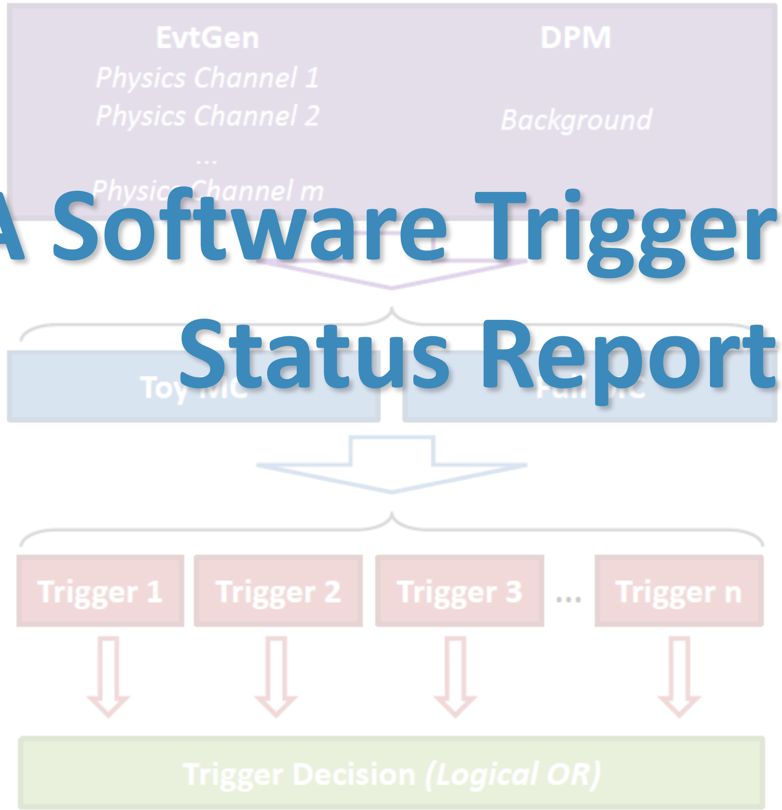
PANDA Software Trigger
Status Report



PANDA Collaboration Meeting

Computing Session

March 2014, GSI

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Status Report about to be released

Present status of the PANDA software trigger

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Abstract

This note presents the current status of the PANDA software trigger project. Apart from the present results obtained from Monte Carlo simulated events for various PANDA physics channels of interest, the task is definded and intersections to the DAQ and detector projects are pointed out.

Contents

58 pages (including appendix)

Definition of Software Trigger Task

Duties of the Software Trigger Group

- Find principle potential by starting from idealised conditions
- Identify observables allowing signal/background separation
- Develop algorithms suppressing data rate at high efficiencies
- Determine performance for different scenarios

Connected issues

- Define a complete list of physics channels
- Develop realistic online-like reconstruction
  (→ time-based simulation + event building + online reco algo's)
- Implement selection algorithms on appropriate online compute elements like FPGA, GPU, ...
- Acquisition and handling of the information necessary to perform selection (DAQ level)

Toy & Full MC

Assumption: tracking, neutral reco, PID & event building works

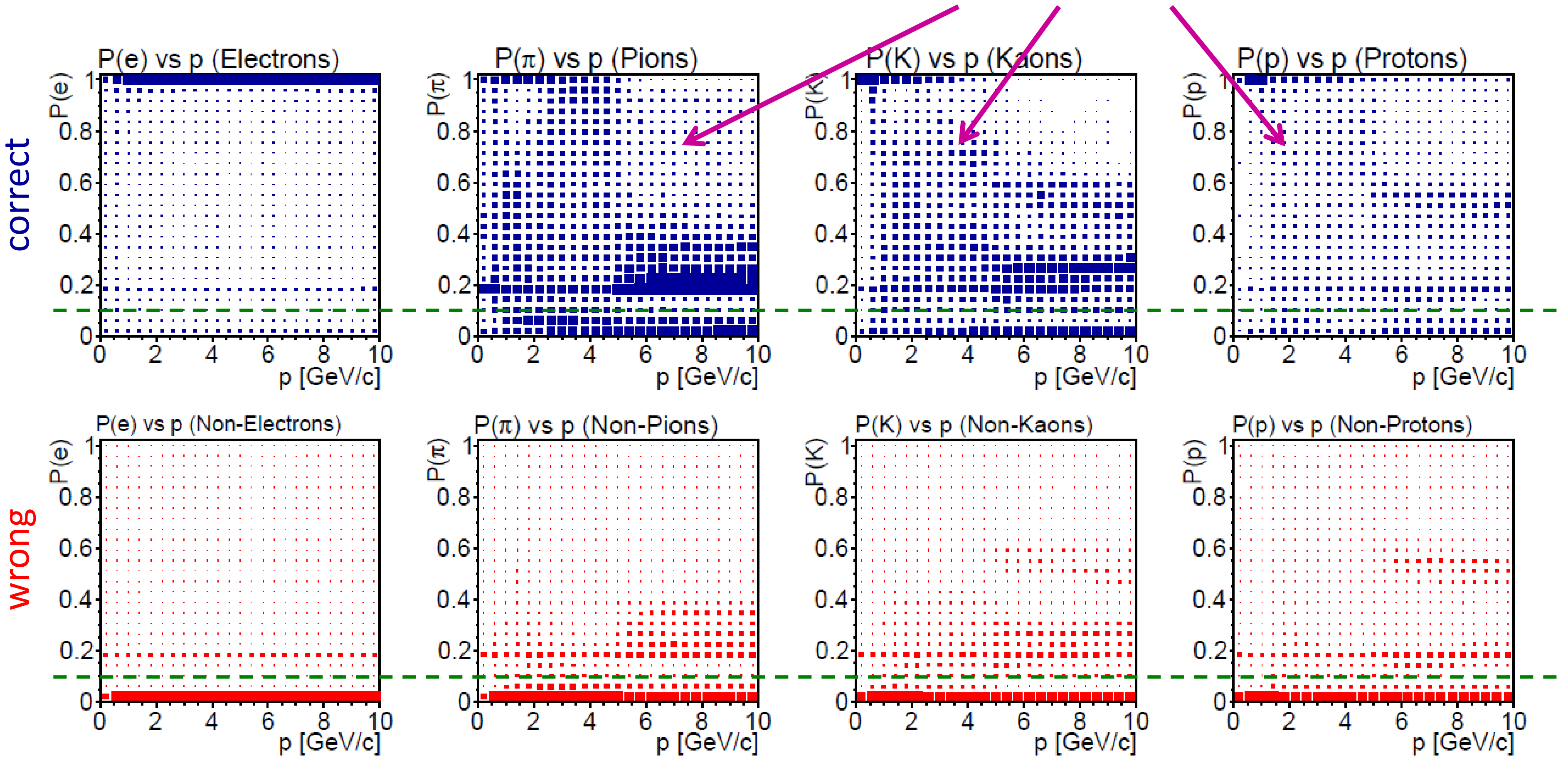
- Toy MC *(50k each signal, 500k DPM)*
  - ➢ Find principal potential under defined conditions
  - – Tracking: $\varepsilon_{trk} = 95\%$, $\Delta p/p = 5\%$, $\Delta\theta = \Delta\varphi = 1$ mrad
  - – PID: $\varepsilon_{PID} = 95\%$, mis-ID = 5%
  - – Neutrals: $\Delta E/E = 5\%$, $\Delta\theta = \Delta\varphi = 3$ mrad

- Full MC *(500k each signal, 1M DPM)*
  - ➢ More realistic, but stick to the current sotware
  - – PandaROOT release/jan14, external packages apr13
  - – Tracks: $p > 100$ MeV/c
  - – Neutrals: $E > 100$ MeV
  - – PID: $P > 10\%$

