Detectors for the MBA Lattice

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for the XSD Detectors Group

16 October, 2013

Dreams and Detectors:

Please re-evaluate detector plans…

See this as an opportunity to do something really nice for the facility…

George S., post BESAC report

http://www.flickr.com/photos/argonne/3863002428/

This talk:

- Open questions:
  - What are the detector priorities for the MBA lattice?
  - What needs are likely to be met by industry?
  - What would you like to see developed by the Detectors Group?
- Goal: Get you dreaming about detectors before the workshop

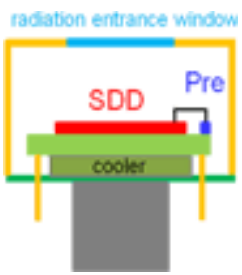
- Outline:
  - Perceived needs
    - Spectroscopic Detectors
    - Area Detectors
    - Other
  - New detectors available commercially within the next few years
  - Possible development directions unmet by industry and solicitation for feedback
    - Suggestions in need of feedback and motivation
  - Programs to preview new detector technologies at the APS

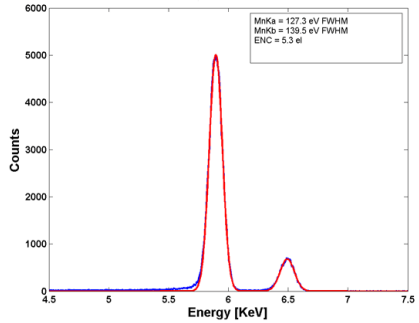
Spectroscopic Detectors

1. High throughput spectroscopic detectors:
   - Most common request of all
   - SDDs top out at ~200 kHz, limitation with current source
   - Trade-off: Good resolution requires shaping time of ~several μs
   - Potential is there with silicon - bottleneck is electronics
2. SDD arrays; integrated detectors
   - Well planned instruments with detector optimized for particular science
   - Increasing # of elements and covering more solid angle – will also increase total rate
3. High energy spectroscopic detectors
   - Much work with Vortex done >20 keV; NSLSII turn-on may push energies higher
   - Options other than germanium
4. High Resolution spectroscopic detectors
   - Silicon limited to ~125 eV (FWHM) for Mn K_α, but could do game-changing science with 1-2 eV resolution
   - Superconducting technologies: Mkids, TES

Spectroscopic Detectors: High Throughput Electronics

XGLAB
X and Gamma Ray Electronics





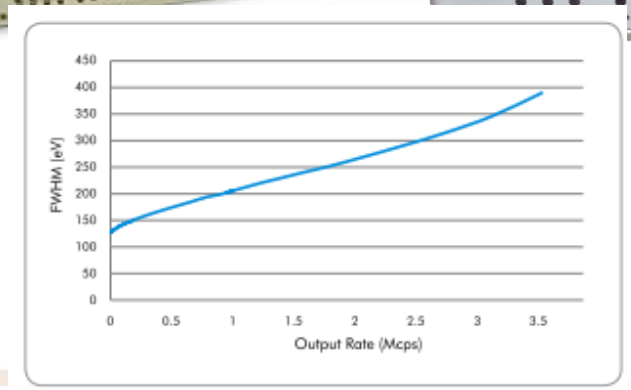
127 eV FWHM with 250 ns peaking time

Cube pre-amp:

- Italian company marketing readout ASIC for SDDs
- Lower capacitance than standard JFET readout – better noise performance; good Si resolution with fast shaping times
- Available on next-gen SDDs (Ketek, Amptek, Vortex)
- Pictures and more info: http://www.xglab.it/

New shaping electronics:

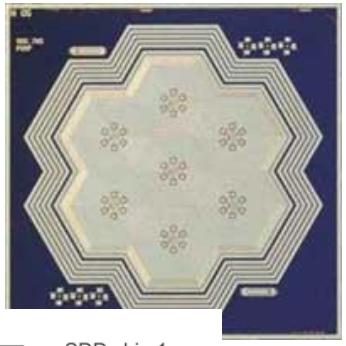
- FalconX from XIA and Xpress3 from Quantum use advanced fitting techniques to lower shaping time
- MHz rates from standard (JFET) SDDs
- Images and more info: http://www.xia.com, http://www.quantumdetectors.com



