Comparison of Standard Jets Reconstruction Algorithms in pp, pAu and AA collisions for STAR

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Jet p_t resolution, jet angular resolution and efficiency of standard jet finders (UA1 and CDF style) for pp, pAu, CC and SiSi interactions are investigated for $p_t \sim 10$GeV/c at the STAR. HIJING generator and simple assumptions about detector resolution were used.

1 Detector and Resolution

The usual characteristics of STAR[1] were used. The acceptance for charge particles is $|\eta| \leq 2$, for neutral ones $|\eta| \leq 1$. K_L^0 mesons and neutrons are not detected. A lateral segmentation of $\delta\phi = 10^0$ and $\delta\eta = 0.1$ was used for electromagnetic calorimeter grid.

The resolution of main detectors (TPC+SVT and EMC) is embedded by the following manner[2]:

- $\sigma(\frac{\Delta p_t}{p_t})$ for TPC+SVT is taken from picture 4A-10 at Ref.2: for particles with $p_t \leq 0.4$GeV/c $\sigma(\frac{\Delta p_t}{p_t})$=0.016 and for particles with $p_t \geq 0.4$ Gev/c $\sigma(\frac{\Delta p_t}{p_t})$ changes linearly from 0.016 at p_t of 0.4GeV/c to 0.038 at 12GeV/c;
- $\sigma(\frac{\Delta E}{E})$ in EMC for gammas is 0.02 $+0.16/\sqrt{E}$ (information in Ref.2 page 4-31).

2 Events Simulation and Jet Finders

The simulation of events was made using HIJING model[3] in package EVZ from standard STAR library. The following set of parameters was used for event generator HIJING:

- $\sqrt{s} = 200$ Gev;
- the impact parameter varies from 0.0 to 0.75 fm;
- the option for initial and final radiation was included;
- the sample jet with $p_t \geq 10$ Gev/c.

The UA1 style[4] (subroutine LUCELL from JETSET7.2[5]) and CDF style[6] (authors Doug Shy and Matt Bloomer) jet finding algorithms were used to study the efficiency of jet identification.

The following values of parameters were used for LUCELL (UA1 style):

- the threshold for "seed" tower = 1 Gev;
- the threshold for jet energy = 5 Gev;
- the jet cone size = 0.7.

For CDF style the next set of parameters was used:

- the threshold for "seed" towers = 1.5GeV;
- the threshold for adjacent cells for forming preclusters = 0.1GeV;
- the threshold for addition cells for centroid = 0.01GeV;
- the jet cone size = 0.7;
- the overlap parameter for adjacent clusters = 0.5.

3 Jet finder efficiency definition

The efficiency definition largely depends on data processing and on what is to be compared.

We look through all reconstructed clusters and select for comparison clusters with high values of p_t in η window ($|\eta| \leq 0.5$). For one jet reconstruction efficiency definition the parton was determined with minimal value of angle between it and the cluster with high value of p_t. For analysis the histogram of angle mentioned above was used. N_{jet} is the number of events with an angle less 0.7 radian without background. The value of background was determined from the region of angles between 0.7 and 1.5 radian in assumption that it is constant. If N_{parton} is the number of events with one or two partons from hard scattering in η window then one jet reconstruction efficiency is defined by the following formula:

$$eff1 = \frac{N_{jet} * 100}{N_{parton}}$$

For definition of two jets efficiency the angle between two jets in window with high value of p_t and angle between two partons from hard scattering were calculated. For analysis the histogram of difference between these angles was used. This histogram was fitted by the sum of gaussian and constant. Gaussian is good events (N_{dijets}) and constant represents background events. If $N_{dipartons}$ is the number of events with two partons in η window then two jet reconstruction efficiency is defined as:

$$eff2 = \frac{N_{dijets} * 100}{N_{dipartons}}$$

The ratio N_{jet} or N_{dijet} to the number of entries into respective histogram is important for understanding the quality of algorithms also. It is worthwhile to say that these definitions of efficiencies are correct for small number of jets in detector.

4 What with what to compare ?

The next not quite simple question is what with what to compare. This question arises from limited acceptance of STAR detector and some physical phenomena: initial and final radiations and background from remnant of hadrons.

4.1 Comparison with partons from hard scattering

The sample of events was used without initial radiation for more clear comprehension of such peculiarity. Two partons from initial hard scattering were used for comparison. Picture 1 illustrates kinematic characteristics of partons from hard interaction. The main peculiarity is the little value of transverse projection of summary momentum of two partons. Partons have almost equal and opposite value of p_t.

On pictures 2a and 2c we see clear peak with tail. The value of efficiency is low. On pictures 2b and 2d we have distributions with mean values$\sim$3 Gev/c and r.m.s deviation $\sim$2 Gev/c. The mean values demonstrate energy losses because detector doesn't detect K_L^0 mesons and neutrons. But this value is very large and it is difficult to explain it by undetected energy of K_L^0 mesons and neutrons.

Why do we have tail, low value of efficiency and big value of energy losses? This problem is clearly fixed and explained by OPAL Collaboration [7]. The terminology from this paper is used on further. The parton shower exists on parton level before hadronisation instead of two partons from initial hard collision. That is why we must compare jets on parton level (A) and jets on particle level (B). The situation is complicated by limited acceptance and a background from remnants of hadrons.

The OPAL conception helps to understand main pecularities of such comparison. Events from tails on pictures 2a and 2c are events in which any parton from hard scattering either radiates several considerably energetic gluons and majority of hadronisation products from these gluons doesn't hit on detector or partons from remnants of hadrons merge with any initial parton. Usually these two processes occur simultaneously.

For definition of jets on parton level a simple procedure was used. Only two parameters were utilized: the cone size R and energy cutoff ε. Values would be 0.7 and 5GeV respectively. The procedure works as follows:

1. The parton with biggest p_t is selected and pseudorapidity η_0 and polar angle ϕ_0 is determined;

2. The vector sum of momentum of all partons in cone with radius R and axis with coordinate (η_0,ϕ_0) in $\eta - \phi$ space is determined and assumed as a momenta of parton jet. All partons from this cone are excluded from further consideration;

3. Steps 1 and 2 are repeated if any more partons exist;

4. Jets with energy less than ε are rejected from further analysis.

We define the following quantities to characterize the quality of the jet finder as was made in OPAL paper.

The jet p_t resolution, σ_{p_t}, is the r.m.s deviation of the distribution of the difference in p_t between the jets found at level A and corresponding jets found at level B. These distributions are shown on pictures 2b and 2d.

The jet angular resolution, σ_θ, is the mean of distribution of the angles between the jets found at level A and corresponding jets found at level B. These distributions are shown on picture 2a and 2c.

4.2 Comparison with jets on parton level

For next comparison we select jets from level A and level B. Picture 3 has analogous distribution as picture 2 but with essential distinctions. We have larger efficiencies. Tails are almost absent. Mean values of distributions on pictures 3b and 3d are in several times less than on corresponding pictures 2b and 2d. This means that K_L^0 mesons and neutrons carry out on average only 5$\div$10% of jet energy. This is more realistic comparison between parton and particle levels.

5 Jet Finders on pp, pA and AA collisions

Initial radiation was switched on for further analysis. Five thousands events were generated for pp and pAu collisions and one thousand events for CC and SiSi collisions.

The quality of jet finding is illustrated by pictures 4-7 for one jet events and by pictures 8-11 in the case of two jets. We have similar situation in cases of pp and pAu interactions with large value of efficiency and little background. The situation deteriorated in case of CC interaction and SiSi interaction. Efficiency decreased and background grew with increasing atomic number. σ_{p_t} changes for the worse also varying from $\sim$ 2.3GeV/c in case of pp interaction to almost 5GeV/c in case of SiSi interaction. σ_θ also grew from $\sim$ 0.25 in case of pp interaction to almost 0.7 in case of SiSi interaction. This definition of efficiency is not applicable for two jet events for CC and SiSi interactions.

