



Looking for charm production in NOvA

Final talk

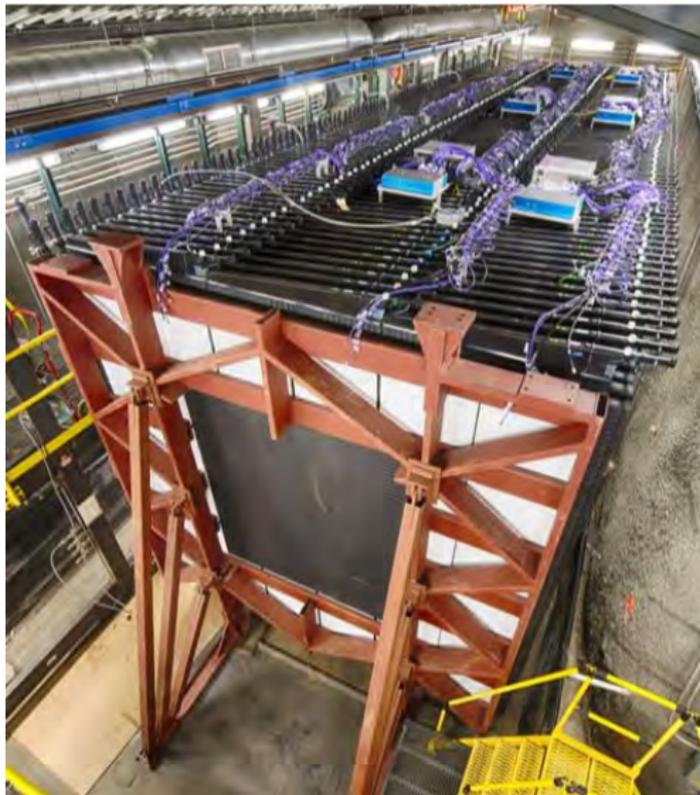
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Sep 23 2016, Fermilab

Supervisor: Keith Matera

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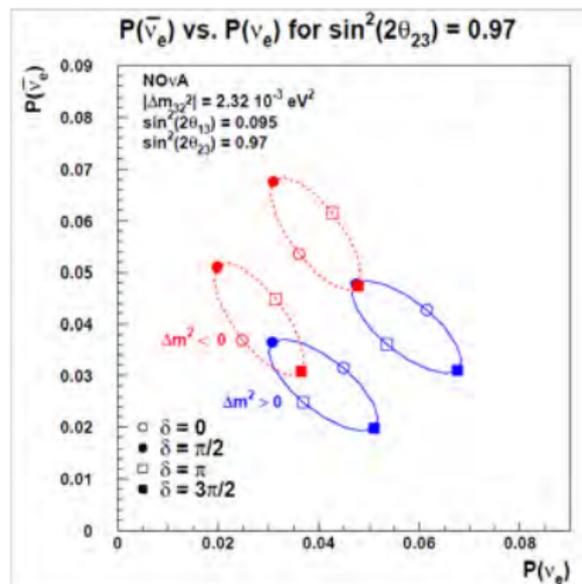


The NOvA Experiment - oscillation analysis goals

- NOvA = NuMI Off-axis ν_e Appearance

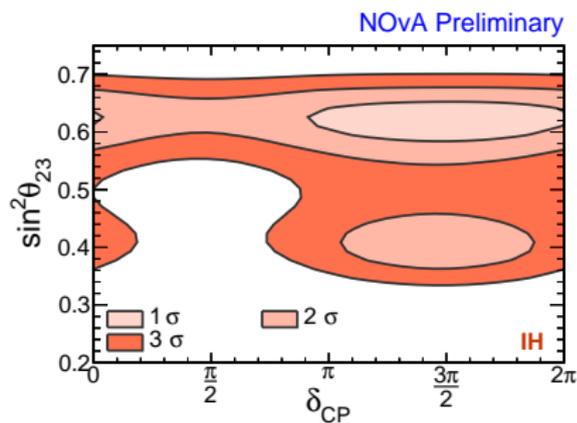
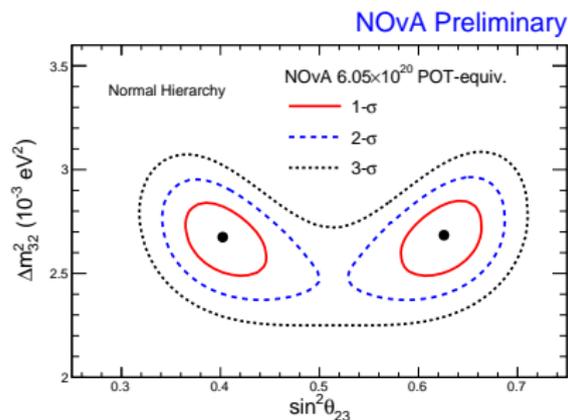
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{13}s_{23}c_{12}e^{i\delta} & c_{23}c_{12} - s_{13}s_{23}s_{12}e^{i\delta} & c_{13}s_{23} \\ s_{23}s_{12} - s_{13}c_{23}c_{12}e^{i\delta} & -s_{23}c_{12} - s_{13}c_{23}s_{12}e^{i\delta} & c_{13}c_{23} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- Oscillation of ν_μ to ν_μ (disappearance)
- Oscillation of ν_μ to ν_e (appearance)
- Neutrino masses ordering Δm^2
- Symmetry between matter and antimatter δ_{CP}

