Artificial Intelligence in Industry-4.0

Report *RF-modulation classifier*

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1 *Artificial Intelligence*

2 *Data pre-processing*

3 *Neural net training*

4 *Neuromorphic algorithm*

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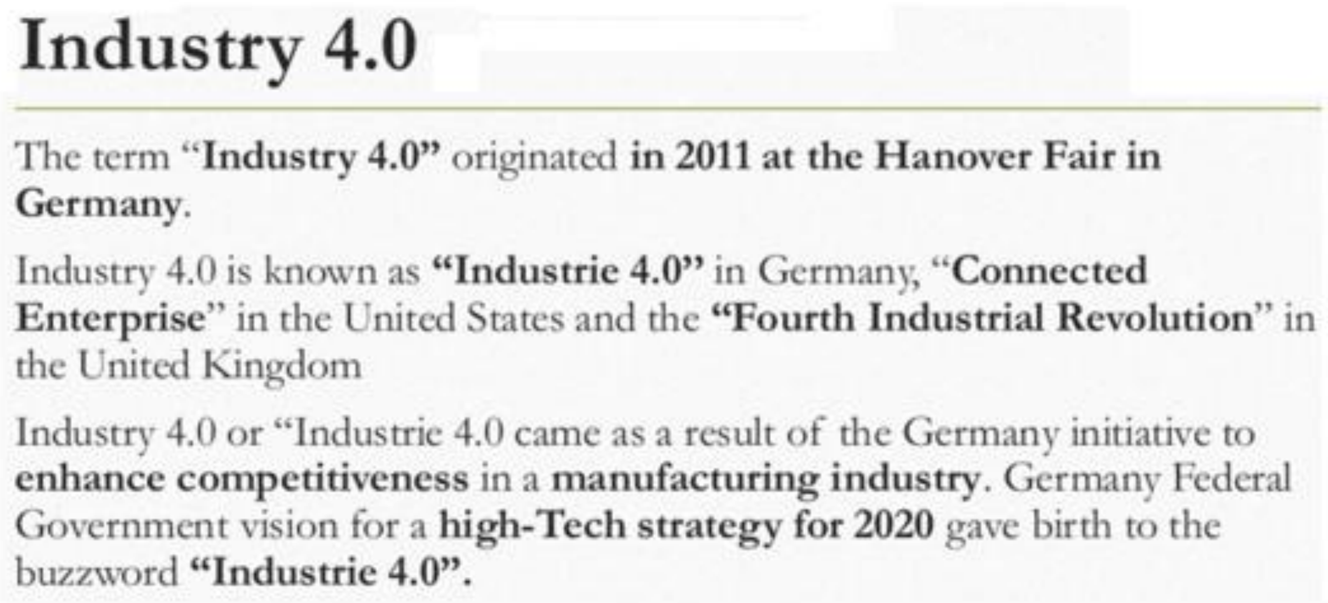
History

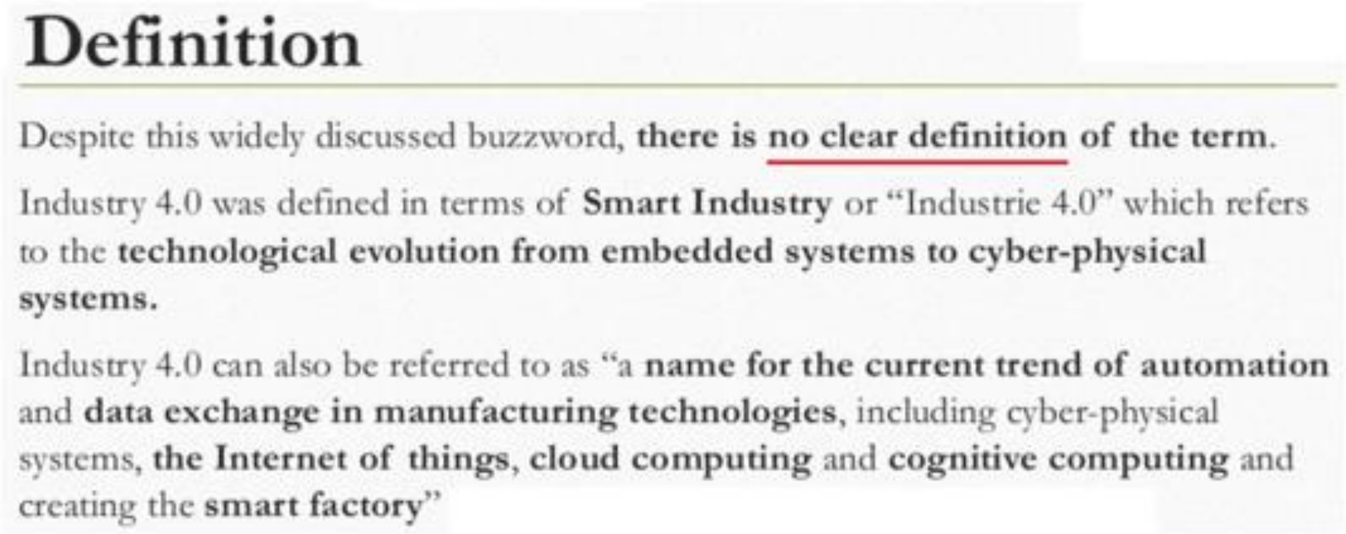


Industry 4.0

The term “**Industry 4.0**” originated **in 2011 at the Hanover Fair in Germany**.

Industry 4.0 is known as **“Industrie 4.0”** in Germany, “**Connected Enterprise**” in the United States and the **“Fourth Industrial Revolution**” in the United Kingdom

Industry 4.0 or “Industrie 4.0 came as a result of the Germany initiative to **enhance competitiveness** in a **manufacturing industry**. Germany Federal Government vision for a **high-Tech strategy for 2020** gave birth to the buzzword **“Industrie 4.0”.**



Definition

Despite this widely discussed buzzword, **there is no clear definition of the term.**

Industry 4.0 was defined in terms of **Smart Industry** or “Industrie 4.0” which refers to the **technological evolution from embedded systems to cyber-physical systems.**

Industry 4.0 can also be referred to as “a **name for the current trend of automation** and **data exchange in manufacturing technologies**, including cyber-physical systems, **the Internet of things**, **cloud computing** and **cognitive computing** and creating the **smart factory**”

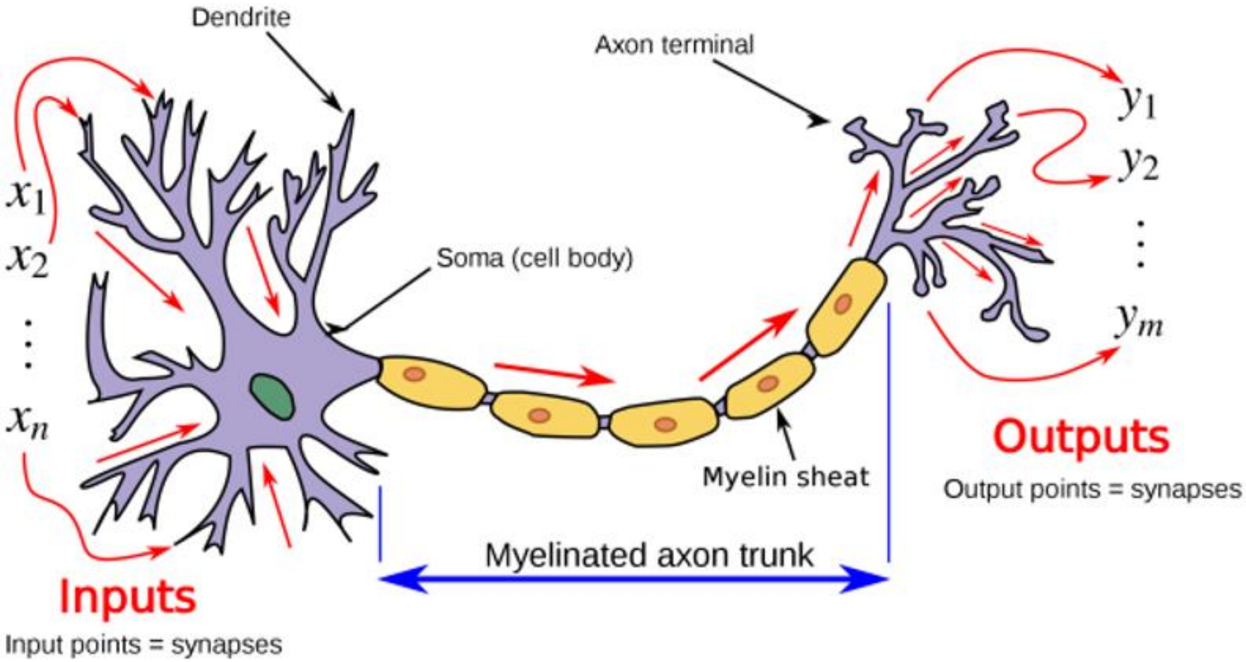
Key Concepts

Bio-analogy

- representation of data selection with:

  - sum

  - threshold



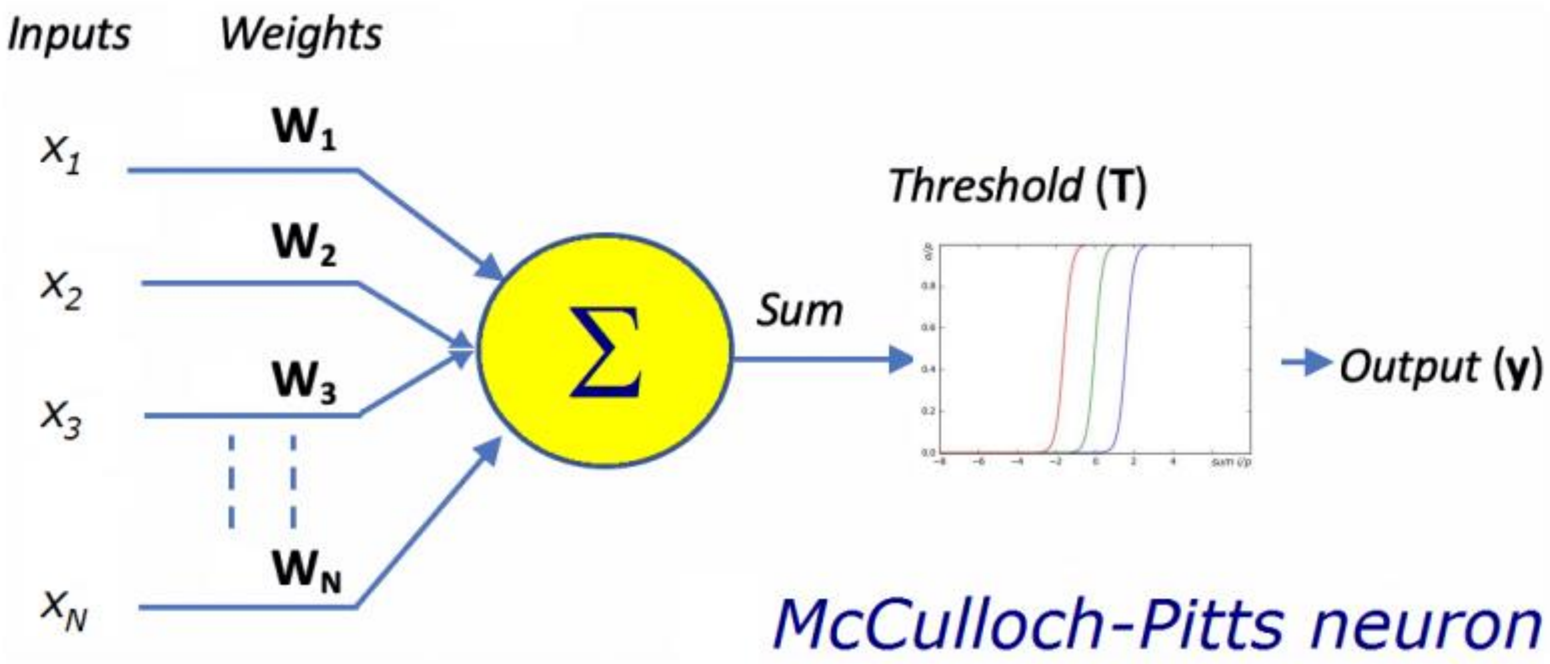
Key Concepts

Artificial Intelligence

- representation of data selection with:

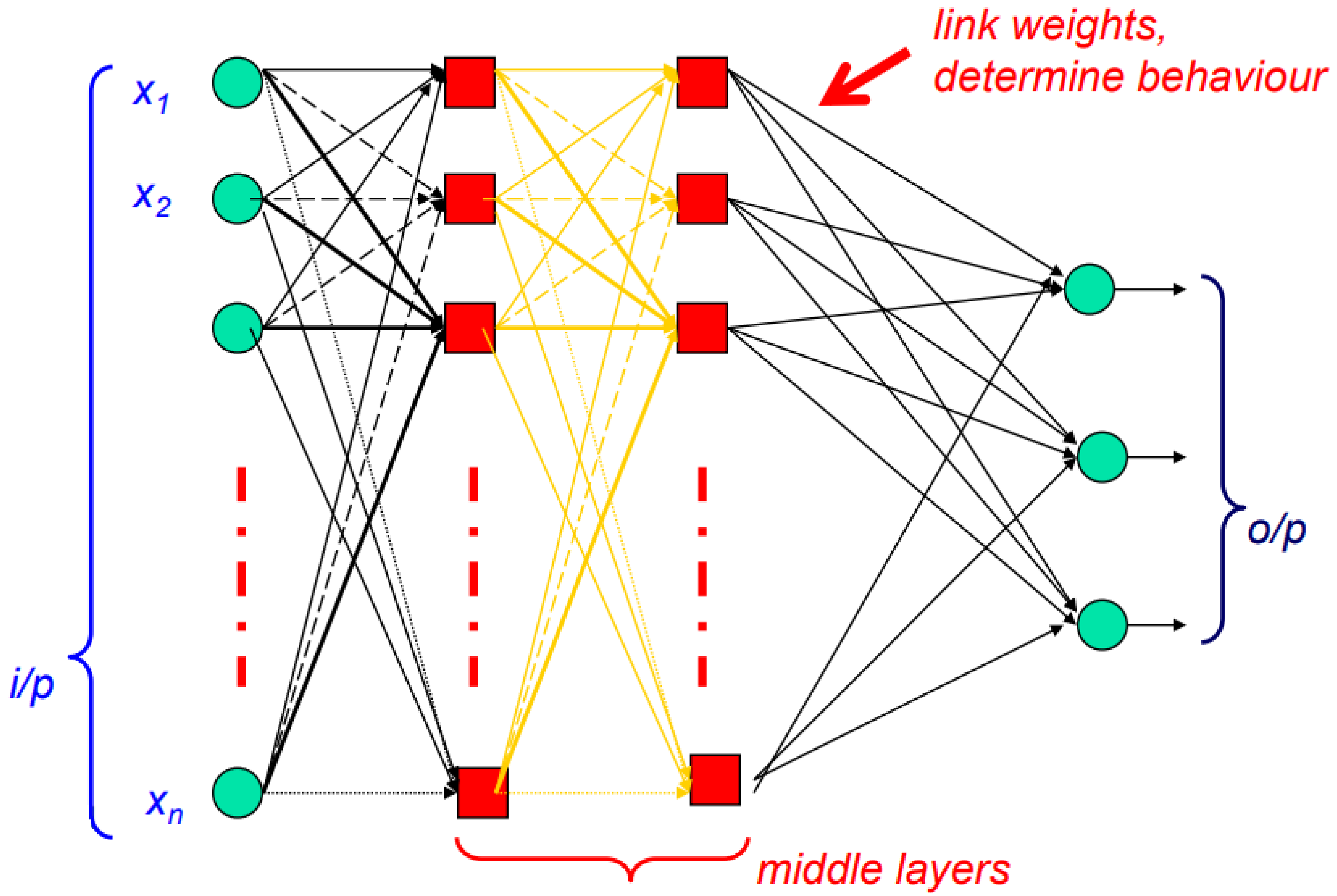
- sum

- threshold



McCulloch-Pitts neuron

Multi-layer perceptron



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Project framework

Hydra accounts

- log onto waves@hydra.jinr.ru
- password = ********
  - choose a student nr.
    - use that directory
    - do not interfere w/ the others
    - we use all the same account
  - "launch" a project: ./addx ELA medium
  - work on the project:
    - compile into libraries: make libs
    - compile test: make test
    - run: make run
    - clean: make clean

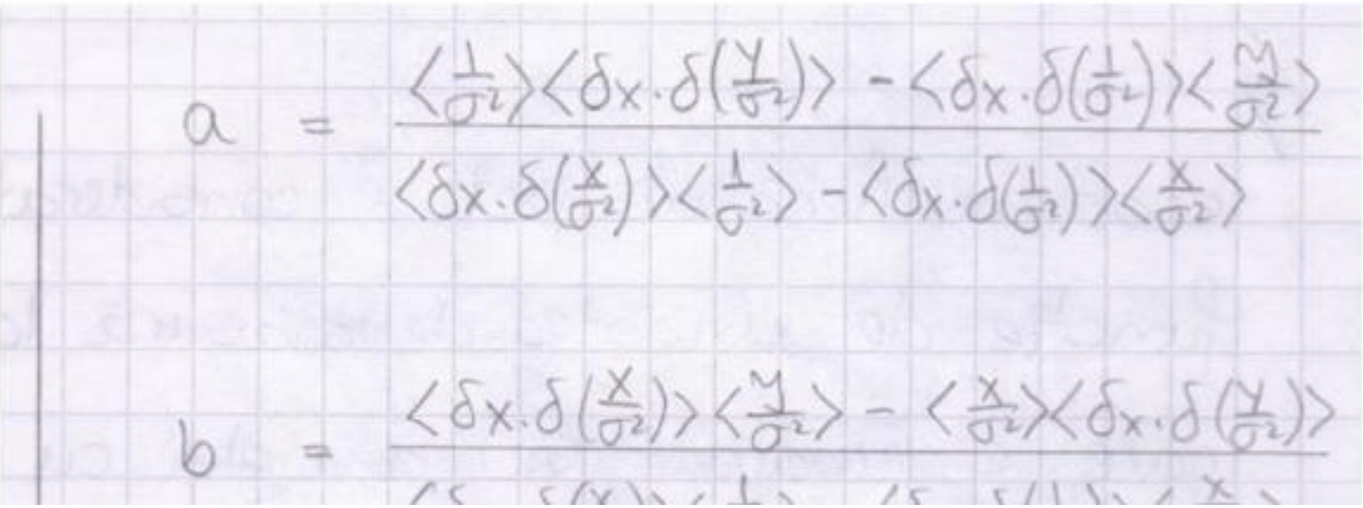
Fit example

C++ resource

Review PROJ

χ^2 ***fits*** - are a first (simple)-application of what you learned so far.

Organise in 3 groups and work these projects. Report your results using the template on the main page of the course.

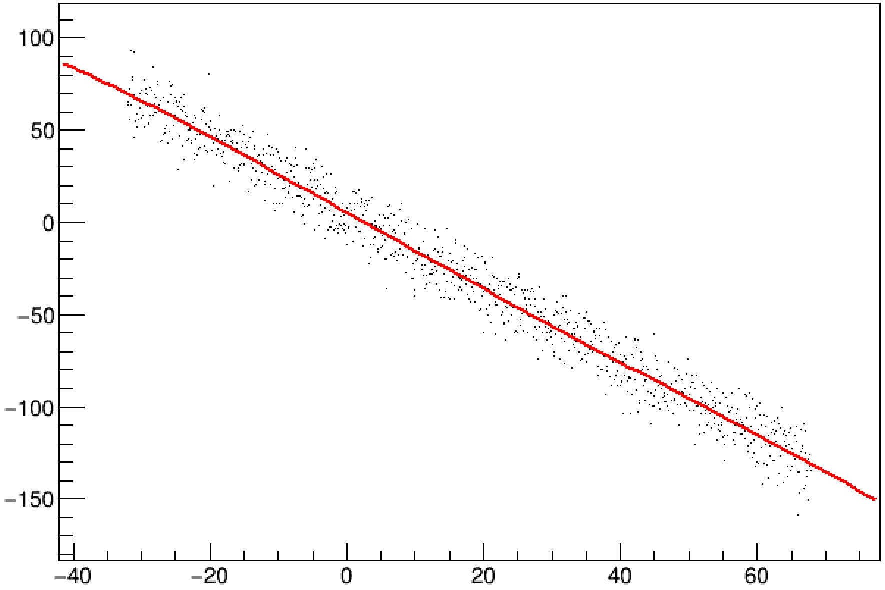


$$a = \frac{\langle\frac{1}{\sigma^2}\rangle\langle\delta x\cdot\delta(\frac{y}{\sigma^2})\rangle - \langle\delta x\cdot\delta(\frac{1}{\sigma^2})\rangle\langle\frac{y}{\sigma^2}\rangle}{\langle\delta x\cdot\delta(\frac{x}{\sigma^2})\rangle\langle\frac{1}{\sigma^2}\rangle - \langle\delta x\cdot\delta(\frac{1}{\sigma^2})\rangle\langle\frac{x}{\sigma^2}\rangle}$$

