ALEPH DATA IN KEY4HEP

An update on the status of the project

Jacopo Fanini, Gerardo Ganis, Marcello Maggi, Juraj Smiesko

Who am I?

In the past:

- Bachelor's degree in Physics @ **Università di Padova**
- Thesis @ **AGATA collaboration**, INFN-LNL
- Science communicator @ **Sperimentando**

UNIVERSITÀ DEGLI STUDI DI PADOVA

Now:

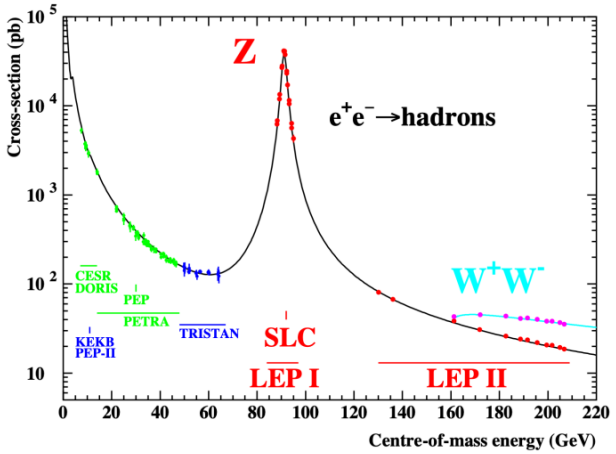
- Master student in Nuclear Engineering @ **Politecnico di Milano**
- Technical student @ **CERN**, started in March

POLITECNICO MILANO 1863

LEP and ALEPH

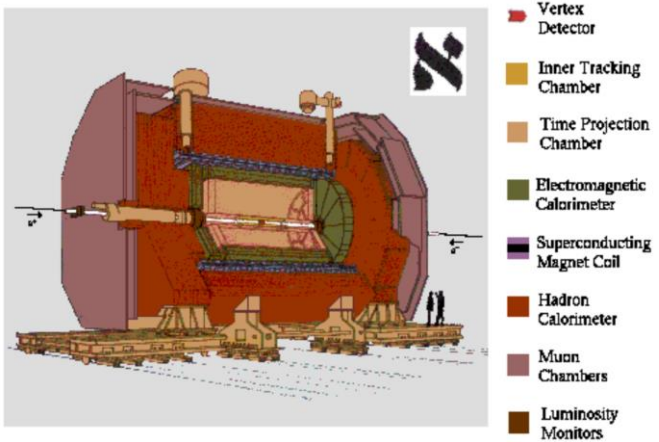
LEP

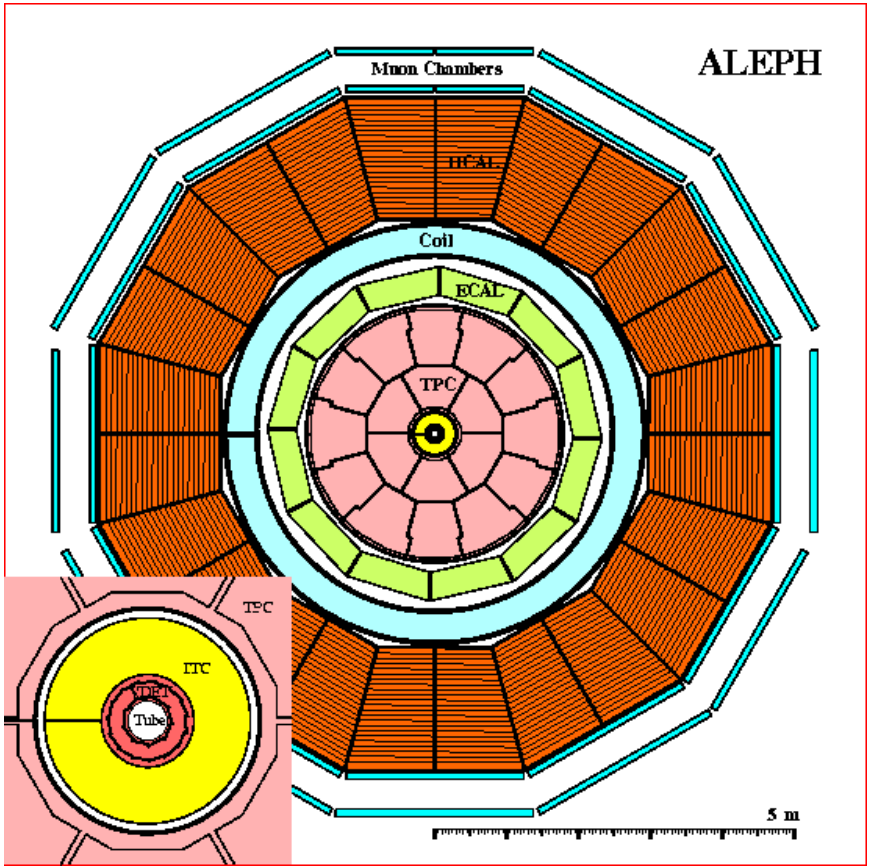
- e^+e^- collider
- Phase 1 (1989-1995): Z production @ 91 GeV
- Phase 2 (1996-2000): W-pair production @ 200 GeV
- 4 experiments: DELPHI, L3, OPAL and…

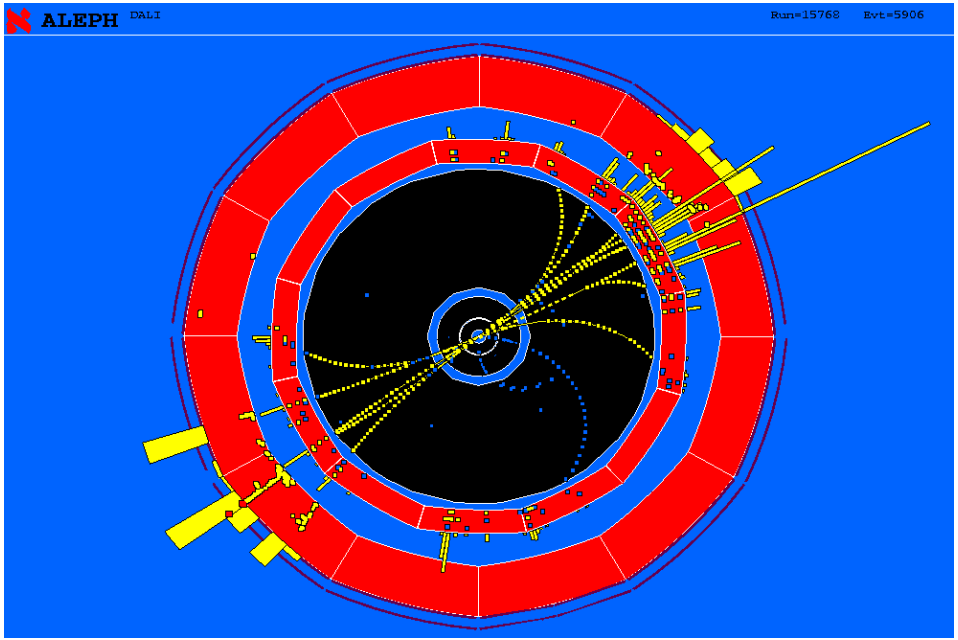


ALEPH

- Typical “onion” experiment with vertex detector, tracking, solenoid magnet, calorimetry and muon system
- Statistics:
  - 4 x 10^6 $e^+e^- \rightarrow q\bar{q}$
  - 5 x 10^5 $e^+e^- \rightarrow l^+l^-$
  - 8 x 10^3 $e^+e^- \rightarrow W^+W^-$




