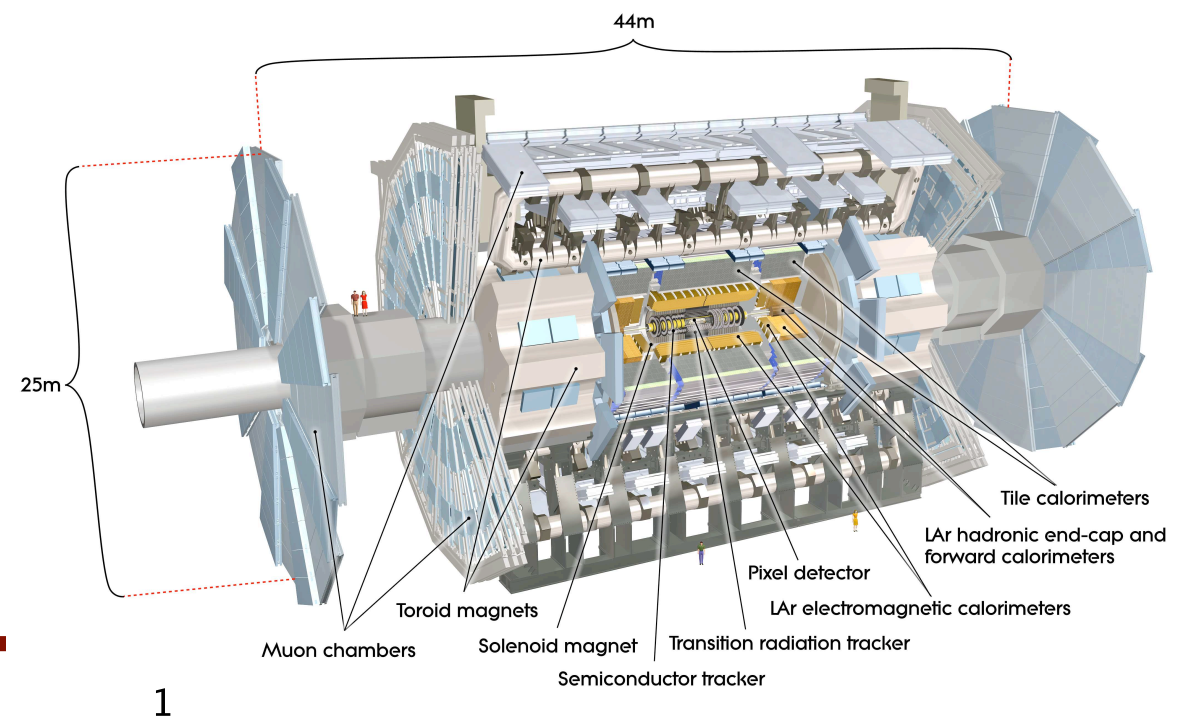
Signal Vertex Selection
and
the Impact of Pile Up on the b-tagging Performance
in the ATLAS experiment

IMPRS Workshop

01.02.10

Johanna Bronner



pile up and minimum bias

proton proton collisions every 25 ns at a centre of mass energy of 14 TeV

$L=10^{34}cm^{-2}s^{-1}$ (design Luminosity)

→in average **20** inelastic proton proton interactions per bunch crossing

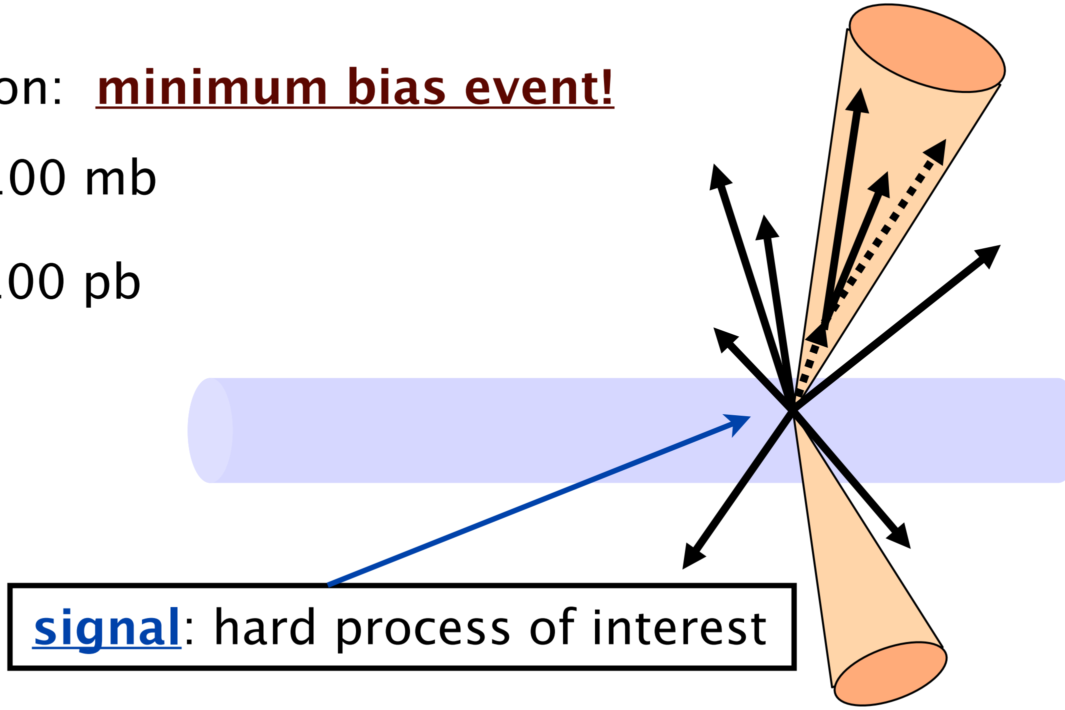
$L=10^{33}cm^{-2}s^{-1}$ (75ns) → 6.9 interactions

$L=10^{32}cm^{-2}s^{-1}$ (450ns) → 4.1 interactions

not further specified inelastic interaction: **minimum bias event!**

total inelastic cross section: $\sigma_{tot} \approx 100$ mb

e.g.: Higgs cross section: $\sigma_{Higgs} < 100$ pb



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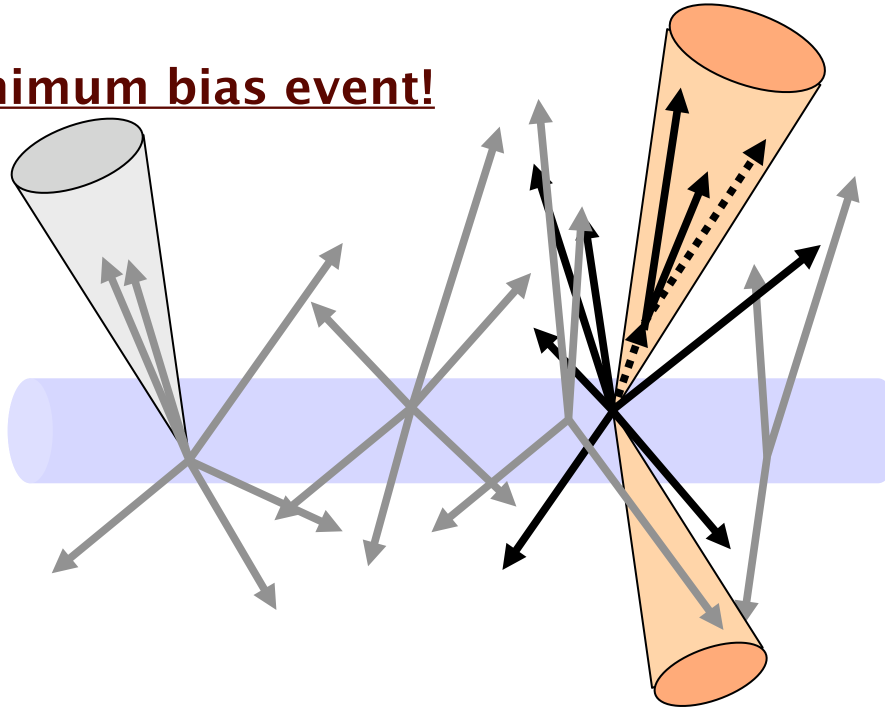
every signal process is overlapped

by several minimum bias events:

(in-time) pile up



primary vertices

interaction region in z-direction (beam direction) is large

→ interaction points (primary vertices) are distinguishable

primary vertex resolution: $\sigma_{vtx,x,y} \sim 12\ \mu m$, $\sigma_{vtx,z} \sim 40\ \mu m$

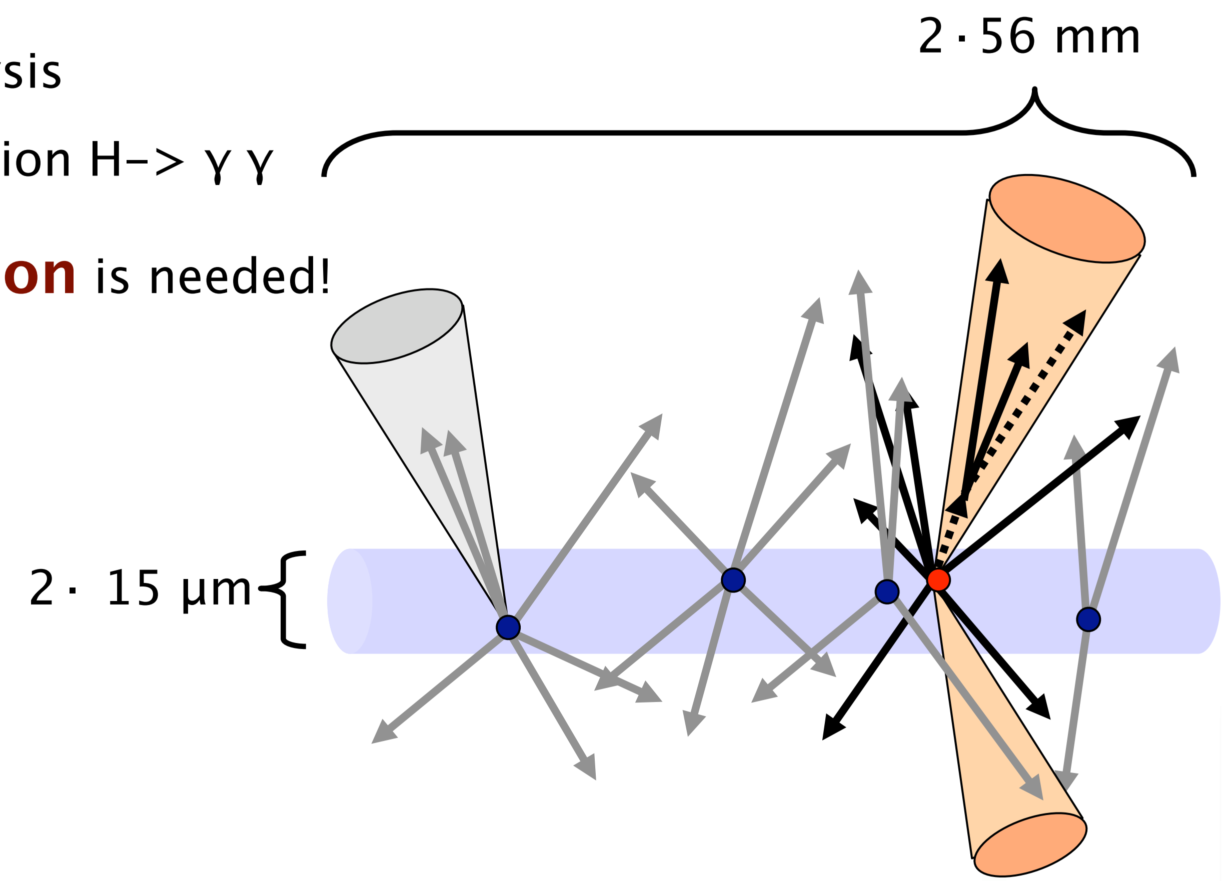
z-position used by physics analysis

e.g. b-tagging, mass resolution H-> γ γ

→ **signal vertex selection** is needed!

