Progress on Optics & Shielding

EUROPEAN SPALLATION SOURCE

P M Bentley

August 28, 2013

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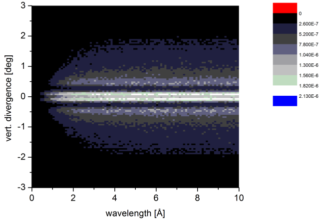
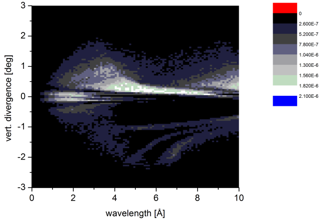
Contributors

Gravity

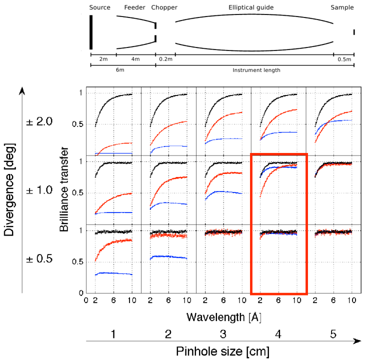
- We really understand gravity now
- It is really important for point to point focussing (small source small sample)





Optimal Pinhole Size

- Bertelsten (Lefmann's group)
- Optimise a generic virtual-source guide
- Most efficient pinhole size is at least 4 cm wide
- As a starting point, aim for 4 cm, but this requires some high-m supermirrors to fully exploit it



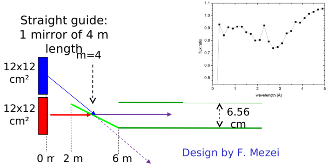
Bispectral Extraction

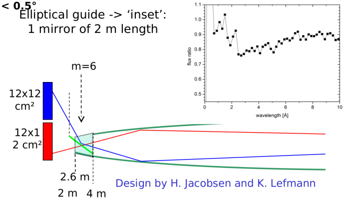
Moderator distance d, min. distance D_0 and cross-over wavelength λ_c given - - choose mirror coating m

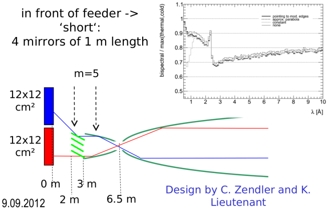
- → mirror inclination: $\alpha = 0.1\ \mathrm{m}\ \lambda_c$
- → mirror center: $D_{mirr} = d/2\tan(\alpha) - L_0$
- → mirror length: $L_{mirr} = 2(D_{mirr} - D_0)/\cos(\alpha)$
- → guide entry: $W_{in} = L_{mirr}\sin(\alpha)$

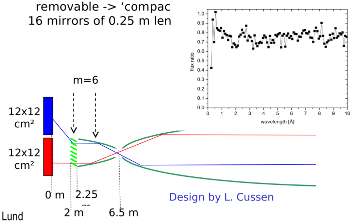
$$efficiency = \frac{flux@sample(bispectral)}{Max(flux@sample(cold),\ flux@sample(thermal))}$$

div < 0.5°



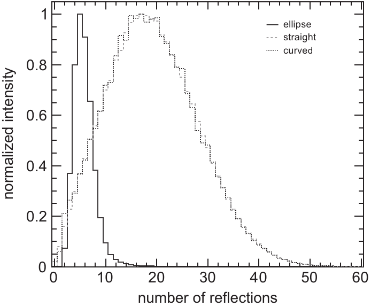






Number of Bounces in Ellipses

- Cussen (Lieutenant's group)
- Number of bounces in ellipses is reduced, but almost *never* one bounce
- Here they compare straight, curved and elliptic shaped guides for cold neutrons



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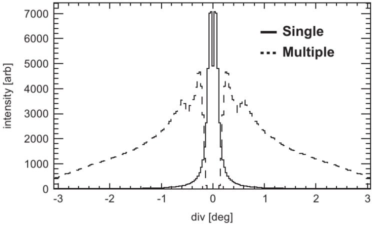
Number of Bounces in Ellipses

- Only low divergence neutrons are singly reflected



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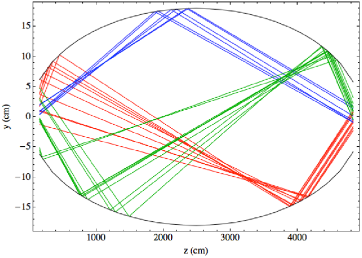
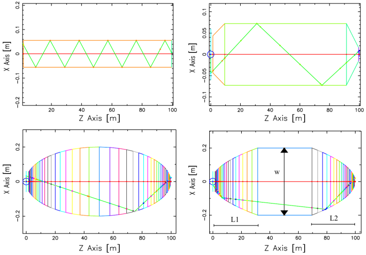
Number of Bounces in Ellipses

