Results using the LISE library with ARIS SpecTcl

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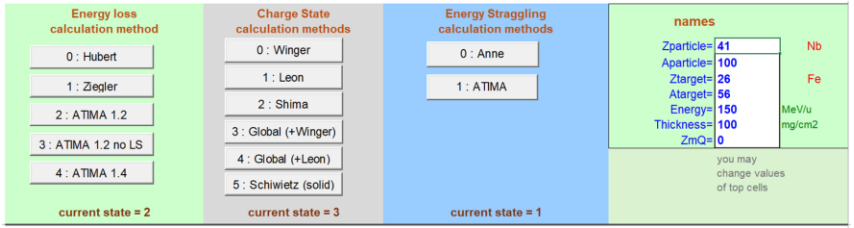
The LISE Library

- Started as a Windows dynamic link library for LISE for Excel, exposing LISE^{++} routines to an external caller.
- Now built for both Windows and Linux; the Linux build (libLISE_excel64.so) is what the ARIS analysis loads.
- Exports energy loss, range in matter, and energy straggling, with selectable stopping-power, charge-state, and straggling models.
- Calling the library gives full access to LISE^{++} calculations without duplicating or modifying either LISE^{++} or SpecTcl source.



function	return	parameters	example	
Energy After Matter	Residual energy in MeV/u	Zparticle, Aparticle Energy [MeV/u] Ztarget, Thickness [mg/cm2]	**143.507**	MeV/u
Energy After Matter with option	Residual energy in MeV/u	Zparticle, Aparticle Energy [MeV/u], Ztarget Thickness [mg/cm2],option	**143.60**	MeV/u
Range In Matter	Range in mg/cm2	Zparticle, Aparticle Energy [MeV/u] Ztarget	**1460.45**	mg/cm2
Range In Matter with option	Range in mg/cm2	Zparticle, Aparticle Energy [MeV/u] Ztarget, option	**1441.74**	mg/cm2
StragglingEnergy	energy straggling in material [MeV/u]	Zparticle, Aparticle Energy [MeV/u] Ztarget, Thickness [mg/cm2]	**0.043**	MeV/u
StragglingRange	range straggling in material [mg/cm2]	Zparticle, Aparticle Energy [MeV/u] Ztarget	**1.853**	mg/cm2
Stopping power	Hubert - option=0	Zparticle, Aparticle Energy [MeV/u] Ztarget	**6.306**	MeV/(mg/cm^2)

LISE for Excel interface showing some of the functions that can be used in SpecTcl

How to Use the Library

1. **Load the shared object.** Open `libLISE_excel64.so` and declare each function's argument.
2. **Set your calculation options.** `set_loss` (stopping-power), `set_charge_state`, `set_straggling`. Each choice persists until you change it, and the options can be seen in the previous slide.
3. **Call the calculation functions.** Range, energy loss, straggling, and charge state functions all use the models you set in step 2.
4. **Override per call when needed.** `_option` variants let you set what option to use with out the set_ functions.

```
lib.global_code.argtypes = [ctypes.c_int, ctypes.c_double, ctypes.c_int, ctypes.c_int, ctypes.c_double, ctypes.c_double, cty
lib.global_code.restype = ctypes.c_double

Z, M = 41, 101
E = 150.0
Zt =26
thick = 98.0
option = 1
ZminusQ = 0
ZmQ_out, ZmQ_in = 0, 0
Ab, At = 27.0, 20.0
fast = 1
qe = 2

print("global_code:", lib.global_code(ZmQ_out, Ab, Z, ZmQ_in, E, At, Zt, thick, option, fast))
```

Available Library Functions

Energy loss & range:

`trange(z,m,e,zt)` – range in matter (mg/cm²)

`treste(z,m,e,zt,thick)` – residual E after a layer

`stopping_power(z,m,e,zt,opt)`

`straggling_energy / _range`

Isotope masses:

`isotope_mass(z,m)` – nuclear mass

`isotope_mAtom(z,m)` – atomic mass

`isotope_mqe(z,m,qe) / mqq`

Charge states:

`charge_qmean(e,Zb,Zt,opt)` – mean charge

`charge_double` – returns the charge as a double

`charge_dq` – charge change

`chargeSchiwietzGas(...)`

`global_code(...)` – GLOBAL charge-state code

Config functions:

`set_loss(i)` – stopping-power model

`set_charge_state(i)` / `set_straggling(i)`

`show_option(opt)` – read current model

See examples: https://github.com/Kaloyano/LISE-Linux-Examples

Preparing the Environment

- Once the libLISE_excel64.so.3.0.1 file has been built use ldd libLISE… to show all of the libraries needed
- Set up a shell to load the required libraries
  - An example can be seen in orange

busterdaq_LISE — environment setup

```
#!/bin/bash
DAQVERSION=11.3-027

export SINGULARITY_SHELL=/bin/bash

export DAQROOT=/usr/opt/daq/$DAQVERSION
export DAQBIN=$DAQROOT/bin
export DAQLIB=$DAQROOT/lib
export DAQINC=$DAQROOT/include
export PYTHONPATH=$DAQROOT/pythonLibs:$PYTHONPATH
set DAQROOT  $DAQROOT
#echo "daqroot="$DAQROOT

# for aquisition over ssh pipes
export SING_IMAGE=/usr/opt/nscl-buster.img
echo /usr/opt/opt-buster:/usr/opt > ~/.singularity_bindpoints
echo /scratch >> ~/.singularity_bindpoints
echo /mnt/misc/sw/indep >>  ~/.singularity_bindpoints
echo /mnt/misc/sw/x86_64/all >> ~/.singularity_bindpoints
echo /usr/lib/x86_64-linux-gnu/modulecmd.tcl >> ~/.singularity_bindpoints

COMMON_BINDPOINTS="--bind /etc/timezone,/usr/opt/opt-buster:/usr/opt,/scratch,/mnt/misc/sw/indep,/mnt/misc/sw/x86_64/all,/usr/lib/x86_64-linux-gnu/modulecmd.tcl"

case `hostname`
in
spdaq* | ctlrm-daq* | u*pc* | daqcompute*)
    PERNETWORK_BINDPOINTS="--bind /mnt/events/arisdaq"
;;

#expanalysis* )
aris-analysis)
    PERNETWORK_BINDPOINTS="--bind /mnt/rawdata/arisdaq"
;;


*)
   PERNETWORK_BINDPOINTS=""
esac

export SINGULARITYENV_LD_LIBRARY_PATH=/user/arisdaq/PID/liseLib/qtLibs:/user/arisdaq/PID/liseLib:$LD_LIBRARY_PATH

TZ=America/New_York singularity shell $COMMON_BINDPOINTS $PERNETWORK_BINDPOINTS $SING_IMAGE
```

Connecting to SpecTcl

- The busterdaq_LISE shell loads the required libraries.
- CAris.cpp opens the LISE library with dlopen(RTLD_LAZY) and resolves each function with dlsym.
- Calculation options are set once at load.
  - A complete list of calculation options can be seen in image on Slide 2
  - There will be calibration parameters added that allow for swapping between options
- Two functions drive the physics: trange for range in matter and treste for residual energy after a layer.

```
        //============================================================================ liseLib begin
#ifdef _useLiseLib
    const char* libName = "libLISE_excel64.so.3.0.1";
    liseLib = dlopen(libName, RTLD_LAZY);
    if (!liseLib) {
        std::cerr << "Failed to load libLISE_excel64.so.3.0.1: " << dlerror() << std::endl;
    } else {
        std::cout << "Successfully loaded libLISE_excel64.so.3.0.1" << std::endl;

        typedef void (*set_option_func)(int);
        typedef int  (*show_option_func)(int);

        set_option_func set_loss                = (set_option_func)dlsym(liseLib, "set_loss");
        set_option_func set_charge_state = (set_option_func)dlsym(liseLib, "set_charge_state");
        set_option_func set_straggling   = (set_option_func)dlsym(liseLib, "set_straggling");
        show_option_func show_option     = (show_option_func)dlsym(liseLib, "show_option");

        if (set_loss) set_loss(4);
        if (set_charge_state) set_charge_state(3);
        if (set_straggling) set_straggling(1);

        if (show_option) {
            std::cout << "[Options] loss: " << show_option(0)
                      << ", charge: " << show_option(1)
                      << ", straggling: " << show_option(2) << std::endl;
        }

        trange = (trange_func_ptr)dlsym(liseLib, "trange");
        if (!trange) {
            std::cerr << "Failed to load trange function: " << dlerror() << std::endl;
                }

        teloss = (teloss_func_ptr)dlsym(liseLib, "treste");
        if (!teloss) {
            std::cerr << "Failed to load teloss function: " << dlerror() << std::endl;
        }
    }
#endif
        //============================================================================ liseLib end
```

