The HFT: a Heavy Flavor Tracker at STAR

- Physics motivations
- Detector design
- Simulation Results

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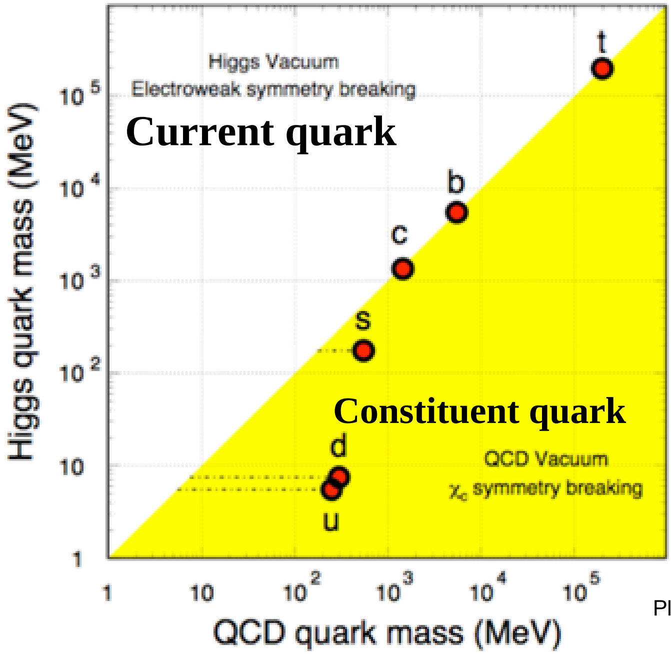
for the STAR Collaboration

"Heavy Flavor" is the Final Frontier

The QGP is the universally accepted hypothesis at RHIC

next step: proof of **thermalisation** of the **light quarks**

charm and beauty are unique in their **mass** structure



Plot: N. Xu

flow of charm : key element …

Mc≈1.5 GeV >> Λ_{QCD} >> M_{uds}

Unique probe

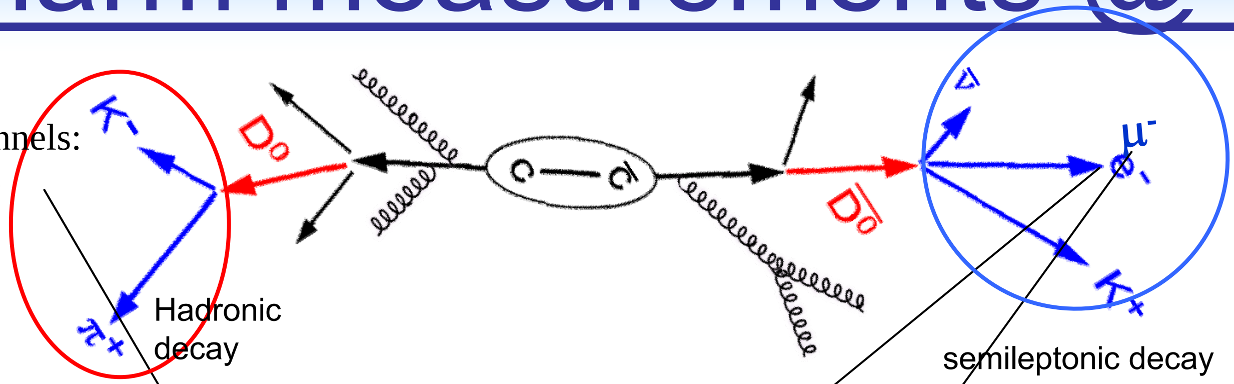
If **heavy quarks flow:**

- **frequent interactions** among all quarks
- **light quarks** (u,d,s) likely to **be thermalized**

Charm measurements @ STAR

- Hadronic decay channels:

$D_0 \rightarrow K\pi$ (B.R.: 3.8%)

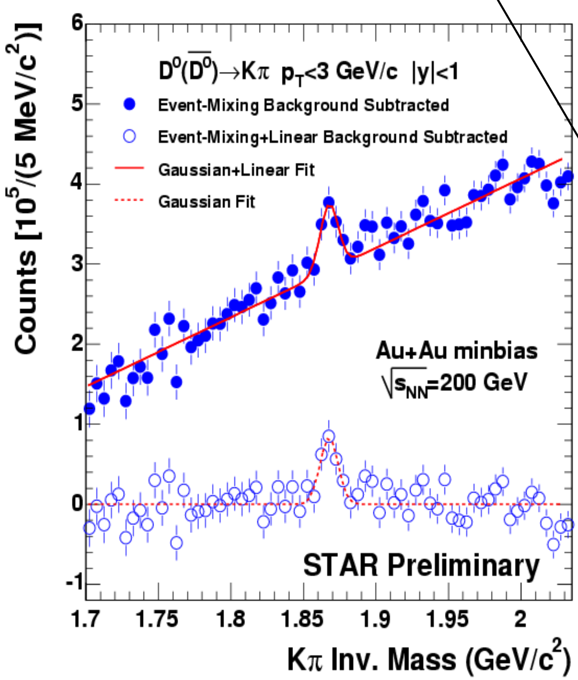


$c \rightarrow e^{+}$ + anything

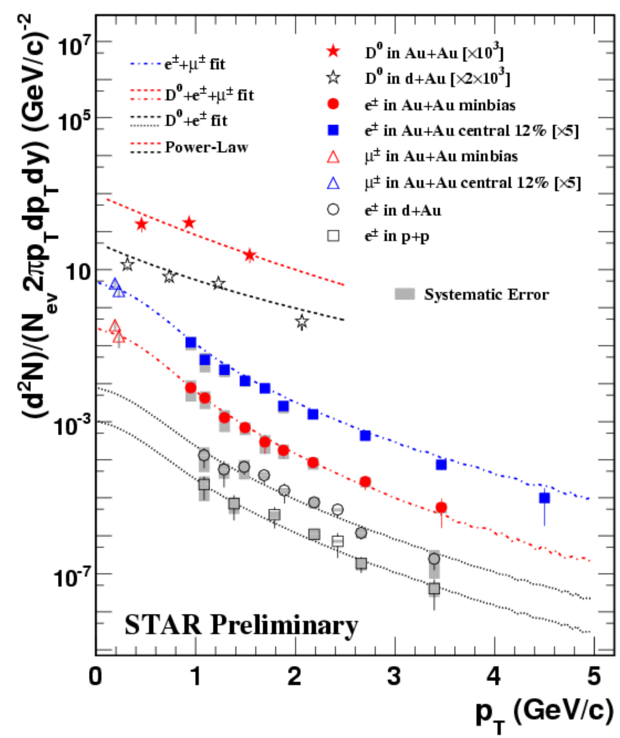
$c \rightarrow \mu^{+}$ + anything

$D^{0} \rightarrow e^{+}$ + anything

$D^{0} \rightarrow \mu^{+}$ + anything



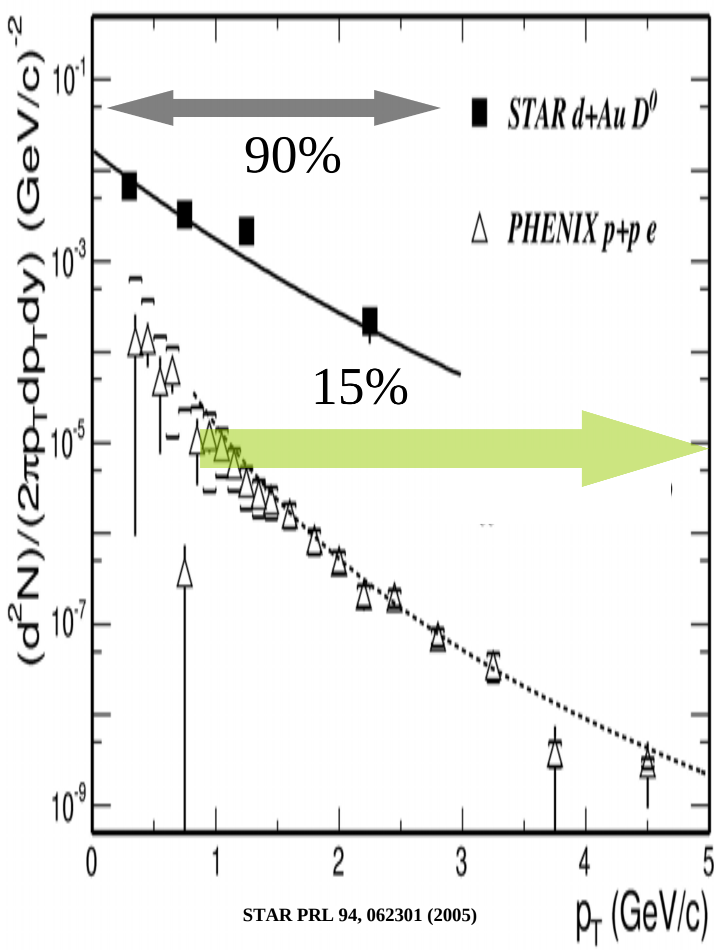
- o **hadronic** "Direct" D^0 reconstruction
  (event. Mixing technique)
- o **muon** from charm semileptonic decay
- o **electron** from heavy quark semileptonic decay