Full MC PID

- Particle Identification: P > 10%

Hadron PID worse than before due to often missing DIRC info



Channel List

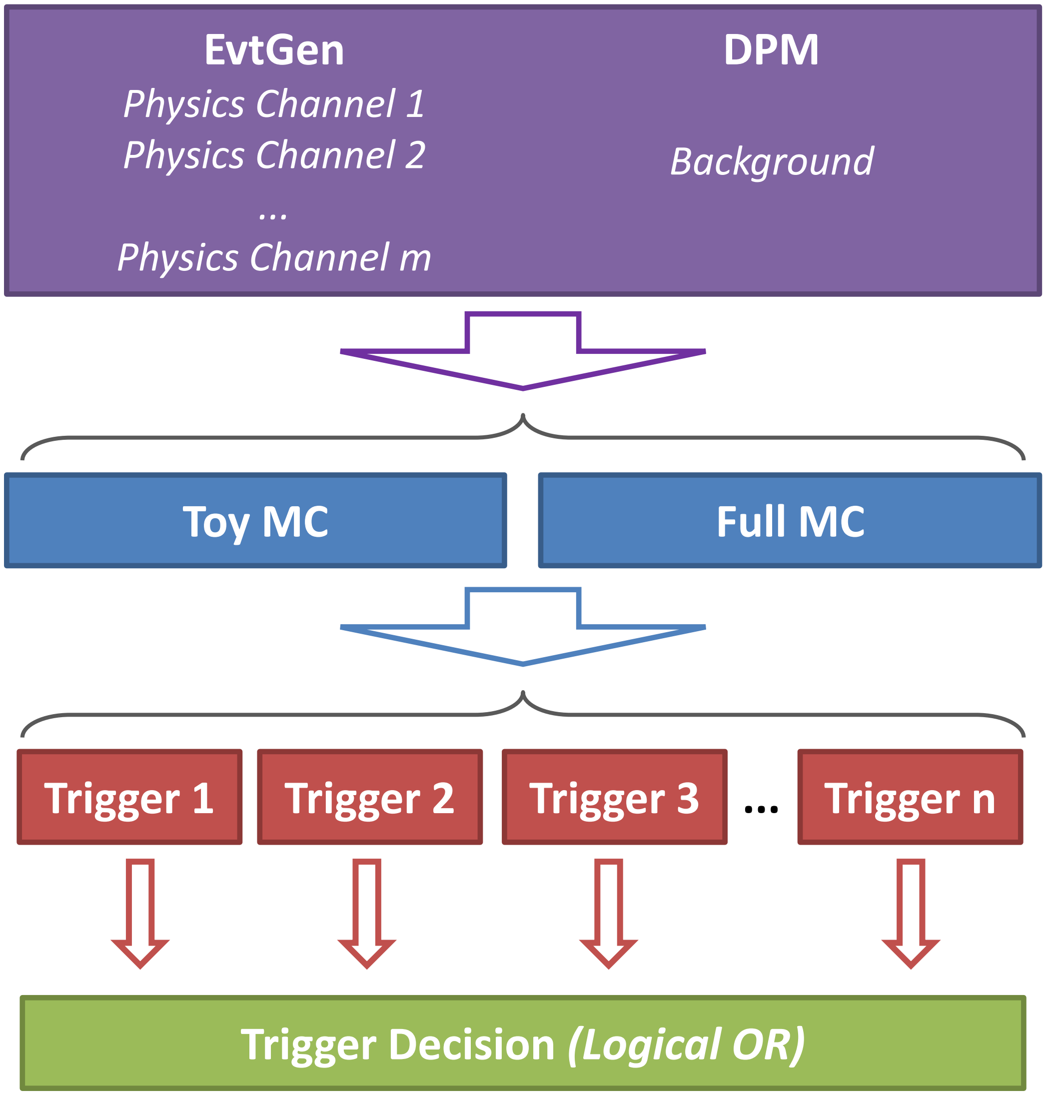
- 10 Channels under investigation

Physics topic	Reaction channel	Code	Trigger	Tag
Electromagnetic	$p\bar{p} \to e^+e^-$	ee	$p\bar{p} \to e^+e^-$	e^+e^-
Exotics	$p\bar{p} \to \phi_{(1)}\phi_{(2)}$; $\phi_{(1)} \to$ trigger, $\phi_{(2)} \to X$	Phi	$\phi \to K^+K^-$	ϕ
Charmonium	$p\bar{p} \to \eta_c\pi^+\pi^-$; $\eta_c \to$ trigger	Etac	$\eta_c \to K_SK^-\pi^+$	η_c
	$p\bar{p} \to J/\psi\,\pi^+\pi^-$; $J/\psi \to$ trigger	J2e	$J/\psi \to e^+e^-$	$J/\psi(2e)$
	$p\bar{p} \to J/\psi\,\pi^+\pi^-$; $J/\psi \to$ trigger	J2mu	$J/\psi \to \mu^+\mu^-$	$J/\psi(2\mu)$
Open charm	$p\bar{p} \to D^0\overline{D^0}$; $D^0 \to$ trigger; $\overline{D^0} \to X$	D0	$D^0 \to K^-\pi^+$	D^0
	$p\bar{p} \to D^+D^-$; $D^+ \to$ trigger, $D^- \to X$	Dch	$D^+ \to K^-\pi^+\pi^+$	D^+
	$p\bar{p} \to D_s^+D_s^-$; $D_s^+ \to$ trigger, $D_s^- \to X$	Ds	$D_s^+ \to K^+K^-\pi^+$	D_s^+
Baryons	$p\bar{p} \to \Lambda\bar{\Lambda}$; $\Lambda \to$ trigger; $\bar{\Lambda} \to X$	Lam	$\Lambda \to p\pi^-$	Λ
	$p\bar{p} \to \Lambda_c\bar{\Lambda}_c$; $\Lambda_c \to$ trigger; $\bar{\Lambda}_c \to X$	Lamc	$\Lambda_c \to p\mathrm{K}^-\pi^+$	Λ_c
Background	$p\bar{p}$ generic (DPM)	DPM	–	–

- Data sets at 4 different center-of-mass energies

$\sqrt{s}$ [GeV]	$p_{\bar{p}}$ [GeV/c]	ee	Phi	Etac	J2e	J2mu	D0	Dch	Ds	Lam	Lamc	DPM
2.4	1.91	X	X	–	–	–	–	–	–	X	–	X
3.77	6.57	X	X	X	X	X	X	X	–	X	–	X
4.5	9.81	X	X	X	X	X	X	X	X	X	–	X
5.5	15.15	X	X	X	X	X	X	X	X	X	X	X

Strategy



Event Generation

- *Signal*
- *Background*

Simulation & Reconstruction

Event Filtering

- *Combinatorics*
- *Mass Window Selection*
- *Trigger Specific Selection* → *Event Tagging*

Global Trigger Tag

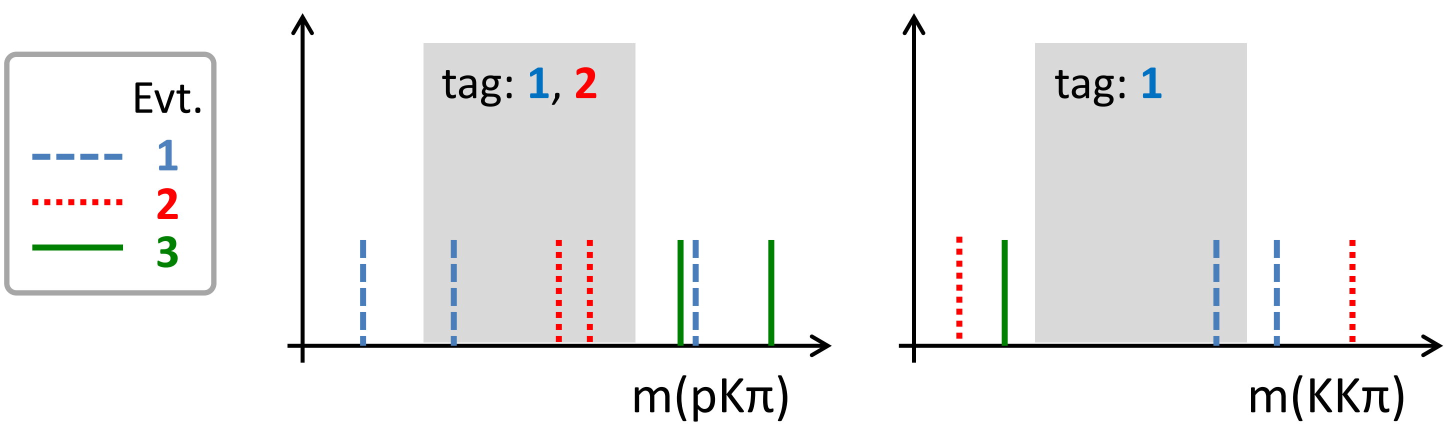
Event Based Efficiency

- All presented efficiencies are event based
- In general: $\varepsilon_{tot} < \sum \varepsilon_{trig}$
- Four different cases:
  1. *Trigger* T_X tags due to *correctly* reconstructed candidate X
  2. T_X tags due to *random* cand. form event containing *signal X*
  3. T_Y tags due to *random* cand. from event containing *signal X*
  4. T_X tags due to *random* cand. from *background*

(Cases 1–2: ε_X; cases 1–3: ε_{tot})

$\Lambda_c^{\pm}$: $\varepsilon_1 = 2/3 = 66\%$

$D_s^{\pm}$: $\varepsilon_2 = 1/3 = 33\%$



$\varepsilon_{tot} = 2/3 = 66\%$
$< \varepsilon_1 + \varepsilon_2$

Selection Optimisation

- Four different selection approaches have been studied
  - Preselection
    - Combinatorics
    - Mass window cut ±8σ around nominal mass
  - High Signal Efficiency *(manually)*
    - Retain 90% of efficiency per trigger line w.r.t. preseletion
  - High Background Suppression *(manually)*
    - Reject 99.9% DPM in total (all triggers simultaneous)
  - TMVA based
    - Classification problem in multi-dimensional parameter space
    - Proper handling of correlations between observables

- Each trigger line @ each energy → individual optimisation!

Observables

O(100) event and candidate related observables considered

Short cut	Description
e, px, py, pz	components of 4-vector for composite/daughters (lab)
ecm, pxcm, pycm, pzcm	components of 4-vector for composite/daughters (cms)
p	momentum p of reconstructed candidate/daughters (lab, cms)
pcm	momentum p of reconstructed candidate (cms)
pt	transvers momentum p_t of reconstructed candidate/daughters
tht, phi	angles of candidate/daughters (lab)
thtcm, phicm	angles of candidate/daughters (lab, cms)
pide, pidmu, pidpi, pidk, pidp	PID probabilities of daughters
oang, decang	opening/decay angle of 2-body candidates
pocvx, pocvy, pocvz, pocqa	Vertex quality of POCA finder for charged daughters
various	if daughter is π^0, detailed information about itself and the two photons
various	if daughter is K_S^0, detailed information about itself and the two pions
npart	multiplicity of all particles in event
nneut	multiplicity of neutral particles in event
nchrg	multiplicity of charged particles in event
npide	multiplicity of electrons
lnpide	multiplicity of electrons with loose PID ($P > 0.25$)
l1npide	multiplicity of electrons with loose PID ($P > 0.25$) and $p > 1$ GeV/c
tnpide	multiplicity of electrons with tight PID ($P > 0.5$)
t1npide	multiplicity of electrons with tight PID ($P > 0.5$) and $p > 1$ GeV/c
vtnpide	multiplicity of electrons with very tight PID ($P > 0.9$)
...	*last 6 variables also for muons, pions, kaons, protons*
np05, ..., np50	multiplicity of particles with $p > [0.5, 1.0, 2.0, 3.0, 4.0, 5.0]$ GeV/c (cms)
np05l, ..., np50l	multiplicity of particles with $p > [0.5, 1.0, 2.0, 3.0, 4.0, 5.0]$ GeV/c (lab)
npt05, ..., npt30	multiplicity of particles with $p_t > [0.5, 1.0, 1.5, 2.0, 2.5, 3.0]$ GeV/c
nne003l, ..., nne05l	multiplicity of neutral part. with $E > [0.03, 0.05, 0.1, 0.5]$ GeV (lab)
ncp005, ..., ncp10	multiplicity of charged part. with $p > [0.03, 0.05, 0.1, 0.5]$ GeV/c (cms)
ncp005l, ..., ncp10l	multiplicity of charged part. with $p > [0.03, 0.05, 0.1, 0.5]$ GeV/c (lab)
pmax	maximum particle momentum in event (cms)
pmaxl	maximum particle momentum in event (lab)
ptmax	maximum transvers particle momentum in event
pmin	minimum particle momentum in event (cms)
pminl	minimum particle momentum in event (lab)
ptmin	minimum transvers particle momentum in event
prapmax	maximum pseudorapidity of a particle in event

