Beauty 2000
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Experience with HERA-B Vertexing

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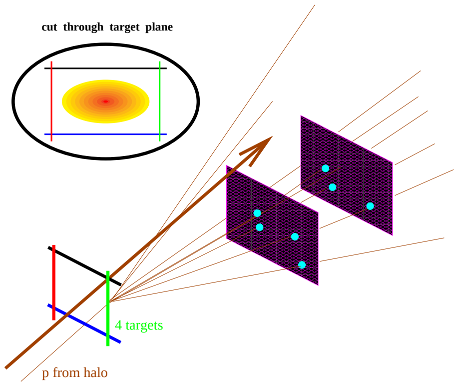
- The HERA-B Experiment: Goal and Design
  - The Vertex Detector
- Primary Vertices
- J/ψ Vertices
- B Vertices
- Conclusions

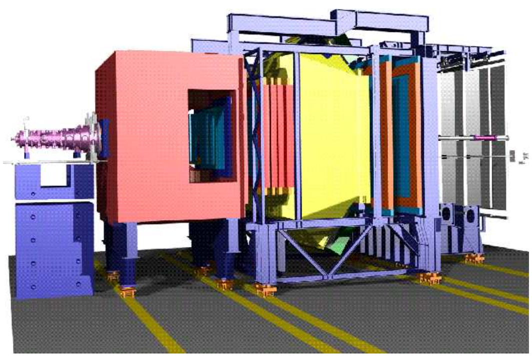
The HERA-B Experiment

DESY, Hamburg, Germany

Physics Goal: study B MESONS



- 8 internal target wires
- interacting with the halo of the HERA 920 GeV proton beam



Forward magnetic spectrometer

Tracking:

- silicon vertex detector
- MSGCs
- honeycomb chambers

Particle identification:

- RICH
- ECAL
- TRD
- muon chambers

B meson lifetime $\approx 1.6 \cdot 10^{-12}$ sec

Flight path in HERA-B ≈ 11.8 mm

Hadronic environment +

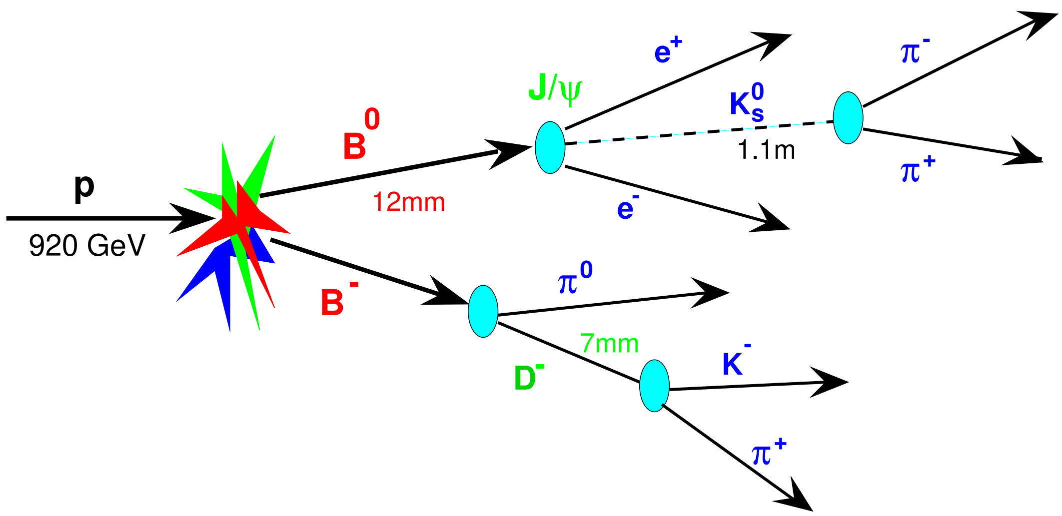
40 MHz int. rate $\equiv < 4 >$ overlapping interactions

$\rightarrow$ High multiplicities and background

VERTEXING IS CRUCIAL

The Requirements

Particle	Lifetime [ps]	Decay path in HERA-B [mm]
B^0	1.55	≈ 11.8
B^+/B^-	1.65	≈ 12.6
$B_s{}^0$	1.49	≈ 11.3
Λ_b	1.23	≈ 9.4
D^0	0.41	≈ 2.7
D^+/D^-	1.05	≈ 7



DESIGN RESOLUTIONS:

Momentum resolution	$\Delta p/p \approx 5 \cdot 10^{-5} p \bigoplus 5 \cdot 10^{-3}$

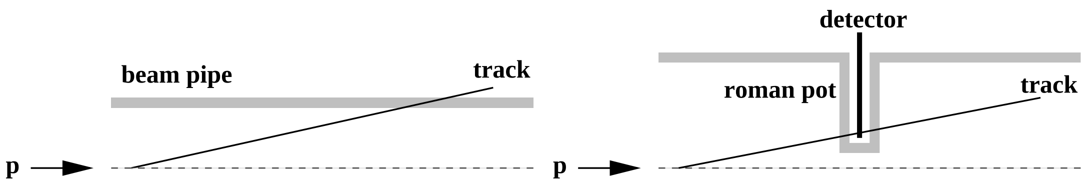
B vertex resolution	$\sigma_z \approx 500\ \mu$m $\sigma_{x,y} \approx 25\ \mu$m

THE VERTEX DETECTOR
IS THE KEY DEVICE !!!

The Vertex Detector

The requirements

- High position resolution
  (500 μm along the flight direction, 25 μm transversally).
  The position resolution is mostly limited by multiple scattering → limit material
  (Roman pot system, double sided detectors, ...)



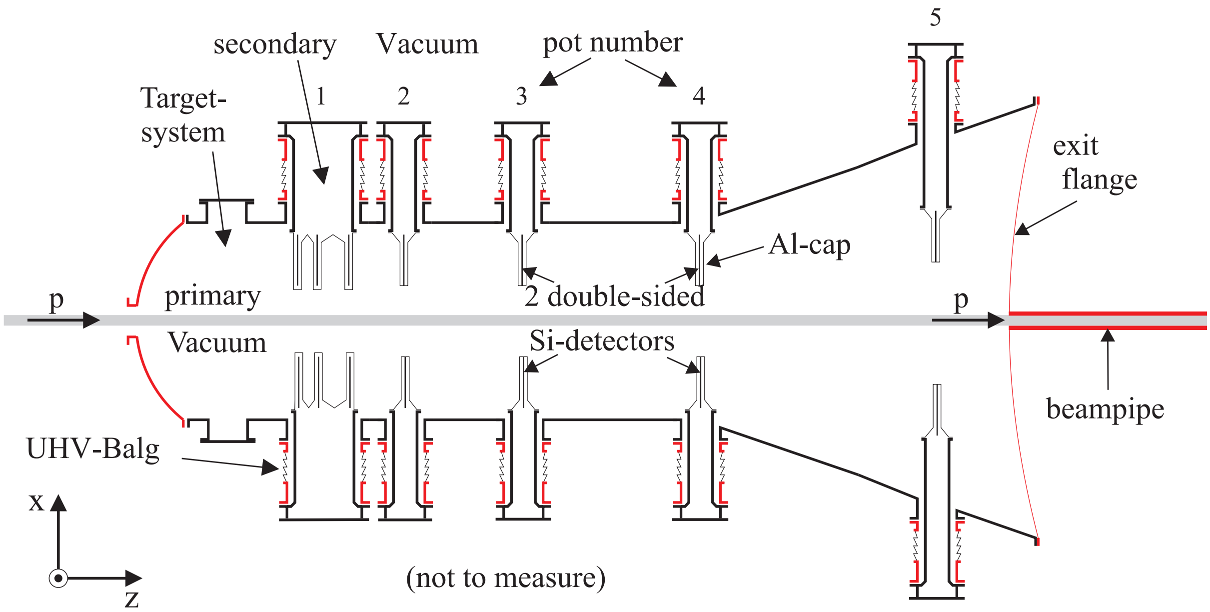
- large acceptance

- perform independent pattern recognition

- high rates → fast readout with analog pipeline
  → high granularity to limit occupancy
  → $3 \cdot 10^{14}$ particles/cm^2 per year, at the hot spot (non-uniformly distributed, $\propto 1/r^2$)
  → radiation hardness

The Vertex Detector

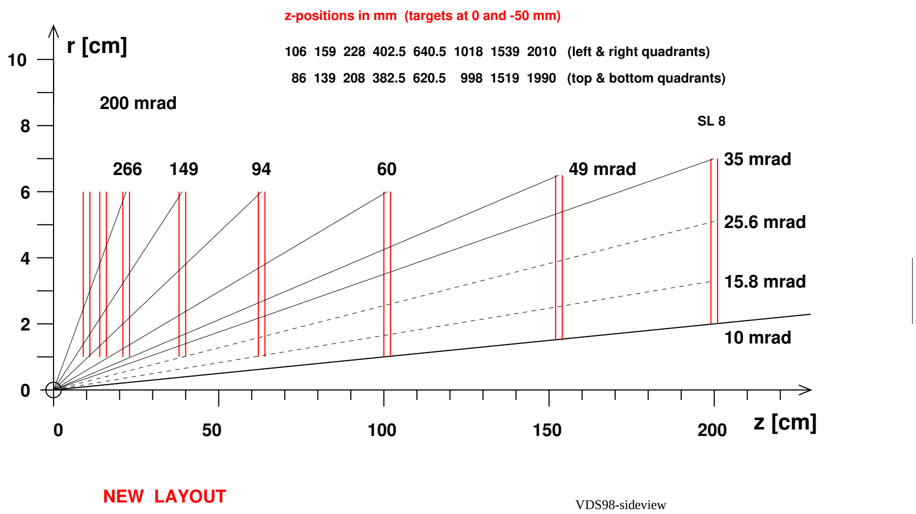
Vacuum vessel (2m long) with a Roman pot system:



8 superlayers perpendicular to the beam
2 double sided microstrip detectors each → 4 views/superlayer
64 detectors, 150k readout channels at 50 μm readout pitch

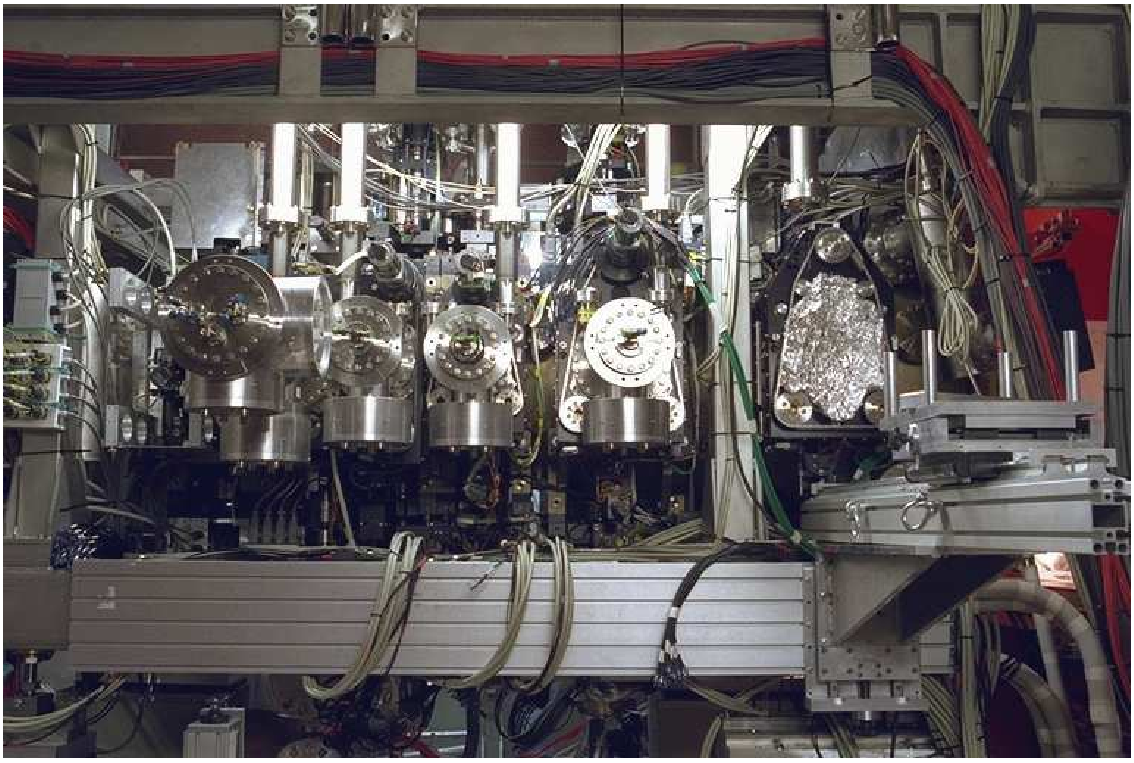
Geometrical acceptance:

10-250 mrad → independent track finding

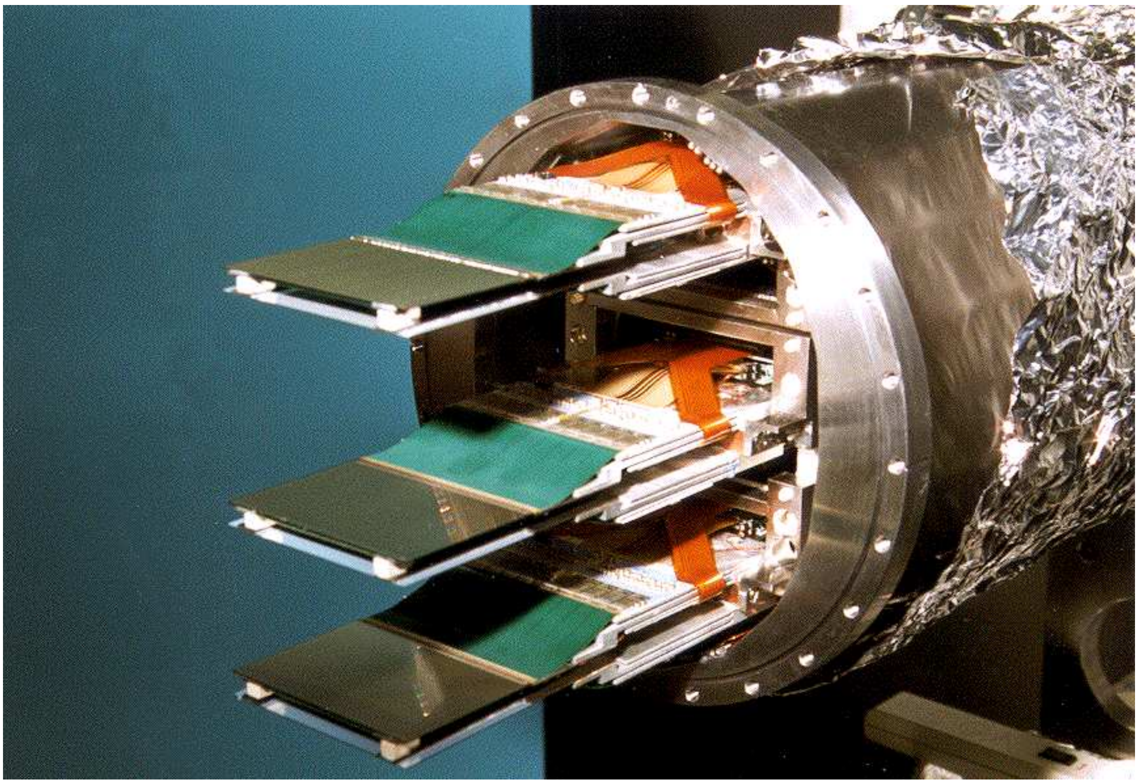


The Hardware

The vacuum vessel:



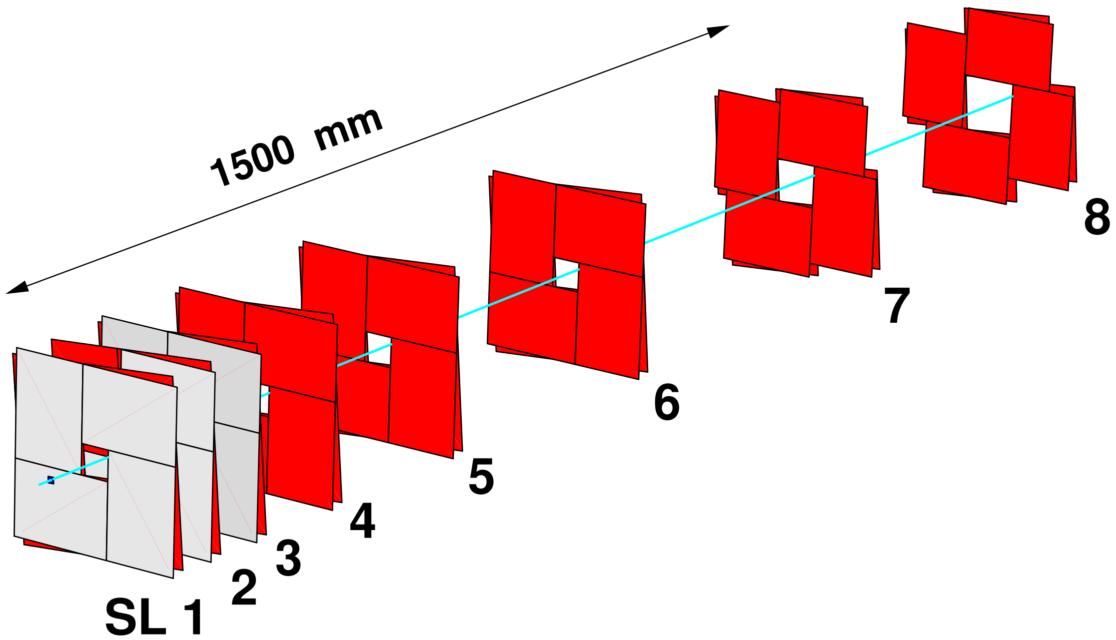
A few modules:



The Vertex Detector in 2000

SL1 - 3: 3 views

SL4 - 8: 4 views



- All 8 superlayers fully equipped
- 64 detectors: 52 double sided
  12 single sided
- 1056 chips (Helix128-2.2)
- 135,168 strips
- Geometrical acceptance starting at 15 mrad

Detector efficiency:	97-99 %
$S/N_{n-sides(p-sides)}$	20-25 (15-20)
Noise rate:	0.05-0.1 %
Single hit resolution:	$\approx$ 3 μm
Multiple scattering contribution:	$\approx$ 10 μm

$\boxed{\text{Alignment}}$

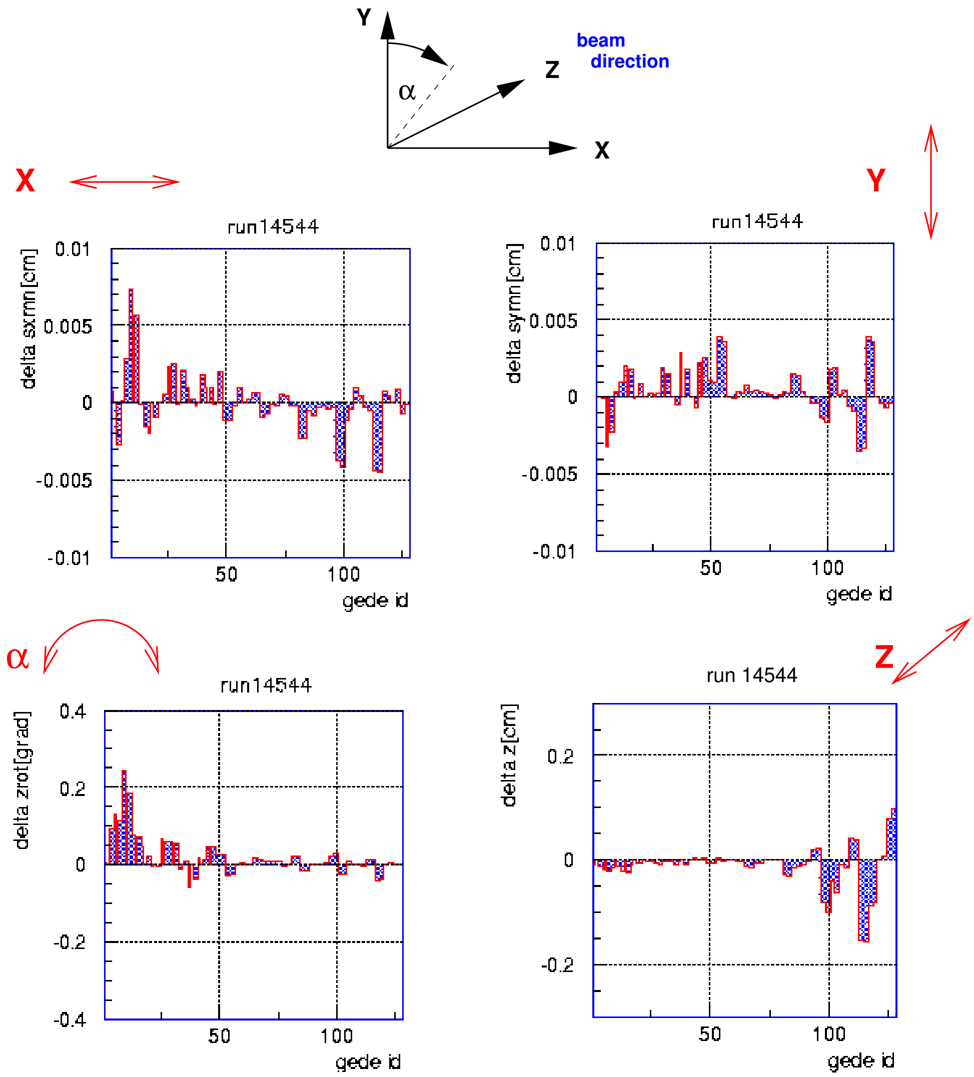
of a movable Roman Pot System

= insertion + retraction (11-12 mm) twice per day

PRECISION OF $\approx$ 5 μm

in (x,y) within one quadrant

$\rightarrow$ STABILITY OVER ONE WEEK:



Tracking in the Vertex Detector

CATS:

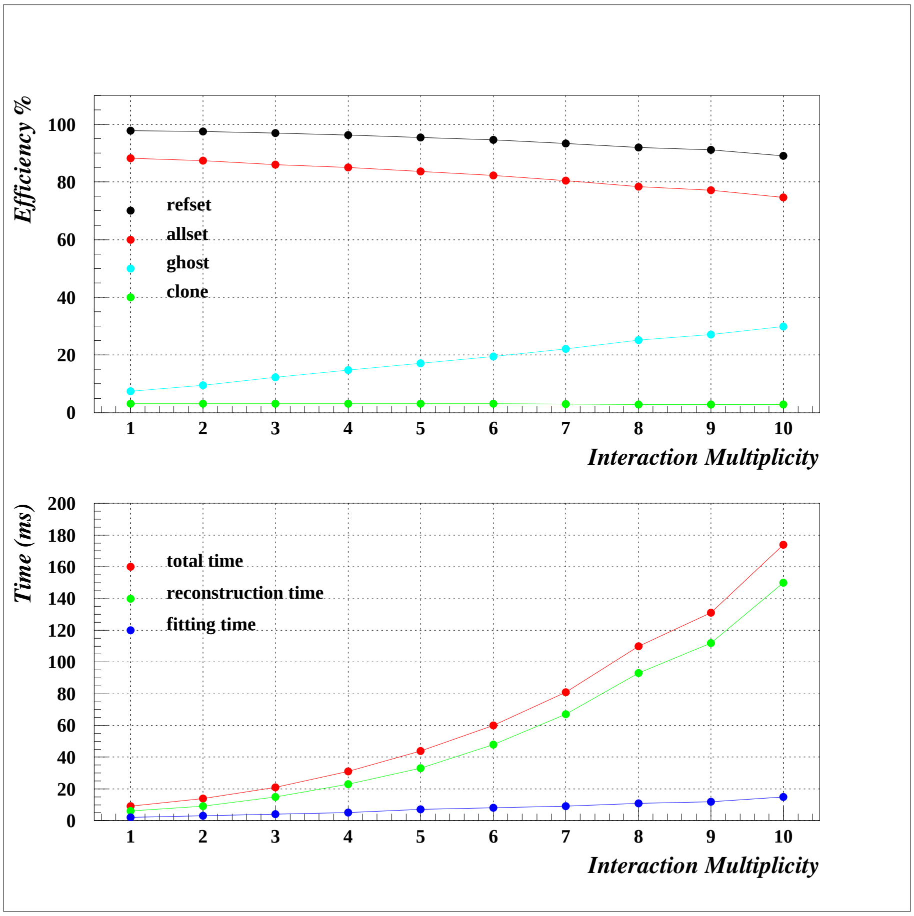
A Cellular Automaton for Tracking in Silicon

with track fitting algorithm based on the discrete Kalman filter

Reconstruction efficiency on MC events:

CATS	Ref. Set	Clones	Ghosts	Time
1 int	98.3%	3.1%	4.9%	5 ms
$< 4 >$ int	96.5%	3.2%	14.3%	33 ms

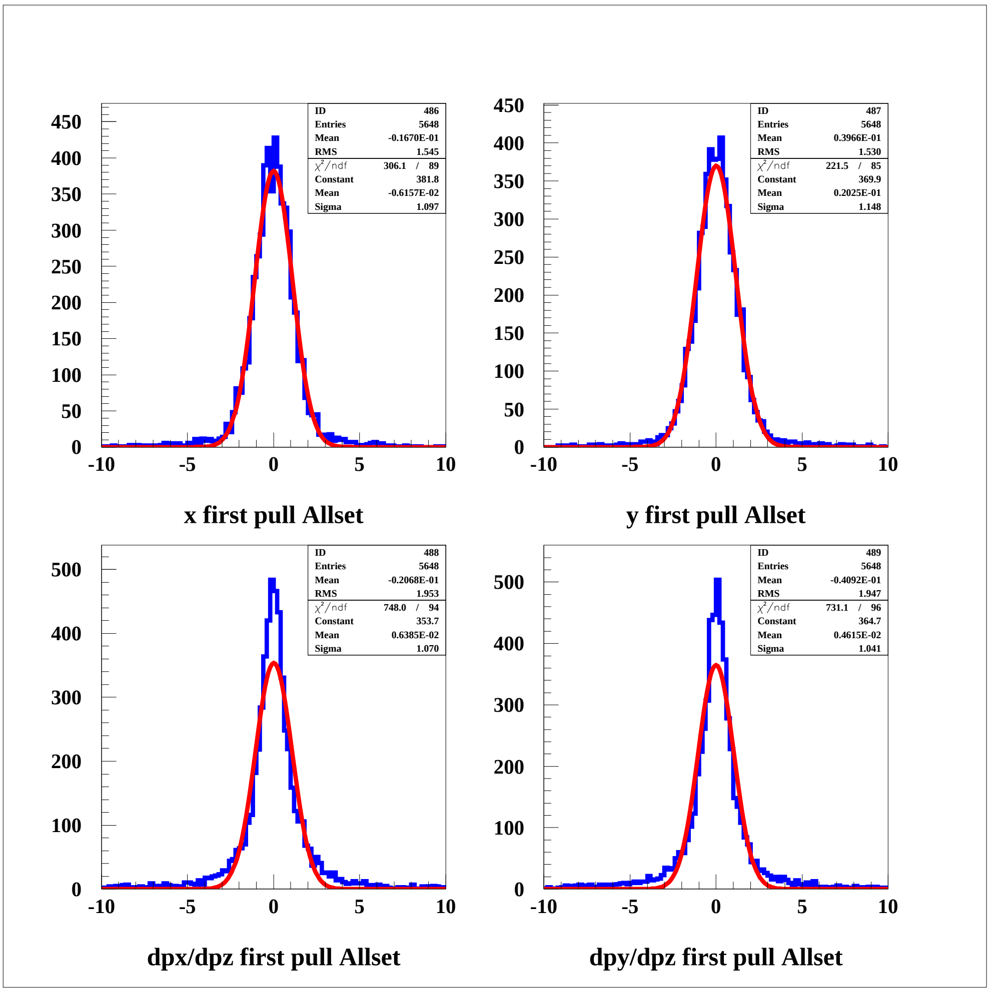
PERFORMANCE EVALUATION



Tracking: CATS

TRACK ERRORS

ESTIMATE OF RESIDUALS AND PULLS WITH MC EVENTS



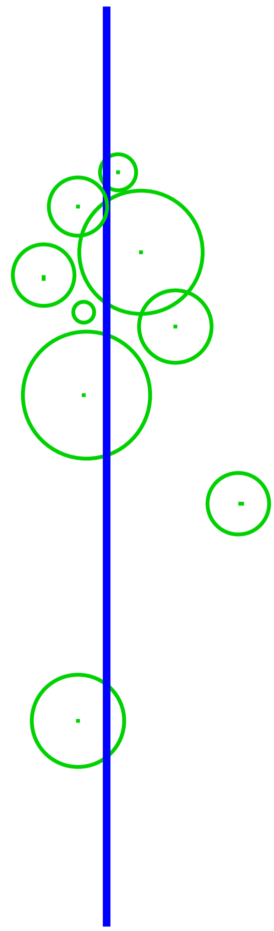
σ of residual	first hit plane	last hit plane
x_0, μm	10.4	10.5
y_0, μm	10.7	10.4
t_x, mrad	0.53	0.82
t_y, mrad	0.54	0.82

Vertexing: ROVER

Reconstruction Of VERtices

PRIMARY VERTICES
THE ALGORITHM

- extrapolate all tracks (+cov. matrix) back to the target wire plane(s)
- CLUSTER DEFINITION
  collect tracks overlapping with the wire within 3.5σ
- GEOMETRICAL FIT
  $\rightarrow$ use of momenta



MOVING TARGET WIRES !

$\rightarrow$ WIRE FOLLOWING

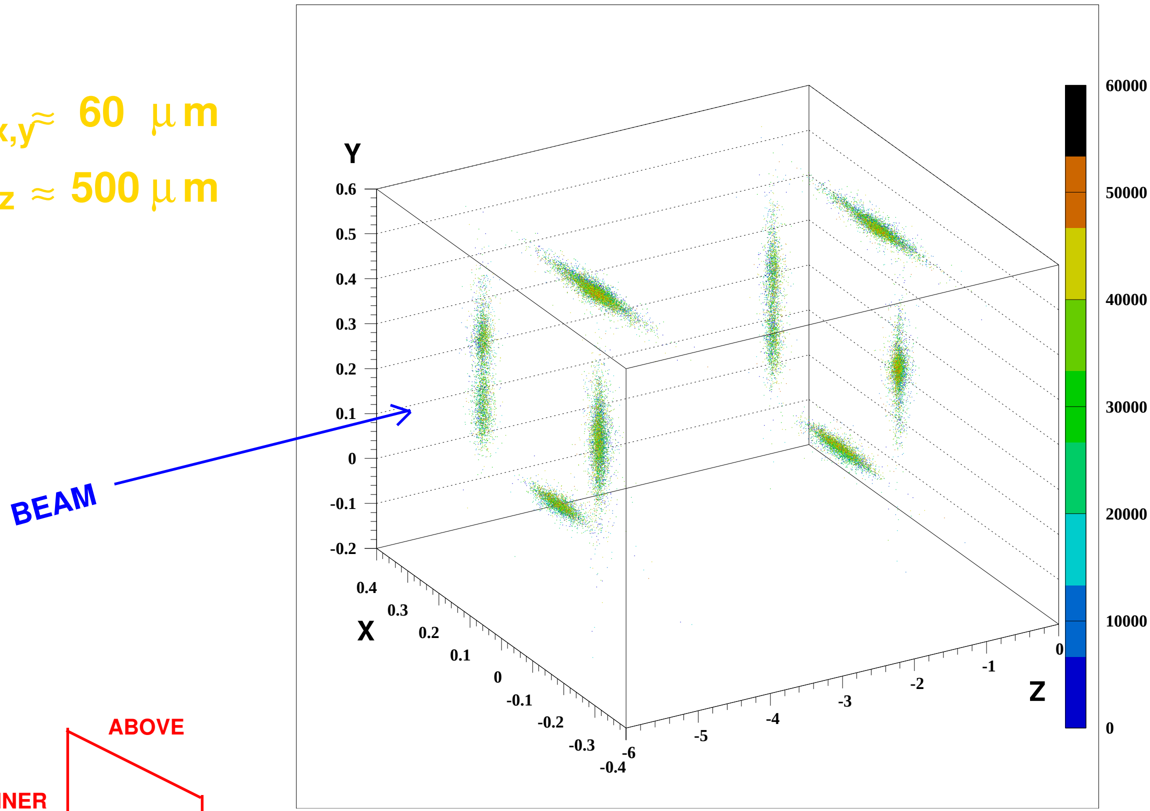
no wire constraint yet

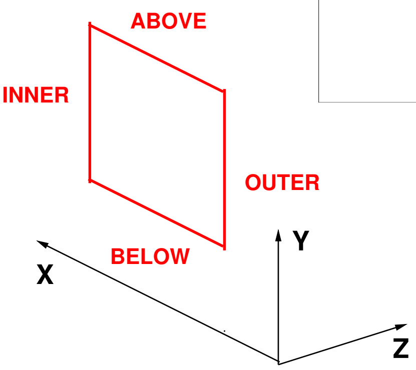
Primary Vertex Reconstruction

Run 14503 - 8 target wires

$\sigma_{x,y} \approx$ 60 μm

$\sigma_z \approx$ 500 μm



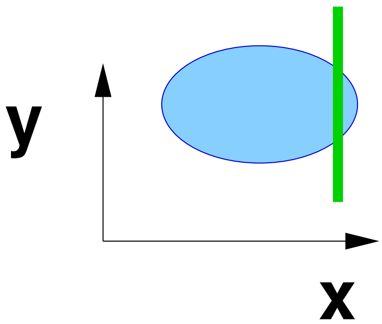


Target	Material	A	dx/dy [μm]	dz [μm]
Above 1	Titanium	48	50	500
Inner 1	Titanium	48	50	500
Below 1	Titanium	48	50	500
Outer 1	Titanium	48	50	500
Above 2	Aluminum	27	50	500
Inner 2	Carbon	12	50	1000
Below 2	Tungsten	184	50	500
Outer 2	Titanium	48	50	50