ALEPH
Muon Chambers
HCAL
Coil
ECAL
TPC
TPC
ITC
VDET
Tube
5 m


ALEPH
DALI
Run=15768
Evt=5906

Reasons

- **Data preservation:** to conserve the possibility and capacity of extracting new science from the data
- **EDM4hep test:** to use the new Event Data Model for the first time with real, non simulated data
- **Training on real data:** to give physicists the opportunity to train by analyzing real data, with a view to FCC-ee
- (my Master thesis)

See also: ALEPH data in Key4HEP, M. Maggi

Computing environment

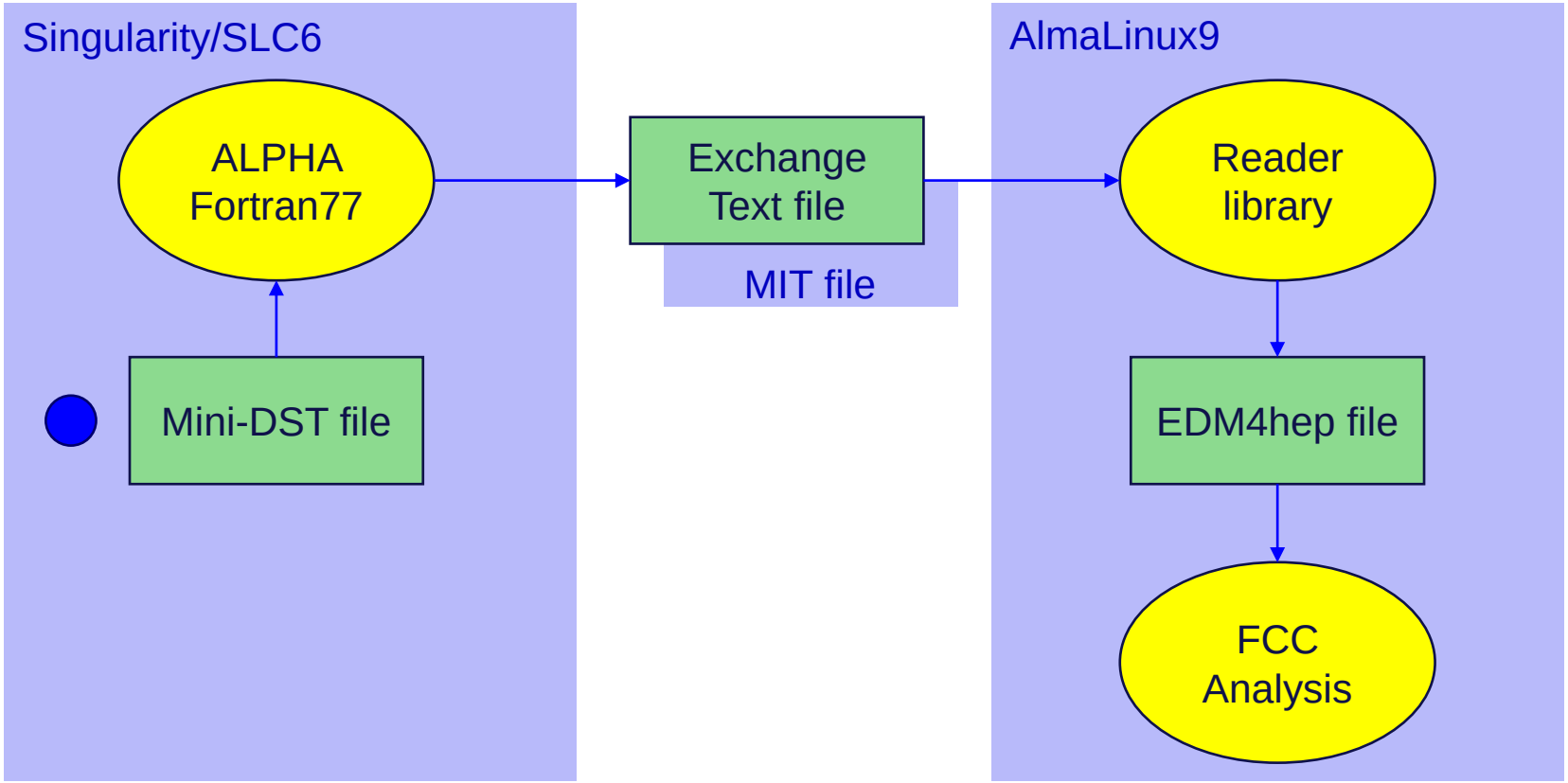
- Last functional environment: **Linux SLC6**
  (bit to bit validation, no recompilation needed)
  - GCC 3.4
  - G77 3.4
  - CERN Library 2005

  Available at *cvmfs/aleph.cern.ch/*

- Data are accessed via containers that reproduce the old computing environment:

Singularity + CernVM is used

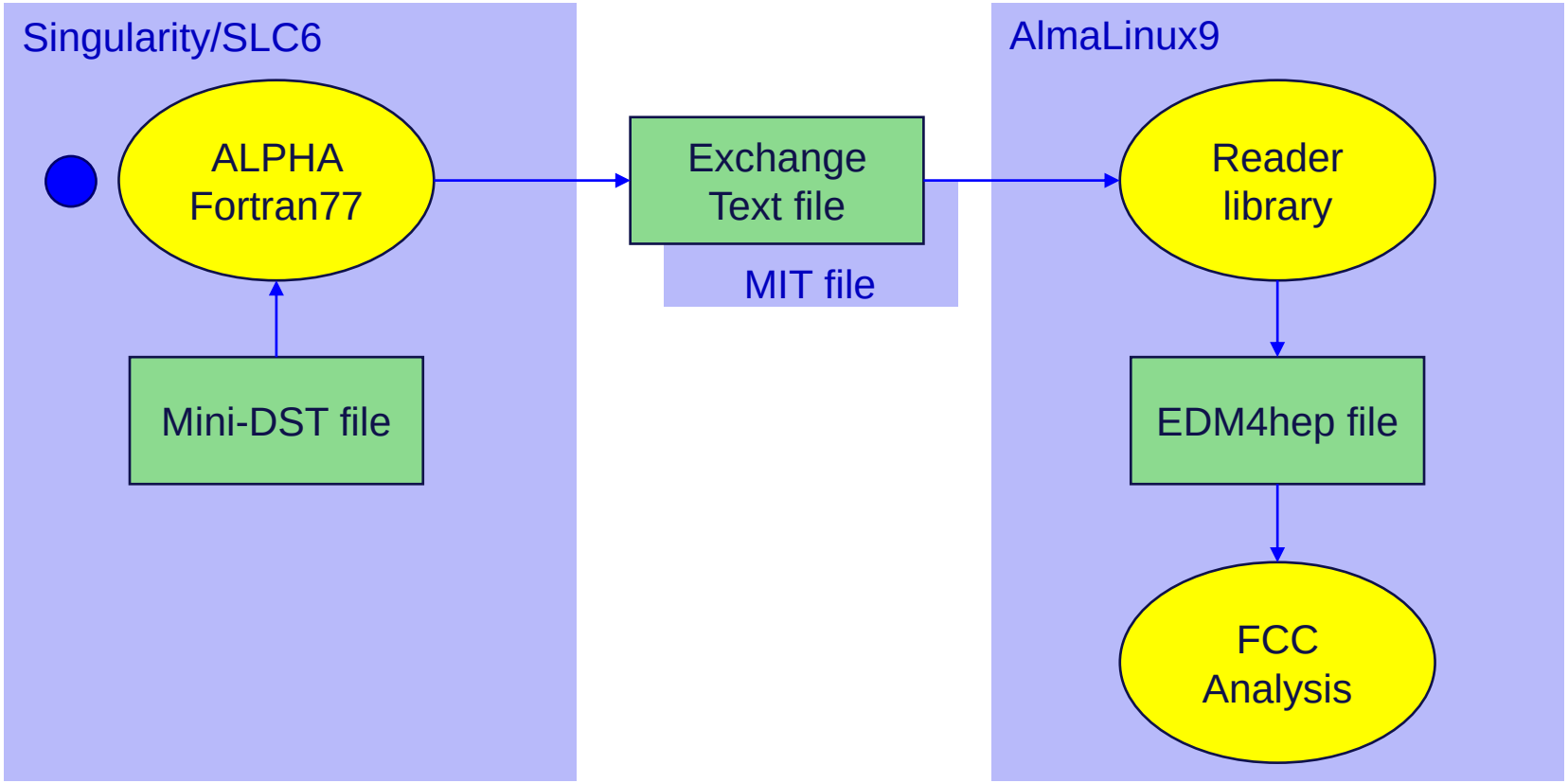
Workflow


Singularity/SLC6
ALPHA
Fortran77
Mini-DST file
Exchange
Text file
MIT file
AlmaLinux9
Reader
library
EDM4hep file
FCC
Analysis

Mini-DST files

- Reduced format created from DST for space saving
- One run record per run and at least one event record per run
  - **Event records**: tracks, vertices, calorimetric objects, energy flow and jets, γ, e, μ identification, HV status, trigger
- In the future: direct access to DST files
- Both Mini-DST and DST available on EOS at */eos/experiment/aleph*

Workflow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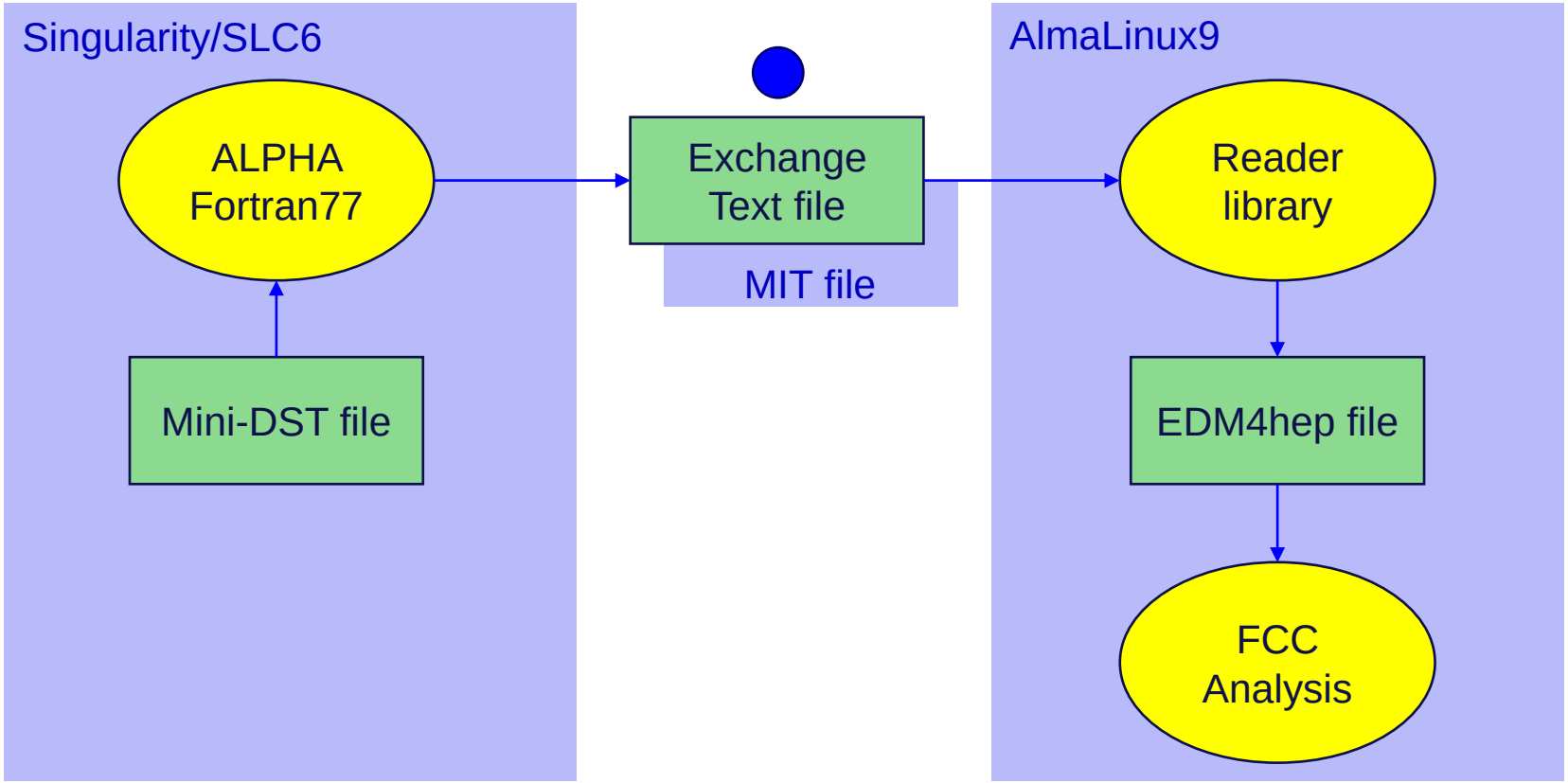
ALPHA

