Status of sPHENIX TPC Simulations and Calculations

for

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TPC simulation goals

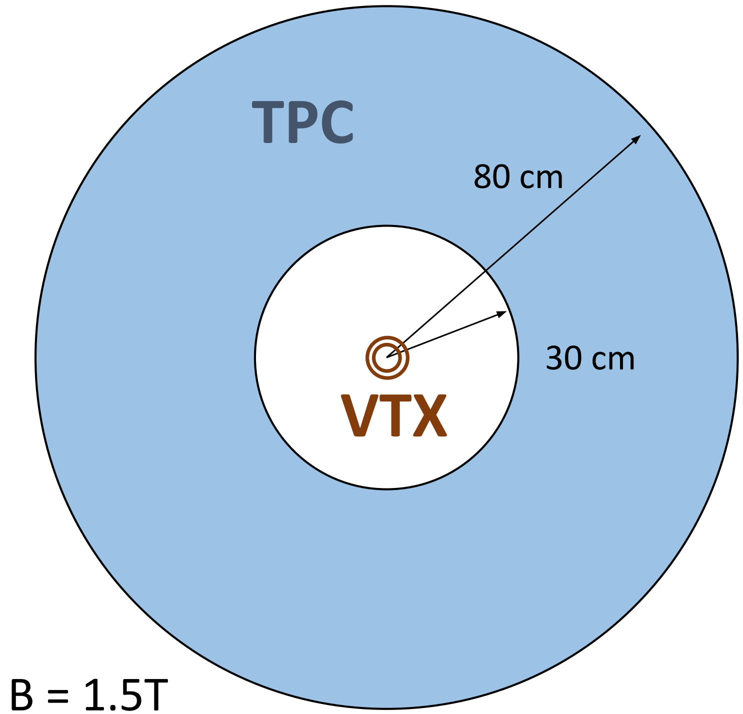
- Evaluate cost/benefit to add TPC to sPHENIX
- Primary figure-of-merit = Upsilon mass resl'n
- Additional physics considerations
  - jet fragmentation
  - jet-medium interations
  - fluctuations (wishful BES topic)
  - day-1 EIC detector (wishful, but not crazy)

Implementation Strategy

1. Analytic methods for space-to-momentum resolution (Gluckstern) extended to decay-width
2. Fast simulation to study TPC gas, E-field, and readout pitch for tracking and dE/dx
3. Full scale simulation to be developed or borrowed to study distortion effects

TPC parameters for this study

A sPHENIX Tracking Solution: TPC & 2 Pixel Layers



Design parameters and performance consistent with ILC TPC prototypes

TPC

- T2K gas volume from 30cm to 80cm
- |y|< 1 ⟶ z_{max} ~ ± 80cm
- 60 radial readout layer with Δr ~ 8mm
- Readout plane with 1.2mm pads in rφ
  - approximately 350,000 readout channel
- Assume 40 MHz FADC ⟶ Δz ~ 2mm
  - approximately 400 samples per readout channel

VTX layers 1 & 2

- Silicon tracker design

- Assume also 220 V/cm and T2K gas

Analytic Calculation

Estimate of Momentum and Mass Resolution from first Principles

See technical note TN468 for details

all coefficients calculate analytically

Momentum measurement:

- Gluckstern formula
- VTX constraint
- multiple scattering
- polar angle θ dependen

$$\frac{\sigma_p}{p} = \sqrt{\left(\frac{\sigma_{ms}}{\sqrt{\sin\theta}}\right)^2 + \left(\sigma_{det}\; p\sin\theta\right)^2 + \left(\sigma_\theta^{det}\;\cot\theta\sin\theta\right)^2 + \left(\frac{\sigma_\theta^{ms}}{\sqrt{\sin_\theta}}\;\frac{\cot\theta}{p}\right)^2}$$

0.066 (σ_{ms}), 0.00105 (σ_{det}), 0.0011 (σ_θ^{det}), 0.0025 (σ_θ^{ms})

Mass resolution:

- momentum
- opening angle (negligi

$$\frac{\sigma_m}{m} = \frac{1}{2}\sqrt{\left(\frac{\sigma_{p_1}}{p_1}\right)^2 + \left(\frac{\sigma_{p_2}}{p_2}\right)^2 + \left(\frac{\sin\theta_{pair}\sigma_{\theta_{pair}}}{1-\cos\theta_{pair}}\right)^2}.$$

actual ΔE calculate semi-analytically

- Bremsstrahlung

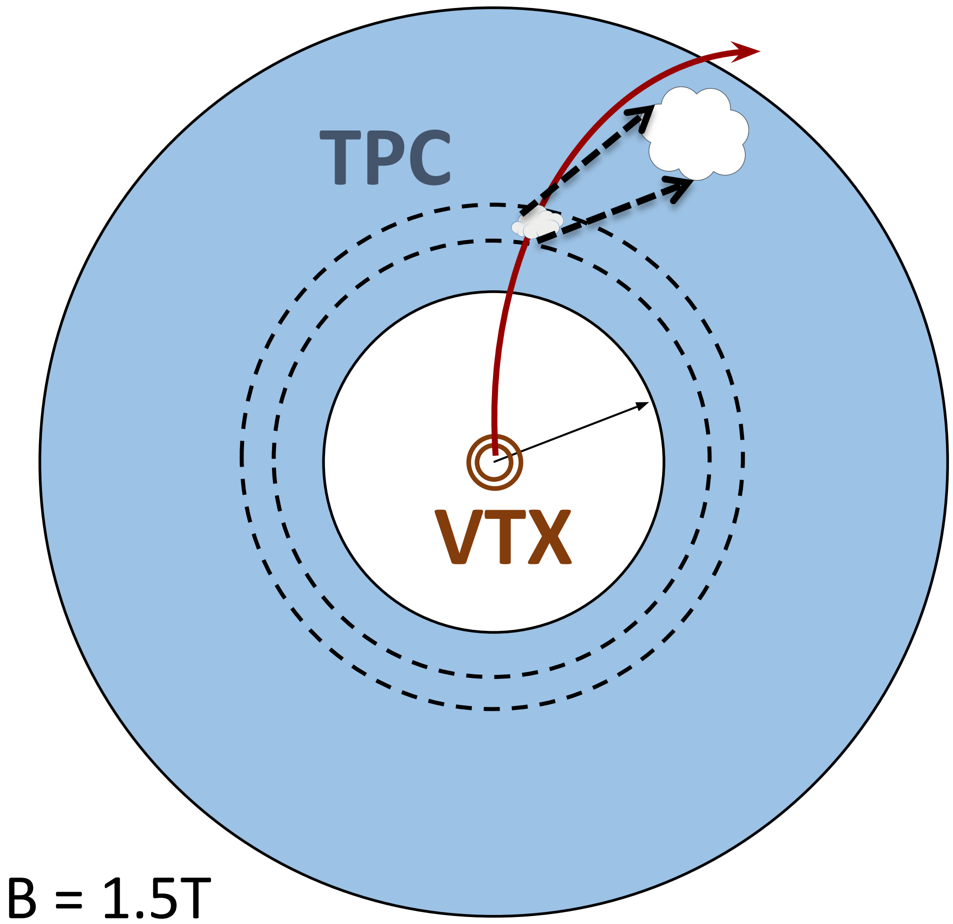
$k = \Delta E / E$

average photons emitted with energy spectrum

$$N_\gamma = \frac{L}{X_0}\left(\frac{4}{3}\;\ln\frac{k_{max}}{k_{min}} - \frac{4(k_{max}-k_{min})}{3} + \frac{k_{max}^2 - k_{min}^2}{2}\right)$$

$$\frac{d\sigma}{dk} = \frac{A}{X_0 N_A k}\left(\frac{4}{3} - \frac{4}{3}k + k^2\right)$$

