Production of D^+/D^- Mesons in Heavy–Ion Collisions

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Outline

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- STAR Experiment
- Dataset and Analysis Method
- Traditional Analysis
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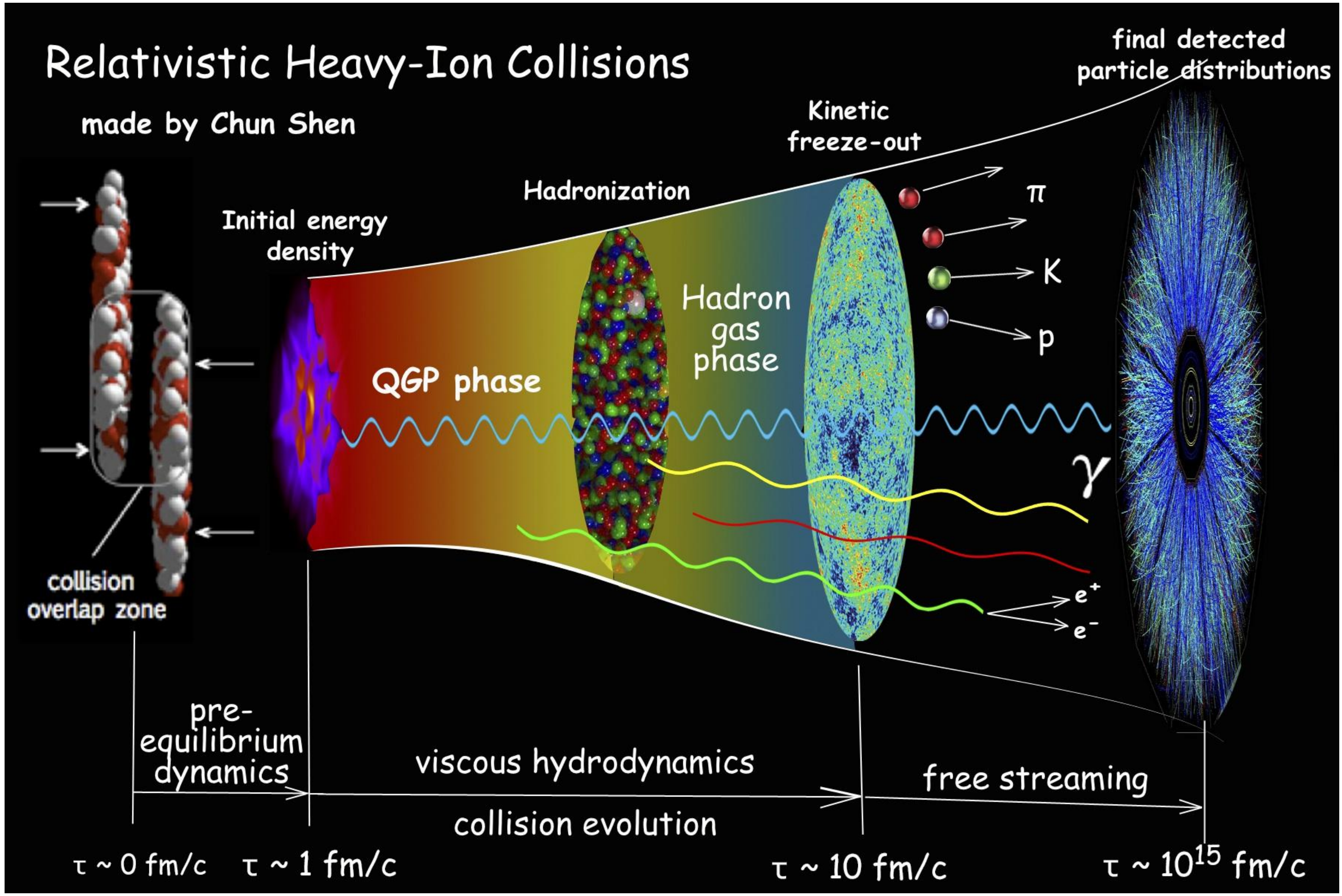
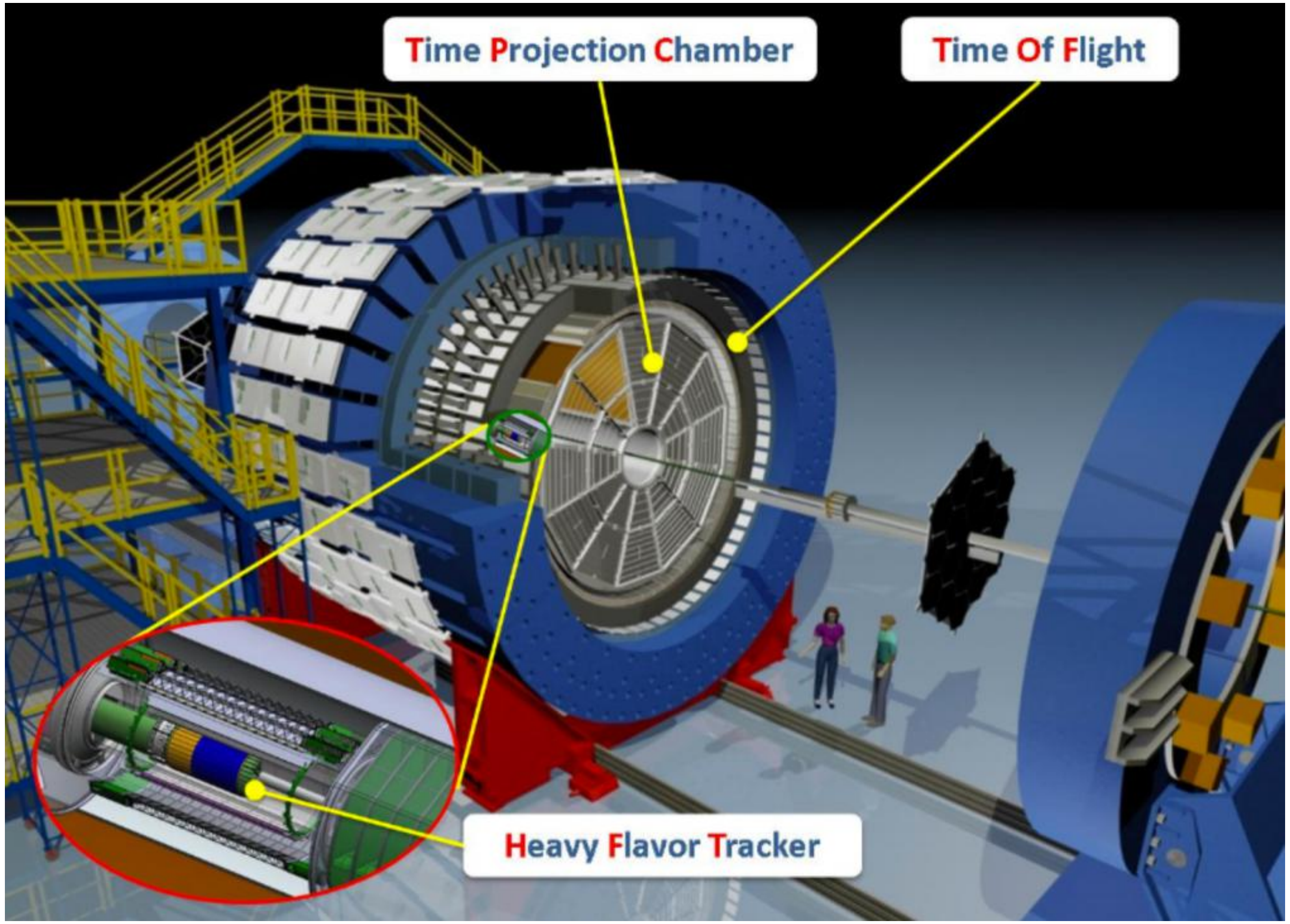
  - Raw yield extraction
  - Yield correction
  - $D^{\pm}$ spectrum
- Improvement Using TMVA
  - BDT training
  - Results
  - Comparison

Motivation

- heavy quarks serve as a probe in the QGP
- created in first moments after collision – experience entire evolution
- we measure the energy loss of the charm quark inside the hot medium



STAR Experiment

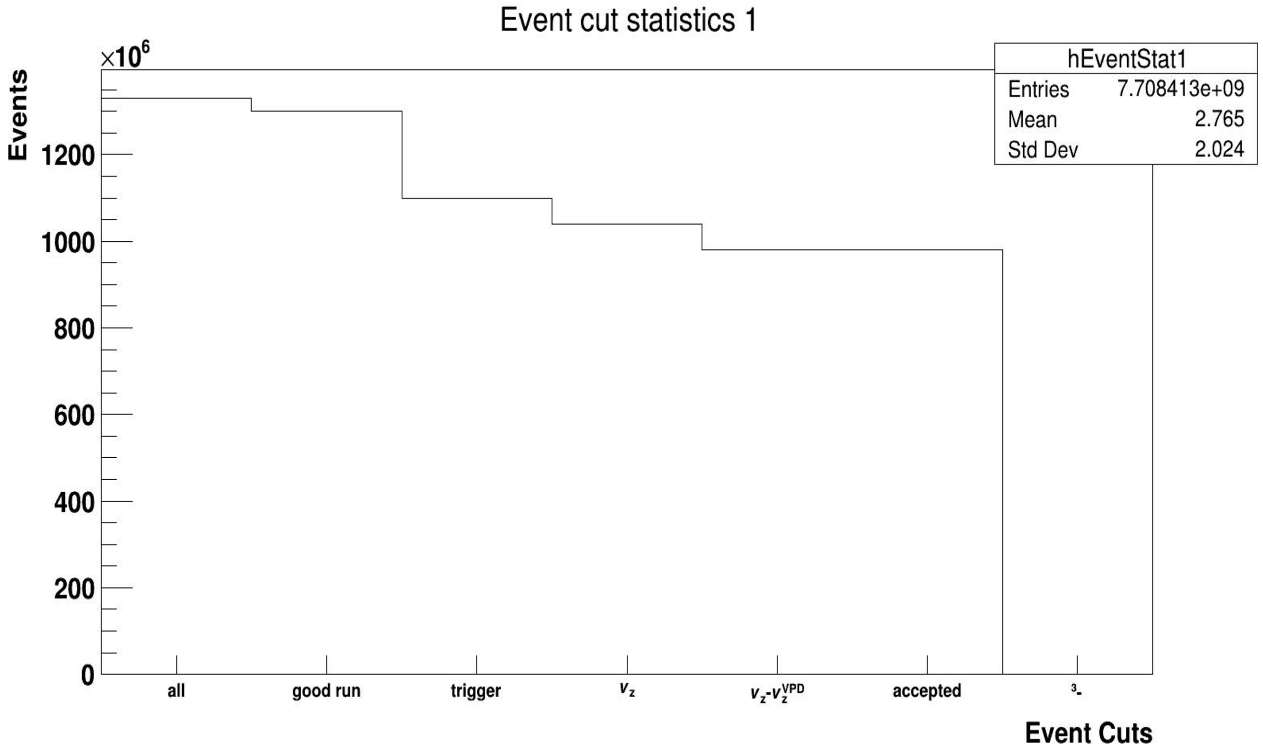


- TPC – tracking, PID (dE/dx)
- TOF – PID (1/beta)
- HFT – Heavy Flavor Tracker
  - 3 active layers of silicon detectors
  - operating 2014–2016
  - excellent spatial resolution – short–lived particles measurable (Λ_c, $D^{\pm}$,...)

Dataset

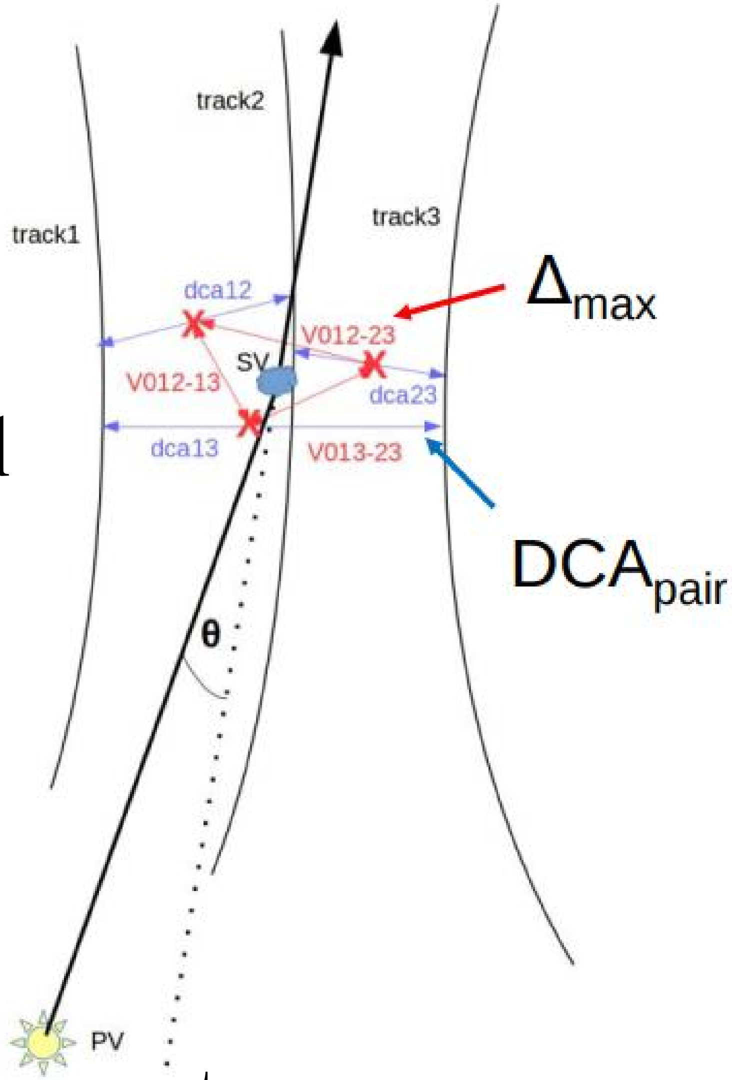
- 2014 Au–Au collisions at 200 GeV
- 1.33 B MB events from picoDst files
- trigger ID: 450050, 450060, 450005, 450015, 450025
- event cuts:

  $|V_z| < 6$ cm, $|V_z - V_z^{VPD}| < 3$ cm
- 980 M after event cuts
- events with runId < 15107008 rejected
- 20 M events with cent = −1 rejected
- about **780 M** events analyzed (probably more available)



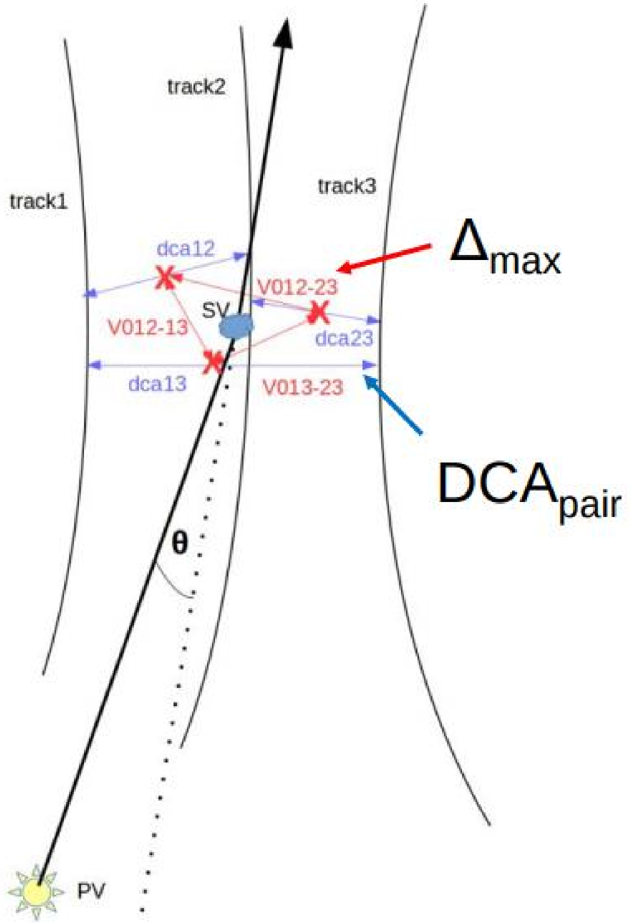
Analysis Method

- $D^{\pm} \to K^{\mp} \pi^{\pm} \pi^{\pm}$ BR: (8.98 ± 0.28) %
- other $K\pi\pi$ combinations used as background
- Topological variables for $K\pi\pi$ candidates
  - DCA of K and π to the primary vertex
  - $D^{\pm}$ decay length (distance between PV and SV)
  - Pointing angle (θ)
  - Distance of pair vertices (Δ_{max})
  - DCA of $K\pi$ and $\pi\pi$ pairs
- $K\pi\pi$ triplets ($D^{\pm}$ candidates) created with open cuts



Traditional Cuts

Type	Cut	Value(s)
Event Selection	Distance from primary vertex	$\|V_z\| < 6$ cm
	VPD distance from PV	$\|V_{zVPD}\| < 3$
Track Selection	TPC Hits	$N_{TPC} > 20$
	HFT Hits	All 3 layers
	Pseudorapidity	$\|\eta\| < 1$
PID	Daughter transverse momentum	$p_T > 0.5$ GeV/c
	D meson transverse momentum	$p_T > 1$ GeV/c
	Daughter TOF inverse velocity	$\|\frac{1}{\beta} - \frac{1}{\beta_{th}}\| < 0.03$
	TPC energy loss deviation - pions	$\|n_\sigma\| < 3$
	TPC energy loss deviation - kaons	$\|n_\sigma\| < 2$
Topological Cuts	Daughter pairs DCA	$DCA_{pair} < 80$ μm
	D meson decay length	$30 < c\tau < 2000$ μm
	Vertex triangle side length	$\Delta_{max} < 200$ μm
	Pointing angle	$\cos\theta > 0.997$
	Pion DCA to primary vertex	$DCA_\pi > 100$ μm
	Kaon DCA to primary vertex	$DCA_K > 80$ μm

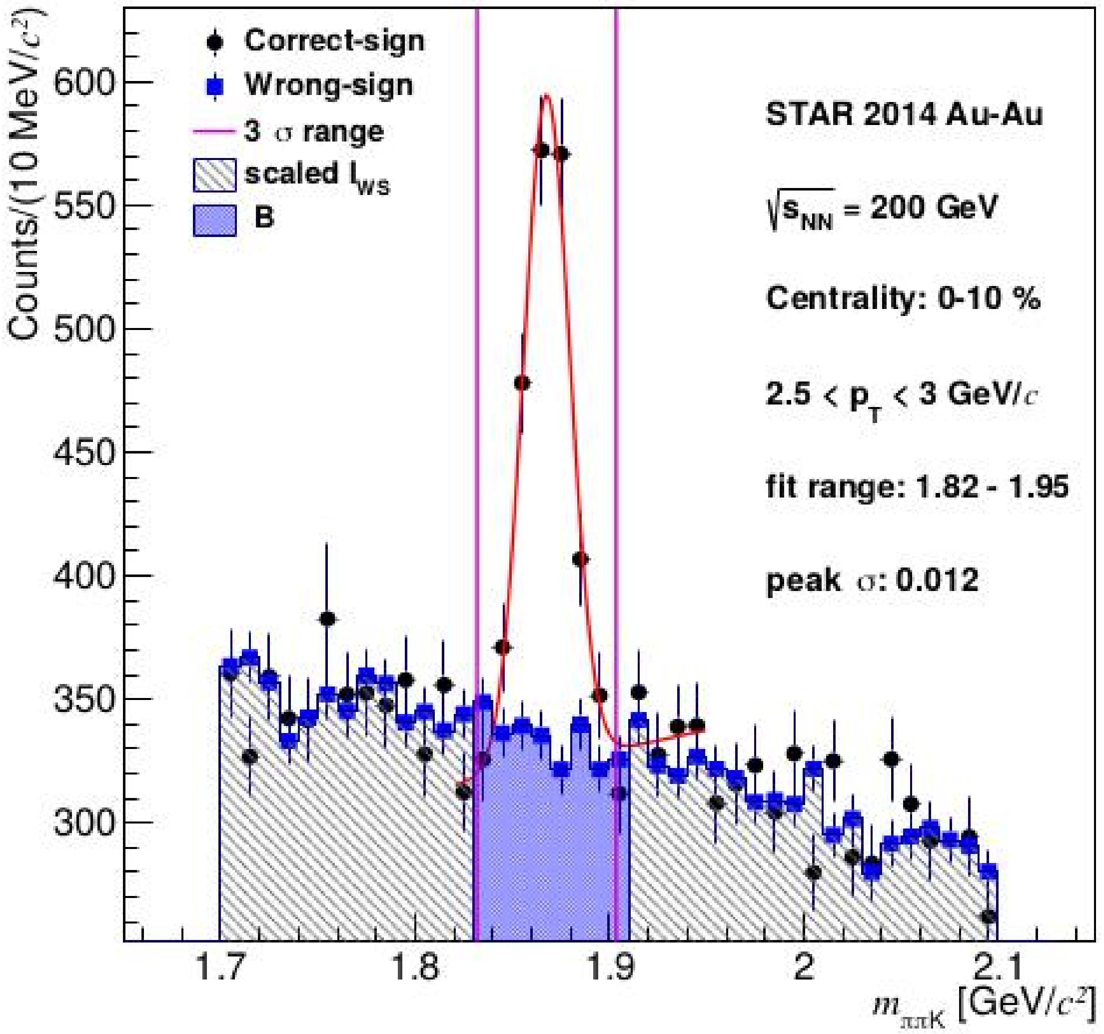


Only difference in cos θ
0.998 –> 0.997

Hybrid TOF approach – use TOF information when good hit available

Raw Yield Extraction

- after cuts: 660 k correct–sign, 1.9 M wrong–sign combinations in total
- fit peak region of correct–sign histogram with gaus+pol1
- obtain # of correct–sign (I_{CS}) and wrong–sign (I_{WS}) combinations outside the 3 σ range using bin counting
- scale wrong–sign histogram by $I_{CS}/I_{WS} \approx ⅓$



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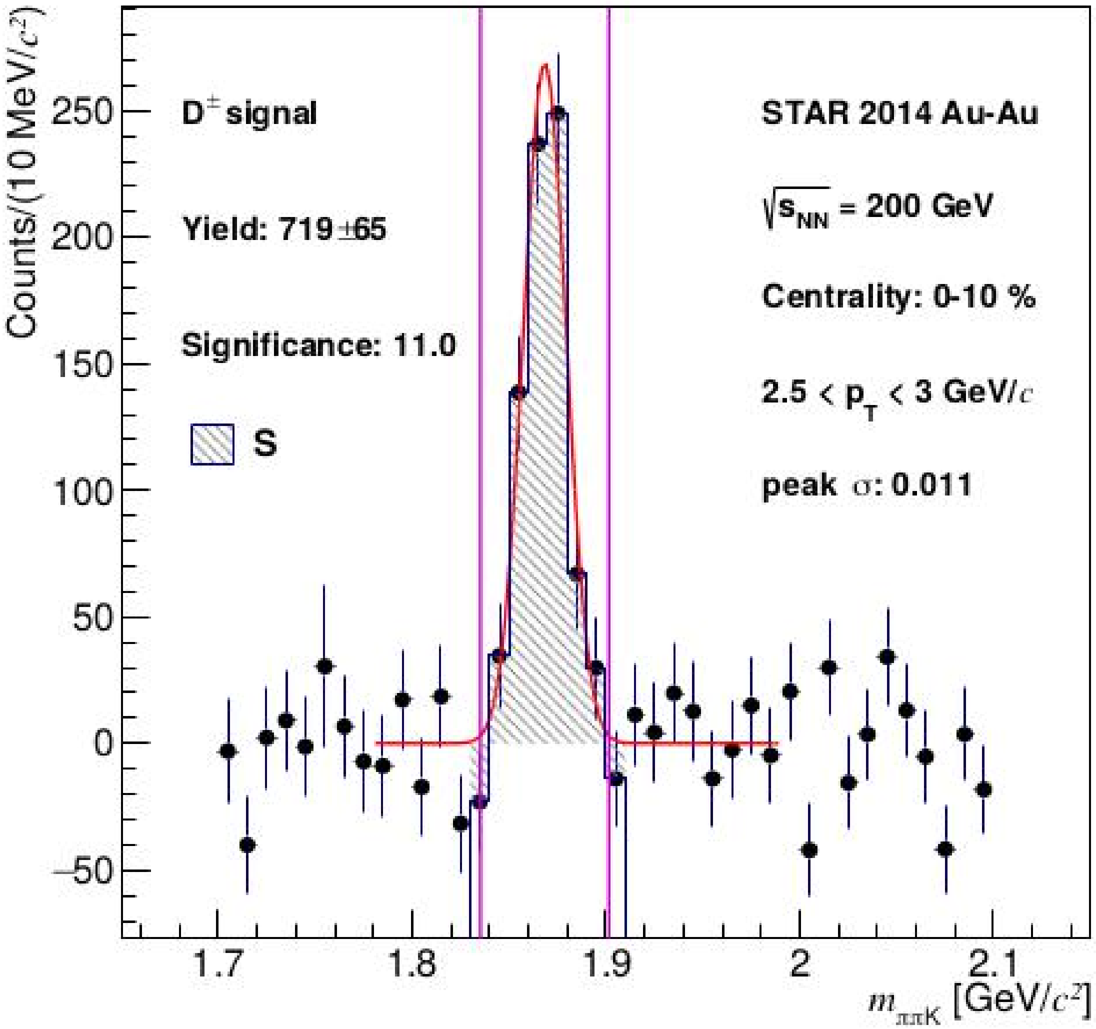
- fit peak region of correct–sign histogram with gaus+pol1
- obtain # of correct–sign (I_{CS}) and wrong–sign (I_{WS}) combinations outside the 3 σ range using bin counting
- scale wrong–sign histogram by $I_{CS}/I_{WS} \approx 1/3$
- subtract wrong–sign from correct–sign histogram
- fit the signal peak with gaus
- count bins within 3 σ range –> Raw Yield (S)
- calculate significance = $S/\sqrt{S+(1+I_{CS}/I_{WS})B}$
- 12 p_T bins (1–10 GeV/c)
- 4 centrality bins (0–10, 10–40, 40–80, 0–80 %)
- yields with significance < 3 were rejected



