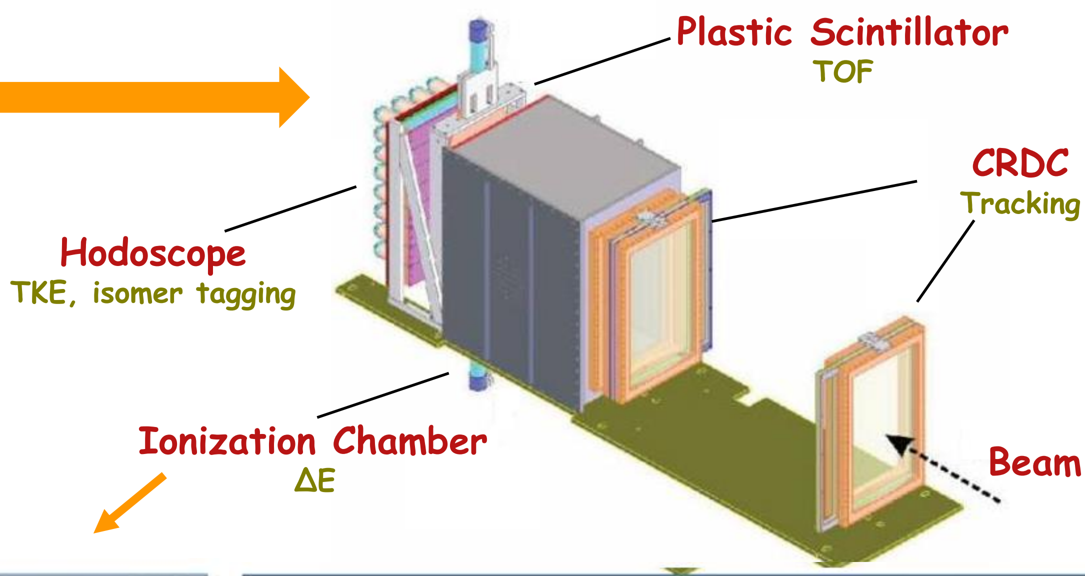
Fast-beam experiment with the S800



Current Design of the S800 FP Detectors 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)

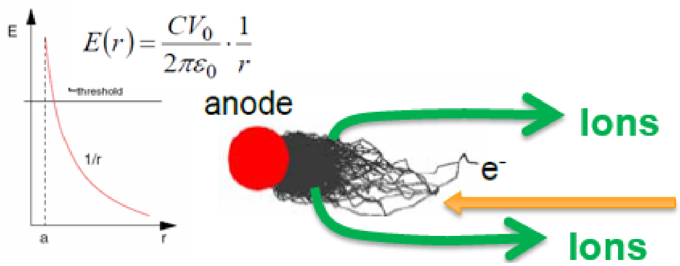
- -) *Slow detector → low rate (<5KHz)*
- -) *Low SNR*
- -) *Good resolution only up to Z=50*

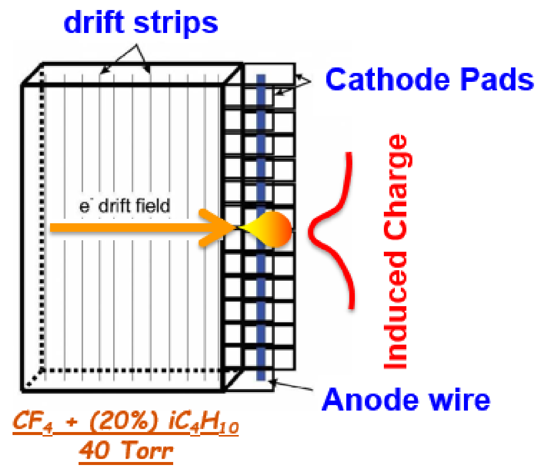
Cathode Readout Drift Chamber (CRDC):
Position and angles
Two CRDCs, 1 m apart, with 30x60 cm^2 effective area
filled with CF4/(20%)iC_4H_{10}

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

Goal 1 → Upgrade of the DC gas avalanche readout

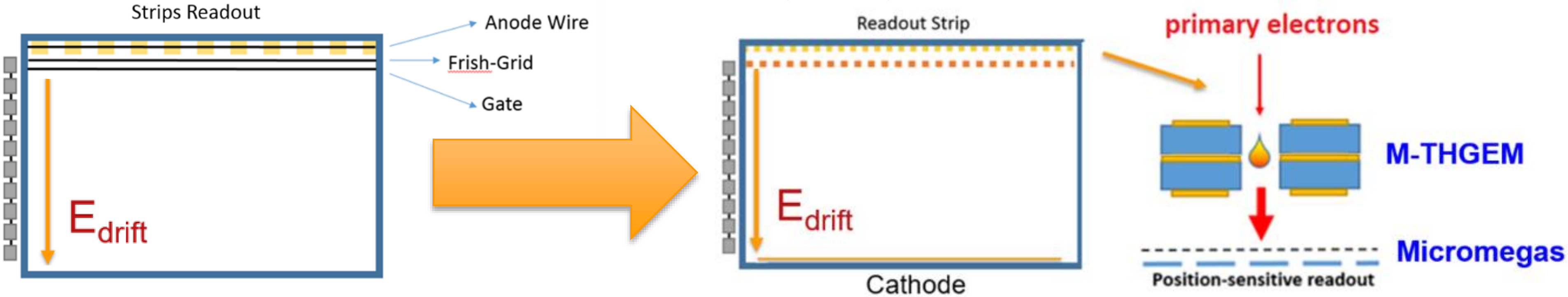
Wire-Based Detector:
"Mechanics", Economic but
Secondary effects ➔ Gain limits
Space charge ➔ Counting-rate limits
Aging ➔ Damage after long-term operation





Goal → development of a new readout based on a hybrid MPGD structure, for the upgrade of the Cathode-Readout Drift-Chamber (CRDC) based tracking system

CRDC **MPGD-DC**



Position-sensitive Micromegas readout

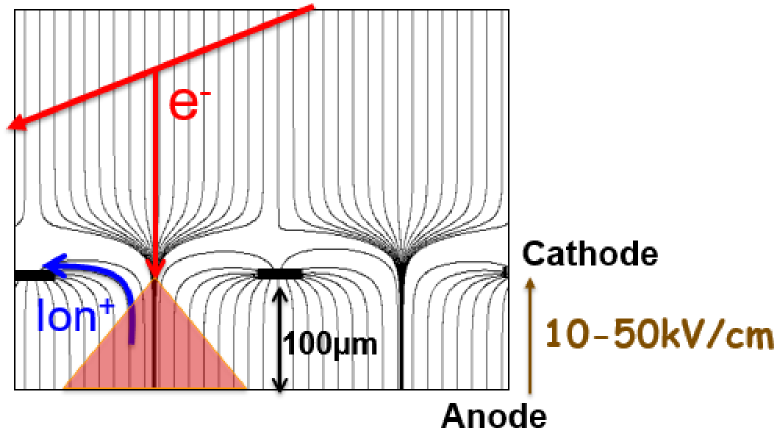
Giomataris et al. NIM A 376 (1996) 29

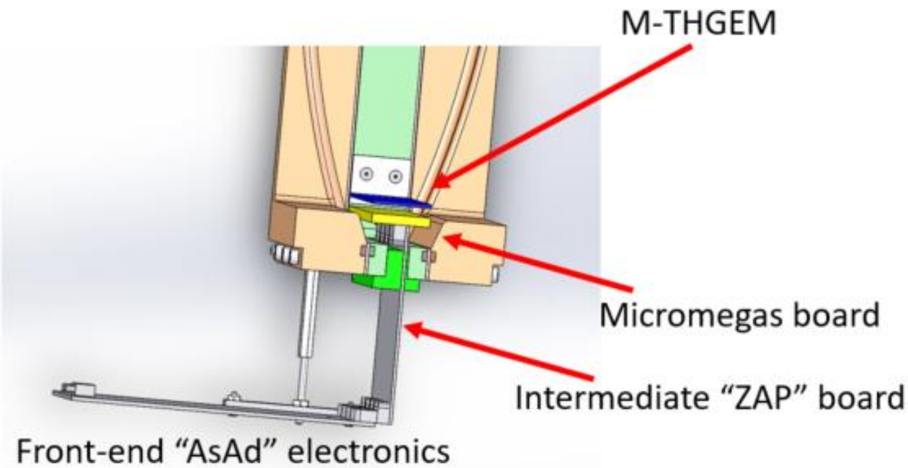
Micromesh Gaseous Chamber:

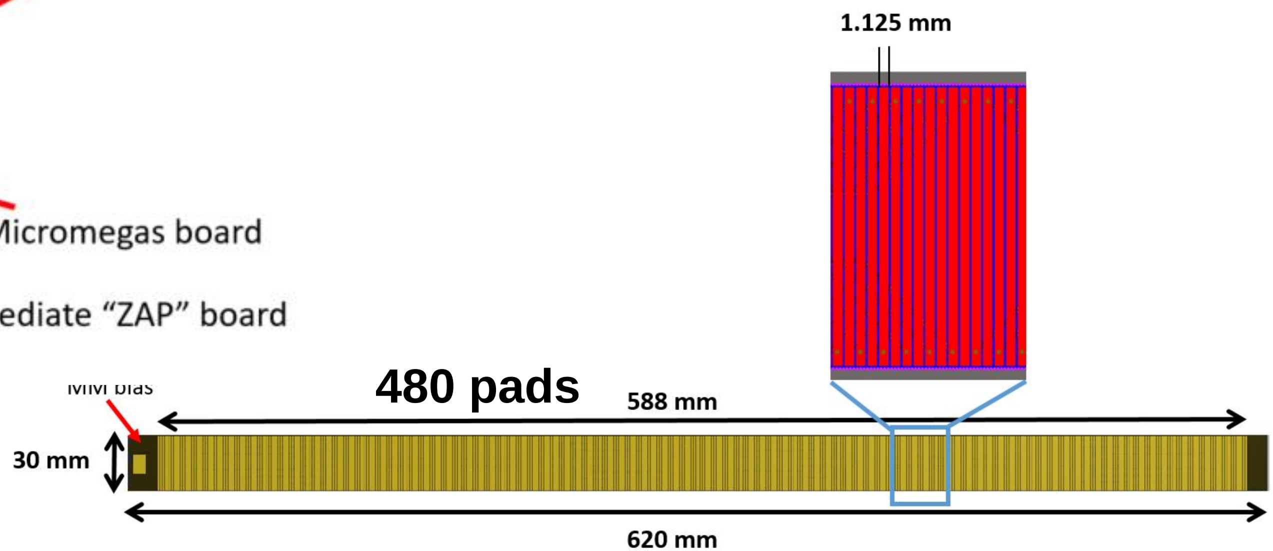
-) a thin mesh supported by 50-100 μm insulating pillars, mounted above readout structure

-) E field similar to parallel plate detector.

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

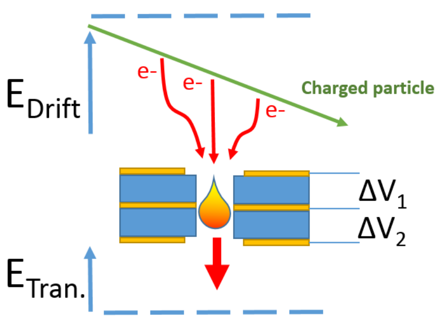




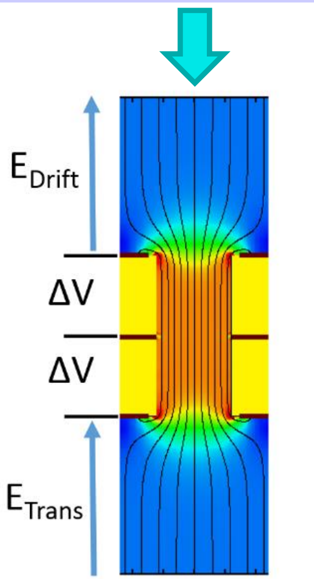


Multi-layer THGEM (M-THGEM)

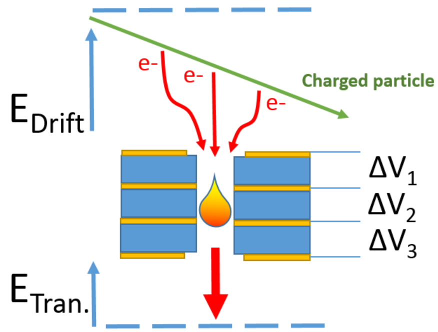
Manufactured by multi-layer PCB technique out of FR4/G-10/ceramic substrate



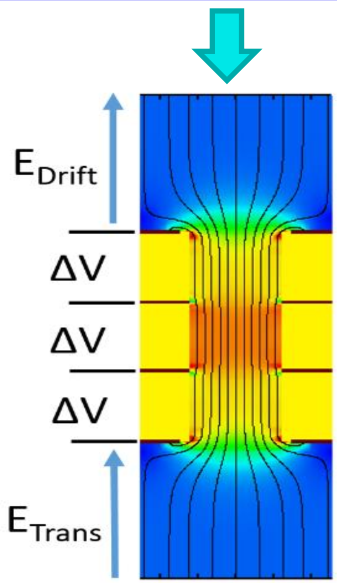
2-Layer M-THGEM



Low pressure applications



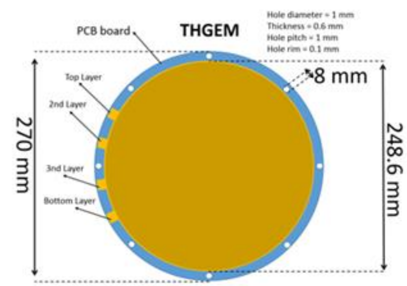
3-Layer M-THGEM

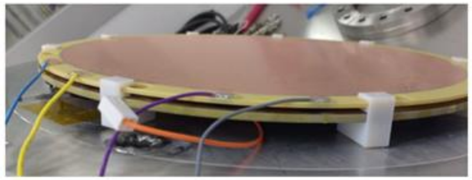


AT-TPC & pure gases

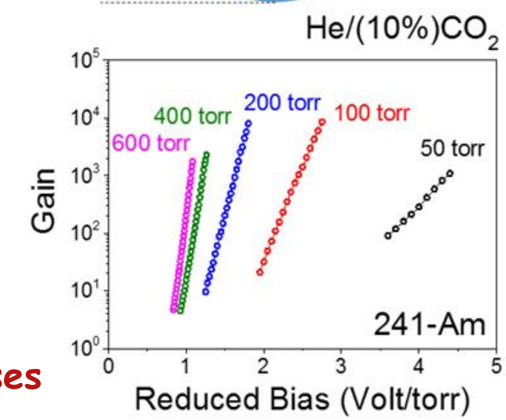
- -) No loss of charge ➔ high gain @ low voltage
- -) Robust avalanche confinement
  ➔ lower secondary effects
- -) Long avalanche region
  ➔ high gain @ low pressure
- -) Field geometry stabilized by inner electrodes
  ➔ reduced charging-up