Both algorithms work very similarly in all cases of interactions. CDF style is more effective but it has larger background. More essential difference exists in mean value of the distribution of p_t difference (subpictures b and d). The mean value given by CDF algorithm is less than the value given by UA1 algorithm. This is very important for understanding how to calculate energy of jet on level A from energy of jet on level B.

It is worthwhile to mention that in the case of AuAu collision the question "what with what to compare" is quite incomprehensible. In both occasions many jets exist and correspondence possibly can't be set between parton and particle levels by using standard methods. The problem of jet quenching claims for new ideas in registration of this phenomenon as a test of QGP.

6 Comparison with another experiments

The UA1 collaboration[8] gives values for one jet efficiency greater 90% and $\sigma(\frac{\Delta p_t}{p_t}) \sim 30\%$ for $p_t \sim$ 10GeV/c what is in a good agreement with results presented above for pp and pAu collisions.

The comparison of accuracy of angular variables is more difficult because another quantities are quoted in literature and as a rule for $p_t \geq$ 20GeV/c. For angular variables the UA1 collaboration[9] gives values $\sigma_\phi \sim 6^o$ and $\sigma_\theta \sim 0.04$ from Monte-Carlo simulation and values $\sigma_\phi \sim 10^o$ and $\sigma_\theta \sim 0.1$ from comparison of jet axis found using only calorimeter and jet axis found using only tracking part of detector for jets with $p_t \geq$ 20GeV/c. These values coincide with my calculations within a factor ~ 2.

The OPAL collaboration[7] makes careful analysis but in another conditions. Typical values are for $\sigma_{p_t} \sim 2\div10$GeV/c and for $\sigma_\theta \sim 3^o\div20^o$, what also doesn't contradict with results given above.

Conclusion

Standard methods are applicable to STAR for pp and pAu interactions with value of efficiency and accuracies in determination of partons characteristics for p_t ~10GeV/c as in another expirements (UA1,UA2 and etc). More careful analysis is required for energy definition of partons. For nucleus-nucleus collisions the measurement is possible only for light ions.

References

[1] Conceptual Design Reports for the Solenoidal Tracker At Rhic, The STAR Collaboration, PUB-5347(1992).
[2] The Electromagnetic Calorimeter for the STAR, A Conceptual Design Reports, The STAR Collaboration, PUB-5380(1993).
[3] M.Gyulassy, X.Wang, Lawrence Berkeley Laboratory Preprint LBL-32246(1994).
[4] UA1 Collaboration, G.Arnison *et al.*, Phys. Lett. **123B**(1983) 115;
[5] T. Sjöstrand, CERN-TH.6488/92(1992).
[6] CDF Collaboration, F.Abe *et al.*, Phys. Rev. **D45**(1992) 1448.
[7] OPAL Collaboration, CERN-PPE/94-51.
[8] UA1 Collaboration, G.Albajar *et al.*, Nucl. Phys. **B309** (1988) 405.

Picture Captions

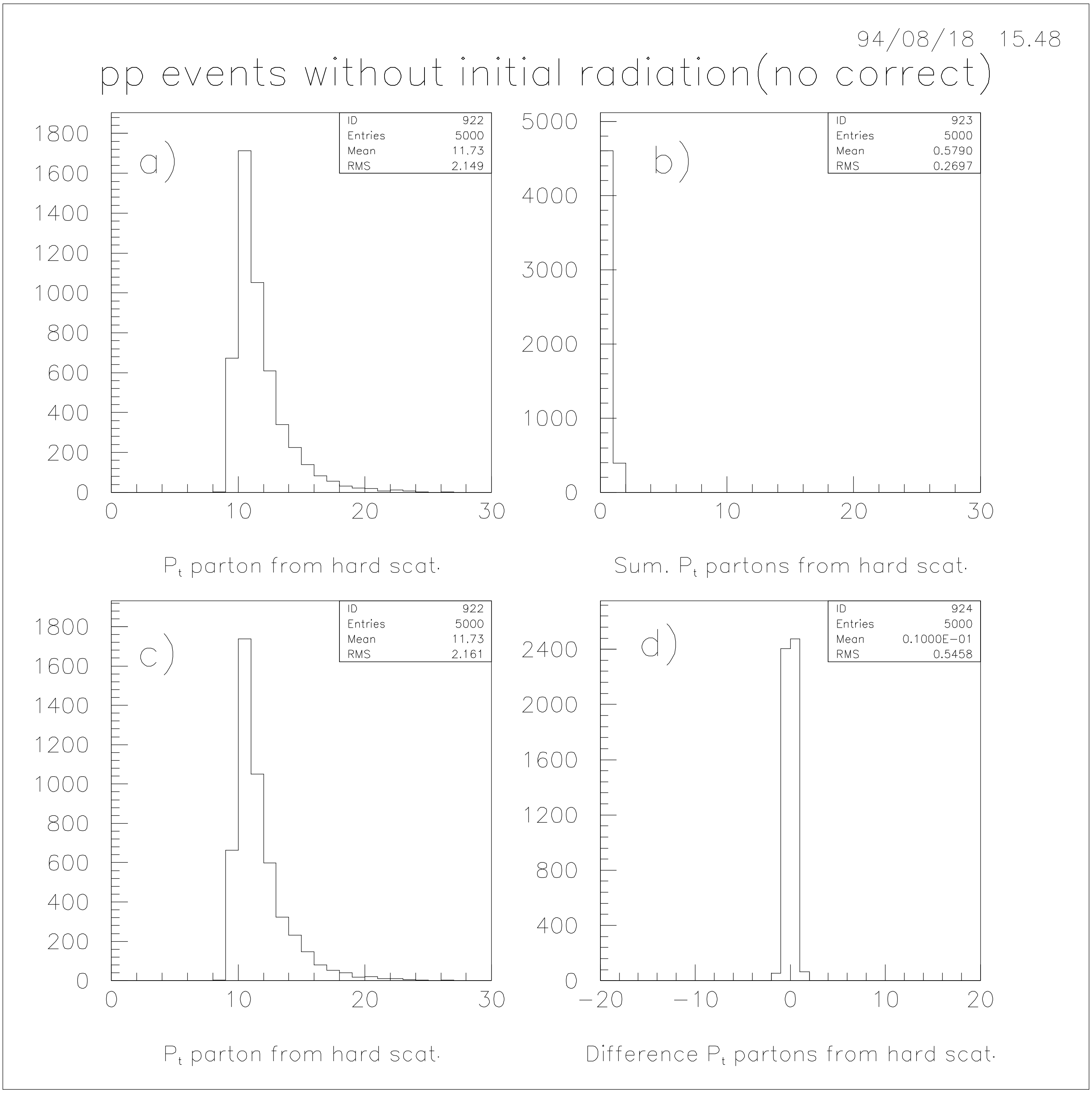
Initial radiation is switched off for pictures 1,2,3.
Picture 1.a and 1.c p_t distribution two partons from hard collision.
Picture 1.b Distribution of p_t of summary moment of partons from hard collision.
Picture 1.d Distribution of difference between p_t for first and second partons from hard collision.
Picture 2.a Distribution of angle between jet(UA1)with highest p_t and nearest parton from hard collision.
Picture 2.b Distribution of difference p_t between jet(UA1)with highest p_t and nearest parton from hard collision.
Picture 2.c Distribution of angle between jet(CDF) with highest p_t and

nearest parton from hard collision.
Picture 2.d Distribution of difference p_t between jet(CDF) with highest p_t and nearest parton from hard collision.
Picture 3.a Distribution of angle between jet(UA1)with highest p_t and nearest parton jet.
Picture 3.b Distribution of difference p_t between jet(UA1)with highest p_t and nearest parton jet.
Picture 3.c Distribution of angle between jet(CDF) with highest p_t and nearest parton jet.
Picture 3.d Distribution of difference p_t between jet(CDF) with highest p_t and nearest parton jet.

