

Rekonstrukce podivných hadronů pomocí KF Particle Finder

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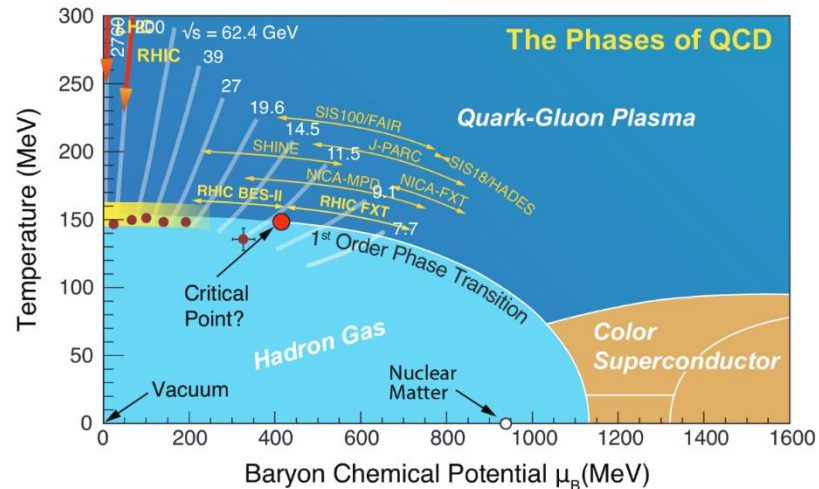
WEJCF 2020, Bílý Potok

Obsah

1. Kvark-gluonové plasma a fázový diagram QCD
2. Úvod do KF Particle
3. Experiment STAR
4. STAR High Level Trigger
5. Výsledky rekonstrukce Λ
 1. Au+Au, 27 AGeV (KF Particle Finder + TMVA)
 2. Au+Au, 14.6 AGeV
 3. Pevný terčík
6. Shrnutí

Kvark-gluonové plasma

- Stav hmoty existující za extrémních teplot a tlaků
- Asymptoticky volné kvarky, gluony
- Experimentální pozorování
 - RHIC, LHC
 - Produkce podivnosti, potlačení jetů, kvarkonia, eliptický tok, ...
- Zkoumá se přechod mezi hadronovým plynem a QGP
 - Povaha? Kritický bod?
- Mapování QCD diagramu – kolize při různých energiích (různé hodnoty baryonového chemického potenciálu μ_B)
- Potřeba zvyšovat **luminozitu** při nízkých hodnotách $\sqrt{s_{NN}}$
 - BES, pevný terčik, CBM, ...
 - **Jak se vypořádat s vysokým množstvím dat?**

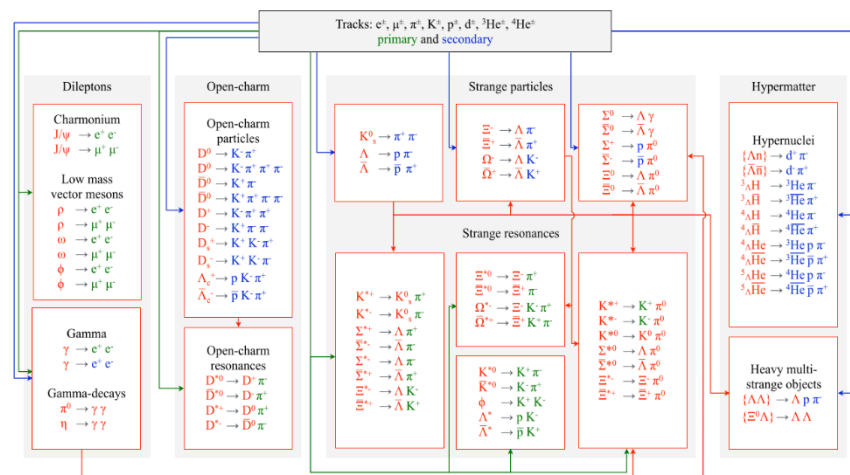
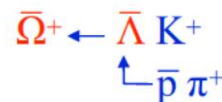
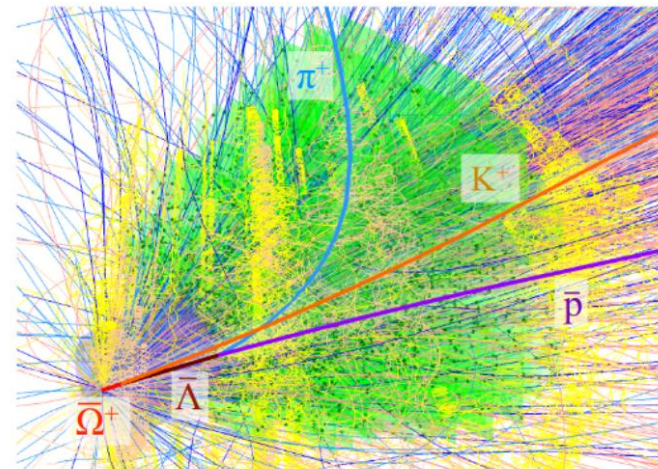


	Collision Energy (GeV)				
	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Fixed Target Energy (GeV)	3.0	3.2	3.5	3.9	4.5
Fixed Target μ_B (MeV)	721	699	666	633	589
Proposed Event Goals in BES-II	100	160	230	300	400
BES-I Events	4	N/A	12	20	36

Chi Yang, <https://doi.org/10.1016/j.nuclphysa.2017.05.042>

Úvod do KF Particle

- C++ balíček vyvinutý skupinou FIAS pro účely CBM a kompletní rekonstrukce krátce žijících částic
- Založený na Kalmanově filtru
- Popisuje částice pomocí stavového vektoru a kovarianční matice
- Kovarianční matice obsahuje informace o **chybách** trajektorií a efektivitě detektoru
- **Nezávislý na geometrii experimentu** – úspěšně implementován na STAR – TFG, HLT
- **KF Particle Finder**
 - umožňuje rekonstrukci částic, rozpadových řetězců
 - Umožňuje výpočet statistických kritérií, které lze použít pro eliminaci pozadí při rekonstrukci částic
 - Paralelizace (SIMD)



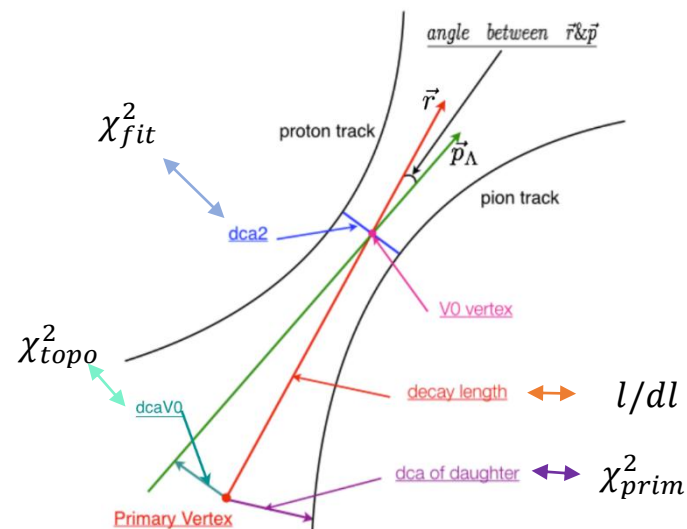
KF Particle — S. Gorbunov, "On-line reconstruction algorithms for the CBM and ALICE experiments," Dissertation thesis, Goethe University of Frankfurt, 2012, <http://publikationen.uni-frankfurt.de/frontdoor/index/index/docId/29538>

KF Particle Finder — M. Zyzak, "Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR," Dissertation thesis, Goethe University of Frankfurt, 2016, <http://publikationen.uni-frankfurt.de/frontdoor/index/index/docId/41428>

KF Particle Tutorial — M. Zyzak, https://drupal.star.bnl.gov/STAR/system/files/KFParticleTutorial_11.12.2018.pdf

Rekonstrukce vertexu

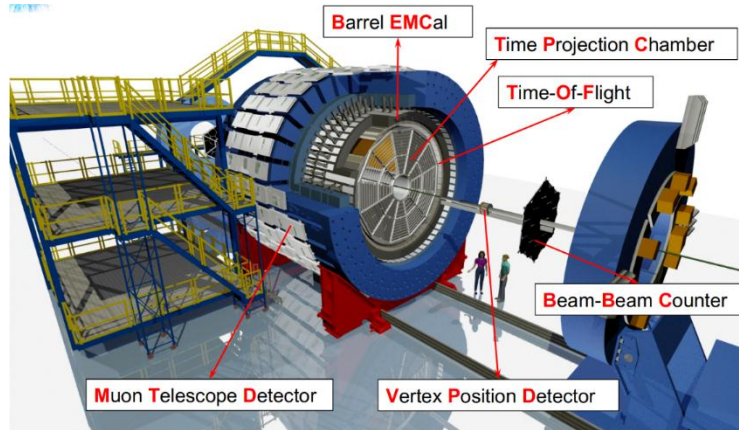
- **Standardní přístup:** řezy v datech na absolutní hodnoty topologických veličin
- **KF Particle:** řezy na ***pravděpodobnosti***
- **Kovarianční matice** obsahuje informace o **chybách trajektorií** a efektivitě detektoru
- Chyby parametrů jsou použity pro výpočet **statistických kritérií** založených na χ^2 distribuci
- Lze očekávat zlepšení v efektivitě rekonstrukce pro nízké příčné hybnosti, kaskádové rozpady