my task:

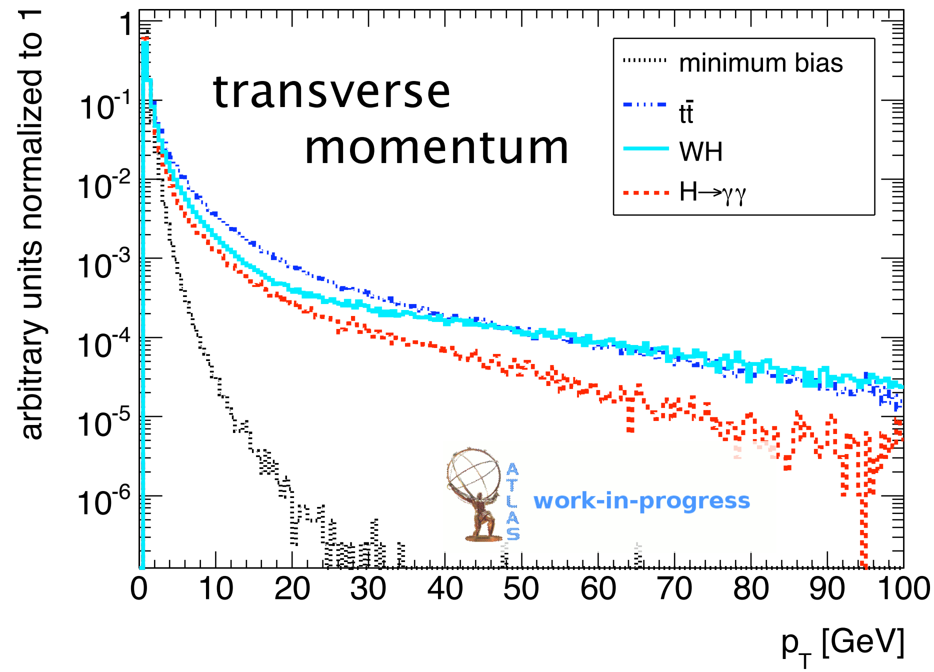
- **development of new vertex selection methods**
- **comparison of different algorithms**

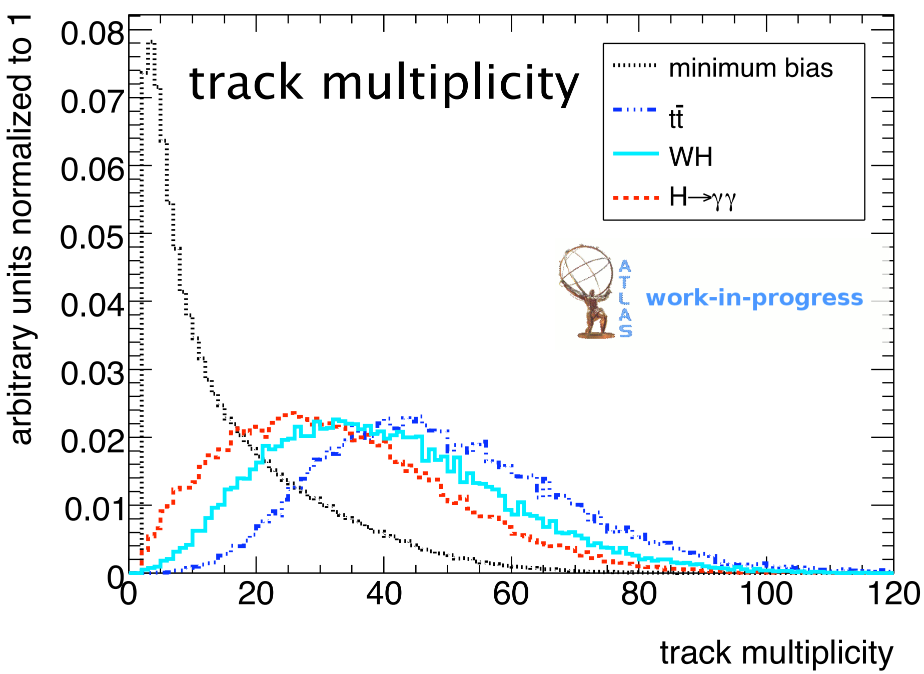


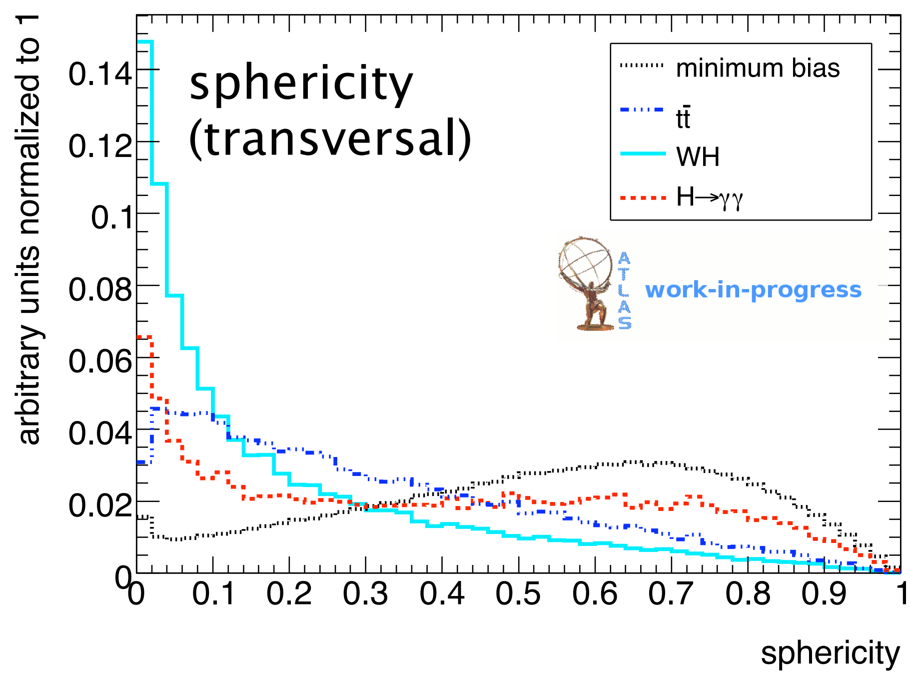
track and vertex properties

signal processes used:

$t\bar{t}$	easy for vertex selection
WH	moderate
$H \rightarrow \gamma\gamma$	challenging





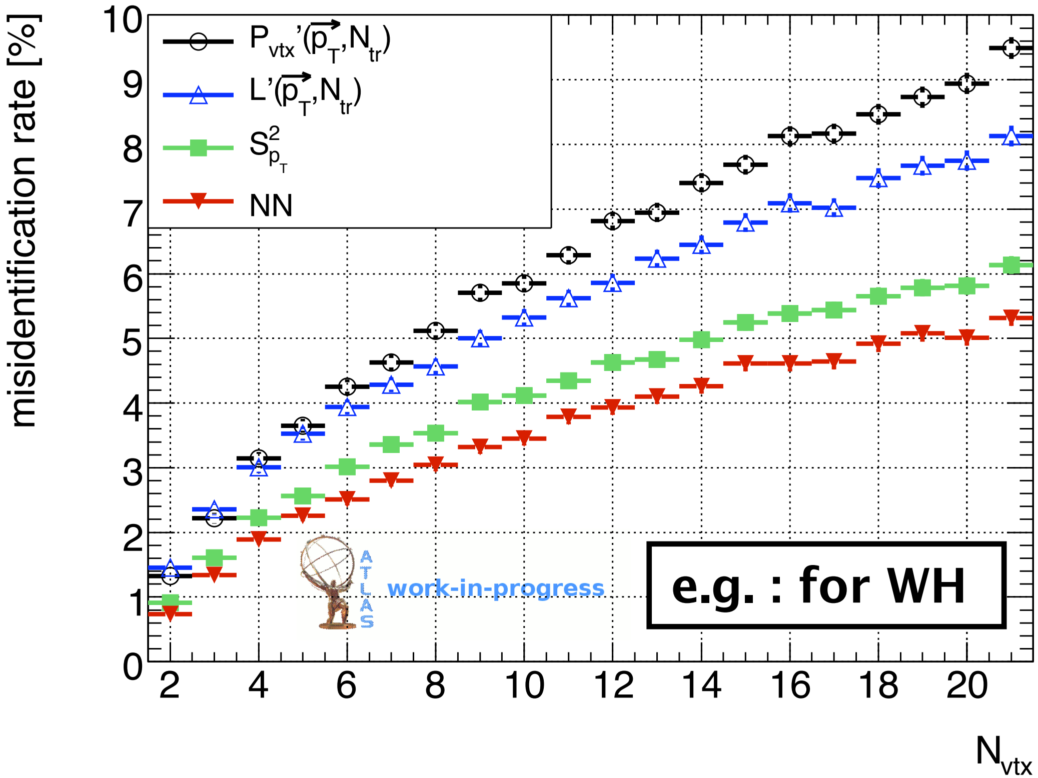


vertex selection methods

- sum of transverse momentum: $$S^2_{p_T} = \sum_{N_{tr}} p_T^2$$
- likelihood ratio: $$L'(\vec{p}_T, N_{tr})$$
- vertex probability: $$P'_{vtx}(\vec{p}_T, N_{tr})$$
  - **advantage**: only minimum bias hypothesis needed!
- neural network $$NN(\mu_j(\vec{p}_T), N_{tr}, \Psi)$$
  - input variables: track multiplicity, sphericity and the moments μ of the p_T distribution

comparing selection methods

misidentification rate (=fraction of events, where the signal was not selected)
vs. vertex multiplicity (N_{vtx})



- likelihood L and vertex probability P_{vtx} not optimal due to correlations
- neural network shows the best performance
- same conclusion for H-> γγ und ttbar

signal vertex selection tool

ATLAS software tool for vertex selection implemented

- vertex selection now independent of primary vertex reconstruction
- so far S_{pT}, P_{vtx} and NN available

misidentification rate on WH sample with $<N_{mb}>$ = 6.9

old method: $\sum p_T^2 \sqrt{N_{tr}}$: 4.5±0.1 %

new tool: $S_{pT}{}^2$: 3.8±0.1 % (now default)

NN : 3.4±0.1 %

misidentification rate of $S_{pT}{}^2$:

ttbar : 0.38±0.02%

WH: 3.8±0.01%

H->γγ: 40±0.5 %

b–tagging algorithms

b–tagging: separation of b–jets from c– and light–jets(u,d,s)