Initial radiation is switched on for pictures 4-11.
Picture 4.a Distribution of angle between jet(UA1)with highest p_t and nearest parton jet for pp interactions.
Picture 4.b Distribution of difference p_t between jet(UA1)with highest p_t and nearest parton jet for pp interactions.
Picture 4.c Distribution of angle between jet(CDF) with highest p_t and nearest parton jet for pp interactions.
Picture 4.d Distribution of difference p_t between jet(CDF) with highest p_t and nearest parton jet for pp interactions.

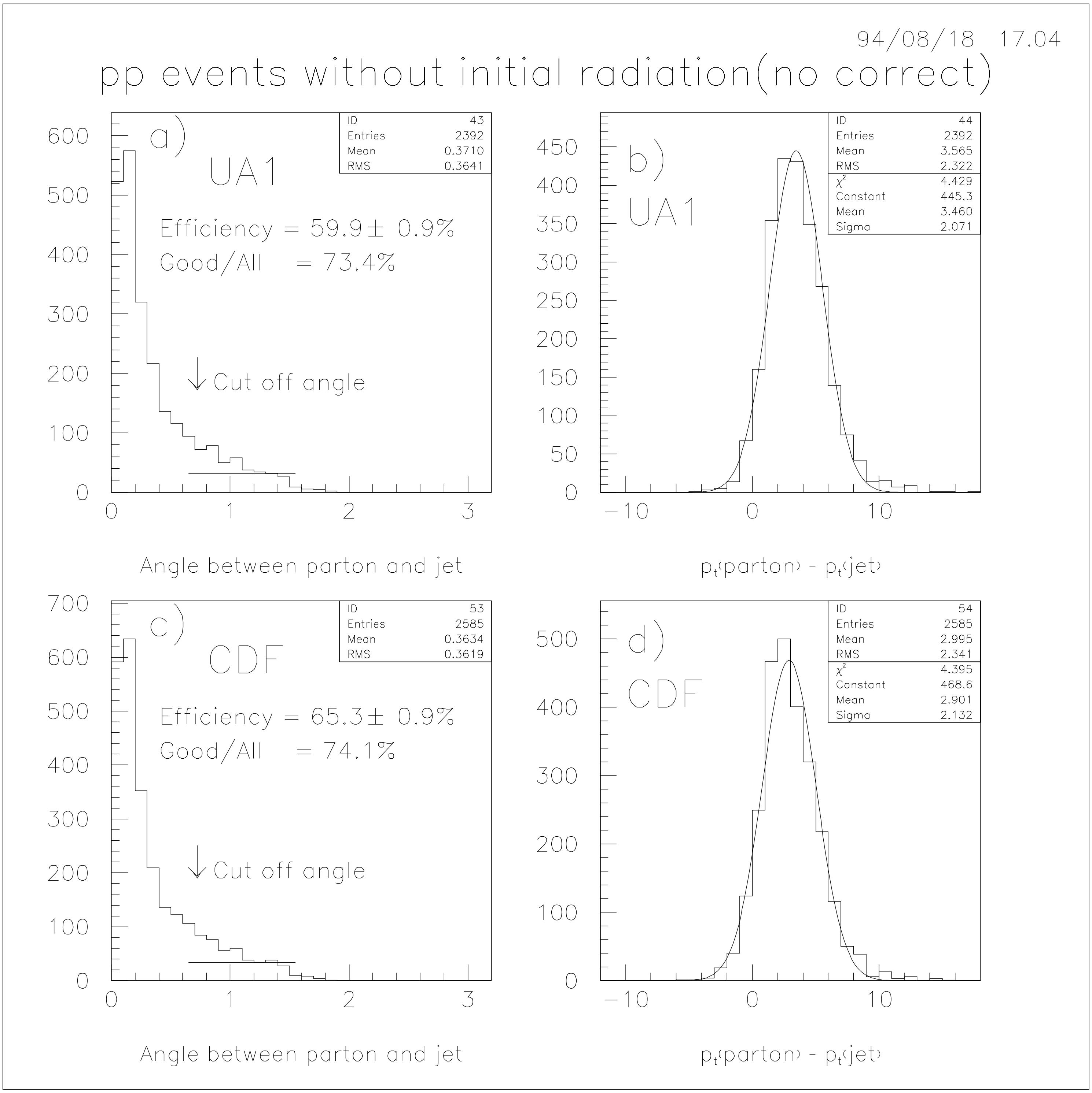
Pictures 5,6,7 are analogous to picture 4 for pAu, CC and SiSi interactions respectively.
Picture 8.a Distribution of difference of p_t between two jets(UA1)with highest p_t for pp interactions.
Picture 8.b Distribution of difference of angles between two parton jets and between two jets(UA1)with highest p_t for pp interactions.
Picture 8.c Distribution of difference of p_t between two jets(CDF) with highest p_t for pp interactions.
Picture 8.d Distribution of difference of angles between two parton jets and between two jets(CDF) with highest p_t for pp interactions.

Pictures 9,10,11 are analogous to picture 8 for pAu, CC and SiSi interactions respectively.

