Hadron ID for Future Linear Colliders?

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SLAC Linear Collider Detector Group
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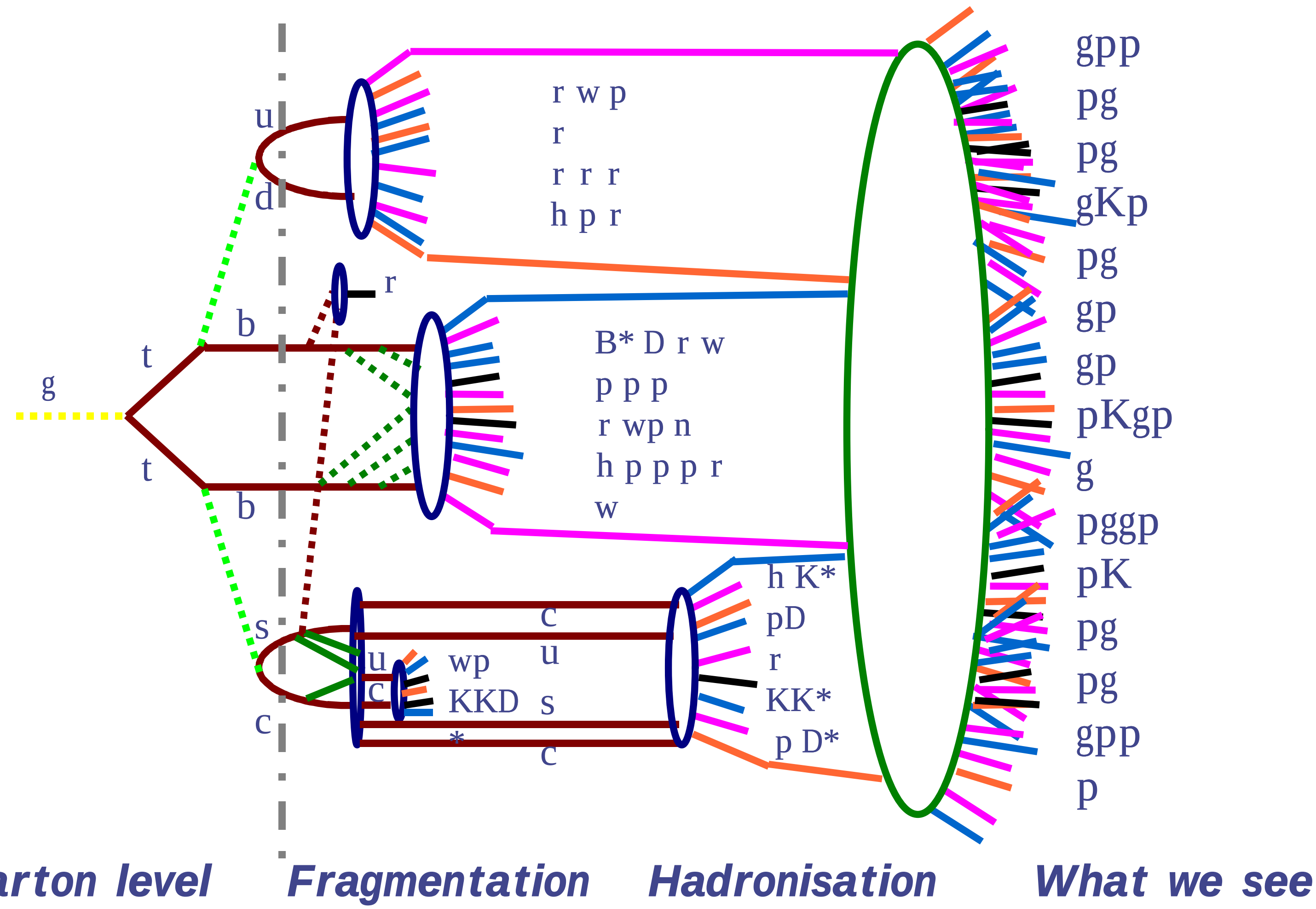
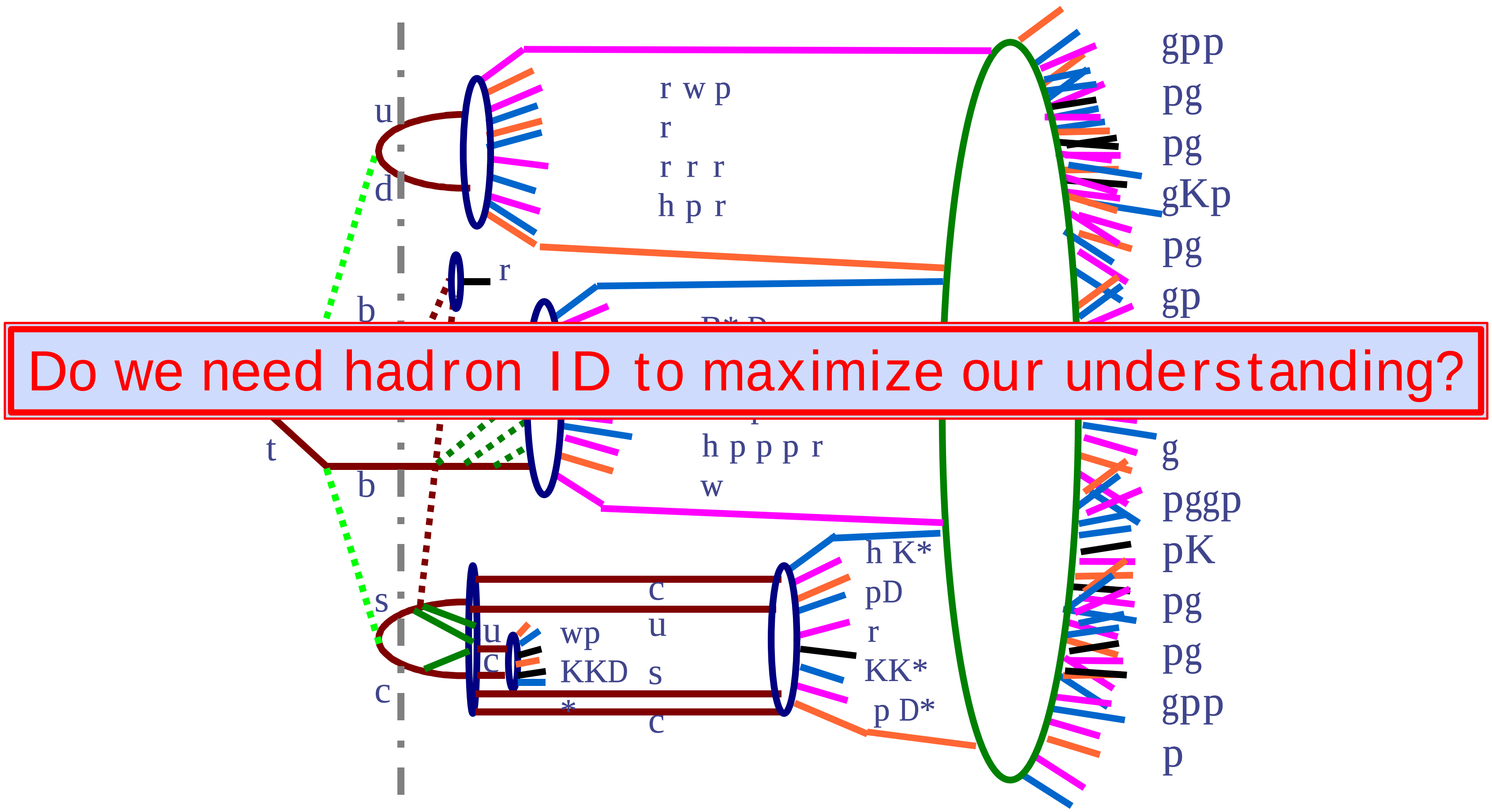
Outline

- Hadron ID – what's it good for?
  - Example 1: W $\rightarrow$ c tagging (Technicolor)
  - Example 2: Neutral B meson tagging
- LCD/JAS PID tools
  - dE/dx module
  - Analysis tools examples
  - Performance
  - Event display with PID info
- Future/Conclusions