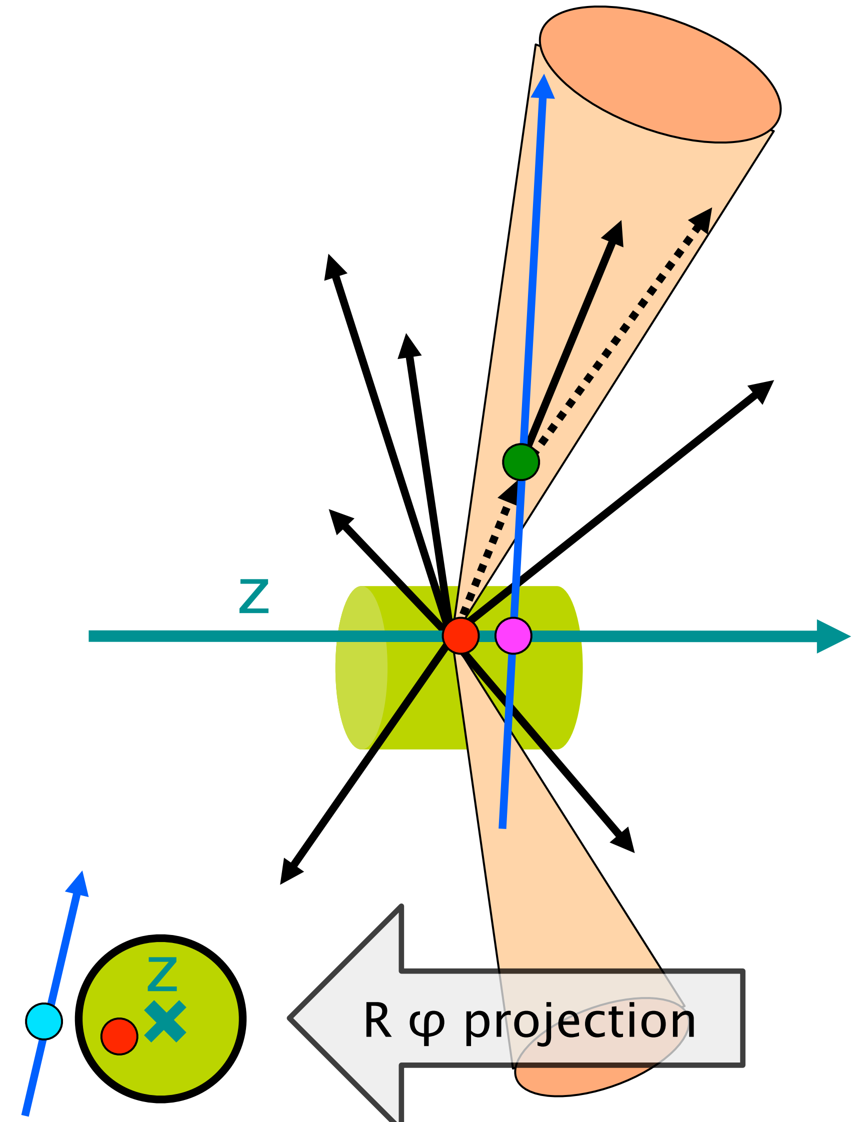
B–hadron characteristic: lifetime τ_B=1.5 ps

->flight length ~3 mm

-> reconstructable secondary vertex (SV)

investigated b–tagging algorithms:

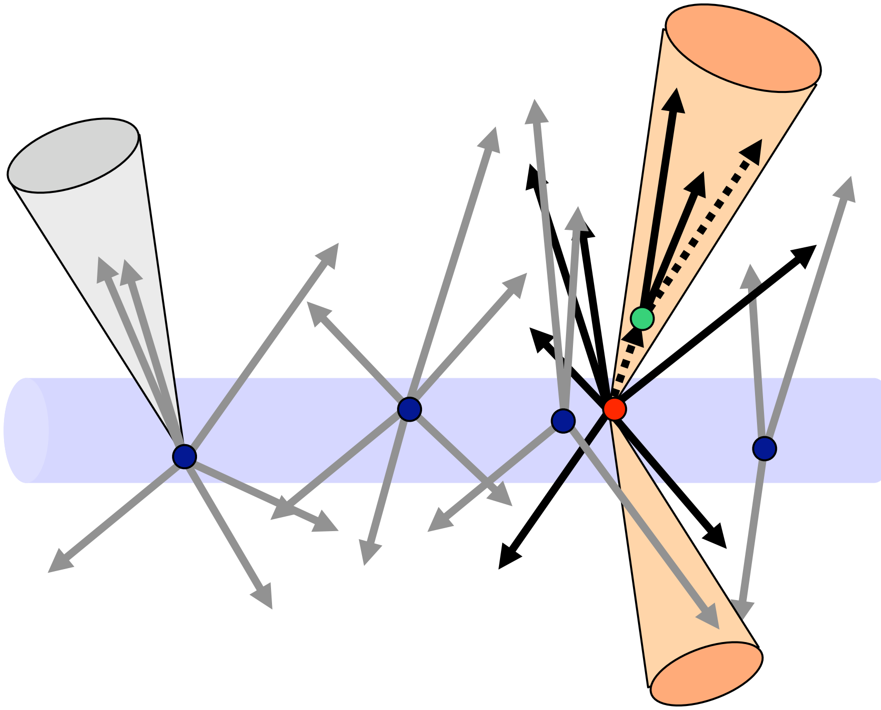
- **IP2D**: based on transversal (| – |) impact parameter
- **IP3D**: based on longitudinal (| – |) and transversal impact parameter
- further SV1 and COMB algorithms studied



pile up and b-tagging

First step of b-tagging:

- track selection to remove minimum bias tracks ($z_{tr} - z_{pv}$)



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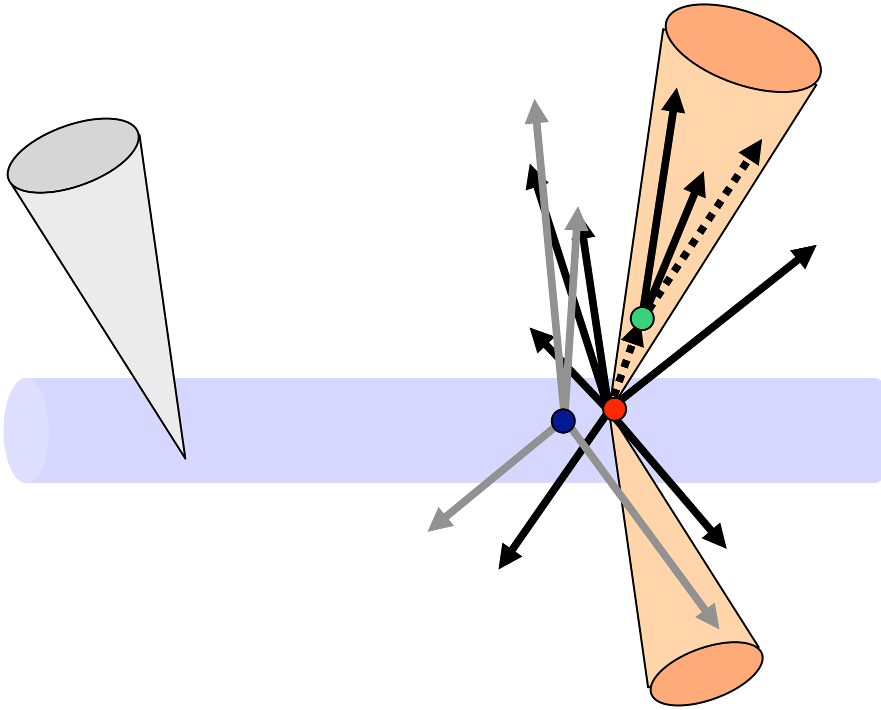


pile up and b-tagging

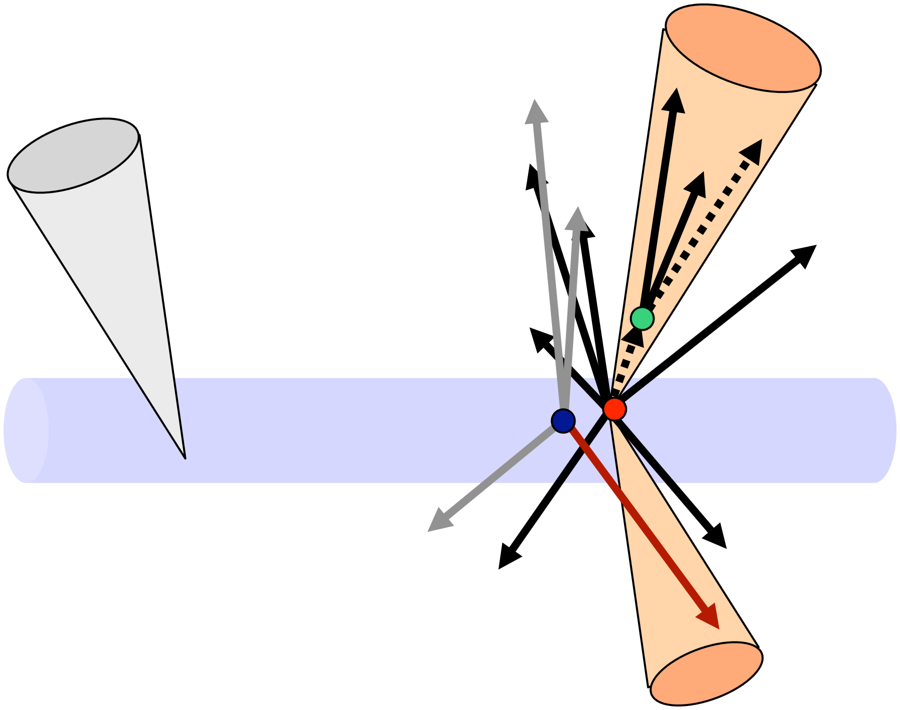
First step of b-tagging:

- track selection to remove minimum bias tracks ($z_{tr}-z_{pv}$)

b-tagging degrades due to:

pile up tracks:

contamination of min. bias tracks in signal jets



pile up and b-tagging

First step of b-tagging:

• track selection to remove minimum bias tracks ($z_{tr}-z_{pv}$)

b-tagging degrades due to:

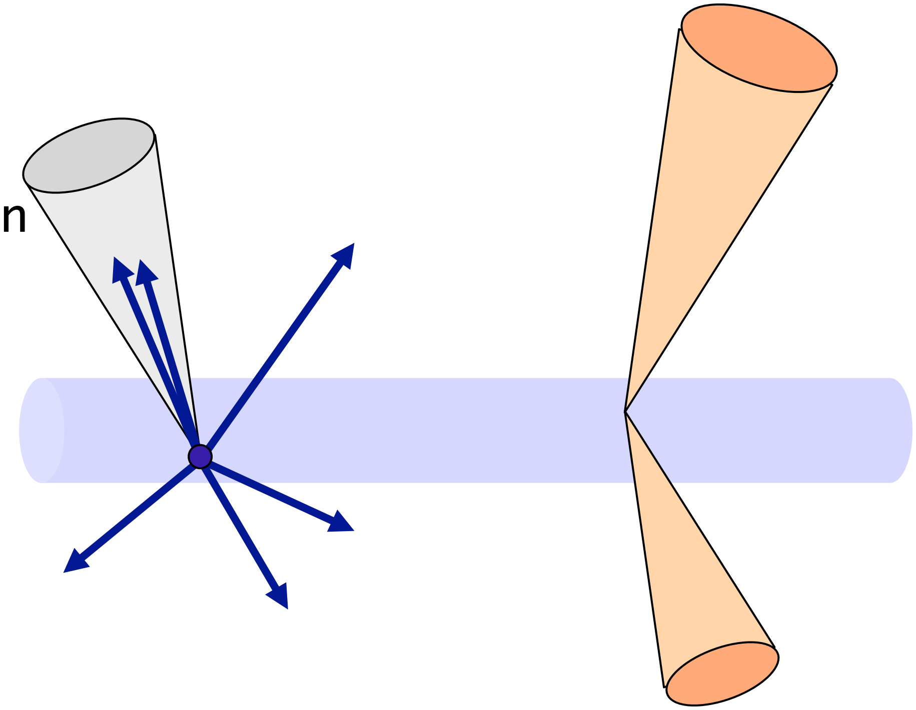
pile up tracks:

contamination of min. bias tracks in signal jets

signal vertex misidentification:

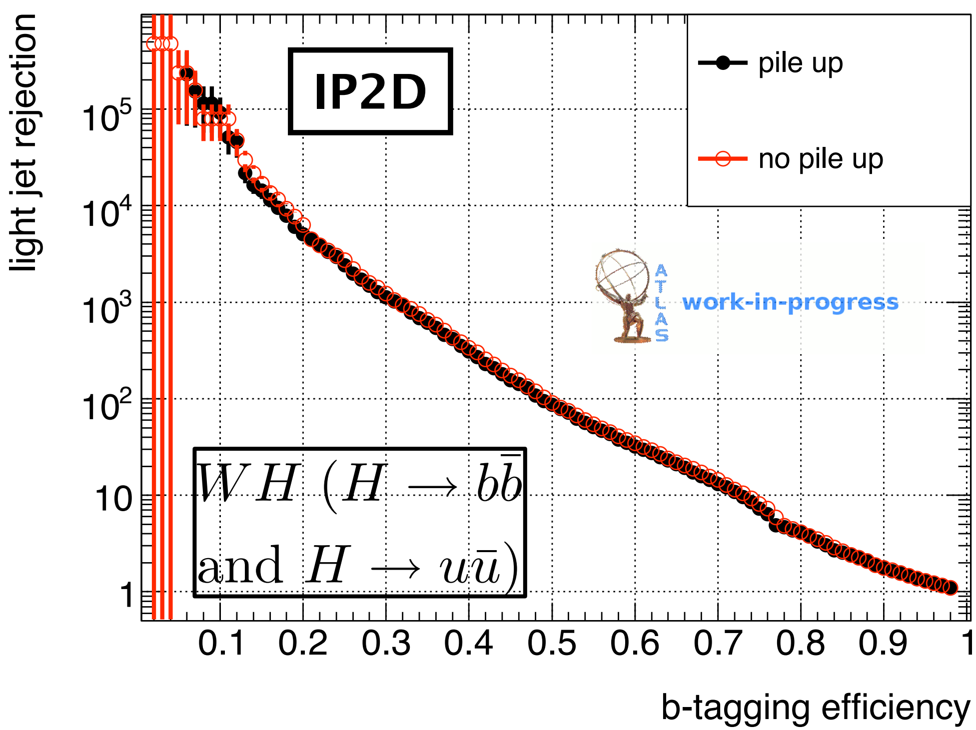
no tracks left in signal jets after track selection