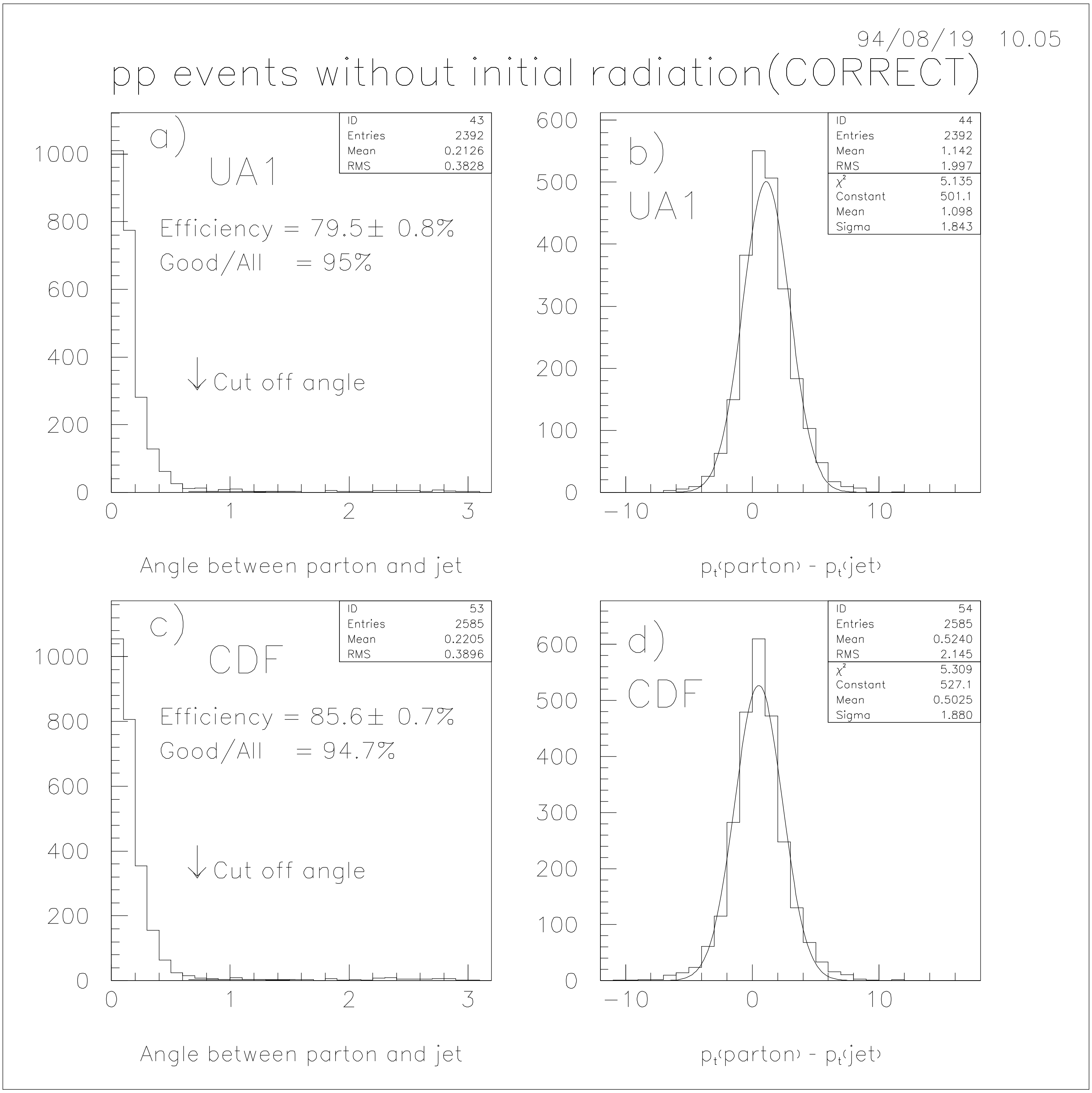


94/08/18 15.48
pp events without initial radiation(no correct)
a)
ID 922
Entries 5000
Mean 11.73
RMS 2.149
P_t parton from hard scat.
b)
ID 923
Entries 5000
Mean 0.5790
RMS 0.2697
Sum. P_t partons from hard scat.
c)
ID 922
Entries 5000
Mean 11.73
RMS 2.161
P_t parton from hard scat.
d)
ID 924
Entries 5000
Mean 0.1000E−01
RMS 0.5458
Difference P_t partons from hard scat.

Picture 1

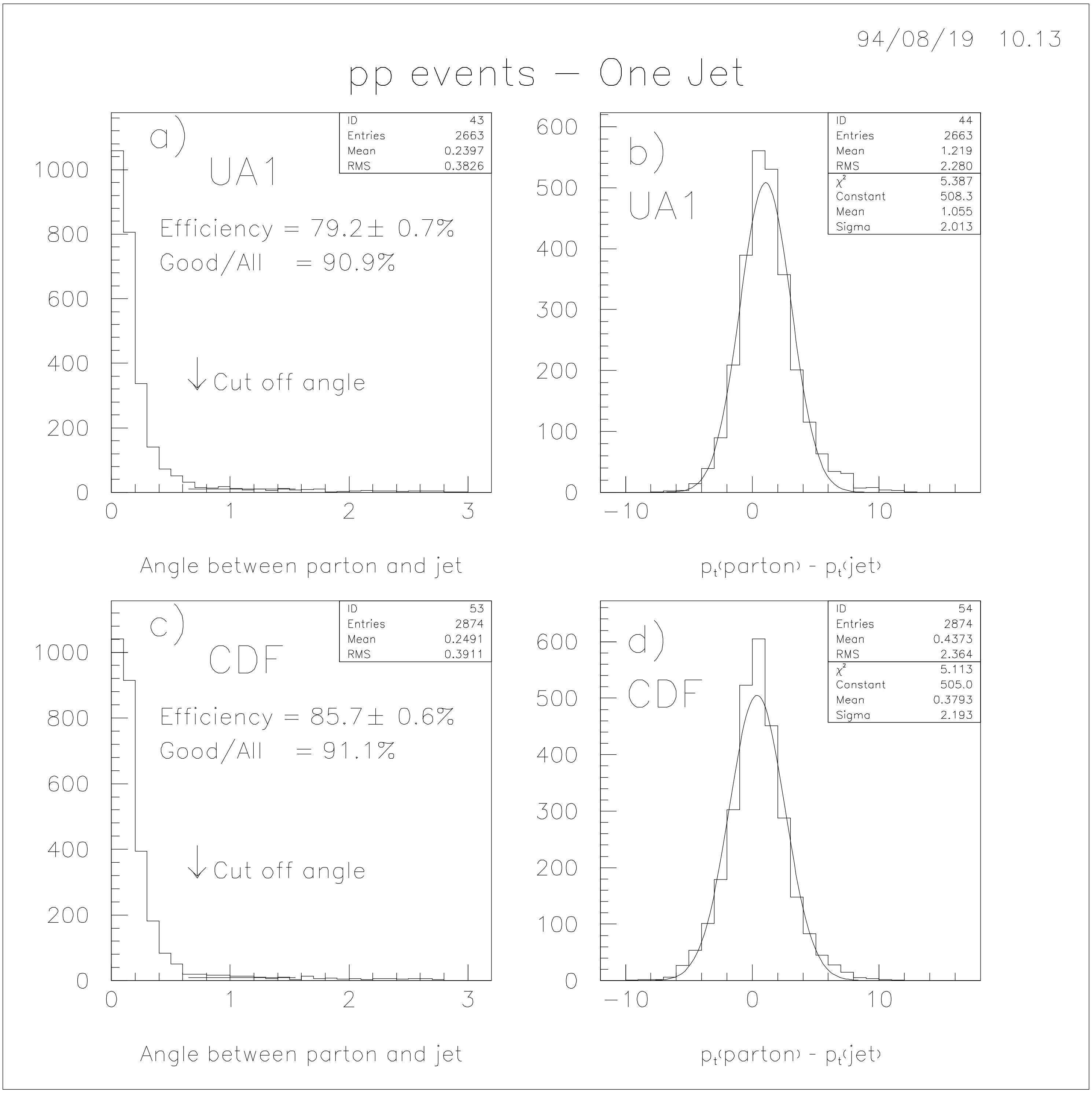

94/08/18 17.04
pp events without initial radiation(no correct)
a)
UA1
ID 43
Entries 2392
Mean 0.3710
RMS 0.3641
Efficiency = 59.9± 0.9%
Good/All = 73.4%
Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 2392
Mean 3.565
RMS 2.322
χ² 4.429
Constant 445.3
Mean 3.460
Sigma 2.071
pt(parton) - pt(jet)
c)
CDF
ID 53
Entries 2585
Mean 0.3634
RMS 0.3619
Efficiency = 65.3± 0.9%
Good/All = 74.1%
Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 2585
Mean 2.995
RMS 2.341
χ² 4.395
Constant 468.6
Mean 2.901
Sigma 2.132
pt(parton) - pt(jet)