Haibin QM05 nucl-ex/0510063

detail in Haibin, Jaro & Frank 's talks

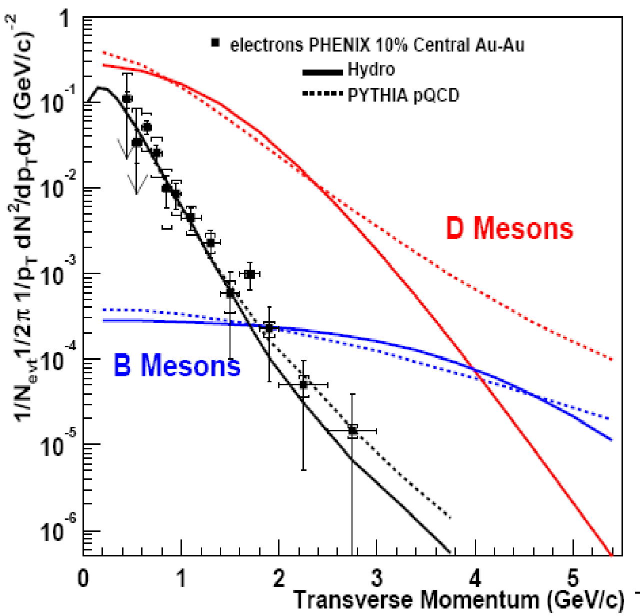
Open questions



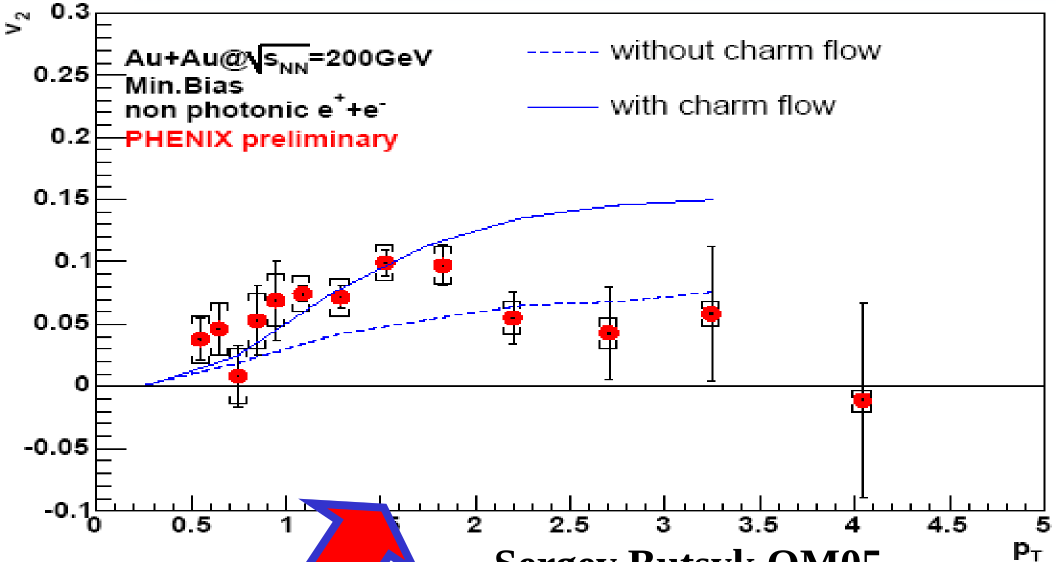
STAR PRL 94, 062301 (2005)

- o **Precisely understand** the charm cross-section
- o **Low P_T** is crucial
- o e^- are **not** direct probes (come ftom D and B)

S. Batsouli, et al, Phys.Lett.B 557 (2003) *26*



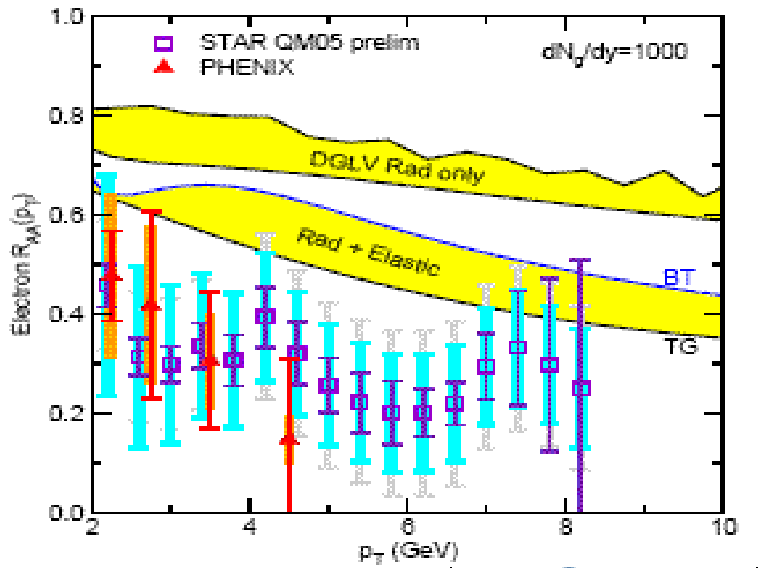
Open questions (2)

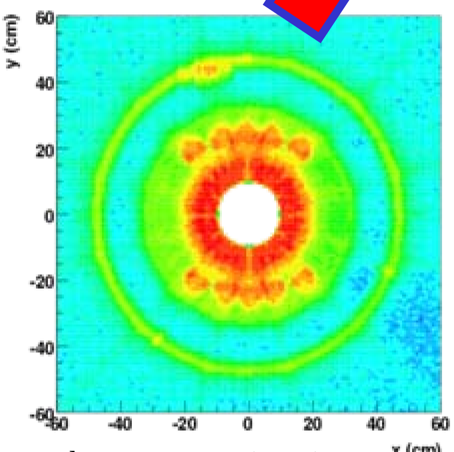


Sergey Butsyk QM05

- Large **systematics** on v2
- due to **Photonic background**
- Need large **statistics** to check **predictions**
- R_{AA} challenge to **theory**

M.Djordjevic (SQM06)



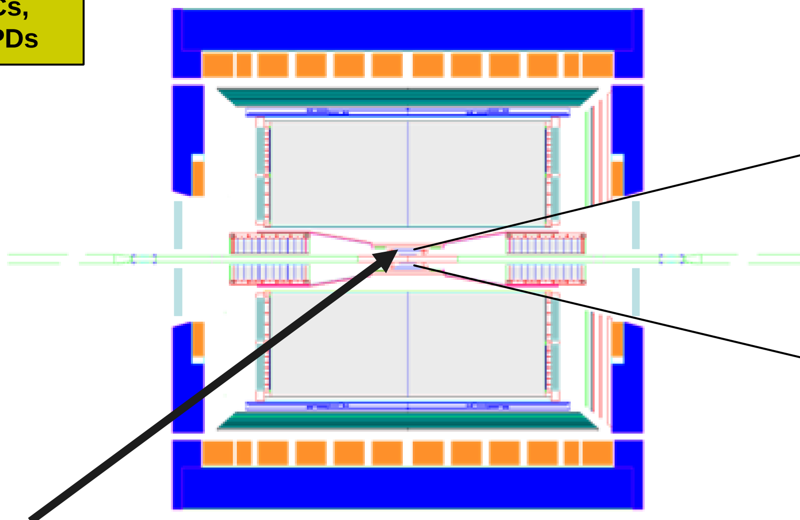


Photon conversions in star

Need Direct (topological) Charm measurements

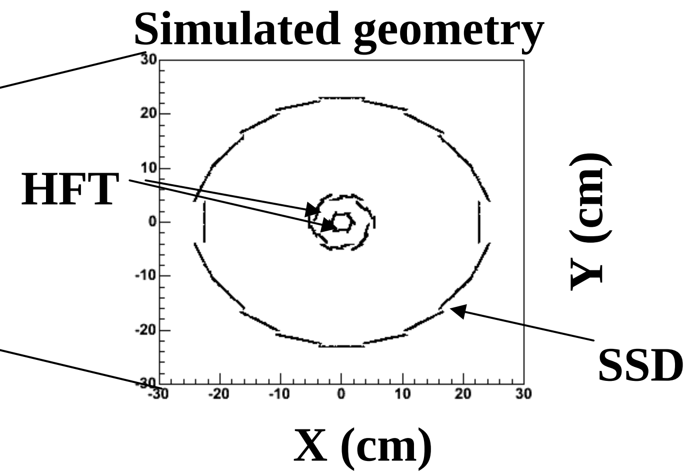
The *Heavy Flavor Tracker* in STAR

Not Shown: pVPDs, ZDCs, PMD, and FPDs



The HFT

The STAR detector at RHIC.



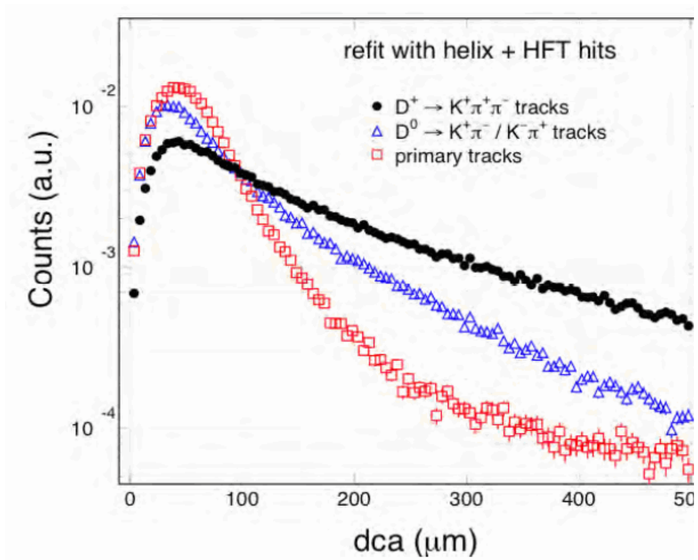
- 2 layers

  Radius : 1.5 cm and 5 cm , 24 ladders

  -2 cm x 20 cm each

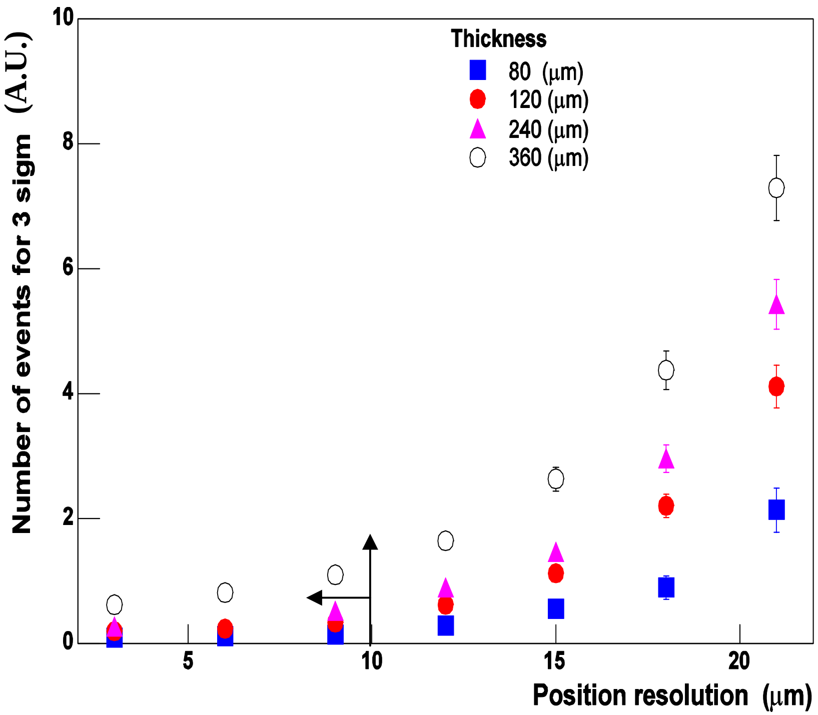
  CMOS pixel sensors because we need :

  - high **precision** (detector resolution : **10 μm**)
  - a **thin detecor** (**260 μm equi. Si**) per layer
  - a **fast detector** (proto. **4 ms** integration time)
  - low power consumption (**< 100 mW/cm²**)
  - Moderate radiation tolerance (**5 – 10 kRad/year**)



Where are the limits?

