Vertex Finding in Pile-up Rich Events for pp and dAu Collisions at STAR

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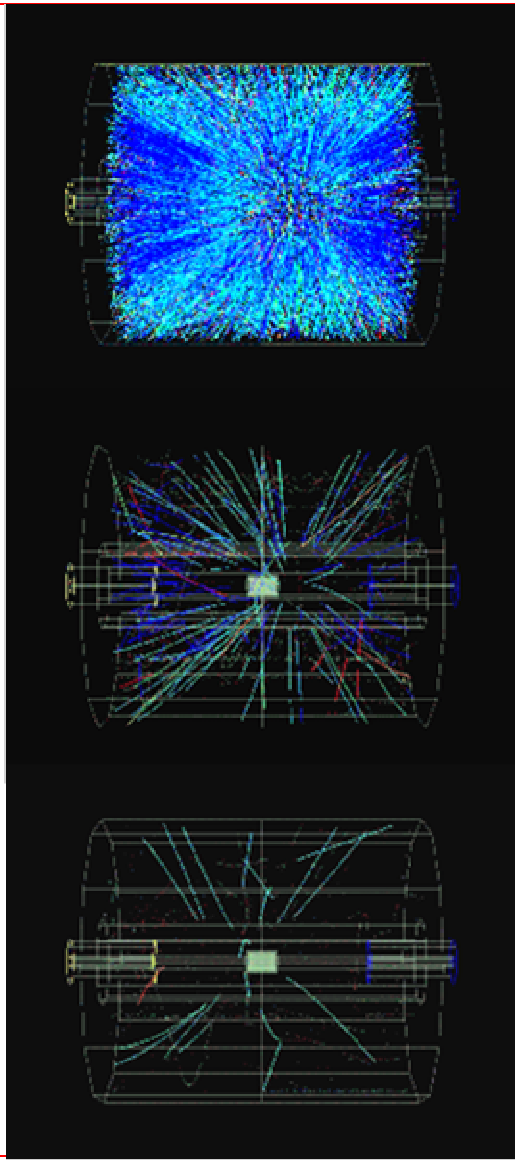
Outline

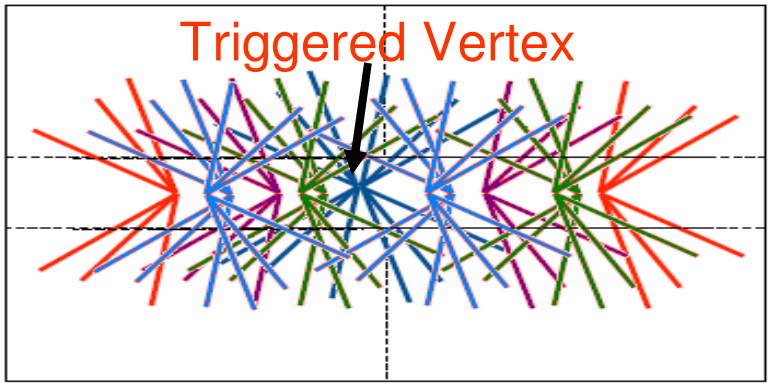
- Introduction
- Description of STAR detectors
- Vertexing Methods and Challenges
  - pp
  - dAu and AuAu
- Evaluation of algorithms on 2008 data

Introduction

- Vertex location is key for the determination of many physics variables in all collisions
- Challenge: high luminosity + long detector readout time records multiple vertices/event
- In 2008 STAR used 2 approaches to find the triggered vertex
  - Pile-Up Proof Vertexer (PPV) in pp
  - "Minuit based" Vertexer (MinuitVF) in dAu and AuAu

