PANDA Software Trigger Status (2015)

PANDA DAQ Workshop

Grünberg, Mar. 2017

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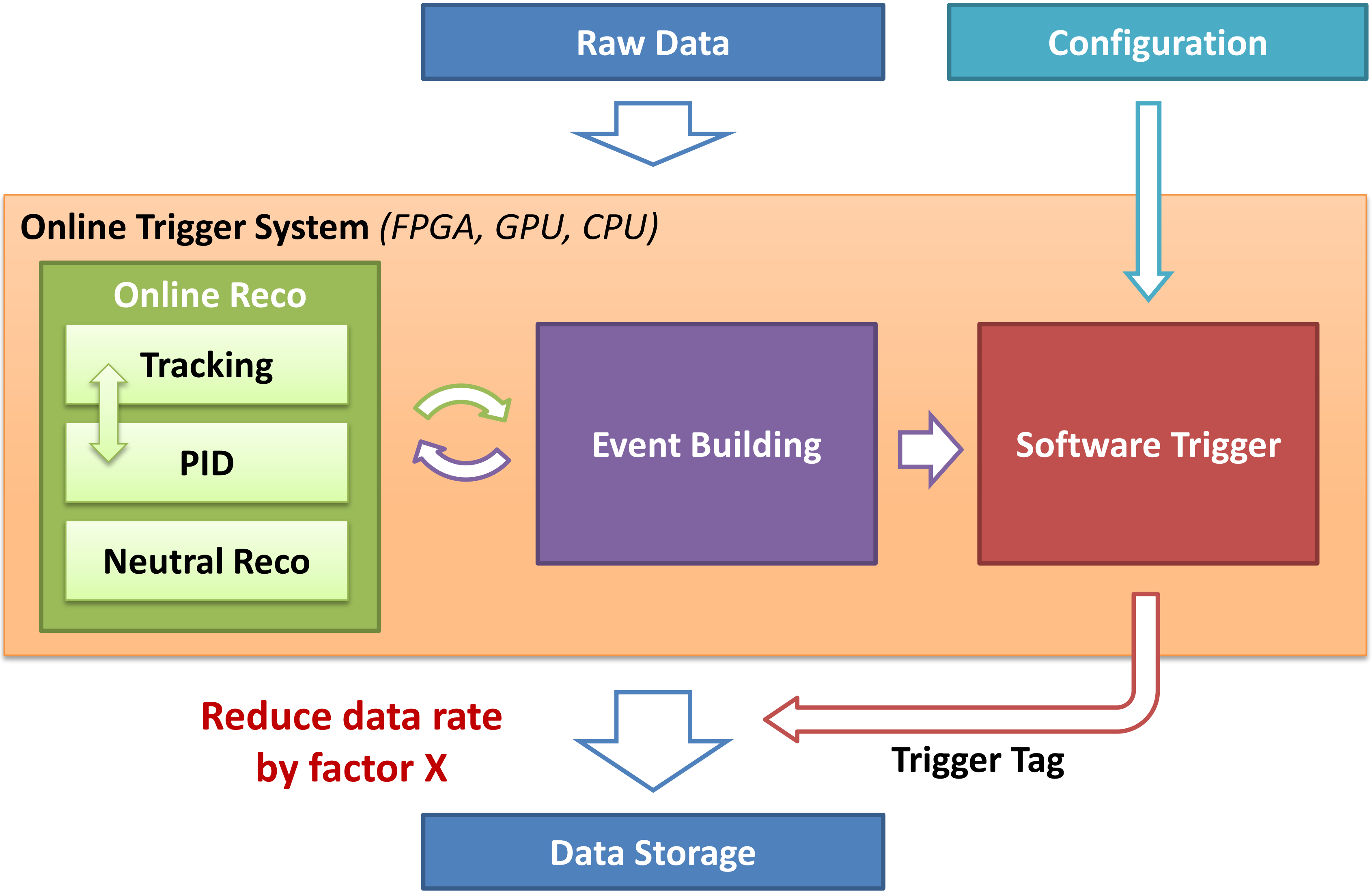
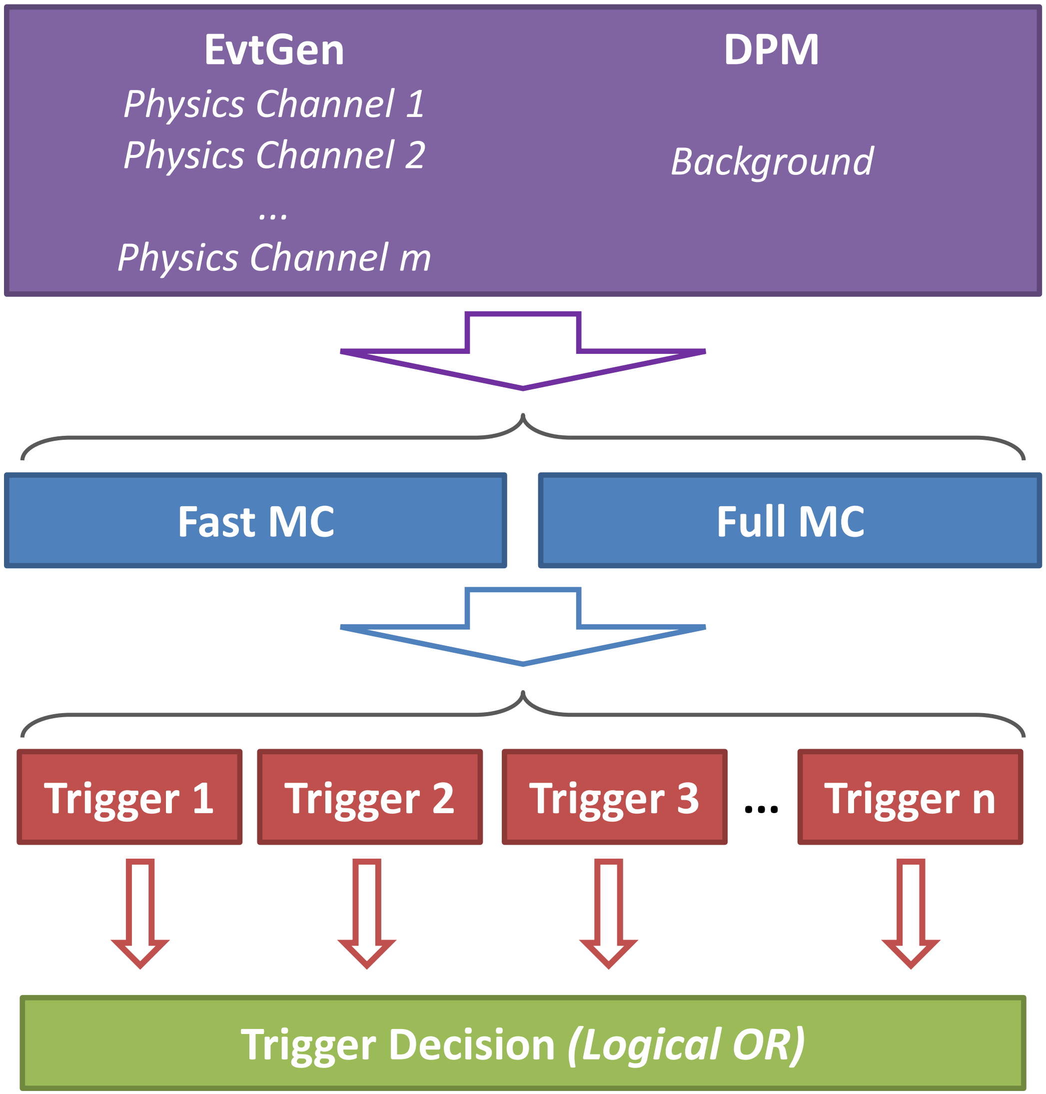
Software Trigger within Trigger System



Strategy for Investigation



Event Generation

- *Signal*
- *Background*

Simulation & Reconstruction

Event Filtering

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

Global Trigger Tag

Extended Trigger Scheme

- Status report 2014
  - n = 10 trigger lines
  - m = 10 signal event types
  - 4 energies

- Extended scheme March 2015
  - n = 57 trigger lines *(added subdecays and new modes)*
  - m = 791 signal event types *(considering different recoils)*
  - 7 energies

'Complete' List of Triggers

Tr#	Res.	Channels (BR[%])	N	Code	Σ BR[%]
1	η_c	$K^+K^-\pi^0$ (1.2), $K_SK^\pm\pi^\mp$ (2.4), $\gamma\gamma$, $K^+K^-\pi^+\pi^-\pi^0$ (3.5), $K_SK^\pm\pi^+\pi^-\pi^\mp$ (1.8)	5	22x	8.3
2	J/ψ	e^+e^- (5.9), $\mu^+\mu^-$ (5.9)	2	20x	11.9
3	χ_{c0}	$\pi^+\pi^- K^+K^-$ (1.8), $K^\pm\pi^\mp K_S\pi^0$ (0.8)	2	24x	2.6
4	D^0	$K^-\pi^+$ (3.9), $K^-\pi^+\pi^0$ (13.9), $K^-2\pi^+\pi^-$ (8.1), $K_S\pi^+\pi^-\pi^0$ (3.7), $K_S\pi^+\pi^-$ (2.0)	5	10x	31.6
5	D^+	$K^-2\pi^+$ (9.4), $K^-2\pi^+\pi^0$ (6.1), $K_S2\pi^+\pi^-$ (2.1), $K_S\pi^+\pi^0$ (4.8)	4	12x	22.4
6	D_s^+	$K^+K^-\pi^\pm$ (5.5), $K^+K^-\pi^\pm\pi^0$ (5.6)	2	14x	11.1
7	D^{*0}	$D^0\pi^0$ (61.9), $D^0\gamma$ (38.1)	10	11x	31.6
8	D^{*+}	$D^0\pi^+$ (67.7), $D^+\pi^0$ (30.7)	9	13x	28.7
9	D_s^{*+}	$D_s^+\gamma$ (94.2)	2	15x	10.5
10	Λ	$p\pi^-$ (63.9)	1	400	63.9
11	Λ_c^+	$pK^\mp\pi^\pm$ (5.0), $pK^\mp\pi^\pm\pi^0$ (3.4), $pK_S\pi^0$ (1.2)	3	42x	9.6
12	Σ^+	$p\pi^0$ (51.6)	1	410	51.6
13	ϕ	K^+K^- (48.9)	1	500	48.9
14	e^+e^-X	NR; X = none / γ / π^0	3	60x	
15	$\mu^+\mu^-X$	NR; X = none / γ / π^0	3	62x	
16	$\gamma\gamma X$	NR; X = none / γ / π^0	3	64x	
17	$\gamma\pi^0$	NR	1	660	

Triggers/modes from report

All K_S mode include BR($K_S \rightarrow \pi^+\pi^-$)

Σ=57

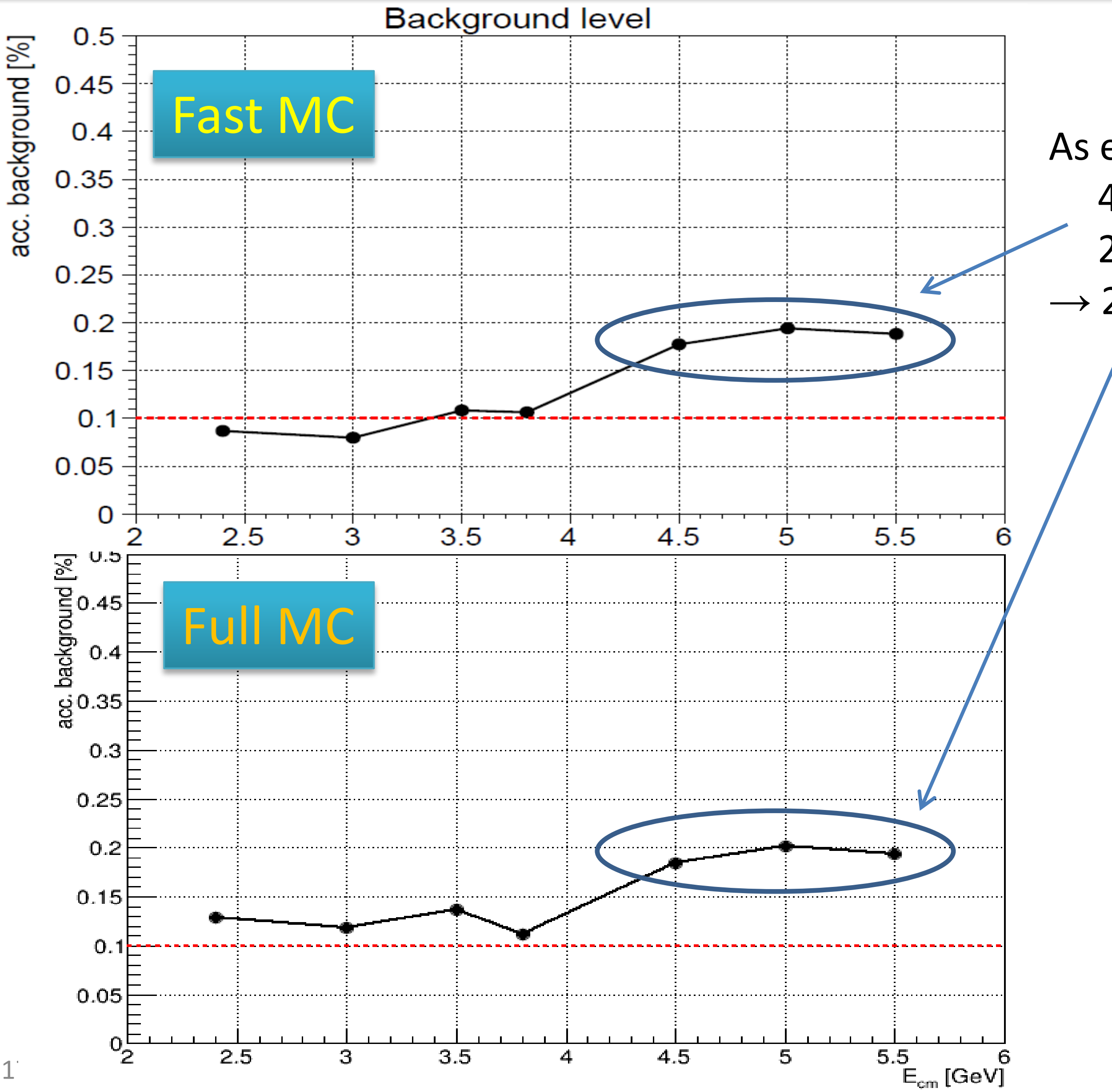
Automatized Selection Optimisation

For each trigger line (TL) @ each energy, apply procedure:

- Reconstruct signal candidates based on full event information
- Perform preselection: cut on inv. mass (+ D* mass diff. cut)
- Define variables for further selection:
  - Event shape variables (~ 40)
  - Candidate specific variables (~ 50, depending on decay)
- While background fraction for TL > 0.1‰ (0.05 ‰ for E_{cm}>3.5)
  1. Inspect all available variables
  2. Find variable+cut with max bkg reduction @ ε_{signal} = 95% relative to previous efficiency (*MC truth matched* signals)
  3. Apply cut on this variable → re-iterate

Applied for **Fast MC** and **Full MC**

Total Background Level vs. E_{cm} (Fast & Full)



As expected:

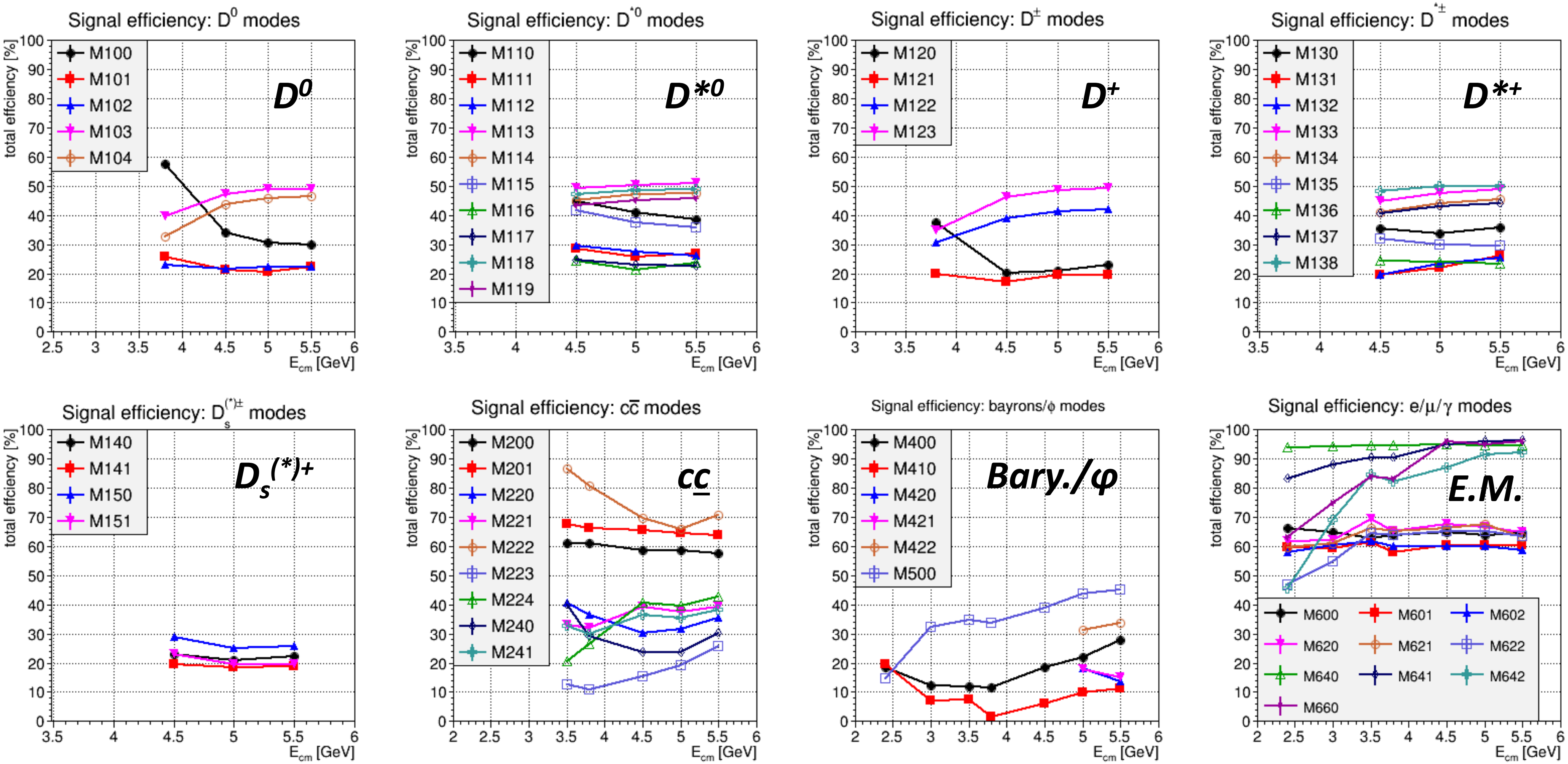
4x more trigger lines

2x harder suppr./TL

→ 2x total background lvl

Total Signal Efficiencies (ε_{tot}) vs. E_{cm} (Fast MC)

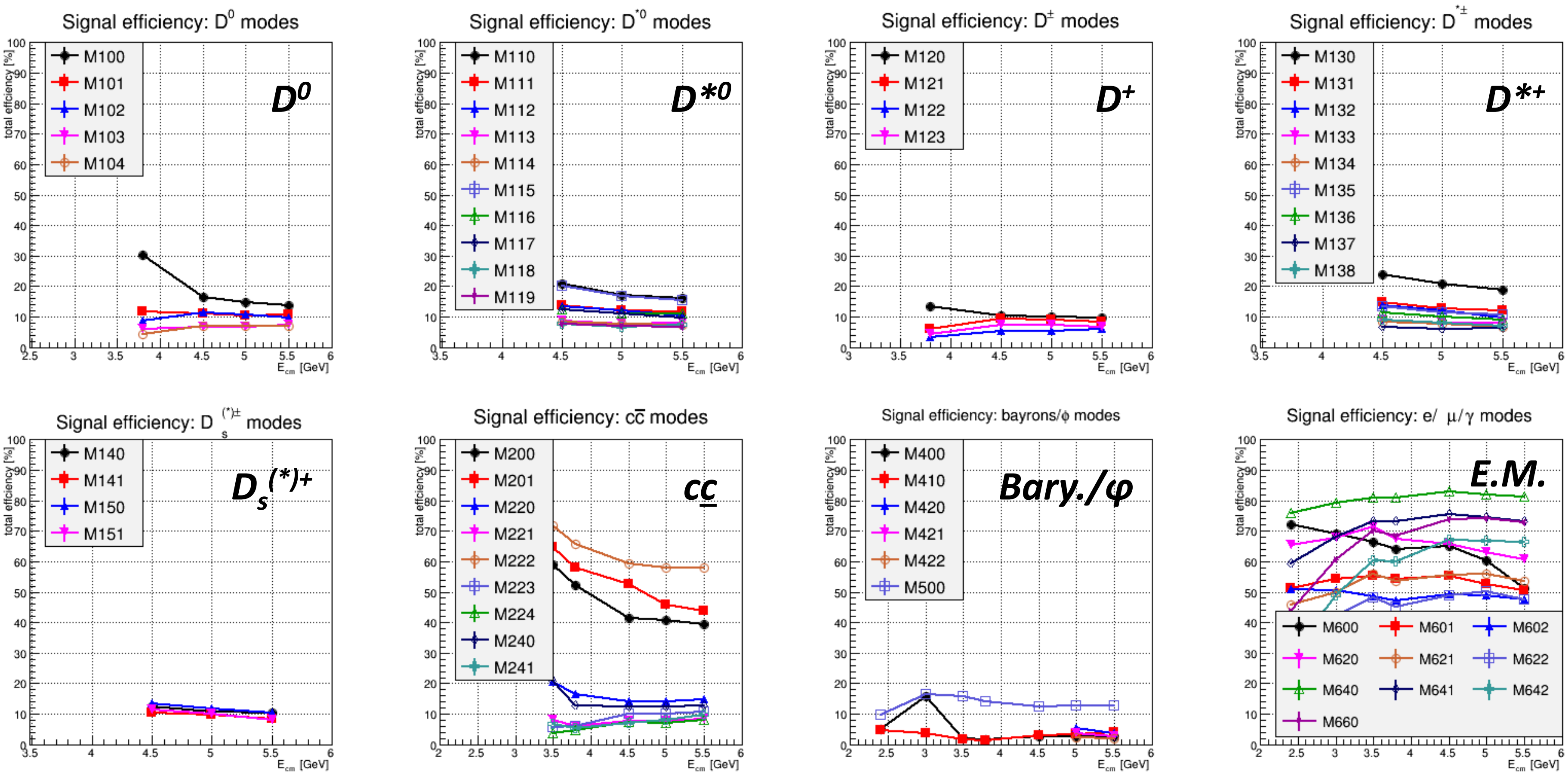
(Each point → selection optimization for a TL @ energy, N=247 in total)



Results for FastSim quite satisfactory: ε_{tot} = 20 ... 50 %

Total Signal Efficiencies (ε_{tot}) vs. E_{cm} (Full MC)

(Each point → selection optimization for a TL @ energy, N=247 in total)



FullSim performs worse : ε_{tot} = 5 ... 20 % (except J/ψ and e.m.)

Prerequisites for "reliable" prediction

#	Subject	Idealized	Realistic	Requires
1	Simulation detail	Fast Sim	Full Sim	
2	Simulation stream	event based	event building (timebased)	
3	Reco quality	offline	online	8
4	Selection observables	unlimited	online available	2,3,8
5	Trigger signatures	ad-hoc	requested/agreed on	
6	Reliability of bkg shape	single generator	various generators	
7	Pre-reco BG veto	not needed	needed (i.e. online reco impossible for all events)	2,3
8	Implementation	standard PC	dedicated hardware	

Available	*Partly available*	*Not available*

Performance might drop with more realistic simulation.