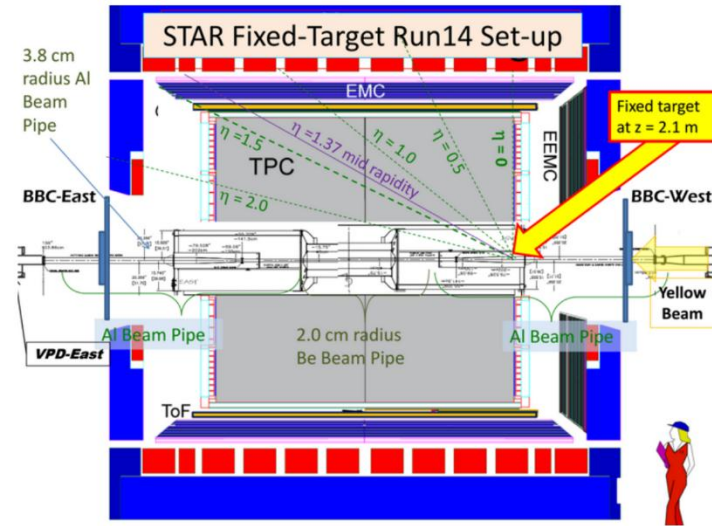
$$\chi_{prim}^2 = \Delta\vec{r}^T (\mathbf{C}_{track} + \mathbf{C}_{PV})^{-1} \Delta\vec{r}$$

Experiment STAR

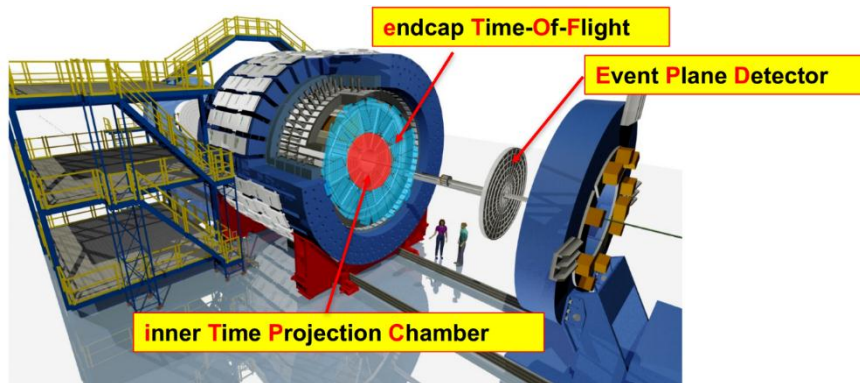
Au+Au, 27 AGeV (2018)



FXT, 3.9 AGeV

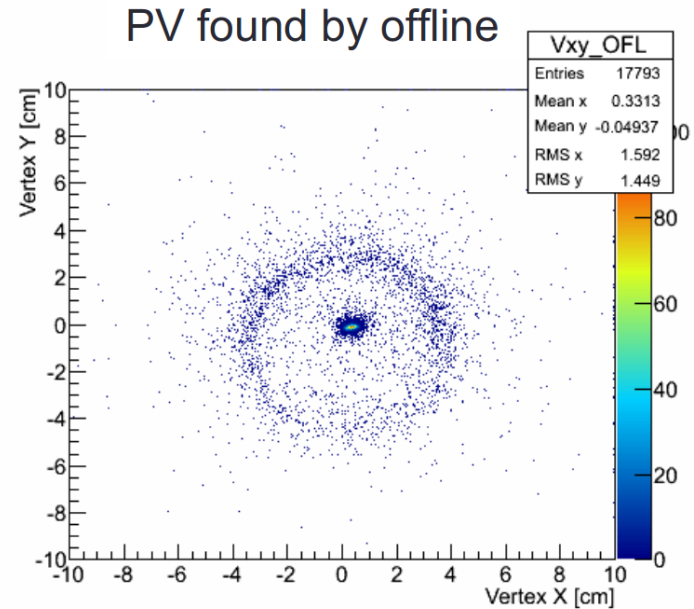
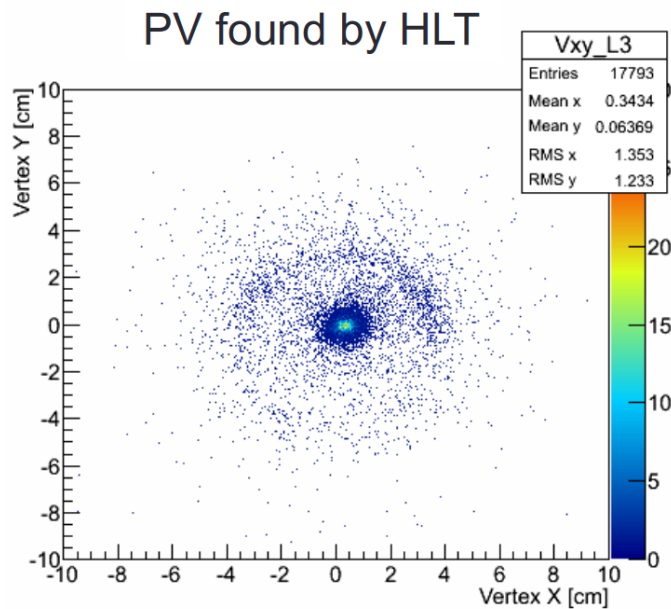


Au+Au, 14.6 AGeV (2019)



STAR High Level Trigger

- High Level Trigger, Tracking Focus Group
- Trigger kombinující informace ze všech subdetektorů
- Online analýza eventů, rekonstrukce PV, monitorování svazku,...
- Okamžitá zpětná vazba pro operátory urychlovače
- **Expresní produkce dat** pro fyzikální analýzu offline

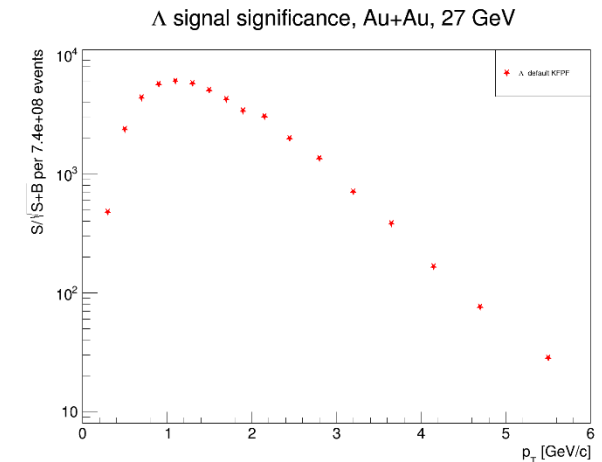
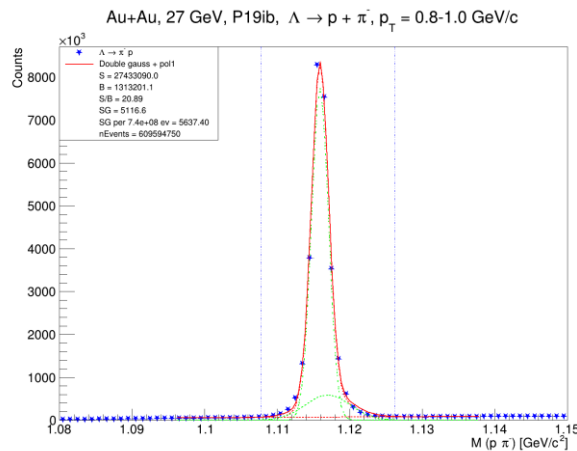
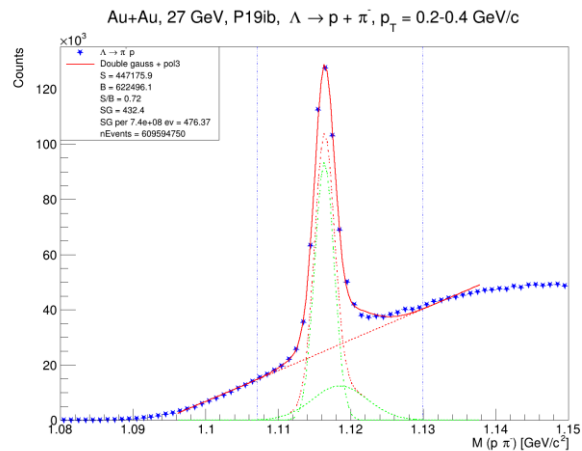
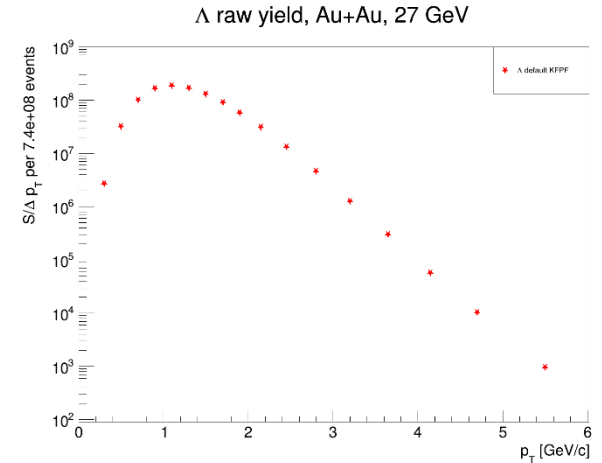


Rekonstrukce Λ s KF Particle Finder

- Signál rekonstruován v rozmezí $p_T = 0.2-6.0$ GeV/c
 - **Nejnižší $p_T = 0.2 - 0.4$ GeV/c**
 - Dosavadní analýzy na STAR $p_T = 0.4 - 0.6$ GeV/c
- Fitování signálu:
 - Dvojitá Gaussovská distribuce + polynomické pozadí

Řezy KFPF

- $\chi^2_{fit} < 10$
- $l/dl > 5$
- $l > 5$ cm
- $\chi^2_{prim} > 18.6$
- $\chi^2_{topo} < 5$
- $d_{max} < 1$ cm