Fast TPC simulator pictograph



- Determine ΔE thru radial segment from Geant
- Convert to ionization electrons
- Parameterize charge cloud diffusion with z_{drift}
- Distribute electrons across 2D pads
- Reconstruct hits with cluster finder
- Fit track through hits
- Calculate dE/dx (not implemented yet)

Fast TPC simulator equations

- General formula for Gaussian diffusion width
  - $\sigma^2_z = D^2_t z_{drift}/N_t + \sigma^2_{z0}$
  - $\sigma^2_{r\phi} = D^2_t z_{drift}/N_t/(1+\omega^2\tau^2) + \sigma^2_0$
- Parameters
  - N_t = ionization electrons (PDG tables)
  - $\omega\tau = v_{drift}B/E$
  - v_{drift}, D_t obtained from measurement or Magboltz
- For T2K gas (95-3-2), 220 V/cm, 1.45 Tesla
  - use measurements made for ILC study (next slide)
  - use σ_0 measured for triple-GEM readout

ILC study comparison

Comparison with calculated values,
http://www-hep.phys.saga-u.ac.jp:80/ILC-TPC/gas/

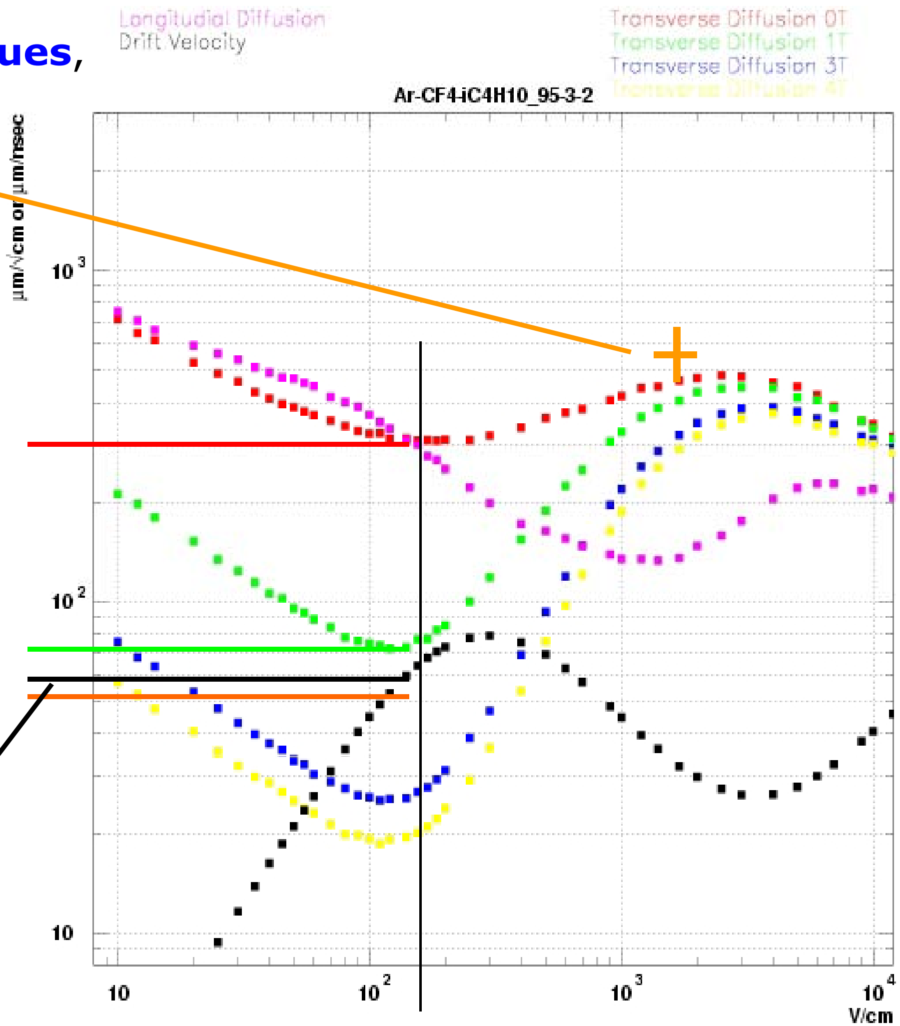
D(GEM), B=1.45 or 1.0 Tesla
measured 0.55 mm/(cm½)
about 1.4 x calculated