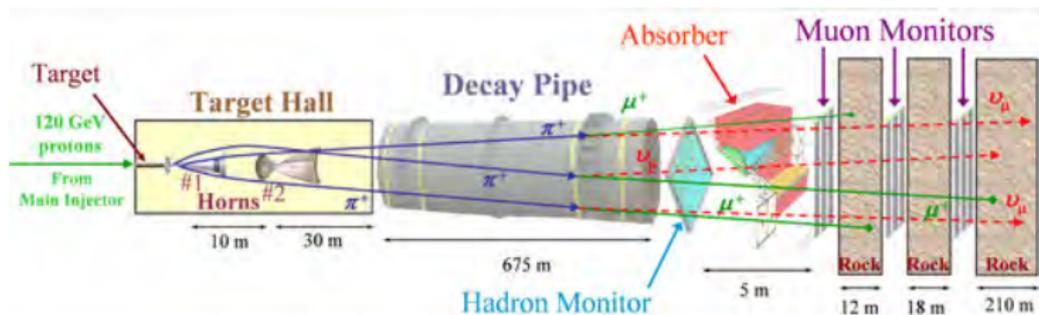


The NOvA Experiment - the most recent results

- Excludes maximal mixing at 2.5σ from ν_μ disappearance
- So far $\delta_{CP} \sim \frac{3\pi}{2}$ is slightly preferred from ν_e appearance



The NOvA Experiment - neutrino production

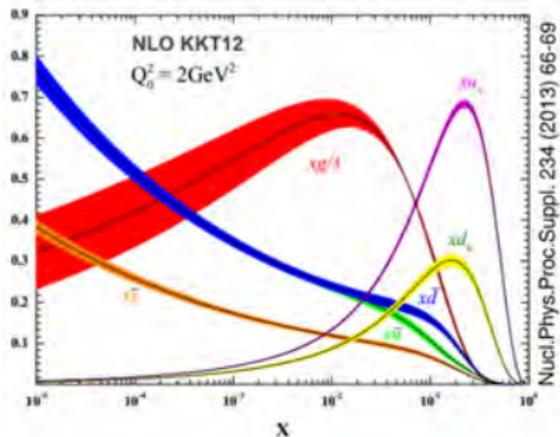
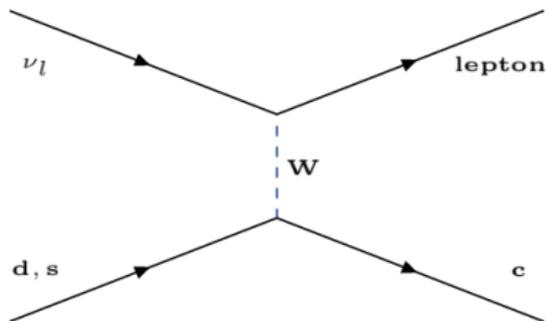


- NuMI beam to the graphite target
- Focused with 2 magnetic horns
- π^\pm decay in pipe into μ and ν
- μ stop in absorber
- Near detector at Fermilab, ILLINOIS
- Far detector in Ash River, MINNESOTA
- NOvA 14.6 mRad off-axis
- Spectrum peaks at 2 GeV with long high energy tail \rightarrow charm production



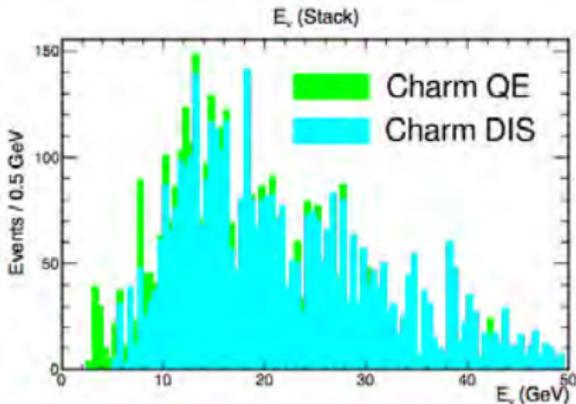
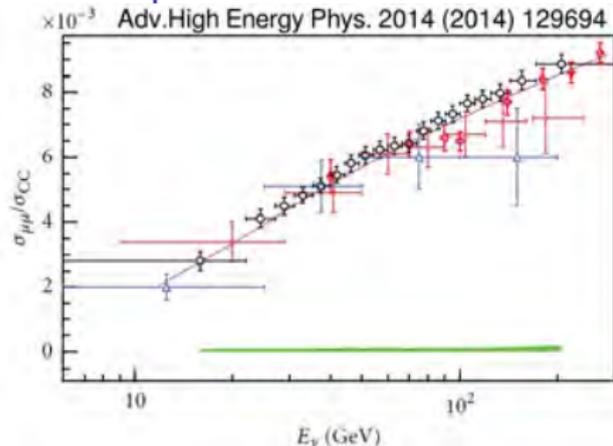
Charm production - motivation

- Charm quark from valence or sea quark
- Forms hadrons \rightarrow decay to $\mu + X$



- Measurement of the cross section
- Probability density function of strange quark?