- Program designed for **ALeph PHysics Analysis**
- Internal input/output management
- Easy access to physical variables, without detailed knowledge of ALEPH data structure
- User has to provide three Fortran routines/macros for job initialization, event processing and job termination
- Access to reconstructed object is obtained via DO loops

```
      WRITE(*,10) KRUN, KEVT, KNCHT, KNCOT, QELEP
      NCHTOT= 0
      DO ICHT= KFCHT,KLCHT
        CALL QDEDX(ICHT,NHYP,RMASS,QHYP,RI,NS,TL,RIEXP,SIGMA,IER)
        WRITE(*,9)
        WRITE(*,*) ICHT-KFCHT+1, QP(ICHT), IER, RI, NS, TL
        WRITE(*,11) '(e-)', RIEXP(1), '(pi)', RIEXP(2), '(k)',
     +  RIEXP(3), '(p)', RIEXP(4)
        WRITE(*,11) '(e-)', SIGMA(1), '(pi)', SIGMA(2), '(k)',
     +  SIGMA(3), '(p)', SIGMA(4)
        DO I = 1, 4
          CHI2(I) = ((RI - RIEXP(I)) / SIGMA(I)) ** 2
        ENDDO
        WRITE(*,11) '(e-)', CHI2(1), '(pi)', CHI2(2), '(k)',
     +  CHI2(3), '(p)', CHI2(4)
      ENDDO
9     FORMAT(1X,72('-'))
10    FORMAT(1X,4(I6,2X),F9.3)
11    FORMAT(1X, 4(A4, 2X, F8.4, 2X))
```

Workflow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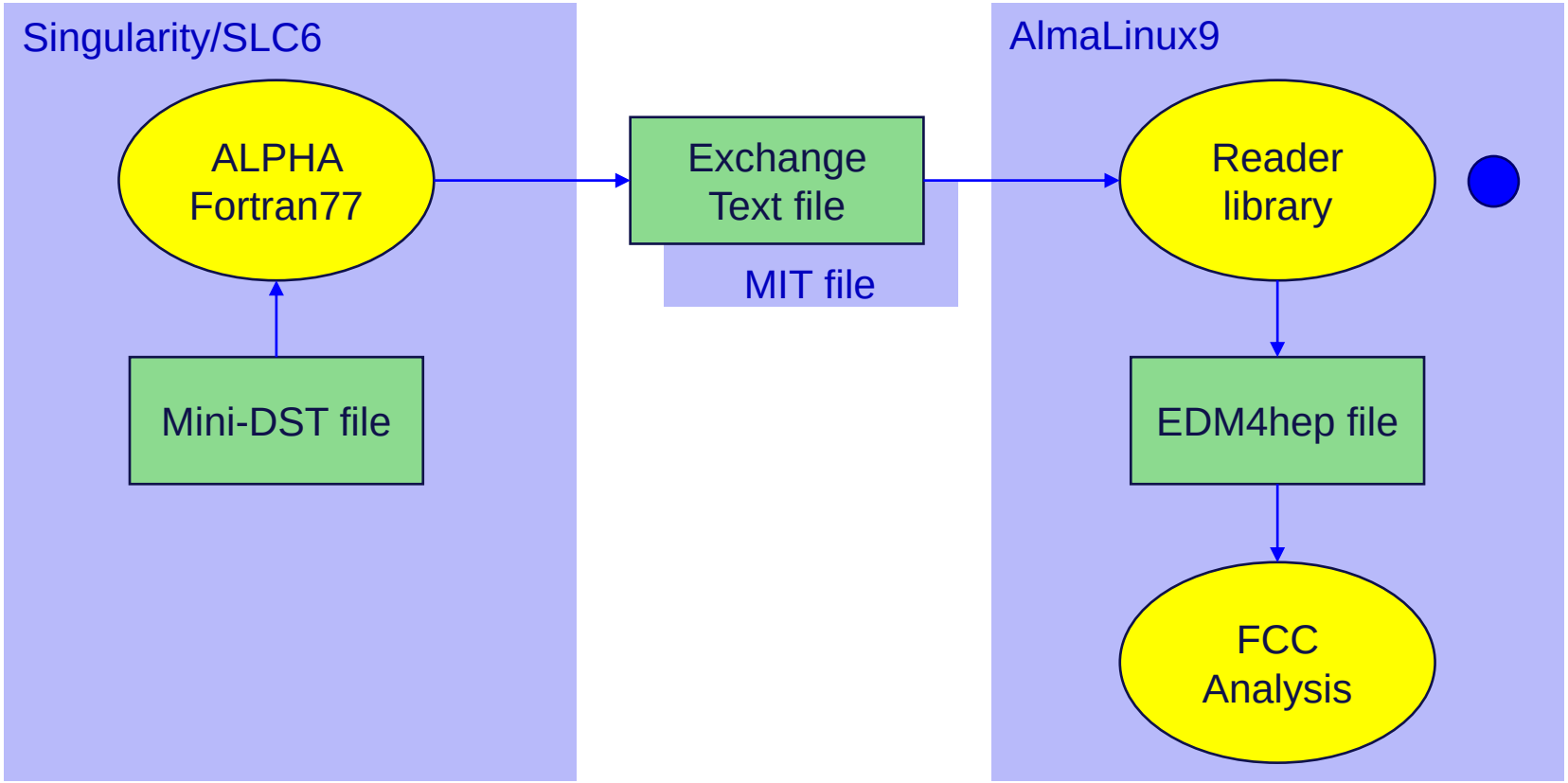
The “MIT format”

```
ALEPH_DATA RUN = 35482 EVENT    15 ECM =   91.650 GEV
 Primary vertex info flag =  4 vx = -0.0802 vy =  0.0308 ex =  0.0019 ey =  0.0000
px=   -0.375 py=   -0.045 pz=    0.035 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.725 z0=    1.155 ntpc= 16 nitc=  0 nvdet= 1 track=   1 de/dx code=0 (e-)  -6.56 (pi-)   0.45 (K-) -11.91 (p) -27.42
px=   -0.264 py=   -0.026 pz=    0.018 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.047 z0=    1.373 ntpc= 11 nitc=  2 nvdet= 2 track=   2 de/dx code=0 (e-)  -2.65 (pi-)   0.56 (K-) -10.64 (p) -24.37
px=    6.591 py=    1.108 pz=    0.591 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.009 z0=    1.338 ntpc= 17 nitc=  2 nvdet= 2 track=   3 de/dx code=0 (e-)  -3.14 (pi-)  -0.35 (K-)   2.04 (p)   3.41
px=   30.342 py=    4.278 pz=    1.145 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.006 z0=    1.337 ntpc= 15 nitc=  0 nvdet= 2 track=   4 de/dx code=0 (e-)  -2.00 (pi-)  -0.71 (K-)   0.68 (p)   1.75
px=   -7.908 py=   -1.061 pz=   -0.332 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.009 z0=    1.331 ntpc= 21 nitc=  0 nvdet= 2 track=   5 de/dx code=0 (e-)  -3.45 (pi-)  -0.35 (K-)   2.26 (p)   3.85
px=   -2.927 py=   -0.017 pz=   -0.687 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.004 z0=    1.343 ntpc= 18 nitc=  3 nvdet= 2 track=   6 de/dx code=0 (e-)  -2.84 (pi-)   0.40 (K-)   2.42 (p)   2.89
px=   -1.499 py=   -0.338 pz=    0.108 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=    0.424 z0=    0.932 ntpc= 20 nitc=  4 nvdet= 0 track=   7 de/dx code=0 (e-)  -5.40 (pi-)  -0.50 (K-)   0.95 (p)  -0.99
px=    1.498 py=    0.681 pz=    0.439 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.011 z0=    1.323 ntpc= 17 nitc=  2 nvdet= 2 track=   8 de/dx code=0 (e-)  -5.48 (pi-)   0.08 (K-)   1.94 (p)   0.09
