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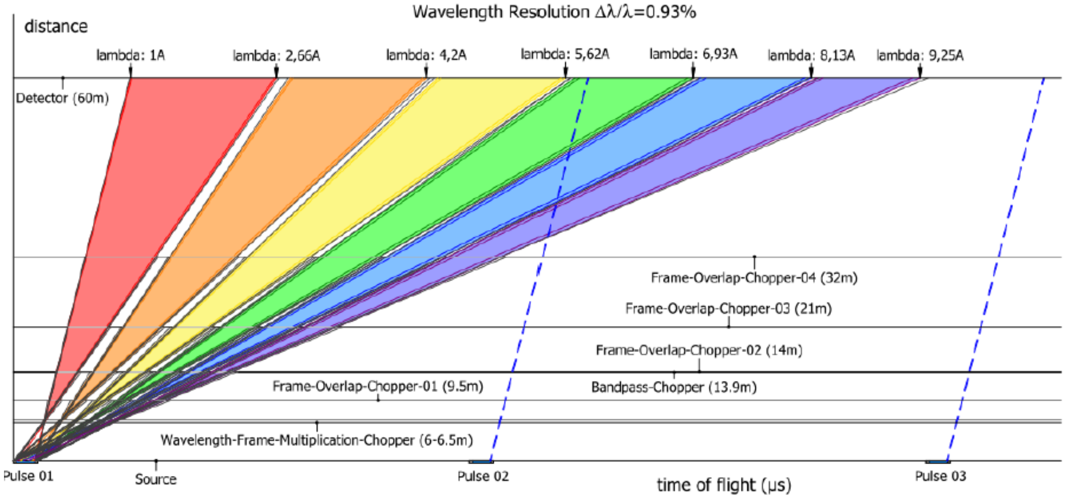
Detectors for the ODIN beamline

11.9.2018

Imaging at ESS: ODIN beamline

- Same time-averaged flux as ILL, but with time structure
- Complex geometry of guide system to transport a large fraction of neutrons to the detector 60m away from the source
- Elaborate chopper system to shape the beam and tune energy resolution
- Wide range of applications:
  - Hydrogen detection in energy research
  - Magnetic structure observation for material science and engineering
  - Crystallinity studies of building materials
  - Space-resolved SANS for biology
  - And many more!
- But we need detectors!



Detector requirements for ODIN

- 3 main requirements:

1. High spatial resolution (< 10 um)
2. High temporal resolution (< 1 us)
3. Big Field of View (> 20 x 20 cm2)

- … plus others such as high repetition rate, strong resistance to radiation…

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Temporal resolution

Field of View

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Spatial resolution

Scintillator+camera

A-Si flat panel detector

Imaging plate

Field of View

Temporal resolution

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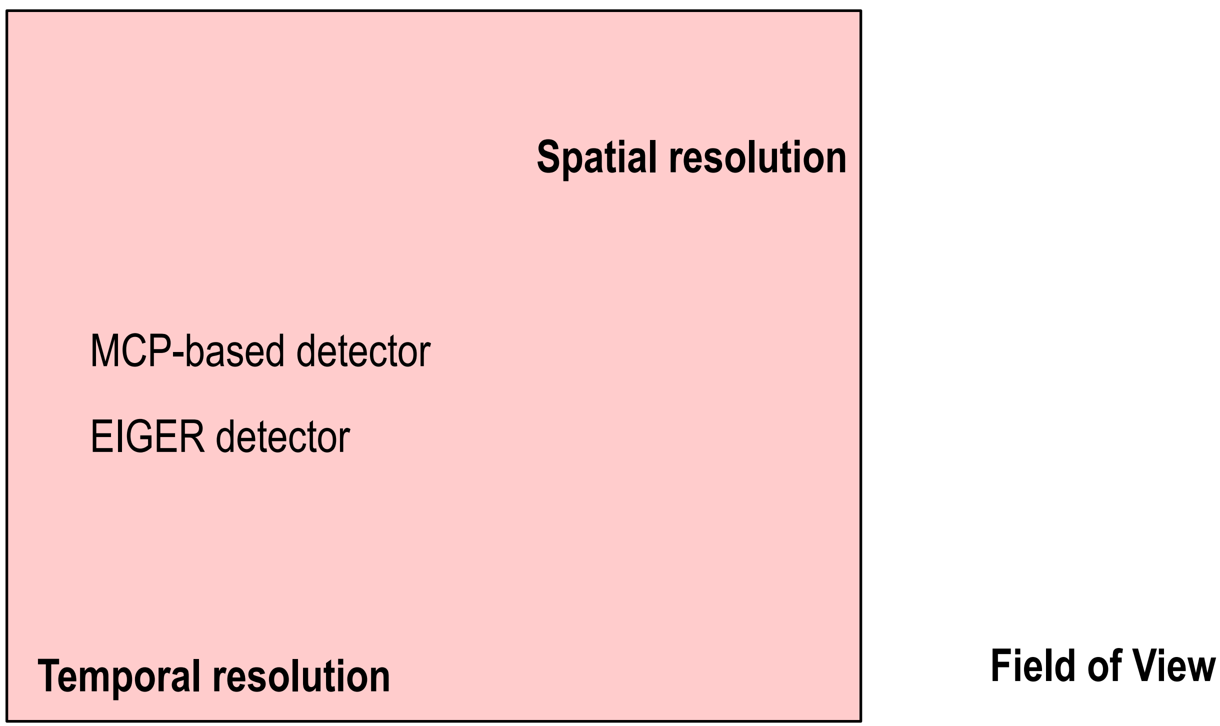