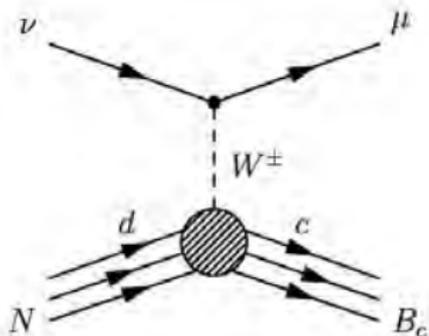
Charm production - outlooks



- NOMAD measured neutrino-induced charm production by taking the ratio of rates of dimuon to single muon neutrino interaction events
- The energy spectrum of charm production events at NOvA is shown to the right
- We can compare, and maybe provide complementary measurements in the 0-20 GeV region

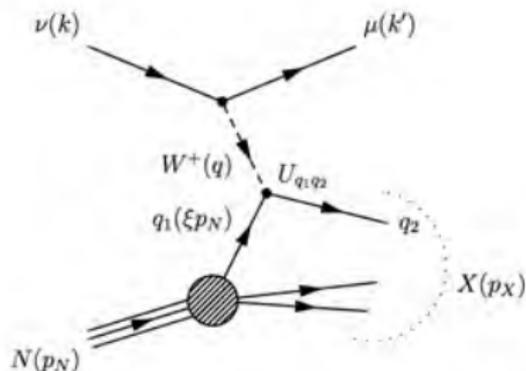
Charm production - two types

Quasi-elastic



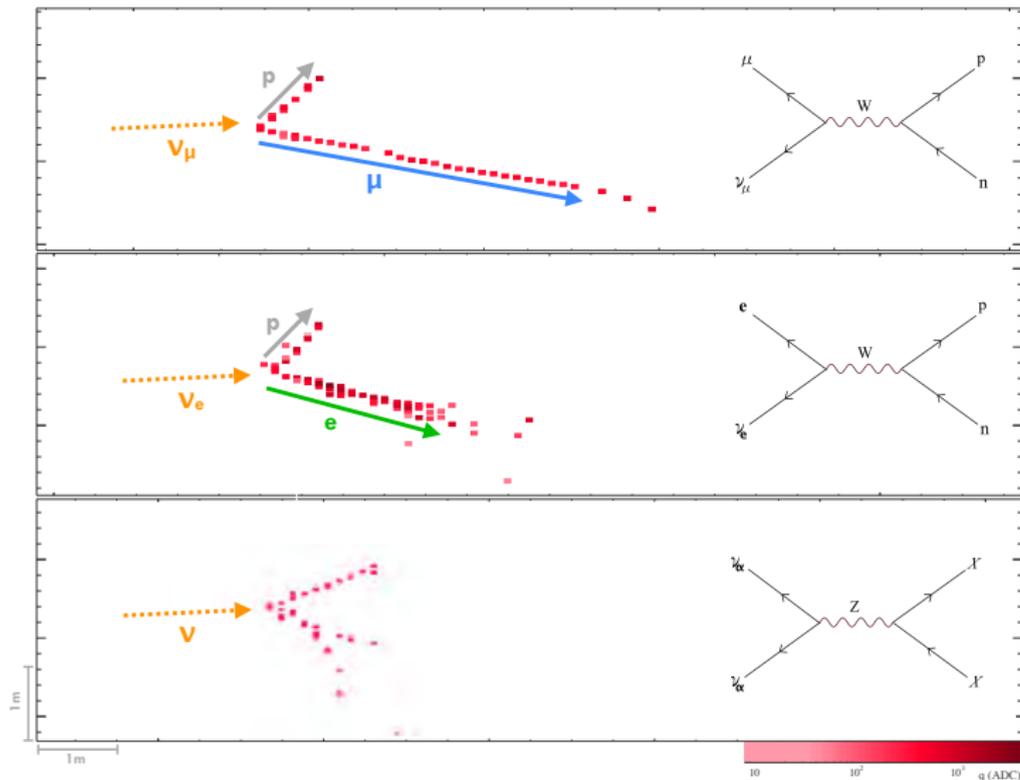
- Clean
- Charmed baryons
- $\Lambda_c \sim 2.3$ GeV