Raw Yields and Significances

	0–10 % (124.6 M evts)		10–40 % (304.8 M evts)		40–80 % (351.6 M evts)		0–80 % (781.0 M evts)	
p_T [GeV/c]	Yield [–]	Sig. [–]	Yield [–]	Sig. [–]	Yield [–]	Sig. [–]	Yield [–]	Sig. [–]
1.0 – 2.0	337 ± 136	2.5	1254 ± 212	5.9	387 ± 39	9.8	2116 ± 333	6.4
2.0 – 2.5	485 ± 117	4.1	1705 ± 100	17.0	449 ± 26	17.4	2639 ± 156	16.9
2.5 – 3.0	719 ± 65	11.0	1690 ± 64	26.5	484 ± 24	20.5	2895 ± 95	30.6
3.0 – 3.5	470 ± 38	12.5	1227 ± 43	28.3	394 ± 21	19.2	2090 ± 60	34.8
3.5 – 4.0	279 ± 23	12.1	811 ± 32	25.2	267 ± 17	15.7	1351 ± 43	31.6
4.0 – 4.5	166 ± 17	9.9	467 ± 24	19.6	165 ± 13	12.3	807 ± 32	25.3
4.5 – 5.0	75 ± 11	6.9	290 ± 18	15.7	98 ± 11	8.9	469 ± 24	19.3
5.0 – 5.5	55 ± 9	5.8	178 ± 15	12.2	63 ± 9	7.0	294 ± 19	15.3
5.5 – 6.0	33 ± 6	5.4	98 ± 11	9.0	31 ± 6	5.1	162 ± 14	11.6
6.0 – 7.0	24 ± 6	3.9	100 ± 11	9.3	30 ± 6	5.0	154 ± 14	11.2
7.0 – 8.0	11 ± 4	3.0	31 ± 7	4.7	6 ± 4	1.7	53 ± 8	6.6
8.0 – 10.0	2 ± 1	1.3	19 ± 5	4.1	7 ± 3	1.9	25 ± 6	3.9

Yield Correction

- Raw yield –> Invariant yield

$$\frac{d^2N}{dp_T dy}\frac{1}{2\pi p_T} = \frac{Y_{raw}}{2\pi N_{ch} \cdot N_{events} \cdot BR \cdot p_T \cdot \Delta p_T \cdot \Delta y \cdot Eff(p_T)}$$

detector efficiencyXacceptance
from fast–sim, still work in progress

2 (+, –)

(8.98 ± 0.28) %

2

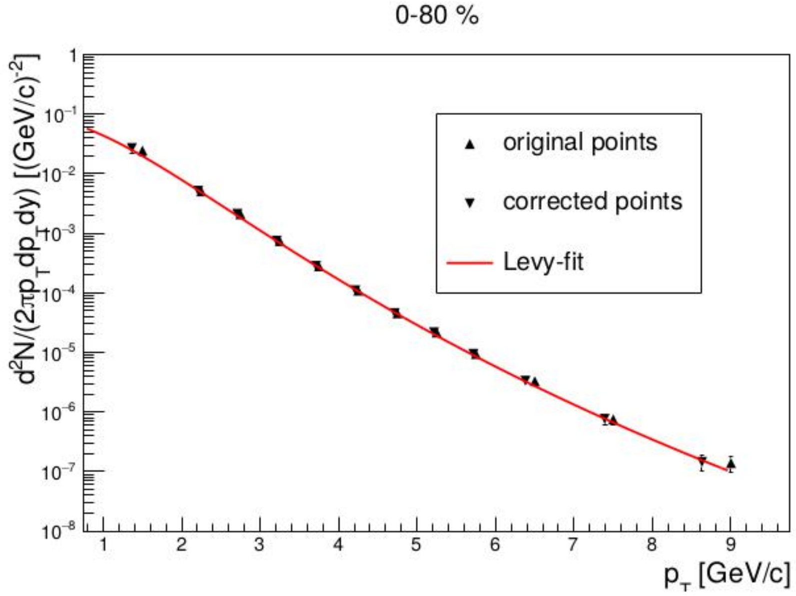
Centrality [%]	$N_{events} \cdot 10^6$ [-]
0-10	124.7
10-40	304.8
40-80	351.6
0-80	781.0

these p_T points are placed incorrectly
at the middle of the bin –> bin width correction

p_T Spectrum Correction

- iterative process to find the correct position of the p_T points, to account for the shape of the spectrum inside the bin
- we need to find weighted average
- we use the Levy function (m = 1.870 GeV/c²):
- the process converges after 2–3 iterations
- we use the new value to recalculate the inv. yield

$$f(p_T) = \frac{a}{2\pi} \cdot \frac{(c-1)(c-2)}{((bc+m)(m(c-1)+bc))} \cdot \left(\frac{bc+\sqrt{p_T^2+m^2}}{bc+m}\right)^{-c}$$

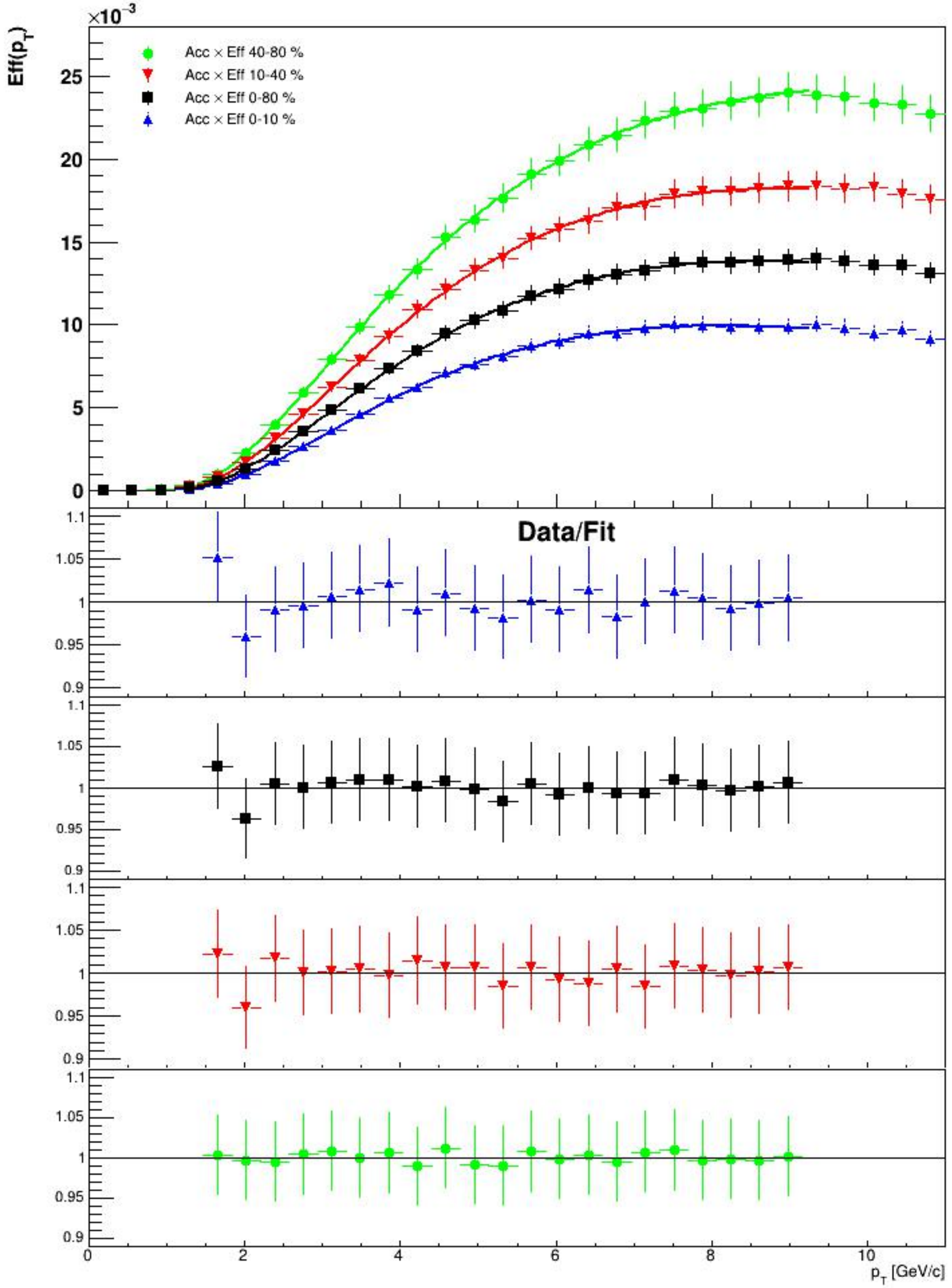


EfficiencyXAcceptance

- data–driven fast simulator (PYTHIA) validated
by HIJING to 5 % accuracy (planned switch to EventGen)
- inputs:
  - TPC momentum resolution – from embedding
  - TPC efficiency – from embedding
  - TOF matching efficiency – from data
  - HFT matching efficiency – from data
  - DCA resolution – from data
  - V_z position – from data
- fit by non–physical function:

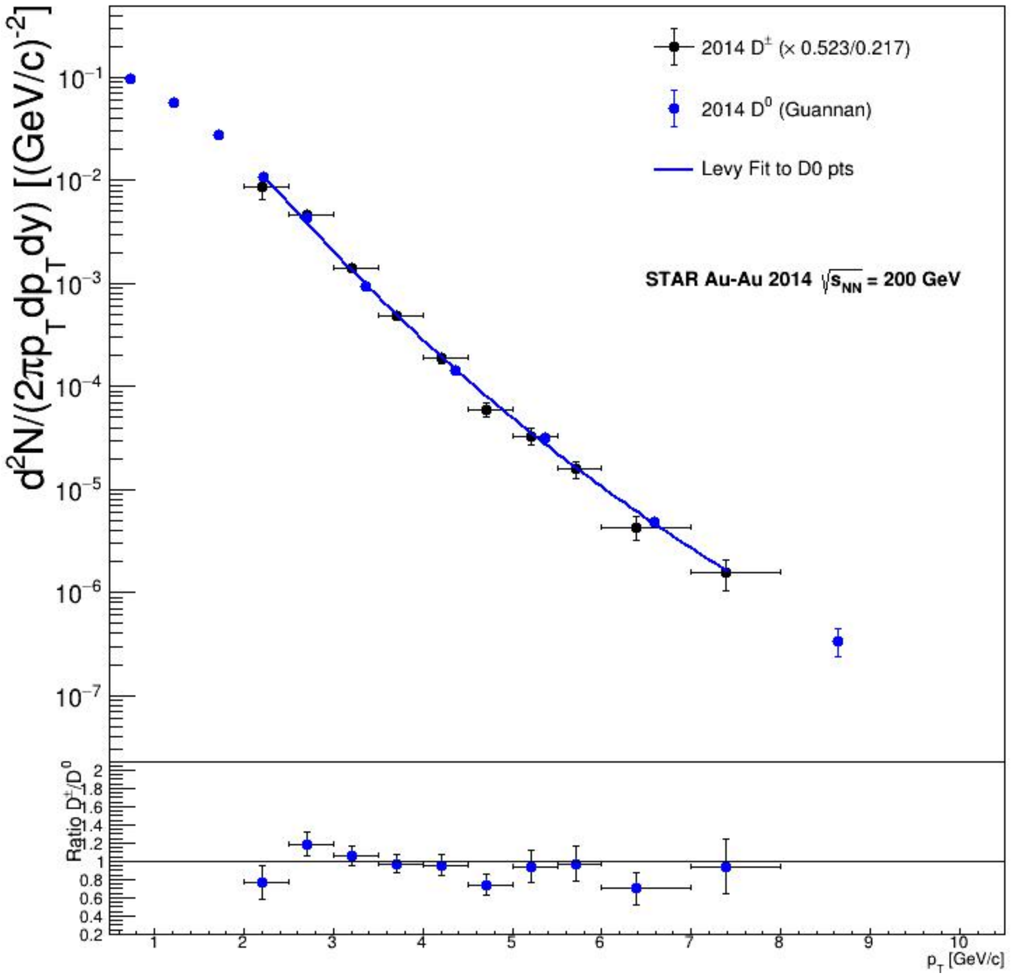
$$Eff(p_T) = Ae^{-(\frac{B}{p_T})^C} e^{-(\frac{p_T - D}{E})^2}$$

- need to add hybrid TOF efficiency
- missing primary vertex resolution correction (should be minor)