TMVA trénink – Boosted Decision Trees

1. Učení

- Volnější řezy
- Signál: VMC simulace **čistého** signálu, termální pT spektrum
- Pozadí: vzorek z dat (20%), oblast kolem píku signálu

2. Sken signifikance

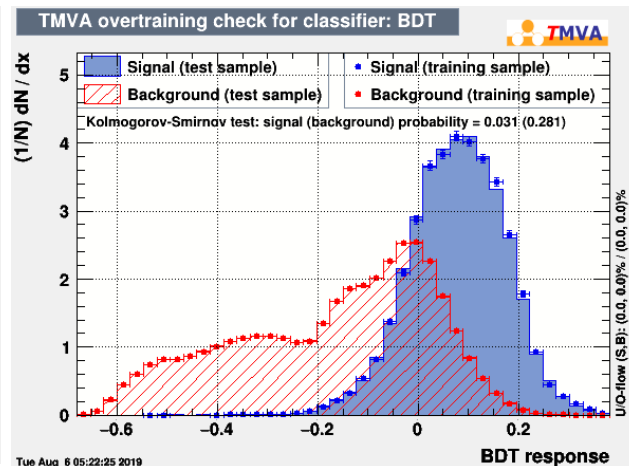
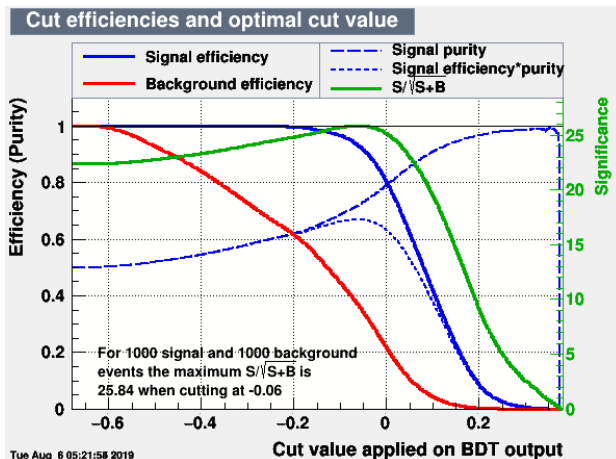
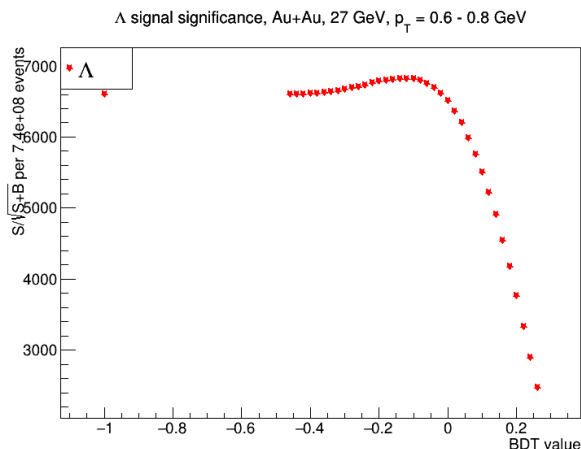
- Aplikace BDT na **odlišný** vzorek (3%), hledání ideálního řezu na BDT odezvu

3. Aplikace na celou statistiku

- Použití TMVA::Reader přímo v KFPF

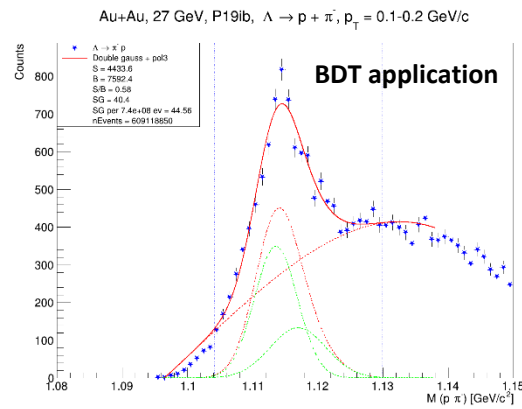
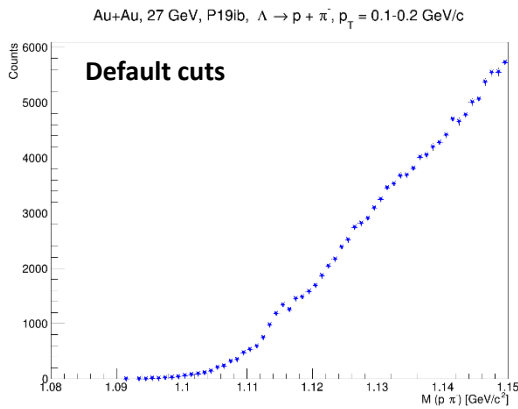
Řezy pro trénink

- $\chi^2_{fit} < 14$
- $l/dl > 3$
- $l > 1$ cm
- $\chi^2_{prim} > 3$
- $\chi^2_{topo} < 5$
- $d_{max} < 1$ cm
- Soft ToF PID mode

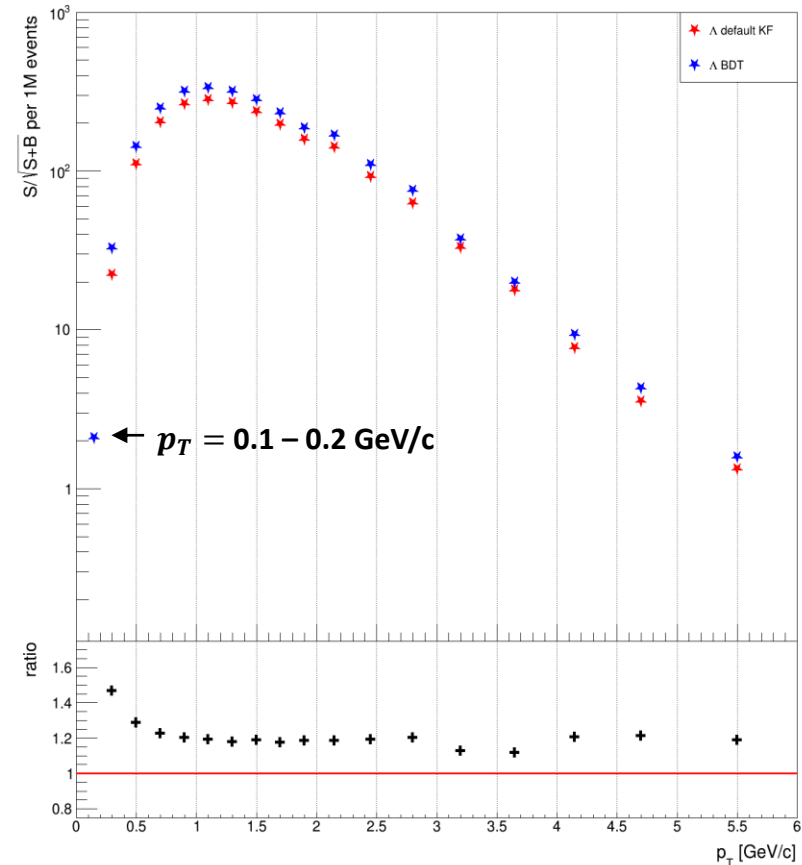


KFPF: Výchozí řezy vs. TMVA

- TMVA vylepšuje signifikanci v celém spektru p_T
- Umožňuje rekonstrukci signálu pro $p_T = 0.1 - 0.2 \text{ GeV}/c$