px=   -3.652 py=   -0.185 pz=   -0.575 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.162 z0=    0.576 ntpc= 11 nitc=  2 nvdet= 0 track=   9 de/dx code=0 (e-)  -6.14 (pi-)  -3.43 (K-)  -1.60 (p)  -1.00
px=   -0.960 py=    0.049 pz=   -0.215 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.008 z0=    1.325 ntpc= 14 nitc=  0 nvdet= 1 track=  11 de/dx code=0 (e-)  -4.47 (pi-)  -0.34 (K-)  -0.45 (p)  -4.05
px=    0.418 py=    0.139 pz=    0.306 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.193 z0=    1.345 ntpc= 15 nitc=  2 nvdet= 2 track=  13 de/dx code=0 (e-)  -6.66 (pi-)   1.31 (K-)  -6.34 (p) -19.28
px=    1.857 py=    0.245 pz=    0.030 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    0.822 py=    0.140 pz=    0.069 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    1.333 py=    0.117 pz=    0.260 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    0.959 py=    0.203 pz=    0.198 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    1.350 py=    0.585 pz=   -0.109 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=   -2.373 py=   -0.260 pz=    0.081 m=    0.022 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=   -3.243 py=   -0.473 pz=    0.049 m=    0.001 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=   -2.128 py=    0.011 pz=   -0.584 m=    0.021 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=   -9.851 py=   -1.656 pz=   -0.410 m=    1.269 charge=  0.0 pwflag=  5 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
vx=    -7.49 vy=    -1.23 vz=     1.85 chi2 =    0.000 type=0 Ntrk=  2
 Track=     1 px=  -0.377 py=  -0.011 pz=   0.037
 Track=     2 px=  -0.259 py=  -0.059 pz=   0.013
vx=    -0.11 vy=     0.03 vz=     1.34 chi2 =    0.000 type=0 Ntrk=  2
 Track=     3 px=   6.585 py=   1.108 pz=   0.590
 Track=     4 px=  30.165 py=   4.248 pz=   1.137
vx=    -6.15 vy=    -0.76 vz=     1.79 chi2 =    0.000 type=0 Ntrk=  2
 Track=     7 px=  -1.505 py=  -0.311 pz=   0.108
 Track=     2 px=  -0.260 py=  -0.054 pz=   0.018
vx=    -5.00 vy=    -0.63 vz=     1.12 chi2 =    0.000 type=0 Ntrk=  2
 Track=     7 px=  -1.505 py=  -0.314 pz=   0.113
 Track=     5 px=  -7.907 py=  -1.084 pz=  -0.332
vx=    -1.95 vy=     0.02 vz=     0.90 chi2 =    0.000 type=0 Ntrk=  2
 Track=     7 px=  -1.502 py=  -0.327 pz=   0.114
 Track=     6 px=  -2.927 py=  -0.026 pz=  -0.687
vx=    -0.09 vy=     0.04 vz=     1.32 chi2 =    0.000 type=0 Ntrk=  2
 Track=     8 px=   1.498 py=   0.681 pz=   0.438
 Track=    13 px=   0.416 py=   0.145 pz=   0.307
primary vertex compatibility track   1 chi= -999.00 track   2 chi= -999.00
primary vertex compatibility track   3 chi= -999.00 track   4 chi= -999.00
primary vertex compatibility track   7 chi= -999.00 track   2 chi= -999.00
primary vertex compatibility track   7 chi= -999.00 track   5 chi= -999.00
primary vertex compatibility track   7 chi= -999.00 track   6 chi= -999.00
primary vertex compatibility track   8 chi= -999.00 track  13 chi= -999.00
END_EVENT
```