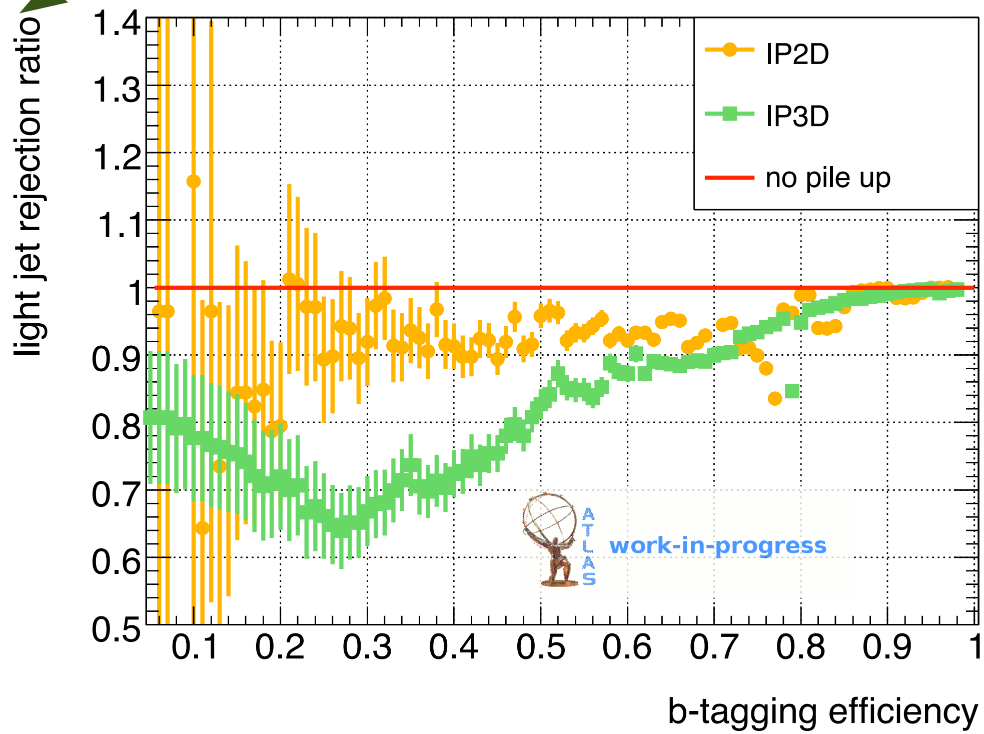
both effects could be studied independently



contamination of pile up tracks

$$\text{light jet rejection ratio} = \frac{\text{light jet rejection in the presence of pile up}(N_{mb} = 6.9)}{\text{non pile up case}}$$



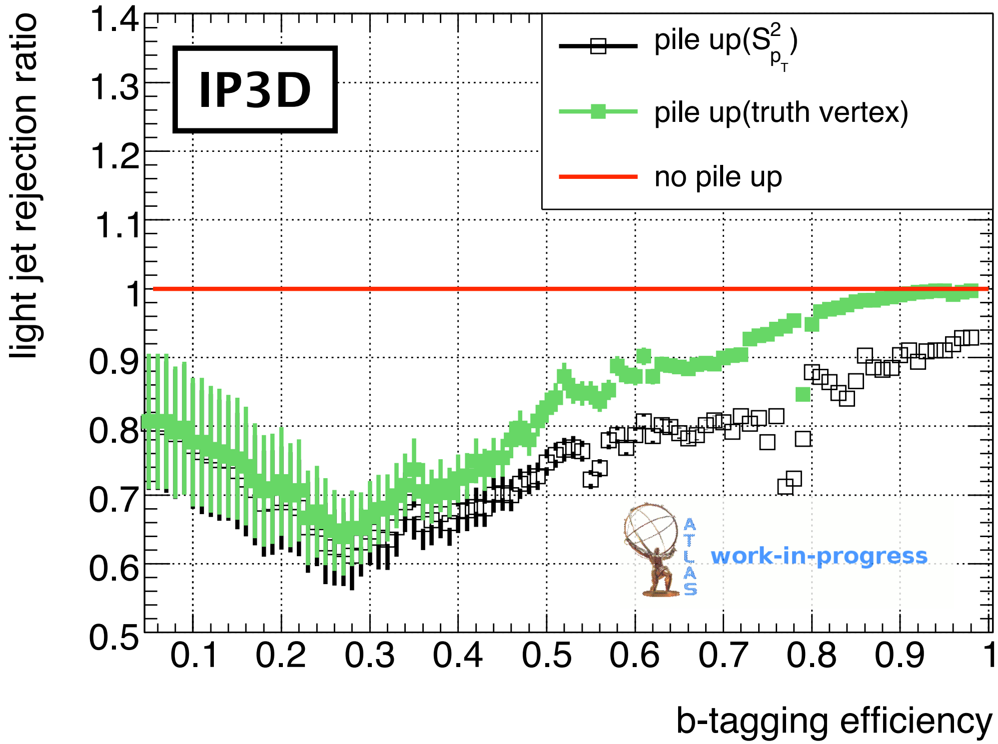


- e.g. for b-tagging efficiency 60%-> light jet rejection degrades ~10%
- IP3D more effected by pile up than IP2D, because min. bias tracks fake lifetime in z-direction, (but overall performance of IP3D is better)

both effects combined

in green: track contamination, but no vertex misidentification

in black: track contamination and vertex misidentification



for a b-tagging efficiency of 60% the light jet rejection degrades additional 10% already for low luminosity!

(reminder: misidentification for WH and <N_{mb}> = 6.9 : 3.8%)

summary

- identification of signal vertex crucial for physics analysis

  e.g. b-tagging

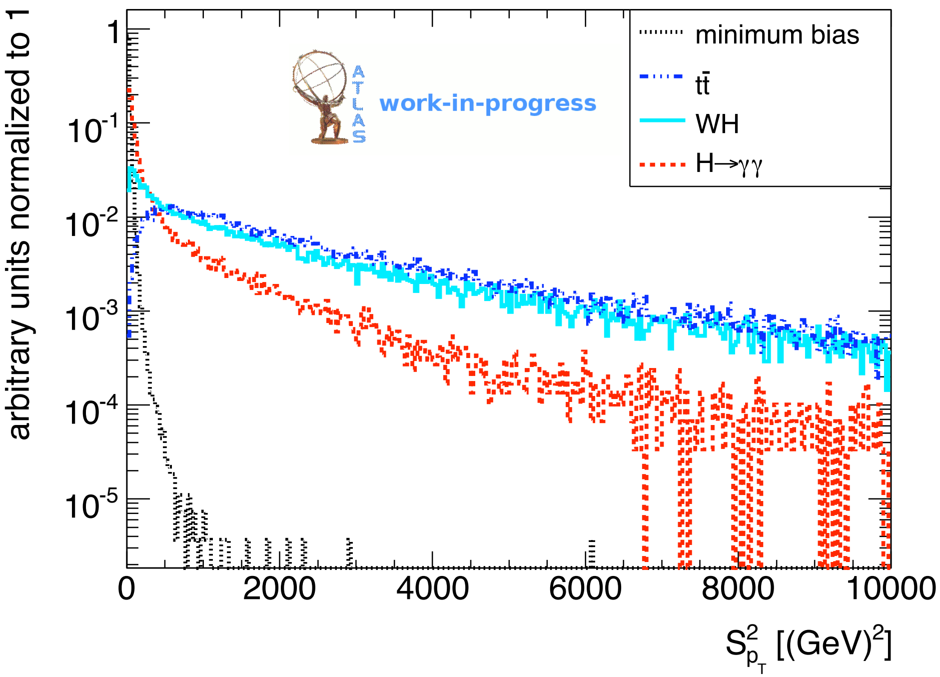
- development of several new methods for signal vertex selection
  - neural network and sum p_T^2 show best performance
  - likelihood and vertex probability not optimal due to correlations
  - tool implemented in official ATLAS Software

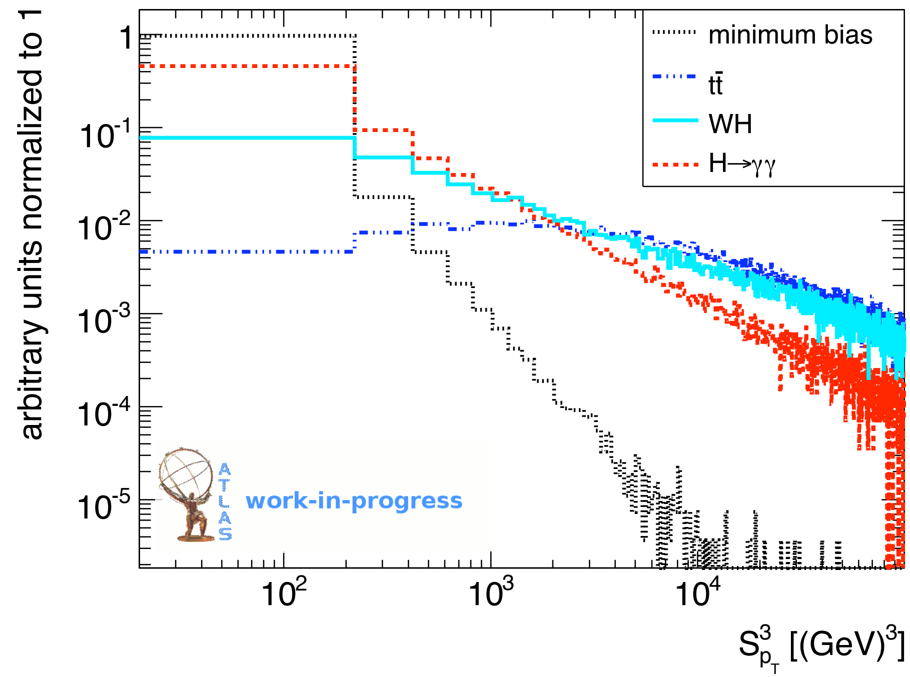
- investigation of b-tagging degradation due to pile up (N_{mb}=6.9)
  - disentanglement of two effects: track contamination and vertex misidentification
  - both effects leave significant impact: ~10% for b-tagging efficiency of 60% already for low luminosity
  - at design luminosity more severe degradation expected

