Universität Münster

Combination and Reinterpretation of LHC SUSY Searches

arXiv: 2403.11715

Alexander Feike, Juri Fiaschi, Benjamin Fuks, Michael Klasen, Alexander Puck Neuwirth

SUSY 2024

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living.knowledge

Motivation

- SM is incomplete $\rightarrow$ SUSY might yield some answers
- no SUSY particles found, so far
- experimental analyses pushed the lower bounds on SUSY masses into the TeV regime (exact limits depend on the considered model)

our goal: push the mass limits even further by combining different CMS and ATLAS analyses

relevant processes: $p\,p \rightarrow \tilde{q}\,\bar{\tilde{q}}\ (+j\,j)$ $\quad p\,p \rightarrow \tilde{q}\,\tilde{\chi}_1^0\ (+j\,j)$ $\quad p\,p \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0\ (+j\,j)$

decay: $\tilde{q} \rightarrow q\,\tilde{\chi}_1^0$

Scenario: LSP Bino

- decouple all SUSY particles but $\tilde{\chi}_1^0$ and $\tilde{u}_R$
- diagonal neutralino mixing $\tilde{\chi}_1^0 = \tilde{B}^0$
- $m_{\tilde{\chi}_1^0} < m_{\tilde{q}}$

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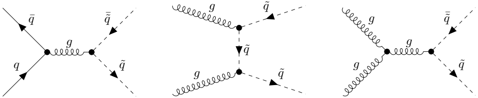
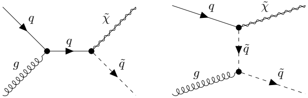
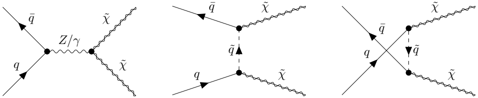
$\tilde{q}\bar{\tilde{q}}$, squark-squark, $\mathcal{O}(\alpha_S^2)$:



$\tilde{q}\tilde{\chi}$, gaugino-squark, $\mathcal{O}(\alpha_S \alpha)$:



$\tilde{\chi}\tilde{\chi}$, gaugino-gaugino, $\mathcal{O}(\alpha^2)$:



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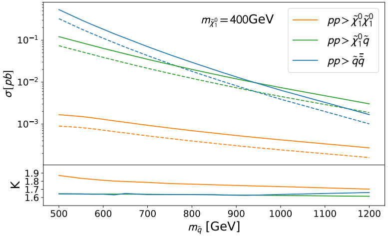
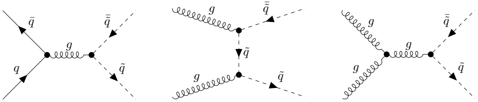
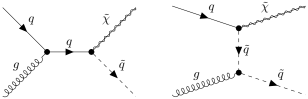


dashed=LO, solid=higher order

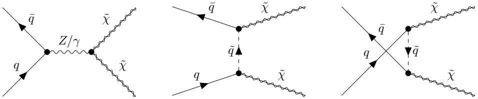
$\tilde{q}\bar{\tilde{q}}$, squark-squark, $\mathcal{O}(a_S^2)$:



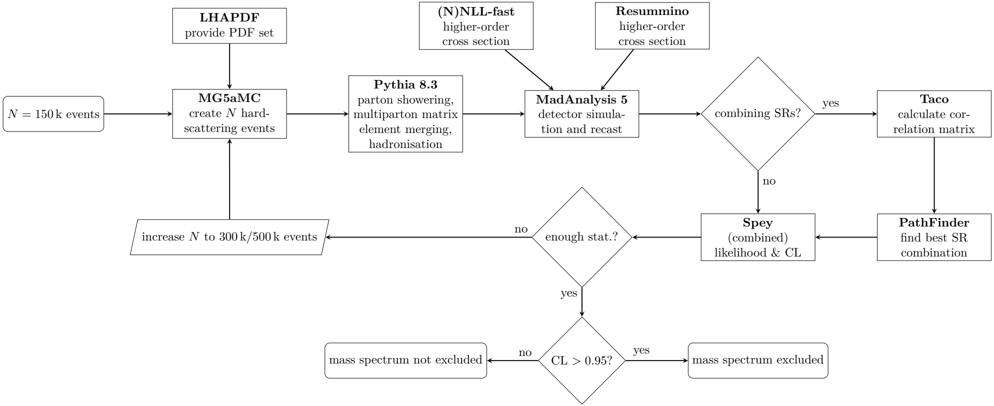
$\tilde{q}\tilde{x}$, gaugino-squark, $\mathcal{O}(a_S a)$:



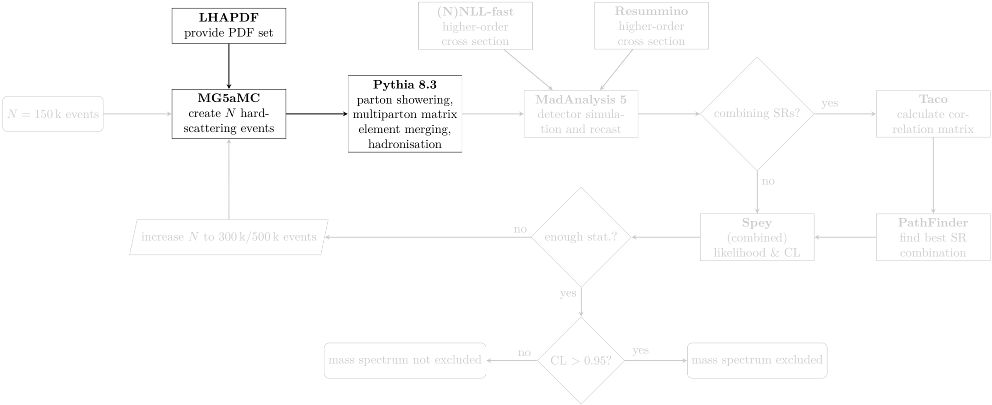
$\tilde{x}\tilde{x}$, gaugino-gaugino, $\mathcal{O}(a^2)$:



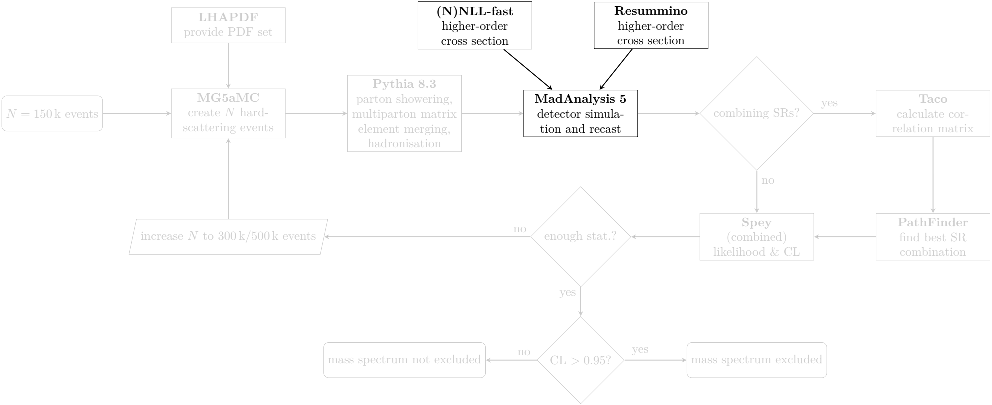
Toolchain


LHAPDF
provide PDF set
(N)NLL-fast
higher-order
cross section
Resummino
higher-order
cross section
$N = 150\,\mathrm{k}$ events
MG5aMC
create N hard-
scattering events
Pythia 8.3
parton showering,
multiparton matrix
element merging,
hadronisation
MadAnalysis 5
detector simula-
tion and recast
combining SRs?
yes
Taco
calculate cor-
relation matrix
no
increase N to $300\,\mathrm{k}/500\,\mathrm{k}$ events
no
enough stat.?
Spey
(combined)
likelihood & CL
PathFinder
find best SR
combination
yes
mass spectrum not excluded
no
CL > 0.95?
yes
mass spectrum excluded