The Challenge



The Challenge



Parton level ***Fragmentation*** ***Hadronisation*** ***What we see***

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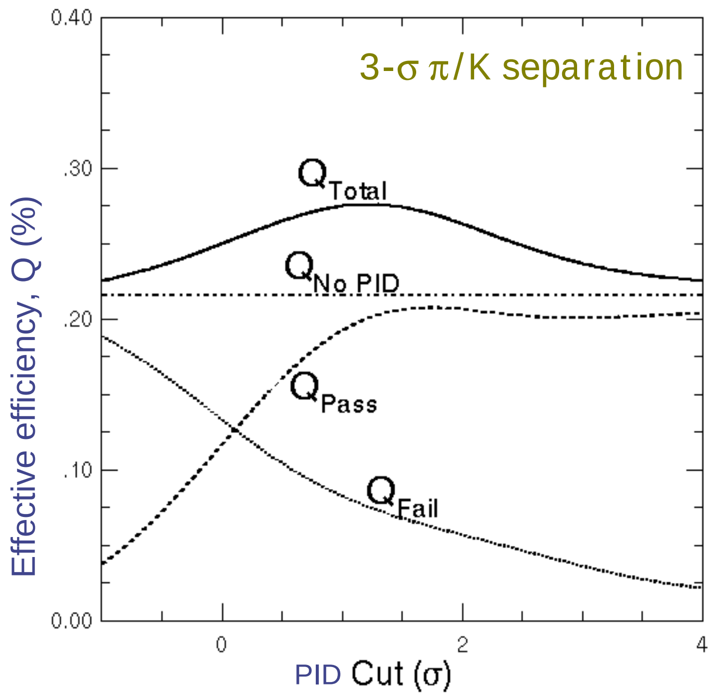
Ex. 1: W+W-: Technicolor Resonance

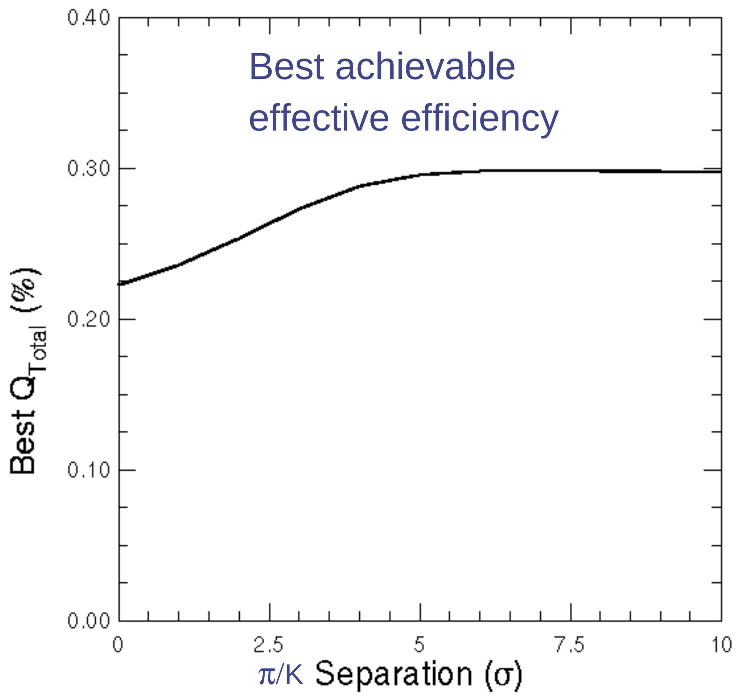
Abi Soffer & Wolfgang Wolniak

- Technicolor theories predict vector resonance production of longitudinally polarized $W^{\pm}$ boson pairs at the linear collider
  - *if supersymmetry is not found, studying this phenomenon may turn out to be the prime physics of the linear collider program.*
- Requires measuring the helicity angle of the $W^{\pm}$ decay
  - easily determined in leptonic decays
  - using hadronic decays requires tagging the up- or down-type quark jet
- c-quark jets may be tagged by detecting the charmed particle's decay vertex
  - Define effective efficiency, $Q=\varepsilon(2p-1)^2$, where ε = efficiency, p=purity
  - Q is ≈ 22% for a center-of-mass energy of 500 GeV, and ≈ 42% for 1500 GeV.
  - in order to make a significant statistical improvement in the analysis, Q must be at least, say, 60%.
- Can we increase the efficiency using charged particle identification?

Tag efficiency with PID

- Select higher purity sample by requiring that at least one track originating from the charm vertex, D-> Kπ, is a kaon (≈ 39%)



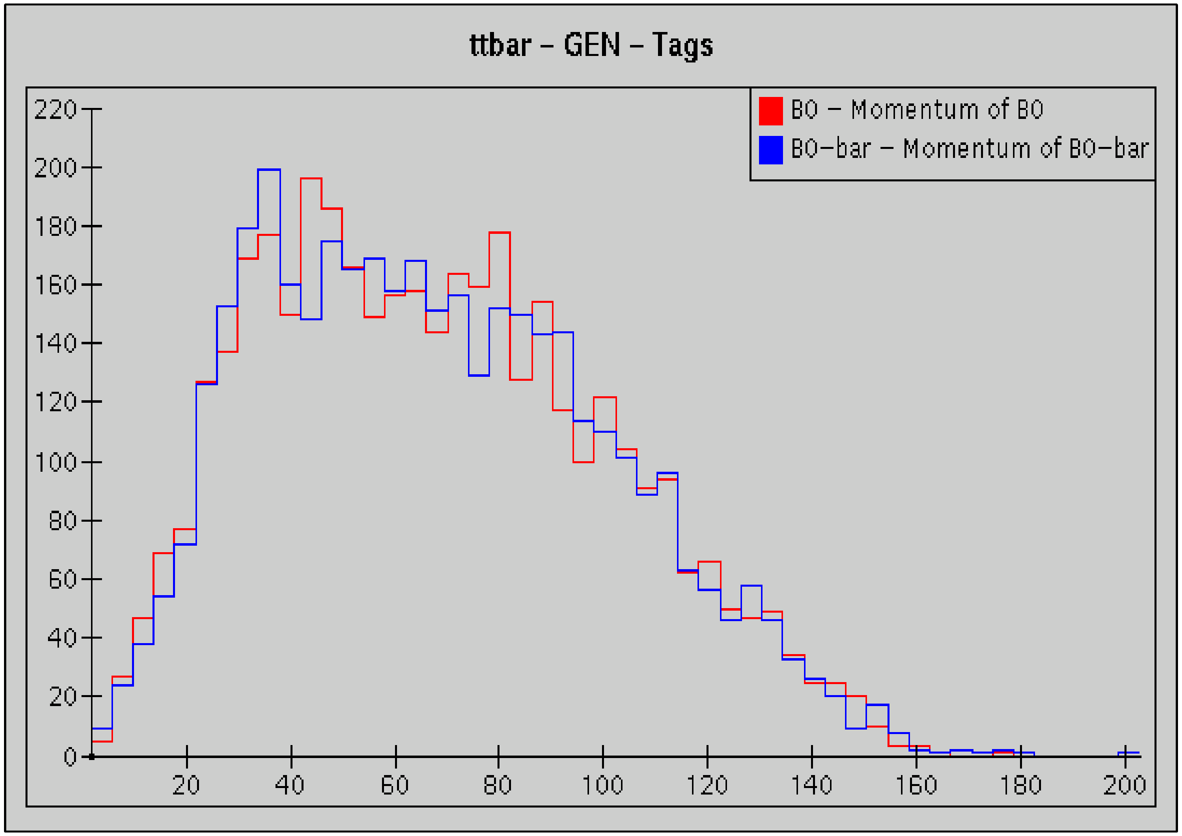


- Modest improvement of 25%, even w/ perfect ID
- Typical of hadron ID gains we have investigated

Ex. 2: B^0 meson tagging in top events

- Pandora 2.1 (M.Peskin) beam configuration: NLC500
  - Center of mass energy = 500 GeV
  - Polarisation: e^-= -0.80, e^+=0.0
- Pythia for fragmentation and hadronisation
  - Pythia 6.136, StdHEP 4.07 (CERNLIB 2000)
  - Pandora interface by T. Barklow & M. Iwasaki
- Most plots from 10,000 ttbar events
  - few months at design luminosity ($5x10^{33}cm^{-2}s^{-1}$)
- Have also looked at generic qqbar (q=u,d,s,c,b) & Z-Higgs