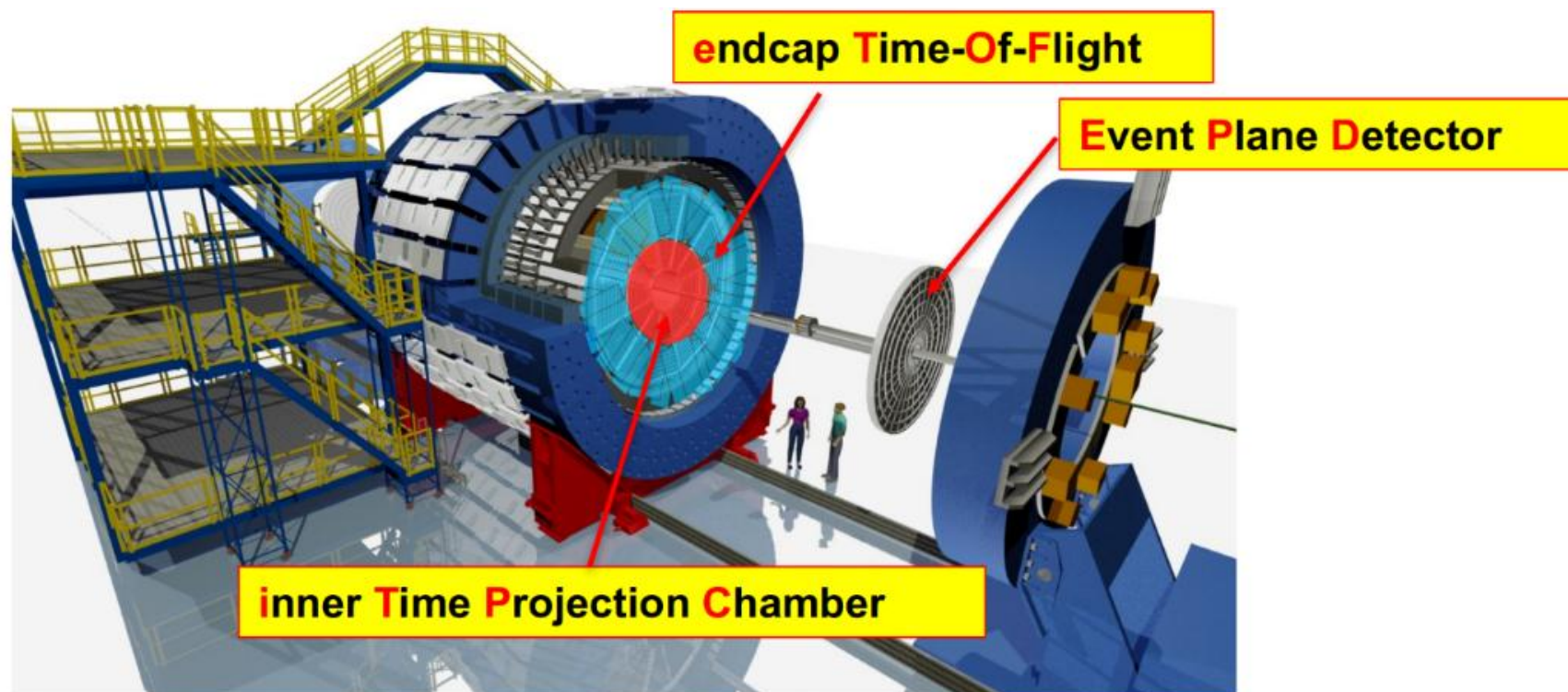


Λ signal significance, Au+Au, 27 GeV



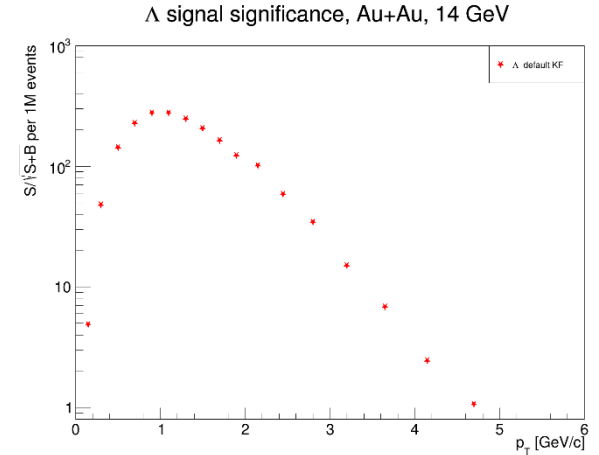
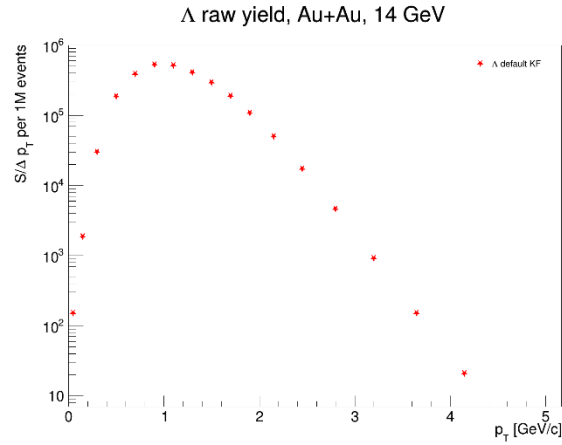
Au + Au at 14.6 AGeV

- Run 2019, Au+Au 14.6 AGeV
- Expresní produkce
- **iTPC**



Rekonstrukce signálu

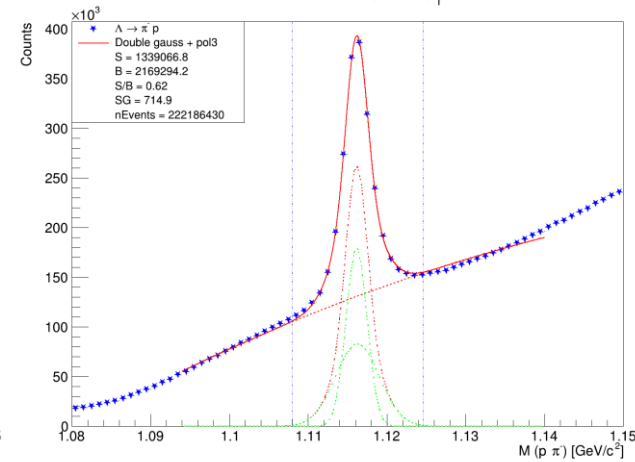
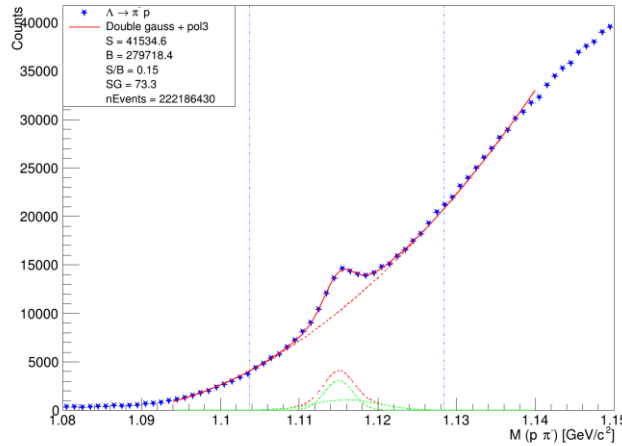
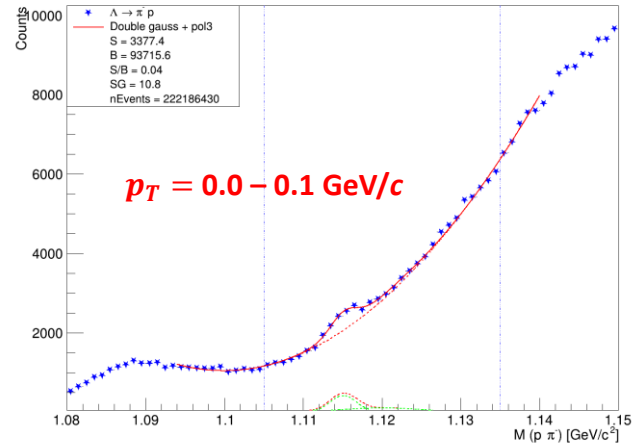
- Lze rekonstruovat signál téměř do $p_T = 0 \text{ GeV}/c$



Au+Au, 14 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.0-0.1 \text{ GeV}/c$

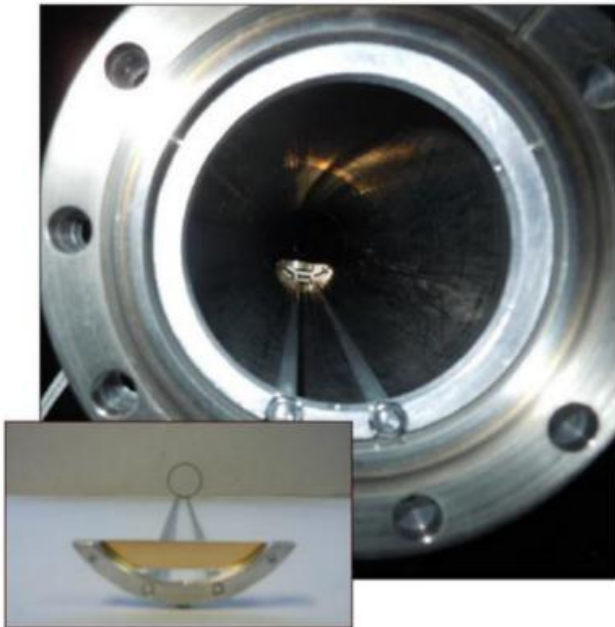
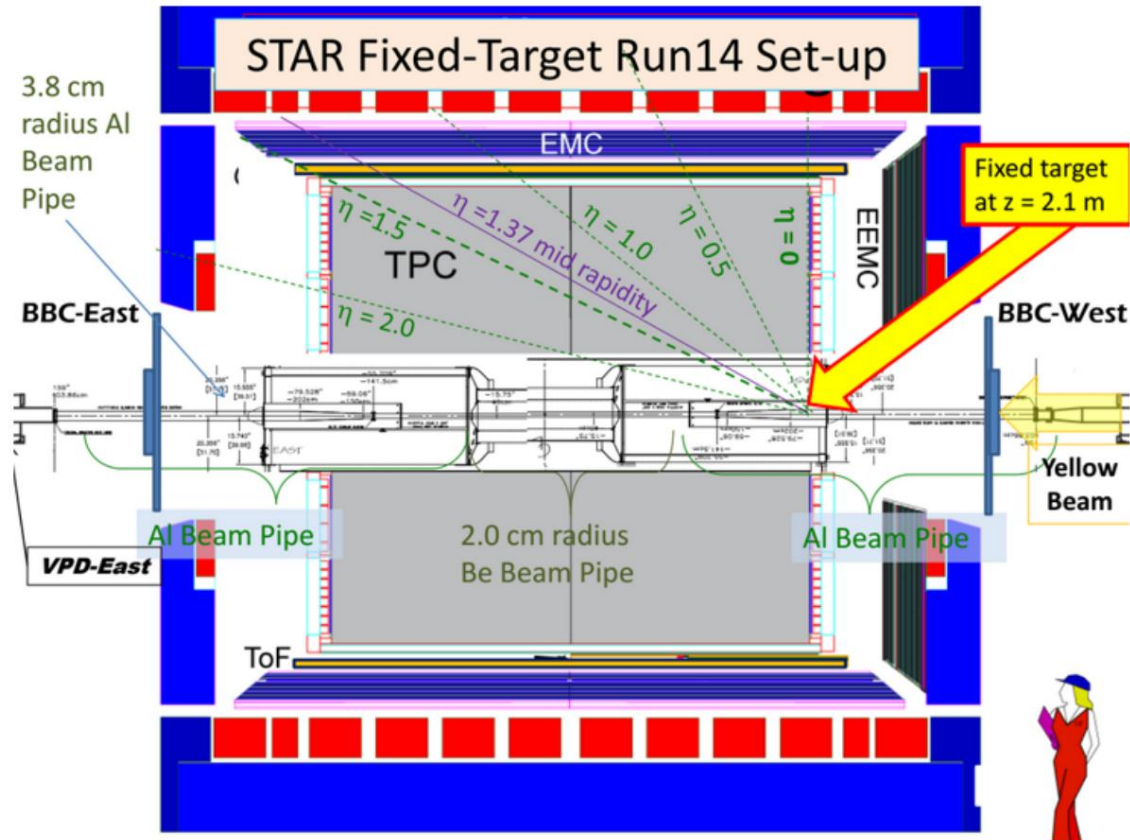
Au+Au, 14 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.1-0.2 \text{ GeV}/c$