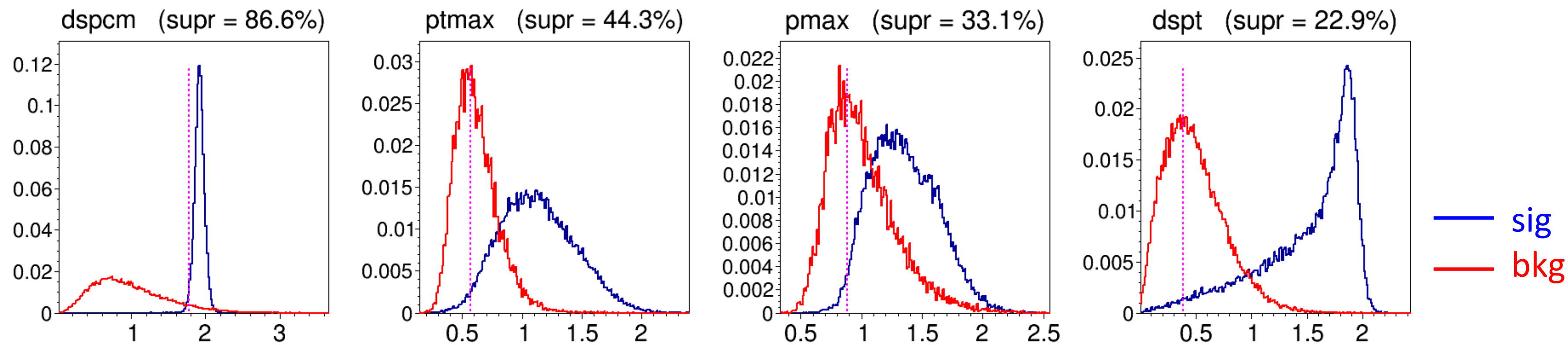
Short cut	Description
sumpc	sum of momenta of charged particles in event (cms)
sumpcl	sum of momenta of charged particles in event (lab)
sumen	sum of energies of neutral particles in event (cms)
sumenl	sum of energies of neutral particles in event (lab)
sumpt	sum of transverse momenta of all particles in event (cms)
sumptl	sum of transverse momenta of all particles in event (lab)
sumptc	sum of transverse momenta of charged particles in event (cms)
sumptcl	sum of transverse momenta of charged particles in event (lab)
sumetn	sum of transverse energies of neutral particles in event (cms)
sumetnl	sum of transverse energies of neutral particles in event (lab)
sumpt05, sumpt10	sum of transverse momenta of all particles with $p_t > [0.5, 1.0]$ GeV/c
sumpc05, sumpc10	sum of momenta of charged particles with $p > [0.5, 1.0]$ GeV/c (cms)
sumpc05l, sumpc10l	sum of momenta of charged particles with $p > [0.5, 1.0]$ GeV/c (lab)
sumen05, sumen10	sum of energies of neutral particles with $E > [0.5, 1.0]$ GeV (cms)
sumen05l, sumen10l	sum of energies of neutral particles with $E > [0.5, 1.0]$ GeV (lab)
thr	Event shape: Magnitude of thrust (cms)
sph	Event shape: Sphericity (cms)
cir	Event shape: Circularity (cms)
apl	Event shape: Aplanarity (cms)
pla	Event shape: Planarity (cms)
fw1	Event shape: 1. Fox-Wolfram Moment $R_1 = H_1/H_0$ (cms)
fw2	Event shape: 2. Fox-Wolfram Moment $R_2 = H_2/H_0$ (cms)
fw3	Event shape: 3. Fox-Wolfram Moment $R_3 = H_3/H_0$ (cms)
fw4	Event shape: 4. Fox-Wolfram Moment $R_4 = H_4/H_0$ (cms)
fw5	Event shape: 5. Fox-Wolfram Moment $R_5 = H_5/H_0$ (cms)

Identification of Selection Observables

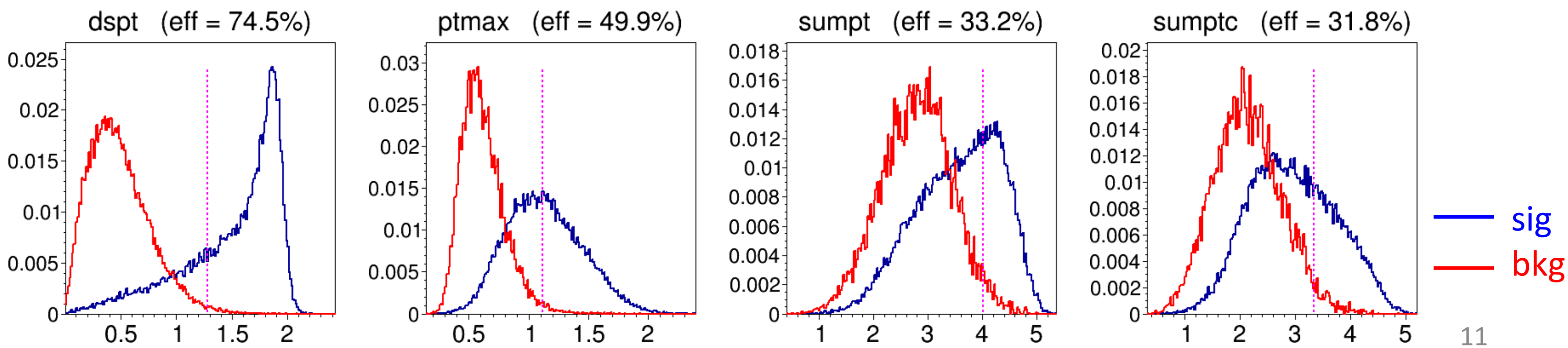
Observable ranking *(hint for manual optimisation):*

- Example: D_s@5.5 GeV

- Fixed efficiency (e.g. 98%)→ ranking by best background suppression



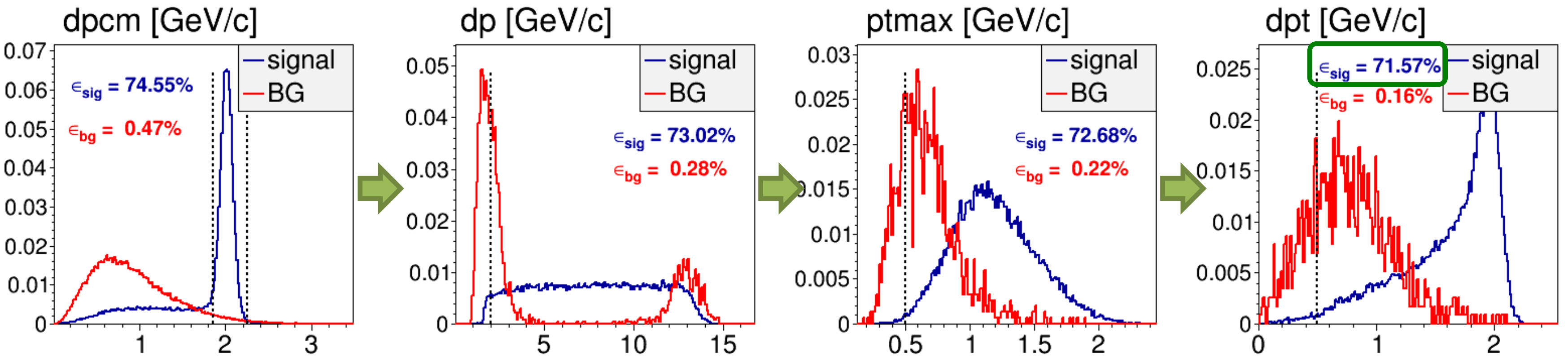
- Fixed suppression (e.g. 98%) → ranking by best signal efficiency



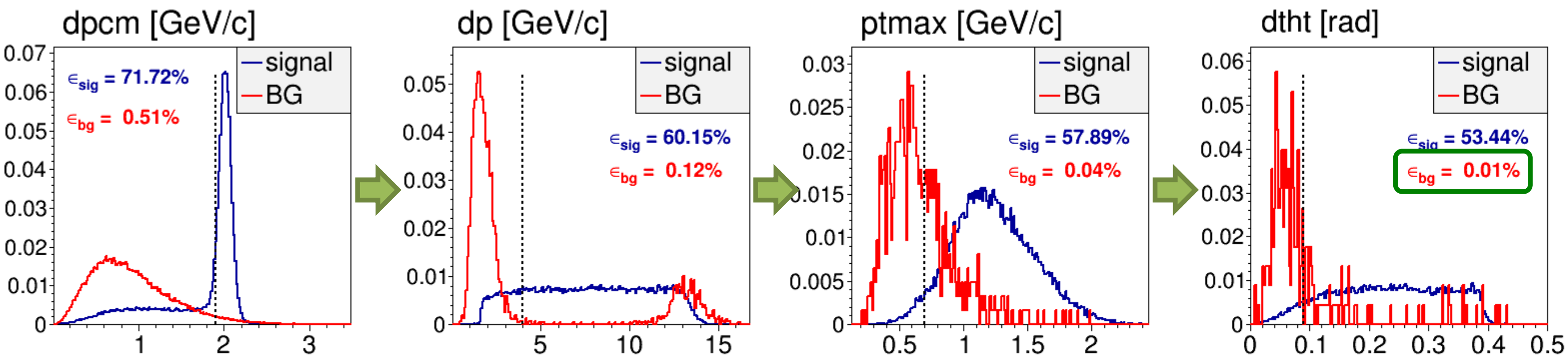
Selection Example

D± trigger on D±/DPM data @ 5.5 GeV: $\varepsilon_{sig,ini}$ = 79.4%

High efficiency optimisation (ε_{sig} / $\varepsilon_{sig,ini}$ ≈ 90%)



High suppression optimisation (ε_{bg} = 0.01%)

