Open charm measurement with HFT at STAR

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(for the STAR Collaboration)

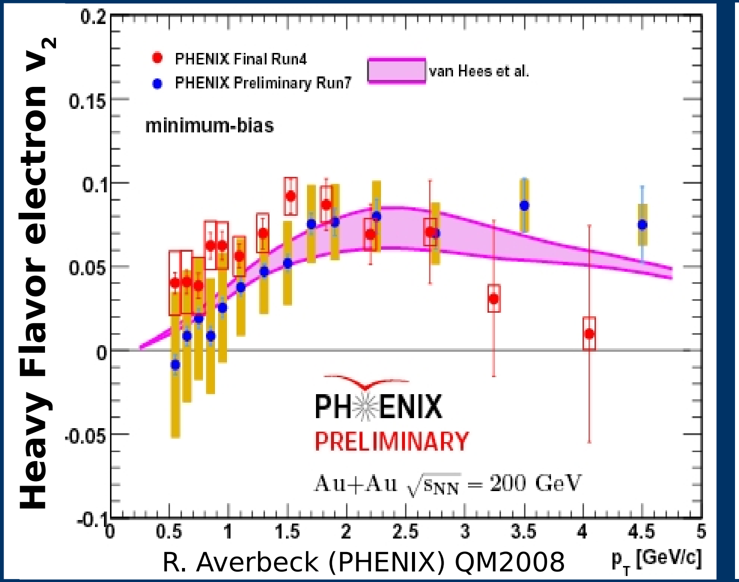
Hot Quarks 2008
Aspen Lodge in Estes Park, CO
August 22nd, 2008

*: Nuclear Physics Institute ASCR, Rez/Prague, Czech Republic

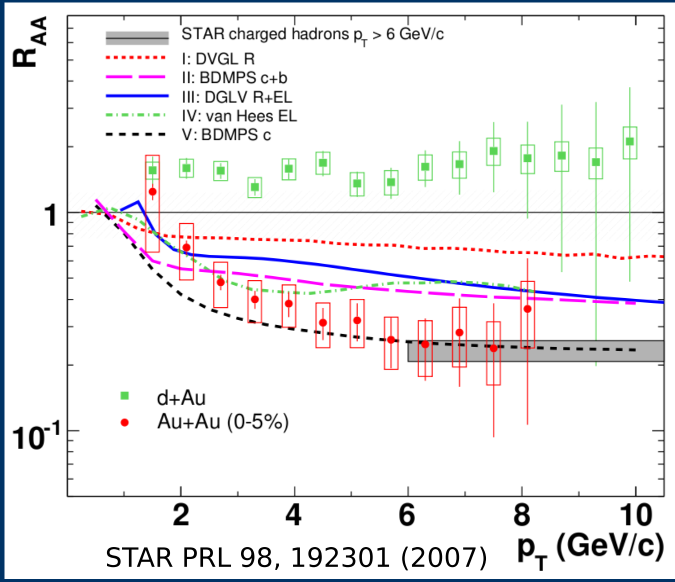
Open charm physics at RHIC

- heavy quarks are produced early in the collision
- they derive mass from the Higgs field - stay massive even during chiral symmetry restoration

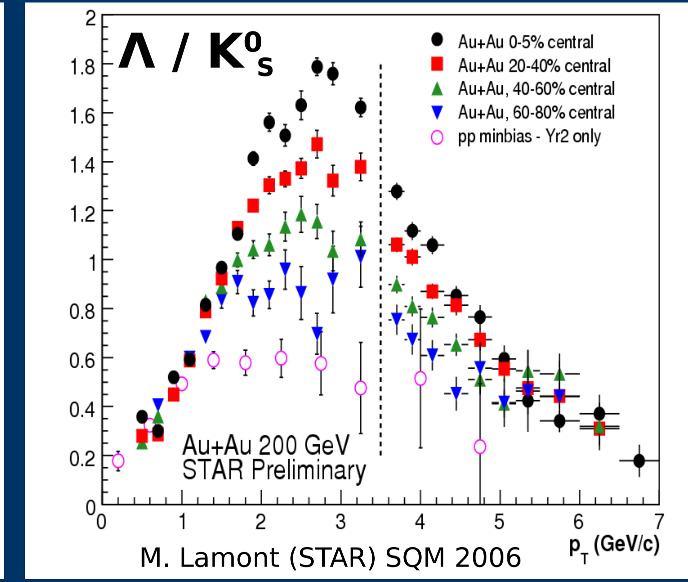
does charm quark flow? **charm energy loss?** **Λ_c/D^0 enhancement?**



R. Averbeck (PHENIX) QM2008



STAR PRL 98, 192301 (2007)



M. Lamont (STAR) SQM 2006

so far, heavy flavor v_2 and R_{AA} have been measured **indirectly** using decay electrons

Open charm physics at RHIC

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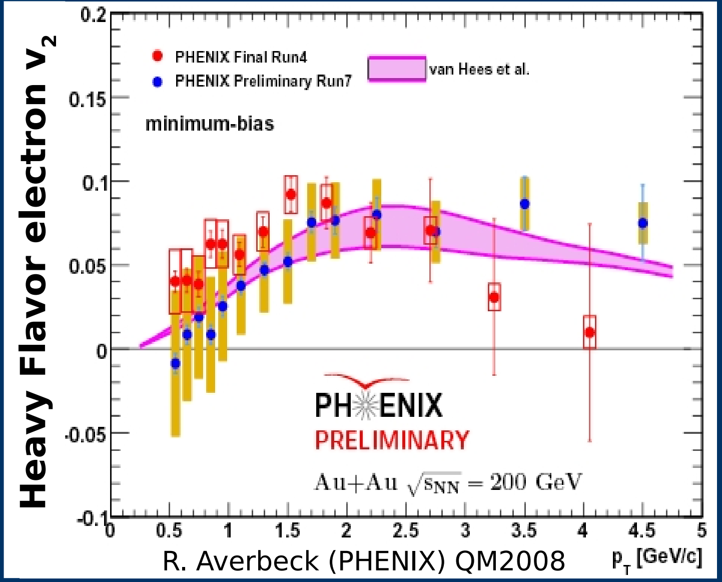
does charm quark flow?



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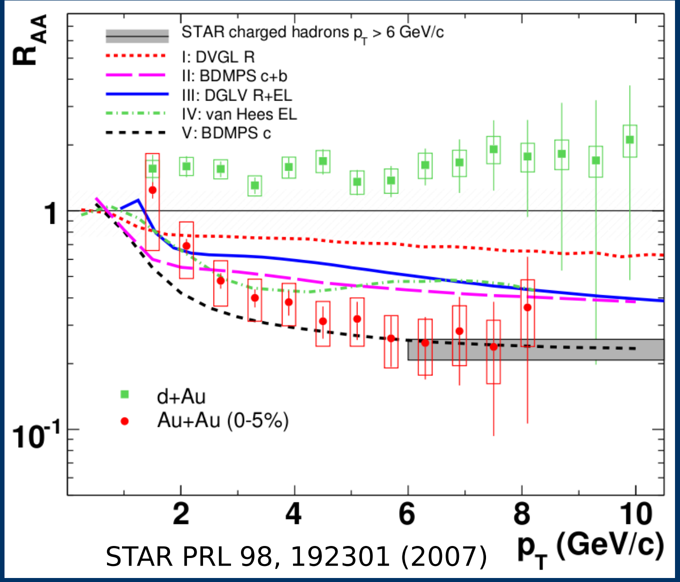
charm energy loss?



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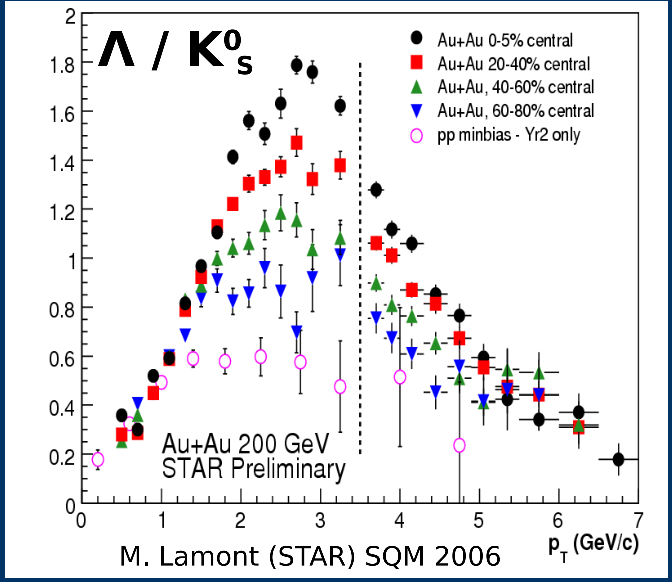
Λ_c/D^0 enhancement?



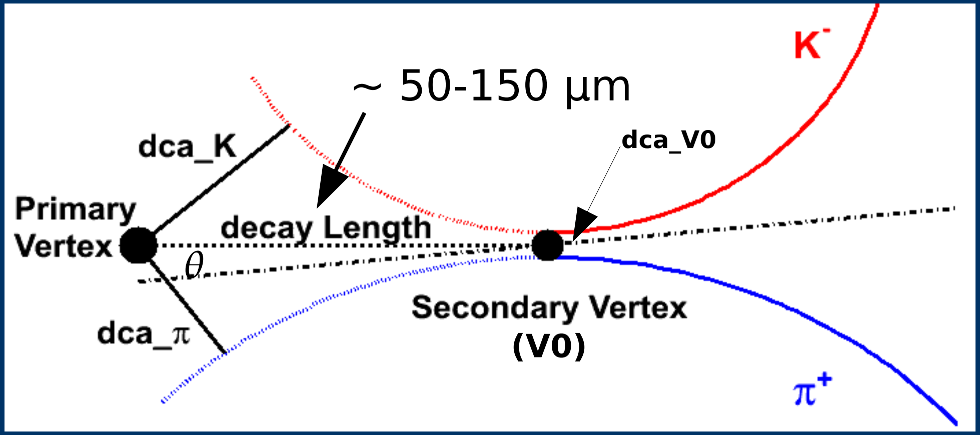
M. Lamont (STAR) SQM 2006

so far, heavy flavor v_2 and R_{AA} have been measured **indirectly** using decay electrons

direct reconstruction of open charm decays necessary for precision measurements...