- «Hadronic» events (≥ 5 charged particles)
- High level informations: reconstructed particles from particle flow and V0s
- This format can (will) be replaced by a more general **JSON** data interchange format

See also the conference paper by Yi Chen et al.

Workflow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From MIT files to EDM4hep

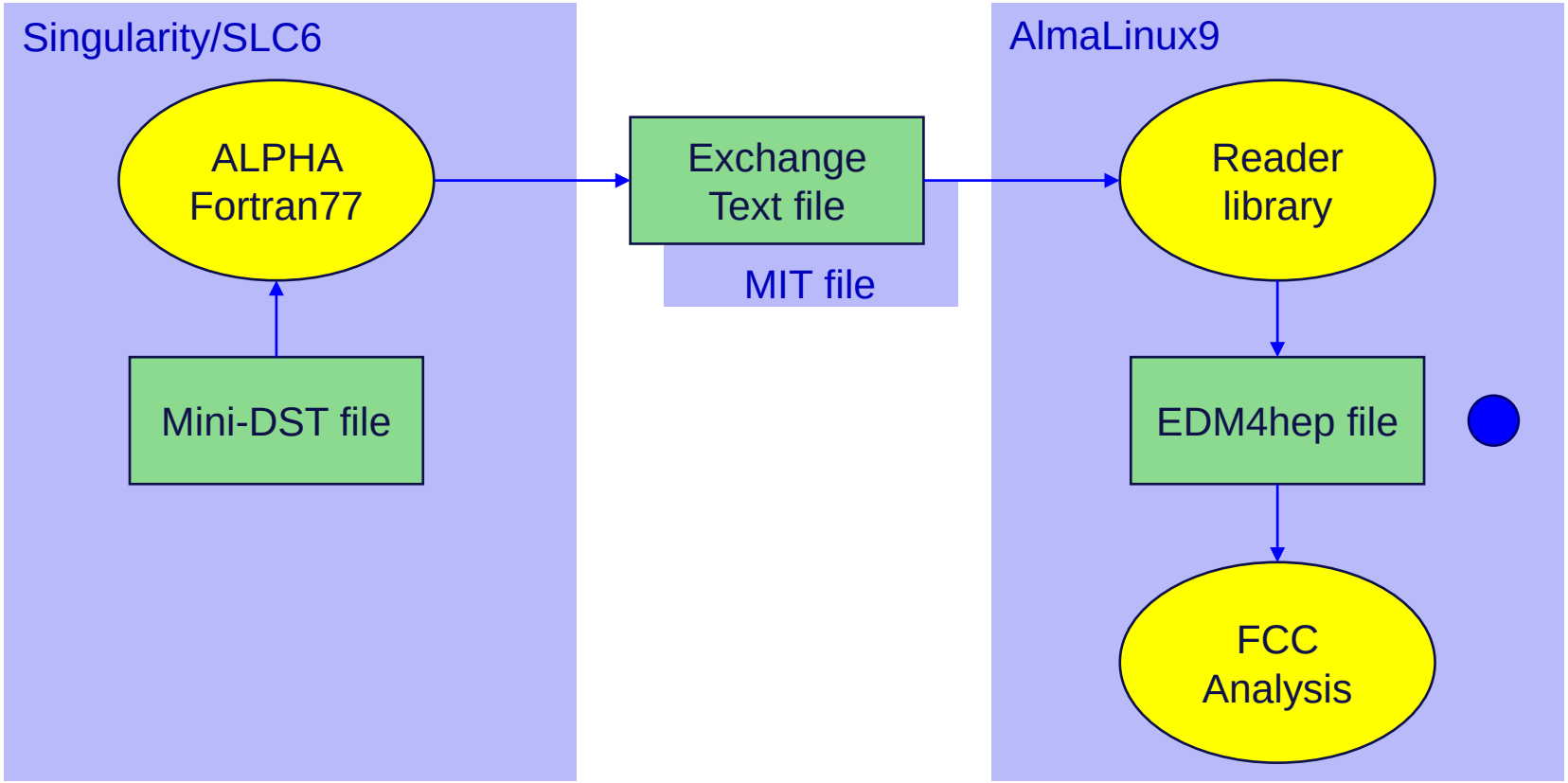
- Library for reading the MIT file line by line, extract (some) event and particles data and store them into structures
- C++ routine that saves these data structures producing EDM4hep ROOT files
- Next steps:
  - **Validation:** extract all the data used by MIT people for their analysis in order to produce EDM4hep ROOT files, which will be reanalyzed by them to validate the chain
  - **Deepening:** enrich the spectrum of data extracted to produce more detailed EDM4hep ROOT files

MIT file mapping

```
ALEPH_DATA RUN = 35482 EVENT    15 ECM =   91.650 GEV
 Primary vertex info flag =  4 vx = -0.0802 vy =  0.0308 ex =  0.0019 ey =  0.0000
px=   -0.375 py=   -0.045 pz=    0.035 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.725 z0=    1.155 ntpc= 16 nitc=  0 nvdet= 1 track=   1 de/dx code=0 (e-)  -6.56 (pi-)   0.45 (K-) -11.91 (p) -27.42
px=   -0.264 py=   -0.026 pz=    0.018 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.047 z0=    1.373 ntpc= 11 nitc=  2 nvdet= 2 track=   2 de/dx code=0 (e-)  -2.65 (pi-)   0.56 (K-) -10.64 (p) -24.37
px=    6.591 py=    1.108 pz=    0.591 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.009 z0=    1.338 ntpc= 17 nitc=  2 nvdet= 2 track=   3 de/dx code=0 (e-)  -3.14 (pi-)  -0.35 (K-)   2.04 (p)   3.41
px=   30.342 py=    4.278 pz=    1.145 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.006 z0=    1.337 ntpc= 15 nitc=  0 nvdet= 2 track=   4 de/dx code=0 (e-)  -2.00 (pi-)  -0.71 (K-)   0.68 (p)   1.75
px=   -7.908 py=   -1.061 pz=   -0.332 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.009 z0=    1.331 ntpc= 21 nitc=  0 nvdet= 2 track=   5 de/dx code=0 (e-)  -3.45 (pi-)  -0.35 (K-)   2.26 (p)   3.85
px=   -2.927 py=   -0.017 pz=   -0.687 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.004 z0=    1.343 ntpc= 18 nitc=  3 nvdet= 2 track=   6 de/dx code=0 (e-)  -2.84 (pi-)   0.40 (K-)   2.42 (p)   2.89
px=   -1.499 py=   -0.338 pz=    0.108 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=    0.424 z0=    0.932 ntpc= 20 nitc=  4 nvdet= 0 track=   7 de/dx code=0 (e-)  -5.40 (pi-)  -0.50 (K-)   0.95 (p)  -0.99
px=    1.498 py=    0.681 pz=    0.439 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.011 z0=    1.323 ntpc= 17 nitc=  2 nvdet= 2 track=   8 de/dx code=0 (e-)  -5.48 (pi-)   0.08 (K-)   1.94 (p)   0.09
px=   -3.652 py=   -0.185 pz=   -0.575 m=    0.140 charge=  1.0 pwflag=  0 lock= 1 d0=   -0.162 z0=    0.576 ntpc= 11 nitc=  2 nvdet= 0 track=   9 de/dx code=0 (e-)  -6.14 (pi-)  -3.43 (K-)  -1.60 (p)  -1.00
px=   -0.960 py=    0.049 pz=   -0.215 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=    0.008 z0=    1.325 ntpc= 14 nitc=  0 nvdet= 1 track=  11 de/dx code=0 (e-)  -4.47 (pi-)  -0.34 (K-)  -0.45 (p)  -4.05
px=    0.418 py=    0.139 pz=    0.306 m=    0.140 charge= -1.0 pwflag=  0 lock= 1 d0=   -0.193 z0=    1.345 ntpc= 15 nitc=  2 nvdet= 2 track=  13 de/dx code=0 (e-)  -6.66 (pi-)   1.31 (K-)  -6.34 (p) -19.28
px=    1.857 py=    0.245 pz=    0.030 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    0.822 py=    0.140 pz=    0.069 m=    0.000 charge=  0.0 pwflag=  4 lock= 1 d0=   -1.000 z0=   -1.000 ntpc=  0 nitc=  0 nvdet= 0 track=   0 de/dx code=1 (e-)  -1.00 (pi-)  -1.00 (K-)  -1.00 (p)  -1.00
px=    1.333 py=    0.117 ... .00 (K-)  -1.00 (p)  -1.00
px=    0.959 py=    0.203 ... .00 (K-)  -1.00 (p)  -1.00
px=    1.350 py=    0.585 ... .00 (K-)  -1.00 (p)  -1.00
px=   -2.373 py=   -0.260 ... .00 (K-)  -1.00 (p)  -1.00
px=   -3.243 py=   -0.473 ... .00 (K-)  -1.00 (p)  -1.00
px=   -2.128 py=    0.011 ... .00 (K-)  -1.00 (p)  -1.00
px=   -9.851 py=   -1.656 ... .00 (K-)  -1.00 (p)  -1.00
```

```
#------- ReconstructedParticle
edm4hep::ReconstructedParticle:
  Description: "Reconstructed Particle"
  Author: "EDM4hep authors"
  Members:
    - int32_t                  PDG              // PDG of the reconstructed particle.
    - float                    energy [GeV]      // energy of the reconstructed particle. Four momentum state is not kept c
    - edm4hep::Vector3f        momentum [GeV]  //  particle momentum. Four momentum state is not kept consistent internal
    - edm4hep::Vector3f        referencePoint [mm] // reference, i.e. where the particle has been measured
    - float                    charge           // charge of the reconstructed particle
    - float                    mass  [GeV]      //  mass of the reconstructed particle, set independently from four vector.
    - float                    goodnessOfPID    // overall goodness of the PID on a scale of [0;1]
    - edm4hep::CovMatrix4f     covMatrix        // covariance matrix of the reconstructed particle 4vector
  OneToOneRelations:
    - edm4hep::Vertex            startVertex     // start vertex associated to this particle
  OneToManyRelations:
    - edm4hep::Cluster                  clusters     // clusters that have been used for this particle
    - edm4hep::Track                    tracks       // tracks that have been used for this particle
    - edm4hep::ReconstructedParticle particles     // reconstructed particles that have been combined to this particle
```