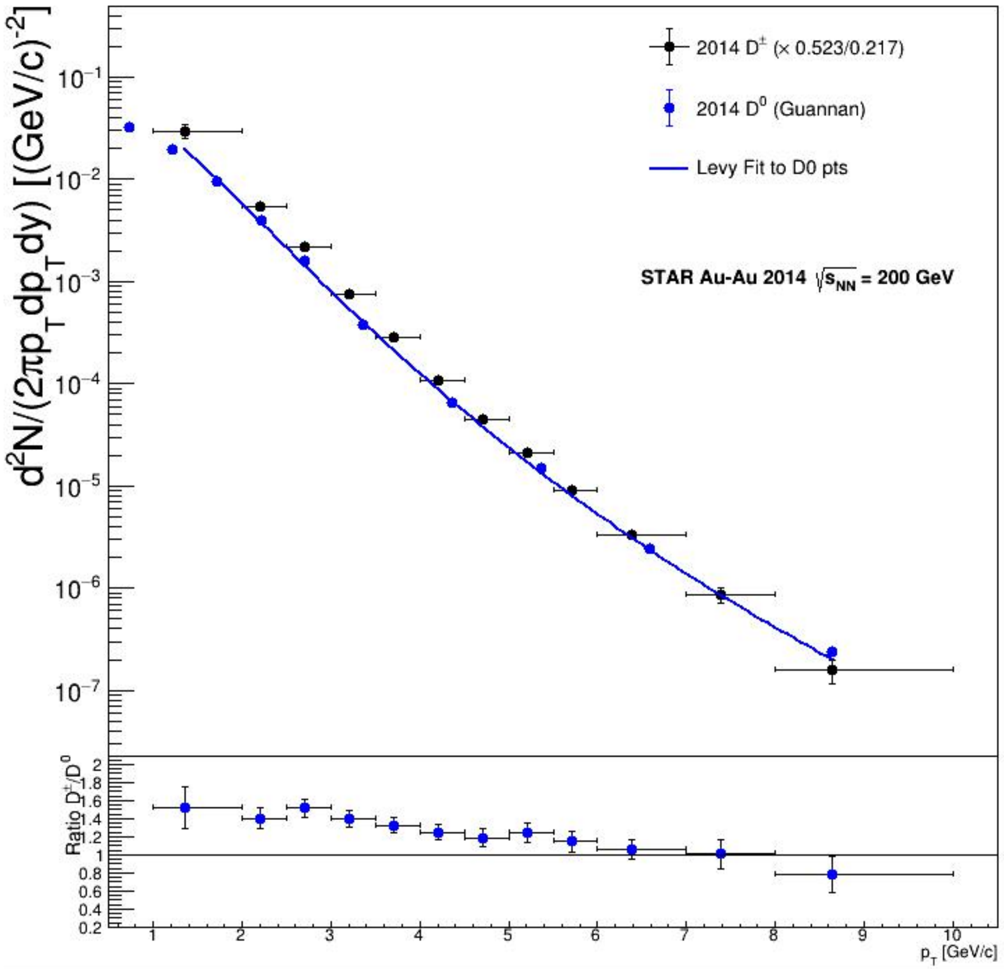
Results – p_T spectra

$D^{\pm}$ invariant yield, 0-10 %

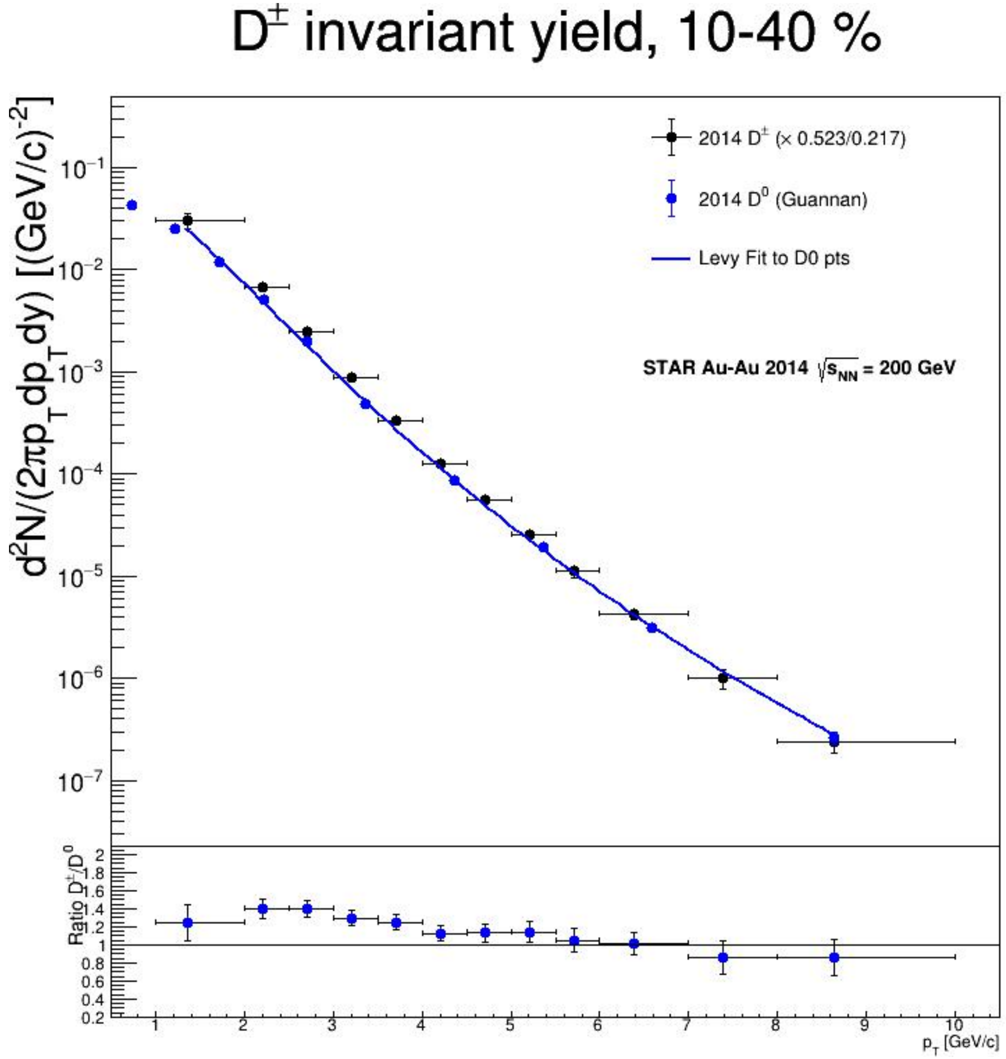


Levy fit with fixed first parameter

$D^{\pm}$ invariant yield, 0-80 %



Results – p_T spectra



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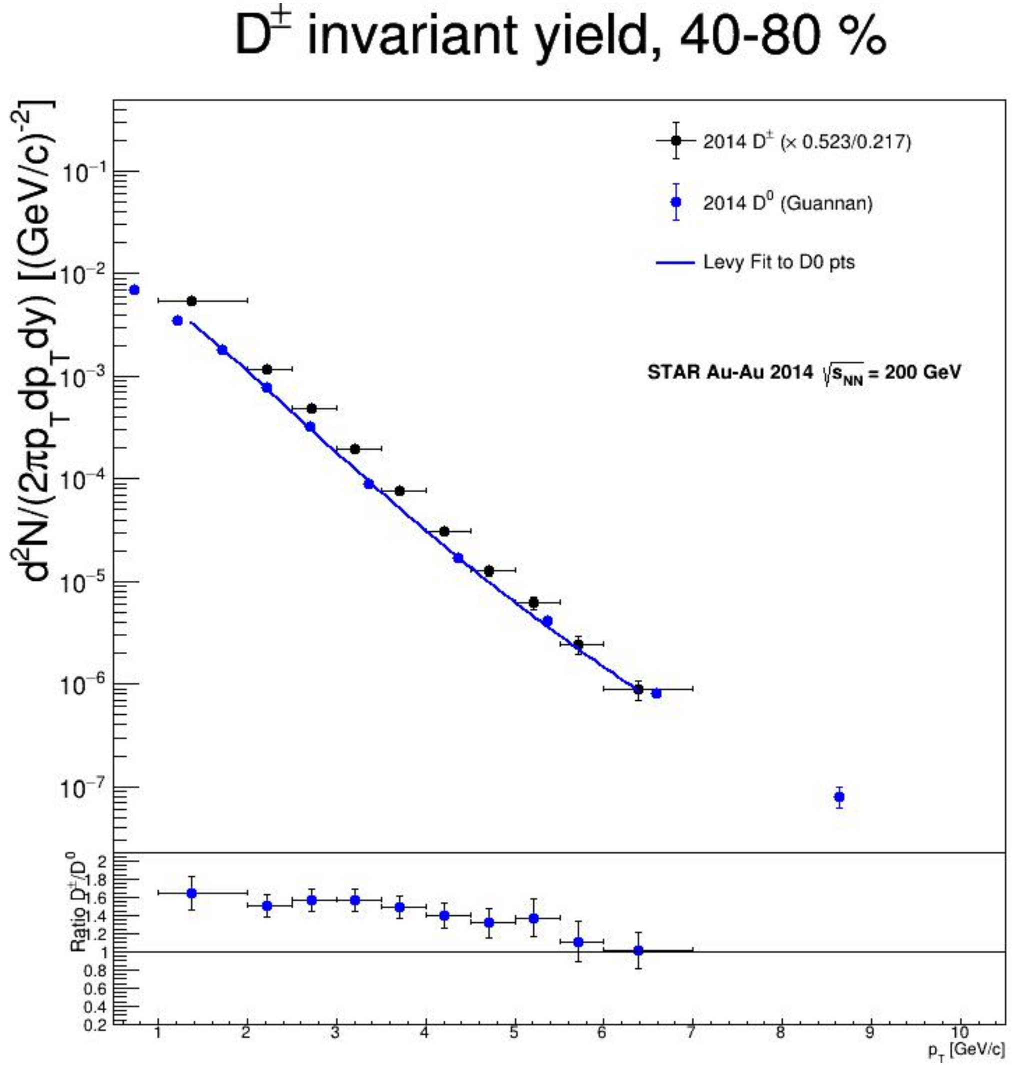
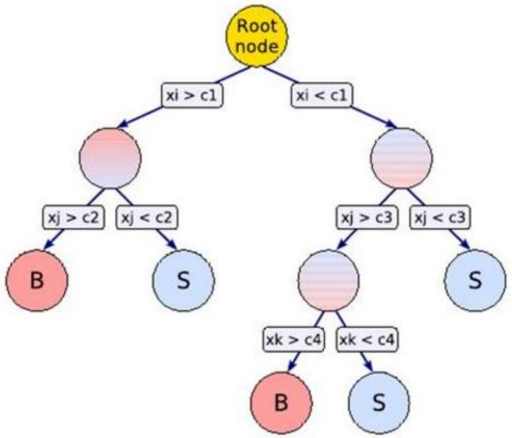


TMVA Improvement

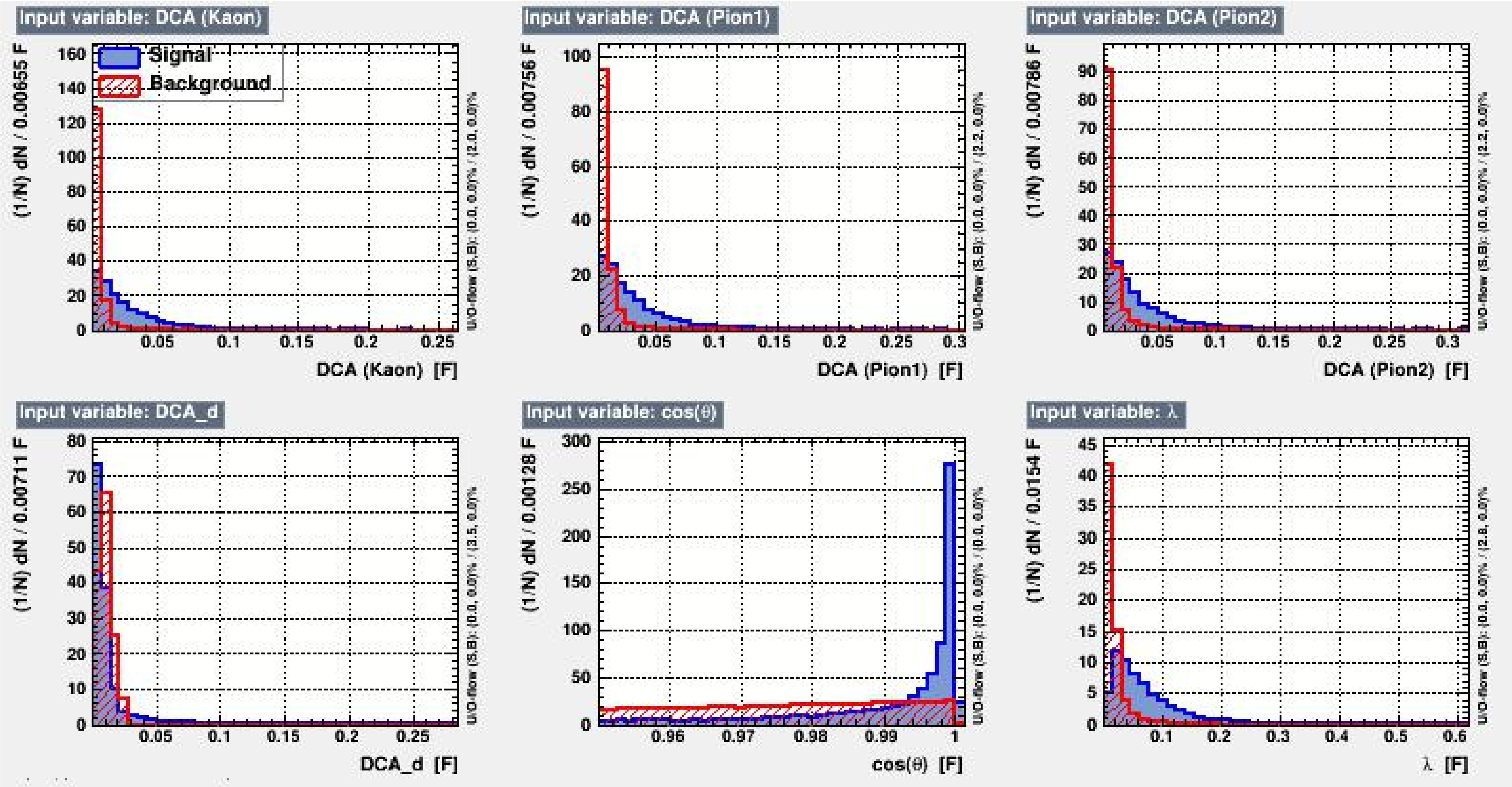
- we use Boosted Decision Trees (BDT) to improve the signal significance
- training signal sample from simulations (8.37 M), background from data – wrong sign combinations (8.41 M)



- variables used:
  - k_dca, pi1_dca, pi2_dca, dcaMax
  - CosTheta, D_decayL
- 850 trees with depth 3 (standard settings) – boosting
- dependence on variables boiled down to 1 number – BDT response