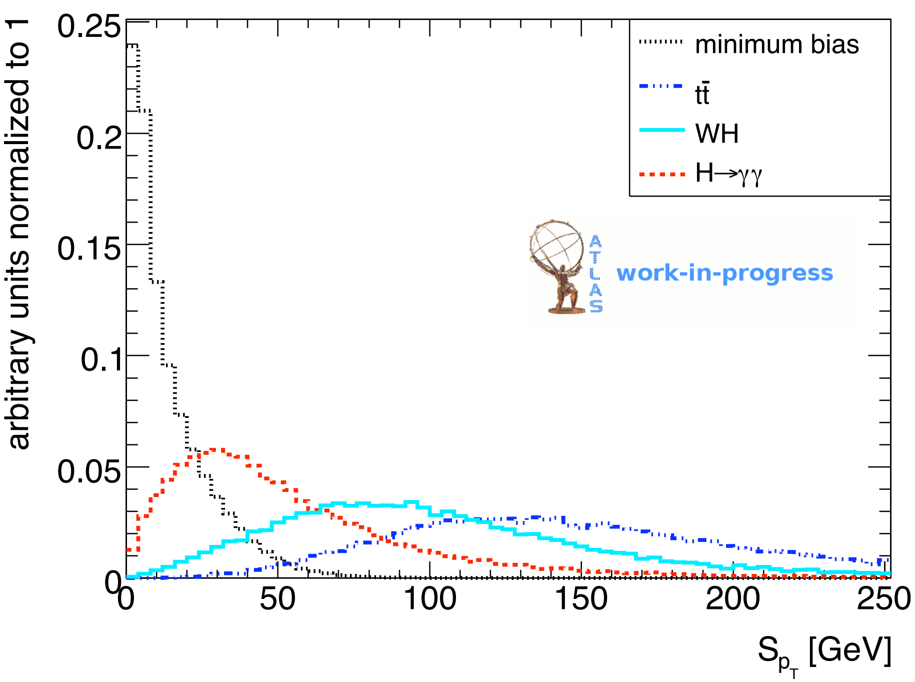
Backup:

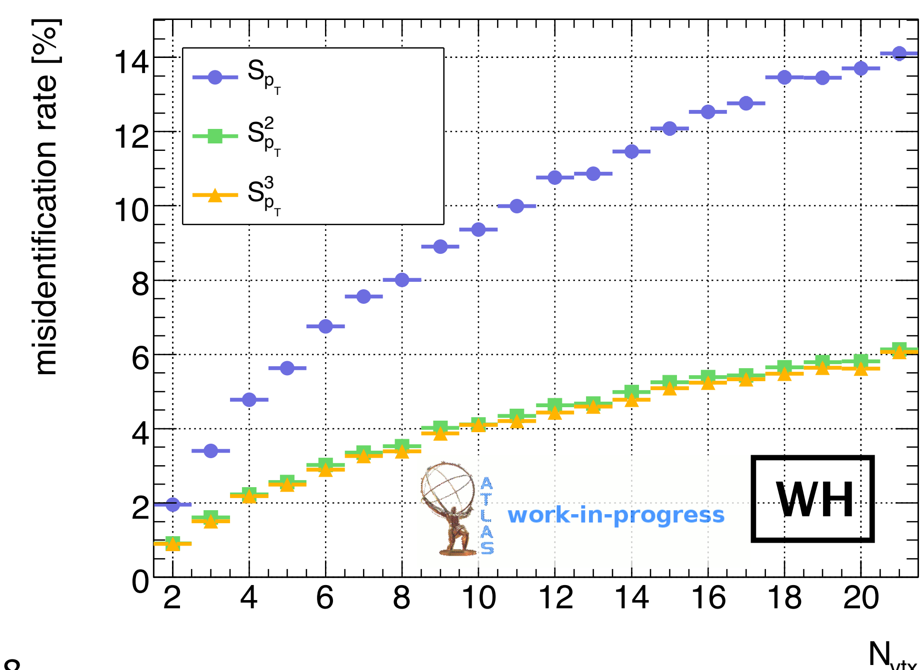
Physikalisches Institut
Albert-Ludwigs-Universität Freiburg

S_{pT} method

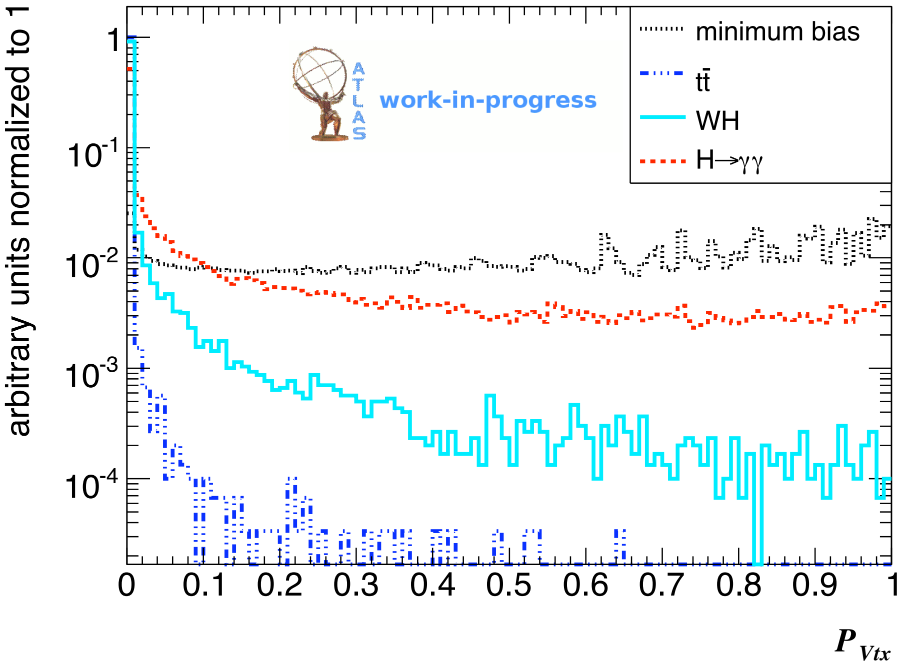


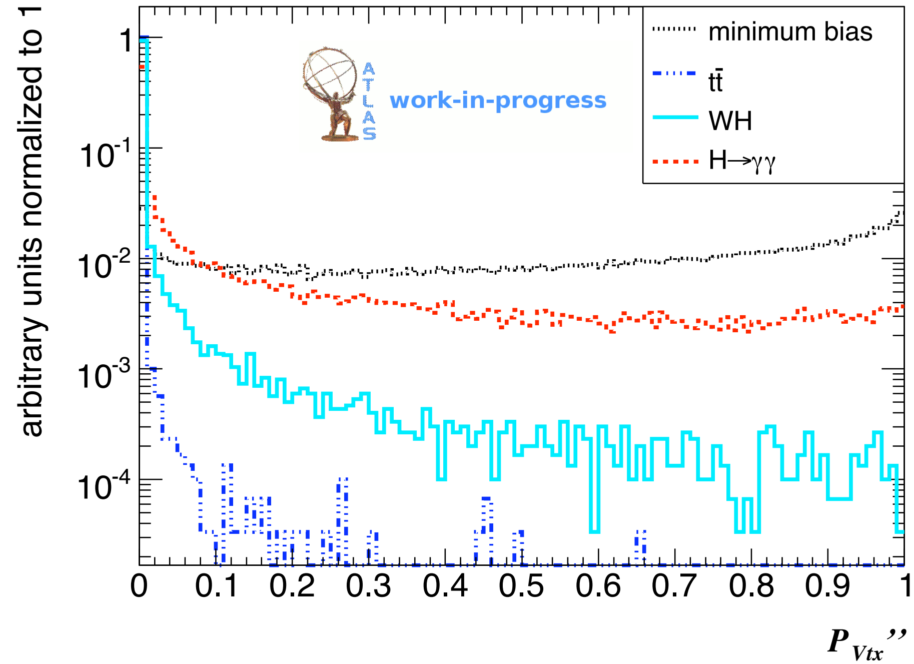






vertex probability





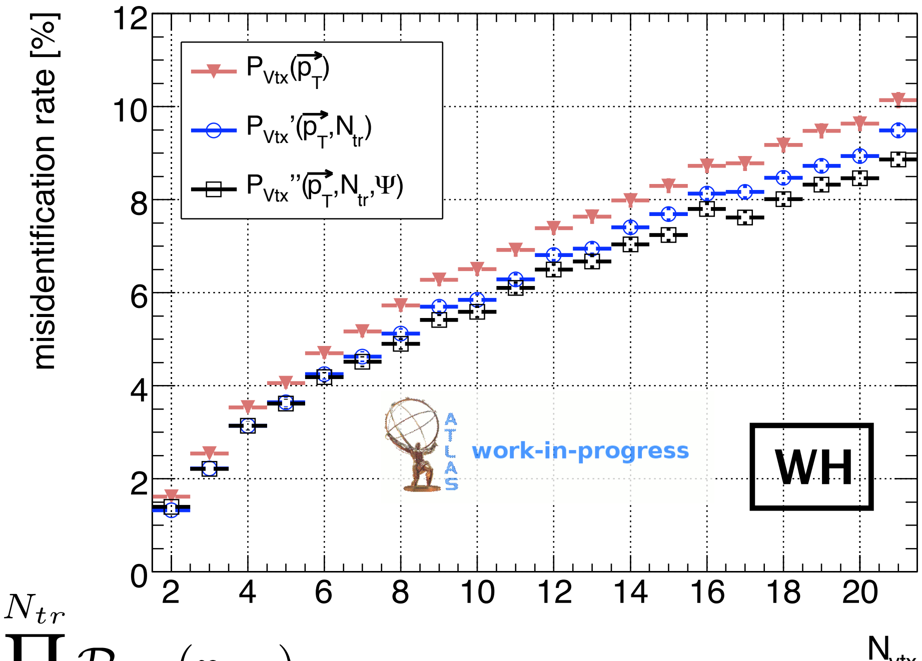
Vertex probability:

1. track compatibility with min. bias hypothesis:

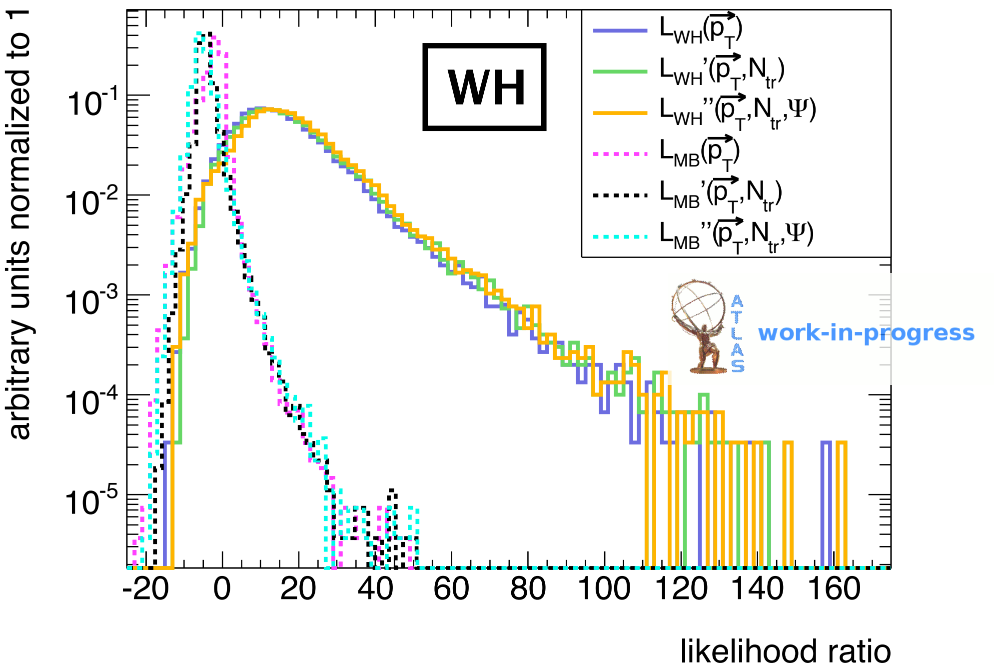
$$\mathcal{P}_{tr,i}(p_{T,i}) = \int_{p_{T,i}}^{\infty} pdf^{mb}(p_T)dp_T$$

