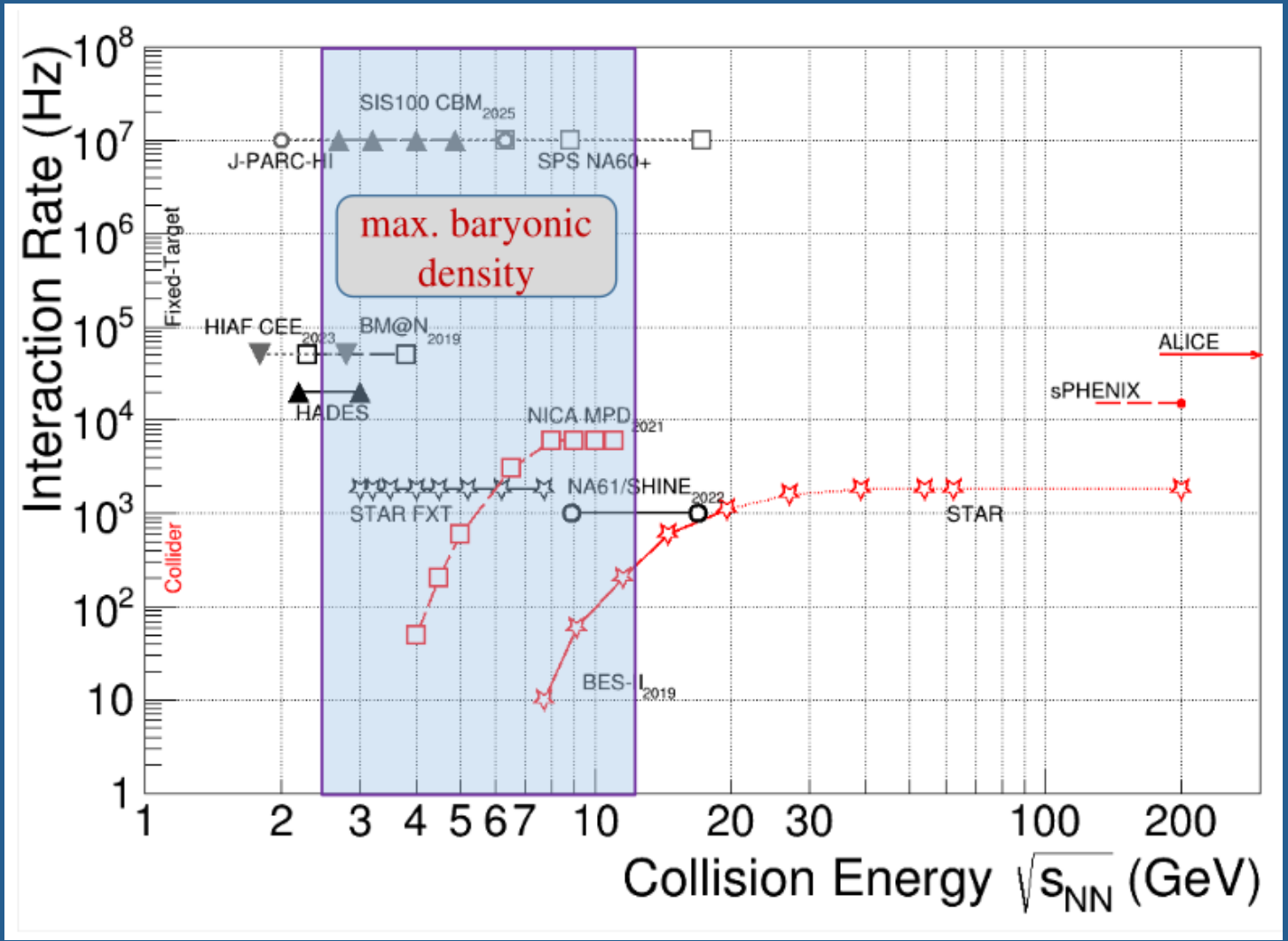
PWG5 (Heavy Flavour) summary

Alexander Zinchenko

Outline

1. Charm production cross-section
2. Scope of activities
3. Inner Tracking System (ITS) studies
4. Related Work Packages:
    1. ITS track reconstruction
    2. Exclusive D-meson decay selection
5. D-meson semileptonic decays
6. J/ψ → e+e- selection
7. Summary

