ALEPH DATA IN EDM4HEP

Reasons, current status and future prospects

Gerardo Ganis, Marcello Maggi, Juraj Smiesko, Jacopo Fanini

Motivations

- **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
- **New analysis and optimization of algorithms:** to apply and test new analysis techniques (e.g. machine learning algorithms) on LEP data
- **Data preservation:** to conserve the possibility and capacity of extracting new science from the data
- **Validation of simulations tools**

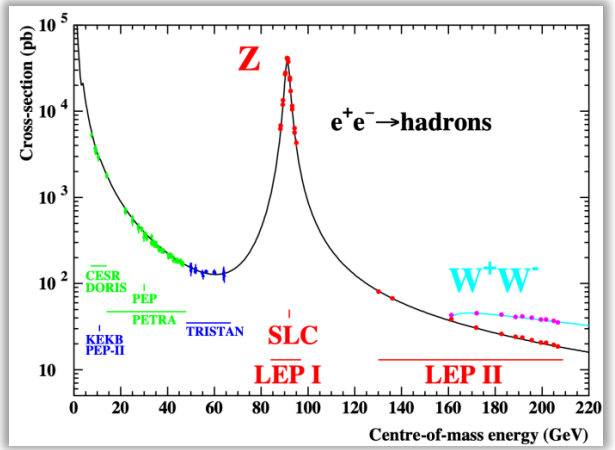
See also:
M. Maggi, ALEPH data in Key4HEP
G. Ganis, Opportunities offered by LEP data@EDM4hep

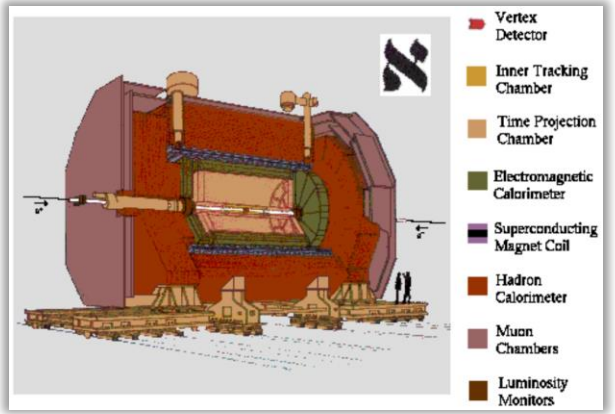
ALEPH Data Reminder

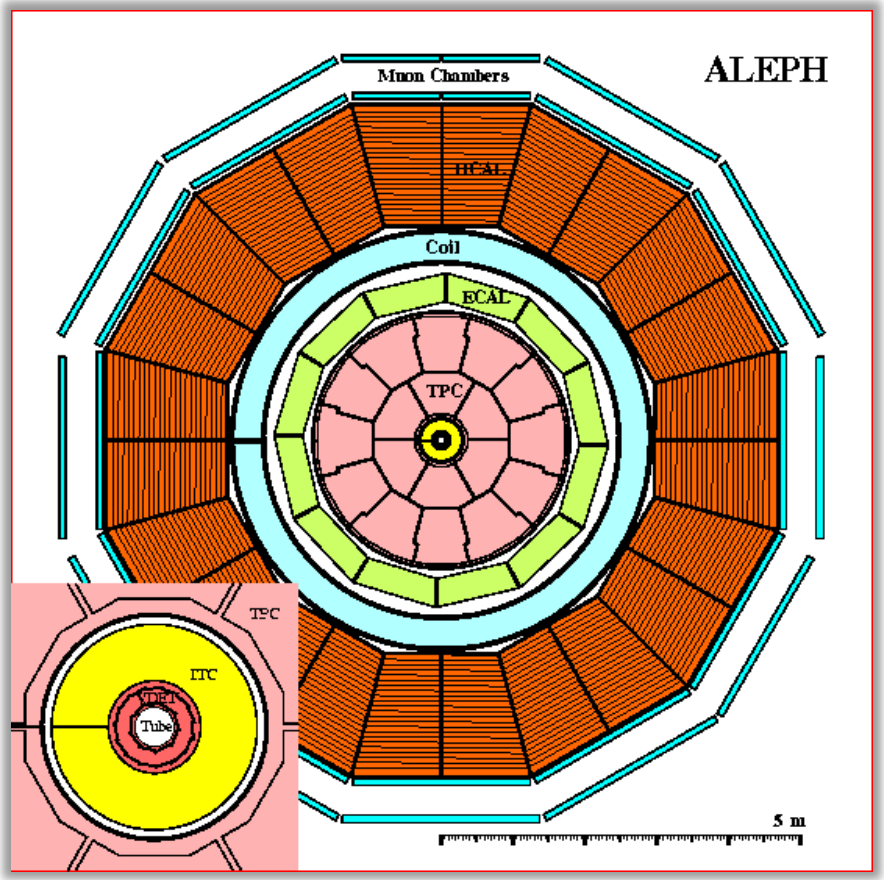
LEP and ALEPH

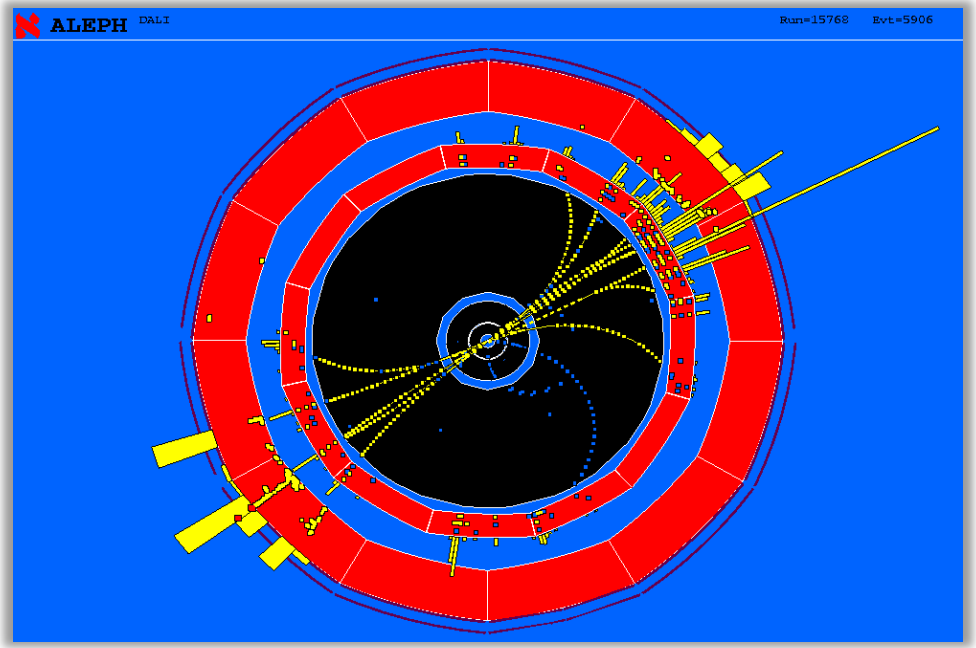
- **LEP**
  - e^+e^- collider
  - Phase 1 (‘89-’95): Z production @ ~91 GeV
  - Phase 2 (‘96-’00): W-pair production @ ~160-209 GeV
  - 4 experiments: DELPHI, L3, OPAL and…