What are the effects of **Multiple Coulomb Scattering** and detector **resolution**?



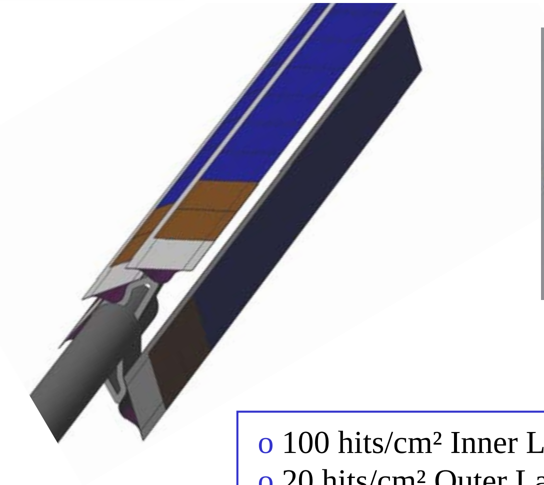
Sub detectors	D0 N evt. for 3 σ	D_s^+ N evt for 3 σ
TPC+SVT	12.6 M	500 M (K0s + K+)
TPC+SVT+TOF	2.6 M	100M
TPC+SSD+HFT	12 k	5M ($\phi+\pi^+$)
TPC+SSD+HFT + "TOF"	10 k	2 M ($\phi+\pi^+$)

Thickness

- Detector resolution 10 μm OK
- Thin detector (240-360 μm)

Position resolution

Mechanical design

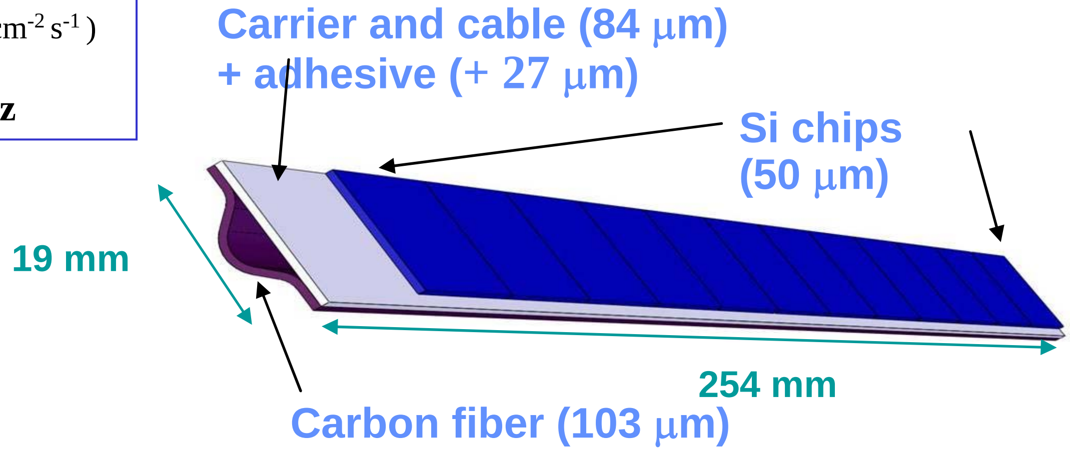


Prototype Carrier

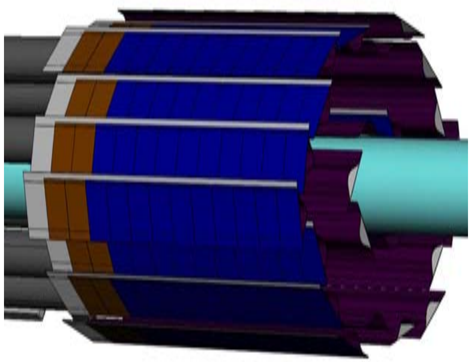
Prototype Cu conductor cable

X_0 =0.090 % (for Al conductors)

- 100 hits/cm² Inner Layer,
- 20 hits/cm² Outer Layer (L = 10^{27} cm^{-2} s^{-1})
- Average event size = **90 KB**
- Event size = **90 MB/sec at 1KHz**



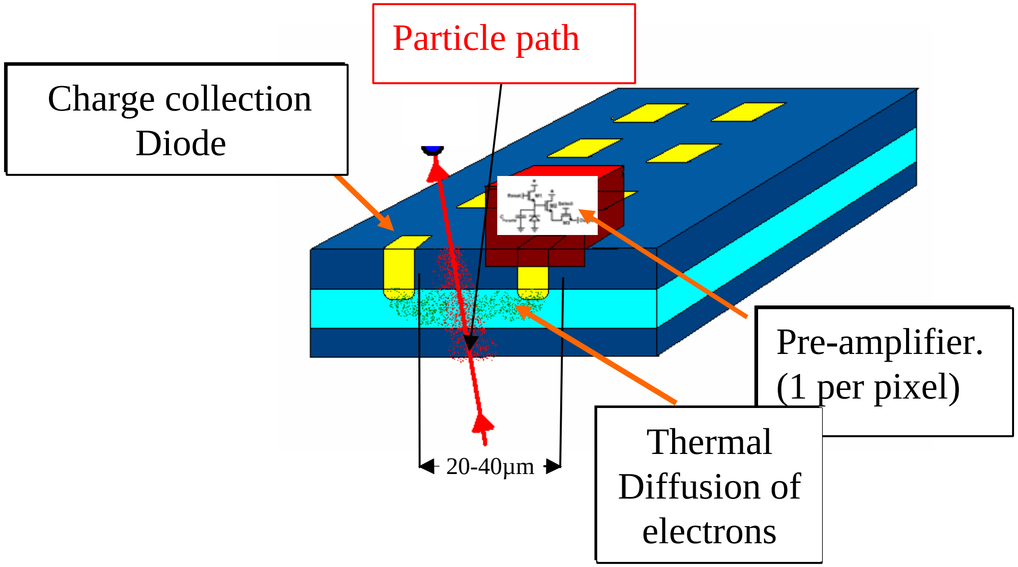
One HFT ladder (working Geometry)

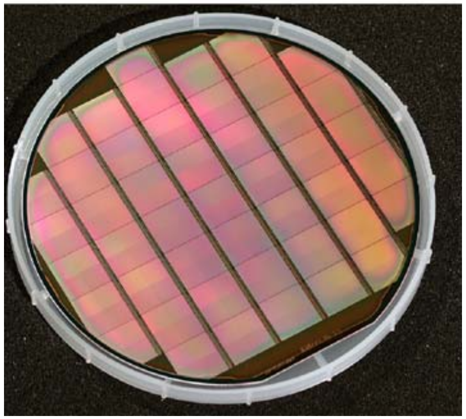


HFT (Side View)

- Total Rad. length < 0.28 X_0 (260 μm) **per layer**
- Air-cooled

CMOS Active Pixel Sensors





MIMOSA5 APS wafer

o **AMS 0.35 µm** opto. Technology

Current prototype (Mimo*2):

o 128x64 pixels

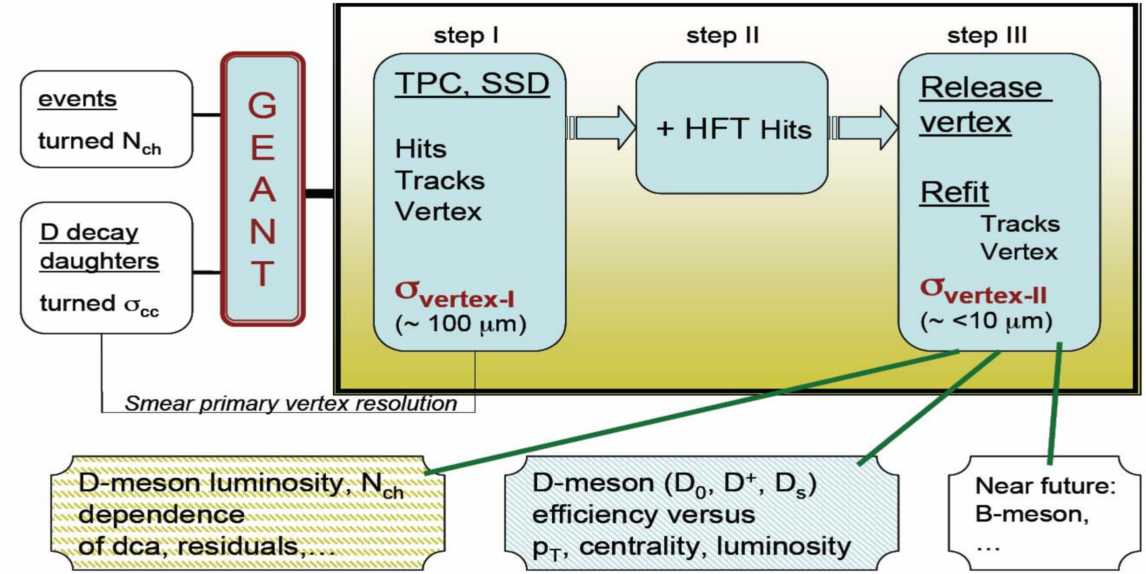
Full scale HFT prototype:

o **640 pixels** in a row **x 320 column** / sector
o 2 sectors / detector
o 4 ms readout time (50 MHz pixel read clock)
o Analog readout