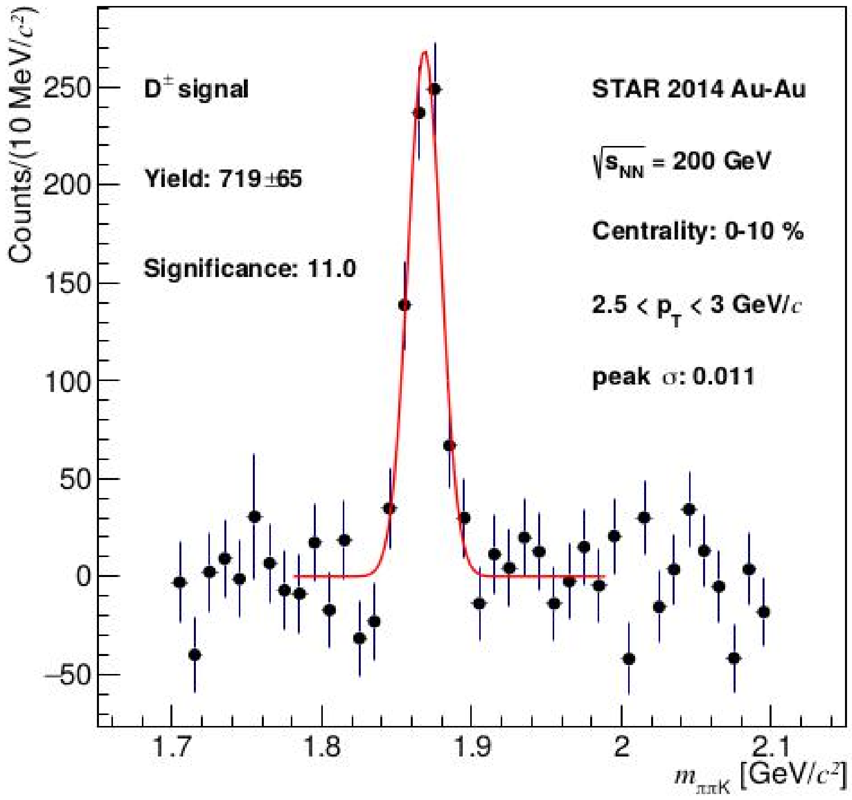
  (–1 = pure background, 1 = pure signal in ideal case)