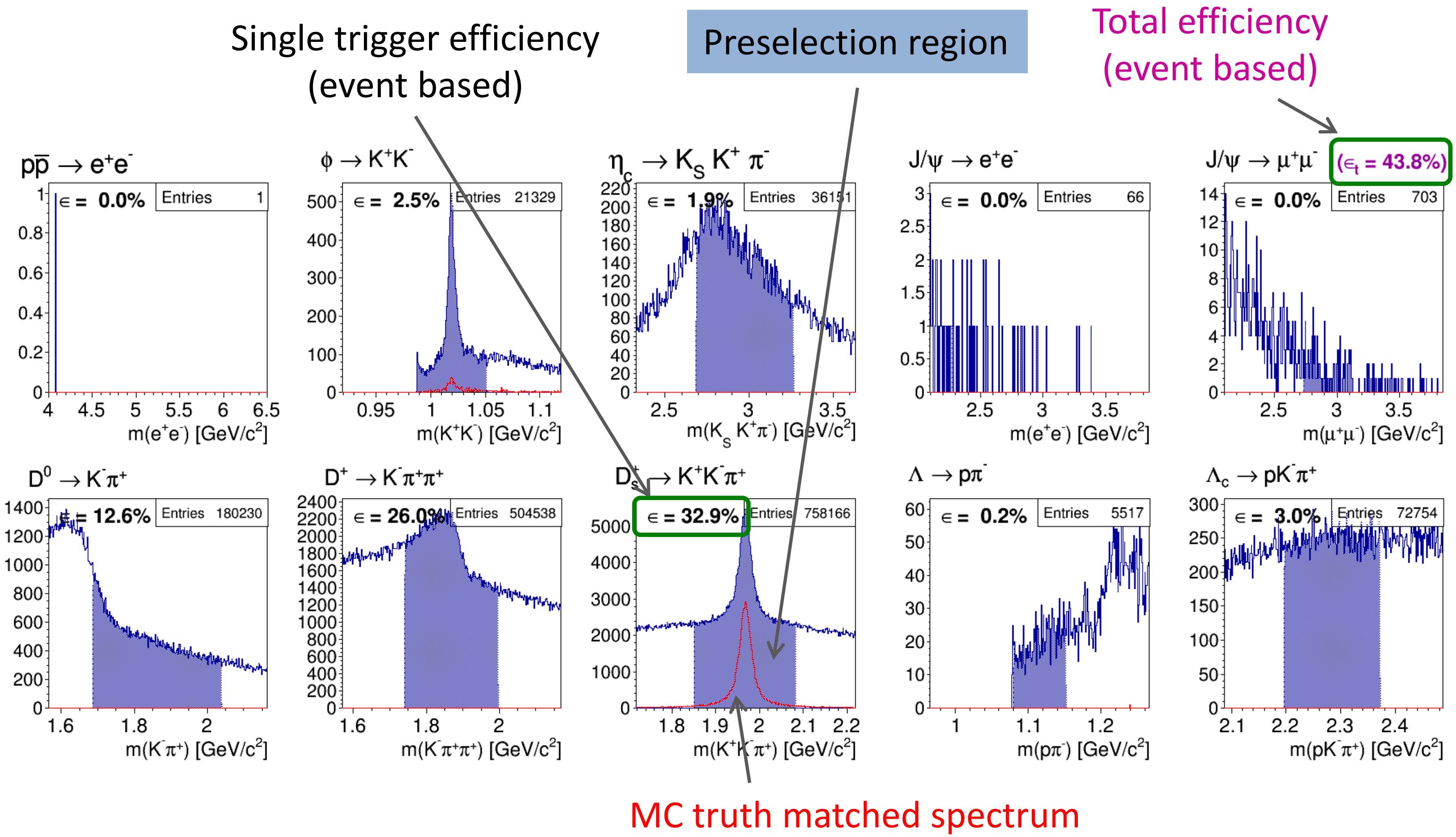


Toy MC – High Efficiency Algorithms

$\sqrt{s}$	Trigger	Selection	ϵ_{sig}	ϵ_{bg}
2.4	$p\bar{p} \to e^+e^-$	-	79.4	0.009
2.4	$\phi(K^+K^-)$	pmax<0.6 & phipcm>0.55 & phipcm<0.7	84.0	0.041
2.4	$\Lambda(p\pi^-)$	abs(lampcm-0.44)<0.04 & fw1>0.1 & fw2>0.1	82.6	0.028
3.77	$p\bar{p} \to e^+e^-$	-	79.2	0.001
...				
4.5	$D^0(K^-\pi^+)$	abs(d0pcm-1.27)<0.13 & ptmax>0.64 & d0e>2.7	76.5	0.235
4.5	$D^+(K^-\pi^+\pi^+)$	abs(dpcm-1.255)<0.105 & de>2.6 & ptmax>0.48 & dtht<0.33	72.4	0.483
4.5	$D_s^+(K^+K^-\pi^+)$	abs(dspcm-1.095)<0.096 & dse>2.9 & ptmax>0.39 & dstht<0.28	73.7	0.311
4.5	$\Lambda(p\pi^-)$	lampcm>1.7 & fw2>0.75 & lamtht>0.09 & fw4>0.5 & pmax>1.4	80.7	0.013
5.5	$p\bar{p} \to e^+e^-$	-	78.9	0.000
5.5	$\phi(K^+K^-)$	thr>0.955 & phipcm>2	87.1	0.001
5.5	$\eta_c(K_S K^-\pi^+)$	ptmax>0.75 & pmax>1.1 & sumptc>2.8 & sumpc>4	65.6	0.115
5.5	$J/\psi(e^+e^-)$	sumptc>2.1 & pmax>1.5	77.2	0.010
5.5	$J/\psi(\mu^+\mu^-)$	sumptc>2.1 & pmax>1.5	79.7	0.010
5.5	$D^0(K^-\pi^+)$	d0pcm>1.84 & sumpt>2.1 & d0e>2.1 & ptmax>0.8 & d0tht<0.45	77.1	0.074
5.5	$D^+(K^-\pi^+\pi^+)$	abs(dpcm-2.05)<0.2 & dp>2 & dpt>0.5 & ptmax>0.5	71.6	0.165
5.5	$D_s^+(K^+K^-\pi^+)$	abs(dspcm-1.96)<0.24 & ptmax>0.55 & dse>3	73.0	0.151
5.5	$\Lambda(p\pi^-)$	fw2>0.87 & sumptc>0.9 & lampcm>2.2 & fw1>-0.1	82.5	0.004
5.5	$\Lambda_c(pK^-\pi^+)$	abs(lamcpcm-1.54)<0.16 & fw1>-0.05 & lamcp>3.3 & sumptc>1.3	72.1	0.493

The 10 Trigger Lines (e.g. D_s data @ 5.5GeV)

- Each plot → invariant mass of trigger specific candidates



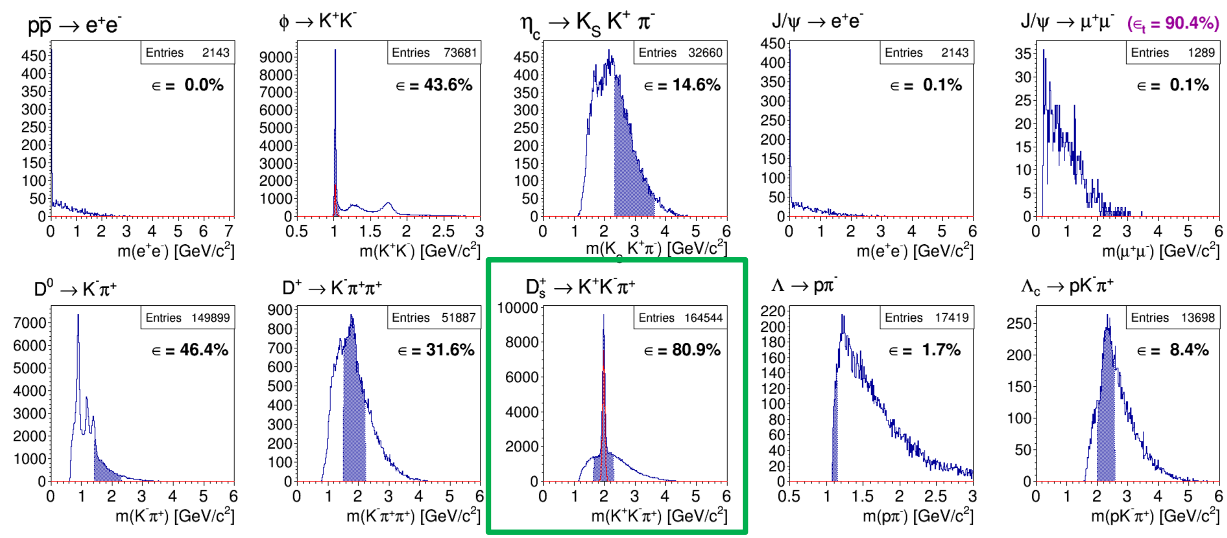
Toy MC Example – Preselection

Data set (5.5GeV)

Ds → K+ K- pi+

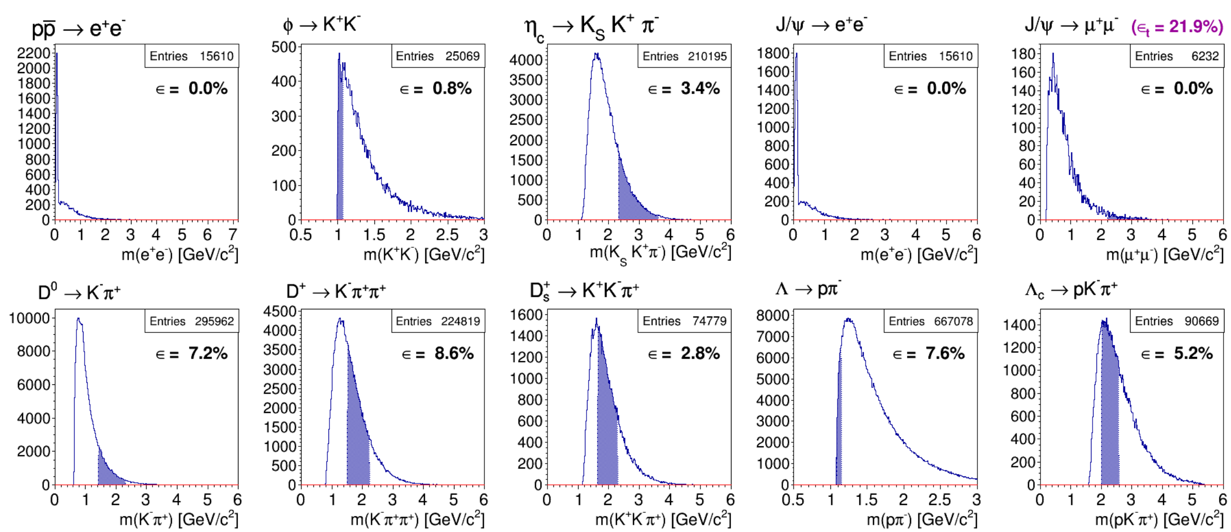
ε_{trig} = 80.9%

ε_{tot} = 90.4%



DPM

ε_{tot} = 21.9%



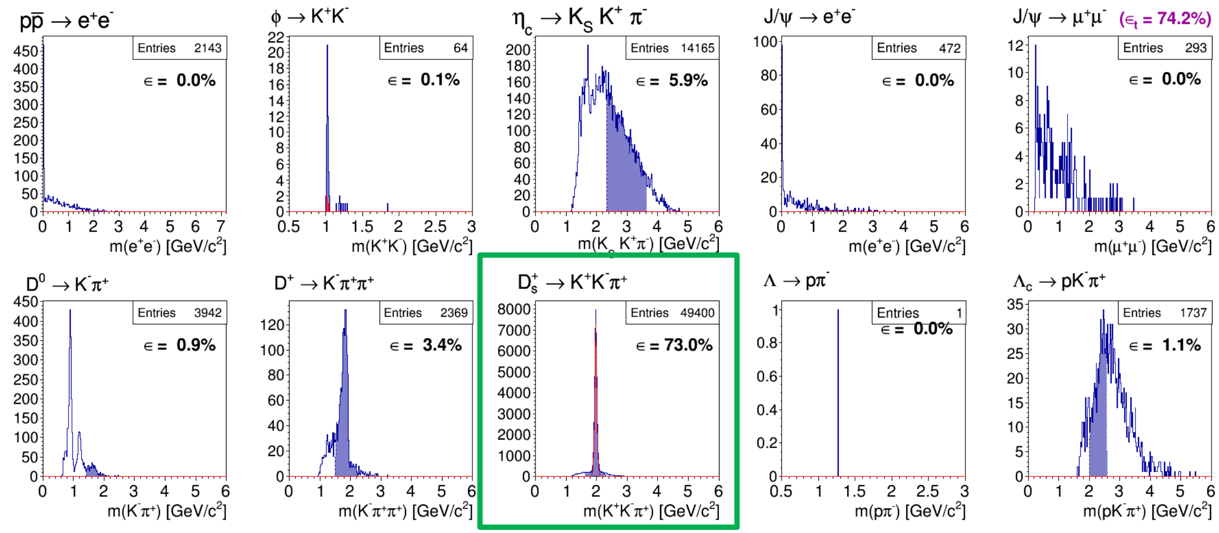
Toy MC Example – High Efficiency

Data set (5.5GeV)