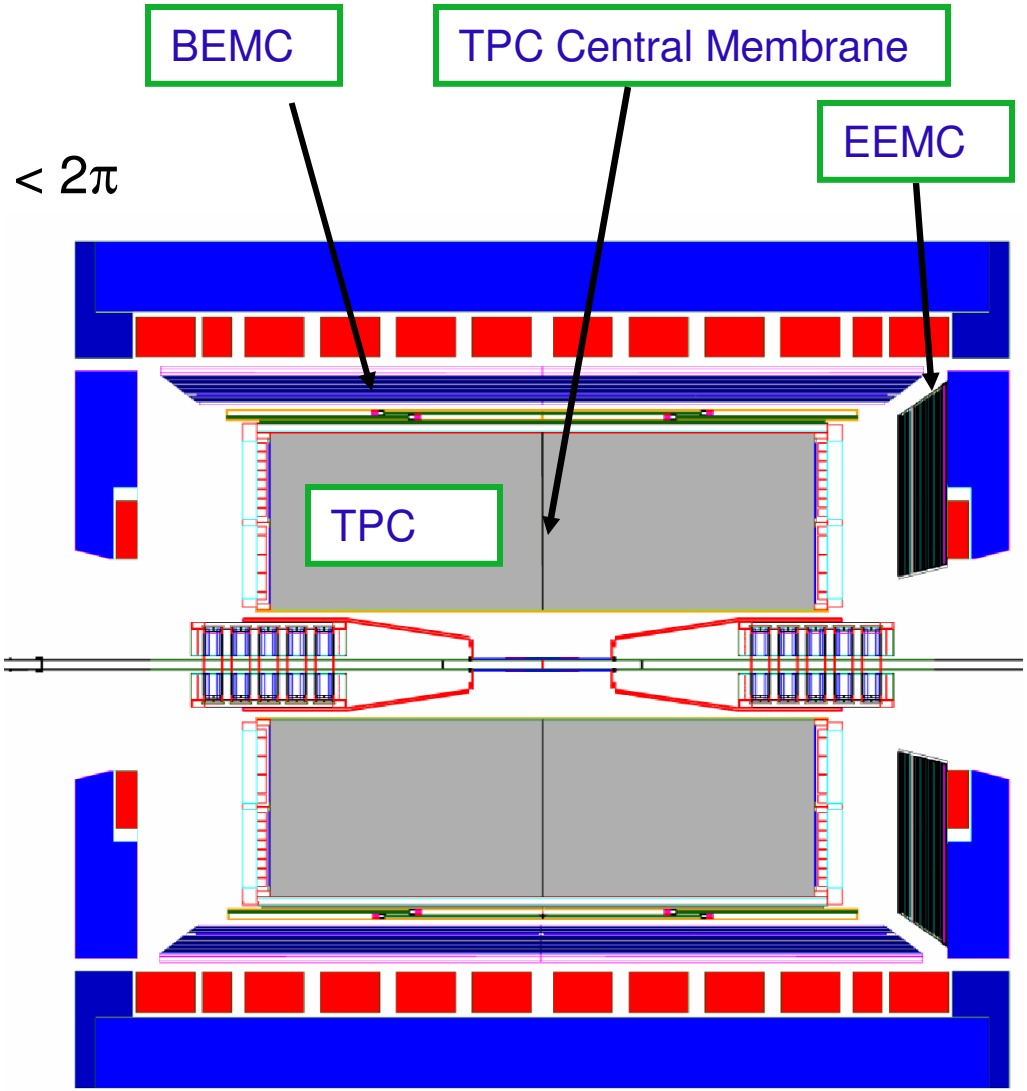


Cartoon of pile-up vertices in the STAR detector



STAR TPC and EMC

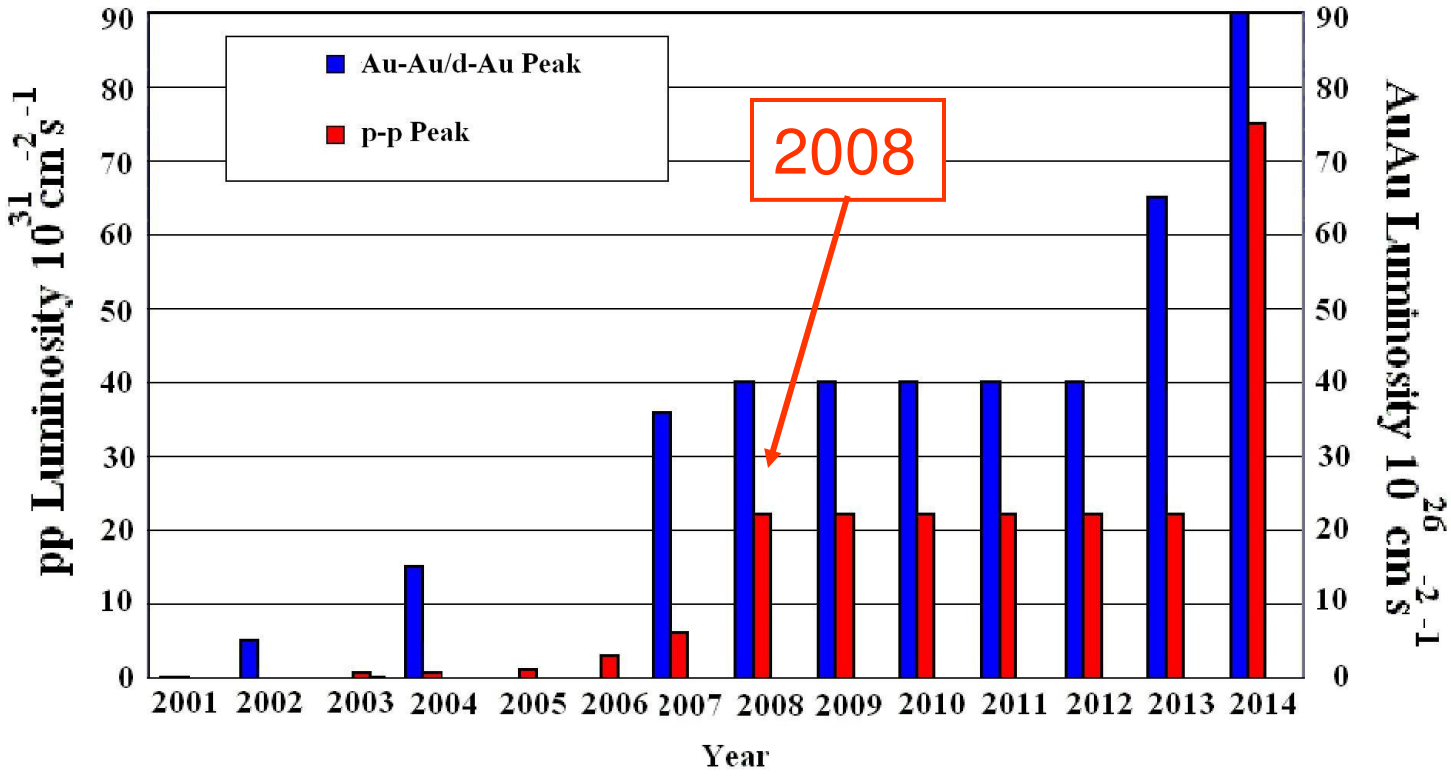
- Barrel Electromagnetic Calorimeter (BEMC)
  - Acceptance: $|\eta| < 1$, $0 < \phi < 2\pi$
  - Fast Detector ~μs to clear detector
- Time Projection Chamber (TPC)
  - Acceptance: $|\eta| < 1.8$, $0 < \phi < 2\pi$
  - Slow Detector ~ 80 μs
- EMC End Cap (EEMC)
  - Acceptance: $1.1 < |\eta| < 2$, $0 < \phi < 2\pi$