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CIPix

Delay-based wire chambers

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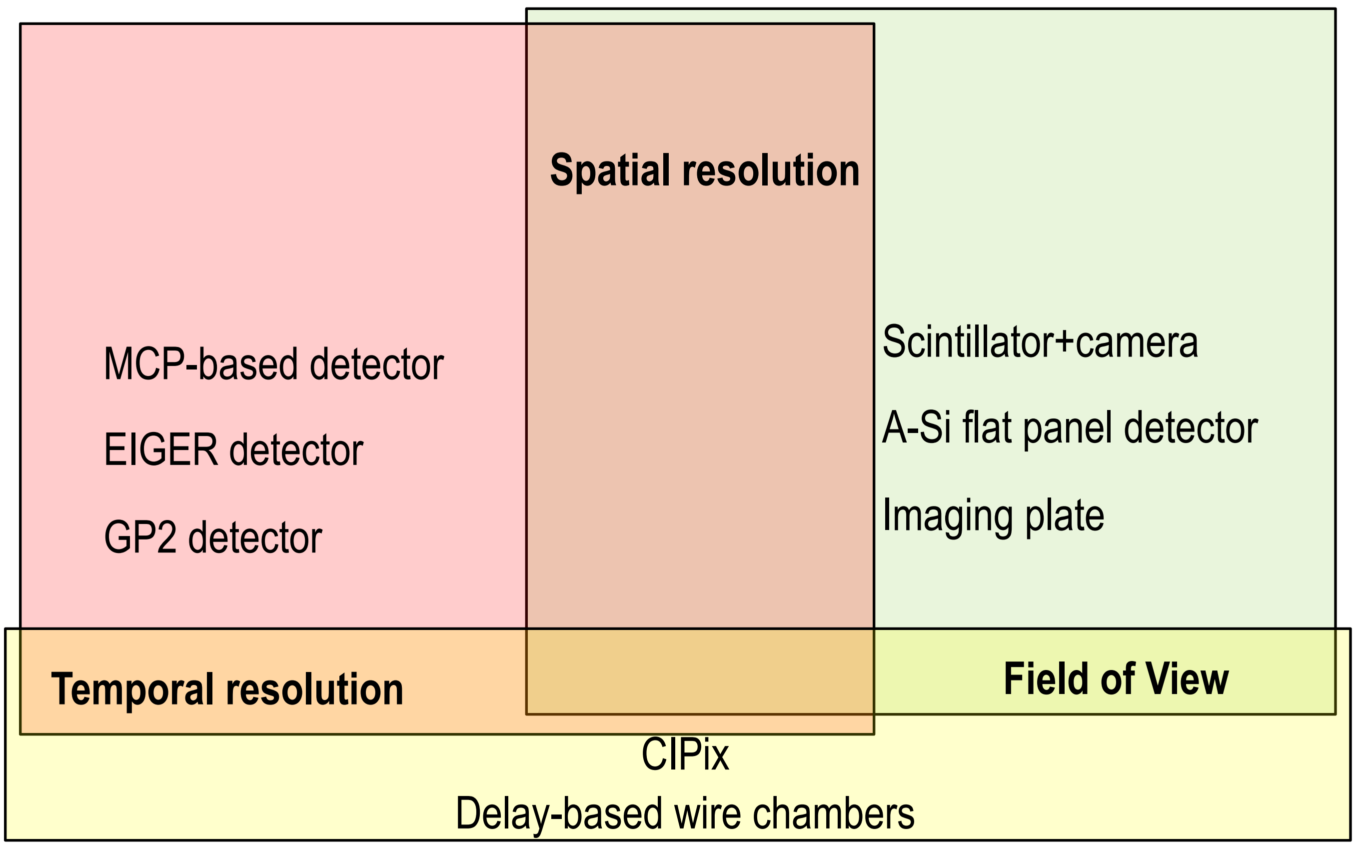

