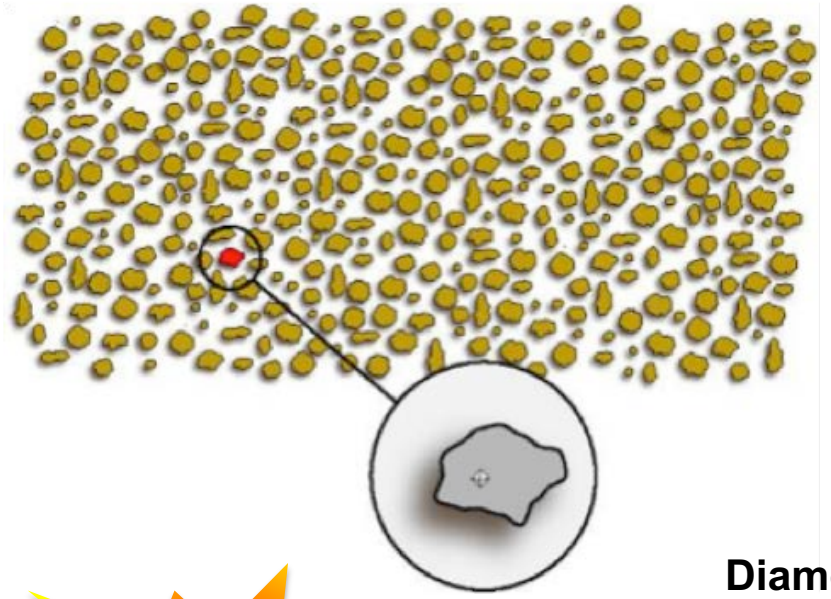
MinPET – 4IR, Tech Transfer, Innovation, Commercialisation



4IR

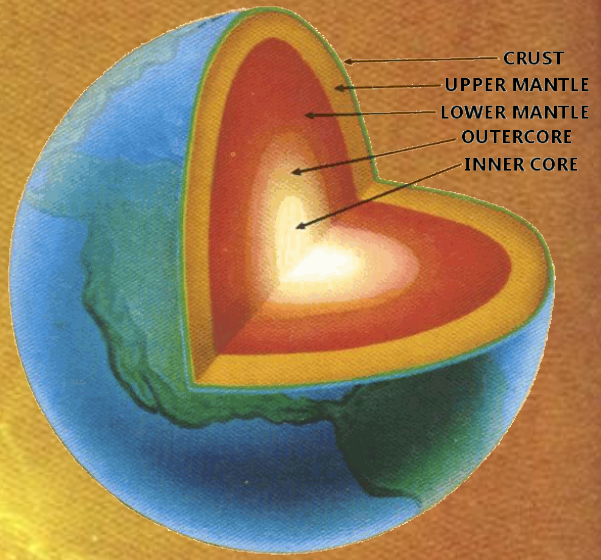
MINPET
DIAMONDS | SORTED

Diamonds are rare but valuable

- 1.7 cpht ~ 3.4 parts per billion.
- In “lumps”, not finely dispersed.
- Extreme case for high value buried in waste
- Global rough diamond market 153 M ct, 2017 ~ 15.4 B$
- Breakage also significant driver

MinPET Benefits

- Less plant, less processing less energy, less water, greener
- Marginal mines viable, longer life of mine, mine in arid regions
- Audit tailings and return to greenfield
- Protect diamonds from breakage



- **Natural diamond genesis was mainly billions of years ago, a much younger earth.**
- **They had their genesis at 200-600 km depth, and then a long residence at about 100km depth**
- **They were brought to the surface tens of millions of years ago, transported by volcanic material.**
- **They are now either in kimberlite pipes or dispersed alluvially.**

- **There won't be any new natural diamond production.**
- **We need to protect what we have.**

Earliest use of diamond by humans

4500 BC
Chinese axes

Archeological evidence that the Chinese could polish Corrundum, implying they had some diamond

Wikipedia

Diamond History

The Valley of the Diamonds

Diamond mining in the Indian Kingdom of Motupalli

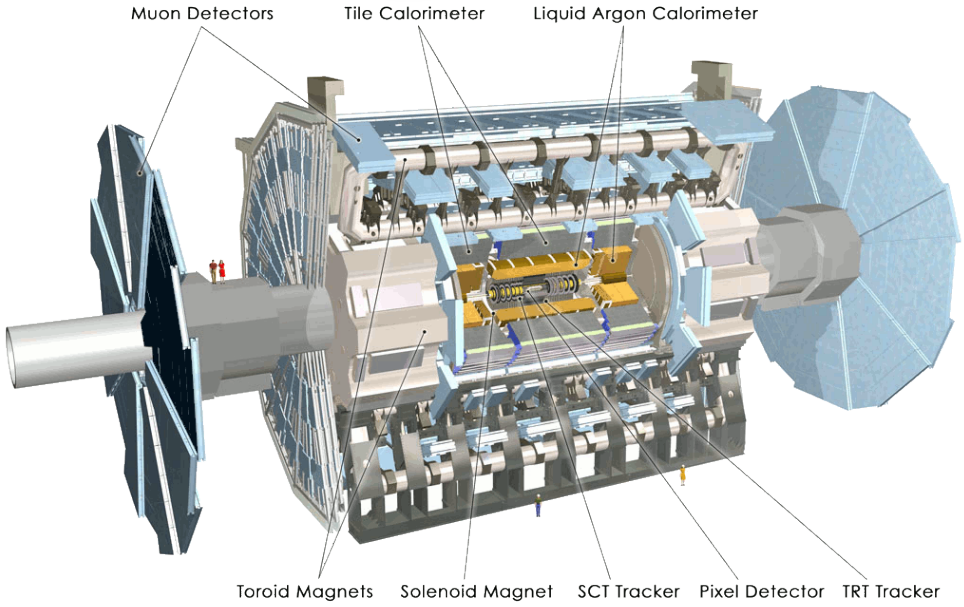
1600's

From "The Hope Diamond"
by Richard Kurin
(not original ref)

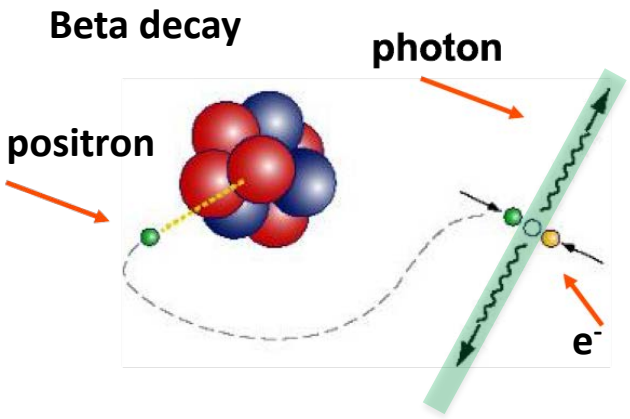
MinPET – 4IR, Tech Transfer, Innovation, Commercialisation

MinPET developments have benefitted from ATLAS at CERN

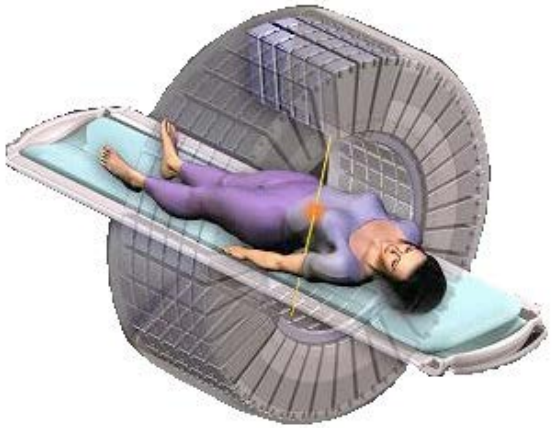
- Sensor development
- Simulation
- High data throughput
- Big Data analysis
- High Performance Computing
- Human resources
- Machine learning



What is PET ……. Medical PET …… the idea

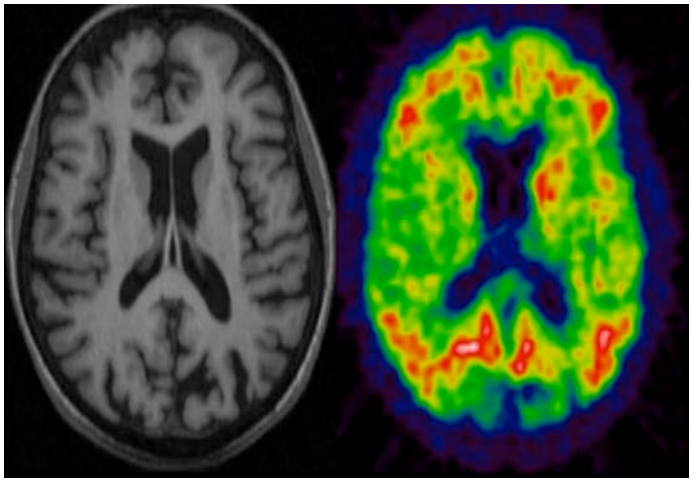


Positron
Emmission
Tomography

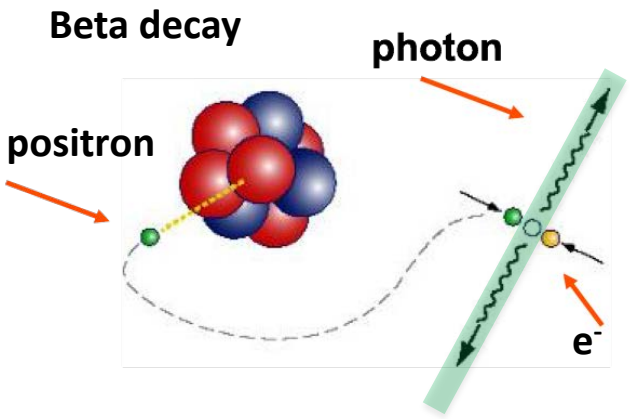


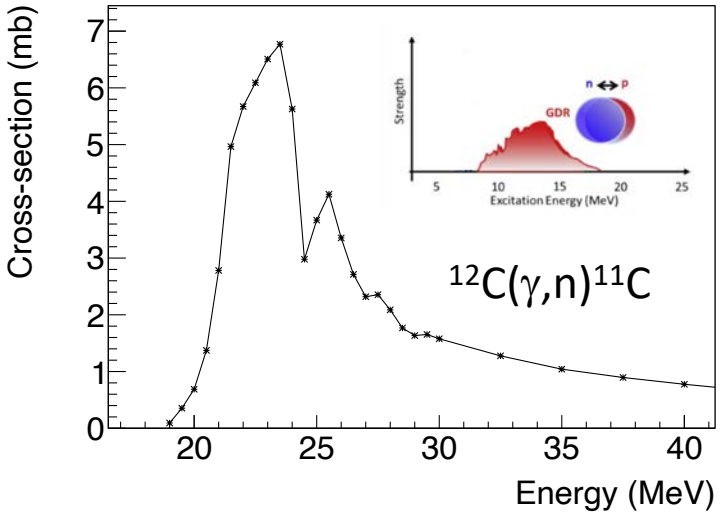
Inject patient with radio-labelled sugar / biomolecule.
Targets a metabolic function.

- Cancer metabolizes fast
- Active areas of the brain too



What is PET ……. Mineral PET …… the idea





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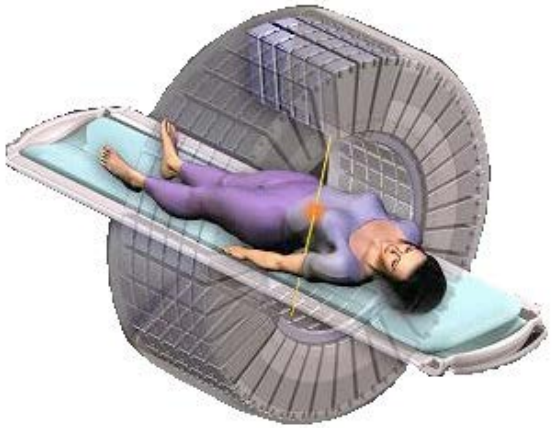

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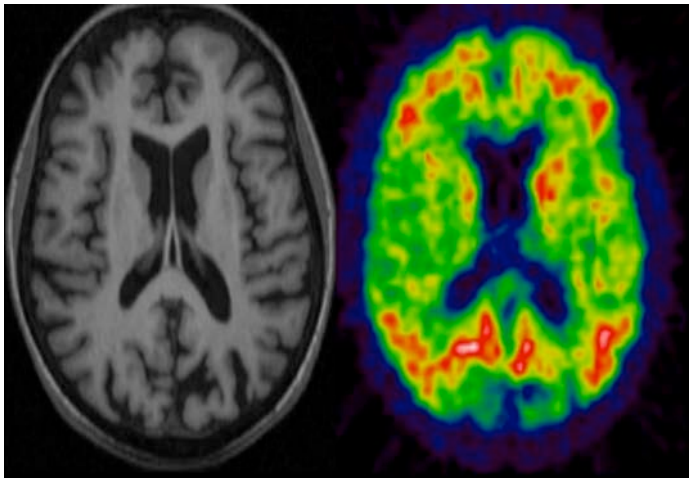