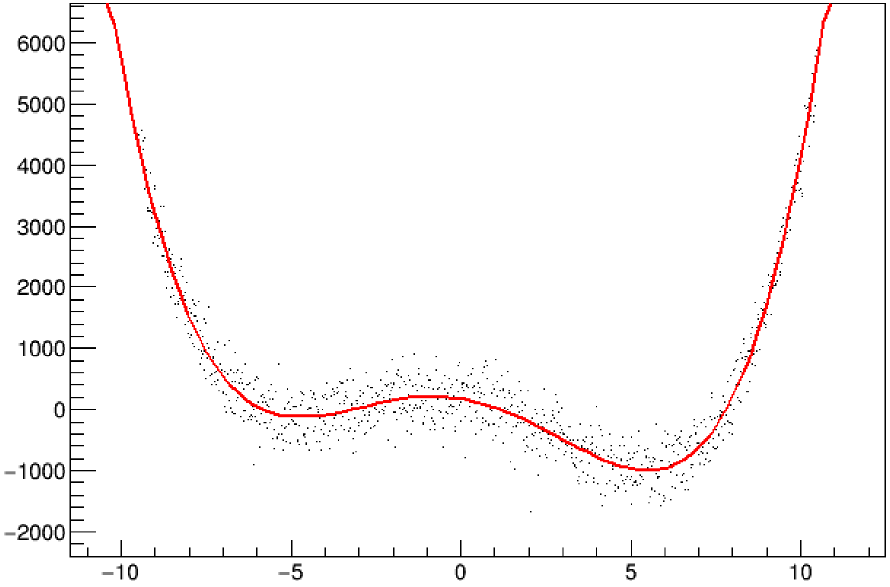
$$b = \frac{\langle\delta x\cdot\delta(\frac{x}{\sigma^2})\rangle\langle\frac{y}{\sigma^2}\rangle - \langle\frac{x}{\sigma^2}\rangle\langle\delta x\cdot\delta(\frac{y}{\sigma^2})\rangle}{\langle\delta x\cdot\delta(\frac{x}{\sigma^2})\rangle\langle\frac{1}{\sigma^2}\rangle - \langle\delta x\cdot\delta(\frac{1}{\sigma^2})\rangle\langle\frac{x}{\sigma^2}\rangle}$$

Fit example

Linear Fit

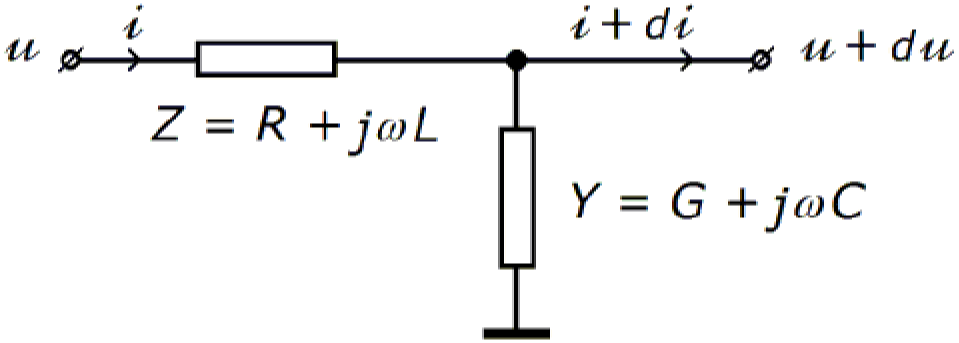


Quartic Fit



SU2 package

- *model dispersion of a square wave on a transmission line:*



$$-\begin{pmatrix}1&0\\0&1\end{pmatrix}\partial_x \equiv \begin{pmatrix}0&L\\C&0\end{pmatrix}\partial_t + \begin{pmatrix}0&R\\G&0\end{pmatrix}\Bigg|_{\begin{pmatrix}u\\i\end{pmatrix}}$$

HybriLIT Experience

$Z_0 = Y_0^{-1} = \sqrt{L/C}$, line characteristic impedance

$\lambda_d^{-1} = (RY_0 - GZ_0)/2$, dispersion length

$\lambda_a^{-1} = (RY_0 + GZ_0)/2$, attenuation length

$c = 1/\sqrt{LC}$, signal propagation speed

- equation: $\partial_x + \sigma_1(\partial_{ct} + \lambda_a^{-1}) + j\sigma_2\lambda_d^{-1} = 0\,|_{\psi}$

$$\Downarrow \quad \psi = e^{-ct/\lambda_a}\phi$$

$$\partial_x + \sigma_1\partial_{ct} + j\sigma_2\lambda_d^{-1} = 0\,|_{\phi}$$

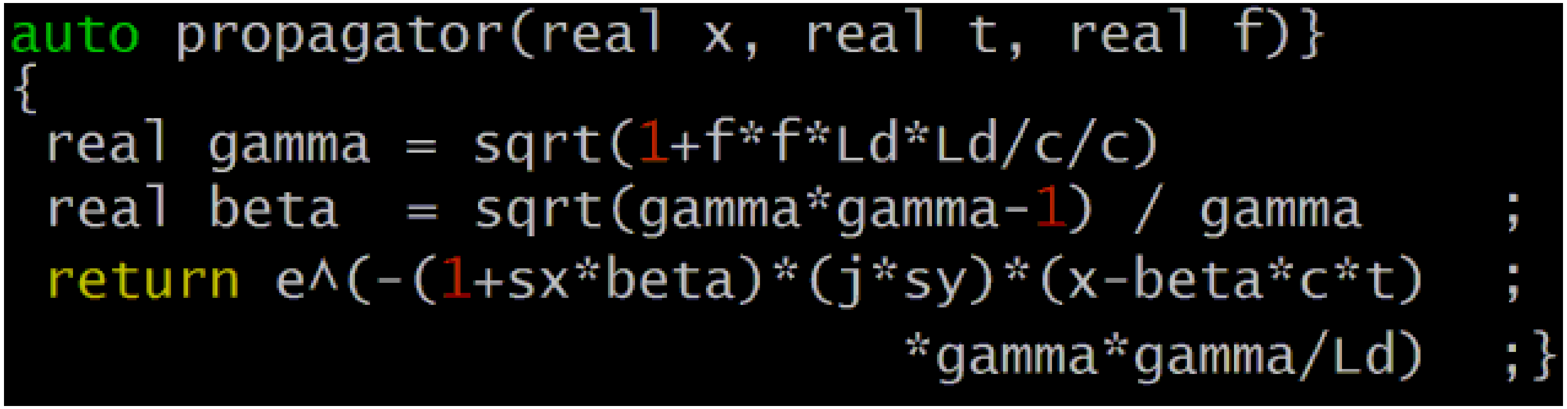
- solution:

$$\phi = e^{-\gamma^2(1+\sigma_1\beta)\frac{j\sigma_2}{\lambda_d}(x-vt)}\,|_{\phi_0}$$

HybriLIT Experience

SU2 package

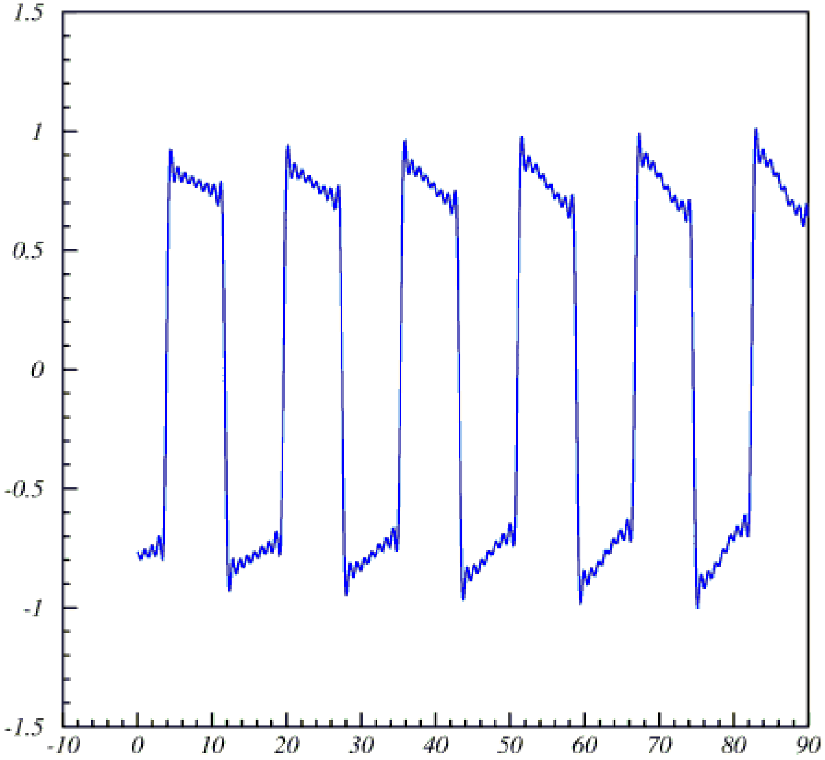
- *I used the SU2 package to model the propagator:*



```
auto propagator(real x, real t, real f)}
{
 real gamma = sqrt(1+f*f*Ld*Ld/c/c)
 real beta  = sqrt(gamma*gamma-1) / gamma        ;
 return e^(-(1+sx*beta)*(j*sy)*(x-beta*c*t)    ;
                          *gamma*gamma/Ld)    ;}
```

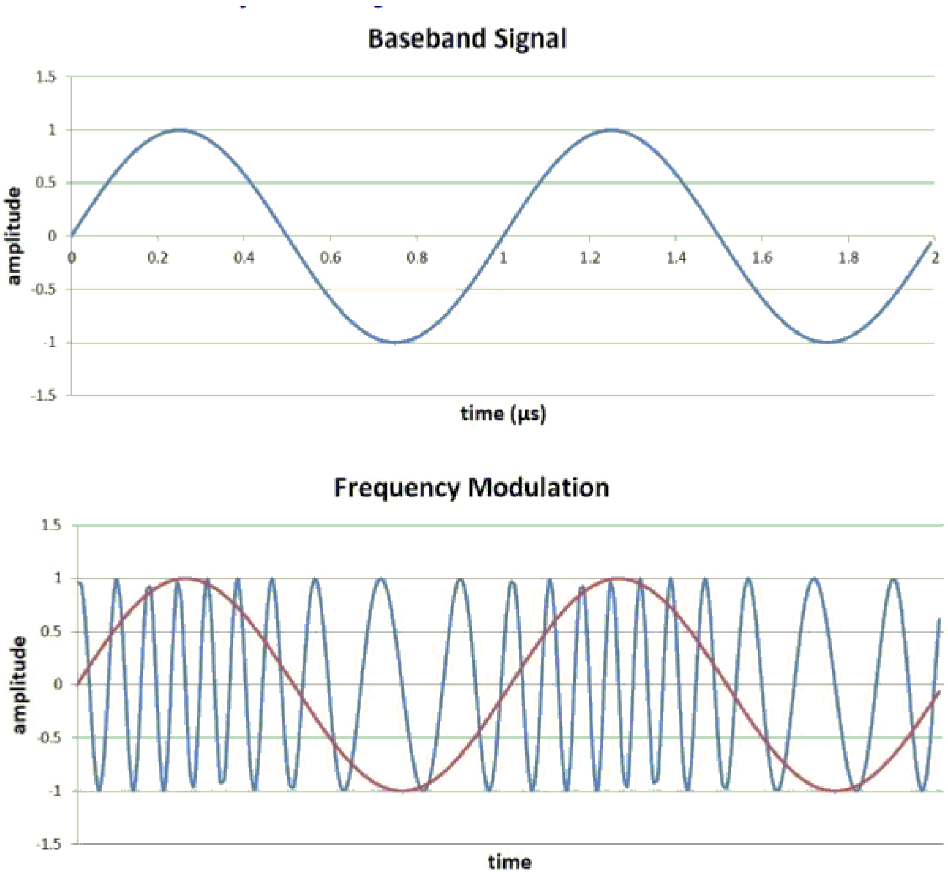
SU2 package

- I used the SU2 package to model the propagator:



RF modulation types

Radio frequency modulation



Shift keying:

- *ASK, amplitude*
- *FSK, frequency*
- *PSK, phase*
- *ASK-LSB*
- *ASK-USB*

Determination of: (ped, A, f, ϕ)

Magic sample number

- *RF wave* $y = p + Asin(2\pi f t + \phi)$

sampling	*1 : 3.675*
$f_0 =$	*12ooo Hz*
Δ	*1 / 44100 s*

- *pedestal: find from average*

$$\langle y \rangle = p + A_e sin\left(2\pi f t \frac{t_i + t_f}{2} + \phi\right) sinc\left(\frac{2\pi f \Delta t}{2}\right)$$

$$A_e = \frac{A}{sinc(\pi f \Delta)}$$

- *magic N: Δ t = 11 Δ … δ p = 0.0023* A_e

Determination of: (*ped, A, f, ϕ*)

Amplitude

- same N = 11 : $\langle\, \delta^2 y \,\rangle = A_e \langle\, \delta^2 (sin) \,\rangle$

Frequency

- same N = 11 :

$$\langle\, y(y - y_{k\Delta}) \,\rangle = pA_e(\langle\, sin \,\rangle - \langle\, sin_{k\Delta} \,\rangle)$$

$$+$$

$$A_e^2(\langle\, sin^2 \,\rangle - \langle\, sin \cdot sin_{k\Delta} \,\rangle)$$

$$\simeq A_e^2 sin^2\left(\frac{2\pi f k\Delta}{2}\right)$$

$$\simeq \pi k \Delta A_e^2 sin(2\pi f k\Delta) \cdot \delta f$$

(k = 1 ; max sensitivity)

Determination of: (*ped, A, f, ϕ*)

Phase

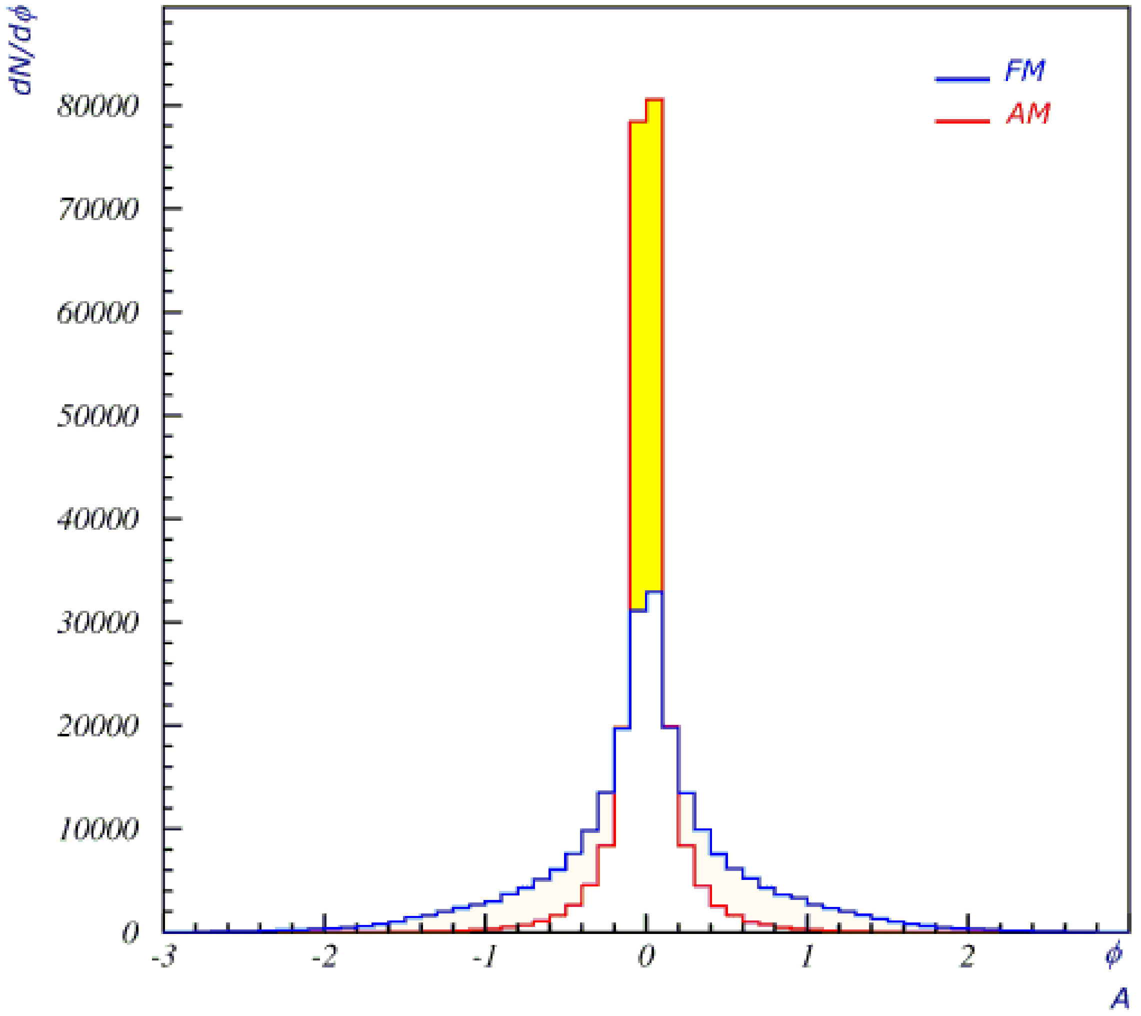
- $\delta\phi = \phi_{current} - \phi_{previous}$

$$\langle\, y \cdot cos(\pi f t) \,\rangle \simeq \frac{A_e}{2} sin\phi$$

- next: form features

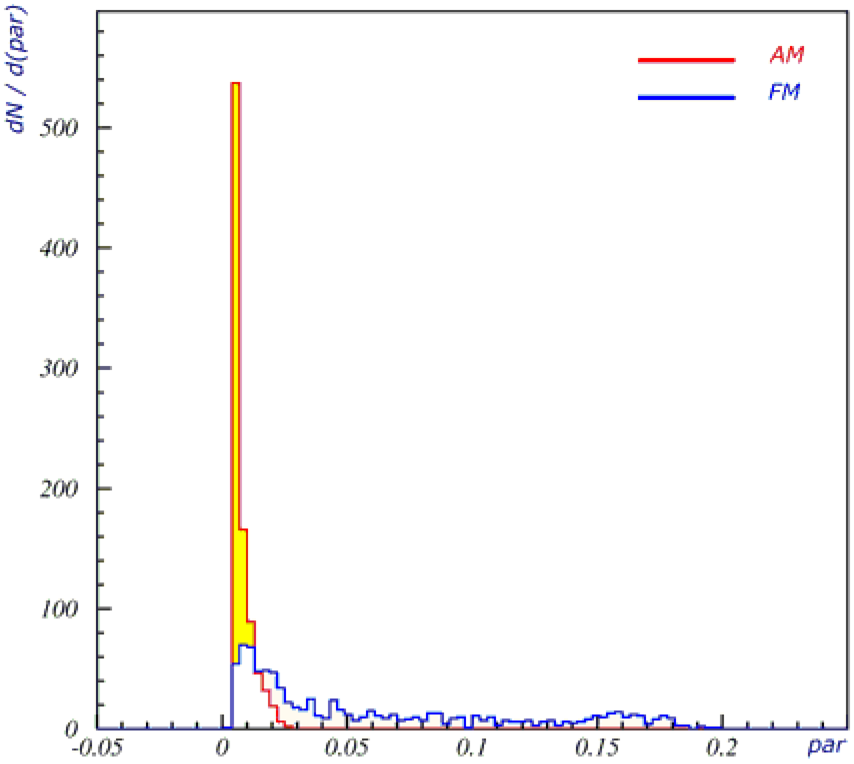
Determination of: (*ped, A, f, ϕ*)

Distributions

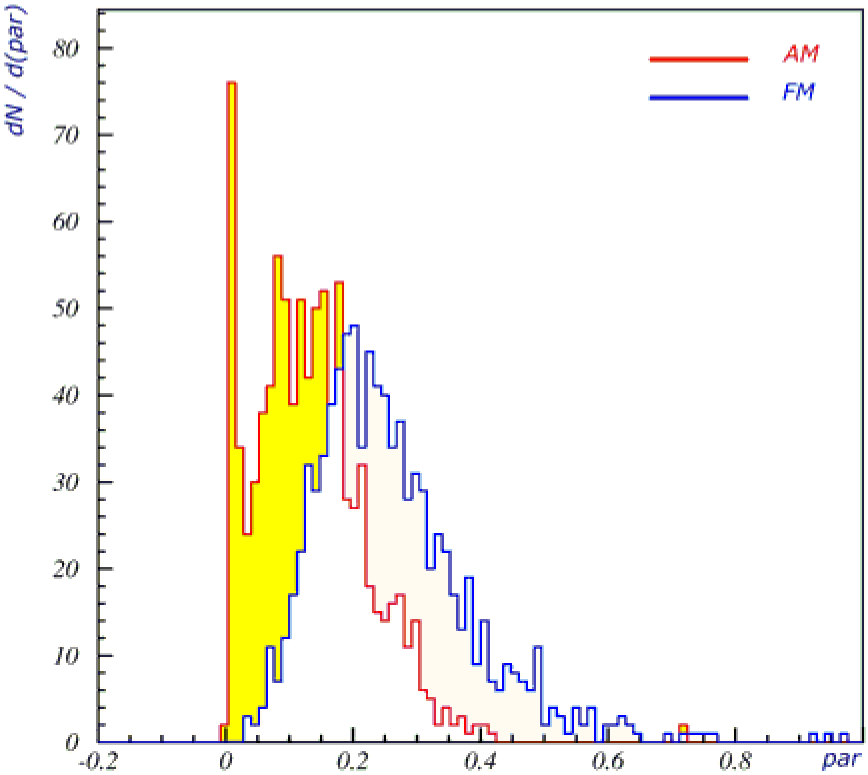


Determination of: (*ped, A, f, ϕ*)