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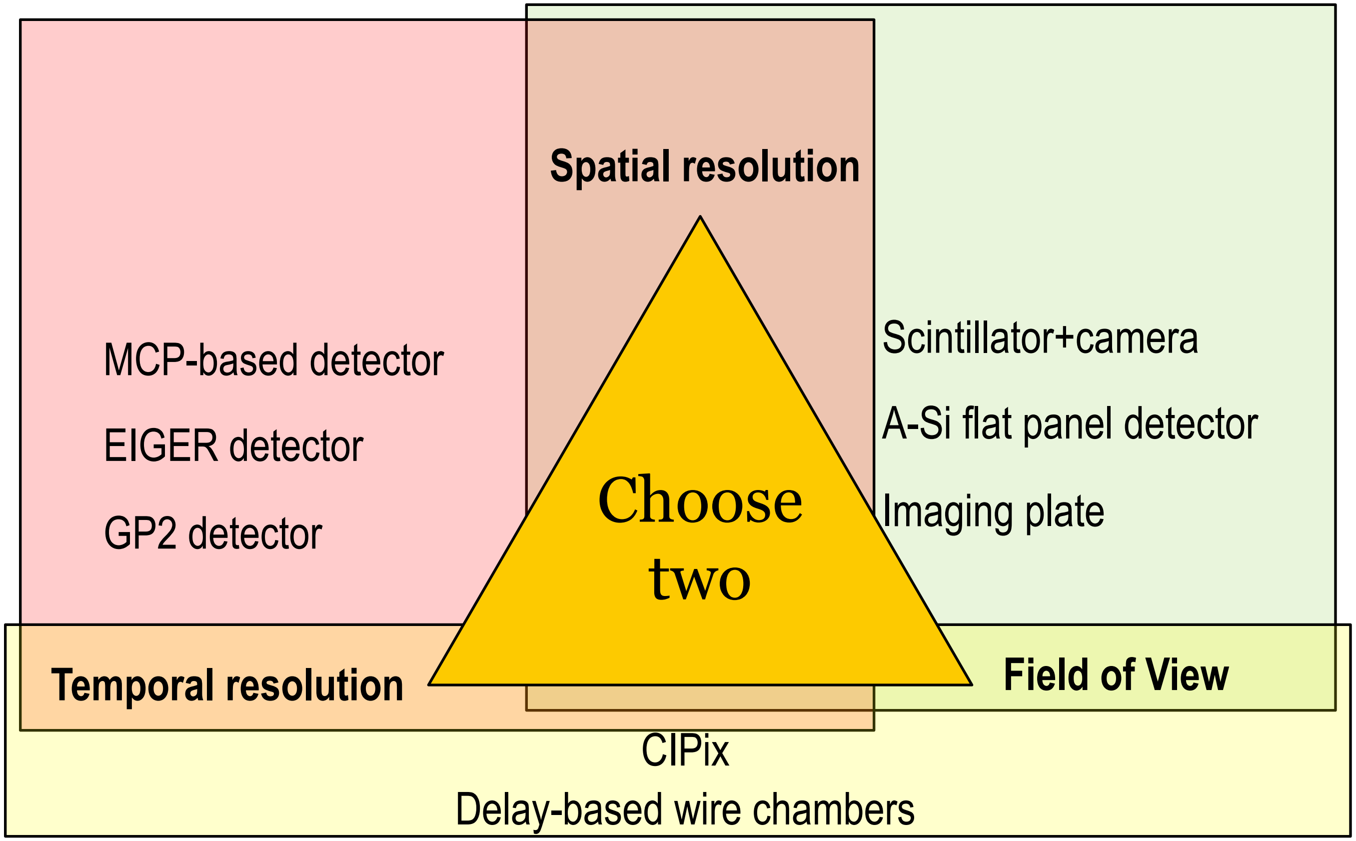

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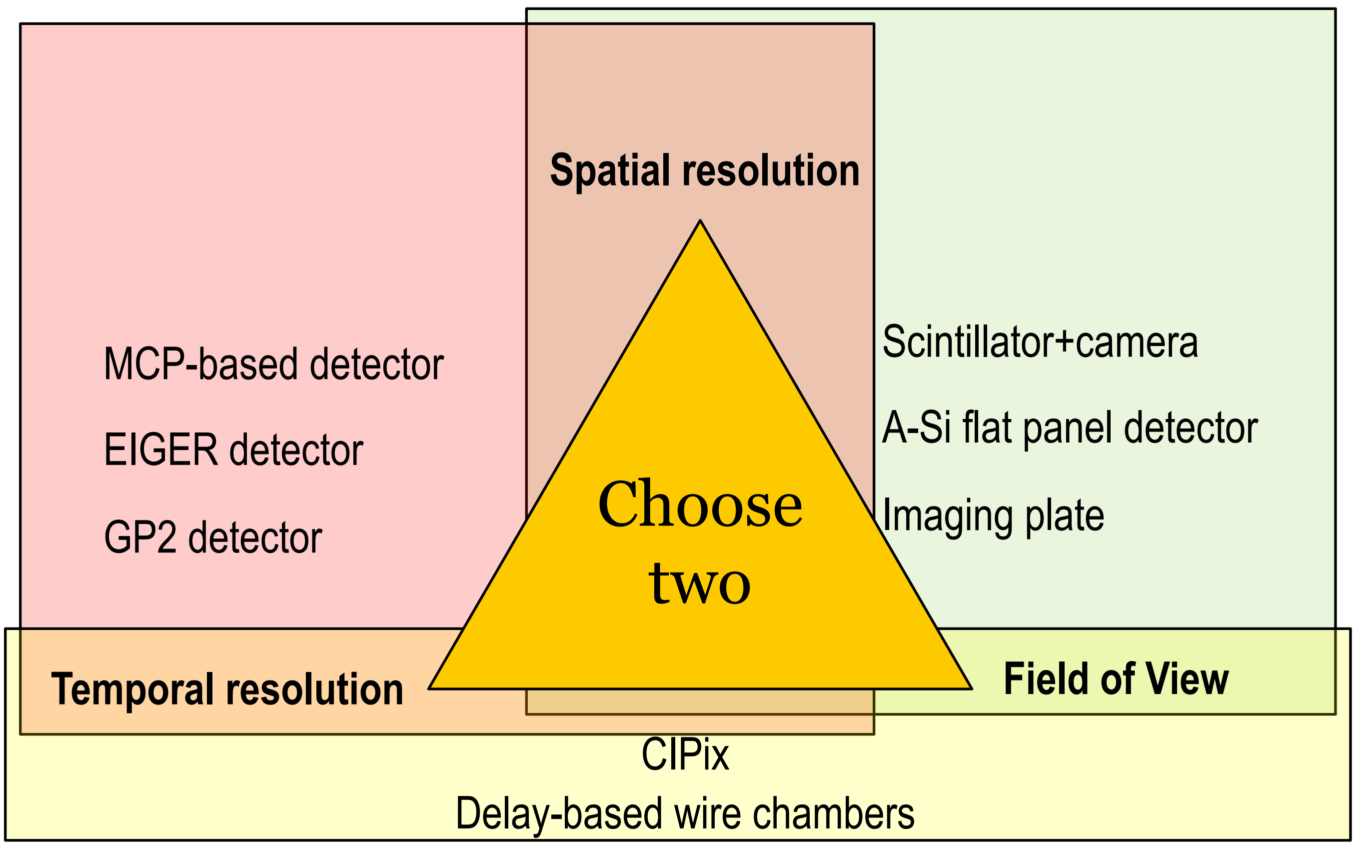
No detector currently achieve all these goals at the same time, a suite of detectors will be needed