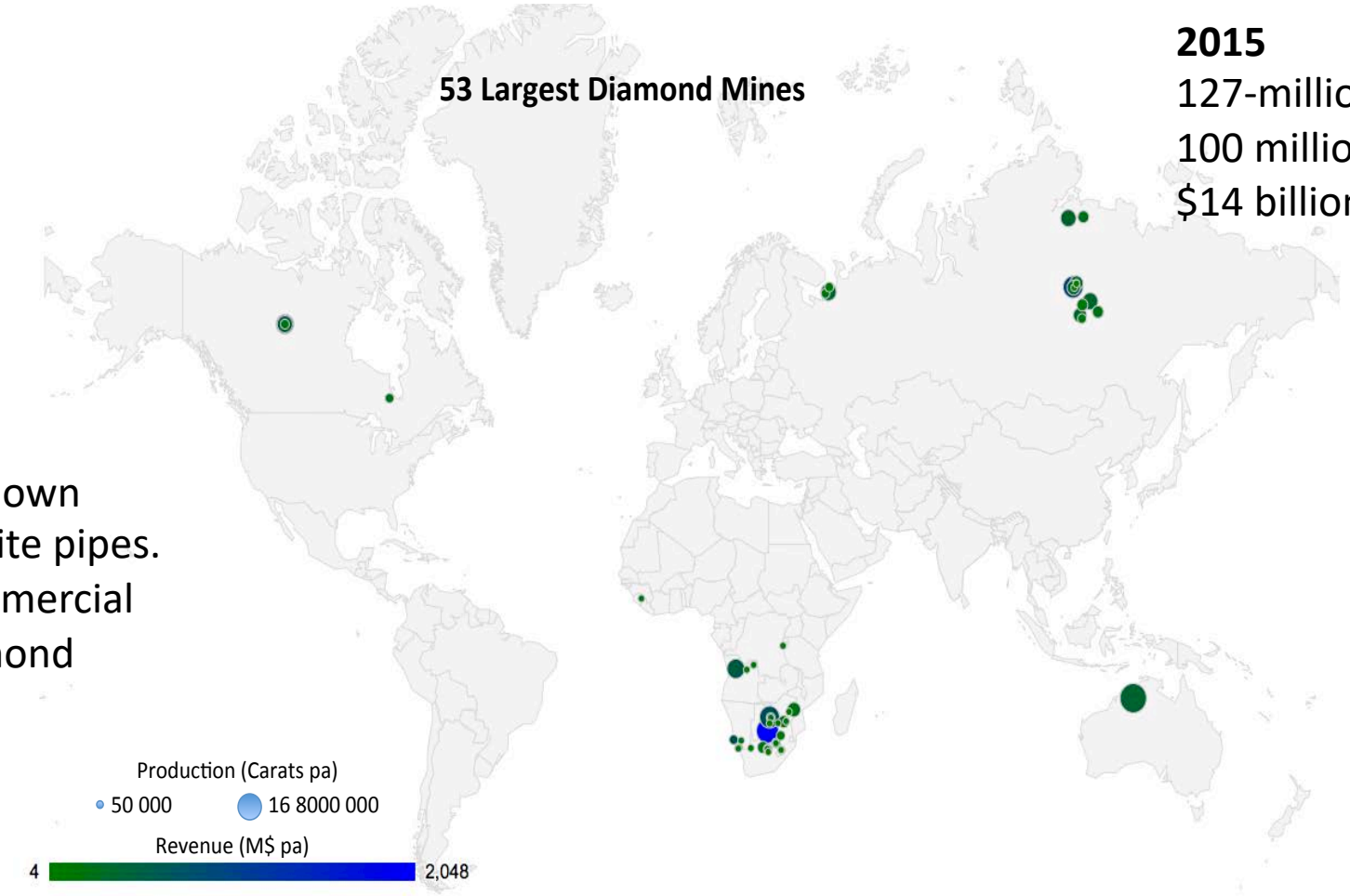
The extreme example of something very valuable in barren rock

Mirny Diamond Mine in Siberia, Russia, very big ….

But now mined out !

A lot of rock must be processed !

Where are diamonds to be found ?



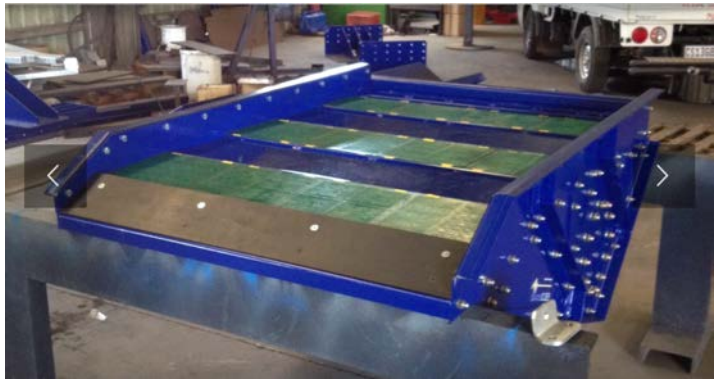
2015
127-million carats
100 million tons
$14 billion

- 6000 known kimberlite pipes.
- 1% commercial
- 60 diamond mines

Tradiational diamond recovery is expensive, destructive

Successive stages of crushing

Centrifuge



Grease table

Expensive → breakage

The Diamond breakage issue

Diamond Breakage – Loss of Revenue

19.46 carats

US$ 215 000

51.27 carats

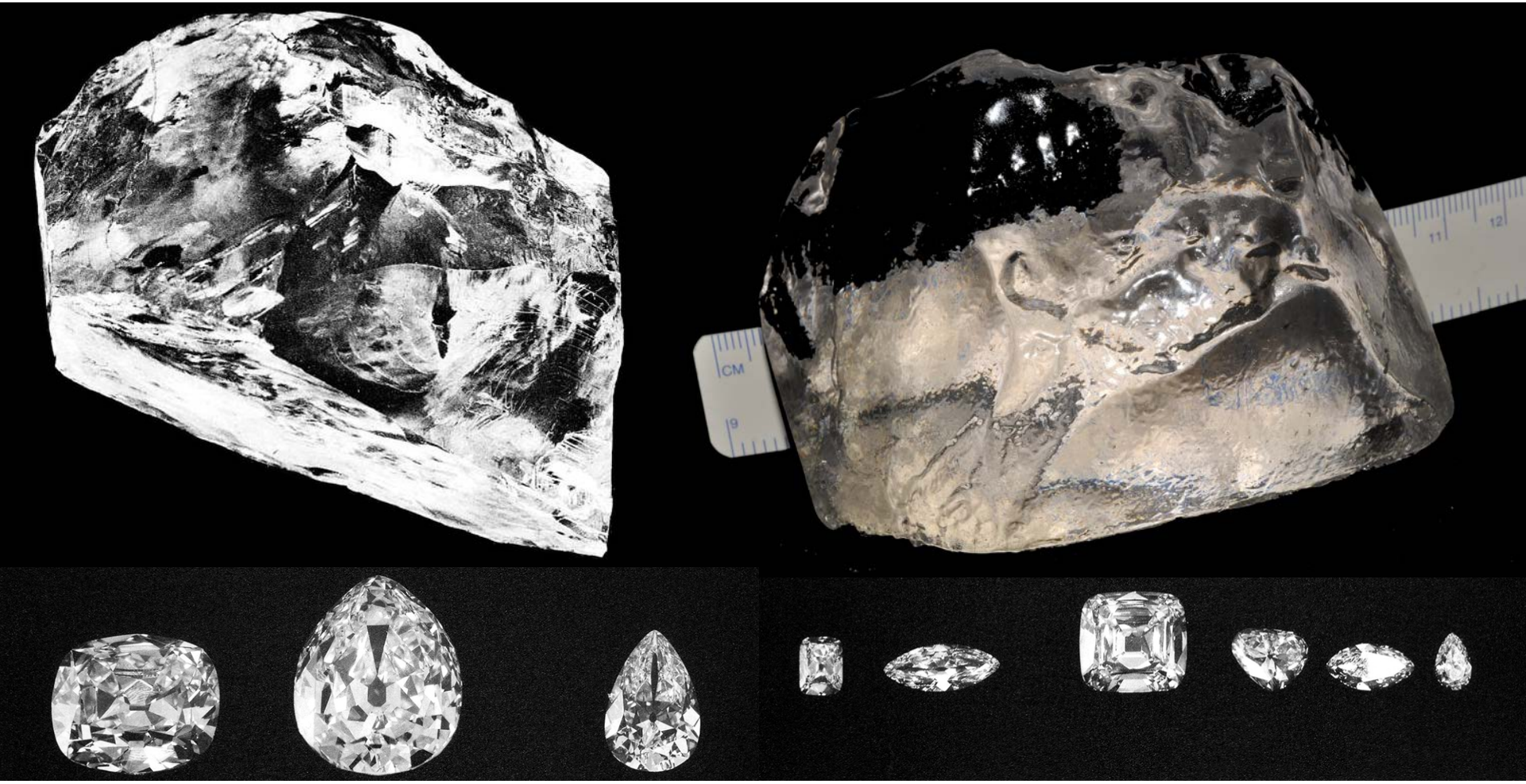
US$ 6 900 000

Total value as two stones: US$ 7 135 000
Total value as one unbroken stone: US$ 17 700 000

US$ values are approximate
Estimate loss of $10m

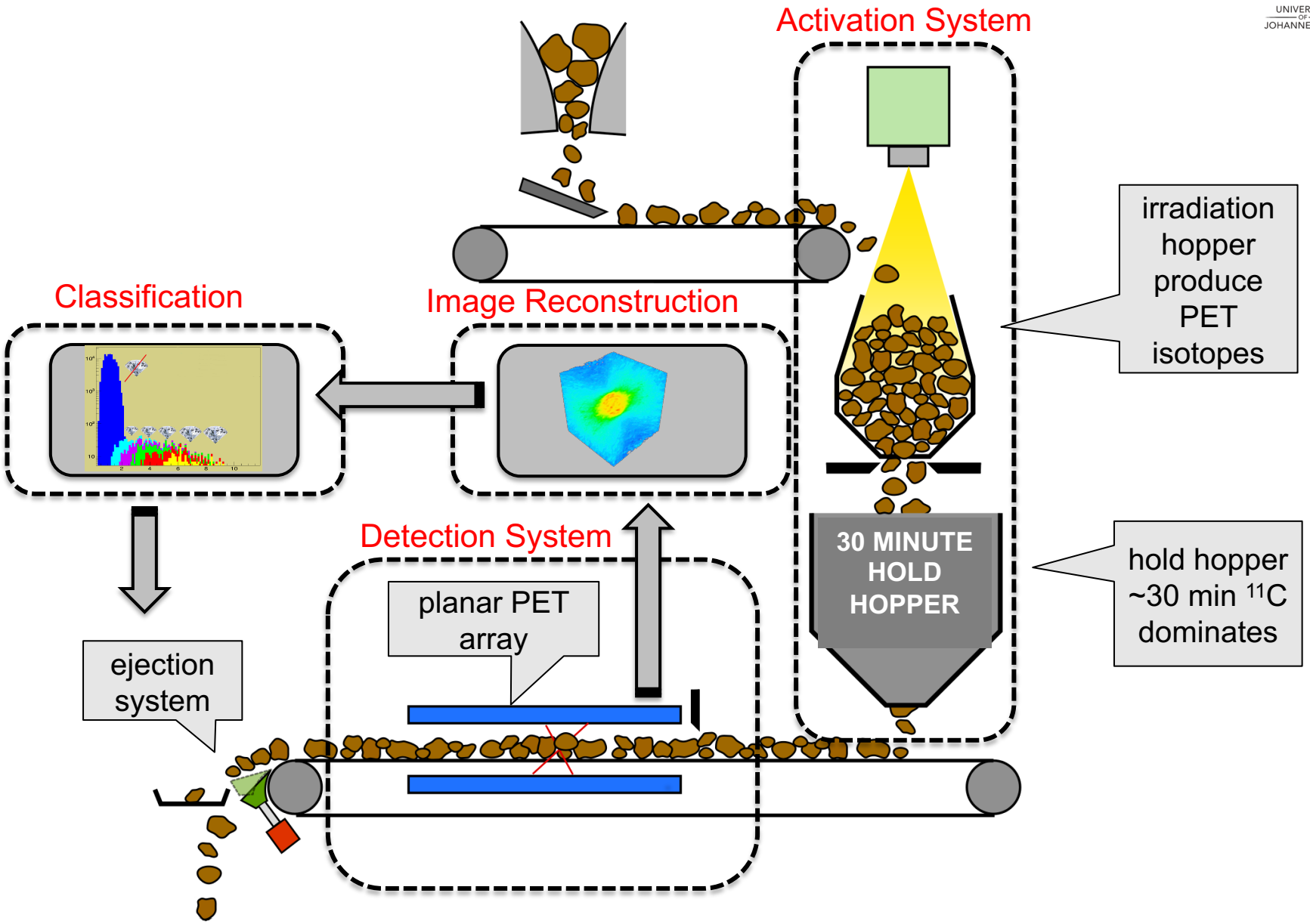
The Diamond breakage issue

Stippled face vs cleaved face ….. breakage ?



The Cullinan, about 3107 ct, was maybe twice as big ?

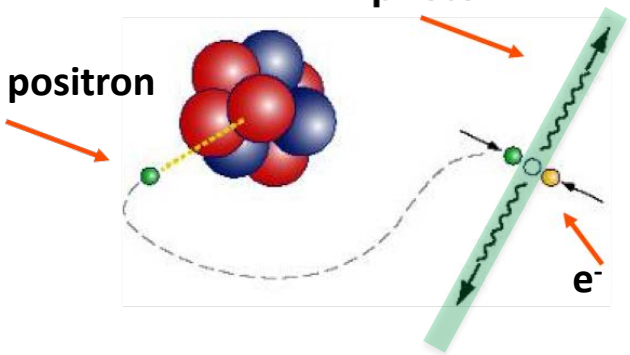
MinPET in a Nutshell



PET Lines of Response (LoR)