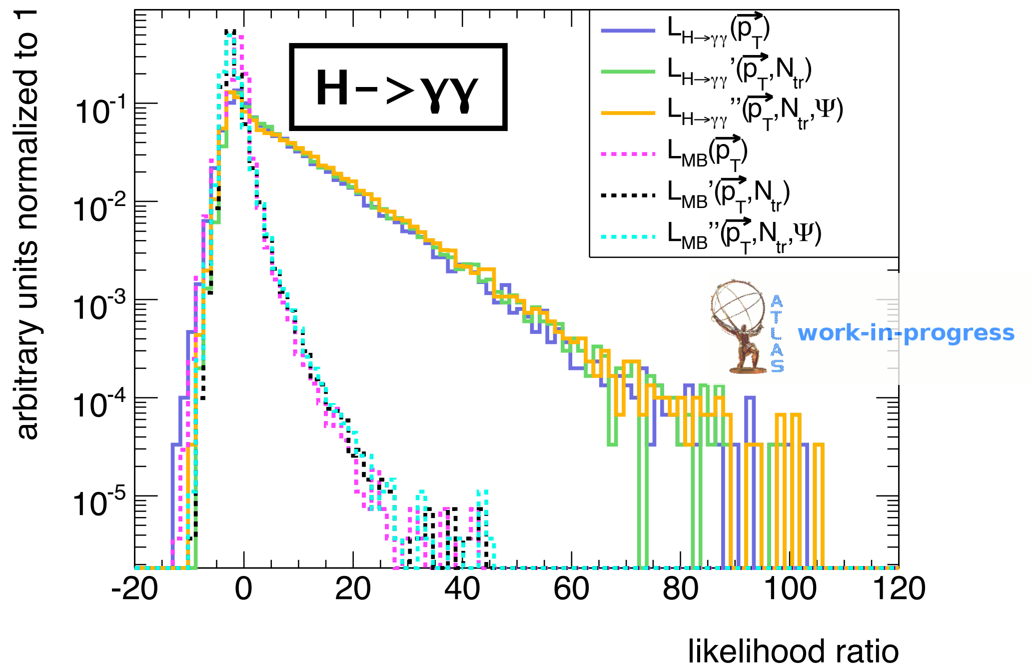
2. probability of a vertex with a set of tracks with $\vec{p}_T = (p_{T,1}, ..., p_{T,N_{tr}})$, to be a min. bias vertex:

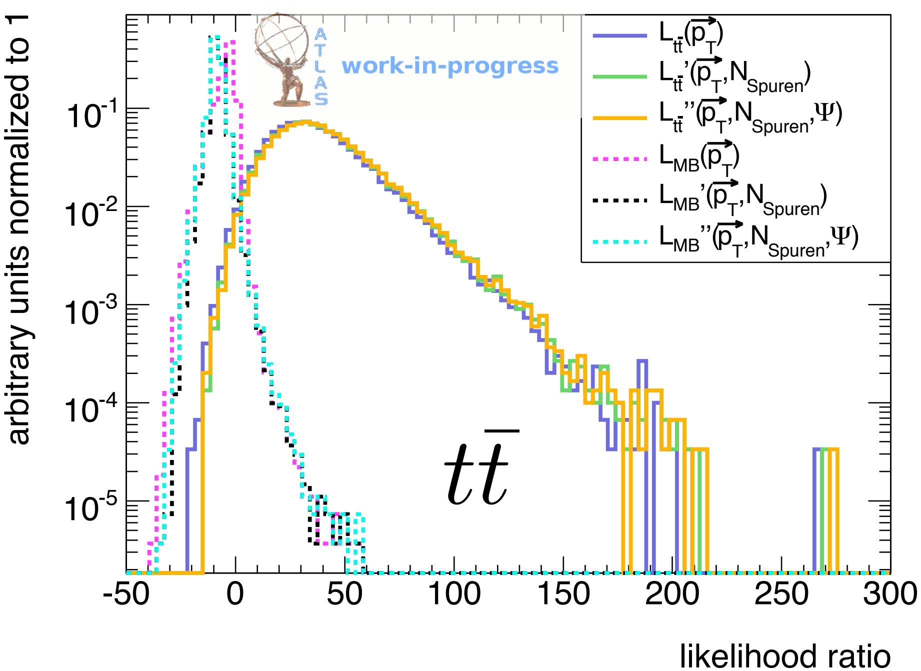
$$\mathcal{P}_{vtx}(\vec{p}_T) = \mathcal{P}_0 \sum_{j=0}^{N_{tr}-1} \frac{(-\ln \mathcal{P}_0)^j}{j!} \quad \text{with: } \mathcal{P}_0 = \prod_{i=1}^{N_{tr}} \mathcal{P}_{tr,i}(p_{T,i})$$

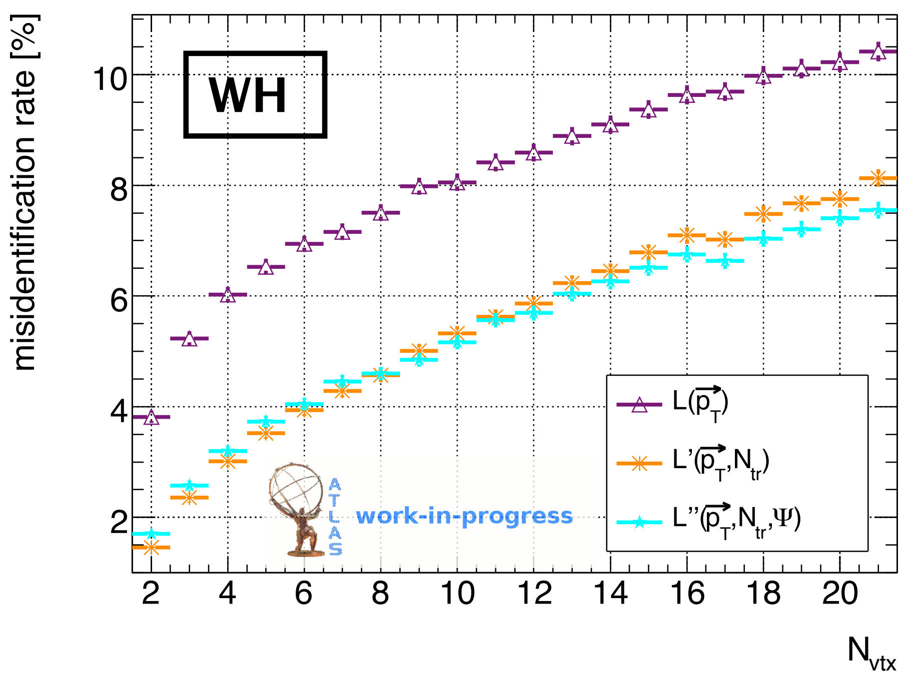


likelihood ratio









NN for vertex selection

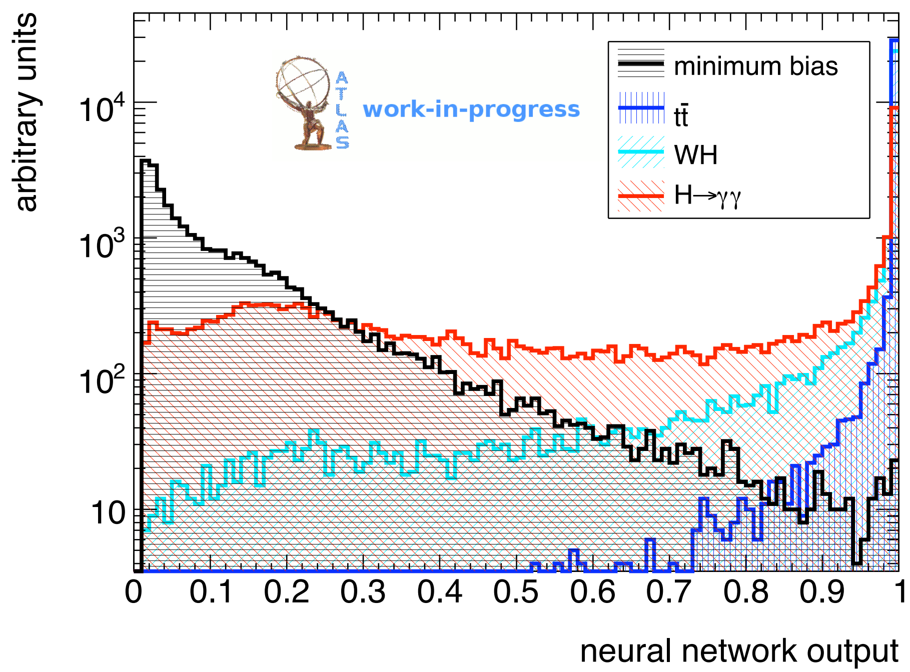
- Neural network:

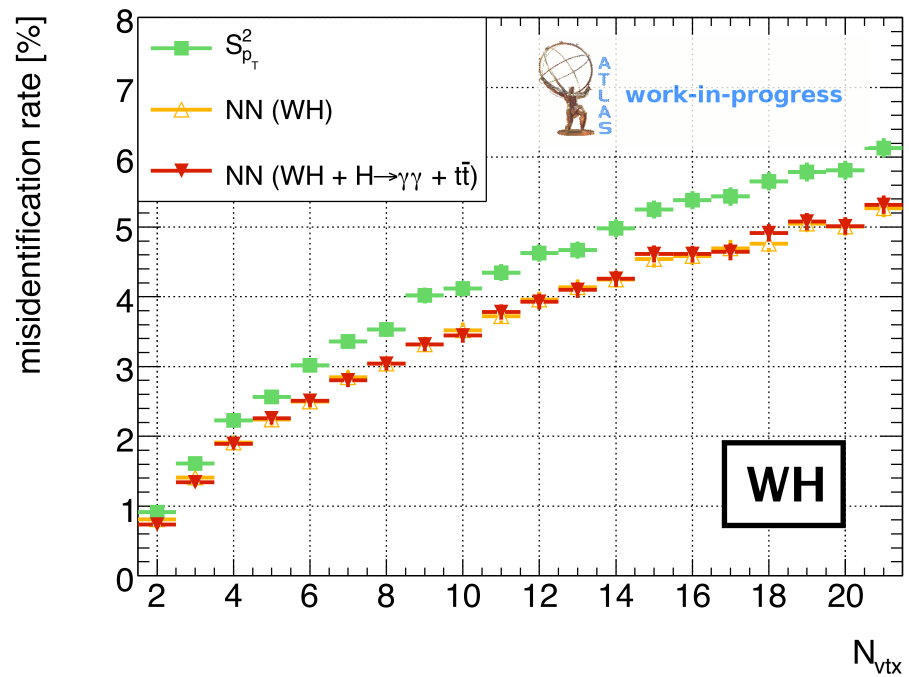
Input variables: Track multiplicity and Sphericity and 10 first moments of p_T-distribution

$$\mu_0 = \frac{1}{N_{tr}} \sum_{i=1}^{Ntr} p_{T,i}$$

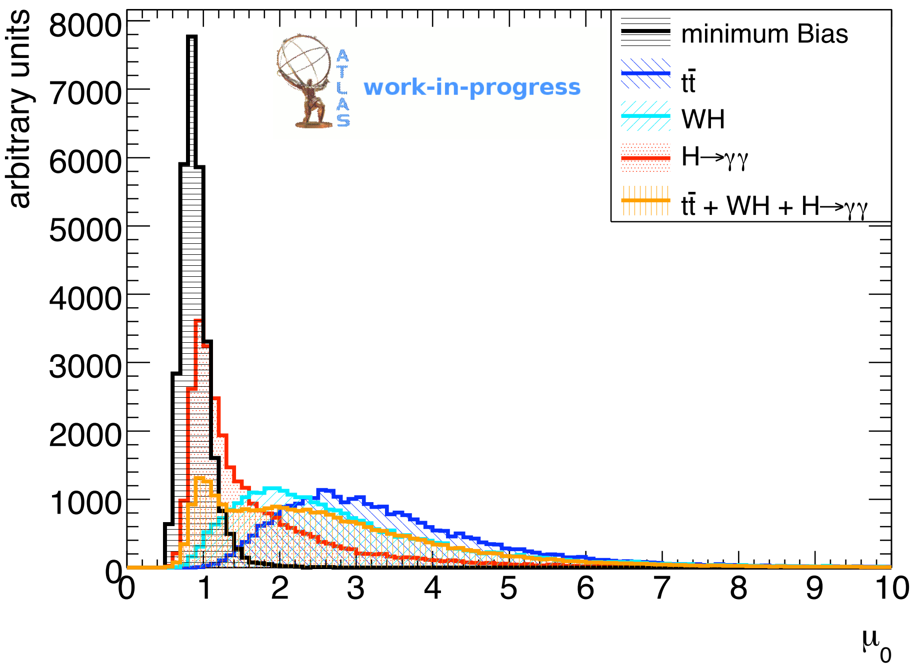
$$\mu_j = \frac{1}{N_{tr}} \sum_{i=1}^{Ntr} (p_{T,i} - \mu_0)^j \quad (j > 0)$$