Workflow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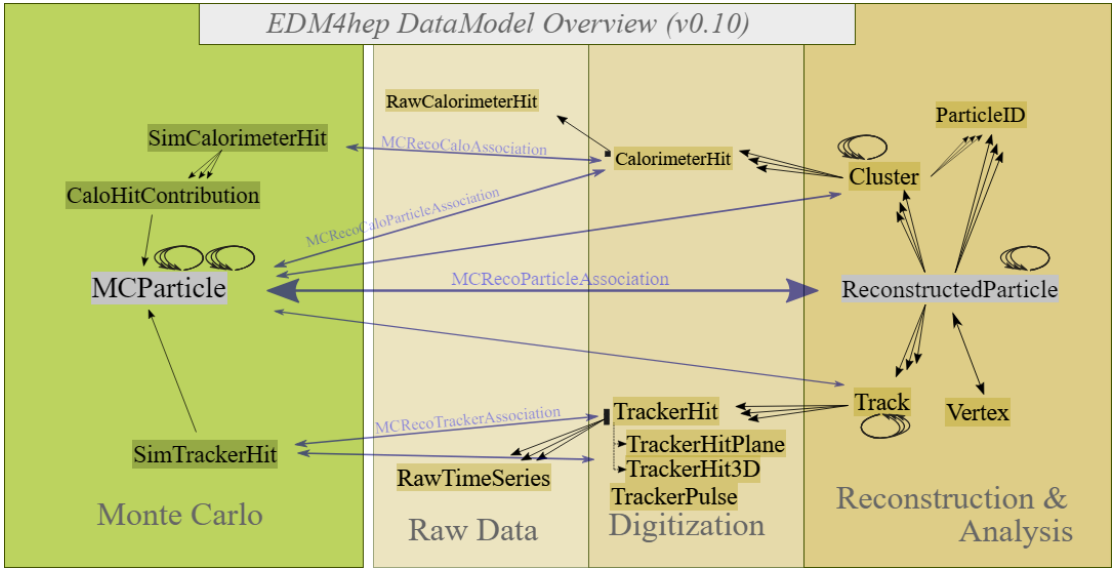
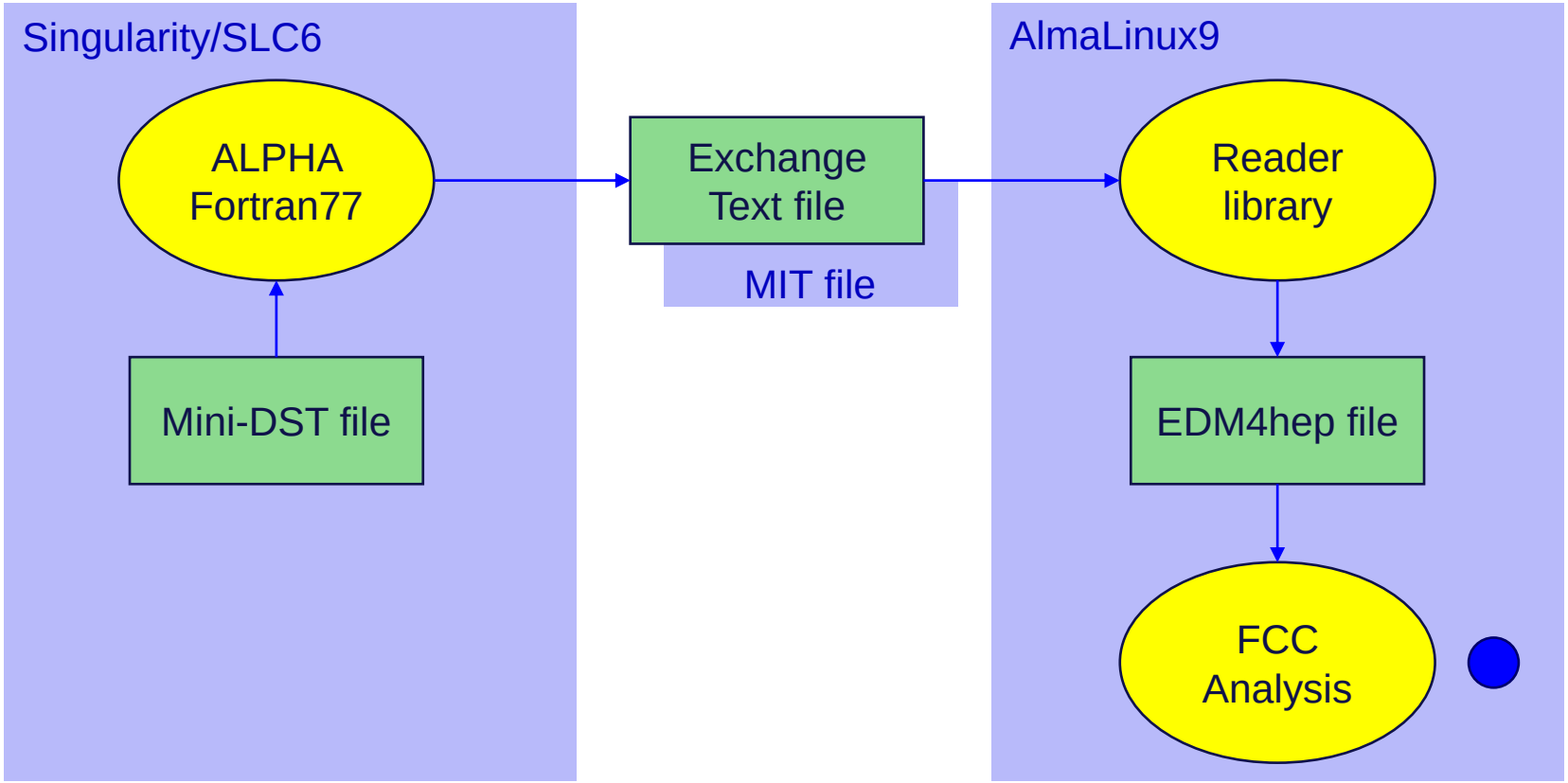
EDM4hep file