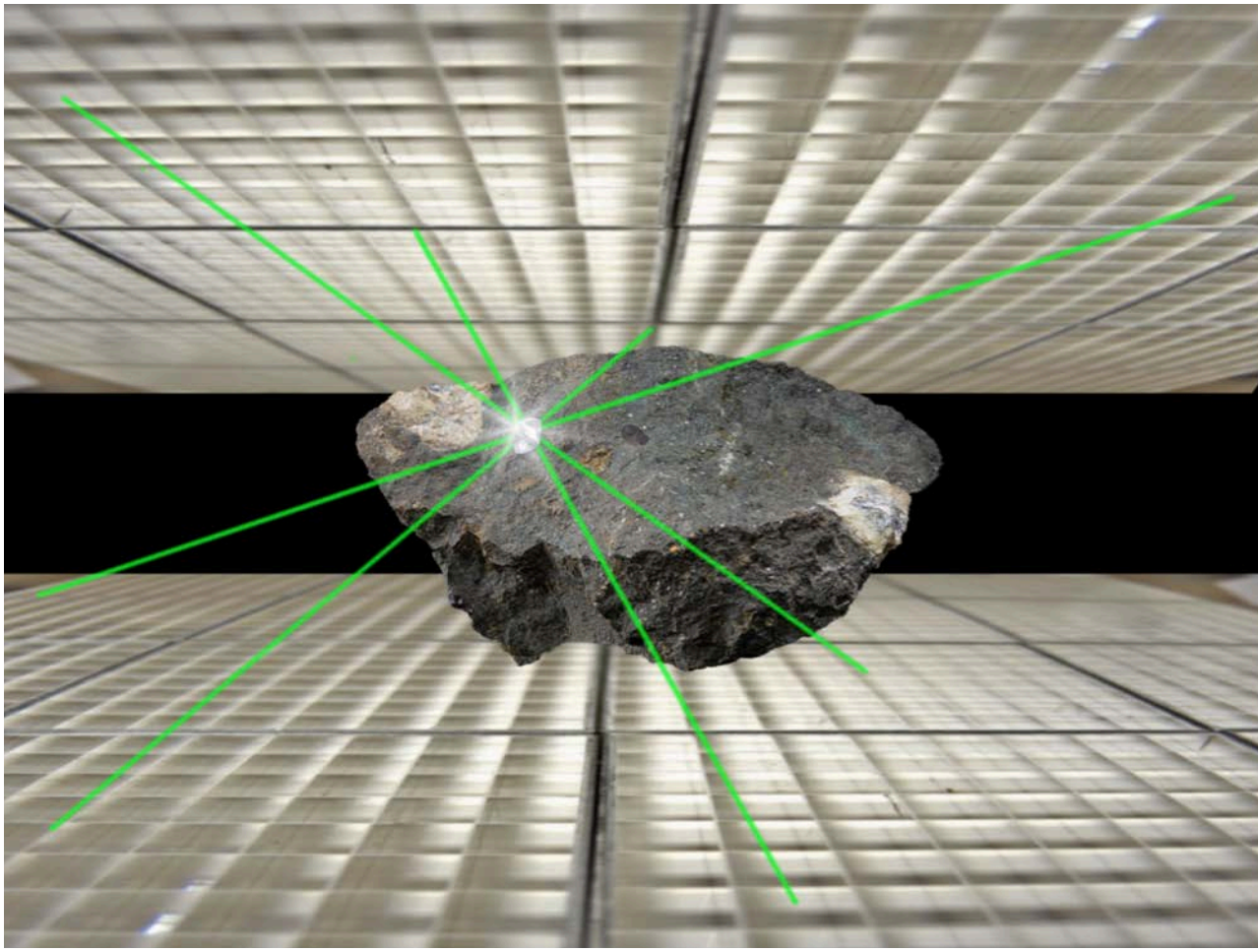
Irradiation converts normal ^{12}C to ^{11}C by irradiation with high energy photons

^{11}C beta decay



…. Detection ……

…. Reconstruction ……

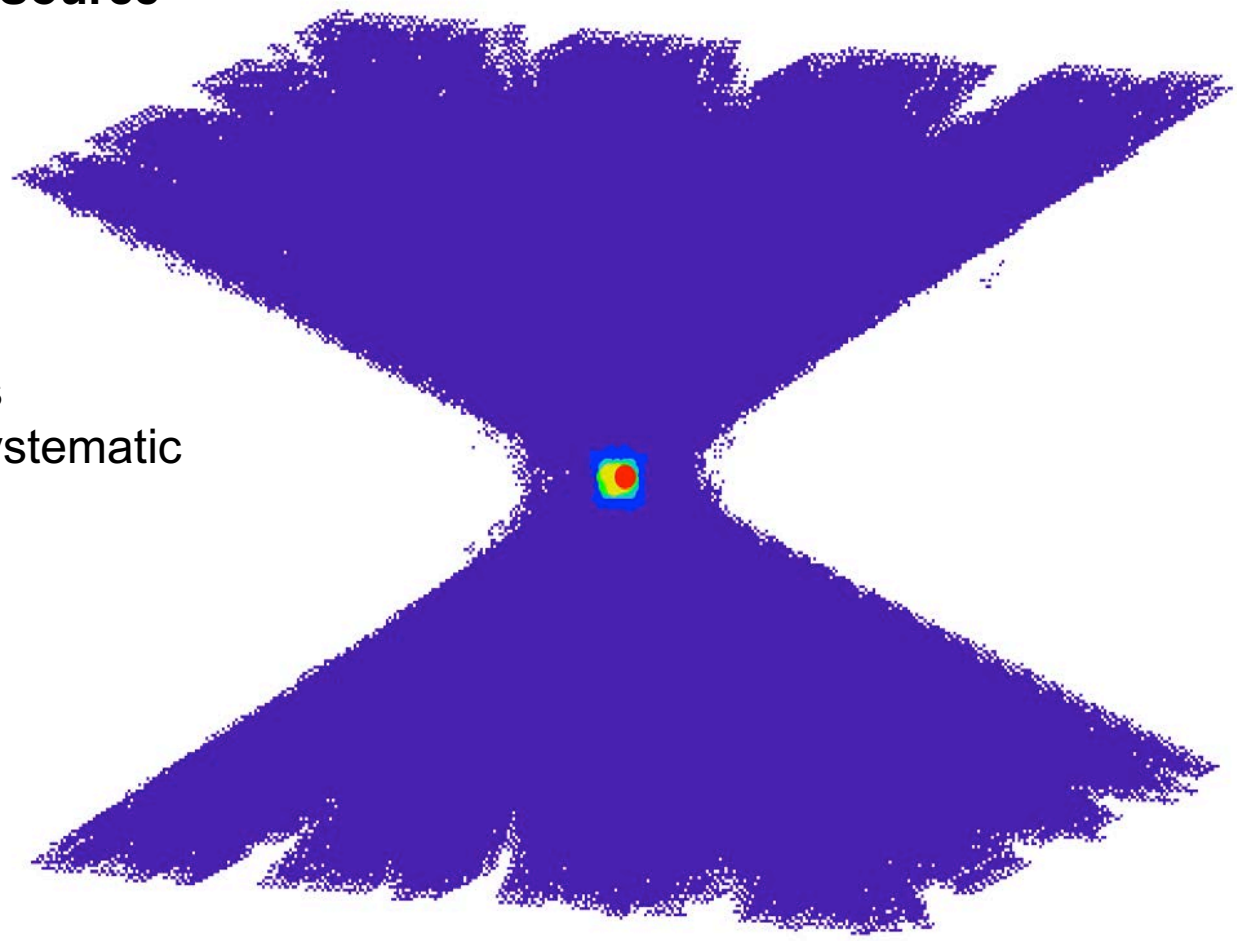


PET Lines of Response (LoR)

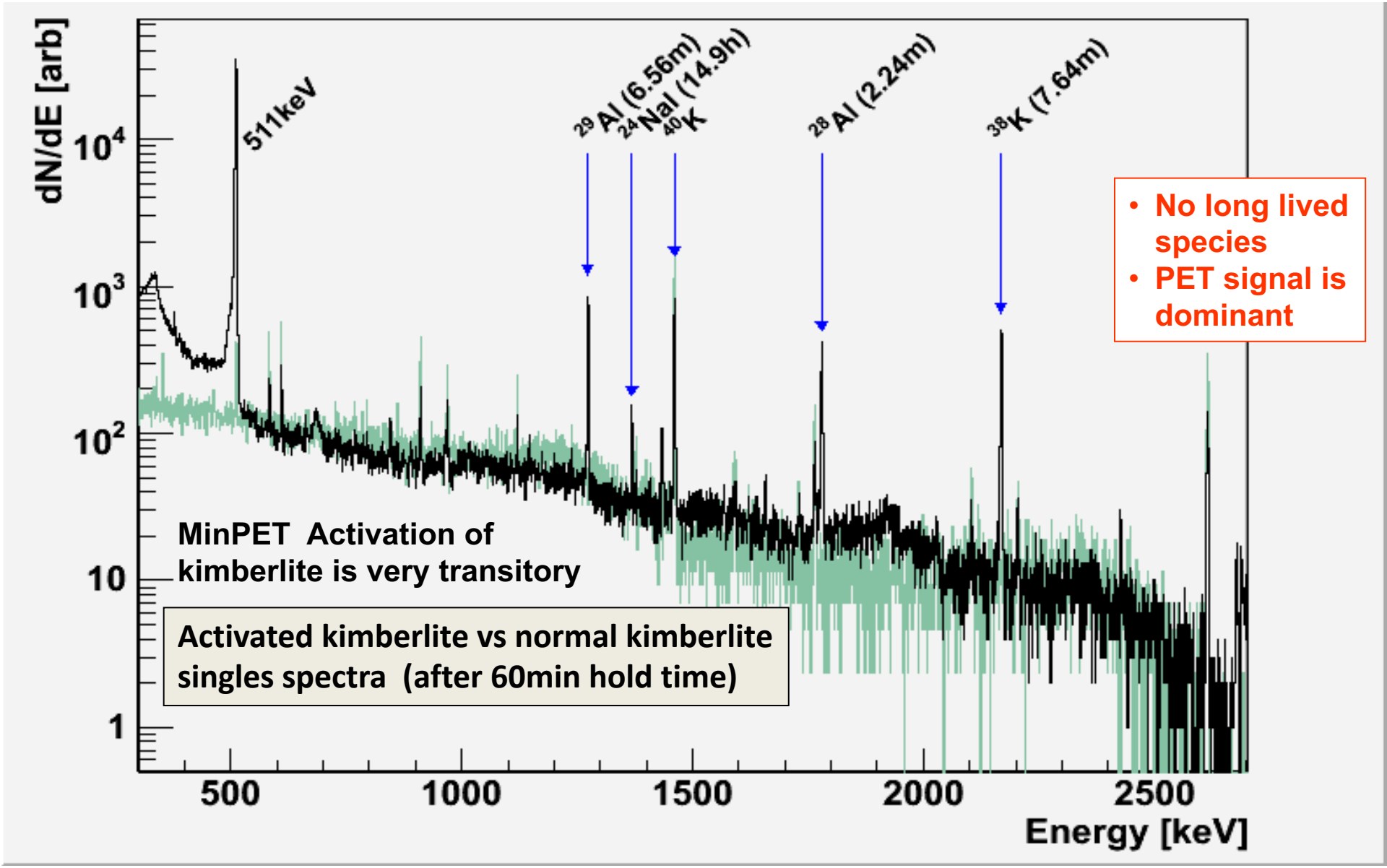
Reconstruction of a Point Source
Back projection

Need
1,000,000 Lines
of Response per rock.

Technological developments
compensated unforeseen systematic
problems exactly.

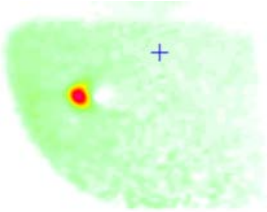


Comparison of activated and normal kimberlite

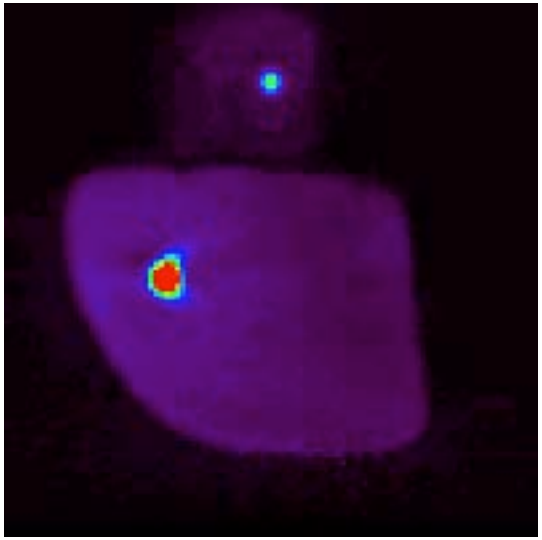


- No long lived species
- PET signal is dominant

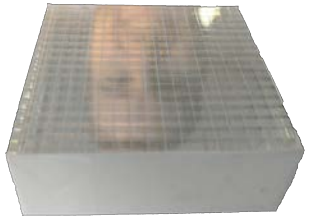
MinPET in a Hospital



5cm

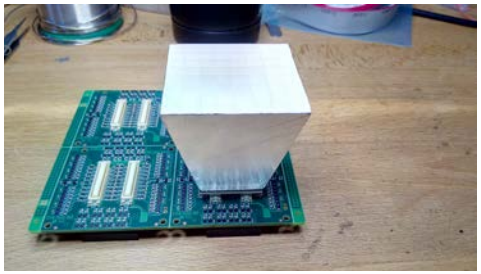


First "killer" experiment (2007)
Karolinska Hospital
Medical Gamma therapy + Medical PET



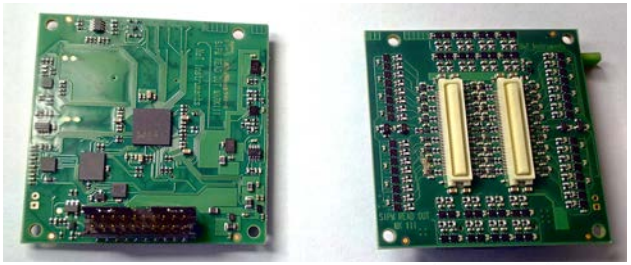
Detector Development – with Italian Partner