Parameter - 1



Parameter - 2

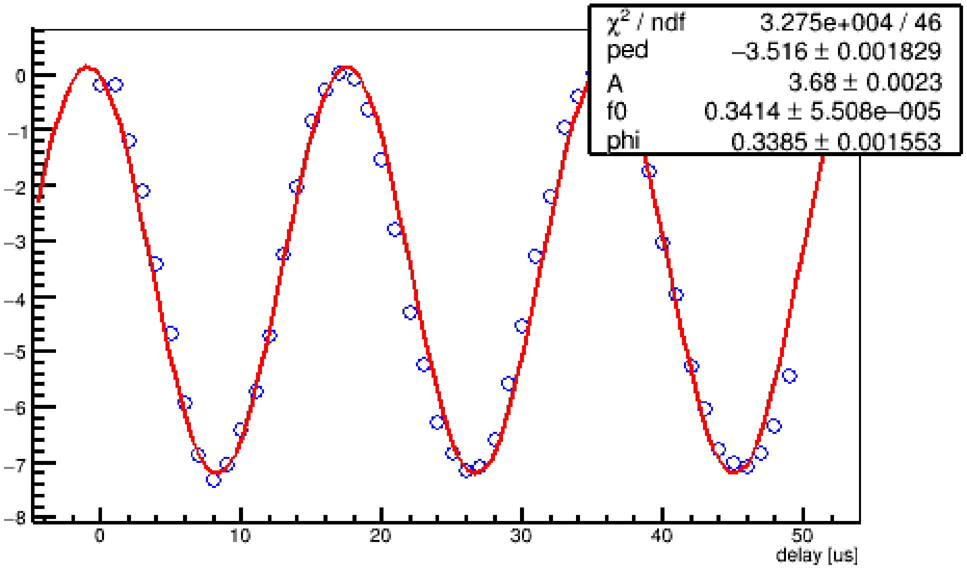


ROOT package

- *I downloaded from CERN the ROOT-5.34 (Windows)*

- *I learned how to write my own macro and do fits*

```
// __________________ ROOT FITS ________________________

void myfit() {

// TGraph gr  ("data.txt", "%lg %lg");
// TGraph grr ("test.txt", "%lg %*lg %lg")
// TGraph grrr("test.txt", "%lg %*lg %*lg %lg")

gStyle->SetOptFit   (1)
gStyle->SetLineWidth(2)


TGraphErrors* gr = new TGraphErrors("z2.txt")

Int_t N = gr->GetN()
Double_t x,y
  for (Int_t i=0; i<N; i++) {
    gr->GetPoint     (i,      x,      y)
    gr->SetPointError(i,   0.01,   0.01)
    gr->SetPoint     (i,  x/1.0,      y)


TF1 fit("fit", "([0]+[1]*cos(x*[2]+[3]))", 0, 50)

    fit.SetParName  (0, "ped"  )                            ;
    fit.SetParName  (1, "A"    )                            ;
    fit.SetParName  (2, "f0"  )                            ;
    fit.SetParName  (3, "phi"  )                            ;

    fit.SetParameter(0, .500 )                            ;
    fit.SetParameter(1,  .500 )                            ;
    fit.SetParameter(2, .400 )                            ;
    fit.SetParameter(3, 1.000 )                            ;

  gr->Fit("fit")                                            ;
```



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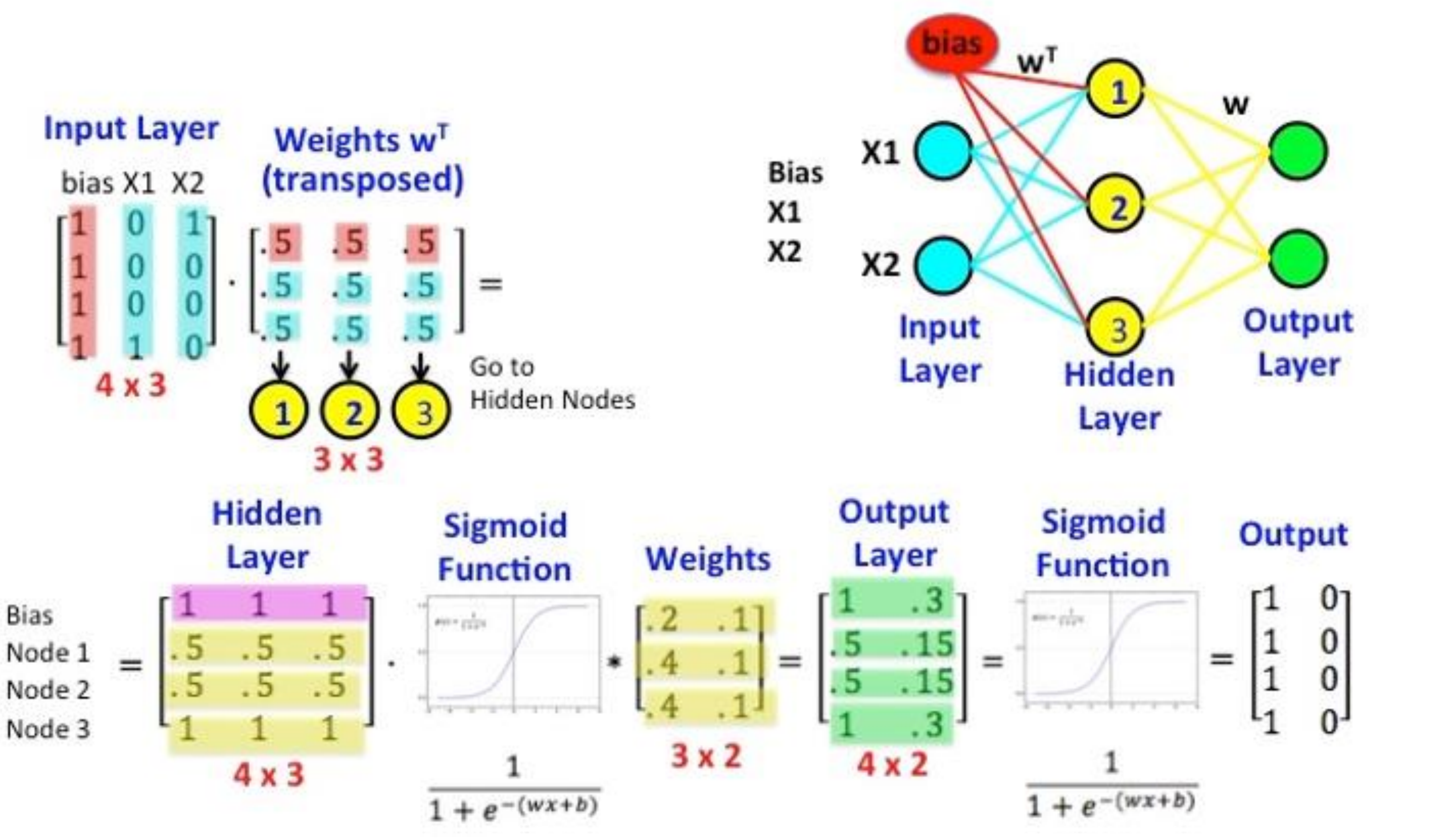
ROOT MLP

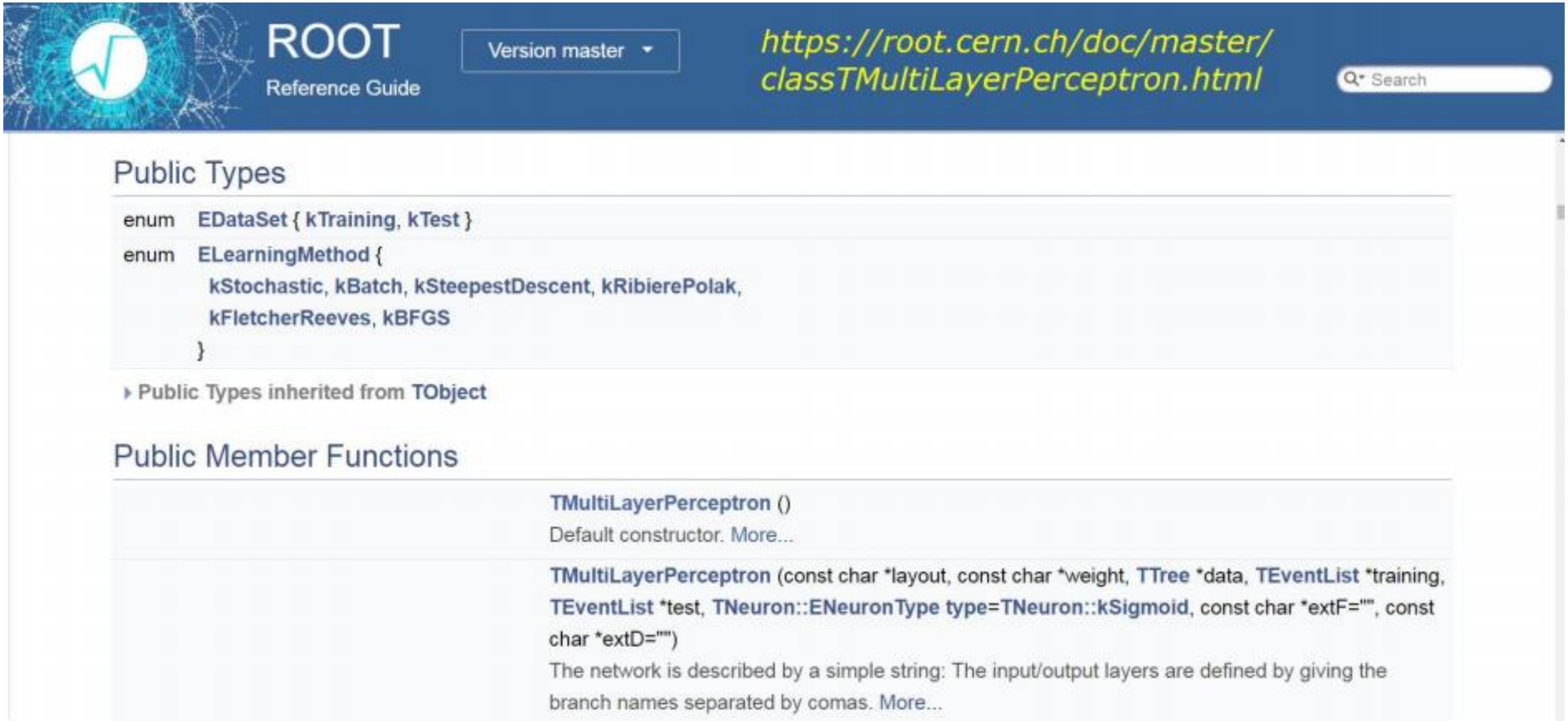
MLP run-through



$$\begin{array}{ccc} \text{bias} & X1 & X2 \end{array} \quad \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} .5 & .5 & .5 \\ .5 & .5 & .5 \\ .5 & .5 & .5 \end{bmatrix} =$$

$$= \begin{bmatrix} 1 & 1 & 1 \\ .5 & .5 & .5 \\ .5 & .5 & .5 \\ 1 & 1 & 1 \end{bmatrix} \cdot \frac{1}{1+e^{-(wx+b)}} * \begin{bmatrix} .2 & .1 \\ .4 & .1 \\ .4 & .1 \end{bmatrix} = \begin{bmatrix} 1 & .3 \\ .5 & .15 \\ .5 & .15 \\ 1 & .3 \end{bmatrix} = \frac{1}{1+e^{-(wx+b)}} = \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