Main results at T = 25°C and $t_{r.o.}$ = 0.8 & 4 ms:

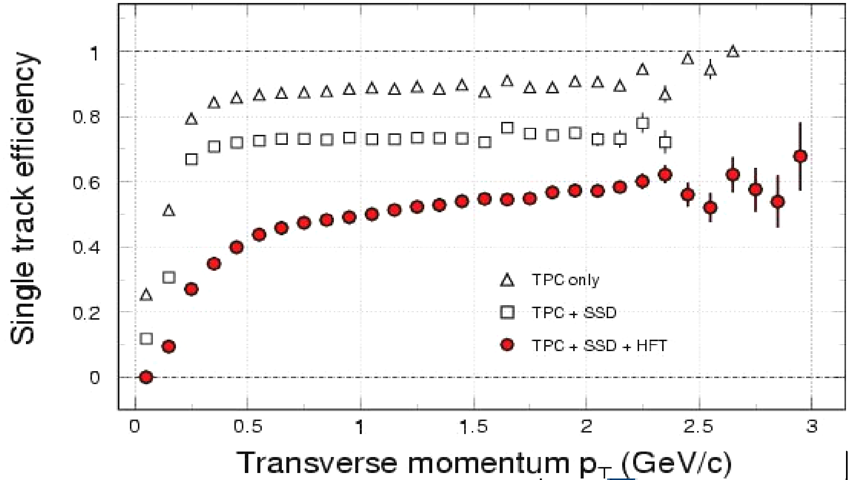
- $\therefore$ **N $\sim$ 11 - 14 e^- ENC**
- $\therefore$ **S/N $\sim$ 15 - 21 (MPV)**
- $\therefore$ $\epsilon_{det} \gtrsim$ **99.8 %**
- $\therefore$ $\sigma_{sp} \sim$ **3 μm (from MIMOSA-9)**
- $\therefore$ **power dissipation $\sim$ 40 mW/cm^2**

HFT Simulation & Tracking



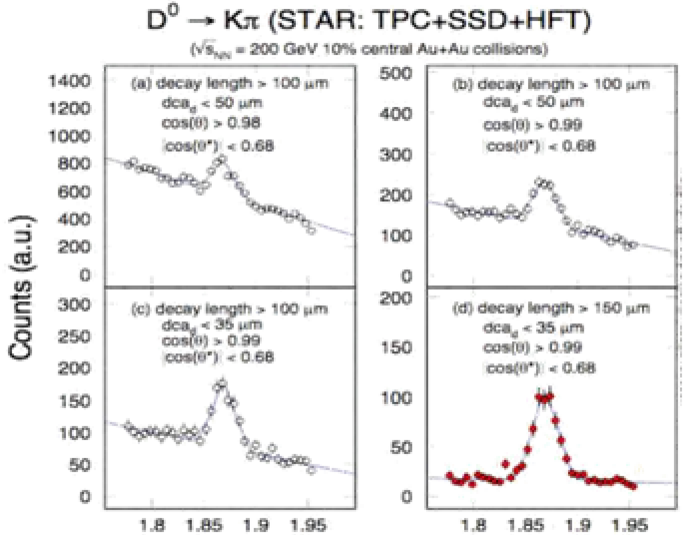
oIn the simulated config.. (**TPC + SSD +HFT**) a **vertex constraint** in used to achieve reasonable **performances** at **low P_T**

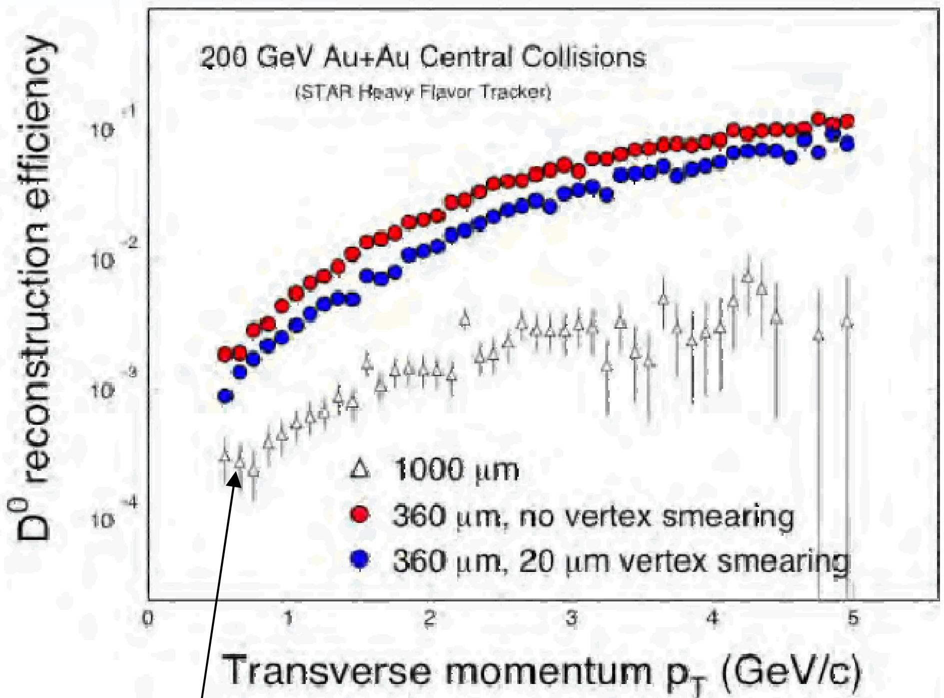
Prototype efficiency
- Vertex constraint
- TPC + SSD + HFT
- 45-60%
All efficiencies quoted are absolute
- Candidate tracks for the HFT have TPC and SSD efficiency folded in



D^0 study

D^0 invariant mass with different cut sets.

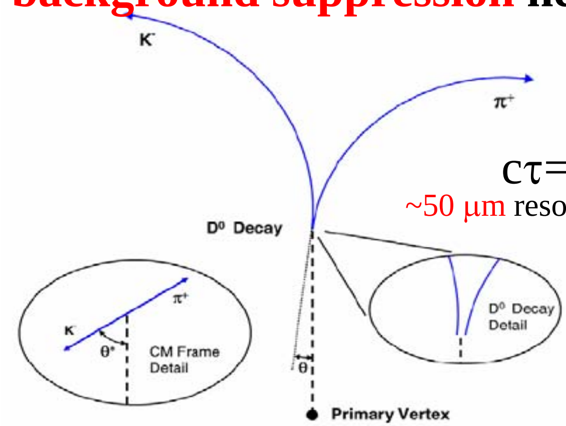




D^0 efficiency.

thick Si 1000 μm effective Si thickness (ALICE like)

No background suppression needed



Direct topological D^0 reconstruction

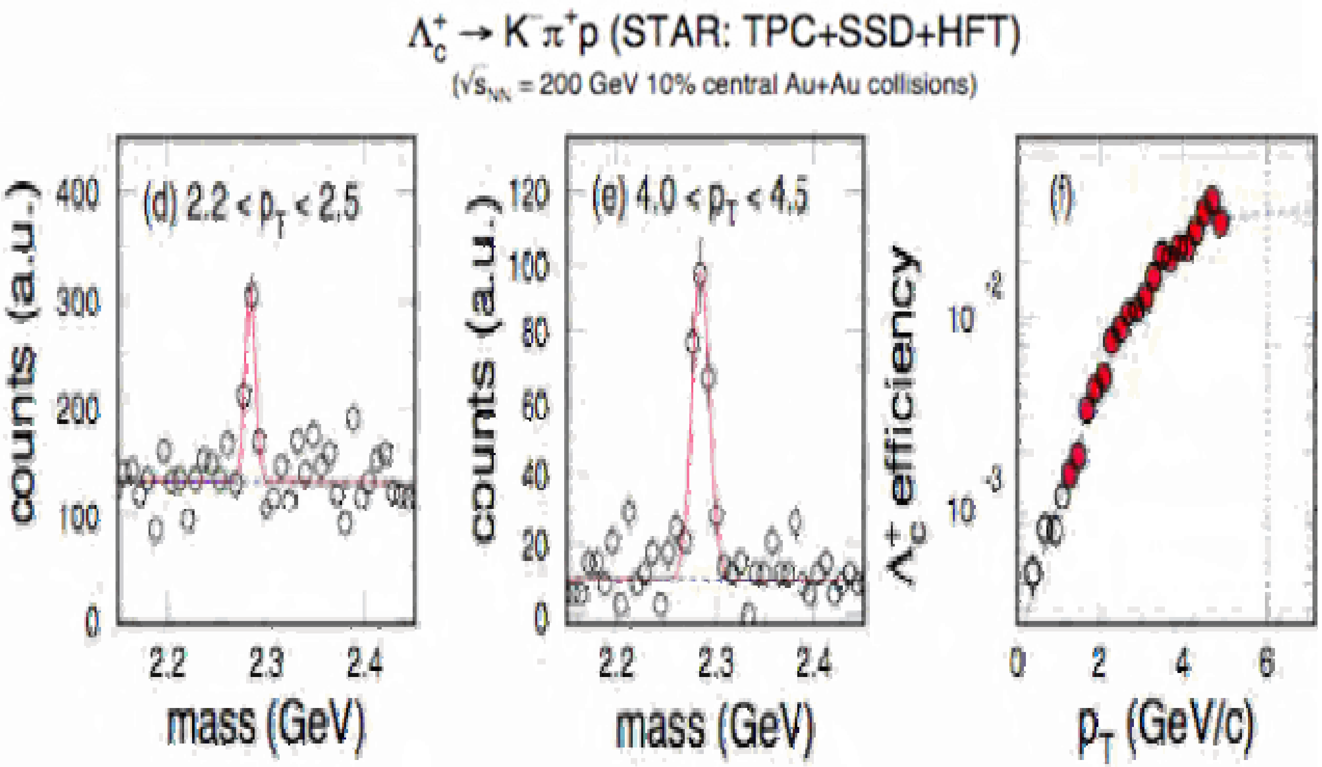
$c\tau$=124 μm !