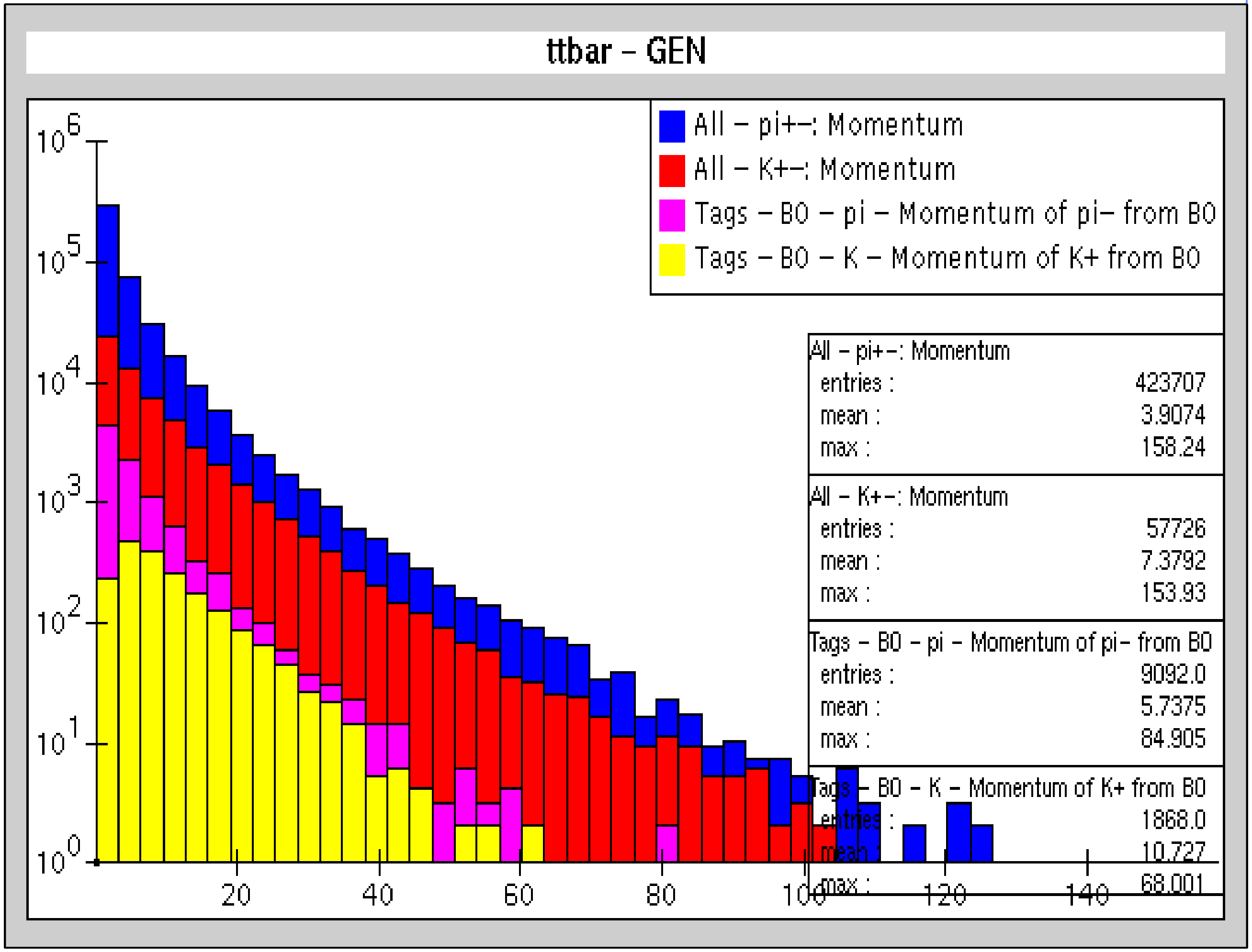
B^0 Momenta



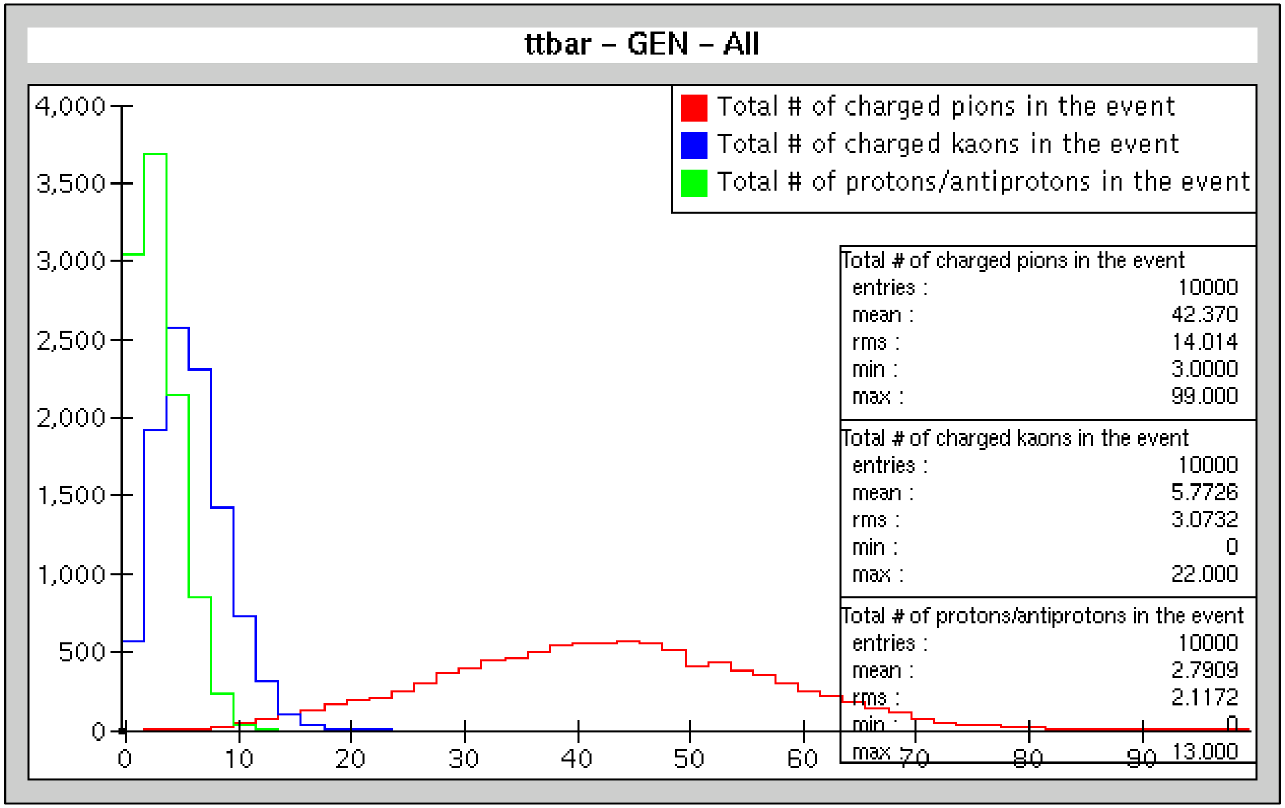
- Assume these will be well reconstructed by vertexing

Charge Particle Momenta

	<p(π)>	<p(K)>
All	3.9	7.4
Tagged B0	5.7	10.7



Charge Particle Multiplicities



Parameterized PID Performance

- Ideal detector with perfect ID
- “Standard” TPC
- SLD CRID
- TESLA TPC
- Super-DIRC + Standard TPC
- 1 atm. Super-TPC
- 5 atm. Super-TPC

TPC	K eff.	p mis-ID
0.35 < p < 0.85	0.50	0.023
1.5 < p < 20.	0.50	0.16
2.0 < p < 8	0.50	0.023

*TESLA TPC**	K eff.	p mis-ID
0.35 < p < 0.85	0.50	0.023
1.5 < p < 20.	0.50	0.16
2.0 < p < 13.6	0.50	0.023

*Super-TPC1***	K eff.	p mis-ID
0.35 < p < 0.85	0.50	0.023
1.75 < p < 65.	0.50	0.023
2.50 < p < 40.	0.50	0.010

*Super-TPC5***	K eff.	p mis-ID
0.35 < p < 0.60	0.84	0.003
0.60 < p < 0.90	0.50	0.023
1.25 < p < 50.	0.50	0.023
1.75 < p < 30.	0.84	0.003