- **ALEPH**
  - Typical “onion” experiment: vertex detector, tracking, solenoid magnet, calorimetry, muon system
  - Luminosity
    - LEP1: 200 pb^{-1}
    - LEP2: 688 pb^{-1}
  - Statistics:
    - ~ 4 x 10^6 $e^+e^- \to q\bar{q}$, ~ 8 x 10^3 $e^+e^- \to W^+W^-$






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


ALEPH
DALI
Run=15768
Evt=5906

Formats and sizes

- Several formats:
  - **RAW**: direct information from detector, no reconstruction
  - **POT**: reconstructed data
  - **DST**: as POT, but without noise and background
  - **Mini-DST**: high level analysis results, scaled, integerized and compressed

- Sizes (LEP1 data sample):
  - RAW: 2063 GB
  - POT: 975 GB
  - DST: 154 GB
  - Mini-DST: 38 GB

Computing environment

- Last binary build: **Linux SLC4**
- 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

- These environments can still be recreated on **today's lxplus** (**AlmaLinux9**) via **Apptainer/Singularity** + **CernVM**

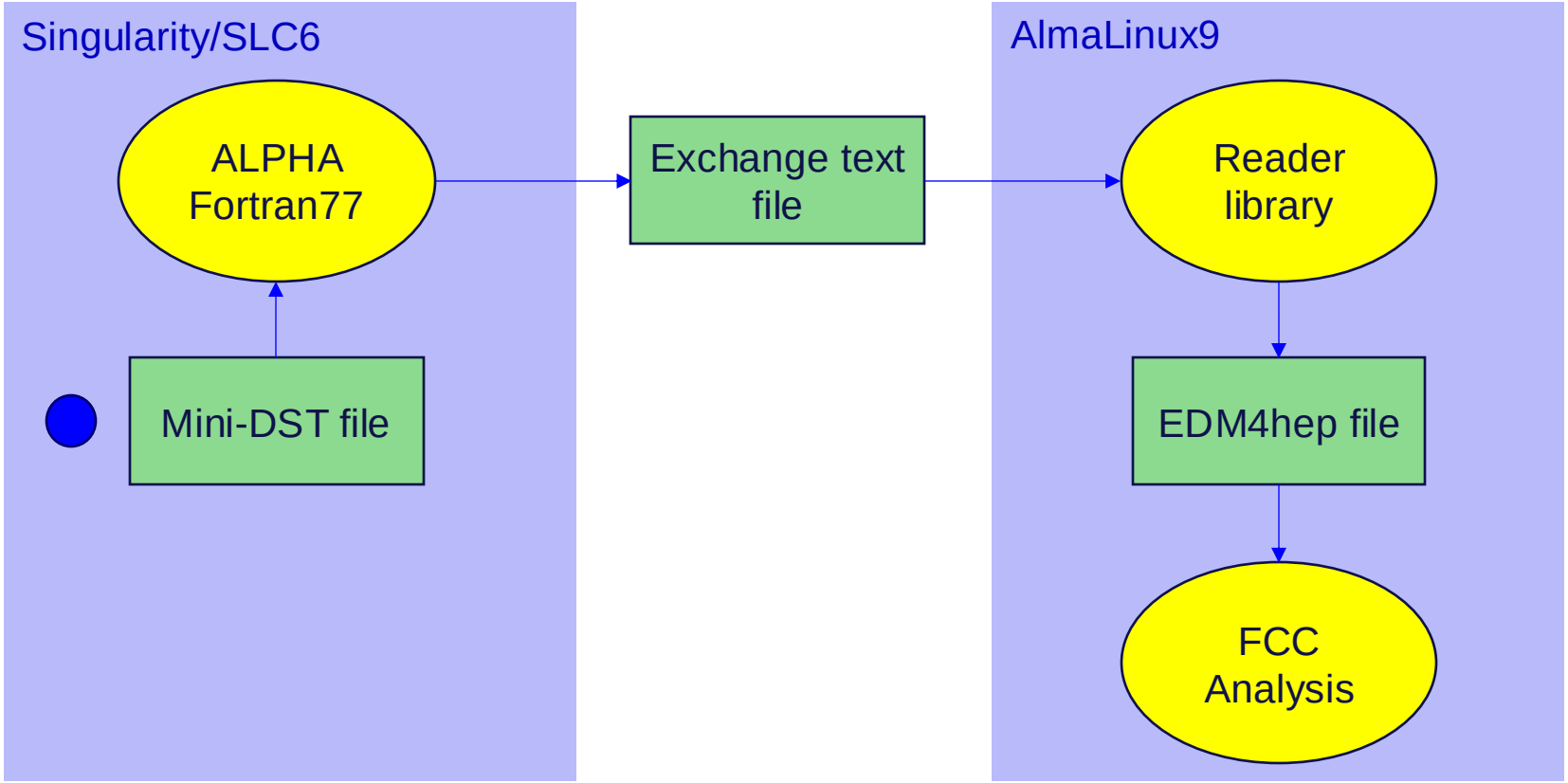
```
[jfanini@lxplus973 ~]$
[jfanini@lxplus973 ~]$ aleph-slc6

 Welcome to ALEPH @ SLC6

 HOME     =  /afs/cern.ch/user/j/jfanini/public/aleph
 WORKDIR  =  /afs/cern.ch/user/j/jfanini
 ALEPHGIT =  /afs/cern.ch/user/j/jfanini/public/aleph/GIT
Singularity SLC6:/afs/cern.ch/user/j/jfanini>
```