Ds → K+ K- pi+

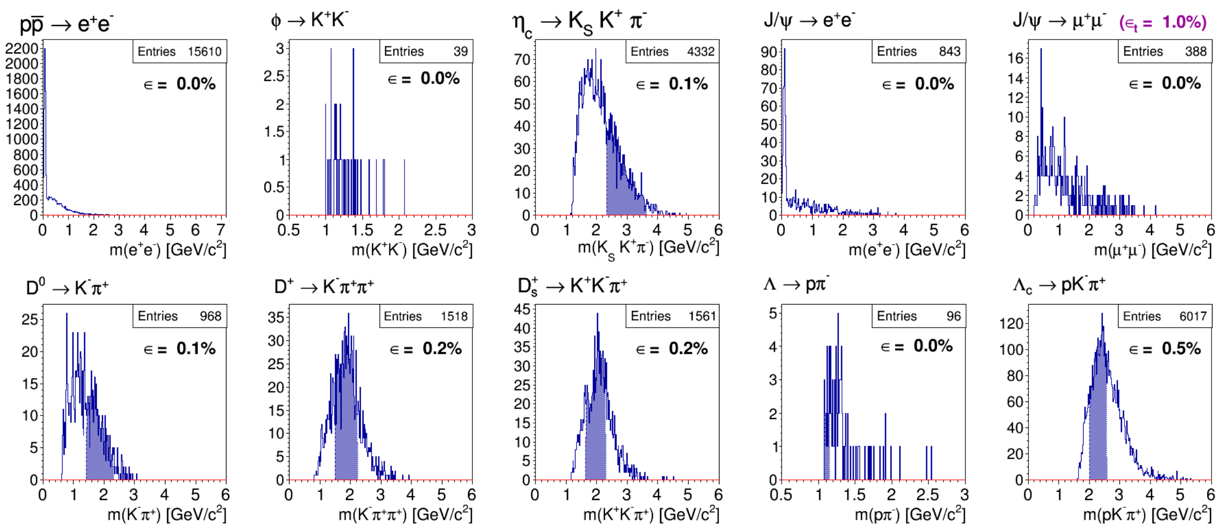
ε_{trig} = 73.0%

ε_{tot} = 74.2%



DPM

ε_{tot} = 1.0%



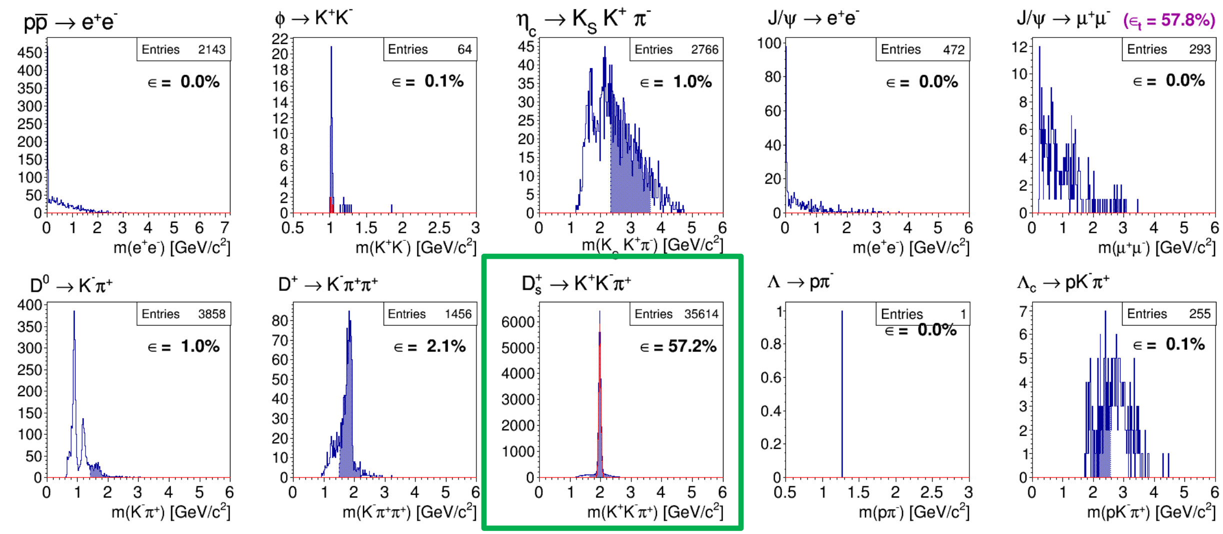
Toy MC Example – High Suppression

Data set (5.5GeV)