Au+Au, 14 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.2-0.4 \text{ GeV}/c$



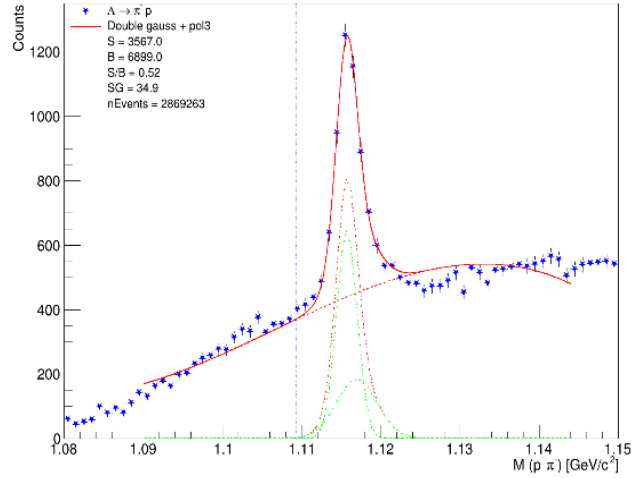
Pevný terčik, 3.9 AGeV

- Run 2019
- $E_{\text{beam}} = 7.3 \text{ AGeV}$
- Odlišná geometrie
- Expresní produkce

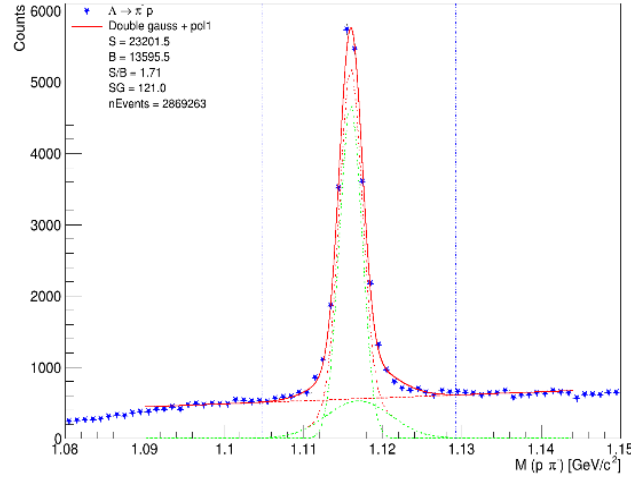


Rekonstrukce signálu

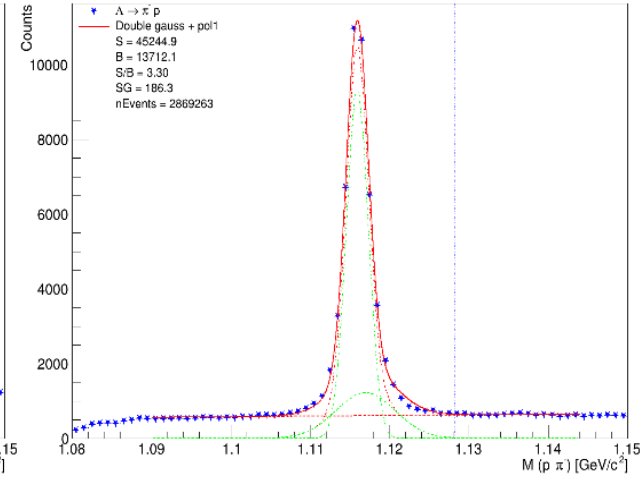
Fixed target, 7.3 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.2-0.4$ GeV/c



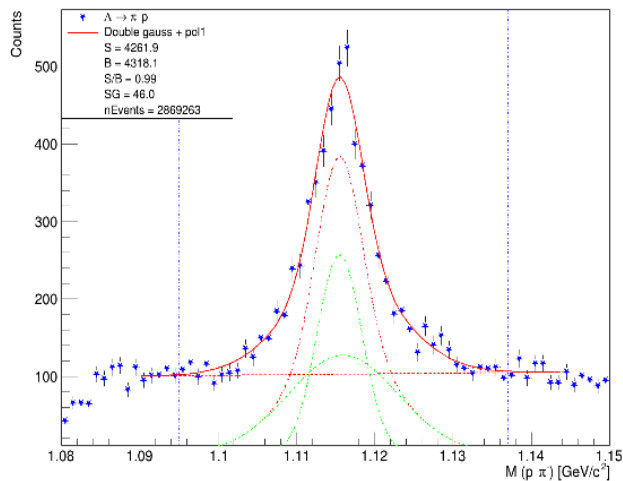
Fixed target, 7.3 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.4-0.6$ GeV/c



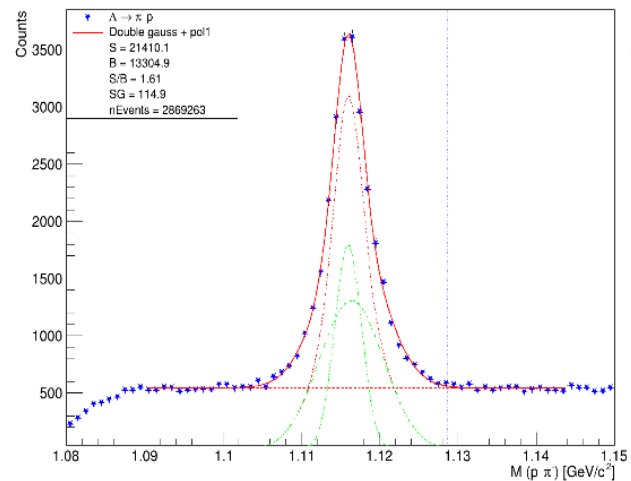
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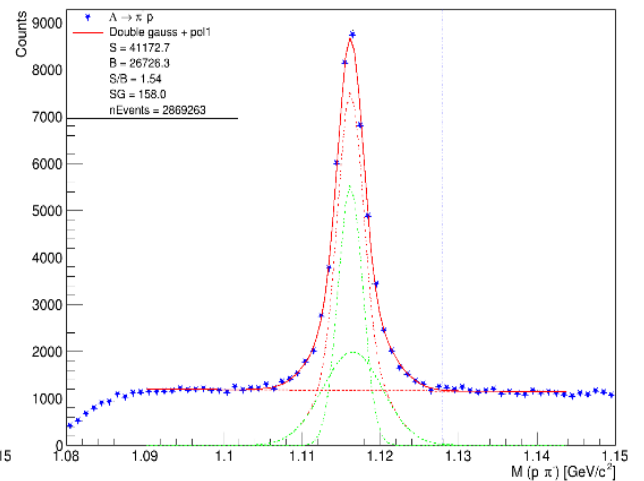
Fixed target, 7.3 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $-1.75 < y < -1.50$



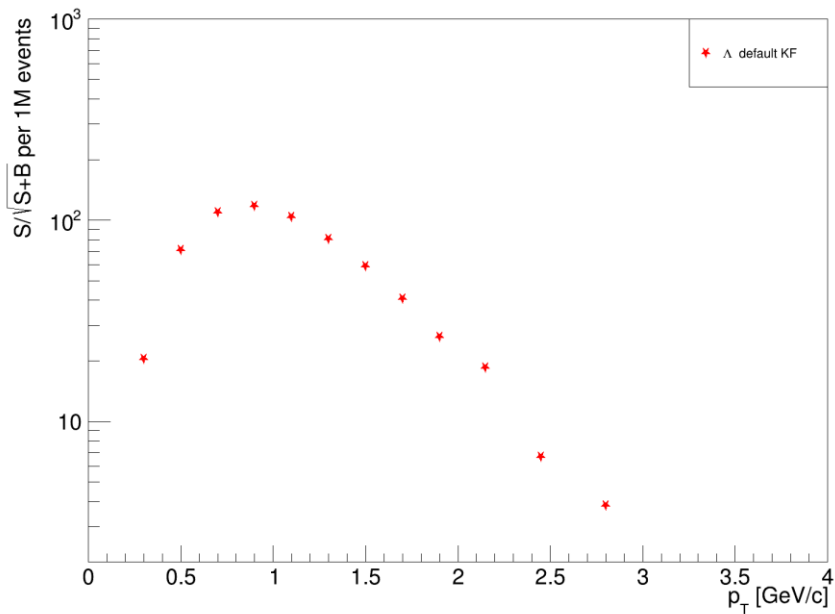
Fixed target, 7.3 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $-1.50 < y < -1.25$