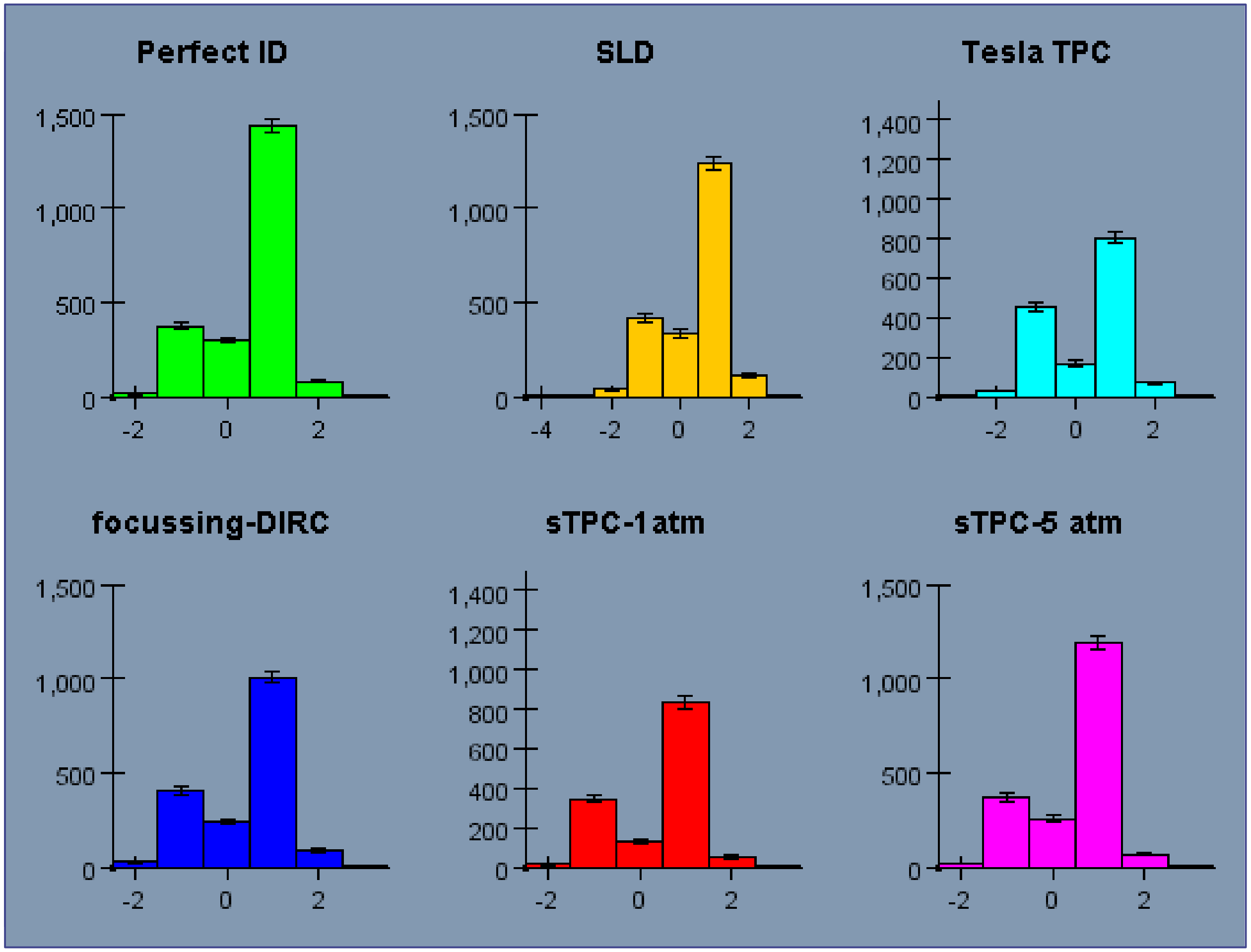
*S-DIRC +TESLA TPC**	K eff.	p mis-ID
0.35 < p < 0.85	0.50	0.023
1.5 < p < 20.	0.50	0.16
2.0 < p < 13.6	0.50	0.023
0.8 < p < 1.0	0.70	0.01
1.0 < p < 7.0	0.99	0.02

TPC + CRID	K eff.	p mis-ID
0.35 < p < 0.85	0.50	0.023
1.5 < p < 20.	0.95	0.03
2.0 < p < 3.0	0.95	0.06
20. < p < 30.	0.50	0.023

*M. Hauschild LCWS2000

** 1 and 5 atms. H. Yamamoto LCWS1999

Kaon Net-Charge from B^0



* use of util tools: findID, findAncestors, netCharge, getStable

Analyzing Power with PID

$\zeta = (N(Q_{Knet}>0) - N(Q_{Knet}<0)) / N_B$

	Perfect ID	SLD +TPC	f-DIRC +TPC	Tesla TPC	sTPC 1-atm	sTPC 5-atm
Fraction of B events w/ $N_K > 0$	0.56	0.55	0.45	0.39	0.35	0.48
Fraction w/ correct-sign tag	0.39	0.35	0.28	0.22	0.22	0.32
Analyzing power, ζ	0.29	0.23	0.17	0.09	0.13	0.22
ζ / ζ[Perfect]	1.0	0.77	0.58	0.33	0.48	0.79

- SLD/DELPHI RICH much better than 1–atm *optimised* TPC
- 5-atm TPC similar to RICH performance
- Tesla TPC a.p. enhanced almost factor of 2 by f-DIRC

New Particle ID Tools in LCD/JAS

xxxxFastRecon

xxxx = dEdx, DIRC, (TOF,) (Cal/Mu/Vxd)

e.g. dE/dx Bethe-Bloch each particle type

↓

xxxxFastPID

e.g. ln(likelihood) differences

↓

Particle ID Combiner

Combine subsystems ln(L)

Generate "convenience" flags

e.g. isaKaon, notaPion etc.

http://hep45.hep.colostate.edu/~wilson/flc/jas/pid/

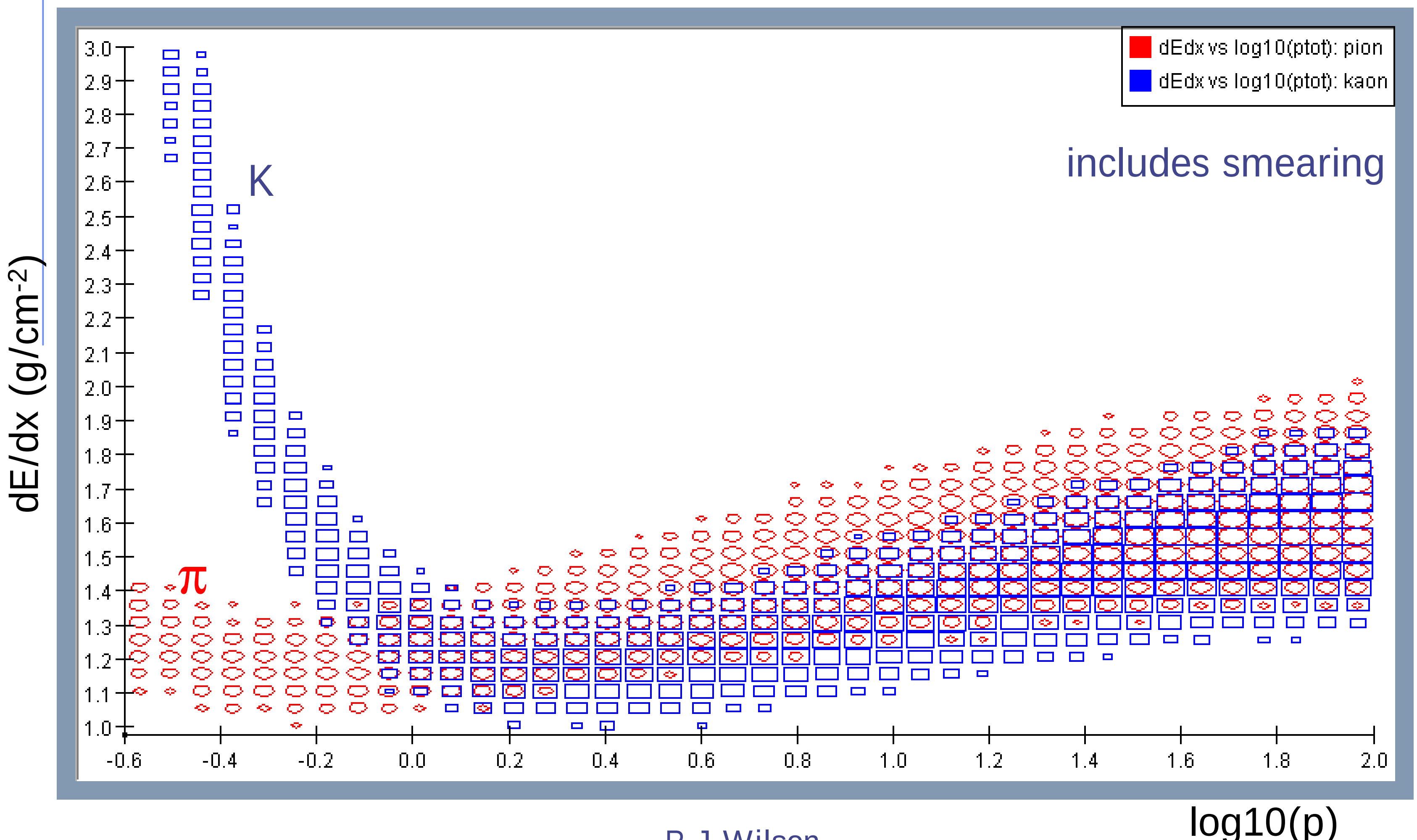
dE/dx Energy Loss

- Truncated Bethe-Bloch – Snowmass package form was

$$\frac{dE}{dx} \propto \frac{1}{b^2}\left(\frac{1}{2}\log\frac{2m_e b^2 g^2 T_0}{I^2} - \frac{b^2}{2}\left(1+\frac{T_0}{T_{\max}}\right) - \frac{d}{2}\right)$$