Ds → K+ K- pi+

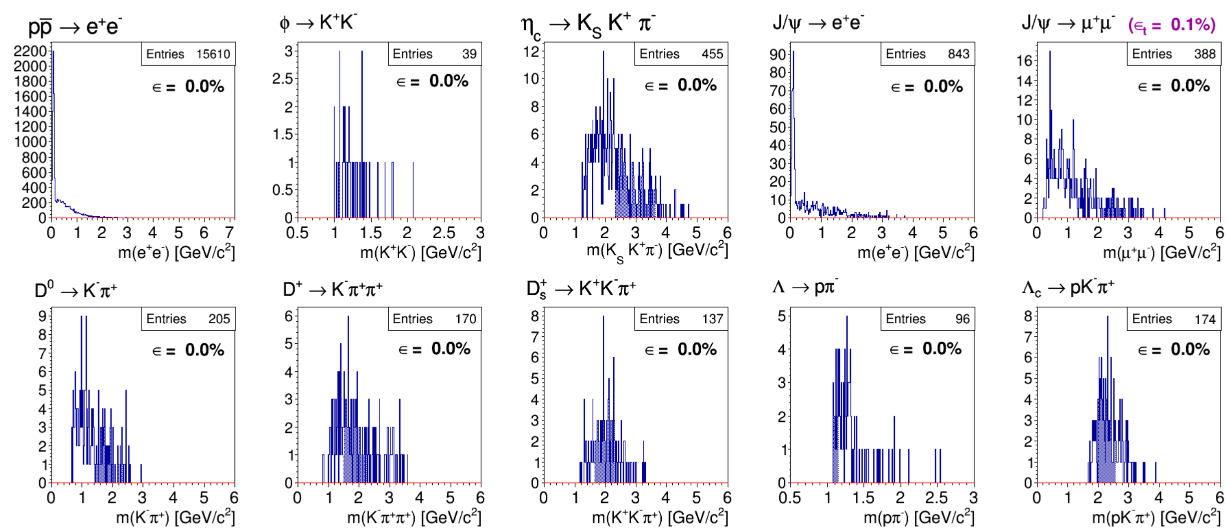
ε_{trig} = 57.2%

ε_{tot} = 57.8%

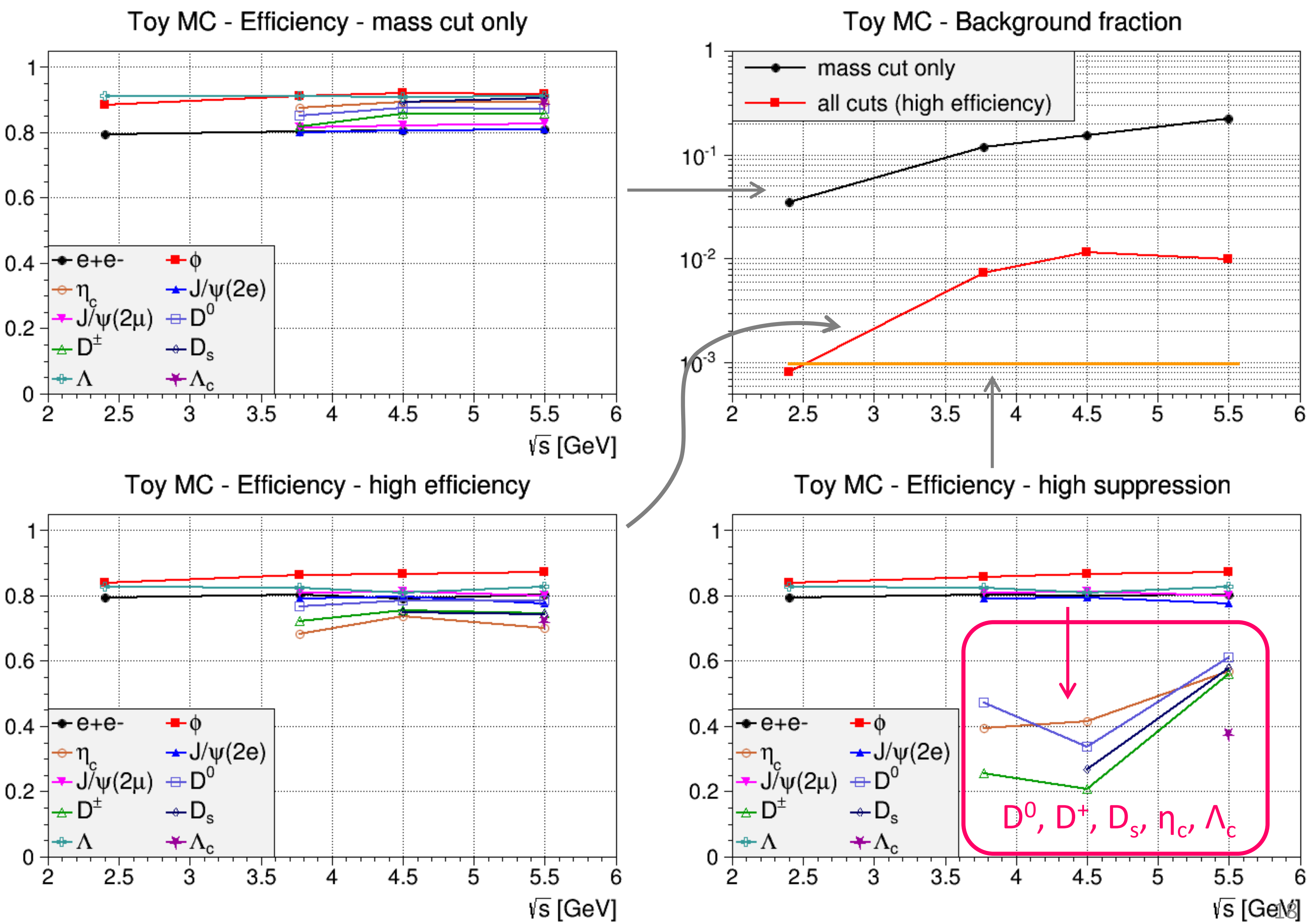


DPM

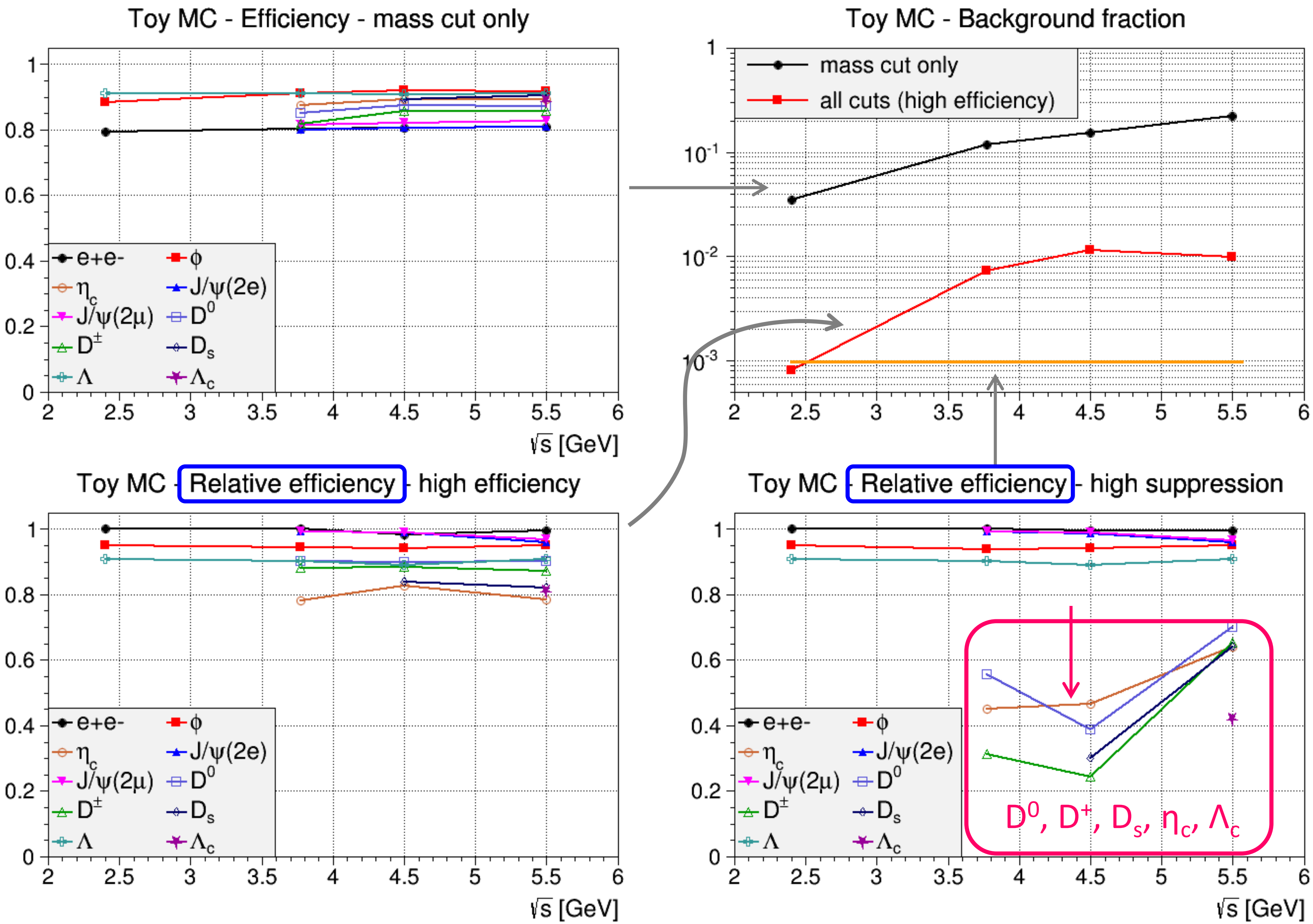
ε_{tot} = 0.1%



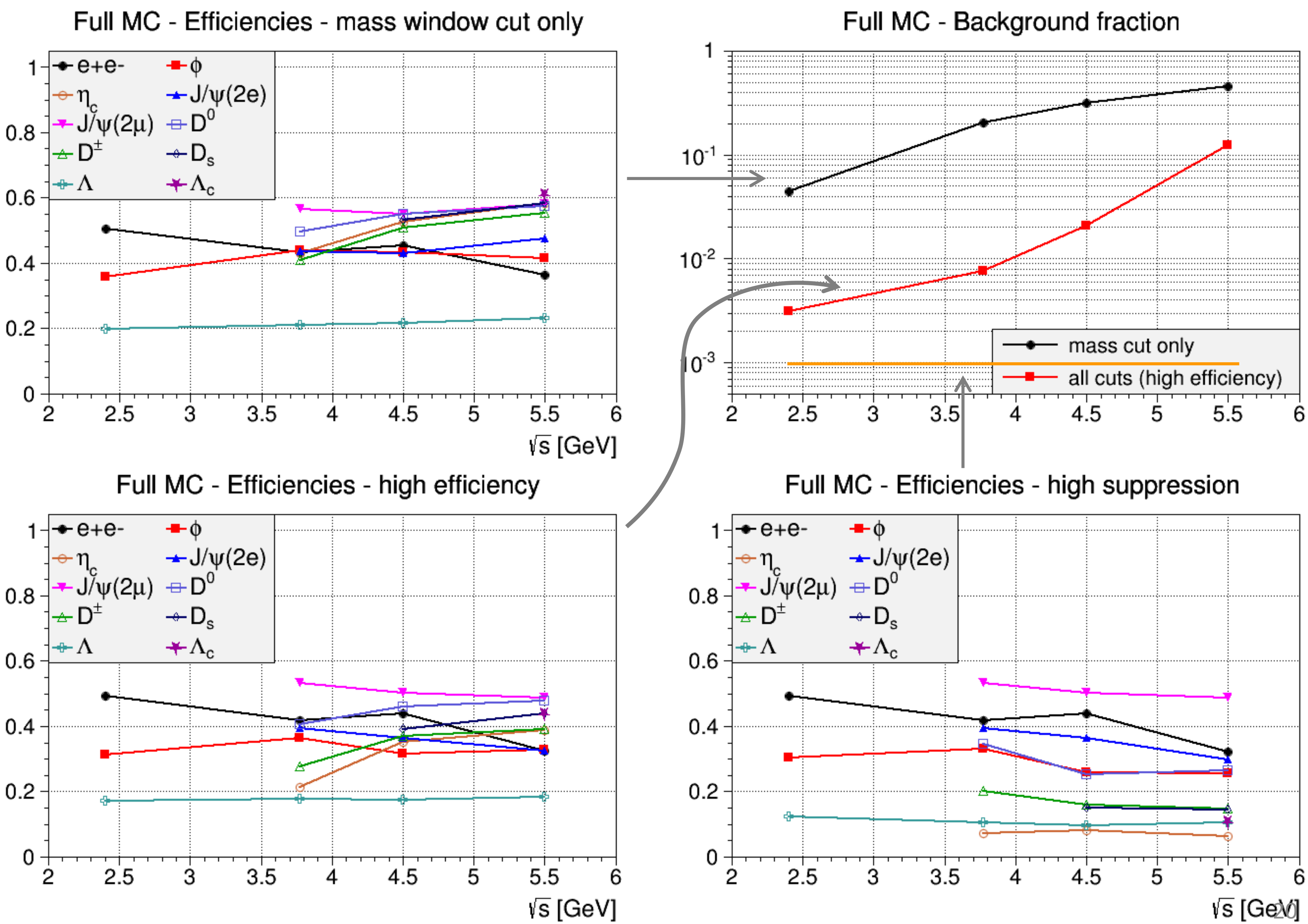
Toy MC – Efficiency Summary



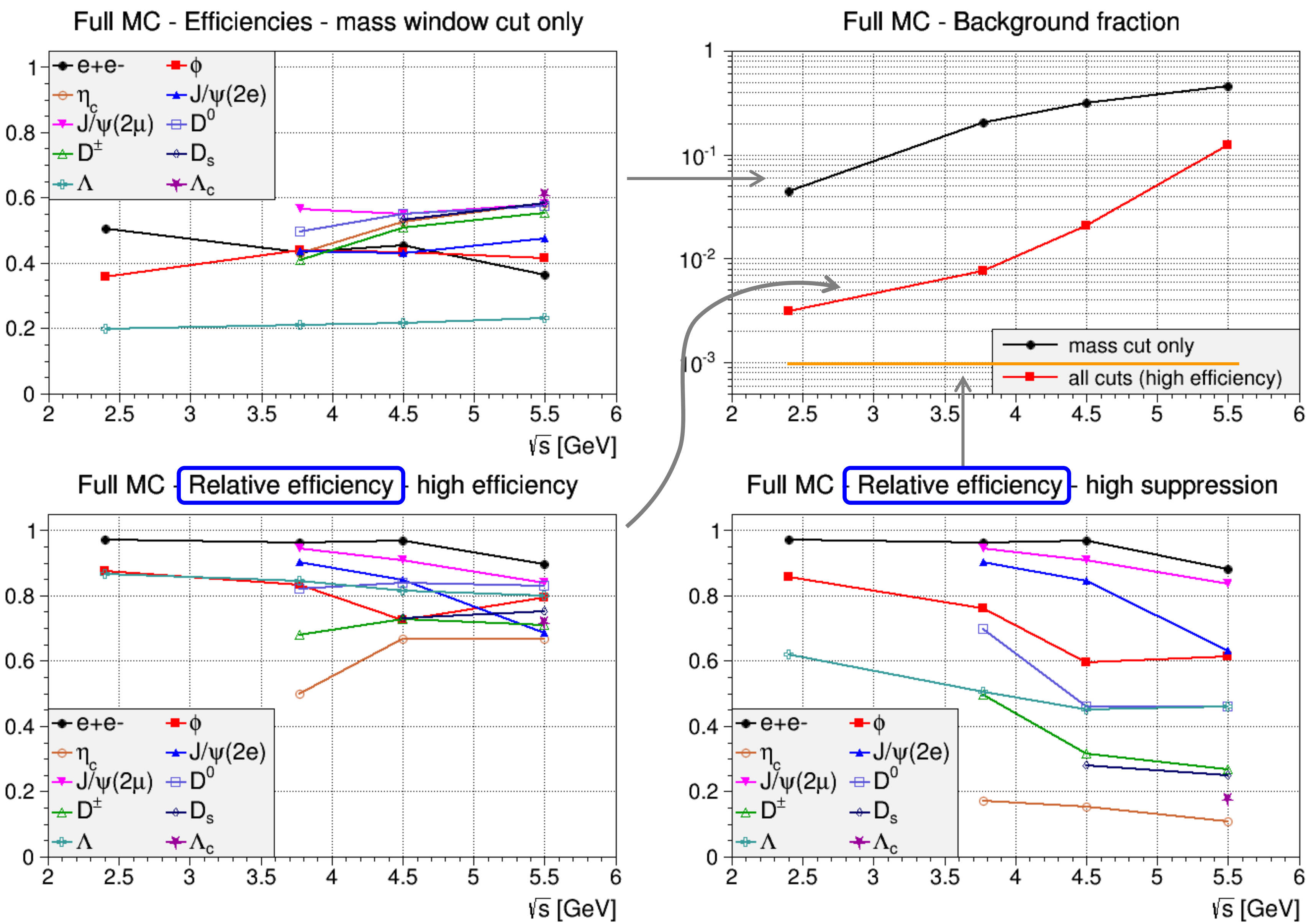
Toy MC – Relative Efficiencies



Full MC – Efficiency Summary

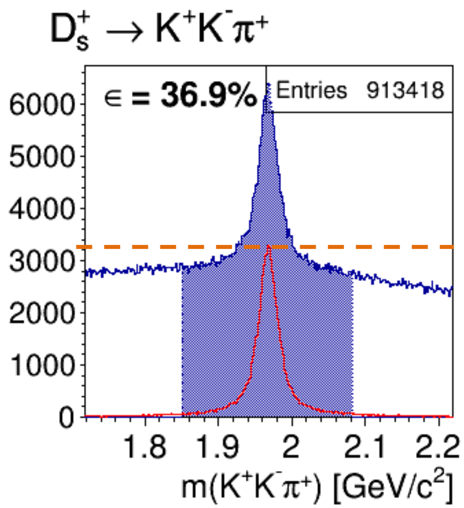


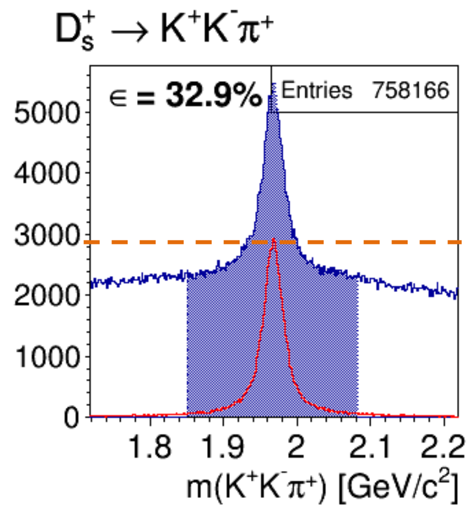
Full MC – Relative Efficiencies

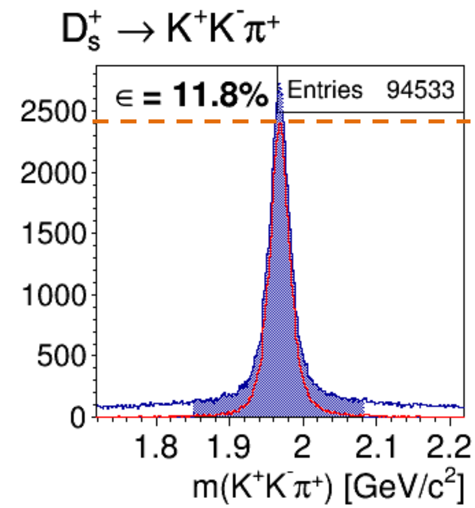


Interesting observation...

	Mass cut only	High Efficiency	High Suppression
Trigger eff	ε_{trig} = 36.9%	ε_{trig} = 32.9% rel: 89%	ε_{trig} = 11.8% rel: 32%







	Mass cut only	High Efficiency	High Suppression
MCT peak	N = 3300	N = 2900 rel: 88%	N = 2400 rel: 73%

→ High eff@loose criteria due to non-MCT combinatorics!

Summary/Conclusion

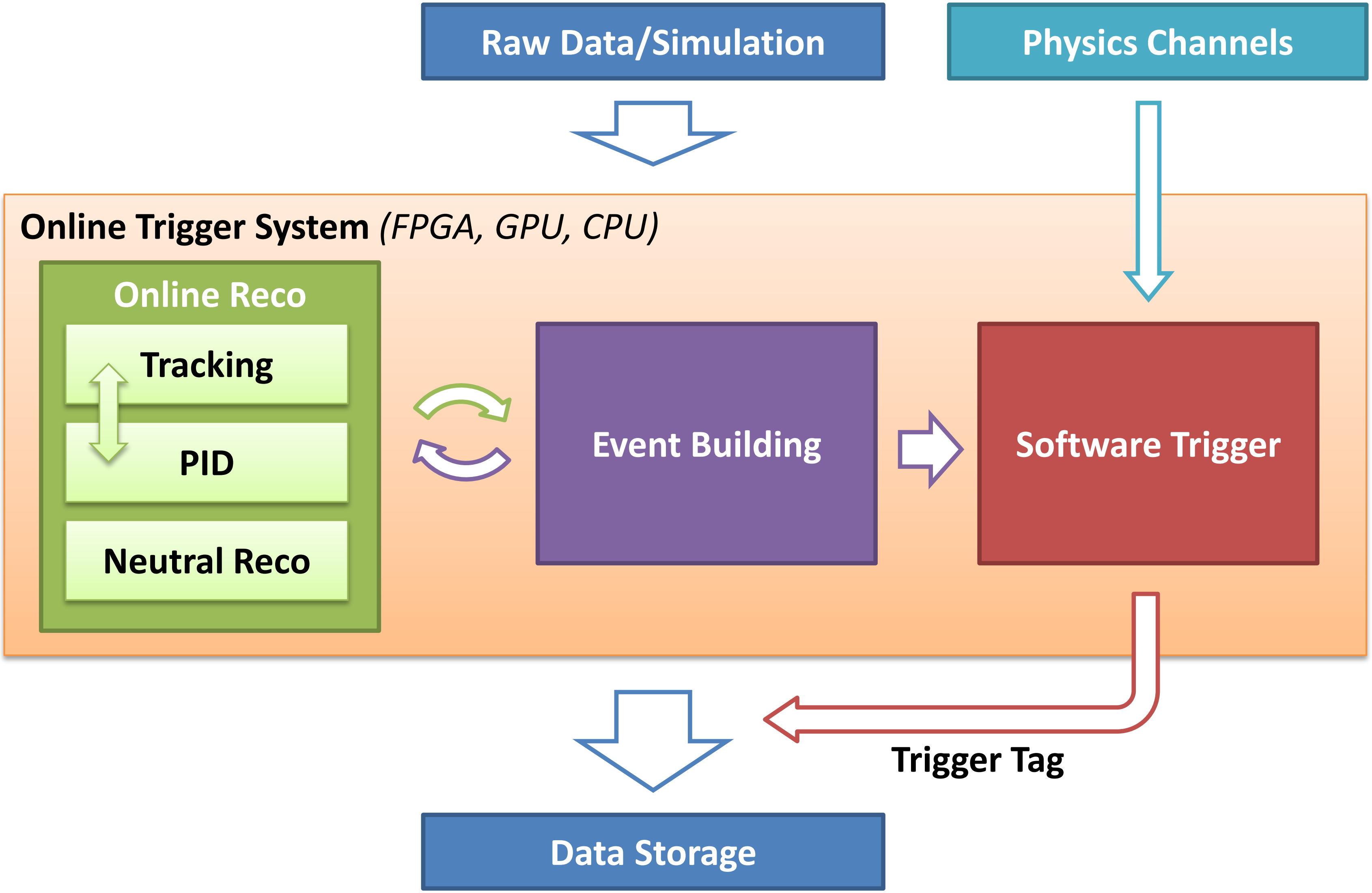
- Background level increases with cms-energy
- Individual selection algorithm for each trigger at each energy
- Background reduction of 1/1000 can be reached, but at cost of signal efficiency
- Additional trigger lines costs individual efficiency