- Common **Event Data Model** for future HEP experiments, despite the differences regarding collision environments and detector technologies
- It contains general structures to store data and user-defined structures can be added as needed



Workflow

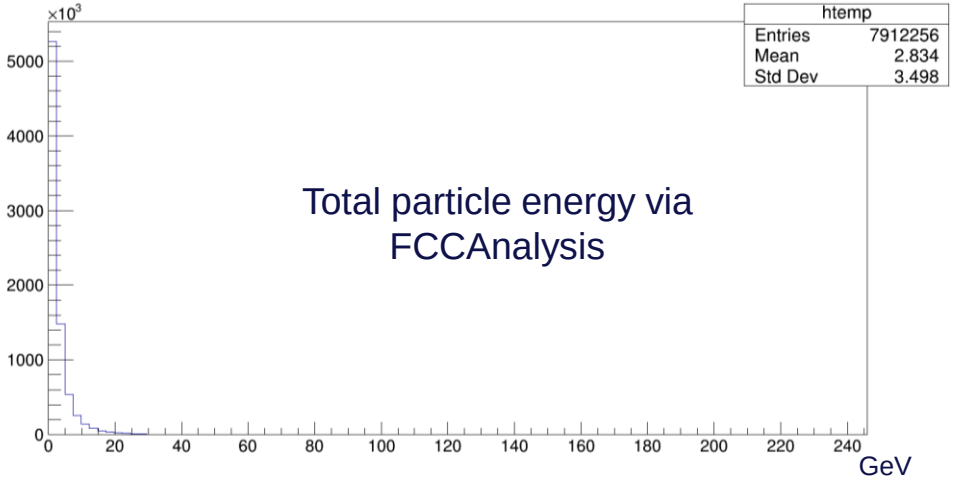

Singularity/SLC6
ALPHA
Fortran77
Mini-DST file
Exchange
Text file
MIT file
AlmaLinux9
Reader
library
EDM4hep file
FCC
Analysis

FCCAnalysis

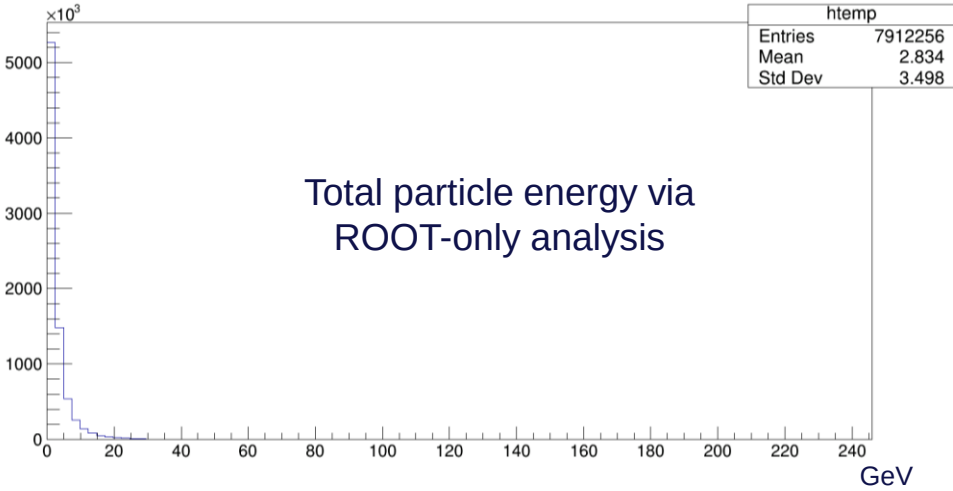
- **Common framework** for FCC related analyses, taking EDM4hep input ROOT files and producing histograms
- Based on **ROOT RDataFrame** for the construction of the computational graph
- Actions are lazy evaluated
- Some analysis routines are pre-defined, users can define their own directly as JIT compiled C++ functions/functors

Validation

- Will be carried out by prof. Lee's group (MIT)
- As a first check, files obtained from the workflow output were compared with a ROOT file obtained directly from the "MIT format": their match is very good



Total particle energy via FCCAnalysis



Total particle energy via ROOT-only analysis

Summarizing

What has been done

- Set up a first chain of programs to convert the original ALEPH files (Mini-DST) to EDM4hep files, which can be analyzed with FCCAnalyses

What will be done include

- Validation of the chain by MIT collaborators
- Consolidate access to low level data (ALPHA, Fortran77)
- Define a complete and general text exchange format for extracting the data
  - Using JSON or similar
- Identify EDM4hep structures for low-level information
  - This might result in the need to augment the EDM4hep offer

Example: track information mapping

```
                                        Subschema: MiniDSTBanks
+------+
| DTRA |  Fitted Track - Derived from
+------+  FRFT (and PFRF)
.............................................................
    1          I    Number of Words per Track (=27)
    2          I    Number of Tracks
.............................................................
    1    CH  I    CHarge           [-1,1]
                     Charge
    2    P0  I    P                [0,*]
                     Momentum of Fitted Track (MeV)
    3    TH  I    THeta            [0,*]
                     Theta of Fitted Track (mrad/10)
    4    PH  I    PHi              [0,*]
                     Phi of Fitted Track (mrad/10)
    5    D0  I    D0               [*,*]
                     Distance of Closest Approach to z-Axis (micron)
    6    Z0  I    Z0               [*,*]
                     Z Coordinate at D0 (micron)
  7-11   ER  I    ERrors           [0,*]
                     Eigen-values as in PFRF
   12    TF  I    TFitprob         [0,1000]
                     Track Fit: Chisq/DoF * 10
   13    HO  I    HitsObs          [0,*]
                     Hit Pattern Observed in Tracking Devices.
```

Exchange Text file

```
  # Parametrized description of a particle track
edm4hep::TrackState:
  Members:
    - int32_t location // for use with At{Other|IP|FirstHit|LastHit|Calorimeter|Vertex
    - float D0 // transverse impact parameter
    - float phi // azimuthal angle
    - float omega [1/mm] // is the signed curvature of the track
    - float Z0 // longitudinal impact parameter
    - float tanLambda // lambda is the dip angle of the track in r-z
    - float time [ns] // time of the track at this trackstate
    - edm4hep::Vector3f referencePoint [mm] // Reference point of the track parameters
    - edm4hep::CovMatrix6f covMatrix // covariance matrix of the track parameters.
```

Thank you for your attention

In depth documentation

- Data Preservation in HEP: paper by DPHEP collaboration on data preservation reasons and strategies
- ALEPH GitLab: source code and some general information about the experiment
- ALEPH website: old public webpage of the ALEPH collaboration
- ALPHA User's Guide: description of ALPHA analysis routines
- EDM4hep GitHub: source code of the general Event Data Model