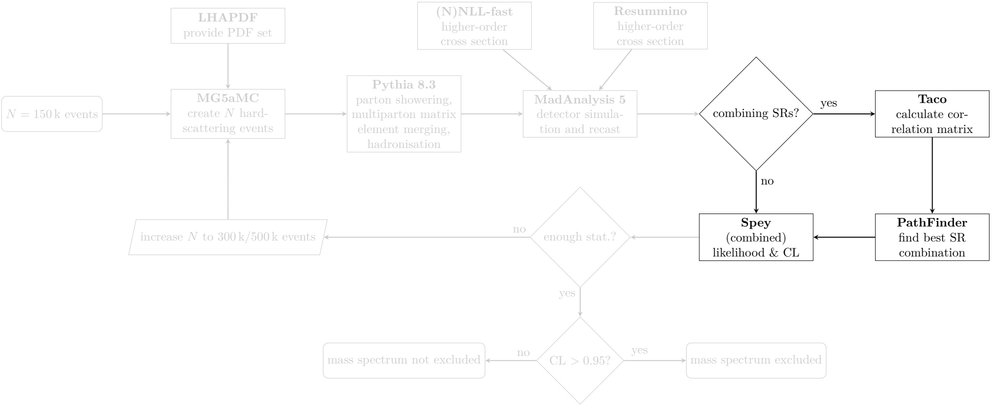
Event Generation



Recasting Analyses



Combination



Combination

MA5 output $\rightarrow$ TACO [arXiv: 2209.00025] $\rightarrow$ correlation matrix

- symmetric SR×SR matrix incorporating SRs from multiple analyses
- set threshold $T \leq 0.01$
- ATLAS and CMS SRs uncorrelated

$$
\begin{array}{c} \\ \mathrm{SR1} \\ \mathrm{SR2} \\ \vdots \\ \mathrm{SR}(n-1) \\ \mathrm{SR}n \end{array}
\begin{array}{c} \begin{array}{ccccc} \mathrm{SR1} & \mathrm{SR2} & \cdots & \mathrm{SR}(n-1) & \mathrm{SR}n \end{array} \\
\begin{pmatrix} 1 & 0.7 & \cdots & 0.9 & 0.4 \\ 0.7 & 1 & \cdots & 0.6 & 0.005 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0.9 & 0.6 & \cdots & 1 & 0.8 \\ 0.4 & 0.005 & \cdots & 0.8 & 1 \end{pmatrix} \end{array}
$$

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	SR1	SR2	$\cdots$	SR$(n-1)$	SRn
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SR2	0.7	1	$\cdots$	0.6	0.005
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
SR$(n-1)$	0.9	0.6	$\cdots$	1	0.8
SRn	0.4	0.005	$\cdots$	0.8	1

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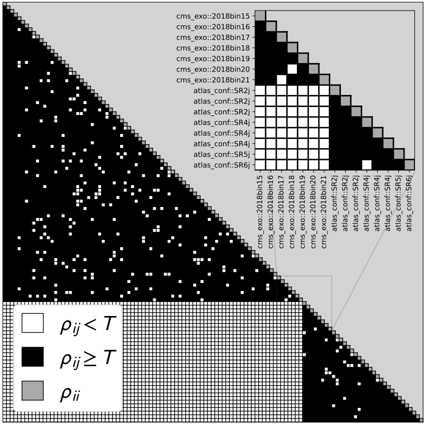
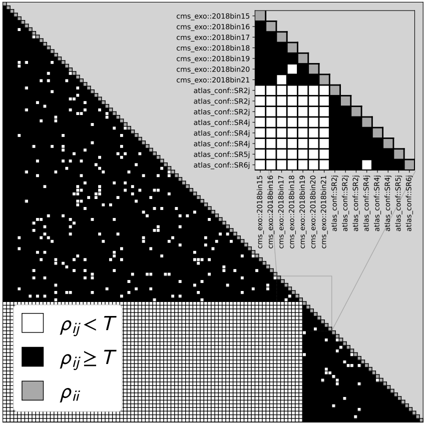
Correlation matrix