Picture 2

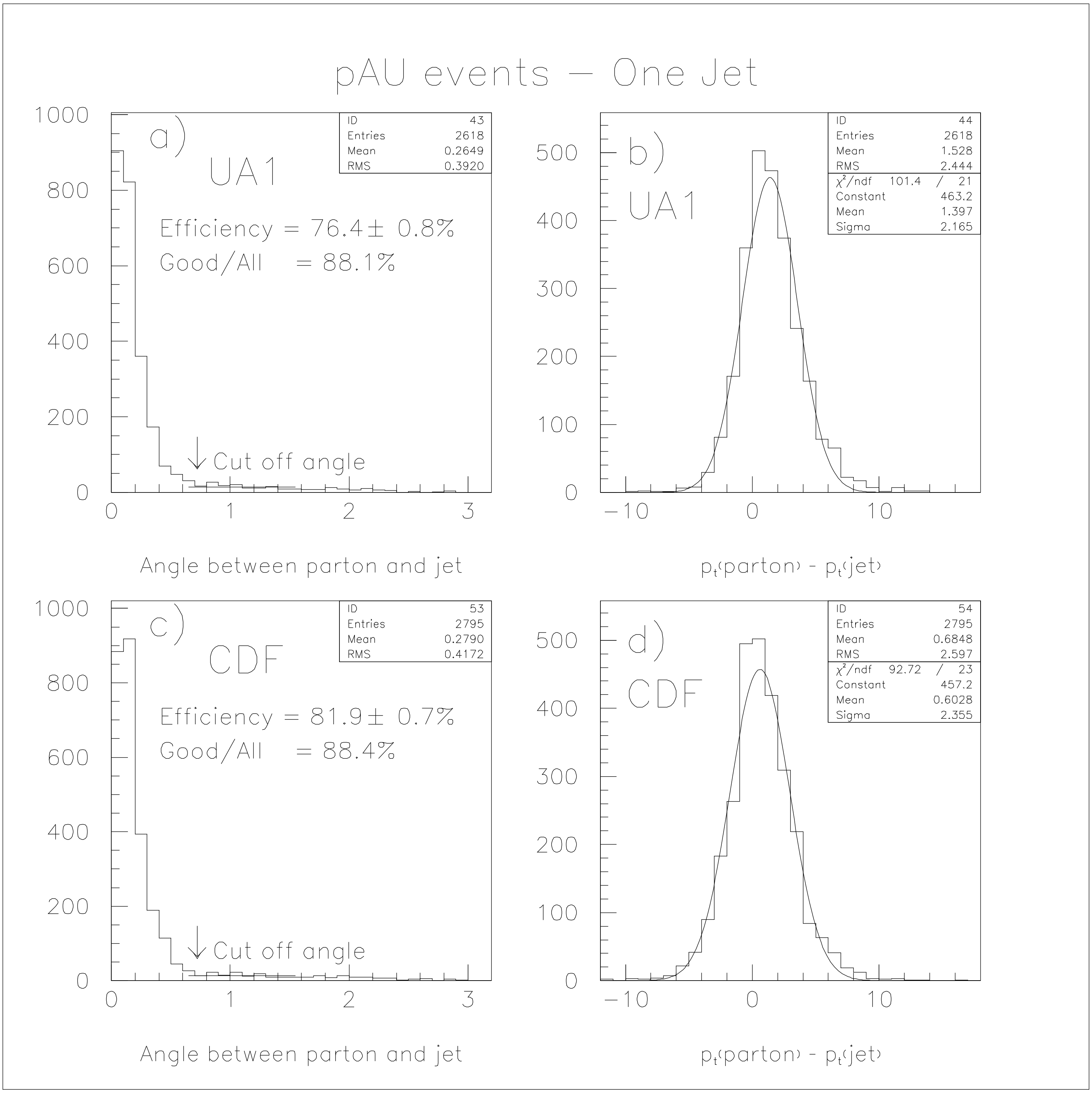


94/08/19 10.05
pp events without initial radiation(CORRECT)
a)
UA1
ID 43
Entries 2392
Mean 0.2126
RMS 0.3828
Efficiency = 79.5± 0.8%
Good/All = 95%
↓Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 2392
Mean 1.142
RMS 1.997
χ² 5.135
Constant 501.1
Mean 1.098
Sigma 1.843
pt(parton) - pt(jet)
c)
CDF
ID 53
Entries 2585
Mean 0.2205
RMS 0.3896
Efficiency = 85.6± 0.7%
Good/All = 94.7%
↓Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 2585
Mean 0.5240
RMS 2.145
χ² 5.309
Constant 527.1
Mean 0.5025
Sigma 1.880
pt(parton) - pt(jet)

Picture 3

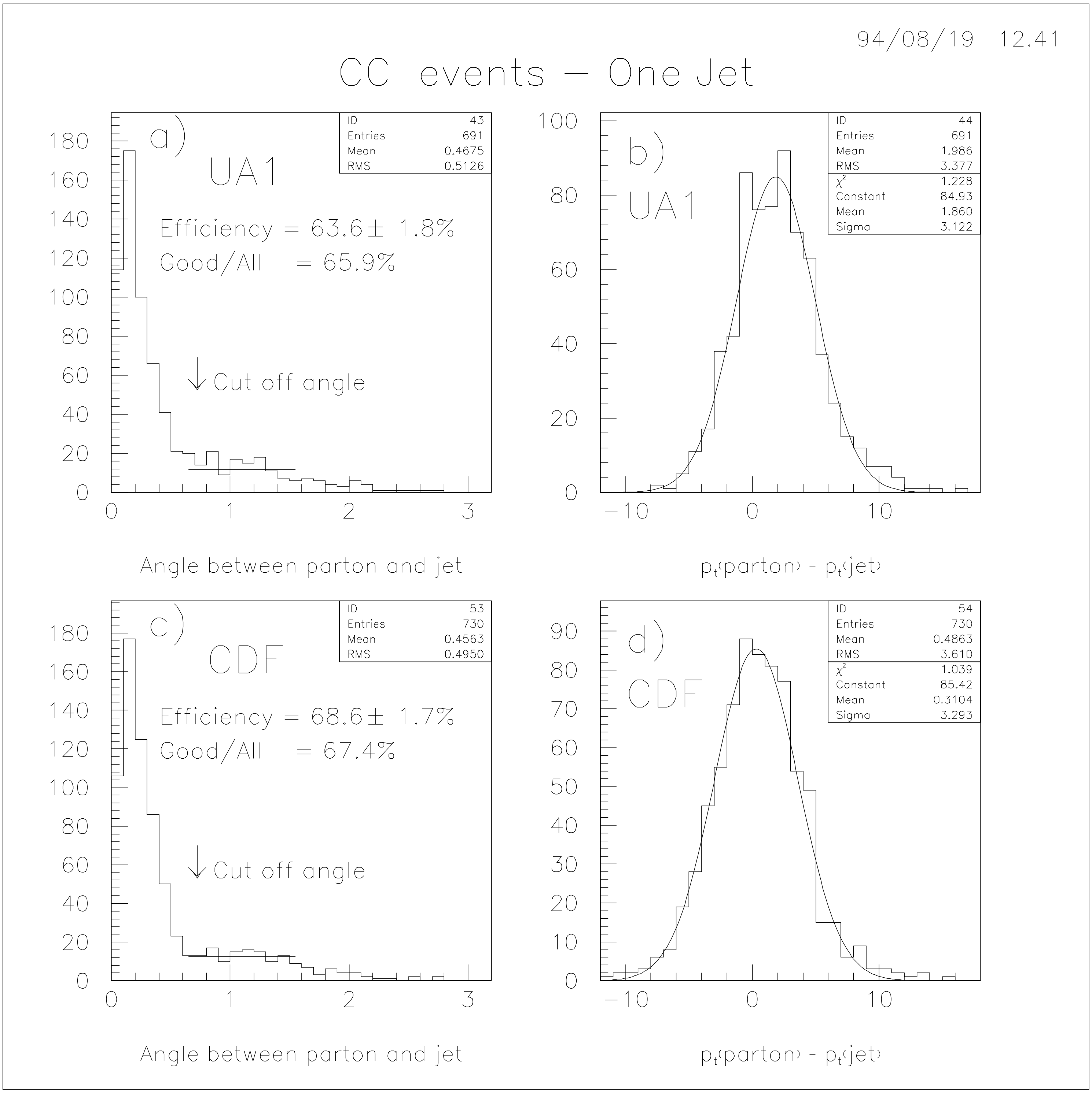

94/08/19 10.13
pp events — One Jet
a)
UA1
ID 43
Entries 2663
Mean 0.2397
RMS 0.3826
Efficiency = 79.2± 0.7%
Good/All = 90.9%
↓Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 2663
Mean 1.219
RMS 2.280
χ² 5.387
Constant 508.3
Mean 1.055
Sigma 2.013
pt(parton) - pt(jet)
c)
CDF
ID 53
Entries 2874
Mean 0.2491
RMS 0.3911
Efficiency = 85.7± 0.6%
Good/All = 91.1%
↓Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 2874
Mean 0.4373
RMS 2.364
χ² 5.113
Constant 505.0
Mean 0.3793
Sigma 2.193
pt(parton) - pt(jet)