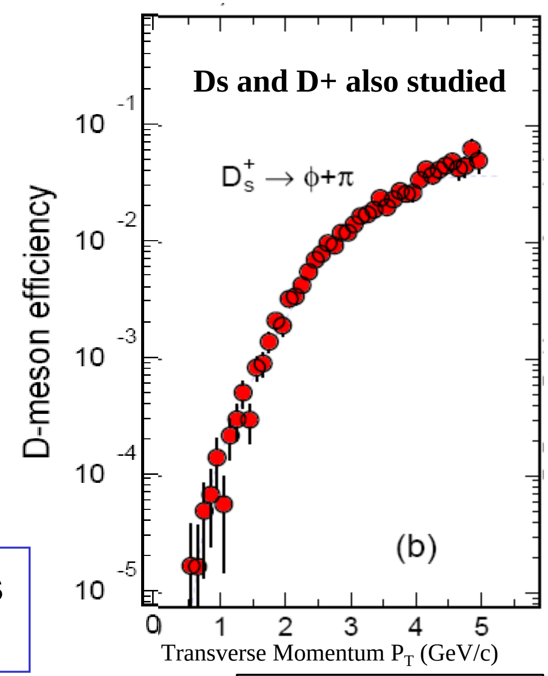
~50 μm resolution on displaced vertex

Multi-variable methods used
to maximize the significance
while minimizing the background

Λ_c & D_s

- o **3 body** decays
- o 1st charm **baryon**
- o Charm **baryon/meson**/ ratios **=> coalescence**





D_s^+/ D^0, D_s^+/ D^+ and J/ψ / D^0 are sensitive probes of **thermal charm production**

v_2 / rates estimates

(a) dN/dp_T distributions for D-mesons.

Scaled by $<N_{bin}> = 290$, corresponds to the minimum bias Au+Au collisions at RHIC.

(b) Assumed v_2 distributions for D-mesons.

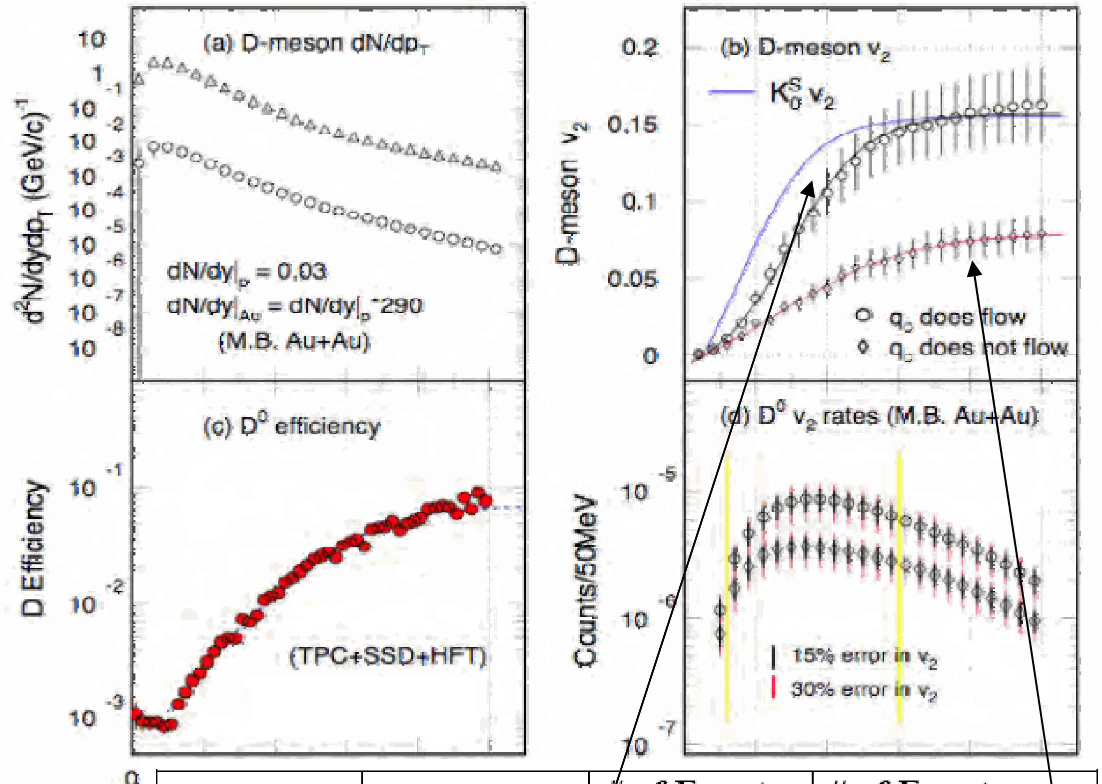
---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

(c) D^0 efficiency with TPC+SSD+HFT.

(d) D^0 meson v_2 rates from minimum bias Au+Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.



p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

STAR run 4: 50M events

Summary

To address current **open questions** **we need :**

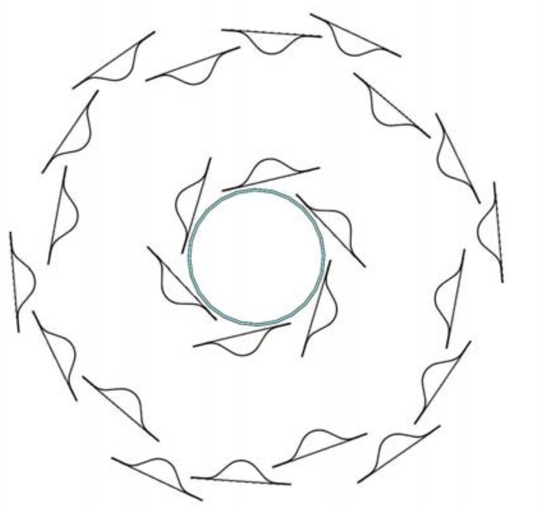
- **Direct topological reconstruction of Charm and precise V_2**

- The HFT detector will be **very thin** (< 0.28 X_0 per layer) and **precise** (~10 μm) and use the **CMOS** technology.

- Key measurements
  - **Charm Spectra, R_{AA} & R_{cp}**
  - **Angular Correlations**

- Full scale prototype in STAR ~2009,
 final detector (fast version) :~ 2011

The star HFT Group



- Z. Xu
- Y. Chen, S. Kleinfelder, A. Koohi, S. Li
- H. Huang, A. Tai
- V. Kushpil, M. Sumbera
- B. Surrow, G. Van Nieuwenhuizen
- I. Kotov
- C. Colledani, W. Dulinski, A. Himmi, C. Hu, A. Shabetai, M. Szelezniak, I. Valin, M. Winter
- L. Greiner, Y. Lu, H.S. Matis, M. Oldenburg, H.G. Ritter, F. Retiere, A. Rose, L. Ruan, K. Schweda, E. Sichtermann, J.H. Thomas, H. Wieman, N. Xu, Y. Zhang

Thank you!

Proposal available very soon

Backup

Coalescence of Charm Quarks?

	e-p and e^+-e^- average	Pythia	Statistical coalescence
$f(c \to D^+)$	0.232	0.162	0.21
$f(c \to D^0)$	0.549	0.639	0.483
$f(c \to D_s^+)$	0.101	0.125	0.182
$f(c \to \Lambda_c^+)$	0.076	0.066	0.080
$f(c \to J/\psi)$		0.006	0.057

Andronic et al.,. *Phys. Lett.* B571, 36 (2003).

Table 1: Charm quark fragmentation functions. The D^+ and D^0 yields include feed-down from D^{*+} and D^{*0} decays.

D_s^+/ D^0, D_s^+/ D^+ and J/ψ / D^0 are sensitive probes of **thermal charm production** & history

- Charm **fragments** into a variety of **hadrons**
- If Charm quarks **equilibrate** with the **surrounding medium** then they might **coalesce** with the **light quarks**
  - which would imply they **travel a large distance** in the **thermalized** medium
- **Coalescence** Increases the yield of Λ_c and J/ψ by 80% and a factor of 10, respectively
- Systematic errors cancel in D_s^+/D^+ due to similar decay channels

Photonic Backgrounds reduced with the HFT

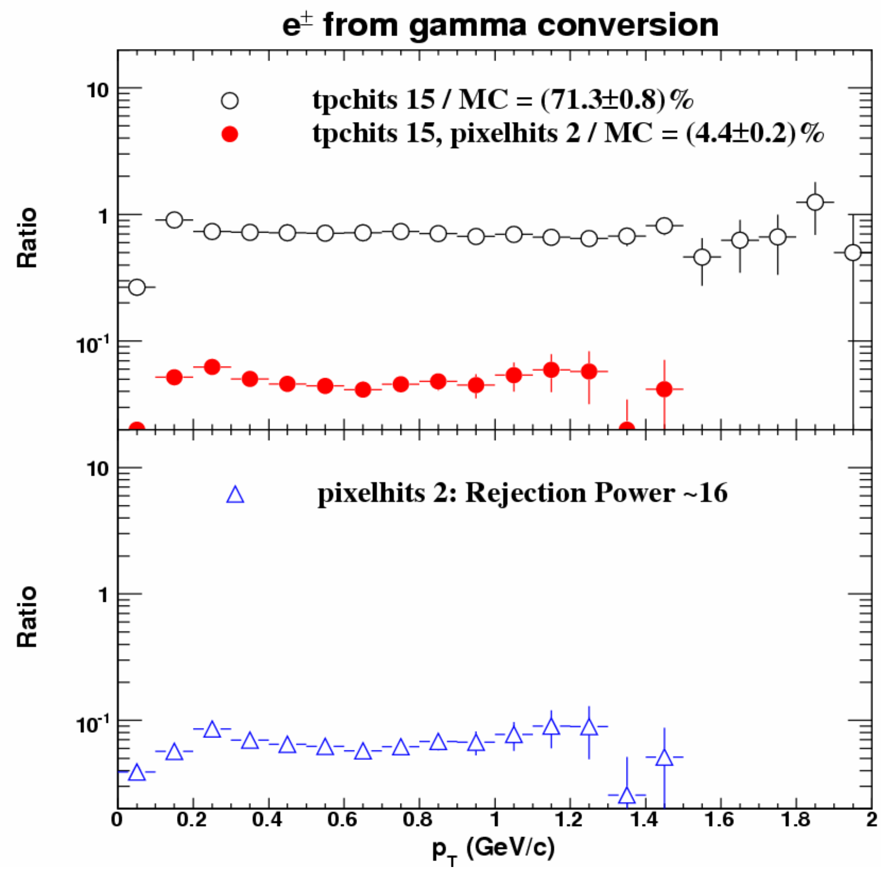


Figure: Electron p_T spectra from γ conversions reconstructed by requiring TPC tracking or TPC hits and 2 HFT hits. The rejection factor is about 16:1