How SpecTcl Calculated Z, A, and q

- First the velocity is calculated by using the reconstructed flight path length and the calibrated ToF to get both β and γ
- A/q comes from rigidity and velocity
  - $A/q = B\rho / (3.1071 \cdot \beta \cdot \gamma)$
- Z is obtained from the energy loss measured in the PIN and silicon detectors
- q is calculated using the calibrated TKE and from there we can calculate A
  - $q = TKE / [(\gamma - 1) \cdot u \cdot (A/q)]$
- These calculations are all needed before LISE range and energy loss functions can be called

Calculations Part #1

- To do the calculations we need energy per nucleon
- Brho2Energy is used and converts the magnetic rigidity to MeV/u
- Energy is calculated and the integer form of A and Z are used to calculate the Range

```
//WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW

double Brho2Energy(double Brho, double M, double Q) {
    if (Q == 0) return 0.0;
    double Gamma_Beta = Brho / 3.107129578 / M * Q;
    double gamma = sqrt(1 + Gamma_Beta * Gamma_Beta);

    return (gamma - 1.0) * 931.494013;
}
//WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW

void ARISparticleID::CalcRange(int Zt) {
#ifdef _useLiseLib
    int targetZ = (Zt > 0) ? Zt : 14;

    if (ARIS::trange && Q.isValid() && Am3Z.isValid() && ZmQ.isValid() && brho.isValid()) {

        int Zint = int(Z + 0.5);
        double aCalc = 3.0*Z + Am3Z;
        int Aint = int(aCalc + 0.5);

        if (Zint > 120) {
            range.setInvalid();
            return;
        }

        if (Zint <= 0 || Aint <= 0 || targetZ <= 0) {
            range.setInvalid();
            return;
        }

        double energy = Brho2Energy(brho, aCalc, Q);
        double result = ARIS::trange(Zint, Aint, energy, targetZ);
        range = result;
    } else {
        range.setInvalid();
    }
#endif
}
```

Calculations Part #2

- The initial Setup for the energy loss is identical except for the thickness variable
  - Currently hard coded, but will eventually be a tunable parameter
- *teloss* returned the remaining energy so it is subtracted from the initial energy

```
void ARISparticleID::CalcEnergyLoss(int Zt) {
#ifdef _useLiseLib

    if (!ARIS::teloss) {
        std::cerr << "Error: teloss function not loaded" << std::endl;
        dE_Calc.setInvalid();
        dE_per_u_Calc.setInvalid();
        return;
    }

    int targetZ = (Zt > 0) ? Zt : 14;
    double thickness = 69.636;

    if (Z.isValid() && Am3Z.isValid() && ZmQ.isValid() && brho.isValid() && Q.isValid()) {

        int Zint = int(Z + 0.5);

        if (Zint > 120) {
            dE_Calc.setInvalid();
            dE_per_u_Calc.setInvalid();
            return;
        }

        double aCalc = 3.0*Z + Am3Z;
        int Aint = int(aCalc + 0.5);
        int Qint = int(Q + 0.5);
        double qCalc = Z - ZmQ;
        double energyPerU = Brho2Energy(brho, aCalc, Q);
```