Spatial resolution + Wide field of view

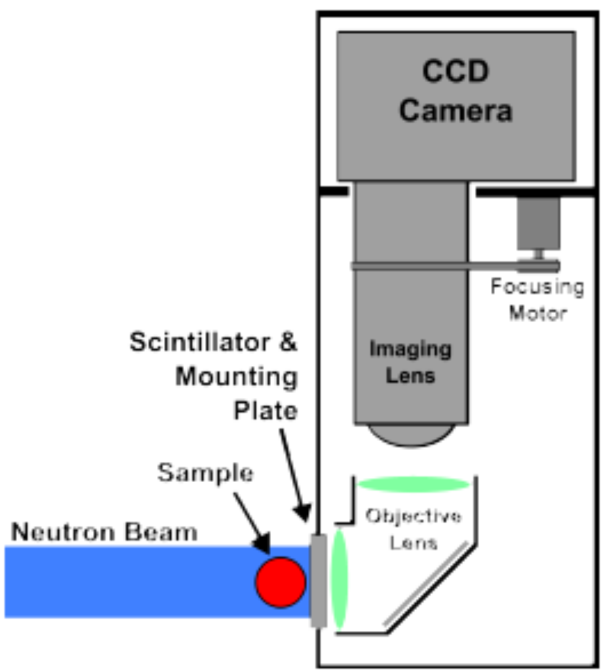
- 3 main options available:

	Resolution	Field of view	Speed	Technological readiness	Downsides	Applications
Imaging plate	✓✓	✓✓	✗	✓	SLOW!!!	White beam imaging with high resolution of big objects
Camera + scintillator	✓✓	✓	* ✓	✓		Working horse!
a-Si flat panel	✓	✓	✓	✗	Not ready yet	White beam imaging when space is an issue

Camera-based detectors

- Customizable FoV and pixel size
- CCD camera are most common, but slow
- sCMOS are picking up, and they are much faster

- NOT (yet) fast enough for ToF resolved imaging at the highest energy resolution