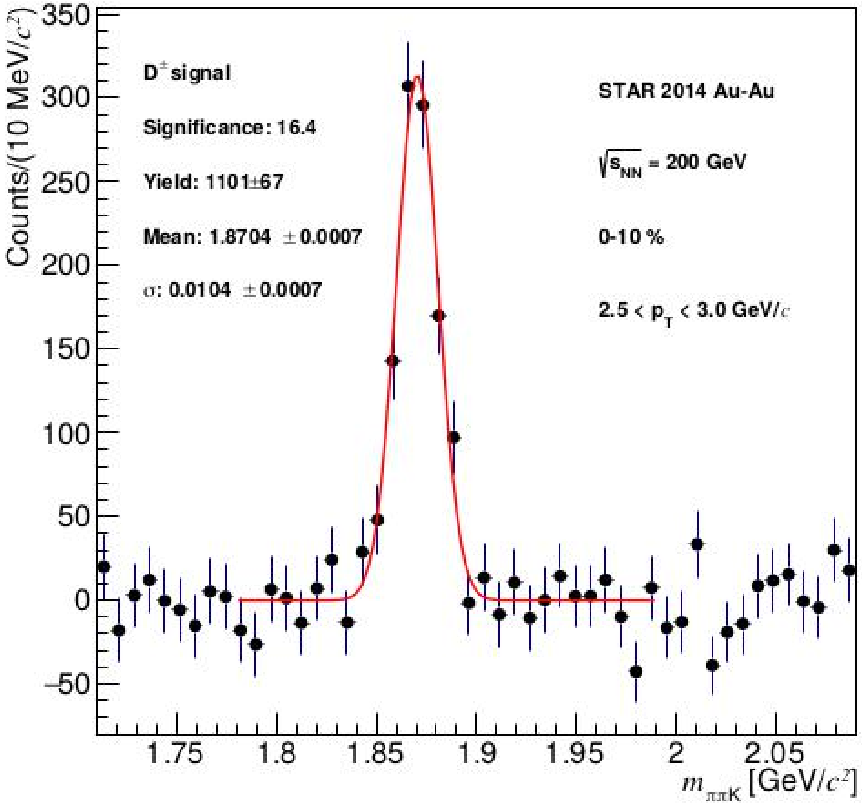
BDT Variables Distributions

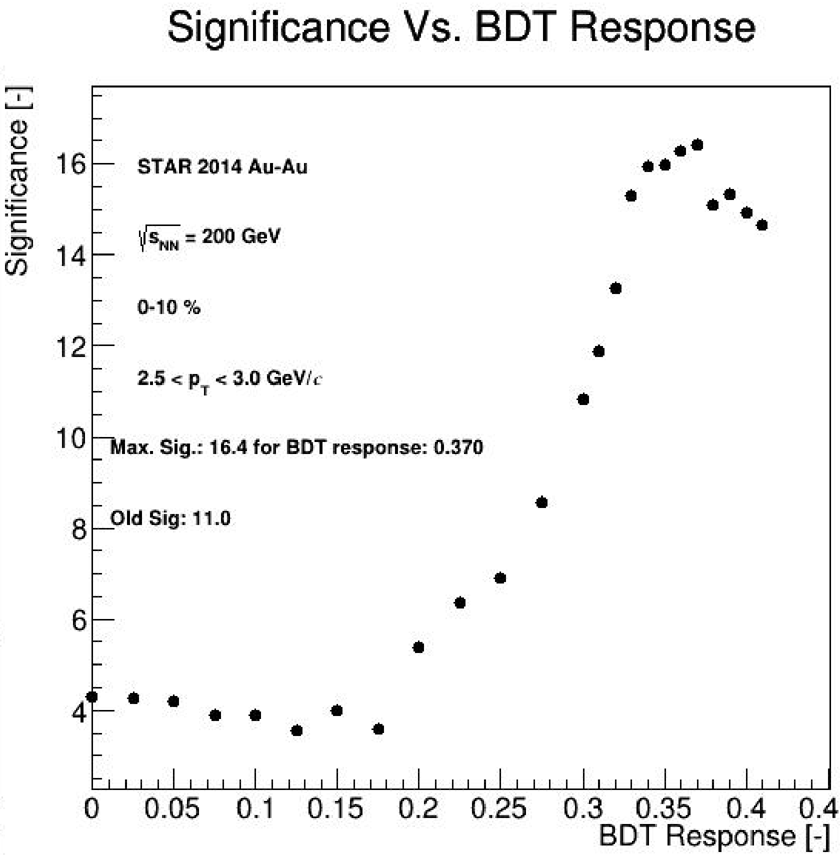


Cuts vs. TMVA BDT

improvement of significance by a factor of 1.5

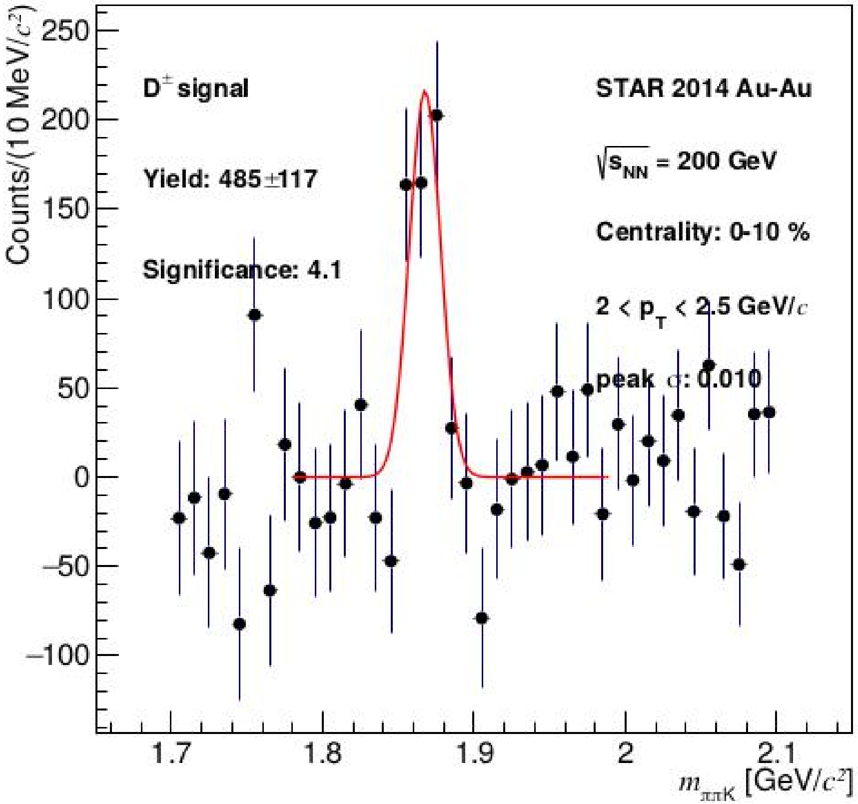


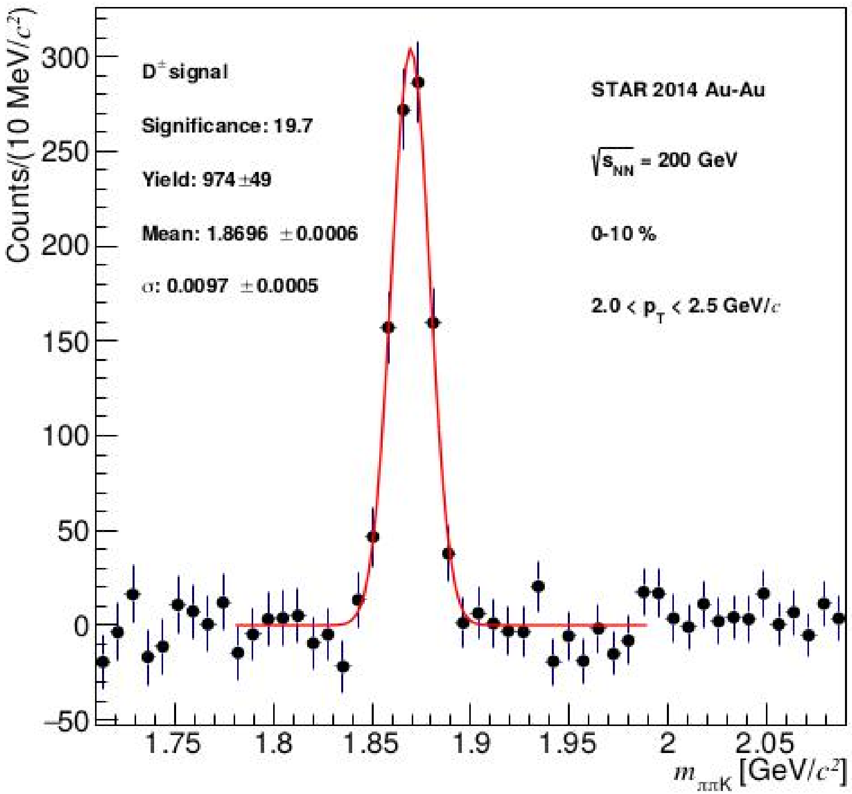




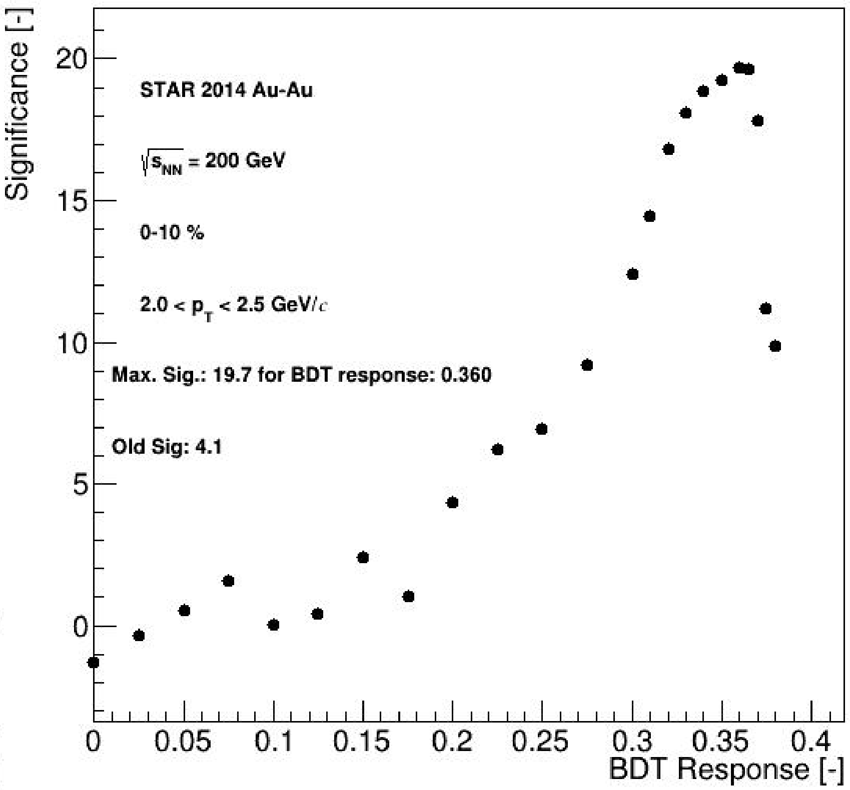
Cuts vs. TMVA BDT

larger improvement for lower p_T –factor of 4.8



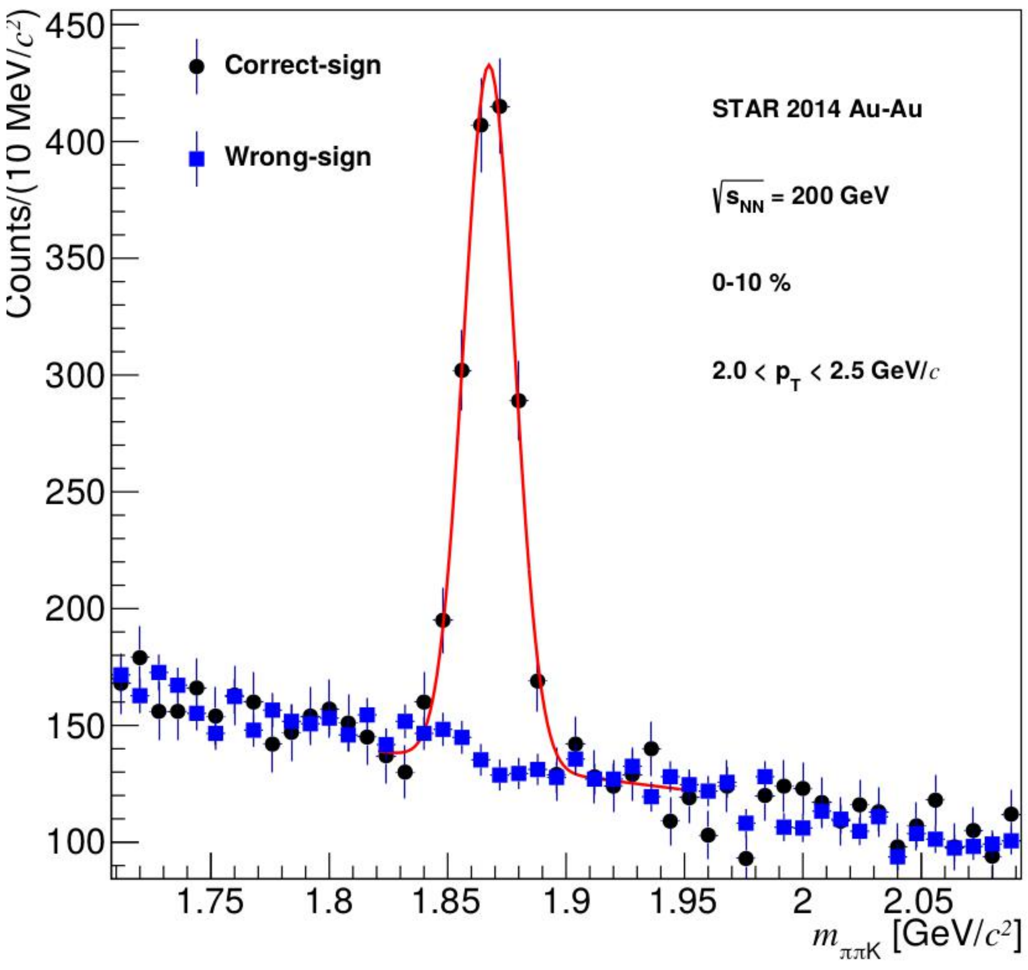


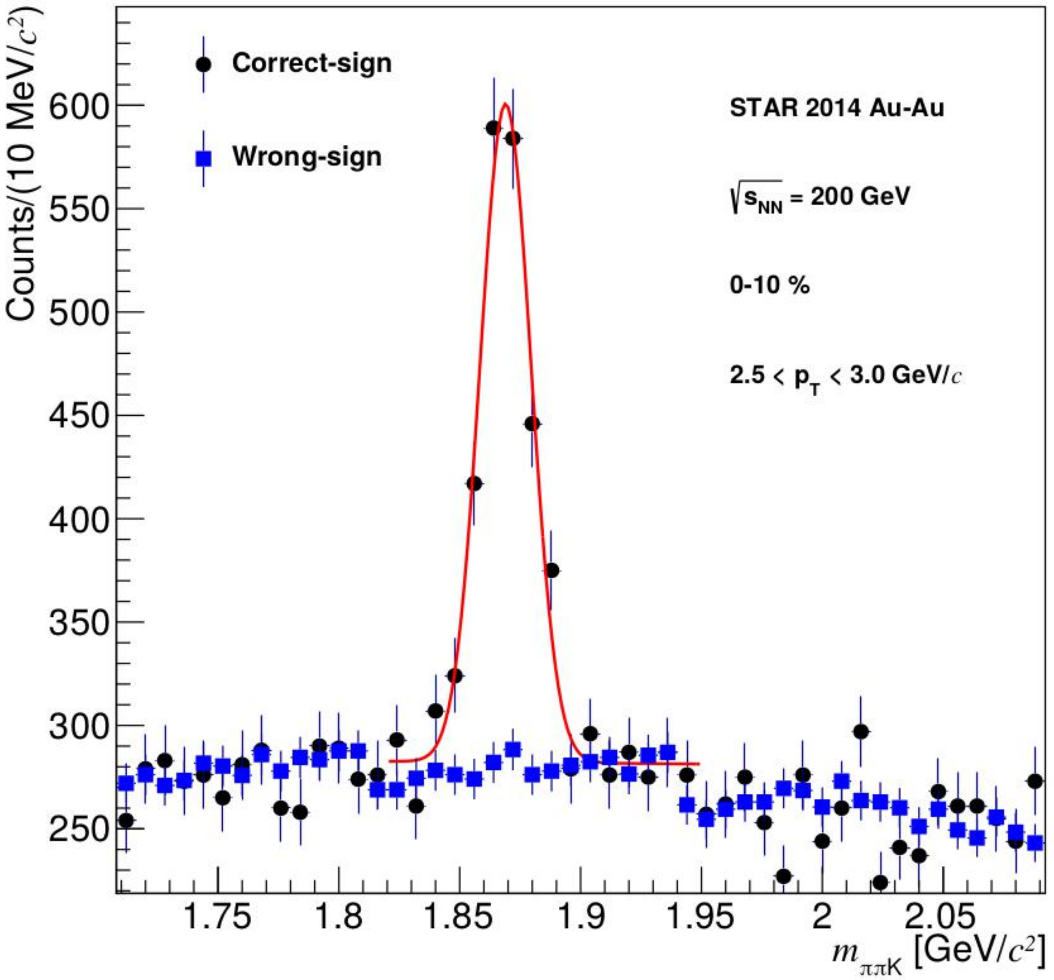
Significance Vs. BDT Response



for higher p_T , the change is not that great –> the BDT settings need to be tuned

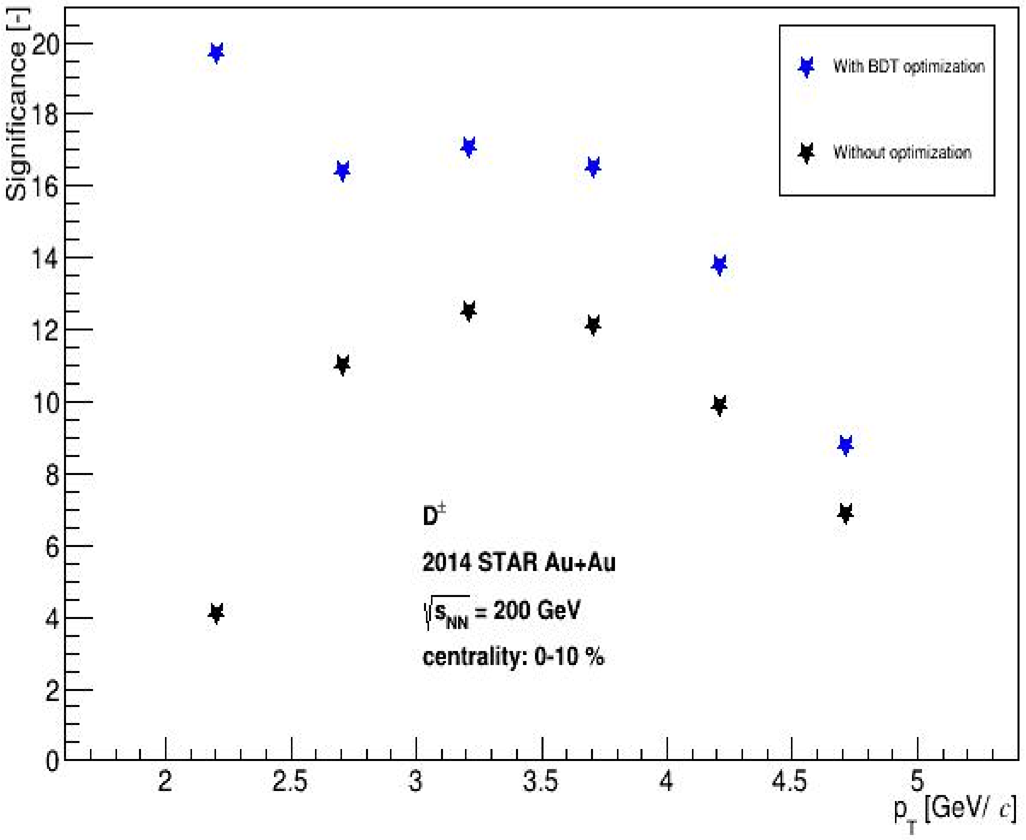
BDT Consistency Check – no peak in wrong-signs





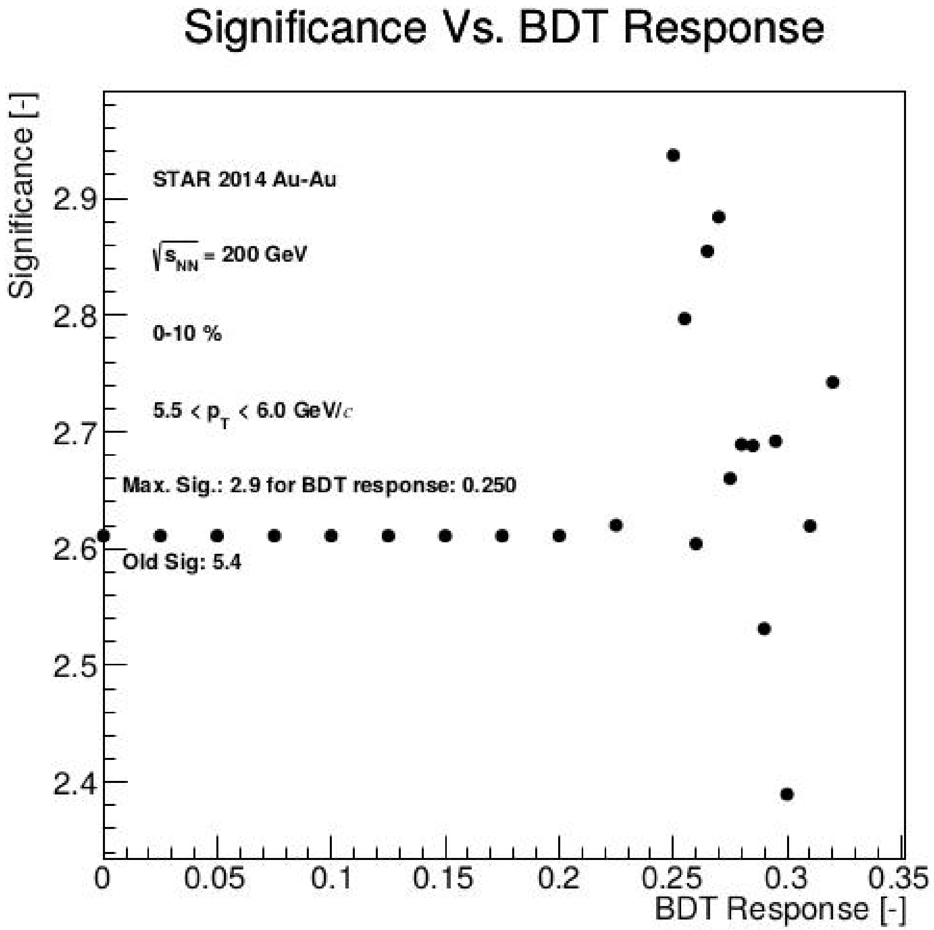
Comparison Cuts vs. BDT

124.6 M events	0–10 % traditional		0–10 % BDT		Ratio BDT/Trd.
p_T [GeV/c]	Yield [–]	Sig. [–]	Yield [–]	Sig. [–]	
2.0 – 2.5	485 ± 117	4.1	974 ± 49	19.7	4.8
2.5 – 3.0	719 ± 65	11.0	1101 ± 67	16.4	1.5
3.0 – 3.5	470 ± 38	12.5	533 ± 31	17.1	1.4
3.5 – 4.0	279 ± 23	12.1	468 ± 28	16.5	1.4
4.0 – 4.5	166 ± 17	9.9	264 ± 19	13.8	1.4
4.5 – 5.0	75 ± 11	6.9	110 ± 13	8.8	1.3
5.0 – 5.5*	55 ± 9	5.8	89 ± 13	6.9	1.2
5.5 – 6.0*	33 ± 6	5.4	43 ± 15	2.9	0.5