To Do List (when Software Ready)

- Impact on signal phase space distributions *(started)*
- Further test of robustness of efficiencies/bkg suppression
- Investigate interpolation of selection algorithms w.r.t. E_{cm}
- Systematic study of various suppression factors
  → optimisation for different luminosity settings
- Impact of realistic event building & event mixing
- Impact of online reco quality
- Investigate pre-reco background rejection
- Investigate performance issues (e.g. CPU demand)
- Add triggers for hypernuclei, hadrons in matter (no input yet)

First Look: Trigger impact to PHSP

- Evaluate relative efficiency w/ and w/o trigger

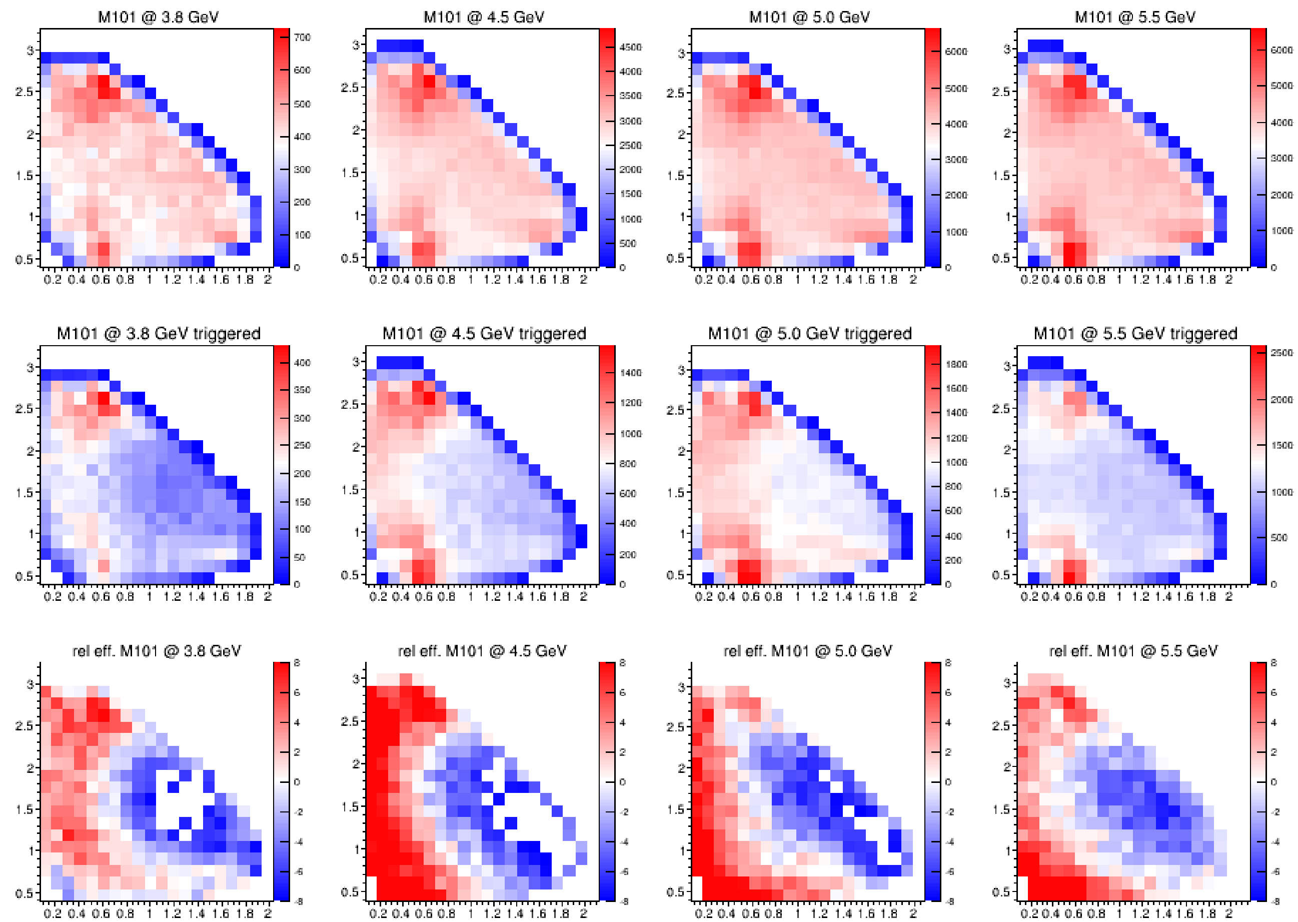
Example: $D^0 \rightarrow K\,\pi\,\pi^0$ (M101)

E_{cm} [GeV] 3.8 4.5 5.0 5.5

Pure Reco

w/ Trigger

Deviation [σ] from avg. eff.



Manpower Situation

- People assigned to Software Trigger
  - Klaus Götzen (coord.)
  - Ralf Kliemt
  - Frank Nerling
  - Donghee Kang (left PANDA 2016)

- Prospective manpower for ST project $\lesssim$1.0 FTE

- If this project should progress and be successful
  → need more people
  → but first of all need the requirements fulfilled!

Conclusion

- Proof-of-principle done meeting suppression requirements

- Results of Fast and Full MC differ
  - Background level < 0.2% over full energy range
  - Fast MC looks ok: ε_{sig} > 20%, up to 50% ... 90%
  - Full MC insufficient: $\varepsilon_{sig} \approx$ 10% (better for J/ψ and E.M.)

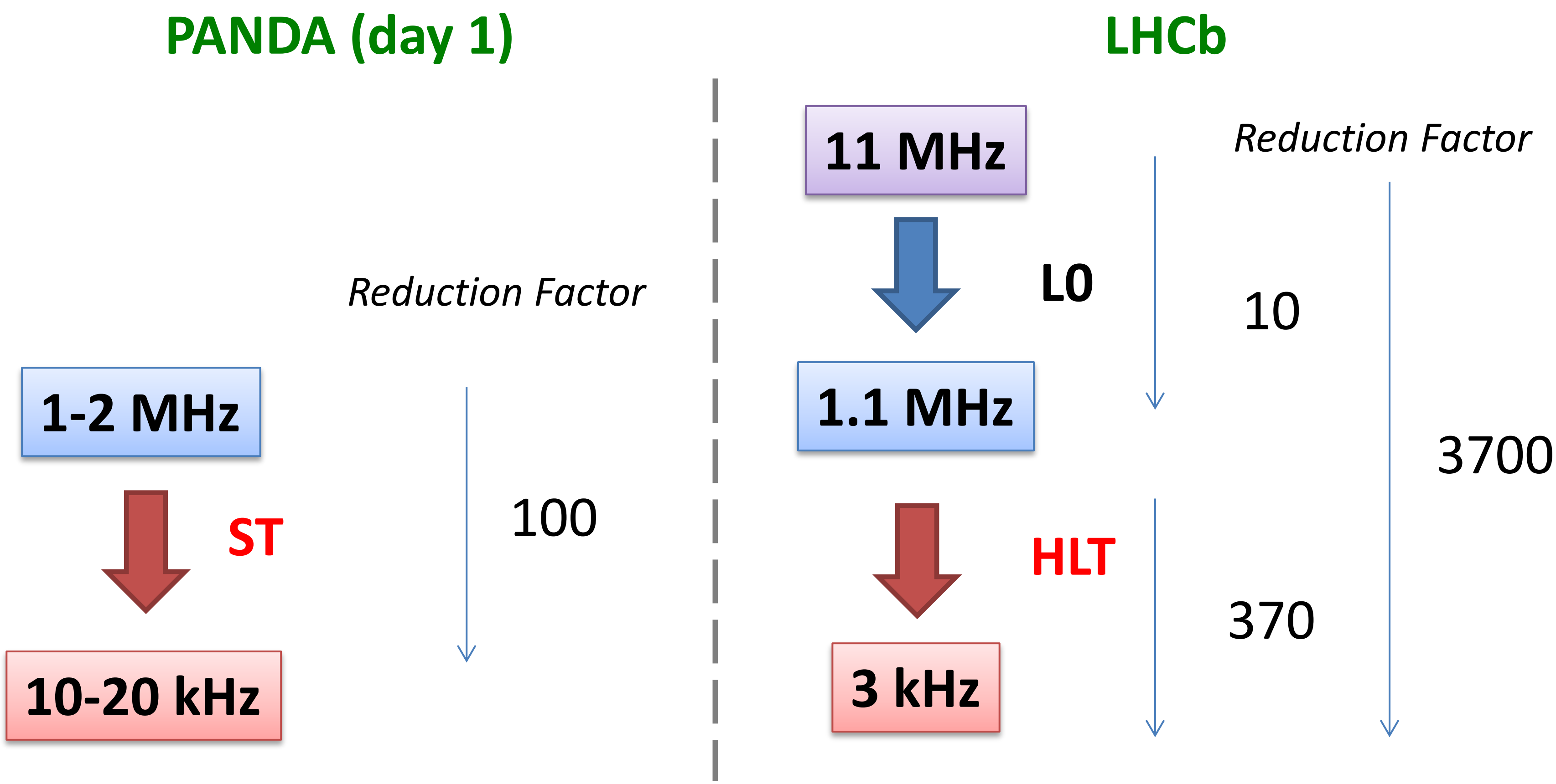
- Reliable predictions depend on further software development
  → not under our control/responsibility

- Manpower insufficient (mid-/long-term)

- New strategies/ideas
  - Releasing suppression factor for low luminosity situation
  - Grouping of channels with similar properties/x-sections

Other cases: LHCb - High Level Trigger

- LHCb also uses a High Level Trigger (HLT) *arXiv:1211.3055v2*
- How does it compare to PANDA (day 1)?



Comparing Numbers

- **LHCb High Level Trigger**
  - C++ program, running on 26110 nodes in Event Filter Farm
  - L0 rate 1 MHz → available reco time $t_{online} < 25 - 30$ ms
    - 2 stages: HLT 1 → 40 kHz; HLT 2 → 3 kHz
  - Offline Event Reco $t_{offline} = 2$s/ev
  - Need 6000 nodes to reconstruct 1s data in 1s

- **PANDA (day 1)**
  - Assumption: 20000 nodes (CPU)
  - Event rate 1 MHz → available reco time $t_{online} < 20$ms
  - Residual rate 20 kHz with $t_{offline} \approx 1$s/ev
  - Need 20000 nodes to reconstruct 1s data in 1s
  - Partial reco during refill periods of duty cycle:
    - W/o RESR, $t_{fill} \approx 1500$ s expected each cycle ($t_{cycle} < 10000$s)

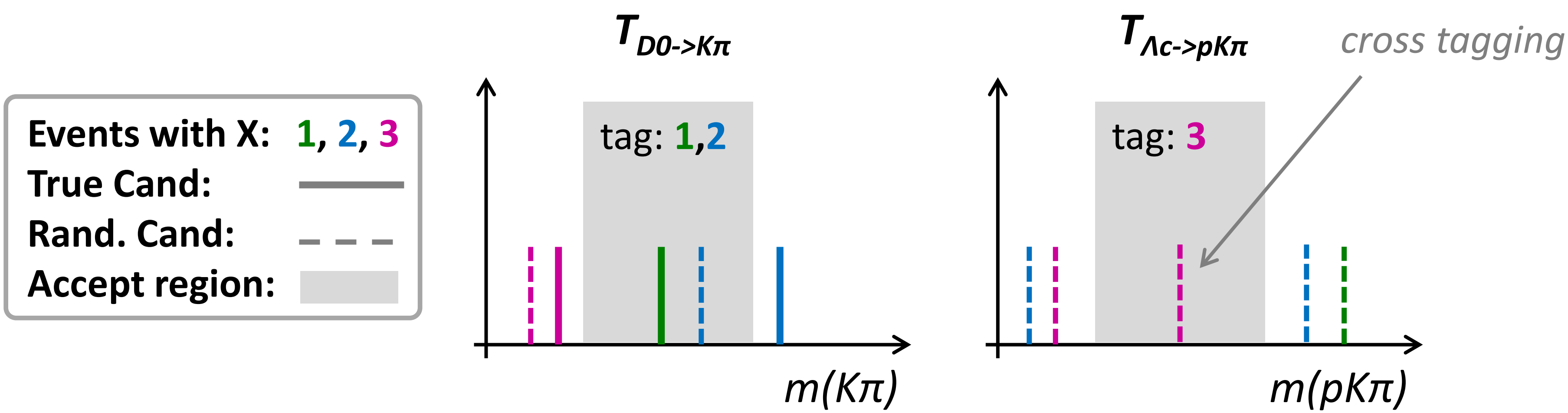
BACKUP

Event Based Efficiency

Only interested in **event efficiencies**

1. Event with signal X (e.g. $D^0 \rightarrow K\pi$) is tagged by corresponding trigger line due to **true**/**random** candidate
2. Event with signal X is tagged by another trigger line due to **random** candidate (*cross tagging*)

ε_X (item 1); ε_{tot} (items 1 and 2)



Data Types

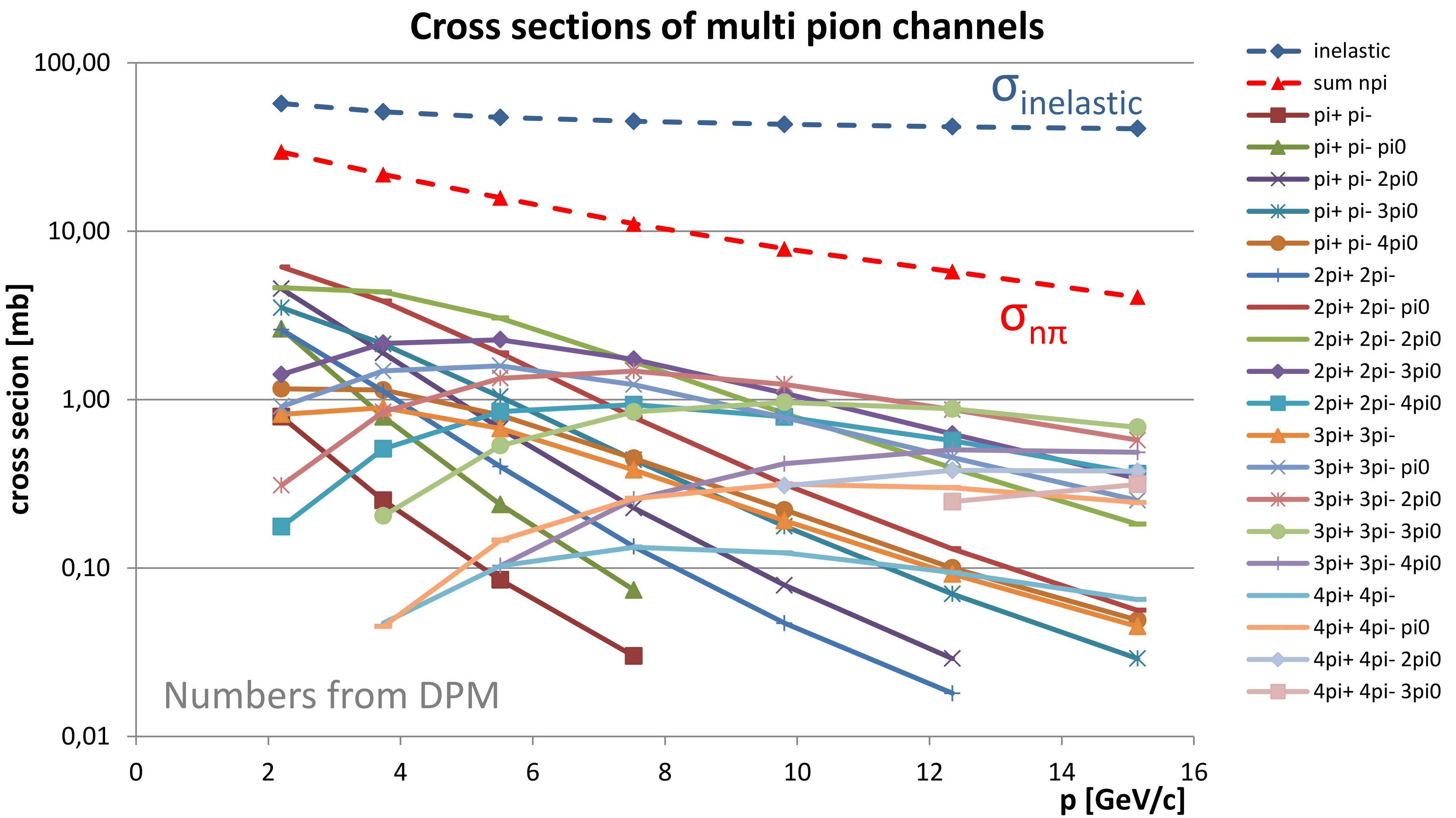
Target data modes for individual trigger lines are defined as:

- E.-M. modes (10 in total)
  - excl.: e^+e^- / $\mu^+\mu^-$ / $\gamma\gamma$ + (none, γ, π^0)
  - excl.: $\gamma\pi^0$
- Charmonium / ϕ (up to 10 each)
  - $c\underline{c}$ / ϕ + X
- Baryons (up to 10 each)
  - $B\,\underline{B}$ + X *(and c.c.)*
- Open-Charm (up to 20 each)
  - $D\,\underline{D}$ + X / $D\,\underline{D^*}$ + X *(and c.c.)* for D decays
  - $D^*\,\underline{D^*}$ + X / $D^*\,\underline{D}$ + X *(and c.c.)* for D* decays

- In total: up to **791 data types** *(depending on E_{cm})*
  $32 \cdot 20$ open charm + $15 \cdot 10$ $c\underline{c}$/ϕ/baryons + 10 excl. – 9 (too high E_{cm})

Multi-pion veto for BG suppression

- Is veto for multi-pion events effective for bkg suppression?

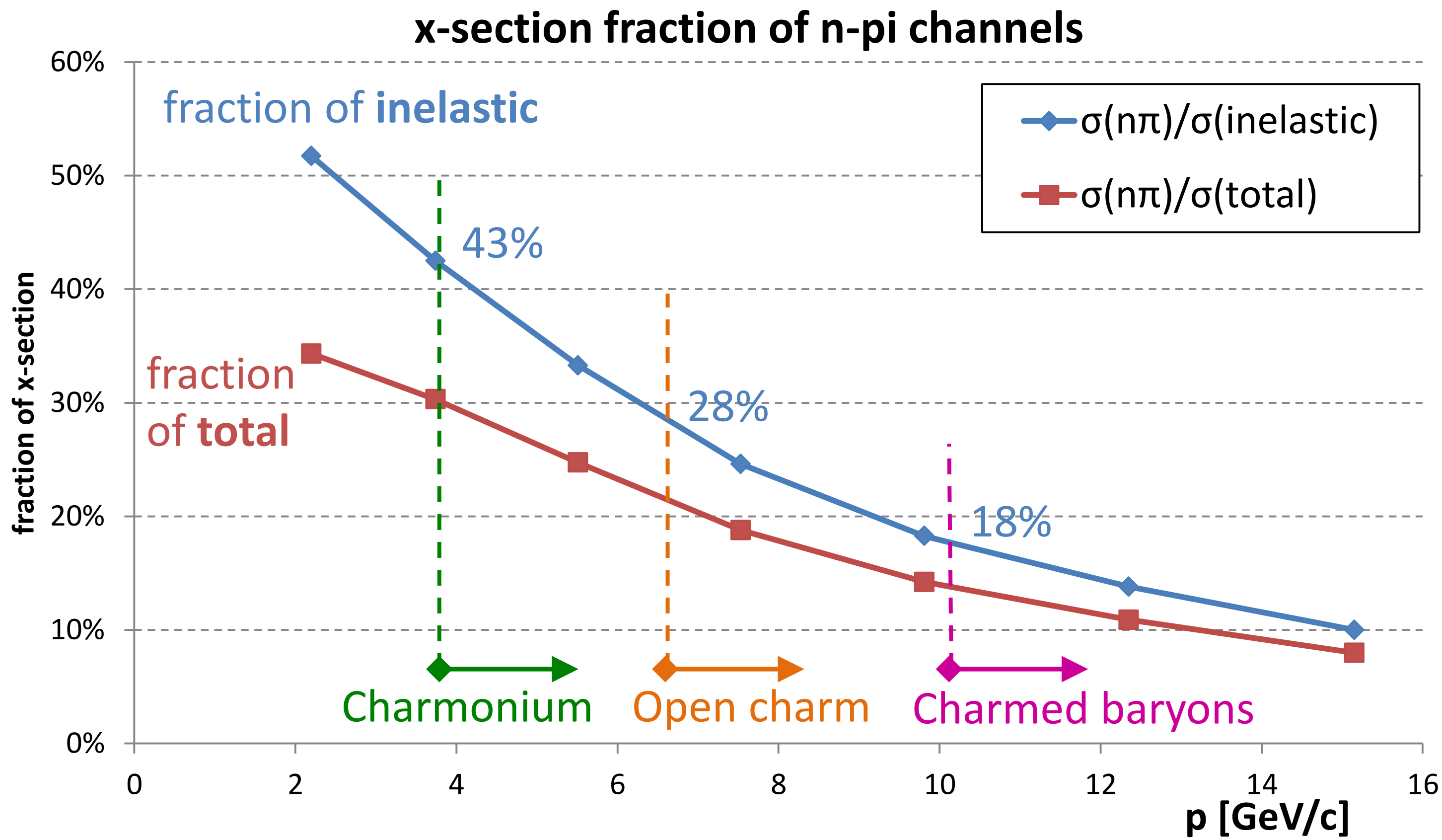


New idea: Multi-pion veto

Seems not very promising

→ only rather small fraction of inelastic background is multi-pion

(even if identified with high efficiency & purity would be insufficient)

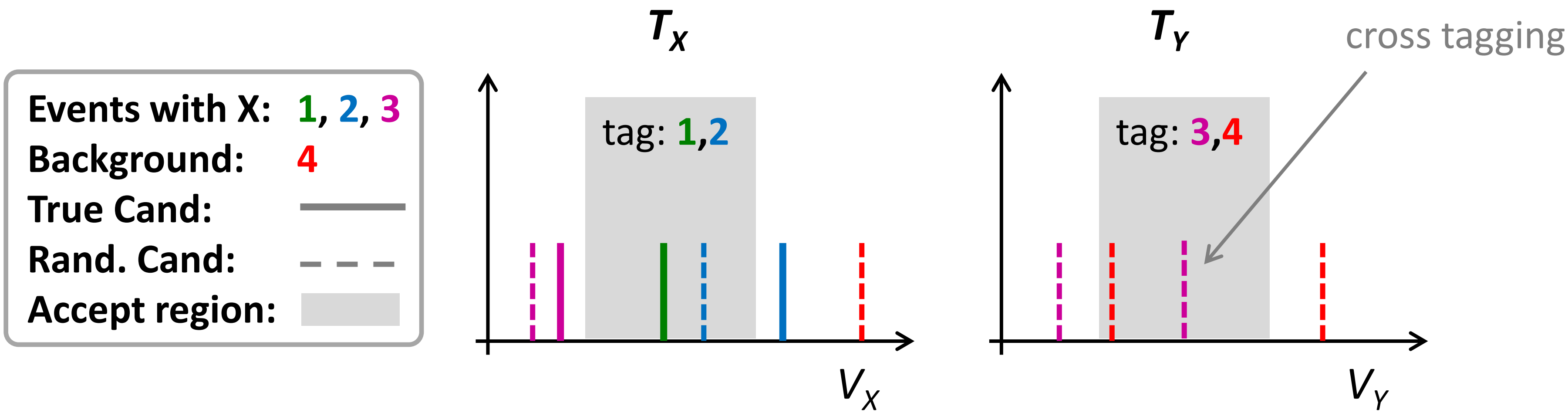


Why a Software Trigger at all?

- Low signal cross sections $\sigma_{signal} \approx$ pb ... nb scale
  → Need high luminosity to achieve enough signal statistics
- High lumi $L = 2 \cdot 10^{32}$ $cm^{-2}s^{-1}$ + large σ_{tot} = 50 ... 100 mb
  → Reaction rate up to 10 ... 20 MHz
  → Signal fraction $\leq O(10^{-4})$
- Data rate with 10 kB/event: 200 GB/s
- Data amount with 50% duty cycle: **3000 PB/year**
  → Completely unaffordable to store and keep all!
  → Required reduction factor ≈ 1/1000
- Signal and background events look very similar

⇨ Sophisticated event filter on high level information needed!

Event Based Efficiency



- Different cases for positive tag on signal/background
  1. *Trigger T_X* tags due to *correctly* reconstructed candidate *X*
  2. *T_X* tags due to *random* cand. from event containing *signal X*
  3. *T_Y* tags due to *random* cand. from event containing *signal X*
  4. *T_i* tags due to *random* cand. from *background*

(Cases 1–2: ε_X; cases 1–3: ε_{tot})

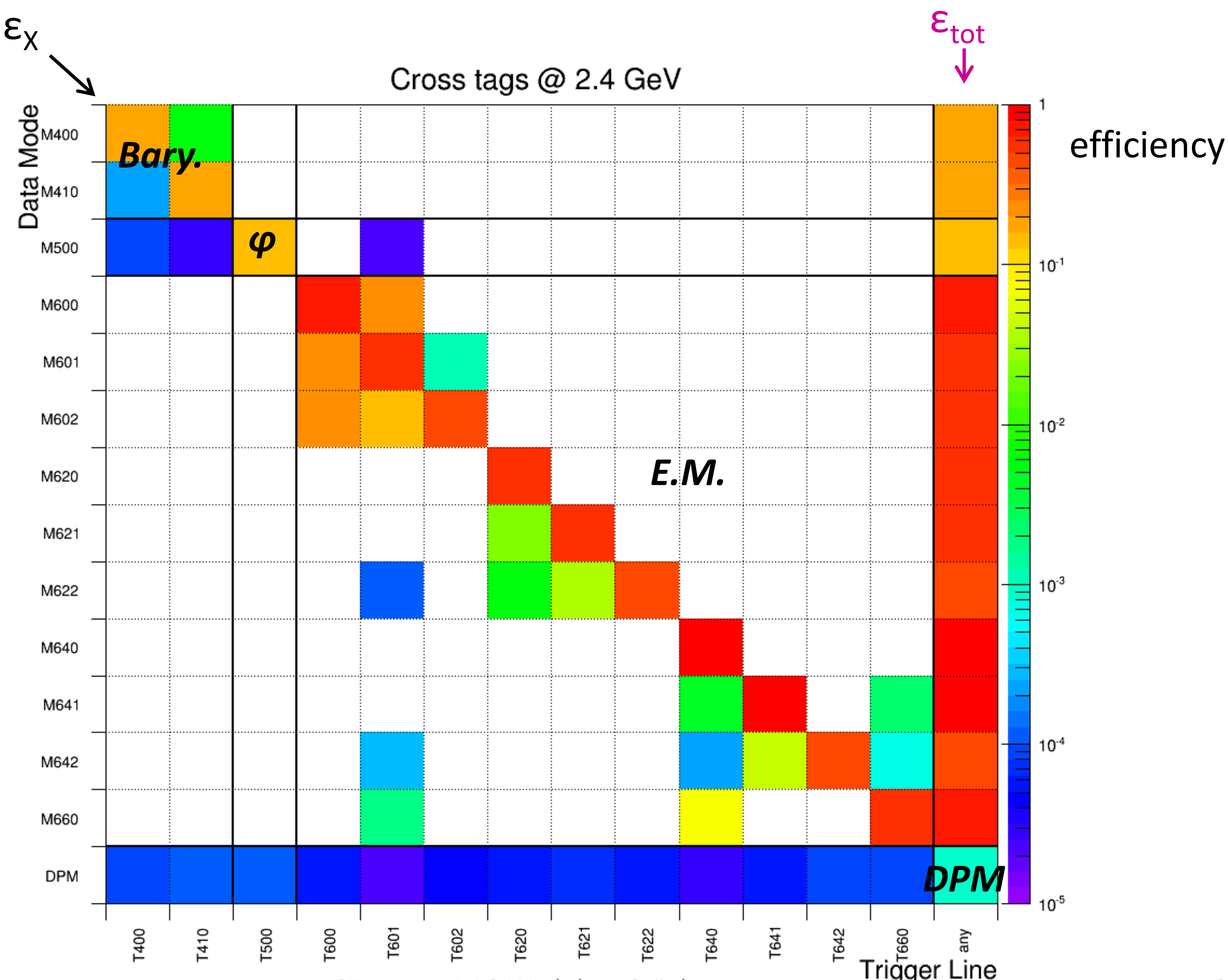
Recoils X under study

- 10 different recoils under consideration
- Not necessarily all recoils are accessible at the same time for a certain E_{cm}
- Data sets of one signal mode with different recoils are merged