Collision Rates and Multiplicity

As luminosity increases

# of Vertices in the TPC increases



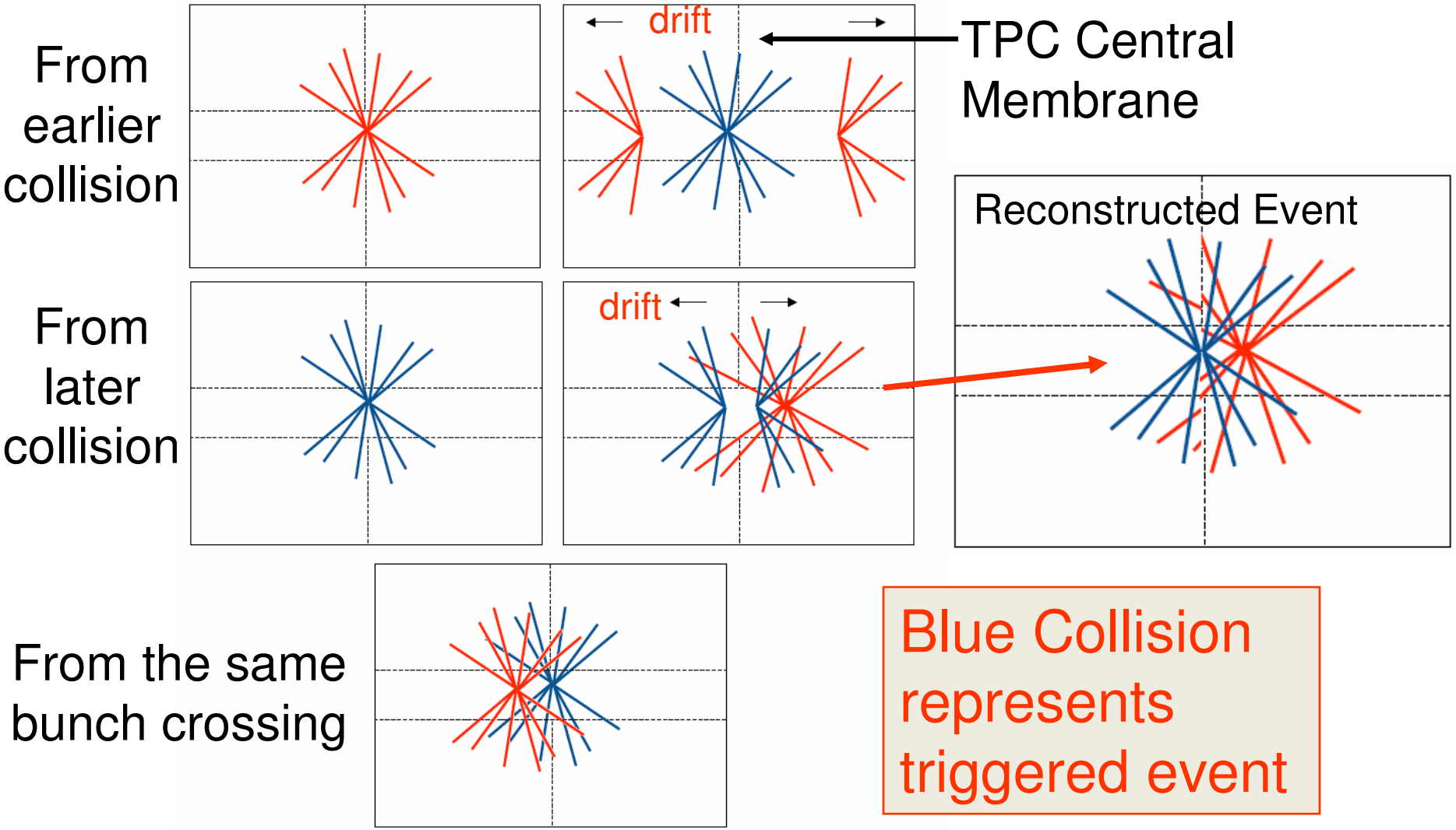
dAu 2008

- Collision Rate is ~200-300 kHz
- ~20 collisions in the TPC
- # Tracks in Unit Rapidity ~11-13

pp 2008

- Collision Rate is ~400-500 kHz
- ~36 collisions in the TPC
- # Tracks in Unit Rapidity ~3-4

Pile-Up in STAR TPC

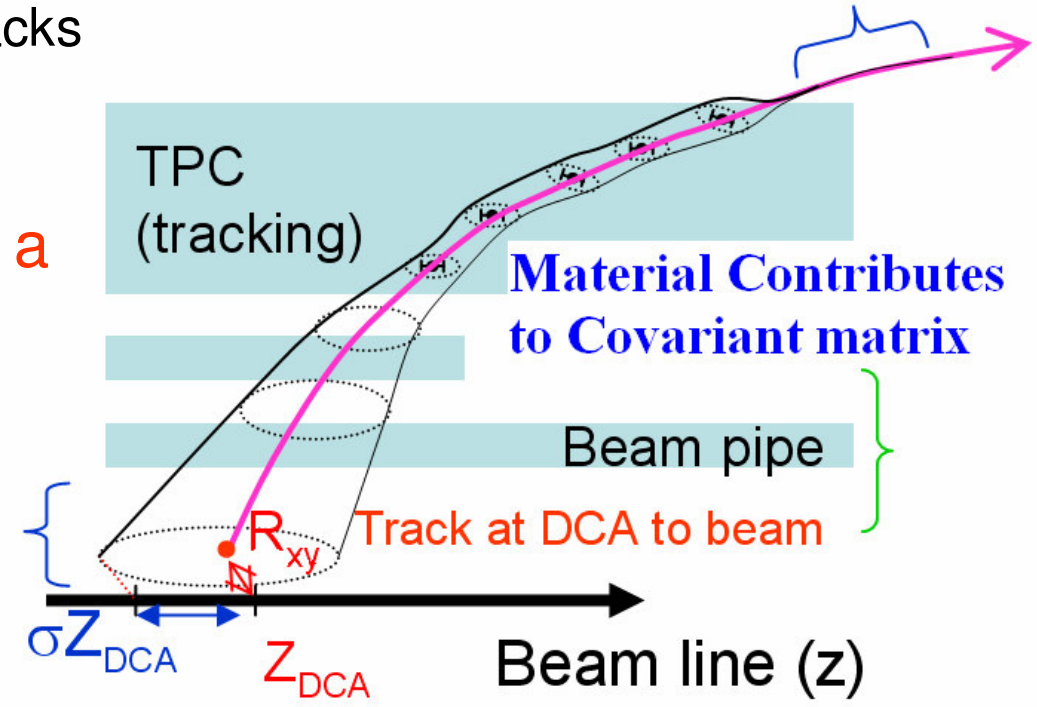


PPV Method

- From each event "Good" tracks are selected
  - Within 3 cm of the beamline
  - Minimum Track pT = 0.20 GeV/c
  - Min TPC Fit fraction = 0.7
    - Removes Pile-Up Tracks

