Technology & Physics of a Photon Collider at NLC

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LC Study Group, SLAC

January 15, 2002

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

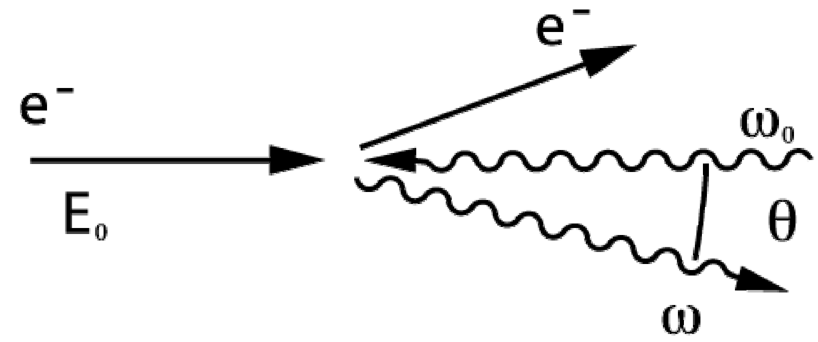
Outline

- Review the basic principles behind photon production through Compton back-scattering.
- Discuss the engineering required to actually realize a photon collider.
  - Lasers, Optics, Interaction Region design
- Overview of the NLC Final Focus System.
  - Optimization for $\gamma\gamma$ luminosity
- Physics opportunities at a $\gamma\gamma$ Collider
  - Probe "LHC wedge", CP properties, tan β, H^3 coupling

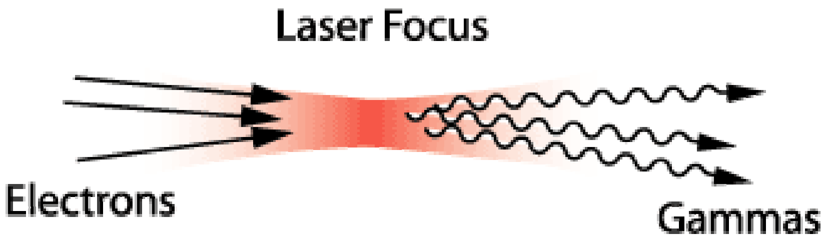
Basic components exist (laser, optics, IR design)
Complete engineering design presented at Snowmass

Compton back-scattering

- Two body process
  - Correlation between outgoing photon angle and energy
  - Maximum energy when the photon is colinear with the incoming electron

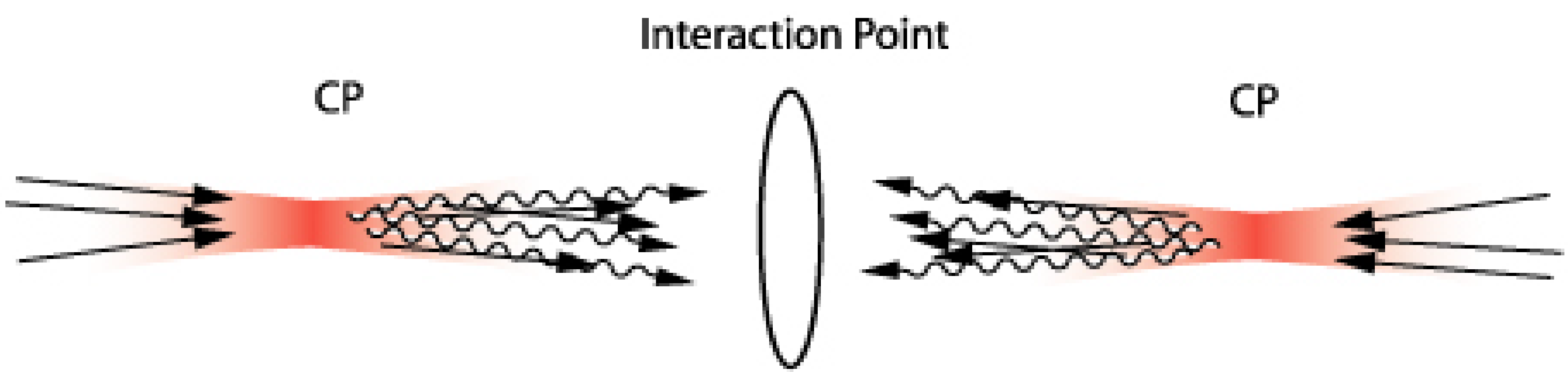


- Proposed by Ginzburg et al. (1982) for producing a photon collider
  - Collide a high power laser pulse with an electron beam to produce a high energy photon beam



Gamma-Gamma collisions

- Since high energy photons are co-linear with the incoming electron direction they focus to the same spot.
  - Lasers are powerful enough to convert most of the incoming electrons
  - High energy $\gamma\gamma$ luminosity is large
- Low energy photons and electrons also travel to the IP and produce a tail of low energy interactions.
- The beam - beam interaction at the IP
  - Produces additional low energy beamstrahlung photons
  - Deflects the low energy spent electrons.

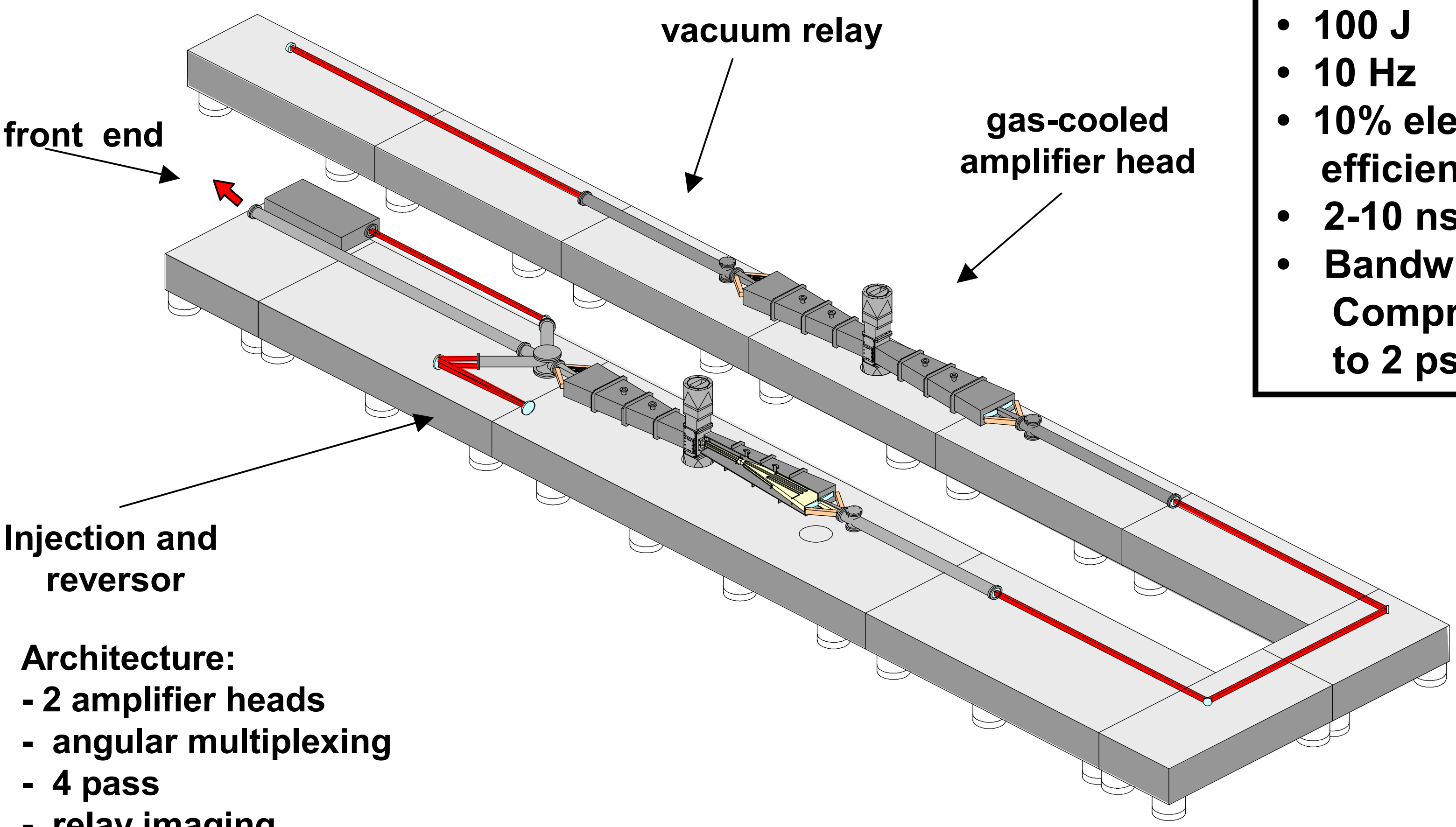


Lasers requirements

- Laser pulses of
  - 1 Joule, 1.8 ps FWHM, 1 micron wavelength
- One for each electron bunch
  - 95 bunches / train x 120 Hz = 11400 pulses / second
    - Total laser power 10kW
  - 2.8 ns between bunches

- Requires:
  - High peak power (1 TeraWatt)
  - High Average power (10 kW)
  - Correct pulse format (95 pulses @ 2.8 ns spacing x 120 Hz)

The Mercury laser will utilize three key technologies: gas cooling, diodes, and Yb:S-FAP crystals

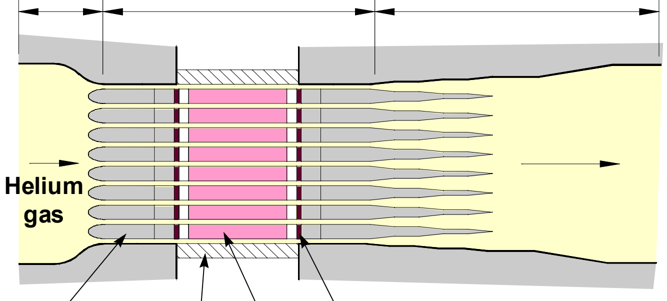


Goals:
- 100 J
- 10 Hz
- 10% electrical efficiency
- 2-10 ns
- Bandwidth to Compress to 2 ps

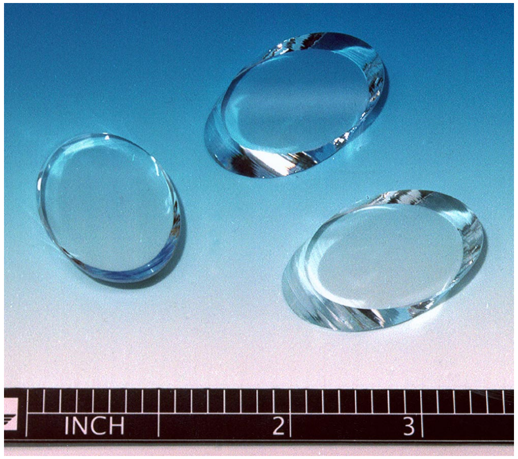
Architecture:
- 2 amplifier heads
- angular multiplexing
- 4 pass
- relay imaging
- wavefront correction

We are developing diode-pump solid state lasers as the next-generation fusion driver - Mercury will deliver 100 J at 10 Hz with 10% efficiency.

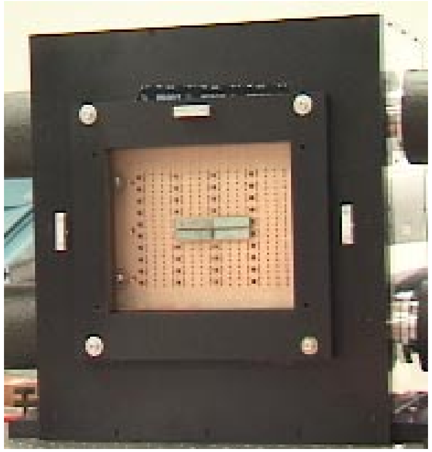
Gas concept



Mercury Lab

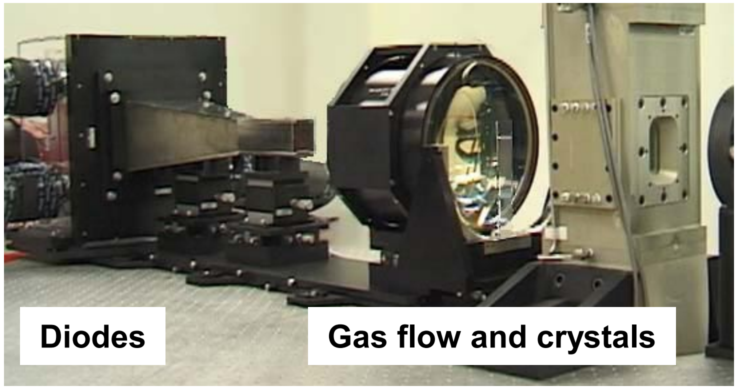


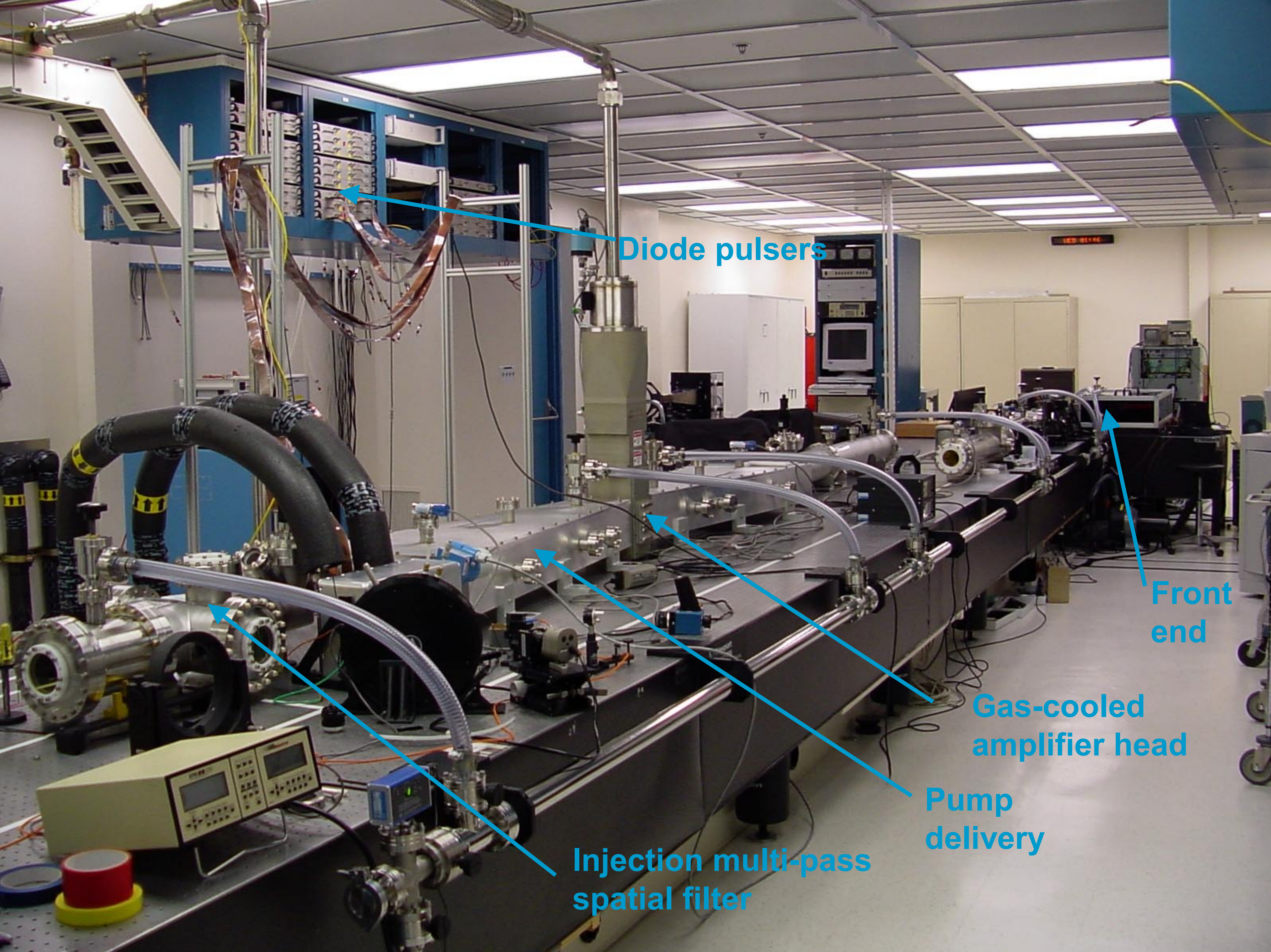
Yb:S-FAP crystals



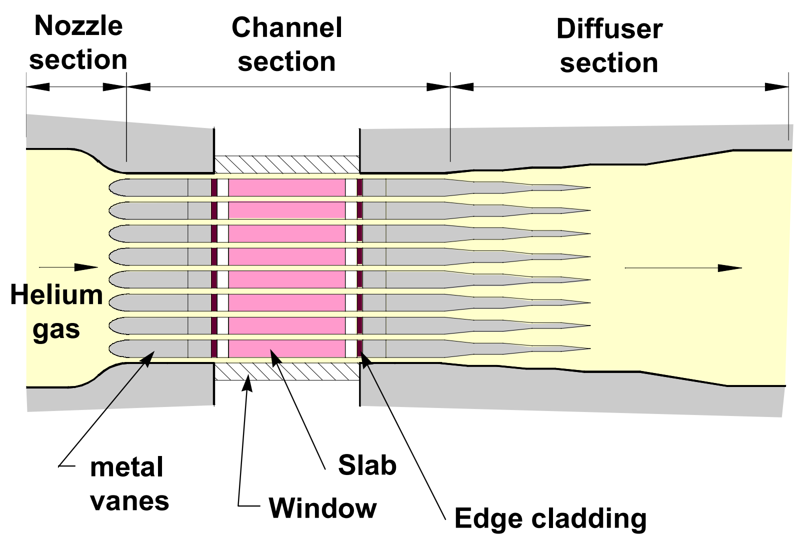
Diode array capable of 160 kW

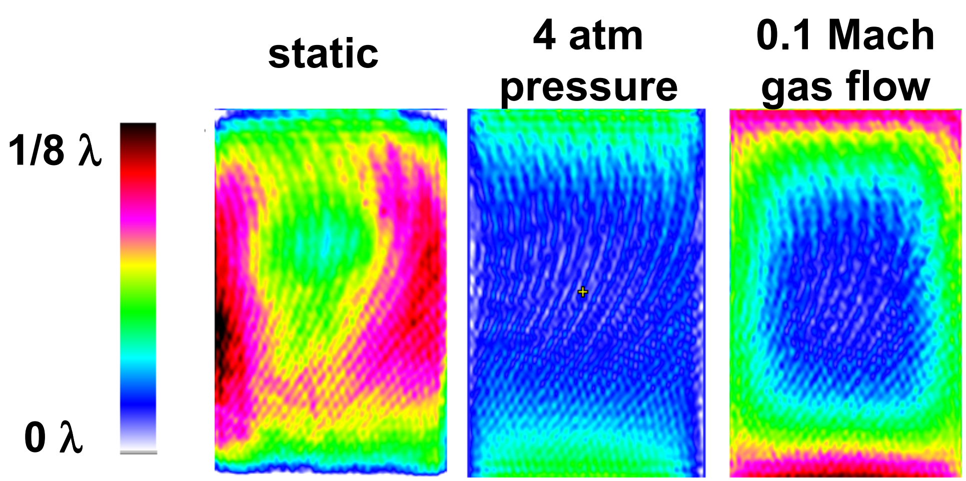
Pump Delivery



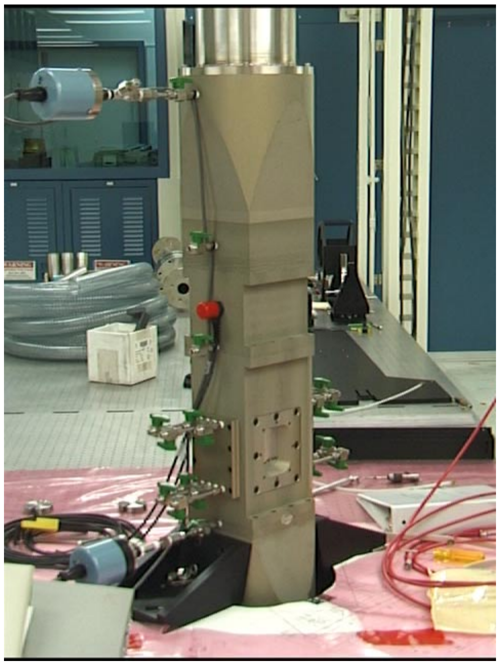

Diode pulsers
Front end
Gas-cooled amplifier head
Pump delivery
Injection multi-pass spatial filter