- We understand really well the interaction between multiple bounces and optical aberrations



Guide Shape

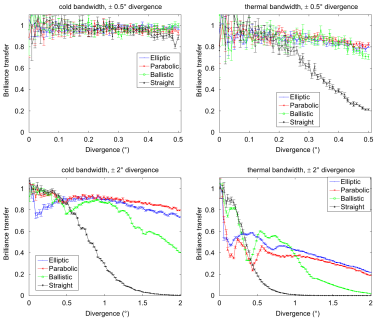
- Klenø (Lefmann's group)
- If you compare properly optimised systems the ballistic performance is equal



Klenø *et al*, Nuclear Instruments and Methods in Physics Research A 696 (2012), 7584

Guide Shape

- ...then performance is the same
- and we can reduce cost



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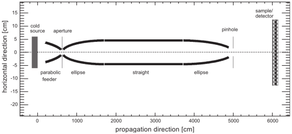
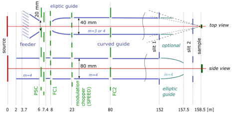
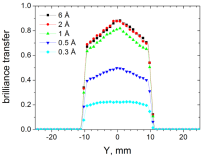
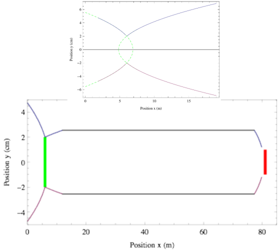
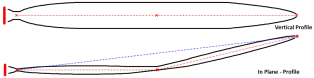
“Standard” Guide — Ballistic with Conic Sections

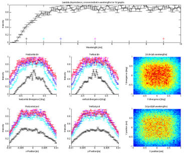


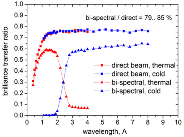






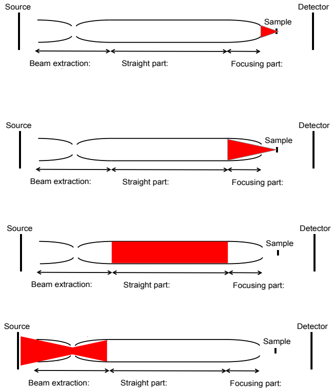






"Standard" Guide — Ballistic with Conic Sections

- Specify λ, div, beam size
- Tells you baseline focussing geometry immediately
- ...and the straight/curved part in the middle (R, w, λ, m)
- ...and phase space mapping at start



Conclusions

- The risks on guides now should be considered LOW.
- We are confident that we can deliver neutrons efficiently and without crazy costs
- Nonetheless, much work in instrument projects to adapt this to their needs

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Collaborators (No particular order...)

- N Cherkashyna (ESS)
- K Kanaki (ESS)
- D DiJulio (ESS)
- T Kittelmann (ESS)
- U Filges (PSI)
- P Deen (ESS)
- R Connatser (ESS)
- R Hall-Wilton (ESS)
- K Herwig (SNS)
- B Winn (SNS)
- K Fissum (Lund U./MAX-IV)
- T Shea (ESS)
- J Carpenter (ORNL)
- G Ehlers (SNS)
- G Greene (SNS)
- M Hagen (SNS)
- R Connatser (ESS)
- E Klinkby (ESS)
- L Zanini (ESS)
- K Batkov (ESS)
- S Ansell (ISIS)
- G Skoro (ISIS)
- C Frost (ISIS)
- P M Bentley (ESS/Uppsala U.)

Collaborators

EUROPEAN SPALLATION SOURCE

SNS SPALLATION NEUTRON SOURCE

PAUL SCHERRER INSTITUT PSI

ISIS

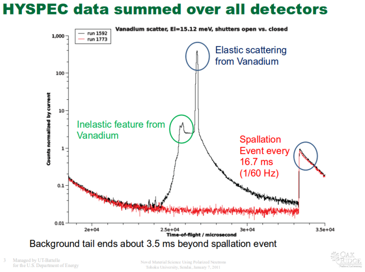
LUND UNIVERSITY

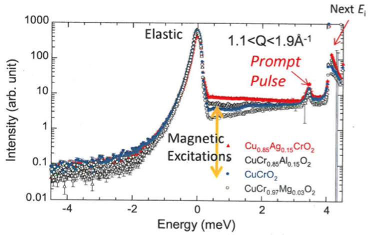
MAX IV LABORATORY

UPPSALA UNIVERSITET

Some Background

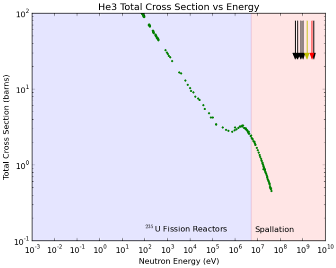
- HYSPEC at SNS — this data deliberately measured to illustrate problem
- AMATERAS at JPARC
- A few existing instruments compromised
- Significant hindrance and/or performance hit
- Parts of parameter space are unusable
- Indications many are dealing with it