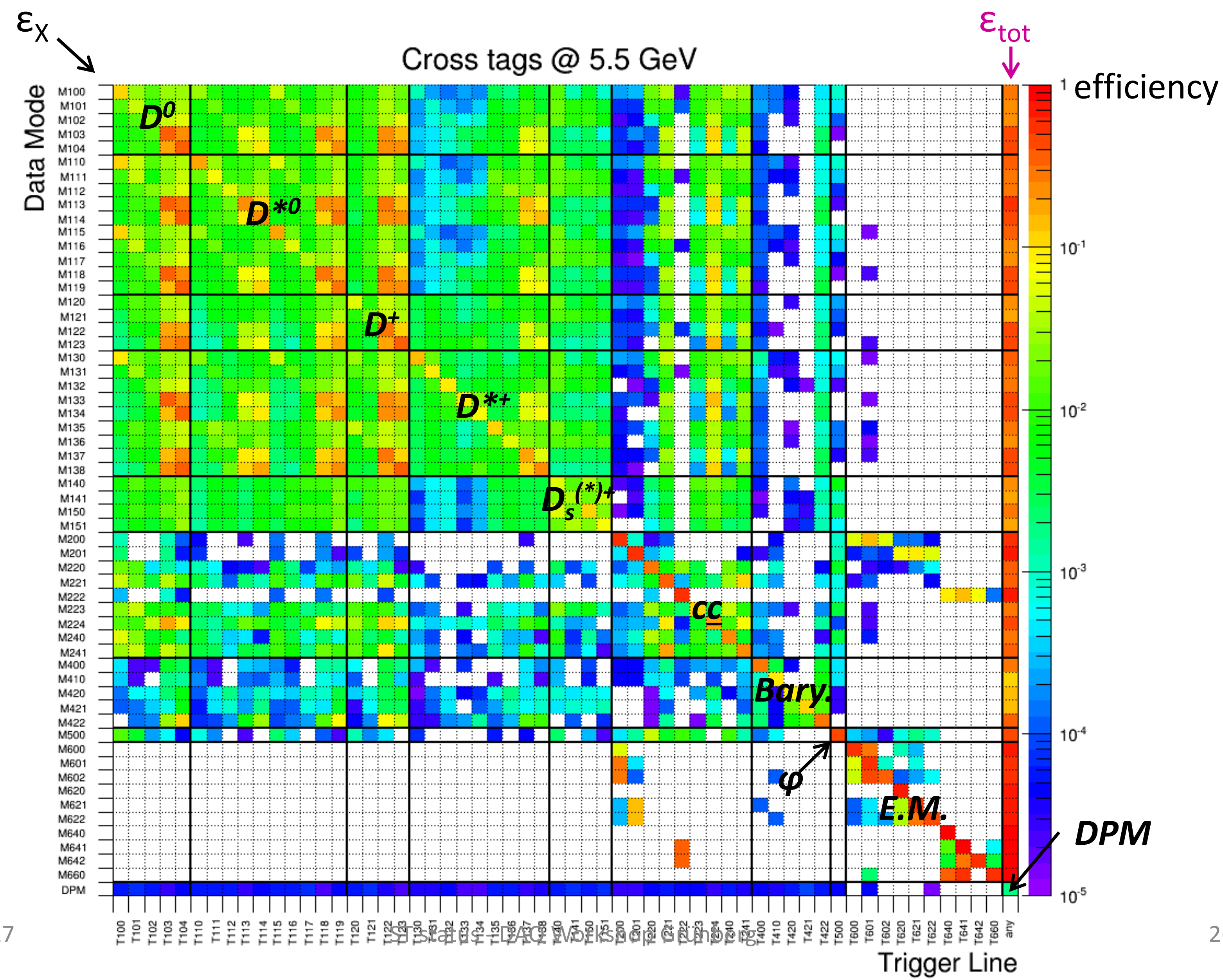
  → Here: Efficiencies are averaged over recoils (→ possible bias)

Number	Mode
00	*no recoil*
01	γ
02	π^0
03	η
04	$\pi^0 \pi^0$
05	$\pi^+ \pi^-$
06	$K^+ K^-$
07	$K^0 \underline{K}^0$
08	$\eta\eta$
09	$\pi^+ \pi^- \pi^0$

Tagging @ 2.4 GeV (Fast MC)



Tagging @ 5.5 GeV (Fast MC)



Trigger Line Decay Modes

100 : D0 -> K- pi+ cc
101 : D0 -> K- pi+ pi0 cc
102 : D0 -> K- pi+ pi+ pi- cc
103 : D0 -> K_S0 pi+ pi- cc
104 : D0 -> K_S0 pi+ pi- pi0 cc

110 : D*0 -> D0 [K- pi+] pi0 cc
111 : D*0 -> D0 [K- pi+ pi0] pi0 cc
112 : D*0 -> D0 [K- pi+ pi+ pi-] pi0 cc
113 : D*0 -> D0 [K_S0 pi+ pi-] pi0 cc
114 : D*0 -> D0 [K_S0 pi+ pi- pi0] pi0 cc

115 : D*0 -> D0 [K- pi+] gam cc
116 : D*0 -> D0 [K- pi+ pi0] gam cc
117 : D*0 -> D0 [K- pi+ pi+ pi-] gam cc
118 : D*0 -> D0 [K_S0 pi+ pi-] gam cc
119 : D*0 -> D0 [K_S0 pi+ pi- pi0] gam cc

120 : D+ -> K- pi+ pi+ cc
121 : D+ -> K- pi+ pi+ pi0 cc
122 : D+ -> K_S0 pi+ pi0 cc
123 : D+ -> K_S0 pi+ pi+ pi- cc

130 : D*+ -> D0 [K- pi+] pi+ cc
131 : D*+ -> D0 [K- pi+ pi0] pi+ cc
132 : D*+ -> D0 [K- pi+ pi+ pi-] pi+ cc
133 : D*+ -> D0 [K_S0 pi+ pi-] pi+ cc
134 : D*+ -> D0 [K_S0 pi+ pi- pi0] pi+ cc

135 : D*+ -> D+ [K- pi+ pi+] pi0 cc
136 : D*+ -> D+ [K- pi+ pi+ pi0] pi0 cc
137 : D*+ -> D+ [K_S0 pi+ pi0] pi0 cc
138 : D*+ -> D+ [K_S0 pi+ pi+ pi-] pi0 cc

140 : D_s+ -> K+ K- pi+ cc
141 : D_s+ -> K+ K- pi+ pi0 cc

150 : D*_s+ -> D_s+ [K+ K- pi+] gam cc
151 : D*_s+ -> D_s+ [K+ K- pi+ pi0] gam cc

200 : J/psi -> e+ e-
201 : J/psi -> mu+ mu-

220 : eta_c -> K+ K- pi0
221 : eta_c -> K_S0 K- pi+ cc
222 : eta_c -> gam gam
223 : eta_c -> K+ K- pi+ pi- pi0
224 : eta_c -> K_S0 K- pi+ pi- pi+ cc

240 : chi_0c -> pi+ pi- K+ K-
241 : chi_0c -> K+ pi- K_S0 pi0 cc

400 : Lambda0 -> proton pi- cc

410 : Sigma+ -> proton pi0 cc

420 : Lambda_c+ -> proton K- pi+ cc
421 : Lambda_c+ -> proton K- pi+ pi0 cc
422 : Lambda_c+ -> proton K_S0 pi0 cc

500 : phi -> K+ K-

600 : pbp0 -> e+ e-
601 : pbp0 -> e+ e- gam
602 : pbp0 -> e+ e- pi0

620 : pbp0 -> mu+ mu-
621 : pbp0 -> mu+ mu- gam
622 : pbp0 -> mu+ mu- pi0

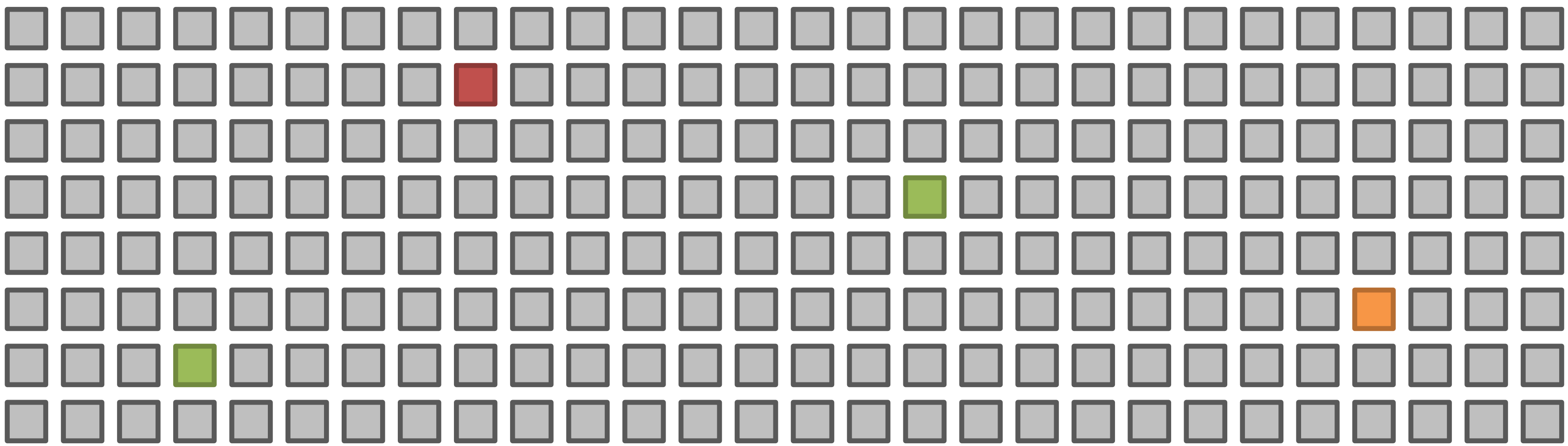
640 : pbp0 -> gam gam
641 : pbp0 -> gam gam gam
642 : pbp0 -> gam gam pi0

660 : pbp0 -> pi0 gam

Partial tagging w/o reco + event building?

Tag part of the signal channels before reco/event building?

Events: Bkg Sig 1 Sig 2 Sig 3, 4, ...



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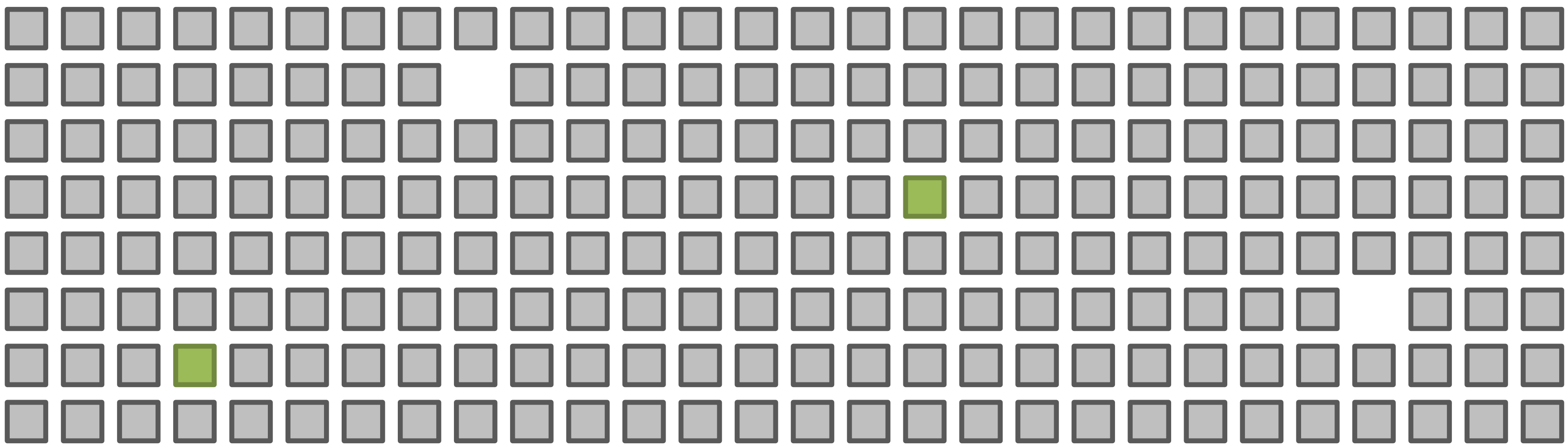

Problems

- Even with pre reco tags for Sig 1 (≈0.01%) and Sig 2 (≈0.01%)
  → Full reco needed for 99.98% of events for Sig 3, 4, ...