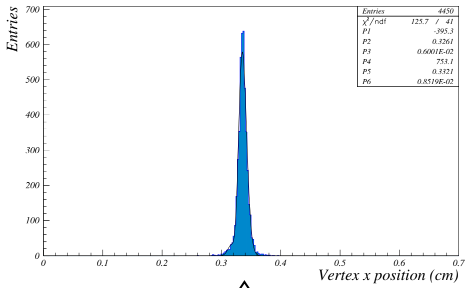
Primary Vertex Distribution

RUN 16665 - 5 MHz - minimum bias events

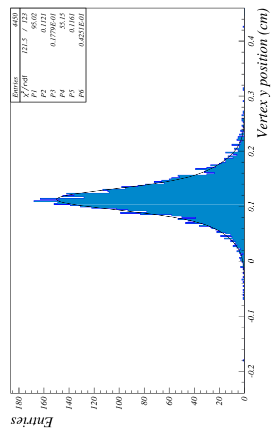
INNER 2 **Carbon** **(dx=50 μm, dz= 1mm)**

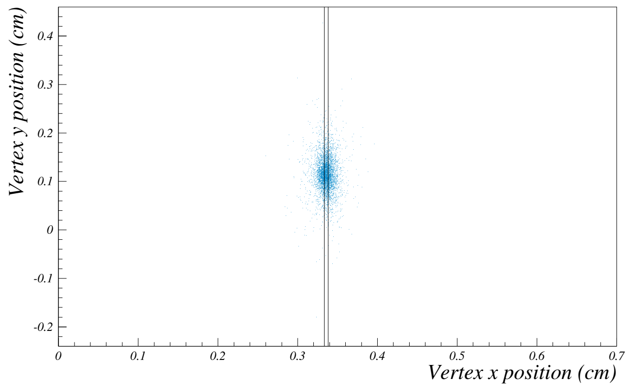


$\sigma_x \approx$ 70 μm

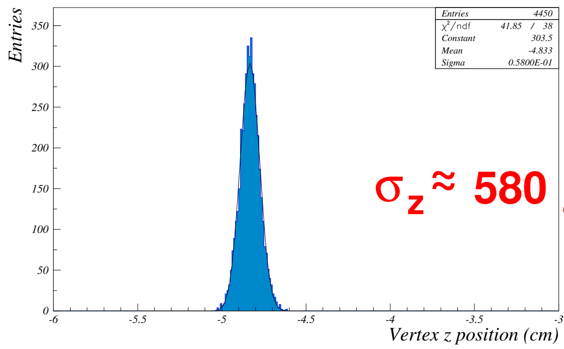


$\sigma_y \approx$ 320 μm





BEAM



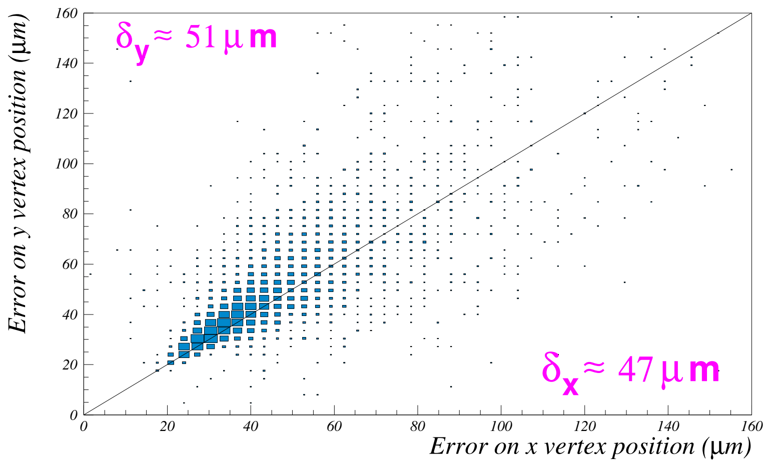
$\sigma_z \approx$ 580 μm

$\sigma_z^{MC} \approx$ 550 μm

Primary Vertex Errors

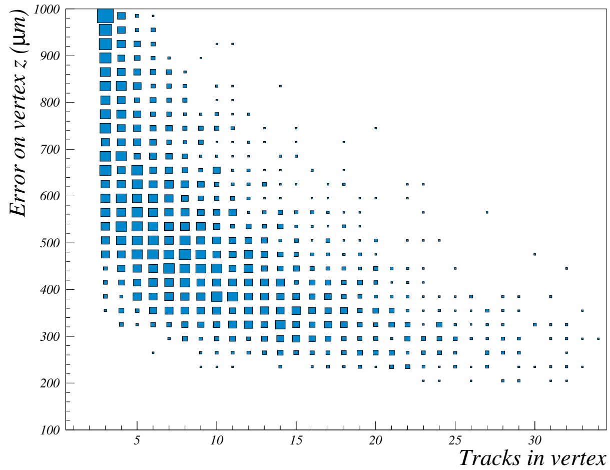
Errors on vertex position in x and y

ASYMMETRIES OF THE x AND y ERRORS INDICATE MISASSOCIATION OF TRACKS TO THE VERTEX

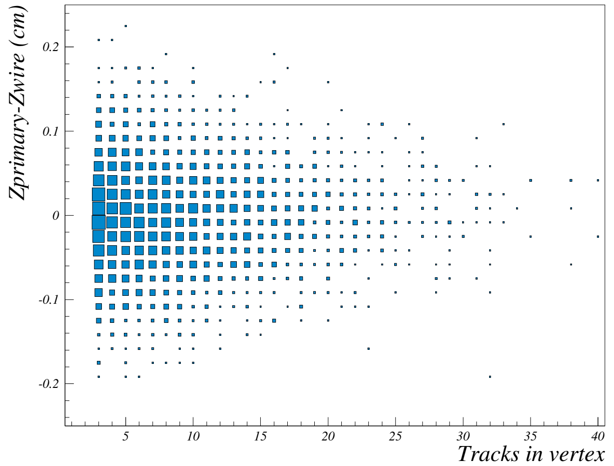


The resolution increases with the number of tracks included in the vertex

ERROR ON Z POSITION



$Z_{reconstructed}$ - Z_{wire}

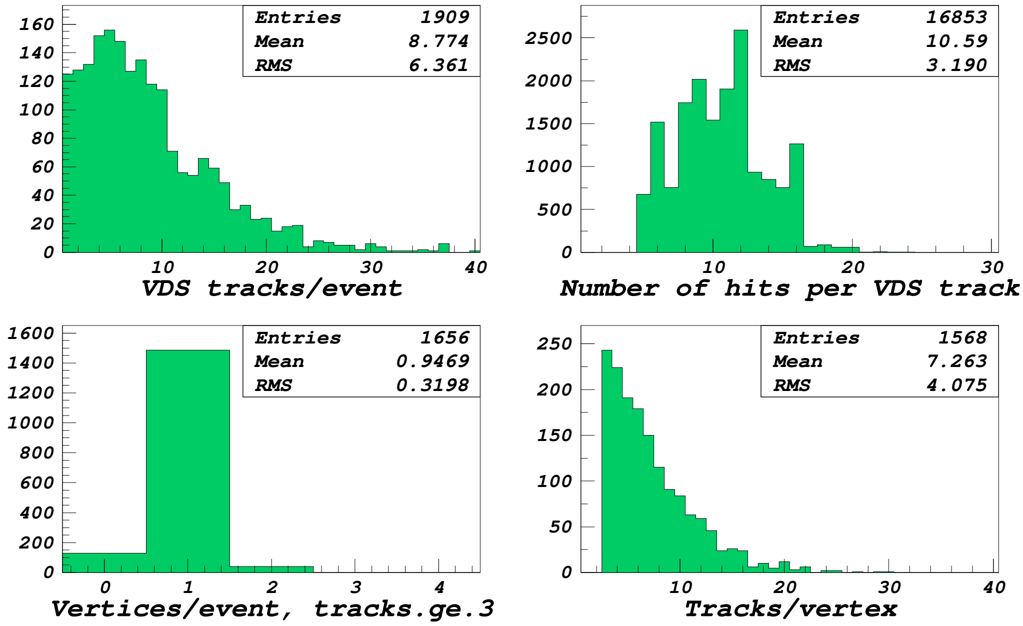


Performance on Monte Carlo Events

- Inelastic interactions (Fritiof)
- 1 interaction/event
- realistic detector simulation ($\approx$ 10% agreement)