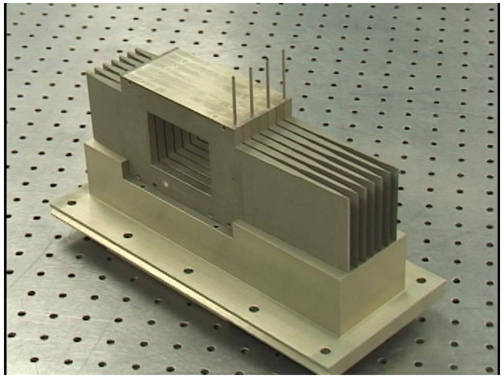
Pressure, Gas Flow Contributes 1/16 Wave to Wavefront Distortion



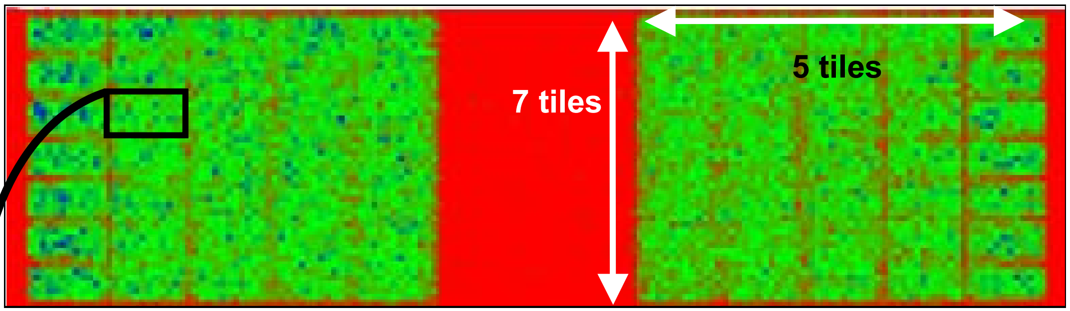


Gas cooled head and vanes



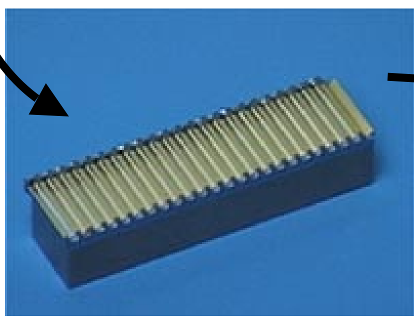


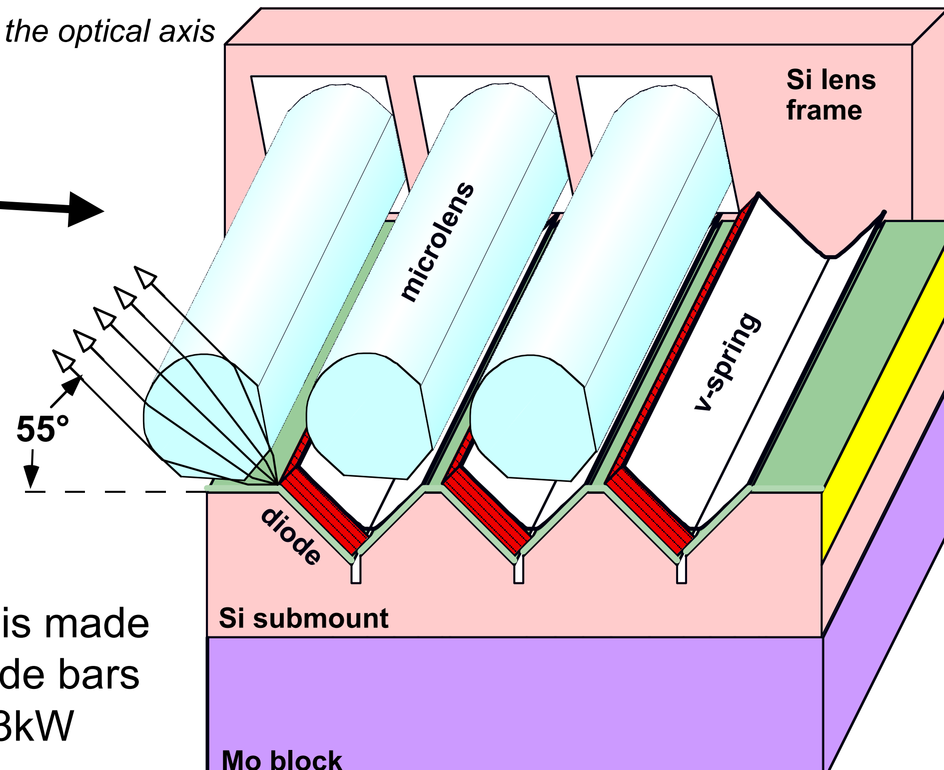
Diode pumping enables high average power
Matching diode output wavelength to the laser amplifier pump band gives 25% power efficiency



Diode light distribution (green) obtained in a plane normal to the optical axis

4 pairs of diode arrays like these are required for Mercury ⇒ 644 kW

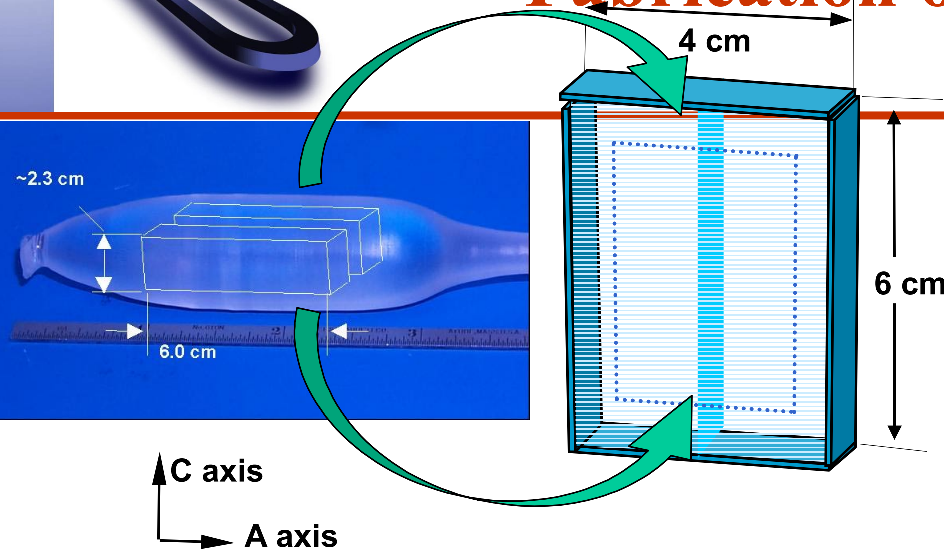




Each array is made of 5x7 =35 tiles per array ⇒ 161 kW

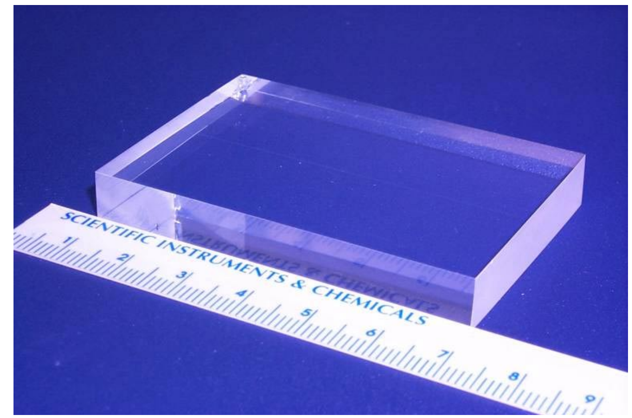
Each tile is made of 23 diode bars ⇒ 2.3kW

Fabrication of Yb:S-FAP Crystals

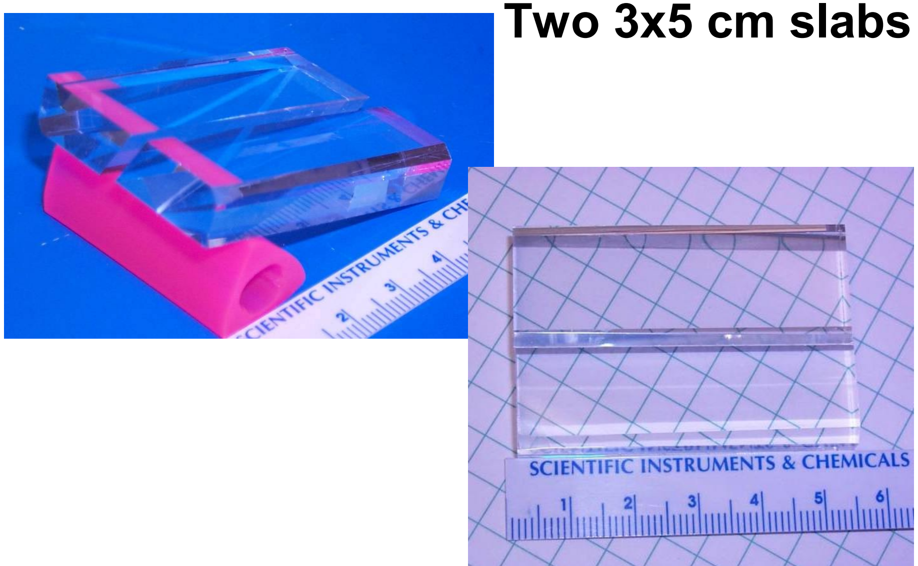


Goal

A full size 4x6 cm amplifier slab



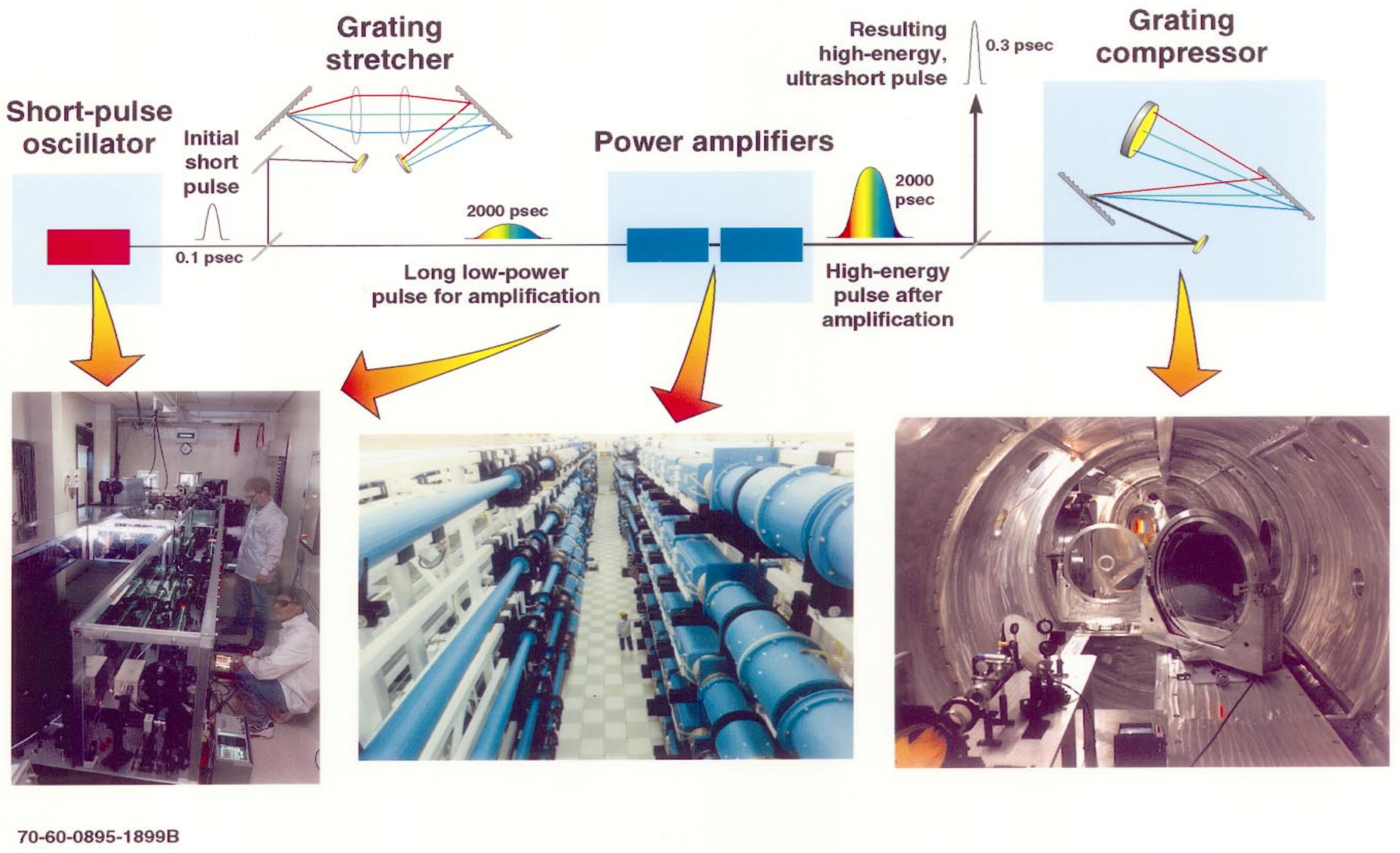
Two 3x5 cm slabs



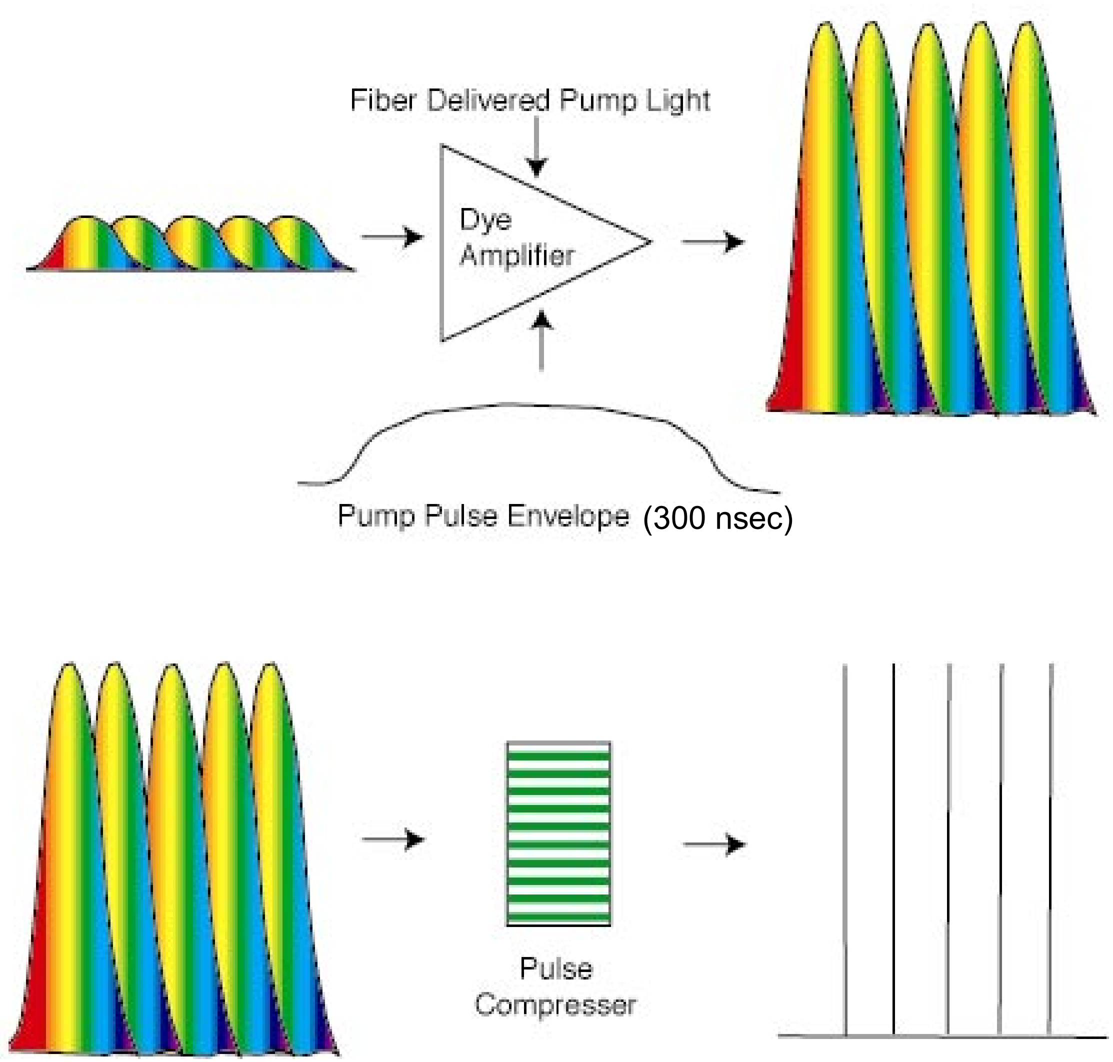
Status

- One full size bonded amplifier slab completed
  - awaiting polish and AR coating
- Two smaller slabs (usable) also completed and await finishing
- Processes are not completely reproducible at this point

Chirped pulse amplification allows high peak power picosecond pulses

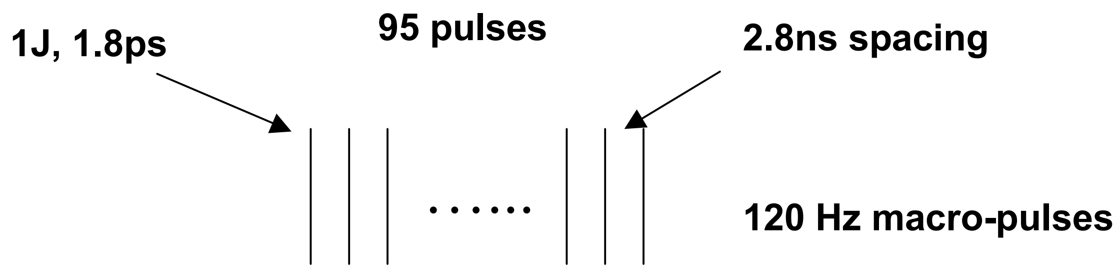


Wide band amplifier allows polychromatic components of the pulses to be linearly to amplified. Subsequent re-compression gives short, separated pulses.