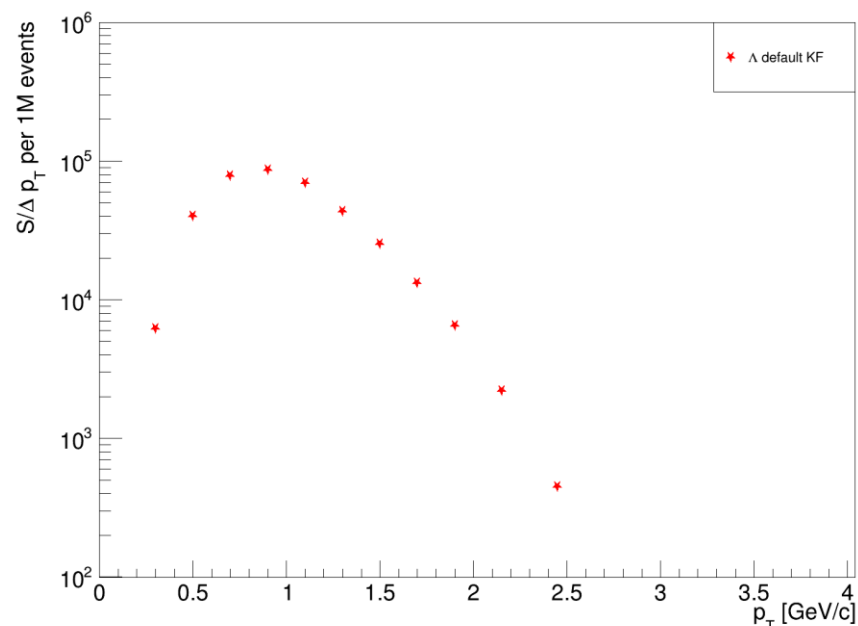
Fixed target, 7.3 GeV, TFG19e, $\Lambda \rightarrow p + \pi^-$, $-1.25 < y < -1.00$



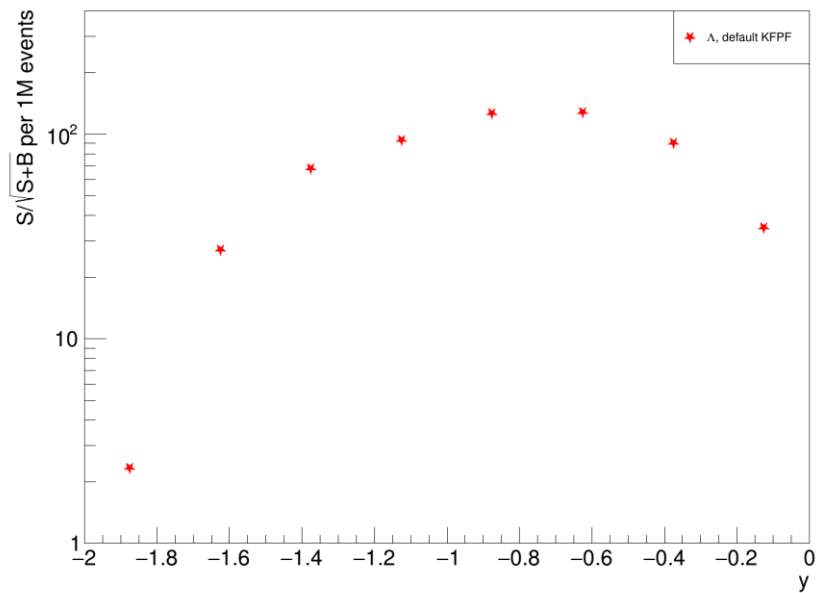
Λ signal significance, Fixed target, 7.3 GeV



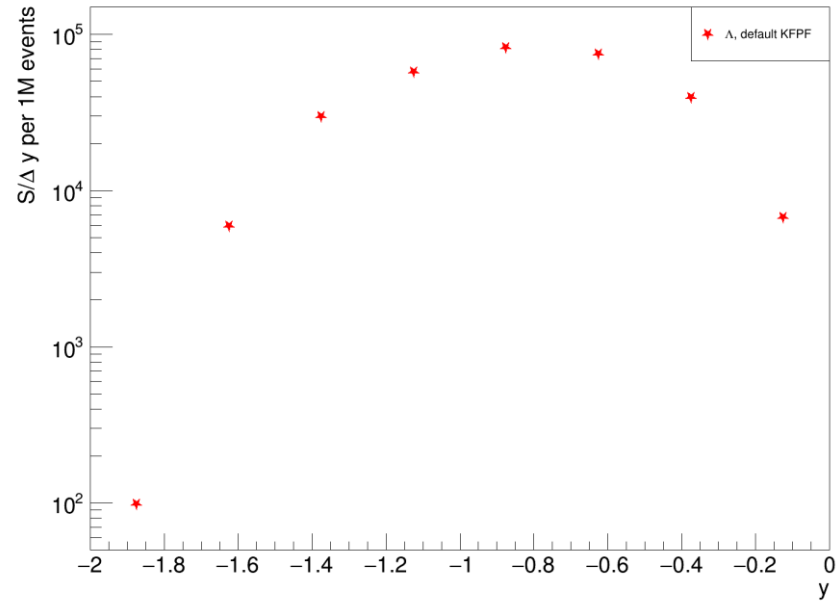
Λ raw yield, fixed target, 7.3 GeV



Λ signal significance per 1M events, fixed target, 7.3 GeV



Λ raw yield per 1M events, fixed target, 7.3 GeV



Shrnutí

- STAR Beam Energy Scan program se soustředí na měření srážek zlato-zlato při nízkých energiích – mapování QCD diagramu
- Stávající a budoucí experimenty na nízkých energiích potřebují zvyšovat luminozitu – je třeba zpracovávat vysoké toky dat
- Online rekonstrukce – CBM, KF Particle
- KF Particle Finder lze úspěšně použít pro offline analýzu dat na experimentech s různou geometrií
- Slibné signifikance v rekonstrukci Λ s nízkou p_T , aplikace TMVA
- TO DO: multistrange baryony, BDT, VMC simulace, efektivita, spektra

Reference

1. KF Particle — **S. Gorbunov**, “On-line reconstruction algorithms for the CBM and ALICE experiments,” Dissertation thesis, Goethe University of Frankfurt, 2012, <http://publikationen.uni-frankfurt.de/frontdoor/index/index/docId/29538>
2. KF Particle Finder — **M. Zyzak**, “Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR,” Dissertation thesis, Goethe University of Frankfurt, 2016, <http://publikationen.uni-frankfurt.de/frontdoor/index/index/docId/41428>
3. KF Particle Tutorial – **M. Zyzak**, https://drupal.star.bnl.gov/STAR/system/files/KFParticleTutorial_11.12.2018.pdf
4. Strange particle measurements in Au+Au 27 GeV - **Yue Hang Leng**, <https://drupal.star.bnl.gov/STAR/system/files/LFSUPC20190603.pdf>
5. Analysis note for K_S^0 , Λ , $\bar{\Lambda}$, E^- , E^+ production in Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27$ and 39 GeV – **Xianglei Zhu**, https://drupal.star.bnl.gov/STAR/system/files/Analysis_note_KsLaXi.pdf

Děkuji za pozornost.

Backup slides

Dataset, event selection, KFPF selection, 27 AGeV

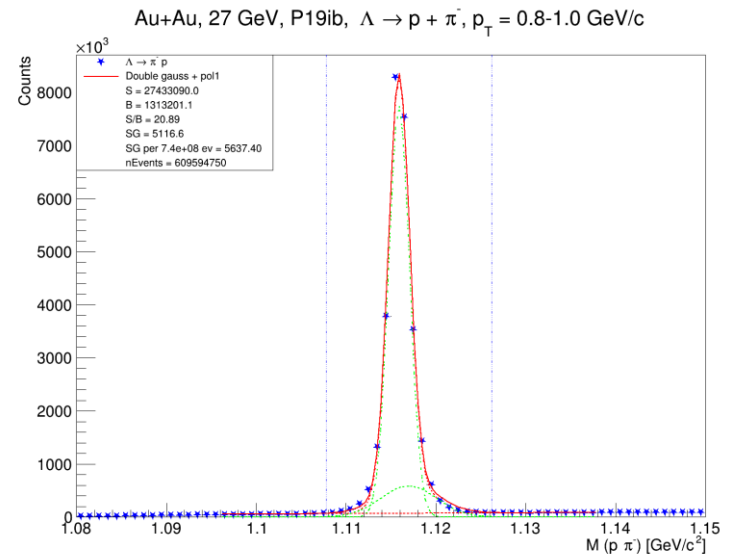
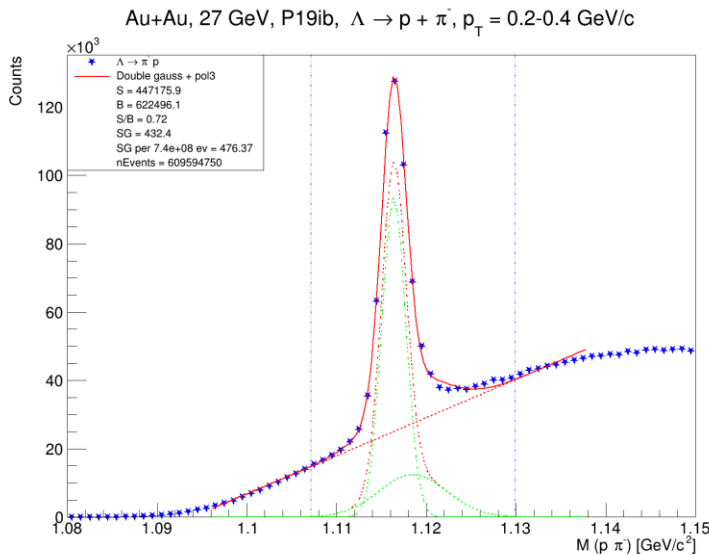
- Run 2018, Au+Au 27 GeV
- Production P19ib, library SL19b
- MB events sampled: $6.1 \cdot 10^8$
- Events after selection: $3.7 \cdot 10^8$
 - $|V_z| < 70$ cm
 - More than 10% primary tracks