TRACKS/EVENT = 8.8
DATA = 9.7

HITS/TRACK = 10.6
DATA = 9.9



VERTICES/EVENT = 0.95
DATA = 1.01

TRACKS/VERTEX = 7.3
DATA = 8.1

PRIMARY VERTEX RECONSTRUCTION

efficiency $\approx$ 93 %

ghost rate $\approx$ 3 %

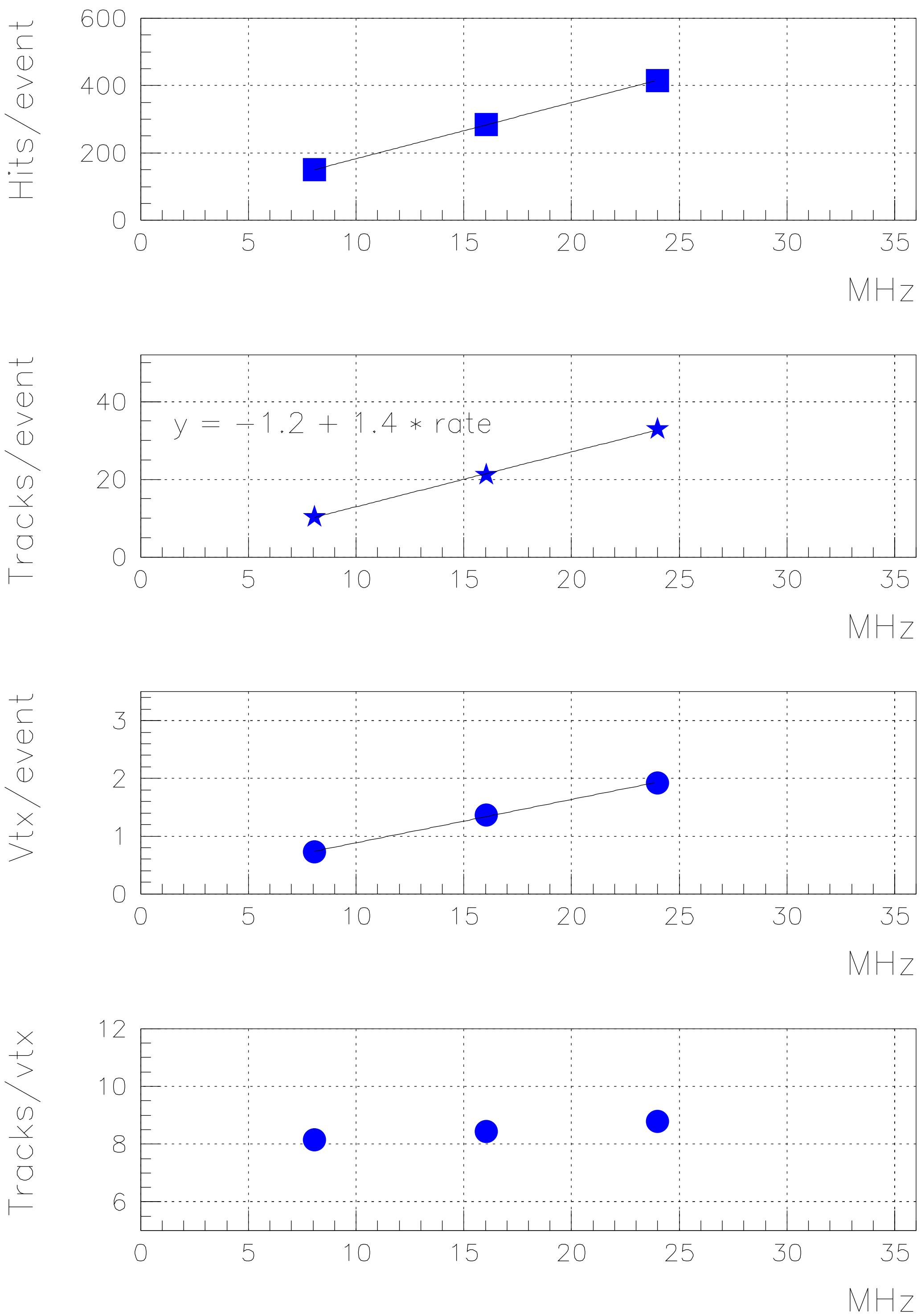
clone rate $\approx$ 2 %

EFFICIENCY/GHOST/CLONE RATE WITH MULTIPLE INTERACTIONS DEPEND ON TARGET CONFIGURATION AND BEAM CONDITIONS

Results from a Target Scan

FIRST TARGET STATION - 1999 data

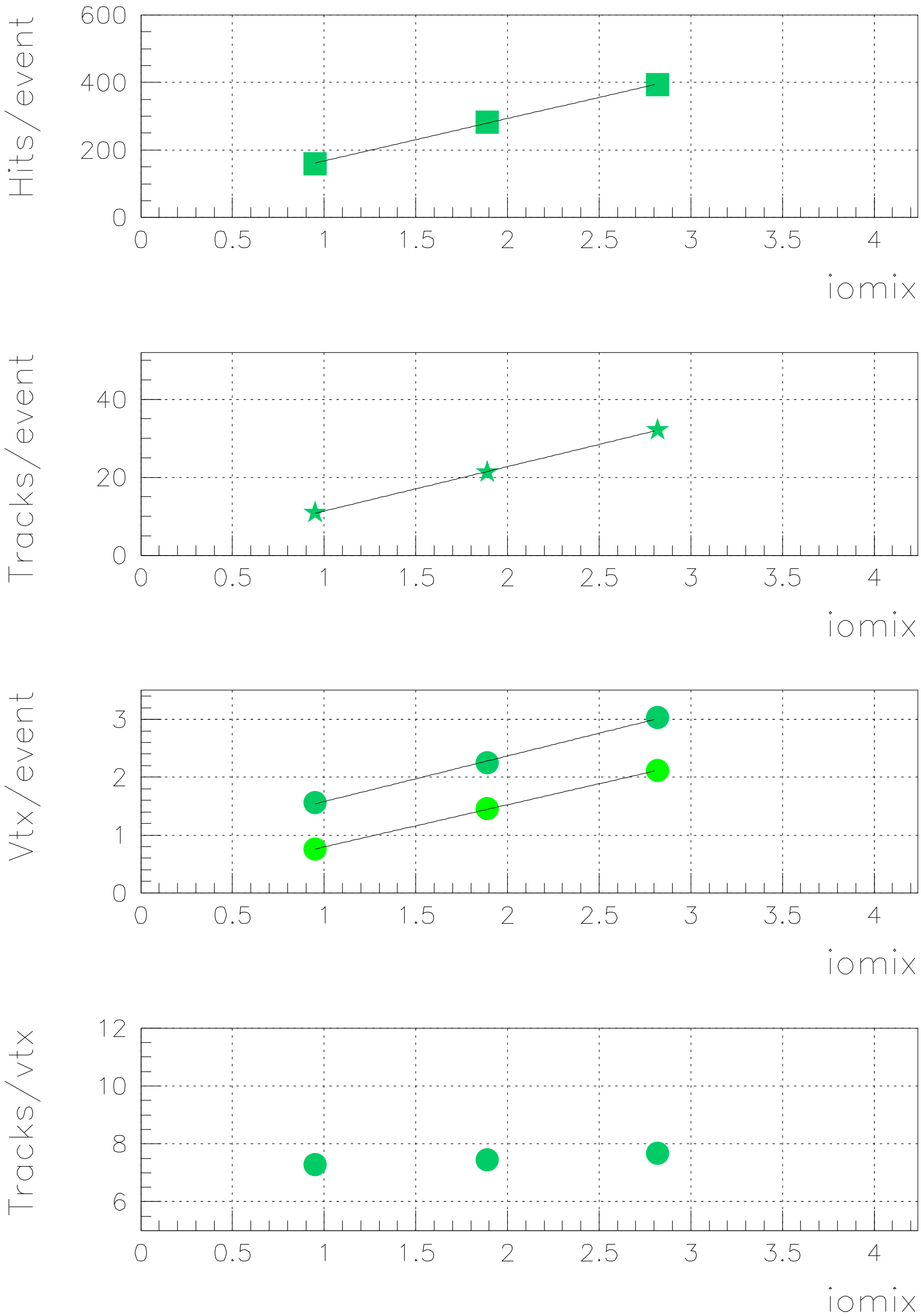
ANALYSIS OF RATE SCAN DATA ...



Results from a Target Scan

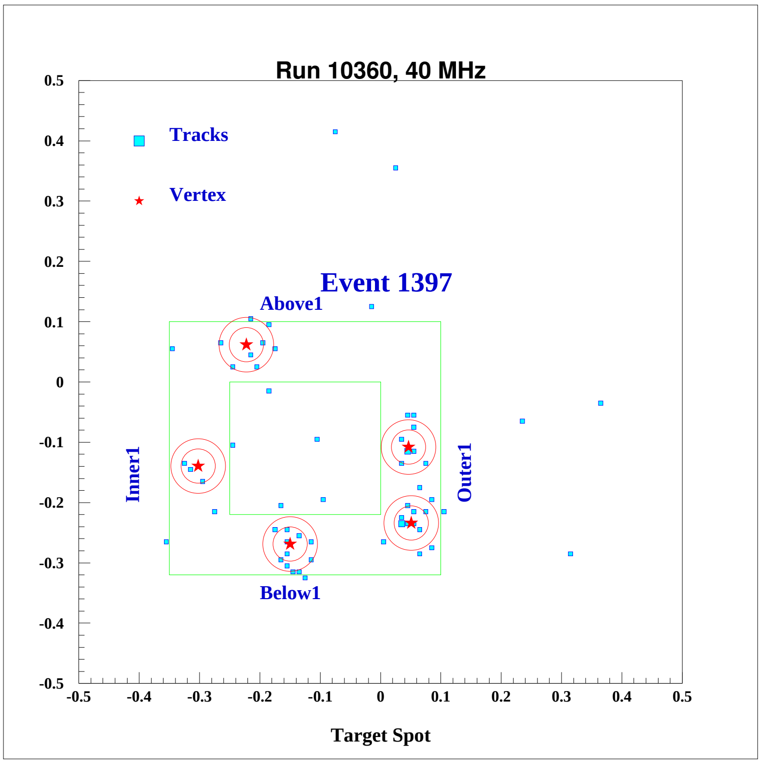
... AND COMPARISON WITH MC

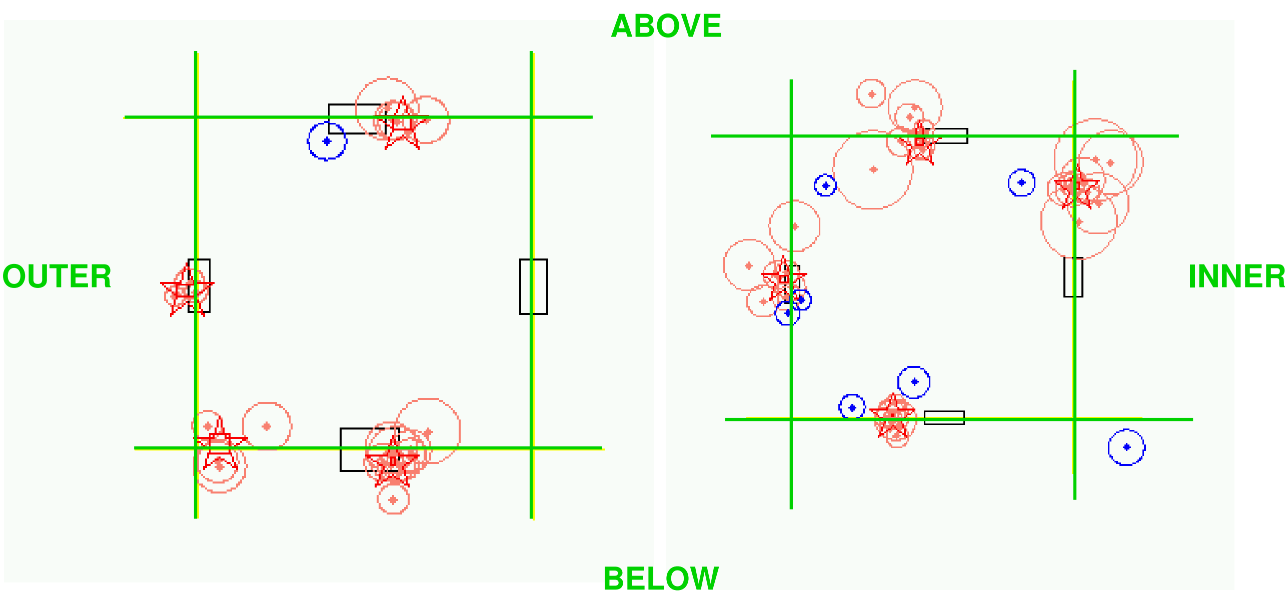
98% detector efficiency, 0.1% noise rate



Primary Vertex Separation

Excellent separation of vertices:

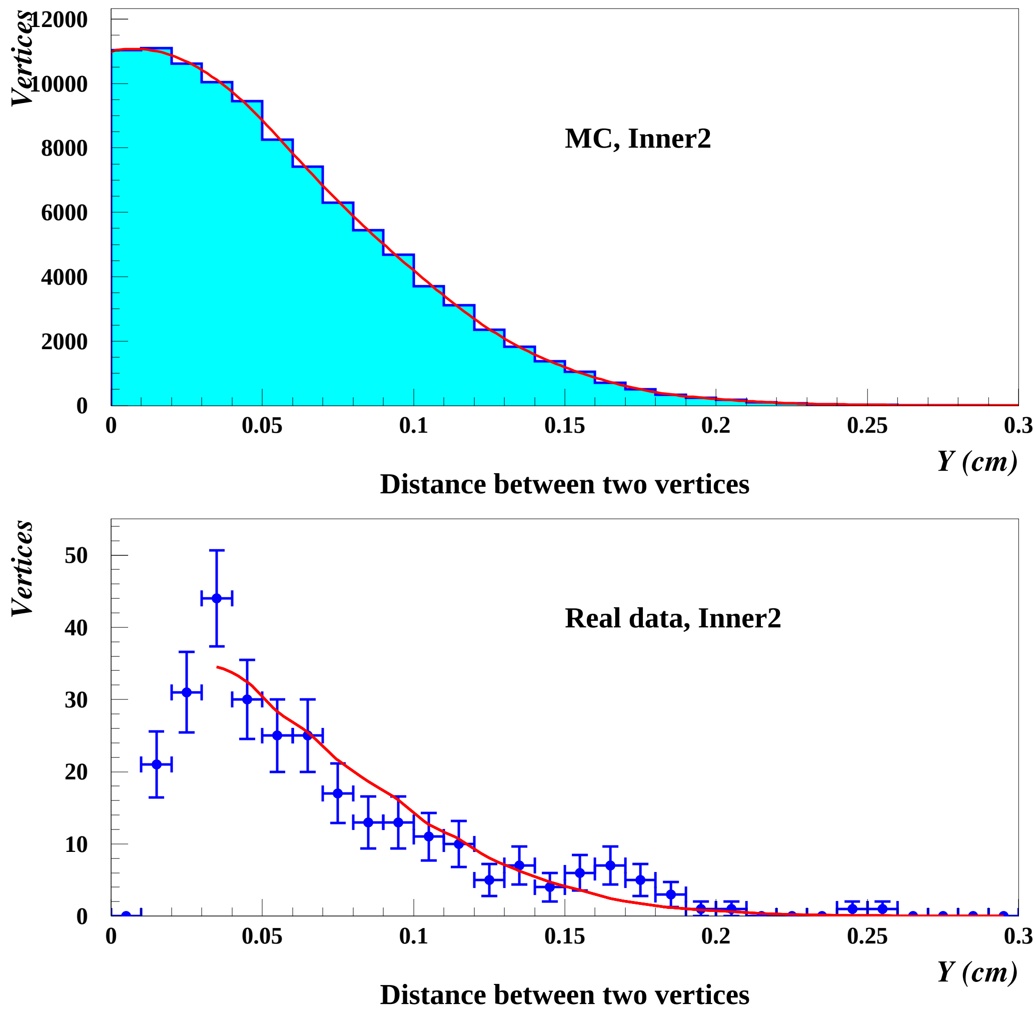




Primary Vertex Separation

ABILITY OF ROVER TO SEPARATE
TWO VERTICES ON THE SAME WIRE

MC, INNER 2: Distance between any two vertices



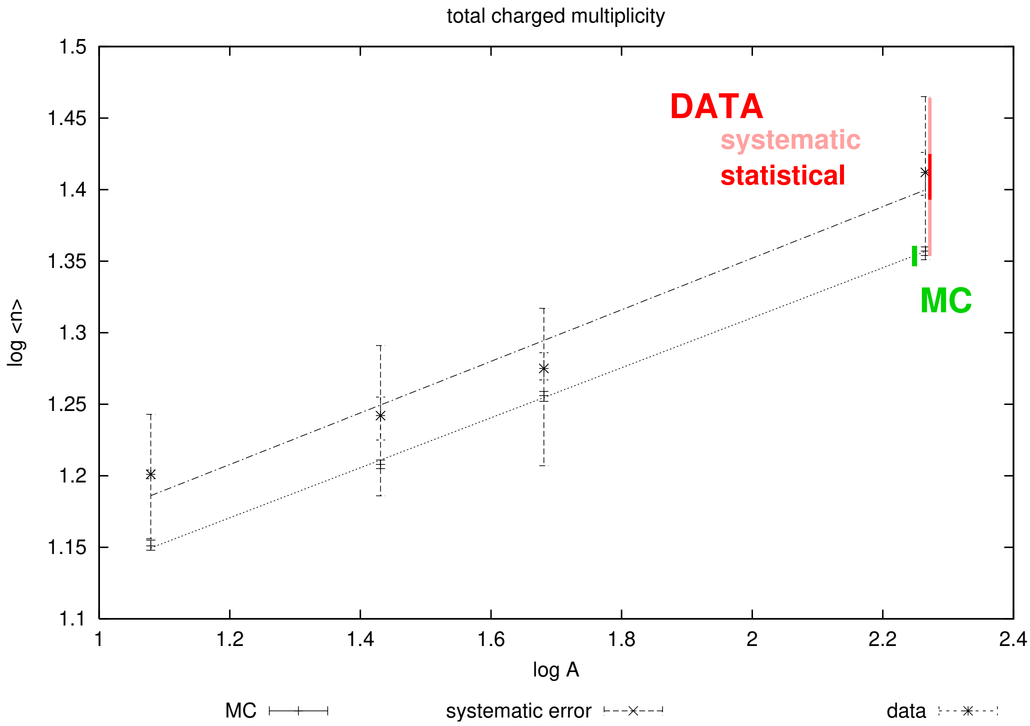
DATA, INNER 2: Distance between two vertices

Scaled MC simulation

GOOD SEPARATION FROM $\approx$ 350 μm

Primaries: Data Analysis

TRACK MULTIPLICITY DEPENDING ON TARGET MATERIAL



Total multiplicity for charged particles:

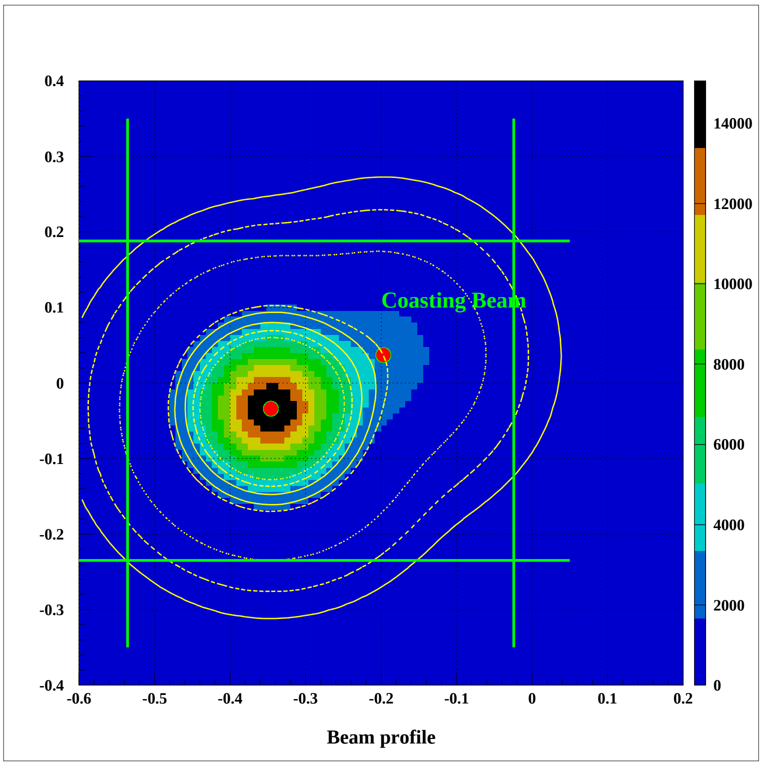
$$
\begin{aligned}
<n>^{C} &= 15.9 \pm 0.1 \pm 1.6 \\
<n>^{A}l &= 17.4 \pm 0.6 \pm 2.1 \\
<n>^{T}i &= 18.9 \pm 0.4 \pm 1.9 \\
<n>^{W} &= 25.8 \pm 0.9 \pm 3.4
\end{aligned}
$$

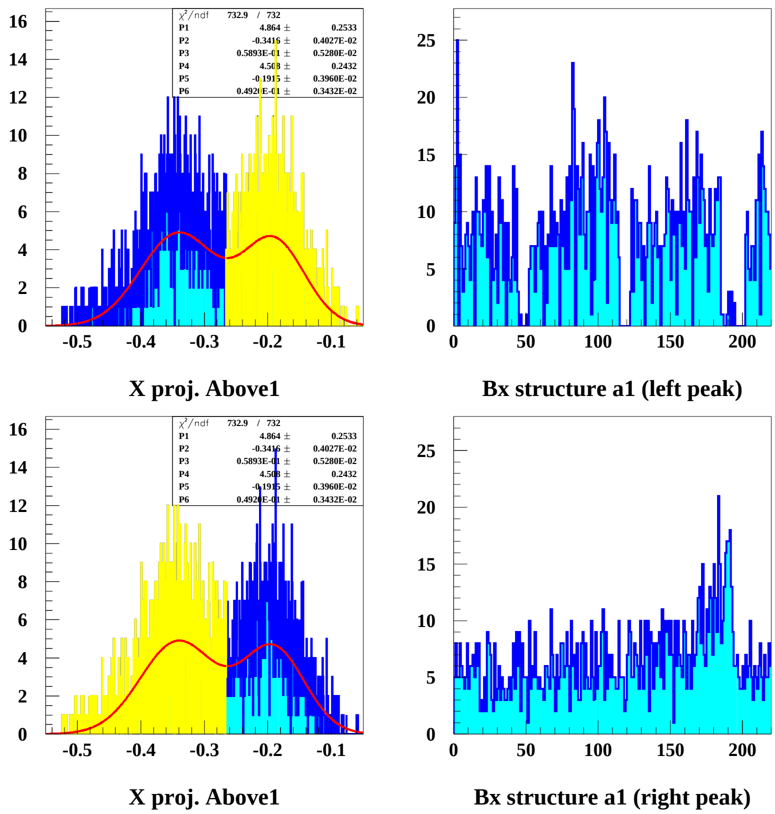
A dependence:

assumption: $<n> \propto A^{\alpha}$

$$
\begin{aligned}
\alpha^{FRITIOF} &= 0.1747 \pm 0.0025 \\
\alpha^{data} &= 0.1802 \pm 0.0232
\end{aligned}
$$

Beam Studies: Coasting Beam

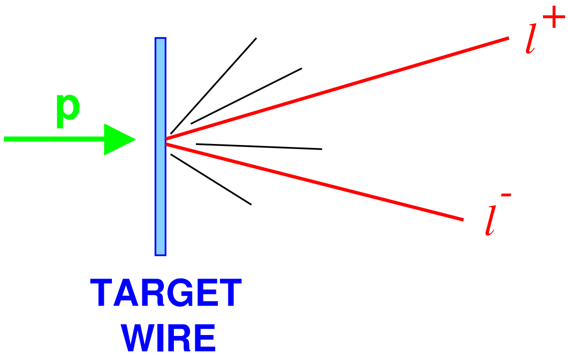




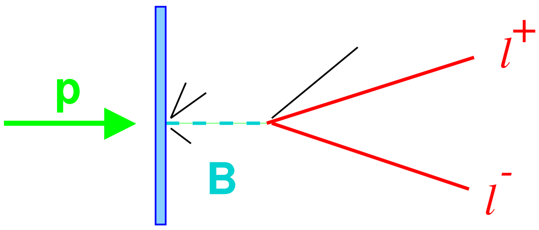
J/ψ Reconstruction

- **WE TRIGGER ON** $J/\psi \rightarrow e^+e^-$
  $\rightarrow \mu^+\mu^-$

- **DIRECT** J/ψ



DETACHED



$B \rightarrow J/\psi\ X$
$B^0 \rightarrow J/\psi\ K^0_s$

$\Downarrow$

J/ψ VERTEX

(2 TRACKS!!)