Pulse Format drives the Laser architecture

NLC bunch format



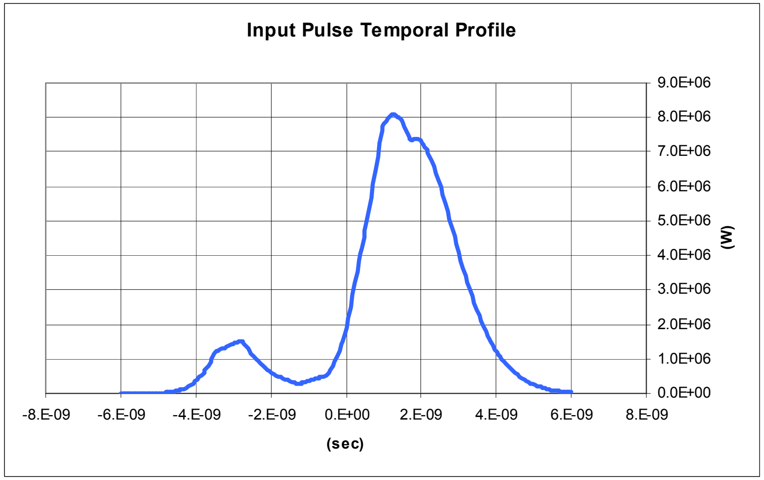
ZDR 1996

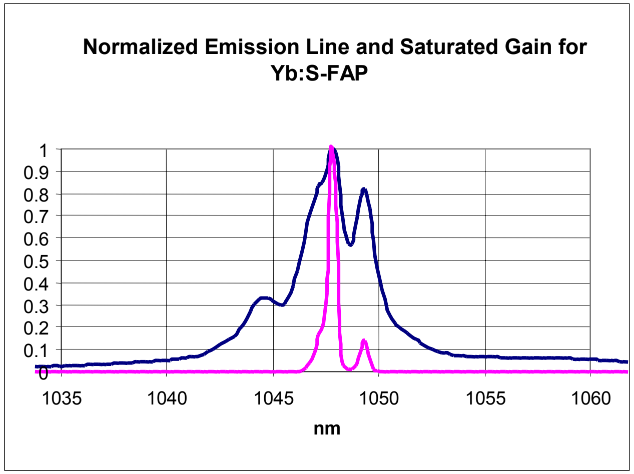
100 small lasers
1 J, 100 Hz
ns switches to spatially and
Combine sub-pulses to macro-pulse

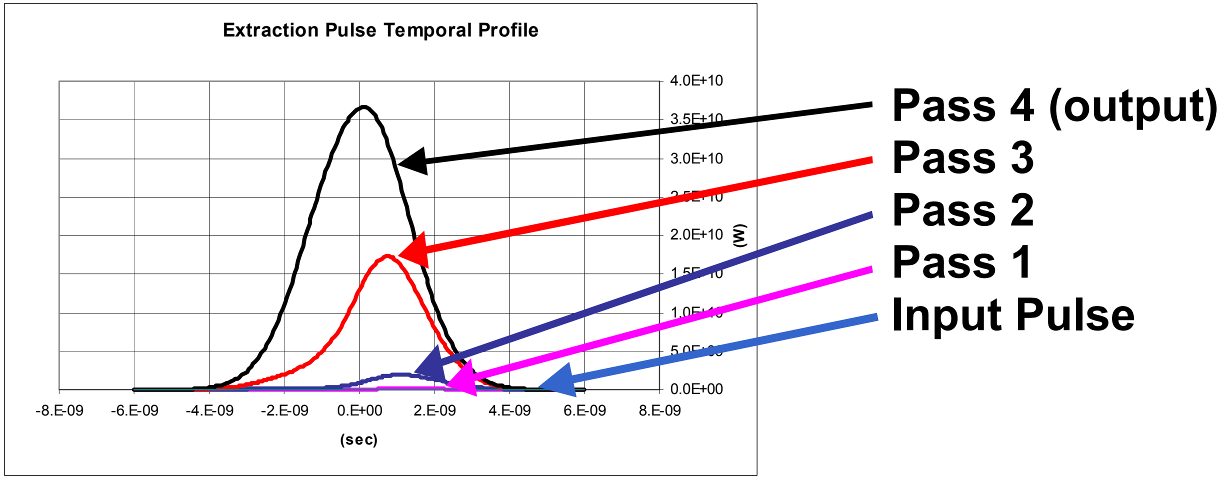
New Mercury

12 larger lasers
100 J, 10 Hz
Simple 10 Hz spatial combiner
Break macro-pulse into sub-pulses

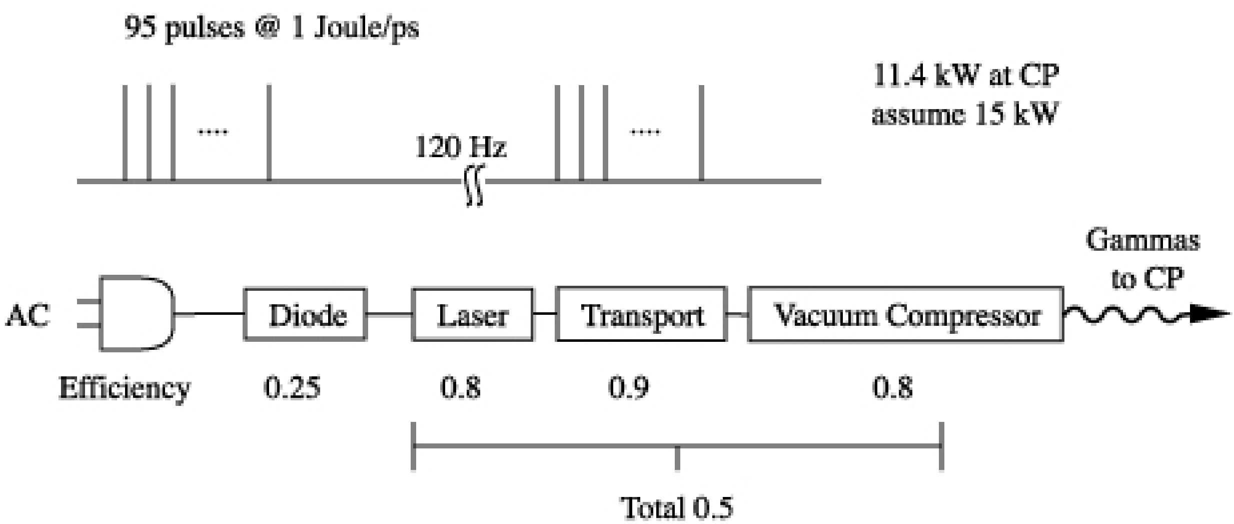
Appropriate spectral sculpting of the input pulse can lead to a linearly chirped gaussian output pulse (2 psec stretched output pulse case)







Diode requirements



w/ 100% contingency
@ \$5 / Watt

Total peak diode power

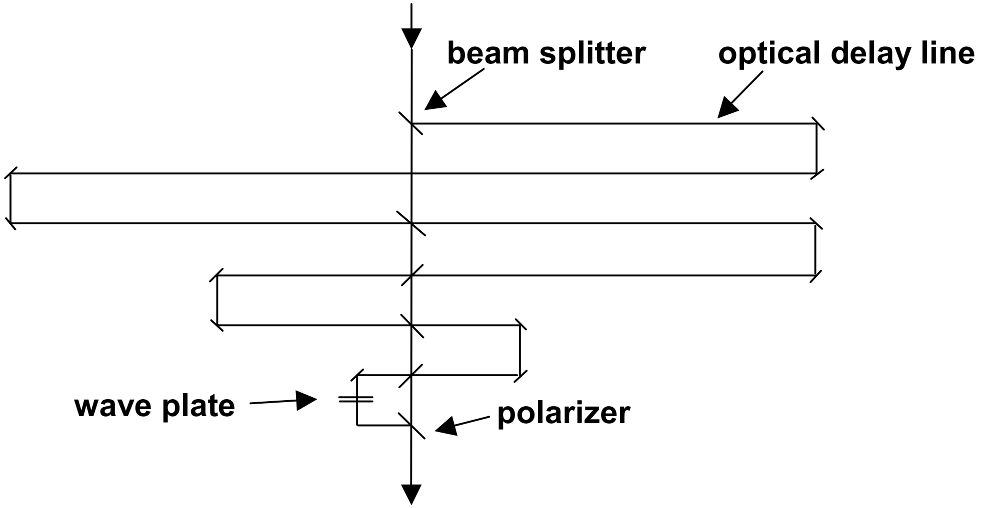
$$N_{lasers} \cdot \frac{Energy\,/\,pulse}{\varepsilon \cdot \tau_{upper}} = 12 \cdot \frac{100\,Joules}{0.5 \cdot 10^{-3}\,\text{sec}} \cong 2.5MW = \$24M$$

Average Power

$$\frac{\text{Total Power Required}}{\varepsilon_{\text{Tot}}} = \frac{15\ \text{kW}}{0.1} = 150\ \text{kW}$$

Optical Pulse Train Generation

- 100 J macro-pulse from laser converted to train of 1 J subpulses
- Combination of beam splitters and optical delay lines gives two with string of pulses
- Two beams combined on polarizer to give single beam
  - alternating linear polarization in pulses
  - 96 pulses (3 x 2^5)



γγ Laser System Cost Estimate ($01)

- Capital costs

$M	
20	lasers
40	diodes (at $5/W)
10	optics system
20	building
20	development program
40	contingency
$150M	total

- Operating costs

$M/y	
8	diodes at $5/W (5y or 10^9 shot lifetime)
4	labor
4	power
4	contingency
$20M/y	

$\gamma\gamma$ Laser Summary

- Pulse format of 1μm γ-γ laser must match electron bunch format
- Mercury laser amplifier under development by DOE can serve as γ-γ laser
  - laser under construction with single head to be completed in FY01
- New front end for Mercury laser will generate input pulse format needed
- Optical Compression Amplification and use of pulse string generation optics can modify Mercury pulse format to γ-γ requirements

DOE Mercury laser project can serve as the demonstration prototype for the γ-γ laser project

NLC - The Next Linear Collider Project

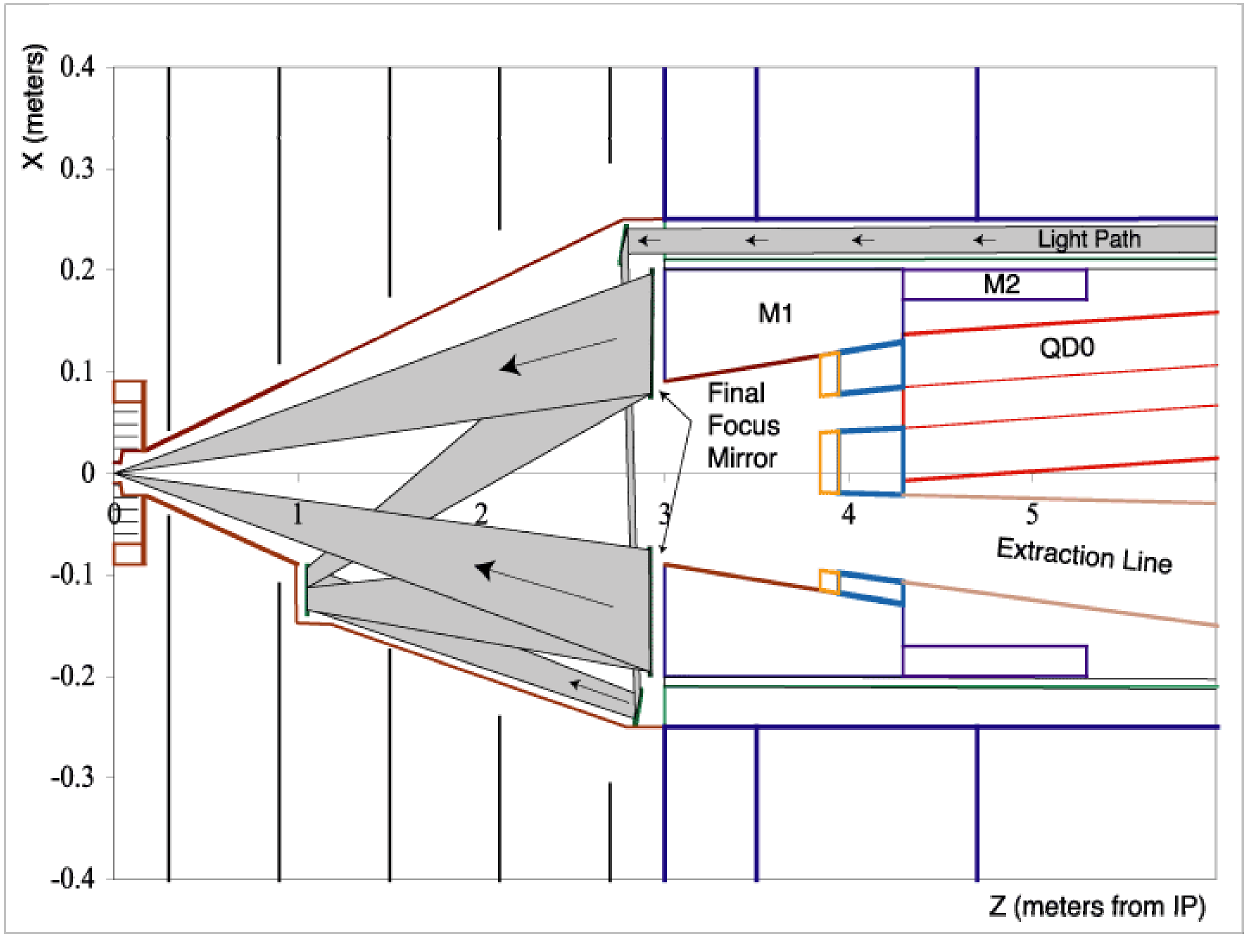
$\gamma\gamma$ Optics Prototyping and LINX $\gamma\gamma$

David Asner/LLNL

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

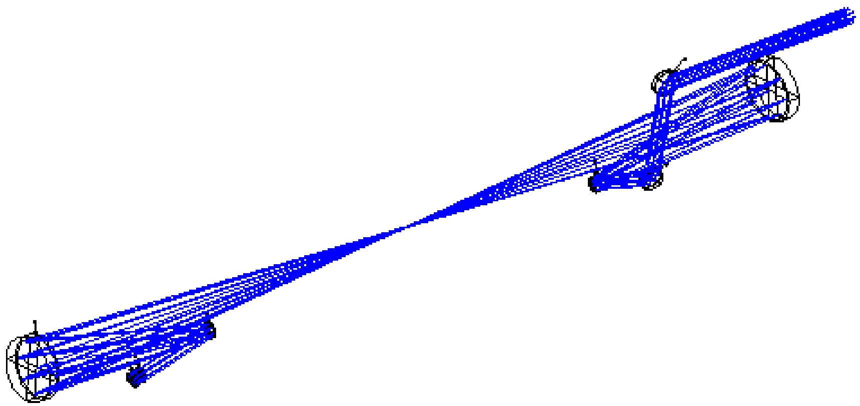
Focusing mirrors - tight fit

LCD - Large with new mirror placement

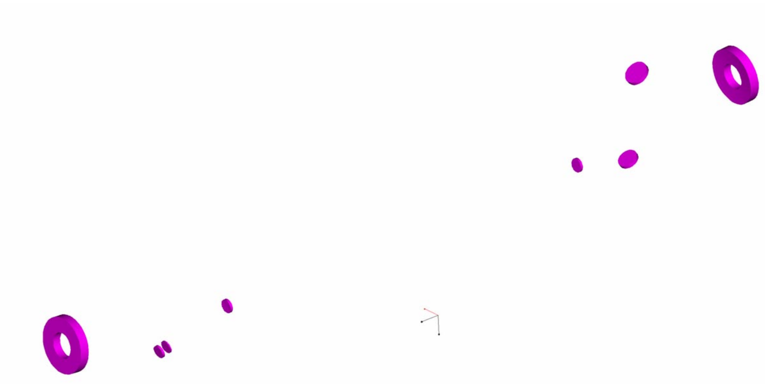


- Essentially identical to e^+e^- IR
- 30 mRad x-angle
- Extraction line ± 10 mRadian
- New mirror design 6 cm thick, with central hole 7 cm radius.
  - Remove all material from the flight path of the backgrounds