Default KFPF cuts

- $\chi_{geom}^2 < 10$
- $l/dl > 5$
- $l > 5$ cm
- $\chi_{prim}^2 > 18.6$
- $\chi_{topo}^2 < 5$
- $d_{max} < 1$ cm

Raw yield calculation

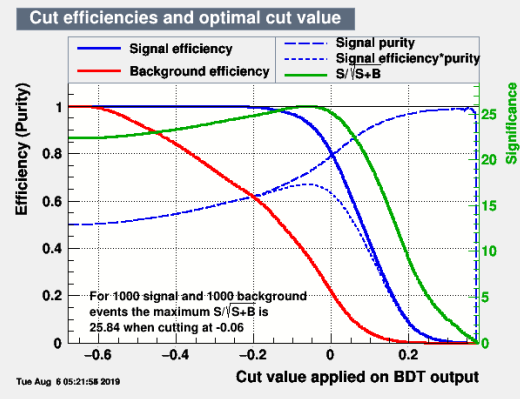
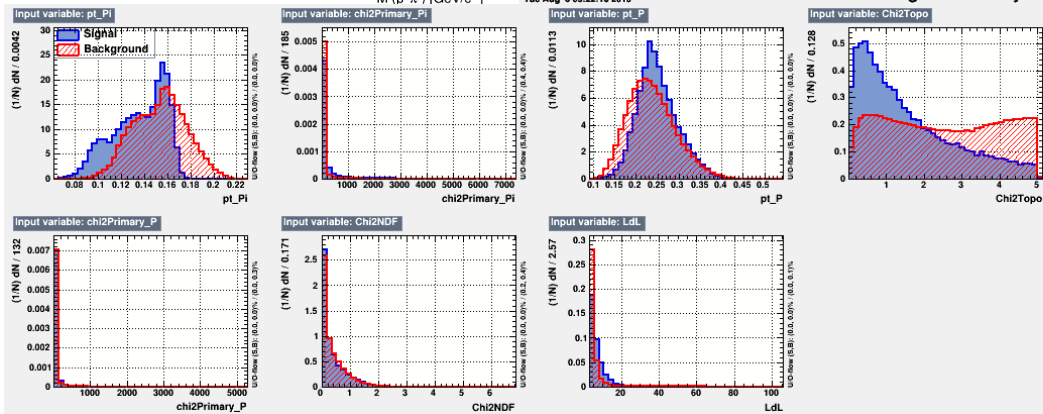
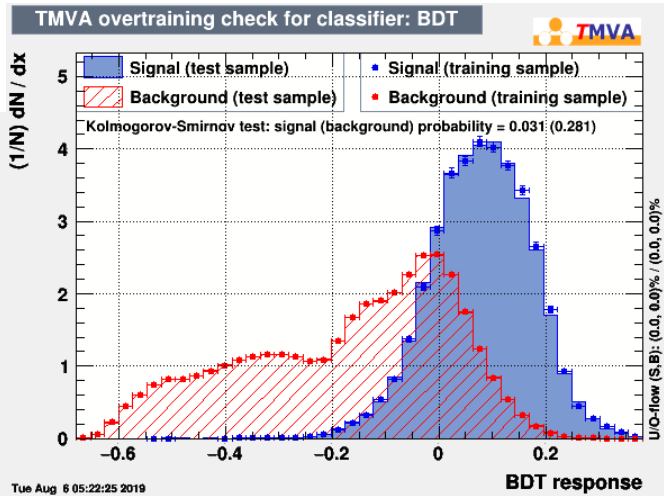
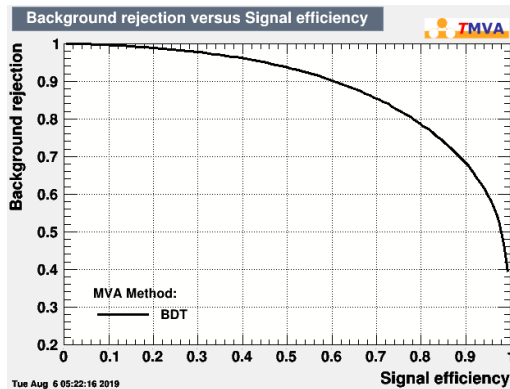
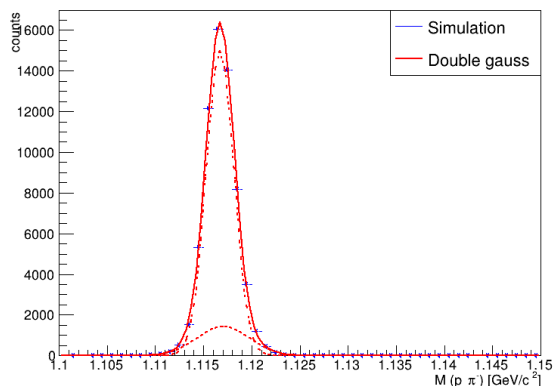
- Fitting:
 - For $p_T = 0.2 - 0.4$ GeV: **double Gaussian** with **pol3** background
 - For $p_T > 0.4$ GeV: **double Gaussian** with **pol1** background
- S = bin count in 3σ window – integral of polynomial background
- significance = $S/\sqrt{S+B}$
- **Lowest** transverse momentum bin: $p_T = 0.2 - 0.4$ GeV/c



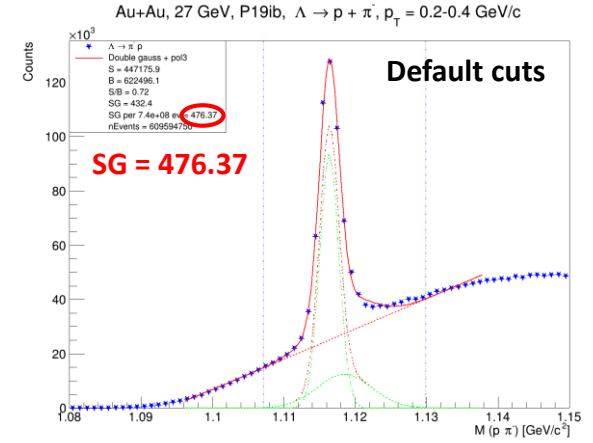
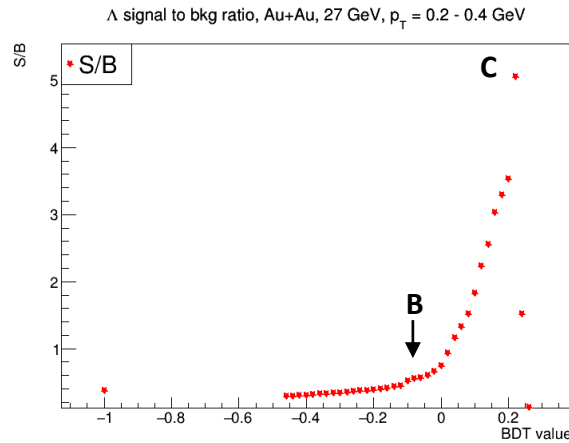
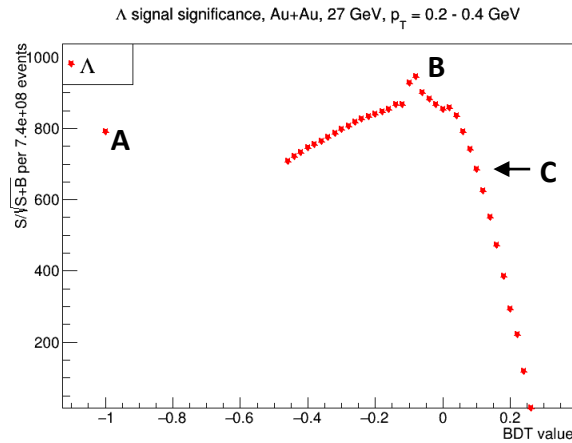
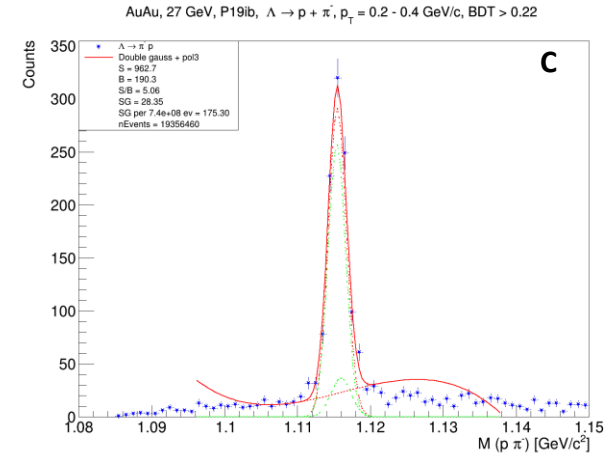
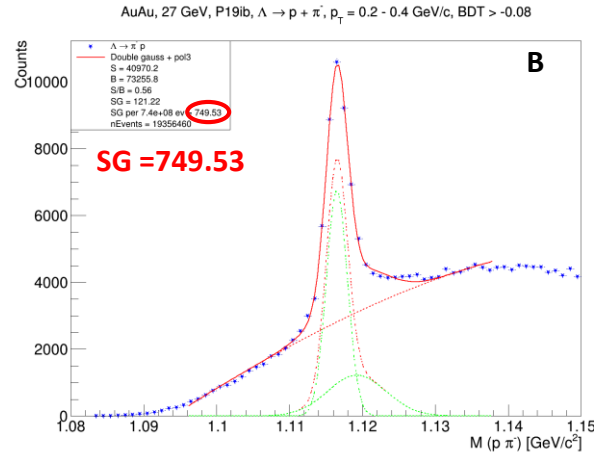
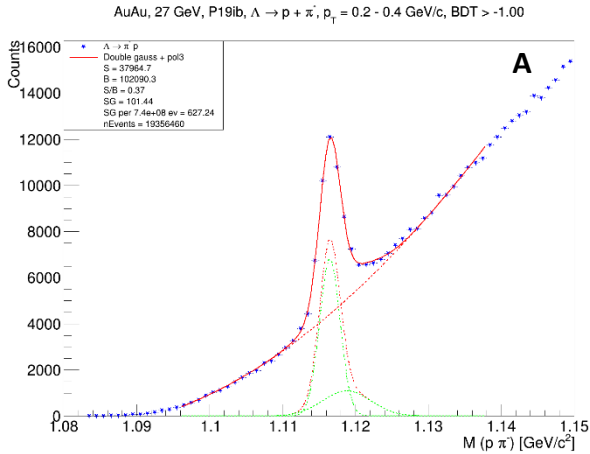
TMVA training example