Deep-inelastic

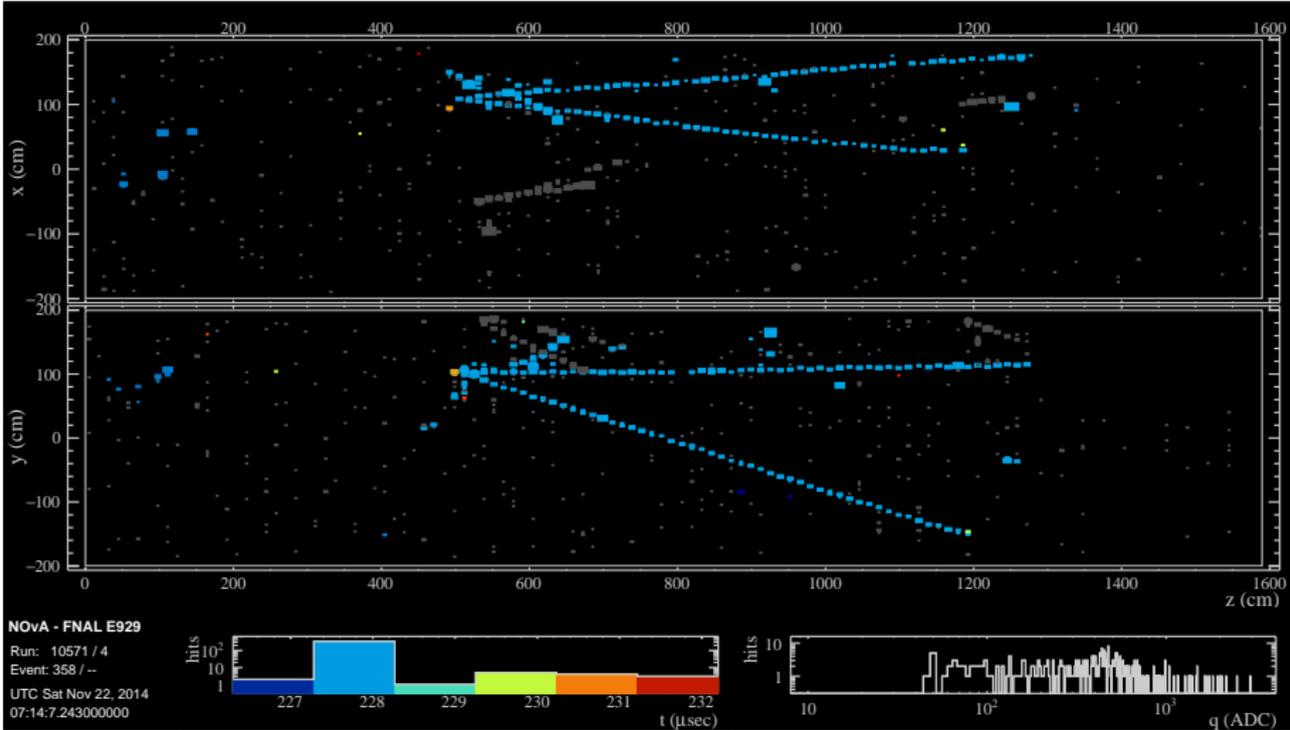


- Mess
- Charmed mesons (+ baryons)
- $D_c + p \sim 2.8$ GeV

Event display - what non-charm interactions look like



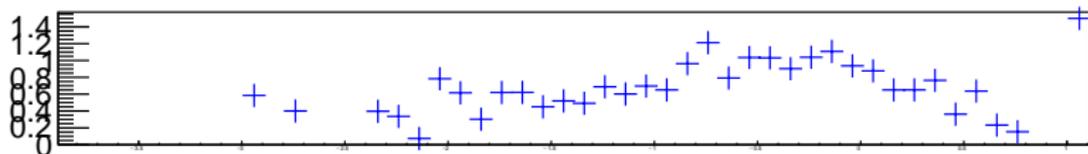
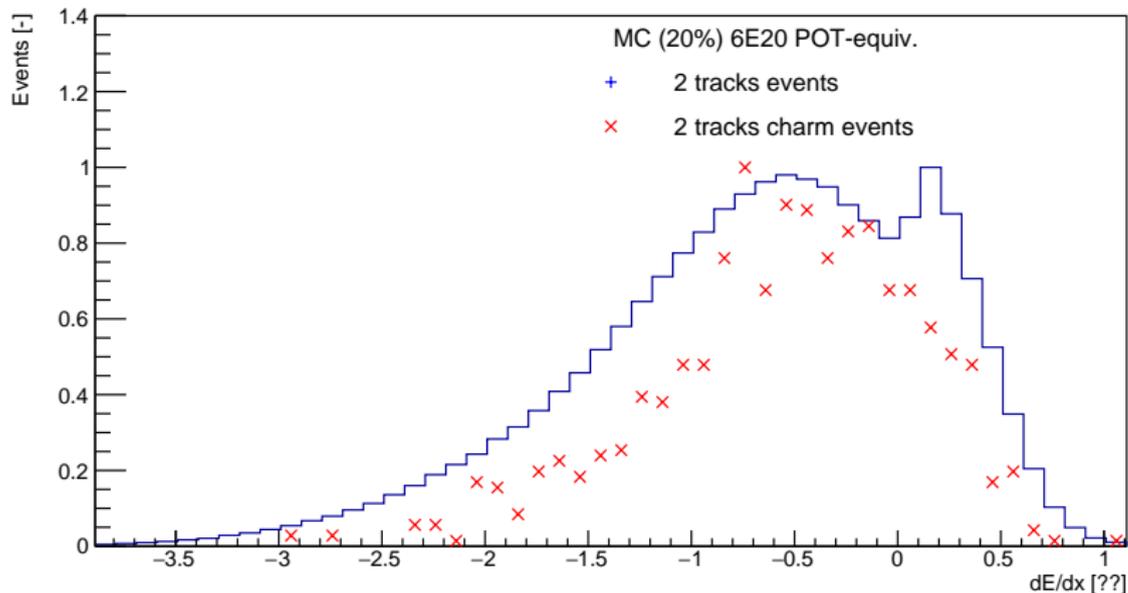
Event display - what charm interactions look like (in MC)