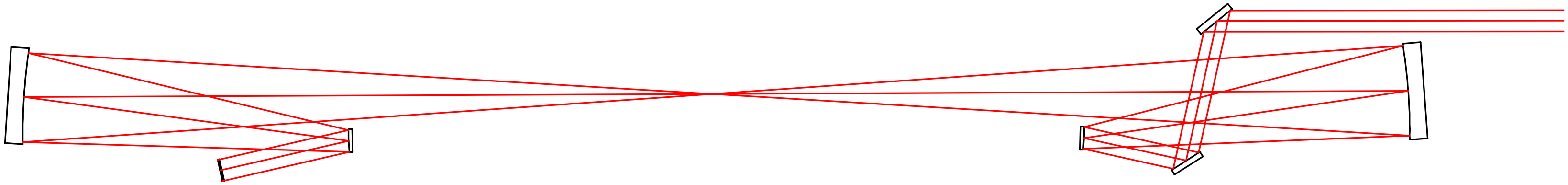
Packaging the Following Optical Train



Optics & beampath

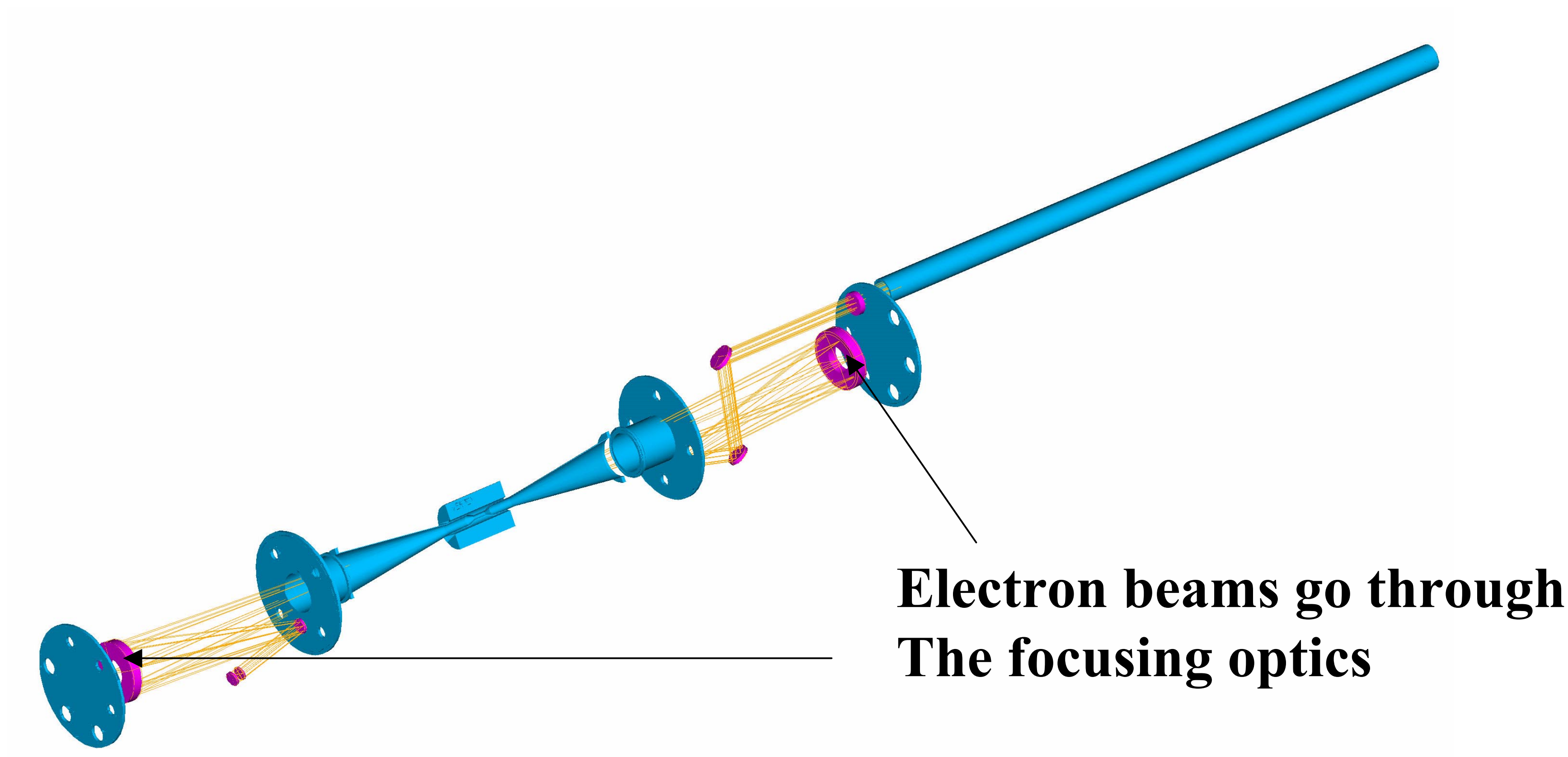


Optics only



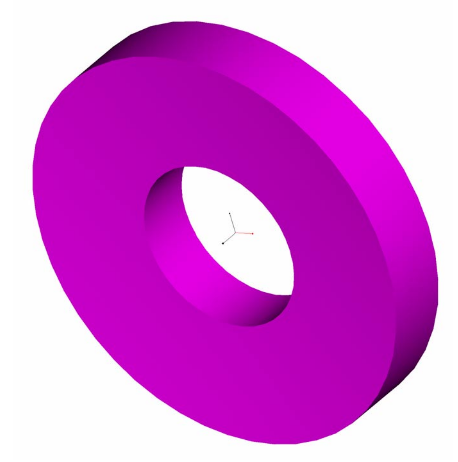
Side view of optics and beampath

Must Accommodate Electron Beam Paths

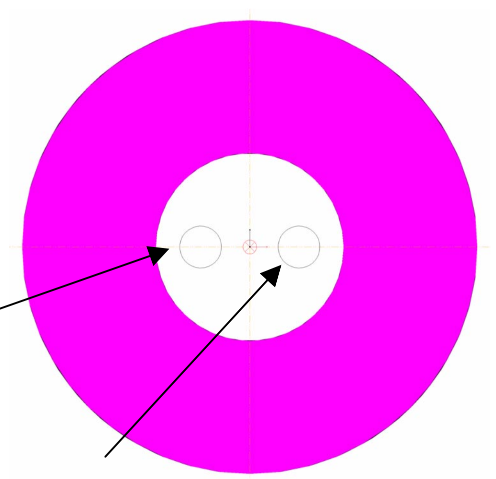


A central hole in the two end mirrors allows charged particle and background transport

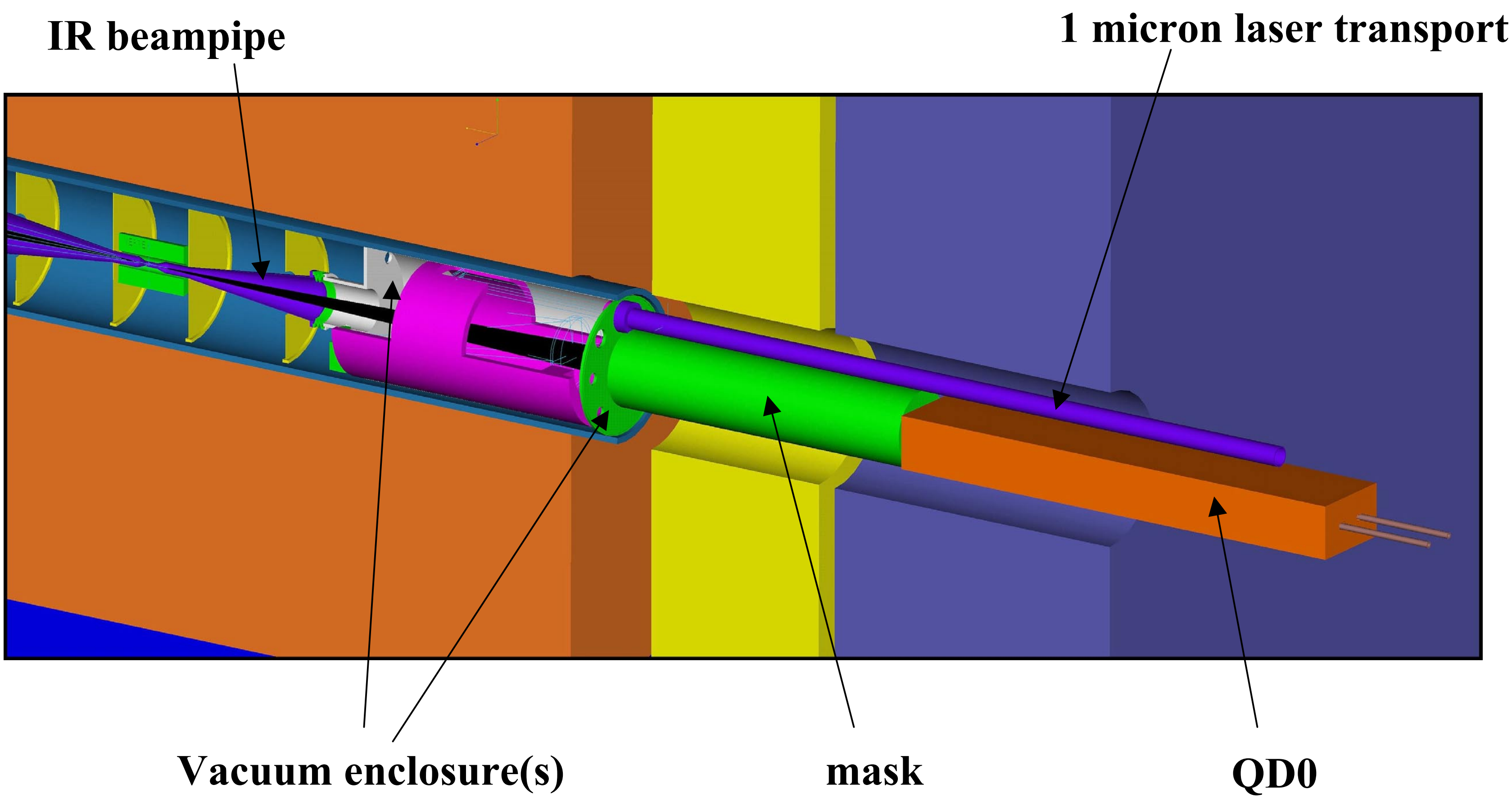
- **Final focusing optic must be closely aligned to the electron beams**
  - **beam must pass through center of optic**



- **Hole in primary optic for electron beams also allows passage of most of the background particles**

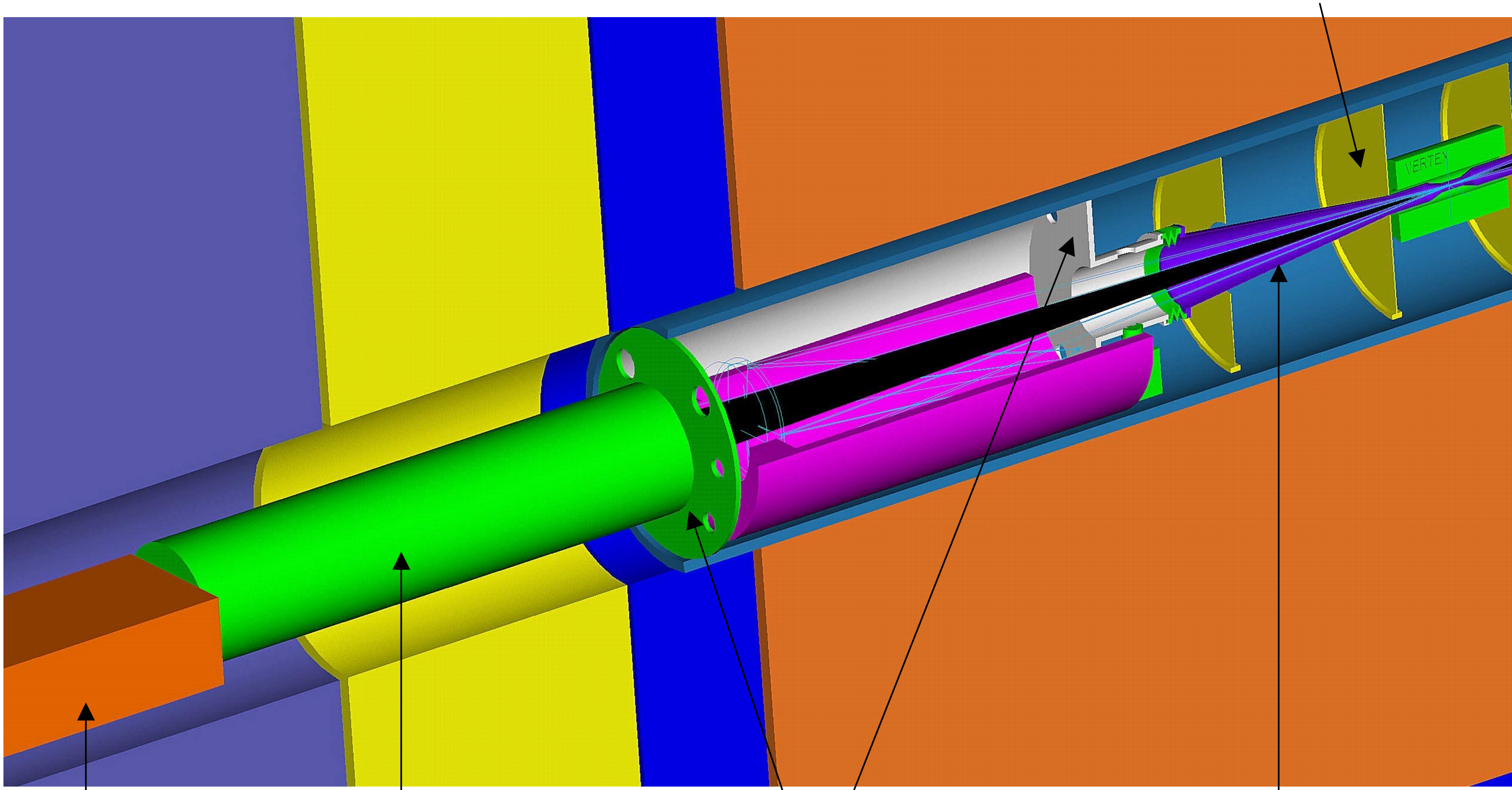


2D IR Region Layout (incoming leg)



2D IR Region Layout (reflected leg)

Silicon disks



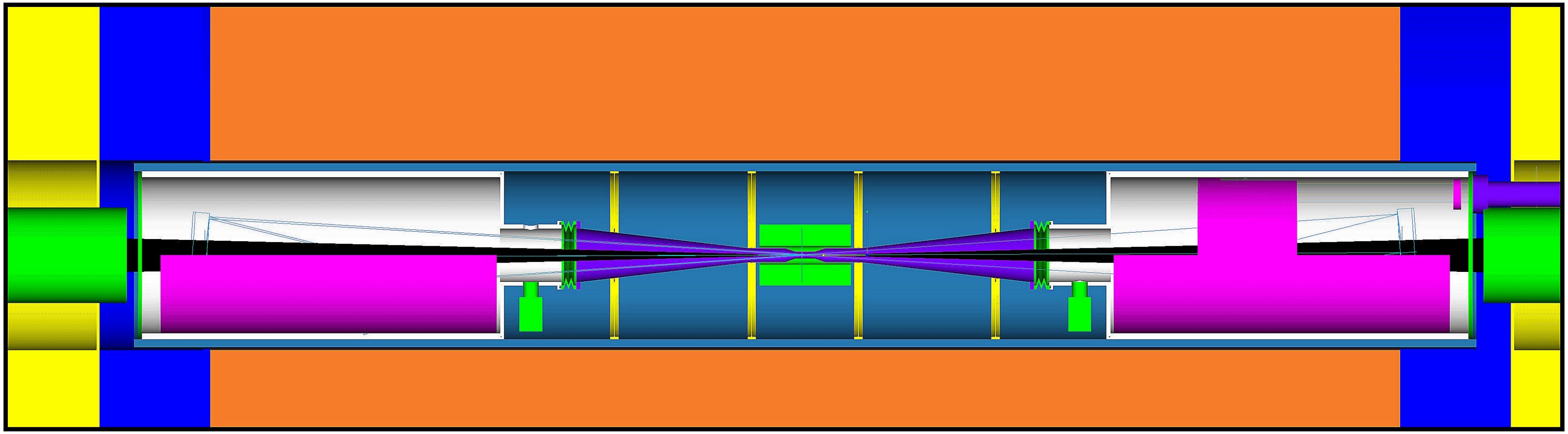
QD0

mask

Vacuum enclosure

beampipe

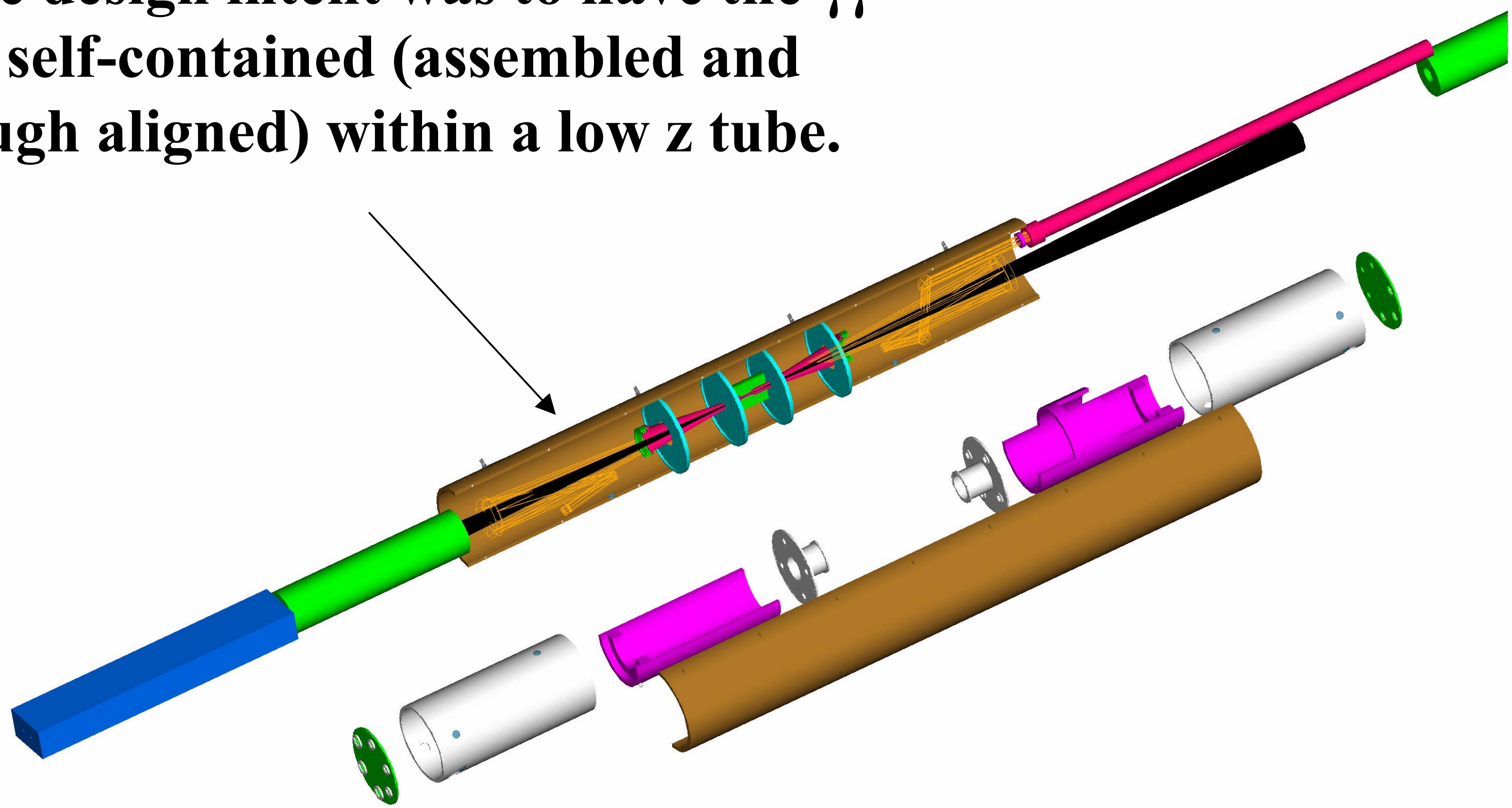
Several features are unique to a γγ collider IR



- Cylindrical carbon fiber outer tube
- Vacuum boundary with transition from thick cylinder to thin beampipe.
    - Sections of "strongback" for optical support
- Thermal Management

Optical Train-IR buildup contained within the carbon fiber-honeycomb tube

The design intent was to have the γγ IR self-contained (assembled and rough aligned) within a low z tube.