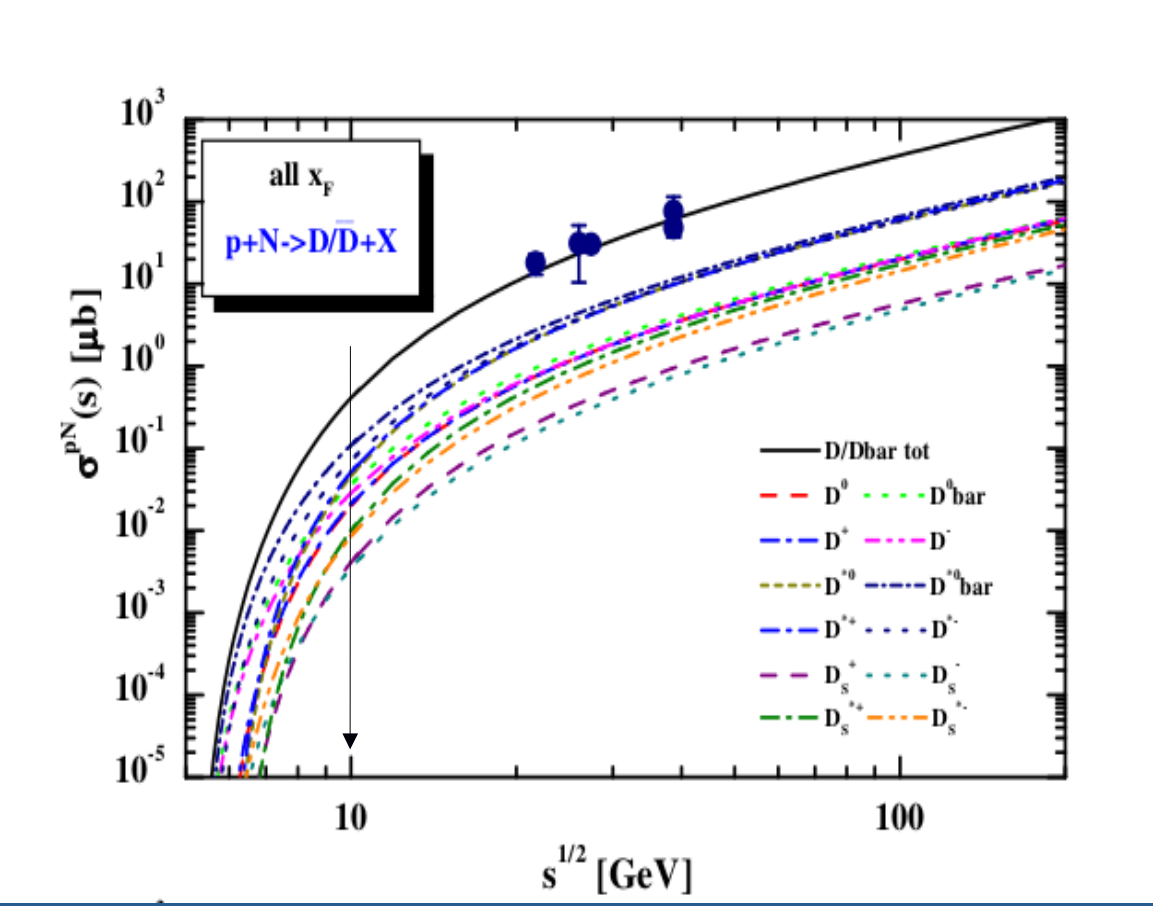
Landscape of heavy-ion experiments

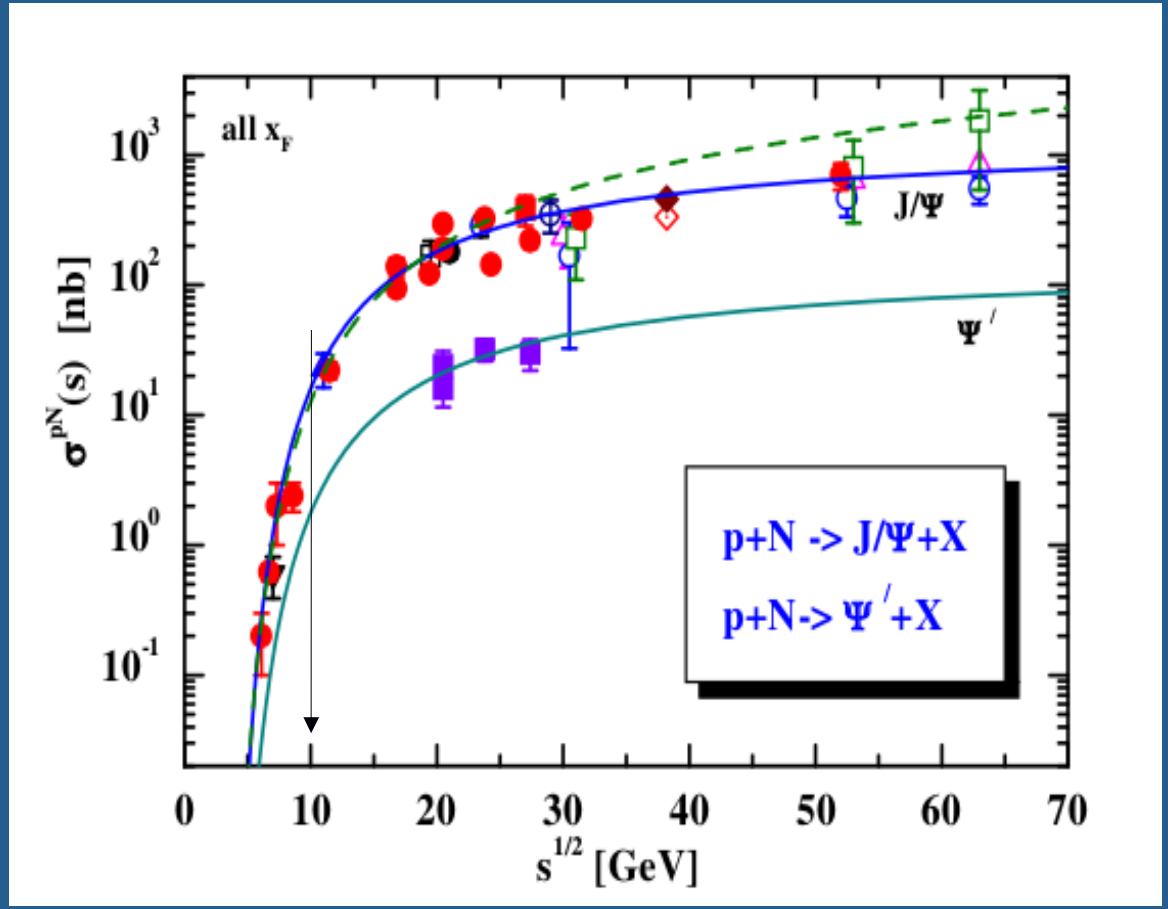


- At present, MPD/NICA, NA61/SHINE at SPS and CBM/SIS100 have charm studies in their physics programs.

Hadron	Decay channel	$c\bar{\tau}$ [μm]	BR
D^0	$\pi^+ + K^-$	123	3.89%
D^+	$\pi^+ + \pi^+ K^-$	312	9.22%
D_s^+	$\pi^+ + K^- + K^+$	150	5.50%
Λ_c	$p + \pi^+ + K^-$	60	5.00%
J/ψ	$e^- + e^+$		6.00%

Charm production cross-sections





- W. Cassing, E. L. Bratkovskaya, A. Sibirtsev, “Open charm production in relativistic nucleus-nucleus collisions”, arXiv:nucl-th/0010071, 2001

Charm production cross-sections

√s = 7 GeV

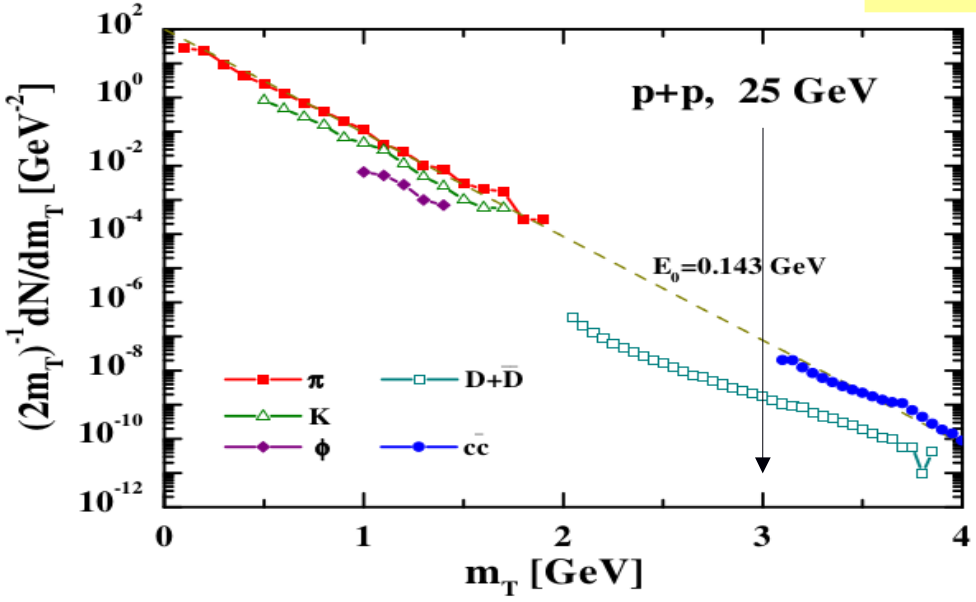


FIG. 5. The transverse mass specta from pp collisions at $T_{lab} = 25$ GeV for pions (full squares), kaons (open triangles), and ϕ-mesons (full rhombes) from the LUND string model [52] as implemented in HSD. The $D + \bar{D}$ meson (open squares) and charmonium (full dots) spectra – including the decay $\chi_c \to J/\Psi + \gamma$ – result from the parametrizations specified in Section 2. The dashed line shows an exponential with slope parameter $E_0 = 0.143$ GeV.

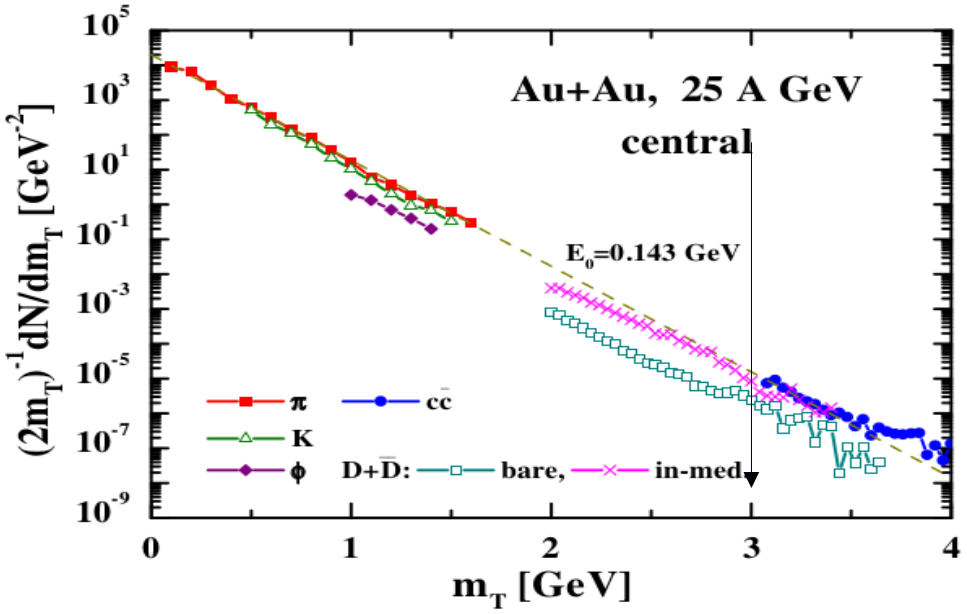


FIG. 16. The transverse mass spectra of pions (full squares), kaons (open triangles), ϕ-mesons (full rhombes), $D + \bar{D}$ mesons (open squares) and $J/\Psi, \Psi'$ mesons (full dots) in the HSD approach for a central $Au + Au$ collision at 25 A·GeV without including self energies for the mesons. The crosses stand for the D-meson m_T spectra when including an attractive mass shift according to [9]. The thin dashed line shows an exponential with slope parameter $E_0 = 0.143$ GeV. Note that final state elastic scattering of kaons and ϕ-mesons with pions has been discarded in the calculations.