BGO segmented scintillator crystals

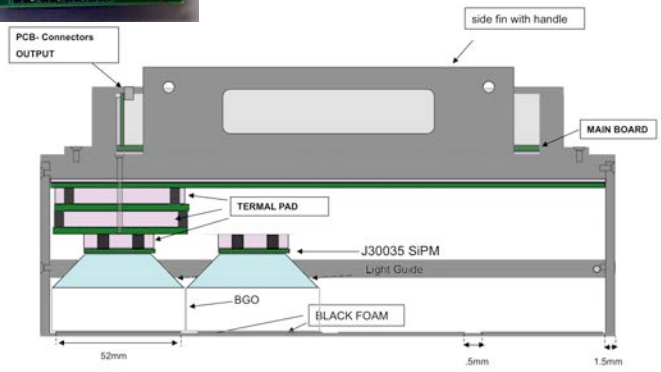


Light guide concentrator to SiPM

High throughput front end electronics



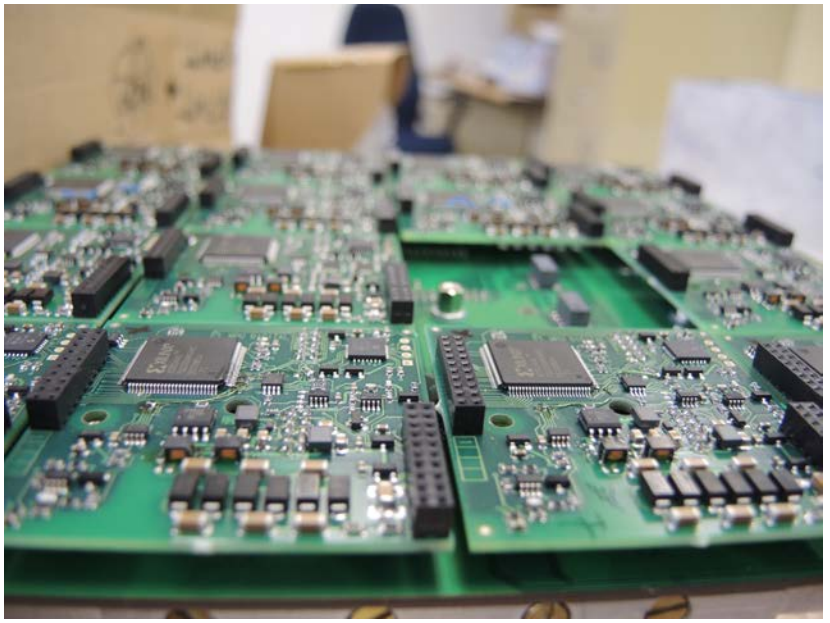
Housing



R&D jointly Italy and SA

Detector development

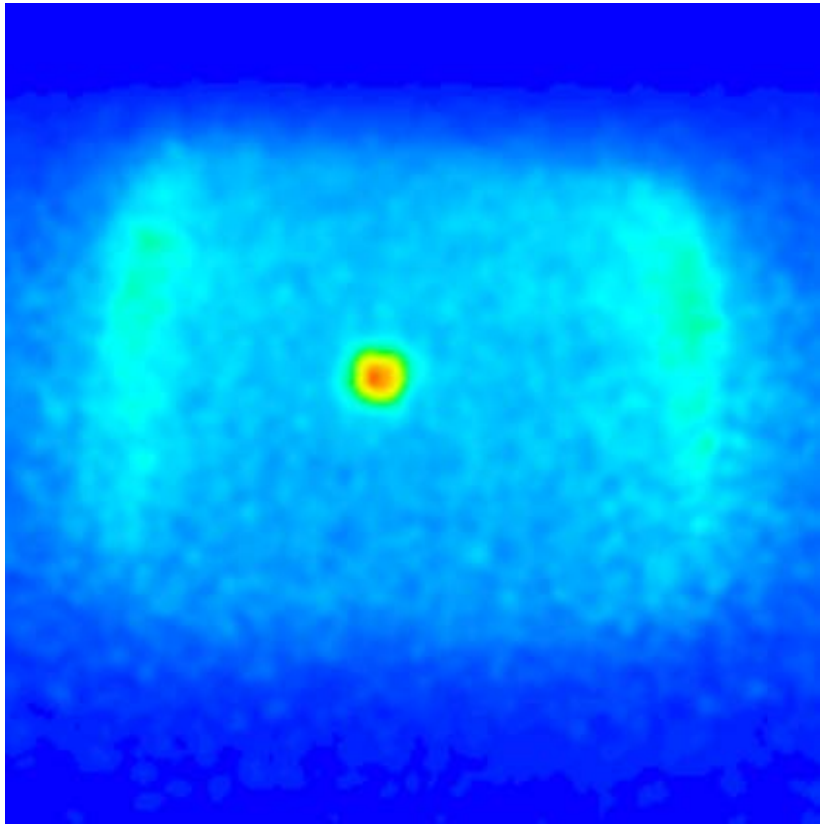
- IAEA Country Programme Framework Technical Cooperation: circa R2.8M
- Development of Mk3 detectors with NeT Instruments
- TIA seed fund: visit to commission detectors



Typical results

10 cm cube kimberlite
2.3kg

12.5 carat diamond



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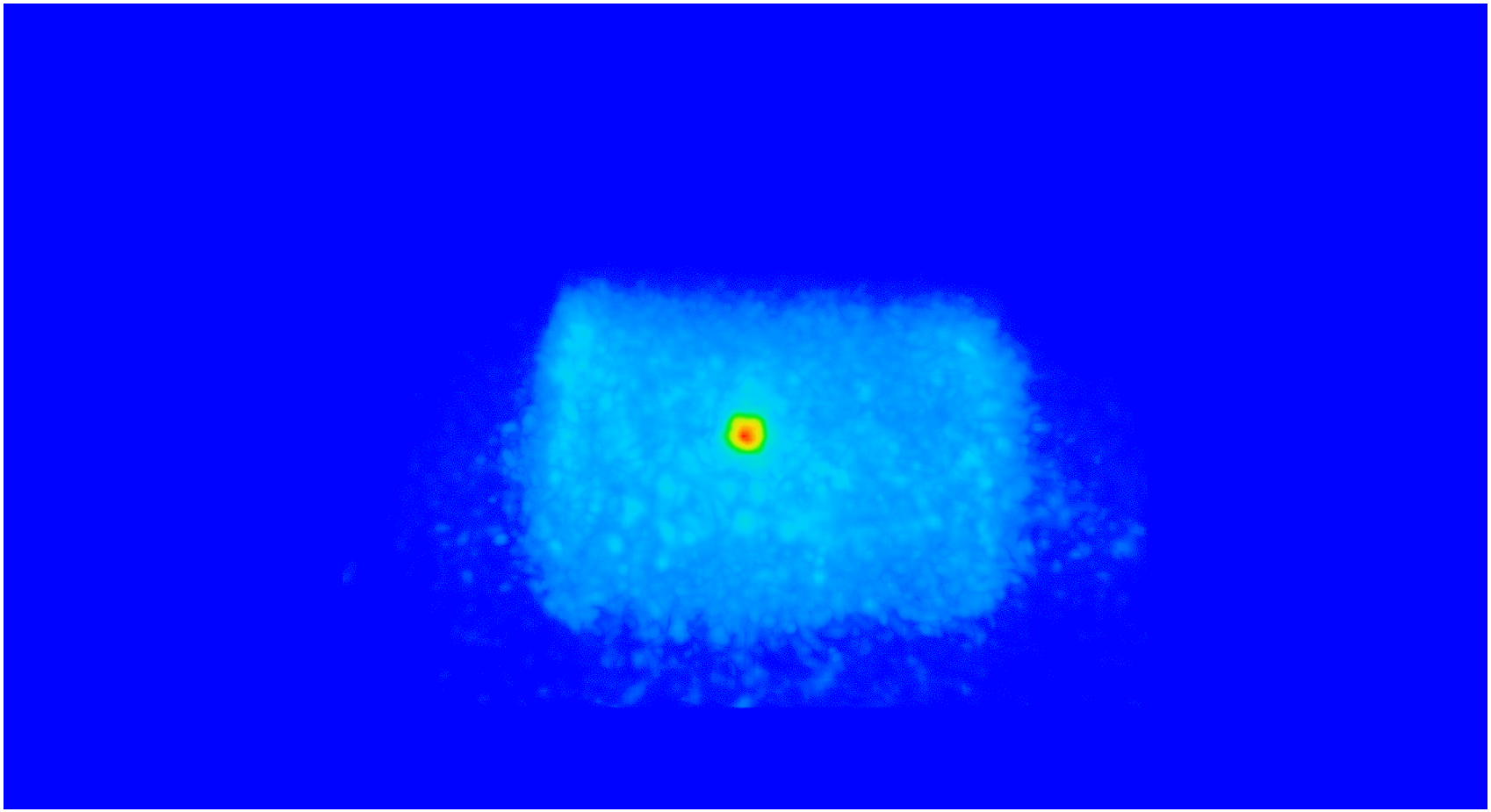

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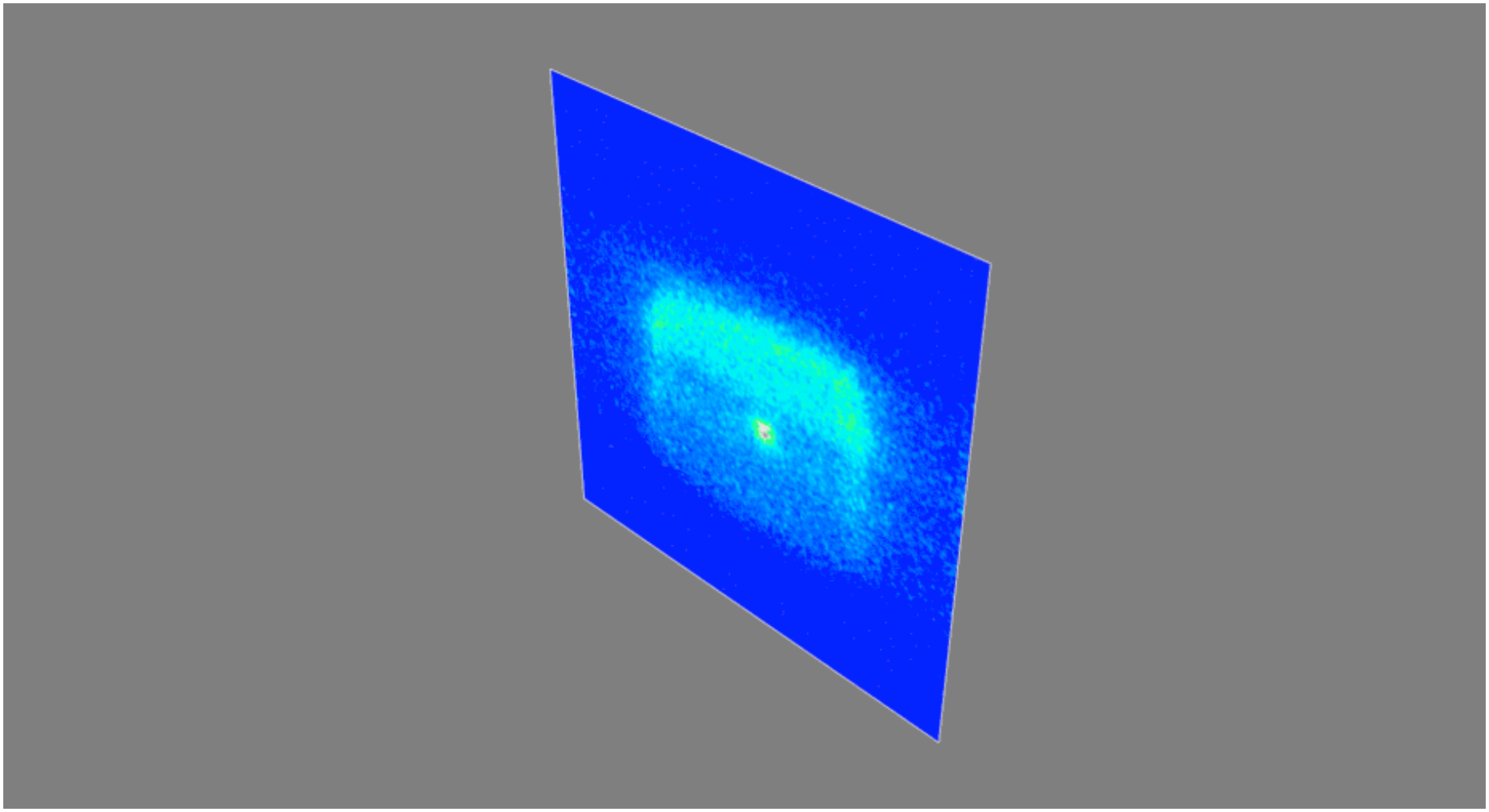
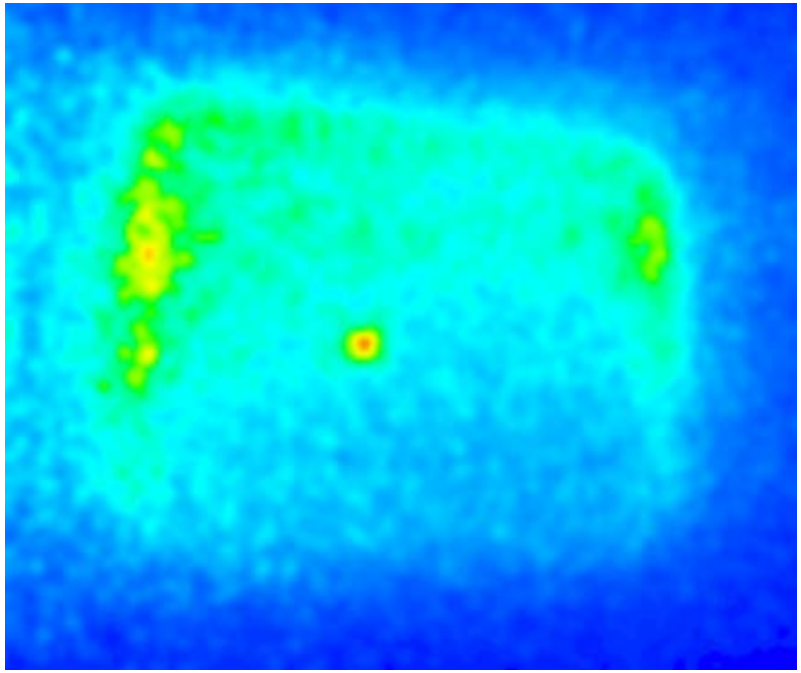


Typical results

10 cm cube kimberlite
2.3kg

7 mm diamond
2.9 carat



$CaCO_3$

$^{40}Ca \rightarrow {}^{38}K$

$^{16}O \rightarrow {}^{15}O$

$^{12}C \rightarrow {}^{11}C$

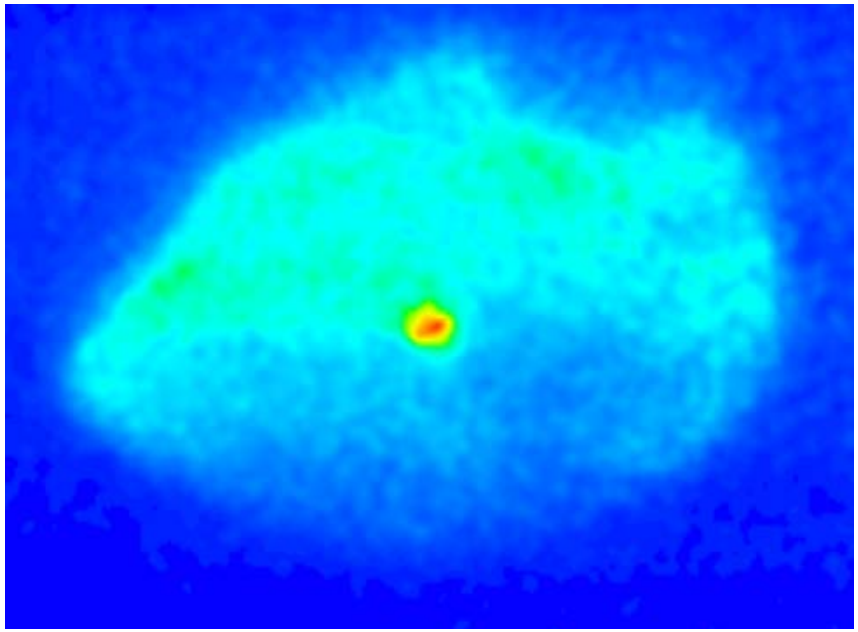
All three are PET isotopes

Worst case of “background”