- Did not reproduce H. Yamamoto plots from LCWS99.
- Replace density effect term, δ, and gas parameters with R.M. Sternheimer *et al.* form.
- Use knock-on electron cut 50 keV, depends on B-field but π/K separation fairly insensitive for range 10-100 keV.
- Have not compared with measurements or full simulation at high momenta, okay at low.

dE/dx loss vs. momentum



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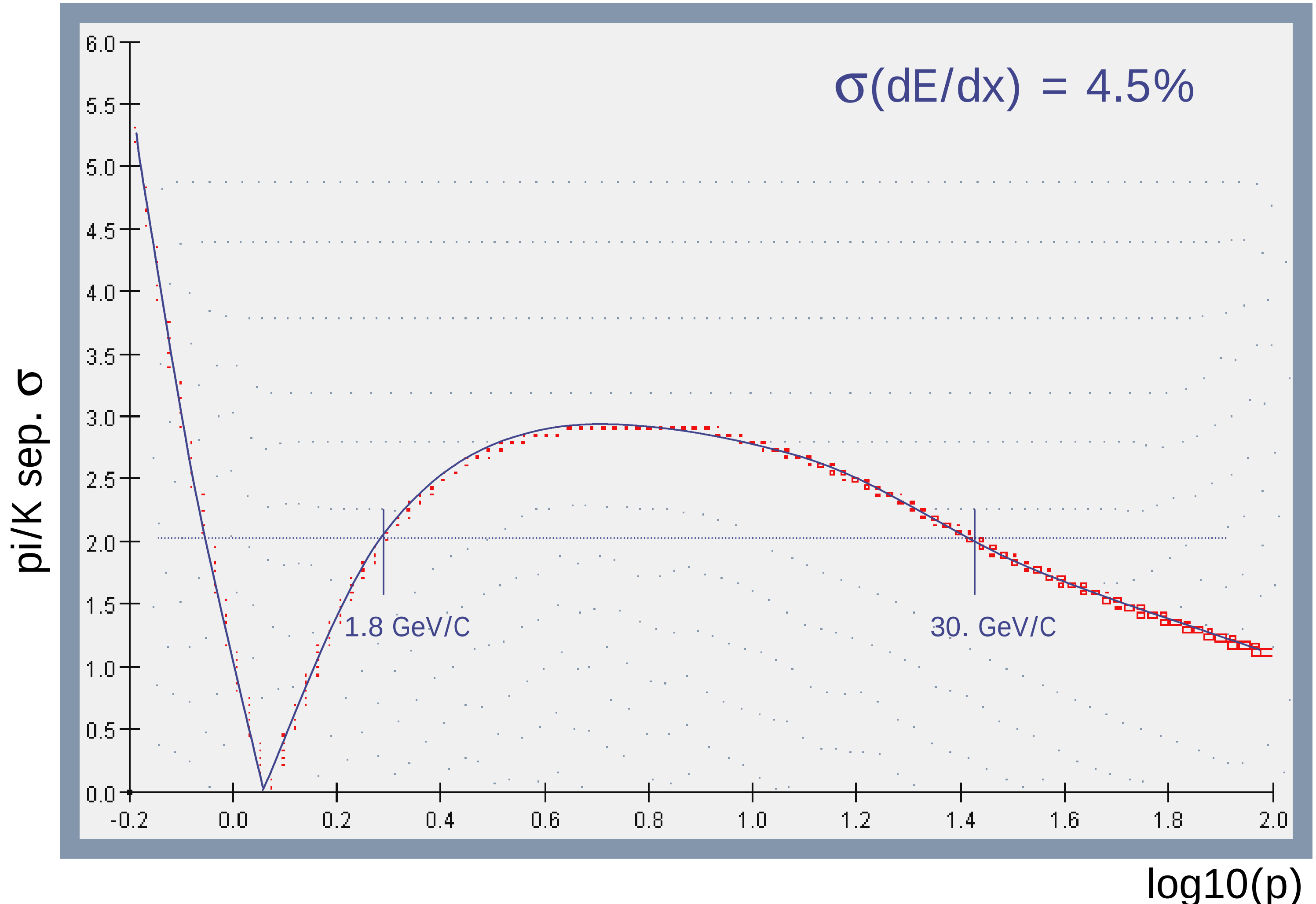
dE/dx – pi/K separation



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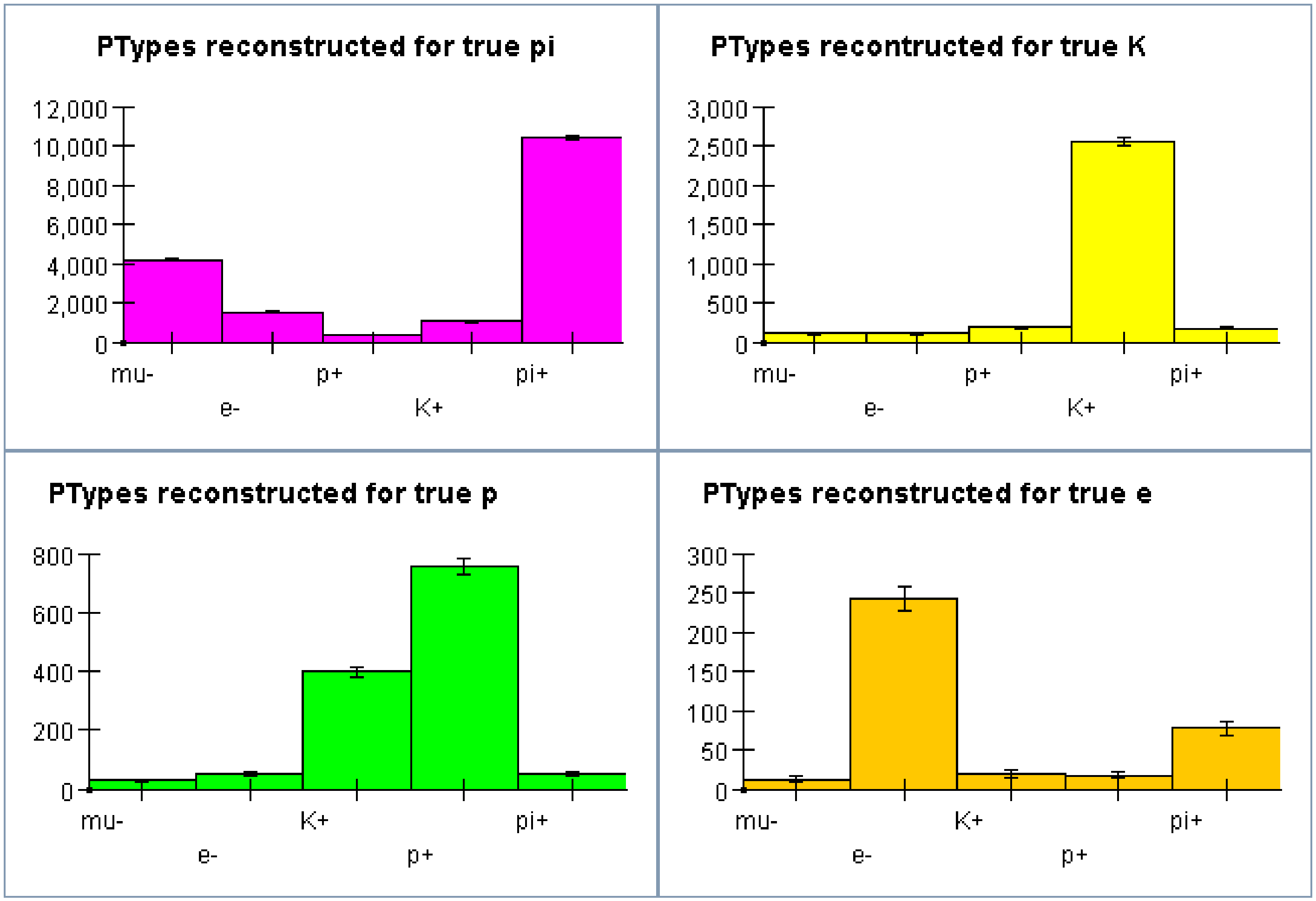
dE/dx – Reconstructed IDs