Conversion Chain

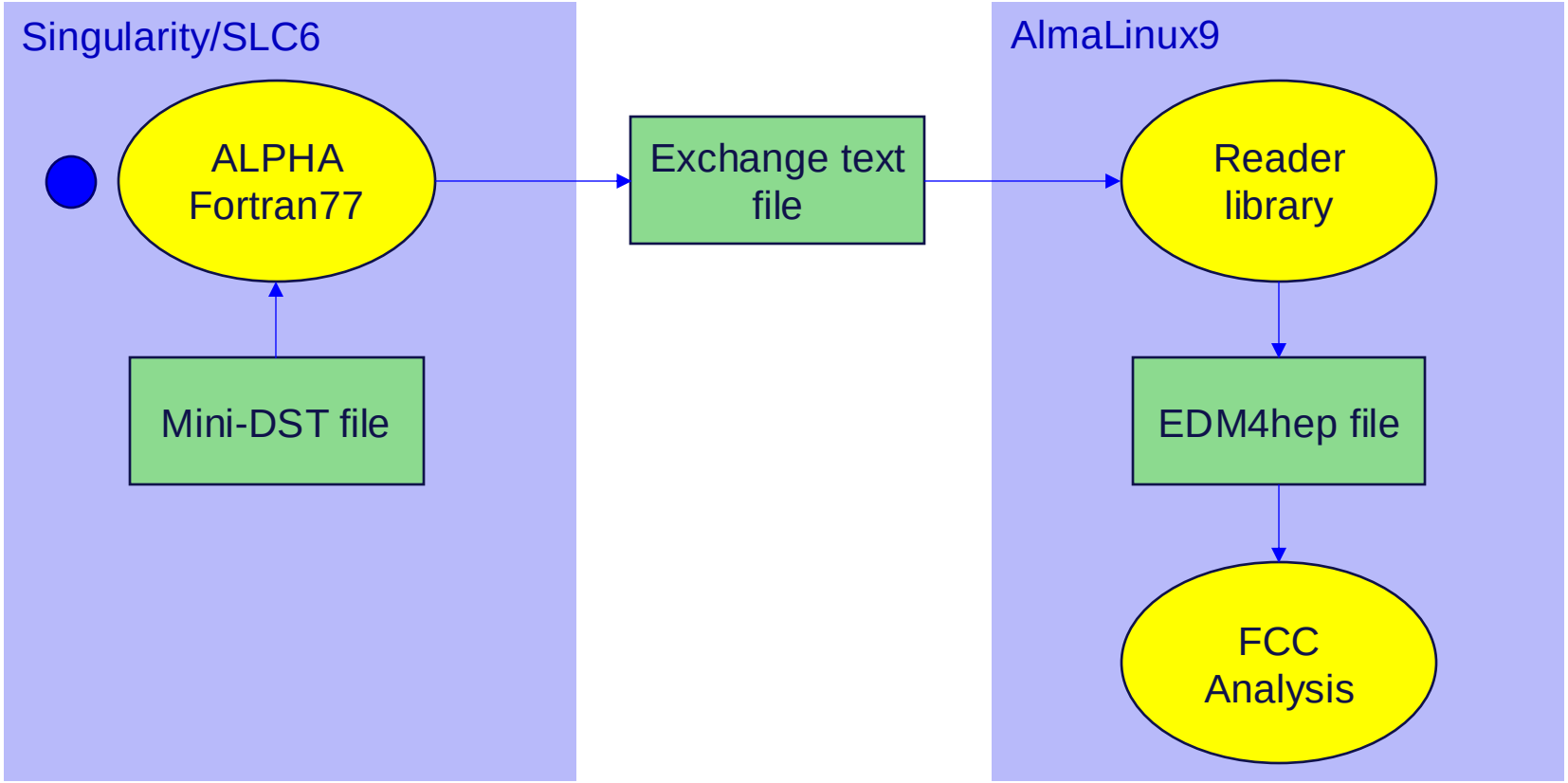
Workflow


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

Focus on 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 detector status, trigger
- Both Mini-DST and DST available on EOS at /eos/experiment/aleph
- Possible next step: direct access to DST files

Workflow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ALPHA
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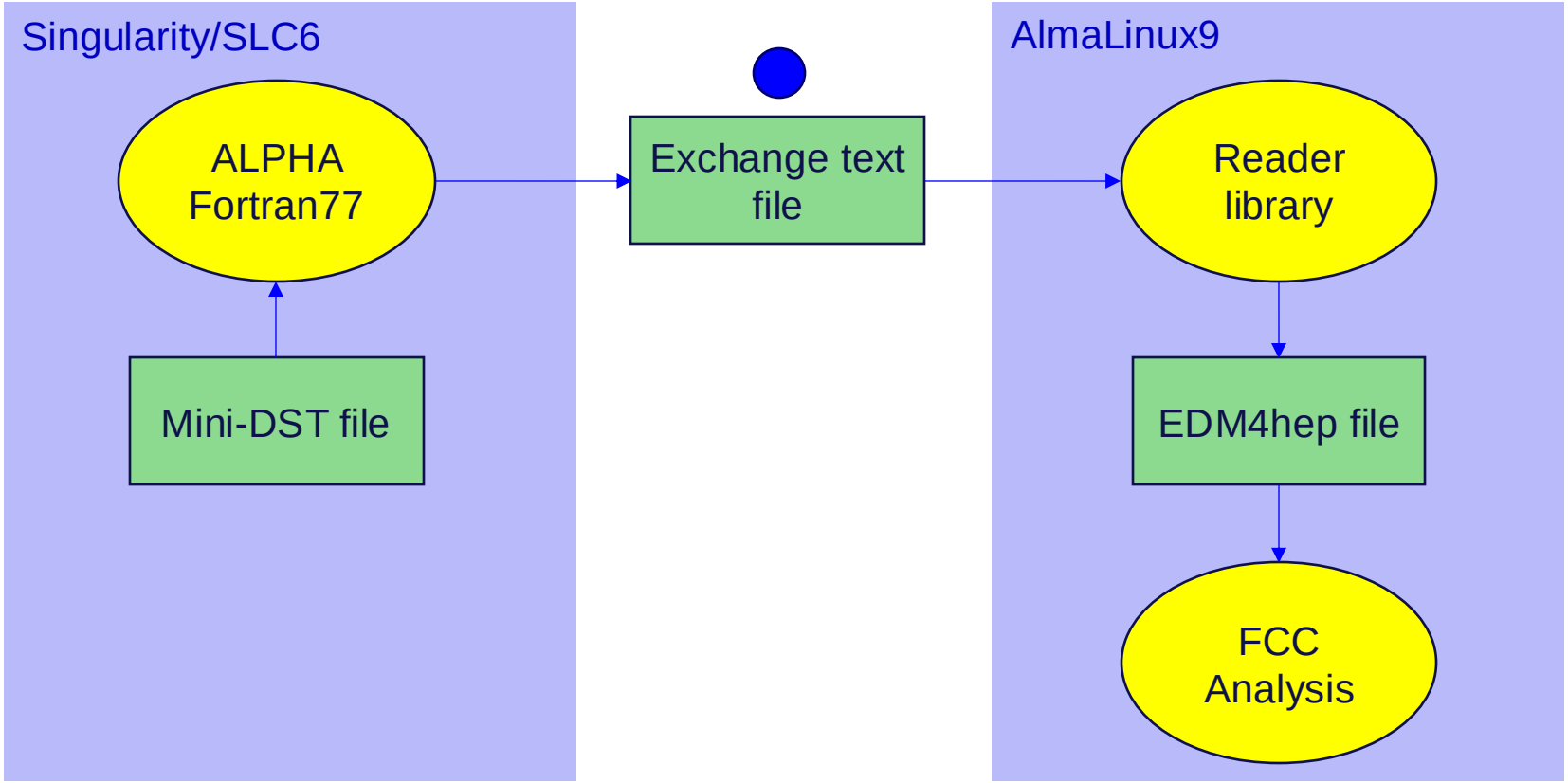
ALPHA