- find most constraining combination of uncorrelated SRs
- assign weight $\rightarrow$ log likelihood ratio
- sort matrix & run `PathFinder`
- pass best combination to statistics tool `Spey` [arXiv: 2307.06996]

Correlation matrix



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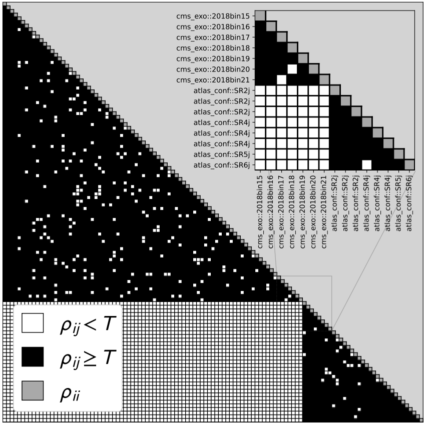

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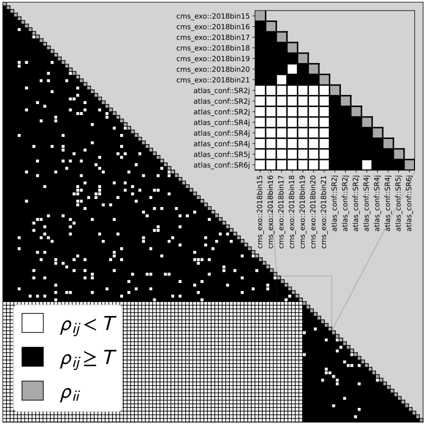

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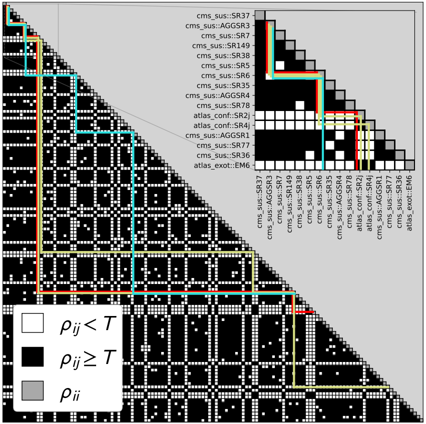

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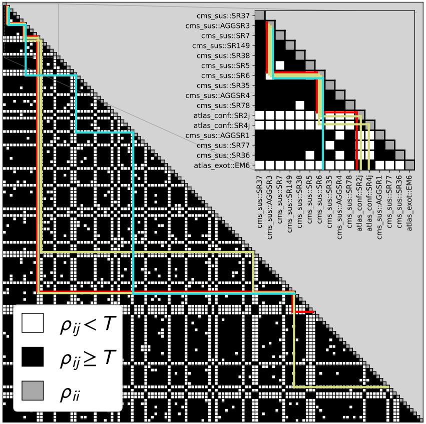

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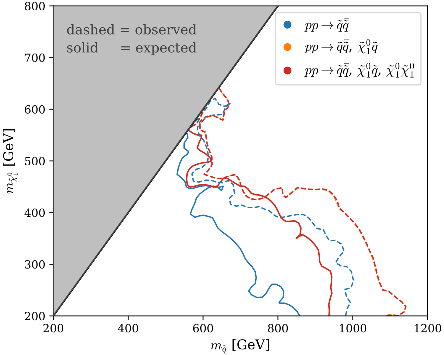
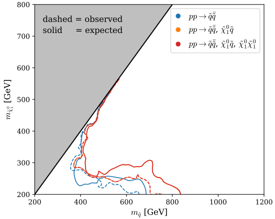
Single analysis exclusion