- TMVA plots for $p_T = 0.2 - 0.4$ GeV

Δ pure signal simulation, VFMCE2018



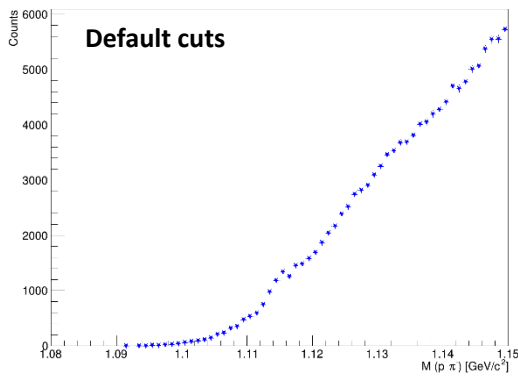
Significance scan example, $p_T = 0.2 - 2.4$ GeV/c



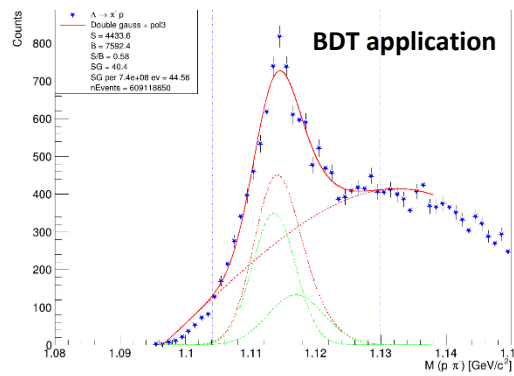
KFP: TMVA vs. default cuts

- TMVA improves significance throughout whole p_T spectrum
- Also enables reconstruction at very low $p_T = 0.1 - 0.2$ GeV/c
- KFP more effective than conventional analysis with topological cuts

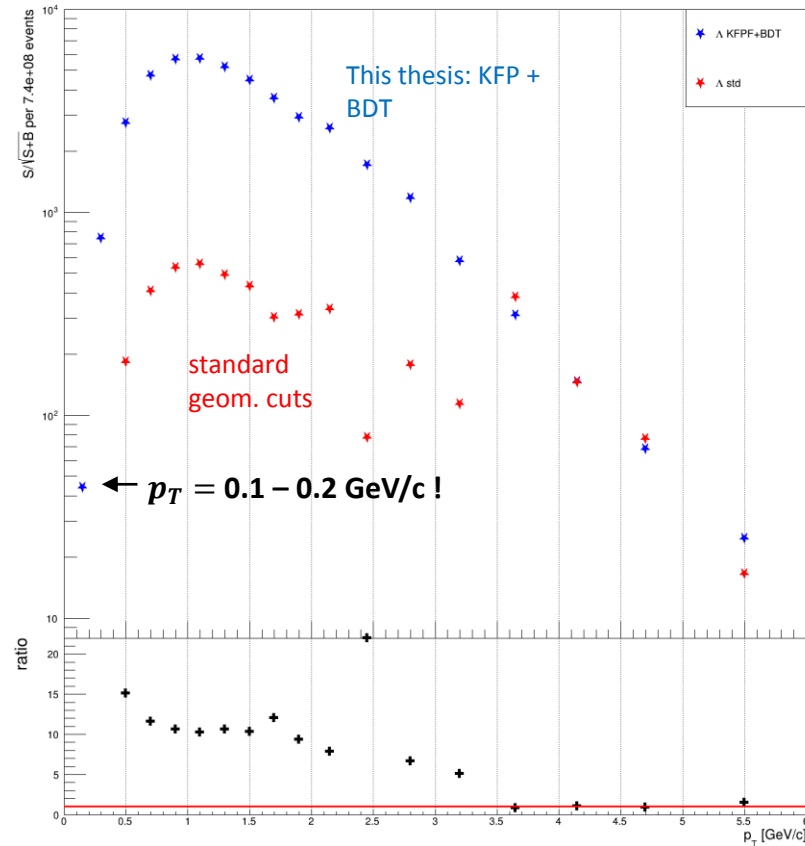
Au+Au, 27 GeV, P191b, $\Lambda \rightarrow \rho + \pi$, $p_T = 0.1-0.2$ GeV/c



Au+Au, 27 GeV, P191b, $\Lambda \rightarrow \rho + \pi$, $p_T = 0.1-0.2$ GeV/c



Λ signal significance, Au+Au, 27 GeV



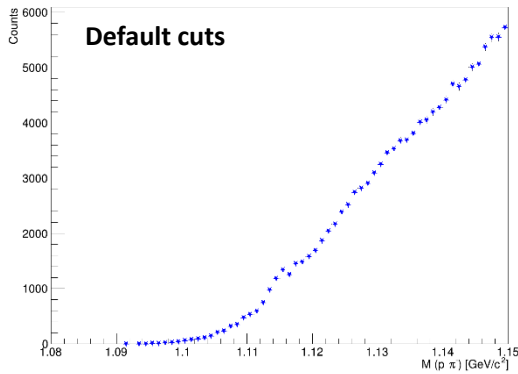
- Analysis note - https://drupal.star.bnl.gov/STAR/system/files/Analysis_note_KsLaXi.pdf
- Invariant mass plots - https://www.star.bnl.gov/protected/lfsupc/zhux/belongpaper/massfitting/la/auau27_la_invmass_cut0_nqaus4.0.pdf

$$SG = \frac{N}{\delta N} \quad \delta N = \sqrt{\sum \delta N_i^2}$$

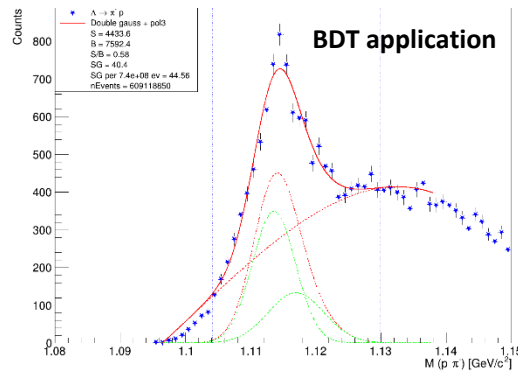
KFP: TMVA vs. default cuts

- TMVA improves significance throughout whole p_T spectrum
- Also enables reconstruction at very low $p_T = 0.1 - 0.2 \text{ GeV}/c$
- KFP more effective than conventional analysis with topological cuts

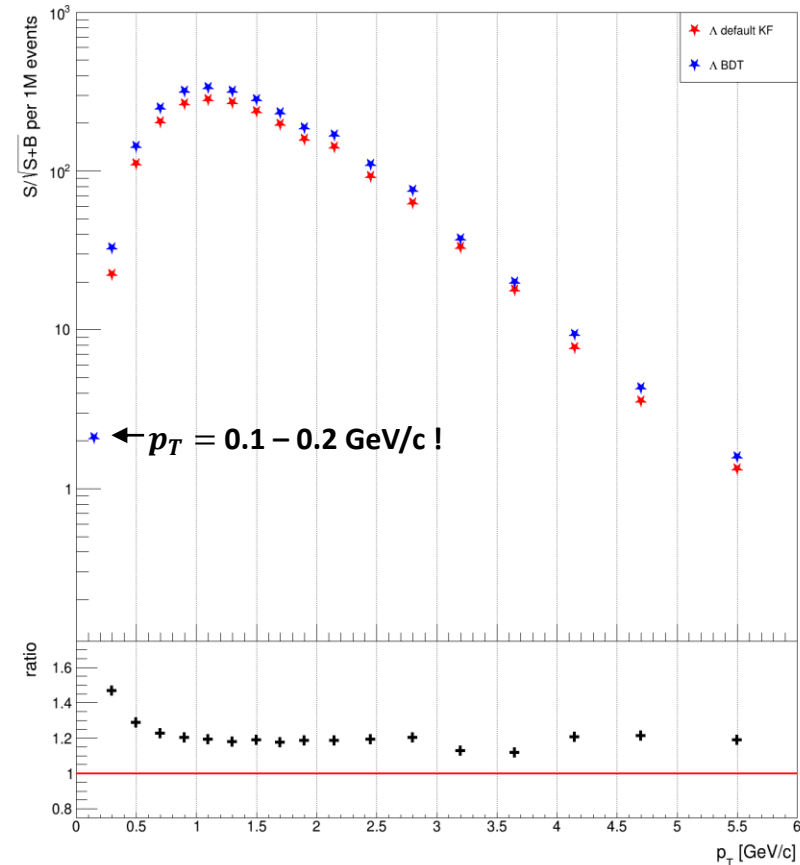
Au+Au, 27 GeV, P191b, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.1-0.2 \text{ GeV}/c$



Au+Au, 27 GeV, P191b, $\Lambda \rightarrow p + \pi^-$, $p_T = 0.1-0.2 \text{ GeV}/c$



Λ signal significance, Au+Au, 27 GeV



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