Picture 4

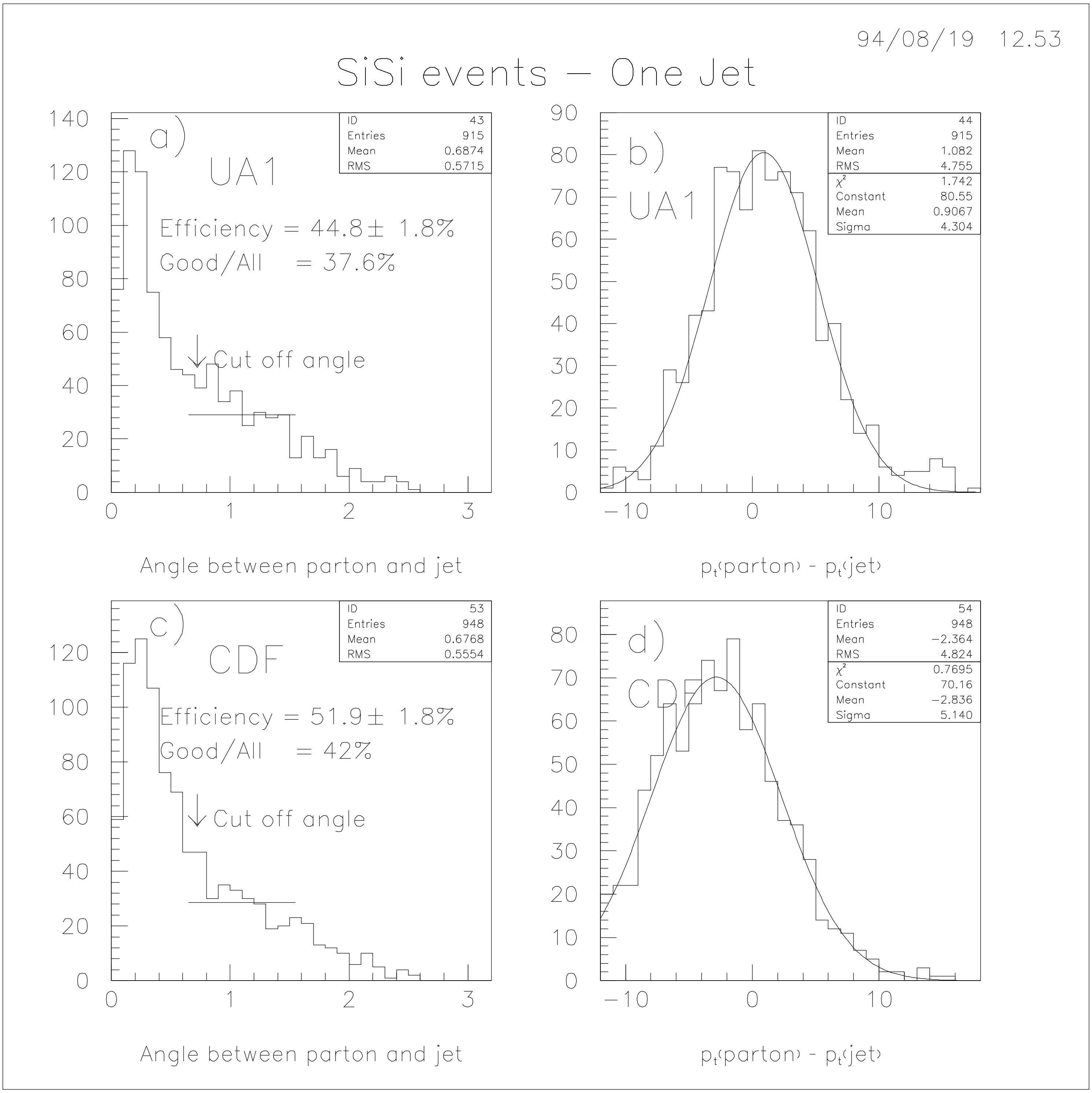


pAU events – One Jet
a)
UA1
Efficiency = 76.4± 0.8%
Good/All = 88.1%
ID 43
Entries 2618
Mean 0.2649
RMS 0.3920
Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 2618
Mean 1.528
RMS 2.444
χ²/ndf 101.4 / 21
Constant 463.2
Mean 1.397
Sigma 2.165
pt(parton) - pt(jet)
c)
CDF
Efficiency = 81.9± 0.7%
Good/All = 88.4%
ID 53
Entries 2795
Mean 0.2790
RMS 0.4172
Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 2795
Mean 0.6848
RMS 2.597
χ²/ndf 92.72 / 23
Constant 457.2
Mean 0.6028
Sigma 2.355
pt(parton) - pt(jet)

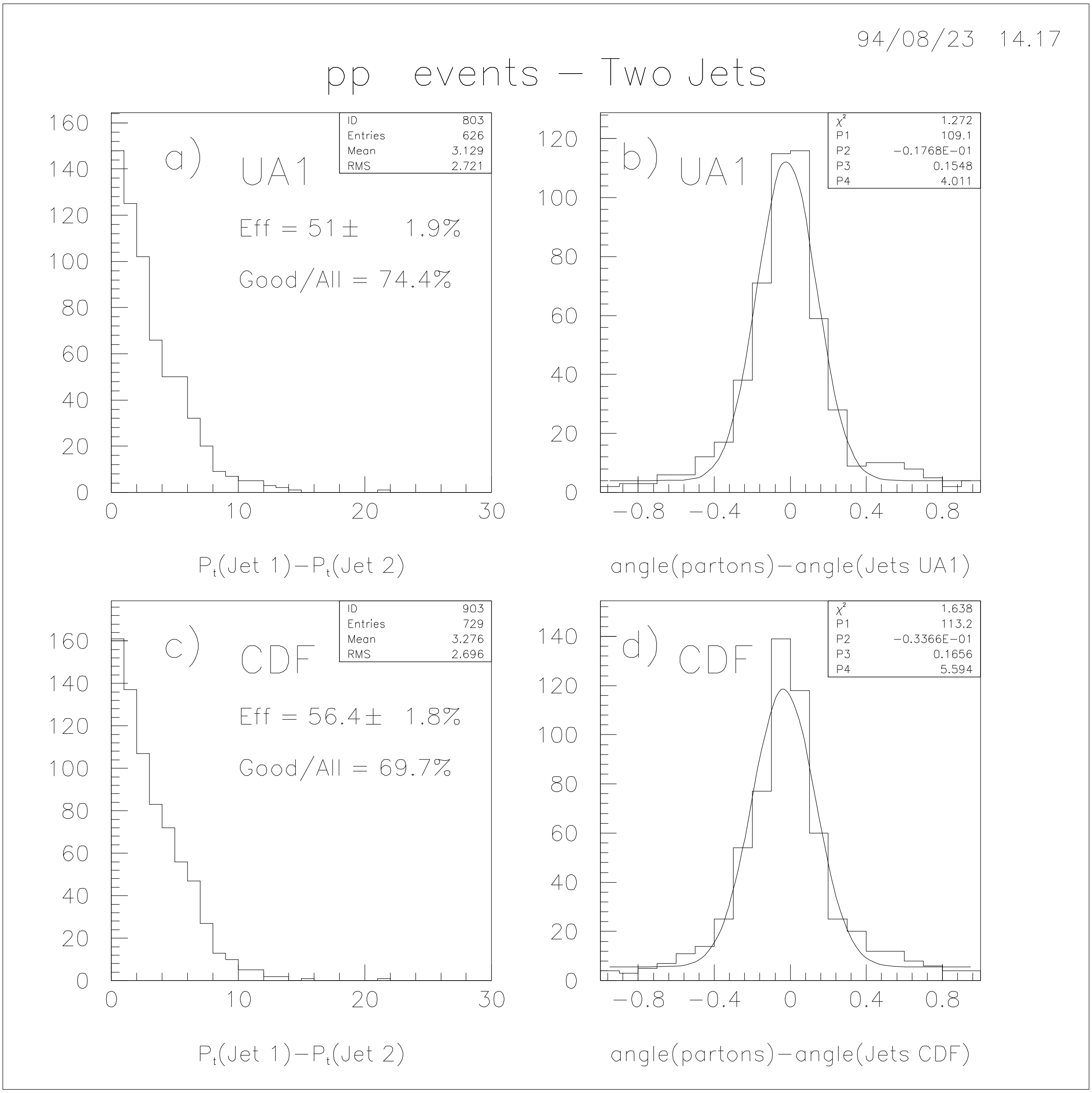
Picture 5


94/08/19 12.41
CC events – One Jet
a)
UA1
ID 43
Entries 691
Mean 0.4675
RMS 0.5126
Efficiency = 63.6± 1.8%
Good/All = 65.9%
Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 691
Mean 1.986
RMS 3.377
χ² 1.228
Constant 84.93
Mean 1.860
Sigma 3.122
pt(parton) - pt(jet)
c)
CDF
ID 53
Entries 730
Mean 0.4563
RMS 0.4950
Efficiency = 68.6± 1.7%
Good/All = 67.4%
Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 730
Mean 0.4863
RMS 3.610
χ² 1.039
Constant 85.42
Mean 0.3104
Sigma 3.293
pt(parton) - pt(jet)