- The **ALeph PHysics Analysis** tool (ALPHA) has been used to loop over the ALEPH Mini-DST banks and print out them directly

- Some issues:
  - Two types of banks: linear and tabular
  - In Mini-DST data are stored scaled and integerised, then ALPHA use them to fill POT/Julia banks, where data are mainly floats (and some strings)
  - Some correction/calibration data are hardcoded in ALPHA algorithms and not included in the data banks

```
      SUBROUTINE DUMPBANKI(NAME, UNIT, IER)
      IMPLICIT    NONE
#include "qdecl.h"
#include "qcde.h"
      CHARACTER*4 NAME
      INTEGER     UNIT, IER
C - Local variables
      INTEGER     I, J
      INTEGER     NLINK, IBK, IBANK, NROWS, NCOLS, NAMIND
C - ALPHA macros
#include "qmacro.h"
      IER = 0
C - Connect to the bank
      IBK= NAMIND(NAME)
      IF( IBK.EQ.0 ) THEN
        WRITE(*,*) 'DUMPBANK: Bank ', NAME, ' cannot be found! '
        IER = 1
        RETURN
      END IF
      IBANK = IW(IBK)
C - Number of rows
      NROWS = LROWS(IBANK)
      NCOLS = LCOLS(IBANK)
      WRITE(UNIT, *) NAME, NROWS, NCOLS
C - Loop
      COUNTER = 3
      DO I=1,NROWS
        DO J=1, NCOLS-1
            WRITE(UNIT,1001) ITABL(IBANK,I,J)
        END DO
           WRITE(UNIT,2001) ITABL(IBANK,I,NCOLS)
      END DO
 1001 FORMAT(I20, $)
 2001 FORMAT(I20)
      RETURN
      END
```

Workflow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Text exchange format

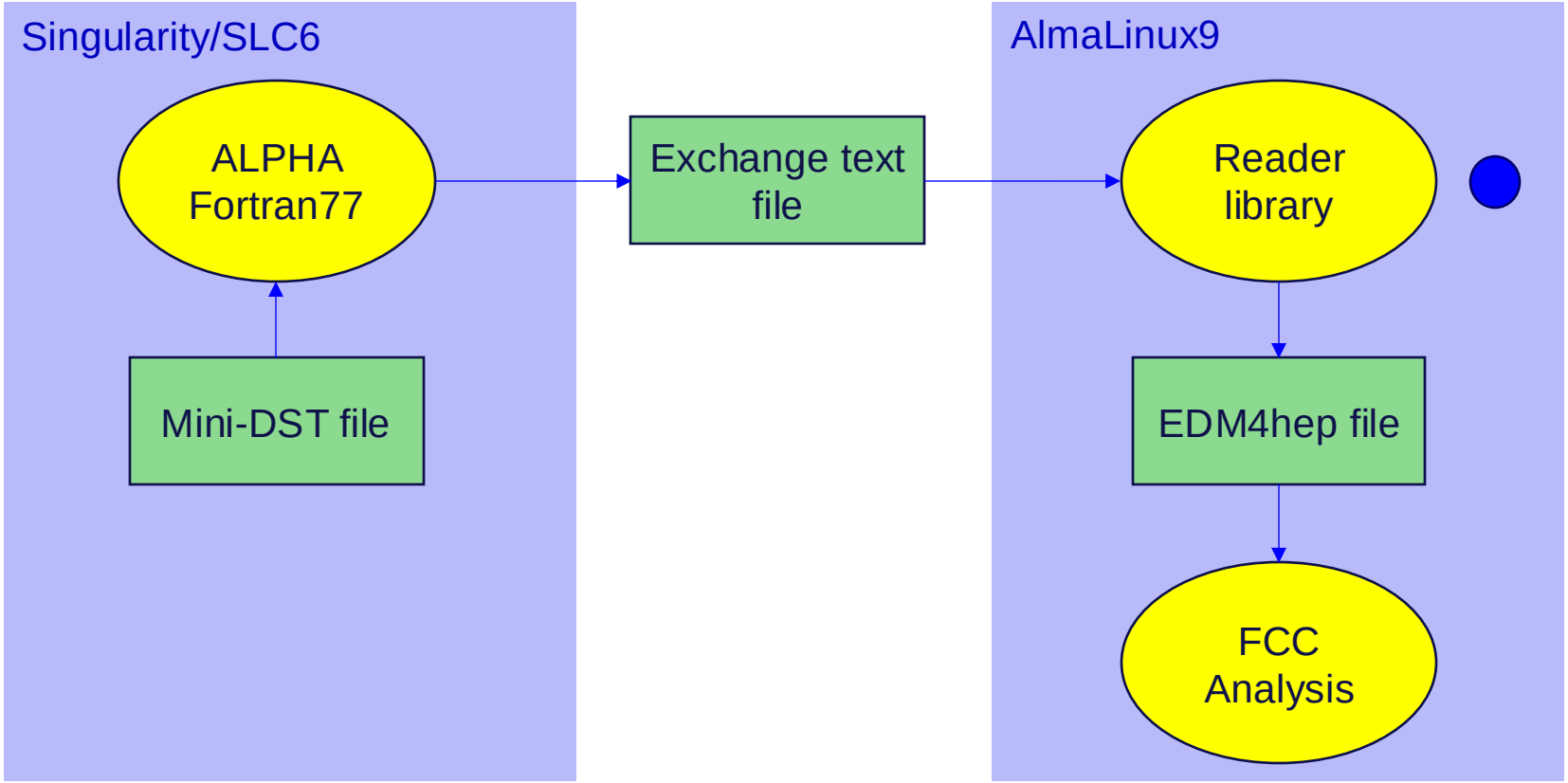
- Data stored in POT/Julia banks are printed in the text exchange format as integers values

- It has been decided to use a simple **text file**:

+
  - Easy to produce, directly by Fortran routines
  - Easy to read, directly by C++ routines
  - Allows to remove a layer of code (with respect, e.g., to JSON)

−
  - Hand-written code for reading the text file and filling EDM4hep data structures

Workflow


Singularity/SLC6
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Text reader and EDM4hep writer