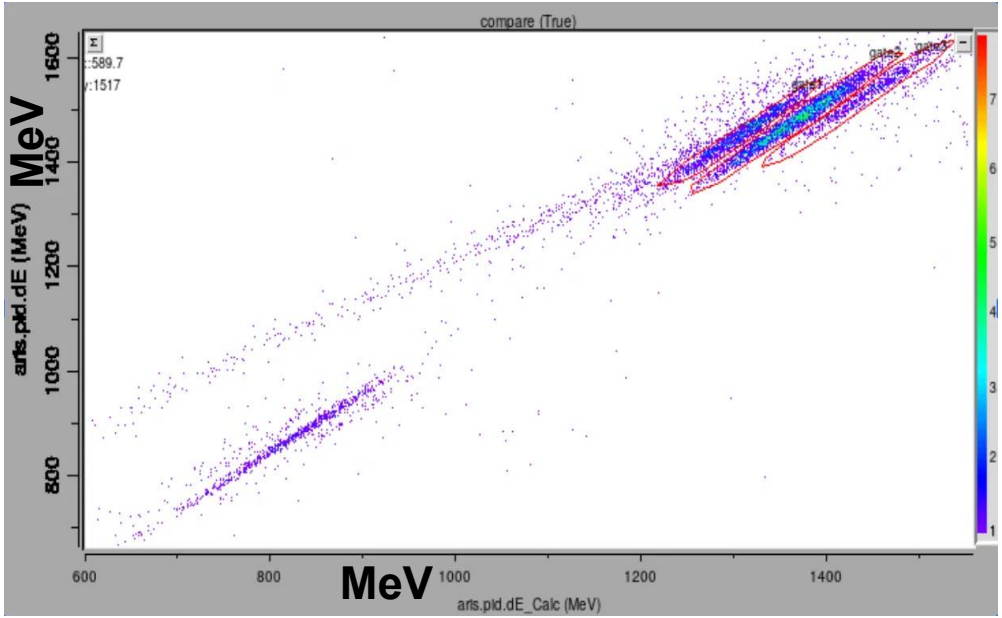
```
        double eResPerU = ARIS::teloss(Zint, Aint, energyPerU, targetZ, thickness);

        std::cerr << "[CalcEnergyLoss]"
                  << " eResPerU=" << eResPerU
                  << " dE_per_u_Calc=" << energyPerU - eResPerU
                  << " dE_Calc=" << energyPerU*aCalc - eResPerU*aCalc
                  << std::endl;

        if (eResPerU > 0 && eResPerU < energyPerU) {
            double eResidual = eResPerU * aCalc;
            dE_Calc = energyPerU*aCalc - eResidual;
            dE_per_u_Calc = energyPerU - eResPerU;
        } else {
            std::cerr << "[CalcEnergyLoss] eResPerU out of range: eResPerU="
                      << eResPerU << " energyPerU=" << energyPerU << std::endl;
            dE_Calc.setInvalid();
            dE_per_u_Calc.setInvalid();
        }
    } else {
        std::cerr << "[CalcEnergyLoss] invalid inputs:"
                  << " Z.isValid()="    << Z.isValid()
                  << " Am3Z.isValid()=" << Am3Z.isValid()
                  << " ZmQ.isValid()="  << ZmQ.isValid()
                  << " brho.isValid()=" << brho.isValid()
                  << " Q.isValid()="    << Q.isValid()
                  << std::endl;
        dE_Calc.setInvalid();
        dE_per_u_Calc.setInvalid();
    }
#endif
}
//WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
```

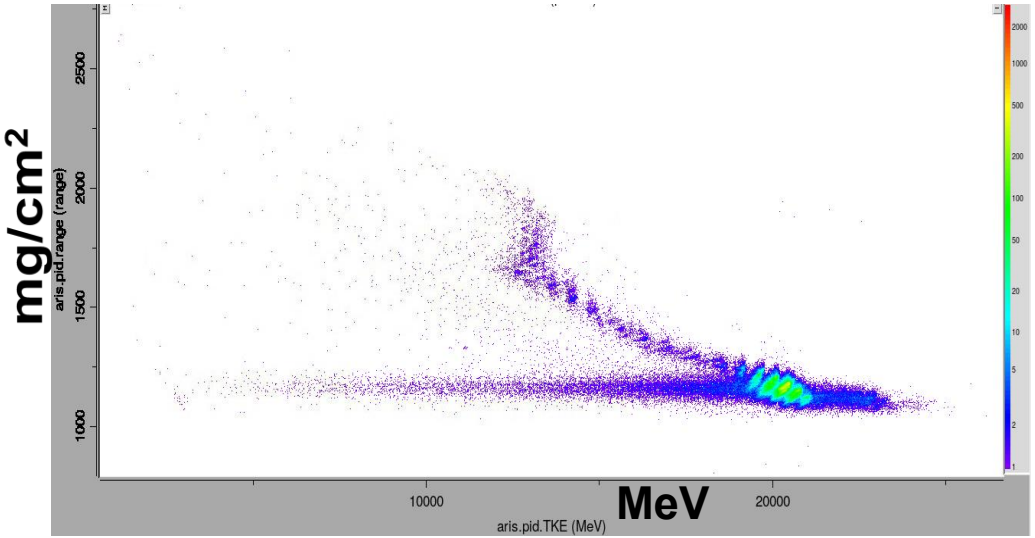
Results #1

- The two energies don't line up meaning a TKE calibration or thickness used is incorrect
- There are also three different lines corresponding to charge states.
- This is because when we do Brho2Energy we use Q meaning the initial energy is different for dE_Calc