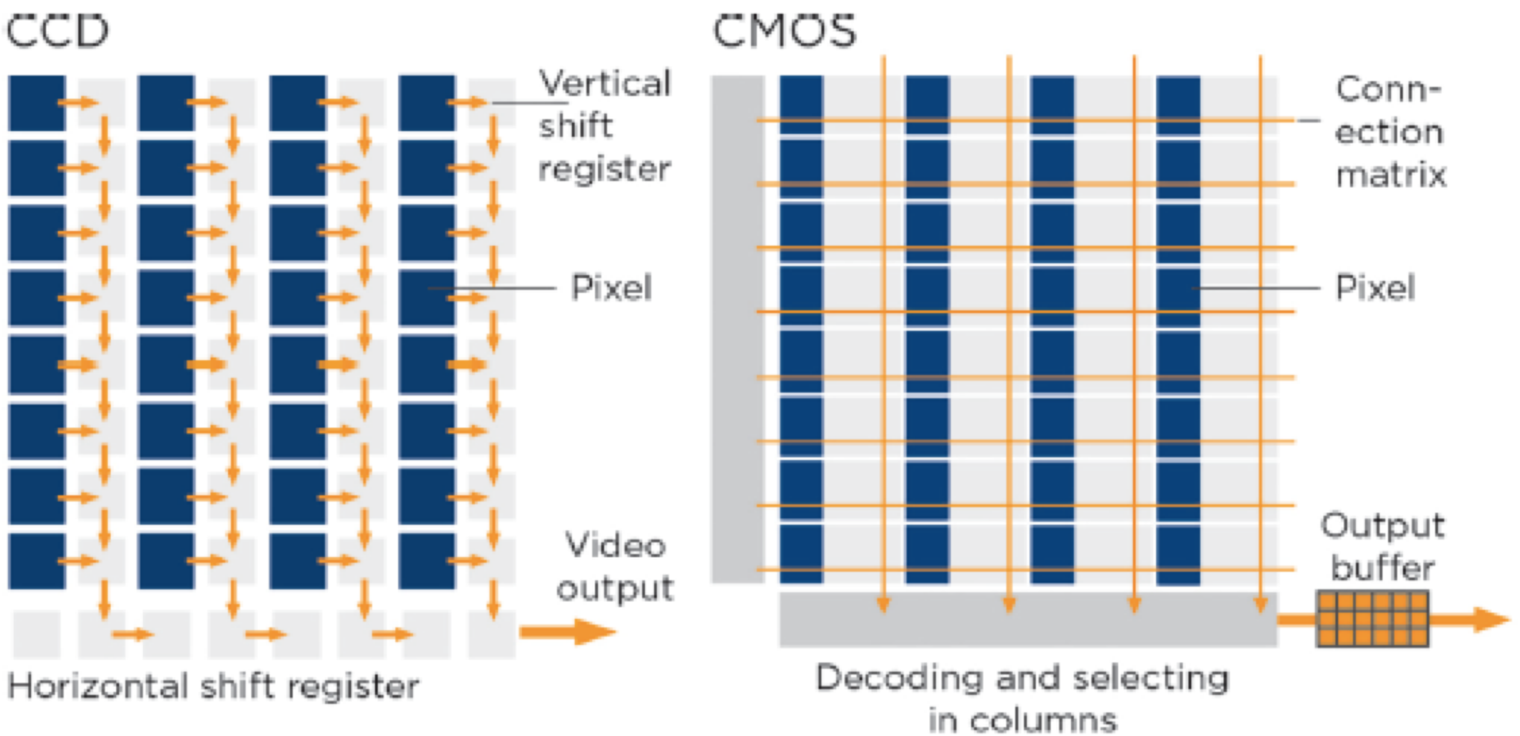
doi:10.1088/1748-0221/7/02/P02014

Desirable upgrades

Cameras:

1. Faster readout
2. Smaller pixels

CCDs vs sCMOS



S

CCDs vs sCMOS

CCD

- Charge Coupled Device

- Most commonly used
- More expensive than sCMOS
- Can be cooled more than sCMOS
- Has lower noise levels
- Has an exposure time-dependent DC
- Can be exposed for longer time (typically higher full well capacity)
- Long readout time
- More pixel area is photosensitive (better low light performances)

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sCMOS

- (scientific) Complementary Metal Oxide Semiconductor
- More and more widespread
- Cheaper than CCD
- Cooled to a higher temperature
- Higher noise level
- DC is constant
- Limited exposure time
- Fast readout (up to >100 full frames per second)
- Lower low light performances

Scintillators

- Two main branches:

1. Tertiary compounds (absorber + phosphor + binder): e.g. LiF + ZnS:Cu + binder
2. Binary compound (absorber and phosphor in the same molecule + binder): e.g. Gadox + binder

- Late onset of scintillation and afterglow limit their use for time dependent imaging

$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H$

$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He + \gamma$

$n + {}^{nat}Gd \rightarrow Gd^{*}$ + conversion electron

Desirable upgrades

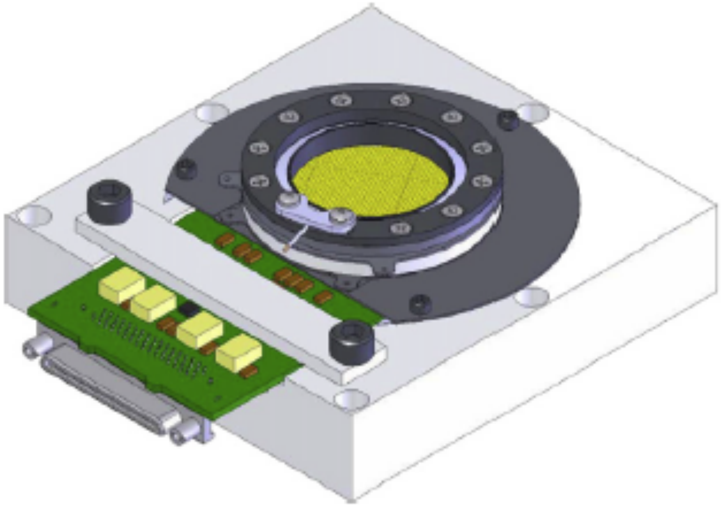
1. More stability
2. Faster scintillation
3. Pursuing ^{10}B-based materials
4. Engineering

Spatial resolution + temporal resolution

- MCP-based detectors are already on the market right now

- Time resolution: 1 us
- Spatial resolution: 50 um (15 um in centroid mode)

- The field of view is small
- At the highest possible resolution, the flux they can accept is limited



doi:10.1016/j.nima.2008.03.116

Desirable upgrades

MCP:

1. Bigger FoV
2. Higher accepted flux
3. Better linearity
4. No readout gaps

Example: MCP based detector (Berkeley)