ROOT MLP



https://root.cern.ch/doc/master/classTMultiLayerPerceptron.html

Public Types

```
enum   EDataSet { kTraining, kTest }
enum   ELearningMethod {
         kStochastic, kBatch, kSteepestDescent, kRibierePolak,
         kFletcherReeves, kBFGS
       }
```

▸ Public Types inherited from TObject

Public Member Functions

```
TMultiLayerPerceptron ()
```

Default constructor. More...

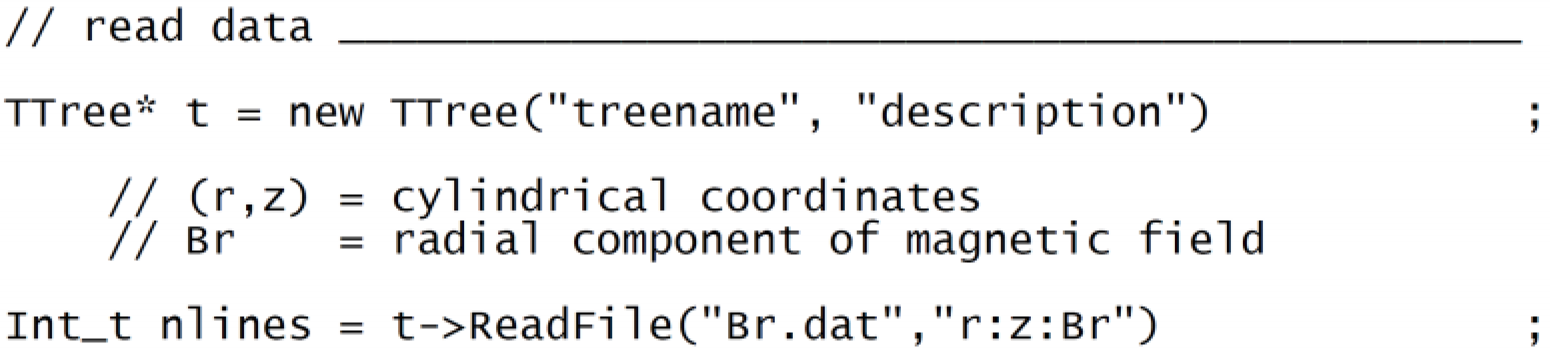
```
TMultiLayerPerceptron (const char *layout, const char *weight, TTree *data, TEventList *training,
TEventList *test, TNeuron::ENeuronType type=TNeuron::kSigmoid, const char *extF="", const
char *extD="")
```

The network is described by a simple string: The input/output layers are defined by giving the branch names separated by comas. More...

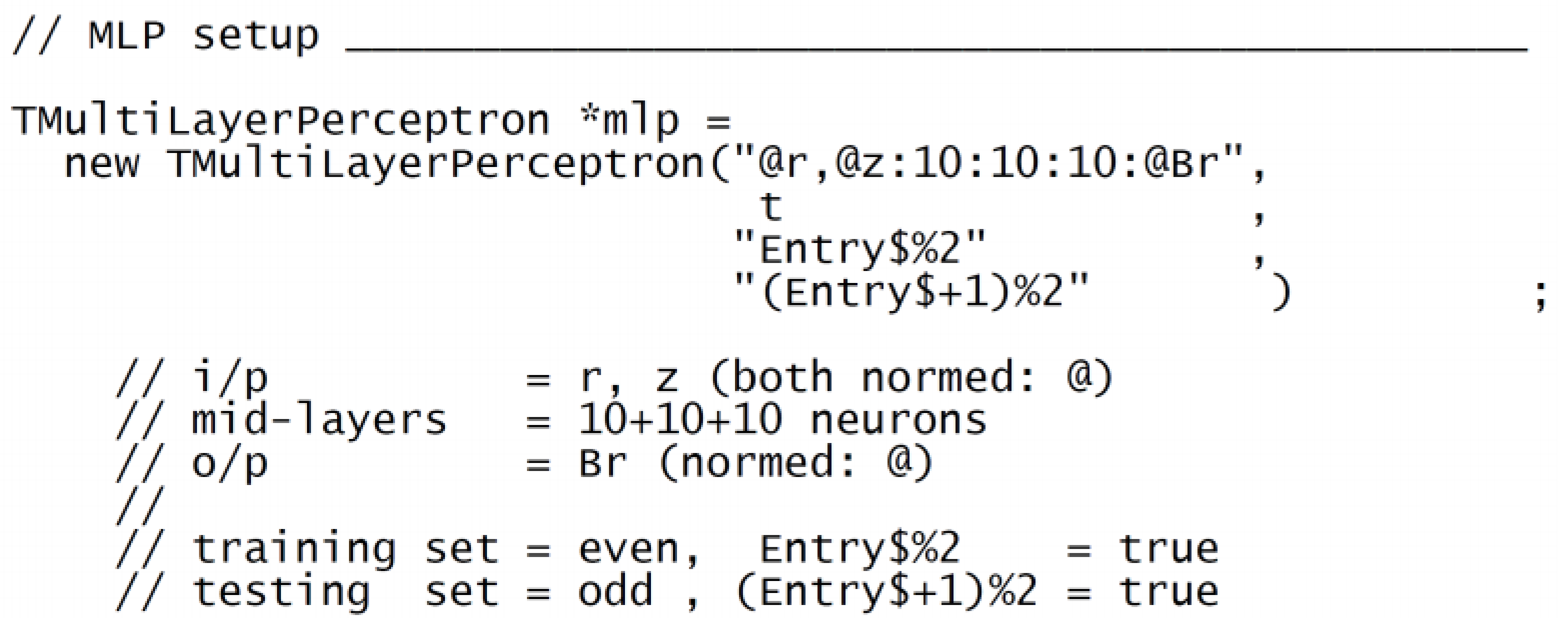
Regression analysis

Learn a function

- *example: radial field of a magnet*

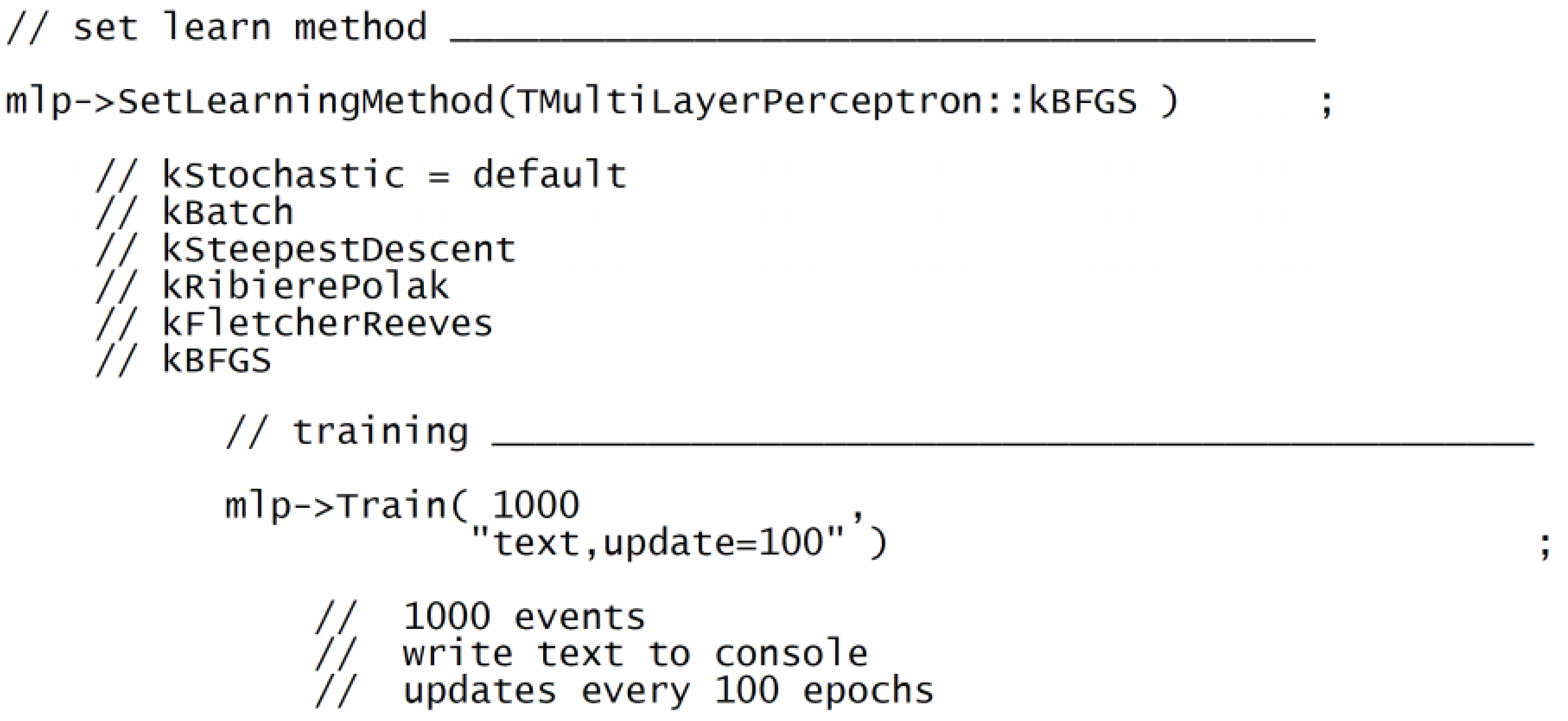


```
// read data ____________________________________________

TTree* t = new TTree("treename", "description")          ;

    // (r,z) = cylindrical coordinates
    // Br    = radial component of magnetic field

Int_t nlines = t->ReadFile("Br.dat","r:z:Br")             ;
```