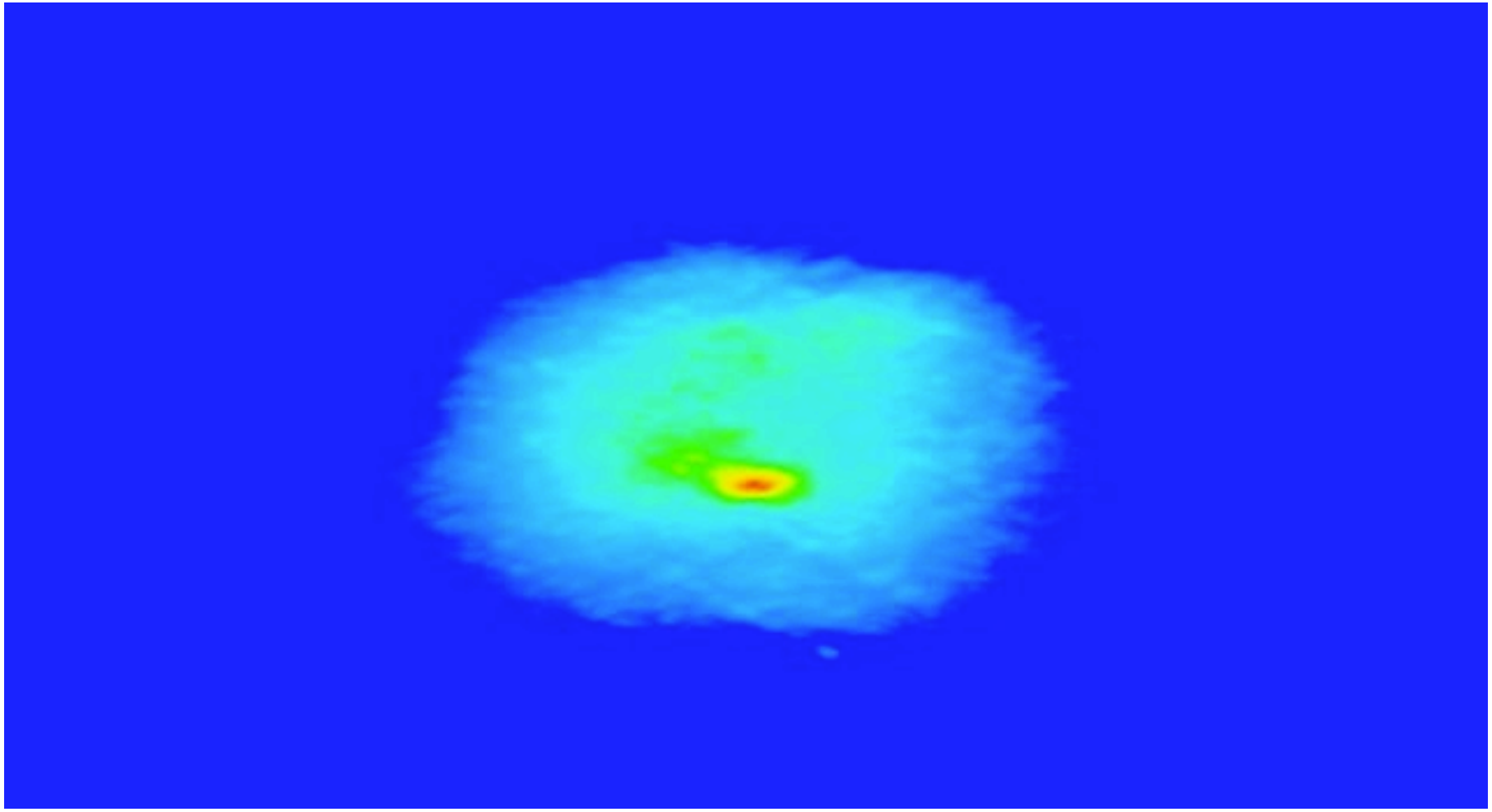
Typical results

10.3 ct diamond

1.431 kg of Calcite
L = 15cm



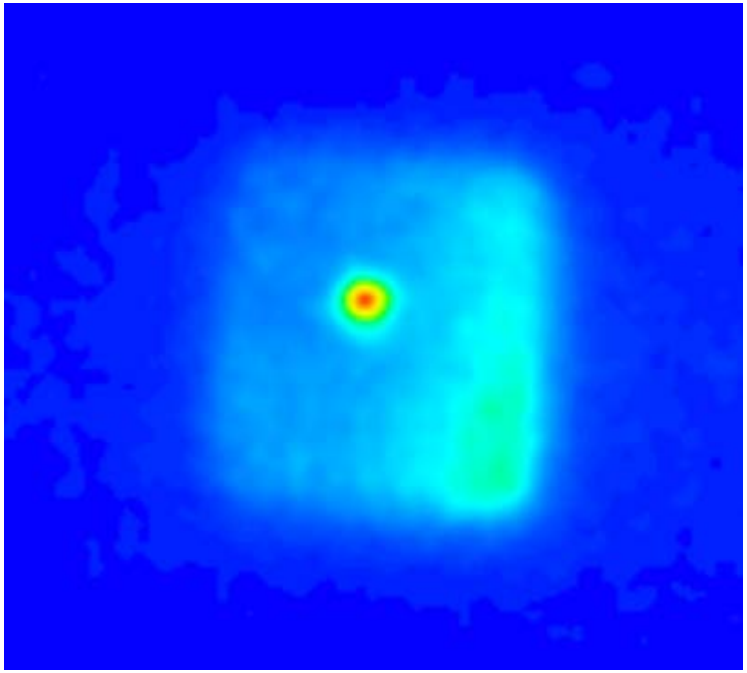
Typical results



Typical results

350g kimberlite (50mm)

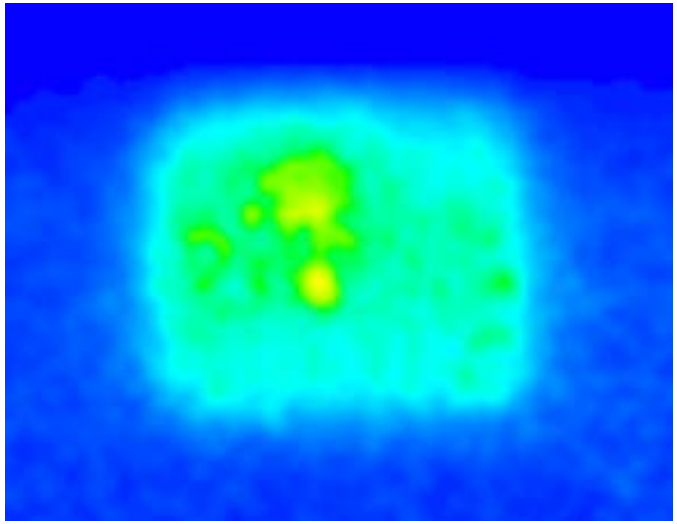
2.9 carat diamond



Typical results

350g kimberlite (50mm)

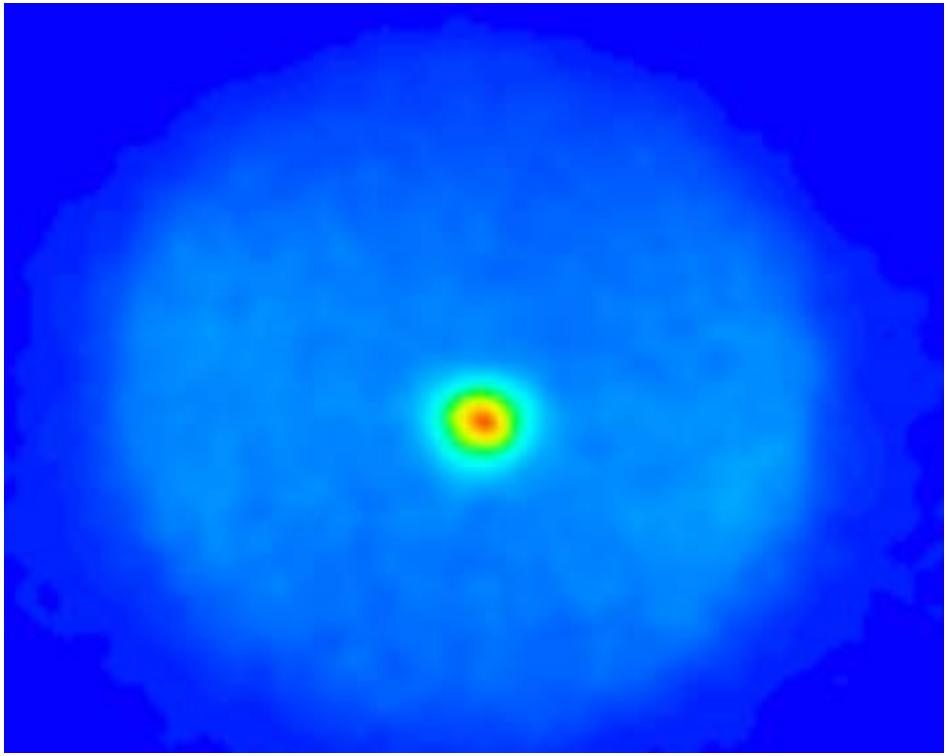
0.23 carat diamond
4 x 5.5 x 0.6 mm^3
F = 3mm