- DISTRIBUTION, QUALITY, ERRORS
- DISTANCE FROM PRIMARY

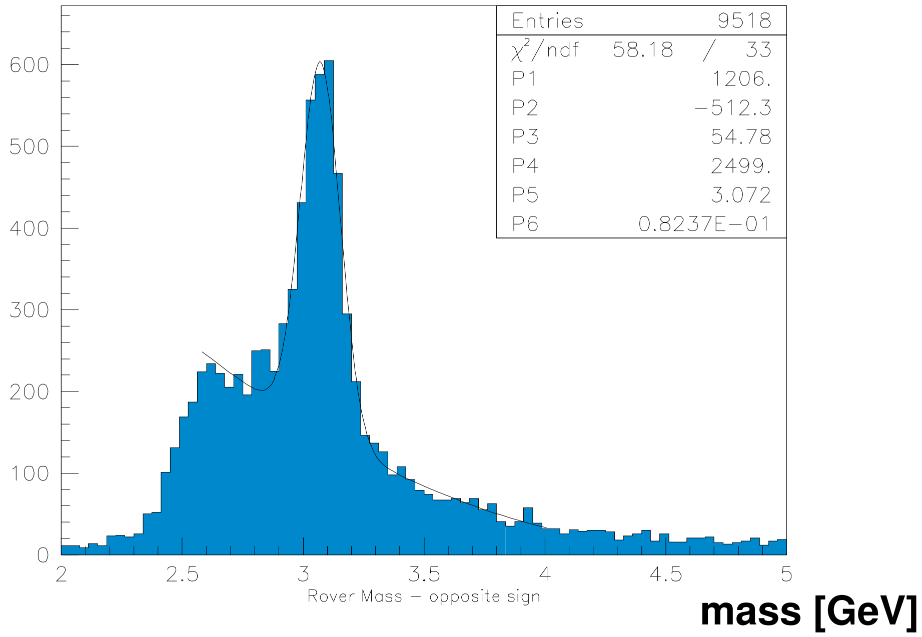
J/ψ Reconstruction

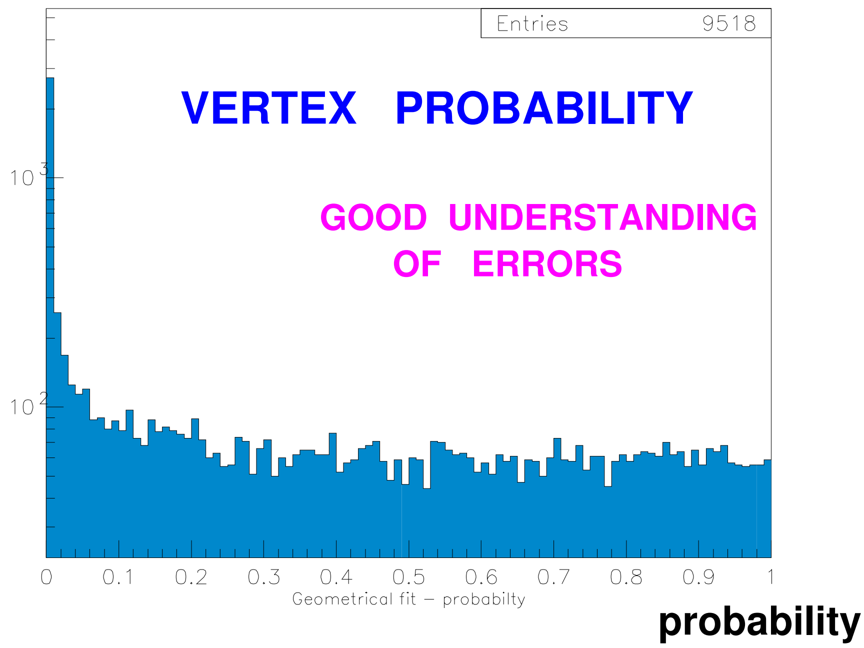
DATA: J/$\psi \rightarrow \mu^+\mu^-$

The geometrical fit:

- VDS tracks are refit with SLT momentum

PEAK WIDTH: 80 MeV → 4% res.
OFFLINE RECONSTRUCTION: 60 MeV → 2.6% res.
GOAL → 1.5% res.

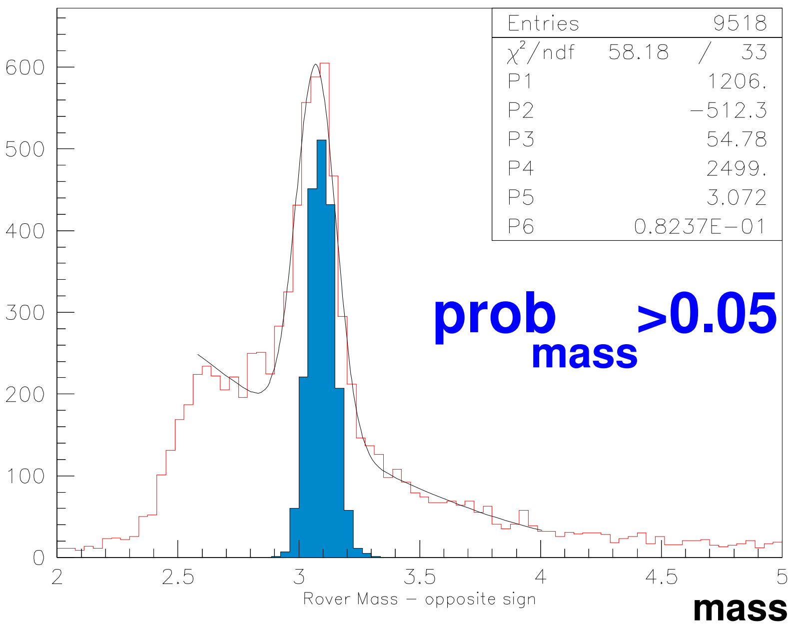




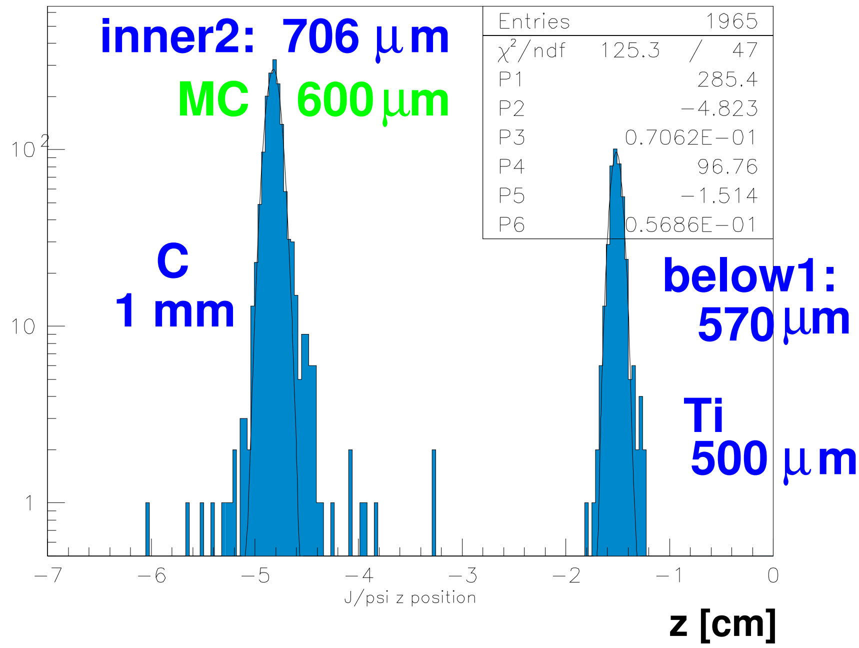
J/ψ Reconstruction

DATA: J/$\psi \rightarrow \mu^+\mu^-$

The mass constraint fit:



J/ψ VERTEX Z DISTRIBUTION



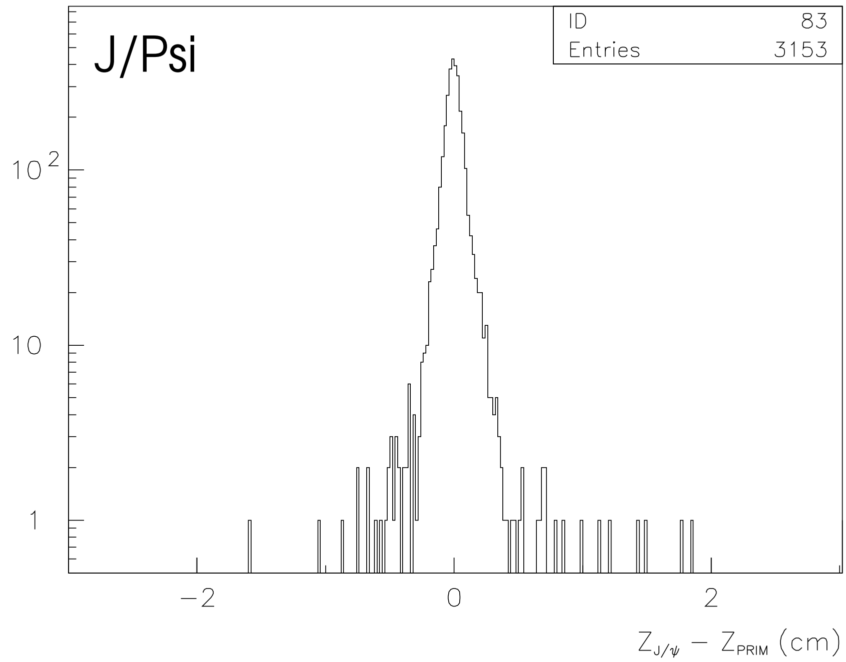
MC: vertex resolution = 350 μ m

$$\oplus \frac{\text{wire}}{\sqrt{12}} \oplus \text{misalignment} \oplus \text{non J}/\psi\text{'s}$$