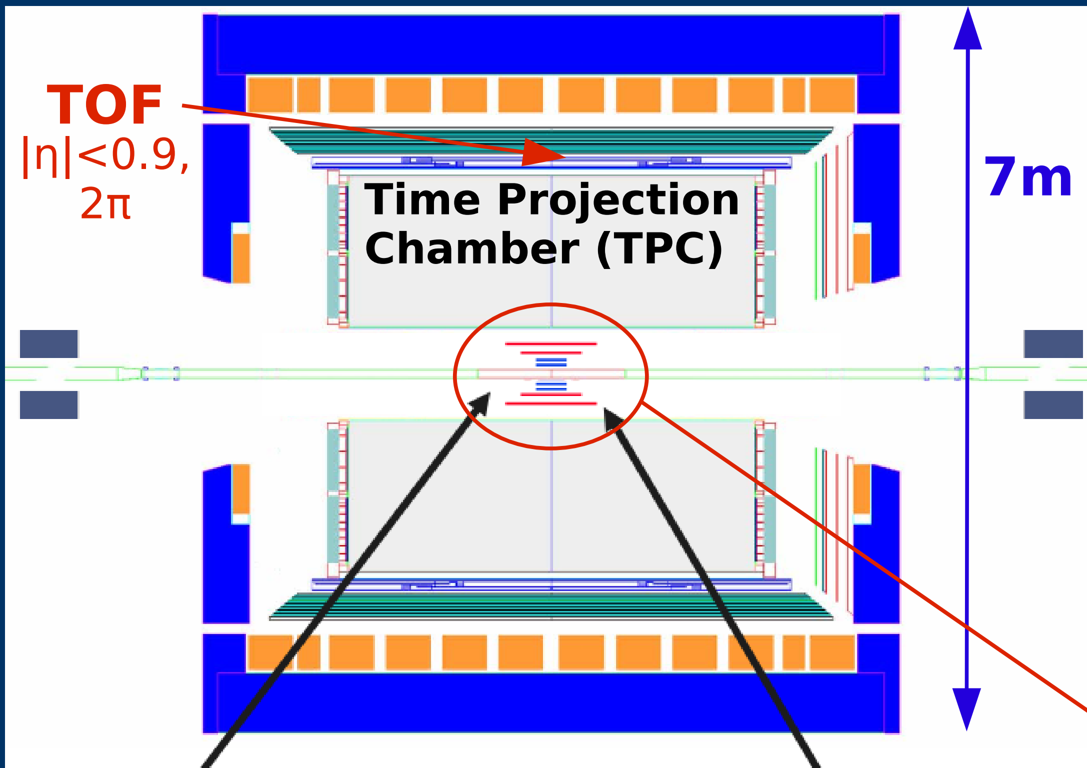
New detector requirements

- large background in central Au+Au (200 GeV) -> topological reconstruction needed



- STAR needs a high resolution displaced vertex detector:
  - measure down to very low p_T : thin detector to minimize Multiple Coulomb Scattering
  - high luminosity (RHIC-II: ~ 50 kHz minimum bias rate – stochastic cooling): the detector has to be fast & radiation hard

STAR with proposed Heavy Flavor Tracker (HFT)

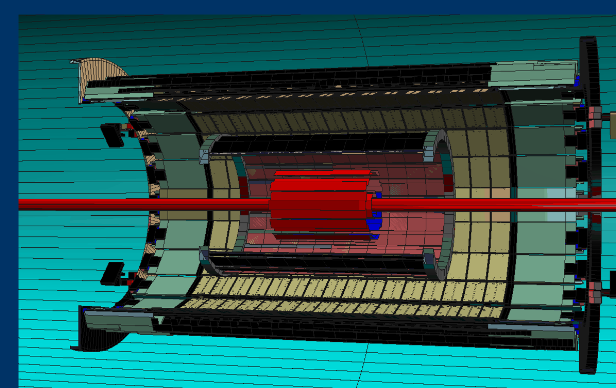


HFT

Silicon Strip
Detector (SSD)

the goal of inner tracking:

- extend TPC tracks to lower radii --> deliver ultimate impact parameter ("pointing") resolution, enabling topological identification of heavy flavor
- acceptance: 2π, |η| < 1.0



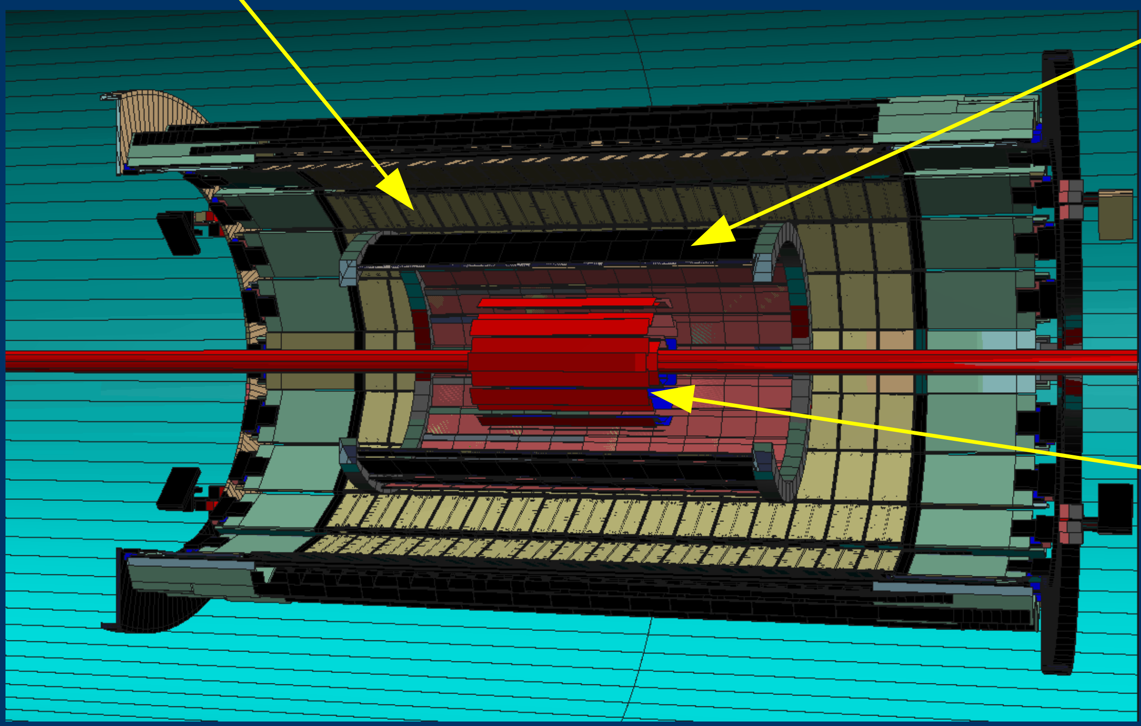
graded pointing resolution:
TPC --> SSD --> HFT --> Primary Vertex (PV)

Heavy Flavor Tracker design

- PIXEL detector – 2 layers, thin active pixels

  \+
- Intermediate Silicon Tracker (IST) – 1 layer, fast strips

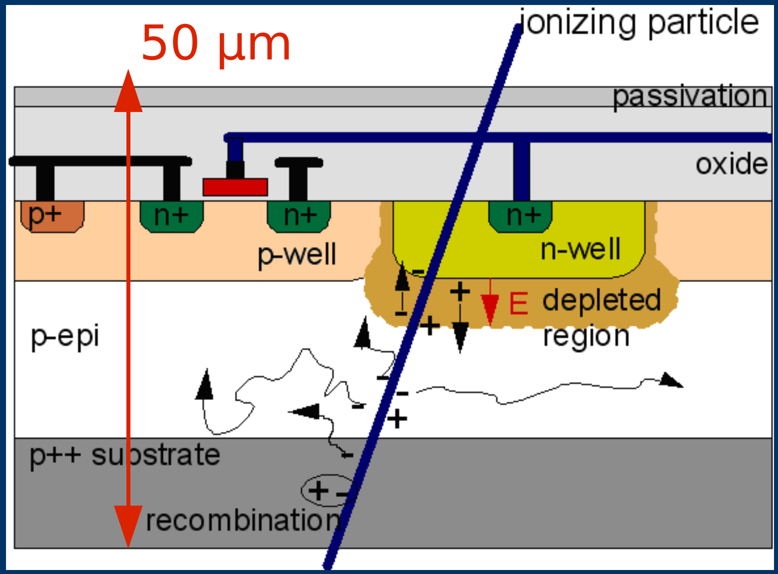
SSD: r=23cm, existing detector, double-sided strips, 1% X_0

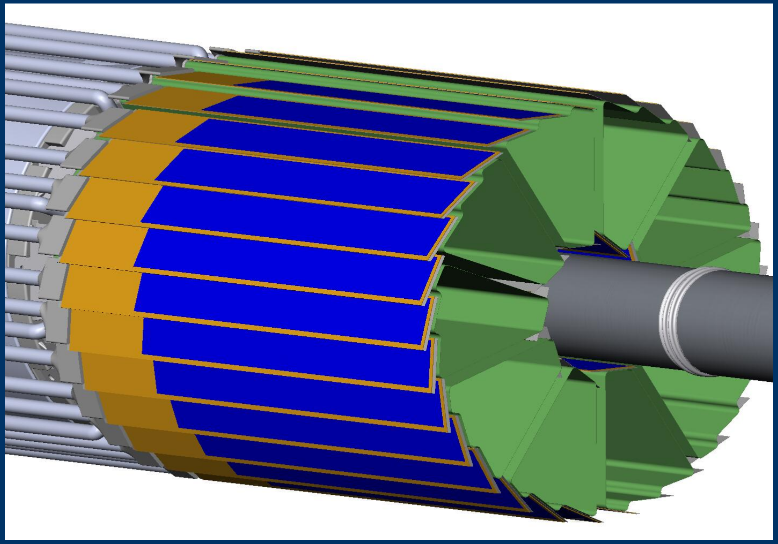


IST: r=14cm
- improve hit finding at outer PIXEL layer: RHIC-II luminosity – hit density 8 cm^{-2}
- 500 μm thick 1cm long strips along beam direction, 1.2% X_0

PIXEL: r=2.5cm and r=8cm
- deliver ultimate pointing resolution
- hit density at first layer ~ 60 cm^{-2}: not an issue

PIXEL detector
(IPHC Strasbourg + LBNL)



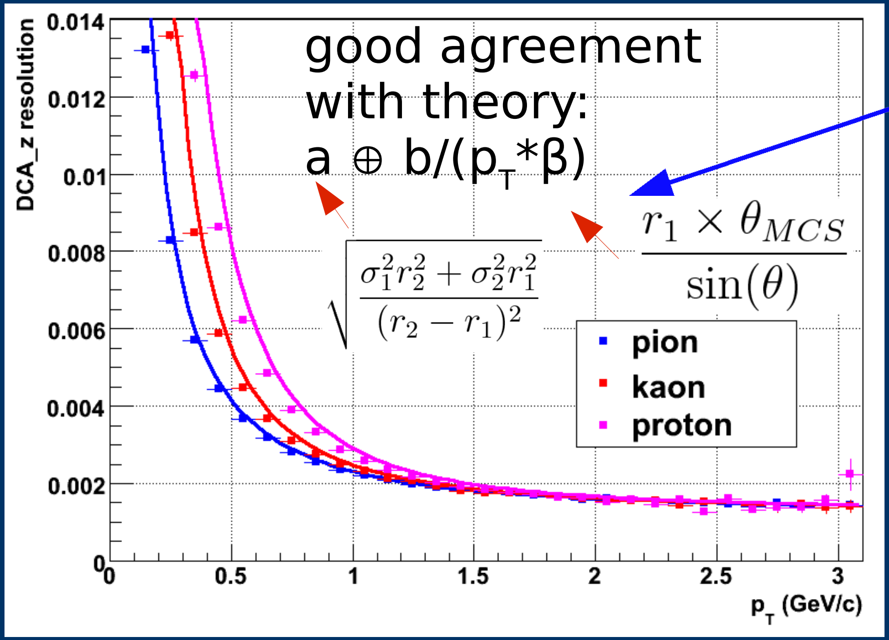


- novel Monolithic Active Pixel Sensors
- CMOS technology, radiation tolerant
- 18 µm pixel pitch, thin depletion region
- signal collection:
  - ➔ diffusion of e^- created in 15 µm thick p-epi
  - ➔ small contribution from p++ sub e^-
  - ➔ collection time ~ 100 ns
- overall material budget: 0.28% X_0 / layer
- continuous readout, integrates hits during readout frame (~200 µs) – hit densities correspond to 10 piled-up minbias collisions
- current prototypes (MimoSTAR):
  - ➔ 2 ms integration time, analog readout
- final MAPS sensor design:
  - ➔ 200 µs integration time, digital readout, on-chip cluster finding
  - ➔ full-size detector installation ~2012