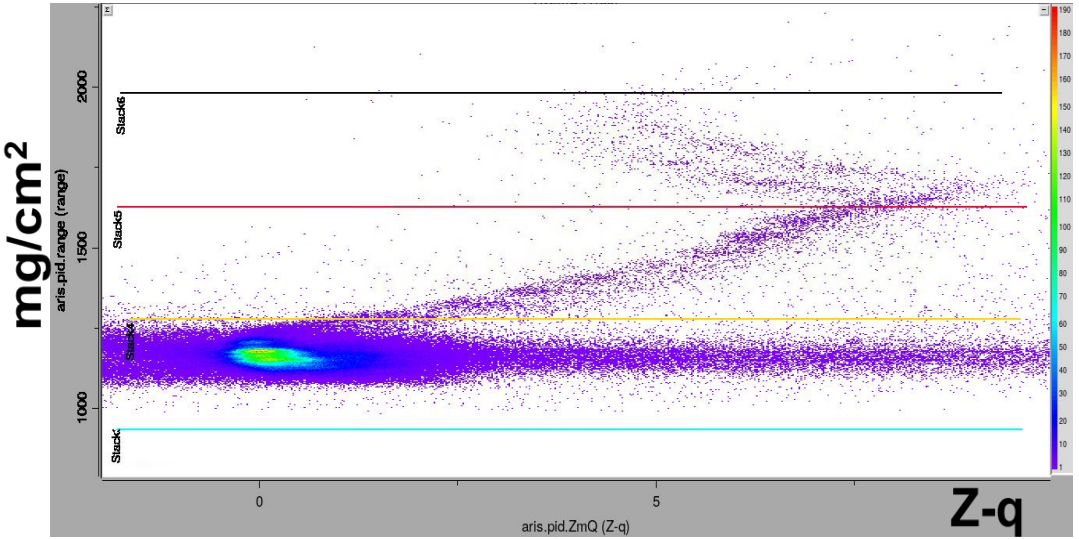
Results #2

- Noticeable noise around the 1200 mg/cm^2 area
- Steady downward trend with some breakdown near the 1750-2000 range



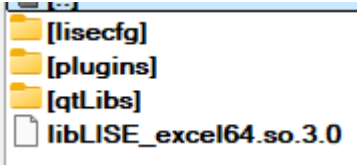
Results #3

- The horizontal lines mark the end of each detector in the stack. Where the distribution crosses them tells you which ions stop in which detector.
- Same noise as previously seen around the 1200 (mg/cm^2) area
- Same break down as the previous result
- Most likely punch through causing incomplete TKE



Access to LISE Library for Linux

http://lise.frib.msu.edu/work/SpecTcl/liseLib-3-0-1.zip



Next Steps

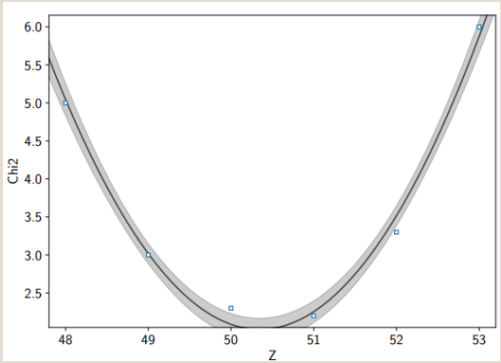
Near term

- Use the dE vs dE_Calc plots to evaluate and then refine the TKE calibration.
- Fit the offset from the diagonal and use the range calculations to extract an effective silicon thickness.
- Apply the predicted range as a cut to separate stopped events from punch-through and reaction events.