- Event displays only for cross check
 - Impossible to look at every event
- Analytic tools (CAF, ROOT...)
- Steps of the analysis:
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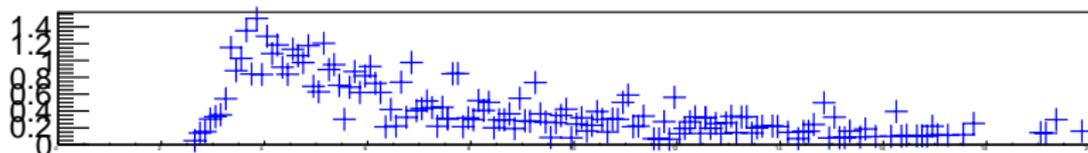
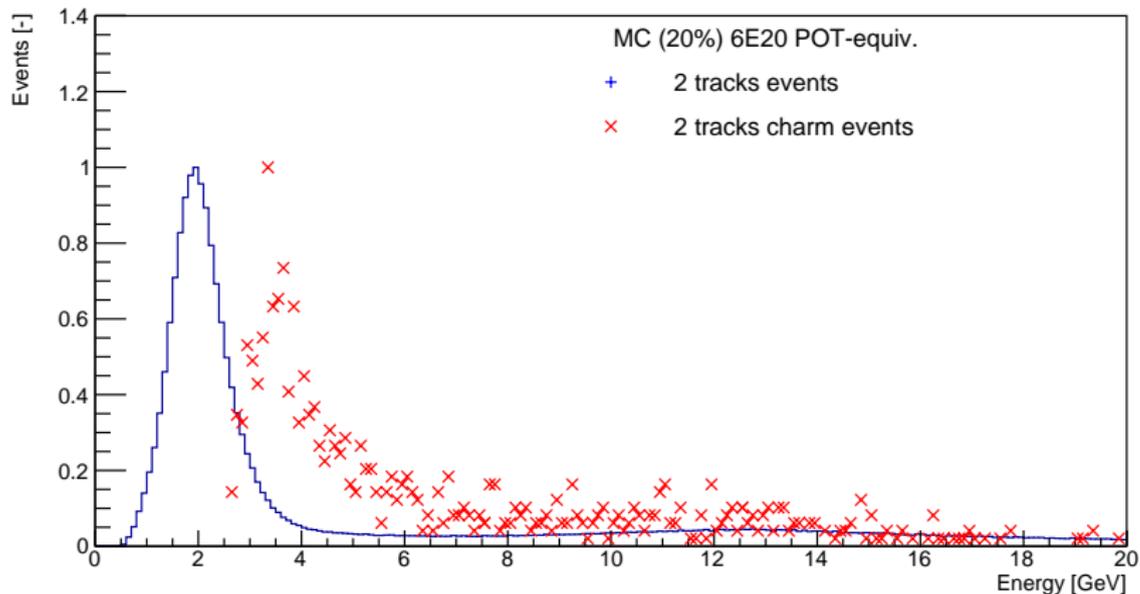
MC plots - log-likelihood

Log-likelihood value from dE/dx (bkg)

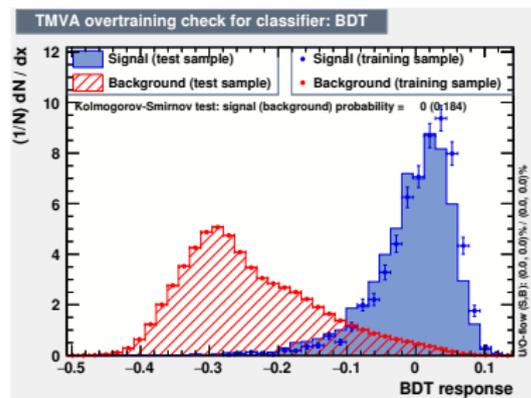


MC plots - energy

True energy of neutrino (bkg)

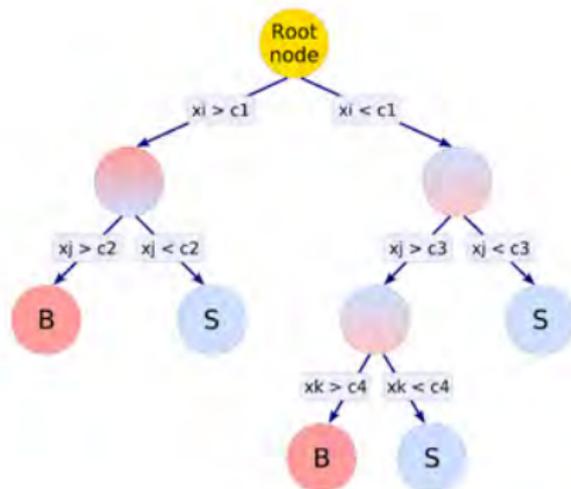


- The **T**oolkit for **M**ultivariate **A**nalysis
- Machine learning environment
- Designed for high-energy physics
- Implemented in ROOT \rightarrow C++ and ROOT classes
- A pack of multivariate classification/regression methods
- Boosted decision tree