- **Direct topological** reconstruction of charm avoids the single electron **background problem**
- But the HFT can also **reduce the conversion** electron backgrounds by judicious cuts in the TPC & HFT
- The HFT enables better **single electron measurements**

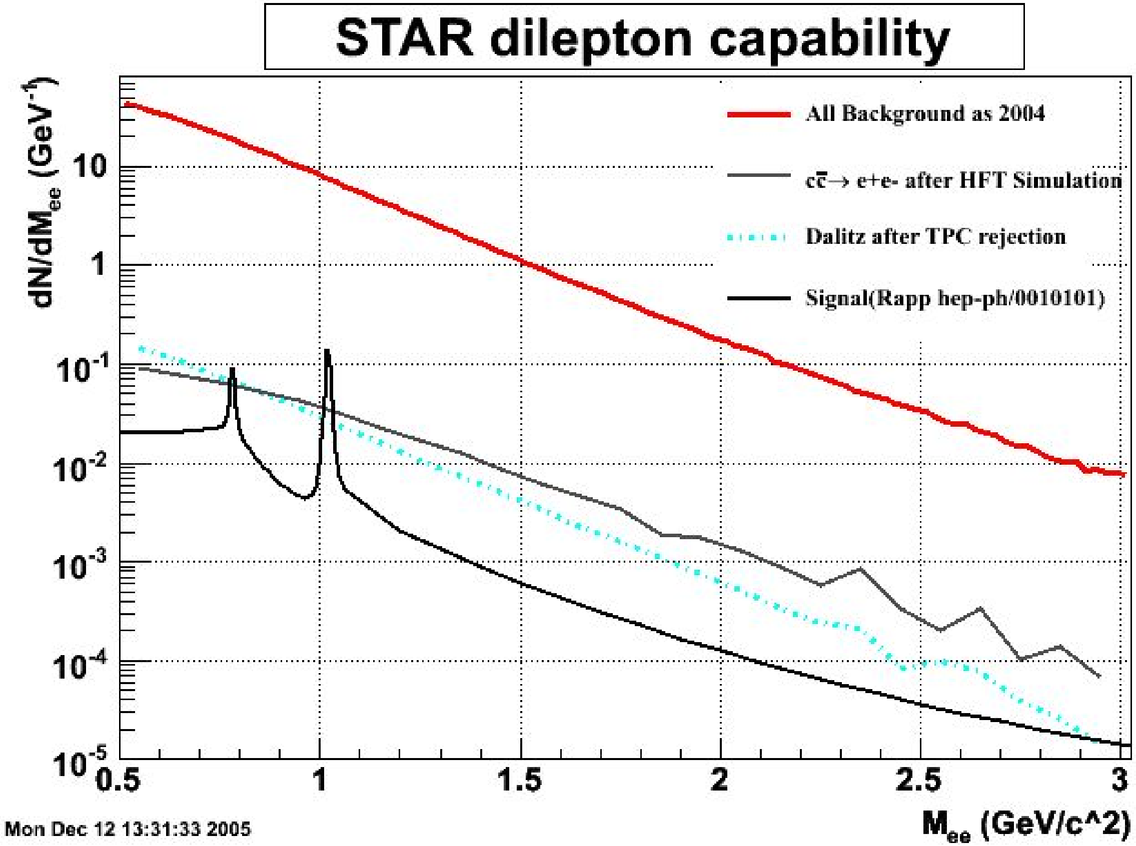
Hit Occupency

	HFT Outer Layer	HFT Inner Layer
Radius	5.0 cm	1.5 cm
Hit Flux	5600 Hz/cm^2	28,750 Hz/cm^2
Hit Density 4 ms Integration	22.5/cm^2	115/cm^2
Projected Tracking Window Area	0.6 mm^2	0.15 mm^2
HFT Hit Resolving Area	0.001 mm^2	0.001 mm^2
Probability of HFT Pileup	0.3%	1%

Occupancy Same Event Contribution

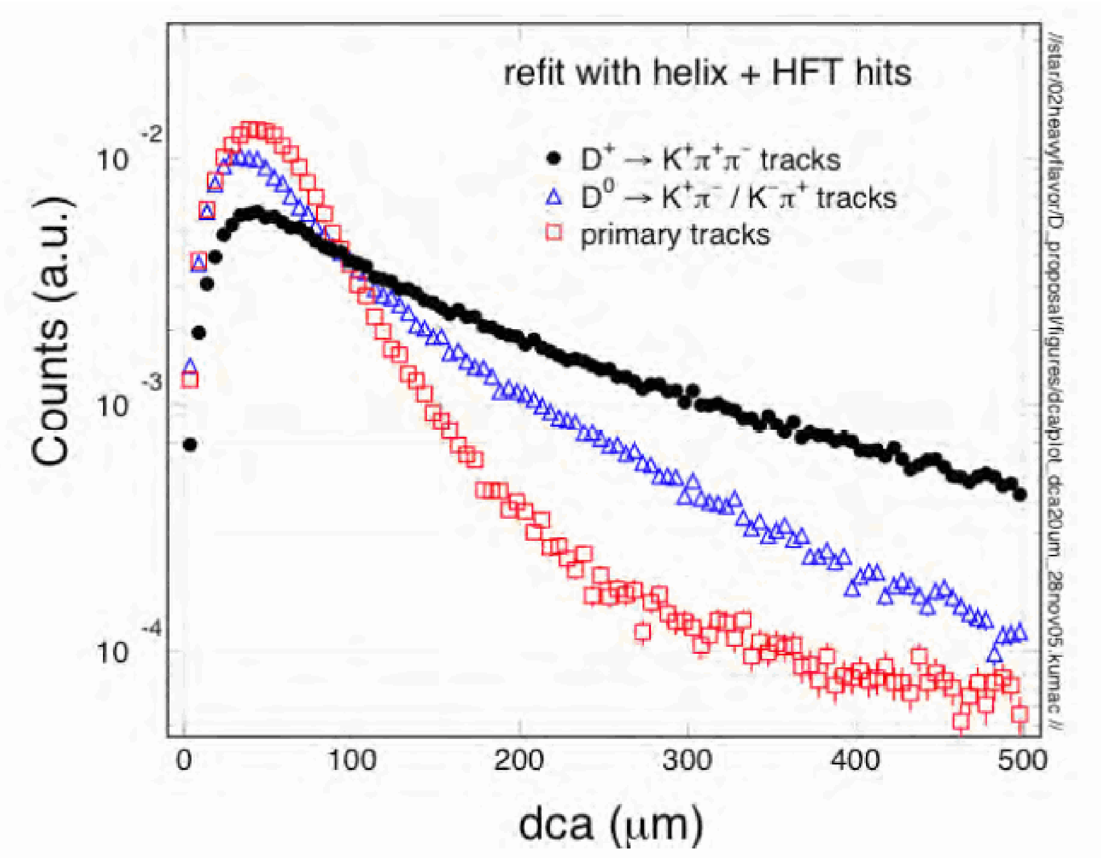
	HFT Outer Layer	HFT Inner Layer
Radius	5.0 cm	1.5 cm
Hit Density Au + Au Central Collision	1.8/cm^2	7.4/cm^2
Projected Tracking Window Area	0.6 mm^2	0.15 mm^2
HFT Hit Resolving Area	0.001 mm^2	0.001 mm^2
Probability of HFT Pileup	0.02%	0.09%

Dilepton



TOF+HFT can resolve dilepton signals from background

dca distributions



Difference between the charm meson daughter tracks and the background primary tracks!

Cuts for charm hadrons

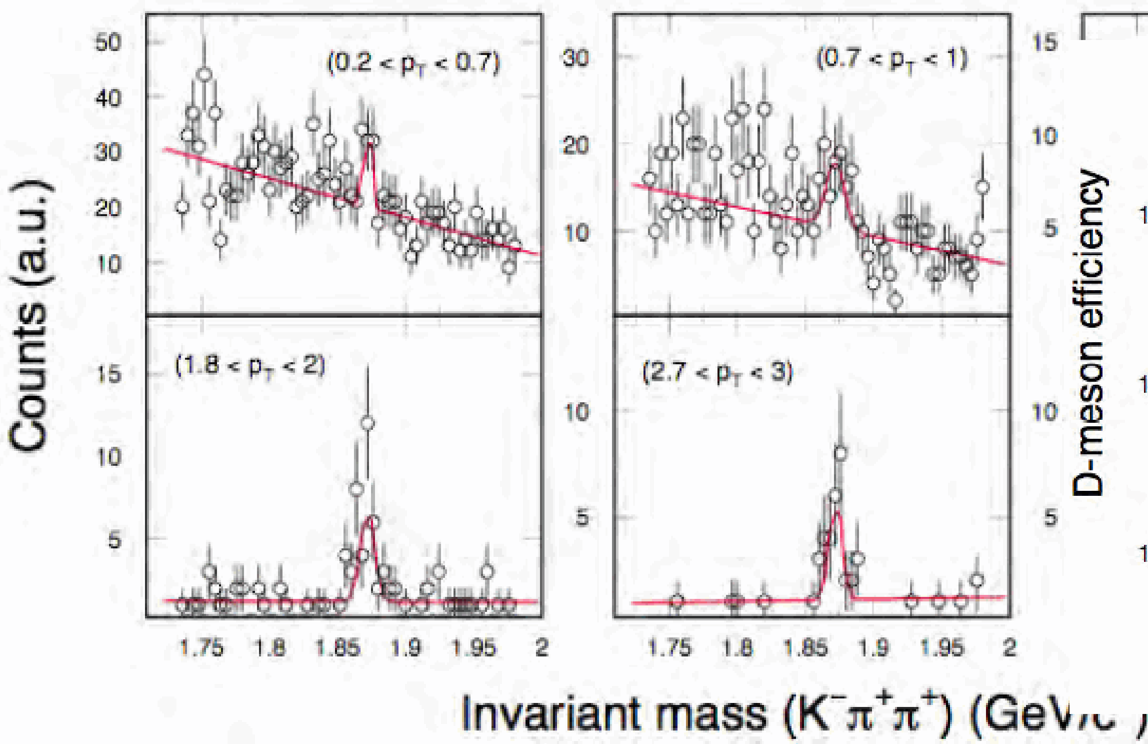
The input charm hadron spectra followed exponential distributions,