D_t, B=0, measured 0.298 mm/(cm½)

D_t, B=1.0T, measured 0.071 mm/(cm½)

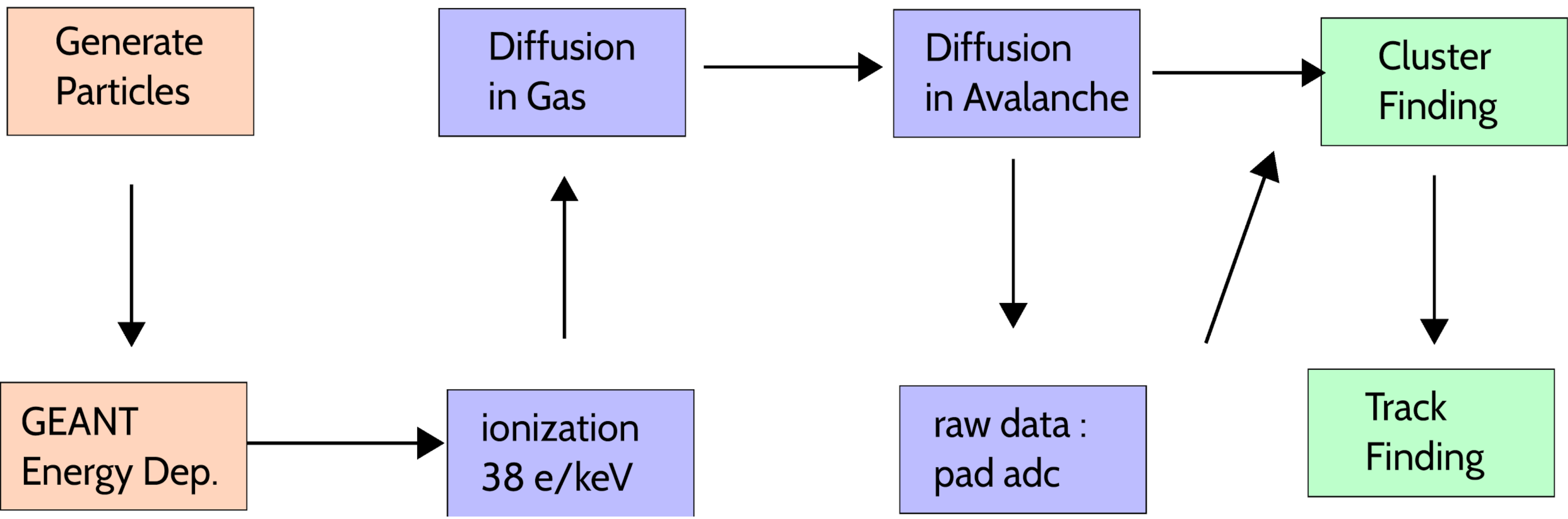
D_t, B=1.45T, measured 0.052 mm/(cm½)