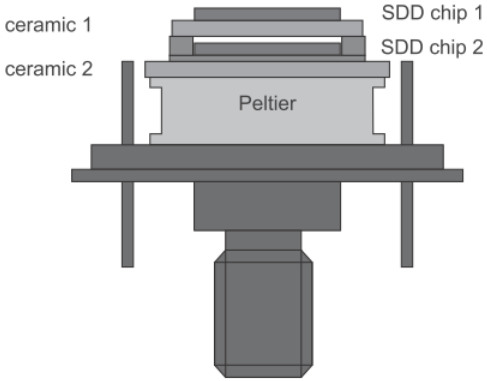
Energy resolution vs. count rate for Xpress 3

Spectroscopic detectors: PNSensor

- PNSensor makes and sells silicon drift detector elements
  - Found in many commercial SDDs (Bruker)
- Makes large-area, multi-element SDD arrays in various configurations
  - Up to 5 cm^2 active area in many channels
  - Vortex ME4 has only 150 mm^2 active area
- Sensitivity at higher energies:
  - Stacked assembly of two 450μm-thick SDDs
  - Double efficiency at higher energies.

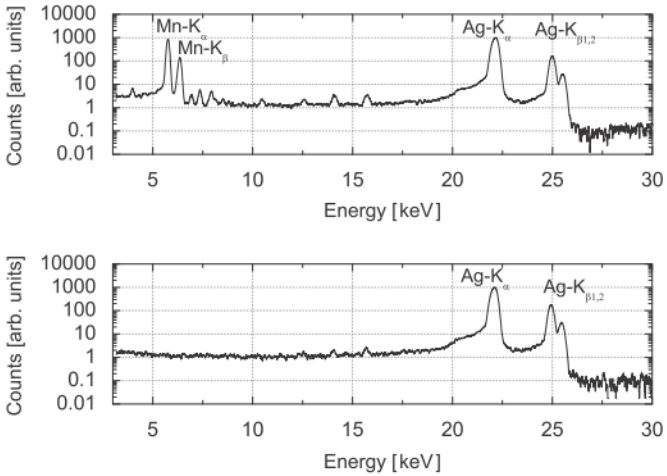


Source: http://www.pnsensor.de/Welcome/Products___Sales/SDD_Multi_Cells/index.php



Stack of two SDDS: Essentially doubles efficiency at higher energies.

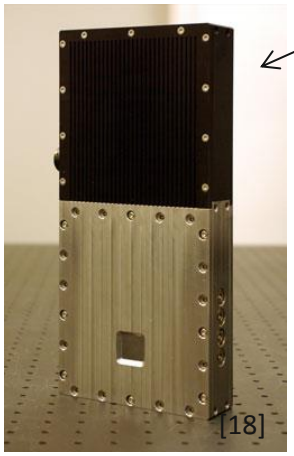
Spectrum from each diode – lower energy lines do not penetrate 1st diode.



Source: D.M. Schlosser et al, NIM A 624, (2010), 270-276.

Spectroscopic Detectors

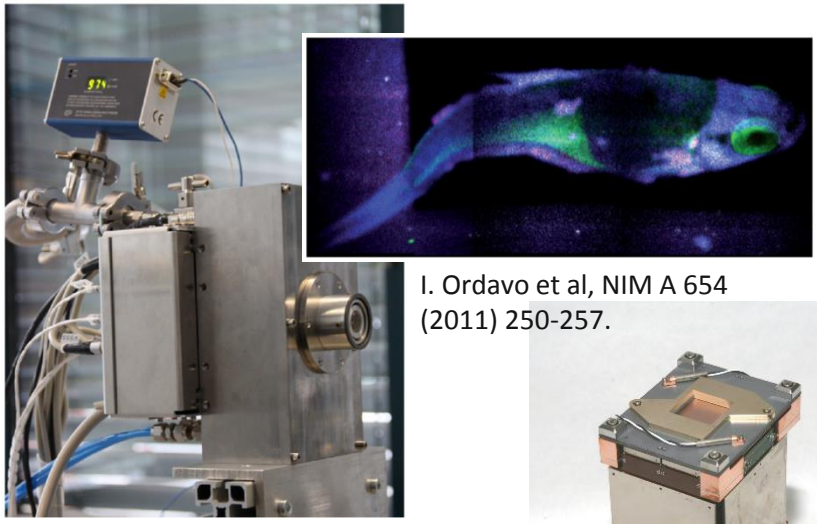
- MAIA Detector
  - Pixelated Silicon Energy Dispersive Detector by BNL and CSIRO
  - High total count rates via pixelation
  - Energy resolution: ~250 eV
  - Next version incorporates SDDs