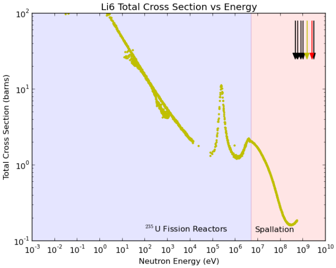


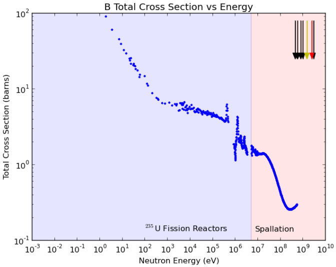


Invisible Demons

- You cannot measure > 100 keV neutrons directly with thermal neutron detectors
- This problem has been difficult to track down







Scary Rumours

- It comes from the accelerator, weak points in shielding
- ...A2T region, badly shielded collimation
- ...Your own beamline if you screw up your line of sight shielding
- ...sub-optimal target design
- ...sub-optimal beamstop design
- ...straight guides with poor lateral shielding

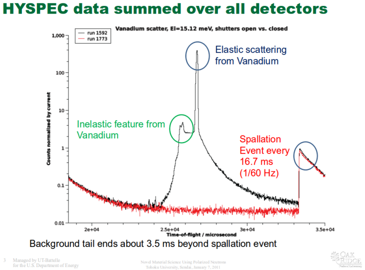
ESS Needs to Solve This

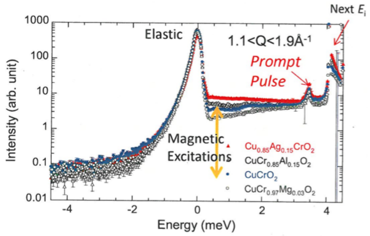
- 70% of the ESS instruments are potentially affected
- This is because of the long pulse & instrument optimisation

Instrument	Potentially Affecte
Cold Chopper Spectrometer	Y
Pulsed Mono. Powder Diff.	
Broad-Band Small Sample SANS	Y
Horizontal Reflectometer	Y
Macromolecular Diff.	
Multi-Purpose Imaging	
Cold Crystal Analyser Spec.	Y
Single Crystal Magn. Diff.	
High-Resolution Spin Echo	Y
Wide-Angle Spin Echo	Y
Backscattering Spec.	Y
Bi-Spectral Chopper Spec.	
Fundamental & Particle Phys.	Y
Vertical Refl	Y

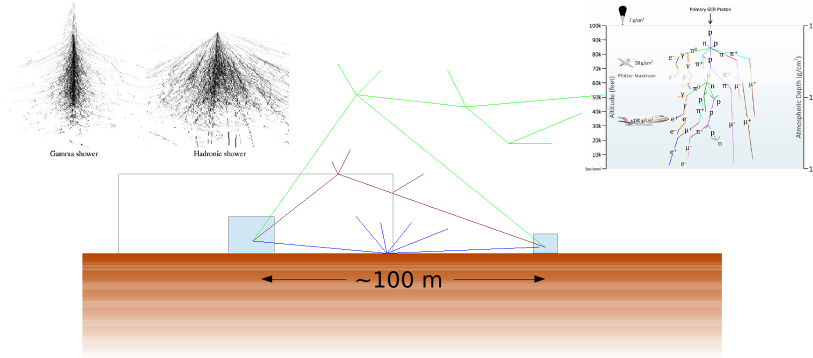
Design Goal

- Fulfilling radioprotection still leaves orders of magnitude of BG to tidy up
- Factor of 100 would solve the problem
- Sounds expensive but this is “only” 2 metres of concrete, or 30 cm of W close-in





Skyshine

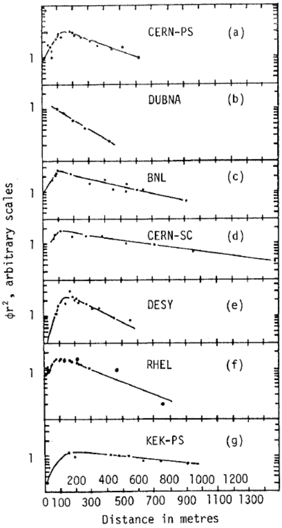

Gamma shower
Hadronic shower
~100 m
Primary GCR Proton
Pfotzer Maximum
Altitude (feet)
Atmospheric Depth (g/cm²)
Sea Level

Skyshine

- Peak at ∼100 metres for many accelerators
- Comes from *everywhere* that high-energy particles escape

$$\phi(r) = \frac{aQ}{4\pi r^2}\left[1 - \exp\left(\frac{-r}{\mu}\right)\right]\exp\left(\frac{-r}{\lambda}\right)$$