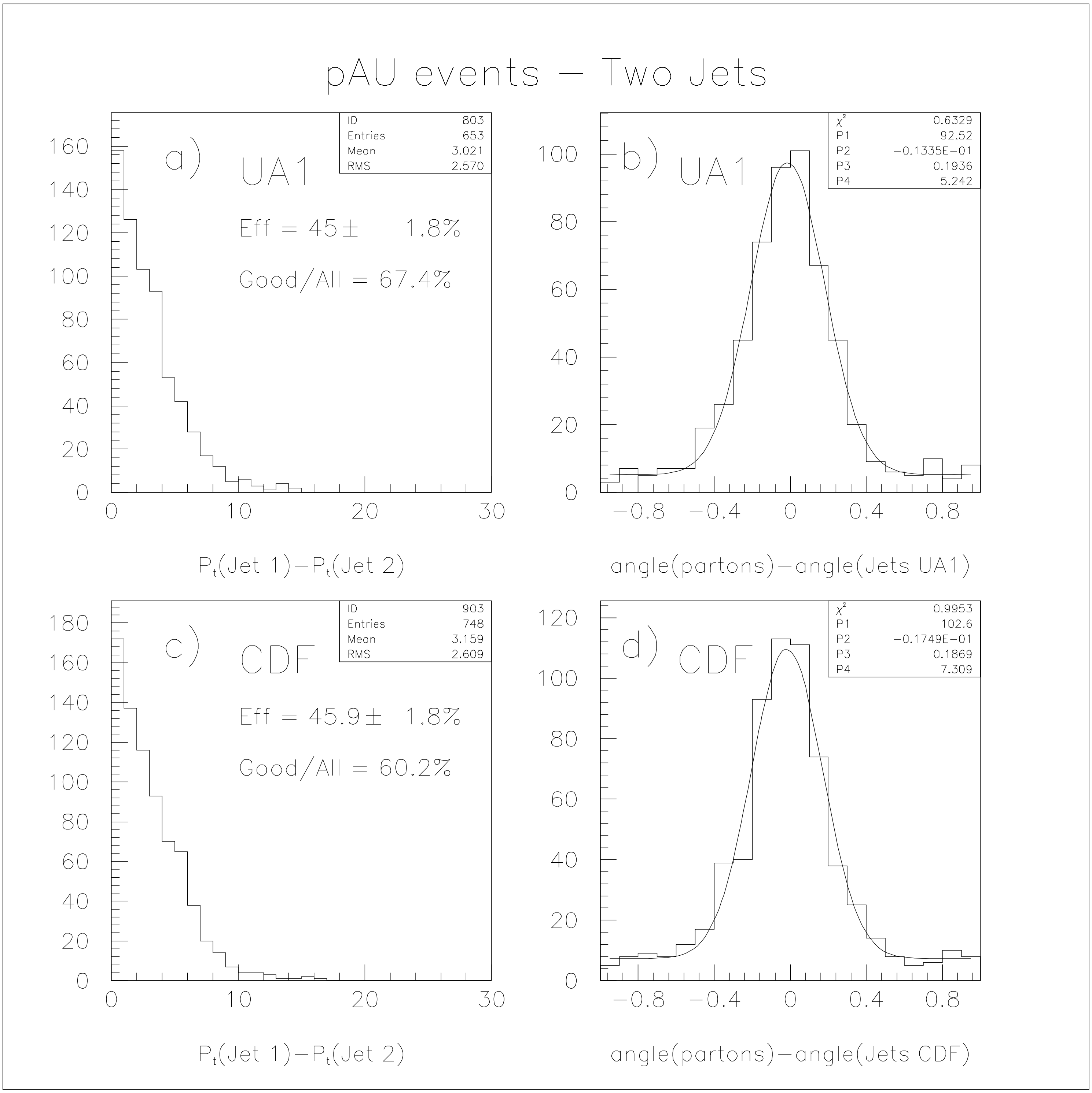
Picture 6


94/08/19 12.53
SiSi events – One Jet
a)
UA1
ID 43
Entries 915
Mean 0.6874
RMS 0.5715
Efficiency = 44.8± 1.8%
Good/All = 37.6%
Cut off angle
Angle between parton and jet
b)
UA1
ID 44
Entries 915
Mean 1.082
RMS 4.755
χ² 1.742
Constant 80.55
Mean 0.9067
Sigma 4.304
pt(parton) - pt(jet)
c)
CDF
ID 53
Entries 948
Mean 0.6768
RMS 0.5554
Efficiency = 51.9± 1.8%
Good/All = 42%
Cut off angle
Angle between parton and jet
d)
CDF
ID 54
Entries 948
Mean −2.364
RMS 4.824
χ² 0.7695
Constant 70.16
Mean −2.836
Sigma 5.140
pt(parton) - pt(jet)