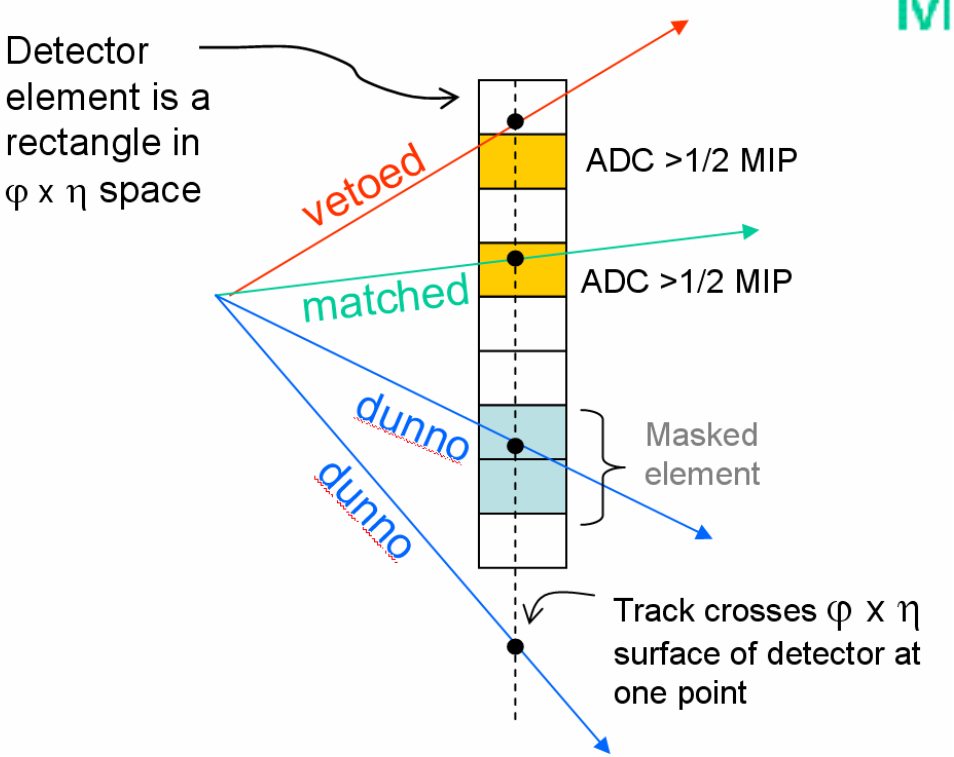
Beam Line is a linear equation in x,y,z based on a first pass unconstrained vertexing fit

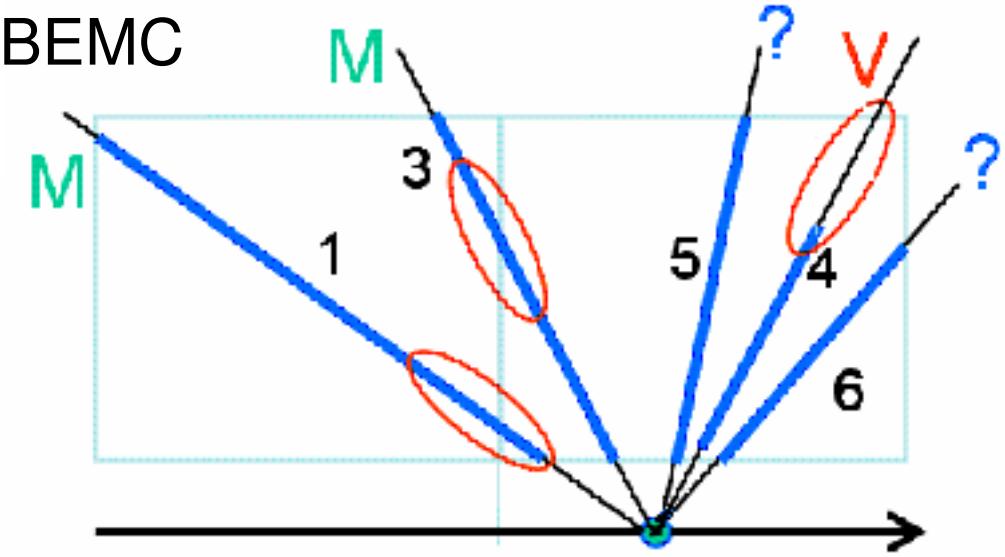
Covariant matrix used to estimated errors at DCA