- $a \approx 2.8$; $\mu \approx 56$ m; $\lambda \approx$ 100's m



Stevenson & Thomas, Health Physics 46 (1984), p115

Skyshine

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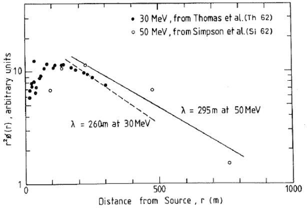
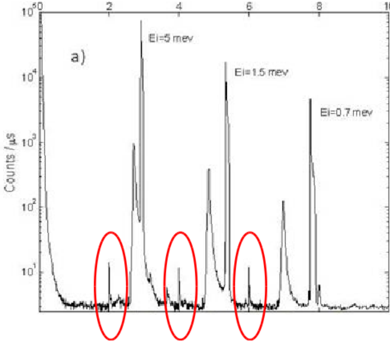


FIG. 8. Comparison of the effective absorption length for 30 and 50 MeV with data fr Rutherford Laboratory Proton Linear Accelerator (Th62; Si62).

Stevenson & Thomas, Health Physics 46 (1984), p115

Skyshine

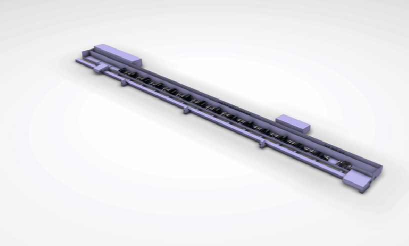
- Almost certainly what we see on LET from TS1



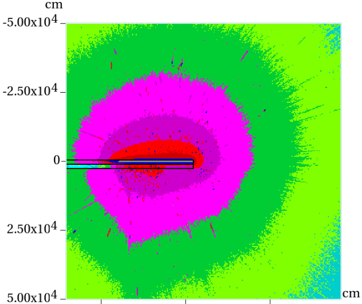
Many thanks to Rob Bewley for this excellent picture

Skyshine — Accelerator and Stubs

- Stubs feed RF power into LINAC
- Path for secondaries to escape into air
- Currently studying shielding on berm and klystron roof
- Intense activity on this right now
- (Relatively easy, but expensive, to shield)
- Radiological reqs are not enough



Taken from ESS TDR



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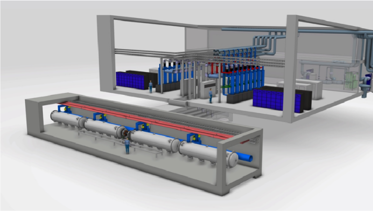
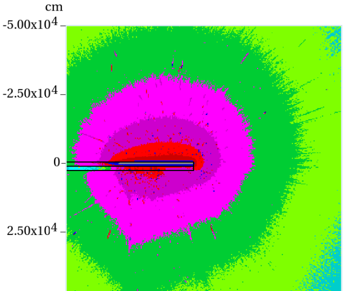


Figure 4.135: A typical stub (from the medium beta sec

Taken from ESS TDR



A2T Region — Rastering

- Effort lead by Tom Shea to redesign this
- New baseline has tiny beam that is rastered on the target during the pulse
- Lissajous figures (remember oscilloscopes with x-y out of phase)
- *Very* roughly: at least an order of magnitude reduction

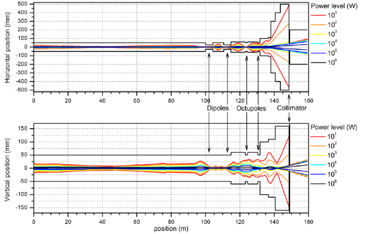
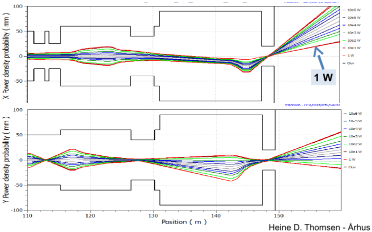


Figure 4.123: Horizontal and vertical particle density plots along the HEBT. The apertures, inside the vacuum chambers, are outlined.

Taken from ESS TDR



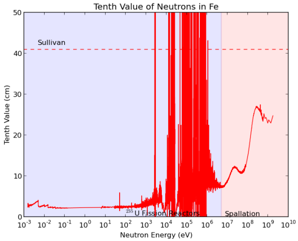
Heine D. Thomsen - Århus

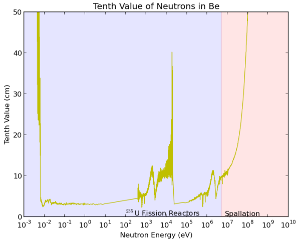
Shielding

- Iron-based shielding is relatively cheap, *however...*
- Cost $\propto$ mass
- Moving shielding in reduces cost by r^p
- $p = 1, 2, 3$ depending on process and geometry
- And Fe has a number of significant problems