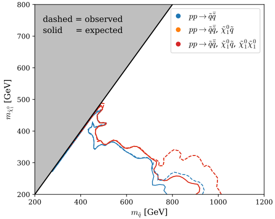
CMS-SUS-19-006



Single analysis exclusion

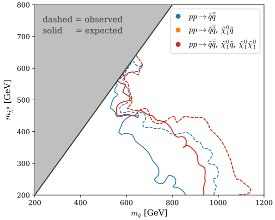
ATLAS-EXOT-2018-06

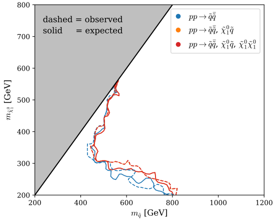




ATLAS-CONF-2019-040

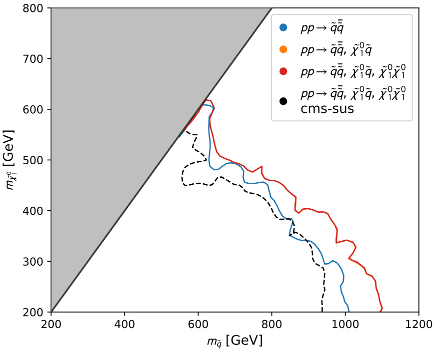
CMS-SUS-19-006



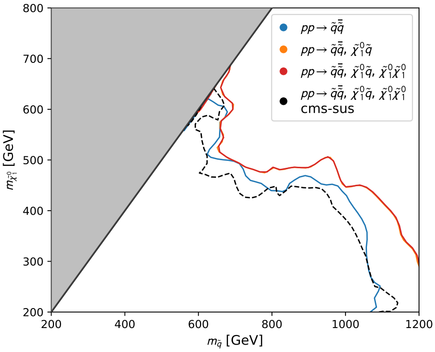


CMS-EXO-20-004

Combined analyses

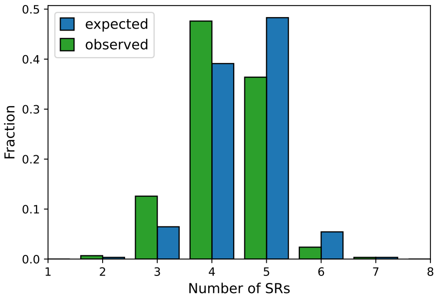


(a) expected

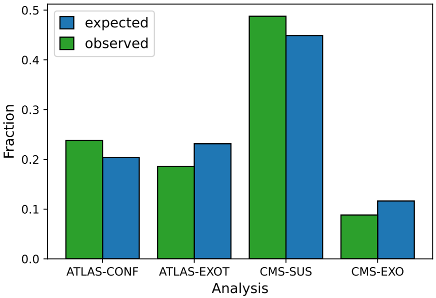


(b) observed

Combined analyses



(a) Number of combined SRs

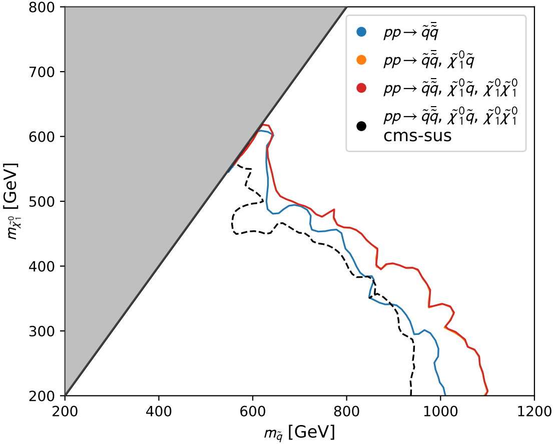


(b) Share of the different analyses

Conclusion

- recast LHC analyses in a simplified SUSY model considering $\tilde{q}\bar{\tilde{q}}$, $\tilde{\chi}_1^0\tilde{q}$ and $\tilde{\chi}_1^0\tilde{\chi}_1^0$ production
- successfully combined uncorrelated SRs from ATLAS and CMS

  $\rightarrow$ significant gain in exclusion power
- step towards maximizing information gain from existing data



Backup

Versions, PDFs, etc.