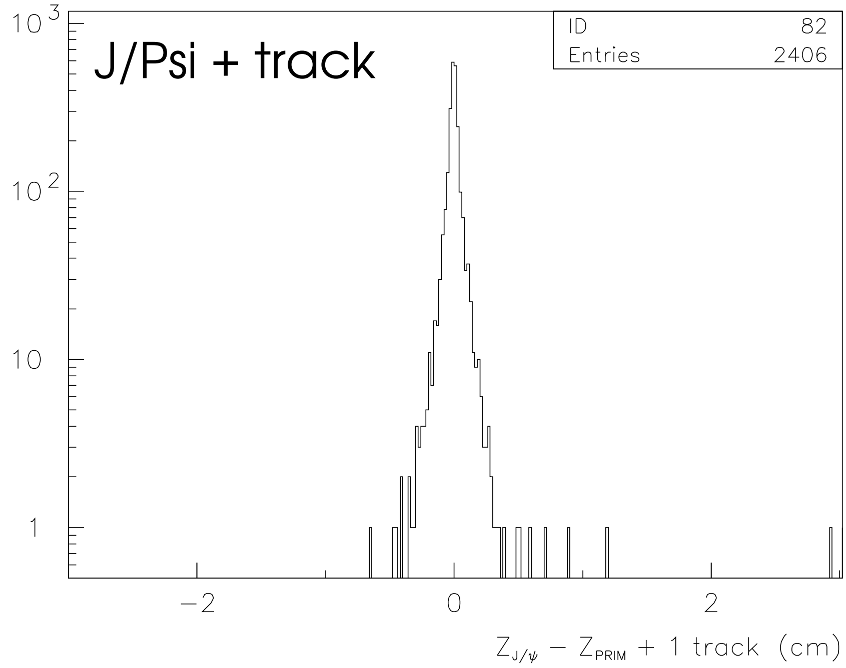
J/ψ Vertex Distribution

DISTANCE from PRIMARY

J/ψ ALONE



J/ψ + 1 TRACK

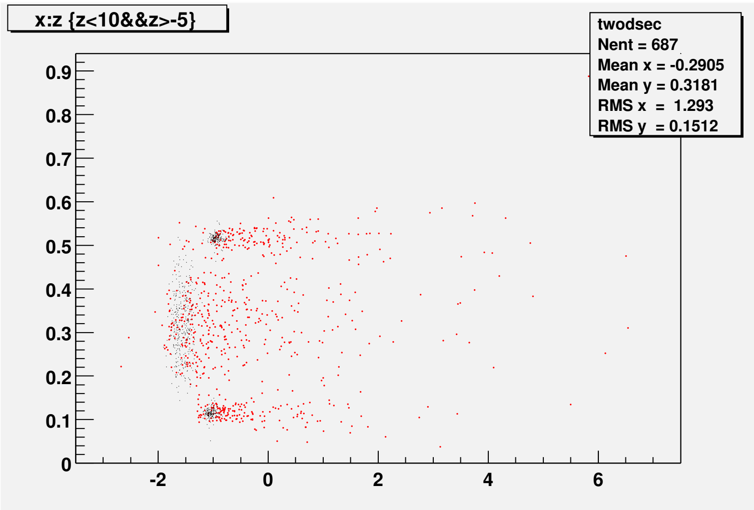


→ CHASING DETACHED VERTICES

→ $b\bar{b}$ PRODUCTION CROSS SECTION

Secondary Vertices: $B^0 \rightarrow J/\psi K_s^0$

MC study with no track momentum and no mass constraint

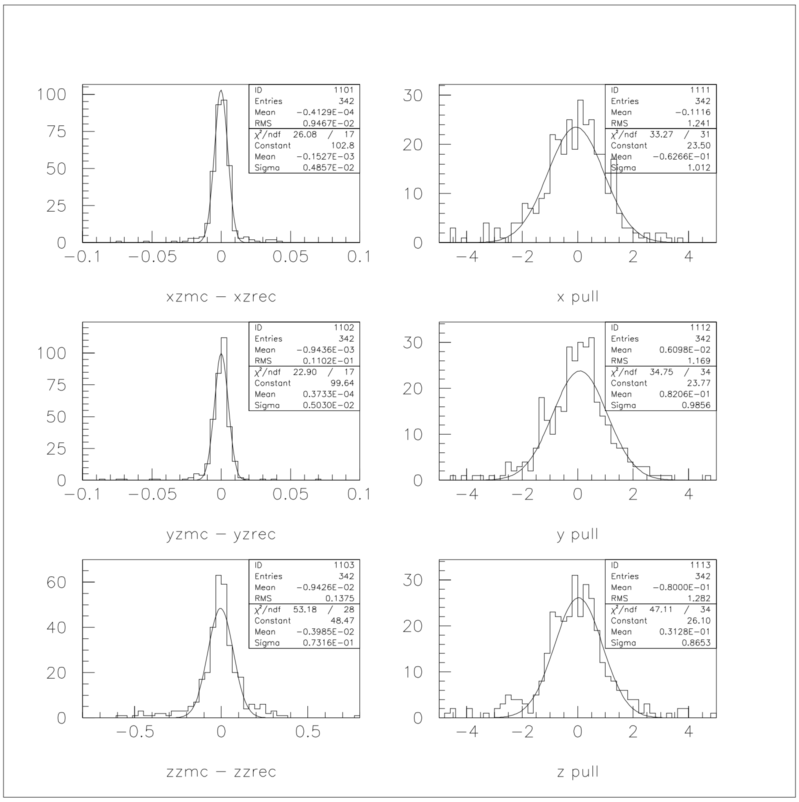


Primary and secondary vertices can clearly be distinguished

Resolution:
70μm in x,y
700μm in z

+ Momentum:
(2% smearing)
375μm in z

+ Mass Constraint:
325μm in z

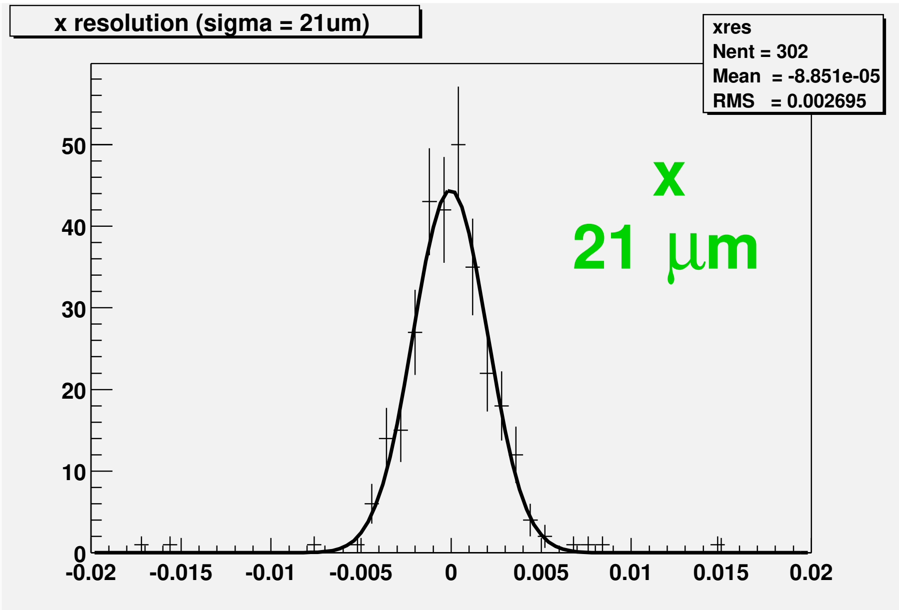


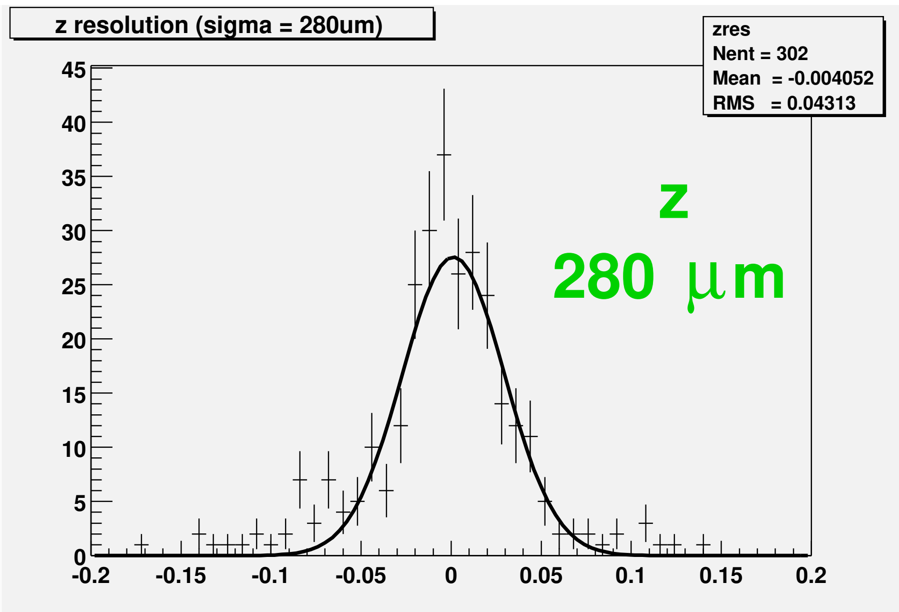
4 Track Secondary Vertices:

$\mathbf{B}_s \rightarrow J/\psi\ \phi \rightarrow e^+e^-K^+K^-$

MC study with mass constraint

VERTEX RESOLUTION (4 TRACKS!)





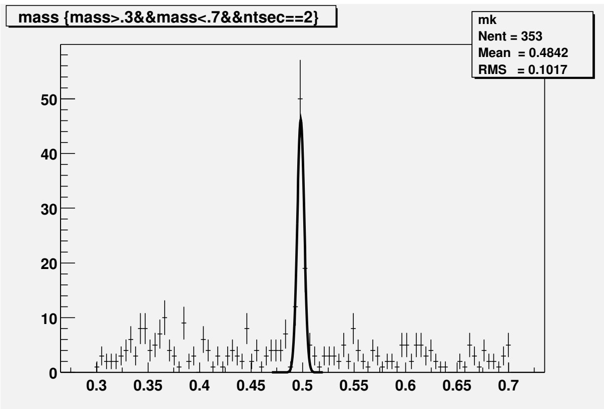
VDS tracks are refit with MC momenta smeared by 1%

Unbiased Secondary Finder

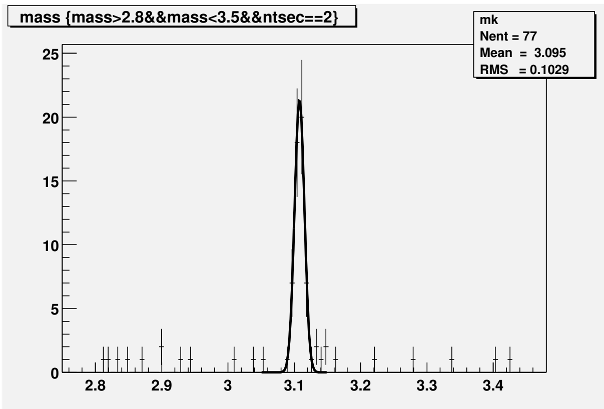
- first find primary vertices
- then use all tracks not used in primaries to try and make secondaries (unconstrained fit)
- MC events: $\mathrm{B}_s \to J/\psi\ \phi \to e^+e^-K^+K^-$ and
  $\mathrm{B}_s \to J/\psi\ \phi \to \mu^+\mu^-K^+K^-$
- VDS tracks are refit with MC momenta smeared by 1%
- assume charged π mass for every track

TWO TRACK VERTICES

$K_s^0 \to \pi^+\pi^-$



$J/\psi \to \mu^+\mu^-$

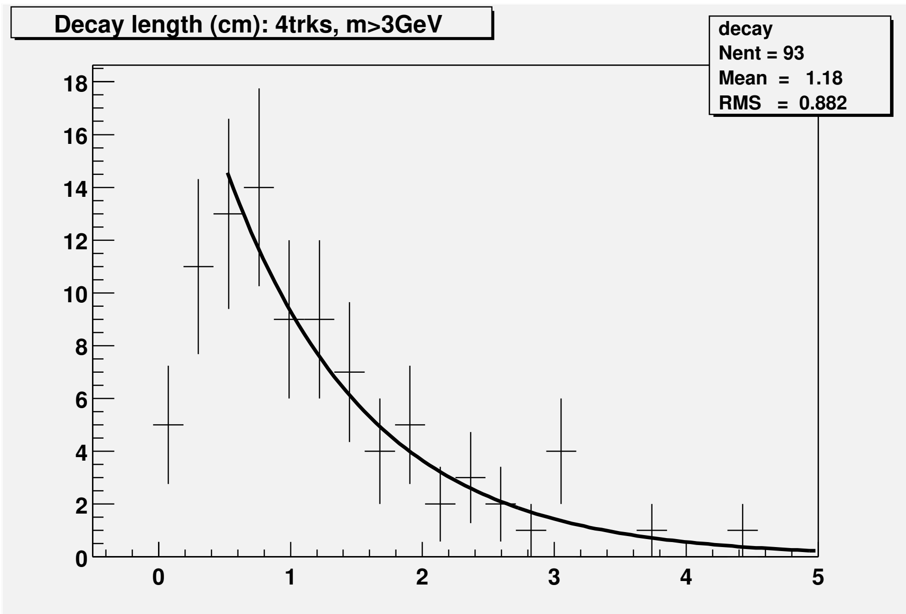


- no opposite-sign selection
- no particle identification

Unbiased Secondary Finder

THREE AND FOUR TRACK VERTICES

Mass.ge.3 tracks.ge.4



- VDS tracks are refit with MC momenta smeared by 1%
- clean separation, no entries with negative decay length
- 1 cm decay length within errors in all cases

CLEAR POTENTIAL
TO MEASURE LIFETIMES !
(e.g. try the Λ_b!)

Conclusions

- The HERA-B detector is installed and operational, in the commissioning phase.
- First interesting data were recorded during this year data taking
- The Vertex Detector is essentially commissioned and showed excellent performance
- Results from the reconstruction of primary and secondary vertices were shown: the design resolutions are reached!
- The measurement of lifetimes and production cross sections is in view