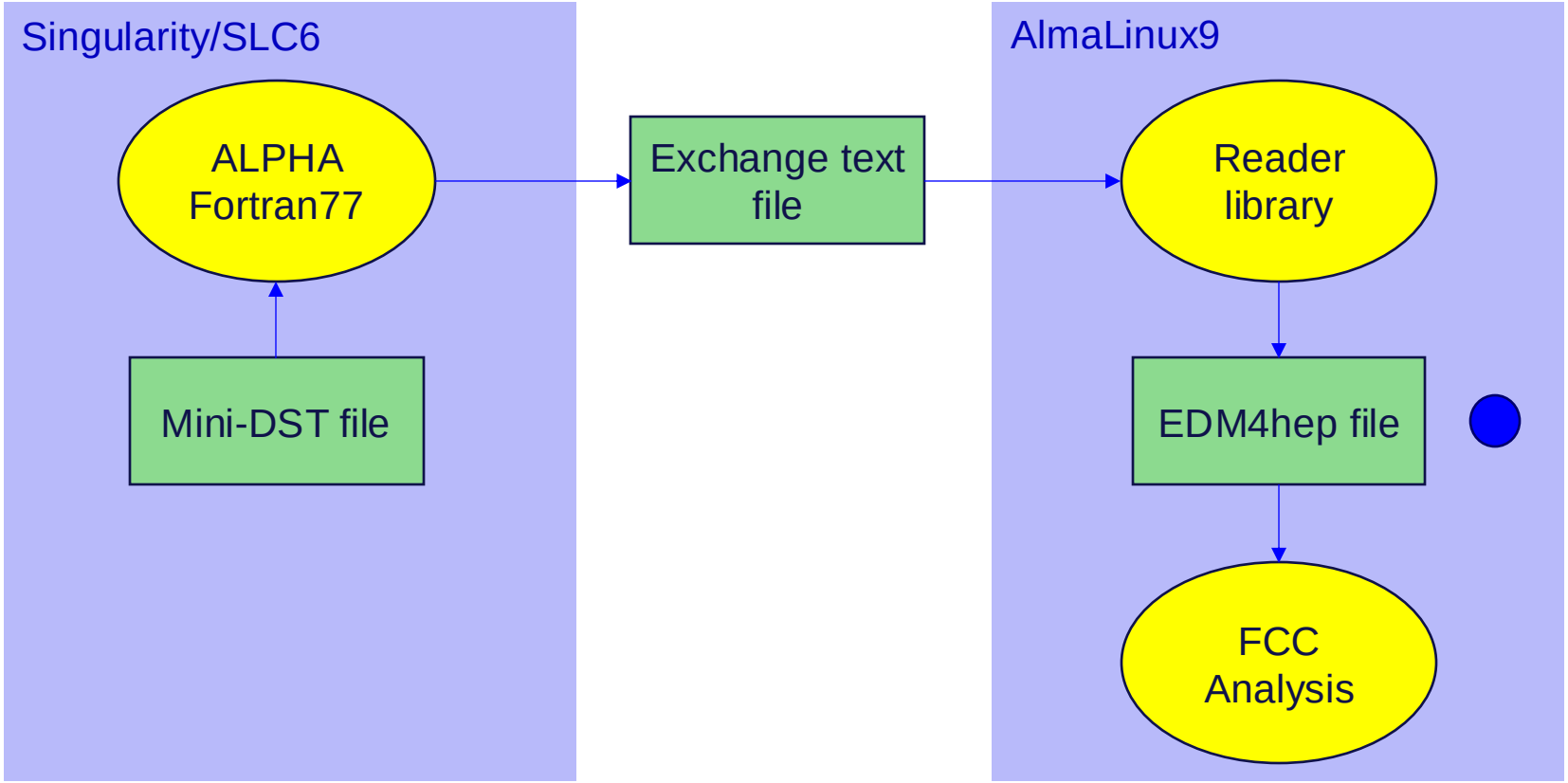
- C++ functions and programs for
  - Reading the intermediate exchange text file through a dedicated library
  - Converting the integer values in floats (IEEE-754) or strings
  - Filling some EDM4hep data structures and relations

- Using EDM4hep nightlies, first stable release is expected soon

```
// Function to convert an integer to a float with IEE754
float intToFloat(uint32_t intRepresentation) {
    union {
        uint32_t i;
        float f;
    } converter;

    converter.i = intRepresentation;
    return converter.f;
}
```

Workflow


Singularity/SLC6
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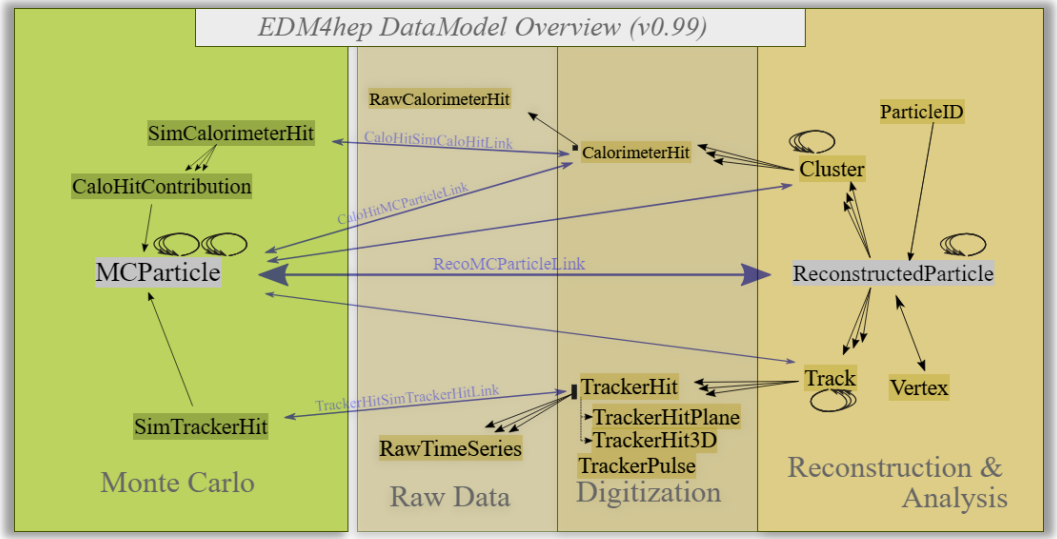
EDM4hep structures

- EDM4hep, part of Key4hep framework, might become a general and standard data format for data structures and file format of future experiments

- One-to-one correspondence between a particle from Particle Flow algorithm and an EDM4hep ReconstructedParticle



- **Conversion goal**: energy flow, vertexes w/ covariances, tracks w/ covariances, calo objects, …