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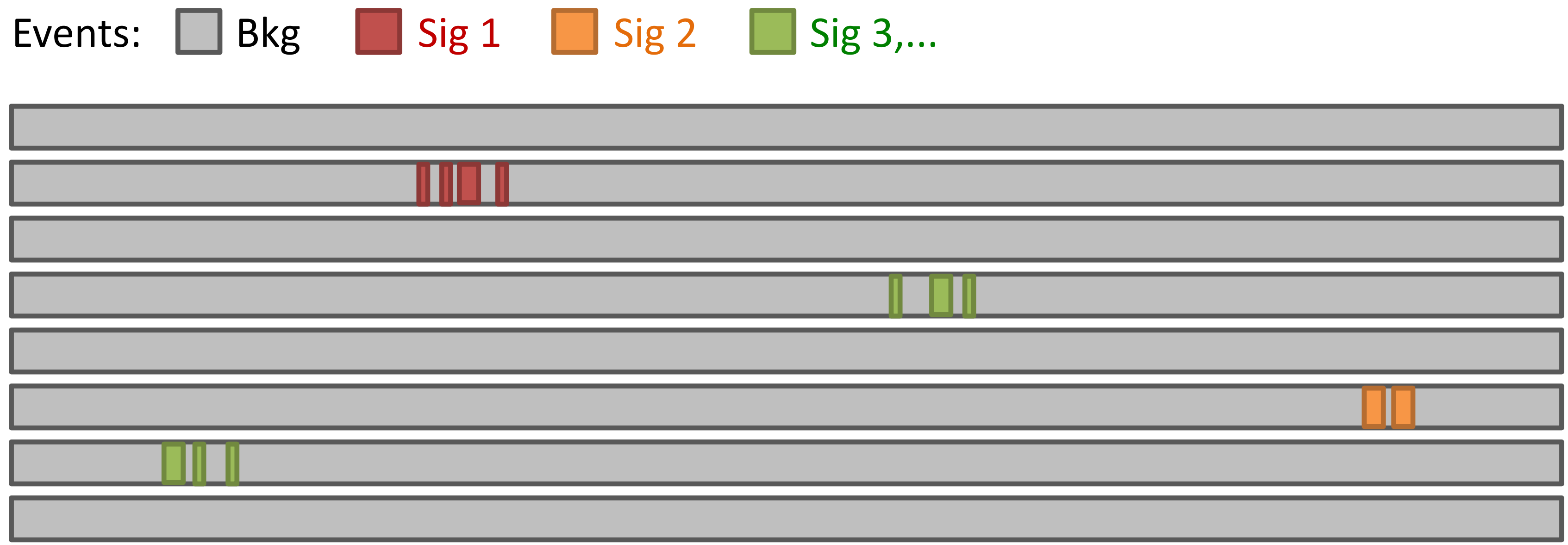


Problems

- Even with pre reco tags for Sig 1 (≈0.01%) and Sig 2 (≈0.01%)
  → Full reco needed for 99.98% of events for Sig 3,...
- Without event building: What data packages to be stored?
- Pre-reco tagging only useful as common bkg veto for all signals

Charmonia

Reaction	Trigger #	via decay	Taggable
η_c + X	1		8.3%
J/ψ + X	2		11.9%
χ_{c0}(1P) + X	3		2.6%
χ_{c1}(1P) + X	2	J/ψ γ (34,4%)	4.1%
χ_{c2}(1P) + X	2	J/ψ γ (19,5%)	2.3%
h_c + X	1	η_c γ (54,3%)	4.5%
η_c(2S) + X	--		0.0%
ψ(2S) + X	2	J/ψ X (59,6%)	7.1%
ψ(3770) + X	4,5	$D^0\underline{D}^0$ (52%), D^+D^-(41%)	44,0%
X(3823) + X	2	χ_{c1} γ (?)	< 4.1%
X(3872) + X	2	J/ψ $\pi^+ \pi^-$ (>2,6%), $D^0\underline{D}^0\pi^0$ (>32%)	> 17.4%
Z_c^+(3900) + X	2,4,5,7,8	J/ψ π^+ (?), (DD*)+ (?)	< 11.9%
Z_c^0(3900) + X	2	J/ψ π^0 (?)	< 11.9%
χ_{c0}(2P) + X	4,7	$D^{0*}\underline{D}^0$ (>71%)	32.0%
χ_{c2}(2P) + X	4,5	$D\underline{D}$ (?)	< 39%
X(3940) + X	4,5,7,8	$D\underline{D}$* (>45% @ 90CL)	> 20%
Z^+(4020) + X	7,8	$D^*\underline{D}^*$ (?)	< 49%
ψ(4040) + X	4,5	$D\underline{D}$ (?)	< 40%
Z^+(4050) + X	2	χ_{c1} π^+ (?)	< 4.1%
ψ(4160) + X	4,5,7,8	$D\underline{D}$, $D\underline{D}^*$, $D^*\underline{D}^*$ (?)	< 40%
X(4160) + X	7,8	$D^*\underline{D}^*$ (?)	< 49%
X(4250) + X	2	χ_{c1} π^+ (?)	< 4.1%
X(4260) + X	2	J/ψ X (?)	< 11.9%
X(4350) + X	2,13	J/ψ ϕ (?)	< 54.9%
X(4360) + X	2	ψ(2S) $\pi^+ \pi^-$ (?)	< 7.1%
ψ(4415) + X	4,5,6,7,8,9	$D\underline{D}$, $D_s^+D_s^-$ (?)	< 20%
Z^+(4430) + X	2	ψ(2S) π^+ (?)	< 7.1%
X(4660) + X	2	ψ(2S) $\pi^+ \pi^-$ (?)	< 7.1%

Open Charm

Reaction	Trigger #	via decay	Taggable
$D^0 \underline{D}^0 + X$	4		53.3%
$D^0 \underline{D}^{0*} + X$	4,7		45.0%
$D^{0*} \underline{D}^{0*} + X$	7		35.3%
$D^+ D^- + X$	5		39.8%
$D^+ D^{-*} + X$	5,8		44.3%
$D^{+*} D^{-*} + X$	8		48.6%
$D_s^+ D_s^- + X$	6		21.0%
$D_s^+ D_s^{-*} + X$	6,9		20.4%
$D_s^{+*} D_s^{-*} + X$	9		19.8%
$D_s^+ D_{s0}^*(2317)^-$	6	$D_s^+ \pi^0$ (?)	>11.1%
$D_s^{+*} D_{s0}^*(2317)^-$	6,9	$D_s^+ \pi^0$ (?)	>10.5%
$D_s^+ D_{s1}(2460)^-$	6,9	$D_s^{+*} \pi^0$ (48%), $D_s^+\gamma$ (18%)	17.3%
$D_s^{+*} D_{s1}(2460)^-$	6,9	$D_s^{+*} \pi^0$ (48%), $D_s^+\gamma$ (18%)	16.7%
$D_s^+ D_{s1}(2536)^-$	6,8	$D^{*+} K^0$ (85%)	32.5%
$D_s^{+*} D_{s1}(2536)^-$	8,9	$D^{*+} K^0$ (85%)	32.0%
$D_s^+ D_{s2}^*(2573)^-$	4,6	D^0 K (?)	>11.1%
$D_s^{+*} D_{s2}^*(2573)^-$	4,9	D^0 K (?)	>10.5%

Baryons & Light Hadrons

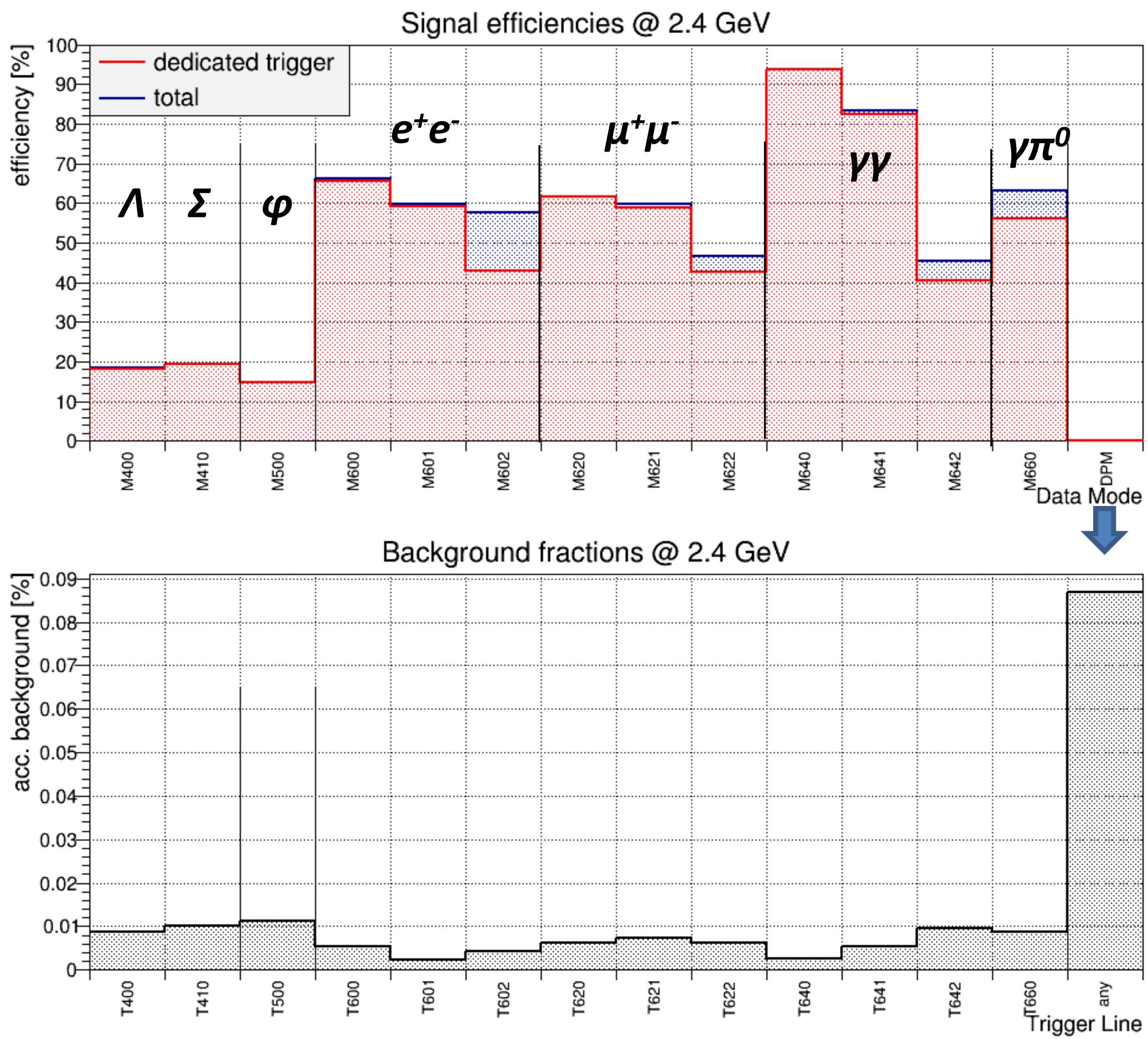
Reaction	Trigger #	via decay	Taggable
$\Lambda\underline{\Lambda}$ + X	10		87.0%
$\Sigma^+ \underline{\Sigma}^-$ + X	12		76.5%
$\Sigma^0 \underline{\Sigma}^0$ + X	10	$\Lambda\ \gamma$ (100%)	87.0%
$\Sigma^- \underline{\Sigma}^+$ + X	--		0.0%
$\Xi^0 \underline{\Xi}^0$ + X	10	$\Lambda\ \pi^0$ (99,5%)	86.7%
$\Xi^- \underline{\Xi}^+$ + X	10	$\Lambda\ \pi^-$ (99,9%)	86.9%
$\Omega^- \Omega^+$ + X	10	Λ K(67,8%), $\Xi^0\ \pi^-$ (23,6%)	82.6%
$\Lambda_c^+ \underline{\Lambda}_c^-$ + X	11		18.2%
Λ_c^+(..), Σ_c^+(..), Ξ_c(..)	4,11	Λ_c X (?), p D^0 (?)	?

Reaction	Trigger #	via decay	Taggable
ϕ + X	13		48.9%
$e^+ e^-$	14		100.0%
$e^+ e^-$ X	14		100.0%
$\mu^+ \mu^-$	15		100.0%
$\mu^+ \mu^-$ X	15		100.0%
$\gamma\ \gamma$	16		100.0%
$\gamma\ \gamma$ X	16		100.0%
other light hadrons	min bias		100.0%

→ Looks quite complete (at least for spectroscopy & EMP)!