- Open charm, charmed baryons and non-leptonic charmonium are more difficult to separated from background
- Cross tagging effect could be important, strongly depending on full trigger system configuration

Open issues/next steps

- Software Trigger related
  - Phase space distortion after triggering?
  - Add missing physics cases (Hypernuclei, in-matter phys.)
  - Triggering with sparse information possible?
- Physics related
  - Final/complete list of trigger lines
  - Always simultaneous tagging or different configurations?
  - Robustness of triggers → alternative background generator
- Computing/DAQ related
  - Time-based simulation + real event building
  - Algorithms suitable for online reconstruction
  - Data flow management (e.g. 0MQ)
  - Implementation of algorithms on FPGA/GPU

BACKUP

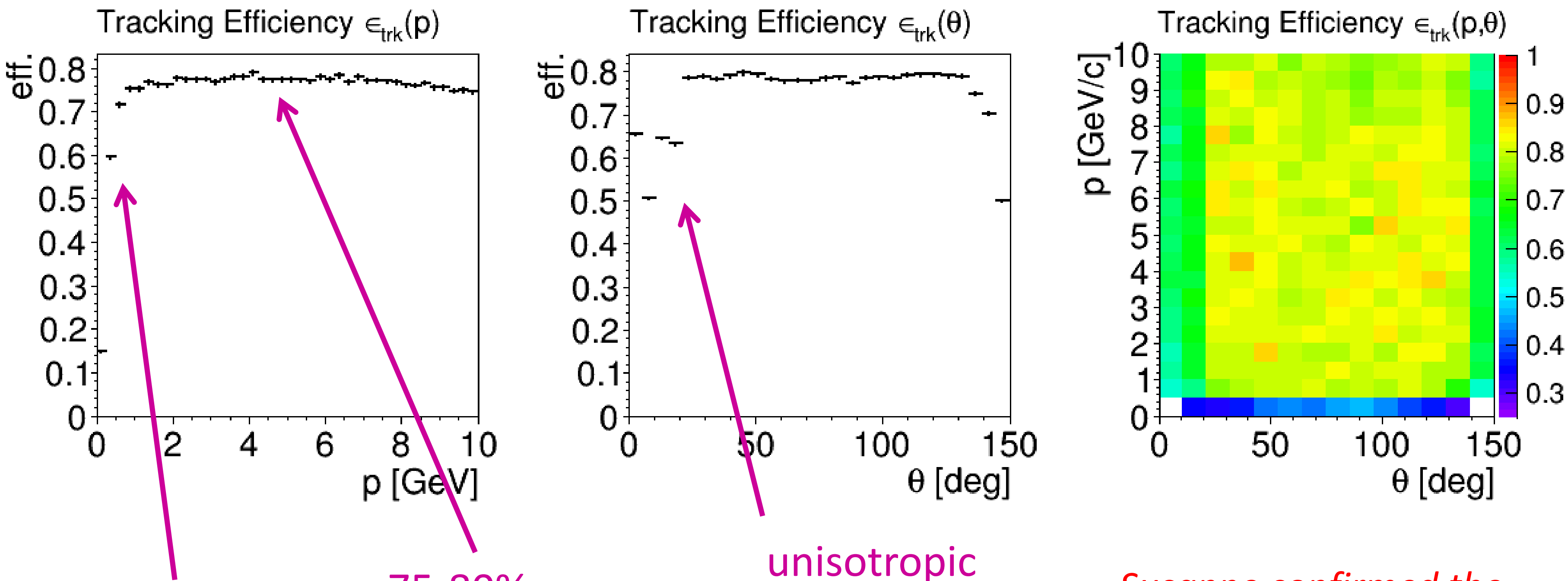
Software Trigger within Trigger System



Full MC Tracking - Discrepancy!

Current tracking efficiency lower than in STT TDR

(target pipe region taken out by $||\varphi| - 90°| > 4°$ for plots below)



drop at low momenta

75-80% average

unisotropic in FWD region

Susanne confirmed the TDR numbers – has to be clarified.