- **Next step:** convert Monte Carlo data, which have also the truth information

- Even with little data, things can be tricky…

```
Subschema: EflowJULPOTBanks
+------+
| EFOL |  Energy FlOw eLements
+------+

  1      I  Number of words/element (=11)
  2      I  Number of elements

  1  PX  F  PX            [-999.,999.]
            Weighted component x
  2  PY  F  PY            [-999.,999.]
            Weighted component y
  3  PZ  F  PZ            [-999.,999.]
            Weighted component z
  4  EW  F  EnergyW       [-999.,999.]
            Element weighted by E-Flow coefficients
  5  WE  F  WEight        [0.0,99.]
            Weight applied to E-Flow element
  6  TY  I  TYpe          [0,10]
            Object type
            0 = Track
            1 = Electron
            2 = Muon
            3 = Track from V0
            4 = Electromagnetic
            5 = Ecal hadron/residu
            6 = Hcal element
            7 = Lcal element
  7  LE  I  LinkEcal      [0,999]
            Peco # associated
  8  LT  I  LinkTrak      [0,999]
            Track # associated
  9  LH  I  LinkHcal      [0,999]
            Phco # associated
  10 LC  I  LinkCalo      [0,999]
            Calobject # associated
  11 LJ  I  LinkJet       [0,100]
            Jet # associated
```

```
#-------- ReconstructedParticle
edm4hep::ReconstructedParticle:
  Description: "Reconstructed Particle"
  Author: "EDM4hep authors"
  Members:
    - int32_t                PDG              // PDG of
    - float                  energy [GeV]     // energy
    - edm4hep::Vector3f      momentum [GeV]   //  parti
    - edm4hep::Vector3f      referencePoint [mm] // re
    - float                  charge           // charge
    - float                  mass  [GeV]      //  mass c
    - float                  goodnessOfPID    // overall
    - edm4hep::CovMatrix4f   covMatrix        // covaria
```

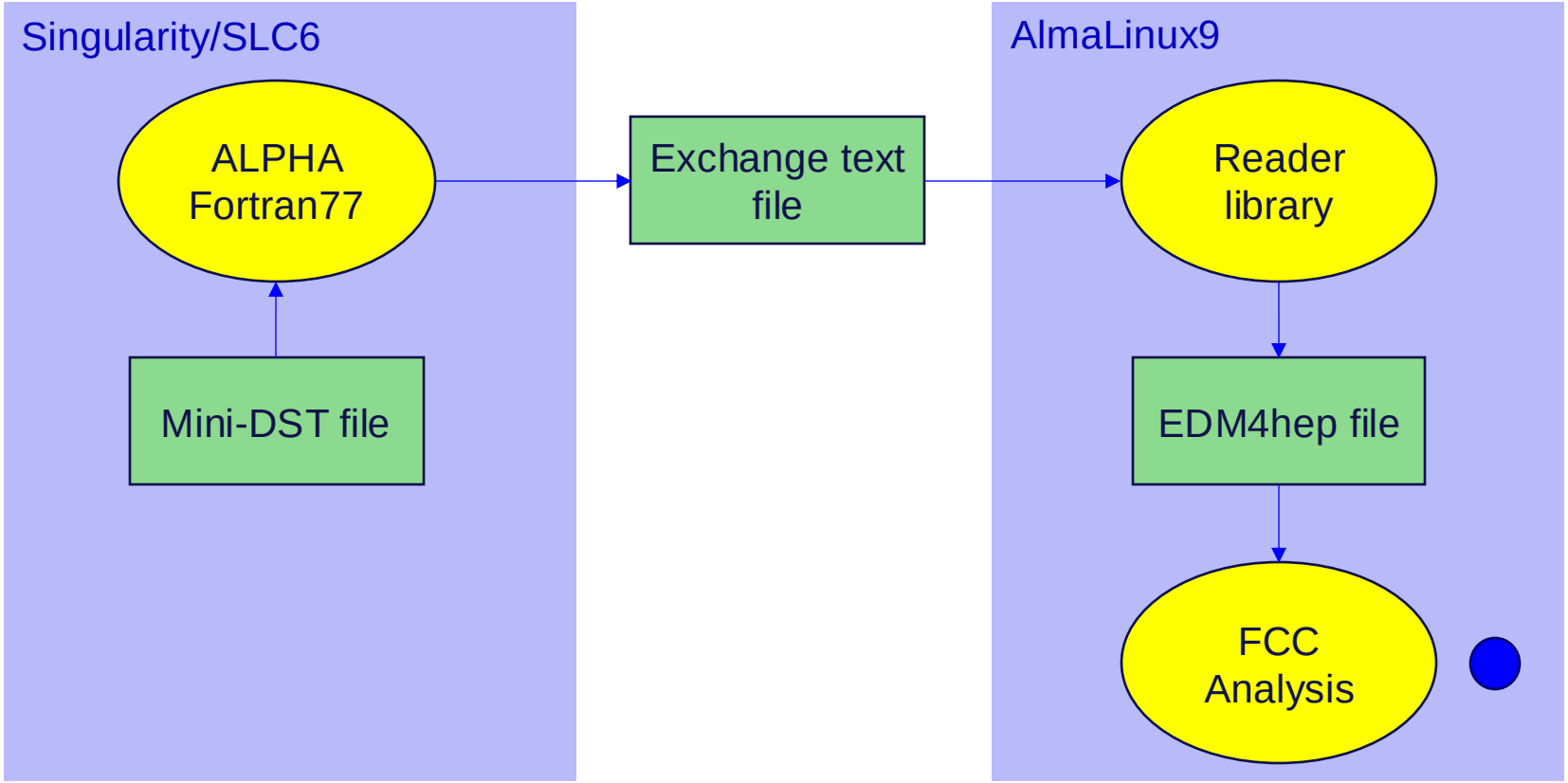
```
  # Parametrized description of a particle tra
edm4hep::TrackState:
  Members:
    - int32_t location // for use with At{Othe
    - float D0 // transverse impact parameter
    - float phi // azimuthal angle
    - float omega [1/mm] // is the signed curv
    - float Z0 // longitudinal impact paramete
    - float tanLambda // lambda is the dip ang
    - float time [ns] // time of the track at
    - edm4hep::Vector3f referencePoint [mm] //
    - edm4hep::CovMatrix6f covMatrix // covar
```

```
Subschema: JULPOTFitTrack
+------+
| FRFT |  Global Geometrical track FiT
+------+  NR=0.(JUL)

  1      I  Number of words/track (=30)
  2      I  Number of tracks

  1  IR  F  InverseRadi     [*,*]
            Inverse radius of curvature in x-y
            projection
            signed +ve if track bends
            counterclockwise
            -ve if tracks bends clockwise
  2  TL  F  TanLambda       [*,*]
            tangent of dip angle
  3  P0  F  Phi0            [0.0,6.3]
            Phi at closest point of approach to
            line x=y=0
  4  D0  F  D0              [-180.,180.]
            Closest distance of approach to line
            x=y=0
            in the x-y plane (impact parameter)
            (signed +ve if particle has a positive
            angular
            momemtum around the origin, -ve
            otherwise)
  5  Z0  F  Z0              [-220.,220.]
            Z-coordinate at D0
```