- W. Cassing, E. L. Bratkovskaya, A. Sibirtsev, “Open charm production in relativistic nucleus-nucleus collisions”, arXiv:nucl-th/0010071, 2001

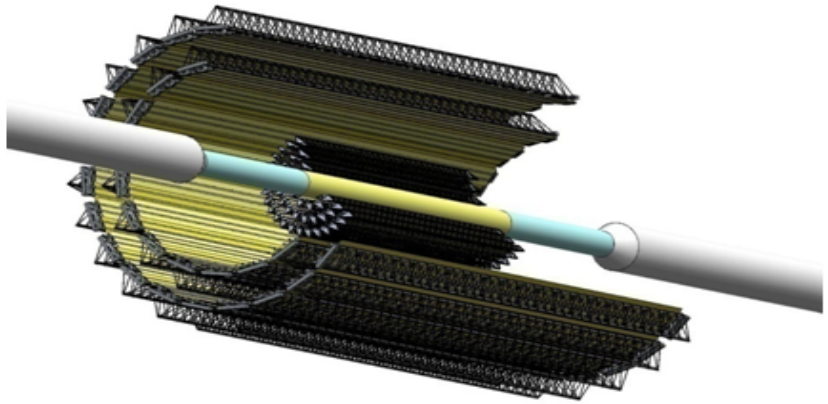
Scope of activities

1. Open charm studies: exclusive decays → Inner Tracking System (ITS) performance evaluation (synergy with ITS project) → dedicated track reconstruction methods (“Vector Finder”)
2. Semi-leptonic decays and charmonia → lepton (electron) tagging (synergy with dilepton studies)

MPD Inner Tracking System based on MAPS

Reconstruction of charmed particles in Au+Au central collisions with MPD ITS3+TPC tracking system

Kondratev V., Murin Yu.



MPD WPG5

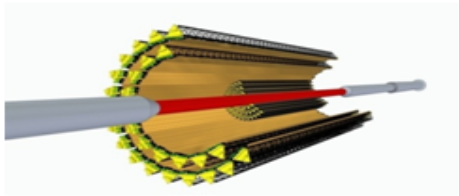
MPD Inner Tracking System based on MAPS

MPD ITS geometric models

Two ITS geometric models were used for simulation:

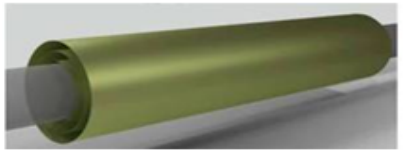
1) project model (ITS-5-40) with 5 layers consisting of ladders with standard MAPS

Sensitive area: 15×30 mm²
Thickness: 50 µm
Number of pixels: 512×1024
Pixel size: 28×28 µm².



2) ITS3-like model (ITS-5-35) with OB consisting of 2 layers of standard MAPS and IB consisting of 3 layers of bended staves of MAPS (15 um pitch) with large area and thickness of 30 µm

Size of bended MAPS:
1 layer – 280*56.5 mm²
2 layer – 280*75.5 mm²
3 layer – 280*94.0 mm²

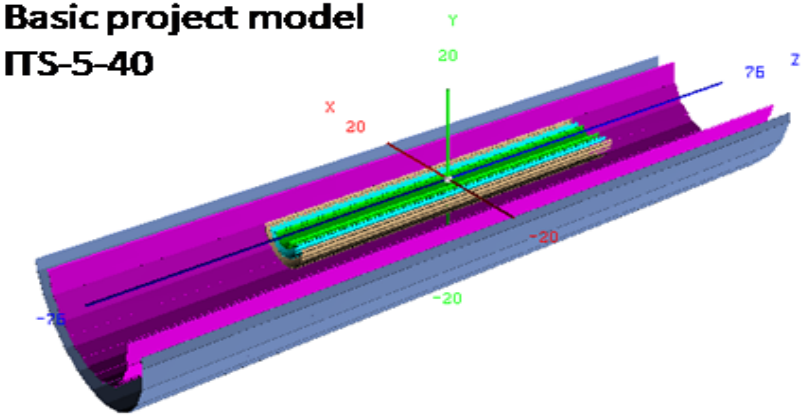


2

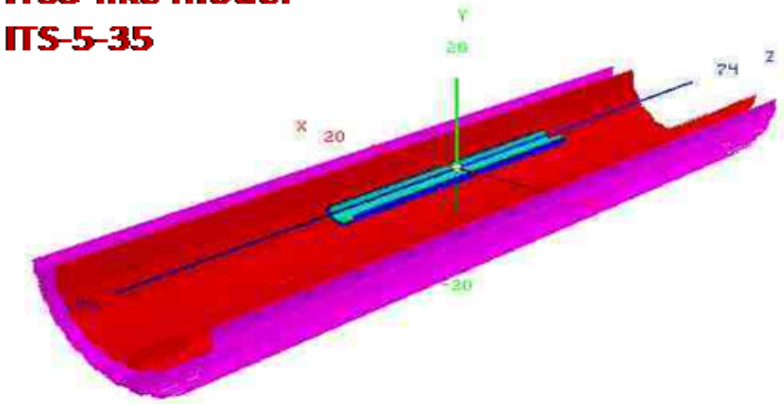
MPD Inner Tracking System based on MAPS

MPD ITS geometric models

Basic project model
ITS-5-40



ITS3-like model
ITS-5-35



Layer	No of MAPS	R_{min}, mm	R_{max}, mm	Length, mm
1	24 *12	22.4	26.7	750
2	24*22	40.7	45.9	750
3	24*32	59.8	65.1	750
4	98*36	144.5	147.9	1526
5	98*48	194.4	197.6	1526

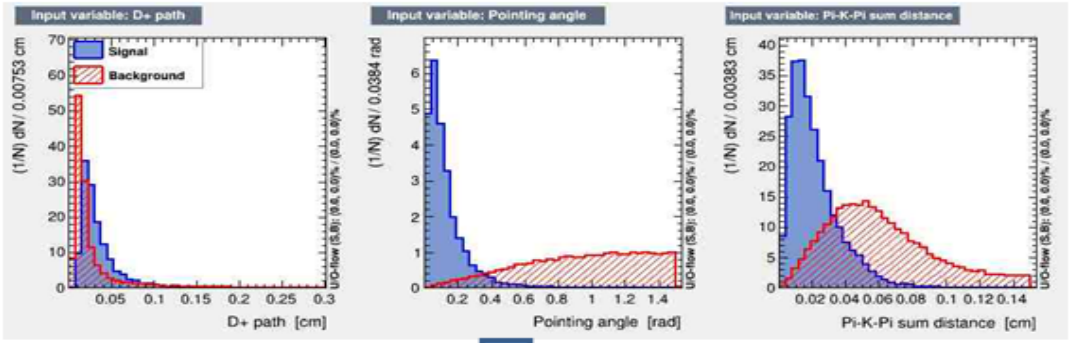
Layer	No of MAPS	R_{min}, mm	R_{max}, mm	Length, mm
1	4	18	18.03	560
2	4	24	24.03	560
3	4	30	30.03	560
4	98*36	144.5	147.9	1526
5	98*48	194.4	197.6	1526