Simulations of HFT performance

- HIJING central Au+Au with added D^0/Λ_C, 20 k events
- pile-up at RHIC-II $\mathscr{L}$ for 200 μs integration time of PIXEL:
  - ➔ pseudo-random hits added
  - ➔ significant contribution of UPC electrons for PIXEL1 layer
- assuming PID with TOF: 90% efficient, separation of K/π: p_T<1.6 GeV/c, (K+π)/p: p_T<3.0 GeV/c

track impact parameter resolution:



pointing resolution delivered by PIXEL detector

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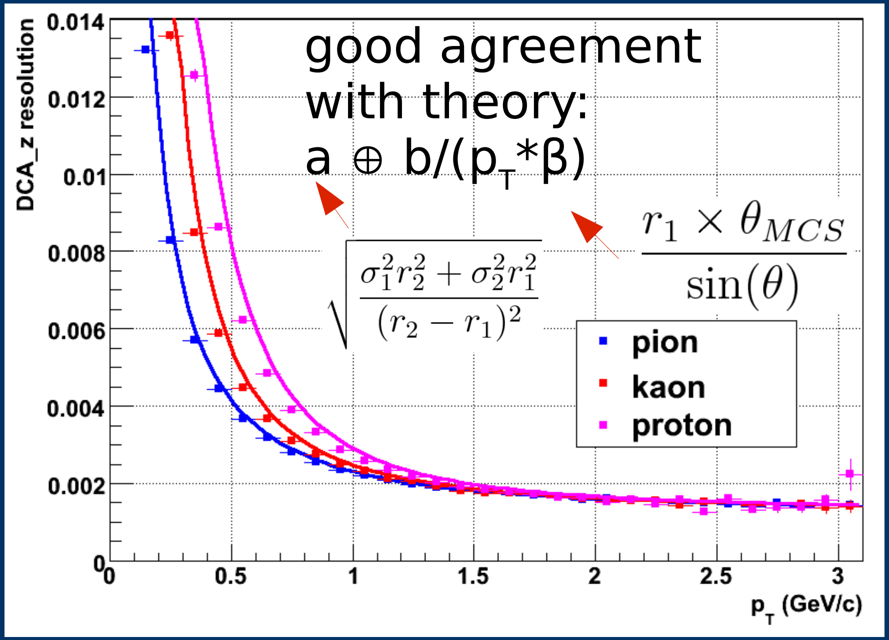


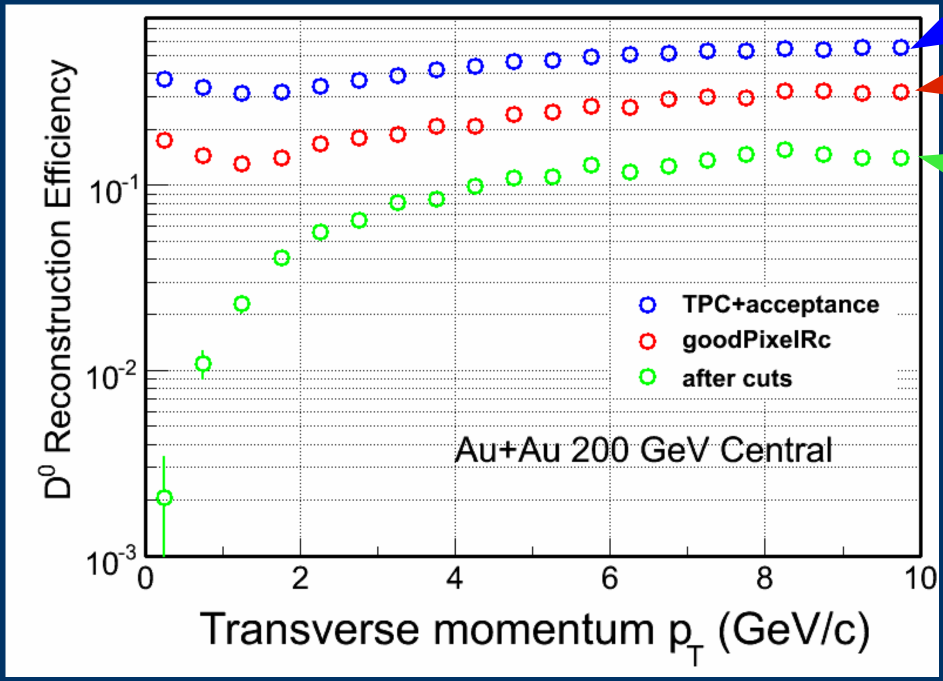
upcoming simulations – expect better results:

- geometry changed (optimised IST design)
- RHIC-II luminosity dropped (80 kHz with electron cooling)
- pixel size decreased (from 30 μm)

no systematic errors
perfect alignment

D^0 reconstruction

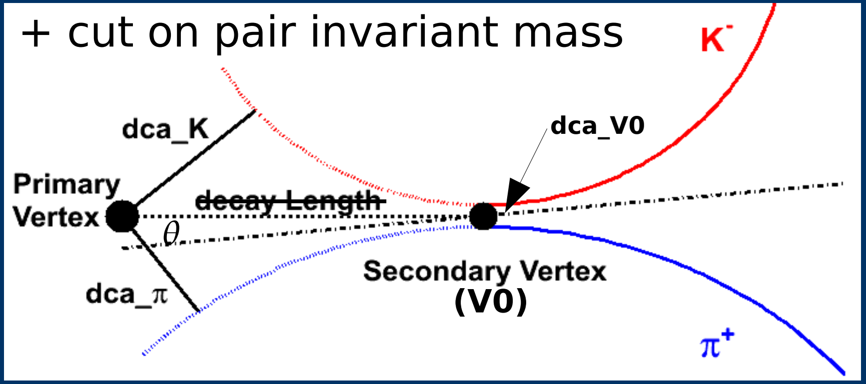
- $D^0 \rightarrow K^- \pi^+$, B.R. 3.8%; <u>cτ = 123 μm</u>; m = 1.865 GeV/c^2
- assuming:
  - N_{bin} scaling for D^0 yields, p+p: dN/dy = 0.002
  - power-law p_T spectrum: $dN/dp_T = p_T * (1+p_T/p_0)^{-n}$ $\langle p_T \rangle$ = 1.0 GeV/c, n=11



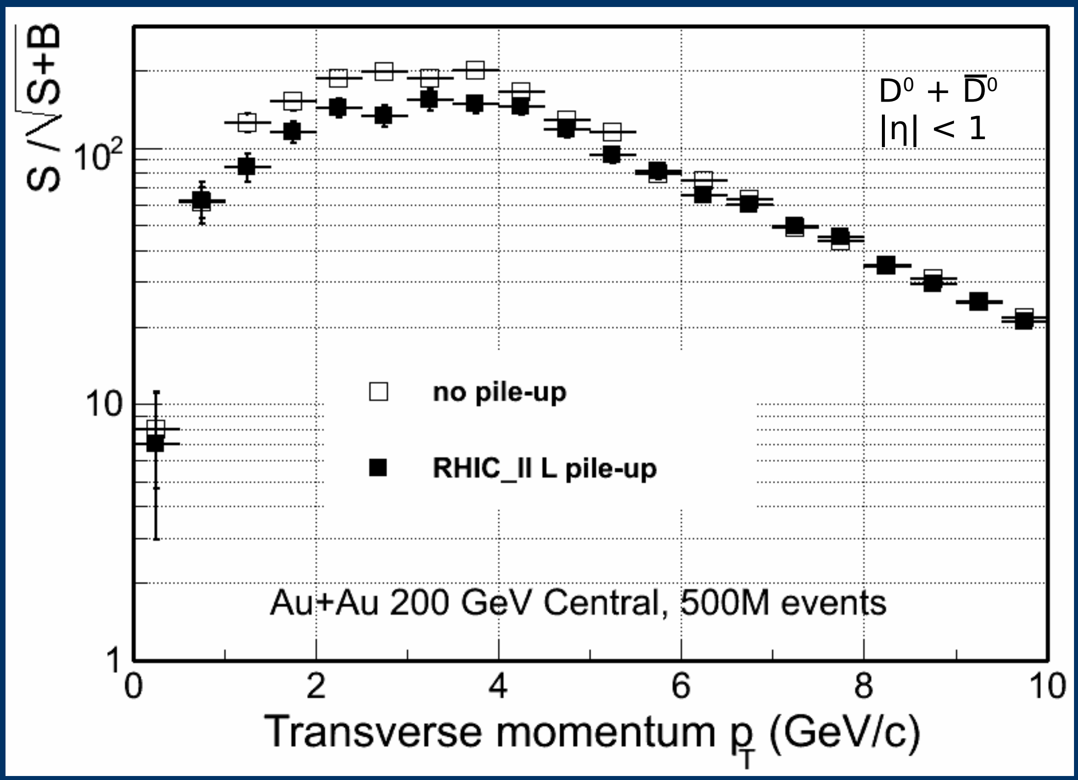
TPC reco + PIXEL acceptance

require good reconstructed hits in both PIXEL layers

after topological cuts:

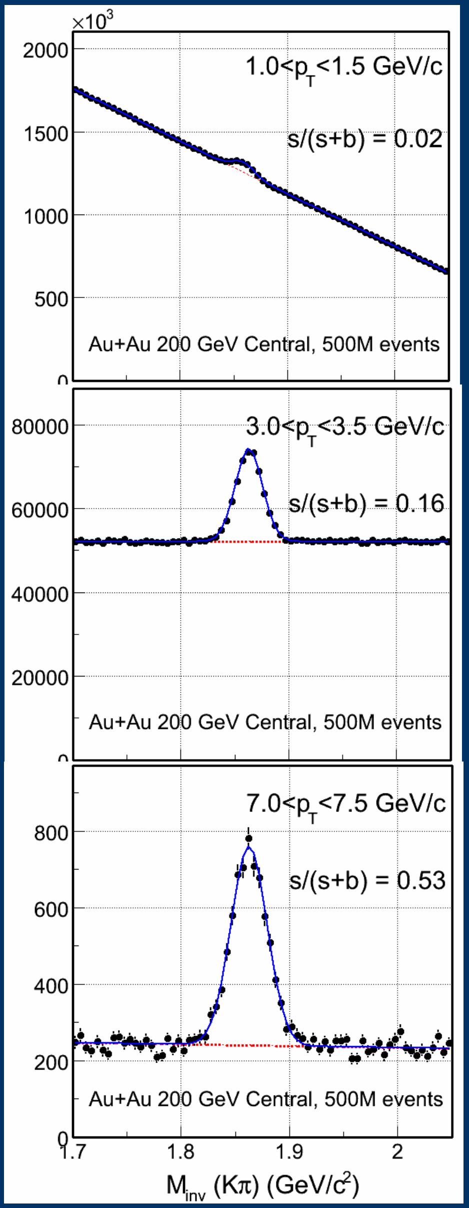


D^0 – signal from 500M central Au+Au events



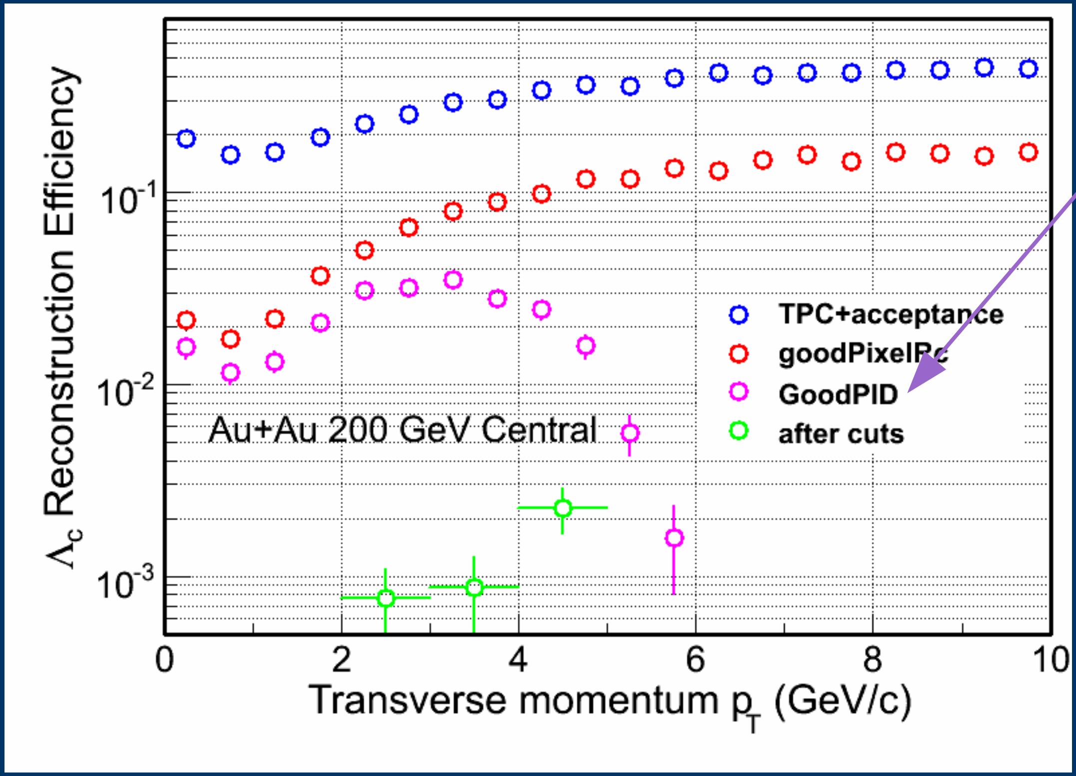
despite significant effect of pile-up, detector performance still very good

estimated mass peaks



Λ_c reconstruction

- $\Lambda_C \rightarrow K^- \pi^+ p$, B.R. 5%; **<u>cτ = 60 μm</u>;** m = 2.286 GeV/c^2
- for the case of no enhancement: $\Lambda_C/D^0 \sim 0.2$

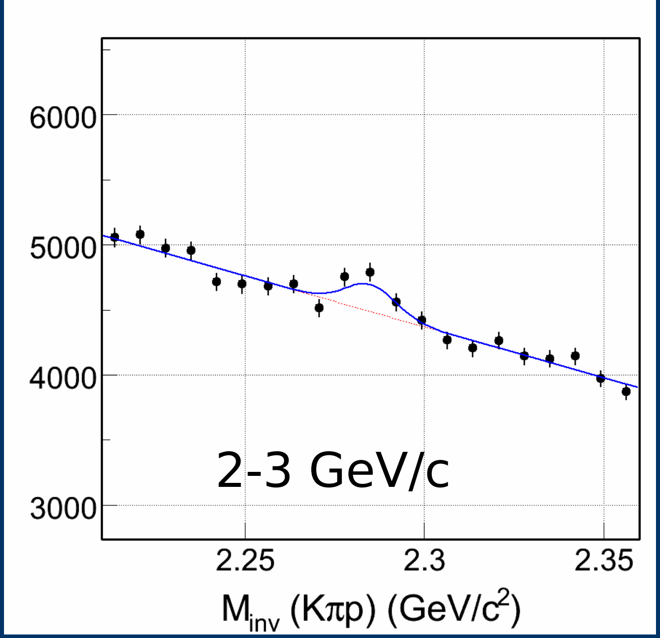


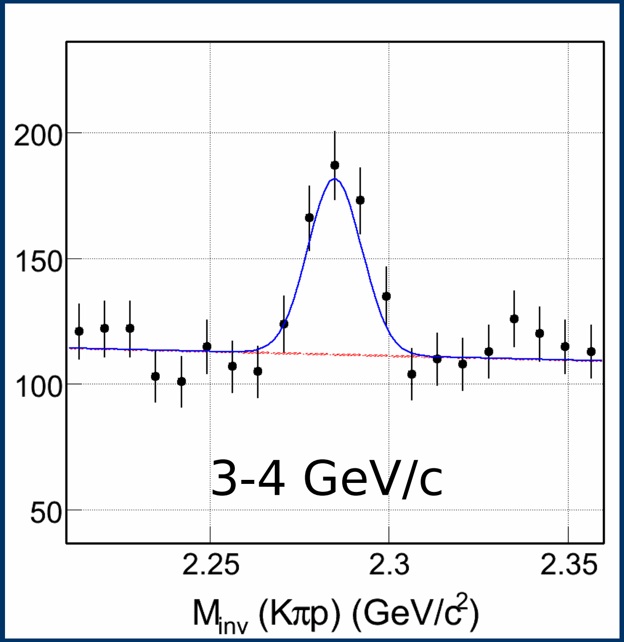
PID of daughter tracks required to reduce combinatorial background – gives better signal significance for p_T<5 GeV/c, although it limits acceptance

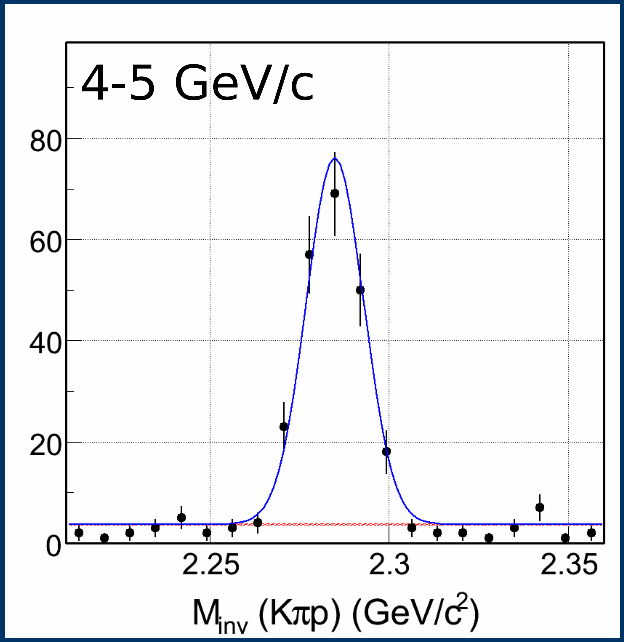
- can't get 3 sigma signal for p_T<2 GeV/c
- optimized cuts for p_T 2-5 GeV/c, where we want to measure (enhanced?) Λ_C/D^0 ratio

Λ_c signal significance
500M central Au+Au events

- due to lower yield and large backgrounds, it's much worse than for D^0
- estimated mass peaks for no Λ_c/D^0 enhancement:



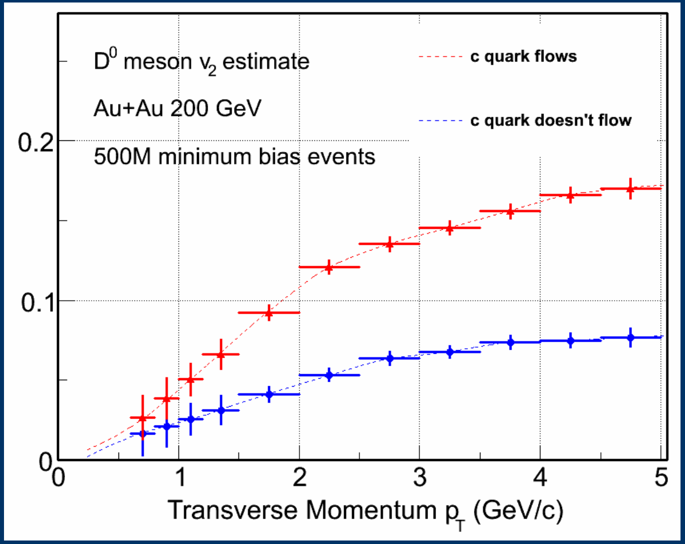


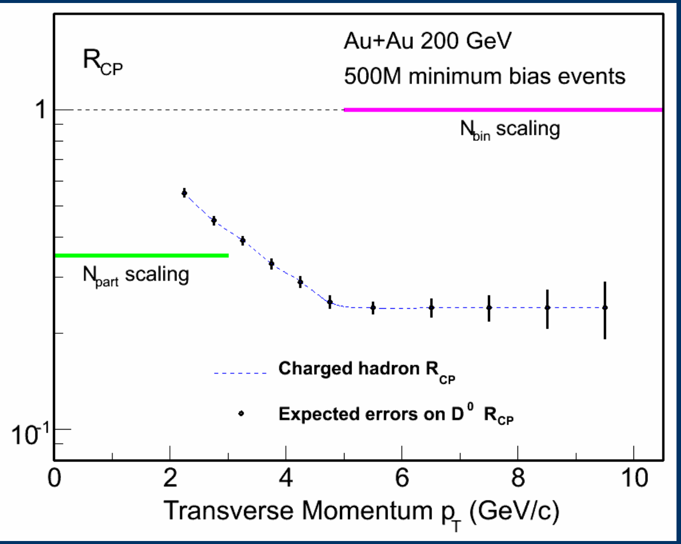


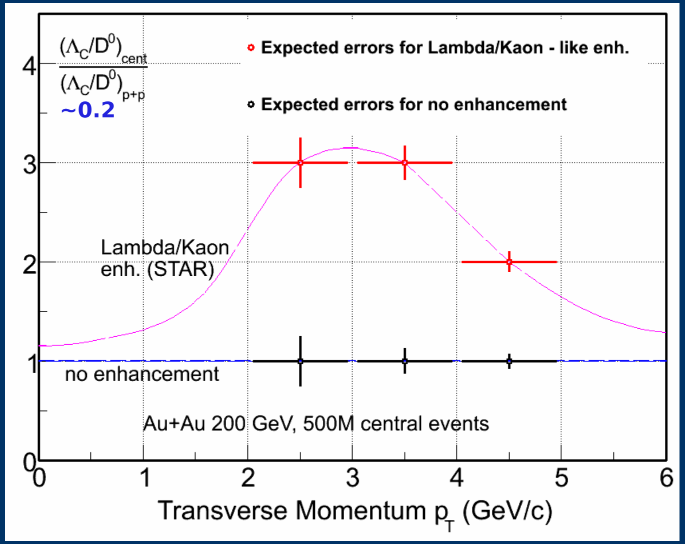
signal:	500	180	200
background:	19k	470	20
s/sqrt(s+b):	4	8	14
s/(s+b):	0.03	0.3	0.9

Expected first results

year 1 | year 2







- v_2 of D^0 meson – flow of c quark
- extreme scenarios:
  - $v_2(c) = v_2(q)$
  - $v_2(c) = 0$

- pin down energy loss of c quark
- test mechanisms of energy loss in the medium

- Λ_C yield
- does the B/M anomaly persist in heavy quark sector?