Shielding

- Iron has many XS minima in keV – MeV region
- Compare with Be, with known transparencies
- *Fe is transparent between 10 keV and 1 MeV region*

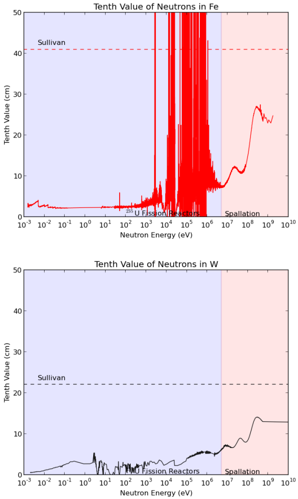




Data from EXFOR / Brookhaven

Shielding

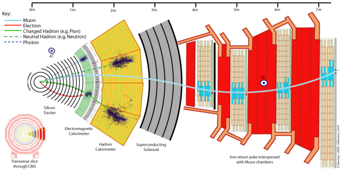
- We know tungsten works better
- The problem there is cost, *however...*
- Cost $\propto$ mass
- Moving shielding in reduces cost by r^p
- $p = 1, 2, 3$ depending on process and geometry



Data from EXFOR / Brookhaven

Shielding

- Look again at CMS @ CERN.
- Hadron calorimeters are made from *brass*
- Consider Cu nucleus



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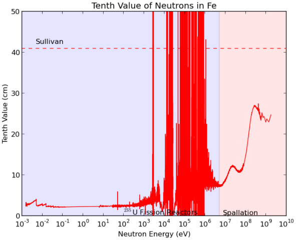
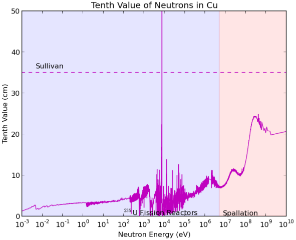
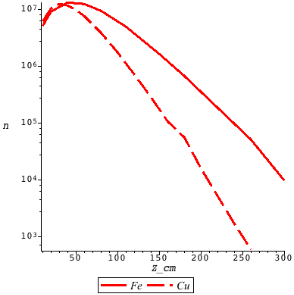


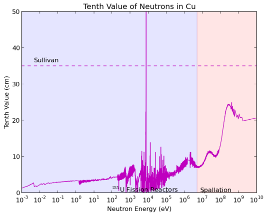


Data from EXFOR / Brookhaven

Fe vs Copper

- Look again at CMS.
- Hadron calorimeters are made from *brass*
- Consider Cu nucleus





Data from EXFOR / Brookhaven

Shielding

- Cu activation concerns some scientists.
- Data from CERN: perhaps not a problem
- Of course, our spectra are different, requires validation
- Problems with Fe tend to be worse than this due to contaminants

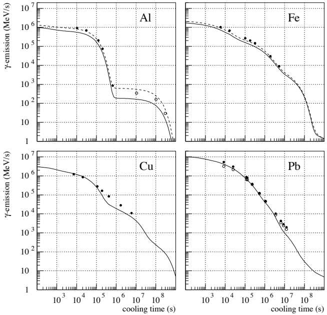
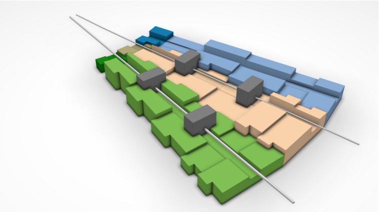


Figure 4: Comparison of calculated (lines) and experimental (dots) total gamma energy emissions from the samples. The solid line shows the FLUKA residual nuclide calculation and the dashed the same complemented with experimental cross section data. The open dots in the Al-comparison show the dose due to Na^{22} calculated from the activity of the last measurement (solid dots). In the Al, Fe and Cu plots the experimental values are based on the photo-peak information. In the Pb-plot the solid dots show the energy from integrating the whole spectrum while the open dots show the dose derived from the photo-peaks found in the spectrum [6].

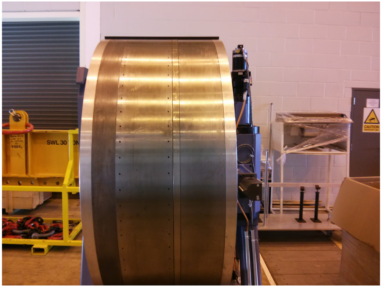
ESS Shielding Bunkers

- 7 times rule: we do 10 times on steps
- Prioritise fast particle planes



Hi-E Collimation Blocks

- Laminates
- These are ISIS chipIR collimators
- Al; Antimony-free Pb; steel; Ni; steel; Al
- ESS collimators will use brass/copper
- These are GA evolved designs, we're ramping that capability up...