Typical results

410g drill core
f = 74 mm
L = 40 mm

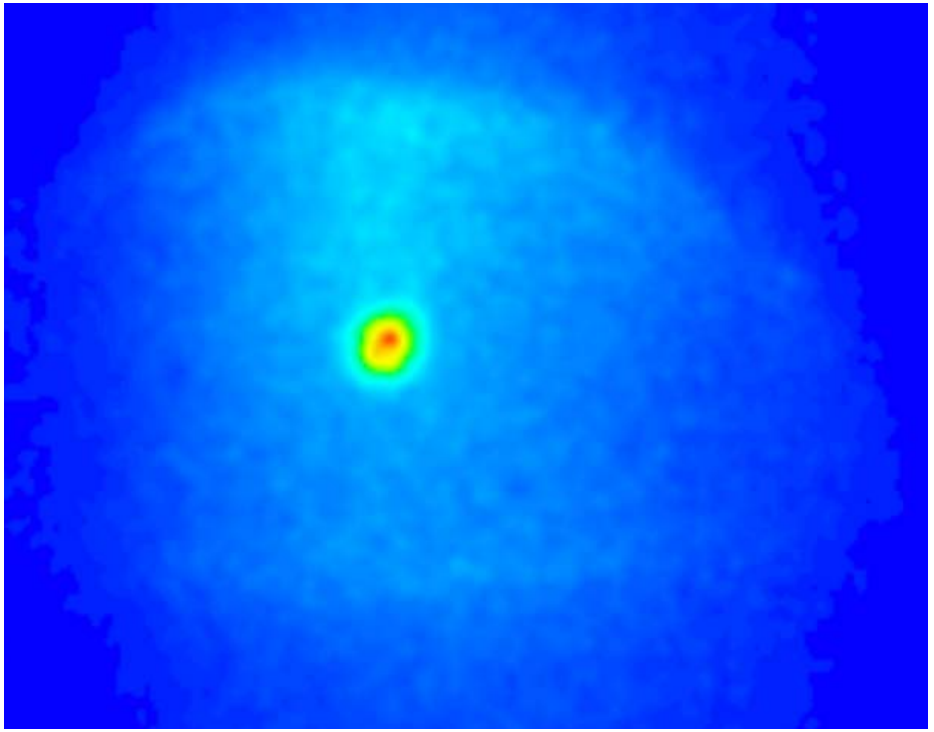
5.0 carat diamond



Typical results

3.33kg kimberlite

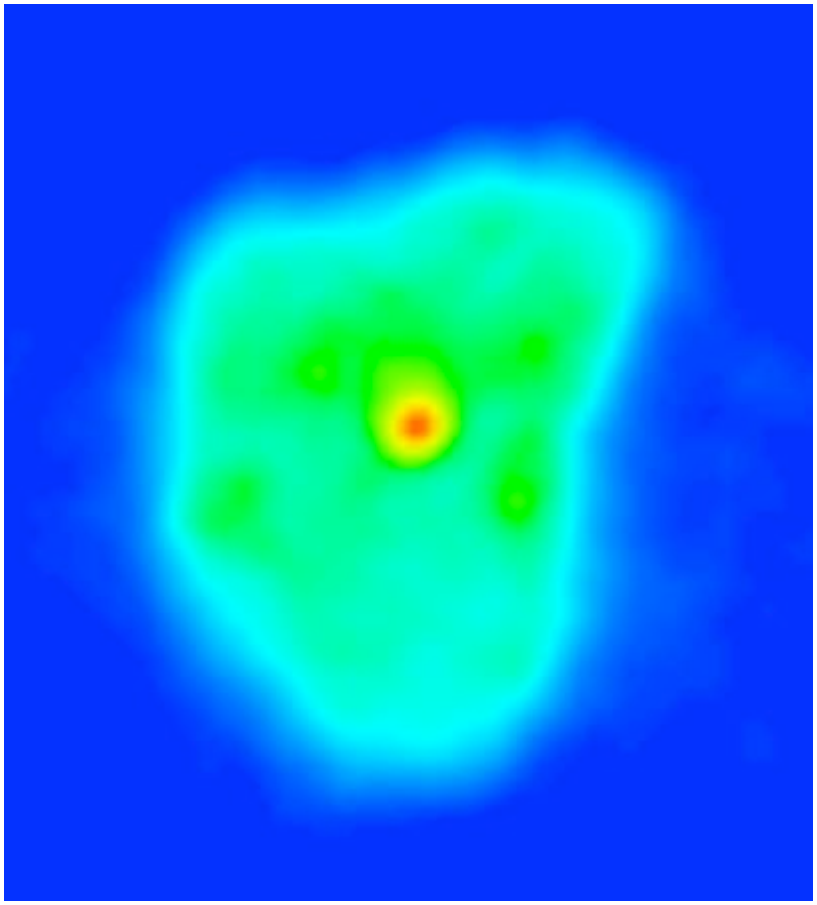
22.9 carat diamond



Typical results

95mm long

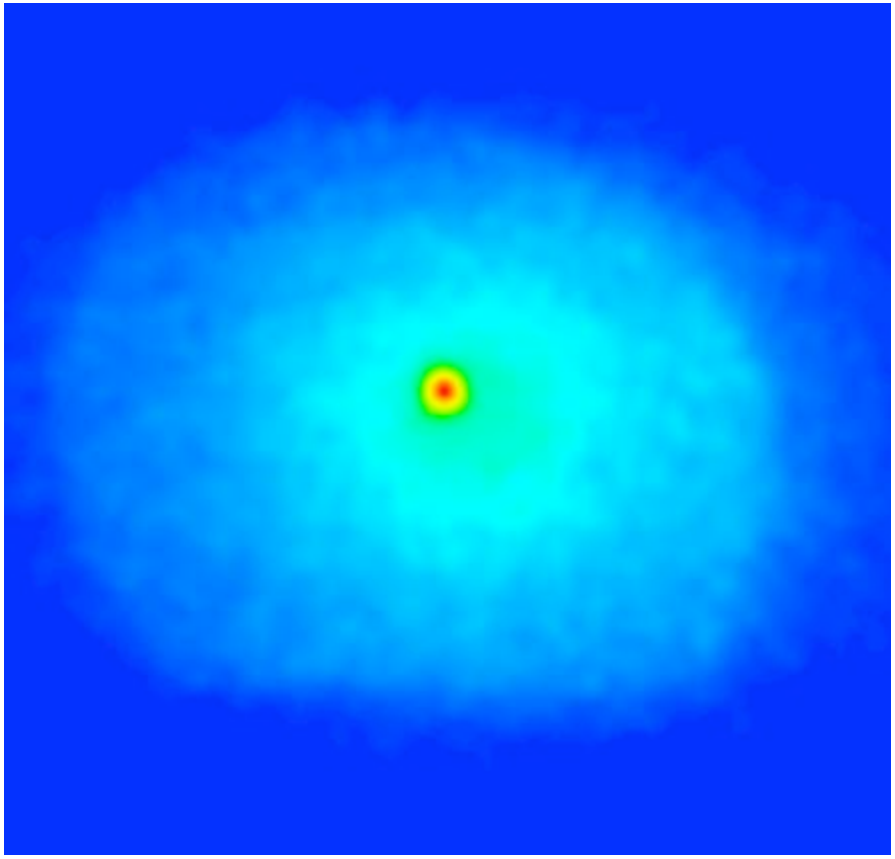
0.91 ct



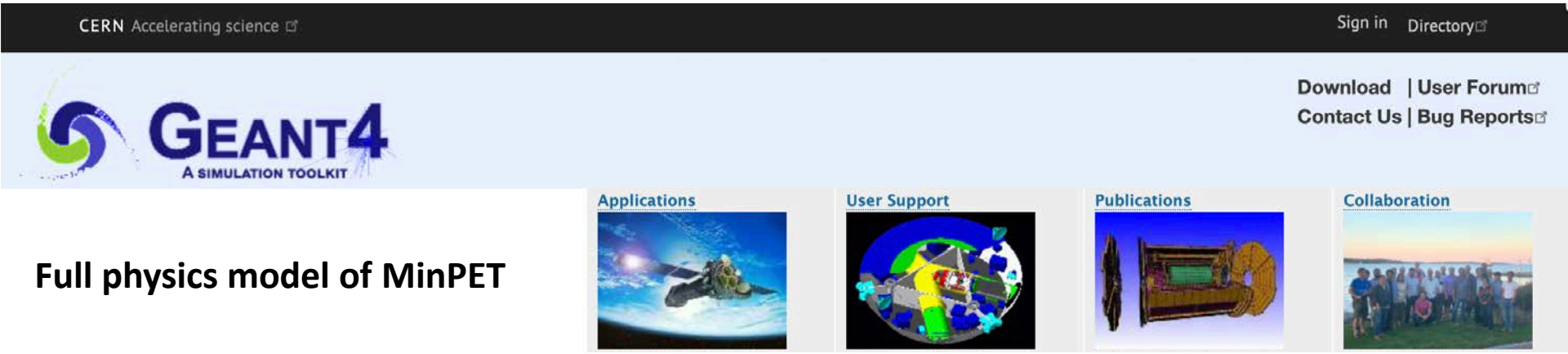
Typical results

5.5 kg
170 mm long

7.9 ct

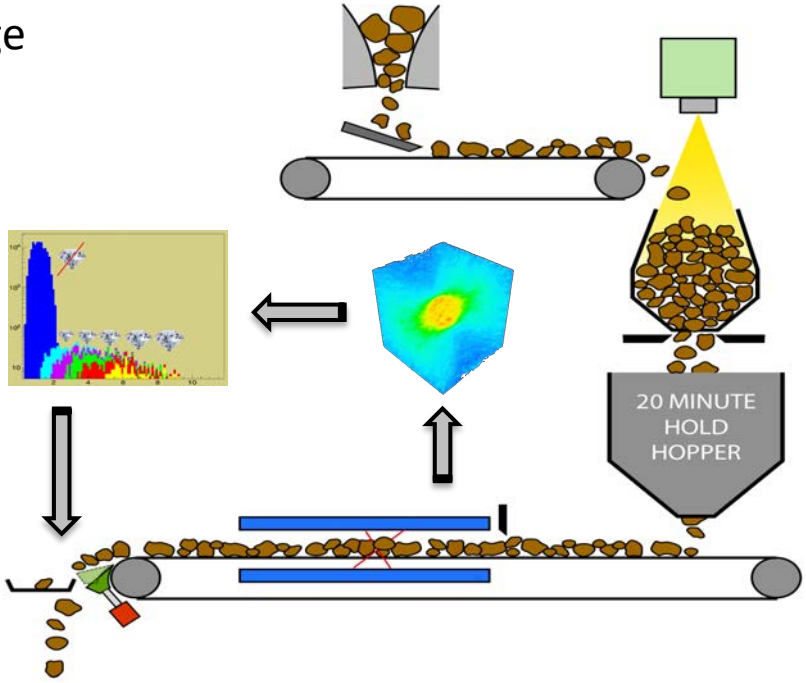


Full Physics Sim : Geant4 Monte Carlo

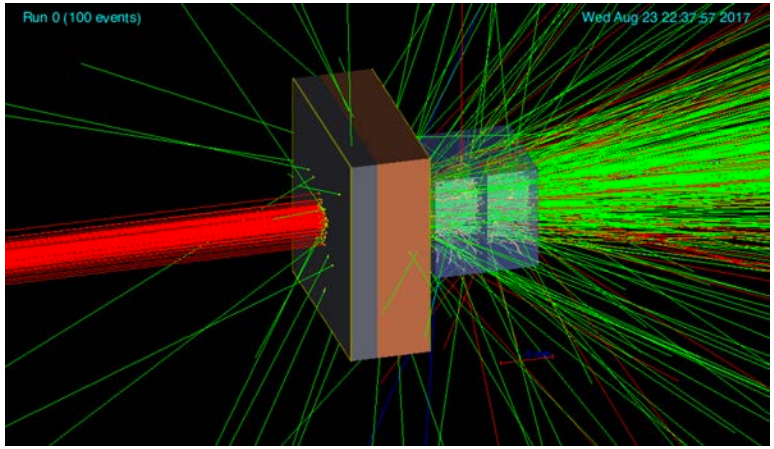


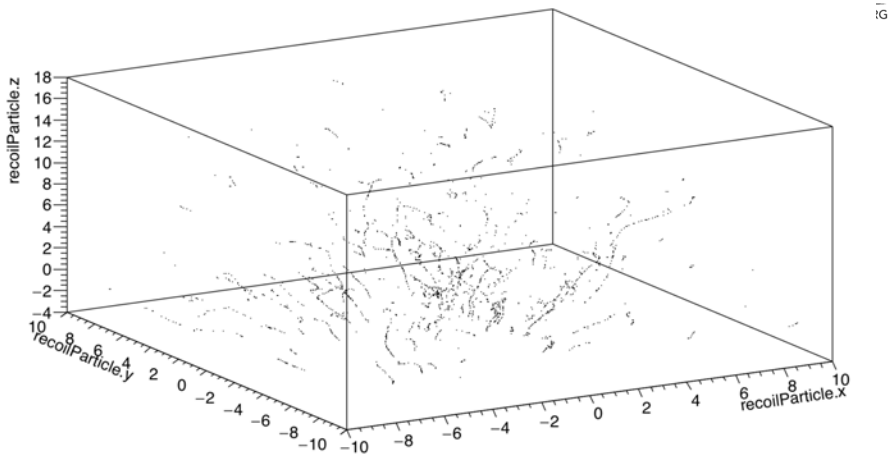
Full physics model of MinPET

- Electron accelerator
- Mixed radiation field from the Activation stage
  - Treat Nuclear Physics with TENDL
  - GDR X(γ,n)Y
  - Other channels and 2nd order processes
- Simulate **moving rockstream**
  - Each time slice separate geant4 run
- Simulate Radiation Damage in Diamond
- Simulate Activation in Kimberlite
- Simulate Detector Response
- Produce Data nTuples **(Sim or Exp)**
- Create 4D Sinogram
- Perform 3D Reconstruction (MLE - GPU)
- Perform AI Classification



Full Physics Sim : Diamond Damage by MinPET



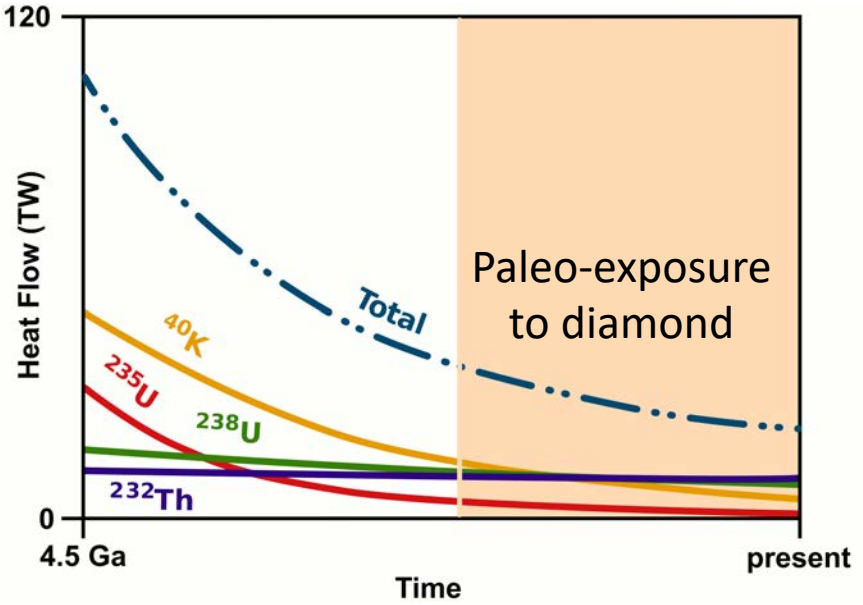


Estimate vacancies produced by shower and secondaries from 40 MeV e-g beam
GR1 @ 0.3 ppb

Paleo-dose
10 Bq/g integrated back in time for 2 billion years

Estimate primary vacancies produced by natural photons > 185 keV

Nature = 10^4 x MinPET dose
(+ some annealing of V and aggregation of defects)



MinPET's effect on diamonds is many orders less than exposure in nature …
Damage study concludes beow low temp laser induced Photo Luminescence

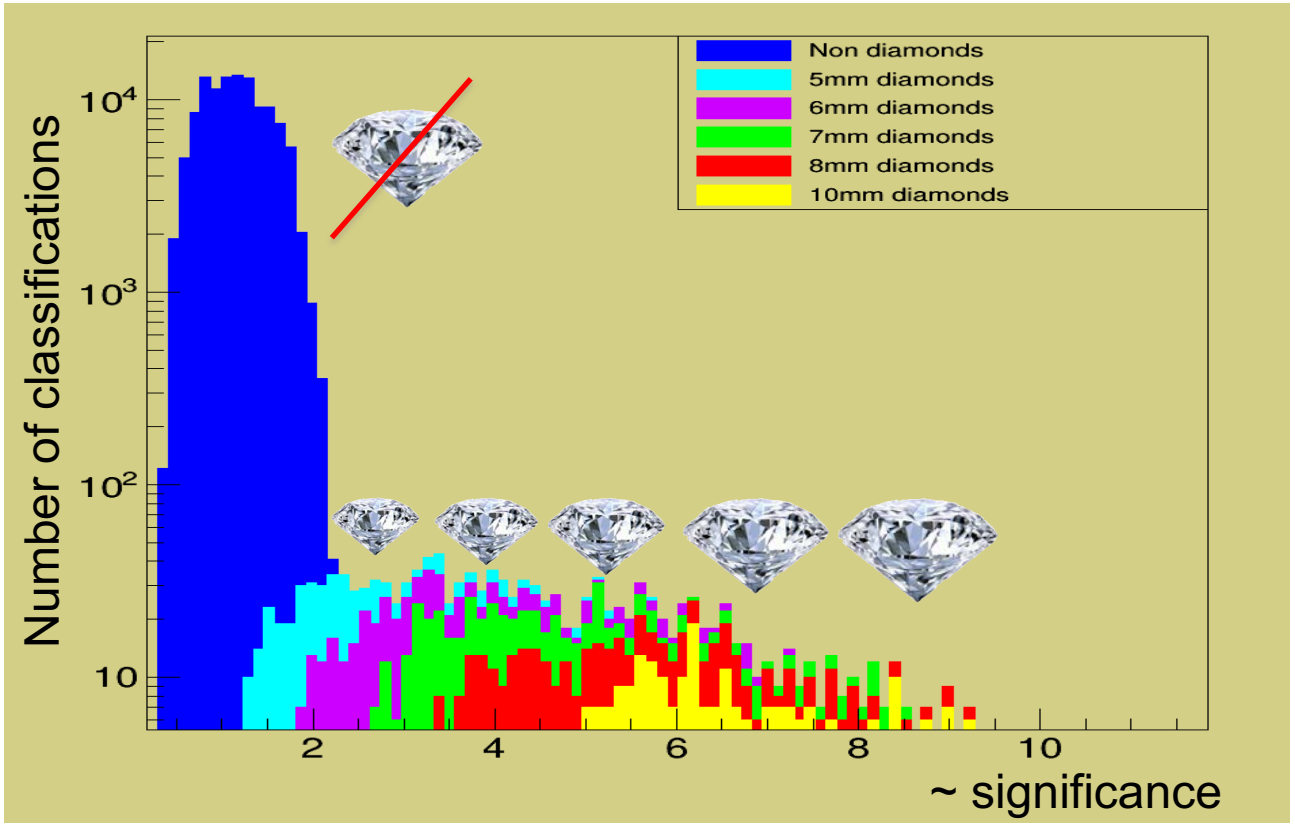
Training data from Simulation

- Big effort to develop accuracy in SIM
- Benchmarking to experiment
- High performance computing
- Large data sets

We now have an "**all singing and all dancing**" **Artificial Intelligence** to classify the diamonds.