PPV Method

- Selected tracks are given weights
  - W = wTPC*wEEMC*wBEMC





Tracks 1+3 Matched

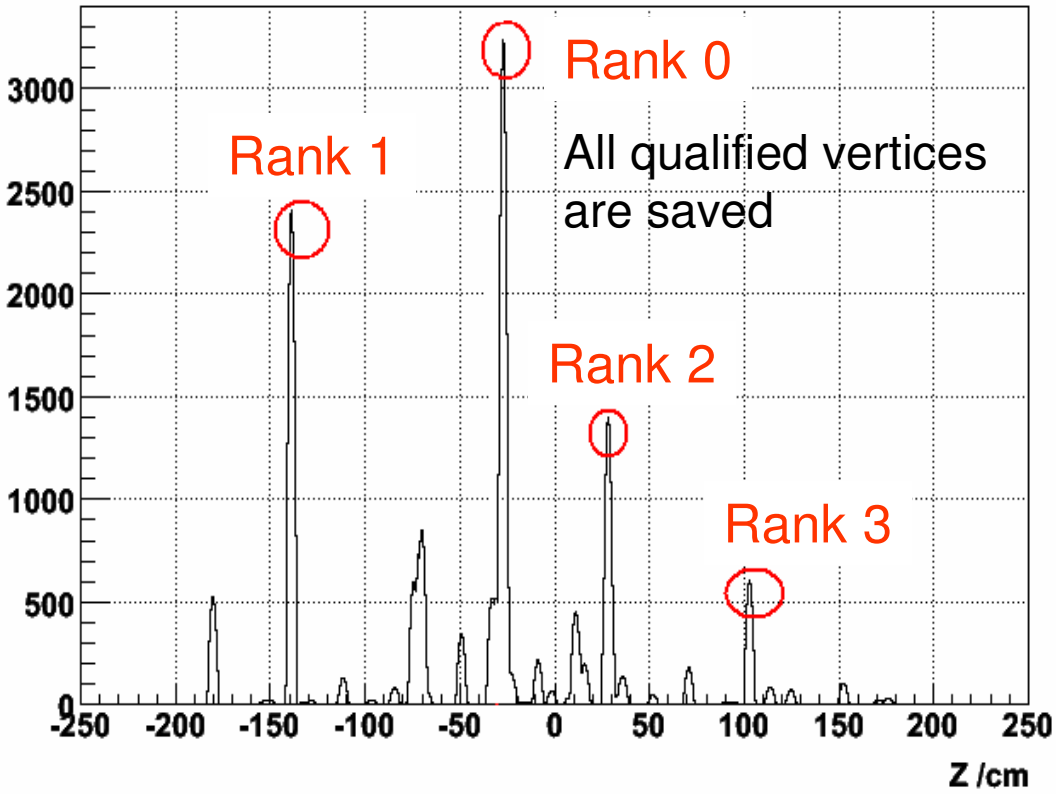
Tracks 5+6 Dunno

Track 4 Vetoed

PPV Method

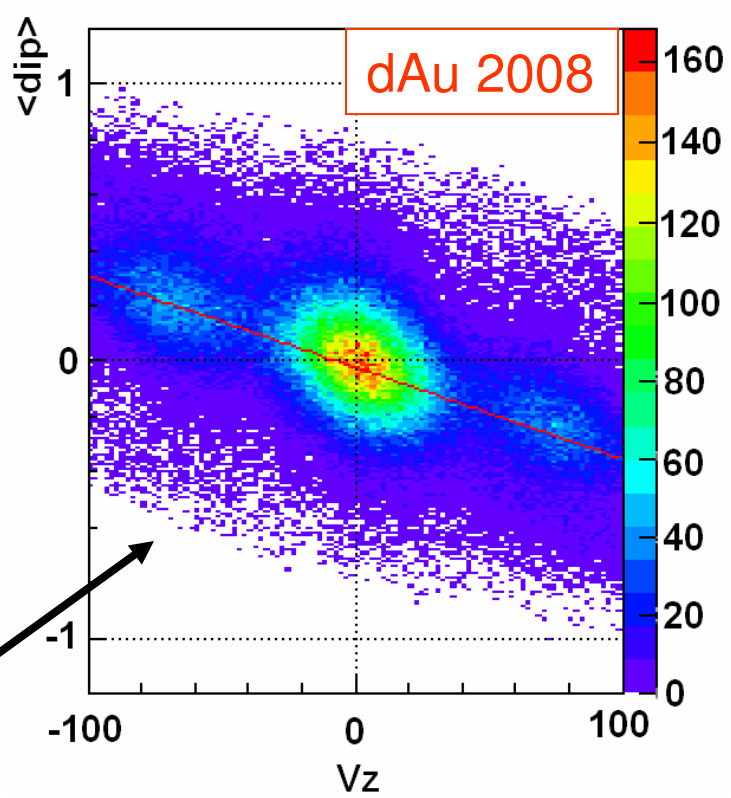
- For each location in Z the Likelihood $L_i(z)$ of all tracks which extrapolate to $|\Delta z|<1.5$ cm is calculated
  - "Probability" that the vertex is located at Z
  - Cumulative Likelihood is the product of $L_i(z)^{Wi}$
  - Wi is the track weight
- Choose Vertex Z location at L_{max}
- Associate Tracks within 3 cm

Vertices require at least 1 track pointing to a fast detector



MinuitVF Method

- Vertex candidates are selected using 5 “Good” tracks
  - point within 6 cm in z
  - within 2 cm of the beamline
- 3D position determined by the MINUIT minimization Routine
  - Minimizes the mean distance of closest approach (DCA).
- Vertex Rank is determined by
  - The <dip angle> of tracks vs z
  - # of tracks which are matched to the BEMC
  - # of tracks which cross the TPC central membrane