ESS Shielding Bunkers

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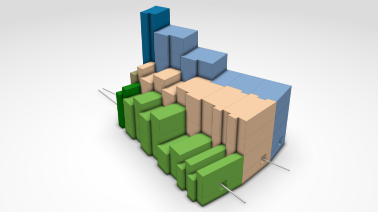
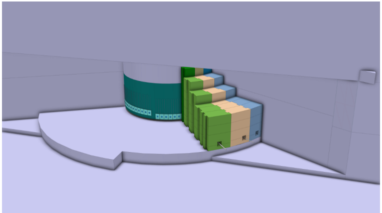
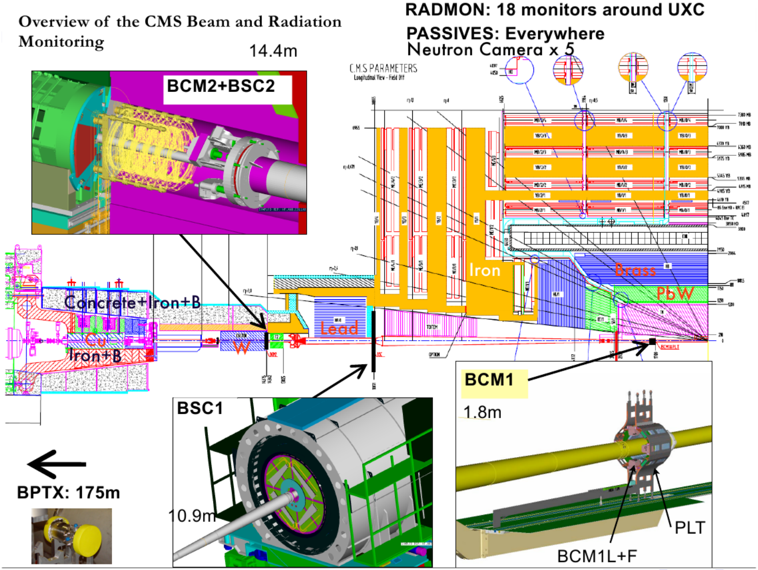




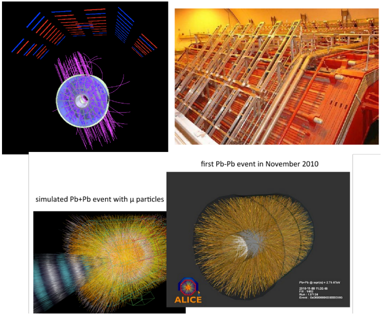
Monitoring on CMS

Overview of the CMS Beam and Radiation Monitoring



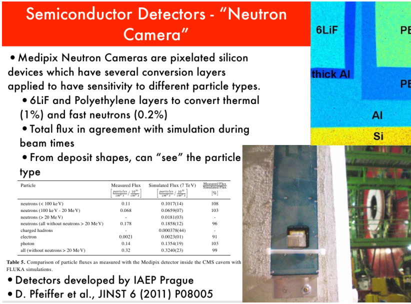
Modelling

- GEANT4
- MCNP
- MARS



Measurements

- $\sim$ 80k Euro on detectors
- *Specifically* for high energy particles
- neutrons, gamma (incl. energy), charged particles
- Measurements begun at PSI already
- Measurements at SNS this autumn...



Semiconductor Detectors - "Neutron Camera"

- Medipix Neutron Cameras are pixelated silicon devices which have several conversion layers applied to have sensitivity to different particle types.
  - 6LiF and Polyethylene layers to convert thermal (1%) and fast neutrons (0.2%)
  - Total flux in agreement with simulation during beam times
  - From deposit shapes, can "see" the particle type

Particle	Measured Flux $\left[\frac{particles}{cm^2 s} / \frac{10^{30}}{cm^2 s}\right]$	Simulated Flux (7 TeV) $\left[\frac{particles}{cm^2 s} / \frac{10^{30}}{cm^2 s}\right]$	$\frac{\text{Measured Flux}}{\text{Simulated Flux}}$ [%]
neutrons (< 100 keV)	0.11	0.1017(14)	108
neutrons (100 keV - 20 MeV)	0.068	0.0659(07)	103
neutrons (> 20 MeV)	-	0.0181(03)	-
neutrons (all without neutrons > 20 MeV)	0.178	0.1858(12)	96
charged hadrons	-	0.000378(44)	-
electron	0.0021	0.0023(01)	91
photon	0.14	0.1354(19)	103
all (without neutrons > 20 MeV)	0.32	0.3240(23)	99

Table 5. Comparison of particle fluxes as measured with the Medipix detector inside the CMS cavern with FLUKA simulations.

- Detectors developed by IAEP Prague
- D. Pfeiffer et al., JINST 6 (2011) P08005

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Breakthrough

We realised that...