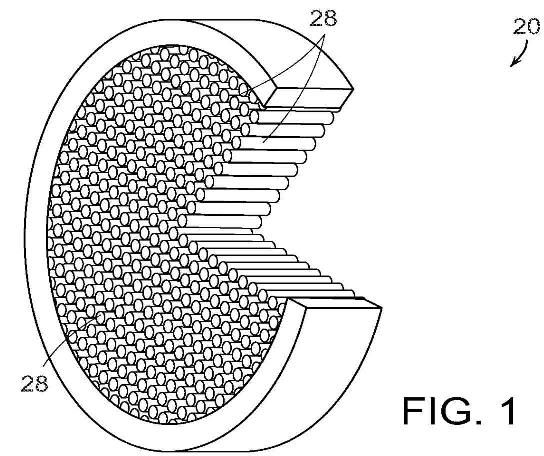
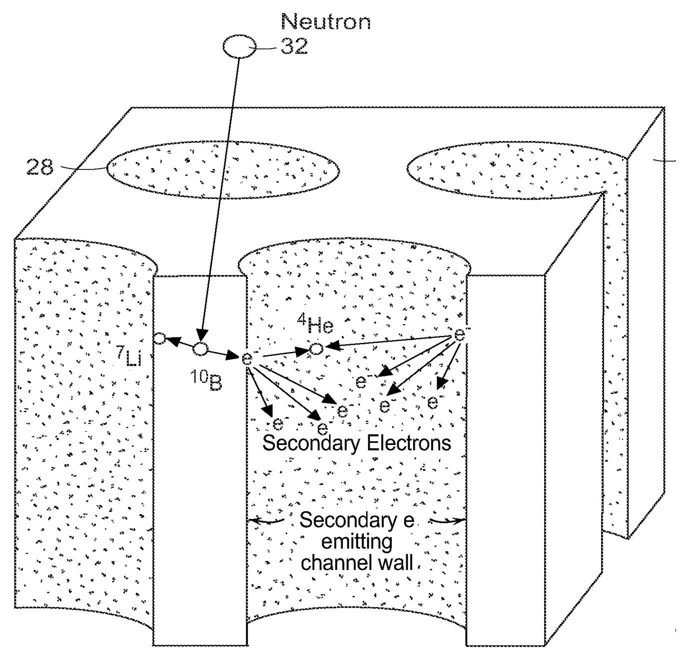


FIG. 1



Example: MCP based detector (Berkeley)

- ^{10}B-loaded glass Micro Channel Plate (MCP)
- Reaction particles create e-
- e- are accelerated and multiplied by HV in vacuum
- TimePix chip readout
- 55um pixel size (fixed)
- 256 x 256 pixels chip, stacked in a 2 x 2 matrix
- Seams between chips
- 28 x 28 cm2
- Single particle counting and arrival time mode
- Able to calculate centroiding
- ns timing capabilities
- Limit on the total flux (10^7n/s/cm^2)
- Readout gaps for buffer reading (older versions)
- Noiseless (except Poisson's)
- BONUS! Resonance imaging

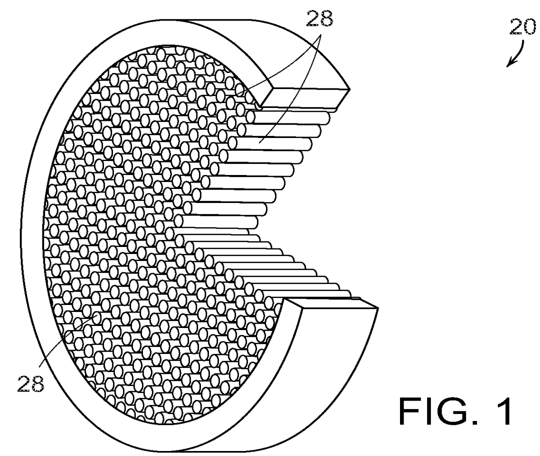
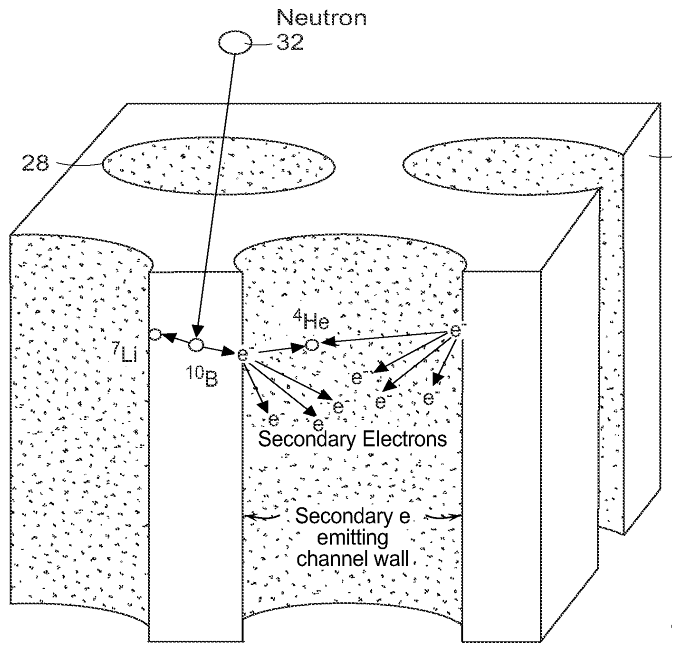
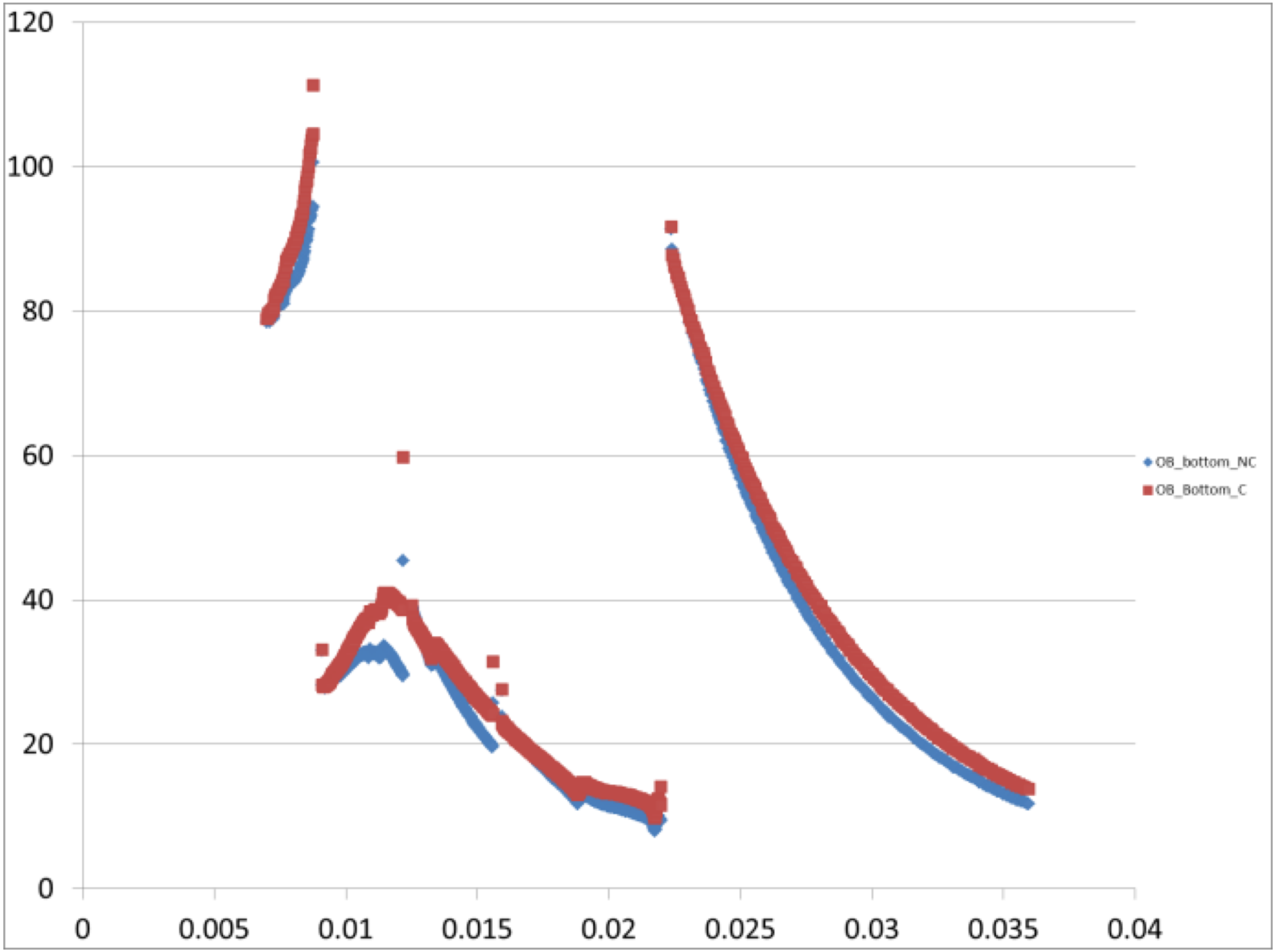