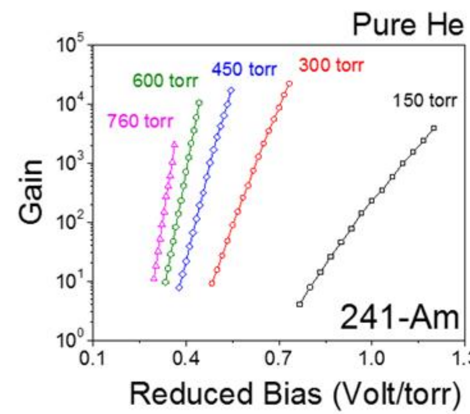
Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)





Single 3-layer M-THGEM

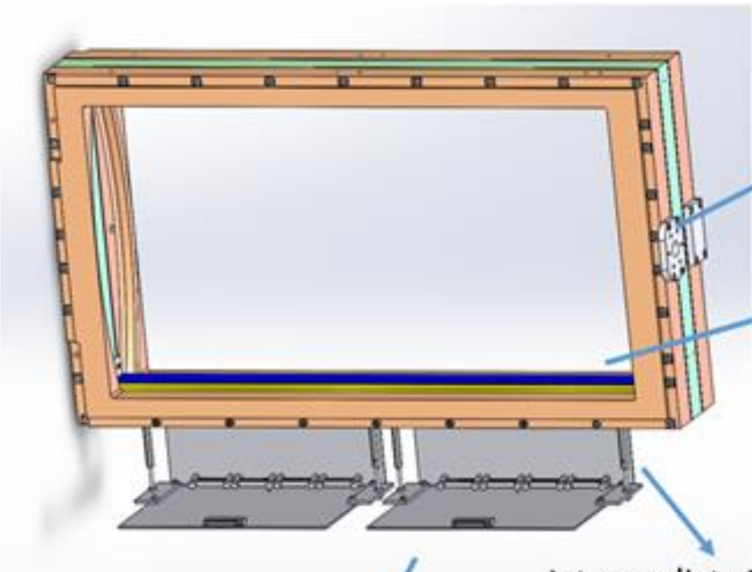


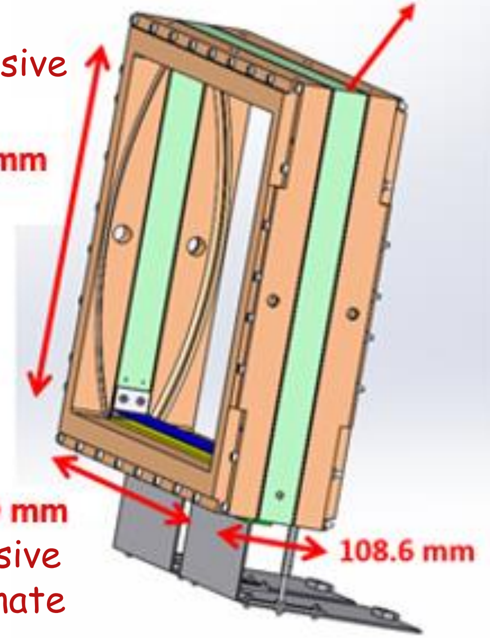


Design of the new MPGD-DC

Drift chamber based on hybrid MPGD readout

$CF_4/20\%iC_4H_{10}$ (40 Torr)





Intermediate Zap board
(include protection circuitries for the GET electronics and 16X2 channels reserved for the Ionization chamber signals)

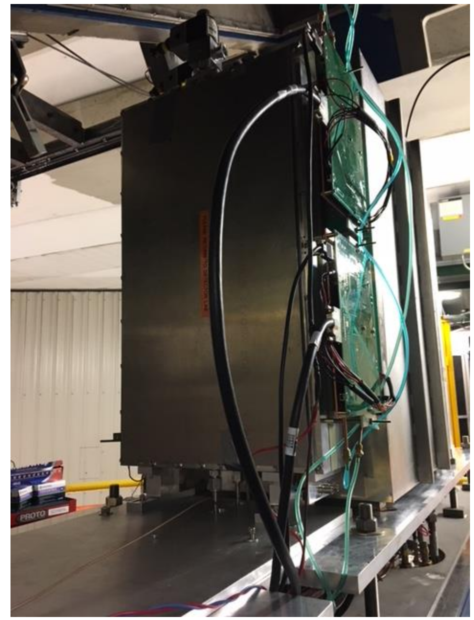
Front end AsAd board
- -) 4 AGET per board, 64 channel each ➔ 512 channels
- -) 480 channels for the MM-readout
- -) 16 channels for the ionization chamber
- -) 16 spare channels

GET electronics fully integrated into the NSCLDAQ

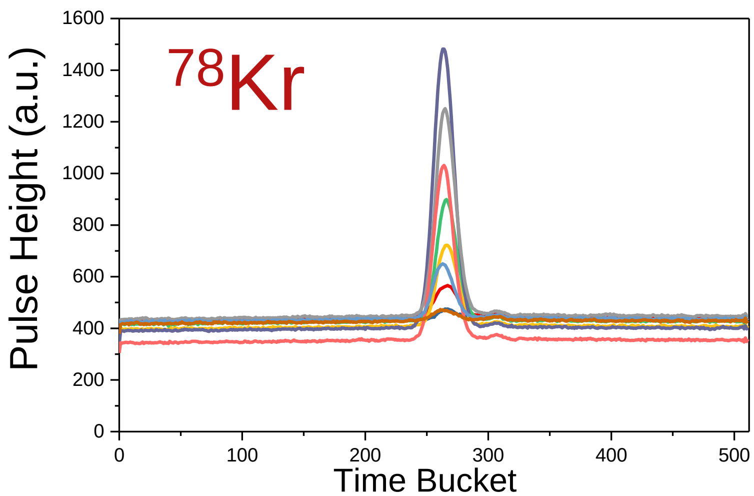
Beam Test @ the S800 focal plane

Settings:

- MPGD-DC detector replaced the $CRDC_2$
- Performance test (~7 hours) with $^{78}Kr^{36+}$ (150 MeV/u) & fragmentation beam cocktail (Z ~ 4 to 36) from ^{86}Kr + Be (2.7 mm)