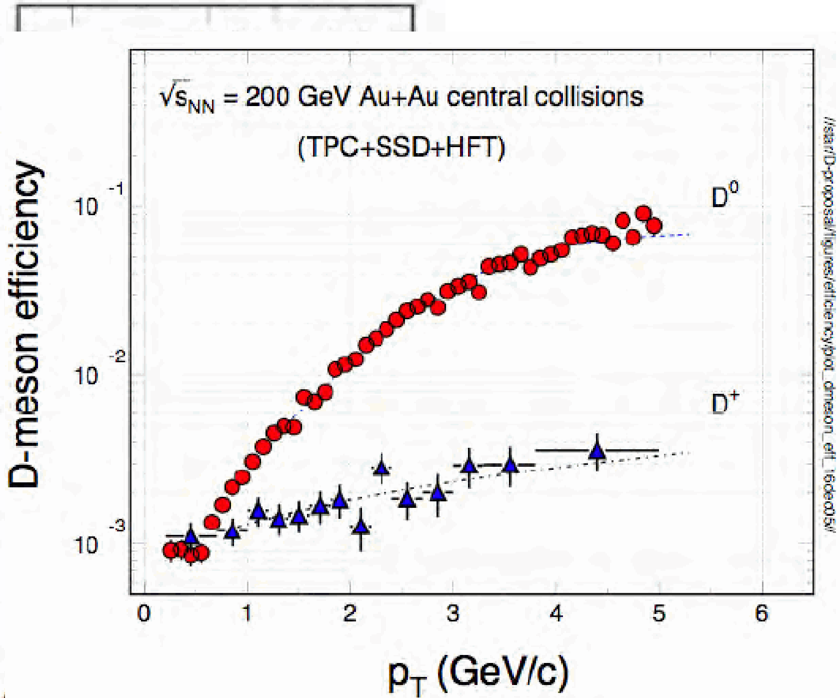
D^0 events: 1.43M D^+ events: 500k Λ_c events: 2.9M

background events: 10.3k

Cuts	D^0	D^+	Λ_c
nFitPts >	15	15	15
$\|\eta\|$ <	1.0	1.0	1.0
HFT hits =	2	2	2
dca(global) ≥		100 μm	35 μm
dca(V_0) ≤	35 μm	100 μm	40 μm
decay length ≥	150 μm	150 μm	50 μm
cos(θ) >	0.996	0.85	0.92
Δm ≤	40 MeV		

D+ signal and efficiency



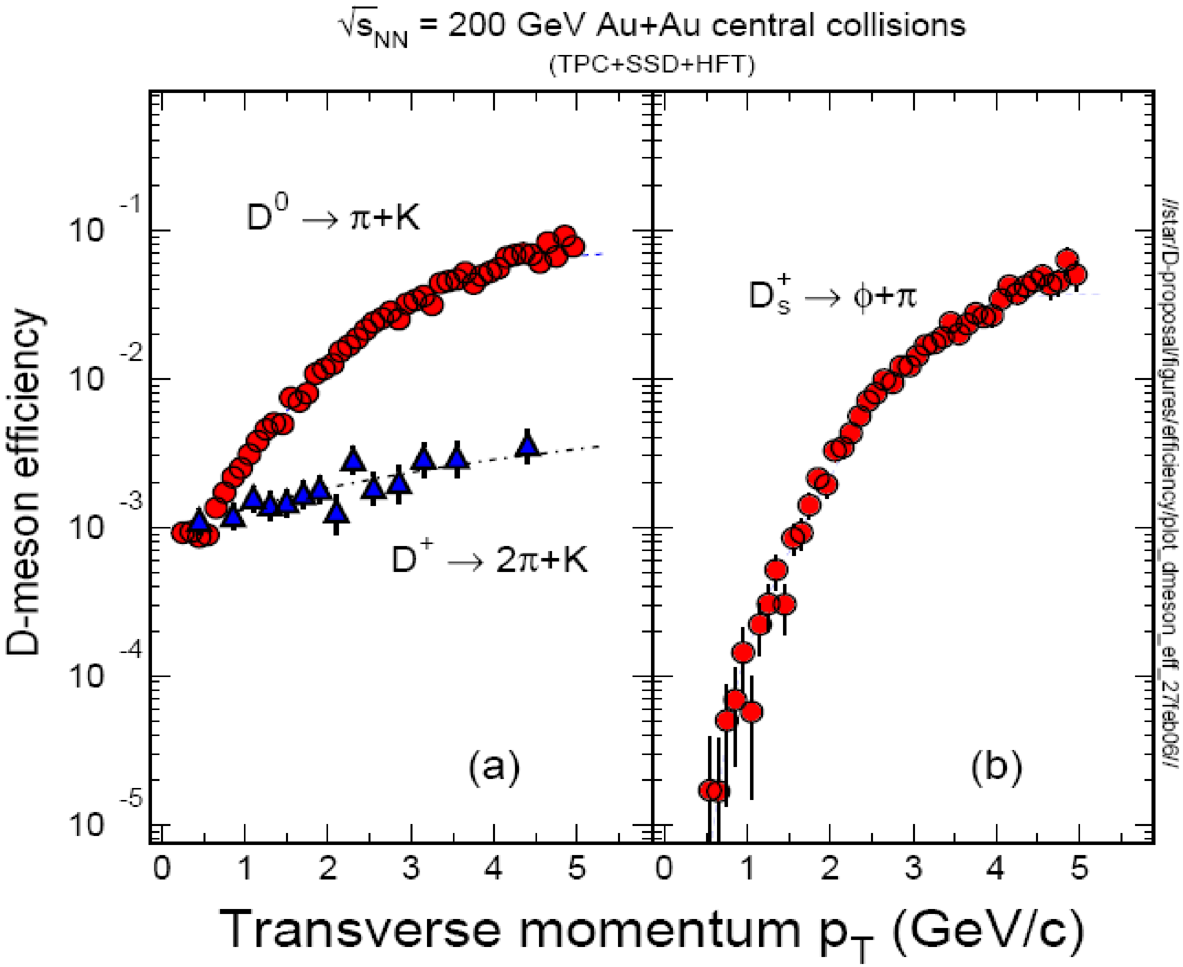


D^+ invariant mass as a function of p_T. The cuts can be opened a bit at high p_T to increase the efficiency, since the background decrease much faster than signal when p_T goes high.

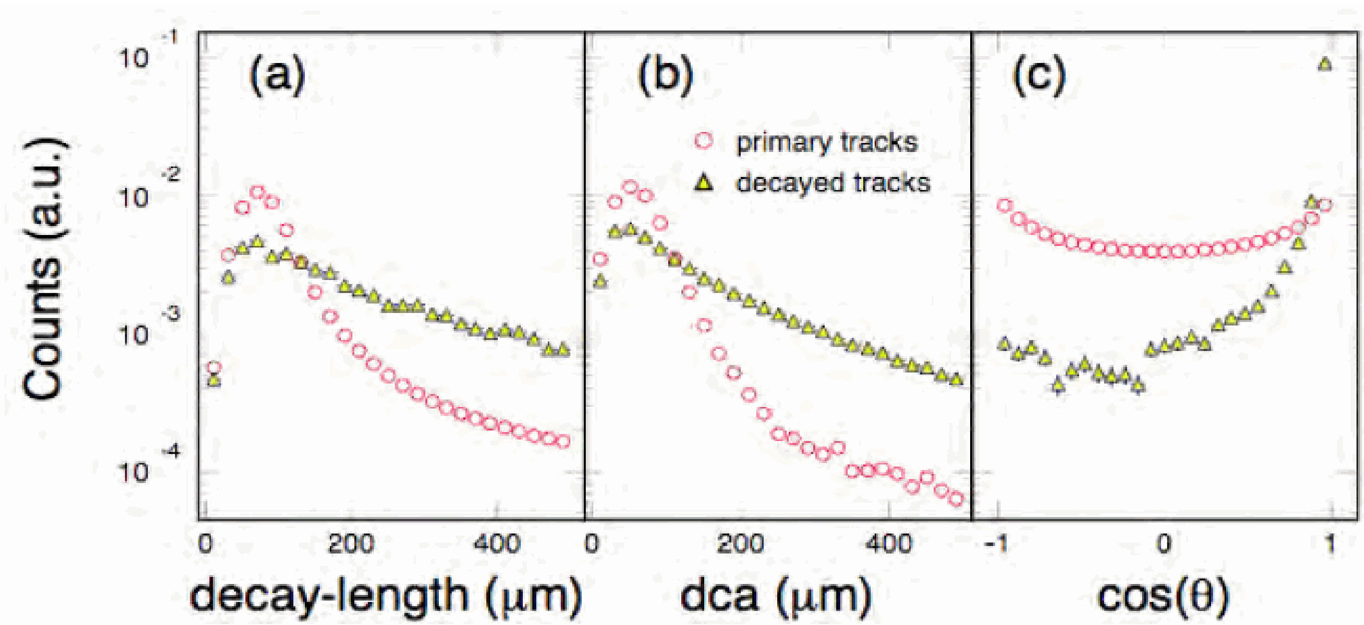
D+ efficiency

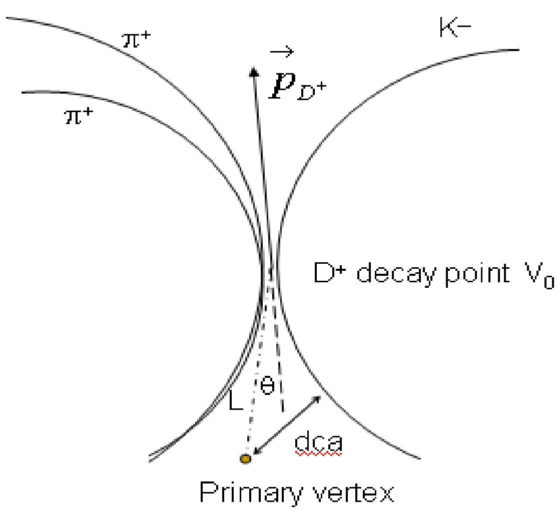
The large difference between D^0 and D^+ efficiencies is caused by the topological cuts used for the reconstruction.