Total Efficiencies & Bgk Levels @ 2.4 GeV (Fast MC)

ε_{tot}
ε_X



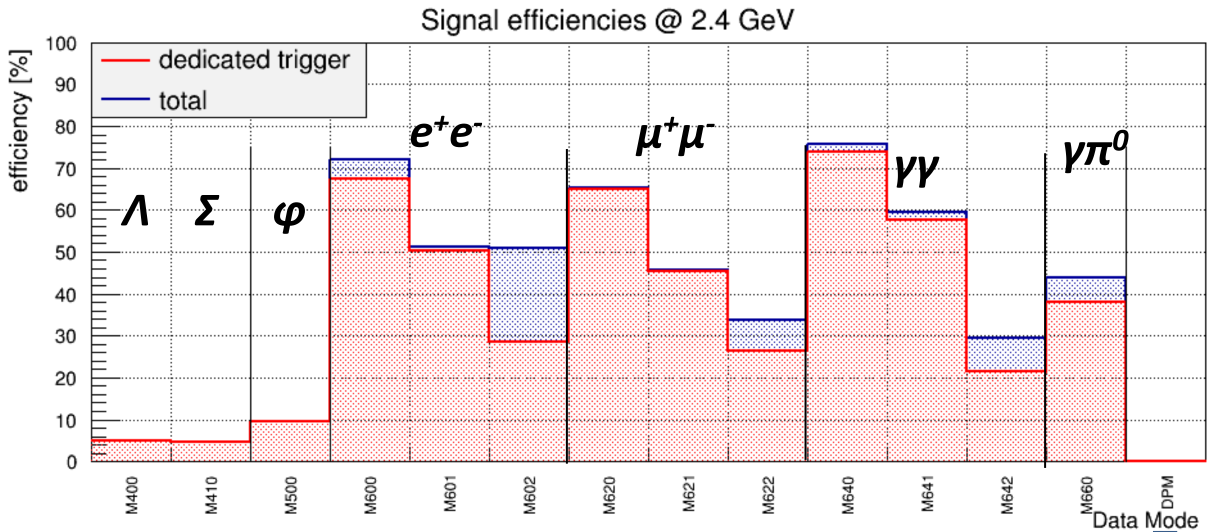
Efficiencies for different data modes

Acceptance of different trigger lines on DPM data

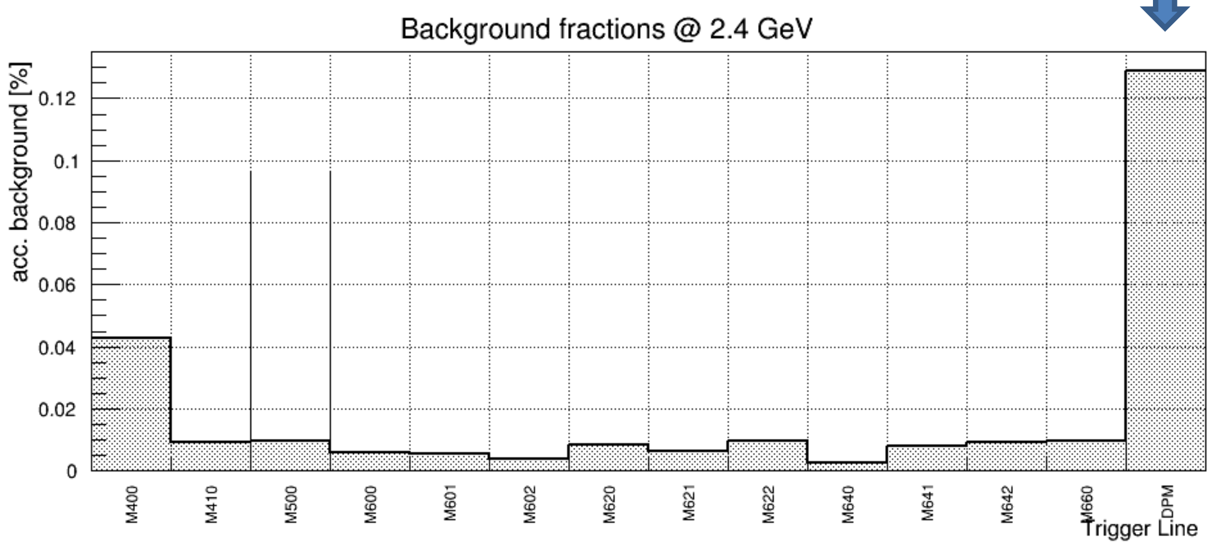
Total Efficiencies & Bgk Levels @ 2.4 GeV (Full MC)

ε_{tot}

ε_X



Efficiencies for different data modes



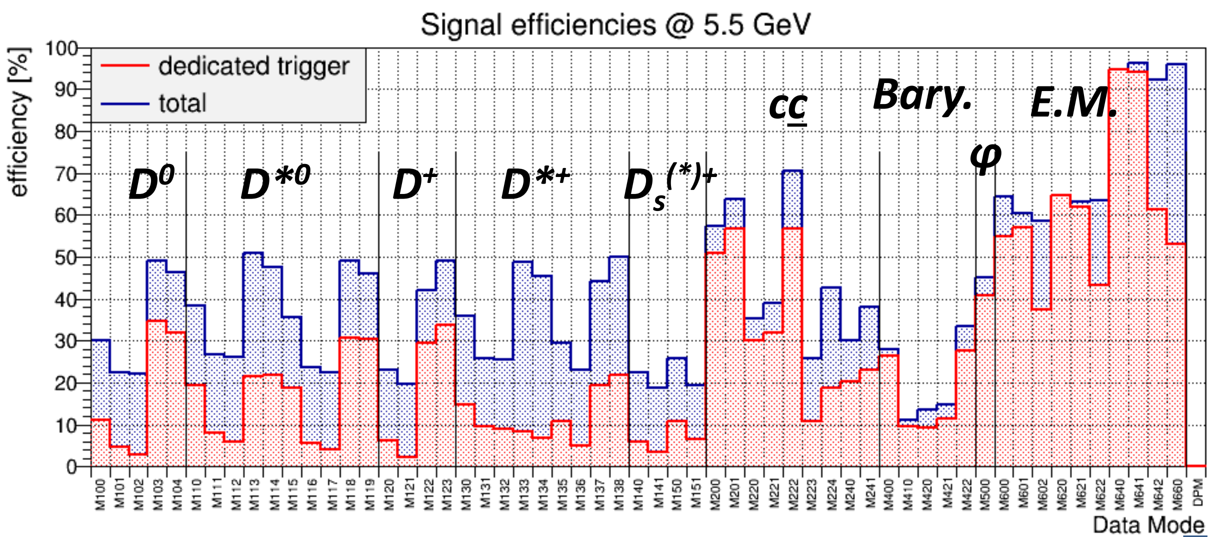
Acceptance of different trigger lines on DPM data

Total Efficiencies & Bgk Levels @ 5.5 GeV (Fast MC)

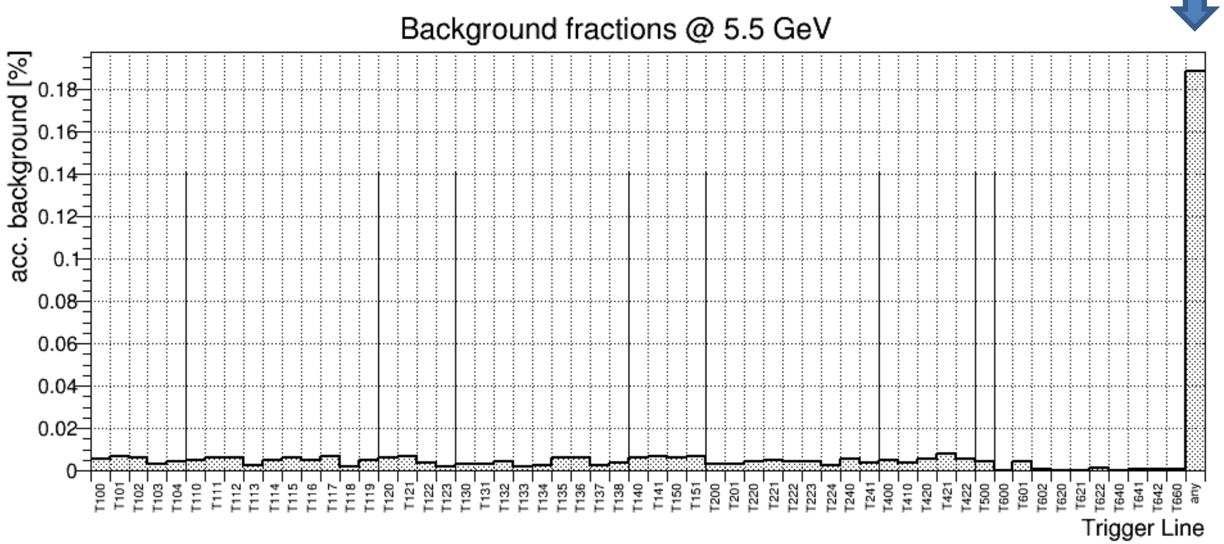
ε_{tot}

ε_X

For D modes cross tagging is strong effect



Efficiencies for different data modes



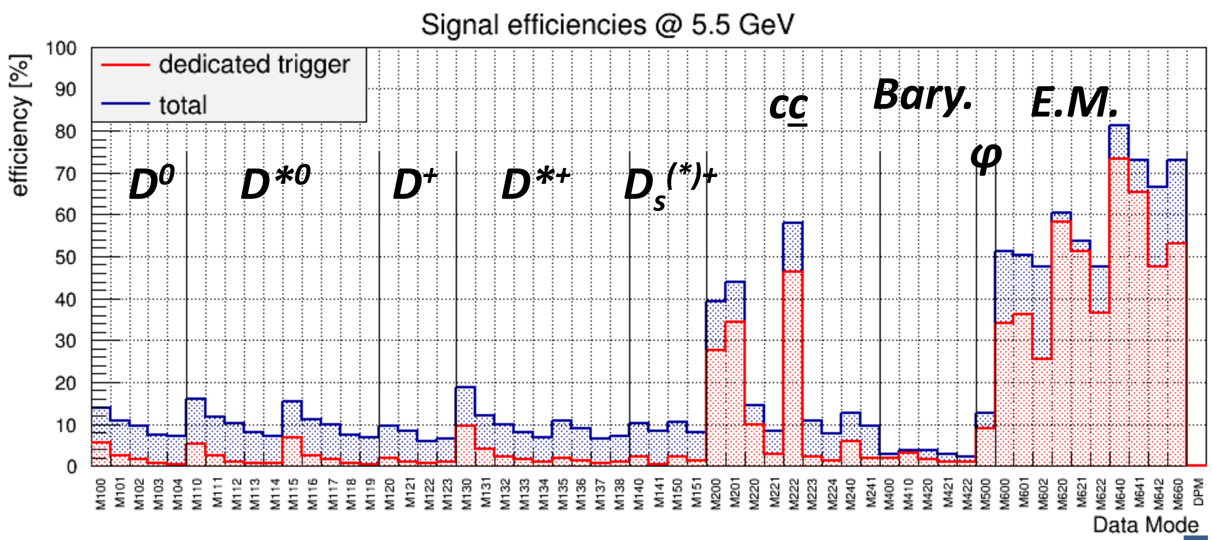
Acceptance of different trigger lines on DPM data

Total Efficiencies & Bgk Levels @ 5.5 GeV (Full MC)

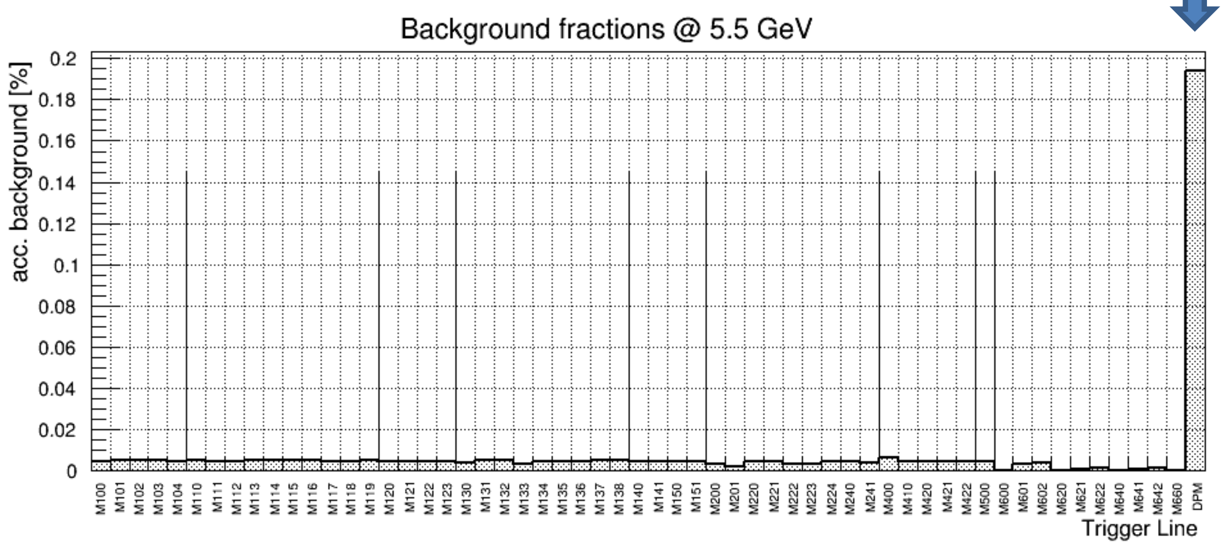
ε_{tot}

ε_X

Full Sim looks much worse



Efficiencies for different data modes



Acceptance of different trigger lines on DPM data

Computing Effort for Scenario Analysis

E_{cm} [GeV]	2.4	3.0	3.5	3.8	4.5	5.0	5.5	Sum
Data modes	26	45	85	118	550	741	792	**2357**
Events [M]*	2.25	3.20	5.20	6.85	28.5	38.0	40.6	**124.5**
Optimisations	13	13	22	31	54	57	57	**247**