- The shutter question is an operational issue addressing top-level requirements and requiring definitions of strategy
- Many of the arguments were statements of requirements, but they were neither clear nor completely defined
- Most of the arguments were statements of risk acceptance and aversion

Breakthrough

...and speed bumps

- Mixed views from advisors
- Cultural differences
- Some facilities less likely to describe problems openly
- Caution is required
- The best data we have is the ISIS data, they have been brilliant
- I Sutton and R Duperrier have been extremely busy crunching it

Breakthrough

- The ESS management now has all required information
- Recommendation on the ESS strategy is imminent

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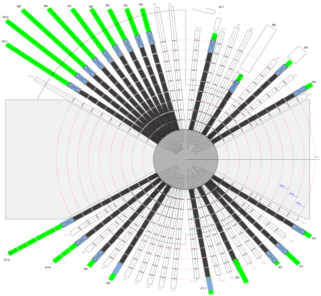
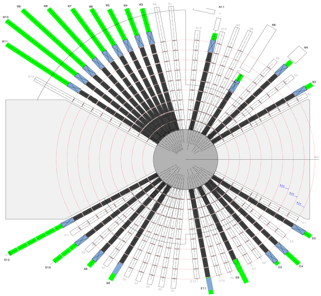
Option 1: Light Shutters

- Light shutters next to, or in, Target Monolith
- Block gamma rays from target when production is off



Option 1: Light Shutters

- Whole facility is black servicability classification
- Can only repair within LOS during shutdown



Option 2: Heavy Internal Shutters

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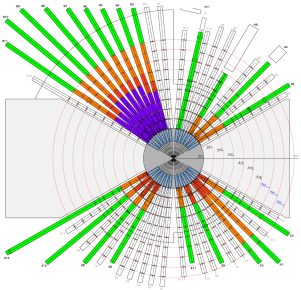
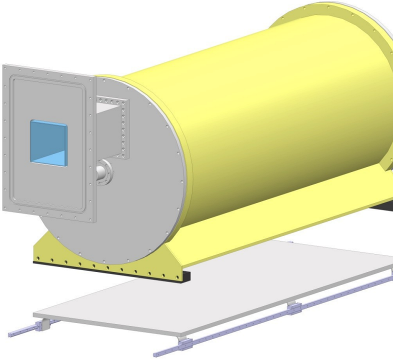
- Maximally non-black servicability classification
- Can perform work with minimum neighbouring beamlines shutdown



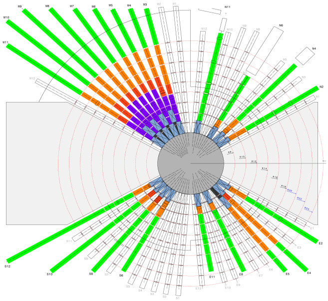
Option 3: Heavy External Shutters

- Large devices outside monolith
- Reduce all radiation types to safe levels downstream on beam axis, even when proton beam is on, with sufficient lateral shielding



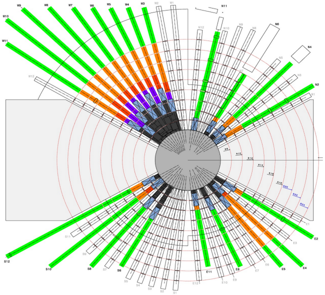
Option 3a: Heavy External Shutters Upstream

- Maximally non-black servicability classification
- Can perform work with minimum neighbouring beamlines shutdown
- Some serious compromises on instrument performance



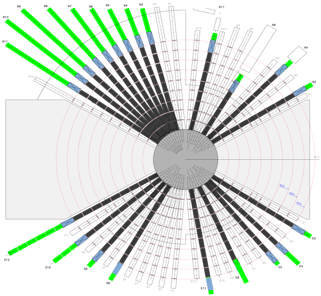
Option 3b: Heavy External Shutters Downstream

- Half of equipment is in black servicability classification
- Only half of equipment can have extended shutdown periods for cooldown or access when required



Option 4: No Shutters Near Monolith

- Guides are bent out of line of sight
- All equipment is in black servicability classification
- Can only repair within LOS during shutdown



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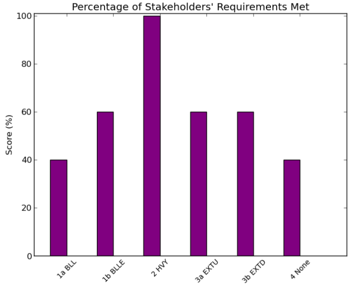
On Upgradability

- Everyone wants to upgrade at some point
- All options: ≥ 30 active instruments
- ALARA = we need shutters somewhere close to monolith

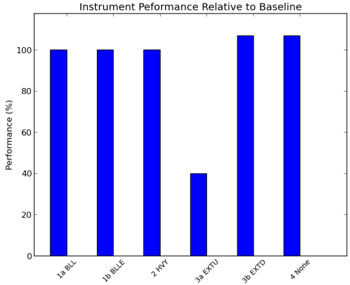
On Meeting Requirements

- Heavy internal shutters meet all requirements
- The other options involve compromises