Waveform traces recorded for each "fired" pad



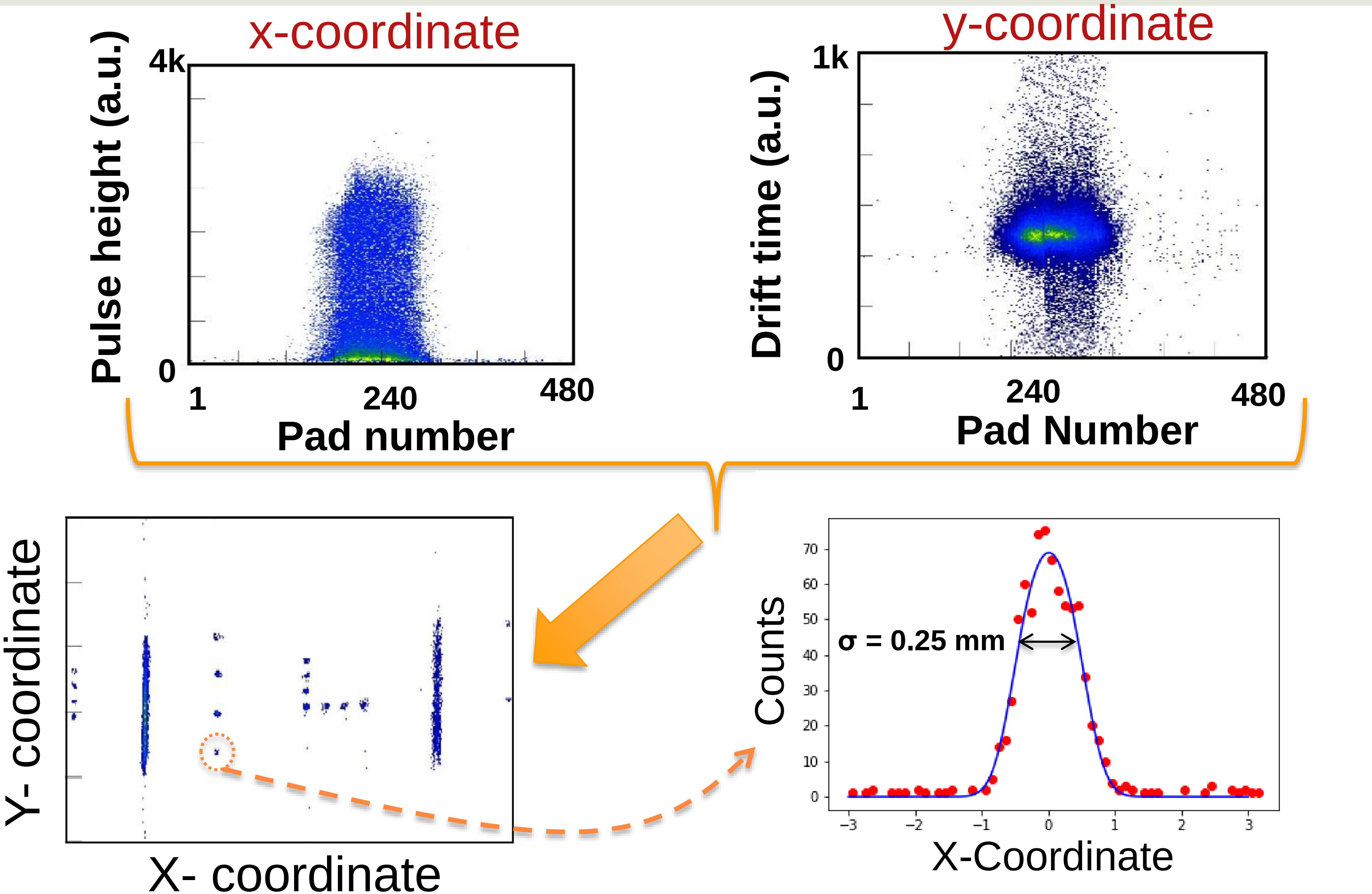
- Number of samples (up to 512 time "buckets")
- Clock "sampling" frequency (time/sample)
- Peaking time; gain
- ...

HITMAKER:
baseline + parabolic fit

- Pulse Height
- Peak location (time)

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

Localization Capability: preliminary results



Summary expected MPGD-DC properties

-) Simple (construction) and robust

→ expected lower aging problems compared to the CRDC

-) Better ions-backflow suppression

→ a few % compared to 60-70% of wire-based detector

-) High detector gain @ low pressure (MM+THGEM)

→ large dynamic range

-) High counting rate

→ faster gas + faster electronics + Multi-hit capability

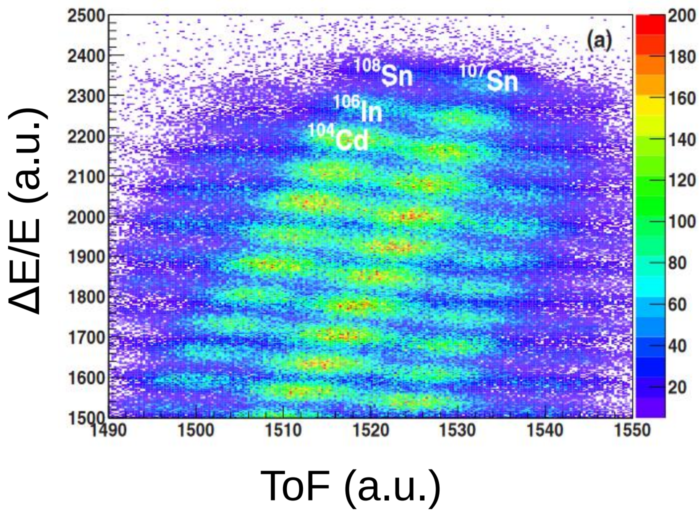
→ expected up to 3 time lower dead time (@ 5kHz beam rate)

-) High granularity (all pad are readout individually)

→ better position resolution along the dispersive coordinate (0.25 mm compared to 0.5 mm of the CRDC)

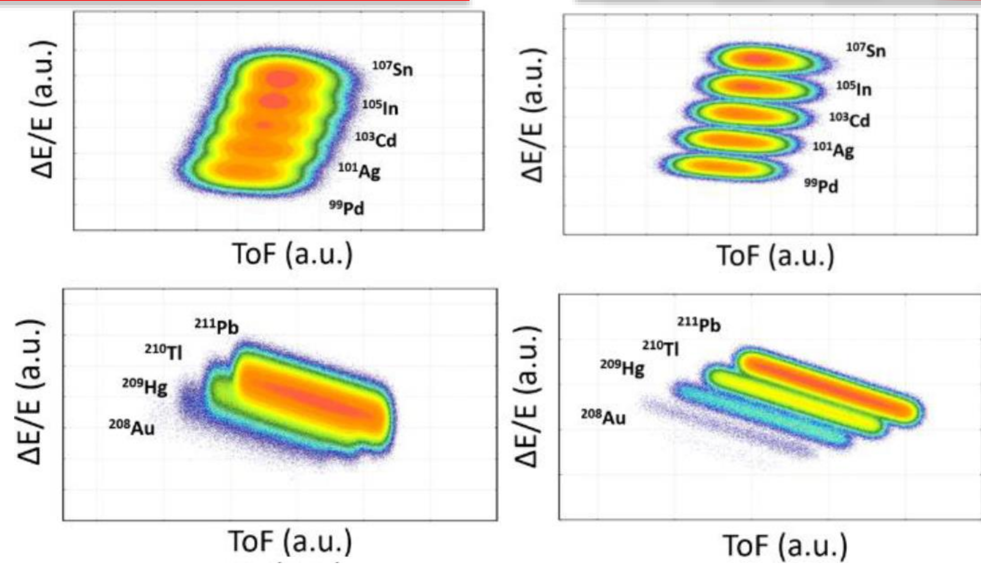
ΔE/E limit of the current S800 PID

- -) ToF typically of 100-150 ns (15 m reaction target – focal plane)
- -) Time resolution (plastic scintillator) ≈ 400 ps (FWHM)
- -) Energy resolution IC ΔE/E ≈ 1.2%
- -) Good PID resolution up to A < 100



Cerizza,et al, Phys. Rev. C 93, 021601 (2016)