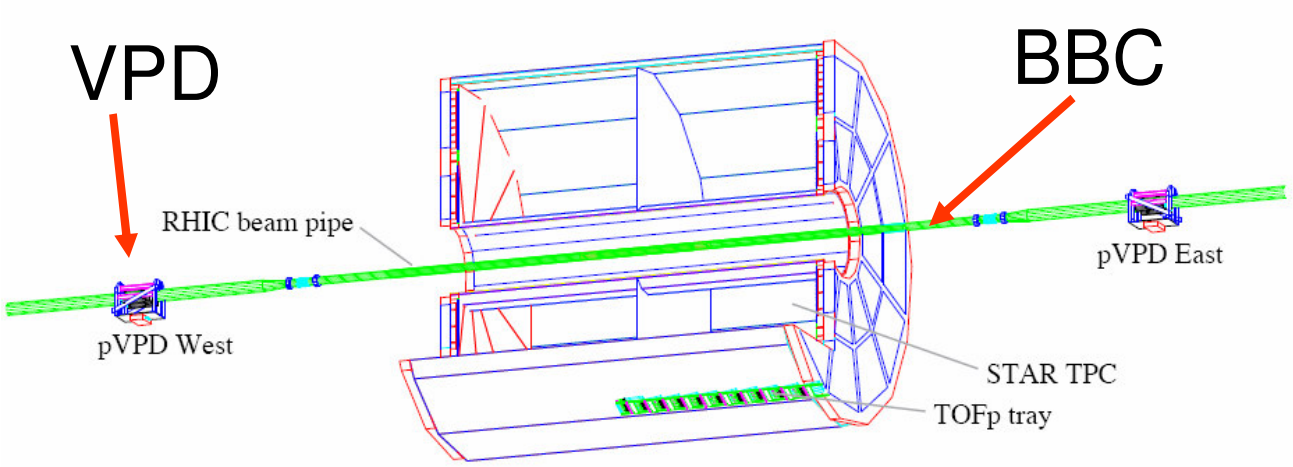


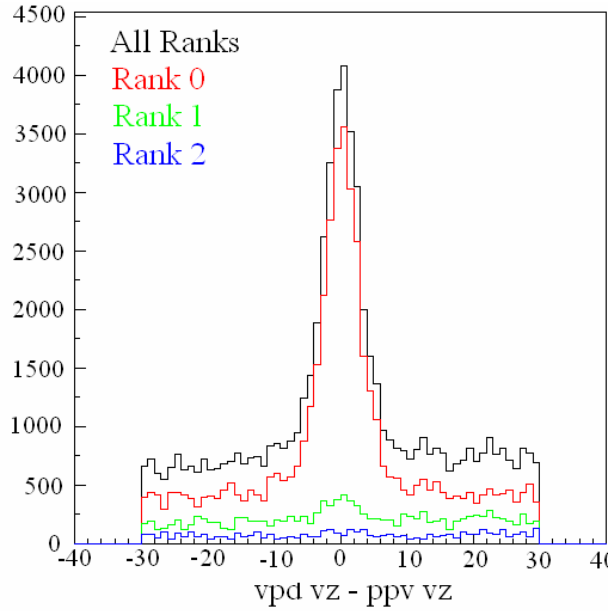
ZDC-only

PPV vs MinuitVF

PPV	MinuitVF
Optimized for pp	Optimized for AuAu
1D fit using beam-line	3D fit
Requires one track pointing to a fast detector	Gives greater weight to vertices with tracks that point to a fast detector
Rank determined by likelihood	Rank determined by <dip angle>, # of matched tracks
Probability of vertex location found by truncated log-likelihood	MINUIT used to minimize distance of closest approach of all tracks

Hardware Vertex Cross-Check





- VPD (Vertex Position Detector)
  - ~5 cm z vertex resolution with Time Of Flight electronics
  - ~25% vertex finding efficiency with pp
  - Z position determined by time difference between west+east
- BBC (Beam Beam Counter)
  - vertex resolution ~20cm at pp (~75% vertex efficiency)

Evaluation Statistics PPV

PPV performance is consistent from 2006 to 2008

Good agreement between hardware and software

2006

Triggers 2006	% with Vertex
zerobias	3.0%
minbias	48.0%
high tower	95.8%

2008 – Increased Luminosity

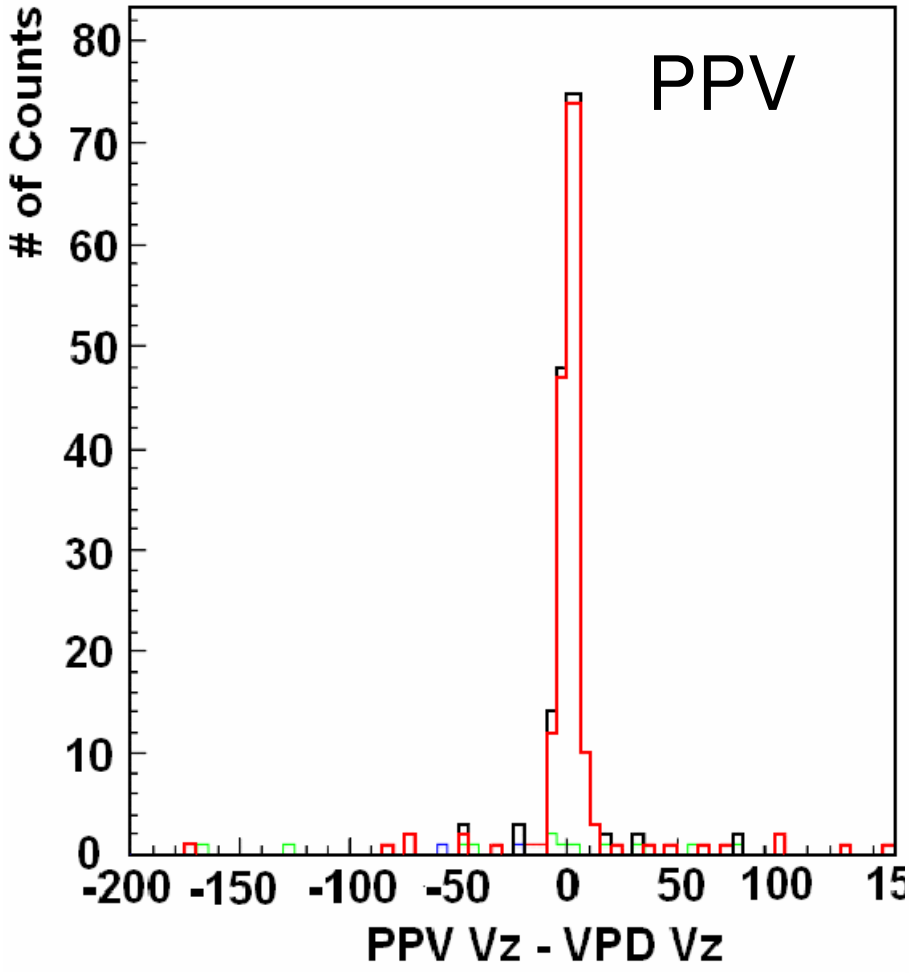
Trigger Name	% with vertex	% match VPD	% match BBC
zerobias	12.2%	80.0%	93.3%
bbc	56.3%	78.4%	87.4%
high tower	96.2%	69.2%	89.4%