Drift velocity: (370-87) bins
40ns/bin, 65cm drift length
V_d =57mm/μs



Alan's TPC Fast Simulator Schematic

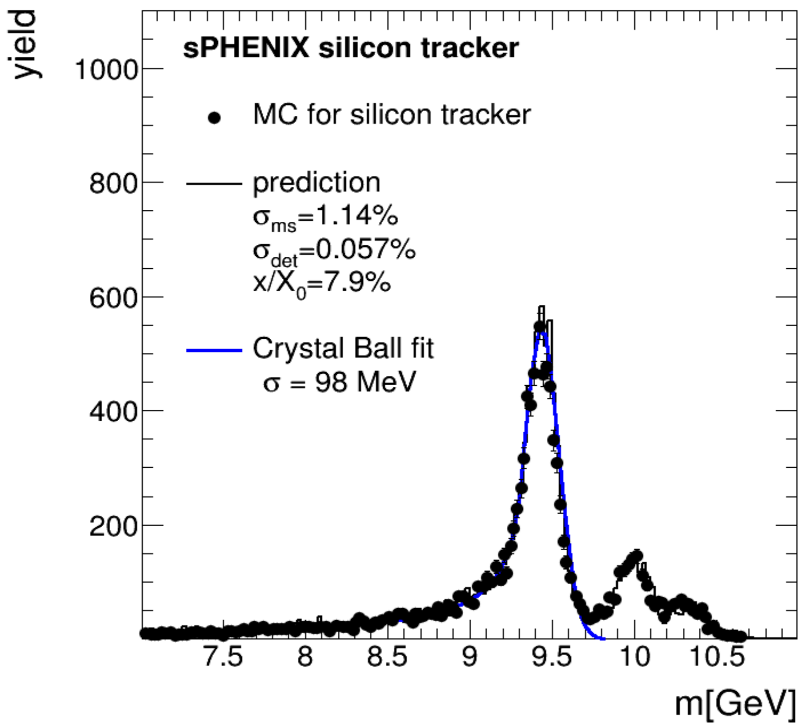
Flow Chart of GEANT Simulation & Analysis

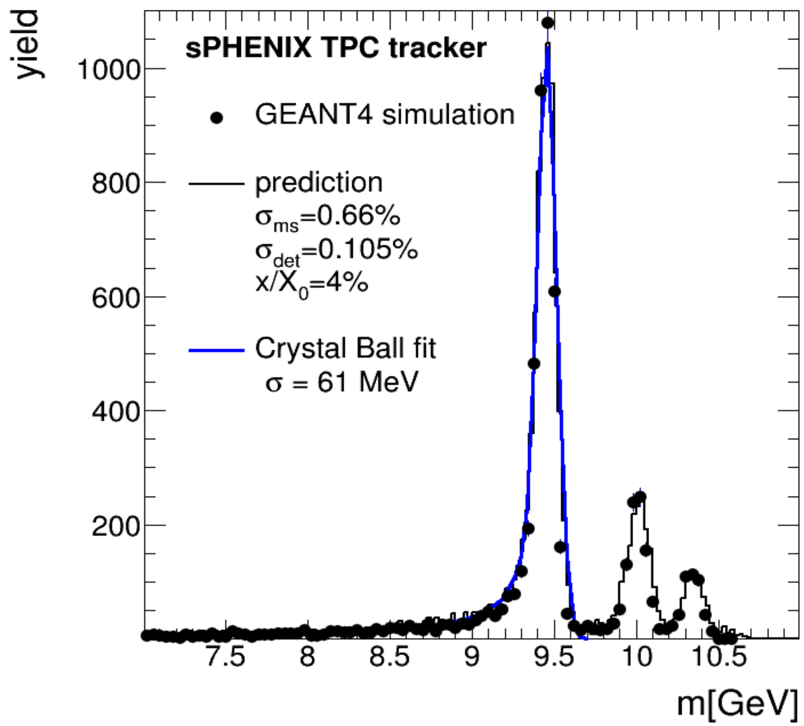


Alan Dion

Comparison Plot for Current Status

GEANT4 Simulation of Upsilon Measurement





- Si Left, TPC Right, Analytic formula in blue
- Fast Simulator ready for Evaluation Studies

Next steps (~1 month)

- Improve charge distribution along track and radial charge sharing
- Study variation with radial and azimuthal readout pitch, TPC gas, E-field, and drift length
- Study resolution, efficiency in high multiplicity environments (pythia, hijing)
- Begin workup of WBS ☹ to estimate project cause for sPHENIX scenario

Next Steps (longer term)

- Develop/borrow/steal slow simulator capability
- Pursue R&D work on amplification, obtain and test readout electronics
- Select tracking scenario for sPHENIX
- Continue communication with other projects !