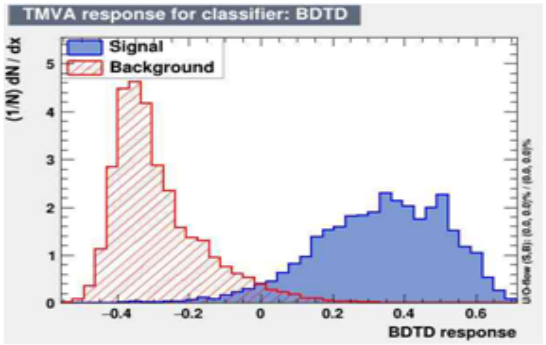
3

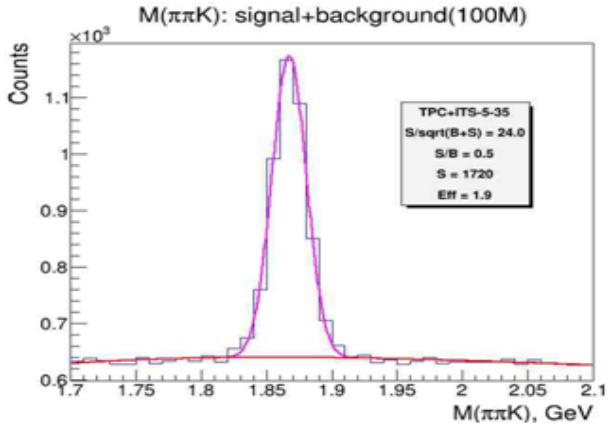
MPD Inner Tracking System based on MAPS

D^+ reconstruction in ITS-5-35 + TPC using VF + TMVA

dca(π), dca(K), dist(πK), λ(D^+), θ(D^+) cuts → BDT cut





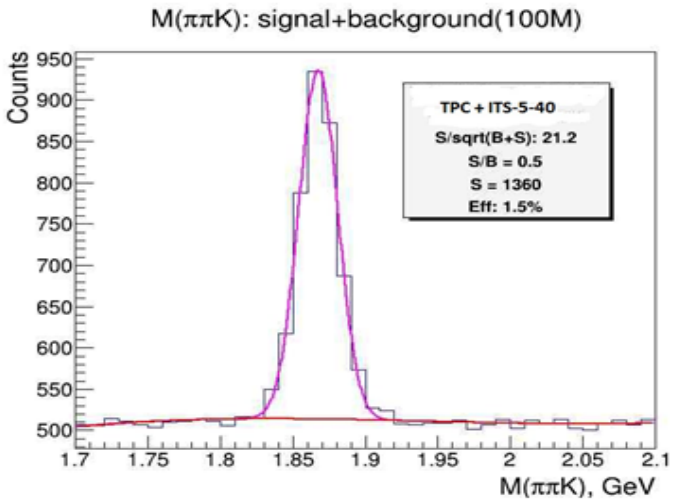


D^+ reconstruction efficiency obtained: ε=1.9%

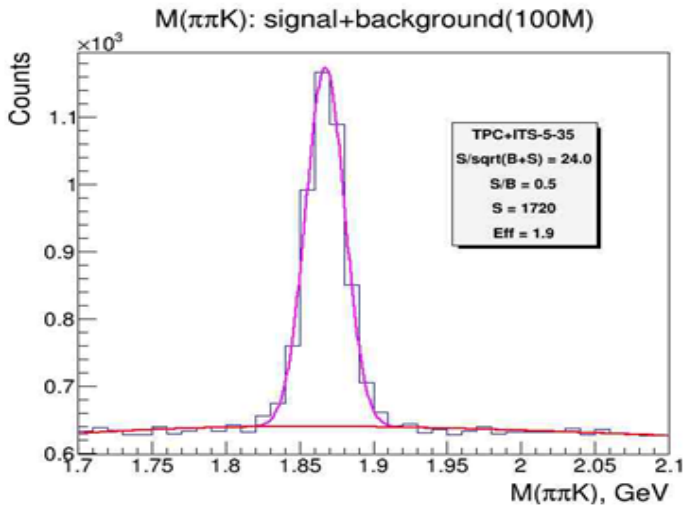
MPD Inner Tracking System based on MAPS

D^+ reconstruction efficiency with two ITS models

Project model



ITS3-like model



ITS	S	S/B	$S/\sqrt{S+B}$	ε, %
ITS-5-40	1360	0.50	21.2	1.5
ITS-5-35	1720	0.50	24.0	1.9

The reconstruction efficiency increases by 25% when using ITS with an Internal Barrel built on the base of a new type of sensors (bended MAPS with large area)

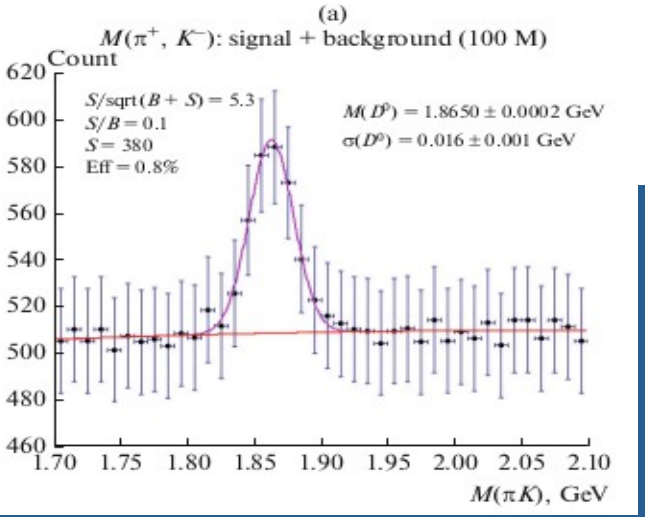
5

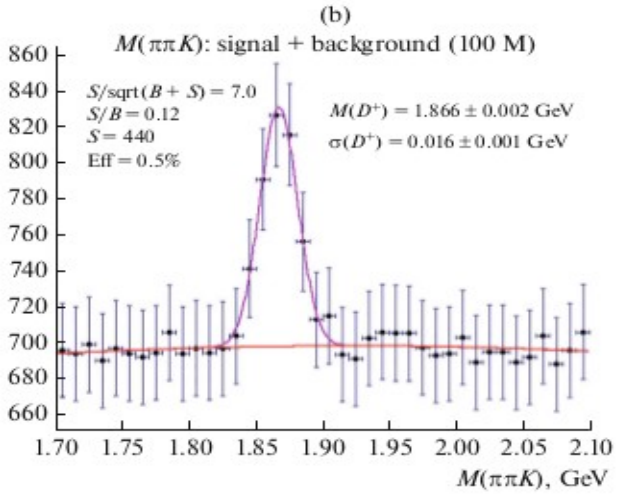
MPD Inner Tracking System based on MAPS

Published articles

1. V. P. Kondratyev, N. A. Maltsev and Yu. A. Murin.
Identification Capability of the Inner Tracking System for Detecting D Mesons at the NICA-MPD Facility.
Bulletin of the Russian Academy of Sciences: Physics, **2022**, Vol. 86, No. 8, pp. 1005–1009.

2. Zherebchevsky, V. I., Maltsev, N. A., Nesterov, D. G., Belokurova, S. N., Vechernin, V. V., Igolkin, S. N., Kondratiev, V. P., Lazareva, T. V., Prokofiev, N. A., Rakhmatullina, A. R. & Feofilov, G. A.
New Technologies for the Vertex Detectors in the NICA Collider Experiments.
Bulletin of the Russian Academy of Sciences: Physics. **2022**, Vol.86,No. 8, pp. 948-955.





RSF Grant for SpbU

Leader: Vladimir Zherebchevsky

Superdense nuclear matter and methods of its study in experiments at the NICA accelerator-storage complex

2023-2025

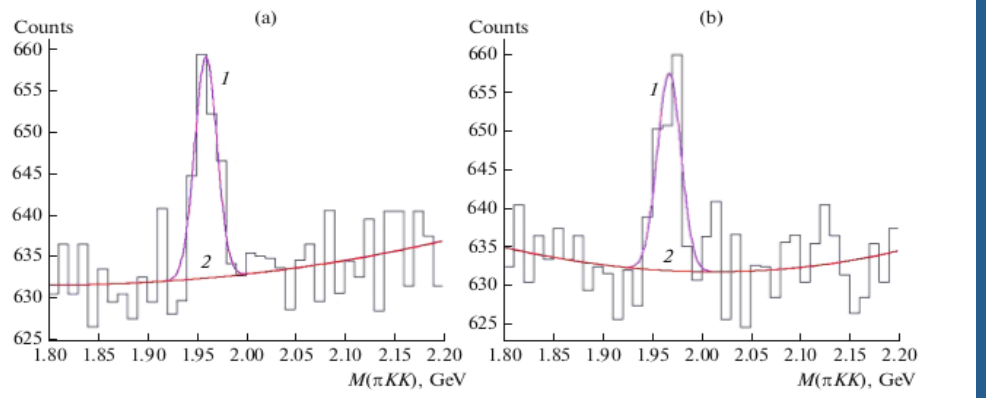
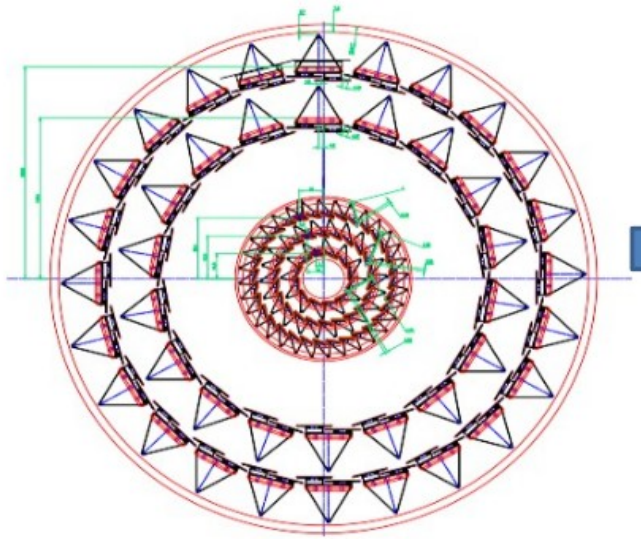


Fig. 3. Signal of D_s^+ mesons in the invariant-mass spectrum, separated according to (a) TC and (b) MVA in 10^8 central Au + Au collisions at $\sqrt{s_{NN}} = 9$ GeV: (*1*) full spectrum, (*2*) residual combinatorial background.