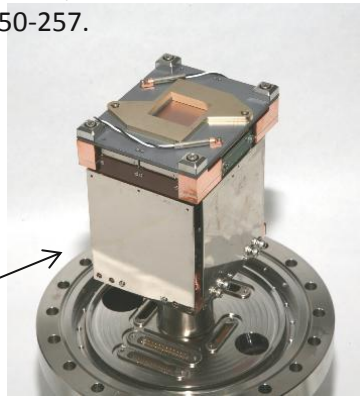
http://www.rdmag.com/award-winners/2011/08/x-ray-detector-delivers-more-pixels-faster-data

http://www.scienceimage.csiro.au/mediarelease/mr11-63.html

- CCD Detectors
  - Can have good energy resolution, lots of pixels, fast frame rates….Could do MHz count rates in single photon counting mode
  - PnCCD:
    - Made by PnDetector (Max Plank Institute)
    - 150 eV resolution; 400 Hz frame rate
  - Fast CCD:
    - LBNL/ANL collaboration
    - Advertised 250 eV resolution, but 1000 eV in practice
    - Have started dialog with Peter Denes about improving resolution
  - Novel applications – simultaneous XRF and imaging



I. Ordavo et al, NIM A 654 (2011) 250-257.



Fast CCD: Image courtesy of LBNL

Superconducting Detectors (MKID/TES)

- **High resolution energy dispersive detectors (ΔE < 2 eV at 6 keV)**
  - Broad range of energy simultaneously
  - Can be designed for soft x-rays (< 1 keV) to hard x-rays (100 keV)
- **Example applications**
  - Enhanced XRF mapping (e.g., L-line overlaps of heavy elements in integrated circuits)
    - No charge collection → Peak-to-Backgrounds > 10,000:1
    - Can degrade energy resolution for higher count rates
  - Chemical mapping at nanoprobes
    - With 1 eV resolution of Kβ gives spin/chemical state similar to edge shifts in XANES
    - Even at 2 eV resolution, you can start to differentiate chemical states from Kβ alone (say, high vs. low spin Fe)
- **Today, 1000-pixel TES array with 2 eV, total count rate of 100 kcps can be built.**
  - Active research to push resolution lower
  - Active research to increase pixel count at APS (MKID project)
    - Leveraging ANL investments in cryogenic cosmology detectors (HEP & MSD)

Slide courtesy of A. Miceli

Spectroscopic Detectors - Some thoughts and possible directions

- Lot of new technologies to increase SDD throughput, but won't necessarily be state-of-the-art in ~10 years
  - Still room for improvement in electronics – 10 MHz in silicon is conceivable.
  - Detectors Group could help with integration of custom instruments:
    - Lots of different pieces available commercially
    - Instruments could be built in –house or with commercial vendor (XIA, SGX, XGLab, PNSensor, etc)
- Energy dispersive CCDs could enable new techniques
  - Spectroscopic imaging
  - Room for APS effort: Continued effort on FastCCD to improve energy resolution and frame rate, software for spectroscopic applications
- Superconducting detectors potentially offer single-eV resolution
  - MKIDS will remain part of in-house program
  - Could develop ties with NIST for work on TES detectors

Area Detectors

- General interest in Eiger/next-gen PADs

1. High energy area detectors
   - Pilatus-like pixelated area detector with Hi-Z sensor
   - Something PE-like with low noise
   - Could do protein crystallography at 30-35 keV to avoid radiation damage
2. High frame rate area detectors
   - ~MHz rates; few kHz rates will be met commercially in next few years
   - XPCS – MHz image rates via sparsified readout
   - Short-lived phenomenon: BioCars, DCS, Pulsed Magnets
3. High Dynamic Range
   - Some uncertainty over counting detectors will be appropriate for DLSR
   - Alternative readout logics that handle more flux
4. Miscellaneous –
   - High resolution optics with wide field of view
   - Soft x-ray area detectors
   - Technique-specific detectors (pump-probe)