Workflow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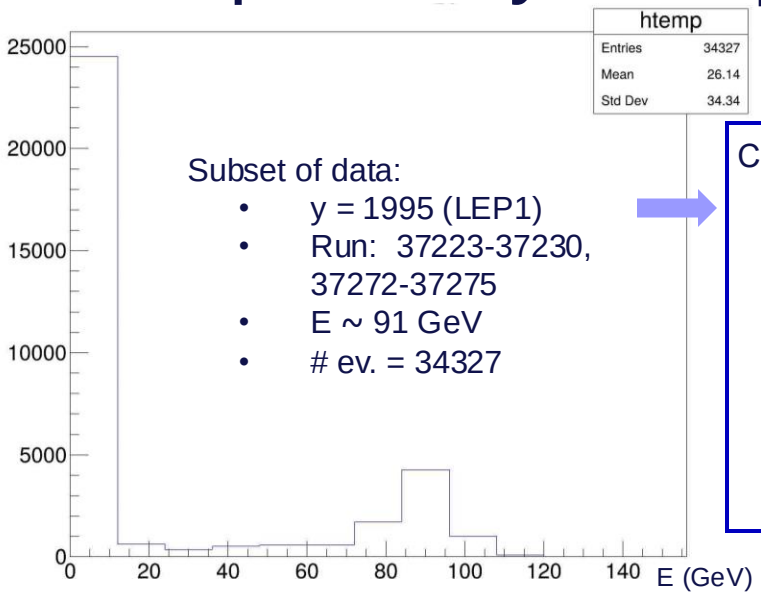
FCCAnalysis

- **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
- It is still under development to meet the needs of the FCC community

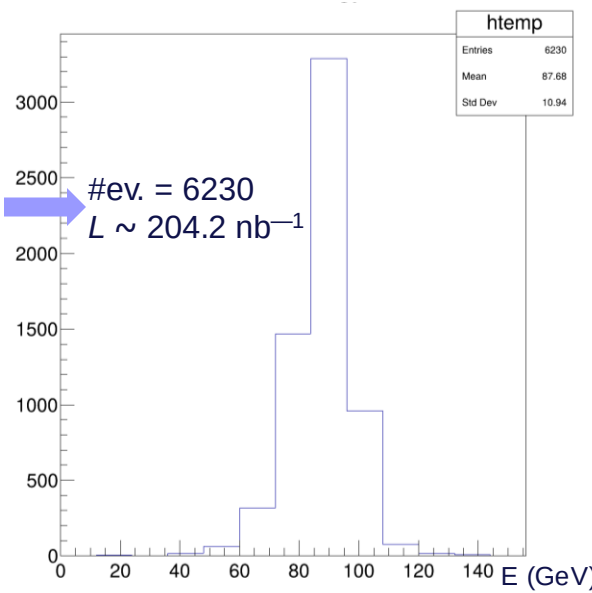
Simple analysis: E_{TOT}



Subset of data:
- y = 1995 (LEP1)
- Run: 37223-37230, 37272-37275
- E ~ 91 GeV
- # ev. = 34327

Cuts: (CLAS 16, "**hadronic events**")
- At least 5 TPC tracks with:
  - |D0| < 2 cm
  - |Z0| < 10 cm
  - TPC coordinates ≥ 4
  - |cos(Θ)| < 0.95
- Total energy of TPC tracks satisfying the above conditions > 0.1 E_{CM}

#ev. = 6230
$L \sim 204.2\ nb^{-1}$



- Same approach has been performed with subsets at E ~ 89 GeV and E ~ 93 GeV. This allow to estimate the hadronic cross section as

$$\sigma = \frac{\#\, ev.}{\mathcal{L}}$$

$\boldsymbol{\sigma_{had@89GeV} = (9.8 \pm 0.1)\ \mathbf{nb}^{*}}$ $\boldsymbol{\sigma_{had@91GeV} = (30.5 \pm 0.4)\ \mathbf{nb}^{*}}$ $\boldsymbol{\sigma_{had@93GeV} = (14.4 \pm 0.1)\ \mathbf{nb}^{*}}$

* the error is the statistical error

Data sizes

- Taking as example the file /eos/experiment/aleph/LEP1/DATA/MINI/1995/Y15223.44.AL
  - Original file: 314 MB
  - Text file: 1.6 GB
  - Zipped text file: 272 MB
  - EDM4hep ROOT file: 155 MB

- Caveat: EDM4hep file contains only a small part of the data dumped in the text file
  - Further data size evaluation needed

Validation

Validation results and plans - preliminary

- A comparison of old/new formats for CLASS 16 selection has been done, applying the selection to EDM4hep converted data using FCCAnalysis: first results are promising

file	#ev. (FCCAnalysis)	#ev. (ALPHA)	diff. %
1992/Y15222.40.AL	22990	22981	0.04%
1993/Y15223.10.AL	21316	21316	0.00%
1994/ZD4007.1.AL	10525	10524	0.01%
1995/Y15223.28.AL	30320	30314	0.02%
1995/Y15223.44.AL	23189	23187	0.01%

- **Next steps**:
  - Investigate the origin of the differences
  - Perform a full ALEPH analysis via FCCAnalysis (or ROOT) and compare the results with the same analysis performed in the past using Fortran-only routines