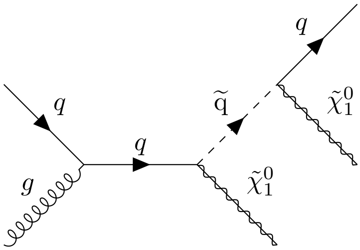
program	version	PDF (N)LO	PDF higher order
MadGraph	MG5_aMC_v3_4_1	MSHT20lo_as130	
Resummino	3.1.1	MSHT20lo_as130	MSHT20nlo_as118
nllfast	nllfast-3.1	MSTW2008LO	MSTW2008NLO
nnllfast	nnllfast-1.1	NLO PDF4LHC15	NNLO PDF4LHC15
MadAnalysis	v1.10.9-beta		
Pythia8	pythia8306		

Event Generation

1. use `MadGraph5` to create events
   - prevent double counting
   - only allow off-shell squarks within process
2. add parton shower with `Pythia8`
   - prevent double counting
   - jet merging with CKKW-L

$p\,p \rightarrow \tilde{q}\,\bar{\tilde{q}}\ (+j\,j)$ $\quad$ $p\,p \rightarrow \tilde{q}\,\tilde{\chi}_1^0\ (+j\,j)$

$p\,p \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0\ (+j\,j)$ $\quad$ decay: $\tilde{q} \rightarrow q\,\tilde{\chi}_1^0$



Cross sections

$$pp \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \qquad \sigma = \sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{MG}} \, \frac{\sigma(\mathrm{aNNLO+NNLL})_{\mathrm{NLO}}^{\mathrm{RS}}}{\sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{RS}}}$$

$$pp \to \tilde{\chi}_1^0 \tilde{\mathrm{q}} \qquad \sigma = \sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{MG}} \, \frac{\sigma(\mathrm{NLO+NLL})_{\mathrm{NLO}}^{\mathrm{RS}}}{\sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{RS}}}$$

$$pp \to \tilde{\mathrm{q}} \bar{\tilde{\mathrm{q}}} \qquad \sigma = \sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{MG}} \, \frac{\sigma(\mathrm{NLO})_{\mathrm{NLO}}^{\mathrm{nllfast}}}{\sigma(\mathrm{LO})_{\mathrm{LO}}^{\mathrm{nllfast}}} \, \frac{\sigma(\mathrm{aNNLO+NNLL})_{\mathrm{NNLO}}^{\mathrm{nnllfast}}}{\sigma(\mathrm{NLO})_{\mathrm{NLO}}^{\mathrm{nnllfast}}}$$

Analyses

cuts	ATLAS-EXOT	ATLAS-CONF	CMS-SUS	CMS-EXO
veto	e, μ, τ, γ	e, μ	e, μ, γ	e, μ, τ, γ, b-jet
N_j	≥ 1	≥ 2	≥ 2	≥ 1
E_T^{miss}	> 200 GeV	> 300 GeV	-	> 250 GeV
$\lvert n \rvert$	< 2.4	-	< 2.4	< 2.4
$p_T(j_1)$	> 150 GeV	> 200 GeV	-	> 100 GeV
$p_T(j_2,\ldots,j_{N_j})$	> 30 GeV	> 50 GeV	-	-
$\Delta\Phi(\text{jet}, \mathbf{p}_T^{\text{miss}})$	›0.4	> 0.2	›0.5	›0.5
m_{eff}	-	> 800 GeV	-	-
H_T	-	-	›300 GeV	-
$\lvert \vec{H}_T^{\text{miss}} \rvert$	-	-	›300 GeV	-

$$m_{\text{eff}} = E_T^{\text{miss}} + \sum_{p_T > 50\text{ GeV}} p_T(j)$$

$$H_T = \sum_{|n|<2.4} p_T(j)$$

$$\vec{H}_T^{\text{miss}} = \sum_{|n|<5} \vec{p}_T(j)$$