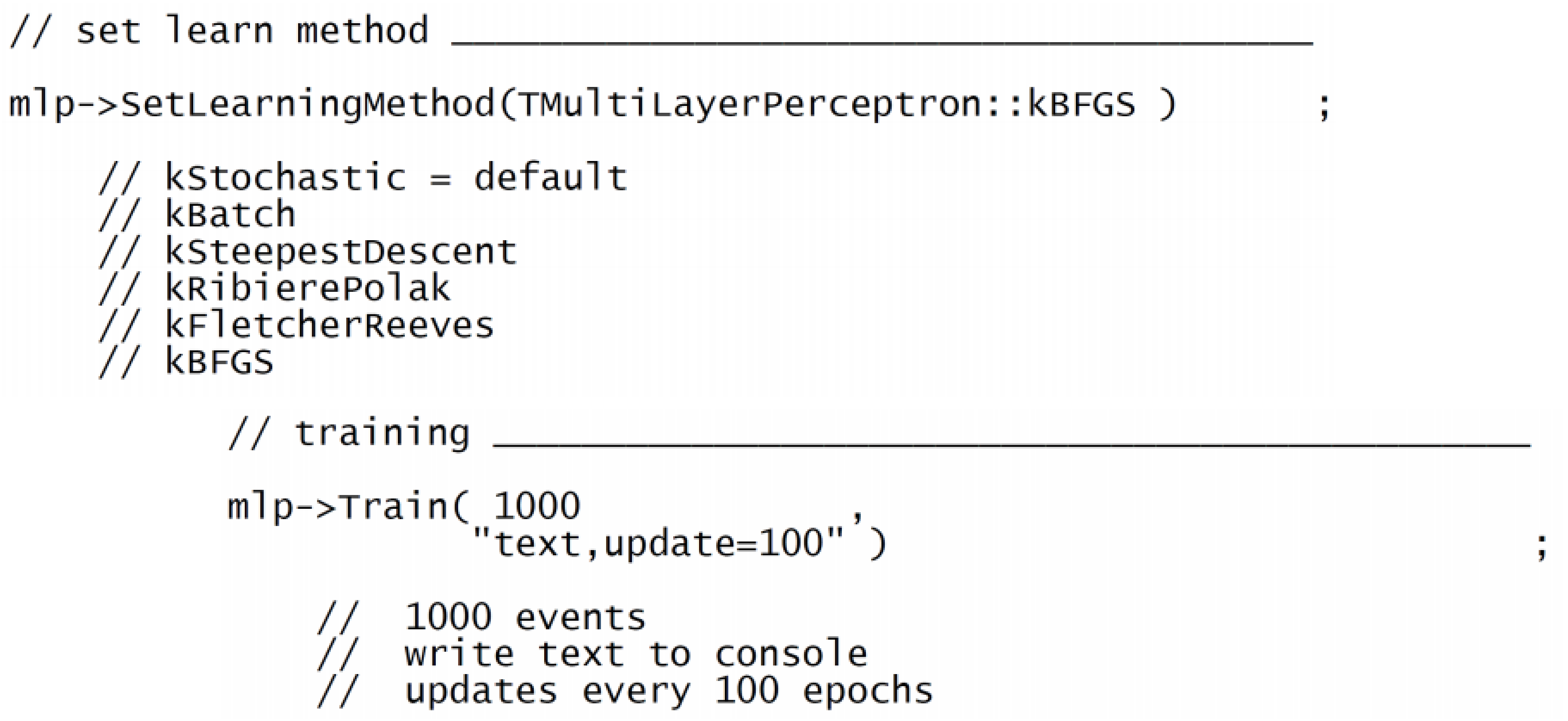
```
// MLP setup ____________________________________________

TMultiLayerPerceptron *mlp =
  new TMultiLayerPerceptron("@r,@z:10:10:10:@Br",
                           t                  ,
                          "Entry$%2"          ,
                          "(Entry$+1)%2"       )          ;

    // i/p           = r, z (both normed: @)
    // mid-layers    = 10+10+10 neurons
    // o/p           = Br (normed: @)
    //
    // training set = even,  Entry$%2     = true
    // testing  set = odd , (Entry$+1)%2 = true
```

Regression analysis



```
// set learn method ______________________________________

mlp->SetLearningMethod(TMultiLayerPerceptron::kBFGS )      ;

    // kStochastic = default
    // kBatch
    // kSteepestDescent
    // kRibierePolak
    // kFletcherReeves
    // kBFGS

          // training _______________________________________________

          mlp->Train( 1000                  ,
                     "text,update=100" )                          ;

              //  1000 events
              //  write text to console
              //  updates every 100 epochs
```

Regression analysis



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// set learn method ______________________________________

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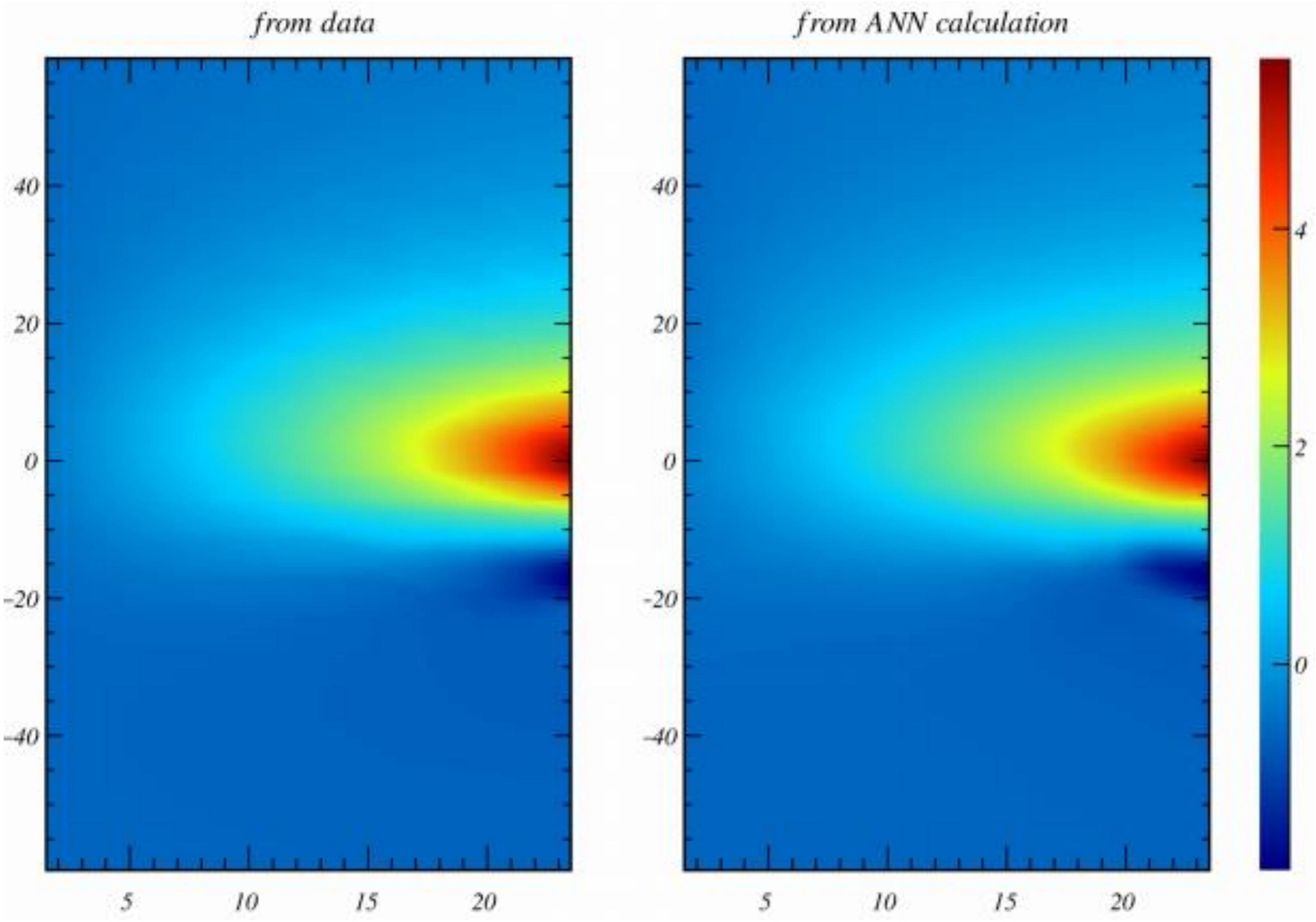
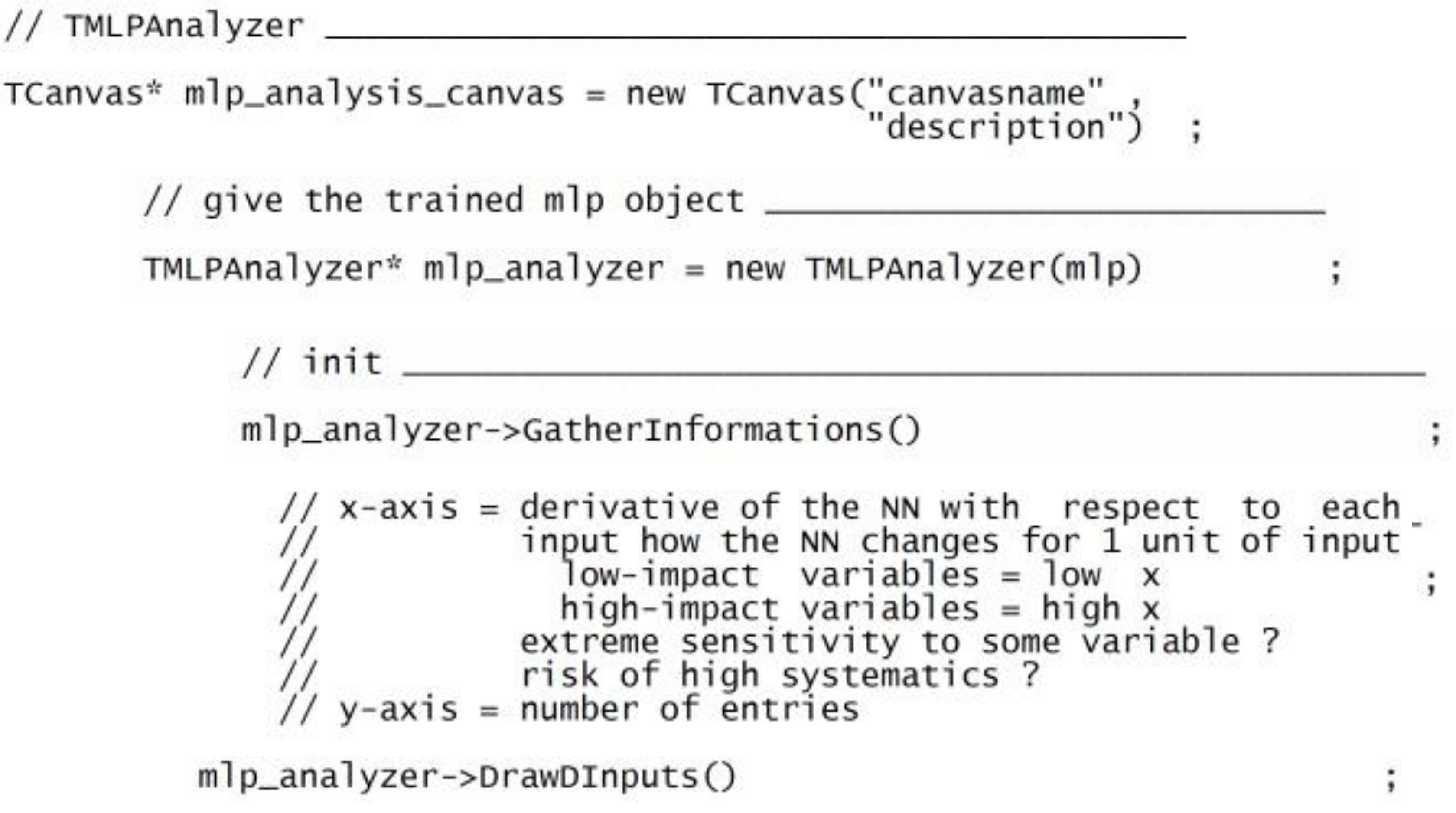
Regression analysis