Summary

- Heavy Flavor Tracker design approaching its final form
- HFT will perform topological reconstruction of open charm - precision measurements of D^0 meson v_2 and R_{CP}, Λ_C/D^0 ratio
- Heavy Flavor Tracker at STAR experiment will deliver key measurements to understand the properties of created medium and will make RHIC-II heavy flavor program competitive with the LHC


Thanks!

Backup

Recent articles

for more information about RHIC-II and theory, see for example:

A. D. Frawley, T. Ullrich and R. Vogt:
Heavy flavor in heavy-ion collisions at RHIC and RHIC II
(arXiv:0806.1013)

Ralf Rapp and Hendrik van Hees:
Heavy Quark Diffusion as a Probe of the Quark-Gluon Plasma
(arXiv: 0803.0901)

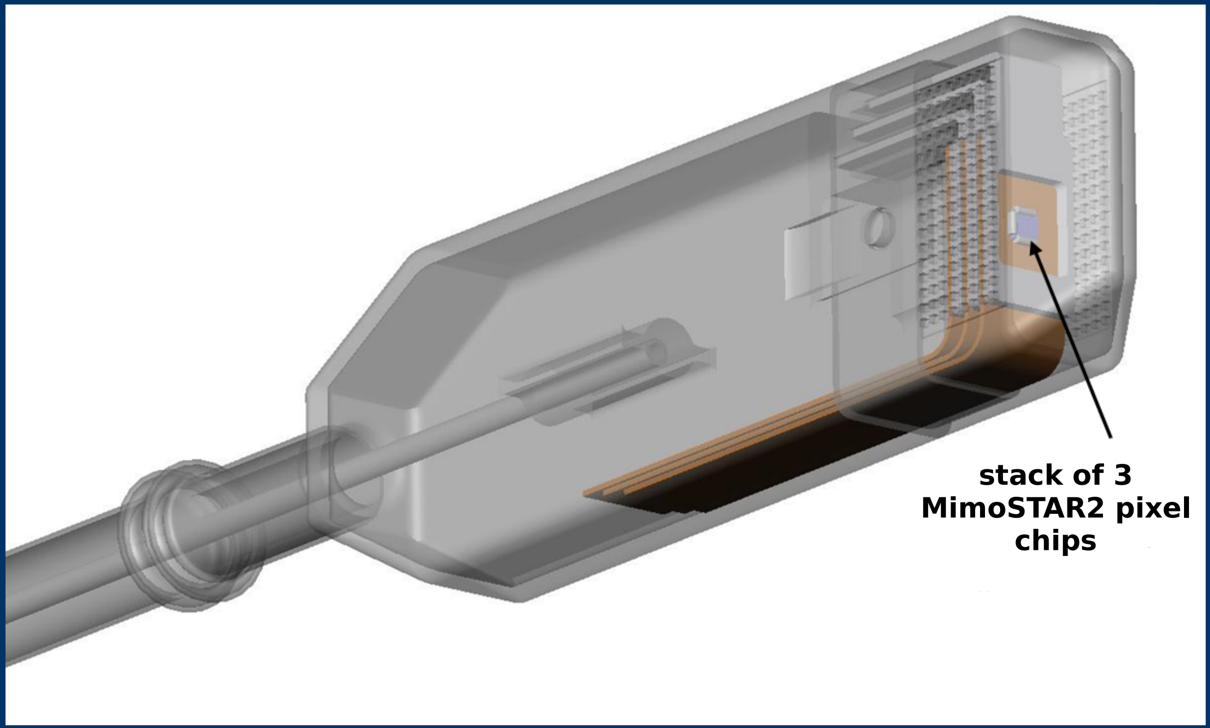
more on MAPS

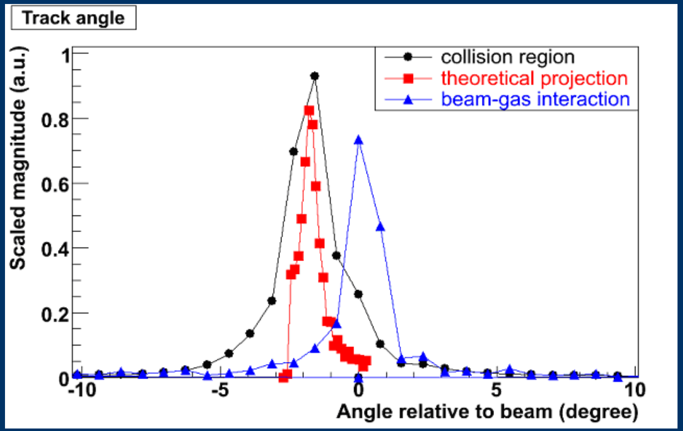
- old design (30 micron pitch)
  - diode 4.5 x 4.5 microns, ~2 microns thick
  - 14 microns p-epi thickness
  - substrate contribution ~ 20%
  - lifetimes epi: 10 mus, sub: 10 ns

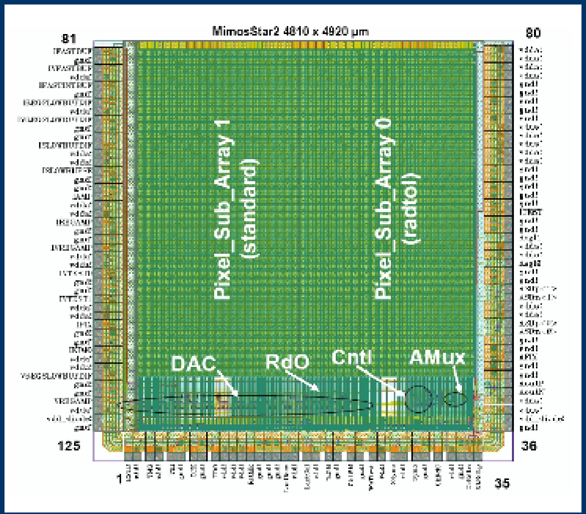
- electron diffusion: D = 3500 microns^2 / mus, therefore sigma = sqrt(2*D*t) is 80 microns in 1 mus, 8 microns in 10ns

- Si:
  - Z=14 A=28 rho=2.33 g/cm^3
  - dE/dx|MIP = 1.664 MeV/(g/cm^2) = 388 eV/micron (Bethe-Bloch)
  - Bichsel most prob. in 80 micron layer only 250 eV/micron!

MimoSTAR2


stack of 3
MimoSTAR2 pixel
chips


Track angle
collision region
theoretical projection
beam-gas interaction
Scaled magnitude (a.u.)
0
0.2
0.4
0.6
0.8
1
-10
-5
0
5
10
Angle relative to beam (degree)


MimosStar2 4810 x 4920 μm
Pixel_Sub_Array 1
(standard)
Pixel_Sub_Array 0
(radtol)
DAC
RdO
Cntl
AMux
81
80
125
36
1
35

MIMOSTAR 2/3 technology

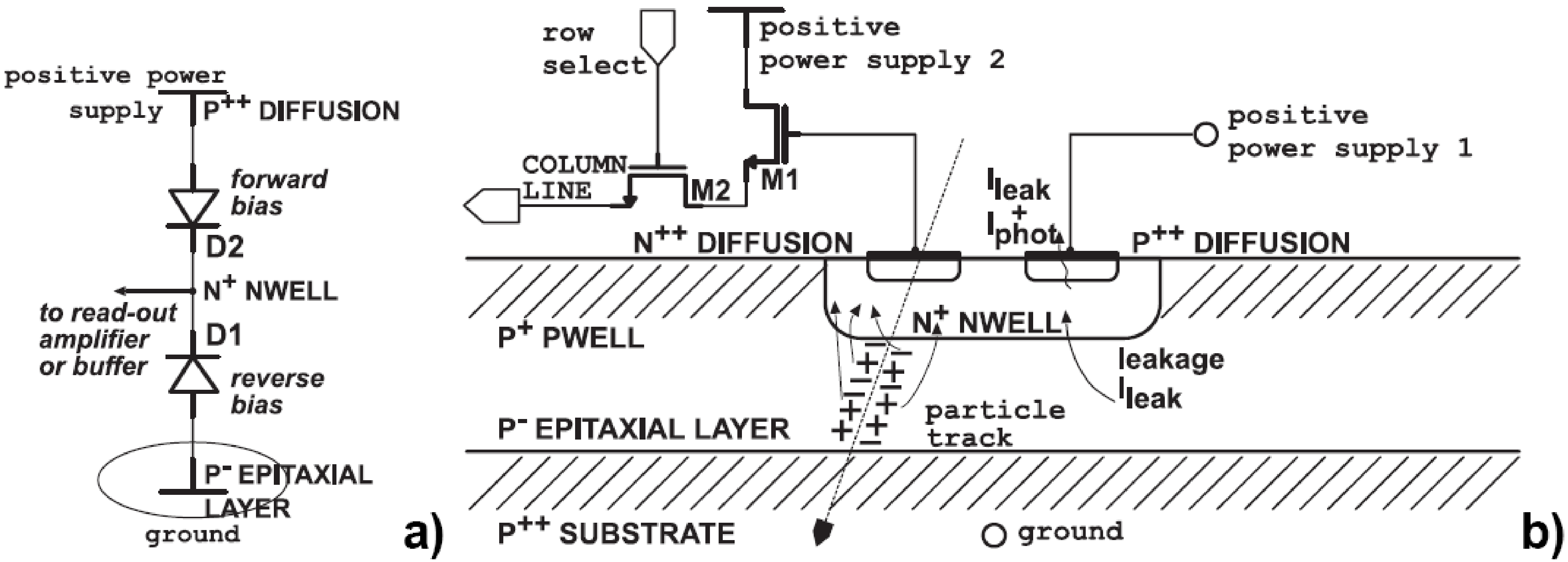
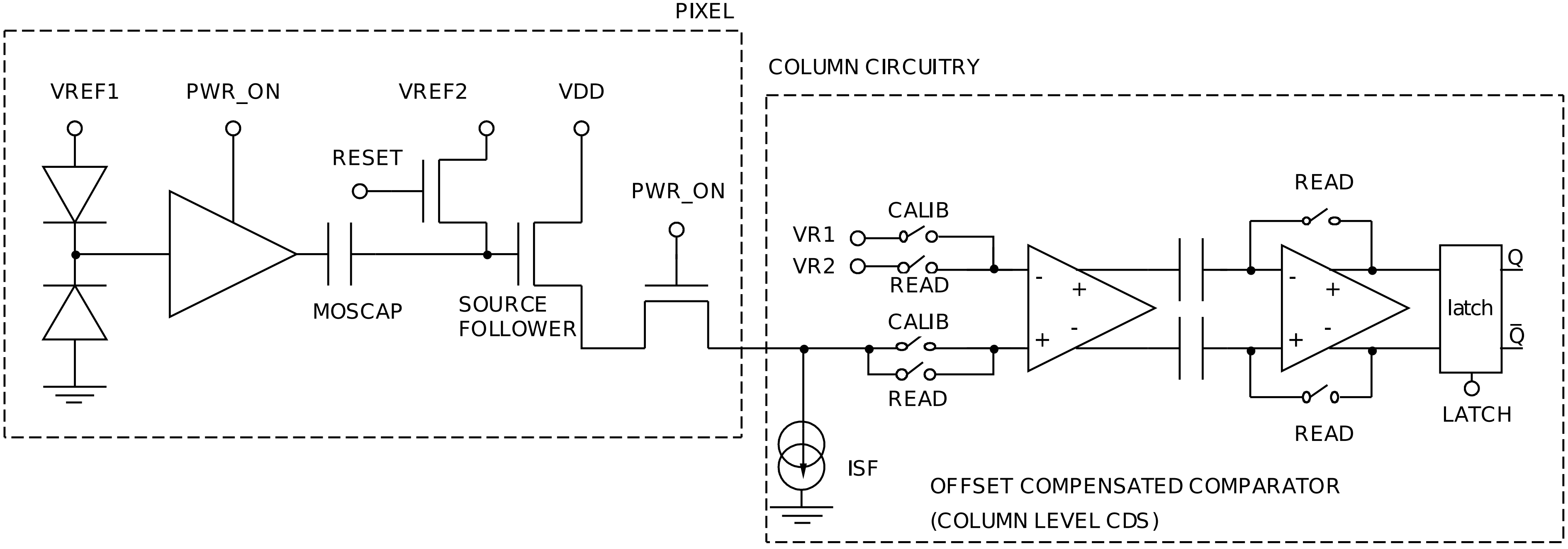