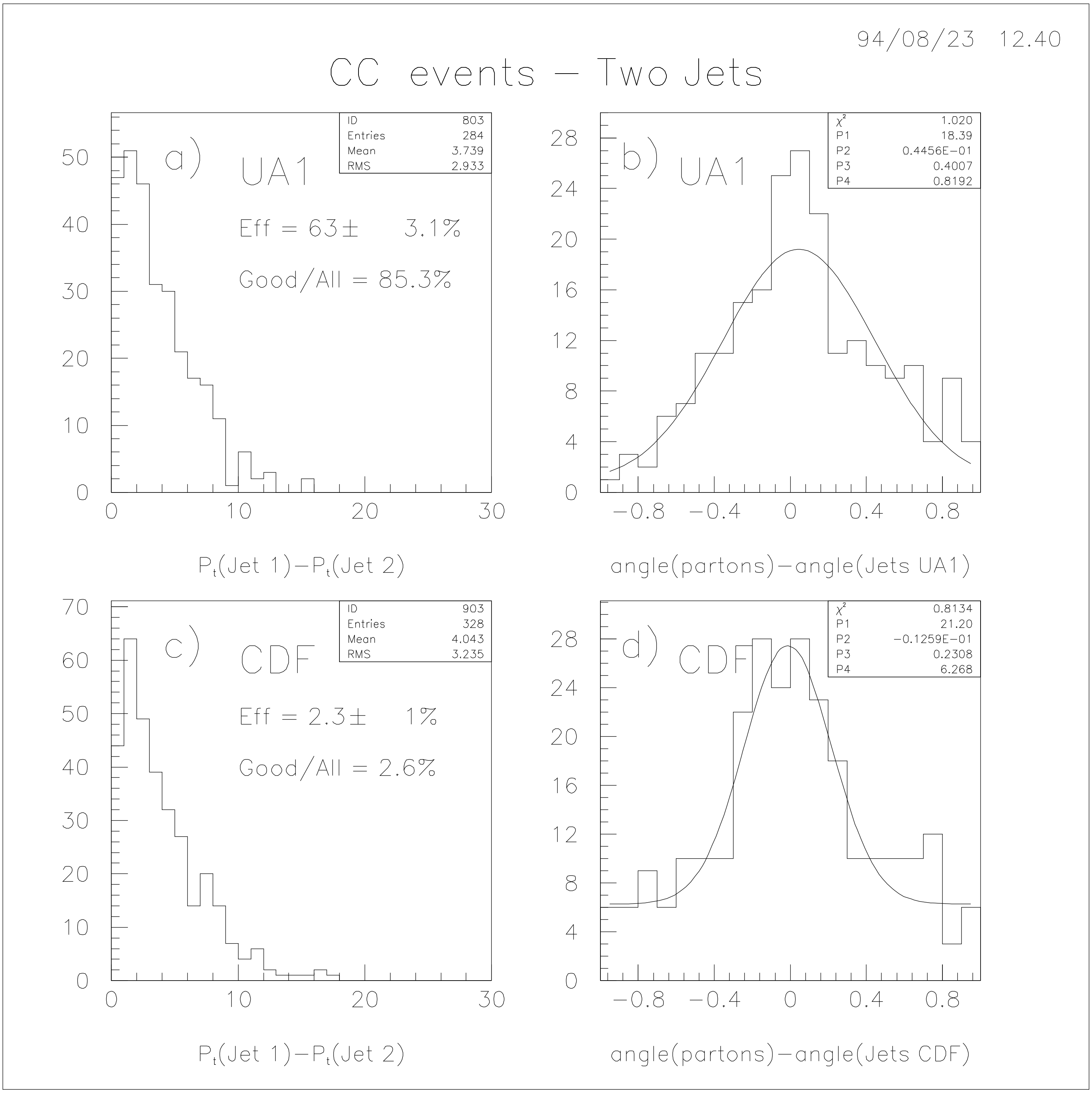
Picture 7


94/08/23 14.17
pp events – Two Jets
ID 803
Entries 626
Mean 3.129
RMS 2.721
a) UA1
Eff = 51 ± 1.9%
Good/All = 74.4%
P_t(Jet 1)–P_t(Jet 2)
χ² 1.272
P1 109.1
P2 –0.1768E–01
P3 0.1548
P4 4.011
b) UA1
angle(partons)–angle(Jets UA1)
ID 903
Entries 729
Mean 3.276
RMS 2.696
c) CDF
Eff = 56.4 ± 1.8%
Good/All = 69.7%
P_t(Jet 1)–P_t(Jet 2)
χ² 1.638
P1 113.2
P2 –0.3366E–01
P3 0.1656
P4 5.594
d) CDF
angle(partons)–angle(Jets CDF)

Picture 8

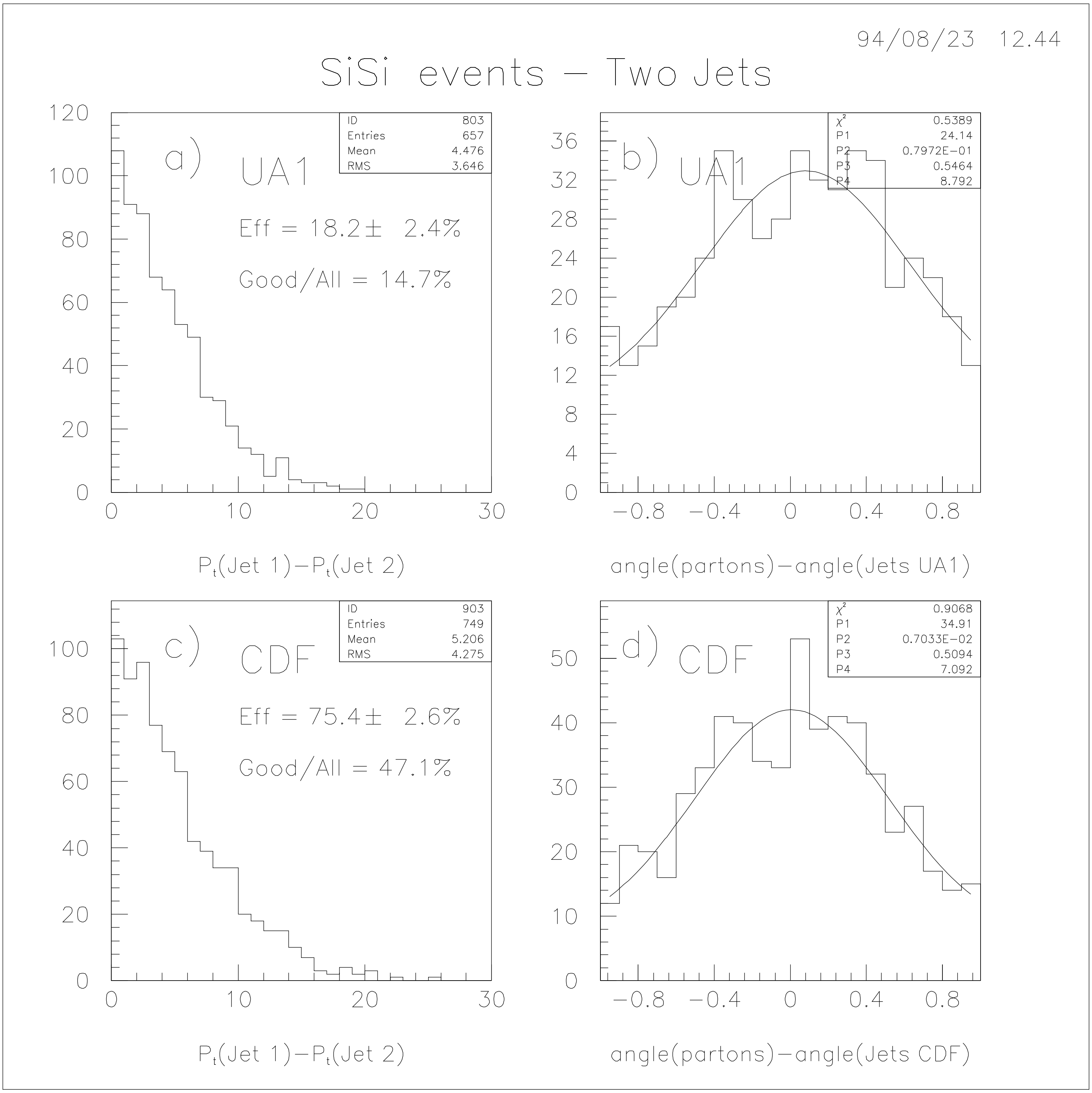

pAU events – Two Jets
ID 803
Entries 653
Mean 3.021
RMS 2.570
a) UA1
Eff = 45± 1.8%
Good/All = 67.4%
P_t(Jet 1)–P_t(Jet 2)
χ² 0.6329
P1 92.52
P2 –0.1335E–01
P3 0.1936
P4 5.242
b) UA1
angle(partons)–angle(Jets UA1)
ID 903
Entries 748
Mean 3.159
RMS 2.609
c) CDF
Eff = 45.9± 1.8%
Good/All = 60.2%
P_t(Jet 1)–P_t(Jet 2)
χ² 0.9953
P1 102.6
P2 –0.1749E–01
P3 0.1869
P4 7.309
d) CDF
angle(partons)–angle(Jets CDF)

Picture 9



94/08/23 12.40
CC events – Two Jets
a) UA1
ID 803
Entries 284
Mean 3.739
RMS 2.933
Eff = 63± 3.1%
Good/All = 85.3%
P_t(Jet 1)–P_t(Jet 2)
b) UA1
χ² 1.020
P1 18.39
P2 0.4456E–01
P3 0.4007
P4 0.8192
angle(partons)–angle(Jets UA1)
c) CDF
ID 903
Entries 328
Mean 4.043
RMS 3.235
Eff = 2.3± 1%
Good/All = 2.6%
P_t(Jet 1)–P_t(Jet 2)
d) CDF
χ² 0.8134
P1 21.20
P2 –0.1259E–01
P3 0.2308
P4 6.268
angle(partons)–angle(Jets CDF)

Picture 10


94/08/23 12.44
SiSi events – Two Jets
ID 803
Entries 657
Mean 4.476
RMS 3.646
a) UA1
Eff = 18.2 ± 2.4%
Good/All = 14.7%
P_t(Jet 1)–P_t(Jet 2)
χ² 0.5389
P1 24.14
P2 0.7972E–01
P3 0.5464
P4 8.792
b) UA1
angle(partons)–angle(Jets UA1)
ID 903
Entries 749
Mean 5.206
RMS 4.275
c) CDF
Eff = 75.4 ± 2.6%
Good/All = 47.1%
P_t(Jet 1)–P_t(Jet 2)
χ² 0.9068
P1 34.91
P2 0.7033E–02
P3 0.5094
P4 7.092
d) CDF
angle(partons)–angle(Jets CDF)

Picture 11