Constant dE/dx resolution = 4.5%



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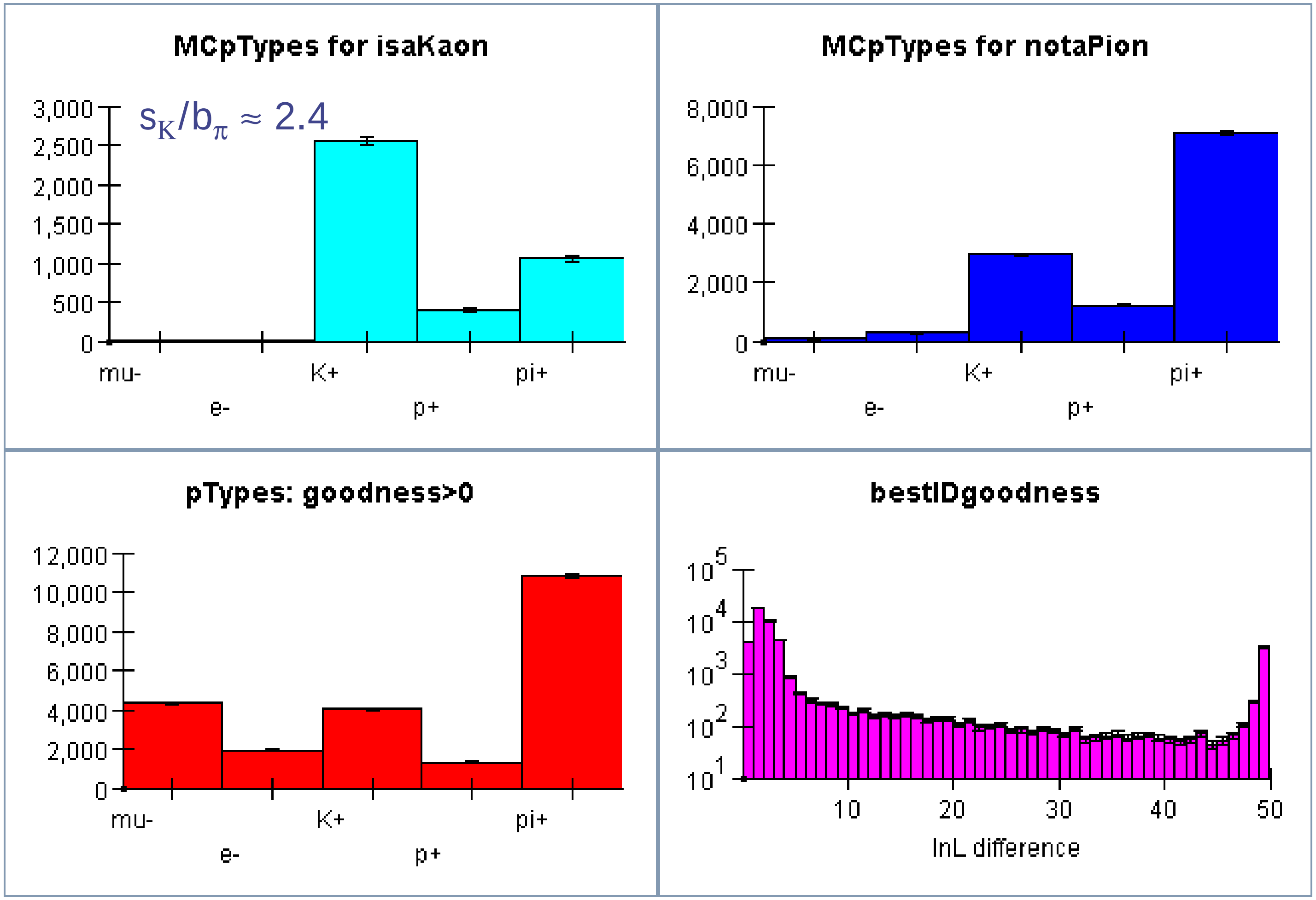
dE/dx – Particle type convenience flags

Constant dE/dx resolution = 4.5%



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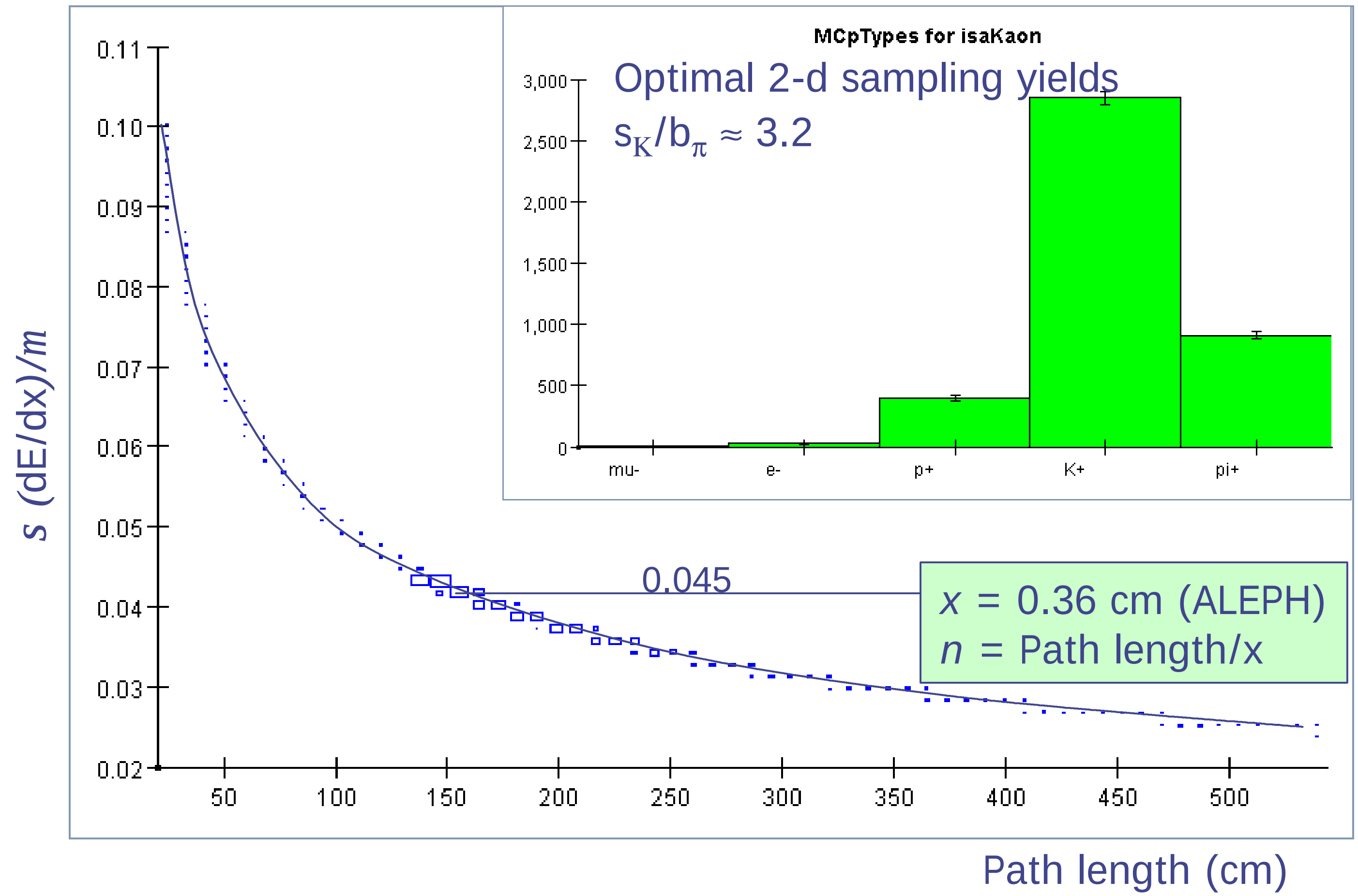
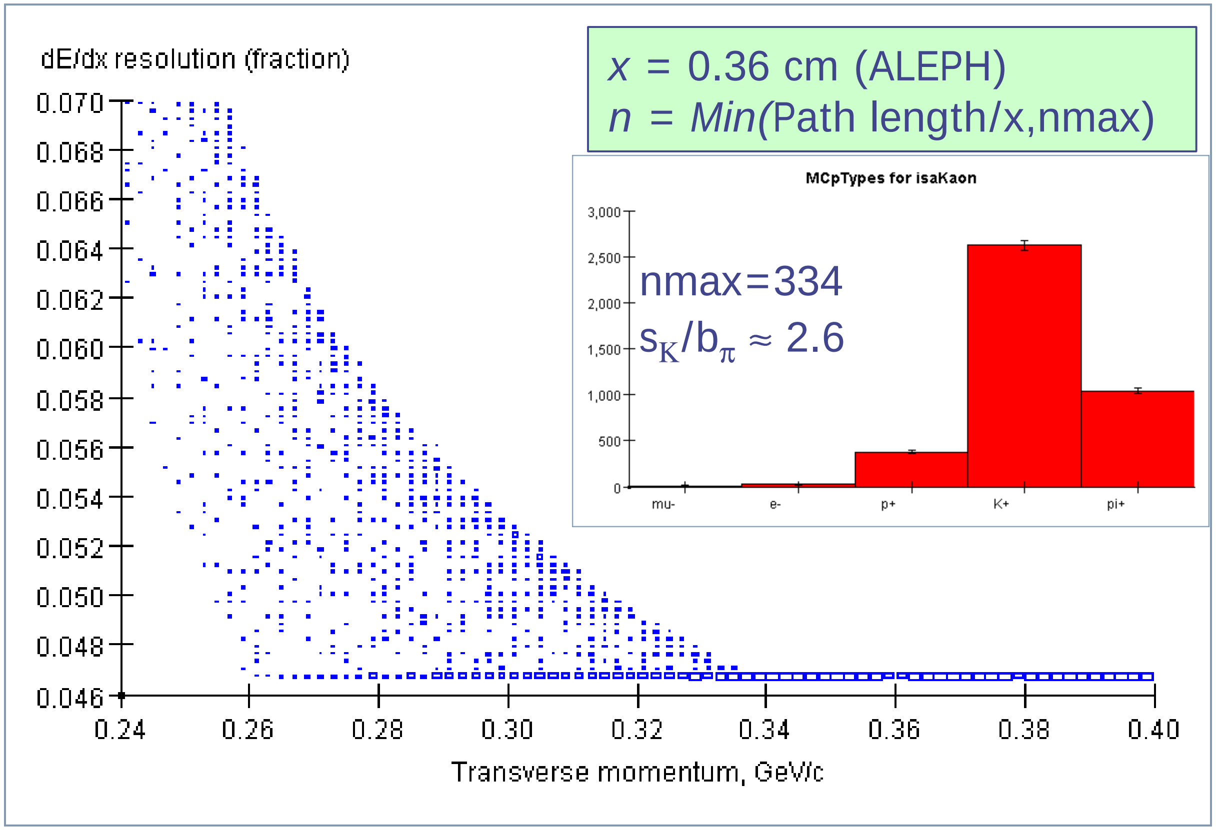
dE/dx – $\sigma(dE/dx)/\mu = 0.41\ n^{-0.43}\ x^{-0.32}$ *