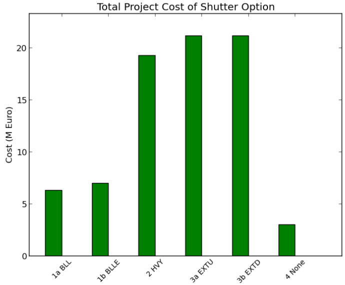
On Instrument Beam Performance

- Difference between heavy shutter options is marginal
- Upstream option potentially carries significant performance compromise



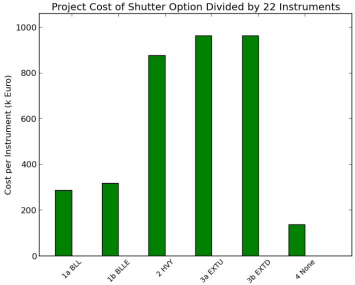
On Project Cost

- Difference between heavy shutter options is marginal
- $\sim$ 10% of instrument budget



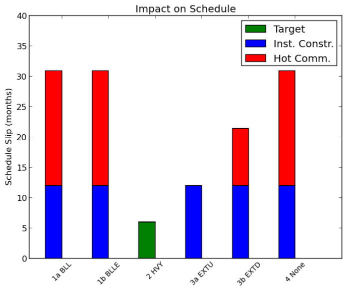
On Project Cost Per Instrument

- Difference between heavy shutter options is marginal
- $\sim$ 10% of instrument budget.



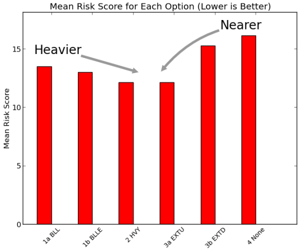
On Schedule

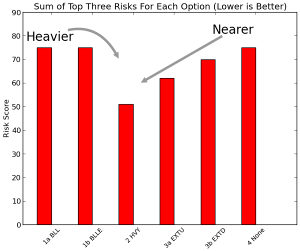
- Heavy internal shutters = 6 month delay for Target WP4
- R. Connatser detailed planning: 12 mo delay for last 4 instruments
- (Operations & Construction do not mix)
- Start early, choose all instruments by 2019
- Of course, cash flow, planning, politics...



On Risk

- Risk decreases as shutter weight increases
- Risk decreases as shutter moves closer to source
- This is basic shielding common sense
- Risk decreases with increasing functionality
- You have fewer restrictions when situation requires flexibility





Project Balance

- Where to place risk, dose, complexity, cost?
- In Guide Halls?
- In Target?

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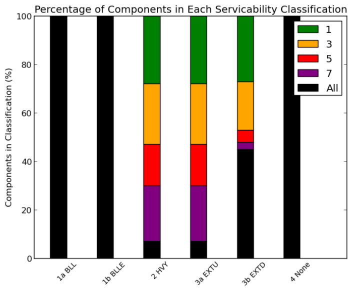
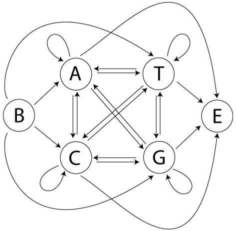
On Operations

- $>$ 600 Components in Analysis
- Heavy shutter at source $=$ half of ESS guide hall out of black servicability classification
- Changing purple to black: significant transfer of risk to availability
- Figure even more important with multiple failures.

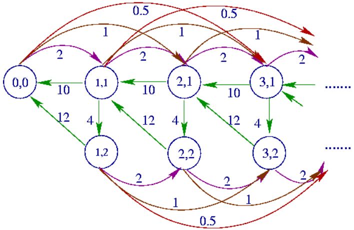


On Operations

- Systems Engineering Models of Operational Failures and Repairs
- Markov Chains: same maths as disordered magnetism, finance, earthquakes, human language...
- I Sutton supported by R Duperrier



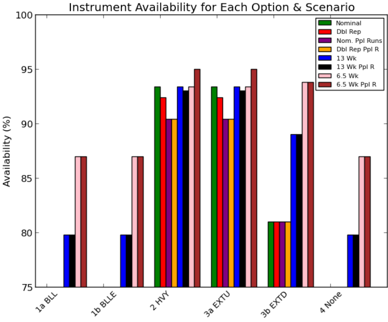
http://www.cs.wm.edu/MAMSolver/Examples.html



http://carrot.mcb.uconn.edu/ ol-gazh/bioinf2010/class10.html

On Operations

- We need heavy shutters close in to get to 95% availability target
- Indications that some optimisation of schedule could help in all cases



Conclusions

- Guide risks low
- Great progress on background
- Guides and background: exemplary teamwork across all involved facilities and groups
- Decision on shutters can now be taken, requried information is on the table