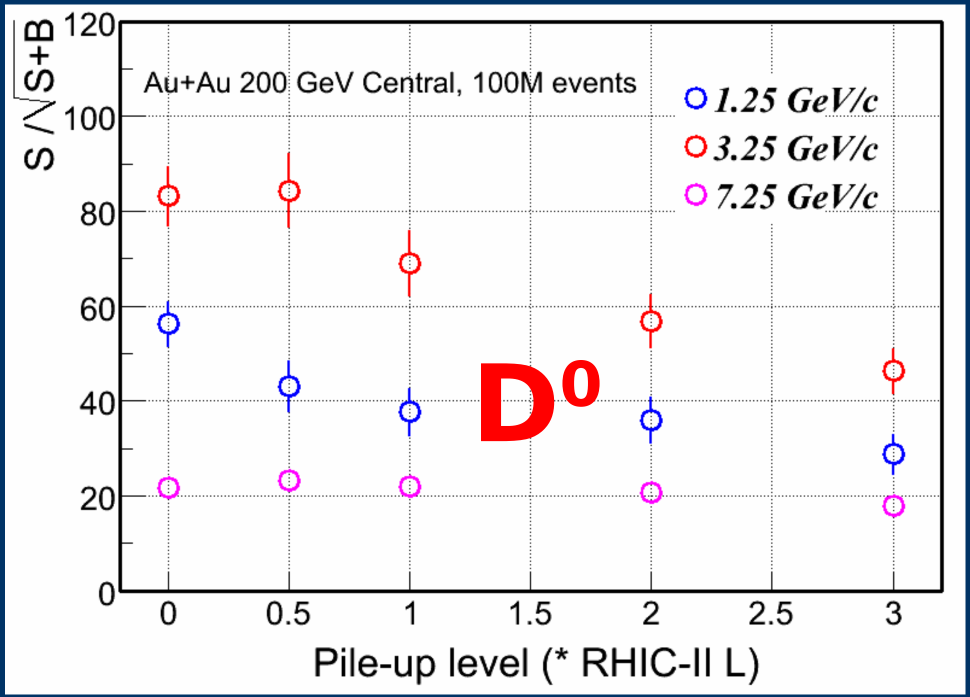
Figure 7-5: Two-diode logarithmic pixel, (a) principle of continuous reverse biasing, (b) conceptual design of pixel structure exploiting continuous reverse bias of the diode for charge collection.

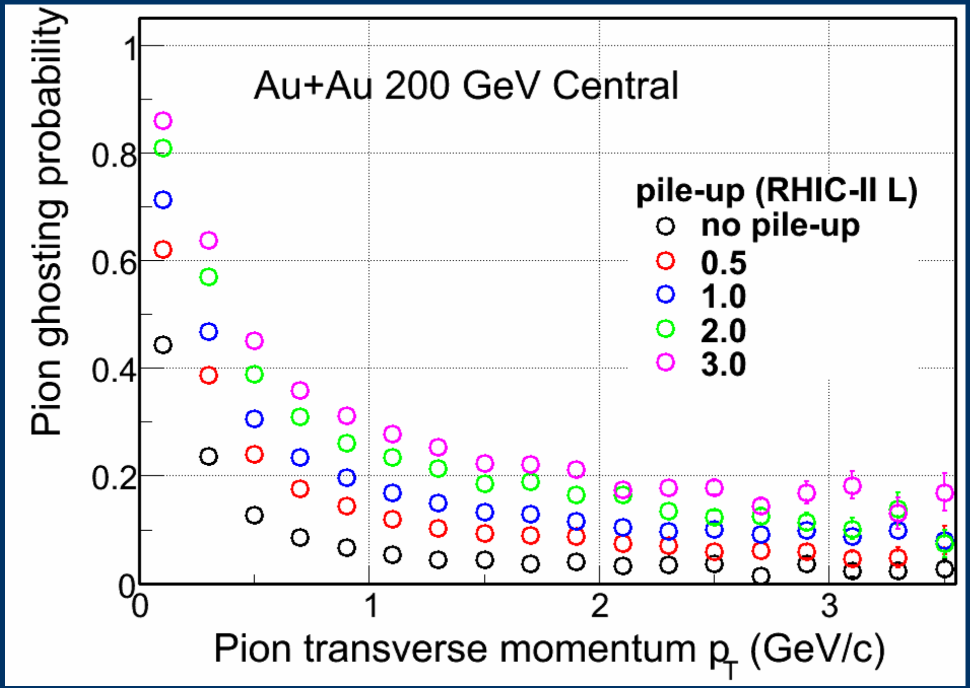
Phase 1 / Ultimate technology (MIMOSA8/16/22)



Howard Wiemann – HFT CD0 review (February 2008, BNL)

higher luminosities + ghosting





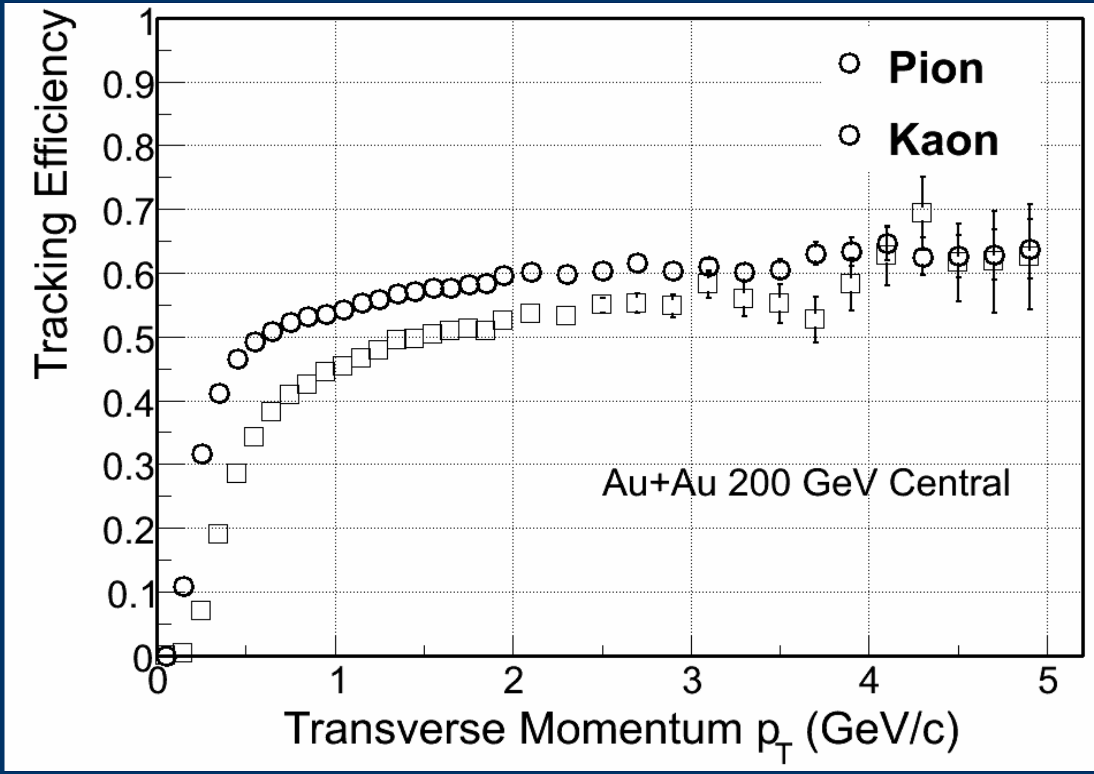
detector designs

	current design		simulated design	
layer	r (cm)	Hit resolution (r-φ x z) (μm x μm)	r (cm)	Hit resolution (r-φ x z) (μm x μm)
SSD	23	30 x 699	23	30 x 699
IST2-B	-	-	17	17 x 12000
IST2-A	-	-	17	12000 x 17
IST1	14	115 x 2900	12	17 x 5500
PIXEL2	8	5 x 5	7	9 x 9
PIXEL1	2.5	5 x 5	2.5	9 x 9

	simulated design	
layer	central collision hit density (cm^{-2})	RHIC-II pile-up hit density (cm^{-2})
SSD	0.21	-
IST2-B	0.38	-
IST2-A	0.38	-
IST1	0.77	-
PIXEL2	2.3	6.0
PIXEL1	17.8	43