Next-gen PADS: Dectris Eiger

Chip Features

	PILATUS3	EIGER
Radiation tolerance	Radiation tolerant design	Same
Chip size	17.54 x 10.45 mm^2	19.3 x 20.1 mm^2 -> 2 x
Pixel size	172 x 172 μm^2	75 x 75 μm^2 -> / 5.3
Pixel array	60 x 97 = 5820	256 x 256 = 65536 -> 11.3 x
Count rate	$10*10^6$ x-rays/pixel/s	$2*10^6$ x-rays/pixel/s
Counter	20 bit	12 bit (8 and 4 bit mode)
Continuous readout	No	Yes
Clock speed	150 MHz	100 MHz DDR
Threshold adjustment	6 bit DAC	Same
Overflow control	Yes	Yes

Smaller pixels, so more required to fill same area as typical Pilatus sensor. 1M Eiger is ~ 80 mm X 80 mm.

Still has count-rate limitations - ~10^{12} γ/s max on 1M detector

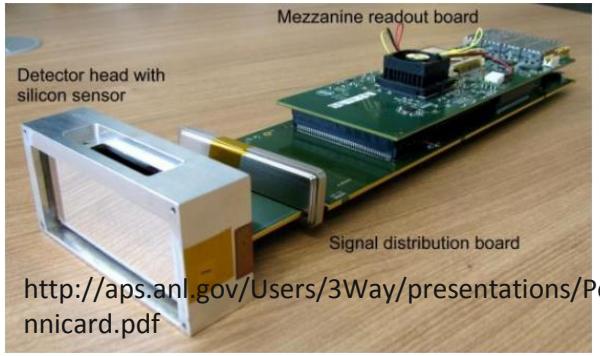
Less counter depth, but faster image rates. 3kHz @ 12 bits, but 9 kHz @ 4 bits

3 | EIGER detector family - CleS 24-JAN-13 DECTRIS® detecting the future

Slide from C. SchulzeBriese, Eiger Workshop, 2013. Available as download from dectris.com.

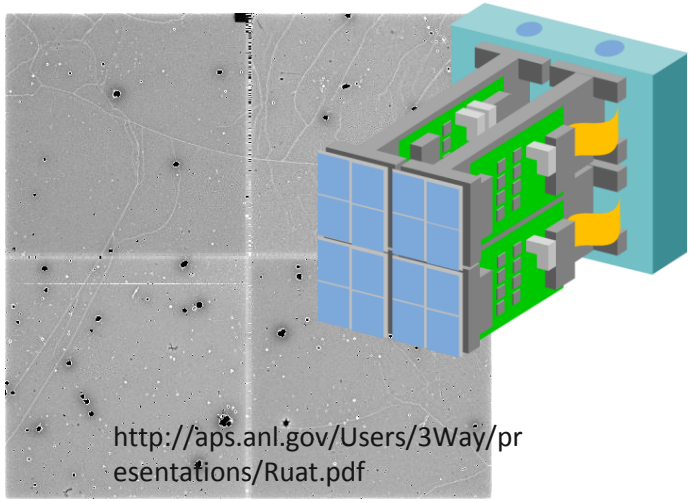
Net-gen PADs: Medipix3

- "Research" chip developed at CERN for large collaboration
  - Licensed to various institutes and companies throughout Europe
  - DESY, ESRF both have versions, commercialization likely by Amsterdam Scientific
- Competitive with Eiger:
  - kHz imaging (depends heavily on readout)
  - 55μm pixel with 2 counters and dual discriminators
  - Inter-pixel communication via ASIC adds flexibility:
    - Handles charge splitting between smaller pixels
    - Bin pixels and have multiple counters and energy windows
  - Same kind of count rate limitations
- Standard European research platform for edgeless sensors and Hi-z sensors
  - First commercial detectors likely Si sensor with standard modular construction
- http://medipix.web.cern.ch/medipix/pages/medipix3.php