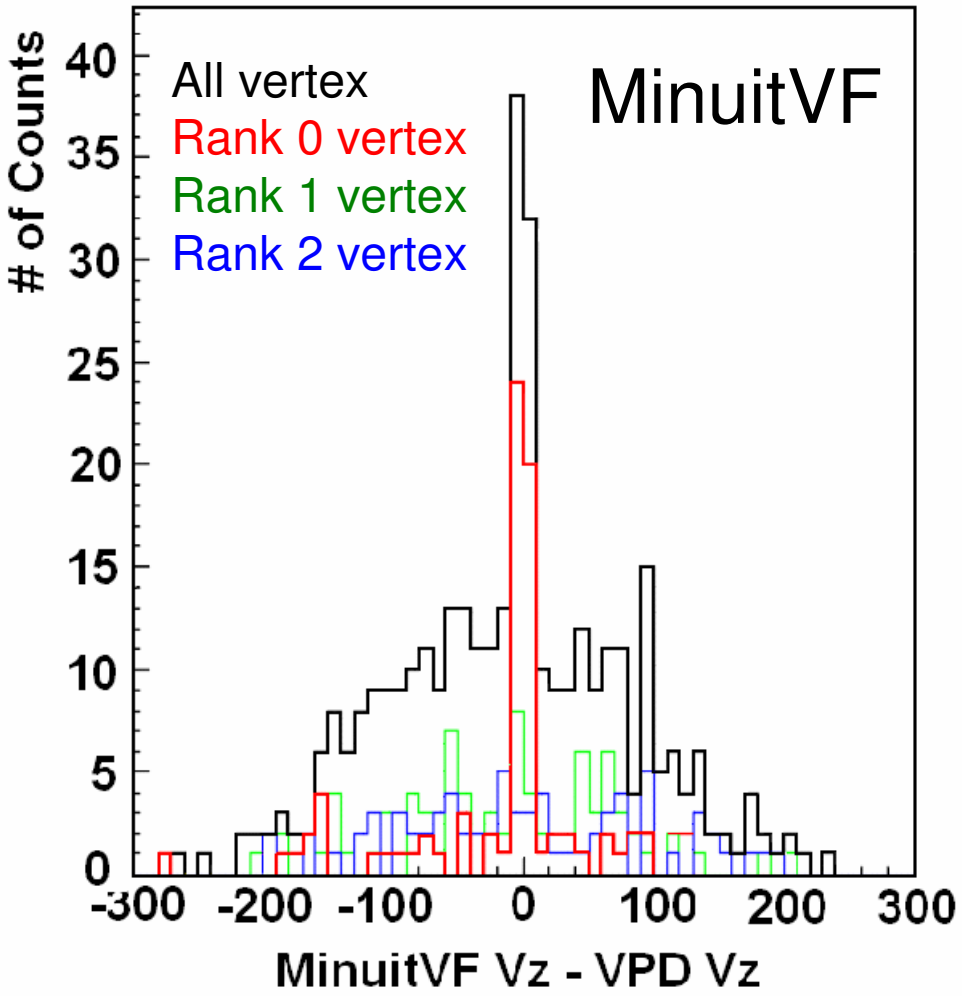
Peak luminosity increased by factor of ~4 but vertex finding efficiency is similar