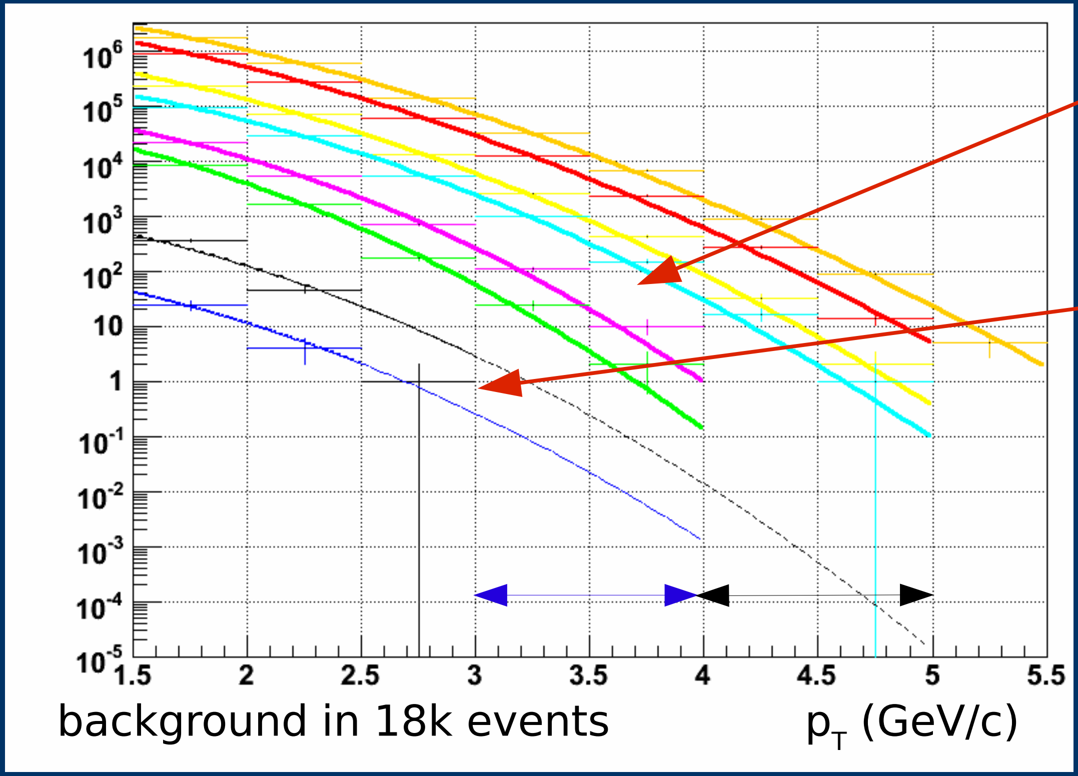
PIXEL1: significant contribution from UPC electrons

Single track efficiency



2 good PIXEL hits
TPC eff+acceptance at high p_T: ~90%

Lc – details on S and B

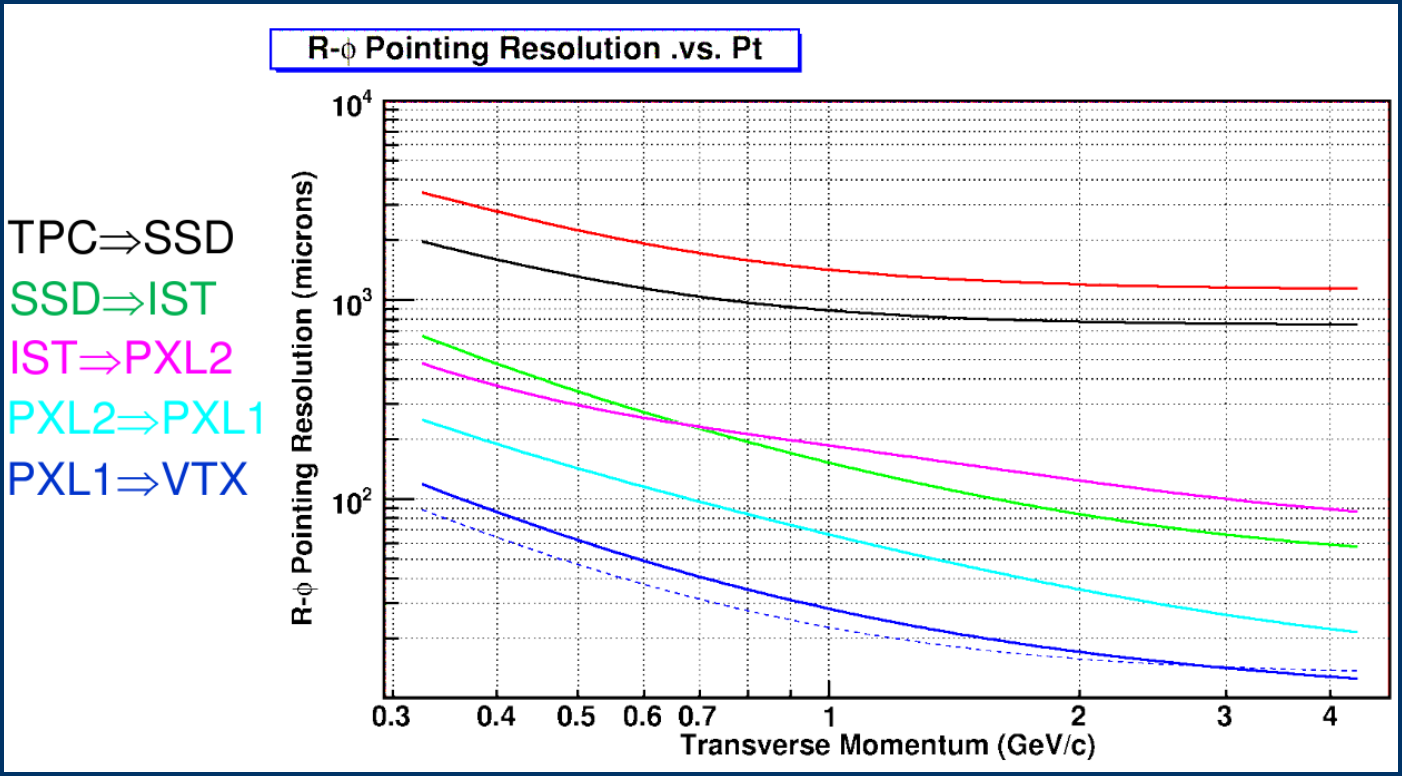


looser cuts, fit formula:
exp(-a * x^b), gives:
a ~ 0.6-0.8, b ~ 1.9-2.2

fitted for bg estimate in:
3-4 GeV/c (blue)
4-5 GeV/c (black)
fits reasonably well for:
a ~ 0.7-0.8, b ~ 2.05-2.2
taken the worst case:
a = 0.7, b = 2.05

500M central events, no
Lc/D0 enhancement

TPC --> PIXEL: pointing res.

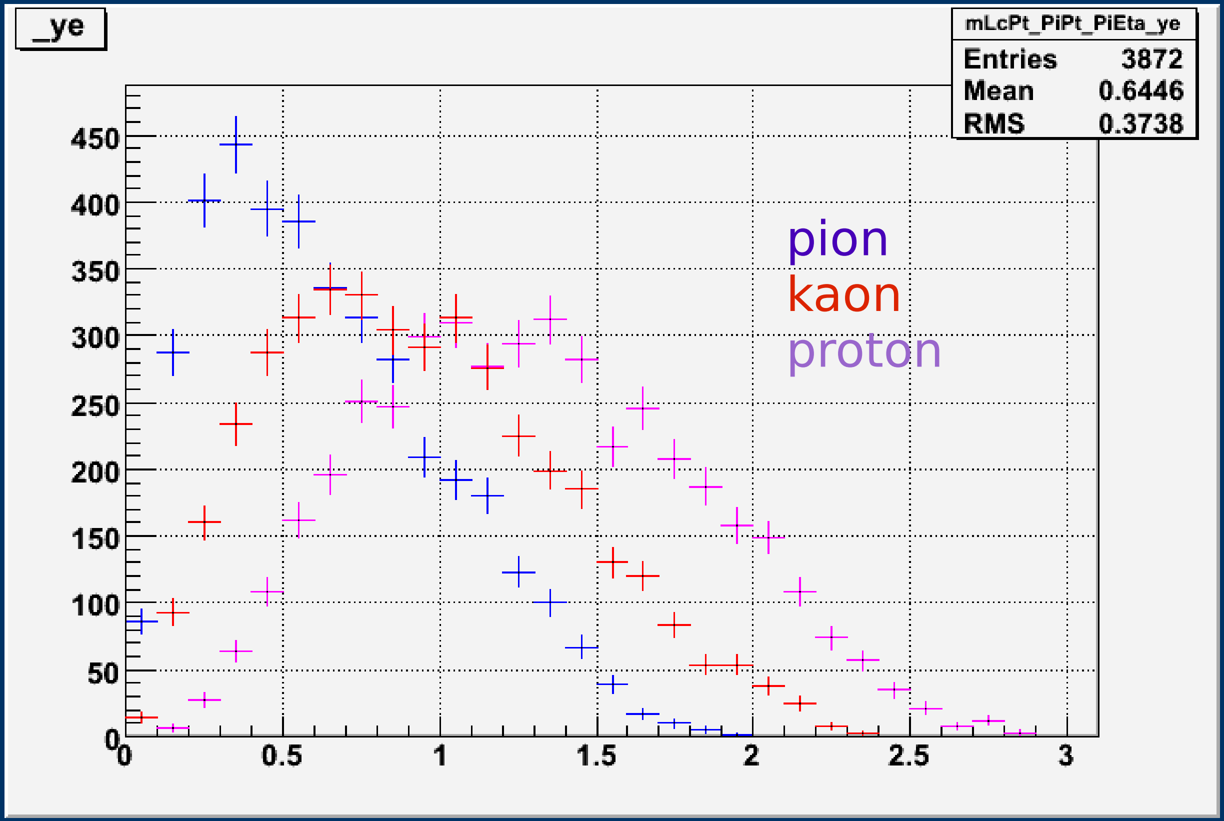


Open charm hadrons & decays

particle	mass (GeV)	cTau (microns)	decay	B.R. (%)	res. mass	res. width
D0	1.865	122.9	K- Pi+	3.8		
			K- Pi+ Pi+ Pi-	7.7		
D+	1.870	311.8	K- Pi+ Pi+ non-res	7.5		
			K*bar^0 Pi+ --> K- Pi+ Pi+	1.1	896 MeV	50 MeV
Ds+	1.968	149.9	phi Pi+ --> K- K+ Pi+	2.2	1020 MeV	4 MeV
			K*bar^0 K+ --> K- K+ Pi+	2.5	896 MeV	50 MeV
Lc+	2.286	59.9	p K- Pi+ non-res.	2.8		
			p K*bar^0 --> p K- Pi+	1.6	896 MeV	50 MeV
			Lambda* Pi+ --> p K- Pi+	1.8	1520 MeV	16 MeV

selected (useful) decay modes, PDGLive 2007
for Lc, most promising resonant decay channel is the one with Lambda*
another good: Ds+ --> phi Pi+ --> K- K+ Pi+