H. Walenta et al. – *n*= #samples, *x*= sampling distance (cm)

dE/dx – $s(\mathrm{dE/dx})/m = 0.41\, n^{-0.43}\, x^{-0.32}$ *

$s\,(\mathrm{dE/dx})/m$



Path length (cm)

H. Walenta et al. – n= #samples, x= sampling distance (cm)

Effic./Purity in Top Events @ 500GeV

PIDAnalyzer_W01: DETECTOR --> **L2** <-- PID sep. thresholds: PiK=Kpi=KP= **2 sigma**

	Reco.:	e	mu	pi	K	p	Sum
True: e	970	107	17	63	26	11	224
True: mu	683	22	54	51	2	2	131
True: pi	35915	1429	571	6736	345	148	9229
True: K	5177	112	0	53	**1968**	28	2161
True: p	2466	36	0	14	353	**468**	871
	Sum	1706	642	6917	2694	657	

ID efficiency matrix, %

11	1.7	6.4	2.6	1.1
3.2	7.9	7.4	0.29	0.29
3.9	1.5	18	0.96	0.41
2.1	0	1.0	**38**	0.54
1.4	0	0.57	14	**19**

ID purity matrix, %

6.2	2.6	0.91	0.97	1.6
1.2	8.4	0.74	0.07	0.30
83	88	97	12	22
6.5	0	0.77	**73**	4.2
2.1	0	0.20	13	**71**

Effic./Purity ... add a super-DIRC

PIDAnalyzer_W01: DETECTOR --> **L2 +DIRC** <-- PID sep. thresholds: PiK=Kpi=KP= **2 sigma**

	Reco.:	e		mu		pi		K		p		Sum	
True: e	970	107	188	17	13	63	94	26	16	11	3	224	314
True: mu	683	22	27	54	76	51	71	2	1	2	0	131	175
True: pi	35915	1429	1268	571	1749	6736	16279	345	167	148	24	9229	19487
True: K	5177	112	50	0	1	53	16	**1968**	**3665**	28	26	2161	3758
True: p	2466	36	4	0	0	14	2	353	114	**468**	**1820**	871	1940
	Sum	1706	1537	642	1839	6917	16462	2694	3963	657	1873		

ID efficiency matrix, %

11	19	1.7	1.3	6.4	9.6	2.6	1.6	1.1	0.31
3.2	3.9	7.9	11	7.4	10	0.29	0.15	0.29	0
3.9	3.5	1.5	4.8	18	45	0.96	0.46	0.41	0.07
2.1	0.97	0	0.02	1.0	0.31	**38**	**70**	0.54	0.50
1.4	0.16	0	0	0.57	0.08	14	4.6	**19**	**73**

ID purity matrix, %

6.2	12	2.6	0.71	0.91	0.57	0.97	0.40	1.6	0.16
1.2	1.7	8.4	4.1	0.74	0.43	0.07	0.03	0.30	0
83	82	88	95	97	98	12	4.2	22	1.2
6.5	3.2	0	0.05	0.77	0.1	**73**	**92**	4.2	1.3
2.1	0.26	0	0	0.20	0.01	13	2.8	**71**	**97**

Effic./Purity … demand 3 sigma

PIDAnalyzer_W01: DETECTOR --> **L2+DIRC** <-- PID sep. thresholds: PiK=Kpi=KP= **3 sigma**

	Reco.:	e		mu		pi		K		p		Sum	
True: e	970	131	189	13	26	20	53	3	2	6	1	173	271
True: mu	683	25	21	46	62	7	49	0	0	0	0	78	132
True: pi	35915	1534	1182	615	1697	3529	14627	1	6	28	1	5707	17513
True: K	5177	94	40	3	1	0	0	**699**	**2978**	0	1	796	3020
True: p	2466	42	2	0	0	0	0	105	31	**316**	**1689**	463	1722
	Sum	1826	1434	677	1786	3556	14729	808	3017	350	1692		