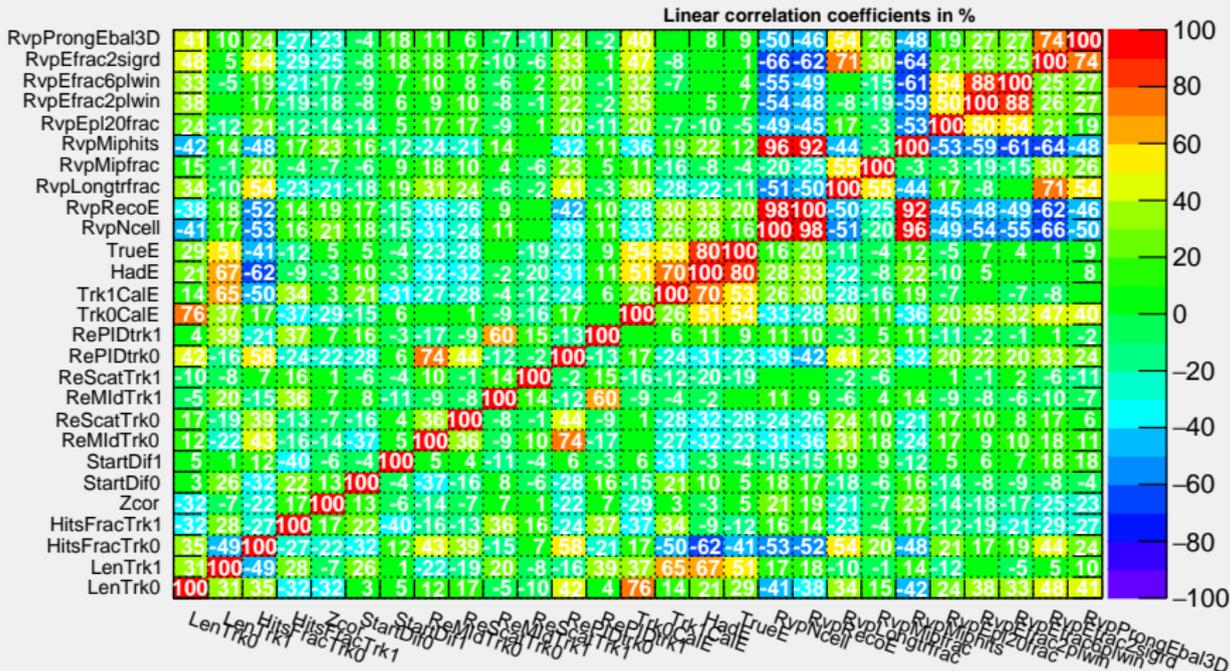
Boosted decision tree

- Binary tree structured classifier
- Each branch several nodes
- Decision signal/bkg based on a cut on a single variable
- Each node different variable
- Each branch different criteria
- Tree needs to be trained
- Boosted \rightarrow more trees \rightarrow forest (lowers fluctuation sensitivity)



Correlation of variables

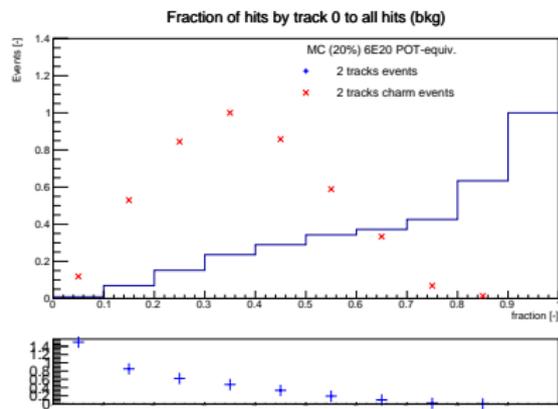
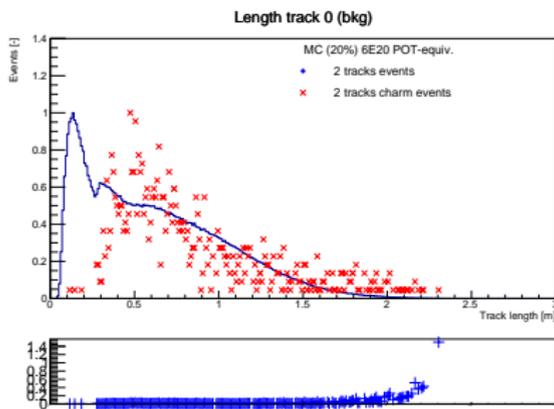
Correlation Matrix (signal)



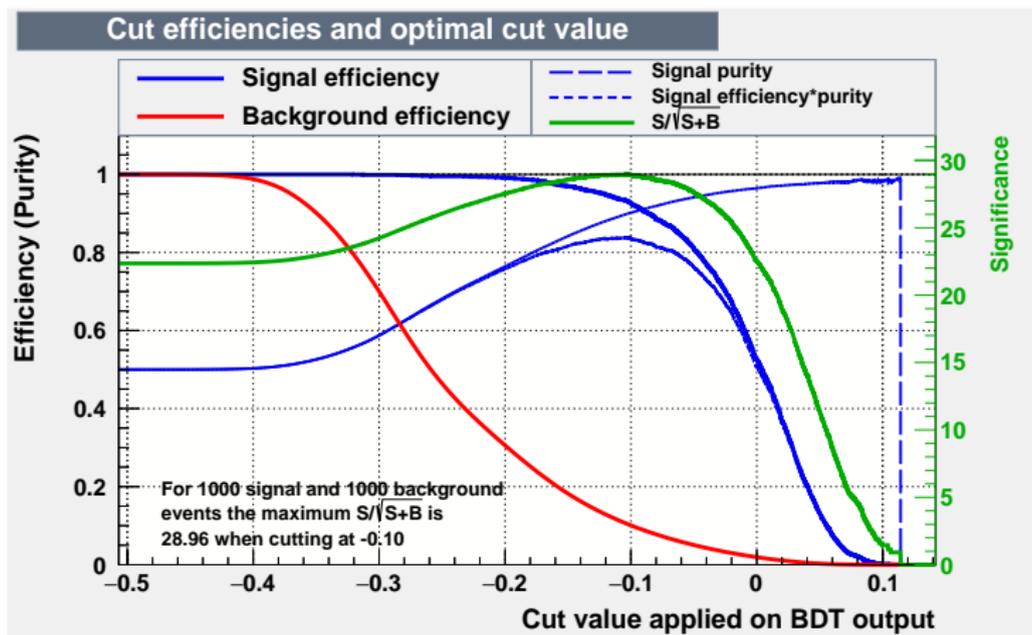
Mostly no significant correlations deteriorating the training