Detection → Classification

t < 5 s



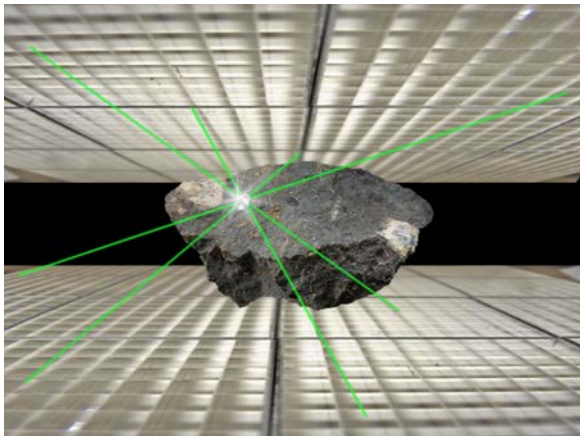
A FDH is when all actors perform with all costumes and props in sequence

Take home message .....

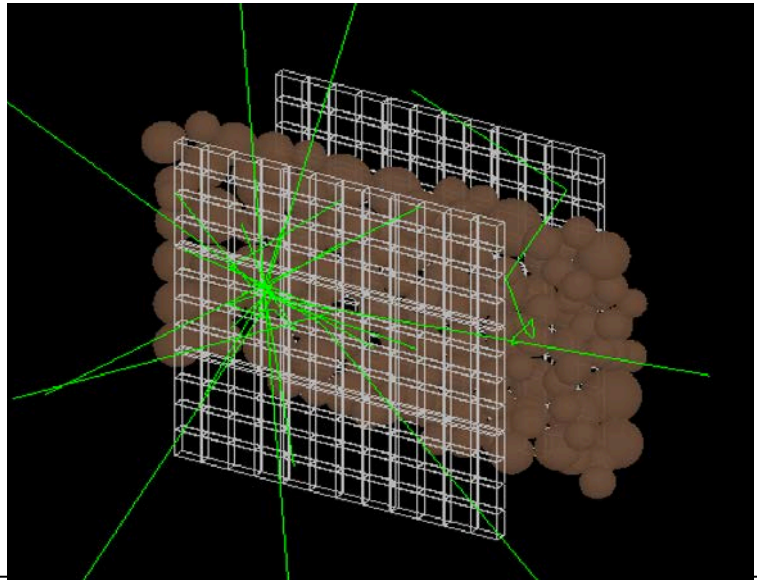
Demonstrated MinPET in a **FULL-DRESS-REHEARSAL**
Rate equivalent to 1 MinPET unit ... Run of Mine ... 500 tph

Benchmarked Computer Simulations for FDR

Complete exclusion of "unknown unknowns" to 10%



Validated scale-up tool



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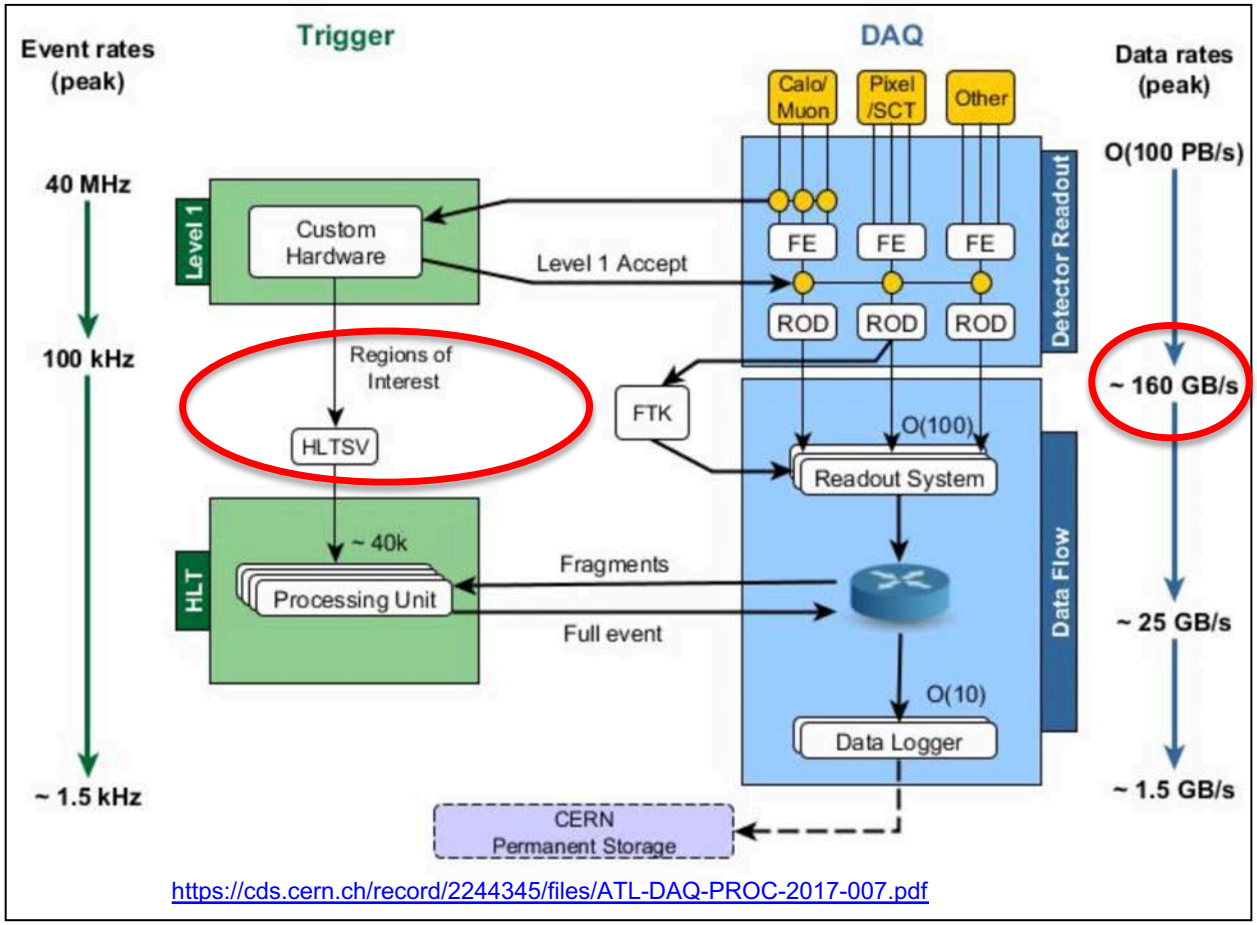
Scale-up : Data Rates - we need to process 16 GBs
How does ATLAS do this with 160 GBs ?

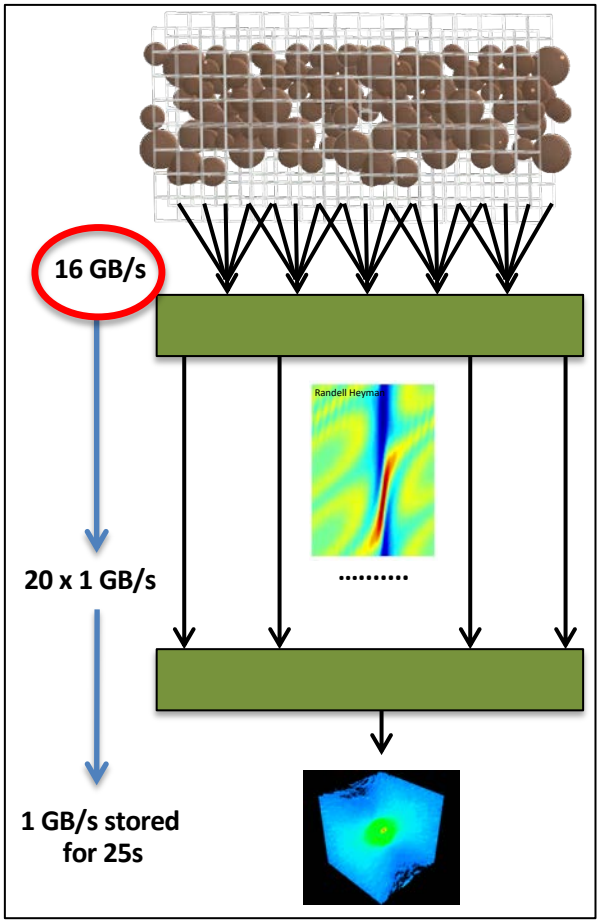
Partition data into Regions of Interest, analyze in parallel, then data fusion