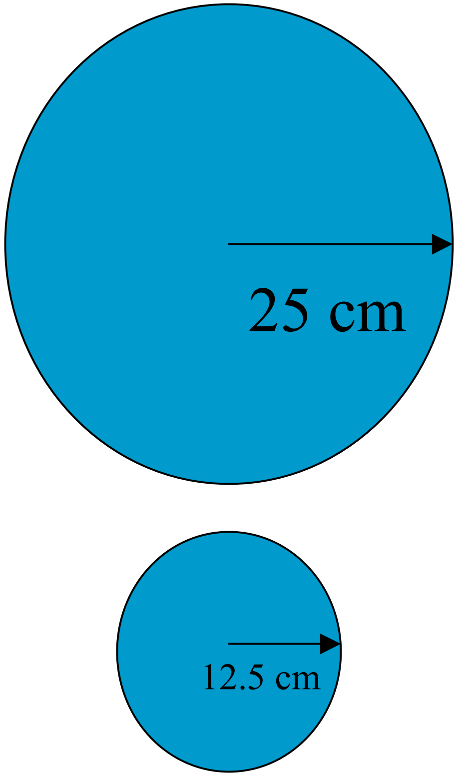
IR Design Status

- Basic optics concept - done for ZDR '96
- Integration with detector & accelerator - done
- Mechanical engineering and packaging - 1st pass done
- Pointing and steering controls - to be designed this FY
- Beam diagnostics - to be designed this FY
- 1/2 scale prototype - to be built this FY
  - Stage 1:
    - Test bed for design of beam diagnostics and controls
  - Stage 2:
    - Low energy $\gamma\gamma$ running at LINX

Actual running at low energy tests all of the issues involved with a $\gamma\gamma$ collider except for the high average power damage issues.

1/2 scale advantages

- More likely to fit whatever accelerator and detector configuration is chosen for LINX
- Optics are cheaper and lead times reduced.



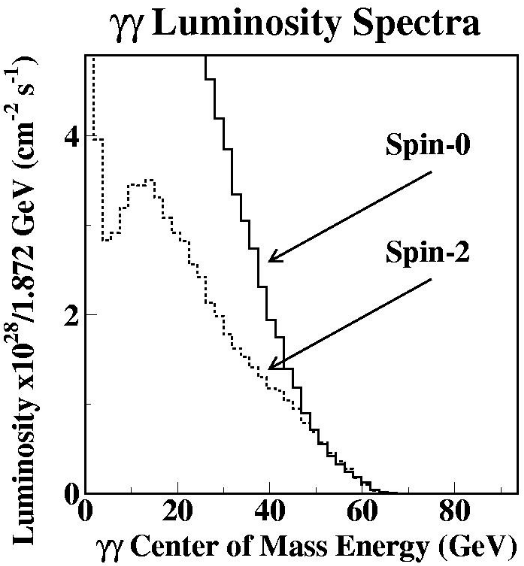
R of 25 cm → 12.5 cm
L of 4m → 2 m

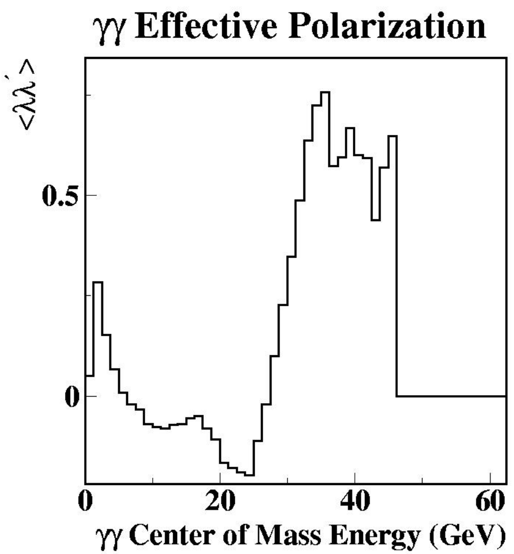
Low energy γγ collisions

- "LINX"
  - A proposal to use the SLC as a Linear collider Beam Delivery Test Bed. Adding lasers and optics would allow low energy γγ collisions

Energy (GeV)	30 e^-e^+	45 e^-e^-
β_x/β_y (mm)	8/0.1	8/0.1
$\varepsilon_x/\varepsilon_y$ ($\times10^{-5}$)	1.6/0.16	2.5/0.5
σ_x/σ_y (μm)	1.48/0.05	1.51/0.08
σ_z(μm)	100	100
N ($\times10^{10}$)	0.6	1.5
Rep Rate (Hz)	30	120
e^- Polarization (%)	80	80
Laser λ (μm)	0.351	0.351

Single pulse @ 30 Hz Easier lasers





Optics identical to those required for LC

Complete test of the optics

Engineering and Physics measurements

- Engineering measurements:
  - Collision stability
  - Two photon hadronic background measurements
  - Data based luminosity measurements that decompose
    - $\gamma\gamma$, $e\gamma$, ee with spin states
- Physics measurements:
  - Two photon hadronic cross section
  - Spin-0 and 2 bound states of bb and cc
  - B_c production from two photon interactions
  - Photon structure function (polarized?)
  - Sufficiently light Higgs is allowed in generalized 2HDM (II) and with NMSSM but is excluded by the MSSM

Required detectors

- For a minimal program we would install only enough to measure the luminosity spectrum
  - Exactly what this entails is still to be studied.
- For a more interesting program we would like to install something more like a 4 pi detector.
  - SLD is there and might be revived.
  - CLEO goes offline in a couple of years, perhaps they might contriubte their detector and expertise.
  - A new detector? Almost certainly beyond the scope of this effort in terms of cost and manpower.

Conclusions

- Optics and Lasers to do low energy $\gamma\gamma$ running at LINX will almost certainly be available before LINX is running in collision mode.
- Upgrading to $\gamma\gamma$ would not be prohibitively expensive given that optics and lasers from LLNL were available.
  - $\gamma\gamma$ running would provide operational experience that would almost eliminate the technical risks of a $\gamma\gamma$ IR at NLC
- If sufficient interest in the physics is available and a detector can be scrounged then real physics might be done as well.

Final Focus System: $\gamma\gamma$ Interaction Region

David Asner/LLNL

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ECFA/DESY Linear Collider Workshop
September 14-18, 2001, Krakow, Poland

Preview

Begin with Beam Delivery System for NLC-500 GeV

- Only modify the Final Focus - Collimator section unchanged
- Leave FFS quadrupoles unchanged
- Double the strength of FFS bending magnets
- Reduce strength of sextupoles by 1/2
- Reduce strength of octupoles, decapoles by 1/4, 1/8

Allows reduction of β^* : Increased geometric luminosity

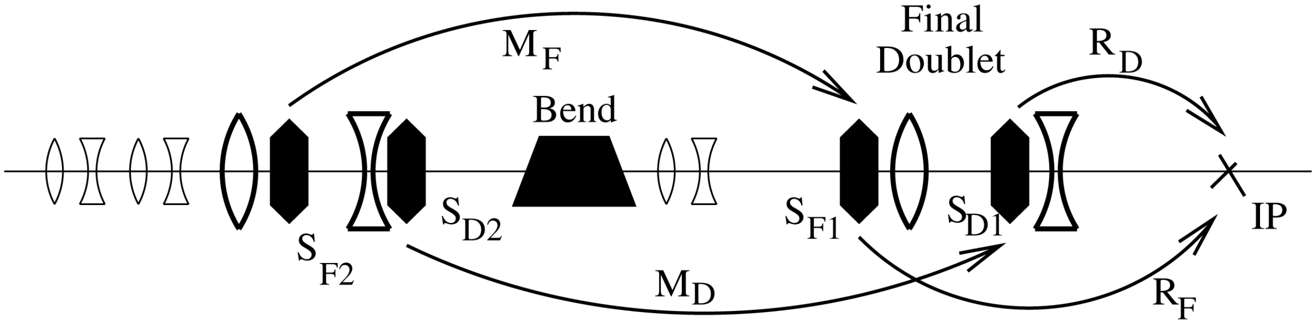
Final Focus: General Overview

FFS must focus beams to small sizes at the IP

- Chromaticity of FF is determined by the final doublet.
- FD chromaticity scales as L^*/β^*, and thus the chromatic dilution of the beam size $\Delta\sigma/\sigma \sim \sigma_E\, L^*/\beta^*$ is very large.
- Design of a FF is driven by the necessity of compensating the FD chromaticity.

See article by P. Raimondi and A. Seryi, in Proceedings of LINAC 2000 [physics/0008072]

Principles of the “ideal” FF



- **A Final Doublet is required to provide the necessary demagnification.**
- **The chromaticity is cancelled locally by two sextupoles interleaved with the FD together with a bend upstream to generate dispersion across them.**
- **Geometric aberrations of the FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend.**
- **Four more quadrupoles are needed for β-matching**

Final Focus System: $\gamma\gamma$ IR

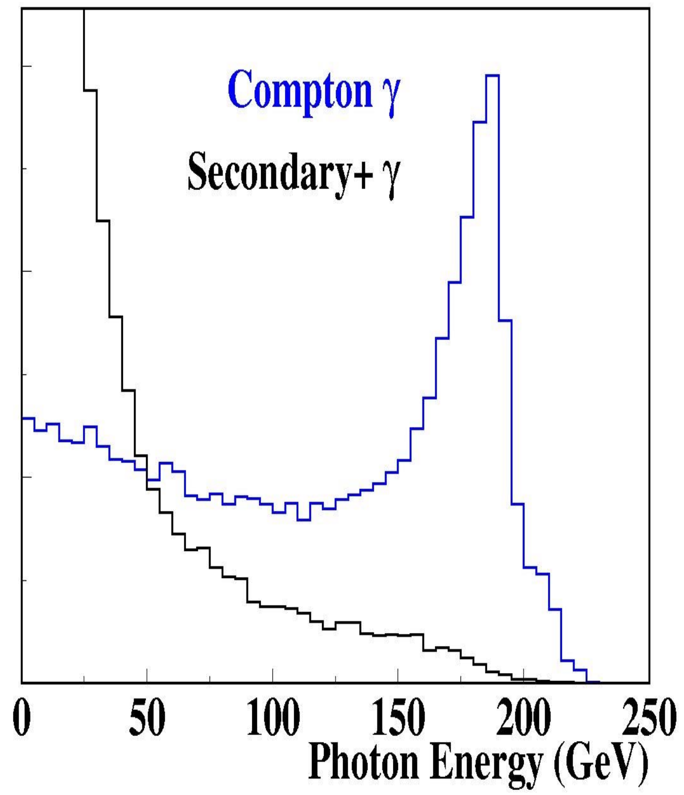
High energy photons produced from Compton backscattering of 1μ laser off electron beam

Standard FFS for e^+e^- could be used for $\gamma\gamma$ IR

- Flat beams chosen for e^+e^- to minimize beamstraahlung and preserve small ΔE

Not an issue for $\gamma\gamma$

- Desire re-optimized FFS without flat beam constraint
- Maximize luminosity
- Reduce stabilization requirements



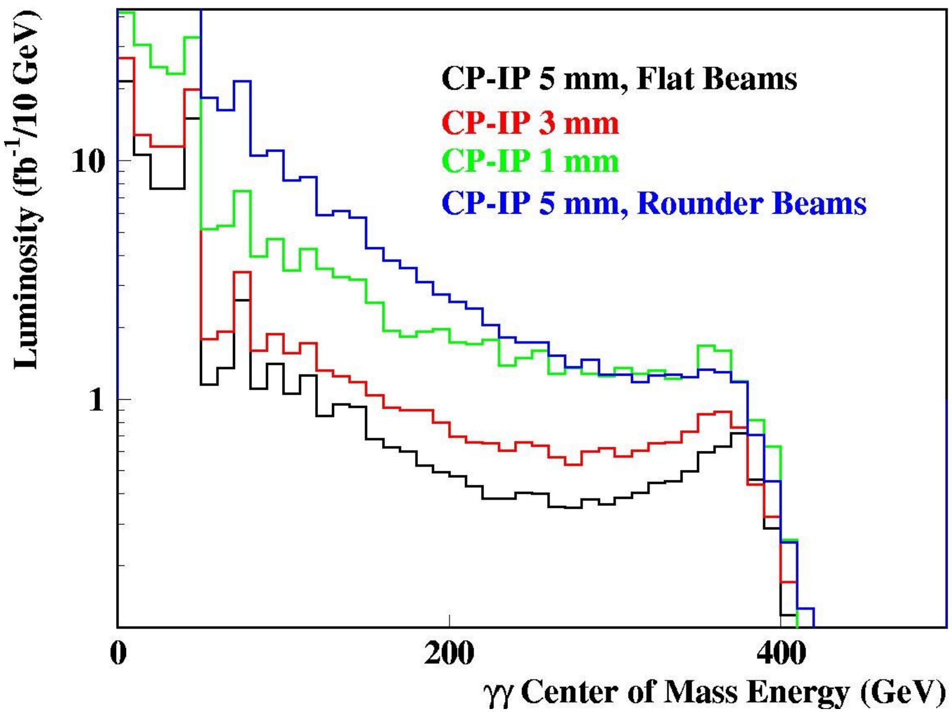
Luminosity Considerations

- Highest luminosity attained for smallest spot size
  - Smallest beta functions yield smallest spot size
  - $\sigma_x = (\beta_x \varepsilon_x)^{1/2}$, $\sigma_y = (\beta_y \varepsilon_y)^{1/2}$
  - Limited by "Hourglass Effect"
    - Expect best results for $\beta_x = \beta_y = \sigma_z$
  - FFS for e^+e^- IR already has $\beta_y = \sigma_z$ but $\beta_x >> \sigma_z$

- Many issues make smaller β_x difficult
  - Synchrotron Radiation
  - Bandwidth though IP and Final Doublet
  - Chromaticity

Luminosity Considerations -II

- Energy-Angle correlation for Compton backscattered γ
  - Angular distribution ~ $1/\gamma$
  - Low energy spot size expands faster than high energy
    - Increasing CP-IP distance reduces low energy lumi
    - Reducing CP-IP distance increases high energy lumi
    - Reducing CP-IP distance decreases polarization at maximum luminosity
  - Varying beam aspect ratio and varying CP-IP distance distinct



Use CP-IP 1mm, Flat Beams

CP-IP 5mm, Rounder Beams at SNOWMASS

Beam Parameters

	NLC-e^+e^-	NLC-$\gamma\gamma$	Tesla-e^+e^-	Tesla-$\gamma\gamma$
Energy(GeV)	500	500	500	500
$\beta x/\beta y$ (mm)	8/0.1	4/0.065	15/0.4	1.5/0.3
$\varepsilon_x/\varepsilon_y$ ($x10^{-8}$)	360/3.5	360/7.1	1000/3	250/3
σ_x/σ_y (nm)	243/2.7	172/3.1	553/5	88/4.3
σ_z(μm)	110	156	300	300
N ($x10^{\wedge 10}$)	0.75	1.5	2	2
Rep Rate (Hz)	120x190	120x95	5x2820	5x2820
L_{geom} ($x10^{34}$ cm^{-2} s^{-1})	1.6	3.8	1.6	12

FFS for e^+e^- best studied

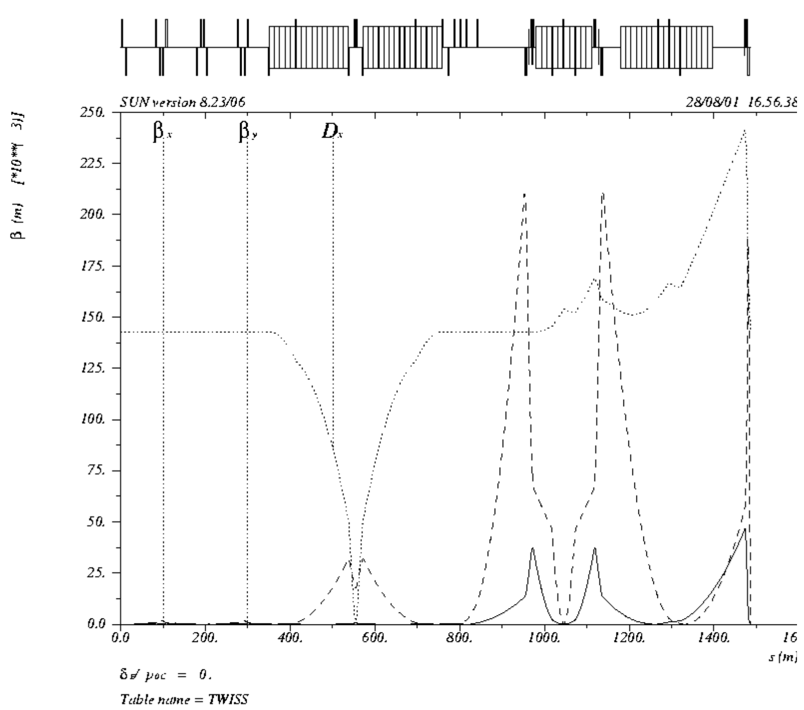
Interested in performance FFS with $\gamma\gamma$ parameters
- aperture
- bandwidth,
- synchrotron radiation
- chromaticity