* the BDT optimization is unstable with current settings

Bad bin example



Summary

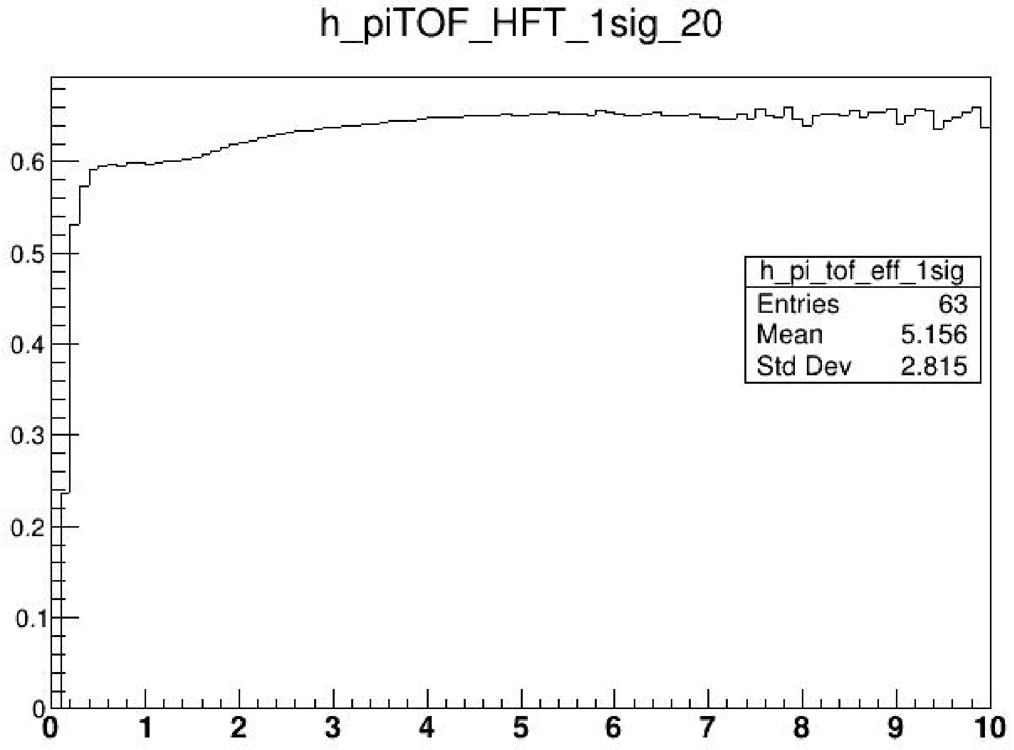
- 2014 data from Au–Au collisions at 200 GeV analyzed using traditional cuts
- $D^{\pm}$ reconstructed with significance > 3 (p_T 1–10 GeV/c for 0–80 %)
- $D^{\pm}$ p_T spectra reconstructed, still missing some corrections to be consistent with D^0 results
- significance of peaks improved using the BDT TMVA method

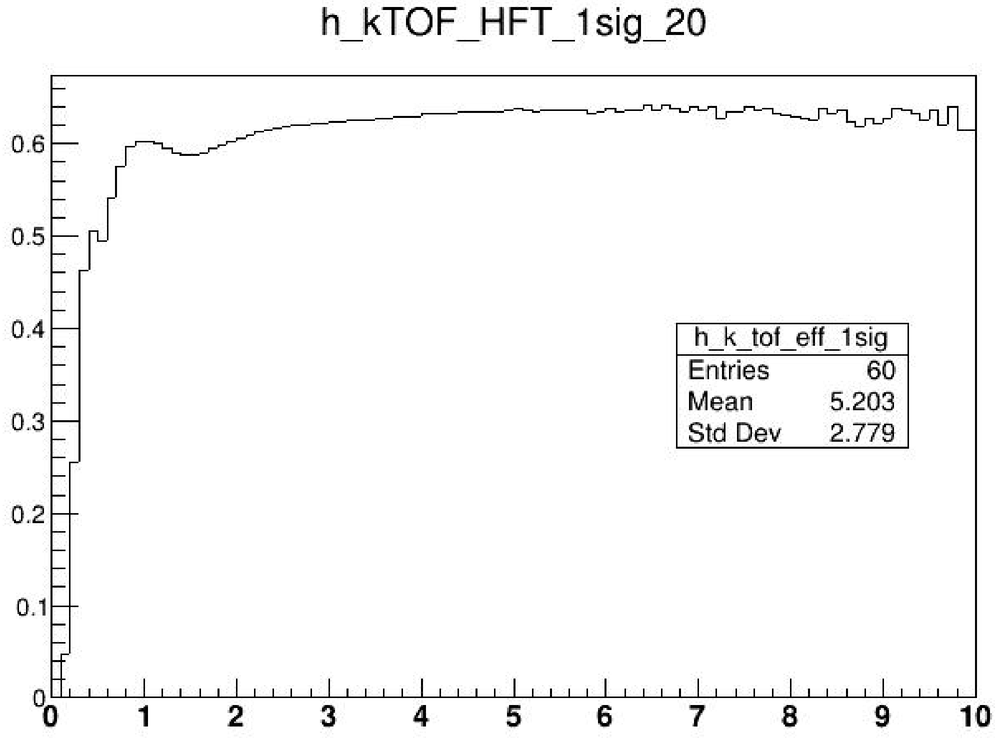
To Do

- improve/obtain results throughout the 0–10 GeV/c p_T range for all centrality bins (daughter p_T cut 0.5 –> 0.3 GeV/c, tune BDT settings for higher p_T)
- calculate Eff(p_T) using BDT cuts
- implement hybrid TOF efficiency
- calculate systematic errors
- obtain nuclear modification factor (R_{AA})