decay kinematics – Lc



daughter p_T peaks at much lower values than for D^0

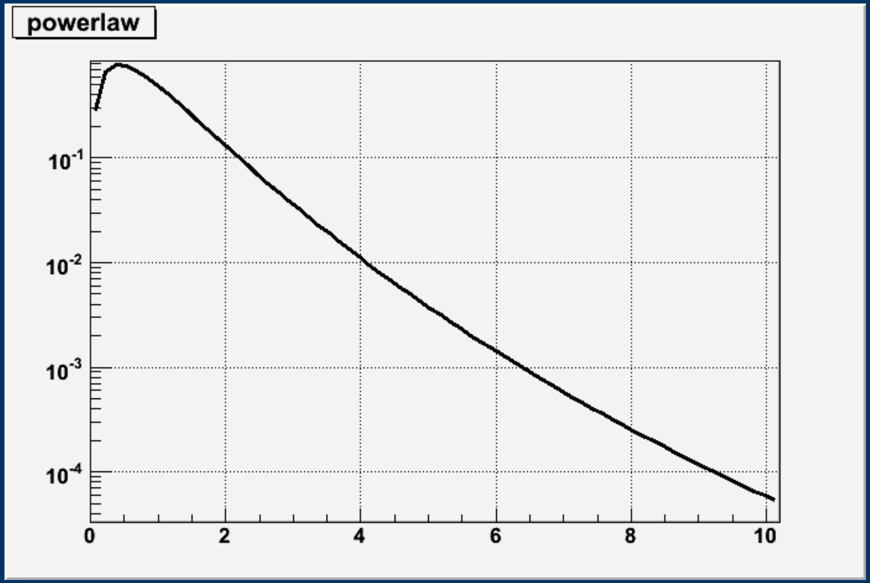
Lc: 2-3 GeV

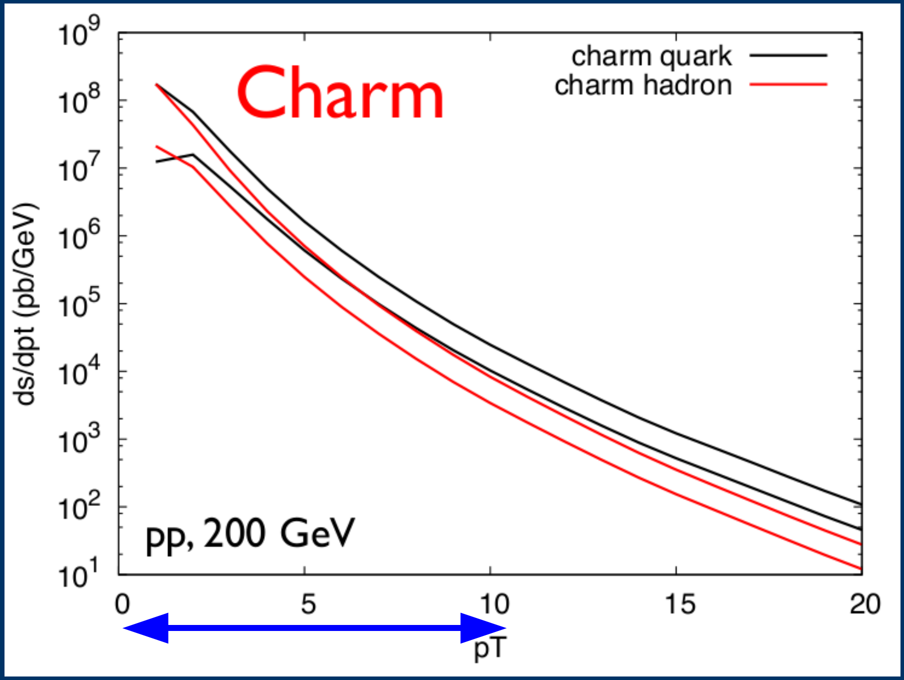
D0 and Lc isolation cuts

	D0		Lc	
	all pT	2-3 GeV	3-4 GeV	4-5 GeV
dca_PV >	50 µm	80 µm	80 µm	60 µm
dca_V0 <	50 µm	1.9 sigma	1.9 sigma	1.9 sigma
cos (theta) >	0.98	0.996	0.996	0.995
Minv (GeV) >	1.83	2.27	2.27	2.27
Minv (GeV) <	1.90	2.30	2.30	2.30

for Lc cuts optimized for 3 different p_T bins,
tighter than for D0 (much bigger background)
for D0 same cuts for all pT bins...

pT spectra – FONLL & power-law

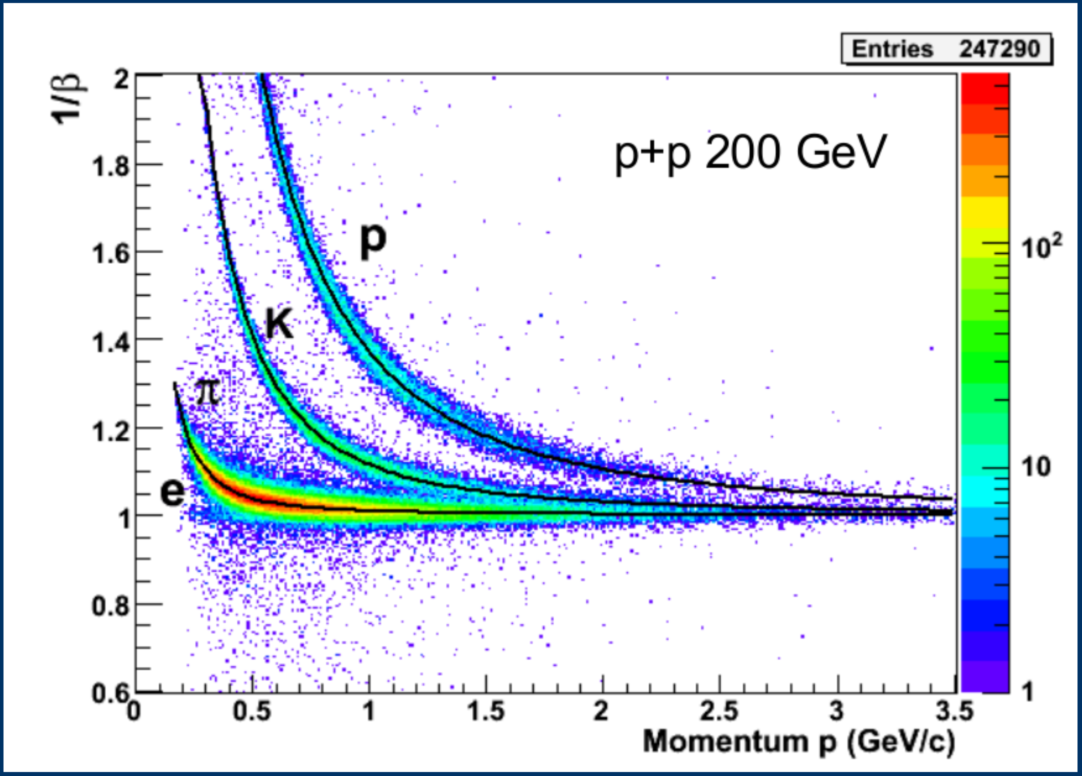




M. Cacciari, Bad Honnef, June 2008
http://www.physi.uni-heidelberg.de/~kschweda/heavy-quarks/M._Cacciari.pdf

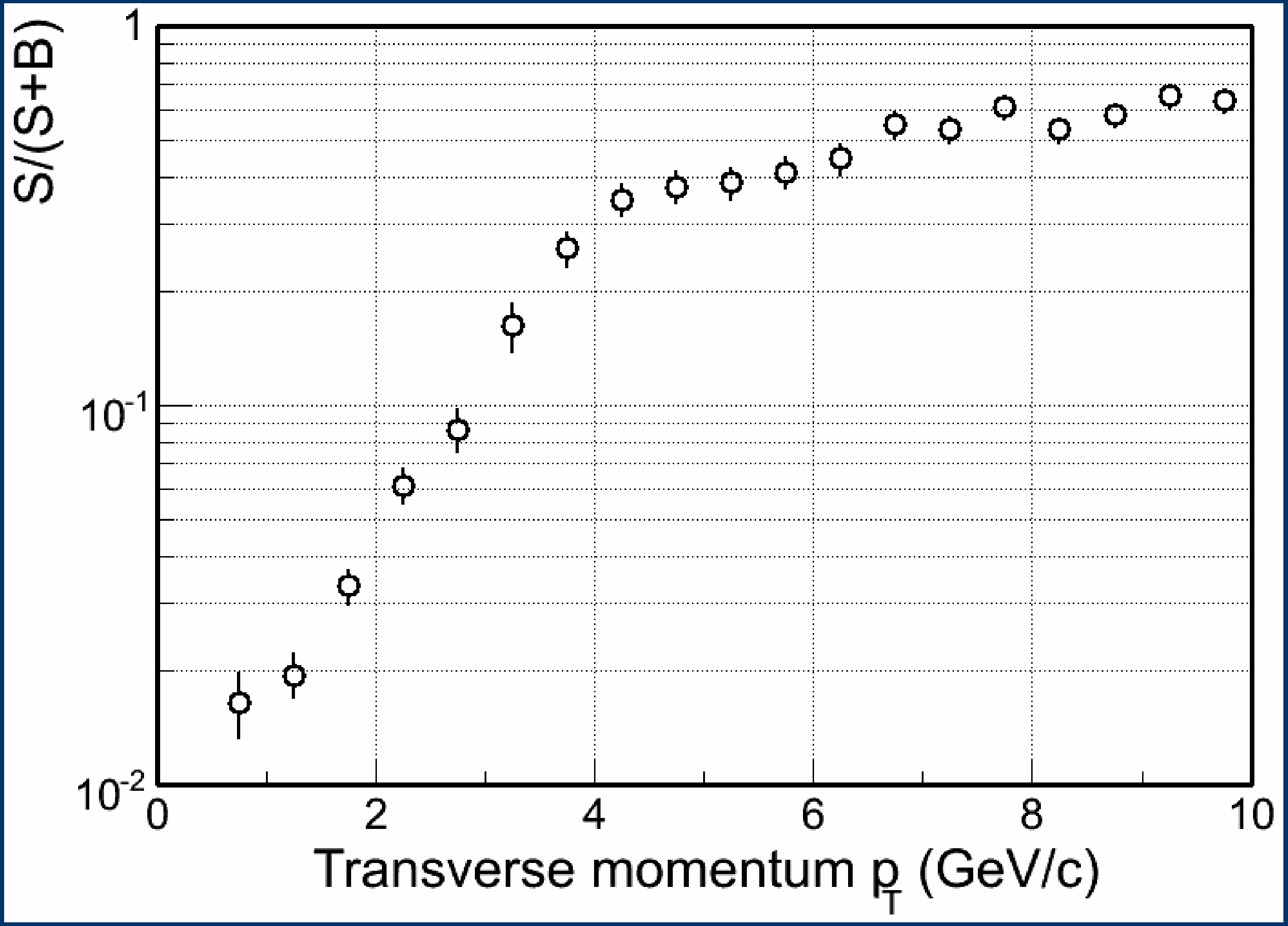
STAR TOF + DAQ 1000

in 2008 run, 1 (of 24) upgraded TPC sector, and 5 (of 120) TOF trays operational and in commissioning



picture: Xin Dong, March 2008

D^0 signal purity



RHIC-II
pileup