Zerobias increase is proportional to pile-up rate

PPV-VPD match = Δvz = 20 cm PPV-BBC match = Δvz = 60 cm

MinuitVF vs PPV Comparison in pp

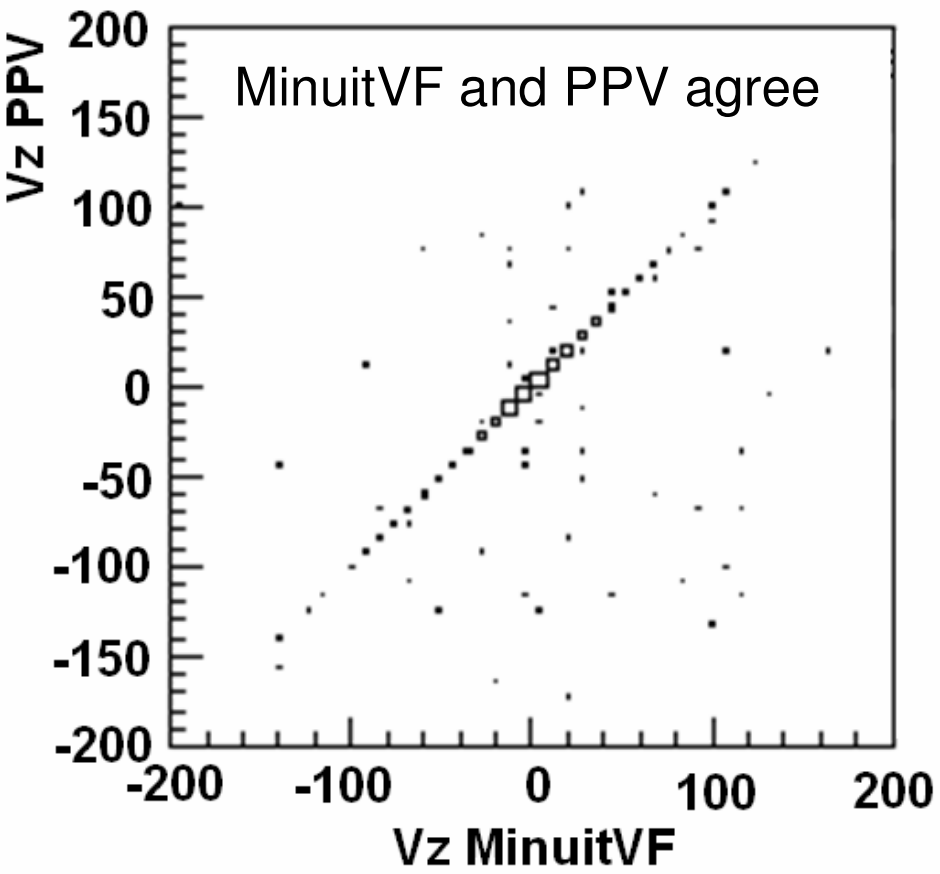


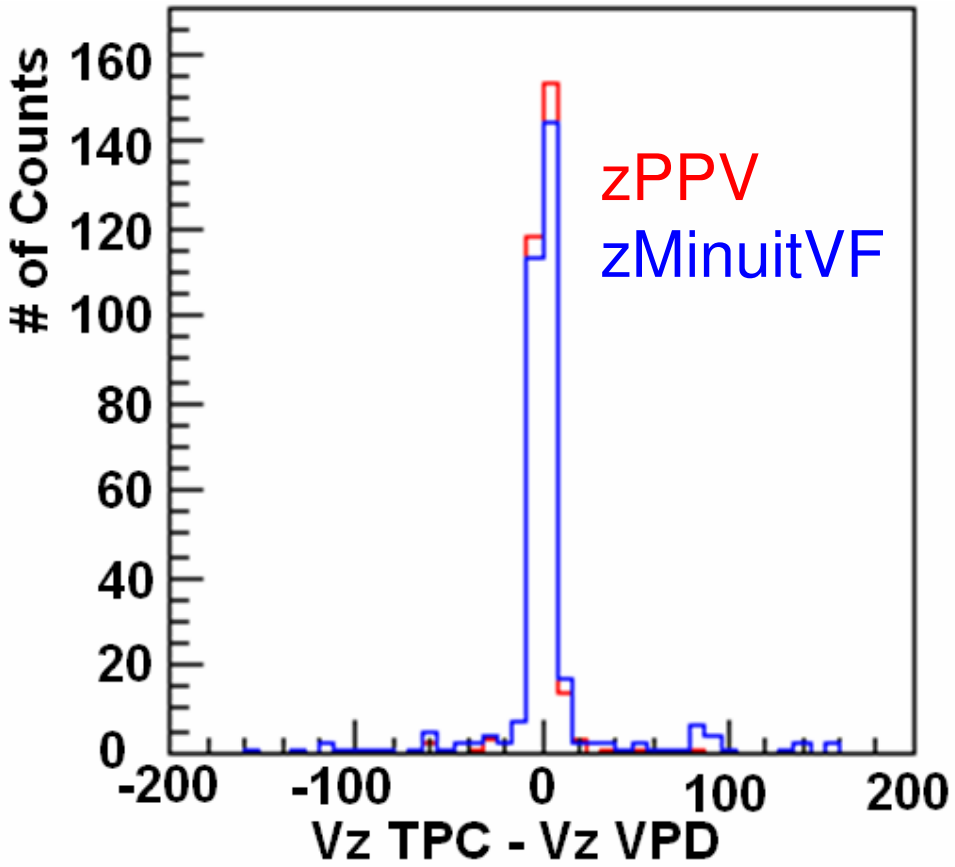


Note: MinuitVF was optimized for AA. What about dAu?

Run8 PP
FMSSlow

MinuitVF vs PPV Comparison in dAu





MinuitVF optimized for AuAu - # Tracks in Unit Rapidity ~ 70 (minbias)
dAu - # Tracks in Unit Rapidity ~11-13
PPV optimized for pp - # Tracks in Unit Rapidity ~3-4

Conclusion

- Physics analyses require accurate knowledge of the vertex location that has fired the relevant trigger
- PPV achieves vertex reconstruction efficiencies for pp in 2008 similar to 2006
  - Vertex finders handle increased pile-up in 2008
  - Expected to handle RHIC II luminosity (~x4 from now)
- Both vertex finding algorithms work efficiently for the appropriate ion species
  - Correlation between software + hardware indicates we're finding the right vertex
- MinuitVF or PPV can be used for dAu

Back-Up Slides

Z-Vertex Based on Likelihood

Likelihood $L_i(z)$ of vertex being at z if Z_{DCA} of i-th track is $z_i \pm \sigma_i$

$$L_i(z) = \exp \frac{-(z - z_i)^2}{2\sigma_i^2} \cdot const_i$$

Limits minimal separation of vertices

Truncated cumulative likelihood $L^c(z)$, tracks contribute only for $|z-z_i| < c$, **c=1.5 cm**

$$L^c(z) = \prod_i^{tracks} \left(L_i^c(z)\right)^{W_i} \quad where \quad W_i = track\ weight\ from\ matching$$

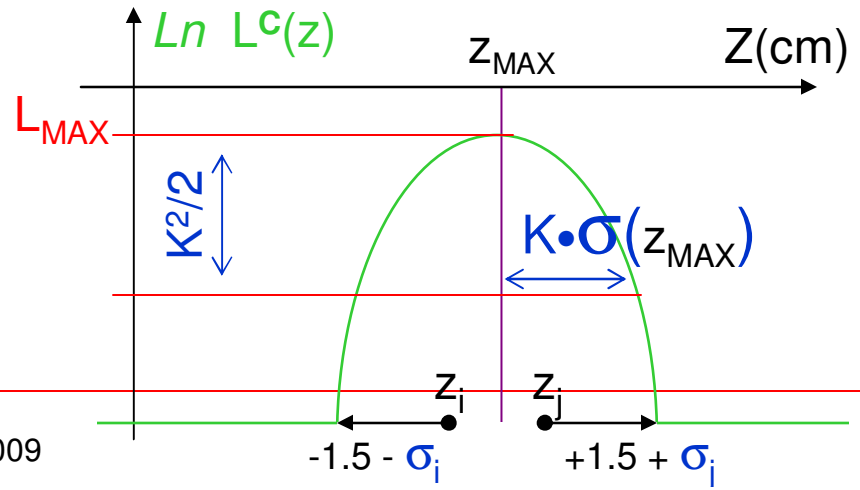
$$L_i^c(z) = \begin{cases} L_i(z) & for \quad |z - z_i| < c \\ L_i(z_i + c) = const & otherwise \end{cases}$$

Solution: Z & σZ of the vertex:

$$\max\{L^c(z)\} \rightarrow z_{MAX}$$

$$\ln[L^c{}_{MAX}] - K^2/2 = K \cdot \sigma(z_{MAX})$$

e.g. $K = 4 \rightarrow \Delta L^c = 8$



PPV Finder Method

- Truncated Cumulative Likelihood histogram created
  - Likelihood of a vertex at z given a track with a Z_{DCA} of z_i is $L_i(z)\ \alpha\ \exp(-(z-z_i)^2/2\sigma_i^2)$
  - $L^c(z) = \Pi\ (L_i^c(z))^W$
    - Tracks only contribute when $|z-z_i| < 3$ cm
- Choose Vertex z location at L_{max}
  - Associate tracks if $|V_z - z_i| < 3 + \sigma_i$
  - Keep vertices with at least 2 tracks that have matched in the fast detectors
- Repeat above step until all tracks have been associated