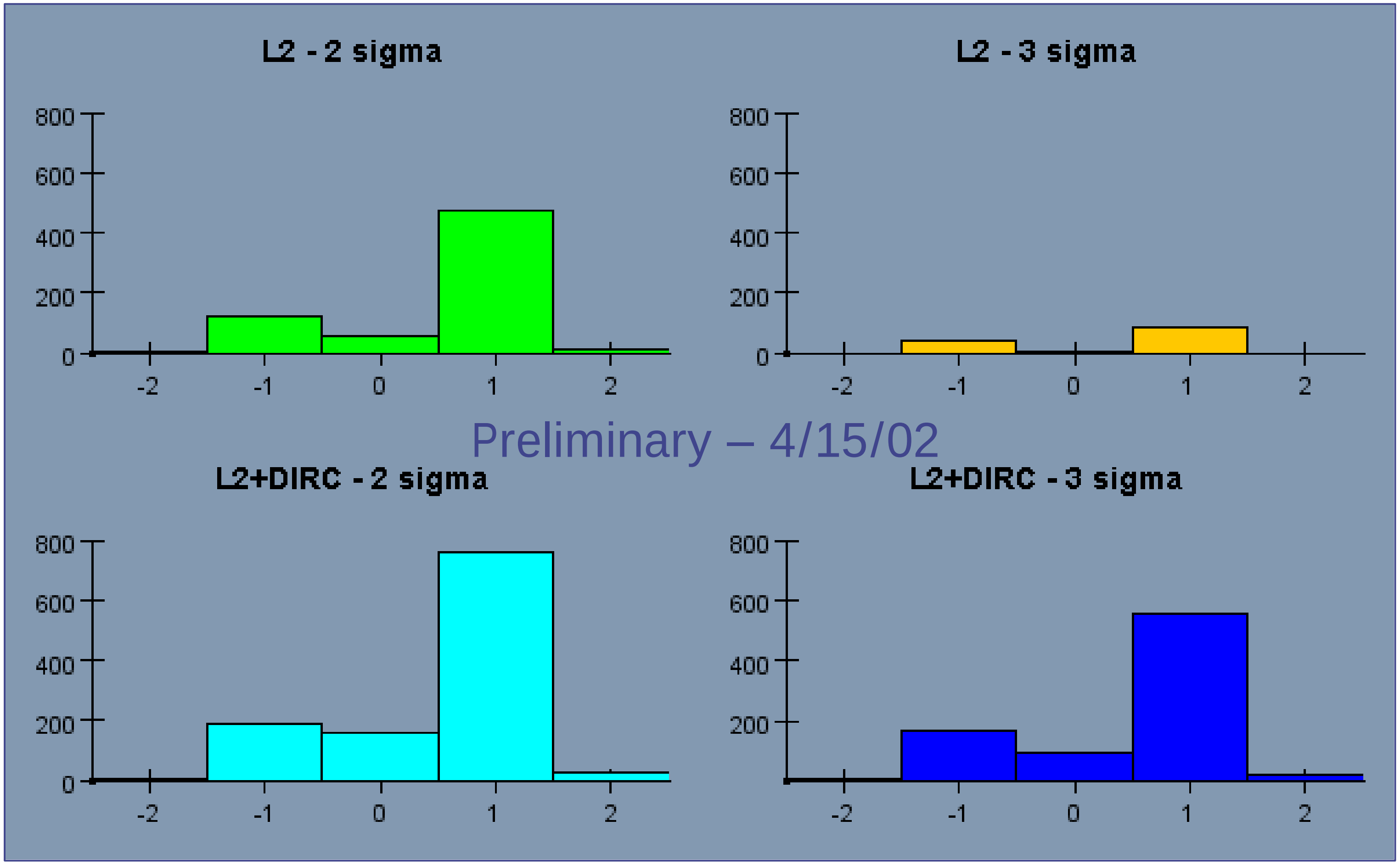
ID efficiency matrix, %

13	19	1.3	2.6	2.0	5.4	0.31	0.21	0.62	0.10
3.6	3.0	6.7	9.0	1.0	7.1	0	0	0	0
4.2	3.2	1.7	4.7	9.8	40	0	0.02	0.08	0
1.8	0.77	0.06	0.02	0	0	**13**	**57**	0	0.02
1.7	0.08	0	0	0	0	4.2	1.2	**12**	**68**

ID purity matrix, %

7.1	13	1.9	1.4	0.56	0.36	0.37	0.07	1.7	0.06
1.3	1.4	6.7	3.4	0.20	0.33	0	0	0	0
84	82	90	95	99	99	0.12	0.20	8.0	0.06
5.1	2.7	0.44	0.06	0	0	**86**	**98**	0	0.06
2.3	0.14	0	0	0	0	13	1.0	**90**	**99**

Net Charge of IDed K from B^0 Decays



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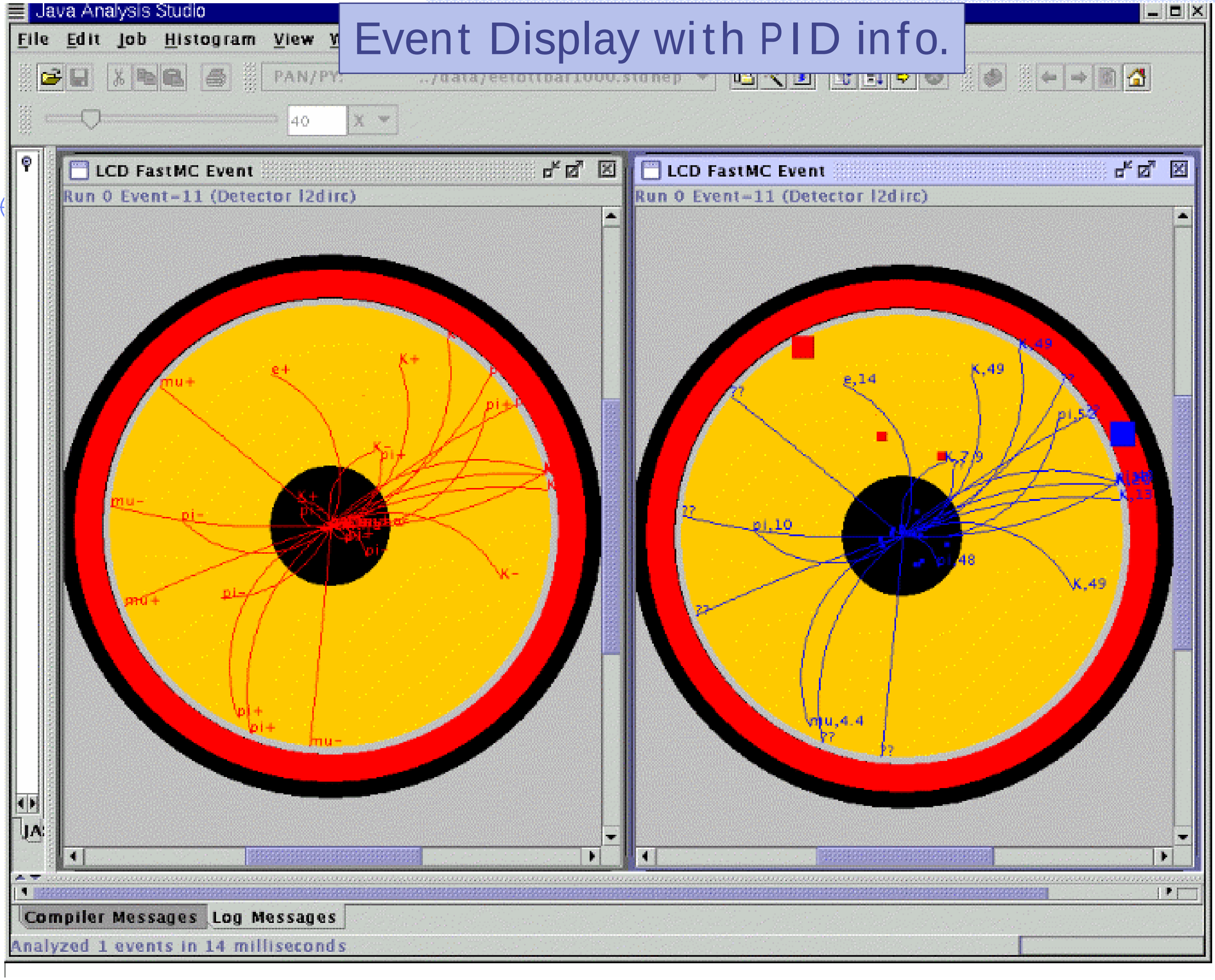
FastPID – Performance

- 650 MHz laptop, 256 MB RAM
- 1000 t-tbar Pandora/Pythia events at 500 GeV CM
  - stdHEP file size ≈ 20 MB
  - $\langle n_{charge} \rangle \approx 50$, $\langle p_K \rangle \approx 7$ GeV/c

- Charged track smearing only: 22 secs
- dEdX + PID: 25 secs,
- + DIRC: 27 secs.
- Efficiency/purity analysis w/ 24 histograms: 28 secs.

Event Display with PID info.



Future for the PID Tools

- Improve the dE/dx model
  - Reconcile with Yamamoto plots
  - Compare with data/full simulation
  - Different gases, sampling parameters etc.
- Complete other example modules (DIRC/TOF)
- Investigate merging cal/mu/vxd info.
- Investigate merging with FastMC module

Conclusions

- *Still* no compelling argument for hadron-ID … but a "gut" feeling that is *still* shared by many.
- Solice in the "free" dE/dx information…
- Which is not there in an all-silicon tracker
  - What will it take to be comfortable with almost complete abandonment of hadron ID?
  - Worth a (minimal) hadron-ID add-on?

Conclusions ... contd.

- General agreement on the need to "work hard" on dE/dx
- New PID fast simulation tools are available
- Particle ID Sub-Group of the N.A. Linear Collider Working Group will persist
  - request by Jim Brau & Mark Oreglia
- May reorganize as a PID effort with a broader cross-subsystem scope

Conclusions ... contd.

- An opportunity for the SLAC LCD group?