FIG. 1



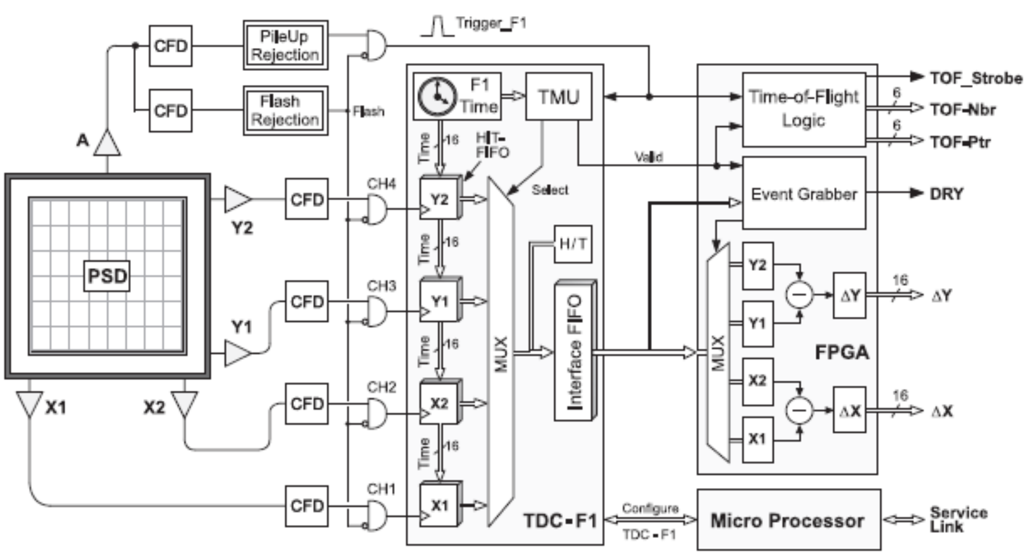
Overlap correction



Field of View + Time resolution

- Delay-line based wire chambers from scattering community
- ToF resolution: 1ns
- Field of view: 30 x 30 cm2 (or more)
- High neutron cross section
- Low gamma sensitivity

- Spatial resolution: 1mm
- Limited count rate capabilities



DOI: 10.1007/s003390201651

Desirable upgrades

Delay-line wire chambers:

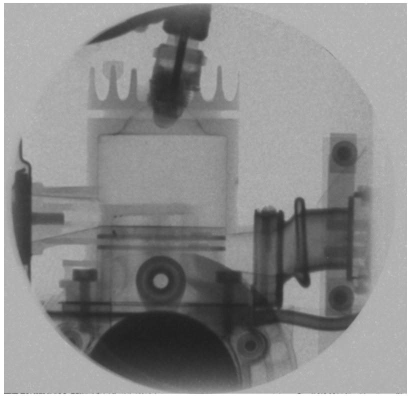
1. Smaller pixels
2. Higher accepted flux (somewhat comes along the first requirement)

Special conditions setups

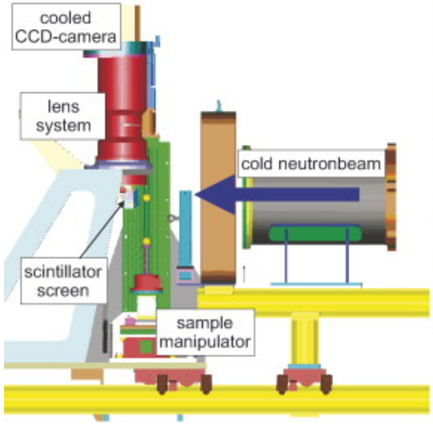
The aforementioned setups do not cover the whole range of scopes of ODIN

Special setups (and special detectors) are foreseen for special conditions.

1. Stroboscopic imaging:
   1. a time-gated and intensified camera
   2. An ad-hoc software for storing different frames per cycle



2. Very high resolution imaging (<10 um)
   1. Ad-hoc camera
   2. Ad-hoc scintillator
   3. Ad-hoc optics (both neutrons and camera objective)



DOI: 10.1016/j.nima.2007.03.017

A word about data rate and volume

Detector type	Technique	file size (MB)	exposure time per file	number of file per hour	data rate (GB/h)	typical exposure time / experiment	data volume (GB) / experiment
Camera	White beam radiography	8	10 s	360	2.8	1 h	3
	White beam tomography/time series	8	10 s	360	2.8	10 h	28
	Fast white beam tomography	8	0.01 s	360000	2812.5	10 min	469
	Fast white beam time series	8	0.01 s	360000	2812.5	10 s	8
MCP	ToF radiography	0.5	30 min	6000	2.9	2 h	6
	ToF tomography	0.5	20 min	9000	4.4	24 h	105
	ToF time series	0.5	2 min	90000	43.9	5 h	220
	ToF NGI	0.5	15 min	10800	5.3	10 h	53

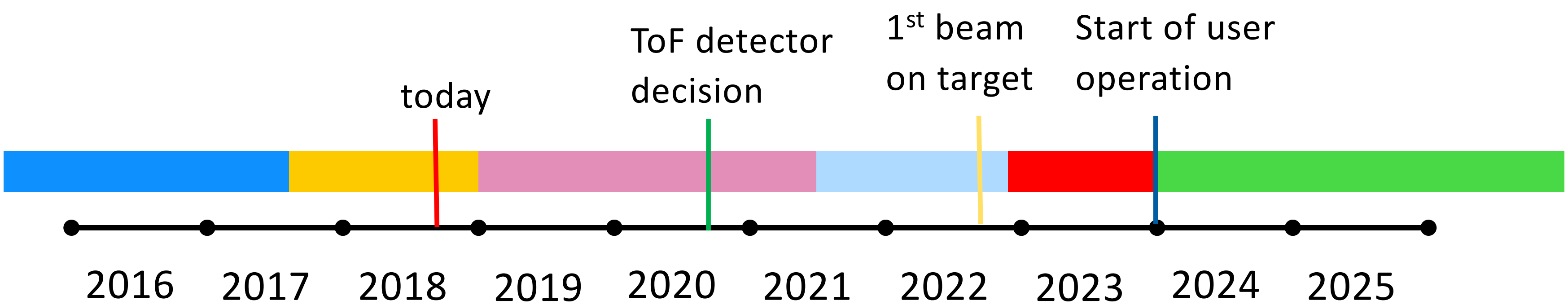
Numbers given for a current experiment at a medium flux facility

Red numbers: limited by flux

Green numbers: limited by (current) technology

Remarks

- Detectors for ODIN are commercial products
- All already implemented in EPICS in some forms
- All controllable with NICOS
- The choice of the specific detector/technology will be made later in the project to leverage the best/latest developments (2020)



- "event mode" might mean something different
- Event mode should be first demonstrated and then potentially employed at ODIN
- In the meantime, standard "image-by-image" mode shall be still available, at least in parallel

Thank you for your attention!

PAUL SCHERRER INSTITUT PSI

A word about data rate and volume

Step	Measurement	Raw data produced (GB)	exposure time (h)	average data rate (GB/h)	raw+corrected (GB)
1	Radiographs	22.0	14.5	1.5	65.9
2	Furnace test	5.2	1	5.2	15.6
3	Sample alignment	0.5	0.5	1.0	1.5
4	Measurement sample 1-3	33.0	17	1.9	99.0
5	Radiographs	20.0	8	2.5	60.0
6	Alignment	1.0	0.5	2.0	3.0
7	Tomography	63.0	24	2.6	189.0
8	Measurement sample 4-6	49.0	14.5	3.4	147.0
9	Calibration sample	0.5	0.5	1.0	1.5
	total	**194.1**	**80.5**	**2.4**	**582.4**