Expect $\gamma\gamma$ luminosity proportional to L_{geom} □□

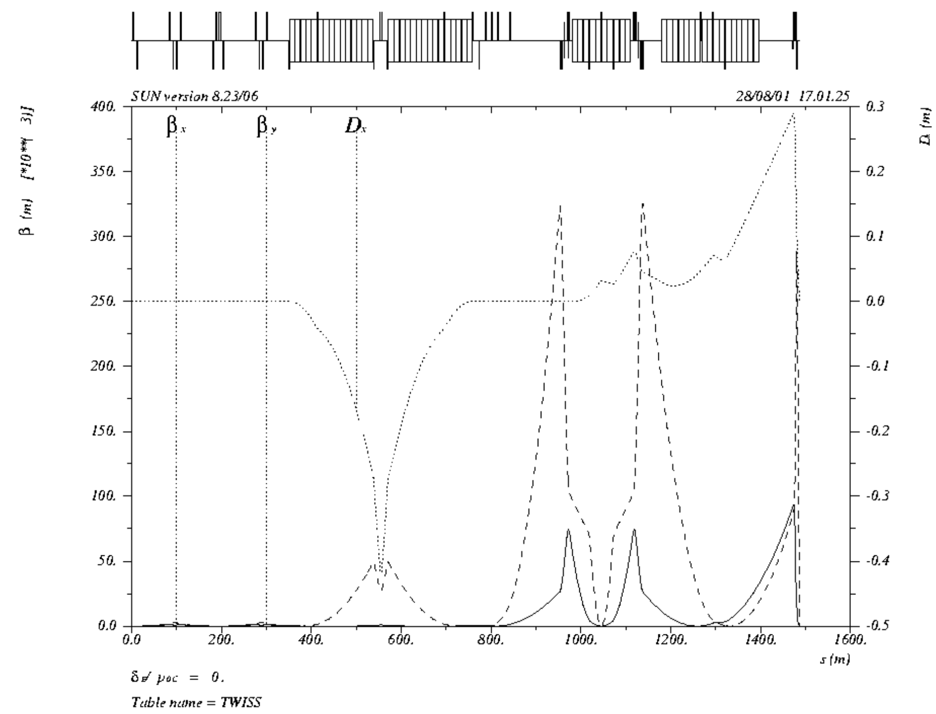
- neglects many effects related to FFS

Standard NLC vs γγ FFS: Aperture

Standard NLC FFS



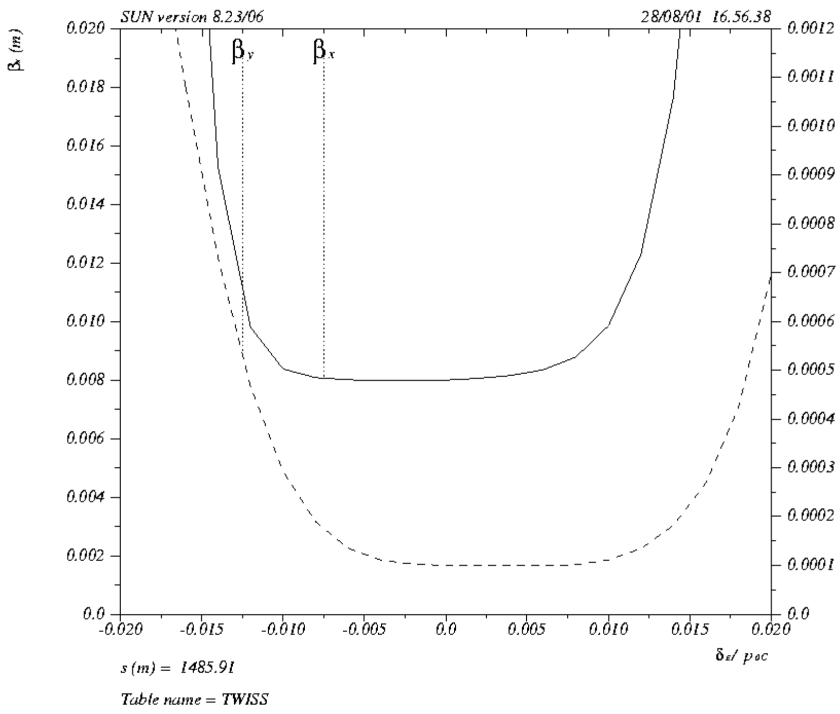
New γγ FFS



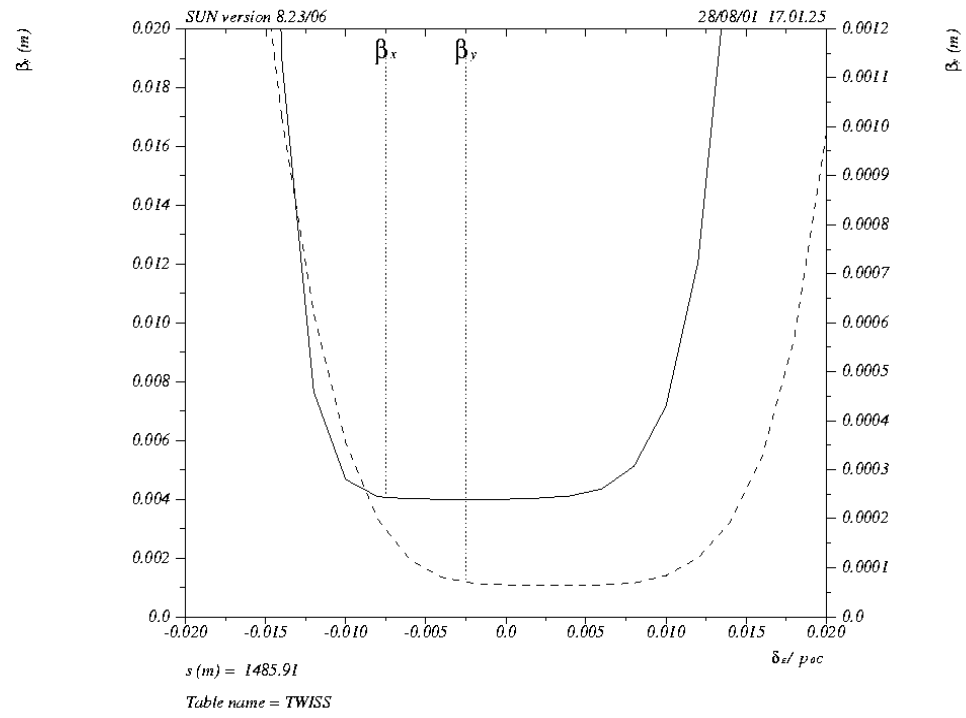
Beam Size in Final Doublet 40%larger: σ_x=814μ,σ_y=205μ

Standard NLC vs γγ FFS: Bandwidth

Standard NLC FFS



New γγ FFS



Sufficient IP Bandwidth for “Batman” Energy Spread - 0.3% RMS

Final Focus System for $\gamma\gamma$

Begin with Beam Delivery System for NLC-500 GeV

- Only modify the Final Focus - Collimator section unchanged
- Leave FFS quadrupoles unchanged
- Double the strength of FFS bending magnets
- Reduce strength of sextupoles by 1/2
- Reduce strength of octupoles, decapoles by 1/4, 1/8

Allows reduction of β^*: Increased geometric luminosity

- β_x=4mm, β_y=65μm and $L_{geom}=3.8x10^{34}$ cm^{-2} s^{-1}: 80% L_{geom} is attained
- -13% due to ΔE/E, -7% due to synch. rad. in dipoles (-4%) and quads (-3%)
- Final doublet aperture and IP bandwidth acceptable
- Hourglass effect not negligible for $\gamma\gamma$ parameters with σ_z=156μm
- 15% and 25% reduction in fraction of L_{geom} for β_y=100μm and β_y =65μm

Conclusion

BDS system for γγ IR is very similar to BDS for IR1

- Benefit from experience with SLC and FFTB
- Further improvements likely applicable to γγ FFS
- Minimizes design issues regarding IR2

New γγ FFS achieved 2.5x more peak Luminosity compared to γγ FFS presented at SNOWMASS

- Comparable increase over SNOWMASS results for Standard Model Higgs factory with E_{beam} = 80-100 GeV

NLC - The Next Linear Collider Project

Higgs Physics at a $\gamma\gamma$ Collider

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

David Asner/LLNL

Introduction

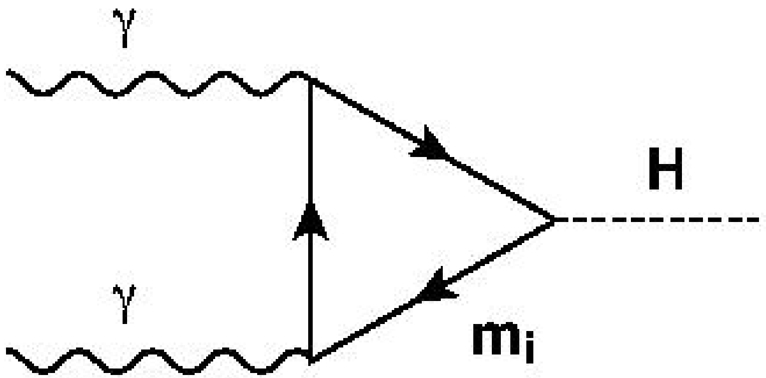
- This talk is based on work done with Jack Gunion and Jeff Gronberg:
  - Detecting and Studying Higgs Bosons in Two-Photon Collisions at a Linear Collider: hep-ph/0110230
  - Submitted to Phys. Rev. D
- Other recent papers on topic:
  - S. Solder-Rembold, G. Jikia
    - hep-ex/0101056
  - M.M. Muhlleitner, M. Kramer, M.Spira, P.M. Zerwas
    - hep-ph/0101083

Introduction

- Employ CAIN simulation for luminosity
  - Includes many non-linear effects
  - Big impact on strategy
- Laser does not have an adjustable wavelength
  - $x = 4E_{beam}\ \omega_{laser}/m^2c^4$ varies with machine energy
  - Tripler option μ -> 1/3 μ is only flexibility
  - E = 206 GeV, x = 1.86 and E = 160 GeV, x=4.33 with tripler both luminosity spectra peak at 120 GeV
- We consider
  - E = 160 GeV, x=4.33 with tripler – circular polarization
  - E = 206 GeV, x = 1.86 – linear polarization
  - E = 630 GeV, x = 5.69 – luminosity peaks near 500 GeV

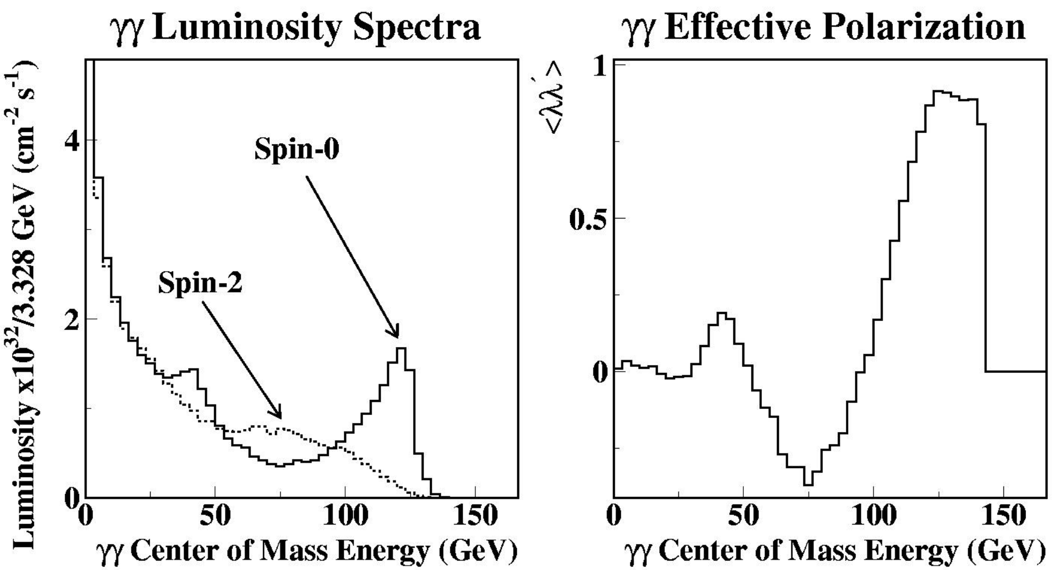
Physics Motivation

- Unique capability to measure two-photon width of Higgs
  - All particles with charge whose mass arises (in part) from Higgs contribute
  - Contribution does not decouple in the infinite mass limit for loop particle
  - Contribution asymptotes to a value that depends on loop particle spin
- CP composition of Higgs determined through control of photon polarization
- Heavy H^0,A^0 can be produced singly
  - Significantly greater mass reach than $e^+e^- \to H^0A^0$
  - Probes LHC/LC(e^+e^-) Higgs wedge where only h^0 is observed in MSSM



Study of Light Higgs Boson

- Higgs Production (M_h=120 GeV)
  - Circular polarization - 10000 higgs/10^7s
  - Linear polarization - 5000 higgs/10^7s
- Measure N(γγ -> h -> bb)
  - Combined with measurement of B(h->bb) yields Γ(h->γγ)
- Dominant background γγ->cc(g),bb(g)
  - Large spin-2 component suppressed due to circular polarization
  - Large cc background suppressed by b-tagging



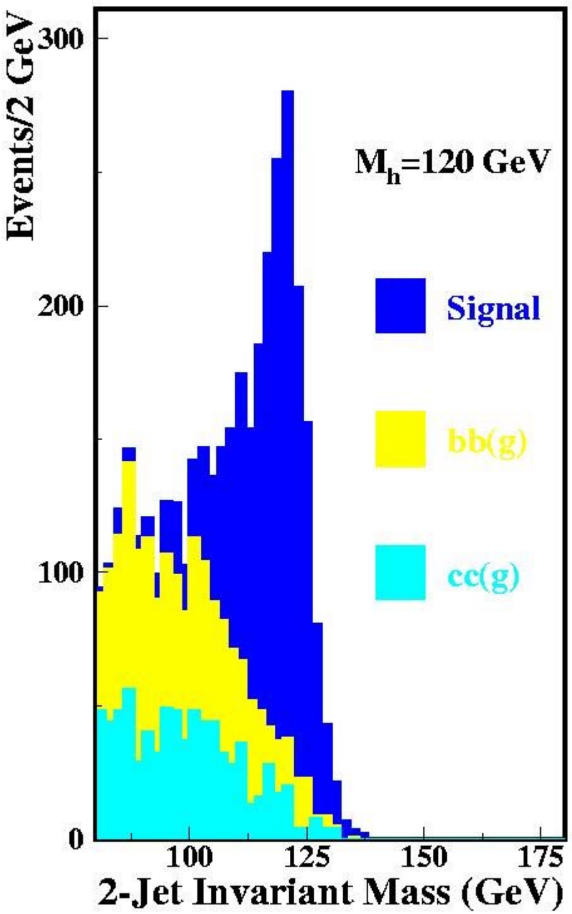
Beam Parameters

Energy (GeV)	80	103
β_x/β_y (mm)	1.4/0.08	1.5/0.08
$\varepsilon_x/\varepsilon_y$ (x10^{-8})	360/7.1	360/7.1
σ_x/σ_y (nm)	179/6.0	164/5.3
σ_z(μm)	156	156
N (x10^{10})	1.5	1.5
Rep Rate (Hz)	120x95	120x95
e^- Polarization (%)	80	80
Laser λ (μm)	0.351	1.053

Analysis Description

- Analysis is similar but not identical to the Jikia & Soldner-Rembold paper – hep-ex/0101056
  - Same jet reconstruction algorithm (Durham, y=0.02)
  - Background predicted by Pythia and LC Fact MC
  - Signal is generated with Pandora-Pythia
- Analysis Cuts
  - Tracks, Showers $|\cos \Theta| < 0.9$ in laboratory frame
  - Track momentum > 200 MeV, Shower Energy > 100 MeV
  - $|\cos \Theta^*| < 0.5$ in the $\gamma\gamma$ center of mass
  - Require 2 Jets back-to-back: $|p_{1i}+p_{2i}| < 12$ GeV, i=x,y,z
  - Assumed b-tagging efficiency 70%, charm efficiency 3.5%
- $\langle\lambda\lambda`\rangle$ not close to 1, $J_z = \pm 2$ dominates backgrounds
  - Elaborate radiative corrections are not a big effect, not included

Higgs Signal: Circular Polarization



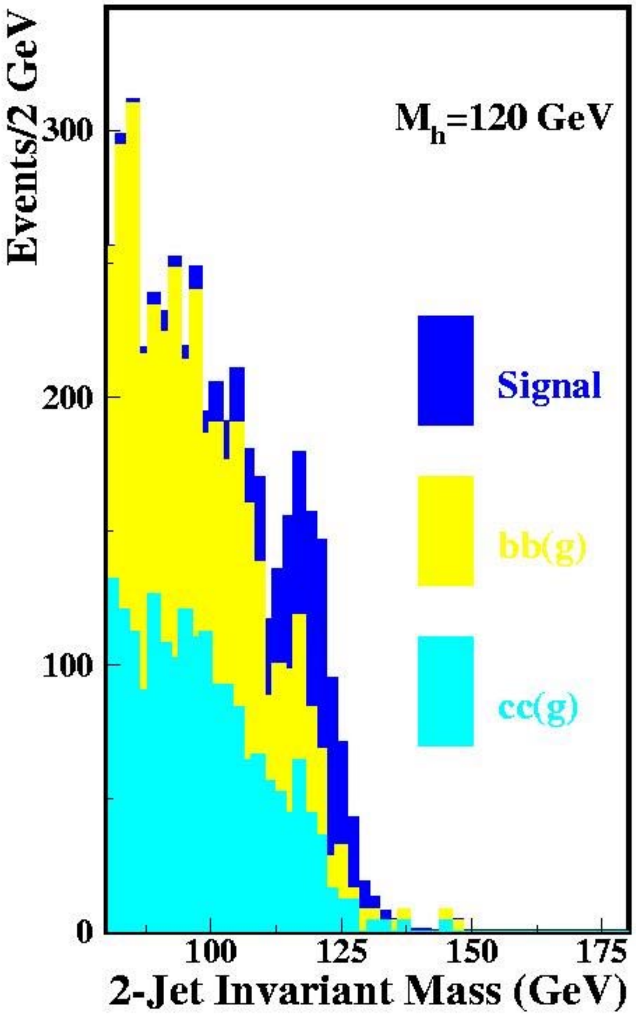
- Signal Monte Carlo generated with Pandora-Pythia
- Background Monte Carlo generated with modified Pythia
  - Spin dependent cross sections
  - Interfaced to CAIN spin dependent luminosity functions
- E = 160 GeV, frequency tripler
- Expect 1450 signal events and 335 background events with M_h>110 GeV
  - Statistical error of $(S+B)^{1/2}/S \sim 2.9\%$ on