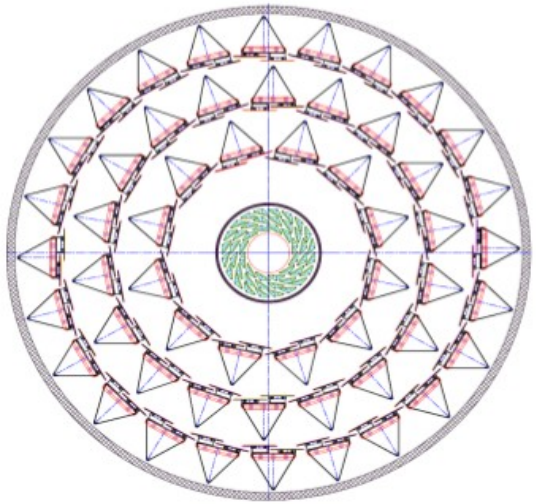
MPD Inner Tracking System based on MAPS

All-MAPS “development” model of the MPD ITS

5 layers



6 layers



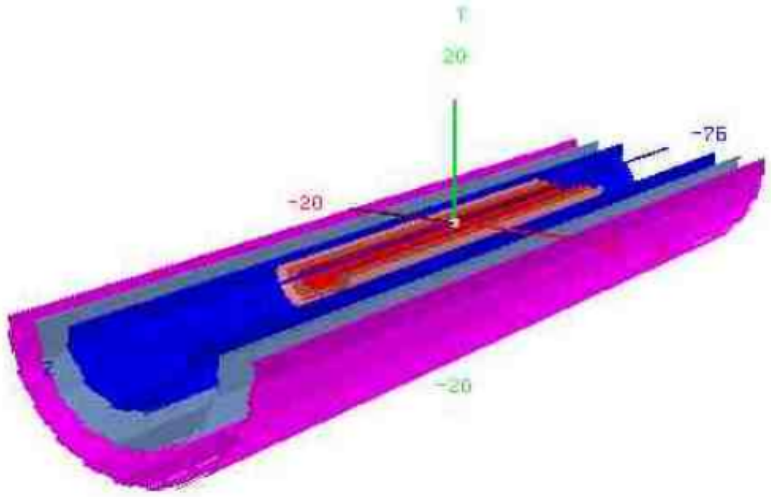
V. Kondratiev,
Yu. Murin

MPD Inner Tracking System based on MAPS

Geometric model of 6 layer ITS used for development of simulation software package

OB - 3 layers of ALPDE-like MAPS (15*30 mm²) with effective thickness of 700 µm

IB - 3 layers of ALPIDE-like MAPS (15*30 mm²) with effective thickness of 50 µm (IB -"development" configuration)

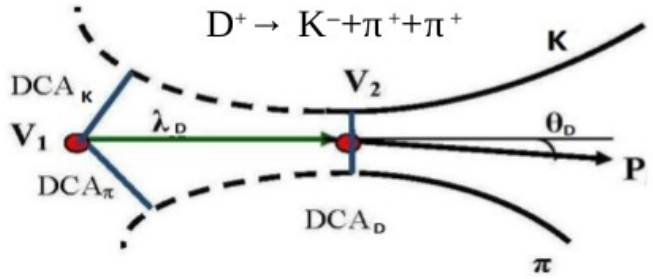


Layer	R_{min}, mm	R_{max}, mm	Length, mm
1	22.4	26.7	750*
2	40.7	45.9	750*
3	59.8	65.1	750*
4	93.2	96.7	1526
5	144.5	147.9	1526
6	194.4	197.6	1526

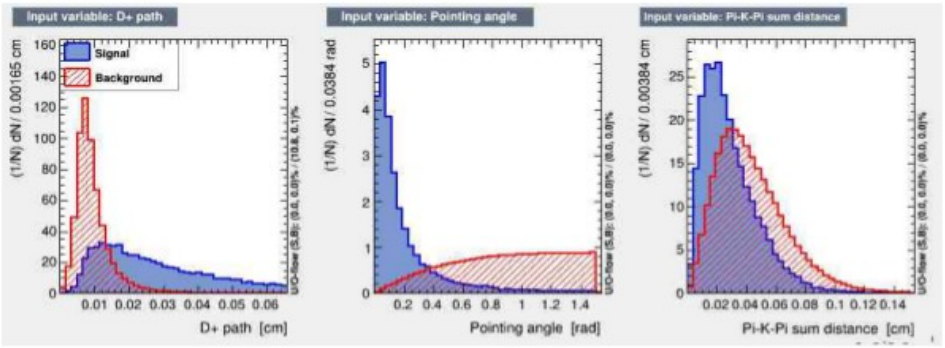
Beam pipe diameter – 40 mm

Pont-like source

MPD Inner Tracking System based on MAPS

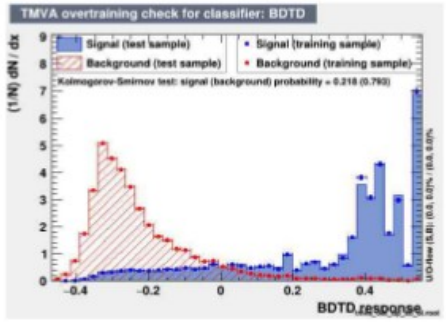


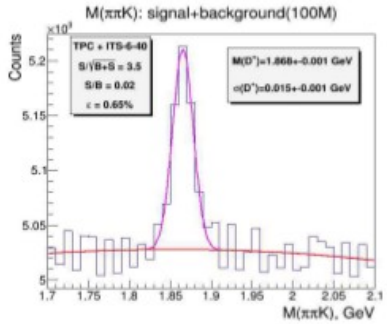
Used methods :
1) Track finder: KF
2) Particle identification: TOF + dE/dx
3) Track analysis: ML (MVA)



MVA input:
λ_D (D^+ path),
θ_D (pointing angle),
DCA_D (π-K-π sum distance)

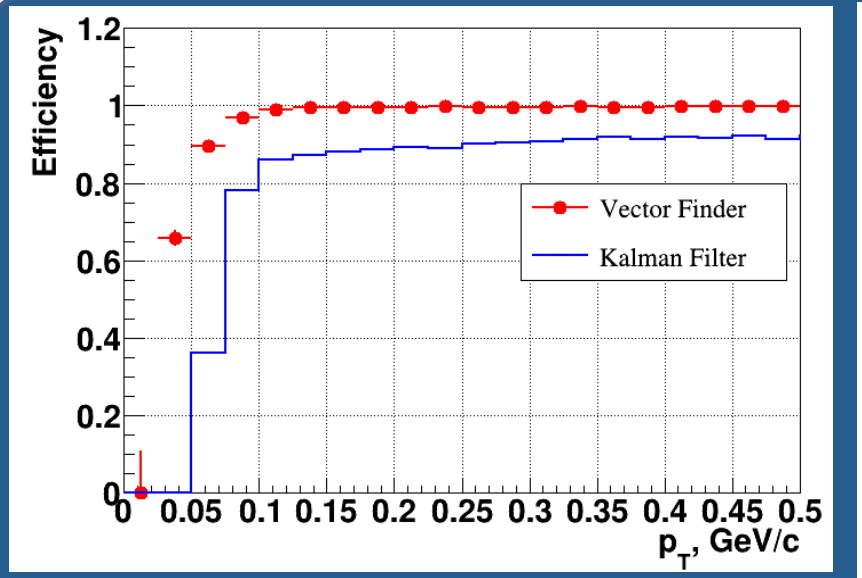
MVA cuts:
DCA(π, K) > 0.012 cm,
BDT_response>0.35