ATLAS



https://cds.cern.ch/record/2244345/files/ATL-DAQ-PROC-2017-007.pdf

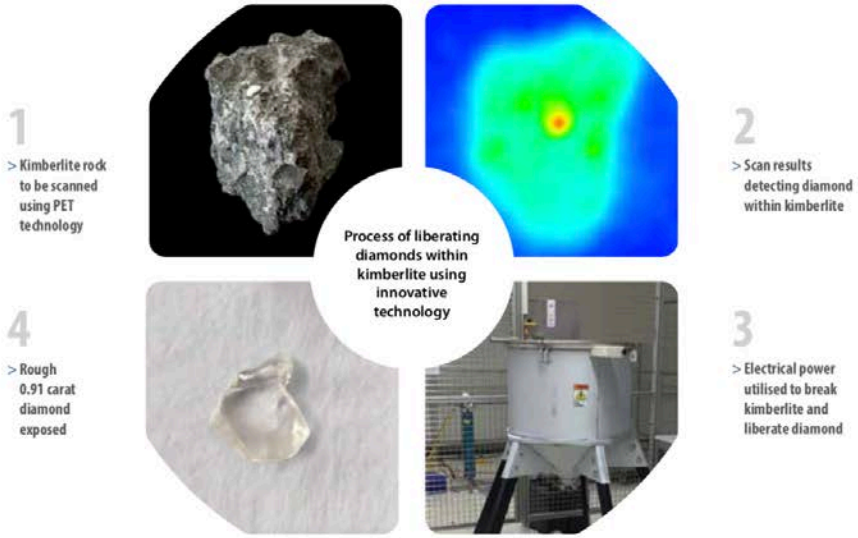
MinPET



Gem Diamonds own Letśeng mine in Lesotho

Joint research with Gem Diamonds

Producer of especially large



Gem Diamonds Annual Report and Accounts 2017

gemdiamonds.com

The Lesotho Legend 910 carats

Lesotho Promise 603 carats

Letšeng Star 550 carats

Letšeng Legacy 493 carats

Leseli La Letšeng 478 carats

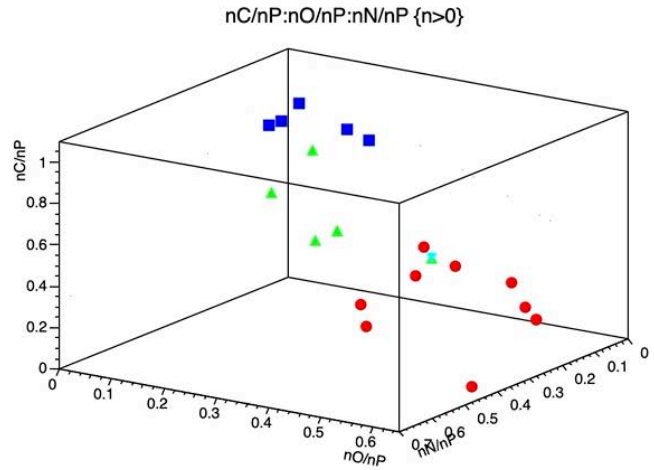
Analysis of

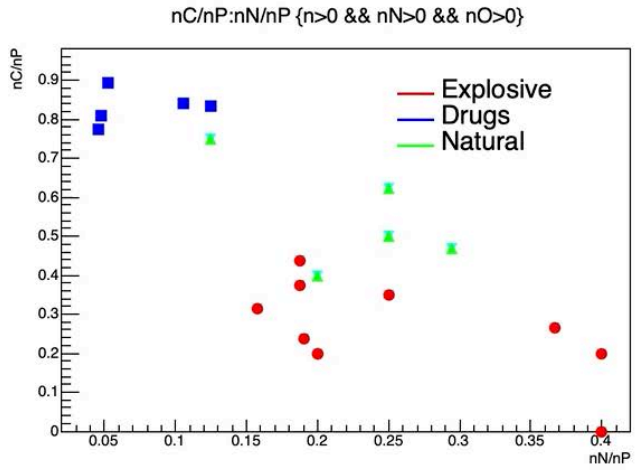
- Coal

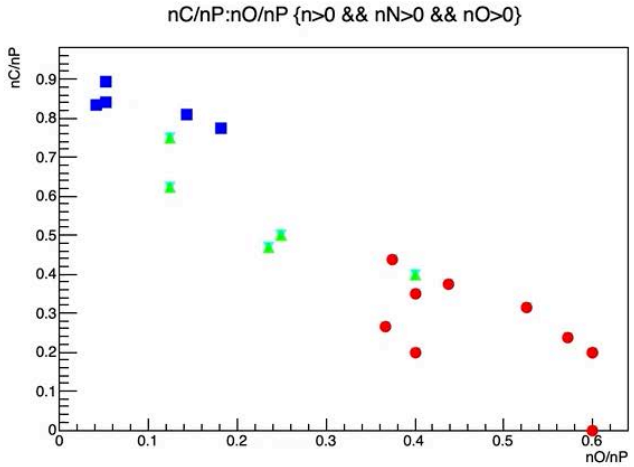
C – Calorific Value

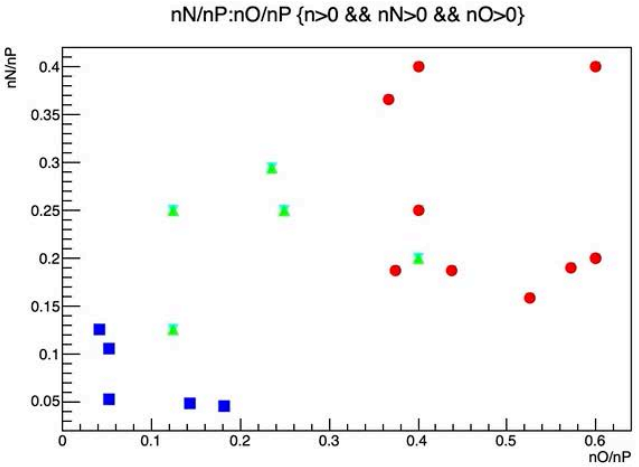
O – Moisture

- Explosives
- Narcotics
- Plastics







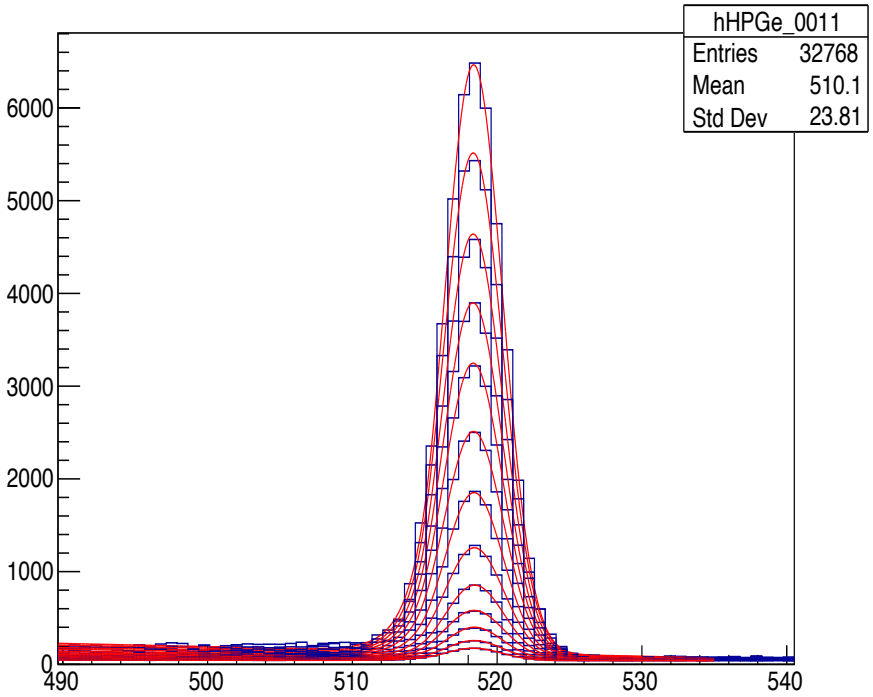


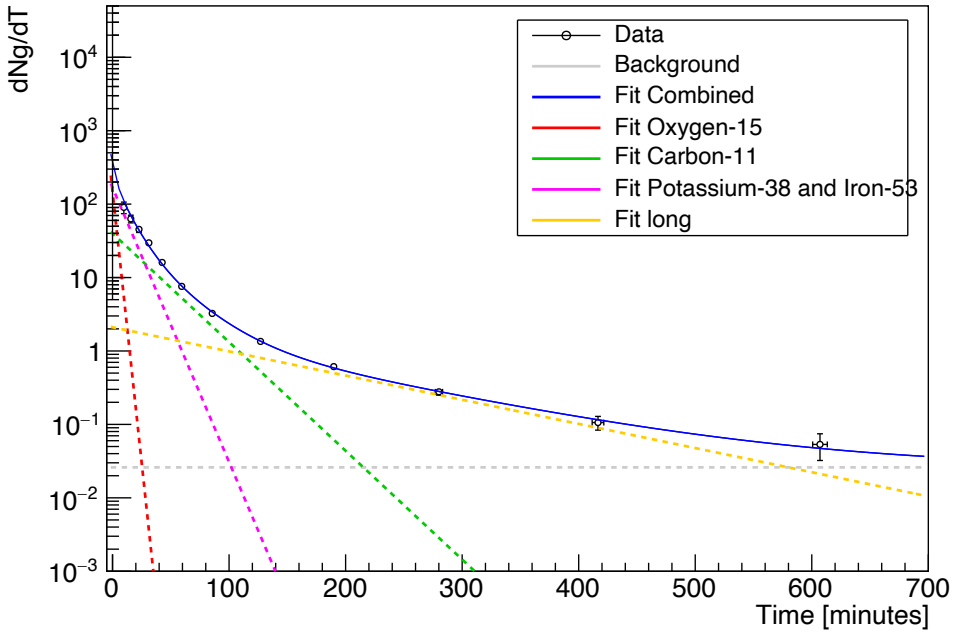
Measure Coal quality

- Carbon as a proxy for Calorific value
- Oxygen as a proxy for Moisture content

Must be on-line, real-time

PolyPET – Element sensitive PET

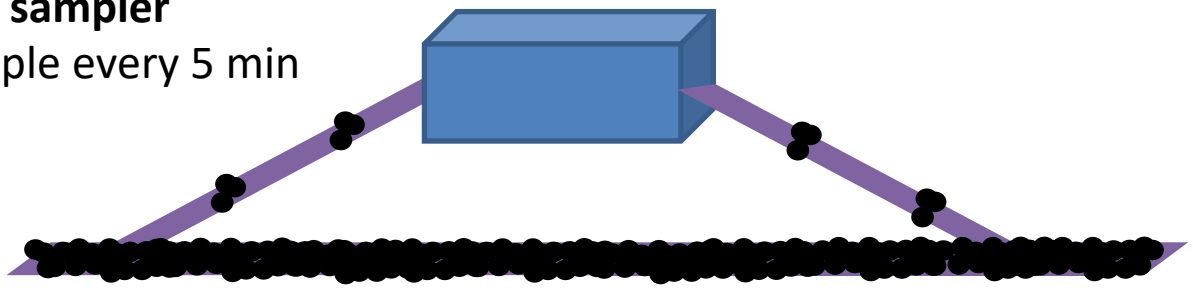




- Time differential detection of PET activity
- Each isotope has its own half life
- Elemental analysis by lifetime analysis

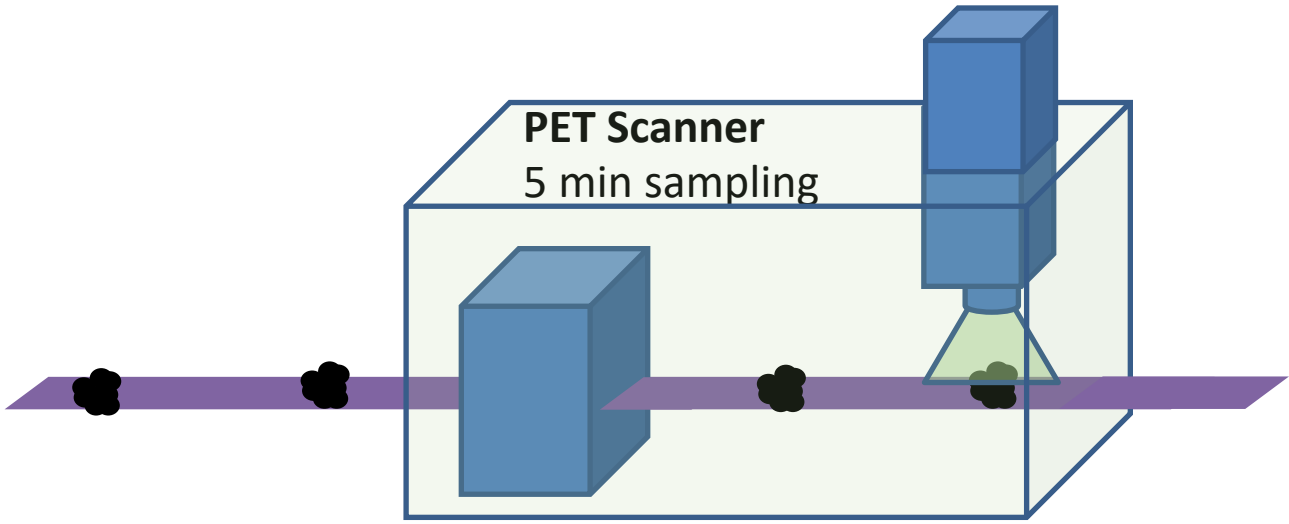
PolyPET – Element sensitive PET

PolyPET sampler
3kg sample every 5 min

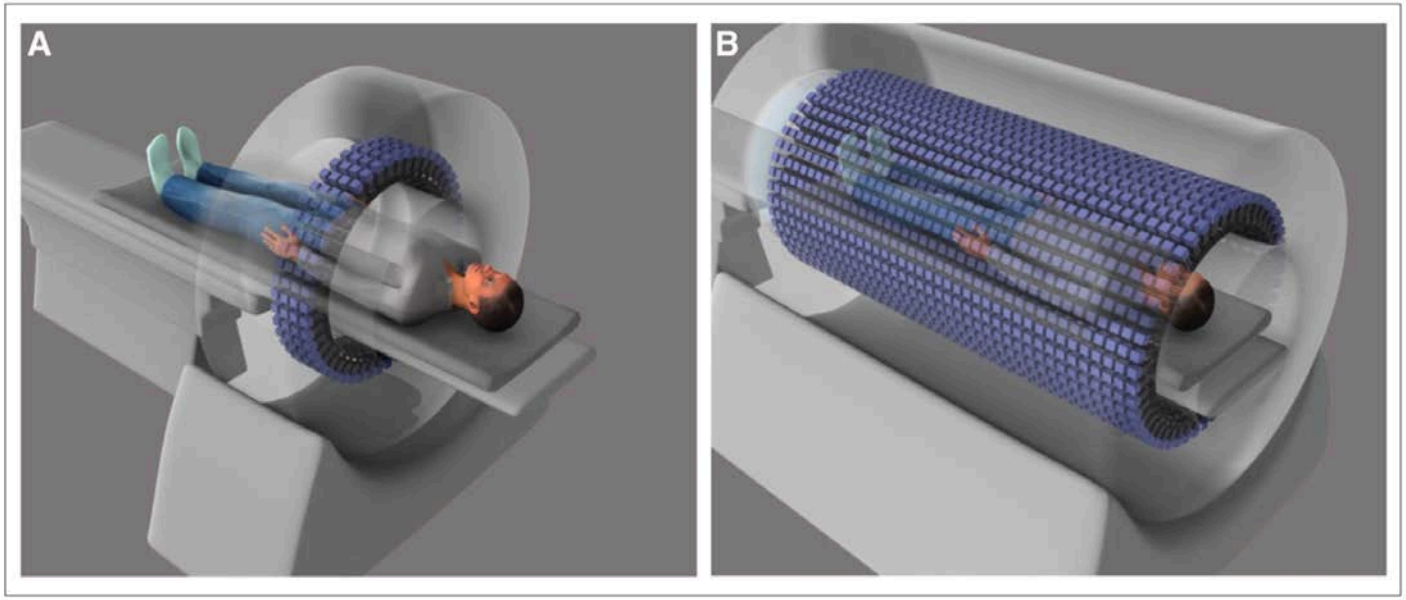


Main supply belt

Activation
40 MeV electrons
Bremsstrahlung target

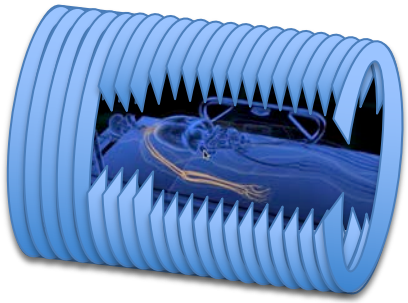


Total Body PET



- 40 x more efficient
  - Lower dose, multiple scans
  - Time variation (mili seconds) – PET Video
  - Time variation (minutes) - Dynamics

Disruptive Medical Technology.

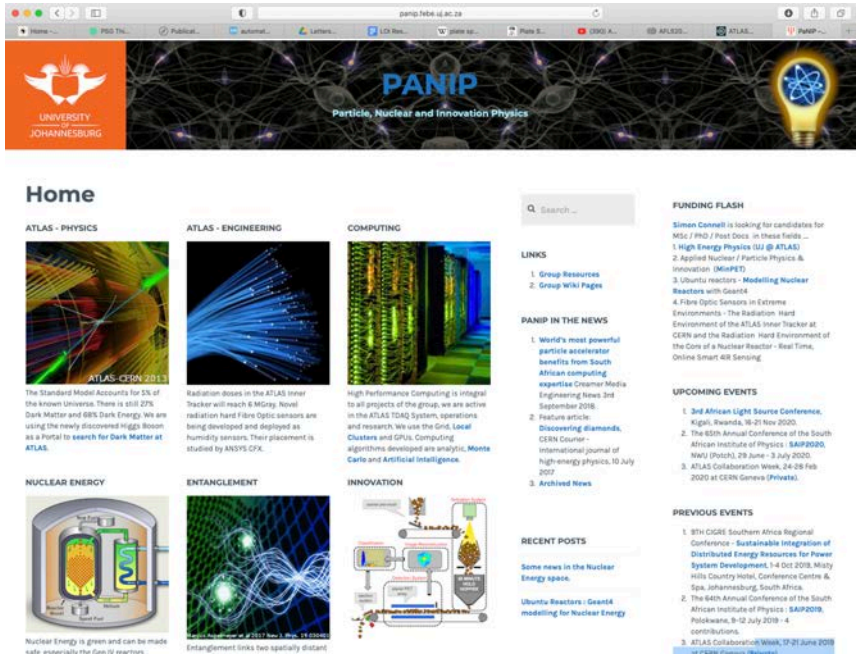


Innovation, Commercialisation

1. **Fundamental Research + Idea**
2. Disclosure then Protection of IP with TTO
   - 11 Patents related to MinPET
   - Secrecy
2. Market Research
3. Economic Modelling
4. Business Case
5. Plant Integration
6. Benchmark Competitor Technologies
7. Fund Raising
8. Proto-type Development
9. Technology Readiness Levels
10. Scale – up
11. Legal Issues (challenges to IP)
12. Various impediments (need grit)
13. Discussion to levels of CEOs in companies
14. Venture capital
15. Technology Partners
16. Customers

Students Welcome

https://panip.febe.uj.ac.za



Partners, Funders

For Nico, and all of you …. Thank You

The warriors of the Zulu Impi called out to the young men:
Grow up to be yet braver than we !

IP jointly held by :

UNIVERSITY OF JOHANNESBURG

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Funders :

UNIVERSITY OF JOHANNESBURG

NRF National Research Foundation

IAEA

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

technology innovation AGENCY

BATEMAN

MULTOTEC

THRIP TECHNOLOGY AND HUMAN RESOURCES FOR INDUSTRY PROGRAMME

GEM DIAMONDS

Research collaborations :

NeT instruments

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necsa We're in your world

MULTOTEC

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

Karolinska Institutet

Engineering Company Conversations

FLSmidth

adp

IMS ENGINEERING

ELB ELB GROUP