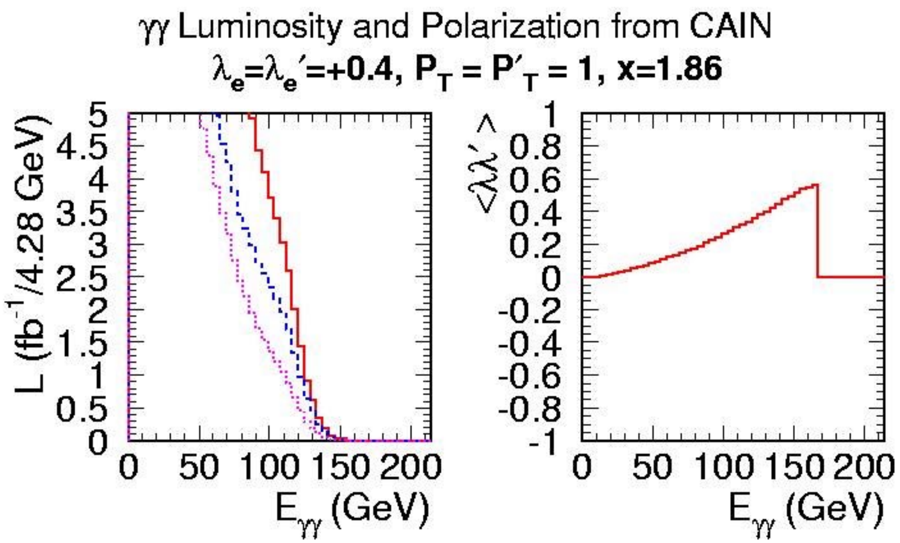
    N($\gamma\gamma$->h->bb)

CP Determination of SM Higgs

- For Higgs boson of pure CP, cross section $\sim(1+\langle\lambda\lambda`\rangle+CP\langle\lambda_T\lambda`_T\rangle\cos 2\delta)$
  - CP = +1 (CP = -1) for a pure CP-even (CP-odd) Higgs
  - δ is the angle of polarization between the transverse polarization of the laser photons
  - Asymmetry for parallel vs perpendicular orientation $A=(N_{par}-N_{perp})/(N_{par}+N_{perp}) \sim CP\langle\lambda_T\lambda`_T\rangle/(1+\langle\lambda\lambda`\rangle)$ which is positive (negative) for a CP-even (CP-odd)
- bb(g) and cc(g) backgrounds contribute to denominator of A and dilute asymmetry

Higgs Signal: Linear Polarization





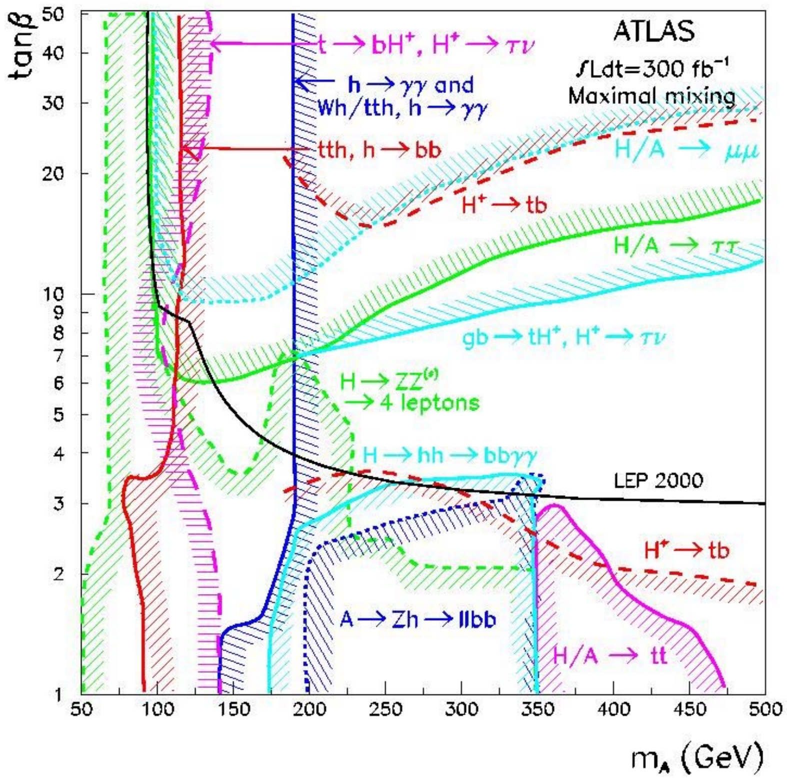
- CP nature of Higgs determined by production asymmetry between parallel and perpendicular laser polarization
- 100% laser polarization corresponds to 60% linear polarization for backscattered γ. help
- E=206 GeV, standard 1μ laser
- CP-even Higgs: Expect $180(1+0.6^2)+220$ events in parallel config and $180(1-0.6^2)+220$ events in perpendicular config on a total background of 440 events with $M_h > 114$ GeV
  - $A \sim 130/800 = +0.16$ CP-even
  - $A \sim -130/800 = -0.16$ CP-odd
  - $\delta A = 0.017$, $\delta A/A = \delta CP/CP = 0.11$

Heavy MSSM H^0 and A^0

- Consider scenario in which SUSY has been discovered
  - Expect two doublet MSSM Higgs sector to be present
- Possible that only h^0 of MSSM will be discovered during LC e^+e^- collisions and LHC operation
  - Energy $< m_A{}^0 + m_H{}^0 \sim 2m_A{}^0$ and $< 2m_H{}^{\pm} \sim 2m_A{}^0$ so pair processes are kinematically forbidden
  - $m_A{}^0$, $\tan\beta$ values are such that LHC cannot detect H^0, A^0, $H^{\pm}$
- $\gamma\gamma$ collider provides best opportunity for H^0, A^0 detection

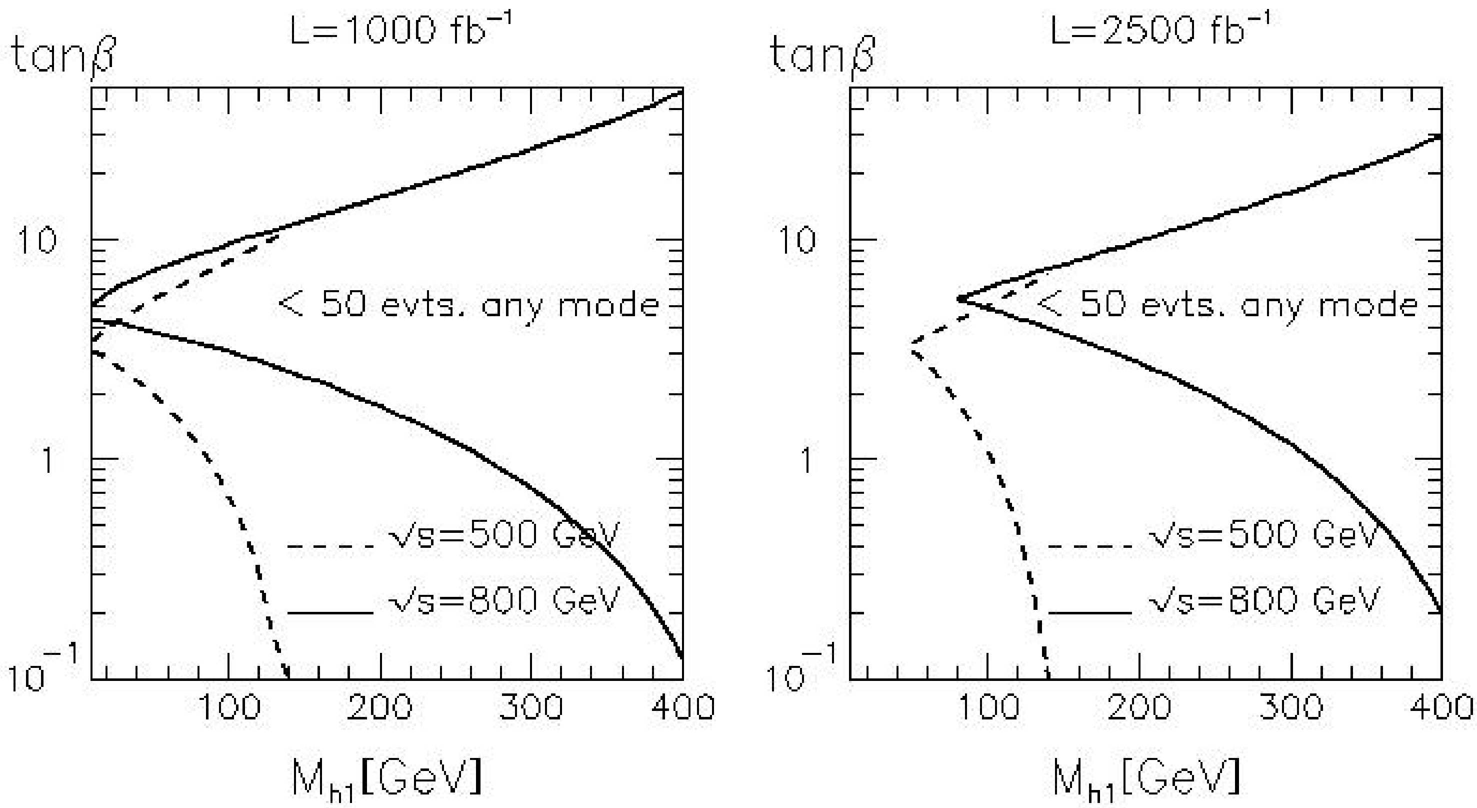
Search for Heavy Higgs

There is a region starting at M_{A^0}= 200 GeV at tanβ=6, widening to 2.5 < tanβ< 15 at M_{A^0} = 500 GeV for which the LHC cannot directly observe any of the heavy MSSM Higgs bosons



5σ discovery

Search for Heavy Higgs

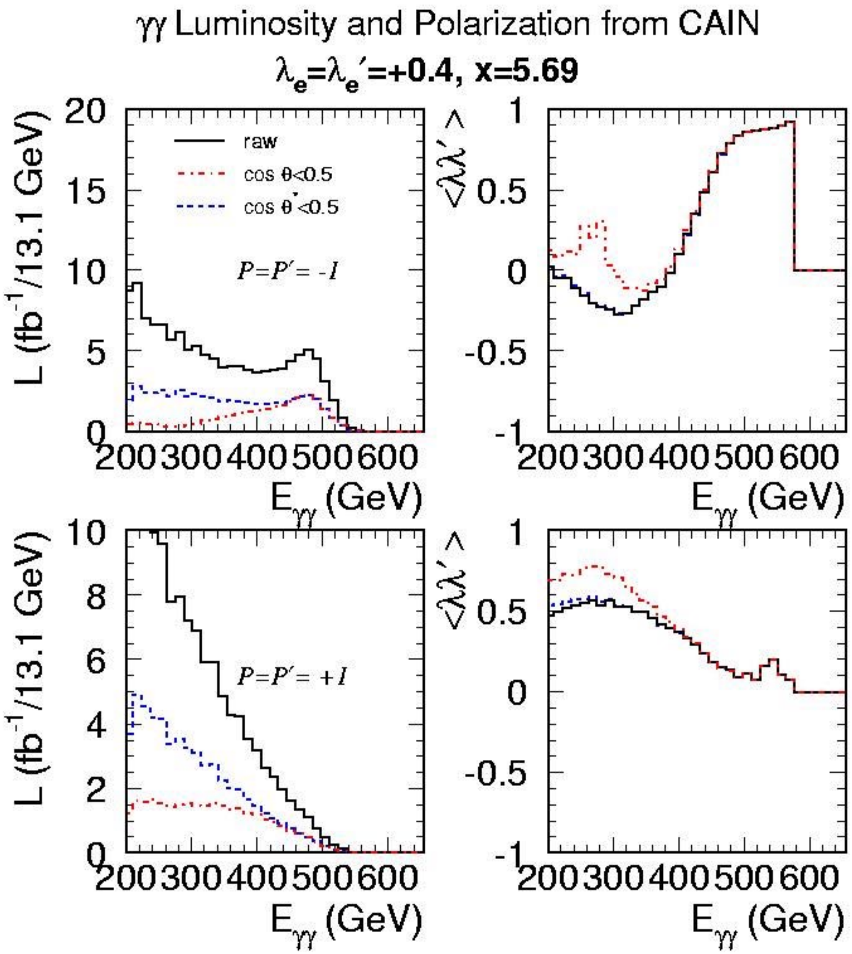


- This wedge is not covered at the LC-e^+e^-
- For e^+e^- -> tt+H^0,A^0 and e^+e^- ->bb+H^0,A^0 the wedge is even larger
- e^+e^- -> ZH^0H^0, ZA^0A^0 only probe M_{A^0}<150 GeV using 20 events in 1 ab^{-1}

Search for Heavy Higgs

- Consider E = 630 GeV, γγ luminosity peak at 500 GeV
- Single production of heavy H^0,A^0 in γγ collisions
  - Significantly greater mass reach than $e^+e^- \rightarrow H^0A^0$
- Perform a broadband search that exploits the continuous γγ luminosity function
  - Potentially more efficient use of luminosity than an energy scan
- Evaluate the impact of
  - Significantly boosted H^0,A^0
  - Significantly reduced $\langle\lambda\lambda`\rangle$
  - Resolved photon backgrounds

Luminosity: Heavy Higgs Analysis



Consider LC with E=630 GeV to probe for Higgs up to 500 GeV

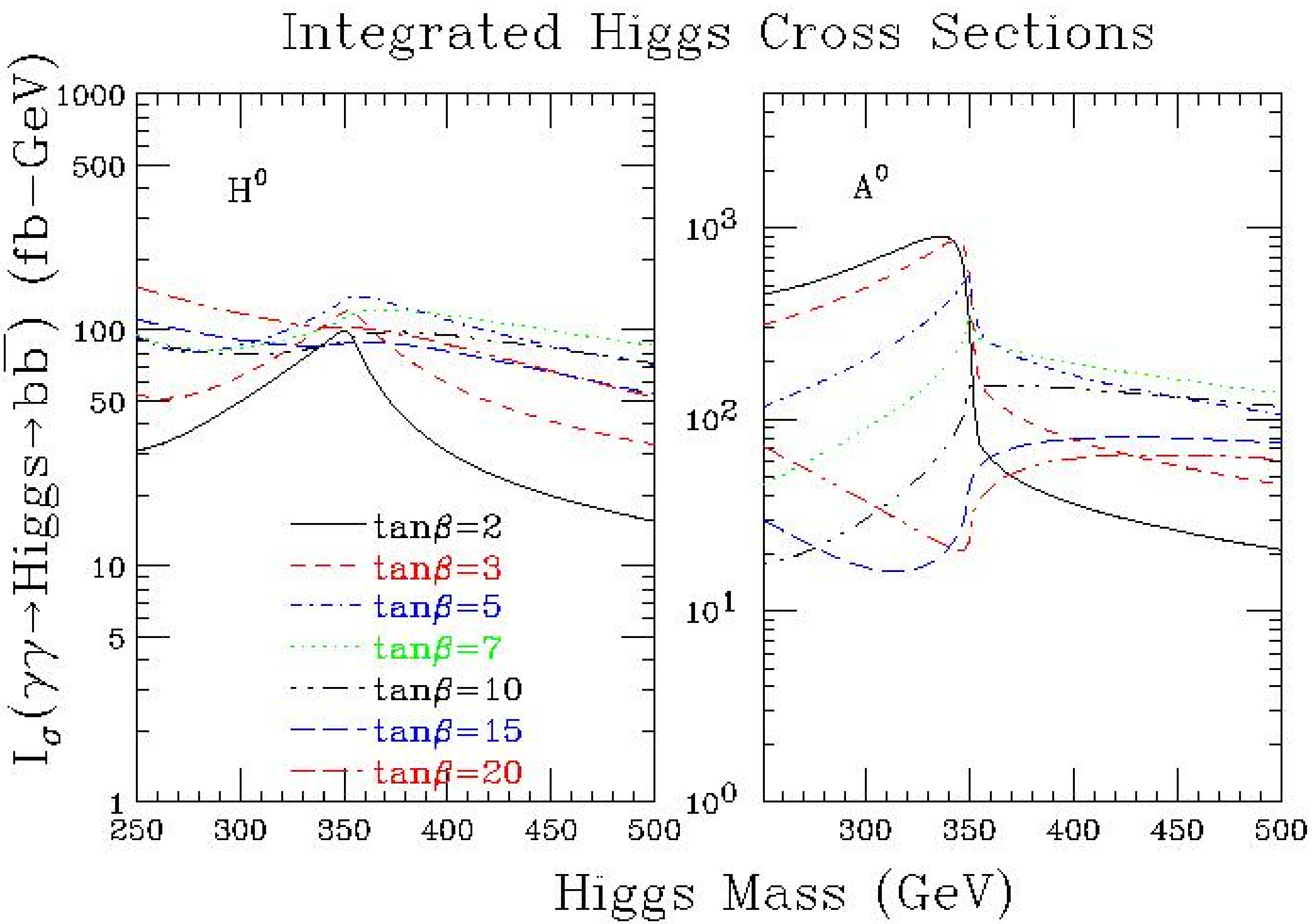
Three independent choices for relative e^- and laser polarization