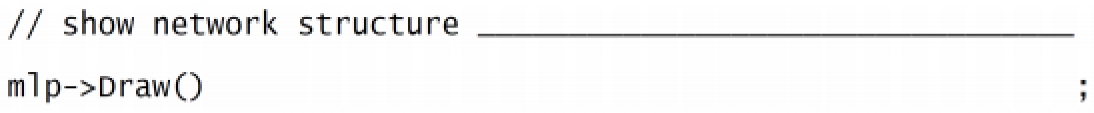


Regression analysis

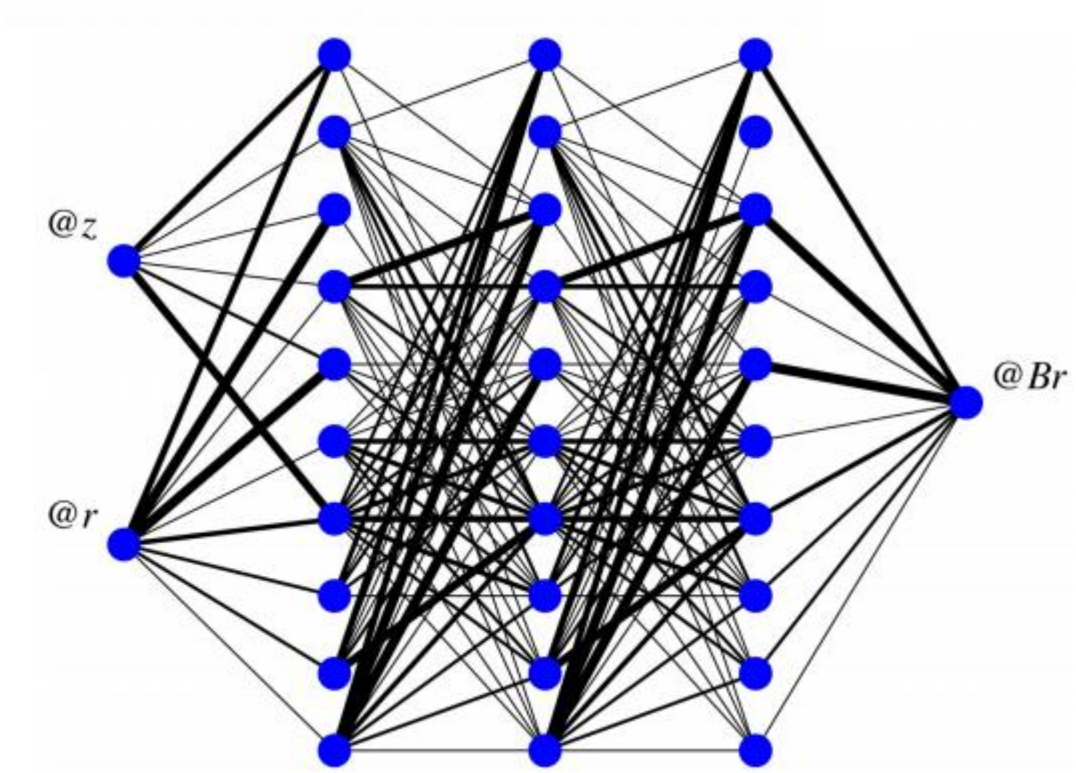


```
// TMLPAnalyzer ____________________________________________

TCanvas* mlp_analysis_canvas = new TCanvas("canvasname" ,
                                           "description")  ;

       // give the trained mlp object ____________________________

       TMLPAnalyzer* mlp_analyzer = new TMLPAnalyzer(mlp)       ;

            // init _____________________________________________

            mlp_analyzer->GatherInformations()                   ;

              // x-axis = derivative of the NN with  respect  to  each
              //          input how the NN changes for 1 unit of input
              //            low-impact  variables = low  x            ;
              //            high-impact variables = high x
              //          extreme sensitivity to some variable ?
              //          risk of high systematics ?
              // y-axis = number of entries

          mlp_analyzer->DrawDInputs()                              ;
```

Regression analysis



```
// show network structure ________________________________
mlp->Draw()                                                 ;
```



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Neuromorphic algorithm

RF-modulation classification

- I tested various combinations of the parameters (ped, A, f, □):

- to form features for the multi-layer perceptron and

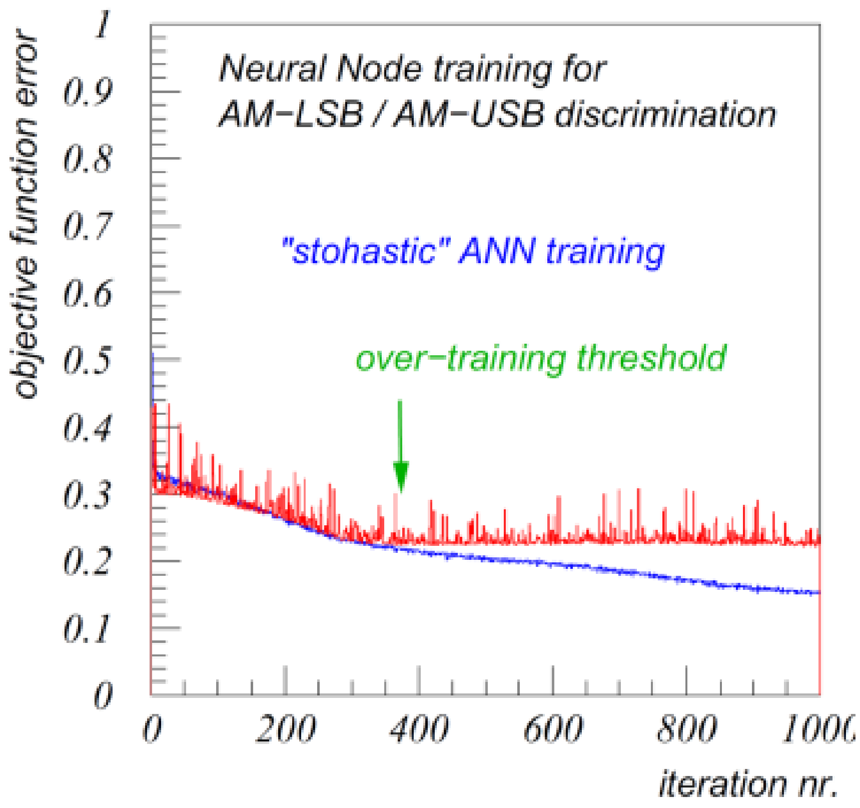
- train a neural network to discriminate:

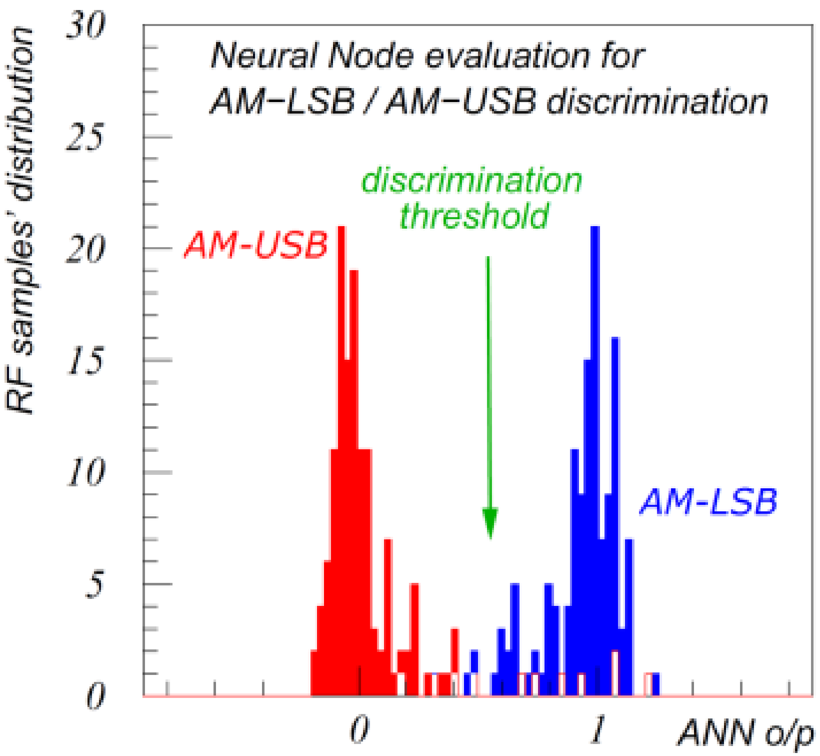
AM-LSB vs. AM-USB modulation

- I evaluated the neural network and the results were very good

Neuromorphic algorithm

AM-LSB vs. AM-USB classification





neural network training

neural network evaluation

Conclusions

Personal opinions

- *I learned more advanced aspects of C++ (separate model compilation, issue limited instantiation, polymorphism, SFINAE)*
- *- We had access to the supercomputing cluster HybriLIT of JINR, which was very cool*
- *- I learned to use the ROOT package from CERN and the Multi-Layer Perceptron utilities inside it*
- *- We were given example data and code for a number of neuro-software applications – of which I detailed here the RF-modulation classifier*
- *- The professors were very good and friendly, I highly recommend this student training programme !*