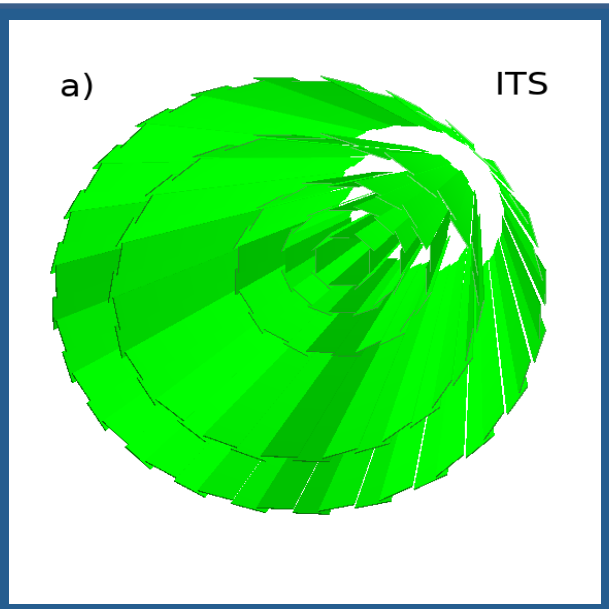


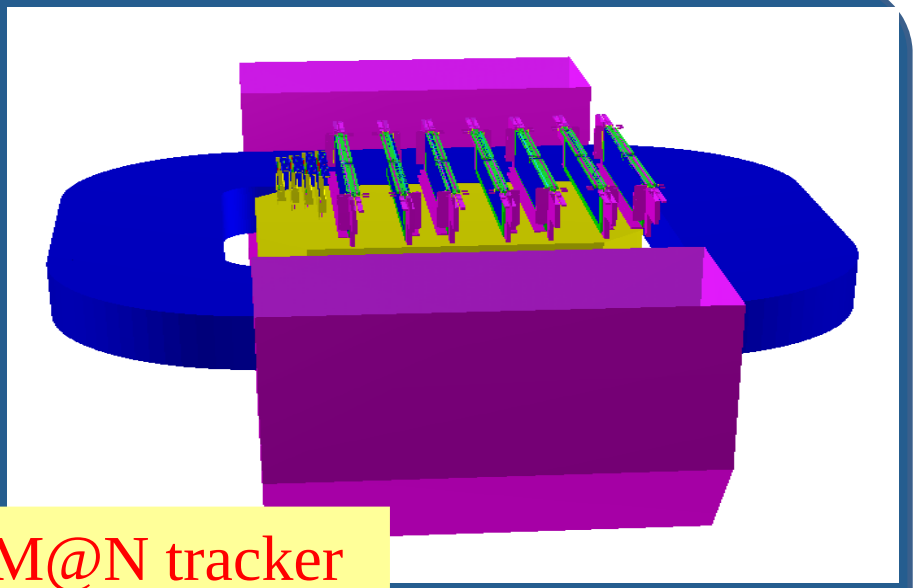


Particle	D^+
Efficiency, %	0.65
Significance	3.5
S/B(2σ) ratio	0.02

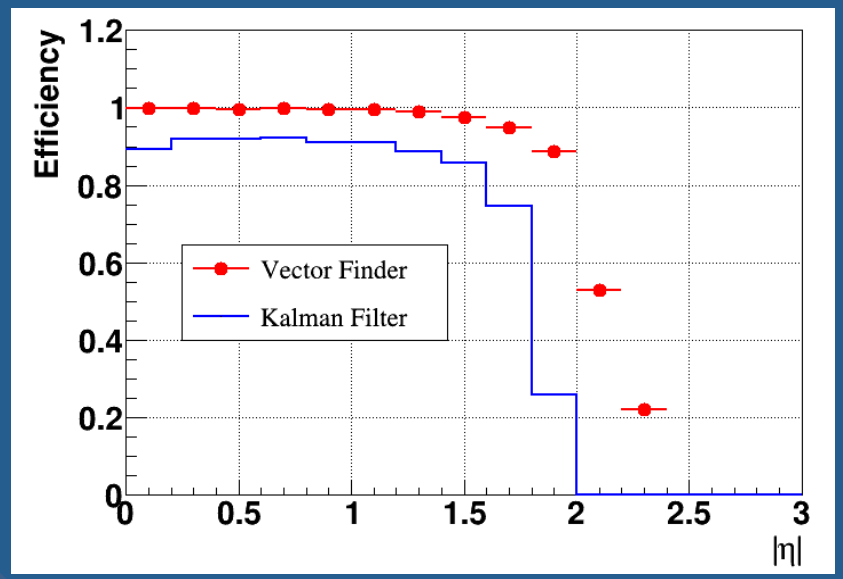
Track reconstruction: Vector Finder for ITS

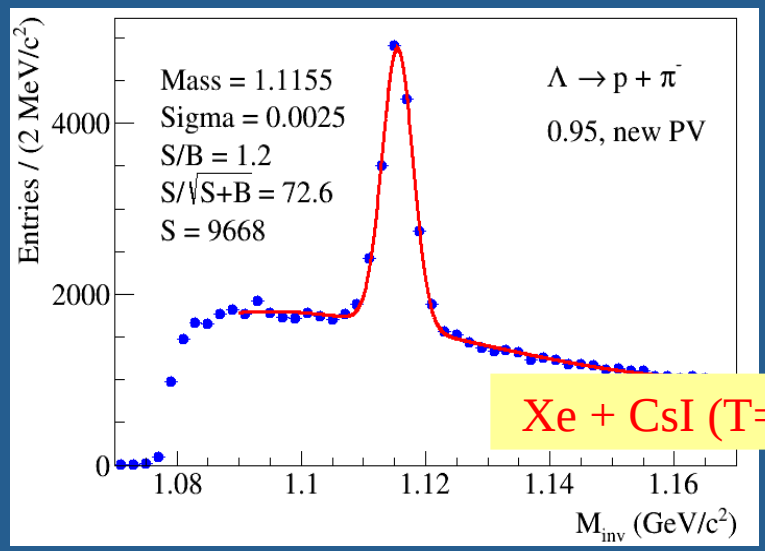


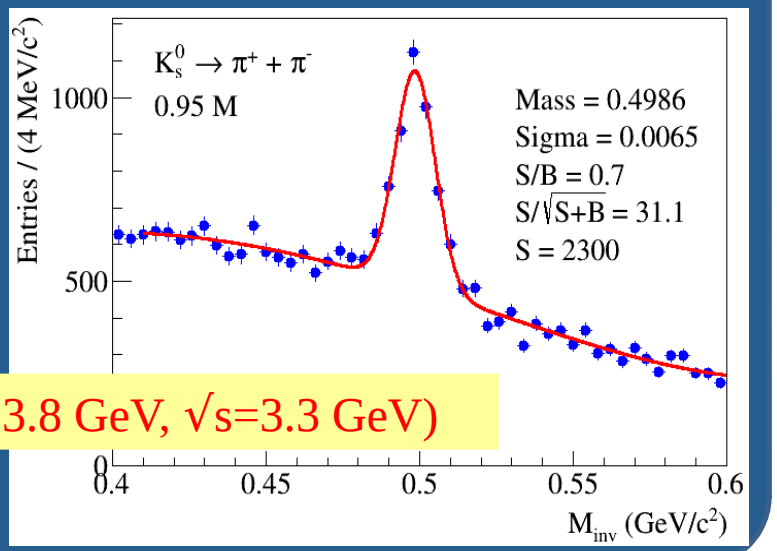




BM@N tracker







Xe + CsI (T=3.8 GeV, √s=3.3 GeV)

Semileptonic decays: inclusive electrons (83+% of ECAL modules will be ready)

D^+ DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Inclusive modes		
Γ_1	e^+ semileptonic	(16.07 ± 0.30) %	
Γ_2	μ^+ anything	(17.6 ± 3.2) %	
Γ_3	K^- anything	(25.7 ± 1.4) %	
Γ_4	$\overline{K}^0$ anything + K^0 anything	(61 ± 5) %	
Γ_5	K^+ anything	(5.9 ± 0.8) %	
Γ_6	$K^*(892)^-$ anything	(6 ± 5) %	
Γ_7	$\overline{K}^*(892)^0$ anything	(23 ± 5) %	
Γ_8	$K^*(892)^0$ anything	< 6.6 %	CL=90%
Γ_9	η anything	(6.3 ± 0.7) %	
Γ_{10}	η' anything	(1.04 ± 0.18) %	
Γ_{11}	ϕ anything	(1.12 ± 0.04) %	

D^0 DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Topological modes			
Γ_1	0-prongs	[a]	(15 ± 6) %	
Γ_2	2-prongs		(71 ± 6) %	
Γ_3	4-prongs	[b]	(14.6 ± 0.5) %	
Γ_4	6-prongs	[c]	(6.5 ± 1.3) $\times 10^{-4}$	
	Inclusive modes			
Γ_5	e^+ anything	[d]	(6.49 ± 0.11) %	
Γ_6	μ^+ anything		(6.8 ± 0.6) %	
Γ_7	K^- anything		(54.7 ± 2.8) %	S=1.3
Γ_8	$\overline{K}^0$ anything + K^0 anything		(47 ± 4) %	
Γ_9	K^+ anything		(3.4 ± 0.4) %	
Γ_{10}	$K^*(892)^-$ anything		(15 ± 9) %	

Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

B.I. Abelev,[9] M.M. Aggarwal,[30] Z. Ahammed,[45] B.D. Anderson,[20] D. Arkhipkin,[13] G.S. Averichev,[12] Y. Bai,[28] J. Balewski,[17] O. Barannikova,[9] L.S. Barnby,[2] J. Baudot,[18] S. Baumgart,[50] V.V. Belaga,[12] A. Bellingeri-Laurikainen,[40] R. Bellwied,[48] F. Benedosso,[28] R.R. Betts,[9] S. Bhardwaj,[35] A. Bhasin,[19] A.K. Bhati,[30] H. Bichsel,[47] J. Bielcik,[50] J. Bielcikova,[50] L.C. Bland,[3] S-L. Blyth,[22] M. Bombara,[2] B.E. Bonner,[36] M. Botje,[28]