(1.2%) *Present Ion Chamber* | *Proposed ELOSS* **(0.4%)**

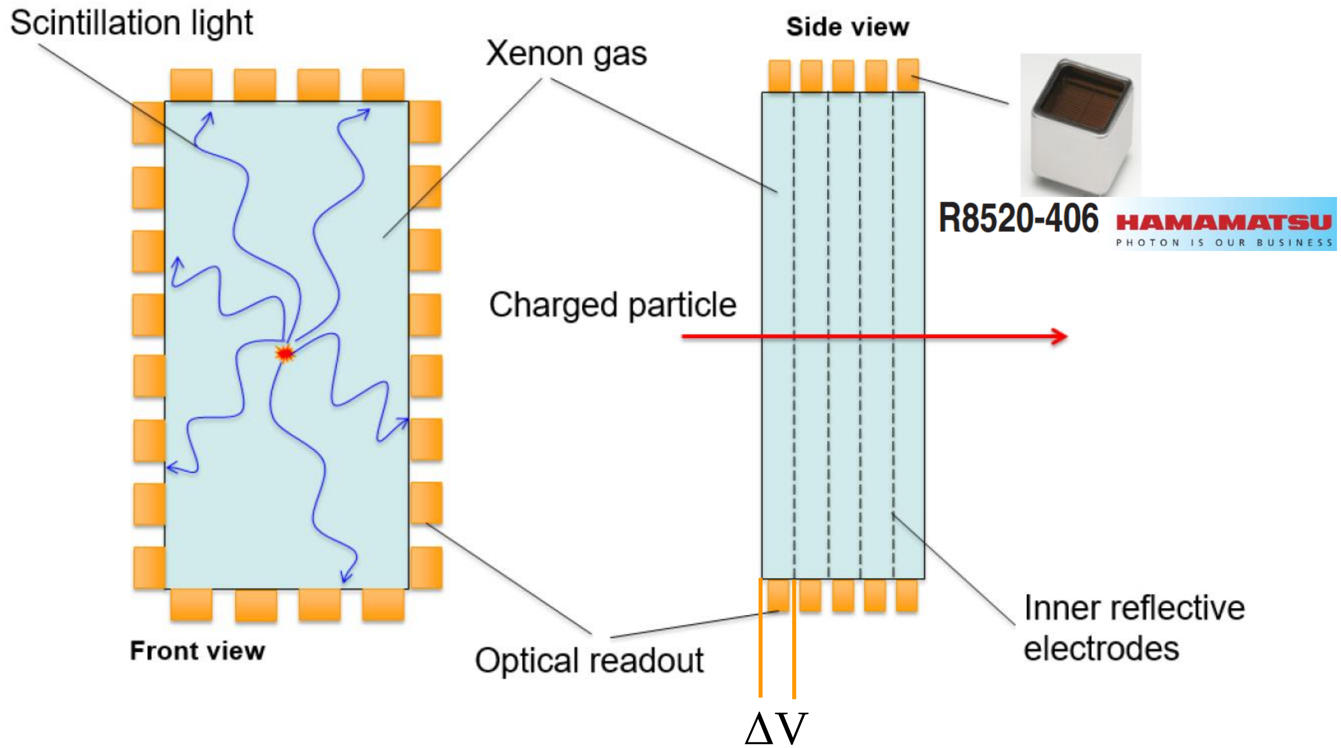


Lise++ Simulations

Improve ΔE/E to explore new regions of the nuclear chart for nuclear structure and nuclear astrophysical studies ➔ heavier beams expected from FRIB!

Goal 2 → ΔE/E measurement using Ionization chamber with optical readout

Energy Loss Optical Ionization System (ELOSS)



OIC operational principle:

-) Gas excitation created along the particle track -> optionally electroluminescence mode of operation

-) De-excitation with emission of prompt (fast decay time), scintillation photons (178 nm wavelength)

-) The light is reflected by Al-foils → large photon collection efficiency

-) Light readout with array of PMTs

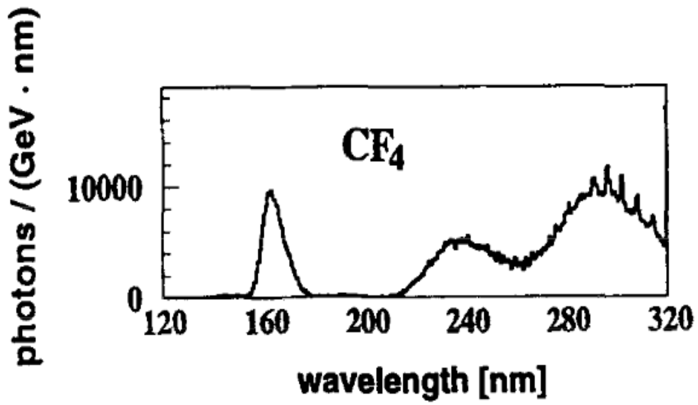
-) Processed information ➔ΔE/E, Timing, Position capability

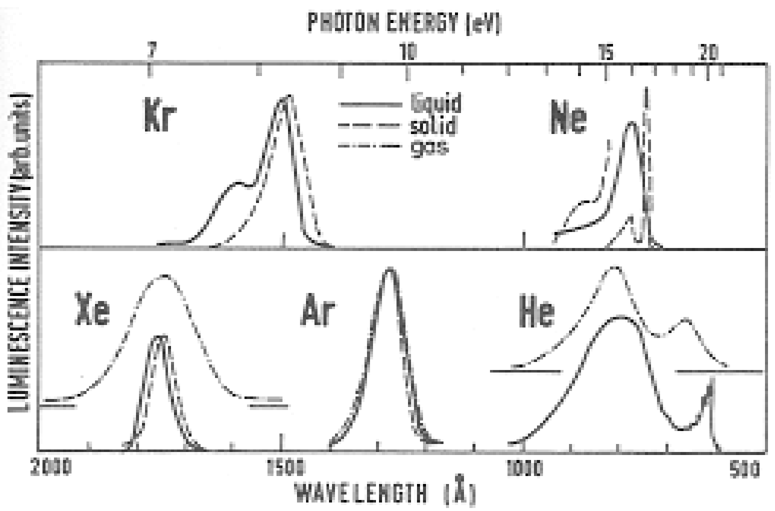
Choice of the scintillating medium

Noble gas & Mixtures

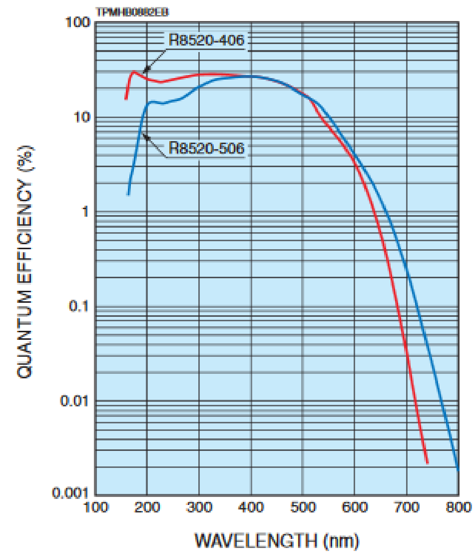
	Z (A)	ionization [e-/keV]	scintillation [photon/keV]
He	2 (4)	39	15
Ne	10 (20)	46	7
Ar	18 (40)	42	40
Kr	36 (84)	49	25
Xe	54 (131)	64	46

Alternative solutions → wavelength shifter
-) Halocarbon-14 mixed with a noble gas (i.e. Ar)
-) Ar/Xe mixture