http://aps.anl.gov/Users/3Way/presentations/Pennicard.pdf

DESY LAMBDA Detector Prototype



http://aps.anl.gov/Users/3Way/presentations/Ruat.pdf

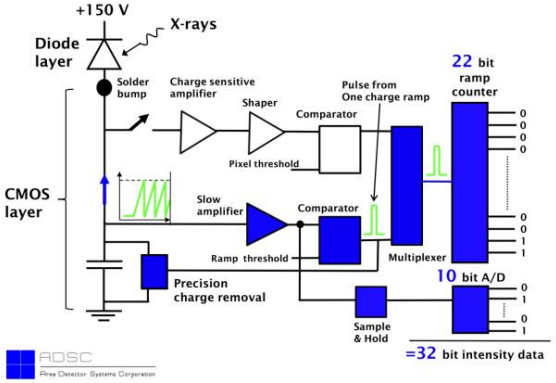
ESRF Smartpix with CdTe sensor

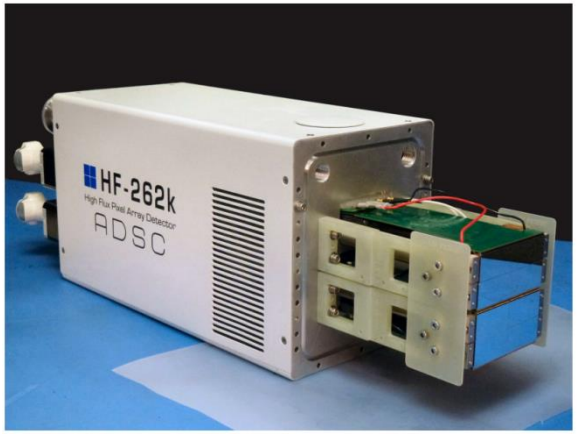
Do you really want a counting detector?

- Assume you're running a 1M Eiger at fastest frame rate (3kHz) in full 12-bit mode
  - Will be able to count 330 μs/exposure
  - Assume negligible deadtime (3 μs/exposure)
  - Eiger has count rate limitation of 2 MHz/pixel
- In a single exposure, you can count 660 photons/pixel
  - Total photons per frame: 6.6×10^8
- If you run for a second a record 3k exposures, you can capture at most $2X10^{12}$ photons/second.
  - Caveat: Simple model assumes homogeneous distribution of signal
- What about 12-bit dynamic range?
  - Can count 4k photons/pixel before readout
  - Really only determines how long you can count before readout – 2 ms at top count rate before saturating counter
- Counting detectors – really for low-signal situations
- Integrating detector:
  - $10^{4\text{-}5}$ photons/pixel/exposure; ~10^{15} photons/second for 1M-type detector.
  - Signal-to-noise: Comparable data quality to counting detector with discriminator

Area Detectors: Coming Soon

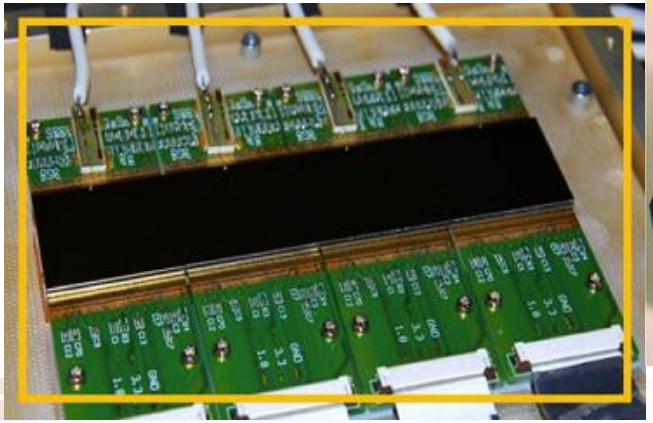
Images courtesy Ron Hamlin, ADSC





- ADSC
  - Dual Mode PAD
  - Selectable pixel logic – single photon counting or ramp counting (quantized integrating)
  - Total of ~32 bits dynamic range
  - 150 μm pixel size; 1kHz frame rate
- Pixirad: Commercial PAD with CdTe sensor
  - Relatively thin sensor efficient to ~50 KeV
  - 60 μm hexagonal pixel; 200 Hz image rate
  - More info: http://pixirad.pi.infn.it/
  - Marie Ruat: Will see many companies marketing CdTe in next few years.