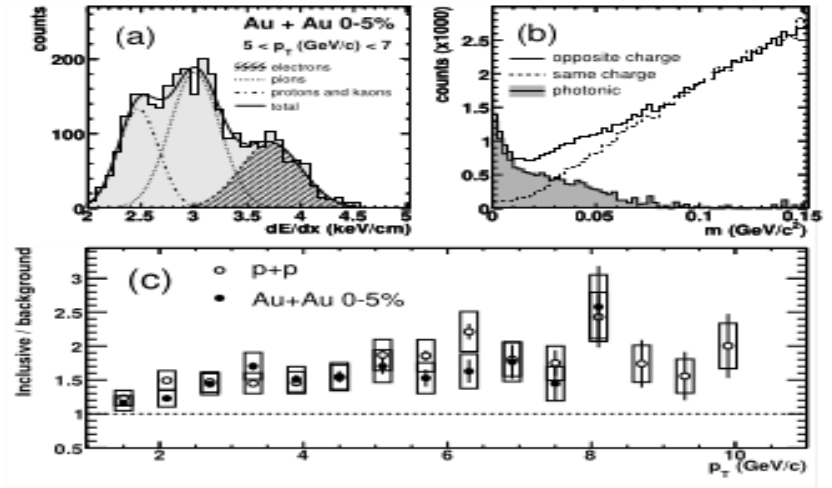


FIG. 1: (a) dE/dx projections for $5 < p_T(\mathrm{GeV}/c) < 7$ in central Au+Au events after EMC and SMD cuts. The lines are Gaussian fits for $p + K$, π, and electron yields. (b) Invariant e^+e^- mass spectrum. (c) Ratio of inclusive and background electron yield vs. p_T for $p+p$ and Au+Au collisions. Vertical bars are statistical errors, boxes are systematic uncertainties.

Semileptonic decays: inclusive electrons (83+% of ECAL modules will be ready)

Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

B.I. Abelev,[9] M.M. Aggarwal,[30] Z. Ahammed,[45] B.D. Anderson,[20] D. Arkhipkin,[13] G.S. Averichev,[12] Y. Bai,[28] J. Balewski,[17] O. Barannikova,[9] L.S. Barnby,[2] J. Baudot,[18] S. Baumgart,[50] V.V. Belaga,[12] A. Bellingeri-Laurikainen,[40] R. Bellwied,[48] F. Benedosso,[28] R.R. Betts,[9] S. Bhardwaj,[35] A. Bhasin,[19] A.K. Bhati,[30] H. Bichsel,[47] J. Bielcik,[50] J. Bielcikova,[50] L.C. Bland,[3] S-L. Blyth,[22] M. Bombara,[2] B.E. Bonner,[36] M. Botje,[28]

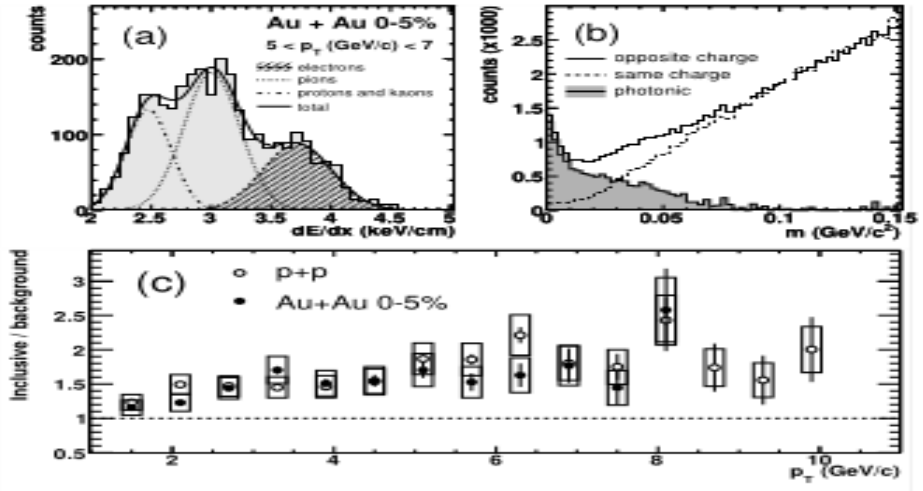


FIG. 1: (a) dE/dx projections for $5 < p_T(\mathrm{GeV}/c) < 7$ in central Au+Au events after EMC and SMD cuts. The lines are Gaussian fits for $p + K$, π, and electron yields. (b) Invariant e^+e^- mass spectrum. (c) Ratio of inclusive and background electron yield vs. p_T for $p+p$ and Au+Au collisions. Vertical bars are statistical errors, boxes are systematic uncertainties.

Erratum: Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [Phys. Rev. Lett. 98,192301 (2007)]

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Erratum (2011)

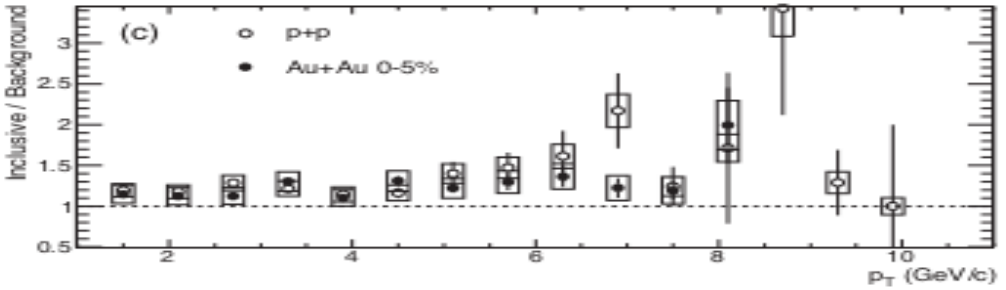


FIG. 1: (c) Ratio of inclusive and background electron yield vs. p_T for $p+p$ and Au+Au collisions. Vertical bars are statistical errors, boxes are systematic uncertainties.

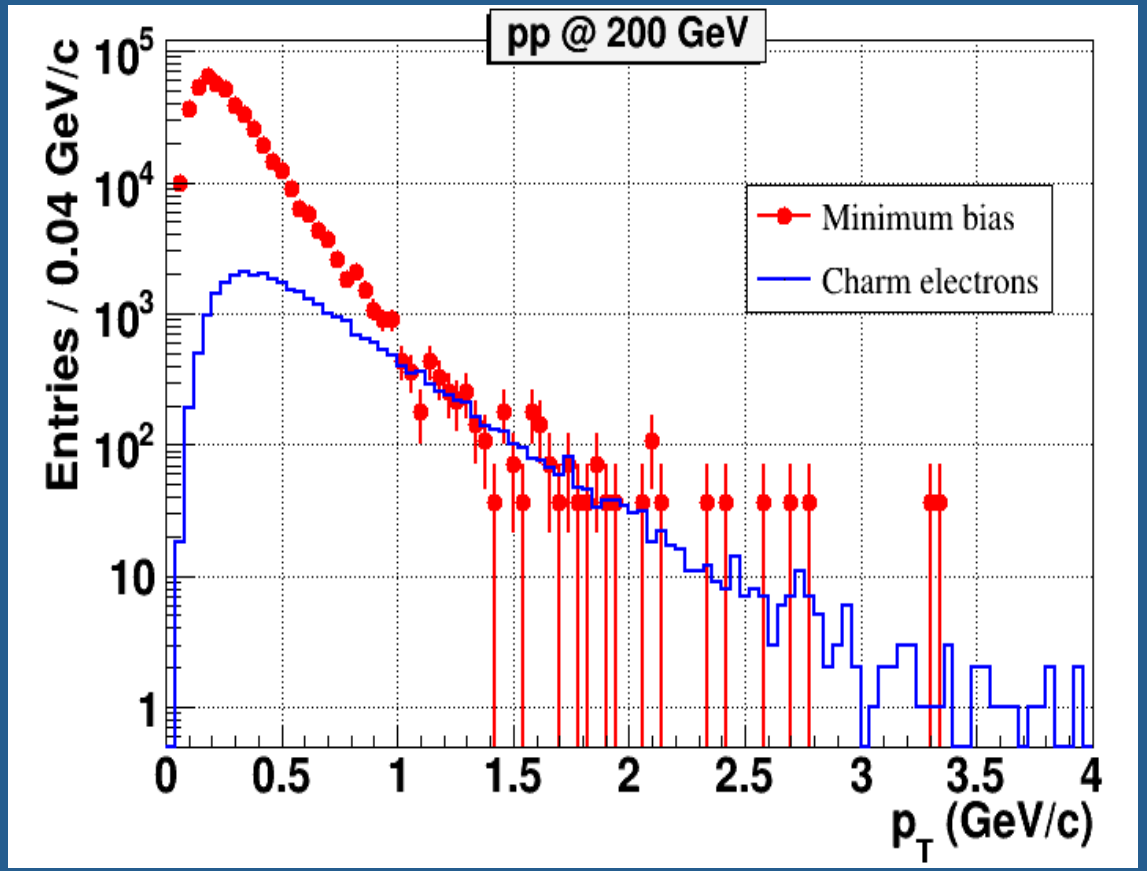
Semileptonic decays: inclusive electrons