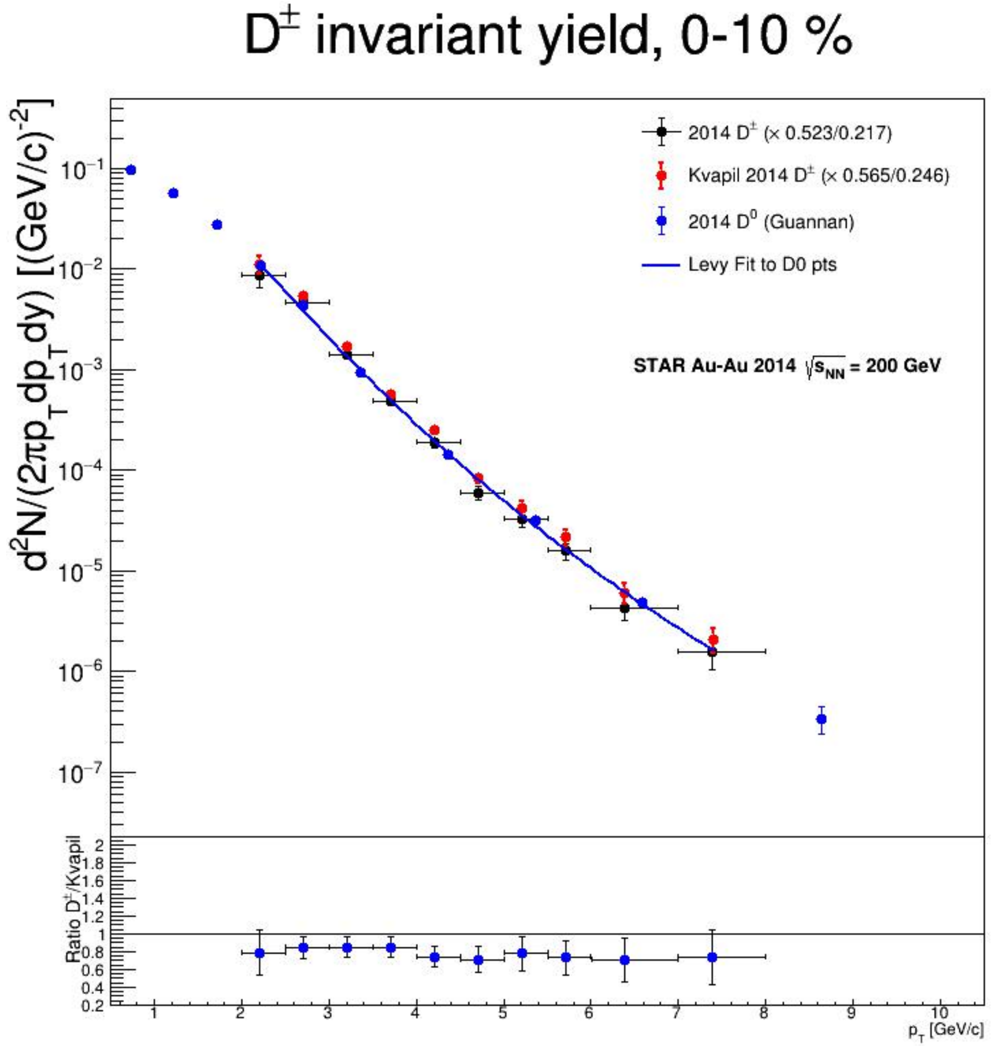
BACKUP

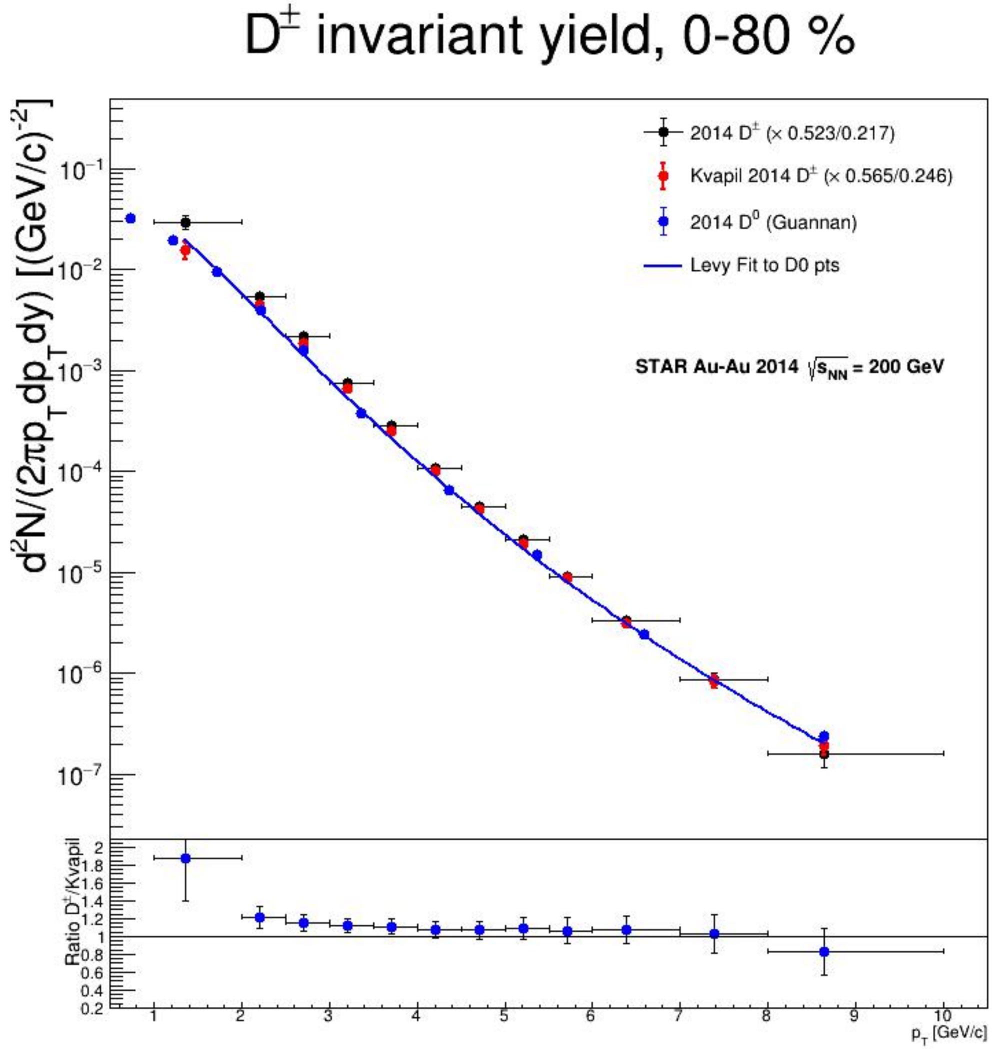
1 sig. tracks TOF+TPC+HFT/TPC+HFT





Comparison with Kvapil





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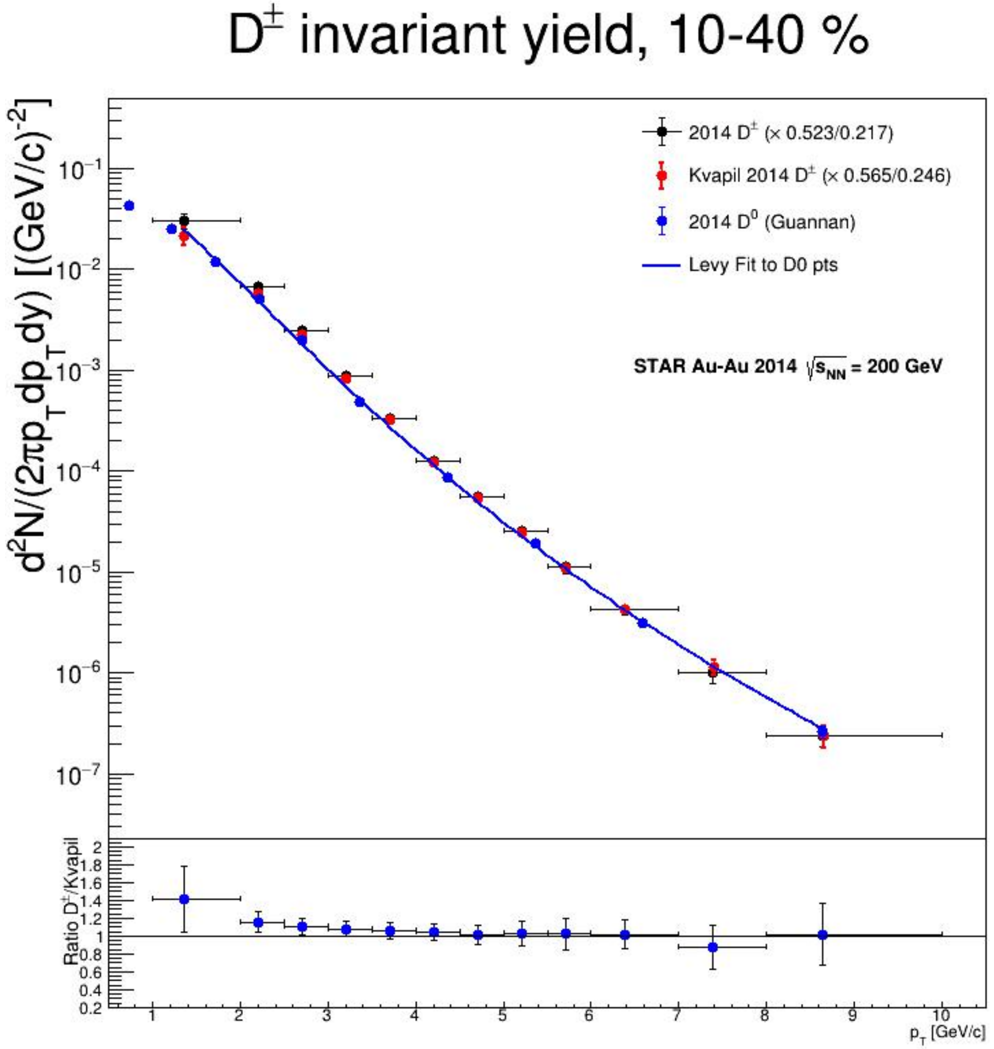
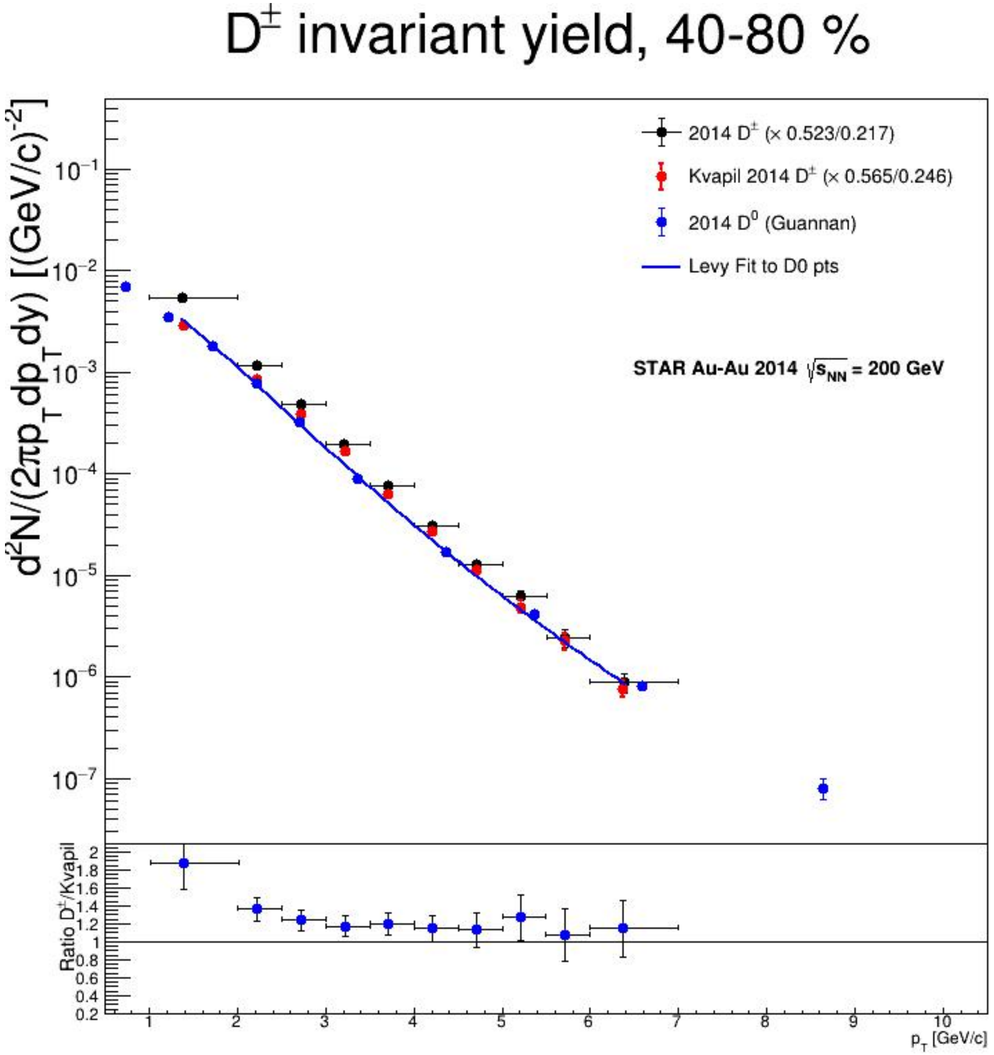




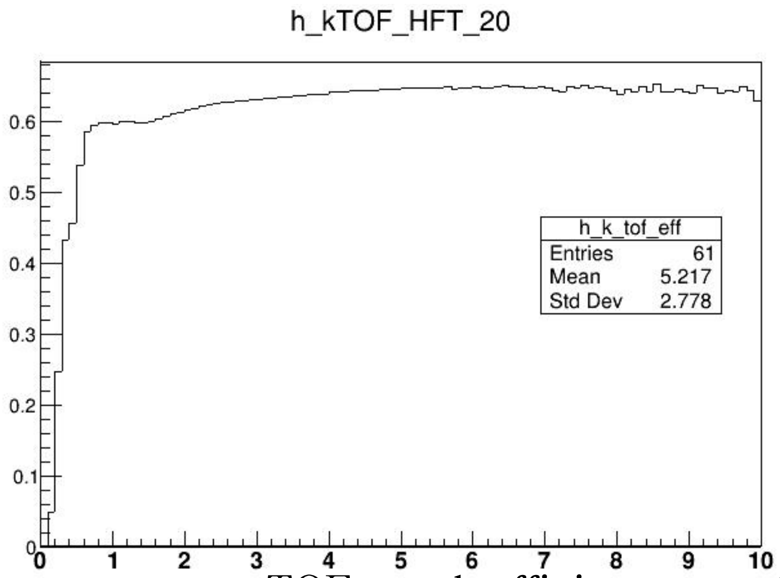
Hybrid TOF Efficiency

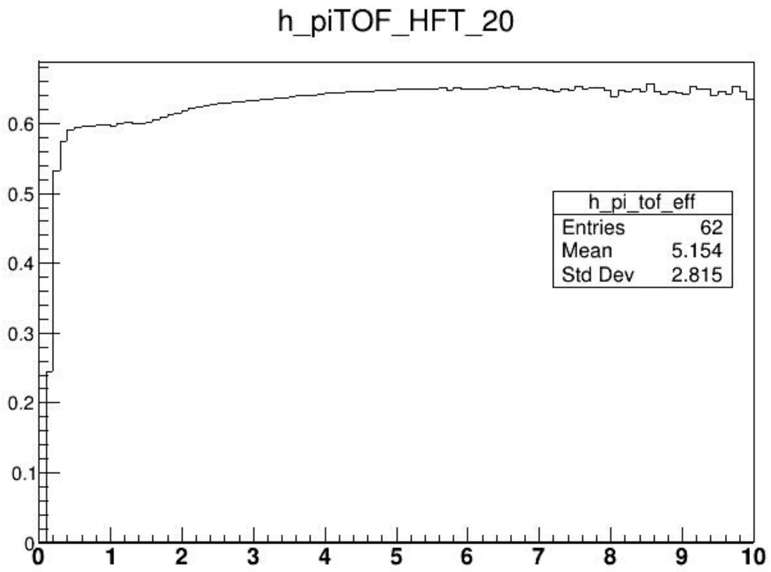
- tracks with TOF hit have additional correction factor: TOF PID cut efficiency
- TOF PID eff. for 2 sigma kaons: 0.917
- 3 sigma pions: 0.970
- single track PID eff: $\varepsilon_{PID}(TPC\&TOF) = (1 - \varepsilon_{TofMatch} + \varepsilon_{TofMatch} \times \varepsilon_{TofPID}) \times \varepsilon_{TPC}$
- our $D^{\pm}$ from 3 tracks

-> "worst case" scenario:

0.970 x 0.970 x 0.917 = 0,862

- should be implemented soon



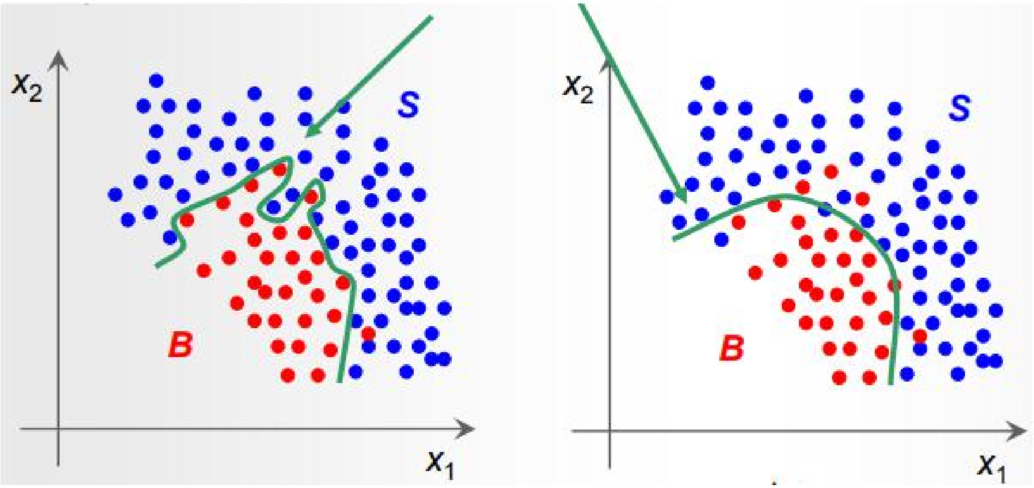


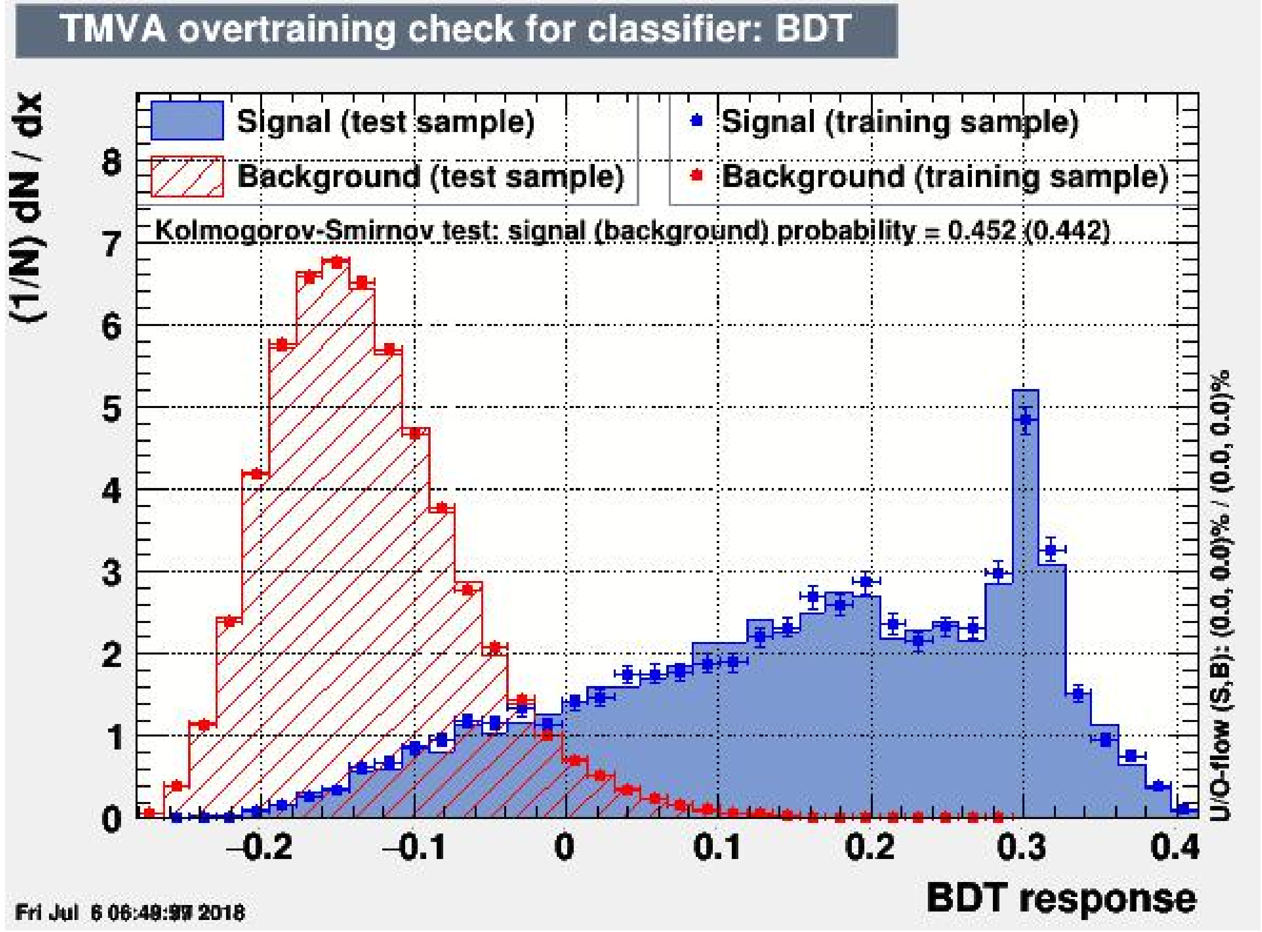
TOF match efficiency: cca 60 % of high-p_T tracks have good TOF hit

BDT Overtraining Check

- we want to avoid overtraining on statistical fluctuations

overtrained   good





for $2.5 < p_T < 3.0$ GeV/c, 0–10 %