Bragg Curve Z calibration

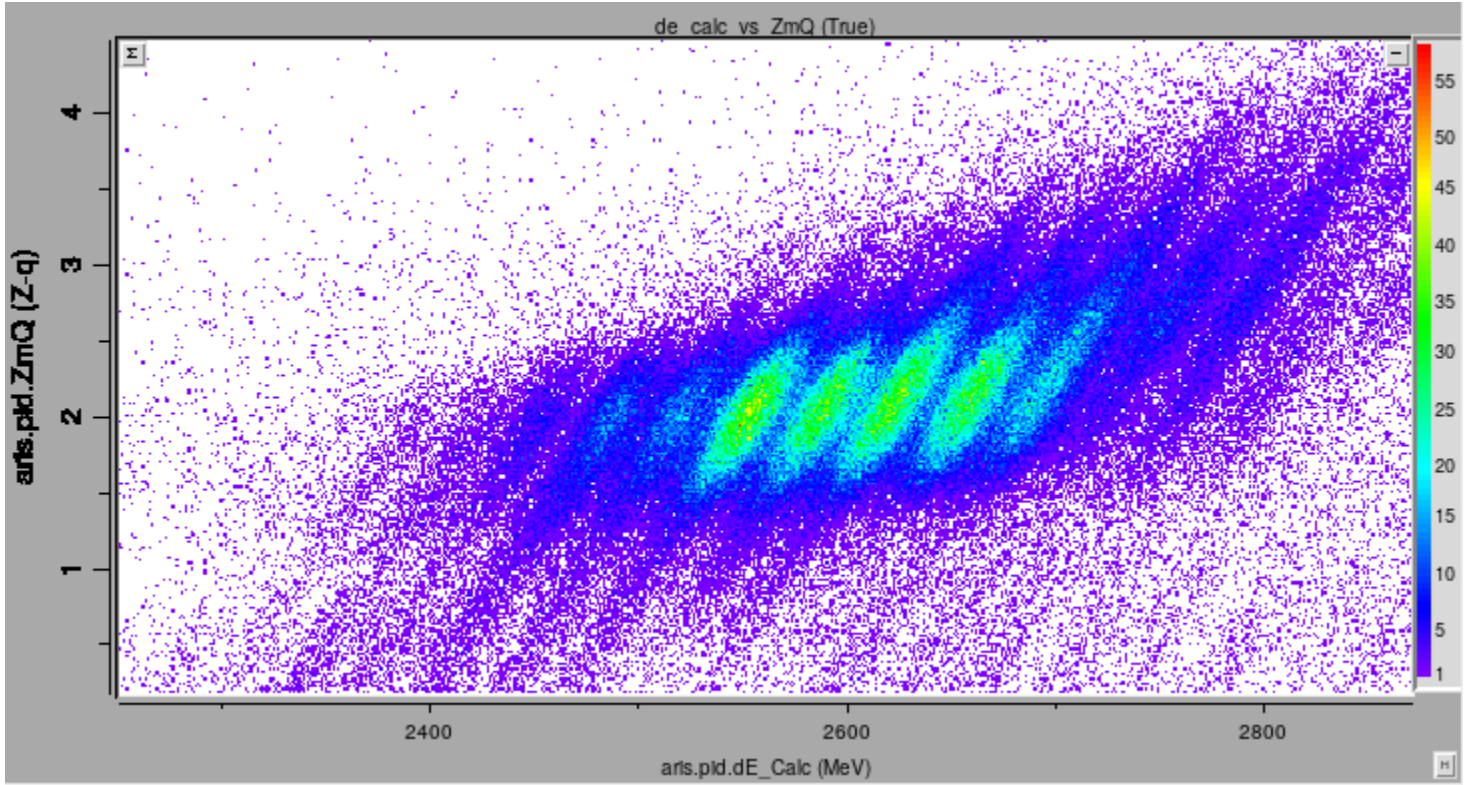
- Use the LISE library to predict dE in each layer of the silicon stack.
- Compare predicted against measured dE.
- Scan Z over a range compute χ^2 for each trial value.
- Take the minimum of the scan as the fitted Z_Bragg.

Obtaining Z_Bragg



- Three scan points: parabolic interpolation through the minimum.
- More than three: quadratic fit to the χ^2 curve.
- The example shown returns Z_Bragg = 50.35.

Supplement


de_calc_vs_ZmQ (True)
arts.pid.ZmQ (Z-q)
1
2
3
4
2400
2600
2800
arts.pid.dE_Calc (MeV)
55
50
45
40
35
30
25
20
15
10
5
1