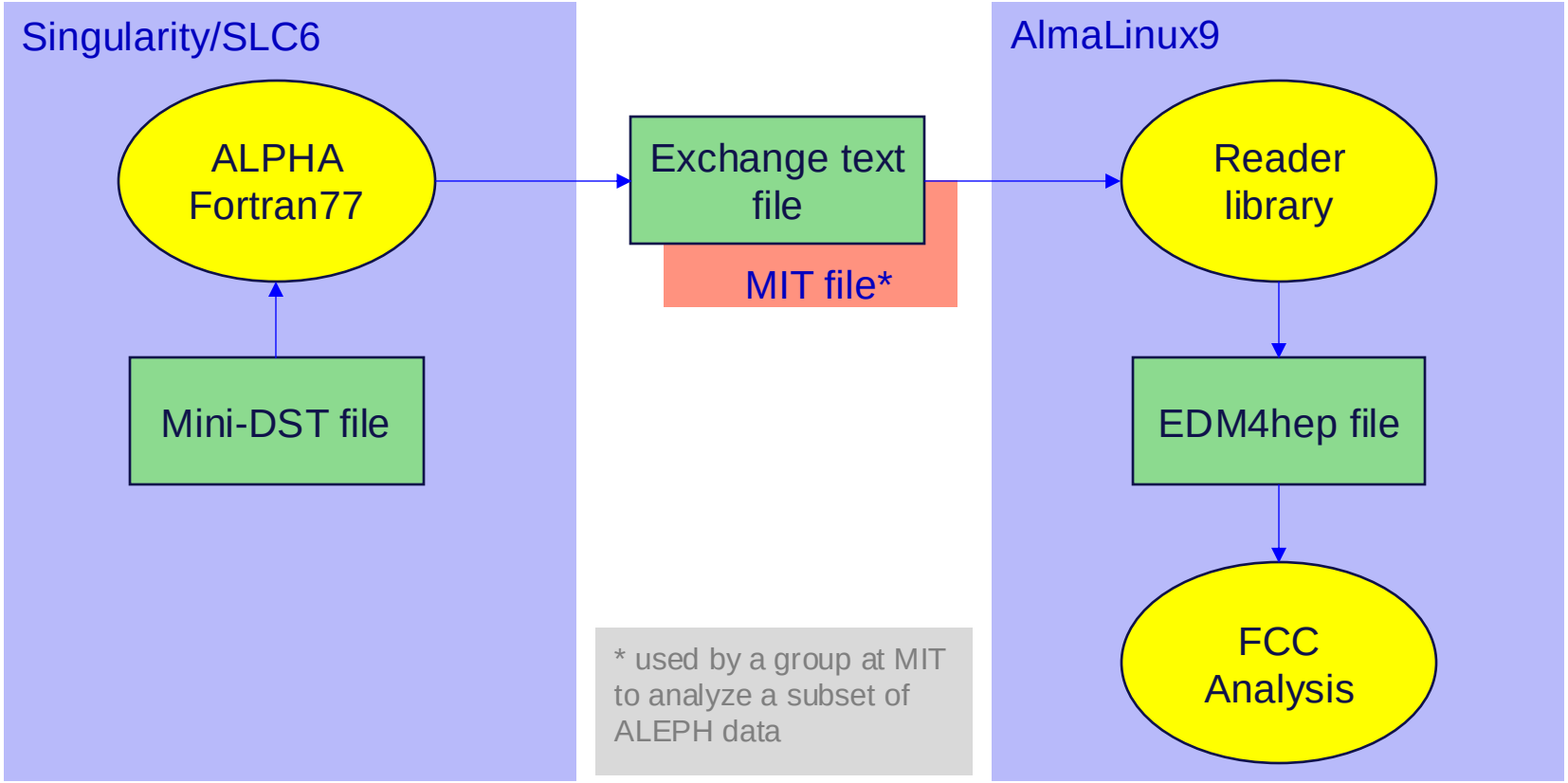
Validation with MIT

- A group from MIT re-analyzed a subset of ALEPH data in recent years, thanks to M. Maggi
  - CLAS 16 hadronic events (≥ 5 charged particles)
  - High level informations: reconstructed particles from particle flow, V0s, dE/dX

```
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
```

See also:
Yi Chen et al., First measurement of anti-kT jet spectra and jet substructure using the archived ALEPH e+e- data at 91.2 GeV, 41st ICHEP
Yi Chen, Revisiting the ALEPH Archived e^+e^- Data, CERN EP Seminar

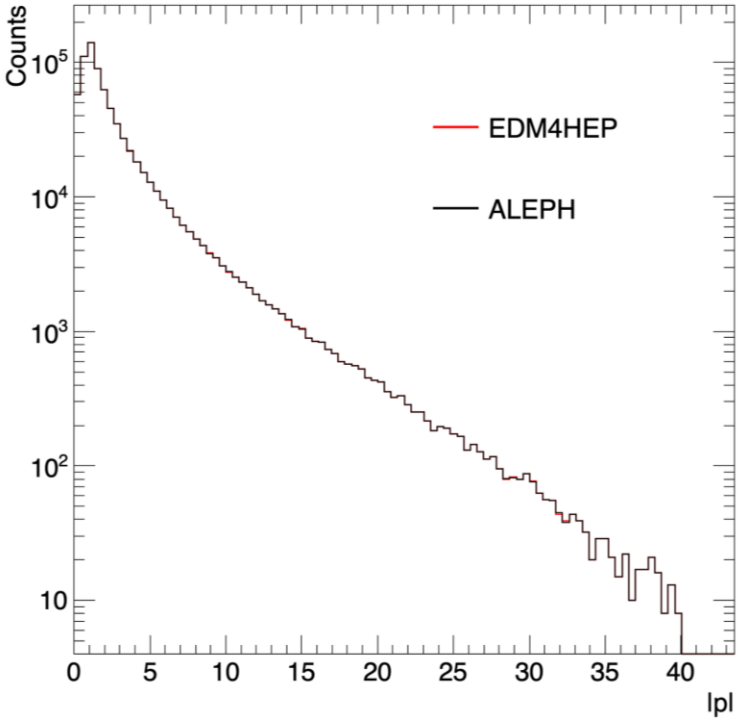
Workflow - MIT



Strategy and preliminary results

- Since ROOT is the most widely diffused analysis framework in HEP, it is convenient to make the EDM4hep files easily analyzable with it
- A tutorial with an example to extract a flat ROOT TTree from the EDM4hep file using EDM4hep Utilities has been produced
- Users can define their functions to store in the TTree the relevant quantities for validation/analysis
- Positive preliminary feedbacks

Courtesy of Yi Chen

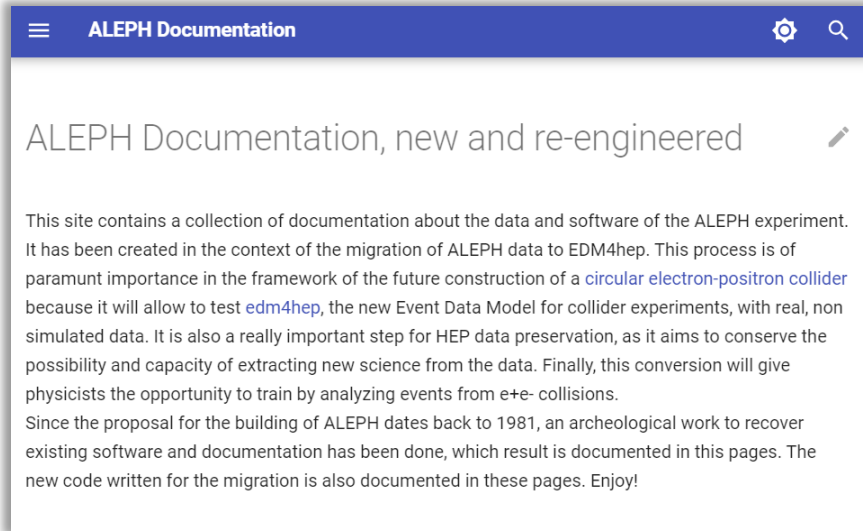


Summary & Outlook

Summarizing: what has been done

- Found a way to access directly **low level data** (ALPHA)
- Defined a general **exchange format** for data extraction (text file)
- Filled **EDM4hep** structures and relations
- Began **validation** of the workflow
  - CLASS 16 cuts
  - Provided MIT colleagues with tools to do initial validation of the conversion chain
- Collected archeological information and tutorials on a website (beta version)

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



Work ahead

- Prepare for processing **Monte Carlo data**, including truth information
- Understand better the conventions to be used in the **EDM4hep production**
- Migrate **database with meta-data** (fill, run, luminosity, detector status, …) to a modern backend and interface
  - Including new location of files on EOS
- Better quantify the average **size** of the intermediate text file and the EDM4hep output file
- **Validate the workflow** by repeating a full analysis previously done by ALEPH collaboration (and iterating with MIT)

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