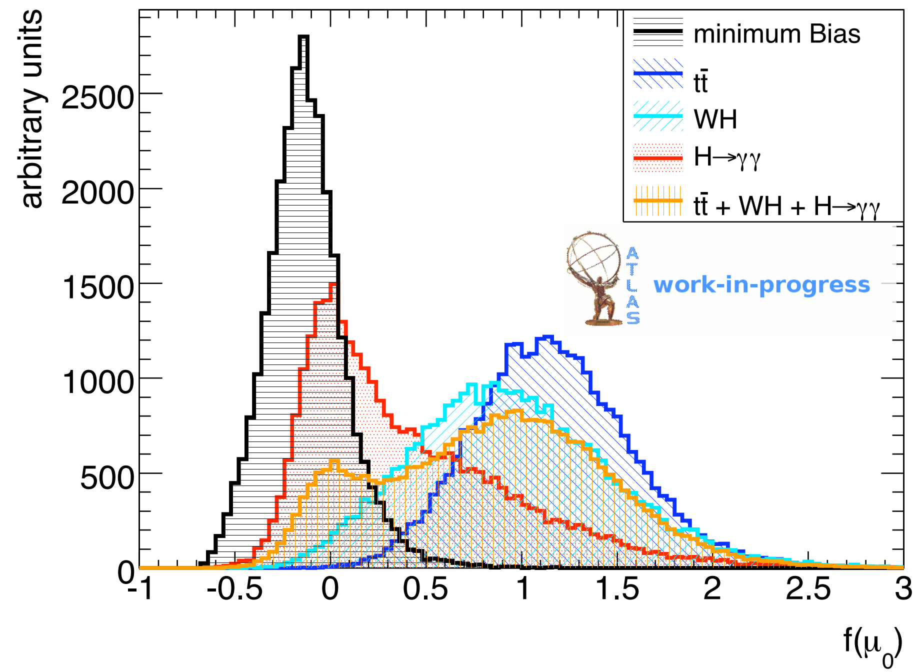
output of signal unspecific network

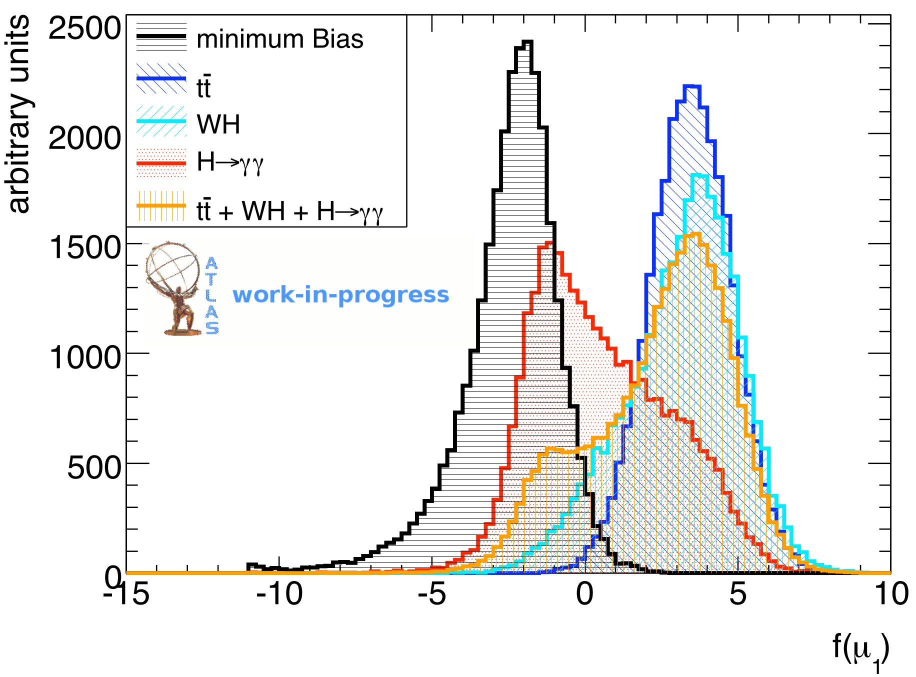


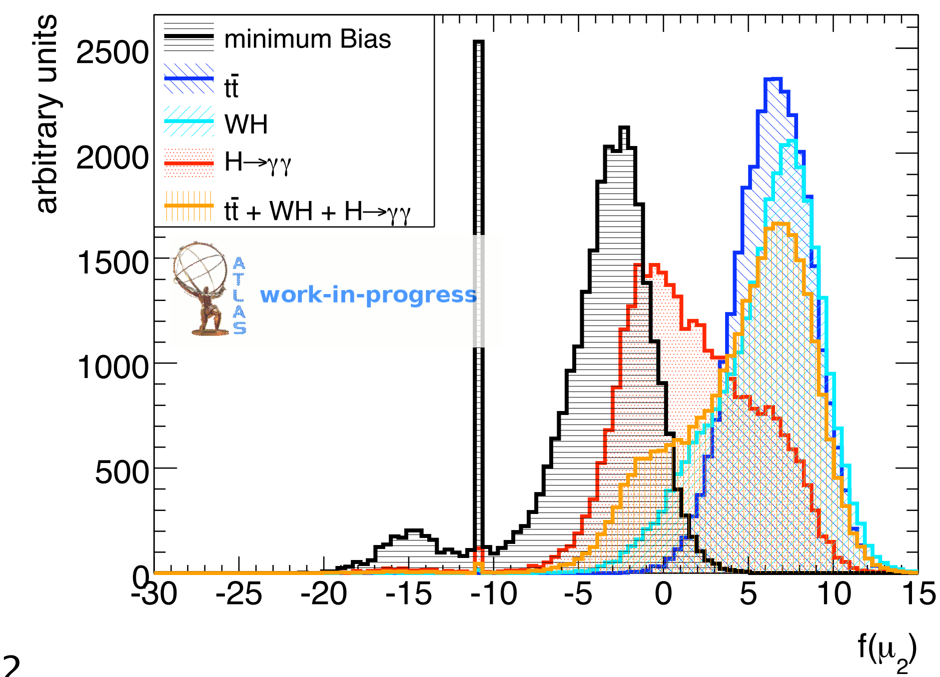


moments of p_T–distribution





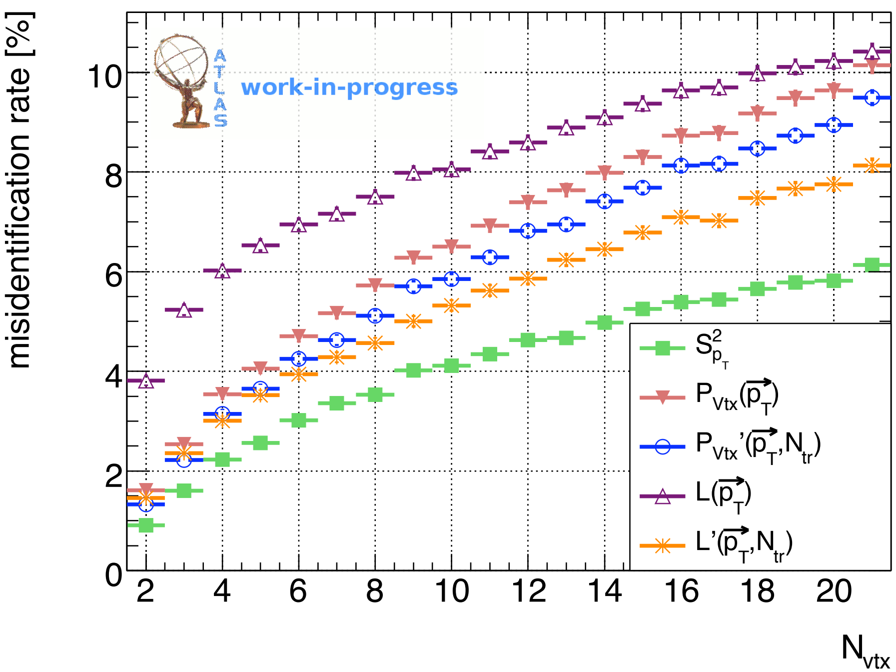




correlation test

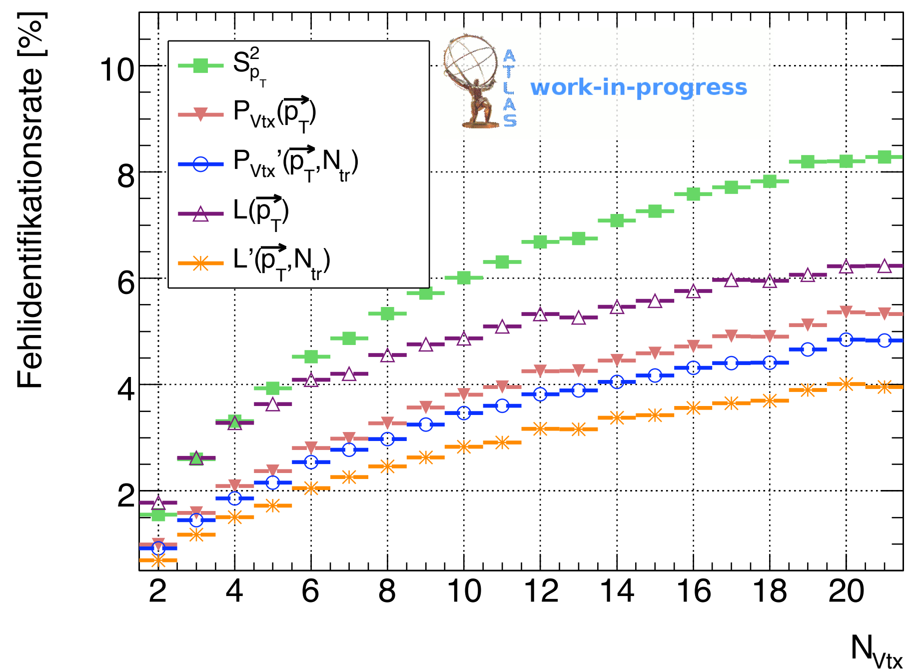
„real“ simulated vertices:

here correlation possible



Monte-Carlo toy studie:

uncorrelated input variables!