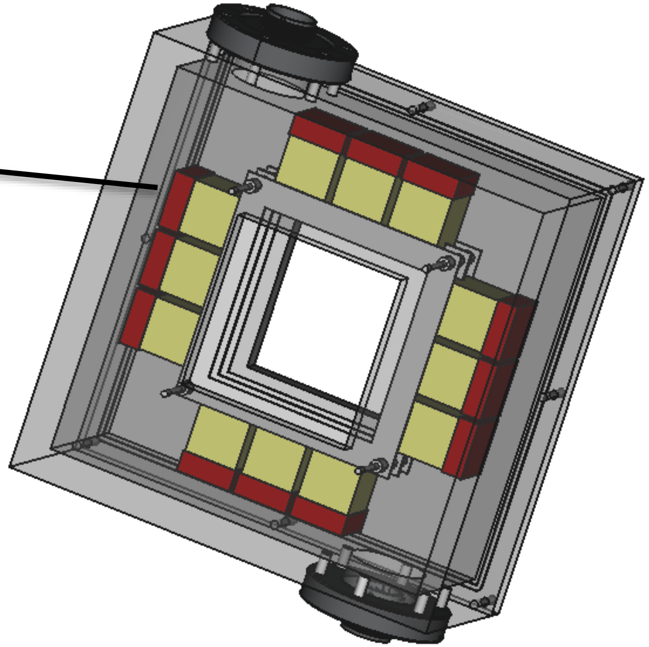


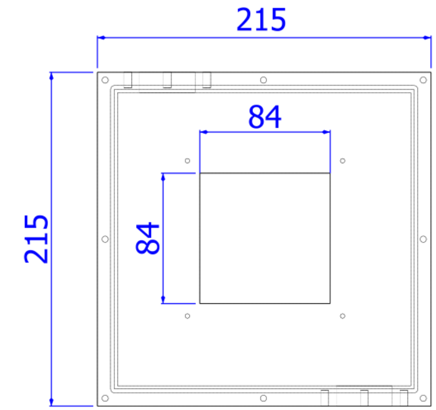
Developed for LXe-TPC
Dark Matter Search



ELOSS prototype: design and work plan

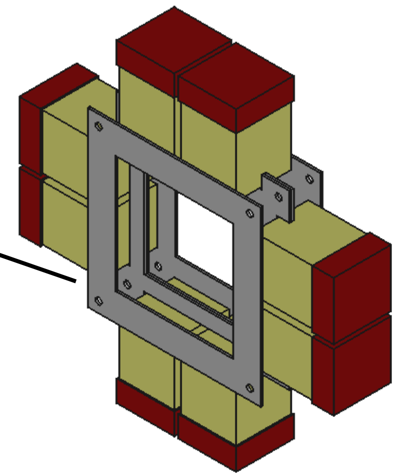
12 PMTs for an effective area of 84x84 mm^2





Stimulated scintillation configuration

Electrodes



Work plan:

-) Operation mode (Efficiency and resolution)

  -) Primary scintillation vs stimulated electroluminescence

  -) Scintillating gases (Xe, Xe/CF_4, Ar/Xe, …)

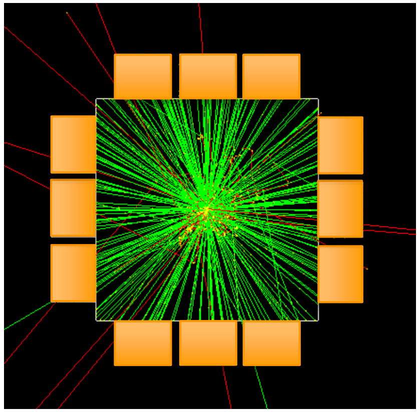
-) Electroluminescence yield vs voltage (ionization chamber mode)

-) Electroluminescence yield vs gas pressure

-) Time resolution under difference operational conditions

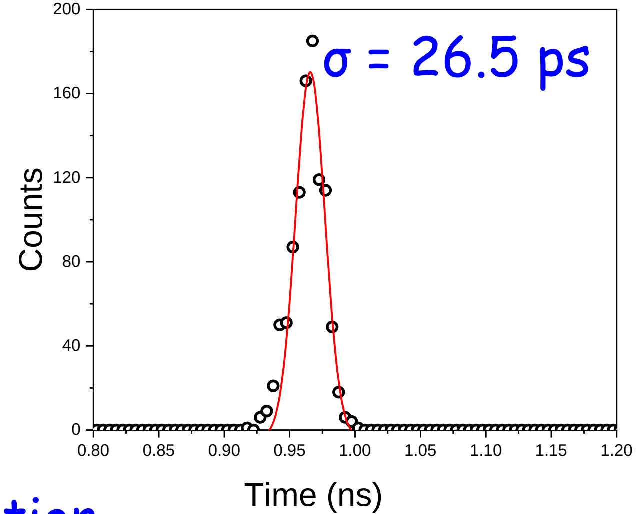
ELOSS Prototype: GEANT4 simulations results

1 atm Xe (2.5 cm absorption thickness)

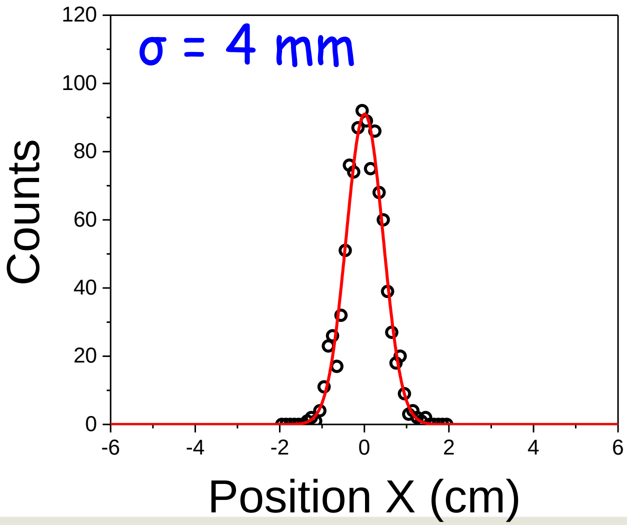


GEANT4 snapshot
with a reduced W_{SC}

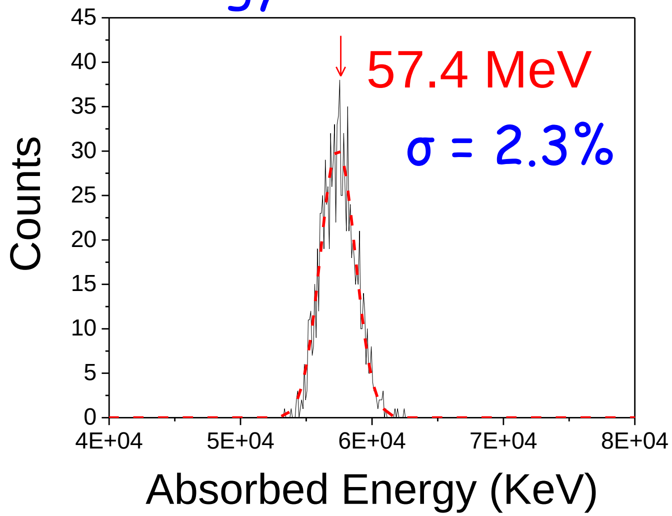
Time resolution



Position Resolution



Energy resolution



Summary expected ELOSS properties

Compared to conventional IC:

-) A ("3 times") better resolving power

-) Sensitivity to high-Z particles (above Z = 50)

-) Larger dynamic range (sensitive also to light particles)