Images:
http://pixirad.pi.infn.it/



Dexela CMOS Panels

- Recently introduced flat panel detector for medical imaging
- Thick CSI phosphor + cmos photosensor
- Some benefits over amorphous Si PE:
  - Smaller pixels: 75 μm
  - Faster frame rates: 30 Hz at full resolution
  - Lower noise, but comparable dynamic range
- Modest cost:
  - ~$80K for 290 mm X 230 mm
- Recently tested at Sector 1

Images: http://www.dexela.com/cmos.aspx

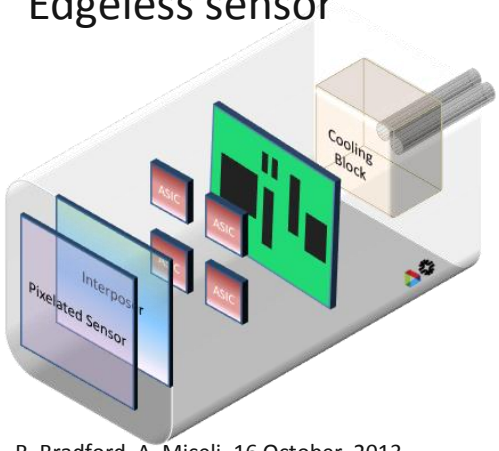
Area Detectors: Possible Directions

- The following look like possible directions for development initiatives:
  - MHz imaging
  - High dynamic range PAD with modest pixel size (<100 μm)

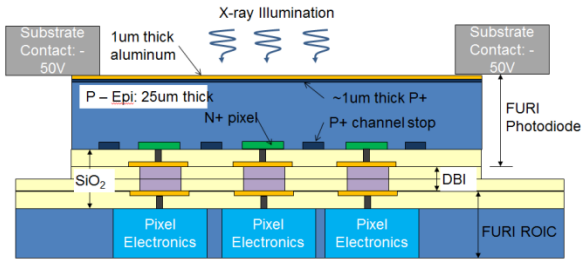
MHz Options:

FASPAX:

- Similar in concept to AGIPD
- Buffers 48 images
- 100 μm pixel
- More dynamic range
- Edgeless sensor



R. Bradford, A. Miceli, 16 October, 2013



Graphic courtesy of John Porter

Sandia PAD:

- Records 2 frames within 10 ns window
- Simple ASIC + thin silicon sensor (25-100 μm)

Have also started dialog with SLAC about the detectors program for LCLSII

- BESAC report wants XFEL upgrade to do MHz rep. rates
- Have already had extended discussions about APS/SLAC collaboration.

Other Needs

1. Structured Scintillator
   - Some requests for local expertise
2. APD Arrays
   - Pixelated fast counting applications
3. Beam Position Monitors with 100 nm resolution
   - Will be needed for micro-crystallography
4. Lots of small specialized projects
   - Specialized diodes
   - Single-chip counting detector for use in beam flux monitor
   - High energy strip detector for powder diffraction

Please dream a bit….

- Discussion presents our best analysis of needs, what will be available commercially, and what development directions may be useful for the APS
  - Not clear if this actually represents needs of the MBA lattice
  - Believe this is still under development
- Some advice as you brainstorm:
  - Start from what we've presented, and think 10 years from now
  - Detectors tend to be relevant for ~5 years
  - Eiger, Medipix3, etc will all be obsolete by the time APS-U comes online – 2 generations likely to go by
  - Enough time to do some real development
- Please put anything on the table – final directions likely fleshed out as project scoped.
  - Will work to seed more impactful ideas – LDRD or Upgrade R&D funds
- Please keep in touch
  - I'm available for one-on-one discussions; happy to come to your group/planning meetings
  - Your house or mine: Happy to arrange discussions with Detectors Group

Short Term Measures

- Wise man once said: Didn't know what we could do with a Pilatus until we put in on our beamline (Mark Rivers)
- Series of demos:
  - Will try to bring as many new systems to the APS as possible for demos and beamline testing
    - Presentation from Vendor
    - Extended loan of equipment that can be circulated for hands-on trials at beamlines
  - 1st guest: Pixirad coming November 18
  - Will try to get ADSC, Quantum, XIA, etc

- Detector Pool equipment
  - Lots of requests for new equipment in Detector Pool
    - Would love to work with you to build a case
    - Present to management at "budgetarily appropriate" moments…

Conclusions

- Miserable with your current detector?

- Something can be done
  - Lots of new detectors debuting in next few years
  - Don't have to just go commercial: If you don't see what you need there are time and capacity to do significant development
    - Group here is ready to go
    - Have developed ties to other groups
    - Will be clever to meet as many needs economically
- Planning requires your input
  - Detectors Group is a resource that you can use
  - Please stay in touch!

http://deadcurious.com/2013/02/06/movie-review-les-miserables/