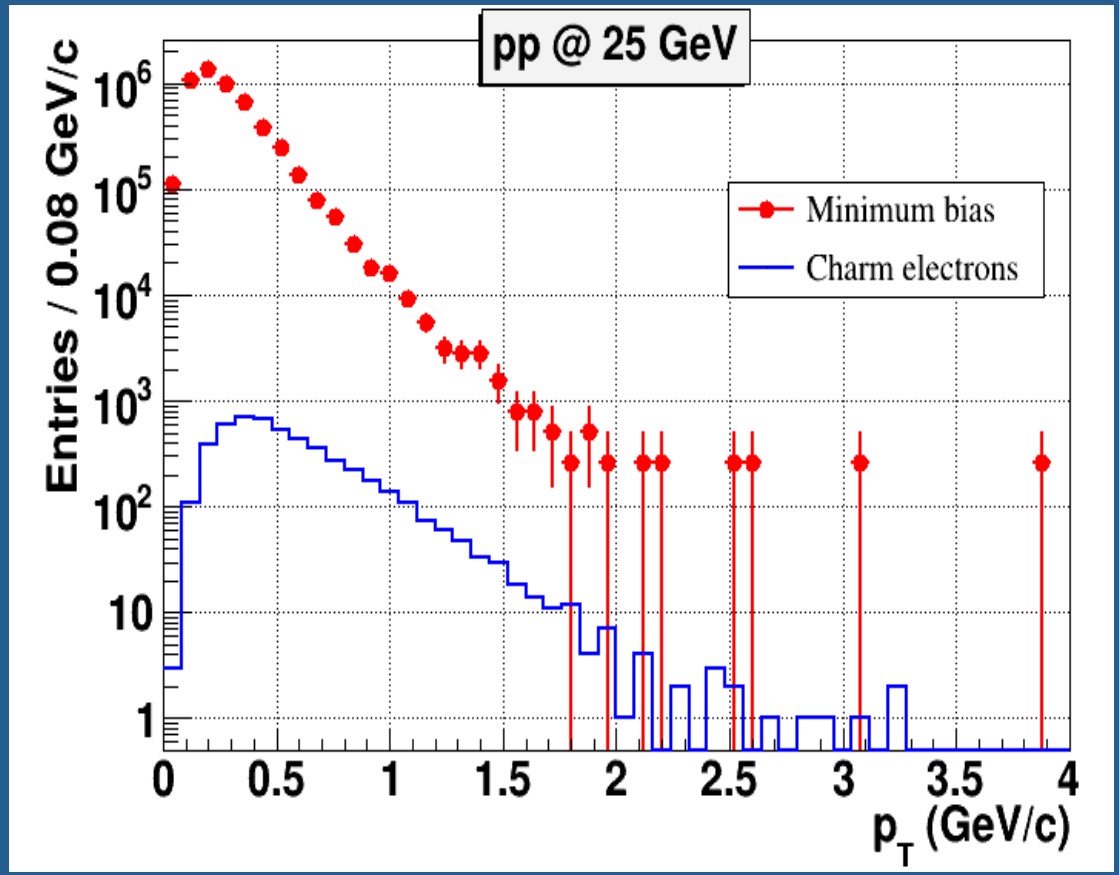
1. Cross-sections from Pythia8

2. pp @ 200 GeV:
3. minimum bias 28.485 mb, D → e+- $7.833*10^{-2}$ mb
4. L = 100 nb^{-1}: $2.8*10^{+9}$ min. bias and $7.8*10^{+6}$ D electrons

5. pp @ 25 GeV:
6. Minimum bias 23.921 mb, D → e+- $4.591*10^{-4}$ mb
7. L = 100 nb^{-1}: $2.4*10^{+9}$ min. bias and $4.6*10^{+4}$ D electrons

Semileptonic decays: inclusive electrons





Hidden charm: J/ψ → e+e-

1. Cross-sections from Pythia8

pp @ 25 GeV:

Minimum bias 23.921 mb,

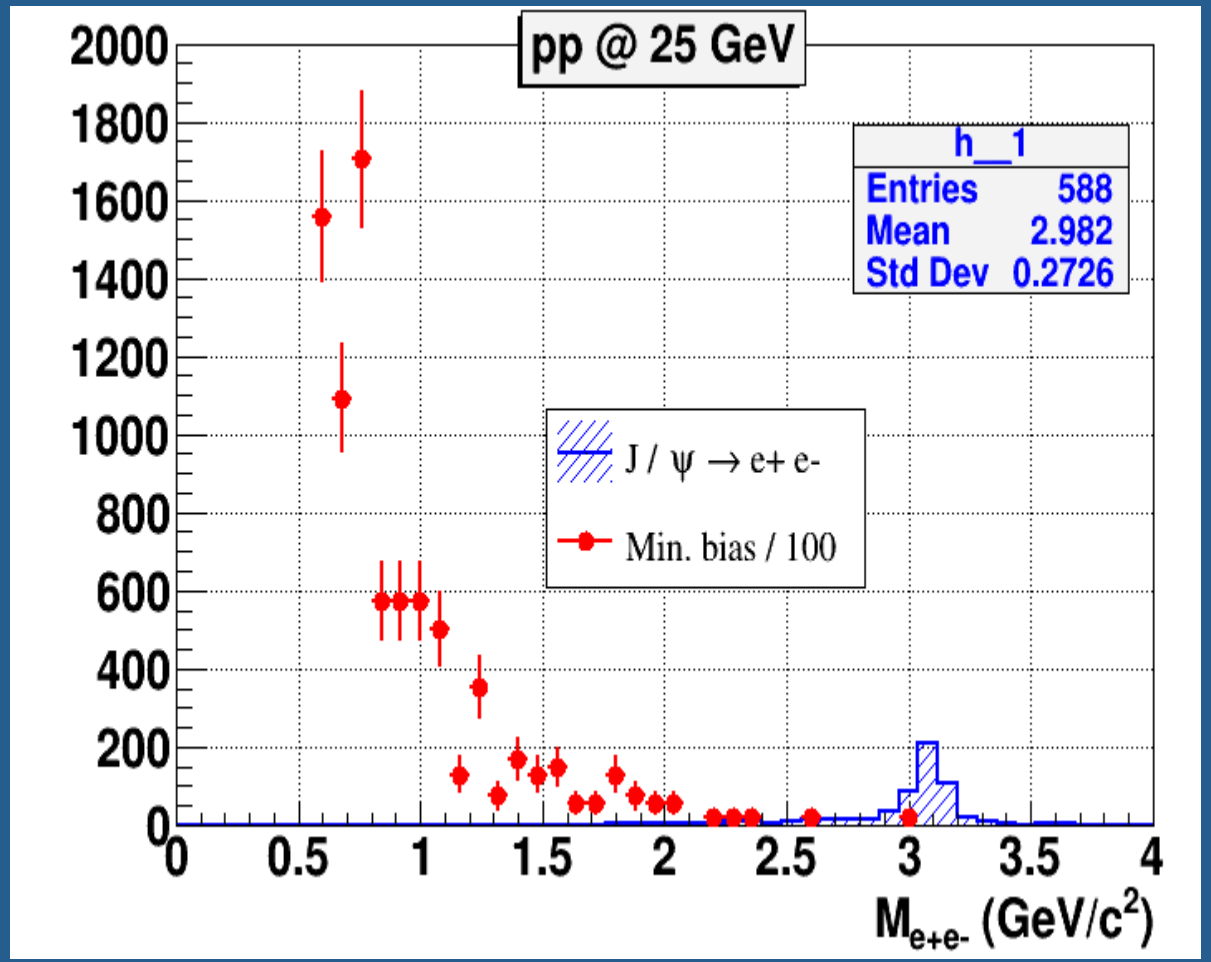
J/ψ → e+- $6.458*10^{-6}$ mb

L = 155 nb^{-1}: $3.7*10^{+9}$ min. bias and

$1.0*10^{+3}$ J/ψ electrons

pp @ 11 GeV

J/ψ → e+- $0.271*10^{-6}$ mb



Outlook

- The MPD experiment can potentially contribute to charm studies in heavy-ion collisions
- Studies of the ITS performance and design optimization for open charm measurements are ongoing
- Feasibility of open charm semi-leptonic decay measurements and J/ψ to e+e- are still an open question