Ds+ signal and efficiency



Background rejection for D+

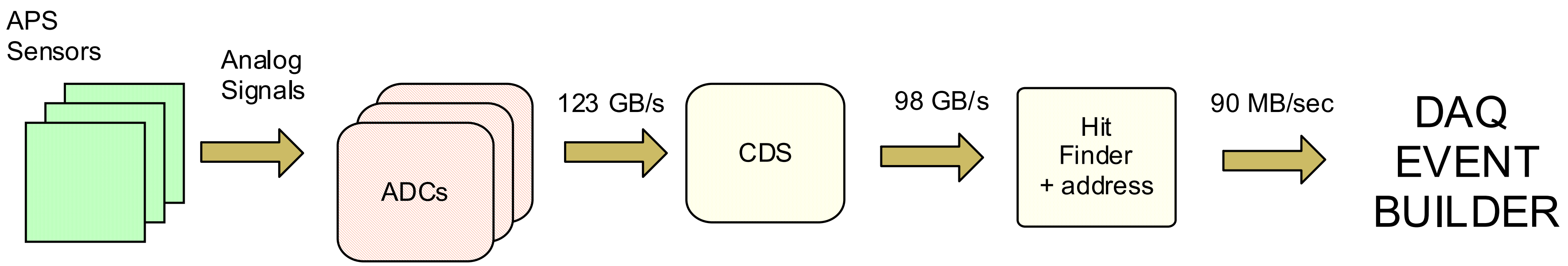




fraction of loss:

cuts	dca (um)			cos(θ)			dec-L (um)		
	20	50	75	0.75	0.85	0.95	100	130	150
primary	10%	46%	72%	82%	88%	96%	64%	79%	84%
D^+-tracks	5%	22%	35%	17%	22%	33%	31%	42%	48%

Data Rates



- 100 hits/cm^2 Inner Layer, 20 hits/cm^2 Outer Layer (L = 10^{27})
- Average event size = 90 KB
- Event size = 90 MB/sec at 1KHz
- 24 fibers
- 12 RORC (4 readout PCs)

Prototype Cable

- ~ 100 traces (2 LVDS pairs / sensor, clk, power, gnd, cntl)
- 4 layer design, 25 µm kapton, 20 µm Al conductor
- Impedance controlled signal / clock pairs with power and ground geometrically arranged as shielding.

Prototype Cu conductor cable

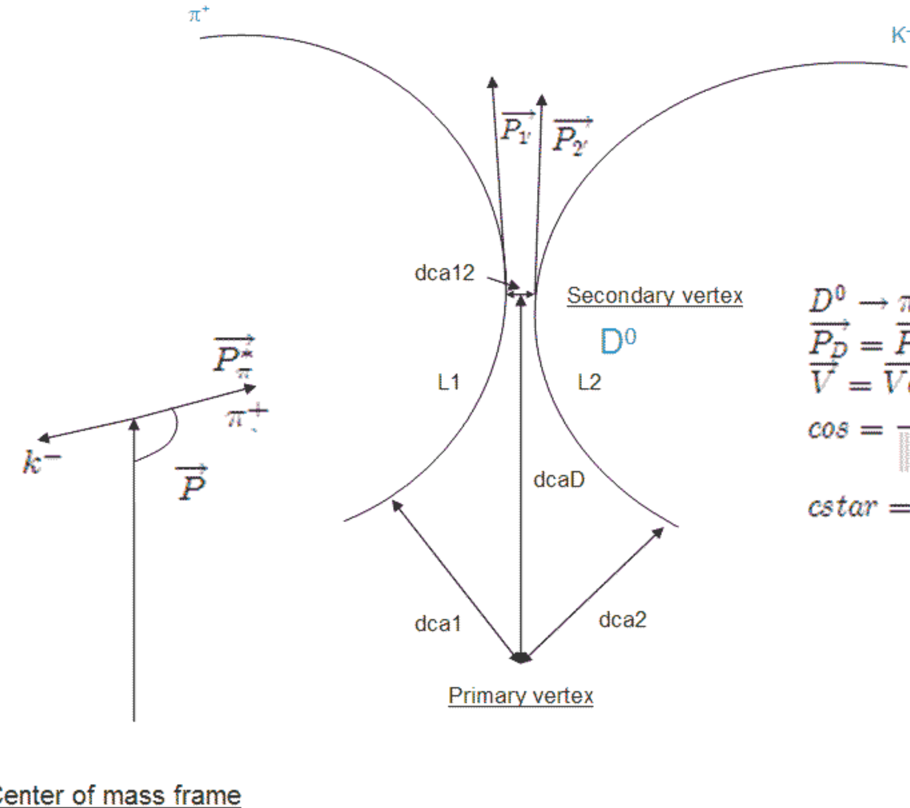
X_0 =0.090 % (for Al conductors)

D^0 Reconstruction

D0 6 variables

Ds 9 variables

Reconstruction of $D^0 \to \pi^+ K^-$



$$D^0 \to \pi^+ K^- : \quad c\tau = 124.4\ \mu m$$

$$\vec{P_D} = \vec{P_{1'}} + \vec{P_{2'}}$$

$$\vec{V} = \overrightarrow{Vertex2} - \overrightarrow{VertexP}$$

$$cos = \frac{\vec{P_D}.\vec{V}}{\|\vec{P_D}\|\|\vec{V}\|}$$

$$cstar = \frac{\vec{P^*_\pi}.\vec{P}}{\|\vec{P^*_\pi}\|\|\vec{P}\|}$$

-> Classical study

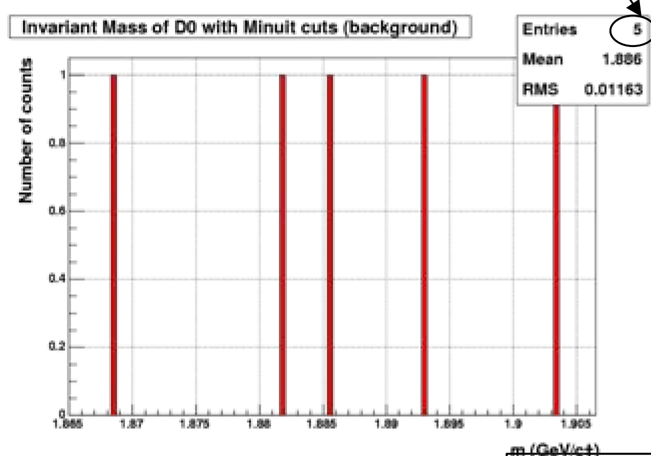
Minuit

Maximize the Significance →

Minimize $N = 3^2 * (S+B) / S^2$

Less background,
But sometimes it goes to 0!

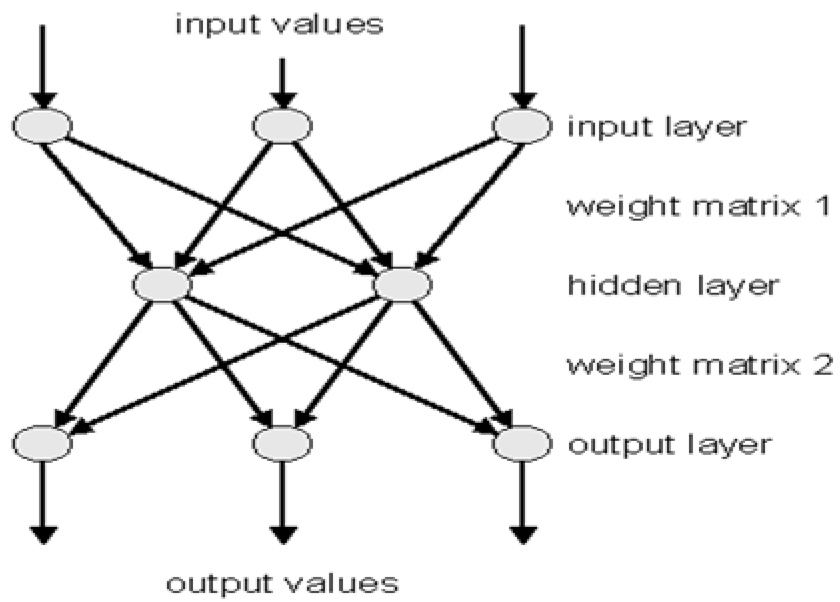
(micron)	(micro n)	dca12 (cm)	dcad (cm)	cos	c*	Inv Mass Min (Gev)	Inv Mass Max (GeV)	Sig
3	80	0.002592	0.011811	0.996943	0.854565	1.772301	1.96769	11853
6	8 0	.00793 4	0.015779	0.999457	0.888059	1.222892	2.517108	12346
18	80	0.008253	0.019841	0.991872	0.802094	1.827590	1.912410	350 9



Event Mixing is used
to get more statistics

Neural Netork : Why? How? What to expect?

What's a Neural Networks ?



Input:
m , dca12, dcaD,c*
and cos

How to use it :

It takes a TTree as input (merges signal and background)
You can set weights manually (I did not).
Set the number of **hidden neurons (12 in 1 layer)**
Set 2 EventLists : training and test

Output :
- signal (0)
- background (1)