Pre-selection cuts - BDT's suggestions

- Suggests some pre-selection cuts
 - Length of the longest track >152 cm
 - Length of the 2. longest track >16 cm
 - Ratio of hits of the longest track <0.88
 - Ratio of hits of the 2. longest track <0.64
- Makes sense



BDT output cut value



Expected sig/bkg ratio

- BDT trains the tree with Monte Carlo
- Creates a set of weights for each variable
- Applied on data and used to compare with our cut value ← decision!
- We looked on MC to predict ratio of signal to background

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- Sig/bkg = 0.001 ← very bad ☹

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- Possible ways to improve cuts:
 - Get event displays of signal and background after BDT
 - Investigate more correlations between variables used for BDT
 - Talk to as many expert as possible to collect other opinions

Conclusion

- Difficult to separate charm dimuon events from background
- Consider different variables?
- Check correlations?
- Use different charm decay modes?



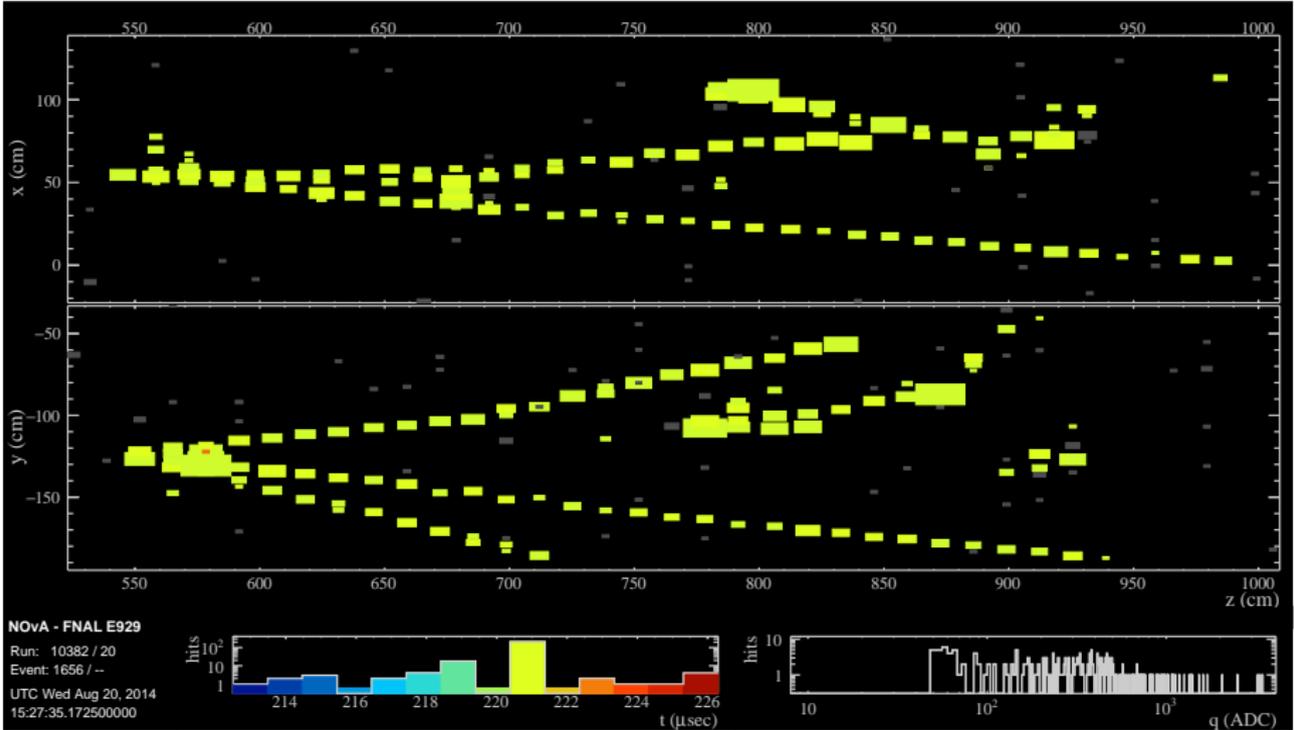
Thank you for your attention



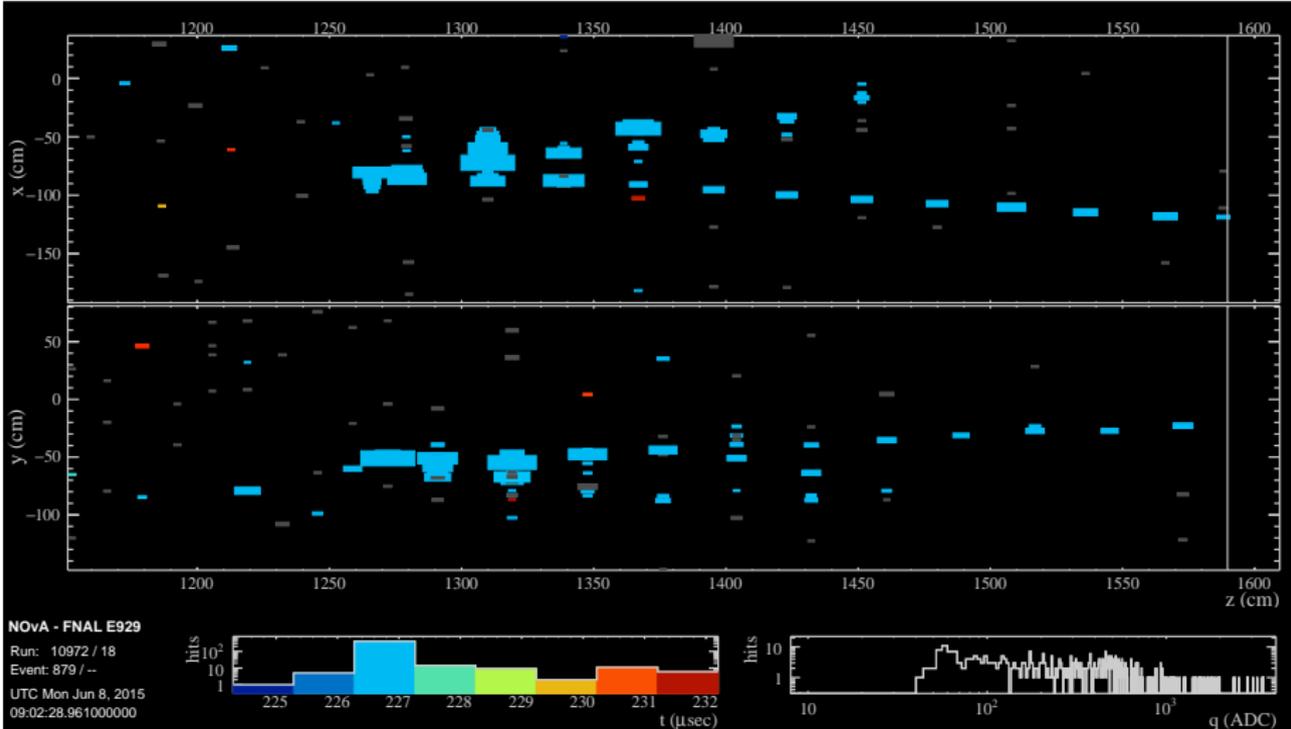
I hate reading
other people's code.

BACK UP

Event display - background event after cut on BDT output

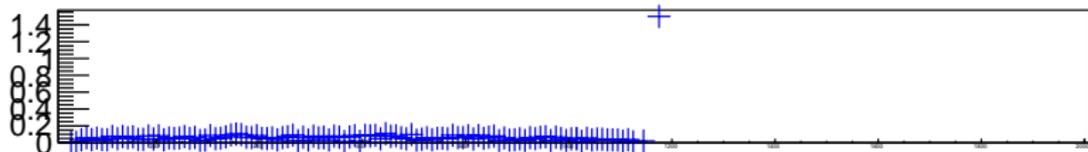
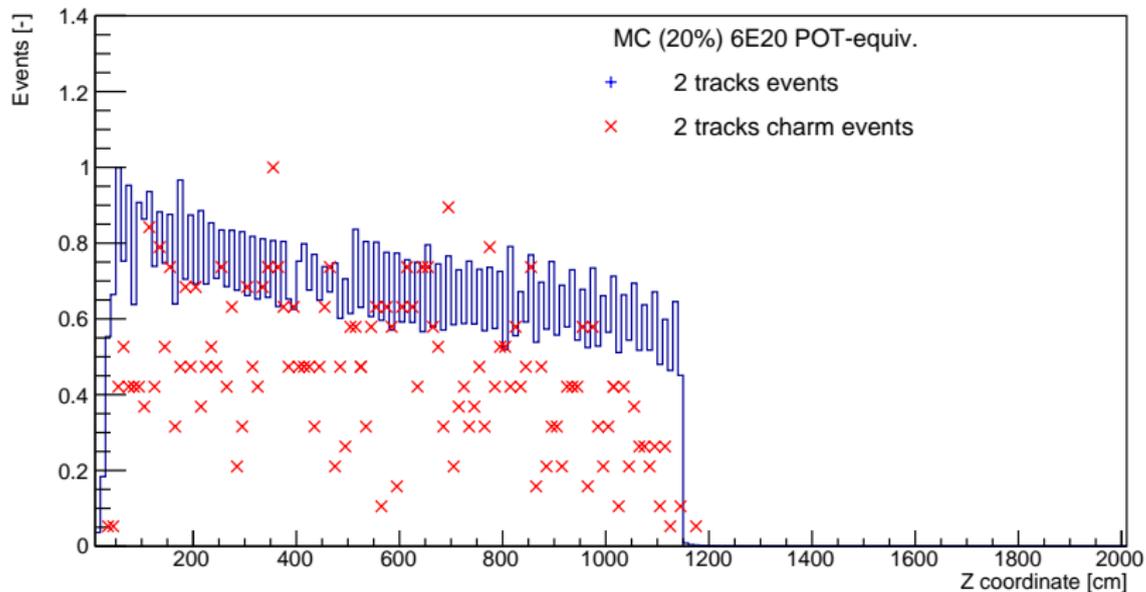


Event display - signal event after cut on BDT output



MC plots - Z coordinate of start of the longest track

Z coord. of track start (bkg)



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