➔ changing the pressure of the filling gas

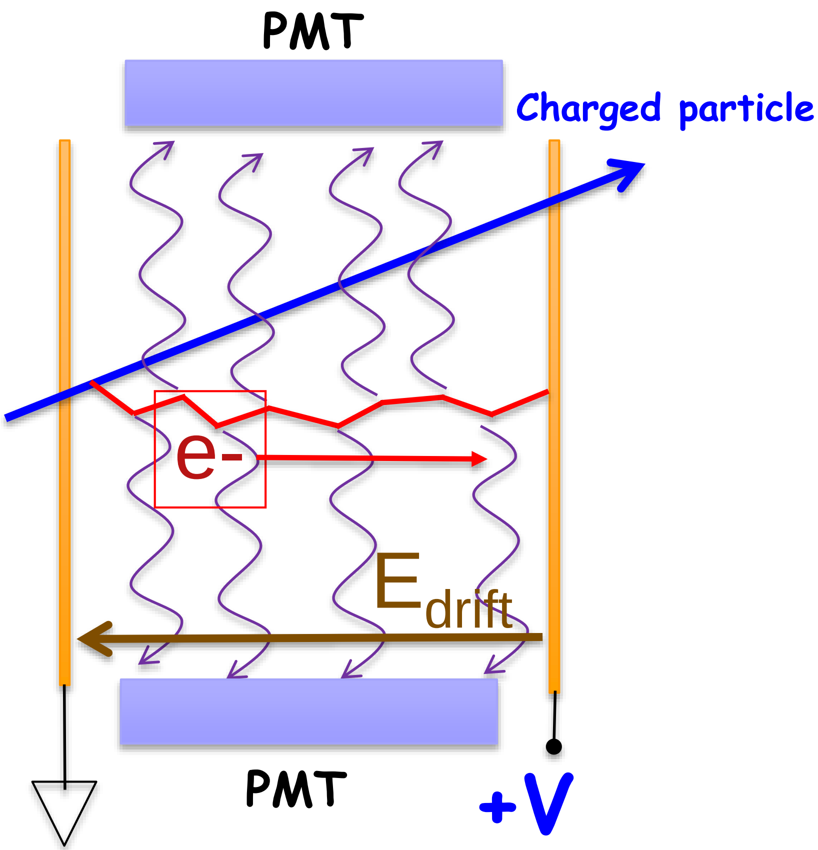
-) Higher rate capability (up to a few hundred of KHz)

➔ i.e. Xe the light is emitted within a few hundred ns

-) Good time resolution (< 100 psec) – not possible with IC

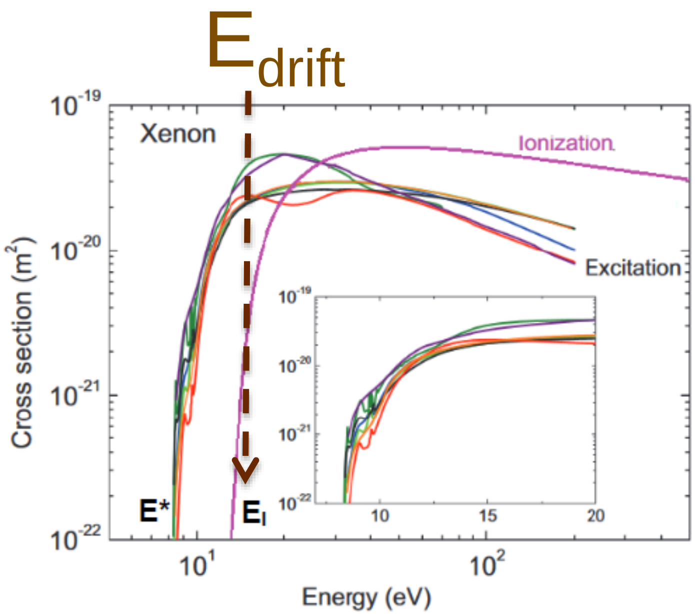
-) Localization capability (< 4 mm) – not possible with IC

Stimulated Light Emission



Properties of Electroluminescence (no amplification):

-) Good linearity (# of ph. vs ΔE/E)
-) Good intrinsic energy resolution (no amplification)
-) Large dynamic range (large pressure range)
-) Conversion region & (optical) readout capacitive decoupled
-) Single photo-electron sensitivity ➔ High SNR
-) Isotropic emission ➔ use reflectors for high ph. collection
-) No aging problems
-) Timing (a few tens of ps) and localization (a few mm)
➔ not possible with conventional IC

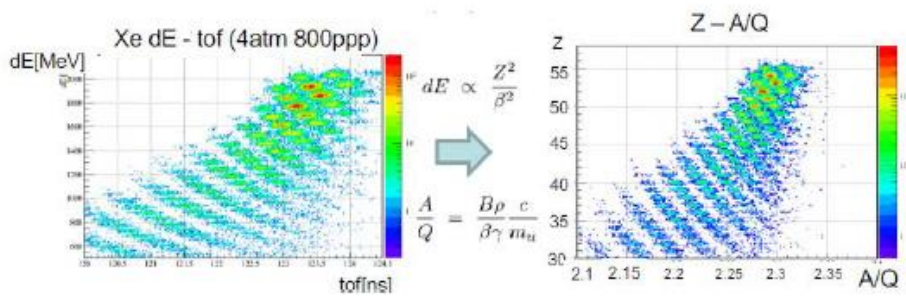


Preliminary results from other groups

Presented at the DREB2018 - 10th International Conference on Direct Reactions with Exotic Beams

Development of the gaseous Xe scintillation detector for the particle identification of high intensity and heavy RI beams

T.Harada[A,B], J.Zenihiro[B], S.Terashima[B,C], Y.Matsuda[B,D], H.Sakaguchi[E], S.Ota[F], M.Dozono[F], K.Kawata[F], K.Kasamatsu[B,D], S.Ishida[B,D]
Toho Univ.[A], RIKEN Nishina Center[B], Beihang Univ.[C], CYRIC, Tohoku Univ.[D]
RCNP, Osaka Univ.[E], CNS, Univ. of Tokyo[F],

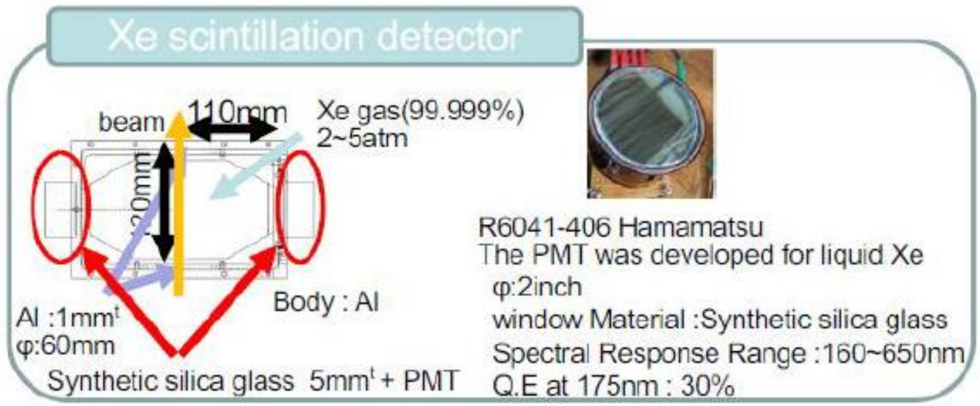


Energy resolution
- the energy resolution 1.0% is achieved. (Xe 3atm ~ 5atm)