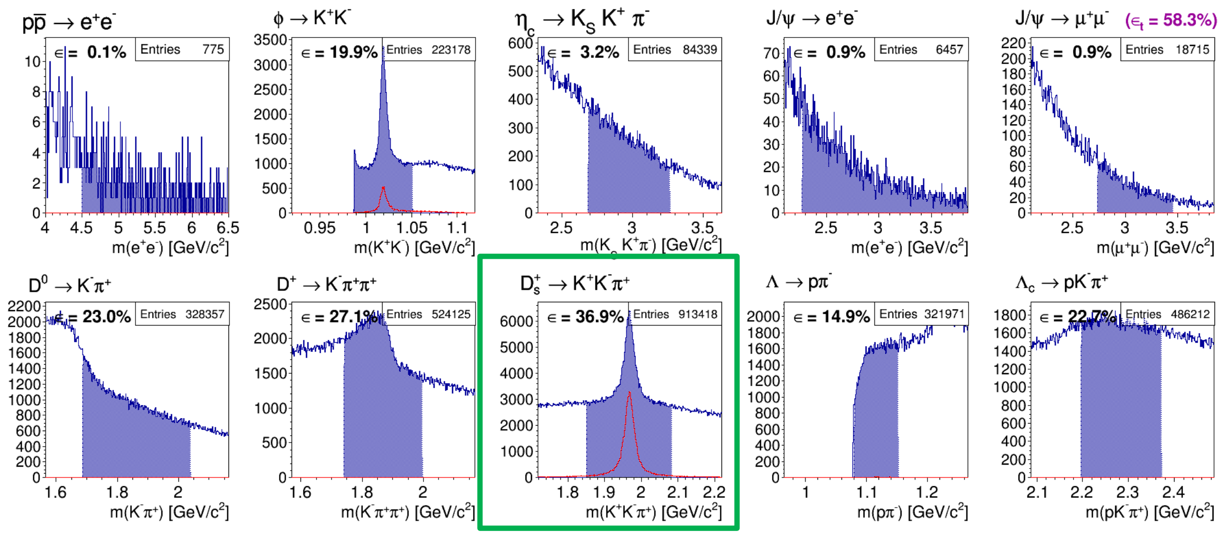
Full MC Example – Preselection

Data set (5.5GeV)

Ds → K+ K- pi+

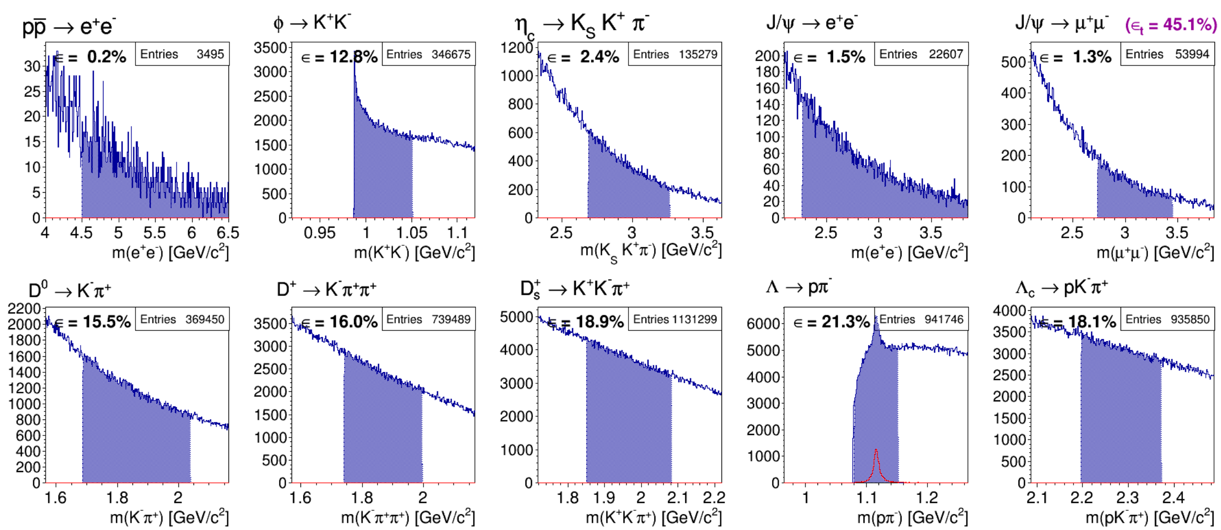
ε_{trig} = 36.9%

ε_{tot} = 58.3%



DPM

ε_{tot} = 45.1%



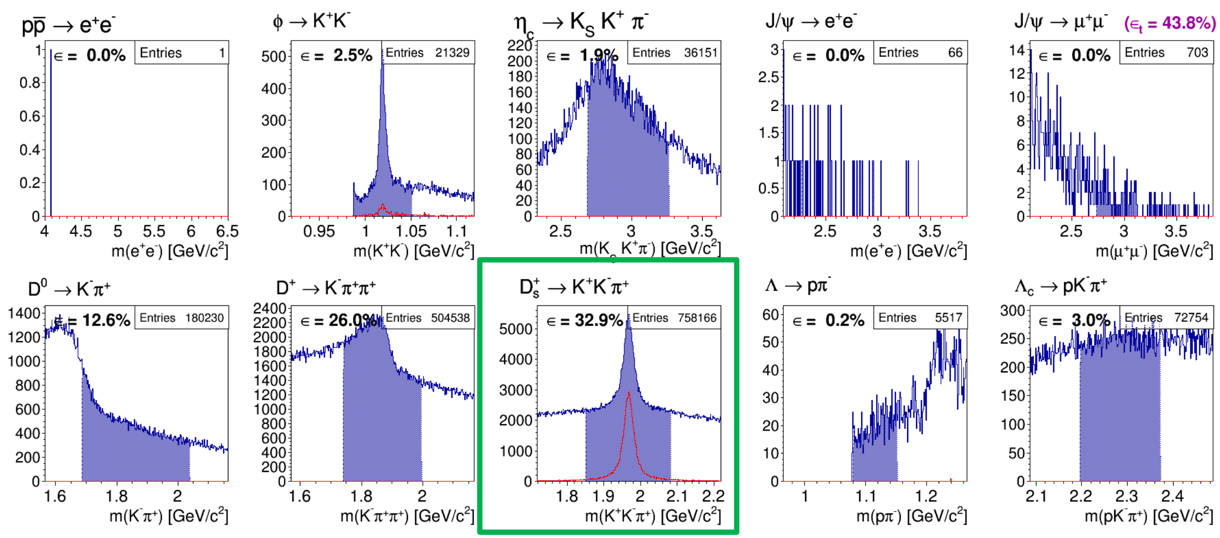
Full MC Example – High Efficiency

Data set (5.5GeV)

Ds → K+ K- pi+

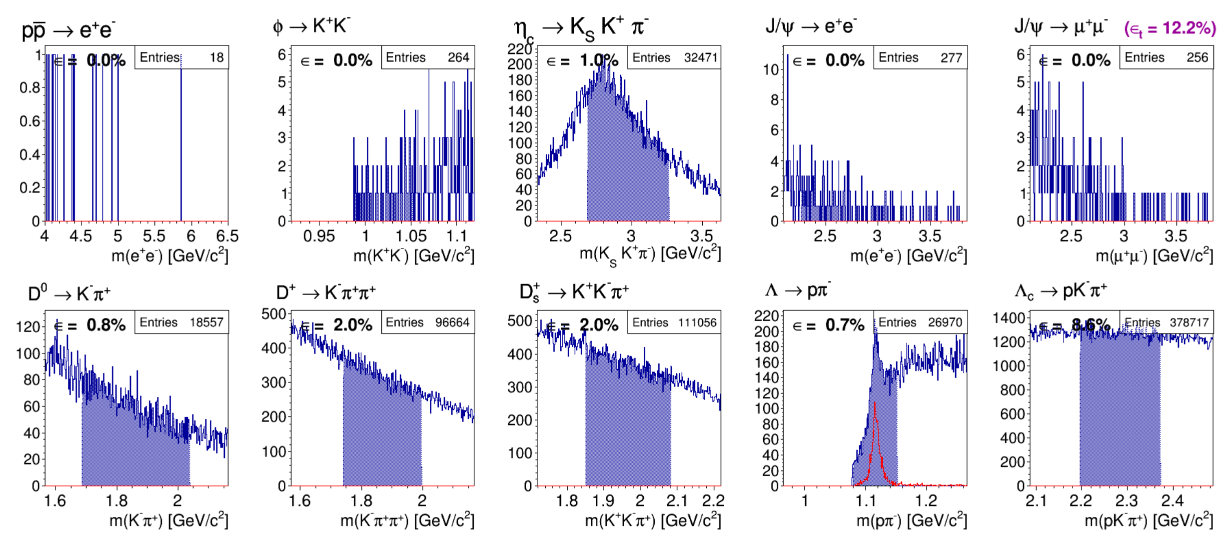
$\varepsilon_{trig} = 32.9\%$

$\varepsilon_{tot} = 43.8\%$



DPM

$\varepsilon_{tot} = 12.2\%$



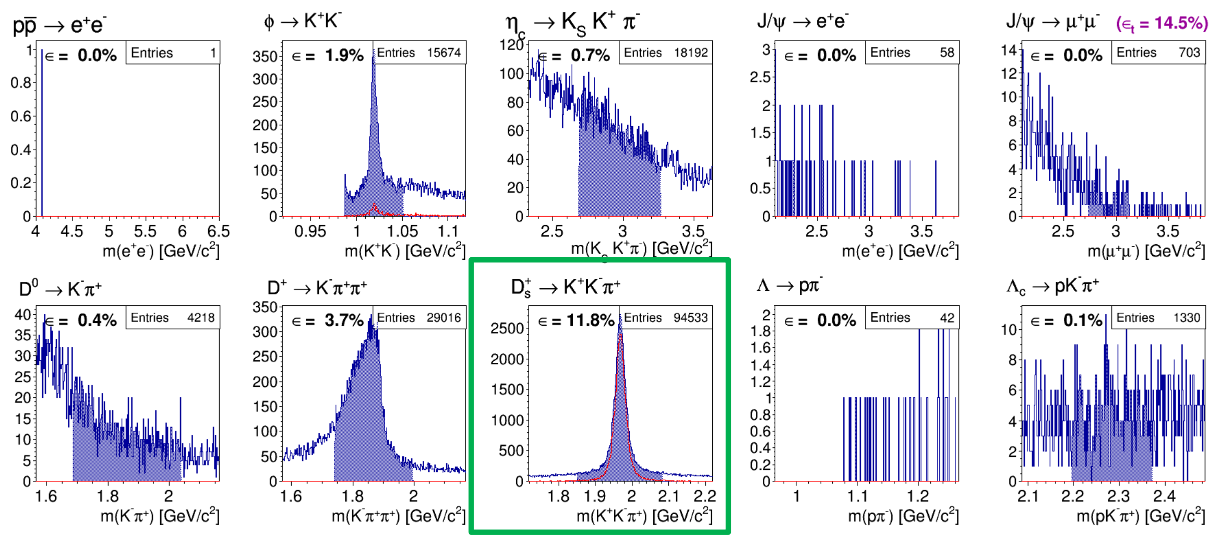
Full MC Example – High Suppression

Data set (5.5GeV)

Ds → K+ K- pi+

ε_{trig} = 11.8%

ε_{tot} = 14.5%



DPM

ε_{tot} = 0.1%