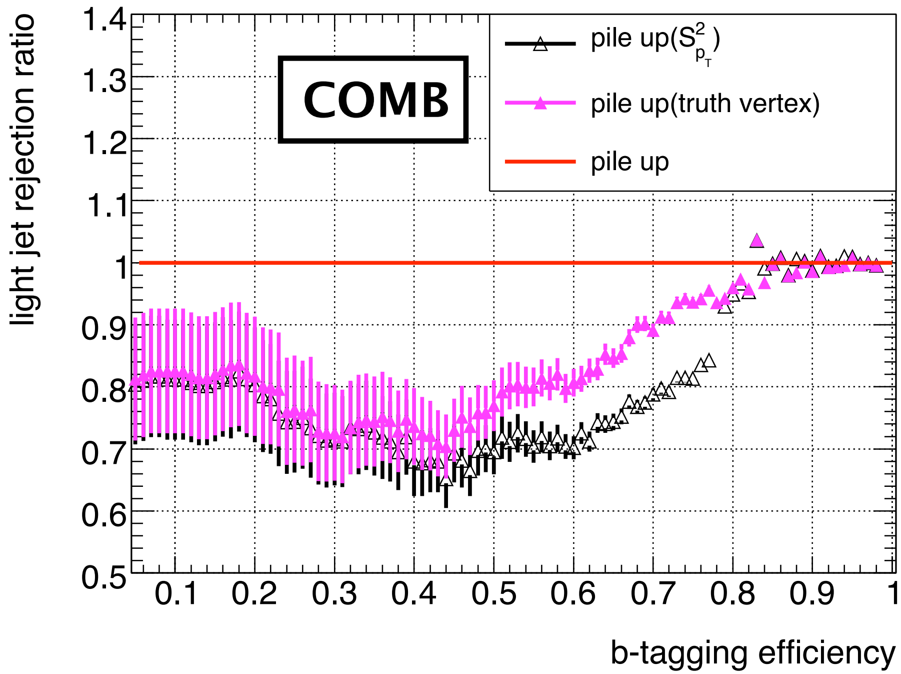


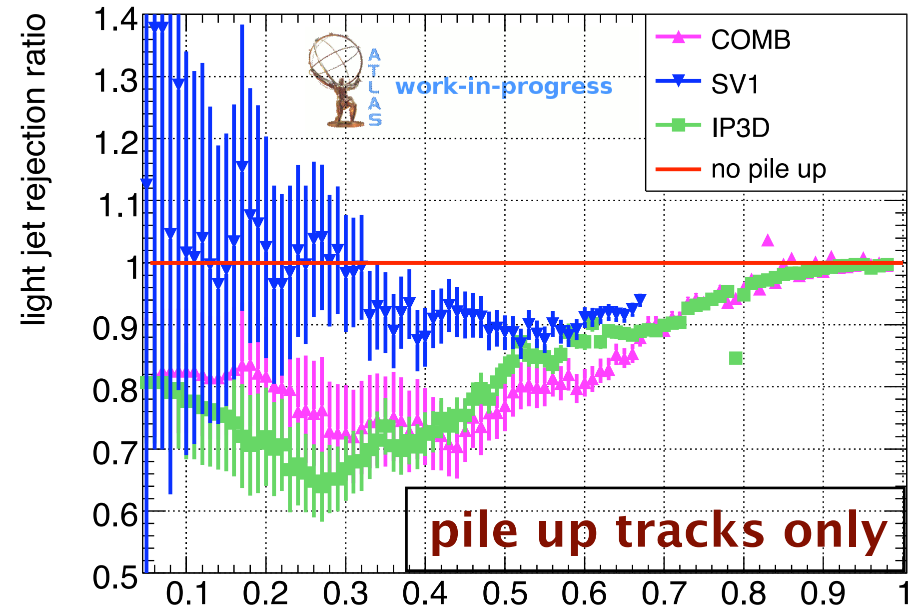
final vertex selection results

Misidentification rate:

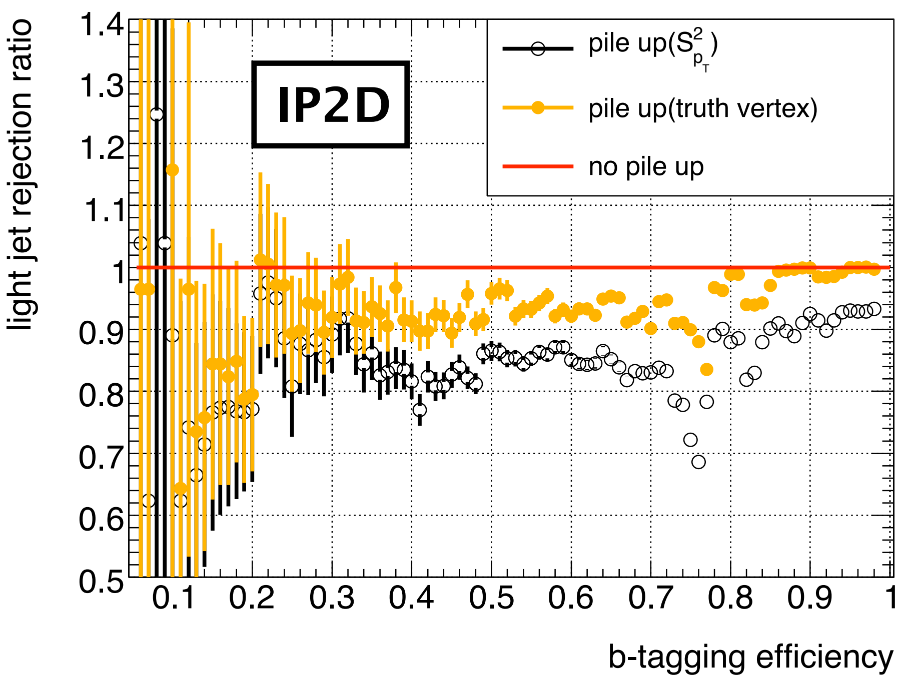
	N_{mb}	$\sum p_T^2 \cdot \sqrt{N_{tr}}$	$\mathcal{P}_{Vtx}(\vec{p_T})$	$\mathcal{S}^2_{p_T}$	NN
$t\bar{t}$	4.1	$(0.33 \pm 0.01)\%$	$(0.42 \pm 0.02)\%$	$(0.24 \pm 0.01)\%$	$(0.20 \pm 0.01)\%$
	6.9	$(0.49 \pm 0.02)\%$	$(0.63 \pm 0.02)\%$	$(0.38 \pm 0.02)\%$	$(0.32 \pm 0.02)\%$
WH	4.1	$(3.2 \pm 0.1)\%$	$(4.0 \pm 0.1)\%$	$(2.7 \pm 0.1)\%$	$(2.5 \pm 0.1)\%$
	6.9	$(4.5 \pm 0.1)\%$	$(5.6 \pm 0.1)\%$	$(3.8 \pm 0.1)\%$	$(3.4 \pm 0.1)\%$
$H \rightarrow \gamma\gamma$	4.1	$(23.1 \pm 0.2)\%$	$(28.9 \pm 0.2)\%$	$(22.2 \pm 0.2)\%$	$(21.9 \pm 0.2)\%$
	6.9	$(43.3 \pm 0.5)\%$	$(42.9 \pm 0.5)\%$	$(40.4 \pm 0.5)\%$	$(37.9 \pm 0.5)\%$

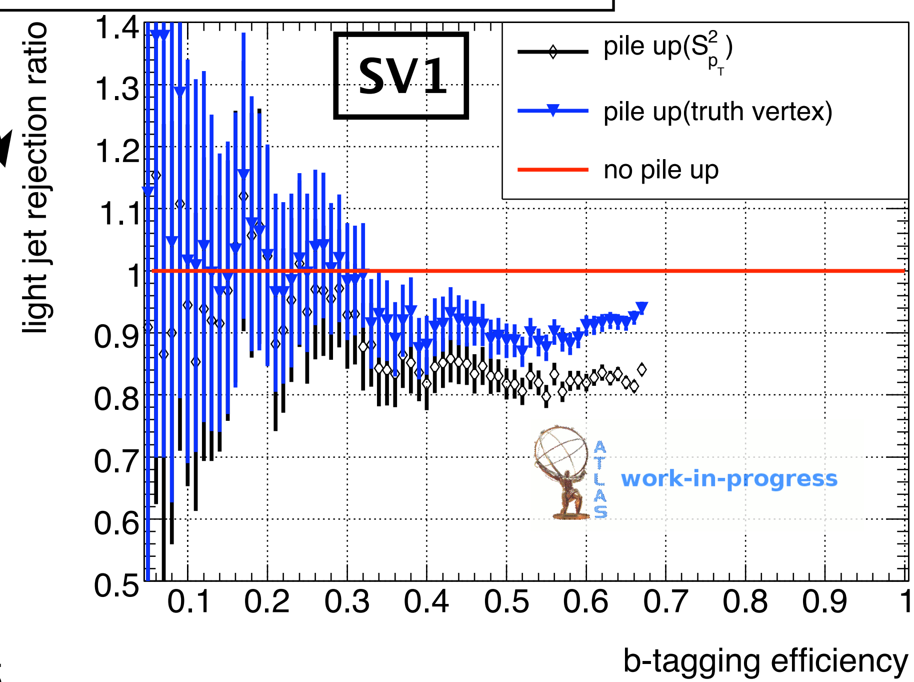
b-tagging plots



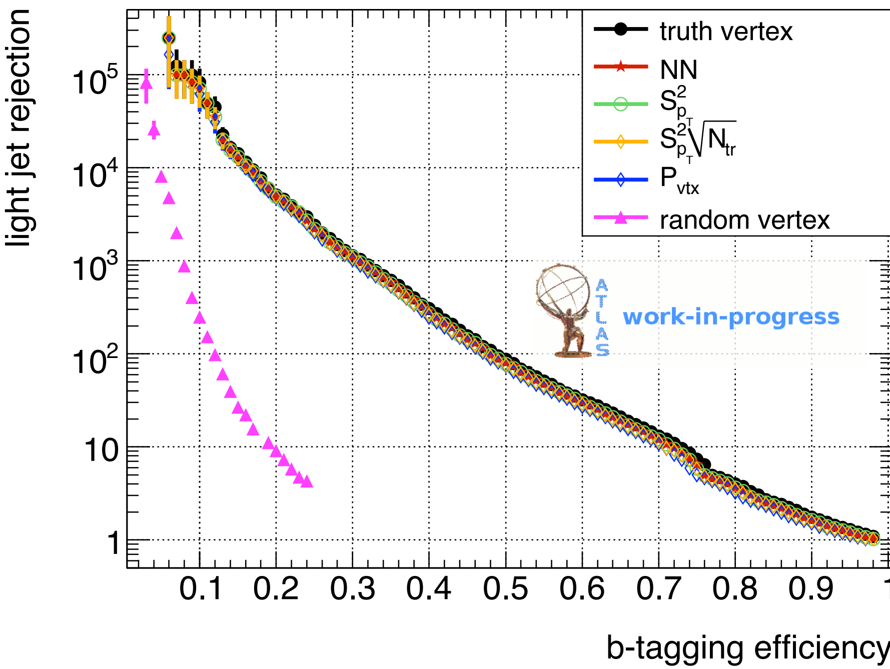


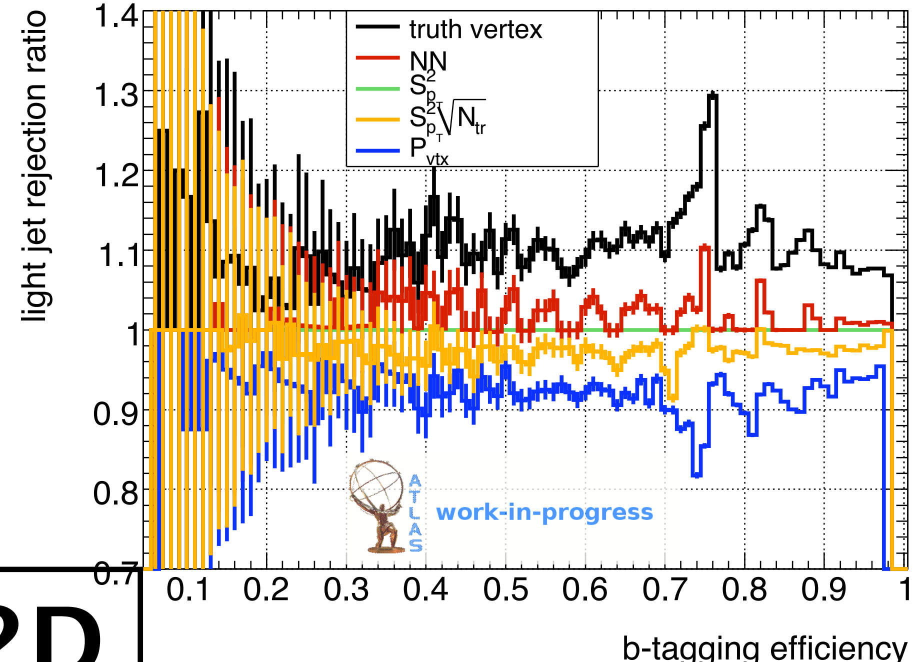
pile up tracks and vtx. misid.





some more b-tagging plots





IP2D