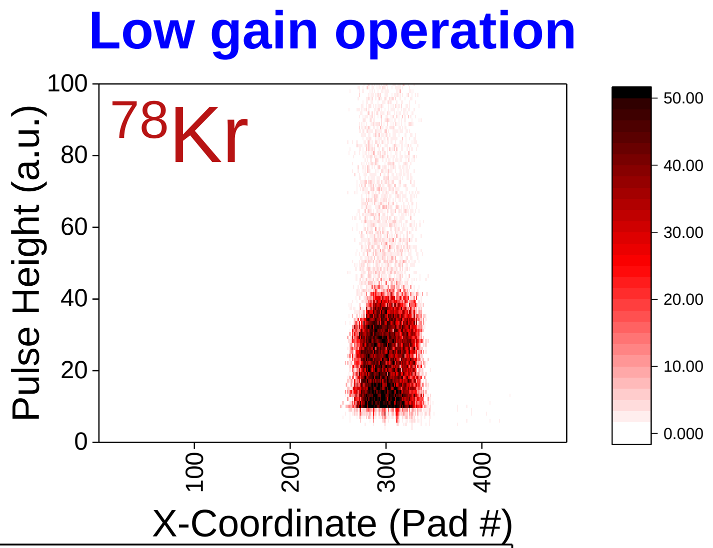
Time resolution (F3 Pla TDC - Xe TDC)
- The time resolution 130ps is achieved. (Xe 4atm)

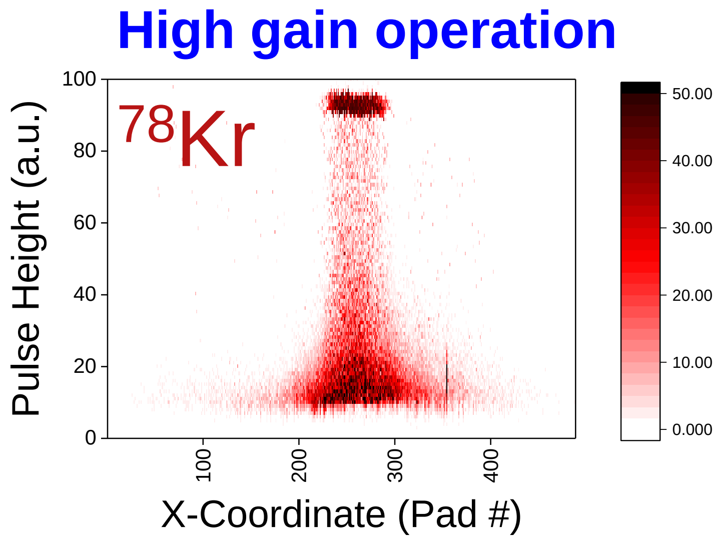
Secondary beam (A/Q ~2.3 @ 300MeV/u)

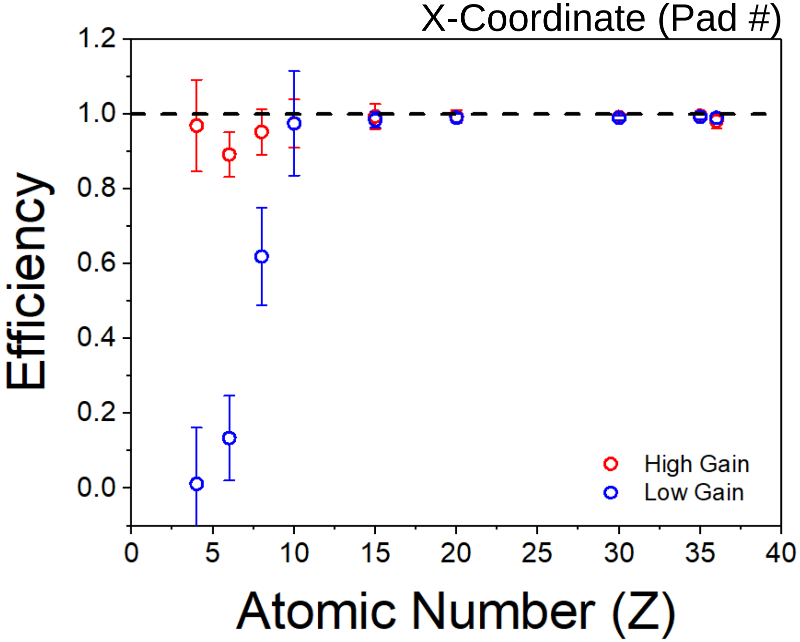
Z and A/Q were deduced from TOF between F1 Pla and F3 Pla and energy loss information of Xe detector, The resolution of ΔZ = 0.2 (5σ separation) is achieved.
- The resolution of dZ = 0.27 (Z=54) in high rate beam (55kppp) is achieved. (low rate : dZ = 0.19 at Z=54)



Detector efficiency vs Z-number







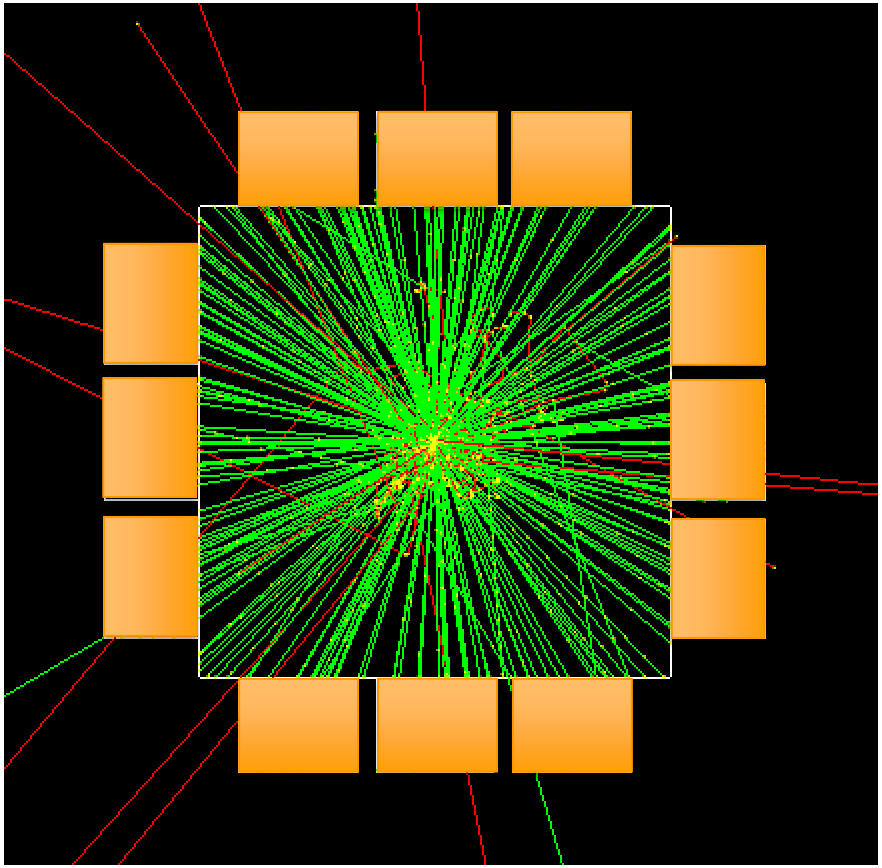
Large dynamic range!

Full detection efficiency for light elements (Z<10) recovered @ high detector gain.

Localization of saturated traces based on fitting distribution tails.

ELOSS Prototype: GEANT4 simulations

GEANT4 snapshot with a reduced W_{SC}



Beam ➔ $^{78}Kr^{36+}$ (140 MeV/u)

GEANT4 parameters (Xe gas)

Primary scintillation yield W_{SC} = 7 ph/KeV

Literature ➔ 13.8 ph/KeV soft X-rays – Arxiv:1009.2719

➔ 16.3 ph/KeV gamma - Arxiv:1409.2853

A lower W_{SC} is used to take into account gas impurity quenching & other effects (filling factor =0.64)

Hamamatsu PMT QE ➔ 30%

Xe gas pressure ➔ 1 atm

IC length ➔ 25.7 cm

Foil reflectivity = 100% (Al foil) **-> ≈90%**