Type-I P=P\`=1,
achieves modest <λλ\`> near $1/2E_{max}$

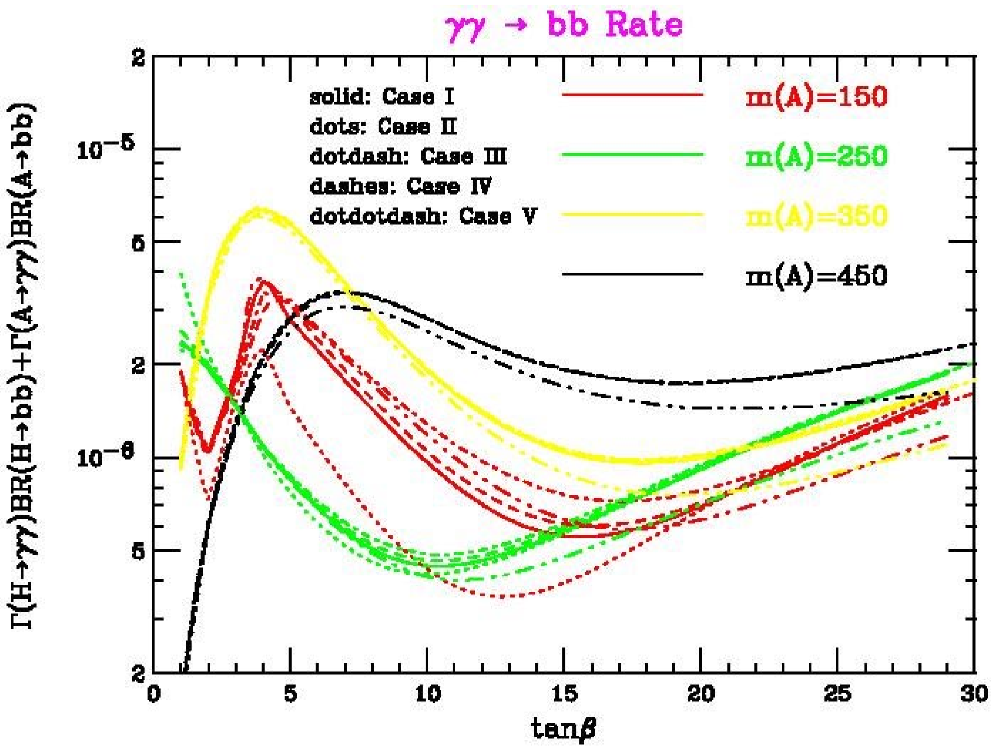
Type-II P=P\`=-1,
peak luminosity and <λλ\`> near E_{max}

Type-III P=1,P\`=-1,
Never achieves significant <λλ\`>

Signal Cross Sections



Model Dependence of Cross Sections



I: max-mix, m_{susy} =μ= 1TeV, no Δ_b

II: max-mix, m_{susy} =-μ= 1TeV, no Δ_b

III: no-mix, m_{susy} =μ= 1TeV, no Δ_b

IV: max-mix, m_{susy} =1 TeV, μ=0, no Δ_b

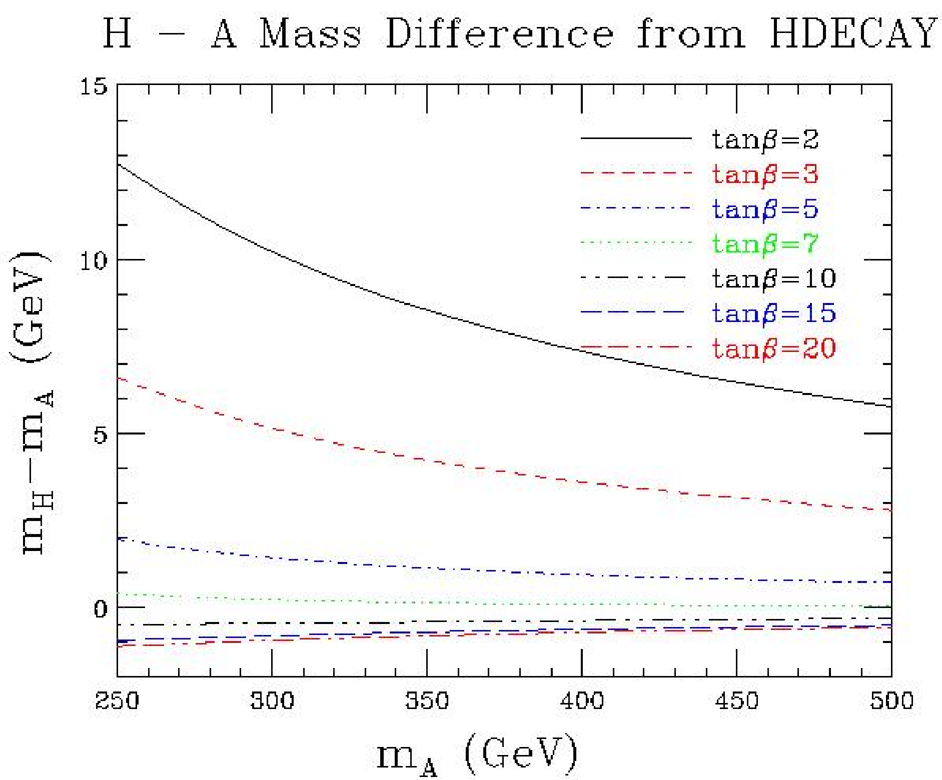
V: max-mix, m_{susy} =μ= 1TeV, w. Δ_b

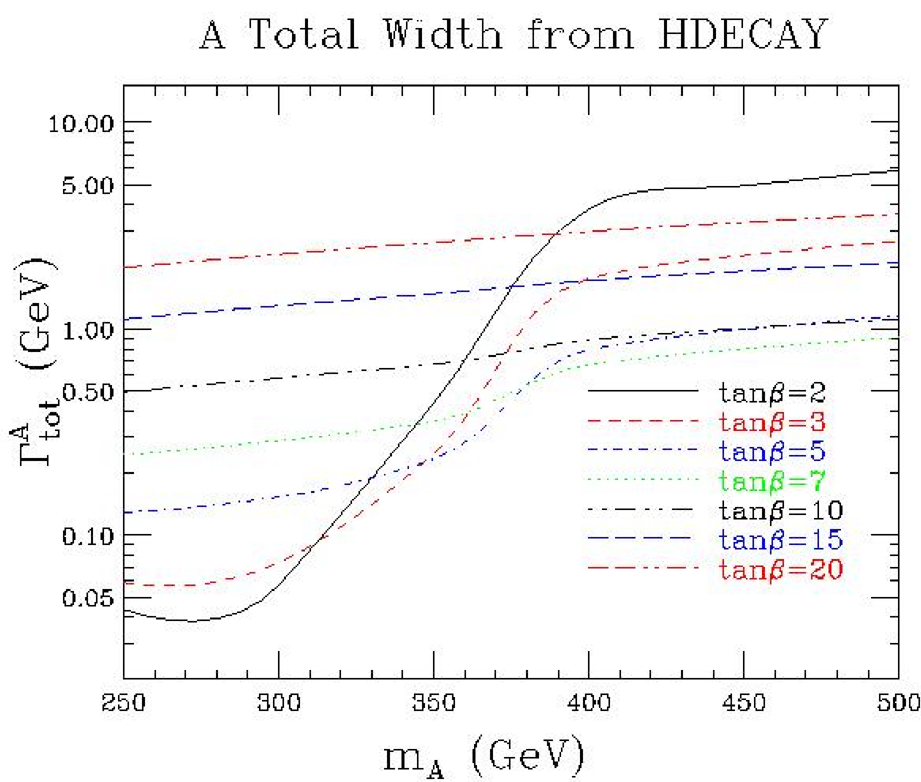
Model independent except for large-μ, large tanβ SUSY loop corrections to bb coupling

More Analysis Details

- Since $\langle\lambda\lambda'\rangle$ is never close to 1, $J_z=\pm 2$ dominates
- Background computed with polarization
  - Thanks to Mrenna for special version of Pythia
- Cuts are the same as light Higgs analysis except 2 Jets back to back cut is now only in x,y.
  - Retain efficiency for boosted Higgs
- Mass resolutions are under study
  - Expect 3 GeV at m=250 GeV and 6 GeV at m=500 GeV
  - Simliar to estimates from Tesla
- We assume 50% of Higgs event fall into 10 GeV bin
  - Accounts for mass resolution
  - H^0, A^0 mass and width difference

H^0, A^0 Mass Difference, Total Width





Heavy Higgs Yield

Number of reconstructed Higgs in 10^7s type-I/type-II

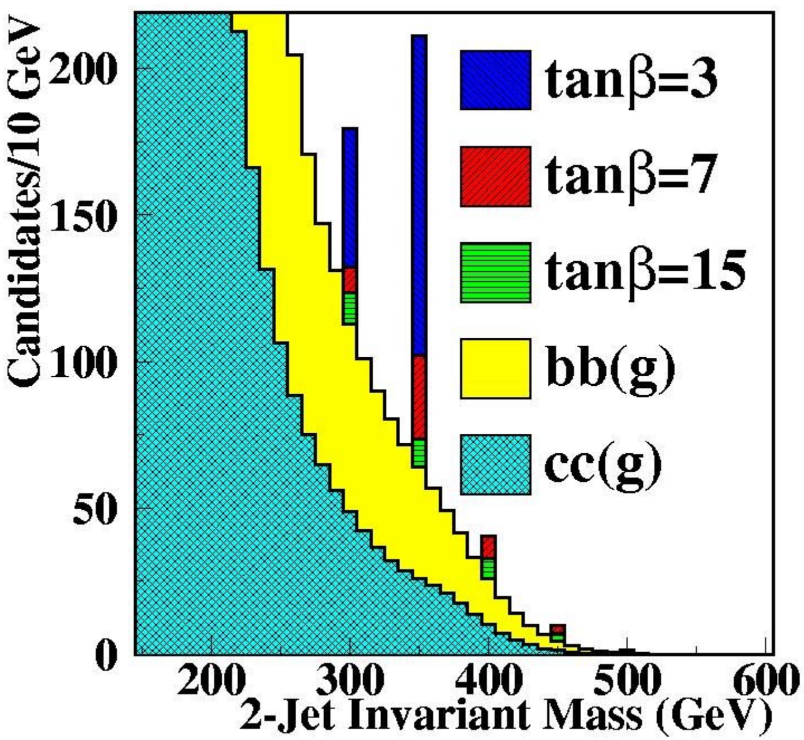
M_A (GeV)	tanβ=2	3	5	7	10	15	20	BKGD
250	121/39	91/29	52/17	35/11	28/9	36/12	57/18	272/555
300	141/44	110/34	58/18	34/11	22/7	21/7	31/10	90/271
350	55/24	92/41	94/42	60/27	32/14	17/8	17/7	70/130
400	5/5	11/10	22/21	25/23	19/18	13/12	12/11	13/86
450	2/6	3/12	8/28	9/33	8/27	5/19	5/17	5/8
500	0/4	1/8	2/18	2/23	2/20	1/13	1/12	1/2

Reconstruct only H,A->bb

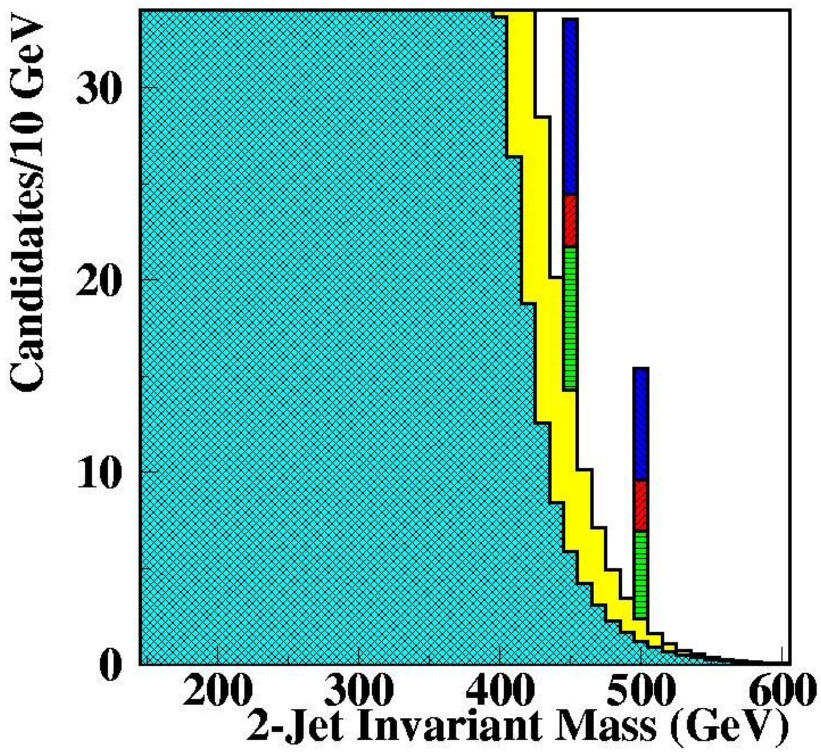
Reconstruction efficiency ~35%
cos Θ* < 0.5 most significant cut

Heavy Higgs Signal and Background

Broadband Type-I

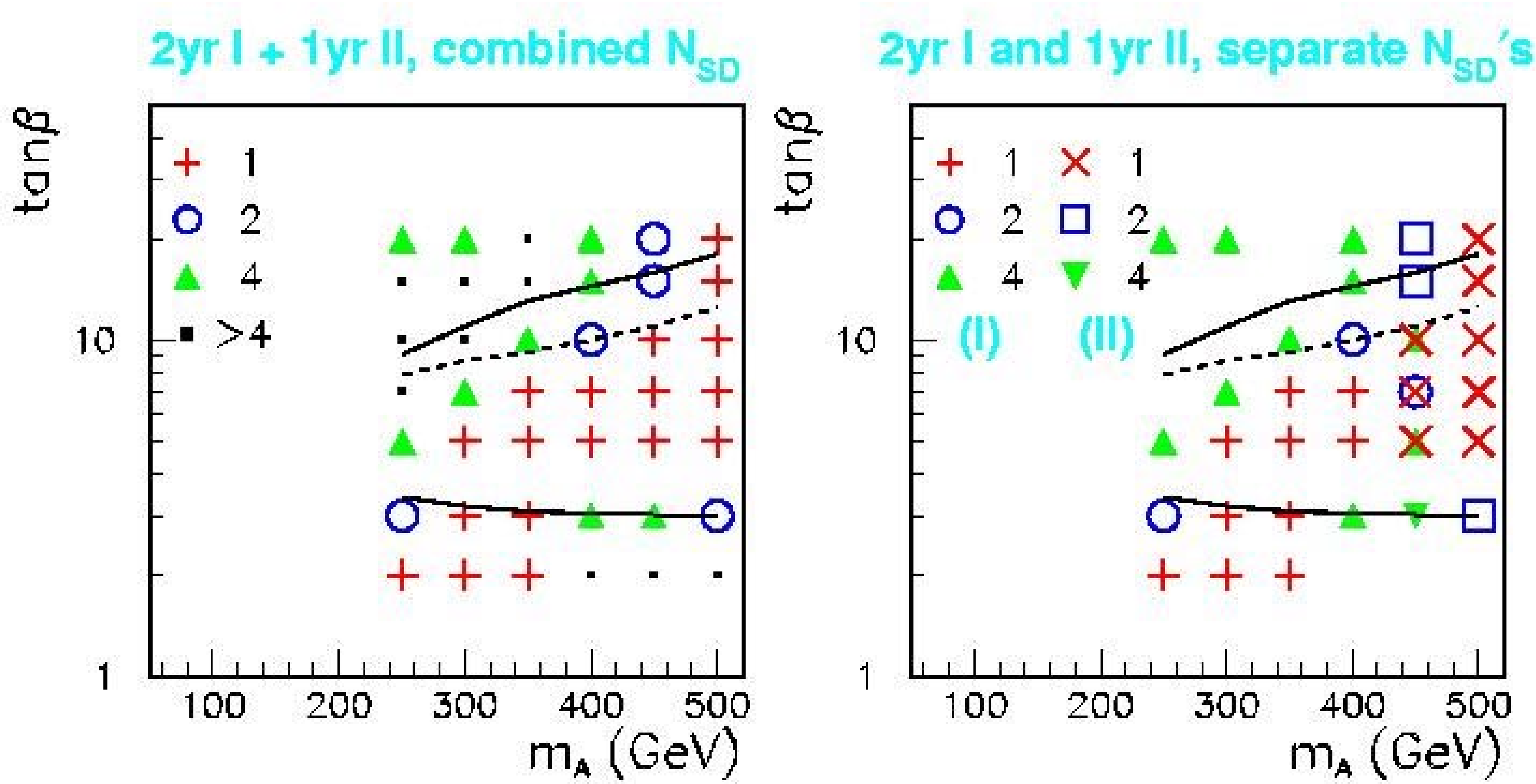


Broadband Type-II



Assume 50% of Higgs candidates reconstructed in 10 GeV bin

Luminosity Required for 4σ Discovery



2/3 of LHC "wedge" (M_A<500 GeV) probed using only bb final

Conclusions

- Redesigned Final Focus yields factor of 2-3x increase in luminosity since SNOWMASS 2001

Light Higgs Study: One Snowmass Year

- Measure N($\gamma\gamma$ -> h -> bb) with a precision of 2.9%
- CP composition of h determined by measuring production asymmetry
  - Expect A=0.079+/-0.017 for CP-even h
  - Expect A=-0.079+/-0.017 for CP-odd h

Heavy Higgs Study:

- Broadband Search for H,A provides sensitivity to LHC wedge
- H^0,A^0 -> bb probes 65% of LHC wedge in $3x10^7$ s
- Complete study will include H->hh, A->Zh and H-> tt decay channels and improve sensitivity to low tanβ region.
- Anticipate >85% coverage of LHC wedge in $2x10^7$s.

Future Study:

- Simulate resolved photon backgrounds within a GEANT detector simulation.
- Study sensitivity of photon collider to tanβ, CP of H^0,A^0 and Higgs self coupling.

Additional Comments

- Must verify H^0, A^0 mass resolutions
  - Work in progress, general agreement that assumption are reasonable
- Resolved photon background must be evaluated for NLC
  - Tesla bunch spacing reduces impact
- A factor of 2 more luminosity may be attainable at Tesla
  - Due to rep. rate and bunch charge
- Tesla study assumed 90% e^- polarization rather than 80%
- Determination of $\tan\beta$, CP of H^0/A^0 and H^3 coupling in progress
- Similar study of 2HDM where only A^0 is light (hep-ph/0110320)
  - Probes about 40% of parameter space not accessible at LC e^+e^- or LHC