*per E_{cm}: 1M bkg events + N x 50k events/signal mode

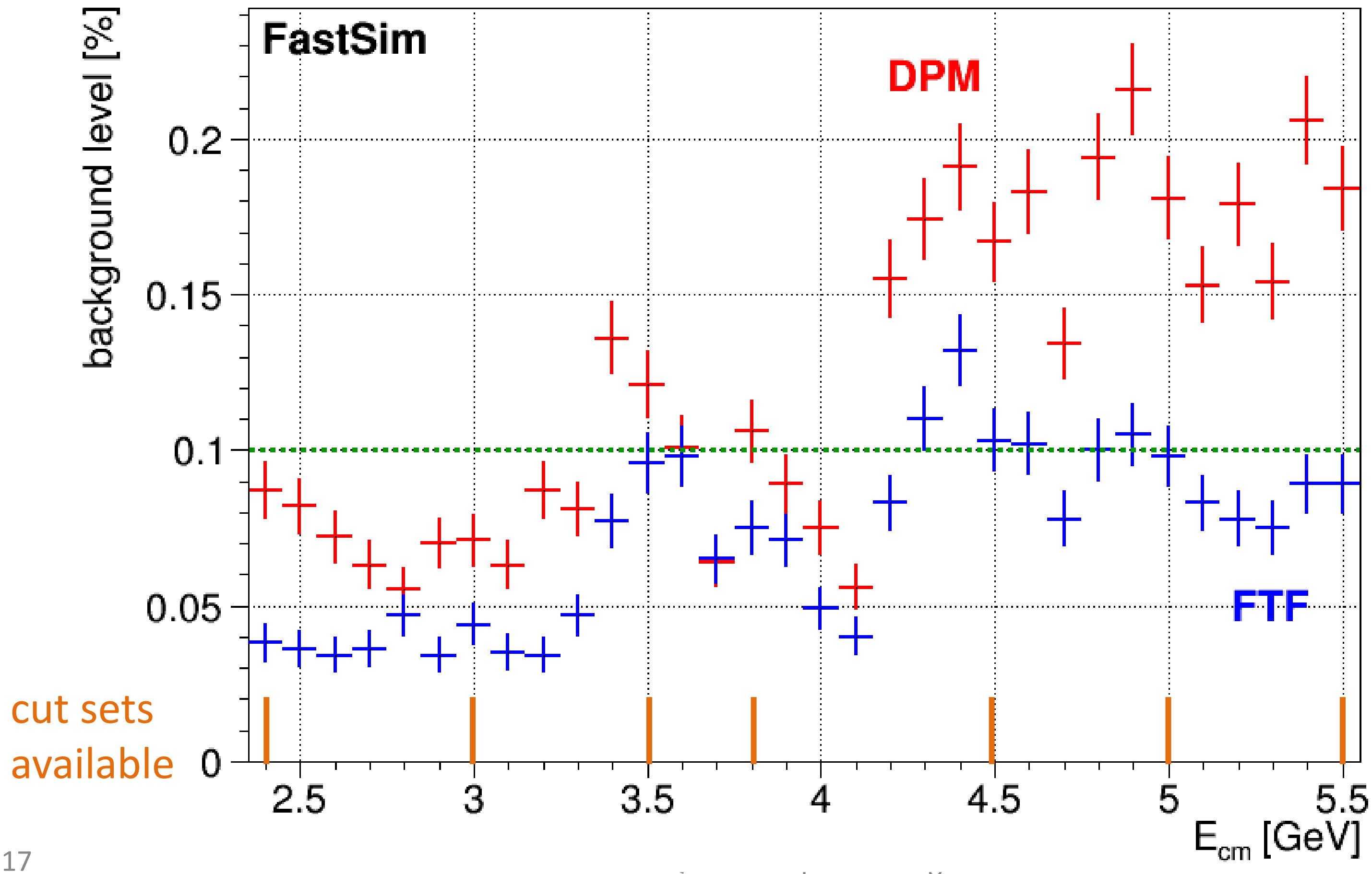
Full Simulation

- 300,000 jobs on Prometheus@GSI (1000 events/job)
  - 1 week for simulation (2000 cores in parallel)
- ca. 20 TB of data consisting of
  - Simulation data (8.5 TB)
  - SoftTrigger specific output (11.5 TB)
- 247 automated optimisations on n-tuples & re-application
  - 10 days additional run time

Robustness of Background Level (Fast MC)

- Training with DPM → apply to events from FTF generator
- Application of selection next by for intermediate points

→ Suppression looks quite robust and consistent!



First Look: Trigger impact to PHSP

- Evaluate relative efficiency w/ and w/o trigger

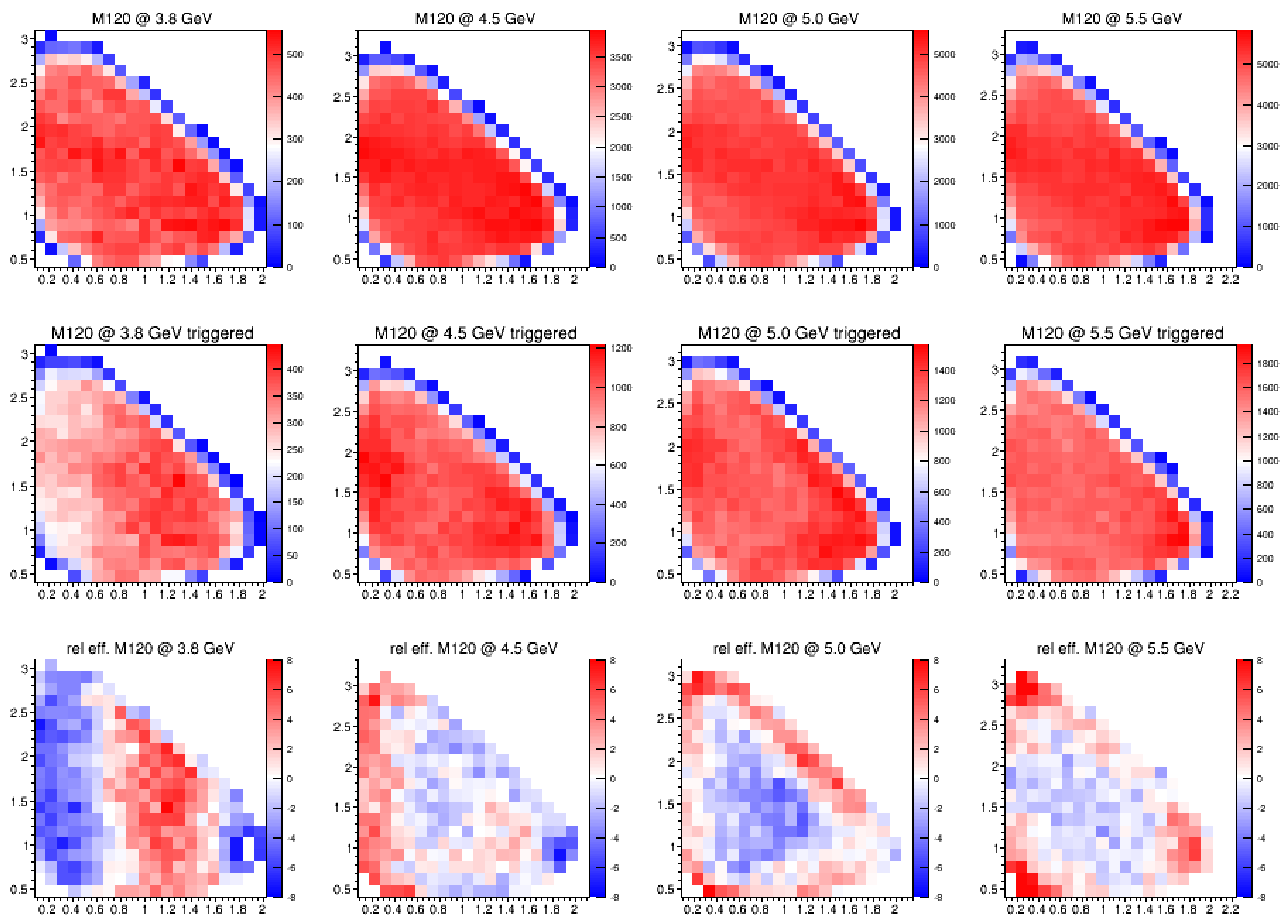
Example: $D^+ \rightarrow K \pi \pi$ (M120)

E_{cm} [GeV] | 3.8 | 4.5 | 5.0 | 5.5

Pure Reco

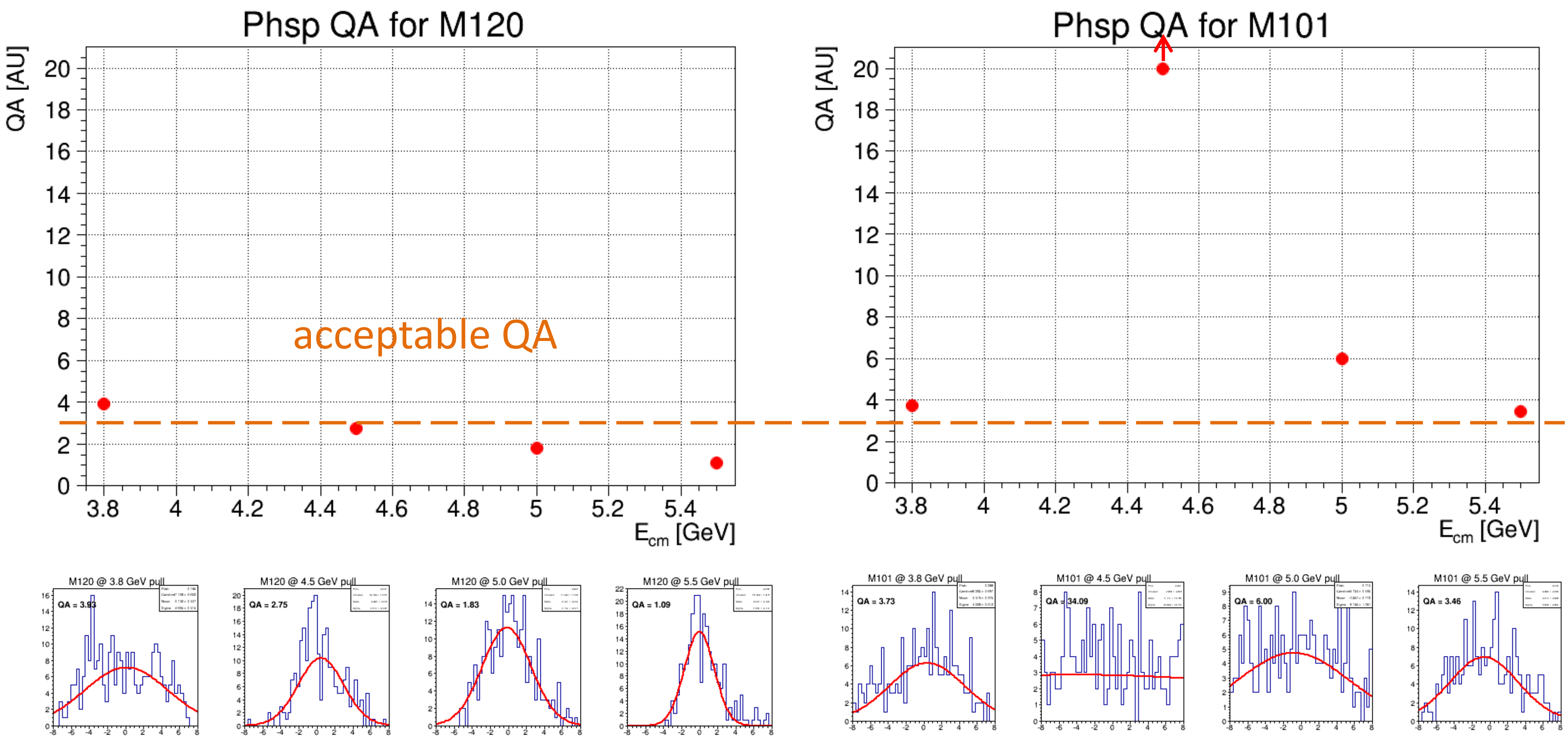
w/ Trigger

Deviation [σ] from avg. eff.



Define some QA Measure

- QA function = 'arbitrary' mixture of pull / coverage quality



→ needs more systematic study and reasonable QA estimate